Red novae (stellar mergers) with LSST

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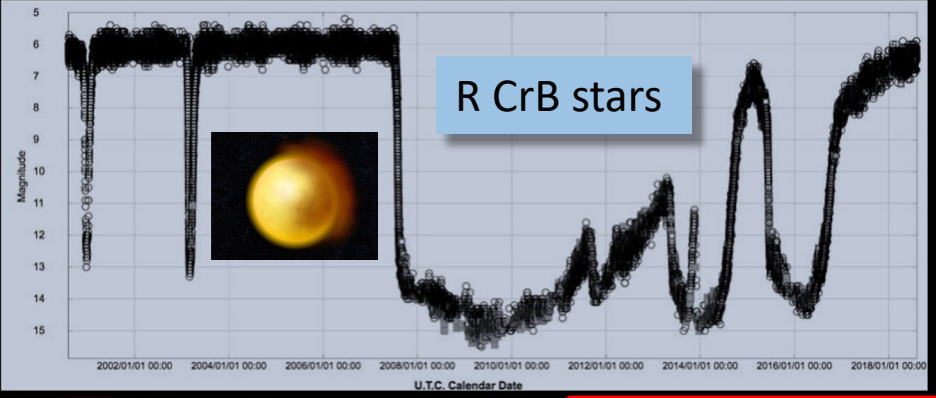


the great eruption of η Car

some pre-planetary nebulae

(Boomerang)

products of mergers of noncompact stars are common

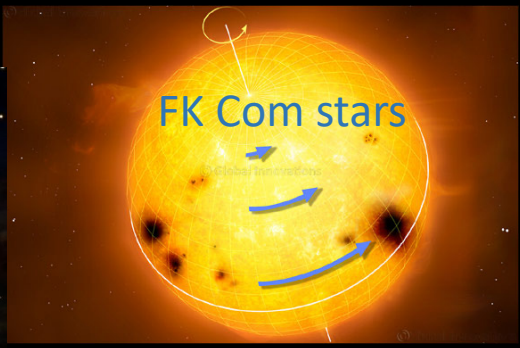
HD 45166

★ chemically peculiar stars

★ R –type stars

anomalous Cepheids

protostars OMC1 source *I*



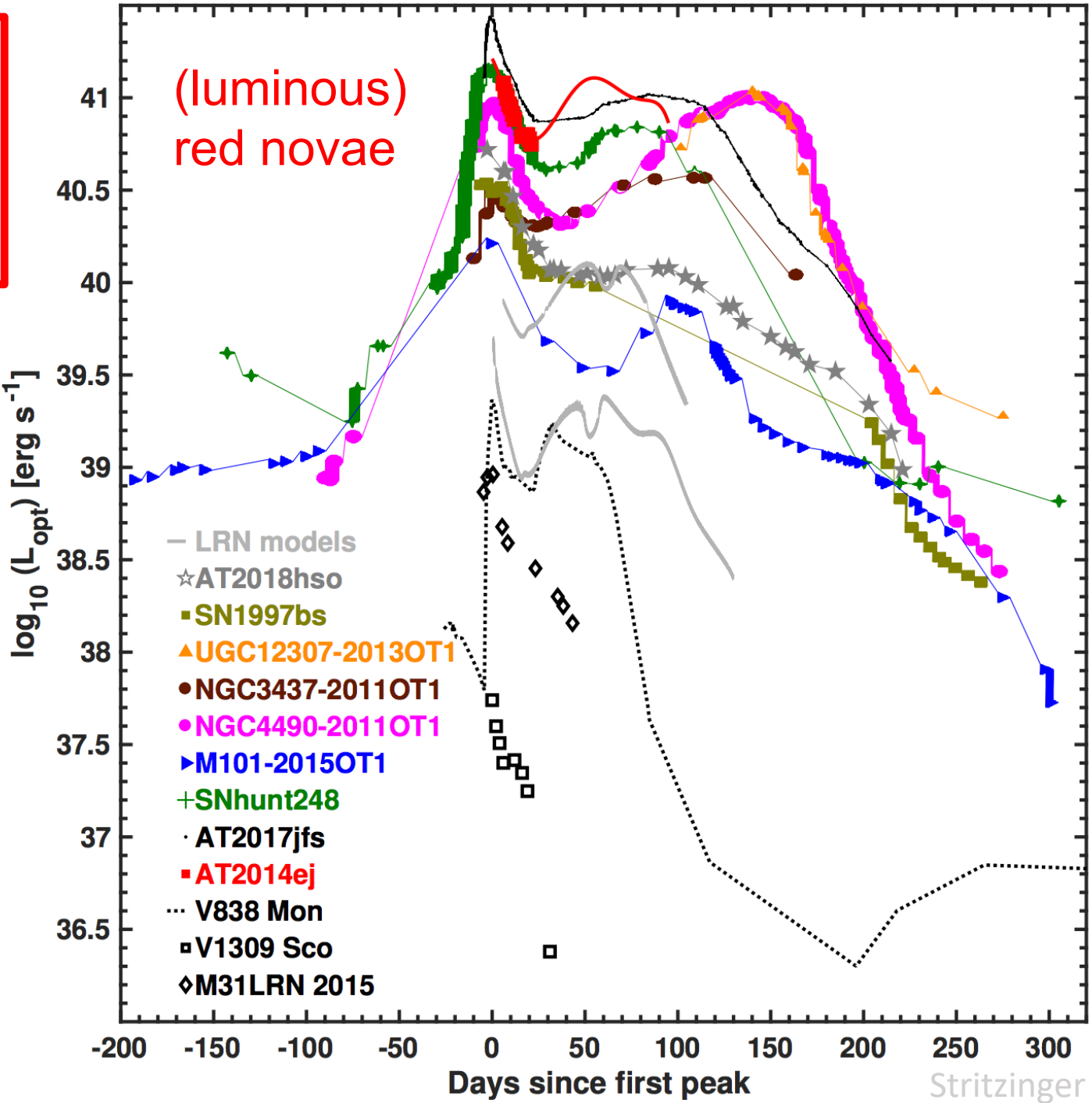
the progenitor of SN 1987A

★ some blue strugglers

★ hot sub-dwarfs

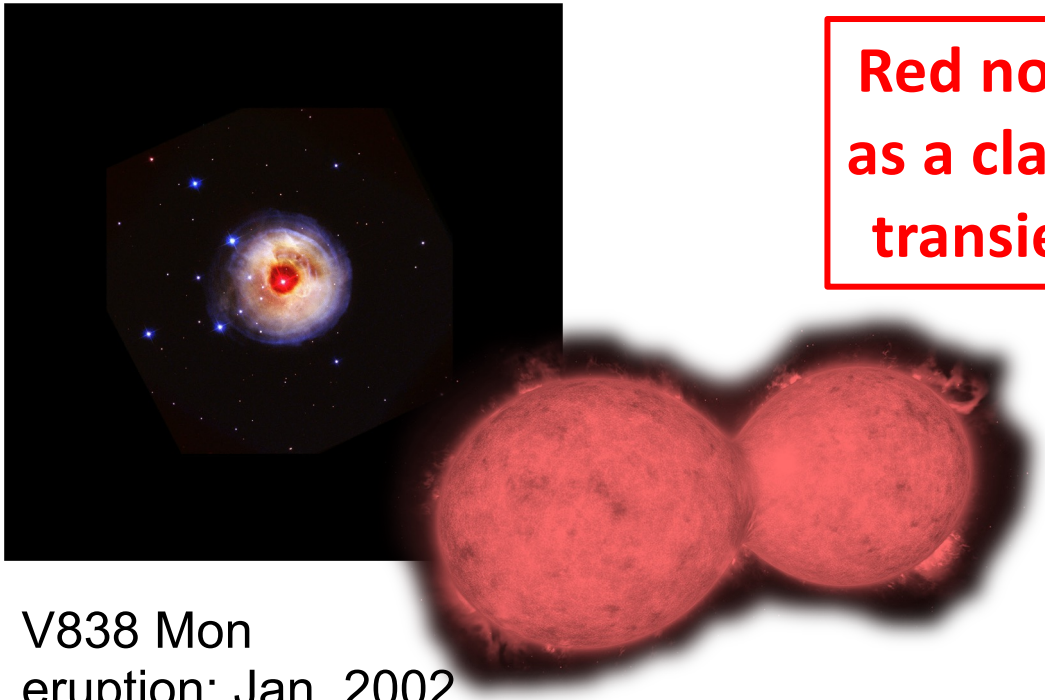
★ Be & B[e] stars

zoo of
light curves
of red novae
Galactic and
extragalactic

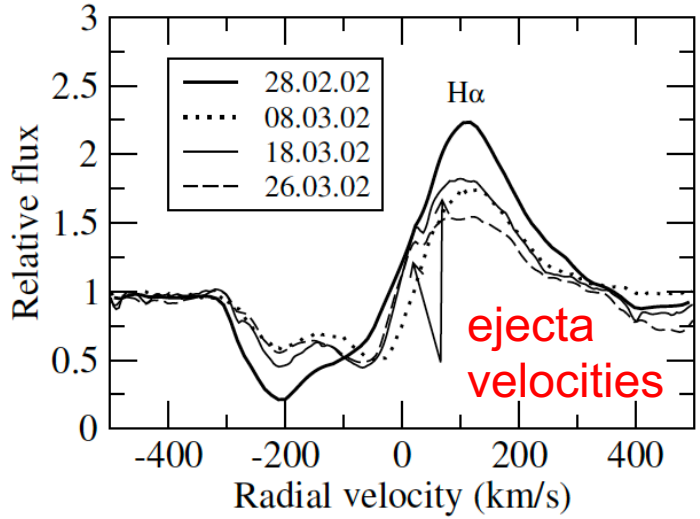


Stritzinger et al. 2020

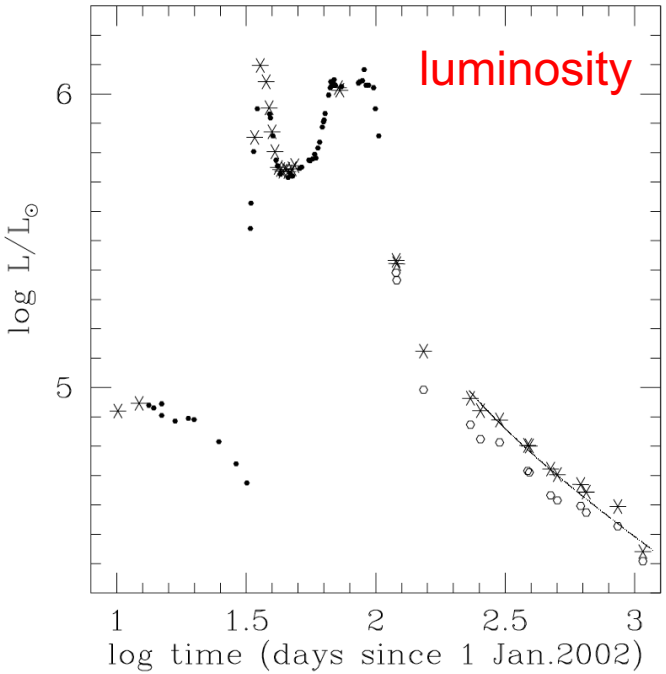
Red novae as a class of transients

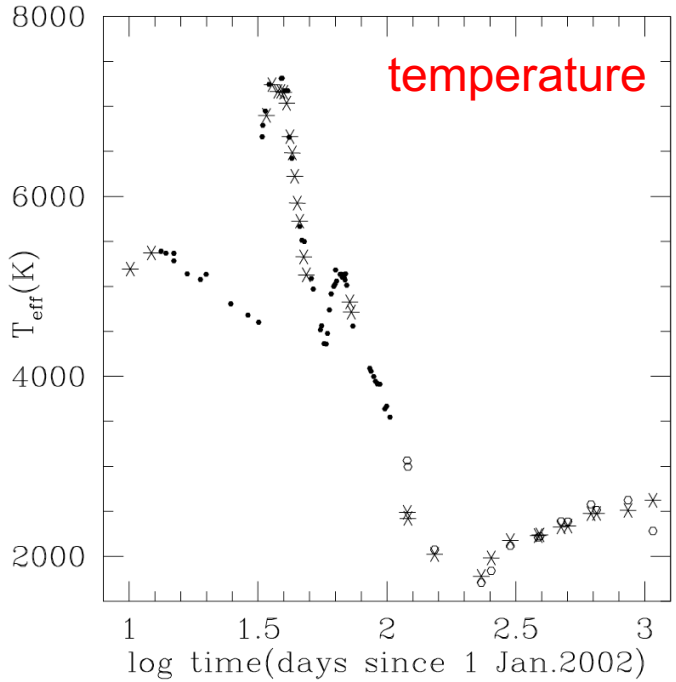


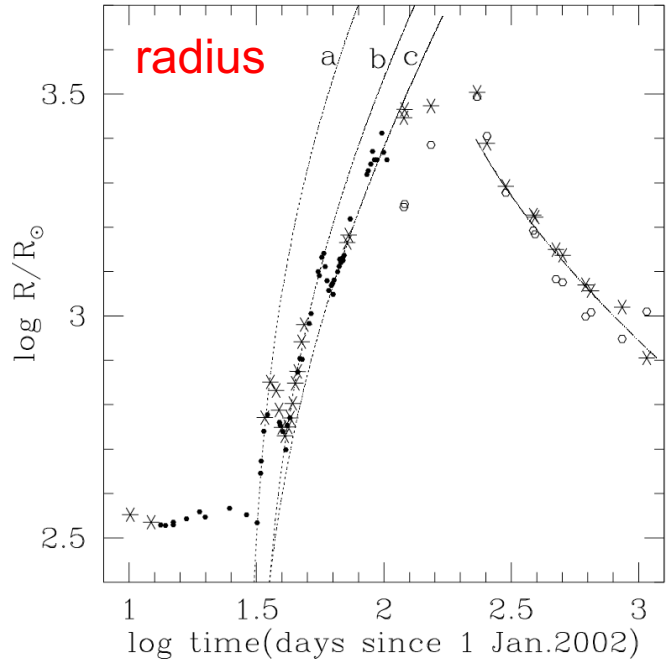
V838 Mon
eruption: Jan. 2002



Kolka & Kipper
Tylenda et al.



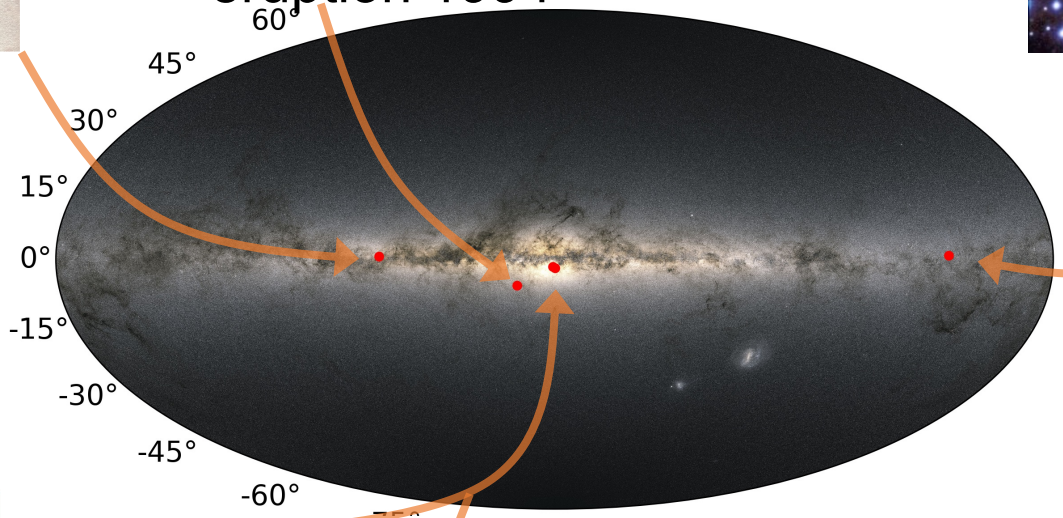


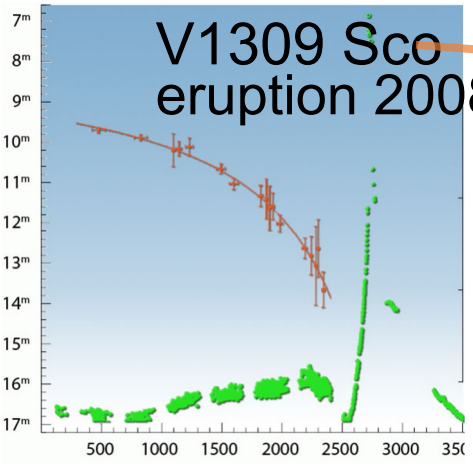


CK Vul
(*Nova 1670*)

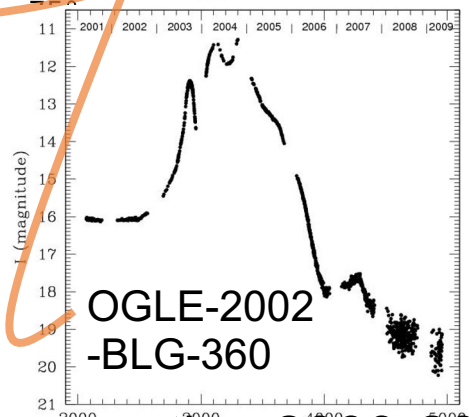
V4332 Sgr
eruption 1994

V838 Mon
eruption: 2002





V1309 Sco
eruption 2008



OGLE-2002
-BLG-360

eruption 2003-2005

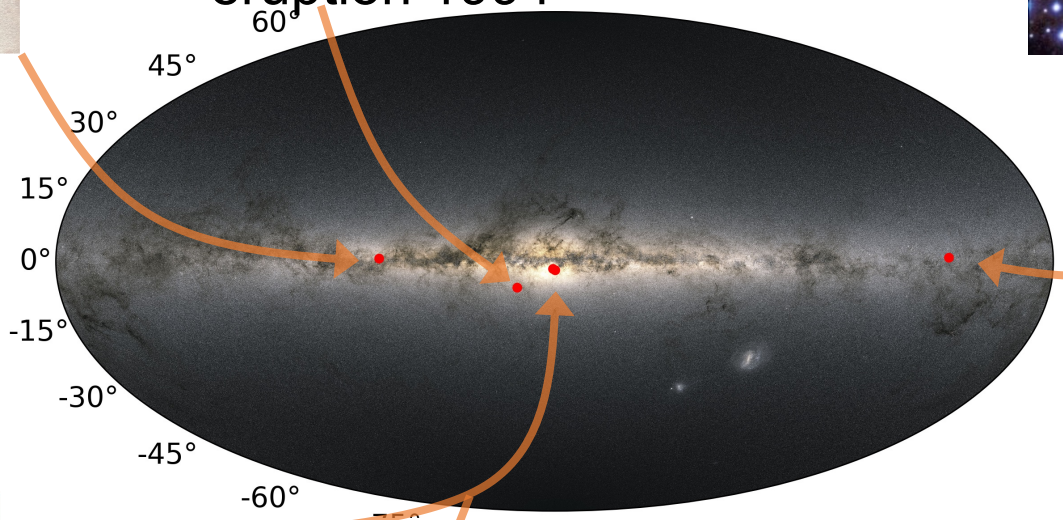
5+ Galactic red novae

RGB+WD

CK Vul
(*Nova 1670*)

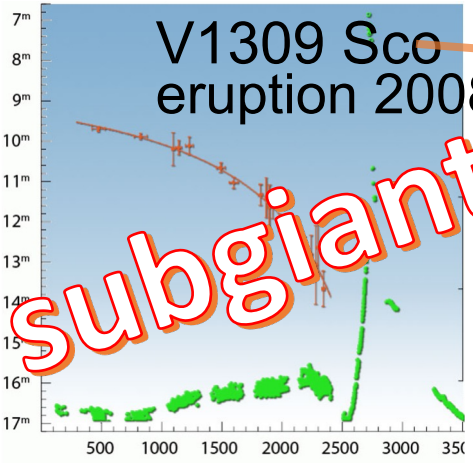
subgiants

V4332 Sgr
eruption 1994



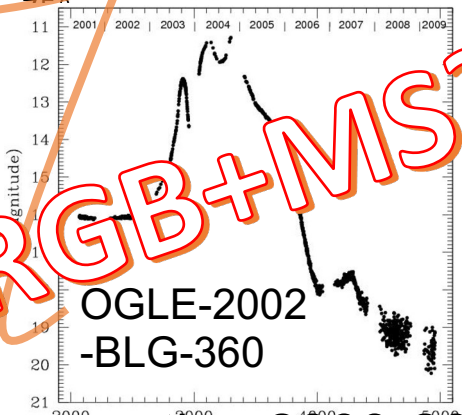
YSO+MS

V838 Mon
eruption: 2002



V1309 Sco
eruption 2008

subgiants



OGLE-2002
-BLG-360

RGB+MS?

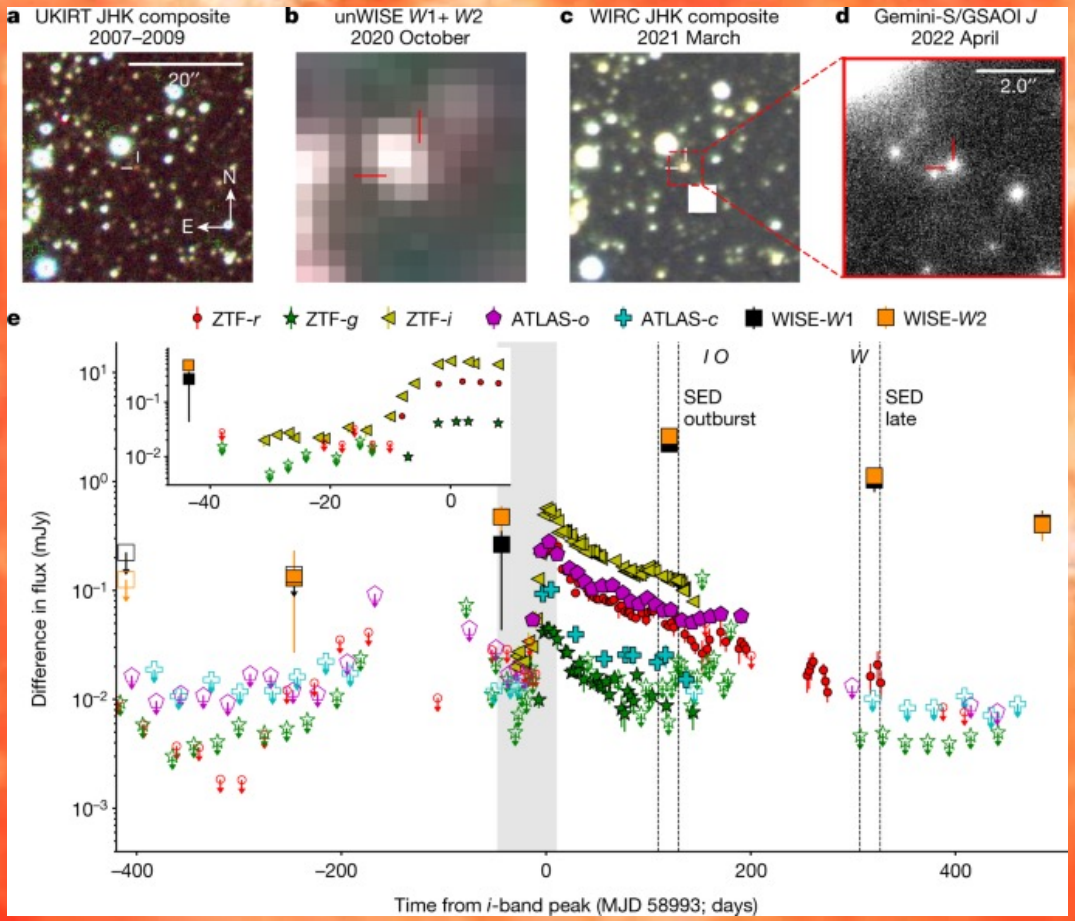
eruption 2003-2005

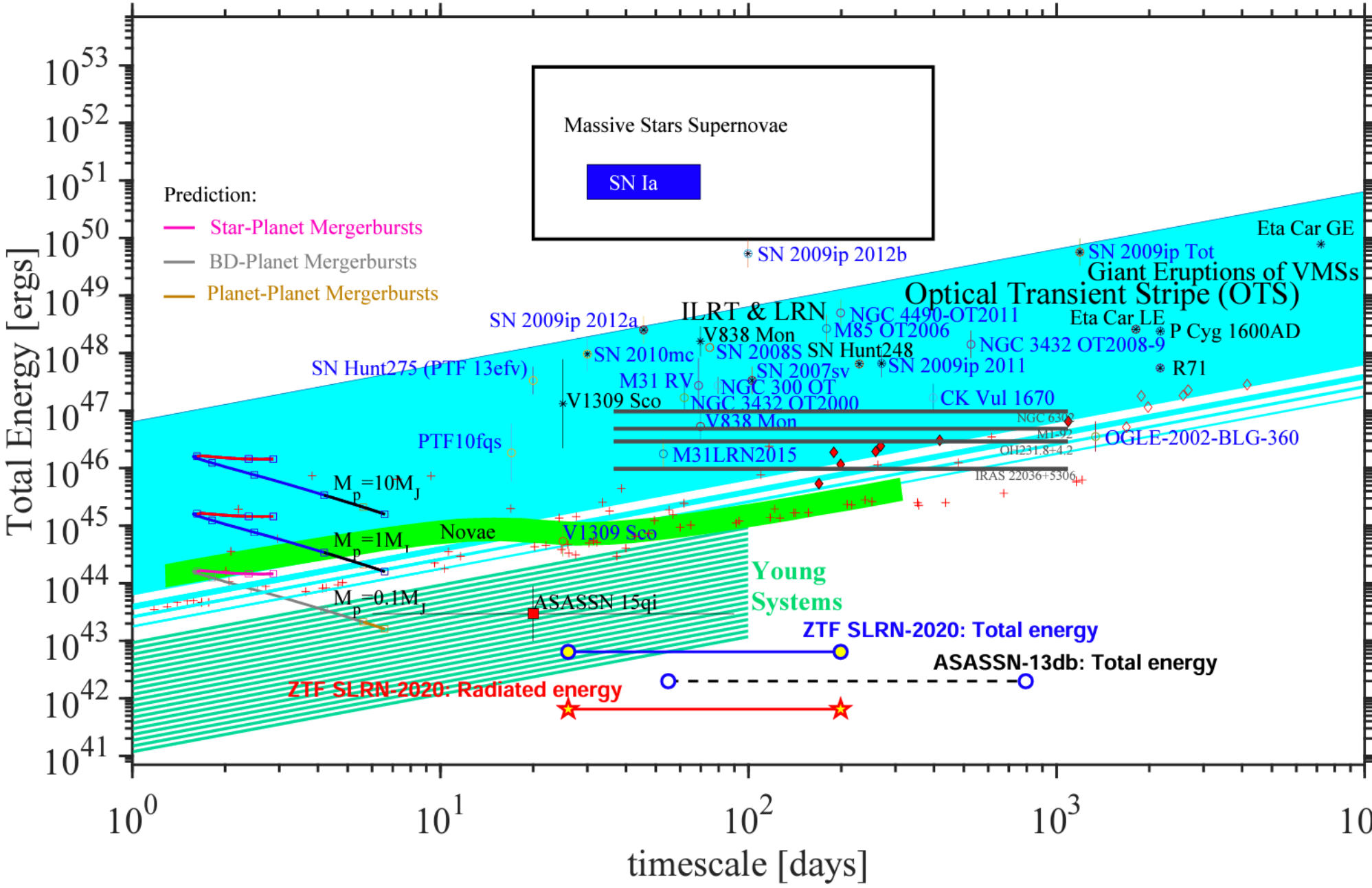
5+ Galactic red novae

ZTF SLRN-2020 (subluminous red nova, <10 M_{Jup}+1 $M_{\odot}$) 100 $L_{\odot}$
K. De at al. May 2023, *Nature*

star+planet red novae

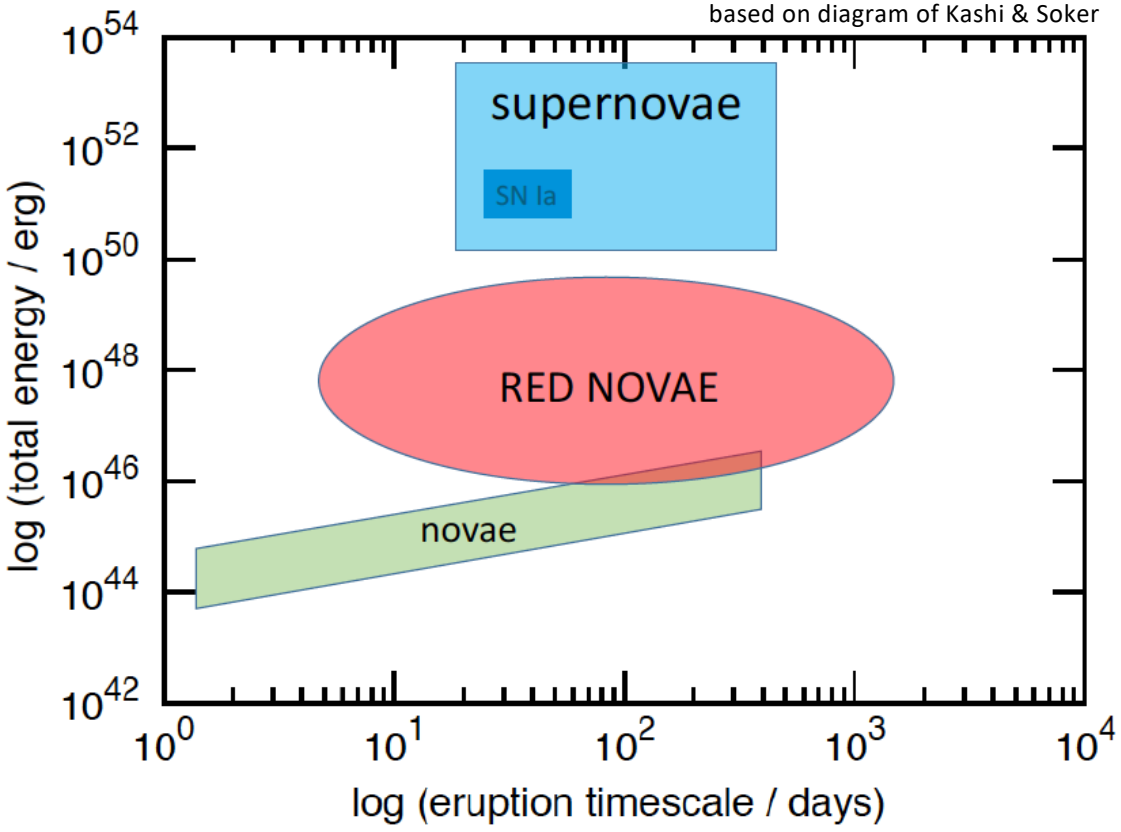
Other transients reported: ASASSN-15qi,ASASSN-13db (possibly YSOs)



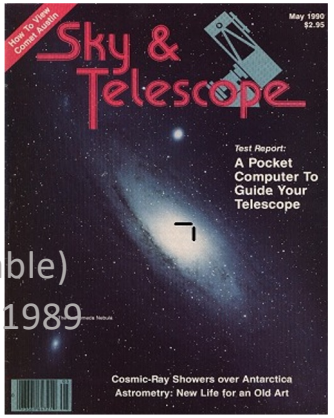

Massive Stars Supernovae
SN Ia
Prediction:
Star-Planet Mergerbursts
BD-Planet Mergerbursts
Planet-Planet Mergerbursts
Optical Transient Stripe (OTS)
Giant Eruptions of VMSs
ILRT & LRN
Novae
Young Systems
SN 2009ip 2012b
SN 2009ip Tot
Eta Car GE
Eta Car LE
SN 2009ip 2012a
V838 Mon
NGC 4490-OT2011
M85 OT2006
P Cyg 1600AD
SN 2010mc
SN 2008S SN Hunt248
NGC 3432 OT2008-9
SN Hunt275 (PTF 13efv)
SN 2007sv
SN 2009ip 2011
R71
M31 RV
NGC 300 OT
V1309 Sco
NGC 3432 OT2000
CK Vul 1670
PTF10fqs
OGLE-2002-BLG-360
M31LRN2015
M_p=10M_J
M_p=1M_J
M_p=0.1M_J
ASASSN 15qi
ZTF SLRN-2020: Total energy
ASASSN-13db: Total energy
ZTF SLRN-2020: Radiated energy
Total Energy [ergs]
timescale [days]

Red novae fame goes extragalactic!

based on diagram of Kashi & Soker



M31-RV
(Red Variable)
eruption: 1989

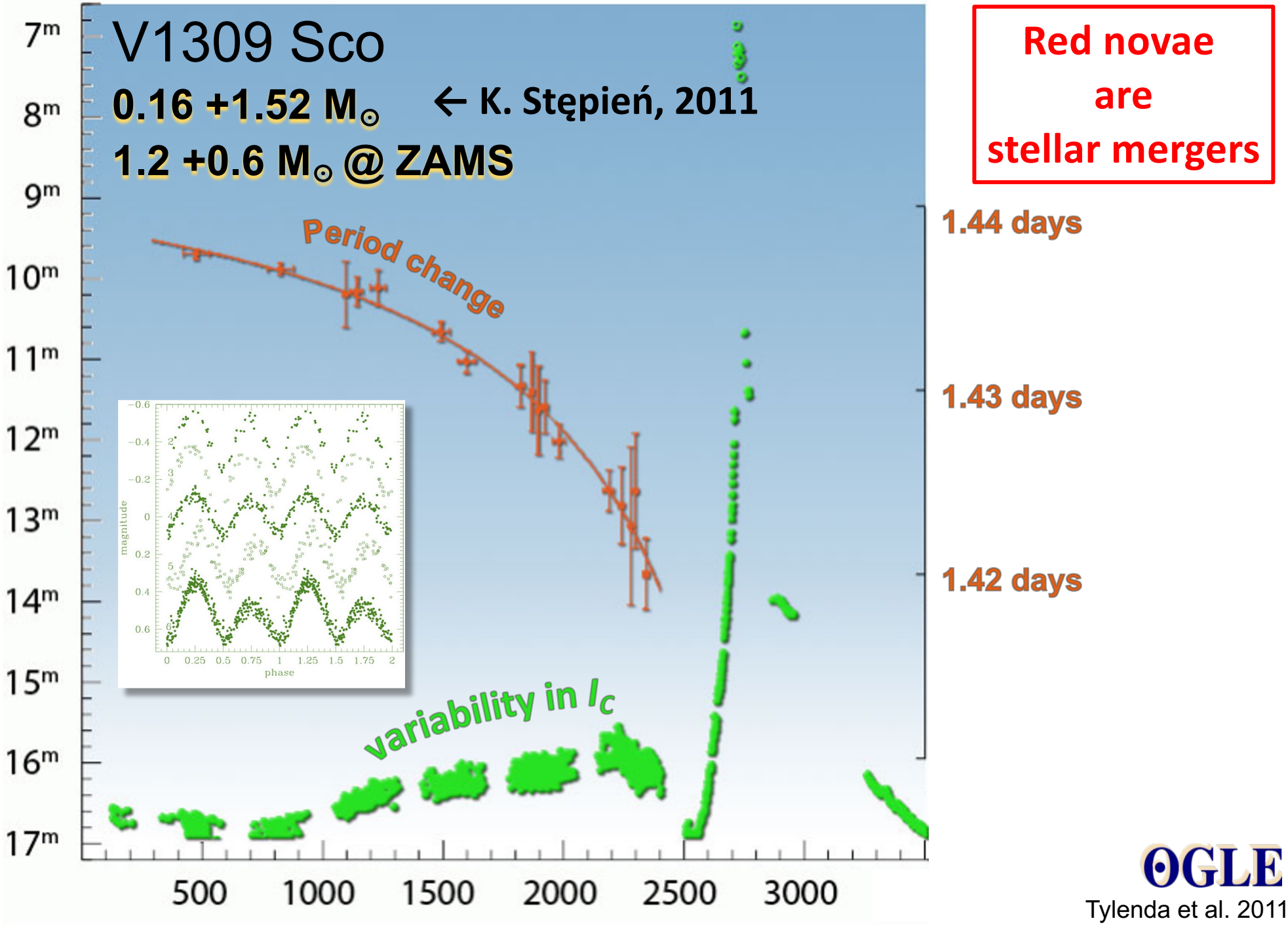


extragalactic (luminous) **red novae**:

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

and more !

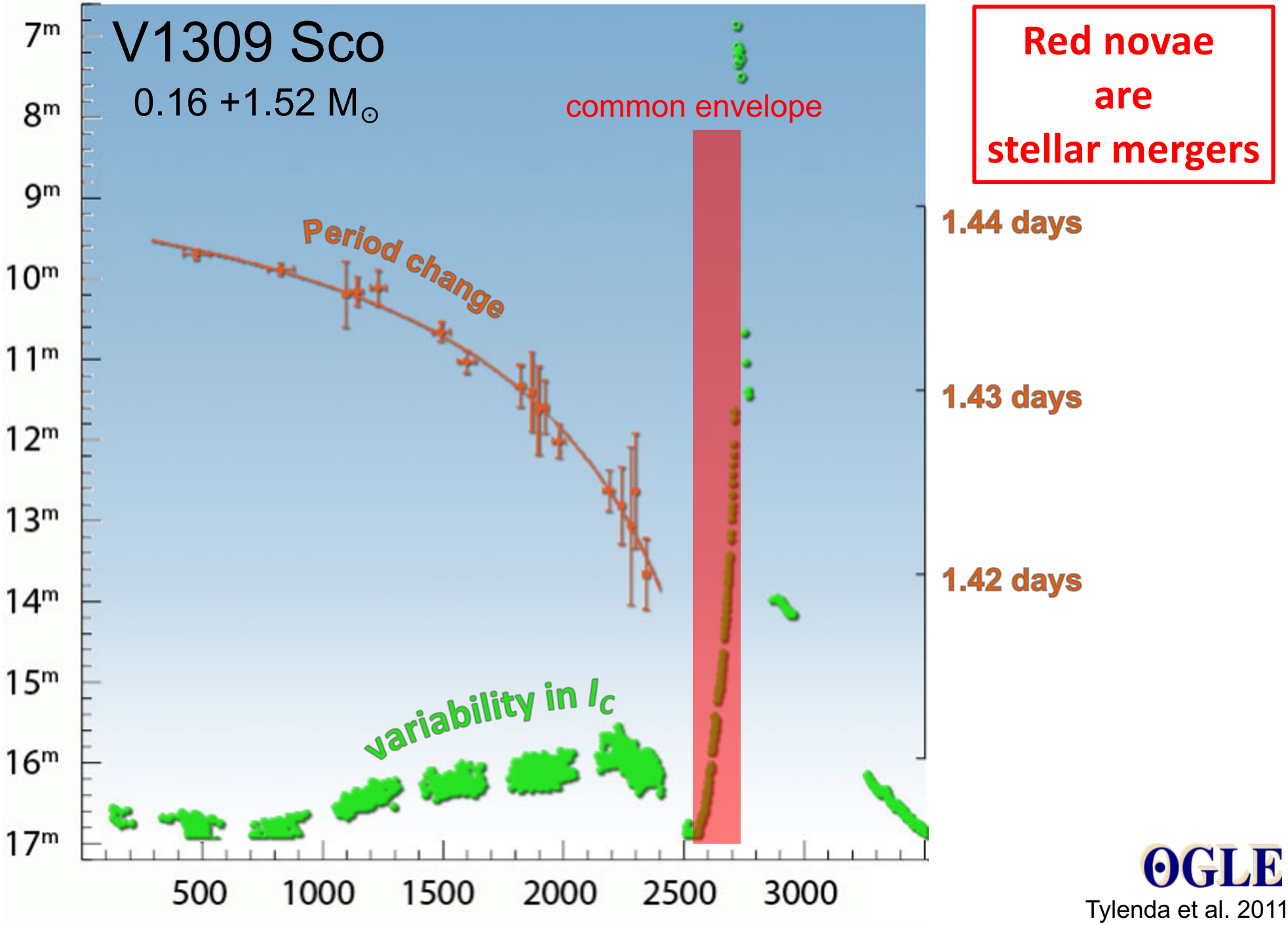
too weak to be observed after their outbursts



Red novae are stellar mergers

OGLE

Tylenda et al. 2011



Red novae are stellar mergers

OGLE

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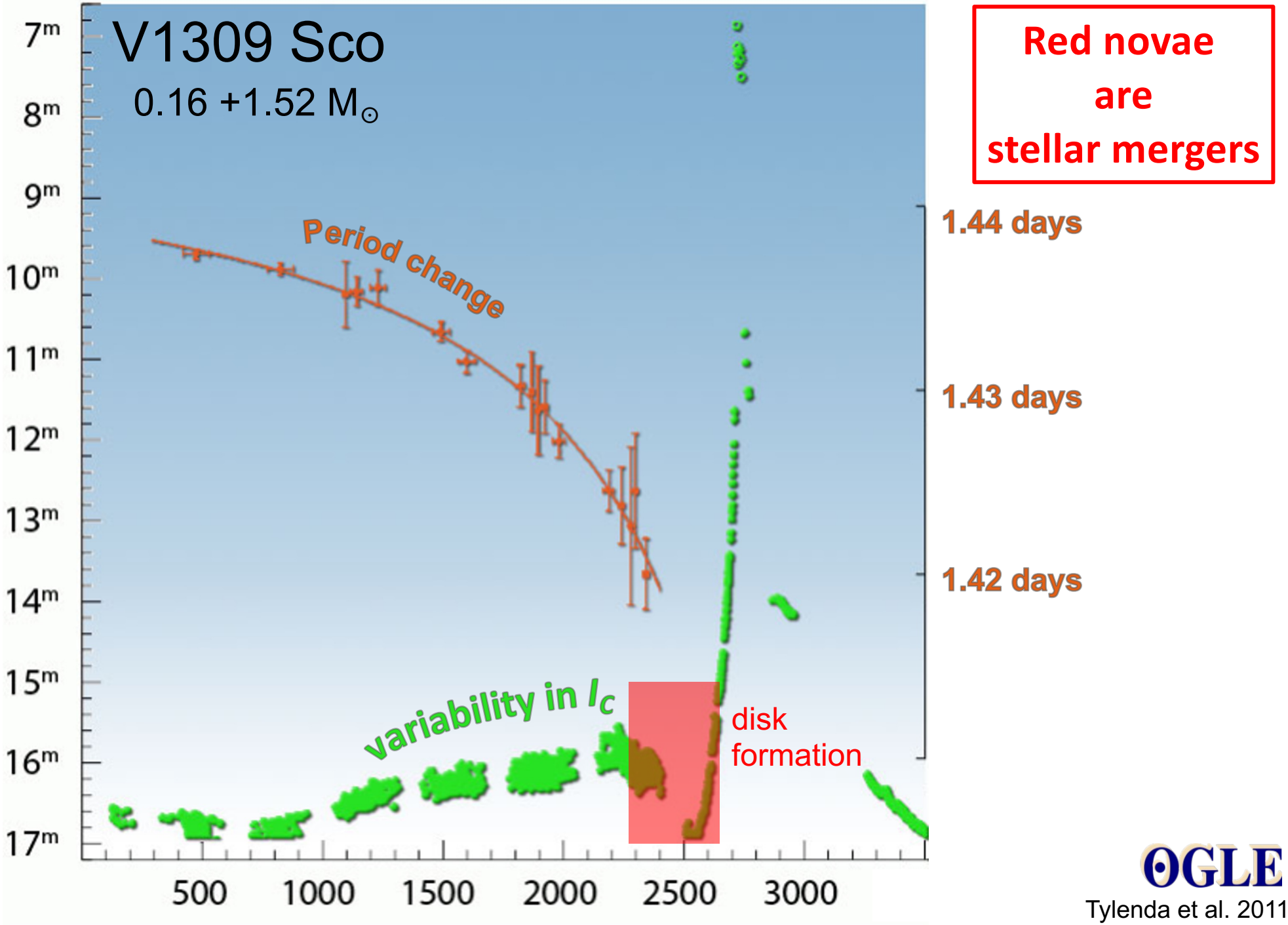

Red novae are stellar mergers

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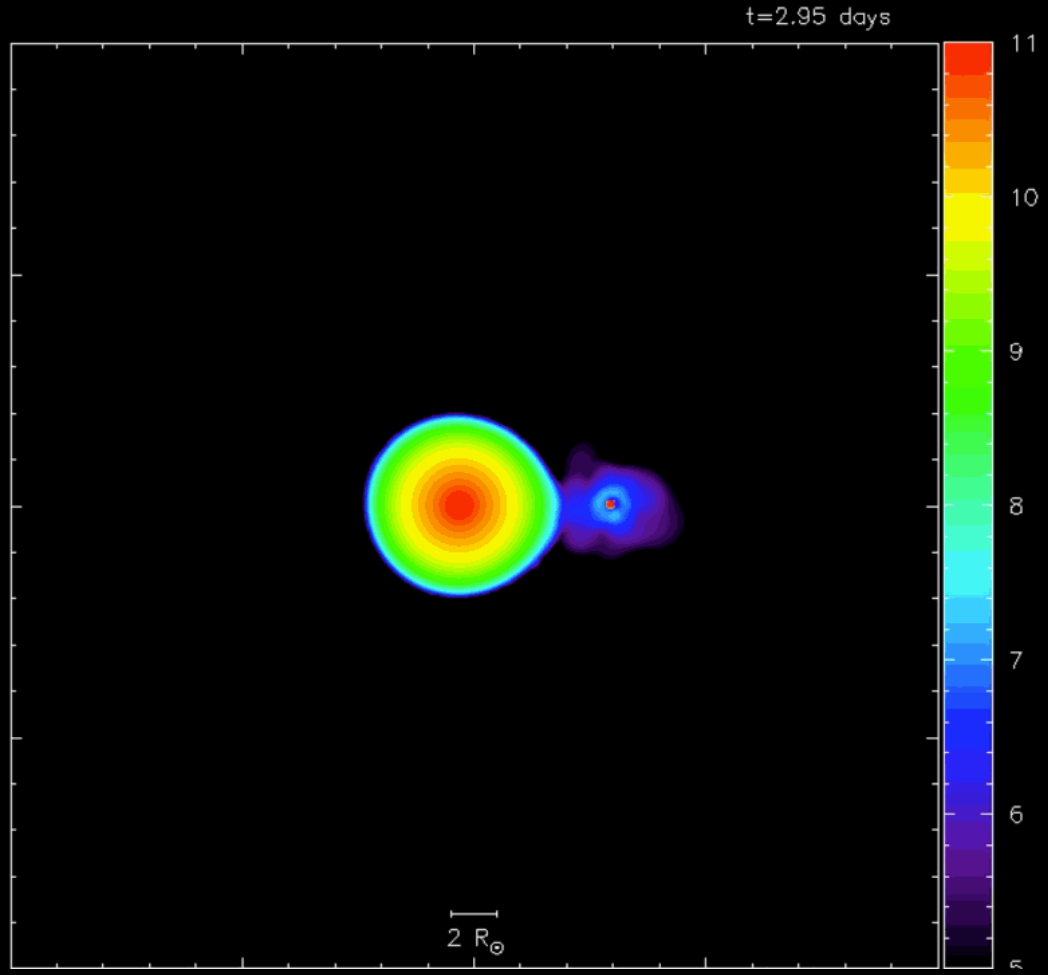
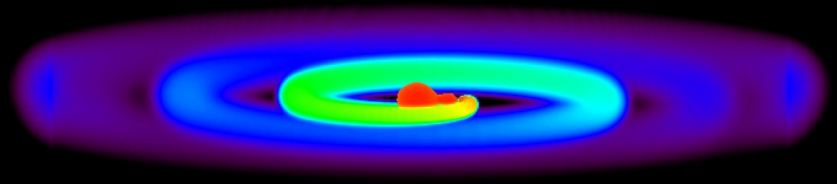


Nandez et al. 2013
view from above the binary

mergers
are associated
with mass loss

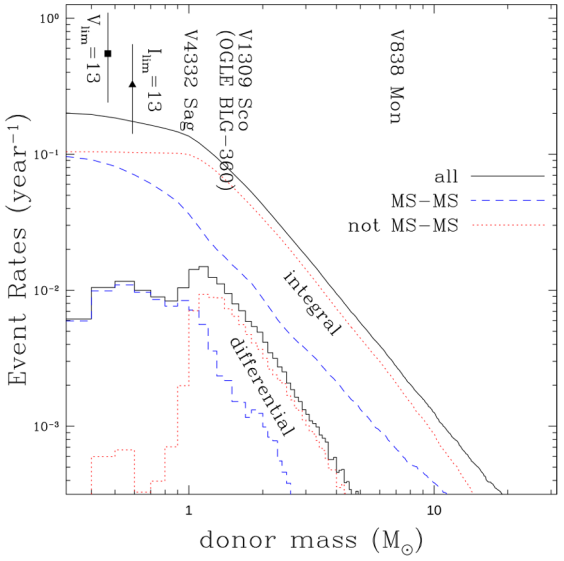


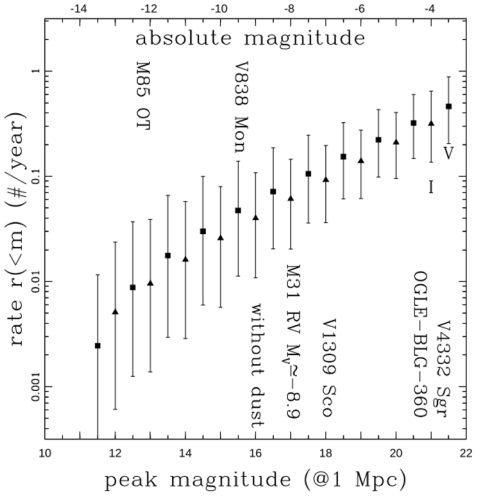
Pejcha et al. 2017
side view


How to enlarge the sample?
LSST to the rescue?

predicted red-nova rates:

- **observed rates corrected for completeness, biases**
- **population synthesis plus some model of merger physics**





Stellar Mergers are Common

C. S. Kochanek[1,2], Scott M. Adams[1,2] and Krzysztof Belczynski[3,4]

[1] *Department of Astronomy, The Ohio State University, 140 West 18th Avenue, Columbus OH 43210*

[2] *Center for Cosmology and AstroParticle Physics, The Ohio State University, 191 W. Woodruff Avenue, Columbus OH 43210*

[3] *Astronomical Observatory, Warsaw University, Al. Ujazdowskie 4, 00-478 Warsaw, Poland (kbelczyn@astrouw.edu.pl)*

[4] *Center for Gravitational Wave Astronomy, University of Texas at Brownsville, Brownsville, TX 78520*

Soker & Tylenda 2006: 1 in 10-50 yr in MW

Kochanek et al. (2014), based on bright MW events, no correction for incompleteness:

- 2 faint red novae per decade per galaxy (one V1309 Sco/10 yr)
- plenty of missed low-luminosity events
- $N \sim L^{-1.4}$ at $-11 < M_r < -16$ mag
- Bayesian statistics

Howitt et al. (2023) used population synthesis

- 8×10^{-4} Mpc^{-3} yr^{-1}
- 2 bright event per 10 yr per galaxy

But! No red nova in the MW since 2008

predicted red-nova rates:

- **observed rates corrected for completeness, biases**
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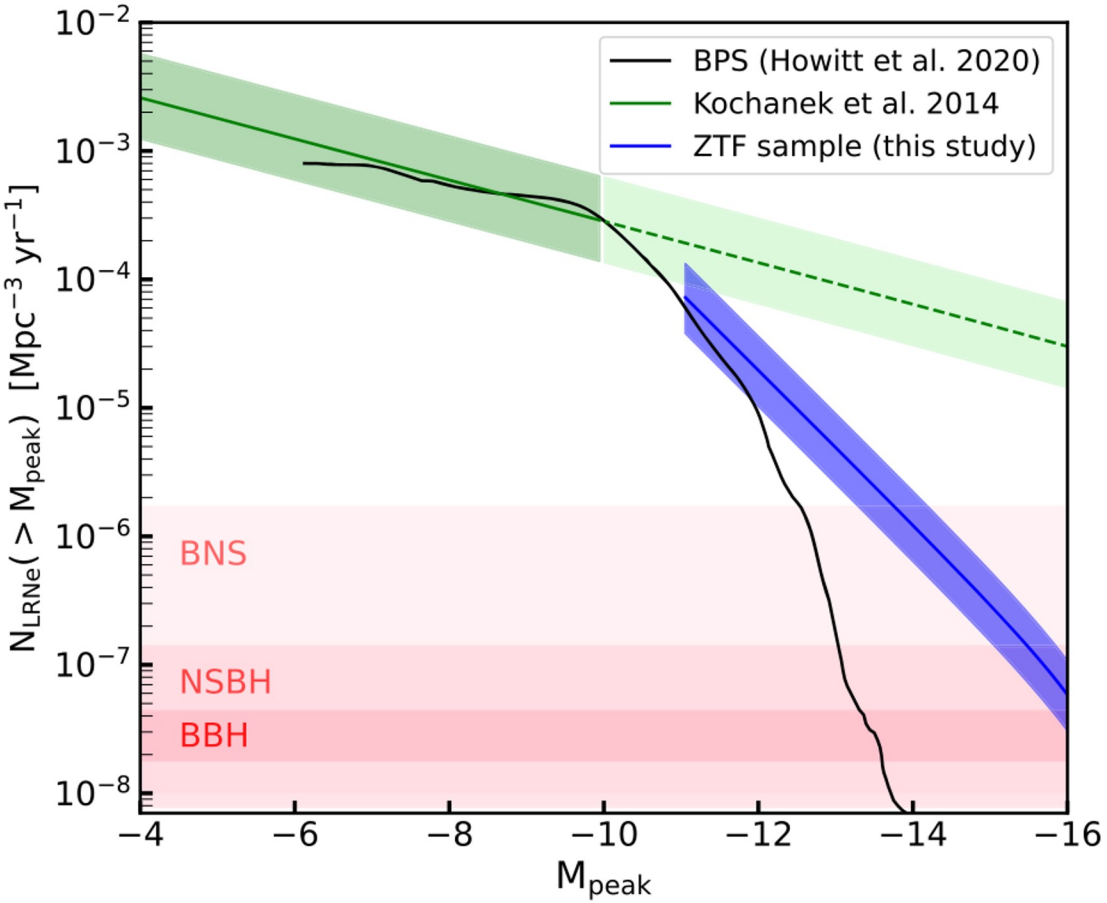
THE ASTROPHYSICAL JOURNAL, 948:137 (27pp), 2023 May 10



ZTF survey (extragalactic events only)

- bias corrected
- 5 per year
- $N \sim L^{-2.5}$
- not all real mergers?
- red novae more frequent than kilonovae
- Common-envelope progenitors of BH/NS mergers are also red novae?

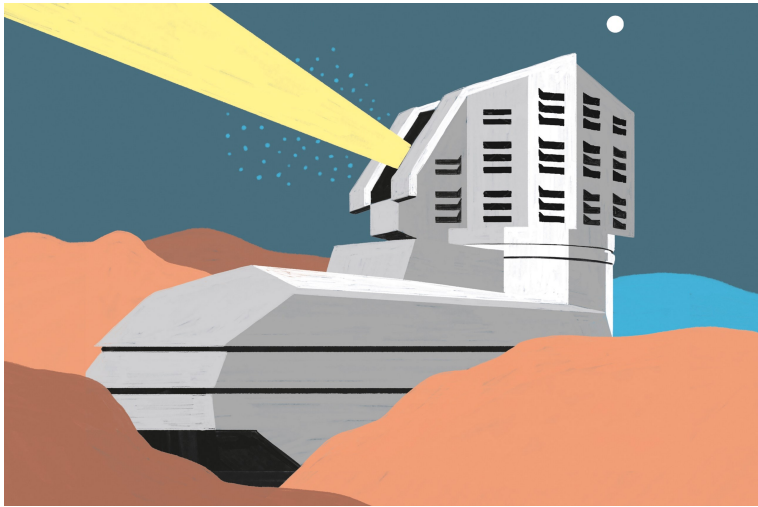
Karambelkar et al. 2023

Red novae in LSST**, 10 yr cadence

300-1500 red novae detected (Mr<13.5 mag)
  how many of these will be recognized?
  strong contamination from accretion events, especially from YSOs
  few will be bright enough for spectroscopic follow ups

a few cases of contact binary decay as in V1309 Sco (cadence 10 yr!)

use LSST rates to get populations synthesis / merger physics right
  possible binomial distributions for mergers vs common envelope systems



**Based on calculations of
Howitt et al. 2020, Karambelkar et al. 2023

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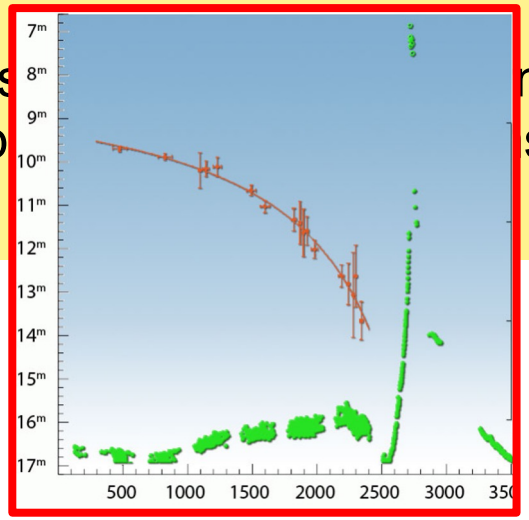

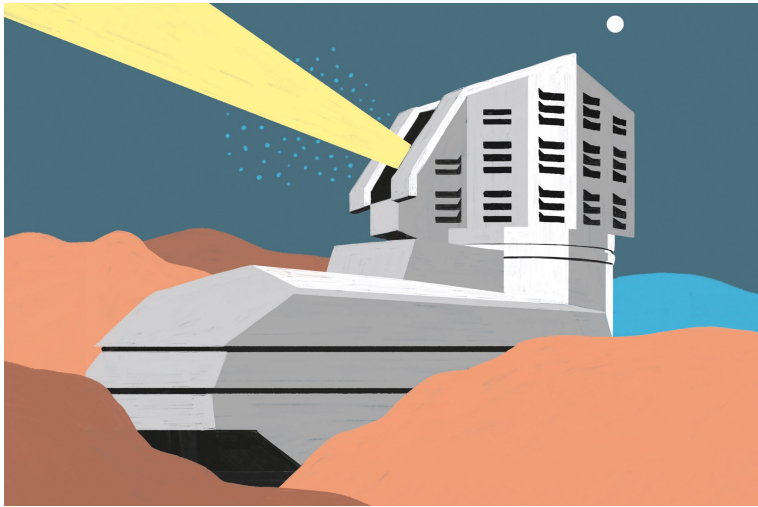

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Thank you