#55 :: 8 Years of Science with Chandra Symposium :: 2007 Oct 22–25 Huntsville AL

Detection of Short Timescale Variability in Capella

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Capella is a bright active binary (G1 III/G8 III; **Figure 1**) whose coronal luminosity has been remarkably steady over many decades of EUV and X-ray observations, and thus has been a frequent target for calibration observations. Numerous studies have attempted to detect intensity variability on it over various timescales, and have found long term variations of $\sim 10-20\%$. Here, we analyze 205 ks of Capella data (**Figure 2, Table 1**) obtained for calibration purposes with the HRC-I on Chandra. Capella registers at approx 22 ct s^{-1} in this configuration, and due to the high data quality, we unambiguously detect variability at various timescales. We find that a clear signal for variability is present for timescales $\lesssim$ 20 ks (**Figure 3**), and that the light curves show evidence for excess fluctuation over that expected from a purely Poisson process (**Figure 4, Table 2**). This overdispersion is consistent with variability at the 2-7% level, and suggests that the coronae on the binary components of Capella are composed of low-density plasma and low-lying loops.

Table 2. Overdispersion

δ [s]	$\rho_{\rm frac}$	$\rho_{\rm diff}$	ρ_{χ^2}
		mean±stddev	
25	1.35±0.15	0.84±0.40	1.83±0.40
50	1.41±0.31	1.08±1.26	2.06±1.25
100	1.50±0.43	1.44±1.87	2.39±1.84
		min/median/max	
25	1.03 / 1.37 /1.71	0.07 / 0.87 / 1.93	1.06 / 1.86 / 2.92
50	1.02 / 1.39 / 3.06	0.05 / 0.92 / 8.35	1.04 / 1.90 / 9.26
100	1.00 / 1.45 / 3.41	-0.01 / 1.09 / 10.64	0.97 / 2.05 / 11.42

Table 1. *Chandra*/HRC-I observations of Capella

ObsID	Start Time [yr-mon-day hr:min:sec]	Exposure [s]	SIM Offset [mm]	count rate [ct s^{-1}]
6558	2006-01-10 14:33:16	5142.0	-57	20.52 ± 0.068
6557	2006-01-10 13:01:26	5137.9	-54	20.15 ± 0.067
6556	2006-01-10 11:29:36	5141.9	-51	20.07 ± 0.066
6555	2006-01-10 09:44:07	5135.6	-48	20.23 ± 0.066
6554	2005-12-23 02:32:04	5139.8	-45	21.16 ± 0.067
8359	2007-01-21 16:29:27	5124.5	-42	22.55 ± 0.069
8358	2007-01-20 22:43:07	5130.1	-39	22.98 ± 0.069
8357	2007-01-20 21:11:17	5132.1	-36	22.61 ± 0.068
8356	2007-01-20 19:17:53	4743.4	-33	22.75 ± 0.071
8355	2007-01-17 23:12:05	5133.3	-30	21.37 ± 0.066
8354	2007-01-17 21:40:15	5117.3	-27	21.38 ± 0.065
8353	2007-01-17 20:08:25	5128.8	-24	21.48 ± 0.065
6553	2005-12-20 01:30:43	5187.0	-21	21.26 ± 0.064
6552	2005-12-25 10:08:33	5146.2	-18	21.70 ± 0.065
6551	2005-12-25 08:36:43	5142.7	-15	21.81 ± 0.065
6550	2005-12-25 07:04:53	5146.9	-12	21.91 ± 0.065
6549	2005-12-25 05:14:59	5140.4	-9	21.72 ± 0.065
6548	2005-12-23 01:00:14	5137.2	-6	20.92 ± 0.064
6547	2005-12-22 23:20:27	5141.3	-3	21.02 ± 0.063
6559	2006-01-10 16:05:06	5140.7	0	19.69 ± 0.061
8360	2007-01-21 18:15:43	5102.4	0	21.82 ± 0.065
6540	2005-12-06 16:01:25	5138.5	3	22.15 ± 0.065
6541	2005-12-07 20:58:02	4756.7	6	21.83 ± 0.068
6542	2005-12-07 22:39:40	5109.5	9	21.46 ± 0.065
6543	2005-12-06 17:52:33	5146.6	12	22.58 ± 0.067
6544	2005-12-06 19:24:23	5158.8	15	22.71 ± 0.067
6545	2005-12-19 22:12:06	5139.1	18	21.43 ± 0.065
6546	2005-12-20 00:05:46	5140.4	21	21.66 ± 0.066
8352	2007-01-17 18:36:36	5129.6	24	21.36 ± 0.065
8351	2007-01-17 17:04:46	5129.6	27	21.15 ± 0.065
8350	2007-01-17 15:32:55	5129.8	30	21.07 ± 0.065
8349	2007-01-17 14:01:05	5131.5	33	21.21 ± 0.065
8348	2007-01-17 12:29:16	5129.9	36	21.11 ± 0.065
8347	2007-01-17 10:57:25	5132.1	39	20.80 ± 0.065
8346	2007-01-17 09:25:36	5131.8	42	21.16 ± 0.066
8345	2007-01-17 07:42:33	5130.1	45	21.03 ± 0.066
8344	2007-01-15 06:10:28	5236.3	48	21.17 ± 0.065
8343	2007-01-15 04:36:53	5236.6	51	21.31 ± 0.066
8342	2007-01-15 03:03:18	5236.5	54	21.49 ± 0.066
8341	2007-01-15 01:15:47	5192.1	57	21.76 ± 0.068

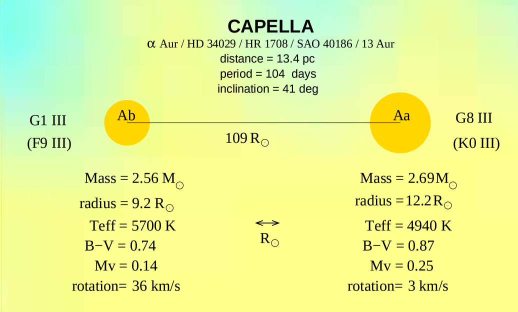

Figure 1: A scaled sketch of the Capella system

Figure 2: 205 ks of Capella with the *Chandra*/HRC-I. The combined light curve of all the observations are shown. The black histogram denotes the count rate for a binning of 100 s, and overlaid on it is the count rate for a binning of 500 s (green histogram). The data gaps between observations are excluded, and indicated by vertical red lines (solid when the gaps are > 100 s, dashed otherwise). The data comprise 40 ObsIDs (noted at the top of each segment, along with the day since 2005-dec-01 that the observation started). The SIM offset at which each observation is carried out is indicated at the bottom of each segment.

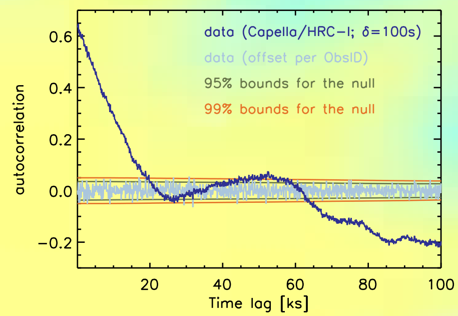

Figure 3: Autocorrelation in the light curve of Capella. The autocorrelation for a light curve binned by 100 s is shown as the dark blue curve, computed for different lag times. The expected autocorrelation for a light curve with no variability is 0 for all non-zero lag times, and the 95% and 99% uncertainty bounds on it are shown as horizontal lines (green and red respectively). The bounds are computed via Monte Carlo simulations of a flat light curve with the same mean and number of bins. There is clear evidence for variability at timescales $\lesssim$ 20 ks. In contrast, the autocorrelation for a light curve constructed by offsetting it by the mean count rate in each ObsID (pale blue curve) shows no evidence of variability.

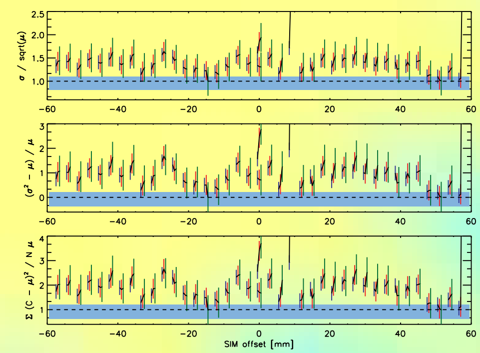

Figure 4: Overdispersion in the light curve in each Capella ObsID. The overdispersion measures $\rho_{\rm frac}$ (top), $\rho_{\rm diff}$ (middle), and ρ_{χ^2} (bottom) are calculated for each ObsID for different values of the light curve bin sizes $\delta = 25, 50, 100$ s, and are denoted by the thin vertical lines grouped around the SIM offset for that observation. The lines are offset from each other for clarity and have δ increasing from left to right, and the measured values for each ObsID are connected by dark lines. The vertical lines represent the $\pm 3\sigma$ error bars for the *null*, determined from Monte Carlo simulations of a model without any intrinsic variability but matching the count rate and exposure time of the observation. The values expected for the null model are shown for each $\rho_{()}$ as the horizontal dashed line. The overdispersion measures computed for the combined HZ 43 data (for a binning that matches $\delta = 25$ s for Capella) is shown as the pale blue band whose width corresponds to the $\pm 3\sigma$ error bounds determined the same way as for Capella.

MEASURE OF OVERDISPERSION

$$\rho_{\rm frac} \equiv \frac{\sigma_J(\delta)}{\sqrt{\mu_J(\delta)}}$$

$$\rho_{\rm diff} \equiv \frac{\sigma_J^2(\delta) - \mu_J(\delta)}{\mu_J(\delta)}$$

$$\rho_{\chi^2} \equiv \sum_{i=1}^{N_\delta} \frac{[C(t_i; J, \delta)^2 - \mu_J(\delta)]^2}{N_\delta \mu_J(\delta)}$$

CALIBRATION

- Crucial because observations are done at different locations on the HRC-I
- Relative QE calibration accurate to $\approx$ 1% (Posson-Brown & Kashyap, 2007, CCW#124)
- Effect of correcting light curves for QE variations is negligible; overdispersion values are changed by $\lesssim$ 3%
- Comparison with HZ 43, a DA White Dwarf with no known variability, hence ideal comparison target
- $\approx 10^5$ ct observed over 31.3 ks at the aimpoint, similar to Capella in 5 ks: overdispersion at various bin sizes are fully consistent with statistical error

SUMMARY

- We have analyzed a deep *Chandra*/HRC-I observation of the active binary Capella, which is expected to vary at all timescales, but hasn't been seen to
- We confirm the existence of long duration variability on Capella
- We detect the existence of short timescale variability, which is decoupled from the longer timescales (autocorrelation zero-crossing at ~20 ks)
- We analyze each of the independent 5 ks observation segments and find that the counts are overdispersed compared to Poisson
- The observed overdispersion is consistent with intensity variations of $\approx 2-7\%$ over 5 ks (and thus cannot be part of a long term trend)
- This suggests that the coronal plasma density must be $n_e \lesssim 10^9$ cm^{-3} and that the coronal loops are likely low-lying, with heights $\sim 10^9$ cm

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This research was supported by NASA contract NAS8–39073 to the Chandra X–Ray Center