X-Ray Measurements of Coronal Abundances

Stephen A. Drake

Universities Space Research Association and Code 660.2, Goddard Space Flight Center, Greenbelt, MD 20771

Abstract. The availability of high throughput, moderate-resolution X-ray spectroscopes, such as those currently operating on the Japanese/US *ASCA* observatory, has enabled the measurements of the elemental abundances in stellar coronae. I discuss the assumptions inherent in such abundance analyses, and the potential sources and magnitudes of uncertainties associated with them. The results to date show that almost all stars whose X-ray spectra have been studied in detail show a general deficiency of heavy elements in their coronae relative to the solar photospheric values by factors of $\sim 2-5$. This is somewhat unexpected since most of the stars studied are believed to be normal Population I stars, and no such systematic effect has been observed in the solar corona. Independent analyses of high-resolution extreme-ultraviolet spectra of a number of stars have generally found similar results, indicating that the apparent metal-deficiency is almost certainly not an artifact. I discuss the reliability of the individual abundances for those elements which have strong lines in the *ASCA* spectral range.

1. Introduction

It is impossible to cover every aspect of the subject of stellar coronal abundances in the length constraints of the present review, so I will primarily limit it to the discussion of the abundances inferred from **X-ray spectroscopy of late-type, 'coronal' stars**. There have recently been published some excellent reviews and research papers on the topic of the **solar** coronal and energetic particle abundances, e.g., Meyer (1991), Reames (1992), Feldman (1992), Laming *et al.* (1995), Fludra & Schmelz (1995), Meyer (1996), and thus I will only briefly touch upon these results. Likewise, the discussion of stellar coronal abundances as determined by observations in the **extreme-ultraviolet (EUV)** using the *Extreme Ultraviolet Explorer* (*EUVE*) and *Solar Heliospheric Observatory* (*SOHO*) spectrometers will be limited, and readers should refer for more details to the recent articles by Mason & Monsignori Fossi (1994), Schrijver *et al.* (1995), and Drake *et al.* 1995. These exclusions essentially mean that this review will concentrate on the interpretation of the soft X-ray spectra of stars of spectral types F through M that have been obtained by the *Advanced Satellite for Cosmology and Astrophysics* (*ASCA)* since its launch on February 20, 1993. Furthermore, since analyses of many of the spectra that *ASCA* has obtained have in many cases not yet been published, in my comparisons of theoretically predicted versus observed spectra I will perforce mostly use *ASCA* data that I and my collaborators have obtained as part of several of our own Guest Investigator programs.

The structure of this review is as follows: in §2, I describe the theoretical concept of a coronal plasma, and the assumptions that are incorporated when calculating the X-ray spectrum emitted by such a plasma; in §3, I give some examples of the *ASCA* spectra that have obtained of cool stars; in §4, I summarize the coronal elemental abundances that such analyses have yielded and address the issue of how uncertain are these determinations; and, in §5, I summarize my conclusions and present some suggestions as for promising avenues for future studies in this area.

2. Coronal Plasma Models

Coronal plasma models have been extensively used, initially to model the solar coronal spectrum (hence the name), subsequently to model the spectra of other types of astrophysical plasmas, e.g., supernovae remnants, stellar coronae, shocked regions in the winds of hot stars, etc., that have physical conditions more or less similar to the solar corona. Good recent reviews of such models have been given by Mewe (1991) and Raymond & Brickhouse (1995). For present purposes, I will concentrate on (a) a discussion of the 'built-in' assumptions typically incorporated in these models, (b) an examination of potential sources of errors in these models, and (c) how such model spectra are compared with observed spectra of astrophysical plasmas so as to infer physical parameters such as the elemental abundances.

A coronal plasma model is an 'ideal' construct in that real plasmas, while they may in many ways approximate it, will always violate some or all of its defining requirements, viz: the plasma (i) is collisionally ionized and radiatively cooled, (ii) is in ionization equilibrium, (iii) is optically thin at all energies to its radiation, (iv) has electron and ion components with Maxwellian energy distributions with the same temperature, and (v) is not affected by any external radiation through processes like photoionization. Conditions close to these are often found in low-density ($N_e \leq 10^{10}$ cm^{-3}), high-temperature ($T_e \sim 10^{6-8}$K) plasmas such as the solar corona. Given these assumptions and assuming that the atomic physics for line and continuum emission is accurately described, for any specified T_e, N_e, and adopted set of elemental abundances, the emissivity per unit volume of the model plasma as a function of energy, or model spectrum, can be calculated. The most commonly used coronal plasma codes nowadays appear to be the Mewe & Kaastra (or MEKA), Raymond & Smith, and Landini & Monsignori Fossi codes. Since there are thousands of lines of astrophysically abundant elements in the ultraviolet, EUV, and soft X-ray spectral regions that contribute, together with continuum processes such as free-free, bound-free, and two-photon emission, these coronal emission models require large amounts of atomic data.

What are the primary sources of uncertainty in these coronal models? The major internal uncertainties are probably (i) the particular ionization equilibrium that has been adopted, and (ii) error and omissions in the tabulated lines, their predicted energies and collsion strengths. This latter problem is particularly acute in the Fe L-shell region of 0.5 to 1.5 keV (8 to 24 Å) which contains a large number of lines, principally the $n = 3$ and $n = 4$ to $n = 2$ 'L-shell' line complexes from a variety of ionization stages of Fe (Fe XVII - XIV), the analogous Ni L-shell complexes, as well as the resonance lines of the He- and H-like ions of N, O, Ne, and Mg. Liedahl *et al.* (1995) have discussed the deficiencies of the Fe L-shell atomic data that were included in pre-1995 versions of the standard coronal plasma models, and recent versions of these codes (e.g., the MEKAL code of Mewe, Kaastra, & Liedahl 1995) have incorporated these updated to the atomic data, but further improvements are still clearly necessary, e.g., to the Ni L-shell lines' atomic data.

The major external uncertainty in using such coronal models to fit observed spectra is that of ascertaining whether the physical conditions in the astrophysical plasma match those assumed in the model. For example, most stellar coronae are probably not in an isothermal, constant-density, optically thin, steady state, but have both temperature and density variations, at least some strong resonance lines that are optically thick, and can exhibit variability on timescales as short as minutes (during flares). There is also some evidence from studies of the solar transition region and corona (Laming *et al.* 1995) that there may be elemental abundance stratification as a function of temperature. Another possible complication is the presence of 'non-thermal' continuum emission that might contaminate the otherwise thermal coronal emission.

The effects of all these departures from 'ideal' coronal models need to be examined on a case-by- case basis, but some general and reasonably secure conclusions can be stated. Firstly, when modeling observed soft X-ray spectra of stellar coronae with sufficient signal-to-noise, isothermal models are almost invariably unacceptable, and at least two discrete temperature components are required. However, as first noted by Craig & Brown (1976), low- and moderate-resolution soft x-ray spectra are rather insensitive to the finer details of the temperature structure of the emitting plasma, and in general the inversion procedure to find the emission measure $\mathrm{EM} = \int N_e^2 dV$ as a function of temperature (the so-called differential emission measure or DEM) is ill-defined. Thus, for example, all *ASCA* spectra of stars that have been modeled to date can typically be well-fit by models with either 2, 3, or 4 discrete-temperature (hereafter 2-T, 3-T, or 4-T) components, or by more complex functional representations such as high-order polynomials. Other effects such as those due to high densities and optical depth, while they can affect specific lines and line ratios quite strongly, are probably negligible, at least at the spectral resolution of present soft X-ray spectrometers (see Mewe 1991 and Singh *et al.* 1996 for a more detailed discussion). Finally, nonthermal continua and departures from equilibrium conditions are probably not significant in most stellar coronae, with the possible exception of during the impulsive phases of flares: since most stellar coronal spectra are accumulated over periods of hours to days, these effects should normally be negligible.

The standard way in which the spectra of astrophysical plasmas are compared with those predicted by coronal plasma models is to use 'global' fitting procedures such as those that are incorporated into the XSPEC and SPEX spectral analysis software packages. An initial model is adopted, with an assumed temperature structure and set of elemental abundances, together with an estimated interstellar hydrogen column density n_H. Thus, if one uses a 2-T model with abundances assumed to be the same as those in the solar photosphere, this means that there are 5 free parameters (the temperature and emission measure of each component and n_H) in such a model. The values of the free parameters are varied until, in the context of this particular model, the best fit of the calculated with the observed spectrum is obtained. Failure of such 'solar-abundance' models to fit the observed spectra then presumably would imply that the elemental abundances prevailing in stellar coronae are not in the same proportions as in the solar photosphere. Since much of the solar coronal plasma also does not appear to have the same abundances as are found in the solar photosphere, it is perhaps not too surprising that, as discussed below, stellar coronae also appear to have peculiar elemental abundances

3. *ASCA* Spectroscopy of Stellar Coronae: The Data and the Modeling

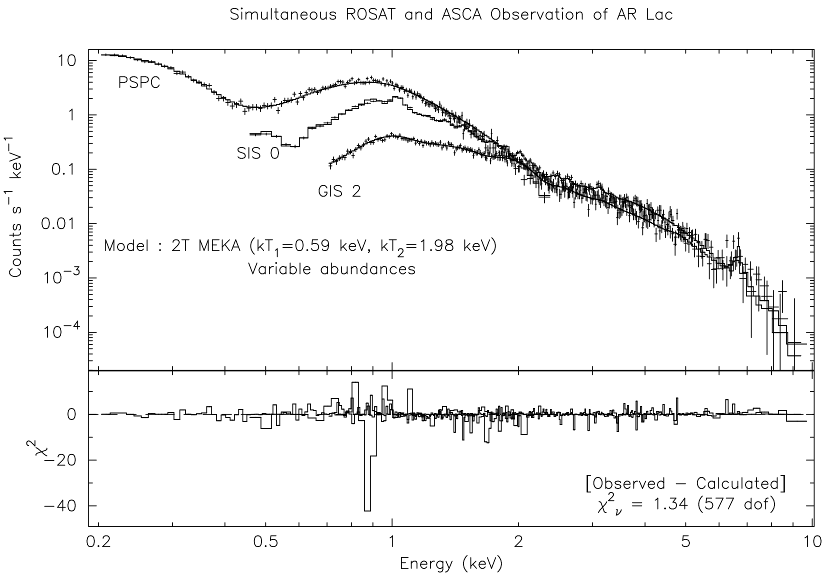

Figure 1. The simultaneous *ASCA* SIS 0 and GIS 2, and *ROSAT* PSPC spectra of AR Lac are plotted as crosses and the best-fit, 2-T variable-abundance MEKA model as the histograms in the top box, while the resultant contributions to the χ^2 statistic are shown in the lower box, all as a function of energy (from Singh *et al.* 1996). The hotter component has an emission measure 1.5 times that of the cooler one. The best-fit abundances for this model are shown in Fig. 3.

The *ASCA* Observatory has been described in some detail by Tanaka *et al.* (1994), so here I will only very briefly summarize its salient characteristics. It comprises four imaging X-ray telescope (Serlemitsos *et al.* 1995) at the foci of which are two Solid State Imaging Spectrometers, SIS0 and SIS1 (Burke *et al.* 1991), and two GAs Imaging Spectrometers, GIS2 and GIS3 (Ohashi *et al.* 1991), respectively. The energy coverages of the two types of detectors are quite similar ($0.5 - 10$ keV for the SIS's compared to $0.8 - 10$ keV for the GIS's), but the energy resolution of the SIS's (2% FWHM at 5.9 keV decreasing to 6% at 1.0 keV) is a factor of $3 - 4$ better than that of the GIS's. Because this latter property makes them more sensitive to line emission, I will mostly limit my discussion to SIS spectra. The effective areas of the 4 detectors are similar ($\sim 100 - 150$ cm^2) over the central part ($1.5 - 5.0$ keV) of their energy ranges. In our group's experience, an accumulated SIS total counts of $\geq 10^4$ is required in order to obtain good constraints on the properties of a coronal-type X-ray source.

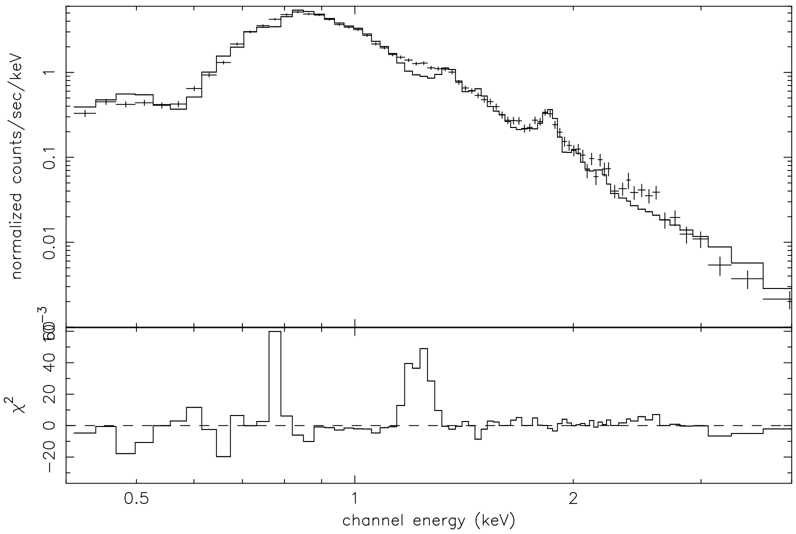

Figure 2. The same as in Fig. 1, but showing the *ASCA* SIS 0 spectrum of Capella and the best-fit 2-T variable-abundance MEKAL model (i.e., the MEKA model with the Fe L-shell atomic data updated), from Drake *et al.* (1996). Notice the poor fit of the model in the vicinity of the Ne X Lyman$-\beta$ line at 1.2 keV. The temperatures of the two components are 0.55 and 0.9 keV with the hotter component having an emission measure 0.47 times that of the cooler one. The best-fit abundances for this model are shown in Fig. 4.

Some examples of *ASCA* spectra, showing both the actual data as well as the best-fit model spectra, of the RS CVn binary AR Lac (chosen as an example of a relatively hard coronal source), and the nearby active binary system Capella (a fairly soft coronal source), are shown in Figures 1 and 2, respectively. The particular best-fit models that I show here are 2-T models in which the elemental abundances were allowed to vary from their solar photospheric values (but the abundance patterns of the two components were assumed to be identical). For the solar photospheric reference abundances, I have adopted the values given by Anders & Grevesse 1989: notice that more recent estimates of the Fe abundance in the solar photosphere (e.g., Grevesse *et al.* 1992) are about 0.15 dex smaller than the Anders & Grevesse Fe value of log $N_{Fe} = 7.67$. I show the elemental abundances as determined from these coronal spectra as a function of their first ionization potentials (FIP) in Fig. 3 (AR Lac) and Fig. 4 (Capella).

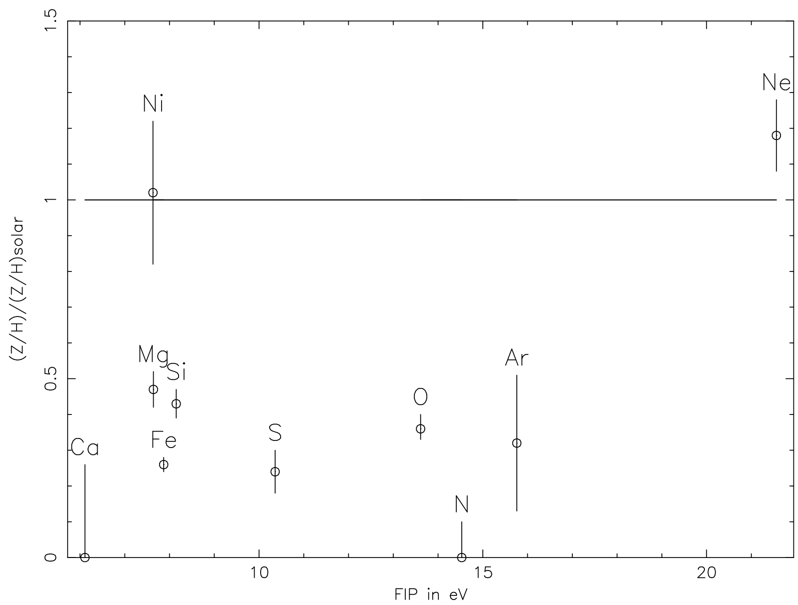

Figure 3. The elemental abundances which give the best fit to the *ASCA* SIS 0, GIS 2, and *ROSAT* PSPC spectra of AR Lac are plotted as a function of first ionization potential. The error bars shown are the formal-fit errors only and do not include the possible systematic errors that are discussed in the text.

Notice that, except for the elements Ni and Ne in AR Lac, all elements appear to have lower abundances than in the solar photosphere (hereafter referred to as subsolar abundances). Typical depletions range from factors of 2 to ≥ 5. The error bars shown indicate the formal-fit errors and mostly reflect the errors due to counting statistics. In AR Lac there is no evidence for any trend of the depletion factor with FIP, whereas in Capella there is some evidence that elements with FIP values greater than 10 eV are more depleted than those with low-FIP values. This low- versus high-FIP effect is seen in the solar corona where the ratio of their respective depletions is about 4 (cf. Feldman 1992), and it is generally (but not unanimously: see Fludra & Schmelz 1995) believed that it is the abundances of the low-FIP elements that are enhanced relative to their photospheric values. The results shown here for Capella are more consistent

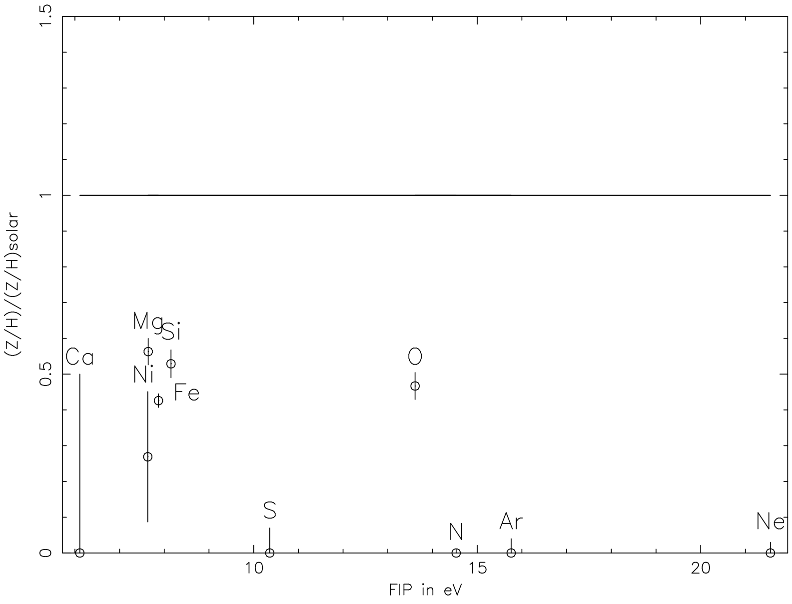

Figure 4. The elemental abundances and their formal-fit errors, for the best-fit model to the *ASCA* SIS 0 spectrum of Capella, are plotted as a function of first ionization potential.

with the alternate hypothesis that it is the high-FIP elements that are depleted in the solar corona, but, as noted below, the systematic uncertainties in the derived abundances of 2 of the 4 high-FIP elements (Ne and N) are large, so that this is not a strong conclusion.

The spectrum of AR Lac is very similar to the *ASCA* spectra of other very active binaries, e.g., Algol and RZ Cas, and the very active single K dwarf Speedy Mic, and the temperatures and abundances inferred for these other stars are likewise similar to those inferred for AR Lac. Likewise, the *ASCA* spectra of the intermediate-activity giant β Cet and dwarf star π^1 UMA are similar to that of Capella, and again similar temperature structures and abundance patterns are inferred. This suggests that it may be the activity level of a corona, as determined by the X-ray luminosity L_x or surface flux S_x, for example, that influences the elemental abundances that prevail in the coronal structures: the RS CVn and Algol binaries with $L_x \sim 10^{31}$ erg s^{-1} thus show one pattern, while moderate activity dwarf and giant stars with $L_x \sim 10^{29-30}$ erg s^{-1} show a different pattern. To this date, no *ASCA* observation has been made of a star with a low-activity corona similar to that of the sun ($L_x \leq 10^{28}$ erg s^{-1}) in order to see whether a solar-like FIP-effect is evident in its soft X-ray spectrum.

Mewe *et al.* (1996) have analyzed simultaneous *ASCA* and *EUVE* spectra of the very active, single K dwarf AB Dor using the SPEX spectral analysis package and (a) confirmed that the coronal plasma of this active star has an essentially bimodal distribution and (b) inferred coronal abundances that are depleted relative to their solar values by factors of $2-3$ for the best-determined elements, except for Mg (0.86 times solar) and Ne (1.5 times solar). The average depletion of ~ 0.5 that Mewe *et al.* infer for AB Dor is not as extreme as the ~ 0.25 value that our group has inferred for the very similar star Speedy Mic. Given the differences in the analysis techniques and datasets it remains to be seen whether or not this difference is significant.

4. *ASCA* Spectroscopy of Stellar Coronae: The Elemental Abundances

Table 1. Lines of He- and H-like Ions of Abundant Elements in 0.4 - 10 keV Range.

Ion	Energy keV	Wavelength Å	Formation Temperature (log T in K)
N VI	0.43	28.8	6.2
N VII	0.50	24.8	6.3
O VII	0.57	21.6	6.3
O VIII	0.65	19.0	6.5
Ne IX	0.92	13.4	6.6
Ne X	1.02	12.1	6.8
Mg XI	1.35	9.17	6.8
Mg XII	1.47	8.42	7.0
Si XIII	1.86	6.65	7.0
Si XIV	2.01	6.18	7.2
S XV	2.46	5.04	7.2
S XVI	2.62	4.73	7.4
Ar XVII	3.14	3.95	7.35
Ar XVIII	3.32	3.73	7.6
Ca XIX	3.90	3.18	7.45
Ca XX	4.10	3.02	7.75
Fe XXV	6.70	1.85	7.85
Fe XXVI	6.97	1.78	8.2
Ni XXVII	7.80	1.59	7.95
Ni XXVIII	8.05	1.54	8.3

How Reliable are *ASCA*-Derived Coronal Abundances? The answer to this question is a function of (i) how good of a representation of the real corona the best-fit model is, (ii) which element is being referred to, and (iii) how well-exposed the particular *ASCA* spectrum under consideration is in the spectral region(s) containing the strongest line(s) of this element. Some concerns were raised in the 'early days' of *ASCA* analysis as to whether the very simplified temperature structures (usually 2-T or 3-T models) generally adopted were systematically biasing the values of the elemental abundances that were being inferred. Our group and others (e.g., Singh *et al.* 1995, 1996; Kaastra *et al.* 1996) have extensively tested this possibility by fitting the same observed *ASCA* spectra with both 2-T, power-law DEM, and high-order polynomial DEM models and the general conclusion is that the same pattern of elemental abundances (at least within the combined statistical errors) is recovered by all those models which can acceptably fit the data. What about the individual elements which have strong lines in the soft X-ray region and hence measurable abundances? I have listed the energies and corresponding wavelengths of the 9 elements which have the resonance line complexes of their He- and H-like ions in the *ASCA* spectral range in Table 1. It is in essence the fit to these lines that yields the relative elemental abundances, while it is the line-to-continuum ratio that determines their normalization relative to hydrogen. The errors quoted in the tables giving the results of analyses of *ASCA* spectra (e.g., White *et al.* 1994, Drake *et al.* 1994, Singh *et al.* 1995, 1996) and shown here in Figs. 3 and 4 are typically $0.05 - 0.2$ dex and are the formal fit errors, and thus should be regarded as lower limits to the 'real' errors. The relative magnitudes of the errors in the individual abundance parameters, for instance, are indicative of which elemental abundances are best and which are least well-determined, and are fairly robust. I now discuss the accuracy of the abundances on an element-by-element basis.

Fe. The Fe abundance is determined by the contrast of the L-shell 'hump' at 1 keV compared to the higher-energy continuum in soft sources like Capella and β Ceti, and by the additional ratio of the He-like Fe XXV K feature at 6.7 keV to the continuum in the harder spectra of active binary stars. The Fe abundances inferred using the K line are generally consistent with those obtained from the L complex in those stars whose spectra are hard enough that the K line is detected, according to both analyses of coronal spectra (e.g., Singh *et al.* 1996) and of the X-ray spectra of clusters of galaxies (Mushotzky *et al.* 1996). This suggests that any systematic uncertainties in the inferred Fe abundances due to the uncertainties in the atomic physics of L-shell region are smaller than the typical statistical uncertainties for Fe (i.e., ≤ 0.1 dex). The reality of the low Fe abundances inferred from *ASCA* spectra of coronal stars is supported by *EUVE* spectra of cool stars (e.g., Schrijver *et al.* 1995) which also show lower than expected contrast of Fe lines to the EUV continuum than is predicted by solar-abundance models.

Si. The Si abundance is predominantly determined from the Si XIII/XIV complex at 1.9 keV: this feature is strong, and should not suffer from significant contamination from other species, and the atomic physics of these H- and He-like ions should be fairly accurately known. The major external uncertainty in the Si abundance is due to the presence of Si in the SIS spectrometer itself. Mushotzky *et al.* (1996) have studied this problem, and conclude that uncertainty in the SIS calibration due to this is quite small, and that the resultant uncertainty in nay inferred Si abundance is ≤ 0.1 dex.

S. The S abundance is mostly based on the observed strength of the He- and H-like S XV/XVI complex at 2.5 keV: this feature is predicted to be quite strong in solar-abundance coronal plasmas of the temperatures that prevail in active stellar coronae, but is often weaker than this in actual spectra, hence the inferred S underabundances.

Mg. The Mg abundance is based on the observed strength of the the He- and H-like Mg XI/XII complex at 1.4 keV: this feature is also predicted to be one of the most distinguishable ones present in coronal plasmas, and indeed usually is. It does suffer from confusion due to lines of other species, primarily Ni and Fe lines, particularly for plasmas with significant material at temperatures ≥ 1 keV. Mushotzky *et al.* (1996) discuss in more detail the confusion in this spectral region, uncertainties in the detector response, and the resultant uncertainties in the inferred Mg abundances: they conclude that the latter are probably greater than the typical statistical uncertainties found for this element, i.e., ≥ 0.2 dex.

O. The O abundance is mostly derived from the observed strength of the O VIII line at 0.65 keV: this feature is not seen as an individual line in *ASCA* SIS spectra but is blended with the low-energy edge of the Fe L shell complex which is predicted for these temperatures to be at ~ 0.73 keV. Again, as Mushotzky *et al.* (1996) note, the presence of O in the SIS detector itself, as well as the position of this feature close to the low-energy edge of the SIS's spectra range, do certainly add a systematic uncertainty to any inferred O abundances, but, as for Si, they estimate that it is relatively small (≤ 0.1 dex).

Ca. The Ca abundance is mostly based on the He-like and H-like Ca XIX/XX feature at 4.0 keV (a relatively unconfused region) that is observable in high signal-to-noise *ASCA* spectra of the harder coronal sources. The uncertainties in the Ca abundance are thus believed to be dominated by the statistical errors.

Ar. The Ar abundance is primarily based on the He-like and H-like Ar XVII/XVIII complex that is predicted to be at 3.3 keV. Similarly to the Ca line, the Ar line is in a relatively unconfused spectral region, and the uncertainties in the inferred Ar abundance should be predominantly statistical.

Ne. The stongest predicted lines of Ne are in the K-shell complex at 1.0 keV which lies right in the middle of the Fe L complex. Despite this, Mushotzky*et al.* (1996) present evidence based on simulations that Ne abundances inferred from *ASCA* spectra do not seem to exhibit any significant systematic errors. However, a recent analysis of the *ASCA* SIS spectra of the relatively soft coronal sources Capella and β Cet (Drake *et al.* 1996) has found that the best-fit MEKAL models to these spectra have great difficulty in fitting this region of the spectrum, and, indeed, prefer that the Ne abundance be vanishingly small, suggesting that there may be significant systematic problems in the inferred Ne abundances for at least some coronal sources. Thus, Ne abundances measured by *ASCA* should be treated with some caution, in my opinion.

N. The abundance of N in *ASCA* spectra is primarily inferred from the presence (or absence) of a line feature due to N VII Ly α at 0.50 keV, which is predicted to be strong in solar-abundance plasmas (and whose atomic physics is known very accurately). To my knowledge, no SIS spectrum of any star has shown evidence for this feature, implying either a universal absence of N in stellar coronae, or that the effective area of the SIS has been substantially overestimated at this energy, which lies close to the low-energy cut-off and hence in a spectral region where the effective area is rapidly decreasing towards shorter energies. An *ASCA* Calibration Workshop held in December 1995 has, in fact, concluded that the current SIS calibration below 0.6 keV is unreliable.

Ni. The Ni L-shell complex sunstantially overlaps in energy the Fe L-shell complex. The Ni K-shell line complex lies at a very high energy (8.1 keV) and has never, to my knowledge been detected in any coronal source. The uncertainties in the atomic physics of the Ni L-shell lines are probably large, and I hope that Liedahl and his collaborators will do the same type of thorough review of these Ni lines as they did for their Fe L-shell counterparts. Until such a study is done, any Ni abundance measured by *ASCA* should be taken with several grains of salt: I estimate that the present systematic uncertainties for Ni are ≥ 0.3 dex.

5. Conclusions

The abundances of stellar coronae measured by *ASCA* indicate that the heavy element to hydrogen ratios in these plasmas is are (at face value) only about one-third of their solar photospheric values. The best-determined abundances of elements like Fe, Si, and S are estimated to have total (statistical plus systematic) errors of 0.1-0.2 dex that rival the accuracy at which photospheric abundances can be measured from the optical spectra of stars, while the errors for some of the other elements such as Mg, Ne, and Ni are somewhat larger. Various explanations have been offered to explain these findings:

(i) that the abundances are really subsolar, either due to their photospheric abundances being subsolar and their coronae reflecting this, or to the operation of a differentiation mechanism in their coronae. There is in fact a long-standing finding (Naftilan & Drake 1977) which may support the first alternative, recently confirmed with better data and a larger sample (e.g. Randich *et al.* 1994), that the active stars in many RS CVn binary systems exhibit underabundances in their photospheric Fe abundances of factors of several to 10 compared to the solar value. However, since single stars like AB Dor which have solar photospheric abundances also exhibit subsolar coronal abundances, a different explanation would have to found for these stars.

(ii) that the weakness of the lines relative to the continuum is some kind of artifact unrelated to the elemental abundances; e.g., there is an extra non-thermal continuum in the soft X-ray region, or that the lines are supressed due to radiative transfer effects, or that the apparent continuum is actually dominated by a cloud of line emission from thousands of weak lines that have not been included in the line lists used by the plasma codes. None of these suggestions seem likely in my opinion: the fact that a similar result is inferred from analyses of EUV spectra of stars, e.g., Schrijver *et al.* (1995), Stern *et al.* (1995), Mewe *et al.* (1995) means that any such proposed mechanism must operate with about the same magnitude in both the X-ray and EUV spectral regions, which seems somewhat implausible.

Where should we go from here? In my opinion, we should use the remaining *ASCA* observing cycles to try and obtain high S/N (≥ 100) spectra of a wider range of coronal stars, particularly concentrating on stars that are (a) less pathological in their activity levels than the RS CVn and Algol binaries that dominated the early *ASCA* observations of stars, and (b) have well-determined photospheric abundances. Joint observations with *EUVE* and/or observations of stars for which *EUVE* spectra have been or will be obtained should prove particularly invaluable.

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