Magnetic coronae and circumstellar disks - insights from the Coordinated Synoptic Investigation of NGC2264 (CSI-NGC2264)

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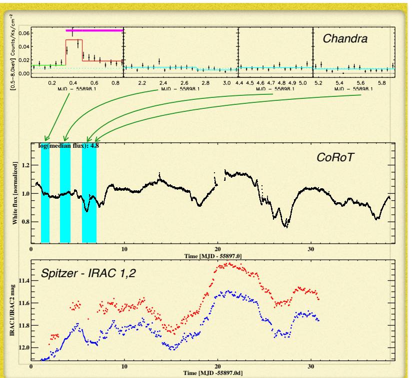
Abstract

Young stellar objects interact with their proto-planetary disks through radiation and magnetic fields. X-ray/UV coronal and accretion-shock emission may drive gas ionization and heating and, consequently, photo-evaporation and disk dispersal. The magnetosphere connecting the star and inner disk mediates mass and angular momentum exchanges and modifies the disk structure. These interconnected processes are highly dynamic and involve material emitting in different bands: the inner disk dust (mIR), the stellar photosphere (optical), accretion shocks (UV/X-rays), and coronae (X-rays).

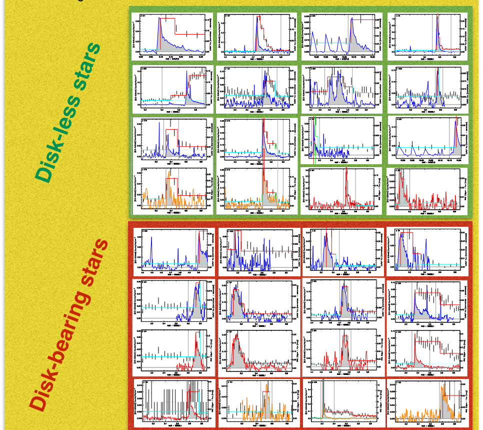
The Coordinated Synoptic Investigation of NGC2264 (CSI-NGC2264) consisted of an unprecedented multi-wavelength month-long observing campaign of the NGC2264 region. Three space telescopes (*Spitzer*, *CoRoT*, and *Chandra*) simultaneously monitored a rich sample of ~3Myr old stars in the mIR, optical, and X-ray bands, providing new insights on the dynamics of the respective emitting regions and their interactions.

Here we discuss preliminary results on the correlation between X-ray and optical/mIR variability. We focus on **magnetic flares** and on the overall relation between **non-flaring** X-ray (coronal) and optical (photospheric) **emission**. As for flares, for the first time, we observe the heating phase (in the optical), the decay (in X-rays), and, possibly, the disk response to the flare (in the mIR). We then report on the first attempts, with this rich dataset, to correlate the non-flaring X-ray variability, with the optical emission for different classes of stars.

Data



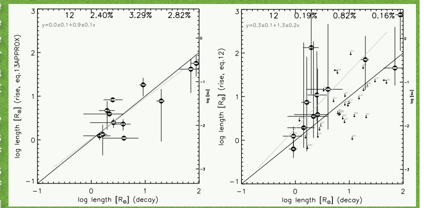
Example of simultaneous light-curves obtained for one object, with *Chandra* (top), *CoRoT* (middle) and *Spitzer* (bottom). The *Chandra* dataset is split into four segments with temporal coverage indicated by the cyan boxes in the CoRoT light-curves.



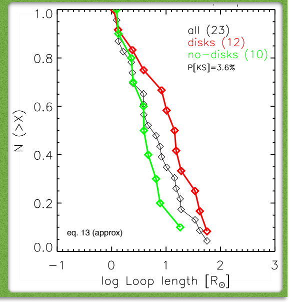
Flares observed simultaneously in X-rays and in the optical and/or mIR bands. Black error bars indicate the *Chandra* lightcurves; blue, orange, and red lines indicate, respectively, the *CoRoT*, IRAC [3.6] and IRAC [4.5] lightcurves. Some flares, when three of the bands are available, are shown in two panels.

Flares - Loop lengths from modeling of the decay and rise phases in X-rays

Up to five separate estimates for the length of flaring loops were obtained from modeling of the decay and rise phases, using the relations given by Reale (2007). We show below how two estimates from the analysis of the rise phase compare with that from the decay phase. Although error bars are often large, a reasonable agreement between all estimates, some of which are fully independent, is found. This strengthens the reliability of the loop length estimations and, in particular, those of exceptionally long flaring loops, e.g. longer than ~0.1 AU (~20 solar radii), first found by Favata et al. (2005), and whose existence has been debated in the last few years.

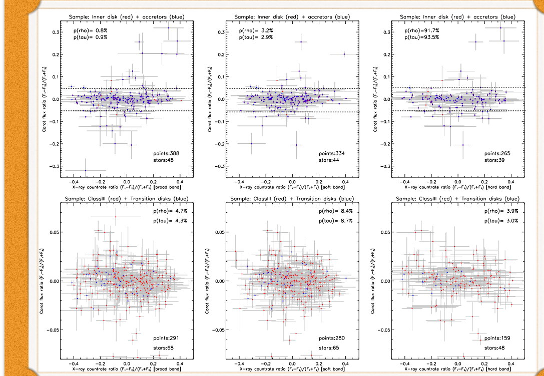


Cumulative distributions of loop lengths derived from one of the four possible analyses of the rise phases (similar results are obtained with the other methods). We show distributions for the full sample of flaring loops, and for loops on stars with and without circumstellar disks. The loops on stars with disks appear to be systematically longer than those on disk-less stars. A Kolmogorov-Smirnov (KS) test confirm this difference with moderate confidence. Moreover, some of the loops are estimated longer than ~20 solar radii, consistently with previous results based on the analysis of the decay phases.



Non flaring optical/X-ray variability

Excluding time segments with evident X-ray flares, we compare the X-ray and optical variabilities following the approach of Flaccomio et al. (2010), i.e we plot the fractional flux variations in the optical and X-ray bands against each other, for each star and each pair of observing segments (as defined by the *Chandra* observations, see first figure on the left). Initial results are shown below, considering three X-ray spectral bands (full, soft, and hard, from left to right) and four different stellar sub-samples: accretors and stars with inner disks in the top row, and stars with no inner disk (transition disks) and with no disk (class III) in the bottom row. The latter groups shows much smaller optical variabilities and a hint of anti-correlated optical/hard X-ray variability (note the different vertical scales in the two rows; the dotted lines in the upper panels indicate the approximate range of optical variability in the lower panels). Some of the stars with active disks, on the other hand, seem to show correlated optical/X-ray variability.



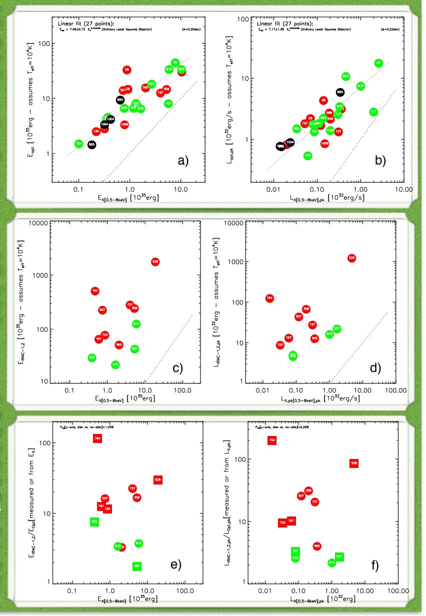
Flares - from the m-IR to X-rays - heating and disk response

Flare energies and peak luminosities in the X-ray band [0.5-8.0keV] were measured through time-resolved spectral analysis of the *Chandra* data. Likewise, *bolometric* energies and peak luminosities from the optical and mIR flares were estimated from the *CoRoT* and *Spitzer* lightcurves, respectively, assuming an emission spectrum of a 10^4 K photosphere. Here we compare the X-ray, optical, and mIR quantities, distinguishing flares on disk-bearing sources (red symbols), disk-less ones (green symbols) and stars with uncertain classification (black symbols).

- The optical flare energies (and peak luminosities) are well correlated with the X-ray values, confirming the strong (causal?) physical connection between the two events. The optical/UV emission is ~5-10 times larger than the soft X-ray one.

- The flare energies and luminosities estimated from the mIR are less correlated with those of the X-ray events. Flares on disk-bearing stars appear to be more energetic and brighter in the mIR with respect to those on disk-less stars.

- We here compare the bolometric fluxes derived from the mIR with those derived from the optical data (when available, plotted as circles) *or* estimated from the relations with the X-ray quantities in panels a) and b) (squares). The mIR emission of most flares on disk-bearing stars is 10-100 stronger than expected from a 10^4 K *photospheric* emission producing the CoRoT event. These mIR excesses are much less pronounced for flares on disk-less stars, for which the photometry is thus consistent with smaller deviations from the assumed spectrum.



Conclusions

- Loop lengths
  - Estimates obtained with different methods are consistent
  - Flaring loops on stars with circumstellar disks appear longer than those on diskless stars. Coronae might be more extended because of magnetic star-disk interactions, and the longest loops might extend to the inner disk.
- Correlation between optical and X-rays emitted energy
  - Optical flares trace the plasma heating at the foot-points of magnetic loops. A small and rather fixed fraction of the energy deposited at the footpoints is converted into soft X-ray emission.
  - Flares on stars with disks have large mIR excesses with respect to flares on disk-less stars. This might be due to the heating of dust grains at the inner disk edge due to optical/X-ray irradiation from the flaring foot-points and coronal loops.
- Non flaring variability
  - Stars with active disks vary much more in the optical band than stars with no disks, or passive ones. The X-ray and optical variability might correlate differently in the two cases: a direct correlation is observed in some accreting stars, as already observed by Flaccomio et al. (2010) and attributed to variable and simultaneous shadowing of coronae and photospheres by disk structures. No correlation is clearly observed in disk-less stars.

References

Favata et al., ApJs, **160** 469-502 (2005)
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Reale, A&A **471** 271-279 (2007)

Acknowledgements

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