THE ROTATION OF THE Be STAR γ CAS

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(Paper read by T. R. Stoeckley)

Abstract. A period of 0.7 days has been found in the peak separation and V/R ratio of the double emission profiles of Hγ and Hβ in this star. The phenomenon is believed to arise from short lived condensations near the base of an equatorially extended atmosphere, and the period to be that of rotation of the star. The deduced stellar diameter is 7 $R_{\odot}$. Further considerations on the emission line profiles lead to a model of an equatorial ring extending 1–2 stellar radii with angular velocity decreasing outwards, and viewed at an axial inclination of some 60°.

1. Introduction

γ Cas is a well-known bright Be star, whose spectrum was investigated quite extensively some 30 years ago, when it showed prominent shell lines (Beer, 1956). Recent photoelectric line profile studies made by Hutchings (1967, 1968a) have shown that the double emission peaks in the Balmer lines vary rapidly and irregularly from minute to minute, as well as showing larger scale changes in intensity over periods of the order of weeks. An intensive study was made of the Hγ and Hβ profiles during the winter of 1968–9 and from some 140 scans there is now also evidence for a period in the separation and V/R ratio of the peaks, which is about 0.7 days.

2. The Observations

The observations were made with the coude scanner of the Victoria 48″ telescope (Hutchings, 1968a) and have a probable error of $\pm 1\%$ of the continuum and a time

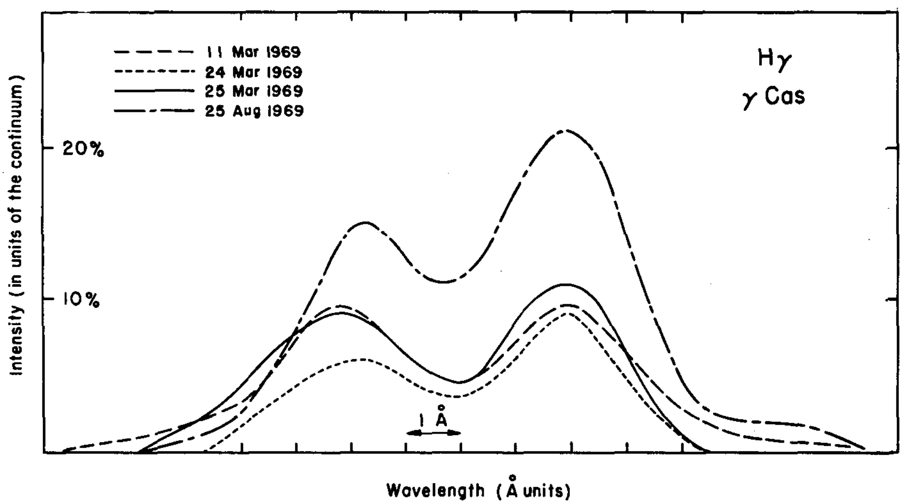

Fig. 1. Observed Hγ profiles in γ Cas with 20 min time resolution.

A. Slettebak (ed.), Stellar Rotation, 283–286. *All Rights Reserved*

resolution of some 5 min. Figure 1 shows some typical Hγ profiles which represent mean profiles over periods of about 20 min. The minute-to-minute variations are therefore eliminated and the diagram illustrates the day-to-day and longer term changes observed. The lower three profiles show the type of V/R and peak separation changes which have been found to be periodic and have typical amplitudes in these changes. The upper profile shows how the whole feature strengthened between March and August 1969.

The periodic variation, partly hidden in the rapid irregular fluctuations, was found in all series of observations taken within some 10 days of each other. Over longer times discontinuous phase shifts were found. Figure 2 shows the observations and

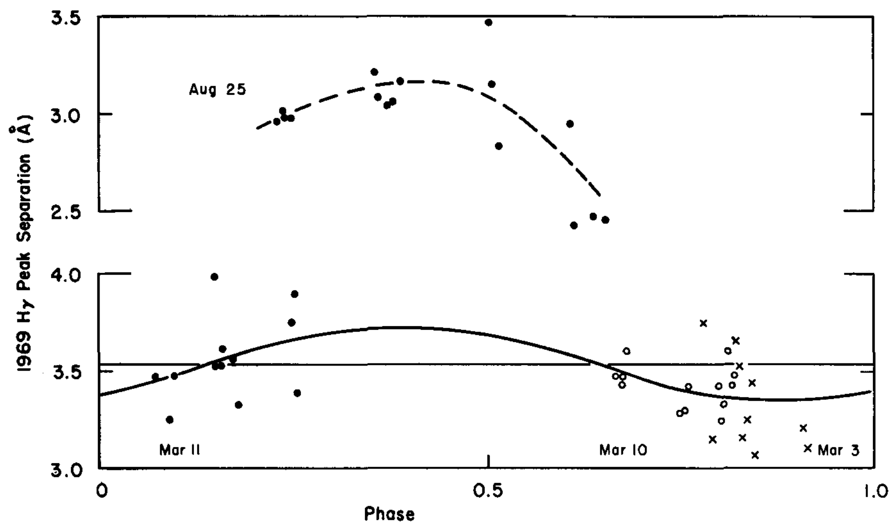

Fig. 2. Observed Hγ peak separation variation and fitted sinusoidal curves.

fitted sinusiodal curve for two typical sets of observations. The period was found by means of a computer program provided by Hill (1969). The mean separation of the peaks is 3.2 Å for Hβ and 3.4Å for Hγ, with a standard deviation of 0.05 Å in each case. The mean amplitude of the periodic variation is 0.5 Å for all coherent sets of observations. The value of V/R varies more widely from month to month, but has a typical periodic amplitude of about 10%.

3. Discussion

The star is classified as B0 IVe by most workers and is evidently a fast rotator. Following Roxburgh and Strittmatter (1965) and Stoeckley (1968) it seems likely that the star is a class IV or V star rotating at equatorial breakup velocity, with an equatorially extended envelope in which the emission lines are formed. This approach has been developed by Hutchings (1968b), in which it is suggested that the star is viewed from within 30° of the equator-on position.

The breakup velocity of rotation of the star is close to 500 km/sec at the equator, so that if we assume the period of 0.7 days to be the rotation period of the photosphere we derive a stellar radius of 7 $R_\odot$. This is in close agreement with accepted values for the radius of such a star.

We now attempt to justify this assumption by checking that it leads to a self consistent model of the star. If the star is losing matter through an equatorial region of zero gravity we may expect that this part of the photosphere fluctuates irregularly in brightness and density and may release occasional condensations of gas whose density is higher than the mean. These condensations would rise slowly and disperse in the outer layers, possibly losing angular momentum. Such condensations would appear irregularly and may last for several days during which they are detectable as a strengthening of the main emission peak alternately on the V and R sides as the mass rotates. The mass-loss mechanism in such a star is not yet understood (Limber and Marlborough, 1968) but it is here suggested that radiation pressure may be sufficient in the zero gravity equatorial region. The P Cygni profile of C IV at 1550 Å observed in γ Cas by Morton (1970) supports this. Loss of angular momentum in the disc at some distance (1–2 R*) from the photosphere therefore need not result in the collapse of the disc, and is in any case demanded by the observed Hγ and Hβ peak separations, which correspond to a $V \sin i$ of some 200 km/sec. The postulated lower-lying condensations therefore give rise to the observed periodic variation in peak separation by having a higher angular velocity.

There are two more points in support of this model. The observed profiles never show the R component weaker than the V. This is incompatible with a static rotating envelope, but as shown by Hutchings (1968b) is easily explainable if the entire equatorial envelope has a small outward velocity. Some preliminary line profile calculations have been made, which cannot be described in full here. They are similar to those previously published, but use an excitation-height relation similar to that deduced for the Orion supergiants (Hutchings, 1970). It was possible to match the observed Hγ

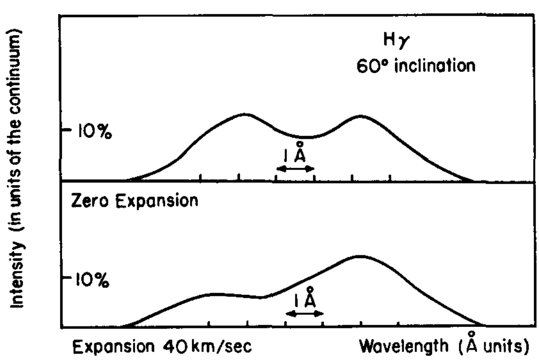

Fig. 3. Computed Hγ profiles for 60° inclined star expanding at 0–40 km/sec.

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and Hβ profiles using an axial inclination of 60° to the line of sight and a surface expansion velocity of $\simeq 20$ km/sec (Figure 3).

The final point of agreement is that of the mean separation of the peaks. These correspond to velocities of 240 km/sec for Hγ and 200 km/sec for Hβ. This sort of discrepancy is found in several Be stars of this type (e.g. κ Dra) and can be explained by two effects. The stronger Balmer lines are formed through more extended regions of the disc than the weaker ones, so that if the star is equator-on the effect must be caused by a lower angular velocity in the outer disc; if the axis is inclined the central part of the emission feature may be filled in by emission seen over the pole of the star. This filling in will be stronger for the stronger Balmer lines. It is possible to distinguish between these effects by comparing computed and observed profiles, and optimum fit in the case of γ Cas is indicated at about a 60° inclination and angular velocity decreasing by a factor of 2 in 1 R^*.

At present it is difficult to see how any other model can explain all the observations. Further computations are being made to refine the above results and to derive a mass-loss estimate. These will be published in full in due course.

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Discussion

Collins: What sort of error estimates would you put on your results ($i = 60°$, etc.)?

Hutchings: The figures quoted in the paper are preliminary ones, but work in the few weeks since writing them down indicates that i has a p.e. range of 50°–75°, $\omega \sim (R/R^*)^x$ where $0.8 < x < 1.2$, and a mean expansion velocity of 20 km/sec $\pm$ 10 km/sec (which is indistinguishable from a velocity field rising exponentially to 50 km/sec at $\simeq 3R^*$). With so many free parameters it seems possible to reproduce the profiles observed with combinations of figures within the above ranges.

Jordahl: An observed $V \sin i$ of 300 km/sec for a breakup velocity of 500 km/sec would give $\sin i = 0.6$ whereas $\sin 60° = 0.833$. How good is the observed $V \sin i$?

Hutchings: $V \sin i$ is quoted as 300 km/sec by Boyarchuk and Kopylov but I cannot comment on the accuracy of this. Dr. Stoeckley has shown that this should be corrected for gravity darkening to yield a value of some 400 km/sec, which is then in reasonable agreement with my results. I would in any case regard an analysis of emission line profiles, such as mine, as giving a more reliable value for i.

Stoeckley: Do you mean it when you suggest that angular *momentum* is lost by the shell? Why? Do you mean angular *velocity*?

Hutchings: What I meant was angular velocity. There seems little doubt about this, but whether momentum is lost is a more tricky question, and we need a better idea of the density-height relation to answer it. If viscous or radiative forces are considerable they may be responsible for converting angular to outward momentum, and in the case of higher density condensations, they may transfer angular momentum to the remainder of the envelope.