T TAURI STARS AND FLARE STARS: COMMON PROPERTIES AND DIFFERENCES

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ABSTRACT. T Tauri stars and flare stars are both magnetically active late-type stars of low mass and low to moderate luminosities. The flares observed in these two classes of variables show similar properties and, thus, probably have the same physical origin. On the other hand, at least the majority of the classical T Tauri stars seem to be surrounded by cool, dusty (accretion) disks, which are absent or undetectable in most classical flare stars.

1 Common Properties

Similarities between the flare stars (FSs) and the T Tauri stars (TTSs) have been noted in many earlier papers (see e.g. Haro 1957, 1976, Ambartsumian and Mirzoyan 1975, Mirzoyan 1977). New high-quality observations of TTSs obtained in recent years at many different wavelengths, and summarized, e.g., by Bertout (1989) and Appenzeller and Mundt (1989), confirm the presence of many common properties. However, the new observational data also demonstrate the presence of characteristic differences between these two classes of variable late-type stars.

A characteristic property shared by the TTSs and the FSs is the occurence of flares, i.e. short-term brightness outbursts with a rapid rise and a slower decline. Although in individual TTSs flares seem to occur less frequently than in classical flare stars, the properties of the T Tauri flares observed at UV and visual wavelengths (see e.g. Kilyachkov and Shevchenko 1976), at X-rays (Feigelson and DeCampli 1981, Montmerle et al. 1983, Walter and Kuhi 1984), and at radio wavelengths (Feigelson and Montmerle 1985, André et al. 1987, Stine et al. 1988, Feigelson 1988) agree well with those found for classical flare stars.

Flares are known to occur in all subclasses of the TTSs, including strong-emission classical TTS (such as DG Tau and RW Aur), weak-emission TTSs, and post-TTSs (such as DoAr 21). Additional support for a common origin of the FS and TTS flares is indicated by the occurrence of spectral signatures typical for stellar flares in

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the short-term emission-line variations of classical TTSs (see e.g. Appenzeller at al. 1983).

Another common property of FSs and TTSs are quasi-periodic light variations, which are generally assumed to be caused by magnetic star spots on the surface of rotating stars, and which provide indirect evidence for extensive photospheric magnetic fields in FSs as well as in TTSs. In the case of the FSs the quasi-periodic variations have been known since many years from the systematic investigation by Krzeminski and Kraft (1967) and many subsequent papers. For the TTSs this phenomenon has been studied, e.g., by Hoffmeister (1965), Rydgren et al. (1984), Bouvier et al. (1986), Herbst et al. (1986), Vrba et al. (1986, 1988, 1989), Herbst and Koret (1988), and Bouvier and Bertout (1989).

2 Differences

Among the empirical properties which are observed for TTSs, but *not* in classical FSs, are strong, cool, and sometimes surprisingly well collimated stellar winds or outflows (cf. e.g. Lada 1985, Mundt 1988, Appenzeller and Mundt 1989) and cool, dusty circumstellar evelopes (cf. e.g. Chini 1989). Line profile studies provide conclusive evidence, that these cool envelopes show a disk structure and extend to at least about 100 AU from the stars (cf. e.g. Appenzeller 1983, Jankovics et al. 1983, Appenzeller 1989).

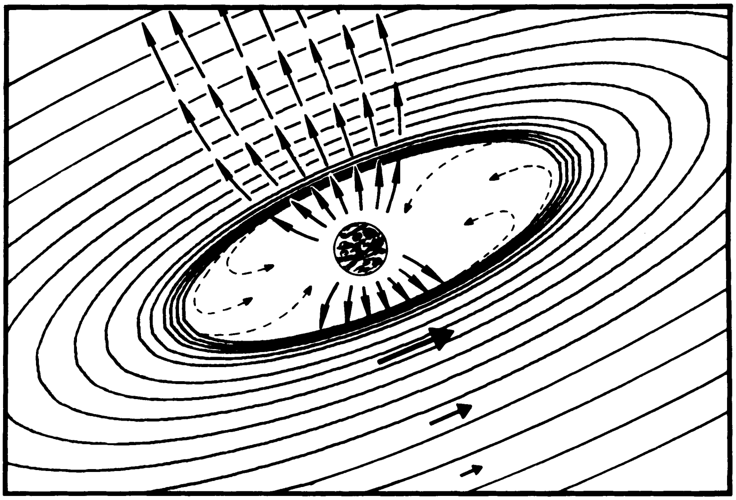

Figure 1: Schematic outline of the accretion disk model of classical T Tauri stars

As shown by Bertout et al. (1988), Basri and Bertout (1989), and others, the observed continuum energy distribution and many other observed properties of the classical TTSs can be explained by assuming that (turbulent or magnetic) angular momentum transfer results in a heating of the disks and in an accretion flow to the central star . Since TTSs are known to rotate much more slowly than the Keplerian orbital velocity near their surfaces, there must be a transition zone or "boundary layer" between the inner edge of the accretion disk and the stellar surface. In this zone at least half of the initial potential energy of the accreted matter is converted into heat. From the presence of strongly redshifted absorption features of the Na I resonance lines (and sometimes also of Fe II, Ca II, Balmer, and other lines) it is clear that at least part of the TTSs have extended regions of (more or less) free falling matter inside the inner disk boundary (cf. Figure 1). The absence of orbiting material in these inner zones may be due to the interaction with the slowly rotating magnetic field of the central star. In some TTSs (such as DR Tau, cf. Appenzeller et al. 1988) observed infall velocities up to to about 400 km s^{-1} (i.e. of the order of the surface escape velocity) indicate that the free fall zone extends over at least several stellar radii. In this case most of the boundary-layer energy dissipation is expected to take place in a shock front close to the stellar surface.

The rotating magnetic field also provides a mechanism for driving and collimating the observed winds along the direction of the rotation axis. Because of its high specific angular momentum this rotationally driven wind efficiently removes the angular momentum of the accreted matter (cf., e.g., Pudritz 1988, Appenzeller 1989).

In the case of the classical FSs, we have no evidence for either cool circumstellar disks or for mass accretion. Very likely the FSs represent a later evolutionary phase of the low-mass stellar evolution, where the disks have been depleted by the accretion flows and other effects (e.g. the formation of planets). An intermediate stage may be the weak-emission line or "naked" TTSs which (at least in part) have cool circumstellar disks (Chini 1989), but show no indications of significant mass accretion.

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BLAAUW: In your presentation I did not hear reference to the interstellar medium within which these stars are located. This question occurred to me particularly when you spoke about the cases with observable inflow of matter. Should this be directly related to the ISM? Do we know a star with inflow situated in a "clean, empty" volume?

GYULBUDAGHIAN: Did you observe the change of duplicity of emission lines during the change of line widths (i.e. sometimes the right component is seen, sometimes the left, sometimes both)?

APPENZELLER: Yes. All T Tauri stars with double-peaked Balmer lines which we looked at showed strong variations of the relative strength of the blue and red peaks.

BASTIEN: I have two comments to make. One must be careful when interpreting line profiles of extreme T Tauri stars, e.g. HL Tauri, which are seen nearly edge on. The light from these stars is reflected by the circumstellar disk and this complicates the interpretation of line profiles. Secondly, in the Monte Carlo results of circumstellar disks which I described earlier,there has to be a "hole" or empty region close to the star as you suggested. The results of these models are sensitive to the size of the hole and the distribution of matter in the inner disk region. Therefore, it may be possible to learn about this interesting region close to the star from these models.

MIRZOYAN: Many years ago in the Bamberg colloquium you tried to show that the majority of the T Tauri stars have anti-P Cygni spectral line profiles. What is your opinion on this problem now?

APPENZELLER: Current disk models of the T Tauri stars (TTS) predict that all classical T Tauri stars (CTTS) have mass accretion. How often this mass accretion manifests itself in inverse P Cygni profiles is unclear. Observationally we know at present between 30 and 40 TTS where inverse P Cygni profiles have been observed at least once. I guess that this is about 50 % of all CTTS which have been observed at sufficient spectral resolution. So the estimate made in Bamberg may still be correct.