



Publication Year	2017
Acceptance in OA	2020-07-27T09:28:42Z
Title	Time resolved X-ray spectral analysis during optical dips and accretion bursts in stars with disks of NGC 2264 from Chandra/ACIS-I and CoRoT data
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Handle	http://hdl.handle.net/20.500.12386/26642



X-Ray Universe - 2017

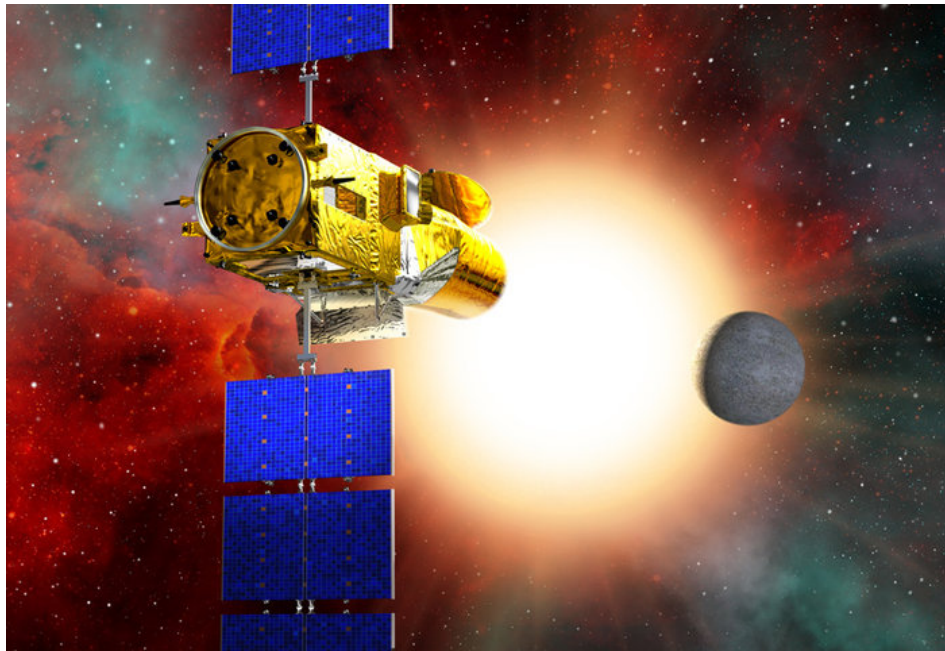


Time resolved X-ray spectral analysis during optical dips and accretion bursts in stars with disks of NGC2264 from Chandra/ACIS-I and CoRoT data

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

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The CSI-2264 Team**

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

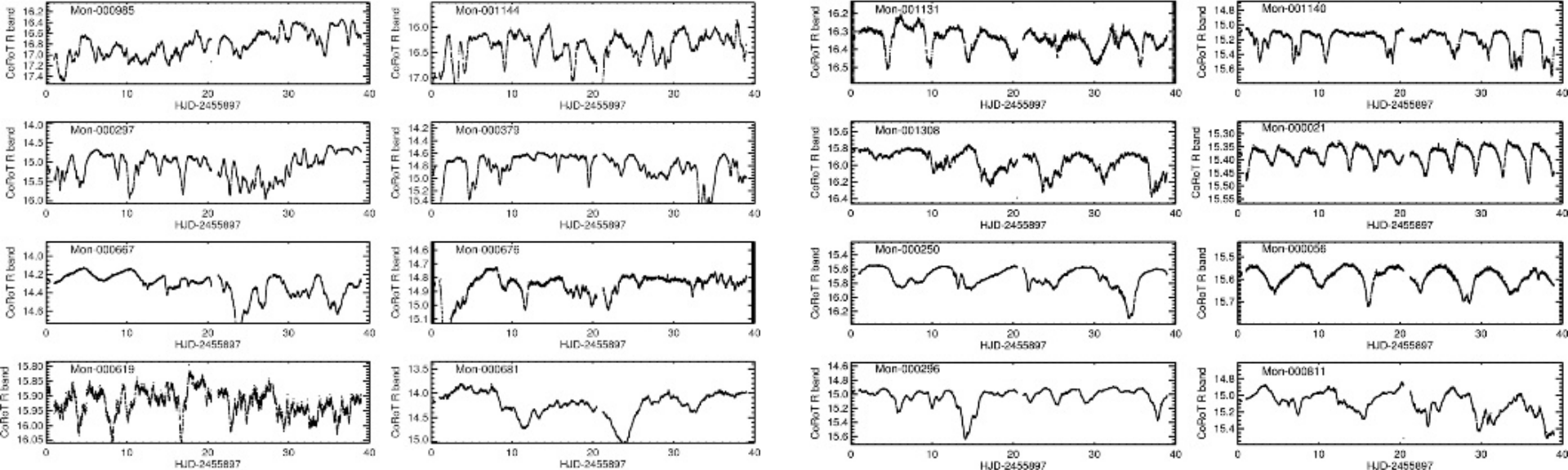
An unprecedented cooperative project involving simultaneous observations of NGC 2264 with 15 ground and space telescopes, from X-rays to mid-infrared. [*e.g. Cody et al. 2014*]

TABLE 1
Coordinated Synoptic Investigation of NGC 2264: observations

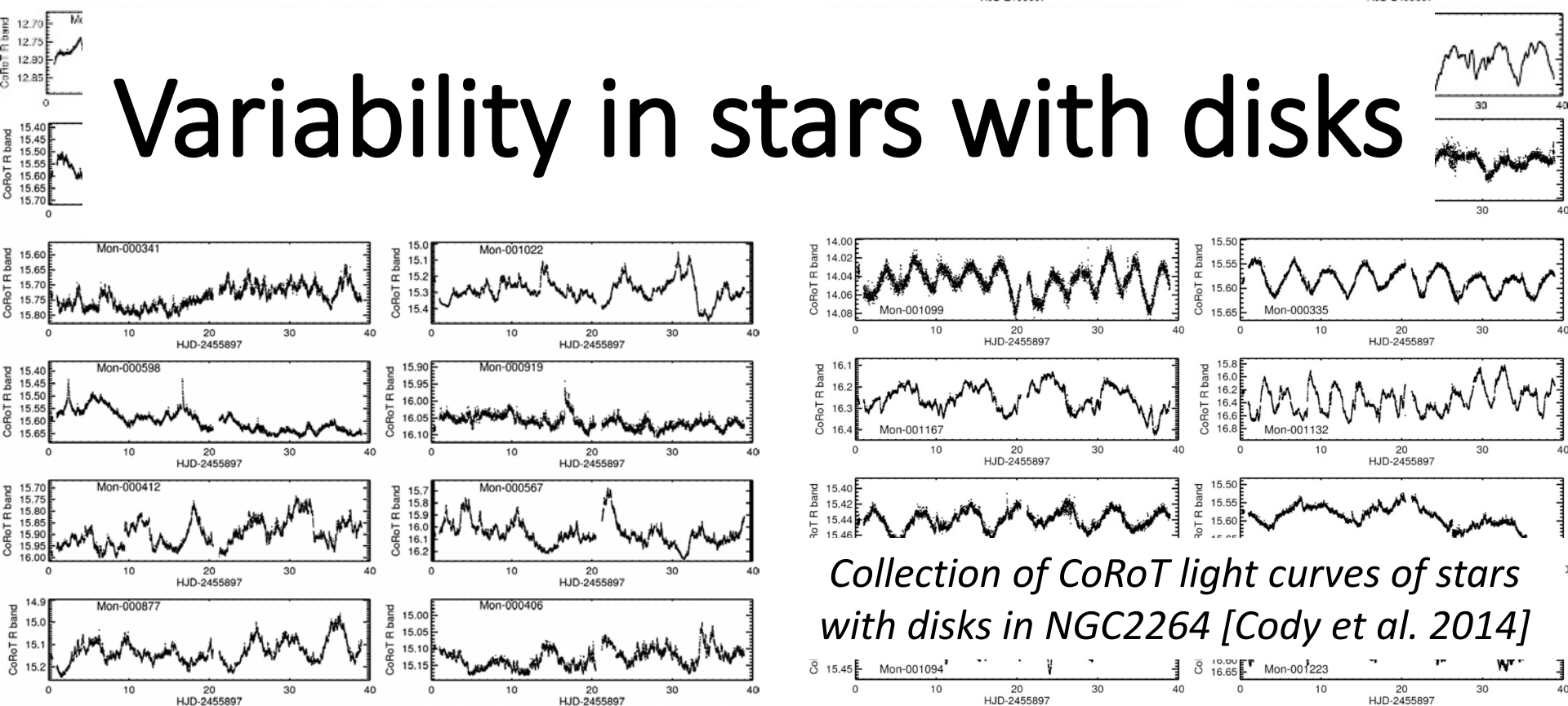
Telescope	Instrument	Dates	Band(s)	Time Sampling
<i>Spitzer</i>	IRAC/mapping	Dec. 3, 2011–Jan. 1, 2012	3.6 μm , 4.5 μm	101 min
<i>Spitzer</i>	IRAC/staring	Dec. 3; Dec. 5–6; Dec. 7–8; Dec. 8–9, 2011	3.6 μm , 4.5 μm	15 s
<i>CoRoT</i>	E2 CCD	Dec. 1, 2011–Jan. 3, 2012	3000–10000 Å	32 s (high cadence), 512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



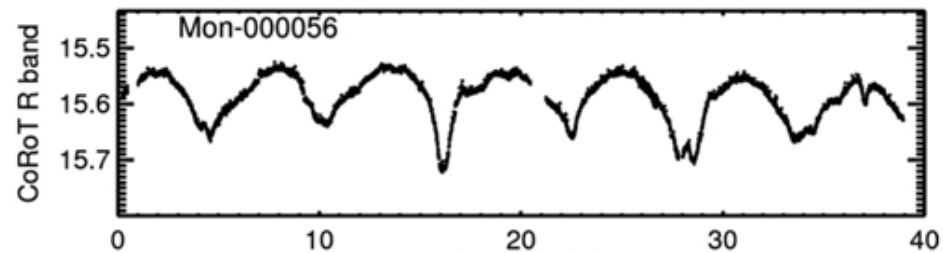
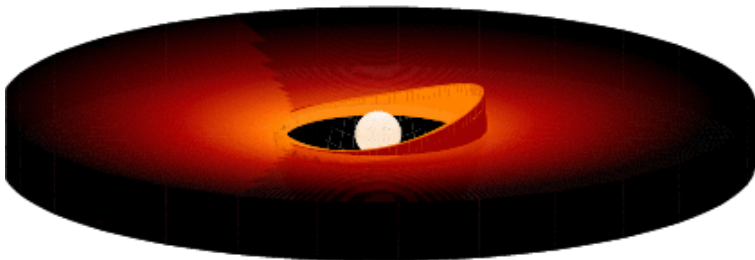
Variability in stars with disks



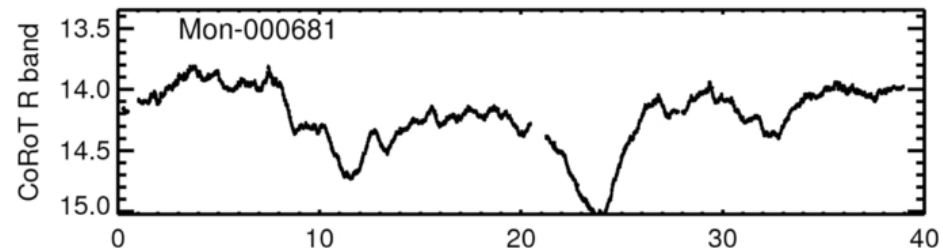
Collection of CoRoT light curves of stars with disks in NGC2264 [Cody et al. 2014]

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)

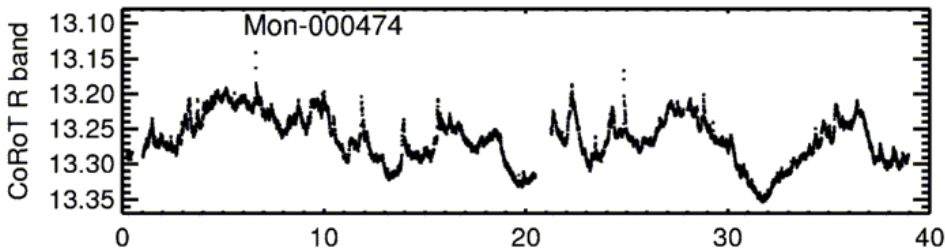


Two stars with dips observed with CoRoT in NGC2264 [Cody et al. 2014]

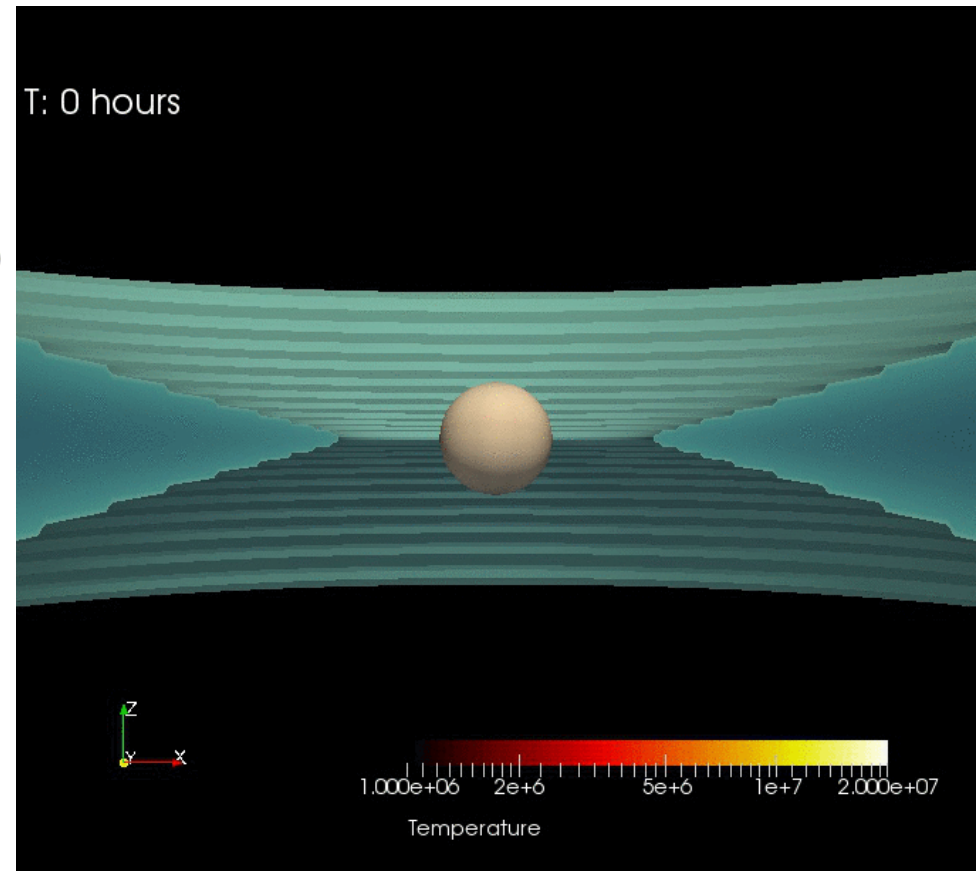


Optical variability in stars with disks - accretion

- 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)



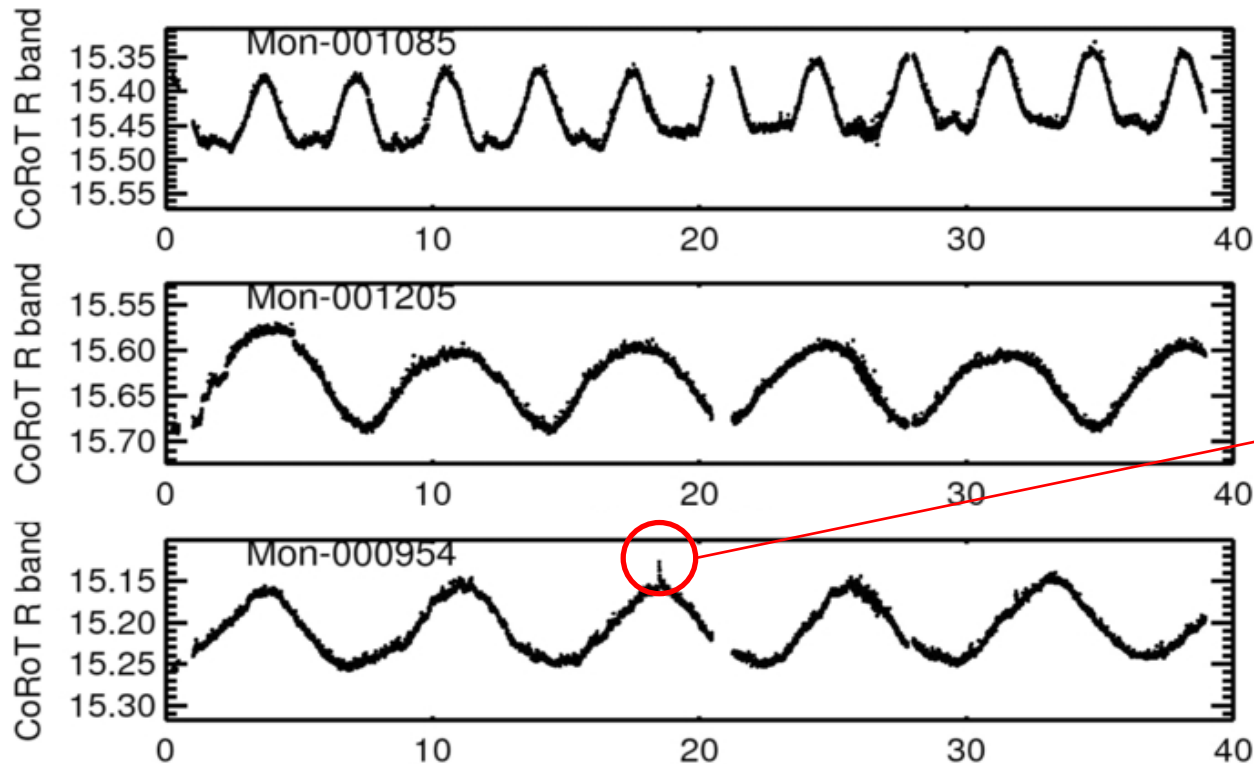
- Accretion streams, which may contain also dust, can obscure the central star and produce narrow dips with $\text{FWHM}_{\text{dip}}/P_{\text{star}} < 0.25$ [Stauffer et al. 2015]
- The energetic optical emission from accretion hot spots (10^4K blackbody) can be modulated by stellar rotation



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; Argyroffi et al. 2011; Curran et al. 2011*]). But difficult to distinguish from the coronal soft X-ray emission and self-absorption is crucial [*Argyroffi et al. 2011; Bonito et al. 2014*].
- Soft X-ray emission from accretion spots can be rotationally modulated (e.g. V4046 Sgr [*Argyroffi 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*].

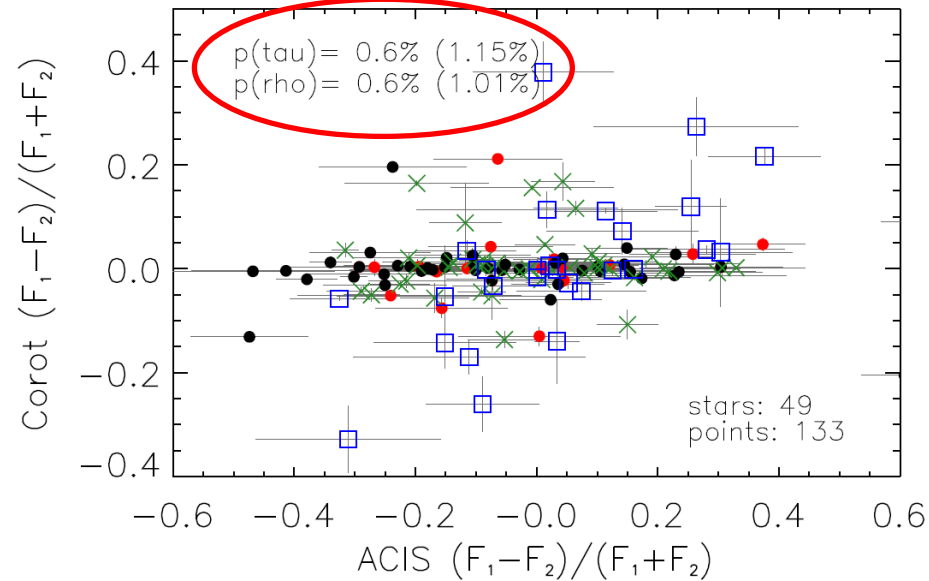


Global Optical vs. X-ray variability observed

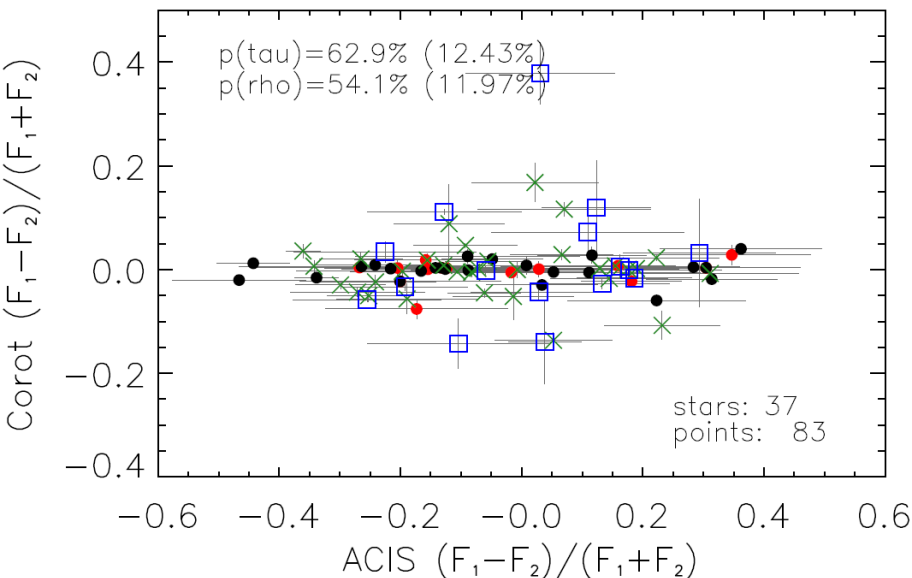
Comparison of the flux observed in two consecutive Chandra epochs in:

- 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)

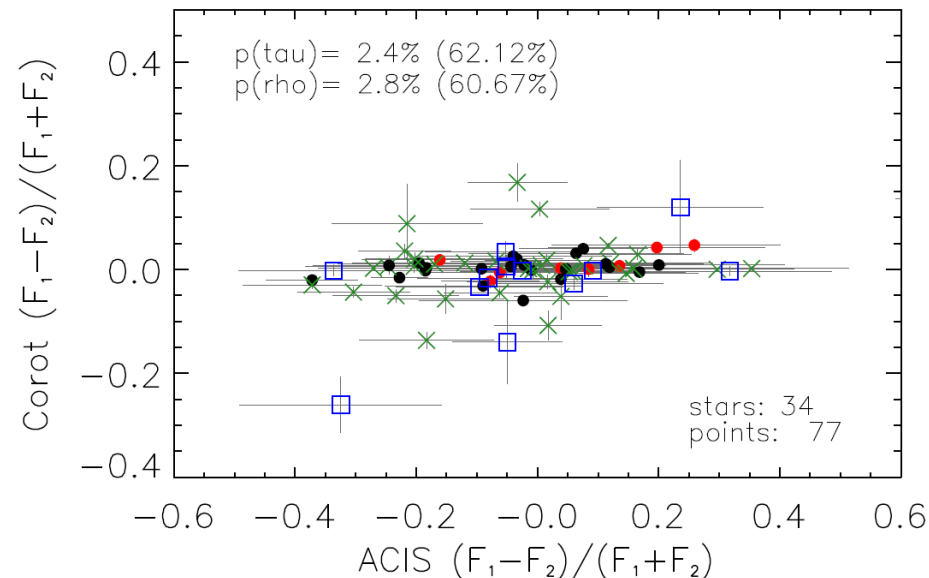
broad band; Stars with disks



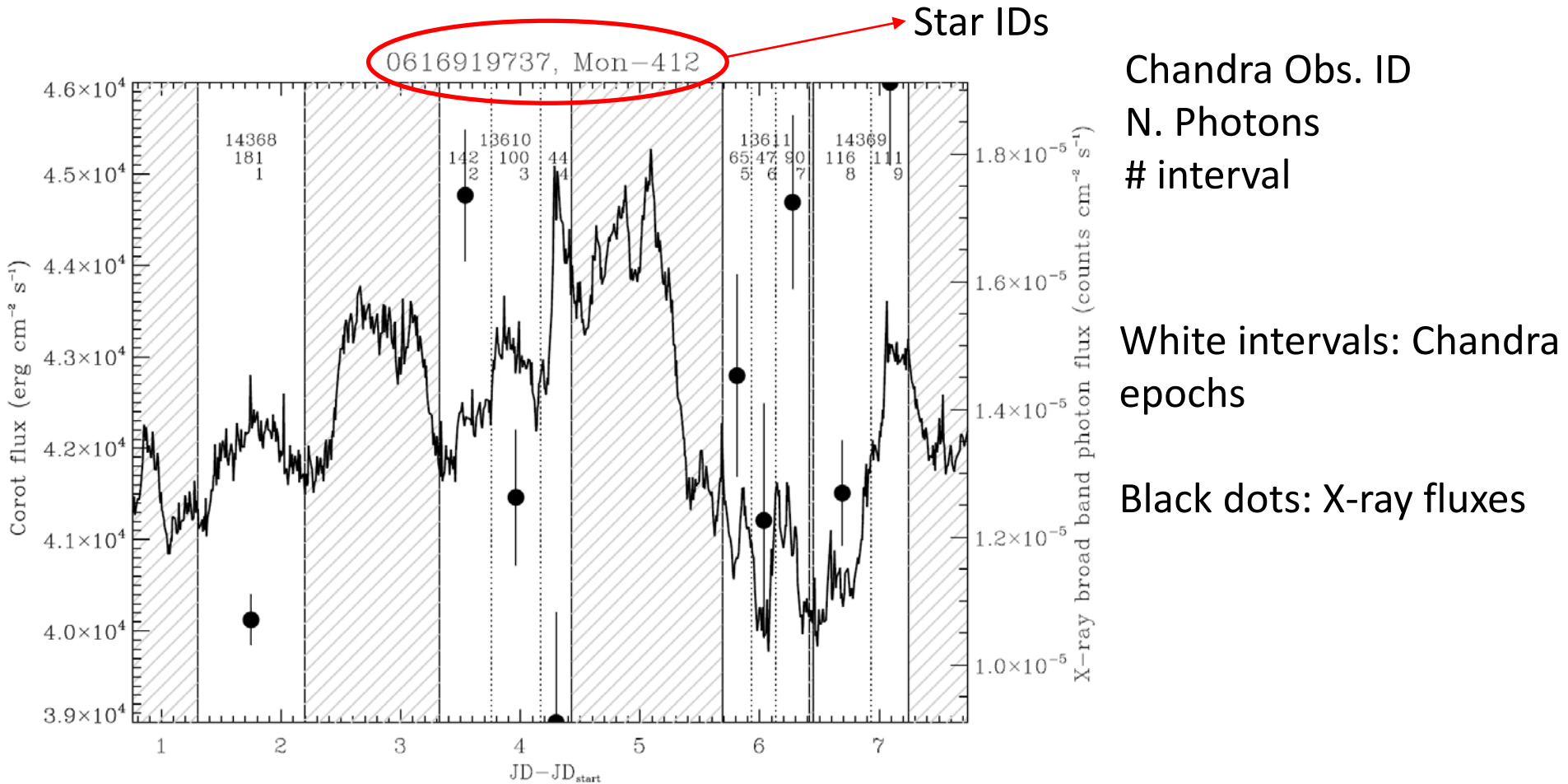
hard band; Stars with disks



soft band; Stars with disks

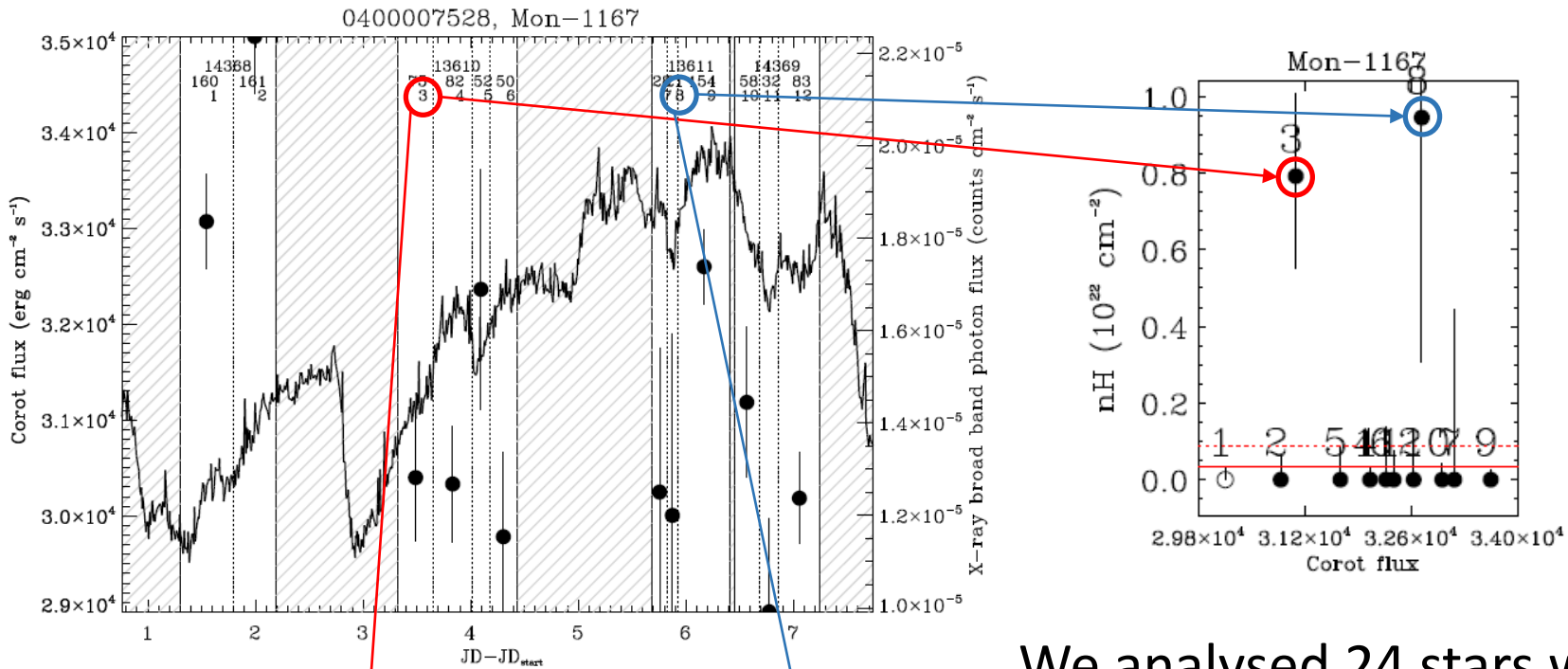


The analysis – CoRoT light curves as template



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”

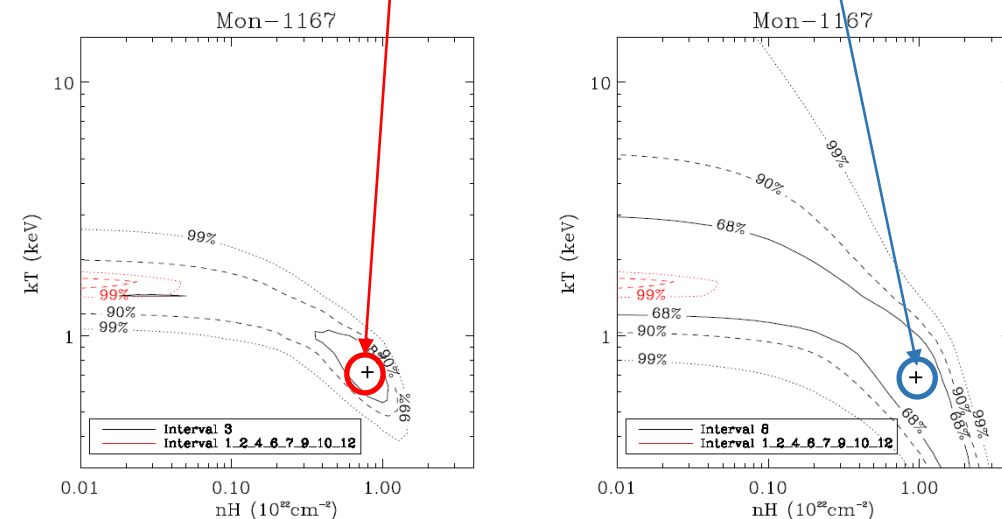
The analysis – dippers



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

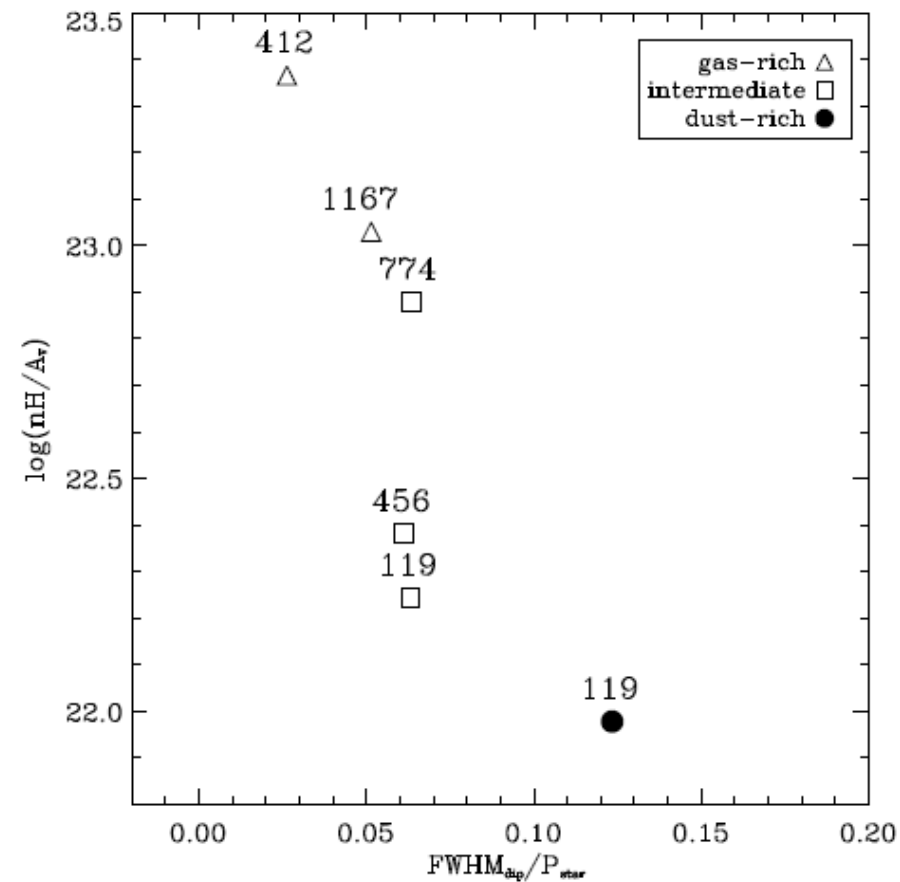
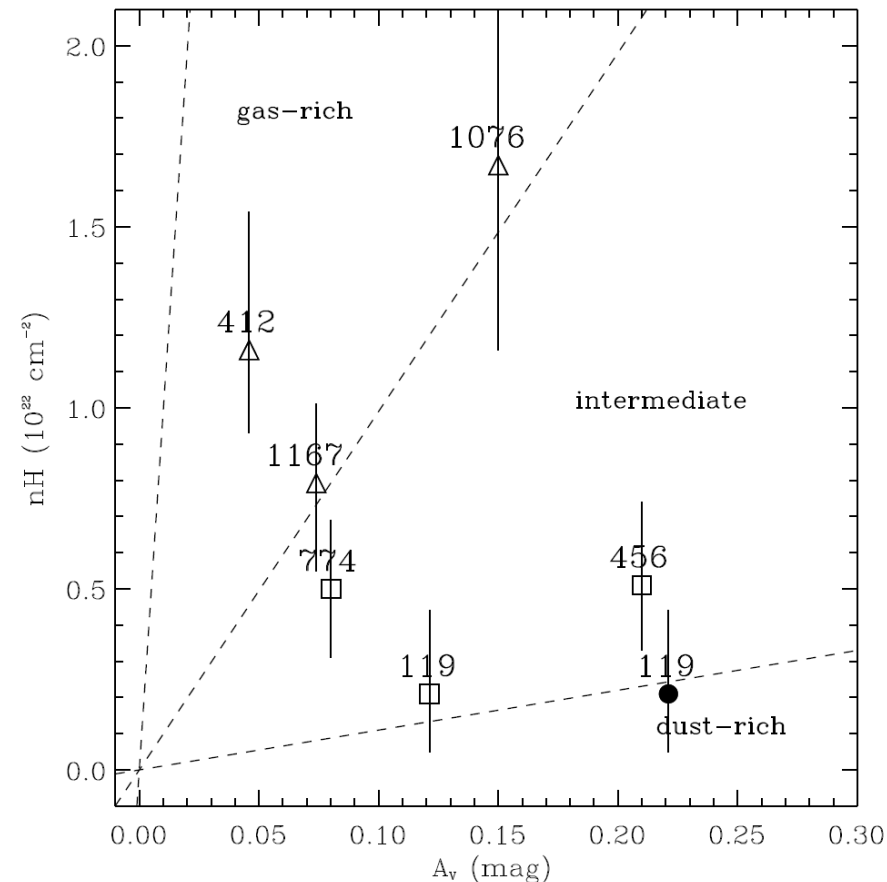
In 9 stars NH is observed to increase during the optical dip.

Evidence for absorption of X-rays by circumstellar material.

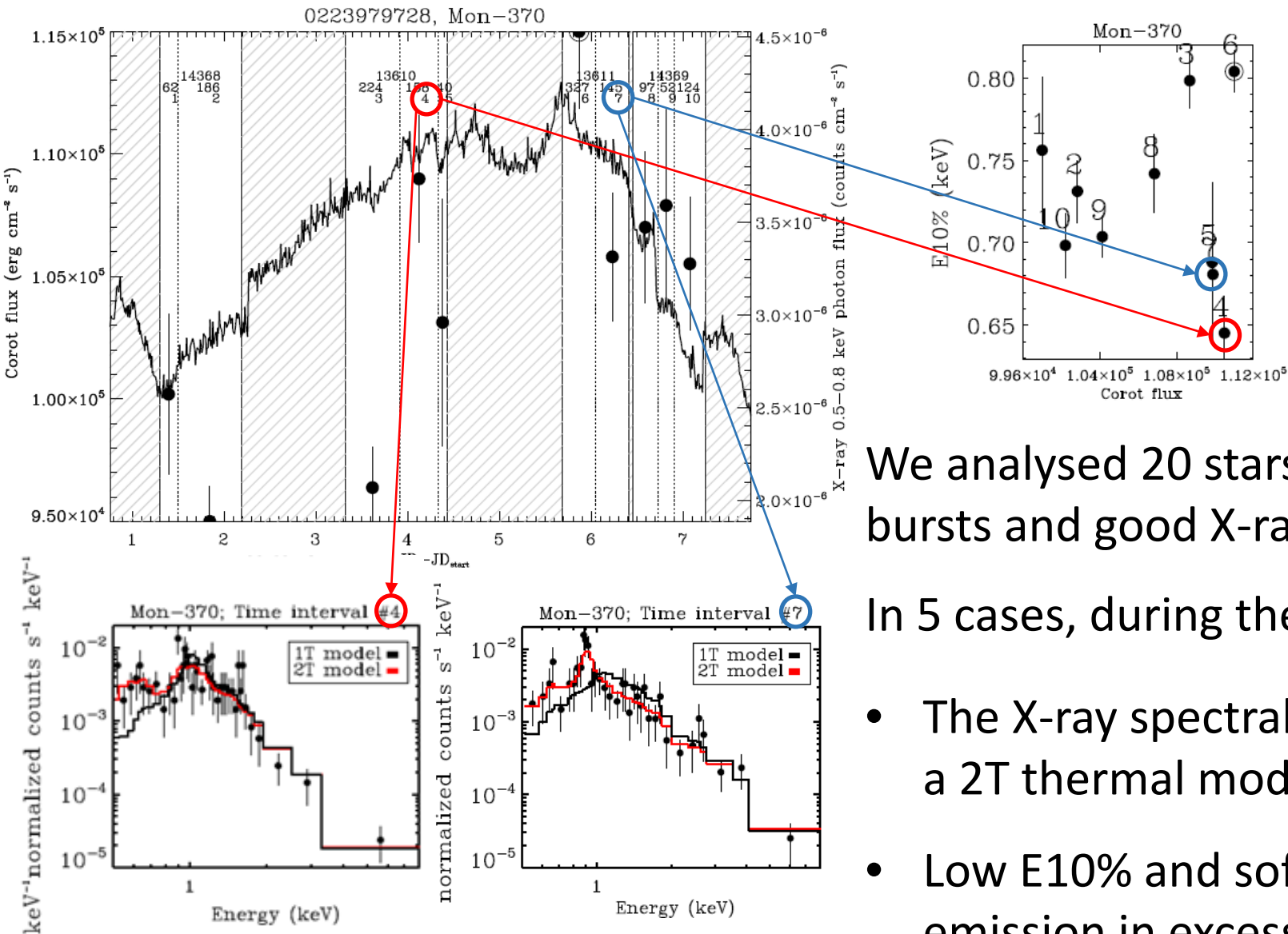


The analysis – dippers

In 6 dippers 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. $\log(N_{\text{H}}/A_{\text{V}}) > 22$) and narrow ($\text{FWHM}_{\text{dip}}/P_{\text{star}} < 0.15$) 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:

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

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

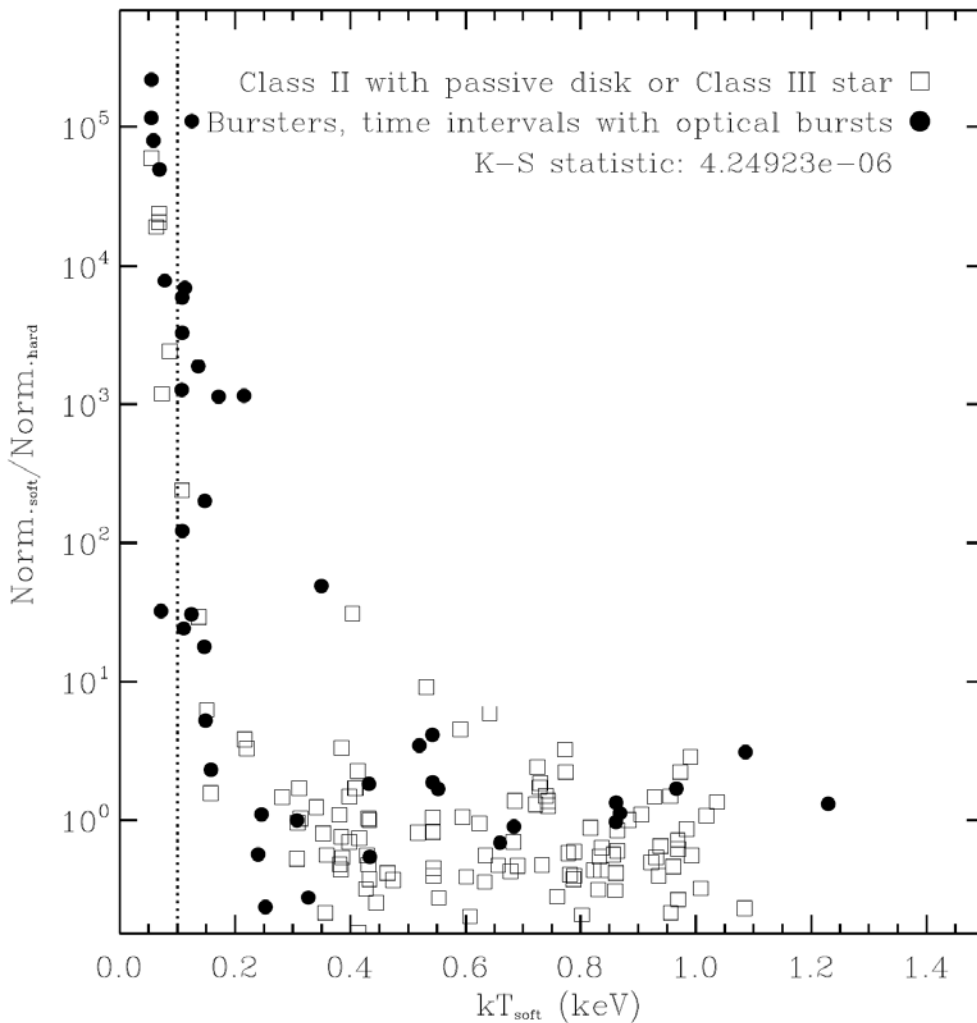
$$v_{\text{pre}}^2 = \frac{16kT_{\text{post}}}{3\mu m_H}$$

In these two stars:

- T_{soft} about 0.15 keV and $v_{\text{preshock}} = 350\text{-}360$ km/h
- free fall radii about $2R_{\text{star}}$ 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.

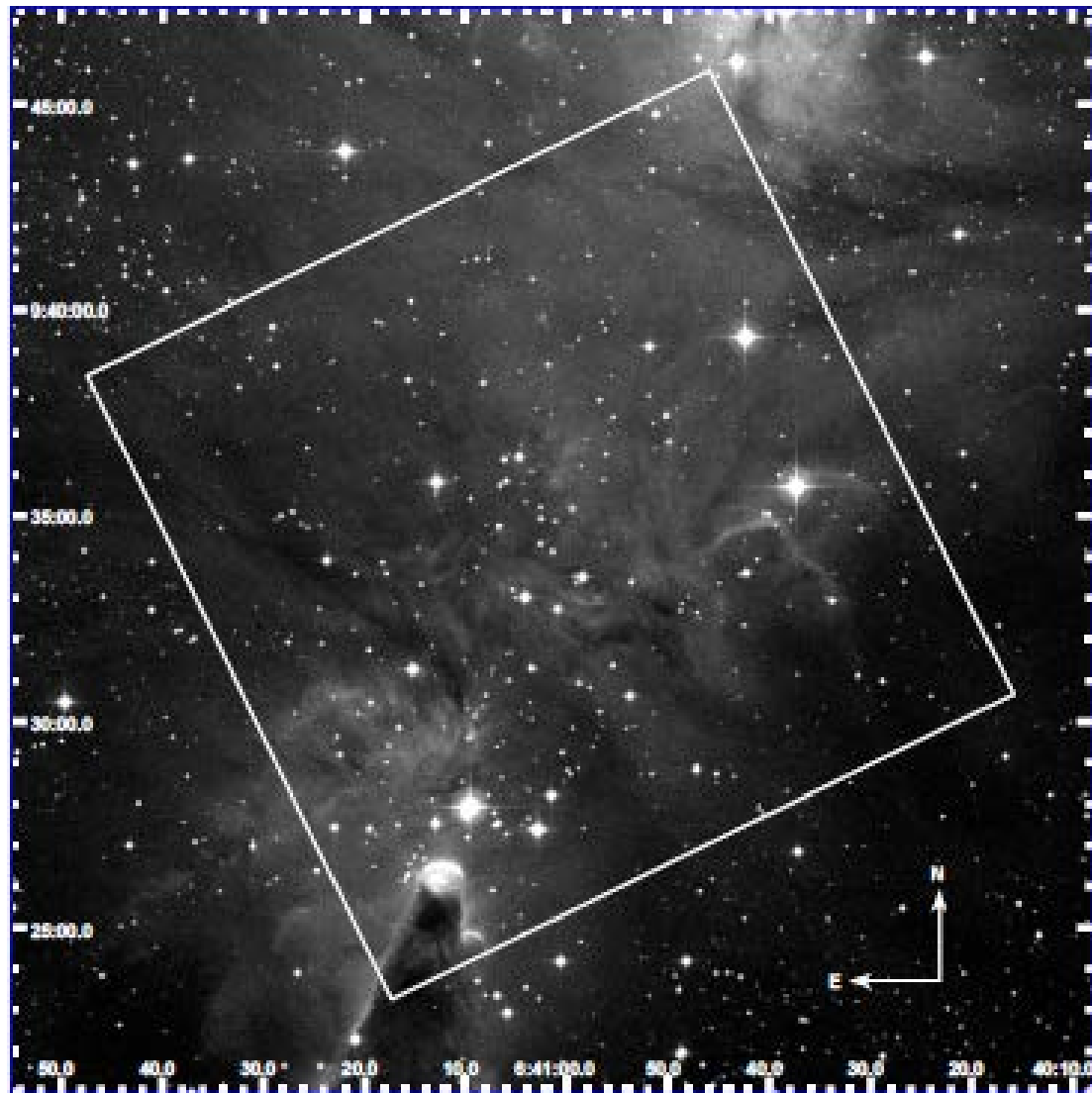
We compared the normalizations of soft and hard components

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

