X-RAY OBSERVATIONS OF STELLAR CORONAE AND WINDS

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Since the discovery in 1974 by Heise *et al.* (1975) with the ANS satellite of X-ray flares from YZ CMi and UV Cet, only a few attempts to observe X-rays from flare stars have succeeded. On the other hand, the discovery of X-ray emission from Capella by Catura, Acton and Johnson (1975) in a rocket flight has been followed by so many detections of RS CVn binaries by the low energy detectors (0.15 - 3 keV) of the HEAO A2 experiment that, while Catura *et al.* estimated that many variable soft X-ray sources probably exist, Walter, Charles and Bowyer (1978) could identify the RS CVn systems as a class of quiescent sources. They have higher temperatures than at first predicted, so they are ideal for detection in the energy range 1/4 keV to a few keV, and the high space density provides many close candidates. Further information on these sources is now available from the GSFC Solid State Spectrometer Experiment on the *Einstein* Observatory, which with energy resolution of 140 eV can resolve the major complexes of line emission from Si, S, Fe and less abundant elements that are an important part of the emission of 10 million degree plasmas. The imaging experiments on the *Einstein* Observatory have detected X-ray emission from subsets of all types of stars, and results on the luminosities, variability and temperatures are just beginning to come out.

A survey of known RS CVn binaries with the HEAO A2 experiment has recently been reported by Walter *et al.* (1979). Out of 59 RS CVn binaries, 15 were detected at fluxes corresponding to luminosities of 10^{30} - 10^{32} ergs/s. Upper limits for regular, long and short period systems [as classified by Hall (1976)] still allow the remaining sources to have similar luminosities as well. The Solid State Spectrometer has detected 8 of these, in some cases with the same, in others different, luminosities. Evidence for variations by up to factors of 5 is accumulating.

Catura, Acton and Johnson (1975) found their data from Capella characterized by a bremsstrahlung temperature of 8×10^6 K. The HEAO A2 experiment also observed a temperature about as high (Cash *et al.* 1978) and in addition showed evidence for an emission feature at 0.85 keV, the correct energy for an Fe XVII and Fe XVIII blend that a solar abundance of iron would produce in a 7.4×10^6 K gas in collisional equilibrium. Sensi-

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tivity of the line to temperature allowed Cash *et al.* to severely limit any contribution of gas, at least with solar abundance of Fe, in the range 5×10^5 - 3×10^6 K, including the temperature which Haish and Linsky (1976) pointed out would be more reasonable for an acoustically heated corona. The HEAO A2 experiment found an even higher temperature for UX Ari (12×10^6 K) with, however, a strong upper limit on the Fe line emission seen in the Capella spectrum (Walter *et al.* 1978). Almost as high a temperature has been found for σ CrB (Agrawal, Riegler and Garmire 1979) and similar values of broad band "colors" for other detections (Walter *et al.* 1979). As Walter *et al.* (1979) pointed out, these results suggested that temperatures too hot for the gas to be gravitationally bound were the rule. Tha values of mass loss implied for escaping gas, 10^{-9} $M_\odot$/y, are discussed in attempts to explain period changes [see Hall (1976) and DeCampli and Baliunas (1979)] as well as evolution (Popper and Ulrich 1977), but a wind at these temperatures would carry away 10 times as much energy as it would radiate, and no mechanism for providing for such an energy loss or evidence for such a flow of energy is known.

The temperatures obtained by the Solid State Spectrometer for the 8 RS CVn sources are all in the range $(6 - 25)\times10^6$ K. Capella shows definite deviations from a single isothermal model, which can be adequately described by a second component of $\sim 46\times10^6$ K (Holt *et al.* 1979). The temperature of 25×10^6 K found for UX Ari was about twice as hot as that seen by Walter *et al.* (1978). The range of emission integrals 10^{53} - 10^{55} cm^{-3} is 10^4 - 10^6 higher than for the Sun.

Not only Fe emission is evident in the spectrum of Capella, but Mg, Si and S as well. On the other hand, in addition to UX Ari, RS CVn and AR Lac show less than 10% of solar abundances of Fe. For all these sources the apparent abundances of Si and S may be several tenths of solar. Two sources, λ And and HK Lac, barely in the long period RS CVn group with periods of 20.5 and 24.2 days, like Capella do show evidence of Fe. The apparent underabundances of heavy elements, as well as overabundances in Capella in the two-temperature models, could be caused by complications not taken account of in the collisional equilibrium models. The underabundances, however, are reminiscent of the results of Naftilan (1975) and Naftilan and Drake (1977) from chromospheric lines.

The high temperatures have encouraged the solar analogy for the X-ray emission that would seem a natural counterpart of the solar-like model of the optical properties. In the latter the active regions are confined predominantly to one hemisphere. As Walter *et al.* (1978) pointed out, the X-rays should then peak out of phase with the photometric wave, they should be unaffected by primary eclipse and they should on the average be significantly reduced during secondary eclipse. The model also suggests variability due to flare events and to quantization of spots on the surface. The data to date indicates variability by factors ~ 5, some of it flare related and some cases suggesting correlation with the photometric wave. Walter *et al.* (1979) estimate that if a confined emission region above the usually dark hemisphere of the cool star was responsible for the light curve HEAO A2 observed, the emission region extended no more than 1/10 a stellar radius above the surface. White (1979) has found that flux for AR Lac during one secondary eclipse was 30% lower than the flux during a primary eclipse and that, if eclipse is responsible, the X-ray emission region was half a stellar radius above the surface and extended across the entire face of the K0 subgiant, despite the photometric wave being at phase 1/4. Changes by about the same amount have been observed from RS CVn, which have not been related to special phases. More observations are needed to prove the phase dependence expected in the star spot model. Also, while relatively high fluxes during some part of a radio or Hα flare (White, Sanford and Weiler 1978, Newell *et al.* 1979) are very suggestive of a simultaneous X-ray flare, no X-ray flare has been followed through a rise and decline.

In the solar analogy the $(6 - 25)\times10^6$ K gas is tied to these stars by magnetic loops as the $(2 - 12)\times10^6$ K gas of solar X-ray flares is tied to the Sun. Rosner, Tucker and Vaiana (1978) derived the relation $T = 1.4\times10^3\ (pL)^{1/3}$, assuming a constant pressure along a loop of length $2L$ and constant deposition of energy along the loop. They reported the relation adequately obeyed for flares on the Sun. For transition region pressures about the same, dimensions larger by a factor of 10, which is certainly the case for Capella if the dimensions scale as the stellar radius, correspond indeed to temperatures only 2 - 3 times as large. Walter *et al.* (1979) have used the emission integral to relate, in this model, the fraction of stellar surface covered with loops, the length of the loops, and the number of loops to the chromospheric pressure. The same model applied to the Solid State Spectrometer data on temperature and emission integral predicts pressures $\gtrsim$ dynes/cm^2, while chromospheric pressures for Capella, interpreted as Capella A (Haisch and Linsky 1976) or Capella B (Ayres and Linsky 1979) and λ And (Baliunas *et al.* 1979) are a factor of 10 less. This discrepancy may be due to the simplicity of the model and application under inappropriate conditions.

With respect to both temperatures and X-ray emission integrals, the larger flares of flare stars (Kahn *et al.* 1979) and the X-ray emission from Algol are similar to the RS CVn's, as they also are with respect to radio emission. White (1979) suggests that the X-rays from Algol could also be from a magnetically confined corona of the K star rather than from the vicinity of the B star. The Solid State Spectrometer observations showed no evidence of a difference between primary and secondary eclipse.

While one or two examples of these categories of stars have been known to emit X-rays since ∿ 1974, data from the HEAO A2 experiment first and now from the *Einstein* Observatory are showing that X-ray emission is a common characteristic and have begun to constrain its geometry and dynamics.

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