ERUPTIVE PHENOMENA AS A SOURCE OF THE OBSERVED VARIATIONS OF INTRINSIC POLARIZATION IN LONG-PERIOD AND T TAURI VARIABLES

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ABSTRACT

The correlation between the rapid rise of intrinsic polarization, increasing U-B and enhanced equivalent width of Balmer, H and K emission lines is interpreted as a consequence of the activation of colour centres in circumstellar silicate dust by X/UV photons from flares. The temperature dependence of bleaching is discussed and the number of centres producing polarization changes is estimated.

Flare activity of some T Tauri stars with individual events being 10^3 times more energetic than large solar flares has been recently reported by Worden et al. (1981). The energies released at X/UV and optical wavelengths by a flare have characteristic values L(X/UV, flare) $\simeq$0.05 L(X/UV, star) and L(opt, flare)$\simeq$2.4x 0.05 L(X/UV, star). Infrared studies by Cohen 41981), Rydgren et al.(1982) and others have confirmed the presence of circumstellar silicate dust around many T Tauri stars. Dust is considered to cause the infrared excess observed in these stars and perhaps the intrinsic polarization as well. A strong interaction of flare X/UV photons and stellar wind particles with dust is thus expected. We suggest that this interaction can relate to the variations of polarization degree.

Simultaneous observations referring to brightness (UBVR, H_α) and polarization (P_V) of T Tauri itself, carried out by Redkina et al. (1980) with a 70-cm telescope at Gissara Observatory show clearly the correlation mentioned above (Fig. 1). The mean error in the U-band is 0.02-0.05 mag, in B, V is 0.01-0.03 mag and in H_α is 0.02-0.04 mag. The polarization degree is accurate to 0.1-0.14%. The joint observational program of T Tauri star DI Cep has been reported by Grinin et al. (1980). In Fig. 2 can be seen some strong UV bursts of long duration, such as at JD 2442640. The simultaneous rise of polarization degree and U-B was first mentioned by Shawl (1975) for Mira at phase 0.8.

P. B. Byrne and M. Rodonò (eds.), Activity in Red-Dwarf Stars, 515–518.

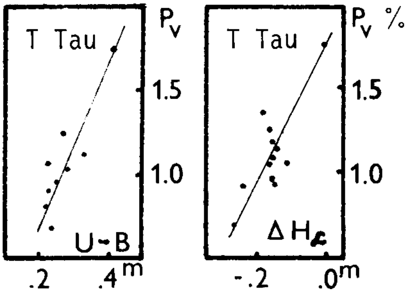

Fig. 1 (by Redkina et al.,1981)

Flaring processes in Mira variables can be created by a shock wave propagating through the atmosphere just at this phase (Wing, 1979). If the following interpretation of this phenomena proves to be valid, the underlying process causing polarization variability should be quite common among the stars with circumstellar dust.

Let us consider circumstellar dust as the only agent responsible for the varying polarization. Several theoretical models of dust envelopes have been suggested, such as: polarization due to scattered starlight on moving circumstellar dust clouds; sudden condensation/evaporation of grains by decreased/increased temperature; or enhanced alignment of nonspherical dust grains by increasing magnetic field due to the Davis-Greenstein mechanism (for review see Greenberg, 1976). However, a detailed discussion of these models shows that none of them proceed so quickly as to explain the simultaneous rise of P and other observed characteristic unless unlikely physical conditions in the envelope are assumed. This was the very reason for seeking models with a more flexible response to flare events.

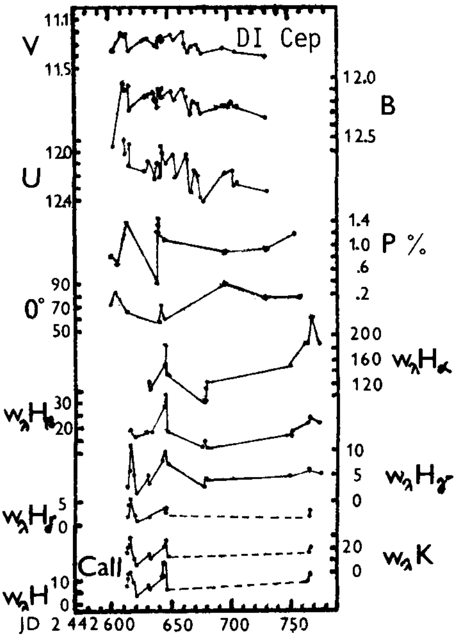

Fig. 2 (by Grinin et al.,1980)

As suggested by Svatos (1980) the X/UV activation of color centers (CC) in silicates could explain the polarization rise. Short wavelength irradiation leads to an increase of the imaginary part (k) of the refractive index for a wide variety of silicates and glasses, as has been shown in the comprehensive laboratory study by Kats and Stevels (1956). Let us now consider a model of a circumstellar shell with as few free parameters (and assumptions) as possible, which can account both for T Tauri stars and Miras:

- the dust grains are needle-shaped of radii 0.1-1.0μm (with no distribution function), being perfectly aligned, consisting mainly of silicates with complex refractive index $m=1.7-ik$;
- the only particles projected on the stellar disk are assumed to

polarize starlight (polarization is seen in the transmitted light); $\tau \simeq 0.1$.

Simple formulae by Hulst (1957) giving efficiency factors of cross-section for very long thin cylinders can be applied:

$$Q_{||} = -\pi^2 a\lambda^{-1}\, I_m(m^2-1),\quad Q_{\perp} = -2\pi^2 a\lambda^{-1}\, I_m(m^2-1)/(m^2+1)\ ;$$

where subscript $||$, $\perp$ refer to the light wave oscillating in parallel and perpendicular direction with respect to the axis of the cylinder.

By definition, the polarization degree is

$$P = \left| I\ \exp(-\tau_{\perp}) - I\ \exp(-\tau_{||}) \right| / \left| I\ \exp(-\tau_{\perp}) + I\ \exp(-\tau_{||}) \right|$$

where I is the luminosity of the star. Substituing $\tau = N\,\ell\,Q\,C$, where $N\,\ell$ is the column density and C the geometrical cross-section of one grain, a linear relation between P and k is found. As a consequence of this we obtain (replacing P by ΔP and k by Δk)

$$\Delta P = 42.7\ N\,\ell\,a^3\,\lambda^{-1}\,\Delta k .$$

If the concentration (n) of CC in circumstellar dust is comparable with that in common glasses, i.e. at least 10^{18} per gram, the column density of CC per cm^2 required for an increase ΔP is $\simeq 10^{13}\,\Delta P\,\lambda(\mu m)\Delta k^{-1}$. If ΔP=1%, number of X/UV photons per 1 CC at a distance ≃ 50 R ($\simeq 150 R_{\odot}$) from a T Tauri star or at a distance 4-5 R ($\simeq$700-900 $R_{\odot}$) from a Mira star is of order 10-100 per sec. Supposing a 10% efficiency of CC's production, this rate is sufficient to maintan CCs completely activated in the case of absent thermal bleaching.

In the most simplified model the thermal bleaching is a two-body reaction inverse to the activation of CC. The temperature dependence of CC's bulk concentration (n) is given by the equation

$$-\frac{dn}{dt} = K\ \exp\,(E/kT)n^2\ ,$$

where E is the activation energy and K is the constant characteristic for the given kind of CC. During the flare, the dust particles are being heated and hence $T \sim t$ can be substituted in the equation above. The solution n(T) rapidly fades at temperature $T_a \simeq 700$ K depending on the kind of CC due to progressive annealing of CC.

In conclusion, the CC's production in dust during steady continuous flaring or during quiet phases is balanced by thermal bleaching. Following immediately the X/UV burst, the production of CC exceeds their decay, and enhanced polarization should be observable until the dust temperature reaches T_a, which can still occur during the flare (Fig.2). The stream of particles from flare reaches the dust region with a delay, so that we can neglect it in this simple model.

Thus, simultaneous polarimetry and spectroscopy with convenient time resolution, specifically for T Tauri stars rather than for long-period variables, seems to be fundamental for understanding the intrinsic polarization. The crucial point for theoretical models is a good timing of the polarization rise and enhanced line emission and the subsequent polarization fall and the rise of infrared thermal flux from circumstellar dust.

REFERENCES

Greenberg J.M. 1976, "Interstellar Dust", in Cosmic Dust, ed. McDonnell.

Grinin V.P., Efimov J.S., Krasnobabtsev V.I., Shachovskaya N.I., Shachovskoy N.M., Shcherbakov A.G., Zaitseva G.V., Kolotolov E.A., Shanin G.I., Kiselev N.N., Gyulaliev C.G. and Salmanov I.R. 1980, Peremennye Zvezdy 21, 247 (in russian).

Hulst H.C. 1957, "Light Scattering by Small Particles", Chapman and Hall.

Kats A. and Stevels J. 1956, Philips Res.Rep. 11, 115.

Redkina N.P., Zubarev A.V. and Chernova G.P. 1981, Astron.Circ. USSR No. 1149 (in russian).

Rydgren A.E., Schmelz J.T. and Vrba F.J. 1982, Astrophys.J. 256, 168.

Shawl S.J. 1975, Astron.J. 80, 602.

Svatos J. 1980, Bull.Astron.Inst.Czech. 31, 302.

Wing R.F. 1979, "Mira Variables, an Informal Review", Contr.Perkins Obs. Ser.II No. 80.

Worden S.P., Schneeberger T.J., Kuhn J.R. and Africano J.L. 1981, Astrophys.J. 244, 520.