Insights into Star Birth from VVV

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Rainbows2015

University of Hertfordshire

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Outline

- Discovery of MNors, a new kind of eruptive variable YSO.
  - Background
  - UKIDSS suggests YSOs are the commonest high amplitude IR variables
  - VVV photometry and Magellan/FIRE spectroscopy
- VVVX velocity mapping of the Milky Way
  - Essential complement to GAIA, 4MOST and MOONS

Variability in Young Stellar Objects (YSOs)

- Most (93%) pre-main sequence stars are
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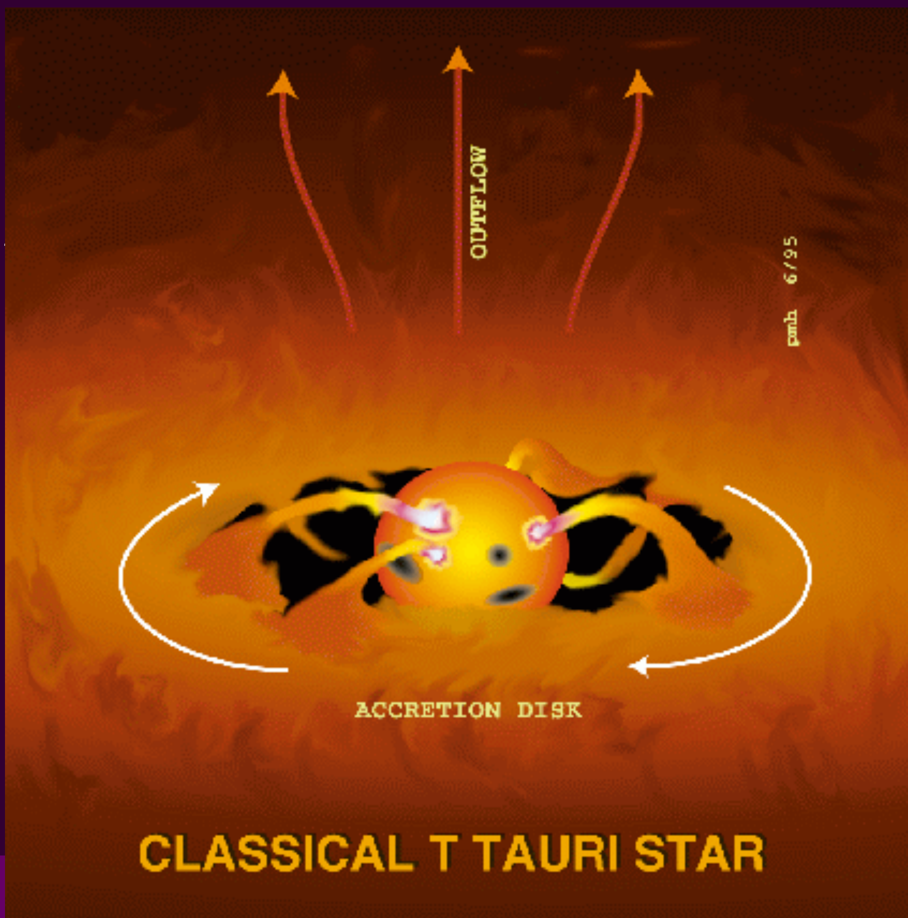
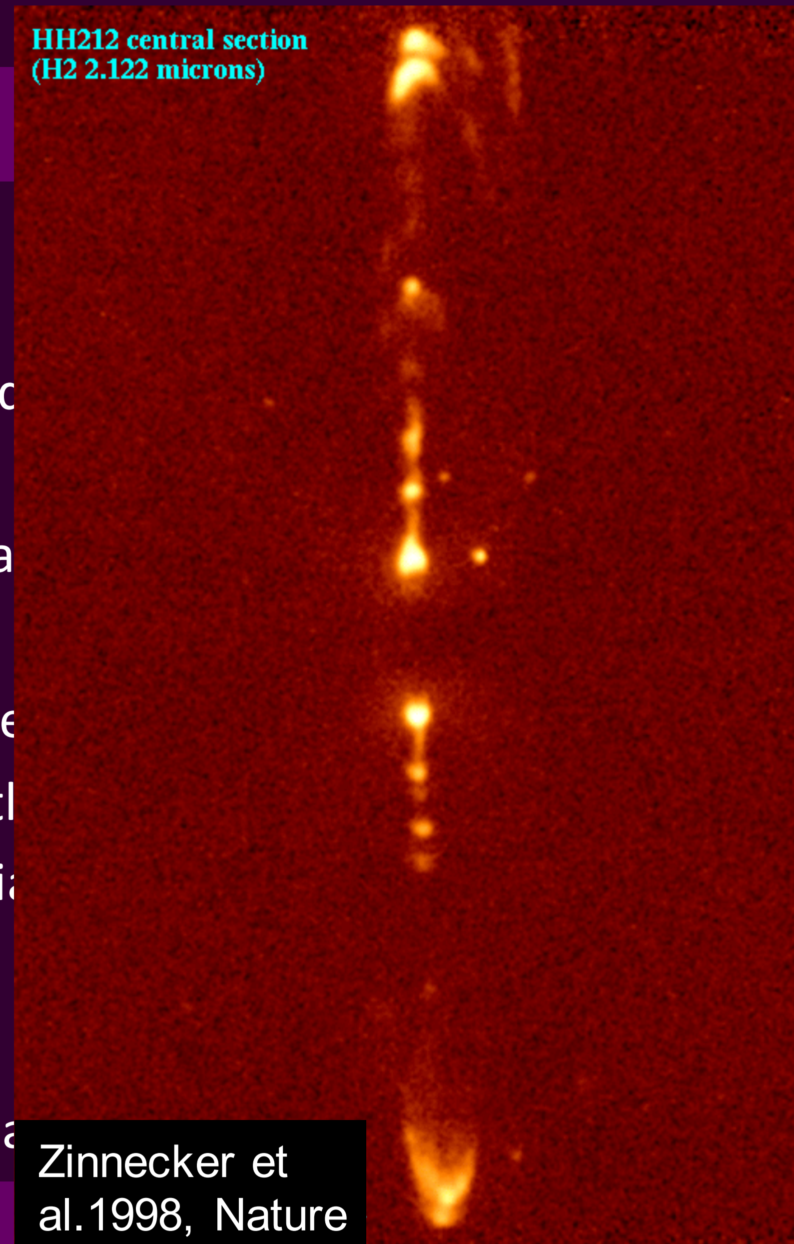
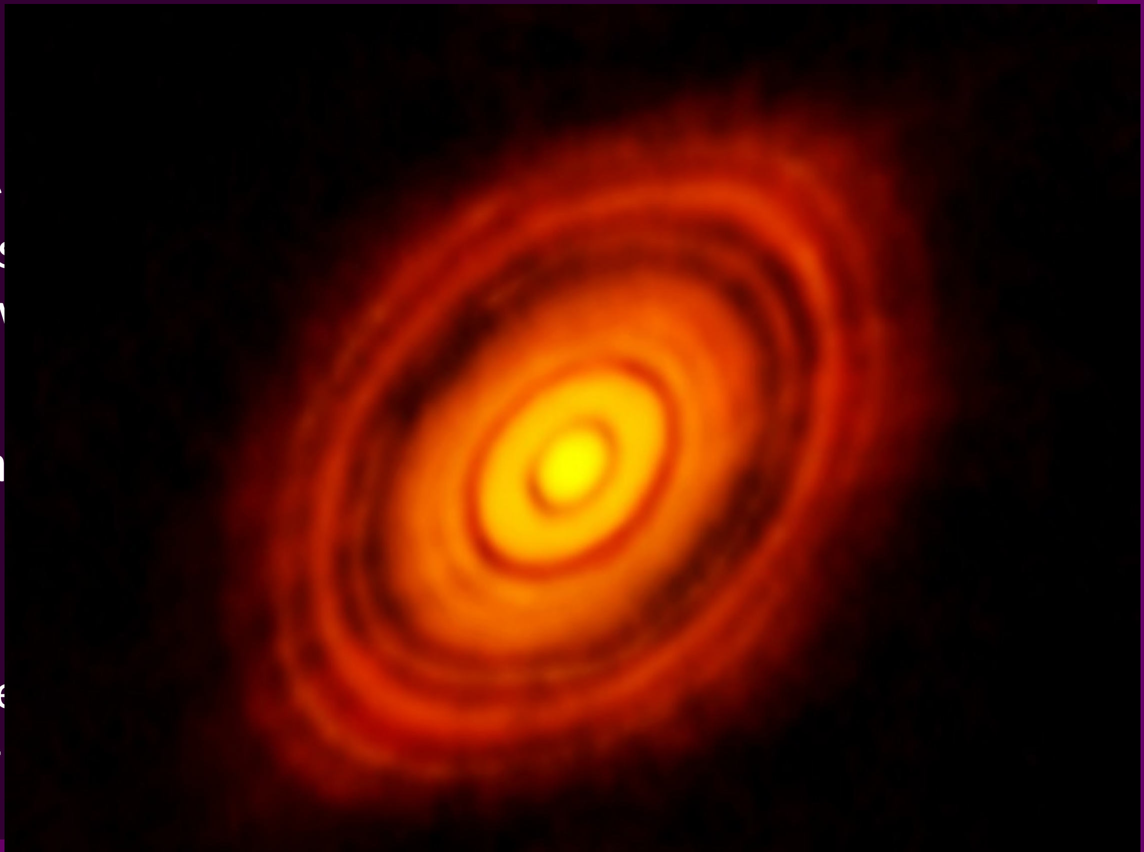




Zinnecker et al.1998, Nature

Importance of eruptive variability

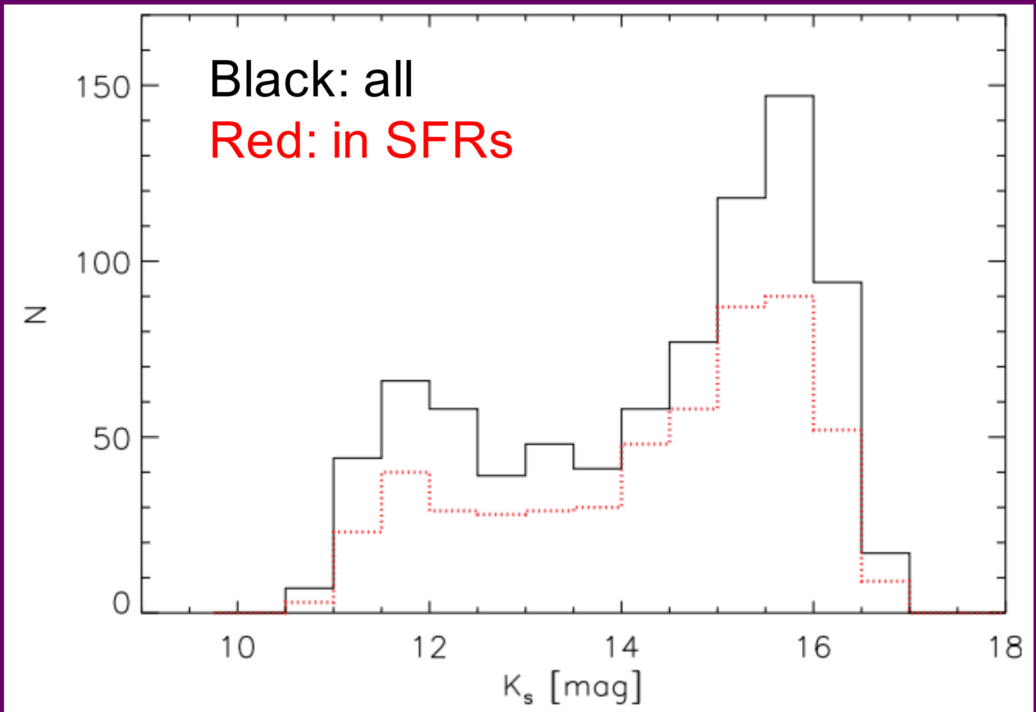
- Outbursts due to unstable accretion are thought to be common among pre-main sequence (PMS) stars....
- May explain the scatter in HR
- Could also solve the "Luminos
al.(2009) - most YSOs have lo
- ....and it would mean that ma
- The theory is tricky: maybe the
or GPI+MRI, or binar



HL Tau, 2014, ALMA partnership

VVV and UKIDSS IR searches – many discoveries

- UKIDSS: 2 epochs, showed that YSOs are likely the commonest type of high amplitude IR variable. Contreras Pena et al.2014, MNRAS, 439, 1829
- VVV: searched the 2010-12 data for ΔKs>1 mag sources <u>seen at all epochs</u>.
  Focussed on the -1<b<1° region at l=295-350° that has HERSCHEL and *Spitzer* data.
- <u>**Found 816 sources down to K=16, of which 91 have ΔK>2 mag.**</u>

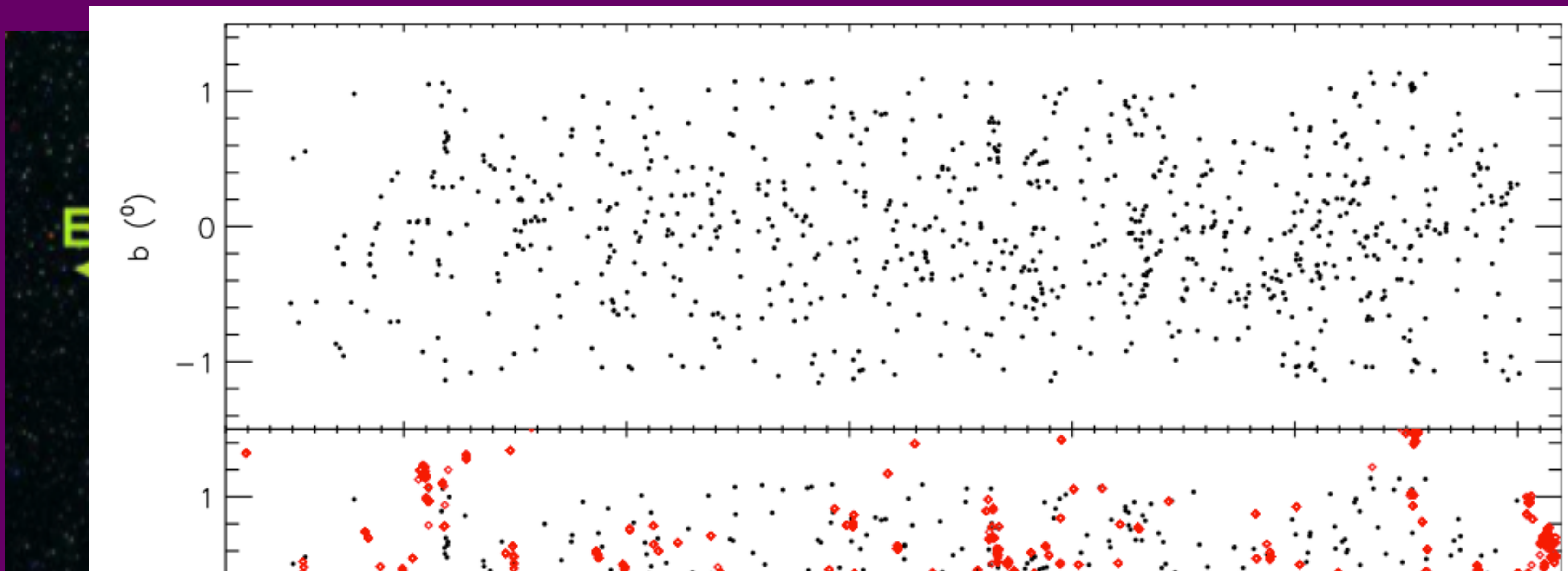


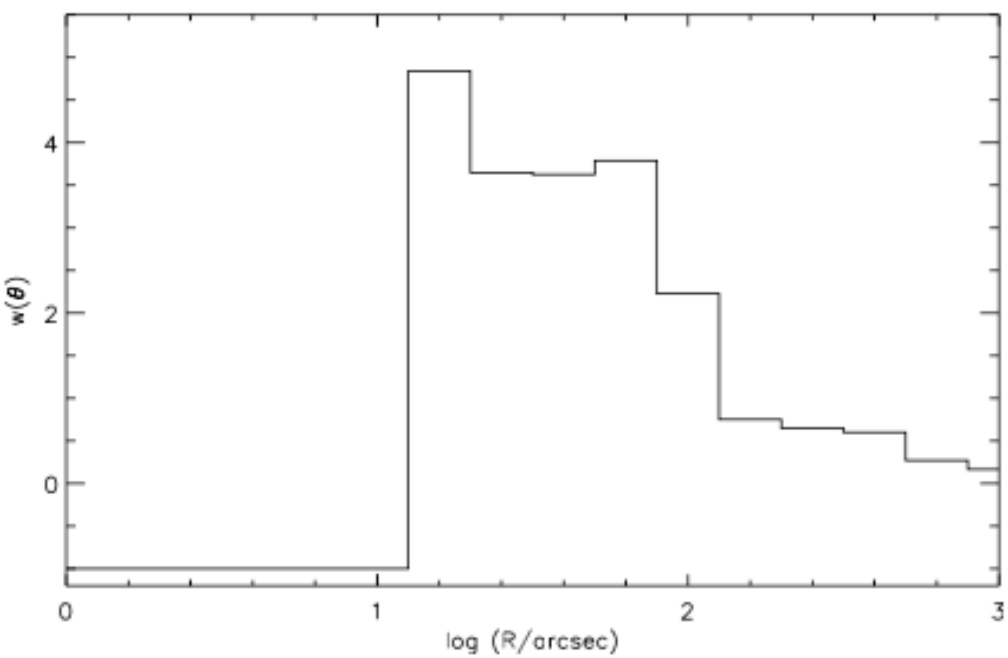
65% in SFRs – YSOs

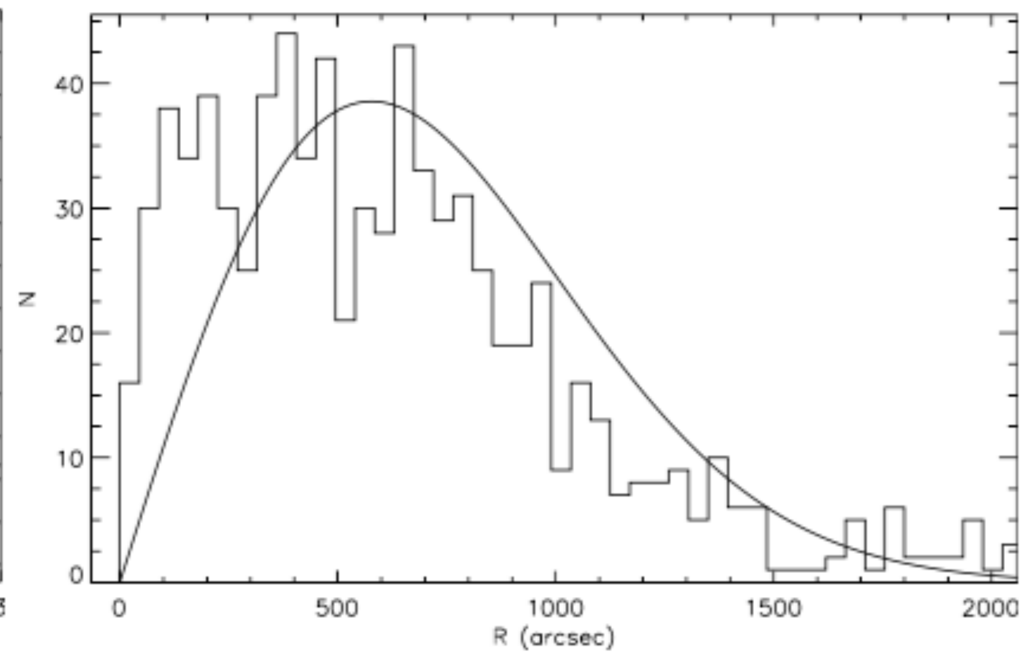
Method has ~50% completeness

Also dusty Miras and Eclipsing Binaries

Properties – clustering in SFRs



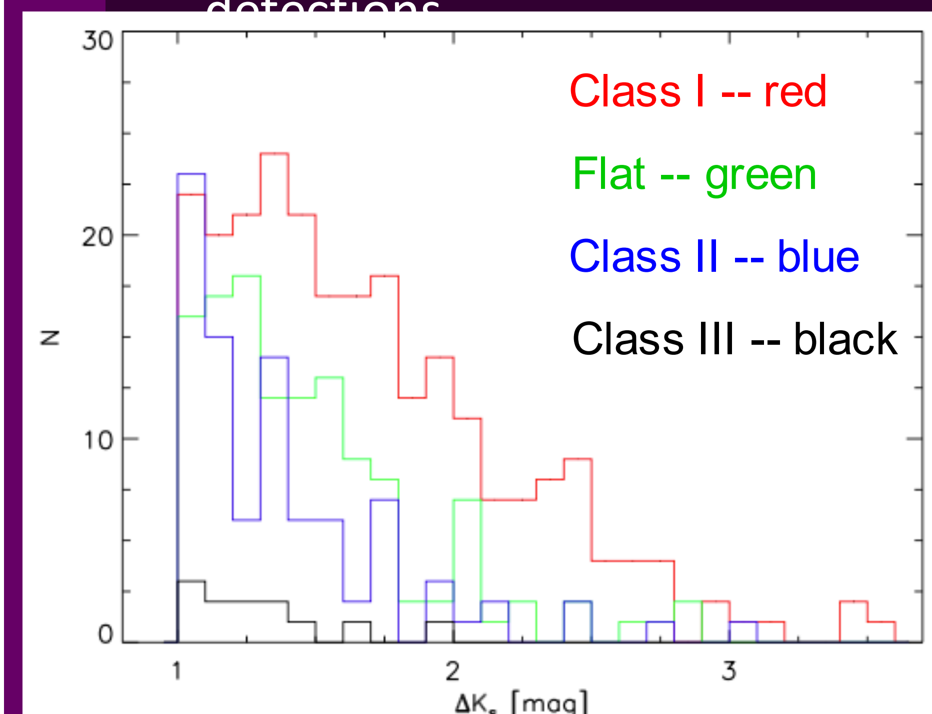


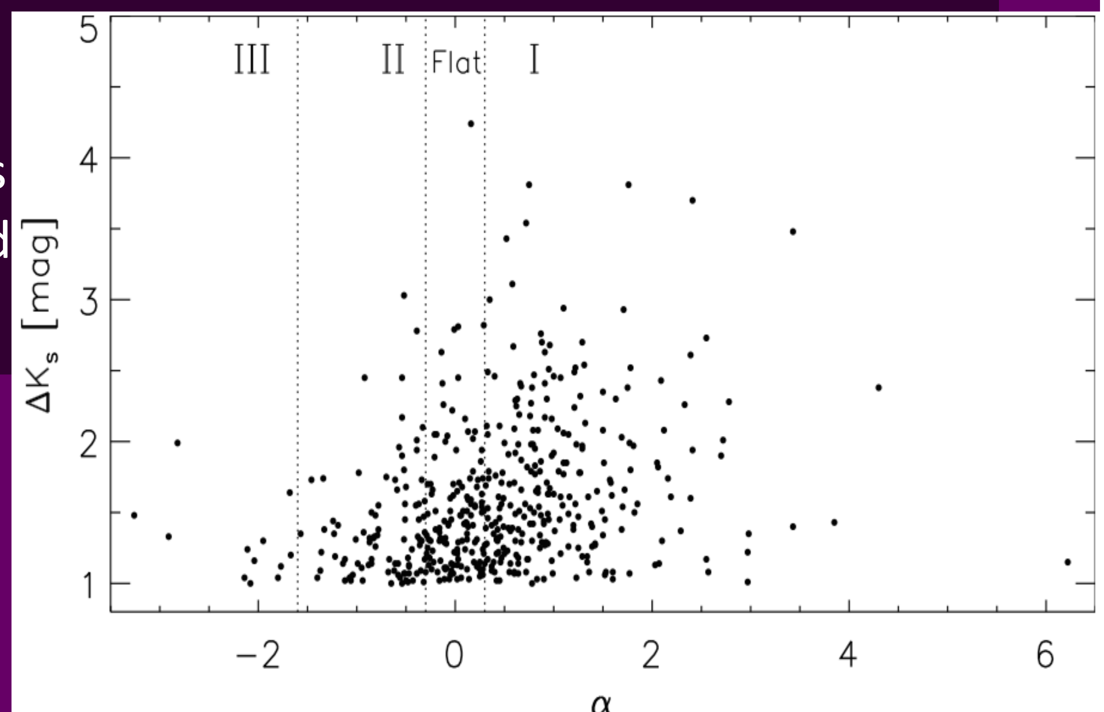


Colours, SEDs and Amplitudes

- Very red (the vast majority)
  - Higher amplitude ➔ redder near IR colours and SEDs
  - 70% of ΔKs>2 sources are J band drop-outs.

- 316 WISE 23 um detections and 147 *Herschel* Hi-Gal 70-500 um detections

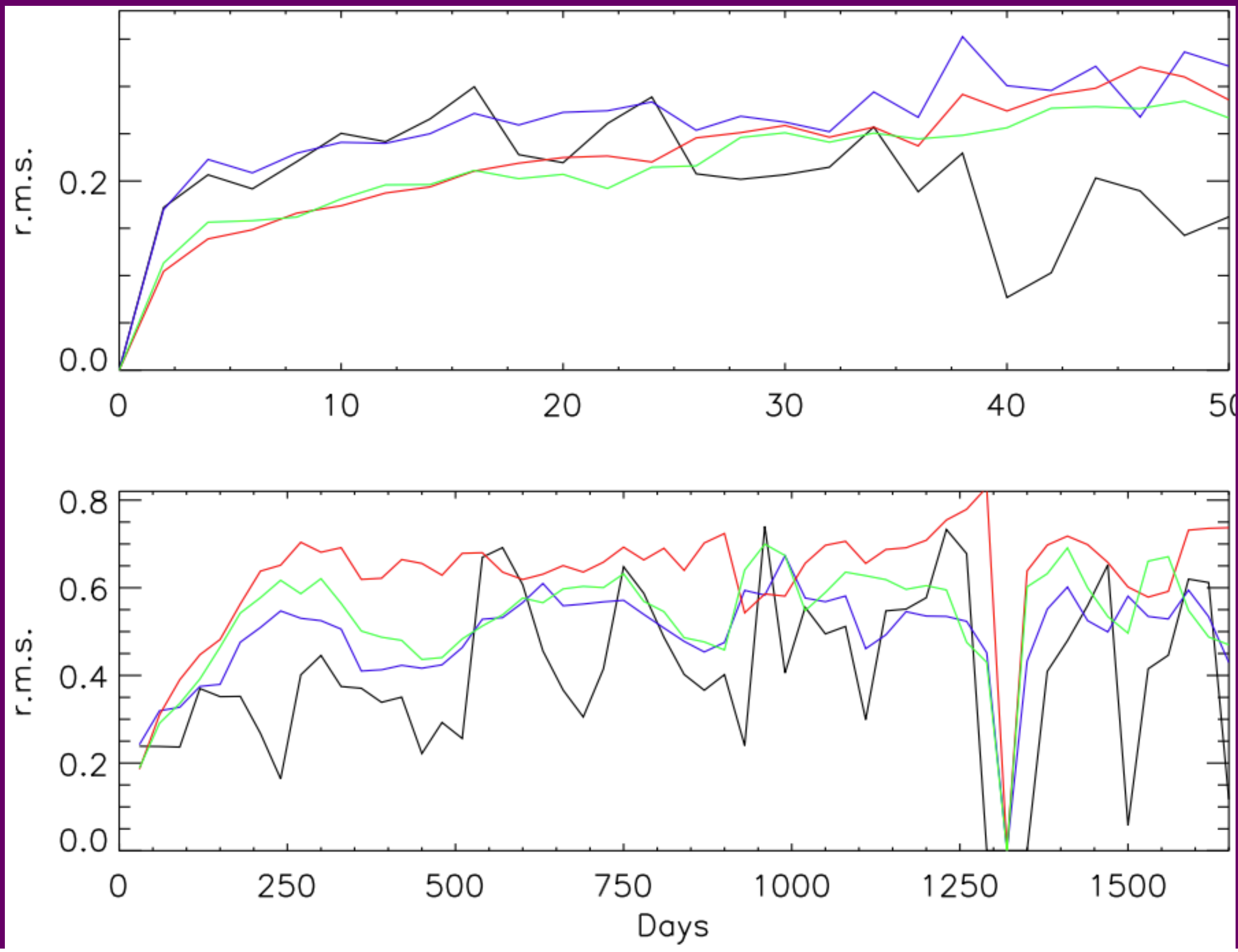




Time domain properties

Variability on all timescales up to ~250-300 days.

Class II & III YSOs (T Tauri) vary most on rotational timescales (days)
Class I and flat spectrum YSOs vary most on all longer timescales.



Class I -- red

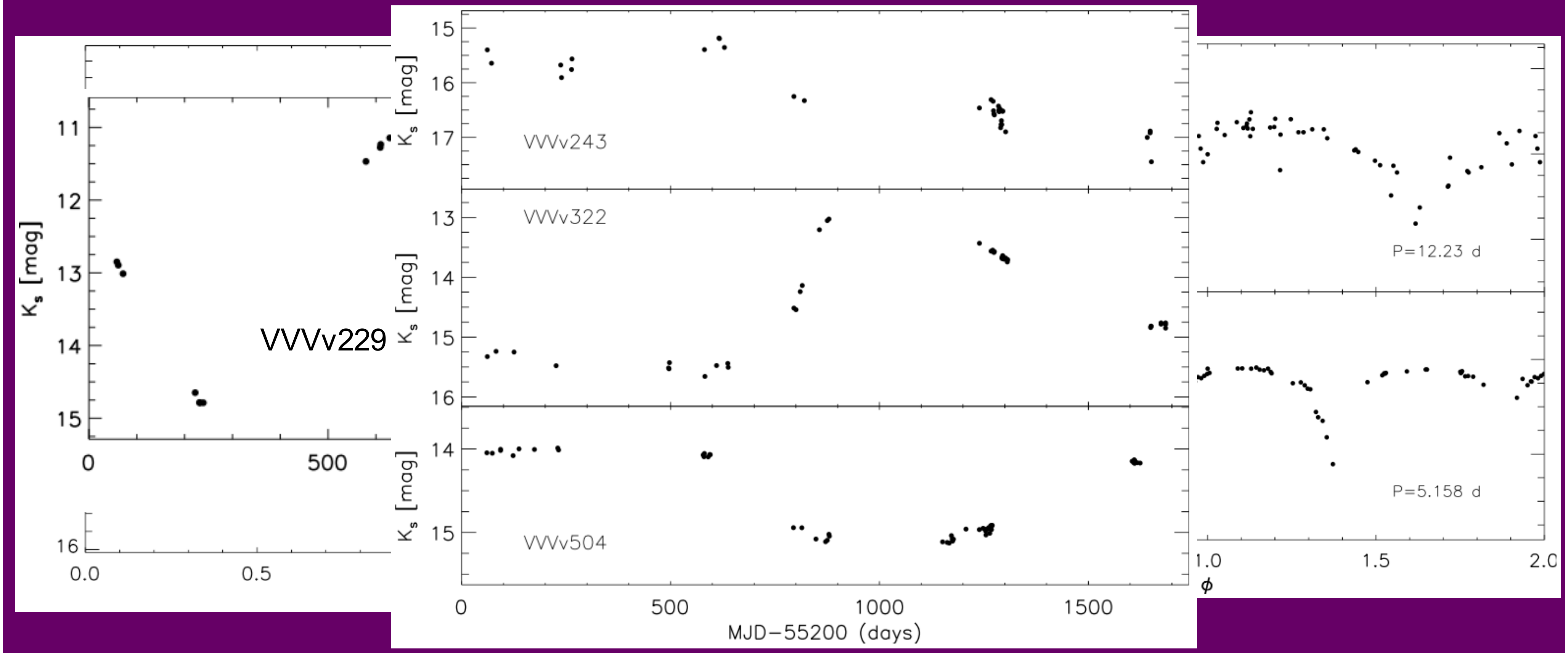
Flat -- green

Class II -- blue

Class III -- black

Light curves types in SFRs

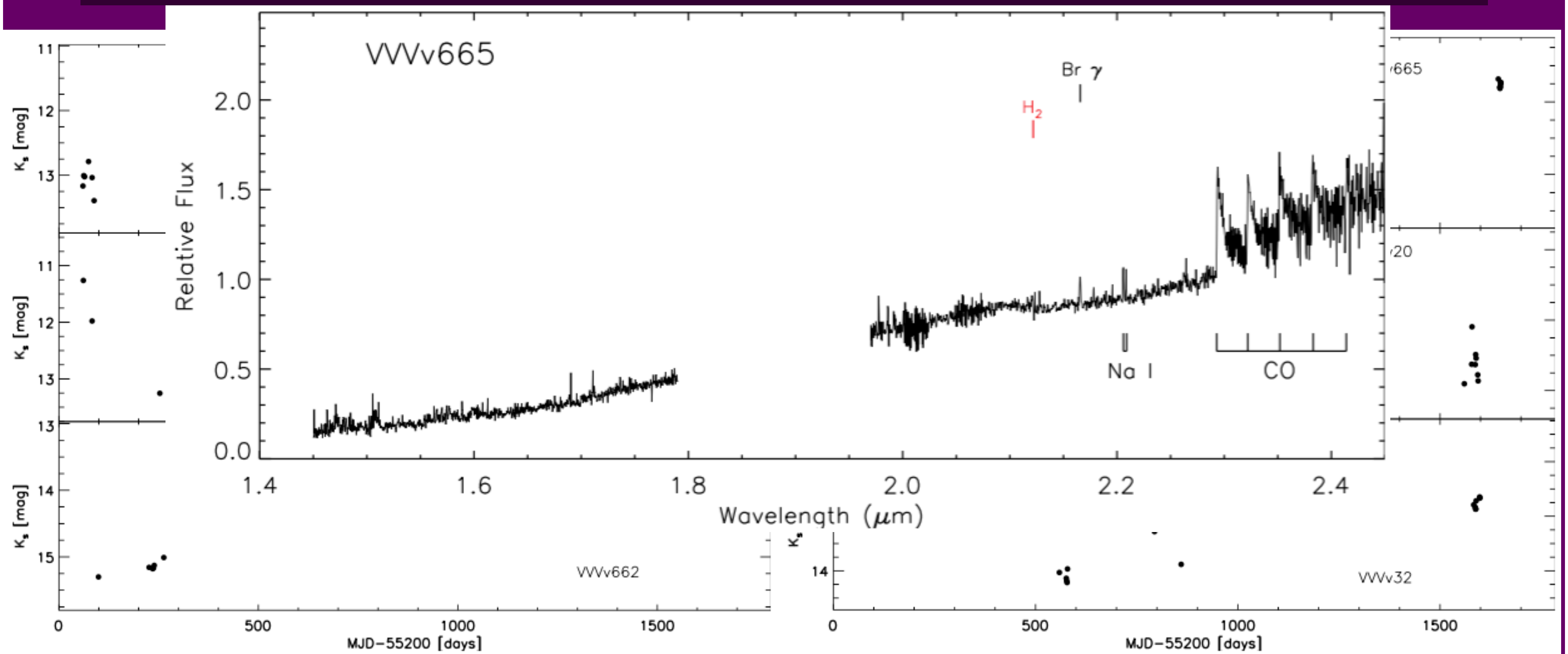
- Periodic: short period or long period
- Non-periodic: faders, eruptive, dippers



Eruptive light curves and spectra

- Can be periodic, or quasi-periodic, but not smooth like Miras.
- More often not periodic. **Outbursts last typically 1 to 5 years.**
- **31 spectra, mostly emission line YSOs, like EXors, but longer outbursts.**

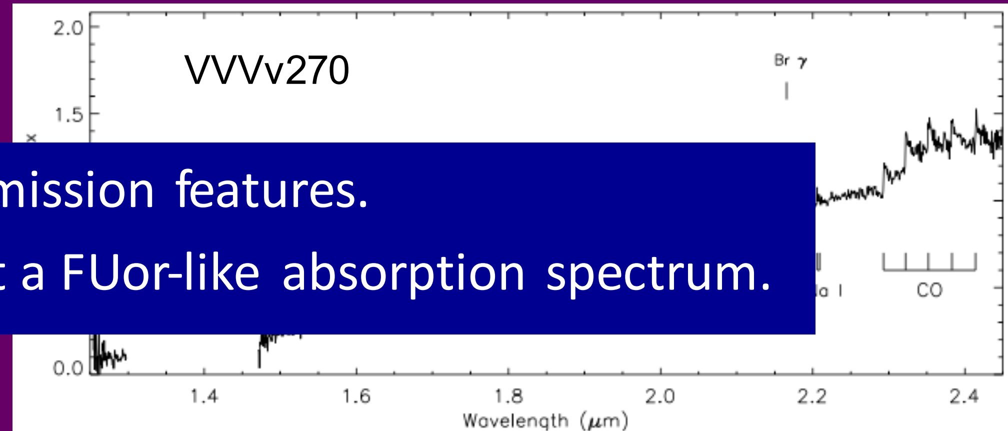
  We mainly see the disk, not the star.

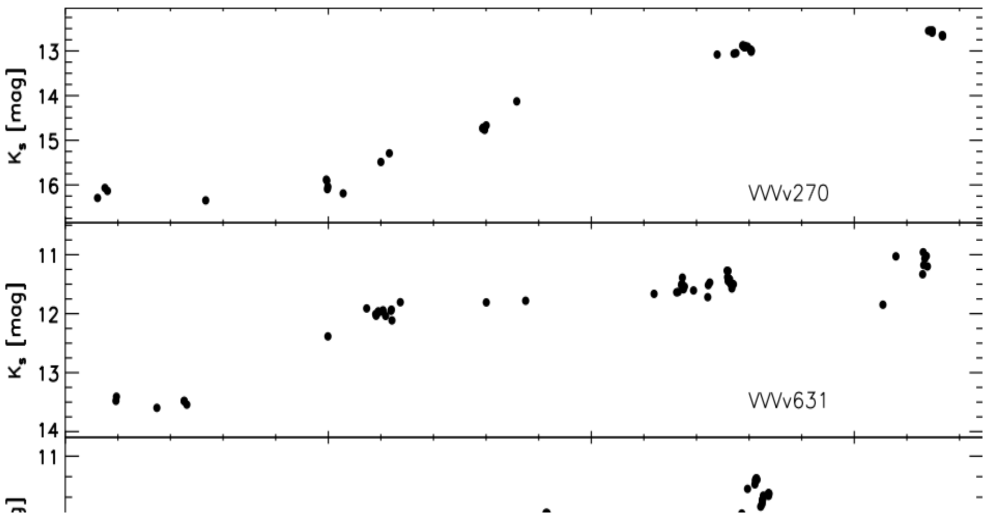


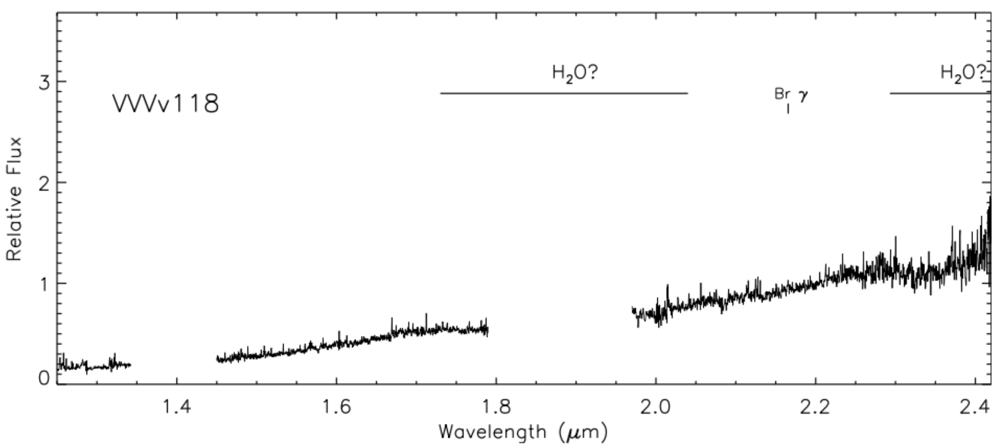
Rarer spectra: 3 FUors and 1 Exor?

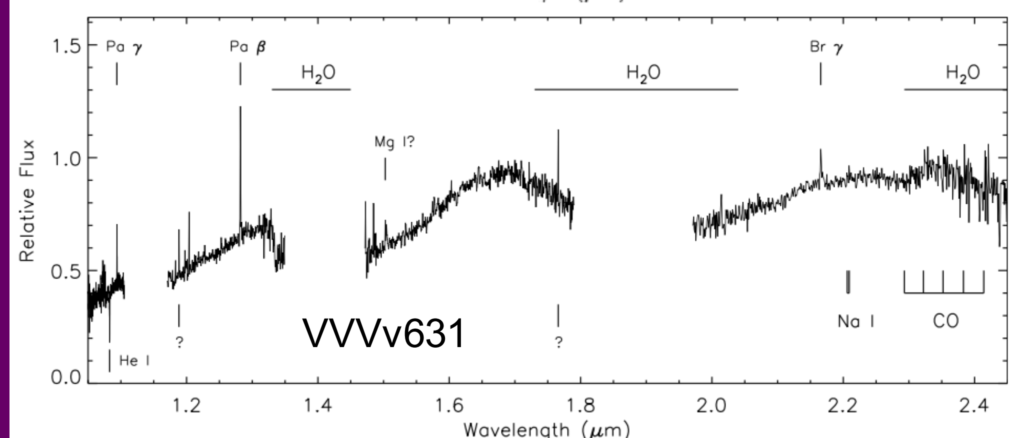
NO, not FUors, because the spectra have emission features.

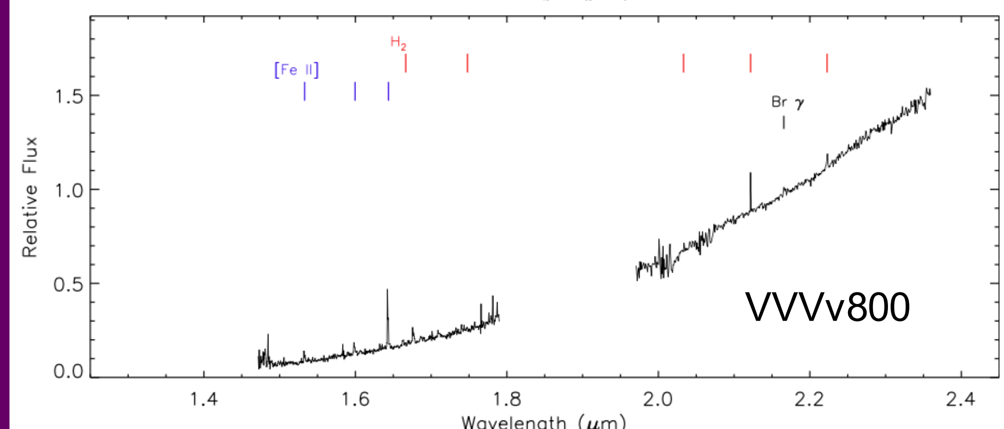
Also, no EXors: v118 has short outbursts but a FUor-like absorption spectrum.





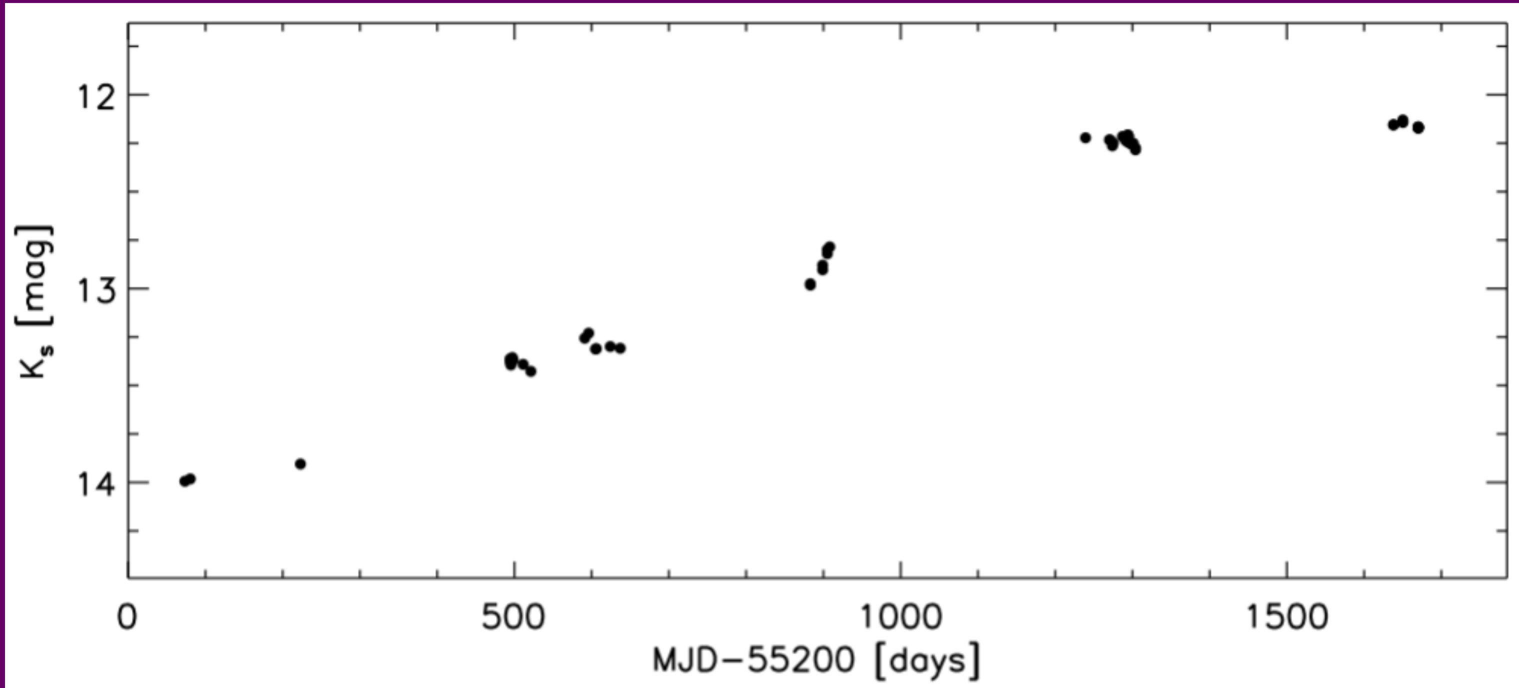


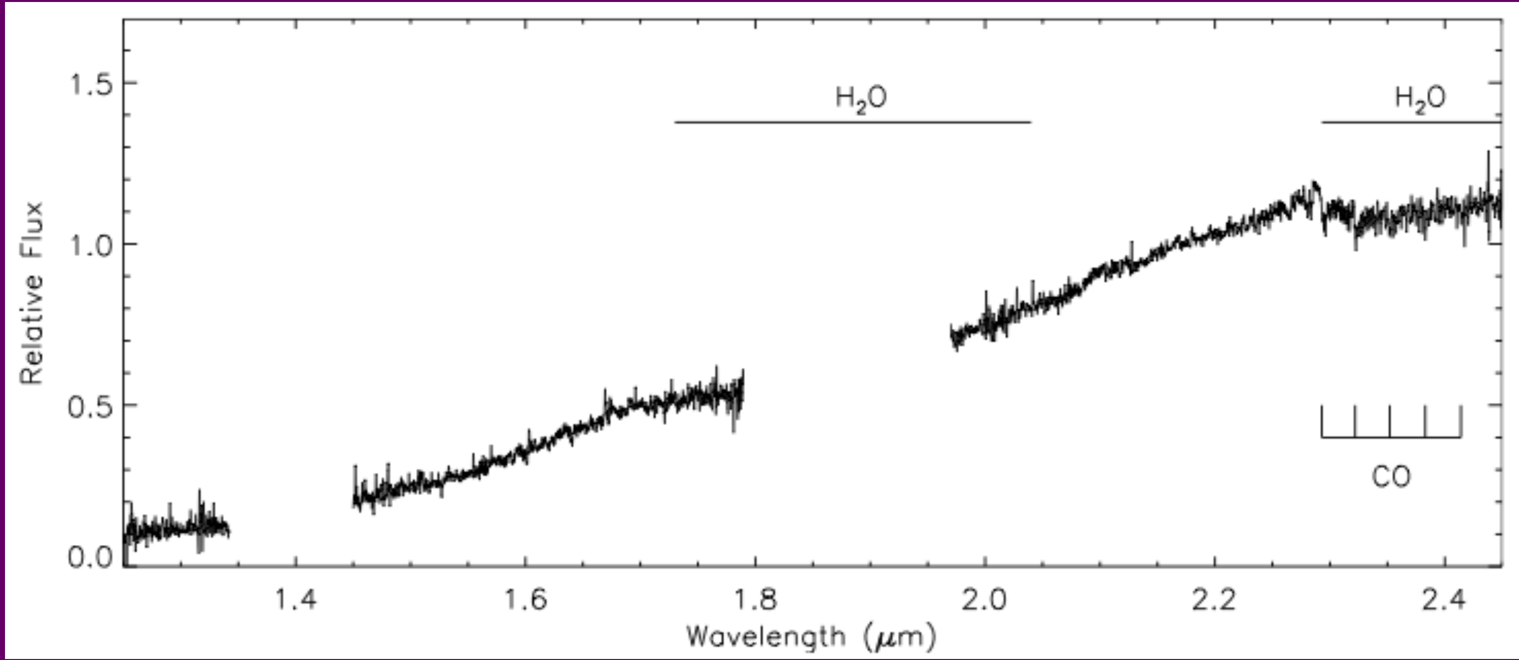




VVVv721

a token FUor



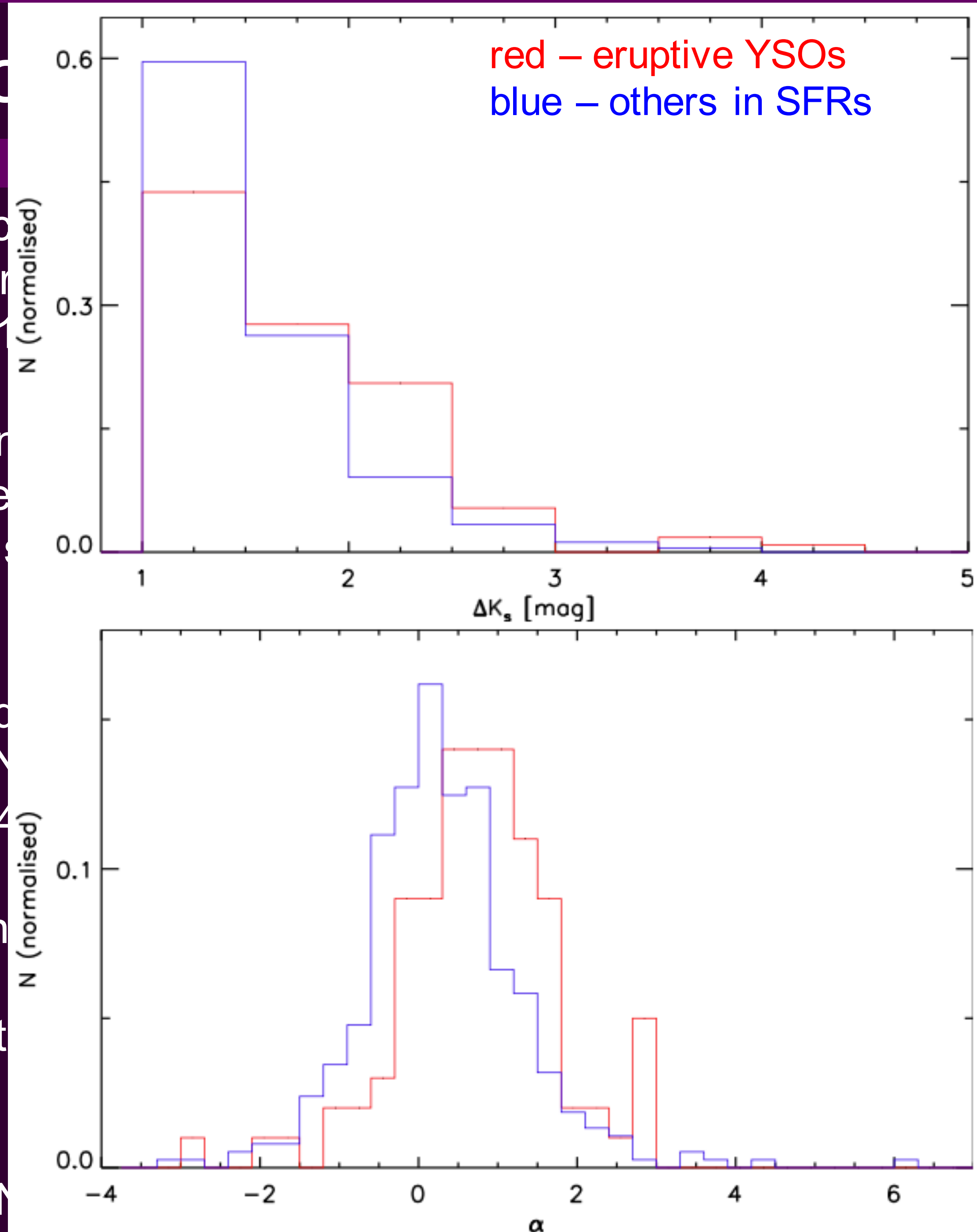


Observatic

526 high amplitude variables projec
 73 / 73 LPVs (dusty Mira inter
 162 with short periods (ΔKs ~ 1
 112 eruptive
 38 faders (fading eruptions ar
 44 dippers (“short extinction e
 24 eclipsing binaries (some us

Spectra of 30 bright eruptive candic
 21 MNors (after V1647 in McN
 2 FUors (eruptions lasting >4
 7 possibly normal YSOs (~1
 1 unclassified object (uniden

WISE+NEOWISE colours show ext
the spectroscopic sample.



Conclude: our selection is good. MN
variable YSOs. VVV has vastly increased the number of known YSOs.

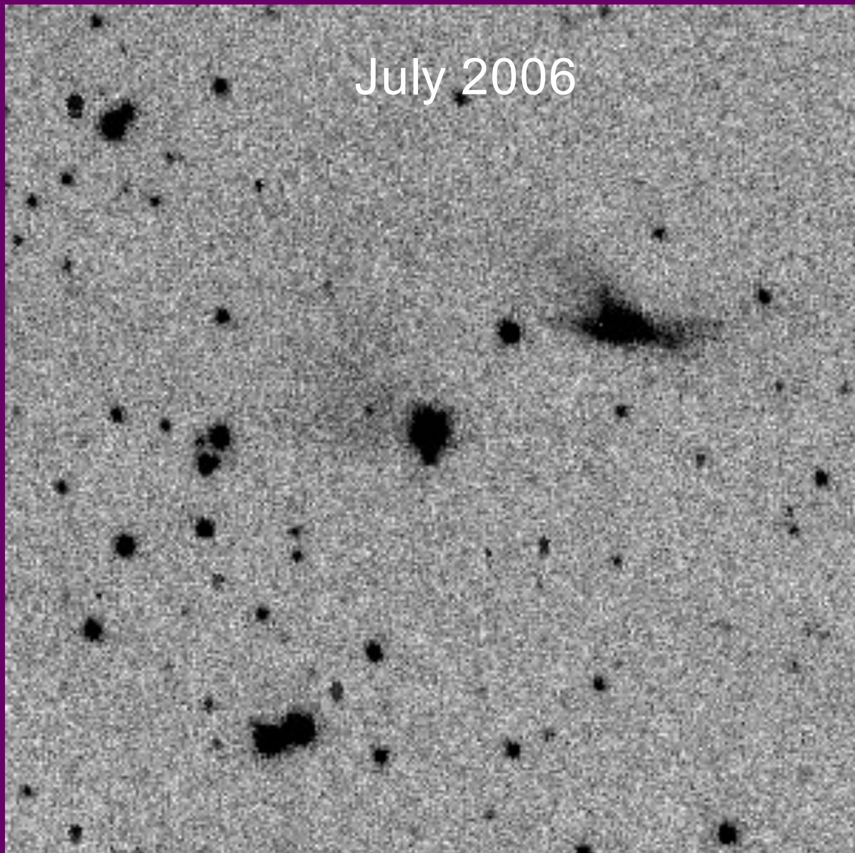
Summary

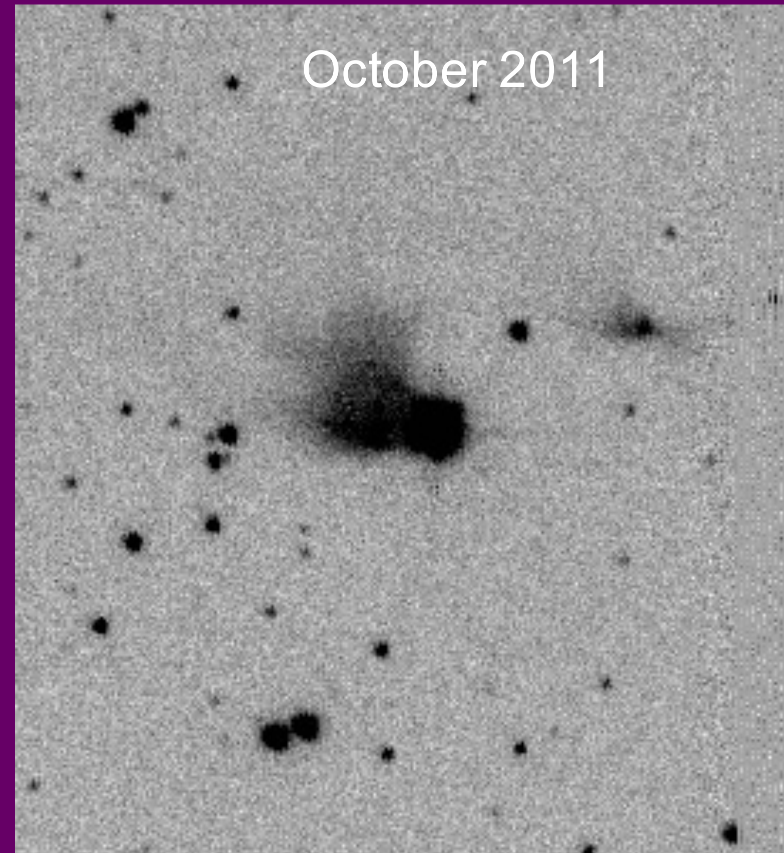
- Most (~65%) high amplitude IR variables are in star formation regions.
  - Mostly intermediate mass YSOs at a few kpc
- Extreme variability is more common at the earlier stages of pre-main sequence evolution, when average accretion rates are higher.
- Spectra, masses & light curves are diverse. To understand them we need:
  - SED modelling of the accretion disk and envelope through the eruption cycle
  - Velocity resolved spectra (CRIRES+, MOONS) , especially of CO emission & absorption.
  - AO & mid-IR imaging, ALMA, CHANDRA
- VVV will allow us to quantify the incidence of eruptive variability on timescales up to 5 years.
- VVVX: 9-10 yr baseline, fill gap from EXors to FUors. Repetitions?

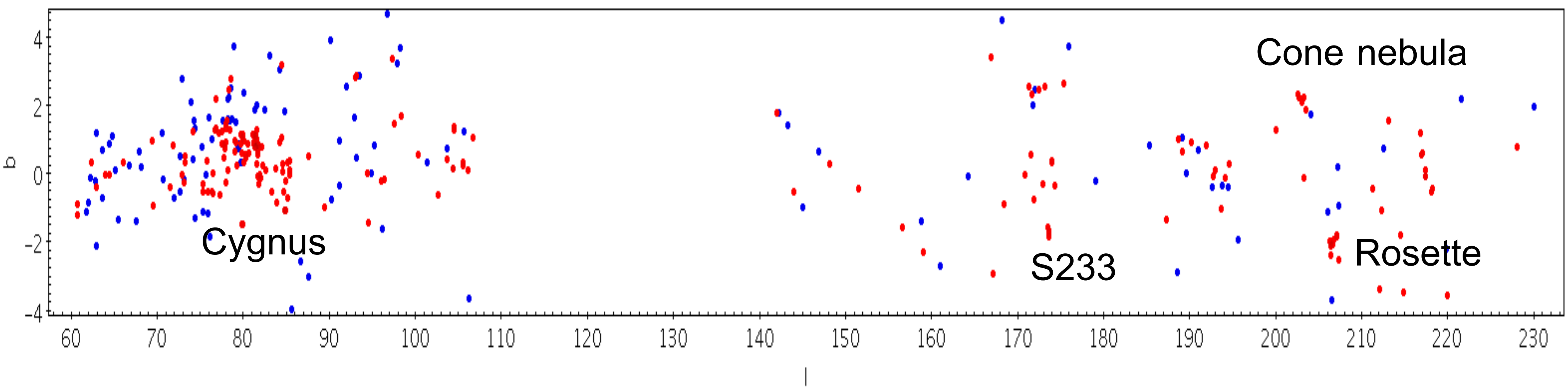
  10x larger sample including low mass YSOs in nearby SF regions.

VVVX astrometry

- VVV: already has proper motion at 680 micro-arcsec/yr precision
- VVVX: would reach 200 micro-arcsec/yr with 25 epochs in 2017-2019
  - 11 km/s at 12 kpc.
- This enables 5D mapping of the Milky Way, spiral arms, bulge, bar
  - Cepheids, RR Lyraes, red clump giants.
  - Galactic population modelling with velocities (Besançon code).
- Essential complement to GAIA mission
  - VVVX + MOONS/APOGEE carries on from GAIA + 4MOST/WEAVE


July 2006


October 2011


Cone nebula
Cygnus
S233
Rosette
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Results - parallax