Accretion-driven Eruptive Variables in Nearby Star-Forming Regions

Hariharan D. S. Muthu[1] and Philip W. Lucas[1]

[1] Centre for Astrophysics Research, University of Hertfordshire, Hatfield, UK

Abstract

We present our progress on a comprehensive search of the VVV database aimed at identifying new intermediate amplitude variables and extending existing IR variable catalogues. A total of 267 new eruptive variable sources were found, with amplitudes $1.5 \leq \Delta Ks \leq 4.0$ mag, categorized based on their light curve morphology and variability timescales. Using associations with star-forming regions (SFRs) and available spectroscopic data, we identified the variable YSOs among other candidates. To refine the classification, a Gaussian Mixture Model was applied to assess the likelihood of these sources being associated with nearby open clusters, using astrometric parameters. These newly identified eruptive YSOs will enable a comprehensive study of the parent population and physical parameters of this large sample-set. This dataset will facilitate the investigation of correlations among spectra, light curves, SEDs, age, and stellar mass. It will also help us explore how the incidence of eruptive variability is influenced by evolutionary stage, mass, and cluster environments like stellar density and UV radiation.

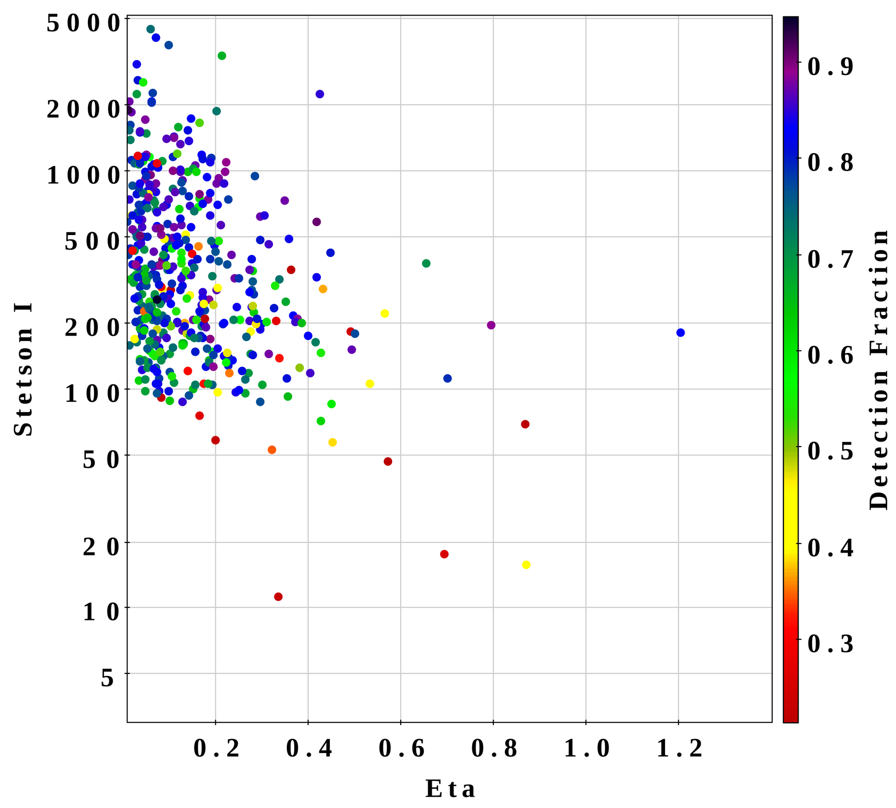
Background

Accretion-driven eruptive variability in YSOs is driven by episodic accretion, a model proposed to address the luminosity problem in protostars, which appeared dimmer than predicted by earlier models (Kenyon and Hartmann 1995). This model suggests that protostars gain most of their mass through short, intense bursts of accretion, followed by extended periods of low-level accretion, rather than through continuous steady accretion. Historically, eruptive YSOs undergoing accretion outbursts have been observed in optical bands and thus classified as FU Orionis (FUor) and EX Lupi (EXor) stars, based on their photo-spectroscopic features. Latest multi-wavelength studies, spanning from optical to mid-IR, have revealed a significant subset of variable YSOs with mixed photo-spectroscopic traits, termed MNors (Contreras Peña et al. 2017a) or V1647 Ori-like objects (Fischer et al. 2022), which differ from the two classical categories. These findings challenge the strict separation between the two classes, highlighting the need for further analysis and a larger sample of outbursting YSOs.

Motivation

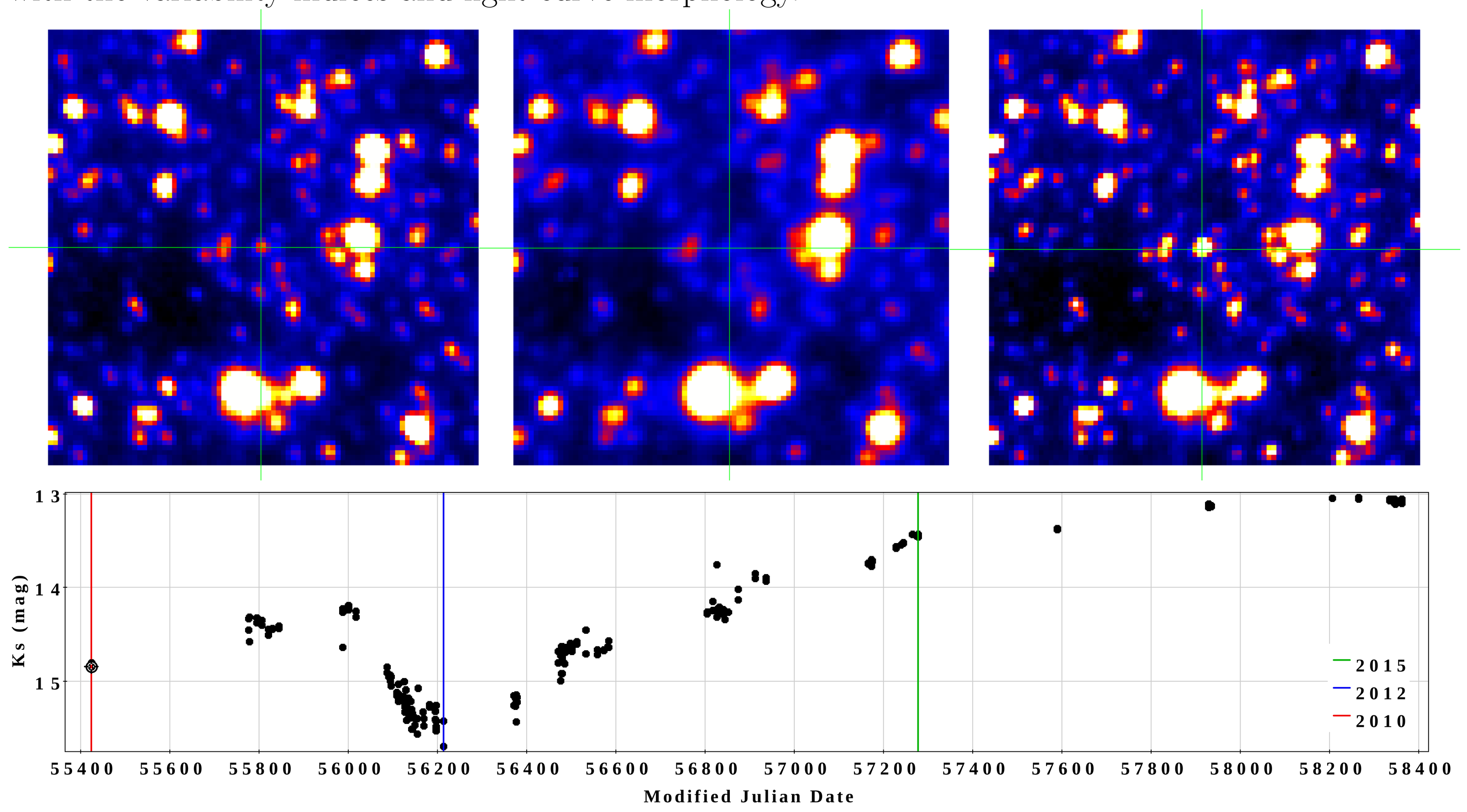
Recent discoveries highlight a diverse range of photo-spectroscopic morphologies in eruptive variables with lower amplitude variations ($\Delta Ks \leq 4$ mag). This diversity can be attributed to differences in observation timing and several physical factors such as stellar mass, density, evolutionary stage (age), and potentially different disc instability mechanisms. Since episodic accretion impacts stellar mass, planet formation, disk chemistry, and the location of snowlines for different ices, it is important to determine the incidence of eruptive variability resulting from episodic accretion. Understanding the correlation between the incidence of eruptive variability and stellar parameters such as age, mass, density, and environment is a key to improving future models of stellar evolution. Additionally, the episodic accretion model may help us explain the luminosity spread observed in pre-main-sequence stars on the HR diagram.

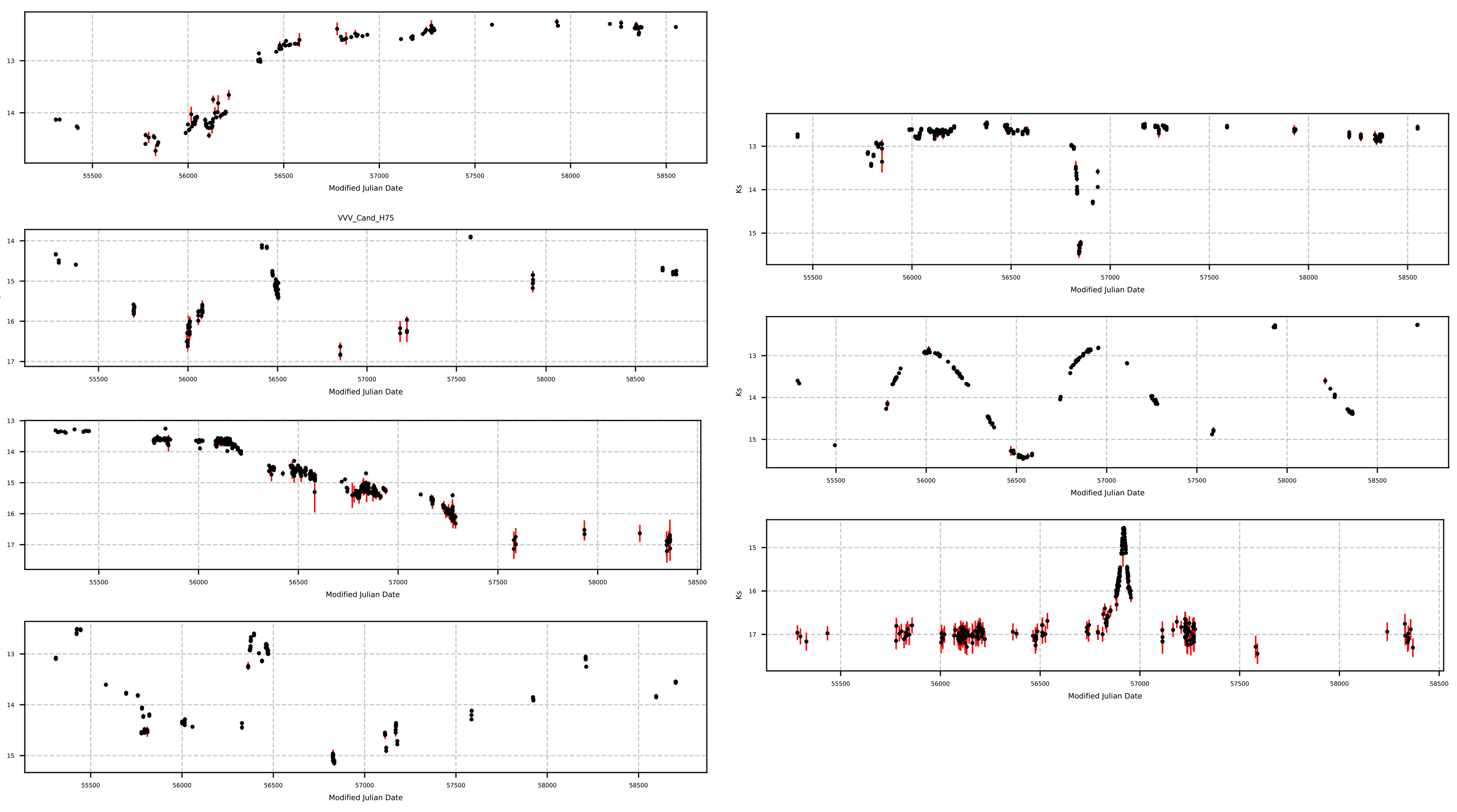
VVV Variables



The plot presents the Stetson index (I) versus the von Neumann index (η) for the 267 newly identified variables from the VVV near-IR survey, with amplitudes in the range of 1 mag $\leq \Delta Ks \leq 4$ mag (indicated by filled circles). Each point is color-coded to the fraction of images of the field in which the source was detected. This distribution depicts the methods employed for identifying bona fide variables from interlopers by utilizing these variability indices combined with thorough visual inspection.

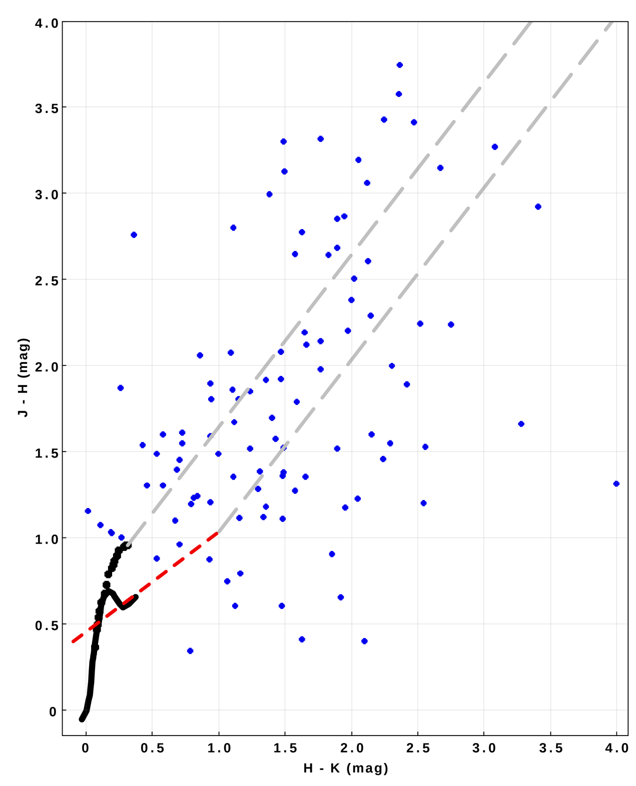
VVV image of one of the variable sources, IAU name VVV J174657.14-283909.95, captures its outburst phases at three different times. The top images show the source in 2010, 2012, and 2015 (from left to right). Bottom image, the light curve includes colored isochrones, marking the approximate brightness levels of the source within the observed light curve morphology. This sequence of images supports the classification of this object as a genuine variable source along with the variability indices and light curve morphology.



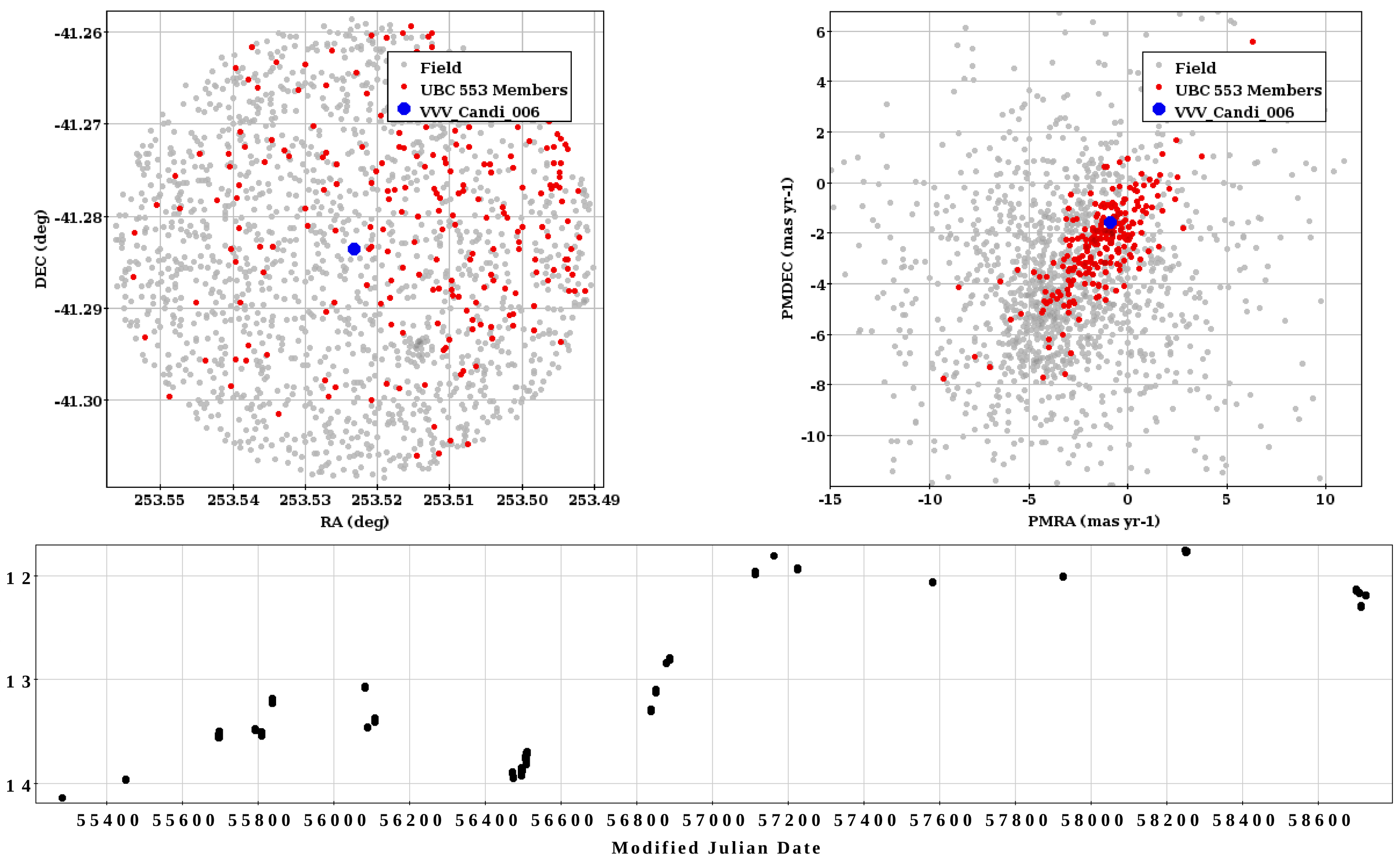


Examples of light curve morphologies observed in our variable stars search using VVV data. On the left - From Top to Bottom: i) Eruptive long-term variability; ii) Eruptive short-term variability; iii) Fader candidate; iv) Eruptive Multi-Timescale Variability; On the right: i) Dipper source ii) Periodic source with sinusoidal light curve, and, iii) Microlensing event.

YSOs?



The Near-IR 2MASS JHKs color-color diagram (J-H vs. H-Ks) features a red line indicating the loci of Classical T Tauri Stars (CTTSs) as described by Meyer et al. (1997), and a black dashed line representing the reddening paths from CTTSs and the Giant branch. Variable YSOs, primarily of Class 0 and Class I, exhibit high color excess due to significant obscuration due to disc/envelope, which is reflected in their positions on the color-color diagram. This high color excess serves as one of the key indicators for classifying these sources as YSOs.



We utilized the Gaussian Mixture Model with Expectation-Maximization (a probabilistic density estimation model) to obtain quantifiable probabilities of source associations with clusters based on spatial parameters, parallax, and proper motions. Cluster parameters were obtained from various published optical and near-infrared star cluster catalogs. As an illustration, we present the spatial and proper motion distribution along with the light curve for the VVVc6 source. This source is associated with the cluster UBC 553, which has a distance of approximately 1.5 kpc, an age of around 10 Myr (Castro-Ginard et al. 2020), and a membership probability of about 0.98.

Work in progress

In the ongoing phase of this work, we will integrate newly discovered eruptive YSOs with variable YSO data from recent VVV studies to analyze their parent population and physical characteristics. This will facilitate a robust statistical analysis of eruptive variability across YSO classes (Class I, II, and Flat-spectrum) and its correlation with quiescent luminosity, SFR age, and environment. Additionally, the spectroscopic data from the bright variable sources observed with VLT XSHOOTER will help us further validate the quality of our YSO classifications.

Research Questions:

1. How does the cluster environment influence the incidence of eruptive variability?
2. What is the correlation between variability and stellar mass?
3. Does the timescale of outbursts vary with age or evolutionary stage?

References

Kenyon, S. and Hartmann, L., 1995, APJ, 101, 117.
Contreras Peña, C et al., 2017a, MNRAS, 465, 3011.
Fischer, W. et al., 2022, Protostars and Planets VII, 534, 355.
Castro-Ginard, A. et al., 2020, A&A, 635, A45.