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AN INTERPRETATION OF THE CHANGES OBSERVED IN V1057 CYGNI

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SUMARIO

Se sugiere que el aumento del brillo de V1057 Cygni, una estrella T-Tauri, de la magnitud fotográfica 15.5 a la magnitud 10.0 y el cambio de su tipo espectral de aproximadamente K0 a A1, puede explicarse como resultado de un reajuste rápido de la distribución de la masa en la estrella y la consecuente liberación de la energía potencial en forma de energía radiativa. El reajuste de la masa puede ser provocado por un evento no-térmico, significativamente violento en esta estrella de tipo T-Tauri.

ABSTRACT

It is argued that the brightening of V1057 Cygni, a T-Tauri star, roughly from photographic magnitude 15.5 to 10.0 and its change of spectral type from about K0 to A1, at which the star appears to remain, may be explained by a fast readjustment of mass distribution in the star and the consequent release of potential energy as radiation. The readjustment of the mass is believed to be triggered by a significantly violent non-thermal event in this T-Tauri star.

I. Introduction

In the present communication we draw attention to a process by which the remarkable changes shown by the star V1057 Cygni may possibly be explained. The changes referred to were discovered recently by Welin (1971); they consist in the brightening —as of 1969— by 5-6 magnitudes of this faint and variable star (normally varying between magnitudes 15.5 and 16.5) involved in NGC 7000, the North America Nebula, and the associated change of its spectrum to an earlier type.

V1057 Cygni is included by Herbig (1958) in his list of emission line stars as LkHα 190, with the remark that "...it shows an advanced T-Tauri type spectrum". Of the available data on V1057 (Herbig and Harlan 1971) we mention here only those that are relevant to our purpose. In a time interval of 250 days, the brightness of this star has increased to $m_{pg} = 10$, where it seems to have remained since the end of 1969; meanwhile, its spectrum has changed from about K0 to A1. We shall adopt Herbig and Harlan's data at face value and shall moreover assume that both before and after the brightening of this star its integrated radiation is mainly thermal, represented by that of a black body.

II. Physical Parameters of the Star

Let L, R and T denote the bolometric luminosity, the photospheric radius and the effective temperature of V1057 just before the brightening, at time t_1. After the brightening, at t_2, ($t_2 = t_1 +$ 250 days), we can write:

$$\alpha L = 4 \pi \beta^2 R^2 \sigma \gamma^4 T^4 \qquad (1)$$

where α, β and γ are the factors by which L, R and T are altered. Then,

$$\alpha = \beta^2 \gamma^4$$

For a brightening of 5.5 magnitudes $\alpha \approx 160$ and for $T = 4000°$ at t_1 and $T = 10000°$ at t_2, γ is equal to 2.5 With these values: $\beta \approx 2$ is obtained. One thus finds that the photospheric radius at present is about 2 times its value at t_1.

The main problem is to specify the physical process, which, within a lapse of 250 days, causes an increase of the energy output by a factor of about 160 —which energy appears to remain nearly constant— and an increase of the radius of the star to about twice its earlier value.

III. Some Physical Circumstances Relevant to our Interpretation

The pre-main sequence evolutionary stage, in which T-Tauri stars are believed to be, is characterized theoretically by a gradual contraction. The more or less violent events, which the T-Tauri stars exhibit, are not taken into account in the evolutionary models, as it is probable that their effect may normally be considered negligible. The T-Tauri phenomenon itself is not yet understood, however, it appears that non-thermal processes in limited regions of the star underlie the phenomenon.

The steadiness and the rather long duration of the rise in brightness of V1057 Cygni, its permanence so far at the maximum brightness attained, and particularly the change of the spectral type suggest strongly that the changes in this star are of a fundamental nature, involving the star as a whole. It is conceivable that in some unusual cases the T-Tauri phenomenon may be so exceptionally violent and deep-seated in the star as to provoke fast and drastic changes, such as a readjustment of the stellar mass distribution. A loss of gravitational potential energy from such readjustment would well provide the observed increase of radiation energy as will be shown below.

That a non-thermal event has possibly occurred in the star is strengthened by the recent measurements of the infrared indices (Woolf 1971, Mendoza 1971) which presumably are much larger now than earlier (Haro 1971). In the present context we do not discuss the direct consequences of the non-thermal phenomenon but consider it only as a triggering agent for the fundamental changes undergone by the stellar configuration. A rapid loss of energy and even of mass during the non-thermal event may constitute the essence of the triggering mechanism.

Many interesting consequences are expected to follow the formation of a core denser than earlier. It is true that nuclear reactions may become operative at the ensuing higher temperatures and densities but the lag in time will be rather large, such that no immediate effects will be observable.

The formation of a denser core will, in general, cause an expansion of the outer layers of the star (see for example, Sears and Brownlee 1965). Spectral studies (Herbig and Harlan 1971) show indeed that the atmosphere of V1057 Cygni is expanding at a fast rate. Moreover, as we emphasized above, the photosphere has expanded to twice its former radius; it may still be expanding.

IV. Gravitation as the Source of Energy Released

Detailed computation of the change in potential energy will not be attempted now, since such a procedure would require a knowledge of the distribution of mass in V1057 initially and during the stage of readjustment. However, a rough estimate may be made by recourse to polytropic spheres. The potential energy, Ω, of a polytropic sphere of index n is given by:

$$-\Omega = \frac{3}{5-n} G \frac{M^2}{R} , \qquad (2)$$

where G is the gravitational constant M, the mass and R is, as above, the radius of the configuration. The representation of the stellar configuration by a polytrope is made solely for the sake of convenience; as is well known the central condensation increases with increasing n. It is also clear from the above formula that for the same R, $|\Omega|$ increases with the increase of n.

At time t_1 V1057 Cygni is presumably wholly convective and n can be taken as 1.5. Let n_2 and n_3 denote the polytropic indices at t_2 and t_3 respectively where $t_3 = t_2 + 250$ days. As the configuration passes on to a higher polytropic index one half of the gravitational energy available is expected to be liberated as radiation.* For $\Delta\Omega = \Omega_1 - \Omega_2$ from t_1 to t_2 one has

$$\Delta\Omega = \frac{GM^2}{R} \left[\frac{3}{2(5-n_2)} - \frac{3}{5-n_1} \right] \qquad (3)$$

Here the factor 2 in the denominator of the first term in the parenthesis is due to the circumstance that the radius of the star at t_2 is twice that at t_1. $\Delta\Omega$ is next set equal to the energy radiated from t_1 to t_2.

This energy is computed by assuming, for want of knowledge of the light curve, that the variation from minimum to maximum light is linear in the magnitude scale. The energy thus obtained is 2.41×10^{44} ergs. While the energy radiated in the constant maximum phase, from t_2 to t_3 is found to be 1.16×10^{45} ergs.

With these values computations of the polytropic indices n_2 and n_3 are performed — using an equation similar to (3) for n_3 — with three different values for the mass of V1057 Cygni, namely for $M = 0.5$, 1.0 and 2.0 solar masses, respectively. The results are given in Table 1. The radius of the configuration is adopted as $2R_\odot$ at t_1 and $4R_\odot$ at t_2 and thereafter.

An estimate of the time needed for the configuration to attain eventually the state of $n = 4$ starting from the state $n = 3.25$ assuming that the energy output of the star remains constant yields 3.6×10^4 years.

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* The mode of the conversion of this gravitational energy into thermal energy is not discussed in the present context.

Table 1 shows that the polytropic indices at t_2 and t_3 for all three masses are only slightly larger than 3.25 increasing slightly with time. These values are not implausible and suggest that V1057 Cygni may indeed have envolved very rapidly.

TABLE 1

Polytropic Indices at Different Epochs Before and After the Brightening

Epoch	$0.5M_\odot$	$1M_\odot$	$2M_\odot$
t_1	1.5†	1.5†	1.5†
t_2	$3.25 + 2.0 \times 10^{-5}$	$3.25 + 5.1 \times 10^{-6}$	$3.25 + 1.3 \times 10^{-6}$
t_3	$3.25 + 1.2 \times 10^{-4}$	$3.25 + 2.9 \times 10^{-5}$	$3.25 + 4.4 \times 10^{-6}$

† Assumed.
t_1 = Time just before the brightening.
$t_2 = t_1 + 250$ days (when maximum brightness is attained).
$t_3 = t_2 + 250$ days (during the constant maximum brightness).

V. Conclusions

We have shown that the main production of the excess energy observed in V1057 Cygni may be gravitational. If so, it may be expected that at least in some stars the evolution will be very rapid at a certain pre-main sequence stage at which the transition from the régime of a wholly convective energy transport to one of a wholly radiative energy transport takes place.

On the basis of this phenomenological treatment, it appears that the outcome of the readjustment of matter described here is compatible with the events occurring in V1057 Cygni. However, a detailed analysis of the changes of the relevant physical parameters of the star are desirable for a comprehensive physical study of the consequences of the fast evolution which this star presumably undergoes.

Our interpretation naturally loses its validity if one or more of the assumptions made above are untenable or if the brightening of this star is due entirely to non-thermal mechanisms.

I am indebted to Dr. G. Haro for calling my attention to this star and for stimulating discussions.

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