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Stellar Coronae: The First 25 Years

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Abstract.

"We are going to have to learn from the Sun"
—*A. Fabian, referring to heating mechanisms for accretion disk coronae, COSPAR, Warsaw, 2000.*

Hot X-ray emitting coronae were detected on stars other than the Sun about twenty five years ago. This review describes some of the observational advances that have improved our knowledge of stellar coronae, with an emphasis toward understanding the more active stars.

It was a quarter of a century ago that reports appeared in the literature of the first significant detections of X-rays emitted by the coronae of a stars other than the Sun. The first was the pseudo-serendipitous detection of the Capella system during pointing calibration of a rocket flight carrying a proportional counter experiment for observing Puppis A and the Perseus cluster on 5 April 1974 (Catura et al. 1975[1]). Very shortly afterward, X-rays were detected during planned observations made by the joint Dutch-US Astronomische Nederlandse Satelliet (ANS) of the flare stars UV Ceti and YZ CMi, and of Capella (Heise et al. 1975; Mewe et al. 1975). Capella turned out to be the brightest corona in the X-ray sky after the Sun when not outshone by comparatively rare large flares on other bright candidates.

This very brief review touches on some results of "X-ray" observations of stars in the intervening 25 years that I see as important steps in reaching our current level of understanding, albeit still rather primitive, of the nature of stellar coronae. I use the quotes here because much progress has also been made based on extreme ultraviolet (EUV) observations ($\sim 100 - 900$ Å) taken with the Extreme Ultraviolet Explorer (EUVE)[2]: distinction between science based on arbitrary wavelength regimes such as "X-ray" or "EUV" is a bit silly in this context—it is the energy of the phenomenon being observed that is the distinguishing characteristic of the science. It is sometimes not realised that hot plasmas (eg several 10^6-10^7 K) emit prominent lines in the 100 Å regime from the same Fe XVIII-XXIV ions that can dominate spectra in the ~ 10 Å regime (the former being transitions of the type $\Delta n = 0$ and the latter $\Delta n > 0$).

[1]The PI, Dick Catura, said they chose Capella only for is proximity to the Perseus cluster

[2]EUVE ceased operations at 00:00 GMT January 31 2001 and was placed in safe-hold; it will probably re-enter the atmosphere in 2002-2003.

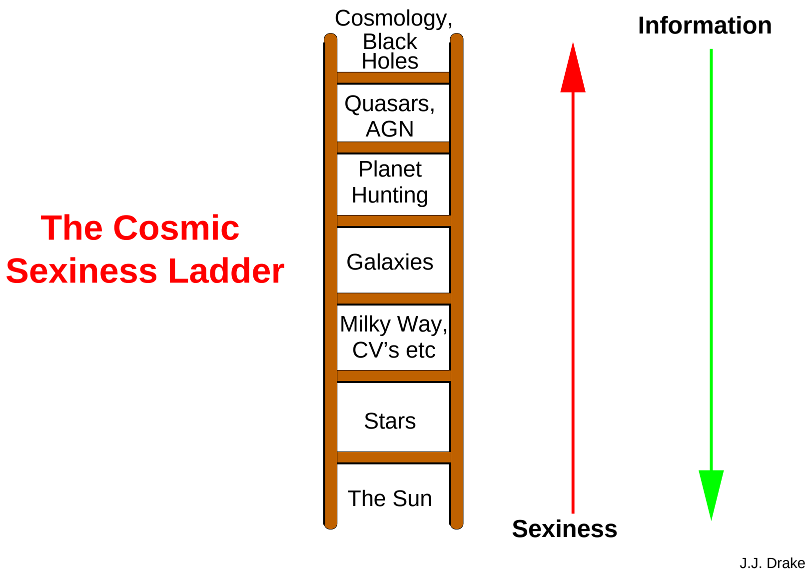

Figure 1. Model of the relative visceral appeal of the different fields of astrophysics. As pointed out by Ehud Behar, atomic physics lies slightly below solar physics. Next down would, I think, be the weather.

A review on stellar coronae in Palermo is a daunting task, faced with the prestigious group of scientists built up here by Vaiana, who could, if anyone can, be called the father of stellar coronae for his drive of the subject and role in the development of instrumentation. I use the speaking time and page limit as an excuse. Notable omissions from this paper are the copious X-ray emitting pre-main sequence stars, and the "normal" (ie non-interacting) giants. Micela (this volume) offers an excellent review of studies of open clusters. I try to aim at building an understanding of the stars most commonly observed in X-ray surveys—stars with significantly higher X-ray luminosities than the Sun. I apologise in advance for omission of many important references—a good fraction of the 12 page limit could easily be taken up by the reference list alone, in addition to silly figures.

1. "The widespread astrophysical practice of declaring the nature of unresolved celestial objects is more entertainment than science" —*Eugene Parker (1996)*

I have outlined the main ingredients that go into a solar-like corona, together with the energy loss terms that tend to dissipate it, in Figure 2. The ingredients are: an input plasma source, that we know can be compositionally fractionated relative to the underlying photosphere (§5); magnetic fields of sufficient strength to confine the plasma; and heating mechanisms. I have intentionally divided it this way because without any one of these ingredients there is no corona. Energy loss terms are kinetic energy, in a wind or in flows back to the photosphere; thermal conduction back toward the photosphere; and radiation. In the solar case, we can, through the right observations, obtain some information on all these loss terms. More obviously, through direct EUV and X-ray imaging, using eg *Yohkoh*, SoHO and TRACE, we can actually see the gist of what is going on. In the stellar case, we have no immediate hope of imaging coronae (however, see §8). Very little is currently know about stellar winds in "coronal" stars and mass loss rates generally remain unknown (see §7). Looking at the other loss terms, radiative loss is proportional to the square of the plasma density (though one has to know the chemical composition—see §5), which can be determined from observation. In order to ascertain conductive losses, one must really have some idea of the morphology of the emitting plasma, which we can only guess at. The only practical approach involves making strong assumptions, such that any radiative losses one could observe in the UV from cooler plasma (10^4-10^5 K) arise from conductive heating by hotter coronal plasma, and then modelling the system. An example of this type of modelling can be found in Griffiths (1999). Conductive losses will dominate over radiative losses for temperatures above a few million K, unless the plasma density is quite high—10^{12} cm^{-3} or more—when radiation dominates.

The job of the observer, then, is to attempt to fathom the physics of all the different processes based only on observations of the radiative losses. Contemplating this, Parker's (1996) outlook tends to appear less skeptical.

2. "Stars along the entire main sequence, of all luminosity classes, pre-main sequence stars as well as very evolved stars, have been detected" —*Vaiana et al. (1981)*

A skeletal historical summary of some of the major advances in coronal physics from a stellar perspective is listed in Table 1. The greatest single observational advance prior to the first detections of stellar coronae in 1974-75 was arguably from the *Skylab* mission, whose battery of UV-X-ray telescopes monitored the Sun over the nine month period of the mission and revealed in great detail the magnetic loop structure of the solar corona (see, eg, Golub & Pasachoff 1997).

On the stellar front, it was really the *Einstein* observatory that produced the single largest breakthrough (see, eg, Sciortino 1993 for an insightful summary of the *Einstein* era). The stellar survey of Vaiana et al. (1981) revealed 143 sources and showed that X-ray emission occurred over nearly the entire main-sequence (some detections of spectral types late B and early A were likely due to UV leaks), and in giant stars earlier than mid-K. The observed luminosities covered a range of 2-3 orders of magnitude for each spectral type, a result that had profound consequences for coronal heating theories. The prevailing view up to the mid-late 1970's was that coronae were heated by acoustic waves generated by the convection zone, a scenario which places the Sun near the most X-ray luminous of late-type stars. The observations instead showed the Sun to be comparatively faint in X-rays, and, in the words of Vaiana in 1979[3], "both the levels of X-ray emission and the general behaviour of the median luminosities disagree with theoretical predictions". The *Einstein* results were a remarkable

[3]Reported by Giacconi 1993

Table 1. Milestones in the Study of Stellar Coronae

1940	Coronal lines identified	Temperatures of ∼million K diagnosed from forbidden Fe lines
1949	Rocket Flight	First solar X-rays detected
1960	Rocket Flight	Pinhole camera produces first X-ray image of solar corona
1965	Rocket Flights	First images of solar coronal structure with grazing incidence optics
1973	Skylab	High resolution EUV/X-ray images of coronal structure
1974-5	Rocket Flight/ ANS	First detection of X-rays from Stellar Coronae (Capella) followed by UV Ceti and YZ CMi
1978	EINSTEIN	Discovery of hot X-ray emitting coronae on a wide range of stars; link with rotation rate and magnetic dynamo
1983	EXOSAT	Dispersed soft X-ray spectra (precursor to *Chandra* LETG); Detailed light curves
1990	ROSAT	First sensitive all-sky survey; confirmation of ubiquity of hot coronae on main-sequence stars F-M,giants
1992	EUVE	First "high" resolution ($\lambda/\Delta\lambda \sim 200$) stellar coronal spectra: temperature structure; plasma density; abundances
1993,6	ASCA, SAX	Extensive board-band low resolution observations
1999	Chandra, XMM	First sensitive high resolution ($\lambda/\Delta\lambda \sim 1000$) soft X-ray spectra: first detailed X-ray plasma diagnostics

demonstration of the power of sacrificing the spatial resolution and detail afforded by studies of the Sun for the chance to observe stars with a wide range of fundamental parameters. One further discovery was that stellar X-ray luminosities were highly correlated with rotation velocity (Walter & Bowyer 1981; Pallavicini et al. 1981), as had been found for chromospheric activity indicators in the 1960's. Combined with evidence from solar observations that acoustic waves did not propagate up through the transition region, the *Einstein* results were a significant factor in making the paradigm shift from acoustically heated coronae to coronae heated magnetically as a result of dynamo action excited by stellar rotation. An exception to this was the case of the O-B stars, whose X-ray emission is thought most likely to result from shock-excited radiatively driven winds, although a more solar-like coronal component is not yet ruled out (see, eg, Kahn et al. 2001; Waldron & Cassinelli 2001).

One further important discovery from the *Einstein* survey was that spectral hardness increased with X-ray luminosity, indicating that the more active stars have hotter coronae (Schmitt et al. 1990).

Following a decade after the *Einstein* survey, the more sensitive and extensive ROSAT mission was to confirm in great detail that all late-type dwarfs (F-M) and giants down to mid-K are X-ray sources and have hot coronae (Schmitt

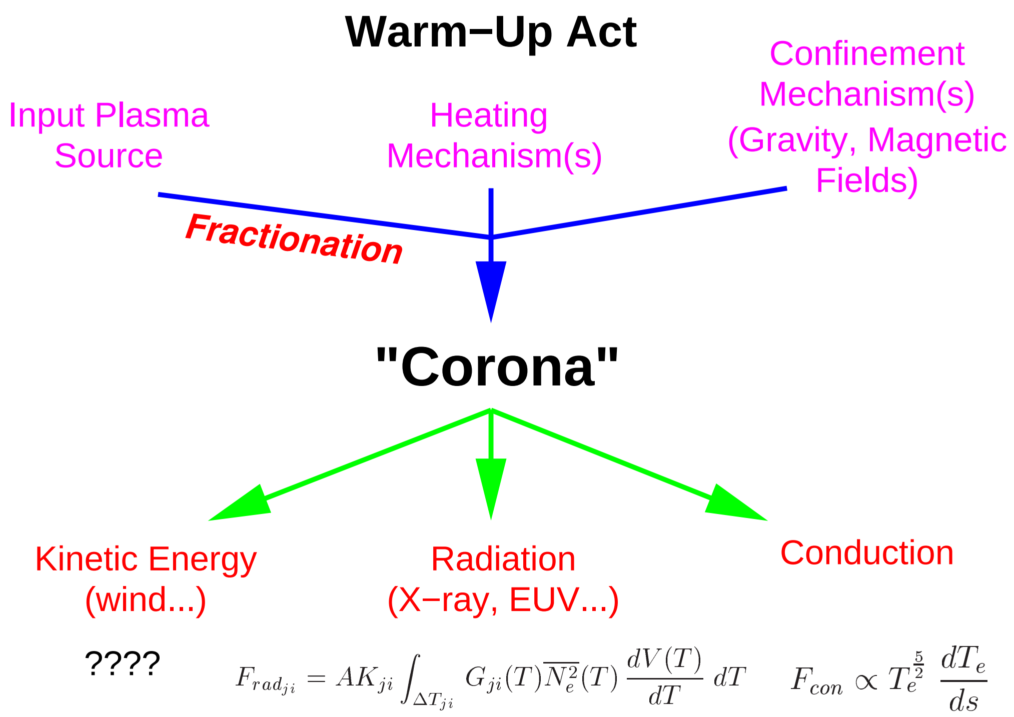

Figure 2. Illustration of the ingredients required to make a solar-like corona and the energy loss terms that tend to dissipate it.

1997). Observations of larger numbers of field stars and open clusters (see also Micela, this volume) enabled a more detailed examination of the connection between coronal activity and dynamos. A natural "dynamo number" that drops out of mean field dynamo theory is the ratio of rotation period to convective turnover time, P_r/τ_c (also referred to as the Rossby number). It was found that when chromospheric activity indicators where compared to this Rossby number the correlation became much tighter than for the rotation period alone (Noyes et al. 1984). This same tight correlation is also manifest in the X-ray regime, as is nicely illustrated in the relation between the ratio of X-ray to bolometric luminosity L_X/L_{bol} (a measure of the efficiency of turning the available energy into coronal losses) and P_r/τ_c for open clusters and field stars shown in Pattern & Simon (1996). Looking back at Figure 2 to what I have termed the three essential coronal ingredients of an input plasma source, magnetic confinement, and heating, to me it is remarkable that we can describe with reasonable success the level of coronal activity over a wide range of spectral types using only the two parameters rotation period and convective turn over time. I will return briefly to this in section §6.

The sensitive ROSAT survey enabled significant volume-limited studies of stellar X-ray emission. From Schmitt's (1997) study of F-K dwarfs, I note two results in particular: (i) the minimum surface X-ray flux level found is similar to that of solar coronal holes, indicating that this non-zero flux represents a basal activity minimum; (ii) the maximum surface flux found exceeds the surface flux level in solar active regions. This latter result was not really new in that, eg, Vaiana & Rosner (1978) had already pointed out that the Sun completely covered with active regions would have an X-ray luminosity of $\sim 2 \times 10^{29}$ erg s^{-1}—two or so orders of magnitude lower than the very brightest stellar coronae. How, then, are the very active stars explained?

3. "If George Field with a snap of his theoretical fingers can extend the range of EUV observations by 1,000 times, who knows what may be possible in real life?" —*S. Bowyer*

The Extreme Ultraviolet Explorer (EUVE) enabled for the first time "high" resolution spectroscopy ($\lambda/\Delta\lambda \sim 200$) of stellar coronae and the application of spectroscopic plasma diagnostics that hitherto had only been feasible for the Sun. The EUVE spectrometers covered the wavelength range 70-750 Å, within which spectral lines from ions formed at temperatures ranging from a few 10^5 K to 2 10^7 K can be found. EUVE opened up the determination of plasma temperature, density and element abundances; at a similar time in the early 1990's the low resolution CCD pulse height spectra of ASCA enabled some temperature discrimination beyond that of ROSAT, and also promised access to element abundances (see §5). A summary of EUV stellar physics can be found in Bowyer, Drake & Vennes (2000), and Drake (1996).

To my mind, the most important contribution of EUVE was in diagnosing plasma densities. Through the equation for radiative loss from a single spectral line (Figure 2), it can be seen that the emitted line flux (and continua) for a plasma of given composition is essentially proportional to the emitting volume and the square of the density; for a given flux, the plasma density then defines the emitting volume. Observations of density-sensitive lines of Fe IX-XIV in stars with activity levels similar to the Sun (based on L_X and rotation rate) such as the α Cen AB system (unresolved at EUVE resolution) and Procyon (F5IV), yielded values of $N_e \sim 10^9$-10^{10} cm^{-3} (eg review by Laming 1998). Coupled with the emission measures as a function of temperature, derived using Fe lines from ions formed at a range of different temperatures, which appeared similar to typical solar coronal emission measure distributions ($EM \propto T^{3/2}$ with a peak EM at $T \sim 2\,10^6$ K), to first order it was clear that these coronae were likely quite similar to the solar corona.

In contrast, in order to explain coronae 100 times brighter than a Sun covered in active regions, either the plasma density must be higher, or the corona much more extended and voluminous—both notable departures from solar coronal structure. Eclipsing systems offer potentially valuable information on whether active stellar coronae are extended or compact, as Walter et al. (1983) exploited in carefully-timed observations of the RS CVn-type binary AR Lac at primary and secondary eclipse. Eclipses were seen, indicating compact coronae, but with a hint that extended components might be present. However, eclipses tended to evade some later observations of both AR Lac and TY Pyx by EXOSAT (eg Pallavicini 1993), whose high orbit enabled long periods of continuous viewing. Bolstered by additional evidence from radio observations that the radio-emitting (gyro-synchrotron) regions of these coronae appeared to be several stellar radii in size, some concluded that the X-ray (thermal) coronae must be very large. There is no solid basis for the connection, since the electron population responsible for the radio emission is completely different to that which excites the line and continuum emission and they need not be cospatial. It appears (to me) that the EXOSAT observations must have been somewhat of an unlikely fluke—eclipses have been seen in just about all eclipsing systems observed since (eg Schmitt 1998), indicating that these very active coronae must in fact be quite compact (see also Favata, this volume, for recent developments). One also has to remember that these systems can be quite variable on timescales similar to the durations of eclipses, and eclipse signatures can get wiped out.

Also fashionable (and still today) were suggestions that the emission originated from the region between the two stars of an active binary, where magnetic fields might interact. Recent *Chandra* HETG observations of the RS CVn-type binary V711 Tau (K1IV+G5V) have sufficient resolving power (~ 1000) to see the orbitally-induced Doppler shift that locates the majority of the emission on K1 subgiant, and not in between the two stars (Ayres et al. 2001).

Just how compact the active coronae are could in principle be ascertained from EUVE density determinations. Initial estimates using lines of Fe XXI and Fe XXII formed at 10^7 K or so yielded $N_e \sim 10^{12}$-10^{13} cm^{-3} for active systems such as V711 Tau, AU Mic, σ Gem and Capella (eg review by Drake 1996). Such high densities imply tiny surface filling factors of 1-10 % and scale heights based on simple plasma loop models of only 100-10,000 km. At cooler temperatures, Fe XII-XIV lines indicated densities of 10^{10} cm^{-3}, again similar to solar active regions. These results suggested that the 10^7 K plasma is structured quite differently to the 10^6 K material. However, one problem with the EUVE analyses is that, at the resolution of the EUVE spectrometers, the Fe XXI and Fe XXII diagnostics are blended. The often used Fe XXI 102.35 Å, for example, is blended with lines of O VIII and when compared with Fe XXI 128.73 Å can yield a spuriously high density. While the densities are likely still "high" (10^{11} or higher), good quality *Chandra* spectra are still needed for confirming these density estimates for the hot plasma. Densities of 10^{10} cm^{-3} have very recently been confirmed for the cooler 10^6 K plasma in the Capella coronae based the He-like ions of O (see, eg, the contributions of Brinkman and Canizares, this volume), and for V711 Tau (Drake, as yet unpublished).

4. "We envision a model wherein continual flaring associated with the complex of star spots provides sufficient energy injection to power a 10^7 K corona" —*Walter et al. (1978)*

While the 10^6 K plasma on the active stars appears similar to solar active regions, and the hot plasma appears to be of higher density and relatively compact, the nature of the hotter plasma remains a puzzle. I think part of the answer can be gleaned from looking at the "intermediate activity" stars—stars with L_X 10 or 100 times that of the active Sun. Plasma densities based on EUVE observations of Fe XIII and Fe XIV lines in ϵ Eri (K2V) and ξ Boo A are $N_e \sim 10^9$-10^{10} cm^{-3}—similar again to solar active regions. Drake et al. (2001) have recently shown that, in addition to plasma densities, the coronal temperature structures of ξ Boo A and ϵ Eri are also very similar to that of the brightest solar active regions. Moreover, the X-ray luminosities of these stars can be understood if the stars are entirely covered in these active regions. However, the more active of the two, ξ Boo A, shows a "hot extension" to its EM distribution, up to 10^7 K—a hint of the hot plasma that dominates the very active stars. This ties in with some important earlier work of Güdel and co-workers based on rough EM distributions derived from ASCA and ROSAT observations of solar analogues of different ages ("The Sun in Time"). Güdel et al. (1997) found in the young and more rapid rotators a considerable portion of the EM residing at temperatures of $\sim 10^7$ K, but with a significant EM at solar active region temperatures of a few 10^6 K, and that the hot component gradually disappeared toward older, more slowly rotating stars. This hot component is the same plasma Drake et al. (2001) see in ξ Boo A. Güdel (1997) succeeded in mimicing these EM distributions with a distribution of hydrodynamic flare events, suggesting that flare heating plays a dominant role in these stars.

EUVE Deep Survey (DS) observations are very useful for investigating time-variability of coronal emission because of the long (days-weeks) observing times spent on some stellar targets. Audard et al. (2000 in references therein) and Kashyap et al. (in preparation) have investigated the frequency distributions of flare energies in different stars using long EUVE DS observations. Using both flare detection techniques and monte carlo simulations of flare distributions theese authors conclude that the variability observed in EUV fluxes of active stellar coronae is largely consistent with this emission being due primarily to a superposition of flare events. If correct, the conclusion is that the hot plasma on active stars is flaring plasma, with a similar plasma density to that found in solar flares ($\sim 10^{11} - 10^{12}$ cm^{-3}). As Walter et al. (1978) discussed, this is not a new suggestion, though the grounds for the conclusion are now somewhat more substantial.

5. "One may then ask whether the chemical composition of the low corona actually differs from that of the photosphere" —*Pottasch (1963)*

The insight of Pottasch (1963) was aided by some oscillator strengths of the day for neutral Fe lines being too high by about an order of magnitude, leading to underestimates of the photospheric abundances compared to Pottasch's coronal values. Nevertheless, two or so decades later the review of Meyer (1985) summarised a growing body of evidence confirming that Pottasch's suspicions were correct. In the solar corona, the compositional differences appear to be related primarily to the element first ionization potentials (FIPs) in that the abundances of elements with FIP$\lesssim 10$ eV (e.g. Mg, Si, Fe) are enhanced compared to abundances of high FIP ($\gtrsim 10$ eV; e.g. O, Ne, Ar) elements by an as yet unidentified mechanism that preferentially feeds the corona with ions from material at chromospheric temperatures. In other stars, examples of this "FIP effect" have been found in stellar coronae with solar-like and intermediate activity levels, based on analyses of EUVE spectra. In contrast, analyses of EUVE, ASCA and BeppoSAX spectra of more active stars have shown their coronae to be metal poor, though in some cases it is possible that the metal paucity is also shared by the parent photospheres. These results are reviewed and discussed by, e.g., Feldman & Laming (2000), S.A. Drake (1996) and references therein.

Starting with *Ginga* observations of the RS CVn-like binary UX Ari (Stern et al. 1992), apparent *increases* in coronal abundances during large flare events have been reported for some active stars, based mostly on analyses of low resolution X-ray spectra but also including joint EUVE and ASCA observations (eg Mewe et al. 1997; Güdel et al. 1999). While I caution that apparent abundance changes accompanying changes in plasma temperature, as occurs in the flare observations, could be the result of errors in adopted ion populations, it is tempting to invoke chromospheric evaporation of compositionally unadulterated plasma into the metal-depleted corona to explain these results, as various authors have done.

Adding further confusion to the gamut of coronal abundance anomalies is the recent observation of large Ne abundances in the *XMM-Newton* and *Chandra* spectra of V711 Tau (Brinkman et al., 2001; Drake et al. 2001). The former also claim a linear relation between logarithmic abundance and element FIP, though the latter did not find convincing evidence for this. Based on a literature survey of published ASCA analyses, Drake (2001) pointed out that enhanced Ne abundances appear to be a common feature of all active stars. The reasons for the Ne enhancements are not yet clear, though Brinkman et al. (2001) and Drake et al. (2001) both point out that some solar flare events have been observed to be Ne rich.

While difficult to understand at present, I remain convinced that coronal abundance anomalies will yield valuable insights into the physical processes that sustain stellar coronae.

6. "Why are there no order-of-magnitude X-ray activity cycles in these active stars?" —*Stern (1999)*

Stern (1999; see also Kashyap & Drake 1999, Drake et al. 1996) reviewed evidence that long-term soft X-ray variability in active stars as judged by different observations made by X-ray instruments such as the ROSAT and *Einstein* proportional counters over periods of a decade or more, amounts typically to only a factor of two or so—much less than the order of magnitude or more that the solar corona shows from solar minimum to maximum. These authors suggested that a turbulent dynamo instead of a large scale field $\alpha - \omega$ dynamo might dominate the activity of these stars.

Related to this I think is the observation that there appears to be no change in L_X/L_{bol} in the late main sequence, going from stars that have radiative cores to stars that are supposedly fully convective (Fleming et al. 1995; though this is still not entirely without controversy). This is important because standard mean field α-ω dynamo theory relies on a differential rotation located at the boundary between the radiative core and convective envelope to generate the seed toroidal field which is amplified and transformed into a poloidal field (and vice-versa) by the helicity in convective motions (the α-effect).

It appears to me most likely that if the coronal X-ray loss efficiency is unaffected by lack of a radiative core in relatively active and fully convective stars, then the convective core is irrelevant in higher mass stars where it is present—at least in late K and early M dwarfs. We are left then with a turbulent (α^2) dynamo in active stars, such as that discussed by Durney, De Young & Roxburgh

(1993). Such a dynamo would not be prone to the periodic field reversal as happens with the large scale solar field, and, provided stellar rotation is sufficiently rapid to influence convection and give it a definite handedness, large scale fields could result from turbulence-driven dynamo processes (D. Hughes, private communication). I suggest that the turbulent dynamo also underscores the tightness of the L_X/L_{bol} vs Rossby number correlation: the only relevant parameters for the underlying dynamo are then the rotation velocity to drive the convective helicity through the Coriolis force, and the convection zone depth.

7. "Using physical parameters which are reliably determined from X-ray data, we show that thermal winds from cool dwarfs cause $\dot{M}$ to exceed the solar value by factors of 10^3 or more" —*Mullan (1996)*

While the Sun provides us with a nearby example of a late-type main sequence mass-losing star, its mass loss rate as measured *in situ* by different spacecraft amounts to only about $\sim 2\times 10^{-14} M_\odot$/yr—orders of magnitude lower than any direct non-solar measurements or upper limits for mass loss rates. Some theoretical estimates of mass loss rates for active stars (eg Mullan 1996) are as high as a few $10^{-11} M_\odot$ yr^{-1}. Such mass loss rates would be a significant source of ISM enrichment, and would have important effects on the coronal energy balance (Figure 2). Very recent indirect estimates of mass loss rates for α Cen and Proxima by Wood et al. (2001) based on observations of the Ly-α absorption from heliospheric H I heated by the stellar wind-ISM interaction have yielded rates of $\sim 2\dot{M}_\odot$ and $\sim 0.2\dot{M}_\odot$, respectively.

Wargelin & Drake (2001) have shown that X-ray emission due to charge exchange interactions of the ionized wind with the neutral ISM should be detectable for nearby late-type dwarfs, and for more distant stars if the mass loss rates are indeed substantially higher than the solar value. The signature would be diffuse X-ray emission surrounding the star on spatial scales of up to a few arcsec and should be detectable in *Chandra* ACIS-S images with exposures of a few tens of ks. If observed, such emission could provide hitherto unobtainable information on wind geometry, ion composition, mass-loss rates, and the distribution of neutral gas in the ISM.

8. "A perfect 10 on the Drake scale of sexiness" —*W. Cash*

Webster Cash's remark and kind indulgence was aimed at the proposed future micro-arcsecond X-ray Imaging Mission (MAXIM; see Cash's contribution to this volume) view of matter around the supposed black hole in the core of M87. However, at a level of about 8 on the same scale would surely be the resolved disk of an active star. It hardly need be said that such images would enable substantial advances in the field of stellar coronae.

Nearer home, one important step is higher spectral resolution to better understand the dynamics of hot plasma (again, Figure 2). While we relish for some fleeting moments the resolving powers of *Chandra* and *XMM-Newton*, it should not go unnoticed that these instruments are really only of "moderate" resolution because the intrinsic spectral line profiles are not resolved. To resolve fully the Doppler widths of spectral lines at temperatures of 10^6-10^7 K requires a resolving power not much short of about 10,000—a figure not even approached by any slated future missions. As the *Chandra* and *XMM-Newton* missions demonstrate, it is very difficult to reach resolving powers of more than 1000 with a reasonable effective area in the soft X-ray range where most the line diagnostics are (5-25 Å) at a reasonable cost. However, to do so in the EUV near 100 Å where similar plasma diagnostics can be found is relatively easy and cheap using multi-layer, normal incidence optics. Such missions have been proposed but not yet accepted. The downside to this wavelength regime is that the number of accessible extragalactic objects higher on the *Cosmic Sexiness Ladder* than things like stellar coronae is small. Unfortunately, the scientific gain in this remaining unexplored window of true high resolution high energy spectroscopy tends to have less influence on mission development than position on the ladder. I don't think Parker would disagree with that.

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