LETG

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Extraction: it hurt us a lot more than it's going to hurt you

One key aspect of data reduction for the *Chandra* transmission grating spectrometers is spectrum *extraction*. Just one of the many dental surgery terms that cross over into astrophysics, *extraction* descriptively refers to the operation of making the one-dimensional spectrum from the two-dimensional distribution of background counts and source counts dispersed by the gratings. In concept, the operation is simple: make straight incisions in the data along either side of the dispersed spectrum, lift out the flap of tg_r–tg_d surface and sum up the counts in the cross-dispersion direction. Similar procedures can be performed for adjacent background regions to effect background estimation or subtraction. The operation as a whole is accomplished less painfully than for teeth using the CIAO `tgextract` routine (where I can finally reveal that *tg* does not stand for "tooth from gum", but—and you'll kick yourselves—"transmission grating").

While the operation itself is straightforward, knowing exactly how much of the spectrum you have extracted is a bit more tricky. Unlike a tooth, it is not possible to get the whole thing cleanly because the roots of the spectrum are widely spread, beyond the typical extraction region.

The image of a point source spectrum on the detector is essentially the point spread function of the combined mirror and grating system spread out in the dispersion direction. In the case of the HETG, whose grating bars are supported on robust thin films of polyimide, very little is added to the mirror PSF. Understanding how much of the total signal is extracted in a given region is then akin to understanding the encircled energy fraction within a region for a point source, and can be estimated through careful calibration of raytrace simulations. The colloquial term for the fraction of the incident signal that is extracted is in fact the `EEFRAC`.

Things are of course not so simple for our rascally ward the LETG. The gold LETG grating bars are supported on an array of "coarse" and "fine" gold support structures that have their own dispersion patterns (see *Chandra* Newsletter 17 for an account of my blundering attempt to understand one aspect of this). The coarse support structure is a triangular reticulation and is responsible for that pretty six-pointed star pattern around zeroth order (and really bright lines). The coarse triangular lattice supports a grid of parallel fine support bars oriented perpendicular to the main grating bars themselves. This fine support structure produces a cat's whiskers-like cross-dispersion pattern illustrated, together with the 0th order star, in Figure 1. In order to understand the fraction of the incident flux that is extracted by our judicious application of scalpel, we need to understand additionally the power dispersed by the support structure as well as its spatial distribution.

Unfortunately, the parameters of the support structures are not known with sufficient precision for an analytical or numerical diffraction model solution to the problem. Working without the aid of anaesthetic, calibration ace Brad Wargelin instead used real patients (and patience), in the form of observations of bright, soft sources, to get an empirical calibration of the cross-dispersed power (see Figure 2), tracing the the signal out to 10th order in some cases. The resulting empirical EEFRAC calibration was implemented in CALDB 4.6.9, together with a commensurate but opposite change in the HRC-S quantum efficiency so as to maintain the same effective area—much like enduring several rounds of dental surgery to install a crown that leaves your smile looking just the same.

The optimum cross-dispersion width for spectrum extraction depends on the balance between source and background signal-to-noise ratio—the stronger the signal relative to the background, the larger the region can be to maximize signal collection. This width will also vary along the length of the spectrum owing to several different characteristics of LETGS spectra. The Rowland geometry focus increasingly departs from the imaging one toward longer wavelengths and the spectral trace consequently becomes increasingly broad in the cross-dispersion direction. The instrument effective area also decreases in the same direction, whereas the background rate is more uniform. To account for the astigmatic cross-dispersion broadening, a simple "bow tie" shaped region has been used since launch, and Brad's careful analysis of bright sources revealed that this shape can be significantly improved. He discovered there is a fairly broad plateau in optimum extraction region size, and derived this width for a one-size-fits-all default region. The optimized source and background extraction regions are illustrated together with the corresponding standard bow tie regions in Figure 3.

There were two further complications to the whole process of implementing the new extraction specification: during the course of the analysis Brad discovered the alignment of the spectral trace along the detector was subject to small but significant secular change, and that the spectral trace itself was not perfectly straight due to slight spatial distortions in the detector event position determination. These deviations from perfect alignment turn out to be important for an optimized extraction region and Brad had to devise algorithms to remove them.

The scripts to straighten the spectral trace and use the revised extraction efficiency are described at *http://cxc.cfa.harvard.edu/cal/letg/LetgHrcEEFRAC/*. The increase in signal-to-noise ratio of the resulting spectra can be especially noticeable for long observations with large accumulated background. The whole package should be adopted as the standard approach in a future CIAO release.

LETG Sees Star Shredded (or Julienned?) by Black Hole

On November 22, 2014 the All-Sky Automated Survey for Supernovae (ASAS-SN) discovered a bright object, dubbed ASASSN-14li, that appeared to be coincident with the center of the galaxy PGC 043234. The way the light intensity from the event evolved matched that expected from a stellar "tidal disruption event". The disruption occurs because of tidal forces—the side of the star closest to the black hole is accelerated more strongly than that further away. Since stars are not such rigid bodies, the star ends up getting shredded. Just one of the many cookery terms that cross over into astrophysics, shredding, combined with the subsequent orbit around the black hole, leads to the formation of a hot accretion disk.

A group lead by Jon Miller at the University of Michigan used three X-ray telescopes—*Chandra*, *Swift* and *XMM-Newton*—to observe the high energy emission that was expected from the nascent disk of ASASSN-14li. *Chandra* deployed the LETG+HRC-S, and both the LETGS and the *XMM-Newton* RGS obtained high quality spectra of the object (Miller et al. 2016). These spectra showed mildly blue-shifted absorption lines revealing material moving outward from the central object at speeds of a few hundred km per second—too slow to escape the gravitational field of the black hole. This material is probably levitated by the pressure of the intense light from the energised gas, similar to the radiatively-driven outflows of massive stars. The gas flow is consistent with a rotating wind from the inner region of the disk, or with a filament of disrupted stellar gas at the further reaches of its elliptical orbit. The combination of large ground-based optical surveys with the wide field of view of the HRC-I has opened up new opportunities to study variable stars and potentially fundamental physics. ■

Acknowledgements:

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References

Miller, Jon M., Kaastra, Jelle S., Miller, M. Coleman, Reynolds, Mark T., Brown, Gregory, Cenko, S. Bradley, Drake, Jeremy J., Gezari, Suvi, Guillochon, James, Gultekin, Kayhan, Irwin, Jimmy, Levan, Andrew, Maitra, Dipankar, Maksym, W. Peter, Mushotzky, Richard, O'Brien, Paul, Paerels, Frits, de Plaa, Jelle, Ramirez-Ruiz, Enrico, Strohmayer, Tod, & Tanvir, Nial 2015, *Flows of X-ray gas reveal the disruption of a star by a massive black hole*, Nature, 526, 542

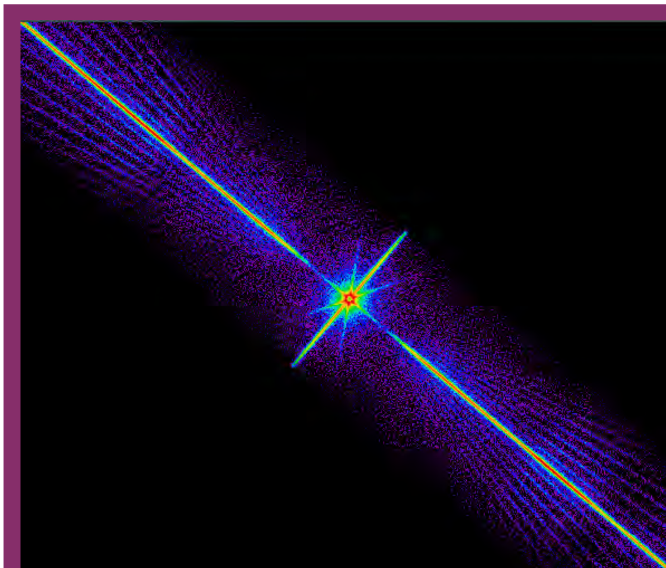

Figure 1: HRC-S central plate detector image from the LETG observation of accreting black hole candidate XTE J1118+480. The 0th order and its six-pointed star resulting from coarse support structure diffraction can be seen at the center of the image, together with the dispersed spectrum either side and the various orders of its "cat's whiskers" fine support structure cross-dispersion diffraction pattern.

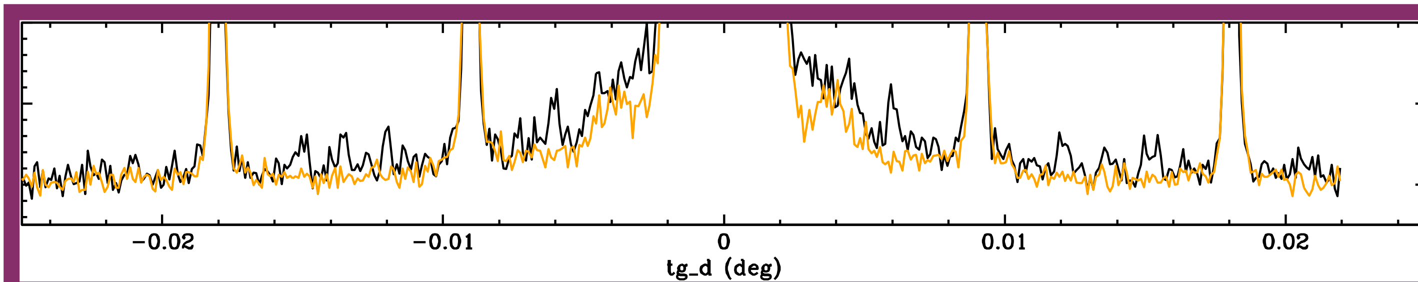

Figure 2: Cross-dispersion profile for LETG+HRC-S spectra of the nova supersoft source KT Eri (orange) and the blazar Mkn421 (black). The conspicuous peaks either side of 0th order are from fine support structure diffraction. The Mkn421 profile is broader in the core because of higher order throughput in the main spectrum and includes extra cross-dispersion peaks. The distinct shoulders on the KT Eri profile between the core and the 1st cross-dispersion peak are from coarse-support-structure diffraction. The power in this cross-dispersed signal has now been calibrated and included in optimized spectrum extraction regions. Figure courtesy of Brad Wargelin.

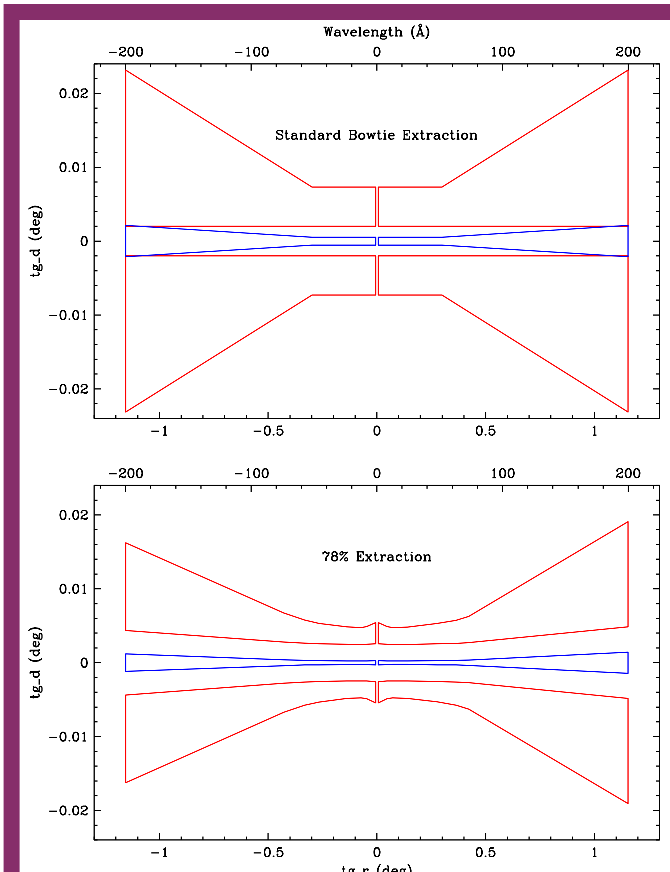

Figure 3: The standard bow tie and new optimized source (blue) and background (red) extraction regions for LETG spectra. Figure courtesy of Brad Wargelin.

Additional Info

Back cover illustration and caption related to this article:

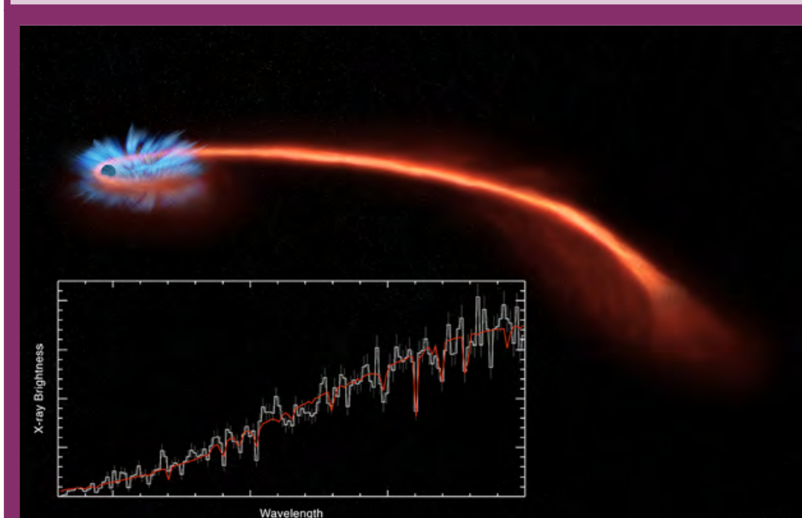

Illustration showing a disk of stellar debris around the black hole, and a long tail of ejected shredded star. The X-ray spectrum obtained with the Chandra LETGS (seen in the inset box) and XMM-Newton *both show clear evidence for blue-shifted absorption lines, providing evidence for a disk wind blowing towards us and away from the central black hole.*