X-RAY OBSERVATIONS OF STARS: FIRST RESULTS FROM ROSAT

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The Impact of the ROSAT All-sky Survey on Stellar X-ray Astronomy

At the time of writing (i.e., September 1991), the ROSAT all-sky survey has been completed and almost the entire sky has been scanned with an imaging X-ray telescope down to a limiting flux of approximately 2 $10^{-13} erg/s/cm^2$ in the pass band $0.1 - 2.0$ keV; in regions of deeper exposures near the poles of the ecliptic considerably fainter flux limits have been achieved. While the processing and analysis of this huge body of data is still in progress and hence final results on the number of detected sources and their distribution in flux are not yet available, the total number of detected X-ray sources will be around 60 000. Preliminary results from optical identifications of selected fields show that about one quarter of the X-ray sources discovered at high galactic latitudes come from by comparison nearby stellar sources (Fleming 1991), while at lower galactic latitudes up to one half of the detected X-ray sources are of stellar origin; in areas occupied by star forming regions (for example, Orion) or open clusters (for example, Hyades or Pleiades) a large number of the detected X-ray sources can be identified with young stars, yielding up to 80 percent of the total source count as galactic stars. For the whole of the ROSAT all-sky survey we may therefore expect about one third of the total sources to be of stellar origin. The vast majority of these stellar X-ray sources is of coronal origin (i.e., late-type low mass stars). Only a relatively small number of stellar X-ray sources will be associated with early-type massive stars where the X-ray emission is thought to arise from instabilities in their radiatively driven winds or metal-poor degenerate stars where the X-ray emission comes from portions of the atmosphere considerably hotter than the optically visible photosphere. From the preliminary analyses performed so far it is already clear now that supersoft sources such as white dwarfs do not constitute a major fraction of the X-ray source population found in the ROSAT all-sky survey and the number of newly X-ray discovered white dwarfs will certainly be considerably less than one thousand. The X-ray emitting late-type stars are commonly referred to as "active" stars, and the ROSAT all-sky survey catalog will comprise the most extensive list of such objects.

It is essential to keep mind that X-ray selected samples of stars consist almost exclusively of such "active" stars. This can be seen through the following simple calculation: Consider the Sun as a prototype of a non-active star with a soft X-ray luminosity of $\sim 10^{27} erg/s$. At a flux limit of 2 $10^{-13} erg/cm^2/s$, such an object can be detected out to a distance of 9 pc; within this distance there are approximately $\sim$ 200 stars. Therefore, if the Sun were indeed the paradigm for stellar X-ray emission, the stellar source content of the ROSAT all-sky survey would be almost negligible. Since this is not the case, stellar X-ray emission levels must typically be much higher than those found for the Sun.

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The physical basis for all the activity phenomena observed in late-type stars is usually thought to be a magnetic dynamo, which is responsible for the generation of the magnetic fields whose magnetic energy sustains the observed activity phenomena. Of considerable interest in this context is the study of the evolution of activity (as evidenced by X-ray emission) and age. Open galactic clusters are of course the targets of choice for these studies. All such clusters have been scanned during the course of the all-sky survey, allowing the detection of the more luminous X-ray sources (i.e., the limiting X-ray luminosities are $log\ L_X \sim 5\ 10^{28} erg/s$ at the Hyades distance, and $log\ L_X \sim 4\ 10^{29} erg/s$ at the Pleiades distance). In the Hyades cluster more than 100 cluster members could be idenfied among the ROSAT all-sky X-ray sources, while in the case of the more distant clusters, a few dozen X-ray sources can be identified with known cluster members. Deeper pointed observations have so far been carried out on the Hyades, Pleiades and α Per clusters with much lower limiting X-ray fluxes; these deeper observations allow the detection of stars with X-ray emission levels similar that to the Sun at the Hyades distance.

A major advantage of the ROSAT all-sky survey is the availability of pulse height spectra, which define up to four more or less independent bands over the PSPC band pass. Count statistics limits the useful number of bands often to two, a soft band (0.1 - 0.28 keV) and a hard band (0.5 - 2.0 keV). The X-ray sky looks quite different in those two bands. X-ray emission from the quiet Sun arises from plasma in active regions with temperatures of $\sim 2\ 10^6 K$; such plasma emits almost exculsively in the soft PSPC band with very little energy appearing at energies above $0.5 keV$. Higher energy emission in the Sun is encountered only during flares, i.e., not in a steady but rather in transient form. Essentially all active stars are detected in ROSAT's hard band; the nearby active stars also exhibit strong emission in the soft band. These emission patterns are indicative of plasma with temperatures of $10^7 K$ or more, and the ROSAT all-sky survey results thus show the ubiquity of such hot plasma in active star coronae. It is almost certain that this high temperature emission is radiated in a steady fashion and not in the form of (also existing) flares.

Lastly, the observing mode during the all-sky survey offers interesting possibilities to explore the time variability of coronal X-ray emission. The all-sky survey was carried out in such a way that at any given time a great circle on the sky was scanned. The scan period was linked to the orbital period of $\sim$ 96 minutes; any particular region of the sky was viewed for about 25 seconds during a single scan. Any particular source was scanned for at least two days (corresponding about about 30 scans) and up to thirty days and more in the vicinity of the ecliptic poles. The scan great circle was at approximately 90 degrees from the Sun and moved with the solar motion. In this fashion the whole sky was covered within six months. Therefore the all-sky survey measurements thus represent a light curve covering the time scales of long duration flares (i.e., a few hours) as well as that of stellar rotation (i.e., half a day to a month). For sources at favorable locations near the ecliptic poles such as AB Dor, Gl 687, ω Dra the ROSAT all-sky survey produced a hitherto unprecedented time series spanning many rotational periods of these objects. Interestingly, so far no convincing examples for rotational modulation could be found in the all-sky survey. Flares, on the other hand, were observed in abundance, for example, on nearby flare stars such as Prox Cen, on RS CVn systems such as HR 1099 and even on rather distant flare stars in open clusters.

References

Fleming, T.A., 1991, personal communication