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X-ray Emission from Young Stars in Suburban Orion

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Abstract. X-ray emission from > 100 pre-main sequence (PMS) stars in the Orion star-forming complex is studied in a 20-ks observation by *XMM-Newton*. No relation between the ratio of X-ray and bolometric luminosities, L_X/L_{bol}, and rotation period or Rossby number is exhibited, though the action of a solar-like dynamo is not excluded because all stars would appear to be in the "saturated regime" of such a dynamo. Low-mass stars showing a strong $U - V$ excess have lower median X-ray luminosity, suggesting that accretion suppresses magnetic activity.

1. Introduction

Young ($t \sim 10^6$ yr) late-type stars are powerful X-ray emitters, exhibiting luminosities, L_X, up to 10^4 times that of the active solar corona. A solar-like dynamo, that acts through the coupling of rotational and convective motions, is anticipated to generate more magnetic activity – and hence more coronal X-ray emission – in a star with shorter rotation period (P) and deeper convective envelope (hence longer convective turnover time, τ_C) as expected of stellar youth. Indeed, inverse correlations of L_X/L_{bol} with P and Rossby number ($N_R = P/\tau_C$) are demonstrated by main sequence stars, although saturation of the X-ray emission occurs at $L_X/L_{bol} \approx 10^{-3}$ for $N_R < 0.1$ (e.g. Pizzolato et al. 2003). Young stars may simply exhibit the very extreme of solar-like activity. Alternatively, a near-fully-convective interior may not support a solar-like dynamo that generates an inverse correlation of rotation and X-ray emission; also accretion from, or the magnetic field of, a circumstellar disk may influence the activity of such young stars.

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2. Previous Studies

X-ray surveys of star-forming regions (SFRs) have produced apparently conflicting conclusions. Studies of the nearby Taurus molecular cloud, which is spawning exclusively low-mass stars over a wide area of sky, have found an inverse correlation of L_X/L_{bol} with P that indicates the action of a solar-like dynamo (Bouvier 1990; Damiani & Micela 1995; Neuhäuser et al. 1995; Wichmann et al. 2000; Stelzer & Neuhäuser 2001), but have also found that stars with disks, inferred from strong Hα emission, show lower L_X (Neuhäuser et al. 1995; Stelzer & Neuhäuser 2001). Conversely, recent studies of the Orion Nebula Cluster (ONC), the richest site of star-formation in the local Galaxy, centrally condensed around the high-mass stars of the Trapezium, have found no evidence for the inverse correlation of L_X/L_{bol} and P or N_R (Feigelson et al. 2003; Flaccomio et al. 2003a), in agreement with earlier studies of the ONC (Gagné, Caillault & Stauffer 1995) and Chameleon I (Feigelson et al. 1993). However, the stars in the ONC are still consistent with being in the saturated regime of the solar dynamo. Feigelson et al. (2003) saw no significant difference in the L_X of stars with or without circumstellar disks (inferred from near-infrared emission), as also reported in the Chameleon I (Lawson et al. 1996), NGC 2264 (Flaccomio et al. 2000), ρ Oph (Grosso et al. 2000), IC 348 (Preibisch and Zinnecker 2002) and NGC 1333 (Getman et al. 2002) SFRs. In contrast, Flaccomio et al. (2003a) found stars showing evidence for accretion, through strong Ca II emission, to have clearly lower median L_X, and found the same trend after reanalysis of the NGC 2264 and Chameleon I data (Flaccomio, Micela & Sciortino 2003).

These differences may reflect real physical differences between different SFRs but more likely result from uncertainties concerning sample completeness and reliability of the chosen accretion or disk indicator. We use *XMM-Newton* to investigate the X-ray emission from > 100 young stars in a field $50'$ north of the ONC metropolis, a 'suburban' area of the Orion star-forming complex that is not centrally condensed around high-mass stars.

3. Observation and Data Analysis

Exposure times of 20 ks in each MOS camera and 15 ks in the PN were achieved. Source detection was performed on the mosaicked image (0.3–4.5 keV) of all three EPIC instruments, finding 193 sources with a sensitivity limit of $L_X \sim 10^{29}$ erg s^{-1}. X-ray luminosity was estimated from the total EPIC count-rate by using two hardness ratios to model the spectrum- and absorption-dependent conversion from count-rate to unabsorbed source flux, and assuming a distance of 450 pc. The field contains ≈ 250 stars with optical photometry consistent with being low-mass ($< 1.4 M_\odot$) members of the Orion star-forming complex ('Orion locus', Rebull et al. 2000). We used the stellar models of Baraffe et al. (1998) to estimate the mass and bolometric luminosity of each star, based on 2MASS JHK photometry (Cutri et al. 2003), assuming an age of 3 Myr; ages of 1–10 Myr produced negligible difference in the overall results. 62 of these stars have measured rotation periods (Stassun et al. 1999; Carpenter, Hillenbrand & Skrutskie 2001; Rebull 2001) and for each of these stars with mass in the range 0.5–1.2 M$_\odot$, we could estimate convective turnover time from the models

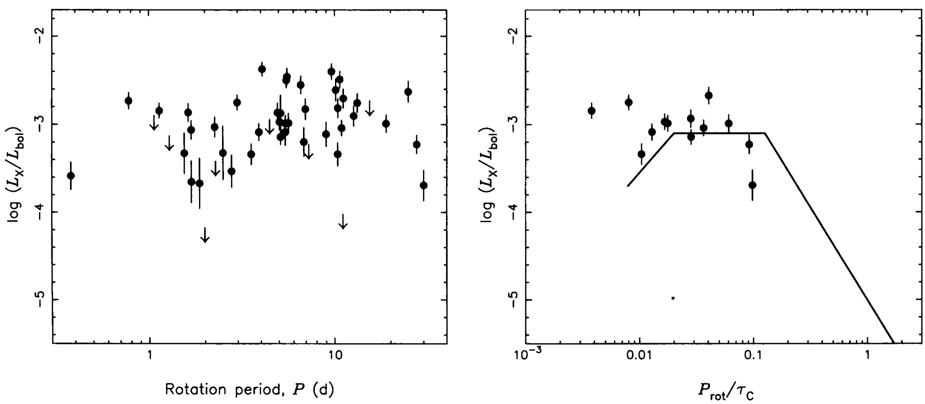

Figure 1. Left: L_X/L_{bol} vs. rotation period. Right: L_X/L_{bol} vs. Rossby number. The bold line marks the correlation exhibited by main-sequence stars (Feigelson et al. 2003; Randich 2000).

of Kim & Demarque (1996, fig. 3), and hence calculate Rossby number. 120 Orion locus stars had X-ray-detected counterparts, and upper limits to L_X were estimated for undetected stars.

4. The Influence of Rotation

47 of the 62 Orion locus stars with measured rotation periods were detected as X-ray sources, including all 14 stars with calculated Rossby numbers. There is no clear anticorrelation of L_X/L_{bol} with rotation period (Fig. 1, left) or Rossby number (Fig. 1, right). However, this does not rule out the action of a solar-like dynamo as Fig. 1 (right) demonstrates that these stars fall in the saturated regime of the solar-like dynamo – even though some rotate no faster than our Sun – due to their extremely long convective turnover times ($\sim$ 300 d). Fig. 1 (right) shows no evidence for the super-saturation phenomenon of decreasing L_X/L_{bol} with decreasing N_R observed for the fastest-rotating stars, and shows notably smaller scatter than seen by Feigelson et al. (2003; fig. 8c), possibly because we corrected for absorption in our calculation of X-ray luminosity.

5. The Influence of Accretion Disks

The innermost part of an accretion disk reaching close to the stellar surface should emit violet and UV light excess to that expected from the photosphere alone. In Fig. 2 (left) we plot $U-V$ vs. $V-I$ for the Orion locus stars. The bold line shows the $U-V$ colour expected of a zero-age main sequence (ZAMS) star at each dereddened $V-I$ colour. We consider only stars with $(V-I)_0 > 1.4$, as the ZAMS is steeper at lower $V-I$ and dereddening uncertainties may make unreliable the calculation of $U-V$ excess, $\Delta(U-V)$. This effectively reduces the available sample of stars to those with mass < 0.5 $M_\odot$. We follow Rebull et al.

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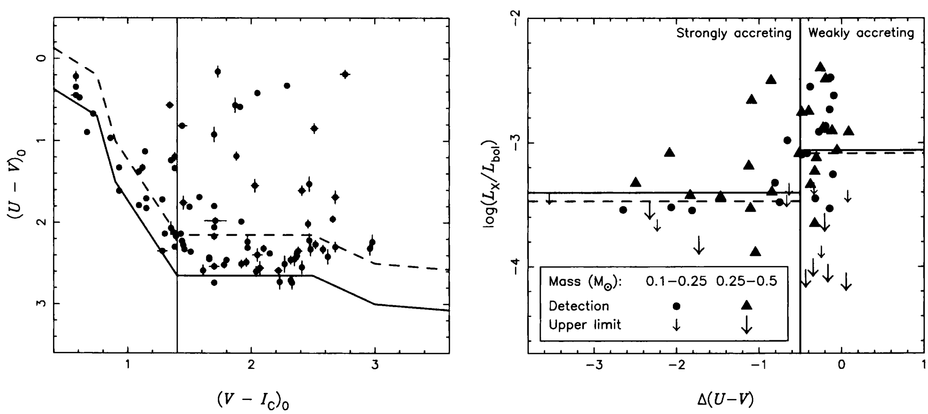

Figure 2. Left: $U-V$ vs. $V-I$. Bold line marks the ZAMS; dashed line the adopted boundary between strongly and weakly accreting stars. Only stars right of the vertical line are included in our analysis. Right: L_X/L_{bol} vs. $U-V$ excess for low-mass stars. Strongly-accreting stars show lower median L_X/L_{bol} (bold and dashed lines for 0.25–0.5 and 0.1–0.25 $M_\odot$, respectively) than weakly-accreting stars.

(2000) in interpreting stars with $\Delta(U-V) < -0.5$ as strongly accreting, and the remainder as weakly accreting. In Fig. 2 (right) we plot L_X/L_{bol} against $U-V$ excess for stars in two mass bins: 0.1–0.25 and 0.25–0.5 $M_\odot$. For both mass samples the median L_X/L_{bol} of the strong accretors is a factor ≈ 2.5 lower than that of the weak accretors, though the scatter is large. The difference between the samples is much smaller than the order of magnitude found by Flaccomio et al. (2003a) for stars in the ONC, and factor of ≈ 6 found by Stelzer & Neuhäuser (2001) for stars in Taurus, which may indicate contamination of our weakly-accreting sample by older non-members, or may reflect the use of a different accretion indicator. Our result is nevertheless supportive of the finding that accretion suppresses the X-ray emission from young stars. As no dependence of X-ray luminosity on rotation is observed, one cannot attribute this suppression to braking of the star's rotation by the disk reducing the efficiency of the dynamo. One alternative possibility is that the interaction of the magnetic fields of star and inner disk distorts the coronal field configuration in such a way as to reduce the available volume in which hot, X-ray-emitting plasma can be confined.

6. Summary and Future Work

We have observed with *XMM-Newton* a sample of $>$ 100 X-ray-emitting young stars in a field $50'$ north of the Orion Nebula Cluster, where star-formation is not centrally condensed around high-mass stars. In contrast to studies of main-sequence solar-like stars with a similar range of rotation periods (0.3–30 d), we found no anticorrelation of L_X/L_{bol} with rotation period or Rossby number. However, the long convective turnover times of these young stars place them in

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the saturated regime of the solar-like dynamo, so we cannot rule out such an origin of the magnetic activity. Low-mass stars with $U-V$ excess exhibited median X-ray luminosity a factor ≈ 2.5 lower than that of stars without, suggesting that accretion suppresses the X-ray emission of young stars. These results qualitatively support those emanating from *Chandra* studies of the ONC. The inclusion of other fields in the Orion star-forming complex observed by *XMM-Newton* should facilitate more detailed studies of the effects of rotation and accretion on X-ray emission from young stars and allow quantitative comparisons with the rich population of the ONC.

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