MAGNETIC ACTIVITY OF T TAURI STARS

T. MONTMERLE
Service d'Astrophysique, Centre d'Etudes de Saclay
91191 Gif-sur-Yvette Cedex, France

1. Introduction

T Tauri stars (TTS) are low-mass ($M \lesssim 1M_\odot$) pre-main sequence (PMS) stars (for a general review, see Bertout 1989). They have long been known to be variable from near-UV to near-IR wavelengths, on timescales ranging from a few minutes to a few decades. They are observed to flare in many wavenlength rages, from X-rays to the radio, and all the existing evidence is consistent with a very strong magnetic activity, in many ways analogous to solar activity (for a review, see, *e.g.*, Montmerle *et al.* 1991).

2. X-Ray Evidence: Flares

The *Einstein* observatory obtained images in the spectral band ~ 0.4 to $\sim 4keV$ of several nearby dark clouds: ρ Ophiuchi, Taurus-Auriga, Chameleon, and others ($d \sim 160pc$), as well as Orion ($d \sim 450pc$). (For reviews, see, *e.g.*, Feigelson, Giampapa, and Vrba 1991, Pallavicini 1991). New images will come from the recently launched *ROSAT* mission.

X-ray emission between 10^{29} and up to several $10^{31} erg.s^{-1}$ in the *Einstein* band is a general property of low-mass PMS stars: "classical" TTS (CTTS), which display broad emission lines, UV and IR excesses, as well as "weak" TTS (WTTS), which lack these features, and which were discovered only through their X-ray emission (Walter *et al.* 1988). The spectra are consistent with bremsstrahlung emission from a hot ($kT \sim 1keV$, i.e., $T \sim 10^7 K$) plasma with typical line-of-sight absorption $N_H \sim 10^{21} cm^{-2}$, *i.e.*, $A_v \sim 1-2$. Much evidence has accumulated in favor of the existence of large X-ray flares. The variations are typically factors of 2-20 in amplitude and are statistically similar to the distribution of peak X-ray emission in solar flares. These flares have X-ray luminosities up to 10^6 times those seen on the modern Sun, are considerably stronger than flares on dMe flare stars, and are quite similar to flares observed on RS CVn close binary systems. Application of simple loop models suggest that the temperatures ($T \sim 10^7 K$), plasma densities ($n \sim 10^{10} cm^{-3}$) and magnetic field strengths ($B_* \sim 1kG$ at the base of the loop) are not remarkably different from solar flares. But the inferred loop sizes ($l \sim 10^{11} cm$) are large, in general comparable to R_* (i.e., $\sim 2R_\odot$), and sometimes as large as 2 R_*.

3. Optical Evidence: Starspots

In the past decade, systematic photometric studies on a timescale of a few days have led to the detection of periodic light-curves for a number of TTS (CTTS and WTTS alike), which can often be modelled by a single large starspot (or an assembly of smaller starspots)

J. Bergeron (ed.), Highlights of Astronomy, Vol. 9, 653–654.

covering typically 10 % of the stellar surface, cooler than the stellar photosphere by several $100K$ (see, *e.g.*, Bouvier and Bertout 1989). The properties of these starspots are very similar to those found on other magnetically active stars, such as RS CVn systems and BY Draconis stars. The lifetime of TTS spots greatly varies from one star to another, up to several years. In some stars, however, the photometric modulation may disappear from one season to another. This suggests that modulation of the stellar luminosity by spots is indeed the main mechanism responsible for day-to-day variability in these stars.

4. Radio Evidence: Non-Thermal Emission and Magnetic Fields

The numerous VLA observations available have shown that $\sim$ 10 % of TTS are radio emitters at the level of a flux density sensitivity $\sim 0.5mJy$. For CTTS, the radio emission is most likely of thermal origin, and consistent with the existence of intense ionized stellar winds around these stars, the size of the emitting region being typically $R \sim 1000R_*$. In the case of WTTS, the emission is almost certainly nonthermal, and probably due to gyrosynchrotron radiation occurring in large (several R_*) magnetic loops near the stellar surface. The evidence includes strong variability, polarization, and VLBI detection.

As in X-rays, strong variability was found for WTTS by way of long or repeated observations spread over several years (*e.g.*, Stine *et al.* 1988). The exact timescale for variability is unknown, but variations in flux of factors of at least 2 have been found in a few hours, and up to 10 within a few months. The most direct radio signature of the presence of magnetic fields is the detection of circular and/or linear polarization. Weak ($\sim$ 7 %) circularly polarized radio emission has been detected in a very young object, the embedded B3 star S1 in the ρ Ophiuchi cloud, suggesting the presence of a large-scale (*i.e.*, several R_*) magnetosphere, with B_* similar to what prevails on the well-known magnetic B stars ($1 - 10kG$). Direct access to the magnetic field size are provided by VLBI studies of the "bright" ($S_{6cm} > 1mJy$) stellar radio sources in Ophiuchus and Taurus. These observations have confirmed model predictions for S1 (André *et al.* 1991), and demonstrated that the radio emission of most or all WTTS is nonthermal (Phillips, Lonsdale, and Feigelson 1991). The radio emission may be shown to come from regions 10-30 R_* in size, and $B_* \sim$ a few kG.

5. Conclusion

Existing evidence, drawn in particular from X-ray and radio observations, shows that T Tauri stars and other young objects display an intense magnetic activity. The solar analogy is found to be consistent with most of the observations, and allows to demonstrate that, while the surface values of the magnetic fields are essentially those of solar active regions, their derived sizes are much larger, and may reach a few tens of stellar radii.

References

André, Ph., Phillips, R.B., Lestrade, J.-F., and Klein, K.L.: 1991, *Astrophys. J.*, in press.
Bertout, C.: 1989, *Ann. Rev. Astr. Ap.* **23**, 351.
Bouvier, J., and Bertout, C.: 1989, *Astron. Astrophys.* **211**, 99.
Feigelson, E.D., *et al.*: 1991, *The Sun in Time*, Univ. of Arizona, in press.
Montmerle, T., *et al.*: 1991, *Protostars and Planets III*, Univ. of Arizona, in press.
Pallavicini, R. 1989, *Astron. Astrophys. Rev.* **1**, 177.
Phillips, R.B., Lonsdale, C.J., and Feigelson, E.D.: 1991, *Astrophys. J.*, in press.
Stine, P.C., Feigelson, E.D., André, Ph., and Montmerle, T.: 1988, *Astron. J.* **96**, 1394.
Walter, F.M., *et al.*: 1988, *Astron. J.* **96**, 297.