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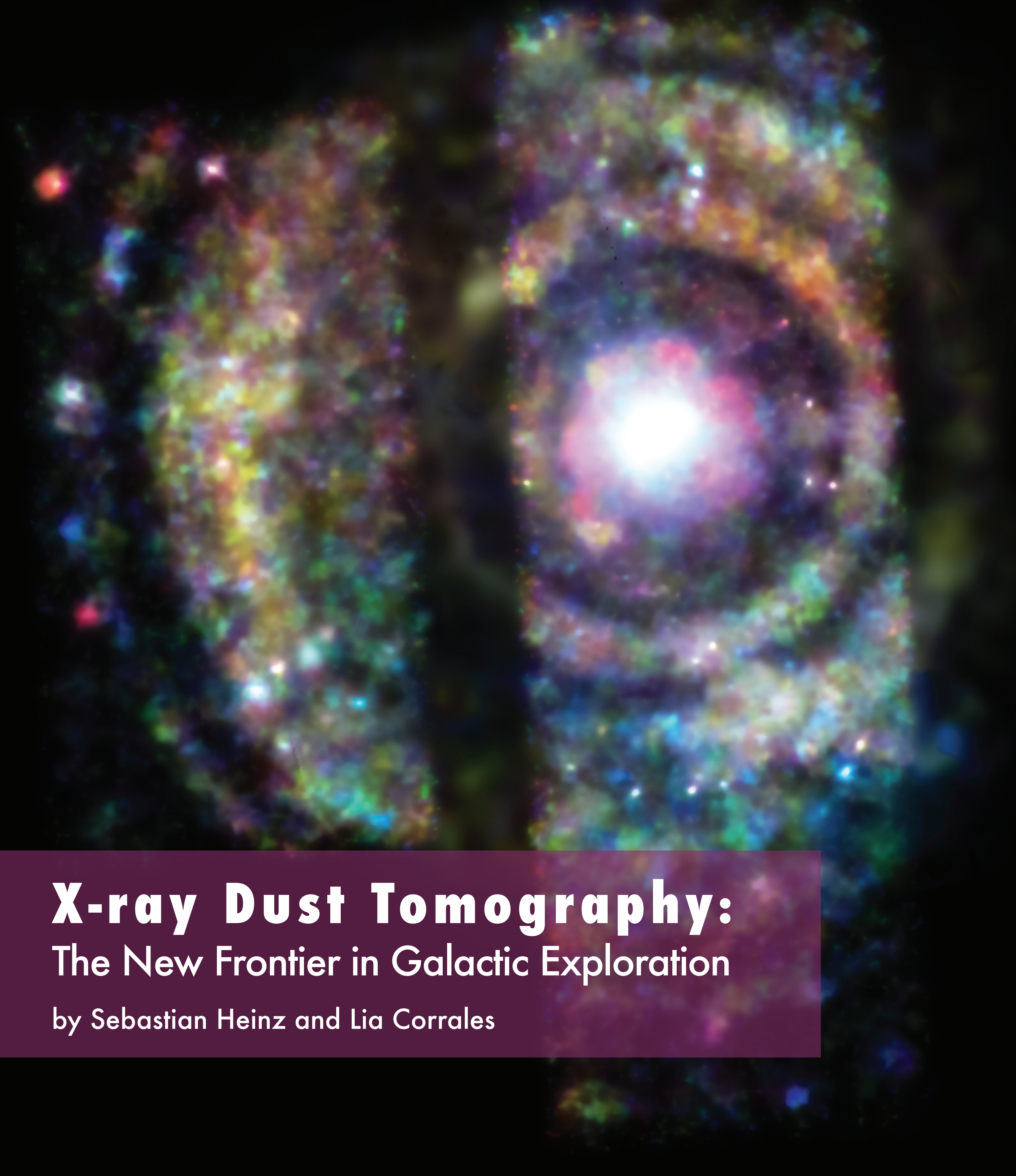

## X-ray Dust Tomography:
### The New Frontier in Galactic Exploration

by Sebastian Heinz and Lia Corrales

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# X-ray Dust Tomography: the New Frontier in Galactic Exploration

Sebastian Heinz & Lia Corrales

Imagine a dusty basement with bright sunlight streaming through a narrow window: The rays of light will reflect off tiny dust particles floating through the air, creating a silver stream of light. This is dust scattering in action, an illustration of a process happening throughout the universe.

When astronomers discuss dust, they refer to something much less macroscopic than the kind of dust you might wipe up from your window sill or the dust-bunny you find in a hard-to-reach corner under your bed. Astronomical dust is anything bigger than a molecule (a typical dust grain spans anywhere from a few hundredths to a few tens of microns, orders of magnitude smaller than the width of a human hair) and is typically the only kind of solid matter found in interstellar space. Around 90-100% of interstellar silicon, magnesium, and iron—the same materials that comprise the Earth's crust—are locked in solid form.

This is no coincidence: Dust serves as an interstellar transport for these materials. Interstellar dust also plays a vital role in forming new stars—and planets—by shielding molecular gas from destructive ultraviolet light so that it can form the dense, cold, clouds that are the nurseries of stars. Dust grains also serve as a catalyst by providing a surface for chemical reactions on which to form complex molecules and ices in molecular clouds and protostellar disks.

It is probably fair to say that the typical astronomer will have an underdeveloped appreciation for interstellar dust. That's because dust gets in the way of observations at visible and shorter wavelengths and makes life harder for astronomers by absorbing and scattering photons, making images darker and, at X-ray wavelengths, blurrier.

But dust deserves a second look not just because it is a key ingredient in the formation of planets and stars: Dust can also be an important observational tool. For example, infrared astronomers have long used the emission from cool dust grains at long wavelengths to search for concentrations of dense gas that are invisible at other wavelengths to find heavily obscured black holes in the centers of distant galaxies.

Much of our knowledge of interstellar dust is indirectly inferred from meteoritic materials, extinction curves spanning the infrared to ultraviolet, comparisons of gas phase metal line absorption to solar abundance (depletion), and some infrared absorption and emission lines, many of which come from unidentified molecular species (Draine 2003b). X-ray light can provide crucial insight into many outstanding dust questions through the phenomenon of absorption and scattering.

The prospect of scattering of X-rays by interstellar dust (Overbeck 1965) was realized almost immediately following the discovery of the first X-ray point sources outside of the solar system (Giacconi 1962) and has been a mainstay of studies of interstellar gas ever since. Surveys of X-ray scattering halos have been used to measure relationships between optical extinction, gas column, and distance (Predehl & Schmitt 1995, Valencic & Smith 2015).

With the launch of the current generation of flagship X-ray imaging telescopes, *Chandra*, *XMM-Newton*, and *Swift*, a new diagnostic has become available to X-ray astronomers: High-resolution dust tomography from X-ray scattering studies, that is, the use of dust scattering echoes to measure distances, to map the distribution of matter throughout the galaxy, and to determine the properties of interstellar dust grains.

**Dust Echoes and Halos Explained**

X-ray scattering has long been used as a laboratory tool to study the structure of solid matter through Bragg-crystallography. Like solid matter in the lab, interstellar dust grains can scatter X-ray photons. They can also absorb X-rays, and whether a photon is absorbed or scattered by a dust grain (or whether it just flies by unaffected) is set by the dust scattering cross section—the probability of a photon being scattered in a particular direction by a dust grain—which depends very strongly on the angle at which the photon interacts with the dust grain and the outgoing angle of the scattered photon.

Scattering is restricted to very small angles, a degree or smaller, and all X-ray dust scattering is forward-scattering. Dust scattering cross sections are so small that typically only a few percent of the X-ray light gets scattered. In order to see meaningful surface brightness from scattering, one needs both a bright X-ray source and significant amount of dust between the observer and the source.

At any given time the Galaxy is illuminated by dozens of bright point sources, all powered by compact objects: Neutron stars and black holes. These sources

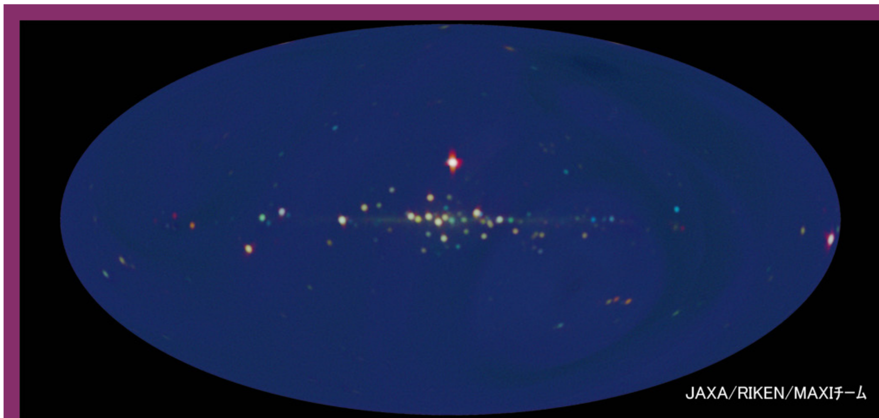



*Figure 1: X-ray image of the entire sky from several years of observation, taken by the MAXI instrument aboard the International Space Station (Matsuoka et al. 2009), showing dozens of sources in the plane of the Milky Way.*

make excellent beacons around which we can study the interaction of X-ray light with interstellar dust. Figure 1 shows an image of the X-ray sky, taken by the MAXI instrument onboard the International Space Station, dotted with bright point sources.

Most bright X-ray sources lie in the plane of the Milky Way, which is good news for the study of dust because most of the Galaxy's dust is found right along that plane. How, then, does interstellar dust interact with the X-rays emanating from a distant source, and what do we see with *Chandra* as a result? Observationally, we can categorize the signal into three groups, based on the appearance and information content that can be extracted:

Constant dust scattering halos are formed by persistently bright X-ray sources behind a thick veil of dust. These fuzzy hazes of X-ray light were first discovered by the Einstein X-ray Telescope (Rolf 1983) and have been studied for decades. They are the easiest to observe—just point your X-ray telescope at a bright X-ray point source in the plane of the Galaxy—but hardest to extract information from because the interplay between scattering angle and dust location is hard to disentangle.

Variable dust scattering halos are formed by bright, but variable X-ray sources behind a thick veil of dust.

X-ray ring echoes are, in a sense, the jackpot of echo studies: they are rare and hard to observe—only three bright, large ring echoes have been observed to date—but they offer the cleanest, most detailed and easily interpreted signal.

This article will focus on the last two relatively new avenues of dust study, where *Chandra* can truly shine: variable scattering halos and ring echoes.

The front cover of this newsletter shows the 2014 echo from the neutron star Circinus X-1, with four colorful rings, centered on the source. To understand why we see multiple rings and what kind of information is encoded in images like this, it is instructive to go through the signal step by step, illustrated by the cartoon in Figure 2.

Suppose a neutron star emits a flash of X-rays. Without any dust between us and the neutron star, all we would see is a single flash of X-rays from the position of the source.

How does dust alter the signal? Dust grains can scatter some of the X-ray photons initially emitted by the neutron star in (slightly) different directions towards our telescope. We will see these scattered X-rays arriving from a different direction in the sky with a time delay compared to the flash of X-rays arriving directly from the black hole. Because of the change in direction, the path the scattered photons take is longer than the direct path from the source—typically a few days.

X-rays arriving at the telescope some time after the initial flash must have been scattered on the surface of an ellipsoid, with the telescope and the X-ray source at the two focal points. That is because an ellipsoid is the surface of constant path length between the two focal points and any point on the surface, so any photon scattered on the surface of that ellipsoid will have traveled the same distance to the observer. The longer the time delay (the later the observation) the larger the ellipsoid. Because of the large distance involved and the small angles that scattering is restricted to, dust scattering ellipsoids are extremely long—about a thousand times longer than they are wide, so the scattering ellipsoid in the cartoon is not to scale.

While dust can be found throughout interstellar space, the largest concentrations along any given direction are located inside dense, cold, molecular clouds. We will see scattered photons mostly from the intersection of the scattering ellipsoid and the dust clouds—each forming a ring in space that will appear as a ring on the sky. The longer the delay (the later the image is taken), the larger the ellipsoid and the larger the ring.

Each cloud between us and the source intersects the scattering ellipsoid at a different place and creates its

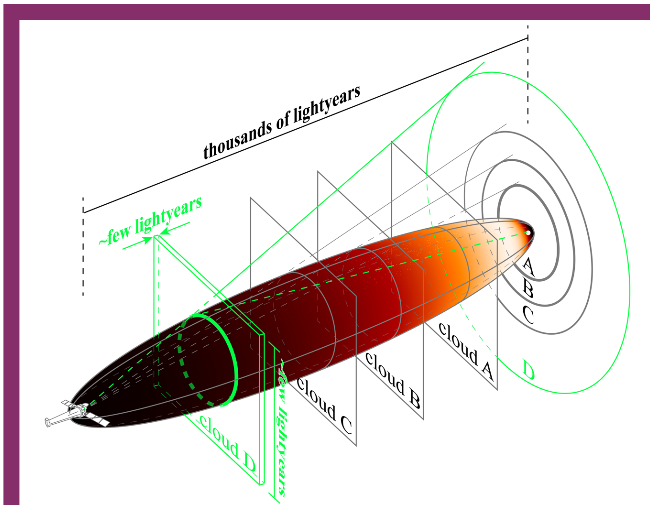



*Figure 2: An illustration of dust scattering: The echo of a an X-ray flare from an X-ray source (white dot) is produced on the surface of an ellipsoid (shaded surface). We see rings from the locations where dust clouds between Earth and the source intersect the ellipsoid. Each cloud produces a different ring. The echo is brightest where the shade of the ellipsoid is lightest. The illustration is not to scale: In reality, the ellipsoid is highly elongate: thousands of lightyears long and only a few light-years across. In this example, the green cloud and light path demonstrate the generation of the outermost ring.*

own echo ring; the closer the cloud, the larger the ring will appear in the sky. By measuring the size of the ring and the time delay, we can measure the relative positions of the clouds between us and the source.

The brightness of the rings depends on where on the scattering ellipsoid they are created—there is a sweet spot with maximum brightness per amount of dust. Rings from clouds that are closer or farther than that spot are progressively dimmer.

If the flare lasts for a longer time, a few days or even weeks, the rings become thicker. The longer the flare, the thicker the rings appear on the sky. This explains the difference between ring echoes and dust scattering halos: If the source is not flaring at all but shining continuously, like many Galactic X-ray sources, there is no ring—the entire cloud is illuminated—and we see a diffuse glow that we call a dust scattering halo. Each cloud produces such a halo, making for one fuzzy glow, so we can no longer simply read off the relative position of the dust from the image, making interpretation much harder.

**Ring echoes**

While ring echoes are the most powerful probes in the arsenal of dust scattering studies, they are also hardest to observe:

They require short, bright flares of the source followed by quick dimming, so that the echo is bright and the source does not continue to generate a bright dust scattering halo competing with the rings.

They require a lot of dust between us and the source—only sources in the plane of the Milky Way can produce ring echoes. To put the amount of dust needed into perspective: If we were to compress the amount of gas and dust between us and the source into a sheet of paper, it would have the thickness of card-stock.

They must be observed quickly after the flare—the rings grow in size and fade rapidly, making them unobservable after just a few weeks. Because flares are unpredictable, the observations of rings must be scheduled quickly and on the fly. Such scheduling is hard for most X-ray telescopes, including *Chandra*.

The right kind of flares are rare, and they have to be in an observable part of the sky.

To date, only three bright ring echoes have been observed. However, with every echo we learn how to better schedule telescopes to catch echoes and to analyze the data in new ways, and over the coming decade, echo tomography will become a standard tool in X-ray astronomy.

**1E 1547.0-5408:**

Figure 3 shows an image of the first X-ray ring echo from a Galactic source, the X-ray pulsar 1E 1547.0–5408 that flared in 2009 (Tiengo et al. 2010). It was observed by the *Swift* and *XMM-Newton* telescopes and showed three rings expanding with time.

What can we learn from this echo? The most obvious thing is the location of the dust, in relation to the location of the pulsar, to better than 1% accuracy. Dust clouds are expected to be found preferentially in or near spiral arms, so determining the location of clouds is a way to map the spiral structure of our Galaxy. Something that would take a space-ship and a long trip towards the Andromeda Galaxy to do—making an image of our Galaxy in dust—can be accomplished with a few X-ray observations. Figure 6 overlays the location of the dust clouds towards 1E1547.0-5408 inferred from the echo on the map of the Milky Way.

Better yet, the cloud map we can construct from the echo in a given direction is 3-dimensional: two image dimensions (left-right and up-down relative to the plane of the Galaxy) and one time dimension (delay since the flare) that we can translate into a measurement of depth. This makes X-ray dust studies similar to an MRI machine taking images of the Galaxy's skeletal structure.

**Circinus X-1:**

A light echo itself only measures the relative distance to the source: a given cloud may be at, say, half the distance to the source. To put that dust on the Galactic map, we need to know the distance to the source from some other means.

Trümper & Schönfelder (1973) first proposed to use the echoes themselves to determine the distance, much like bats use echolocation to measure distances. For dust echoes to do this, they must be combined with one more diagnostic. This is best illustrated using the brightest, largest echo observed to date: the 2014 echo from the neutron star Circinus X-1 (Heinz et al. 2015).

In late 2013, Circinus X-1 illuminated the X-ray sky with an enormous flare that lasted two months and made it one of the brightest X-ray sources in the Galaxy. Then it abruptly dimmed. Perfect conditions for this heavily obscured source right in the plane of the Milky Way to exhibit a ring echo. The *Chandra* image in Figure 4 shows a series of four wide rings, centered on the neutron star.

The rings allow a detailed reconstruction of the dust distribution between us and the source, showing the presence of at least for dust clouds. The rings are much wider than those of 1E 1547.0-5408 because the flare lasted for almost two months.

*Figure 4: Chandra image of the 2014 ring echo of the neutron star Circinus X-1. The image shows four colorful rings, centered on the neutron star (blue) and the supernova remnant (red glow). The variation in brightness and color within each ring allows identification with individual molecular clouds found in Carbon Monoxide emission.*

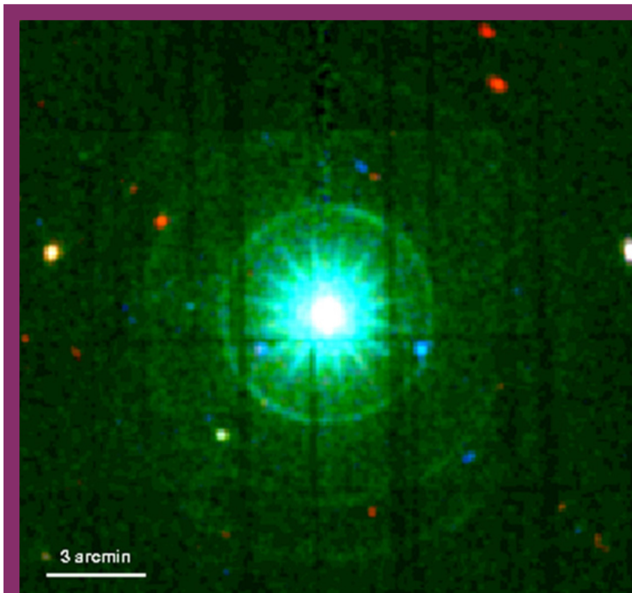



*Figure 3: XMM-Newton* ***image of the first ring echo from a Galactic source, the anomalous X-ray pulsar 1E1547.0-5408, showing three rings (Tiengo et al. 2010).***

Like in the case of 1E1547.0-5408, the distance to the Circinus X-1 was not known before the observation, with estimates ranging from 12,000 to 45,000 lightyears. But unlike in the case of 1E1547.0-5408, the rings of the Cir X-1 echo are not uniformly bright. Each ring has clear bright spots and dark regions. For a ring to be bright in a particular place requires an extra amount of dust in the cloud in that direction. By measuring the brightness of each ring, we can map the distribution of dust within each cloud.

That distribution is different for the different clouds. And because we know that dust clouds are associated with clouds of cold, molecular gas, we can search observations of that gas at other wavelengths for the same fingerprint pattern.

In the case of Cir X-1, this can be done with observations of the Galaxy in Carbon-Monoxide (CO), a common molecule and the most sensitive tracer of cold gas. The entire Southern half of the plane of the Milky Way has been mapped in CO by the Australian Mopra radio telescope (Burton et al. 2013). Each cloud of cold gas and dust along a given direction can be found in the CO data. If the dust cloud responsible for a given ring is densest in a particular point in the sky, the corresponding cloud in CO should be bright

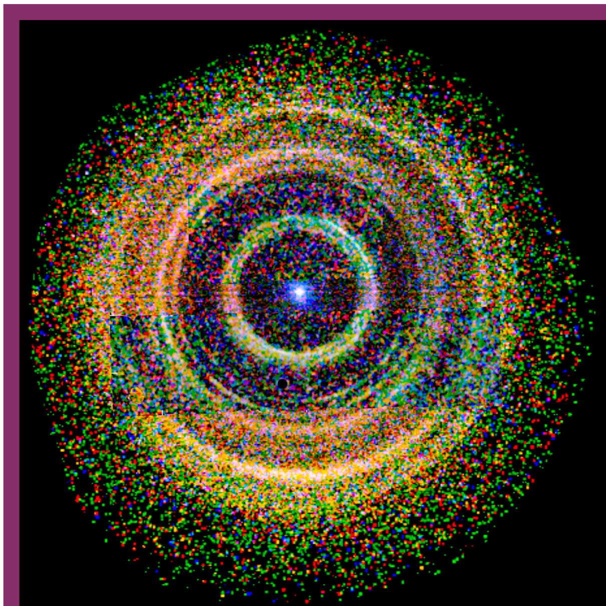


*Figure 5: Combined Chandra and Swift image of the 2015 light echo from V404 Cygni, showing a record-setting eight rings. The distance of 7.2 light-years to the black hole visible in the center of the image is known very precisely, allowing accurate measurement of the distances to the eight clouds responsible for the rings.*

in that spot as well. We can match the dust and CO brightness patterns like fingerprints to identify clouds.

From the Doppler shift of the CO emission line and the law of Galactic rotation, we can measure the distances to both the clouds and the neutron star at the same time. The implication is that Circinus X-1 lies at a distance of about 27,000 light-years—narrowing the uncertainty in the distance to the source from roughly a factor of three to about 15%. After the prediction 43 years ago, X-ray astronomy is now able to measure echolocation distances.

**V404 Cygni:**

Echoes can put dust clouds on the Galactic map, but an equally important question is: what kind of dust are they actually made of? If we have a sufficiently detailed set of measurements, the echo can measure the properties of the dust grains themselves—their composition and sizes. That is because different size dust grains reflect different X-ray energies in preferentially different directions, and different dust mineralogy also leads to different reflectivity at different angles.

In June 2015, the Galactic black hole X-ray binary V404 Cygni went into an extreme outburst, after spending 26 years in quiescence. For a few days it became the brightest source in the X-ray sky, flickering rapidly and then shutting off as quickly as it had gone into outburst (Barthelmy, D'Ai & D'Avanzo 2015, Rodriguez et al. 2015).

The source is located in the plane of the Galaxy, behind a layer of dust thick enough to generate the bright echo found by Beardmore et. al. (2015). They found four expanding and fading rings, setting off a month-long observing campaign.

Both *Swift* and *Chandra* observed the echo, making a perfect tag-team. *Swift* is designed to look rapidly at bright sources, so flexibility is built into the way the mission operates, making it ideal to catch echoes quickly. *Chandra*, on the other hand, has much higher imaging resolution and is more sensitive—making it ideally suited to look at the echo with optimal image fidelity—but harder to re-schedule quickly to look at the echo early on. *Swift* observed the echo early and often, for short snapshots, while *Chandra* spent time looking at the late echo to extract the information at the highest possible resolution.

By combining all observations from *Swift* and *Chandra* in Figure 5, we can reconstruct a detailed image of the entire echo, revealing a record-setting eight rings.

The distance to V404 Cyg—7200 lightyears—is known independently from the echo from previous radio observations (Miller-Jones et al. 2009). The echo therefore measures the distances and sizes of the dust clouds (shown in Figure 6) with almost pinpoint accuracy.

With accurately known distance, the echo can probe the details of dust physics in exacting detail (Vasilopoulos & Petropoulou 2016,Heinz et. al. 2016). To measure a small signal, we need both accuracy and leverage. The leverage in this case comes from the long series of observations—over 52 in all, following the evolution of the rings in brightness and size.

Fitting the extensive data set with different dust models (Mathis, Rumpl, & Nordsieck 1977, Weingartner & Draine 2001, Zubko et al. 2004) shows that the dust is not the same from cloud to cloud: The two clouds closest to V404 Cyg seem to have a significant excess of small dust grains compared to the remaining clouds. Grains are destroyed by shock waves, UV light, and cosmic rays, and the relative lack of large grains in a cloud tells us that the dust in the clouds closest to V404 Cyg was likely processed by a shock, breaking up the large grains to make more small grains.

The dust between us and V404 Cyg is chemically simple—graphite and silicate grains are all that is needed to explain the echo. Complicated grains with ice mantles or mixed chemistry do not fit the data.

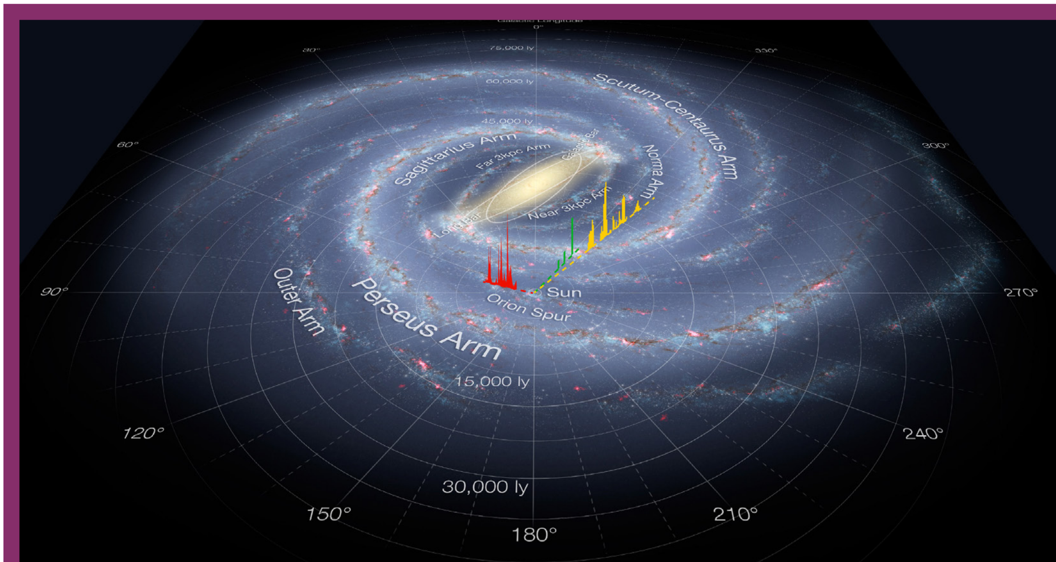



*Figure 6: The dust distributions towards V404 Cygni (red; Heinz et al. 2016), Circinus X-1 (yellow; Heinz et al. 2015), and 1E1547.0-54.08 (green, from Tiengo et al. 2010, assuming distance of 3.9 kpc) derived from the dust echoes, overlaid on an artist's impression of the Milky Way Galaxy (NASA/JPL-Caltech/ESO/R. Hurt). With more data from future echoes, the gaps in coverage to these sources will be filled in. Echoes from other sources will begin filling in the missing sight- lines in the still very sparse image.*

Dust echoes are therefore able to chemically type different Galactic dust environments.

**The Unique Sightline of Cygnus X-3**

Variable scattering halos provide a similar form of diagnostic: When a source with a halo changes brightness, the echo from the change will ripple through the halo. By comparing the change in the halo to the brightness variations of the source, it is possible to constrain the location and scattering properties of the dust (Xiang et al. 2011).

Cyg X-3 is a high mass X-ray binary with one of the brightest scattering halos visible. In its quenched state, Cyg X-3's light curve exhibits steady sinusoidal variations with a period of 4.8 hours. Just 10 arcseconds away, a small X-ray feature imaged by *Chandra* (dubbed Cyg X-3's "Little Friend"; McCollough et al. 2012) also varies in brightness with the same period, but shifted in phase. This is the most distant "Bok globule" ever found—a tiny cloud containing a few solar masses of gas and dust confined to sub-parsec scales—discovered via X-ray scattering!

About 30,000 light-years away, the foreground of Cyg X-3 is host to many interesting environments. In addition to the Little Friend, there is the Perseus arm of the Milky Way and the stellar association Cygnus OB2, which is embedded in the larger Cygnus X star forming region. Cyg X-3 is thereby uniquely positioned as a laboratory for studying different phases of the interstellar medium, the dust growth that occurs in molecular clouds, and dust composition.

Combining the known properties of the sightline towards Cyg X-3 with detailed spectral analysis of the scattering halo, Corrales & Paerels (2015) found evidence that the scattering halo brightness falls significantly below the brightness expected for typical Milky Way dust grain populations. One explanation is that the Cyg OB2 association contains grains that are much larger, by a factor of 5-10, than the typical upper limit for grain sizes in the diffuse interstellar medium.

**Frontiers of Dust Scattering**

In early 2016, with three ring echoes in the archives, each spanning about a half degree across the sky, we are beginning to see the dusty galaxy in high-definition, leaving about 358 Milky Way degrees more to go. With some luck and a lot of hard work, *Chandra* will stay busy over the coming decade.

Alongside new observations, a new suite of models is being developed to study the spectra of echoes and halos in much more detail. The potential to measure details in the molecular structure (Smith et al. 2016, Heinz et al 2016, Corrales et al. 2016) and perhaps even the shapes of dust grains (Hoffman 2016) promise a rich field of study.

And with the launch of the next generation of ultra-sensitive X-ray telescopes—*Athena* and *X-ray Surveyor*—the study of echoes will become orders of magnitude more powerful, allowing the study of echoes up to 100 times fainter than the few cases observed so far, opening up a vast population of potential echoes from both dimmer sources and sources with lower amounts of dust to scatter X-rays.

As the light collecting power of X-ray instruments increases with future missions, we increase our prospects for studying not just echoes from within the Milky Way, but even extragalactic dust with X-ray scattering, with the potential to measure distances to

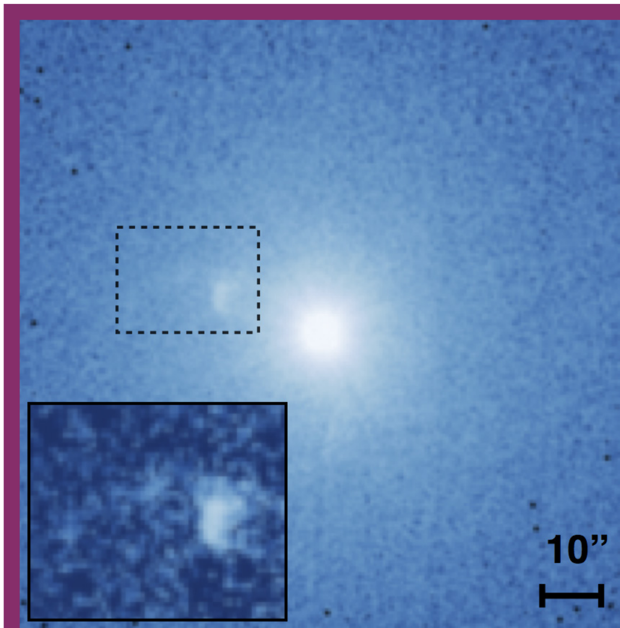



*Figure 7: The high mass X-ray binary Cygnus X-3 has one of the brightest dust scattering halos in the sky. In this 50 ks high resolution image from Chandra, a small knot of X-ray brightness can be seen 16" from the central source. This is Cygnus X-3's "Little Friend", a dense cloud of molecular gas about 0.2 pc in size. The inset shows hints of additional structure around the Little Friend, obtained after subtracting the mean count rates from the smooth dust scattering halo.*

nearby galaxies (Draine & Bond 2004). Given our understanding of the star formation history over cosmic time, current estimates indicate dust in galaxy disks accounts for as little as one third of the overall dust produced in the Universe (Ménard & Fukugita 2012).

Dust can be seen several kpc above the disk of M82, the famous star bursting galaxy whose outflows shine in both the infrared and X-ray. Additionally, cross-correlations between quasar-galaxy and galaxy-galaxy pairs show evidence of reddening at optical wavelengths—a tell-tale sign of dust—in the circumgalactic medium (Ménard et al. 2010, Peek et al. 2015). Since many quasars also shine brightly in the X-ray, this invites the possibility of searching for X-ray scattering from dust in foreground galaxies or the diffuse intergalactic medium.

Only a few percent of a quasar's light would be scattered by extragalactic dust on the path to Earth. We are more likely to find extragalactic dust if a bright quasar suddenly turned off. Much like the Galactic black holes and microquasars we see today, accretion onto the supermassive black holes powering a quasar can be subject to intense fluctuations. These accreting giants could leave behind a dust scattering echo—visible as a solitary ring of X-ray brightness, or "ghost halo"—tens to hundreds of years after the black hole is done eating. With *Chandra*, our sensitivity is mainly limited by the instrument background, and we might only catch one echo over the entire sky (Corrales 2015). The proposed *X-ray Surveyor* mission will have 30 times the collecting area of *Chandra* with the same resolution, making it the ideal laboratory for detecting ghost halos from the high-z Universe. ■

**References:**


Barthelmy, S.D., D'Ai, A., D'Avanzo, P., 2015, GCN, 17929

Beardmore, A.P., Altamirano, D., Kuulkers, E., et al. 2015, ATel, 7736

Burton, M.G., Braiding, C., Glueck, C. et al. 2013, PASA, 30, 40

Corrales, L. 2015, ApJ, 805, 23

Corrales, L.R., García, J., Wilms, J., et al. 2016, MNRAS, 458, 1345

Corrales, L.R., & Paerels, F. 2015, MNRAS, 453, 1121

Draine, B.T. 2003, ApJ, 598, 1026

Draine, B.T. 2003b, ARAA 41, 241

Draine, B.T., & Bond, N.A. 2004, ApJ, 617, 987

Giacconi, R., Gursky, H., Paolini, F.R., & Rossi, B.B., 1962, Phys Rev Letters, 9, 439

Heinz, S. et al. 2015, ApJ, 806, 265

Heinz, S. et al. 2016, ApJ, in press

Hoffman, J., & Draine, B. T. 2016, ApJ, 817, 139

Mathis, J.S., Rumpl, W., & Nordsieck, K.H. 1977, ApJ, 217, 425

Matsuoka, M., Kawasaki, K., Ueno, S., et al. 2009, PASJ, 61, 999

Mauche, C.W., & Gorenstein, P. 1986, ApJ, 302, 371

McCollough, M.L., Smith, R.K., & Valencic, L.A. 2013, ApJ, 762, 2

Ménard, B., & Fukugita, M. 2012, ApJ, 754, 116

Ménard, B., Scranton, R., Fukugita, M., & Richards, G. 2010, MNRAS, 405, 1025

Miller-Jones, J.C.A., Jonker, P.G., Dhawan, V., et al. 2009, ApJL, 706, L230

Overbeck, J.W. 1965, ApJ, 141, 864

Peek, J.E.G., Ménard, B., & Corrales, L. 2015, ApJ, 813, 7

Predehl, P., Burwitz, V., Paerels, F. & Trümper, J. 2000, AAP, 357, L25

Predehl, P., & Schmitt, J.H.M.M. 1995, AAP, 293, 889

Rodriguez, J., Cadolle Bel, M.,Alfonso-Garzón, J., et al 2015, AAP, 581, L9

Rolf, D.P. 1983, Nature, 302, 46

Smith, R.K., Valencic, L.A., & Corrales, L. 2016, ApJ, 818, 143

Tiengo, A., Vianello, G., Esposito, P., et al. 2010, ApJ, 710, 227

Trümper, J., & Schönfelder, V. 1973, AAP, 25, 445

Valencic, L.A., & Smith, R.K. 2015, ApJ, 809, 66

Vasilopoulos, G., & Petropoulou, M. 2016, MNRAS, 455, 4426

Weingartner, J.C. & Draine, B.T. 2001, ApJ, 548, 296

Xiang, J., Lee, J.C., Nowak, M.A., & Wilms, J. 2011, ApJ, 738, 78

Zubko, V., Dwek, E., & Arendt, R.G. 2004, ApJS, 152, 211

## Stephen S. Murray (1944-2015)

It is difficult to capture the essence of an individual and of more than half-a-lifetime of friendship and collaboration in just a few pages. Here, we share a few professional highlights and vignettes about our dear friend and colleague Steve Murray who passed away unexpectedly this past August. Steve was a master builder, a craftsman, a hardware and software expert, a scientist with an inventive, eager and curious mind, and a treasured individual in both his professional and personal lives which of course were deeply intertwined.

**Steve and *Uhuru***

Steve first "came to our attention" in the summer/fall of 1970 when the X-ray group under Riccardo Giacconi at American Science & Engineering (AS&E) was readying for launch of *Uhuru*, the first satellite dedicated to X-ray astronomy. Through his thesis adviser Robbie Vogt, along with Ed Stone and Gordon Garmire, all at Caltech, Steve learned that AS&E was seeking a scientist or two to join our team. He arrived in Cambridge for a job interview, met with a few individuals, and gave a talk, no doubt, about his thesis work which involved the physical processes affecting the propagation of solar flare protons in interplanetary space. The reason we say "no doubt" in the preceding statement is that only one of us (HT) had joined the team at that point, and as Steve was fond of reminding him at appropriate times, he (HT) had dozed through much of Steve's talk, leading Steve to think that he had little chance of being made an offer. In fact, the reality was just the opposite. Steve's expertise with instrumentation, computers, data analysis, and the like made him an instant "must hire" for the AS&E team. An offer was forthcoming and Steve accepted, arriving at AS&E in late December 1970, just a few weeks after *Uhuru* was successfully launched.

Steve immediately engaged in devising new algorithms, developing new software, fixing bugs in existing code, and becoming an expert X-ray astronomer as quickly as possible. His early interests with *Uhuru* included mysterious high galactic latitude sources that were dubbed possible X-ray galaxies, extended emission from clusters of galaxies, source number counts versus flux, and the distribution of the sources on the sky. A particular focus both early on and throughout his career involved surveys and catalogs of sources. Surveys and catalogs with telescopes such as *Chandra* can be challenging, even with arcsecond resolution and precise positions. However, *Uhuru* was not a telescope; it scanned a swath on the sky with proportional counters peering through mechanical collimators. As the detectors traversed a source, a triangular shaped response was seen—with brighter sources for individual transits and with fainter sources only after summing together as many as 50-100 transits obtained over a day. The height of the collimators limited the field in the vertical direction to 10 degrees, while the azimuthal response was either 1 or 10 degrees across, depending on which counters and collimators made the observation. Figure 1 is a map showing lines of position on an equal area sky projection in galactic coordinates. The data were accumulated over ~70 days, covering close to 50% of the sky. The map shows 1171 lines of position. Even for Steve, it was a challenge to unravel all of these lines and determine the locations and intensities of the sources that produced them.

Sometimes, a bright source was detected on two nearly orthogonal scans leading to a crossing with high confidence of detection and a rather precise source location. In complex cases, many lines of positions possibly associated with multiple sources crisscrossed in a given region. Steve developed a maximum likelihood type approach, calculating for each point near a possible source the differential probability that a source at that location produced a given line of position. He

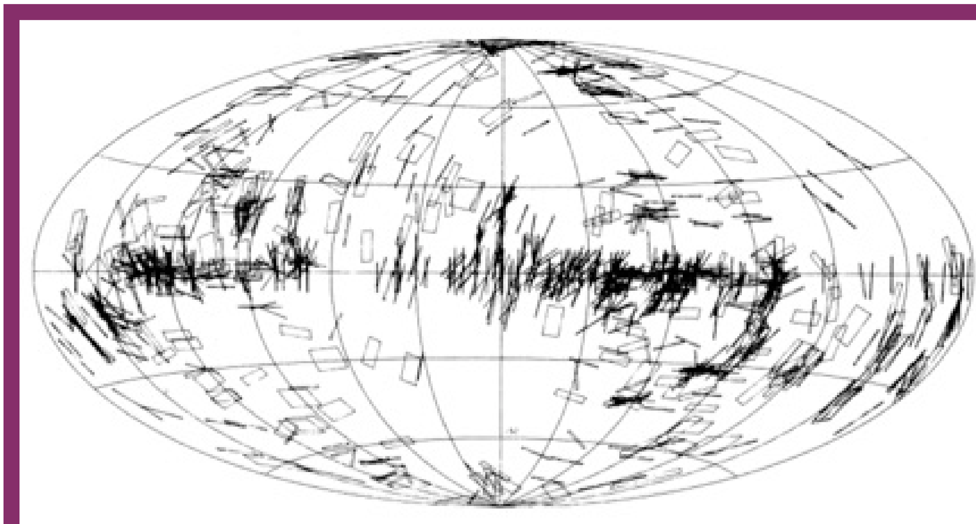


*Figure 1: Lines of position (1171) which result from computer scans of superposed data are plotted on an equal area projection of the sky in Galactic coordinates. The line widths are ± 1σ wide (adapted from Giacconi, Murray, et al. 1972, ApJ, 178, 281).*

then computed the product of the 1-d calculations for all of the relevant lines of position and thereby determined the joint probability density distribution for all of the points in a given region. The point with the maximum probability density was the most likely source location, and integration over regions bounded by iso-probability density contours then determined a 90% confidence region for the source location.

We (Steve and HT) produced an initial version of this catalog for an invited talk Riccardo was giving at the Dec 1971 AAS meeting in San Juan, Puerto Rico. Working long days and ending with an "all-nighter", we finally produced a catalog and taped the all-sky map to the inside of the glass door of the AS&E building for our colleagues to see as they arrived at work. We headed home to catch a few winks and to pack for the AAS meeting. One of the keys to being able to complete our work was Steve's ability to convince the company's computer managers to turn the usually batch-operated system over to us for a couple of days, so that we would have full use of the system to wring out bugs, verify software, and then produce the catalog. The resulting catalog was ultimately published as the 2U catalog with Giacconi, the PI of the mission as first author, and Murray, the catalog guru, as the 2nd author, along with several other team members as co-authors.

**Steve and the *Einstein* Observatory**

In the mid-70's Steve's interests turned back to instrumentation—or was he also responding to cries for help from our X-ray group which had moved from AS&E to the Smithsonian Astrophysical Observatory in July 1973 as part of the creation of the Harvard-Smithsonian Center for Astrophysics? Our team had been selected to lead the 2nd High Energy Astronomy Observatory mission which was renamed the *Einstein Observatory* following launch in 1978. With responsibilities for the scientific oversight of the X-ray telescope and for the design and construction of the two imaging instruments, we regularly broke new ground as the mission development proceeded.

If Technology Readiness Levels (TRLs) existed in the 70's, they were not applied with the rigor or enthusiasm often seen today. In simpler terms, this meant that our expert on telescopes, Leon Van Speybroeck worked closely with NASA and industry to figure out how to meet the specifications for the mirrors, and our team building the high resolution (arc second scale) imaging detectors needed an infusion of Steve and his expertise to help work through several technical challenges. With help also from Kenneth Pounds and Kenton Evans at Leicester U in the UK, we decided on a crossed grid charge detector to read out the micro-channel plates that detected the X-rays focused by the telescope. The detector required an evenly spaced grid of wires wound 128 wires to the inch. Steve developed an innovative technique, working with Harvard undergraduate Priscilla Cushman (now a professor at U. Minnesota involved in dark matter detection) as a summer student. They wound a double strand of wires and then unwound one strand to produce an evenly spaced grid in one direction, and then they repeated

*Figure 2: Steve demonstrating the prototype for the Einstein HRI (courtesy Karen Tucker).*

the step and oriented a second grid at 90 degrees to the first to produce a working 2-dimensional readout.

Quoted in the Star Splitters written by Wallace Tucker to describe the HEAO program, Steve said: "We just kept trying things until something worked. We really played the basement inventors. It took a few years, but after going down many blind alleys, finally we succeeded. In the end it turned out that the simplest ways were the ways that worked."

**Steve and ROSAT**

Following the successful *Einstein* program, Steve was selected as the lead to provide a High Resolution Imager for the German-led ROSAT satellite. Along with Martin Zombeck and others, Steve upgraded the HRI using CsI coatings to achieve a higher quantum efficiency. After the ROSAT All-Sky Survey was completed, the HRI was used in pointed mode to obtain the highest quality ROSAT images. When the proportional counter detectors exhausted their gas supply, the HRI served as the only ROSAT detector for several years of extended operations.

**Steve and *Chandra***

Steve was competitively selected as principal investigator for the *Chandra* High Resolution Camera (HRC) in the mid-1980's. As PI, Steve was fully engaged in all aspects of the design, construction, calibration, integration, and orbital activation of the flight instrument. His direct, steady leadership throughout the entire project was the single most important reason why HRC continues to function well to this day, nearly 17 years after launch. Notwithstanding the hard work and long hours, Steve thoroughly enjoyed all aspects of the construction and development of the HRC. He was equally at home meeting with high-level NASA administrators, writing C code to analyze his data, or tightening screws on a vacuum pipe for sub-assembly testing. He also demanded a high standard of work from himself and those around him. Along with Jon Chappell and Gerry Austin, Steve personally led the flight assembly of the MCP stacks and UV/Ion shields onto the crossed-grid readouts, spending many long hours in the cleanroom to ensure that all the work was done completely and carefully. This level of personal engagement, dedication, and broad competence for a large project serves as an example to the following generation of scientists who will be building the future space observatories. In 2000, Steve received the NASA Exceptional Service Medal in recognition of his work on the *Chandra* HRC.

Steve's principal scientific interests with *Chandra* were X-ray AGN surveys and high timing resolution, and he made important discoveries in these areas. The high spatial and temporal resolution of the *Chandra* HRC clearly separated the emission of the central point source in the PWN 3C 58 from the diffuse nebula, and detected millisecond pulsations from this source (Murray et al. 2002, ApJ, 568, 226). Deep observations of this central point source with the ACIS instrument put strong upper limits on the thermal emission from the central neutron star that were well below the predictions of standard cooling models, suggesting the presence of some exotic cooling mechanism in the neutron star interior (Slane et al. 2002, ApJ, 571, L45). Steve was also heavily involved in the *Chandra* AGN surveys of the DEEP2 and Boötes fields, contributing a significant fraction of the HRC Guaranteed Time Observations (GTO) time to ensure complete X-ray coverage in support of the large multi-wavelength campaigns.

Steve was committed to carrying out the best science with *Chandra*. In addition to those who helped him write the winning proposal and those involved in building the HRC, Steve included "new-comers" who brought along great science ideas. He focused the HRC GTO program on the best and most exciting science, with targets ranging from planets in our Solar system; to stars, supernova remnants, and globular clusters in our Milky Way; to galaxies including Andromeda and elliptical galaxies with hot gas haloes and supermassive black holes in their cores; and to samples of clusters of galaxies that produced new constraints on cosmological constants by measuring cluster growth over cosmological times. Steve often used some of his GTO time to kick-start new projects. These included the first *Chandra* observations of the Bullet Cluster, the initial *Chandra* deep observations of the cluster outskirts of A133, and the beginning of the large X-ray surveys of galaxy clusters detected through the Sunyaev-Zeldovich effect by both the South Pole Telescope and ESA's Planck mission, which later both led to *Chandra* X-ray Visionary Project programs.

The Boötes Survey was perhaps closest to Steve's heart. Boötes combined Steve's HRC GTO observations with *Chandra* GO proposals to survey a 9 square degree region, still the largest *Chandra* contiguous survey. Although the initial *Chandra* observations were short (only 5 ksec), deeper observations followed. The Boötes survey resulted in the detection of thousands of AGN and several tens of groups and clusters of galax-

*Figure 3: Steve in the lab with the Chandra High Resolution Camera*

ies. Three key results from these surveys include:

(1) radio AGN are primarily found in luminous red sequence galaxies, are strongly clustered, and have very low Eddington ratios; X-ray selected AGN are found in "green valley" galaxies, are less clustered, and have higher accretion rates; and IR AGN reside in slightly bluer, less luminous galaxies than X-ray AGN, are weakly clustered, and have higher accretion rates than X-ray or radio AGN (Hickox et al. 2009, ApJ, 696, 891);

(2) based on a sample of more than 330,000 galaxies, radio AGN are, in general, undergoing radiatively inefficient accretion in passive galaxies, while X-ray and IR selected AGN are more radiatively efficient and found in star-forming galaxies, with the galaxy populations of these two AGN types remaining distinct over the last 9 Gyr (Goulding et al. 2014, ApJ, 783, 40);

(3) quasar obscuration is associated with dust enshrouded starburst galaxies (Chen et al. 2015, ApJ, 802, 50).

There are many dozens of publications in the refereed literature that make use of these data, which will continue to be a resource for years to come. Coupled with optical spectroscopy, these observations showed that AGN also map the large-scale structures traced by galaxies. Ground-based MMT-Hectospec observations of the Boötes sources have been invaluable for source detections. Steve was looking forward to MMT-Binospec observations for sources too faint for Hectospec.

**Steve as Administrator and Teacher**

Steve also became Associate Director (AD) for CfA's High Energy Astrophysics Division (HEAD) for about a decade (1992-2003) when Harvey Tananbaum stepped down to become the Director of the *Chandra* X-ray Center (CXC). Steve worked tirelessly to ensure that the unusual organizational structure, with the CXC inside HEAD, actually worked successfully. Alongside the exponential growth of the CXC, Steve maintained the integrity of HEAD and understood the value and synergies of the complex merger. He worked to combine the existing administrative and support structures of HEAD with those being developed for the CXC. To this day, the model that he promoted has allowed the CXC to draw on the resources of HEAD and CfA, while the CXC supports the entire astronomical community in its use of *Chandra*.

While still serving as HRC PI and after a decade as HEAD AD, Steve sought new avenues for his hardware bent. In 2003-2004 he spent a semester as a visiting professor at MIT where he created and taught a course entitled "Proposal Writing for Small NASA Missions." His thoughts were that students needed to know more than how to design or build a mission. They also needed to be able to articulate the rationale for doing a new mission; to lay out a technical approach, schedule, and budget; and to convince others that the mission was compelling and feasible.

After Charles Alcock became CfA Director, Steve and he jointly established a new administrative role for Steve as SAO Deputy Director for Science (2005-2009). Steve was devoted to the collaborative endeavor that is the Harvard-Smithsonian Center for Astrophysics. He developed a comprehensive knowledge across the breadth of SAO science. He supported the development of budgets, coordinated hiring of a new cadre of scientists, and was a key organizer of the CfA Strategic Plan. During his tenure as Deputy Director for Science, he contributed his analytic skills to setting priorities at the Observatory and guided administrative and programmatic efforts in the Director's Office.

Steve moved to Baltimore in 2010 to join his wife Kathryn Flanagan (JWST Mission HEAD, Deputy Director STScI, Interim Director STScI). In Baltimore, Steve served as a Research Professor at JHU (2010-2015), a Visiting Researcher at JHU-APL (2010-2012) and a Senior Research Astronomer at STScI (2013-2015). At JHU, Steve (with Warren Moos) developed and taught the "Introduction to Space Science and Technology" the keystone course in the JHU minor "Space Science and Engineering". At Steve's urging, the course emphasized the design of science mission concepts by the students. Although restricted to upper level undergraduates in the sciences and engineering, the course was quite popular and each year reached its enrollment maximum shortly after registration opened. Looking for a more "hands-on" way to get undergraduates involved in spaceflight missions, Steve began the design of a CubeSat teaching laboratory utilizing funding for new teaching concepts from the Office of the Provost. During the fall of 2014, with a group of undergraduates he began testing CubeSat design tools with the plan to have future undergraduate students design and prepare flight satellites.

**Steve and ADS**

Throughout his moves and changing job descriptions, Steve led the Astrophysics Data System as PI (beginning in 1991/1992), forming a small, elite team supported by NASA. The ADS team revolutionized access to the astrophysics literature by providing free, open digital access to the entire astronomical archive of all major (and nearly all minor) astronomical journals back to their first publication (some into the early 1800's). The ADS corpus presently consists of 11 million bibliographic records, 85 million citations, and close to 4.5 million full-text documents, the world's most complete collection of scholarly content in the physical sciences. The 2002 Harvard-Smithsonian Visiting Committee reported "It is no exaggeration to say that ADS has revolutionized the use of the astronomical literature, dramatically changed the use and focus of astronomical libraries, empowered astronomy research in underdeveloped countries and small institutions, and is probably the most valuable single contribution to astronomy research that the CfA has made in its lifetime."

**Steve and Future Missions**

Steve also devoted a significant fraction of his energy to developing new mission concepts. In particular, he played a central role in the development and evolution of the Wide Field X-ray Telescope (WFXT) and Whipple concepts. The WFXT concept is an X-ray telescope with a large effective area and field of view intended for a deep survey of the extragalactic sky. The primary goals of this mission are to detect clusters with $M>10^{14}\ M_{\odot}$ to z~2 in the surveyed region and to map the distribution of AGN to z~5, ultimately to place unprecedented constraints on the formation and evolution of supermassive black holes (SMBH) and the relationship between SMBHs and their host galaxies. Demonstrating Steve's technical skill and versatility, the Whipple mission concept is a space-based optical observatory to continuously monitor the light curves of tens of thousands of stars at 20 Hz cadence to search for occultations by Kuiper Belt and Oort Cloud objects. The ultimate goal of this mission is to constrain dynamical models of the evolution of the early Solar system. If either or both of these are ultimately funded to flight, the community will owe a further debt to Steve and his ability to define and refine these concepts into state of the art astronomical observatories.

**Steve's Legacy**

Steve has served the community with his unparalleled expertise spanning hardware, technology, and science. Riccardo Giacconi was keenly aware of Steve's unique combination of skills dating back to the development of the 2U catalog and through his work to develop an all-electronic, high-resolution imaging detector for the *Einstein Observatory*. Upon learning of Steve's passing, Riccardo wrote: "Steve and I were very close during the period when we stayed at JHU. We could talk of all aspects of science and express our ideas and our disappointments. He was a very good man and I feel a great loss." Recently Riccardo added: "At JHU, Steve and I discussed at length what we came to call 'Science Systems Engineering', which we summarized with a simple mnemonic: Learn-Think-Plan-Do-and Teach. (Giacconi, R., 2013, Considerations on X-ray Astronomy (Appendix A), Mem. S. A. It., 84, 472 ). Steve was sharing this philosophy and approach to science with his students at JHU."

Steve's legacy continues through the ADS, *Chandra*, and in other software platforms that our community uses every day. Perhaps as importantly, Steve's legacy resides in the colleagues, co-workers, and students who were fortunate enough to work with him. His lifetime of commitment to research, innovation, teaching, and outreach serves as a model and inspiration for us all. To honor Steve's contributions, the *Chandra* HRC project has initiated a Distinguished Lecturer series in Steve's name. As Steve would have demanded, these lectures are promptly posted for public access (see Stephen Murray Distinguished Lectures at *https://www.youtube.com/channel/UCMFEeX24_lviXNhek5-FFLA*) and serve as a constant reminder of the extraordinary breadth and superb quality of Steve's scientific interests. ■

**Prepared by H. Tananbaum, R. Kraft, C. Jones, W. Forman with Input from A. Accomazzi, C. Alcock, R. Brissenden, K. Flanagan, R. Giacconi, M. Kurtz, K. Lestition, W. Moos & A. Preston**

## Daniel E. Harris (1934 - 2015)

*Slugs and Snails and Puppy Dog Tails: jets from an unconventional angle* was the title of Dan Harris' review article presented at the IAU 313 Symposium held in September 2014 at the Galapagos Islands. The symposium was partly dedicated to Dan's work in the area of extragalactic jets and also a celebration of his 80th birthday. He presented a short review of jet properties, the "agents" that carry jet power, synchrotron jets, jet variability and quasar jets. The presentation covered questions that Dan had researched and focused on the *Chandra* discoveries of ubiquitous X-ray jets. Dan had studied extragalactic radio sources since the time of his PhD project in the late 1950's. He had experienced the evolution of X-ray astronomy and contributed to many aspects of modern X-ray astronomy research. This review was Dan's final publication. He died on December 6, 2015.

On March 19th, the day before the spring 2016 equinox, Dan's colleagues, family and friends gathered at the Center for Astrophysics in Cambridge to celebrate Dan's life. Many of us were unaware of the broad interests Dan had and how much he had accomplished in his life outside of astronomy. The title of his IAU review paper conveys Dan's view of the world, connecting many aspects of life, especially art and science. Dan was a researcher in the full meaning of the word. He was an astronomer, explorer, poet, bicyclist, soccer player, carpenter, musician and an activist. He was also a husband, father and grandfather, and devoted a great amount of time to his family who followed him around the world on his many adventures. The proceedings of the IAU 313 Symposium include numerous details of Dan's scientific and personal life, and note his curiosity about the world.

Dan was born in 1934. He graduated from Caltech in 1961 with a PhD thesis titled "The continuous spectra of radio sources with particular reference to non-thermal galactic sources". Since then, he has studied the nature of radio sources using radio and X-ray data. Working with the *Uhuru* and *Einstein* X-ray data, he calculated and discussed the importance of the inverse Compton scattering of cosmic microwave background radiation in these sources. In particular, his 1979 paper, in collaboration with Josh Grindlay, stated the importance of X-ray studies of radio sources by using the inverse Compton process to determine the magnetic field of the source, its electron spectrum and the density content of the cosmic ray reservoir. In 1987 he published a detailed spatial analysis of the *Einstein* HRI image of the quasar 3C273—the highest resolution X-ray image at that time—to locate the X-ray emission associated with the quasar jet. He applied the inverse Compton scattering of cosmic microwave background photons to the relativistic jet electrons (IC/CMB) model to explain the observed X-ray intensity of that jet. At that time, only a few resolved jets had been detected in X-rays, i.e. M87, Centaurus A and 3C273. Later, the ROSAT High Resolution Imager resolved the X-ray emission from the hotspots of Cygnus A which Dan reported in a Letter to Nature in 1994. He argued that the X-ray emission of these hotspots was due to inverse Compton scattering of radio photons on the relativistic electrons, i.e. synchrotron self-Compton (SSC) process.

*Chandra* discoveries of X-ray jets made the last 15 years of Dan's research very exciting. He started compiling the data for X-ray jets on a designated web site. He used the numerous observations of X-ray jets to systematically study jet emission processes in detail. In 2002 he published a paper summarizing the processes responsible for X-ray emission in relativistic jets and later, in 2006, reviewed work on X-ray jets in Annual Reviews of Astronomy and Astrophysics.

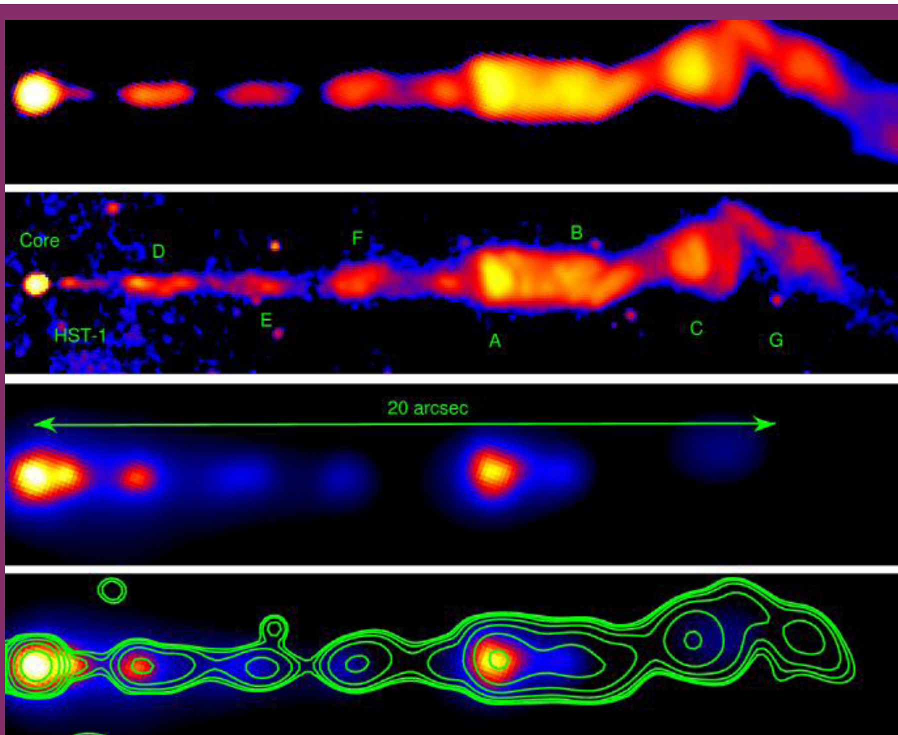



*Figure 1: M87 jet in three bands, rotated to a horizontal orientation (from Marshall et al. 2002). First panel (top to bottom): VLA image at 14.435 GHz with spatial resolution ~0.2 arcseconds. Second panel: The HST Planetary Camera image in the F814W filter from Perlman et al. (2001). Third panel: Adaptively smoothed Chandra X-ray image. Fourth panel: Smoothed Chandra image overlaid with contours of a Gaussian-smoothed HST image matching the Chandra PSF. The HST and VLA images have a logarithmic stretch to bring out faint features, while the X-ray image scaling is linear.*

Dan had been monitoring the M87 jet, studying its multi-band variability and was rewarded by detecting a huge X-ray flare that did not originate in the core of the galaxy, but from a knot in the jet. *Chandra*'s high angular resolution allowed for a clear detection of the X-ray flare from the HST-1 knot of the M87 jet (Harris et al. 2003, 2006). This was a most exciting and important discovery because the knot variability indicated that particle acceleration can occur at large distances from the nucleus. HST-1 was the first jet knot clearly resolved from the nuclear emission by *Chandra* and was the site of the huge flare. In a 2009 paper, Dan presented evidence that the multi-band decrease in the knot intensity was caused by synchrotron cooling, and estimated that the magnetic field strength was consistent with the equipartition field. The *Chandra* X-ray light curve of HST-1 also showed quasi-periodic oscillation on a time scale of six months in the two years prior to the huge flare. The *Chandra* data indicated that the X-ray variability of the nucleus appeared to be at least twice as rapid as that of the HST-1 knot, but still longer than the shortest TeV variability (1-2 days) reported by the H.E.S.S. and MAGIC gamma-ray telescopes. In 2011 Dan described an experiment to locate the site of the TeV variability using *Chandra* and Veritas telescopes and reported that the TeV flares are more likely to originate in the nucleus of M87. The *Chandra* monitoring program is on-going and per-

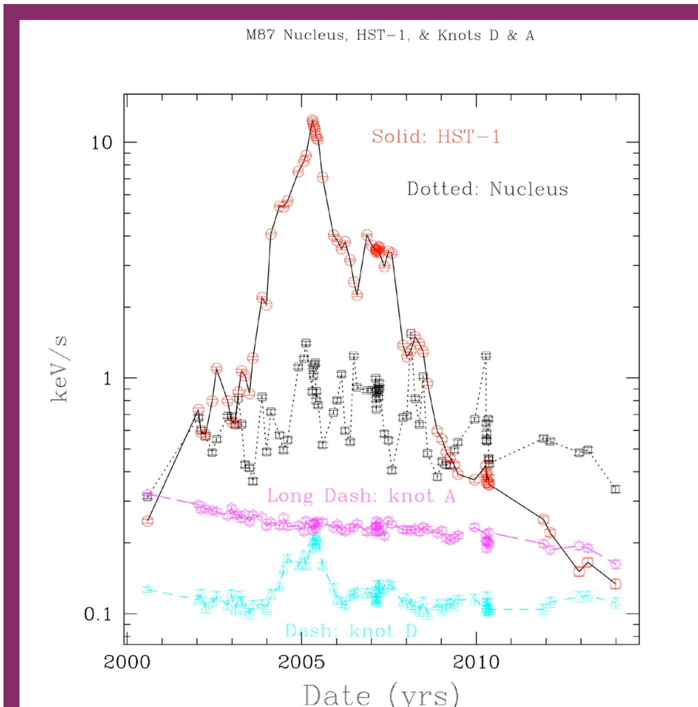



*Figure 2: M87 X-ray in outburst. X-ray lightcurve of M87 nucleus and three knots HST-1, A, D collected over 13 years of Chandra monitoring program led by Dan Harris (Harris et al. 2009). The count rate is shown on the logarithmic scale. A strong and long-lasting outburst of HST-1 knot dominates the lightcurve. The nucleus shows the short-term variability during the same time. During the time HST-1 was peaking, severe pileup corrupted the PSF so that both the nucleus and knot D photometric apertures were collecting only a fraction of HST-1 events.*

haps his colleagues will be able to locate the site via future observation of flares.

Dan had been working in the High Energy Astrophysics Division at the SAO for more than 30 years. He was a member of the *Einstein*, ROSAT and *Chandra* support teams. He worked on the catalogs of X-ray sources using *Einstein* and ROSAT observations. His work in the *Chandra X-ray Center* was focused on source detection and user support. He semi-retired in early 2000, but remained involved with his astrophysical research. ▪

**References**

Harris, D. E., & Grindlay, J. E. 1979, MNRAS, 188, 25
Harris, D. E., & Stern, C. P. 1987, ApJ, 313, 136
Harris, D. E., & Krawczynski, H. 2002, ApJ, 565, 244
Harris, D. E., Biretta, J. A., Junor, W., et al. 2003, ApJL, 586, L41
Harris, D. E., Cheung, C. C., Biretta, J. A., et al. 2006, ApJ, 640, 211
Harris, D. E., & Krawczynski, H. 2006, ARA&A, 44, 463
Harris, D. E., Cheung, C. C., Stawarz, L., Biretta, J. A., & Perlman, E.~S. 2009, ApJ, 699, 305
Harris, D. E., Massaro, F., Cheung, C. C., et al. 2011, ApJ, 743, 177
Harris, D. E. 2015, Extragalactic Jets from Every Angle, 313, 199
AAS Obituary *https://aas.org/obituaries/daniel-e-harris-1934-2015*

**Prepared by Aneta Siemiginowska and Dan Schwartz**

## Director's Log, *Chandra* date: 577065605

**Belinda Wilkes**
*https://twitter.com/BelindaWilkes*

Following a positive 25-year lifetime study of the spacecraft sub-systems in 2014, the *Chandra* team is planning for the long-term, and the past year has seen many related activities. This forward-looking theme is also prevalent in the larger High Energy Astrophysics (HEA) community as NASA begins to plan for missions to be considered by the next decadal survey. *Chandra*'s uniquely high spatial resolution continues to provide ground-breaking science across most of astrophysics and, barring being run over by the proverbial bus, we expect to continue to do so for at least 10 more years (subject, as always, to continued NASA funding). After meeting last summer to discuss the future, the HEA community united behind concepts for an *X-ray Surveyor* mission which would preserve *Chandra*'s spatial resolution but with significantly higher effective area—complementing ESA's *Athena* mission which is planned to launch in the late 2020s. A follow-up workshop in Washington, DC this past October discussed major science topics and questions to be addressed by such a mission, including galaxy formation, the first black holes, stellar birth and death, and the structure of neutron stars. This workshop served as a precursor to the formal NASA Science and Technology Definition Team (STDT) activities which are beginning now.

*Chandra* continues to operate at high efficiency and to accept proposals without restrictions on sky coverage, despite (graceful) aging which results in challenges for observation scheduling. As we carefully balance the thermal status of various spacecraft components, observations may be split into multiple pieces, and we continue to restrict the number of approved constrained observations. In seeking targets at appropriate solar pitch angle for a given schedule, *Chandra* observing cycles now have longer overlap periods. For example, several Cycle 16 observations are scheduled for late summer 2016, while the earliest Cycle 17 observations were made in fall 2015. We continue to guarantee that all approved observations will be completed.

As we look to the future, we aim to ensure that there are no gaps in *Chandra*'s scientific legacy, and that we take full advantage of its capabilities to prepare and shape future missions. The *Chandra* workshop in 2015, "The Universe in High-resolution X-ray Spectra" provided excellent summaries of the current status across various source classes, and included a discussion of areas that need development, related to observations, software, and basic atomic data (article on pp. 34-35). The upcoming 2016 *Chandra* workshop is entitled "*Chandra* Science for the Next Decade" (advertisement on p. 39) and aims to bring together X-ray and multi-wavelength scientists to envisage the future of *Chandra* science in the complex and changing landscape of new missions, telescopes, and big data. Please come and join your voice to the discussion!

On the topic of upcoming missions, we hosted a visit from Professor Takahashi (PI and Project Manager) and Dr. Ohashi (Project Scientist) last fall to discuss collaboration and cooperation with Hitomi (then Astro-H). We had already scheduled our first simultaneous calibration observations, and were looking forward to detailed discussions at the HEAD meeting in Naples when contact with Hitomi was lost. We are deeply sorry that Hitomi was eventually not recoverable and send our commiserations to the team who worked so hard for so many years. Its loss is a major setback for X-ray astronomy, pushing the opportunity for high quality, high-resolution spectra into the future by more than 10 years.

Within the CXC, as several senior staff retire or change their emphasis, we have hired new science staff to ensure a fully-trained workforce for the next decade. This has been an exciting time, our first scientist hires in many years. We were extremely pleased with the number and high quality of the applicants, and we enjoyed interviewing many of them. We were only sorry that we did not have more positions to fill so as to take further advantage of the breadth and depth of talent in our community.

Recent activities at the CXC have been dominated by the bi-annual NASA Senior Review, with the proposal submitted in January and on-site meetings with the review panel in March. While this activity is intense and dominates the work of a significant number of staff, it is always very useful and enjoyable to review our status and, in particular, the science results of the past two years, and to look forward to expected progress over the next two years. Initial, informal feedback from NASA indicates positive response from the panel, and we look forward to their final report which is expected in May.

*Chandra* observed a wide variety of DDT targets in the past year including relatively common source types such as GRBs, transients, and SN, several programs tracking the very bright outburst of LMXB V404 Cyg (see lead science article pp. 1-7), participating with a plethora of NASA missions in observing (and detecting!) Pluto during the New Horizons flyby, and tracking a new outburst in M87. This last target was for a project led for many years by retired CXC scientist Dan Harris, who died late last year (see article on pp. 13-15). The series of five observations, led by his long-time collaborators Teddy Cheung and Francesco Massaro, was successfully completed two days before the extremely well-attended memorial event held for Dan at CfA in March. It was good to be able to report that the science he loved lives on.

Many of you will also have seen a variety of *Chandra* science presented on NASA's Hyperwall at both the IAU in Hawaii and the AAS in Kissimmee, FL. The size of the wall allows for spectacular images that are visible from a great distance and are presented during key morning and afternoon sessions in the exhibit hall. Topics ranged from a general overview of recent *Chandra* science (given by myself), to more detailed science results on jets, galaxy clusters, surveys, galaxies, stars and stellar coronae, the *Chandra* Source Catalog, and image processing techniques presented by experts in each area. Please keep an eye out for us again at the next winter AAS meeting! ▪

## Useful *Chandra* Web Addresses

To Change Your Mailing Address:
http://cxc.harvard.edu/cdo/udb/userdat.html

*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
http://www.sron.nl/divisions/hea/chandra/

MARX simulator
http://space.mit.edu/ASC/MARX/

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

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

## Project Scientist's Report

**Martin C. Weisskopf**

We are very fortunate that *Chandra* will shortly begin its 18th year of operation, with expectations of continuation into the foreseeable future. As the next major U.S. X-ray-astronomy facility will not launch before the late 2020s, the *Chandra* Team recognizes the importance both of maintaining *Chandra*'s unique capabilities for at least another decade and also of preparing for the future.

As the Observatory ages, three issues—(1) thermal, (2) molecular contamination, and (3) radiation damage—are resulting in graceful degradation of the Observatory's performance.

1. Thermal degradation has required progressively more sophisticated mission planning to ensure that each critical component remains within its acceptable temperature range. The overall observing efficiency has remained high; however, observations at thermally unfavorable orientations are subject to limits on pointing duration or on number of operating ACIS CCDs.

2. Molecular contamination on the (cool) ACIS optical blocking filters continues to accumulate, persistently decreasing the low-energy response. Consequently, the *Chandra* Team has undertaken a detailed study of the risk/benefits of baking out the ACIS, revisiting the 2004 decision not to bake out.

3. Radiation degradation of the ACIS CCDs continues to slowly increase the charge-transfer inefficiency—especially of the front-illuminated devices. Fortunately, the *Chandra*'s radiation management program, implemented shortly after the start of science operations, has limited the subsequent rate of radiation damage to acceptable levels. A key component of this program relies upon NOAA-provided real-time space-weather monitoring of low-energy (0.1–1 MeV) protons, which have been most damaging to the front-illuminated CCDs. Working through NASA, the *Chandra* Team has requested NOAA to continue to provide this real-time data stream from the Advanced Composition Explorer (ACE) after the recently launched Deep Space Climate Observatory (DSCOVR) becomes the primary real-time space-weather satellite at L1. NOAA is currently seeking to identify the additional ground stations needed to support this capability.

The recent first detection of gravitational waves—from the coalescence of two ≈30 $M_\odot$ black holes—has spurred excitement for its astrophysical implications, which surely will involve *Chandra* in some way. Also recently, the *Chandra* Team prepared for and completed another Senior Review, which we believe went quite well: We anticipate release of the panel report later this spring.

Turning to the future, the astrophysics community is invigorated by the NASA Astrophysics Division Director's decision to pursue four mission studies in preparation for the 2020 National Academy of Sciences Decadal Survey for Astronomy and Astrophysics. In last year's newsletter, we reported that a subset of the *Chandra* Team had organized an informal science team to initiate preliminary mission concept studies with MSFC's Advanced Concepts Office in support of one such mission. Subsequently, NASA HQ selected a Science and Technology Definition Team (STDT)—with Co-chairs Alexey Vikhlinin (SAO) and Feryal Özel (Arizona) and Study Scientist Jessica Gaskin (MSFC)—to support the study of the "*X-ray Surveyor*" as one of these four missions. ■

## Project Manager's Report

**Roger Brissenden**

*Chandra* has marked over 16 years of successful mission operations with continued excellent operational and scientific performance. Telescope time remained in high demand, with significant oversubscription in the Cycle 17 peer review, held in June. The Cycle 17 review approved 175 proposals, out of 578 submitted by researchers worldwide who requested ~4.9 times more observing time than was available. Among the approved proposals are 13 Large Projects (>300 ks each), which were allotted a total of 6 Ms.

We released the Call for Proposals for Cycle 18 in December, with proposals due in March 2016 and the peer review in June 2016.

As part of NASA's 2016 Senior Review of operating missions, *Chandra X-ray Center* (CXC) and Marshall Space Flight Center program staff submitted the *Chandra* Senior Review proposal in January 2016, and the NASA review committee held a site visit at the CXC in March 2016.

In May 2015 the CXC conducted a review of our mission operations processes, in response to a recommendation by the 2014 Senior Review committee to seek advice from other missions on approaches to increasing the efficiency and sustainability of *Chandra* mission operations. A panel of experts familiar with a range of missions came to the *Chandra* Operations Control Center (OCC) to review our processes, staffing, and planning for the future. The panel's report was positive in its assessment of the CXC's stewardship of *Chandra*, saying, "...the *Chandra* Operations Team has done an excellent job in operating the spacecraft over the last 15 years, maximizing the science return while being excellent custodians of the spacecraft. They have been proactive in making substantial and beneficial modifications to operations during this time period, in order to adapt to hardware issue[s] on the vehicle and funding constraints from NASA. There are no 'low hanging fruit' or 'quick fix' updates that can be made today that will save substantial funding in future years, while maintaining the current risk posture and present level of science return. Given the age and complexity of the spacecraft, the coming years of operations are likely to see an increase in the operations level of effort." The panel made several recommendations that we are acting on, in part by visiting multiple missions to learn from their experiences with efficiency improvement and automation.

The CXC hosted a number of events and reviews in the past year including a workshop, "The Universe in High Resolution X-ray Spectra," held in August 2015, the annual symposium for the Einstein Fellowship program held in October 2015, and NASA's regular review of the CXC's operation in April and September 2015. The *Chandra* Users' Committee met at the CXC in October 2015 and held a telecon in April 2016 to discuss the *Chandra* Source Catalog (CSC) with a focus on an update to the already released early detection list and plans for the final release.

Storms of solar particles caused the operations team to interrupt *Chandra* observing twice during the year to protect the instruments from solar particles. In addition, 15 requests to observe targets of opportunity required the mission planning and flight teams to interrupt and revise on-board command loads. *Chandra* passed through the 2015 eclipse seasons with nominal power and thermal performance. *Chandra* transitioned to safe mode twice (the sixth and seventh safe modes of the mission) due to a trip of the sun position monitor. The safe modes caused no adverse effects, and procedures have been put in place to avoid a similar trip in the future.

*Chandra*'s focal plane instruments, the Advanced CCD Imaging Spectrometer and the High Resolution Camera, have continued to operate well and have had no significant problems. The observatory has continued to warm gradually due to slow degradation of the spacecraft's multi-layer thermal insulation. This warming results in added complications in scheduling observations, but no significant decrease in observing efficiency. All systems at the *Chandra* Operations Control Center continued to perform well in supporting flight operations. *Chandra* data processing proceeded smoothly and data distribution continued to be rapid, with the time from observation to availability of data to the observer averaging ~30 hours.

The CXC's Data System team released software to support *Chandra* users with Cycle 17 observation proposal submissions, the Cycle 17 Peer Review, and the Cycle 18 Call for Proposals. In addition, in June the team completed a multi-year plan to migrate the entire data system from Solaris to 64-bit Linux for all *Chandra* data system operations. CSC (release 2.0) production is in full swing with an estimated 350,000 source detections expected for the catalog that will be published in the fall. An automated system is processing the data that co-adds multiple observations and uses new source detection and background algorithms to include the faintest (~5 net counts on-axis) sources.

During 2015, NASA began implementing structural and funding changes in the way that the activities formerly known as "Education and Public Outreach" are carried out. That reorganization and associated activities will be described in the article on pp. 42-44. This article will be limited to activities carried out under the term "Communications and Public Engagement" (CPE). CXC CPE accomplishments included 12 *Chandra* science press releases, 2 additional in conjunction with other telescopes, 4 non-science press releases (including announcement of the death of HRC PI Steve Murray) and 36 additional images (some releases with multiple images) resulting in 2338 articles in print and electronic news outlets. *Chandra* images were used in 22 releases of HEASARC Picture of the Week, 4 Astronomy Picture of the Day and 7 NASA Picture of the Week. The CXC also produced 42 podcasts on *Chandra* results as well as special series for children, fundamental science topics related to astrophysics, and the International Year of Astronomy. In addition, 44 blog entries were posted, including additions to "Meet the Astronomer" profiles of Principal Investigators of *Chandra* science observations.

We look forward to a new year of continued efficient operations and exciting science results. ■

## Chandra Source Catalog

### Ian Evans, for the CSC team

In the last newsletter, we described many of the enhancements that will be included in the upcoming release 2.0 of the *Chandra* Source Catalog (CSC). The updated catalog will include observations released publicly through the end of 2014, co-adds multiple observations of the same field (pointings co-located within 60 arcsec and obtained using the same instrument) prior to source detection, and uses an improved source detection method that allows us to detect on-axis point sources reliably down to roughly 5 net counts for exposures shorter than the median *Chandra* observation duration (13 ks). Similar to the current catalog release, the updated catalog will tabulate numerous properties (with their associated confidence intervals) for each source, and provide extensive FITS data products for each field and source region that can be used directly for scientific analyses. When complete, the catalog should include information for approximately 400,000 source detections from roughly 10,000 *Chandra* ACIS and HRC-I imaging observations.

Production of release 2.0 is well underway, with almost all of the observed sky having completed the initial source detection phase at the time of writing. The candidate source detections are then analyzed with a new maximum likelihood estimator (MLE) tool that uses Sherpa to fit a model of the local point spread function (PSF) plus underlying background to the observed photon counts distribution to evaluate the likelihood that the candidate source is real. A second model of the local PSF convolved with an elliptical Gaussian (plus background) is also fitted to the data to simulate sources with some inherent extent. In addition to determining source likelihood, fitting with the local PSF also improves source astrometry, particularly for large off-axis angles where PSF asymmetries can bias position centroids.

Roughly ⅔ of the observed sky had been processed through the MLE step as of (Northern) autumn 2015 when we discovered that a few percent of the candidate source detections had poor MLE fits. In some cases, the source positions derived from these fits were in error by several times the local PSF radius (and several times the reported position uncertainties). Such errors would be unacceptable in the final released catalog, so processing was suspended to allow for a detailed investigation and resolution. In many cases, the root cause of the error was that the candidate source detection position was displaced from the actual source position, and therefore the region in which the MLE fit was performed did not properly enclose the source counts (the region is intentionally kept small to avoid confusion between nearby sources in crowded fields). To resolve the problem we have developed a two-stage MLE fitting process where a preliminary fit in an expanded region is used to re-center the final fit region on the counts distribution of the candidate source detection. Several automated quality assurance steps were added to identify cases where the MLE fit may not have completed successfully and send them for human review. A few additional pipeline and quality assurance enhancements were also developed to resolve other minor issues identified during this investigation.

Release 2.0 catalog production with the updated pipelines was restarted in March 2016 and production should be completely caught up by late spring. The remaining steps required to complete the official catalog release include merging detections from multiple overlapping fields, extracting source properties, generating limiting sensitivity maps, and populating the final catalog database. These steps should require roughly an additional 6 months. Once they are completed, release 2.0 will become the default official catalog release accessed by all of our standard catalog interfaces.

Key data for the subset of detections that completed processing through the end of July 2015 were

#### Reminder on the Naming of Sources Detected with Chandra

We want to remind our users of the recomendations regarding the naming of sources detected in *Chandra* observations:
Either register your own acronym with the IAU Task Group on Astronomical Designations:
http://cdsarc.u-strasbg.fr/viz-bin/DicForm

or use the general purpose designation
CXOU Jhhmmss.s±ddmmss
http://cdsarc.u-strasbg.fr/viz-bin/Dic?/2880906

Do not use the acronyms CXO or nCXO (where n is a number). These are reserved for use by the CSC which is a project of the CXC:
http://cdsarc.u-strasbg.fr/viz-bin/Dic?/2812380

For complete recommendations, please refer to:
http://cxc.cfa.harvard.edu/cdo/scipubs.html#NAME

made available to the community in early August as a "preliminary detections list" in FITS binary table format. The preliminary detections list can be accessed through the CSC release 2.0 website (http://cxc.cfa.harvard.edu/csc2/). For each detection, this table 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.

Although the original version of the preliminary detections list does include a few percent of detections impacted by the poor MLE fits issue described above, the vast majority of isolated brighter sources (≳10 counts on-axis) are unaffected. The preliminary detections list will be updated on the website once the data are reprocessed through the two-step MLE process. Readers interested in using the preliminary detections list should understand that these data may undergo revisions and have not received the complete quality assurance assessments that will apply to the final catalog release, and are therefore urged to review the caveats listed on the website carefully.

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 along with several examples and user threads that demonstrate the use of these tools to access the catalog. Updates to the preliminary detections list and news about release 2.0 of the catalog will continue to be added to the website (http://cxc.cfa.harvard.edu/csc2/) as production proceeds. ■

## ACIS

**Richard J. Edgar, Catherine E. Grant, Gregg Germain, John A. ZuHone, and Paul P. Plucinsky**

The ACIS instrument continued to perform well over the past year, conducting the vast majority of observations with *Chandra*. There were no ACIS instrument anomalies that impacted science observing.

Thermal control of the ACIS focal plane and electronics boxes continues to be a significant issue, as does that of other subsystems on the spacecraft. One consequence of the thermal situation is continuing evolution in the misalignment between the Aspect Camera and X-ray telescope boresights. For a couple months in the fall of 2015, there was concern about our ability to place a target into a small (⅛ chip) subarray on ACIS. This has now been resolved in a way that is transparent to users, specifically, every two weeks we use the past pointing performance of the telescope to recompute the alignment matrix used by the spacecraft. This solution assures that a target will reside well within a region even as small as a small subarray on ACIS.

As in previous years, GOs are encouraged to designate chips not required for their science goals as optional (by selecting OFF1, OFF2, etc. on the RPS form) in the order in which the chips would be turned off if required for thermal reasons. Details are given in the Proposers' Observatory Guide (POG) and all users are urged to read the section on optional chips carefully.

The contamination layer continues to accumulate on the ACIS optical blocking filter. The presently released contamination calibration file (labeled N0009 in CALDB 4.6.2) in the Calibration Database does a good job of predicting the contamination in the centers of the chips. However, there is a suggestion from recent calibration observations of 1E1012-7219, Abell 1795, and Markarian 421 that the contaminant may be building up more rapidly near the edges of the blocking filter than the model predictions indicate. The *Chandra* Calibration article (pp. 35-36) discusses this in more detail The charge-transfer inefficiency (CTI) of the front-illuminated (FI) and back-illuminated (BI) CCDs is increasing at the expected rate.

In personnel matters, long-time ACIS team member Royce Buehler of MIT retired in January of 2016. Royce has been responsible for the software that generates and keeps track of the myriad of Science Instrument modes used in ACIS observations, in addition to other operations and analysis tasks. He will be missed, but we are fortunate to have had 20+ years of his attention, and more, on a part-time basis, in the next few years. Catherine Grant at MIT and John ZuHone at SAO have been brought into the operations team.

Several interesting and challenging observations were performed, for example those described in the cover article by Sebastian Heinz. Our colleagues at *Swift* were extremely helpful in monitoring bright and potentially flaring sources, to help ensure the safety of observations with *Chandra*.

A significant activity for the ACIS Operations team this year will be a review and expansion of Standard Operating Procedures (SOPs) to respond to potential instrument anomalies. In cooperation with the MIT instrument team, the existing SOPs have been reviewed and new SOPs recommended for development. For example, a new SOP monitors the checksum of the ACIS flight software, which is stored in an aging EEPROM memory chip. Although this information has been uncorrupted for sixteen years, there is no guarantee that a corruption will not occur. Another general SOP has been developed—and exercised in flight—to respond to cases of anomalous behavior from one video board or Front End Processor (FEP). This SOP suspends the current science run, dumps diagnostic information from that video board and FEP, and then resumes the science run with all CCDs except the affected one. ▪

## Ralph Kraft Appointed as New HRC Principal Investigator

**Belinda Wilkes**

In consultation with NASA, CfA Director Charles Alcock, and HEAD Associate Director Bill Forman, we appointed Ralph Kraft as the HRC Principal Investigator (PI) in September 2015 (press release: *http://chandra.harvard.edu/press/15_releases/press_092815.html*), following the untimely death of the original PI, Stephen Murray, in August 2015 (see article on pp. 8-12).

Ralph received his undergraduate degree in Physics from the University of Pittsburgh in 1988 and his Ph.D. in Astronomy and Astrophysics from Pennsylvania State University in 1995, working on developing CCDs for use in X-ray astronomy. He joined the HRC instrument team upon completion of his doctoral thesis and worked closely with Murray and the engineering team that designed and built the flight instrument. Since *Chandra*'s launch in 1999, Ralph has divided his time between HRC operations to ensure the health and safety of the flight instrument, ongoing analysis of in-flight calibration data, and development of his own science program. In 2013 he was appointed Project Scientist for the HRC instrument team, with primary day-to-day responsibility for the flight instrument.

Ralph has broad scientific interests including the study of clusters of galaxies, black holes, jets, astrophysical hydrodynamics, the formation of structure in the Universe, and development of instrumentation for future mission concepts in both astrophysics and planetary science. He collaborates with a number of groups at SAO, is well-known to CXC staff, and an integral part of the High Energy Astrophysics Division. Based on his long history and experience with the HRC team, he is well-qualified to take on the role of PI, and the *Chandra* team is very much enjoying working with him. ▪

## HRC

**R. Kraft, R. DiStefano, F. Primini**

The big news from the High Resolution Camera (HRC) instrument team is, of course, the passing of our principal investigator, Stephen Murray. A more detailed memorial article can be found on pp. 8-12, but Steve's sudden and unexpected passing shocked and saddened us all. He led the HRC team from the initial development of the instrument concept through construction, calibration and launch. His strong leadership guided the instrument team through all the ups and downs of the development of the flight instrument and post-launch operations. He assembled a strong team of scientists to advise him about how to best use the HRC Guaranteed Observation Time. He was a strong presence in our field, always at the forefront of research both scientifically and technologically. His passing was a great loss to the *Chandra* and broader high-energy astrophysics communities. The impact of his work and his personality will remain with community, particularly within the CXC, for a long time.

The HRC continues to operate well with no major anomalies, although there has been a change in one of the important instrumental trends. Over the past 1.5 years, the rate of gain decrease on the HRC-S has increased. The reason for this change is currently unknown, but the instrument team is trying to understand the phenomenon. There will be little impact on science operations in the short term, but if the gain continues to drop at the present rate we will recommend another high voltage increase later this year or early next year. The last high voltage increase of HRC-S occurred in February 2012. Otherwise the instrument continues to operate well.

The HRC was used for a wide variety of scientific investigations over the past year. This year we focus on a study performed by Drs. Rosanne Di Stefano and Frank Primini on variables in the galactic bulge. The Bulge of our Galaxy is rich in variables of all kinds, including X-ray binaries. Di Stefano and Primini conducted a survey of a portion of the Bulge in Baade's Window, with HRC. Baade's window is attractive for both X-ray and optical surveys because of its relatively low absorption. In fact, Baade's Window has been monitored by numerous gravitational lensing teams such as MACHO, OGLE and MOA for a total of 25 years. These teams have discovered almost 20,000 lensing event candidates while also monitoring millions of variables. Any X-ray source (XRS) discovered in such a well-monitored region may have a long-term optical light curve that can immediately help establish the nature of the source. Furthermore, possible correspondences between XRSs and lensing events offer an exciting possibility.

*Chandra*'s unique angular resolution is a key factor in counterpart studies. However, the HRC field of view is small compared with the size of the desired survey region. This challenge has been faced before. Some groups have conducted wide-field, shallow surveys, while others have gone deep in smaller regions. We decided on a "middle way" in which we used six contiguous HRC fields to cover 1.5 degrees with 30 ksec exposures. This observing strategy also allows us to compare this approach with other observing strategies.

Our preliminary results include a total of 81 newly-discovered XRSs, some of which include optical monitoring, that has provided a treasury of useful information that can help us interpret the X-ray emission and learn more about the XRSs. For example, 23 of the XRSs correspond to OGLE-monitored Be stars, while other counterparts include an RR Lyrae system, an OGLE-identified quasar, an eclipsing binary, a long-period variable, and six objects with currently unclassified variability patterns. In addition, six of the XRSs seem to be matched with Tycho-2 stars, one of which is a star with a planetary system.

With 1130 microlensing events in our fields, there was a non-negligible chance of finding an XRS/lensing-event match. However, we did not find any such matches. Although this was disappointing, it is really only the beginning of the story, since new events are being discovered in this region every year, with the total discovery rate is increasing. Ideally, the discovery of these XRSs can be used inform future discoveries. For example, if a future lensing event coincides with the location of an XRS, that event should receive special attention. If an XRS is part of a lensed system, then new target of opportunity (TOO) X-ray observations can possibly detect the lensing event in X-rays, thus providing a firm prediction of relativity. On the other hand, if the XRS is the lens, then we may be able to measure its mass and multiplicity through a more-detailed multiwavelength monitoring of the system. 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. ■

## HETGS

**Norbert S. Schulz, for the HETGS team**

### Performance, Calibration, and Software

During Cycle 16 and the first part of Cycle 17 the High Energy Transmission Gratings Spectrometer (HETGS) continued to perform nominally. There were 24 targets observed in Cycle 16 in 50 separate observations for a total exposure of 2.5 Ms. This total exposure is very similar to previous *Chandra* cycles and demonstrates that the HETGS is the instrument of choice for spectroscopy, only second to ACIS-S3, which is the main instrument for imaging spectroscopy onboard *Chandra*. Single exposures ranged from 4 to 138 ks with 43 observations in timed event mode and 7 observations in continuous clocking mode. The latter were very bright black hole binary targets exhibiting exceptionally high count rates in the HETG 1st orders of up to 300 cts/s. The target selection was very diverse and included low mass stars, high mass stars, cataclysmic binaries, low-mass neutron star binaries, high mass X-ray binaries, black hole binaries, supernovae, blazars, and active galactic nuclei.

Of these observations three were designated calibration observations. Observations of MKN 421 and 3C273 were performed to monitor the contaminant on the ACIS-S filters. Of specific importance were high amplitude (512 rows) dither observations of MKN 421 at low and high chip locations, which will allow for measurements of the contaminant over a large area of the ACIS spectroscopic array and maps of variations in the contaminant thickness across the array. Unfortunately it appears that the contaminant is accumulating at a fast rate, which is stimulating discussions amongst various groups on attempts to remove significant portions of the contaminant through a bakeout procedure.

The HETGS data were not subject to major changes with respect to calibration or analysis software except for a new order sorting treatment for CC-mode. We now calculate the y-coordinate in order to apply the correct gain and CTI corrections. New releases of CIAO (4.8.1) and CALDB (4.7.1) went into effect by the beginning of this year to accommodate changes in the flight grades that were included for observations taken after November 2009 and to modify quantum efficiencies for CC-GRADED mode observations taken before that date. As it turned out, the inclusion of flight grade G66 events in these observations introduced spurious background events to the spectra below $\sim$1 keV. This means that for observations dated after November 2009 observers should filter out flight grade G66 events from the EVT2 file and re-extract PHA2 spectra until the issue is corrected in an upcoming CALDB release. The modified quantum efficiencies will then be valid for all CC-GRADED mode observations. A corresponding thread can be found at the CIAO CC mode page: (*http://cxc.harvard.edu/ciao*).

**Selected Scientific Highlights**

The science output for the HETGS still reflects a high level of quality. Many papers went into press in the past year highlighting a variety of science topics. The data used included a good mix of new and recent observations, but also many previous cycles from the *Chandra* archive. Topics included accretion disk winds in GRS 1915+105 (Miller et al. 2016), probing Wolf-Rayet winds in WR6 (Huenemoerder et al. 2015), Compton-thick states in NGC 1365 (Nardini et al. 2015), a giant outburst of V404 Cygni (King et al. 2015), X-ray properties of low-mass pre-main sequence stars in the Orion Nebula Cluster (Schulz et al. 2015), a review of the 3.5 keV line in Galaxy Clusters (Phillips et al. 2015), simultaneous observations with NUSTAR of the bursting pulsar GRO J1744-28 (Younes et al. 2015), as well as X-rays from a pole-dominated corona on AB Dor (Drake et al. 2015) to name a few. The following sections highlight some of the science content in more detail.

**Si Kα Emissions**

Early *Chandra* observations of ionized winds such as in Vela X-1, 4U 1700-37, and, more recently, Cyg X-1 detected Si and S Kα emissions from O-, C-, Li-, B-, and Be-like ions. While highly ionized ions from Si, such as the He-like triplet Si XIII with only two electrons left and the H-like ions with only one electron left, are readily observed in a variety of astrophysical X-ray emitting plasmas, these Kα emissions from Si II to Si XII are more rare and stem from cooler and more dense plasma sites. These states have been observed primarily from HMXBs, such as Vela X-1 in eclipse (Schulz et al. 2002) and out of eclipse (Watanabe et al. 2006), 4U 1700-37 (Boroson et al. 2003) and Cyg X-1 (Miskovicova et al. 2016), to name the most prominent examples, but also in the Seyfert 2 galaxy NGC 1068 (Kallman et al. 2014). These emissions (and absorptions) are important diagnostics of the emitting plasma state that can distinguish colder, less ionized plasmas and denser more clumped plasmas from hot coronal plasmas. However, reference atomic data on these states have been surprisingly absent and unambiguous conclusions have been impossible because of the relatively poor accuracy of the calculations. For a long time one had to rely on the Hartree-Fock calculations by House (1969) until the semi-relativistic Hartree-Fock calculations by Palmeri et al. (2008). More recently, Natalie Hell and collaborators from the Lawrence Livermore Laboratories measured these states in situ for He- to Ne-like Si and S ions with an accuracy of better than 1 eV with the electron beam ion traps (EBIT-1, SuperEBIT, and the NASA/GSFC EBIT Calorimeter; Hell et al. 2016). Figure 1 shows a comparison of the out of eclipse Vela X-1 Si spectral region as observed by the *Chandra* HETGS to the laboratory EBIT calorimeter spectrum. All these analyses were performed using the Interactive Spectral Interpreta-

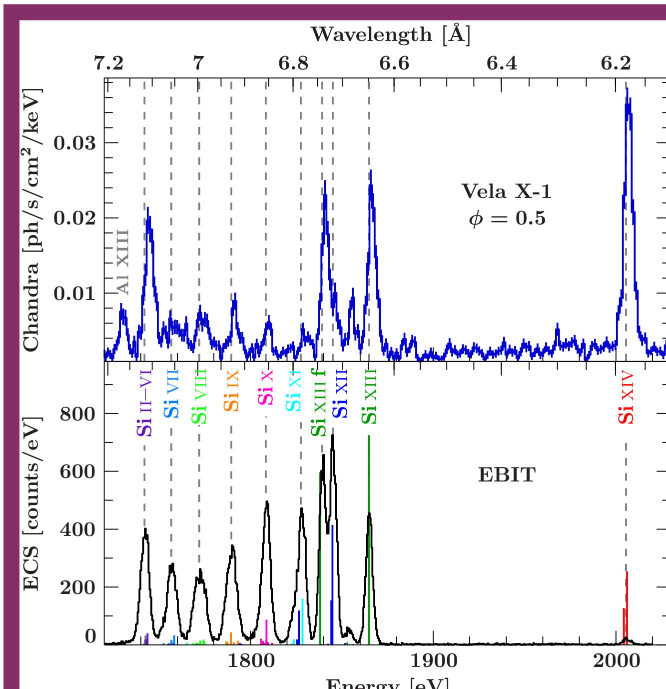



*Figure 1: Comparison of the spectral regions for silicon as observed by the Chandra HETGS in Vela X-1 out of eclipse (OBSID 1927) to the one measured in the laboratory by EBIT (from Hell et al. 2016). Si Kα emission can now be benchmarked to a precision better then 1 eV.*

tion System ISIS (*http://space.mit.edu/ASC/ISIS*) as provided by MIT/CXC (see also Noble & Nowak 2008 and references therein).

**The Spin-Orbit Split in Fe XXVI Transitions**

The HETGS provides superb spectral resolution throughout the soft X-ray band (0.2 and 10 keV). The spectral resolution in the first order of the High Energy Gratings (HEG) spectra is 0.011 Å which corresponds to a resolving power of 180 in the Fe K region and almost 1200 in the O K region. Even better resolution can be achieved by using higher orders. The HEG gratings are optimized to support odd numbered orders and in third order can reach up to 10% efficiency at a resolving power of 540, however, at the expense of bandpass, which, in this case, ranges from 1.5 Å to about 10 Å. For the Fe K region this leads to a resolution of roughly 13 eV, which is sufficient to resolve the spin-orbit coupling in the H-like transitions of Fe XXVI ions that has an energy shift of 21.2 eV. A study of wind absorption in bright black hole binaries by Miller et al. (2015) did just that. Figure 2 shows HEG third order spectra of the Fe K region of four such binaries. Absorptions in these binaries differ depending on the physical properties of the absorber and, at least in the case of GRO J1655-40, the conditions are good enough to see the two spin-orbit split line components for a static absorber (red lines) and a dynamic and thus blue-shifted absorber (blue lines). The split components do not show the atomic ratio of 2:1 because absorption appears saturated, which gives the observer additional clues about column densities in the curve of growth. The data at high resolution also show skewed absorption profiles in Fe XXV showing sensitivity to the very weak absorbing power of the intercombination line component. The forbidden line cannot be observed in absorption because it does not have a measurable electric dipole moment. This study nicely highlights the power of spectral resolution to study astrophysical X-ray plasmas.

**The Orion Nebula Cluster**

The Orion Trapezium stars at the heart of the Orion Nebula Cluster (ONC) provide a perfect laboratory to study the early evolution of very young and diverse stars. The HETGS Orion Legacy Project at MIT accumulated 585 ks of predominantly guaranteed time (GTO) exposure centered on the Orion Trapezium and analyzed the brightest spectra in the HETGS field of view leading to more than half a dozen of papers to date. While these studies focused entirely on the massive and intermediate mass stars, the latest study highlights X-ray spectral emissions from very young low-mass pre-main sequence stars. Figure 3 shows four HETGS spectra from the stellar sample. The study of six stars finds that the spectra are fit by two temperature plasmas with dominating high temperatures of about 40 MK. It was concluded that based on the line ratios no fur-

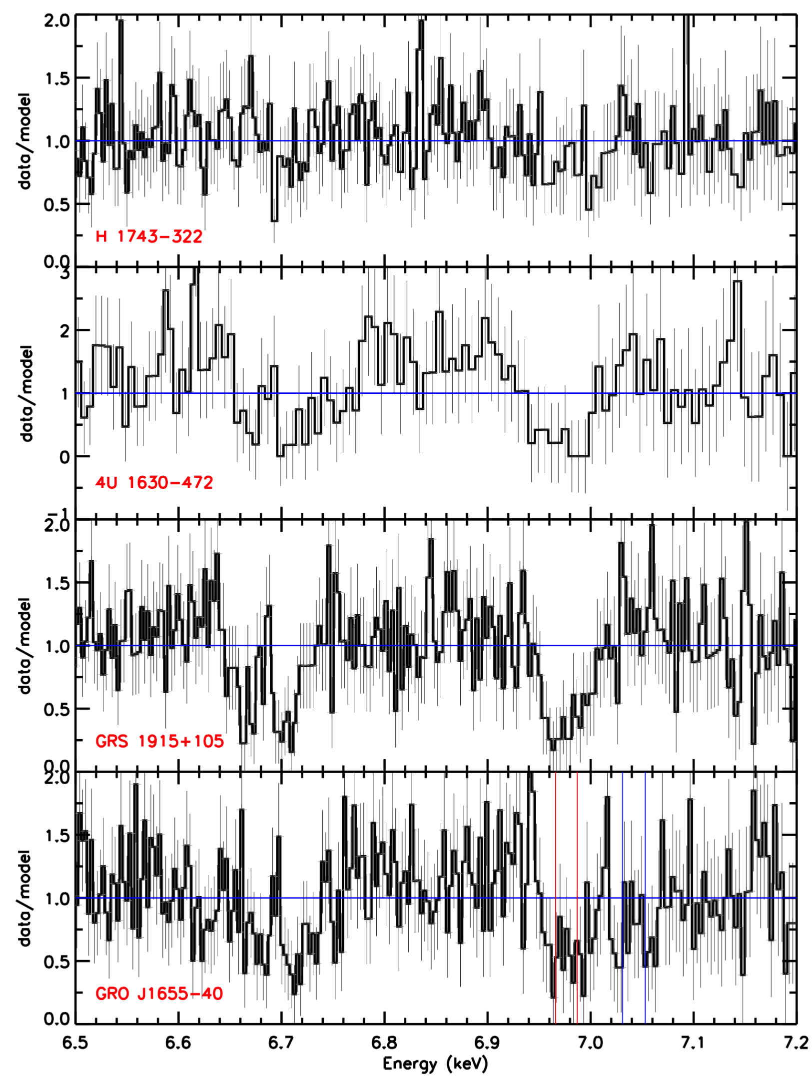



*Figure 2: The Fe K region in four black hole X-ray binaries observed with the high energy gratings (HEG) in third order (from Miller et al. 2015). Some show spurious, some show well developed line absorption from stellar winds. These 3rd order spectra have a spectral resolution of 13 eV allowing the observation spin-orbit multiplets in the Fe XXVI transitions (see red and blue lines).*

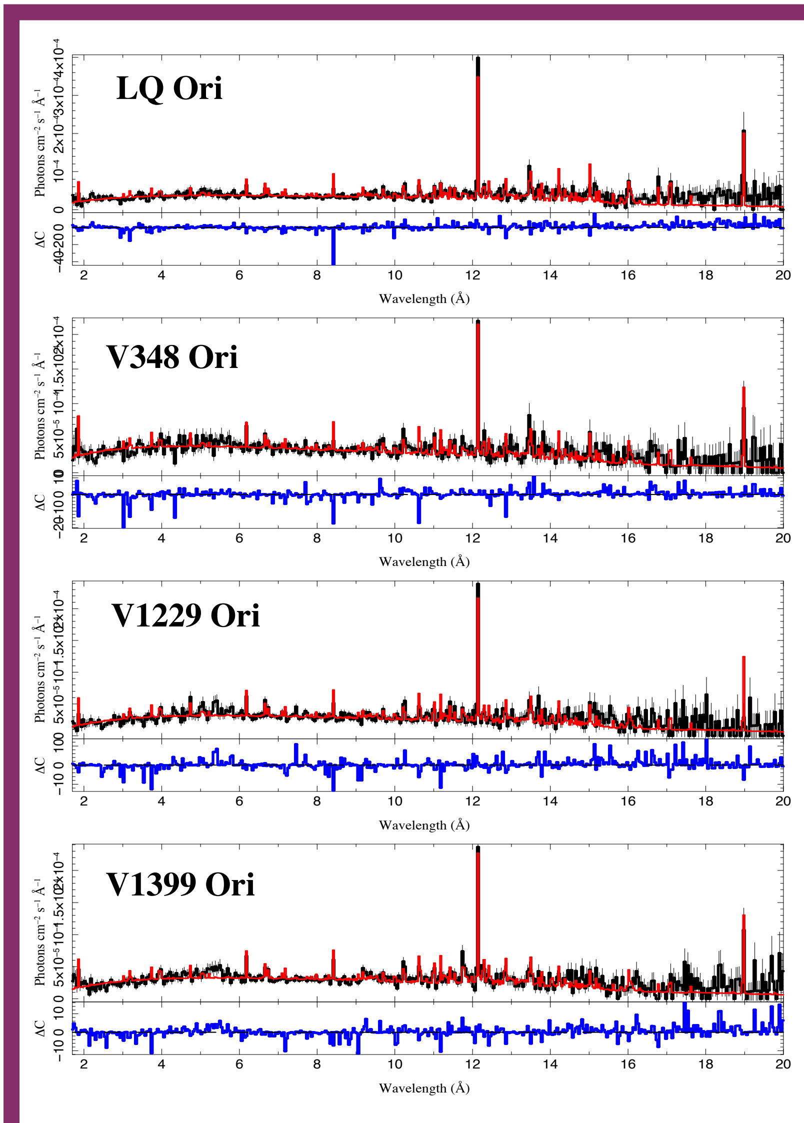



*Figure 3: HETGS spectra of four T Tauri stars in the ONC (from Schulz et al. 2016). The spectra show strong Ne X and O VIII lines, some also strong Fe XXV lines indicating very hot coronal plasmas.*

ther temperature components were needed thus constraining the differential emission measure distribution to two major peaks as predicted by previous lower resolution studies. The total emission measures as well as abundances were comparable to active coronal sources. The stellar surface X-ray flux also correlated well with stellar age within the age range of 0.1 and 10 Myr, signaling a rapid increase of coronal activity in these stars during their young growth. These results demonstrated the power of X-ray line diagnostics to study coronal properties of T Tauri stars in young stellar clusters.

## Probing Wolf-Rayet Winds

In contrast to these low-mass PMS stars, the most massive and luminous stars in the Milky Way, even though they are not much older in age, are already close to the end of their life cycle and exhibit fundamentally different X-ray properties. These Wolf-Rayet stars, which eventually will end in a core-collapse supernova detonation, are characterized by rapid outflows that enrich and energize the interstellar medium (see Huenemoerder et al. 2015 for details). Highly resolved X-ray emissions from these stars are still rare to date and the study by Huenemoerder et al. (2015) illustrates some extraordinary stellar wind emissions. The unusual strength of the He-like forbidden lines relative to their normal early type cousins places the source of the X-ray emissions at tens to hundreds of stellar radii from the photosphere. In O-star winds, however, this is not the case, and it appears that we are looking through a much thinner wind almost down to the photosphere. There is also a significant amount of random variability in the emissions, which is usual for early type stars. Figure 4 (on the next page) shows unusual "fin"-shaped line profiles for some of the unblended lines. Line ratios and the heavily skewed line profiles show that the outflow is optically thick with optical depths well above unity resulting in the heavily absorbed red flanks of the line profiles. This study will help pave the way to a more fundamental theoretical understanding of stellar winds in massive stars (Huenemoerder et al. 2015). ▪

## References


Boroson et al. 2003, ApJ, 592, 516
Drake et al. 2015, ApJ, 802, 62
Hell et al. 2016, ApJ, submitted
House 1969, ApJS, 18, 21
Huenemoerder et al. 2015, ApJ, 815, 29
Kallman et al. 2014, ApJ, 780, 121
King et al. 2015, ApJ, 813, 37
Miller et al. 2016, ApJ, 821, 9
Miller et al. 2015, ApJ, 814, 87
Miskovicova et al. 2016, A&A, arXiv:1604.00364
Nardini et al. 2015, MNRAS, 453, 2558
Noble & Nowak 2008, PASP, 120, 821
Palmeri et al. 2008, ApJS, 177, 408
Phillips et al. 2015, ApJ, 809, 50
Schulz et al. 2015, ApJ, 810, 55
Schulz et al. 2002, ApJ, 564, 21
Watanabe et al. 2006, ApJ, 651, 421
Younes et al. 2015, 804, 43

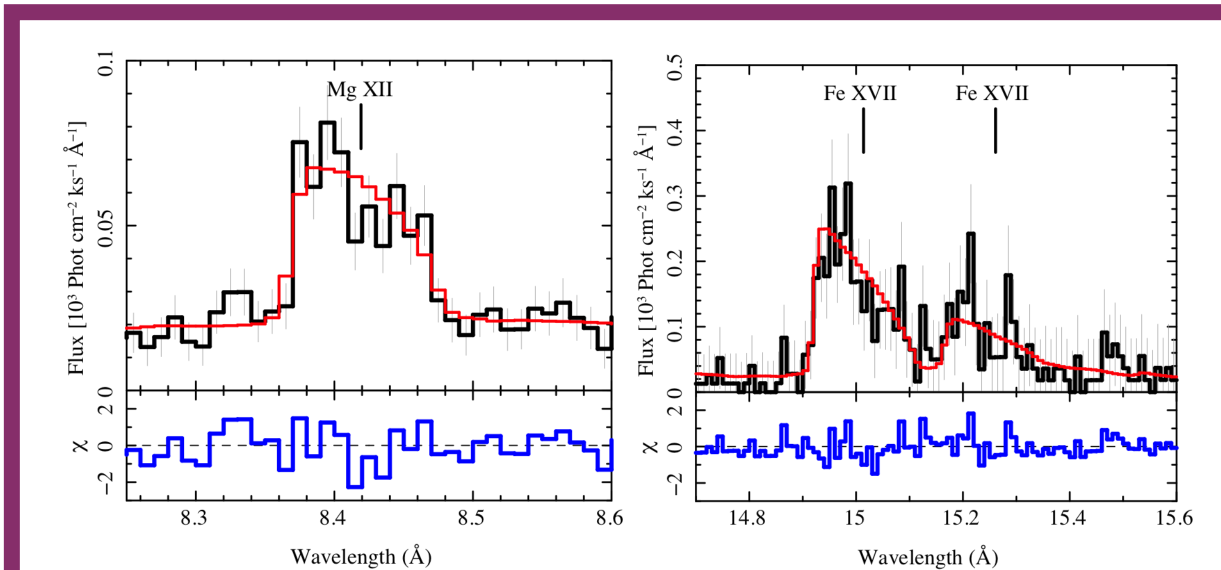



*Figure 4: Model fits (red) to Mg XII (left) and Fe XVII (right) data (black) with residuals showing an unusual fin-like shape of the line profiles (from Huenemoerder et al. 2015).*

## LETG

### Jeremy J. Drake for the LETG Team

**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.

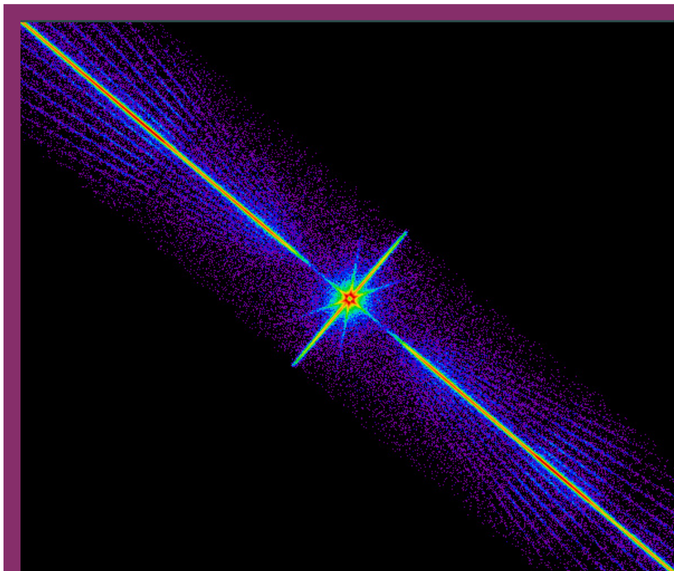


*Figure 1: HRC-S central plate detector image from the LETG observation of accreting black hole candidate XTE J1118+480. The 0th order and its six-pointed star resulting from coarse support structure diffraction can be seen at the center of the image, together with the dispersed spectrum either side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

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

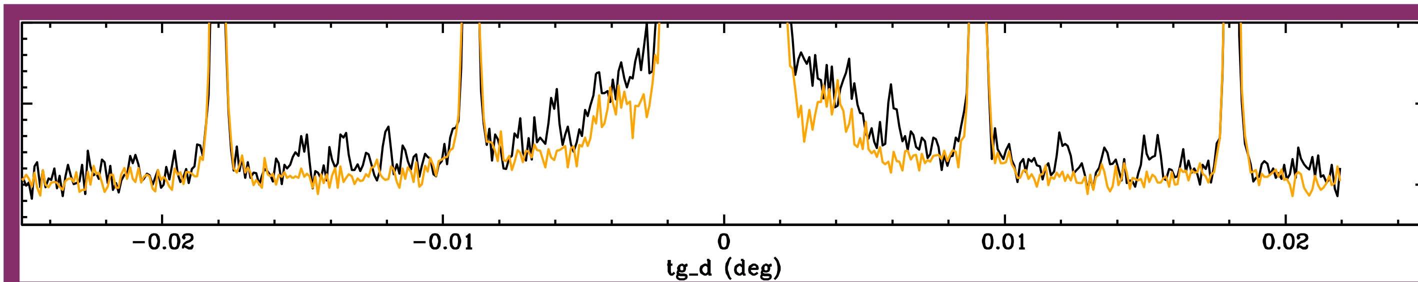



*Figure 2: Cross-dispersion profile for LETG+HRC-S spectra of the nova supersoft source KT Eri (orange) and the blazar Mkn421 (black). The conspicuous peaks either side of 0th order are from fine support structure diffraction. The Mkn421 profile is broader in the core because of higher order throughput 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.*

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:**

JJD thanks the LETG team for useful comments, information and discussion.

**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

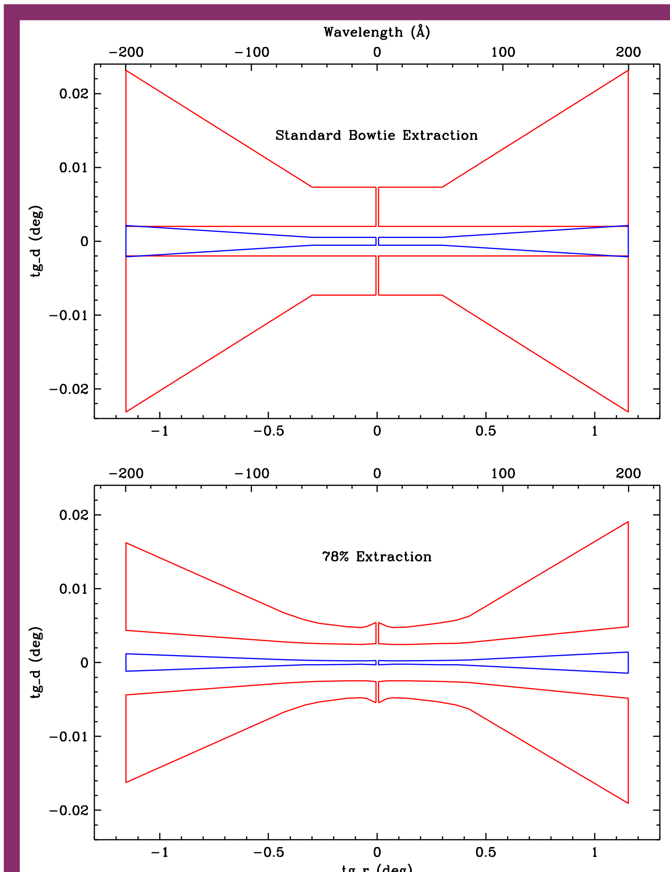



*Figure 3: The standard bow tie and new optimized source (blue) and background (red) extraction regions for LETG spectra. Figure courtesy of Brad Wargelin.*

## Additional Info

See the back cover for an illustration of the star shredded by a black hole and the LETG grating spectroscopy.

# CIAO in 2015-16:
## Work Behind the Scenes Plus Scripts, PSF and Sherpa Python Package

**Antonella Fruscione and Douglas Burke for the CIAO team**

The demand for CIAO (the *Chandra* Data Analysis software) remains steady since 2011 with about 100-150 downloads per month, and has been stronger than ever since the CIAO 4.8 release in December 2015. *Chandra* and non-*Chandra* users continue to take advantage of the growing capabilities that CIAO has to offer and of the extensive documentation which accompany them!

CIAO 4.8—released in Dec 2015 and patched in February 2016—is the latest software release and was primarily a maintenance release to address needed upgrades behind the scenes: bug fixes, support of new compilers and upgrade of off-the-shelf software used in the system.

This release also includes additional support for the analysis of observations in *Continuous Clocking* (CC) mode that directly affects users: both the *acis_process_events* and the *tg_resolve_events* tool have been updated to allow for better calibration of ACIS+HETG data taken in CC mode. The *chandra_repro* script has also been upgraded to take advantage of these changes.

With every major CIAO release a large effort goes into updating all the relevant documentation on the website and in the tools' help files to ensure that any software change is properly reflected in the text. Furthermore, at release time and during the year, new documents are written not only to support and explain changes in software, but also in response to questions or comments from the community.

The *HETG/ACIS-S/CC-Mode Grating Spectra thread*, published in Dec. 2015, belongs to the first category and was newly created to help users working with ACIS/HETG observations in CC mode. The new "Why topic" *Pitfalls using PIMMS for Observed Data* and the FAQ entry *What does "zero length polygon line segment" warning mean?* are two recent documents belonging to the second category.

The "Why topic" highlights the issues that arise from using *PIMMS, the Portable Interactive Multi-Mission Simulator*, and the *CXC proposal planning counterpart* to estimate fluxes from observed count rates. Specifically, the report addresses the fact that for bright sources and especially for large surveys the systematic errors introduced by using PIMMS may become significant and introduce a bias into the results. The new FAQ addresses in detail the reason for a common warning seen while running CIAO tools.

The appearance and the behaviour of the main CIAO download page (the first entry point for the majority of users) has been restructured in CIAO 4.8, with a clearer and more prominent "standard install" button and more precise custom installation options for users with specific needs. The goal is first and foremost to make any part of CIAO, including the installation, as easy as possible for users.

**CIAO scripts**

In the spirit of making CIAO more accessible to all users—including users who are not X-ray astronomy specialists—we have continued the development and improvement of the high level programs (the *CIAO "scripts"*), which have the goal of simplifying the most common types of analysis.

Several scripts were released in the past months, but three are especially worth noting here: *download_obsid_caldb*, *install_marx*, and *simulate_psf*.

Several HelpDesk tickets have reported problems downloading CALDB due to size (3 Gb zipped, 7.5 Gb unzipped). In reality only a small fraction of the *Chandra* CALDB is needed to analyze any given ObsID.

The *download_obsid_caldb* script determines which CALDB files are necessary for a given ObsID and downloads only those missing from the user's existing

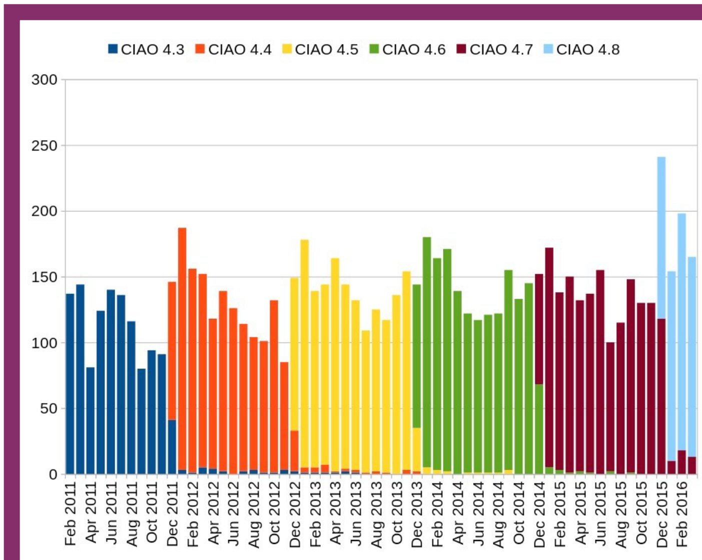



*Figure 1: CIAO monthly download statistics since 2011*

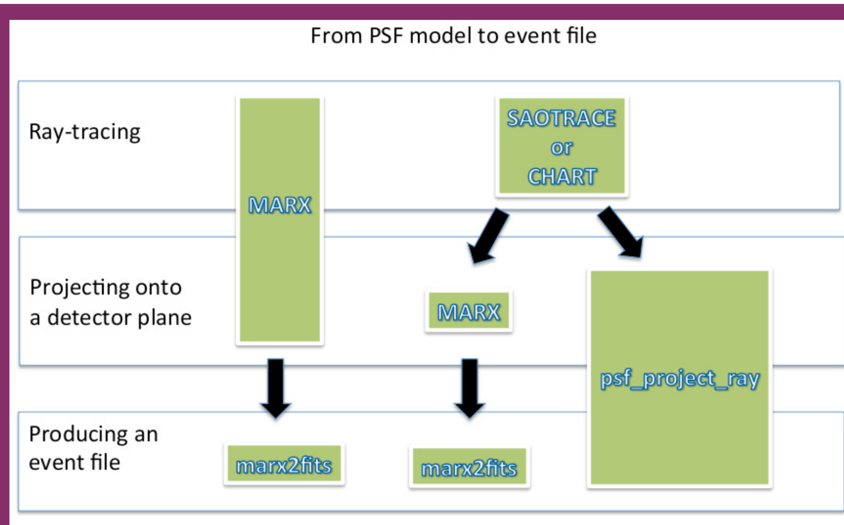



*Figure 2: A schematic view of the PSF modeling paths: while MARX can be used for both ray tracing and projecting onto a detector-specific plane, the rays produced by SAOTrace or ChaRT require an extra step to project the rays onto a detector-specific plane (via MARX) or onto a semi-infinite detector-plane (via psf_project_ray). The psf_project_ray tool produces an events file as output, while the marx2fits routine should be used after running a MARX simulation to obtain an event file. The simulate_psf script currently covers the steps on the left column (MARX + marx2fits) and can project and produce an event file if rayfiles from ChaRT are given as input.*

CALDB. The files are added to user's standard CIAO CALDB location and users can accumulate CALDB files as needed, ObsID by ObsID. It is particularly helpful for users with less-than-fully-reliable internet connections where downloading a multi-GB file can time out. For example, using the new *download_obsid_caldb* script for one ObsID will decrease the size of the necessary download to ~0.3 GB, whereas downloading the entire CALDB would have required ~7.5GB. If the user also needs background files, *download_obsid_caldb* would result in ~0.35 GB instead of the 13 GB required to download the entire CALDB with background files.

The two other scripts aim to simplify the simulation of the *Chandra* PSF:

The *install_marx* script automates the standard steps necessary to download, build, and install *MARX*. (the *Chandra* on-orbit simulator), while *simulate_psf* wraps the complexity of the thread in which MARX is used to simulate an existing observation. The script's design and interface will allow other simulators in the future (e.g. *SAOTrace*) and currently accepts rayfiles generated by *ChaRT* (the CXC web interface to SAOTrace) as input. Both scripts are part of the major effort to collect and disseminate information about the *Chandra* PSF described below.

**PSF Central**

The documentation project called "*PSF Central*" represents an effort to unify under one umbrella the wealth of information about the *Chandra* PSF (dictionary, ahelp files, threads, Why documents etc.) that was previously scattered around the CIAO webpages. The PSF Central website is currently organized in a tool-centric direction (what tools exist related to the *Chandra* PSF) but future plans are to extend it toward a more science-centric direction (e.g., is my source extended? is this jet real? etc.).

Within PSF Central we endeavor to better explain the relationship between SAOTrace, ChaRT, and MARX while simplifying installation and use of these applications.

The two scripts mentioned above, together with a new release of ChaRT that allows for simulations compatible with sub-pixel analysis, are instrumental in achieving this goal.

Several science threads have also been updated or written anew to clarify the use of ChaRT and MARX to simulate existing or planned observations.

**Sherpa Python Fitting**

While Sherpa (the *Chandra* modelling and fitting application) is an integral part of CIAO, a close reading of last year's "15 years in CIAO" *Chandra* newsletter article (Fruscione et al. 2015) will have revealed our parallel project of moving it to the code-development site GitHub so that its development is open to everyone. In this environment, Sherpa can be used for general fitting and can be built independently of the CIAO infrastructure. The project can be found at *https://github.com/sherpa/sherpa/*. The first major release from this work was Sherpa 4.8.0, which is available as a part of the CIAO 4.8 release, as well as directly from GitHub. The newest release, Sherpa 4.8.1, occurred in April 2016.

The primary aims of these releases are to make Sherpa easier to include in other Python projects and to allow users to import the Sherpa module into a Python session. Sherpa is available via the Sherpa Anaconda channel for those who use the Anaconda distribution, as well as directly from GitHub. The plan is to have several minor releases throughout 2016, leading up to a major release in December, which will be coordinated with the next CIAO release. The individual Sherpa releases are also archived by the Zenodo Science Archive, thanks to its integration with GitHub. As an example, the details of the Sherpa 4.8.0 release are available at [https://zenodo.org/record/45243](https://zenodo.org/record/45243).

As befitting our move to a world in which everything is tracked, we now have a number of helpful visualizations to show how development is progressing, such as this "Punch Card" view (hopefully this will not provide painful memories for those readers "lucky" enough to have programmed with actual punch cards):


*Figure 3: "Punch Card" view from Sherpa GitHub*

It is unclear, at this time, whether the lunch talk held by the High-Energy Division here at the Center for Astrophysics can explain the drop off in Sherpa work around mid-day Wednesday. More data is obviously needed!

The preferred installation location for Sherpa is within the Anaconda Python environment. To install Sherpa into a separate environment (called "sherpa" in this example), one could use the following:

```
% conda config --add channels
https://conda.anaconda.org/sherpa
% conda create -n=sherpa python=2.7
sherpa matplotlib astropy ipython
% source activate sherpa
```

Additional installation methods are available, for example, to also build the optional XSPEC model interface, and are described on the standalone Sherpa page at http://cxc.cfa.harvard.edu/contrib/sherpa/.

For anyone interested in using Sherpa in their own project, or adding new functionality, please head on over to [https://github.com/sherpa/sherpa/](https://github.com/sherpa/sherpa/), download the code, and start coding! Development and integration of Sherpa with Astropy will go forward during the summer through the work of a student participating in the "Google Summer of Code" project. ■

## How to stay up-to-date about CIAO and Sherpa

Several channels are available to keep abreast of CIAO and any new development or problems:

- *@ChandraCIAO*
- *ChandraCIAO*
- *+ChandraCIAO*

- Subscribe to the *Chandra* Electronic Announcements at *http://cxc.harvard.edu/cdo/udb/userdat.html*
- Check "What's New" *http://cxc.harvard.edu/ciao/news.html* or subscribe to the CIAO News RSS feed at *http://cxc.harvard.edu/ciao/feed.xml*
- Check the YouTube channel "4ciaodemos" at *http://www.youtube.com/user/4ciaodemos*

Questions to the Sherpa team at the CXC can be made either through the *GitHub web site* or via the *CXC HelpDesk*.

| | SAOTrace | ChaRT | MARX | arfcorr |
|---|---|---|---|---|
| **user interface** | command-line | web interface to SAOTrace | command-line | command-line |
| **how to obtain?** | download → compile → install locally | web-based, no installation required | download → compile → install locally or via `install_marx` | CIAO tool |
| **how many sources?** | multiple sources | individual point sources | multiple sources | individual point sources |
| **current limitations** | does not run on the latest Linux and Mac platforms | limited number of available parameters (but sufficient for typical use cases) | does not include all of the fine HRMA details | only mono-chromatic sources supported |
| **pros** | flexible and powerful; definitive HRMA model | easy to use | high fidelity, and yet easy to use; portable; includes models for HRMA, gratings, and detectors | simple, quick tool |
| **cons** | complex installation and usage; only includes the HRMA model | need to wait for output | not as high-fidelity as SAOTrace for HRMA | circular approximation of the PSF |

*Figure 4: A quick comparison between the different modeling tools available to Chandra users*

## CIAO Workshop - 15 August 2016

The CXC is soliciting interest in a one-day CIAO workshop on August 15, 2016 just prior to the start of the *Chandra Science for the Next Decade* workshop. Depending on the level of interest, the workshop may be extended into the morning of August 16. The CIAO workshop will be tailored to the attendees but usually consists of a few talks in the morning with ample time in the afternoon for hands-on sessions with CXC experts to assist individuals with their specific data analysis questions.

Possible topics for the talks include:

- Introduction to X-ray astronomy
- Advanced CIAO
- Topics in *Chandra* Calibration
- Intro or Advanced Sherpa
- Intro or Advanced MARX
- Intro or Advanced ds9

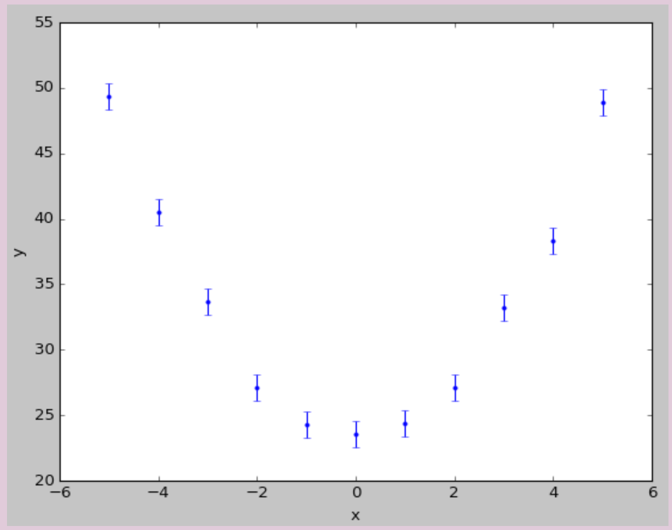
Users interested in attending the CIAO Workshop can find more information at:

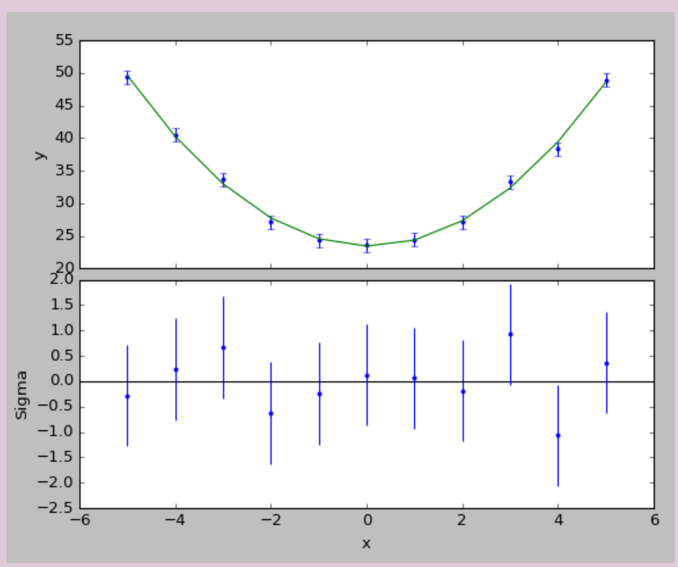
http://cxc.harvard.edu/ciao/workshop/index.html

## An example Sherpa run through

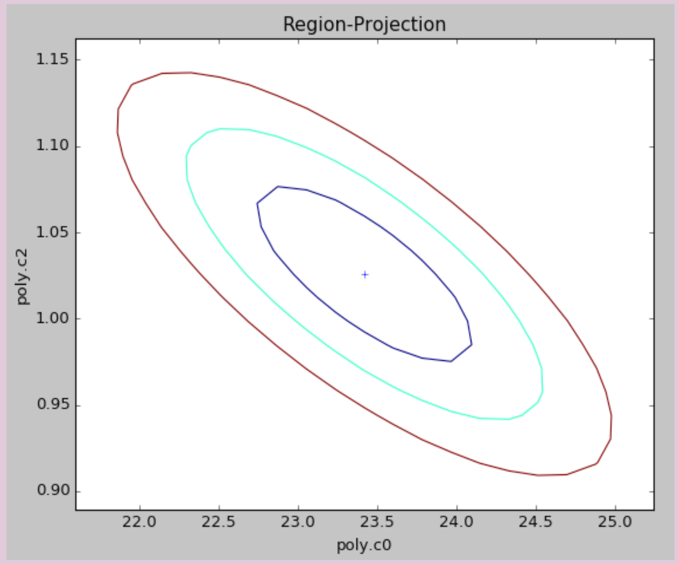
Once installed in the python environment, Sherpa can be imported like any python module. In the following example, we demonstrate fitting of a low-order polynomial to randomized data (this example is based on the “Quick Start” IPython notebook guide provided with Sherpa, which can be found at [http://nbviewer.jupyter.org/github/sherpa/sherpa/blob/master/docs/SherpaQuickStart.ipynb](http://nbviewer.jupyter.org/github/sherpa/sherpa/blob/master/docs/SherpaQuickStart.ipynb)). The warning message lets us know that the version of Sherpa being used does not include the XSPEC models interface, and the --classic and --no-banner flags are used to simplify the screen output of IPython:

```
% ipython --classic --no-banner --pylab
  Using matplotlib backend: Qt4Agg
  >>> from sherpa.astro import ui
  WARNING: failed to import sherpa.astro.xspec;
  XSPEC models will not be available
  >>> import numpy as np
  >>> x = np.arange(-5, 5.1)
  >>> y = x*x + 23.2 +
        np.random.normal(size=x.size)
  >>> e = np.ones(x.size)
  >>> ui.load_arrays(1, x, y, e)
  >>> ui.plot_data()
  >>> ui.set_model(ui.polynom1d.poly)
  >>> print(poly)

  polynom1d.poly
     Param      Type           Value          Min
     -----      ----           -----          ---            ---     -----
     poly.c0    thawed         1  -3.40282e+38   3.40282e+38
     poly.c1    frozen         0  -3.40282e+38   3.40282e+38
     poly.c2    frozen         0  -3.40282e+38   3.40282e+38
     poly.c3    frozen         0  -3.40282e+38   3.40282e+38
     poly.c4    frozen         0  -3.40282e+38   3.40282e+38
     poly.c5    frozen         0  -3.40282e+38   3.40282e+38
     poly.c6    frozen         0  -3.40282e+38   3.40282e+38
     poly.c7    frozen         0  -3.40282e+38   3.40282e+38
     poly.c8    frozen         0  -3.40282e+38   3.40282e+38
     poly.offsetfrozen         0  -3.40282e+38   3.40282e+38
>>> ui.thaw(poly.c1, poly.c2)
>>> ui.fit()
Dataset               = 1
Method                = levmar
Statistic             = chi2
Initial fit statistic = 12653.3
Final fit statistic   = 3.22478 at function evaluation 8
Data points           = 11
Degrees of freedom    = 8
Probability [Q-value] = 0.919469
Reduced statistic     = 0.403098
Change in statistic    = 12650.1
   poly.c0      23.4186
   poly.c1      -0.107496
   poly.c2      1.02587
>>> ui.plot_fit_delchi()

# see figure to the right
```



```
>>> ui.conf()
poly.c0 lower bound:    -0.455477
poly.c0 upper bound:    0.455477
poly.c2 lower bound:    -0.0341394
poly.c1 lower bound:    -0.0953463
poly.c2 upper bound:    0.0341394
poly.c1 upper bound:    0.0953463
Dataset                = 1
Confidence Method      = confidence
Iterative Fit Method    = None
Fitting Method         = levmar
Statistic              = chi2gehrels
confidence 1-sigma (68.2689%) bounds:
   Param     Best-Fit   Lower Bound    Upper Bound
   -----     --------   -----------    -----------
   poly.c0   23.4186    -0.455477      0.455477
   poly.c1   -0.107496  -0.0953463     0.0953463
   poly.c2   1.02587    -0.0341394     0.0341394
>>> ui.reg_proj(poly.c0, poly.c2, nloop=[21, 21])
# see figure to the right
```




## Brainstorming The Universe in High-resolution X-ray Spectra

**Randall Smith**

From August 19-21st, 2015 a group of ~100 X-ray astronomers met in Cambridge, MA to present recent results from X-ray grating spectroscopy with *Chandra* and *XMM-Newton*, as well as to discuss possibilities for the future (*http://cxc.harvard.edu/cdo/hrxs2015/)*. During the meeting, approximately 60 astronomers, separated into 9 tables with 6-8 people per table, took part in a 'brainstorming' session. A series of questions were addressed and participants switched tables after each question. Discussion leaders, who stayed fixed at each table, compiled the results - thanks to Elisa Costantini, Martin Elvis, Dave Huenemoerder, Delphine Porquet, Tim Kallman, Takayuki Yuasa, Nancy Brickhouse, David Cohen, and Lia Corrales. Four questions were addressed and the conclusions for each are summarised below; the complete document is available at *http://cxc.harvard.edu/cdo/hrxs2015/brainstorming.pdf*.

**What important science questions could data from the existing or near-term X-ray high-resolution spectrometers answer? Would data from other existing observatories be needed as well?** A recurring theme in the responses was the need for high-resolution spectroscopic monitoring and variability studies of a range of sources, including stars, X-ray binaries (XRB), stellar mass black holes, novae, and young supernovae. Winds from stars, XRB, and Active Galactic Nuclei (AGN) were also mentioned in the timing/monitoring context but also generally as an area that could be productive with more observations. Finally, abundance studies were highlighted in a range of contexts such as iron-peak element studies in supernova remnants and galaxy clusters, either with the *XMM-Newton* RGS or Hitomi, as well as absorption studies in the Galaxy using bright XRB or beyond using flaring AGN. Another topic frequently mentioned was the need to better exploit the archives of all of these missions.

**What improvements in calibration, lab astrophysics data, or analysis tools are needed to enable us to answer these questions?** The two topics most frequently mentioned (at seven out of the nine tables) were improvements in atomic data and analysis tools. In regards to the atomic data, the participants argued for improvements for some Fe-peak ions (e.g. Mn, Cr, Ni) as well as inner-shell K lines (and for AGN warm absorbers, the M-shell and L-shell inner shell lines), along with better charge exchange rates and diagnostics. A key need was to make it easier for users to access/assess the physics in the models. Another request was a more thorough cross-calibration of optically thin X-ray plasma codes (both collisional and photoionization) to better understand when and where differences arise from various codes. Analysis tools were also held up as needing improvement, starting with the idea that such tools work best if they are constructed collaboratively, not "owned" by one person. General requests were made for better extended-source modeling as well as more flexible photoionization models. Participants expressed the need for IRAF-like automatic tools that could extract intensities of temperature/density diagnostic lines and then search a spectral database to find similar spectral shape/lines. Similarly, participants noted that spectral-timing tools were underdeveloped and that calibration facilities could use improvement. Calibration in general was frequently mentioned, with a number of specific issues such as wavelength calibration accurate to < 100 km/s for wind studies, line profiles in 1st and higher order, and easier-to-use background models.

**What future observations (or new archives with different processing) are needed to answer these questions?** This question provided mixed results – possibly because of the difficulty of determining what precisely would answer the issues raised so far, and possibly because participants were already planning out new proposals to submit. However, there were a number of monitoring proposals described, matching the focus on timing and monitoring raised in the first issue. In this context, it was noted that time allocation committees should be explicitly told that re-observing sources is allowable when the purpose is monitoring. A number of groups also described the benefits from simplifying proposals for coordinated observations with other facilities, especially if ways to increase the available time for such proposals could be found.

**What observations could *Chandra* or *XMM-Newton* do today that would complement future Hitomi or act as pathfinders for *Athena* or *X-ray Surveyor* observations?** Nearly all the tables identified deep observations of crowded/complex fields such as M82, Galactic SNR, and galaxy clusters as a key need, especially for *Chandra* as similar angular resolution will not be available until *X-ray Surveyor* launches. Similarly, the participants highlighted the need for grating spectra on point sources, since even the *Athena* calorimeter will have lower resolution below 1.5 keV than the *Chandra* and *XMM-Newton* gratings. Deep imaging observations of nearby galaxies and especially the LMC and SMC were mentioned, along with the Galactic center region, in order to spatially-resolve sources that might be confused in Hitomi or *Athena* observations. Finally, it was noted that *Chandra*'s angular resolution would be needed to separate the nuclear regions of AGN from the surrounding gas.

**Thanks to all the workshop attendees for making this an excellent conference, and to the participants in the brainstorming exercise for your time and thoughtful suggestions!** ■

## Recent Updates to *Chandra* Calibration

**Larry P. David**

There were seven releases of the *Chandra* calibration database (CALDB) during the past year. In addition to the regularly scheduled updates to the detector gains (quarterly for ACIS and yearly for the HRC), the *Chandra* calibration team also released: 1) A revised extraction region for LETG/HRC-S spectra, 2) an updated version of the HRC-S QE to maintain cross-calibration between LETG/HRC-S and LETG/ACIS-S data, 3) an updated version of the HRC-I QE to maintain cross-calibration between the HRC-S and HRC-I, 4) an additional ACIS-QE to be used with CC-faint mode data taken prior to 2008 (i.e., without the telemetry of flight grade 66), and 5) an adjustment to the low energy gain calibration of S1. Each of these updates to the CALDB is discussed below along with a summary of current calibration projects.

Over the course of the *Chandra* mission, the dispersion axis of LETG/HRC-S data has undergone some shifts in orientation. Software has been developed that corrects any variations in the orientation of the dispersion axis which allows for the implementation of a narrower extraction region for LETG/HRC-S data. The use of a narrower extraction region reduces the background within the extraction region by up to 25% at the expense of only a few percent of the source photons. The implementation of a new extraction region required a re-calibration of the enclosed count fraction in LETG/HRC-S data (i.e., the fraction of total counts within the extraction region as a function of wavelength) and an adjustment to the HRC-S QE to maintain consistent source fluxes. The change in the HRC-S QE also required an adjustment to the HRC-I QE to maintain cross-calibration between these two instruments in imaging mode.

During an LETG/ACIS-S observation, photons with wavelengths between approximately 30 and 65 A are dispersed onto the backside-illuminated S1 CCD. In 2015, the calibration team released a revised gain table for S1 with improvements to the low energy gain (i.e., wavelengths longer than 20 Å) which affects order sorting in gratings observations. Older versions of the S1 gain table lead to some valid events being filtered out in the order sorting process which resulted in LETG/ACIS-S fluxes less than LETG/HRC-S fluxes in the wavelength band covered by the S1 CCD. The current version of the S1 gain table now produces consistent LETG/ACIS-S and LETG/HRC-S fluxes in this wavelength band.

The calibration team continues to monitor the build-up of molecular contamination onto the ACIS filters through periodic imaging observations of Abell 1795 and E0102-72 and gratings observations of Mkn 421, PKS 2155-304 and RXJ 1856-3754. Analysis of these observations over the past year shows that the CALDB version of the ACIS contamination model continues to predict the opacity of the contaminant to within 5-10% on all regions of ACIS-I and on all regions of ACIS-S except for the bottom and top 100-150 rows. Recent observations show that the spatial distribution of the contaminant on the ACIS-S filter has changed over the past few years. The calibration team is presently developing an ACIS contamination model that incorporates a time-dependent spatial model for the contaminant on the ACIS-S filter.

At present, the CALDB contains a single, time-independent, scatter matrix for ACIS (i.e., the probability that a photon of a given energy is detected in a given pulse height). Due to increasing CTI over the course of the mission, and to a lesser extent, warmer operating temperatures, the FWHM spectral resolution of ACIS has degraded by approximately 10-20%. To account for this change in the spectral resolution of ACIS, the calibration team is presently developing a set of time-dependent scatter matrices.

The *Chandra* calibration team continues to support the efforts of the International Astronomical Consortium for High Energy Calibration (IACHEC). The 11th annual IACHEC meeting recently took place in Pune, India on Feb. 29 through Mar. 3, 2016. These meetings bring together calibration scientists from all present and many future X-ray and γ-ray missions. Collaborations established at these meetings have led to a number of cross-calibration papers published in the Journal of Astronomy & Astrophysics. ▪

## Results of the Cycle 17 Peer Review

**Andrea Prestwich**

The observations approved for *Chandra*'s 17th observing cycle are nearly half done. The Cycle 18 Call for Proposals (CfP) was released on 15 December 2015 and the proposal deadline was 15 March 2016. Cycle 16 observations are close to completion.

The Cycle 17 observing and research program was selected as usual, following the recommendations of the peer review panels. The peer review was held June 22-26, 2015 at the Hilton Boston Logan Airport. It was attended by 96 reviewers from all over the world, who sat on 13 panels to discuss the 578 submitted proposals (Figure 1). The "Target Lists and Schedules" link of our website (*cxc.harvard.edu*) provides access to lists of the various approved programs, including abstracts. The peer review panel organization is shown in Table 1.

The total amount of time allocated in Cycle 17 was 16 Ms, including 6 Ms to 13 approved Large Programs (LPs). The time allocated by Cycle 17 review was slightly down from previous cycles because 2 Ms of Cycle 17 time was awarded in Cycle 16 to allow for the X-Ray Visionary Program (XVPs). There was no XVP call in Cycle 17. The overall oversubscription in observing time was 4.9 (Figure 2), typical of the past few cycles (Figure 3).

| | |
|---|---|
| **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 7,8,9 | Galaxies: Diffuse Emission, Clusters of Galaxies |
| Panels 10,11,12 | AGN, Extragalactic Surveys |
| **Big Project Panel:** | LP Proposals |

**Table 1: Peer Review Panel Organization**

A recent study by I. Neill Reid of the Space Telescope Science Institute (2014, PASP, 126, 923) examined the success rate of Hubble Space Telescope proposals as a function of gender. They found that male PIs have a higher success rate than female PIs. In any given cycle the statistical significance is small, but the discrepancy is present in all cycles studied suggesting a systematic effect. The success rate of male and female PIs of *Chandra* proposals is plotted in Figure 5, along with the total fraction of proposals submitted with a female PI. Prior to Cycle 10, there was a definite trend for male PIs to be more successful. However, since Cy-

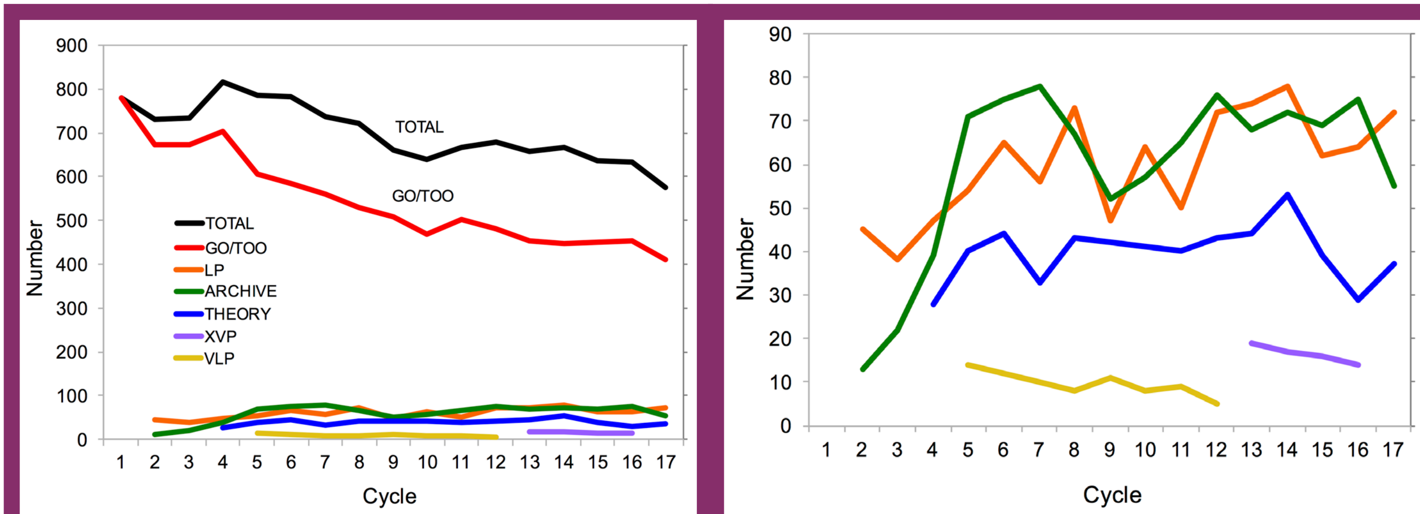



*Figure 1: a: The number of proposals submitted in each proposal category (e.g. GO, LP, Archive etc.) as a function of cycle, b: zoom on lower curves. Since more proposal categories have become available in each cycle, the number classified as GO has decreased as others increased.*

cle 10 there is no statistically significant difference in the success rates of male and female PIs. We tentatively interpret the recent lack of bias as due to the relatively high percentage of female *Chandra* PIs.

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 satisfy 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.

The resulting observing and research program for Cycle 17 was posted on the CXC website on 16 July

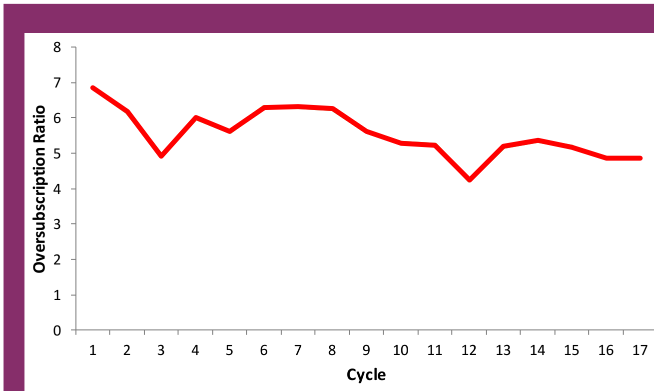



*Figure 2: The final oversubscription in observing time based on requested and allocated time in each cycle. The numbers are remarkably constant.*

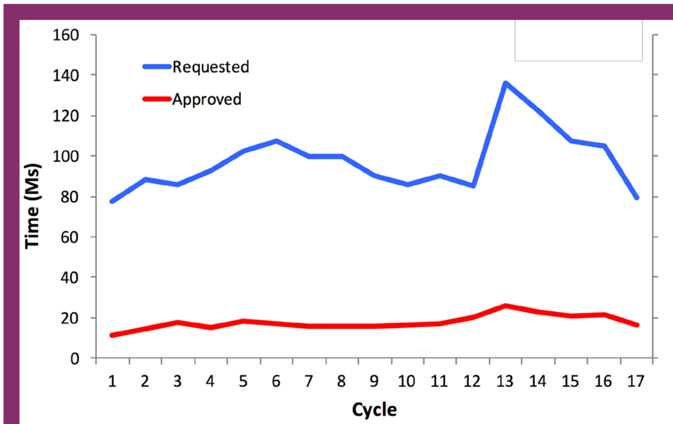



*Figure 3: The requested and approved time as a function of cycle in ks including allowance for the probability of triggering each TOO. The available time increased over the first three cycles, and in Cycle 5 with the introduction of Very Large Projects (VLPs). The subsequent increase in time to be awarded 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.*

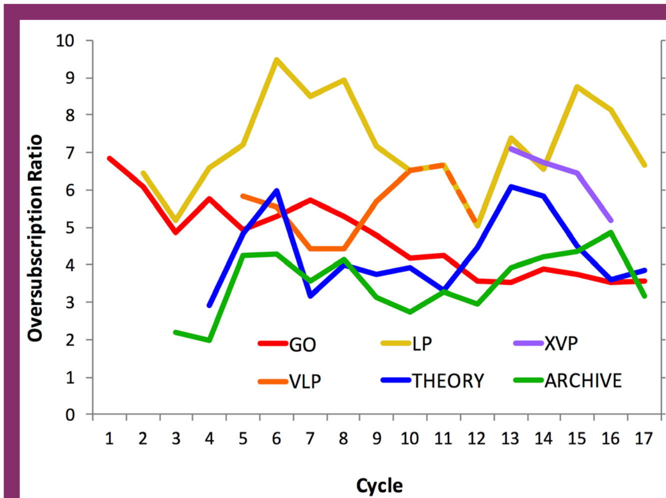



*Figure 4: The effective oversubscription ratio in terms of observing time for each proposal category as a function of cycle. Note that some of the fluctuations are due to small number statistics (e.g. Theory proposals).*

2015, 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

One proposal had joint *Chandra* time pre-allocated by the *Spitzer* Time Allocation Committee. No other observatories allocated time on *Chandra* this Cycle. The *Chandra* review accepted joint proposals with time allocated on: *Hubble* (16), NuSTAR (6), NRAO (14), *Swift* (3), *XMM-Newton* (1) and *Spitzer* (1).

### 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 6.2.8). Each class was allocated an annual quota based on our experience in previous cycles. The same classification scheme was used in Cycles 10-17. 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

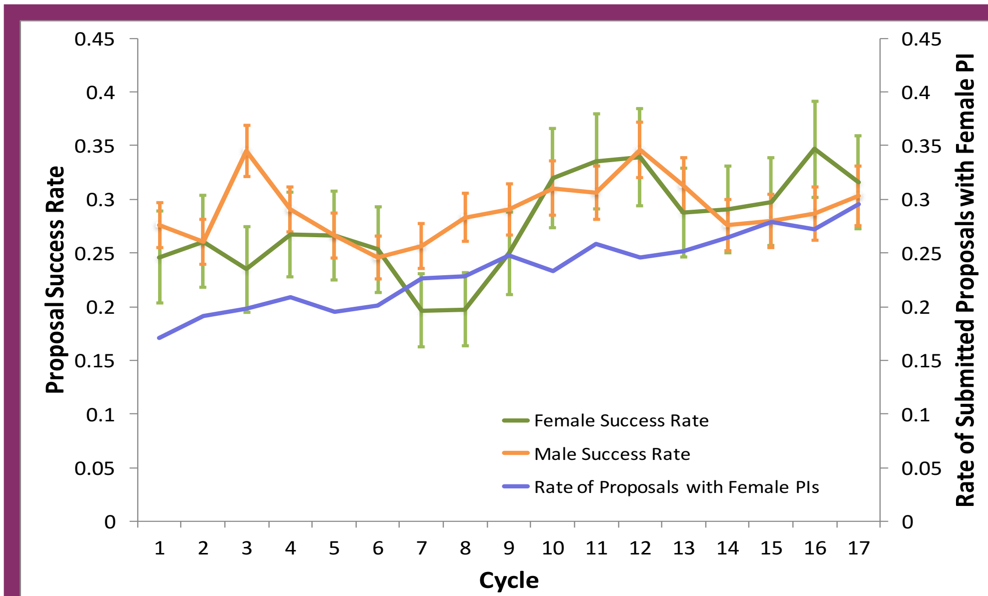



*Figure 5: The success rate of male (orange) and female (green) PIs as a function of cycle, and the overall fraction of female PIs (blue). Since cycle 10, the success rate for female and male PIs has been very similar.*

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 18 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 Sept 2015 at SAO. In Cycle 17 each project was allocated a budget based on the details of the observing program (see CfP Section 9.4). 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 17 on 1 Jan 2016.

### 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 (on the next page) 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. ▪

| | Requested | | Approved | |
|---|---|---|---|---|
| Country | # Props | Time | # Props | Time |
| Australia | 2 | 80 | | |
| Austria | 2 | 250 | | |
| Bulgaria | 1 | 120 | | |
| Canada | 5 | 1157 | 3 | 552 |
| Chile | 4 | 460 | 3 | 420 |
| China | 2 | 80 | | |
| Costa Rica | 1 | 20 | | |
| Denmark | 1 | 0 | | |
| France | 5 | 517 | 1 | 150 |
| Germany | 19 | 3882 | 5 | 715 |
| Greece | 1 | 30 | | |
| India | 6 | 318 | 1 | 45 |
| Ireland | 1 | 160 | | |
| Italy | 36 | 8024 | 8 | 1437 |
| Japan | 12 | 1668.7 | 2 | 150 |
| Korea | 1 | 120 | | |
| Mexico | 1 | 250 | 1 | 250 |
| Netherlands | 14 | 2055 | 4 | 545 |
| South Africa | 2 | 65 | 1 | 50 |
| Spain | 7 | 535 | 1 | 85 |
| Switzerland | 5 | 990 | | |
| Taiwan | 5 | 674 | | |
| Turkey | 3 | 420 | | |
| UK | 24 | 4049 | 6 | 808 |
| Venezuela | 1 | 90 | | |
| USA | 417 | 58215 | 139 | 13584 |
| Foreign | 161 | 26015 | 36 | 5207 |

**Table 2: Requested and Approved Proposals by Country.**

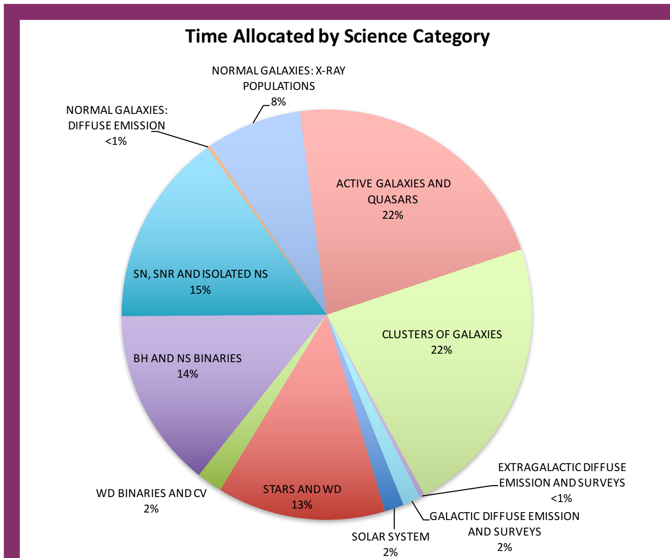



*Figure 6: A pie chart indicating the percentage of Chandra time allocated in each science category. Note that the time available for each science category is determined by the demand.*

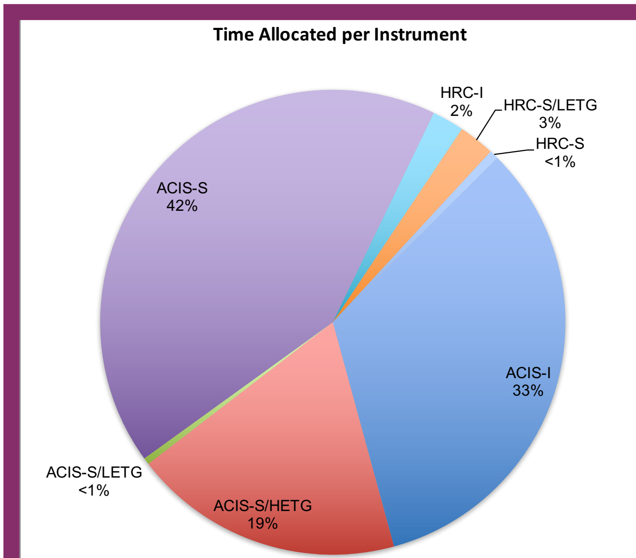



*Figure 7: A pie chart showing the percentage of Chandra time allocated to observations for each instrument configuration.*

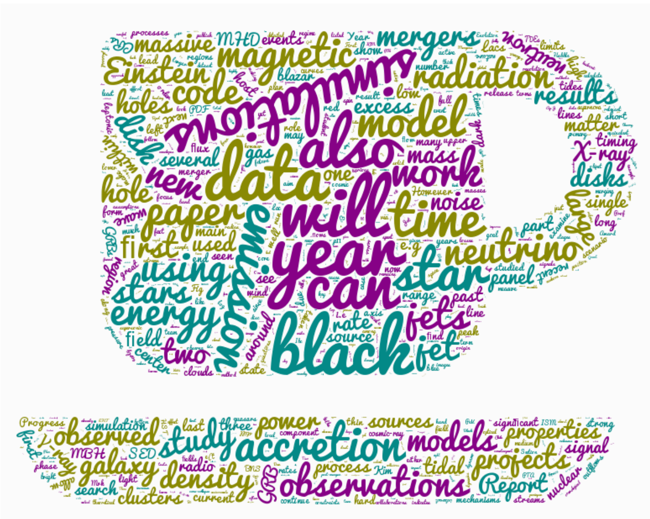
## *Chandra* Users' Committee Membership List

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 |
| Matteo Guainazzi | European Space Agency | matteo.guainazzi@sciops.esa.int |
| Thomas Maccarone | Texas Tech | thomas.maccarone@ttu.edu |
| Paul Martini | Ohio State University | martini@astronomy.ohio-state.edu |
| John Mulchaey | Carnegie Observatories | mulchaey@obs.carnegiescience.edu |
| Rachel Osten | STScI | osten@stsci.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 |

## Einstein Postdoctoral Fellowship Program

**Paul Green**




Inspired as usual by impending deadlines, I took a batch of Annual Reports recently submitted by current Einstein Fellows, and made the accompanying Wordle. 'Year', 'will, and 'can' are the top three words, which makes sense given the indomitable spirit and prodigious annual productivity of this tough gang of astrophysicists. I chose a coffee mug shape to represent the wordle, since caffeine likely plays a significant role in stimulating their research. Curiously, scrutiny of the next three most common words in the wordle hints at an emerging field of ominous 'black data simulations'.

**2016 Selection Panel**

The Einstein Postdoctoral Fellowship selection panel, recruited each year, works hard to select amongst an impressive crop of applicants, many of whom could code and run a suite of 3D-MHD black data simulations of your grandmother before lunch. After reviewing 163 applications, a panel of 13 reviewers met at the CfA in mid-January 2016. Spirited discussions informed the grading process for our initial "discuss list" of 43 applications. Despite encouragement to use the full spread of grades (from 1 to 5) for post-discussion re-grading, most of those 43 applications emerged with grades above four, spawning discussion of ranking to the second decimal place. Our creative Chair even suggested it psychologically advisable to simply strip the integers so that e.g., a 4.7 becomes a 7. Anyway, by the end, we had a "short list" of 22 that the panel thought was both well-chosen and well-balanced. We began making offers the next day, amidst considerable host juggling (only one new Einstein Fellow may be posted to any institution). By Feb 15, we had 6 people decline, and 13 accept. By the end of 2016, these new Einstein Fellows will have fanned out to (you guessed it!) 13 institutions across the country to begin up to three years of research relevant to NASA missions in high energy or gravitational astrophysics, or cosmology.

You can see the fresh crop of 2016 Einstein Fellows and read about the research at *http://cxc.harvard.edu/fellows/fellowslist.html*.

**Alumni Mentors Program**

We have reached out to former Einstein and *Chandra* Fellows to create a network of alumni mentors. Current Einstein Fellows are encouraged to connect with any of the 20 alumni who have so far volunteered. The list of mentors will continue to grow but already represents a strong diversity of sub-fields of astrophysics and post-fellowship trajectories including staff research, faculty and private sector positions.

**Highlights from Current Fellows**

There are highlights too numerous to mention from current Einstein Fellows, but I've chosen a sampler to go with your coffee.

All three finalists for this year's American Physical Society Division of Astrophysics Thesis Award were Einstein Fellows! Blakesley Burkhart (New Frontiers for Diagnosing the Turbulent Nature of the Multiphase Magnetized Interstellar Medium), Liang Dai (Primordial Perturbations in the Early Universe: Theory, Detection, and Implication for Inflation) and Wen-fai Fong (Unveiling the Progenitors of Short Gamma-ray Bursts) presented results at the APS meeting on April 17 in Salt Lake City and Wen-fai Fong was chosen as the winner. Speaking of theses, Maria Petropolou received the Mobilising European Research in Astrophysics and Cosmology (MERAC) prize, awarded by the European Astronomical Society for Best Doctoral Thesis Prize in Theoretical Astrophysics. Congratulations to all!

Using integral ratio (3:2) harmonic X-ray quasi-periodic oscillations, Dheeraj Pasham led a team that published a reliable mass measurement for NGC 1313 X-1, an intermediate-mass black hole of about 5,000 solar masses (press release at *https://cmns.umd.edu/news-events/features/3245*).

Alexander Tchekovskoy and Nick Stone won an NSF award of 10 million GPU hours (1 billion CPU core hours) over a period of 2 years on the Blue Waters supercomputer at the National Center for Supercomputing Applications in Urbana-Champaign.

Justin A. Ellis and Rutger van Haasteren co-authored a study on the prospects of gravitational-wave detection with pulsar timing arrays. They conclude that, even in pessimistic cosmological scenarios where a significant fraction of supermassive black-hole binaries stall, pulsar timing arrays can expect to detect a stochastic background of gravitational waves within the next decade. (Press release: *http://www.jpl.nasa.gov/news/news.php?feature=5505*)

Simeon Bird and collaborators published a paper asking whether primordial black holes—contenders for a significant portion of dark matter in the universe—could have produced the detected LIGO event.

**2016 Einstein Fellows Symposium**

All are invited to attend the 2016 Einstein Fellows Symposium, Oct 18-19 here at the CfA, or watch it live via webcast. The program should be posted soon at *http://cxc.harvard.edu/fellows/program_2016.html*. There is a finite chance that among the results presented, you might find a 3D-MHD black data simulation of your grandmother. ■

## The Group Formerly Known as EPO

**Kathleen Lestition**

As noted in the Project Manager's article, 2015 has been a year of transition for CXC EPO. The restructuring that began several years ago with the removal of the education portfolio from all missions in NASA's Science Mission Directorate (SMD) has now been fully implemented. The activities formerly known as EPO, which included everything from press to formal education activities, have been divided into two areas: Public Communications and Outreach, directed from the NASA Office of Communications (NOC), and the informal and formal education activities now funded under a new NASA Cooperative Agreement directed and administered from SMD.

Public relations and public outreach activities such as our press and image releases, public web site, social media activities, and any digital public information products (including PPT slides of all images for talks) will continue, as before, to be carried out by the CXC: the EPO group is now known as Public Communications and Outreach. This year the NOC initiated a series of thematic "campaigns", putting all SMD press and public outreach programs into one of them. *Chandra* (along with the other Astrophysics Division missions) is in the Solar System and Beyond campaign which highlighted such activities as the 20th anniversary of the discovery of Exoplanets and the New Horizon Fly-By, to both of which *Chandra* was able to contribute. The NOC is also responsible for organizing mission participation in large scale events, such as the Science & Engineering Festival held in Washington DC. The intent is to make SMD mission Public Communications and Public Outreach more cohesive and synergistic with broad NASA goals.

The Manager's article lists the 2015 statistics on press and image releases, number of resulting articles, number of feature images on HEASARC, APOD and NASA image pages, and number of podcasts and blogs. We target podcasts and blogs at several audiences, including segments of the public who prefer video or shorter presentations of our science results, younger children (Space Scoop and *Chandra* Sketches), audiences seeking career information (Meet an Astronomer, Women in the High Energy Universe) and audiences interested in the science topics presented in the Here, There & Everywhere (HTE) and Light: Beyond the Bulb (for International Year of Light) public exhibits.

We continue to track very healthy web and social media statistics. Website hits consistently average above 12M per month, with spikes for releases that generate above average interest, for instance, the SgrA* release at the January 2015 AAS meeting. Podcasts remain the top download from our public site. As of December, we had over 84K Twitter followers, over 255K FaceBook likes, over 34K followers on Google +, and over 1.5M YouTube views.

Conforming to directives from the NOC that no longer allow printing of posters, we transitioned thematic science material from our press and image releases, as well as topics from our public exhibits, to a new allowed format called "infographics". These are collected on-line at *http://chandra.si.edu/resources/illustrations/infographics.html*. In addition we have been able to reprint popular lithographs and some new versions of smaller image handouts, a new line of science-by-topic bookmarks, etc. All are available from our online request form for use with public outreach or education presentations, see *http://chandra.harvard.edu/edu/request.html*. Click on the "List of Materials" to see what is available at any time.

We have developed new areas of products involving the latest technologies in imaging for use both in public outreach and education. We have expertise in producing images in Ultra HD (4K JPG) format and are gradually adding popular images to the collection, see *http://chandra.harvard.edu/photo/4k_images.html*. We prepared hyperwall talks for the AAS meetings. A study of image processing using CasA was prepared and presented on the visualization wall at the Harvard Art Museum. We have posted the files and instructions for printing 3D models of the *Chandra* spacecraft and the CasA supernova remnant online and have developed other 3D resources for use with sight disabled audiences.

Education funding in SMD is now a separate line that is determined yearly in the NASA budget. An award through the Cooperative Agreement Notice (CAN) is now the only mechanism by which SMD missions can undertake education activities. A CAN released in 2015 solicited proposals for a 5-year funding opportunity. The CXC proposed as a Co-I on a proposal led by STScI, along with Co-I's from Sonoma State, JPL and IPAC. Our "Universe of Learning" (UOL) program was selected for funding (along with 26 other awardees). At the end of December we were still in budget negotiations with NASA, but, breaking the timeline on this article, we are finally funded in April 2016! Our activities under the UOL award will continue many of our highly successful education programs, such as our public exhibits, our online activities with image processing and data analysis, our Braille and tactile materials for sight disabled, our 3D imaging and printing products, our collaborations with SAO's Science Education Division on MicroObservatory, PencilCode activities, and our work with the National Science Olympiad and the Christa Corrigan McAuliffe Challenger Center in Framingham MA. Although our ability to carry out education programs this past year was limited by both reduced funding and NASA restrictions, highlights of main accomplishments are described below.

We carried out two public exhibit programs. We completed the last year of a 4-year EPOESS award from NASA to tour the HTE public exhibit which places science concepts relevant to astrophysics in more familiar contexts (*http://hte.si.edu/*). This exhibit toured the US at one venue per month. In addition, the concept was adopted by the US State Department for use in its "American Spaces" exhibits to showcase US science


*Figure 1: Public exhibit (Light:Beyond the Bulb/L:BTB) for the International Year of Light 2015.*

and we continue to work with them on an exciting new project for 2016.

We also won funding from SPIE, the IAU and UNESCO to develop a public exhibit (Light:Beyond the Bulb/L:BTB) for the International Year of Light 2015. We used *Chandra* funding to produce a NASA version focused on space science results (Figure 1). The NASA L:BTB exhibit toured the US at one venue per month. SPIE funded several more. Figure 2 shows the 1-year reach of the HTE exhibit (top), and the L:BTB exhibits (bottom). The open source model enabled organizers worldwide to develop their own exhibits. We also developed Braille/tactile materials with each exhibit and for the US version, translated the content into Spanish. A briefing to Senators during a "Science Day on the Hill" resulted in an exhibition of L:BTB in the US Capitol Rotunda.

A pilot program developed with the Google-sponsored Pencil Code/Hour of Code (Figure 3), which introduced simple coding exercises leading to astronomical images was developed into a NASA approved activity. We gave several workshops to local schools and after and out-of-school programs working with girls and underserved schools: many more are scheduled.

We continued supporting the middle and high school level astronomy competitions of the National Science Olympiad (NSO), a non-profit, volunteer-based program which reaches over 200,000 students each year nationwide. We developed the content for the 2016 competitions, and developed and taped a set of videos as resources for coaches and their student teams. Seventeen workshops were presented at NSO coaches clinics and at National Science Teacher Association meetings.

We collaborated on several activities with the Christa McAuliffe Challenger Center located on the campus of Framingham State University. The exhibit of *Chandra* images prepared for NASA HQ for the *Chandra* 15th anniversary and a copy of HTE remain there on loan. Programming for several classes was developed around these exhibits. A copy of the outdoor exhibit prepared for International Year of Astronomy was loaned for the inaugural Science on State Street festival.

We continue the Astronomy & Aesthetics program to develop best practices in presenting astronomy results to the public. Three papers on this topic were accepted and published in reviewed publications.

We encourage participation by the *Chandra* science community in all aspects of our Communications, Public Outreach and Education activities. We ask that you contact us with newsworthy science stories, ideas for web content, ideas for public outreach or for education activities or products, or to volunteer to present talks or to take part in any of our public activities. ▪

*Figure 2: 1-year reach of the HTE exhibit (top), and the L:BTB exhibits (bottom)*

*Figure 3: Pilot program developed with the Google-sponsored Pencil Code/Hour of Code, which introduced simple coding exercises leading to astronomical images*

## *Chandra*-Related Meetings and Important Dates

**Cycle 18 Peer Review:**
Jun 27–Jul 1, 2016

**Cycle 18 Cost Proposals Due:**
Sep 27, 2016

**Workshop on *Chandra* Science for the Next Decade:**
Aug 16-19, 2016
**Abstract Deadline:**
June 15, 2016
**Registration Deadline:**
June 30, 2016

***Chandra* Users' Committee Meeting:**
Late Sep/Early Oct, 2016

**Einstein Fellows Symposium:**
October 18-19, 2016

**Cycle 18 Start:**
December, 2016

**Cycle 19 Call for Proposals:**
December, 2016

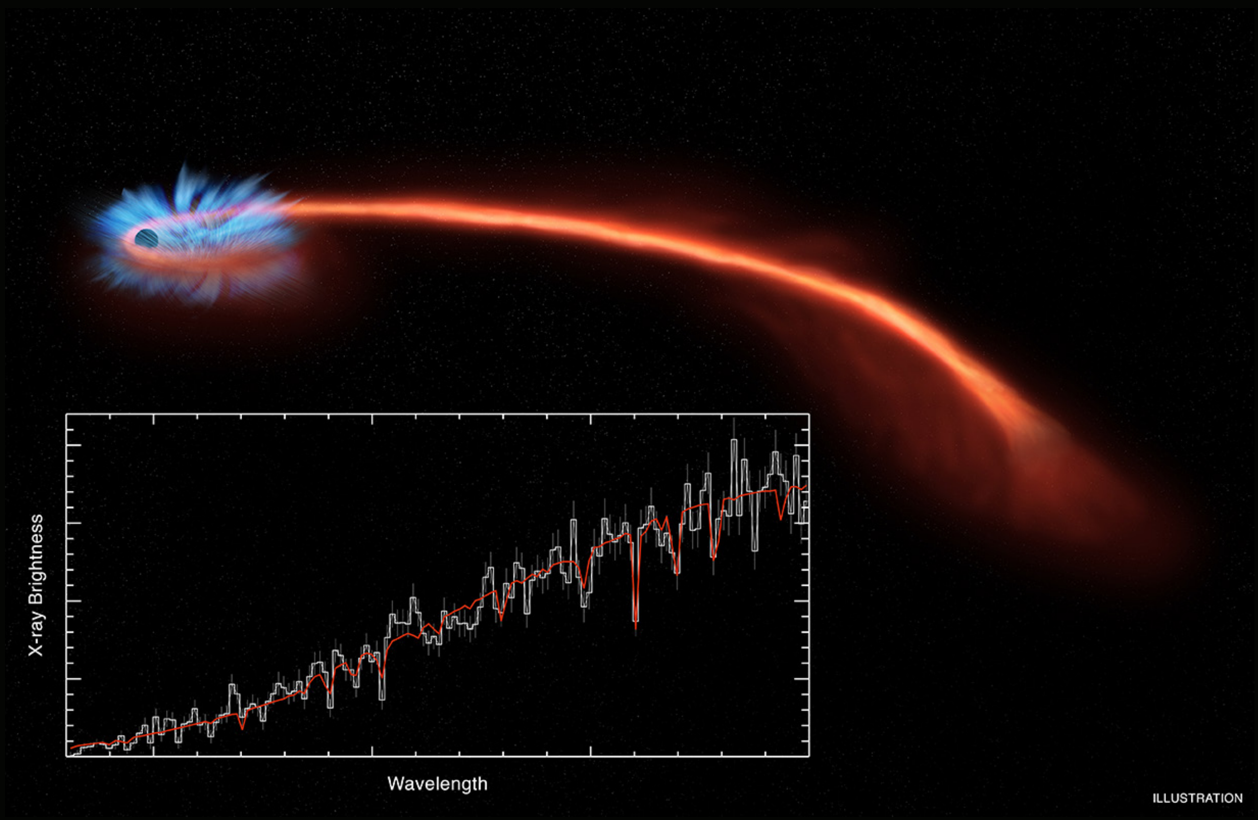
## 2015 Press Releases

**Megan Watzke**

| Date | PI | Object | Title |
|---|---|---|---|
| January 5 | Daryl Haggard (Amherst) | Sgr A* | NASA's *Chandra* Detects Record-Breaking Outburst from Milky Way's Black Hole |
| January 29 | Kim Arcand (CfA) | IYL2015 exhibit | New Exhibit Launches to Celebrate International Year of Light |
| February 25 | Mar Mezcua (CfA) | NGC-2276-3c | NASA's *Chandra* Finds Intriguing Member of Black Hole Family |
| March 4 | Mark Voit (Michigan State) | 200+ galaxy clusters | NASA's *Chandra* Finds Cosmic Showers Halt Galactic Growth |
| March 26 | David Harvey (EPFL) | 72 large cluster collisions | NASA's Hubble, *Chandra* Find Clues That May Help Identify Dark Matter |
| April 6 | CXC Director's Office | | 2015 *Einstein* Fellows Chosen |
| April 30 | Bin Luo (Penn State) | 51 quasars | NASA's *Chandra* Suggests Black Holes Gorging at Excessive Rates |
| May 28 | Eric Perlman (Florida Institute of Technology) | 6 quasars | NASA Telescopes Set Limits on Spacetime Quantum Foam |
| June 23 | Sebastian Heinz (Univ. of Wisconsin) | Circinus X-1 | NASA's *Chandra* Captures X-ray Echoes Pinpointing Distant Neutron Star |
| July 22 | George Pavlov (Penn State) | PSR B1259-63/ LS 2883 | Pulsar Punches Hole in Stellar Disk |
| September 23 | Gabriele Ponti (Max Planck) | Sgr A* | Milky Way's Black Hole Shows Signs of Increased Chatter |
| October 21 | Jon Miller (Univ. of Michigan) | ASASSN-14li | Destroyed Star Rains onto Black Hole, Winds Blow it Back |
| December 21 | Gerritt Schellenberger (Univ. of Bonn) | Zwicky 8338 | *Chandra* Finds Remarkable Galactic Ribbon Unfurled |

Links to all of these press releases can be found at: http://www.chandra.harvard.edu/press/14_releases/.

Additional image releases and other features that were issued during 2015 are available at: http://www.chandra.harvard.edu/photo/chronological15.html.




Published by the
Chandra X-ray Center

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

*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.*

*See full article on pp. 26-28.*