# Observing stellar mergers


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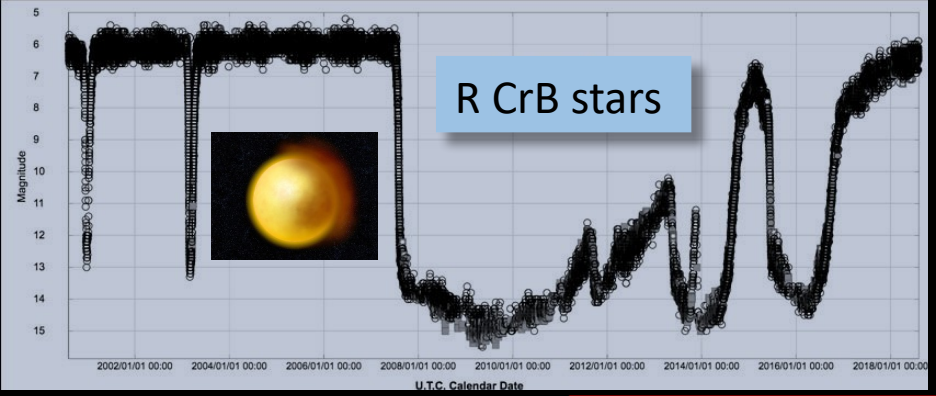
M. Schmidt, K. Menten, et al.

PTA Toruń
14 Sept. 2023





the great eruption of $\eta$ Car

some pre-planetary nebulae

(Boomerang)

products of mergers of noncompact stars are common

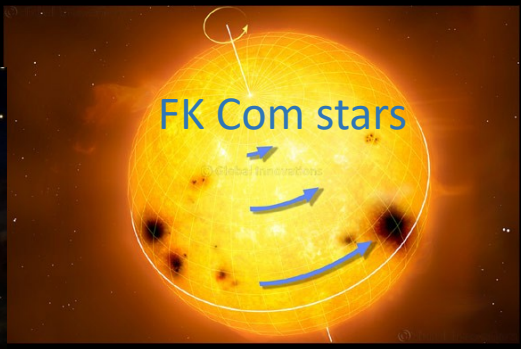
HD 45166

★ chemically peculiar stars

★ R –type stars


anomalous Cepheids

protostars OMC1 source *I*




the progenitor of SN 1987A

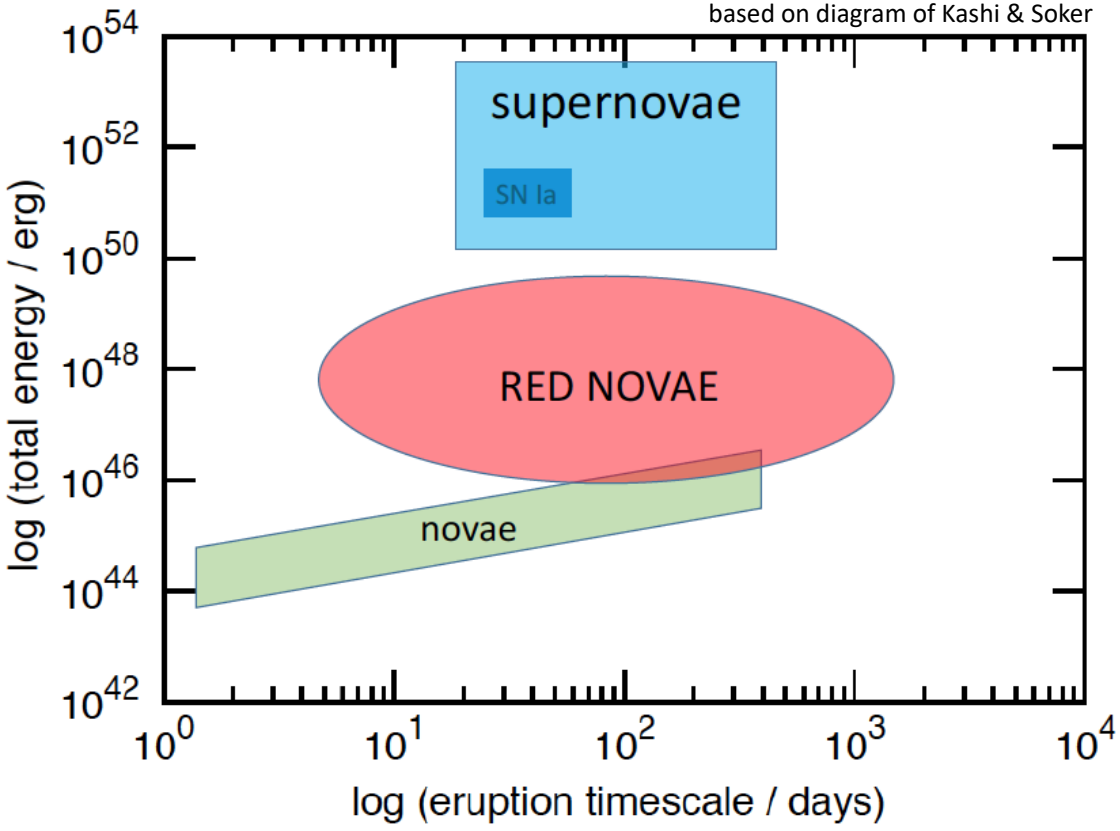
★ some blue strugglers

★ hot sub-dwarfs

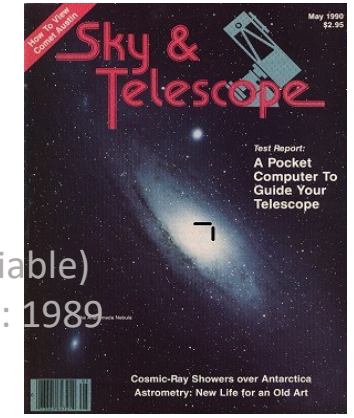
★ Be & B[e] stars

# Red novae fame goes extragalactic!

based on diagram of Kashi & Soker




M31-RV
(Red Variable)
eruption: 1989

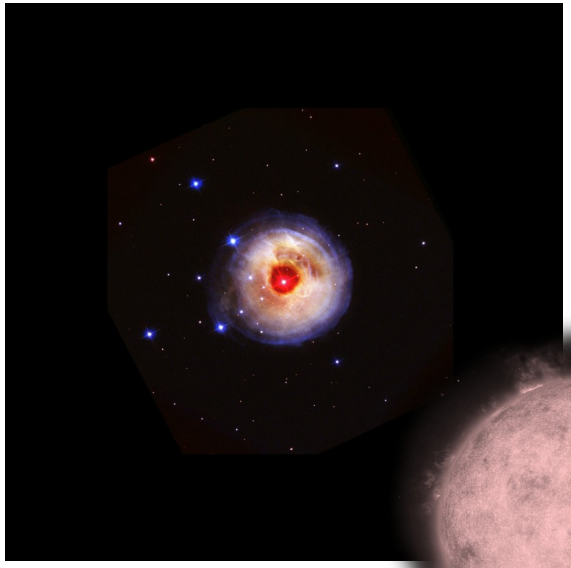


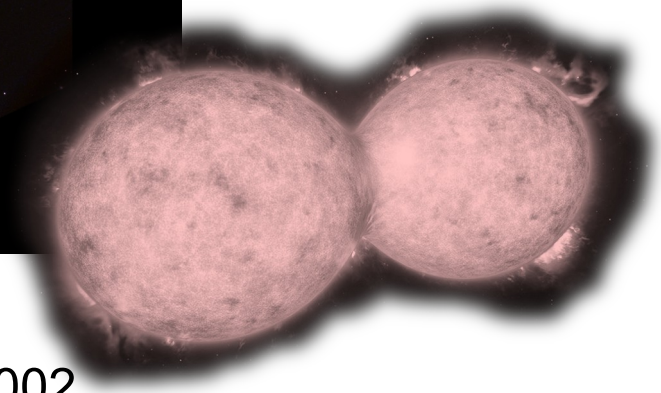

extragalactic (luminous) **red novae**:

M85 OT2006
NGC300 OT2008
PTF10acbp
NGC 4490-OT2011
M31 LRN 2015
M101 OT2015-1
AT 2014ej, AT 2019zhd (M31), AT 2020hat & 2020kog
and more !

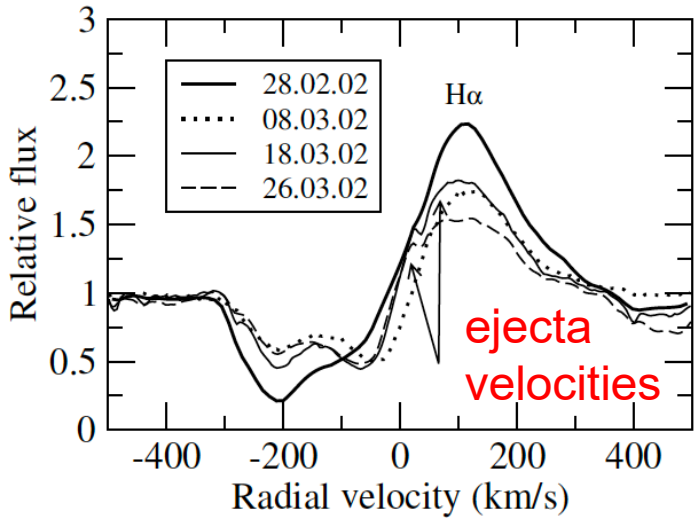
too weak to be observed after their outbursts

# Red novae as a class of transients

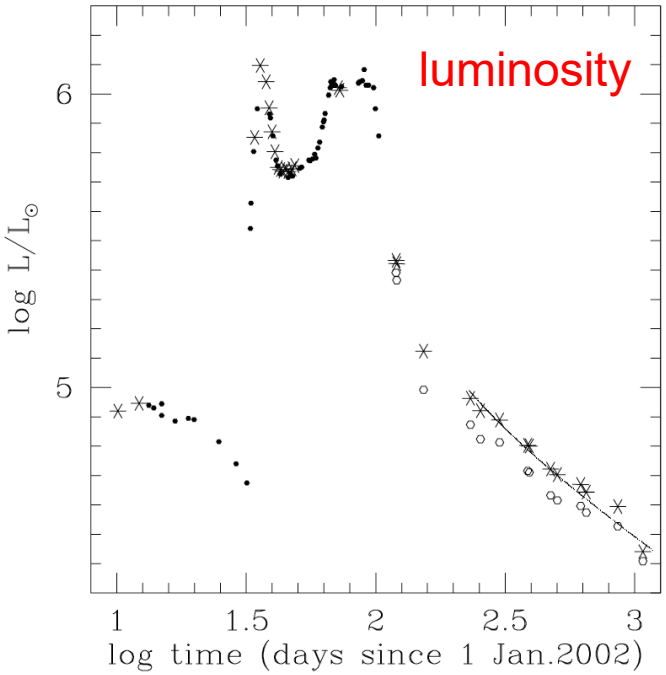


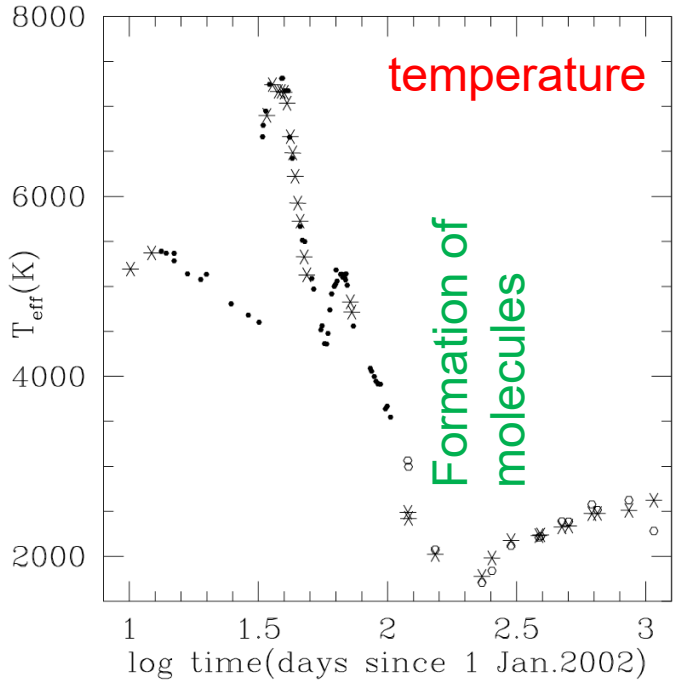


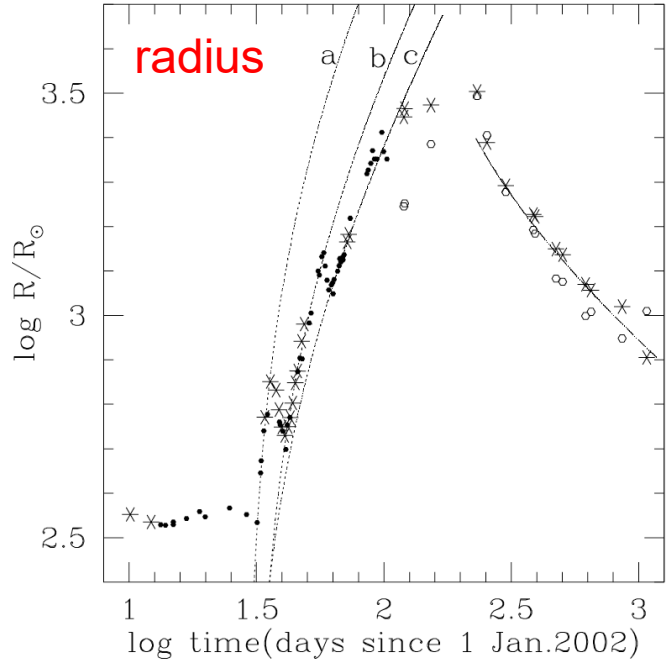
V838 Mon
eruption: Jan. 2002




Kolka & Kipper
Tylenda et al.




RGB+WD

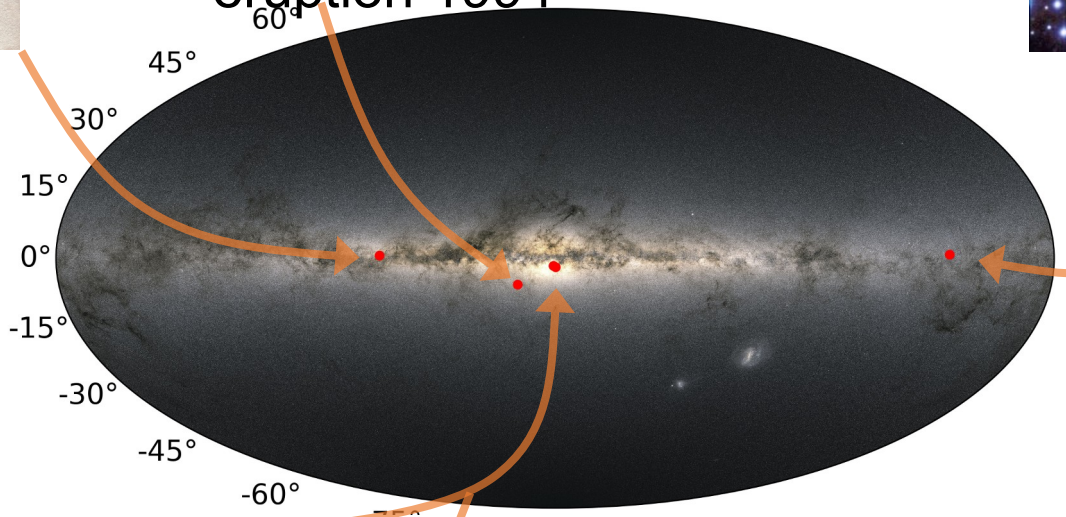
CK Vul
(*Nova 1670*)

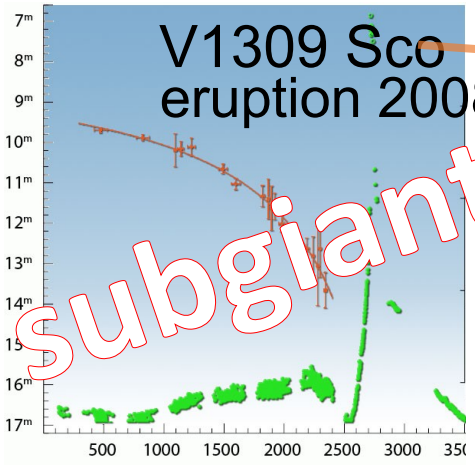
Subgiants

V4332 Sgr
eruption 1994

YSO+MS

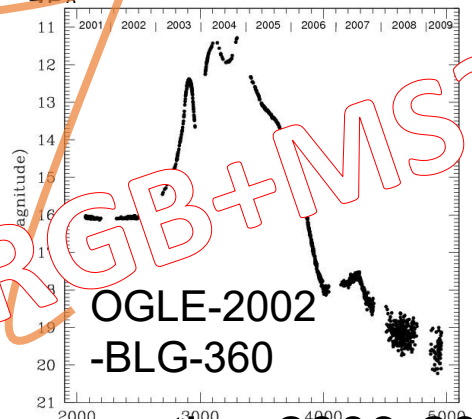
V838 Mon
eruption: 2002




V1309 Sco
eruption 2008

Subgiants




OGLE-2002
-BLG-360

RGB+MS?

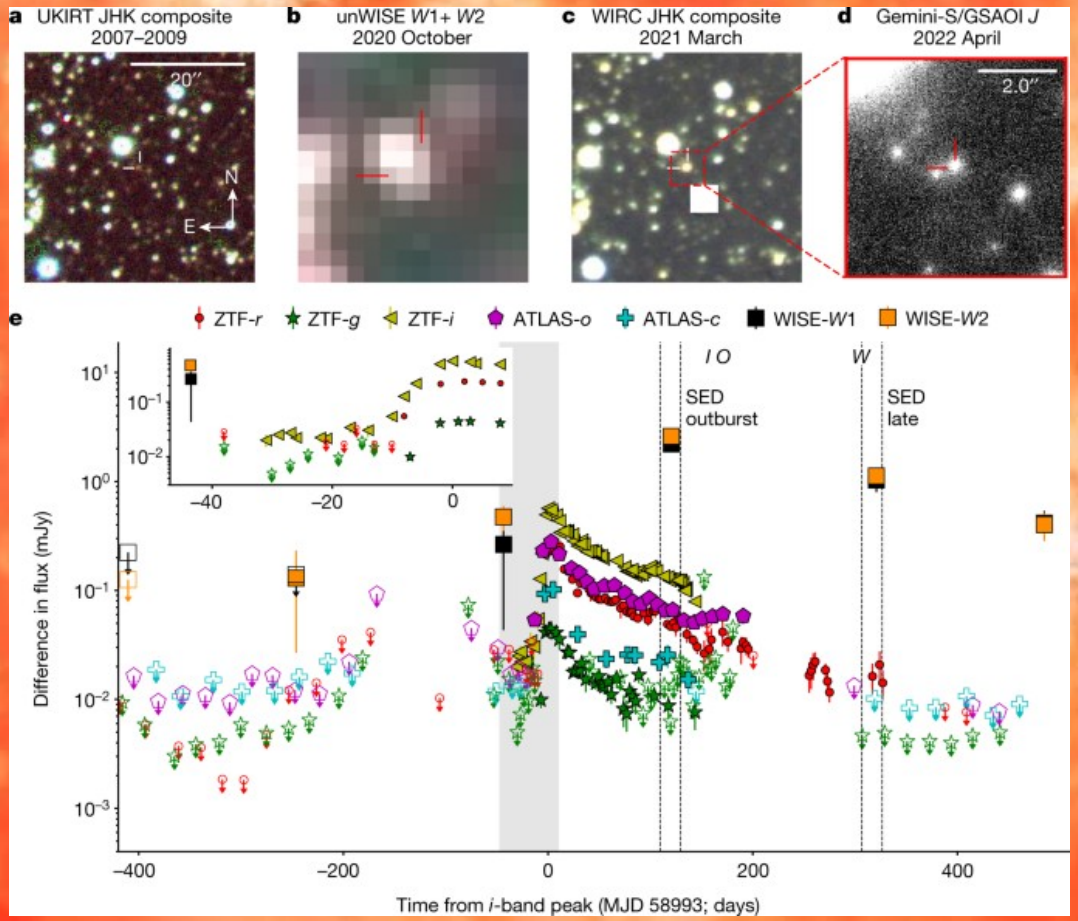
eruption 2003-2005

**5 Galactic red novae**

ZTF SLRN-2020 (subluminous red nova, <10 $M_{Jup}$+1 $M_{\odot}$)
K. De at al. May 2023, *Nature*

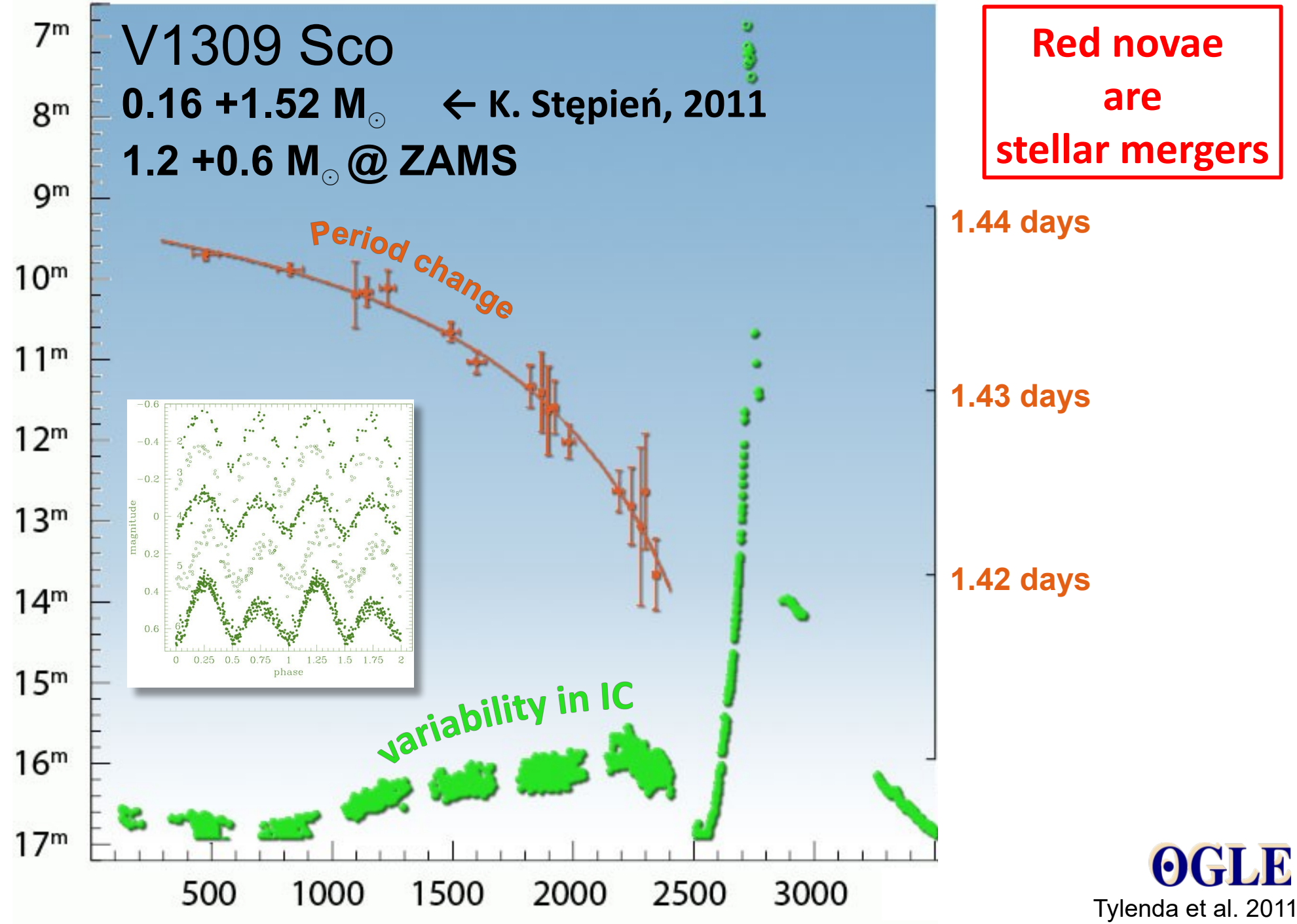
**star+planet red novae?**

*Other transients reported: ASASSN-15qi,ASASSN-13db (possibly YSOs)*



**proof**

Tylenda & Soker




**Red novae are stellar mergers**

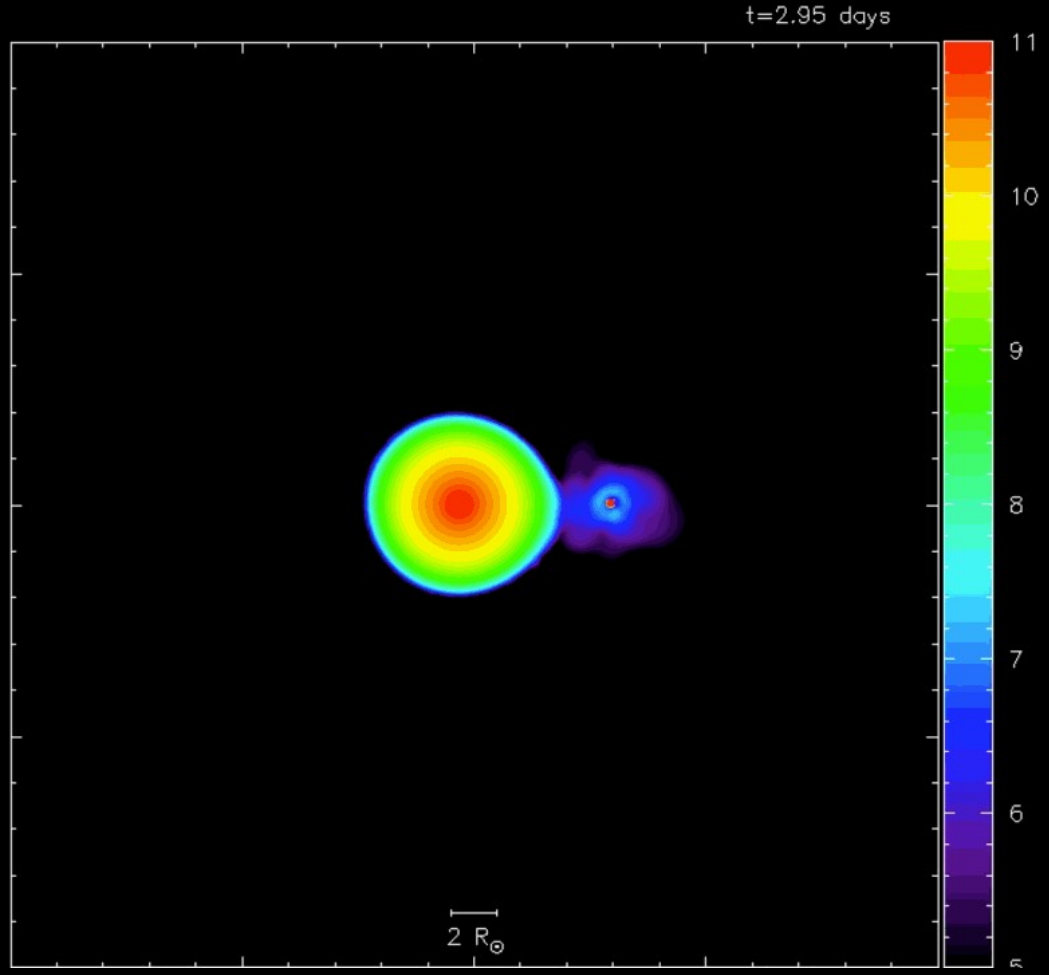
1.44 days

1.43 days

1.42 days

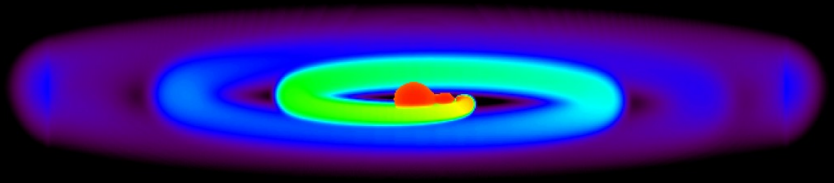
OGLE

Tylenda et al. 2011

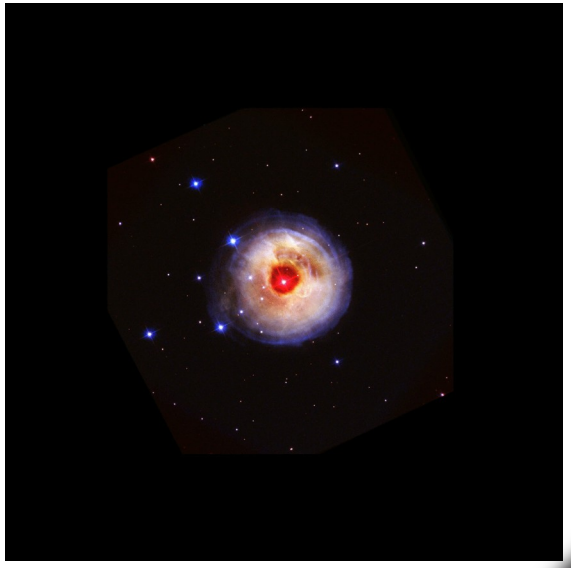



Nandez et al. 2013
view from above the binary

mergers
are associated
with mass loss



Pejcha et al. 2017
side view

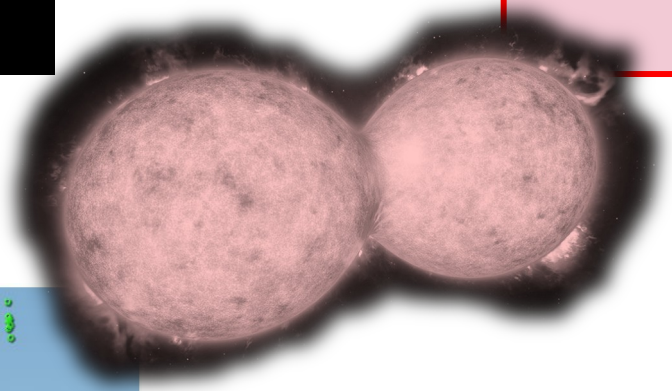


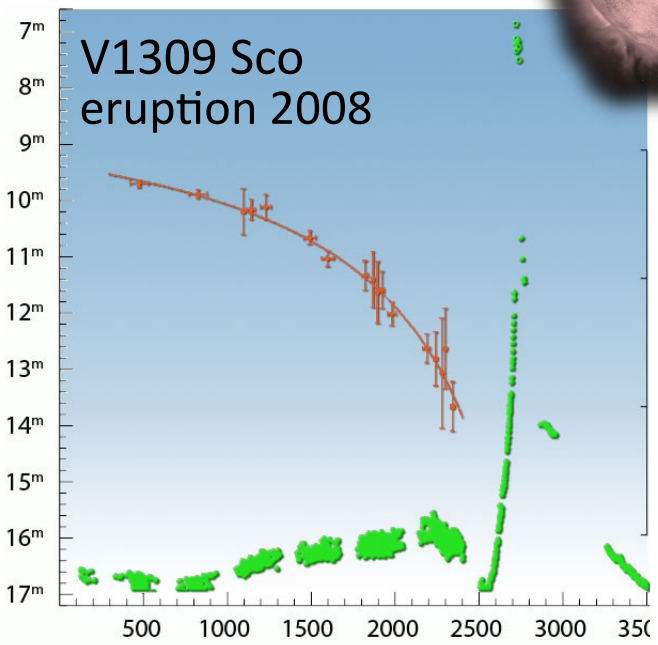
V838 Mon
eruption: 2002

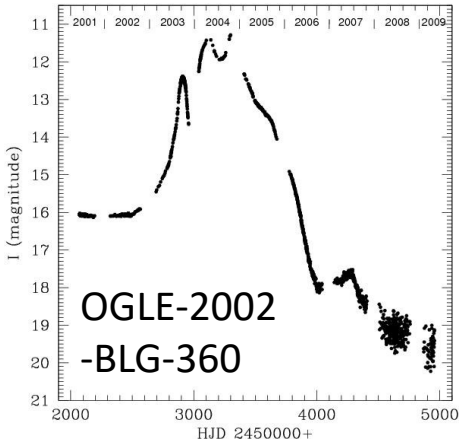
V4332 Sgr
eruption 1994

Constraining merger physics:

- masses dispersed
- angular momentum budget
- stellar rotation/winds
- disks/torii
- magnetic fields
- progenitors

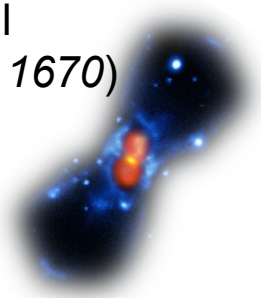




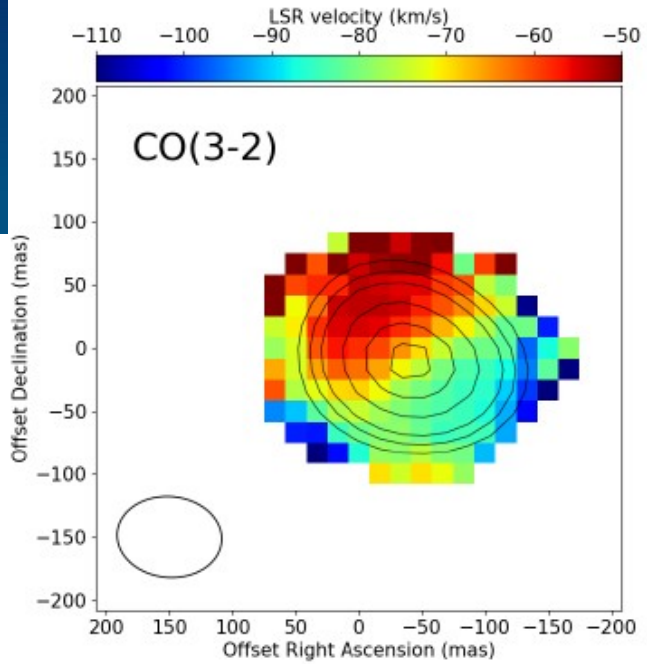

eruption 2003-2005

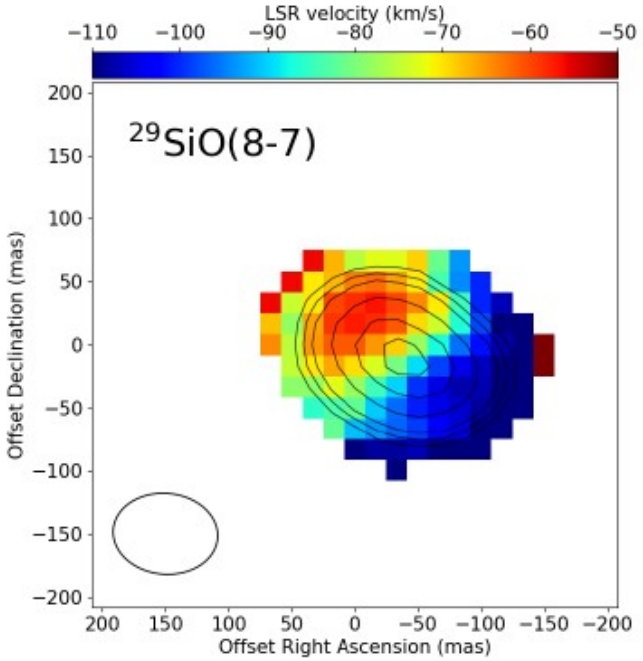

CK Vul
(*Nova 1670*)



ALMA

2019

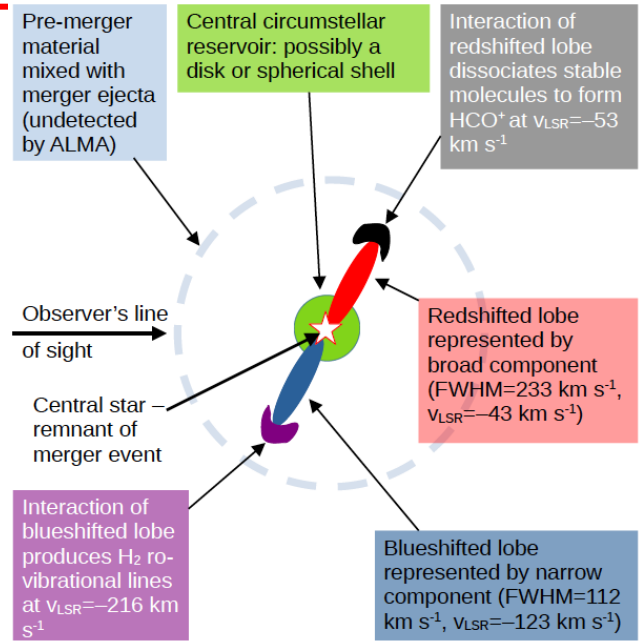


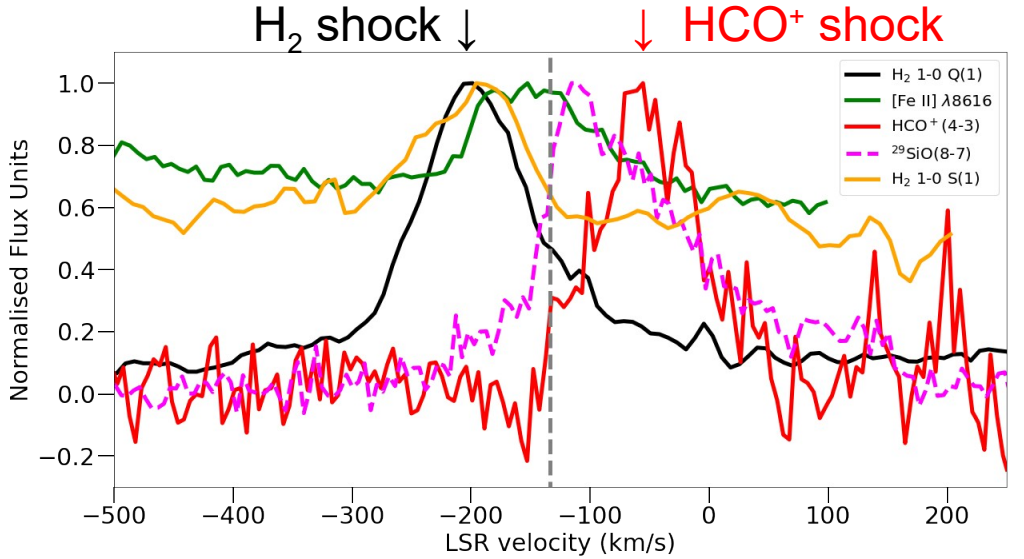




# V1309 Sco ~10-15 yr after merger

Steinmetz et al. 2023, A&A, submitted this month

**Bipolar & shocked**




ESO

# V4332 Sgr

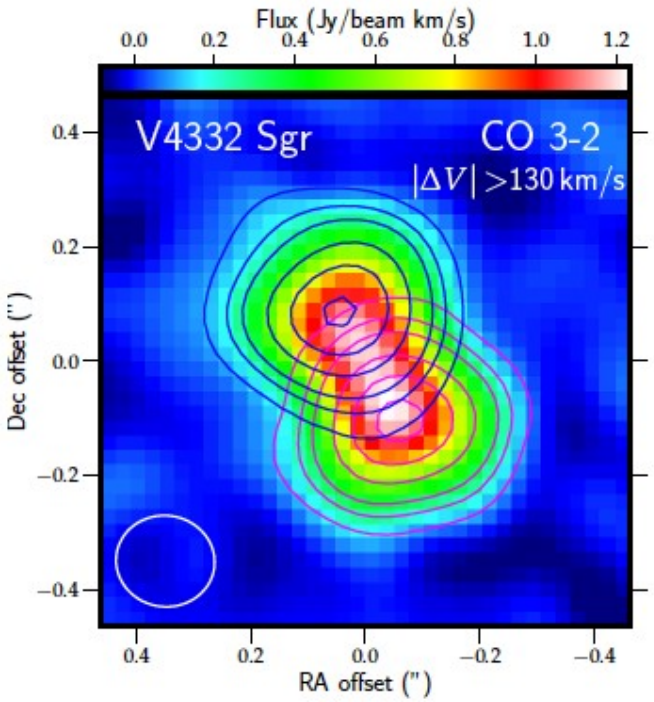
eruption in 1994

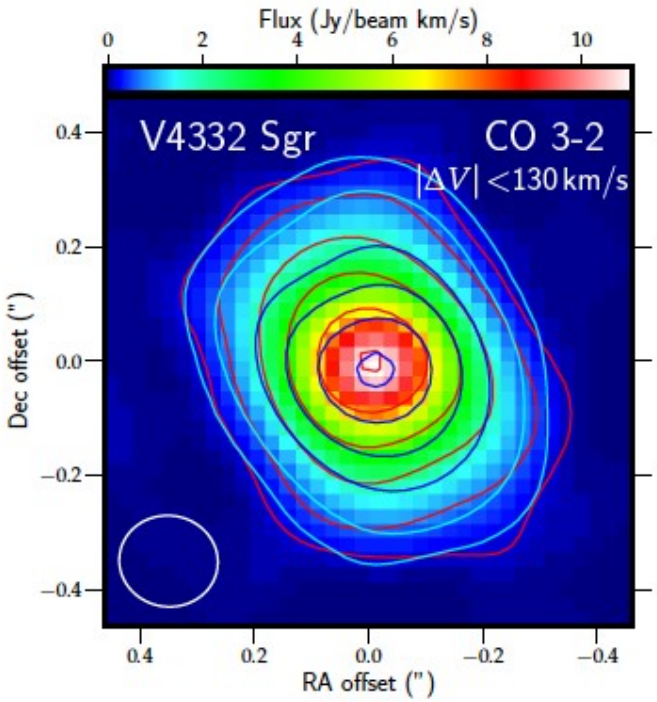
clone of V1309 Sco

ALMA

2016/17

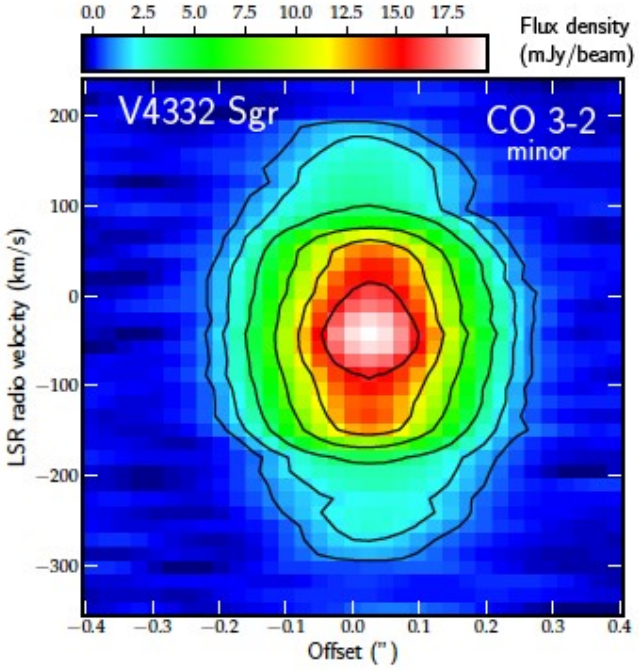
intensity maps

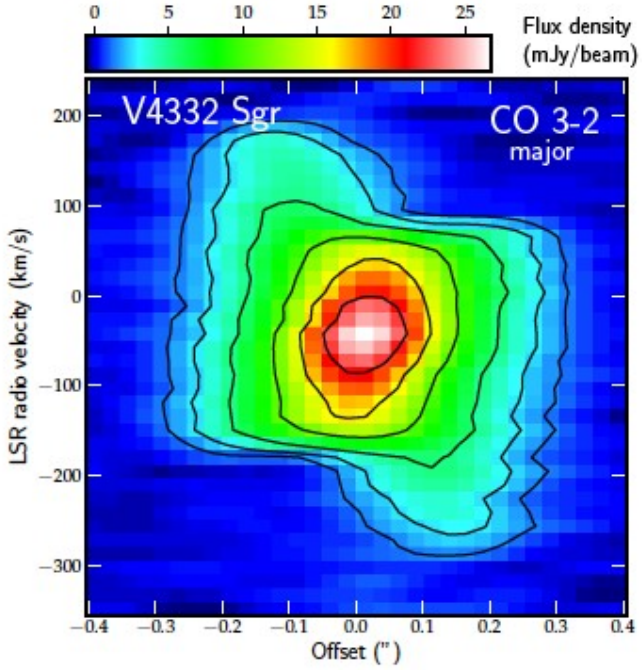



1000 AU at 5 kpc

position-velocity diagrams



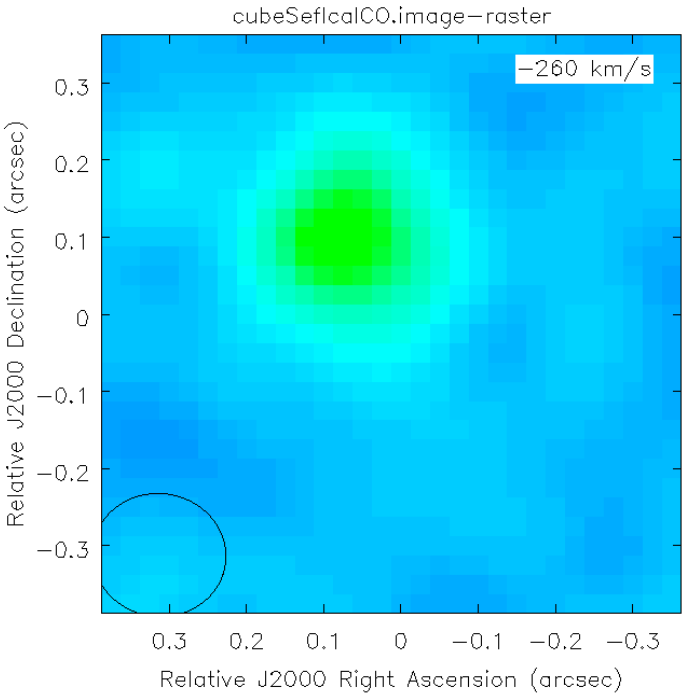



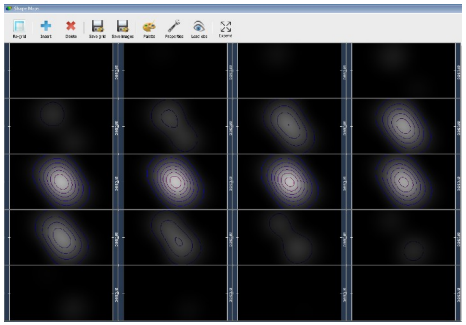

Kamiński+ 2018

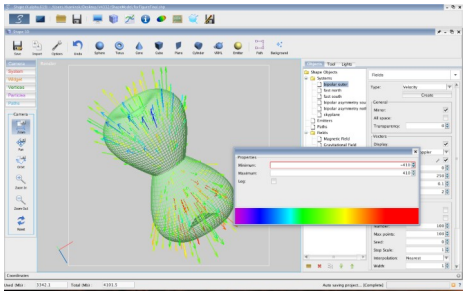
ALMA channel maps
one map per each velocity bin

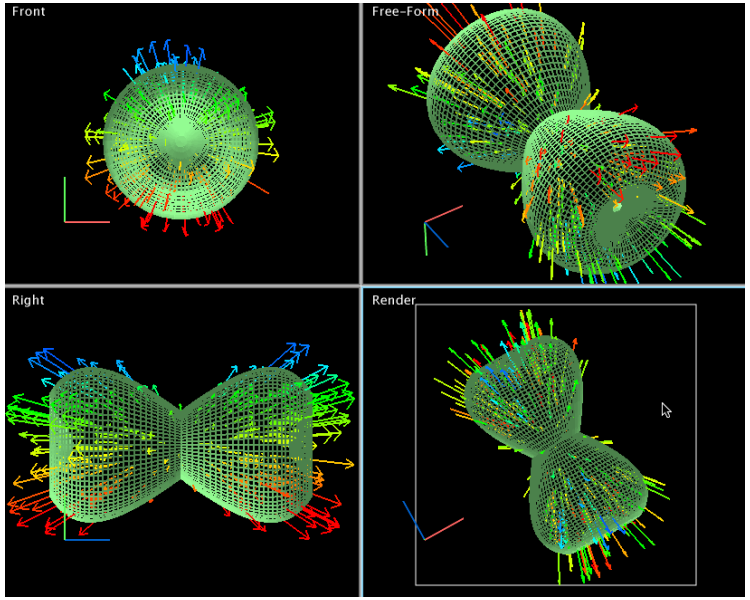
**building a 3D model in *Shape* and radiative transfer**

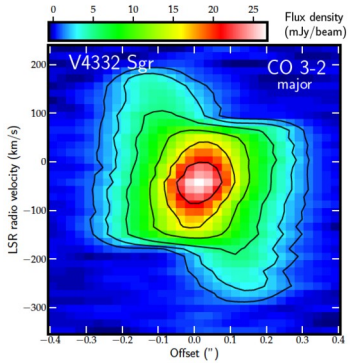
3D structure of the source:
- density
- temperature
- velocity / angular momentum

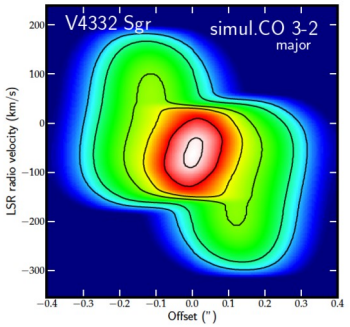


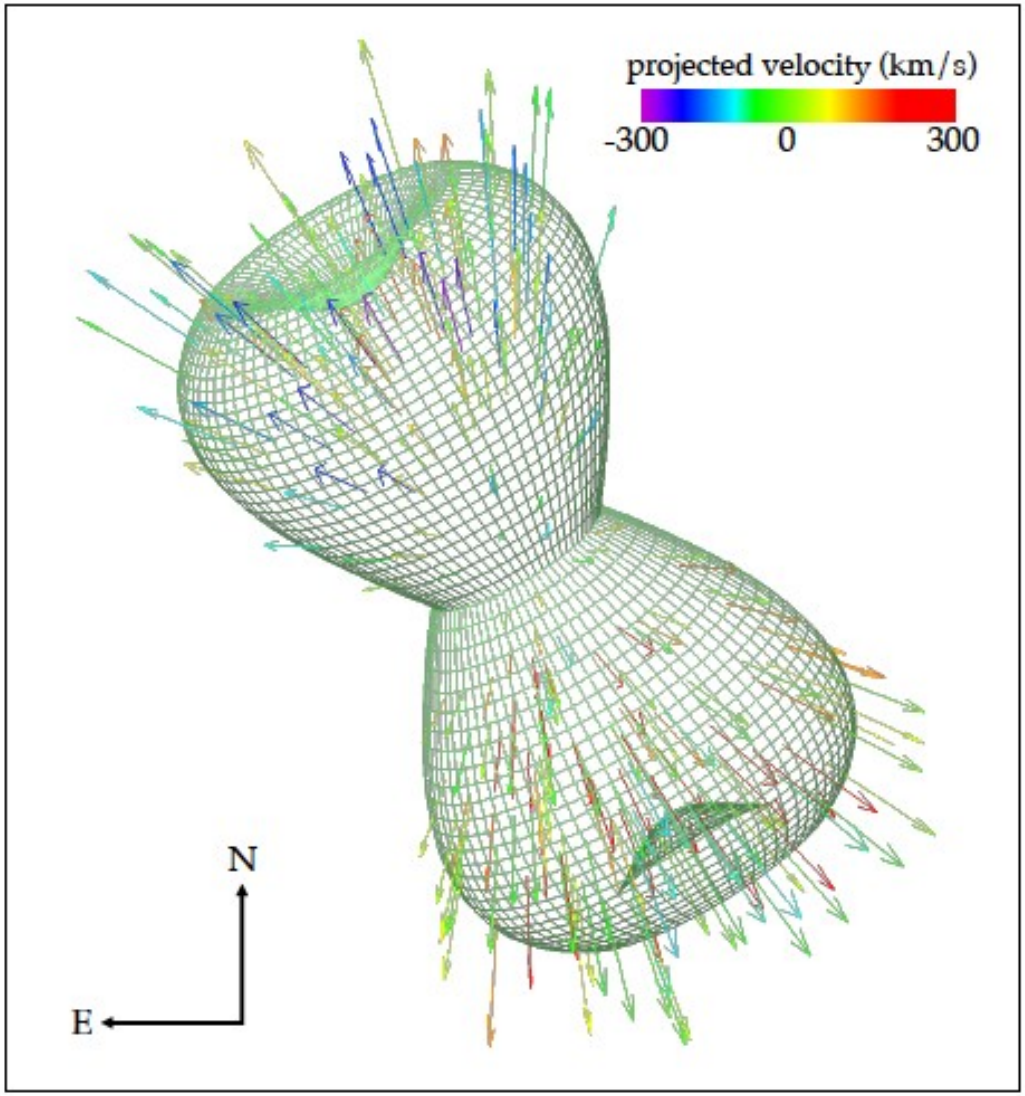


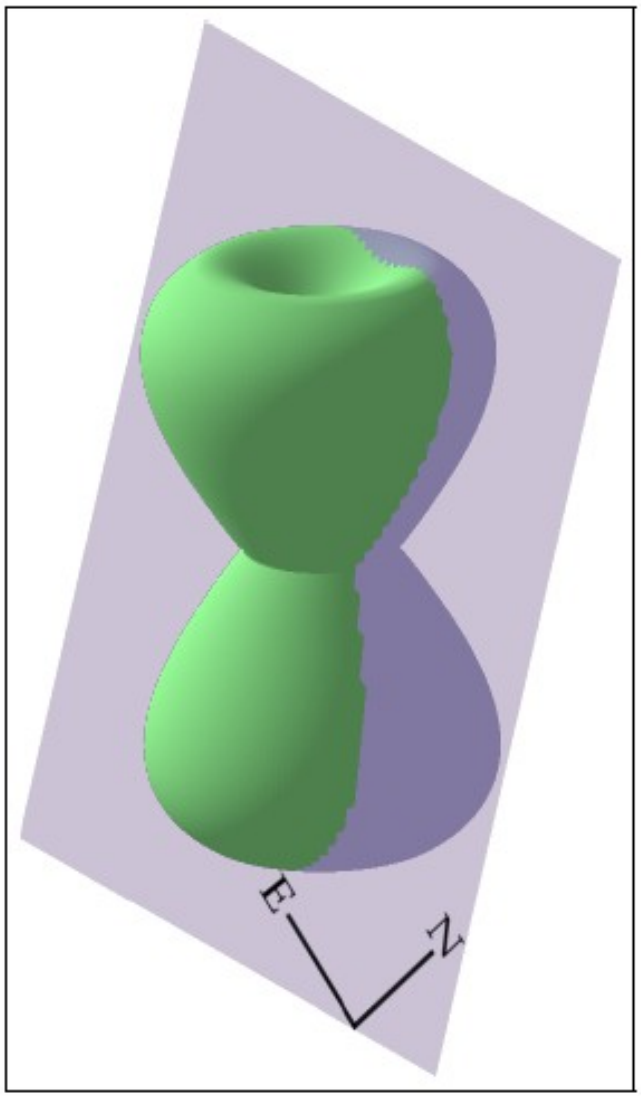



# ALMA results for V4332 Sgr:

model reconstructed from observations



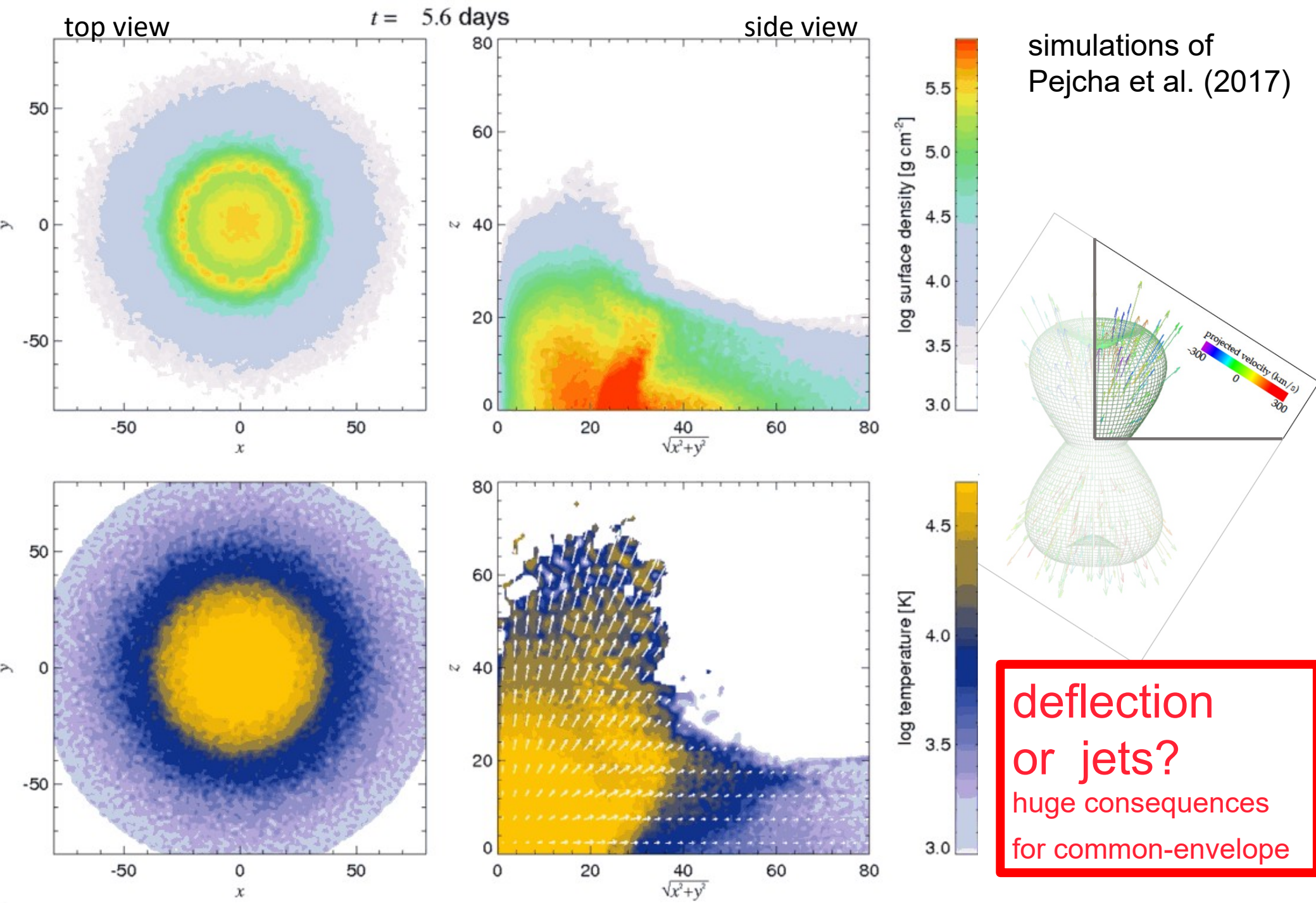



top view

$t =$ 5.6 days

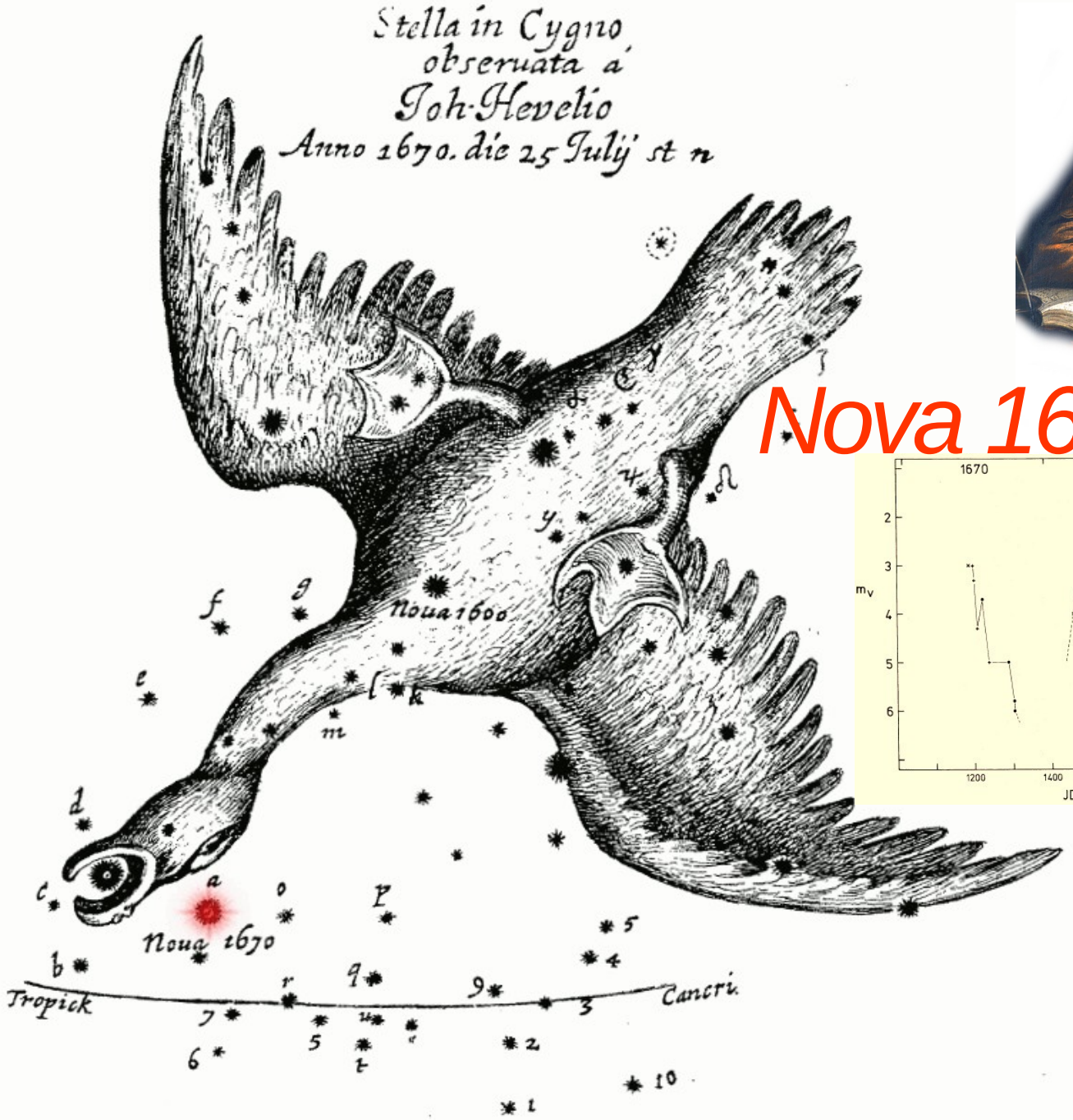
side view

simulations of
Pejcha et al. (2017)

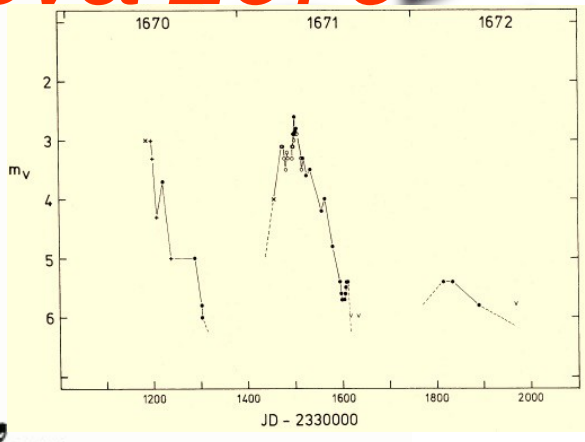



deflection
or jets?

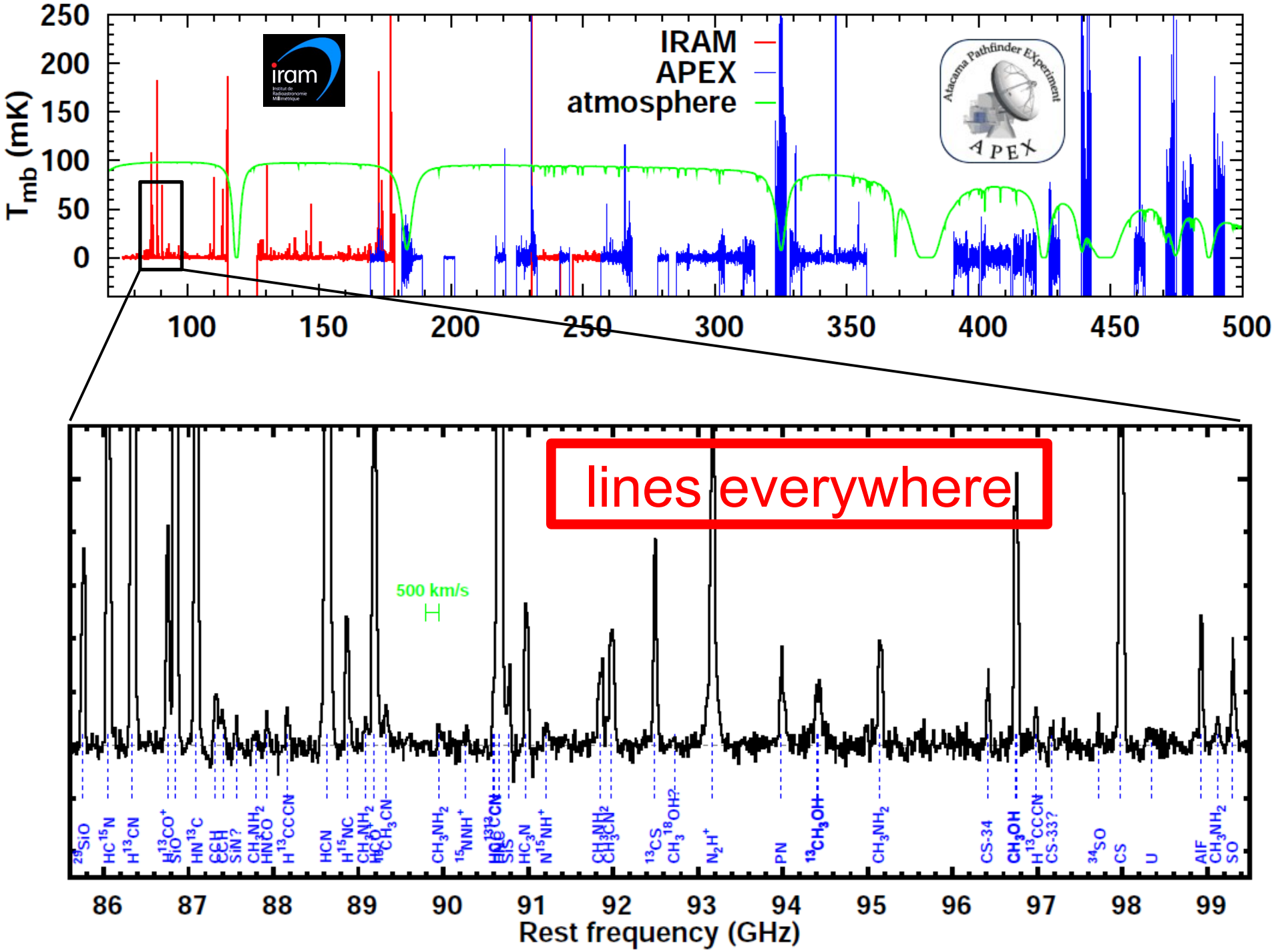
huge consequences
for common-envelope

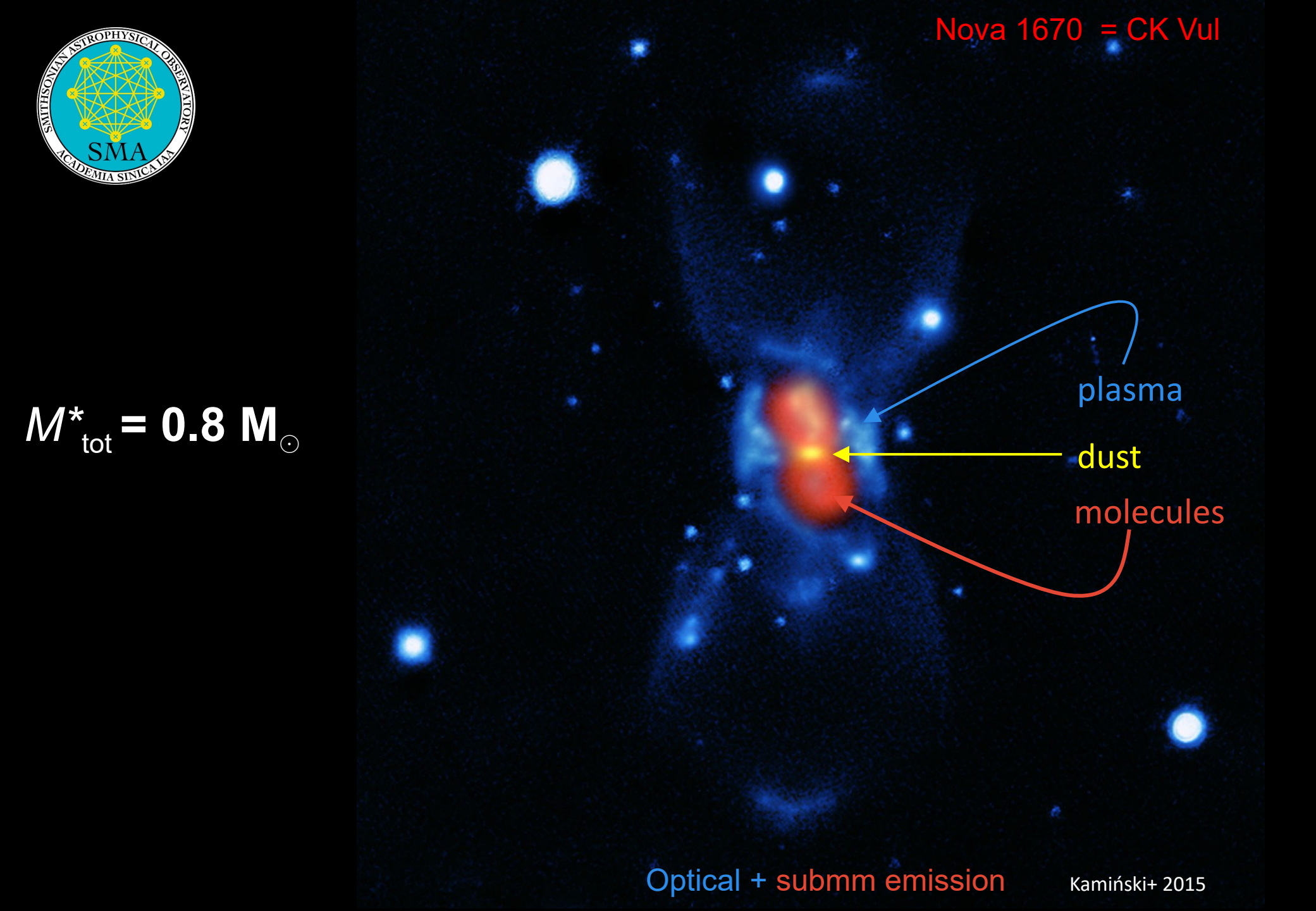



Nova 1670



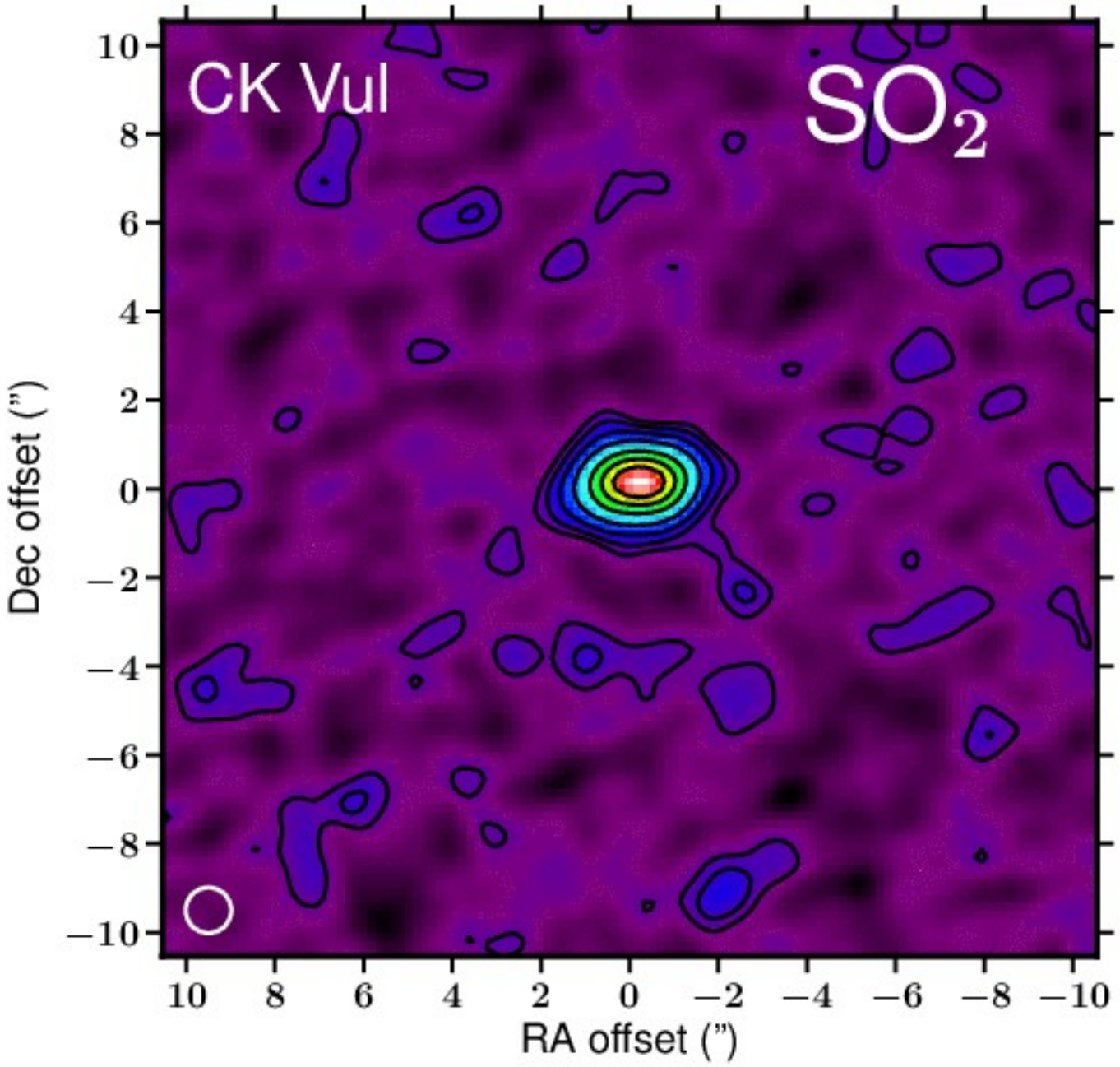

Shara+ 1985


IRAM
APEX
atmosphere
$T_{mb}$ (mK)
250
200
150
100
50
0
100
150
200
250
300
350
400
450
500
lines everywhere
500 km/s
Rest frequency (GHz)
86
87
88
89
90
91
92
93
94
95
96
97
98
99




$M^*_{tot} = 0.8\ M_\odot$

2018: line surve
bands 3,4,5&6



# Molecular ions in CK Vul

rotx = 000°
roty = 000°
rotz = -17°

point symmetry

multiple ejections

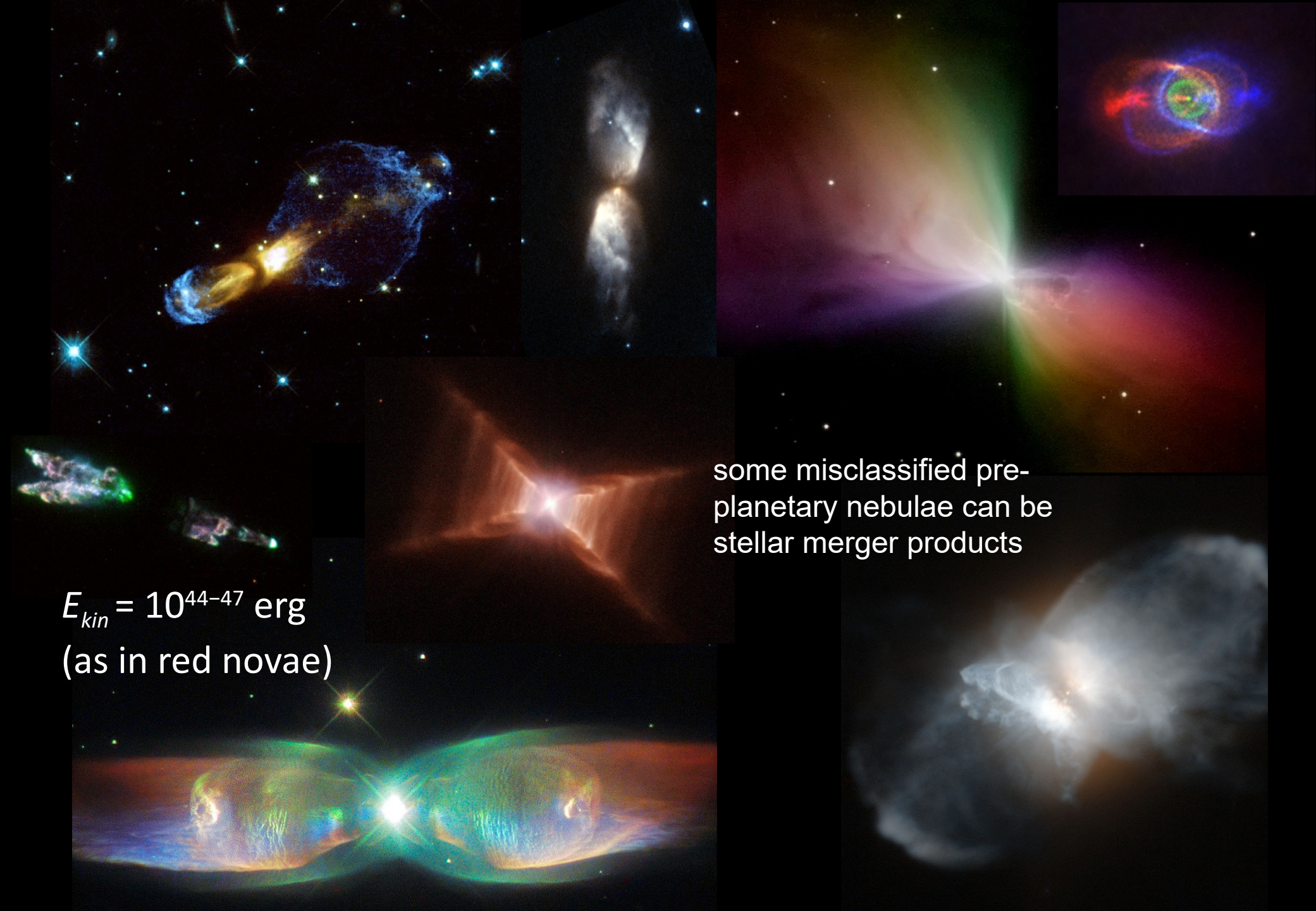
possible jet-type activity

possibly younger than 340 yr

possibly triple? Companion 0.3 $M_{\odot}$

Kamiński et al. 2020

Kamiński et al 2021


some misclassified pre-planetary nebulae can be stellar merger products
$E_{kin} = 10^{44-47}$ erg
(as in red novae)

# Summary

- we can observe stellar collisions in real time
- detailed studies of the geometry of the remnants with interferometers constrain theoretical models of mergers (and of the common envelope phase?)
- Bipolar structures are present in all red nova remnants
  - energy and momentum as in some pre-PNe (similar shaping mechanism?)
  - are some misclassified pre-PNe merger products? (missed red novae)
- Circumstellar shocks are omnipresent and determine the molecular composition
- Mergers likely occur in triple systems

like/dislike
ALMA/ESO?
talk to me

**Member of**

**Scientific Technical Committee, STC**

**and**

**European Science Advisory Committee, ESAC**
**(ALMA matters in ESO)**