PART V

ERUPTIVE AND EXPLOSIVE VARIABLES

EXPLOSIVE AND ERUPTIVE STARS

E. SCHATZMAN
DAF, Observatoire de Meudon, 92190 Meudon, France

Abstract. A summary of the main results and problems concerning explosive and eruptive stars is given. The way in which the observations are related to the internal structure problems is briefly explained. Suggestions for further work are made: (1) dynamo theory, supersonic turbulence, stability of the envelope of T Tau stars; (2) rate of exchange of matter in close binary as the final clue to the thermal runaway theory of novae.

1. Aims and Limits of the Review

Explosive and eruptive stars are two very different classes of non stable stars. This has been shown a long time ago by Schatzman (1955) and by Ledoux (1957) (Table I), by comparing the energy available during the explosive or eruptive phase *E*, and the energy available *Lt* in between two such phases. The comparison is clearly in favour of a nuclear process for the explosive stars, and in favour of a less concentrated storage of energy for the eruptive stars. In fact, it seems quite reasonable to assume that the eruptive processes, similar to the solar eruptive processes, are due to some kind of plasma instability.

TABLE I

The ratio (E/Lt) of the energy available during outbursts and in between outbursts

Class	$\Delta L/L$	E/Lt
Flare stars	5–100	$\simeq 0.01$
T Tauri stars	10– 20	1 ?
U Geminorum stars	30– 50	3 to 5
Recurrent novae	very large	1 to 1/2
Classical novae		1 to 1/2 ?

As far as we are concerned here, we do not intend to deal with all aspects of the eruptive and explosive stars, but only with the properties which derive from the internal constitution of these objects and the instability mechanisms.

2. Eruptive Stars

2.1. PROPERTIES AND CLASSIFICATION

In the absence of a complete understanding of the eruptive stars, it is necessary to rely first on the empirical results concerning this class of stars. It is generally accepted, since the work of Haro (1968), Herbig (1962) and Ambarzoumian and Mirzoyan (1971), that the Herbig-Haro objects, the T Tauri stars and the UV Ceti stars represent an evolutionary sequence. The continuity of the spectroscopic properties is the basis of the idea of the physical continuity of the sequence.

Ledoux et al. (eds.), Stellar Instability and Evolution, 117–121. *All Rights Reserved*

However, the variability of the T Tau stars and that of the UV Ceti stars have a completely different behaviour. The nature of the variability of the UV Ceti stars seems to be well established since Lovell *et al.* (1963), following a suggestion by Schatzman (1959), proved the association of radio bursts (similar to the type III and type II solar radio bursts) with the optical flare stars. The association suggests very strongly that an electromagnetic process, very similar to the process observed at the surface of the Sun, takes place at the surface of the flare stars. This can be interpreted as due to the presence of a deep convective zone, in which a dynamo mechanism generates a system of magnetic spots, which, in turn generate the instability responsible both for the optical flare and for the fast particles which emit or stimulate the radio emission. Observation of the rotation of a dark spot at the surface of d Me stars by Torres and Ferraz Mello (1973) is very much in favour of such an interpretation. Gershberg (1970a, 1970b) claims that the observations are consistent with the assumption that the star has a rotation period of several hours and that the strong flares occur only in some active region of the star surface.

The question of a period of activity, similar to the solar cycle has been raised. The IAU (1970) report of the working group on flare stars mentions that no conclusions have been reached as yet.

The analysis by Kuhi (1964) of the spectrum of the T Tauri stars was very successful in explaining correctly the excitation and the line profile of the emission spectrum. However, his velocity field implies that matter leaves the star without having the escape velocity but does not fall back on the star. A recent model of Prentice (1973) suggests that matter goes up, under the action of buoyancy force, in needle like supersonic eddies which are finally decelerated and then form a rarefied descending atmosphere.

These models account for the T Tau star 'mass ejection' phenomenon, without any net mass loss for the star. Prentice's model presents the interest of building up a dense outer non-turbulent shell. The corresponding inversion density strongly suggests the presence of a Taylor instability. This has not been studied by Prentice, but we can estimate the time scale of the instability $\sigma^2 = \mathrm{gk}$, by assuming that k^{-1} is of the order of the scale height of the supersonic turbulent region. This gives a time scale for the instability of the order of a day. This is clearly not of the order of the time scale of the light variations of T Tauri stars, as given by Herbig (1962).

The suggestion made here is that the T Tauri activity is not a blend of flares of varying intensity but is related to the building of the outer layers. It is not possible, for the time being, to describe more precisely a model of the instability of the T Tauri stars.

2.2. Evolution and Age

The model which relates stellar rotation, age, and electromagnetic activity, is now well accepted. However, the present state of the dynamo theory does not give the possibility of a precise description of the observed phenomena. The dynamo theory, in its various forms (Lerche 1971a, 1971b, and Steinbeck and Krause, 1969) gives a good description of the behaviour of the average magnetic field, including both the effects of helicity and rotation. However, the description of the properties of the rms fluctuations of the magnetic field, $\langle(|\delta B|)^2\rangle^{1/2}$ is still insufficient to lead, for example, to a real understanding of the production of the sun spots. It is likely that the cyclic activity of a star is related to the thickness of the convective zone. A fully convective star is unlikely to behave like a star with a convective zone of finite thickness. In the same way, the rate of change of the activity with the angular velocity is, for the time being a purely empirical fact, without any quantitative estimate, but for the trivial statement that the activity decreases with the angular velocity. This can be considered as being confirmed by the observations of flash stars in clusters. According to Haro (1968), flare stars are less massive and colder in old clusters. As shown by Gershberg and Pikel'ner (1972), the properties of flare stars fit well in the whole picture of stellar evolution, activity and stellar structure.

The amount of energy which goes into mass ejection, and the magnetic field determine the rate of exchange of angular momentum. Gershberg and Pikel'ner (1972) give estimates of the relevant quantities. Unsöld (1957) suggested that a substantial part of the galactic cosmic ray flux has its origin in stellar flares. Hudson *et al.* (1971) suggested the existence of a class of unresolved low luminosity X-ray sources to account for the observations. Edwards (1971) supports the suggestion of Hudson *et al.* but shows that the energy radiated in soft X-rays is probably of the order of 1% of the optical flare energy, more or less in agreement with the value of 10% quoted by Thomas and Teske (1971) for the solar flares.

The frequency of the optical flares as a function of their magnitude has been given by Kunkel (1973). It gives the possibility of estimating more precisely the amount of energy going into the flares, which is altogether a small fraction of the luminosity of the star. As a consequence, the rate of evolution of flare stars is not appreciably changed when including the energy of the flares. This is confirmed by the analysis of Gurzadyan (1971).

Further study of flare stars present a great interest both from the physical and the astrophysical points of view:

(1) It can lead to a better and quantitative understanding of the dynamo mechanism.

(2) It can lead to a better and quantitative understanding of the relation between age and rotation.

(3) Other properties are more directly related to the physics of the surface phenomena (X-rays, cosmic rays, radio emission) and are important both in themselves (e.g. accelerating mechanisms) and for the evolutionary processes.

3. Explosive Stars

3.1. MODELS OF NOVAE AND U GEMINORUM STARS

The suggestion by Schatzman (1956, 1958) that all prenovae and U Geminorum stars are double stars was proved by Kraft (1964). Since that time the greatest advance in the subject was probably the analysis, by Saslaw (1968) of the thermal runaway due to accretion. The white dwarf, in the double star, accretes matter shed from the larger star through the inner Lagrange point.

The thermal runaway depends, for a given mass, both from the internal temperature of the white dwarf and from the rate of accretion. Similar models have been studied by Giannone and Weigert (1967) and by Rose (1968), but failed to yield the typical energy of nova DQ Herculis 1934. By including the effect of an accretion shock Starrfield (1971a, 1971b), succeeded in obtaining the necessary energy. The objections of Schatzman (1965) to the thermal runaway were valid only for a very slow rise of the rate of energy generation and are not valid in the case of fast accretion.

Further work by Starrfield *et al.* (1972), using a more detailed hydrodynamic code, has led to a better agreement. Their result is sustained by the production of ^{13}C, ^{17}O. Further confirmation can be found in the analysis of the isotopic production in hot CNO-Ne cycle by Audouze *et al.* (1973). Altogether, the thermal runaway seems now the well established mechanism of the nova outburst. Weaver (1973) has shown that the model leads to a complete understanding of Nova Aql 1918.

The interest of the thermal runaway is that it can produce an increase in luminosity without any mass loss. This seems to be the case of the U Gem stars. The connection between the theory of thermal runaway and the impulsive generation of non radial oscillations is well established by the observations of Warner (1974).

4. Conclusions

As far as such general considerations are useful, we may notice that the theory of explosive variables is much more advanced than the theory of eruptive variables. The reason is that the explosions depend on thermonuclear processes and transport processes which are fairly well understood and leaves out completely the problem of the accretion rate, which is just kept as a parameter. On the other hand, the mechanism of eruptive variables is due to turbulent processes which remain presently one of the unresolved problems of physics.

References

Ambarzoumian, V. A. and Mirzoyan, L. V.: 1971, *IAU Colloq.* **15**, *Veröffentlichungen der Remeis-Sternwarte Bamberg*, No. 100, p. 98.
Audouze, J., Truran, J. W., and Zimmermann, B. A.: 1973, Orange AID preprint 315.
Edwards, P. J.: 1971, *Nature Phys. Sci.* **234**, 75.
Gershberg, R. E.: 1970a, *Flares of Red Dwarf Stars*, Moscow, transl. into English by D. J. Mullan (Armagh Observatory, Armagh, Northern Ireland).
Gershberg, R. E.: 1970b, in A. Slettebak (ed.), 'Stellar Rotation', *IAU Colloq.* **4**, 249.
Gershberg, R. E. and Pikel'ner, S. B.: 1972, *Comments Astrophys. Space Phys.* **4**, 113.
Giannone, P. and Weigert, A.: 1967, *Z. Astrophys.* **67**, 41.
Gurzadyan, G. A.: 1971, *Bol. Obs. Tonantzintla Tacubaya* **6**, 39.
Haro, G.: 1968, *Stars and Stellar Systems* **7**, 141.
Herbig, G. H.: 1962, in Z. Kopal (ed.), *Advances in Astronomy and Astrophysics*, Vol. 1, 47, Academic Press, London.

Hudson, H. S., Peterson, L. E., and Schwartz, D. A.: 1971, *Nature* **230**, 177.

IAU: 1970, *Transactions of the IAU*, Vol. XIVA, Report of the Working Group on Flare Stars, p. 297.

Kraft, R.: 1964, *Astrophys. J.* **139**, 457.

Kuhi, L.: 1964, *Astrophys. J.* **140**, 1409.

Kunkel, W. E.: 1973, *Astrophys. J. Suppl.* **25**, 1.

Ledoux, P.: 1957, in G. H. Herbig (ed.), *Non Stable Stars*, Cambridge University Press, p. 181.

Lerche, I.: 1971a, *Astrophys. J.* **166**, 627.

Lerche, I.: 1971b, *Astrophys. J.* **166**, 639.

Lovell, P., Whipple, F. L., and Solomon, H, L.: 1963, *Nature* **198**, 228.

Prentice, A. J. R.: 1973, *Astron. Astrophys.* **27**, 237.

Rose, W. K.: 1968, *Astrophys. J.* **152**, 245.

Saslaw, W. C.: 1968, *Monthly Notices Roy. Astron. Soc.* **138**, 337.

Schatzman, E.: 1955, Principes Fondamentaux de Classification Stellaire, Colloque international du CNRS No. 55, Publications du CNRS, Paris, p. 175.

Schatzman, E.: 1956, *Non Stable Stars*, Symposium of the Acad. Sci. of U.S.S.R., Publishing House of the Acad. Sci., Erevan, p. 141.

Schatzman, E.: 1958, *Ann. Astrophys.* **21**, 1.

Schatzman, E.: 1959, in R. N. Bracewell (ed.), 'Paris Symposium on Radio Astronomy', *IAU Symp.* **9**, 552.

Schatzman, E.: 1965, *Stars and Stellar Systems* **8**, 327.

Starrfield, S.: 1971a, *Monthly Notices Roy. Astron. Soc.* **152**, 307.

Starrfield, S.: 1971b, *Monthly Notices Roy. Astron. Soc.* **155**, 129.

Starrfield, S., Truran, J. W., Sparks, W. M., and Kutter, G. S.: 1972, *Astrophys. J.* **176**, 169.

Steenbeck, von M. and Krause, F.: 1969, *Astron. Nachr.* **291**, 49.

Thomas, R. J. and Teske, R. G.: 1971, *Solar Phys.* **16**, 431.

Torres, C. A. O. and Ferraz Mello, S.: 1973, *Astron. Astrophys.* **27**, 231.

Unsöld, A.: 1957, in H. C. van de Hulst (ed.), 'Radio Astronomy', *IAU Symp.* **4**, 238.

Warner, B.: 1974, this volume, p. 125.

Weaver, H.: 1973, private communication.