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TANAGRA: Timing Analysis of Grating Data

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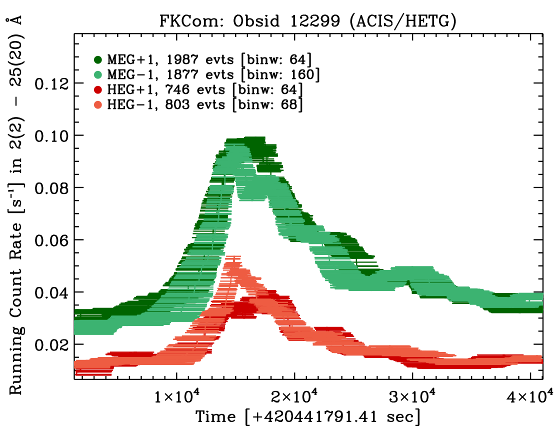
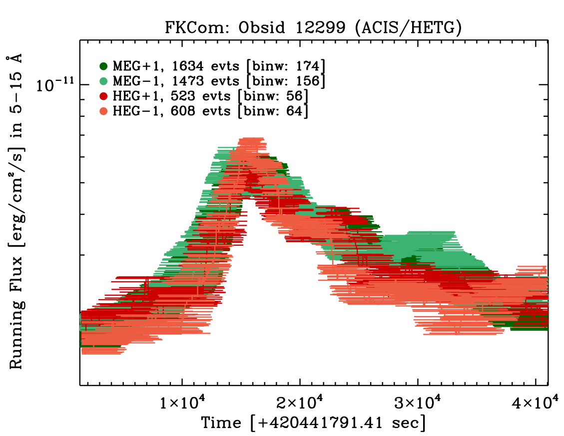
Chandra grating observations form an exceptional dataset of intrinsically interesting objects. They are long-duration and high-quality observations with high-resolutions achieved in both the temporal and spectral domains. Grating spectra of stellar coronae are particularly useful in this regard. Because spectral lines are sensitive to plasma temperature and in some cases to plasma density, detailed diagnostics can be obtained and their evolution tracked in time. For instance, the response of high-temperature lines to a flare can be tracked, as also the behavior of plasma density during a flare. Flares themselves can be found and counted in large numbers over the long exposures. However, the sheer magnitude of the data (currently at 63 objects and 200 ObsIDs) provide immense challenges to uniform analysis. Here, we describe some of the algorithms being brought to bear on the datasets. We focus on methods that provide quick summaries of the data, and show examples of their use. The *Tanagra* products are expected to be available online by the time of the Chandra XV Years Symposium.

Light Curves

We compute running mean light curves in order to avoid binning artifacts. The running mean is taken over a number of photons that is determined dynamically to produce the most useful time resolution. The number of photons is set such that the scatter in the averaged light curve matches the expected statistical scatter.

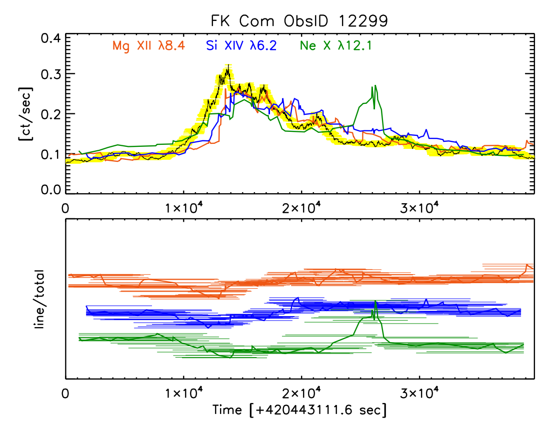


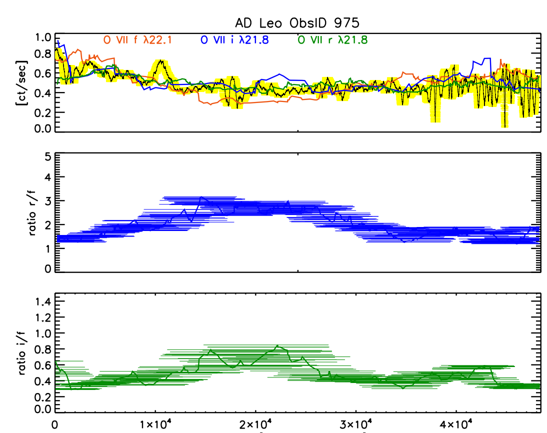


Top panel shows a running mean count rate curve for each of the grating arms for an observation of FK Com (ObsID 12299). **Bottom panel** shows the flux light curves computed over the 5-15 Å range. Horizontal bars denote the time range over which the average is computed. Error bars for individual points are not independent, but for those separated by the indicated width are.

Lines

The high spectral resolution available in these data allow us to explore the temporal variability in specific lines of interest that track temperatures and abundances. For instance, we can test whether the Ne X resonance line intensity and the density-sensitive O VII i/f ratio are correlated with flares.

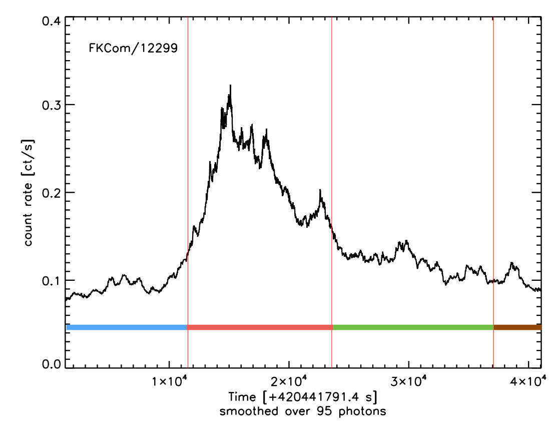


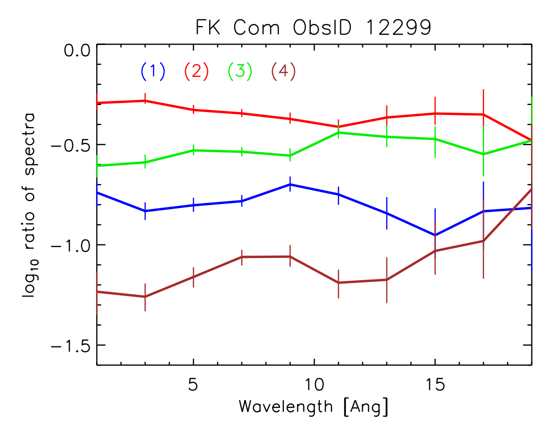


Top panel shows how high-T lines from Mg XII and Si XIV lag the flare onset on FK Com, while Ne X tracks it over most of the flare duration, but shows an excess afterwards. **Bottom panel** shows the temperature-sensitive O VII r/f and density sensitive O VII i/f ratios for AD Leo with a flare at the beginning of the observation. Neither ratio is correlated with the intensity.

Changepoints

We have developed an automated method to determine 2-D changepoints in spectro-temporal data (Wong et al., in prep). Changes in spectra are discerned via changes to a parameterized lines+continuum model in discrete time steps. Unlike the traditional Bayesian Blocks approach, this method is sensitive to changes in spectra as well as intensity.

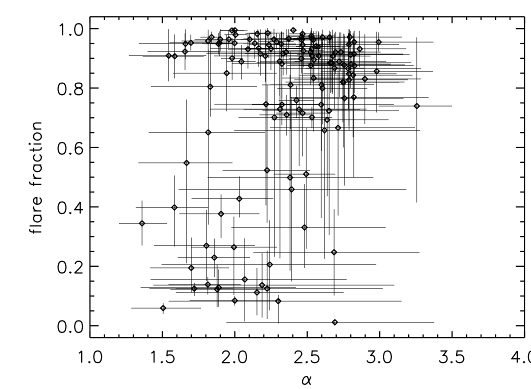


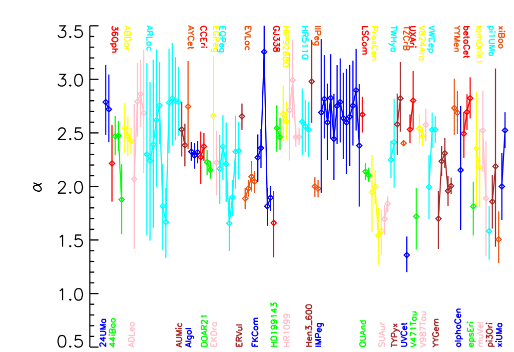


Top panel shows the spectro-temporal segments for FK Com (vertical dashed lines). **Bottom panel** shows the changes in the spectrum on a coarse scale in the different intervals.

Flare Distributions

It has been long known that flare numbers and intensities are distributed as power-laws, $dN(E)/dE \propto E^{-\alpha}$, on the Sun and Sun-like stars. On the Sun, $\alpha \approx 1.8$ over many orders of magnitude. On active stars, measurements of α are typically >2. We have developed a method (see Kashyap et al, 2002, ApJ; Kashyap et al. 2012, SCMA V) that uses a form of Approximate Bayesian Computation to model the photon arrival time differences and determine α down to milliFlare range on stars.





Top panel shows the estimated α and contribution of flares to the signal. **Bottom panel** shows the behavior of α when multiple measurements are possible for a given object. They are mostly consistent with error bars, but some large departures are seen.

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