The flaring activity of pre-main sequence stars in NGC 6530

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Introduction:

The very young open cluster NGC 6530 in the Lagoon Nebula (M8) has been the target of many multi-wavelength studies that revealed a large population of low-mass pre-main sequence stars (e.g. Damiani et al. 2004, Henderson & Stassun 2012, Kalari et al. 2015, Prisinzano et al. 2005, 2007, 2012, Sung et al. 2000). We obtained four XMM-Newton observations of the cluster with the goal to study the X-ray emission from the O-star binary 9 Sgr (Rauw et al. 2016). A first observation was taken in 2001, the other three were obtained in 2013 and 2014. Exposure times range between 19.5 and 24.5 ks.

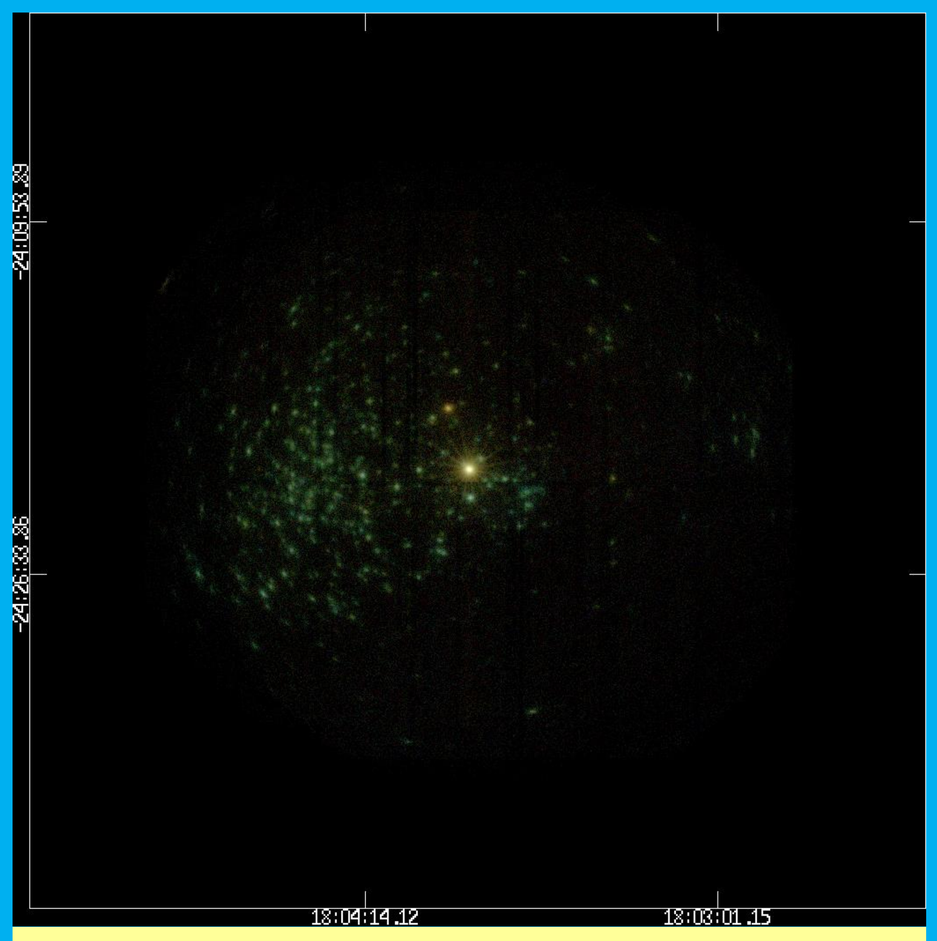


Fig.1: Three-colour image of NGC 6530. Red, green and blue colours correspond to energies of [0.4,0.8], [0.8,1.2] and [1.2,1.4] keV. The bright source in the centre is the O-star binary 9 Sgr (Rauw et al. 2016).

X-ray selected PMS stars in NGC 6530:

Due to straylight contamination by the hard off-axis X-ray binary Sgr X-3, we had to restrict the source detection to the energy range [0.4,1.4] keV. 550 point sources were detected in the combined EPIC images (see Fig. 1). After visual inspection, 352 sources were confirmed. The list of sources was cross-correlated with catalogs of known objects in NGC 6530. The Hertzsprung-Russell diagram of the optical counterparts is shown in Fig. 2 along with isochrones and PMS evolutionary tracks from Siess et al. (2000). The majority of the X-ray selected PMS stars in NGC 6530 have masses between 0.5 and 1 solar masses . Only a small subset are known to display Hα emission.

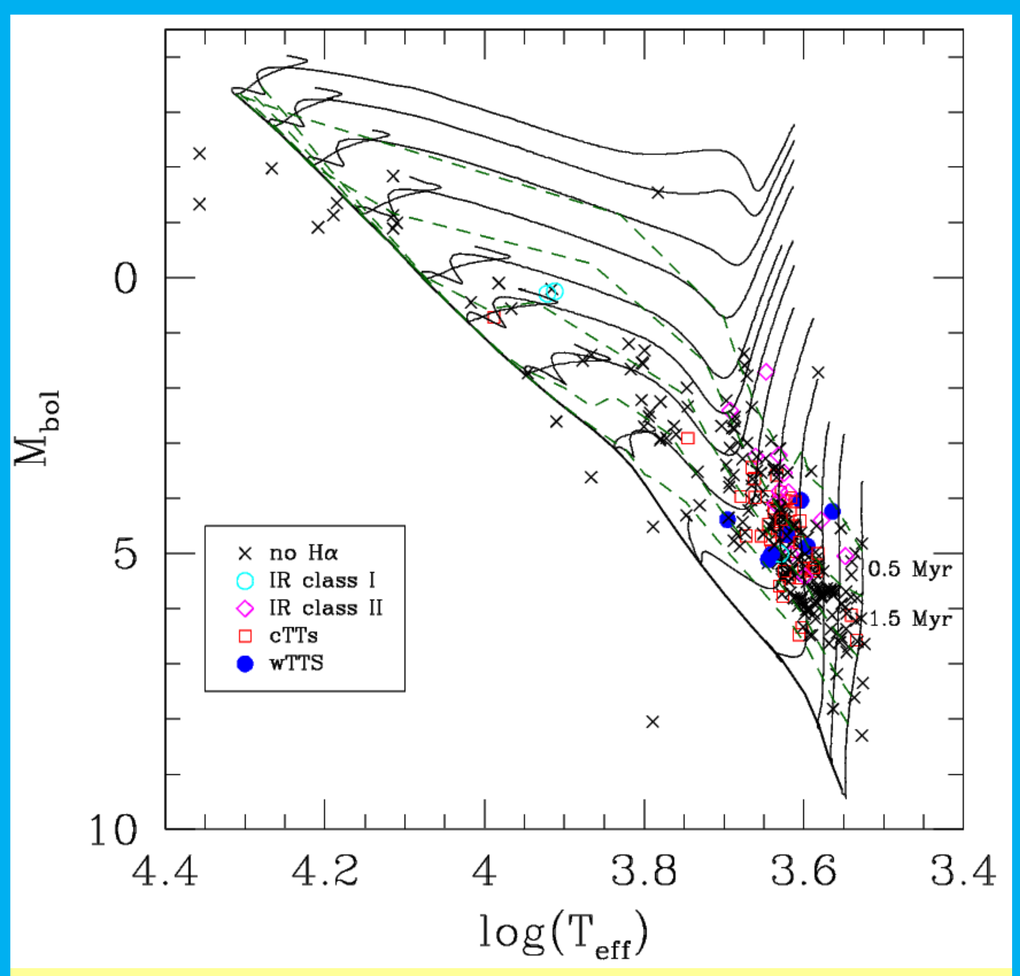


Fig.2: HRD of the X-ray selected stars in NGC 6530. PMS tracks from Siess et al. are shown for masses of 0.3, 0.4, 0.5, 0.7, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0 and 7.0 solar masses.

Rotation rates:

The rotation periods of X-ray selected PMS stars do not differ significantly from the distribution of rotation periods of the full sample of PMS stars in NGC 6530 studied by Henderson & Stassun (2012). We find no trend of the X-ray flux with rotation period (see Fig. 3).

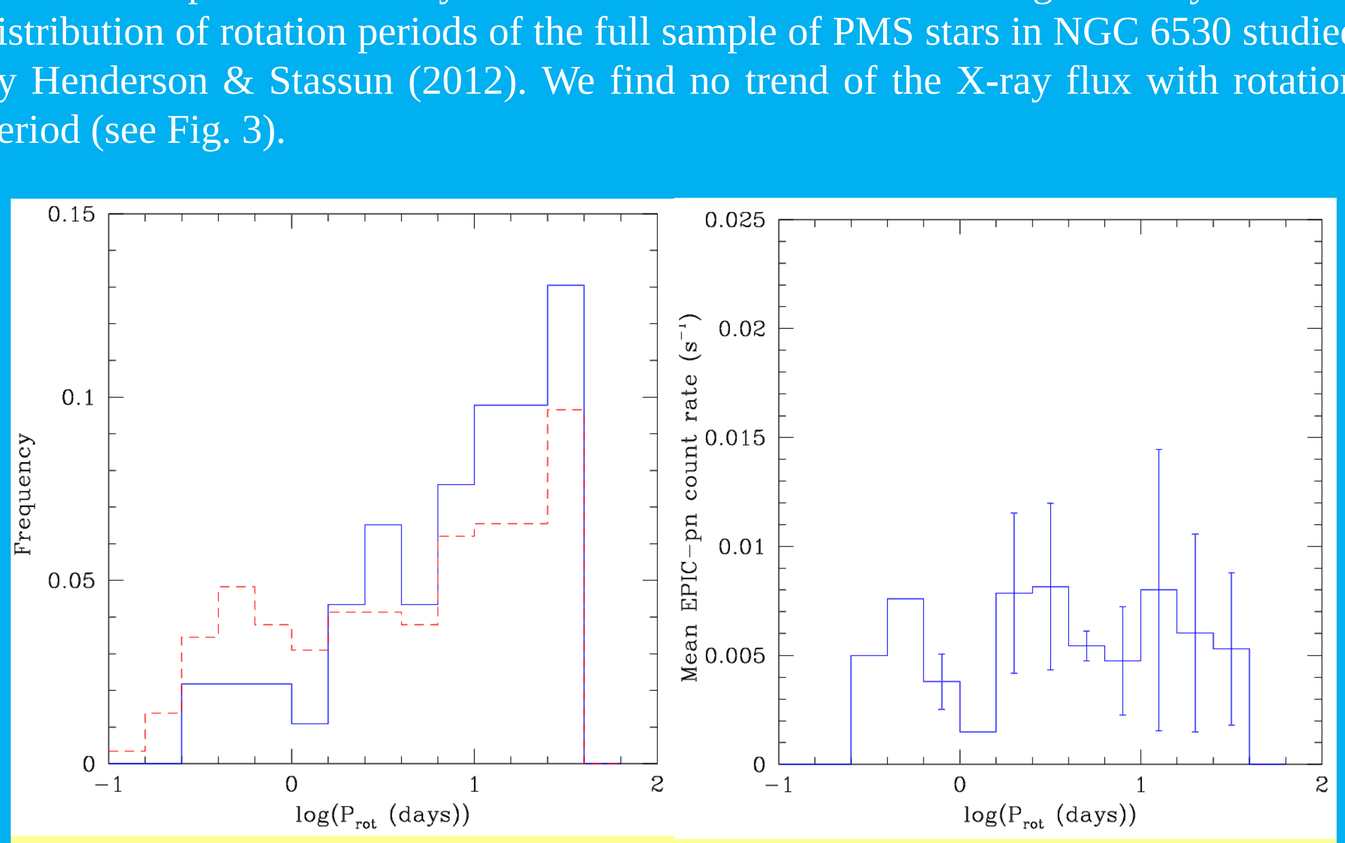
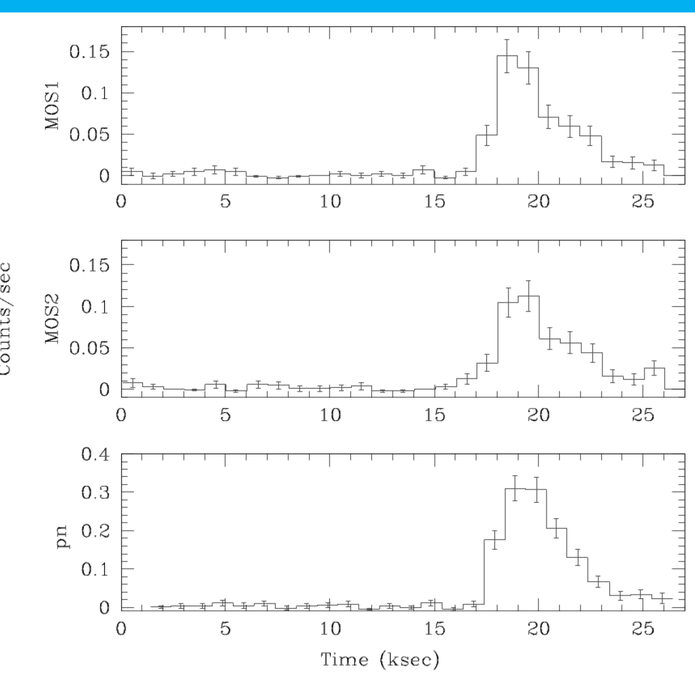


Fig.3: Left: histogram of rotation periods of X-ray selected PMS stars in NGC 6530 (blue) and the full sample of Henderson & Stassun (red, dashed line). Right: histogram of EPIC-pn count rates as a function of rotational period.

Variability:

42% of the sources detected on more than one observation display significant (> 99% significance level) inter-pointing variations. 15 - 24% of the sources display significant intra-pointing variability. Only 3 objects display high contrast flares (e.g. Fig. 4).

Cluster	Age (Myr)	d (kpc)	$N*$	t_{exp} (s)	$t_{on-star}$ (s)	N_{flare}	P_{flare} (s)	Reference
NGC 6231	1 – 12	1.6	446	$170.6\,10^3$	$76.1\,10^6$	10	$7.6\,10^6$	Sana et al. (2007)
Cyg OB2	3 – 7	1.4	174	$138.9\,10^3$	$24.2\,10^6$	8	$3.0\,10^6$	Rauw (2011)
IC 1805	3.5	2.4	170	$48.7\,10^3$	$8.3\,10^6$	1	$8.3\,10^6$	Rauw & Nazé (2016)
NGC 6530	0.3 – 10	1.3	342	$87.8\,10^3$	$30.0\,10^6$	3	10^7	this study



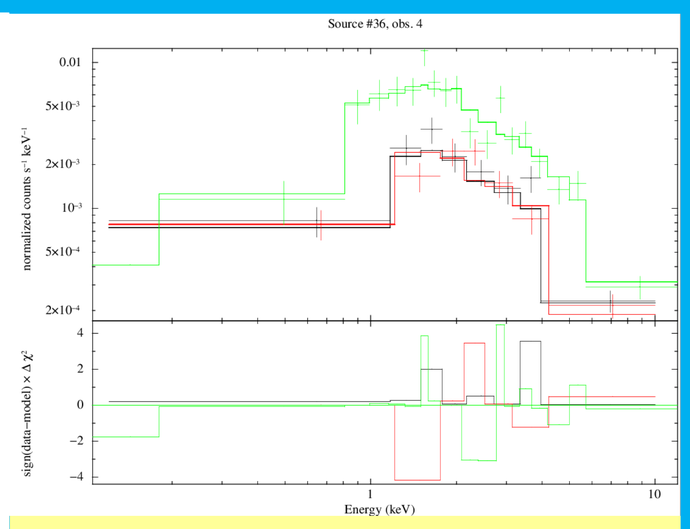


Fig.4: EPIC light curve (left) and spectra (top) of one of the flaring sources in NGC 6530.

Flaring frequency:

Using the approach of McCleary & Wolk (2011), we have estimated the average time between two flares for PMs stars in NGC 6231, Cyg OB2, IC 1805 and NGC 6530. On average a PMS star in NGC 6530 should display a high-contrast flare every ~116 days (i.e. every 10 Ms).

References:

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