IS THERE MASS LOSS IN β CANIS MAJORIS STARS?

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The purpose of this communication is to show that one possible explanation for the asymmetric line profiles observed in β Canis Majoris stars may be the presence of a stellar wind superimposed on a radial or nonradial pulsation.

The observational material consists of Copernicus (OAO-3) scans of the Si III line at 1294.55 Å in the β Canis Majoris variables ν Eridani and σ Scorpii, and in β Canis Majoris itself. The scans were obtained with the U1 scanner, having a resolution of 0.05 Å. With an integration time of 16 sec per point, a scan of about 1.75 Å was obtained in approximately 20 min. This is about one-twelfth the period of ν Eri and one-eighteenth the period of σ Sco and β CMa. Thus the scanning time should not be long enough to produce a significant phase shift between the blue and red wings of the line. During the scans, the U2 carriage was positioned in such a way as to prevent stray light from entering the U1 scanner. The signal-to-noise ratio is about 10. The observations were planned for the maximum phase in the "beat period" of each star, so as to have the maximum probability of observing asymmetric profiles and/or multiple components. However, it was not possible to observe at any given phase in the short (pulsation) period, so complete phase coverage was not obtained in all cases. We wound up with 9 usable scans for β CMa, 7 for σ Sco and 6 for ν Eri.

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The data were filtered by convolution with a gaussian profile. Background counts and scattered light were subtracted before filtering. The scattered light correction amounts to 10-15% of the continuum signal, and is itself uncertain by around 10%. The continuum was usually drawn through the first few points and the last few points of the scan, except for the most asymmetric profiles in σ Sco, which appear to be incomplete. In these cases, a "flat" continuum was drawn by extending the blue continuum. A comparison with extensive U2 scans of these and similar stars indicates that the "local" continuum obtained in this way is almost certainly too low. This will of course affect the numerical values of some of the line parameters, but it should not change the qualitative form of their variation with phase.

The profiles were rectified by dividing out the continuum, and the central depth, half-width and equivalent width were computed. We also computed the bisector of the profile and an asymmetry parameter, defined as the difference between the bisector point at half the line depth and the bisector point at full depth, divided by the mean half-width of the profiles for the star in question.

Figure 1 shows the rectified profiles at five phases in ν Eri, where phase 0 refers to radial-velocity maximum. The wavelength shift produced by the radial-velocity variation has been removed, and the intensity scales for the individual profiles overlap. The continuum level ($I = 1.0$) for each profile is indicated. Similarly, rectified profiles at six phases in σ Sco are shown in Figure 2.

The most asymmetric profile in ν Eri is the first one, at phase $\phi = 0.222$. It has an asymmetry parameter of $A = -0.08$, indicating that the blue wing in this profile is depressed with respect to the red wing. All the other profiles in ν Eri have $|A| \lesssim .04$, making them nearly symmetric. The last three profiles in σ Sco, at $\phi = 0.623$, 0.668, and 0.741, are very asymmetric, with asymmetry parameters of -0.14, -0.20, and -0.27, respectively. Again, the sense of the asymmetry is such that the core is to the red of the midpoint at half depth, so that the blue wing is depressed. The remaining profiles for σ Sco are all symmetric,

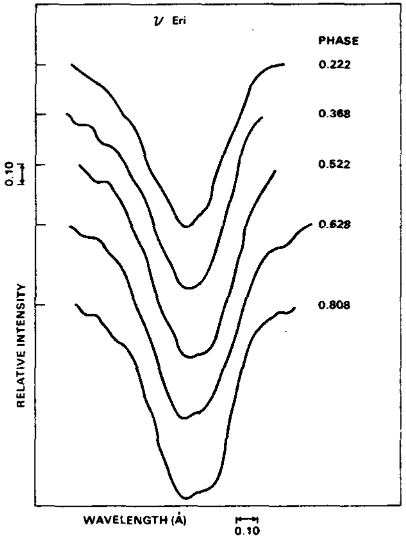

Fig. 1. Variations in the profile of the Si III line at 1294.55 Å in the β CMa-star ν Eridani.

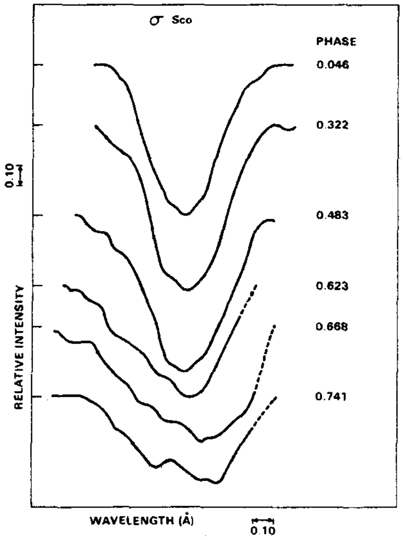

Fig. 2. Variations in the profile of the Si III line at 1294.55 Å in the β CMa-star σ Scorpii.

with $|A| \lesssim .04$.

In ν Eri, the central depth and the half-width both increase slightly with phase, causing the equivalent width to be about 30% larger for $\phi > 0.5$ (ascending branch of the radial-velocity curve) than for $\phi < 0.5$ (descending branch). In σ Sco, on the other hand, the half-width increases dramatically on the ascending branch while the central depth decreases, as can be seen in Figure 2. Thus the equivalent width tends to be conserved. The central depth, half-width, and equivalent width of the profiles for β CMa are essentially constant with phase. Moreover, these profiles are practically symmetric ($|A| < 0.3$) at all phases.

There are two important points to be noted with respect to the profiles in Figures 1 and 2. Firstly, when a large asymmetry is observed, it is always negative (depressed blue wing). Large positive, or redward, asymmetries do not occur in the present data. Secondly, the phase of greatest asymmetry in ν Eri is nearly at the midpoint of the descending branch of the radial-velocity curve, in agreement with the optical observations (Laskarides, Odgers and Climenhaga 1971). But in σ Sco, the phase of greatest asymmetry clearly occurs on the ascending branch of the radial-velocity curve, between phases 0.6 and 0.75. This is in contradiction to the optical observations of Huang and Struve (1955). However, the fact that we observed broad, shallow, asymmetric profiles at nearly the same phase during three different pulsation cycles confirms the reality of this effect. Moreover, we have checked the computation of the ephemeris with great care, and have concluded that the phases are unlikely to be in error by more than 0.1.

Our initial modeling of these line profiles has concentrated on accounting for the predominantly blueward asymmetry, rather than fitting the entire profile point by point. The latter approach requires the fixing of a large number of atomic and atmospheric parameters in addition to the velocity field, and is reserved for future work. We used a computer code that calculates line profiles in a model stellar atmosphere with an arbitrary, depth-dependent velocity field. The models of

Kurucz, Peytremann, and Avrett (1974) with T_{eff} = 20000 K, log g = 4.0 and T_{eff} = 25000 K, log g = 3.5 were both used, with little difference in the asymmetry parameter. The input velocity field was of the form $V = -\alpha \log \tau + V_c$, where τ is the continuum optical depth, and V, α, and V_c are measured in km/s. If α is set equal to zero and V_c alternately takes on positive and negative values, the velocity field simulates a purely radial pulsation. If $V_c = 0$ and $\alpha > 0$, the velocity field simulates a stellar wind. If both α and V_c are non-zero, the two effects are superimposed.

The results of our calculations show that, while radial pulsation in itself produces some asymmetry, this is much smaller than the observed effect, and moreover it is strictly alternating in sign. Thus even the very large value $V_c = \pm 100$ km/s (corresponding to an observed radial-velocity variation of 2K = 170 km/s) gives an asymmetry parameter of only ± .05.

Introducing an accelerating outward flow, or stellar wind (with $V_c = 0$), initially produces a positive asymmetry: for α = 10 km/s, A = + .10. But as α gets larger, the asymmetry becomes more negative, because the velocity shift of the line core becomes greater than the half-width of the profile. Thus for α = 20 km/s, A = + .02, and for α = 40 km/s, A = -.12. When a radial pulsation of $V_c = \pm 50$ km/s is superimposed on a stellar wind with α = 10 km/s, the asymmetry parameter remains predominantly positive; with α = 20 km/s, alternating positive and negative parameters are produced, with larger absolute values than in purely radial pulsation. Finally, with α = 40 km/s, the asymmetry parameter is predominantly negative. This latter situation is illustrated in Figure 3, which shows the computed profiles for α = 40 km/s and V_c = -50,0, and + 50 km/s. The corresponding asymmetry parameters are + .06, -.12, and -.15, respectively.

If the predominantly blueward asymmetry observed in the line profiles of β Canis Majoris stars is evidence for the presence of a stellar wind, these stars must be losing mass to their surroundings. It is generally believed that such stars are too cool to have a radiation-driven stellar wind. But the pulsation itself can drive the wind by

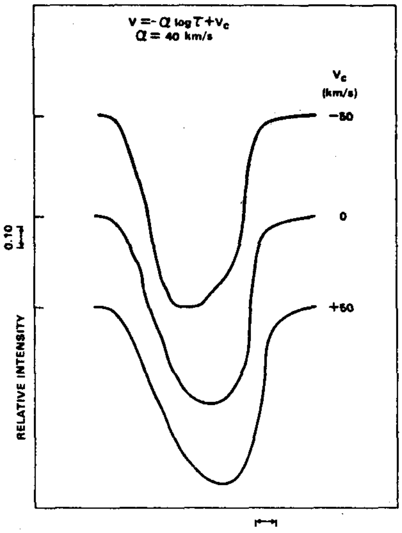

Fig. 3. Theoretical line profiles for Si III 1294.55 Å in a model stellar atmosphere with T_{eff} = 20 000 K, log g = 4.0, and a velocity field of the form $V = -\alpha \log \tau + V_c$, where α = 40 km/s.

dissipation of only a very small fraction of the pulsational energy. However, a note of caution is required. If the rate of mass loss is calculated from the continuity equation, $dM/dt = 4\pi R^2 \rho V$, where R is the stellar radius, and ρ is the density and V the velocity at the depth where the line core is formed, we find that a velocity field with α = 40 km/s implies a mass loss of the order of 10^{-5} $M_\odot$ per year. This is three orders of magnitude larger than the value computed for stars of somewhat earlier spectral type, in which the presence of a stellar wind is well established. If such a large mass loss were present, it would surely have marked observable effects in the stellar spectrum, as well as drastic consequences for the course of stellar evolution.

If the pulsation in β Canis Majoris stars is indeed radial, it is possible that the presence of the velocity field in the stellar atmosphere greatly alters the density structure, so that the rate of mass loss calculated above is not applicable. On the other hand, the pulsation may be nonradial. Osaki (1971) has shown that nonradial pulsation produces a much larger asymmetry than radial pulsation, but also with strictly alternating sign. However, it may be that a very small stellar wind superimposed on a nonradial pulsation will produce the observed negative asymmetry without an excessive mass loss rate. We plan to perform computations to test this hypothesis in the near future.

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DISCUSSION of paper by ROUNTREE LESH and KARP:

FRIEDJUNG: This idea may be ridiculous - but could you explain your profiles by a spot which appeared at certain phases?

ROUNTREE-LESH: Such a spot would be brighter or darker. The light curves are fairly sinusoidal, and I think a spot would do funny things to them. I would need to think this over.

DE LOORE: Mass loss of 10^{-5}/yr is comparable to observed mass losses in luminous O and B stars (10^{-6} $M_\odot$/yr), so I think this is only a factor 10, and not a factor 1000?

ROUNTREE-LESH: I believe that ultraviolet observations of the BoV star τ Sco indicate a mass loss of 10^{-8} $M_\odot$/yr. β Canis Majoris stars are giants or subgiants rather than supergiants, and moreover are cooler than τ Sco - so 10^{-5} $M_\odot$/yr seems high.