X-Ray Universe - 2017

Time resolved X-ray spectral analysis during optical dips and accretion bursts in stars with disks of NGC2264 from Chandra/ACIS-I and CoRoT data

Time resolved X-ray spectral analysis during optical dips and accretion bursts in stars with disks.

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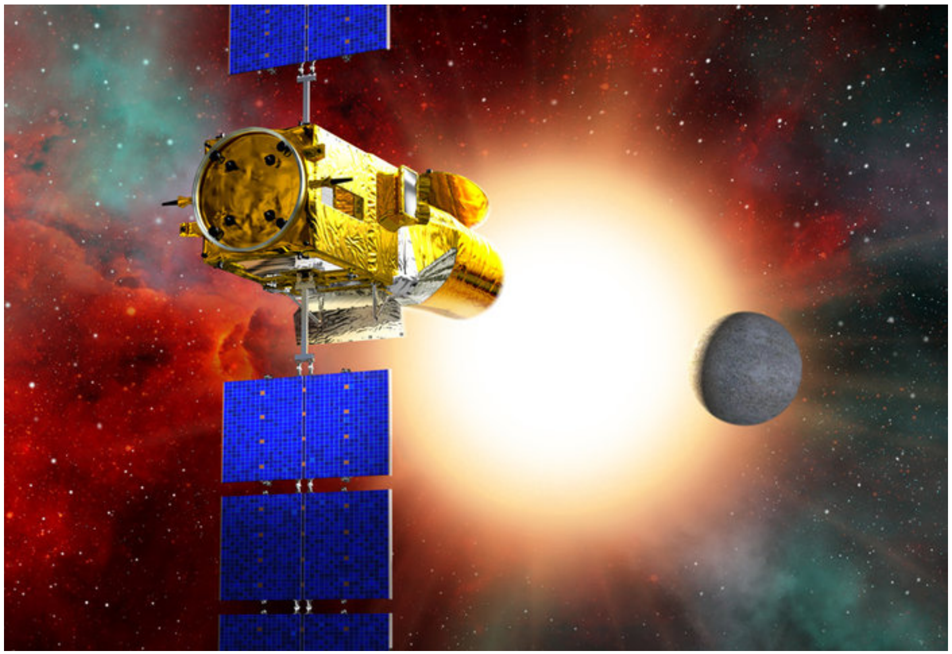
COnvection ROtation and planetary Transits (CoRoT)



CoRoT was a pioneering stellar seismology and exoplanet hunting mission that ran from 2006 to 2014.

CoRoT collected about 160000 light curves with a cadence of 512 sec, or 32 sec for the brighter sources.

CoRoT observed stars in two regions with 10˚ diameter close to the galactic center and anticenter.

NGC 2264

About 2000 sources up to O7V: **the only cluster within 1 kpc from the Sun, besides the ONC, with such a large mass spectrum**.

NGC 2264 is the only young cluster (1-5 Myrs, 760 pc, low average extinction) falling in one of the CoRoT eyes: **A unique opportunity to study variability in Pre-Main Sequence stars.**

Optical image of NGC 2264

The Coordinated Synoptic Investigation of NGC2264

An unprecedented cooperative project involving simultaneous observations of NGC 2264 with 15 ground and space telescopes, from X-rays to mid-infrared. *[e.g. Cody et al. 2014]*

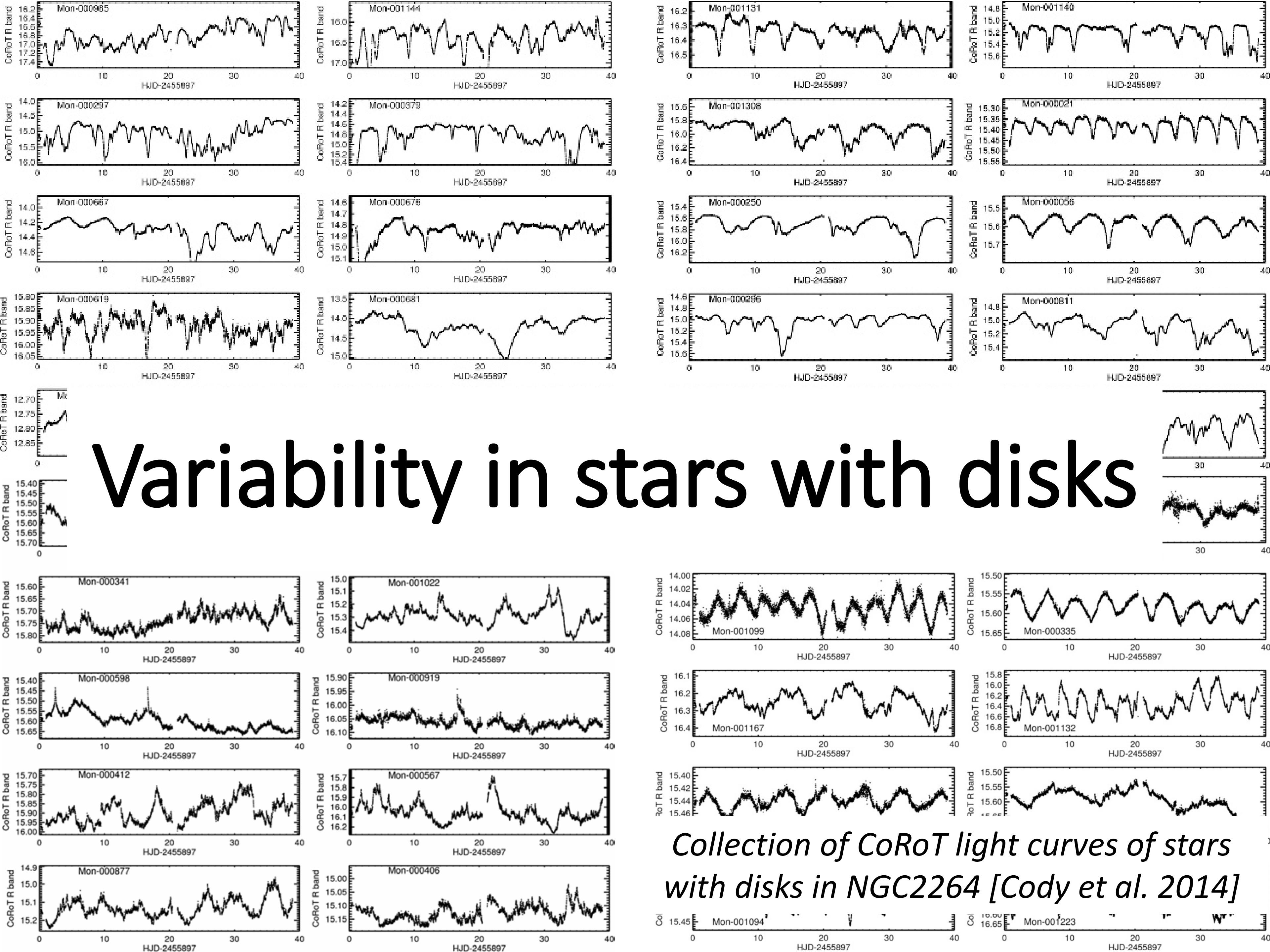
TABLE 1
Coordinated Synoptic Investigation of NGC 2264: observations

Telescope	Instrument	Dates	Band(s)	Time Sampling
Spitzer	IRAC/mapping	Dec. 3, 2011–Jan. 1, 2012	3.6 μm, 4.5 μm	101 min
Spitzer	IRAC/staring	Dec. 3; Dec. 5–6; Dec. 7–8; Dec. 8–9, 2011	3.6 μm, 4.5 μm	15 s
CoRoT	E2 CCD	Dec. 1, 2011– Jan 3, 2012	3000-10000Å	32 s (high cadence), 512 s
MOST	Science CCD	Dec. 5, 2011–Jan. 14, 2012	3500–7500Å	24.1, 51.2 s[1]
Chandra	ACIS-I	Dec. 3, 2011–Dec. 9, 2011	0.5–8 keV	~3.2 s[2]
VLT	Flames, UVES	Dec. 4, 2011–Feb. 29, 2012	4800–6800Å	20–22 epochs
CFHT	MegaCam	Feb. 14, 2012–Feb. 28. 2012	u,r	30 epochs
PAIRITEL	2MASS camera	Dec. 5, 2011–Jan. 3, 2012	J,H,K	1–12 epochs
USNO 40-inch telescope	CCD	Nov. 22, 2011–Mar. 9, 2012	I	912–1026 epochs
Super-LOTIS	CCD	Nov. 11, 2011–Mar. 1, 2012	I	495–522 epochs
NMSU 1m telescope	CCD	Oct. 12, 2011–Mar. 4, 2012	I	47–54 epochs
Lowell 31-inch telescope	CCD	Oct. 12, 2011–Jan. 14, 2012	I	44 epochs
OAN 1.5m telescope	CCD	Jan. 10, 2012–Feb. 15, 2012	V, I	23–28 epochs
KPNO 2.1m telescope	FLAMINGOS	Dec. 16, 2011–Jan. 3, 2012	J,H,K_S	40–52 epochs
FLWO 60-inch telescope	KeplerCam	Nov. 30, 2011–Jan. 26, 2012	U	35–60 epochs
ESO 2.2m telescope	WFI	Dec. 24, 2012–Dec. 29, 2011	U, V, I	25–45 epochs
CAHA 3.5m telescope	Omega 2000	Dec. 5, 2011–Feb. 18, 2012	J,H,K	35 epochs
CAHA 3.5m telescope	LAICA	Jan. 25-26, 2012	u, r	20 epochs

300 ksec in four epochs of **Chandra/ACIS-I** exposure during CoRoT observation

A total of 694 X-ray sources validated, **86 known stars with disks.**

Variability in stars with disks



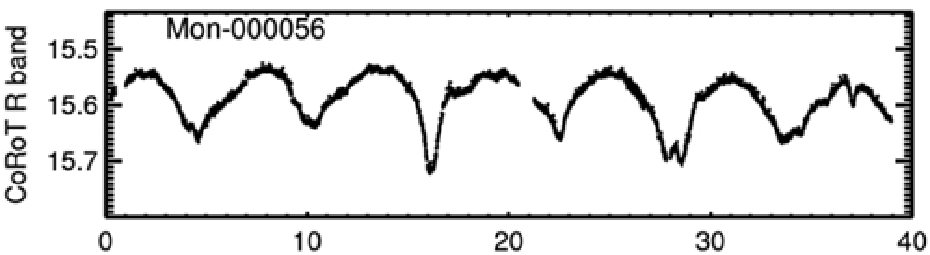
Collection of CoRoT light curves of stars with disks in NGC2264 [Cody et al. 2014]

Optical variability in stars with disks – disk warps

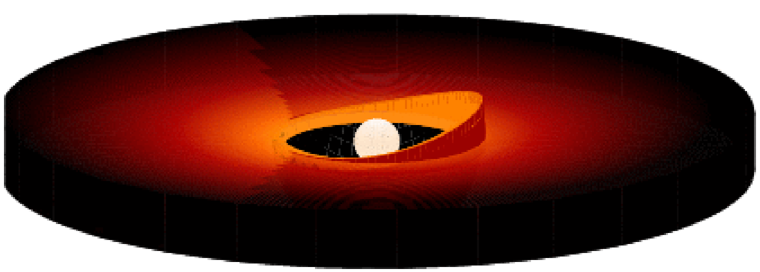
- Recurrent occultation of the central star by warps in the circumstellar disk located close (**few 0.1 AU**) to the co-rotation radius, stable when due to misaligned rotation and magnetic axis (AA Tau variability) *[e.g. Bouvier et al. 1999]*.

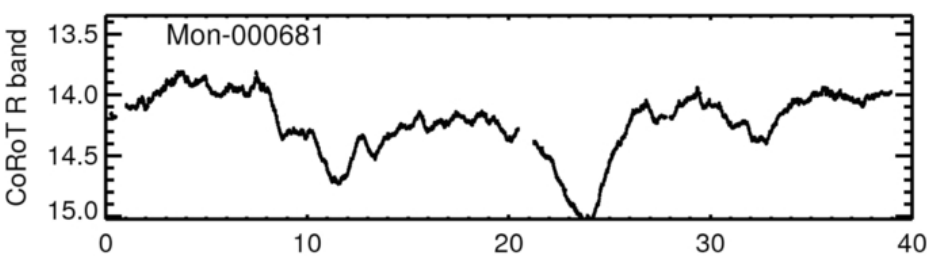
- 40% of the stars with inner disks in NGC2264 are characterized by AA Tau-like variability *[Alencar+2010]*

- Defined as “dippers” by Cody et al. 2015 (21.5% of the whole sample)



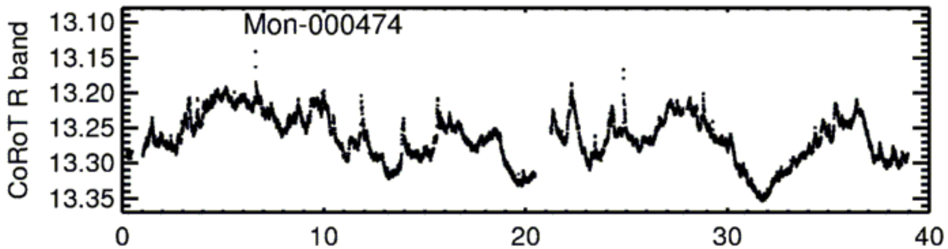
Two stars with dips observed with CoRoT in NGC2264 [Cody et al. 2014]





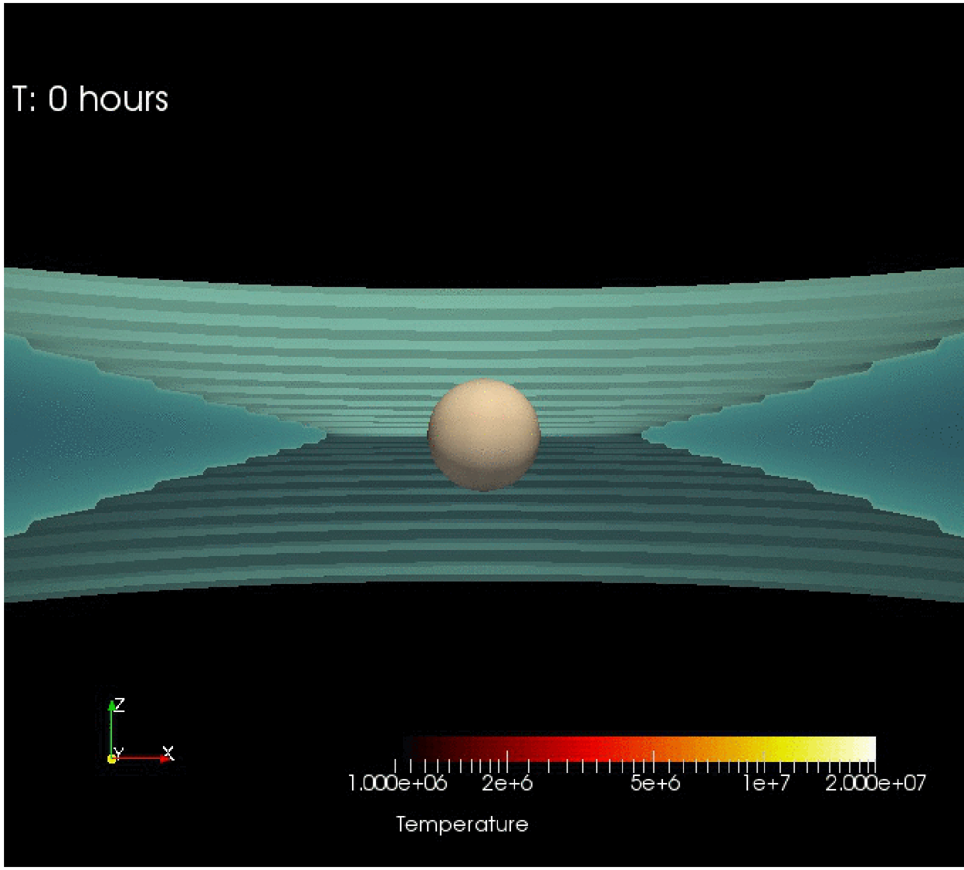
Optical variability in stars with disks - accretion

- accretion can be unsteady and produce short (hours to ~1 day) bursts (5%-50% quiescent level) *[Stauffer et al. 2014]*. 13% of stars with disks in NGC2264 (bursters)



- Accretion streams, which may contain also dust, can obscure the central star and produce narrow dips with $FWHM_{dip}/P_{star}$ < 0.25 *[Stauffer et al. 2015]*

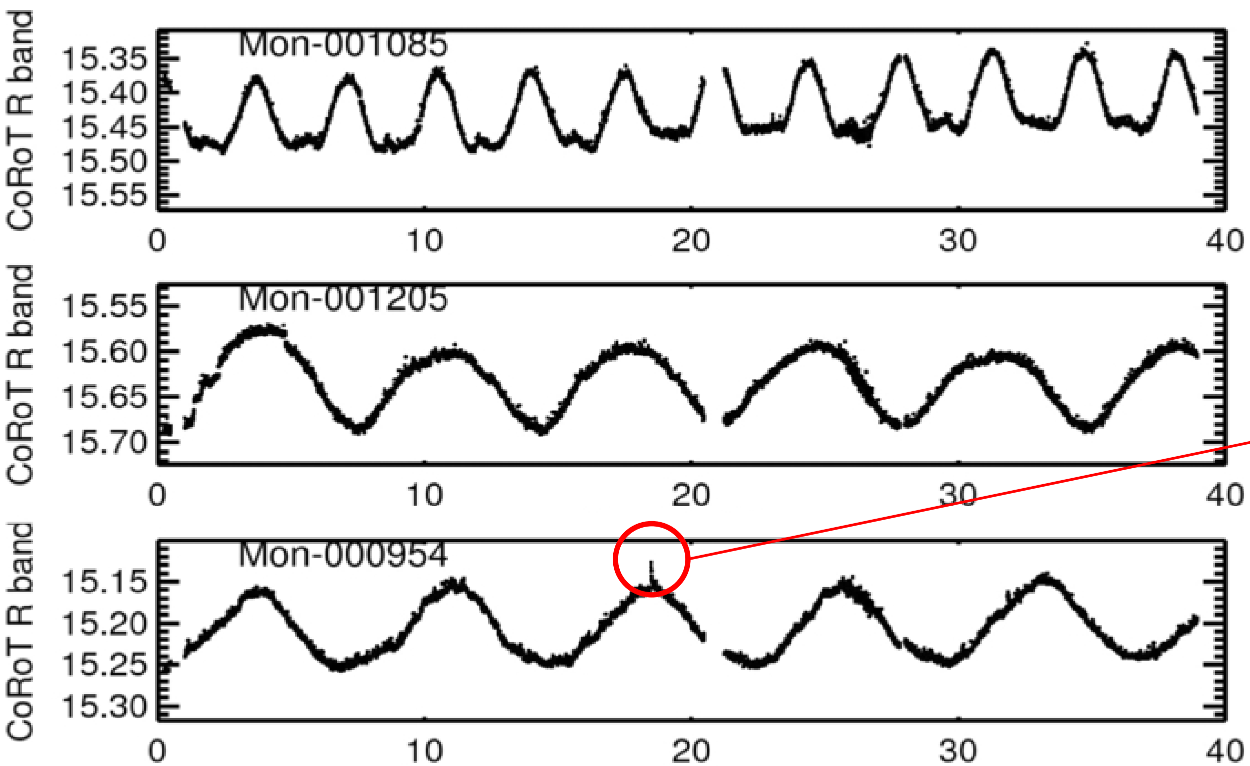
- The energetic optical emission from accretion hot spots (10^4K blackbody) can be modulated by stellar rotation



Simulation of unsteady accretion onto a $1M_{\odot}$ class II star [Colombo et al. in prep.]

Optical variability in stars with disks – stellar activity

- Rotational modulation of photospheric spots.
- Intense flares observed in PMS stars *[e.g, Flaccomio et al. 2003]*; they can be so powerful to be compatible with very large loops reaching the surface of the inner disks *[Favata et al. 2005]*.



Stars with periodic variability (and one flare) observed with CoRoT in NGC2264 [Cody et al. 2014]

X-ray variability in stars with disks

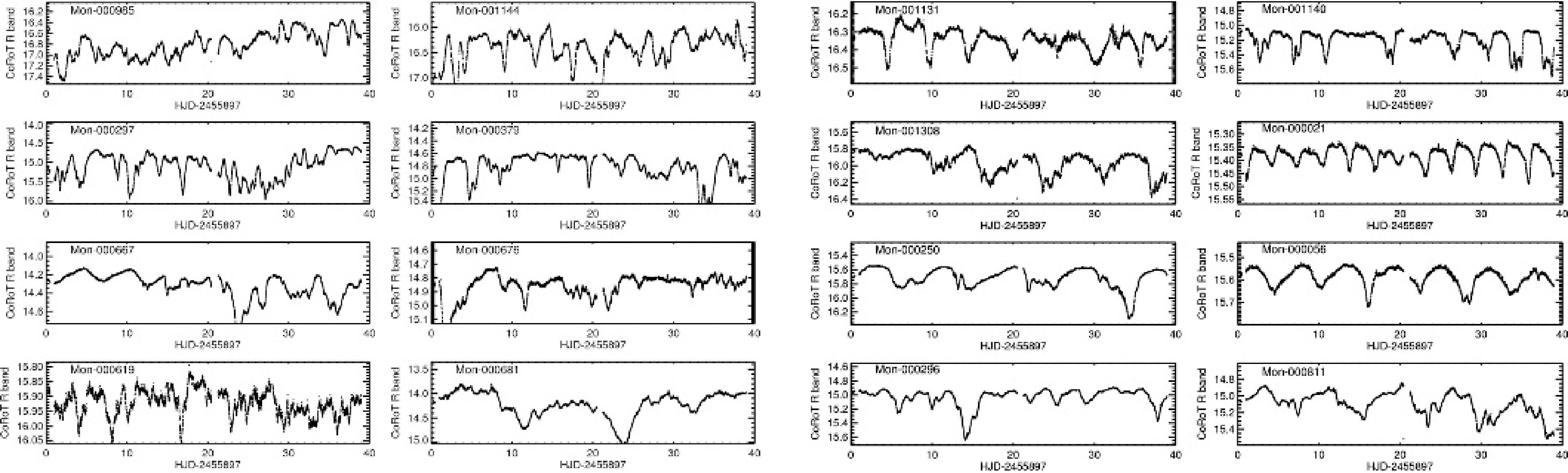
- Accretion contributes to soft X-rays emission *[e.g. Kastner et al. 2002]*, produced in the accretion shocks (e.g. TW Hya and BP Tau, *[Kastner et al. 2002; Stelzer & Schmitt 2004; Schmitt et al. 2005; Argiroffi et al. 2011; Curran et al. 2011]*). But difficult to distinguish from the coronal soft X-ray emission and self-absorption is crucial *[Argiroffi et al. 2011; Bonito et al. 2014]*.

- Soft X-ray emission from accretion spots can be rotationally modulated (e,.g. V4046 Sgr *[Argiroffi et al. 2012]*).

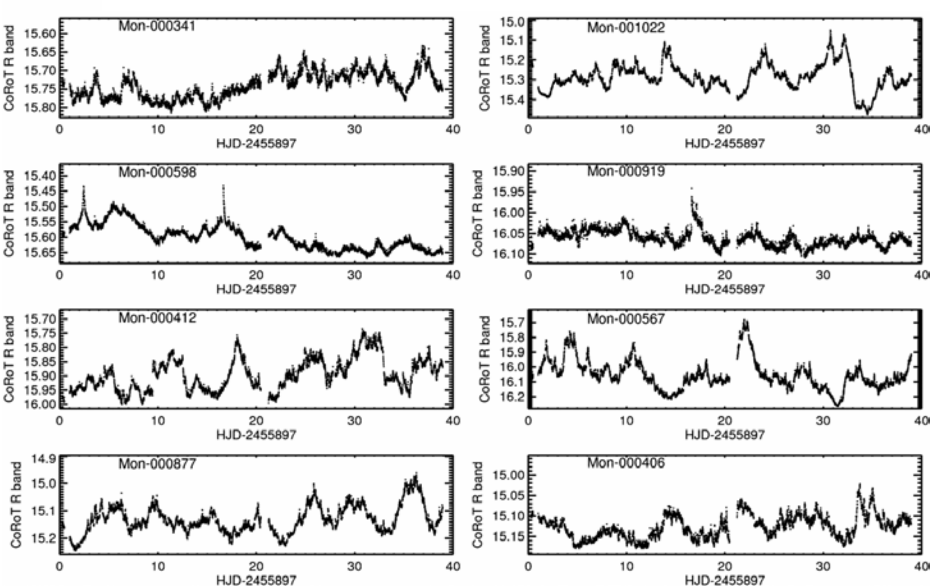
- Variable absorption of the coronal emission by circumstellar and accreting material *[e.g., Flaccomio et al. 2010]*.

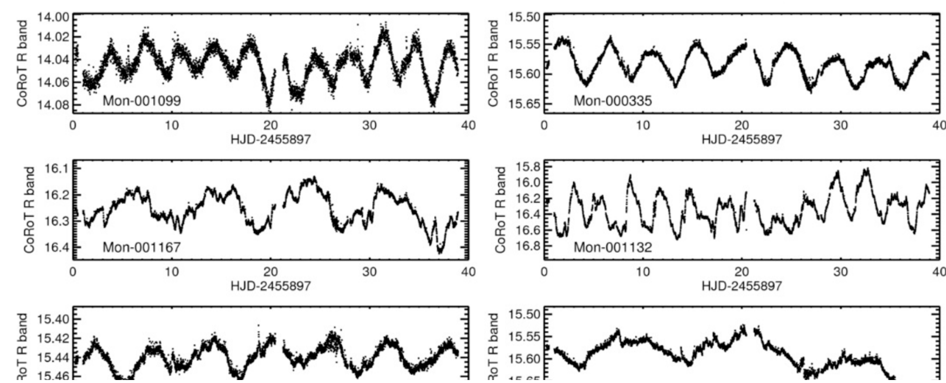
- The most evident source of X-ray variability is flares.

- X-ray emission from coronal active regions can be modulated by stellar rotation *[e.g. Flaccomio et al. 2005]*.

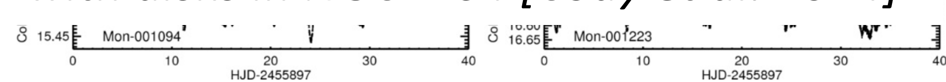


Variability NGC 2264 stars with disks





Collection of CoRoT light curves of stars with disks in NGC2264 [Cody et al. 2014]

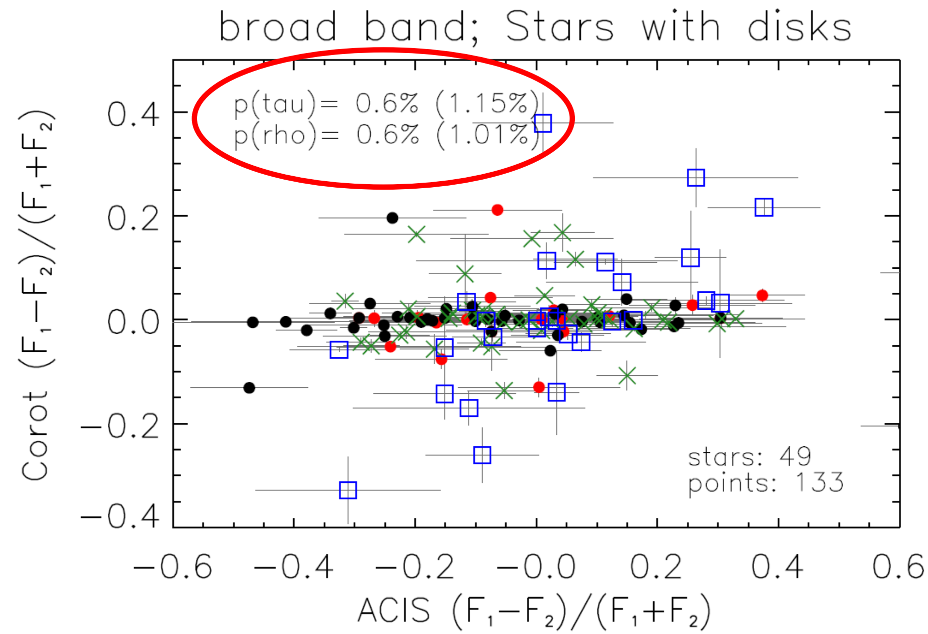


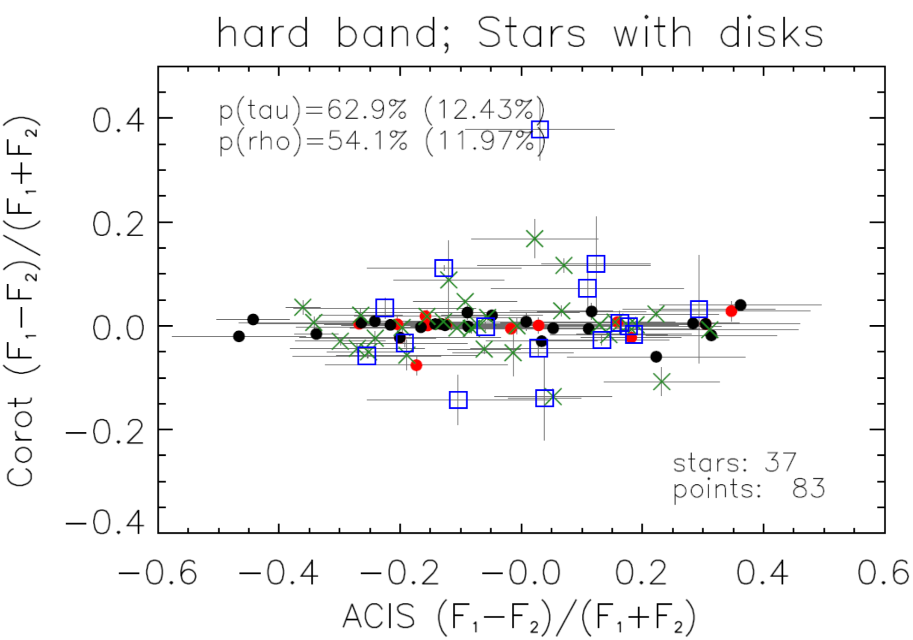
Global Optical vs. X-ray variability observed

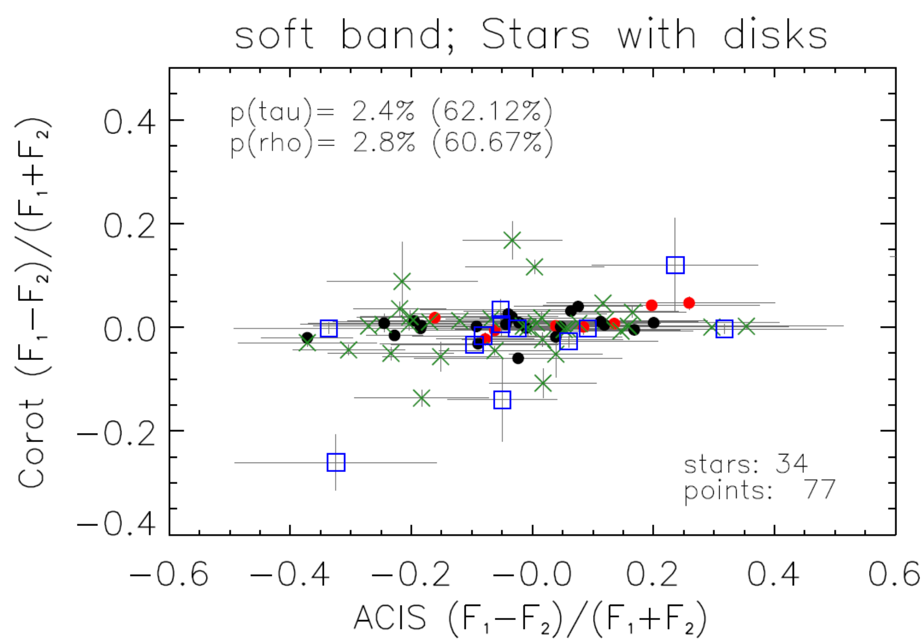
Comparison of the flux observed in two consecutive Chandra epochs in:

i) Stars with at least two epochs with more than 10 X-ray counts

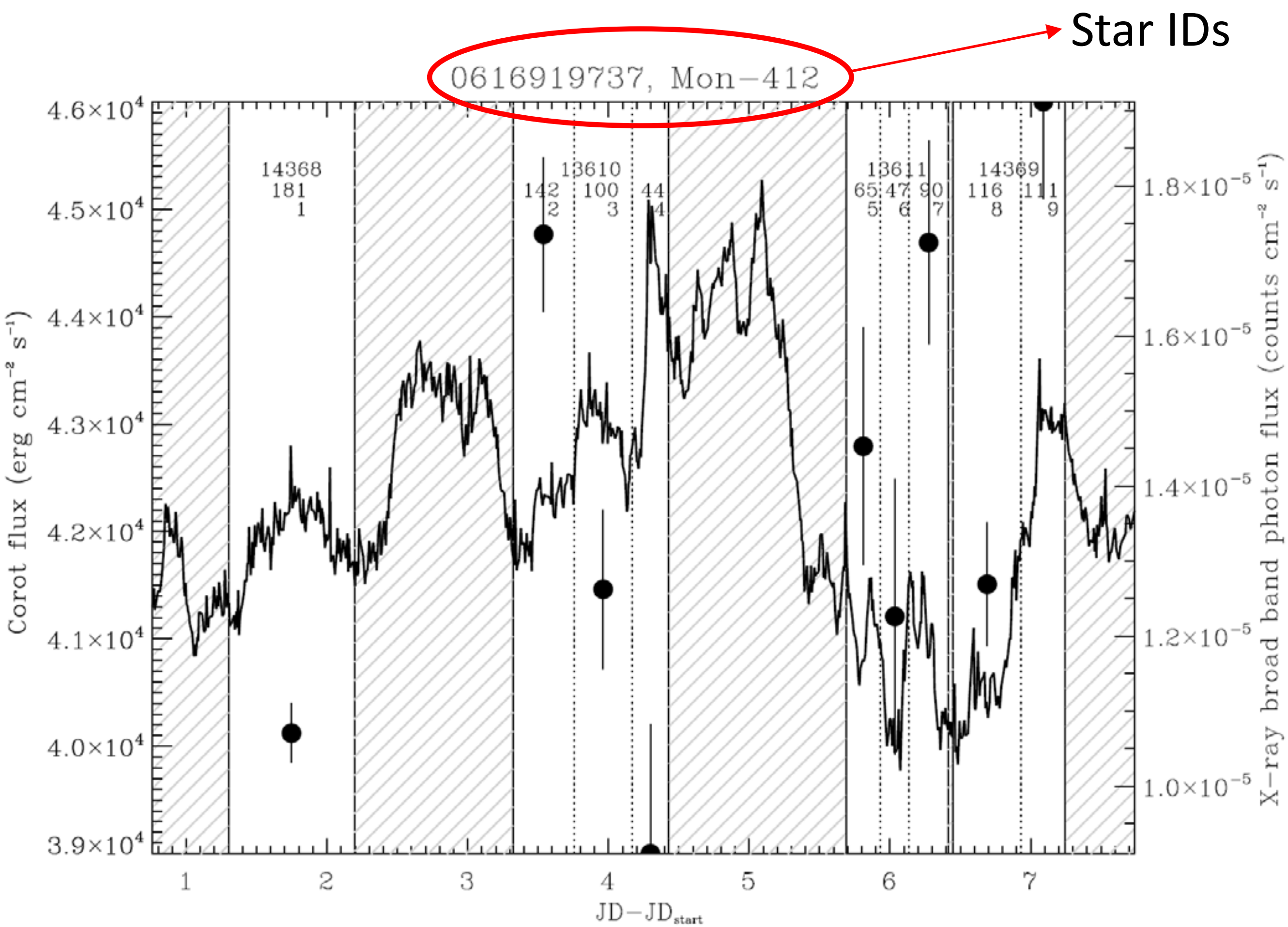
ii) Stars with variability classified by Cody et al. 2015: blue (stars with dips), red (bursters), black (the others)







The analysis – CoRoT light curves as template



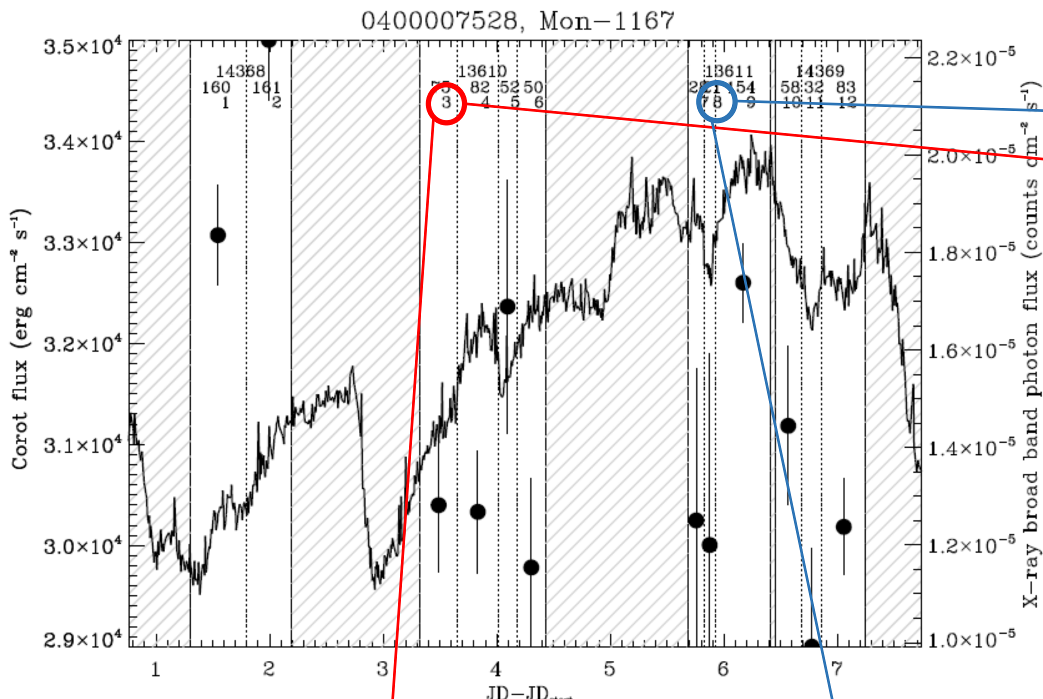
Chandra Obs. ID
N. Photons
interval

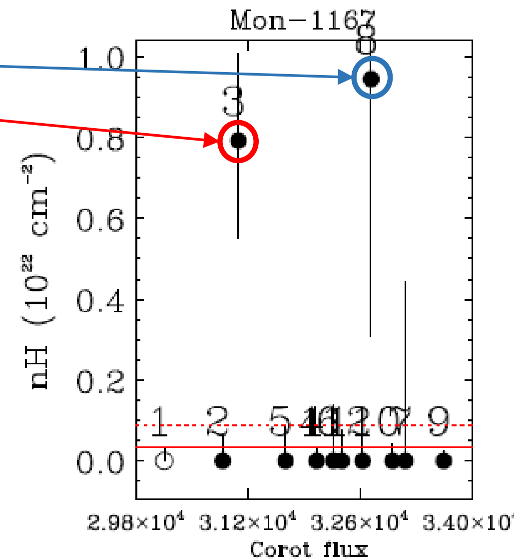
White intervals: Chandra epochs

Black dots: X-ray fluxes

We used the CoRoT light curves to isolate time intervals when interesting phenomena occurred (e.g. bursts and dips), extracted the X-ray photons in these intervals and calculated the “time resolved X-ray properties”

The analysis – dippers

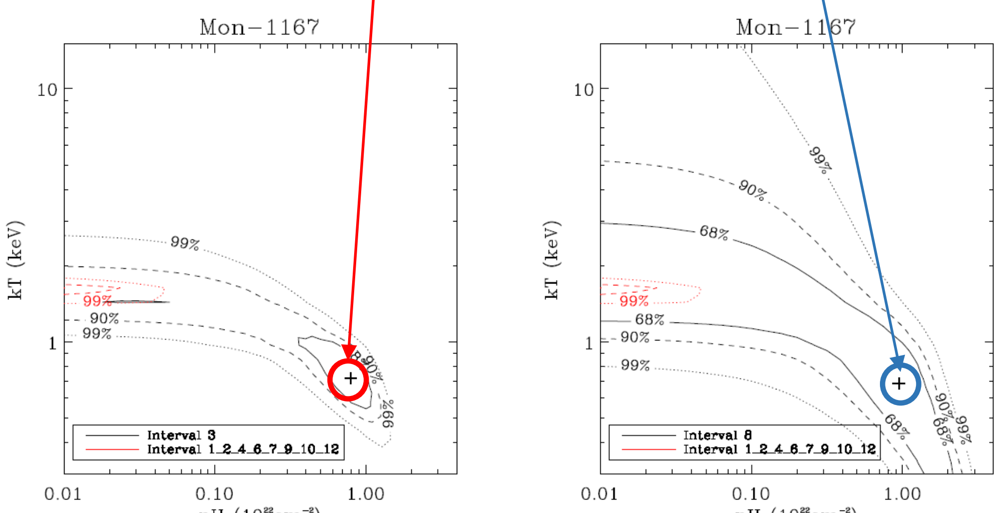




We analysed 24 stars with dips and good X-ray data.

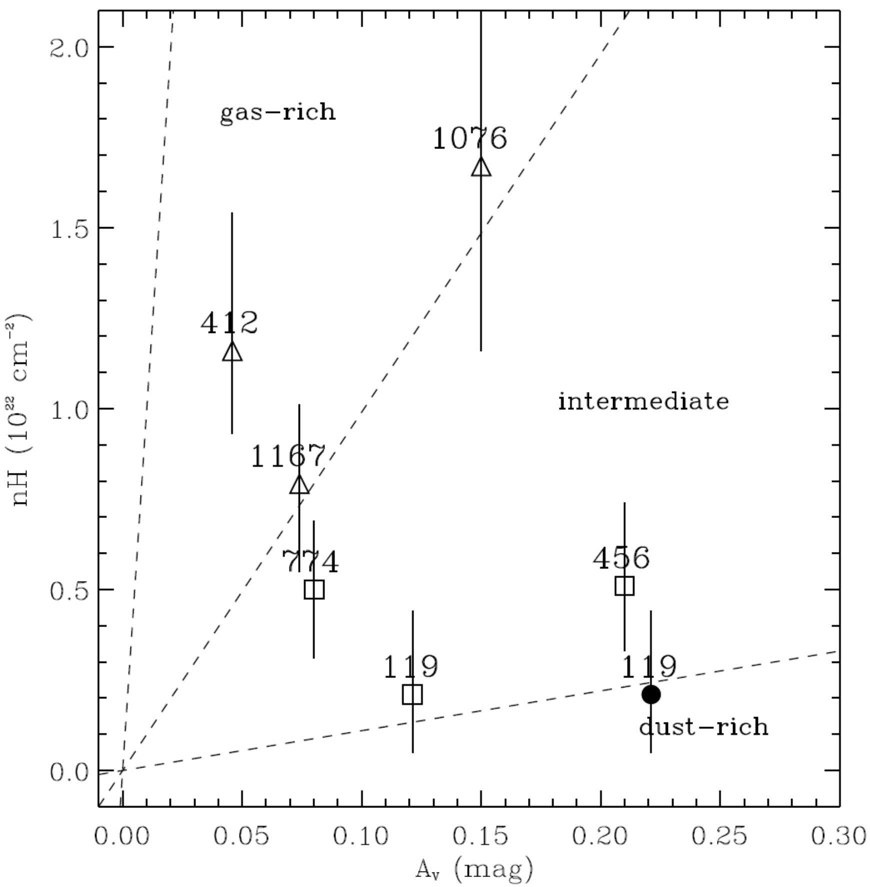
In 9 stars NH is observed to increase during the optical dip.

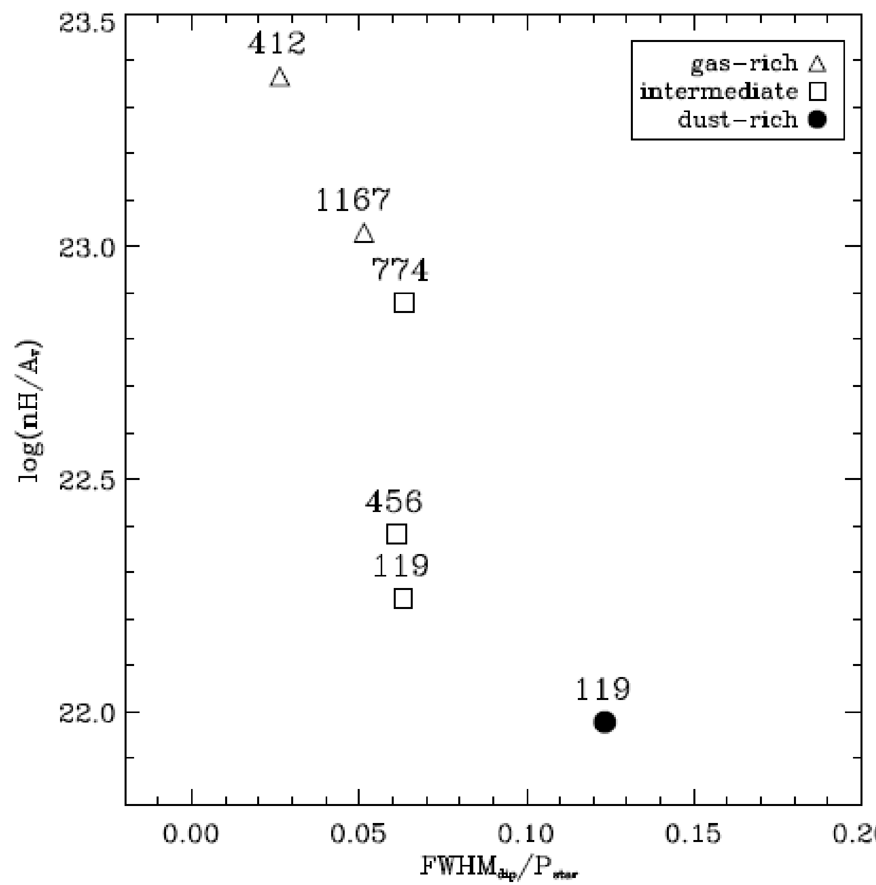
Evidence for absorption of X-rays by circumstellar material.



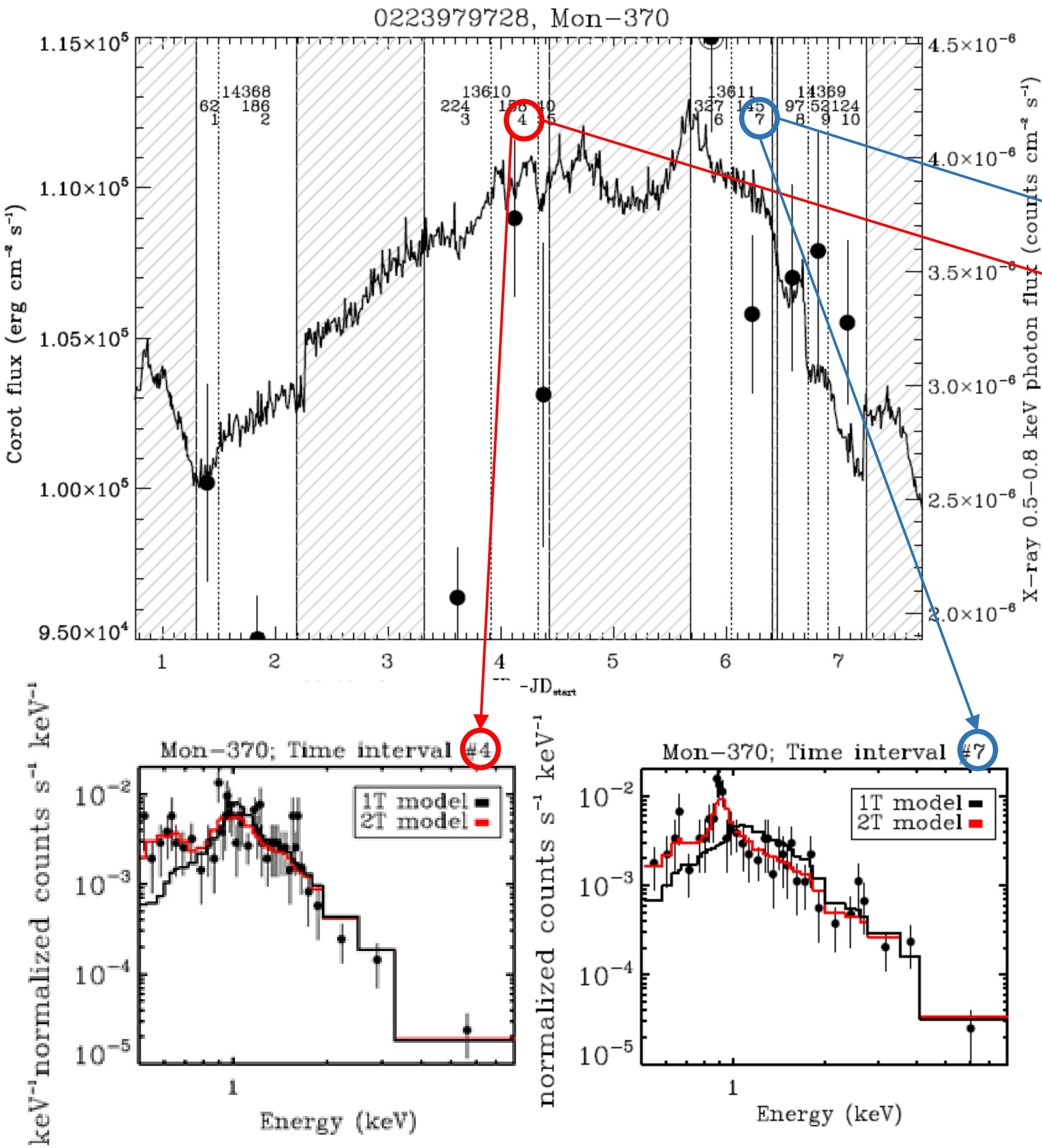
The analysis – dippers

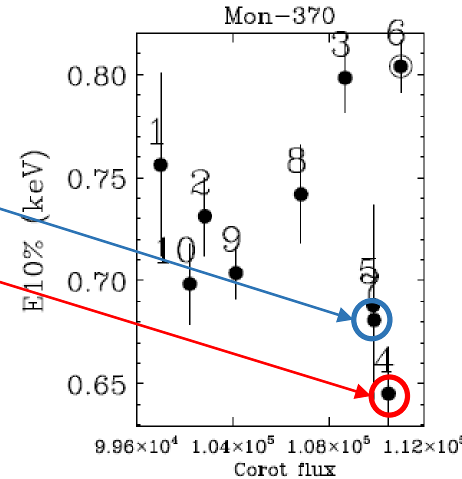
In 6 dips we calculated N_H, A_V, $FWHM_{dip}$, and also have P_{star} *[Venuti et al. in prep.]*, and estimated that they are due by gas-rich (i.e. $\log(N_H/A_V) > 22$) and narrow ($FWHM_{dip}/P_{star} < 0.15$) structures, likely accretion streams. However, our sample is strongly biased.





The analysis – bursters





We analysed 20 stars with bursts and good X-ray data.

In 5 cases, during the bursts:

- The X-ray spectral fit requires a 2T thermal model
- Low E10% and soft X-ray emission in excess compared to the best-fit 1T model

The analysis – bursters

Assuming:

- $T_{soft}=T_{post}$ and strong shock scenario;
- Ignoring energy loss during accretion;

In two cases (Mon-370 and Mon-808) we could calculate $v_{preshock}$ as:

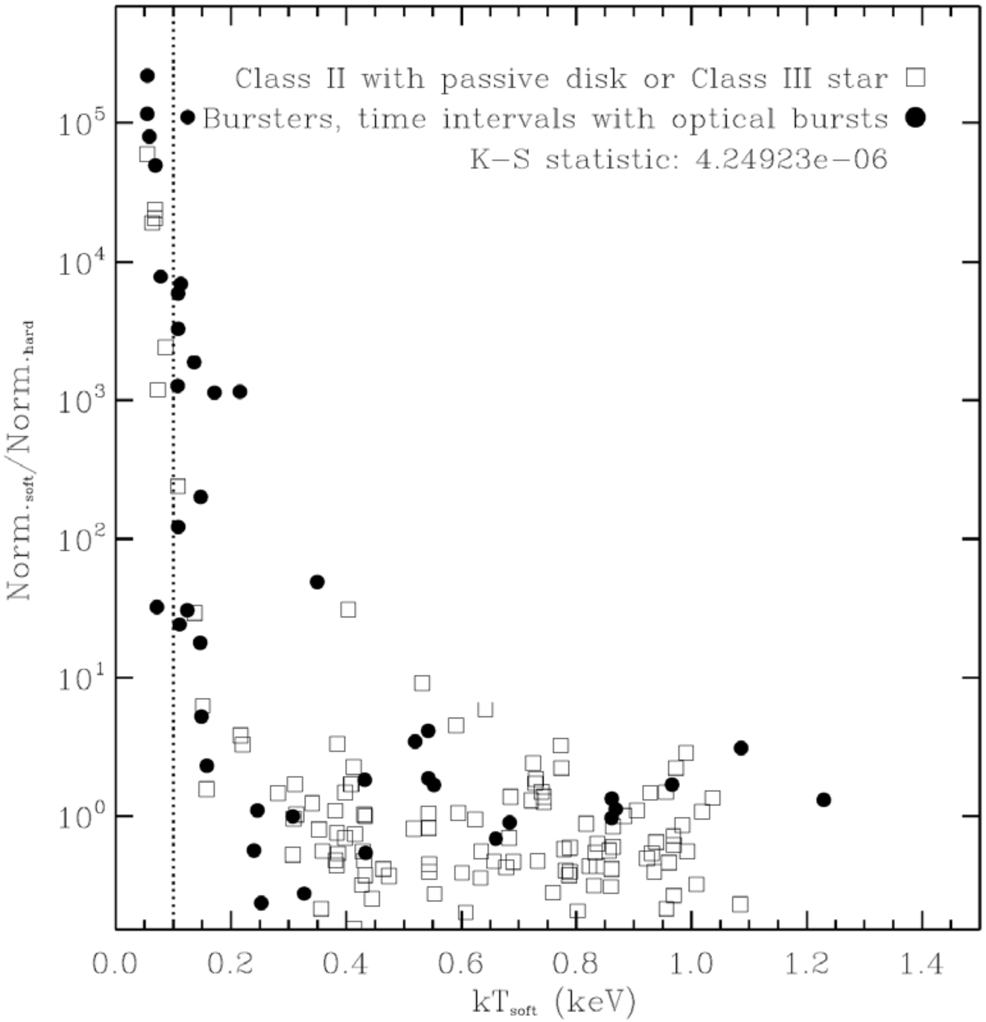
$$v_{pre}^2 = \frac{16kT_{post}}{3\mu m_H}$$

In these two stars:

- T_{soft} about 0.15 keV and $v_{preshock}$=350-360 km/h
- free fall radii about $2R_{star}$, below the expected co-rotation radius (5-10 R_{star} *[Hartmann et al. 1998, Shu et al. 2000]*)

This is the configuration suggested for the unsteady accretion *[e.g. Romanova et al 2012]*

The analysis – bursters



We performed 2T Thermal plasma model X-ray spectral fitting to all the time-intervals we defined.

We compared the normalizations of soft and hard components

We found larger soft-component normalizations during the optical bursts than in the time intervals defined for non accreting stars

CONCLUSIONS

- Variability in class II YSOs is an excellent probe to study the physical properties of the inner region of the disks and the accretion streams.

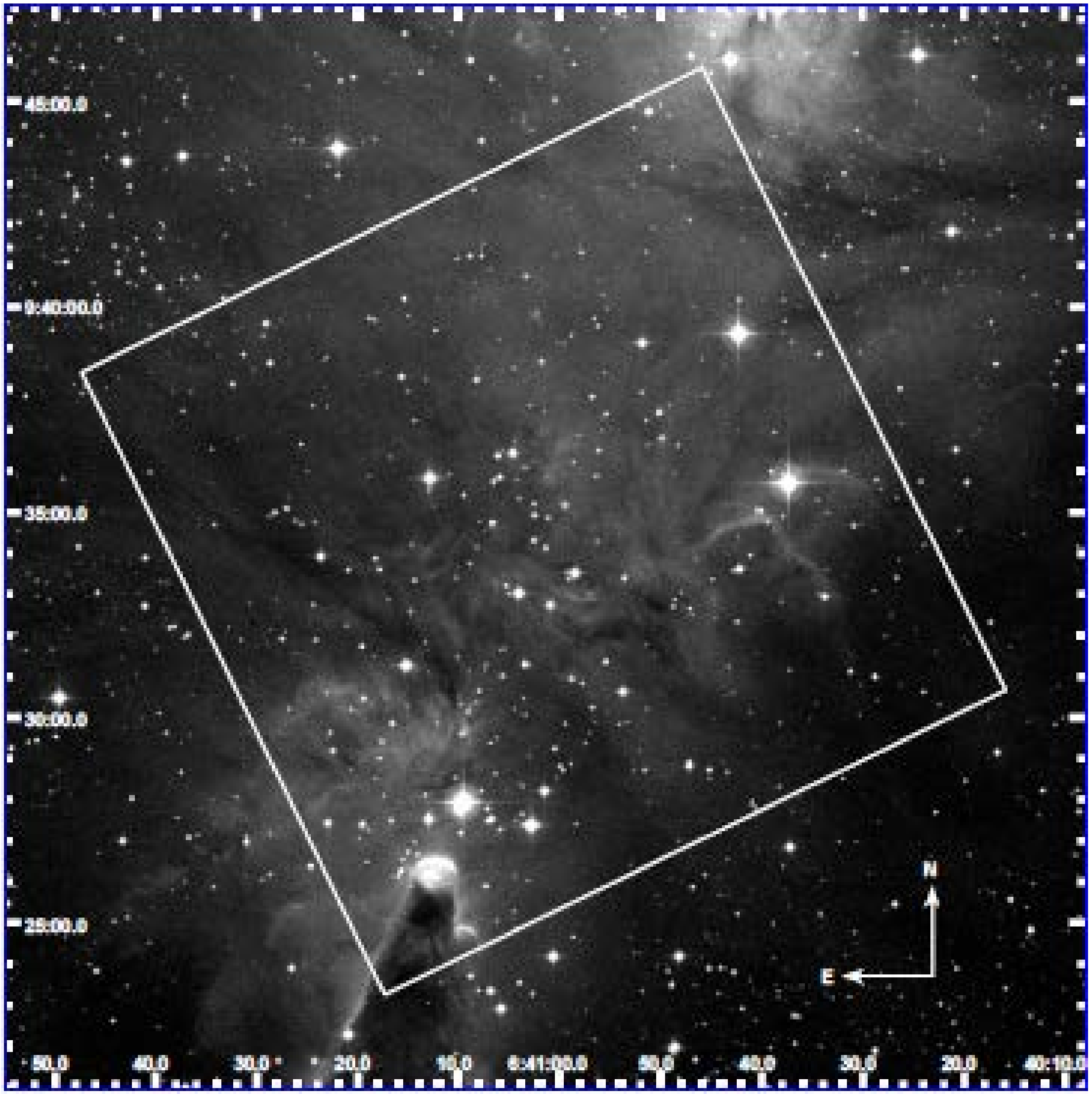
- By analysing optical and X-ray simultaneous variability in stars with disks in NGC 2264 we have found:

  - Evidence for increasing X-ray absorption during optical dips, which are likely due to narrow gas-rich accretion columns

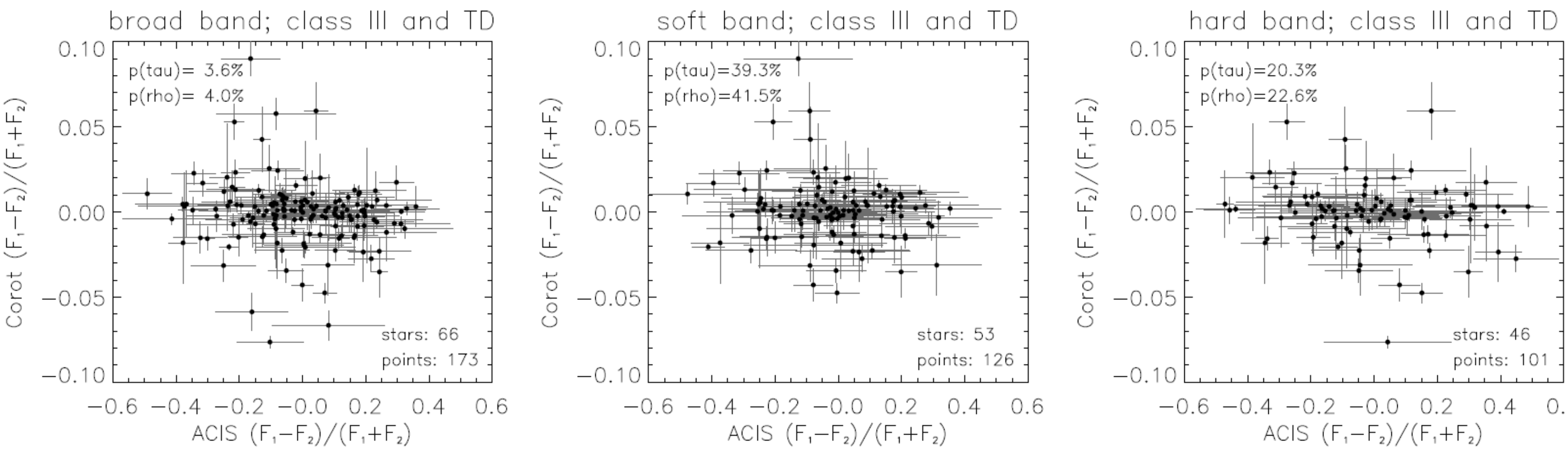
  - Evidence for increasing soft X-ray emission during the optical accretion bursts

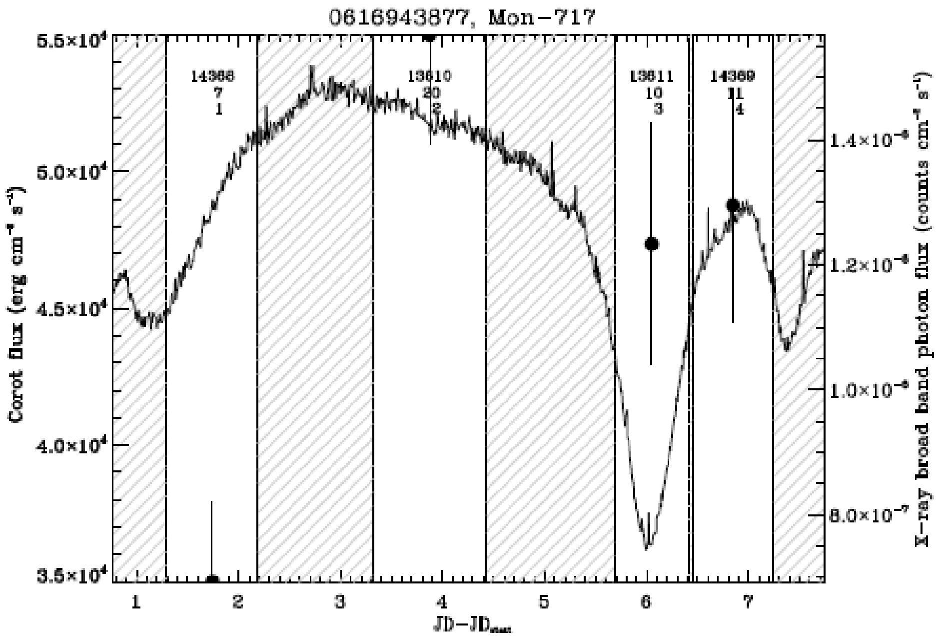
  - In two cases data support unsteady accretion geometry, but under several strong assumptions

“PLEASE HELP ME” - slides

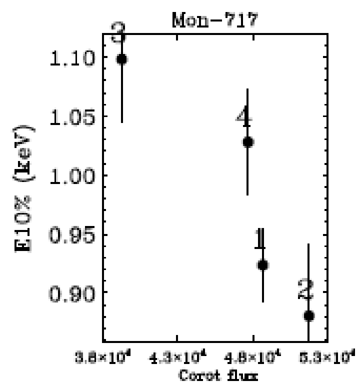


Chandra/ACIS-I Fields

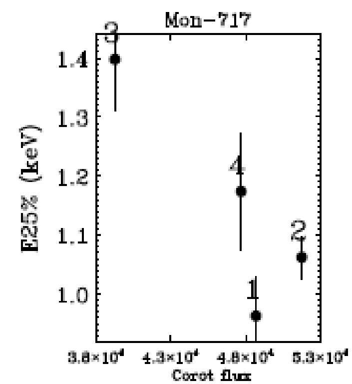

broad band; class III and TD
p(tau)= 3.6%
p(rho)= 4.0%
stars: 66
points: 173
Corot (F1−F2)/(F1+F2)
ACIS (F1−F2)/(F1+F2)
soft band; class III and TD
p(tau)=39.3%
p(rho)=41.5%
stars: 53
points: 126
Corot (F1−F2)/(F1+F2)
ACIS (F1−F2)/(F1+F2)
hard band; class III and TD
p(tau)=20.3%
p(rho)=22.6%
stars: 46
points: 101
Corot (F1−F2)/(F1+F2)
ACIS (F1−F2)/(F1+F2)



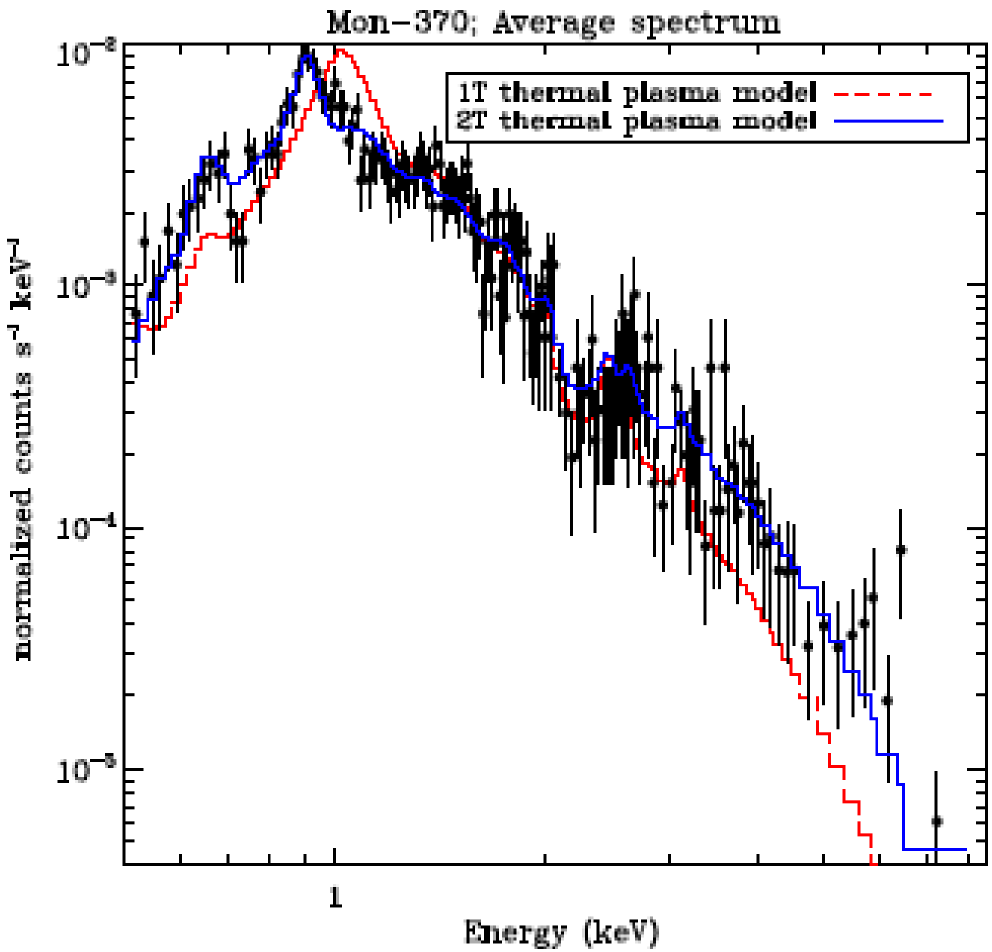
0616943877, Mon-717
14366
7
1
13610
20
2
13611
10
3
14369
11
4
Corot flux (erg cm⁻² s⁻¹)
X-ray broad band photon flux (counts cm⁻² s⁻¹)
JD-JD
5.5×10⁴
5.0×10⁴
4.5×10⁴
4.0×10⁴
3.5×10⁴
1.4×10⁻⁶
1.2×10⁻⁶
1.0×10⁻⁶
8.0×10⁻⁷
1
2
3
4
5
6
7



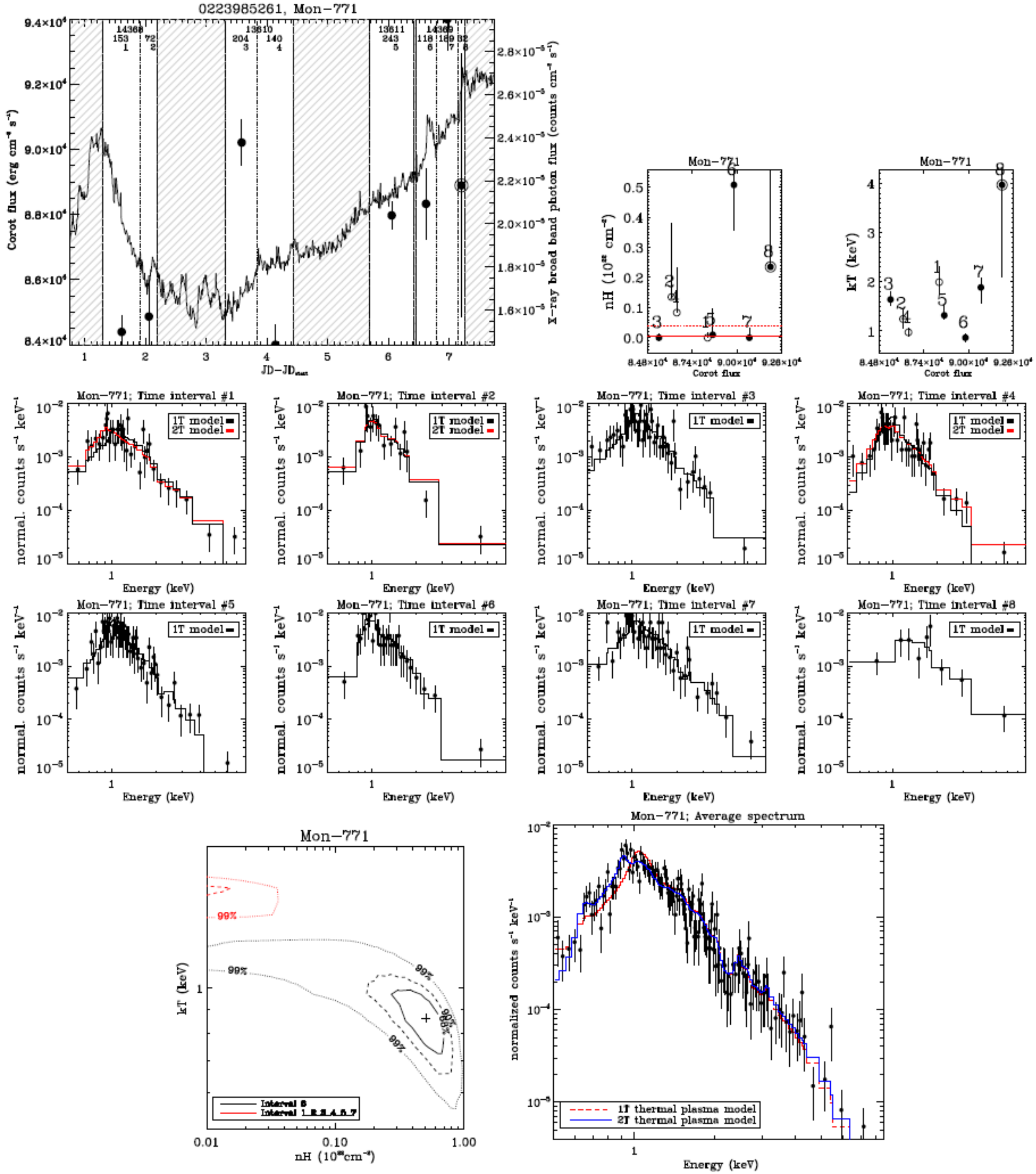
Mon-717
E10% (keV)
Corot flux
1.10
1.05
1.00
0.95
0.90
3.8×10⁴
4.3×10⁴
4.8×10⁴
5.3×10⁴
3
4
1
2

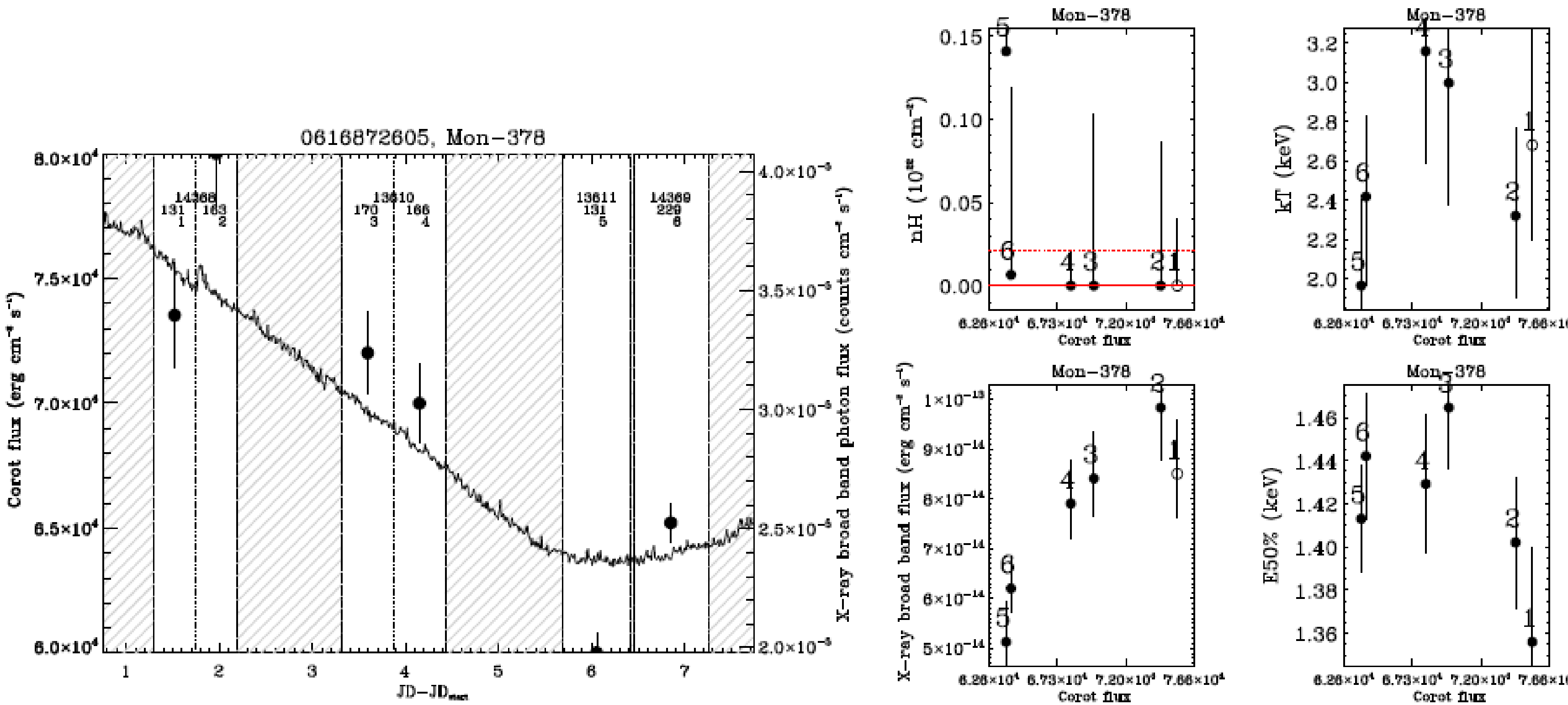


Mon-717
E25% (keV)
Corot flux
1.4
1.3
1.2
1.1
1.0
3.8×10⁴
4.3×10⁴
4.8×10⁴
5.3×10⁴
3
4
2
1



Mon−370; Average spectrum
1T thermal plasma model
2T thermal plasma model
normalized counts s^{-1} keV^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1
Energy (keV)


0223985261, Mon-771
Corot flux (erg cm⁻² s⁻¹)
X-ray broad band photon flux (counts cm⁻² s⁻¹)
JD−JD_start
Mon-771
nH (10²² cm⁻²)
Corot flux
kT (keV)
Mon-771; Time interval #1
Mon-771; Time interval #2
Mon-771; Time interval #3
Mon-771; Time interval #4
Mon-771; Time interval #5
Mon-771; Time interval #6
Mon-771; Time interval #7
Mon-771; Time interval #8
1T model
2T model
normal. counts s⁻¹ keV⁻¹
Energy (keV)
Mon-771
99%
90%
68%
Interval 8
Interval 1,2,3,4,5,6,7
nH (10²²cm⁻²)
Mon-771; Average spectrum
normalized counts s⁻¹ keV⁻¹
1T thermal plasma model
2T thermal plasma model


0616872605, Mon−378
Corot flux (erg cm⁻² s⁻¹)
X-ray broad band photon flux (counts cm⁻² s⁻¹)
JD−JD
14368
131
1
163
2
13610
170
3
166
4
13611
131
5
14369
229
6
Mon−378
nH (10²² cm⁻²)
kT (keV)
X-ray broad band flux (erg cm⁻² s⁻¹)
E50% (keV)
Corot flux