Chandra News

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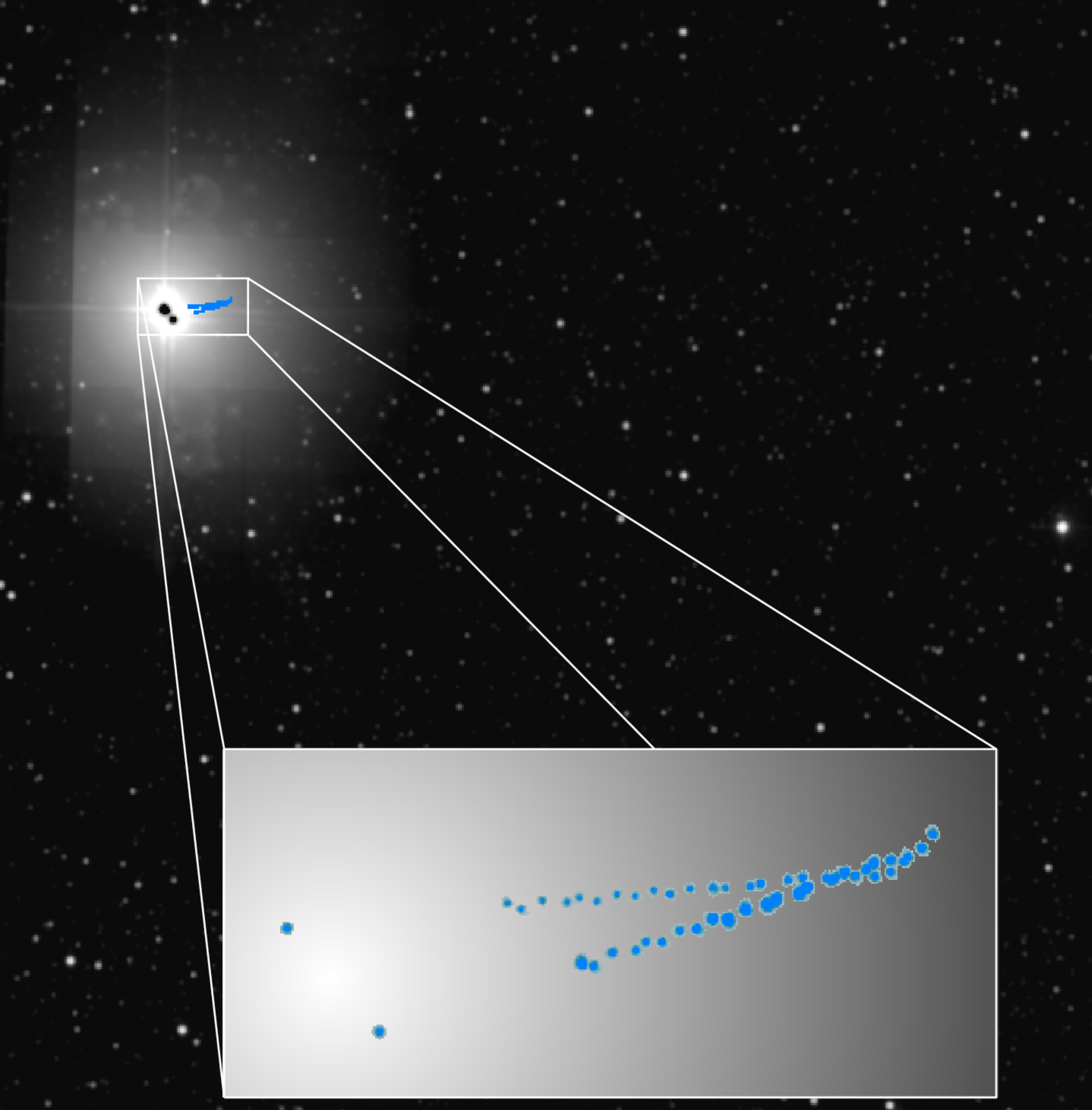
Alpha Centauri at a Crossroads

by Tom Ayres



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Alpha Centauri at a Crossroads

Tom Ayres
Center for Astrophysics and Space Astronomy
University of Colorado
Boulder, Colorado

At the Dillon Dam Brewery

Liz and I were celebrating New Year's Eve up in the mountains, at the Dillon Dam Brewery, with our friend Sally. During the lull after the band's first set, Sally turned to me and asked, slyly, "So, Mr. Astronomer, what's up with the nearest star?" I hesitated, wary of an ASTRO-101 trick question from the mischievous Sally, an education specialist. Accordingly, I launched into a discussion of all the amazing new things we astronomers were learning about our Sun, especially why this cool star (if you consider 6000 Kelvin "cool") has a super-hot, million degree outer atmosphere, the corona. (Mention of the solar "coronal heating problem" caused Liz, of the biotech world, to glaze over a bit: she had heard all this before. To be sure, I often get the same response from colleagues on the "Dark Side," although to be fair, AGN also have hot coronae and their own coronal heating problem.) I continued with an impassioned description of all the good that the Sun does for our Earth, glossing over the bad stuff coming up in the far distant future (as the Sun inexorably brightens), except to mention the impact of solar "Space Weather" on our planet, reason enough to keep a watchful eye on our nearby star.

"Very cute, Tommy," Liz interrupted, "but you know Sally really was asking about the next nearest star." "Well, nice try," I thought. So, I shifted gears into a new mini-lecture about "Proxima b," an Earth-sized, probably rocky, planet in the Habitable Zone of Proxima Centauri, a diminutive red dwarf that still holds the title of the Sun's nearest stellar neighbor. But I didn't stop there. I went on to opine that Proxima was pretty wimpy, as stars go, but, remarkably, has a couple of bigger, more sunlike siblings close-by. Together, these three stars comprise the Alpha Centauri system.

The two larger stars, Alpha Cen A and B, are in a relatively tight 80-year orbit, about the size of the outer Solar System. Tiny C, not much bigger than Jupiter, revolves around the central pair at a great distance, a few hundred times that of Pluto from the Sun, taking perhaps half a million years to make a full circuit. C just happens to be on the sunward side of AB at the moment, temporarily claiming the honor "Proxima."

Alpha Cen A is an early-G-type dwarf, almost identical to our Sun, although slightly more massive, larger, and more luminous. Its companion, Alpha Cen B, is an early-K star, slightly less massive, smaller, and dimmer than the Sun. Stellar structure studies suggest that the system is metal-rich, about twice solar, with an age of perhaps 6 billion years, somewhat older than the Sun (Flannery & Ayres 1978; Eggenberger et al. 2004).

In fact, the nearby hierarchical triple contains examples of all the most common types of the Milky Way's cool stars: those that sustain outer convective envelopes. These "late-type" stars often are afflicted by surface magnetic "starspots" (whose intense fields suppress vertical kinetic transport of energy, leading to local darkening); the heart of stellar activity. This is what powers the Sun's Space Weather, mentioned earlier, with its numerous potentially bad consequences for our technological civilization (GPS and cell phones at risk, need I say more?).

Breakthrough Starshot: Voyage to Alpha Centauri

As I drifted into the discussion of magnetic activity, I sensed I was in danger of losing my—albeit small, though so far politely attentive—audience, so I decided to amp up the Alpha Centauri narrative. "Hey Sals," I asked, "have you heard about the crazy new project called Starshot, to send a swarm of nanobots to Alpha Centauri sometime this century?" Liz knew about this already, and rolled her eyes briefly. I went on to describe the out-of-the-box idea from the

Cover image: 2MASS near-IR field around Alpha Centauri A and B (center black dots) with superimposed montage of Chandra X-ray imaging (blue) of the pair over the past 15 years (see expanded view in inset image). Full map is about 0.5° on a side.

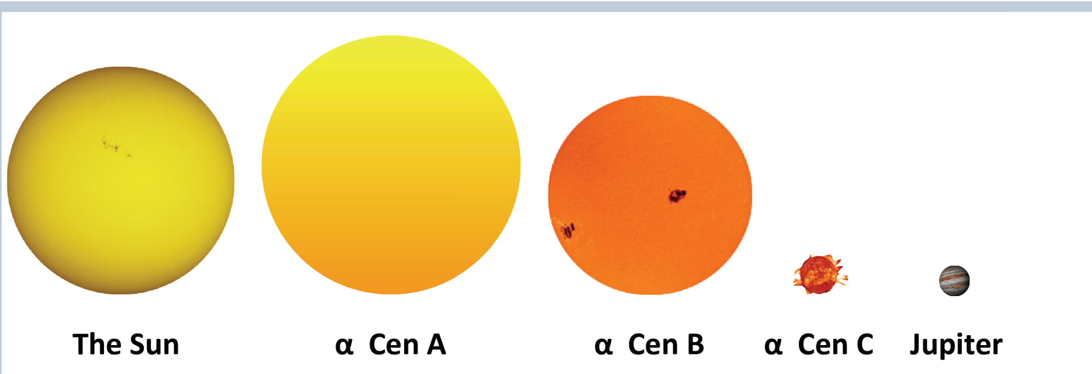

Figure 1: Rogues gallery: Sun, the Alpha Centauri stars, and Jupiter to scale.

Breakthrough Initiatives Foundation to launch credit-card sized "starchips," carried by laser-propelled light sails, for a decades-long trip to nearby stars, ultimately to photograph, up close and personal, any habitable planets around them. I explained that the nearest stars are in fact unimaginably far away. For example, our most advanced rocket-propelled spacecraft—New Horizons, which recently flew past Pluto—would need about a thousand centuries to reach Alpha Centauri, even at its record speed.

To break the "Tyranny of the Rocket Equation," Starshot envisions a one-way trip, traveling fast and light, relying on external propulsion. A giant Earth-based laser "beamer"—effectively a square-kilometer optical telescope—boosts the starchips to a stunning 20% of lightspeed. Even so, the journey to Alpha Centauri would take more than twenty years (with an another 4.3 years for any transmissions from the nanobots back to Earth).

The beamer blasts the photon-sails on their way, staged from a mother ship in high Earth orbit; but also receives, decades later, the faint laser downlinks from the starchips as they race through their brief, hours-long encounter with Alpha Cen. Because the journey has multiple hazards—mainly interstellar dust and gas along the way—you have to send many, perhaps thousands, of the nanobots to hope for a few to survive.

Alpha Cen is an obvious first target of Starshot, because second closest—"Barnard's Star," an unremarkable old red dwarf—is a couple of light years further on. Also, there are three possible hosts for habitable planets in the Alpha Cen system, and we already know there's at least one, Proxima b.

Wacky as it might seem, Starshot is the only way, with foreseeable technology, to explore the nearest stars. Thus, it's worth, well, a shot.

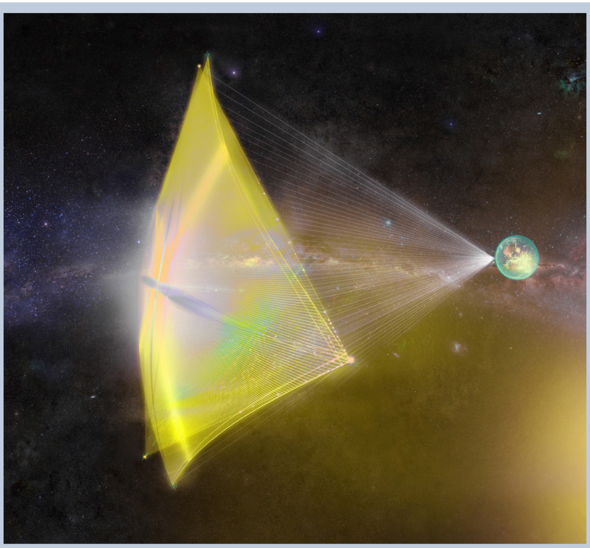

Figure 2: Starshot photon-sail far from Earth, still surfing on the concentrated laser beam from the ground-based phased optical array. Credit: Breakthrough Initiatives Foundation.

The Solar-Stellar Connection

Thankfully—for Liz and Sally—the band returned from its break, and the dancers re-took the floor, in anticipation of the New Year only an hour or so away. With my companions otherwise diverted, my thoughts wandered back to my first encounters with Alpha Centauri, culminating in my more recent high-energy adventures with *Chandra*.

I, and my colleagues, have long been interested in Alpha Cen AB because they are so similar to the Sun; perfect subjects for what we call the "Solar-Stellar Connection." We know a lot about the Sun for the simple reason that it is only light minutes away, whereas the nearest stars are several light years, or more. However, the Sun is just one example of a G-type star at a particular stage of evolution, formed with a specific set of initial chemical abundances, seed magnetic fields, rotation rate and other properties that might, or might not, be representative of G-type stars in general. It's like choosing a person from the crowd at the Dam Brewery, and examining her carefully to deduce what human beings are all about. Sure, you would learn a lot, but then again there would be a lot you would miss. It's the same idea with the Solar-Stellar Connection: build a basic framework anchored in the Sun, then extend outward through—necessarily more superficial—consideration of the more remote stars.

Back in the 1970's, when I was a grad student at Colorado, then postdoc at the Harvard-Smithsonian CfA, we were pretty much stuck analyzing optical activity indicators of the stars, like the faint "chromospheric" cores at the bottoms of the strong K and H resonance absorption lines of singly ionized calcium (at 3933 Å and 3968 Å). The more dependable X-rays (symptomatic of million-degree coronal gas) were mostly beyond reach. Aside from the Sun, only very intense emissions from compact binaries with neutron stars or black holes were known at the time.

The chromosphere, itself, is a temperature inversion layer in the solar atmosphere about 500 kilometers above the Sun's visible surface, something like the Earth's Thermosphere. In the 10,000 K chromosphere, the radiative equilibrium conditions of the cooler photosphere beneath give way to non-equilibrium kinematic and magnetic heating processes that ultimately power the enigmatic, much hotter, corona above. The amount of energy deposited in these layers is small, but the extremely low densities of the outermost regions throttle local cooling, forcing a thermal run-away, ultimately driving the temperatures up to a million degrees, or more. We also know from the Sun that the super-hot gas mostly is bottled up in fine-scale magnetic loops, although some fraction escapes entirely from the corona in the solar wind.

So, I, my thesis advisor Jeff Linsky, and collaborators Alec Rodgers and Bob Kurucz, dutifully modeled the faint optical Ca II chromospheric emission reversals of Alpha Cen AB; work we published in 1976. The stellar variants were very similar to their solar counterparts, indicating that the Alpha Cen twins shared the low-activity state of the Sun, in contrast to other examples of G dwarfs known at the time—mostly very young, fast rotators—that displayed intense Ca II emission cores.

Fortunately, a major transformation in the study of the Alpha Cen stars was about to happen: the dawn of the high-energy astronomy age.

Early High-Energy Exploration of Alpha Centauri

The late 1970's witnessed the birth of modern high-energy astrophysics. In quick succession there was the first High-Energy Astronomy Observatory (HEAO-I), launched August 1977, followed in November 1978 by HEAO-II (later named *Einstein*). Although the Alpha Cen stars are not particularly coronally active, they are so nearby that even this early wave of high-energy observatories was sensitive enough to capture them. In 1978, John Nugent and Gordon Garmire published the first X-ray detection of Alpha Cen AB by HEAO-I, albeit unresolved, at a combined coronal luminosity similar to the Sun at the peak of its 11-year sunspot cycle. Later that year, Leon Golub and colleagues described high-resolution imaging of Alpha Cen AB by the *Einstein* HRI, with the unexpected result that visually dimmer B was more than twice as bright in X-rays as companion A. (The general trend that cooler dwarfs tend to be more coronally active than their warmer cousins later was confirmed through broad stellar surveys by *Einstein* and subsequent X-ray observatories. Why this is the case still is hotly debated.)

The next important advance was the Röntgensatellit (ROSAT), launched in June 1990. ROSAT not only performed an all-sky survey to put stellar coronae, among other high-energy phenomena, into perspective; but also was able to separate AB with its High-Resolution Imager (like that previously on *Einstein*), despite the shrinking Alpha Cen orbit at the time. ROSAT observed AB on a number of occasions, including two month-long campaigns in 1996 (reported by Juergen Schmitt and Carolin Liefke in a 2004 retrospective on the activity of solar neighborhood dwarfs). AB were found to display sunlike coronal variability during the two campaigns, and B was caught flaring a few times. During most of the ROSAT era, B was X-ray brighter than A, although in the final HRI observation in 1998, B had dropped down to A's level. This again reinforced the solar-like nature of the Alpha Cen dwarfs, and the fact that B is the more active of the pair (most of the time).

Contemporary High-Energy Views of Alpha Centauri

The new millennium brought a third generation of high-powered X-ray observatories. The two most significant for the Alpha Cen story were the Advanced X-ray Astrophysics Facility (AXAF, later christened *Chandra*), launched in July 1999, and the X-ray Multi-mirror Mission (re-named *XMM-Newton*) lofted in December of that year.

Alpha Cen was featured in early observations by *Chandra*. A Low-Energy Transmission Grating spectrum of AB was taken during the LETGS commissioning period in late-1999 (published by Ton Raassen and colleagues in 2003). The A and B spectral stripes were isolated spatially thanks to the 20" separation of the pair at the time, and the excellent 1" resolution of the HRC-S readout.

LETGS spectra carry many key tracers of coronal plasma conditions and composition, and can readily distinguish low- and high-activity objects. Ironically, the Alpha Cen X-ray spectra eclipsed anything then (or now) available for the Sun, in terms of broad wavelength coverage and energy resolution. In that epoch, AB were similar in X-ray luminosity; contrary to the *Einstein* observation twenty years earlier when B was brighter.

The "Darkening of the Solar Twin"

After the 1999 *Chandra* LETGS pointing, a several year X-ray hiatus ensued for Alpha Cen. Finally, in 2003, *XMM-Newton* picked up the slack with a long-term program instigated by Jan Robrade, Juergen Schmitt, and Fabio Favata. In 2005, they published a paper entitled, somewhat ominously, "The darkening of the solar twin." Jan and company described a remarkable—perhaps alarming—drop in the X-ray count rate of Alpha Cen A, something like a factor of 50 at the beginning of 2005. The decreasing separation of the AB orbit was beginning to infringe on the 10" resolution of the *XMM-Newton* cameras, but a signal from A should have been seen easily, and wasn't.

The "fainting" of Alpha Cen A, as the authors put it, was completely unprecedented for a sunlike star, as far as we understood at the time. Certainly, the Sun itself had not shown any such behavior during the modern era of high-energy monitoring. The solar soft X-ray flux does rise and fall with the 11-year sunspot cycle, but perhaps with only a factor of 6–10 spread, and Alpha Cen A already was in a relatively low coronal state at the first *XMM-Newton* pointing, prior to the dramatic fall.

There was, however, the outside chance that Alpha Cen A had entered an ultra-low X-ray state, possibly like the Sun's 17th Century "Maunder Minimum," a mostly sunspot-free period that lasted an astonishing seven decades. One line of thought held that this was a time of abnormally low magnetic flux production on a non-cycling Sun. Lacking sunspots, the corona itself might have disappeared, and the X-rays with it. Another school of thought viewed the Maunder episode as nothing more than a very extended normal minimum, and we know that the solar corona and its X-rays weaken, but do not disappear, in recent examples of such minima. However, given the lack of orbiting

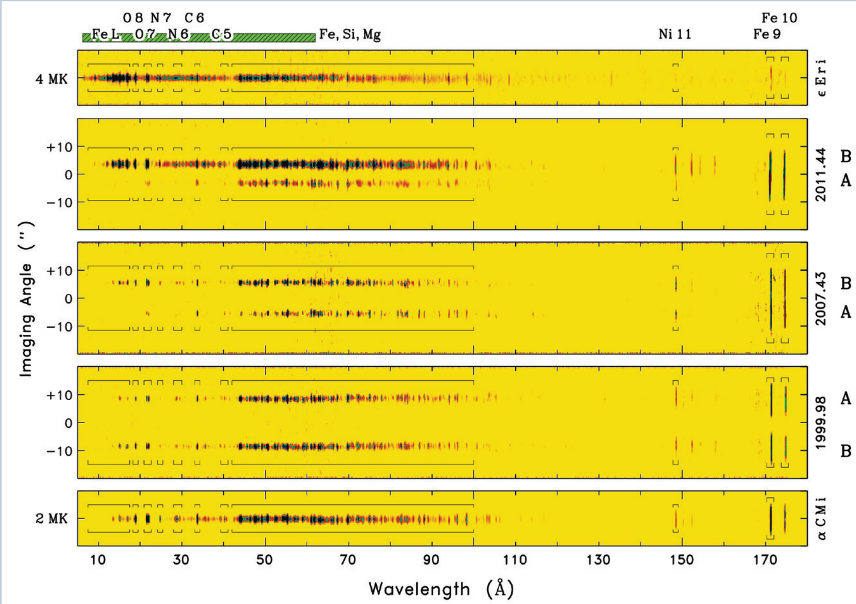

Figure 3: Chandra LETGS spectra of Alpha Cen AB in three epochs; flanked by two reference stars: low-activity mid-F subgiant Procyon (Alpha Canis Minoris) and higher activity early-K dwarf Epsilon Eridani. Chandra easily separates AB, even in 2011 when the orbit was closing rapidly. Also note that the AB positions are reversed in 2007 and 2011 compared with 1999, owing to opposite roll angles. Key spectral features are marked along the top of the panel. Green bar delimits the 0.2-2 keV soft X-ray passband commonly used in coronal comparisons. (Adapted from Ayres [2014].)

solar X-ray monitors during the 17th Century, there was no easy resolution to the debate. There also was a practical side to the matter: the Maunder Minimum coincided with the "Little Ice Age" in Northern Europe, and there were suspicions that solar activity, or lack thereof, might have been responsible in some way for that extreme climatic incident.

Prodded by the extraordinary coronal disappearance of Alpha Cen A, I appealed to the *Chandra* Director's Office (Harvey Tananbaum and Belinda Wilkes) for a small grant of discretionary time to verify the unexpected fading of the solar twin. I chose HRC-I for the experiment because it has a different design than the *XMM-Newton* EPIC cameras, and is much less susceptible to "red leak" from optically bright sources like AB than the CCD-based imagers (including *Chandra* ACIS).

The Director's Office graciously approved three short pointings at roughly six-month intervals. The first observation was carried out October 2005, about eight months after the *XMM-Newton* report of the fainting episode of Alpha Cen A, which had continued through a subsequent pointing in mid-2005. Perhaps a little surprisingly, the October *Chandra* HRC-I image now showed the A component clearly present.

To be sure, Alpha Cen A was in an X-ray low state in October 2005 compared to the LETGS image in late-1999, and the historical highs of the ROSAT era. However, we're only talking factors of 2 or 3, not 50. The subsequent two DDT pointings showed the same result: Alpha Cen A still was mired in an X-ray low state, but not much different from the Sun at sunspot minimum.

Meanwhile, Alpha Cen B was in a relative high state in the initial HRC-I observation of late-2005, well above the LETGS epoch, but similar to the ROSAT era. However, in the second and third HRC-I pointings, B had dropped back toward its historical (initial LETGS) lows.

Through subsequent Guest Observer programs, I and colleagues were able to continue the semi-annual X-ray monitoring of AB, right up to the present day. This remarkable history is summarized in the "streak image" of Figure 4, as well as in Figure 5, which collects together the ROSAT, *XMM-Newton*, and *Chandra* pointings on AB, from the mid-1990's to the present.

The shrinking AB orbit over the past two decades has been countered by improving resolution of the successive generations of high-energy observatories, although in recent years only *Chandra* has been able to cleanly separate the pair. Note the presence of A in the first *XMM-Newton* pointing (early-2003), but rapid fading subsequently. Yet, A was detected clearly in the initial HRC-I observation in late-2005, shortly after the "fainting" episode in *XMM-Newton*, extending to at least mid-year 2005.

So, how could we explain the disappearing act of Alpha Cen A in the *XMM-Newton* pointings 2004-2005? There were two possibilities. Either A had undergone a miraculous recovery from the fainting spell by the time of the HRC-I observation only a couple of months later. Or, there was some hidden issue causing a huge visibility difference between *XMM-Newton* and *Chandra* as far as the A source was concerned. When in doubt, a spectroscopist like myself knows exactly what to do: take a spectrum.

LETGS to the Rescue

We aficionados of spectroscopy always cast our proposals thusly: images are pretty, but spectra are the ultimate astrophysical "deciders." After all, the high-energy spectrum promises a trove of insights concerning the underlying object, or in this case its corona: plasma temperatures, densities, chemical composition, dynamics, and so forth. In reality, however, devious Nature often sees fit to make the true spectrum impossibly more complex to interpret than we would have dreamed possible. To my surprise, then, the second LETGS spectrum of Alpha Cen AB, taken in 2007, actually did completely solve the "case of the missing solar twin."

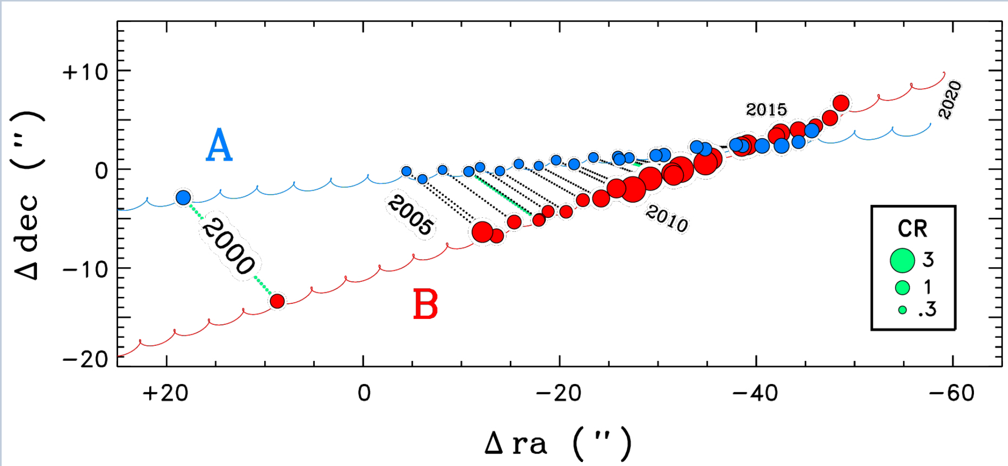

Figure 4: Cartoon version of the Chandra streak image on the front cover. North is up; East to left. Blue dots represent Alpha Cen A, red for B. Squiggly curves are predicted paths on the sky of A and B, including proper motion, orbit, and parallax. Where possible, AB points in the same epoch are connected; green highlights LETGS observations. Sizes of dots represent average count rates according to the legend at lower right.

If you compare the AB traces in the 1999 panel of Figure 3, you will see that they have almost exactly the same appearance: strong Fe IX and Fe X emissions at 170 Å, a forest of Fe M-shell lines from 40–100 Å, sharp O VII and O VIII near 20 Å, and a few Fe L-shell lines below 20 Å. The Fe-L region is populated mainly when the coronal temperatures are a few million degrees, or hotter. If I had mislabeled the 1999 spectra, you would not have been able to tell the difference.

In the 2007 spectrum, the B tracing is almost identical to its counterpart seven years earlier. However, the A spectrum had changed dramatically. To be sure, the long-wavelength Fe IX and Fe X emissions still were prominent; and the intermediate Fe M-shell region still was a forest of barely resolved features. But, notably, the interval below 30 Å was nearly blank: O VII barely visible, O VIII missing, as were all the hotter features shortward in the Fe L-shell. The dimming of the spectrum below 30 Å is a signature of a strong "cooling" of the Alpha Cen A corona (to below a million degrees) in that epoch, and presumably also at the earlier times during the prominent *XMM-Newton* "fainting" episode.

I, and my colleagues Phil Judge, Steve Saar, and Juergen Schmitt, published the new Alpha Cen LETGS spectrum in 2008. Our conclusion was that A's corona had not disappeared after all, because there still was plenty of emission in the Fe M shell and at longer wavelengths; but simply was in a somewhat cooler state. Nevertheless, the effect on the spectrum below 30 Å was profound. If your X-ray detector had poor soft response, you might conclude that the source had disappeared.

In fact, the *XMM-Newton* EPIC cameras require a thick optical blocking filter for bright stars like AB, to avoid overloading the CCD-like sensors with visible photons. The presence of the filter undoubtedly degrades the soft response. Meanwhile, HRC-I can be run wide-open for AB, because its microchannel-plate design is immune to optical loading.

In fact, there is pretty good agreement between EPIC and HRC-I for the slightly more active B component over the epochs in common. It's well known that more active stars tend to have harder coronal energy distributions, and the same is true for a given star over its activity cycle: hotter at maximum, cooler at minimum. Very recently, Jan Robrade and Juergen Schmitt updated their ongoing *XMM-Newton* time series of Alpha Cen, announcing that the A component—which has been steadily increasing in X-ray luminosity in the *Chandra* pointings over recent years—finally had resurfaced in EPIC (although still partially blended with B owing to the coarser spatial resolution of *XMM-Newton*).

In short, how you view a stellar corona depends a lot on the energy response of your instrument, hard or soft. This is an important consideration if, for example, you want to know what the high-energy radiation environment is like, say, at the orbit of a planet in the Habitable Zone of a cool star. Significantly, for low-activity stars like the Sun and Alpha Cen AB, the bulk of the "coronal" luminosity is emitted at the longer wavelengths, beyond 30 Å, mostly outside the commonly used 0.2-2 keV (6-62 Å) reference band.

Thus, while emissions at the shorter wavelengths of, say Alpha Cen A, can vary enormously over the equivalent starspot cycle, the amount of energy involved is small and the "bolometric" X-ray modulation is dominated by the soft component, primarily at the longer wavelengths. At the same time, to be fair, the harder energy radiations might preferentially affect specific chemical pathways on the surface, or in the atmosphere, of an exoplanet, and in that case the cycle modulation could be enormous.

In the final analysis, then, it is important to characterize stellar X-ray cycles at a range of energies, to fully trace the potential influences on orbiting planets, not to mention ferreting out the astrophysical origins of the underlying magnetic oscillation in the first place (Gene Parker's [1970] "Dynamo"). In this sense both *XMM-Newton* and *Chandra* have been acting synergistically in the specific case of Alpha Cen A, which is at the extreme soft end of normal stellar coronal sources.

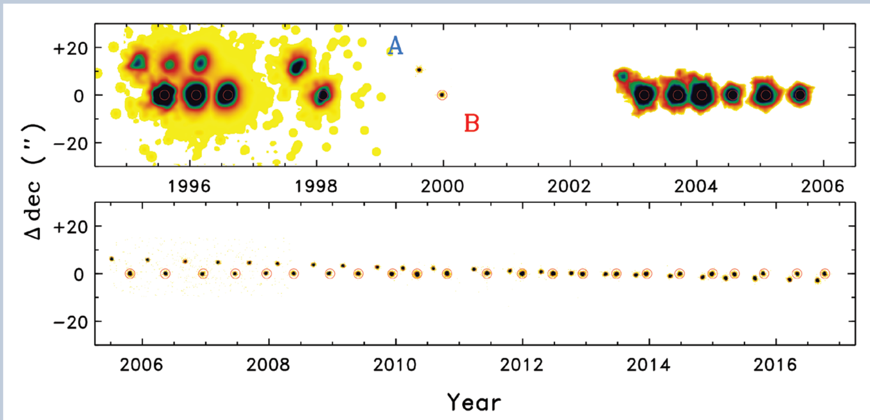

Figure 5: Two decades of soft X-ray imaging of Alpha Cen AB: ROSAT, upper left (including co-added images from two month-long campaigns in 1996); XMM-Newton, upper right (pre-2006, only); initial Chandra LETGS, upper middle; and Chandra HRC-I, lower panel. Images are aligned to predicted location (red circles) of (generally brighter) Alpha Cen B in each epoch, but the AB orientation is preserved.

The Ups and Downs of Alpha Centauri

Although the original purpose of the Director's Discretionary time program was to explore the puzzling disappearance of Alpha Cen A in X-rays, the subsequent GO efforts shifted focus to the activity cycles of AB. After all, at the time we knew almost nothing about stellar high-energy cycles, because only a handful of late-type stars had been subjected to any kind of long-term X-ray scrutiny. Alpha Cen was far and away the best example, with spatially resolved detections of AB dating back to *Einstein*.

When crafting a long-term X-ray program like that for AB, one has to confront a few practical issues. One of the most important is temporal sampling. The more recent *Chandra* (and *XMM-Newton*) efforts have adopted a semi-annual cadence; much shorter than a solar-like cycle (about a decade), but much longer than typical rotational timescales (about a month for the Sun and AB). Can such "snapshot" measurements provide an unbiased view of the coronal evolution?

Fortunately, we have the two periods of intensive, almost daily, monitoring of AB by ROSAT HRI back in 1996; as well as the long-term daily records of the Sun's soft X-ray flux (e.g., from the LISIRD database at CU's Laboratory for Atmospheric and Space Physics). Both examples suggest that X-ray modulations on rotational timescales generally are modest compared with the overall cycle amplitude, so are merely an annoyance.

Transient flares, however, are a bigger worry. A large outburst could temporarily outshine the X-ray star, and skew the semi-annual record. The way around this is to make sure that each high-energy observation is long enough that any transient X-ray enhancements can be recognized above a "quiescent" level. Thankfully, most stellar flares rarely last more than an hour, so a few-hour pointing is sufficient.

Figure 6 illustrates the totality of the time-resolved HRC-I observations of AB. Note the impulsive flare in ObsID 8906 for B, and the decays in both ObsIDs 10980 and 14234, also for B. There are no conspicuous events for A. Also note the "crossing" of the AB count rates toward the end of the sequence, as A is rising to a local maximum, while B is sinking toward a minimum. Coincidentally, this occurred at the same time as the trajectories of the two stars on the sky were intersecting (Figure 4), a double "crossroads" if you will.

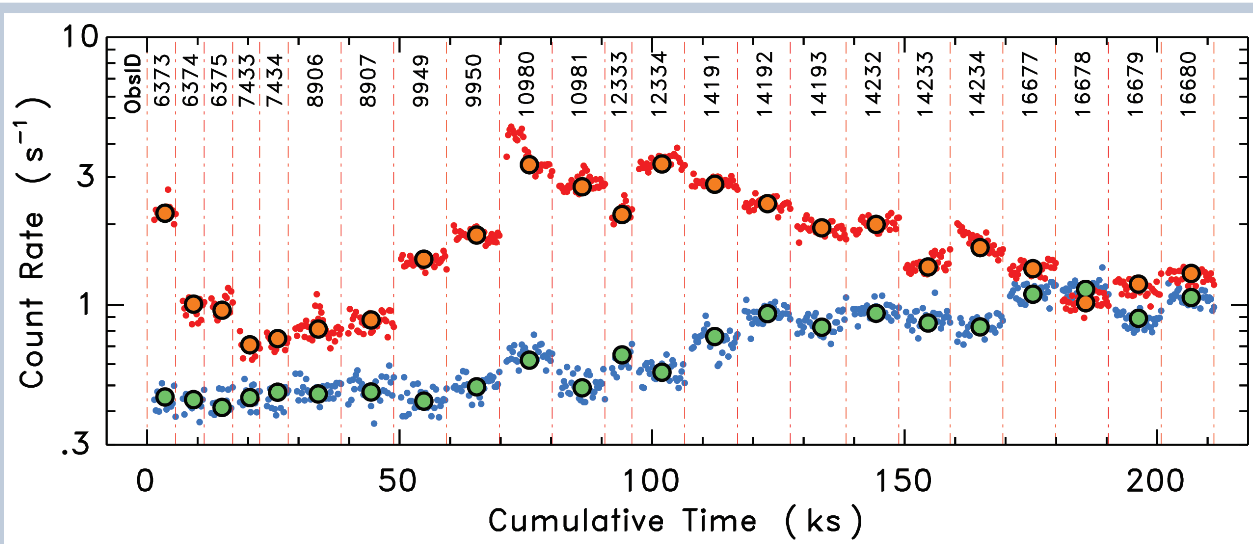

Figure 6: HRC-I time series for Alpha Cen A (blue/green) and B (red/orange). Smaller dots represent count rates binned over 300 second intervals; larger circles are "flare-free" mean values. Vertical dot-dashed lines separate the semi-annual "ObsID" pointings (Adapted from Ayres [2014].)

(Perhaps a triple considering the new attention lavished on Alpha Cen by Starshot, a clear turning point in the study of the system.)

Figure 7 illustrates the X-ray cycles of the Alpha Cen stars in the modern era. The "X-ray Index" is the stellar X-ray luminosity L_X (0.2-2 keV) divided by the bolometric (total) luminosity of the star (L_{bol}), in units of 10^{-7}. The normalization allows a fairer comparison of activity levels. The points to the left (pre-2000) are from ROSAT HRI, while those at 2000 and later are from *Chandra* HRC-I/S (solid circles) and *XMM-Newton* EPIC (asterisks: B only; A would be off-scale on the low side). Blue points are for A; red for B. Small gray dots in the solar time series (middle) are daily values; larger, darker symbols represent 81-day averages (three rotations).

Dot-dashed curves for A (blue) and B (red) are an attempt to match the time series with a log-sinusoidal model. If one accepts these fits at face value, the period for B is about 8.4 years, and for A nearly 20 years; both bracketing the Sun's 11 year average (although the span between the Sun's apparent Cycle 23 MAX, circa 2002, and that of current Cycle 24 in 2015, is on the long side at 13 years).

Figure 7 emphasizes how solar-like AB are in their overall X-ray levels. At the same time, the cycle periods are more disparate: shorter for B, longer for A. This behavior must be an important clue to the operation of the cycling Dynamo; especially for more evolved A, which might be on the verge of developing a convective core (Bazot et al. 2016).

Chandra Astrometry and the Orbit of Alpha Centauri

There is a final aspect of the *Chandra* Alpha Cen time series worth mentioning. Figure 8 depicts the orbit of less-massive B around heavier A (usual binary star convention). Orange points mark HRC-I positions, while the lone green dot is from Hipparcos, circa 1991; together covering a fair fraction of the orbital arc. For *Chandra*, the photon-noise error on a single measurement of the AB relative position is only about 20 milliarcseconds.

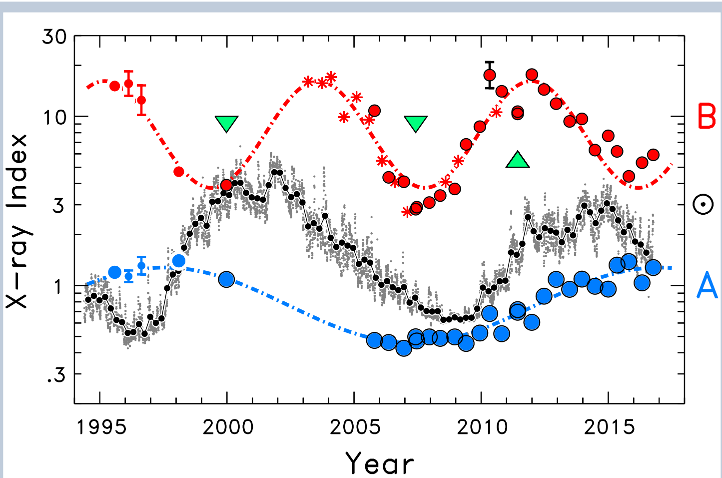

Figure 7. The X-ray ups and downs of Alpha Cen AB, and the Sun, over the past two decades. Green triangles mark times when LETGS spectra were taken. Fortuitously, the LETGS epochs cover nearly the full range of activity states of the two stars. (Adapted from Ayres [2015].)

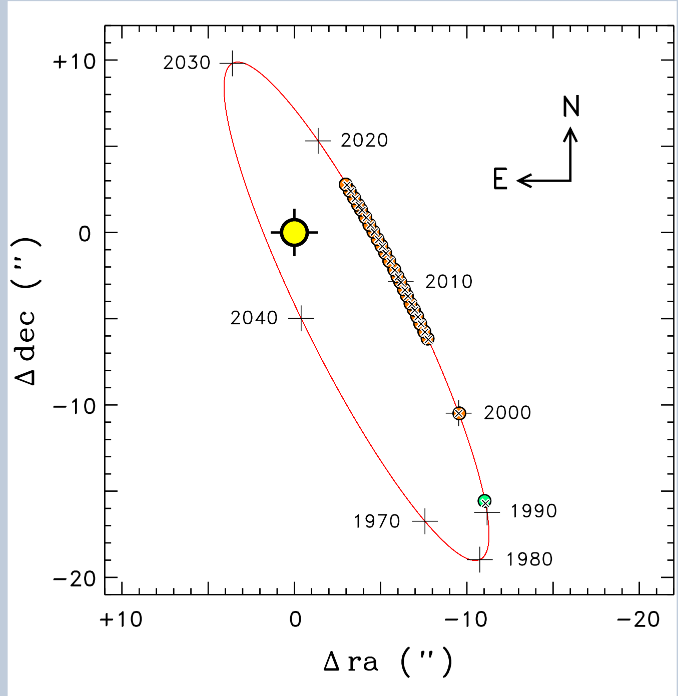

Figure 8. Alpha Cen AB relative orbit as recorded by Chandra (orange dots) and Hipparcos (green dot), compared with predictions (small x's). Decade timestamps (large pluses) are marked around the circumference of the orbit (period is almost exactly 80 years).

Small crosses in Figure 8 represent predictions from the recent Pourbaix & Boffin (2016) ephemeris for AB, derived mainly from high-precision radial velocities collected by the HARPS spectrograph at the VLT in Chile. The agreement is pretty good, but there are discrepancies (e.g., the Hipparcos point). The average vector deviation in RA and DEC was 60 mas: small to be sure, but highly significant with respect to the two dozen measurements. The ability to recognize such small systematic effects is testament to the excellent aspect reconstruction of *Chandra*. This might be of some interest to the Starshot folks, because you'd like to know exactly where A and B will be some decades from now, to properly aim the swarm of nanobots.

Back to the Dam Brewery

My reminiscing was interrupted when I realized the music had stopped, and the people around me were counting down to midnight. I toasted Liz and Sally, and wondered what the New Year might bring. I hoped, of course, for peace and goodwill to all the World's people. But, somewhat selfishly, I thought it would be awesome to not only continue tracking the Alpha Cen stars in their decadal coronal dance, but also enroll other subjects in what you might call the "Dynamo Clinical Trial:" checking the magnetic heartbeats of cool stars. Close visual binaries are a good choice, because you get two stars for the price of one pointing; and semi-annual sampling is not too onerous on the *Chandra* schedulers. HRC-I also is just what the doctor ordered for the coronal soft states of optically bright sunlike stars.

The champagne finally was beginning to do its job, and I had a sudden flashback to my first evening in Rio de Janeiro, for the IAU a few years back. I was on the rooftop of my hotel at a bar overlooking Copacabana beach. I saw then, for the first time, my old friend Alpha Centauri shining brightly above me, together with its neighbor Beta Cen pointing to the iconic Southern Cross. Under that celestial spell, I contemplated the ups and downs and several crossroads of my run-ins with the Alpha Cen system over now four decades. At that moment, I was tempted to shout out loud to the sky, "Twinkle, twinkle little (double) star…" But, thankfully, I ignored the temptation and took a sip of my Caipirinha instead. ▪

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For an overview, I recommend Martin Beech's 2012 article, "A journey through time and space: Alpha Centauri." (Astron & Geophys, 53, 6.10)

For a recent summary of the Breakthrough Starshot project, see "Near-Light-Speed Mission to Alpha Centauri," by Ann Finkbeiner, in Scientific American, 316, 30. (March 2017)

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Director's Log, *Chandra* date: 602294405

Belinda Wilkes

https://twitter.com/BelindaWilkes

During the past year we have continued our theme of planning for the future and assessing *Chandra*'s Legacy.

The summer workshop: "*Chandra* Science for the Next Decade" brought ~150 scientists from all over the world to present their work and discuss ideas for future *Chandra* science along with synergies with new and upcoming missions. A summary is provided on page 38 by one of the chairs of the SOC. The Cycle 19 CfP, released on 15th December 2016, was adjusted to respond to discussions at the meeting, including restoring Very Large Projects (>1Ms) and expanding several of the joint programs to facilitate proposals for Large multi-wavelength science (see What's New in the CfP; http://cxc.harvard.edu/proposer/whatsNew.html). The proposal deadline is 15th March 2017. The 2017 workshop: "From *Chandra* to *Lynx*: Taking the Sharpest X-ray Vision Fainter and Farther" will continue our theme, looking much further into the future as the NASA Mission Concept study for a successor to *Chandra*, "*Lynx*" (formally known as X-ray Surveyor; https://wwwastro.msfc.nasa.gov/Lynx/), moves into full swing (see Workshop advertisement on page 49 and http://cxc.harvard.edu/cdo/cxo2lynx2017). We encourage you to join us as we seek to better define the primary science and requirements for *Lynx*.

Within the CXC, we have hired 6 new science staff over the past 2 years, distributed throughout the science and the data systems divisions (see Table 1), and have adjusted the roles of existing staff as senior staff retire or change their emphasis. The new staff have brought energy and fresh perspectives to the CXC as they learn their roles and get to know those around them. We also celebrated the past, holding extremely well-attended memorial events for Dr. Stephen Murray, the original HRC PI, and Dr. Dan Harris, former CXC scientist (see articles in the 2016 Newsletter).

Name	CXC Group
Akos Bogdan	Calibration
Francesca Civano	Data Systems Operations
Raffaele D'Abrusco	Archive Operations
Rodolfo Montez Jr.	*Chandra* Director's Office
Malgosia Sobolewska	Monitoring and Trends Analysis
John Zuhone	ACIS

Table 1: New Science Hires at the CXC

Late in 2016 we were deeply saddened by the loss of our long-time Lead Flight Director, Dr. Mike Juda, after a long fight with cancer, and of retired HRC scientist, Dr. Martin Zombeck (see articles on page 16 and page 19).

2016 was a NASA Senior Review year. This is always a mixed blessing. Preparing the proposal is a major task involving significant time from many senior staff. While the technical aspects of the observatory do not change radically, the science section is always new, summarizing highlights from *Chandra* science results over the previous 2 years. With an average of ~500 papers per year, the proposal can only hope to skim the surface. On the other hand, the proposal provides an excellent opportunity to learn about the science our community is doing and the major accomplishments and high impact of many of the results. This knowledge feeds down into *Chandra* science talks to the public and the community. The SR2016 panel visited the *Chandra* Operations Control Center in March and met with us, toured the facility and discussed operations, science, impact, the future etc., for 2.5 days. Their report was very positive, stating that they "enthusiastically endorse the recommendation to extend the mission through 2020 and beyond" and that "The stewardship of the observatory remains exemplary. The Project's highest priorities are to maximize the scientific return of the observatory while maintaining the health and safety of the instruments and spacecraft."

At NASA's request, an idea rooted in the SR2016 process, I convened and chaired a meeting (at the Jan 2017 AAS) of staff from currently operating and soon-to-be launched NASA Astrophysics missions to open discussions exploring missing Legacy science and synergies. A particular topic of discussion concerned ways in which to proactively improve communication and coordination of planned observations, beyond those specifically requested by specific projects, so as to maximize the science output and legacy of the archives from our rich fleet of observatories while they are still in operation. I will report on actions and results from these discussions as they move forward.

Over the past year *Chandra* has continued its excellent performance, observing at high efficiency despite the continued challenge of maintaining the thermal balance of the various subsystems. In Cycle 19 there continues to be only one limitation on proposal submission as a result of the resulting operational complexities: a maximum of 2 Ms of observing time will be allocated within 60 degs of the ecliptic poles to Large and Very Large programs (see section 4.2 of the CfP). Science highlights for the year included the completion of the expanded *Chandra* Deep Field South, now totaling 7 Ms on the central region and the topic of a press release at the AAS in Grapevine (refer to the list of press releases on page 37), and a 24 hour period of multi-wavelength monitoring of Sgr A*. In addition to scheduled observations, *Chandra* observed a wide variety of DDT targets during the past year including GRBs, transients, supernovae, neutron stars, pulsars, magnetars and a number of different kinds of X-ray binary, intermediate mass black hole candidates, AGN, and the earth-like-exoplanet-hosting star system Proxima Centauri, well known for its X-ray flares.

Figure 1: Dr. Zurbuchen visiting the Chandra booth at AAS #229

Another major effort during the past year has been our response to NASA's direction to cut back and merge the NASA Astrophysics named fellowship programs, of which the Einstein Fellowship is a part (see article on page 36). NASA aims to retain the diversity of all aspects of this program, in particular to cover the full range of Astrophysics science, going forward. We will continue to work as part of the management team for the merged program, which will start with the 2018 Fellows.

The 2017 AAS in Grapevine, TX brought with it the opportunity to meet the new NASA Associate Administrator for the Science Mission Directorate, Dr. Thomas Zurbuchen. Dr. Zurbuchen spoke at the NASA Exhibit and toured all the NASA mission exhibits, including the *Chandra* booth (Figure 1), spending significant time meeting and talking with staff. He also spoke at the NASA town hall meeting. Dr. Zurbuchen is a scientist, most recently Professor of

Figure 2: The Chandra booth at AAS #229 with new educational activiy in the foreground.

space science and aerospace engineering at the University of Michigan, and his keen interest and broad knowledge of the science and missions of SMD were clear to us all. We look forward to working with him! Once again several *Chandra*-related presentations were given at the NASA hyperwall, which provides a wonderful display to highlight the spectacular *Chandra* and multi-wavelength data. The *Chandra* exhibit also hosted a new educational activity, designed and built in-house by CXC staff members Evan Tingle and Joseph DePasquale, to illustrate the principle of grazing incidence X-ray telescopes such as *Chandra*. This was a great success. Even I managed to adjust the two pairs of mirrors to focus the doubly-reflected rays on the detector. I encourage you to stop by and try it out for yourself at future meetings. ▪

Project Scientist's Report

Martin Weisskopf

Now in its 18th year of operation, the *Chandra* X-ray Observatory continues to provide unique capabilities for high-resolution X-ray imaging and spectroscopy, enabling high-impact research by the astrophysics community. Last year, *Chandra* successfully completed its biennial incremental Senior Review, which stated the following: "There appears to be no impediment to many more years of X-ray observations under the CXC stewardship. The 2016 Senior Review Panel enthusiastically endorses the recommendation to extend the mission through 2020 and beyond."

The *Chandra* Team is dedicated to maximizing the scientific performance and observing efficiency of the Observatory over the next decade as ESA and NASA develop next-generation facility-class X-ray missions. As noted in the Project Scientist's Report in the previous issue (#23) of this Newsletter, three issues are gracefully degrading the Observatory's performance as it ages: (1) thermal warming, (2) radiation damage, and (3) molecular contamination. Here we provide a brief update on the status of each of these issues, which are in fact intertwined.

Degradation of the multilayer insulation (MLI) blanketing the Observatory continues to complicate temperature control of several subsystems and components. However, through sophisticated mission planning—including limits on number of active ACIS CCDs and on pointing duration at thermally unfavorable orientations—accompanied by judicious relaxation of some temperature limits, the observing efficiency has remained high (nearly 70%). The ACIS utilizes passive radiators to cool its focal plane and housing to about −119°C and below −60°C, respectively; heaters on the detector housing were disabled to keep the focal plane as cold as possible, in order to minimize the charge-transfer inefficiency (CTI) of the radiation-damaged CCDs (item 2 below). However, other subsystems utilize heaters only, with no capability for cooling. Such cold-biased subsystems can provide thermal control only if the unregulated temperature is cooler than the desired set point. In some cases, this is no longer the case and the subsystem has "lifted off the heaters"—i.e., the temperature remains above the set point and thus is no longer regulated by the heaters. While this situation does not yet present thermo-mechanical problems, there is potentially an issue concerning molecular contamination (item 3 below), as components out-gas and off-gas more rapidly at higher temperatures.

After radiation damage of the ACIS front-illuminated CCDs during 8 unprotected radiation-belt passes immediately after opening the ACIS door, the CCDs have exhibited acceptably slow rates of CTI increase. In the previous issue of this Newsletter, we noted the potential loss of real-time space-weather monitoring of CCD-damaging low-energy protons, due to NOAA's plan to stop providing the real-time data stream from the Advanced Composition Explorer (ACE) after the Deep Space Climate Observatory (DSCOVR) became its primary real-time space-weather satellite at L1. Fortunately, even with full coverage of DSCOVR, NOAA has been able to provide nearly 70% coverage of ACE, which is adequate for the *Chandra* Team to monitor the intensity of protons that could damage the ACIS CCDs. In addition, solar activity is very low and expected to remain so through solar minimum in 2020 or so. For the record, the most recent stoppage of science due to a radiation event was in 2015 June.

Molecular contamination continues to accumulate on the (cooler) ACIS optical blocking filters, diminishing the instrument's response at low energies. Indeed, since about 2012, the rate of accumulation has been noticeably higher than earlier in the mission and changes in the atomic-edge structure indicate at least two contaminant species. This increased accumulation rate may possibly result from warming of surfaces within the Observatory (item 1 above). As mentioned in the previous issue of this Newsletter, the *Chandra* Team is revisiting the 2004 decision not to bake out the ACIS. Accordingly, a detailed study of the risk/benefits of baking out is currently in progress. In support of this study, Project Science is exercising its contamination-migration simulator to investigate various bake-out scenarios. Concern about temperature-dependent degradation of the CTI (item 2 above) imposes a constraint on the maximum acceptable bake-out temperature. In addition, uncertainties in the contaminants' volatilities and the possible presence of complex physical effects (mixing of multiple components, surface migration, thickness-dependent emissivity, etc.) limit the fidelity of the simulations. Consequently, the primary objective of the simulations is to ensure that the bake-out does no harm—such as leaving more contamination on the filters after the bake-out. ▪

Program Manager's Report

Roger Brissenden, Manager

Chandra has carried out more than 17 years of highly successful and productive science operations and remains unique in its capability for producing the sub-arcsecond X-ray images that are essential to accomplish the science goals of many key X-ray and multi-wavelength investigations in current astrophysical research. Telescope time remains in high demand, with significant oversubscription in the Cycle 18 peer review, held in June. The Cycle 18 review approved 168 proposals (including observation, archive and theory), of 547 submitted by researchers from 25 countries.

NASA has announced its decision to continue the *Chandra* program, potentially through 2030, by extending the *Chandra* X-ray Center (CXC) contract with the Smithsonian Astrophysical Observatory.

In support of NASA's biennial Senior Review of operating missions, *Chandra* X-ray Center and Marshall Space Flight Center (MSFC) program staff submitted the *Chandra* Senior Review proposal in January 2016, and the NASA review committee conducted a site visit at the CXC in March. The committee's report, released in June, praised *Chandra*'s scientific productivity and the program's stewardship of the observatory. The program has submitted to NASA headquarters a plan for responding to the review committee's recommendations.

The Observatory continues to operate extremely well overall but with several incremental changes in performance, due primarily to the gradual accumulation of molecular contamination on the UV filter that protects the ACIS detector, and to progressive degradation of the spacecraft's thermal control surfaces.

Condensation on the UV filter reduces ACIS's sensitivity to low-energy x-rays (but does not affect the HRC). The *Chandra* Project Science group at MSFC, together with CXC staff, continue to consider the possibility of baking out the ACIS filter to remove condensed contamination.

The decline in spacecraft insulation effectiveness results in thermal constraints that require extra effort in scheduling observations and the use of special strategies to ensure continued safe operation in the evolving thermal environment, but has not significantly affected *Chandra*'s observing efficiency.

The combined effects of accumulated radiation damage and increasing temperature on *Chandra*'s aspect camera CCDs have begun to affect the camera's ability to detect faint stars. Left unchecked, this trend would present difficulty in acquiring and tracking guide stars, which could decrease mission efficiency. Several mitigation strategies have been successfully implemented, and further options are under investigation, including a long-term program of testing to assess the feasibility of annealing the CCD detectors.

Science data processing, archiving, and distribution have proceeded smoothly during the year, with average time from observation to data delivery to observers remaining at about a day. Six Targets of Opportunity or Director's Discretionary Time observations required interrupting *Chandra*'s observing activities and uploading a new command load to carry out the new observations. On three occasions the spacecraft transitioned to a safing configuration due either a calibration error in the sun sensor or to an excessive attitude error due the aspect system tracking "warm" camera pixels in place of guide stars. All cases were benign, with no impairment to the spacecraft, and science observations were resumed promptly.

The CXC's Data System team released software to support *Chandra* users submitting Cycle 18 observation proposals, as well as to aid the Cycle 18 Peer Review process. In April the team released a new version of the CIAO data analysis package, and in December software to support the Cycle 19 Call for Proposals.

Release 2 of the *Chandra* Source Catalog (CSC2), which is in production, contains (as of January 2017) approximately 300k source detections, of an estimated 350k total detections expected. We plan to publish a FITS-formatted detection list during the first half of 2017, and to complete the matching of detections across sets of stacked observations and the processing of source properties later in the year. Full release of CSC2 is planned for the fourth quarter of 2017.

In August, the CXC held a workshop "*Chandra* Science for the Next Decade" to provide an opportunity for the scientific community to help guide future *Chandra* scientific programs. The annual Einstein Fellowship Symposium, at which current Einstein Fellows present their recent research results, was held in Cambridge, MA in October. The program is available at: *http://cxc.harvard.edu/fellows/program_2016.html*. NASA conducted its regular reviews of CXC operations in April and November, and the *Chandra* Users' Committee met at the CXC in September.

The CXC Communications and Public Engagement group has been active in issuing image releases, science press releases and other communications of *Chandra* research results, including 13 *Chandra* science press releases, 3 non-science press releases and 24 additional images that resulted in 3229 articles in print and electronic news outlets (through November 2016). *Chandra* images were used in 19 releases of HEASARC Picture of the Week, 1 Astronomy Picture of the Day and 7 releases of NASA Picture of the Week. The CXC produced 33 podcasts on *Chandra* results, as well as the Space Scoop special series for children, and material on science topics related to sports in the Olympics and Paralympics. The group posted 42 blog entries, including additions to "Meet the Astronomer" profiles of Principal Investigators of *Chandra* science observations. A complete listing is available at *http://chandra.harvard.edu/press*. ▪

Chandra Source Catalog

Ian Evans for the *CSC* team

Release 2.0 of the *Chandra* Source Catalog (CSC) includes observations released publicly through the end of 2014, and will include information for of order 350,000 source detections from roughly 10,000 *Chandra* ACIS and HRC-I imaging observations. For each source the CSC will tabulate numerous properties (with their associated confidence intervals) and include extensive FITS data products for each field and source region that will be directly usable for scientific analyses. Multiple observations of the same field (pointings co-located within 60 arcsec and obtained using the same instrument) are co-added, or "stacked," prior to source detection to maximize detectability of sources. An improved source detection method allows detection of point sources reliably down to roughly 5 net counts on-axis, for exposures shorter than the median *Chandra* observation duration.

At the time of writing, roughly 98% of the 7,289 stacked fields have completed the source detection phase, while the remaining 2% are expected to complete processing and quality assurance assessment in the next few weeks. Roughly 5% of the fields that have completed processing will require some level of reprocessing due to problems identified in quality assurance assessment. Once these final fields complete source detection processing, we will immediately update the "preliminary detections list" with the complete set of detections that will be included in the final catalog release. The preliminary detections list is a FITS binary table that is available on the CSC release 2.0 website (*http://cxc.cfa.harvard.edu/csc2/*) that includes position, likelihood, and intensity estimates (a proxy for aperture photometry) in multiple energy bands for ACIS observations and a single energy band for HRC-I observations, together with their associated confidence intervals.

Following the source detection phase, all of the detections from overlapping fields that include the same location on the sky will be matched to identify sources on the sky. Because the size of the *Chandra* PSF is a function of off-axis angle, a single off-axis detection may be resolved into multiple sources by matched on-axis detections. These matches will be reconciled as part of this "master match" phase. This phase will also assign names to distinct sources on the sky, following IAU standard nomenclature. Following master match processing, we will update the CSC release 2.0 website with a "preliminary sources list" that identifies distinct X-ray sources on the sky and matches them to the individual detections in the preliminary detections list.

The remaining steps required to complete the official catalog release include extracting source properties, generating limiting sensitivity maps, and populating the final catalog database. These steps can be executed independently for each set of overlapping stacked fields on the sky, as soon as master match processing is completed for the sources included in those fields. Data for those sources will subsequently be made available through the CSCview web interface. Once these steps are completed for all of the catalog fields, release 2.0 will be made the official catalog release and will be accessible by default through all of our standard catalog interfaces.

The current version of the catalog (release 1.1) as well as extensive user documentation, may be accessed through the CSC website (*http://cxc.cfa.harvard.edu/csc/*). The documentation describes the content and organization of the catalog in detail, and lists important caveats and limitations that should be reviewed prior to using the catalog data. The various user interfaces are described, and there are several examples and user threads that demonstrate the use of these tools to access the catalog. Updates and news about release 2.0 of the catalog will continue to be added to the website (*http://cxc.cfa.harvard.edu/csc2/*) through the end of production.

The 2016 *Chandra* X-ray Observatory Senior Review Committee (SRC) identified the second major release of the *Chandra* Source Catalog (CSC) as a major mission initiative that "… will be one of the most significant CXO legacies." The *Chandra* Source Catalog team appreciates the strong endorsement of CSC project by the SRC. Our plan for the foreseeable future is to provide incremental releases with new data added every few years. A new major version of the entire catalog will be constructed only if there are significant algorithm improvements that warrant full reprocessing. The last legacy release of the CSC will be completed after the end of the *Chandra* mission once all data are reprocessed with the final set of mission calibrations. We hope and expect that this will be many years away!

We are looking forward to providing the community with release 2.0 of the CSC this (Northern) summer, which will (in the words of the SRC) "[enable] studies of a variety of astrophysical objects both on its own and in combination with other multiwavelength surveys." ▪

Authentic Data Inquiry a Focus in STEM Programs

Kathy Lestition

Student-centered inquiry and data analysis are becoming an increasing focus of K-12 STEM programs. When the Education and Public Outreach portfolio was carried out under the scope of the *Chandra* mission and CXC, working with Dr. Terry Matilsky at Rutgers University, we pioneered a program of authentic data analysis activities using the SAO-developed astronomical imaging and data visualization application, SAOImage DS9 (*http://ds9.si.edu*), with a virtual observatory. *Chandra* EPO, and later MIT, ran summer workshops for high school students for 10 years using this program. A longitudinal study carried out by Goodman Associates, an independent evaluation organization, gave evidence that the program strengthened student confidence to succeed in STEM subjects, reinforced interest in STEM subjects and STEM majors, and increased skills in problem solving.

Despite its success, the program was discontinued as Congressional and Agency budget decisions decreased EPO budgets. And finally, as this audience knows, the EPO mandate was removed from missions and restructured into the Cooperative Agreement administered through NASA's Science Mission Directorate (SMD) under which these activities operate today. *Chandra* is a participant in NASA's Universe of Learning (UoL) collaborative that includes STScI, IPAC, JPL and Sonoma State University. *Chandra*-specific partners include SAO's Science Education Division, The National Science Olympiad, and the Christa Corrigan McAuliffe Challenger Center at Framingham State University.

Through these transitions, CXC has kept the student-centered data analysis activities alive in various forms which has led to many more manifestations of such programs and activities. This article describes some of the most interesting.

X-ray Data Analysis in Coursera

After more than a decade of teaching the *Chandra*-based Astrophysics Summer Institute as well as an online full semester course in X-ray data analysis through Rutgers, Terry Matilsky has adapted the material for a broader audience. He developed about 30 video lessons and initiated a Massive Open Online Course (MOOC) through Coursera (*https://www.coursera.org*). This course utilizes SAOImage DS9 to allow sophisticated discussions involving time variability and energy spectra and full immersion for students in *Chandra* observations of objects such as Cas-A, 3C 273, the Bullet Cluster, and Cen X-3. Since 2014, the course has been presented three times via the Coursera platform.

Some relevant statistics. Engaged students exceeded 20,000. (Formal enrollments were higher, but this number represents students that actually accessed the material in some way.) The number of video viewings exceeded 200,000. The total number of students who submitted all (quite challenging) homework assignments and passed with distinction exceeded 1,000.

Much has been made of the low "completion" rates for MOOCS, but it is clear that people use these courses in many ways. A substantial number of students wrote to say how much they enjoyed the material, even though they didn't submit the homework. A regular highlight of the course are the discussion forums, whereby students engage the staff and expand the scope of the data analysis. It is quite gratifying to see spontaneous study groups form, some in foreign languages such as Spanish and Greek. The next session of the course is scheduled to begin on January 23rd, 2017 and will utilize a new Coursera platform that will allow for courses to be run more or less continuously throughout the year.

Collaborative Efforts in the Universe of Learning

As part of the UoL partnership, *Chandra* staff have been collaborating with SAO's MicroObservatory Robotic Telescope team on efforts to create authentic data exploration experiences for a wide variety of astronomy learners. Over 50,000 users per year—including classroom, after-school, museum, and citizen science audiences—currently request and receive astronomical image data from the MicroObservatory telescopes.

Since the suspension of the original data analysis workshops, computer technology developments have enabled progress in connectivity, ease of use, and user-friendly interfaces. The browser-based SAOImage JS9 (*http://js9.si.edu*) program was developed out of SAOImage DS9 to enable wider audience use of data analysis functions. JS9 was consciously designed with features that make it easy for novice learners to see the quantitative information that is behind the image data, thereby allowing them to pursue a wider variety of authentic inquiry projects than could have been supported in the past.

The MicroObservatory (MO) team from SAO's Science Education Department has been working with Eric Mandel from SAO's High Energy Division to create a modified version of the JS9 interface with features customized for MicroObservatory's novice astronomy learners. He has been supporting the MO project by creating targeted JS9 modules that help bridge the gap for "apprentice" astronomers to enhance and analyze their FITS images using the same powerful tools that *Chandra* scientists use.

As all good collaborations do, this one goes both ways—several features requested by the MicroObservatory team to specifically meet the needs of novice users have become standard features of the production version of JS9. One notable example is the live graphic color table that now appears below the JS9 image window, giving users a much more intuitive sense of how their adjustments of contrast, bias, and extrema values affect the visualization of the image data. The next effort of the MO team is to seamlessly integrate many of the images from the *Chandra* Open FITS project into the MicroObservatory JS9 interface, so that users can compare their own MicroObservatory telescope data with that of NASA's multi-wavelength space observatories.

In a similar, but slightly different direction, the CXC UoL team has developed a "scaffolded" model which consolidates all of the data analysis activities developed through *Chandra* EPO and UoL, including pencil and paper data exercises for low-resourced areas (see "Imaging" at http://www.chandra.si.edu/edu/formal/index.html), Open Fits (http://chandra.harvard.edu/graphics/resources/handouts/lithos/openfits_litho.pdf) and student coding programs (http://chandra.harvard.edu/edu/pencilcode/). A future addition currently under development will be a JS9-based program that will allow student analysis and production of multi-wavelength images.

Our UoL partner, the National Science Olympiad, which reaches over 220,000 students through over 7,500 teams nationwide, also uses the data analysis activities for study materials and in astronomy competitions.

Successful Summer Internship at OCC

Finally, in a different area, the CXC has been hosting undergraduate summer interns funded through NASA's Space Grant Consortium to work at the Operations Control Center (OCC). This past summer, two exceptional interns developed a 3D model of the *Chandra* Observatory that visually represents live thermal telemetry data coming down from the spacecraft. Using engineering blueprints to locate thermistors, intern Amy Nuccitelli developed the model while intern Jonathan Brand developed an imbedded interactive 3D display website. This tool is currently used by OCC planners and engineers. See the *Chandra* blog post (http://www.chandra.si.edu/blog/node/612) for more information.

We encourage any of our audience with ideas for inquiry or data analysis activities that can be used with students or the general public, or who want to participate in any of our public programs as a developer, reviewer, or presenter to contact Kathy Lestition at klestition@cfa.harvard.edu. ▪

HiPS: the Future of *Chandra* Data Visualization

Raffaele D'Abrusco

The growing size and complexity of astronomical observations represent an opportunity for discovery and, simultaneously, a challenge for the access and visualization of the data. With *Chandra* observations covering 790 square degrees (~2% of the sky) scattered throughout the sky with multiple overlapping observations, the task of providing a general and flexible framework for the visualization and exploration of this large, heterogeneous dataset can be arduous. The challenge is compounded by the need to keep up with the dramatic improvement of internet technologies and platforms for web-based visualization that are constantly striving to provide users with a seamless and effective experience.

The *Chandra* X-ray Center (CXC) has decided to implement a novel type of data designed to allow easy access, visualization and navigation of public *Chandra* images

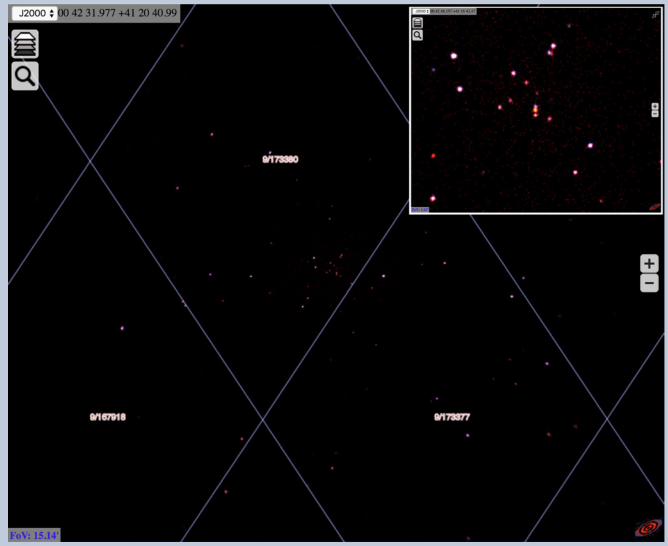


Figure 1: example Chandra HiPS color prototype of the central region of M31. The lines represent the HEALPix grid, the numbers the indices of the tiles and, in the lower left corner, the FOV of the image is shown (~15'). In the upper right corner, a close-up of the core of M31 (FoV: 1.62') is shown.

across all angular scales observed, from large regions of the sky to single pixels. This data product, called Hierarchical Progressive Survey (HiPS), combines single images into a multi-resolution hierarchical structure that can be interactively explored by zooming and panning. HiPS, developed by the Centre de Données astronomiques de Strasbourg (CDS) and currently being codified as a standard by the International Virtual Observatory Alliance (IVOA), was originally designed to visualize all-sky imaging datasets but is also appropriate for the sparse sky coverage achieved by *Chandra*.

HiPS implementation employs the HEALPix tessellation scheme to produce a hierarchy of images resampled onto distinct HEALPix maps of increasing angular resolution and efficiently indexed for quick retrieval. Single, overlapping observations are combined and contribute to each pixel in the common areas for all maps. HiPS are "progressive" because higher order tiles (covering smaller regions of the sky at higher resolutions) are progressively retrieved as one zooms in. To keep the amount of data downloaded small without noticeable degradation of the image quality at each scale, only maps of suitable orders are retrieved while browsing and pixels at each order are grouped into "tiles", the basic data units transmitted to the client from the HiPS server.

HiPS can be displayed in both desktop applications (Aladin; http://aladin.u-strasbg.fr/) and web-based interfaces, like ESAsky (http://sky.esa.int/) and JUDO2 (https://darts.isas.jaxa.jp/astro/judo2/). The HiPS specification allows linking to the metadata of single observations and overlays of different types of data, like catalogs of sources and footprints, providing support for a comprehensive presentation of all data available.

The CXC is working to prototype *Chandra*-based HiPS. The final official color and grayscale *Chandra* HiPS will contain all public archival observations to date, and new, incremental HiPS will be created regularly as new data become public. This technology will help to maximize the scientific return of the mission by facilitating the access to *Chandra* data through as many channels as possible. HiPS also represents a cornerstone for the future of the archival interfaces that will be offered by the *Chandra* Data Archive (*http://cxc.cfa.harvard.edu/cda/*), as it will provide the infrastructure to implement new features designed to enhance the productivity of astronomers by making the X-ray Universe seen by *Chandra* more easily discoverable and navigable. ▪

References and Resources

HiPS → Ferrique, P. et al . 2015, A&A, 578A, 114F
HEALPix → *http://healpix.sourceforge.net/*

Recent Updates to *Chandra* Calibration

Larry P. David

Prior to this year, the ACIS detector gain has been calibrated in three months intervals by co-adding observations of the ACIS external calibration source (ECS). ACIS is exposed to the ECS whenever it is in the stowed position, which occurs during each radiation belt passage. The ECS is composed of the radioactive isotope ^{55}Fe, which has a half life of 2.7 years. Since *Chandra* has been in orbit for over 17 years, the ECS has faded significantly and can no longer be used to calibrate the ACIS gain to the same statistical precision on the same spatial (16" by 16" regions) and temporal (3 months) scales as before. To remedy this situation, the most recent ACIS gain correction file (released in CALDB 4.7.3 on Dec. 15, 2016) was derived by co-adding six months of ECS data (from Feb. through July, 2016). Since the ACIS gain only changes by about 0.1% per three month interval, the gain is still being calibrated to within the requirement of 0.3%. At the present time, the ACIS gain can still be calibrated on the same spatial scale as before, but it will probably become necessary within the next year, or so, to increase the region over which the gain is calibrated. In addition, a set of ACIS QE uniformity maps (one for each chip) were previously released every two years by co-adding ECS data. This can no longer be achieved given the present photon flux from the ECS. The calibration team is presently working on the next set of QE uniformity maps, which will cover a four year time frame from 2012-2016. In anticipation of further dimming of the ECS, the *Chandra* calibration team is investigating strategies for optimizing the ACIS gain and QE uniformity calibration with astronomical sources.

A revised version of the ACIS contamination file was also released in CALDB 4.7.3. There are three main components to the ACIS contamination model: 1) the time-dependence of the condensation rate onto the ACIS filter, 2) the chemical composition of the contaminant, and 3) the spatial distribution of the contaminant on the ACIS filters. Periodic gratings observations over the course of the *Chandra* mission have shown that there have been at least two sources of out-gassed material condensing onto the ACIS filter, each with its own time-dependence and spatial distribution. While the previously released version of the ACIS contamination model continued to accurately predict the opacity of the contaminant near the ACIS-I and ACIS-S aimpoints, the depth of the contaminant toward the edges of the detectors was increasing faster than predicted by the previous contamination model. This necessitated the release of a new contamination model in CALDB 4.7.3 which incorporates an improved spatial model for the distribution of the contaminant on the ACIS filters, and primarily affects the analysis of off-axis objects observed since 2013.

The rich cluster of galaxies, Abell 1795, is one of the primary calibration sources used to monitor the build-up of contamination on the ACIS filters. Abell 1795 has been observed at multiple locations and at multiple times on both ACIS detectors making it the the best source for estimating the systematic uncertainty in ACIS flux measurements due to calibration uncertainties. In conjunction with the latest ACIS contamination model, the rms scatter in the derived 0.5-2.0 keV fluxes (the energy band most affected by contamination) among the full set of Abell 1795 observations (nearly 100) is 2.8%. The corresponding rms scatter in the derived fluxes in the broader 0.5-7.0 keV energy band is 3.4%.

Since launch, the calibration team has monitored the gain and QE of both HRC detectors with periodic observations of the white dwarf HZ43. While the HRC-I has been fairly stable over the course of the mission, the HRC-S gain and QE have steadily declined. This has been accounted for with the release of yearly gain and QE CALDB products. Due to the continued QE and gain decline, the operating high voltage of the HRC-S was increased in 2012 to restore the gain and QE to near launch values. Since 2012, the decline in the HRC-S QE has been about 2-3% per year. At the present time, the CXC calibration team along with the HRC IPI team have decided not to further increase the HRC-S high voltage, since any any adjustment to the high voltage involves some risk to the detector. The calibration team will therefore continue to release annual QE and gain files to produce consistent derived fluxes. The HRC-S effective area file used by PIMMS also will continue to be updated prior to each review cycle. ▪

Michael Juda (1959–2016)

We join with the extended *Chandra* team (CXC, MSFC, the Northrop Grumman and instrument teams) in mourning the untimely loss, on Dec 3rd 2016, of our colleague and friend Dr. Michael (Mike) Juda after a long and valiant fight with cancer. He died surrounded by family, friends, and colleagues, many of whom had kept a vigil at Beth Israel Deaconess Medical Center since his admission just before Thanksgiving.

Mike has long been a critically important leader in the *Chandra* flight and science teams, serving as lead Flight Director and Mission Operations Manager since 2004. His deep knowledge of the spacecraft and its operations, calm and unflappable leadership during spacecraft anomalies, and astute guidance of the development of upgrades and improvements to the spacecraft operations procedures and software have contributed directly to *Chandra*'s longevity and scientific productivity.

Mike received his BSc at Caltech in 1981 followed by his PhD at the University of Madison, Wisconsin in 1988. His doctoral thesis involved very difficult measurements and interpretation of the soft X-ray background below 0.2 keV. Subsequently, as a Research Scientist in the Wisconsin Space Physics Group, he worked with the GSFC/Wisconsin team developing microcalorimeters as high throughput, high spectral resolution X-ray detectors. Mike was hired in 1993 to become the AXAF Science Center (now the *Chandra* X-ray Center) instrument scientist for the microcalorimeter detector, part of the original suite of instruments on the AXAF mission, later rechristened as the *Chandra* X-ray Observatory. However, by the time Mike arrived in January 1994, the calorimeter instrument and its AXAF-S mission had been cancelled. Mike willingly took on the role of instrument operations scientist for the AXAF-I High Resolution Camera (HRC), the radiation monitor detector, and the two transmission gratings—all instruments he had never previously worked on. He was embedded with the HRC instrument Principal Investigator team to help prepare and calibrate that detector, leading to seamless transfer of HRC calibration, software, and operations to the CXC. He provided important insights to ameliorate high HRC background, to deal with misplaced events, and to create and use a timing simulator to restore precise timing capabilities. He monitored the radiation detector through years of extended operations, including dealing with degradation due to increasing temperatures, and salvaging the system's ability to autonomously shut down during high radiation. When the unit finally failed, the *Chandra* software was reprogrammed to utilize the HRC anticoincidence rates to recognize and trigger shut down during high radiation events.

Mike was recognized early for his general understanding of instruments and mission operations. Coupled with his calm and objective approach, he was asked and agreed to become a *Chandra* Flight Director one year after launch. This is an extremely critical assignment. In times of crisis the flight director has ultimate authority over the fate of the mission. In 2004 he became the Lead Flight Director, and the Mission Operations Manager. In the latter role, he oversaw the Northrop-Grumman flight operations team, and the SAO Operations Control Center team. He also continued in his role as HRC operations instrument scientist, supporting and providing operations training to the team through the difficult personnel transition following the death of the PI, Dr. Stephen Murray, in Aug 2015 (see article in 2016 Newsletter). As Flight Director and chairman of the Level 4 Flight Director Board, Mike ensured careful consideration and control of upgrades and improvements to *Chandra*'s flight software and operations, and provided close oversight of all spacecraft commanding.

Through his actions and leadership, Mike provided an impeccable approach to *Chandra* mission operations, overseeing the safety and health of the Observatory. As a result, he contributed directly to maximizing the scientific return and high impact of *Chandra* and to ensuring that the mission continues to operate at a high level of performance 17 years after launch. Mike's exemplary leadership of the *Chandra* operations teams—including during special maneuvers and spacecraft anomalies, at all hours of the day or night—were essential to *Chandra*'s longevity and scientific productivity. During spacecraft anomalies he directed the complex activities of multiple teams with consummate skill and poise. Under his leadership the team efficiently recovered from 100% of anomalies with no harm to the spacecraft, and successfully implemented a wide variety of flight software and operational improvements.

Mike made many contributions to the *Chandra* program's success. One notable example is his leadership of the development and implementation of a new paradigm for protecting the Observatory's X-ray detection instruments from solar radiation. In contrast to the previously used procedure, the new process maintains active control of the spacecraft's pointing while the instruments are safed, greatly reducing the risk of spacecraft component overheating, decreasing the time needed to create a new set of command loads, and increasing the amount of science observing time available. Because the new process affected a great many operational systems, careful planning and exhaustive testing were imperative. Mike led this multi-year effort, working closely with the flight, science and ground operations teams to plan and monitor all aspects of the work, from design to testing and implementation. The new process has performed flawlessly during many uses since installation, decreasing risk to the spacecraft and increasing *Chandra*'s scientific productivity. Mike's leadership was critical to the successful completion of this vital project. A second notable example was his capable and calm leadership during the mission's most exciting (i.e., scariest) event: the thruster gas tank pressure anomaly (see *Chandra* News Issue 17, p26). Sudden drops in pressure seen first on July 19, 2009 and subsequently 12 days later opened the possibility of a ruptured tank or line, which would lead to damage from hydrazine and the loss of momentum unloading capability. Immediate operational constraints were imposed and daily meetings assessed all possible causes. The ultimate conclusion that the issue was a faulty sensor reading was verified in late August via carefully planned thruster firing tests.

From Belinda Wilkes: "As Director, my most vivid memory of Mike in action is answering a phone call while I was driving along the M6 motorway in the UK during a summer vacation in July 2014 to hear Mike's calm and precise voice letting me know that *Chandra* was in Normal Sun Mode. He provided a description of the cause (not acquiring stars), the most likely explanation (a gyro bias jog), a detailed timeline for recovery, answered all my questions, and continued to keep me informed via email and alerts until recovery was complete only ~13 hours later. His detailed understanding of all aspects of the process, technical, procedural and organisational, and his calm, careful and methodical approach, always inspired me with confidence that *Chandra* was in excellent hands."

Mike's effective, unflappable leadership, whether during long-term planning or in the face of the urgency of a spacecraft anomaly, and his ability to enable disparate groups to work smoothly toward a common goal, earned deep respect from all those who worked with him, and represent an aspirational model for staff at all levels. The CXC will never be the same without him, but during his tenure he trained the two current flight directors, the HRC team, and all those around him. We will continue to aspire to his high standards and put into practice the lessons we learned from him, remembering him as we go about our work each day. ▪

Prepared by Belinda Wilkes, Dan Schwartz, Roger Brissenden, Harvey Tananbaum, Ralph Kraft

Chandra-Related Meetings and Important Dates

Cycle 19 Peer Review:
June 19-23, 2017

Cycle 19 Cost Proposals Due:
September 26, 2017

Workshop: From Chandra to Lynx
August 8-10, 2017

***Chandra* Users' Committee Meeting:**
Late September/Early October, 2017

Einstein Fellows Symposium:
October 12-13, 2017

Cycle 20 Call for Proposals:
December 2017

Useful *Chandra* Web Addresses

Chandra:
http://chandra.harvard.edu/

CXC Science Support:
http://cxc.harvard.edu/

Science Publication Guidelines
http://cxc.harvard.edu/cdo/scipubs.html

CIAO Software:
http://cxc.harvard.edu/ciao/

Chandra Calibration:
http://cxc.harvard.edu/cal/

ACIS: Penn State
http://www.astro.psu.edu/xray/axaf/

High Resolution Camera:
http://cxc.harvard.edu/cal/Hrc/

HETG: MIT
http://space.mit.edu/HETG/

LETG: MPE
http://www.mpe.mpg.de/xray/wave/axaf/index.php

LETG: SRON
https://www.sron.nl/astrophysics-chandra-letg

MSFC: Project Science:
http://wwwastro.msfc.nasa.gov/xray/axafps.html

NASA's Chandra Page
https://www.nasa.gov/mission_pages/chandra/main/

ACIS Update

John ZuHone, for the ACIS Team

The ACIS instrument continued to perform well over the past year conducting the vast majority of Guest Observer (GO) observations with *Chandra*. There was only one interruption to the scheduled observations due to anomalies with the ACIS instrument, which was the unexpected power-off of the side A of the Digital Processing Assembly (DPA) on 9 December 2016. Side A of the DPA had spontaneously turned off on three occasions earlier in the mission. For each of those occurrences, the most likely explanation for the anomaly was a single event upset (SEU) that resulted in a spurious power off command to the electronics. An examination of the telemetry from the December 2016 event showed that this anomaly was consistent with the previous anomalies. Based on this conclusion, the ACIS instrument team prepared real-time command procedures to restore the ACIS instrument to its nominal configuration for science observations. The recovery to the nominal configuration was completed 10 hours after the anomaly was detected and science observations resumed soon afterward. Side A of the DPA has functioned nominally since the recovery. Only 29 ks of science time was lost from one observation.

Separately, on December 16, 2016, starting about 4.9 ksec into obsid 18278, data from CCD S1 were missing from every other exposure. The other chips all continued taking data without incident. This anomaly has never occurred in flight before. All subsequent observations, including one in the same ACIS configuration, executed nominally. The most likely cause is an SEU (unrelated to the one that caused the DPA shutdown) in the electronics which were processing the data from S1. It seems unlikely that precisely this anomaly will recur. The ACIS team is currently investigating this anomaly.

In 2016 the quiescent background rates continued to increase rapidly as the Sun becomes less active (see Figure 1). This increases the probability of telemetry saturation, particularly for observations that use Very Faint (VF) mode. Observers should take the increasing background rate into consideration when specifying a telemetry format and choosing the number of optional chips. The background rates will be updated at regular intervals at http://cxc.cfa.harvard.edu/cal/Acis/detailed_info.html.

The contamination layer continues to accumulate on the ACIS optical blocking filter. The contamination calibration model version N0010 was released with CALDB 4.7.3 in December 2016, which includes improved time-dependence and spatial variation of the several components (C, O, and F) known to dominate the chemical composition of the contamination layer (see http://cxc.cfa.harvard.edu/caldb/downloads/Release_notes/CALDB_v4.7.3.html#TD_ACIS_CONTAM_10 for more information). The charge-transfer inefficiency (CTI) of the front-illuminated (FI) and back-illuminated (BI) CCDs continues to increase at the expected rate.

Thermal control of the ACIS focal plane and electronics boxes continues to be a significant issue. The detector housing heater was turned off during the past year to remove one source of heating on the focal plane. It was originally turned on in August 2015 to determine if it would help slow the buildup of the contaminant, but subsequent analysis suggests it was ineffective. As in previous years, GOs are encouraged to designate chips not required for their science goals as optional (by selecting OFF1, OFF2, etc., in the order in which chips would be turned off if necessary, on the RPS form) to help mission planners manage the temperature of ACIS components. Further details are provided in the Proposers' Observatory Guide, and all users are urged to read the section on optional chips carefully. As the satellite continues to age, the need to turn off optional CCDs is likely to increase and therefore the need for GOs to properly specify the number and selection of optional CCDs will increase accordingly. ▪

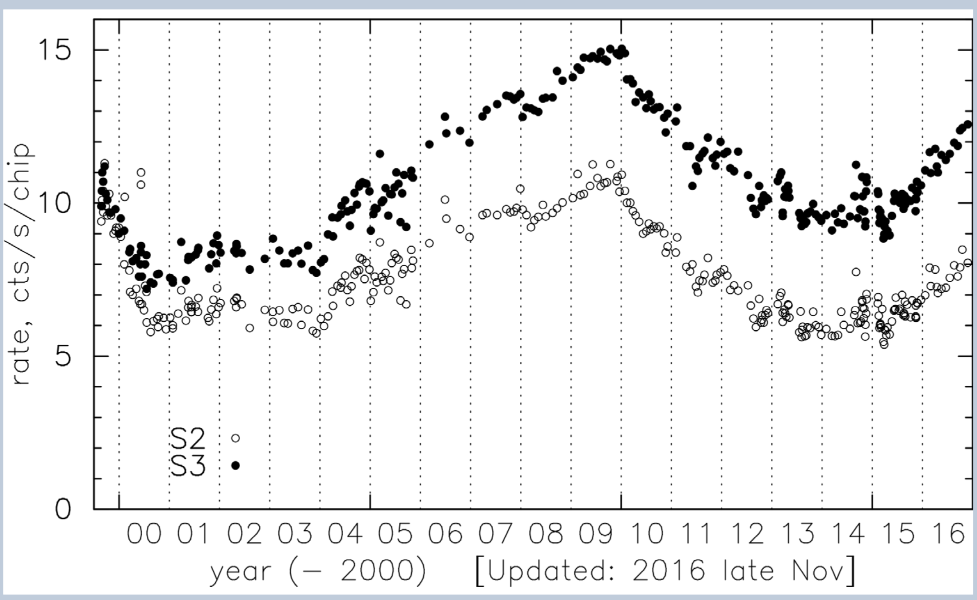
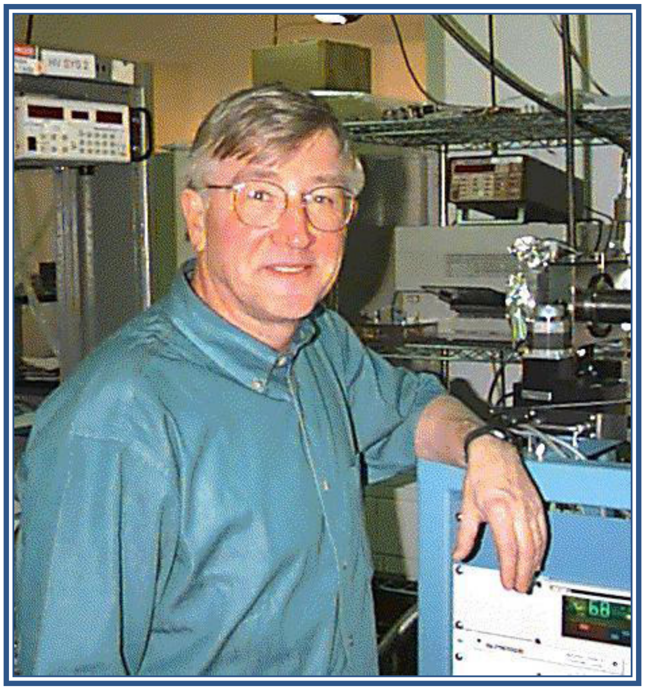


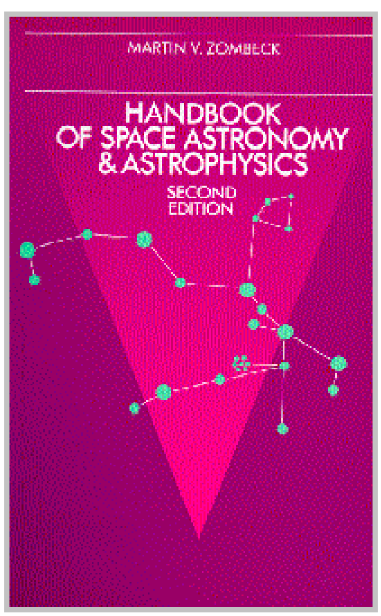
Figure 1: Quiescent background rates for ACIS. Reproduced from Figure 6.27 of the Proposer's Observatory Guide, credit Terry Gaetz; see also Tables 6.9 and 6.10 of the Proposer's Observatory Guide.

Martin Zombeck (1936–2016)



In late September 2016, Martin Zombeck, who had been the HRC project scientist for many years until his retirement in 2005, unexpectedly passed away.

Martin, apart from his scientific accolades and career, was known for his extremely friendly and avuncular nature. He was always the most popular and most in demand emcee at any social function—a great boss, travelling companion and friend. If you were lucky, he was the scientist you got stuck sitting next to on the bus. During his tenure as HRC project scientist, every piece of equipment engendered an appropriate and elaborately detailed operator's manual. Everything from the laboratory thermostat, to the computer clock synchronization was regimented, photographed and documented. His breadth of interests and attention to methodical details are reflected in his never ending "n"th edition "Handbook of Space Astronomy and Astrophysics". Later editions along with their expected chapters on astronomical topics even ventured into wine selection. At the time of his passing, Martin was working on a subsequent edition. Martin will be greatly missed.



Martin was a veteran of SAO and played a key role in developing flight instruments that were mainstays in X-ray astronomy. He began working at American Science and Engineering in the late 1960's on the S-054 X-ray Telescope on Sky Lab to carry out Solar studies and continued that work when he joined the CfA in 1976. By the early 1980's, he had already begun working on the Advanced X-ray Astrophysics Facility (AXAF), which subsequently became *Chandra*. In the early 1980's until June 1984, Martin was the AXAF Mission Support Team Project Scientist.

While still engaged with AXAF and the AXAF Mission Support Team working on demonstrating the high angular resolution capability for AXAF, Martin began working on the ROSAT High Resolution Imager (HRI) in the late 1980's. Martin was one of the ten co-authors of the important paper (over six hundred citations) "The focal plane instrumentation of the ROSAT telescope" (1987, SPIE, 733, 519). He was lead author of the paper describing the ROSAT HRI calibration (1990, SPIE, 1344, 267) and of its orbital performance (1995, SPIE, 2518, 304). Following his work on ROSAT, Martin again contributed to studies supporting the AXAF Mission Support Team. By the mid-1990's Martin had become a key contributor to the High Resolution Camera (HRC) Team for AXAF and served as the HRC Project Scientist starting in 1992. Martin retired from SAO in 2005.

During Martin's hardware activities, he began the compilation of a High Energy Handbook that eventually would see three editions. His High Energy Astrophysics Handbook grew from its first incarnation as SAO Special Report #386 in 1980 through three editions published by Cambridge University Press. While the first 1982 edition was just over 300 pages, the third edition, published in 1997, had expanded to over 700 pages. Martin was actively working on a fourth edition. For the third edition, Nobel laureate Riccardo Giacconi wrote "The Handbook of Space Astronomy and Astrophysics gathers in one place the most frequently-used information in modern astrophysics and presents it in the most useful fashion to the non-specialist in a particular field."

Martin was a highly respected experimentalist and instrument builder, with an easy-going manner with friends and colleagues throughout the US and international high energy communities. He will be missed by all members of the HRC team and the broader *Chandra* community. ▪

Prepared by Almus Kenter, Ralph Kraft, Paul Gorenstein, William Forman

HRC Update

Almus Kenter and Ralph Kraft

Status of Instrument

The most significant news for the HRC community of the past year is the passing of Dr. Michael Juda. A more detailed article on Mike is contained on page 16, but the HRC IPI team would like to acknowledge his tremendous contribution to the long-term health and safety and success of the High Resolution Camera. Among other key *Chandra* tasks, he was the HRC Instrument Scientist from 1993 until his passing in Dec, 2016. As such, he had primary responsibility for the safe and efficient operation of the flight instrument. He also contributed to a wide range of instrument investigations to improve the instrument performance and track down some anomalies, particularly early in the mission. He was a smart, patient, no-nonsense scientist who dedicated his professional life to *Chandra*, and he will be missed. Dr. Daniel Patnaude is now the HRC Instrument Scientist for the CXC, and the IPI team is pleased to work with Dan to maintain the health and safety of the instrument.

The HRC continues to work well with no anomalies or unusual events. In the previous newsletter we presented results from in-orbit calibration data of changes in the gain of the HRC-S. The lifetime of a Microchannel Plate detector is typically measured in terms of extracted charge. In early 2012, it was decided that HRC-S gain had decreased to the point that for some observations, the Quantum Efficiency was being affected, particularly for "soft" (LETG) observations, so the HRC-S high voltage (HV) was increased by one step per plate. Subsequent to this increase in HV, the gain initially recovered. However the gain has since decreased at a much more rapid pace (see Figure 1). It is estimated that the total charge extracted from either detector due to cosmic rays (the dominant source of extracted charge) is only ~5×10^{-4} C cm^{-2}. The amount of extracted charge is roughly two orders of magnitude below where we should expect to see significant gain effects. Nevertheless, the HRC gain has been dropping on both the HRC-I and S detectors since the beginning of the mission.

At first this was puzzling, but now it is understood. So little charge has been extracted from the HRC that the plates are still in their infancy. Early in the HRC program there were several competing thoughts on how to prep the microchannel plates before incorporating them into the instrument. One group (Leicester UK) was of the mind that the plates should undergo a process of stabilization by extracting a certain amount of charge—a process often called "scrubbing". The other group (Cambridge MA) insisted that in single photon counting mode, charge extraction would be so modest that there would never be a need to worry about MCP "lifetime". No scrubbing of HRC MCPs was ever performed. The bottom line for the *Chandra* scientific community is that beyond future high voltages increases (which the HRC was designed for), charge extraction from the HRC MCPs will only be an operational concern on a timescale of centuries.

A Selected HRC Science Observation

SAO's own Brad Wargelin (et.al.) have used the HRC in combination with other observatories to observe Proxima Cen to confirm evidence of a stellar cycle; something that was not initially expected. The observational program was motivated by the discovery that this M5.5 star, which is fully convective, has a multi-year stellar cycle like the Sun's even though it's not supposed to. For more details please see the press release of October 2016 (https://www.cfa.harvard.edu/news/2016-25) that was generated in concert with the publication of the associated paper: (http://hea-www.cfa.harvard.edu/~bradw/cv/papers/ProxCycle.pdf).

For the HRC-I Proxima observations, the instrument was used in an unconventional "commensalistic" mode: while the ACIS was collecting undercover background measurement data and well out of the focal plane, the HRC-I can be still used even though it is at a relatively large off-axis angle (roughly 10 to 26 arcmin) and must operated in NIL (Next in Line) mode. HRC NIL mode is telemetry limited to only ~3.5-ct/s which was adequate for the expected flux for these observations.

Based on fifteen years of optical monitoring, 4 years of *Swift* X-ray/UV data, and 2 HRC observations Wargelin et al find evidence for a 7-yr stellar cycle in Proxima Cen (dMe5.5), a fully convective star. A stellar cycle is very exciting because most models of stellar magnetic activity

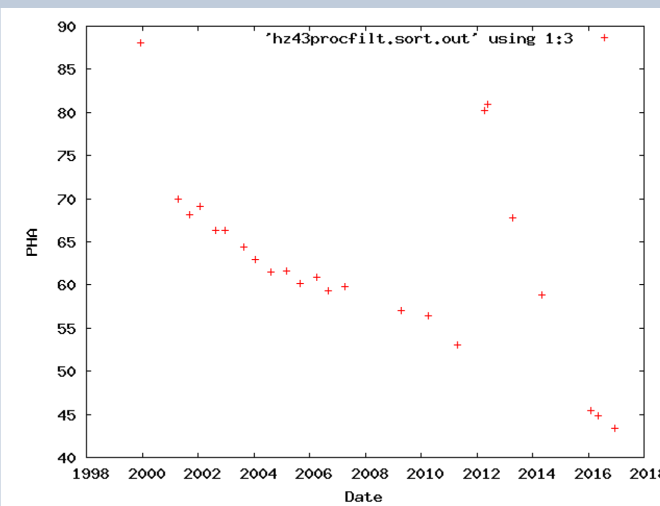


Figure 1: HRC-S gain as a function of time from HZ 43 in-flight calibration observations. Note the change in slope after the HV increase in early 2012. The voltage was increased by one step (~20V) per plate.

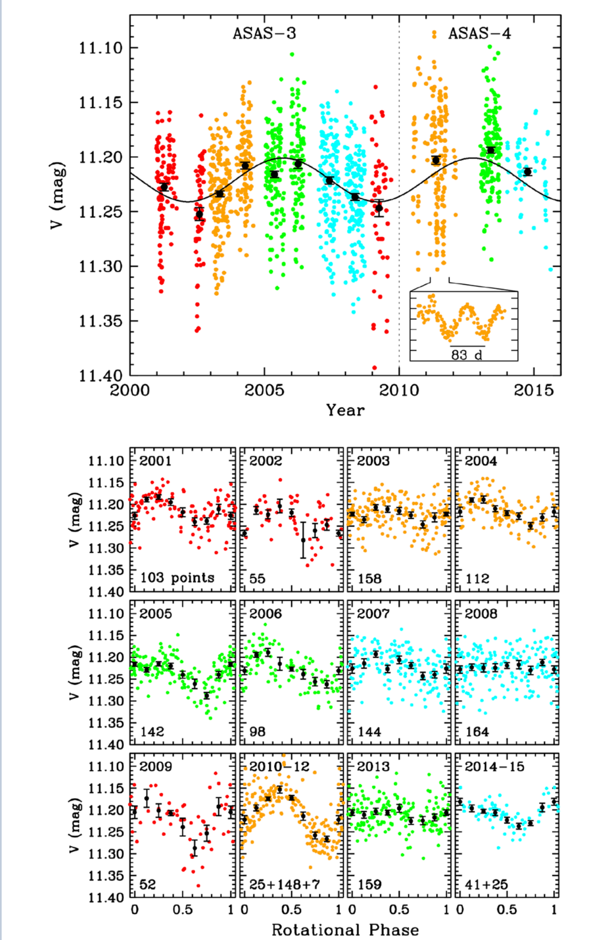


Figure 2. Brad Wargelin (et.al.) have used the HRC-I in combination with other observatories to observe Proxima Cen to confirm evidence of a stellar cycle; something that was not initially expected.

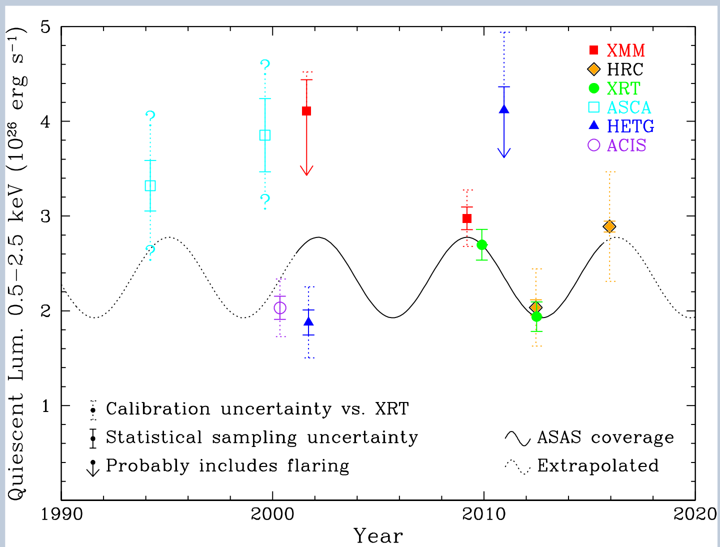


Figure 3. Corresponding optical data for Proxima observations. For details and further context please see referenced paper and press release.

predict such stars cannot support solar-like cycles. Understanding the structure and evolution of Proxima's magnetic field is also important because that's what drives X-ray/UV emission and the stellar wind, which are important factors in modeling the atmosphere (atmospheric stripping) and habitability of its newly discovered exoplanet. And as noted by the discovery announcement, "The robust detection of Proxima b has only been possible after reaching a detailed understanding of how the star changes on timescales from minutes to a decade." Further X-ray measurements are required now, while the cycle appears to be at a maximum, for confirmation and to better characterize Proxima's activity over time. ■

HETGS Update

Herman Marshall

The High Energy Transmission Grating Spectrometer [HETGS, 1] is essentially unchanged since launch. The grating efficiencies were updated in 2011 to bring the high and medium energy grating spectra into better agreement (see the HETGS article in Issue 19 of the *Chandra* Newsletter). Here, I present an update of two possible calibration issues and a summary of some interesting new HETGS results.

For the recent *Chandra* Users Committee (CUC) meeting,[1] I was asked to present two topics. The first one relates to a report that the HETGS line response function (LRF) may require adjustment. The second is about our on-going effort to cross-calibrate the HETGS with other instruments such as *XMM-Newton* and *NuSTAR*.

Line Response Function

Liu (2016, [2]) examined the Fe Kα lines of several active galactic nuclei (AGN) to examine their emission line regions. Liu examined the second and third order versions of the line to improve spectral resolution, which is highly recommended to all HETGS observers when there is sufficient signal. However, the energy dispersions σ_E derived from orders ±2 and ±3 were found to be smaller than that of order ±1 for all AGN in the sample. I examine this discrepancy in this article.

The sample used by Liu consisted of nearby, bright Seyfert galaxies. These include the Circinus galaxy, NGC 4151, NGC 3783, Mrk 3, and NGC 1068. The discrepancies between first order and high orders was most significant for two galaxies, Circinus and Mrk 3, where σ_E=6.2±1.4 eV and $4.9^{+5.2}_{-4.9}$ eV for first order but 9.8±0.9 eV and 19.0 ± 3.9 eV for the combination of second and third orders, respectively. While the individual significances are less than 3σ, collectively, the sample showed smaller energy dispersions for high orders than for first order. Liu suggested that line widths measured were "over-estimated" in first order spectra.

Besides being bright, these Seyfert galaxies share another characteristic: they all have X-ray emission extended on a scale of 3-10" as clearly imaged with *Chandra*. Figure 1 shows that the gratings were generally oriented so that the dispersion axis was along the dimension of smallest extent, extent still plays an important role when measuring emission lines.

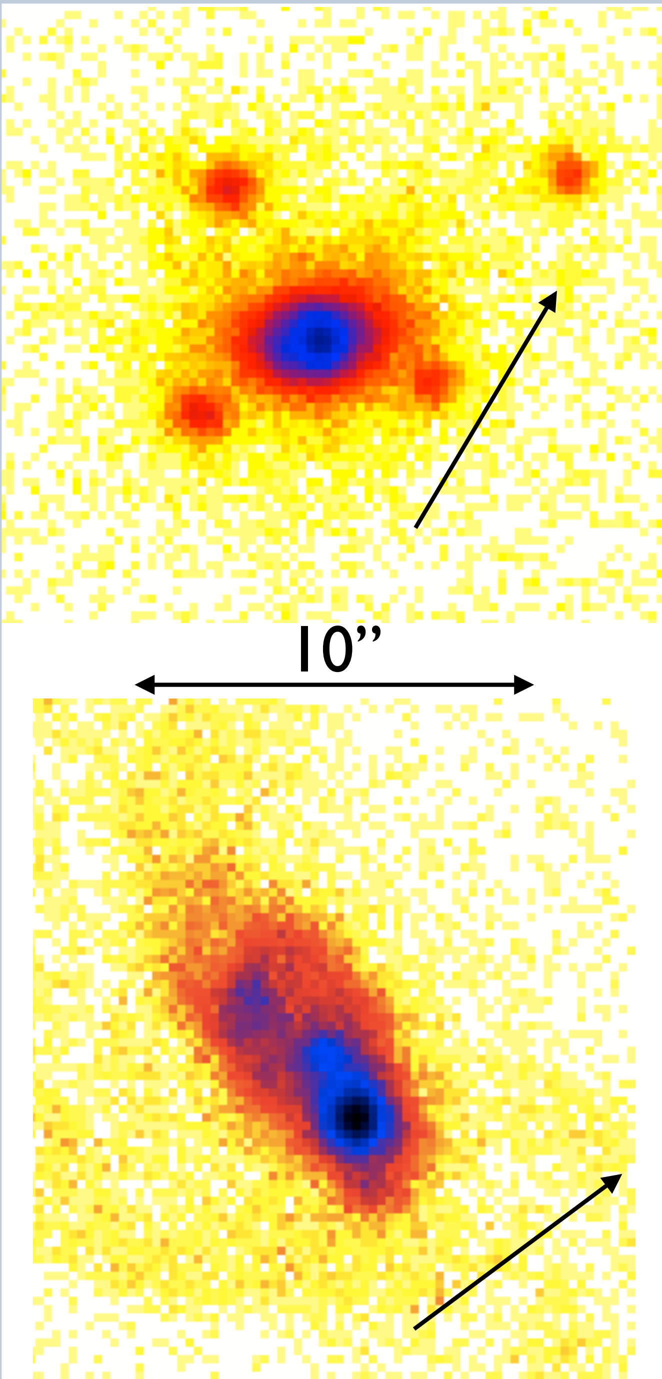


Figure 1: Images of the Circinus galaxy (above) and NGC 1068 (below), as observed in 0th order with the HETGS in long exposures. The average direction of the dispersion is shown by the arrows. Even along the dispersion, the sources are clearly extended.

Quantitatively, one may model a Gaussian line with several contributions to assess the effect of spatial broadening on linewidth. Suppose that all effects have profiles given by Gaussians, with the instrumental broadening given by σ_i in detector space, Doppler broadening given by σ_v in velocity space, and spatial broadening given by σ_θ, in imaging space. Converting each to their effect on the total broadening in physical coordinates x on the detector for wavelength λ and remembering the grating equation $m\lambda = P \sin \alpha = Px/R$ (for small dispersion angles) gives

$$\sigma_x^2 = \sigma_i^2 + (Rm\lambda/Pc)^2\sigma_v^2 + (F\sigma_\theta)^2 \quad (1)$$

where m is the grating order, P is the grating period, R is the Rowland distance of the HETGS, and F is the focal length of the HRMA.

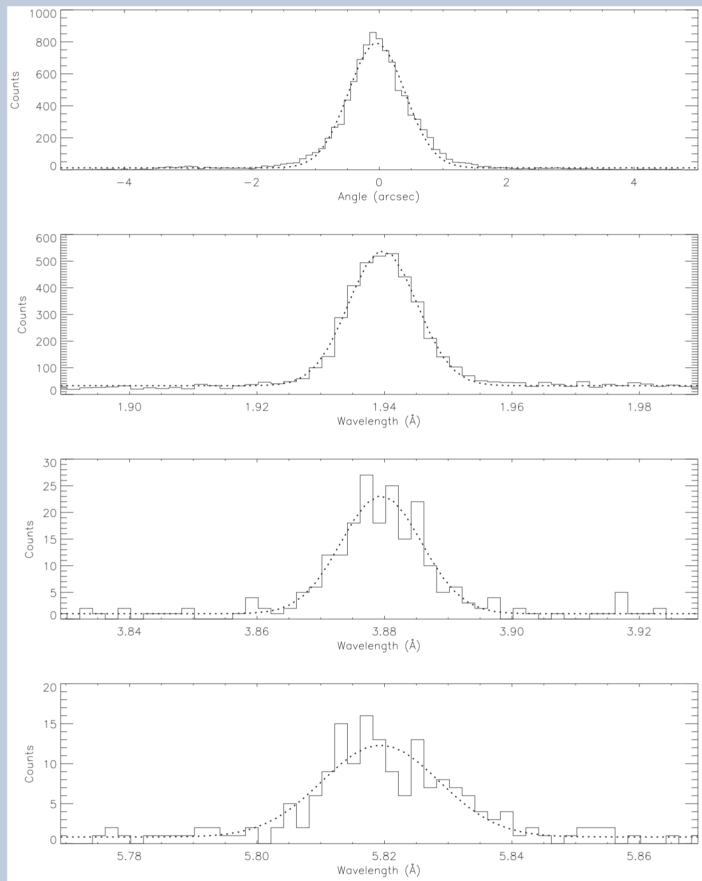


Figure 2: Average profiles taken from many HETGS observations of the Circinus galaxy. Top: Profile of zeroth order (5-6 keV) projected onto the dispersion line of the high energy gratings and fit to a Gaussian. The dispersion of the Gaussian is 0.44", about 30% larger than expected for a point source. 2nd from top: Profile of the Fe Kα line in ±1 orders, summed and fit to a Gaussian. The wavelength region plotted matches the projected angular range of zeroth order and the profile is marginally wider than that of zeroth order due to Doppler broadening. 2nd from bottom: Profile of the Fe Kα line in ±2 orders, as in the panel above. Note that the line appears somewhat broader than in first order. Bottom: Profile of the Fe Kα line in ±3 orders, as in the panel above. Note that the line appears significantly broader than in first order. The extra width is due to Doppler broadening.

Eq. 1 shows that imaging is more important than instrumental broadening when $F\sigma_\theta \gg \sigma_i$; i.e., when a source is resolved. More importantly, instrumental and imaging terms dominate when $m\sigma_v$ is small but as m increases, the linewidth is dominated Doppler broadening. Thus, spatial extent can be ignored only if $\sigma_v \gg 3400\ \sigma_\theta/m\lambda$ km/s for λ in Å and σ_θ in arcsec. For a resolvable source with $\sigma_\theta = 1''$ and examining the Fe Kα line at 1.94 Å using the high energy gratings, then spatial extent is comparable to Doppler broadening when $\sigma_v = 1750$ km/s. In third order, however, this cross-over value drops to 600 km/s. Hence it is clearly advantageous to examine the high order HETGS data where feasible. Figure 2 illustrates this point from profiles of the Fe Kα line as observed from the Circinus galaxy. The 0^{th} order profile was fit by a Gaussian, whose dispersion is only about 30% larger than expected for a point source. The dispersed spectra are progressively wider with grating order, as expected when Doppler broadening is increasingly important relative to spatial and instrumental broadening.

Figure 3 shows HETGS spectra of unresolved stars without significant Doppler motions due to companions [3]. The Fe xxv line at 1.85 Å is unresolved with limits to Doppler broadening at about 100 km/s. These data probably provide the best test of the HETGS LRF and indicate that the released response matrices are adequate for AGN spectroscopy.

Cross Calibration of X-ray Telescopes

The *Chandra* Calibration team has been working on cross-calibration of instruments since launch. In 2005, we teamed up with the *XMM-Newton* calibration scientists to initiate the International Astronomical Consortium for High Energy Calibration (IACHEC) and held our first meeting in 2006. Every high energy mission is or has been represented at our annual meetings. Presentations for all meetings and results from working groups are public.[2]

Recent results from the work of IACHEC include papers on cross-calibration between *NuSTAR*, *Swift*, *Chandra*, *XMM-Newton*, and *Suzaku* using simultaneous observations of two blazars: 3C 273 and PKS 2155-304. Results were published earlier this year by Madsen et al. [4]. Madsen et al. cross-checked instruments pairwise, to ensure significant exposure overlap, measuring fluxes in the 1-5

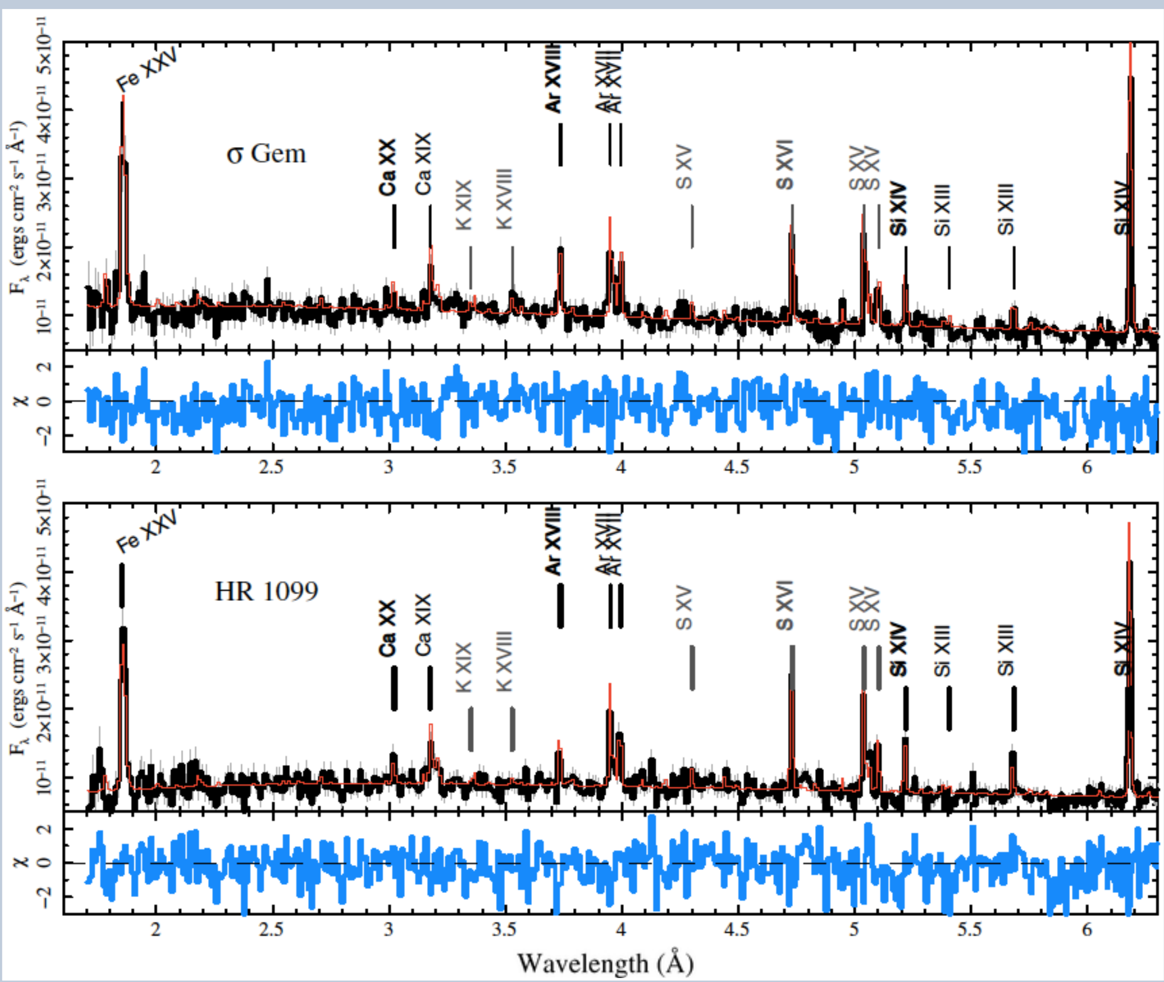


Figure 3: HETGS spectra of two stars [3]. The Fe xxv lines of both are consistent with the expected instrumental resolution.

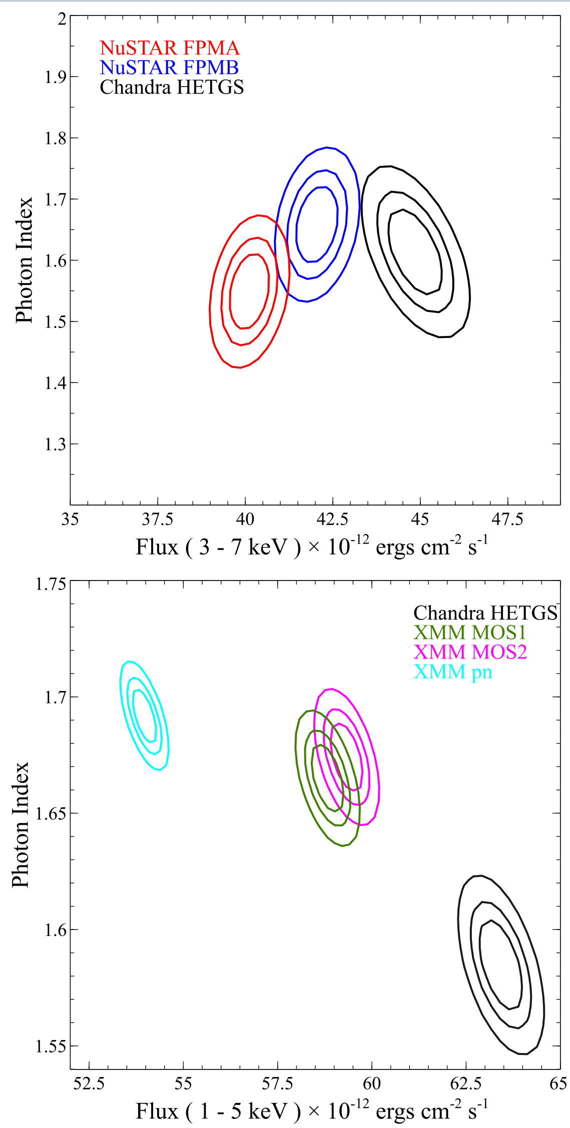


Figure 4: Two figures from Madsen et al. (2017, [4]) cross-checking fluxes determined from HETGS observations taken simultaneously with NuSTAR (top) or XMM-Newton (bottom). These cross-calibration campaigns serve to provide data that will be used to improve spectral agreement between missions.

keV or 3-7 keV bands. There were several disagreements at the 5-10% level, where the HETGS gives higher fluxes than most other missions. These results are similar to those of a previous IACHEC paper by Ishida et al. (2011, [5]) but with a lower level of significance. In a comparison to RXTE, Guver et al. (2016, [6]) found agreement between HETGS and RXTE in the 2-8 keV range to better than 2% using X-ray bursts from GS 1826-238.

By contrast in method, Plucinsky et al. (2017, [7]) used emission lines of highly ionized atoms of O and Ne in the 0.5–1.0 keV range from the supernova remnant 1E 0102.2-7219 to compare the same missions (excluding *NuSTAR*). In this case, the HETGS agrees within 5-10% of the (somewhat arbitrary) reference fluxes. There is significant scatter between instruments, with some high by 10% across the board and some low by 10%.

All these efforts to compare instruments provide the raw data needed to assess systematic errors in instrument calibration. The studies did not aim to actually suggest or encourage corrections but to help users bound potential systematic errors. Generally, we conclude from IACHEC studies that fluxes derived from most X-ray instruments agree to 10% but there are cases where the disagreement between two telescopes is 20% or more, depending on the energy of interest. There are two questions that naturally arise from these findings: "What can we do to obtain agreement?" and "Which instrument is right?" Absolute calibration is extremely difficult, as one might imagine based on decades of work to establish optical photometric standards. So, for now, we set aside the second question and try to answer the first one.

Meanwhile, there are several efforts within IACHEC to devise a way to bring the results from X-ray telescopes into better agreement.[3] One of these is called the "Concordance" project. Outlined at the 2015 meeting of the IACHEC, the goal is to develop a statistical formalism that uses estimates of a priori systematic errors, based on ground calibration and internal flight calibration data. The statistical method is based on "shrinkage estimators", which use the population of results to infer biases (systematic errors) in the outlying measurements. The project is a collaboration between X-ray calibration scientists in the *Chandra* calibration group—Jeremy Drake, Vinay Kashyap, and me—and members of the Harvard University Statistics Department: Prof. Xiao-Li Meng and two students, Yang Chen and Xufei Wang. Chen will lead a paper on the methodology for a statistics journal and I will lead one for an astrophysics journal. See presentations to the CUC and IACHEC for details.

Other IACHEC work focuses on how to analyze data when systematic errors are characterized. These include pyBLoCXS [8, 9] and MCCal [10], all involving *Chandra* calibration scientists. These studies have been used to demonstrate the limitations to measuring spectral parameters in the presence of systematic errors. Drake et al. (2006, [10]), for example, found that systematic errors can dominate the uncertainties in a spectral parameter such as the power law spectral index or thermal temperature when an ACIS observation has as few as 10^4 counts. Again, there are IACHEC presentations about these methods that can provide more details.

Recent HETGS Highlights

The High Energy Transmission Grating Spectrometer continues to provide excellent spectra for detailed examination of source properties. In particular, two papers show very nice spectra of X-ray binaries at high resolution.

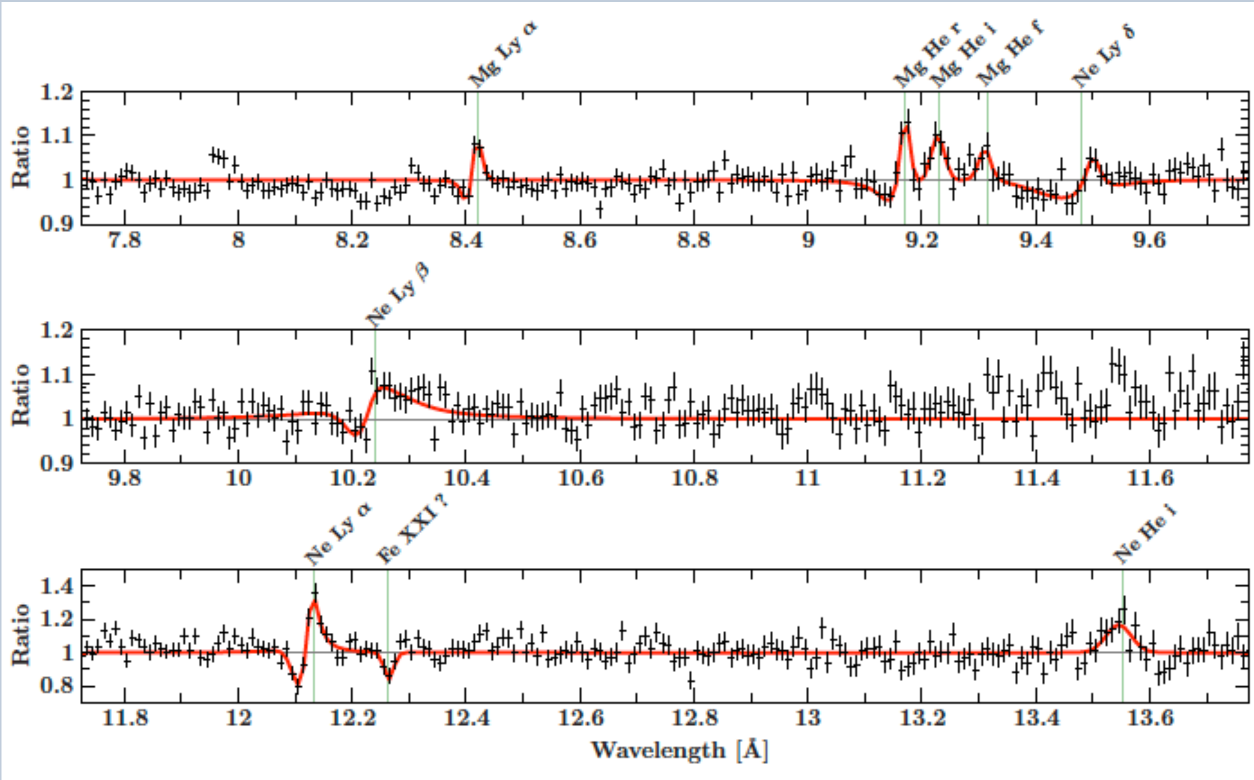


Figure 5: A portion of the HETGS spectrum of Cyg X-1 from ObsID 11044 (Miškovičová et al (2016, [11])). The data were divided by a model consisting of a power law absorbed by cold gas. Several lines show P Cygni profiles, such as Mg Lyα, Ne Lyα, and even Ne Lyβ. The observation is from inferior conjunction, where the disk wind is observed most clearly. Components of He-like Mg XI are readily discerned, providing density diagnostics.

Miškovičová et al.(2016, [11]) found P Cygni profiles in the HETGS spectrum of Cyg X-1. Figure 5 shows P Cygni profiles in many emission lines, informing a model of the focused wind from the companion. They measure wind velocities, column densities, and gas temperatures. From the Mg xi triplet near 9.2 Å can be derived a density estimate of up to $4{\times}10^{13}$ cm^{-3} in the wind.

Miller et al. (2016, [12]) obtained the HETGS spectrum of GX 340+0 in a state that shows strong absorption at 6.9 keV (see Figure 6). If interpreted as absorption by Fe xxv, then the wind velocity is 0.04*c*. They suggest that the wind is driven by radiation pressure, in a manner analogous to broad absorption features in some quasars because the gas has has some low ionization components. Depending on the filling factor of the wind, the kinetic power of the outflow may exceed the luminous power of the disk around the neutron star in the X-ray binary. ■

Footnotes

1 The meeting was held on 27 September 2016. See http://asc.harvard.edu/cdo/cuc/cuc_file16/sep27/ for the agenda and presentations.

2 See the IACHEC web site http://web.mit.edu/iachec/ for more details.

3 For an overview of the efforts of the IACHEC Calibration Uncertainty Working Group, see the IACHEC 2016 summary by Vinay Kashyap, which includes references to other presentations.

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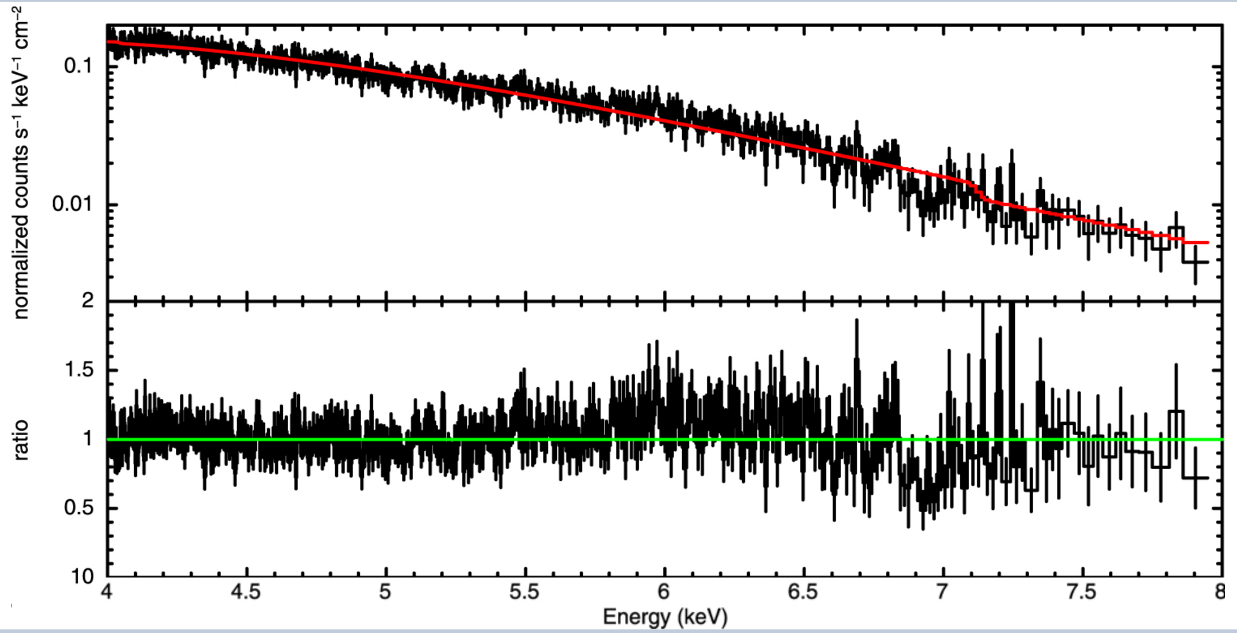

Figure 6: The 4-8 keV spectrum of GX 340+0 from Miller et al. (2016, [12]), ObsID 1922. The fit is to a disk blackbody (top panel) and the ratio to the model is given in the lower panel. The absorption feature near 6.9 keV was modeled as due to Fe xxv with an outflow velocity of 0.04c.

LETG

Jeremy J. Drake for the LETG Team

Item 7

It's like painting the Forth Bridge. At least it used to be, until 2011 when the Forth Bridge painting was unsportingly declared finished for at least another 20 years. Completed in 1890, the Forth Railway Bridge near Edinburgh is a marvelous cantilever design spanning the estuary of the River Forth (the "Firth of Forth"). To stave off the ravages of the somewhat corrosive combination of the North Sea and Scottish weather on its steel structure, it needed, or so the myth went, continuous painting—by the time you finished at one end it was time to go back to the other and start again.

With an inconvenient moratorium on Forth Bridge painting, there is then a clear need in the popular lexicon for a new idiom to represent such unceasing toil. The rather similar Myth of Sisyphus might suffice. Having been a bit naughty, Sisyphus was condemned by the gods to pushing a boulder up to the top of a mountain only for it then to tumble back to the bottom, leaving him to repeat the cycle ad infinitum—a bit reminiscent of trying to teach a small child how to ski. "Like calibrating the LETGS!" has a much better ring to it though, and besides, Sisyphus must have had moments of considerable satisfaction watching his boulder crashing back down the mountain, especially if it was like Mount Washington on a holiday weekend. I would hazard that painters of the Forth Bridge, just like calibrators of the LETGS, did not typically glean such regular wild enjoyment from their travail. "Like calibrating the LETGS!" it is then.

Previous issues of the Newsletter have detailed some of the secular changes in the detectors deployed with the LETG—primarily the HRC-S but also ACIS-S—that necessitate continuous reappraisal of performance and regular calibration updates. In addition to this pre-2011 Forth Bridge painting exercise, there is also a top secret list of calibrations that still need to be performed, but which are deemed of lower priority than the continual tasks of ensuring we understand the effective area and dispersion relation over the full wavelength range. The papyrus scroll on which the secret list is inscribed is solemnly examined in a ritualistic ceremony by the LETG calibration group once or twice a year. Whilst strict ceremonial protocol forbids disclosure of the full details of the list, excerpts read as follows:

> *7. Fix the LETG/HRC-S spectrum/gARF wavelength mismatches.*
>
> ...
>
> *22. Verify that the malleable logarithmic casing surmounting the prefabulated amulite base-plate does in fact ensure that the two spurving bearings are in a direct line with the pentametric fan, as suggested by Quick (1944).*

After weeks of cloistered deliberation and metaphorical black smoke (meeting rooms here having already been designed shortsightedly without chimneys), a candidate rises to the top and is studied and dealt with by the crack calibration team.

At first sight, Item 7 sounds quite grave and meritorious of higher ranking. It actually refers to the problem that the observed spectrum at the very ends of each microchannel plate segment did not match expectations very well (recall there is a central plate flanked by two outer plates, each 10 cm long making up the 30 cm long detector). The extreme ends of the detector show the most ugly departures from the modelled response, but there are few spectra that have used data at the longest wavelengths. The worst case from a scientific perspective is the plate gap region of the negative order shown in Figure 1. The model of the plate gap is poor over the regions ±3 Å from the gap affected by the spacecraft dither.

There are reasons other than dither that might also render data near the plate gaps poor. The plates sit in a strong electric field that accelerates photoelectrons within the pores of the plates much like in a photomultiplier tube. The field in the vicinity of the plate gaps is likely not to be completely uniform, leading to distortion in the inferred positions of photon events. This is seen in fact in the spikes containing such misplaced events at the shoulders of the gap dither region in Figure 1.

All this was not deemed too important because plate gap regions affected by dither have been considered "bad data", retained in level 2 files in case they might be useful but not to be included in formal analyses without very careful treatment. There are no really important spectral diagnostics at the affected wavelengths and, besides, the detector was also designed so that positive and negative orders have gaps at different wavelengths and so coverage with "good" data is still continuous.

With items 1–6 either being long-term analysis problems or having been solved by brilliant strokes of calibration, item 7 then emerged in a billow of white smoke. Our top expert scientists Brad Wargelin and Dave Huenemoerder dug around the roots of the issue and discovered that most of the problem originates because the HRC-S Quantum Efficiency Uniformity (QEU) file had incorrect spatial limits set that did not exactly match the actual detector. This explains the dither-related problems, but what of the spikes of events whose positions have been determined incorrectly? One approach would be to reassess the "degap" map in those regions of the detector. Degap refers to the algorithms and parameters that are applied to fine-tune the positions of photon events, making use of, among other things, the fact that there should be no gaps in data that otherwise appear in raw detector images. This would be a considerable undertaking, requiring a fully two-dimensional degap map instead of the combination of one-dimensional maps we currently use, and a complete rewrite of the degapping software within the data system, and all with no guarantee that event positions could be reconstructed with sufficient accuracy to make them useful: one for the papyrus, perhaps at number 23.

There, a convincing and bullet-proof argument not to embark on doing a lot of hard work. So, what else can we do with these bothersome events? Another approach, and a much more efficient one, is to, well, sweep them under the rug, so to speak. A suitable rug is in fact already built into the software system in the form of a "bad pixel map".

The badpix file contains in essence a list of the regions of the detector that are considered problematic for one reason or another. These regions are excised from Level 2 event files and the resulting holes in the detector response are noted and included when the effective area of the instrument is computed within CIAO. Brad worked out which regions of the plate ends were indeed problematic and swept them under the badpix rug. A comparison between an effective area computed using the combination of the new badpix file and QEU file corrected for the plate ends error and an observed spectrum is illustrated in Figure 2. Note that this is not a model fit, but just an arbitrary scaling of data and effective area. It yields a rather good match.

Item 7 having been dispensed with, several other items have sprung up to take their place in the list, one or two having surprisingly leapfrogged the verification of the spurving bearing alignment in priority ranking. Its never ending really, just like calibrating the LETGS.

On a whim

If Λ Cold Dark Matter Cosmology (ΛCDM) bears any semblance to reality, there must be quite a lot of matter around that is cold and dark, supposedly making up about a quarter of the mass-energy density of the universe. It sounds like lots and lots of pints of Guinness, but it's not. It's peculiar stuff that doesn't really do anything but sit there, like a free-floating mass of untold numbers of teenage boys. But not to worry because there is some warm normal stuff out there too, and maybe even hot, according to hydrodynamical simulations of structure formation.

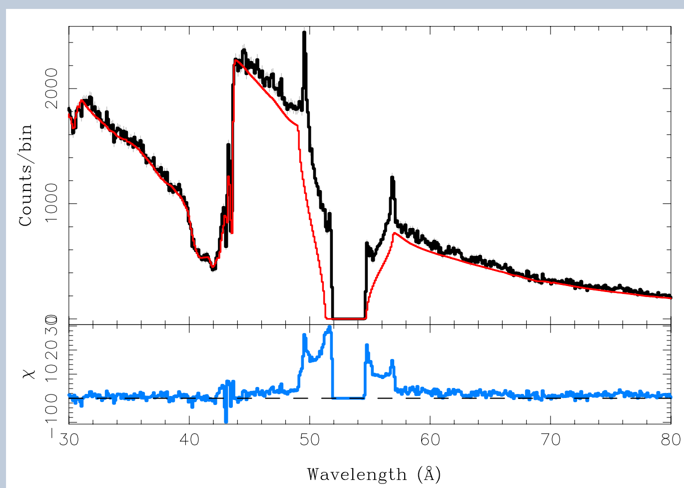

Figure 1: Illustration of residuals around the negative order plate gap in single power law fits to observed spectra of the blazar Mkn 421 ObsID 4149 (Figure courtesy David Huenemoerder).

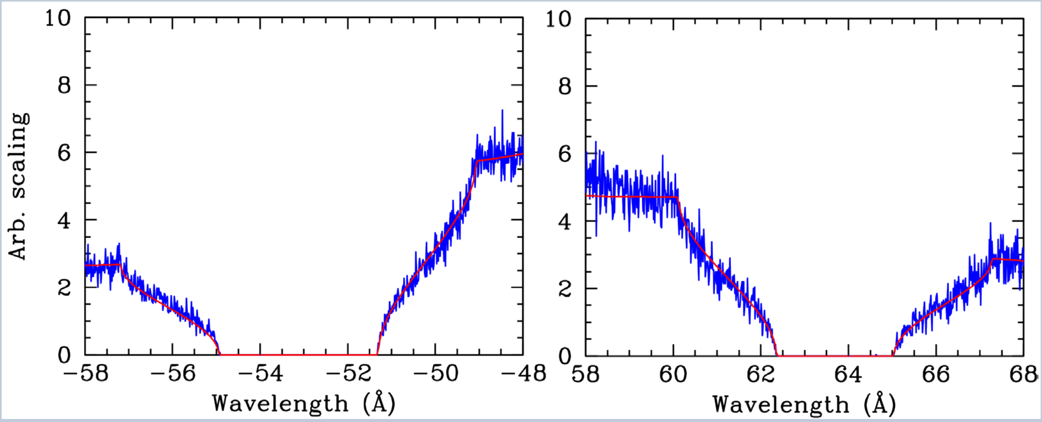

Figure 2: Comparison of data in the vicinity of the negative order plate gap with an effective area computed using revised QEU and badpix files. No spectral model is included and data have been arbitrarily scaled to match the count rate levels in the vicinity of the gap (Figure courtesy Brad Wargelin).

The simulations predict a filamentary web of dark matter within which this warm-hot stuff at temperatures of 100,000 to 10,000,000 K should be embedded, in between the galaxies, making up about half of the baryons in the universe. Since we can't see most of the bits and bobs in the ΛCDM model—95% of them if about 70% is Dark Energy—one might imagine there is considerable interest in trying to see the things we can. The Warm Hot Intergalactic Medium is so diffuse though, at only about one atom per cubic meter, that we can't really see it either. At least not until shining some light on it.

Chandra has been studying the WHIM by shining the light of distant quasars on it, and looking for its shadows in absorption lines due to metals that come from things we can see and know are really there—stars in galaxies. University of Alabama in Huntsville astronomer Max Bonamente and colleagues (Bonamente et al. 2016) reported the possible detection of the WHIM in the line of sight toward the quasar PG 1116+215. Earlier *Hubble* Space Telescope observations had detected several O VI and broad H I Lyman α absorption lines that might be associated with the WHIM. The redshifts measured from those features enabled the search for lines in LETG+HRC-S spectra to be narrowed down to specific wavelengths. Bonamente et al. detected an absorption line in the LETG spectra corresponding to O VIII Kα at a redshift z = 0.0911. Sloan Digital Sky Survey spectroscopic galaxy survey data toward PG 1116+215 also revealed telling evidence for a galaxy filament in the sightline together with other galaxy structures within a few Mpc of the inferred O VIII Kα absorption that support the presence of the inferred WHIM.

While Bonamente et al. note that the LETG detection could benefit from further verification, they point out that combining H I broad line absorption measurements with X-ray data for larger samples has the potential to locate large reservoirs of warm-hot baryons and possibly solve the missing baryons problem (see, e.g., Shull et al. 2012).

It's just the small issue of the dark matter and dark energy left after that. JJD thanks the LETG team for useful comments, information and discussion. ▪

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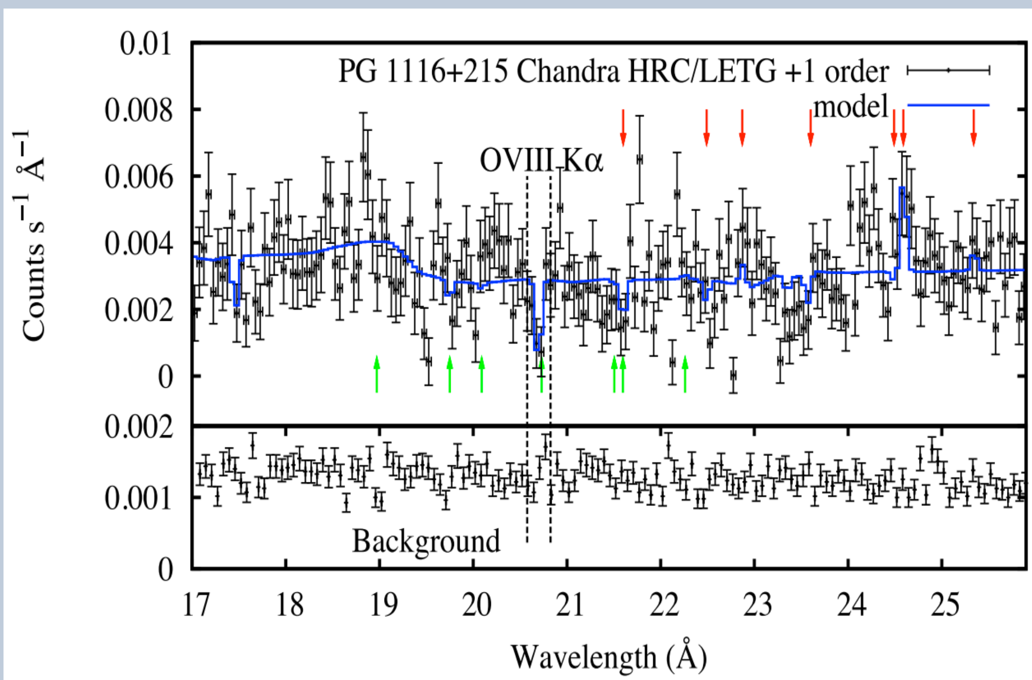


Figure 3: LETG+HRC-S positive order spectrum of PG 1116+215 from Bonamente et al. (2016) together with the fitted model. Arrows mark expected positions of O VII and O VIII Kα lines at redshifts of z = 0, 0.041, 0.059, 0.0928, 0.1337, 0.1385 and 0.1734. The feature at 17.5 Å is possibly O VIII Kβ.

CIAO 4.9 and Beyond

Antonella Fruscione, for the CIAO team

CIAO 4.9 (*http://cxc.cfa.harvard.edu/ciao/index.html*) is the latest installment in the annual releases of the *Chandra* Interactive Analysis of Observations, the software used to analyze *Chandra* data. It was released in December 2016 together with the most recent versions of both the Calibration Database (*CALDB 4.7.3*) and *MARX 5.3.2*, the suite of programs created and maintained by the CXC group at MIT and designed to enable users to simulate the on-orbit performance of the *Chandra* X-ray Observatory.

While CIAO 4.9 is mostly a "maintenance" release (which fixes bugs, supports new compilers and updates some of the required OTS software) it also contains a few changes and improvements worth noticing: not only the support of larger number of operating systems (two for Linux and four for Apple systems), but also the support for Python 3.5 which required updating many parts of code that can now work with either Python 2.7 or Python 3.5.

In *Sherpa*—the modelling and fitting application in CIAO—the most notable improvements were the addition of the *wstat* statistic, an implementation of the Cash statistic where the observed background data is included and does not have to be modelled separately, and the update of the XSPEC models to version 12.9.0d.

Sherpa 4.9.0 is also released on Github as a standalone package for both Python 2.7 and Python 3.5.

Three new "*CIAO scripts*"—high level programs which have the goal to simplify the analysis steps for the most common cases—*blanksky*, *blanksky_image* and *correct_periscope_drift* were released two months before CIAO 4.9. The first two deal with the "blank sky" background and create respectively a blank-sky background dataset tailored to a specific observation and the corresponding output image matched to the user image and its energy filter (see Figure1)

Correct_periscope_drift corrects small (~0.1 arcsec) intra-observation alignment drifts that can be seen in recent, long (>50 ks) observations.

The entire scripts package was updated in the CIAO 4.9 release and to run under Python version 3.5 as well as Python 2.7.

X-ray Data Analysis for the Next Decade

In order to gauge the interest from the community regarding priorities for the future of CIAO and X-ray data analysis in general, a lunchtime panel was held during the *Chandra* Science for the Next Decade workshop. The goal was to hear the thoughts from experts and from the community, regarding the direction the X-ray data analysis (and more specifically—but not exclusively—CIAO) should take for the future.

We invited five colleagues and long-time users of high energy data and software to illustrate their vision and to participate in the discussion initiated by questions from the audience. Koji Mukai from Goddard, Nico Cappelluti from Yale, Ewan O'Sullivan from CfA, Raffaella Margutti from Northwestern, and Joey Nielsen from MIT presented their thoughts on hardware, software and algorithm challenges for the next decade.

The presentation was followed by comments from the audience and comments from users following on-line.

A few points came up repeatedly in the discussion and in particular the desire to use Jupyter Notebook and Python packages such as Astropy, Scipy, and Matplotlib within the CIAO environment, integration with the Anaconda Python environment, and the demand for parallel processing, particularly for some of the core CIAO tools.

Last summer the *Sherpa-Astropy Bridge (Saba)* package was developed to provide Sherpa functionality within the Astropy modeling fitting package. It was done as part of

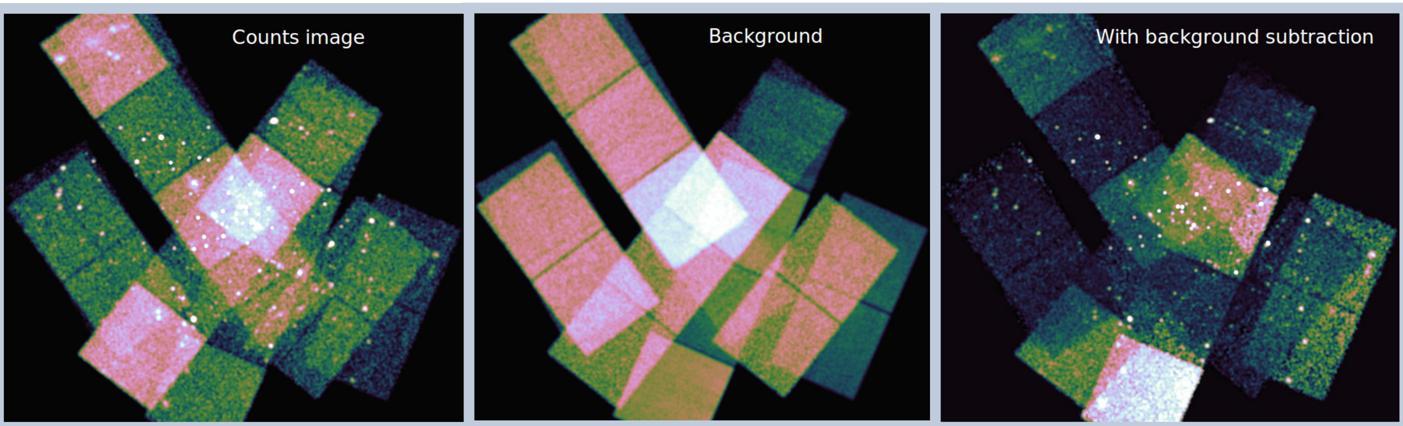


Figure 1: Combined reprojected M101 counts data. For each event file the script finds the CALDB blank sky background for the correct epoch; scales the background exposure time keywords so that scaled particle background-dominated count rates (in the 9-12 keV range) match the data; reprojects to the correct roll angle and adds the correct RA, Dec coordinates. The result is a matched set of background event files which can be used for either image background subtraction (as shown in the figure) or event-based spectral subtraction.

Figure 2: CIAO workshop participants

the Google Summer of Code 2016 under the [OpenAstronomy organization]() by student Michele Costa and the Sherpa team.

Parallelization for CIAO tool would allow processing many sources at once. It is a complex problem since the tools were designed when parallel processing was neither common nor widespread and would require a more fundamental redesign of the software.

An interesting discussion ensued about science algorithms for the future where it became clear that multi-observation and multi-wavelength is forever more the way of the future. Therefore improvements in multi-wavelength spectral analysis and in multi-resolution analysis (for example simultaneous fitting of high and low resolution data or joint analysis of multi-observatory data) were discussed. Easy generation of the PSF and easier analysis of extended sources and grating data were also suggested as priorities for the future. Continuing the development of advanced statistical tools with accessible interfaces for general users was discussed as an important step forward.

Several of the items discussed by the panelists are already included in existing CIAO development priorities. In the future we are planning to improve the support to data analysis of extended source via tools like smoothing and temperature map generation plus improved PSF and extended source fitting. We plan to improve the source flux tool to support multiple observations and a multi observation detect tool is being developed for the production of the *Chandra* Source Catalog. We are also working on upgrades to the current interface in Sherpa to allow non-expert use of the Bayesian analysis and MCMC methods.

Community input regarding the future direction of CIAO is welcome and any user with additional thoughts or suggestions can submit their ideas via the [CXC HelpDesk]().

12th CIAO Workshop

A one and a half day CIAO workshop was held at the CFA in August before the *Chandra* Science for the Next Decade workshop. About twenty students, postdocs and faculty or staff members attended the workshop from around the world. As it is customary in CIAO workshops, the time was split between talks and the hands-on session. Students learned or were updated about the latest advancements in the CIAO data analysis, ds9 for high energy astrophysics (including the DAX extension which allows to run CIAO tools directly from ds9) and the *Chandra* PSF. The hands-on session is truly the highlight of the workshop since it is a time when students experiment on their own, but with the full and prompt support of the CIAO team. This is not only beneficial for the students, but it is a two-way process since invariably the CIAO team learns how "real" users work with the data, the software and the documentation and the outcome of the workshop are improvements in documentations and at times, requests for enhancement in the software.

Future CIAO workshops are planned and will be advertised via the CXC social media and *Chandra* announcements. More details will be available on the CIAO workshops webpage where electronic copies of all the previous presentations are also archived. ■

CIAO Workshop Feedback

Some positive feedback from students:

"Great workshop. I would love to have this more often for people who are new to CIAO so that they can start working on it much faster than just looking through the documentation"

"I thought the workshop was all-around very good."

"You always learn something new from these workshops even if you have analysed *Chandra* data for many years"

And some room for improvement:

"It would be nice maybe to have more talks about the history of *Chandra* and CIAO in general. It was easy to miss how we get to here and knowing about it will help us appreciate the program more."

Chandra Users' Committee Membership List

The Users' Committee represents the larger astronomical community for the *Chandra X-ray Center*.
If you have concerns about *Chandra*, contact one of the members listed below.

Name	Organization	Email
Arjun Dey	NOAO	dey@noao.edu
Mike Eracleous (Chair)	Pennsylvania State University	mce@astro.psu.edu
Dale Frail	NRAO	dfrail@nrao.edu
Elena Gallo	University of Michigan	egallo@umich.edu
Matteo Guainazzi	European Space Agency	matteo.guainazzi@sciops.esa.int
Thomas Maccarone	Texas Tech	thomas.maccarone@ttu.edu
John Mulchaey	Carnegie Observatories	mulchaey@obs.carnegiescience.edu
Feryal Ozel	University of Arizona	fozel@email.arizona.edu
Samar Safi-Harb	University of Manitoba	samar.safi-harb@umanitoba.ca
John Stauffer	IPAC	stauffer@ipac.caltech.edu
Yasunobu Uchiyama	Rikkyo University	y.uchiyama@rikkyo.ac.jp
Ex Officio, Non-Voting		
Jeff Hayes	NASA HQ	jeffrey.hayes-1@nasa.gov
Stefan Immler	NASA HQ	stefan.m.immler@nasa.gov
Wilt Sanders	NASA HQ	wilton.t.sanders@nasa.gov
Allyn Tennant	NASA/MSFC, Project Science	allyn.tennant@msfc.nasa.gov
Martin Weisskopf	NASA/MSFC, Project Scientist	martin.c.weisskopf@nasa.gov
CXC Coordinator		
Andrea Prestwich	CXC Director's Office	aprestwich@cfa.harvard.edu

The Results of the Cycle 18 Peer Review

Andrea Prestwich

The observations approved for *Chandra*'s 18th observing cycle are now underway. The Cycle 19 Call for Proposals (CfP) was released on 15 December 2016 and the proposal deadline is 15 March 2017. Cycle 17 observations are close to completion.

The Cycle 18 observing and research program was selected as usual, following the recommendations of the peer review panels. The peer review was held 28 June–1 July 2016 at the Hilton Boston Logan Airport. It was attended by 91 reviewers from all over the world, who sat on 11 panels to discuss the 547 submitted proposals (Figure 1). Access to lists of approved programs, including abstracts, can be obtained by selecting "Observations and Schedules" and then "Cycle Targets and Statistics" from the menu on the left hand side of our website (*http://cxc.harvard.edu/*). The peer review panel organization is shown in Table 1.

The total amount of time allocated in Cycle 18 was 17.1 Ms, including 5.7 Ms to 10 approved LPs. The overall oversubscription in observing time was 4.6 (Figure 2), typical of the past few cycles (Figure 3). In Cycle 18 the boundary between General Observers (GO) and Large Projects (LPs) was shifted from 300 ks to 400 ks. The primary motivation for this change was to decrease the workload of the peer review by reducing the number of LPs. The number of LPs declined from 71 in Cycle 17 to 48 in Cycle 18, in line with expectations. The total time requested for LPs remained almost constant (40.1 Ms in Cycle 17 vs. 36.3 Ms in Cycle 18).

Following our standard procedure, all proposals were reviewed and graded by the topical panels, based primarily upon their scientific merit, across all proposal types. The topical panels were allotted *Chandra* time to cover the allocation of time for GO observing proposals based upon the demand for time in that panel. Other allocations made to each panel included: joint time, Target of Opportunity TOOs with a <30 day response, time constrained observations in each of 3 classes, time in future cycles, constrained observations in future cycles, and money to fund archive and theory proposals. These allocations were based on the full peer review oversubscription ratio. The topical panels produced a rank-ordered list along with detailed recommendations for individual proposals where relevant. A report was drafted for each proposal by one/two members of a panel and reviewed by the Deputy panel chair before being delivered to the CXC. Panel allocations were modified, either in real time during the review or after its completion, to transfer unused allocations between panels so as to follow the review recommendations as far as possible.

Prior to the review, LPs were distributed to a group of "pundits". Pundits are experienced scientists with broad research interests who focus exclusively on large projects. Pundits were asked to read all LPs and to provide written reports on specific proposals assigned to them. The pundit reports were made available to the topical panels and were incorporated into the panel discussion. LPs were discussed by the topical panels and ranked along with the GO, archive and theory proposals. The recommendations from topical panels were recorded and passed to the Big Project Panel (BPP), which included all topical panel chairs and the pundits. The schedule for the BPP at the review included time for reading and for meeting with appropriate panel members to allow coordination for each subject area. The meeting extended into Friday morning to allow for additional discussion and a consensus on the final rank-ordered lists and to ensure that all observing time was allocated. At least 2 BPP panelists updated each review report to include any BPP discussion that occurred at the review and/or remotely over the following week.

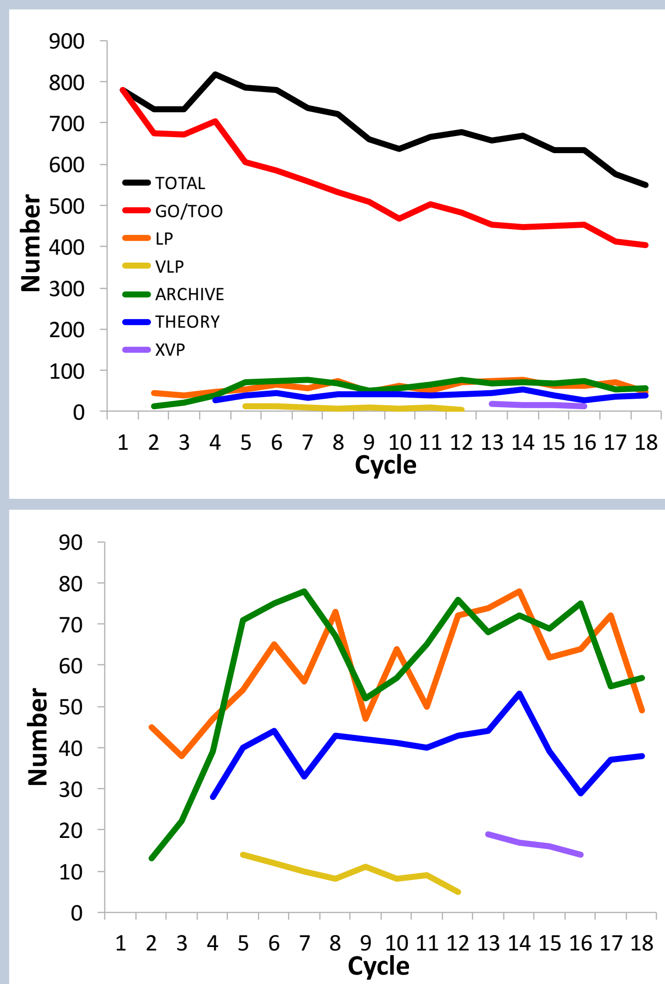


Figure 1: (top) The number of proposals submitted in each proposal category (e.g. GO, LP, Archive etc.) as a function of cycle; (bottom) zoom on lower curves. Since more proposal categories have become available in each cycle, the number classified as GO has decreased as others increased. The total number of submitted proposals has been remarkably constant over the 6 past cycles.

Topical Panels:	
Galactic	
Panels 1,2	Normal Stars, WD, Planetary Systems and Misc.
Panels 3,4	SN, SNR + Isolated NS
Panels 5,6	WD Binaries + CVs, BH and NS Binaries, Galaxies: Populations
Extragalactic	
Panels 7,8	Galaxies: Diffuse Emission, Clusters of Galaxies
Panels 9,10,11	AGN, Extragalactic Surveys
Big Project Panel	LP Proposals

Table 1: Panel Organization

The resulting observing and research program for Cycle 18 was posted on the CXC website on 18 July 2016, following detailed checks by CXC staff and approval by the Selection Official (CXC Director). All peer review reports were reviewed by CXC staff for clarity and consistency with the recommended target list. Budget allocations were determined for proposals which included US-based investigators. Formal e-letters informing the PIs of the results, budget information (when appropriate) and providing the report from the peer review, were e-mailed to each PI in August.

Joint Time Allocation

Two proposals were allocated *Chandra* time by the HST Time Allocation Committee (TAC), one proposal approved by the *Spitzer* TAC and one proposal by the *XMM* TAC. The *Chandra* review accepted joint proposals with time allocated on: *Hubble* (7), *NuSTAR* (7), NRAO (10), NOAO (3), *Swift* (5), and *XMM-Newton* (2).

Constrained Observations

As observers are aware, the biggest challenge to efficient scheduling of *Chandra* observations is in regulating the temperature of the various satellite components (see POG Section 3.3.3). In Cycle 9 we instituted a classification scheme for constrained observations which accounts for the difficulty of scheduling a given observation (CfP Section 4.4.2). Each class was allocated an annual quota based on our experience in previous cycles. The same classification scheme was used in Cycles 10-18. There was a large demand for constrained time such that not all proposals which requested time-constrained observations and had a passing rank (>3.5) could be approved. Effort was made to ensure that the limited number of constrained observations were allocated to the highest-ranked proposals review-wide. Detailed discussions were carried out with panel chairs to record the priorities of their panels in the event that more constrained observations could be allocated. Any uncertainty concerning priorities encountered during the final decision process was discussed with the relevant panel chairs before the recommended target list was finalized.

Please note that the most oversubscribed class was "EASY" while "AVERAGE" was only marginally oversubscribed. In practice these two classes were combined when determining which observations should be allocated time. The same three classes will be retained in Cycle 19 so as to ensure a broad distribution in the requested constraints. *We urge proposers to request the class of constraint required to achieve the science goals.*

Cost Proposals

PIs of proposals with US collaborators were invited to submit a Cost Proposal, due in Sept 2016 at SAO. In Cycle 18 each project was allocated a budget based on the details of the observing program (see CfP Section 10.4). Awards were made at the allocated or requested budget levels, whichever was lower. The award letters were emailed in December, in time for the official start of Cycle 18 on 1 Jan 2017.

Proposal Statistics

Statistics on the results of the peer review can be found on our website: under "Target Lists and Schedules" select the "Statistics" link for a given cycle. We present a subset of those statistics here. Figure 4 displays the effective over-subscription rate for each proposal type as a function of cycle. Figures 6, 7 show the percentage of time allocated to each science category and to each instrument combination. Table 2 lists the numbers of proposals submitted and approved per country of origin. ■

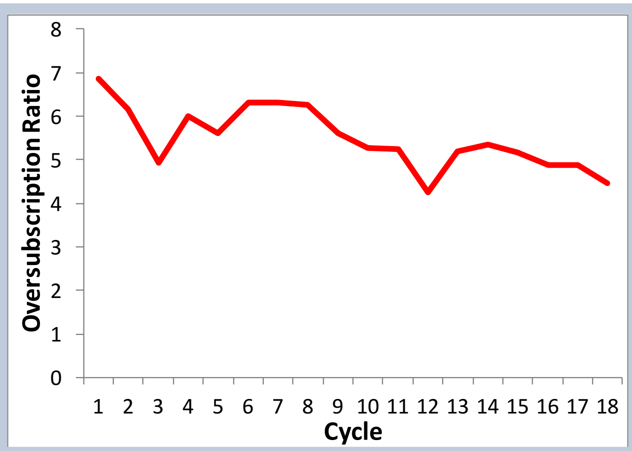


Figure 2: The final oversubscription in observing time based on requested and allocated time in each cycle. The numbers are remarkably constant.

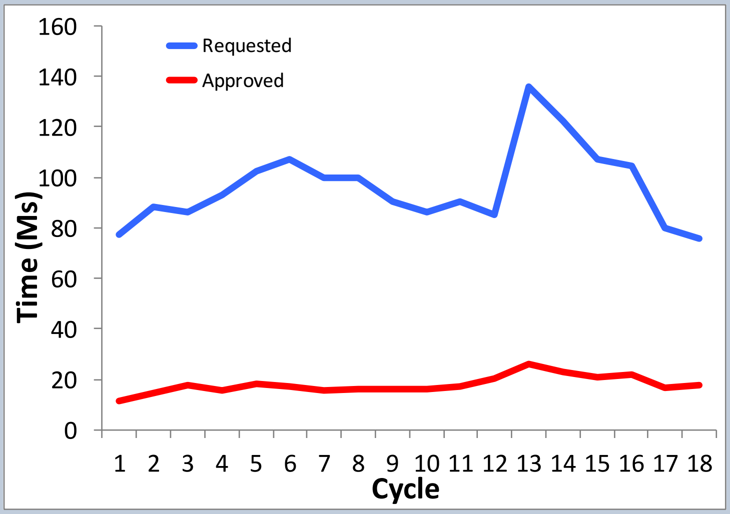


Figure 3: The requested and approved time as a function of cycle in ks including allowance for the probability of triggering each TOO. The available time increased over the first three cycles, and in Cycle 5 with the introduction of Very Large Projects (VLPs). The subsequent increase in time to be awarded due to the increasing observing efficiency and the corresponding increase in requested time in response to the calls for X-ray Visionary Projects (XVPs) in Cycles 13-16 is clear.

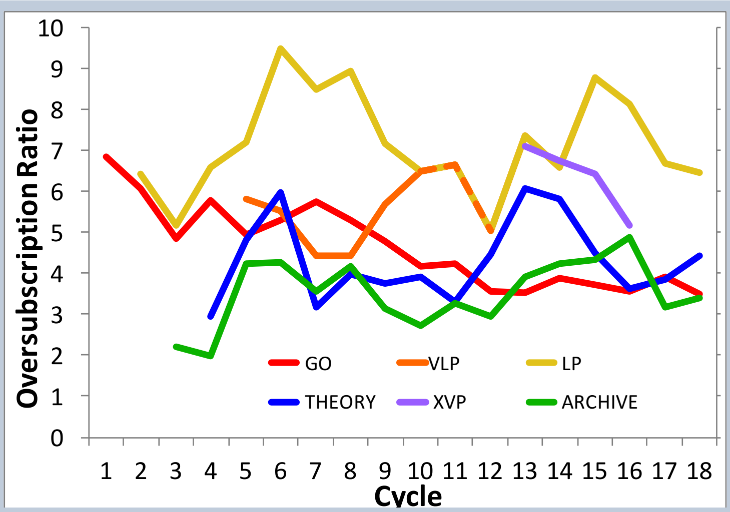


Figure 4: The effective oversubscription ratio in terms of observing time for each proposal category as a function of cycle. Note that some of the fluctuations are due to small number statistics (e.g. Theory proposals).

	Requested		Approved	
Country	# Props	Time	# Props	Time
Australia	5	709	3	619
Austria	2	150		
Belgium	1	405		
Bulgaria	2	200		
Canada	8	1838	4	458
Chile	4	505	1	300
China	3	180	1	150
France	5	567	3	267
Germany	18	3725	5	502
Greece	2	60		
India	6	600	2	130
Italy	22	5377	5	540
Japan	10	844	1	20
Korea	1	60	1	60
Mexico	4	240	1	170
Netherlands	9	862	4	432
Poland	2	145		
Russia	3	67	2	47
South Africa	1	195	1	195
Spain	5	986	2	95
Switzerland	3	285		
Taiwan	3	194		
Turkey	2	240	1	40
UK	26	4453	13	1520
USA	401	58128	118	13880
Foreign	146	22887	50	5545

Table 2: Requested and Approved Proposals by Country.

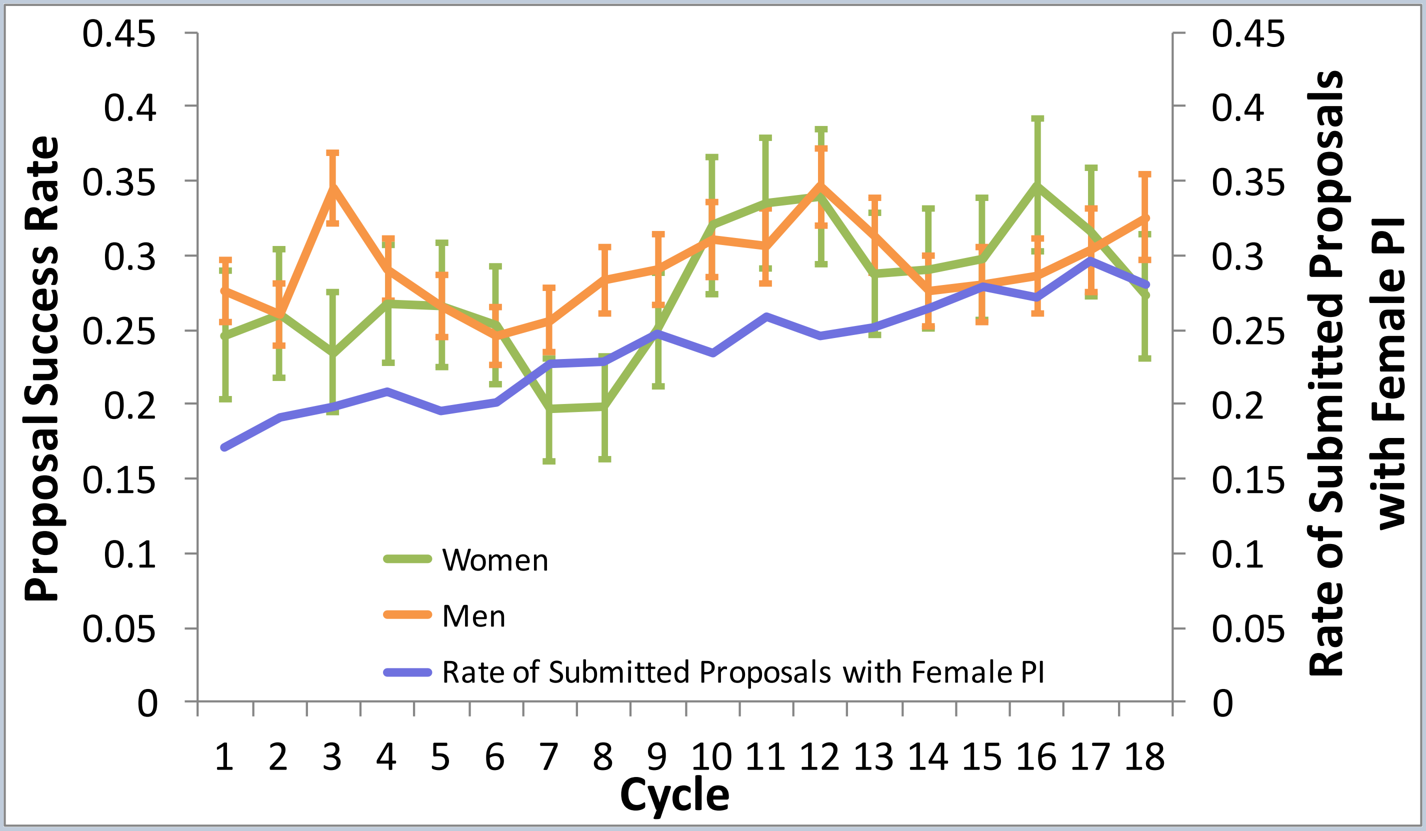


Figure 5: The success rate of male (orange) and female (green) PIs as a function of cycle, and the overall fraction of female PIs (blue). Since cycle 10, the success rate for female and male PIs has been very similar.

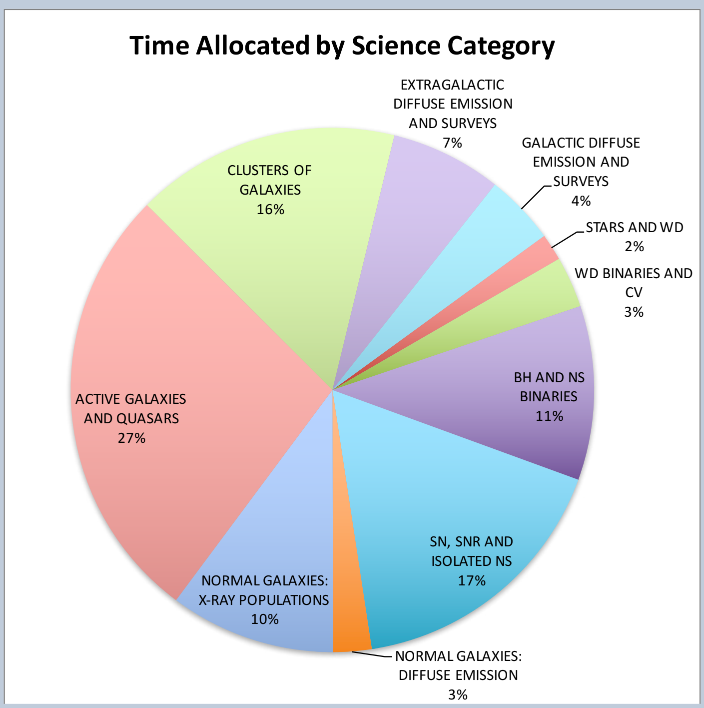


Figure 6: A pie chart indicating the percentage of Chandra time allocated in each science category. Note that the time available for each science category is determined by the demand.

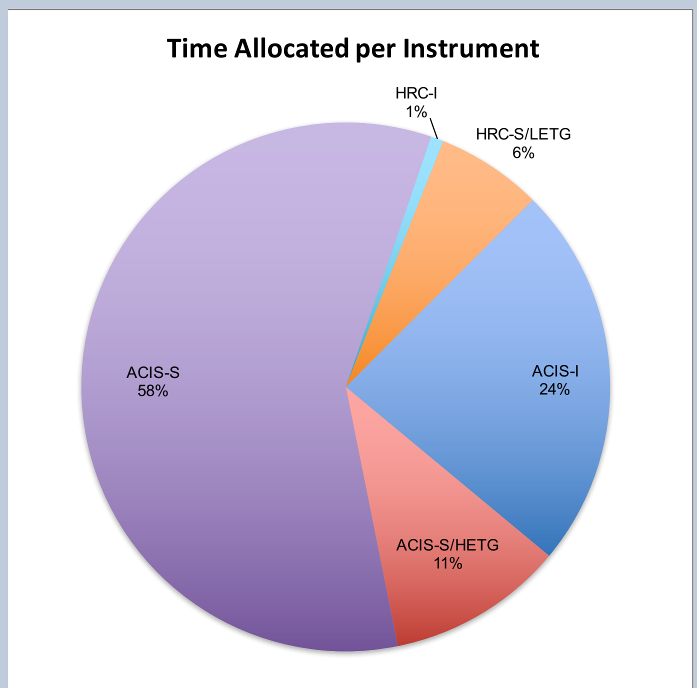


Figure 7: A pie chart showing the percentage of Chandra time allocated to observations for each instrument configuration.

Einstein Fellowship Program

Paul J. Green

Aspiring as ever to political correctness (a much-derided form of empathy), I wondered whether “Fellowship” is a gendered term, since a “fellow” is also used these days to mean a “guy”. But its usage dates way back[1], to c. 1200, when feolahschipe meant "companionship". The sense of "a body of companions" is from the late 13c, which evolved by the 1530s to describe a state of privilege in English colleges.

NASA's Einstein Fellowship fits these definitions and more. As Project Scientist for the Program over the past few years, I am pleased to be facilitating up to 3 years of science research for each of a dozen fellows per year at the U.S. institution of their choice. Einstein Fellows are awarded funds and freedom to pursue their scientific muses, and the results are both impressive and inspiring, as evidenced by their prodigious publications and stunning presentations at the annual Einstein Fellows Symposium.

2017 Applications and Selection

Einstein Fellows' are selected to perform research broadly related to the science goals of the NASA Physics of the Cosmos program. This includes high energy astrophysics relevant to *Chandra*, Fermi, *XMM-Newton*, and future NASA X-ray missions, cosmological investigations relevant to Planck, WFIRST, or new dark energy missions, and gravitational astrophysics relevant to LISA, Pathfinder and subsequent related missions. The proposed research may be observational, instrumental, theoretical, archival or may target sources from these missions at other wavelengths.

Applications for the 2017 Einstein Fellowships were due on Nov 3, 2016, and 156 complete applications were received. These were judiciously assigned to 14 panelists, who met at the CfA on Jan 10-11, 2017 for the difficult job of choosing 8 Einstein Fellows for 2017. The CXC's Andrea Prestwich ably shepherded the proceedings, for which I am grateful. And many thanks as well to the selection panel for all their hard work and diligence. As of this writing, 8 offers have been accepted (4 women, 4 men), amid the usual juggling of preferred host institutions, since we award only one fellowship per host per year. NASA Headquarters will coordinate an official announcement of the winners in conjunction with other fellowship awards sometime in March 2017.

Changes Afoot

Partly to alleviate intense oversubscription in its Astrophysics Research & Analysis (APRA) program, NASA has mandated a significant decrease in the number of its prize (Einstein, Hubble and Sagan) fellowships going forward, and is also seeking to merge management of these fellowships. Details are being worked out, but applicants for 2018 and beyond can expect a single portal and application. The selection panels are likely to meet at the same time, culminating in a merging panel. There may also be changes to fellowship application rules, and to the location and schedule of the annual symposia. Check the CXC website for updates as plans evolve.

Highlights from Current Fellows

Careening into more cheerful territory, what have current Einstein Fellows been up to recently? Let's just mention a sample.

Grant Tremblay (2014) led a paper (2016, Nature, 534, 218) on *Chandra* and ALMA observations of chaotic accretion of cold, clumpy molecular clouds towards the supermassive black hole in the brightest cluster galaxy at the core of the galaxy cluster Abell 2597. Talk about “draining the swamp”! The work was picked up by the press and will be covered in an upcoming Discovery Channel Documentary called "How the Universe Works".

Daniel Gruen (2015) received the University Research Association thesis prize this year and was appointed as co-coordinator of the Dark Energy Survey's Weak Lensing working group.

Lia Corrales (2016) and collaborators used *Chandra* and the SMA to study a mysterious feature within 16 arcseconds of the X-ray binary Cygnus X-3 which varied in phase with it. They showed that Cyg X-3's “Little Friend” is a Bok globule along the line of sight to Cygnus X-3, reflecting its X-ray emission. The application of Milky Way dynamical models allowed this Little Friend to better constrain the distance to Cygnus X-3.

Right here is where a more subtle writer would deftly weave back in the etymology of “fellowship”, creating a satisfying coda. But alas.

More information on NASA's Einstein Fellowship Program can be found at http://cxc.harvard.edu/fellows/. ▪

[1] http://www.etymonline.com

Einstein Fellows Symposium 2017

October 12-13

Harvard-Smithsonian Center for Astrophysics
Cambridge, MA

2016 Press Releases

Megan Watzke

Date	PI	Object	Title
January 5	Eric Schlegel (University Texas San Antonio)	NGC 5195	NASA's *Chandra* Finds Supermassive Black Hole Nearby
January 7	Mark Brodwin (University Missouri-Kansas City)	IDCS J1426.5+3508	NASA's Great Observatories Weigh Massive Young Galaxy Cluster
February 16	Aurora Simionescu (JAXA)	B3 0727+409	Glow from the Big Bang Allows Discovery of Distant Black Hole Jet
March 25	*Chandra* Director's Office	Einstein Fellows	NASA Announces Astronomy and Astrophysics Fellows for 2016
March 30	Sayan Chakraborti (Harvard)	G1.9+0.3	Trigger for Milky Way's Youngest Supernova Identified
April 28	Andrea Morandi (University Alabama-Hunstville)	over 300 galaxy clusters	Probing Dark Energy with Clusters: 'Russian Doll' Galaxy Clusters Reveal Information about Dark Energy
May 24	Fabio Pacucci (Scuola Normale Superiore)	GOODS-S 29323	NASA Telescopes Find Clues For How Giant Black Holes Formed So Quickly
June 27	Bailey Tetarenko (University of Alberta)	VLA J213002.08+120904	Clandestine Black Hole May Represent New Population
July 27	Nicholas Wright (Keele University)	four red dwarf stars	Astronomers Gain New Insight into Magnetic Field of Sun and its Kin
July 28	Kim Arcand (CXC)	AstrOlympics outreach project	The 'AstrOlympics' Open in Time for Summer Games
August 30	Tao Wang (CEA)	CL J1001+0220	Record-breaking Galaxy Cluster Discovered
September 14	Casey Lisse (Johns Hopkins)	Pluto	X-ray Detection Sheds New Light on Pluto
October 19	Jimmy Irwin (University of Alabama)	NGC 4636/NGC 5128	Mysterious Cosmic Objects Erupting in X-rays Discovered
November 21	Michael McCollough (CfA)	Cygnus X-3 and "Little Friend"	A Stellar Circle of Life
December 8	Jingzhe Ma (University of Florida)	SPT 0346-52	Under Construction: Distant Galaxy Churning Out Stars at Remarkable Rate

Links to all of these press releases can be found at: *http://www.chandra.harvard.edu/press/16_releases/*.

Additional image releases and other features that were issued during 2016 are available at: *http://www.chandra.harvard.edu/photo/chronological16.html*.

An August Week: Chandra Science for the Next Decade

Jeremy J. Drake

It was an august week. Quite literally—it was actually August, the 16-19th to be precise. About 120 scientists from around the world converged on the Harvard campus in Cambridge, Massachusetts, to discuss, debate, implore, propose, and invoke a host of other verbs on the topic of *Chandra* Science for the Next Decade.

The CXC sponsors a summer workshop every year. Under the sage stewardship of Director's Office scientist Paul Green, we have tackled a range of highly topical subjects on just about all of the areas of astrophysics that *Chandra* has addressed, with each workshop having concentrated on a particular one. In early 2016 the thought was to tackle something a bit different.

The idea for the meeting was catalysed by a confluence of very encouraging developments associated with the *Chandra* mission. A detailed engineering study of the spacecraft and subsystems in 2014 had found no inherent problems with operations over the next ten years and beyond. The Senior Review enthusiastically endorsed the mission, saying "There appears to be no impediment to many more years of X-ray observations under the CXC stewardship. The 2016 Senior Review Panel enthusiastically endorses the recommendation to extend the mission through 2020 and beyond." NASA is presently in the process of extending the current *Chandra* operations contract out to September 2027. Acceptance of the X-ray Surveyor, now called *Lynx*, as a NASA Mission Concept Study, also heralds the prospects of a new generation X-ray facility, the next step after *Chandra*.

With the prospect that *Chandra* will be in operation for at least another ten years, it was time to reassess where we were with the mission and where was the mission going? Is there anything we have been missing in terms of maximizing the scientific return, and answering major outstanding science questions? And what are these questions going to be in the next decade? What should *Chandra* be doing in the coming years to pave the way for the next generation? How can *Chandra* be best deployed to synergize with new present and near-future capabilities such as ALMA, SKA, LSST, JWST and eROSITA?

A committee of experts was assembled for the Scientific Organizing Committee in February last year, with the author of this article and Chryssa Kouveliotou tasked as chairs. Newly arrived CXC scientist Rudy Montez was dragooned into leading the Local Organizing Committee, and what a fantastic impressment that turned out to be. Initial meetings were convened with the usual delusional wild exuberance typical of the early days of conference planning, in which time to organize stretched to infinity, the number of people we could invite to give talks numbered in the hundreds, all the shortcomings of all the previous conferences any of us had ever been to could be eliminated by the genius of our logistics and the cunning of our method, and minor trifling details like budgets need not be considered. And it was by then into March. The meeting was scheduled for mid-August. What the heck were we thinking?

Paul Green has a special talent for organizing the summer workshop and combined with some years of experience marshalled things along and got them all running as if on a frictionless plane. (On hindsight, the fact the Paul had stepped down from this role should probably have set off some alarm bells had we been paying more attention.) He had put some jolly helpful notes and guidelines together that identified all the many dates by which key milestones had to be passed and crucial minutiae in place in order for the whole process not to concertina into itself and end in a sort of discordant concertina-like chaotic dissonance. I don't think we made a single one of those deadlines.

But somehow—the details are just a blur—everything was made to fall into place and we had a workshop: *Chandra Science for the Next Decade.*

To mix things up a bit, we had decided to try and arrange talks more along physics-based lines rather than topic based. Hence your dismay when your talk on *Chandra* observations of clusters of galaxies was bookended by talks on stellar coronae. The flimsy excuse was that both were observations of what are essentially optically-thin plasmas.

Next Decade workshop attendees discussing the future of the Chandra X-ray Observatory.

Next Decade workshop logo displayed on opening day

insulation is degrading slowly, leading to warming and limits to dwell times at certain solar pitch angles. While this means more complicated scheduling and splitting up longer observations into smaller bites, we still do not have restrictions on accumulated observing times for more problematic areas of the sky. This will eventually change, with the ecliptic poles becoming more difficult to point at.

But the good news by far outweighs the bad: *Chandra*'s science impact continues to be exceptionally high, with 6563 refereed papers up to the beginning of August 2016. This translates to a mean of about 450 papers per year. *Chandra* has also been the focus of about 320 PhD theses worldwide. After 8 years from observation, 90% of *Chandra* data have been published in one or more papers. Our science covers the gamut from solar system objects to the high-redshift universe and everything in between.

Belinda concluded with the Big Questions the meeting was conceived to help define: What major science should *Chandra* address in the next decade? What preparatory science needs to be done to pave the way for *Lynx* and Athena? How can the enormously valuable archive of existing observations be best exploited? How can *Chandra* best be deployed to support multi-wavelength facilities such as ALMA, LOFAR, MWA, LIGO, eROSITA, JWST, LSST, TESS, and then SKA… And what else is needed to facilitate the best science: software updates, additions? Easier data access? More interfacing with other major facilities? Many of these questions were addressed at least to some extent in the next two days.

And it worked, we think: Scientists in every field listened to talks by scientists in just about every other field.

The meeting spanned three full days, starting on Tuesday Aug 16th and ending on Friday Aug 19th. Tuesday was originally a set-up day, but encouraged by IT tech Ray Hemonds' calm assessment that things could be ready by lunch, we scavenged the afternoon to get going. And there really was only one person who could get things going.

Inauguration (biggest ever)

We were honoured to have the first *Chandra* director, Harvey Tananbaum, open the meeting. Harvey of course is the one of the main reasons *Chandra* has been such a roaring success, and he is now deeply interested in seeing the capabilities of *Chandra* be surpassed by a successor. His address built on *Chandra* to extend hope and inspiration to the younger generation of scientists who must inevitably be the ones to build the next generation of missions.

The first session opened with the CXC Director, Belinda Wilkes, giving the State of the Observatory Address, in which, we are glad to report, the traditional conclusion resounded loud and clear "the state of the Observatory is strong!". *Chandra* was launched on July 23 1999 and at the time of Belinda's talk we were just entering our 17th year of operations, with no engineering reasons preventing a further 10 years of operation. But this is not to say we are without challenges going ahead. Belinda noted that the contamination continues to build up on the ACIS filters, sapping our low energy effective area. And the spacecraft thermal

Madness in our Method

Science sessions kicked off within the loose category of "Methods". Martin Elvis argued that commercial space ventures will result in greatly reduced launch costs of missions in the next decade, which will mean we can launch more of them and continue to enjoy an improving panchromatic space-based vista onto the universe. It does sound good and will be great if it works out that way. Winston Churchill's "you can always count on the Americans to do the right thing, after they have tried everything else" does spring to mind though—is the private sector the final answer, or will it all end up costing the same in the end as the inevitable raison d'être of for profit commerce seeking to make as much profit as possible runs its course? Does it work with other mission instruments and subsystems that are already built by the private sector, or do our own "private sector"

Andrea Comastri speaking on the outstanding problems on the nature of supermassive blackholes.

institute labs and facilities do better? It is going to happen though, so let's hope for the best.

Paul Green, fresh, sprightly and smiling as one relieved of a mighty organisational burden, spoke about joint programs. These are important to multi-mission science, avoiding multiple applications to different peer reviews whose available time allocations are not coordinated and might not even overlap very much. Joint programs greatly lower the barriers to meritorious multi-mission projects. A new Joint Contingent Large Programs category was added in Cycle 18 to render large joint programs more feasible. Does more need to be done? Do we need to increase the allotment of joint program and joint contingent large program time? Expanding the program to JWST is being worked; should we expand also to survey facilities such as GAIA, Euclid, TESS and eROSITA? What about new ground-based facilities such as LOFAR and LSST? While immediate answers to these questions were not forthcoming at the meeting, these are clearly things we needed to think more about and soon. Input from the discussions at the meeting triggered by Paul's talk was in fact fed into subsequent decisions later in the year on how to proceed for Cycle 19. One outcome was the expansion of Cycle 19 joint program time, facilitating removal of the Joint Contingent Large Programs proposal category.

Techniques borrowed from the fields of Data Mining and Knowledge Discovery applied to *Chandra* data were the subject of a presentation by Raffaele D'Abrusco. Raffaele emphasised the advantages techniques such as pattern recognition and examining the parameters of our data along different lines to those dictated by our traditional classification schemes can bring. Such techniques will be increasingly important as the legacy of the *Chandra* archive and the samples of the different astrophysical objects continues to grow. And in the theme of new techniques applied to X-ray astronomy, Rosanne Di Stefano highlighted the suitability of *Chandra* data obtained over baselines now exceeding 15 years and in the future hopefully exceeding 25 years, for investigating proper motions. Fast-moving neutron stars, either isolated or in quiescent X-ray binaries, could be a particularly interesting class of sources that are difficult to identify but that could pop out due to palpable proper motion.

Accretion, Cosmology, posters and drinks

Accretion is the ultimate driver of the emission from a large fraction of X-ray sources we study. Two sessions were devoted to talks with an accretion theme, spread across two days. Andrea Comastri gave an invited talk on Active Galactic Nuclei (AGN) physics and evolution, touching on the outstanding problems including the nature of supermassive black hole progenitors—were they light, stellar mass seeds or heavy, and in the thousands of stellar masses?—where and how the first black holes form and grow, and whether quasars contributed to reionization? In what would be a recurring very large project theme throughout the meeting, Andrea argued that a modest 10-15 Ms survey would be needed to address black hole growth in the high-z Universe and the links between central black holes and host galaxy evolution.

David Pooley spoke about the advantages of X-rays for microlensing quasars. X-rays originate from a much more compact region than visible light and provide a far cleaner microlensing signal. This signal is continuing to be applied to problems such as probing quasar accretion disks on microarcsecond scales and assessing the dark matter content of elliptical galaxies. The future is promising provided observations can continue to be made into the next decade: dense temporal sampling of caustic crossings can reveal the detailed structure of the X-ray emitting regions, while the increasing time baseline will provide more powerful probes of dark to stellar matter density ratios.

Stephanie LaMassa speaking about rare high luminosity and high z AGN.

Becky Canning speaking on black hole evolution and cosmic structure.

The symbiosis of AGN and their host galaxies—the ubiquitous "feedback" problem—was touched on by Peter Maksym and Stephanie LaMassa. Peter approached the problem from the perspective of studying the complicated processes at work in the inner kiloparsec of nearby AGN, utilizing *Chandra*'s spatial resolution capabilities to find, perhaps not surprisingly, substantial complexity on sub-arcsecond scales and evidence for large AGN variation and mode switching on short (<<Myr) time scales. He also highlighted the ACIS contaminant as a major problem for further progress due to the relatively soft nature of the diagnostic X-rays. Stephanie pointed out that wide area surveys are the best way to discover the rare high luminosity and high z AGN that can uncover how they evolve and help resolve the relationships between black hole growth and star formation. Her existing work on the "Stripe 82X" survey is helping to fill in our gap in understanding supermassive black hole growth. Of course, the next step would be an even larger survey expanded threefold to 100 deg^2.

AGN also provide signposts to structure in the Universe and in a convenient segue into the first session loosely based on the theme of cosmology, Becky Canning presented results of a survey of AGN in massive galaxy clusters and asked how the evolution of black holes relates to the evolution of cosmic structure? She found that the number density of X-Ray AGN in clusters depends inversely on the host cluster's mass, and work is ongoing on a larger "2nd Generation" survey that should help in understanding the redshift evolution of X-Ray AGN in clusters. *Lynx*, of course, will clean up, but Becky pointed out that much progress will also be made using new facilities in the next decade such as eROSITA combined with WFIRST and ground-based telescopes.

Marat Gilfanov presented results on fluctuations in the CXB surface brightness on scales larger than an arcminute. They discovered a significant large scale structure signal produced by unresolved clusters and groups of galaxies at redshift z~0.6. The number density of galaxy clusters as a function of mass and time places strong constraints on the equation of state of dark energy. Devon Hollowood pointed out that the Dark Energy Surveyor (DES) will use the cluster richness mass proxy, but that the mass-richness relation is not yet well-characterised. He has used *Chandra* observations of the hot cluster gas to quantify the scatter in the mass-richness relation that will be invaluable for the interpretation of the DES results.

Finally in the last talk of the session, Anastasia Fialkov artfully staved off the mad rush to drinks with a compelling argument for synergy between radio 21 cm surveys and high-redshift X-ray surveys to study the ionization and heating of the IGM by high-redshift X-ray sources that imprinted their signature in the neutral hydrogen 21-cm signal from early epochs (z~10-30). Beer and wine kindly sponsored by Harvard College Observatory served in custom-printed "Next" glasses (logo designed by CXC graphic designer Kristin Divona) accompanied celebratory poster viewing and ardent scientific discussion that lasted almost until the start of the first session the next day...

Wednesday

It was to be a packed schedule, touching dexterously upon many of the outstanding problems of high-energy astrophysics. "Outflows 1", hinting subtly that, yes, there would at some point in the future be an "Outflows 2", got us off to a whirlwind start. Winds whirling from hot stars and injecting feedback energy into their environments and the major role *Chandra* has played in advancing our understanding was the topic of the invited presentation by Jesus Toala. Jesus highlighted of the importance of high-resolution X-ray spectra for constraining and testing radiatively-driven stellar wind theory, while *Chandra*'s spatial resolution has been put to work unveiling wind-blown bubbles from massive stars and complexes, enabling measurement and characterization of injection energy. The next vital steps? Large Ms-type studies of lower metallicity regions such as the SMC to

Lidia Oskinova speaking on the winds of massive stars.

probe the role of metals both for metal line-driven outflows in general and on the evolution of massive stars.

Lidia Oskinova then provided a convincing case based on *Chandra* spectroscopy that the winds of the majority of normal massive stars are best studied in X-ray wavelengths. High resolution *Chandra* spectra have demonstrated that X-rays from main-sequence O stars are generated very close to the photosphere and that the hot plasma occupies a large volume and is expanding supersonically. Meanwhile luminous blue variables are X-ray dark, but X-rays and spectral line profiles can be used as diagnostics of mass loss and clumping in OB supergiants, although UV and X-ray observations are required to remove degeneracies. Desiderata for the future include a 1 Ms HETG spectrum of an O star such as ζ Pup. Lidia also noted the potential for neutron stars in high mass binaries for probing massive star winds.

Joey Neilsen shifted the theme to winds from stellar mass black holes, that have been revealed in all their glory and gory detail by high resolution *Chandra* spectra showing ubiquitous blueshifted ionized absorption lines in outbursting high-inclination systems. But Joey pointed out that winds are generally not detected during harder more jet-dominated states. The solution to why not is important for understanding outbursts and how winds might regulate mass accretion, but will require greater theoretical understanding of ionization of disks and winds, thermal instabilities and the wind formation processes in general. Toward much higher mass black holes, Francesco Tombesi showcased the utility of HETG spectra for showing that winds as well as jets play a role in injection of energy into host galaxies. He made the case for future very deep *Chandra* HETG observations, with the unique combination of high-resolution spectra and 0^{th} order imaging, to shed more light on the complex environment in radio and seyfert galaxies.

Salvo Sciortino got us going again after an invigorating coffee break, with an invited talk on stars and exoplanets. The latter of course is a relatively recent addition to high-energy astrophysics, and Salvo presented the case that close-in planets might interact magnetically with the host star corona. The jury is, we think, still out on whether there is any significant interaction, and further work by *Chandra* both on this and exoplanet occultation will be challenging in terms of exposure times required, although the science is compelling. *Chandra* remains essential for deep studies of crowded star-forming regions and some fascinating results are emerging from combined long-term optical monitoring revealing spots and circumstellar disks and simultaneous X-ray observations of flares and other modulations. Cecilia Garraffo followed up with a new idea that promises an explanation for the hitherto puzzling distribution of the rotation velocities of stars in young clusters. Cecilia has performed sophisticated MHD wind simulations that show the

Joey Neilsen speaking on winds from stellar blackholes.

complexity of surface magnetic field is vital for controlling angular momentum loss. Young zero age main sequence stars have complex surface magnetic field morphology that transitions in a pseudo-random way to less complex, at which point magnetic braking is greatly enhanced. *Chandra* serendipitous stellar surveys in the archive and the next decade will play a major role in testing the theory.

Two talks then addressed the hot plasma medium associated with galaxies. Scott Randall argued for the role of heating of the intracluster medium of clusters of galaxies by weak shocks, many of which can occur over the gas cooling timescale. *Chandra* can detect the shock signatures but making progress in the next decade will require long Ms or great observations. Smita Mathur reviewed spectroscopic observations along different sightlines that indicate the presence of a warm-hot circumgalactic medium that might contain the Galaxy's missing baryons. Future observations could extend to other galaxies, though exposure times would be very costly. Joseph Burchett continued the discussion of missing baryons in galaxy clusters in the next session, but of which we give a timely mention here. *Chandra* provides the hot gas mass, while UV and optical spectroscopy probes the warm phase. Characterizing higher redshift clusters and resolving local substructure around individual galaxies are primary next decade goals, requiring extensive new observations but also utilizing growing *Chandra* and HST archives.

Ken Ebisawa returned to our Galaxy with a presentation on the nature of the "Galactic Ridge X-ray Emission (GRXE)"—apparently diffuse emission along the Galactic plane thought to be due to a myriad unresolved point CVs and coronally active stars. Ken noted that there does now appear to be a diffuse emission component, but he also used multiwavelength follow-up of *Chandra* sources to identify a new class of source that might contribute a non-negligible fraction of the GRXE. The best guess as to what these sources are? Detached white dwarf - M dwarf binaries accreting the winds of their companions.

Structure of the Cosmos

It was a good sounding heading and these sessions covered some marvelously varied but sometimes surprisingly connected talks. Pepi Fabbiano delivered a tour de force invited review on *Chandra*'s contribution to galaxy evolution, showcasing progress made on how the final stages of the evolution of different stellar populations, such as supernovae and stellar remnants in binary systems, contribute, together with the gamut of AGN activity and the transfer of energy to hot halos. What for the next decade? *Chandra* spatial resolution is of course paramount, with deep halo studies, of which there are presently very few, and deep studies of circumnuclear regions being highest on the list. This is one of the many fields for which the low energy response is vital and Pepi suggested that observations requiring the low energy response be prioritized.

Dascheng Lin explained how hyper-luminous ($>10^{41}$ erg/s) off-nuclear X-ray sources (HLXs) are strong candidates for the elusive intermediate mass black holes (IMBHs) expected from various processes such as runaway merging of massive stars in young compact star clusters resulting from galactic mergers, or the collapse of Population III stars in the early Universe. *Chandra*'s spatial resolution combined with time domain surveys will present a powerful combination for finding and understanding these objects in the next decade. Scott Barrows continued on this theme, presenting impressive work on a procedure for matching archival *Chandra* data with overlapping coverage of galaxies from optical databases such as the SDSS and *Hubble* to identify offset AGN, ultraluminous X-ray sources, and HLXs. The offsets indicate galaxy mergers that are otherwise very difficult to find. A catalogue of 300 HLXs candidates and 21 IMBH candidates is also expected shortly.

Daniel Wang gave an invigorating talk on the latest from our Galaxy's own supermassive black hole, Sgr A*. *Chandra* has made impressive observations of the Sgr A* region, revealing flares on the central source that make up ⅔ of its observed counts. A massive star colliding wind model appears to match the observations of the accretion flow. Daniel explained that more counts ($> 10^4$) are needed to study the timing and spectral properties of the flares, and that future multi-wavelength coordinated observations should provide valuable insights into the nature of the flare emission and the role of strong gravity.

Too much discussion of cosmic structure inevitably leads down the perilous road to cosmology. Steve Allen's invited talk summarized the latest results on cosmology from galaxy cluster studies and the view of the next decade. Cluster counts as a function of mass and redshift have been crucial in building the current picture of a universe dominated by dark matter and dark energy. He concluded with a resounding "The prospects for progress over the next decade are outstanding", citing new cluster catalogs, hundreds of times larger and with far greater redshift reach, being constructed across a variety of wavelengths. *Chandra* follow-up observations will be vital to exploit these, but large amounts of exposure time will be needed, say 0.5-1.0 Ms/yr over 5-10 years.

Daniel Wang speaking on the supermassive black hole in our Galaxy.

The last two cosmology talks, or more correctly, talks that your capricious SOC placed into a cosmology session, dealt with early black hole formation. Kevin Schawinski has been in search of the "missing seeds". There are very massive quasars at $z\sim6$ with very low space densities but a distinct lack of AGN at $z>6$ in deep *Chandra* pointings. Kevin concludes that black hole seed formation at $z>6$ is highly inefficient and suppressed in most galaxies. Extensive surveys exploring the AGN luminosity function at $4<z<10$ are needed to further understand the seed formation suppression. Nico Cappelluti then pointed out that all the high-redshift AGN that could be detected will be seen in EUCLID, WFIRST, JWST or HST catalogues. The searches for these objects could be more sensitive if the priors from these optical and infrared detections were used. Combinations of filters could also be chosen to maximize the sensitivity of such surveys.

The 30-year Visionary NASA/Astrophysics Division Roadmap identified 4 probes that should be considered in the 2020 Decadal Survey. The science session finished with a talk by Feryal Ozel on the X-ray Surveyor mission concept, later to be named *Lynx*, prior to a discussion session on major missions and synergies. Feryal, the co-chair (with A. Vikhlinin) of the X-ray Surveyor Science and Technology Definition Team, presented their progress on the mission design and summarized the key science that *Lynx* can address, ranging from the first black holes to missing baryons to transit absorption spectroscopy of exoplanets. The theoretical studies of the mission requirements have produced spectacular advances; however, there are challenges, not least of which is the construction of lightweight high angular resolution mirrors, to conform to the Roadmap definition. *Lynx* will be the natural successor to the fantastic legacy that *Chandra* will leave behind, with spatial and low-energy spectral resolution as the distinguishing quantum leaps forward over current missions and Athena in the late 2020's.

Panel Discussion: Synergies with Major Facilities

The panel on *Chandra* Synergies with Major Facilities in the coming decade included speakers representing current (*Hubble*, *XMM-Newton*, *NuSTAR*, LoFAR) and future (eRosita, Euclid, WFIRST, JWST) missions.

Norbert Schartel gave a very detailed description of the complementarity of the two missions, *Chandra* and *XMM*. He pointed out that 400 ks of joint *Chandra*/*XMM* observations covering all classes of objects is available per year and stressed the excellent synergy of the two missions. Finally he noted that *XMM* is focusing on Legacy programs dedicating ~6 Ms over 3 years, and pointed out that if the *Chandra* available time would increase to 1Ms, it would allow for large joint programs. Daniel Stern focused on the spectral range complementarity between *NuSTAR* and *Chandra*, resulting in the most oversubscribed joint program in the last cycle. He also discussed the status of Euclid and WFIRST and commented that the most likely synergy between *Chandra* and these future missions would be follow-up observations of specific targets. Paul Nandra discussed the status of eRosita, an ESA all sky X-ray survey mission, and pointed out that the best synergy would be *Chandra* follow-up of selected eRosita sources (clusters, AGN, transients). He also presented the complementarity between *Chandra* and ATHENA (currently scheduled to launch ~ 2028), as an optimistic look at the *Chandra* future. Rachel Osten discussed the unique science resulting from combining *Chandra* and *Hubble* observations and how it can be maximized by combined programs, such as joint community-enabling initiatives (e.g., supermosaics, Spectroscopic Legacy Archive). She also commented on the extraordinary science combined JWST/*Chandra* observations of transients would afford. Reinout Van Weeren discussed the X-ray–radio synergies giving an excellent presentation of the Radio landscape in the next decade—he noted that the radio community is currently focusing on Large Surveys. The Radio observations seamlessly complement the X-ray data of most astrophysical sources, e.g., compact objects, AGN, clusters.

Audience discussion was vigorous, with many questions levied at such a valuable assemblage of panelists before fatigue and the want of evening entertainment and dinner drew the day to a close.

Poster Panoply

About 45 posters were on display throughout the meeting, ranging from instrument presentations such as Catherine Grant's "Seventeen Years of the Advanced CCD Imaging Spectrometer" to John ZuHone's "The Galaxy Cluster Merger Catalog", and all science inbetween. Pat Broos showcased his impressive work with Leisa Townsley on their ACIS Extract software on Galactic star clusters, while Leisa made the case for *Chandra* observations of infrared dark clouds. Several posters dealt with archival research and Ian Evans expounded on the magnum opus that is Release 2 of the *Chandra* Source Catalog that will "roughly triple the size of the original catalog released in 2009 to an estimated 350,000 detections". Due near the end of this year, we are told.

Using "background" X-ray sources to investigate the WHIM and our Galaxy's ISM was a recurring theme throughout the meeting. Daniel Rogantini furthered the cause of impressive lanterne rouge speaker Sascha Zeegers (see the last meeting session described later) with a poster expounding on the use of synchrotron measurements of fine structure at the Fe K edge to probe grain composition. A similar theme, but silicon-based, was presented by Norbert Schulz, while Lia Corrales reported the preliminary discovery of a dust scattering halo around a recently discovered X-ray transient, SWIFT J174540.7-290015. David Principe's poster extended this to the edge-on pre-MS transitional disks of T Cha and RY Lup whose X-ray emitting coronae shine through the disks and reveal some interesting structure.

Young pre-main-sequence stars in the cluster IC 348 were the targets of a large HETG program described by David Huenemoerder. This work, and Herman Marshall's talk on similar HETG observations of X-ray binaries in M31 (see below), shows that source confusion is not usually an issue for overlapping HETG spectral arms, even in complicated source regions. Costanza Argiroffi and co-workers stretched the bounds of the HETG in yet another dimension by applying its spectacular wavelength precision to detect a 30-40 km/s blueshift of gas accreting onto the classical T Tauri star TW Hya.

X-ray emission from stars was the topic of several other campaigns, with Scott Engle presenting both on the surprising X-ray emission from Cepheids by an as yet unidentified mechanism and on the activity-rotation-age relationship for M dwarfs that are the low hanging fruit of exoplanet surveys. More on the low-mass end came from your present author and co-author Nick Wright, who have found that the rotation-activity relation for sun-like stars extends to fully-convective M dwarfs, implying that radiative-convective tachoclines are not an important ingredient in stellar dynamos. At higher masses, Joy Nichols analysed the line profiles on the O4 If star ζ Pup to look for co-rotating interacting regions and clumpy wind signatures, while Victoria Grinberg expostulated on the use of HMXBs for probing the clumpy winds of massive stars—something also touched upon by Lidia Oskinova's talk mentioned above. Margarita Karovska's poster highlighted *Chandra*'s sub-arcsecond resolution applications to imaging wind-accreting objects such as the Mira binary and other symbiotics. The related cataclysmic variables were SOC expert Koji Mukai's focus, who presented progress understanding the populations of vanilla non-magnetic objects as well as rare X-ray bright CVs.

Black holes of the more modest variety featured through Jifeng Liu's poster arguing ULXs are stellar mass black holes with supercritical accretion rather than intermediate mass black holes, Shuping Yan's work on the "heartbeat" of microquasar GRS 1915+105, Antonella Fruscione's analysis of ULXs in colliding ring galaxies, and Dan Milisavljevic's search for "baby black holes" undergoing accretion and revealed within the thinning debris of recent supernovae.

Bigger ones of the AGN kind, beginning with our own Sgr A* and its environs and the lure of future observations thereof, was the topic of Fred Baganoff's work, while next door in the Andromeda galaxy the central black hole has the attention of Shuinai Zhang whose analysis of *XMM-Newton* data on the bulge suggests that the currently quiescent nucleus had a characteristic luminosity of $\sim 10^{43.5}$ erg/s, about 400,000 years ago. SOC member Francesca Civano has far too many AGN in the 4.6 Ms COSMOS Legacy Survey and so emphasised the glamorous high redshift Universe in her poster. Erendira Huerta analysed and modelled archival high-resolution X-ray spectra of AGN to examine halos and outflows, and Malgosia Sobolewska presented the first results from her X-ray study of "compact symmetric" young radio sources that will be important for constraining models for the earliest stage of radio source evolution and their interaction with the interstellar environment of their host galaxies. Eric Miller showcased a fossil group in formation in the form of Shakhbazyan, a remarkably compact collection massive, red-sequence galaxies.

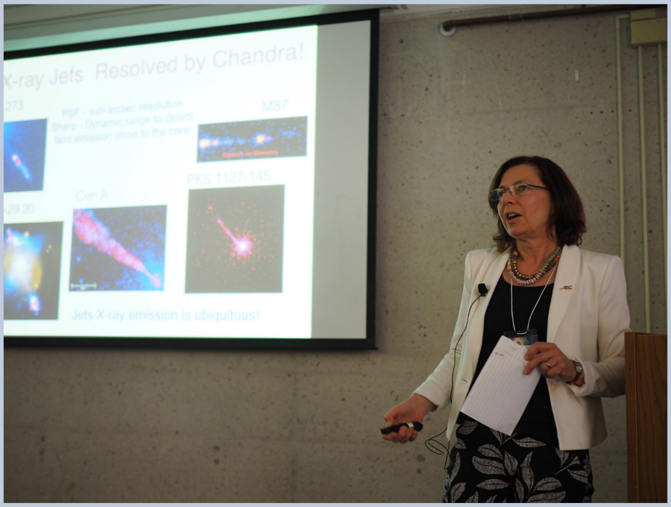
On larger scales, galaxy clusters featured in Gagandeep Anand's presentation on the "wide angle tail" hosting galaxy cluster Abell 623, Emmet Golden-Marx's multiwavelength follow-up observations of the COBRA high-z galaxy cluster survey of "bent lobe" sources in clusters, and Vijaysarathy Bharadwaj analysis of *Chandra* observations of the type II AGN hosting intermediate redshift galaxy cluster ACT J0320.4+0032. Gerrit Schellenberger looked to the future and *Chandra* follow-up of (probably only some of) the 100,000 expected eROSITA detected clusters. Taweewat Somboonpanyakul discussed galaxy clusters hiding in plain sight—why didn't we see them before?!—while Rachel Paterno-Mahler's poster dealt with *Swift* characterization of a strong lens cluster sample.

Several more "technical" posters described various aspects of the *Chandra* archive, data sets, bibliography and software systems, and Laura Brenemen described the promise of the Arcus mission concept for studying the evolution of structure and feedback. All in all, an embarrassment of inspirational riches to talk about over cups of tea and coffee in the morning and glasses of wine and beer in the evening.

More Accretion, Outflows and Hot Thermal Plasmas

In short, everything that was not already covered, except for transients and periodic sources, formed the basis of Friday's first session. Jeno Sokoloski got us going with an entertaining invited talk on "Flows and shell burning of accreting white dwarfs"—novae and symbiotic stars, in essence. Jeno presented some spectacular spectra of nova explosions as well as highlighting the value of resolved observations of nova blasts and remnants, all seasoned with tantalizing hints from gamma ray observations that novae are the sites of some interesting particle acceleration processes.

Jun Yang presented her large X-ray pulsar database compiled from *Chandra*, *XMM-Newton* and RXTE observations of the SMC. The data provide a valuable glimpse into binaries and pulsars in a low metallicity environment, but also highlight the importance of knowing the distance to the sources. Herman Marshall then dazzled the assemblage with HETG observations of the M31 bulge. So many spectra of X-ray binaries! They all overlap in a complicated way but Herman convinced us (I think!) that data can be disentangled. Back in the SMC, Vallia Antoniou was due to talk about the Visionary Project to survey key regions of the galaxy. But… she just had her baby Konstantina and delegated the task to Andreas Zezas, who touched upon all ground-breaking science the survey is producing. Again, the theme of the low-metallicity environment is a constant undercurrent, and the major pièce de résistance will be X-ray binary formation as a function of stellar population age. Javier Garcia brought up the problem of bright hard-state accretion disk truncation in black hole binaries whose ambiguity in current data remains unresolved and a source of major contention in the field, especially for interpreting measurements of black hole spin. The answer lies in extending to higher energies with joint *Chandra*/*NuSTAR* observations to break the degeneracy in current models.



Aneta Siemiginowska speaking on relativistic jets from AGN.

Morning coffee, though welcome, provided less physical stimulus than high-resolution spectroscopy in the hands of invited speaker Jon Miller. Jon emphasised that *Chandra* remains the flagship high-resolution mission and discussed how *Chandra* spectroscopy of black holes across the mass scale can make key progress over the next decade. Demosthenes Kazanas talked about black hole accretion disk winds, and their importance for angular momentum transport and feedback into their environments. He suggested that that successful wind modelling of HETG X-ray data of GRO 1655-40 using the same techniques as for AGN disk winds argues for the universality of accretion disk wind properties across the entire ($10\ M_{\odot}$–$10^9\ M_{\odot}$) black hole mass range. Missagh Mehdipour continued the theme of black hole disk winds and outflows with impressive modelling of extensive multi-satellite data on NGC 7469 that mapped the ionisation, chemical, and dynamical structure of the outflow.

Myriam Gitti pressed on with feedback in cool-core galaxy clusters from AGN outflows. She noted that future radio surveys with LOFAR and SKA have the potential to increase the number of known radio mini-halos to ~1000 objects. Synergies of these radio surveys with current and future X-ray observations will be crucial for establishing the radio mini-halo origin. Aneta Siemiginowska switched gears to relativistic jets from AGN. After 16 years of *Chandra* observations there are now about 100 X-ray jets associated with radio galaxies and quasars. But these are generally shallow ~10ks observations and key jet physics requires much deeper observations that must surely be made by *Chandra* in the next decade.

Among the black holes, Maurice Leutenegger did a cameo on OB stars winds and assessing the uncertainties on mass loss rate estimates based on X-ray spectral line profiles. They are crucial measurements and uncertainties are now probably at a level of about 50%—much less than the factors of a few difference between theory and measurement, with measurements always lower.

The afternoon ushered in the hot thermal plasmas. Helen Russell's lucid invited talk went back to feedback in galaxy clusters by AGN and driving of both hot and cold gas flows. Helen showed some impressive ALMA data revealing several kpc long molecular gas filaments. Radio bubbles supply large-scale heating to stabilise cluster atmospheres and lift gas in their wakes. In the next decade, *Chandra* observations of X-ray structure coupled with ALMA molecular gas tracers will be a powerful diagnostic of cluster feedback.

Redshifts diminished in the next three talks on stars and exoplanets. Tom Ayres showcased *Chandra* observations of the α Cen that have revealed a solar-like magnetic cyclic variation of X-rays, pointing out that if we are sending missions to the α Cen system we must continue to observe and characterize it in detail don't miss Tom's article on alpha Cen on page 1 of this issue). Scott Wolk presented evidence that there might be some observable degree of magnetic interaction between stars and close-in planets, and that the latter might in fact inhibit stellar angular momentum loss. He also noted that transit absorption measurements in X-rays can help characterise planetary atmospheric extent and chemical composition. Slightly further afield, Ignazio Pillitteri highlighted the synergy between *Chandra* and Gaia observations of young stellar clusters, where *Chandra* pinpoints the young stars and Gaia tells us about their motion and distance, allowing us to unravel cluster structure and dynamical evolution.

In the countdown to the Key Legacy Projects panel discussion, Alessandro Paggi wrapped up with some tantalizing snippets on X-ray mass profiles from the *Chandra* Gal-

Tom Ayres speaking on solar-like variations of X-rays from α Cen.

axy Atlas being developed by Paggi and co-workers. This rich resource is already producing interesting results on gas structure, with NGC 4649 having a smooth, essentially hydrostatic equilibrium gas structure while NGC 5846 shows evidence of sloshing and galactic interaction.

Panel Discussion: Key Legacy Projects

So, we had sat through two and a half days of a meeting in which speaker after speaker had made a case that large amounts of exposure time were needed to push forward with key science. But what are the key projects *Chandra* really needs to do? Everyone has an opinion and it was time for another panel discussion! Our panelists were chosen for both their relevant expertise but also their experience with *Chandra*. Daniel Wang, PI of numerous *Chandra* programs on Galactic as well as extragalactic objects, both point sources and diffuse emission; Alexey Vikhlinin, SAO lead for the *Lynx* effort and PI of numerous *Chandra* observations of galaxy clusters; Fabrizio Fiore, Director of Osservatorio Astronomico di Roma specializing in extragalactic high energy astrophysics and cosmology with extensive *XMM-Newton* and *Chandra* experience; and Leisa Townsley, probably *Chandra*'s most successful large project PI and pioneer of studies of massive star forming regions. Oh, and there was one more sitting at the end of the table—a British holiday maker bearing a striking resemblance to supernova remnant and plasma physics expert Martin Laming of the Naval Research Laboratory, who could not attend himself due to cumbersome military travel approval processes. Each had 10 minutes to summarize their key project that *Chandra* must do in the next decade.

So what were their key projects? In brief, Wang: further observations of Sgr A* and surrounding regions; megaseconds required. Vikhlinin: Deep imaging of faint, extended objects to make use of *Chandra*'s excellent capability to isolate and remove faint point sources, such as cluster and galaxy group outskirts, high-density large scale structures and galaxy cluster progenitors; circumgalactic media and galaxy winds, Galactic ISM; quite a few megaseconds required. Townsley: the big picture of Galactic star formation by surveying whole giant molecular filaments (in Leisa's words, "study the forest ecology, not just the butterflies and tigers"); several megaseconds required. Fiore: the first black holes in joint observations with JWST; observations of candidate first galaxy groups and clusters selected by radio and FIR surveys; formation of the first structures and the role of feedback using joint *Chandra* and JWST observations; and again joint JWST and *Chandra* observations of shocks and halos in unbiased AGN surveys; in all, several megaseconds required. The British holiday maker favoured deep observations of supernova filaments in order to resolve the fundamental physics of astrophysical shocks; but it needs megaseconds.

Raffaela Margutti speaking on X-rays from supernovae.

The common thread through these presentations and subsequent discussion was that very large programs are needed in order to enable all this key but expensive science. Note that in the last AO there was no very large program ("X-ray Visionary Program" as it was last called) category. While presentations and discussion were going on, SOC wizard Francesca Civano implemented a live text feed such that comments and questions could be submitted by members of the audience either signed or anonymously. The need for very large programs came up again and again, with comments submitted by some surprising names including Luke Skywalker and Genghis Khan. We are pleased to report that the clamour was not ignored and that VLPs ("Very Large Programs") are back for this coming AO.

The reward for having survived the panel discussion was a delightful conference dinner and drinks, accompanied by the unburdened, relaxed Paul Green and guitarist friend Bill Morris, with a guest appearance on violin by Chelsea MacLeod.

It's always difficult being on the last day

But kickoff by Raffaela Margutti went down like an opening keynote, and gave one the rather unsettling feeling that we are just wasting time on our current science and should switch to studying supernovae! X-rays from SNe can be broadly categorized under the heading of interaction of the blast with the progenitor environment, and Raffaela covered the different aspects that X-rays can teach us about the astrophysics of the progenitors—pinning down the end of lifetime structure and mass loss, for example—as well as the nature of the explosion itself. Kari Frank followed up in the same context with a presentation on SN1987a that *Chandra* has observed at 6 month intervals for the last 16 years. Struggling to compress all the science this entails into his contributed talk, Kari just slapped up a banner "Lots of interesting results!". In short, measurements of the blast tell


Musical entertainment during the dinner banquet from (left to right) Paul Green, Bill Morris, and Chelsea MacLeod.

us all about the circumstellar medium and blue supergiant progenitor mass loss at the time of collapse, as well as enabling dissection of the blast energetics, all in unprecedented detail. Observations will continue into the next decade. Kazimierz Borkowski expanded the topic to other expanding SNe observed by *Chandra* that are revealing the details of the explosion and progenitor mass loss and structure. The only downside to these spectacular studies is that there is not a huge number of objects to continue with!

While the neutron star from SN 1987a has not been detected yet in X-rays, Slavko Bogdanov talked about the only three transitional millisecond pulsars that had and that are beginning to answer questions regarding how transitions to and from accreting states—presumably responsible for the spinup—occur and how X-ray mode switching, flares, and jet driving occur. Statistics and cool star expert Vinay Kashyap segued to flares on late-type stars observed by *Chandra* gratings that are revealing new and puzzling behaviour in flaring plasma; of note is that harder X-ray emission tends to lag behind full-band integrated light, and that lines formed at similar temperatures do not all respond in the same way.

Down the home straight, Oleg Kargaltsev presented a spectacular invited review on Pulsar Wind Nebulae (PWNe), unequivocally establishing the unique contributions of *Chandra* in that field. He showed that the discovery of PWNe increased dramatically after the launch of *Chandra*, with 90 new PWN found thanks to the unique *Chandra* spatial resolution and low background. Further, besides Crab and Vela, the morphology of multiple PWNe was shown to be clearly affected by the PSR motion (including head-tail PWNe) resulting in elongated structures.

The meeting was wrapped up by a dazzlingly diverse splash of five talks. Chandrayee Maitra presented *Chandra* observations of PSR J0855-4644 that revealed a pulsar wind nebula with a double torus and jet-like structure. Max Bonamente and team discovered a new OVIII K-alpha X-ray absorption line system towards the quasar PG 1116+215 in LETG observations (see the LETG article on page 26 for further details). The use of the HETG to probe the chemical composition and temperature structure of the ISM of our Galaxy using bright background sources was discussed by Efrain Gattuz, who found predominantly neutral gas but with smaller amounts of gas over a range of ionization states. Konstantina Anastasopoulou has been busy analyzing a deep *Chandra* observation of the X-ray luminous interacting galaxy system Arp 299 and has found a rather large population of 20 ULXs, in addition to diffuse hot gas and an extended soft X-ray plume signalling a large scale outflow.

And at the end of a raucous, chaotic, brilliant three days of the highest level astrophysics, we were left with dust. Interstellar dust, and a masterclass by Sascha Seegers who expounded on all that can be done in the next decade with the *Chandra* HETGS using bright X-ray binaries as background sources. X-ray absorption fine structure can help reveal dust grain composition as well as the bulk chemical composition.

It became obvious during the week that *Chandra* will be tackling absolute top-rank science in the years to come. We have only just started. *Chandra* Science for the Next Decade. It was an august week.[1] It has been an august 16 years. It will be an august Next Decade. ▪

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[1] Talks and abstracts can be found at http://cxc.cfa.harvard.edu/cdo/next_decade2016/program.html


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Scenes from *Chandra Science for the Next Decade*

(from top to bottom, left to right) Oleg Kargaltsev speaking on pulsar wind nebulae. Jun Yang speaking on X-ray pulsars in the SMC. Salvo Sciortino (left) and Giusi Micela (right) enjoying the selection of posters. Rosanne Di Stefano after speaking about investigating proper motions amongst the Chandra decades-long archive. Synergies with Major Facilities Panelists (left to right): Reinout Van Weeren, Daniel Stern, Norbert Schartel, Rachel Osten, Paul Nandra.

(full article on page 38)

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