HETG Update

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HETG in Absorption

In this year's HETG update, I want to take the opportunity to delve deep into the relation between the HETG and absorption. There is some bad news (possibly with a work-around), but also some good news: On the one hand, the increasing contamination on ACIS reduces the effective area at the soft end of the HETG range so much that observations of e.g., stellar O VII triplets now require very long exposure times for all but the brightest stars. It seems that this trend will continue for the foreseeable future (L. David in this issue). In the first section of this article, I will show our efforts to open up a new mode for HETG users which would pair the HETG with the HRC to overcome this problem.

On the other hand, absorption in the far-away universe (as opposed to absorption on the CCD) is something that can help us learn about the structure of AGN and the properties of the intergalactic or interstellar medium. So, as a positive counterpoint, I'll highlight some recent use of the HETG to study absorption in the universe in a productive way.

Experimenting With a New Setup: HETG/HRC-I

The HETG is used almost exclusively with ACIS as a detector (there are only two exceptions to this rule in the entire history of *Chandra*, which I will discuss later), and if you use ACIS for grating spectroscopy, you want to use ACIS-S. As most readers of this newsletter surely know, ACIS-S consists of 6 CCDs arranged in a long array that catches both the positive and the negative diffraction orders of the HETG. The image on the detector has the form of an "X", because the HETG has two parts, the HEG (high-energy grating) and the MEG (medium energy grating), each of which is responsible for one of the legs of the "X" (Canizares et al., 2005). The CCDs of ACIS-S do not lie on a plane, instead they are tangential to the Rowland circle.

The Gunk and the Goo Steal our Soft Photons

The HETG disperses the photons, and the ACIS CCDs detect them. At least that's the plan. With increasing contamination on the ACIS chips, more and more of the soft photons are absorbed by the gunk and goo that sits on top of the ACIS filters. This is not so much an issue for the HEG, which is–surprise–most efficient for high-energy photons that pass through the absorbing layer, but more of an issue for the MEG.

What Can We Do?

ACIS has been designed with the option of a bake-out, where the chips would be heated to remove all that gunk, but such a bake-out also poses a significant risk to the instrument (see, e.g., the Project Scientist's Report in the 2017 newsletter). Absent a bake-out, we have basically three options to mitigate the impact of the contaminant on HETG observations: (1) stop using the HETGS for any science case that requires data longward of 15 Å, (2) increase integration time for observations (in some cases, much much longer), or, (3) use a detector other than ACIS.

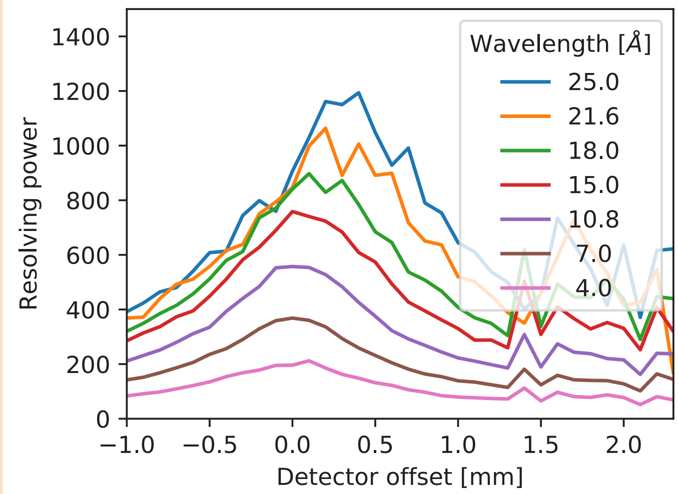

Figure 1: Expected spectral resolving power for HETG/HRC-I for different focus offsets based on MARX ray-trace simulations.

When *Chandra* was launched, there was a clear expectation what grating and detector combinations would be useful together and looking at all observations carried out in 2017, the community continues to follow that pattern. Excluding calibration observations, there were 88 observations with HETG and all of them use ACIS-S as the detector of choice; in the same year there were 26 LETG observations and all of them used HRC-S as detector. There is a good reason why this is the standard choice: ACIS is sensitive over the energy range covered by HETG spectroscopy and the intrinsic energy resolution of the CCDs allows the observer to separate the diffraction orders, thus making it much easier to analyze the extracted spectra compared to spectra acquired from the LETG/HRC-S combination where higher order photons are confused with the first order signal. However, the LETG more efficiently disperses longer wavelength photons where the ACIS sensitivity is low, thus making the HRC the detector of choice for LETG observations.

Could We Use HRC as a Detector for HETG Observations?

Let's just say that again: "the LETG more efficiently disperses longer wavelength photons where the ACIS sensitivity is low, thus making the HRC the detector of choice for LETG observations". With increasing contamination on the ACIS optical blocking filters, this statement starts to become true for HETG observations as well. To detect long wavelength photons with ACIS requires longer and longer integration times; thus, using the HETG with the HRC is an option worth investigating. However, there is no such thing as a free lunch. If we use the HRC, we can no longer rely on the CCD energy resolution to perform order sorting–just as it is true for LETG/HRC observations.

Motivation to Test HETG/HRC

If an observation aims specifically for diagnostics at relatively long wavelengths (say the OVIII line at 18.97 Å, or the OVII triplet around 22 Å), one might use the LETG instead of the HETG in the first place. However, we usually need to analyze all the signal that we can get. The HETG is ahead of the LETG in at least two areas: First, the HETG has a higher spectral resolving power than the LETG. If a science case requires the very best resolution we can get, then we have to use the HETG. Second, the HETG offers a higher effective area at wavelengths shortward of 15 Å. If the science requires good signal in this region, again, we have no choice but use the HETG.

As an example, consider the X-ray activity from classical T Tauri stars (Günther et al. 2010). These are young, low-mass, pre-main sequence stars in the phase of planet formation. They are still surrounded by an accretion disk, and mass falls from this disk onto the stellar surface where it forms an accretion shock. The shock is hot enough to be seen in X-rays. To measure densities and temperatures in the shock, the OVII triplet (~22 Å) and the NeIX triplet (~13.5 Å) must be observed. The latter is often contaminated by Fe lines; HETG resolution is required to resolve those lines. Because the spectrum is dominated by known emission lines, order sorting is less of a problem than in continuum dominated sources–knowing the wavelength of the line enables the observer to distinguish between first and third order features.

One More Twist: HRC-I vs. HRC-S

Chandra has two HRC detectors, one optimized for imaging (HRC-I) and one for spectroscopic observations (HRC-S). Similar to ACIS-S, the HRC-S is made of segments that are mounted to approximate the Rowland circle. Most LETG observations use the HRC-S. However, the background in the HRC-S is much higher than in the HRC-I, because the anti-coincidence shield of the HRC-S is not functional. In fact, the background alone would saturate the *Chandra* telemetry, hence only limited regions of the detector can be send to the ground. Since the LETG disperses the spectrum along a single line, the telemetry is not saturated. However, the two legs of the dispersed HETG spectrum spread across a larger chip region, in fact, so much larger that the most distant dispersed spectrum might fall off the chip. So, we opt to use the HRC-I as the detector. The HRC-I is not as long as the HRC-S, but HRC-I is large enough to capture essentially all the dispersed HETG spectrum. "But" I hear you say "HRC-I is flat!" and thus the spectrum will be out of focus. True, I say, but not very much. The distance between the flat HRC-I surface and the Rowland torus is small compared to the diameter of the Rowland circle (about 10 m) and the loss of resolving power is acceptable. Additionally, a user can adjust the focus position of the detector plane to determine exactly where the flat detector intersects with the Rowland circle. Figure 1 shows MARX simulations for an HETG/HRC-I setup with different focus positions. Without an offset, short wavelength photons, which get diffracted only by a small angle, are in focus. For larger offsets, photons at increasingly longer wavelength, i.e., those that get diffracted further away from the optical axis, are in focus. For example, the optimal spectral resolving power for the OVII triplet (21.6 Å) is achieved at a focus position of ~+0.25 mm. However, the resolving power distributions are wide, so even with the flat HRC-I a large region of the dispersed HETG spectrum will still achieve a better resolving power than LETG observations.

Data from HETG/HRC-I Observations

So far, there are two HETG/HRC-I observations in the archive. The first one is ObsID 13712 (target GX 3+1, Figure 2). The object is a very bright continuum source and the

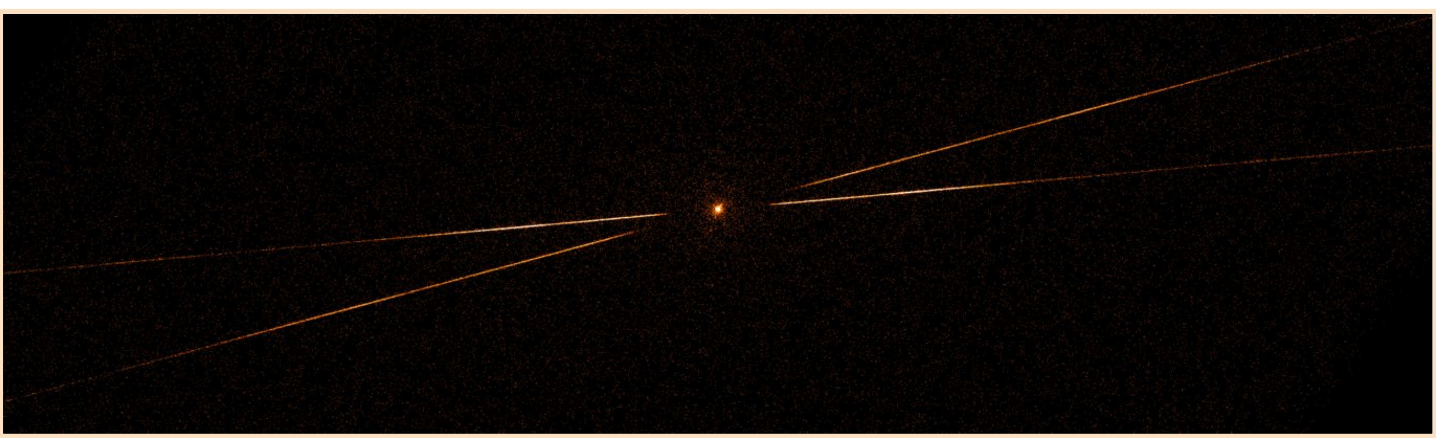

Figure 2: GX 3+1 (ObsID 13712) observed with HETG/HRC-I. The source is very bright and HEG and MEG arms can be seen easily on the detector image.

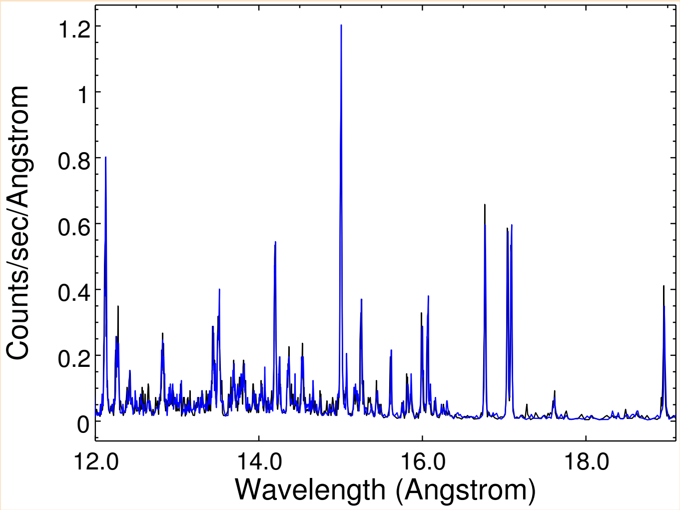

Figure 3: One section of the MEG Spectrum of Capella, observed with HETG/HRC-I. Black: negative orders. Blue: positive orders

HETG was used to reduce the count rate in zeroth order. The dispersed spectrum is visible on the detector, but of limited scientific use. The second observation (ObsID 19837) is from Capella, an active star and regularly observed calibration source, which was taken specifically to test the HETG/HRC-I mode (Figure 3). The position of the emission lines in the spectrum are well known, although their flux levels do change.

Presently, the processing of HETG/HRC-I observations is limited since the configuration is not yet fully supported, i.e., there are no CIAO threads to process the data and the required calibration products are not included in the CALDB. There is plenty of signal in the spectrum. Using a select sample of emission lines with little to no confusion, we can model the core of the HETG line spread function (LSF) with a simple Gaussian (*http://space.mit.edu/CXC/LSF/LSF_0002/LSF_build2.html*) to determine the resolving power and compare it to the values presented in Figure 1. This comparison is shown in Figure 4. As expected for a grating dispersed spectrum, the resolving power increases with wavelength and behavior in the observations is similar to that seen in Figure 1. Note that the O VII lines at 21.6 Å and 22.1 Å are not very bright and thus the uncertainties are large.

Does HETG/HRC-I Work?

The observation of Capella was a successful test of using the HETG with HRC-I. However, more work, specifically in the calibration and CIAO data analysis tools, is needed before this mode can be used routinely. At the current time, this HETG/HRC-I configuration is only warranted for a few special cases where the LEG resolving power is insufficient but emission lines in the range 15–25 Å are crucial. On the other hand, with increasing contamination there will be more and more cases where the HRC can offer better overall performance than ACIS-S.

The Good News: What We Can Learn from Absorption

In this section, we highlight two recent scientific results that are based on absorption line spectroscopy using HETG data. The first example re-analyzes archival HETG observations to consider aspects of the data that were not central to the original observation. The data archive of existing HETG observations is quite rich and grows with every new cycle. The HETG instrument team tries to make it as easy as possible to view and retrieve archival data for example through the TGCat web-archive (*http://tgcat.mit.edu*). TGCat offers quicklook images of all reduced datasets and science-ready data products for download.

Fu et al. 2017 presented a new study of the bright Seyfert I galaxy NGC 3783. This target has accumulated more than 1 Ms of exposure time with *Chandra*/HETG and a number of previous publications have studied the spectral absorption lines to derive the properties of warm absorbers—with sometimes inconsistent results. The novelty of the Fu et al. (2017) study is the simultaneous fit of X-ray data from *Chandra*/HETG and UV data from *HST*/COS (both observations were taken within a few days of each other) to constrain the properties of the warm absorbers. Their simultaneous fit produces a model that requires a total of five warm absorbers. They report that only two of these seem to be in pressure balance, so that they can be described by a static model. A more detailed treatment is required to understand the remaining clouds. For example, two smaller clouds seem to have been blown out from the torus only very recently. The authors estimate a total mass outflow of 0.2–4 solar masses per year.

The second example of HETG absorption spectroscopy we highlight considered absorption between us and low-mass X-ray binaries (LMXB). Schulz et al. (2016) analyze

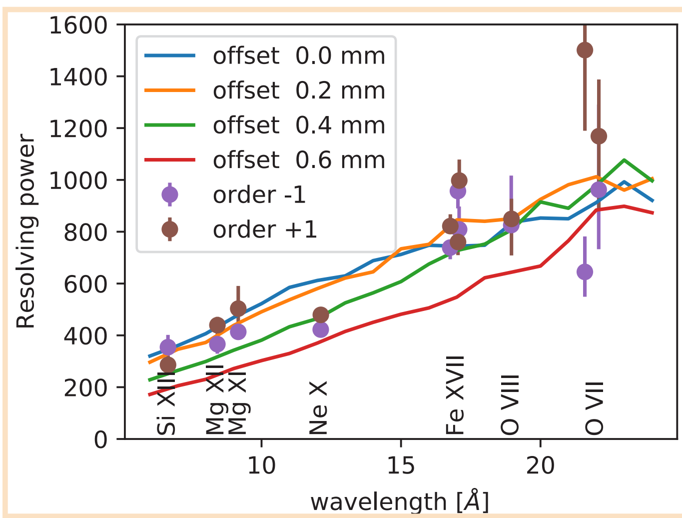

Figure 4: Predicted and observed resolving power for HETG/HRC-I observations. Capella was observed with a focus offset of +0.24 mm. Labels indicate which lines were used to measure the resolving power.

HETG spectra towards several galactic LMXBs and in particular study the Si edge at 1.844 keV. There are several features near the Si edge which are caused by Si that is not free in atomic form, but where the energy of the edge is shifted because of ionization or because the Si is bound in dust grains. The edge feature is also measurably broadened due to the turbulent velocity of the gas by a few hundred km/s. The high turbulence and the ionization state indicate that most of the absorbing mass is located close to the LMXBs. In addition, Schulz et al. find that the edge structure can be variable on the time scale of days as the Si responds to changing ionization from the LMXB.

Summary

The HETG team is actively investigating observations with HETG/HRC-I. We hope that this combination can be useful for observers who want to use the HETG, but also require good signal between 15 and 25 Å. We have presented some promising preliminary work using this configuration, but note that this configuration is presently not supported for general observers. ■

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