letters to nature

Discovery of a corona around an early-type star and the problem of mass loss

THE star τ Sco, HD149438, spectral type B0 V, was observed spectroscopically by the Princeton telescope-spectrometer on the Copernicus satellite during June and July 1973. This star is well known[1] as being one of the few early type stars with a small projected rotational velocity, v-sin$i$=20 km s^{-1}, thus showing narrow spectral lines with a minimum of overlap or blending. So the spectrum of the star was scanned with a resolution of 0.05 Å over the entire wavelength range from 950 Å to 1,560 Å to obtain a prototype ultraviolet spectrum for an early-B star. This spectrum is in preparation by Rogerson and Upson.

Apart from the numerous spectral features with a full width at half maximum (FWHM) of about 20 km s^{-1} which originate in the photosphere of the star, and the interstellar absorption lines, the spectrum also shows a few very wide absorption lines. These lines are identified as belonging to the spectra of O VI at 1,032 and 1,038 Å, NV at 1,239 and 1,243 Å and Si IV at 1,394 and 1,403 Å. The lines are highly asymmetric with the largest depression close to the laboratory wavelengths and an enhanced short-wavelength wing, which extends to a Doppler velocity of about −1,000 km s^{-1}. This suggests that the lines are formed in the expanding outer layers of the atmosphere.

The strong presence of O^{5+} and N^{4+} ions in the outer layers of the star is surprising. From the visual and ultraviolet spectrum the temperature of the stellar photosphere is determined to be about 30,000 K and the stellar atmosphere models predict that the temperature in the layers above the photosphere is less. To produce a significant fraction of the observed highly ionised atoms, the temperature in the outer layers must be[2] of the order of 1×10^5–5×10^5 K. (The production of O^{5+} and N^{4+} by radiative ionisations can be neglected since the required stellar radiation in the far ultraviolet is very strongly absorbed in the photosphere by neutral hydrogen atoms and ionised helium atoms.) Therefore, the temperature in the atmosphere of τ Sco must decrease with height in the photosphere, go through a minimum in higher layers and then increase again to at least a few hundred thousand K.

A similar temperature structure is known in the solar atmosphere, where the minimum is about 4,200 K and from there on the temperature increases outward throughout the chromosphere until it reaches a more or less constant value of about 2×10^6 K in the corona. The large temperature is due to the dissipation of mechanical energy in the form of acoustic waves in the lower chromosphere and possibly by Alfven waves in the corona[3]. The mechanical energy in the Sun is supposed to originate in the unstable hydrogen convection zone below the photosphere.

Main sequence stars with effective temperatures greater than about 8,300 K are not expected to have well developed hydrogen convection zones nor to generate a large mechanical energy flux which could produce a stellar corona[4].

A possible mechanism for generating a mechanical energy flux in hot stars has been proposed by Hearn[5,6]. He has pointed out that in the presence of a strong radiation field, such as in early type stars, density waves can grow and propagate outwards due to the absorption of radiation. This theory predicts a mechanical energy flux of the order of 10^7 erg cm^{-2} s^{-1} for a main sequence B0 star, which in analogy to the solar chromosphere, seems to be sufficient to heat the outer layers to a few hundred thousand K.

The presence of a high temperature region (called a corona, in analogy to the solar case) around early type stars may provide the clue to the understanding of mass loss from hot stars. The observed expansion velocities are generally accepted to be caused by radiation pressure acting primarily on the resonance lines of abundant ions[7]. An important limitation to the efficiency of this mechanism is the fact that the line transitions which are most suitable for absorbing momentum from the radiative flux in the outer atmospheric layers are also extremely effective in the photospheric layers in the reduction of the needed flux. This problem can be illustrated by the very small rates of mass loss predicted by Lucy and Solomon for stars with effective temperatures slightly greater than 30,000 K, at type B0, where the photospheric C IV lines are very strong.

This difficulty is overcome if the outer atmosphere is hotter than the photosphere, because the abundant ions in the outer atmosphere are different from the photospheric constituents. The presence of O VI ions in the corona, having resonance lines at wavelengths near the stellar flux maximum, is especially important in this respect. If 10% of the coronal oxygen atoms are in the form of O^{5+} and the oxygen abundance is the same as in the Sun, the outward directed radiative force exerted on the gas due to the O VI lines exceeds the inward directed gravitational attraction by a factor of four in τ Sco. A preliminary estimate indicates a rate of mass loss of about $10^{-8} M_\odot$ yr^{-1}. This is about two orders of magnitude less than the mass loss rate from the Orion OB supergiants[8].

How unique is τ Sco? In its visible spectrum there is no indication that the star is different from other B0 V stars, except for its small projected rotational velocity. If the star is normal, as we expect, other early-B stars may be surrounded by coronae as well. A preliminary check of the Copernicus files has indicated that traces of O VI lines are detectable on the lower resolution spectra of several other early type stars. Further details will be published elsewhere.

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