Simultaneous CoRoT, Spitzer, and Chandra observations of PMS stars in NGC2264

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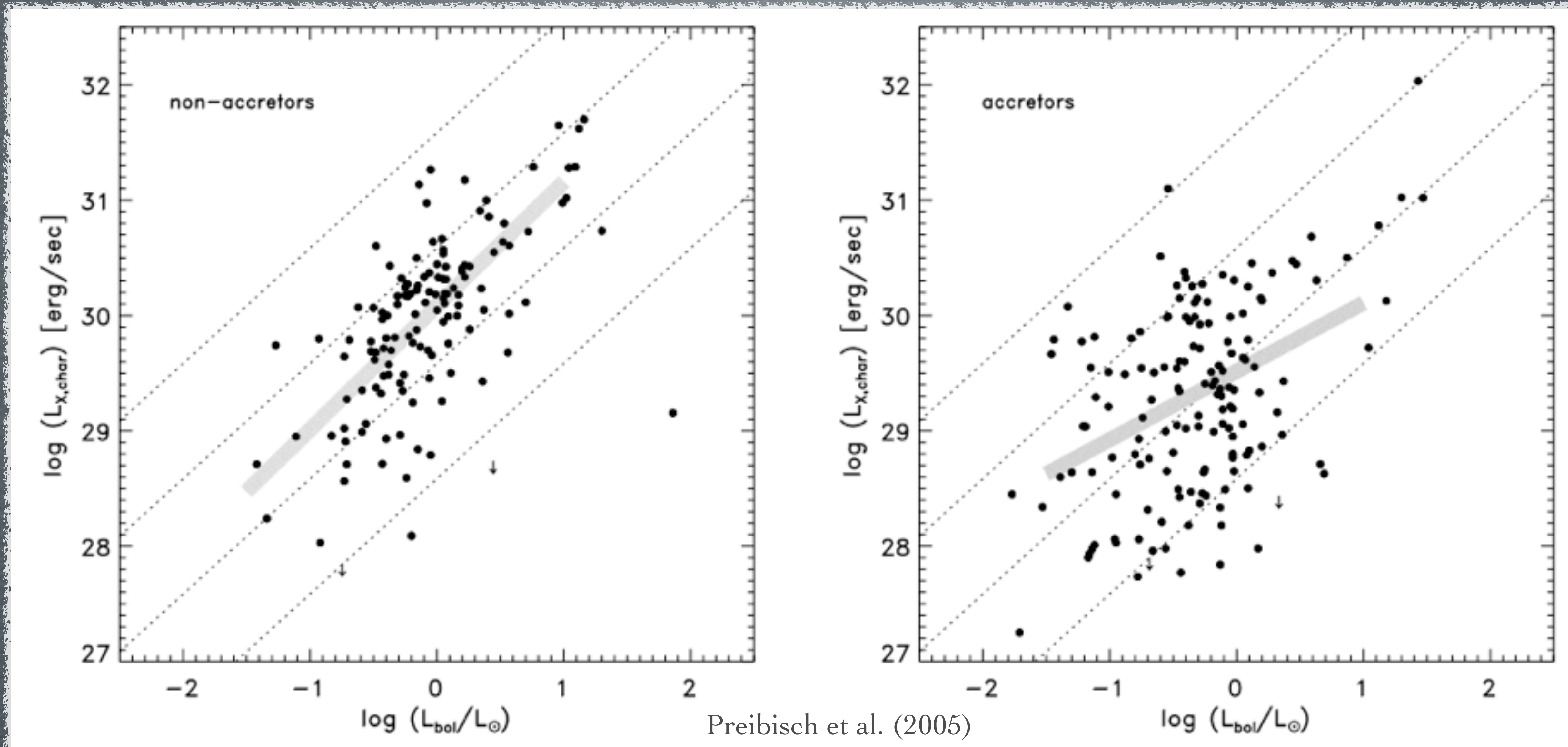
and the CSI collaboration

X-ray emission from young stars?

- PMS stars, both CTTSs and WTTSs, 10-1000 times brighter in X-rays than MS stars
- X-rays from coronae and accretion shocks. Effects important:
  - Heat and ionize circumstellar disks
    - Photo-evaporation and dispersal
    - Disk viscosity through MRI
      - mass accretion rate
      - dynamical evolution of the disk including planet formation
  - Erode the atmospheres of closeby gaseous planets
- Flares produce high energy radiation and particles and may be particularly relevant

X-ray emission of W/CTTS

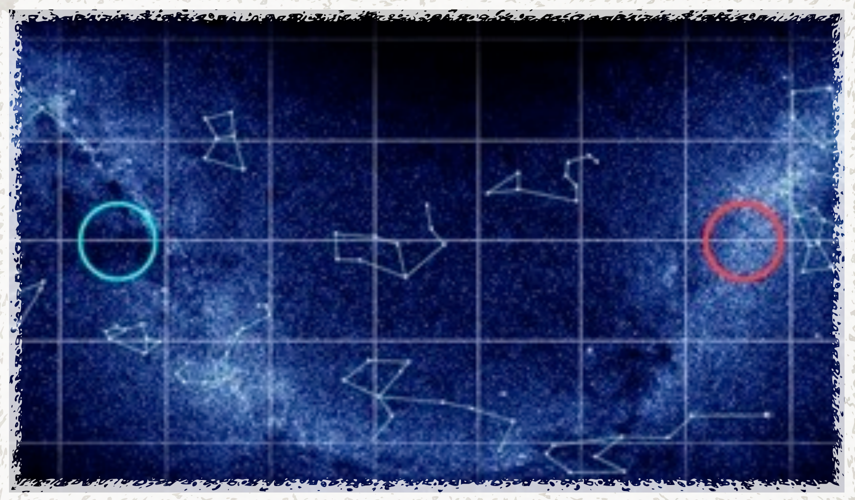


Preibisch et al. (2005)

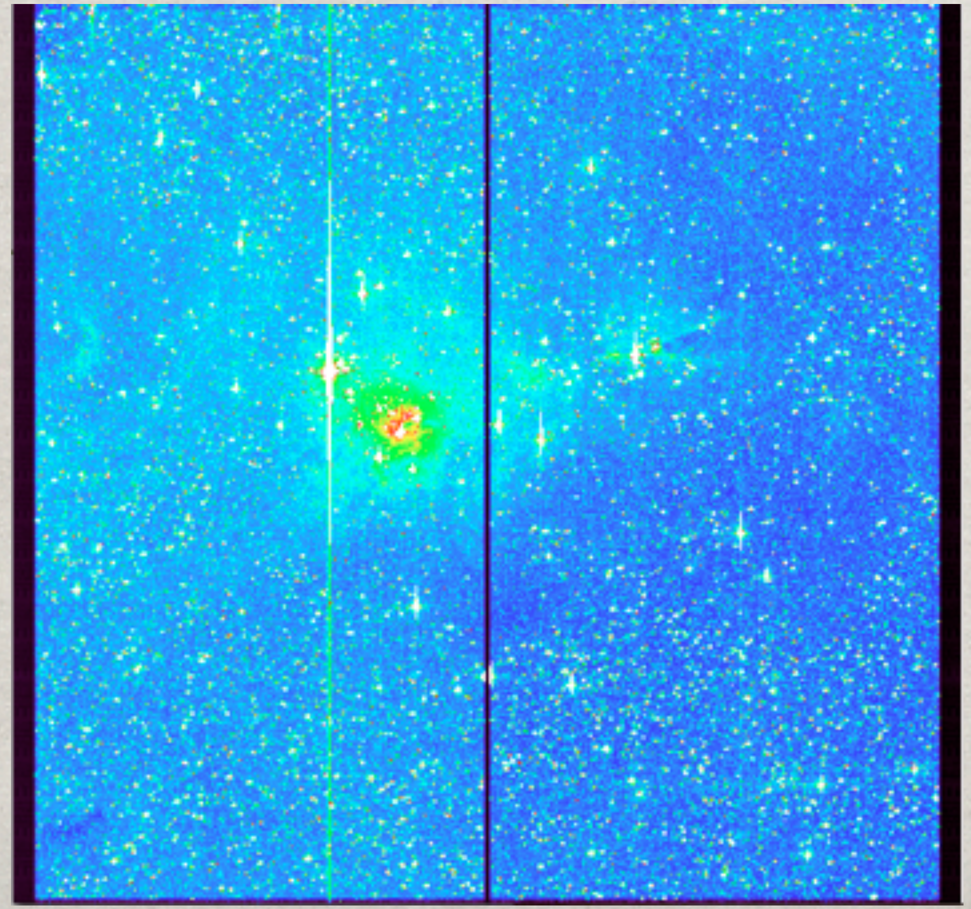
- WTTS have almost "saturated" X-ray emission: log L_X/L_{bol} ~ -3
- CTTS have, on average, lower and more scattered X-ray luminosities than WTTS of the same mass/L_{bol} (e.g. Flaccomio et al. 2003, Preibisch et al 2005)
  - **Cause or effect? (Drake et al. 2009)**
  - **Does accretion affect (depress) activity? And how?**

The CoRoT NGC 2264 short runs

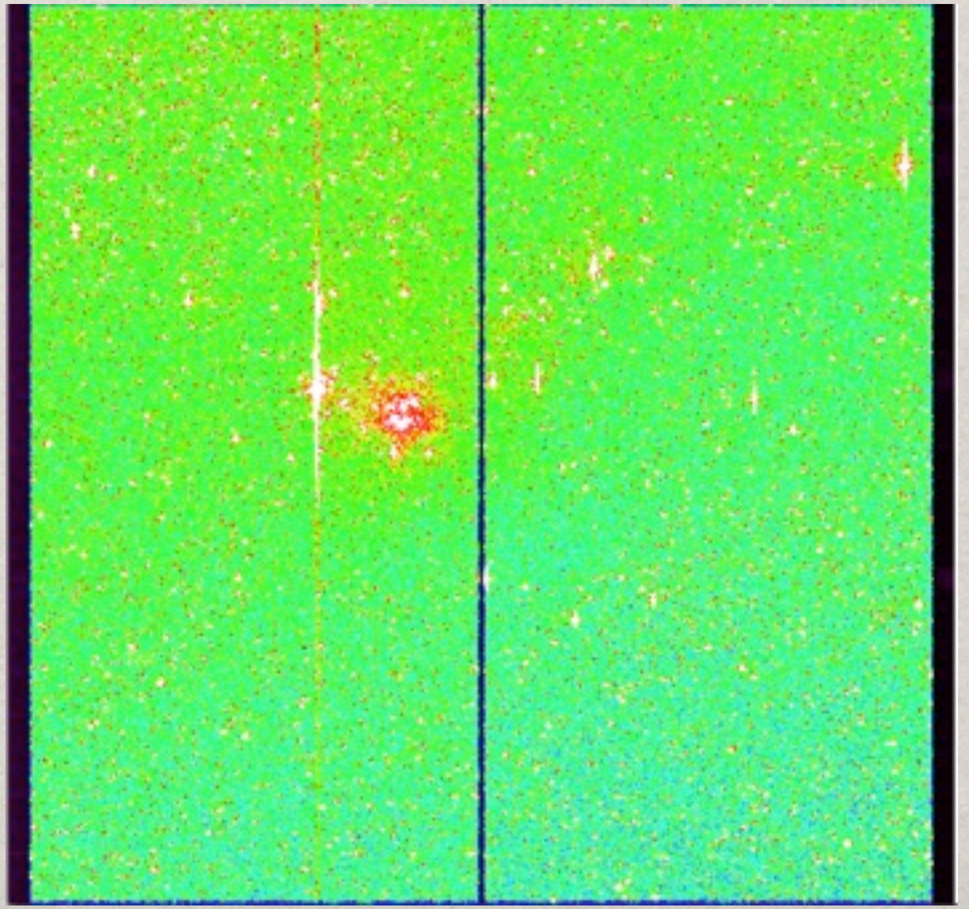
- NGC 2264
  - d~ 760 pc
  - age ~3 Myr
  - The only SFR in the "CoROT eyes"



SRa01 (23.5d in March 2008)
coordinated by F. Favata

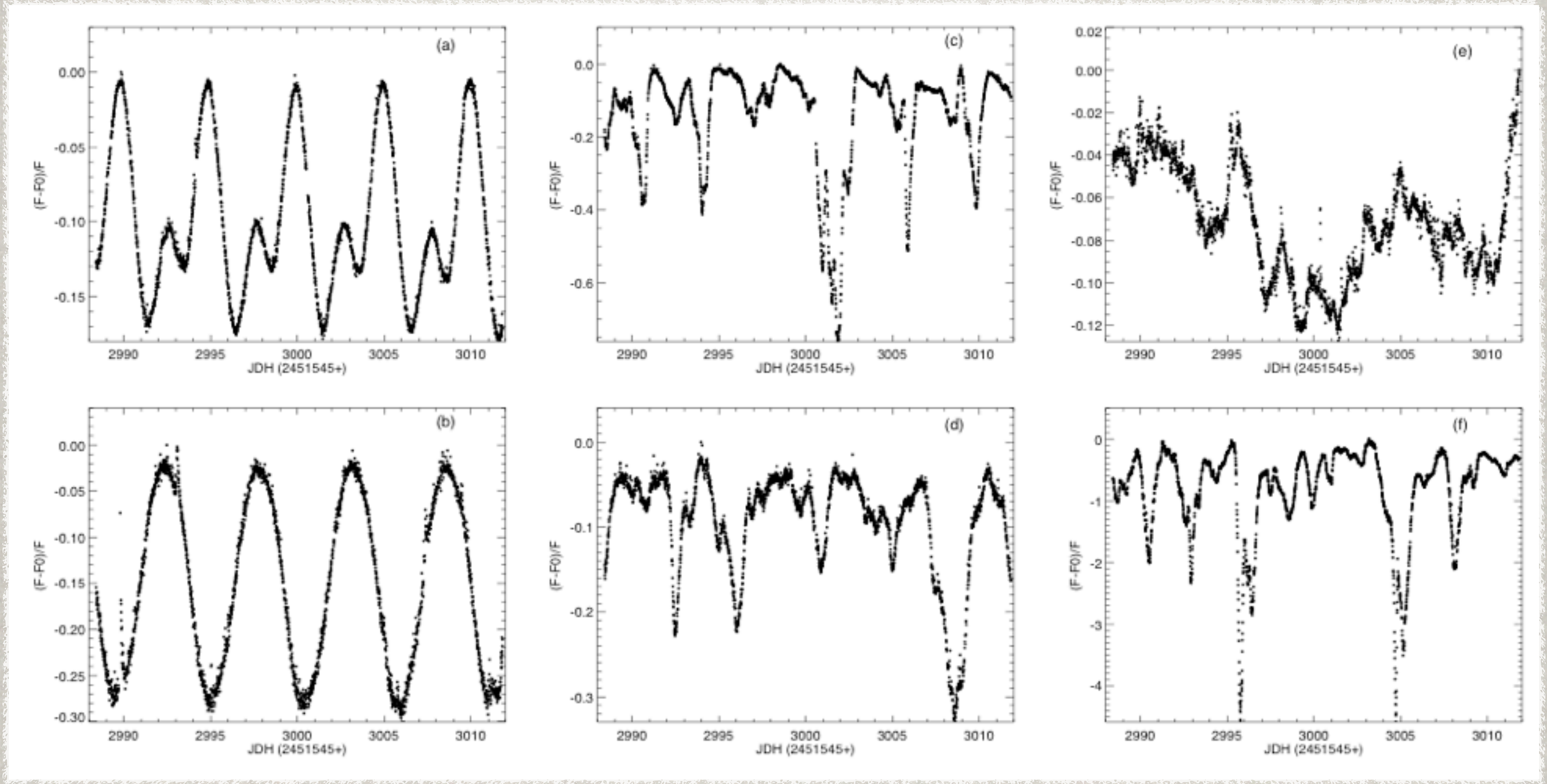


SRa05 (CSI - 40d in December 2011)
coordinated by G. Micela



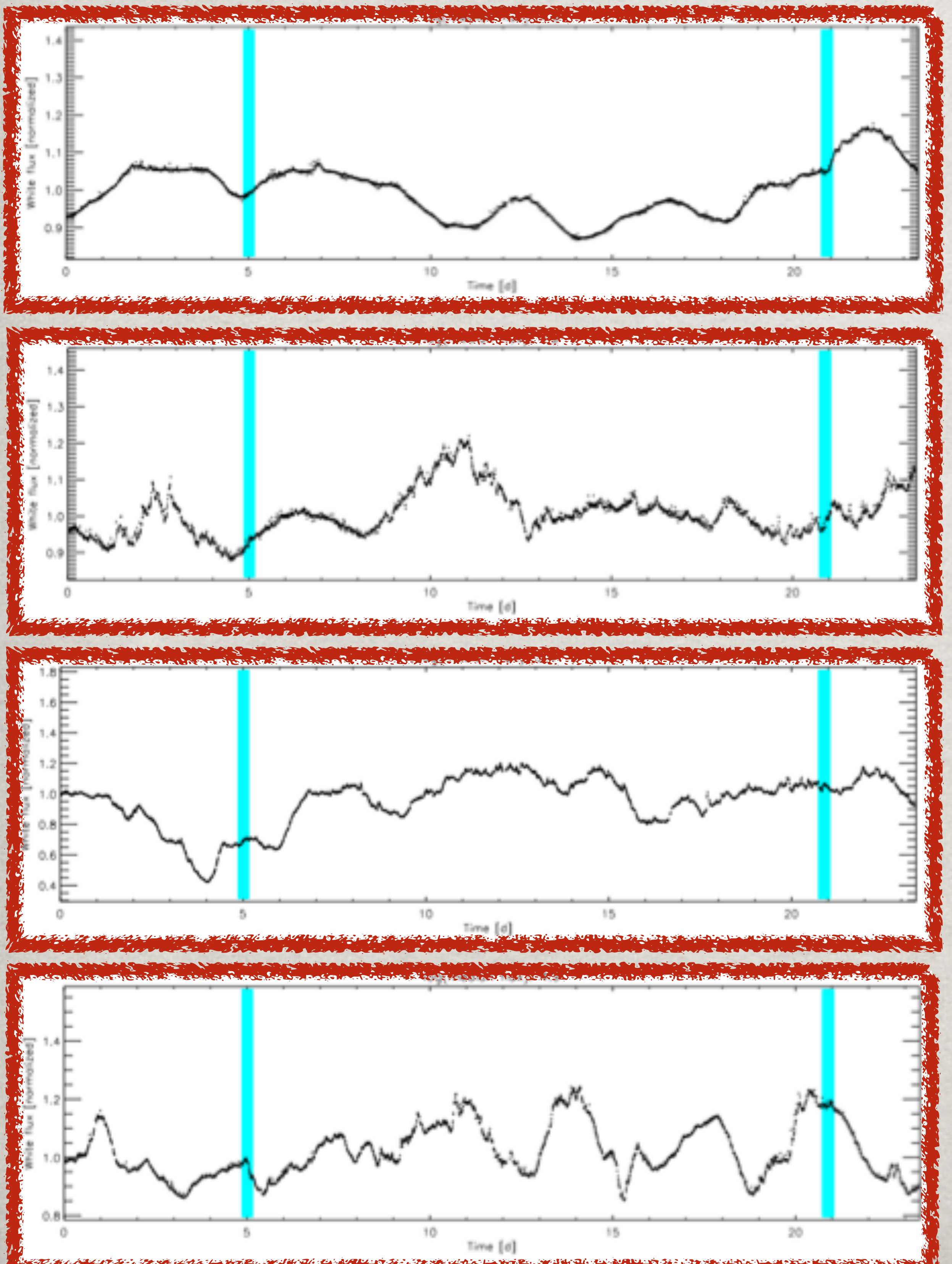
Optical variability - Alencar et al. (2010)

Spot-like | AA Tau-like | Irregular

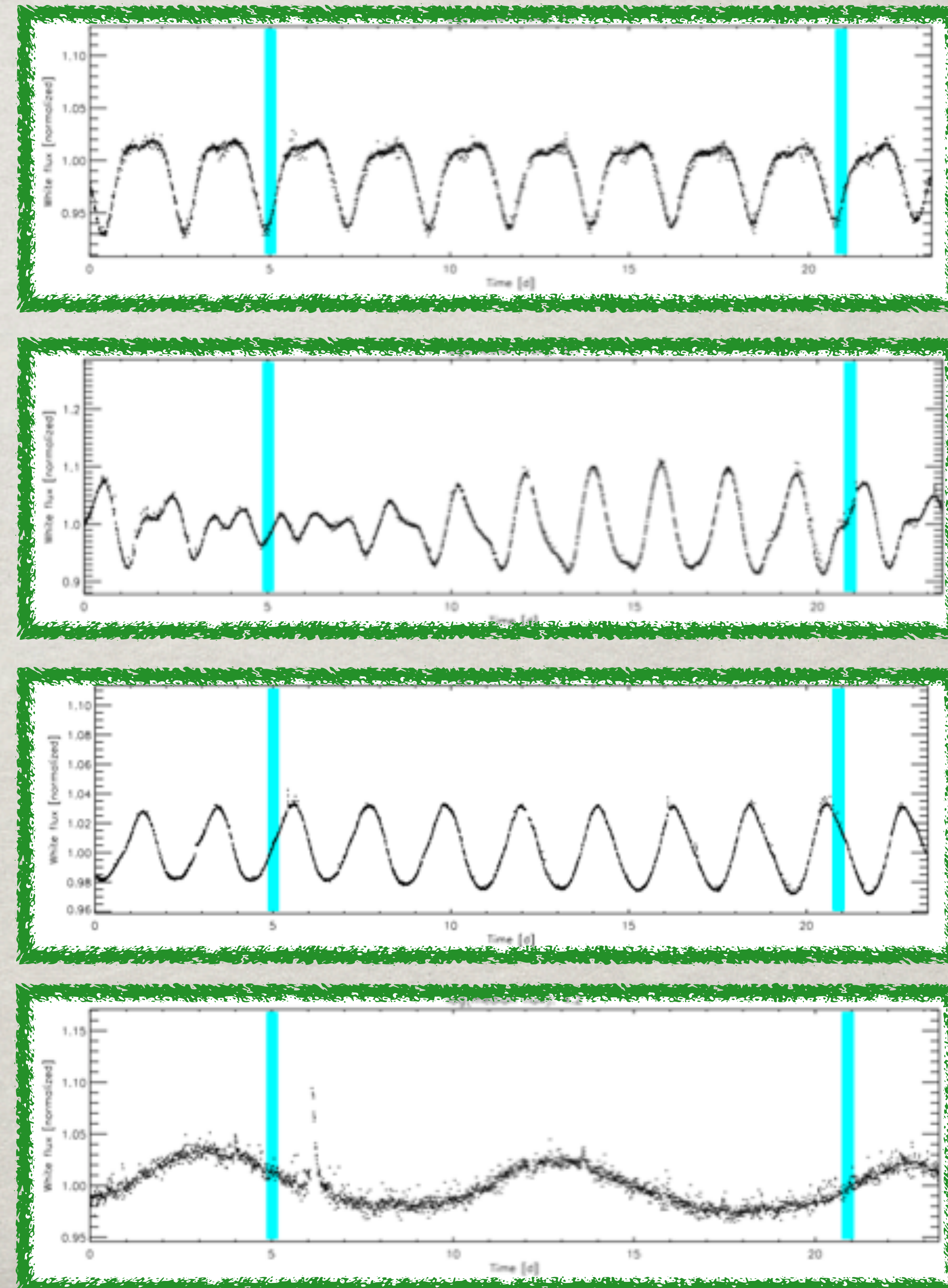


The 2008 CoRoT/Chandra data

CTTS

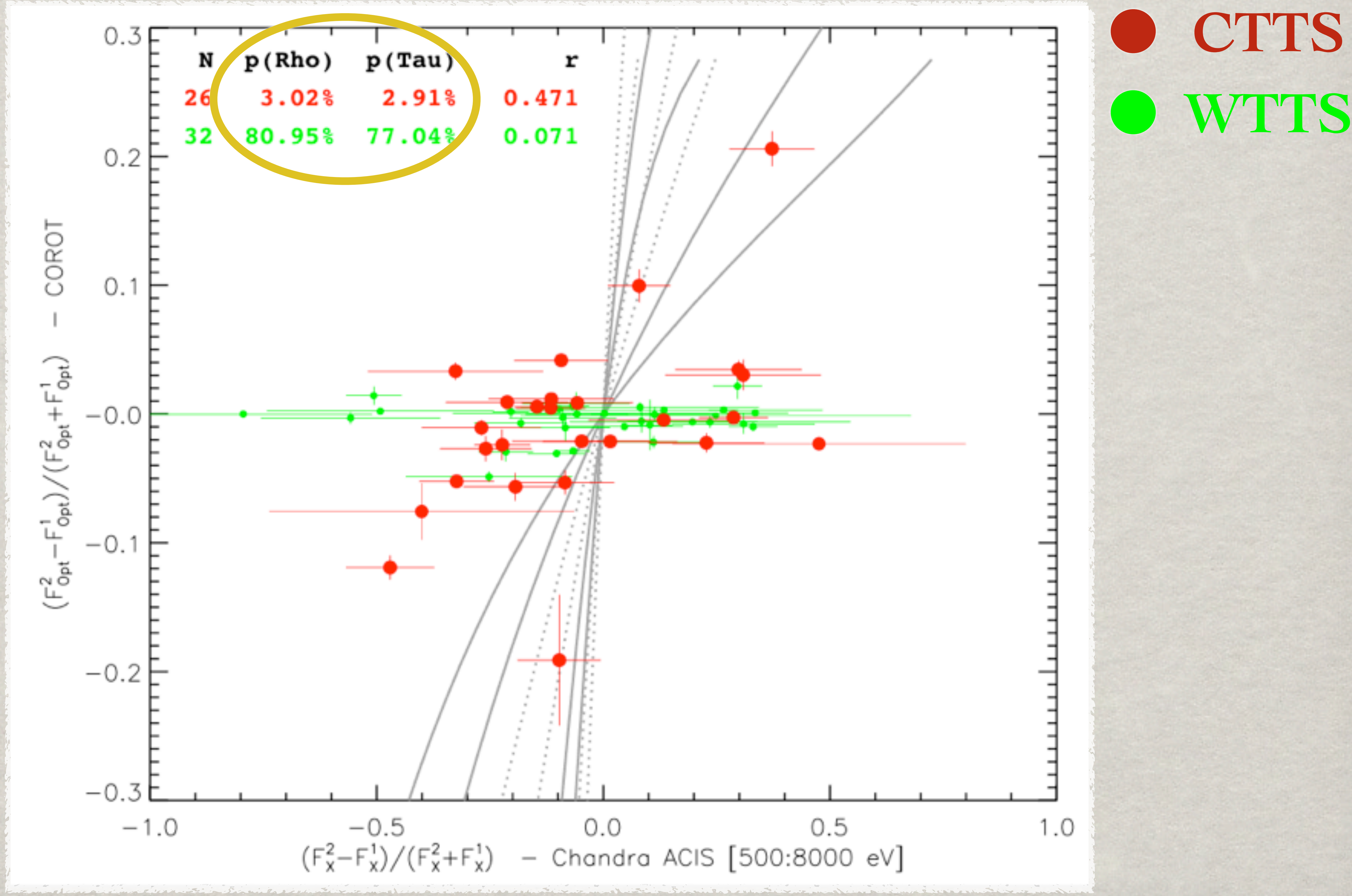


WTTS



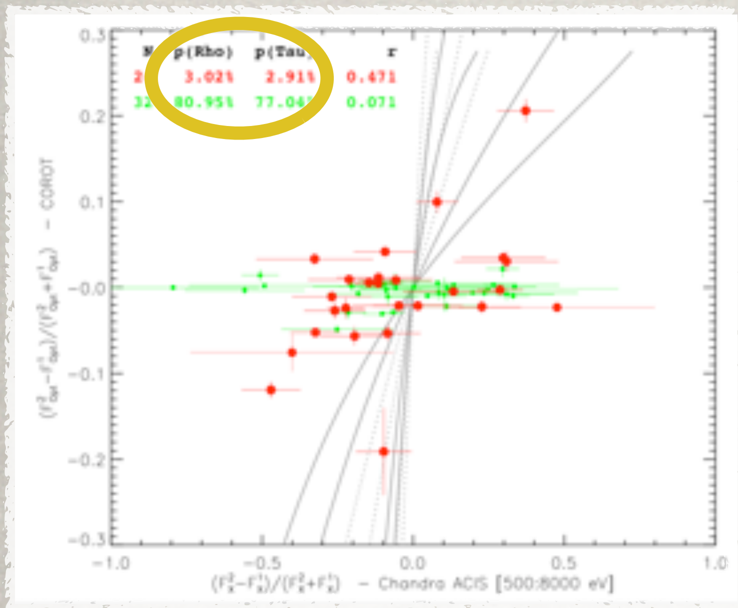
Optical vs. X-ray variability

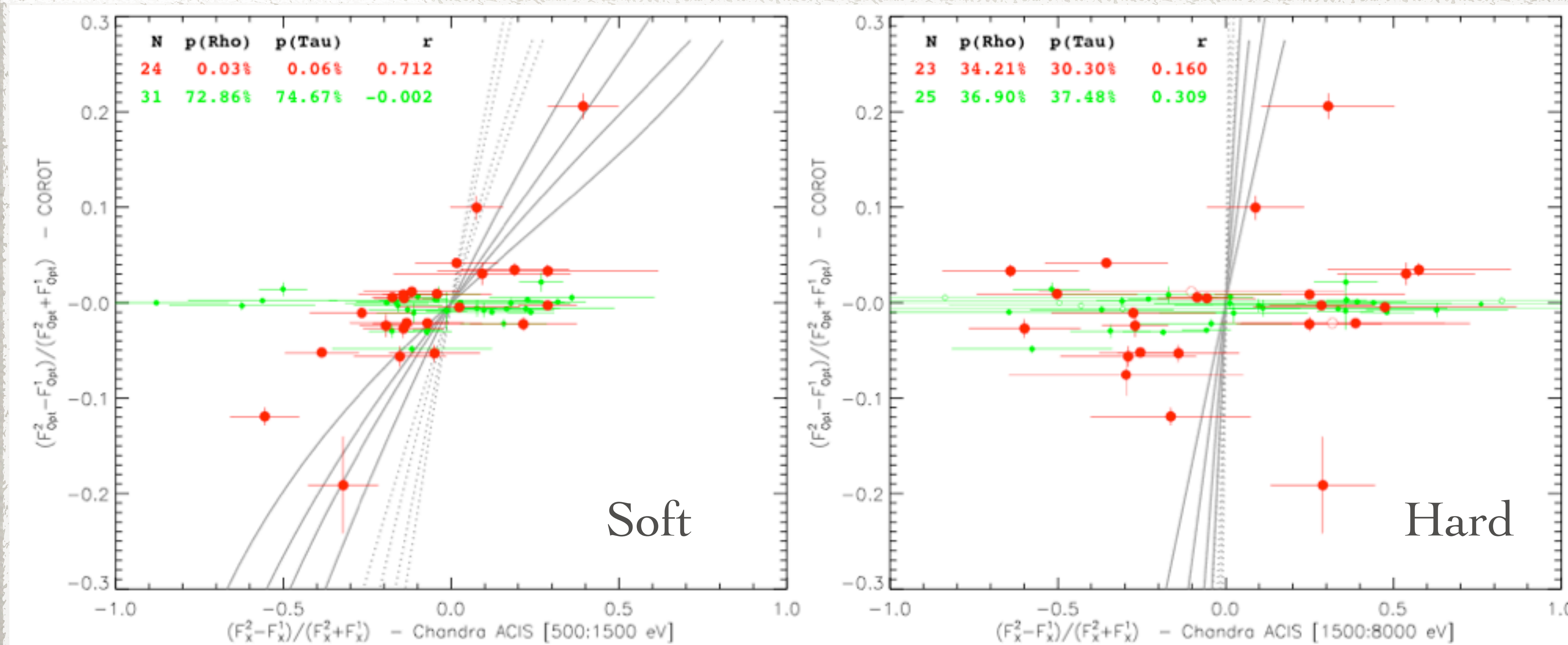
Flaccomio et al. (2010)



Optical vs. X-ray variability

Flaccomio et al. (2010)

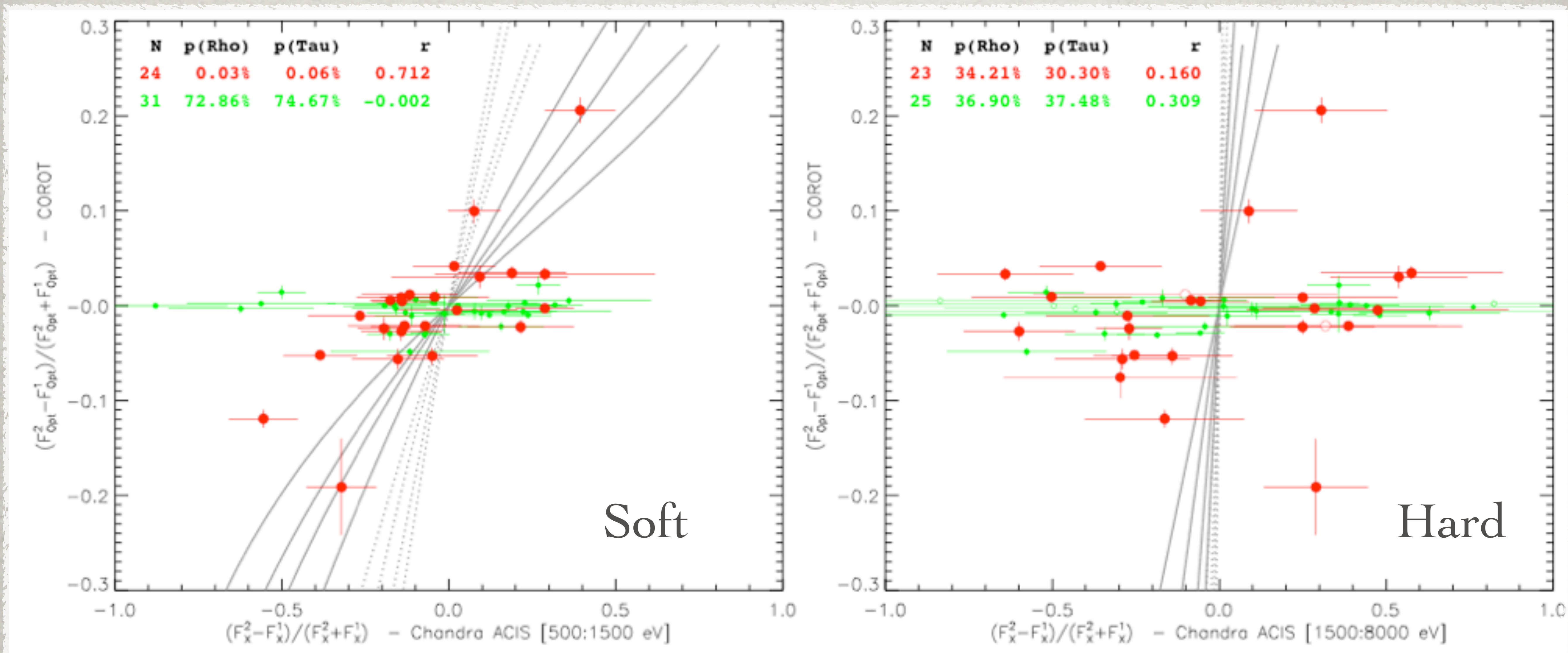




Optical vs. X-ray variability

Flaccomio et al. (2010)

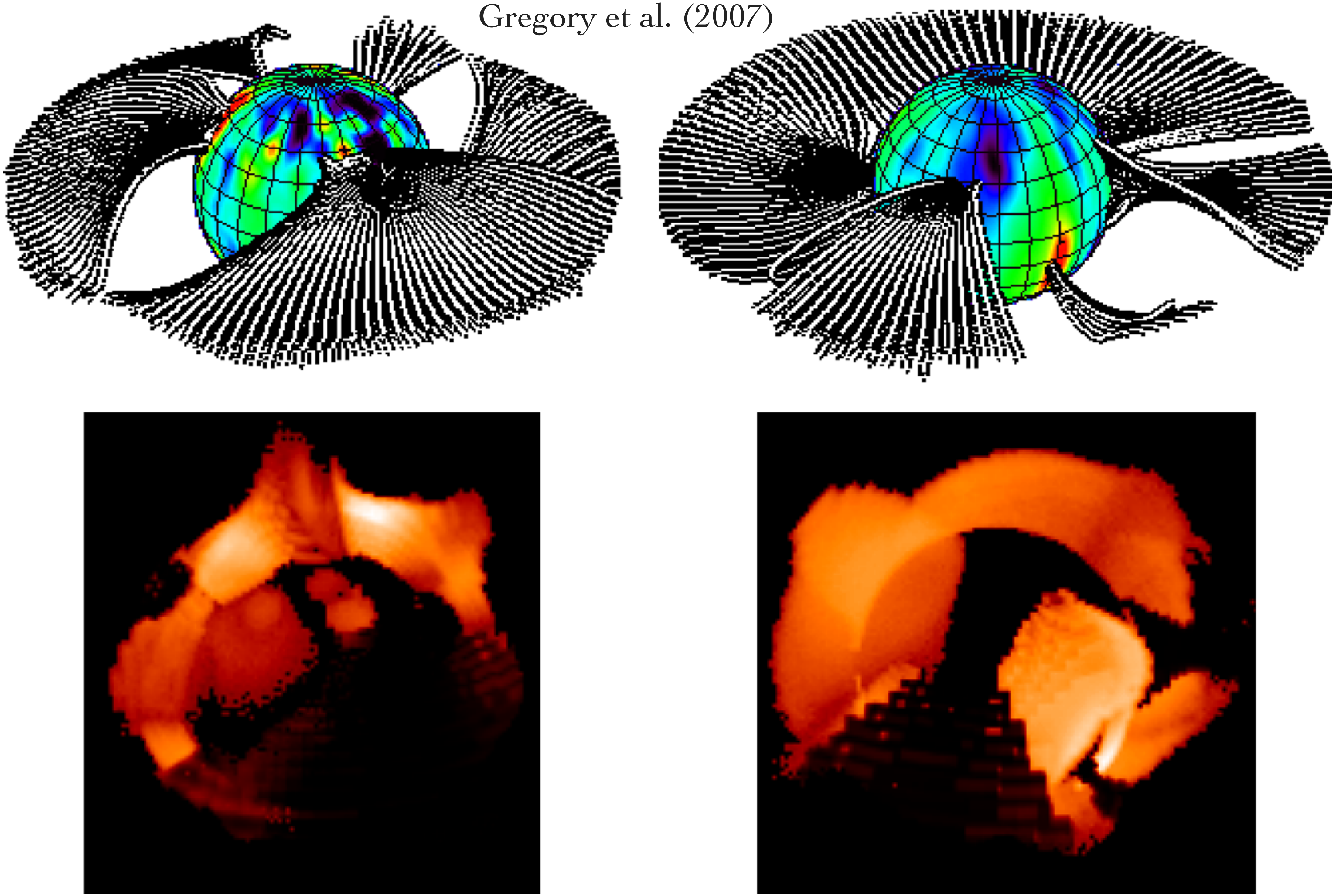
- CTTS
- WTTS



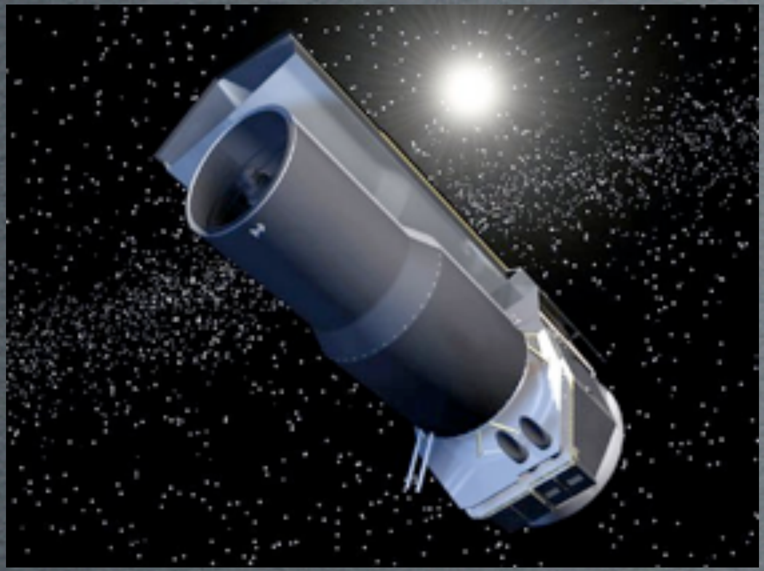
- Variable X-ray + optical emission from the accretion spot
  - The observed amplitudes (up to 40% and 100% for CoRoT and Chandra, respectively) would imply that the broad-band optical emission and the soft X-ray emission are dominated by the accretion shock. Not likely.
- Variable circumstellar absorption
  - Observed e.g. in AA Tau, and explain a large fraction of the large amplitude optical lightcurves (Alencar et al. 2010)

Obscuration by accretion streams

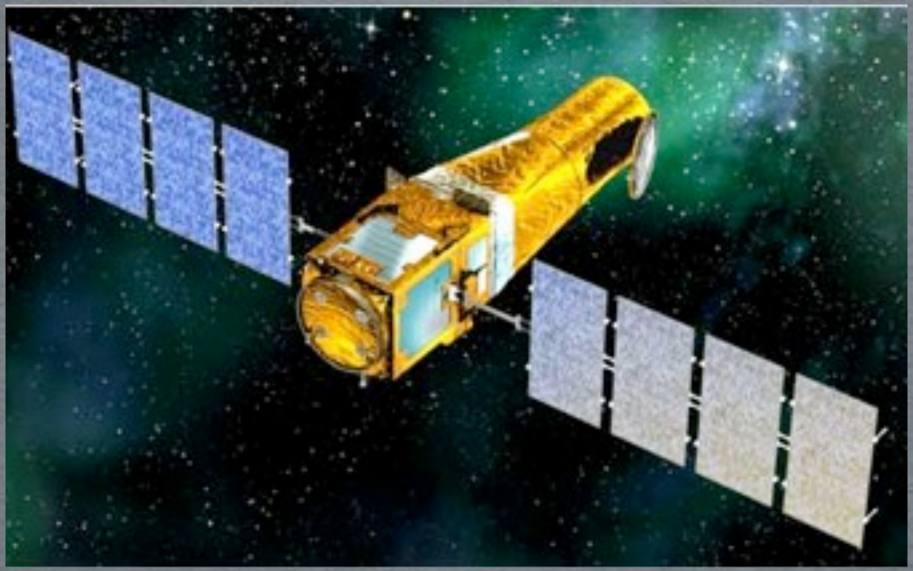
Gregory et al. (2007)



The Coordinated Synoptic Investigation of NGC 2264 (CSI)

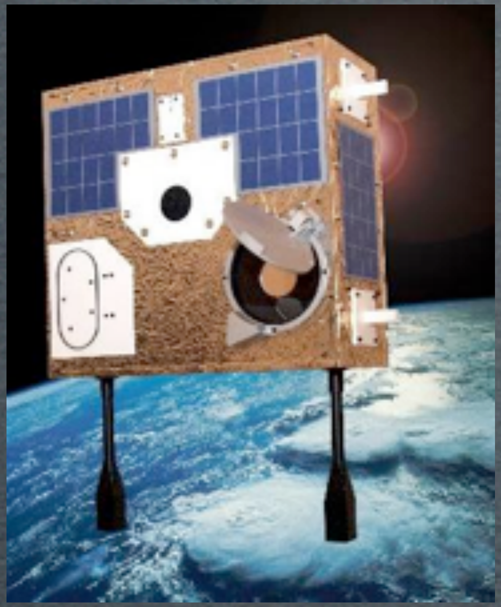


CoRoT: 40d, optical



Spitzer: 30d @ 3.6, 4.5 μm

Chandra/ACIS: 300ks (3.5d)



MOST: 40d, optical

VLT/Flames: ~20 epochs

Ground-based monitoring
U-K bands: ~3 months

The CSI collaboration

Spitzer PI: John Stauffer

Ann Marie Cody
Jérôme Bouvier
Konstanze Zwintz
Ettore Flaccomio
Peter Plavchan
Kevin Covey
Lynne Hillenbrand
Fabio Favata
Rob Gutermuth
Barbara Whitney
John Carpenter
Franck Marchis
Amy McQuillan
Joe Hora
María Morales Calderon
Sylvia Alencar
Suzanne Aigrain

Chandra/CoRoT PI: Giuseppina Micela

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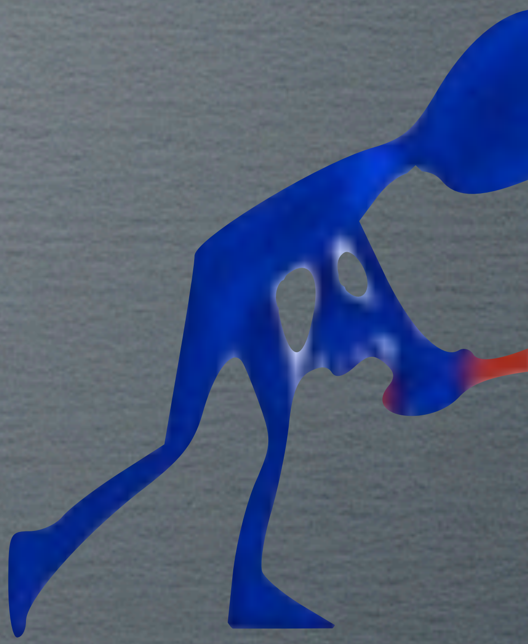
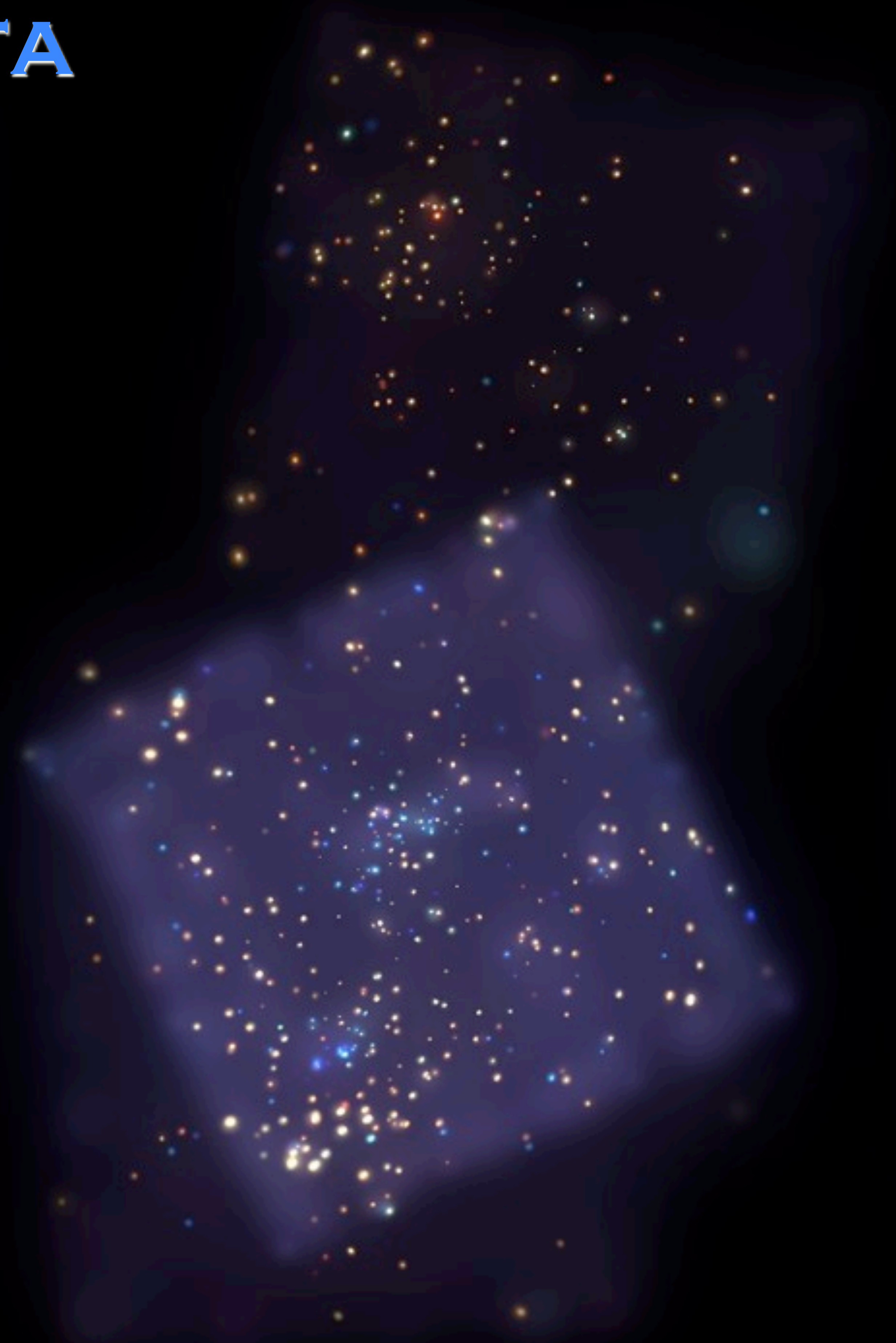
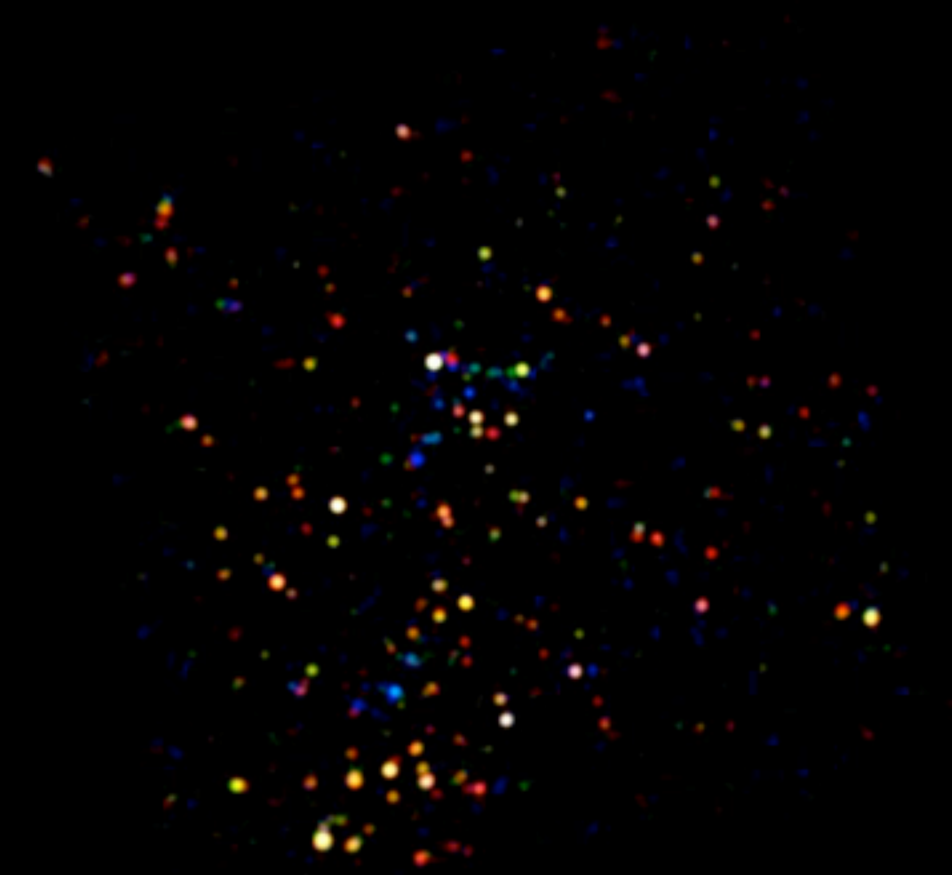
Luisa Rebull
Gabor Furesz
Paula Teixeira
Laura Affer
Neal Turner
David Barrado
Hervé Buoy
Laura Venuti
Inseok Song
Fred Vrba
Jorge Lillo Box
Sean Carey
Susan Terebey
Jon Holtzmann
Ed Gillen
Alan Watson



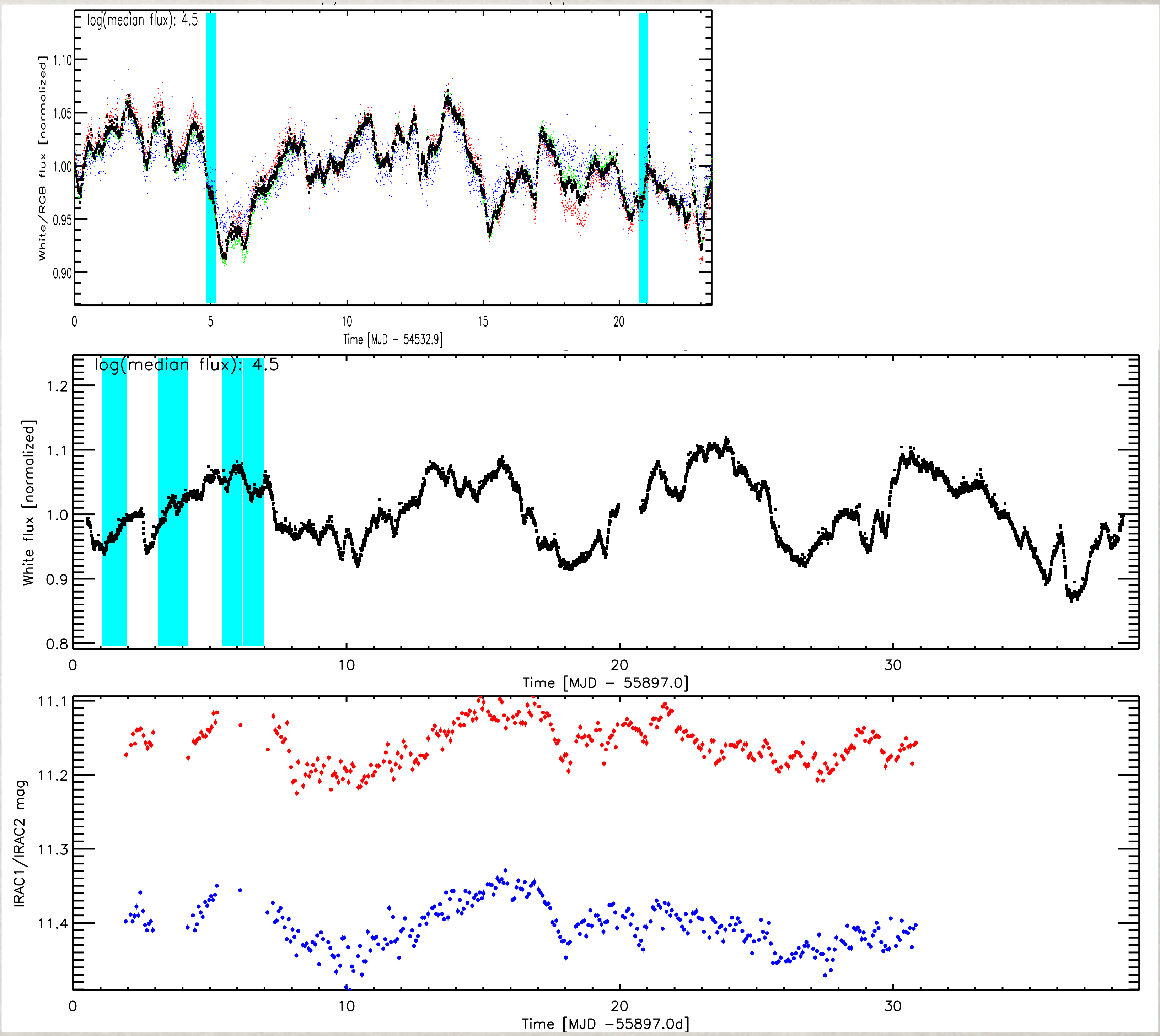
CSI CHANDRA
DATA





CSI Chandra Observations

- Four observation segments
- Total exposure time:
  297 ks (75 + 94 + 61 +67)
- Time span: ~6 days
  > P_{rot} for most stars
  > 0.5 P_{rot}



FLARES

- Best observed in soft X-rays, but most of the energy emitted at other wavelengths
- Optical flaring studied on the Sun, active binaries, M-type stars. The optical emission traces the heating events, but its emission mechanism still not entirely clear.

- Flares on PMS stars:
  - 4-6 orders of magnitude more energetic than on the Sun
  - Duration from hours to >1d
  - Some events apparently from long loops, maybe connecting the star with the inner disk

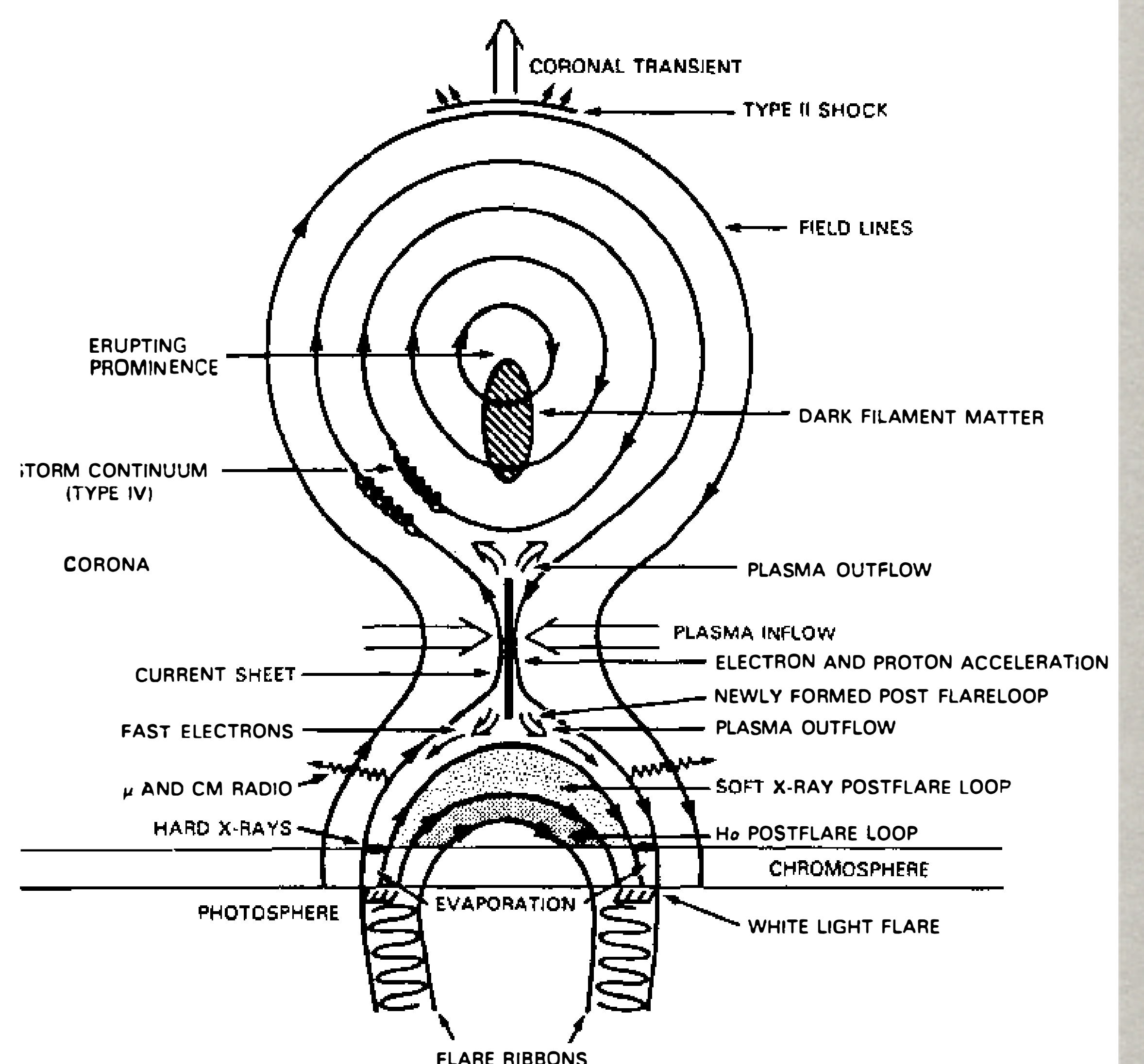
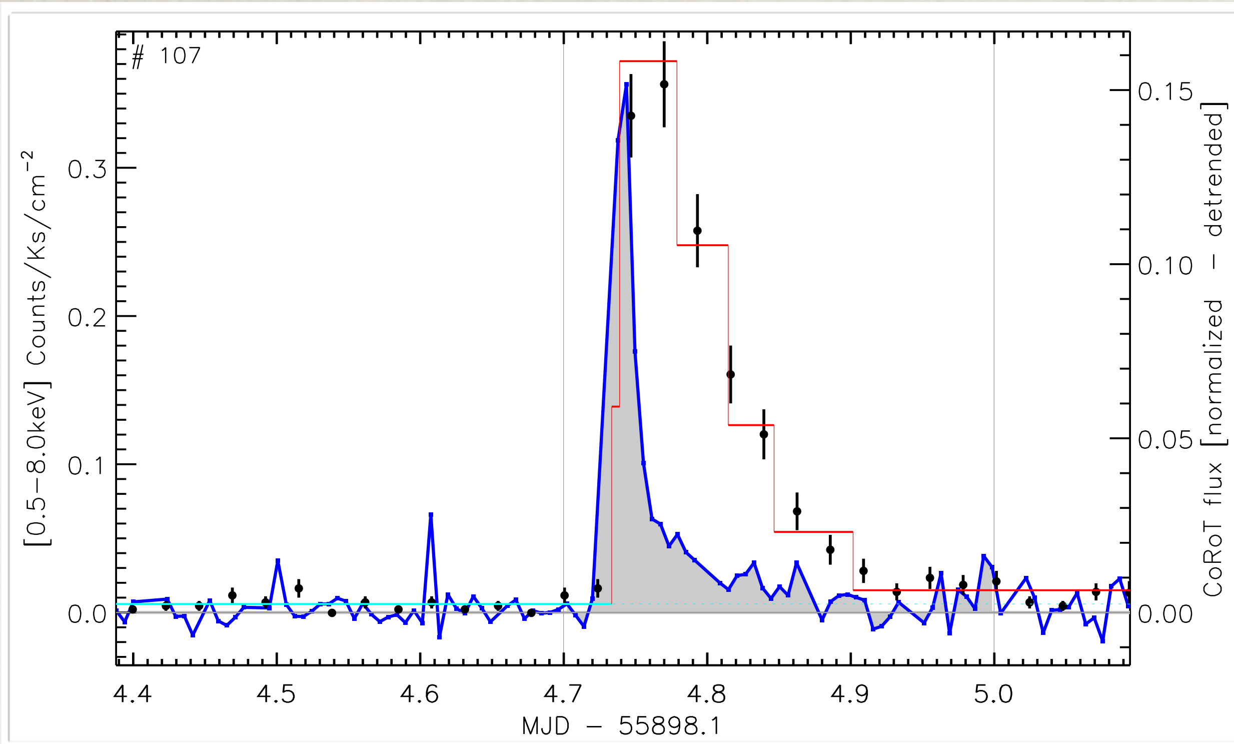
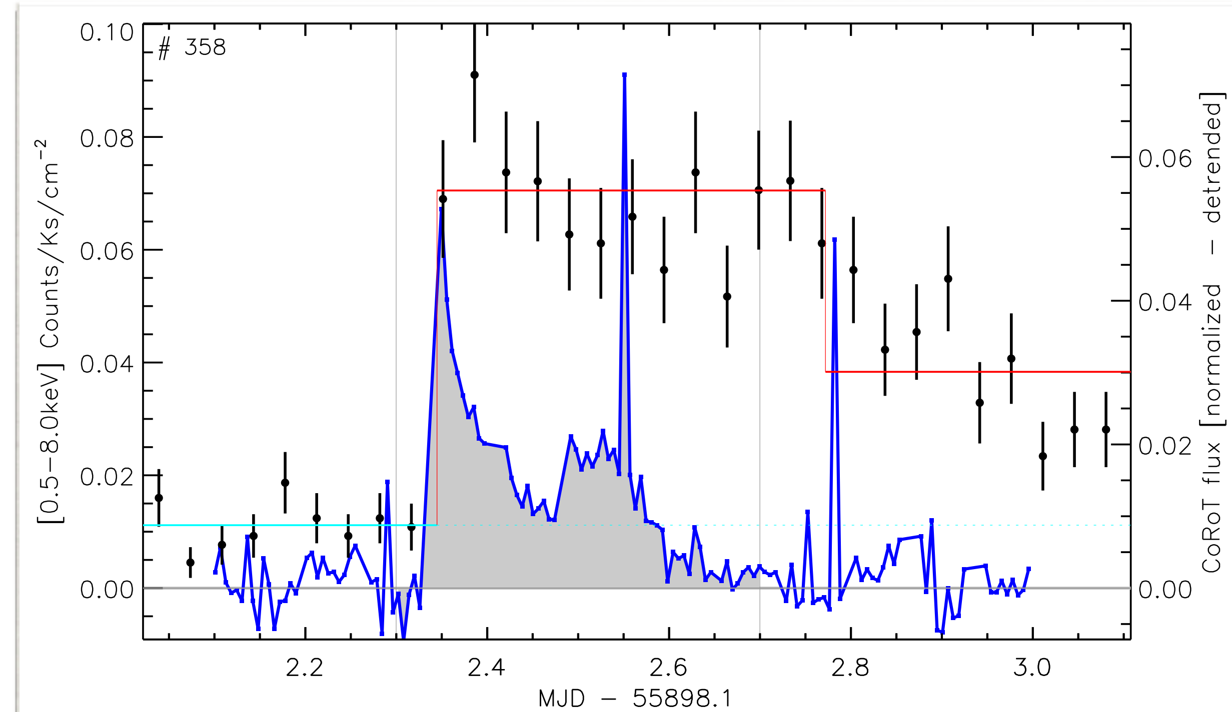


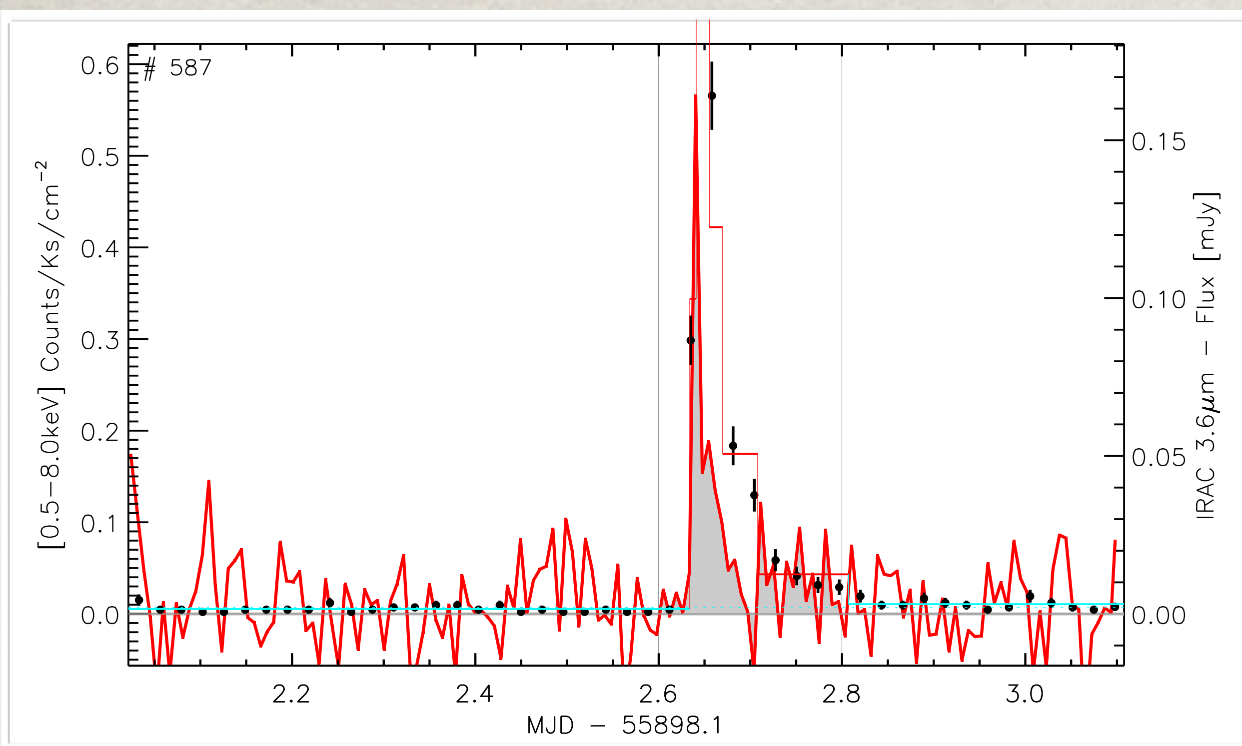
Figure 3 The global structure of the Martens & Kuin two-ribbon flare model showing the location of the major observed energy conversion processes, viewed in a cross section along the neutral line (from Martens & Kuin 1990).

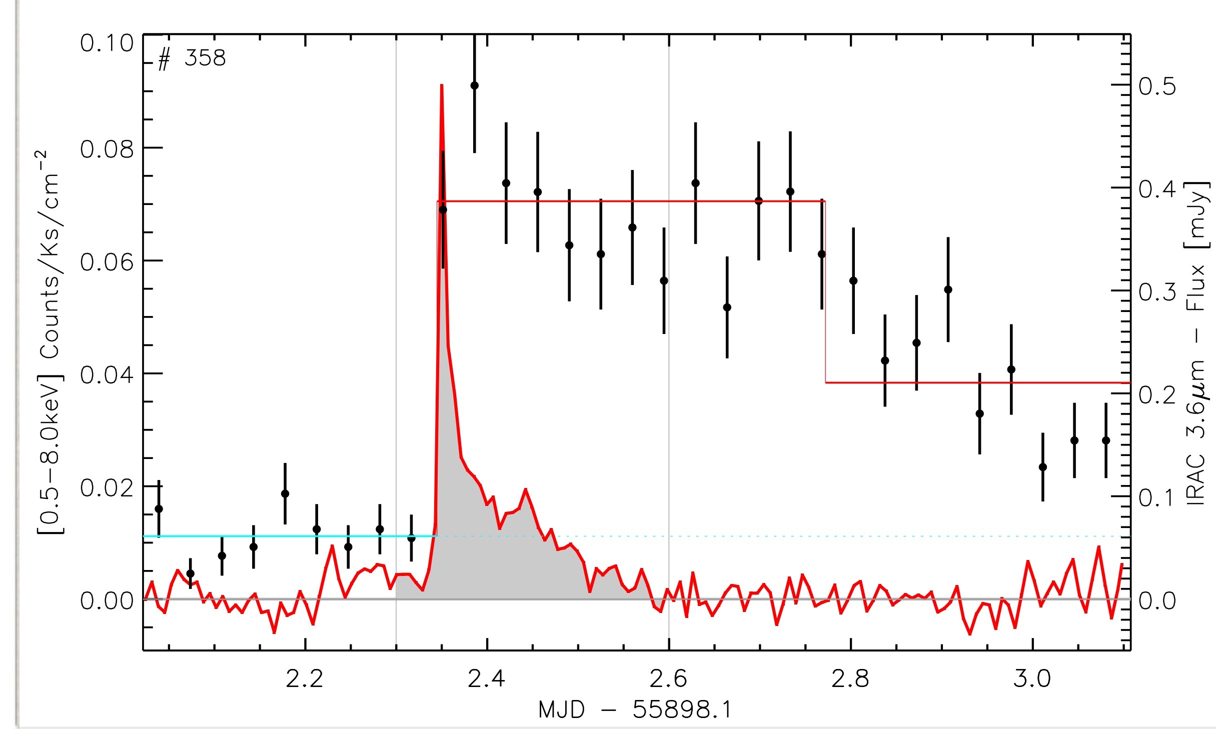
- To my knowledge, optical observations of flares on PMS stars are very scarce (1?), and there are **no simultaneous optical/X-ray observations.** Also no mIR observations?
- mIR/X-ray observations might provide evidence of X-ray heating of the inner disk

Chandra/CoRoT/Spitzer FLARES

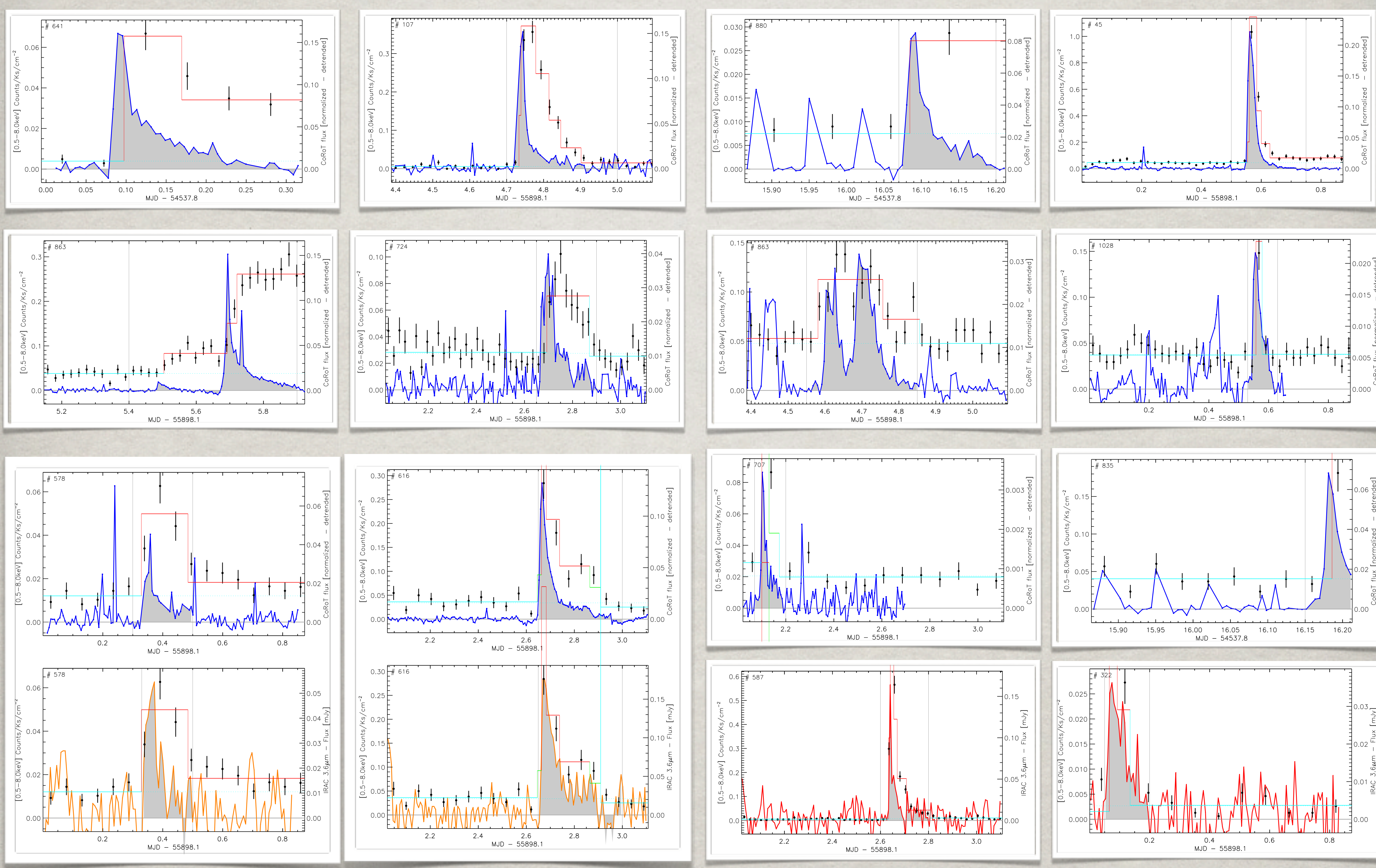








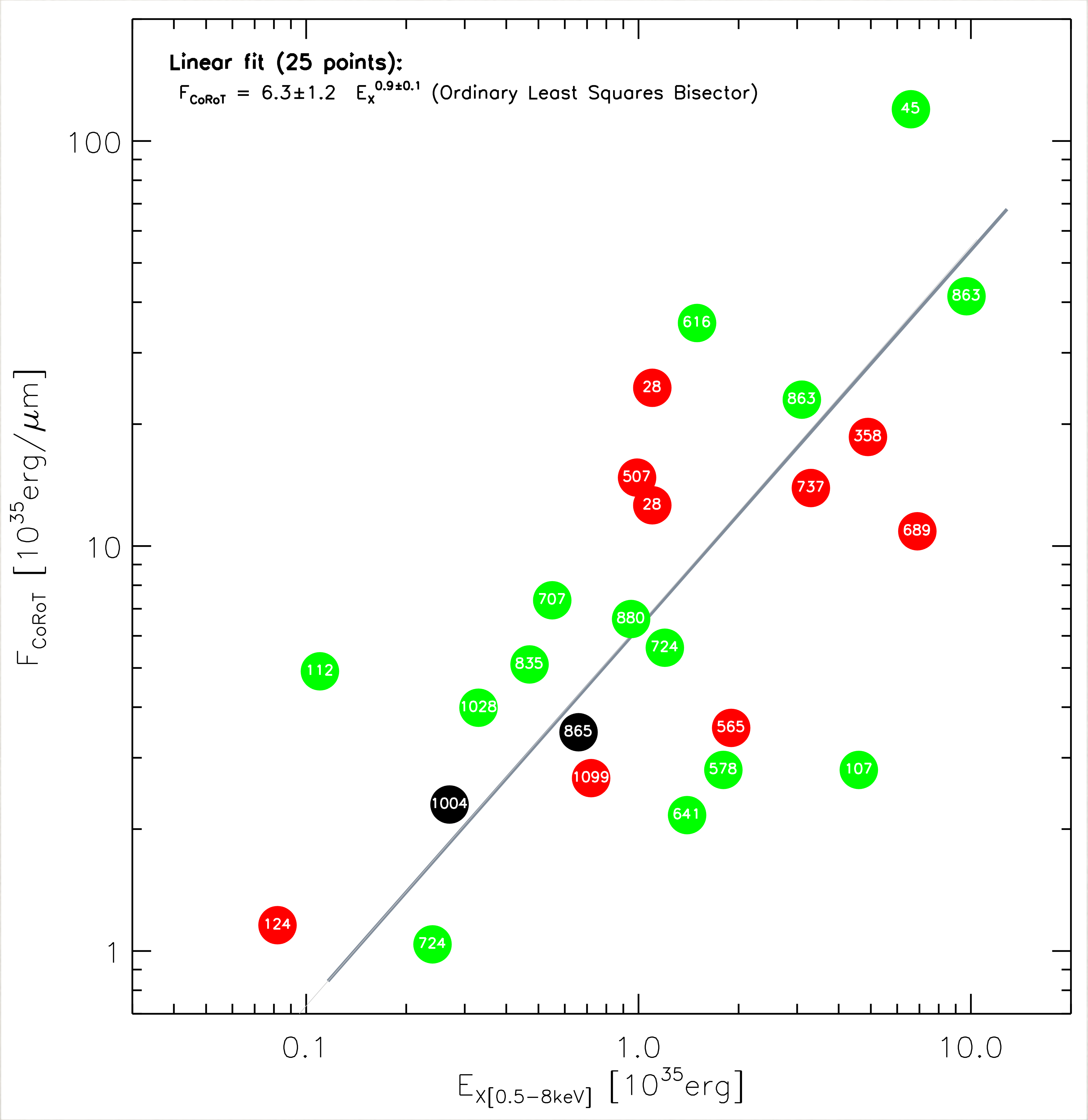
WTTSs/stars with no circumstellar disk



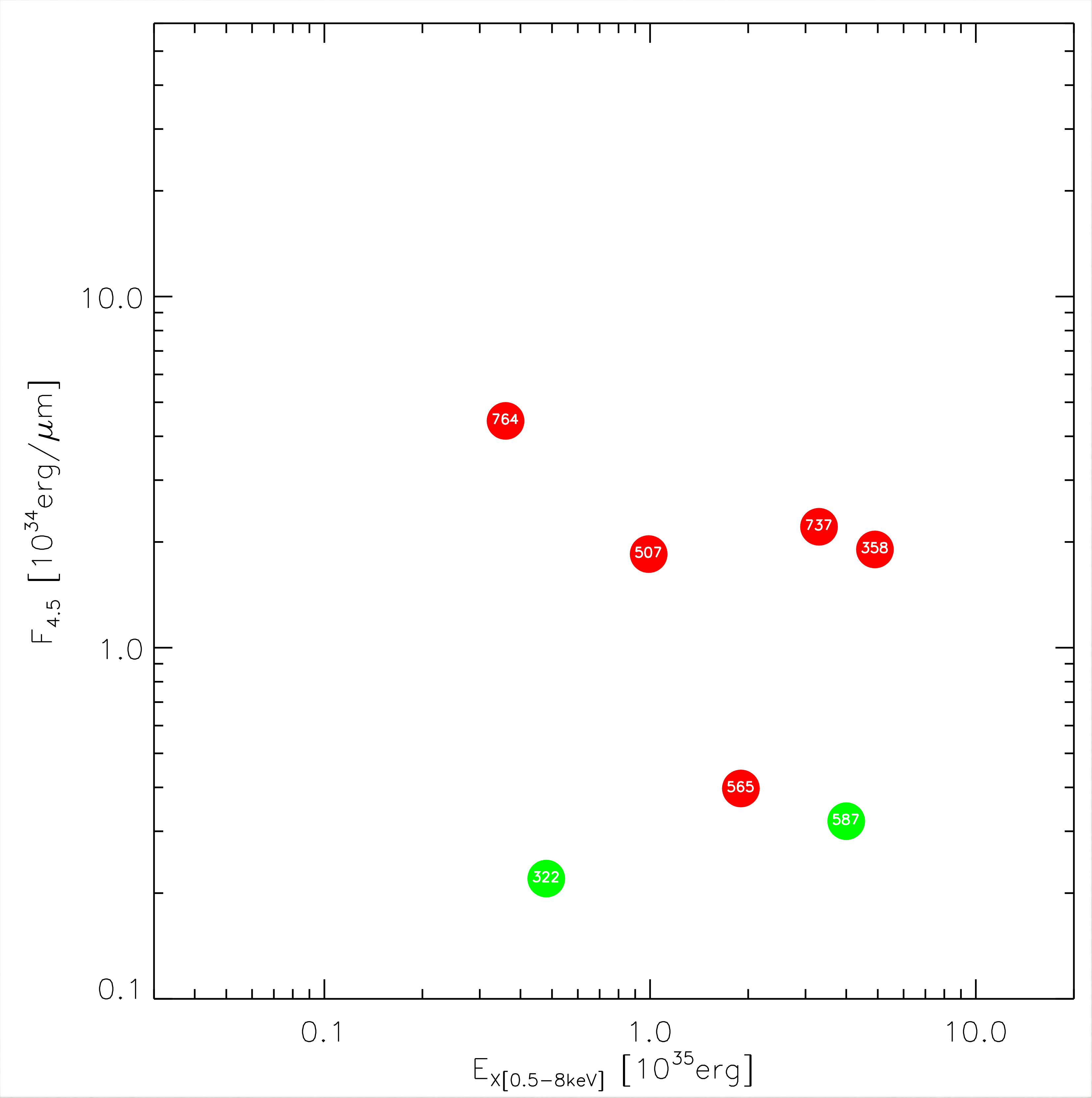
CTTSs/stars with circumstellar disks

Optical vs. X-ray emitted energy

● CTTS
● WTTS

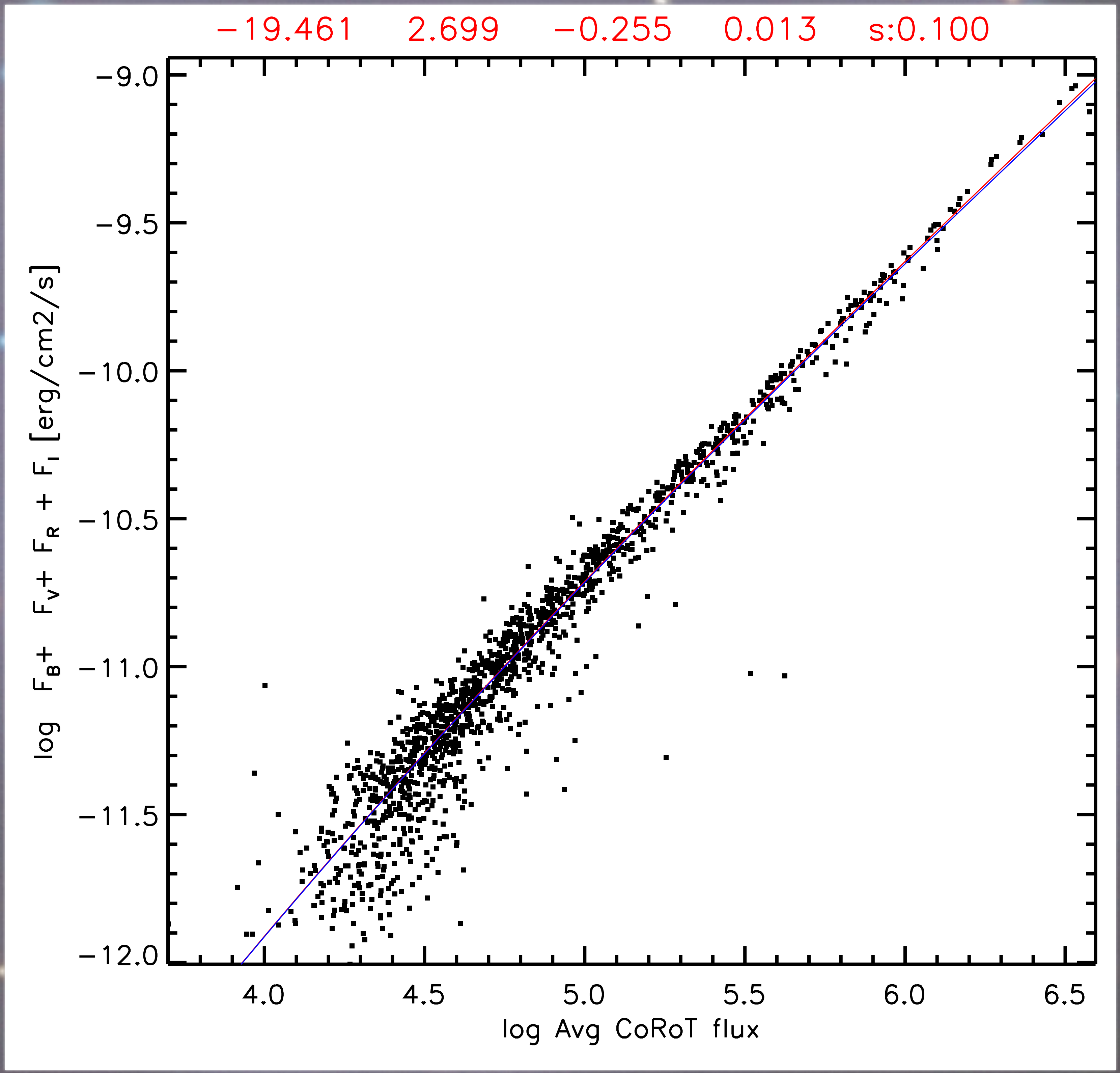


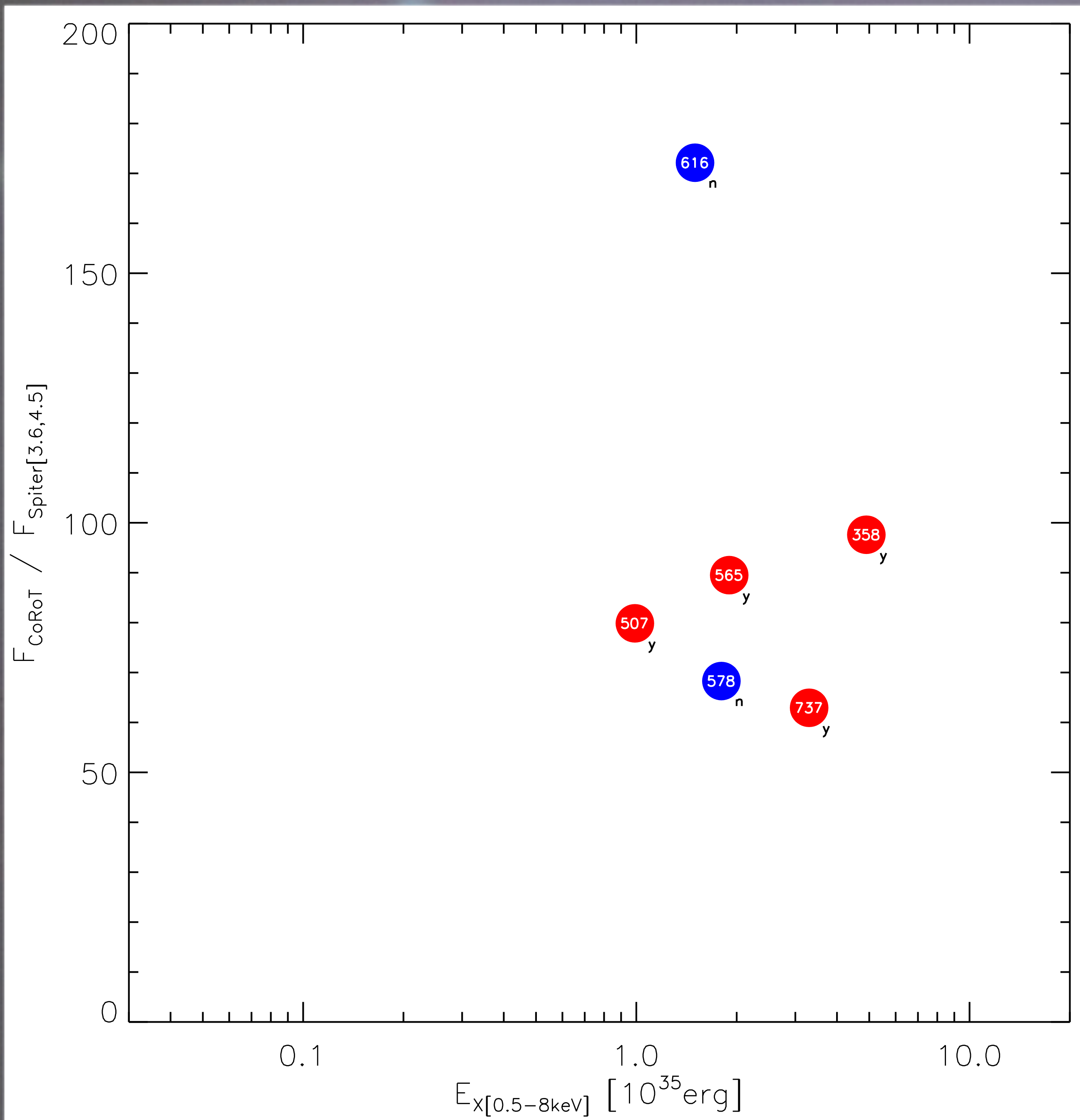
mIR vs. X-ray emitted energy

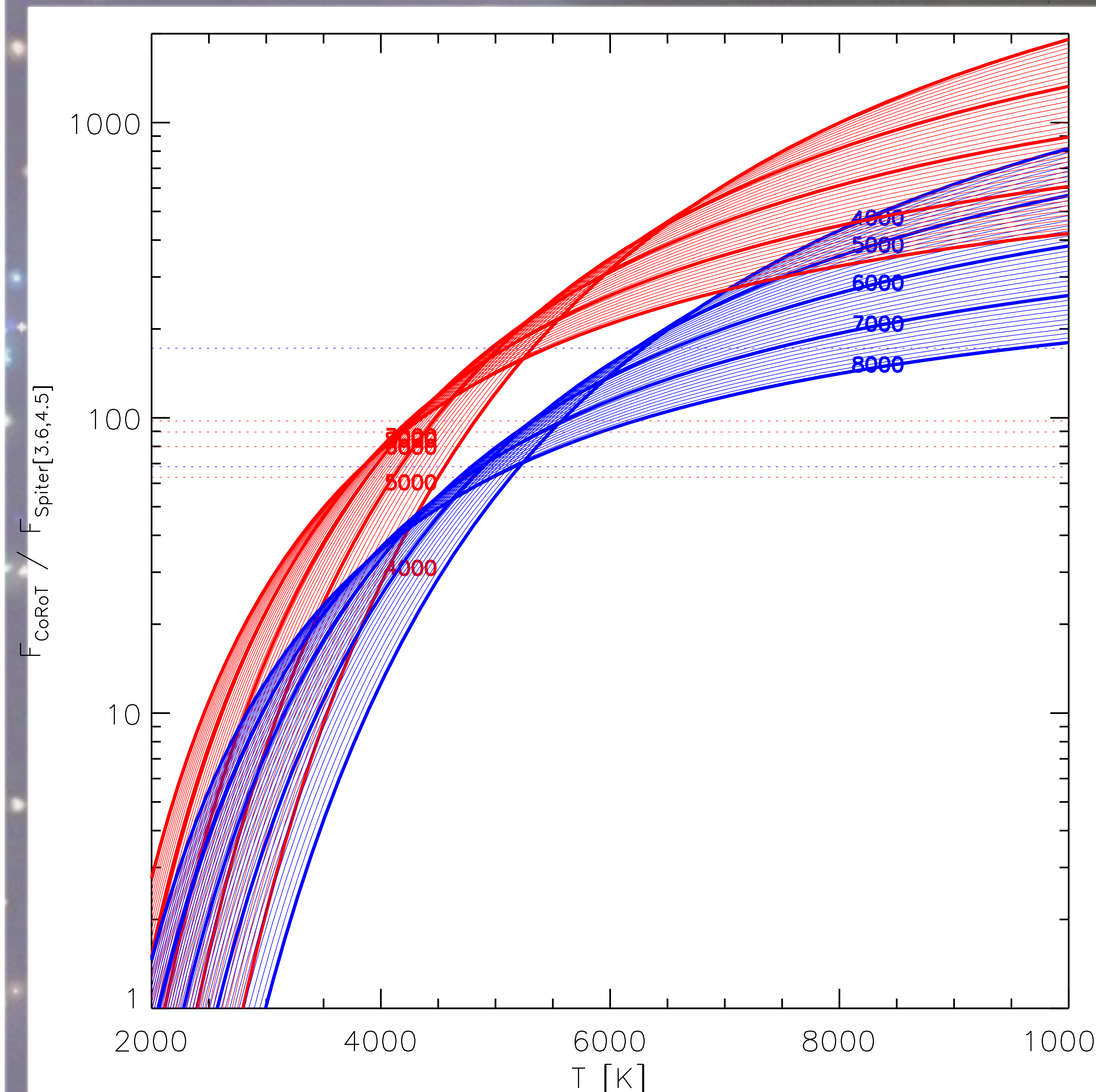


Conclusions

- The correlation between optical (CoRoT) and soft X-ray variabilities of CTTS suggests that time variable circumstellar absorption crucially affects the observed activity levels.
- The first ever (to my knowledge) simultaneous optical/mIR/X-ray observations of flares on PMS stars show that:
  - The optical emission often traces flare heating (at least on WTTSs)
  - The energy emitted in the optical and X-ray bands seem to be linearly correlated.
  - More energy is emitted in the optical rather than in X-rays
  - We are likely seeing the direct response (heating) of the inner disk to the stellar X-ray emission
- A lot more to do with the CSI dataset, a treasure chest awaiting full exploitation


−19.461 2.699 −0.255 0.013 s:0.100
log F_B+ F_V+ F_R + F_I [erg/cm2/s]
log Avg CoRoT flux
−9.0
−9.5
−10.0
−10.5
−11.0
−11.5
−12.0
4.0
4.5
5.0
5.5
6.0
6.5


200
150
100
50
0
0.1
1.0
10.0
F_{CoRoT} / $F_{Spiter[3.6,4.5]}$
$E_{X[0.5-8keV]}$ [10^{35}erg]
616 n
358 y
565 y
507 y
578 n
737 y


1000
100
10
1
2000
4000
6000
8000
10000
T [K]
F_{CoRoT} / $F_{Spiter[3.6,4.5]}$
4000
5000
6000
7000
8000
5000
4000