C. de Jager and K. Eriksson

The large-scale atmospheric motion field of Alpha Orionis

ABSTRACT

Two periods of variability have been found by Dupree et al. in Betelgeuze, one of 440 d and one of 11 years. We ascribe the first to atmospheric gravity waves (wavelength between R/3 and R/30) and the latter to gravity waves of very low mode number.

VARIABILITY OF ALPHA ORIONIS

Dupree et al. (1991) have studied the variability of Alpha Ori by means of observations of light and radial velocity over a time span of 6.5 years. The variability must be due to pulsations because there is good correspondence between the variations of light and of radial velocity. Figure 1 gives a power spectrum of the Mg II h line flux. Although it shows many peaks it is evident that the diagram contains only one physically significant period, viz. the one at $\omega = 0.84\ yr^{-1}$, corresponding to 440 days. The peaks at integer values of ω are spurious and are due to the annual interruptions in the observations. The one at $\omega = 0.15$ corresponds to the period of observation, 6.5 years. The other peaks are due to beats between the three above periods and their overtones.

Dupree et all also mentioned the existence of a period of 11 years, but that one can not be brought forward by these observations, which cover a shorter period of time.

The question we discuss in this Note is that of the physical interpretation of these two periods. Dupree et al. (1991) ascribe the first one to pulsations of the star in its fundamental mode and offer no explanation for the second, but we will give arguments that the first period (440 d) is of atmospheric rather than stellar origin. We also think that there are reasons to think that the 11 yrs period is of atmospheric origin.

ATMOSPHERIC GRAVITY WAVES

Motions in a non-magnetic atmosphere can be gravity waves or pressure (shock) waves. The properties of atmospheric motions to be expected can be studied by means of a diagnostic diagram, in the way as described by De Jager et al. (1991). Here, we will

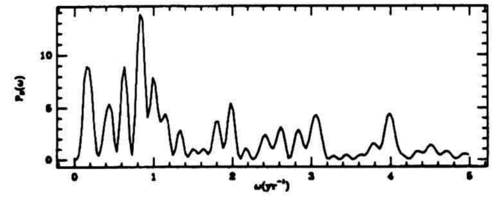

Figure 1: Power diagram of the variability of Betelgeuze (from Dupree et al., 1990)

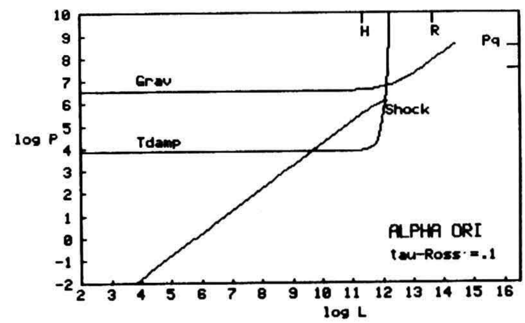

Figure 2: Diagnostic diagram of the motions in Betelgeuze

present such a diagram for an optical depth of $\tau_R = 0.1$. To that end one should know the values of the thermodynamic variables at that level.

From the summarizing list of De Jager, Nieuwenhuijzen and Van der Hucht (1988) we read $T_{eff} = 3580$ K and log $(L/L_{\odot}) = 4.88$, yielding R = 600 $R_{\odot}$. Evolution calculations yield a mass of 15 solar masses, yielding g = 1 cm s^{-2}. But the effective temperature is uncertain, depending on the interpretation of photometric and spectral data. T. Tsuji (private comm.) informed us that in his opinion an effective temperature of 3600 to 3700 K is very well possible, next to a value of 3900 K, previously suggested by him. As a suitable 'average' we take T_{eff} = 3750 K and log g = 0.

With data from a photospheric model derived by one of us (K.E.) we computed the diagnostic diagram for $\tau_R = 0.1$, shown in Figure 2. The diagram gives the relation between the wavelength L and the period P of atmospheric waves. Gravity waves can occur above the line labeled Grav and below the line labeled Trad, hence in a small area for large P and L values. Pressure (shock) waves can only occur along the line labeled Shock. The photospheric density scale height H and stellar radius R are marked along the upper abscissa. Along the right hand ordinate the two observed periods are marked by the short tick marks labeled Pq.

We conclude that the 440 days period can be interpreted as the period of gravity waves with a wavelength between R/3 and R/30. The waves must propagate nearly horizontally, because the line labeled Grav corresponds with waves propagating horizontally, while other angles would correspond with waves with longer periods. This conclusion does not agree with that of Dupree et al., who ascribed this period to oscillations of the star as a whole, instead as to photospheric internal gravity waves, as we suggest here.

The 11 years period would in this view be due to gravity waves with a wavelength equal to the stellar circumference, or - what is the same - to photospheric non-linear pulsations with $l = 1$.

The two kinds of gravity waves must be excited by lower seated convective motions.

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AUTHOR'S ADDRESSES

Cornelis de Jager
Laboratory for Space Research
Sorbonnelaan 2
3584 CA UTRECHT, The Netherlands

Kjell Eriksson
Astronomiska Observatoriet
Box 515
S-75 120 UPPSALA, Sweden