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FUors, EXors, and the role of intermediate objects

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ABSTRACT

The studies of FUors, EXors, and other young eruptive stars are very important for understanding the earliest stages of pre-main-sequence evolution. We describe the current situation in this field. This is a short version of the review presented at the conference "Non-Stationary Processes in the Protoplanetary Disks and Their Observational Manifestations" held at the Crimean Astrophysical Observatory.

Key words: young variable stars, eruptive activity, FUors, EXors

1 Introduction

Eruptive young stellar objects (YSOs) make up a negligible fraction of known YSOs. But it is their study that can be very important for understanding the early stages of the evolution of low- and medium-mass stars. And we still do not know whether the phenomenon of eruption is a short-term but ordinary event at this evolutionary stage or whether it occurs only under special circumstances.

Eruptive YSO classes

- FUors
- FU Ori-like
- EXors
- Intermediate objects

Next, we briefly discuss the properties of these objects.

2 FUors and FU Ori-like objects

The four so-called **classical FUors** are FU Ori, V1057 Cyg, V1515 Cyg, and V1735 Cyg.

The outburst of FU Ori was discovered about 90 years ago; other three objects were found in the 70s. On the basis of these discoveries, a new distinct class of young eruptive stars was introduced (Herbig, 1966; Ambartsumian, 1971). The general features of FU Ori-like objects or simply FUors (the name suggested by Ambartsumian) were defined in Herbig (1977).

The general properties of FUors in the optical and IR ranges (Herbig, 1977; Audard et al., 2014; Connelley, Reipurth, 2018)

1. An optical flare (~ 5–6 mag) with a very slow decline (or none at all).
2. In optics, the spectrum of an F–G supergiant without emission except for the P Cyg-type profiles in the H_α and some other strong lines.
3. A gradual change in spectral type with wavelength.
4. Deep CO absorption bands at 2.29 μm.
5. The bolometric luminosity after a flare is usually about 100–300 $L_\odot$.
6. The illumination of small reflection nebulae.
7. In most cases, they are the sources of collimated flows.

Outdated terms that can take on a new meaning

Pre-fuors (i.e., progenitors of FUors). A very active YSO, V1331 Cyg, was once suggested as an example of the future FUor. However, we presently know two classical T Tau-type stars (CTTS) that became FUors: V1057 Cyg and V2493 Cyg.

Post-fuors. Nothing is currently known about them. Could they be EXors?

Sub-fuors. While there is no good definition of this term (they must be objects that are in some sense less active than FUors), we can only guess which stars they should be – perhaps EXors or MNors?

A list of FUors

The number of known FUors has been growing very slowly during the past 40 years. Certain objects were excluded from this class after follow-up observations. The currently accepted approach introduces two sub-classes: FUors (i.e., objects with an observed outburst) and FUor-like objects (i.e., stars with spectra and other features typical of FUors after eruption). The current (2021–22) list, which is based on the atlas of Connelley, Reipurth (2018) with several additions, is presented below.

FUors

- RNO 1B (V710 Cas)
- V582 Aur
- V883 Ori

- V2775 Ori (HOPS 223) *
- FU Ori
- V900 Mon
- V960 Mon (2MASS J06593158-0405277)
- V1515 Cyg
- V2493 Cyg (HBC 722)
- V2494 Cyg (HH381 IRS)
- V1057 Cyg
- V2495 Cyg (Braid star) *
- V1735 Cyg
- V733 Cep (Persson's star)
- Gaia 18dvy
- PGIR 20dci *

FU Ori-like objects

- RNO 1C
- PP13 S *
- L1551 IRS5 (HBC393) *
- Haro 5a/6a IRS *
- IRAS 05450+0019 *
- Z CMa
- BBW 76 (V646 Pup)
- V371 Ser *
- Pars 21
- IRAS 21169+6804 (CB230 A)
- HH 354 IRS *

The stars marked by an asterisk (*) are visible only in the IR range.

Additionally, a high-mass and luminosity object, PTF 14jg, should be mentioned, which perhaps can be considered as a "superfuor".

3 EXors

The class of EXors (by the name of the prototype star EX Lupi) was introduced by Herbig (1989), who defined them as T Tauri-type stars with flares of large amplitude (up to 5 mag) but short in time and repetitive. They may be the next stage of evolution after FUors. As emphasized by Herbig (1989), it is impossible to distinguish them spectrally from other CTTS.

According to Herbig (1989, 2008), the **classical EXors** are UZ Tau E, VY Tau, EX Lup, NY Ori, V1118 Ori (Chanal's star), V1143 Ori (Sugano's star). PV Cep and DR Tau were also considered but rejected.

Probably important features of classical EXors

1. Flare amplitudes are comparable to FUors, but they have a much shorter duration – from several months to several years.
2. Bolometric luminosities during an outburst are usually of the order of 5–30 $L_\odot$.
3. EXors are not associated with small cometary nebulae.
4. EXors are not related to jets and outflows.

Supposed EXors

There is no definite list because the boundaries of the class itself are vague. "The original list of EXors has changed little since 1989" (Audard et al., 2014). "New EXors" (Lorenzetti et al., 2012) was an attempt to identify eruptive objects similar to classical EXors in the total mass of CTTS. As a result of these and other works, the following objects were considered as EXors: V512 Per (SVS 13), V1180 Cas, XZ Tau (N), LDN1415 IRS, V1647 Ori, GM Cha, OO Ser, V2492 Cyg, GM Cep, PV Cep, and V723 Car (turned out to be a massive object).

Most of the candidates for EXors subsequently disappeared from this list according to various criteria (in terms of luminosity, mass, character of variability, etc.); a number of them passed into the class of intermediate objects. Besides, almost all "new EXors" turned out to be associated with optical outflows and cometary nebulae.

An analysis of the evolutionary position of EXors (Moody and Stahler, 2017) leads to the conclusion that almost all "new EXors" are deeply embedded in dust objects; classical EXors are somewhat older; and only a small part of pre-main-sequence (PMS) stars are a subject to EXor-type outbursts. In recent years, a detailed study of EXors, the EXORCISM program, has been started. In the course of this program (Giannini et al., 2022), in addition to 6 classical EXors, as well as PV Cep and DR Tau stars, the following objects were subjected to detailed studies: XZ Tau N, V350 Cep, ASASSN-13db (a very low-luminosity object), V1647 Ori, iPTF15afq. Undoubtedly, some of them are also intermediate objects. Additionally, among the most recent findings of the probable EXor-type objects, Gaia 20eae and ESO-H$_\alpha$99 should be mentioned.

4 Intermediate objects

This class of eruptive PMS objects cannot be precisely defined yet, but it certainly exists and has a number of common properties (at least in the visible range), combining FUors and EXors characteristics in various proportions.

1. Like FUors, they are usually associated with collimated outflows and small nebulae.
2. Outbursts last several years (between FUors and EXors).
3. They often have emission spectra of classical TTS.
4. Bolometric luminosities are moderate.

The first recognized intermediate object is V1647 Ori (McNeil's object) found in 2004 (McNeil et al., 2004).

The name MNors (coined from "McNeil's star" and apparently premature as no definitions exist yet) was proposed by Contreras Peña at al. (2017) when searching for eruptive IR variables deeply immersed in dark clouds. It is possible that some of 15 objects, which are discovered by this group, with a flare duration of 1–4 years are indeed related to FUors and EXors. An infrared variable object, UKIDSS-J185318.36+012454.5, recently found at BAO can also be added to this list.

For obvious reasons, it is difficult to compile a complete current list of such objects, but it is expected to include at least 20 objects. A number of objects were identified on the basis of actually observed outbursts, a few more – as the probable FUor-like stars (with a spectrum similar to the post-outburst stage, which, however, changed a few years later; see, in particular, Connelley, Reipurth (2018)).

Intermediate objects of the first group (with an unusual lightcurve)

- V1647 Ori (McNeil's Object)

- V346 Nor (HH57 IRS)
- OO Ser
- V1180 Cas
- PV Cep
- V350 Cep
- V2492 Cyg
- V899 Mon
- IRAS 20390+4642 (Gaia19bey)
- 2MASS 22352345+7517076
- 2MASS 08104579-3604310 (Gaia19ajj)
- HOPS 383 – an object of Class 0 visible only in the IR range
- V1318 Cyg S – can it be a very slow FUor?

Intermediate objects of the second group (distinguished by the optical and IR spectra)

- IRAS 06297+1021W
- AR 6a (V912 Mon)
- AR 6b
- IRAS 18270-0153W
- IRAS 06393+0913 (can be a brown dwarf)
- IRAS 18341-0113S (can be a brown dwarf)

5 New examples of unusual eruptive PMS stars

5.1 V1318 Cyg S (LkH$_\alpha$ 225): a very slow FUor?

This emission-line star was dicovered by Herbig (1960). Until 1991, it demonstrated a strong TTS-type variability with occasional flare-ups.

Magakian et al. (2019) found an atypical brightness increase (> 5 mag) in 2015.

The object developed to the HAeBe star with 750 $L_\odot$ in the optical range after an outburst. Its spectrum shows strong P Cyg-type absorptions and also typical CTTS emissions.

The blue spectrum is very reminiscent of classical FUors; in the red and IR ranges, it is closer to Gaia 19ajj, V2492 Cyg, and V1647 Ori. The mass of the star can be as high as 8 $M_\odot$ (Magakian et al., 2019; Hillenbrand et al., 2022).

5.2 PV Cep: a super-EXor?

This variable star and the related variable nebula were discovered at BAO in 1977 (Gyulbudaghian, Magakian, 1977). PV Cep shows powerful (up to 5 mag) flares lasting for several years, with the last peak in 2017. It is presently at a minimum.

PV Cep has an emission-rich CTTS-type spectrum. Forbidden emissions are split into 4 variable components. The spectral type is estimated as G4. The bolometric luminosity reaches 100 $L_\odot$ at a maximum and about 20 $L_\odot$ at a minimum. The accretion rate is about $10^{-6} M_\odot$ y^{-1}, which is quite a high value.

In addition to high luminosity and amplitude of flares, PV Cep is a source of powerful and extended optical and molecular outflows (Andreasyan et al., 2021; Giannini et al., 2022).

5.3 V350 Cep: a mini-FUor?

V350 Cep is located in the NGC 7129 star-forming region. It was discovered at BAO in 1977 (Gyulbudaghian, Sarkisyan, 1977). After a rise by 4.5 magnitudes in the early 70s, the star remains at the same level; thus, its light curve is almost FUor-type. The UXor-like fadings up to 2 mag were observed two or three times; then the brightness was restored. (Semkov et al., 2017)

V350 Cep has a rich emission spectrum of the classical TTS, which does not change; the spectral type is M0-M2. V350 Cep can be a source of the HH flow. Its bolometric luminosity after an outburst is quite low: 3.3 $L_\odot$.

5.4 V565 Mon

This little-studied variable star illuminates a triangle reflection nebula, Pars 17, and produces an HH outflow. It is also an extremely bright mid-IR source. The bolometric luminosity of V565 Mon is high: 130 $L_\odot$. However, it cannot be considered as a typical HAeBe star since its spectral type is probably near G0. The only emission line (excluding the forbidden lines probably belonging to jet) is double-peaked H$_\alpha$. On the other hand, the most unusual is the presence of strong BaII absorption lines in its spectrum. Their existence suggests either the low-gravity atmosphere (typical of FUors) or the inexplicable overabundance of barium in a very young star. All these features summarized in Andreasyan (2021) do not allow an easy classification of this object.

6 Conclusions

If eruptions of YSOs are indeed due to the abrupt changes in the accretion rate, their observed manifestations are very different. We can see several classes of them.

FUors: more or less well-defined. Apparently, a very rare or short term.

EXors: the final number of discovered objects is unclear; there is also no exact definition. There may be two groups of similar objects at a slightly different evolutionary stage.

Intermediate objects: their great variety is of no doubt. Some of them appear to push the limits of usually accepted definitions of FUors and EXors. The most interesting objects for further research.

MNors: they may not deserve a separate class.

HAeBe stars and other massive objects: could some of them develop into FUors after eruptions?

In addition, all these manifestations can be mixed with UXor-type activity.

Young eruptive objects can also be found among certain IR sources of Class I, which change brightness and become noticeable in the optical range.

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References

Ambartsumian V.A., 1971. Astrofizika, vol. 7, p. 557. (In Russ.)

Andreasyan H.R., 2021. Res. Astron. Astrophys., vol. 21, p. 064.

Andreasyan H.R., Magakian T.Yu., Movsessian T.A., Moiseev A.V., 2021. Astrophysics, vol. 64, p. 187.

Audard M., Ábráham P., Dunham M.M., et al., 2014. In Beuther H., Klessen Ralf S., Dullemond Cornelis P., and Henning T. (Eds.), Protostars and Planets VI. University of Arizona Press, Tucson, pp. 387–410.

Connelley M.S., Reipurth B., 2018, Astrophys. J., vol. 861, p. 145.

Contreras Peña C., Lucas P.W., Kurtev R., et al., 2017. Mon. Not. Roy. Astron. Soc., vol. 465, p. 3039.

Giannini T., Giunta A., Gangi M., et al., 2022. Astrophys. J., vol. 929, p. 129.

Gyulbudaghian A.L., Magakian T.Yu., 1977. Pis'ma Astron. Zhurn., vol. 3, p. 113.

Gyulbudagyan A.L., Sarkisyan R.A., 1977. Astron. Tsirk., vol. 972, p. 7.

Herbig G.H., 1960. Astrophys. J. Suppl. Ser., vol. 4, p. 337.

Herbig G.H., 1966. Vistas in Astronomy, vol. 8, p. 109.

Herbig G.H., 1977. Astrophys. J., vol. 217, p. 693.

Herbig G.H., 1989. ESO Workshop on Low Mass Star Formation and Pre-Main Sequence Objects, pp. 233–246.

Herbig G.H., 2008. Astron. J., vol. 135, p. 637.

Hillenbrand L.A., Isaacson H., Rodriguez A.C., et al., 2022. Astron. J., vol. 163, p. 115.

Lorenzetti D., Antoniucci S., Giannini T., et al., 2012. Astrophys. J., vol. 749, p. 188.

Magakian T.Yu., Movsessian T.A., Andreasyan H.R., Gevorgyan M.H., 2019. Astron. Astrophys., vol. 625, p. A13.

McNeil J.W., Reipurth B., Meech K., 2004. IAU Circ., no. 8284.

Moody M.S.L., Stahler S.W., 2017. Astron. Astrophys., vol. 600, p. 133.

Semkov E.H., Ibryamov S.I., Peneva S.P., 2017. Bulg. Astron. J., vol. 27, p. 75.