Hot and glowing: the high energy emission of the very young stellar object Elias 29

A joint X-ray view with XMM and NuSTAR.

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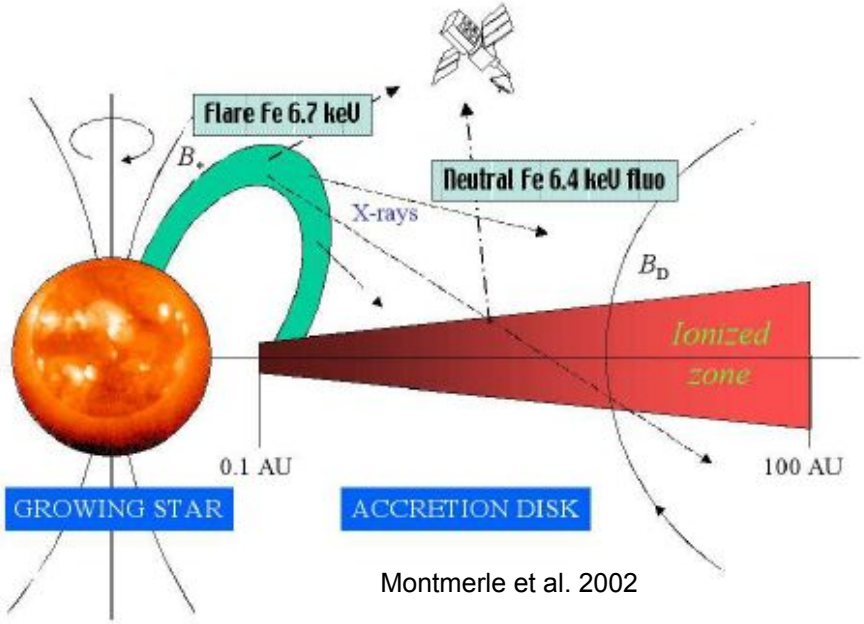
Fe fluorescence in YSOs with disks

Excitation of the Kα line of neutral or low ionized Fe (Kallman+2004)
A “forest” of lines between 6.35 keV and 6.69 keV depending on the physical conditions of the Fe.

Causes:
- *Photons* at E>7.11 keV
- Collisional excitation by *high energy electrons* in magnetized streams (Giardino+2007, Favata 2005, Emslie+1986)



Montmerle et al. 2002

YSOs with 6.4 keV Fe fluorescence

First detection of fluorescence in a YSO: YLW16A in Rho Oph (Imanishi et al. 2001)

Other YSOs with fluorescence: Elias 29 (Favata et al. 2005)

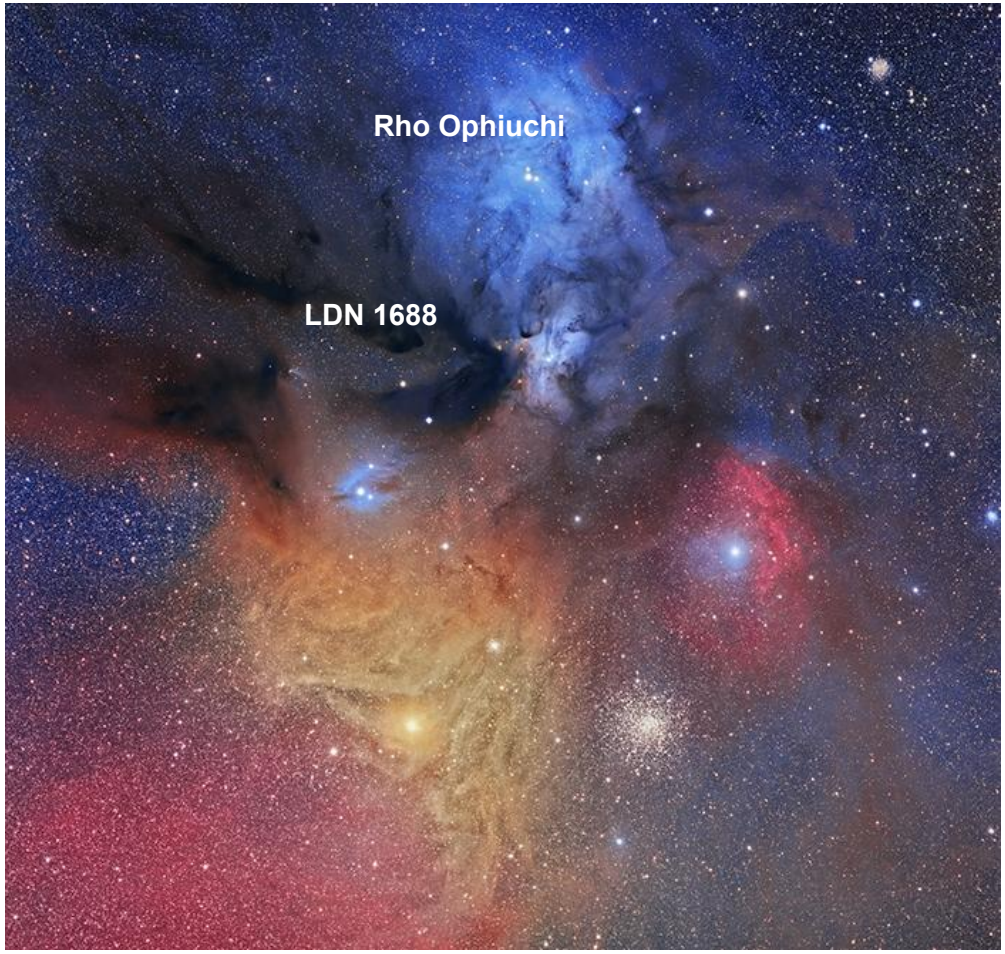
7 YSOs with disks in ONC (Tsujimoto et al .2005)

Variable EW of the fluorescence in Elias 29 (Giardino et al. 2007).

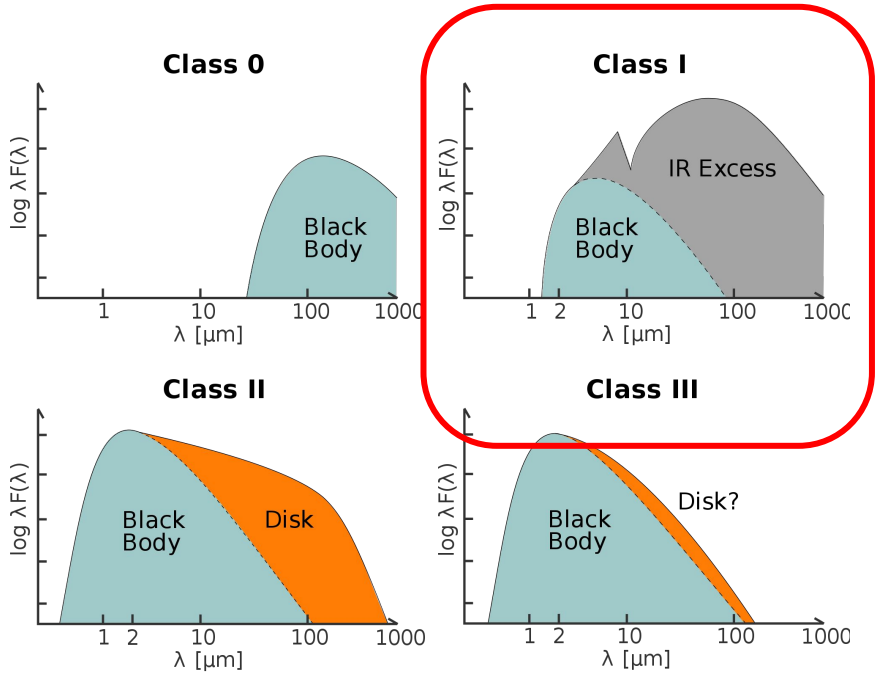
EW_{fluo} > 150 eV difficult to explain with photoionization of the disk (George & Fabian 1991, Drake et al. 2008).

Which scenario for Elias 29? Need for soft+hard X-ray observations: dedicated program with **XMM & NuSTAR**

Elias 29 a young active Class I YSO in the Rho Ophiuchi Dark Cloud



Elias 29 a young active Class I of the Rho Ophiuchi Dark Cloud showing Fe fluorescence



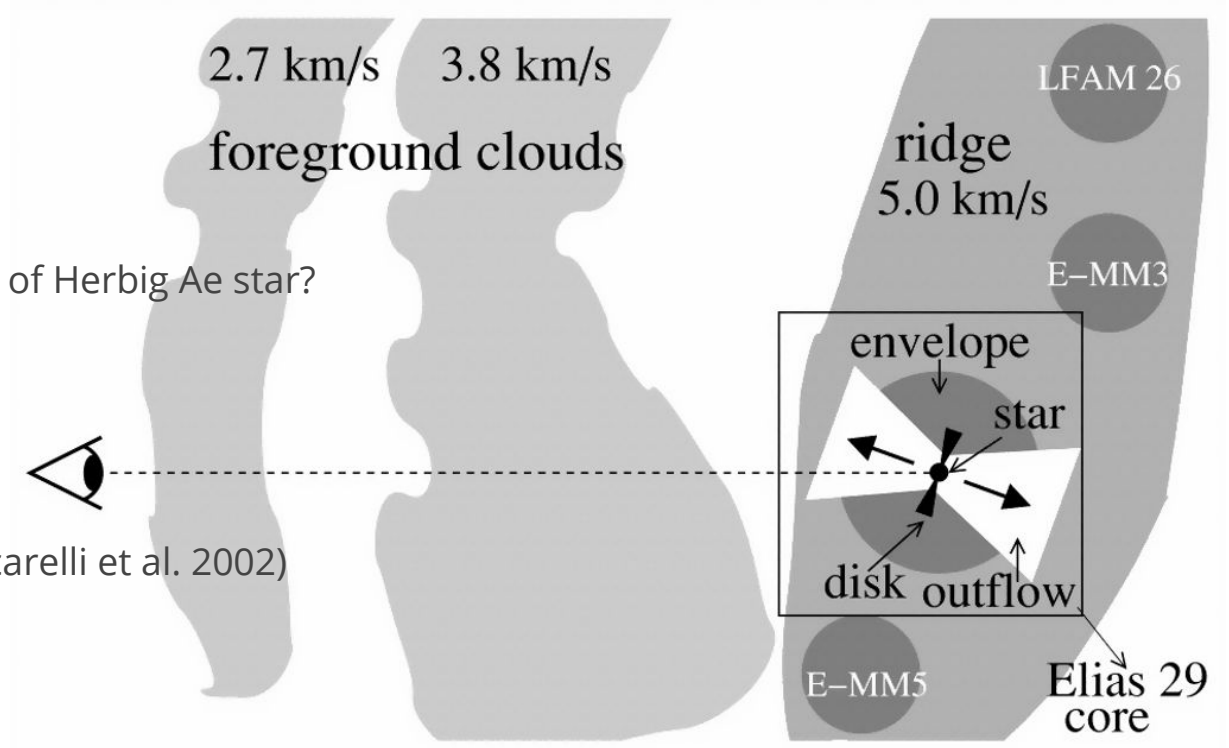
Elias 29

T_{eff}~5750 K, M~3 $M_{\odot}$ progenitor of Herbig Ae star?

Disk: **R~ 0.1-500 AU**

i<60° (Boogert et al. 2002)

"Super-heated" gas in disk (Ceccarelli et al. 2002)



Cartoon from Boogert et al. 2002

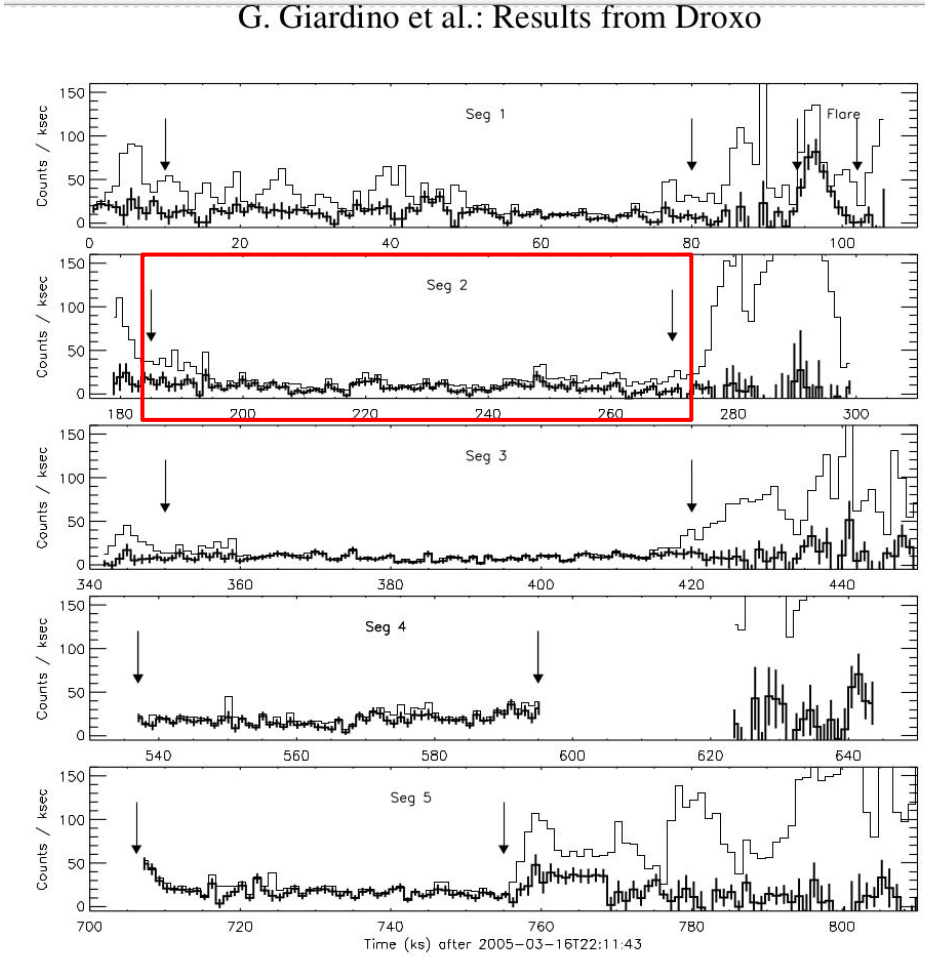
X-rays from Elias 29

Favata+2005: EW_{fluo}~160 eV

DROXO ~ 500 ks with XMM

Quiescent most of the time

Two flares, one entirely observed.



X-ray Spectra of Elias 29

Hot corona kT~4 keV

N_H ~5-7 ·10^{22} cm^{-2}

Variable fluorescent emission at ~6.4 keV (Giardino+2007)

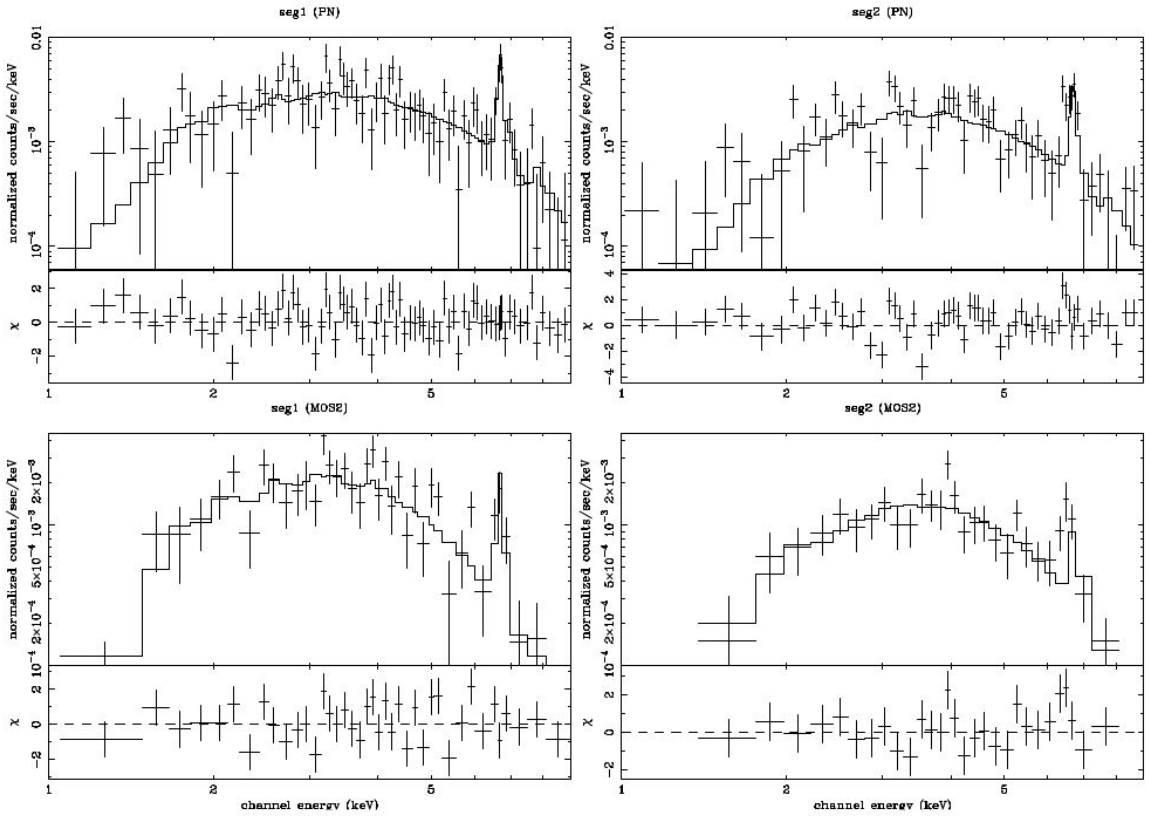
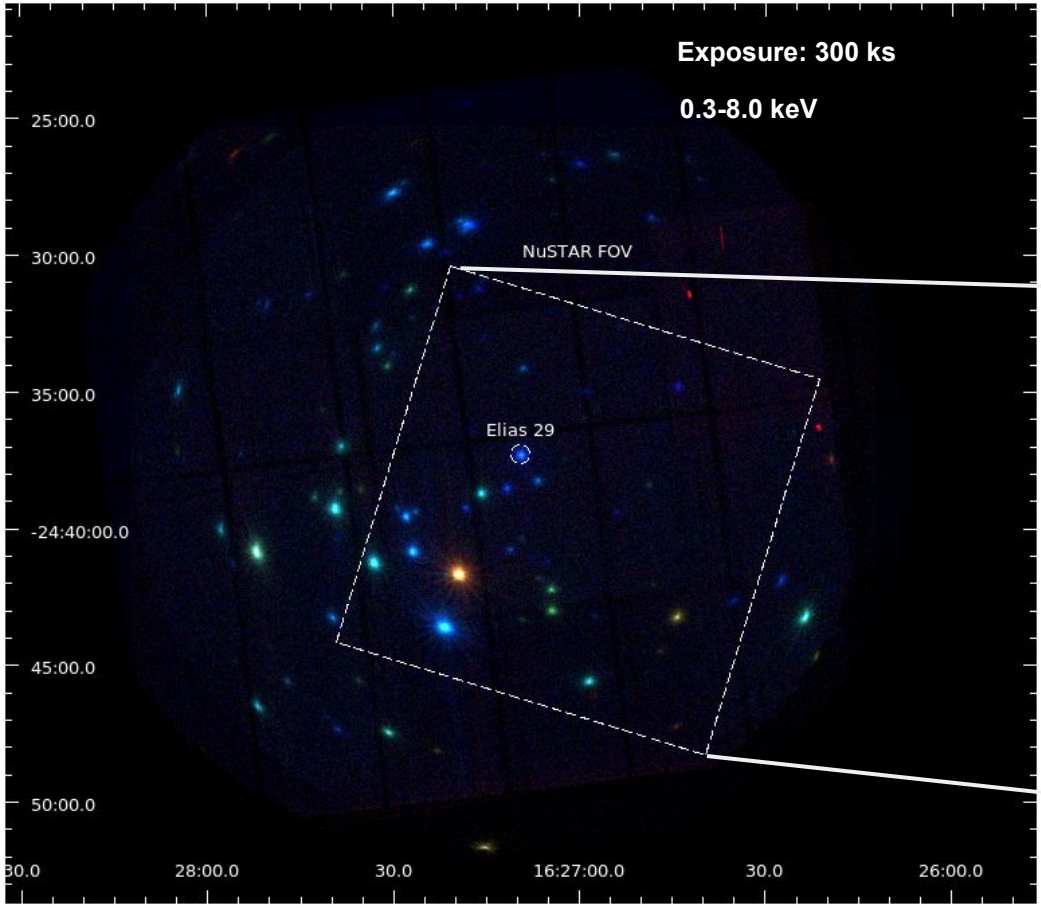
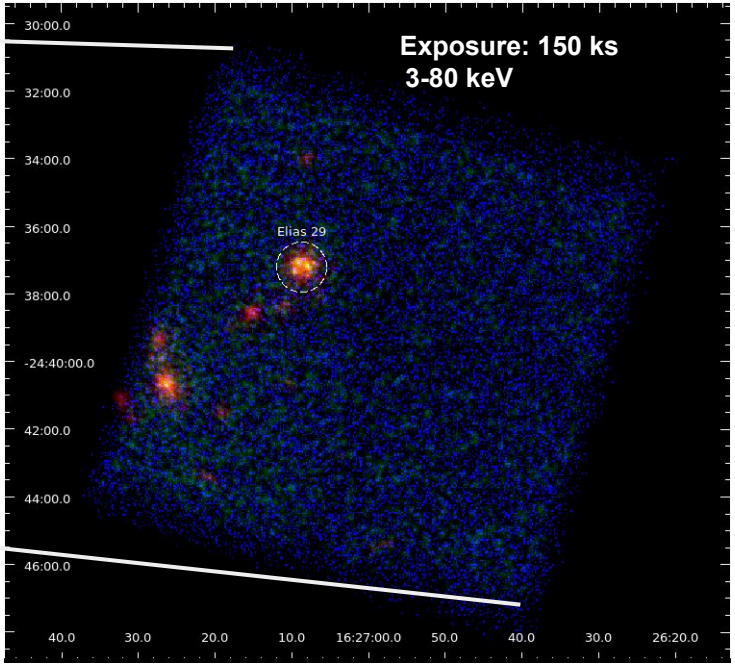


Fig. 2. Elias 29 spectra from PN (*top*) and MOS2 (*bottom*) with spectral fits, during "seg1" (before the flare, *left*) and "seg2" (after the flare, *right*). The spectra (from the two time intervals) are very similar in overall shape and amplitude, and the fits (with an absorbed 1T plasma model) result in very similar parameters. During "seg2", however, a significant excess of emission at 6.4 keV is present, which is not visible in the data from "seg1". All the spectra are rebinned to a minimum of 20 source counts per (variable width) spectral bin.

XMM & NuSTAR observations

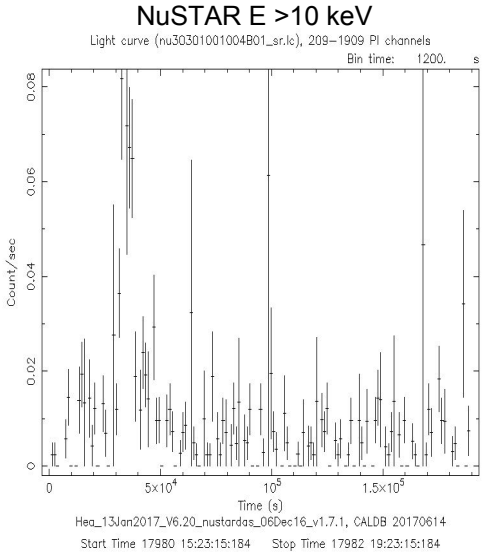


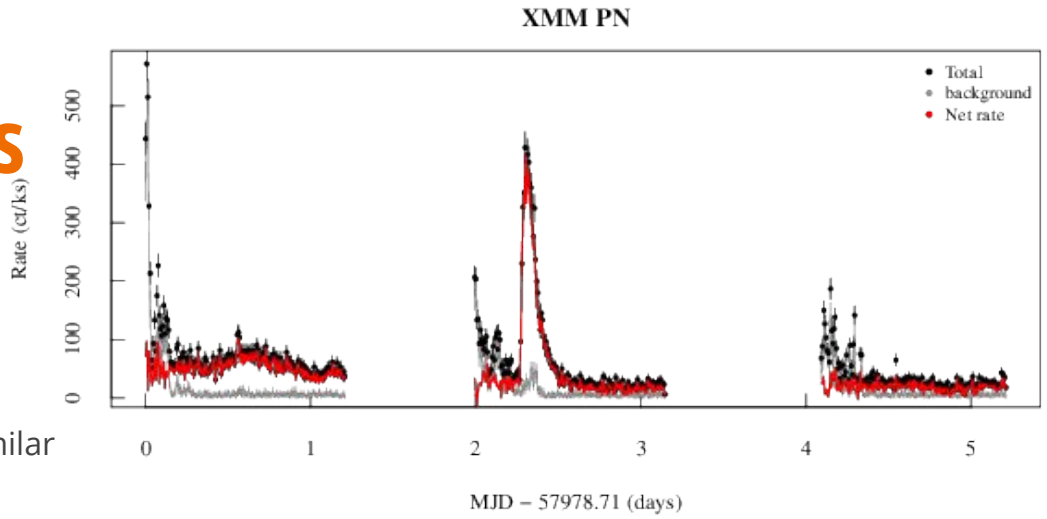


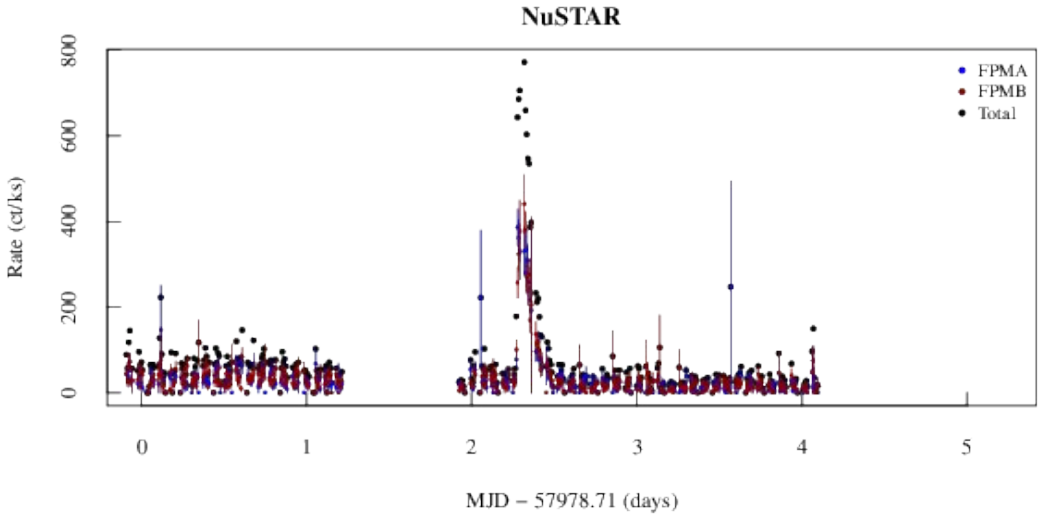
Elias 29: light curves

Modulation in the first PN observation

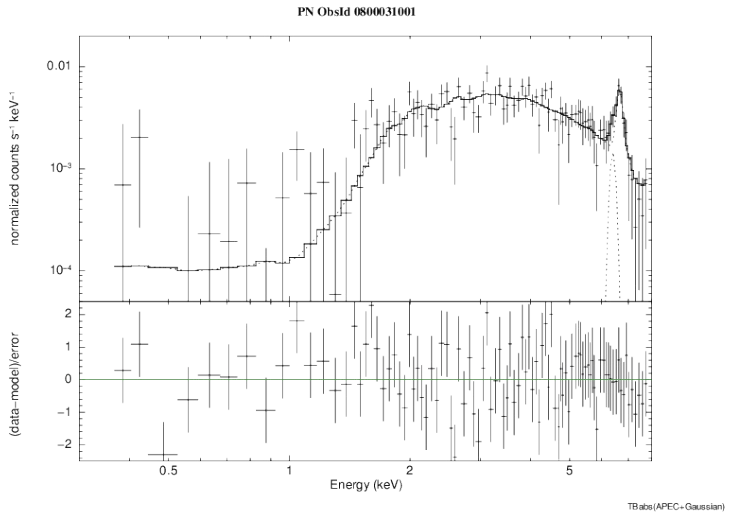
Flare, duration ~20 ks, exponential decay, very similar to the flare observed in DROXO (Giardino+2007)



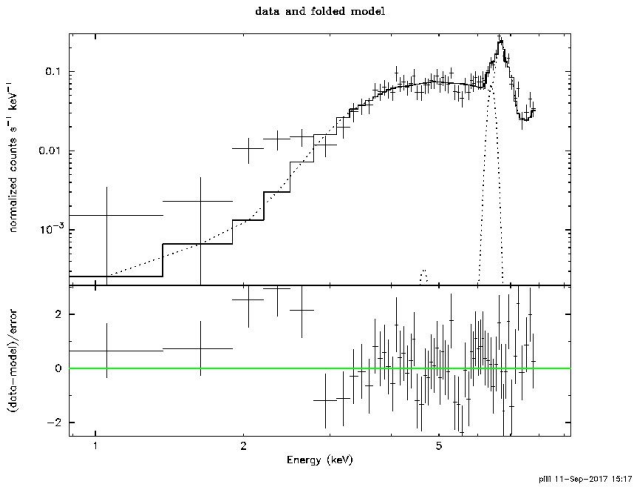




X-ray spectra: XMM PN



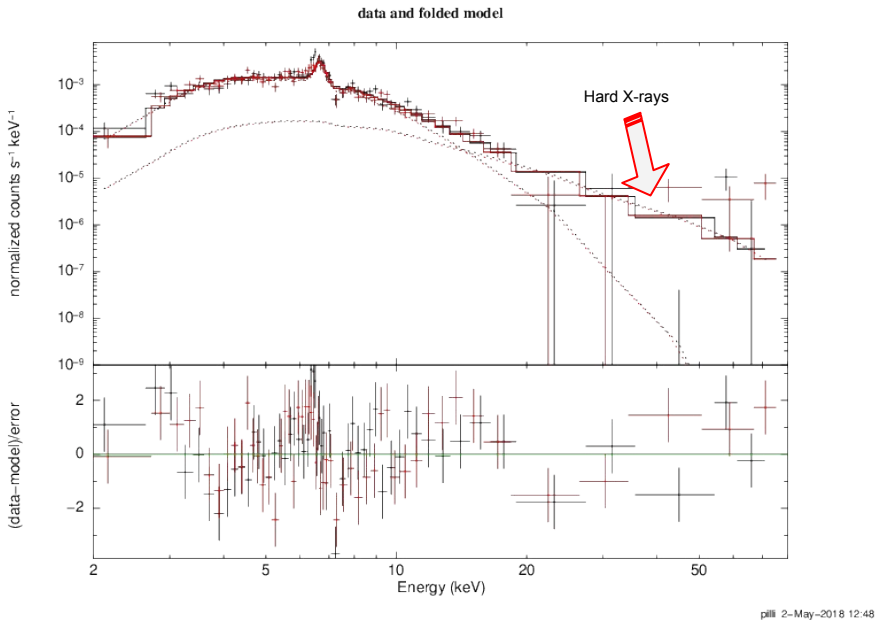
Quiescent phase
Thermal + Gaussian



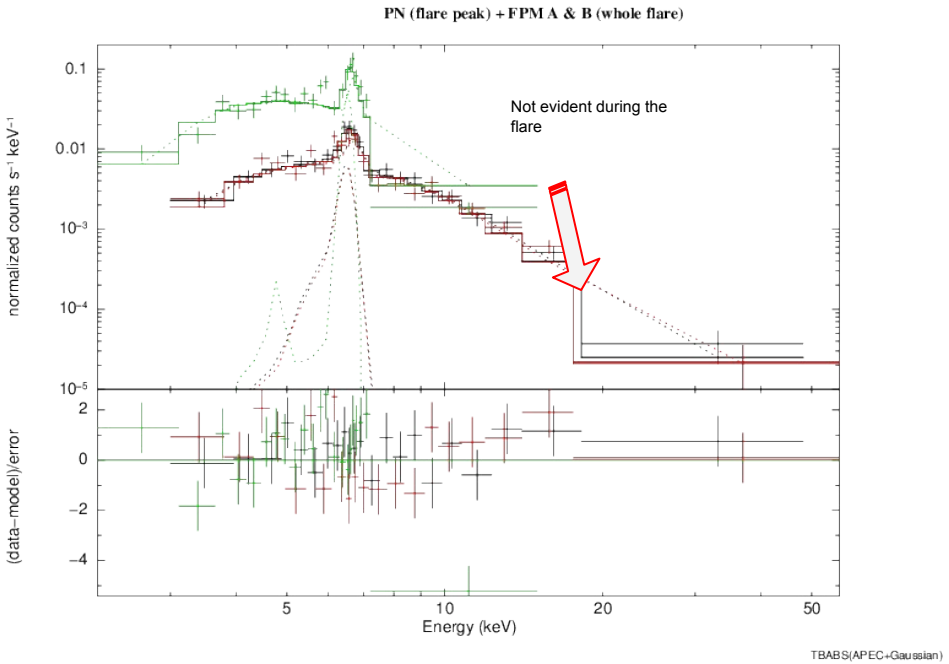
Flare peak, thermal + Gaussian

kT ~ 4 keV
N_H~ 5 x10^{22} cm^{-2}
Variable EW(6.4 keV) 0.1-0.5 keV

X-ray spectra: NuSTAR



Average spectrum full exposure
Thermal + power law, index~1.5



Flare only, thermal + Gaussian
Green is PN

Soft - hard X-ray flux relationship

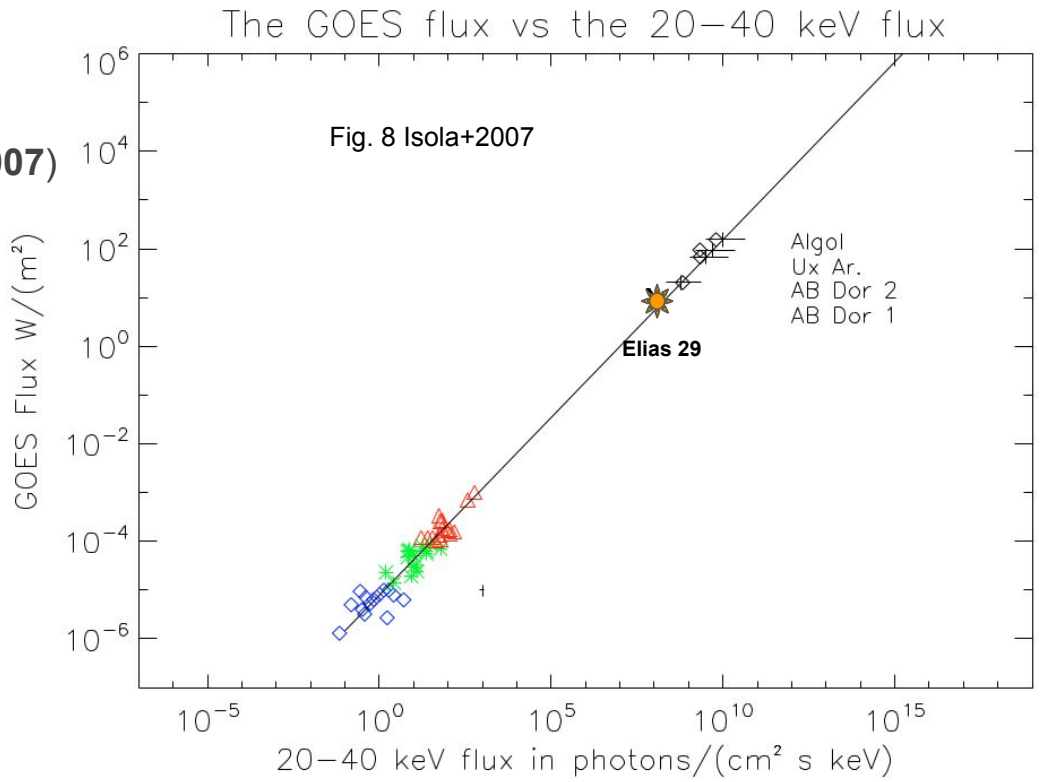
$F_{(1.6\text{-}12.4\ keV)} \sim 7.83 \cdot 10^{-6} F^{0.73}_{(20\text{-}40\ keV)}$ (Isola+2007)

$F_{1.6\text{-}12.4\ keV} \sim 1.8\ 10^{-14}$ W/m^2 (XMM) ~ **11 W/m^2 at 1 AU**

$F_{20\text{-}40\ keV} \sim 5\ 10^{-7}$ photons s^{-1} cm^{-2} keV^{-1} (NuSTAR)
-> **3.05 10^8 phot. cm^{-2} / keV at 1 AU**

does fit Isola+2007 relationship: $F_{soft,predicted} \sim 12.2$ W/m^2

Fig. 8 Isola+2007



Two causes for the fluorescence?

High energy (E>7.11 keV) photons (from flare mainly), not enough to produce EW in excess of ~150 eV in a disk.

Hard X-ray emission from non thermal electrons, thick target model by, e.g., Emslie+1986. NuSTAR faint hard X-ray emission hints at this contribution.

Flare analysis

Flare duration ~ 20 ks

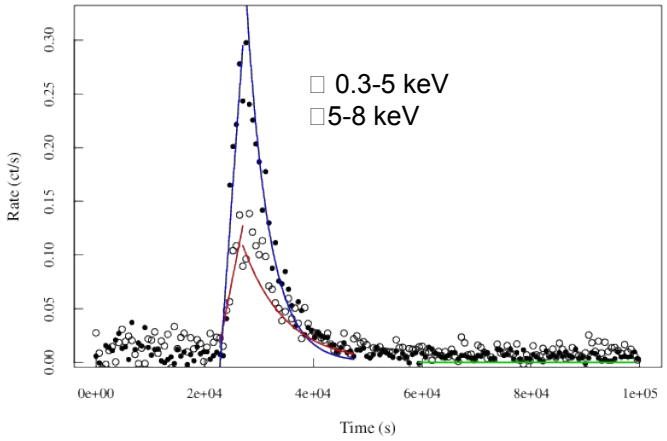
kT_{peak}~6.7 keV

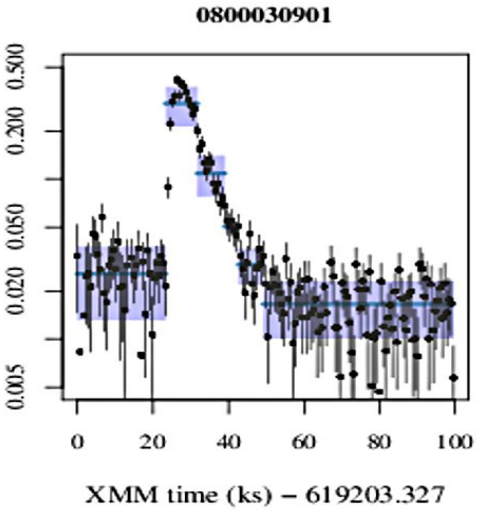
T_{max} ~ 185 MK

Rise: *t*~3 ks

Decay: $r \sim e^{-t/\tau}$; $\tau \sim 7.6$ ks

N_H rises up of a factor 5-10 during flares as observed in previous flares with ASCA and XMM





Flare analysis

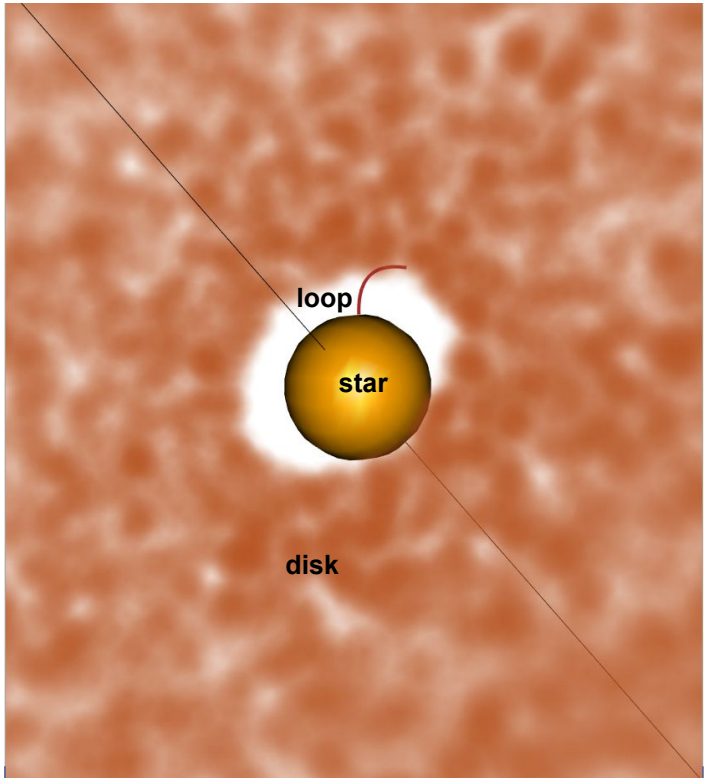
Diagnostics of stellar flares (Reale+2007)

L ~ 0.9-2.3 R⊙ comparable to the inner disk radius

B >= 500 G

Either a *normal* coronal loop or a structure connecting star and inner disk edge.

Flare X-rays pass through denser gas?
(Kamata et al., 1997)



Conclusions

XMM + NuSTAR 300 ks long observation of Elias 29

Detected a faint but significant non-thermal hard emission

Variable fluorescent emission not related to flaring activity

Fluorescence could be partly due to hard X-ray photons and partly due to high energy electrons

Flare in a compact loop that could connect the star to the very close inner edge of the disk

N_H increases during flares probes the structure of gas around Elias 29

This is the state of art of soft+hard X-ray observations for Elias 29 and its class of YSOs, we need ATHENA for gaining a deeper insight