Very high amplitude protostellar eruptions discovered by VVV and WISE

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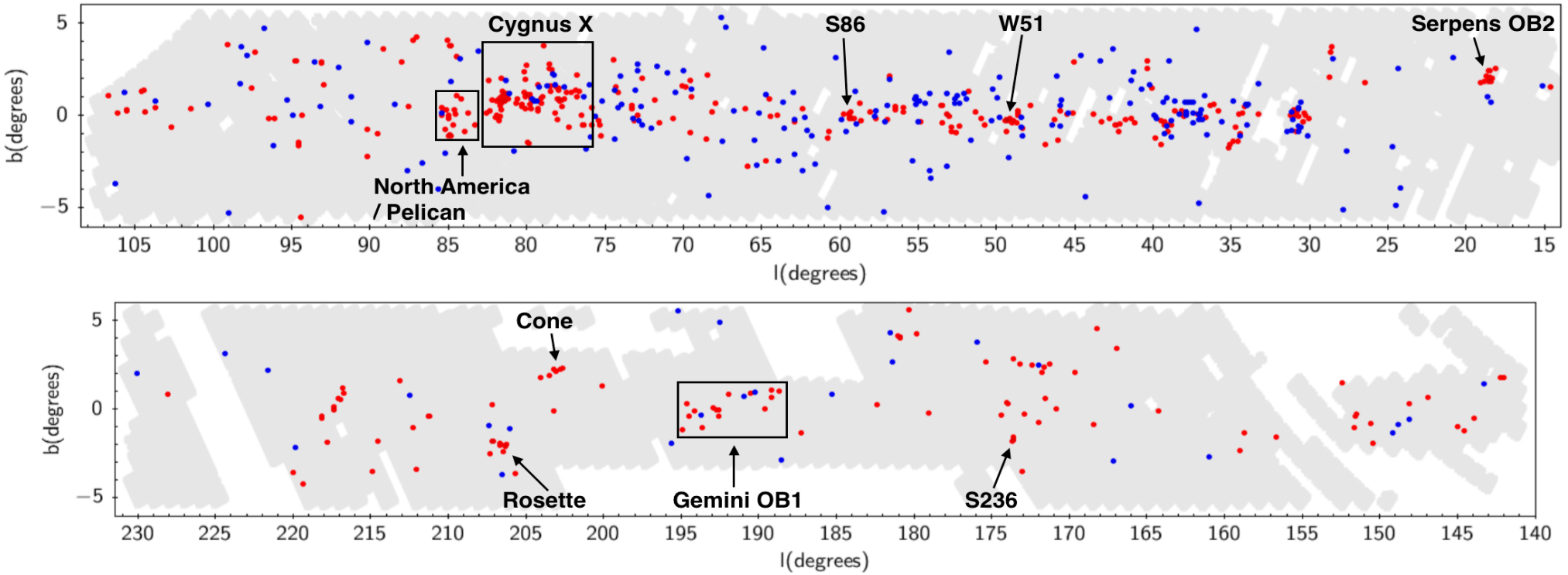
University of Hertfordshire

VVV and UKIDSS GPS: many YSO discoveries

UGPS catalogue of 618 high amplitude variables across 1470 sq deg of the plane.

~60% are YSOs, also other interesting things…. (Lucas et al. 2017, MNRAS, 472, 2990)



YSOs dominate the near IR variable sky at high amplitudes

New VVV/VVVX searches

(1) VVV DR4 public database of aperture photometry of tiles (CASU pipeline)

- Select high amplitude (ΔKs > 3 mag) variables from 2010-2013 data
- 105 variables found, including 27 YSOs mostly with ΔKs = 3 to 4.5 mag.
- Xshooter spectra recently obtained --> Zhen Guo's talk.

(2) VIRAC2 PSF photometry database for pawprint data (DoPhot)
(Leigh Smith et al. 2021a,b,c, in prep)

- 9.5 year light curves (2010-2019)
- More reliable, more complete, deeper in crowded fields
- PM & parallax on the Gaia DR2 absolute astrometric reference frame
- Improved absolute and relative "VICAL" photometric calibration

- Selected (ΔKs > 4 mag) variables using Stetson I and von Neumann Eta indices

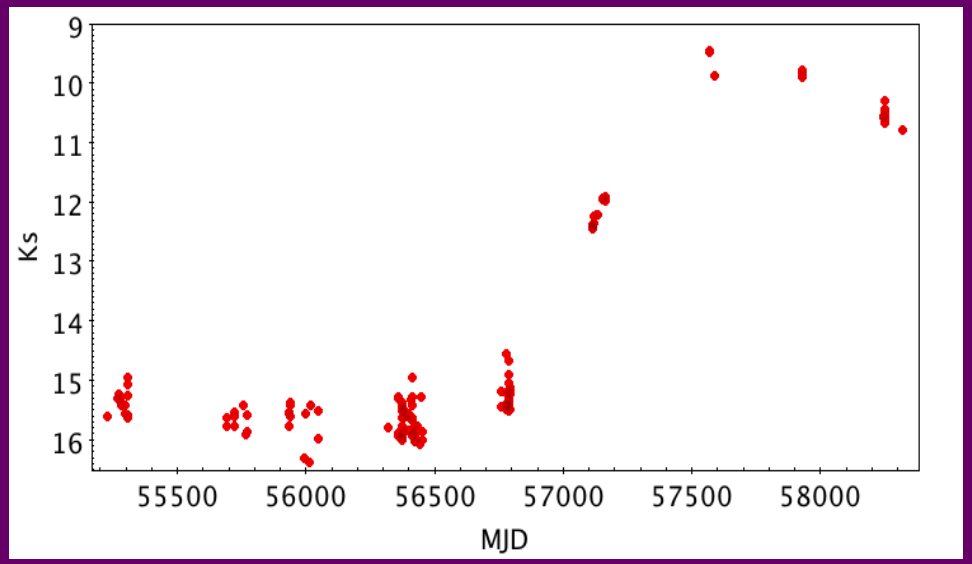
Searched all VVV/VVVX 9.5 year light curves for ΔKs>4 mag variables and transients

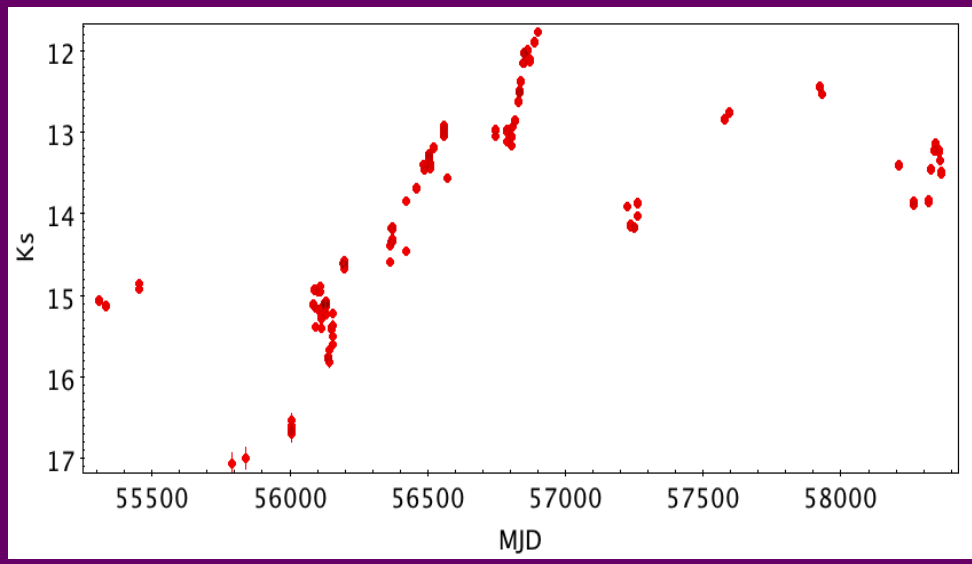
- Found 223 variable stars and transients with ΔKs > 4 mag. 65% are new.
- Real: YSOs, transients (classical novae ?), microlenses, dusty LPVs…
  - unusual objects like VVV-WIT-08 “the giant star that vanished”, L. Smith subm.
- False positives: Bright stars, asteroids, blends, real low amplitude variables, bad images, high proper motion stars, array edge defects, small defects.

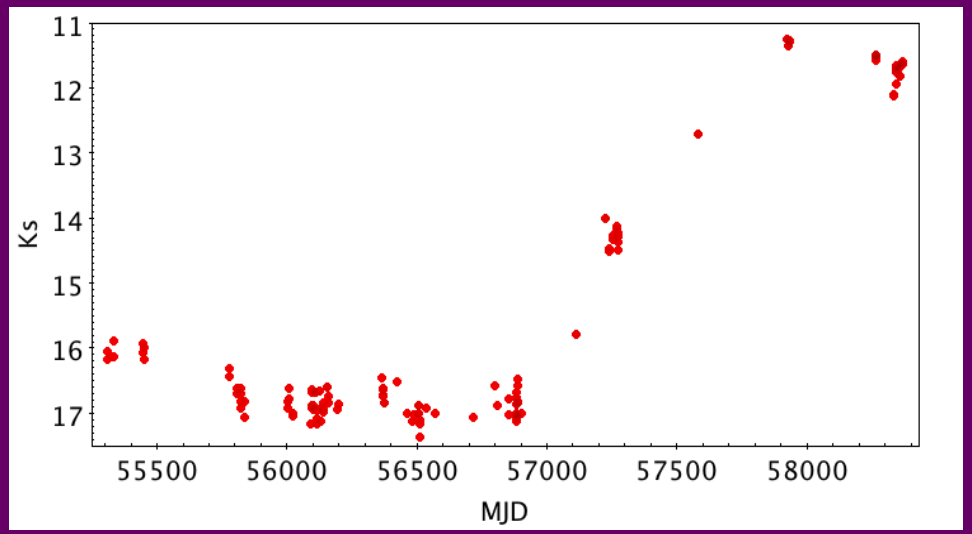
VVV/VVVX VIRAC2 discoveries

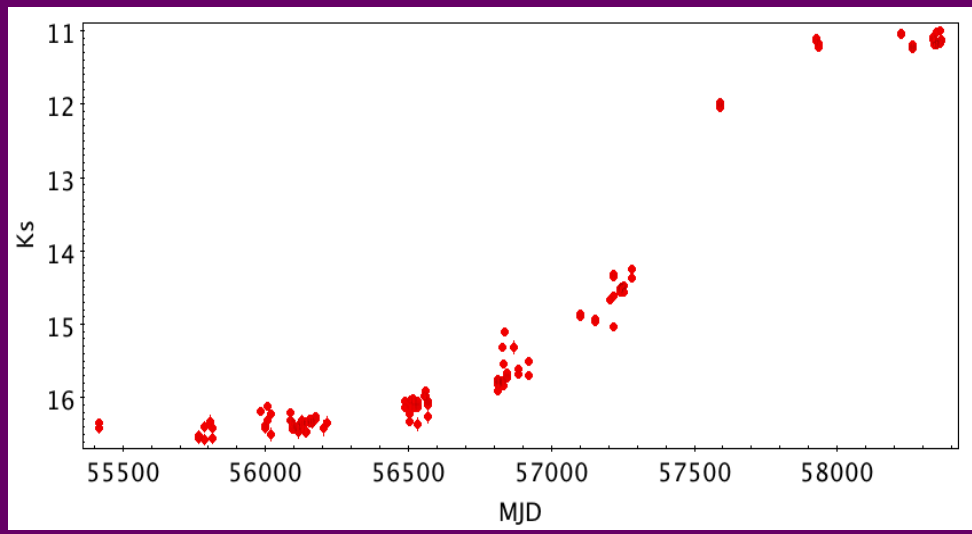
- Amongst 223 variable stars…
  - 64 YSOs
    - ~42 eruptive (includes some faders)
    - ~12 dippers (likely extinction events)
    - ~10 ambiguous

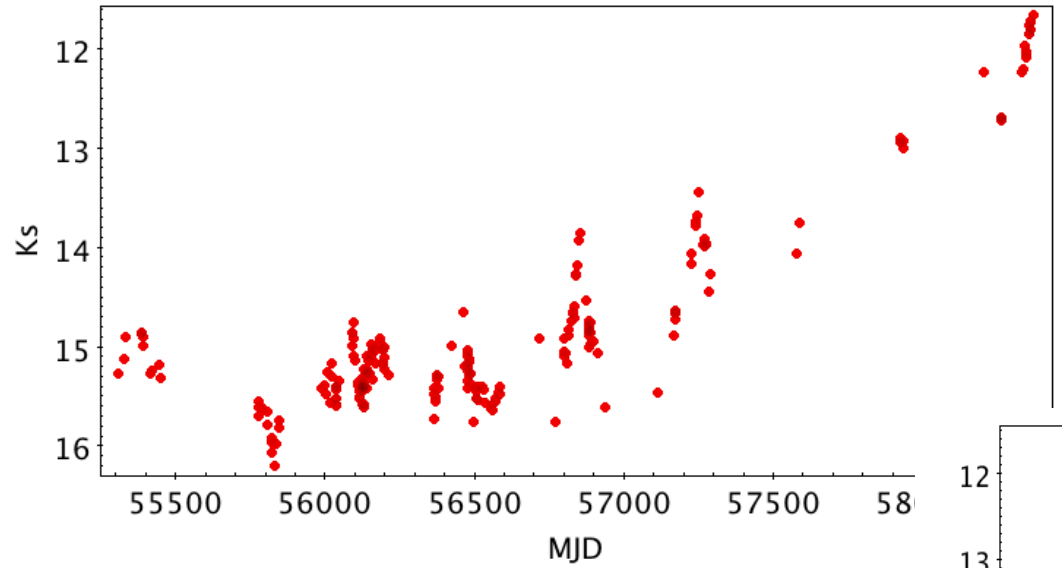
YSO light curves







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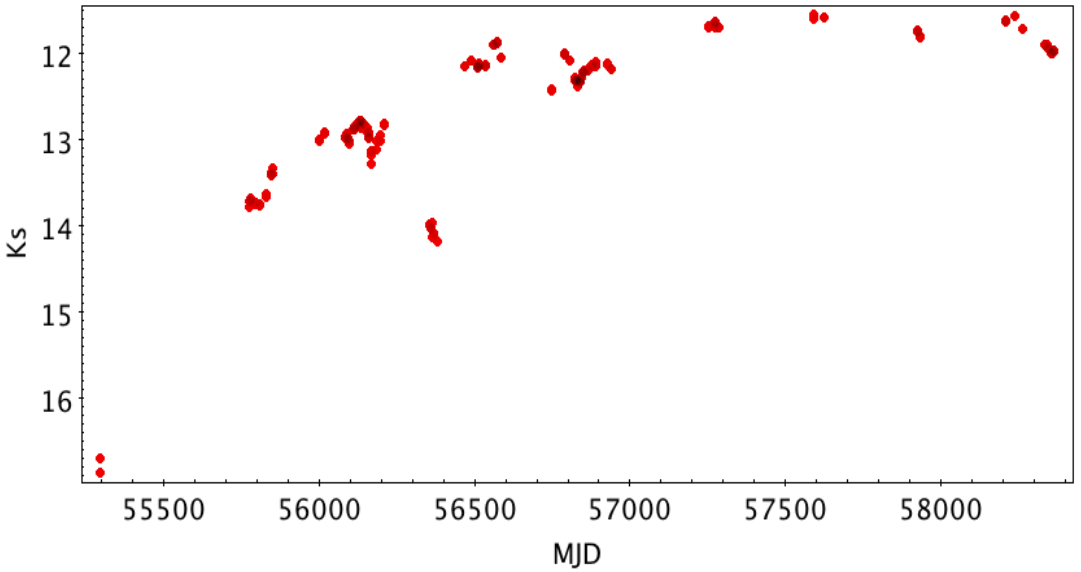
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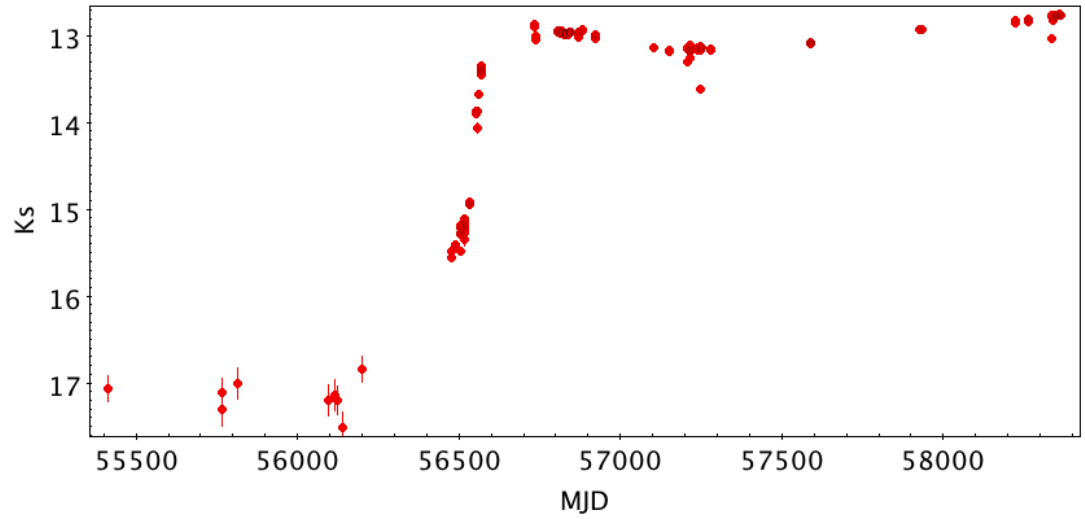
Ks
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MJD

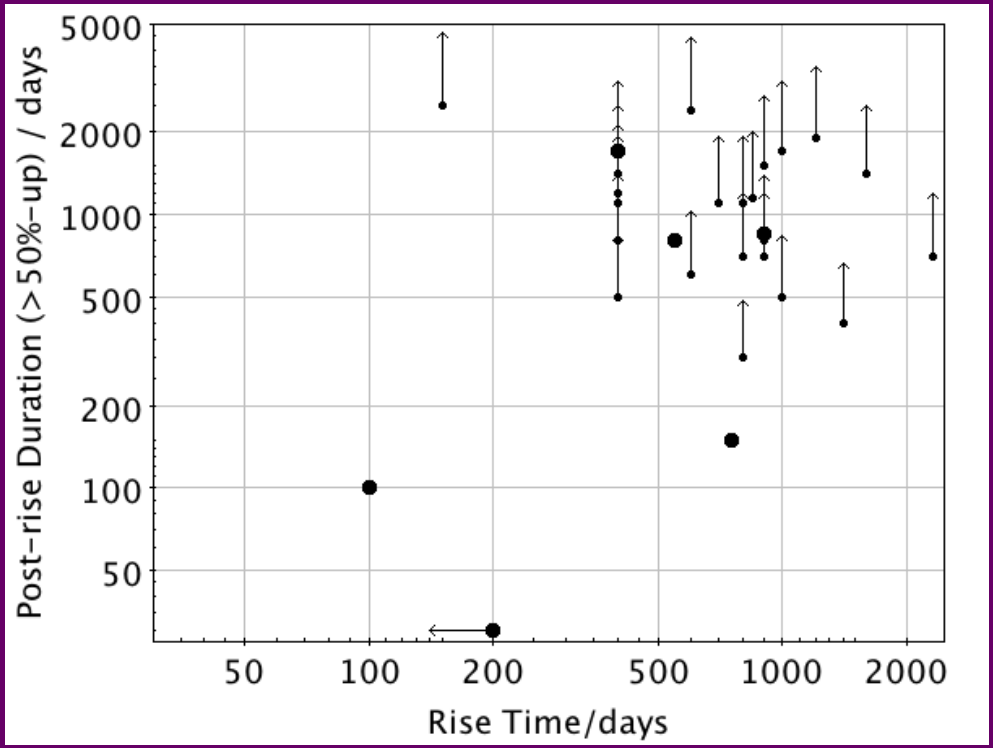
Typical properties of ΔKs>4 mag eruptions

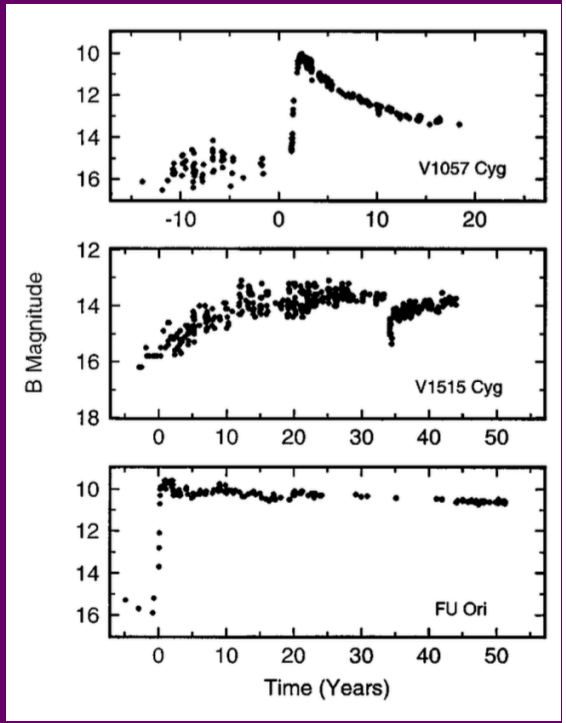
Slow rise: 2-3 years

Long duration: > 3 yr after initial peak

Total duration >5 yr

This is longer than the 1 to 4 yr we had thought for lower amplitude eruptions in CP17a.

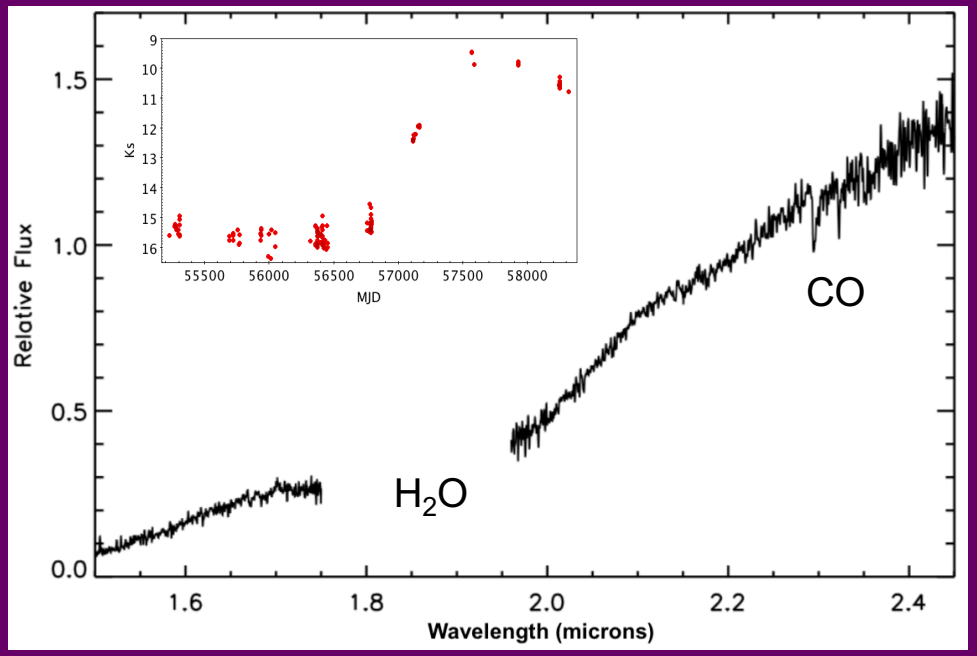


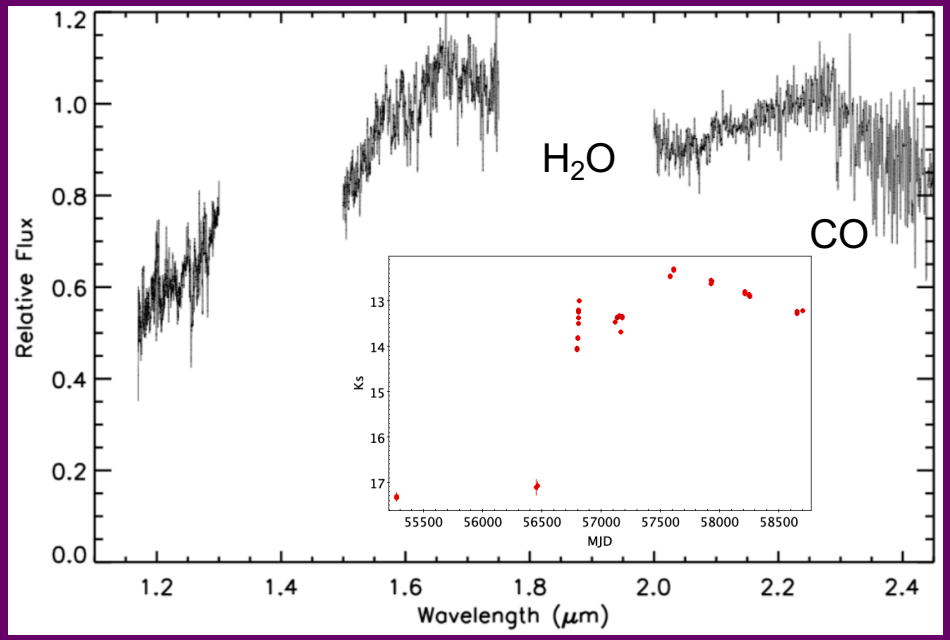


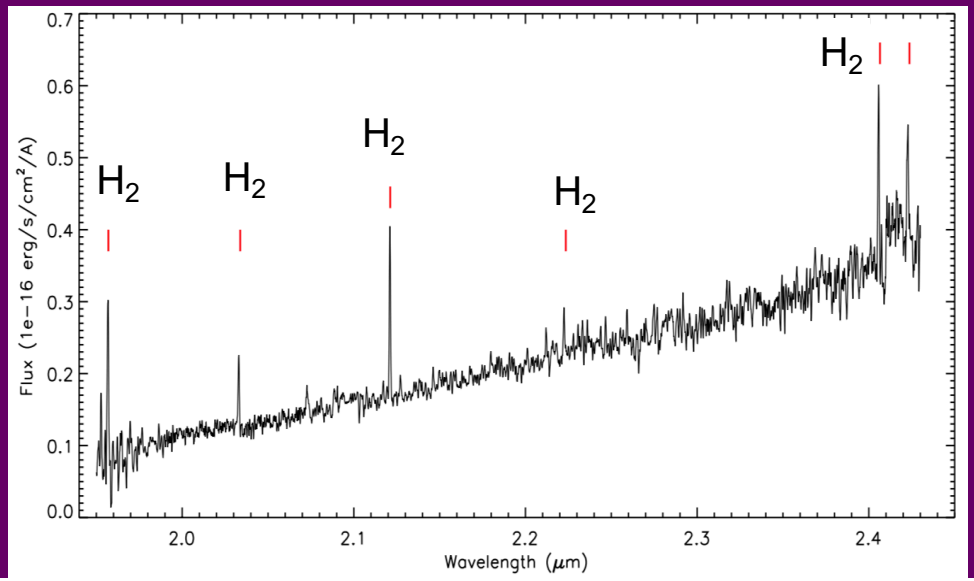
Also, periodic variability not seen.

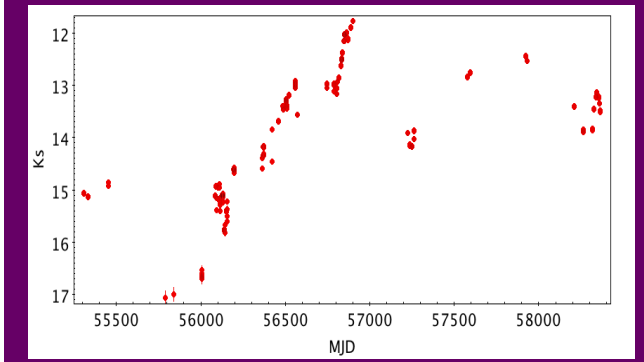
Spectroscopic confirmation of eruptive YSOs

Work in progress … Covid interrupted, but promising so far.

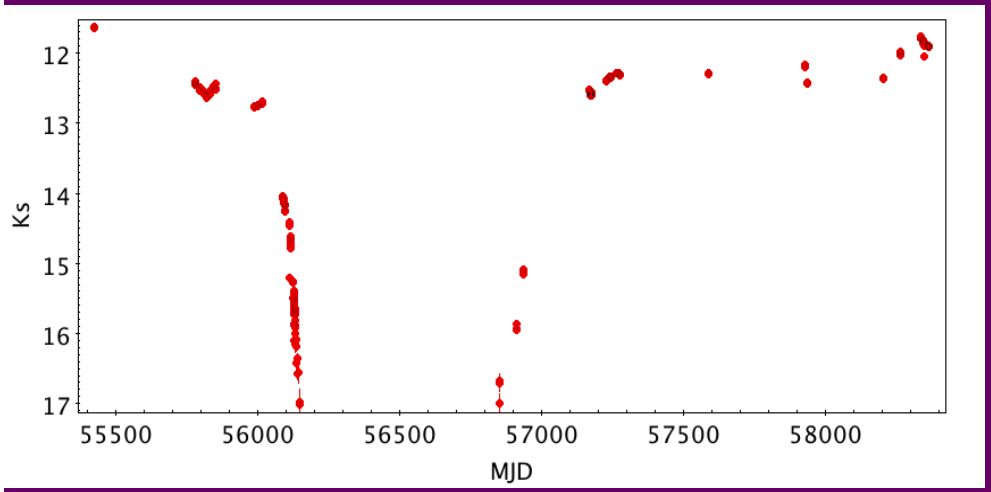


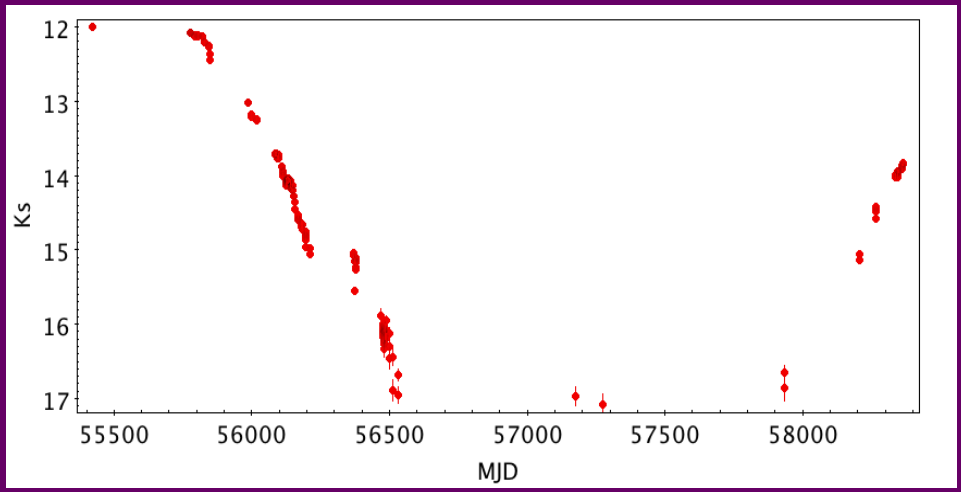


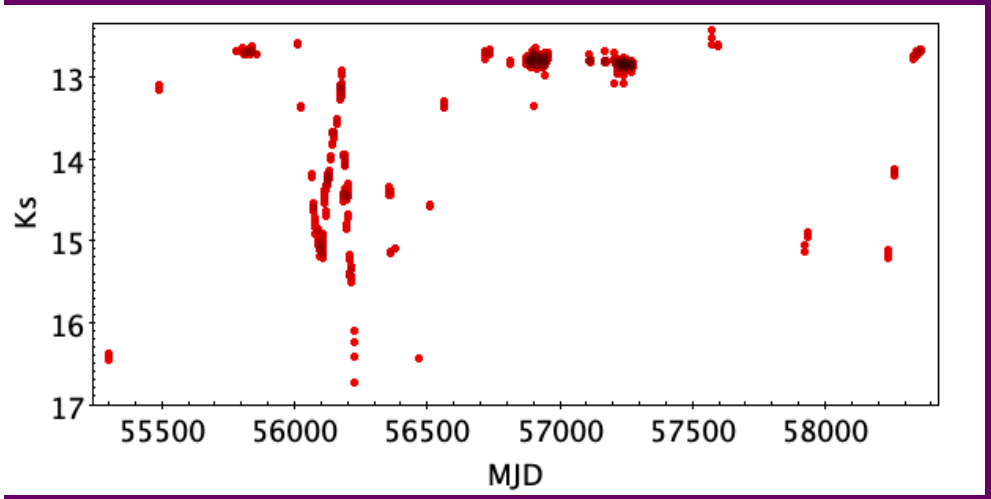


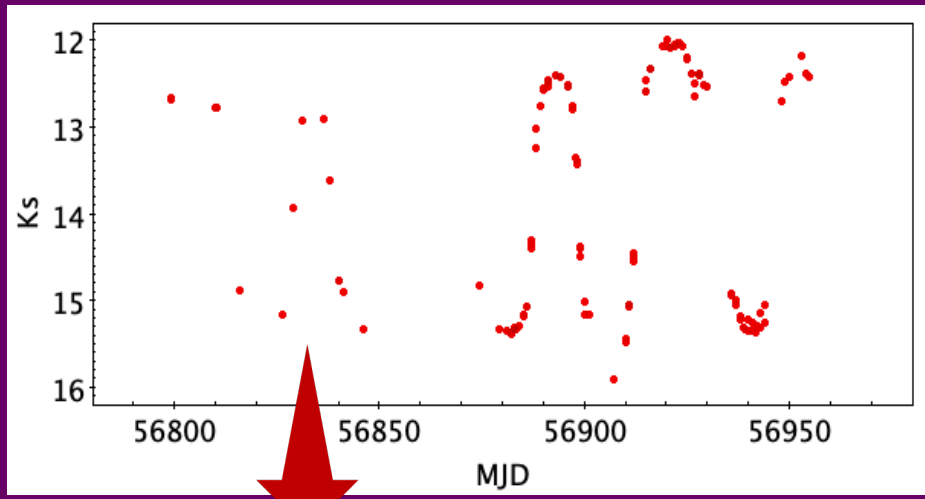


Extinction events: occultations by warped disc or circumbinary disc, like AA Tau (Bouvier et al.2013, A&A, 557, A77)









Likely clone of KH15D (V582 Aur)

Herbst W. et al., 2002, PASP, 114, 1167

Chiang E. & Murray-Clay R. A., 2004, ApJ, 607, 913

WISE 1422-6115: mid-IR discoveries in the WISE database (Lucas et al.2020b, MNRAS, 499, 1805)

- Followed from VVV-WIT-01, a red transient in an Infrared Dark Cloud (Lucas et al.2020a, MNRAS) suspected to be a protostellar collision.
- I searched for additional red transients and highly variable stars within the 7139 IRDCs in the catalogue of Peretto et al.(2016) using the WISE/NEOWISE and VVV/VIRAC2 databases.
- My time domain catalogue of 500,000 bright WISE stars yielded 23 highly variable stars ($\Delta W1 > 2$ mag or $\Delta W2 > 2$ mag) and no new transients.
- 13 YSOs and 10 LPVs (probably dusty Miras).
- Match to Spitzer/GLIMPSE data showed an 8 mag mid-IR event in WISE 1422-6115.

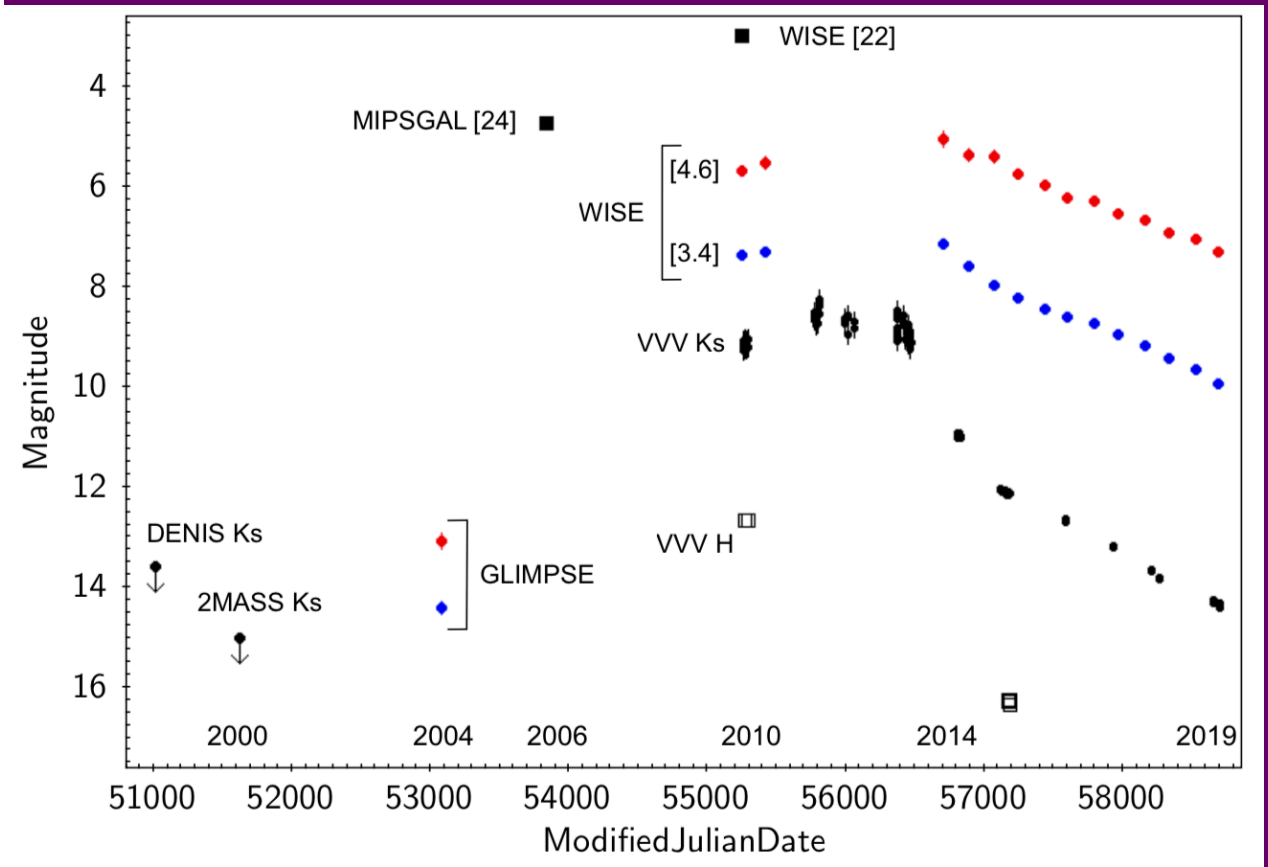
Table of 23 WISE/NEOWISE variable stars

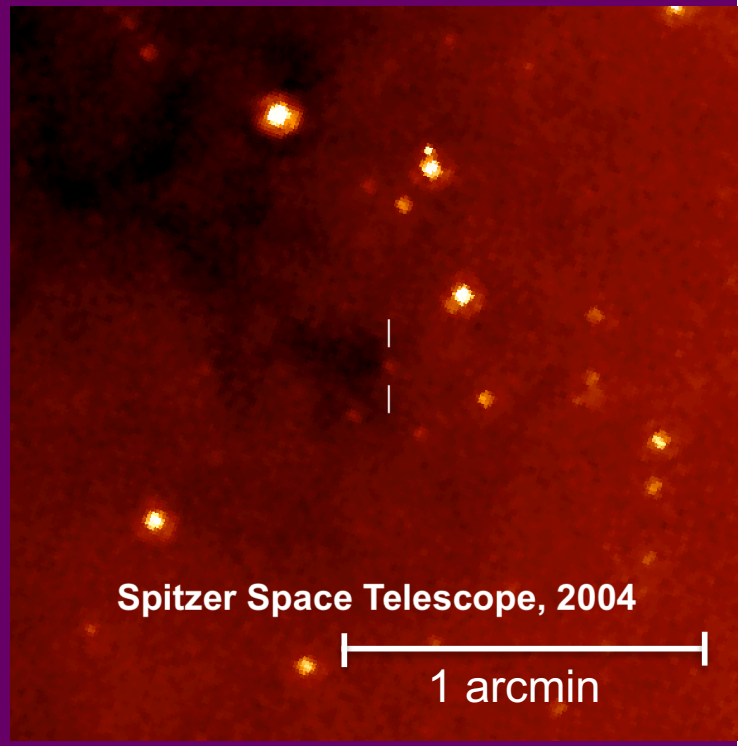
Table 1. Visually confirmed high-amplitude *WISE* variable stars in IRDCs.

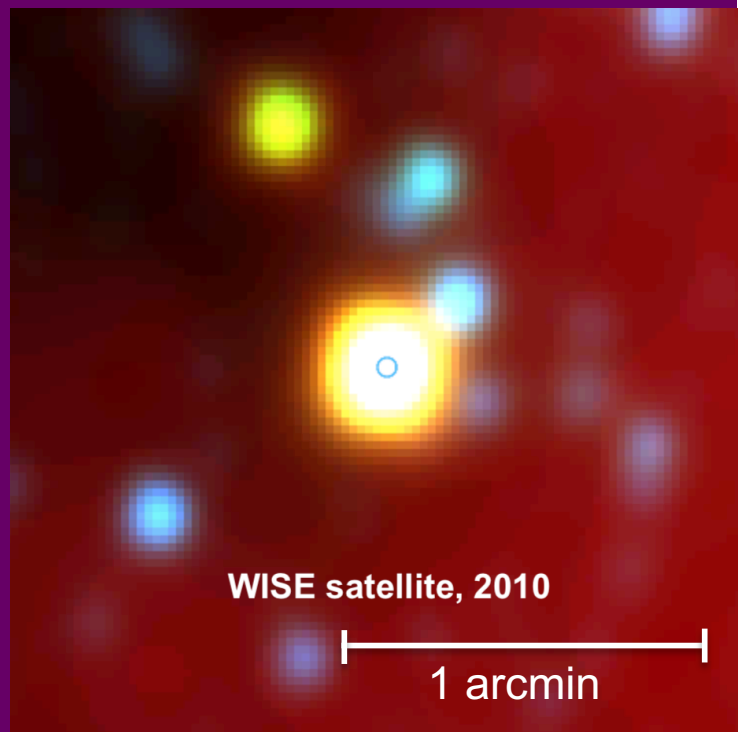
No.	Name	RA[a]	Dec.[a]	$\overline{W1}$	$\overline{W2}$	$\Delta W1$	$\Delta W2$	Type	Period (d)	Notes and other identifications
1	WISEA J134444.02−623127.4	206.1835	−62.5244	9.39	6.51	2.32	2.22	AGB	634.1 ± 3.1	[RMB2008] G309.0355−00.2858
2	WISEA J142238.82−611553.7	215.6620	−61.2650	8.05	5.80	1.87	1.54	YSO		Main subject of this work
3	WISE J142345.85−612540.7[b]	215.9411	−61.4282	13.01	11.44	3.74	3.67	YSO		
4	WISEA J154914.33−543423.6	237.3096	−54.5733	11.41	9.53	2.86	2.18	YSO		
5	WISEA J163957.05−462614.2	249.9877	−46.4374	8.69	6.10	1.88	1.76	AGB	639.7 ± 5.0	
6	WISEA J165035.47−444959.5	252.6479	−44.8332	10.02	6.91	2.47	1.87	AGB	689.4 ± 3.6	[RMB2008] G340.7273−00.2234
7	WISEA J165250.41−443908.4	253.2103	−44.6524	10.59	7.02	1.83	1.85	AGB	760.9 ± 6.4	[RMB2008] G341.1209−00.4163
8	WISEA J165344.39−432819.2	253.4351	−43.4720	12.96	10.51	5.26	3.28	YSO		VVVv746, [RMB2008] G342.1371+00.2054
9	WISEA J170547.35−411307.5	256.4473	−41.2187	12.57	9.79	3.21	2.26	YSO		
10	WISEA J171910.90−390226.9	259.7952	−39.0409	12.05	9.83	3.28	2.16	YSO		VVVv422
11	WISEA J172258.05−370309.6	260.7421	−37.0526	7.95	6.64	1.99	1.50	AGB	514.8 ± 3.4	IRAS 17195−3700
12	WISEA J181041.21−191040.2	272.6718	−19.1778	11.09	9.34	2.97	2.31	AGB	371.6 ± 4.8	[RMB2008] G011.3064−00.0637
13	WISEA J181426.60−172921.9	273.6110	−17.4894	8.59	6.34	1.66	1.95	YSO		[RMB2008] G013.2154−00.0350, YSO candidate in Marton et al.(2016).
14	WISEA J181704.22−162554.0	274.2676	−16.4318	9.72	6.69	2.01	1.80	AGB	891.0 ± 7.5	
15	WISEA J181725.67−170211.7	274.3572	−17.0366	12.24	8.61	3.25	2.09	YSO		[RMB2008] G013.9529−00.4460
16	WISEA J181736.79−165006.2	274.4031	−16.8351	8.37	7.00	2.50	1.73	AGB	501.7 ± 7.3	
17	WISEA J181832.84−133239.3	274.6368	−13.5443	11.54	9.23	2.61	2.60	YSO		[RMB2008] G017.1562+00.9715
18	WISEA J181849.10−140818.3	274.7048	−14.1384	7.93	5.81	1.42	1.59	AGB	235.0 ± 0.6	[RMB2008] G016.6638+00.6324
19	WISEA J182025.44−163608.8	275.1059	−16.6024	10.61	9.43	2.60	2.28	YSO		[RMB2008] G014.6746−00.8724
20	WISEA J182712.94−124904.8	276.8040	−12.8180	7.57	5.89	1.33	1.62	AGB	788.8 ± 8.3	[RMB2008] G018.7877−00.5509
21	WISEA J185720.27+015711.8	284.3344	1.9534	7.88	6.96	3.47	3.23	YSO		[RMB2008] G035.3429−00.4212, 4.6 mag fainter in GLIMPSE.
22	WISEA J190424.69+054106.8	286.1031	5.6853	10.03	8.59	2.03	2.01	YSO		Source 245 in Lucas et al.(2017), YSO candidate in Marton et al.(2016)
23	WISEA J195146.18+272458.7	297.9423	27.4163	9.59	7.43	2.04	1.20	YSO		[RMB2008] G063.9380+00.2509, YSO candidate in Marton et al.(2016).

Notes. [a]The coordinates of source 21 given in decimal degrees are taken from UKIDSS, in order to distinguish this star from an optically brighter neighbour (see the main text). All other sources have *WISE*-based coordinates from our time domain catalogue. All are equinox J2000 values.
[b]Source 3 is not included in the AllWISE catalogue so the name is taken from the WISE All-Sky release.

Light curve of WISE 1422-6115





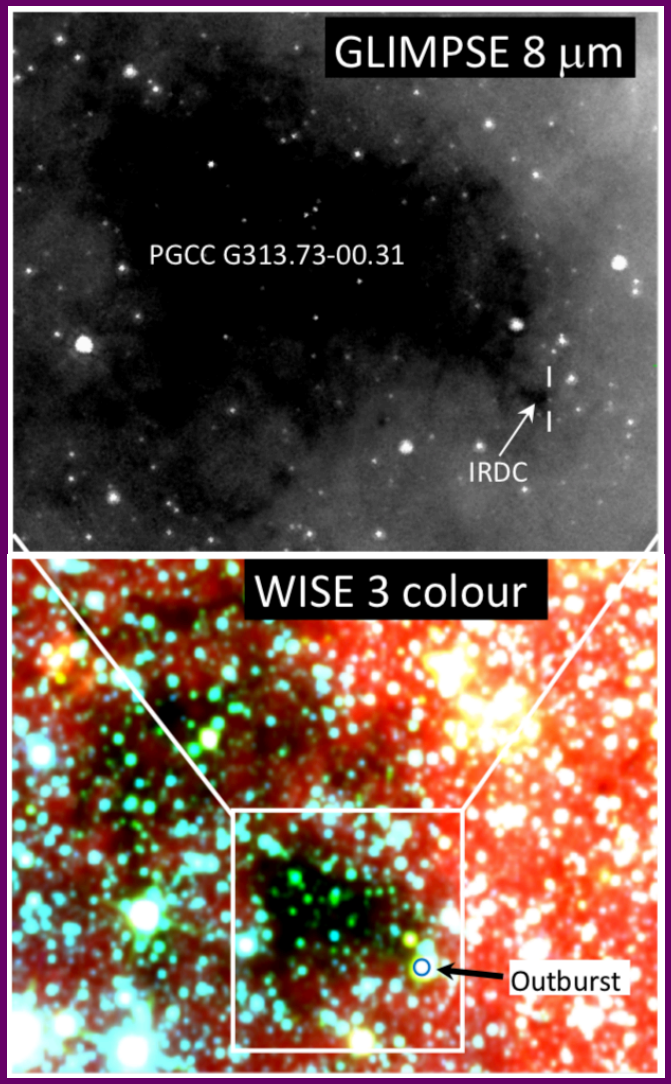


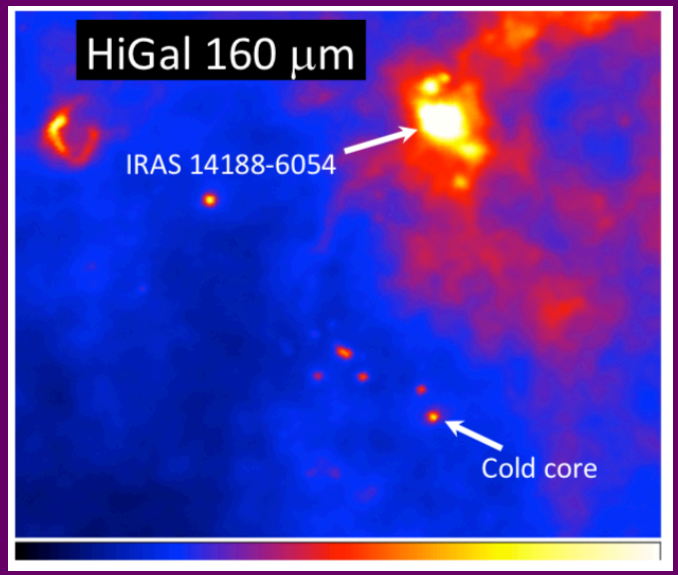
Environment

Embedded in a ~50 $M_\odot$ cold *Herschel* / HiGal cloud core listed by Elia et al.(2017, MNRAS, 471, 100).

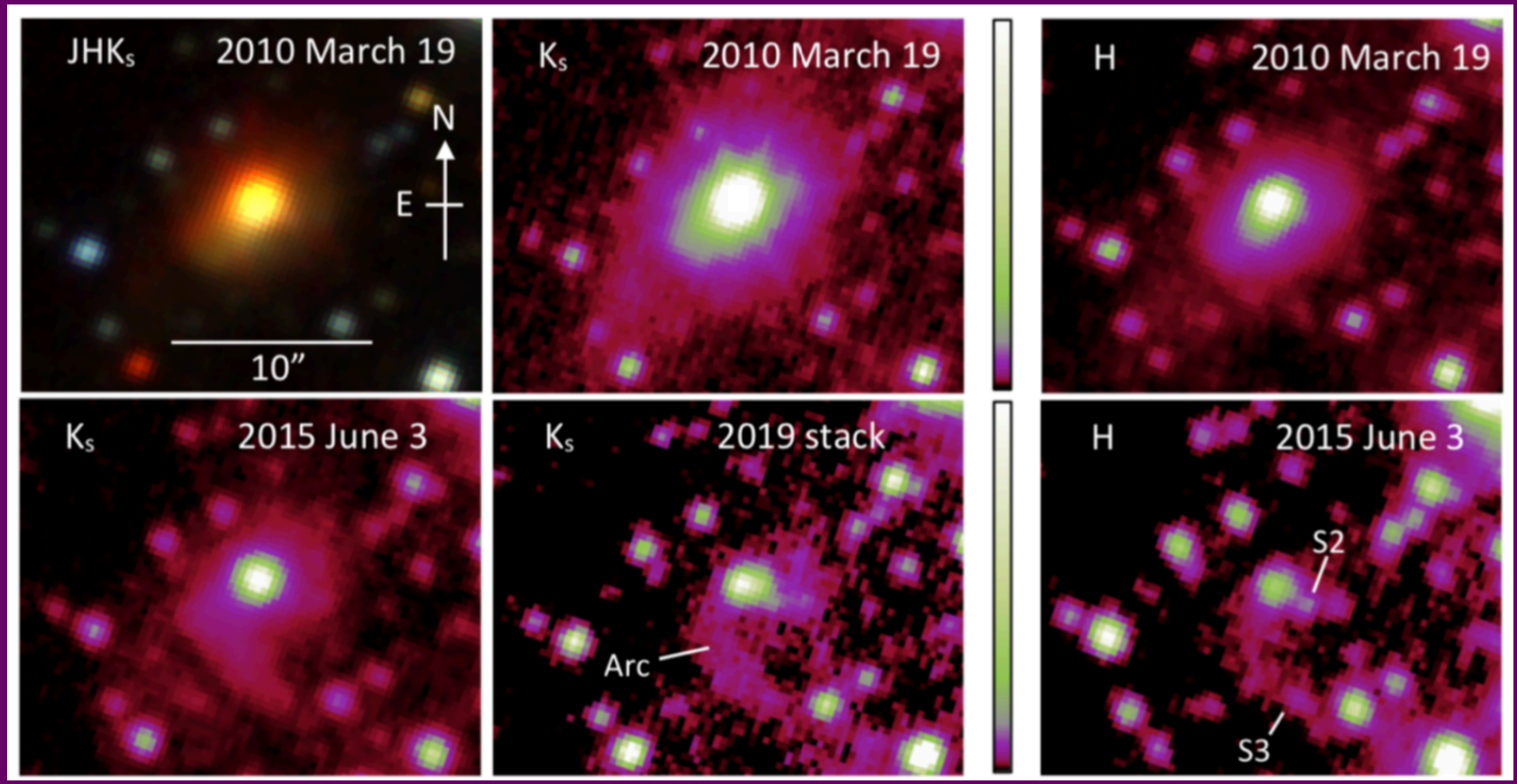
~2.6 kpc distance

On the edge of a larger "Planck Galactic cold clump`` and the IRAS 14188-6055 HII region.



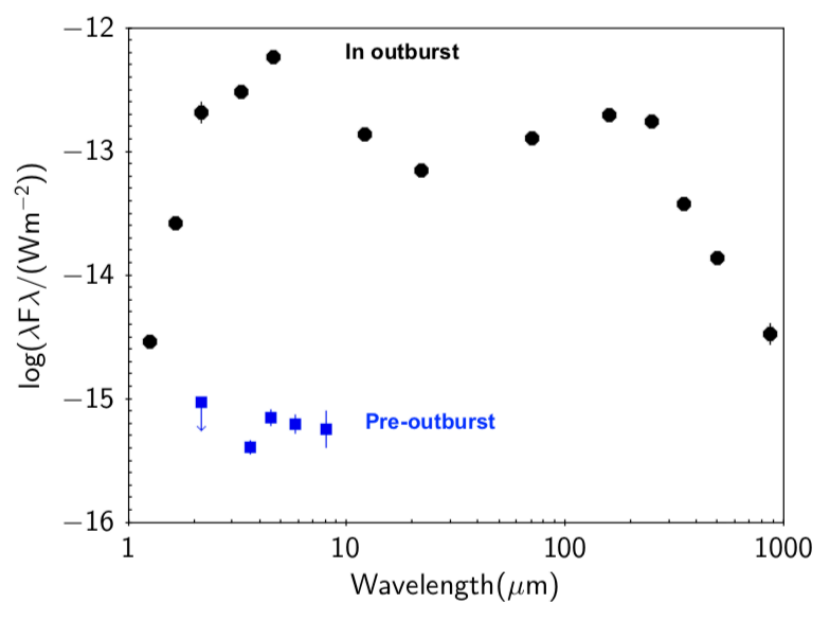


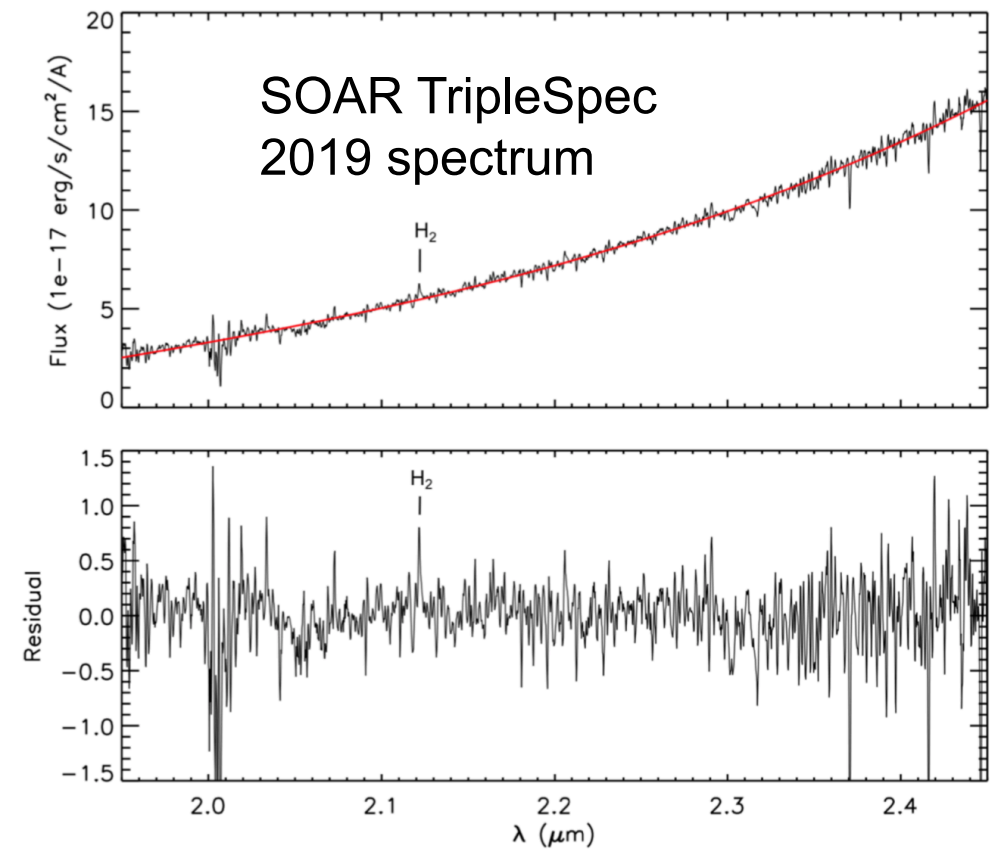
VVV images: large cometary nebula and filament



A sign of ejected matter from an earlier outburst? (Liu et al. 2016, Takami et al. 2018, Vorobyov et al. 2020)

SED and spectrum





Low mass class I YSO pre-outburst

Surprising peak in SED at 4.5 um in outburst implies T = 800-1000 K, R ~ 4.5 au.

Reprocessed radiation due to edge-on disc view??

L = a few x10^2 $L_\odot$ enough to have heated the whole cloud core slightly.

A very cool event

T = 800 - 1000 K in 2010
Became redder as it brightened:
T = 600 - 800 K in 2014.
Implies outward progression thru the disc

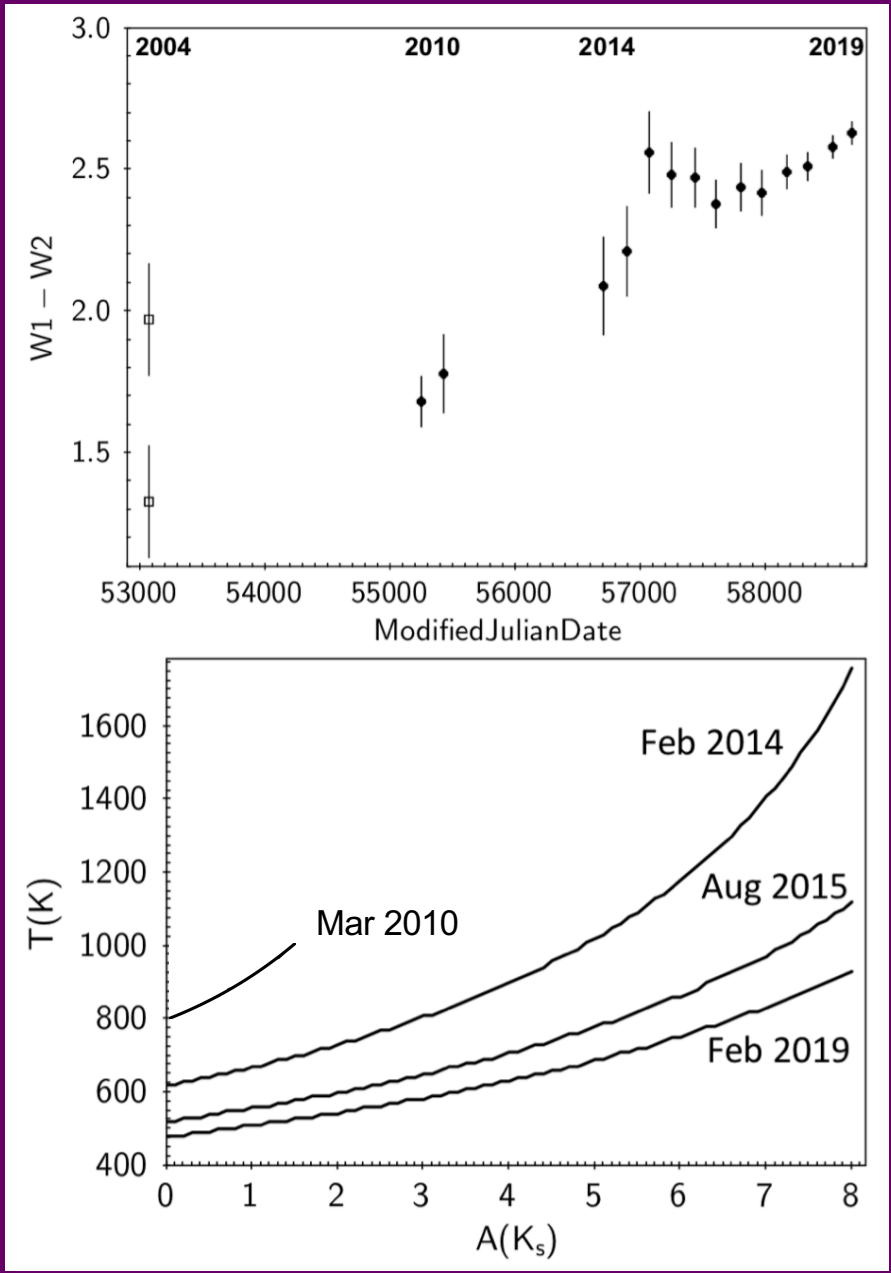
Further cooling as it faded after 2014.

Lack of the high temperature matter might be explained by infalling fragment models (E. Vorobyov) still under development.

Or reprocessing & edge-on disc.

Outward progression consistent with MRI models or some thermal-viscous instability models.

Contrasts with inward progression of Gaia 17 bpi (Hillenbrand et al. 2018).



Summary

VVV/VVVX VIRAC2 PSF-based database is transformative.

- Most outbursts take place in class I YSOs.
- Highest amplitude ($\Delta K_s > 4$ mag) outbursts rise slowly (years) with rare exceptions

  FUor-like absorption spectra may be more common ?

- Periodic variability not seen at $\Delta K_s > 4$ mag (but see Zhen's talk).
- Not many "multiple timescale" variables at $\Delta K_s > 4$ mag (see Zhen's talk).

- Outward progression indicated for WISE 1422-6115, a ~10 yr eruption like OO Ser.
- Variety of behaviours suggests multiple processes can cause episodic accretion.

WISE/NEOWISE data are a hitherto untapped treasure trove for eruptive YSOs.

- High res ALMA/near IR follow up of WISE 1422-6115 would be helpful.