

Mergers, Ejections and Disturbances

Observations of common envelope physics across the stellar lifecycle

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A blast from the past: CK Vulpeculae

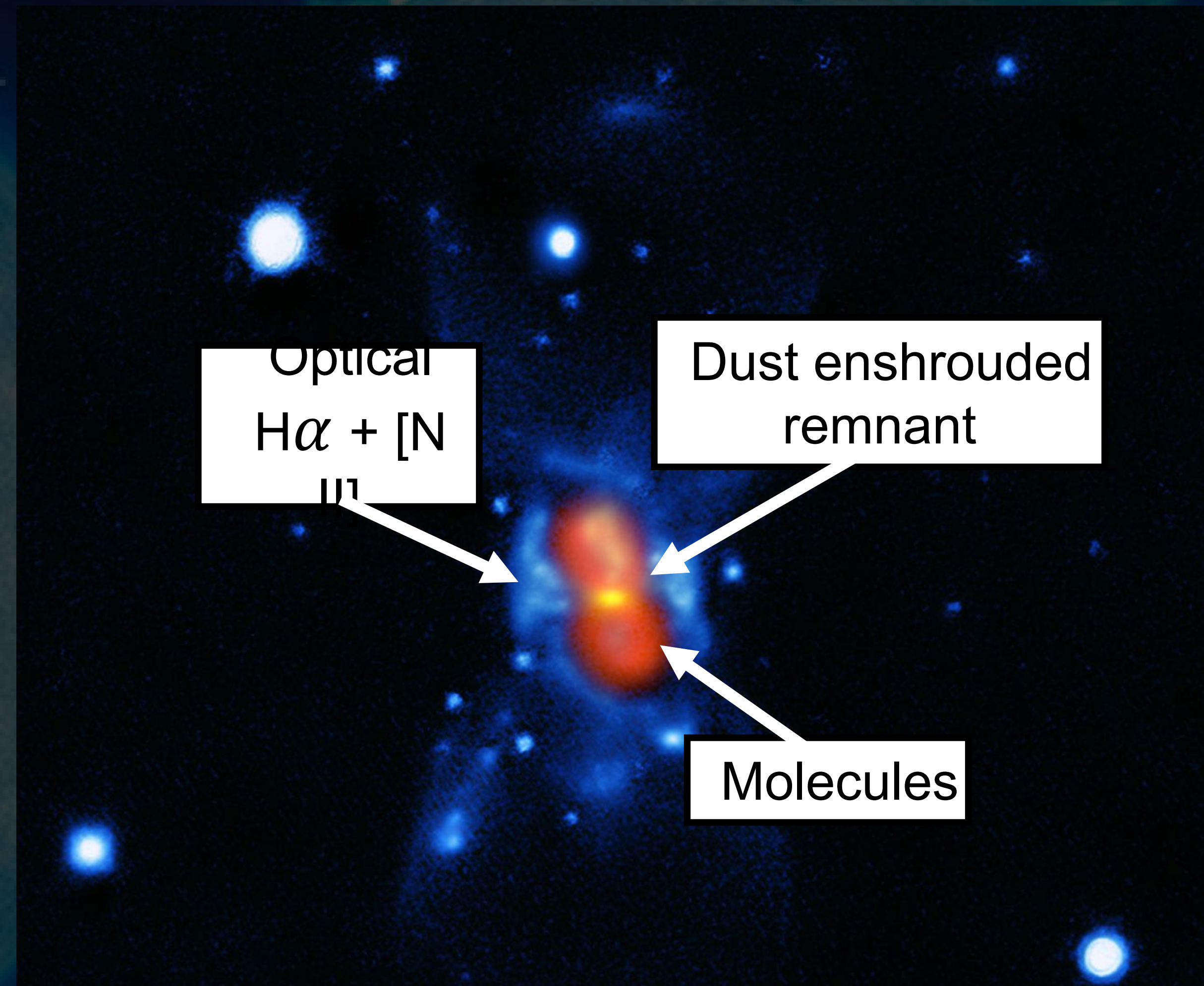
Hevelius 1670, Shara+
1985

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

Country	United States
State	Maryland
County	Anne Arundel
Founded	1649
Incorporated	1708
Named for	Princess Anne of Denmark & Norway



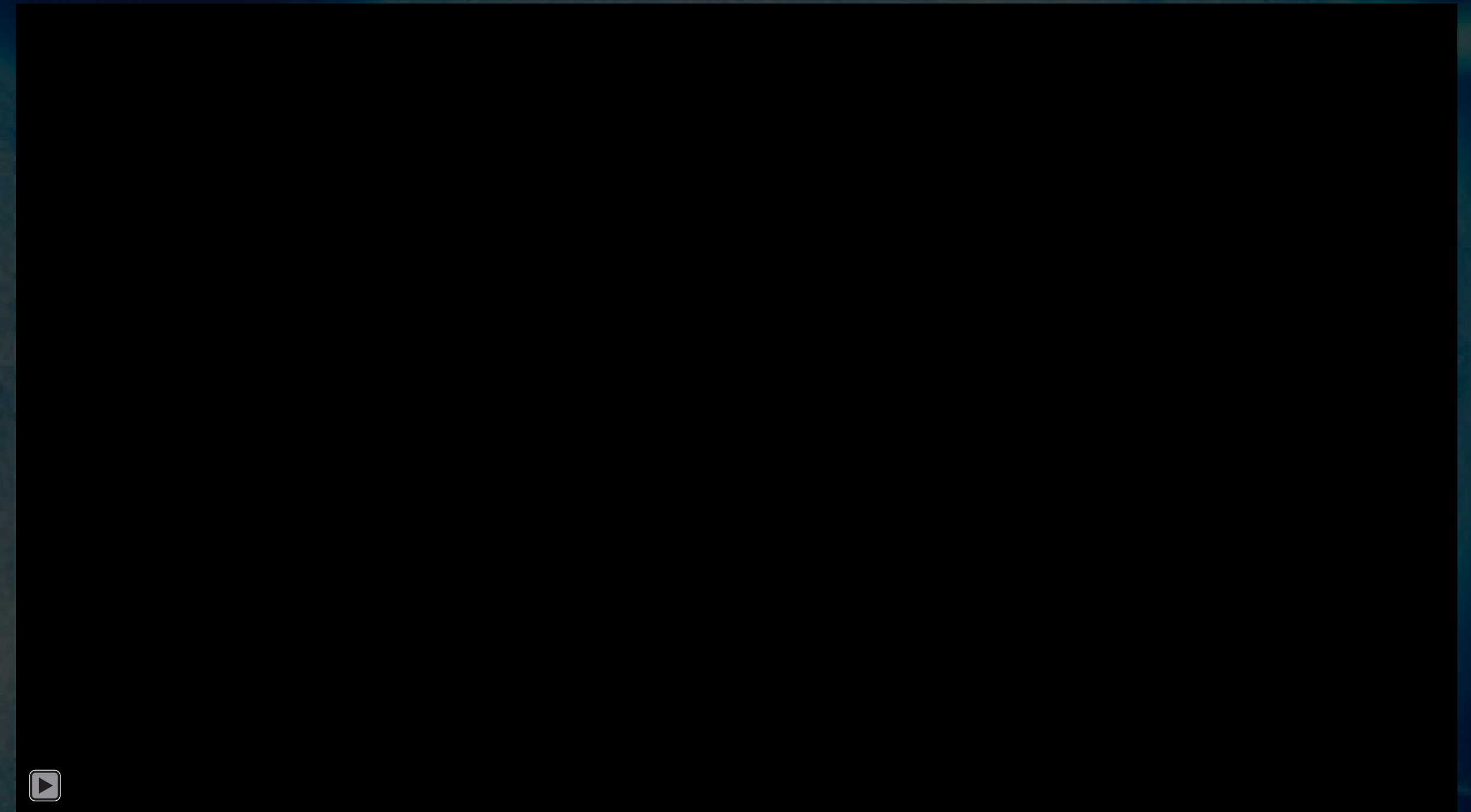
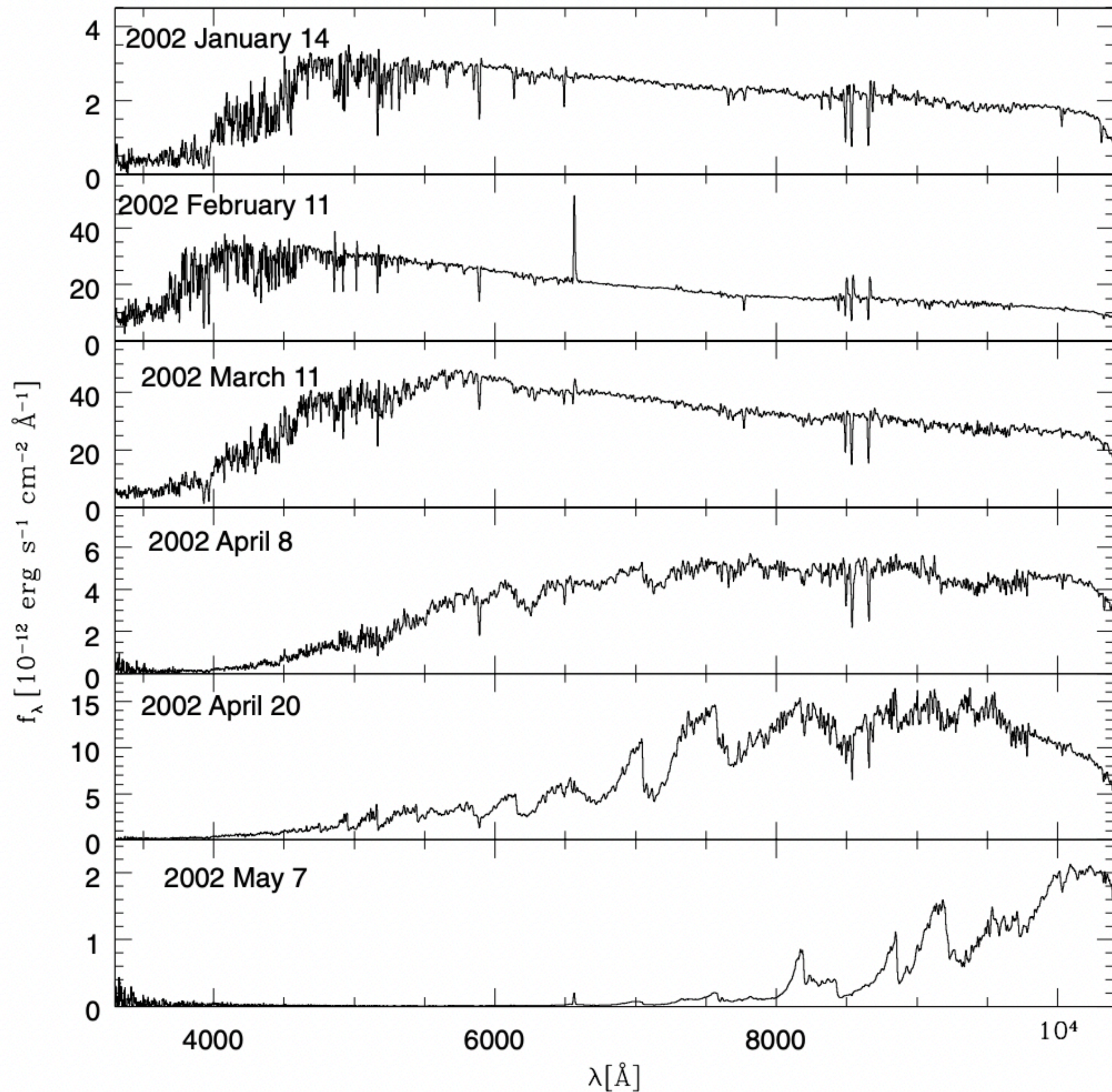
First (Western)
historical record of a
nova?



Credit: ESO/T.
Kaminski

Harrison 1996; Evans+ 2002; Kato 2003; Hajduk+ 2007, 2013;
Evans+ 2016; Kaminski+ 2017; Eyres+ 2018; Tylanda+ 2019;
Kaminski+ 2020, 2021; Banerjee+ 2020

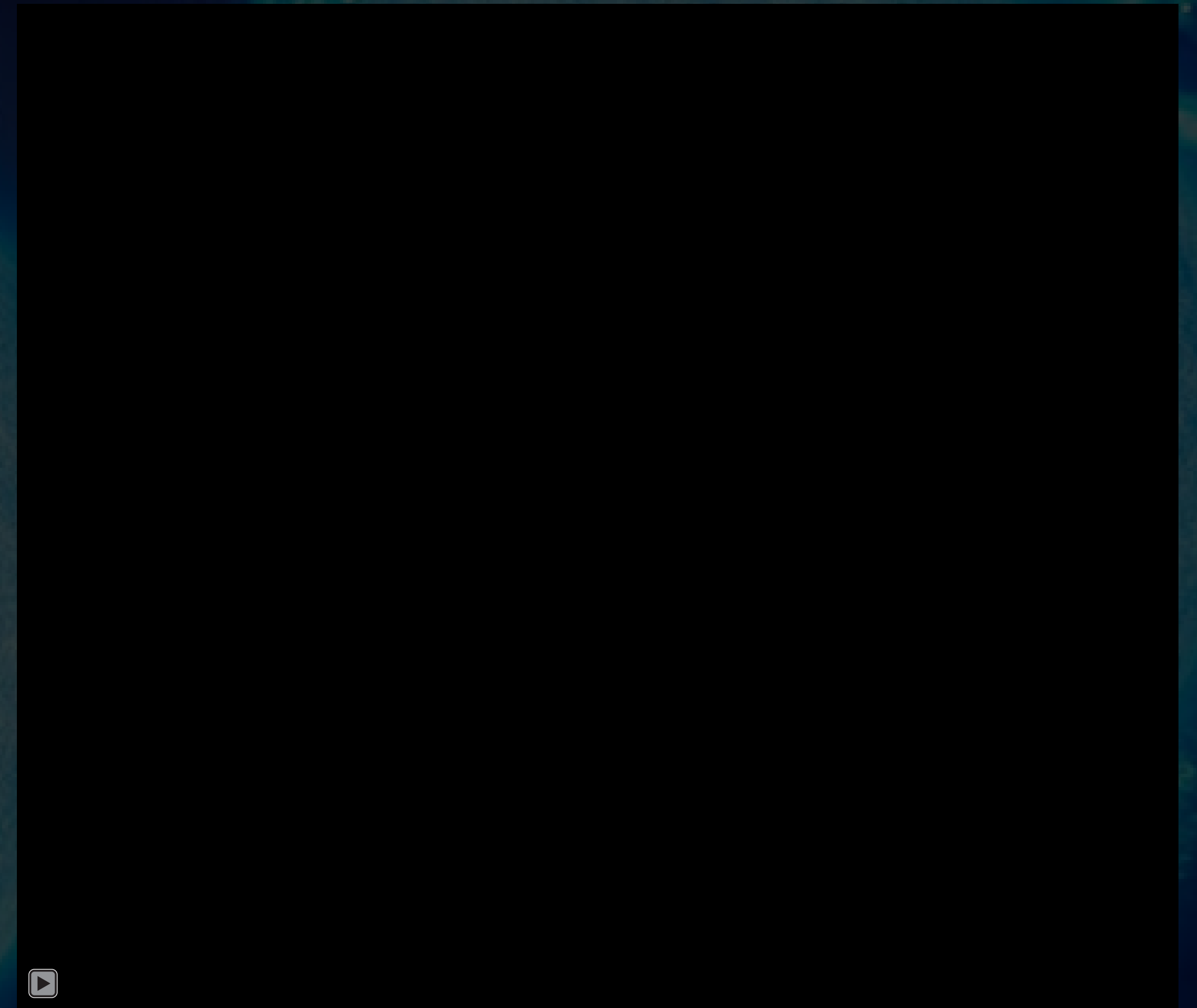
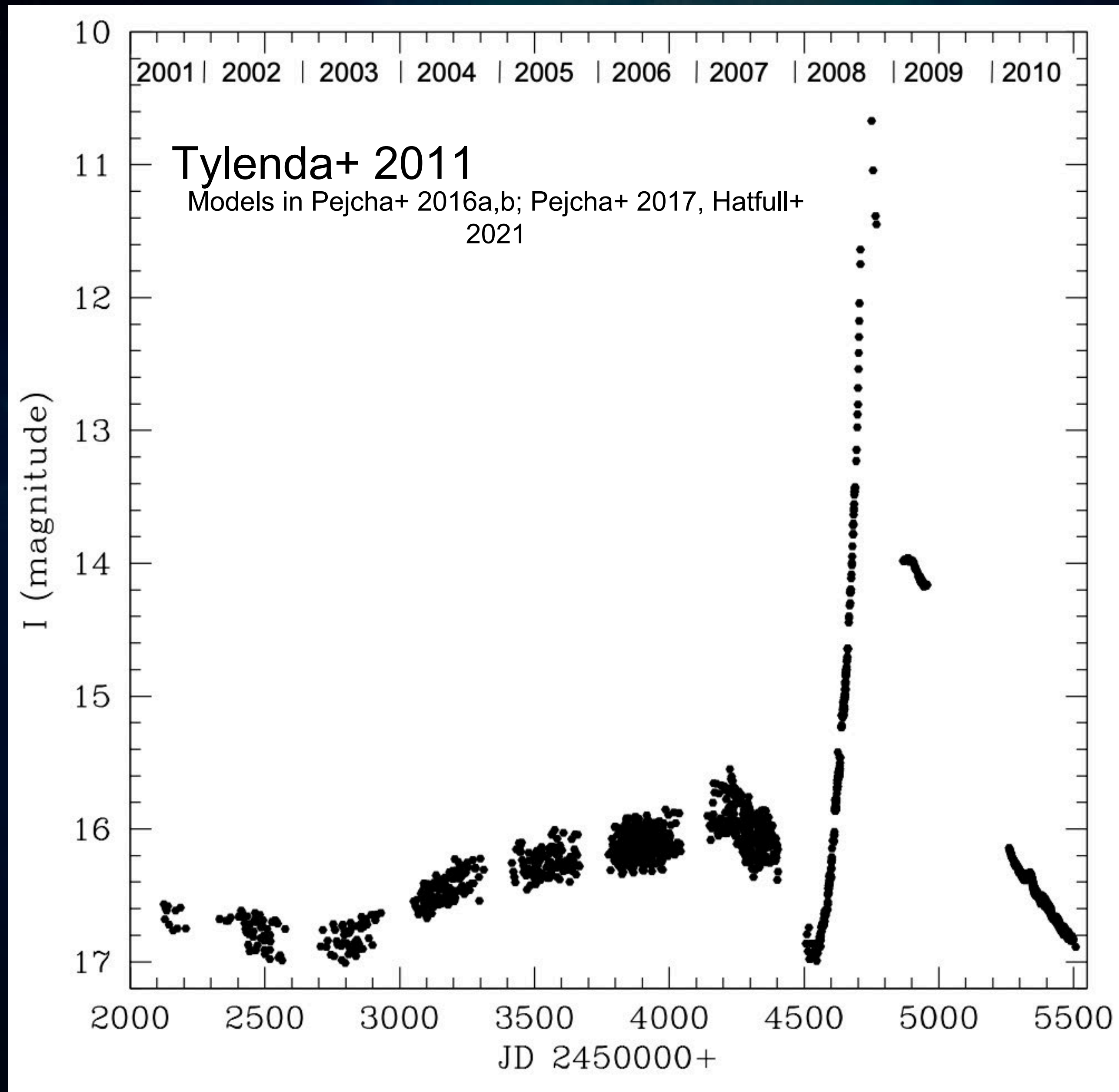
The V838 Mon class of objects



Rushen + 2000; Mahan + 2002, 2003; Banerjee + 2002; Graessle + 2003; Evans+ 2003; Tylanda 2004; Lynch+ 2004; Tylanda & Soker 2006

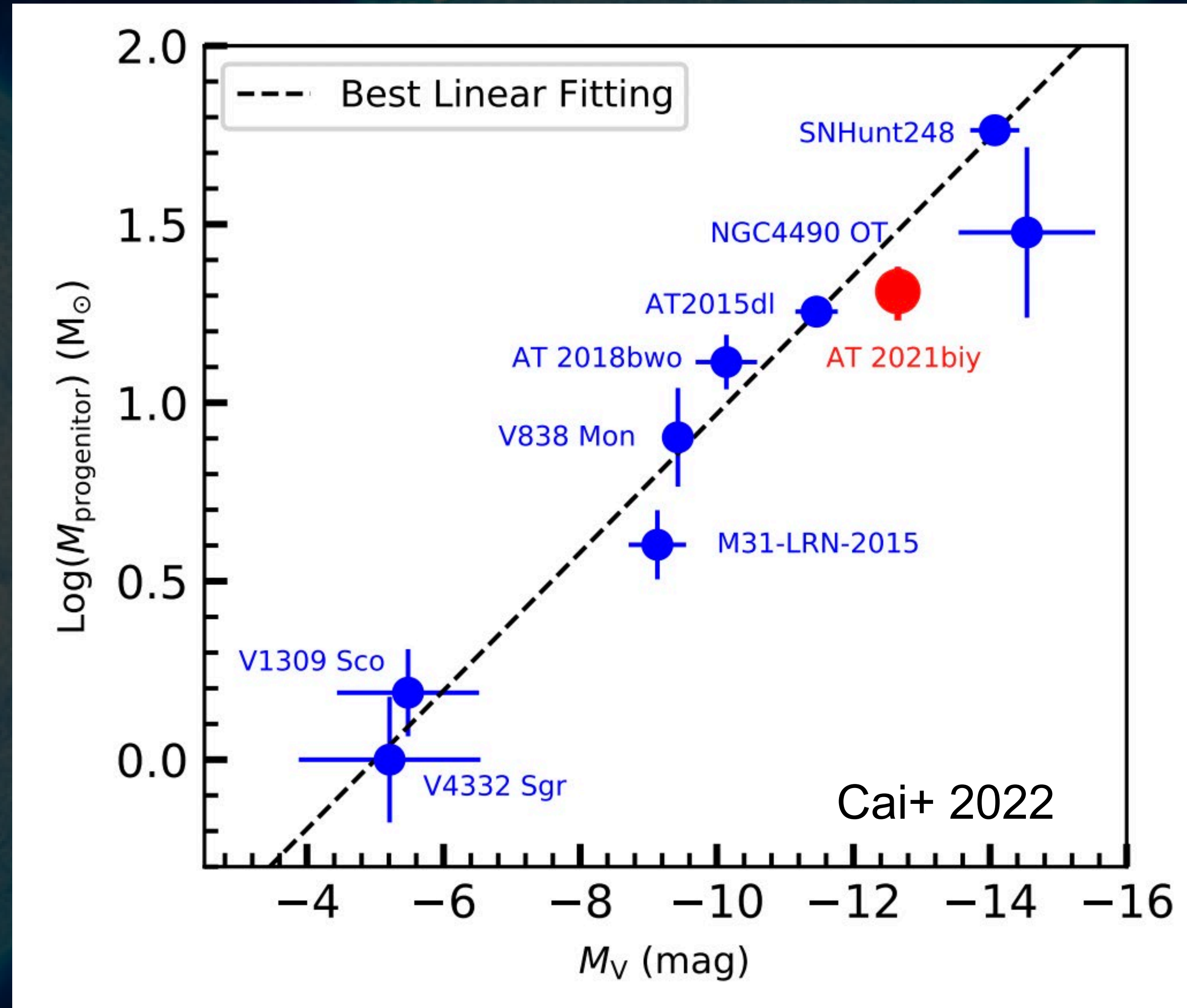
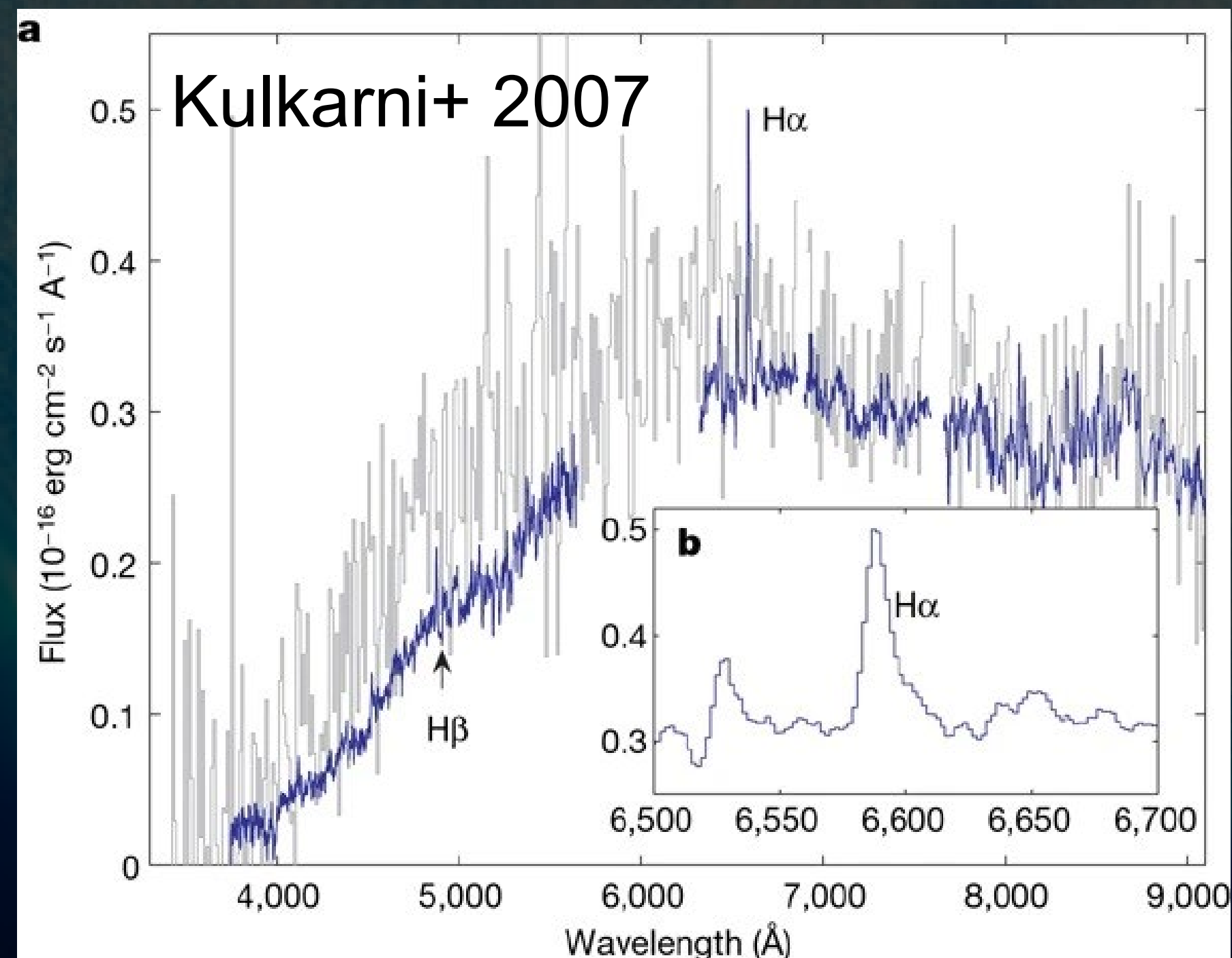
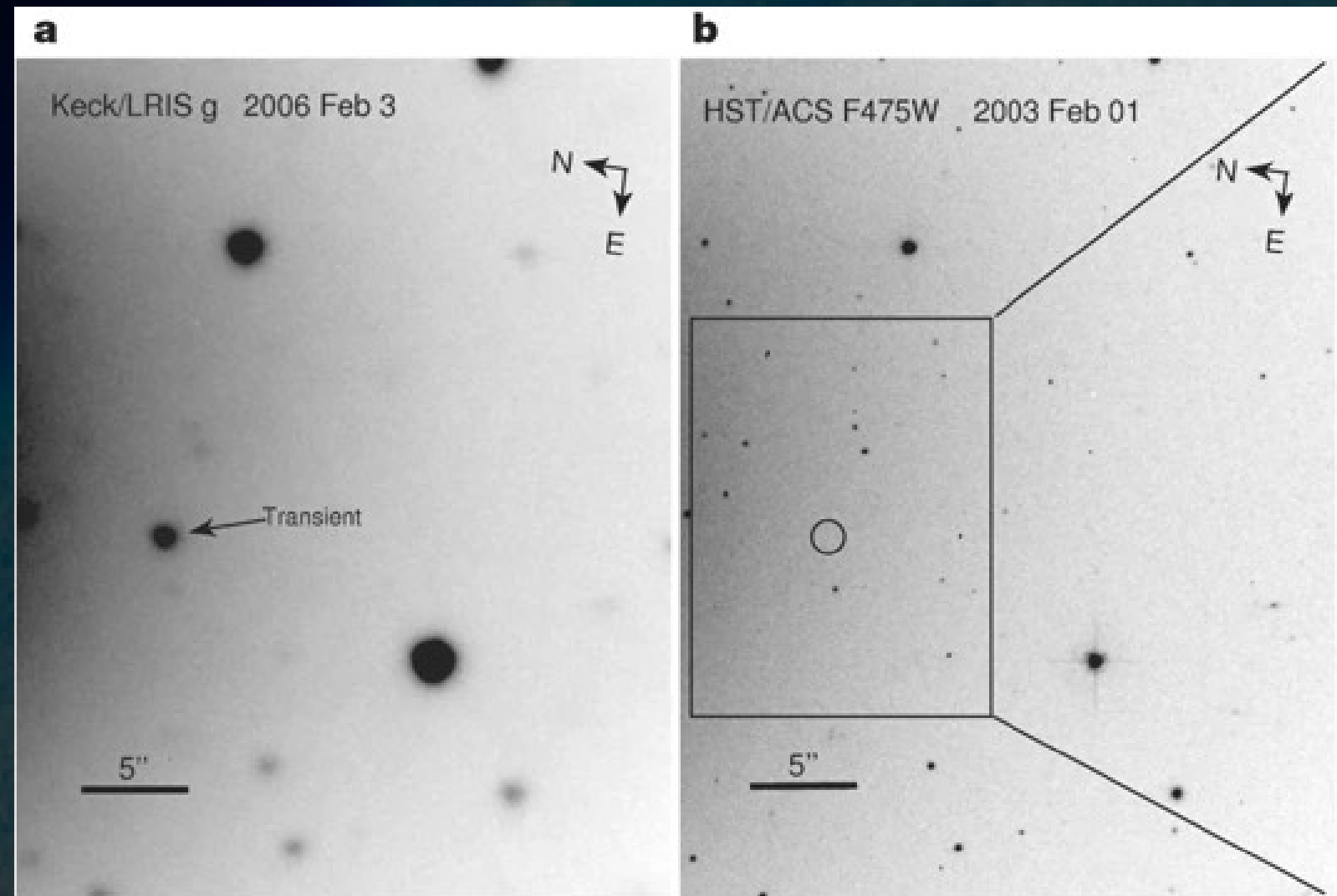
- Characteristic red-ward evolution of spectrum
- “Cold” photosphere few months after outburst
- Dust enshrouded remnant for years - decades

The Rosetta Stone: V1309 Scorpii



Links many Galactic objects to the merger class: V4332 Sgr (Martini+ 1999, Tylenda+ 2004), M31 RV (Rich+ 1989), V838 Mon, OGLE-2002-BLG-360 (Tylenda+ 2013)

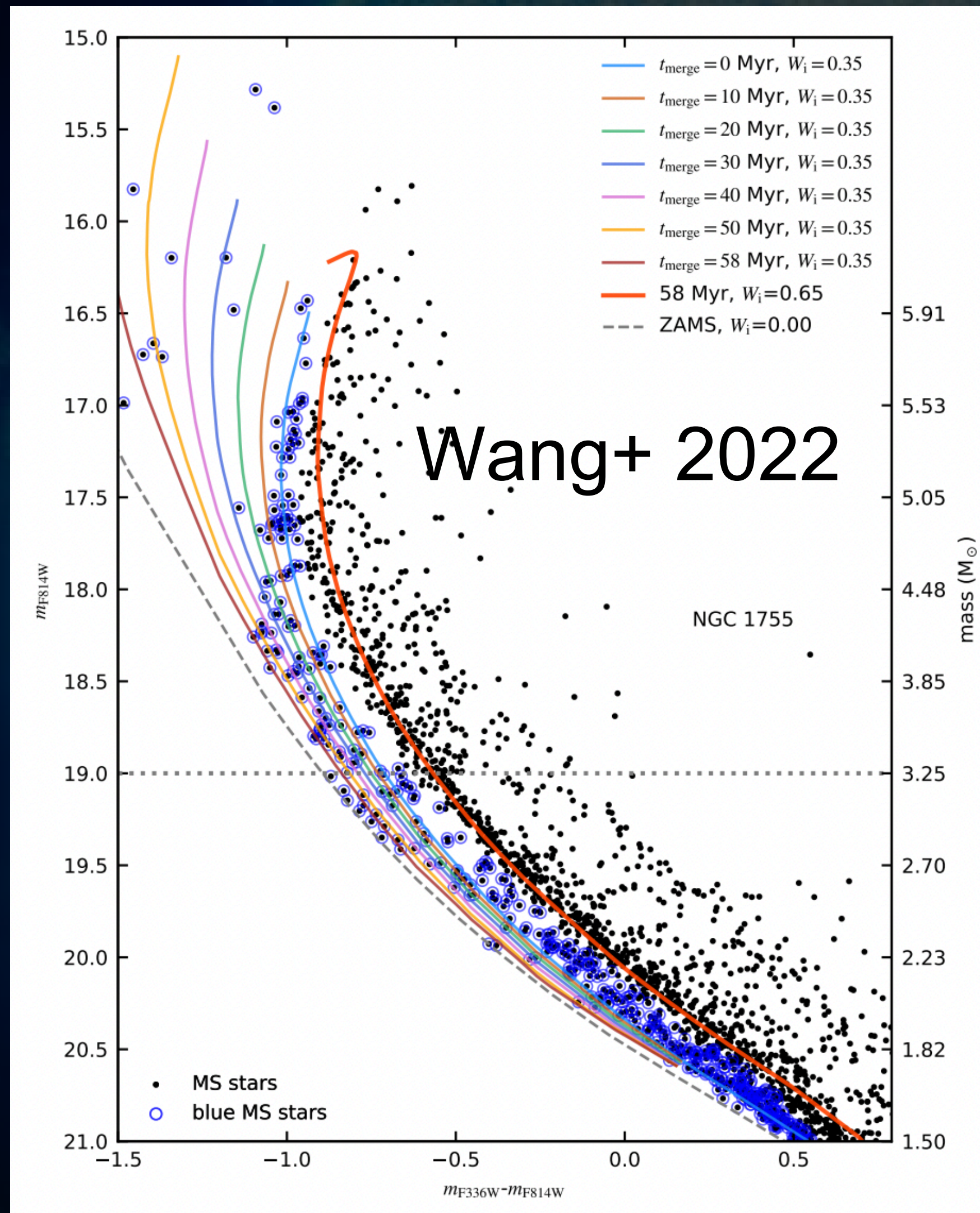
The Extragalactic Analogs: Luminous Red Novae



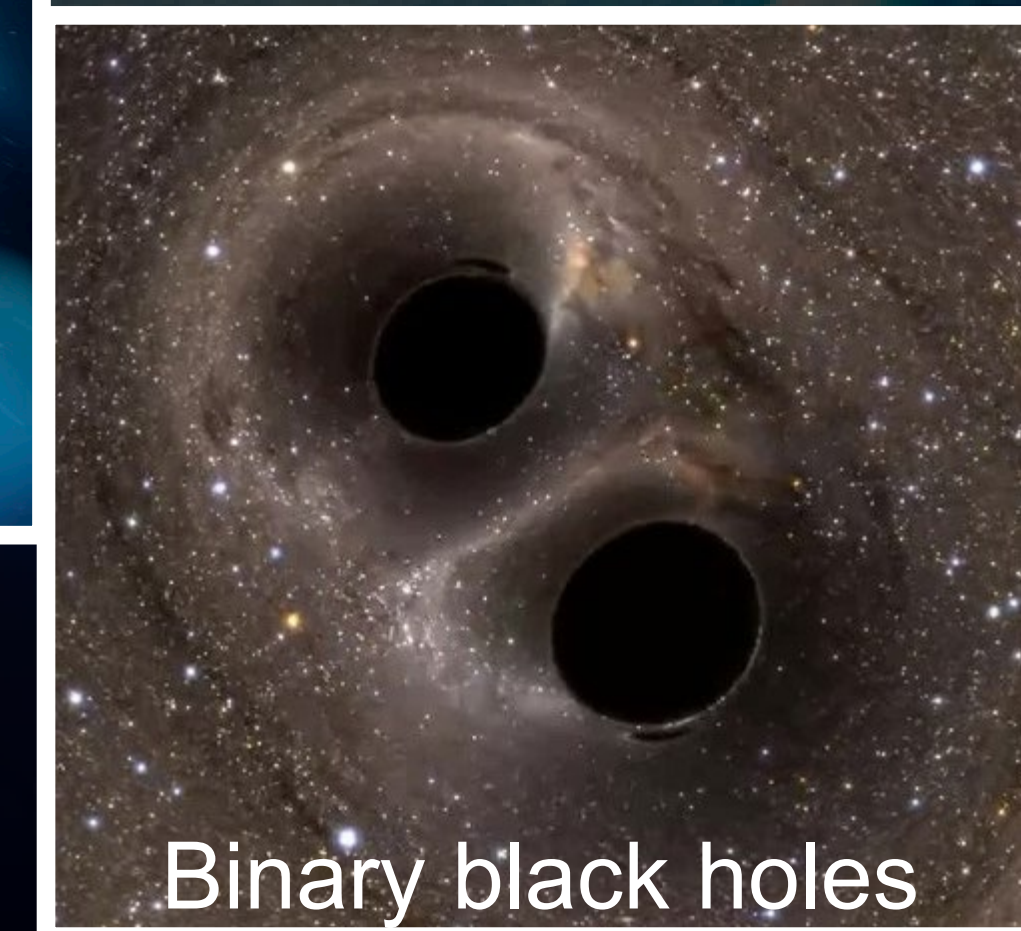
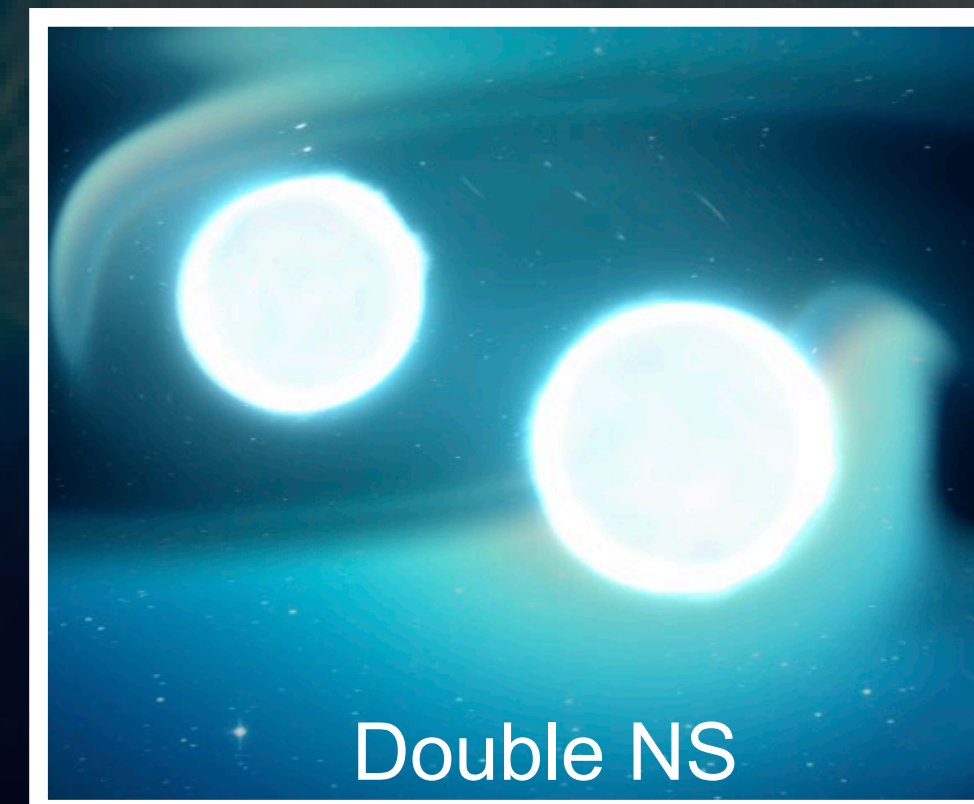
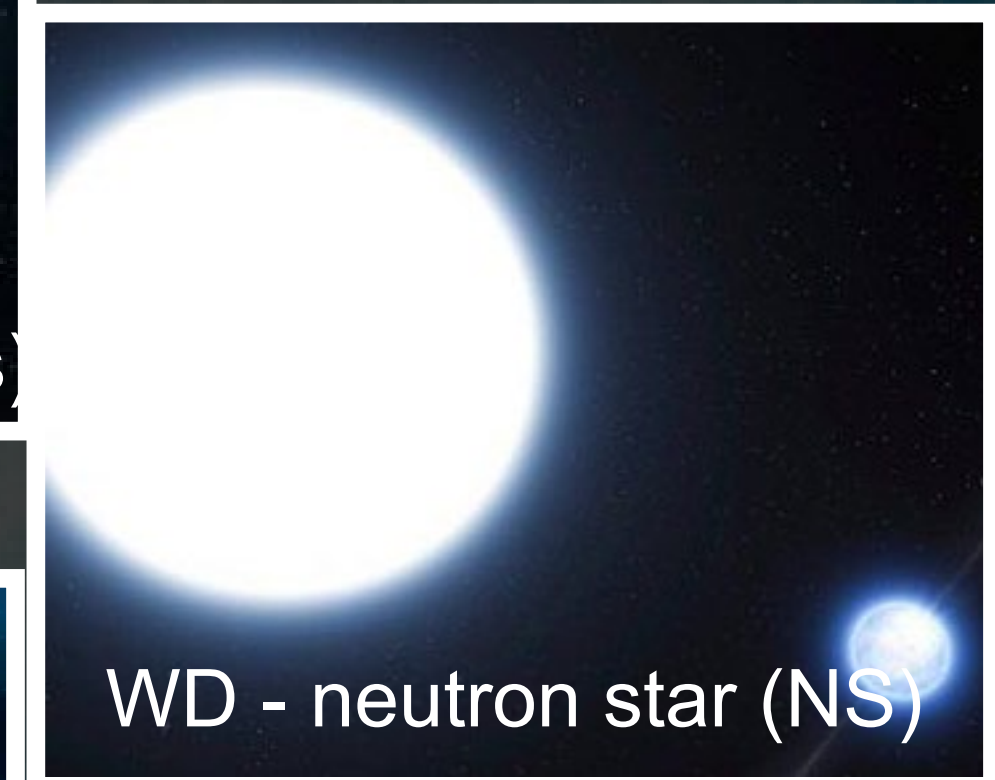
Kasliwal+ 2011; Ivanova+ 2013; Williams+ 2015; Goranskij+ 2016; Pejcha+ 2016; Smith+ 2016; Lipunov+ 2017; MacLeod+ 2017; Blagorodnova+ 2017, 2020, 2021; Pastorello+ 2019a,b, 2021a,b; Stritzinger+ 2020; Cai+ 2019, 2022;

In the multi-messenger landscape

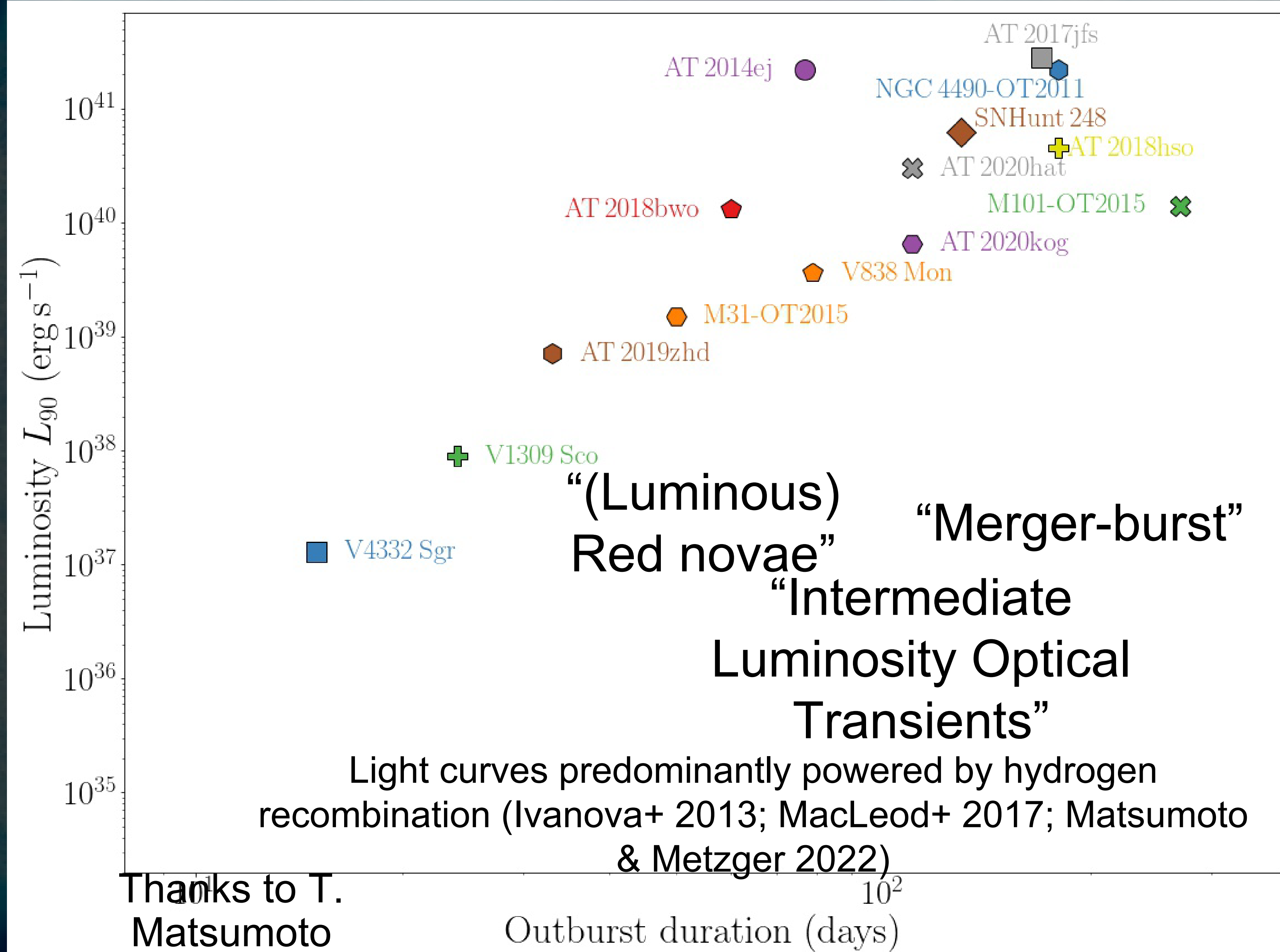
Mergers fundamentally alter stellar life cycles and produce multi-messenger remnants



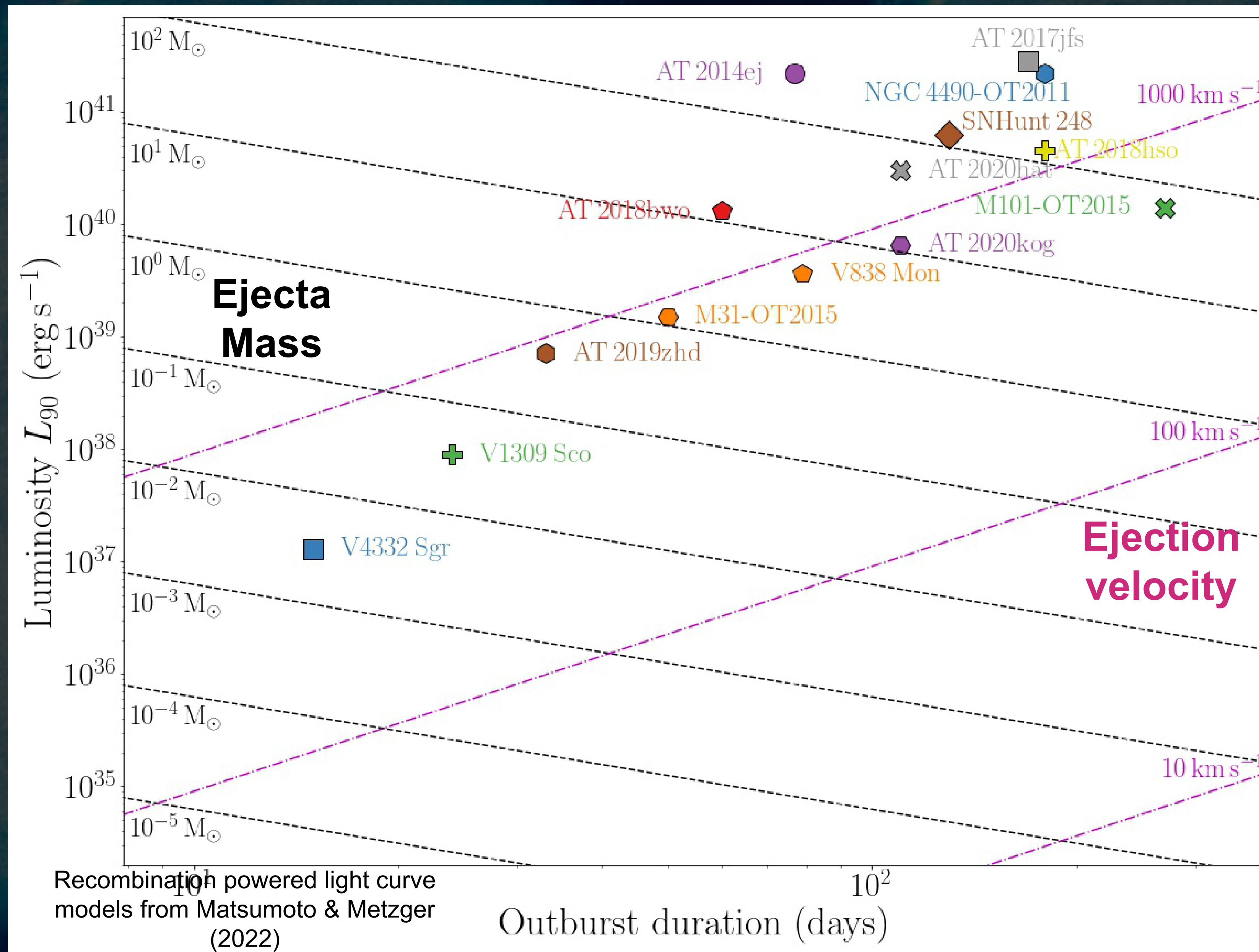
~1/3 of stars in stellar clusters consistent with merger products, have different mass function



The Landscape of Merger Driven Transients



The Landscape of Merger Driven Transients



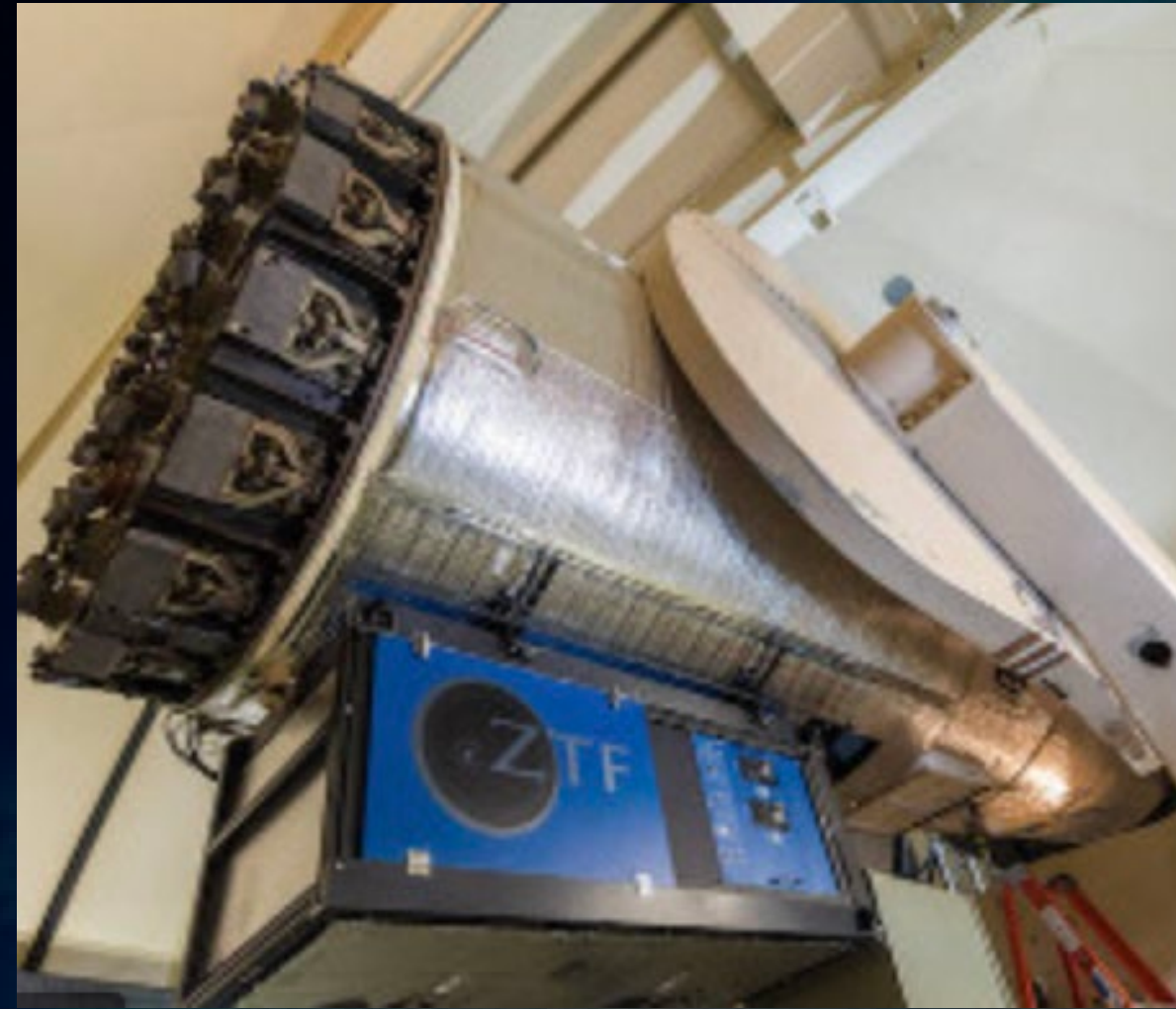
Where do we go next?

- The extremes of common envelope events
- A complete inventory of red novae in our Galactic backyard
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- Demographics of luminous red novae in nearby galaxies
- The Before and After: Binary death spirals and dusty remnants

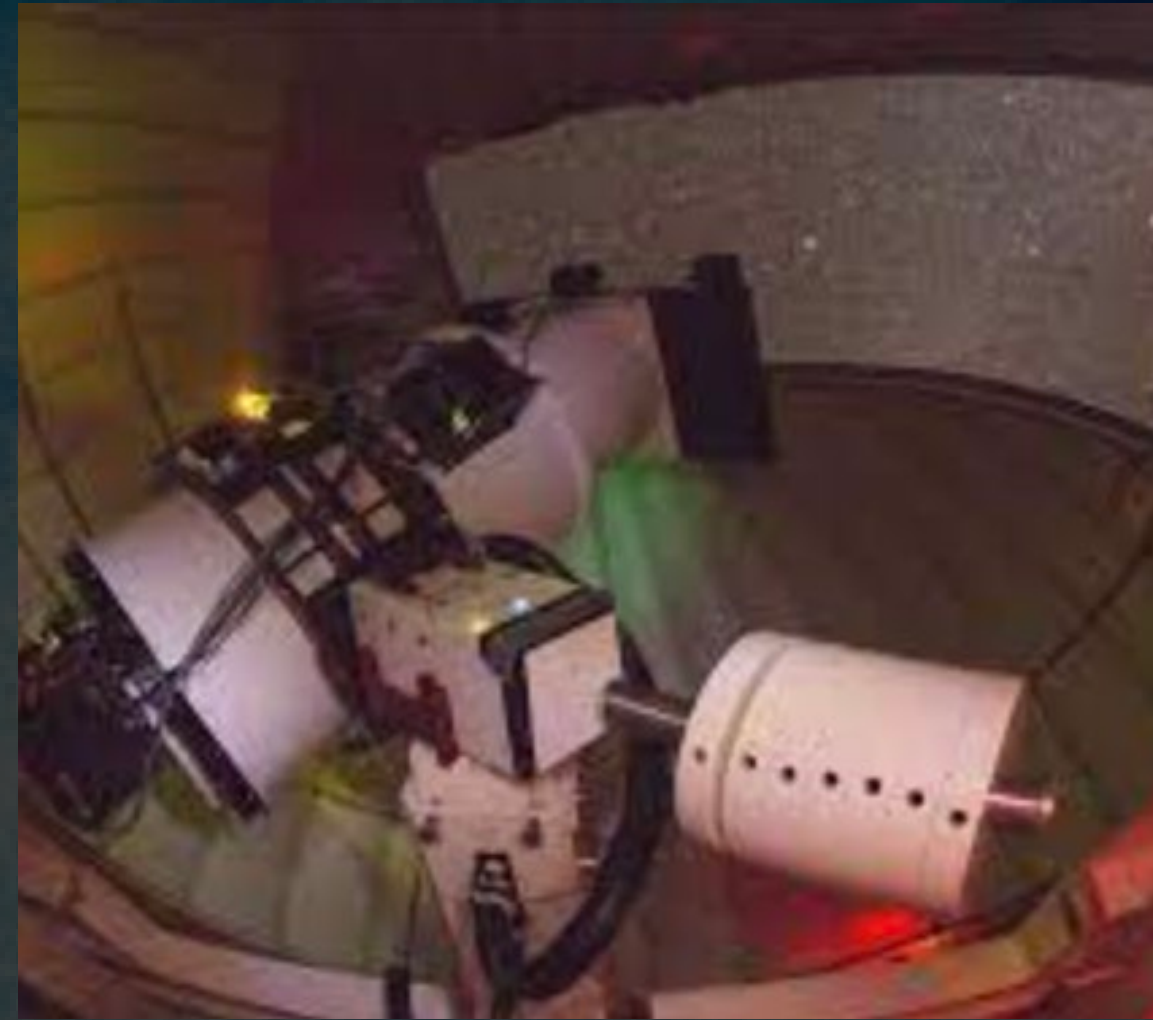
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The Golden Era for all-sky surveys



ZTF



ATLAS



ASASSN



OGLE



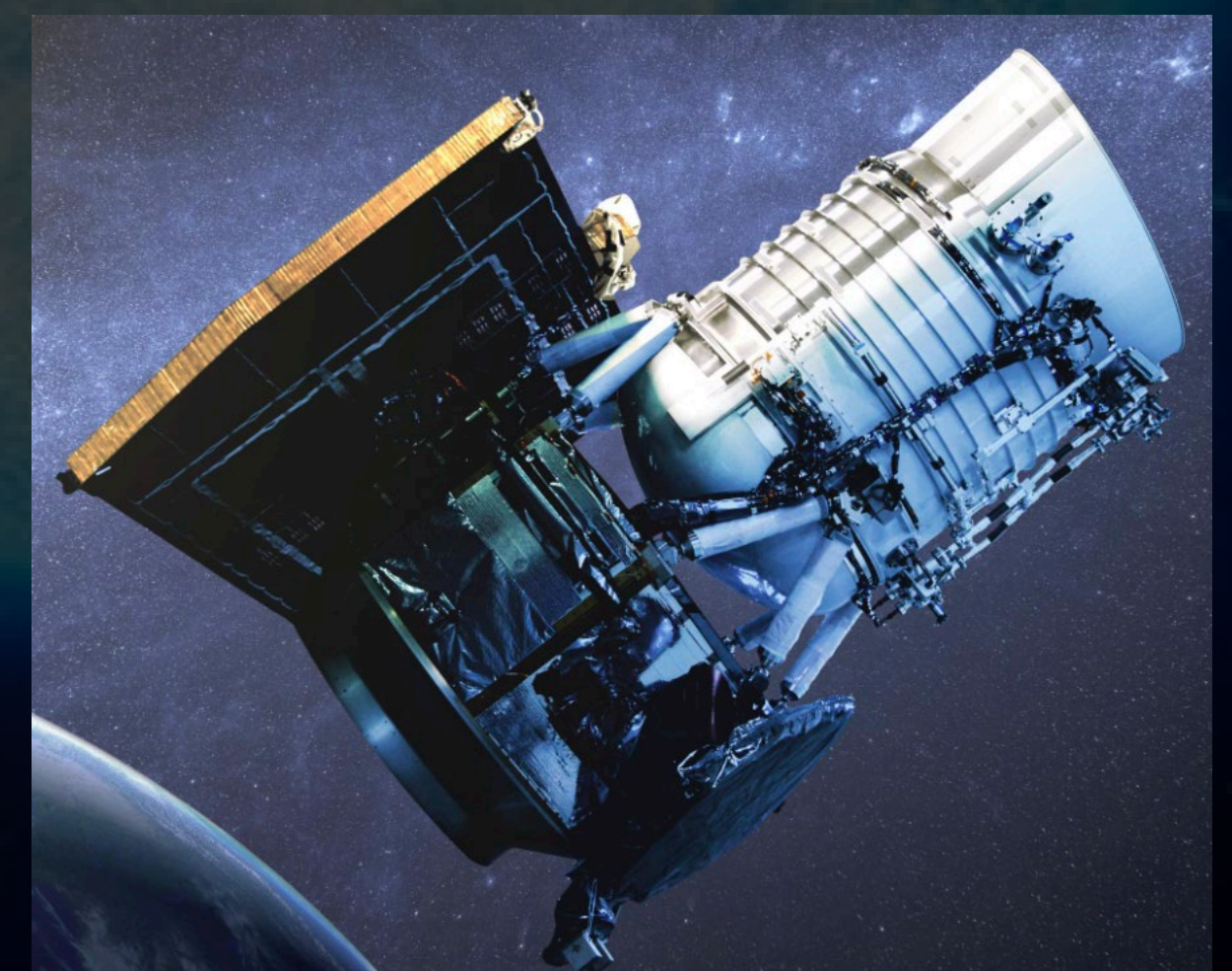
MeerLICHT



GOTO

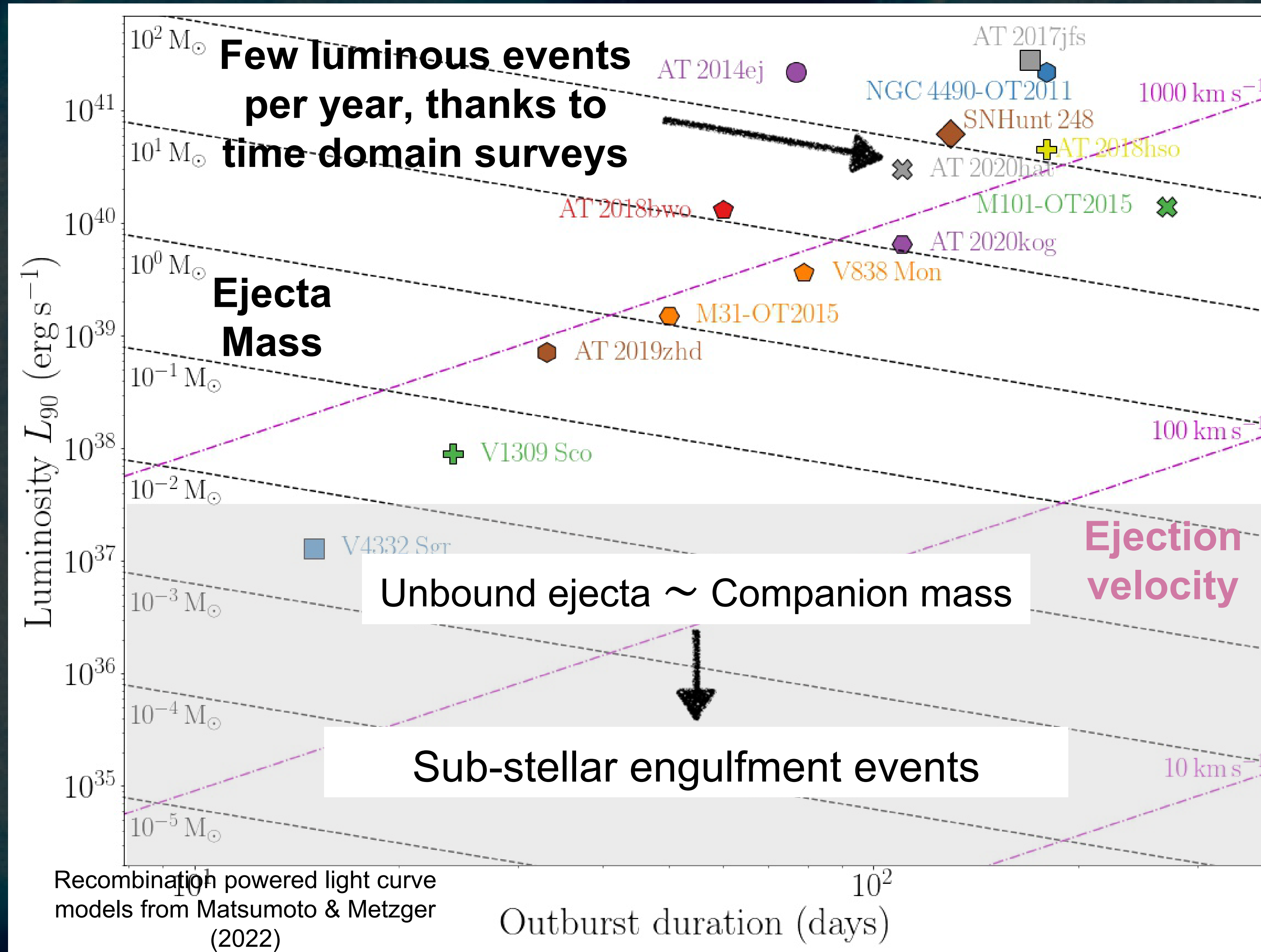


Gattini-IR

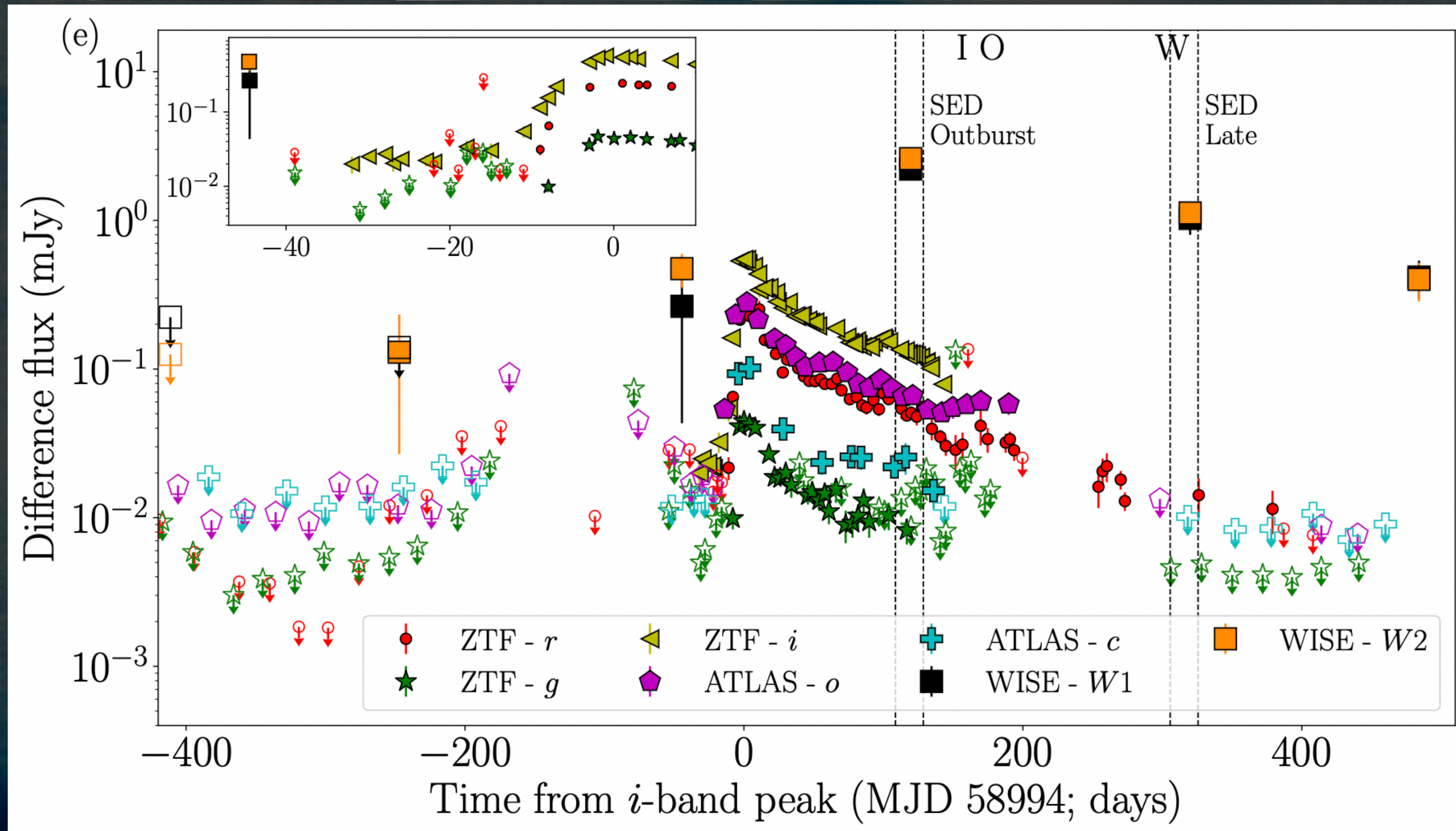
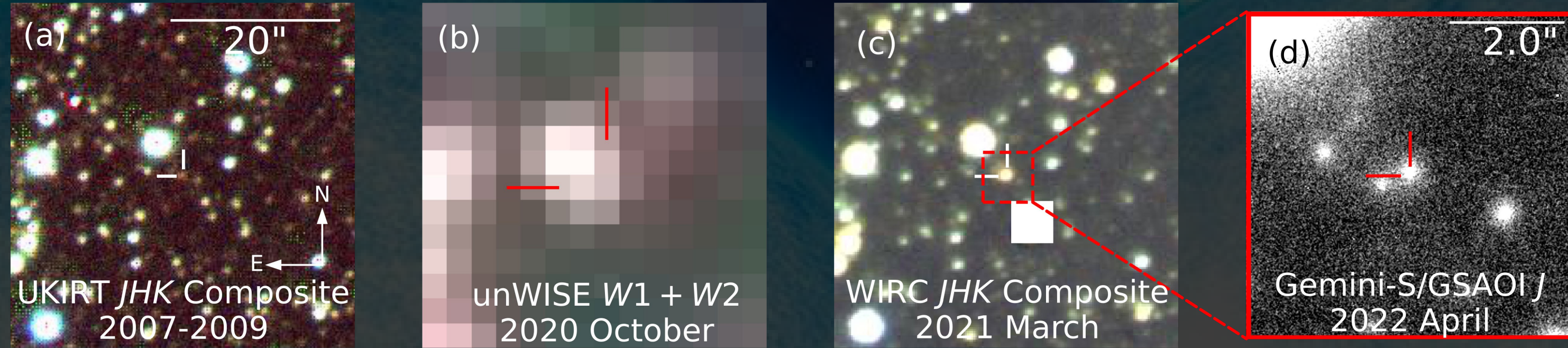


WISE

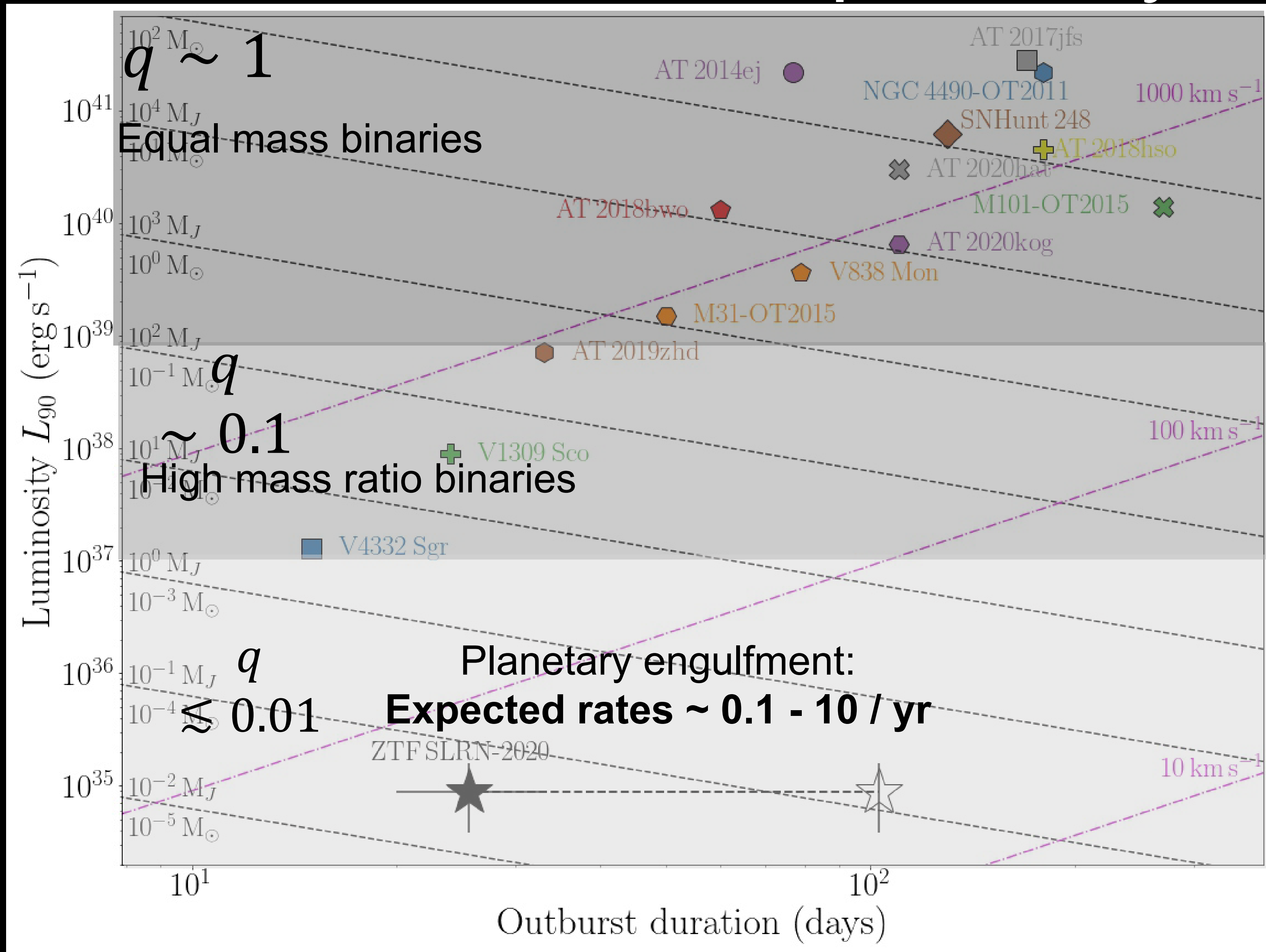
The Landscape of Merger Driven Transients



A star “disturbed” by a planetary companion



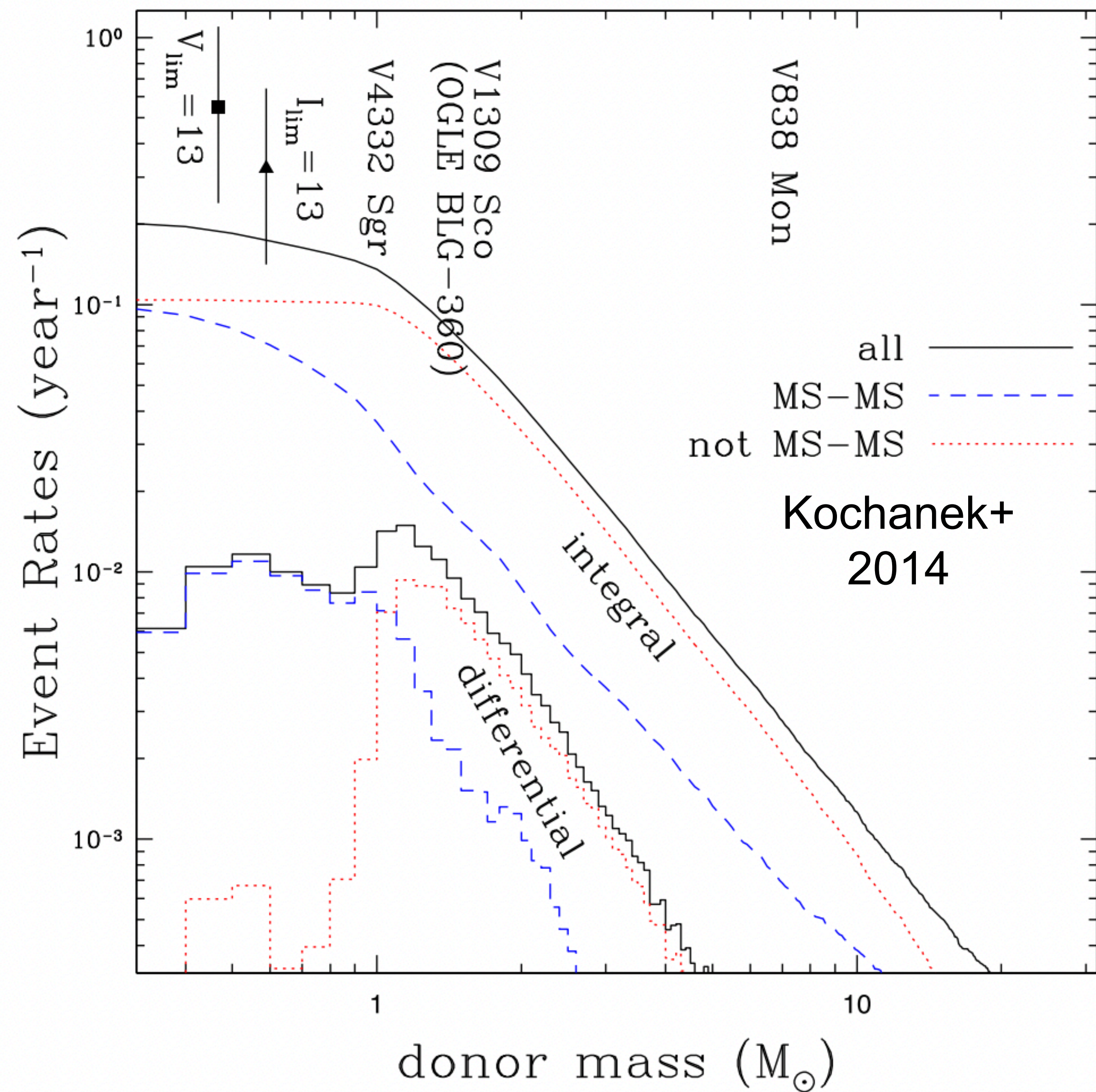
Sub-luminous" red novae from planetary engulfment



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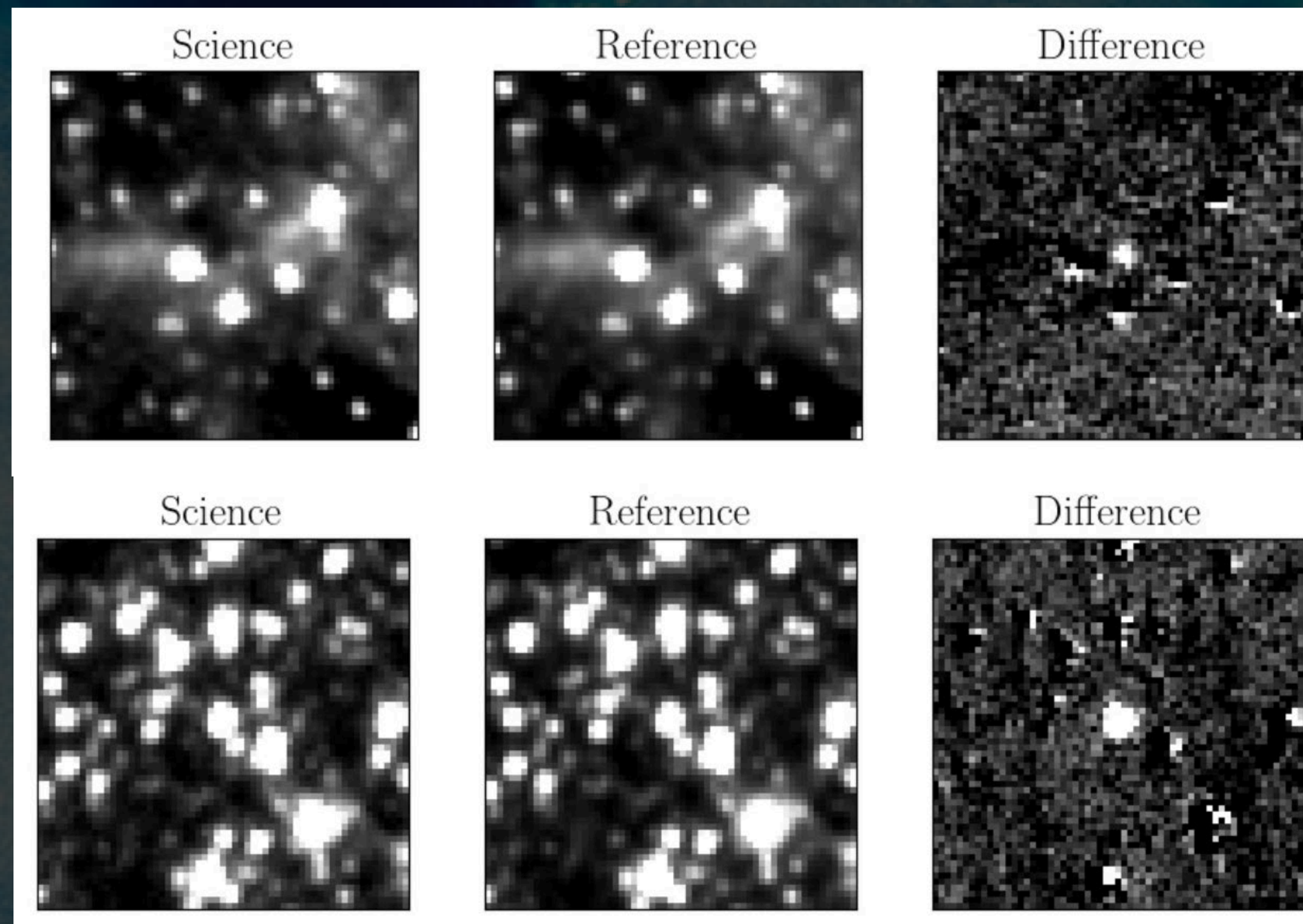
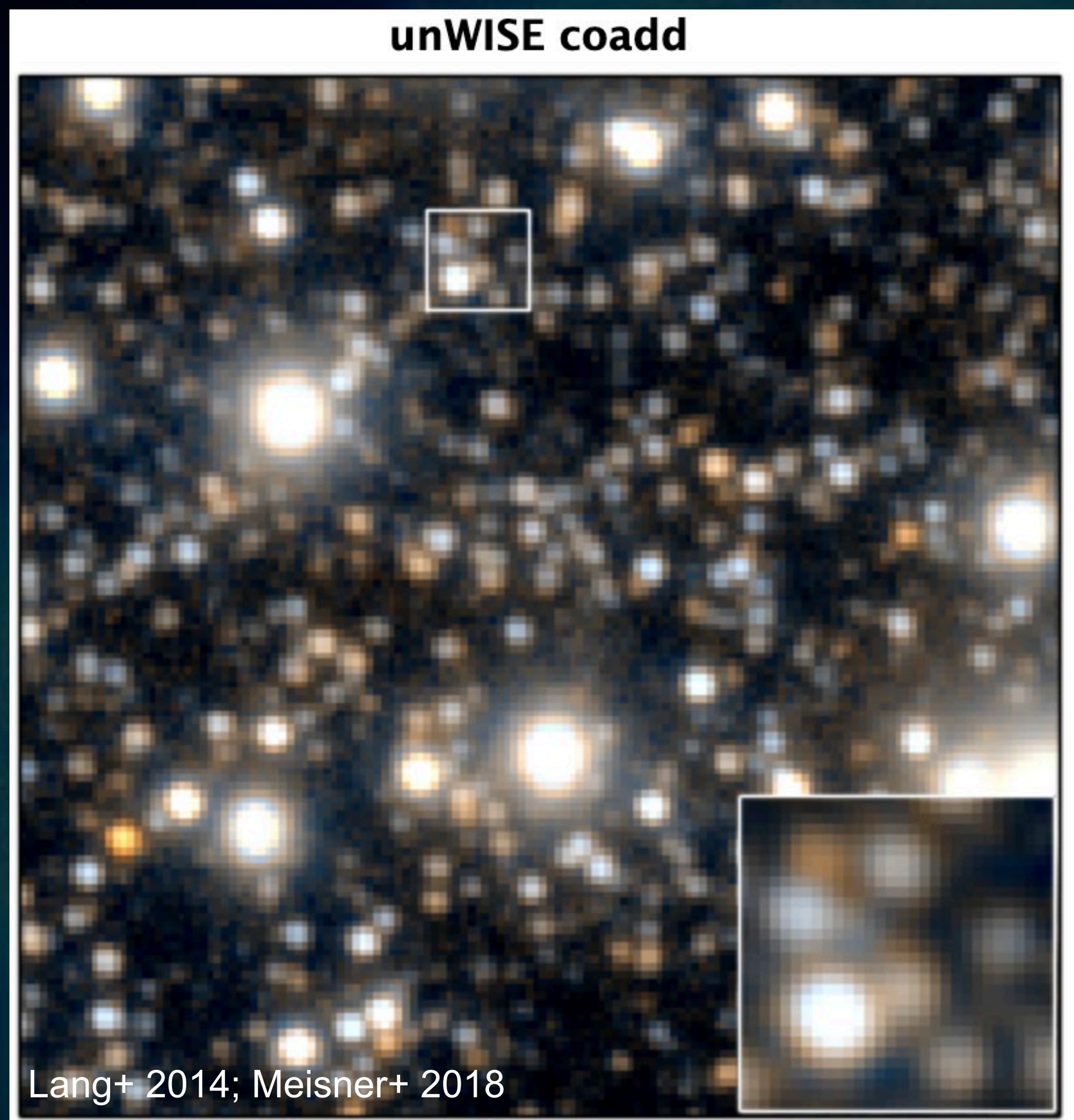
Where are the missing Galactic mergers in the last decade?



Finding them where they are
the brightest: the Mid-infrared



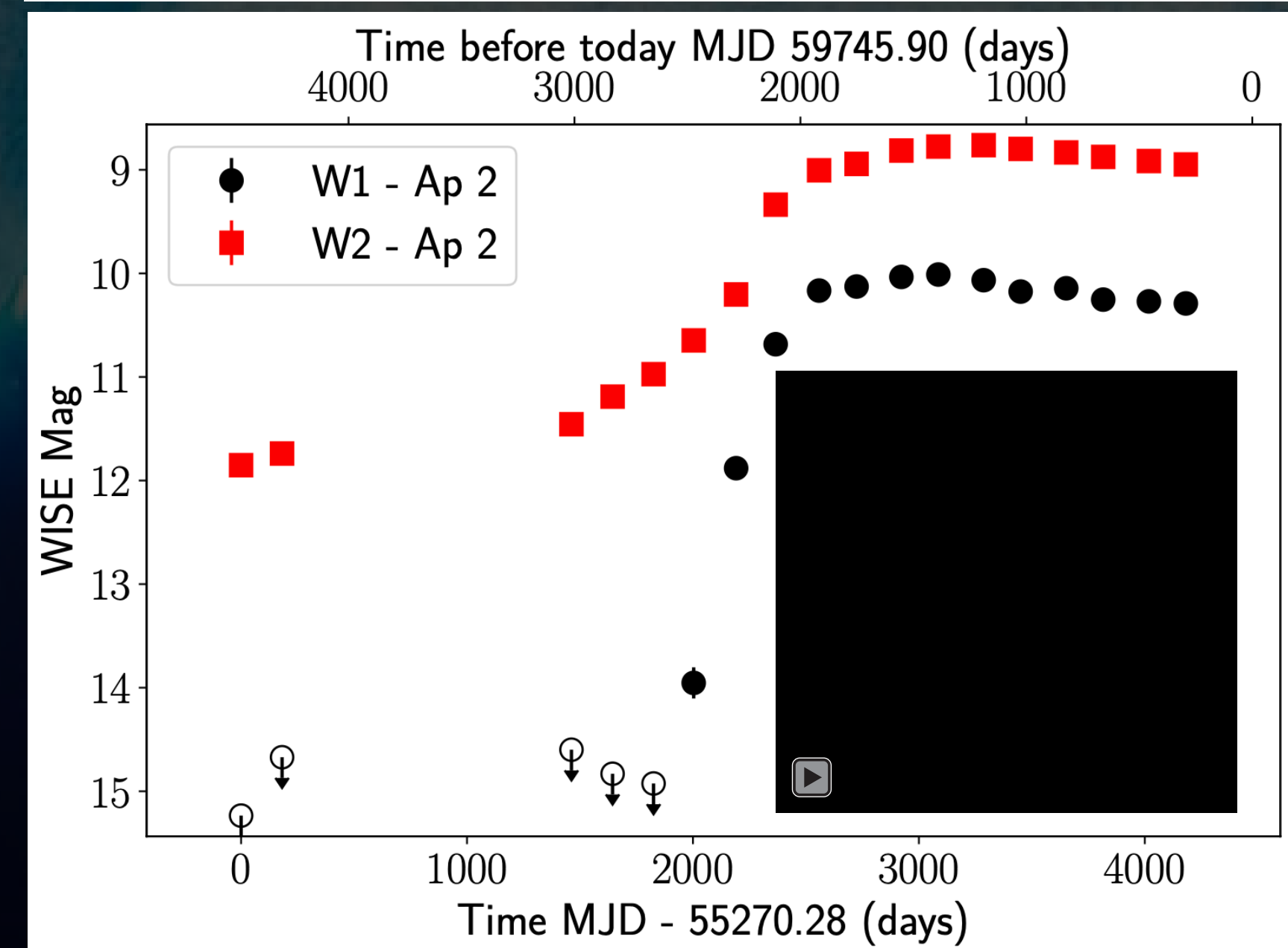
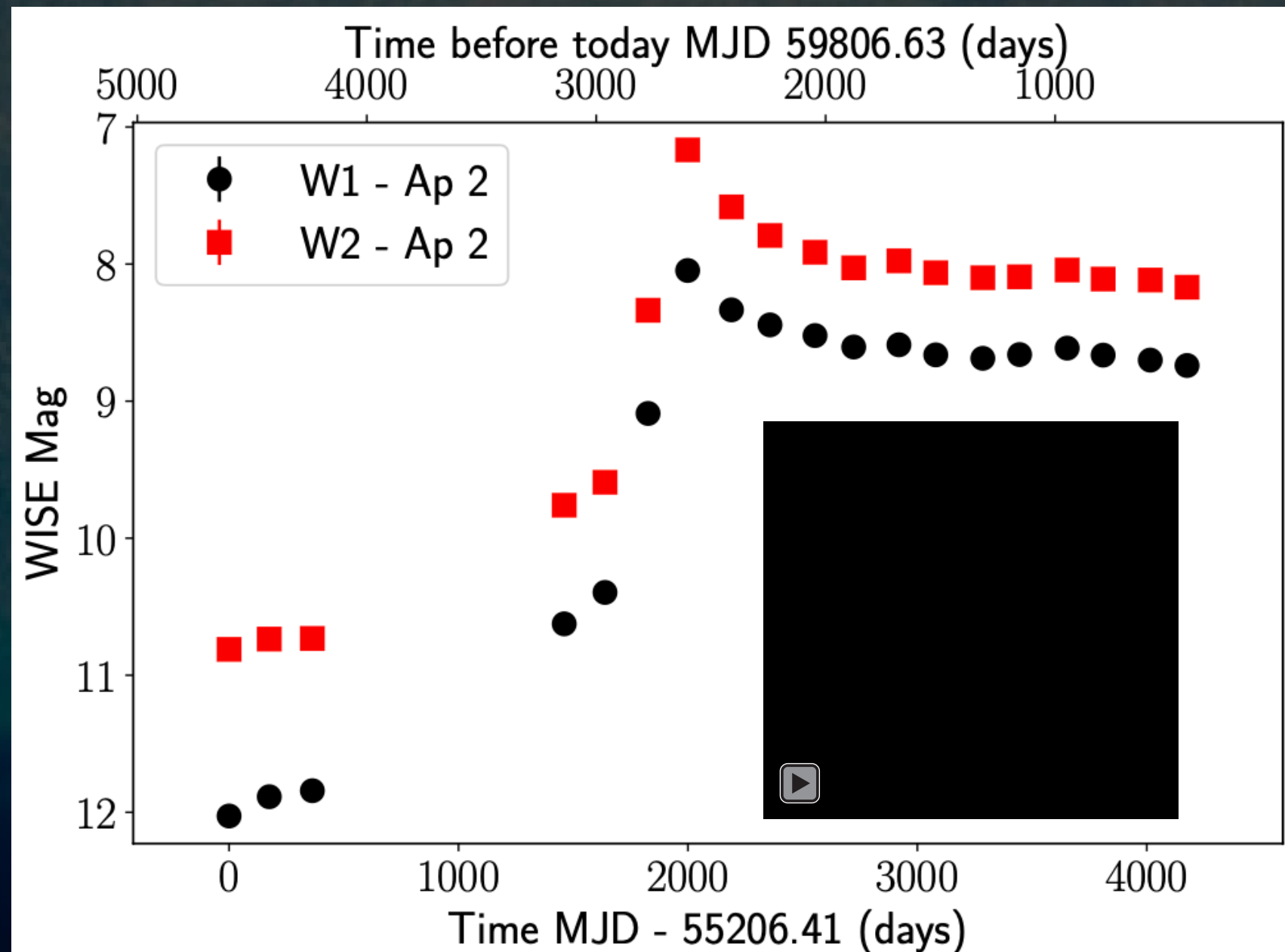
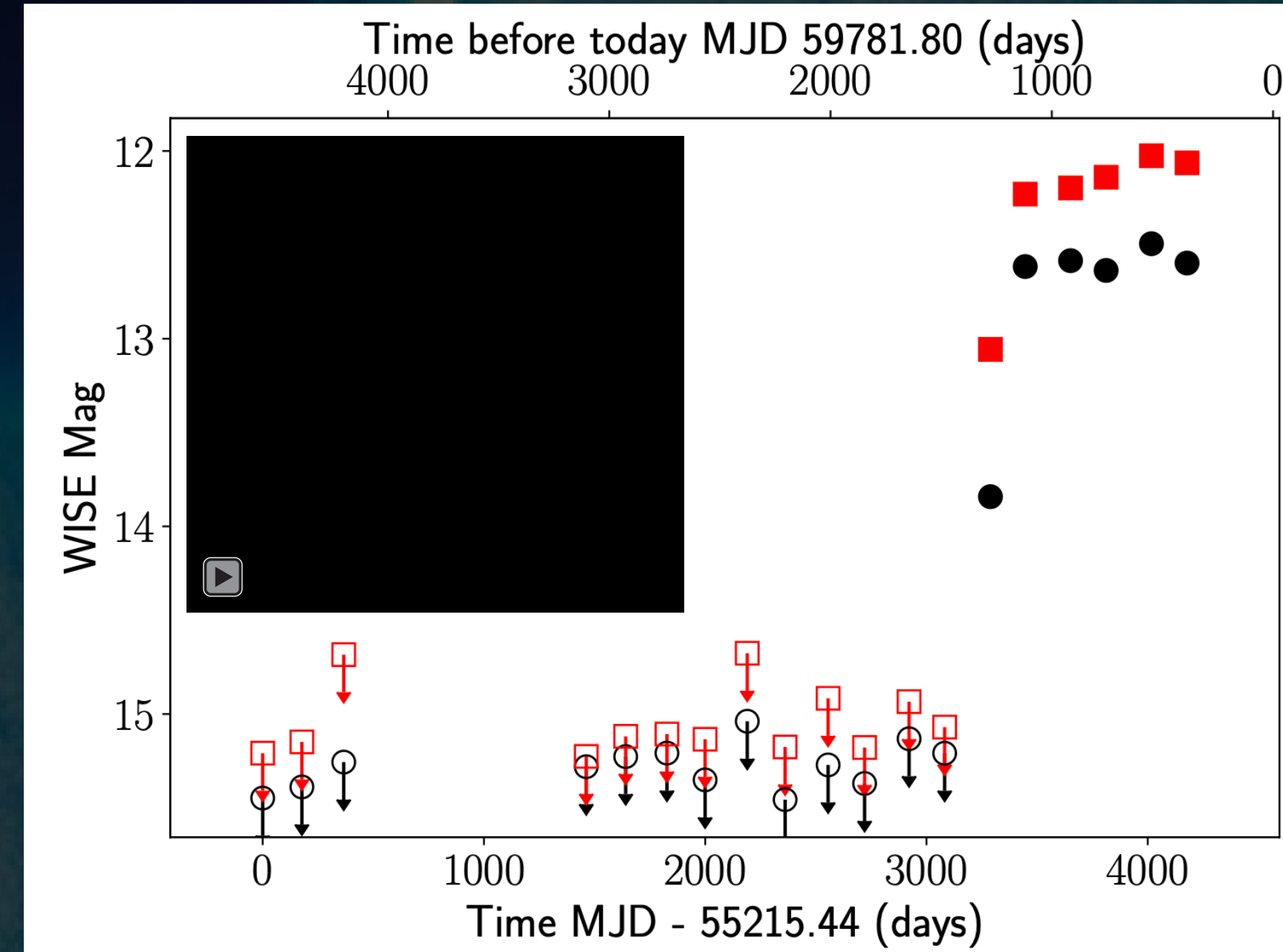
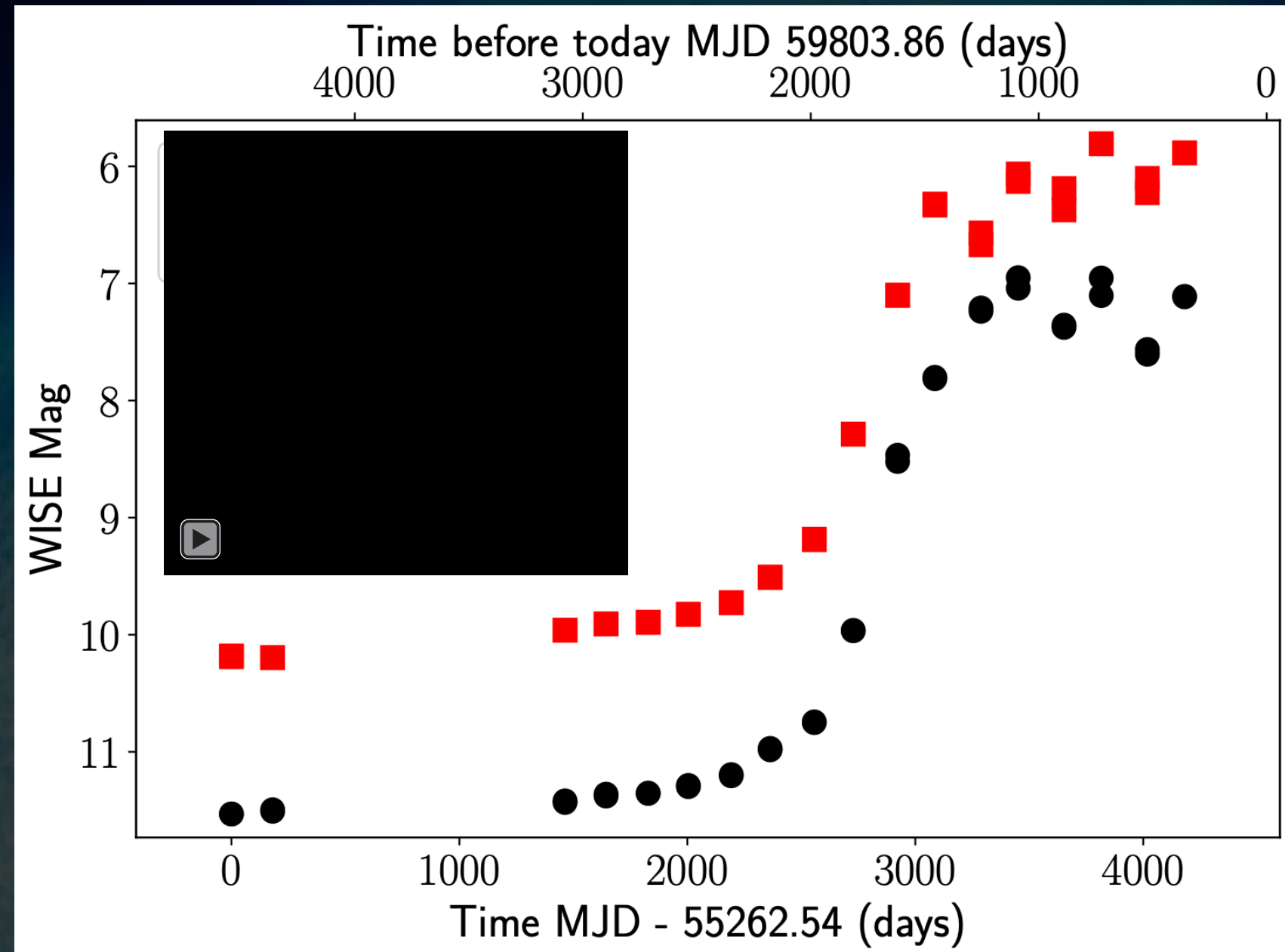
The WISE Transient Search



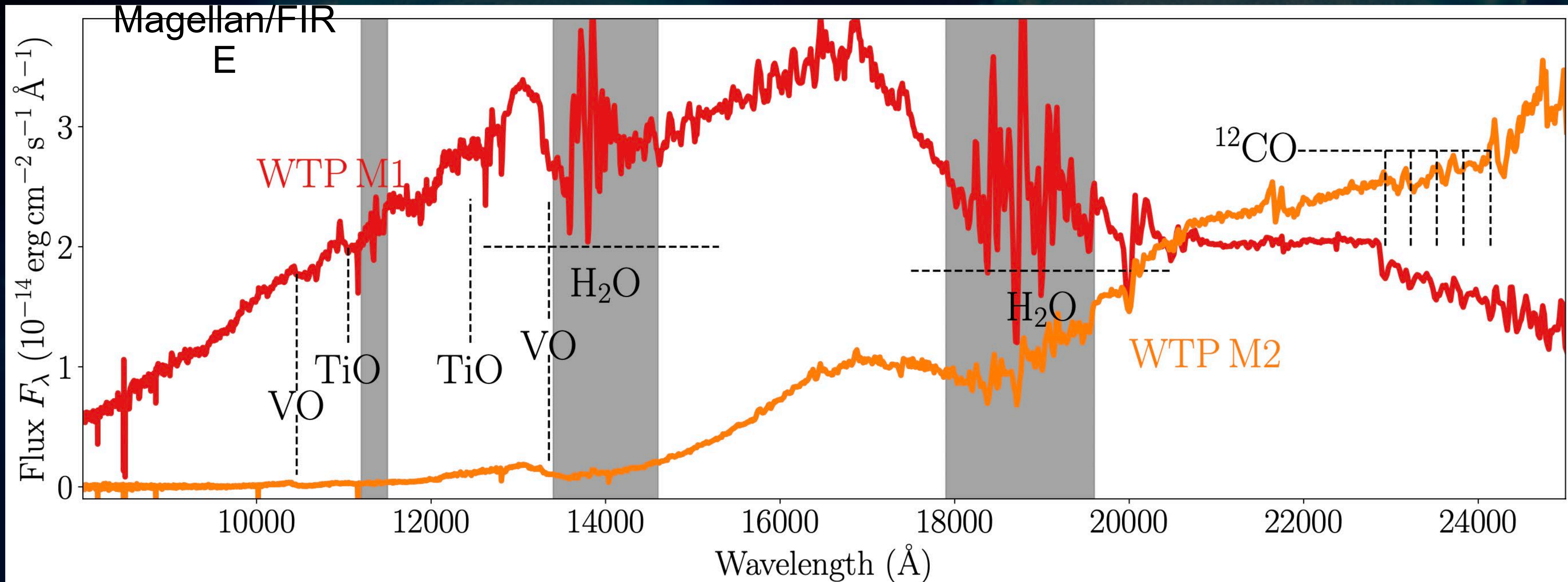
Sample of **~15 M** mid-IR transients in **~ 12 years** of data

In collaboration with Meisner, Lang, Schlafly (unWISE team), MacLeod, Loeb, Conroy, Patel (CfA), Kara, Eilers, Panagiotou, Masterson, Chakrabarty, Simcoe, Teague (MIT), Lau (JAXA), Jencson (Arizona), Hillenbrand, Kasliwal, Earley, Karambelkar (Caltech)

A population of hidden eruptions in the Galactic plane



Pilot ground-based spectroscopic follow-up



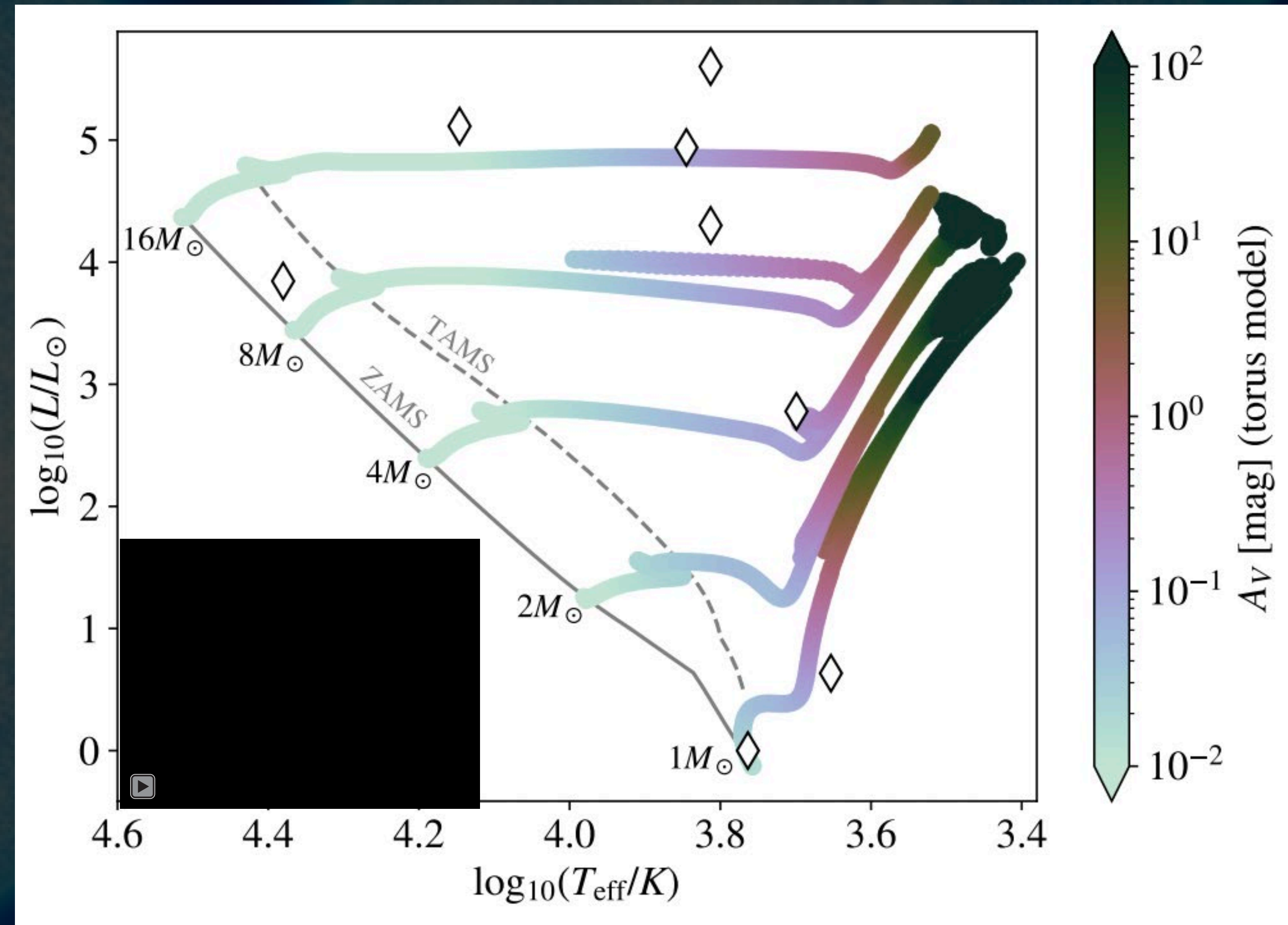
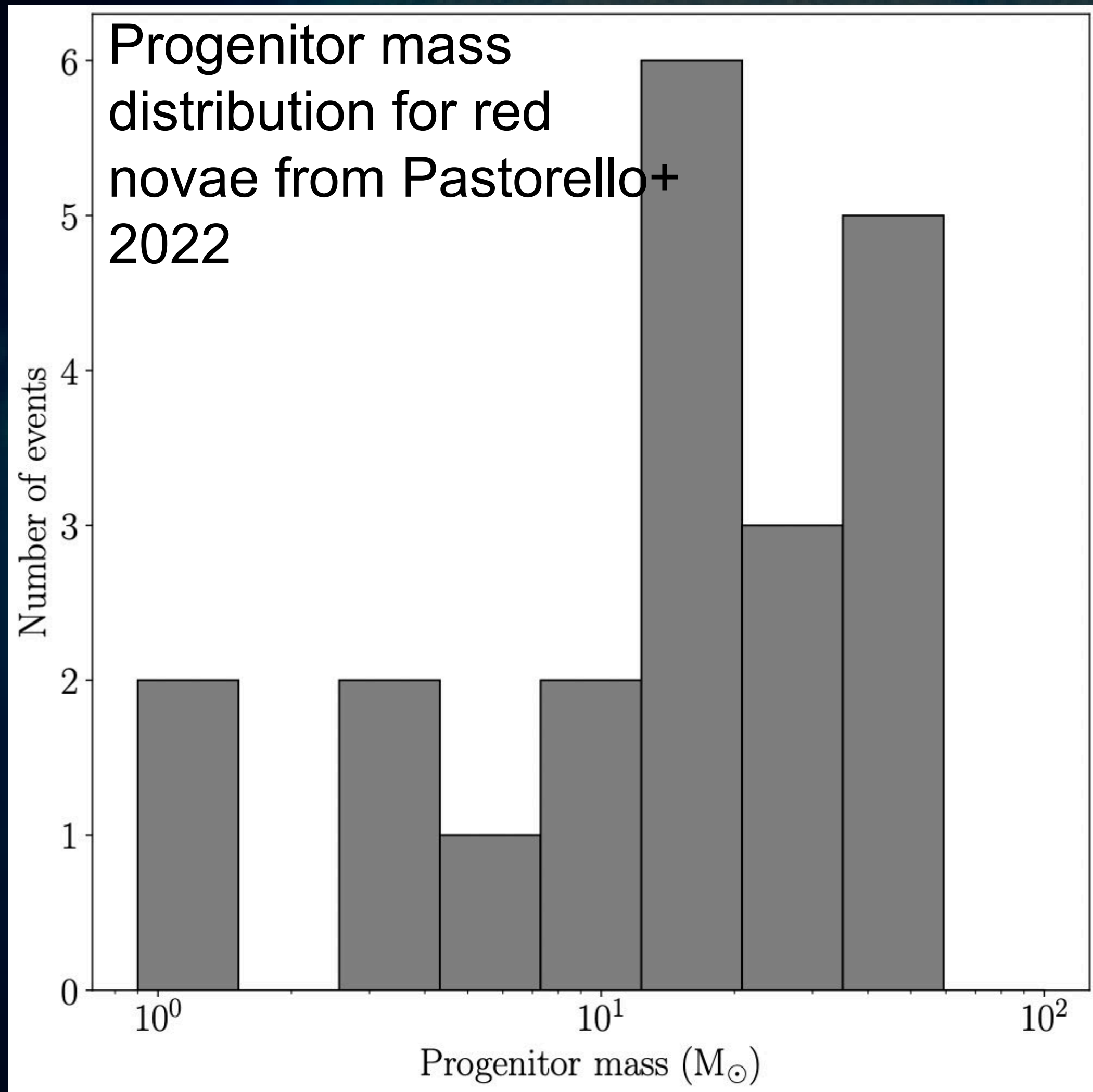
- Cold photospheric absorption features like M stars; weak/no emission lines
- Progressively redder colors in optical (where available); no counterparts in many cases
- Mid-IR luminosity $\sim 10^3 - 10^4 L_\odot$ in cases where distances available (e.g. Gaia, H2)

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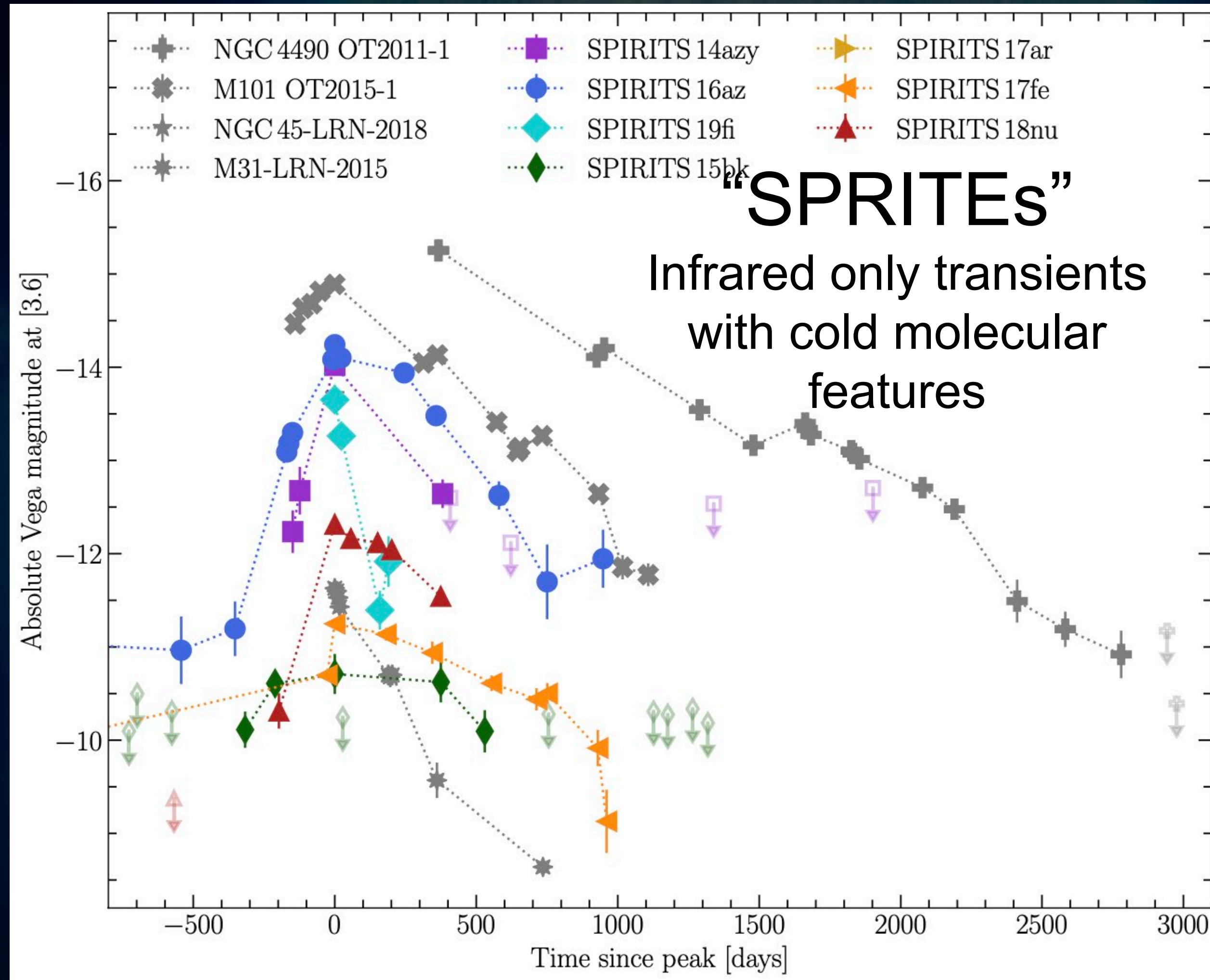
Are optically discovered events biased to certain progenitors?

MacLeod, De & Loeb 2022

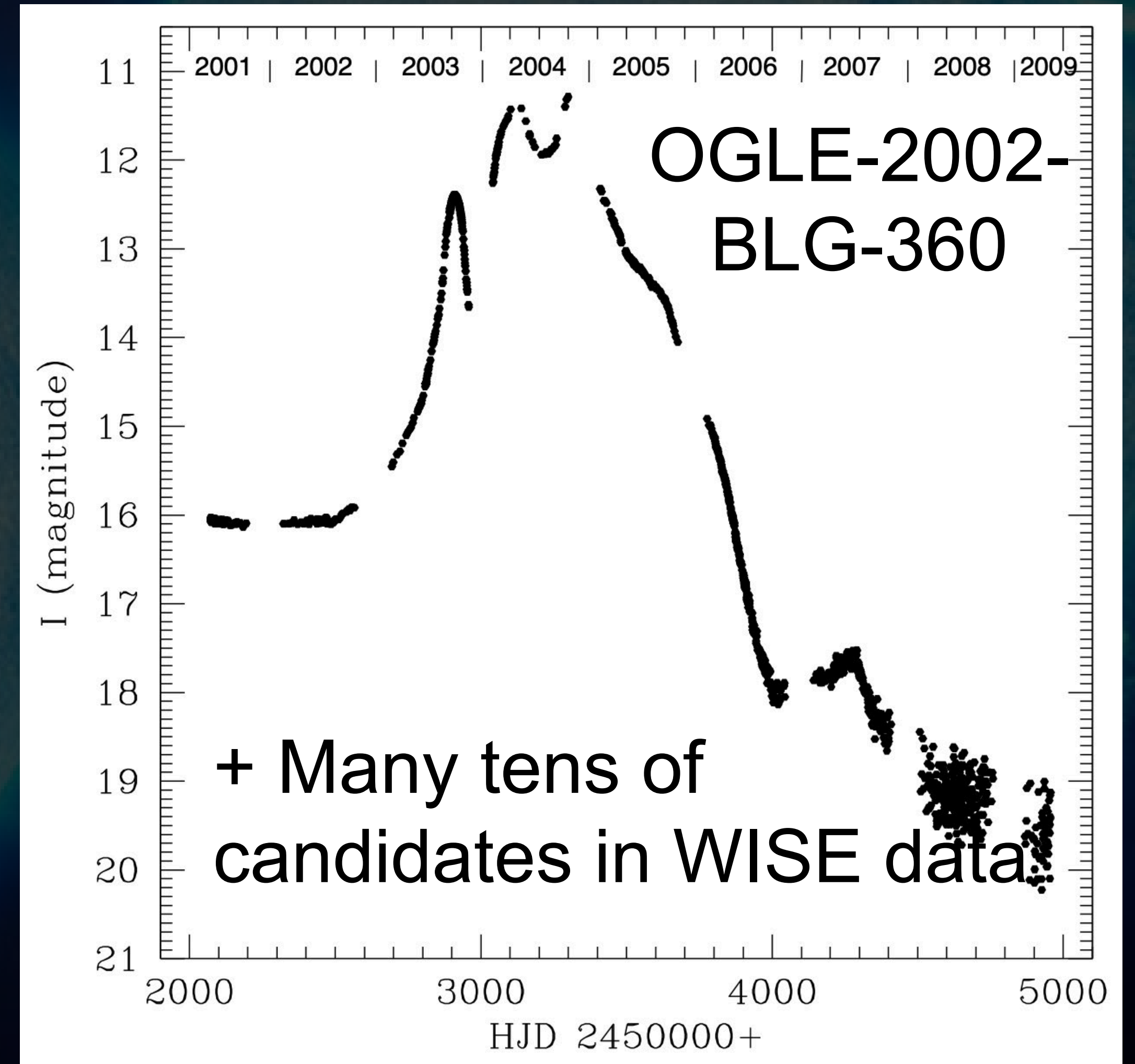


Evidence for infrared-only events from existing searches

Jencson+ in prep



Tylenda+ 2013

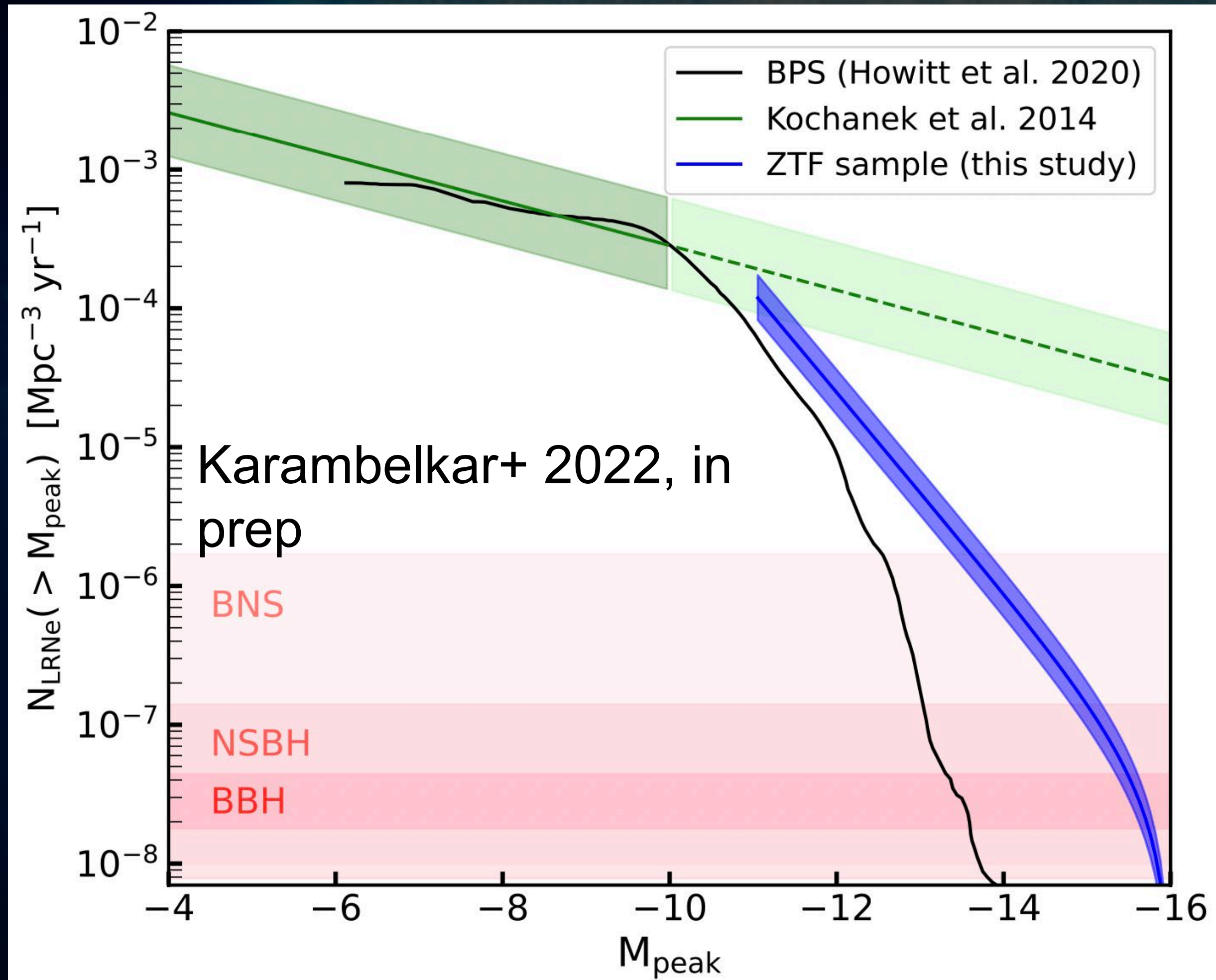


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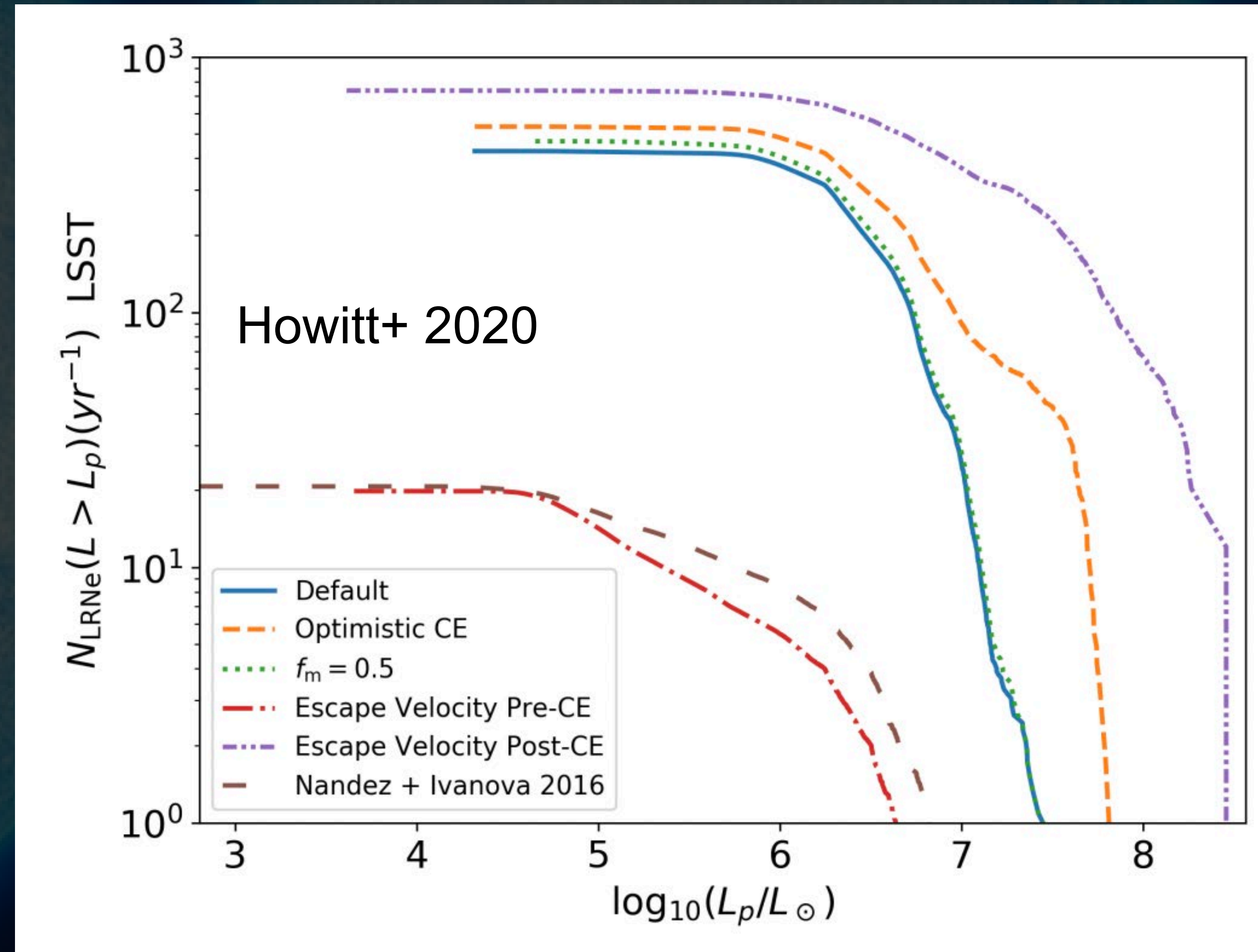
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Ongoing surveys are setting the stage for the Rubin era

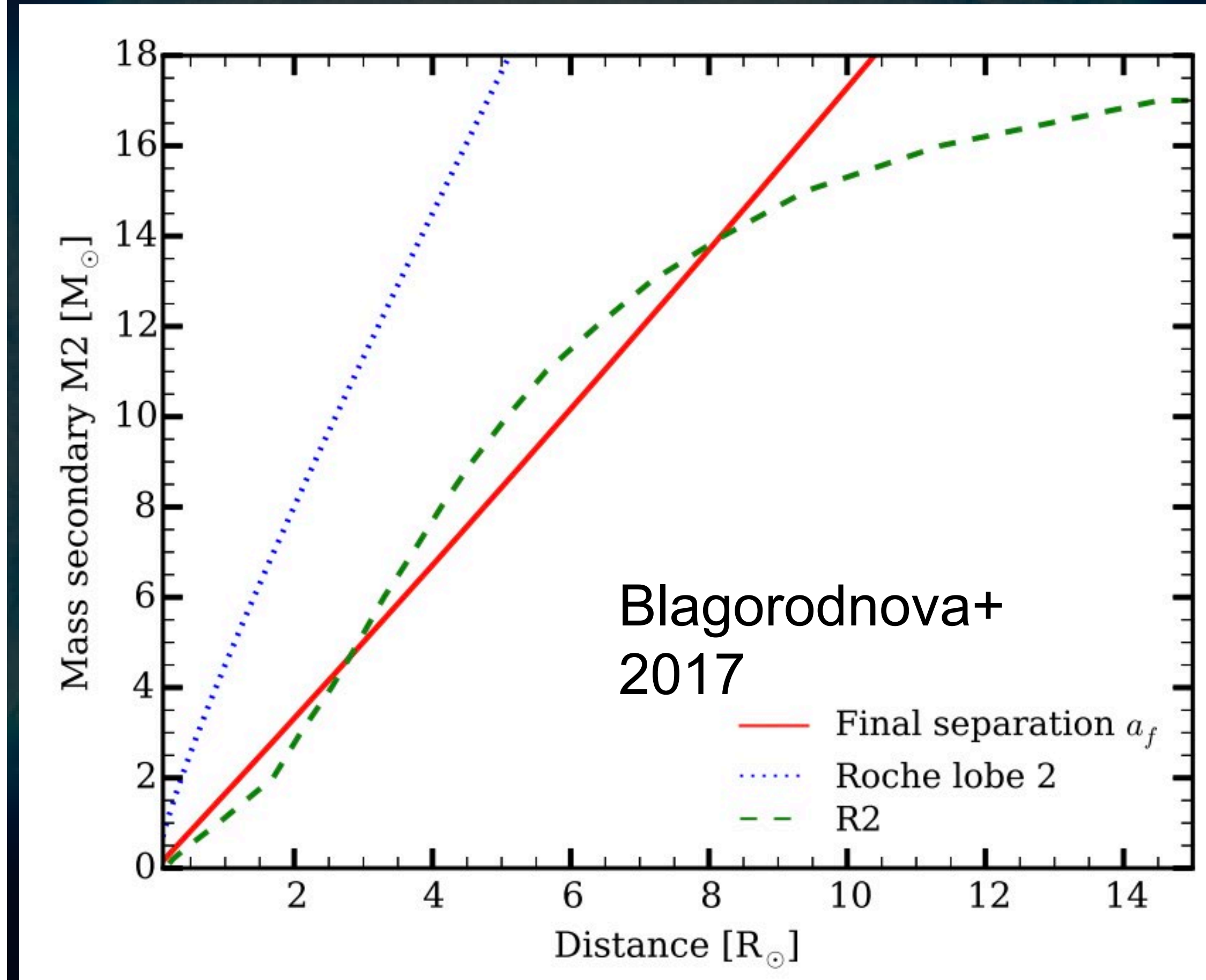
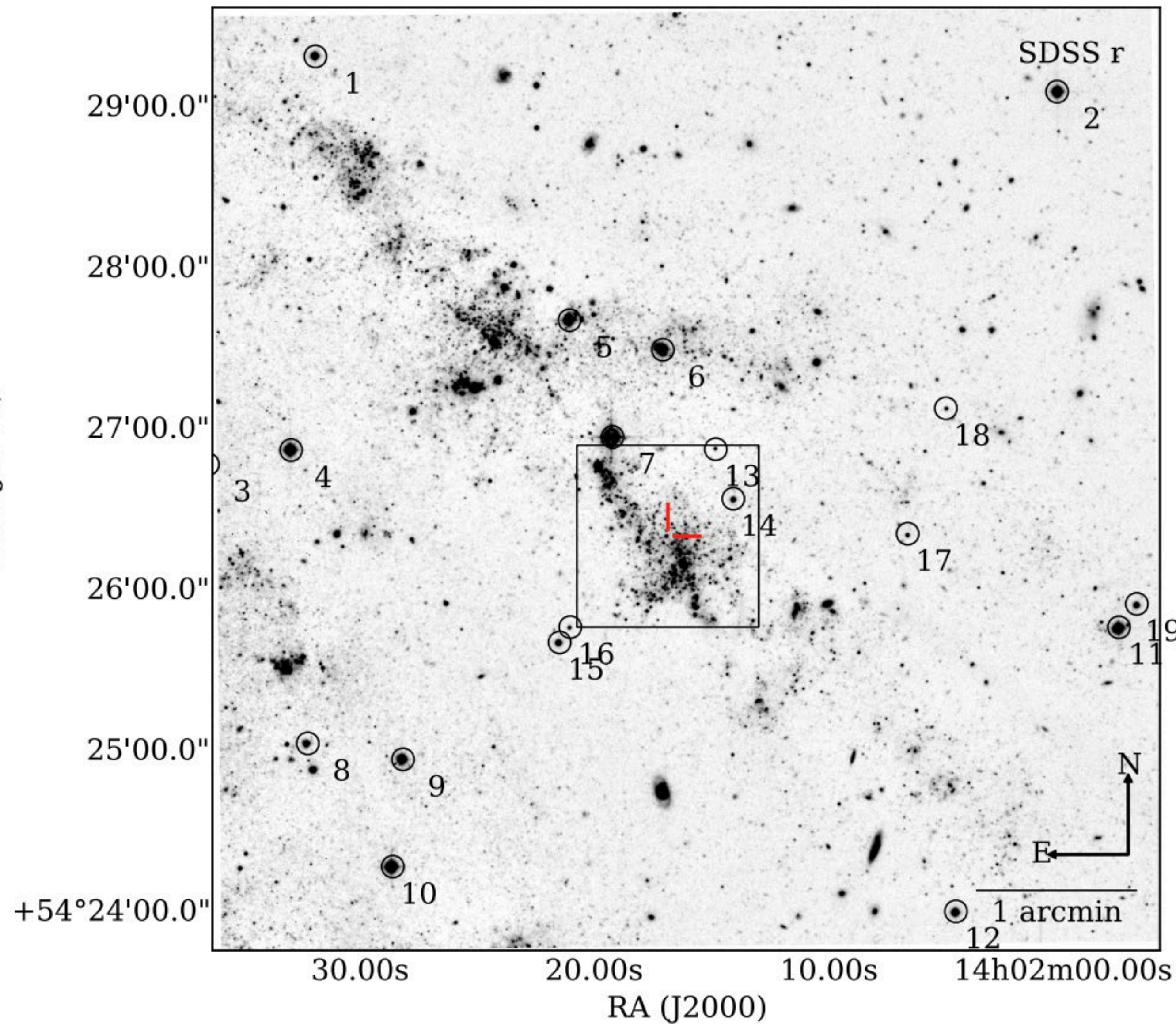
Luminous red nova sample from
ZTF



Predictions for Rubin



To eject or not to eject, that is the question

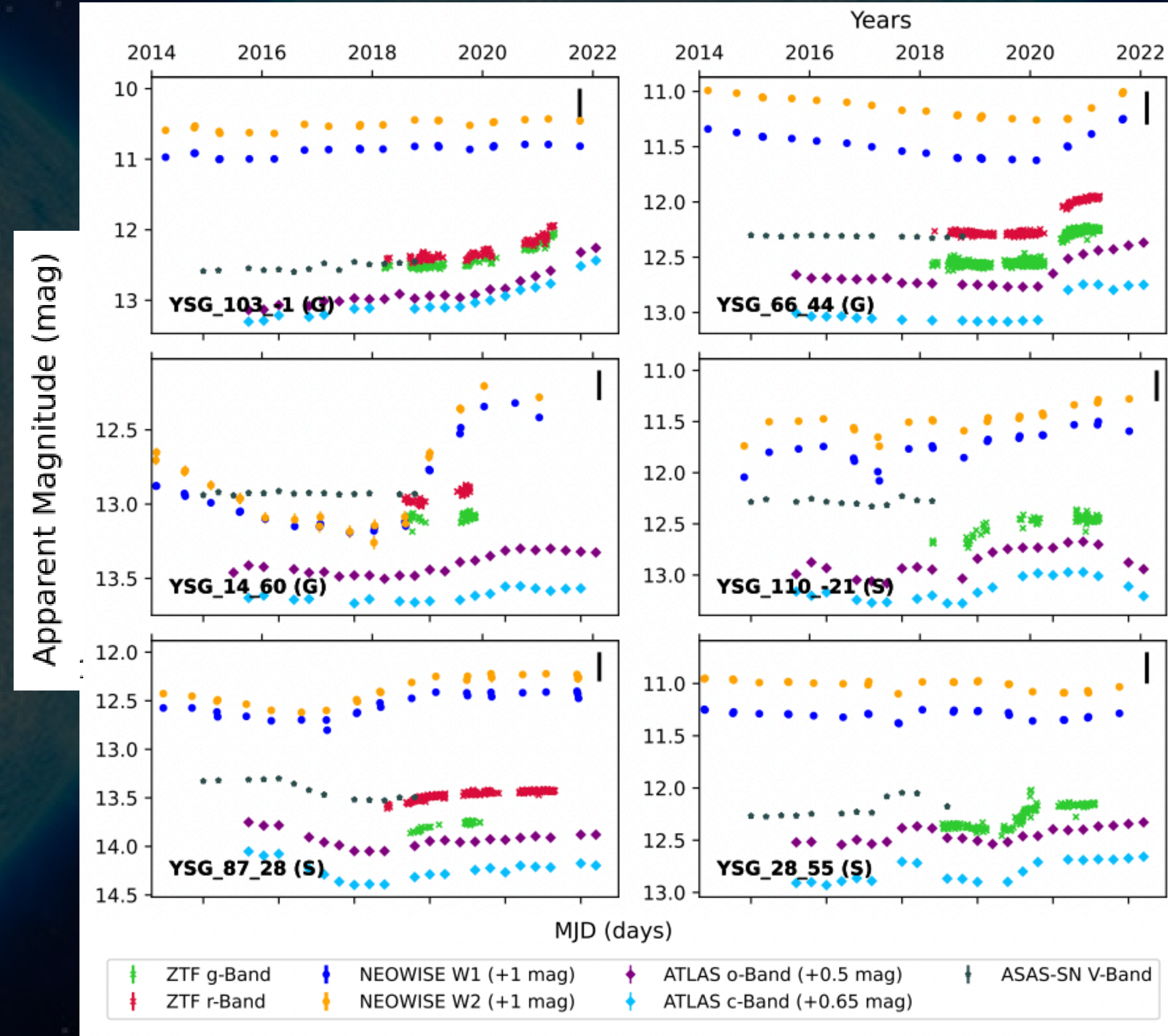
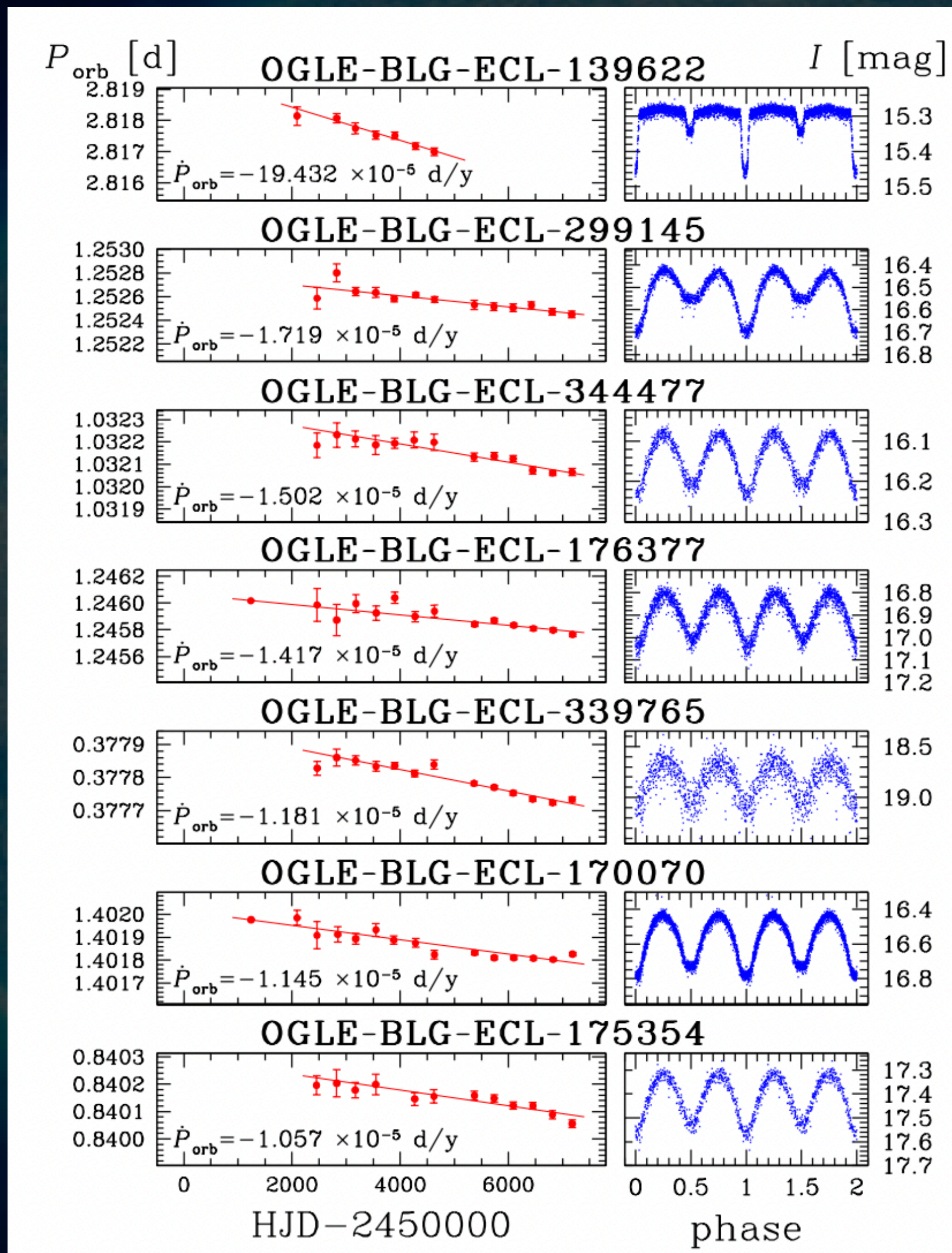


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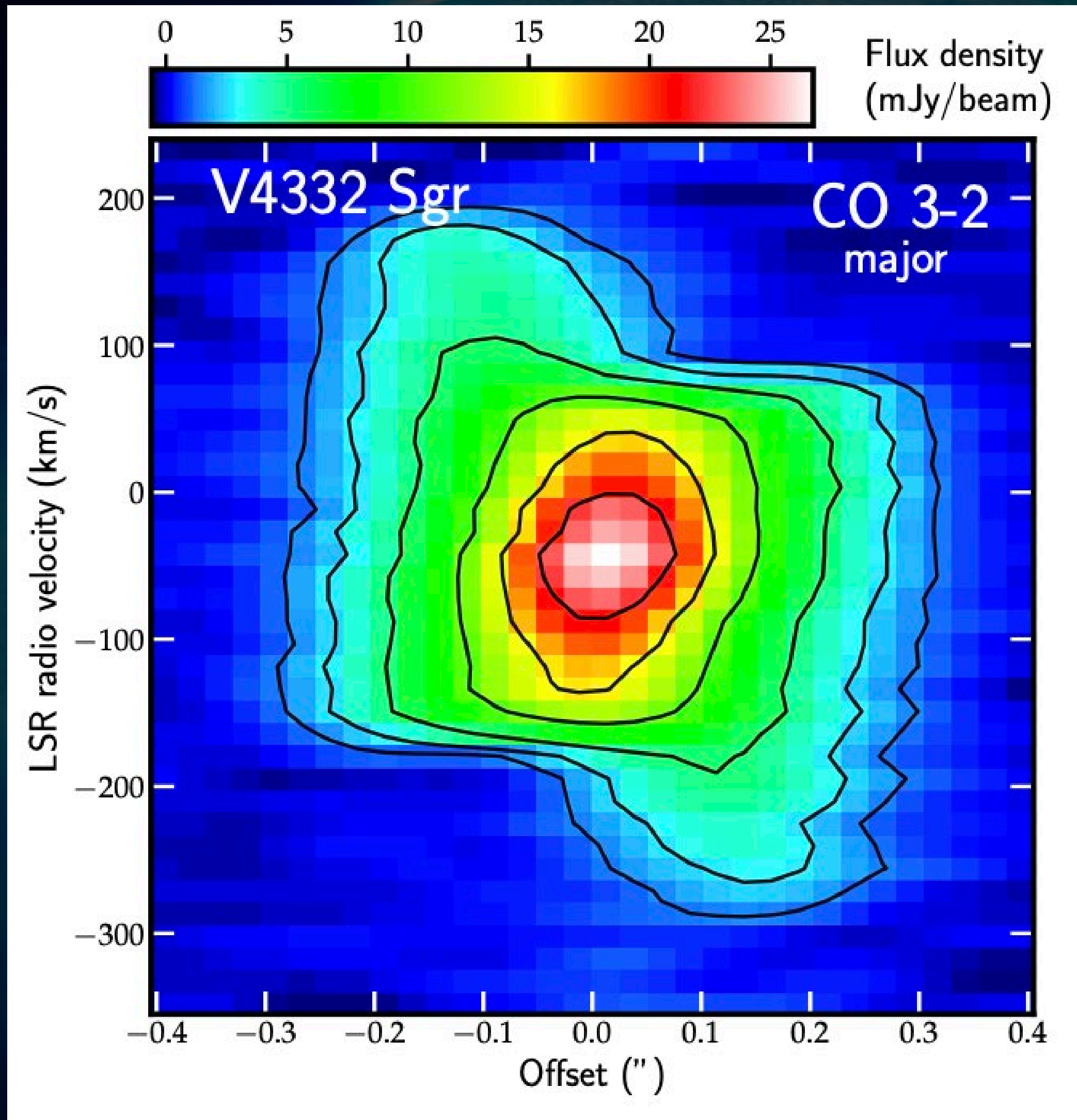
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Pietrukowicz+ 2017 Spotting red nova progenitors

Addison+ 2022

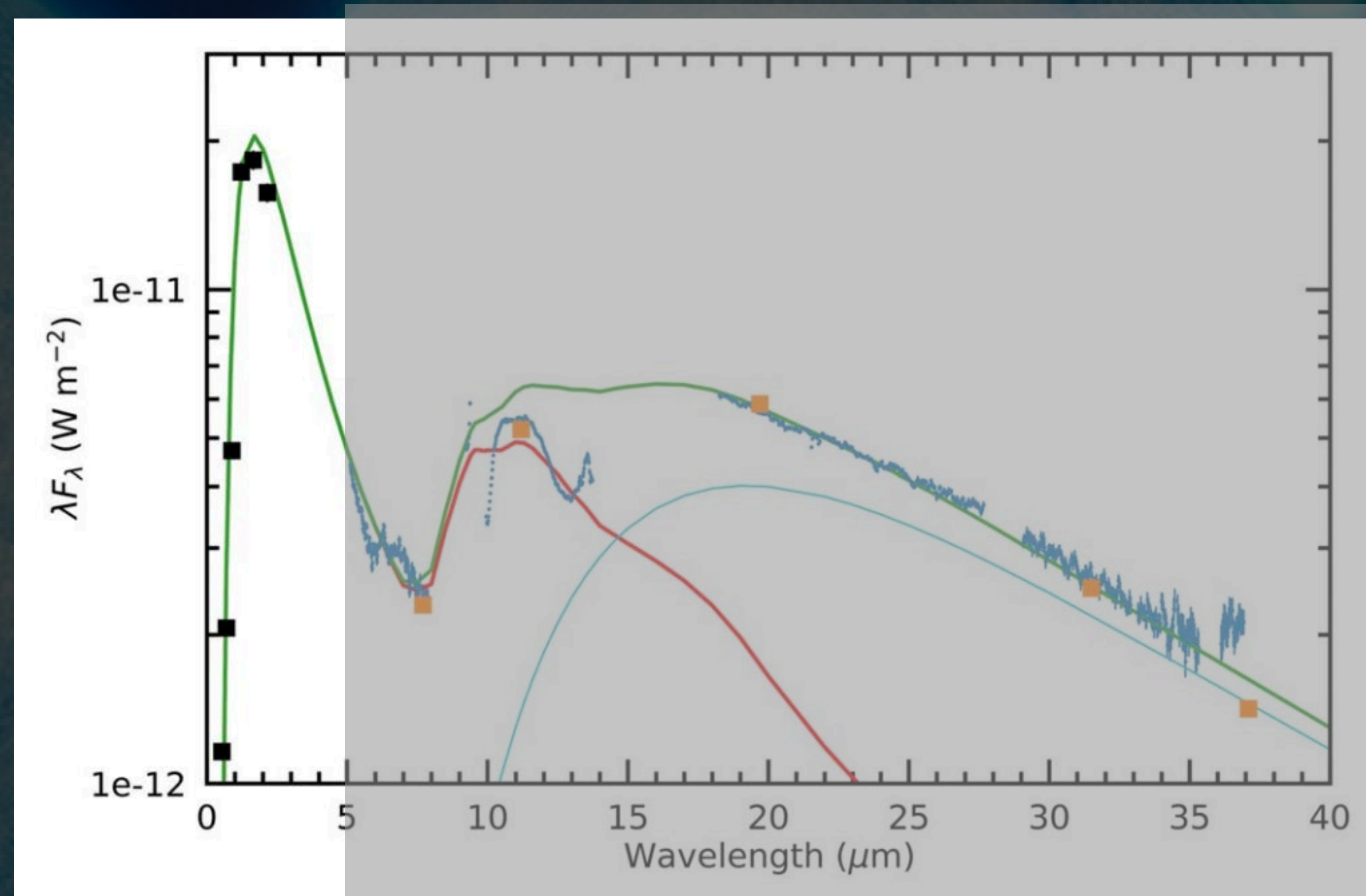


Exquisite dust/molecular factories



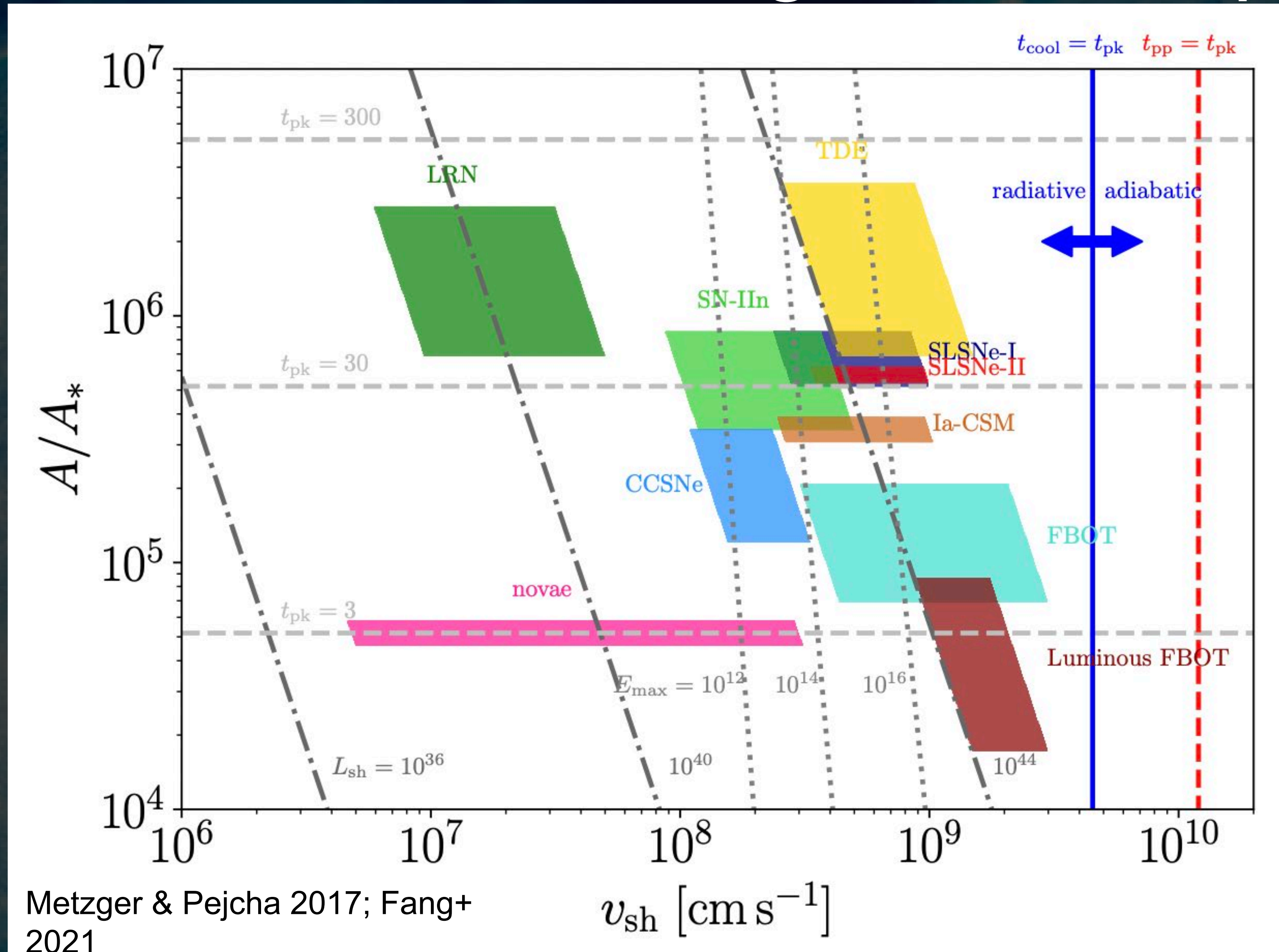
Kaminski+ 2017, 2018, 2020, 2021a,b; Evans + 2017, Ortiz-Leon+ 2020; Deguchi+ 2005, 2007; Claussen+ 2007

Need new observational capabilities



Woodward+ 2021; Banerjee+ 2005, 2006; Sparks+ 2008; Chesneau+ 2014; Loebman+ 2015; Exter+ 2016;

In the multi-messenger landscape



Unlikely to be a major contributor to the neutrino background

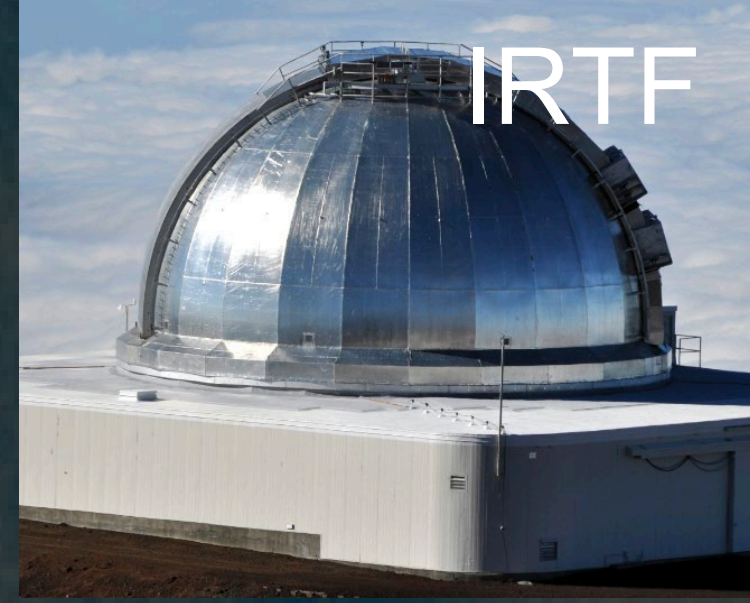
Some rare classes of mergers may have jets and produce neutrinos (Grichener & Soker 2019)

What capabilities are needed

Discovery - The extragalactic landscape (~ hundreds per year)

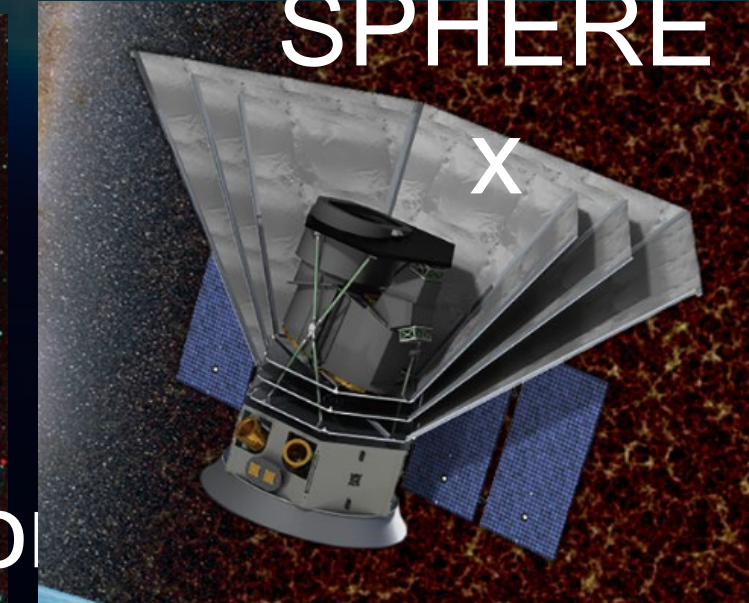
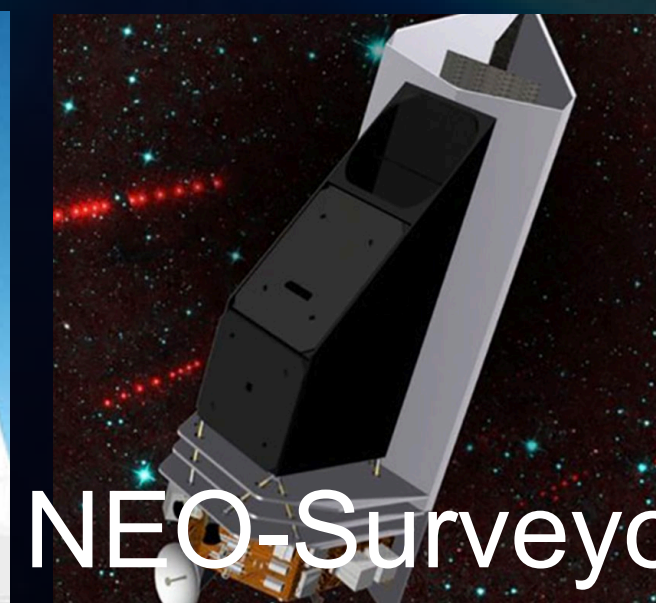
Optical + Infrared surveys necessary to identify events, detect all classes

Sensitive (even very low resolution!) infrared spectroscopy for unambiguous confirmation



Discovery - The Galactic landscape [up to ~ 10(?) per year]

Given extinction in the plane, infrared surveys will be essential to both i) distinguish regular optical outbursts and ii) find (nearly all) obscured events



What capabilities are needed

Characterization

- **Sensitive Optical spectroscopy:**
 - Outburst: Outflow velocities, temperatures, abundances, dust formation (**IRTF, Keck**)
 - Remnants: Peculiar chemical abundances (Kaminski+ 2022), planetary compositions (Soares-Furtado+ 2021) (**JWST**)
- **Infrared spectroscopy:**
 - **Near-infrared:** Molecular chemistry, dust formation, grain size evolution (**IRTF, Keck, JWST**)
 - **Mid and far-infrared:** Grain condensation, dust evolution, and studying the dustiest events Stellar mergers are uniquely **pure infrared transients!** (**JWST, Far-IR Probe?**)
- **Radio/X-ray:**
 - **Sub-mm** observations particularly interesting for red novae: outflow chemistry, ejecta kinematics, ejection geometry, total ejecta mass (**SMA, ALMA**)
 - **Cm-band** maser observations to constrain distances via maser emission (**VLA**)
 - **X-ray** emission possible (Metzger+ 2012) [**Swift (follow-up), STAR-X (searches)**]

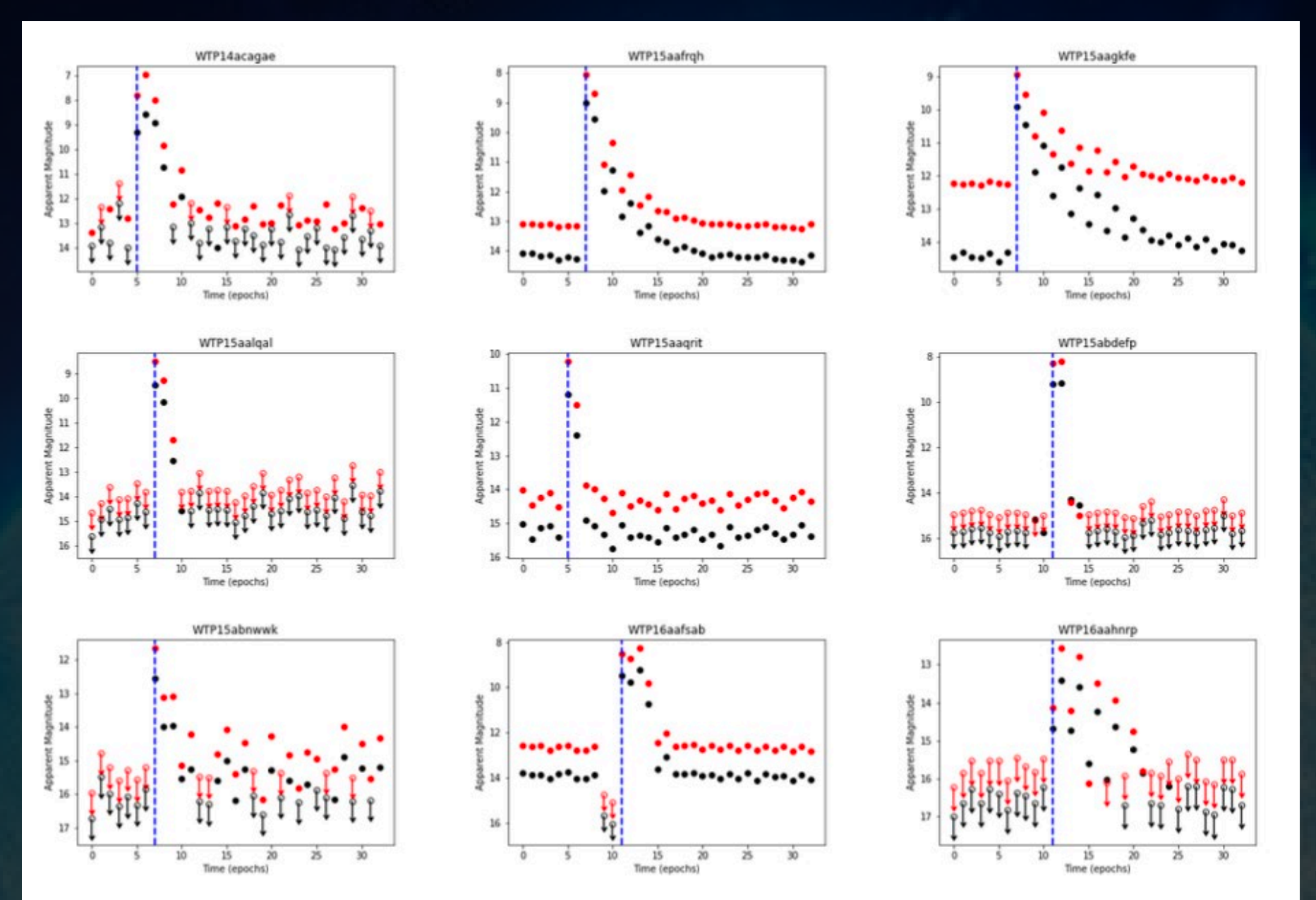
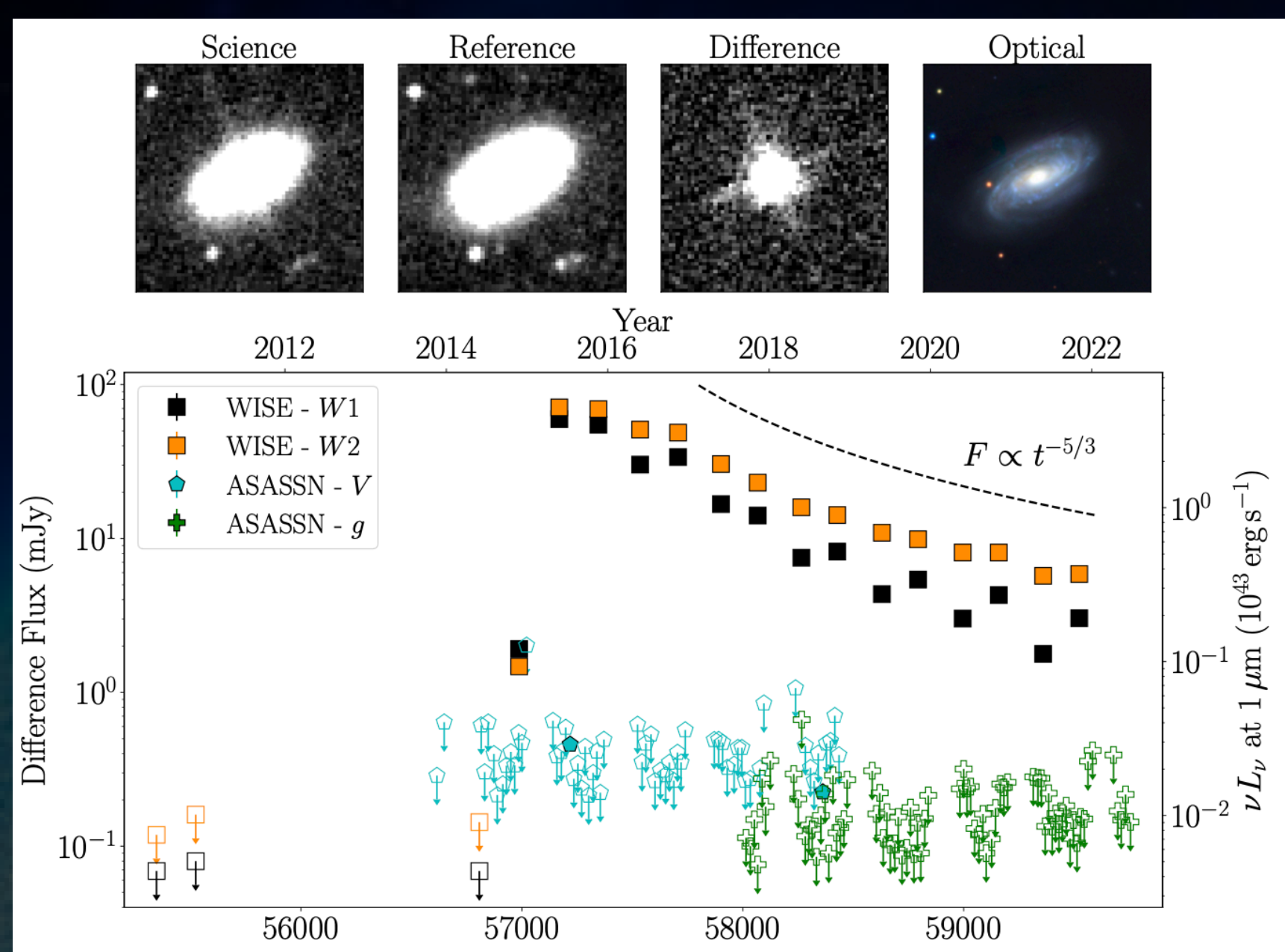
What capabilities are needed

Progenitors and remnants

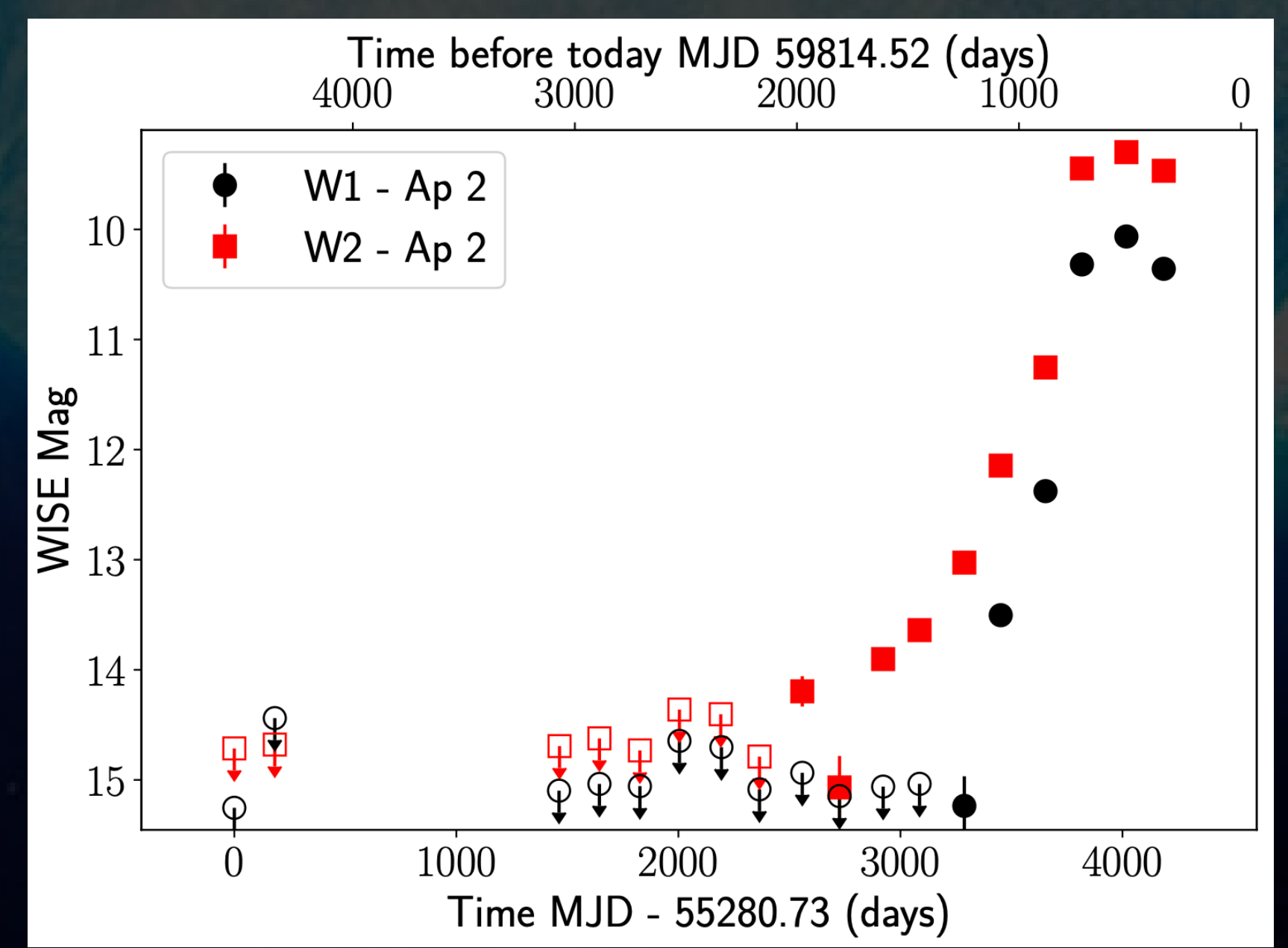
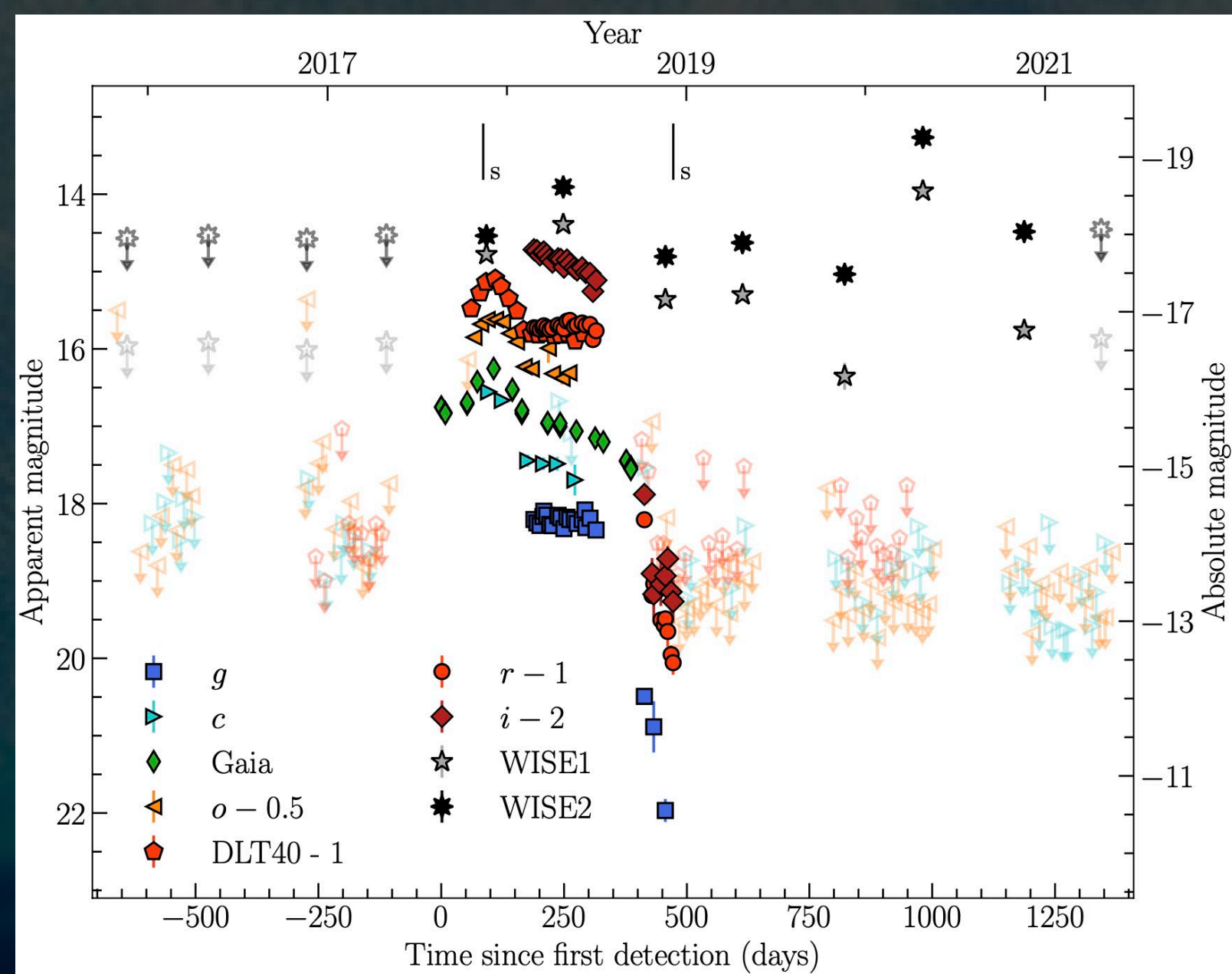
- **Multi-epoch space-based optical/infrared imaging of nearby galaxies** will regularly enable identification of extra-galactic merger progenitors (**HST, JWST, Roman**)
- Complete **space-based infrared imaging of the Galactic plane** to routinely identify and characterize progenitors of mergers, their evolutionary stage (**Roman**)
- Ultra-violet capabilities to trace the **long-term evolution of merger remnants** (towards Blue Stragglers, as in V1309 Sco) and study the population of post-CE binaries (**UVEX**)

Observational and theoretical infrastructure

- Ground-based surveys (especially in IR) are setting the stage for the upcoming sensitive IR follow-up fleet in TDA (**JWST, Roman, Far-IR Probe**), offer complementary capabilities
- The rich WISE transients stream demonstrates the need for real-time transient identification and alerts for all upcoming space-based flagship facilities.
- Theoretical work on both progenitors (binary populations) and common envelope ejections



Dust Obscured nearby TDEs (Panagiotou+ in prep) Galactic Accreting Binaries (Zuckerman+ in prep)



supernovae with late time interaction (Jencson+ in prep) Large Galactic outbursts (Earley+ in prep)

Thanks!

kde1@mit.edu

[dekishalay.github.io](https://github.com/dekishalay)

