Novae and related stellar transients

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Novae and related stellar transients

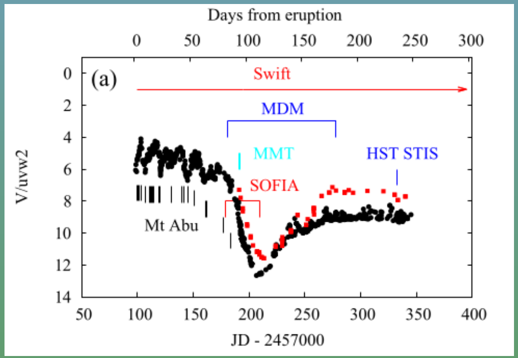
- Novae
- Very late thermal pulses
- Stellar mergers

All are:

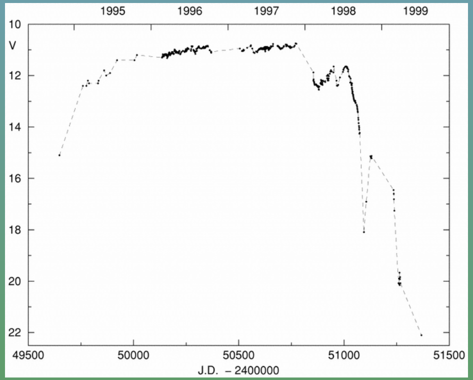
- transient eruptive variables reaching $L_{bol} \sim 10^4 – 10^6 L_{sun}$
- inject material having non-solar abundances into the ISM.
- Variable in the near/mid-IR over timescales ~ months – years.

Novae and related stellar transients

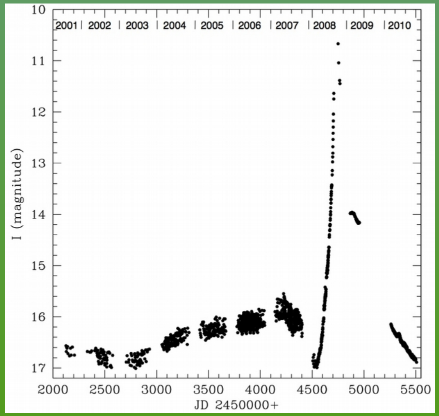
- Novae



- Very late thermal pulses

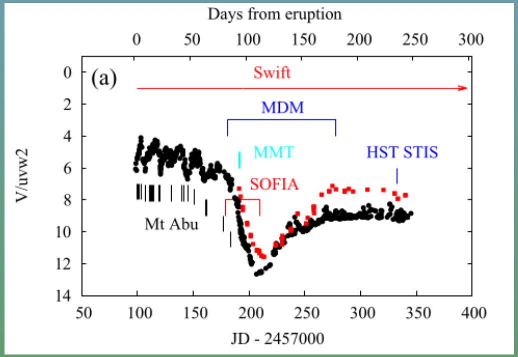


- Stellar mergers



Novae and related stellar transients

- Novae



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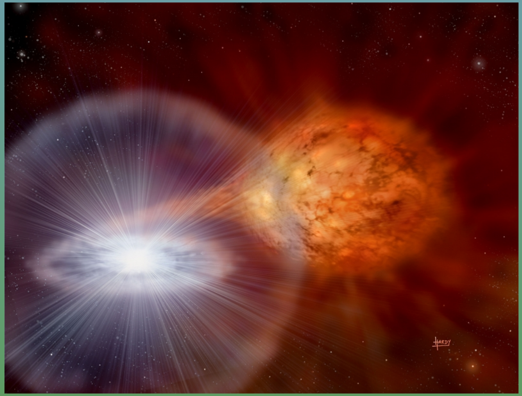
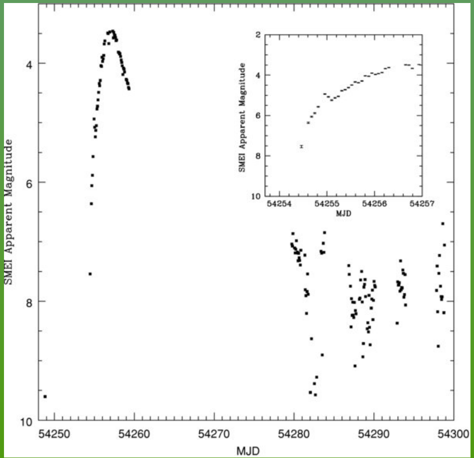
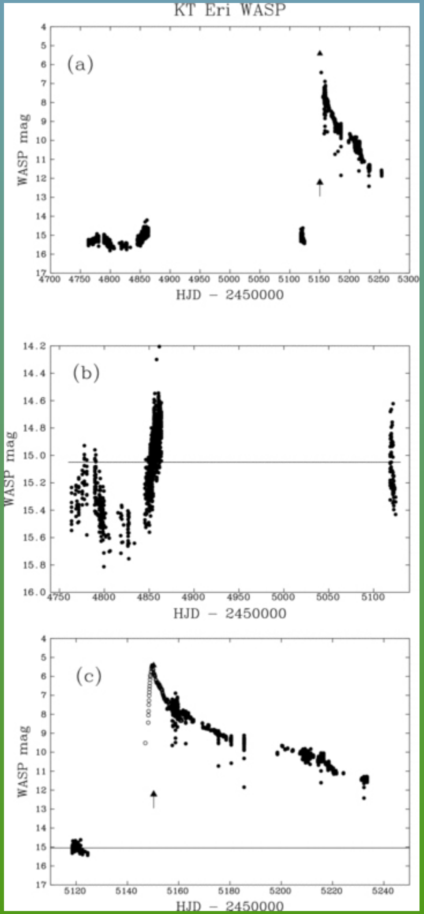


- Semi-detached binary. WD with cool secondary.
- Mass transfer from cool component to WD via accretion disc.
- Base of accreted material becomes degenerate and hot ⟶ ThermoNuclear Runaway.
- ⟶ Nova explosion.
- ~10^{-4} Msun of material, enriched in C, N, O, Al, Mg is ejected at ~1000km/s.





Hounsell+, 2010, ApJ, 274, 480
McQuillin+, 2012, MNRAS, 419, 330
David Hardy

Novae and related stellar transients

In a classical nova eruption we get:

- dust formation – silicate and hydrocarbons – if the WD is of CO type
- fine structure line emission
- occasionally coronal emission
- eventual evolution into a resolvable remnant

If the mass ejected in nova eruption < mass accreted onto the WD, then novae are potential SN Ia progenitors (Starrfield +, 2020, ApJ, 895, 70)

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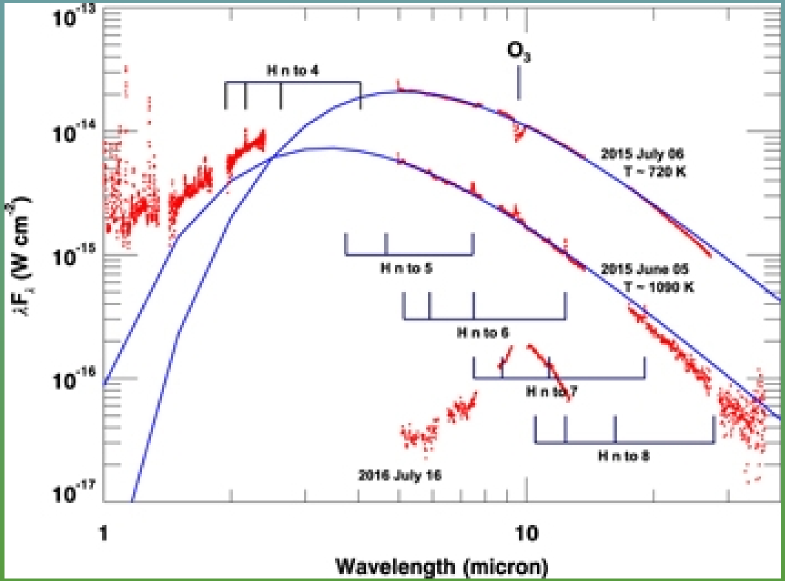

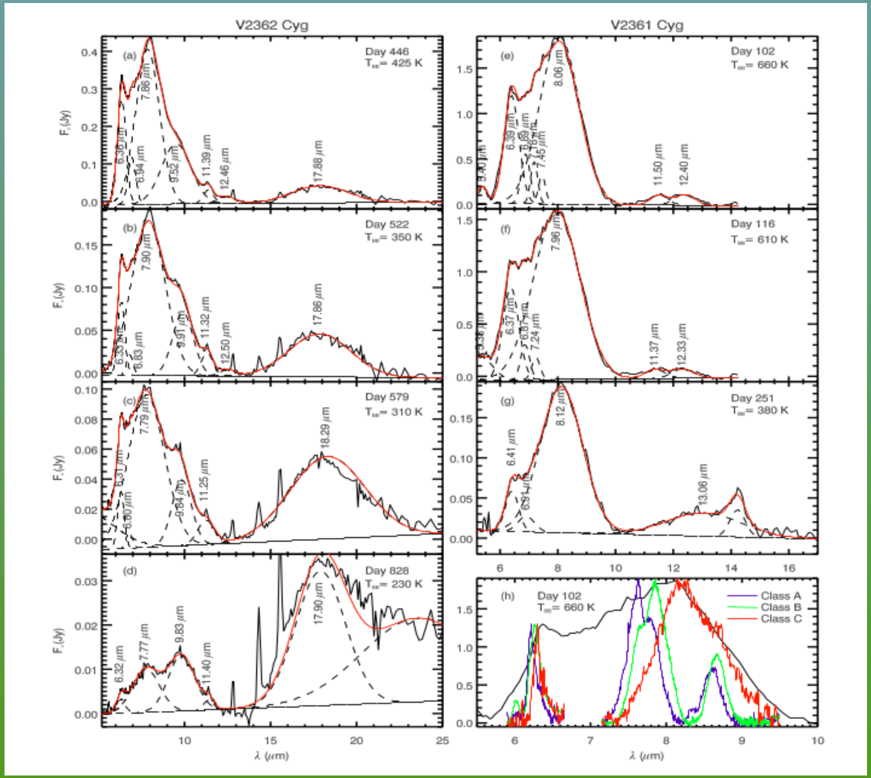

Evolution of silicate and hydrocarbon features in classical novae (Gehrz+, 2015, ApJ, 858,78. Helton+, 2011, "PAHs and the Universe")

Novae and related stellar transients

Species	Transition	λ (μm)	E.P. (eV)	I. P. (eV)
[Na III]	$^2P_{1/2}-^2P_{3/2}$	7.3177	47.29	71.62
[Ar V]	$^3P_2-^3P_1$	7.9016	59.81	75.02
[Ar III]	$^3P_1-^3P_2$	8.9914	27.63	40.74
[Na IV]	$^3P_1-^3P_2$	9.0410	71.62	98.91
[S IV]	$^2P_{3/2}-^2P_{1/2}$	10.5105	34.79	47.22
[Ca V]	$^3P_0-^3P_1$	11.4820	67.27	84.50
[Ne II]	$^2P_{1/2}-^2P_{3/2}$	12.8136	21.56	40.96
[Ar V]	$^3P_1-^3P_0$	13.1022	59.81	75.02
[Ne III]	$^3P_1-^3P_2$	15.5551	40.96	63.45
[S III]	$^3P_2-^3P_1$	18.7130	23.34	34.79
[Na IV]	$^3P_0-^3P_1$	21.2900	71.62	98.91
[Ar III]	$^3P_0-^3P_1$	21.8302	27.63	40.74
[O IV]	$^2P_{3/2}-^2P_{1/2}$	25.8903	54.93	77.41
[S III]	$^3P_1-^3P_0$	33.4810	23.34	34.79
[Ne III]	$^3P_0-^3P_1$	36.0135	40.96	63.45

Species	Transition	λ (μm)	E.P. (eV)	I. P. (eV)
[Mg VII]	$^3P_2-^3P_1$	5.5032	186.51	224.95
[Mg V]	$^3P_1-^3P_2$	5.6099	109.24	141.27
[Al VIII]	$^3P_1-^3P_0$	5.8500	241.44	284.60
[Ca VII]	$^3P_1-^3P_0$	6.1540	108.78	127.20
[Si VII]	$^3P_0-^3P_1$	6.4922	205.05	246.52
[Ne VI]	$^2P_{3/2}-^2P_{1/2}$	7.6524	126.21	157.93
[Na VI]	$^3P_2-^3P_1$	8.6106	138.39	172.15
[Mg VII]	$^3P_1-^3P_0$	9.0090	186.51	224.95
[Al VI]	$^3P_0-^3{}_1$	9.1160	153.83	190.48
[Mg V]	$^3{}_0-^3P_1$	13.5213	109.24	141.27
[Ne V]	$^3P_2-^3P_1$	14.3217	97.12	126.21
[Na VI]	$^3P_1-^3P_0$	14.3964	138.39	172.15
[Ne V]	$^3P_1-^3P_0$	24.3175	97.12	126.21

Expected fine structure and coronal lines in erupting novae
Highlighted lines routinely observed
(Evans & Gehrz, 2012, BASI, 40, 2013)

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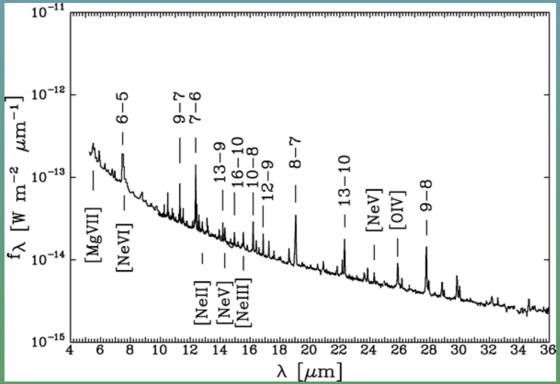
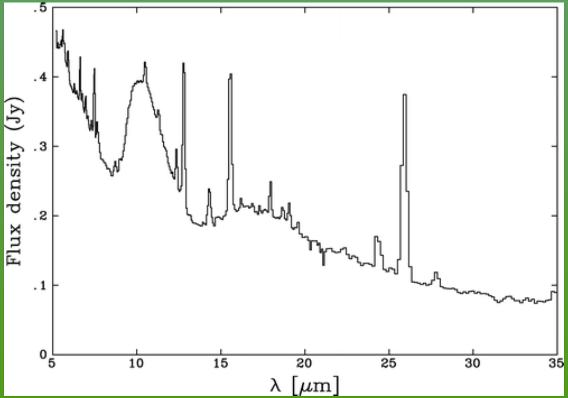
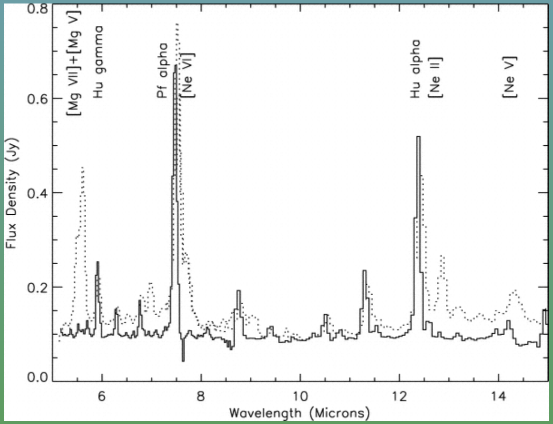
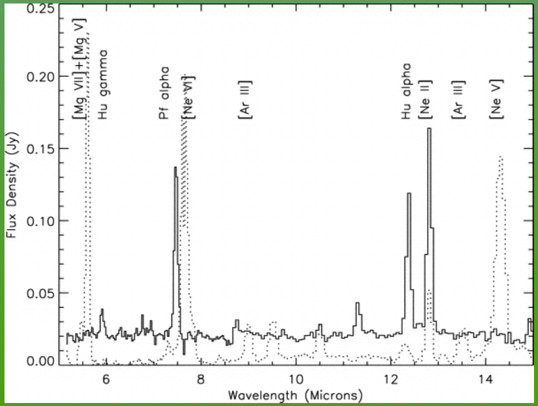


Left: coronal and fine structure emission, and silicate emission, in the recurrent nova RS Oph (Evans+, 2007, ApJL, 663, L29; 671, L157)





Right: fine structure line emission in a neon nova (dotted lines) and a CO nova (Schwarz+, 2007, AJ, 134, 516)



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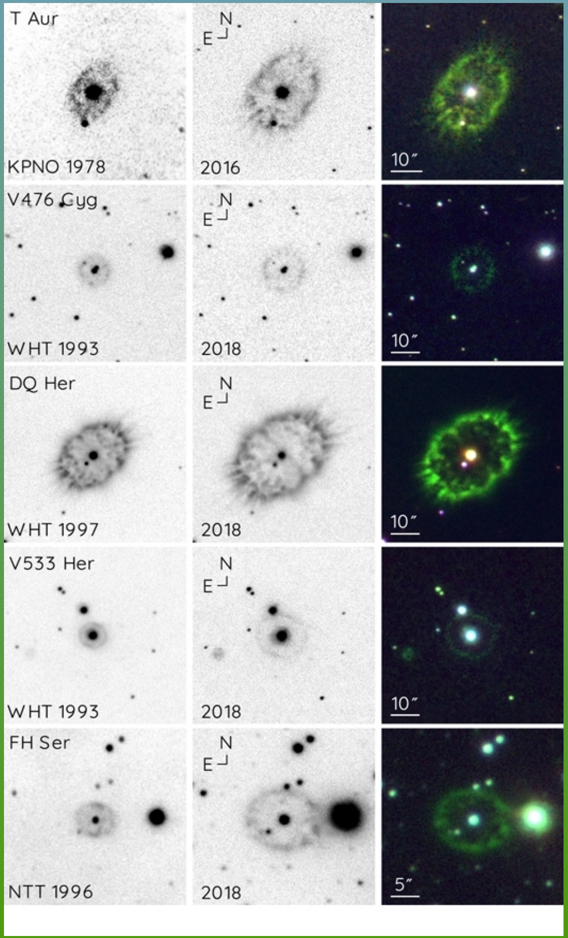
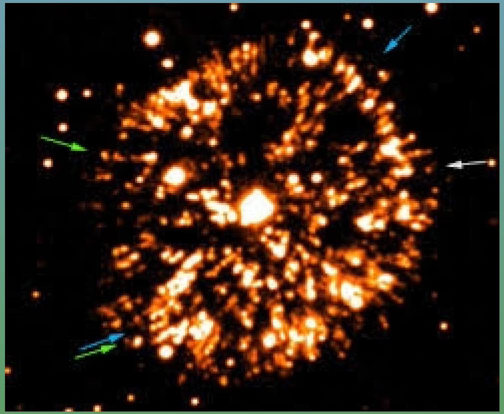
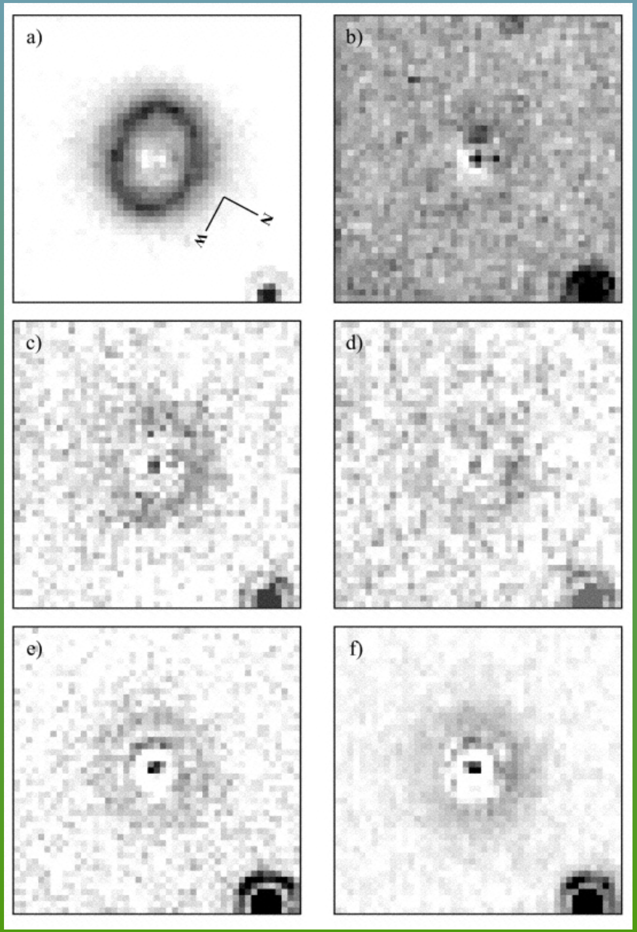




After a few decades, the ejected material may be resolved.

R. Corradi.
Krautter+, 2002, AJ, 124, 2888.
Santamaria+, 2020, ApJ, 892, 60



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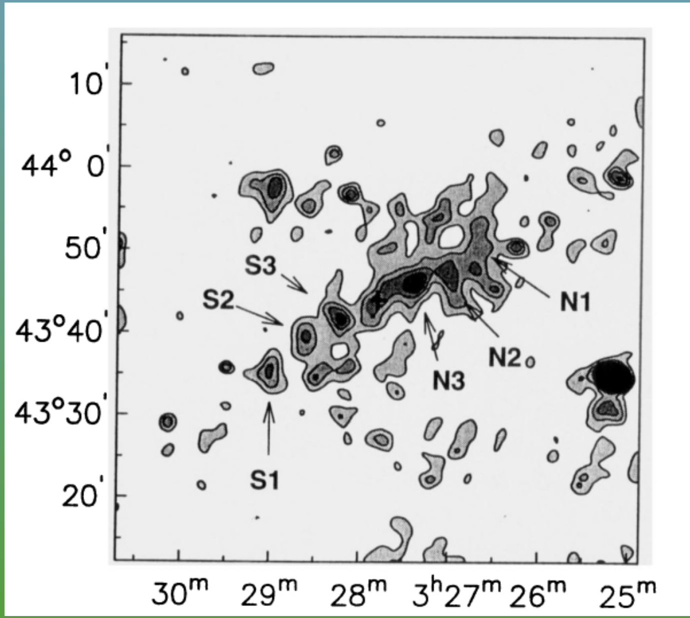

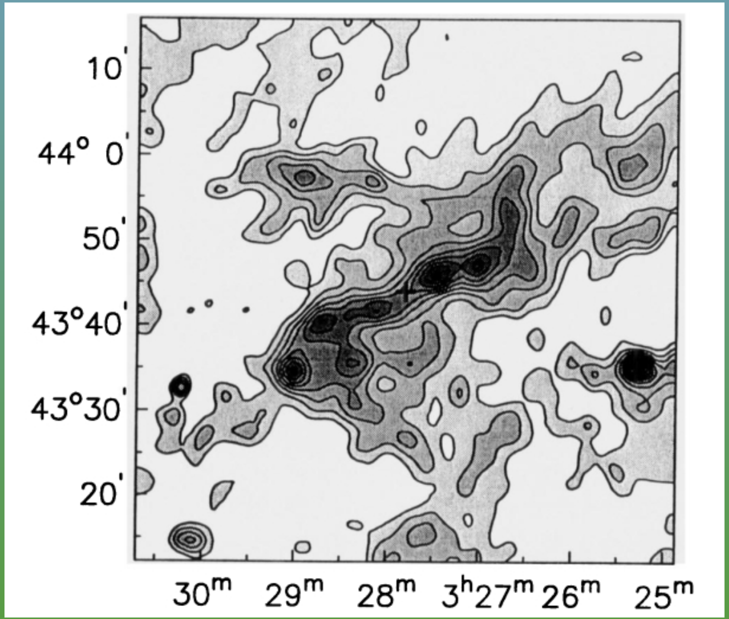

Far-IR (IRAS) maps of region of 1901 nova GK Per – showing extended emission.
Possibly due to the evolution of the WD to a VLTP following RL overflow.
The 1901 eruption was the first in this system (Dougherty+, 1996, A&A, 306, 547)

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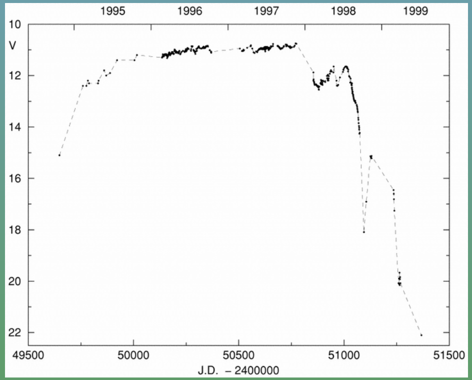

- Very late thermal pulses

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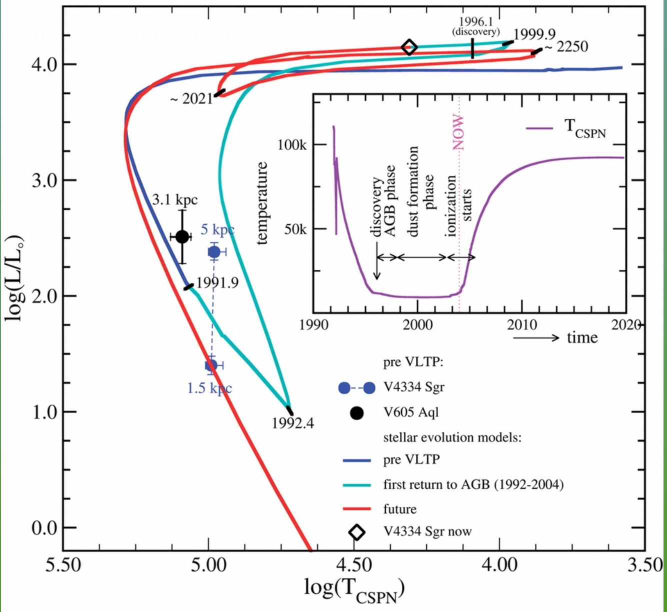
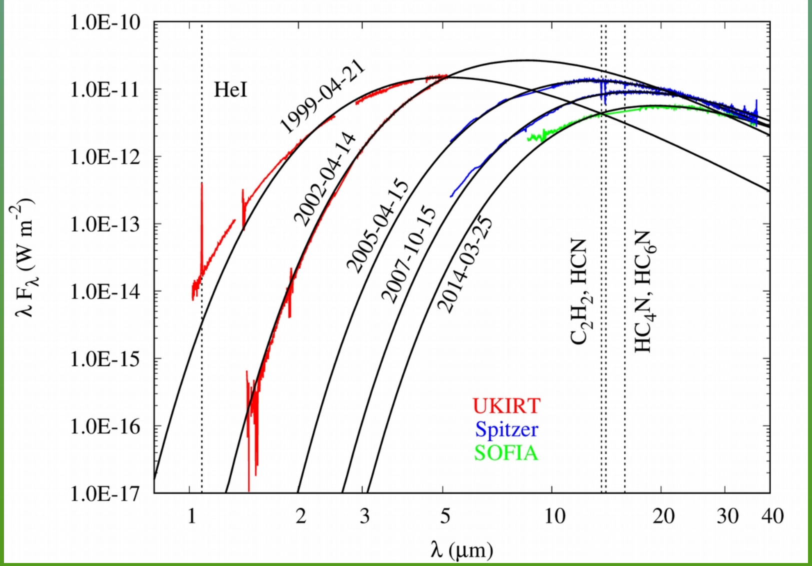


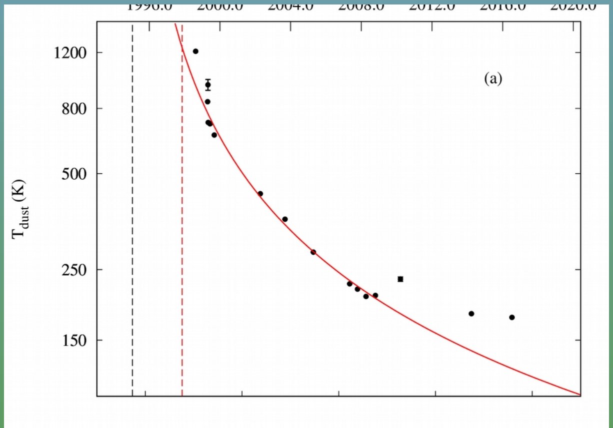
- Solar-mass star evolves towards WD region of HR; in ~25% of cases residual He shell may be ignited so star rebrightens eruptively – it becomes a "Born-Again Giant".
- Gives us a glimpse as to the possible fate of the Sun.
- Evolution very rapid – "Stellar evolution in real time".
- At centre of ancient PN. Sites of carbon and hydrocarbon chemistry.
- Grossly non-solar isotopic ratios (e.g. $^{12}C/^{13}C \sim 4$).

Hajduk+, 2005, Science, 308, 231

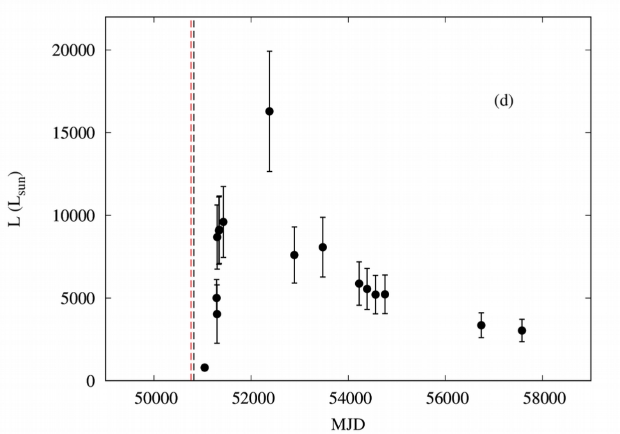
Novae and related stellar transients

IR evolution of a VLTP (Sakurai's Object) over ~15 years as seen by UKIRT, Spitzer, SOFIA, showing luminosity changes, cooling of dust shell and the presence of small hydrocarbon molecules (Evans+, 2020, MNRAS, 493, 1277)





SOFIA observations point to additional mass-loss after 2008



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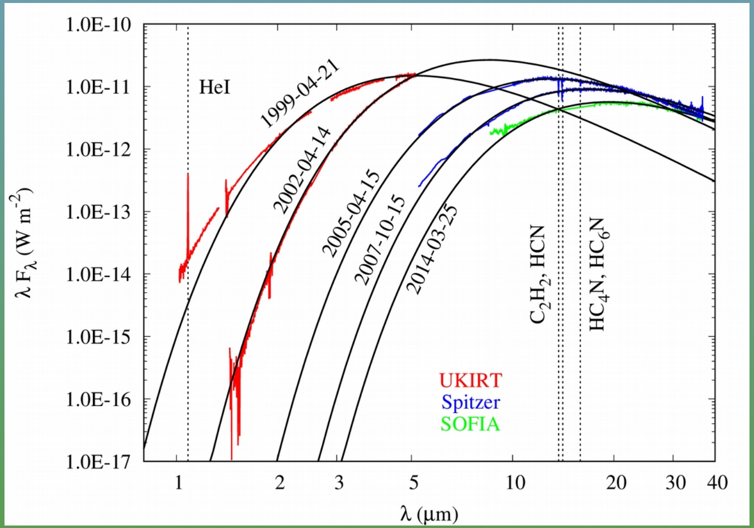
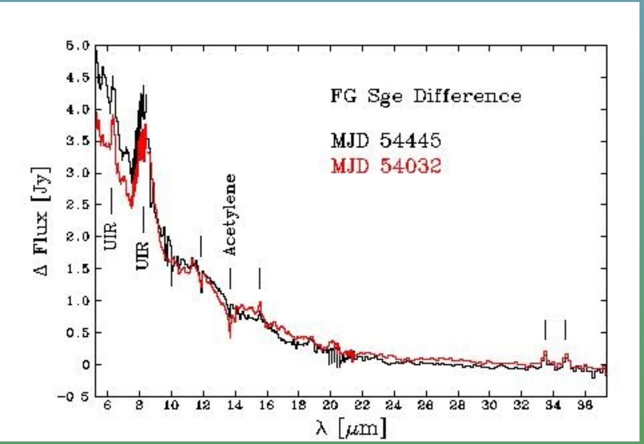
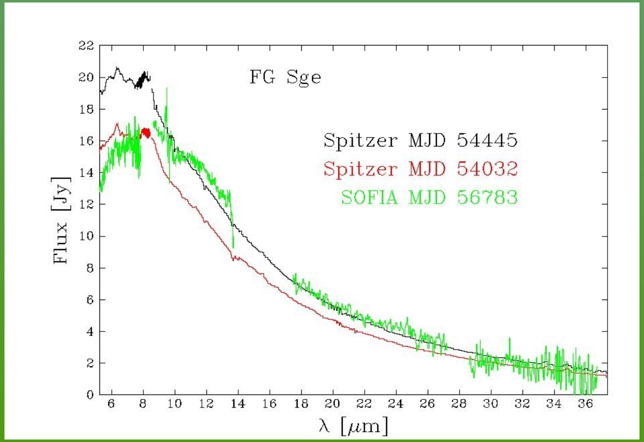


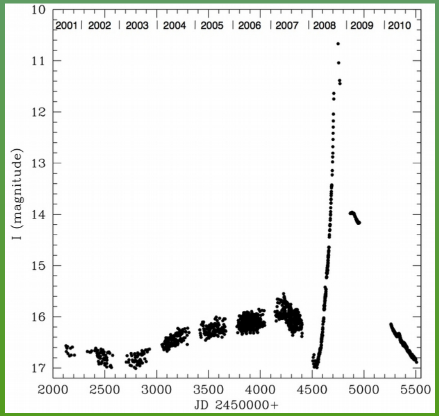




Sakurai (1996 BAG, above) shows plain carbon dust, but FG Sge (~1900 BAG, right) shows UIRs

Novae and related stellar transients

- Stellar mergers



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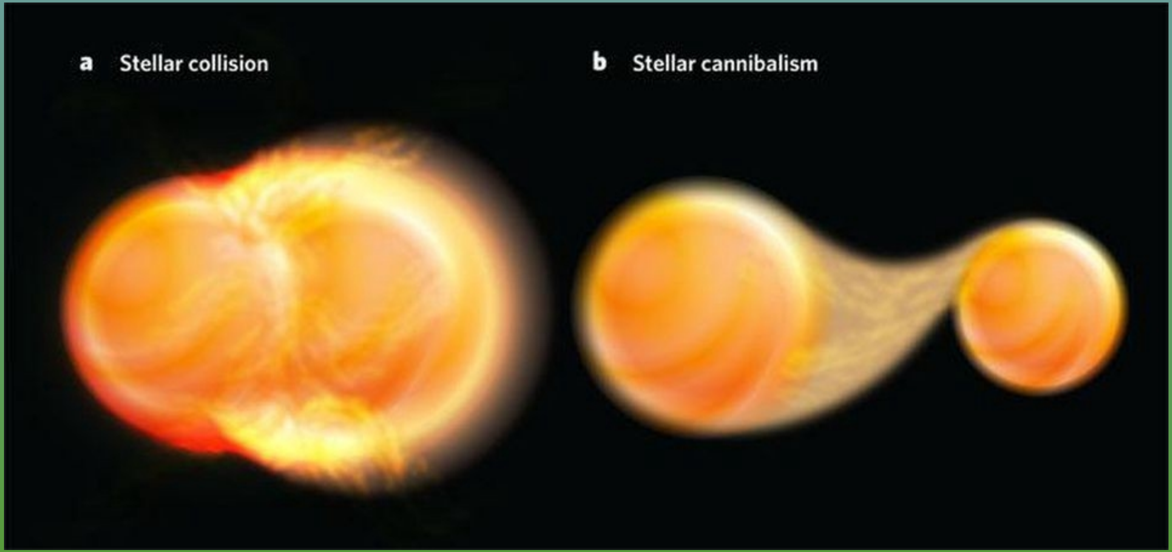
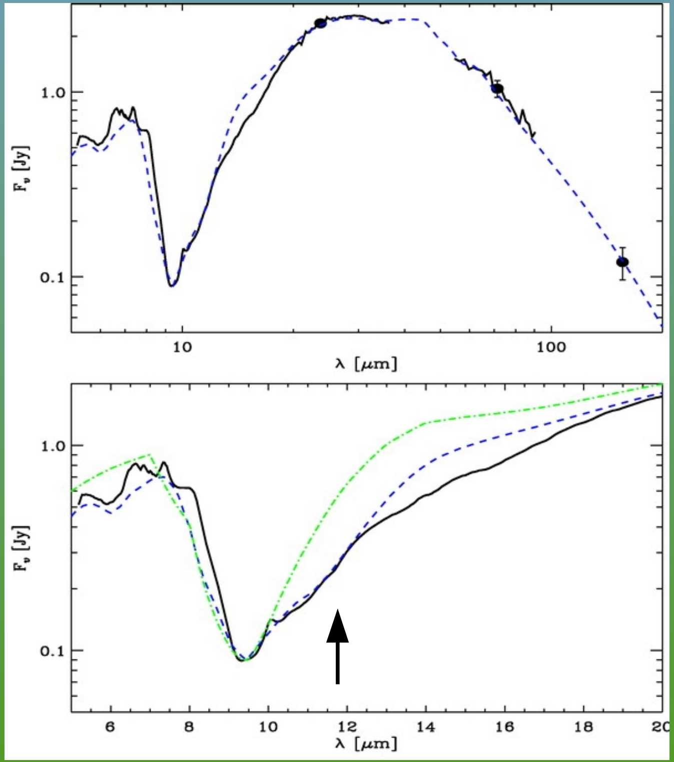


- Stellar mergers
- V838 Mon, V4332 Sgr, V1309 Sco etc.

Novae and related stellar transients

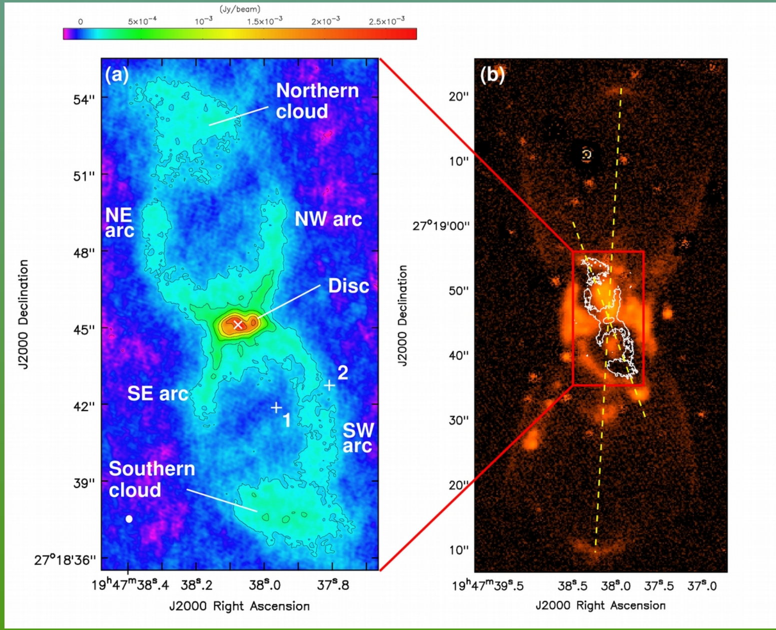


Left: Spitzer spectroscopy of the stellar merger V4332 Sgr (Banerjee+, 2007, ApJ, 666, L25)

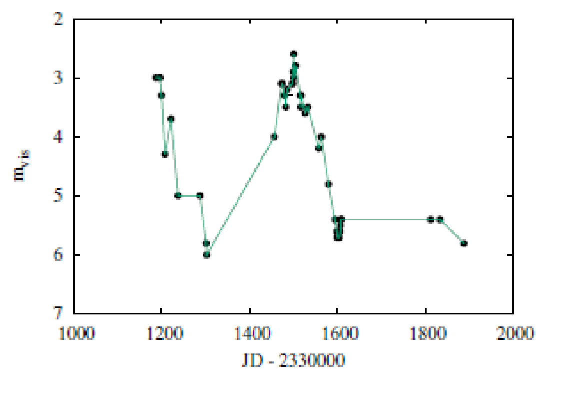
Arrows indicate Al_2O_3 feature

Novae and related stellar transients

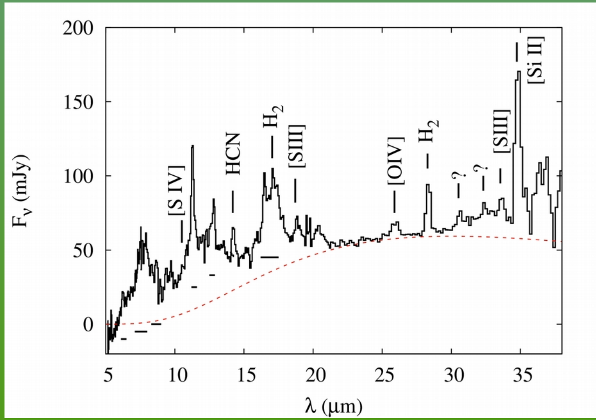
CKVul – a brown dwarf-WD merger in 1670. Complex dust distribution; rich in organic molecules. Below – ALMA image (Eyres+, 2020, MNRAS, 493, 1328).

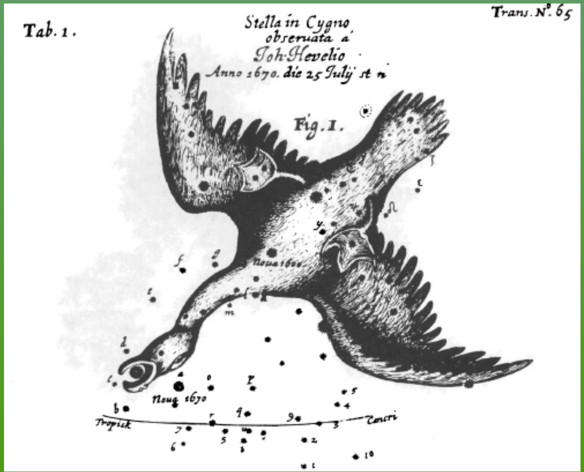


Right, 1670 light curve and Finding chart (Shara+, 1985, ApJ, 294, 271)



Below, Spitzer IRS Spectrum (Evans+, 2016, MNRAS, 457, 2871)





Novae and related stellar transients

For novae and related stellar transients,
SOFIA is providing:

- abundances – from nebular, fine structure and coronal lines;
- dust mineralogy – dust condensation sequences; dust composition and evolution; in novae, VLTPs and mergers;
- insight into the evolution of a VLTP.

Novae and related stellar transients

- To study the variable IR Universe we require *continuity* – to monitor variability of IR spectra over ≥ 10 years
- ⟶ synoptic coverage with same (or equivalent) instruments for long periods of time
- ⟶ spectroscopic capability at resolution ~500 – 1000 out to *at least* 30μm to reach several diagnostic emission lines and silicate mineralogical features longward of 28μm (to give edge over JWST)
- Imaging – with filters having $\lambda/\Delta\lambda \sim 10$, out to at least 30μm – to determine abundance gradients

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