THE X-RAY CORONAE OF INTERMEDIATE-MASS G GIANTS

P. Gondoin

European Space Agency, ESTEC - Postbus 299, 2200 AG Noordwijk, The Netherlands

ABSTRACT

I present analysis results of the XMM-Newton spectra of intermediate-mass G giants, that are known to be chromospherically active and to have high X-ray luminosities. Series of line of highly ionized Fe and several Lyman lines of hydrogen-like ions and triplet lines of helium-like ions are visible in their X-ray spectra, most notably from O and Ne. Analysis results suggest a scenario where the coronae of these stars are dominated by large magnetic structures similar in size to interconnecting loops between solar active regions but significantly hotter. The surface area coverage of these active regions can exceed 30-50 % depending on the star rotation period. The interaction of these structures themselves seems to induce a permanent flaring activity responsible for heating plasma to coronal temperatures higher than 10 MK. The analysis of a sample of G giants with similar evolutionary status shows evidence that their surface magnetic flux increases approximately linearly with their angular rotation velocity. Remarkably, the relation differs from the power law dependence with an index of 2 that is observed for main sequence stars.

Key words: stellar coronae; magnetic activity; X-rays.

1. INTRODUCTION

One major topic of stellar activity is to explain how phenomena seen on the Sun and stars, and especially magnetic phenomena, depend on stellar parameters such as rotation rate, mass and age. One magnetic field diagnostic for cool stars is coronal X-ray emission. A relation between X-ray luminosities and rotation has been reported for late-type dwarfs but the connection between rotation and activity is less evident among giants. This paper reports on the results of an investigation to test whether such a relation exists among intermediate mass (1.5 $M_\odot < M < 3.0\,M_\odot$) G giants. The study uses XMM-Newton observations of a sample of G giants with similar masses and evolutionary status and with known rotational periods.

2. X-RAY PROPERTIES

XMM-Newton spectra of G giants (see Fig. 1) were fitted with optically thin plasma emission models. The best fit models suggest two major plasma components at temperatures in the range 6 to 9 MK and 10 to 90 MK, respectively. The temperature of the "cool" plasma component is reminiscent of solar type active regions, while the hot component may be caused by disruptions of magnetic fields associated to a permanent flaring activity. Assuming that these active regions consist of similar loops with constant pressure, temperature and cross section, characteristic surface coverage, loop sizes and electron densities can be derived. The results (see Table 1) suggest that the effect of rotation on G giants is to increase their surface coverage with solar-like active regions. This coverage would be a factor 2 to 3 higher for fast ($P < 4$ days) rotating giants compared to slow (> 9 days) rotating giants.

Flare indicators include X-ray light curve variability, the emission measure and maximum temperature of hot ($T > 10$ MK) plasma, the presence of an Fe K-shell line around 6.7 keV indicative of the presence of iron in high states of ionization, and an enhancement of the oxygen and neon abundance relative to iron. The emission measure and temperature of hot plasma seem to increase with the rotation rate. This supports the idea that the flaring rate on giants could increase with the stellar rotation rate. This statement is corroborated by the fact that iron in high ionization states and large Ne abundance enhancements are detected in fast rotating giants (e.g. V1794 Cygni and FK Comae) and not in slowly rotating giants (e.g. V390 Aurigae and δ CrB).

3. X-RAY ACTIVITY AND ROTATION

The quiescent coronal activity of intermediate-mass G giants, as measured by their X-ray surface flux, increases approximately linearly with the angular rotation velocity and with the inverse of the Rossby number (Gondoin 2006). Even the most rapidly rotating G giants do not reach the canonical log(Lx/Lbol) $\approx$ -3 saturation level.

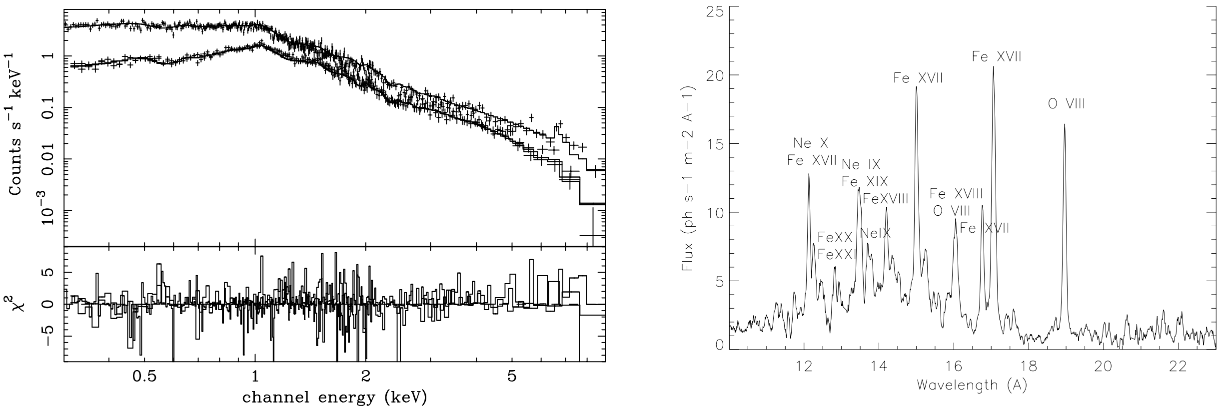

Figure 1. XMM-Newton EPIC spectrum of V 1794 Cygni (left) and RGS spectrum of δ Cr B (right).

Table 1. Active region coverage and parameters of a simple coronal loop model for G giants with different rotation rates.

	P (days)	Coverage (%)	T (10^6 K)	EM (10^{52} cm^{-3})	L (10^9 cm)	n_e (10^{10} cm^{-3})
δ CrB	59	24	6.5	34	5	2
HR 9024	23	15–31	7.5–7.7	62–72	9–12	1.3–1.7
V390 Aur	9.8	25–30	7.2	19	13	1.1
V1794 Cyg	3.3	55–88	7.9–8.1	35–43	13–14	1.2–1.3
FK Com	2.4	30–50	8.5	41	30	0.6

The effect of rapid rotation on these stars could result mainly in an increased coverage of their surface with magnetic close loop structures. This in turn would result in more frequent flares responsible for the important emission measure of hot plasmas above 10 MK. Remarkably, the relation between X-ray to bolometric luminosity ratio and the Rossby number or rotation period for G giants differs from the power law dependence with an index of about - 2 that is observed for main-sequence stars (see Fig.2). Using a model for global circulation in outer stellar convection zones, Kitchatinov and Rudiger (1999) found that the differential rotation of giants is large and solar-like. They concluded that the dynamo regime is similar in G giants and in G dwarfs. One main characteristic of giants is the rapid evolution of their internal structure. Hence, it is possible that the fast expansion of their convective zone does not leave them sufficient time to converge to a unified rotation-activity relation. The lower slope of the activity-rotation relationship for giants and the larger dispersion of the measurements around the best linear fit could be a consequence of this rapid evolution.

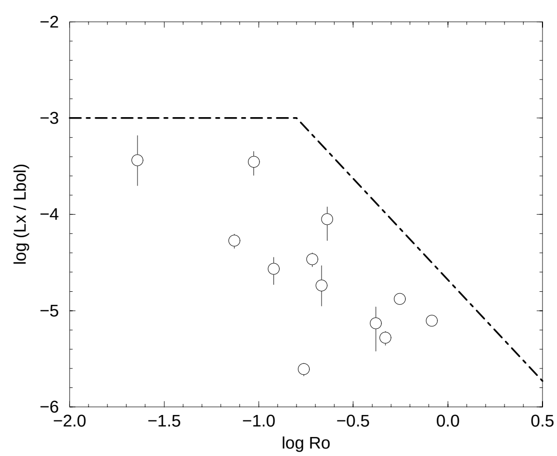

Figure 2. X-ray to bolometric luminosity ratio as a function of Rossby number for intermediate-mass G giants compared to the relation (dot-dashed line) found for dwarfs (e.g. Randich 2000).

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