Stellar X-ray Astronomy: Perspectives for the New Millennium

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Abstract

The last two decades have seen the emergence of a new field in stellar astrophysics: Stellar X-ray astronomy. With the advent of soft X-ray imagery X-ray emission was found from many thousands of solar-like stars. I will summarize the most important findings of X-ray surveys of late type stars. Some results of eclipse observations to determine stellar structure will be reviewed. X-ray spectroscopy will be discussed from the point of view of density diagnostics.

1 Introduction

A new view of the Sun opened when high-resolution soft X-ray telescopes became available to study the solar corona. The high temperature of the outermost layers of the Sun had been known since the 1940's, when the mysterious coronal lines seen in the optical were finally identified as forbidden emission lines from highly ionized iron (Grottian 1939). The solar X-ray images were quite surprising: The X-ray emission was far from being anywhere close to spherically symmetric, rather a great number of loop-like structures filled with X-ray emitting plasma were discovered. Obviously magnetic fields had to play a key role both in structuring and heating the solar corona.

But what about stars? There is no way to study stellar coronae in the optical waveband through the use of forbidden lines – any rather weak coronal emission will be overwhelmed by the strong photospheric emission. Hot coronal plasma loses the bulk of its energy in the X-ray range, and not surprisingly, a systematic study of stellar coronae is only possible in the X-ray domain. The number of known X-ray sources has tremendously increased over the last two decades. I list the number of known coronal X-ray sources as a function of time in Tab. 1. At the time of writing we know X-ray emission from more than 20,000 stars, and with *Chandra* and XMM-Newton operating hopefully throughout the next decade, this number will rapidly increase again. As is obvious from Tab. 1, the breakthrough of stellar X-ray astronomy came with the advent of imaging soft X-ray telescopes, with the *Einstein Observatory* – operated between 1978 and 1981 – being the first such facility. The *Einstein Observatory* demonstrated for the first time the ubiquity of stellar X-ray emission. At the time this was a big – since unexpected – surprise. But why should stellar X-ray emission be considered as a surprise, given that the Sun is a soft X-ray source? The surprise was not the fact that other stars are X-ray sources, but rather the surprise was their high level of X-ray emission. Given the Sun's soft X-ray luminosity of $\approx 2 \times 10^{27}$ erg/sec at solar maximum, it is trivial to compute the distance out to which solar-like X-ray emission can be detected at the sensitivity level of the ROSAT all-sky survey of $f_{X,lim} \sim 2 \times 10^{-13}$ erg/cm^2/sec. The answer is 9 pc, i. e., a distance small compared to the dimensions of the Galaxy. A sphere of 9 pc radius around the Sun does not contain 20,000 stars. Obviously there must exist stars with significantly higher activity levels which dominate the X-ray number counts. One then concludes that the Sun is by no means "typical" as far its activity and X-ray emission is concerned and that surface temperature and total luminosity, the two parameters determining the position of a star in the HR-diagram, do not predict the level of activity and specifically the level of X-ray emission of a given star.

Solar physics is limited by the uniqueness of the Sun. Solar physicists can only watch and observe what is happening on the Sun. But what would solar activity be like if the Sun were more massive or less massive, spinning faster or more slowly? What was the Sun like when it was young? How active will it be in its old age? The answers to those questions are difficult to come by from studying only the Sun, but with the large number of detected coronal X-ray sources we can in fact probe the dependence of stellar activity on stellar parameters like age, mass and rotation. By studying other stars the questions posed above can actually be reasonably addressed and this is what the solar-stellar connection is all about.

Most of stellar astrophysics before the 1980's had concentrated on stellar photospheres and interiors. Modeling and interpreting photospheric spectral absorption lines using atomic physics and radiative transfer theory in order to derive chemical abundances, stellar radii and gravities, and the modeling of the thermonuclear processes in the stellar interiors allowed the calculation of stellar evolution from which the life cycle of a star in the HR-diagram could be determined. With the new high-energy windows provided by X-ray and UV satellites such as IUE, *Einstein Observatory*, HST, ROSAT, EXOSAT, *Ginga*, EUVE, ASCA, and BeppoSAX the attention has shifted from the interiors and photospheres to outer atmospheric "activity." This name is derived from solar active regions – areas of plage, sunspots and flare sites – but now referring to a much broader range of phenomena. X-ray emission was discovered from multi-million degree coronae as well as stellar flares, that can be 10,000 times more intense than those observed on the Sun. Nonthermal radio emission demonstrates the presence of copious amounts of ions and electrons moving at relativistic speeds, and output variations indicate the presence of

Table 1: Coronal X-ray sources

Year		Number of known sources
1948	Sun	1
1975	Sun, Capella	2
1978	RS CVn systems	8
1981	*Einstein Observatory*	≈ 1500
1991	*ROSAT*	> 20000

extremely large magnetic field concentrations on the surfaces and presumably also coronae of so-called active stars. All this stellar activity is thought to be driven by magnetic fields, which in turn are generated via the stellar rotation and turbulence. None of these parameters, rotation, turbulence, and magnetic fields, played a major role in the modeling of stellar photospheres and interiors.

2 What can be learnt from the Sun?

The first and obvious question to ask is what one would be able to infer about the solar corona if the Sun were placed at a distance of, say, 10 pc and only "stellar" data, i. e. disk-integrated data, were at our disposal. The Sun would appear as a rather weak, albeit clearly detectable, soft X-ray source. The solar corona would not be detectable in any optical forbidden line, nor in the hard X-ray or in the radio range. Ignoring short term variability in the form of flares, the Sun's total X-ray output undergoes significant changes on the cycle time scale of eleven years with variability amplitudes of a factor 10–100 depending on the precise spectral range chosen. On the rotation time scale of one month, the observed variability amplitude is a factor ≈ 3. Rotational modulation can often been seen in the Sun's total broad band X-ray emission (cf., Zombeck *et al.* 1979), i. e., in data covering similar spectral bands as the *Einstein* and ROSAT stellar X-ray data. The observed solar X-ray emission never drops to zero, but remains at typically a third of fourth of the observed peak emission. In "stellar language" one would say that the same percentage of flux is not rotationally modulated, however, as is clear from the many solar images, it is not the case that this flux is located at high altitudes above the solar surface or near the poles. The cyclic variability of the solar X-ray emission has been most impressively demonstrated with long-term synoptic series of *YOHKOH* images, which show the dramatic change of the appearance of the solar X-ray corona in the time between 1992 and 1996 between solar maximum and solar minimum. All types of solar variability, i. e., flares, rotational modulation and cyclic changes, could easily be detected even for a weak X-ray source like the Sun at typical stellar distances **given sufficient data coverage**. Obviously the latter is the problem; monitoring programs do not tend to get favorable ratings by time allocation committees.

High resolution spectroscopic observations of the full solar disk similar to the stellar observations from the spectrometers on board EUVE and now on board *Chandra* and XMM-Newton, have been available in a solar context for more than twenty years ago (cf., Malinovsky & Heroux 1973). The same methods of analysis that were applied to these solar data can now be applied to the new stellar data. In this fashion information on stellar coronal temperatures, emission measures, coronal chemical abundances, coronal densities and some structural information can be obtained.

3 Stellar coronae across the HR-diagram

Our knowledge of coronal X-ray emission has been derived almost exclusively from observations carried out with the *Einstein Observatory*, (operated between 1978 and 1981) and ROSAT (operated between 1990 and 1998). Stars were of course observed also with other X-ray satellites such as EXOSAT, ASCA and BeppoSAX, but the contributions from those missions were geared to more specific topics. I consider the important findings in the field of stellar X-ray astronomy as follows:

1. The discovery of hot, X-ray emitting coronae on almost all types of stars with outer convection located on the main sequence.
2. The discovery of a dividing line in the H-R diagram separating stars evolving away from the main sequence into two groups, i. e., stars with hot coronae and stars with cool winds.
3. The discovery of relations between activity (as measured in terms of X-ray emission) and the rotation of stars.
4. Observations of X-ray flares on other stars.

3.1 X-ray emission from late type dwarf stars

Observations with the *Einstein Observatory* had already demonstrated the ubiquitous occurrence of X-ray emission from main sequence stars with outer convection zones. In particularly it appeared that that onset of outer convection zones as predicted by stellar structure theory is reflected by a rather vigorous onset of activity. This issue was first addressed observationally by Schmitt et al. (1985), who found an enormous increase in detection rate when going from stars with $B-V \sim 0.2$ to stars with $B-V \sim 0.5$. Schmitt (1997) and Schmitt et al. (1995) performed a systematic volume-limited study of all known solar-like F and G type dwarf stars ($d < 13$ pc) and K and M dwarf stars ($d < 7$ pc) using the ROSAT all-sky survey and pointed follow-up data (for stars not detected in the survey data). The basic result of this study is plotted in Fig. 1 as X-ray surface flux F_X vs. B–V color for the solar-like stars studied by Schmitt (1997) as well as the K and M stars within 7 pc studied by Schmitt et al. (1995). None of the three A-type stars in the immediate solar vicinity could be detected as X-ray sources, but for stars cooler than

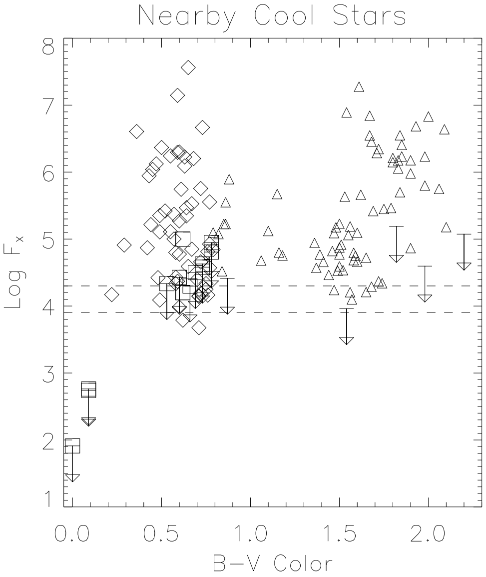

Figure 1: Mean X-ray surface brightness F_X vs. $B-V$ color for nearby stars (including A-type stars drawn as upper limits). F and G type stars are plotted with diamonds, K and M type stars (as discussed by Schmitt et al. 1995) with upward triangles. For comparison the typical X-ray surface flux level (in the PSPC band pass) from solar coronal holes is shown by the two dashed curves. Clearly the observed solar coronal hole surface flux provides a good description of the observed stellar minimum X-ray flux.

≈ 8000 K, the full range of X-ray activity is observed. The now available complete sample allows one to ascertain the question whether really **all** solar-like stars do possess coronae since the new sample is truly complete in the sense that all stars known within a distance of 13 pc from the Sun were observed with sufficient sensitivity to detect solar-like X-ray emission levels (and even below). The detection rate among the F-type stars is very large, the hottest and among the F-type stars only non-detection being the star Gl 364 classified as F9 IV. The detection rate among the G-type stars exceeds 80 %, with all non-detections resulting from the lower sensitivity ROSAT survey data. One must therefore conclude that coronal formation on solar-like stars represents an ubiquitous phenomenon. A corona containing hot plasma (T > 10^6 K) is always formed at the interface between a turbulent outer convection zone and space, and X-ray dark solar-like stars do not exist (at least within the immediate solar environment).

It is interesting to compare the mean X-ray surface fluxes for all stars of spectral type F through M (cf., Fig. 1). As obvious from Fig. 1, one observes a large spread in activity over ≈ 4 orders of magnitude essentially independent of spectral type. However, one also notices in Fig. 1 the existence of a rather well defined lower envelope F_{lim} to the observed mean X-ray surface flux distribution. The apparent cutoff at surface fluxes of $F_{lim} \approx 10^4$ erg/cm^2/sec is not a question of lacking sensitivity since the non-detected A-type stars do indeed have upper limits below F_{lim}. Because of the samples' completeness properties both for the F and G stars as well as the K and M stars, one can state that among cool dwarfs stars with X-ray surface fluxes below F_{lim} do not exist (in the considered volumes of space). The lower limit to the X-ray surface flux compares well with the observed X-ray surface flux from solar coronal holes, which is indicated by the horizontal lines in Fig. 1. It is suggestive to interpret the stars observed at their minimum flux levels as stars surrounded by coronal holes without any active regions.

3.2 Late M dwarfs and brown dwarfs

According to the common paradigm of stellar activity one needs both convection and rotation as necessary ingredients for the observed plethora of activity phenomena. Just as the onset of convection for late A/early F stars is of importance for dynamo theory, so is the very bottom of the main sequence. According to the stellar structure theory stars of spectral type dM5 or later, or in terms of mass, stars with masses below about 0.3 $M_\odot$, are expected to be fully convective, and should therefore not have a radiative-convective interface. Such an interface is often employed by dynamo models to provide a place for magnetic flux storage, which otherwise would very quickly escape to the stellar surface because of the combined effects of convection and magnetic buoyancy. The observed X-ray properties of M-dwarfs do not change for such fully convective dwarfs. Considering the ratio L_X/L_{bol}, i. e., the efficiency, with which convective flux is eventually converted into X-ray flux, one does not find any evidence for any change neither for very low mass stars (Fleming et al. 1993), nor for field stars (Schmitt et al. 1995). While it is true that one of the latest known star, LHS 2924, could not be detected by Fleming et al. (1993), as well as BRI 0021–0214 (Neuhäuser et al. 1999), other rather similar stars have been detected (i. e., LHS 3003, cf. Schmitt et al. 1995), suggesting that the apparent lack of detections of very low mass stars is due only to insufficient sensitivity given the the rather large distance of these objects (for LHS 2924 one finds an upper limit of only $L_x/L_{bol} < 4.5\ 10^{-5}$), and that X-ray emission probably occurs right to the bottom of the main sequence. Interestingly, X-ray emission has even been detected for a few brown dwarfs (Neuhäuser and Comerón 1998), i. e., objects below the hydrogen burning limit, but the small number of hitherto detected brown dwarfs prevents any far reaching conclusions. In summary, for the X-ray properties of a main-sequence stars it appears to be irrelevant whether the star's interior is fully convective or not.

3.3 X-ray emission from giants and supergiants

The existence of an X-ray dividing line (XDL) among giant stars was first established by the *Einstein Observatory*. Hot coronae with temperatures $T \sim 10^6$ K or higher were found precisely for those stars where UV spectra obtained with the IUE satellite had indicated the presence of material at transition region temperatures (through, for example, CIV emission), while stars without such transition region emission were also devoid of coronal soft X-ray emission (cf., Linsky and Haisch 1979; Ayres et al. 1981), and instead indicate the presence of cool, massive winds. The existence of the XDL has been impressively confirmed by the extensive material of the ROSAT All Sky Survey (cf., Haisch, Schmitt & Rosso 1991) as well as the ROSAT pointing program (cf., Hünsch et al. 1996). Hünsch et al. (1997) have produced a final catalog of detections of giants and supergiants listed in the BSC and detected in the RASS data; for 3839 such stars they find a total of 450 positional matches. Hünsch and collaborators have studied the few stars in seeming conflict with the dividing line (Haisch, Schmitt & Rosso 1991, Hünsch et al. 1996) and confirm the concept of an X-ray dividing line (XDL).

Just like on the main-sequence, X-ray emission for giants to the left of the dividing line seems to be ubiquitous. In the study of a complete volume-limited sample of giants within 25 pc around the Sun using both ROSAT survey and pointing data Hünsch et al. (1996) found that all stars, which remained undetected in the survey data but observed in the pointing program with sufficient sensitivity to detect solar-like emission levels, were in fact detected, a finding, which led to the conclusion that giants to the left of the XDL, which all have outer convection zones, are also ubiquitous X-ray emitters. For giants the XDL occurs across a very narrow region in the H-R diagram. Thus a G giant (to the left of the XDL) can have a rather high X-ray luminosity of up to $L_X \sim 3 \times 10^{30}$ ergs s^{-1}, although such objects seem to be relatively rare while K giants to the right of the XDL can be almost five orders of magnitude fainter. For example, Ayres, Fleming and Schmitt (1991) were not able to detect the nearby giant Arcturus and obtained an upper limit of $L_X < 3 \times 10^{25}$ ergs s^{-1}; expressing this upper limit in terms of mean X-ray surface flux, this X-ray non-detection is more than 1000 times fainter than a solar coronal hole (cf., Fig. 1). As the visually brightest and nearest K giant, Arcturus is the best non-coronal star to study, however, it may not be "typical". It does appear to have some C IV emission (Ayres et al. 1995) with f_{CIV}/f_{bol}, but much weaker than the Sun, hence it ought to be old and of rather low mass.

The concept of a dividing line seems to disappear, however, among the brighter giants and supergiants. Among those stars there is a group of stars exhibiting both signatures of transition region material (as inferred from CIV line detections) as well as cool winds (inferred from UV line profiles), i. e., the so-called hybrid stars. When these objects were first proposed as a new class by Hartmann, Dupree and Raymond (1980) and by Reimers (1982) it was unknown whether they actually possessed X-ray coronae. As a result

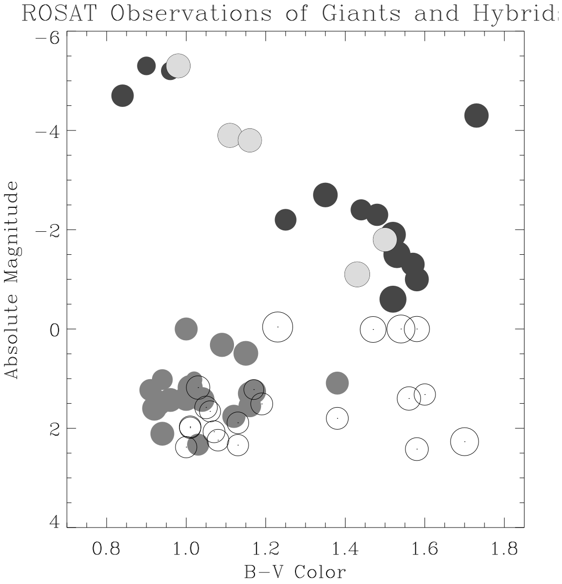

Figure 2: X-ray "bubblegram" of a complete sample of giants within 25 pc around the Sun (from Hünsch et al. 1996) and hybrid stars (discussed by Reimers et al. 1996). Plotted are the HR-diagram positions of nearby giants detected as X-ray sources (dark gray circles), the positions of nearby giants not detected as X-ray sources (white circles), the positions of hybrid stars detected as X-ray sources (black circles) and those of hybrid stars not detected as X-ray sources (light grey circles).

of extensive ROSAT observations hybrid stars are now known to possess hot coronal plasma at temperatures in the $10^6 - 10^7$ K range (Haisch, Schmitt & Rosso 1992; Reimers & Schmitt 1992; Kashyap et al. 1994; Reimers et al. 1996). The observational situation is summarized in Fig. 2, where the stars reported by Hünsch et al. (1996) within 25 pc around the Sun and the hybrid stars discussed by Reimers et al. (1996) are shown in an HR-diagram. The nearby giants detected as X-ray sources are plotted as dark gray circles, those not detected as X-ray sources as white circles, the X-ray detected hybrid stars are shown as black circles and the hybrid stars not detected as X-ray sources as light grey circles. As is obvious from Fig. 2, the XDL shows very clearly up for giants of luminosity class III, while most of the hybrid stars have been detected as X-ray sources, some of them having a spectral type which puts them well beyond the XDL for luminosity class II giants. The general concept of a dividing line has been questioned by Hünsch and Schröder (1996), who propose a somewhat different scenario. They plot the X-ray detected giants and hybrid stars in a Hertzsprung-Russell diagram and note that all X-ray detections lie to the left of an evolutionary track with $M = 1.25\ M_{\odot}$. Thus in their scenario stars never actually cross the XDL, rather the XDL is interpreted as an effect of stellar evolution, since low-mass stars ascending the giant branch are restricted to a rather narrow mass range and must therefore be rather rare.

Stars with masses $\geq 1.3 M_\odot$ are not expected to develop dynamo activity while on the main sequence since they are either fully radiative or have core convection zones at best. Stars with spectral types later than about B1.5V do not appear to be bona fide X-ray sources (Berghöfer et al. 1997). Therefore there is no apparent mechanism to brake the often observed very rapid rotation of such stars. However, as the stars evolve off the main sequence to become giants, one expects dynamo-sustaining convective envelopes to develop. An onset of coronal emission and a "coronal gap" between the main sequence and the turn-on point for such intermediate mass stars are therefore expected to arise. Observational evidence for such an "onset of convection" among giants has yet to be produced.

4 Coronal structure

Given the enormous range of X-ray luminosities of solar-like stars, one wonders how those stars, which essentially look like the Sun, manage to produce orders of magnitude higher X-ray outputs. What, then, do stellar coronal structures look like? If one assumes, going along with the solar analogy, that the X-ray emitting plasma is magnetically confined in magnetic loops, should one then expect simply more loops than typically visible on the solar surface, higher density loops or longer loops in order to account for the observed values of EM and L_X? Only solar observations have the luxury of spatial resolution, stellar coronae always appear as point sources. The classical method to address the question of stellar coronal structures are eclipse studies in suitably chosen systems where one tries to constrain the emitting plasma volume from the observed light curve. Starting with the eclipse studies of the eclipsing RS CVn system AR LAC (Walter, Gibson and Basri 1983), quite a number of such systems have been observed with the *EXOSAT*, ROSAT and EUVE satellites; for a review of such observations see Schmitt (1998). In most of the systems studies both components are late type stars and hence coronally active. Disentangling the light curve is a non-trivial task (cf. Schmitt 1996), and it is clear that for the purposes of eclipse mapping systems with one X-ray dark component, i. e., those containing an A-type or B-type star, are quite preferable. An extremely interesting system in this context is the nearby binary α CrB. The primary component is of spectral type A0V, the secondary component of spectral type G5V; the two stars are in an eccentric orbit (e = 0.37) of 17.36 days. The system shows photometric eclipses, with primary eclipse (i. e., G star in front of A star) being annular, and secondary eclipse (i. e., A star in front of G star) being total; further, the system is a double lined spectroscopic binary. The radii of the binary components can be determined from light curve modeling as 3.0 and 0.9 $R_\odot$ for A and G component respectively, and further, a full solution of the orbit motion (including the orbit inclination) can be obtained.

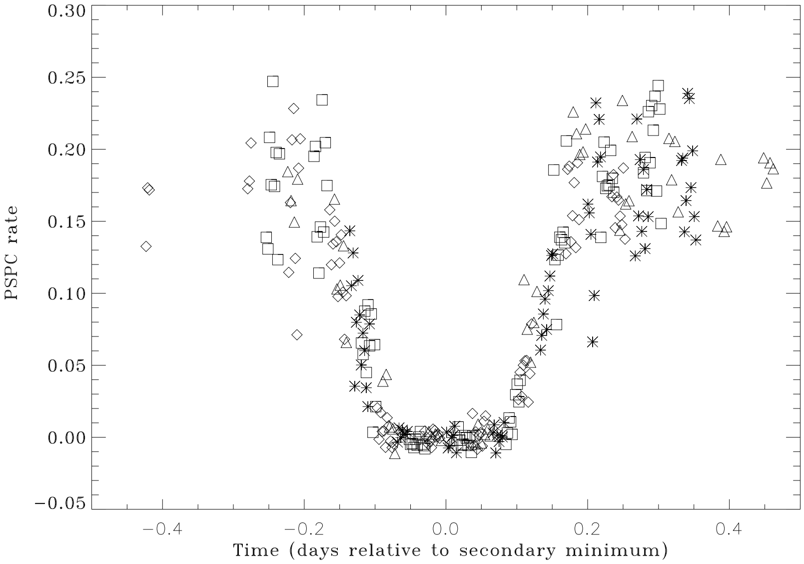

Figure 3: Overlay of all available ROSAT PSPC observations of α CrB. A total eclipse is seen in all observations and the length of totality is well defined.

α CrB is thought to be a member of the Ursa Major Stream, hence it should be relatively young ($\sim$ 400 Myrs) and the G-star should exhibit activity at the Hyades level. These expectations were confirmed by the RASS detection of α CrB. At X-ray wavelengths one expects the A-type star to be dark, hence a total X-ray eclipse should occur at the time of optical secondary minimum. PSPC observations of the optical secondary eclipse were carried out on July 12 1992, July 28–29 1993 , and Aug 15–16 1993. In Fig. 3 I show the superimposed light curves of all three observations; as is obvious from Fig. 3, total X-ray eclipses were observed in all three cases, and the total duration of the X-ray eclipse $t_{dur,X-ray} = 0.356 \pm 0.027$ days agrees very well with the total duration of the optical eclipse $t_{dur,opt} = 0.35925$ days. It therefore appears to be the case that the spatial extent of α CrB B's corona is more or less confined to its visible surface, or putting it differently, the height of the corona above the limb appears to be considerably less than a solar radius.

5 X-ray spectroscopy: Coronal densities

The spectrometers available on the EUVE satellite provided a breakthrough for stellar EUV and X-ray spectroscopy. For the first time over a broad energy band individual spectral lines (rather than complicated line complexes or pseudo-continua) could be clearly identified, detected and spectral diagnostics could be carried out without taking recourse to "global model fitting

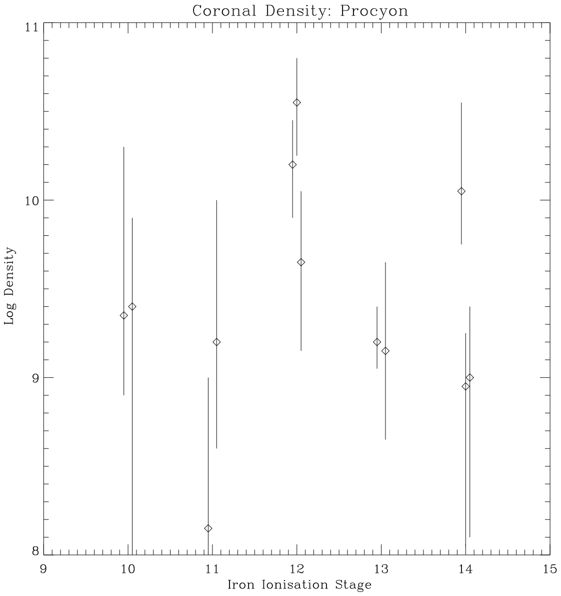

Figure 4: Coronal density vs. ionization stage of Fe derived from EUVE observations of Procyon.

procedures”. In particular it is possible to use ratios of suitable lines to derive density estimates of the emitting plasma. High quality spectra are available for the nearby low-activity cool stars Procyon and α Cen for such studies; a detailed discussion of the various density sensitive line ratios has been presented by Schmitt et al. (1996). A graphical overview of the derived densities is presented in Fig. 4, where the calculated coronal density (and error) is plotted as a function of the iron ionization stage; note that these ionization stages roughly correspond to peak formation temperatures of log T $\sim$ 6.0 for Fe X to log T $\sim$ 6.3 for Fe XIV. As can be seen from Fig. 4, most of the obtained densities are consistent within their errors with solar active region densities of 2×10^9 cm^{-3}. Obviously the errors for some of the densities are still uncomfortably large, and Schmitt et al. (1996) discuss possible explanations. The derived densities are certainly consistent with the plasma densities encountered in solar active regions, but are not consistent with densities either in solar coronal holes ($n_e \approx 10^8$ cm^{-3}) or solar flares ($n_e > 10^{10}$ cm^{-3}). Similar conclusions apply to the case of α Cen.

6 Future Prospects: Chandra and XMM-Newton

The situation is different for active stars. In active stars the whole coronal ionization balance is shifted towards higher temperatures and in fact the emission is dominated by lines of iron in ionization stages XVIII–XXIV, no or only extremely weak lines of iron in ionization stages IX–XVI are detected, which dominate the EUV spectra of the Sun, Procyon and α Cen. Therefore other lines must be used for density diagnostics. Some authors have published coronal densities in active stars. For example, Dupree *et al.* (1993) derive coronal densities between $4\ 10^{10}$–$1\ 10^{13}$ cm^{-3} using various line ratios of Fe XXI in the active RS CVn Capella. Monsignori Fossi *et al.* (1996) investigate the time-resolved EUVE SW spectrum of a flare on the dMe star AU Mic and find densities in excess of $1\ 10^{12}$ cm^{-3} using the ratio of Fe XXI $\lambda\lambda$ (142.15+142.26)/128.73. Generally, in a low density plasma the strongest line produced by Fe XXI is the 128 Å line, which is detected in virtually all active stars. In a high density plasma ($n_e > 10^{13}$ cm^{-3}), other lines of the Fe XXI ion rival or even exceed the strength of the 128 Å line, while at densities $n_e < 10^{13}$ cm^{-3} Fe XXI 128 Å dominates. Observationally, the 128 Å line always seems to be the strongest Fe XXI line, suggesting that coronal densities ought not to exceed $n_e \sim 10^{13}$ cm^{-3}, and the other Fe XXI lines are weaker and it is not always clear that they have been clearly detected. This is certainly an important area of study for *Chandra* high resolution observations.

X-ray astronomy in the first decade of the next millennium will be dominated by the large X-ray observatories, NASA's Advanced X-ray Astronomy Facility now called Chandra and ESA's X-ray multiple mirror mission XMM, now called XMM-Newton, both of which were successfully launched in 1999. Both missions will significantly exceed previously flown experiments both in terms of collecting area and spectral resolution. For example, the reflection grating on XMM (RGS) will provide good spectral resolution ($\approx 1-2$ eV) with an collecting area of ~ 200 cm^2, i. e., the collecting area of the ROSAT PSPC! To further put things in perspective, the typical collecting area of EUVE is $\sim$ 1 cm^2! The largest spectral resolution will be obtained with the Low Energy Transmission Grating (LETG) on board AXAF, which will achieve a spectral resolution $\lambda/\Delta\lambda \sim 2200$ at a wavelength of 170 Å. This again constitutes an order of magnitude increase compared to EUVE.

The capabilities of Chandra and XMM-Newton have been described in many papers (see, for example, Güdel and Mewe 1998), and I will therefore skip this material. To summarize their potential in one sentence: For the first non-solar X-ray astronomers will be able to do an honest job in spectroscopy.

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