The Quality and Stability of Chandra Telescope Pointing and Spacial Resolution

Ping Zhao (SAO)

For the past decade, Chandra X-ray Observatory revolutionized the X-ray astronomy as being the first, and so far the only, X-ray telescope achieving sub-arcsecond spacial resolution. Chandra is comprised of three principal elements: the High Resolution Mirror Assembly (HRMA), Pointing Control and Aspect Determination (PCAD) system, and the Science Instrument Module (SIM), which is where the X-ray detectors mounted and is connected to the HRMA by a 10-meter long Optical Bench Assembly. To achieve and retain the unprecedented imaging quality, it is critical that these three principal elements to stay rigid and stable for the entire life time of the Chandra operation. I will review the issues of telescope pointing stability, optical Axis, aimpoint and their impacts to the Chandra operation, and evaluate the integrity and stability of the telescope. I will show images taken from all four detectors in the past decade to demonstrate the quality and stability of the Chandra spacial resolution.

Discarding the Tea Leaves: Whats in store for the HRMA Effective Area

Diab Jerius (SAO)
Richard Edgar (SAO), Brad Wargelin (SAO), Ping Zhao (SAO), Terry Gaetz (SAO)

Our estimation of the effective area of Chandras mirrors is based in part on achieving a harmonious agreement with ground calibration data. This has proved challenging due to the inevitable imperfections in the data as well as in our knowledge and ability to correct for them. We discuss our latest efforts in re-analyzing the XRCF data and how they affect the current published HRMA Effective Area, as well as possible future improvements, if any.

Summary of the Recent Update to the Chandra HRMA Calibration

Terrance Gaetz (SAO)
Richard Edgar (SAO), Diab Jerius (SAO), Ping Zhao (SAO)

Following a lengthy reexamination of the ground calibration data and the raytrace model, a revision of the HRMA effective area (version N0008) was released 2009 January 21 as part of patch 4.1.1 to the Chandra CALDB. The new HRMA effective area model takes into account the small surface contamination now known to be present pre-launch, and also incorporates a new weighting of the prelaunch measurements from the ground calibration. The new model improves the agreement with other observatories for temperature estimates for hot galaxy clusters, but also has the effect of lowering the effective area at low energies. We will review some of the considerations which went into the model and the various tests of the new model.

More Parametrization of the Chandra Point Spread Function

Jean Connelly (SAO)
Diab Jerius (SAO), Terry Gaetz (SAO)

The Chandra X-ray Observatory point spread function (PSF) is a complex function of source position and energy. On-orbit calibration observations with sufficient S/N sample only a small fraction of the possible parameter space, and are complicated by detector systematics. Thus, the standard method of analyzing Chandra data uses the standard Chandra optics model as a reference. The optics model accurately simulates the telescope's PSF, but as it is a raytrace based technique, it can be time-consuming to run and is not always appropriate for a given analysis task.

We have previously presented a simple parametrization of the PSF for off-axis point sources. This has proven to be useful for many analysis purposes and in many cases obviates the need for users to run lengthy raytraces. Here we present new data to validate this method and offer more finely sampled parametrization products for all detectors.

Studies of the Point-Spread Function of the Chandra High Resolution Camera

Michael Juda (SAO)
Margarita Karovska (SAO)

The Chandra High Resolution Camera (HRC) should provide an ideal imaging match to the High-Resolution Mirror Assembly (HRMA). The laboratory-measured intrinsic resolution of the HRC is ∼20 microns FWHM. HRC event positions are determined via a centroiding method rather than by using discrete pixels. This event position reconstruction method and any non-ideal performance of the detector electronics can introduce distortions in event locations that, when combined with spacecraft dither, produce artifacts in source images. We compare ray-traces of the HRMA response for "on-axis" observations of AR Lac and Capella as they move through their dither patterns to images produced from filtered event lists, in order to characterize the effective intrinsic PSF of the HRC-I.

An edge-like feature in high signal-to-noise ratio spectra of galaxy clusters

En-Hsin Peng (MIT)
Karl Andersson (MIT), Mark Bautz (MIT)

We present tentative evidence that there is a ∼10% absorption near the Si edge around 1.75 keV for the ACIS-I instruments. From observations of galaxy clusters, we find that previously reported high hard-band to broad-band temperature ratio in many clusters observed with Chandra, not supported by XMM-Newton data, may be resulting from this absorption. Modeling this residual feature and discussing its implication will be presented.

On Calibrations using the Crab Nebula as a Standard Candle

Martin Weisskopf (NASA/MSFC)
Matteo Guainazzi (ESAC), Keith Jahoda (NASA/GSFC), Nikolai Shaposhnikov (U. MD), Stephen O'Dell (NASA/MSFC), Vyacheslav Zavlin (USRA/MSFC), Colleen Wilson-Hodge (NASA/MSFC), Ronald Elsner (NASA/MSFC)

Inspired by a recent paper (Kirsch et al. 2005) on possible use of the Crab Nebula as a standard candle for calibrating X-ray response functions, we examine possible consequences of intrinsic departures from a single (absorbed) power law upon such calibrations. We limited our analyses to three more modern X-ray instruments – the ROSAT/PSPC, the RXTE/PCA, and the XMM-Newton/EPIC-pn. The results are unexpected and indicate a need to refine two of the three response functions studied. The implications for Chandra will be discussed.

Using 1E 0102.2-7219 and G21.5-0.9 to Cross-calibrate Chandra, XMM, Swift & Suzaku

Paul Plucinsky (SAO)
Joe DePasquale (SAO), Jennifer Posson-Brown (SAO), A.M.T. Pollock (ESAC), Dan Dewey (MIT), Frank Haberl (MPE), Andrew Beardmore (University of Leices), Steve Sembay (University of Leices), Eric Miller (MIT), Masahiro Tsujimoto (ISAS)

We will present the latest results on using the SMC SNR 1E 0102.2-7219 and the Galactic SNR G21.5-0.9 as cross-calibration sources for Chandra, XMM, Swift, and Suzaku. This cross-calibration effort grew out of the efforts of the International Astronomical Consortium for High Energy Calibration to define standard candles for X-ray Astronomy. We have assembled a team with members from each of the missions to analyze the E0102 data with the same model in a consistent manner. We published the results of that analysis in Plucinsky et. al. 2008. We have updated this analysis due to the changes in the calibration files since the 2008 paper. E0102 has a line-dominated spectrum with most of the flux in the 0.3-2.5 keV bandpass. G21.5-0.9 has a highly-absorbed power-law spectrum with most of the flux in the 2.0-10.0 keV bandpass. Therefore, the two sources complement each other well. The process of analyzing the E0102 data is fairly mature amongst the missions however, the G21.5-0.9 analysis is just beginning in earnest.

Cross spectral calibration between Suzaku and Chandra with the BL Lac object PKS2155-304

Manabu Ishida (Institute of Space and Astronautical Science)

In order to carry out cross spectral calibration of the three major X-ray astronomy missions, Suzaku, Chandra, and XMM-Newton, we have organized a series of nearly simultaneous observations since 2005, roughly once per year. In this talk, I will present results of comparison of spectra of Suzaku XIS and Chandra HRC+LEG in 2006 and ACIS+LEG in 2008.

Combining Statistical and Systematic Uncertainties for High Counts Spectra

Hyunsook Lee (SAO)
Vinay Kashyap (SAO), Aneta Siemiginowska (SAO), Jeremy Drake (SAO), Pete Ratzlaff (SAO), David van Dyk (UC Irvine), Alanna Connors (Eureka Scientific)

Instrument effective areas are generally known to accuracies of approximately 5%, with occasional larger uncertainties at certain wavebands. They will clearly affect spectral fitting results, and the derived parameter values will depend on the particular effective area chosen for the analysis. This is an issue that affects high-counts, high-quality data more than low-counts spectra because systematic uncertainties may produce a larger variance in the parameters than statistical uncertainties, whereas statistical uncertainties dominate for low counts spectra.

If there exist different instances of plausible effective areas that span the systematic variations that may be present in their calibration, then we show that their effect can be easily computed using existing tools like Sherpa. Here we present a well-known and simple statistical technique that combines the variances due to statistical and systematic uncertainties. We demonstrate its effectiveness with simulation examples using typical variations expected of ACIS-S effective areas. We show that approximately 20 full-fledged spectral fits, carried out with different effective areas, are needed to capture the full extent of calibration uncertainty in the parameter error estimate. We apply this technique to a set of observed AGN spectra and directly demonstrate the relevance of such calculations.

This work was supported by NASA-AISRP grant NNG06GF17G (HL, AC) and by CXC NASA contract NAS8-39073 (VLK, AS, JJD, PR).

A Monte Carlo Method for Including Chandra Instrument Response Uncertainties in Parameter Estimation Studies

Jeremy Drake (SAO)
Peter Ratzlaff (SAO), Vinay Kashyap (SAO), Chandra MC Uncertainties Team (SAO)

Including allowance for instrument calibration uncertainties in data analysis is technically challenging in terms of both understanding and specifying the uncertainties themselves, and in developing appropriate algorithms to employ them. Calibration uncertainties are generally correlated in complicated ways, rendering traditional methods of error analysis inappropriate. Here we describe a Monte Carlo method in which current knowledge of the response of the Chandra ACIS instrument is represented by random sampling of plausible perturbations to a nominal response function. The resulting set of response functions are employed in parameter estimation exercises to assess the effects of the instrument uncertainties on derived parameter values. We use this method to assess the limiting accuracy of Chandra for understanding typical X-ray source model parameters. We briefly describe a code slated for public release that will enable end users to perform similar full error analyses on Chandra ACIS observations.

Towards the Definition of High Energy Calibration Standards: The International Astronomical Consortium for High Energy Calibration (IACHEC)

Paul Plucinsky (SAO)

The IACHEC aims to provide standards for high energy calibration and supervise cross calibration between different missions. This goal is reached through Working Groups, involving around 40 astronomers worldwide. In these Groups, IACHEC members cooperate to define calibration standards and procedures. Their scope is primarily a practical one: a set of data and results (eventually published in referred journals) will be the outcome of a coordinated and standardized analysis of reference sources ("high-energy standard candles")

A New Gain Map and Pulse-Height Filter for the LETG/HRC-S Spectrometer

Bradford J. Wargelin (SAO)
Peter W. Ratzlaff (SAO), Michael Juda (SAO)

We describe the development of a time-dependent gain map for Chandras High Resolution Camera for Spectroscopy (HRC-S), a microchannel plate detector that is used with the Low Energy Transmission Grating (LETG). We also describe a wavelength dependent pulse-height filter for LETG/HRC-S data that reduces the detector background by 50-70% (relative to standard Level 2 processing) at wavelengths longer than ∼25 Angstroms, with a loss of 1.25% of valid X-ray events.

The Imaging and Spectral Performance of the HRC

Vinay Kashyap (CXC)
Jennifer Posson-Brown (CXC)

We present some recent developments in characterizing the spectral response of the HRC-I and the HRC-S/LETG, with an emphasis on how they can improve imaging analyses. For instance, the new HRC-I RMF can be used to minimize background contamination by setting up PI filters optimized for a given source. Post-degap residual systematic deviations in event locations on the HRC-S are characterized by measuring deviations in the locations of high-resolution spectral lines observed with the LETGS+HRC-S.

Revisions to the HRC-S Quantum Efficiency at Energies above the Carbon Edge

R. Nicholas Durham (SAO)
Jeremy J. Drake (SAO)

The HRC-S quantum efficiency (QE) is partially based on in-flight calibration using sources of X-rays employed as standard candles. Early in-flight calibration of the HRC-S QE at energies above the C edge (> 0.28 keV) was based on a high quality 1999 observation of the blazar PKS2155-304. Since that time, the Chandra LETGS has accumulated several further observations of PKS2155-304 and, by chance, an observation of the blazar Mkn 421 caught during a particularly X-ray bright phase. A thorough re-examination of the HRC-S QE is prompted by this accumulated data, and by recent revisions to the HRMA effective area that have a knock-on effect on detector calibration based on in-flight observations. We describe the data sets and methods used for the recalibration, and the impact of the revisions on typical LETG+HRC-S analyses.

SUMAMPS-based gain maps and RMF for the HRC-I

Jennifer Posson-Brown (SAO)
Vinay Kashyap (SAO)

For both the HRC-I and HRC-S, the scaled sum of amplifier signals (SUMAMPS) is a better proxy for spectral response than the PHA. Here we discuss the creation of a set of time-dependent gain maps and an RMF for the HRC-I based on and for use with scaled SUMAMPS. Using observations of AR Lac, G21.5-0.9 and HZ 43 taken regularly since launch, we model the time dependence of the gain decline with an exponential plus linear function. The resulting time-dependent gain maps convert scaled SUMAMPS into "SUMAMPS pulse invariant" (SPI), allowing for comparison of source profiles taken at different epochs or locations on the detector. We apply these gain corrections to HRC-I/LETG observations of HR 1099, PKS 2155-304, and Cygnus X-2 and use this data to create a redistribution matrix (RMF). The RMF is derived by modeling the SPI profiles at given wavelength bins with two Gaussians. The RMF captures the gross energy resolution of the HRC-I and can be used to interpret hardness ratios or quantile plots.

How to Create a HRC Background Map for an Observation

Takashi Isobe (SAO/CXC)
Michael Juda (SAO/CXC)

We explain in this presentation how to incorporate an HRC stowed background map to create a better HRC fluxed map. The “ring” artifacts which appear on the flux map are due to applying a HRMA vignetting correction to the particle background. Subtracting an estimate for the particle background from the observation before exposure correcting should eliminate these artifacts.

Updating the Chandra ACIS Contamination Model

Herman Marshall (MIT Kavli Institute)
Alexey Vikhlinin (SAO), Joe DePasquale (SAO), Larry David (SAO)

We present a new model of the temporal and spectral dependence of the ACIS contamination model. Data from the ACIS external calibration source (ECS), clusters of galaxies, and 1E0102 are used to generate the new model. This model improves the fit to the ECS data and is designed so that cluster spectra and 1E0102 line strengths should not depend on time.

Developing contributed software to correct for the temperature dependence of charge transfer inefficiency

Jennifer Posson-Brown (SAO)
Catherine Grant (MIT), Glenn Allen (MIT), Paul Plucinsky (SAO), Dale Graessle (SAO), Richard Edgar (SAO)

The spectral resolution of the ACIS CCDs is substantially improved by a charge transfer inefficiency (CTI) correction algorithm included in acis_process_events. However, the behavior of the charge traps that cause CTI is temperature dependent: warmer-than-nominal focal plane temperatures reduce the effectiveness of the correction algorithm. As the insulation on the exterior of the SIM and the ACIS radiator shade have aged, the surfaces around the ACIS focal plane and radiator have become warmer, leading to focal plane temperatures which are sometimes a few degrees warmer than desired, particularly for observations done at spacecraft pitch angles greater than ∼120 degrees. The ACIS team successfully reduced average focal plane temperatures by shutting off the detector housing heater in April 2008, but many warm observations exist in the archive, and observations done at "tail-Sun" attitudes still often have warm focal plane temperatures. In this presentation, we will review the temperature dependence of ACIS performance and the development of a temperature-dependent CTI correction algorithm. We will then discuss the implementation of this algorithm as contributed IDL software designed to work with current CALDB products and CIAO tools.

Charge Transfer Inefficiency in the ACIS Continuous Clocking Mode

Richard Edgar (SAO)

Due to different clocking characteristics, the Charge Transfer Inefficiency (CTI) of ACIS in the Continuous Clocking (CC) mode differs from that in the Timed Exposure (TE) mode.

We characterize the CTI of ACIS in the continuous clocking mode, using HETG data and observations of the external calibration source (ECS). Since the effect depends strongly on the CHIPY coordinate (distance from the readout), it is necessary to use indirect information to estimate this coordinate.

We present a calibration of the ACIS CTI in CC mode, and a method using existing software tools for correcting its effects for some sky-looking data. At present only the front-illuminated chips are calibrated.

High Energy Transmission Grating Spectra in Continuous Clocking Mode

Norbert Schulz (MIT)

High resolution spectra of bright X-ray sources are commonly performed using the continuous clocking (CC)-mode of the ACIS spectrometer mainly to avoid spectral degradation caused by photon pile-up. This presentation summarizes the impact of this mode on the final spectra in terms of order sorting, validation of the ACIS response, quantification of charge transfer inefficiency (CTI) effects and grade distributions with respect to the more standard timed-event (TE) mode. A specific set of calibration observations where we transmitted all standard and non-standard flight grades allowed us to test most recent trap maps for CTI correction in HETG cc-mode spectra. We present results from this specific test and evaluate the impact on bright cc-mode HETG spectra. Specifically very bright sources remain problematic and we outline current limitations as well as a few guidelines for future observations.

ACIS after ten years: Detector performance then, now, and into the next decade

Catherine Grant (MIT Kavli Institute)

ACIS continues to perform well more than a decade after launch. Over the lifetime of the Chandra observatory, the performance of ACIS has evolved. We will present the current status of the ACIS instrument, some results from the instrument teams monitoring program and our expectations for the future.

Notes