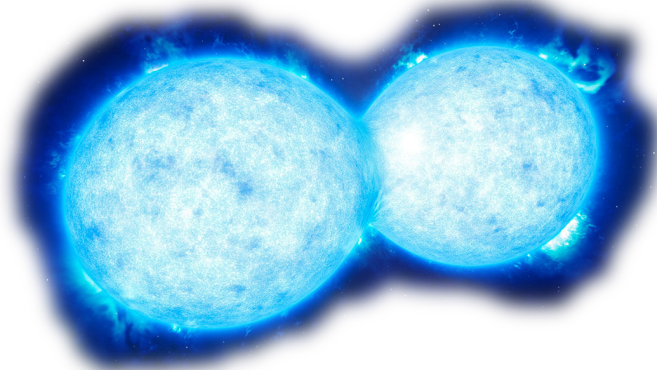


Observing remnants of **red novae**: how binaries merge?



Tomek Kamiński
SMA fellow

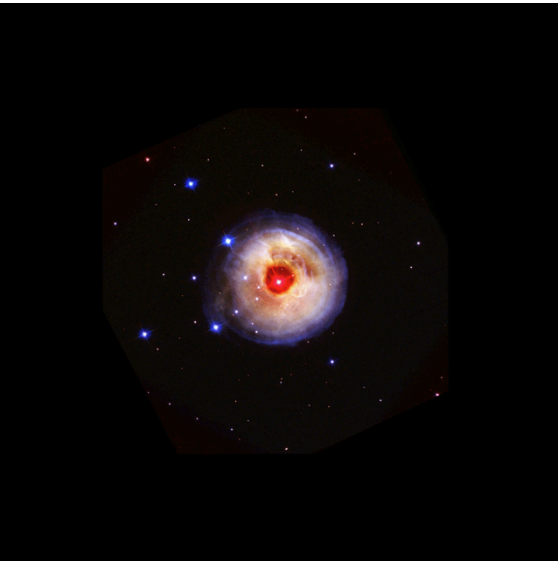
Harvard-Smithsonian Center for Astrophysics

and

R. Tylenda, K. Menten, N. Patel, K. Young, W. Steffen et al.



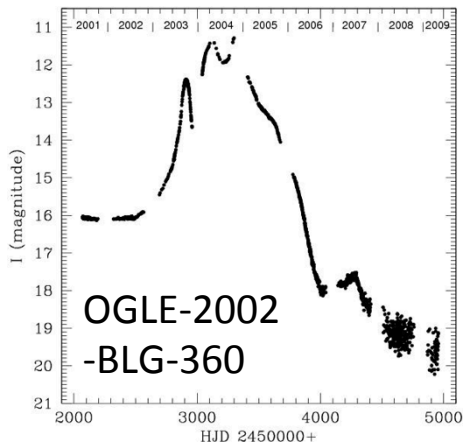
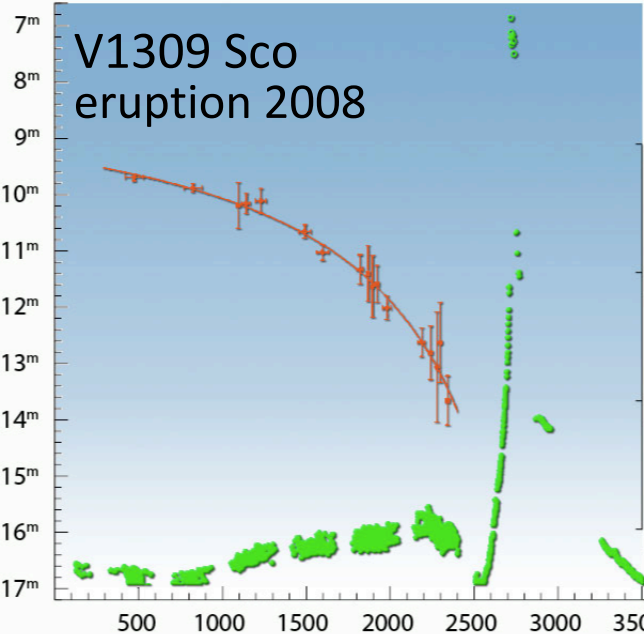
V838 Mon
light echo
2002-2006
HST Bond et al.



V4332 Sgr
eruption 1994

Galactic
red novae
a.k.a red transients

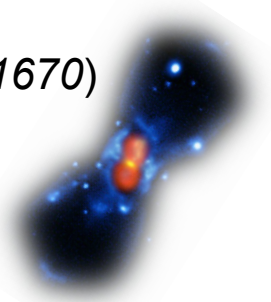
V838 Mon
eruption: 2002



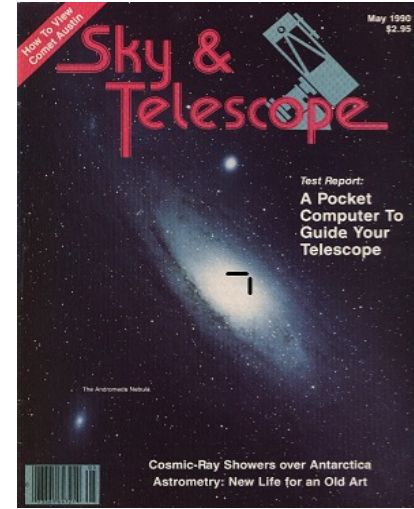
eruption 2003-2005



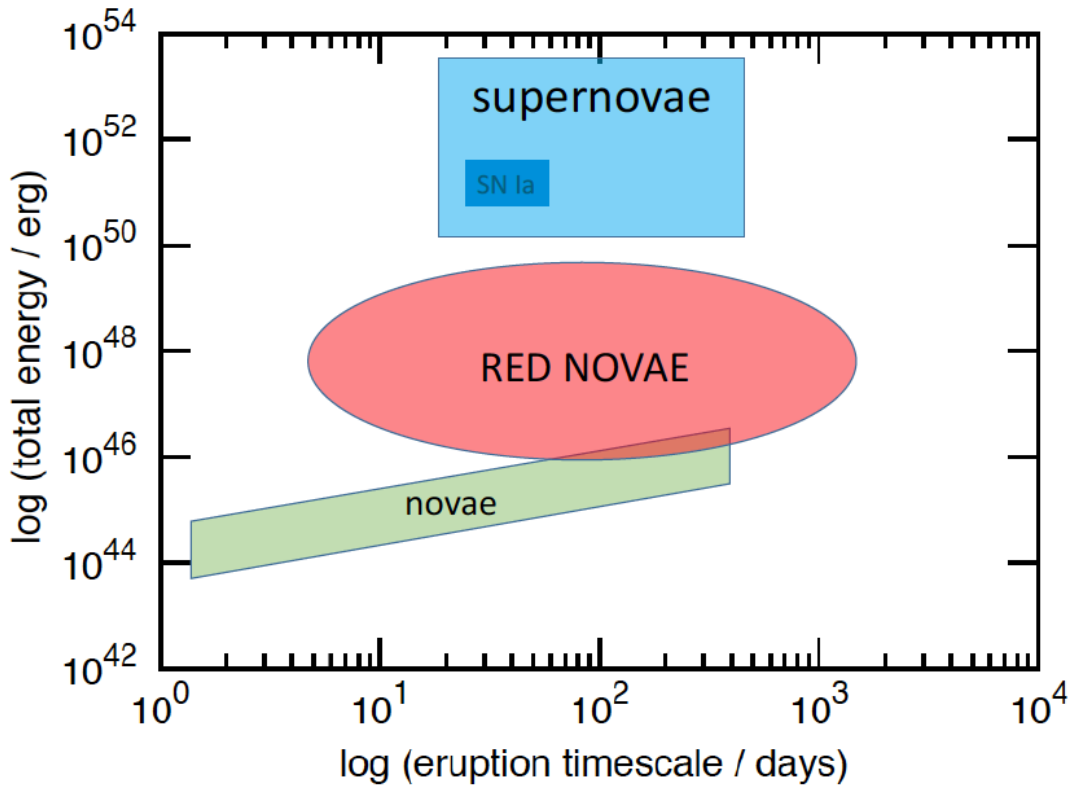
CK Vul
(Nova 1670)



Red novae can be extragalactic



M31-RV
(Red Variable)
eruption: 1989



based on diagram of Kashi & Soker

extragalactic **red novae**:

M85 OT2006
NGC300 OT2008
PTF10acbp
NGC 4490-OT2011
M31 LRN 2015
M101 OT2015-1
and more !

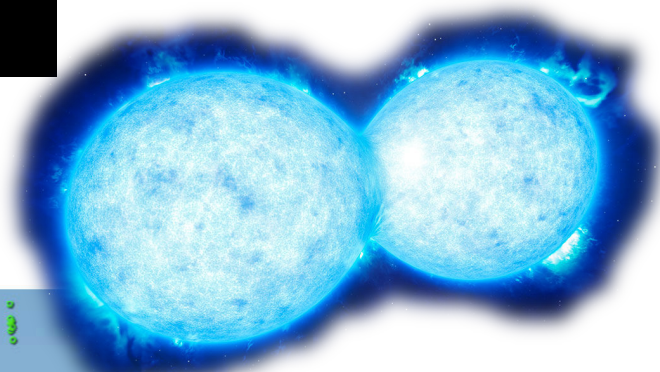
too weak to be observed after their
outbursts

Soker & Tytenda 2003
Tytenda & Soker 2006
Tytenda+ 2011

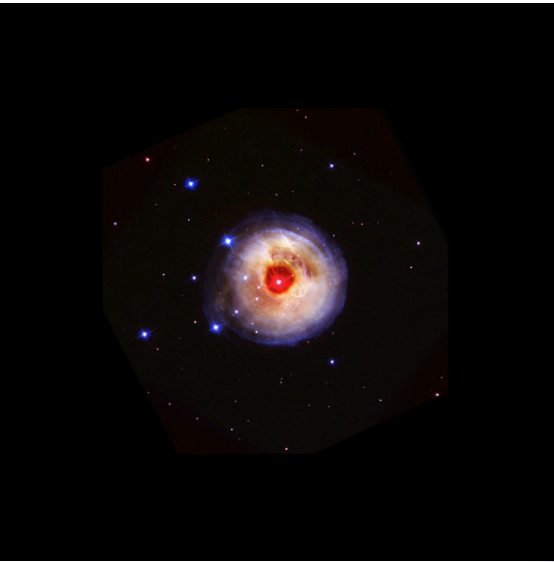
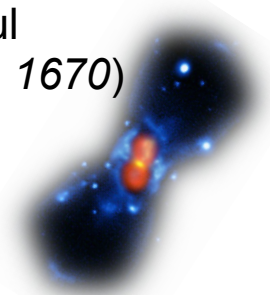
Red novae are stellar mergers



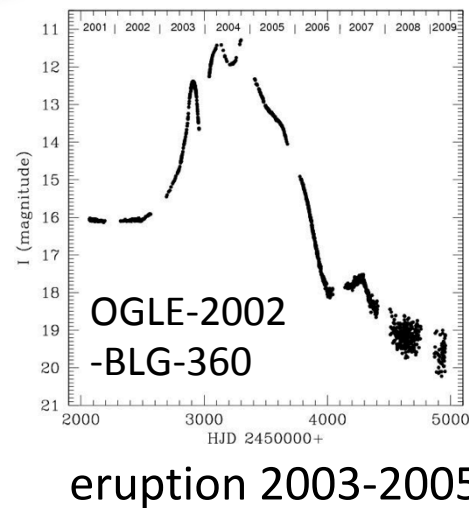
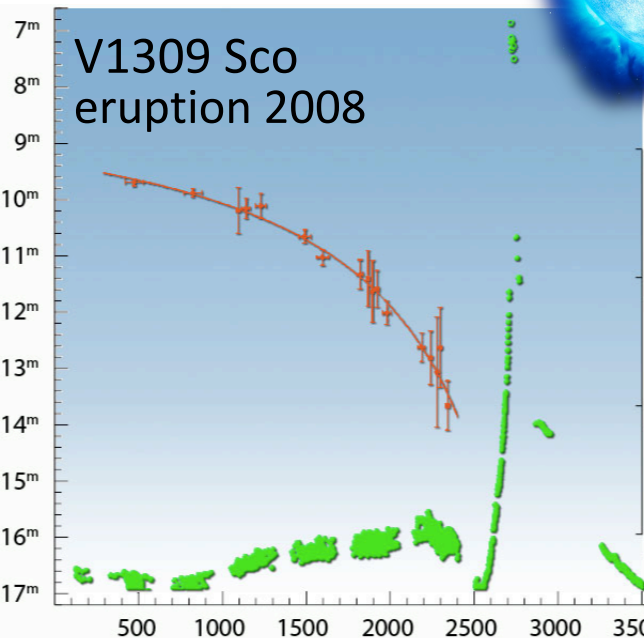
V4332 Sgr
eruption 1994



CK Vul
(Nova 1670)

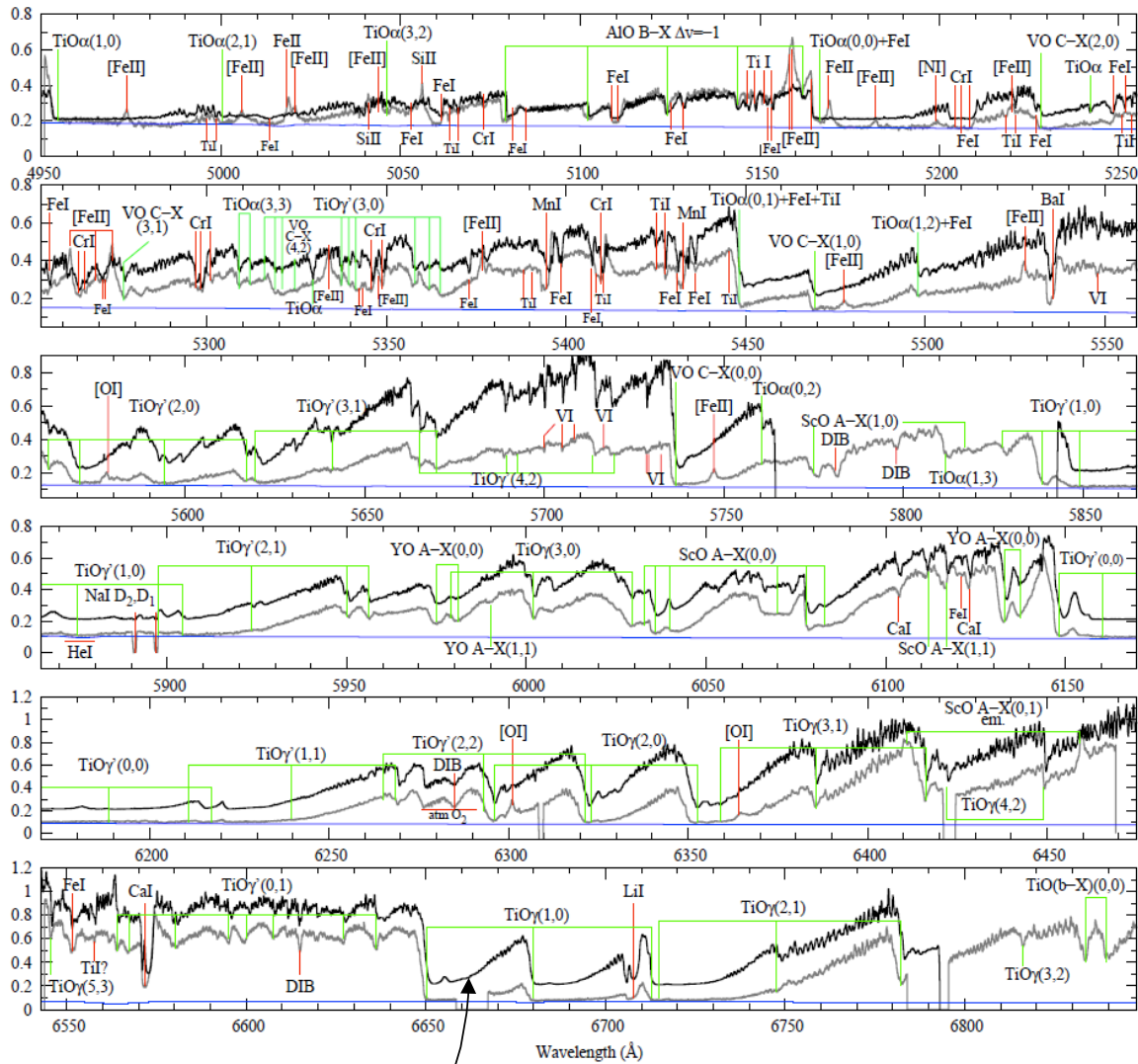


V838 Mon
eruption: 2002



merger remnant in V838 Mon

optical studies: 2005 vs 2009



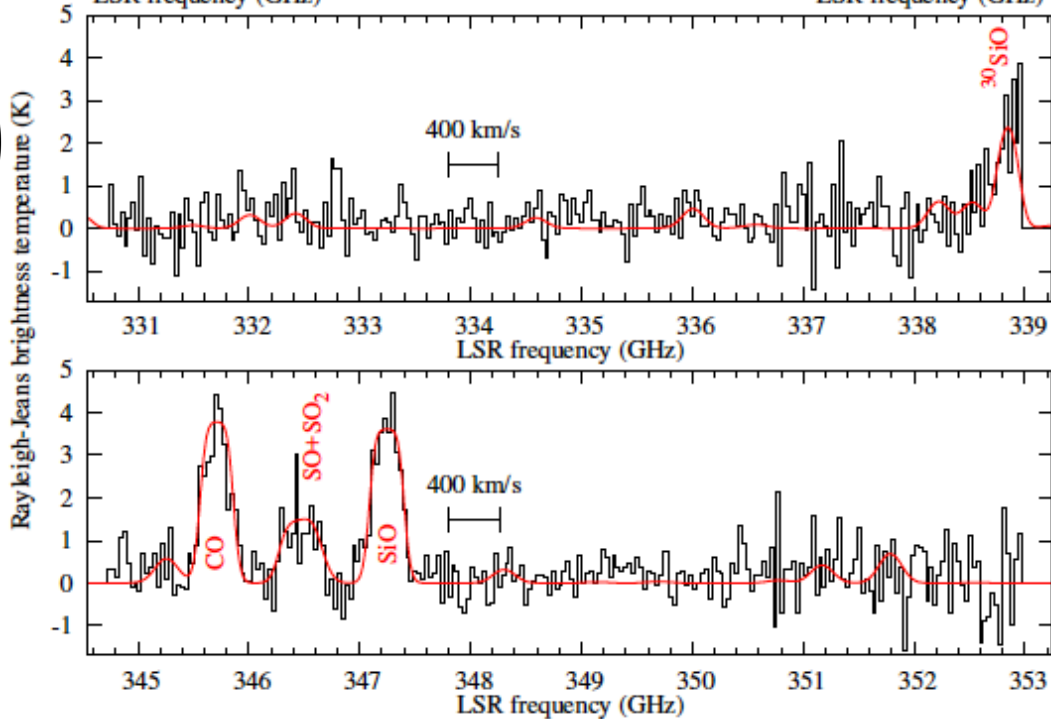
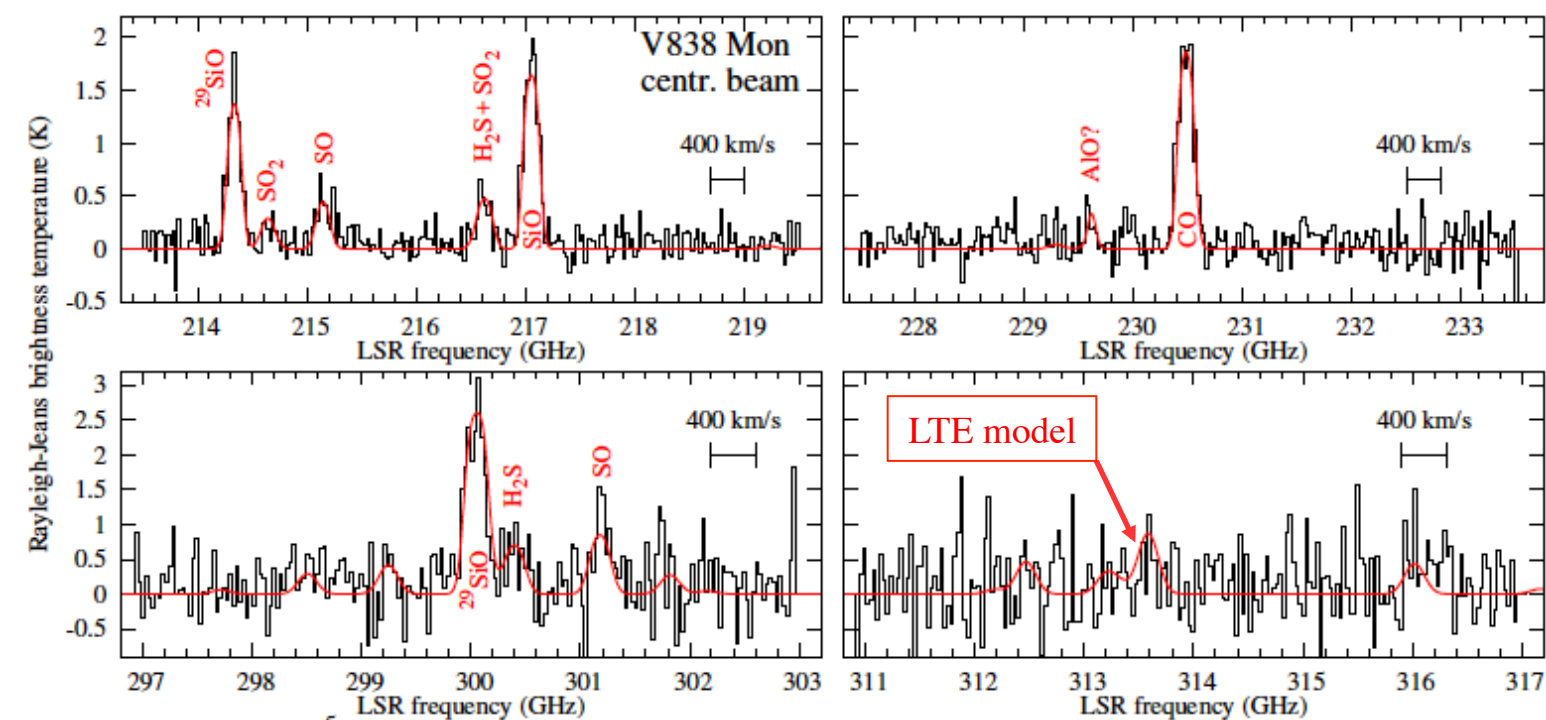
V838 Mon
eruption: 2002

M-type giant
+ cool
circumstellar
gas

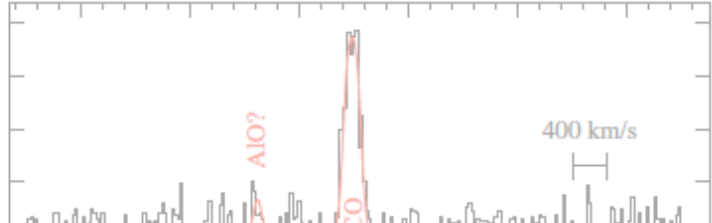
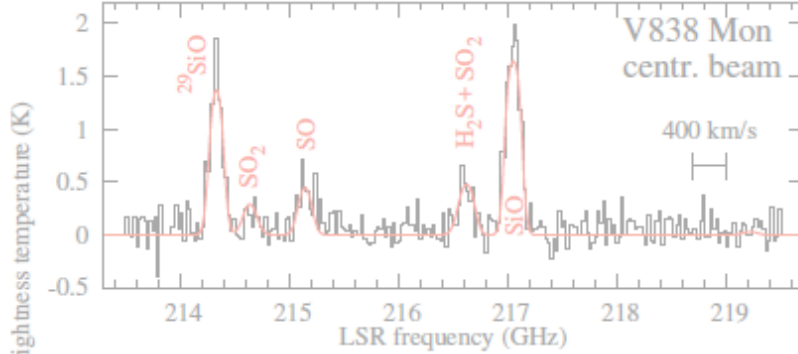
remarkably strong molecular
bands in absorption

Kamiński+2009
Tylenda+2009
Tylenda+2011





**SWARM (3 quadrants)
spectrum of V838 Mon
from 2016**



SWARM spectrum of V838 Mon

O-rich gas: CO, SiO(+iso), SO, SO₂, H₂S, AIO

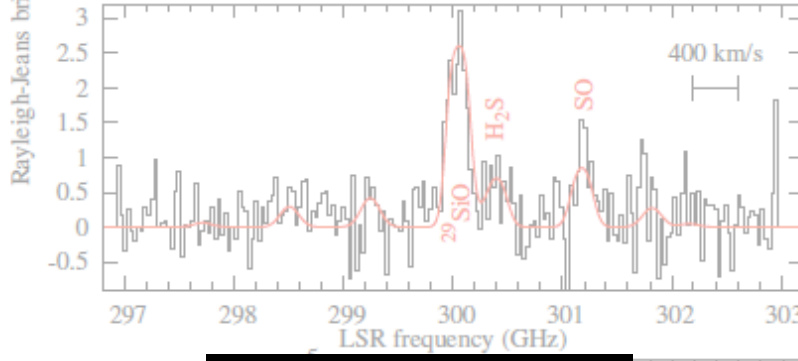
$T_{\text{ex}} = 70\text{--}210$ K (LTE)

column densities (\Rightarrow relative abundances)

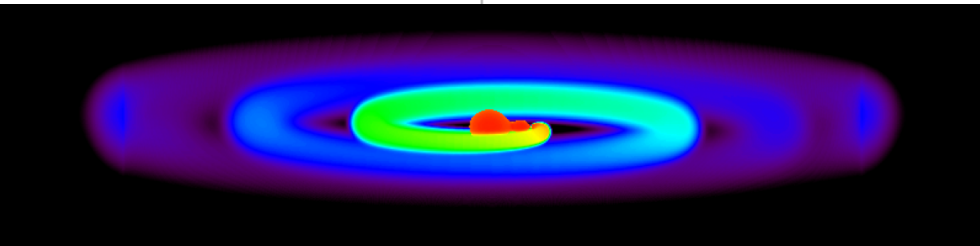
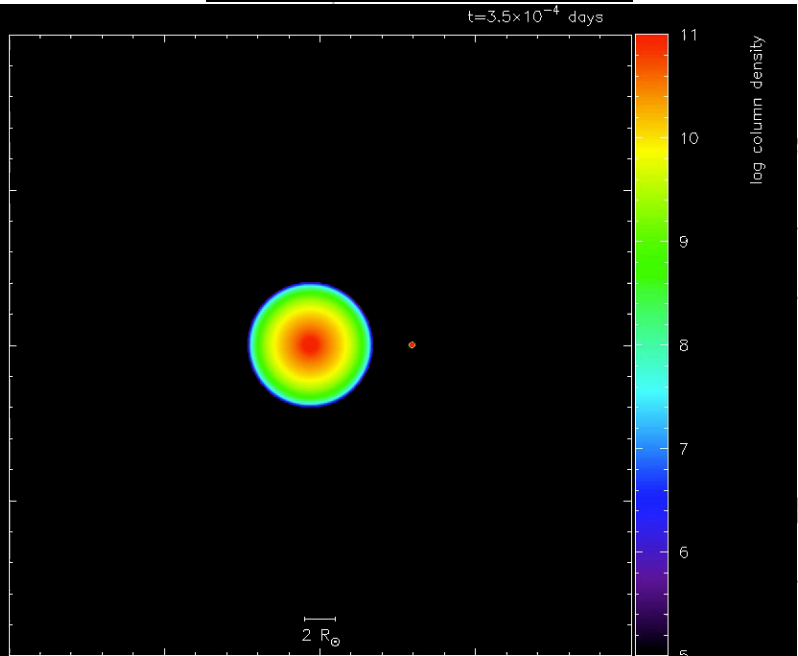
total mass $0.05 M_{\odot}$ (at canonical H₂/CO)
or 1% of the mass of the merged system
(progenitor binary of $8 M_{\odot}$ and $0.3 M_{\odot}$)

lost just before or after the 2002 explosion?

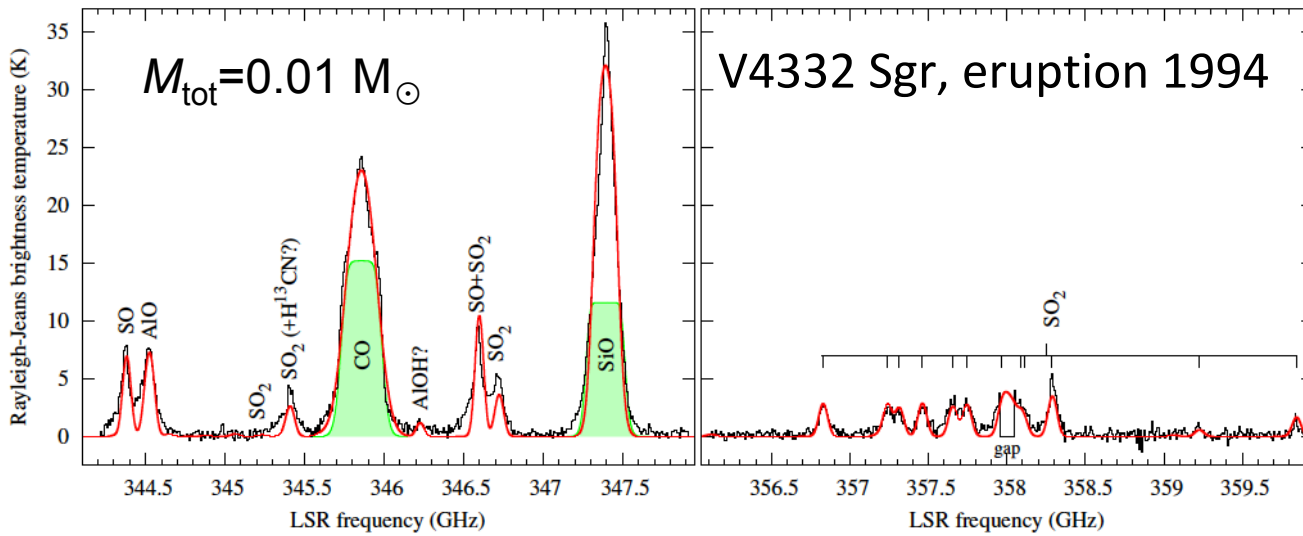
$E_{\text{kin}} = 10^{46}$ erg



Nandez et al. 2013

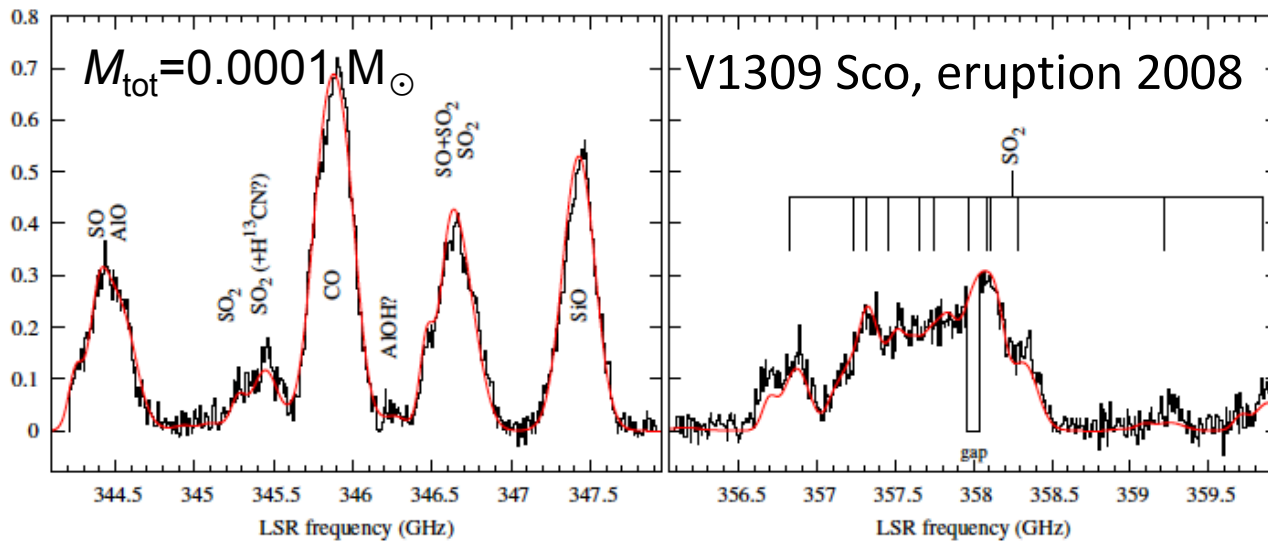


Kamiński et al. 2018



narrow-band observations with ALMA of two other Galactic red novae

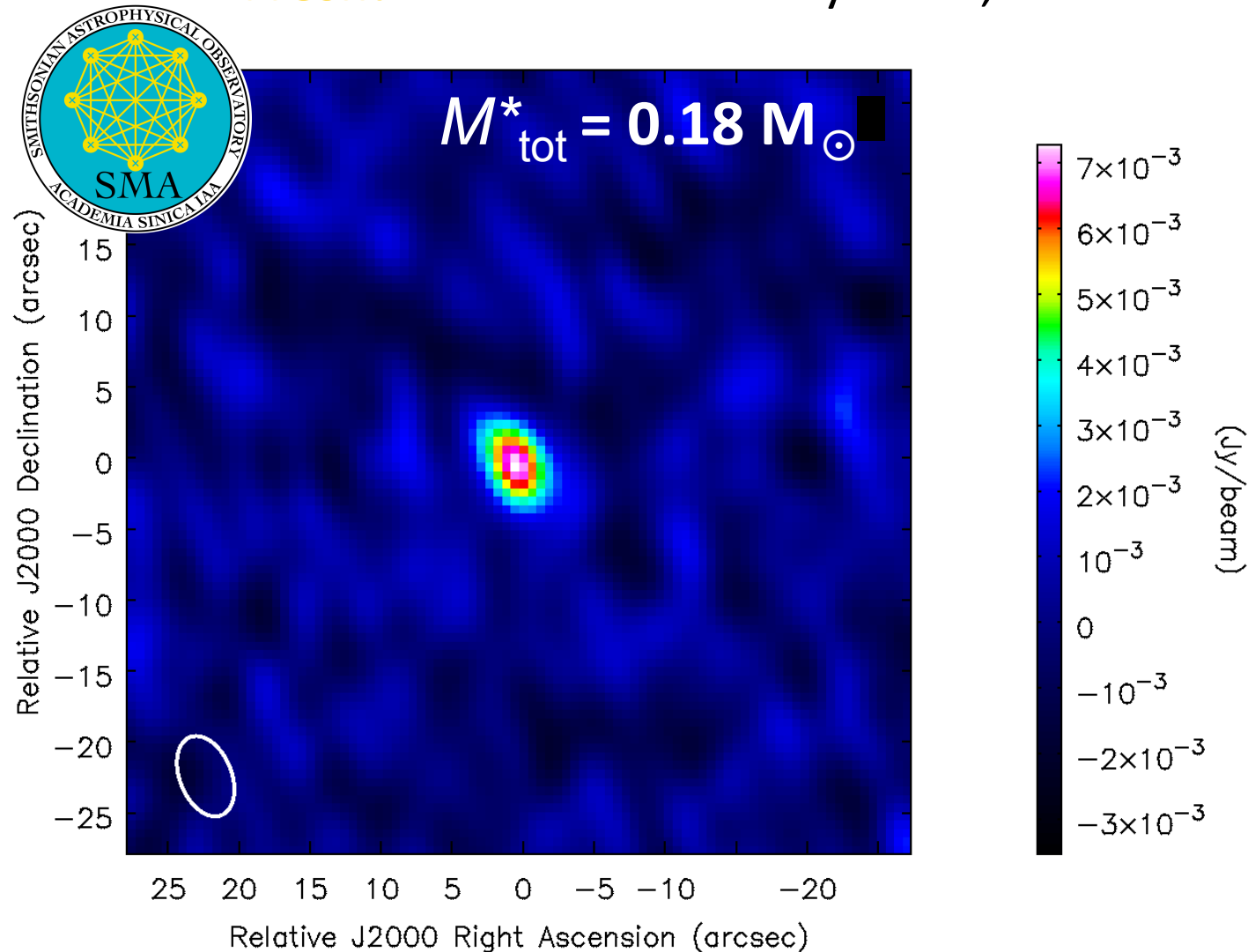
- ➔ similar gas composition
- ➔ and physical conditions as in V838 Mon



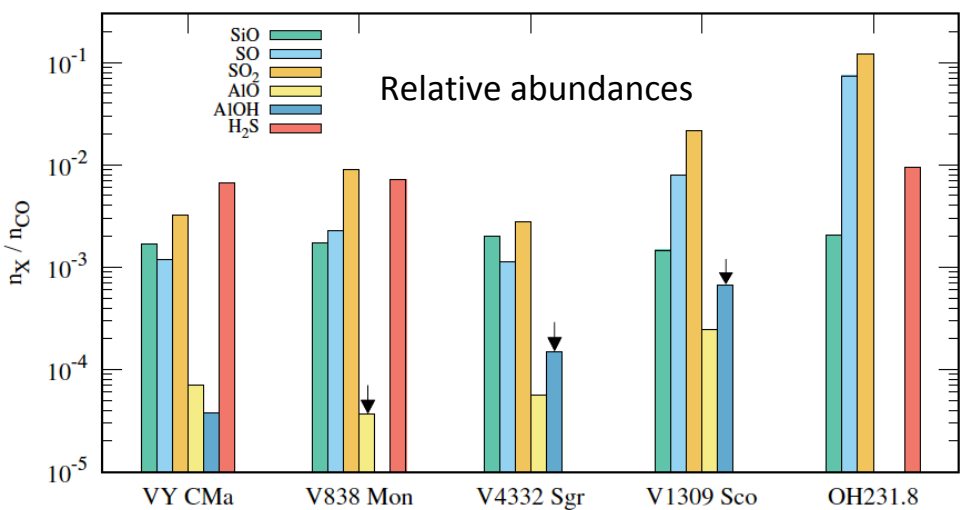
First mm detection of **BLG-360**

First mm continuum detection in a young **red nova**

Fresh! SMA filler from July 2 & 7, 2018



*total mass:
@ 8.2 kpc
@ 100 K
@ ISM grains



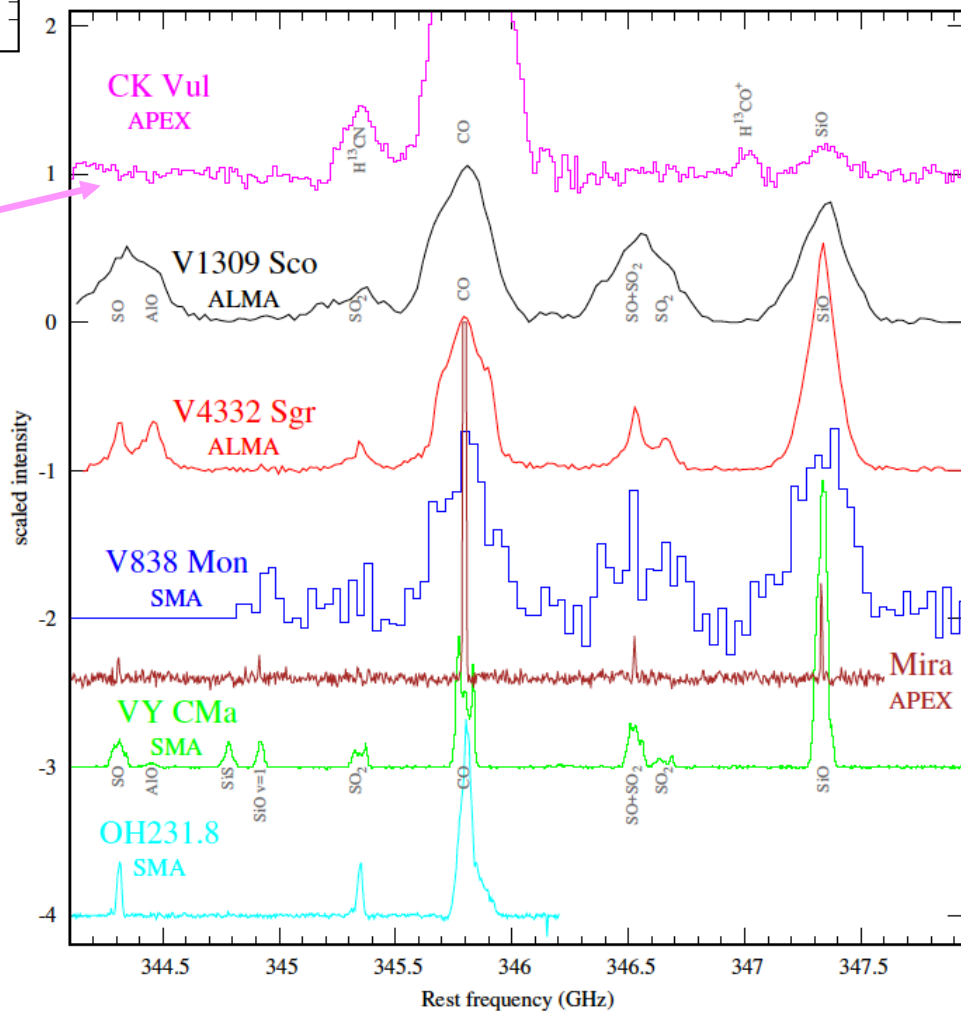
submm spectra of red novae are similar to spectra of O-rich evolved stars

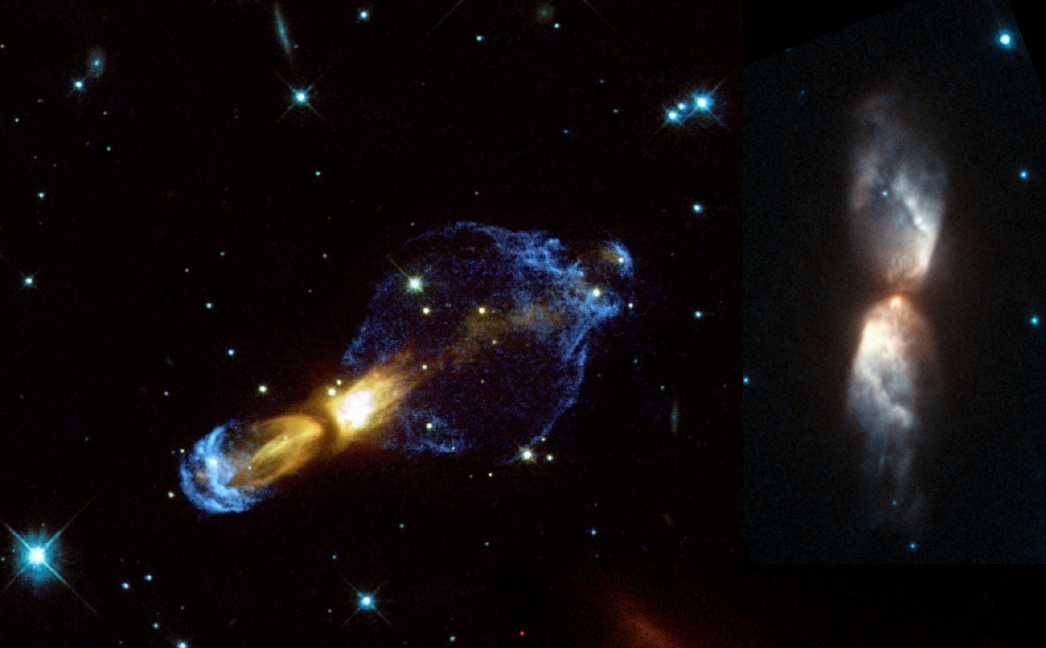
- ➔ similar molecules abundances
- ➔ similar excitation conditions

CK Vul is the only C-rich red nova

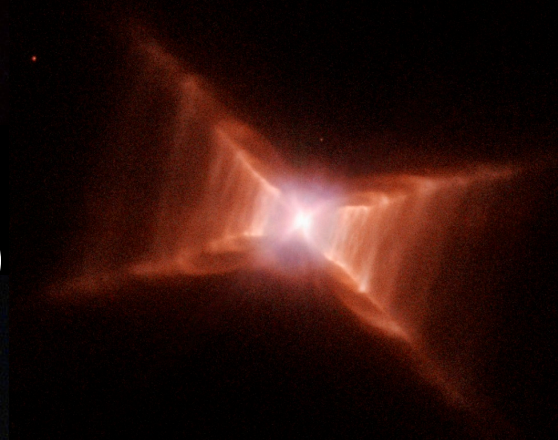
red novae

- AGB star →
- red supergiant →
- pre-planetary nebula →

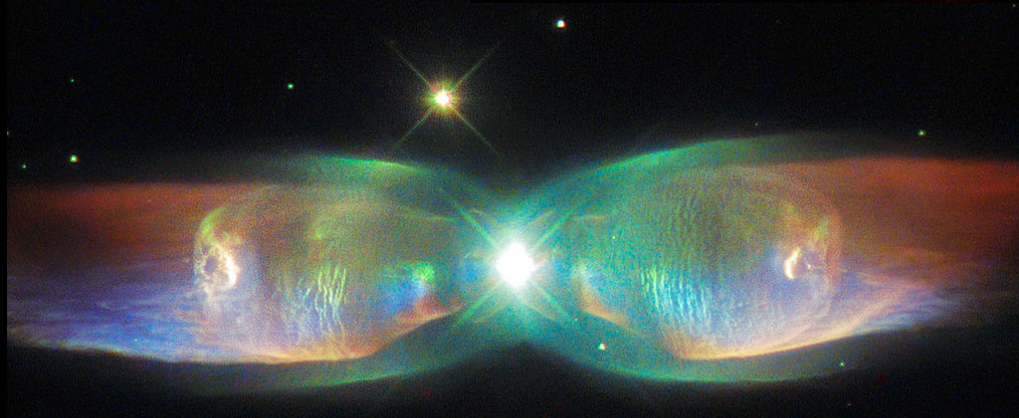




$E_{kin} = 10^{44-47}$ erg
(as in red novae)

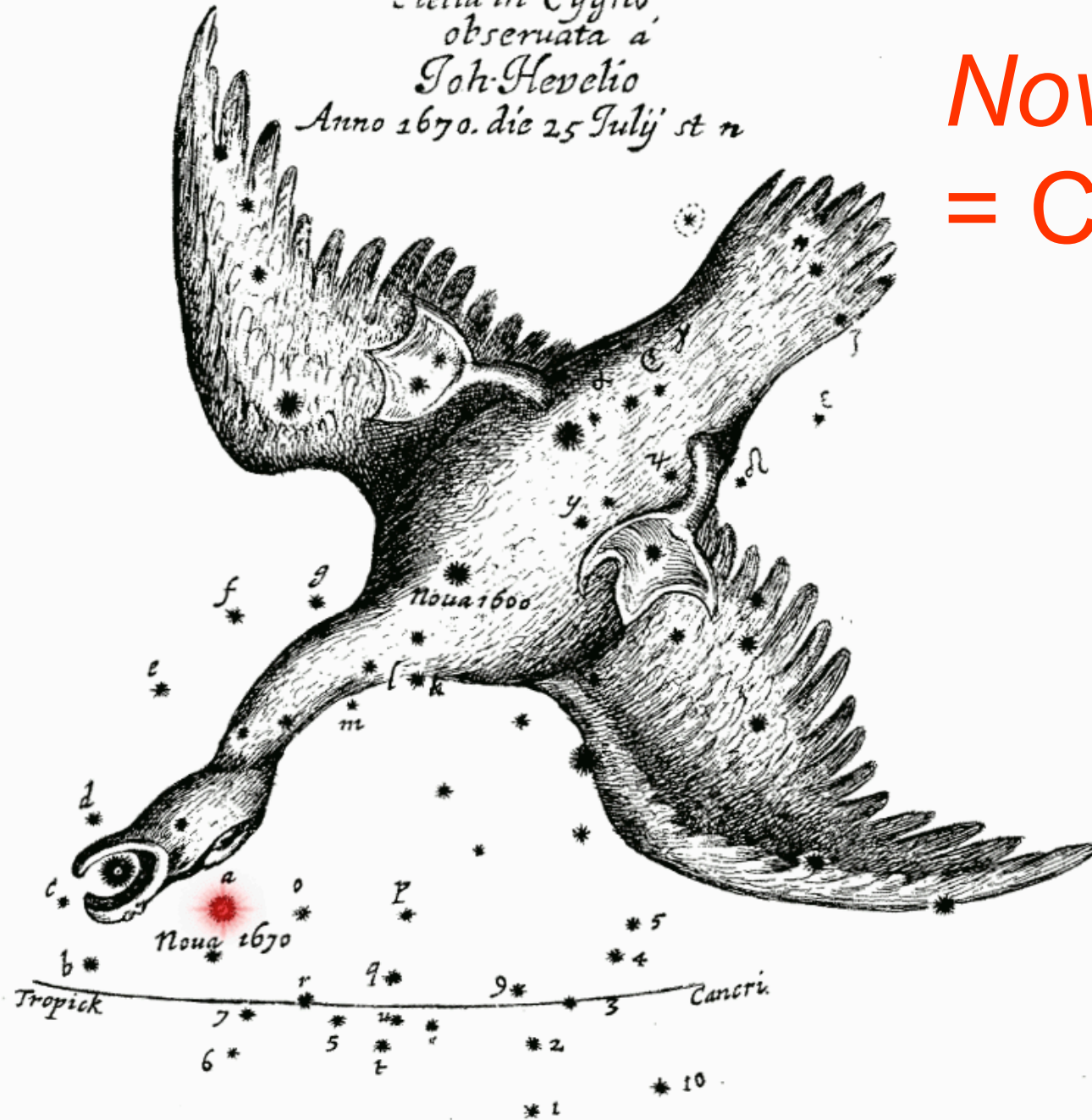


some planetary nebulae and
pre-planetary nebulae can be
stellar merger products



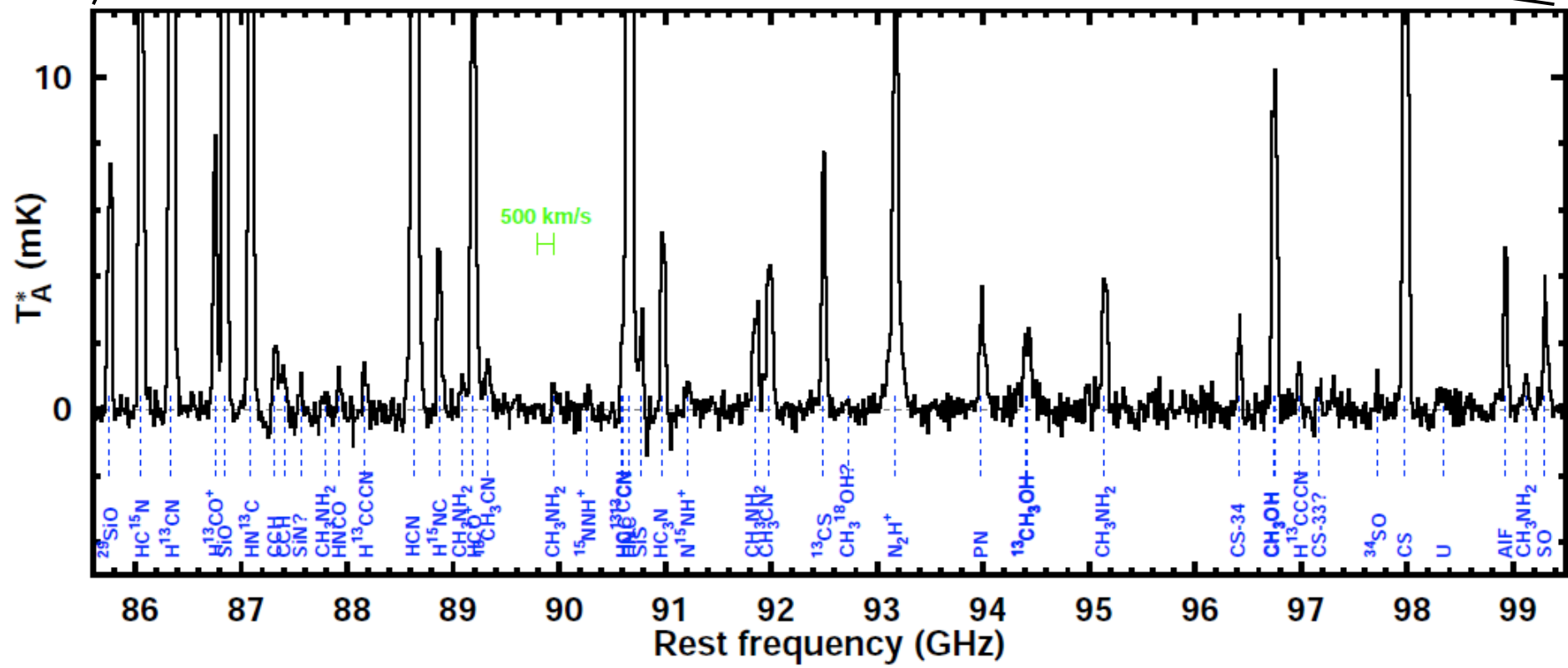
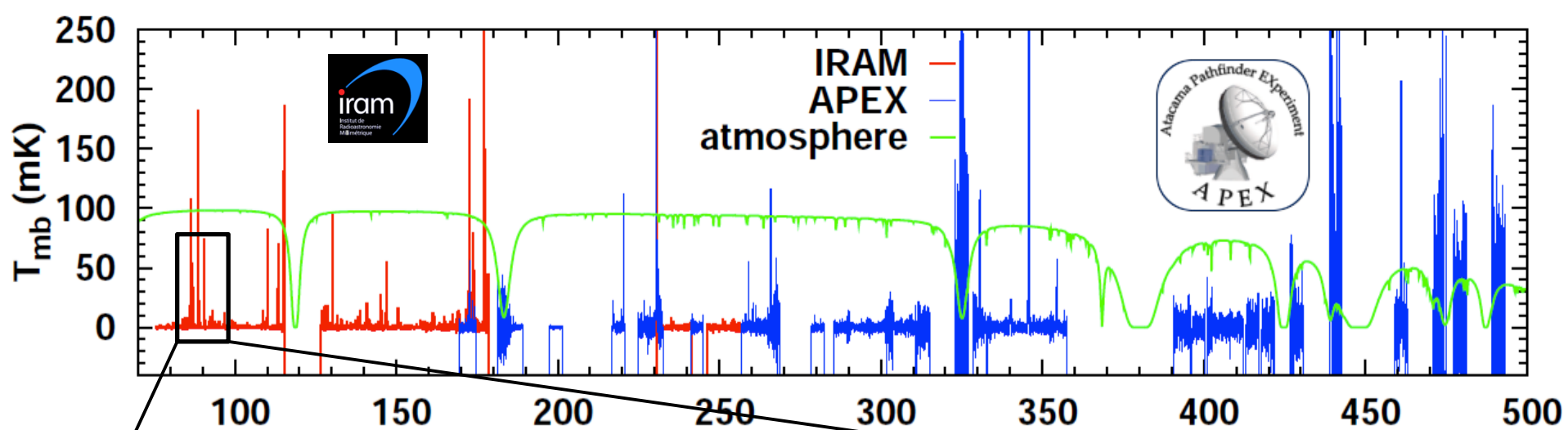
Stella in Cygno,
observata a
Joh. Hevelio
Anno 1670. die 25 Julij st n

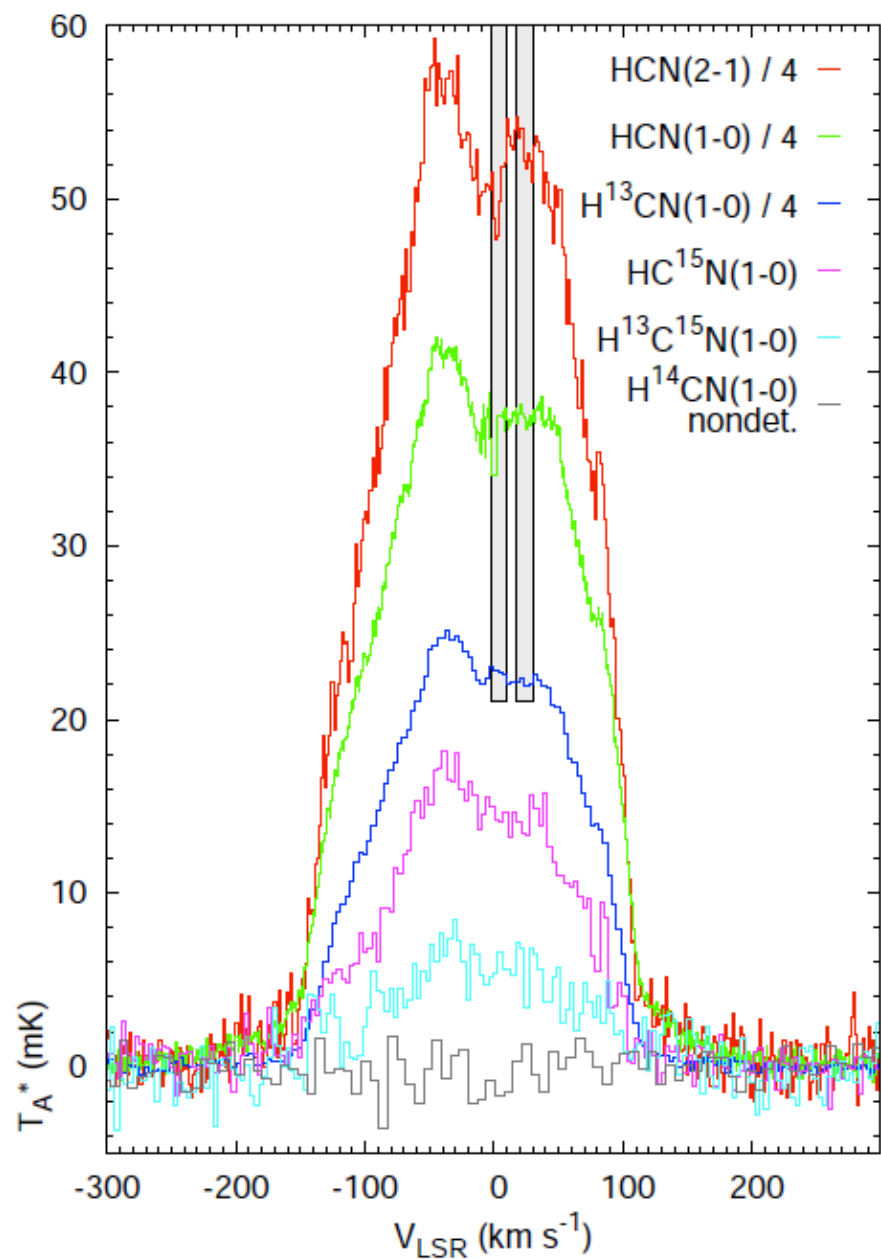
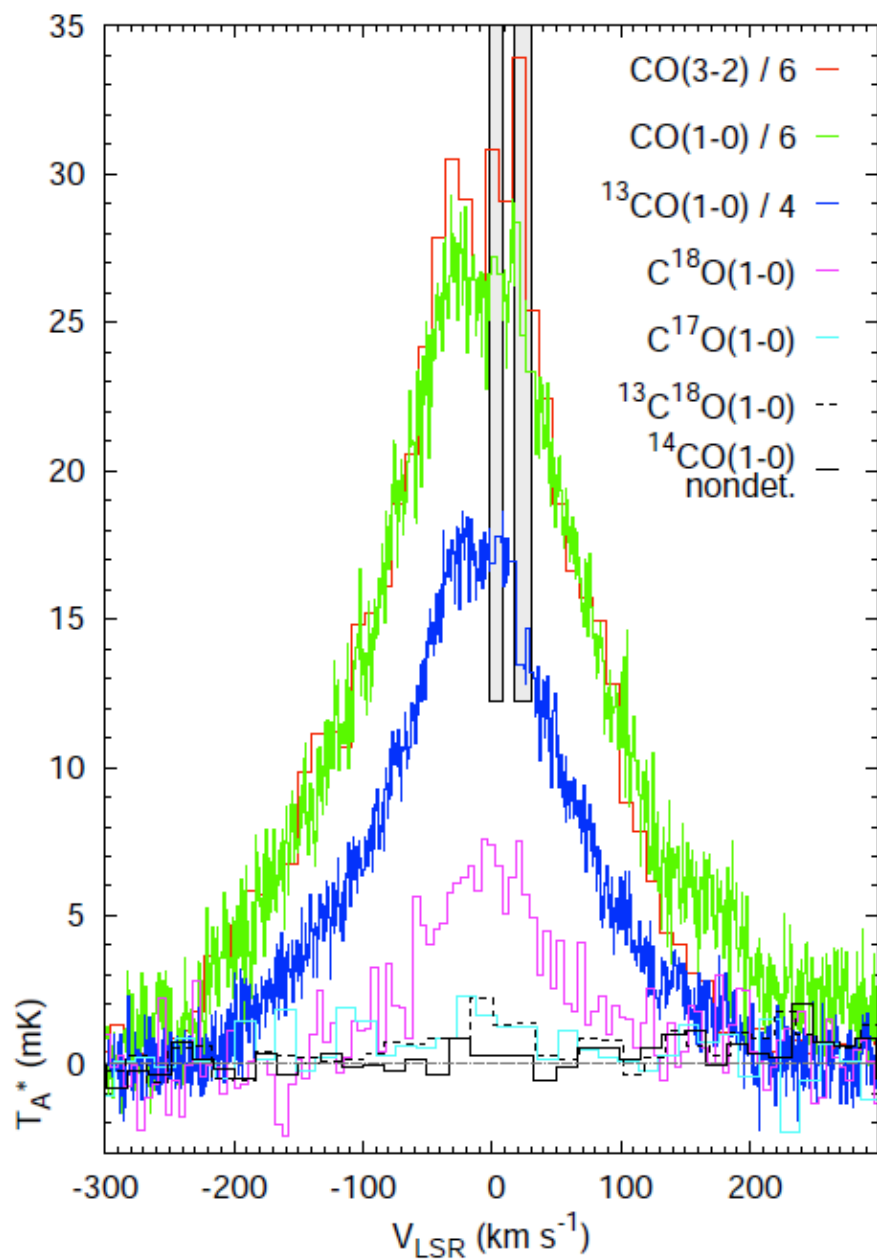
Nova 1670 = CK Vul



Johannes Hevelius







Most peculiar isotopic composition (single dish)



CK Vul	Solar
$^{12}\text{C}/^{13}\text{C} = 3.8 \pm 1.0$	89.3
$^{13}\text{C}/^{14}\text{C} > 141$	
$^{14}\text{N}/^{15}\text{N} = 20 \pm 10$	441
$^{16}\text{O}/^{18}\text{O} = 36 \pm 14$	498.8
$^{18}\text{O}/^{17}\text{O} \gtrsim 5$	5.4
$^{27}\text{Al}/^{26}\text{Al} = 6.0 \pm 0.9$	
$^{28}\text{Si}/^{29}\text{Si} = 6.7 \pm 0.4$	19.7
$^{29}\text{Si}/^{30}\text{Si} = 1.0 \pm 0.1$	0.7
$^{32}\text{S}/^{34}\text{S} = 14 \pm 3$	22.5
$^{32}\text{S}/^{33}\text{S} > 34$	126.6



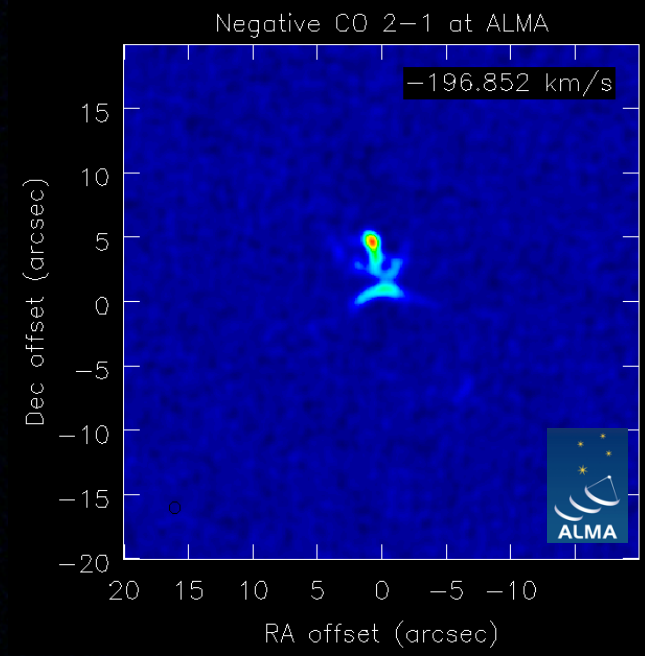
CK Vul



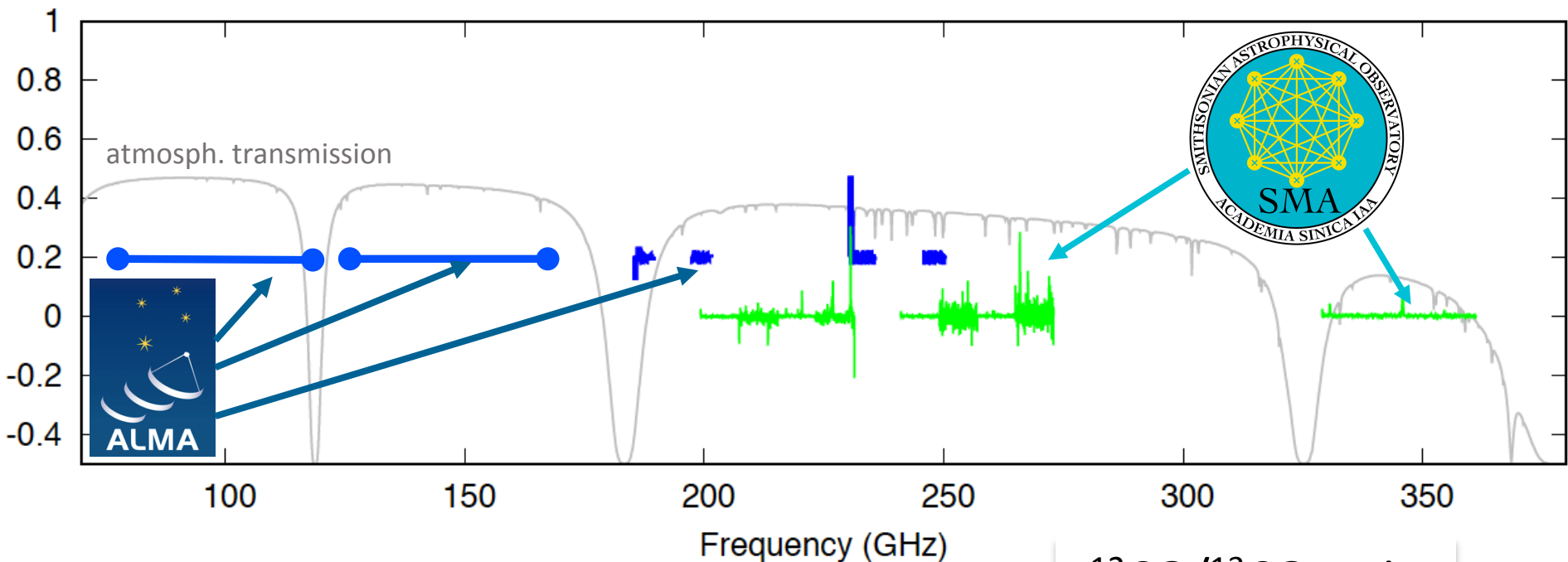
plasma (opt.)

dust (SMA)

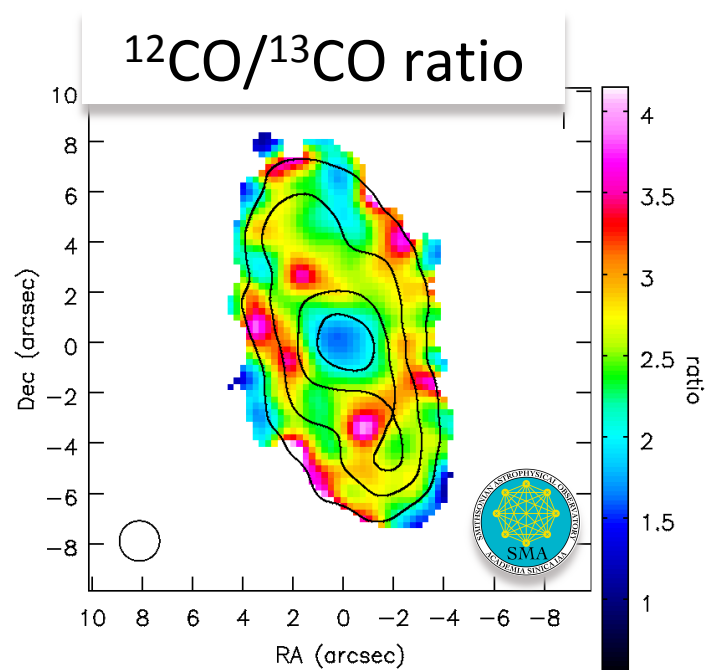
molecules (SMA)



Imaging line survey of CK Vul at ALMA & SMA (ongoing)



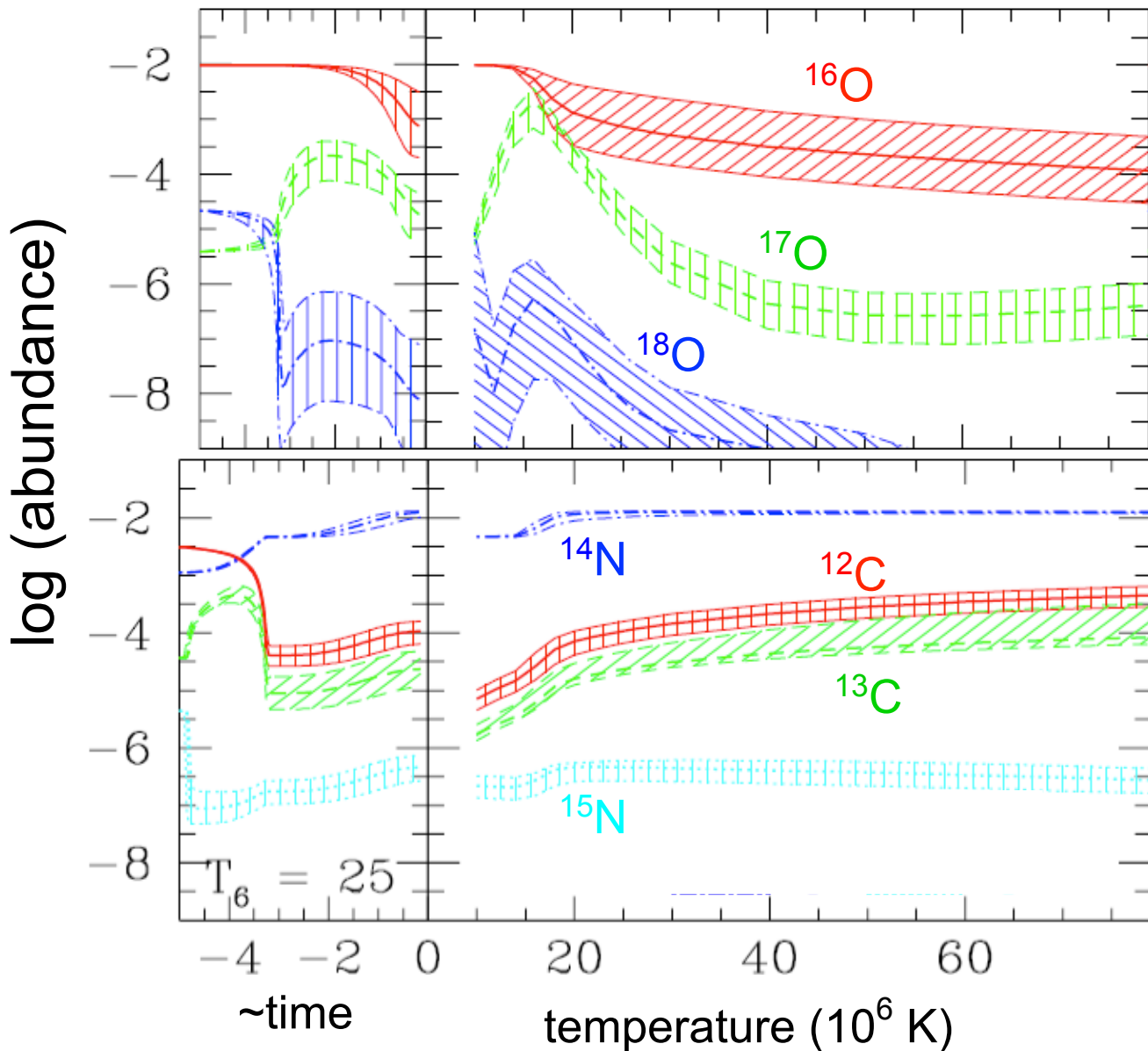
SMA data from 2018 →





Thank you

CK Vul's progenitor: CNO processing



CK Vul:

$$^{16}\text{O}/^{17}\text{O} \approx 100$$

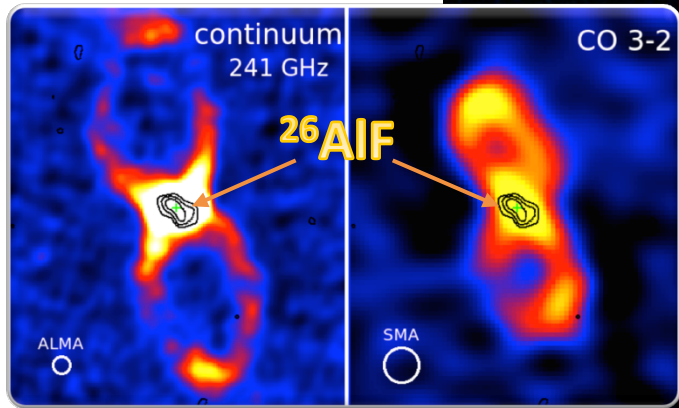
$$^{16}\text{O}/^{18}\text{O} \approx 30$$

$$^{12}\text{C}/^{13}\text{C} = 3-4 \quad \checkmark$$

$$^{14}\text{N}/^{15}\text{N} \approx 17$$

plots from Arnould+ 1999

☞ hot CNO burning and incomplete He burning

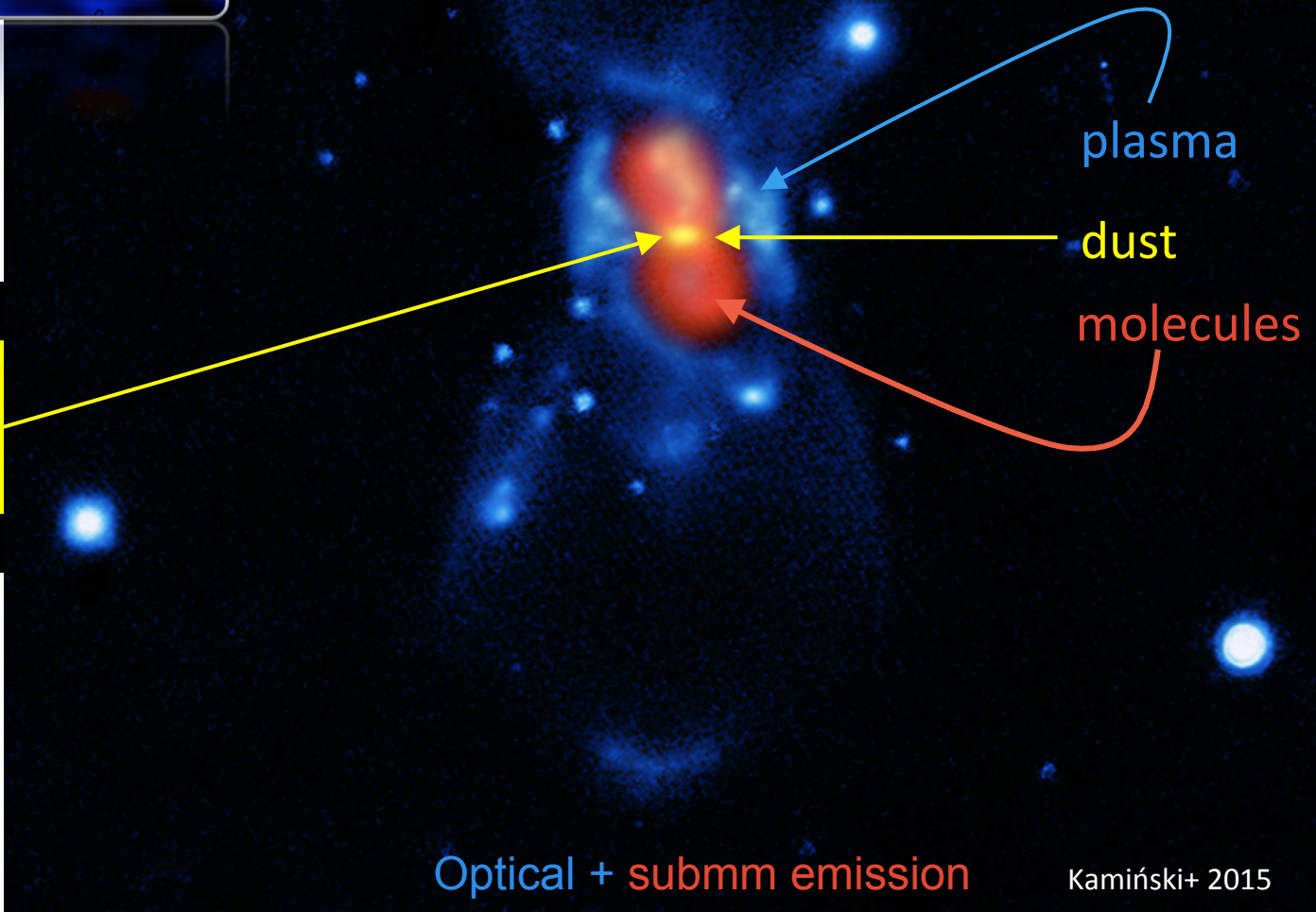


CAUTION



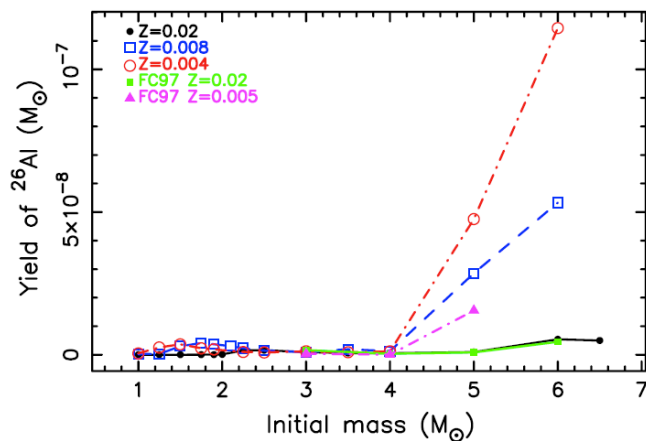
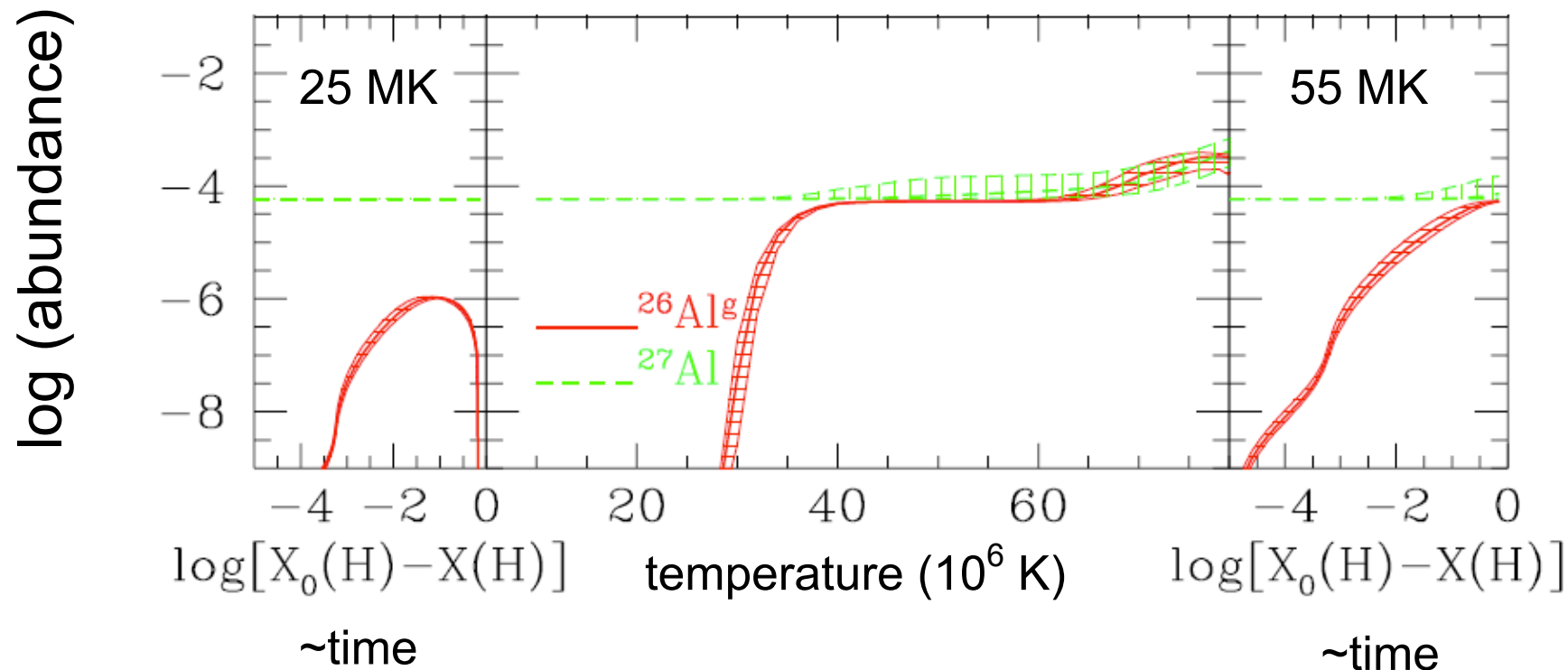
RADIOACTIVE

²⁶AlF



MgAl chain

CK Vul: $^{27}\text{Al}/^{26}\text{Al} \approx 6$



plots from Arnould+ 1999

AGB models
Karakas & Latanzio 2003

COMPTEL map of the Galactic emission from ^{26}Al decays

