The Hunt for UFOs with Chandra–HETGS

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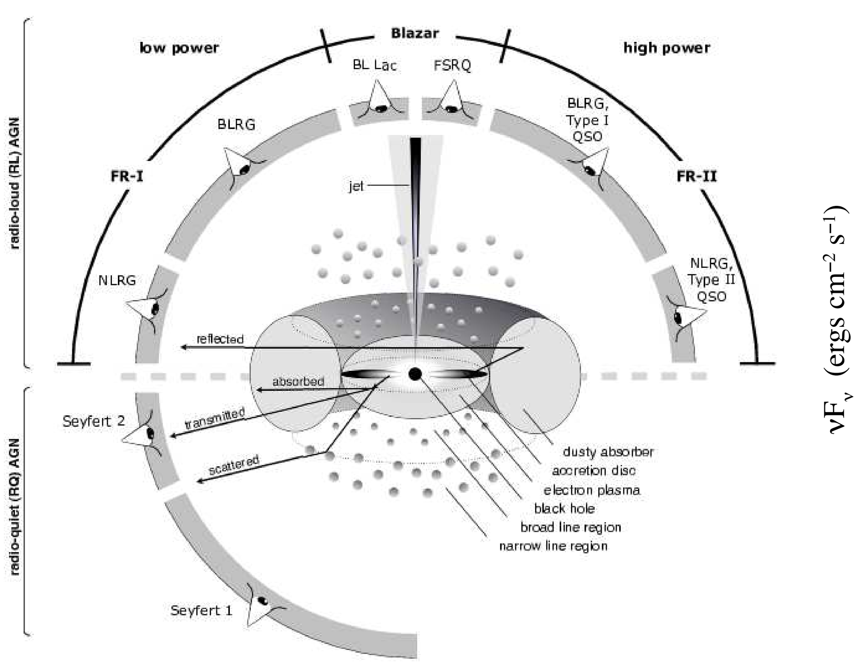
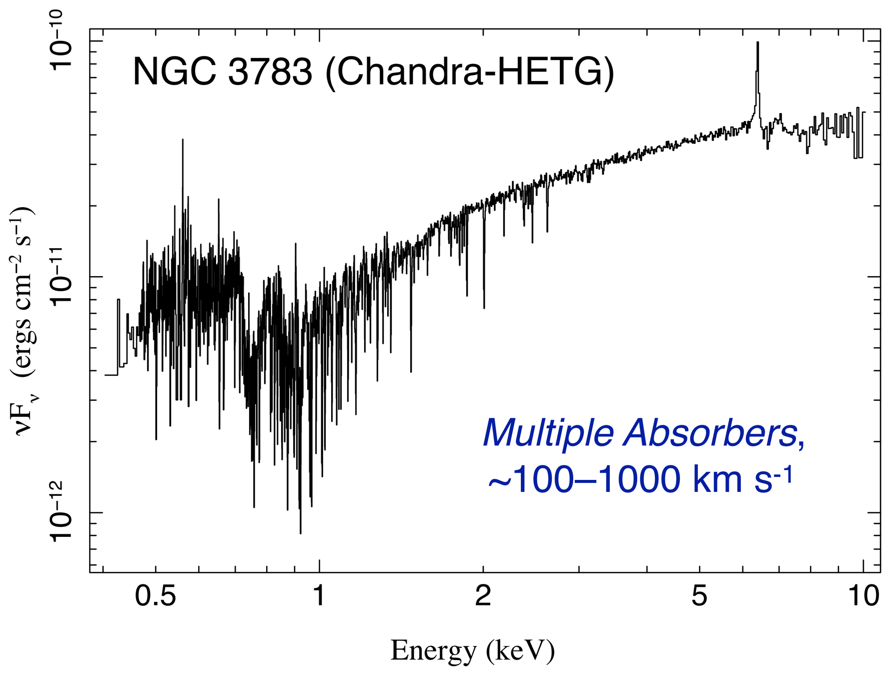
Ultra-fast Outflows (UFOs) in Active Galactic Nuclei (AGN) were first suggested based upon low spectral resolution CCD data in the 6-8 keV range, and were ascribed to absorption by highly ionized Fe. In this region, CCD resolution is not dramatically below that of gratings. Further evidence for UFOs has been claimed from high spectral resolution observations with the *XMM-Newton/Reflection Gratings Spectrometer* (*RGS*), and has been extended to Ultra-Luminous X-ray (ULX) sources. The <2 keV region, however, is extremely crowded, and UFO models often posit multiple absorbers with a range of blueshifts. It is not clear that even *RGS* resolution suffices. We discuss two recent UFO studies using the *Chandra-High Energy Transmission Gratings Spectrometer* (*HETGS*). We gain from improved resolution, but suffer from low effective area. First, for the AGN PG1211+143, we were able to verify the presence of an absorber outflowing at 0.056*c*. Next, for the ULX NGC 1313 X-1 we are still trying to determine if there is evidence for a UFO, and if not, do our observations contradict prior *RGS* studies?

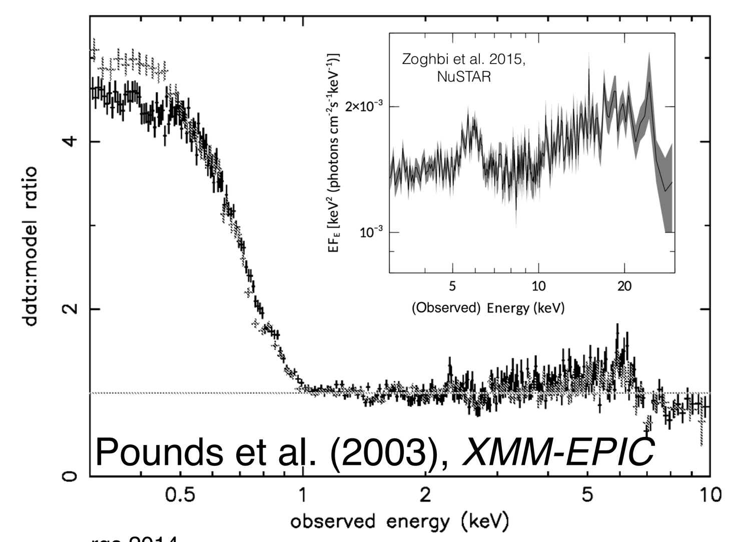
Warm Absorbers

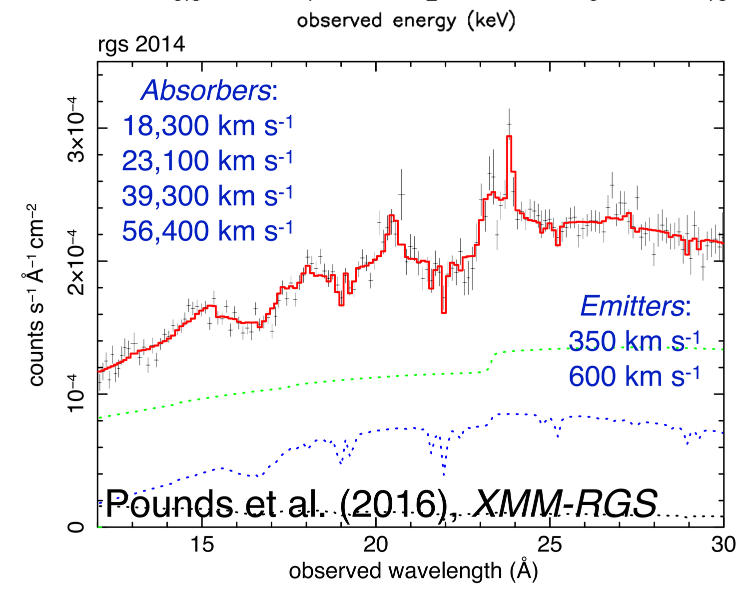




- The "Standard Model" of AGN (see diagram above; Beckmann & Shrader 2012) accounts for multiple spectral components: direct and reflected continuum, with the latter from both near (relativistically smeared) and far (narrow) from the central black hole, plus viewing angle-dependent absorption components.
- Warm absorbers have been identified since the days of CCD-resolution spectroscopic studies. *Chandra-HETGS* (and *XMM-Newton/RGS*) resolve these into multiple ionization components, with typical velocities of only ~100–1000 km s^{-1}. The above example shows *Chandra-HETGS* observations of the Seyfert NGC 3783 (Brenneman et al., 2011).
- What is the evidence for *Ultra-fast Outflows* (UFOs), with velocities ≳10% the speed of light?

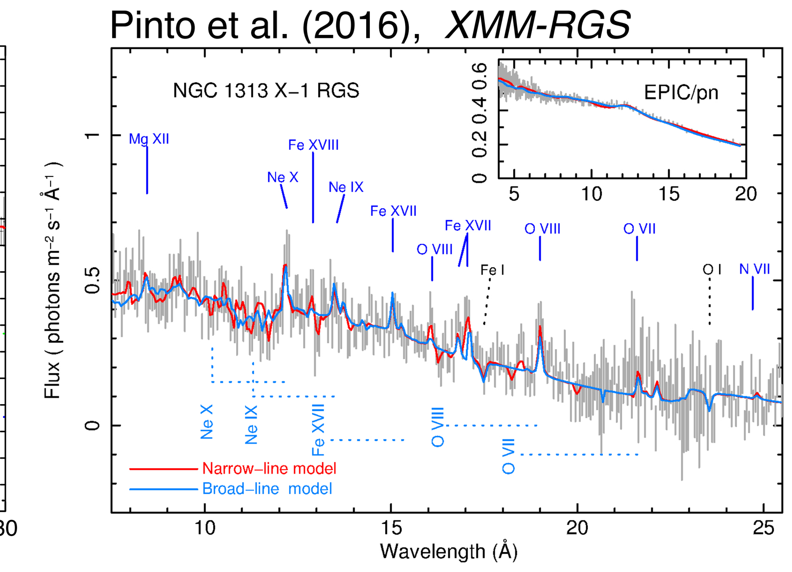
Ultra Fast Outflows – PG 1211+143 and NGC 1313 X-1



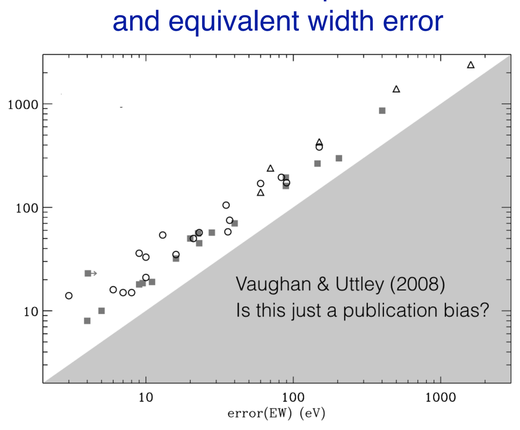


- CCD spectra provided evidence for 0.08*c* outflow in PG 1211+143, via, Mg, S, and Fe absorption (Pounds et al. 2003). *NuSTAR* does not see these (Zoghbi et al. 2015; due to poorer resolution, limited bandpass, or source/absorber variability?)
- Analysis of further *XMM-Newton/RGS* observations have indicated multiple emission and extreme velocity absorption components (Pounds et al. 2016).
- *XMM-Newton/RGS* spectra of the ULX NGC 1313 X-1 have been modeled with systemic emission/absorption components, and an outflow component with velocity 0.2*c* (Pinto et al. 2016; see also *NuSTAR* confirmation, Walton et al. 2016).
- Vaughan & Uttley (2008) have pointed out possible statistical biases in UFO studies: *high spectral resolution is needed to disentangle components & velocities.*

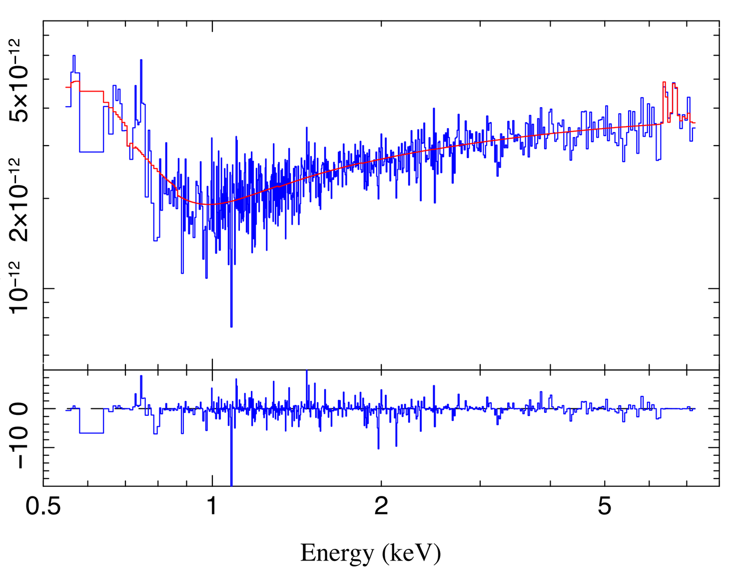
Pinto et al. (2016), *XMM-RGS*

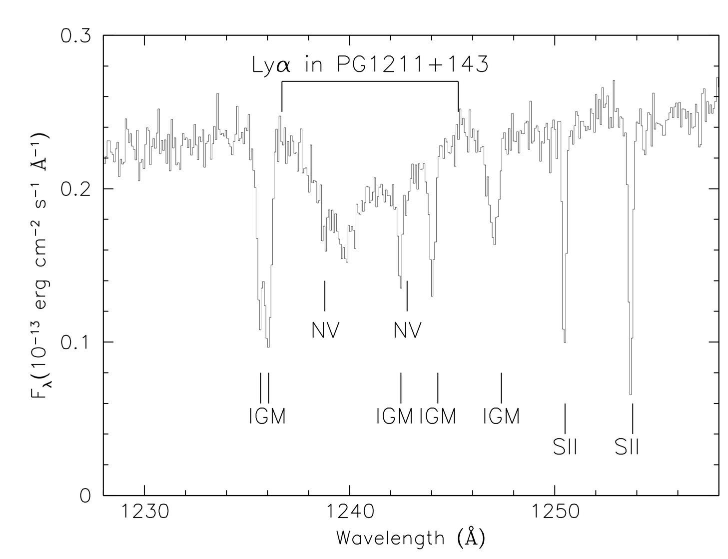


correlation of UFO equivalent width and equivalent width error

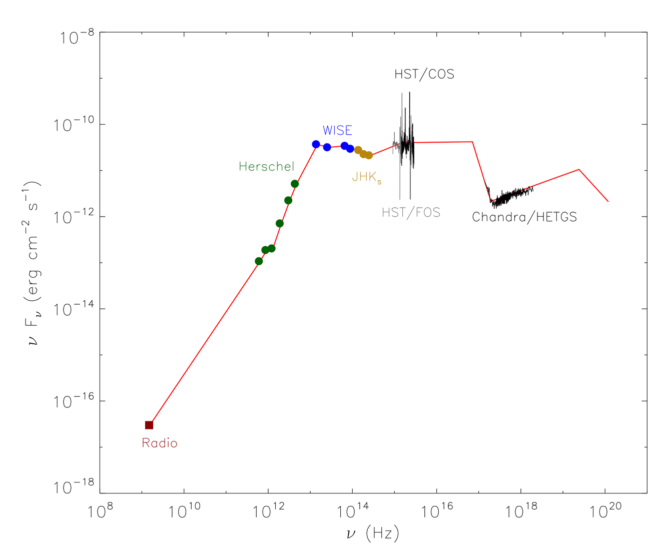


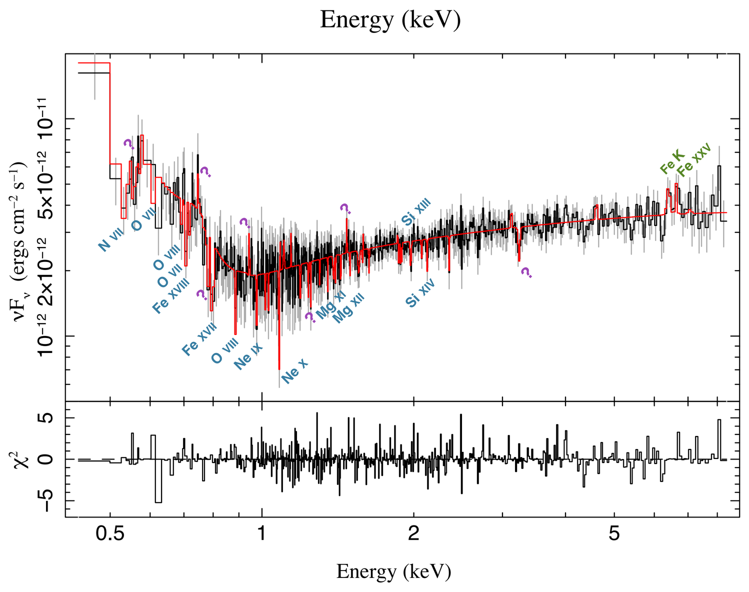
PG 1211+143 High Resolution Spectra

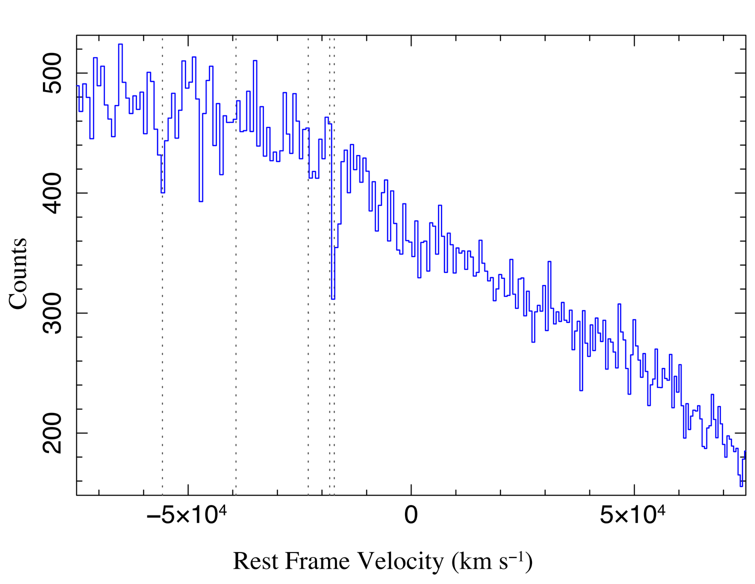


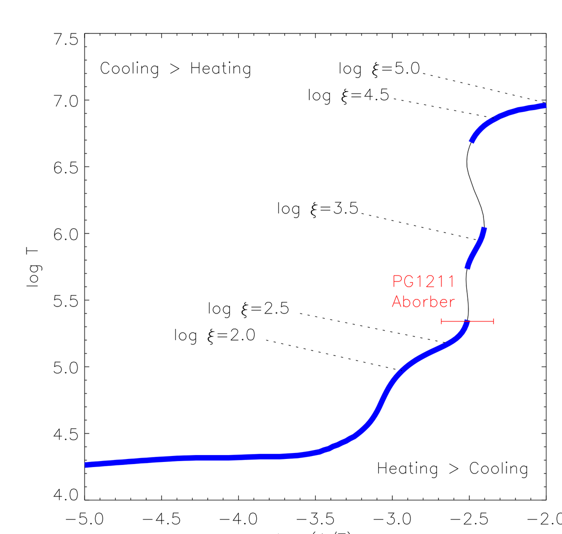


- We conducted a 500 ks campaign (April 2015) of *Chandra-HETGS* observations of PG 1211+143, which included contemporaneous *Hubble-Space Telescope-Cosmic Origins Spectrograph* (*HST-COS*) spectra. Results are described in Danehkar et al. (2018) and Kriss et al. (2018).
- Phenomenologically fit (including narrow Fe lines at rest), flux-corrected spectra (upper, far left; *shown in the Cosmological rest frame*) exhibit a prominent residual consistent with Ne X blueshifted at 0.056*c*.
- A blind line search (see below) *performed on unbinned data* finds features consistent with 0.056*c* blueshifted lines (lower, far left). Rebinning into rest-frame velocity bins (based upon known H- and He-like species) finds prominent absorption at 0.056*c* (lower, near left). Locations of blue shifted absorbers identified by Pounds et al. (2003, 2016) are shown. Only the 0.056*c* absorber is identified in individual features (a 0.19*c* absorber might be seen collectively).
- An absorber consistent with 0.056*c* blueshifted Ly α is detected with *HST-COS* (upper, near left).
- The spectral energy distribution (SED) was created from multi-wavelength data (upper, right), which was then used to create warm absorber models for the spectra. These models fit well, with a column density of log(N_H/cm^{-2}) ~ 21.5 and ionization parameter of log(ξ/erg s^{-1} cm) ~ 2.9.
- The warm absorber fitted to the X-ray spectra is roughly consistent with the *HST-COS* absorber.
- The fitted warm absorber is consistent with being on the cusp between a thermally stable/unstable zone in heating/cooling diagrams (lower, right).

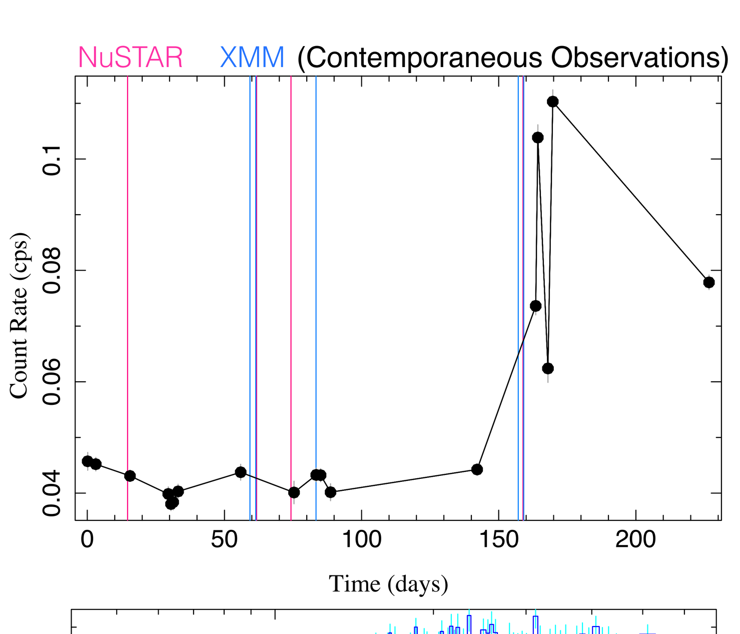


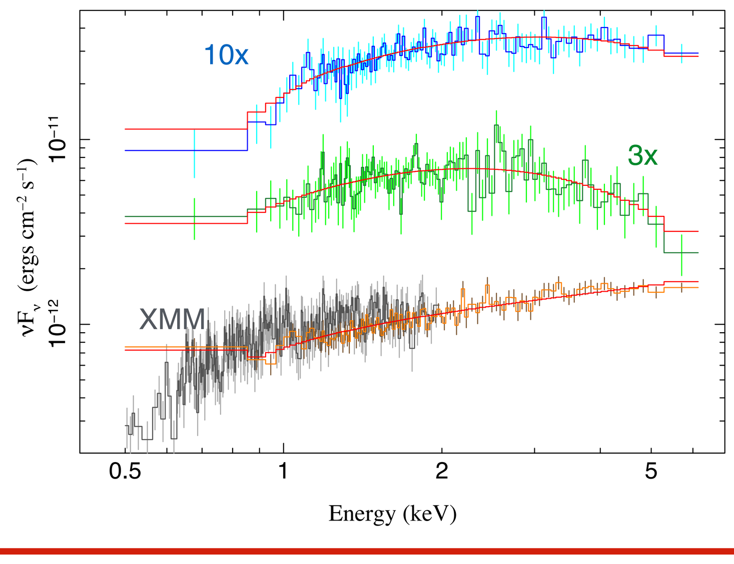


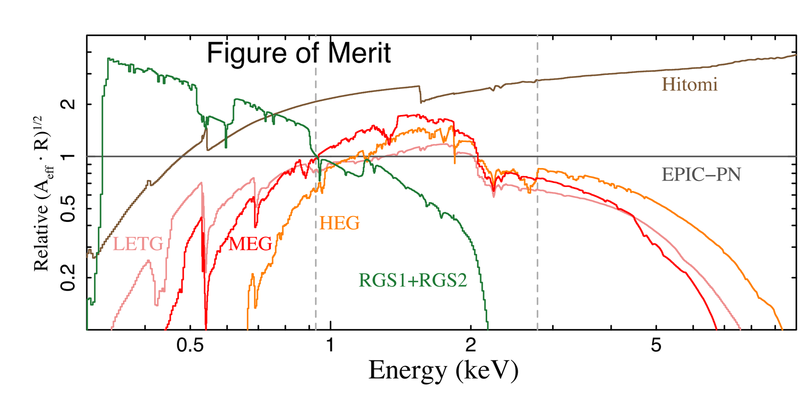


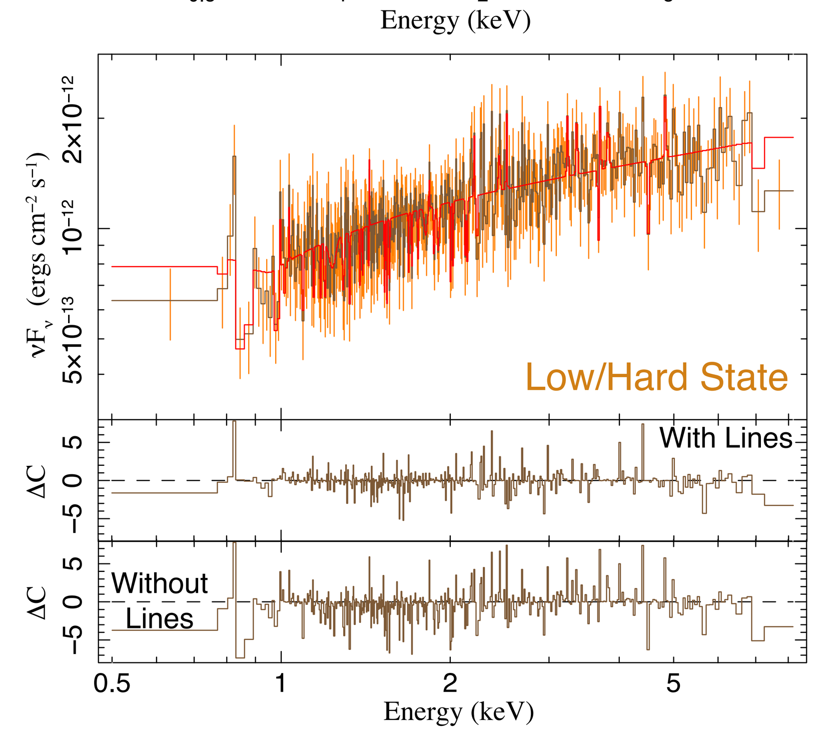


NGC 1313 X-1 High Resolution Spectra

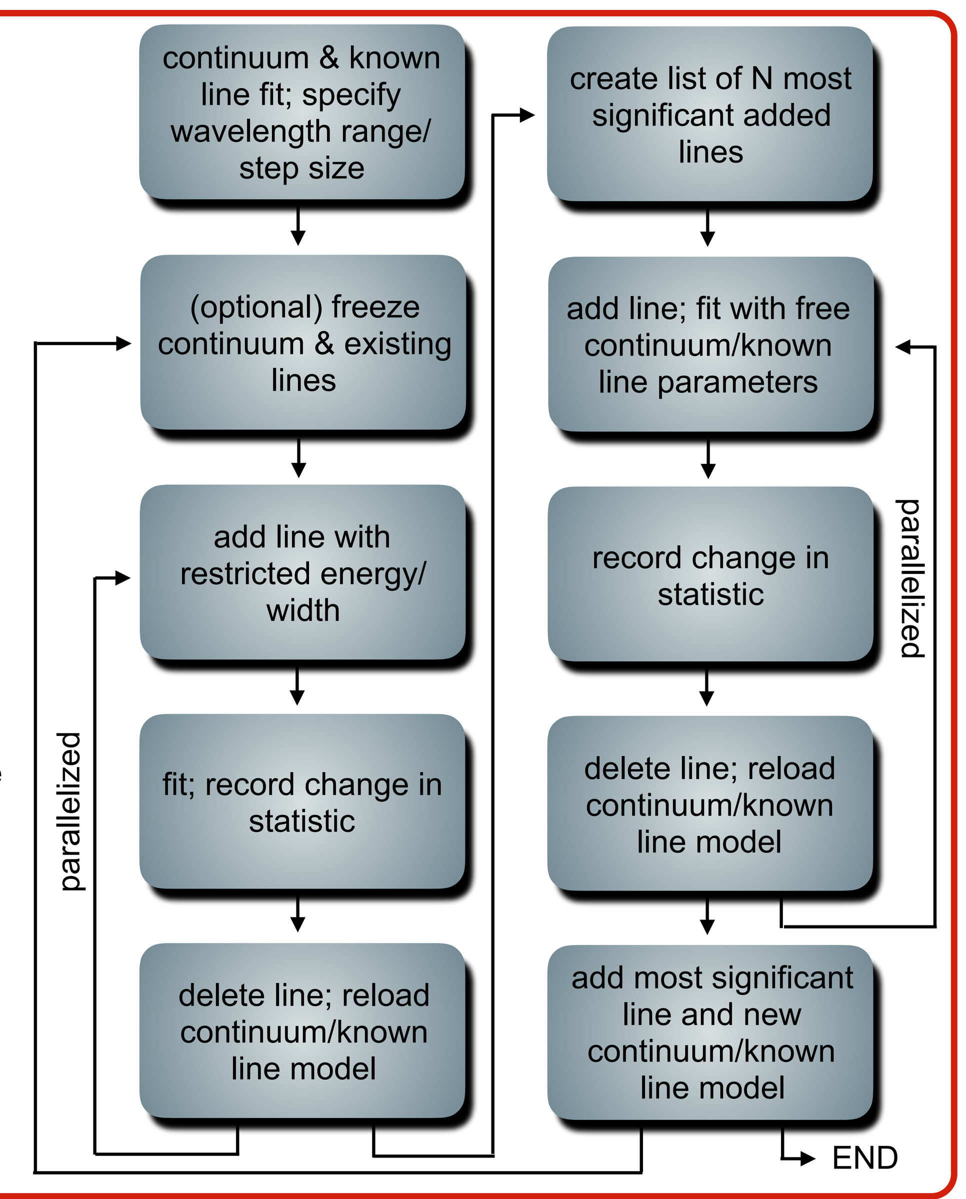








- We apply these techniques to *Chandra-HETGS* spectra of NGC 1313 X-1, which should be more sensitive than *XMM/RGS* ~0.9–3 keV (upper, near left; Nowak 2017).
- 500 ksec of Guaranteed Time Observations (GTO) were obtained July–December 2017. Most spectra are in a low/hard state similar to those of Pinto et al. (2016). (See light curve upper, far left; and spectra lower, far left).
- We perform a blind line search to unbinned data (see flow diagram, right). Contrary to most searches (e.g., Zoghbi et al. 2015) we do not use fixed line energies or widths, but perform true fits (taking advantage of multi-core parallelization).
- Emission/absorption lines can be added to the spectra, but statistical improvements to the spectra are modest (lower, near left). This is true regardless of state.
- Contrary to PG 1211+143, no pattern emerges among the fitted lines, and folding on velocity bins does not reveal any prominent absorption or emission systems.
- The code rewrites the model after each fit iteration, renaming lines to user specifications and reordering by wavelength or energy in the parameter file. Lines are applied additively or multiplicatively, the latter to avoid "negative counts" absorption.
- Next step in code development is to scan spectra with multiple lines simultaneously, with a hierarchy of functional ties among parameters. (E.g., one set of redshift ties could be associated with similar ionization states, a second set of ties on wavelength and/or amplitude could be associated with line series.) Are absorbers only statistically significant in families of lines?



Acknowledgements

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