Conference Summary

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**Abstract.** About fifty papers were presented during the conference. In this Summary I select some results which appear to me to be particularly interesting and important. I include my own remarks on some issues that were discussed.

1. Introduction

This has been a well organized, stimulating, and enjoyable meeting. We have seen examples of the beautiful spectra and high resolution images that have been obtained so far with *Chandra* and *XMM-Newton*. We have also heard about further analyses of data from previous X-ray satellites, and it has been good to see the new results presented in the context of what was learned from these earlier missions. The Sun shows us what may be occurring on at least other main-sequence stars. Previous studies of its X-ray spectrum, at times of low activity and during flares, are of great benefit in understanding the spectra of other sources. We were reminded that observations of solar and stellar radio emission are also important, providing information on the population of high energy electrons. Nor must we forget that chromospheric and transition region emission also indicate stellar activity. We need to understand the whole atmosphere of a star and X-ray astronomers should be aware of the equally impressive spectra being obtained with the Space Telescope Imaging Spectrometer (STIS) on the Hubble Space Telescope (HST).

Following Jeff Linsky’s perceptive historical introduction, taking us through the five ages of X-ray astronomy, about fifty papers were delivered in the five days of the Conference. My choice of points to highlight here therefore has to be a personal one; a task made harder by the high quality of the talks and material presented. I have arranged my summary under six headings; atomic data and spectral analysis issues; plasma diagnostic techniques; element abundances; active regions, flares and high energy phenomena; heating processes, the solar wind and dynamos (somewhat disparate, but covering areas where we can learn from the Sun); and young stars, low-mass stars and brown dwarfs. There is, of course, considerable overlap between these topics.

2. Atomic data and spectral analysis issues

The high spectral resolution of the new X-ray observations with *Chandra* and *XMM-Newton* is placing new demands on those providing atomic data. The
stronger lines observed have been previously identified from solar spectra, but as stressed by Doschek, these spectra did not provide a comprehensive wavelength coverage for individual flares. The early line lists did not include many of the transitions which can lead to numerous weak lines. These can contribute to the apparent continuum and can be blended with lines which are important for plasma diagnostics. It is also important to establish where there are regions free of line emission, so that by matching these, the continuum can be calculated at other wavelengths, and because line-to-continuum ratios provide a means of determining element abundances. Now that lines can be resolved it is important to use all the information in the spectra, e.g. to find emission measure loci from individual lines, and hence derive the emission measure distribution (EMD).

Brickhouse described how the Astrophysical Plasma Emission Code (APEC) (Smith et al. 2001) is being used to test these issues. This code includes many more transitions than did the earlier ones in common use for analyzing spectra from the Einstein Observatory, ROSAT and Ginga. She stressed the need for an iterative approach in analysing the new higher resolution line spectra. Stronger lines which are not unduly sensitive to the electron density \( N_e \) can be used to find the EMD; this can be used to compute the total spectrum, including the weak lines and the free-free continuum (for hot sources). Potential blends can be identified and line-free regions found. The diagnostic line ratios can then be extracted and \( N_e \) determined. The whole process can then be repeated in an iterative manner taking into account the dependence on \( N_e \) for all lines. A similar type of procedure is currently used in analysing UV stellar spectra, although the chromospheric continuum (free-bound in origin) is not always computed. She addressed the important issue of continuum subtraction in the region around the O\( \text{VII} \) (helium-like) lines, which may account for the different line ratios being measured by different groups and illustrated the effects of weak blends that occur in the region around the Mg\( \text{XI} \) lines.

Line emissivity codes now contain more transitions and improved excitation rates. However, further work on lines resulting from the excitation of levels with moderately high quantum numbers \((n, l)\) is still required. This is a reflection of the complexity of the spectra and not a criticism of those who are working hard to provide the community with the best possible codes. The CHIANTI code (v.3, Dere et al. 2001) (see contributions by Mason & Del Zanna and Del Zanna & Mason) which is being used in several packages, has now been extended to include the lines of the helium-like ions.

Laming reassured us that the accuracy of modern collisional excitation rates should be acceptable, provided the calculations include the important effects of resonances. Nevertheless, there are some specific problems. He pointed out that in solar flare spectra, but not all laboratory spectra, there are still problems in understanding the intensity ratios of lines of Fe\( \text{XVII} \) from transitions between the \( 2p^53s \), \( 2p^53d \) and \( 2p^6 \) configurations around 17 Å and 15 Å, respectively. He stressed that excitation to quite high \( n \) states, and their decays through the above excited levels, can be important. He pointed out that the discrepancies in the solar spectra might be resolved if the electron temperature (\( T_e \)) where the lines are predominantly formed were lower than that usually used, thus increasing the effect of resonances.
The situation regarding the relative ion populations is less satisfactory. There are significant differences between different sets of calculations in the peak ion populations and the temperatures at which they occur, in particular for important ions such as Fe XV and Fe XVI (see also Sim & Jordan). However, the calculations by Mazzotta et al. (1998) use recent rates for di-electronic recombination, and should give improved ion populations in the low-density limit. Although the reductions in the di-electronic recombination rates in the presence of a finite density are small in the solar corona (but are significant in the mid-transition region and below), reduced rates may be required in high density sources such as the RS CVn binary stars and stellar flares.

3. Plasma diagnostic techniques

As we all know, it is essential to measure $N_e$ in order to find the volume (or thickness) of the emitting region from the emission measure. It is also important to measure the variation of the electron pressure ($P_e$) with $T_e$. If hydrostatic equilibrium is appropriate, then in main-sequence stars, where turbulent velocities are relatively small, $P_e$ is expected to be approximately constant over the transition region and inner corona. This can be shown by expressing the variation in $P_e^2$ in terms of the integral of the EMD (see Jordan et al. 1987). Given sufficiently accurate line ratios and atomic data, departures from hydrostatic equilibrium might be found, which could indicate that emission is arising from physically unconnected regions. In lower gravity stars, where the turbulent pressure exceeds $P_e$, in hydrostatic equilibrium the values of $P_e$ can increase with $T_e$ (see Griffiths & Jordan 1998). Brickhouse and Dupree presented evidence that $P_e$ is not constant in Capella; the values in the lower transition region and at $T_e \simeq 10^8$ K are both smaller than that at $\simeq 10^7$ K.

Judge reminded us that we are always measuring a mean value of $N_e$, and that because of the nature of the inversion problem, the solutions are non-unique. Also, the solar and stellar plasma is composed of unresolved structures. Judge prefers a 'forward' approach, in which one starts with assumed physics, then calculates the expected spectrum, for comparison with the observations. I prefer to use the observations to find out as much as possible about the likely physical processes, before undertaking theoretical modelling. While we cannot find $N_e$ in unresolved plasma elements, the effect of a range of values on the physical processes can be considered. We have to make the best of a bad job, but this can be done in an intelligent manner. Eventually, both approaches should lead to the same conclusions.

There are several sets of line intensity ratios which are being used to measure $N_e$. With the improved spectral resolution and sensitivity of the new X-ray spectra, line ratios in FeXIX and FeXXI can be used with more confidence. Dupree discussed some examples (Capella and RS CVn binaries) where very high densities ($\simeq 10^{12} - 10^{13}$ cm$^{-3}$) were being found. Similar results were mentioned by several speakers.

The lines of the helium-like ions are being widely used to measure $N_e$ through the ratio of the intensity of the intersystem plus magnetic quadrupole lines ($1s2p \, ^3P_{1,2} - 1s^2 \, ^1S_0$) to that of the forbidden (magnetic dipole) line ($1s2s \, ^3S_1 - 1s^2 \, ^1S_0$) (see e.g. papers by Maggio et al., Miller and Ness et al.). It is
over thirty years since this technique was developed in the solar context (Gabriel & Jordan 1969); at that time the possibility of applications to stellar spectra seemed very remote and it is very satisfying to see these now being made. As discussed in Section 2, when analysing these line intensities, care must be taken over the choice of continuum and the influence of blends.

Doschek reminded us that the He I- and H I-like ions can exist over a wide range of $T_e$, so, unlike the situation for lower ions, it cannot be assumed that the lines are formed near the peak in the relative ion abundance. This property may underly the results presented by Ness et al., in which they show that the ratio of the intensities of the H I-like and He I-line ions of nitrogen and oxygen (a proxy for $T_e$) increases with the stellar X-ray flux. In solar flares, the lines of Ca XIX and Fe XXV are formed at temperatures well below those of maximum ion abundance. The Li I-like satellite lines only become strong in the high-Z elements, but some information on $T_e$ may be obtainable using the type of spectral line fitting used in the analysis of solar flare spectra. The ratio of the intensity of the He I-like ion resonance line to that of the total intensity of the triplet lines is also potentially useful in checking $T_e$, although high line opacities will selectively affect the resonance line.

We were shown some beautiful spectra of O/B stars, in which the appearance of the He I-like ion lines is quite different from that in the Sun and other cool stars (see papers by Miller and Schultz et al.). This is due to the importance of the UV radiation field in exciting the 1s2s $^3S - 1s2p$ $^3P$ transitions, thus mimicking very high densities. Similar, but less extreme effects are also observed in late-type stars (Ness et al.). In the Sun, only the transitions in C V are affected by the near UV photospheric/ chromospheric radiation field (Gabriel & Jordan 1969). The analysis of the O/B star spectra is leading to new information on the structure of hot star outer atmospheres and winds, and it seems that the highest ions occur very close to the stellar surface, before the regions where shocks can be formed. Cassinelli & MacGregor (2000) have suggested that magnetic fields may be generated by dynamo action at the convective core-radiative zone boundary. This is a dramatic example of how the new X-ray spectra are leading to entirely new information about emitting sources.

4. Element abundances and their variations

In analyses of early low resolution X-ray spectra, the abundances ($N_E/N_H$) were often treated as a free parameter, along with the interstellar absorption, $T_e$ and $EM(V)$. Fits in terms of multiple values of $T_e$ and $EM(V)$ further increased the number of free parameters. With the new X-ray spectra, analyses of individual lines can be made with fewer initial assumptions. Ideally, emission measure loci can be used to find the EMD for each element, and the relative abundances which give the best unique EMD can be found. In practice, it may be difficult to observe sufficient lines to give a good overlap in the range of $T_e$ for each element. However, as discussed in Section 2, if the continuum level can be established, line to continuum ratios can also yield $N_E/N_H$.

Element abundances were reviewed by Feldman (see below) and were discussed in many talks. Two basic types of abundance differences, compared with the solar photospheric values, are observed. The first is the relative overabun-
dance of elements with low first ionization potentials, the FIP effect; the second is the inverse FIP effect, sometimes called the metal abundance deficiency (MAD) syndrome. The comparative studies of RS CVn systems, Capella and main-sequence stars by Audard (discussed also by Drake) show clear differences in relative abundances. While HR 1099 and UX Ari, the most active binaries with the highest maximum temperatures, show an inverse FIP effect, this is absent in Capella. Single main-sequence stars can show a FIP effect in their upper transition region and corona, or an inverse FIP effect. Laming et al. (1996) found a roughly solar FIP effect from analyses of EUVE spectra of ε Eri (K2 V). Using new X-ray spectra an inverse FIP effect has been found in AD Leo (dM4.5e) and Gl355 (K2 Ve) (see papers by Maggio et al. and Corvino et al.). Drake and Audard reminded us that comparisons need to be made with the stellar photospheric abundances, which may be poorly known.

Observations during a stellar flare on HR 1099 (Audard et al.) show that the inverse FIP effect decreases as \( T_e \) increases. This type of evidence is convincing, although the lines of iron, silicon and oxygen used do not have an ideal overlap in temperature. Line to continuum ratios, however, do give a similar result. On the other hand, in the active main-sequence star binary \( \sigma^2 \) CrB, Osten et al. find a low iron abundance which varies little between times of quiescence and flaring. Favata reported a flare on Algol, observed with SAX, in which the iron abundance rose more rapidly than the emission measure, at the beginning of a flare, and then decreased more rapidly than either \( T_e \) or the emission measure. This is a particularly useful observation as it provides a new test of mechanisms proposed to account for abundance variations. At present the physical understanding of these effects is lagging behind the observations.

Feldman reviewed solar observations from which a FIP effect is implied. Solar observations are particularly important since they show us just where abundances variations are occurring. It appears that in coronal holes, the relative abundances are the same as those in the photosphere; this agrees with the results for the fast solar wind (discussed by Marsch) which originates in the holes. However, Feldman has found a FIP effect of a factor of up to four in the quiet Sun. This conflicts with our studies (Jordan, Macpherson, & Smith 2001) of line ratios in a coronal hole, in the quiet Sun just outside the hole, and at quiet Sun centre. We find no significant changes in the ratio of the intensities of the C II and Si III resonances lines between these regions. We would easily see systematic changes of a factor of two to four. Similarly, in studies of the lower transition regions of G/K dwarfs we have not found significant FIP effects in the Si/C line ratios. On the other hand, there do appear to be systematic and large changes in the ratios of lines of Mg VI and Ne VI in solar active regions, which depend on the B-field configuration and loop evolution (Sheeley 1995, and see also Mason & Del Zanna). Low lying, relatively high density loops have cosmic relative abundances (the neon abundance cannot be measured in the photosphere); larger, lower density loops show the FIP effect.

The abundances adopted affect the emission measures derived from line fluxes; if they are not constant, or there is not a good overlap in \( T_e \) between lines of different elements, they can affect the shape of the EMD. For given abundances, the shape of the intrinsic EMD is determined by the terms of the energy balance equation and non-constant area filling factors (see e.g. Jordan
1996). As pointed out by Sim, for a given coronal $P_e$ and $T_e$, there is a maximum value of the emission measure that can satisfy the local balance between the net thermal conduction and radiative losses. Thus the abundances can affect the area filling factor derived from this critical solution. However, the total coronal radiation losses derived are not affected, provided the same abundances are used in the radiative power-loss function adopted and in the derivation of the emission measures, and because the radiative losses are a directly observable quantity.

Finally, as discussed by Micela, the stellar metallicity is important in determining the convective turn-over time ($\tau_c$) at the base of the convection zone, which appears in dynamo related parameters such as the Rossby number. For stars earlier than about G0V, she finds that $\tau_c$ increases with the metallicity.

5. Active regions, flares and high energy phenomena

Observations in the 1970’s, in particular those made with instruments on the Apollo Telescope Mount on Skylab taught us a great deal about active regions and the sets of loops of which they are composed (e.g. low lying loops tend to be hotter and denser than larger loops, cool loops tend to be more dynamic, emission from transition region lines can occur at heights apparently greater than their equilibrium isothermal scale-height). More recent observations with higher spatial and spectral resolution are, of course, improving our understanding of these phenomena. Mason described some results from observations with the CDS instrument on SOHO.

Klimchuk reviewed the systematic behaviour of active region loop parameters, such as loop lengths and pressures, and their correlations with the magnetic field projected from photospheric values. He found better agreement with theories involving reconnection of stressed magnetic fields than with those involving wave dissipation processes. I pointed out that by arranging the heating flux in terms of the plasma parameters and non-dimensional parameters (such as $\langle \delta B^2 \rangle /B^2$ and the plasma $\beta$), and balancing the heating flux against either thermal conduction or radiation (when the radiative power-loss scales as $T_e^{-1/2}$) must lead to the scaling $PL \propto T^3$. The actual heating process affects only the constant of proportionality, which includes $\beta$. Thus $P, L$ and $T$ (and ideally, $B$), must be measured simultaneously in order to test heating theories.

Orlando presented a method of analysing the contributions from active regions on other stars. With Peres and Reale, he has used observations with the Soft X-ray Telescope on Yohkoh to study the effects of rotational modulation from a single active region on the total EMD. The spectra that would be observed using the ACIS instrument on Chandra and the PSPC instrument on ROSAT were then simulated. The separate contributions of the quiescent corona (at sunspot minimum) and the active region could be easily distinguished. With sufficiently long observing runs, the method could be very useful.

Rapidly rotating stars ($P_{rot} < 1$ d) allow studies of coronal structure under extreme conditions (see papers by Collier Cameron et al. and Hussain). Observations of the variations with time in the Hα line profile have shown the presence of cool stellar prominence material within hot coronae. AB Dor is the now classic example. Similar effects have now been observed in the Ca II H&K lines, the Mg II h&k lines and in the Si IV and C IV resonance lines. Resonance scattering at high
velocities produces a broad component to the Si IV and C IV line profiles (Brandt et al. 2000). More recent observations and theoretical considerations show that the prominence material tends to accumulate at the co-rotational radius, within large magnetic loop structures. When the condensations occur within the co-rotation radius, and away from the equatorial plane, more complex magnetic field geometries are required to support them. As Collier Cameron stressed, observations of prominences offer a new way of exploring the 3D structure of such stellar coronae.

I can only select a few points from the large amount of material presented on solar and stellar flares. Doschek reviewed what we have learned about solar flares from a variety of early satellites. While some flares do show the morphology and range of phenomena predicted by reconnection theories, he selected some particular observational issues which have yet to be explained by present theories. First, there is a correlation between flare peak emission measures and peak temperatures. If the high temperature drives thermal conduction, which through evaporation drives the emitting mass, I would expect a scaling such as \( E m \propto T^4/L \). However, it should be possible to explore the scalings expected through numerical simulations. Secondly, a strong stationary component is observed during the period when blue-shifted components in lines are present. Simulations suggest that during the evaporative conduction phase, the blue-shifted component should dominate. Thirdly, the large line broadening observed, usually interpreted as due to non-thermal motions, does not appear to be restricted to a particular region of a flare, and it is not yet clear how this line broadening is related to the impulsive phase hard X-ray bursts. Fourthly, the morphology of some flares is puzzling. Images obtained with Yohkoh and TRACE show bright regions at the top of loops, which appear to have a higher pressure than the loop legs for significant lengths of time, and also asymmetric emission from loop legs.

Harra also presented results from Yohkoh. During the impulsive phase, in compact flares, there is not only the well-known hard X-ray foot point emission, but also a weaker, high energy source above the top of the flaring loop. Such flares can also show the presence of high velocity plasma at even greater heights. Both phenomena could indicate the type of magnetic field reconnection usually associated with long-duration events (see Shibata et al. 1995). Images and plasma flow measurements obtained during some long duration events do broadly follow the predictions of reconnection models. Both the early and more recent observations have shown that non-thermal line widths increase prior to a flare, but in a flare observed with Yohkoh these peaked before the main flare event.

Brown (John) pointed out how the high spatial and spectral resolution of the forthcoming HESSI mission should provide valuable new information on the high energy electron distribution function during solar flares, and on energetic flare ions. In particular, it may be possible to determine the energy at which the distribution function becomes non-Maxwellian. The new observations could reveal the importance of very high energy electrons in producing the impulsive phase power, and their acceleration in the primary magnetic energy release.

X-ray observations of stellar flares were discussed by Schmitt, Reale and Favata. In binary systems the location and extent of a flare can sometimes be deduced. Schmitt presented clear evidence for the polar location and large length
(≈ \(R_\star/2\)) of a high X-ray luminosity flare on the K-star component of Algol. Favata gave other examples of polar flares. In this context, there was considerable interest in numerical simulations presented by Schrijver which showed what the magnetic field and cycle of the Sun might look like if the Sun had a rotation period of only about a day. Rings of magnetic flux of opposite polarity approached the poles in rapid succession, and there were no intervals of weak fields at the poles.

Favata discussed the properties of large stellar flares which show many of the characteristics of solar long duration events and compact loop flares. Long duration events often show a double exponential form of the luminosity decay curve. A decrease in the decay rate can indicate a fresh input of energy. Stellar flares can have X-ray luminosities \(L_X\) which are a substantial fraction of the stellar luminosity \(L_\star\). We do not know how the stellar photosphere or stellar evolution might be affected by the strong magnetic fields implied.

Reale reviewed methods of flare modelling, and concluded that the use of hydromagnetic codes provided the best approach. He (and Favata) warned that most simpler methods used in interpreting the decay phase tend to overestimate the lengths of the flaring loops. Diagnostic diagrams which plot \(T_e\) against \(EM(V)^{1/2}\) are very valuable in identifying the different phases of the flare; the heating phase, where both \(T_e\) and \(EM(V)\) are increasing, the evaporative phase, which is the region between \(T_{max}\) and \(EM(V)_{max}\), and the decay phase, where continued heating can be deduced from the observed gradient of the plot. We used this approach to guide our analysis of the large flare on EQ1839.6+8002 (Pan et al. 1997), which showed all these features. I’d like to point out that one can adapt the simple approach often used to allow for a varying length of the emitting plasma, rather than adopting a fixed loop length. Some cooling times in the literature are not self-consistent, since they do not allow for the enthalpy flux implied by the variation of the flare parameters found. There seems to have been no systematic study of the duration of the evaporative phase (given by the time between \(T_{max}\) and \(EM(V)_{max}\)) and other flare parameters, which could be explored through numerical simulations.

Güdel stressed the importance of a multi-wavelength approach to studies of stellar flares, including radio wavelength observations to detect the presence of very high energy electrons. He showed how the energy release in the initial phase of stellar flares can be studied from the radio emission. In some flares there was an impressive correlation between the radio luminosity \(L_R\) and the time derivative of \(L_X\), but not with \(L_X\) itself. This correlation (the Neupert Effect) was first noted in the context of solar flares (Neupert 1968). Radio synchrotron emission from mildly relativistic electrons trapped in magnetic fields is observed to extend to several stellar radii around several stars and binary systems. Radio emission from stellar flares was also discussed by White. One result of interest to stellar active regions is that over the past 30 years, the sense of the circular polarization of the gyrosynchrotron radio emission from many stars, including HR1099 and UX Ari has not changed. As pointed out by Gibson (1983), this may be due to the orientation of these binary systems, so that the emission is dominated by a single hemisphere and its leading spot polarity.
6. Heating processes, the solar wind and dynamos

6.1. Heating processes

The source of heating for the quiescent solar corona and active regions is still not certain, but it is generally agreed that the energy is released from the magnetic field, through either the dissipation of MHD waves or magnetic reconnection. There is still a great deal of interest in some form of micro-flaring, from both the observational and theoretical points of view. Litwin reviewed a variety of energy dissipation processes which could be involved in micro-flares. He concluded that in its original form, Parker's version of microflaring from the reconnection of tangled fields may not work in detail, and that there was no clear and obvious dominant energy dissipation process. The contribution of microflaring has been investigated by a number of authors through studies of the frequency distribution of events of different energy as observed with SOHO (see review by Harra). Unfortunately, the results are not clear cut, with the power-law index \((-\gamma)\) having values of \(\gamma\) between about 1.3 to 2.6. A value of \(\gamma\) in excess of 2 is required for the process to be effective. Brown (John) pointed out that even larger values of the power index are required for evaporation in microflaring events to be a significant source of the solar wind, and that new observations with HESSI might be able to resolve the issue if \(\gamma\) were \(\leq 5\). In the stellar context, Güdel showed that the mean quiescent energy losses in X-ray and radio emission are correlated, as one might expect if there were a causal relation between the X-ray emission and high energy electrons produced in microflaring. He also pointed out the correlation between X-ray luminosities and coronal temperatures as supporting evidence. However, as with the correlations discussed in Section 5, the correlations between X-ray luminosities, fluxes or emission measures with temperature are a result of the dimensional form of the energy balance equation. For a radial field geometry this predicts \(E m(h) \propto g_* T_c^3\) (see Montesinos & Jordan 1993), and \(L_X \propto T_c^{3+\alpha} M_*\) (where \(\alpha\) is the power of the temperature in the radiative power-loss function), while for a corona composed of loops of length \(L\) and area \(A\), \(L_X \propto T_c^{4+\alpha} A L^{-1}\). The observed overall correlation is close to \(T_c^{3.5}\).

Peter presented the results of a detailed study of emission line profiles as observed with the SUMER instrument on SOHO. Transition region lines show two components; a Gaussian core plus weaker, broader wings. Such line profiles have been observed in stellar UV spectra obtained with the GHRS (Linsky & Wood 1994; Linsky et al. 1995). Peter has extracted the trends with \(T_c\) for both components, in supergranulation cell boundaries and interiors. The broad wings are absent in the cell interiors. He suggested that the different profiles may be associated with different types of structures and heating processes present in the network boundaries; e.g. the broad component originates in funnels extending up to the corona, and the widths follow the well-known \(T_c^{1/4}\) dependence expected for undamped Alfvén (or sound) waves; the narrow core originates in small closed field regions and could be heated by microflares. As an alternative idea, he suggests that in view of recent results suggesting ion-cyclotron damping of high frequency Alfvén waves in the extended corona, the broad component could be due to high ion temperatures. In the cell interiors he suggests that the broadening could arise as shocks interact with the B-fields of the expanding funnels. Whether or not Peter's proposals are borne out by later work, it is
clear that solar and stellar line profiles are an important part of testing heating mechanisms. Observations of high resolution stellar line profiles with the STIS and with FUSE will also contribute to this type of study.

6.2. The solar wind

Marsch reviewed observations of the solar wind from Ulysses, SOHO and other satellites. The fast solar wind emanates from coronal holes and contains both small scale structure and evidence of Alfvén waves. The location of the origin of the fast wind appears to be junctions in the network pattern, and is not related to polar plumes. The helium abundance, as indicated by the ratio of \( \alpha \) particles and protons, is steady at around 0.06, and as mentioned in Section 4, there is no observed FIP effect. Ion-cyclotron damping of high frequency waves could account for the observed properties of the temperatures parallel and perpendicular to the field direction. In contrast, although the slow wind appears to originate from the streamer belt, its precise origin and source of acceleration is not clear. The total mass-loss-rate in the fast plus slow wind is remarkably constant. One other point which struck me as interesting in the context of global properties is that the rotation of the coronal magnetic field near the Sun is uniform (with a synodic period of 27.2 days) and does not show the surface differential rotation.

6.3. Dynamos

Tobias reviewed dynamo theory, while Saar took a more empirical approach to deduce observational trends in dynamo related parameters. In the Sun and other cool main-sequence stars we have become accustomed to the idea of magnetic fields generated by dynamo action in the region of strong rotational shear at the base of the convection zone. Several of the new results regarding X-ray emission seem to indicate that this type of dynamo is not sufficient and interest has grown in small scale dynamos acting near the solar (and stellar) surface. These could be generated on scales less than or the order of the those for turbulent motions. In the Sun these may be related to the presence of the ‘magnetic carpet’, to activity in the supergranular network and to ephemeral active regions. The more traditional dynamo would account for the large scale aspects of the magnetic field and magnetic cycle. We heard that X-ray emission and flares are present on stars for which large-scale dynamo activity is not expected (e.g. young, intermediate mass stars, very cool M dwarfs and brown dwarfs). The possibility of small-scale dynamos may resolve these apparent problems.

Saar concentrated on finding scaling laws between the periods of stellar activity cycles, \( \omega_{\text{cyc}} \) (based on observations of the Ca II emission lines), and parameters such as the stellar surface rotation rate, \( \Omega \), the Rossby number \( (R_o) \) and the dynamo number. He found a stronger dependence of \( \omega_{\text{cyc}} \) on \( \Omega \) for the inactive stars than for the active stars. Observations of spatially averaged surface magnetic flux densities appear to scale as \( R_o^{-1.2} \), while X-ray fluxes scale as \( R_o^{-1.1} \). On the other hand there seems to be no clear correlation between X-ray fluxes and \( \omega_{\text{cyc}} \). I would like to stress that the theory underlying the apparent correlations between chromospheric and coronal parameters and \( R_o \) needs to be addressed. We broadly understand the correlations between the fluxes of emission lines formed in different parts of the stellar atmosphere and between
coronal parameters such as $E_m(T_c)$, $T_c$ and $P_c$, but not the links to the dynamo generated magnetic fields.

7. Young stars, low-mass stars and brown dwarfs

These stars are grouped together since their discovery as X-ray emitters depends on imaging and brown dwarfs (or candidates) have been found in young star clusters. As the papers presented showed, X-ray observations are providing a powerful way of studying the development and decay of stellar activity in young stars covering a wide range of mass.

The new images of star clusters and star forming regions obtained with Chandra are very impressive; they have shown that young stars of all masses have quiescent and flaring X-ray emission (see papers by Flaccomio et al., Koyama, Preibisch & Zinnecker). From studies of the Orion Nebula Cluster, Flaccomio et al. showed that for stellar masses $M_* \leq 3M_\odot$, $L_X$ increases with $M_*$. A large drop in $L_X/L_{bol}$ for $M_* \simeq 3M_\odot$ is consistent with a change from convective to radiative outer envelopes, suggesting that dynamo related activity is important in the low-mass stars. The median values of $L_X$ and $L_X/L_{bol}$ decrease with age. However, there is no dependence of these parameters on the stellar rotation rates, and this could indicate saturation in the X-ray emission. Infilling of the Ca II lines around 8542 Å can be used to distinguish between stars which are still undergoing significant accretion, and those that are not. In a given mass range, stars with high accretion rates tend to have lower values of $L_X$; some possible explanations were proposed.

Montmerle & Grosso discussed how active accretion discs may play a role in the observed X-ray activity of young stars. Discs may also affect the relation between the stellar surface rotational velocities and the break-up velocity, but even passive discs play an indirect role in the regulation of the angular momentum of the system. There is also evidence of magnetic fields connecting the stars with their circumstellar discs. These may be related to the observational result that weak T Tauri stars are fast rotators, while stronger T Tauri stars are slow rotators, in contrast to the behaviour of cool main-sequence stars.

Chandra observations of X-ray sources in several star forming regions were reviewed by Koyama. Earlier studies with previous X-ray satellites concentrated on low mass stars, which were mainly T Tauri stars. The higher sensitivity of Chandra has led to many more detections of late-phase protostars, which are found to have higher X-ray temperatures and more absorption than the later phase T Tauri stars, and also show strong flares. Highly absorbed X-ray emission is also detected from dust condensations. The power of X-ray observations has been demonstrated by the detection of regions containing high-mass young stars in the giant molecular cloud Sgr B2; the optical absorption is so large that previous studies have used observations at radio and far-infrared wavelengths. Koyama concluded that the high-mass young stellar objects produce variable and hard X-ray emission through magnetic activity, which decreases when stellar winds develop.

Results from a study of the very young cluster IC 348 with Chandra were presented by Preibisch & Zinnecker. About 80% of the known low-mass stars ($3 > M_*/M_\odot > 0.08$) were detected, including 2 embedded sources. They con-
cluded that taking into account selection effects, in contrast to previous suggestions, there is no strong evidence for systematic differences between the X-ray properties of weak and classical T Tauri stars.

Hamaguchi et al. discussed young stars of intermediate mass (Herbig Ae/Be stars) observed with ASCA. On the main-sequence, stars with $10 > M_*/M_\odot > 2$ do not have outer convection zones, and are not significant emitters of X-rays. However the detection of X-ray emission which has similar properties to that of low-mass protostars suggests that the intermediate-mass stars do have magnetic related activity in their early stages, which may be related to fossil fields. Unlike the low-mass stars they do not develop dynamo related activity as the main-sequence is approached and their X-ray emission rapidly decreases.

Giampapa & Fleming discussed the coronae of low-mass stars and brown dwarfs, based on observations with ROSAT and Chandra. They suggest that the M-dwarfs have quiescent X-ray emission, but only the dMe stars have a significant high temperature and variable component. There is no obvious change in $L_X/L_{bol}$ across the region where the stars are expected to become fully convective, but using observations of VB 8 (dMe7e) and a new measurement of a low level of quiescent emission from VB 10 (dMe8e) there appears to be a rapid decline in the quiescent component around spectral type M8 V. They pointed out that (non-photospheric) Hα emission could be useful in selecting even cooler stars as X-ray targets.

Brown dwarfs were detected as X-ray emitters in several of the above star forming regions. In IC 348, Preibisch & Zinnecker discovered emission from 7 of the 25 known brown dwarfs and brown dwarf candidates. Their X-ray properties are similar to those of fully convective very low-mass dwarfs which have coronae. Similarly, Koyama reported detections of 7 of the 18 known brown dwarfs or brown dwarf candidates in the ρ Oph cloud, with properties similar to those of low-mass pre-main-sequence stars. The production of hot plasma in fully convective stars poses challenges for dynamo theory and may indicate small-scale dynamo action in a highly turbulent convection zone (see e.g. Durney, De Young, & Roxburgh 1993). Tsuboi et al. have also detected weak and soft X-ray emission from a middle aged brown dwarf (TWA 5B) for the first time, providing a useful link between the more commonly studied young and old objects.

8. Final remarks

I have not summarized the many studies presented of individual stars or binary systems. We have seen a number of examples of emission measure distributions, but little about their interpretation. The point of finding the EMDs is to interpret them in terms of the atmospheric structure and/or to compare with the predictions of models. The form of the EMD with $T_e$ is determined by the terms of the energy balance equation and any change with $T_e$ in the emitting area. The high quality of the new X-ray observations plus modern atomic data should now be exploited to the full.

I think that one strength of this meeting has been that it has brought together those working on a wide range of stars. In particular, the study of stars of different masses as they evolve from their earliest stages to the main sequence seems to be giving a more coherent picture of the changes in the origin
of magnetic activity. Significant developments are occurring in the understanding of the envelopes and winds of hot stars. In the area of cool stars, the systematic studies of relative abundances and their variations should, eventually, allow us to understand their causes.

Finally, I would like to thank Fabio Favata and Jeremy Drake, and all others involved in the organization of this meeting, for such an excellent conference.

References

Bucolic Dutch scene accompanied alcoholic conference dinner.
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