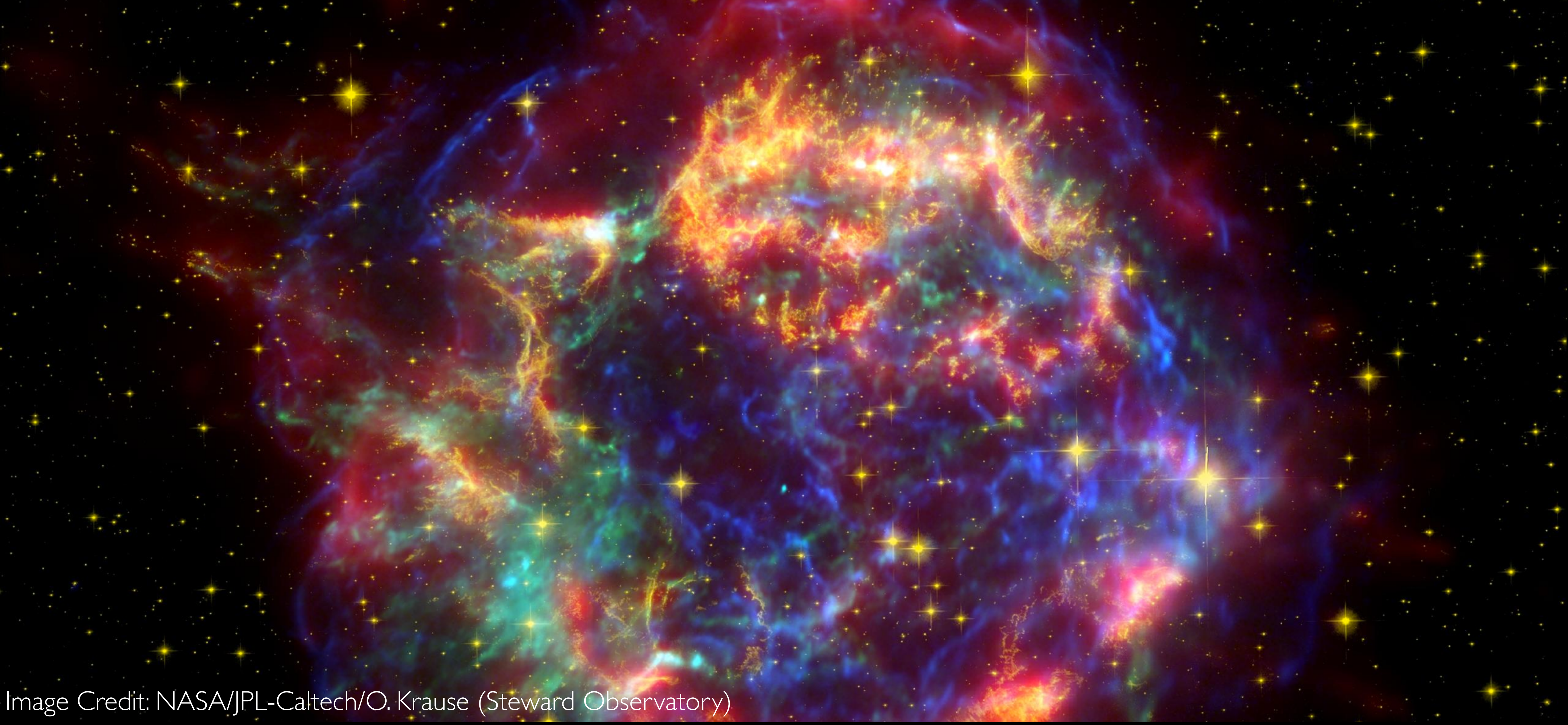


Image Credit: NASA/JPL-Caltech/O. Krause (Steward Observatory)

REVEALING CORE-COLLAPSE SUPERNOVAE AND FAILED EXPLOSIONS WITH *ROMAN*

Jacob Jencson
Postdoctoral Associate, Steward Observatory
Tucson, AZ

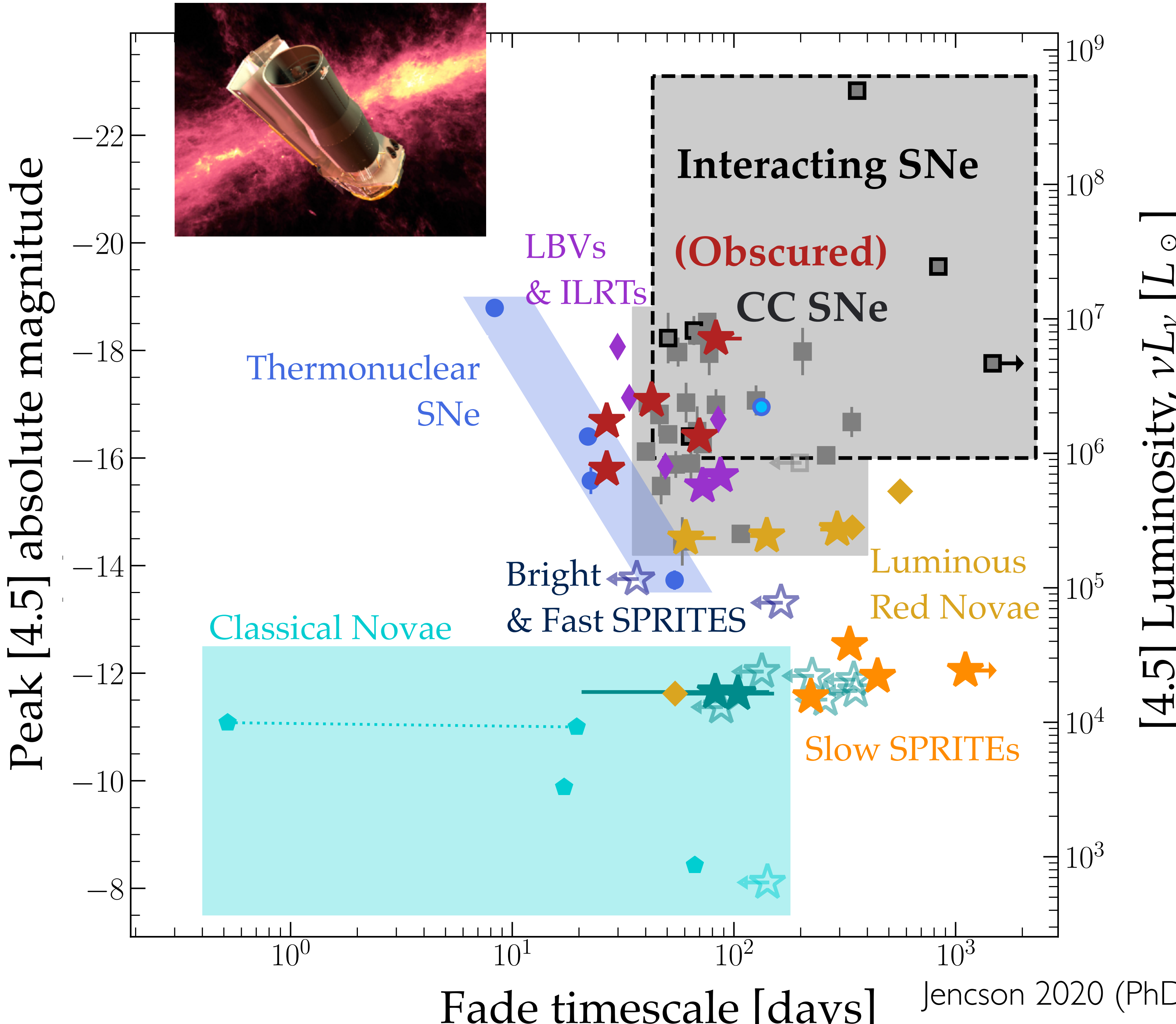
Exploring the Transient Universe with *Roman*
IPAC/Caltech
Pasadena, CA

February 8, 2022

The infrared sky is brimming with massive star fireworks.

SPitzer **I**nfra**R**ed **I**ntensive **T**ransients **S**urvey:
A targeted search of nearby galaxies for transients in the mid-IR (PI M. Kasliwal, Project scientist **J. Jencson**).

Discovered numerous transients from massive stars, some with no detectable optical emission.



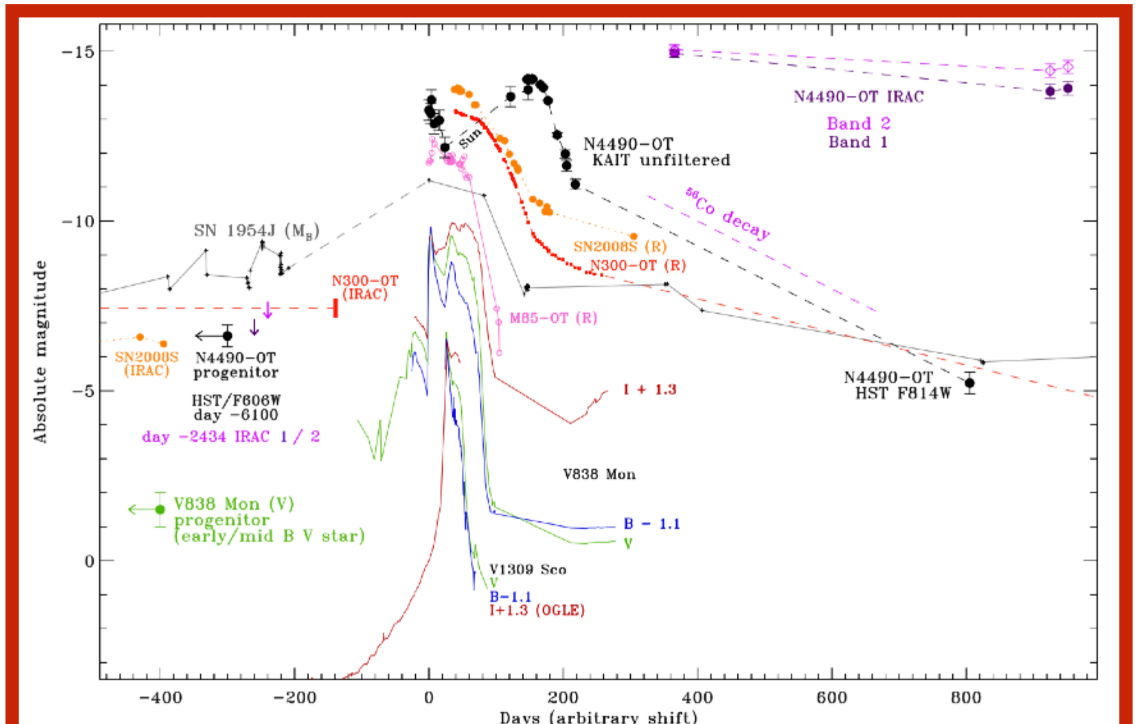
Jencson 2020 (PhDT)

The infrared sky is brimming with massive star fireworks.

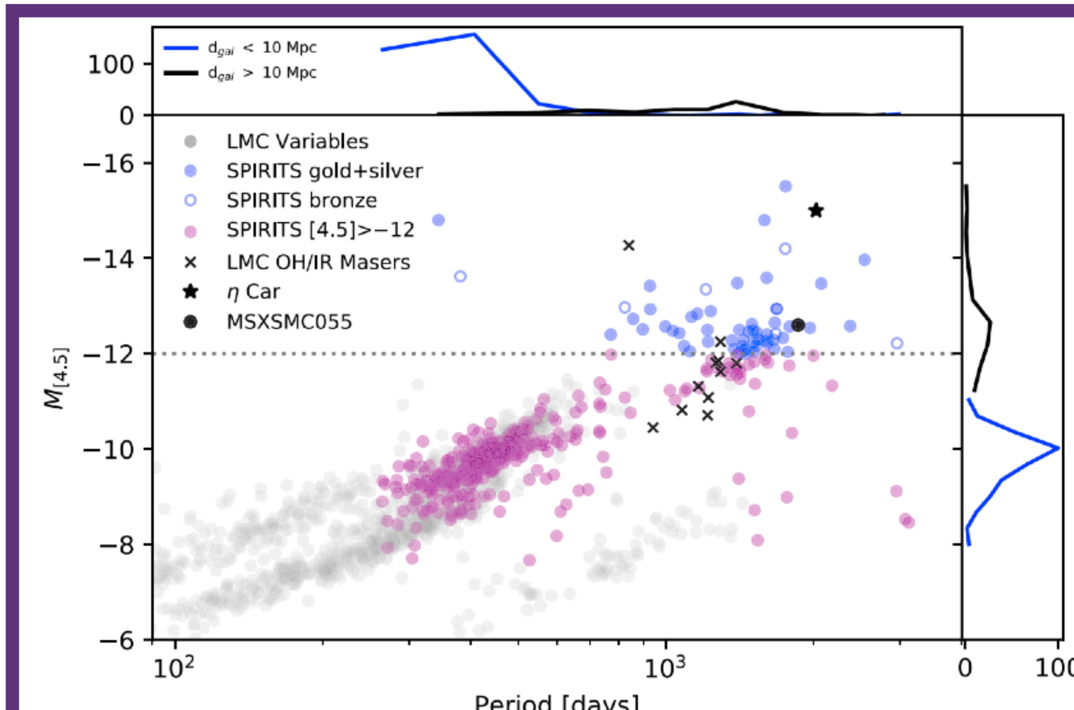
Stellar Mergers
(e.g., Smith+ 2016, Blagorodnova+ 2017, 2021, Jencson+ 2019b)

Outbursts and SN Impostors
(e.g., Jencson+ 2019ab, Andrews+ 2021)

Dust-forming massive binaries
(e.g., Lau+ 2021)



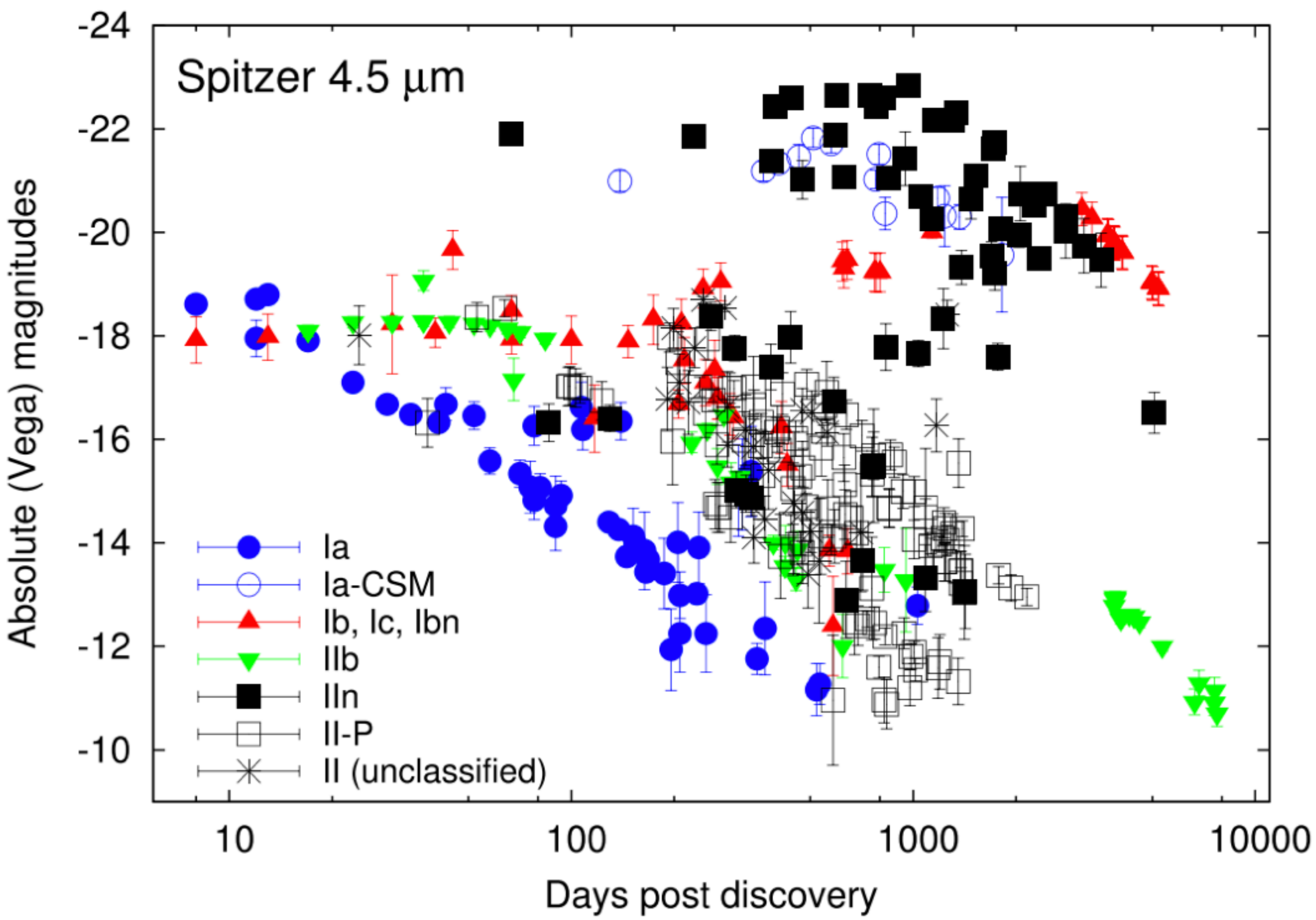
Extremely luminous and long-period variables
(Karambelkar+ 19)



Dusty SNe Iax and dust-free SNe Ia (Fox+ 2016, Johansson+ 2017)

SPIRITS ADS Library:
https://ui.adsabs.harvard.edu/public-libraries/OLBleuZdS0euKOhQJpMUfA

Infrared emission probes the circumstellar environments of supernovae:



Szalai+ 2019

(See also SPIRITS sample in Tinyanont+ 2016)

Progenitor evolution and mass loss

- Circumstellar interaction and shocks
- Dust echos

(e.g., Bode & Evans 1980, Smith 2009, Fox 2011, 2013, Szalai+ 2021)

ISM enrichment and galaxy evolution

- Molecule and dust formation

(e.g., Gall+ 2011, Szalai & Vinkó 2013, Martínez-González+ 2019)

Explosion Geometry

- IR Polarimetry

(e.g., Tinyanont+ 2021)

How do we build a complete census of massive stellar death?

I. Where are the missing core-collapse supernovae?

II. Do all massive stars explode?

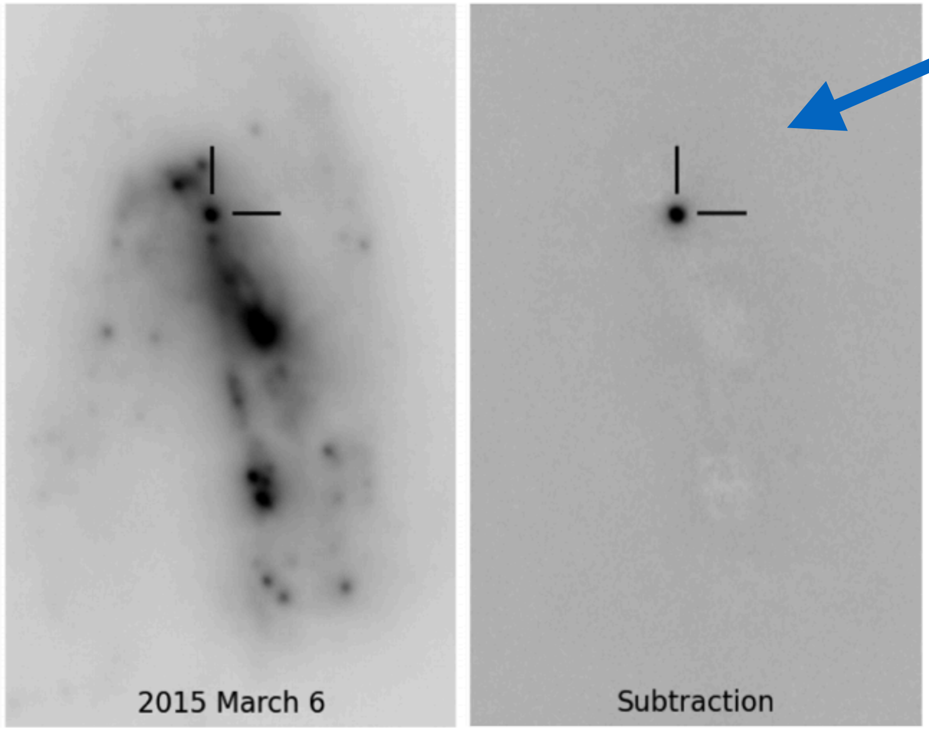
How do we build a complete census of massive stellar death?

I. Where are the missing core-collapse supernovae?

II. Do all massive stars explode?

Many core-collapse supernovae may be heavily obscured.

SN 2015cb in IRAS 17138-1017 with GeMS/GSAOI



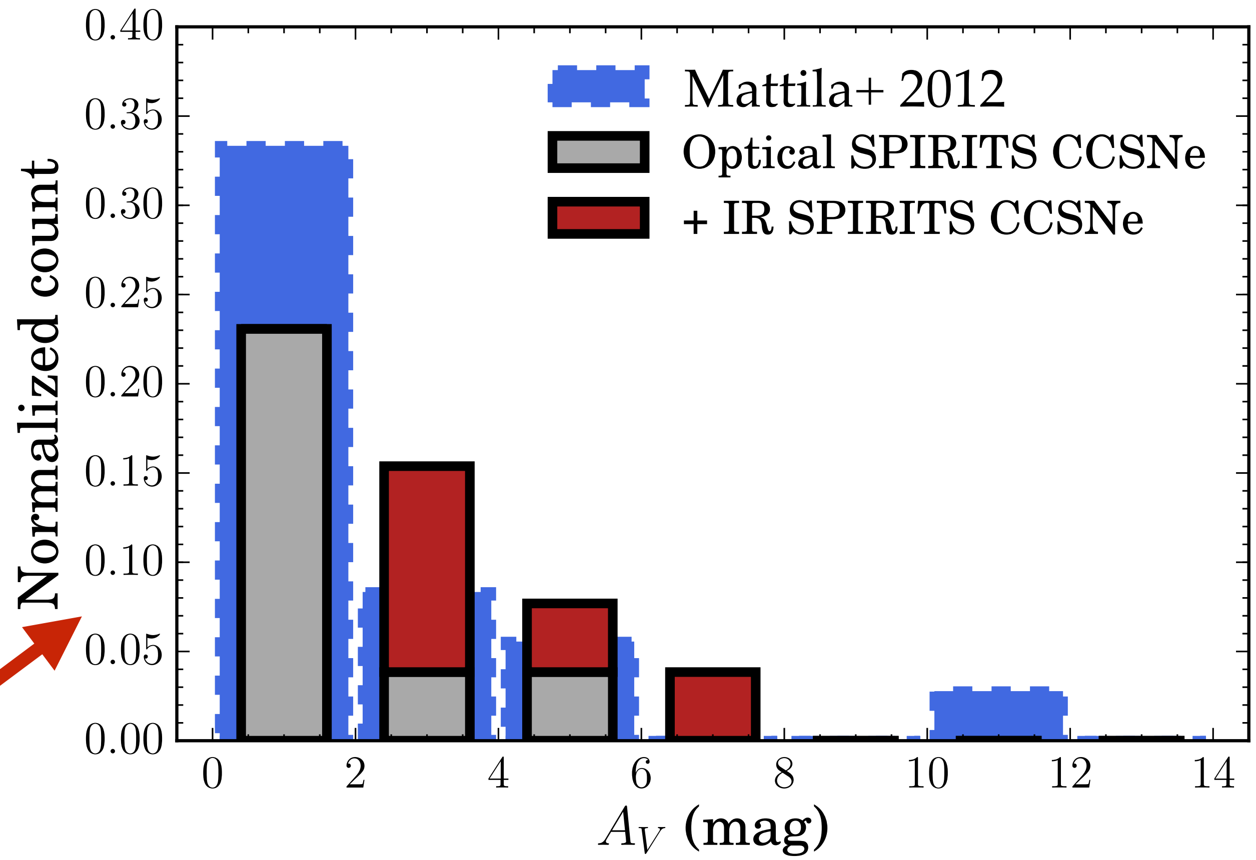
A_V ~ 5 mag
Kool+ 2018

with 2013 reference

Numerous searches of starbursts and (U)LIRGS:

- **Near with *HST* or AO** (e.g., Mattila+ 2007, 2008, Kankare+ 2008, 2012, Kool+ 2018)
- **Radio VLBI** (e.g., Perez-Torres+ 2009, Romero-Cañizales+ 2012)
- **Mid-IR with *Spitzer*** (Fox+ 2021)

SPIRITS found a high fraction of obscured events even in normal galaxies.



Jencson+ 2017, 2018, 2019

How do we build a complete census of massive stellar death?

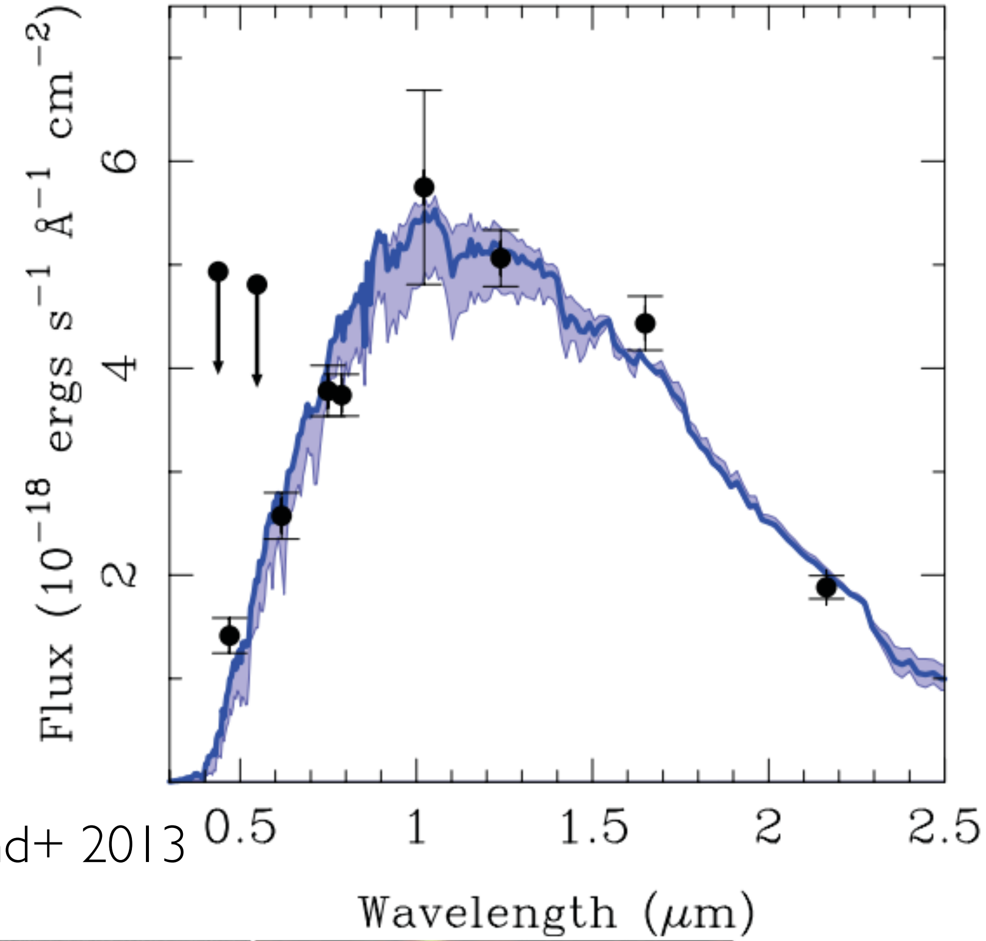
I. Where are the missing core-collapse supernovae?

II. Do *all* massive stars explode?

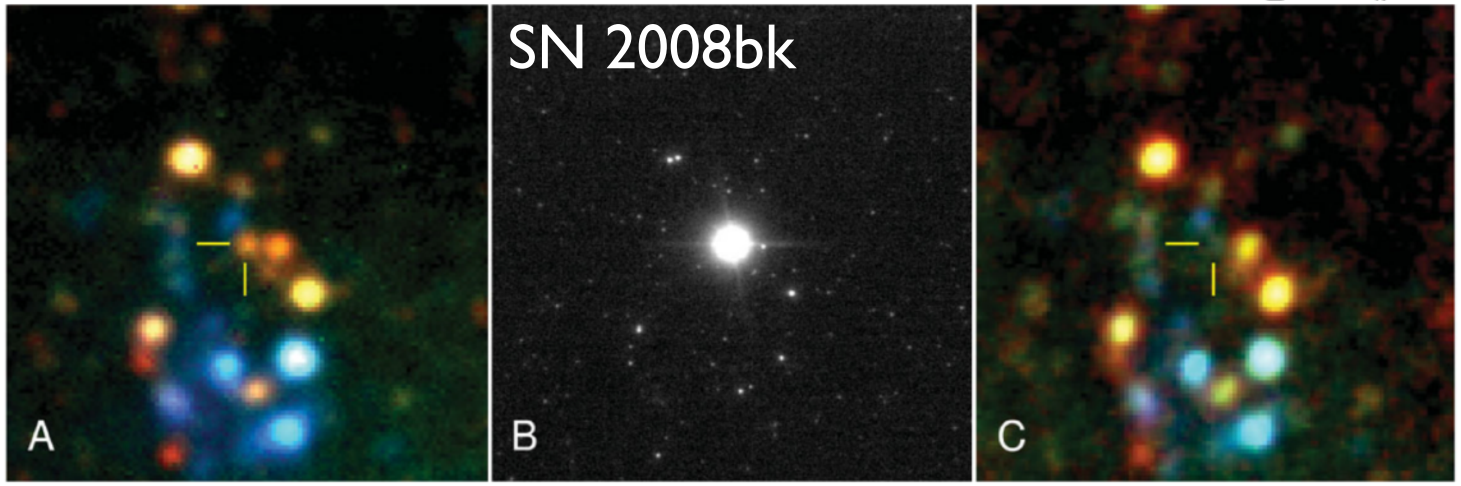
Connecting supernovae to their progenitors: Direct searches in archival imaging

Search for coincident sources in high-resolution (often *HST*) pre-explosion imaging

Ideally, the star's disappearance is confirmed in post-explosion imaging.



Maund+ 2013



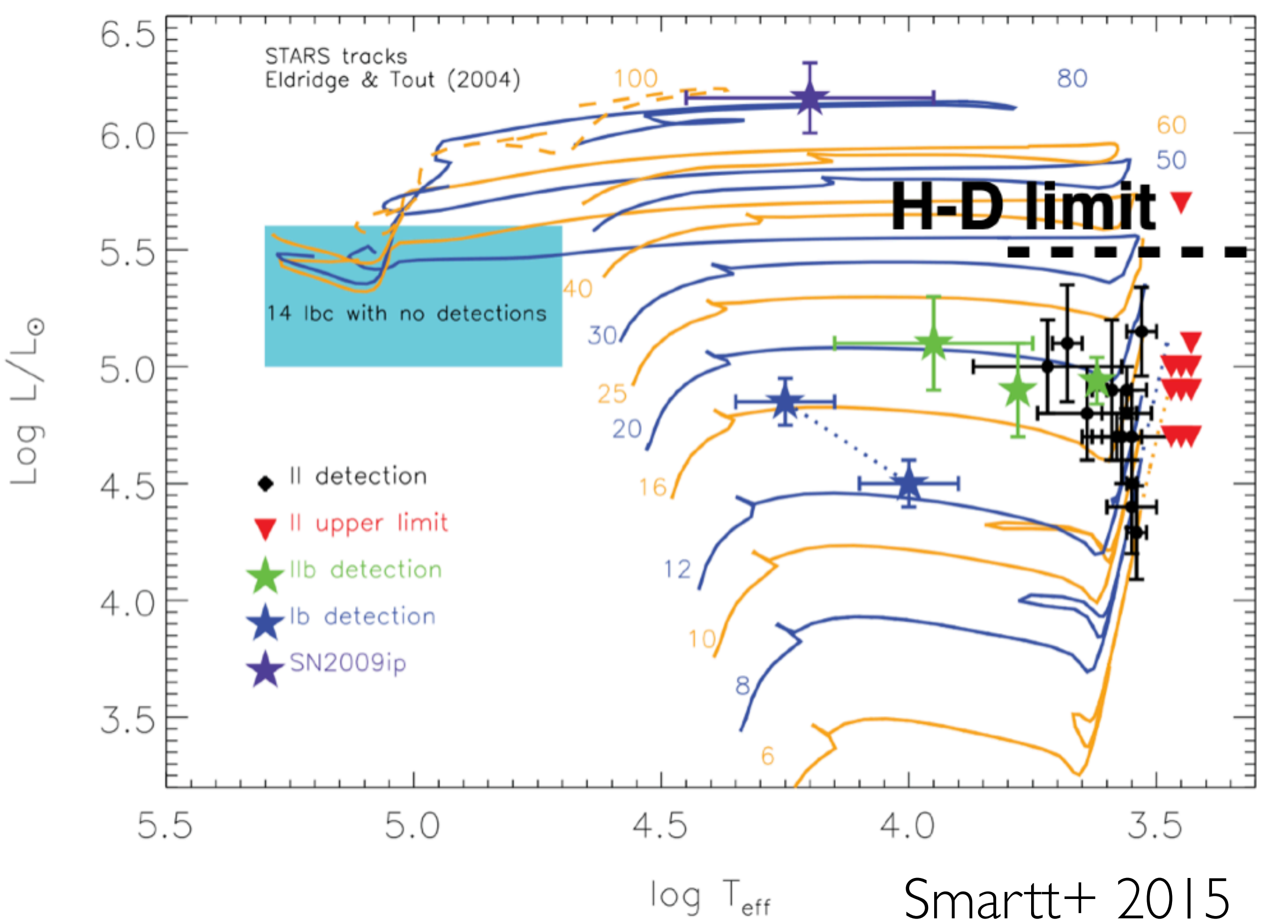
Mattila+ 2010

Do all massive stars explode?

Core structure may determine outcome (e.g., Pejcha & Thompson 2014, Ertl 2016, Sukhbold, Woosley & Heger 2018, Ebinger+ 2020, Ghosh+ 2021).

Some consensus that
>20 $M_\odot$ stars are harder to explode.

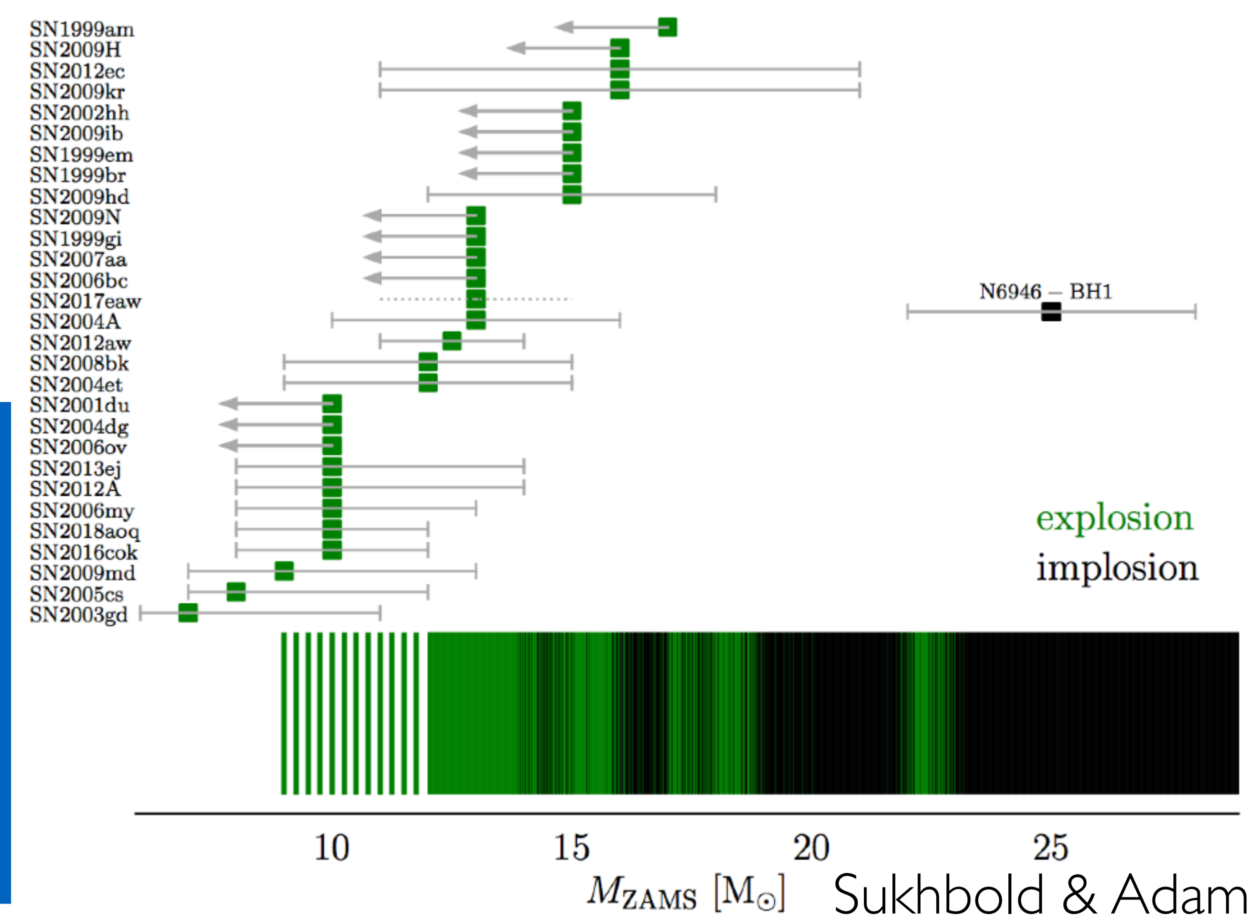
"Islands of Explodability"



Smartt+ 2015

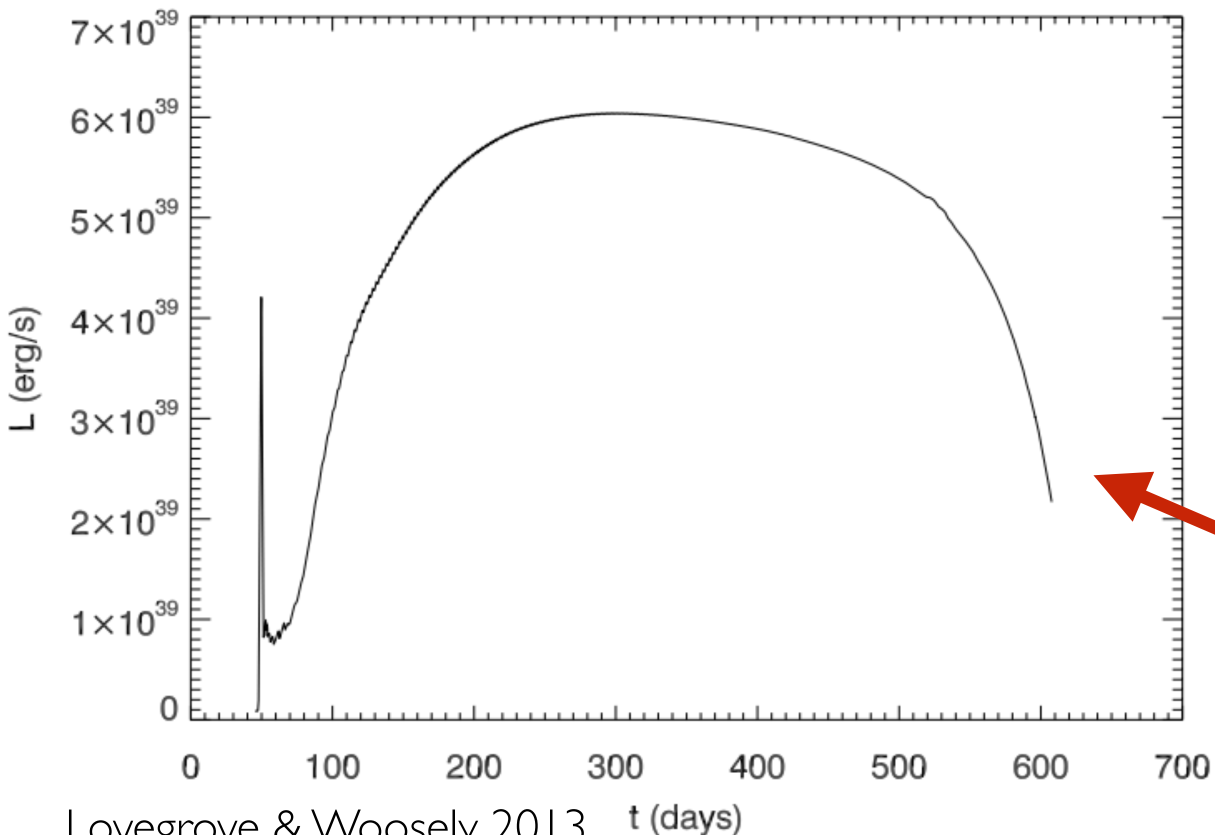
Data from IIP progenitors favors an an upper mass limit ~16-23 $M_\odot$ (Smartt 2009, 2015, Davies & Beasor 2018, 2020ab, Kochanek 2020).

Significance of missing higher mass stars remains low with current sample.



Sukhbold & Adams 2020

Black hole formation may have associated transients.



Lovegrove & Woosely 2013

Loss of core mass to neutrinos can drive a weak shock (Nadezhin 1980).

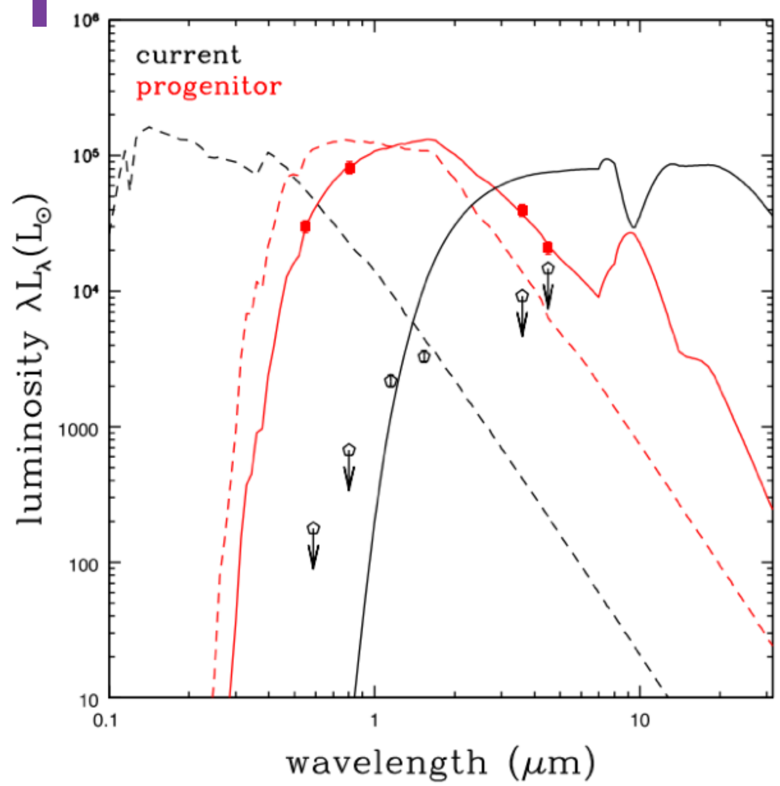
In red supergiants, this may produce a **long-lived, faint red transient** (Lovegrove & Woosely 2013):

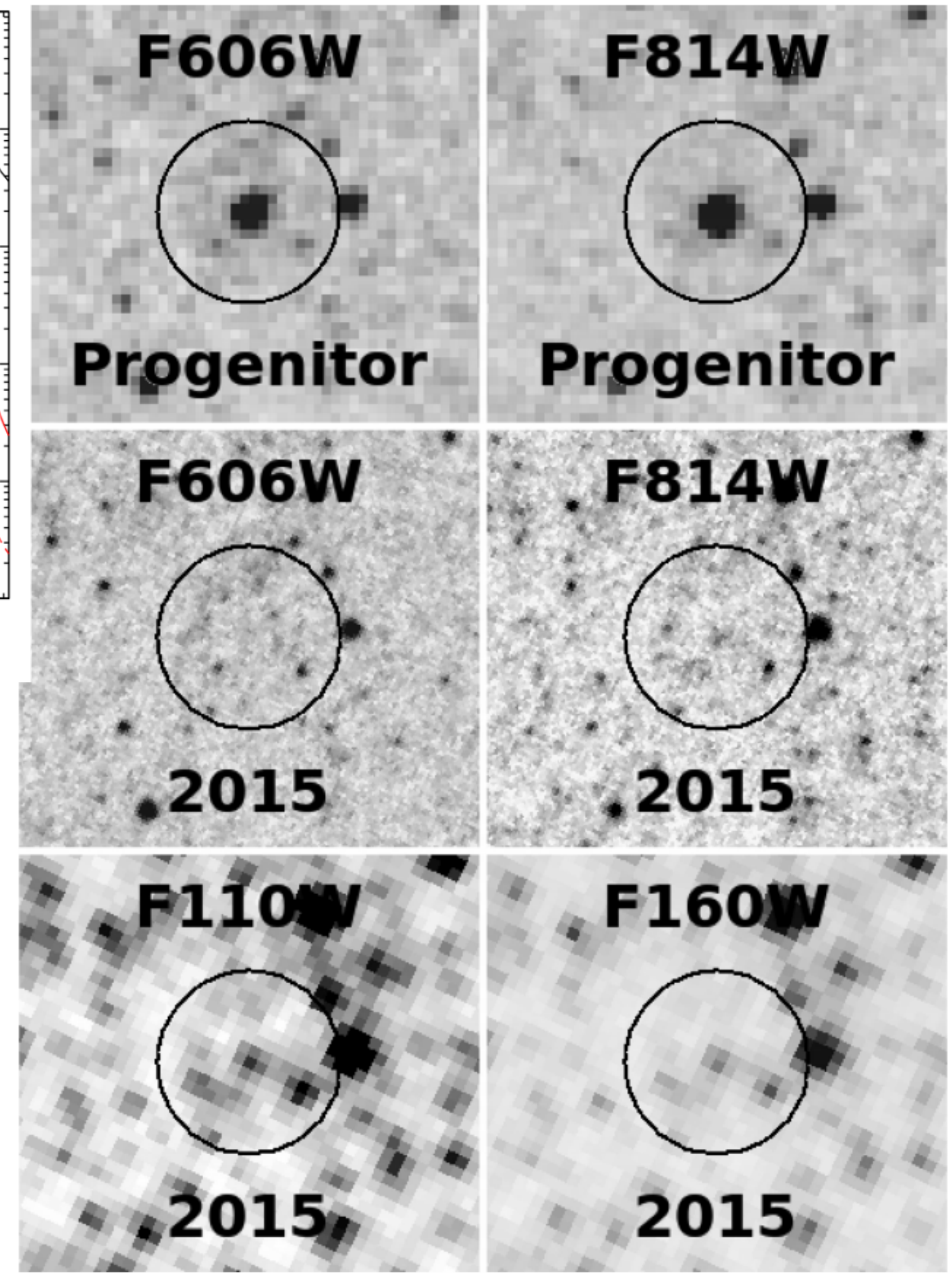
$$E_{\rm tot} \approx 10^{47}\ {\rm erg}$$
$$L \approx 10^{39}\ {\rm erg\ s^{-1}}$$
$$v \approx 100\ {\rm km\ s^{-1}}$$

No such events found in stacked iPTF/ZTF images, but may be accessible with Rubin (Byrne & Fraser 2022).

N6946-BH1: a disappearing ~25 $M_\odot$ star from the LBT

Image credit: NASA





Adams+ 2017

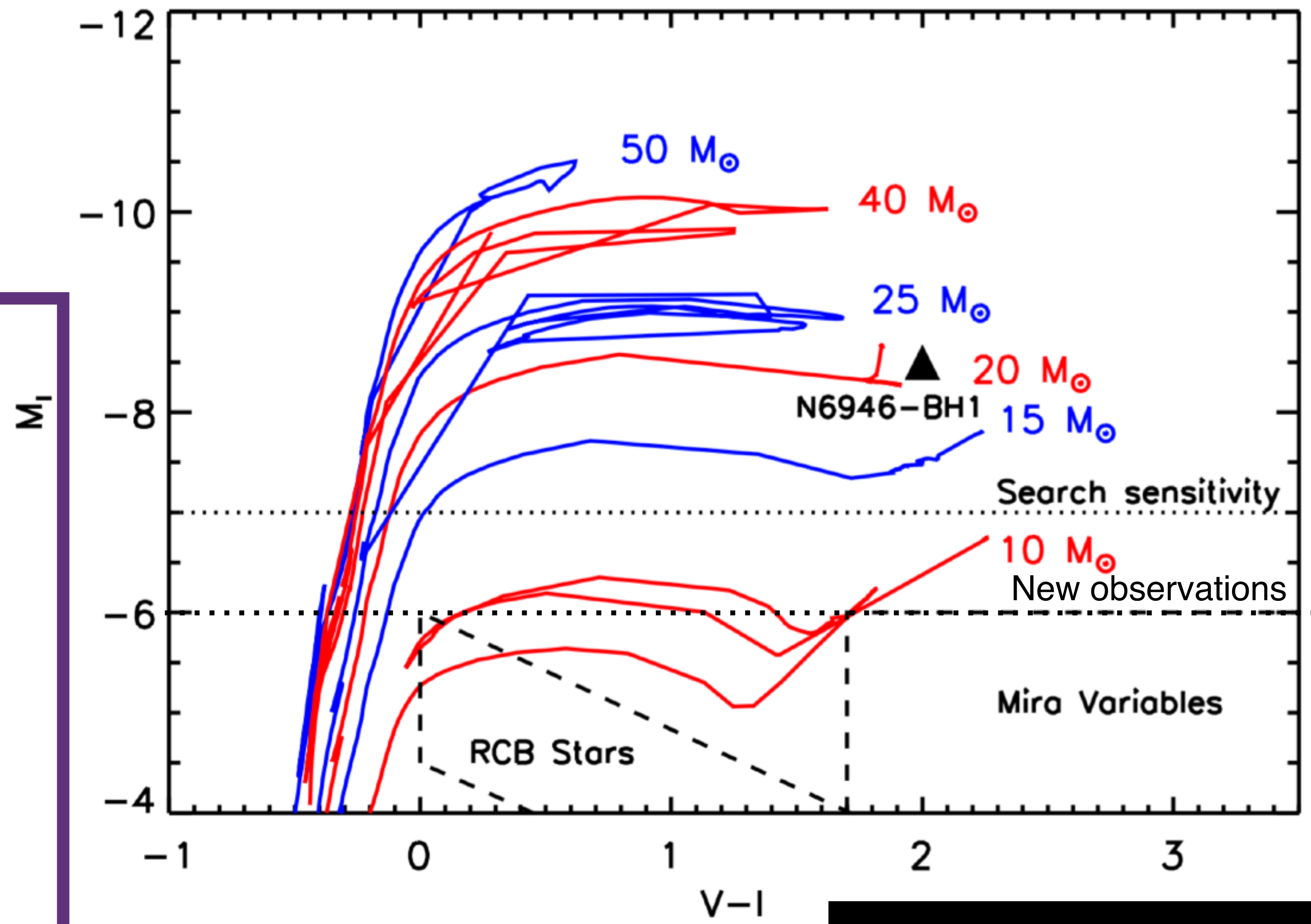
Survey of 27 galaxies within 10 Mpc led by Ohio State (Kochanek+ 2008, Gerke+2015, Adams+ 2017a)

Remnant is much fainter than progenitor, still fading in the IR (Adams+ 2017b, Basinger+ 2021)

New BSG candidate in M101 (Neustadt+ 2021)

Prior search with **archival-only** HST: One YSG candidate, not confirmed (Reynolds+ 2015).

A New Search For Failed Supernovae with HST



Observed a sample of 31 prolific SN-producing galaxies in 2019 (cycle 26; PI D. Sand)

All galaxies at least 2 epochs of prior F814W imaging, many with extensive archival coverage

Extended time baselines with new data is key

Expect ~5-10 in our dataset

In collab. with D. Sand, J. Andrews, N. Smith, J. Strader, S. Valenti, J. Pearson, E. Beasor, B. Rothberg

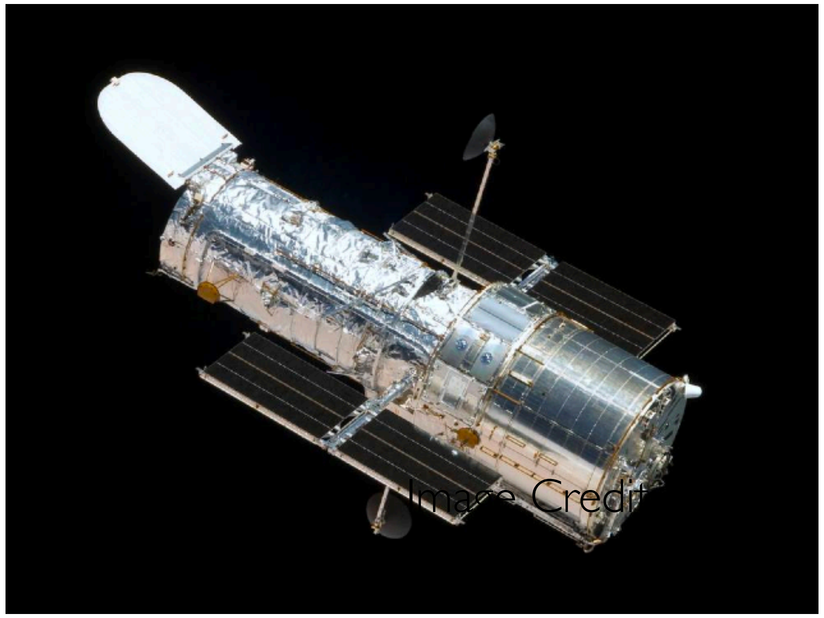
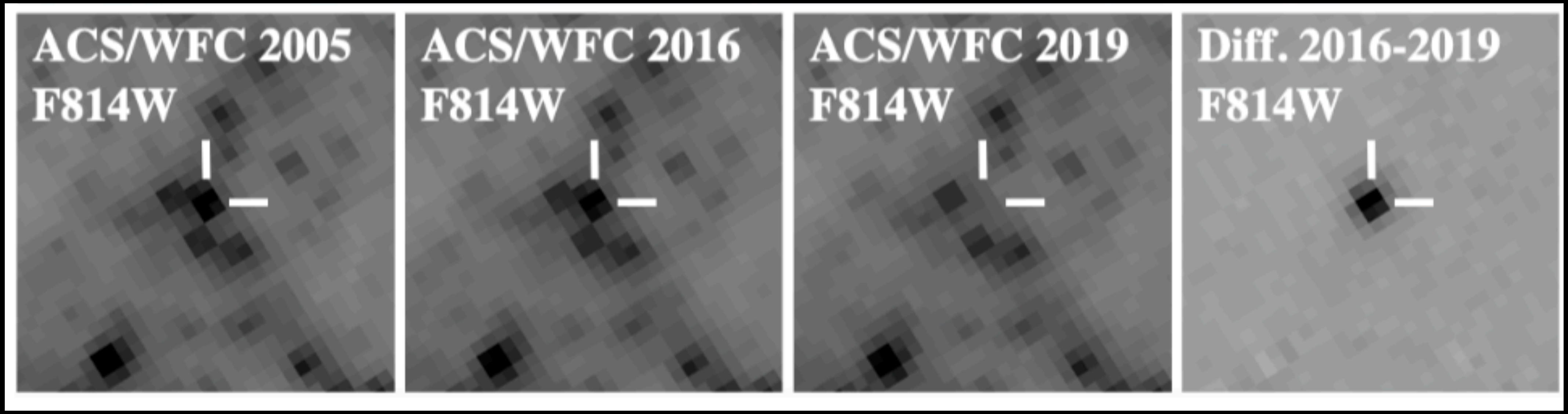


Image credit: NASA

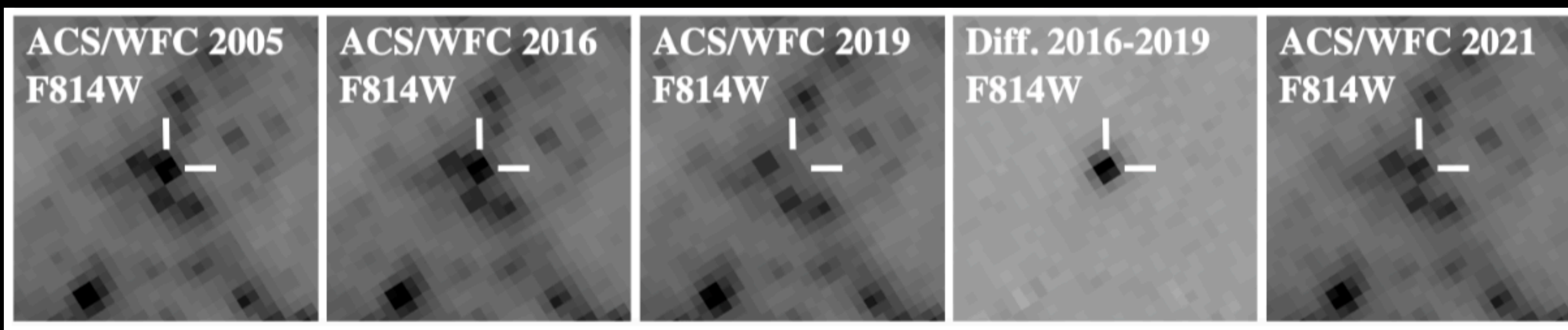
Discovery of a “**disappearing**” star in M51



M51-DS1 (= “Dimming Star” 1)

Jencson+ 2021 (arXiv:2110.11376)

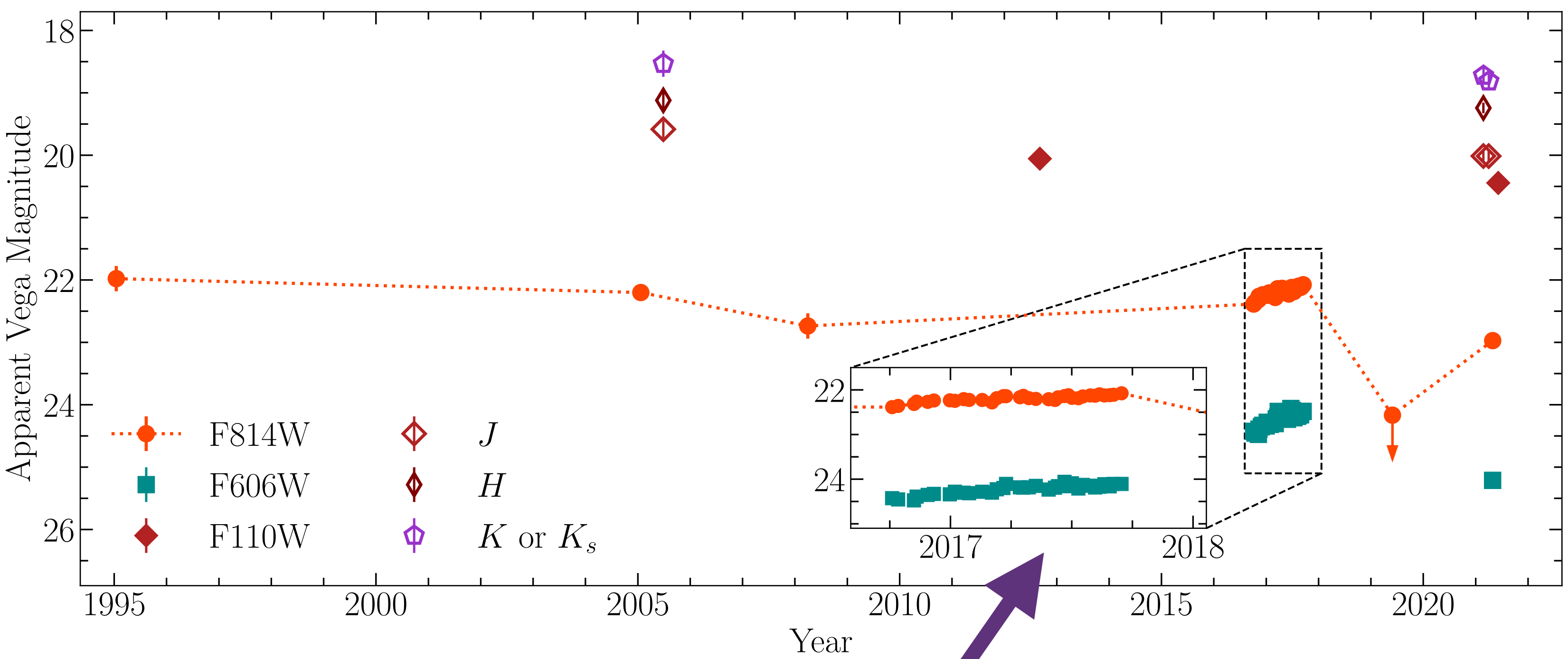
Discovery of a “~~dis~~re-appearing” star in M51



M51-DS1 (= “Dimming Star” 1)

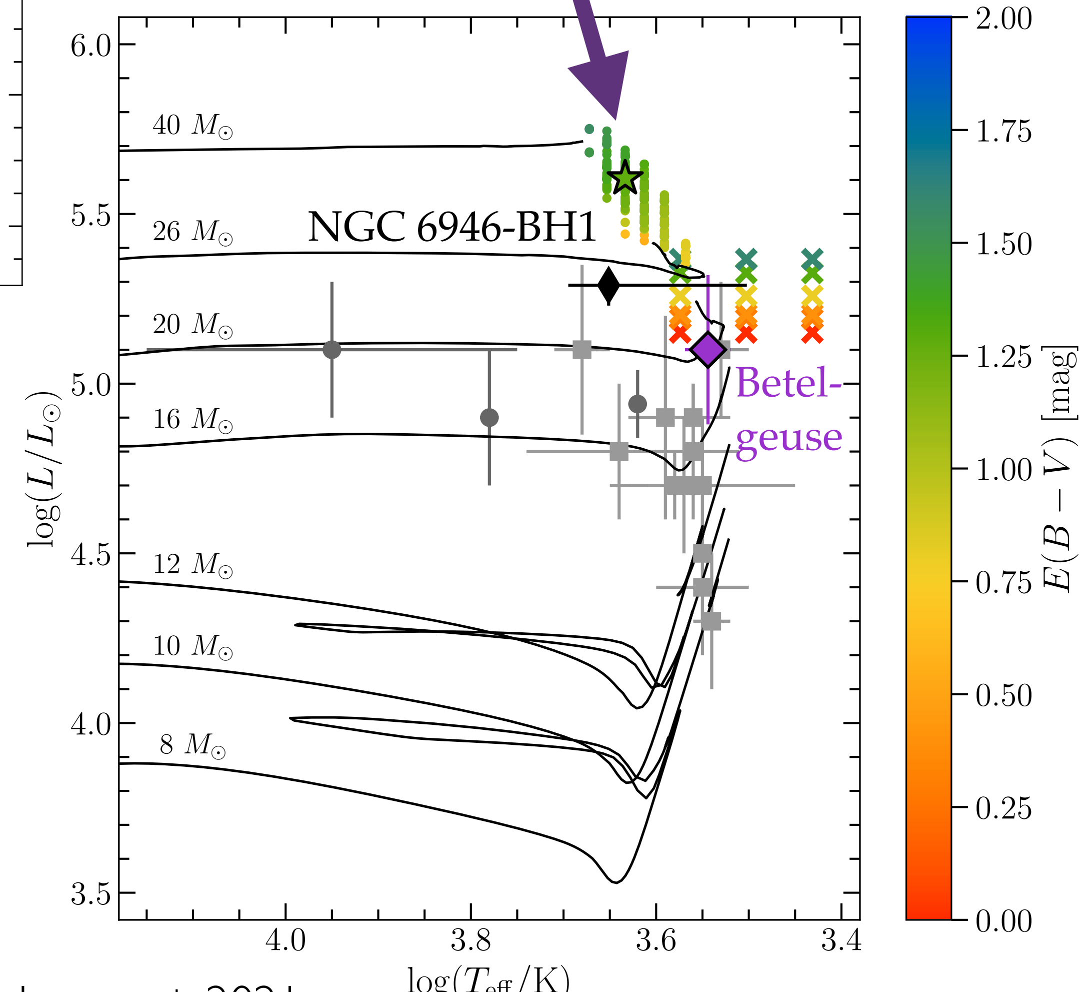
Jencson+ 2021 (arXiv:2110.11376)

Photometry points to a, massive cool supergiant variable.



High-cadence HST program for massive star variability (Conroy+ 2018)

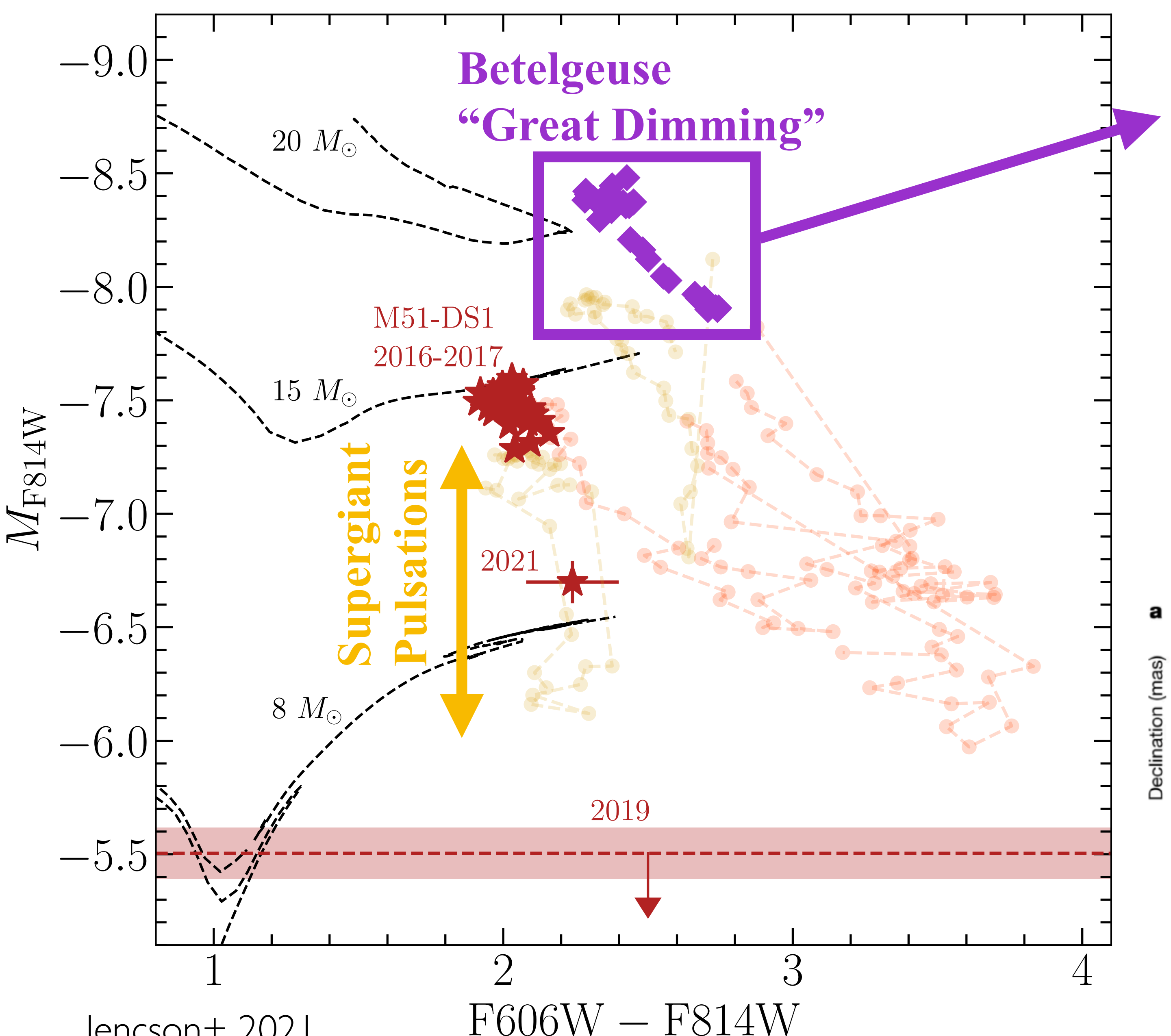
SED modeling suggests high foreground or circumstellar extinction.



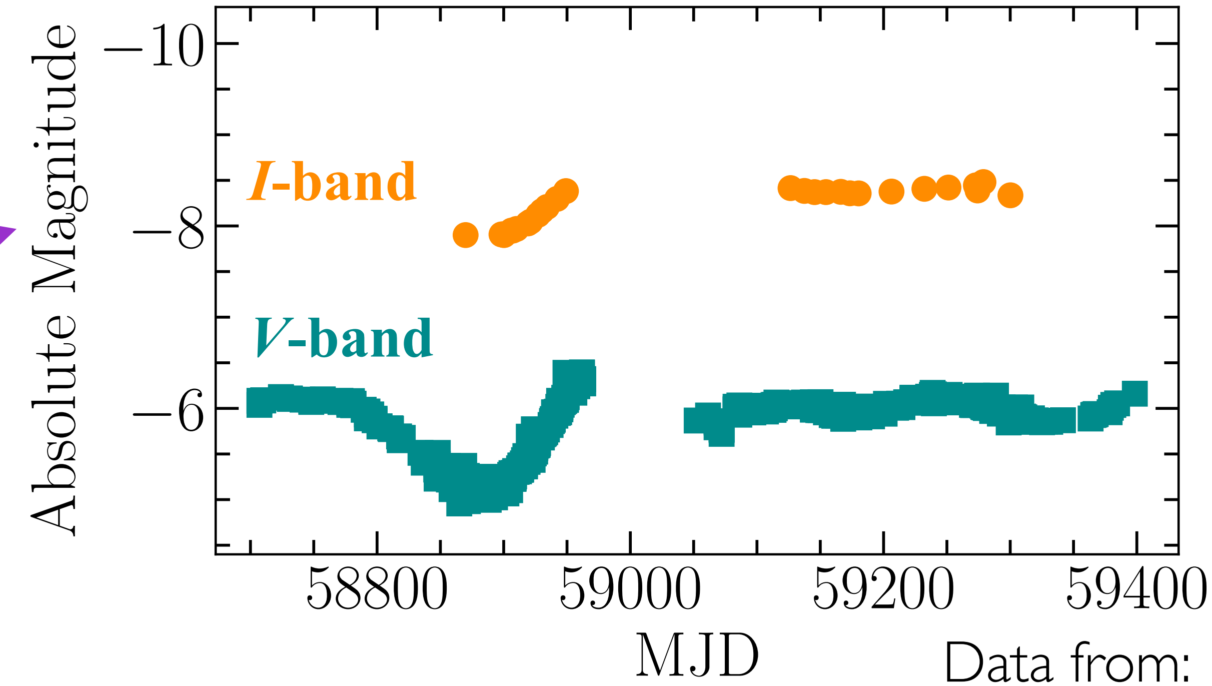
Jencson+ 2021

An even "Greater" Dimming

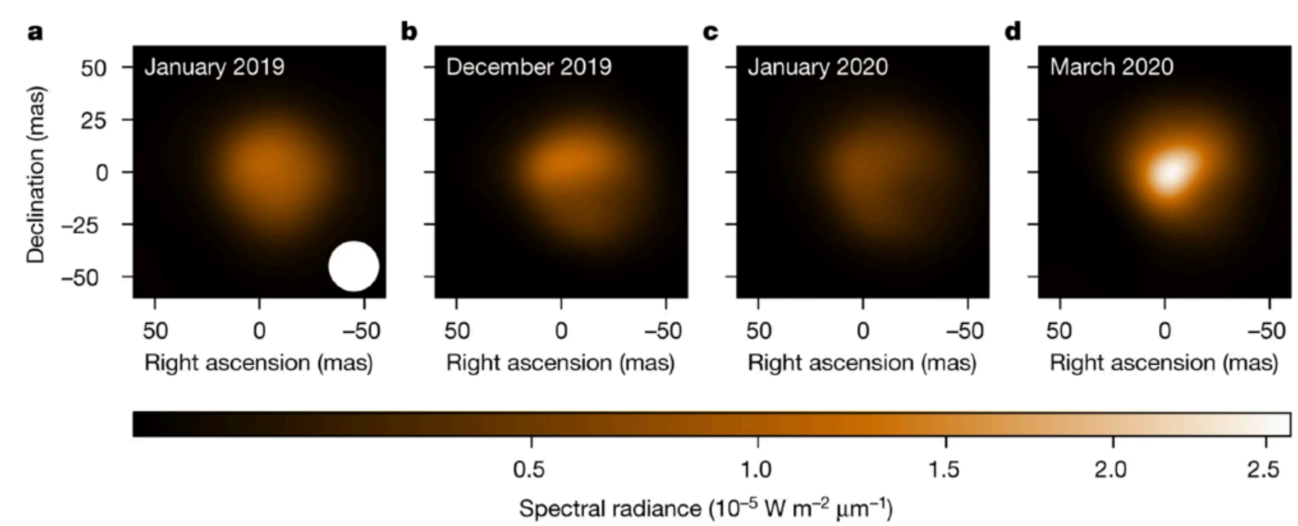
M51-DS1 as an episodic mass-loss event



Jencson+ 2021



Data from:
AAVSO.org



(Montargès+ 2021)

An even “Greater” Dimming

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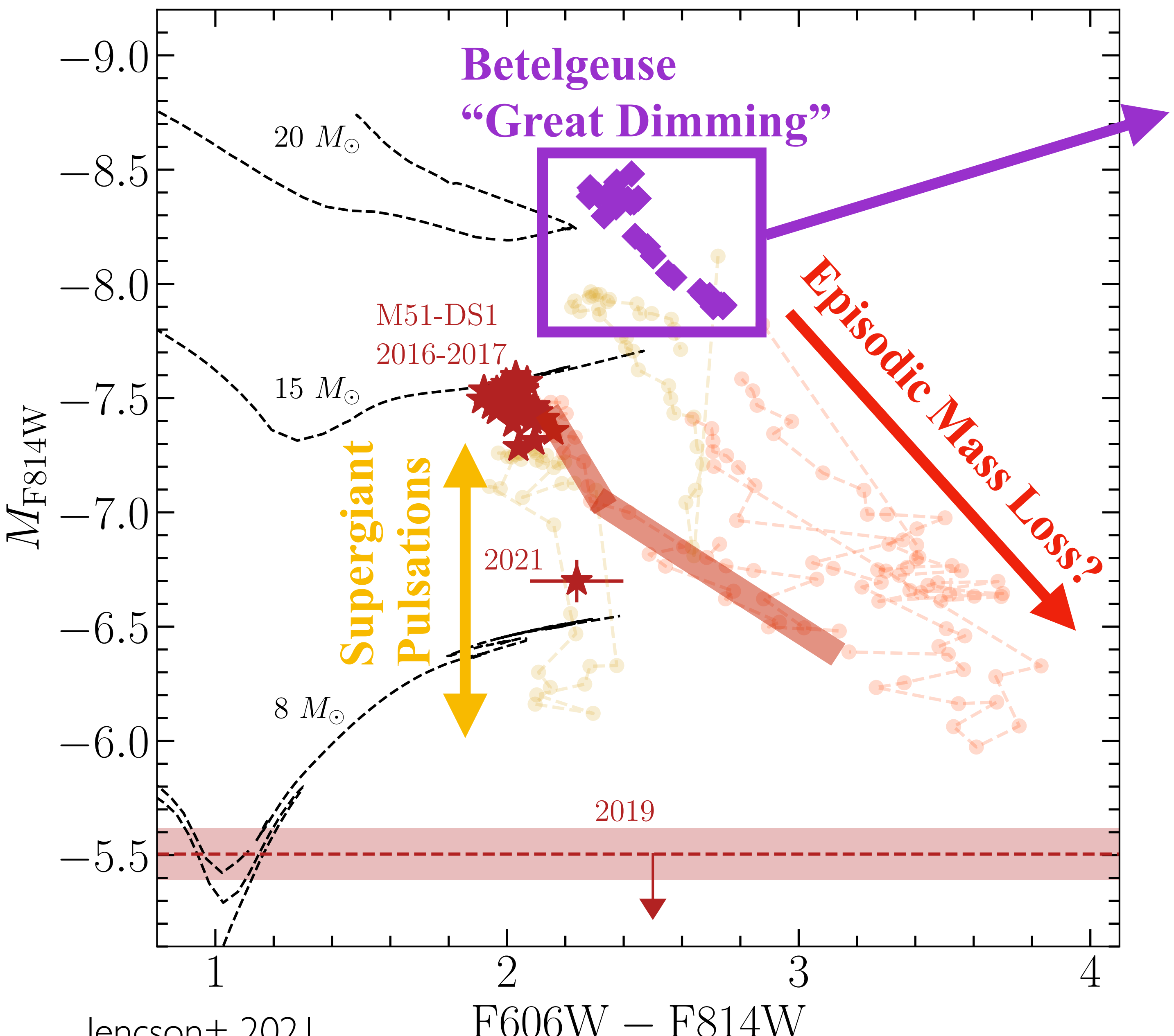
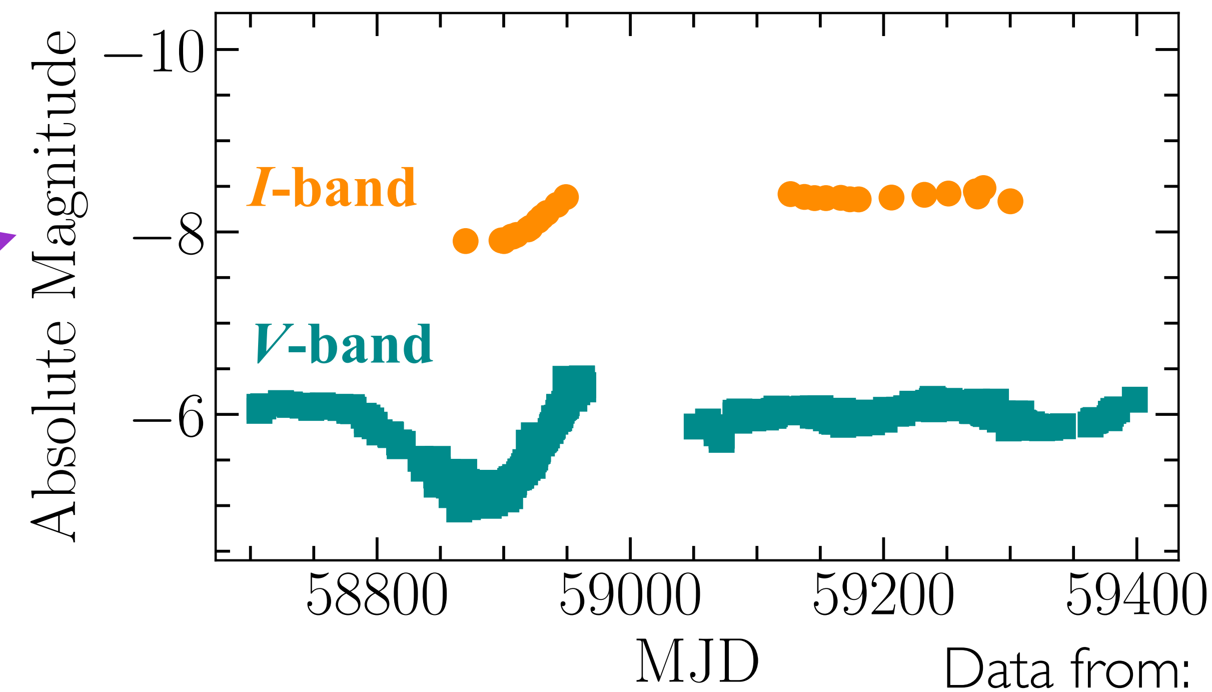


Jencson+ 2021



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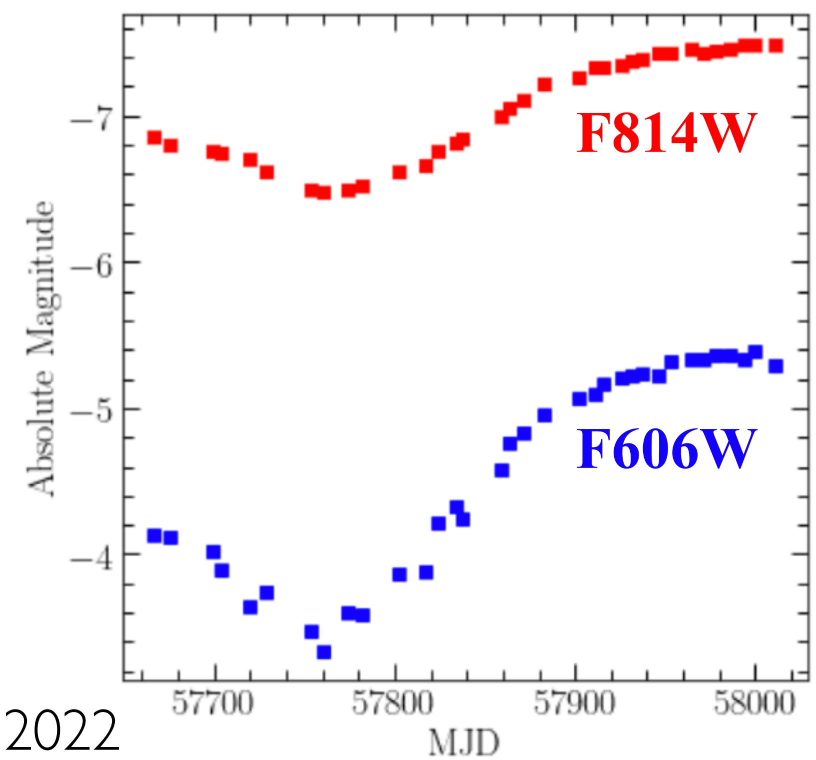


Data from
Conroy+18

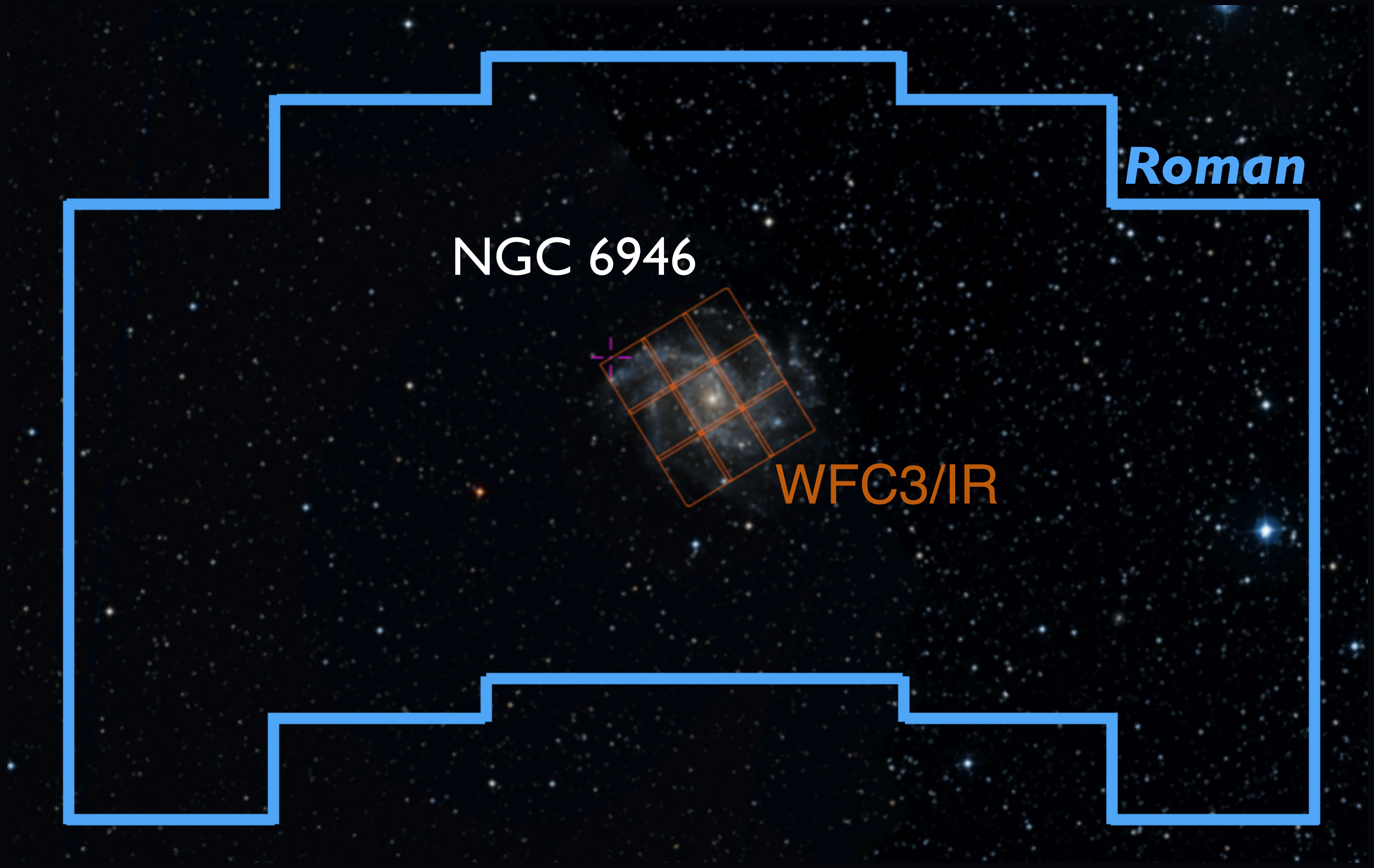
Finding Failed Supernovae with *Roman*

Less hampered by extinction

Many nearby galaxies can be fully mapped without tiling

Growing coverage with WFC3/IR as a baseline for first-pass *Roman* imaging.

Five-year *Roman* survey of 30 galaxies could find ~3-6 failed SNe (7-14 total with WFC3/IR).



Summary

The infrared sky is remarkably dynamic!

- Spitzer uncovered a host of infrared transients and variables of diverse origins.
- Huge discovery space to explore with Roman.

Roman will be a powerful tool to build a complete census of massive stellar death:

- Continue the search for heavily obscured supernovae.
- Build on ongoing work with the LBT and HST to uncover failed supernova explosions.

Auxiliary Slides

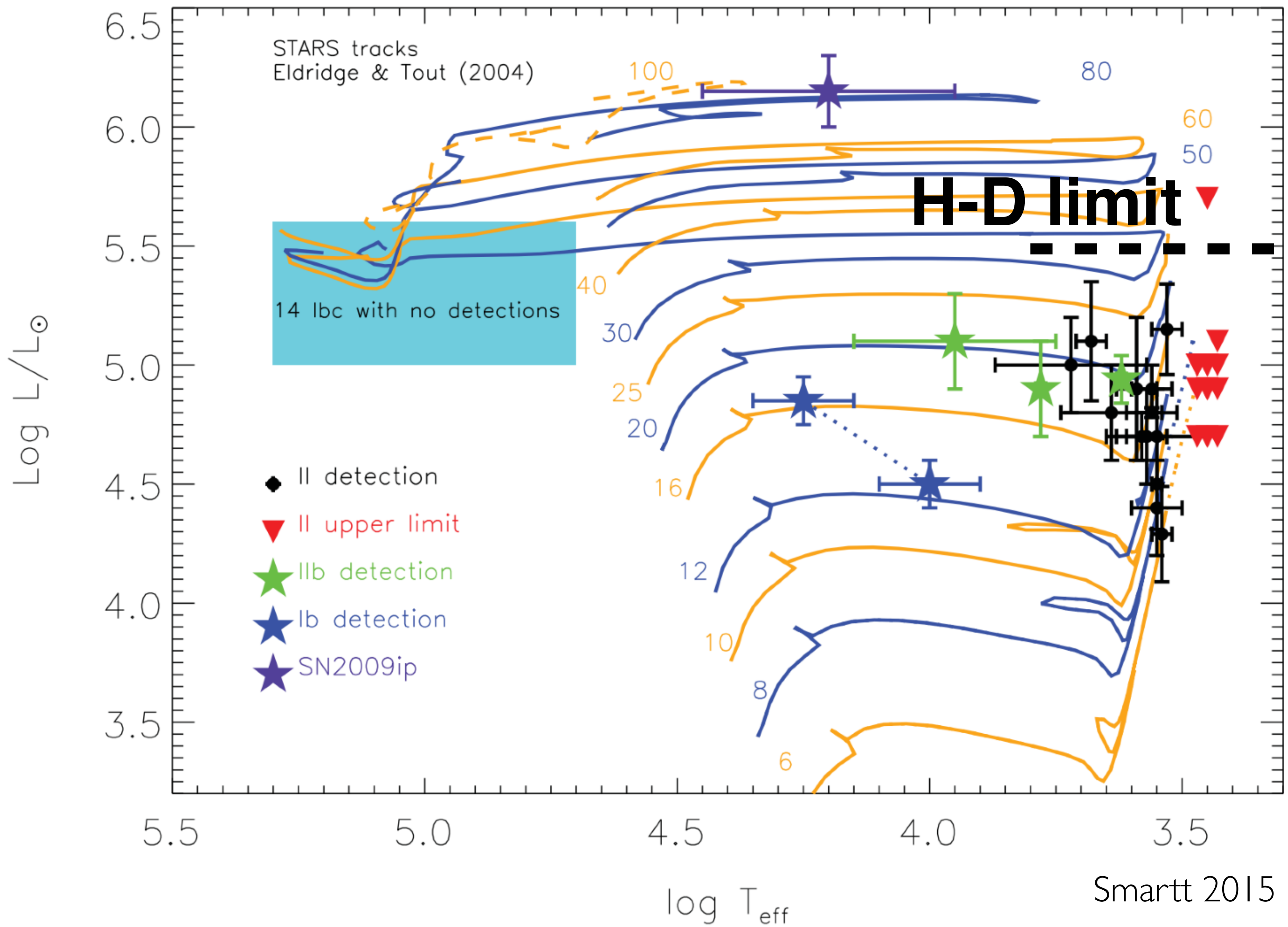
Collection of directly detected progenitors is growing:

Type II:
Red supergiant stars
~7-18 $M_\odot$

Type IIb:
Extended yellow supergiants in binaries
~13-17 $M_\odot$

Types Ibc:
Probably lower mass stars in binaries

Types IIn:
Possibly arising from very massive (~60-80 $M_\odot$) stars like LBVs (also probably binaries)

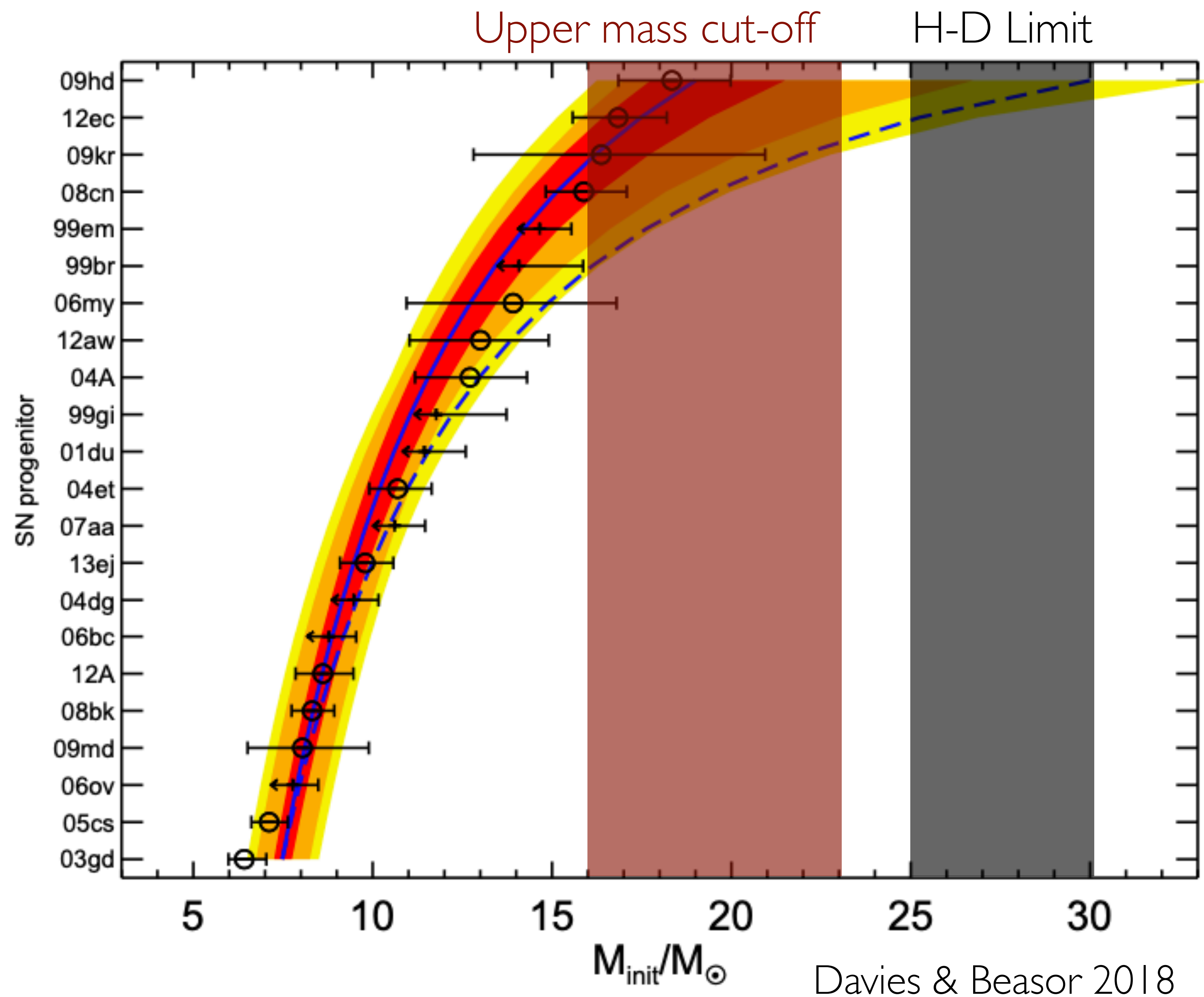


Smartt 2015

Is there evidence for missing high-mass progenitors?

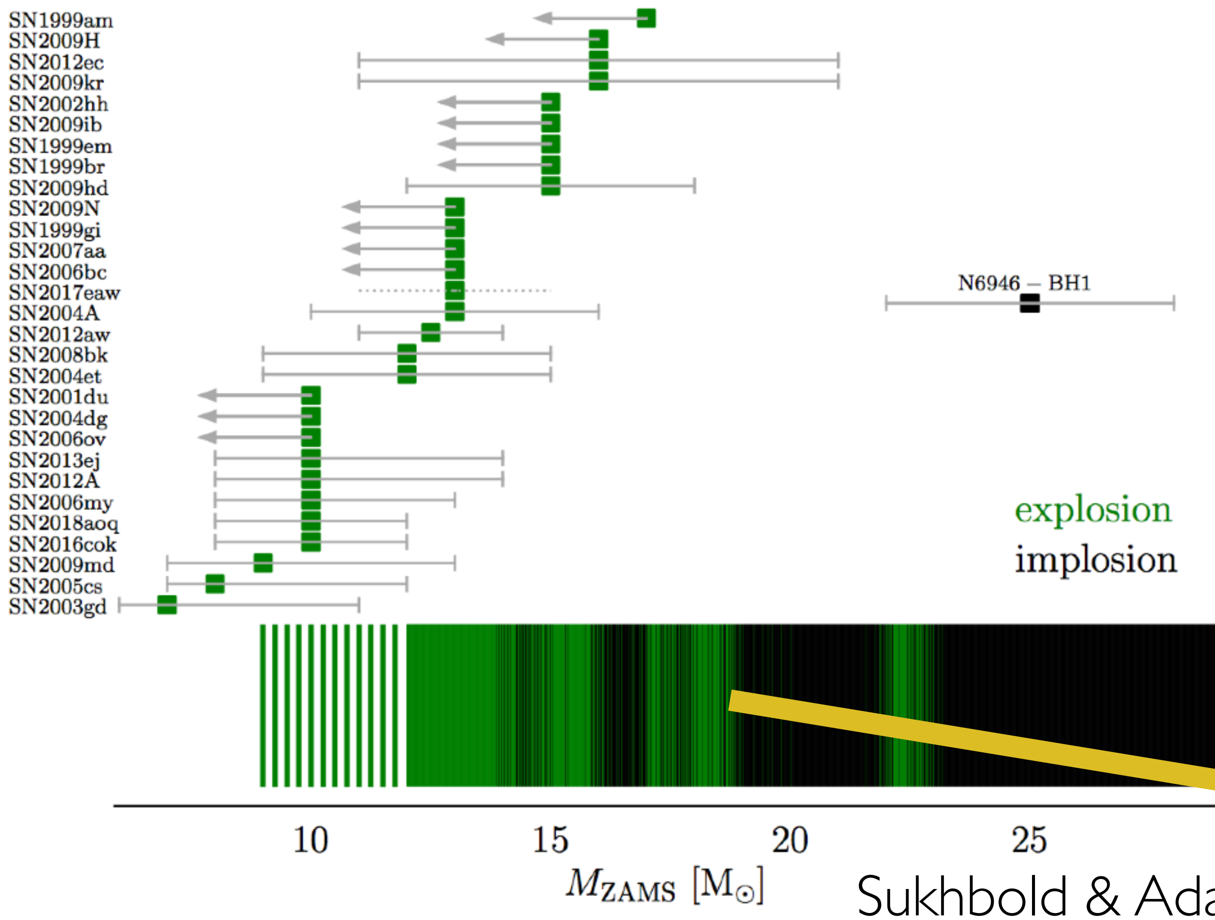
Data favors an an upper mass limit ~16-23 $M_{\odot}$ (Davies & Beasor 2018, 2020ab, Kochanek 2020)

Significance of missing higher mass stars remains low with current sample (Davies & Beasor 2018, 2020ab)



Davies & Beasor 2018

Which stars *should* explode?



Sukhbold & Adams 2020

Core structure may determine outcome (e.g., Pejcha & Thompson 2014, Ertl 2016, Sukhbold, Woosley & Heger 2018, Ebinger+ 2020, Ghosh+ 2021)

Some consensus that
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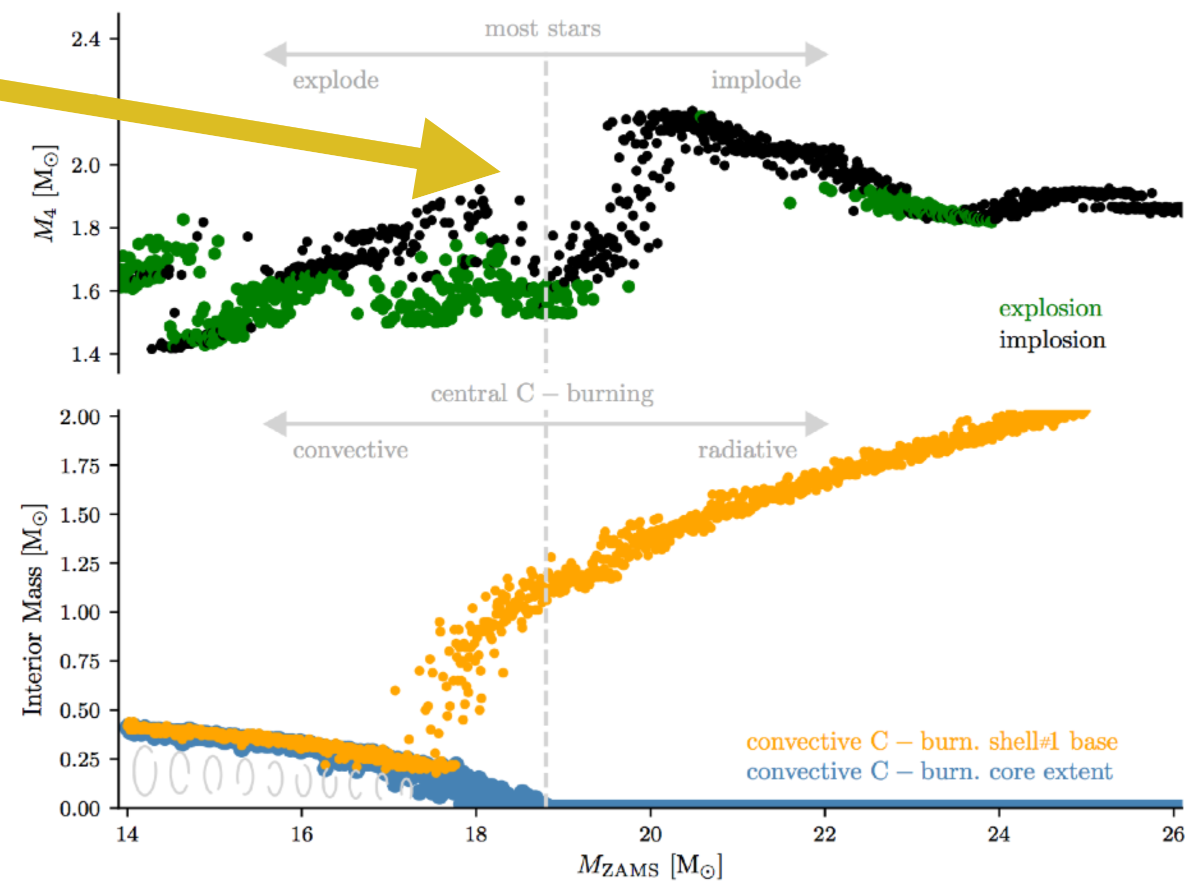
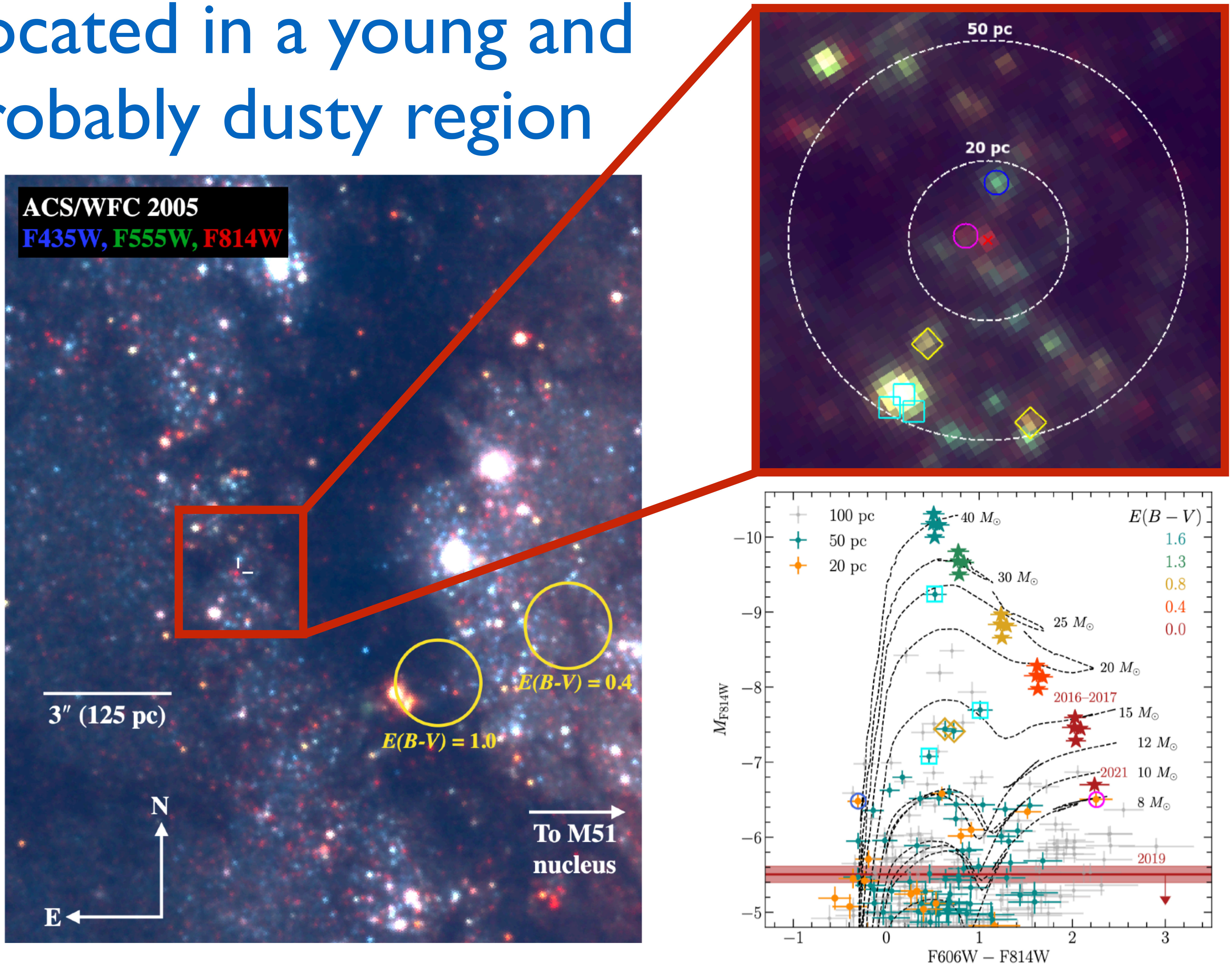
"Islands of Explodability"



Transition tied to core-burning physics:
Convective vs. radiative core C-burning (Sukhbold & Adams 2020)

Located in a young and probably dusty region



Summary and Conclusions

We are conducting a new search with HST to determine the rate and progenitors of failed supernovae.

Our first candidate is a very massive (>20 $M_\odot$), yellow or red supergiant in M51 that underwent an exceptional dimming event in 2019.

Recovery of the star suggests a large mass-loss event (not a failed supernova) - possibly a more extreme version of the "Great Dimming" of Betelgeuse.

These events may be common in cool supergiants.

Data analysis for failed supernova search is ongoing, especially for longest baselines.