ATTACKING THE X-RAY EMISSION PROPERTIES OF YOUNG STARS WITH THE SWORD OF ORION

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Abstract

We present a survey of X-ray emission from young stars in the Sword of Orion star-formation region using XMM-Newton’s EPIC detectors. We find over 850 X-ray sources, of which more than 700 have near-infrared counterparts consistent with being young stars. The survey enables statistical investigation of the dependence of X-ray emission properties of young stars on fundamental stellar parameters (mass, rotation, age) and environmental features (circumstellar disk, active accretion, circumstellar absorption), and study of structure size in individual coronae through analysis of large flares.

Key words: Stars: activity – Stars: coronae – Stars: flare – Stars: pre-main sequence – X-rays: stars

1. Introduction

A young star grows within a complex environment, accreting from a circumstellar disk and driving jets out through a surrounding envelope of dust and molecular gas. Fast rotation and a fully-convective structure also distance the emerging star itself from the familiar Sun. The impact of these circumstances upon a stellar magnetic dynamo, the structure of magnetic field on the star and in its immediate environment, and resultanty the location, temperature, and amount of X-ray-emitting hot plasma within the system is yet to be well established. As the X-ray emission is in turn expected to be the key agent for ionization of circumstellar material, understanding the interaction of these processes is important in understanding the early stages of stellar evolution.

Studies of the X-ray emission from stars in star-forming regions (SFRs) have produced conflicting results as to whether young stars do (e.g. Stelzer & Neuhäuser 2001) or do not (e.g. Feigelson et al. 2003; Flaccomio et al. 2003) demonstrate the same dependence of X-ray luminosity on rotation as main-sequence stars, and as to whether accretion or the presence of a circumstellar disk does (e.g. Stelzer & Neuhäuser 2001; Flaccomio et al. 2003) or does not (e.g. Preibisch & Zinnecker 2002; Feigelson et al. 2003) suppress the observed X-ray luminosity. The conflict has been variously attributed to: real physical differences between different SFRs; biases in sample selection; and incorrect assumptions (e.g. source spectrum, absorbing column density) in calculating X-ray luminosities.

Our survey of the Sword of Orion examines a region of star formation intermediate in star density and mass distribution between the rich, Orion Nebula Cluster (ONC; Feigelson et al. 2003; Flaccomio et al. 2003), centrally concentrated on massive O-type stars whose strong UV radiation may affect evolution of circumstellar material of lower-mass stars, and the sparser Taurus molecular cloud (Stelzer & Neuhäuser 2001), lacking in high-mass stars.

In this paper, we show preliminary results from the survey, including the X-ray and near-infrared (NIR) source content of the field, and examples of spectral and temporal analyses of individual sources.

2. Observations and analysis

The survey consists of four XMM-Newton fields covering a region ~ 2°×0.5°. An optical image (Fig. 1) of the survey area shows the extensive nebulosity, including the Orion Nebula itself, associated with the star-formation activity in this region. In three fields all three EPIC instruments (PN and both MOS cameras) were exposed in Full-Frame mode for ~ 20 ks; in the field centred on the ONC (θ¹ Ori C) itself only the MOS cameras were exposed in Partial Window mode for 36 ks. Each event-list was filtered to exclude events with bad flags and patterns, and times of high background. For each observation, an image in the 0.3–4.5 keV band was created for each operating instrument, and these were mosaicked to make an EPIC image. Source detection was performed using the Science Analysis System (SAS) tasks ewavelet and emldetect. Figure 2 shows a mosaic of the EPIC survey images. The optically-brightest star in the survey, ι Ori, is the bright X-ray source in the southernmost survey field.

3. Results

3.1. Characterization of X-ray sources

We have detected over 850 X-ray sources in the survey. We performed cross-correlation of the X-ray source list with 2MASS sources in the survey area. More than 700 have 2MASS counterparts within 6 arcsec, the vast majority having the photometric properties of young stars (Fig. 3).

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A small fraction of the X-ray-detected stars show the $K$-band excess expected of circumstellar disks; a few show extreme $K$-band excess indicative of further circumstellar material and an early stage (Class I) of evolution.

Much work has been done to characterize the stars in this region by spectral type, mass, age, reddening, rotation period, circumstellar environment (e.g. Hillenbrand 1997; Rebull et al. 2000; Rebull 2001; Carpenter et al. 2001). By studying the dependence of X-ray luminosity, $L_X$, (particularly normalized to a star’s bolometric luminosity, $L_{bol}$) on these parameters we aim to understand the mechanisms driving the X-ray and magnetic activity of these young stars.
3.3. The influence of accretion

Analysis of this subsample also found that low-mass stars ($M < 0.5 \, M_\odot$) showing an excess of $U$-band continuum emission (Rebull et al. 2000), expected from material that is heated as it accretes onto a star, had lower median $L_X/L_{bol}$, by a factor $\approx 2$, than stars showing no such significant excess (Briggs et al. 2004). This implies that accretion plays a role in suppressing the observed X-ray emission.

Stassun et al. (2004) have proposed that columns of accreting material obscure underlying coronal emission, i.e. the absorbing column to X-rays, $N_H$ is higher than would be anticipated from the observed visual extinction, $A_V$. We aim to test this though spectroscopic analysis of strongly- and weakly/non-accreting samples. In a small sample studied so far, we have found the $N_H$ derived from spectral fitting is no more than that expected from optical absorption (Fig. 4).

3.4. Spectral analysis of a young solar analog

Through spectroscopic analysis, we also aim to assess the temperature of the X-ray-emitting plasma of bright sources and investigate its dependence on rotation period and evolutionary stage. Solar-like MS stars show increasing coronal temperature with decreasing rotation period (or Rossby number). Tsujimoto et al. (2002) found that X-ray-bright young stars in earlier evolutionary stages (Class I–II) had higher plasma temperatures than those in later stages (Class III). Few Class II objects have been studied with high-resolution X-ray spectroscopy: while SU Aur (Smith et al. 2004) and RY Tau (Audard et al. 2004) also show hot temperatures, TW Hya has remarkably cool plasma (Kastner et al. 2002; Stelzer & Schmitt 2004).

Figure 5 shows a PN spectrum of Parenago 1778, an approximately 0.75 Myr-old solar analog (according to the models of Siess et al. 2000). The star’s 2MASS photometry shows small excesses in the $H$ and $K$ bands, suggestive of a small circumstellar disk, but there is a strong $U$-band excess (Rebull et al. 2000) indicative of a high accretion rate ($M \sim 3 \times 10^{-8} \, M_\odot \, yr^{-1}$). The X-ray luminosity is very high, $L_X \approx 4 \times 10^{31} \, erg \, s^{-1}$, with $\log(L_X/L_{bol}) \approx -2.4$. A two-temperature fit to the PN spectrum, using the elemental abundances of a very active near-MS star (AB Dor; Sanz-Forcada et al. 2003) requires the hot component to be at $\approx 50$ MK, a temperature observed on MS stars only transiently in very large flares, yet the PN lightcurve of Parenago 1778 does not indicate that such a flare occurred during this observation.

A number of such flares are observed in the survey (e.g. Fig. 6). Hydrodynamic modelling of the temperature...
and emission measure of the flare plasma during the decay phase allows estimation of the size of magnetic loop involved (Reale & Micela 1998). Loop sizes larger than the stellar radius may indicate the flare occurred in magnetic structure bridging the star and a circumstellar disk, or within the disk itself, rather than in a coronal loop on the star.

4. Summary

An XMM-Newton survey of the Sword of Orion star-forming region has yielded over 850 X-ray sources, of which more than 700 have near-infrared counterparts consistent with being young stars. Analysis of a subsample of the survey has indicated that these young stars do not show the activity–rotation relation of solar-like MS stars, and that accretion suppresses the observed X-ray emission of young stars. Absorption of X-rays does not appear to be larger than expected from observed optical extinction. Extremely hot plasma temperatures of \( \approx 50 \) MK are found on at least one young solar analog. Statistical investigations, using the whole sample, of the dependence of X-ray emission levels and plasma temperatures on fundamental stellar parameters and environmental features are being pursued, and detailed analysis of large flares aims to identify the emission region in these systems.

Acknowledgements

Financial support from the Swiss NSF (grant 20-66875.01) is acknowledged. This research is based on observations obtained with XMM-Newton, an ESA mission funded by ESA Member States and the USA (NASA), and makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166; the image presented herein was based on photographic data obtained by the UK Schmidt Telescope, operated by the Anglo-Australian Observatory.

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