X-ray variability in dM stars

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The issue of the variability of coronal emission is a current problem of stellar physics. Properties of X-ray variability, amplitude and time scales give us information on the physics underlying the coronal emission. In present work we present results from a systematic analysis of X-ray variability of nearby M stars, mainly phocused on medium and long term time scales. Taking advantage of archival data of ROSAT-PSPC observations, we explore time scales from days to months. Variability is present at all explored time scales and its amplitude is independent of stellar X-ray and visual luminosity. Results are compared with solar X-ray variability properties suggesting that in dM stars emitting Structures have a spatial distribution more homogenous that in the Sun. Analogous studies on dM stars of the Pleiades indicate that in this cluster the spread observed in the X-ray luminosity function can be explained in terms of variability.

1. Introduction

The study of temporal variations is a very powerful tool to characterize and study the properties of a population of X-ray sources. Studies of typical time scales and amplitude of the observed variability can provide useful information on dimensions and physical conditions of the regions where X-ray emission originates. Comparative studies of the variability properties within a homogeneous class of X-ray sources are useful to determine or constrain the mechanisms generating their X-ray emission. To pursue such studies, a large number of homogenous observations are required. In this work we present some results from a systematic study of X-ray variability on dM stars in the solar neighborhood and in the Pleiades.

The Sun is usually considered to be the prototype of low mass stars and often we extrapolate the knowledge we have on the Sun to the other stars. this approach is certainly very effective but in some cases it has to be applied with caution since the physical conditions of the stars can be different from those in the Sun. In M stars, for example, it is not clear which kind of dynamo is operating and if the solar model can be applied; in this context variability studies and the comparison with the variability properties of the Sun give us an effective tool to test the properties of coronae of dM stars. Previous systematic studies on variability of X-ray emission of dM stars, based on *Einstein* and Exosat observations, concerned mainly short term variability (Ambruster et al. 1987, Collura et al. 1988, Pallavicini et al. 1990).

In this work we have used as reference the solar data from Solrad experiment in the 8-20 Å band. Data have been obtained via Web at http://www.ngdc.noaa.gov/stp/stp.html. The energy bandpass is not exactly the same but it is very similar to that of typical stellar observations. These solar data cover 5 years of observations from March 1968 to February 1973, spanning a time interval comparable with that spanned by ROSAT. The Sun is the only star for which we have a good knowledge of X-ray variability on all time scales (e.g. Vaiana et al. 1973, Vaiana and Tucker 1974, Kreplin 1977, Zombeck et al. 1978, Withbroe et al 1985), that extend from minutes to years. We know in detail the solar properties since we can relate directly the variations observed in the spatially integrated solar X-ray flux to the spatial distribution of such emission as revealed by high-resolution X-ray images. Since no equivalent studies are possible for stars in this

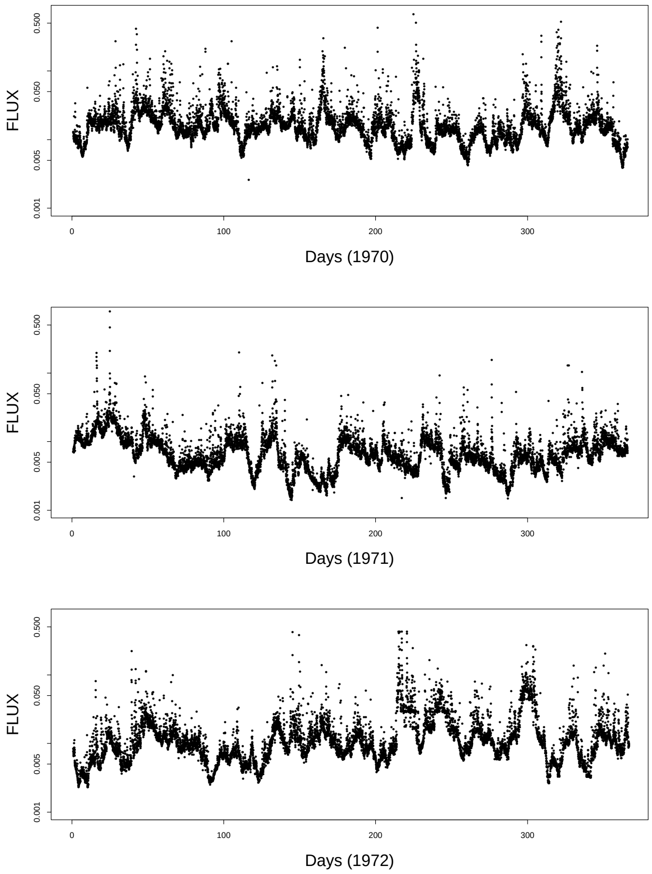

FIGURE 1. Light curve of the Sun as observed by SOLRAD in the 8-20 $\AA$ between 1970 and 1972, each point represents the solar emission integrated in one hour.

context, variability studies allow us to test the properties and the origin of coronae of late-type stars.

For nearby field dM stars we have analyzed ROSAT PSPC pointed observations, that were obtained between 1991 and 1994, while for the Pleiades dM stars we have studied *Einstein* IPC, ROSAT PSPC and ROSAT HRI observations.

In order to compare data obtained with a similar time pattern, for the Sun we have used the hourly data, that well compare with the typical length of ROSAT time orbits, typically of the order of few thousands of seconds. In Fig. 1 we report the light curve of the Sun, in three of the explored years by SOLRAD. These light curves show very clearly the rotational modulation that typically produces amplitude variations of less than a factor 5 and the occurency of flares with amplitude up to two orders of magnitude.

With these data we have computed the time distribution function for the Sun. The curve fits very well with a log-normal distribution with a variance of .09 and gives the fraction of time, in a period of 5 years, that the Sun spends at a given value of X-ray flux. The distribution indicates that the Sun spends more than 70% of the time with an X-ray flux within a factor two of its median value and 90% of the time within a factor three, and that only for 1% of the time the X-ray flux of the Sun is different from its median

Confidence level	Stars $M_v < 13$	Stars $M_v > 13$
$> 99\%$	31 (48%)	14 (67%)
95-99%	4 (6%)	2 (10%)
90-95%	6 (9%)	1 (5%)
<90%	24 (37%)	4 (19%)

TABLE 1. Results of the Kolmogorov-Smirnov test applied to the ROSAT PSPC light curves of dM field stars: In columns 2 and 3 are reported the number of cases for which we can reject the hypothesis that the source is constant at the confidence level indicated in column 1

value by a factor ten. Note, however, that we are studying five years of solar observations just after a solar maximum, hence the previous percentages refer to this period and not to the entire solar cycle. If a stellar population were composed by stars identical to the Sun we expect that the X-ray luminosity function would have the shape of the solar time distribution. To test which fraction of the variance of X-ray luminosity distribution of the late type field star population can be due to variability, we compare this distribution with the luminosity function observed by Schmitt et al. (1995) in the solar neighborhood for G, K and M stars. A comparison of the variances shows that variations such as those observed on the Sun can account at most for 40% of the observed spread for dK stars and for not more than 15% of the spread observed in dG and in dM stars. Hence variations such as those observed in the Sun in a period of 5 years can be responsible for only part of the spread observed in the X-ray luminosity functions of late type field stars. The remaining spread can be due to stellar parameters, such as rotation, but we cannot exclude further contribution from variability on a longer time scale.

2. Stellar observations

We have explored X-ray variability properties of nearby dM stars using the X-ray light curves of the PSPC pointed observations of M stars contained in the CNS3 catalog. Among them we have selected all the stars detected with more than 40 counts and observed at off-axis angle ≤ 48 arcmin. Our sample consists of 55 stars, for a total of 86 distinct observations. A detailed analysis of these data is reported in Marino, Micela, & Peres (in preparation).

Most of the lifetimes are shorter than 10ksec with about half of the observations shorter than 5 ksec. The elapsed times are typically less than 2 days with a tail up to 10-15 days and few stars observed one or two years apart.

To evaluate on statistical grounds the presence of variability, we have applied the Kolmogorov-Smirnov (KS) test on all the stars of our sample. The results are reported in Table 1. We see that most observations, both of the earliest and the latest stars, show significant variability. Furthermore variability does not seem to depend on the activity level.

To further explore the variability properties of our stars we have fragmented each observation into individual orbits, and evaluated the X-ray luminosity in each orbit, retaining those in which the source has been detected with at least 40 counts. In figure 2 we report the cumulative time distribution functions of the stars with at least 10 distinct luminosity values. As it is evident we are looking at stars with very different activity levels with X-ray luminosity spanning more than two orders of magnitude. All these stars

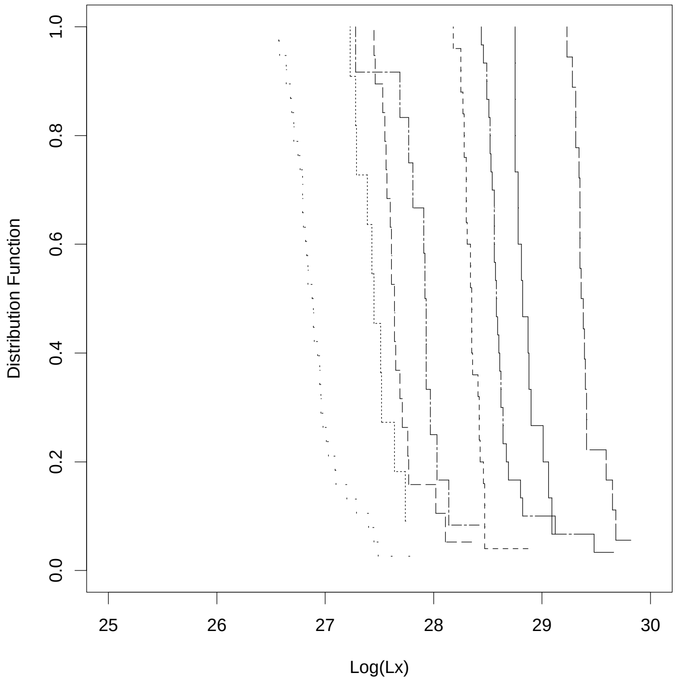

FIGURE 2. Cumulative X-ray time distribution functions of the stars with at least 10 distinct luminosity values. From the left to right: GL551, GL866, GL65, GL294, GJ630.1, GL873, GL388, GL490)

show similar variations independently of the luminosity level. The tail at high value of Lx are typically due to flares.

For each star we compute the distribution of amplitude variation as the ratio between the observed value of Lx and the minimum value observed for that star. Since variability does not seem to depend on the activity level, we compute the normalized cumulative distribution of amplitude variations for the whole sample. The final distribution is shown in figure 3. The plot gives us the fraction of time that a dM star spends with an X-ray activity level larger than a given quantity of its minimum value. So a star spends about half time with a L_x larger than 50% over its minimum value and 10% of the time with a Lx larger than 4 times its minimum value.

With the aim to compare the properties of our sample with those of the Sun we have create a set of 500 samples from the Sun distribution. For each sample we have simulated each of the 32 stars we have used to build the amplitude distribution of fig. 3, drawing from the solar set the same number of observations we have in the PSPC sample. For example, for the 5 stars observed twice, we have randomly selected 5 pairs from the solar light curve (each pair represents a star), then for the 6 stars observed 3 times we have selected 6 sets of 3 points from the solar curve (each set simulates one of these 6 stars), and so on. The idea is to simulate the same pattern of observations typically used for stars, i.e. to simulate the data we would have obtained if we had observed the Sun with the same time pattern used to observe the stars. In this way we can study the Sun with the same bias due of the stellar observations to the time sampling. For each simulated

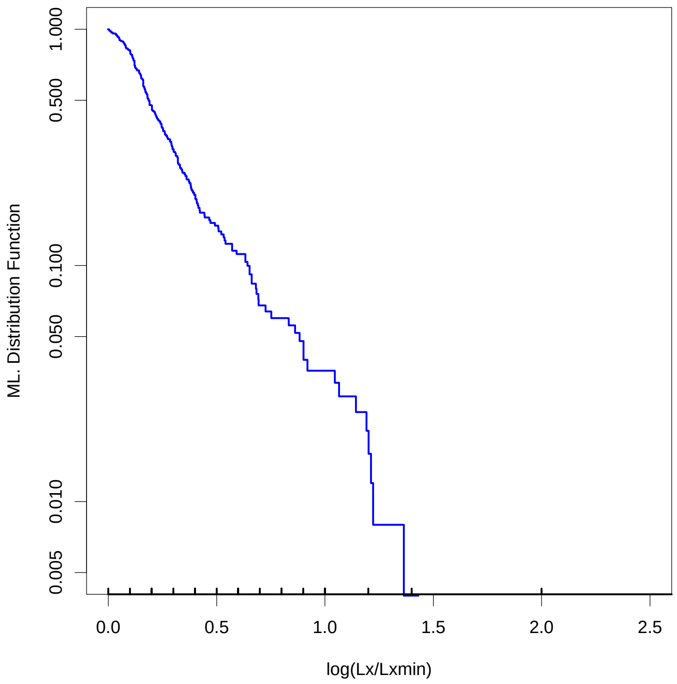

FIGURE 3. Normalized cumulative distribution of amplitude variations for all stars of our field sample.

sample we have computed the distribution of amplitude variation as done for the stars. The region occupied by these simulations, together with the observed dM distribution, is shown in fig.4. We see that the high luminosity tail of our M stars, is consistent with the tail of the solar distribution that typically is due to flares. On the contrary the body of distribution is depressed with respect to the Sun, suggesting that flare distribution for dM stars is similar to that of the Sun, while the variations by a factor 2-5 that in the Sun are due mainly to rotation are less evident in dM stars.

This discrepancy between the distribution of the Sun and that of the nearby dM stars suggests that the spatial distribution of the regions originating the X-ray emission in dM stars is different (and more homogeneous) than in the Sun.

3. Pleiades dM stars

For the Pleiades we take advantage of the *Einstein* IPC, and of the pointed ROSAT PSPC and HRI exposures in the Pleiades direction. For the IPC observations, that were obtained in 1979/1981, we have used the X-ray luminosity reported in literature (Micela et al. 1990).

The PSPC observations were obtained in 1991 and 1992 and we have reanalyzed the images in a homogenous way with a Wavelet based algorithm. When possible we have analyzed separately the single temporal segments of the PSPC observations, taken at well separated times for a total of 7 different images.

The HRI exposures were obtained in 1994-1996, and also for these observations we have

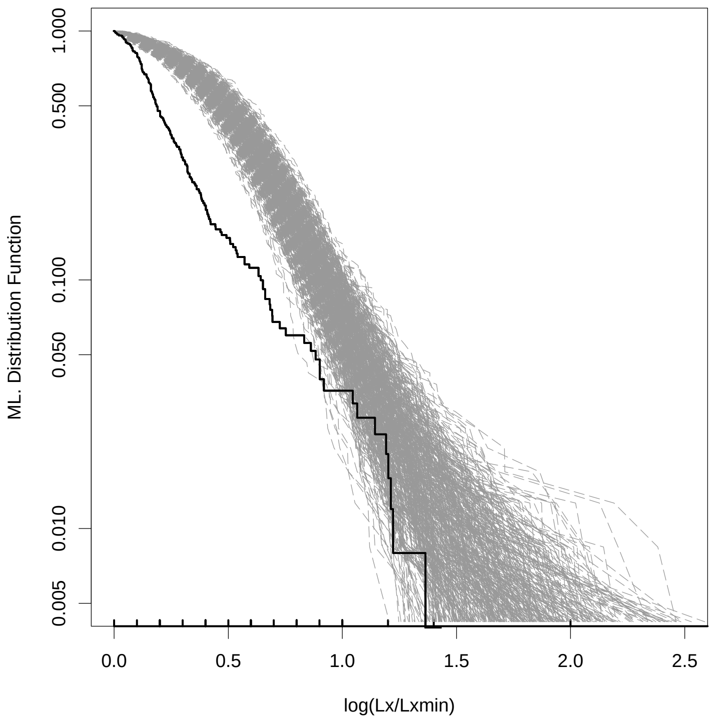

FIGURE 4. Time distribution of X-ray luminosity of nearby dM stars (solid line), compared with the region occupied by the simulations of the time distribution of the solar emission, when the Sun is sampled with the same pattern of the stars. Note the scale logarithmic in ordinate.

used a Wavelet based algorithm applied to each of the temporal segment of observations for a total of 9 different images. We note that the time distribution used for the Pleiades observations is different from that used for the dM field stars, hence the results we obtain for the Pleiades could be not immediately compared with those obtained for the field stars.

Using the same approach used for the dM field stars, we have obtained the distribution of the amplitude variations for the dM Pleiades stars. In this case if we compare this time distribution with the observed luminosity function for Pleiades dM stars we find that most of the observed spread in the luminosity function can be attributed to variability.

In fig. 5 we report the scatter plot of L_x versus the rotation rate for the corresponding star, as measured by the projected equatorial rotation rate $v\ \sin(i)$; vertical line segments connect different measurements of the same star. From the figure we see that for Pleiades dM stars the spread in the activity-rotation relation can be entirely attributed to variability.

4. Summary

In this work we have presented results from a systematic analysis of X-ray light curves of dM stars both in solar neighborhood and in the Pleiades.

We found that X-ray variability is a common phenomenon in dM stars regardless of their "quiescent" activity level and visual magnitude, at least in the explored ranges.

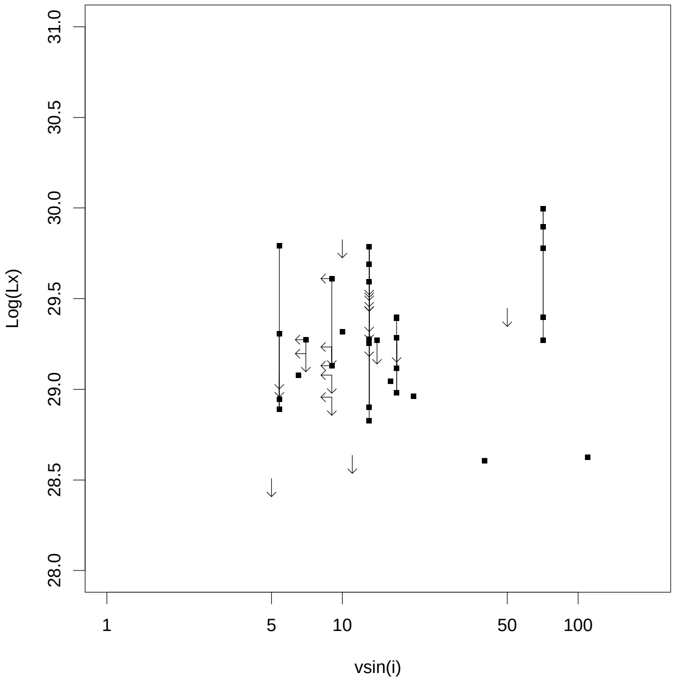

FIGURE 5. Scatter plot of L_x versus the rotation rate, as measured by the projected equatorial rotation rate ($v\ \sin(i)$); vertical line segments connect different measurements of the same star.

The frequency of amplitude variations is consistent with the frequency of X-ray flares observed in the Sun, while rotational modulation is substantially suppressed in dM stars. This suggests that the spatial distribution of emitting structures in dM stars is different from that observed in the Sun.

The spread of the X-ray luminosity function in field dM stars cannot be explained by variability only, while it is entirely explained by variability in dM stars of the Pleiades.

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REFERENCES

AMBRUSTER, C.W., SCIORTINO, S., & GOLUB, L. 1987 *Ap. J. Suppl*, **65**, 273.

COLLURA,A., PASQUINI, L., & SCHMITT, J.H.M.M. 1988 *Astr. & Astroph.* **205**, 197

KREPLIN, R.W., DERE, K.P., HORAN, D.M. & MEEKINS, J.F. 1977 *The solar output and its variations*, Colorado University Press, 187.

MICELA, G., SCIORTINO, S., VAIANA, G. S., HARNDEN, F. R. JR., ROSNER, R., & SCHMITT, J. H. M. M. 1990 *Ap. J.* **348** 557.

PALLAVICINI, R., TAGLIAFERRI, G., & STELLA, L. 1990 *Astr. & Astroph.* **228**, 403

SCHMITT, J. H. M. M., FLEMING, T. A., & GIAMPAPA, M. S. 1995 *Ap. .J.* , **450** 401.

VAIANA, G.S., DAVIS, J.M., GIACCONI, R., KRIEGER, A.S., SILK, J.K., TIMOTHY, A.F. & ZOMBECK M. 1983 *Ap. J. (Letters)* **185**, L47-L51

VAIANA, G.S. & TUCKER, W.H. 1974, *X-ray Astronomy* eds. Giacconi, R., Gursky, H., Reidel, D. 169.

WITHBROE, G.L., HABBAL, S.R. & RONAN, R. 1985 *Sol. Phys.* **95**, 297.

ZOMBECK, M.V., VAIANA, G.S., HAGGERTY, R., KRIEGER, A. S., SILK, J. K. & TIMOTHY, A. 1978 *Ap. J.* **38**, 69.