The Decay of Stellar X-ray Activity

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Summary

Recent studies suggest our understanding of coronal X-ray emission and dynamo decay are severely lacking. We are confronting these discrepancies with new observations and a state-of-the-art model of the decay of stellar X-ray activity. Our results suggest a steeper decay of stellar X-ray luminosity than previously estimated with $L_X / L_{bol} \propto Ro^{\beta}$ and $\beta = -2.68 \pm 0.2$ as opposed to the canonical value of $\beta = -2$. From a scaling analysis of the interface dynamo number equation we find this implies $\Delta\Omega / \Omega \propto \Omega^{0.68}$, i.e. the fractional differential rotation scales with the angular momentum to the power of two-thirds.

We observe clear evidence of coronal super-saturation and find a strong correlation between it and the excess polar updraft predicted by Stępień et al. (2001) as the cause of this phenomenon. Our study also suggests that coronal saturation is caused by a change in the dynamo configuration associated with the internal coupling of radiative and convective layers, and not an actual 'saturation'.

The Rotation – Activity Relationship

- We have compiled a sample of 820 stars with measured L_X and P_{rot} (Figure 1).
- Using an unbiased subset of solar-type stars we fit the slope of the unsaturated regime where $L_X / L_{bol} \propto Ro^{\beta}$ as $\beta = -2.68 \pm 0.2$, steeper than the canonical $\beta = -2$ value [2] by 3.5σ.
- Using a recent scaling analysis for the interface dynamo number [5], this implies $\Delta\Omega / \Omega \propto \Omega^{0.68}$, i.e. the fractional differential rotation scales with the angular momentum to the power of two-thirds.
- A strong correlation is found between the excess polar updraft [6] and a reduction in relative X-ray luminosity for ultrafast rotators implying it is the most likely cause of the super-saturation effect.
- An agreement between the timescales for coronal de-saturation and interior coupling implies that these are linked and we suggests that the saturation effect is actually therefore a different dynamo configuration at work and not a 'saturation'.
- See: Wright, Drake & Mamajek, ApJ, submitted.

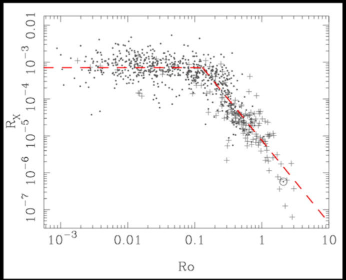


Figure 1. The activity-rotation relation: $R_X = L_X / L_{bol}$ vs. $Ro = P_{rot} / \tau$. The unsaturated regime is fit as $R_X \propto Ro^{-2.68}$, while the saturated regime is argued to be due to a different dynamo configuration at work.

Introduction

Solar and late-type stars emit X-rays through a magnetically confined plasma, or *corona,* at several million Kelvin. The corona is heated by the stellar dynamo, which itself is powered by differential rotation within the star [1,2]. As stars age, they spin-down, and their X-ray luminosity decreases by several orders of magnitude from the ZAMS to the solar age. Existing observations suggest major problems in our understanding of many phenomena associated with coronal X-ray emission, including dynamo decay and the causes of saturation and super-saturation [3,4].

Stellar X-ray sources in the *Chandra*-COSMOS field

- 60 new stellar X-ray sources identified and classified in the Chandra-COSMOS field
- Distances for the sample range from 30 pc – 12 kpc (Figure 2), including Galactic disk and halo sources, as well as the most distant coronal X-ray sources ever detected, most likely in active binaries.
- Many halo stars have hard X-ray spectra with little evidence for flaring, suggesting low-metallicity sources radiate via thermal bremsstrahlung
- See: Wright, Drake & Civano, 2010, ApJ, 725, 480.

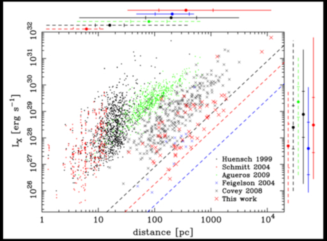
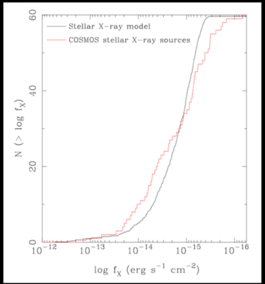


Figure 2. X-ray luminosity versus distance for stars in our sample & compared to other recent samples.

XStar: a new stellar X-ray activity model

- Combined Galactic population synthesis model [7], stellar spin-down using rotational isochrones [8] and the X-ray activity – rotation relationship (see panel, *left*).
- Galactic model calibrated using deep optical photometry of field.
- Outputs can be convolved with X-ray and/or optical completeness limits for the observations to be matched.
- Produces X-ray luminosity distributions or X-ray star counts for comparison with observations (Figure 3) or to estimate sight-line contamination (or star formation or extragalactic studies).

Figure 3. Cumulative X-ray flux distribution from the XStar model compared to observations of the C-COSMOS field. The best-fitting slope to the rotation – activity relation is $\beta = -2.50 \pm 0.30$, though differences between the modeled and observed populations remain, suggesting we still lack an understanding of the X-ray emitting stellar population.



References [1] Parker, 1955, ApJ, 122, 293. [2] Pallavincini et al. 1981, ApJ, 248, 279. [3] Feigelson et al. 2004, ApJ, 611, 1107. [4] Micela et al. 2007, A&A, 461, 977. [5] Montesinos et al. 2001, MNRAS, 326, 877. [6] Stepien et al. 2001, A&A, 370, 157. [7] Girardi et al. 2005, A&A, 436, 895. [8] Barnes 2003, ApJ, 586, 464.