Studying New Problems in Stellar Coronal Physics with AXAF and XMM

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Abstract:
AXAF and XMM have instruments with far higher angular and spectral resolution than ASCA, ROSAT, or Einstein. In particular, we look forward to the first generation of moderate resolution coronal spectroscopy of cool stars. We will summarize here the capabilities of the AXAF and XMM instruments and identify some of the new coronal physics that these instruments will soon allow us to study.

1. Introduction

Today we are poised at the beginning of a new era in stellar coronal astrophysics. AXAF (the Advanced X-ray Astrophysics Facility)\(^1\) will be launched only one year from now, and XMM (the X-ray Multi-Mirror satellite)\(^2\) will follow one year later. These complementary missions will provide at least an order of magnitude improvement in both spectral and angular resolution compared with previous X-ray missions. They will also cover the entire 0.1 to 10 keV X-ray band. Both high-resolution spectra and deep high-resolution images will provide the data critically needed to challenge and refine our rather unsophisticated models of stellar coronae. We look forward to the accurate measurements of plasma temperatures, turbulence, flow velocities, electron densities, abundances, geometrical structure sizes, and heating rates that AXAF and XMM will provide for many diverse stars. These data should lead to a new generation of stellar coronal models with far closer ties to basic physical principles. We hope to determine the extent to which present models of the solar corona, which are based on high-resolution imaging and spectroscopy, can be applied to other stars, in particular to stars that are more active, have lower gravities, and have different effective temperatures, ages, and rotation rates. In this paper we summarize the capabilities of the AXAF and XMM instruments, and illustrate with simulated spectra how these powerful instruments can address critical problems in contemporary stellar coronal research.

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\(^1\)http://asc.harvard.edu/
\(^2\)http://astro.estec.esa.nl/XMM/user/overview/overview_top.html
2. Capabilities of the AXAF Instruments

AXAF consists of a set of four concentric paraboloid/hyperboloid mirror pairs forming the HRMA (High Resolution Mirror Assembly), two sets of transmission gratings, two detector systems, and an Aspect Camera. Figure 1 shows a functional diagram for AXAF. The HRMA mirrors, with 2 Å rms roughness, will provide unprecedented image quality. For point sources observed on-axis, a 1" diameter circle contains 80% of the energy below 1.5 keV. At 6.4 keV, 1" is the 65% encircled energy diameter. This resolution can be compared with the 10" diameter resolution of the ROSAT HRI, the 15"–30" resolution of the XMM EPIC, and the 3' resolution of the ASCA SIS. As we shall see, this remarkable angular resolution, combined with a 17' × 17' field of view and very low detector background count rate [< 4 electrons (rms) per pixel], make AXAF an ideal instrument to study crowded fields like globular clusters, to search for faint X-ray sources, and to examine the precise nature of the cosmic X-ray background. The limiting point-source sensitivity is estimated to be 10^{-14} ergs cm^{-2} s^{-1} in 10^4 seconds.

ACIS (the AXAF CCD Imaging Spectrometer) is a focal plane detector consisting of a square array of four 1024 × 1024 CCDs for imaging (ACIS-I) and a linear array of six CCDs for spectroscopy (ACIS-S). Both arrays approximate the curved Rowland focal surface of the HRMA/grating combinations. Two of the CCDs in ACIS-S are backside illuminated for enhanced effective area below 1.5 keV. Over the 17' × 17' field of view of ACIS-I, more than half of the pixels have better than 1" imaging at low energy. The effective area of ACIS-I, which peaks at 800 cm² near 1.5 keV, is more sensitive to X-rays than the previous X-ray imaging detectors: ASCA–SIS, Einstein–IPC, and ROSAT–PSPC (see Figure 2). The energy resolution of ACIS-I is somewhat better than ASCA with E/ΔE in the range 18–48 depending on energy (see Figure 3), and the background will be lower.

For dispersive spectroscopy, two grating/detector combinations will be most widely used. The HETG (the High Energy Transmission Grating spectrometer), consists of two sets of grating facets which focus onto ACIS-S. The array of grating facets located behind the two outer HRMA mirror pairs, called the MEG (Medium Energy Gratings), is most efficient in the 0.5–2.0 keV range, while the grating facets located behind the two inner HRMA mirror pairs, called the HEG (High Energy Gratings), are most efficient in the 0.7–7 keV range. Both the MEG and HEG achieve resolutions above 1000 (≤ 300 km s⁻¹) at the long-wavelength ends of their respective ranges (see Figure 3). Spectra produced by the HEG and MEG are detected simultaneously by ACIS-S and have appreciable throughput in higher (mostly 2nd, 3rd, and 4th) orders. Since the ACIS-S detectors have sufficient energy resolution to separate orders, spectral lines observed in higher orders may prove useful as diagnostics of coronal flows, temperatures, and turbulence. The HRC (High Resolution Camera) consists of two arrays of CsI-coated microchannel plates with two-dimensional readouts: a square array for imaging (HRC-I) and a linear array for spectroscopy (HRC-S). HRC-I provides better imaging at lower energies than ACIS-I (see Figure 2), but does not have any energy resolution.

The LETG (Low Energy Transmission Grating spectrometer) consists of low-energy grating facets placed behind all four HRMA mirror pairs and focused
AXAF Functional Diagram

Incident X–Ray Photons

HRMA = High Resolution Mirror Assembly

LETG = Low Energy Transmission Grating

High Energy Suppression Filter

"Drake Flat"

HRC–S HRC–I

HRC = High Resolution Camera

ACIS–I ACIS–S

ACIS = AXAF CCD Imaging Spectrometer

Figure 1. A flow chart representing the paths that X-ray photons can follow through the AXAF instruments.
onto the HRC-S. This combination produces the highest spectral resolution on AXAF (see Figure 3), reaching $E/\Delta E \approx 2000$ at energies below 0.1 keV. Unfortunately the overlapping (mostly 1st, 3rd, 4th, and 5th) spectral orders cannot be separated by the HRC-S. As a result, the extraction of unconfused spectra will be a challenge. For emission-line spectra (e.g., stellar coronae) the identification of higher order lines can be simplified by identifying high-energy lines in first order, either with the LETG or the HETG, and iteratively removing higher-order flux. An alternative workaround to this problem involves using a high-energy suppression filter. With some loss of throughput at all energies, the strength of the high-energy lines can be suppressed by moving the HRC-S so that the converging beam reflects off a two-facet mirror. Observations with and without the high-energy suppression filter, also called the “Drake Flat” (see Figure 1), may turn out to be a very useful way of achieving clean low-energy spectra.

3. Capabilities of the XMM Instruments

The XMM telescope consists three telescope modules, each made up of 58 nested paraboloid/hyperboloid pairs with a focal length of 7.5 meters and maximum diameter of 70 cm. At the prime focus of each telescope, EPIC (the European Photon Imaging Camera) obtains images with $30' \times 30'$ fields of view and CCD energy resolution $E/\Delta E$ in the range 25–50. Two of the cameras use MOS CCDs and one uses pn CCDs. The angular resolution with EPIC is about $20''$. The total effective area of all three cameras peaks at 2000 cm$^2$ and covers the range from 0.1 to 10 keV. Thus EPIC exceeds the effective area of ACIS-I but with poorer angular resolution. For fields that are not too crowded, EPIC will be an efficient instrument for imaging and low-resolution spectroscopy.

Near the focus of two of the XMM telescope modules, an array of reflection gratings intercepts about 60% of the converging beam, letting the remaining 40% pass through to be recorded by EPIC as images. The RGS (Reflection Grating Spectrometer) consists of these grating arrays and strip arrays of nine MOS CCDs to record the dispersed X-rays. The overlapping first and second order spectra are separated by the energy resolution of the detectors. The total effective area of the two RGSs peaks at 200 cm$^2$ near 1 keV and extends from 0.35 to 2.5 keV. The peak resolution is $E/\Delta E \approx 800$ (near 0.34 keV in first order and near 0.68 keV in second order).

Table 1 compares the characteristics of the AXAF and XMM satellites and their instruments. While AXAF and XMM are optimized in different ways, both will be vastly superior to the predecessor missions — ASCA, ROSAT, Einstein, and EXOSAT. In particular, AXAF will have the highest angular and spectral resolution, while XMM will have the highest throughput. Both instruments will be in high, elliptical orbits to facilitate long, uninterrupted observing sequences (e.g., for studying coronal variability including flares and rotational modulation). XMM also has an Optical Monitor that will obtain UV and optical photometry simultaneous with the X-ray imaging and spectroscopy.
Figure 2. Effective area of the imaging instruments on AXAF and selected instruments on prior missions (from the AXAF Science Instrument Notebook).
Figure 3. The predicted spectral resolutions of the high-energy (HEG) and medium-energy (MEG) gratings, which obtain data simultaneously, and the low-energy gratings (LEG) are compared to that of the ACIS front-side and back-side illuminated CCDs with undispersed illumination. The predictions of resolution include telescope blurring, pointing accuracy, optical aberrations of the gratings, and detector spatial resolution (from the AXAF Science Instrument Notebook).
Table 1. Comparison of *AXAF* and *XMM* Capabilities

<table>
<thead>
<tr>
<th>Parameters</th>
<th><em>AXAF</em></th>
<th><em>XMM</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Date</td>
<td>21 January 1999</td>
<td>6 August 1999</td>
</tr>
<tr>
<td>Orbital Major Axes (km)</td>
<td>$10,000 \times 140,000$</td>
<td>$7,000 \times 114,000$</td>
</tr>
<tr>
<td>Orbital Period (hr)</td>
<td>64</td>
<td>47.8</td>
</tr>
<tr>
<td>Focal Length (m)</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>Outer Mirror Diameter (cm)</td>
<td>120</td>
<td>70 (3 modules)</td>
</tr>
<tr>
<td>Field of View (')</td>
<td>$17 \times 17$ (ACIS-I)</td>
<td>$30 \times 30$ (EPIC)</td>
</tr>
<tr>
<td>Angular Resolution (&quot;)</td>
<td>1.0 (ACIS-I)$^a$</td>
<td>15–30 (EPIC)</td>
</tr>
<tr>
<td>Energy Range (keV)</td>
<td>0.2–10 (ACIS-S)</td>
<td>0.1–12 (EPIC)</td>
</tr>
<tr>
<td>...</td>
<td>0.5–10 (ACIS-I)</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>0.06–7 (LETG)</td>
<td>0.35–2.5 (RGS)</td>
</tr>
<tr>
<td>...</td>
<td>0.2–10 (HETG)</td>
<td>...</td>
</tr>
<tr>
<td>Peak Effective Area (cm$^2$)</td>
<td>900 (ACIS-S)</td>
<td>2000 (EPIC)</td>
</tr>
<tr>
<td>...</td>
<td>800 (ACIS-I)</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>200 (HRC-I)</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>180 (HETG)</td>
<td>200 (RGS)</td>
</tr>
<tr>
<td>...</td>
<td>50 (LETG)</td>
<td>...</td>
</tr>
<tr>
<td>Resolving Power ($E/\Delta E$)</td>
<td>15–60 (ACIS-I)</td>
<td>25–50 (EPIC)</td>
</tr>
<tr>
<td>...</td>
<td>5–45 (ACIS-S)</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>70–1000 (HETG)</td>
<td>100–800 (RGS)</td>
</tr>
<tr>
<td>...</td>
<td>50–2000 (LETG)</td>
<td>...</td>
</tr>
</tbody>
</table>

$^a$ 80% encircled-energy diameter on-axis below 1.5 keV; 65% at 6.4 keV
4. Problems in Stellar Coronal Physics that can be Solved with AXAF and XMM

4.1. Coronal Electron Densities

Reliable measurements of electron densities in stellar coronae provide at least three kinds of critical information. First, analysis of X-ray line fluxes only yields emission measures as a function of plasma temperature, \( EM(T) = \int n_e^2 dV \). Electron densities at different temperatures would then allow us to infer the volume of the emitting plasma in different temperature ranges. Second, the rate at which an optically thin coronal plasma radiatively cools is proportional to \( \Lambda(T)n_e^2 \), where \( \Lambda(T) \), the radiative loss function, depends on temperature and abundance. Thus the electron density plays a major role in the plasma cooling rate, an important component of the coronal energy balance. Third, the electron density plays an important role in collisional excitation and recombination rates and thus in the coronal ionization balance.

Flux ratios of lines from the same ion but with different collisional rates are often good electron-density diagnostics over several orders of magnitude in density. Fe XXI has a number of such line ratios involving lines in the 98–145 Å range. In their analysis of three Fe XXI line ratios observed by EUVE in the spectrum of Capella (G1 III + G8 III), Dupree et al. (1993) inferred \( \log n_e \) in the range 11.6–13.2. Subsequent analysis of five long integration EUVE spectra of the same star by Brickhouse et al. (1997) led to a somewhat tighter range of densities, \( \log n_e = 11.1–12.5 \).

Other ions also give rise to line ratios that are useful density diagnostics in the LETG, RGS, and HETG spectral ranges. For example, spectra of the He isoelectronic sequence ions contain three lines close together in wavelength that have very different collisional rates. These lines are typically called the resonance (R), intercombination (I), and forbidden (F) lines. Table 2 lists the wavelengths and relative separation \( (E/\Delta E) \) of the I and F lines, the temperature of maximum abundance of the ion, the critical density above which the F/I ratio is very sensitive to electron density, and the spectrographs that can observe and resolve these lines. Figure 4 shows the O VII lines at densities of \( 10^{10}, 10^{11}, 10^{12}, \) and \( 10^{13} \) cm\(^{-3}\) based on a 60 ks LETG simulation of Capella. The forbidden line (F) is detectable at all but the highest density. The bottom panel of Figure 4 shows the theoretical (line) and simulated (points and error bars) line ratios. Figure 4 shows that the 1σ errors in F/I will be small and that high signal-to-noise spectra will place stringent constraints on \( n_e \). RGS simulations indicate that shorter observations will lead to similar results since the RGS has higher throughput than the LETG and the lines are well resolved by both instruments. AXAF and XMM will reduce the uncertainty of density estimates by 1) resolving most line blends, 2) measuring many more density-sensitive lines, and 3) providing many more photons.

4.2. Search for X-Ray Faint Coronae

The large effective areas of the imaging instruments on AXAF and XMM and the possibility of long uninterrupted observations makes it feasible to search for very faint coronae that could not been detected by previous experiments. In particular, the high angular resolution of AXAF, which is comparable to
Figure 4. Simulation of the Capella O\textsc{vii} lines for a 60 ks LETG observation. The lines are labeled with their total counts and the symbols R (resonance line), I (intercombination line), and F (forbidden line). The bottom panel shows the simulated F/I line ratios (dots with error bars) and the predicted line ratios (solid line) for different assumed electron densities.
Table 2. Density Sensitive Lines in the He Isoelectronic Sequence

<table>
<thead>
<tr>
<th>Ion</th>
<th>$\lambda_1$ (Å)</th>
<th>$\lambda_F$ (Å)</th>
<th>$E/\Delta E$</th>
<th>$\log T_{\text{max}}$</th>
<th>$\log n_{\text{crit}}$</th>
<th>Instrument$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C V</td>
<td>40.73</td>
<td>41.47</td>
<td>60</td>
<td>5.50</td>
<td>8.8</td>
<td>L</td>
</tr>
<tr>
<td>O VII</td>
<td>21.80</td>
<td>22.10</td>
<td>75</td>
<td>5.90</td>
<td>10.5</td>
<td>L, H, R</td>
</tr>
<tr>
<td>Ne IX</td>
<td>13.55</td>
<td>13.70</td>
<td>90</td>
<td>6.20</td>
<td>11.8</td>
<td>L, H, R</td>
</tr>
<tr>
<td>Mg XI</td>
<td>9.23</td>
<td>9.32</td>
<td>105</td>
<td>6.40</td>
<td>12.7</td>
<td>L, H, R</td>
</tr>
<tr>
<td>Si XIII</td>
<td>6.69</td>
<td>6.74</td>
<td>135</td>
<td>6.60</td>
<td>13.6</td>
<td>H, R</td>
</tr>
<tr>
<td>Ca XIX</td>
<td>3.19</td>
<td>3.21</td>
<td>170</td>
<td>6.85</td>
<td>14.6</td>
<td>H</td>
</tr>
</tbody>
</table>

$^a$ L=LETG, H=HETG, R=RGS.

ground-based optical resolution, makes it possible to accurately identify very faint sources, even in crowded fields. X-ray faint companions to brighter stars may be detected less than 2$''$ away from their X-ray bright companions. For example, a 60 ks ACIS-I simulation of the Trapezium Cluster predicts that about 300 sources (mostly low-mass pre-main-sequence stars) will be detected in the central 8$'$ x 8$'$ of the field of view down to a luminosity $L_X \approx 10^{29}$ ergs s$^{-1}$.

Perhaps the lowest luminosity corona detected so far is the nearby (1.83 pc) M5 dwarf GJ 699 (Barnard's star) with $L_X \approx 3.8 \times 10^{25}$ ergs s$^{-1}$ (Schmitt et al. 1995). Stars this faint should be detected out to a distance of 60 pc in 100 ks with ACIS-I and to greater distances with EPIC. Do stars at the very end of the hydrogen burning main sequence and the brown dwarfs at masses less than ~0.07 solar masses also have coronae? Long-exposure images of such stars in the field, in the Hyades (45 pc), and in the Pleiades (115 pc) should provide the answer. HETG and RGS spectra of these sources should also provide information on how coronae of fully convective stars differ from coronae of hotter stars like the Sun, which have radiative cores and likely have a different type of magnetic dynamo.

Do A-type stars with very thin convective envelopes emit X-rays? The question remains open because those A-type stars that have been detected as X-ray sources so far could have unseen, late-type (and presumably very young) companions that are optically faint but X-ray bright. High resolution images could identify putative companions if they are located farther than one or two arcseconds from the A star. X-ray spectra of A-type stars may also show clear signatures of low-mass companions: very high coronal temperatures and flares.

Other types of stars with previously undetected X-ray emission include cool giants and supergiants, subdwarfs, and halo stars. Using an 18.6 ks ROSAT PSPC observation of Arcturus (K2 III), Ayres et al. (1991) found no X-ray emission to a limiting luminosity of $L_X \approx 3.2 \times 10^{25}$ ergs s$^{-1}$. ACIS-I and EPIC will go much deeper.
4.3. Coronal Geometry and Structure

Even AXAF does not have the angular resolution to resolve stellar coronae directly, but there are indirect techniques for obtaining information on coronal structure. As previously mentioned, the combination of emission measures and electron densities can be used to predict the effective volume of the emitting plasma at different temperatures. EUVE observations of high temperature ions in active cool stars have identified structures that are very much smaller than the star and are often interpreted as small magnetic loops in the corona. A second technique used with the Einstein, ROSAT, and ASCA satellites (e.g., White et al. 1994) is to observe an eclipsing binary system as one star crosses the disk and off-limb corona of the other star. The RS CVn system AR Lac (G2 IV + K0 IV) is a common target for such experiments, but there are other good eclipsing systems like YY Gem (M0 V + M0 V) and 44 Boo (G0 V + G2 V). The long-duration orbits and large collecting area of AXAF and XMM will lead to improved time resolution and long sequences of uninterrupted observing for these studies.

The high spectral resolution of the LETG and to a lesser extent the HETG and RGS will support the first attempts at coronal Doppler imaging. In the ultraviolet, Neff et al. (1989) and others have Doppler imaged AR Lac by obtaining IUE echelle spectra of the Mg\textsc{ii} lines. This is feasible because the rotational velocities of the stars (46 and 81 km s\(^{-1}\)) are larger than the 30 km s\(^{-1}\) resolution of the spectrograph, and the 232 km s\(^{-1}\) orbital radial velocity difference between the two stars at quadrature is sufficient to separate the Mg\textsc{ii} emission lines of the two stars. Their analysis of a large number of spectra obtained over a complete rotation period led to the identification of three bright active regions in the corona of the K0 IV star with estimates of their sizes and locations on the stellar surface. Can this technique lead to Doppler images of stellar coronae? The highest resolution available with AXAF or XMM is \(E/\Delta E \approx 2000\) (\(\lesssim 150\) km s\(^{-1}\)) with the LETG at \(E < 0.1\) keV \((\lambda > 124\) Å\)). Bright high-energy lines can also be used in higher order. With 150 km s\(^{-1}\) resolution, the LETG will be able to identify which of the AR Lac stars is the brightest in X-rays, but it will not be able to locate bright regions in the corona of either star unless their coronae are very extended and rotating rigidly. The W UMa-type contact binaries like 44 Boo are better candidates for Doppler imaging because these systems rotate more rapidly.

4.4. Coronal Dynamics — Flows and Turbulence

Before AXAF and XMM, no X-ray instrument had the spectral resolution to study dynamical phenomena in stellar coronae. What might the AXAF and XMM spectrometers see? First IUE and then HST/GHRS moderate resolution spectra \((\lambda/\Delta \lambda \approx 20,000)\) revealed that transition region emission lines from late-type dwarf and giant stars show redshifts that increase with temperature to about 10 km s\(^{-1}\) at \(10^5\) K. These redshifts probably indicate downflows along magnetic flux tubes where these lines are bright (Ayres et al. 1988; Wood et al. 1997). At somewhat higher temperatures the redshifts decrease, except for Procyon (F5 IV–V) where they are increasing to temperatures of at least 200,000 K. Does this pattern extend into the corona? Alternatively, we may detect blueshifts in coronal lines indicating the onset of stellar winds.
The only evidence we now have for bulk coronal flows comes from GHRS spectra of the Fe\textsc{xii} 1354 Å line formed at log\(T\) near 10\(^{7}\) K. Analysis of a 9.7 ks moderate-resolution GHRS spectrum of Capella by Linsky et al. (1998) shows no significant flow velocity \((v = -3 \pm 11 \text{ km s}^{-1})\), which they interpret as confinement of the hot coronal plasma by closed magnetic fields. Maran et al. (1994) and Robinson et al. (1996) also found no flow velocity in the 1354 Å line in spectra of AU Mic (M0 Ve) and HR 1099 (G5 IV + K1 IV). The GHRS spectra resolve the Fe\textsc{xii} line and for both stars in the Capella system the FWHM of the line is 87 ± 11 km s\(^{-1}\), which is very similar to the expected broadening by thermal motions alone (90 km s\(^{-1}\)). Thus the nonthermal motions must be very small (< 23 km s\(^{-1}\)). This may place constraints on possible coronal heating mechanisms.

HR 1099's Fe\textsc{xii} 1354 Å line profile can be fit approximately by two Gaussians centered on the radial velocities of the two stars. However, there is additional flux at about –200 km s\(^{-1}\) relative to the K1 IV star. Robinson et al. (1996) suggest that the added flux may indicate high velocity streams. We speculate that this blue-shifted emission may arise from the same physical processes that produces blue-shifted emission in lines such as Ca\textsc{xix} 3.17 Å with velocities up to 400 km s\(^{-1}\) during the first few minutes of solar flares (e.g., Antonucci et al. 1987). This blue-shifted emission during solar flares is usually interpreted as upflowing hot plasma produced by rapid heating and evaporation of gas at the top of the chromosphere by energetic flare particles or shocks. We should look for blue-shifted coronal gas in active stars and in binary systems that may be continuously flaring.

Can the \textit{AXAF} and \textit{XMM} spectrometers measure coronal line widths and shifts accurately? To even begin to measure line widths we need a resolution better than 100 km s\(^{-1}\) corresponding to \(E/\Delta E \approx 3000\); i.e., beyond the capabilities of even the LETG. Figure 5 shows a simulation of a 60 ks spectrum of Capella with the LETG. The top panel shows the 16.8 Å and 17.1 Å lines in first order with a resolution of 300. These same lines appear in the bottom panel in fifth order at 84.0 Å and 85.5 Å with a resolution of about 1500. Note that in fifth order the 17.1 Å line is cleanly split. Although measuring coronal line widths may be beyond the capabilities of \textit{AXAF} and \textit{XMM}, measurements of line shifts can be up to a factor of 10 more precise for lines with good S/N and an accurate velocity scale. Although the absolute wavelength calibrations of the \textit{AXAF} and \textit{XMM} spectrographs will not be precise enough, precise velocities relative to other emission lines may be possible. This will be a challenge, but accurate velocities to even 50 km s\(^{-1}\) may open up new coronal physics.

5. Conclusion

The questions raised so far only begin a rather long list of exciting research topics that \textit{AXAF} and \textit{XMM} will support if cool star researchers will write compelling proposals for observing time. For example, the importance of different heating and cooling mechanisms in cool star coronae must be addressed. We do not yet know whether coronae are heated impulsively (microflares) or continuously, and, if the latter, what types of waves are responsible for the heating. The role of nonthermal electrons in coronal heating is unknown, but we know from
Figure 5. Simulated spectra of Capella with the LETG. The 16.8 Å and 17.1 Å lines seen in the top panel appear in fifth order at 84.0 Å and 85.5 Å in the bottom panel. Note that in fifth order the 17.1 Å line is cleanly split.
flare data and radio emission that nonthermal phenomena are present. Magnetic fields must play critical roles in defining coronal structures, heating, and wind acceleration, but these roles are not yet understood in detail. Other topics await the skilled word-smithing of cool star pundits who will salivate when the calls for proposals ring through our workstations. Veni, vidi, vici.

Acknowledgments. This work is supported by NASA grant H–04630D to the National Institute of Standards and Technology.

Discussion

Helen Mason: Fe xxı (1354 Å) was observed extensively with SMM–UVSP. We saw blue-shifts in the impulsive phase of the flare but much of the time Fe xxı was observed in active regions with its thermal width. We just didn’t publish the results because they didn’t seem very exciting.

Jeffrey Linsky: I would encourage you to look through these data carefully to characterize the times and timescales of the blue-shifts in flares and to determine whether or not blue-shifts are ever seen in active regions outside of obvious flares. It would be interesting to predict phenomena that AXAF and XMM may well see in the more active stars.

References

Frank Fekel and Scott Wolk squinting to see whales.
Meanwhile, on the other side of the boat...
A band of highwaypersons and cutthroats.
Contributed Papers

CD-545
The Companion CS 10 CD-ROM

The companion CD-ROM for the Tenth Cambridge Conference on Cool Stars, Stellar Systems, and the Sun includes all of the contributed (poster) papers in PostScript format, additional files submitted to be published with these Proceedings, and copies of the invited papers and discussion write-ups (also in PostScript format). Several papers have taken advantage of this format to utilize color figures. Others have made interactive versions of their figures using the Ov and Flip applets, included on the CD-ROM.

The CD-ROM is designed to work on several platforms. It can be inserted into a CD-ROM drive and accessed as you would any other data CD-ROM (e.g., as the E: drive on many Intel machines, as a drive folder on Macintosh systems, or mounted as a partition on UNIX systems): please consult the documentation for your particular setup.

The layout of data on the CD-ROM is as follows:

- The top level directory on the CD-ROM has a README file with any last-minute instructions, and a basic set of directions.

- Also in the top level directory is a file called index.htm or index.html. This file is the hypertext "home page" for the CS10 CD-ROM and has links to the Table of Contents, the Author Index and Object Index, and other help files.

To direct your computer's favorite WWW browser to the CS10 CD-ROM, use the URL template file:/path/index.html (or index.htm, if your computer only permits 3-character filename extensions), where path is the identification string for the CD-ROM partition.

- Each paper has been given its own directory. The directory names have been assigned using the first six letters of the first author's last name, the first letter of the first author's first name, and a running number starting with "1" to handle the common situation where one person submitted multiple papers. These directory names are listed in the Table of Contents.

- Each paper’s directory has a corresponding index.html file. This file contains:
  - The title of the paper
  - Author list and affiliations
  - Abstract\(^1\)
  - A link to the PostScript version of the paper
  - A complete list of files included with the submitted paper on the CD-ROM (including alternate version of the figures)

\(^1\)For papers submitted without abstracts, the abstract from the meeting Abstract Book was used.
- Links to HTML pages containing interactive versions of paper figures
- List of Objects (with links to the Object Index)
- A list of links to the WWW mentioned in the text of the paper
- The reference list from the paper, with links (where available) to the Astronomical Data Service

- The PostScript files have the same name as the directory with a “.ps” extension. These files can be printed on a PostScript-capable printer. Papers including color figures may be printed on grayscale printers; we have tried to make sure that doing this will not degrade readability. However, in some cases this was not possible. Several authors included both color and B/W versions of plots. We have included B/W versions of figures as additional files which can also be printed.

We are also pleased to announce that we have also included music from the CS10 banquet, courtesy of Lynda Williams. Those files can be found in the WILLIAL1 directory on the CD-ROM.

Bob Donahue
(Cover artwork by Sheila Sasselov.)

All papers on pages 551 and higher are contained on the companion CD-ROM.