# Eruptive variable protostars from VVV

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The search for high amplitude infrared variable stars in 119 deg$^2$ of the Galactic midplane with the Vista Variables in the Via Lactea (VVV) Survey yields 816 variables with $\Delta K_S$>1 mag in the 2010-2012 data. The sample is strongly concentrated toward areas of star formation and variables found in these regions have SEDs typical of YSOs. We find 106 likely YSOs with eruptive light curves increasing the number of known eruptive variable YSOs by a factor of about 5. The majority are optically obscured systems at earlier stages of evolution than the known FUor and EXor types. We find that eruptive variability is at least an order of magnitude more common in class I YSOs than class II YSOs. The typical 1 to 4 year duration of the outbursts is between those of EXors and FUors. Spectroscopic follow up of a sub-sample of the objects confirms 19 variable stars as new additions to the broad class of eruptive variable YSOs, but we find that most of them do not fit the established subclasses and show a mixture of the spectroscopic characteristics of both subclasses. This is in line with other recent discoveries that have already begun to blur the distinction. Since these previously atypical objects are now the majority amongst embedded members of the class, we propose a new classification for them as “MNors”. This term (pronounced “emnor”) follows V1647 Ori, the illuminating star of McNeil’s Nebula.

## Background

Episodic accretion has been invoked to solve long-standing problems in star formation:

- The luminosity problem (see e.g. Kenyon et al. 1990)
- The scatter observed around the best fitting isochrones in pre-MS clusters (Baraffe et al. 2009, 2012)

Observational support for the idea of episodic accretion arises from: 1) observation of emission knots in jets from outflows of YSOs (Ioannidis & Froebrich 2012), and 2) YSOs displaying sudden rises in luminosity, of up to 6 magnitudes, that last months to 100 yrs (Hartmann & Kenyon 1996).

These young eruptive variables suffer from episodic outbursts due to the abrupt increase of the accretion rate onto the central star. The latter probably being caused by instabilities in the disc (see e.g. Audard 2014).

They are usually divided into 1) FUors, which are characterized by showing long-lasting outbursts (t>30 yrs) and strong CO absorption in their near-IR spectra, and 2) EXors, which display lower amplitude and shorter duration outbursts, as well as near-IR spectra with Br $\gamma$ emission and CO emission/absorption depending on bright/quiescent state.

In order to characterize eruptive variability and to try to establish the incidence of episodic accretion among YSOs, we have searched for high-amplitude variability in the near-IR multi-epoch survey VVV.

## The VVV survey

Using VIRCAM at the VISTA 4.1m Telescope in Paranal, Chile, VVV mapped the Galactic Bulge and adjacent midplane in Z, Y, J, H and $K_S$ with a total area of 560 deg$^2$. The survey ran from 2010-2015.

It provided 2 epochs of contemporaneous ZYJHK$_S$ photometry (2010 and 2015) and 50+ epochs of $K_S$ photometry in a period of 5 years.

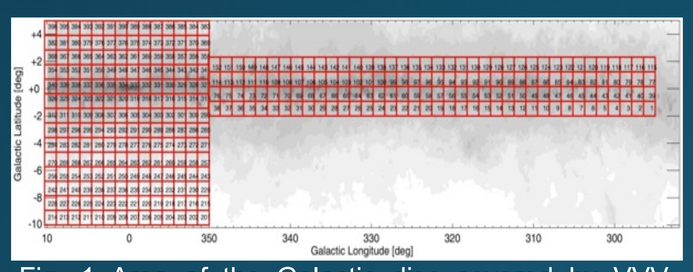



Fig. 1 Area of the Galactic disc covered by VVV. Figure from Minniti et al. 2010

## VVV Search

Original selection from 2010-2012 Ks photometry. We analysed disc tiles with |b|<1°.

- 76 tiles in total
- At least 14 epochs per tile
- 2013-2015 Ks photometry was added later.

Selection requirements

- Classified as star in each catalog.
- $\Delta Ks=Ks_{max}-Ks_{min}$> 1 mag and $\Delta Ks$ to be 3σ above the mean $\Delta Ks$ observed at its magnitude level.

This method yields 5085 variable candidates, visual inspection of images confirms 816 true variable stars (Contreras Peña et al. 2017a). Most of the variables stars are unknown in the literature.

## SFR association

We searched for association with star forming regions (SFRs) using SIMBAD, WISE, Vizier and the Avedisova catalog of SFRs (Avedisova 2002). We estimate that 54% of the sample is likely associated with SFRs.

The SEDs of the objects in these areas support a YSO classification. Most objects have SEDs of class I or flat-spectrum sources.

We estimate that YSOs are the commonest type of high amplitude infrared variable stars in the Galactic disc.

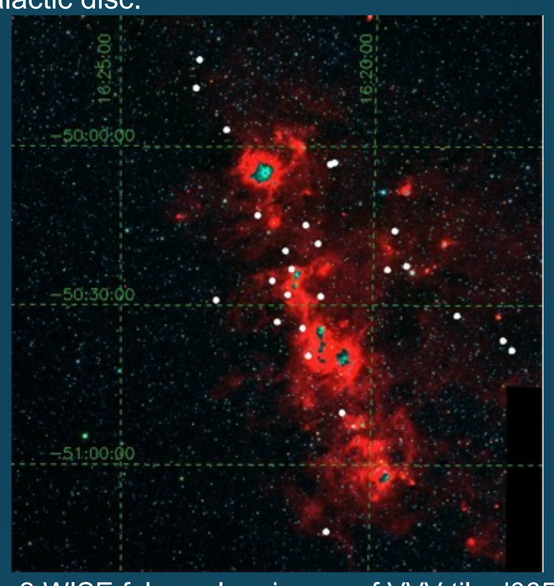



Fig. 2 WISE false colour image of VVV tile d065. The white circles mark the location of high-amplitude variables found in the area.

## Light curve morphology

The large amplitudes are likely due to accretion or extinction related variability. Known mechanisms: cold, hot spots, variable disc inclination, inner hole size are not expected to produce such large changes.

We visually inspected the light curves of our SFR--associated variables in order to gain insight into the physical mechanism causing the brightness variations.

We find:

- Long-term variability (often periodic, t>100 d, YSOs, AGBs).
- Short-term variability (t<100 d).
- Eclipsing binaries.
- Aperiodic variability (faders, dippers).

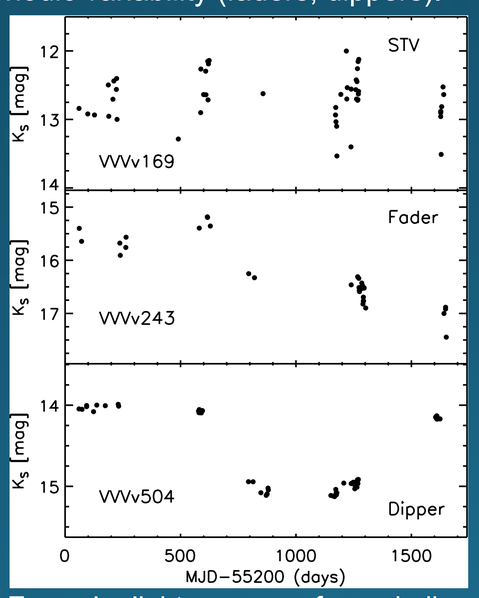



Fig. 3 Example light curves of aperiodic variable stars.

## Eruptive YSOs

We classify 106 objects as likely eruptive YSOs. Their near-IR colour variation argues against extinction-related variability.

The majority are class I YSOs. By considering the ratio of class II to class I YSOs observed in SFRs we find that eruptive variability is 13-17 times more common in class I than class II objects.

The duration of the outbursts appear in the range 1-4 years.

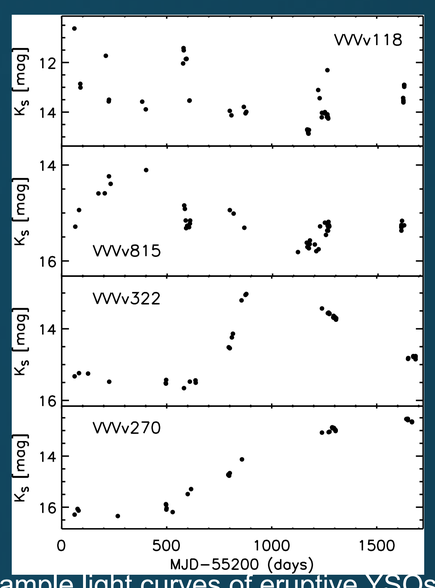



Fig. 4 Example light curves of eruptive YSOs.

## Follow-up

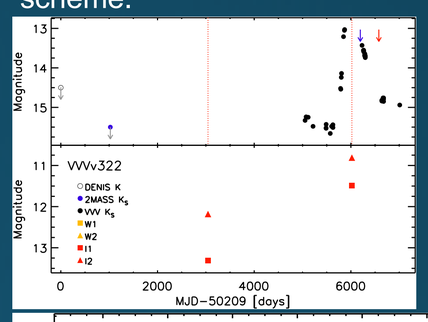
Medium-resolution spectroscopy for 37 VVV objects obtained between 2012-2015, using FIRE (R~6000) at the Baade Telescope in Las Campanas Observatory.

We find that 28 objects display the typical characteristics of YSOs, such as Brγ or $H_2$ lines in emission or CO in emission or absorption (Contreras Peña et al. 2017b).

Fifteen objects show spectroscopic characteristics of being eruptive variables, whilst other four have additional data that support this classification.

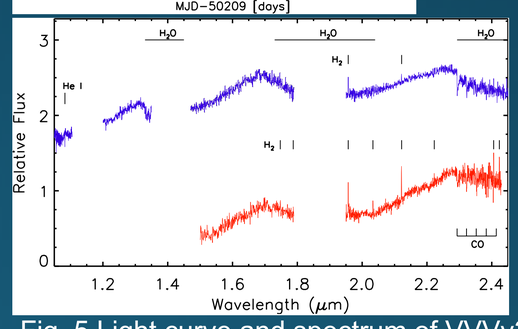
## MNors

The properties of most of the sample differ from the classical EXor and FUor classification scheme.




VVVv322

- SED class α=0.92
- Outburst in 2012
- Duration 3 yrs?




Spectrum of classical FUor.

Fig. 5 Light curve and spectrum of VVVv322

Given the different (and mixed) characteristics of the sample:

- -Longer duration of the outbursts compared to classical EXors but shorter than FUors.
- -Younger than classical EXors and FUors.

We propose a provisional (new?) classification as MNors, following V1647 Ori the illuminating source of the McNeill Nebula (MNO).

## References

Audard, M., et al. 2014, PPVI, 387; Avedisova, V. S. 2002, Astronomy Reports, 46, 193; Baraffe, I., et al. 2009, ApJ, 702, L27; Baraffe, I., et al.2012, ApJ, 756, 118; Contreras Peña, C., et al. 2017a, MNRAS, 465, 3011; Contreras Peña, C., et al. 2017b, MNRAS, 465, 3039; Hartmann, L., & Kenyon, S. J., 1996,ARA&A, 34, 207; Ioannidis, G. & Froebrich, D. 2012, MNRAS, 425, 1380; Kenyon, S. J., et al. 1990, AJ, 99, 869; Minniti, D., et al. 2010, NewA, 15, 433.

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