L. Kohoutek, C. Leitherer, J. Manfroid, A. Moorwood, Th. Neckel, E. Oliva, M. Pakull, W. Schlosser, R. Schulte-Ladbeck, O. Stahl, B. Stenholm, J. van Paradijs, N. Vogt, W. Wargau, B. Wolf, and F. J. Zickgraf. We also thank A. Peacock for granting observing time on EXOSAT, and, last not least, we cordially acknowledge the very valuable work F. Bateson and his amateur astronomers of the RASNZ did for Nova Muscae 1983.

On the Problem of the Luminous Emission Line Stars

R. Viotti, Istituto di Astrofisica Spaziale, Frascati, Italy

Introduction

Emission-line spectra are frequently observed among stars of high intrinsic luminosity. They provide evidence for the presence of extended stellar atmospheres, probably resulting from intense mass outflows. However, the physical relation between the strength of the emission lines and other stellar parameters, such as luminosity, gravitiy, temperature, rate of mass loss, rotation, binarity, etc. is far from clear. This situation is probably the result of the poor knowledge that we have of their basic physical parameters, and of the mechanisms of line formation in extended atmospheres. One major problem for galactic objects is the determination of their distance and interstellar reddening because of their position near the galactic plane. Many objects are also affected by a considerable amount of circumstellar extinction, and these problems make the determination of their intrinsic (bolometric) luminosity even more difficult. Another problem is the correct estimate of their temperature (or radius). In fact, as discussed for instance by de Jager (1980), these superluminous stars generally display a very tenuous stellar atmosphere so that both the brightness temperature and the radius at optical depth equal to unity largely vary with wavelength. The result is that for the most interesting objects their position in the Herzsprung-Russell diagram is quite uncertain, and it is therefore difficult to discuss them in the framework of the current evolutionary theories.

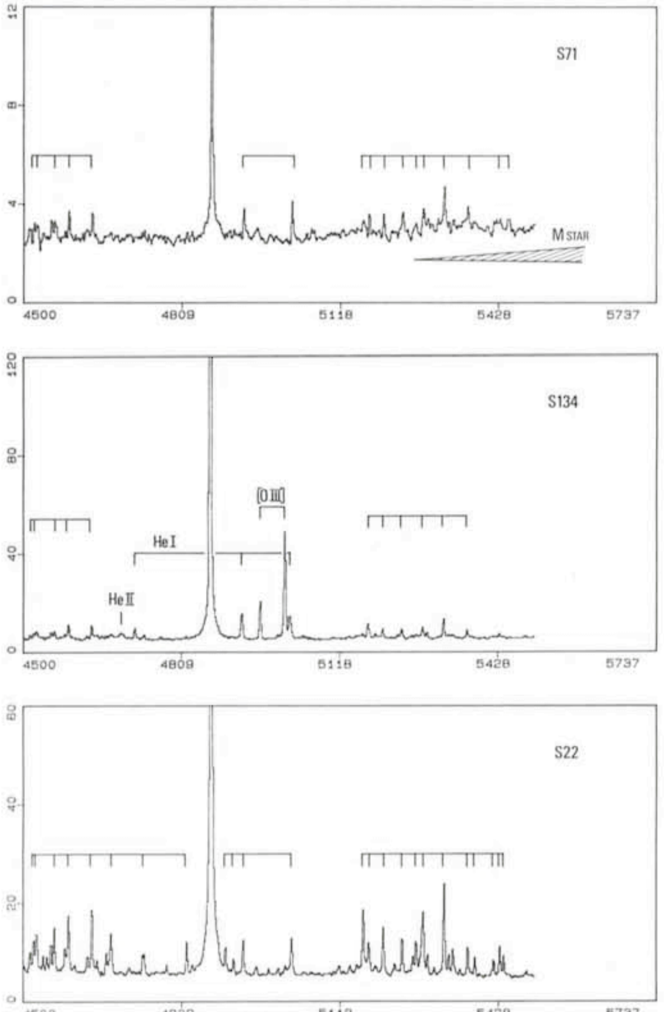

Fig. 1: *The low-resolution spectrum of three LMC emission-line stars: (a) S71, a VV Cep star characterized by low excitation emission lines and an M-type spectrum in the red. The FeII emission lines are marked. (b) S134 (HD 38489) with both low and high ionization emission lines. (c) S22 (HD 34664) with one of the richest Fe II emission spectra. Both S22 and S134 are known to have circumstellar dust shells (Bensammar et al. 1981, Stahl et al. 1984). Spectra taken by R. Gilmozzi on November 21–22, 1983 (ESO 1.5 m + IDS). Fluxes are in units of 10^{-14} erg cm^{-2} s^{-1} Å^{-1}.*

On the other hand, the interest in these stars has recently increased, as they may represent a phase, or different phases of the evolution of massive stars after having left the main sequence (see e.g. the Proceedings of the ESO 1981 Workshop on "The Most Massive Stars"). Because of their high intrinsic luminosity, they can be identified also in distant galaxies, and this has been improved by the wide use of the new astronomical techniques. Obviously, the presence of prominent emission lines makes their identification with wide-field cameras easier than for the more normal early-type supergiants.

The Magellanic Clouds may represent the best laboratory for the study of the behaviour of luminous emission-line stars, since their distance is well known and the interstellar extinction is in general low. In addition, the difference in metallicity and stellar content among the clouds makes them an ideal case to study chemical composition effects. For this reason many projects of systematic investigation of the emission-line stars in the MCs are now under way (e.g. Shore and Sanduleak 1984, Stahl et al. 1985, Gilmozzi et al. 1985), with the aim of determining the main physical characteristics of these objects. In the following we shall illustrate some results obtained from the analysis of the optical (ESO) and ultraviolet (IUE) spectra of galactic and MC superluminous stars.

Spectroscopic Observations

The luminous emission-line stars show a large variety of optical spectra, with different degrees of line excitation and intensity. Fig. 1 shows three examples of Magellanic Cloud stars with emission lines. In general the emission lines are more prominent and more numerous in the brighter objects, while the *photospheric* (not P Cygni) absorptions are weak or not observable at all. Besides hydrogen and helium, Fe II is the most frequently observed ion in the optical spectrum of superluminous stars and is represented by a large number of prominent emission lines (see Fig. 1). Generally, the emission spectrum becomes weaker towards shorter wavelengths, and in the IUE ultraviolet it is replaced by strong absorption features mostly due to singly ionized iron lines. The importance of the study of Fe II in the spectra of emission line stars has only recently been recognized, and many important results have already been obtained from both the observational and theoretical points of view. Emission lines of Fe II have been identified in the optical spectra of many different kinds of objects, including Be stars, symbiotic variables, stellar chromospheres, novae, active galactic nuclei, etc. In the case of the luminous stars, empirical methods for line analysis such as the *Self-Absorption Curve* method have been developed by M. Friedjung and collaborators to derive information about the physics of line formation in expanding stellar envelopes from the optical spectra. When only low-resolution spectra are available, as in the case of the IUE spectra of distant stars, one must attempt to compare the observations with *synthetic spectra* as described for instance by Muratorio et al. (1984). This is illustrated in Fig. 2 where the ultraviolet spectrum of the LMC star R 66 is compared with a synthetic spectrum computed using the Fe II level population and column density derived from the intensity of the optical emission lines.

The Hubble Space Telescope will enable us to observe luminous stars in very distant galaxies. We expect that their ultraviolet spectrum will be dominated by prominent (and variable) absorption features of Fe II and of other ionized metals formed in their extended expanding atmospheres. It is clear from the above arguments, that only the use of spectral synthesis techniques will allow us to derive physical information on these faint objects.

High Resolution Hα Profile

Hα is the most prominent emission line in the optical spectra of these stars. Frequently its equivalent width is so large as to significantly affect broad-band R photometry. For instance, in the two LMC stars S 22 and S 134 the flux in the R filter is about 60 per cent larger than by interpolation of the fluxes from the nearby V and I bands (see Stahl et al. 1985). In such objects the Hα profile can be easily studied at high resolution also in faint objects, including MC stars. In Fig. 3 we show the Hα profiles of three luminous emission-line stars. The observations were made with the CAT-CES system which is in principle limited to the 5th magnitude. S 22 is a LMC star with V = 11.75, but its faint luminosity has not prevented us to observe its Hα line with a resolving power of R = 50,000.

At high resolution Hα displays a complex profile which is different from star to star. For instance, in the three stars in Fig. 3 the Hα profile corresponds to the Beals' P Cygni types I, III and V in AG Car, S 22 and η Car respectively. In the galactic P Cyg star AG Car the narrow absorption is accompanied by very broad wings, probably formed by electron scattering as in the case of P Cyg itself, and by a blue-shifted absorption with a sharp edge which should be related to the terminal velocity of the stellar wind. This profile is variable, sometimes showing a second lower velocity absorption line (Bensammar et al. 1981) which could be attributed to the formation of a dense shell or to a transitory change of the atmospheric structure of AG Car. In S 22 the Hα profile is different with a narrow absorption and

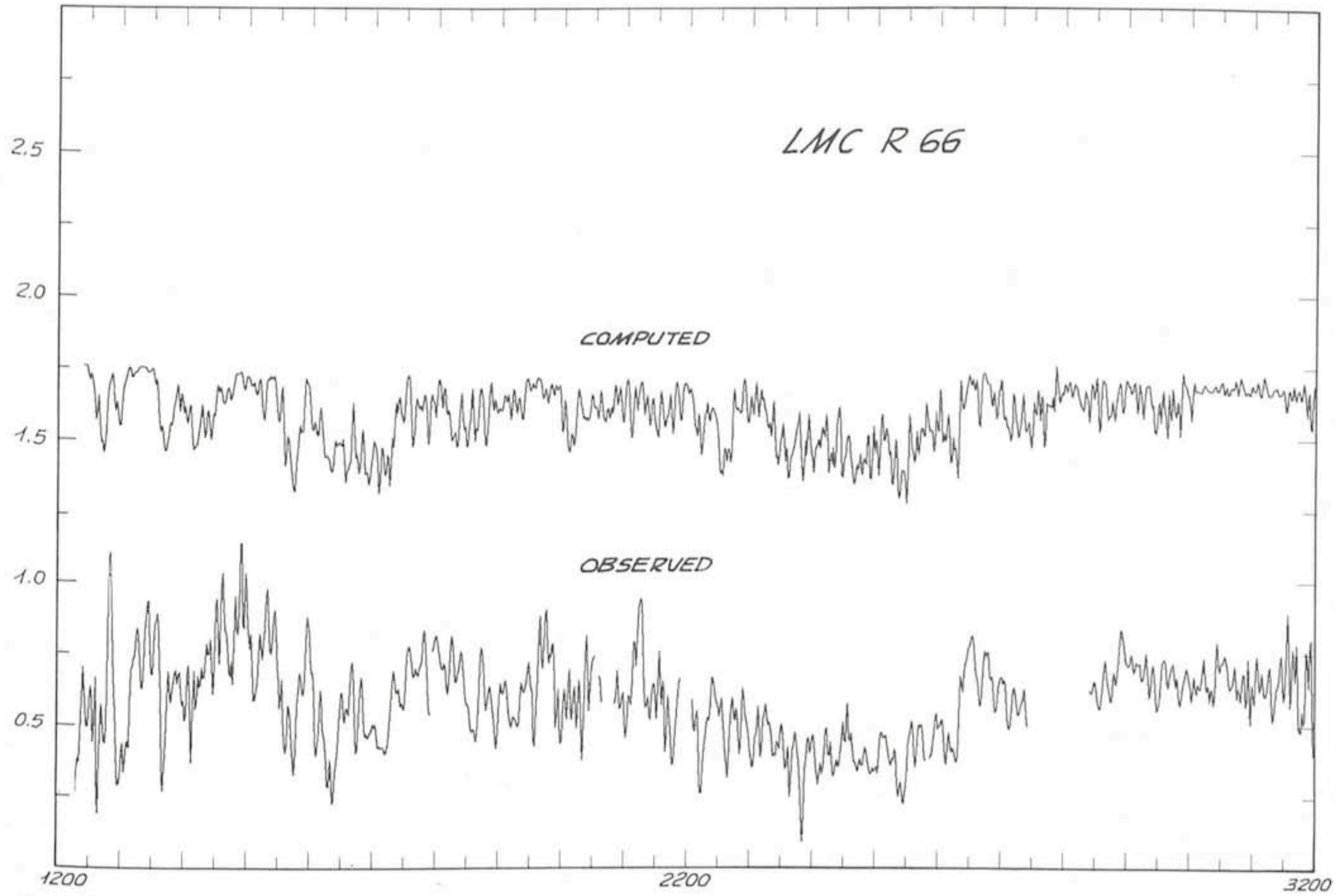

Fig. 2: *The dereddened low-resolution IUE spectrum of the LMC star R66 compared with a computed synthetic spectrum. A constant vertical shift is applied to the computed fluxes. Courtesy of G. Muratorio.*

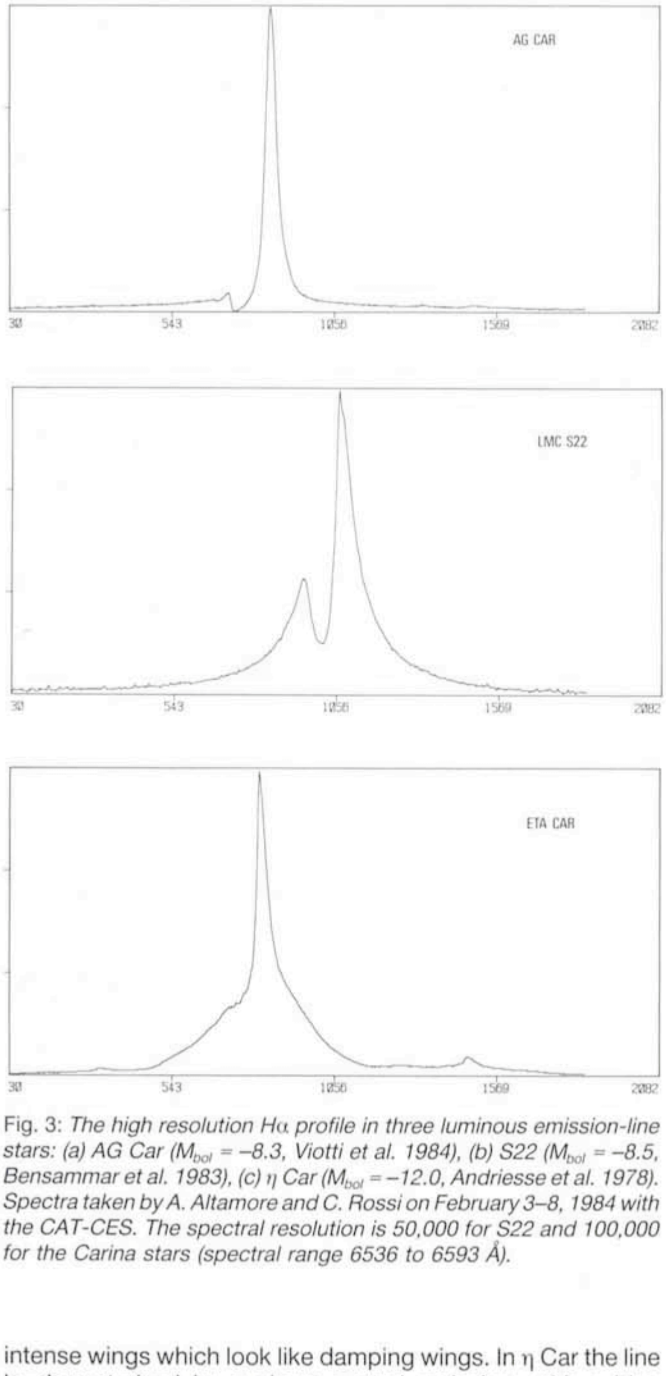

Fig. 3: *The high resolution Hα profile in three luminous emission-line stars: (a) AG Car (M_{bol} = −8.3, Viotti et al. 1984), (b) S22 (M_{bol} = −8.5, Bensammar et al. 1983), (c) η Car (M_{bol} = −12.0, Andriesse et al. 1978). Spectra taken by A. Altamore and C. Rossi on February 3–8, 1984 with the CAT-CES. The spectral resolution is 50,000 for S22 and 100,000 for the Carina stars (spectral range 6536 to 6593 Å).*

intense wings which look like damping wings. In η Car the line is characterized by a sharp central emission, with a blue absorption which is only marginally visible in February 1984, but was stronger in July 1981 (Melnick et al. 1982), and broad asymmetric wings. A similar bi-component structure is also present in the strong emission lines of He I and Fe II, and may indicate the coexistence near the central star of the high velocity dense wind and of a low velocity region.

Variability

Variability is one major characteristic of the brightest emission-line stars. It is known since a long time that irregular small amplitude photometric variations are present in most supergiant stars. The extreme case is represented by the so-called *Hubble-Sandage* or *S Dor* stars showing large photometric and spectroscopic changes on time scales from months to several years. The origin of these variations is still unclear, but in general stars appear bluer at minimum.

An interesting galactic case is represented by the southern variable AG Car whose light curve is characterized by large luminosity variations from V = 6 to 8 mag on time scales of months to years (Mayall 1969). The optical spectrum of this star has been extensively studied by Caputo and Viotti (1970) who found large changes of the excitation of the P Cygni lines. More recently, Viotti et al. (1984) found that during minimum luminosity (V = 7–8) the star displays a *hot* optical spectrum which closely resembles that of its northern counterpart P Cyg. But at maximum luminosity—when V is close to 6 mag—the helium P Cygni lines disappear and the equivalent spectral type is much cooler (A-type). Similar spectral variations are seen in the ultraviolet, and are accompanied by a large increase of the far-UV (IUE, SWP) flux during the phases of low visual luminosity. Viotti et al. and Wolf and Stahl (1982) have found that in spite of the large optical variability, the bolometric magnitude of AG Car remained nearly constant. This behaviour is very similar to that of the S Dor variables. The Large Magellanic Cloud contains a number of such interesting objects (e.g. R 71, R 127 and S Dor itself) extensively studied by the Heidelberg group, showing large spectral and luminosity variations. Also in these objects there is a clear indication that the variations occur at nearly constant bolometric luminosity (e.g. Wolf and Stahl 1983). One is therefore brought to the conclusion that *the variability is only apparent* and most probably caused by changes of the structure of the expanding atmosphere. This causes a flux redistribution of the stellar radiation, so that at minimum luminosity more energy is emitted in the ultraviolet and the star appears bluer and fainter. At maximum the UV flux is lower and the visual flux larger, while the bolometric luminosity remained the same. As we shall show later, a different situation holds in the case of the galactic variable η Car where the large luminosity variations are due to the circumstellar dust.

Apart from the rather spectacular variations of the S Dor variables described above, there are also smaller transient phenomena characterized by changes of the line strength and profile without large photometric variations. The classical example is P Cyg—the prototype of the superluminous emission-line stars—whose spectrum displays a stable absorption at −206 km s^{-1}, representing a shell at large distance from the star, and a variable absorption component at lower velocity formed in a transient shell moving (and accelerating) outwards (Lamers et al. 1984). Similar transient phenomena have also been observed in the peculiar star η Car by Viotti (1969) and Zanella et al. (1984). Again these observations indicate structure changes of the stellar atmospheric envelope, possibly originating by an increase of the mass loss rate, or by ejection of denser shells, so that a kind of perturbation moves outwards across the envelope, causing transient changes of the density

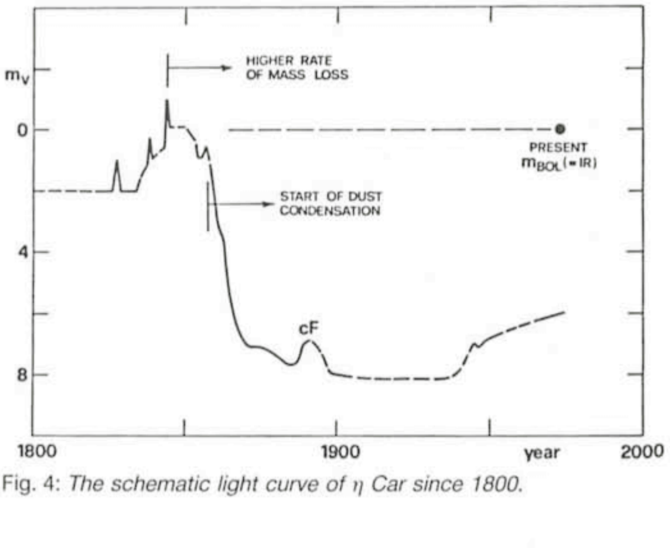

Fig. 4: *The schematic light curve of η Car since 1800.*

and temperature distribution. It is worth noting that if this perturbation is small, one could in principle use the observed spectral variations as a probe of the physical conditions in the outer stellar atmospheres.

Circumstellar Dust

Variability of a peculiar star may also be caused by other physical processes, such as extinction by circumstellar dust regions with variable thickness. The typical case is represented by the galactic superluminous star η Car. This is presently a sixth magnitude star, but 150 years ago it was one of the brightest stars in the sky (Fig. 4). Since 1856 the stellar magnitude gradually decreased, and this suggested the (uncorrect) classification of η Car as a very slow nova. The star is presently a very bright infrared source. Andriesse et al. (1978) found that the bolometric magnitude derived from the infrared energy distribution is close to the estimated bolometric magnitude during the bright phase of last century. This suggests that the large fading after 1856 is due to the start of the dust-condensation process. The optical and ultraviolet radiation of the central star is more and more absorbed by the expanding envelope, and reemitted in the infrared. Presently, the star is in fact surrounded by a small dusty nebula whose total mass is a few solar masses, formed by matter ejected during the past 150 years.

Circumstellar dust is not exceptional among the most luminous emission-line stars. For instance, recent infrared surveys of the Magellanic Clouds have disclosed several stars with IR excess attributed to thermal emission from dust heated by the stellar radiation (Stahl et al. 1984, 1985, Glass 1984). The question is still open whether this dust is protostellar, or formed from the stellar wind in the present or in a previous evolutionary stage of the star. Anyhow, we cannot exclude that in the extreme conditions which cloud be present in the atmospheres of the S Dor and Hupple-Sandage variables, dust grains could be formed and/or accreted in their stellar winds, causing a considerable attenuation of the stellar light. Subsequent changes in the physical conditions of the stellar atmosphere might destroy the grains, or dissipate the dust envelope, resulting in an apparent brightening of the star. It is therefore attractive to conclude that these processes could be at least partly at the origin of the large brightness variations observed in the Hubble-Sandage variables, and that *these variations occur at probably constant bolometric luminosity*, as in the case of η Car.

It is clear from the above arguments that the study of the (variable) structure of the envelopes of luminous emission-line stars is crucial to understand their nature. The problem of the *circumstellar dust* is a particularly interesting one and should deserve more investigation in the future. However, although the most luminous stars have been the subject of a large number of studies in the last years, it is far from clear what is their role in the evolution of massive stars, and, in particular, which are their basic physical parameters, such as temperature, luminosity, chemical abundance, mass and mass-loss rate. More systematic studies are required of a number of representative individual objects in our Galaxy, as well as in the MCs and in external galaxies, in order to provide a more *complete* and *homogeneous* set of observational data which could be useful for making appropriate theoretical models.

I am very grateful to Aldo Altamore, Roberto Gilmozzi, Gerard Muratorio and Corinne Rossi for their collaboration in this investigation, and for providing me with unpublished data, and to Michael Friedjung for discussions and comments on the manuscript.

References

Andriesse, C.D., Donn, B.D., Viotti, R.: 1978, *Mon. Not. R. Astr. Soc.* **185,** 771.
Bensammar, S., Guadenzi, S., Johnson, H.M., Thé, P.S., Zuiderwijk, E.J., Viotti, R.: 1981, *Effects of Mass Loss on Stellar Evolution*, C. Chiosi and R. Stalio eds., D. Reidel, Dordrecht, 67.
Bensammar, S., Friedjung, M., Muratorio, G., Viotti, R.: 1983, *Astron. Astrophys.* **126,** 427.
Caputo, F., Viotti, R.: 1970, *Astron. Astrophys.* **7,** 266.
de Jager, C.: 1980, *The Brightest Stars,* D. Reidel, Dordrecht.
Glass, I.S.: 1984, *Mon. Not. R. Astr. Soc.* **209,** 759.
Gilmozzi, R., Viotti, R., Wolf, O., Zickgraf, F.-J.: 1985, in prep.
Lamers, H.J., Korevaar, P., Cassatella, A.: 1984, *Fourth European IUE Conference,* ESA SP-218, 315.
Mayall, M.W.: 1969, *J.R. Astr. Soc. Canada* **63,** 221.
Melnick, J., Ruiz, M.T., Maza, J.: 1982, *Astron. Astrophys.* **111,** 375.
Muratorio, G., Friedjung, M., Viotti, R.: 1984, Proc. *Fourth European IUE Conference,* Rome, 15–18 May 1984, ESA SP-218, p. 309.
Shore, S.N., Sanduleak, N.: 1984, *Astrophys. J. Suppl. Series* **55,** 1.
Stahl, O., Leitherer, C., Wolf, B., Zickgraf, F.-J.: 1984, *Astron. Astrophys.* **131,** L5.
Stahl, O., Wolf, B., de Groot, M., Leitherer, C.: 1985, *Astron. Astrophys. Suppl.,* in press.
Viotti, R.: 1969, XV Liège Colloquium *Les Transitions Interdites dans les Spectres des Astres,* Université de Liège, Vol. **54,** 333.
Viotti, R.; 1976, *Astrophys. J.* **204,** 293.
Viotti, R., Altamore, A., Barylak, M., Cassatella, A., Gilmozzi, R., Rossi, C.: 1984, *NASA IUE Conference.*
Wolf, B., Stahl, O.: 1982, *Astron. Astrophys.* **112,** 111.
Wolf, B., Stahl, O.: 1983, *The Messenger,* No. **33,** 11.
Zanella, R., Wolf, B., Stahl, O.: 1984, *Astron. Astrophys.* **137,** 79.

Rotation and Activity of T Tauri Stars

J. Bouvier and C. Bertout, Institut d'Astrophysique de Paris

T Tauri stars are late-type, pre-main-sequence stars that, although at present quite active, will evolve in time into stars resembling the Sun. They are emission-line variables with strong ultraviolet and infrared excesses. They display flare-like X-ray emission, and a few can be detected in the radio range as well. Mass-loss rates estimated for these objects reach about $10^{-8} M_{\odot}$ /yr, and some T Tauri winds drive anisotropic, often bipolar, high velocity molecular outflows. A question which naturally arises when studying T Tauri stars is therefore what makes these objects so different from the main-sequence stars they are likely to become. In other words, is the T Tauri phenomenon due to a specific and as yet undetermined physical process, or is it only an exaggerated form of solar-type activity?

Stellar evolution theory might have been able to offer an answer to this question, at least in a first approximation, since pre-main-sequence evolution in spherical symmetry has been computed by various groups. But the T Tauri phase corresponds to the transition between the protostellar and main-sequence stages, and little understood magnetic and convective phenomena are expected to influence the evolution and spectral appearance of the star during this phase. Since the