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Project Tanagra: Stellar Flares in Chandra High−Resolution Spectra

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Abstract

We introduce **Project Tanagra: Timing Analysis of Gratings Data**, a uniform study of archival Chandra gratings observations of active low-mass coronal stars. We include ACIS-S/HETG, ACIS-S/LETG, and HRC-S/LETG observations. Gratings data are optimal for timing analysis since they are free from pile-up and allow for joint spectro-temporal analysis. We discuss techniques for timing analysis of gratings data and explore the distribution of stellar flare energies and the time variability of individual lines fluxes. Here we present preliminary results from four targets: AU Mic, AD Leo, Procyon and sigma Gem. The project website is:

`http://hea-www.harvard.edu/tanagra/`

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Goals

1. **Characterize flare distribution**
   - Processes that generate solar & stellar flares appear to be scale-free: distribution of flare energies is power-law.
   - Power-law distribution has been verified for the Sun over many orders of magnitude of flare energies and range of timescales (Aschwanden et al. 2000, ApJ, 535, 1047).
   - Power law index $\alpha \approx 1.8$ for Sun but generally > 2 for other active stars. Beyond $\alpha = 2$ it becomes possible to attribute all coronal luminosity to increasingly weaker, but more numerous, flares.
2. **Spectro-temporal analysis**
   - Examine changes in spectral lines to characterize variability at different temperatures in stellar coronae.

Processing

1. Download data products from Chandra archive, reprocess with CIAO 4.3, and extract source and background events from dispersed spectrum, 0th order, and transfer streak.
2. Make counts and flux lightcurves for broad band and strong spectral lines; compare line flux changes to overall luminosity variations.
3. Fit stochastic flare model to photon arrival time data using an MCMC-based method. This allows us to find the most likely value of α without direct flare detection. (See Kashyap et al. 2002, 2011 and Saar et al. 2011.)

Initial Results

- Four sources analyzed so far, see Table 1 for stellar and observation parameters, and best-fit α values.
- Example plots shown for AU Mic ObsID 17 (ACIS-S/HETG):
  1. High resolution spectra from MEG and HEG first order, and zeroth order.
  2. Counts and flux lightcurves for dispersed spectrum and zeroth order.
  3. Flux lightcurves for Fe XVII, O VIII, and Ne X lines.
  4. Fractional flare count rate versus α from MCMC iterations.
- An example of line flux variations with temperature, from previous work with Capella, is shown in Figure 5.

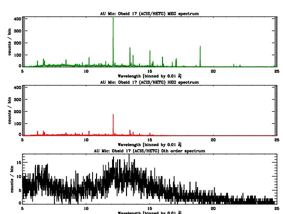

Figure 1 Background-subtracted spectra for AU Mic, ACIS-S/HETG ObsID 17, from MEG (top), HEG (middle) and zeroth order (bottom).

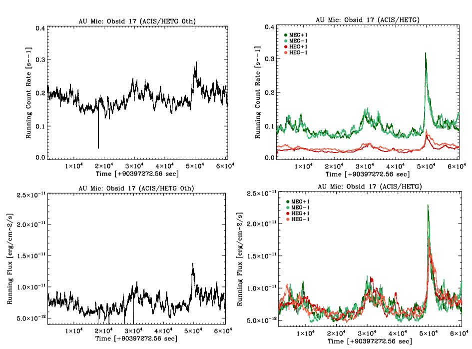

Figure 2 Background-subtracted running lightcurves for AU Mic, ACIS-S/HETG ObsID 17. Left: Zeroth order in counts (top) and flux (bottom). Right: Dispersed events, separated by grating arm and order, in counts (top) and flux (bottom).

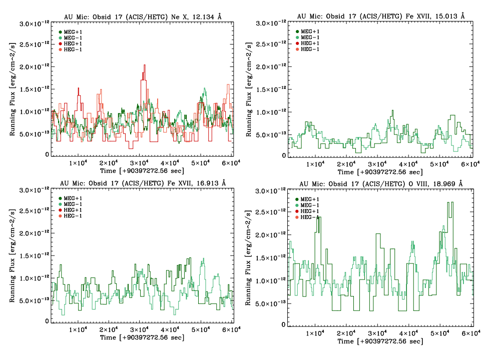

Figure 3 Background-subtracted running flux lightcurves for specific lines in the AU Mic dispersed spectrum (ACIS-S/HETG ObsID 17). Top: Ne X at 12.134 Å (left), Fe XVII at 15.013 Å (right). Bottom: Fe XVII at 16.913 Å (left), O VIII at 18.969 Å (right).

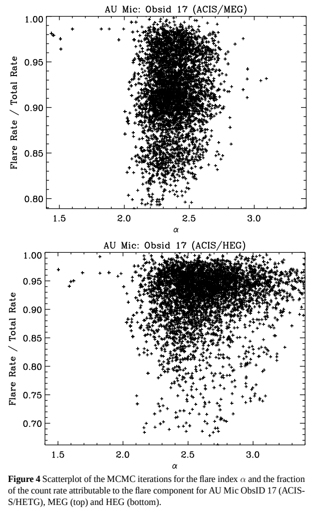

Figure 4 Scatterplot of the MCMC iterations for the flare index α and the fraction of the count rate attributable to the flare component for AU Mic ObsID 17 (ACIS-S/HETG), MEG (top) and HEG (bottom).

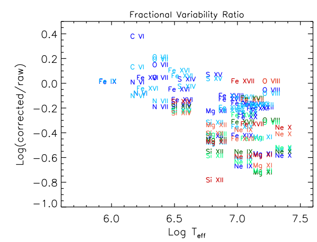

Figure 5 An example line flux variability at different temperatures, from previous work with Chandra gratings observations of Capella (Posson-Brown et al. 2011). Plotted is the log of the ratio of fractional variability ($\frac{\sigma}{\mu}$) in a given line, calculated with the secular (broad band) correction, to fractional variability calculated from the uncorrected line fluxes, as a function of temperature. The lines are color-coded according to grating arm and order: light blue is HRC-S/LEG -1, dark blue is HRC-S/LEG +1, light green is ACIS-S/MEG -1, dark green is ACIS-S/MEG +1, light red is ACIS-S/HEG -1, and dark red is ACIS-S/HEG +1. Ratio values less than one indicate that the fractional variability is greater without the secular correction, implying that the variability is due to the secular trend. The log ratio is anti-correlated with temperature (r=-0.52,p=1.03e-7), indicating that the secular variability is mainly due to hot lines, while cool lines exhibit significant non-secular variability.

Source	Spectral Type	Instrument	ObsID	Observation Date	Exposure (ks)	Best-fit α
Procyon	F5 IV-V	HRC-S/LETG	63	1999-11-06	70.15	1.86±0.29
			1224	1999-11-08	20.93	1.84±0.63
			1461	1999-11-07	70.25	2.26±0.50
			10994	2009-12-15	72.13	1.96±0.30
			12042	2009-12-26	65.84	1.87±0.54
sigma Gem	K1 III	ACIS-S/HETG	5422	2005-05-16	63.86	MEG: 2.67±0.22, HEG: 2.78±0.23
			6282	2005-05-17	58.88	MEG: 2.67±0.22, HEG: 2.64±0.54
AU Mic	M1 Ve	ACIS-S/HETG	17	2000-11-12	59.56	MEG: 2.31±0.16, HEG: 2.44±0.30
		HRC-S/LETG	8894	2008-06-26	50.18	2.08±0.54
AD Leo	M3.5 V	ACIS-S/HETG	2570	2002-06-01	45.90	MEG: 2.55±0.30, HEG: 2.60±0.31
		HRC-S/LETG	24	2000-01-22	10.12	2.01±0.64
			975	2000-10-24	48.41	2.11±0.59

Table 1 Source name, spectral type, Chandra instrument, ObsID, observation date, exposure time, and best-fit α and standard deviation for stars analyzed thus far in Project Tanagra. (For a full list of Tanagra project sources, see `http://hea-www.harvard.edu/tanagra/`.)

We note that the best-fit α values for AD Leo are consistent with previous measurements based on EUVE data (Kashyap et al. 2002, Güdel 2004).

References

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