Simultaneous optical and X-ray variability in the stars with disks in NGC 2264

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Introduction

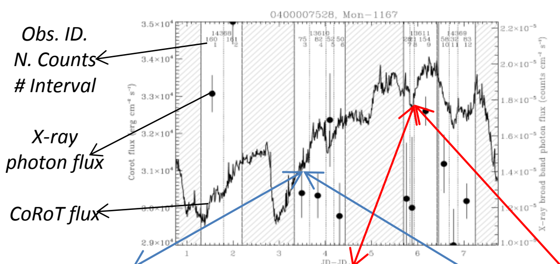
The Coordinated Synoptic Investigation of NGC 2264 (Cody et al. 2014; Stauffer et al 2014) is an unprecedented project involving 15 space and ground telescopes, some of which observed NGC 2264 simultaneously, aimed of studying the time variability of young (1-5 Myrs) stars. We present the analysis of simultaneous optical (CoRoT) and X-ray (Chandra/ACIS-I) observations of 74 stars with disks.

Analysis of the simultaneous CoRoT and ACIS data

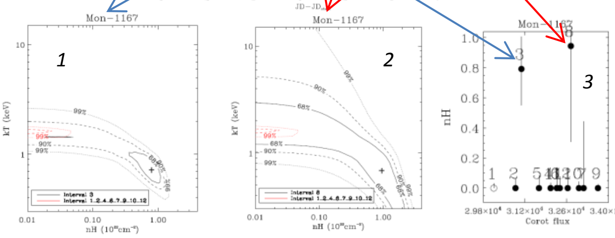
We analyze the white flux CoRoT light curves and the X-ray properties of stars with disks detected both with CoRoT and Chandra. CoRoT light curves are cleaned following the standard reduction pipeline. ACIS events are extracted with ACIS Extract *(Broos et al. 2010)*; spectral analysis performed with Xspec v.12.8.1 *(Arnaud 1996).*

Increasing X-ray absorption during optical dips

In 9/33 stars with variable extinction we observe increasing X-ray absorption during the optical dips, indicating that the circumstellar material is absorbing both the photospheric and the coronal emission.

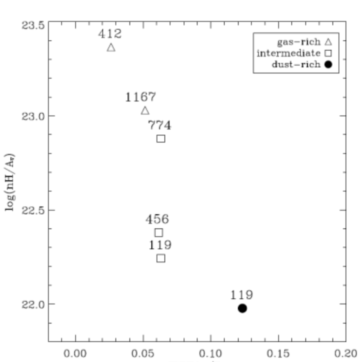


The CoRoT light curves are divided into time intervals which contain dips and bursts, and where we estimate the observed X-ray properties (photon and energy fluxes, NH, kT, etc..)



We analyze the variability of the X-ray properties in the time intervals from the best fit thermal models and verify the results studying the C-stat contours. In Mon-1167, in #3 N_H is larger than other intervals at >68% confidence (Fig. 1); in #8 N_H is the largest from the best fit (Fig. 3) but also N_H=0 at 68% confidence (Fig. 2).

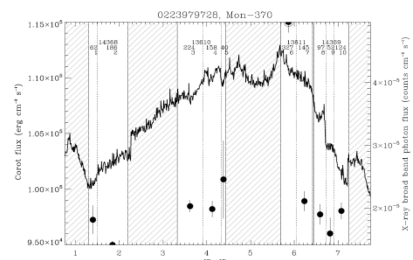
Star	Interval	ΔF_{CoRoT}	ΔAv	ΔnH_{dip}	nH_{aver}	nH/Av	$FWHM_{dip}$	P_{star}	$FWHM_{dip}/P_{star}$
MON-name		%	mag	$10^{22}cm^{-2}$	$10^{22}cm^{-2}$	$10^{22}\ cm^{-2}\ m^{-1}$	days	days	
119	4	8.9	0.12	$0.21^{0.44}_{0.05}$	$0^{0.03}$	1.75	0.2	3.3	0.06
119	6	15.7	0.22	$0.21^{0.44}_{0.05}$	$0^{0.03}$	0.95	0.4	3.3	0.12
412	6	3.5	0.05	$1.20^{1.58}_{0.97}$	$0.04^{0.12}$	23.2	0.2	6.8	0.03
456	6	15.2	0.21	$0.51^{0.74}_{0.33}$	$0^{0.03}$	2.4	0.3	5.1	0.06
774	5	5.7	0.08	$1.07^{1.26}_{0.88}$	$0.54^{0.79}_{0.30}$	7.57	0.2	3.5	0.06
1076	2	10.65	0.15	$1.67^{2.16}_{1.16}$	$0^{0.01}$	11.4	2.7		
1167	3	5.5	0.07	$0.79^{1.01}_{0.55}$	$0^{0.06}$	10.7	0.5	8.8	0.05



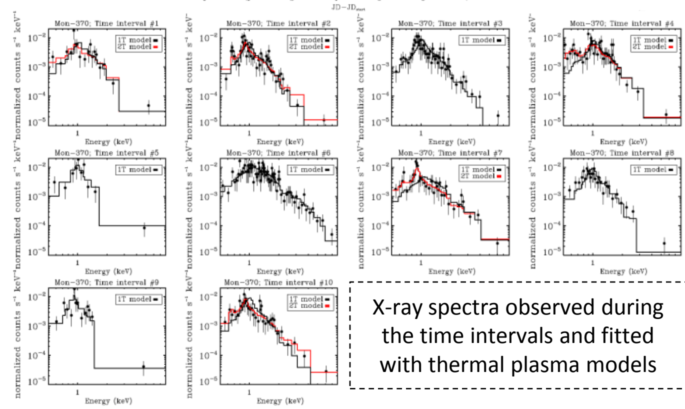
For 7 dips, we calculate: $N_{H(dip)}$ in excess with respect the other intervals; $A_{V(dip)}$ from the reduction of CoRoT flux, and then $N_{H(dip)}/A_{V(dip)}$. In this way, we infer the composition of the obscuring material, being not dust-rich in 6/7 dips, and with $FWHM_{dip}/P_{star}$ < 0.2 which is typical of occultations by accretion streams *(Stauffer et al. 2015)*

Soft X-ray excess during the optical bursts

In 5/27 stars with optical bursts the X-ray spectrum during the bursts show excess of soft X-ray emission (e.g. the fit with 1T thermal plasma model is not good and the emission below 1 keV is larger than the prediction from the 1T best fit model).



Soft X-ray excess in #4 and #7. Evident bursts in #4.



X-ray spectra observed during the time intervals and fitted with thermal plasma models

During six bursts we calculate the pre-shock velocity from kT_{soft} from spectral fit using 2T thermal plasma model (set equal to the post-shock temperature) as: $v_{pre}^2 = \frac{16kT_{post}}{3\mu m_H}$;

and the free-fall radius as: $R_{ff} = {}^{1}/_{(R_{star}^{-1} - v^2/(2GM_{star}))}$

Star	T_{soft}	v_{presh}	R_{FF}	v_∞	$EW_{H\alpha}$
Mon-	keV	km/s	R_{star}	km/s	Å
326	$0.15^{0.25}_{0.07}$	355^{458}_{242}		394	27.9
357	$0.06^{0.07}_{0.04}$	224^{242}_{183}	$8.5^{12.7}_{7.3}$	454	8
370	$0.16^{0.24}_{0.12}$	366^{449}_{317}	$2.0^{2.6}_{1.3}$	512	113.2
474	$0.66^{0.82}_{0.31}$	744^{829}_{510}		423	104.7
474	$0.25^{0.35}_{0.16}$	458^{542}_{366}		423	104.7
808	$0.15^{0.21}_{0.11}$	351^{420}_{304}	$3.7^{4.9}_{2.9}$	519	50.2

Typically R_{cor} ranges from 5 and 10 R_{star} in T Tauri stars. In Mon-326 R_{cor} is 12.3 R_{star}

The soft X-ray excess is likely due to the emission from the accretion shocks. In Mon-370 and Mon-808, the free-fall radii are smaller than the co-rotation radii, which is typical in unstable accretion.