Mem. S.A.It. Vol. 76, 320

Memorie della

FU Orionis systems

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Abstract. FU Orionis variables make up a small class of young low mass T Tauri stars characterized by a strong brightening (up to 6 mag) followed by a gradual fading. FU Orionis stars share a distinctive set of morphological, photometric, and spectroscopic characteristics at different wavelength bands. Steady accretion disk models successfully explain many observations of the FU Orionis. A low mass companion (planet or BD) may be responsible of the outbursts. Periodic variations of the Hα line profile observed in FU Ori, the brightest member of FU Orionis class, can be indicative of the presence of this kind of companion.

Key words. Stars: pre-main-sequence – Stars: accretion – Stars: individual: FU Ori

1. Overview

The FU Orionis (FUor) phenomenon represents a rare and not yet fully understood phase of the early evolution of the low-mass stars. FUors share a distinctive set of morphological, photometric and spectroscopic characteristics.

Most have fan-shaped or coma-shaped reflection nebulae on optical and near-IR images.

Photometrically FUors are characterized by violent and probable recurrent outbursts, during which the stars can increase the bolometric luminosity by two to three orders of magnitude. The light curves (Fig. 1) of the three best studied FUors (i.e. FU Ori itself, V 1515 Cyg and V 1057 Cyg) show remarkable differences between each other. The rise timescale of FU Ori and V 1057 Cyg is very short (of the order of 1 yr), while that of V 1515 Cyg is definitely longer ($t_{rise} \approx$ 20 yr). On the other hand, while FU Ori and V 1515 Cyg have a very long decay time-scale ($t_{decay} \approx$ 50 ÷ 100 yr), V 1057 Cyg decays much faster ($t_{decay} \approx$ 10 yr).

A number of objects are known that are spectroscopically similar to FUors, but for which the outburst phase has not been documented. Quite possible, these represent objects whose outbursts occurred too long ago to have been observed.

Spectroscopically, FUors have no-emission-lines spectra with optical characteristics of G-type supergiants, yet near-IR characteristics of cooler K- or M-type giants/supergiants dominated by deep CO overtone absorption.

All FUors have broad optical or IR absorption lines or both indicating large rotational velocities. The near-IR CO lines have significantly smaller rotational velocities than the optical lines. Many FUors display doubled absorption lines on optical and near-IR spectra. The long-term stability of the doubled absorption lines indicates that the lines are not produced by two stellar components in a binary system.

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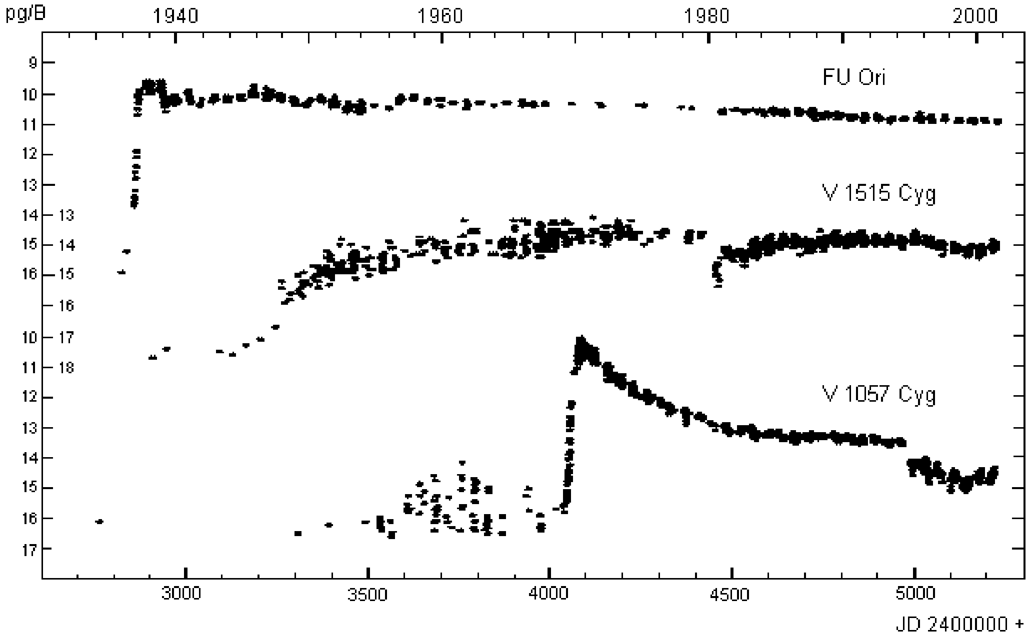

Fig. 1. Optical light curves of the three best studied FUors.

All FUors show large excesses of radiation at both UV and IR wavelengths. The near-IR excess is clearly photospheric in origin, because the CO and H_2O absorption features are very strong. The UV excess appears associated with an A- or F-type photosphere, that is hotter than the G-type photosphere observed at longer wavelengths. In addition to significant far-IR and submm emission, many FUors are strong radio continuum sources at cm wavelengths.

All of the optically bright FUors ($A_v \sim 2 \div 3$ mag) have very strong winds, as indicate by the very broad, deep P Cyg absorption profile seen in the Balmer lines and the low-ionization Na I resonance lines. Typical values for the terminal velocity and the estimated mass loss rate are $V_\infty \sim 300 \div 500$ km s^{-1} and $\dot{M} \sim 10^{-5}$ $M_\odot$ yr^{-1} respectively. The Hα emission component is normally absent or weak. The embedded FUors ($A_v \geq 10$ mag) drive large-scale molecular outflows and bipolar HH outflows.

2. Mechanisms of outburst

According to Hartmann & Kenyon (1985) the FUor outbursts are due to a sudden increase of the mass accretion rate (up to 10^{-4} $M_\odot$ yr^{-1}) in the disk of an otherwise *normal* T Tauri star. This interpretation is suggested by a number of observations:

1. in one case (i.e. V 1057 Cyg) a pre-outburst stellar spectrum is available, it shows typical features of a T Tauri star;
2. the spectral energy distribution (SED) after the outburst is well described in term of accretion disk SEDs;
3. optical and near-IR line profiles are usually double-peaked, as one expects if the lines originate from a differential rotating disk;
4. the gradual decrease in the rotational velocity with increasing wavelength occurs because the longer wavelength emission is produced in more slowly-orbiting material at larger disk radii than the more rapidly moving disk material responsible for the short wavelength emission.

The disk model fails to explain $10 \div 100\,\mu$m SED of many FUors, but the disagreement can be due to the fact that the mid-IR radiation is optical light absorbed and reradiated by a surronding envelope. However, there are still sev-

Table 1. FUor binary systems.

System	Type	Separation (AU)
L 1551 IR 5	Proto-binary	45
Z CMa	FUor + Ae/Be	100
FU Ori	FUor + PMS	225
AR 6A+6B	FUor + FUor	2240
RNO 1B/1C	FUor + FUor	5000

eral unsolved issues where observations and model predictions do not match (Herbig 1989; Herbig et al. 2003). In particular according to Herbig et al. (2003) FUors represent a special subclass of rapidly rotating T Tauri stars.

Several different mechanisms have been suggested to trigger the outbursts:

1. a tidal interaction with a companion star (Bonnell & Bastien 1992), this model is supported by the existence of some binary systems among FUors (Table 1);
2. a gravitational instability in the outer massive disk (Armitage et al. 2001), according to this model the outburst duration is $\sim 10^4$ yr, two order of magnitude longer than the observed ones;
3. a viscous thermal instability (Bell & Lin 1994) in a disk fed at high mass accretion rate from a surrounding envelope, according to this model the disk tends to become unstable at the inner edge, then the instability propagates inside out, producing a slowly rising luminosity compatible with the light curve of V 1515 Cyg. This model cannot explain the rapid time-scale of FU Ori and V 1057 Cyg. In order to obtain a rapid rise, the instability must be first triggered at a large radius, so that the instability propagates outside in.

According to Clarke & Syer (1996) outside-in disk instabilities are a natural consequence of the existence of proto-planetary/proto-stellar companions. Lodato & Clarke (2004) explored the possibility that the thermal instability is triggered away from the

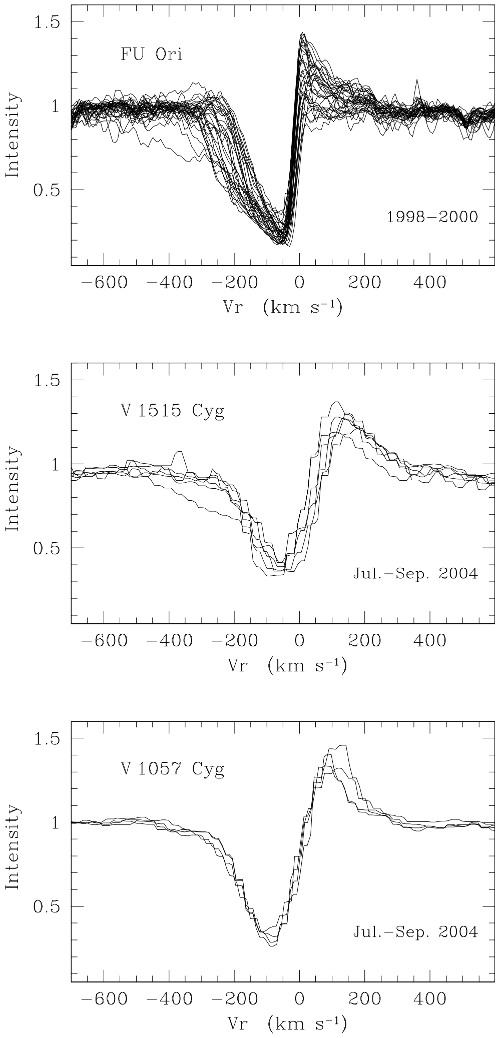

Fig. 2. Variations of the Hα profile of FU Ori in 1998–2000 (upper pannel), V 1057 Cyg in 2004 (middle pannel) and V 1515 Cyg in 2004 (lower pannel).

disk inner edge (at a distance of $\approx 10\,R_\odot$ from the central star) due to the presence of a massive planet embedded in the disk. This planet would lead to a clear spectroscopic signature in the form of a periodic modulation of the double-peaked line profiles observed in FUors with periods corresponding to the orbital frequency of the planet (Clarke & Armitage 2003). Periodic modulations ($P \approx 3$ days) in the

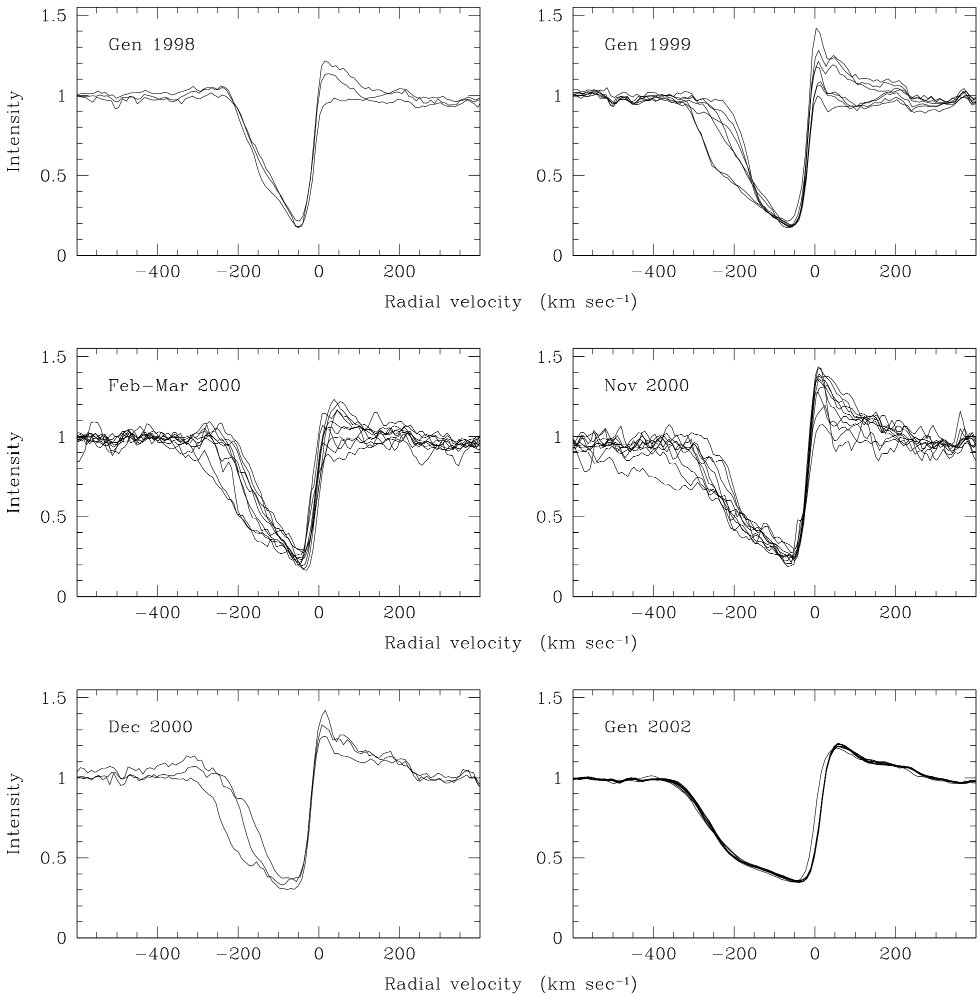

Fig. 3. Variations of the Hα profile of FU Ori in different epochs.

absorption line profiles of FU Ori were observed (Herbig et al. 2003).

3. Hα variability

In an extensive campaign of spectroscopic observations carried out on the three well studied outbursting FUors (i.e. FU Ori, V 1057 Cyg and V 1515 Cyg) we revealed strong variations of the Hα P-Cygni line.

A sample of these observations is shown in fig. 2 and fig. 3. Similar variations were detected in FU Ori and V 1057 Cyg (see Figs. 25 and 26 by Herbig et al. (2003)). There is no correlation between the changes of the absorption and emission components.

The dense time coverage of our spectroscopy on FU Ori makes feasible a search for periodicity. The time series analysis (Scargle 1982) was used to search for periodicity in Hα absorption and emission components. No periodicity is present in Hα absorption component. On the contrary Hα emission component shows a periodicity of 6.70 days (Fig. 4).

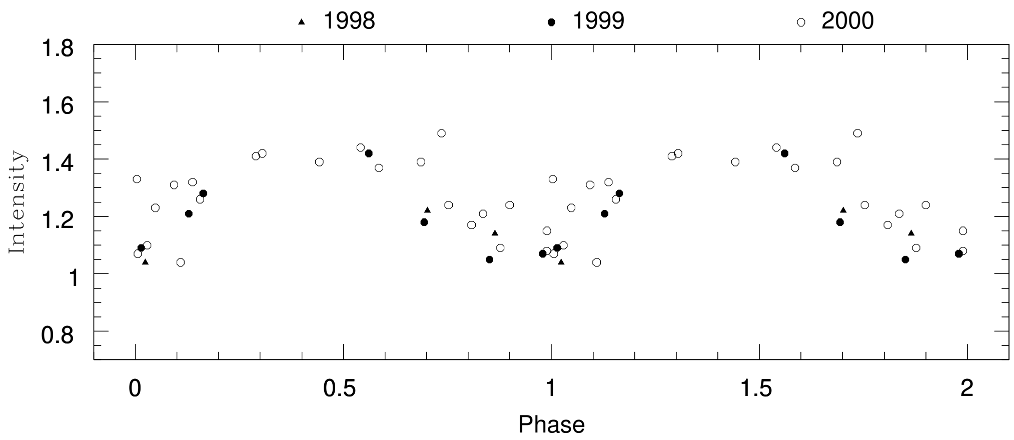

Fig. 4. Phase diagram of the Hα emission component of FU Ori for a period of 6.70 days.

A periodicity of 14.8 days was found in Hα absorption component by (Herbig et al. 2003) in 1997–98, but it disappeared by 2000.

4. Discussion and conclusions

To explain the presence of emission components in the Hα, Na I D, Ca II k and Mg II h,k lines D'Angelo et al. (2000) had to introduce in the FU Ori disk atmosphere a thin layer with temperature inversion at the wind base (like a chromosphere). They were able to reproduce the observed Hα profiles in the spectrum of FU Ori with a reasonable accuracy. D'Angelo et al. (2000) interpreted the observed variations of the Hα profile as resulting from axisymmetric variations in the physical parameters of the wind or, to be more precise, in the temperature and velocity distributions along wind stream lines.

In the frame of this scenario the 6.70 day period of the Hα emission component can be indicative of a periodic variability of the thermodynamic state of a chromosphere-like thin layer, reflecting a thermal instability in the disk.

This instability may be due to effects of mass accretion of a proto-star or massive planet in the disk. The Hα emission component behaviour can be also explained by a periodic occultation of the redshifted material due to the presence of a low mass companion in the disk. If the central star has a mass of 0.5 $M_{\odot}$ the period of 6.70 days corresponds to a keplerian rotation at distance of 11.8 $R_{\odot}$.

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