The Search for Failed Supernovae: Past, Present, and Future

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Rare Gems in Big Data
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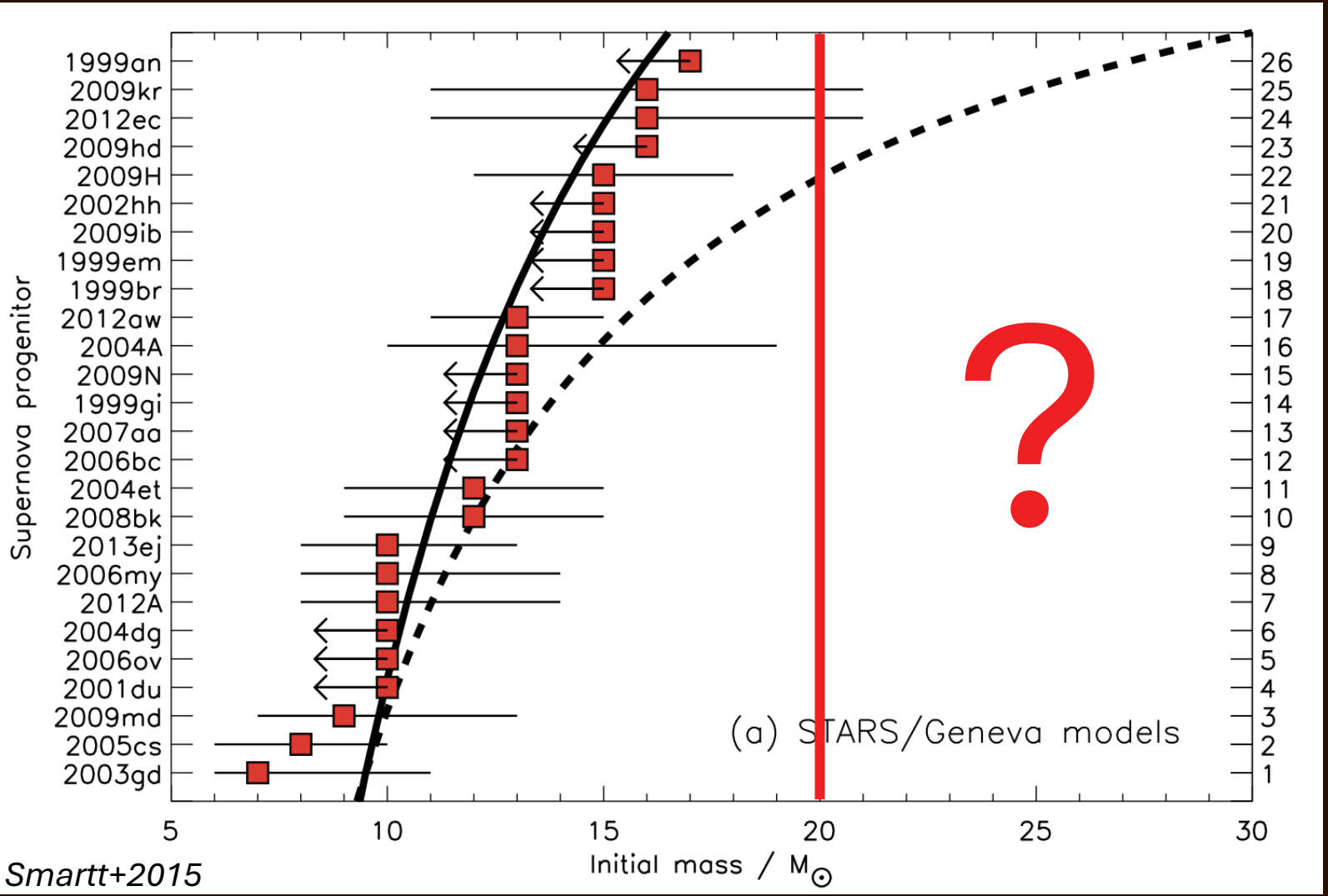
The Red Supergiant Problem?

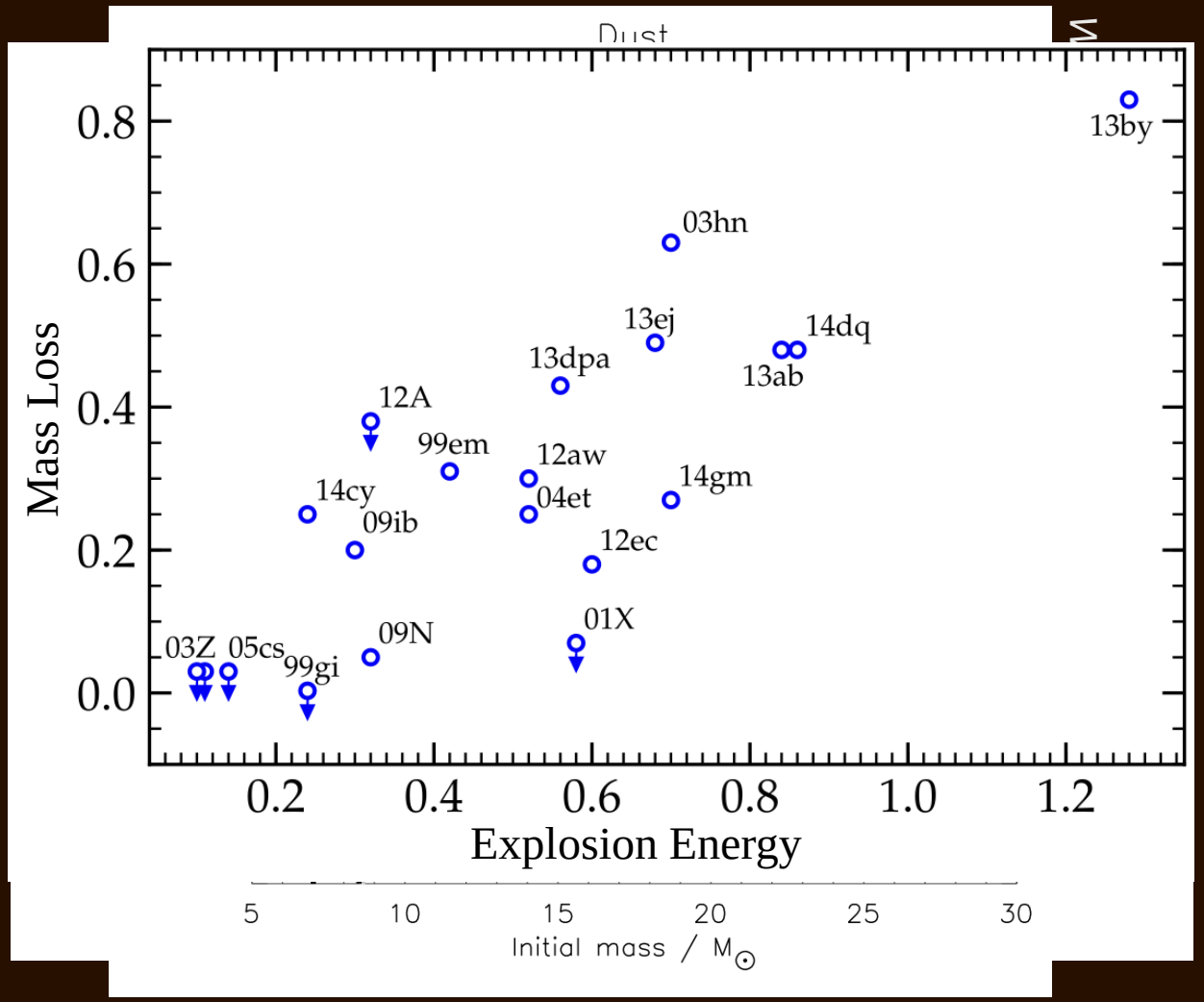


Smartt+2015

- Red supergiants explode as type IIP/L supernovae
- RSGs have been observed up to 30 $M_{\odot}$
- No SNe II with progenitors >20 $M_{\odot}$
- Missing high mass RSGs?

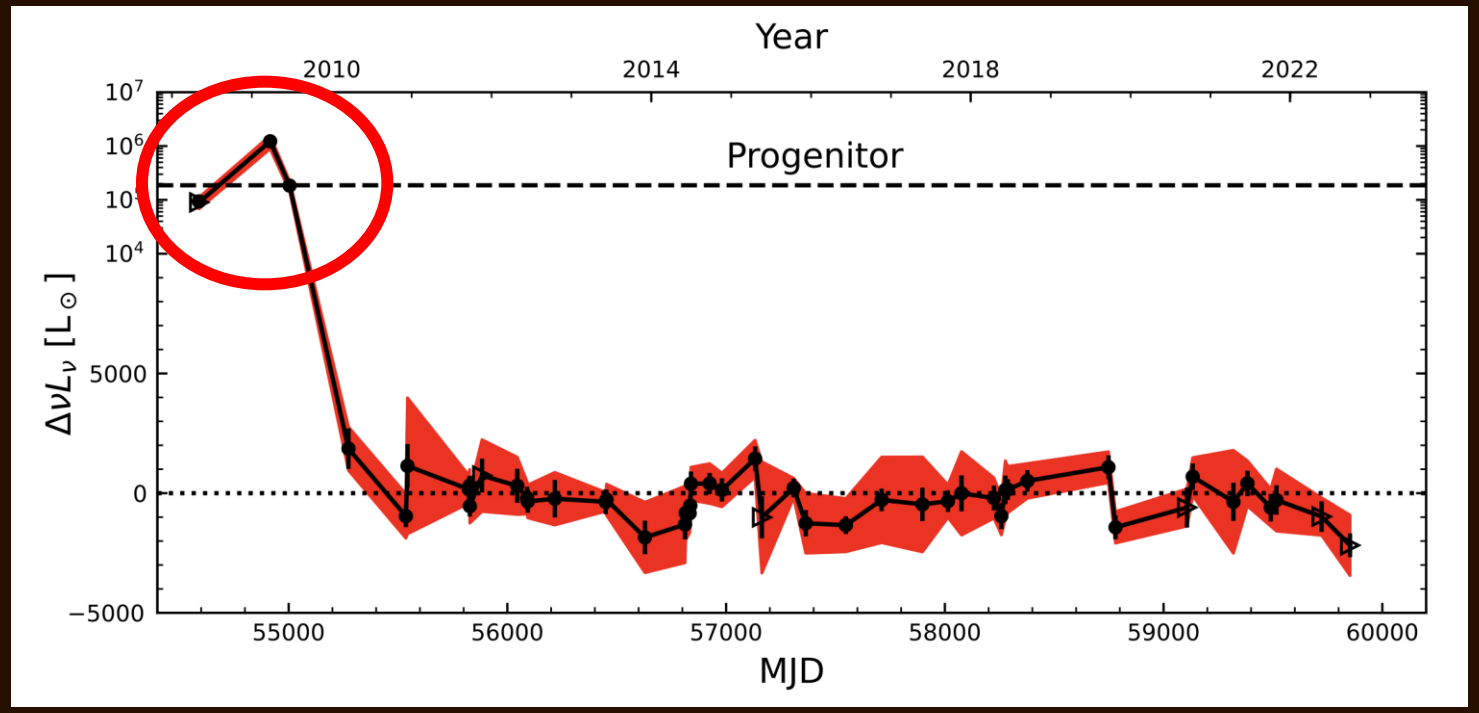
Solutions to the Red Supergiant Problem

- Just haven't seen any explode yet
- The progenitor masses are incorrect
  - Dust attenuation
- Mass loss
- Direct implosion
  - Failed Supernova
  - Provides pathway for low-mass black hole formation

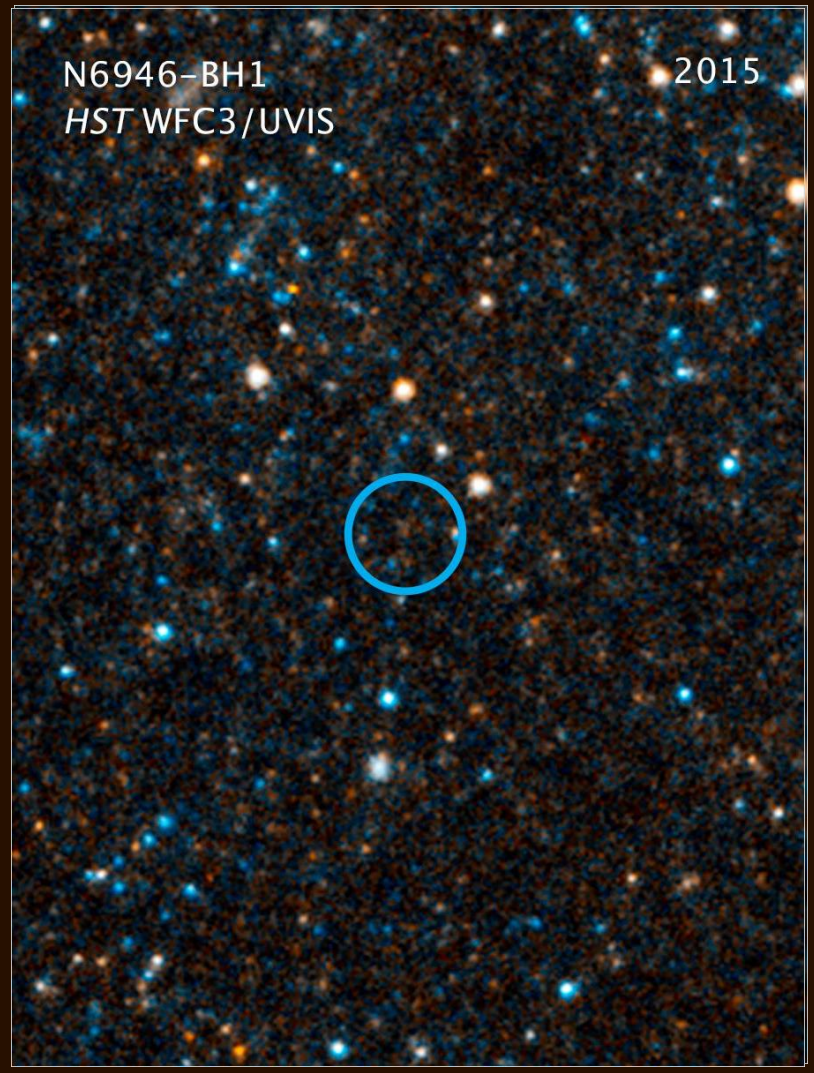


Finding Failed Supernovae

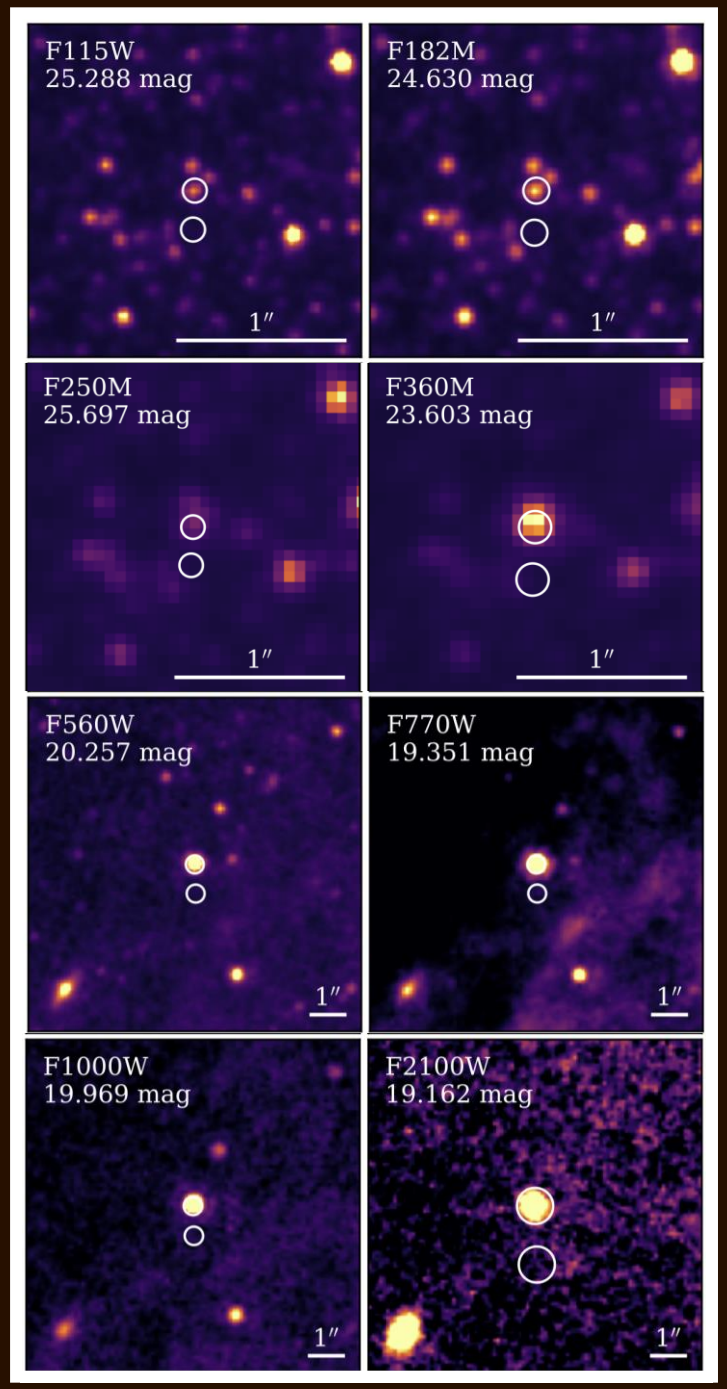
- Three candidates
  - NGC6946-BH1 is the most convincing
  - Still hasn't brightened in the optical



Kochanek+2024



Adams+2017



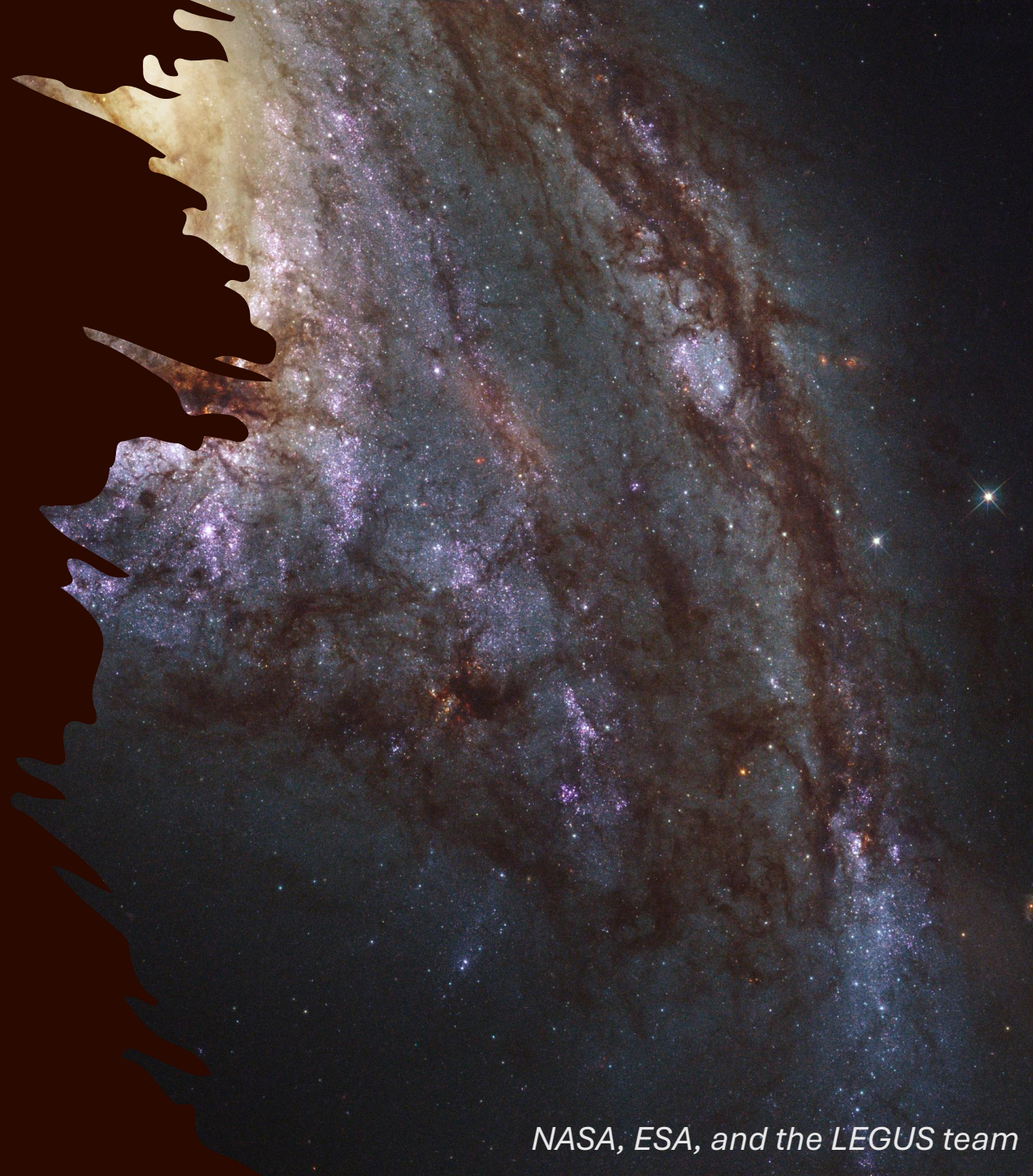
Beasor+2024

JWST Observations of N6946-BH1

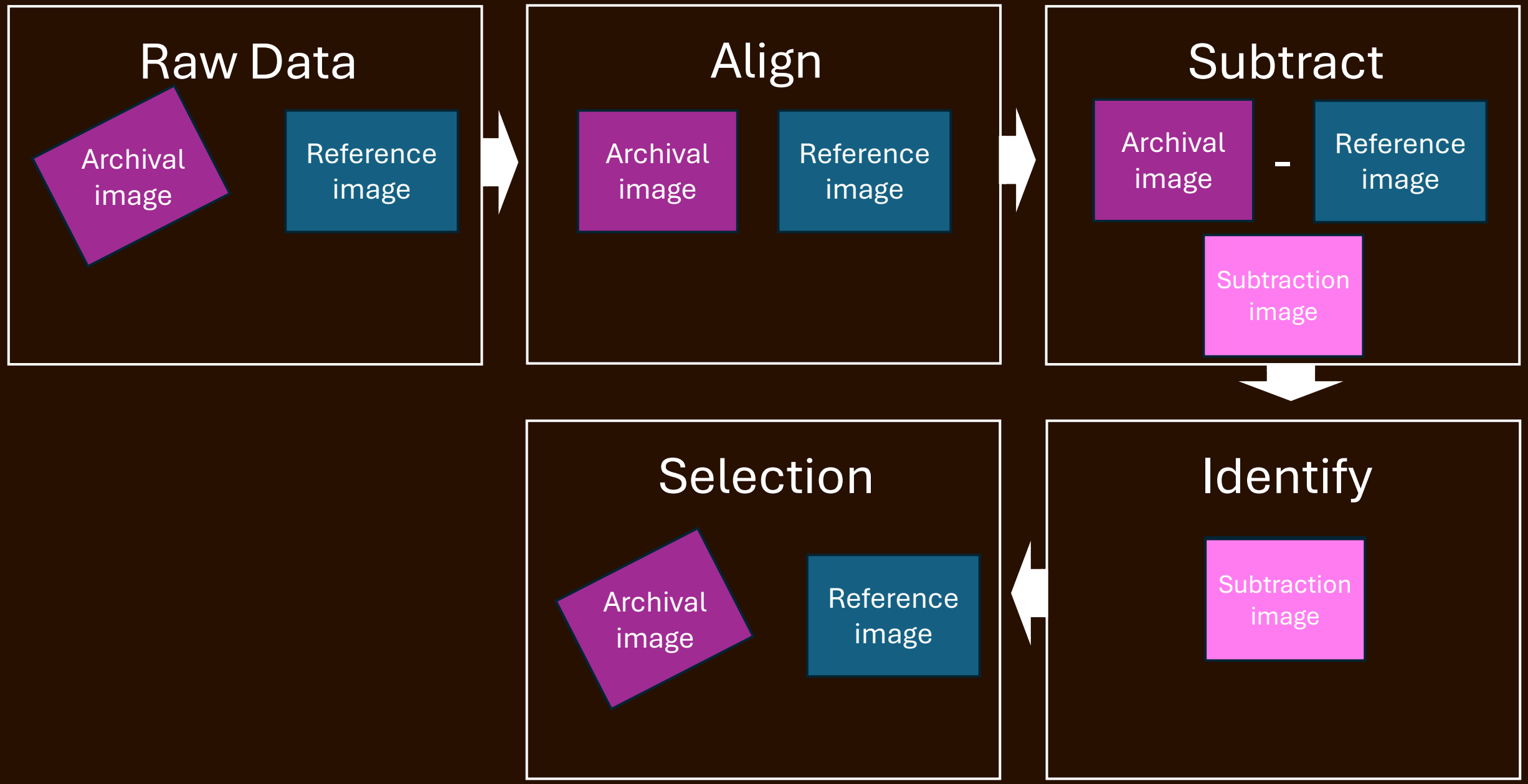
- If failed supernova → no source in IR
- Source is clearly detected
- Possibilities:
  - Failed Supernova with accretion
    - ~15 years since disappearance
  - Outburst forming a dust shell
    - Fainter than pre-disappearance star
    - Merger event?
- Follow-up JWST spectra needed

The HST Failed Supernovae Project

- Observed a sample of 31 galaxies
  - High core-collapse supernovae rates (cycle 26; PI D. Sand)
- >2 epochs of F814W imaging per galaxy
  - Coverage in other HST filters
  - ~10 galaxies with JWST imaging
- 30+ year time baseline
- Based on current predictions, we expect to find **~5-20 new candidates**



NASA, ESA, and the LEGUS team


Raw Data
Archival image
Reference image
Align
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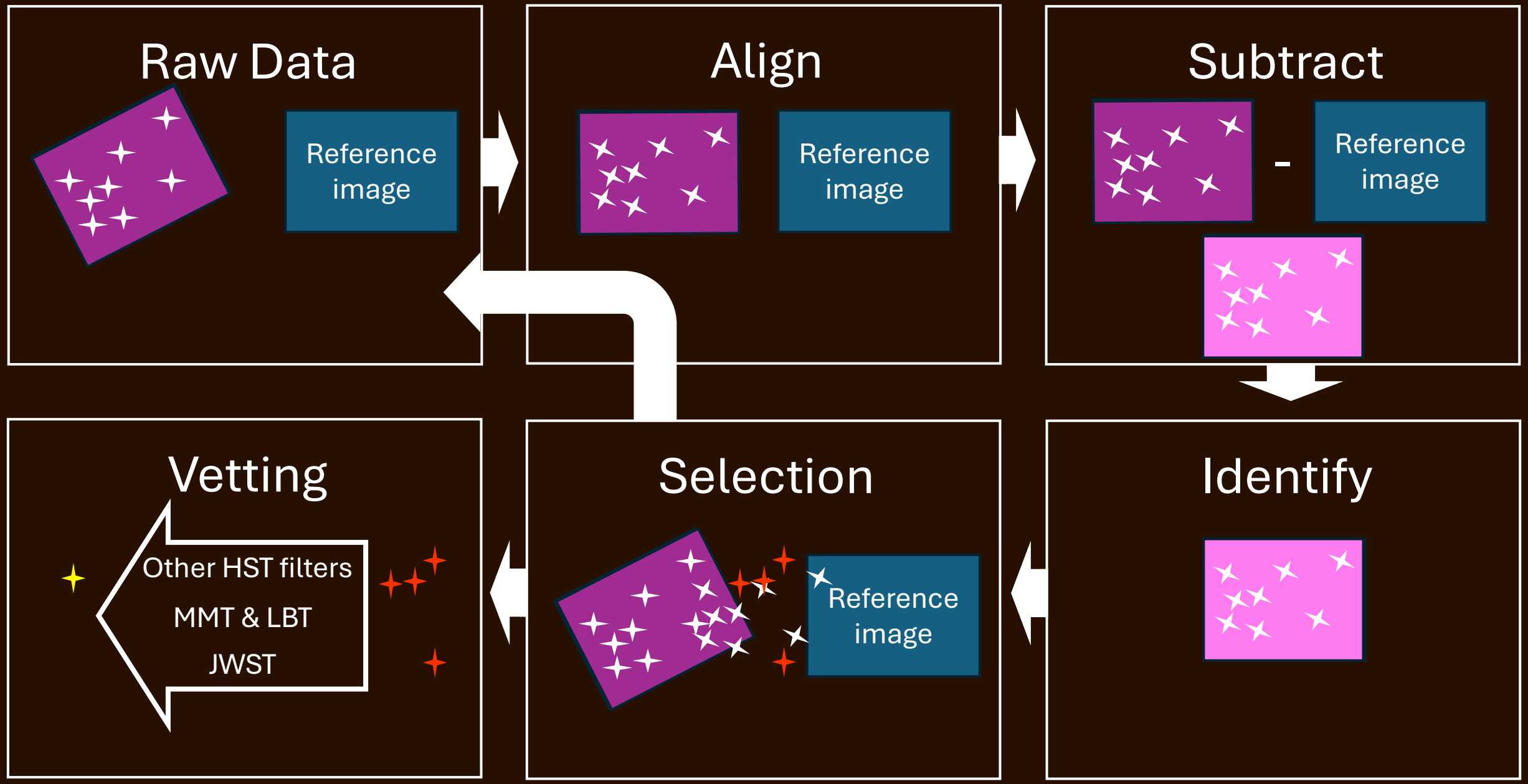
Archival image
Reference image


Raw Data
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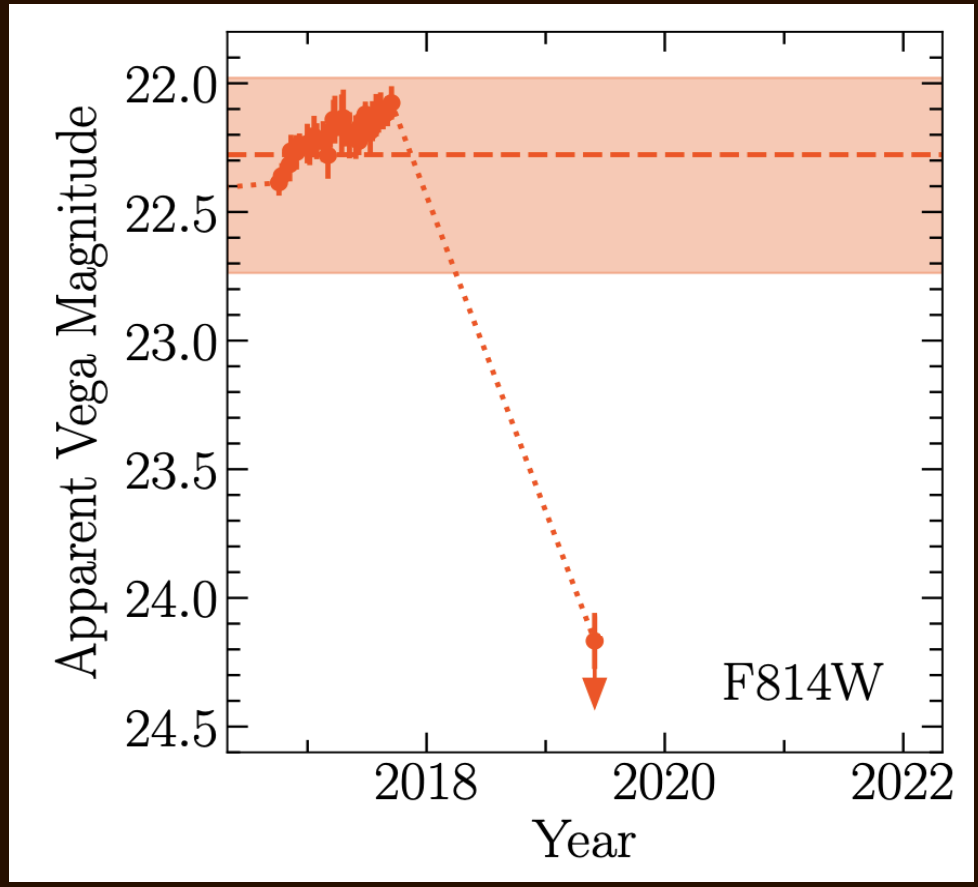
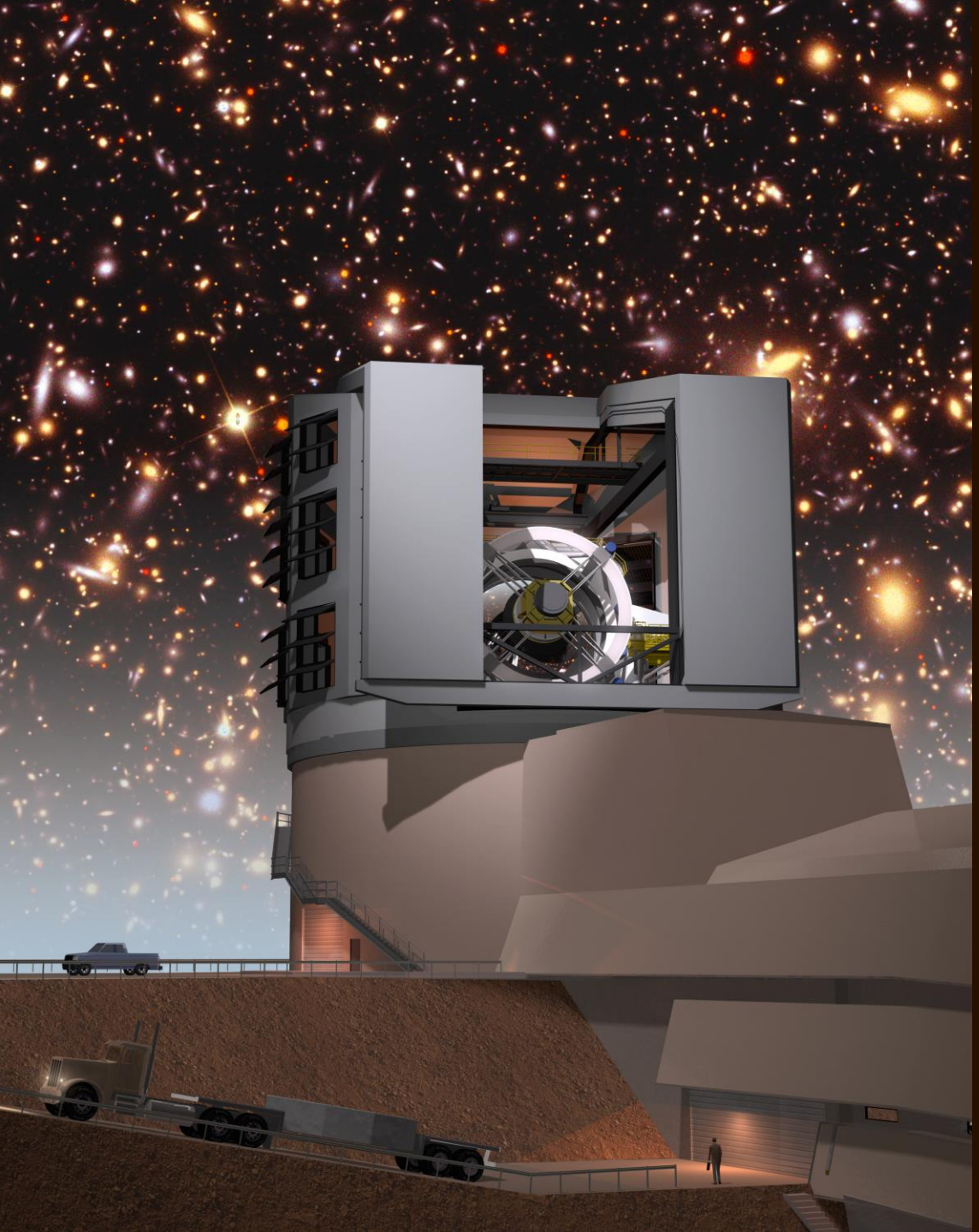
Selection
Reference image
Vetting
Other HST filters
MMT & LBT
JWST

What We've Found

- M51-DS1 ("~~Dis~~Reappearing Star 1")
- yellow or red supergiant that underwent an exceptional dimming in 2019
  - very massive (>20 $M_\odot$)
- large mass-loss event
  - more extreme version of the "Great Dimming" of Betelgeuse



Jencson+2022



In the Era of LSST

- HST search will place upper limit on FSNe rate
- Detect faint outbursts
- In nearby galaxies (D≲15 Mpc):
  - Observe disappearing sources
  - Significant imposters
    - Cadence will allow for rebrightening checks
  - i, z, and y bands are ideal
- Need IR follow-up to confirm
  - JWST and Roman

In Summary

- Failed supernovae are an enticing solution to the red supergiant problem
  - **Not confirmed to exist**
- HST archival data will provide strong upper limit
- Failed supernovae searches are great at uncovering variables “imposters”
- LSST will detect faint transients and may find individual disappearing stars
- We don’t know what failed supernovae look like so vetting will require human element

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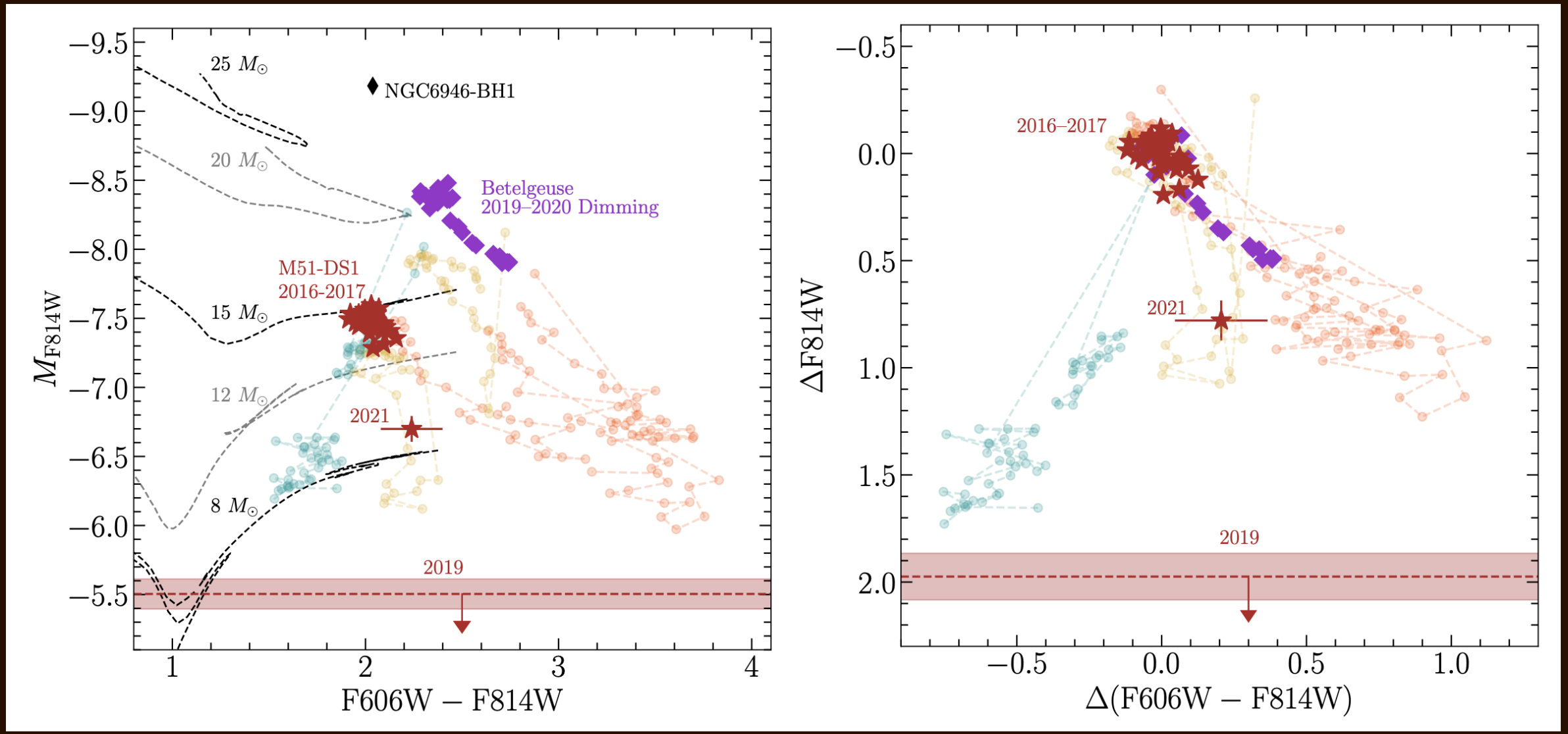
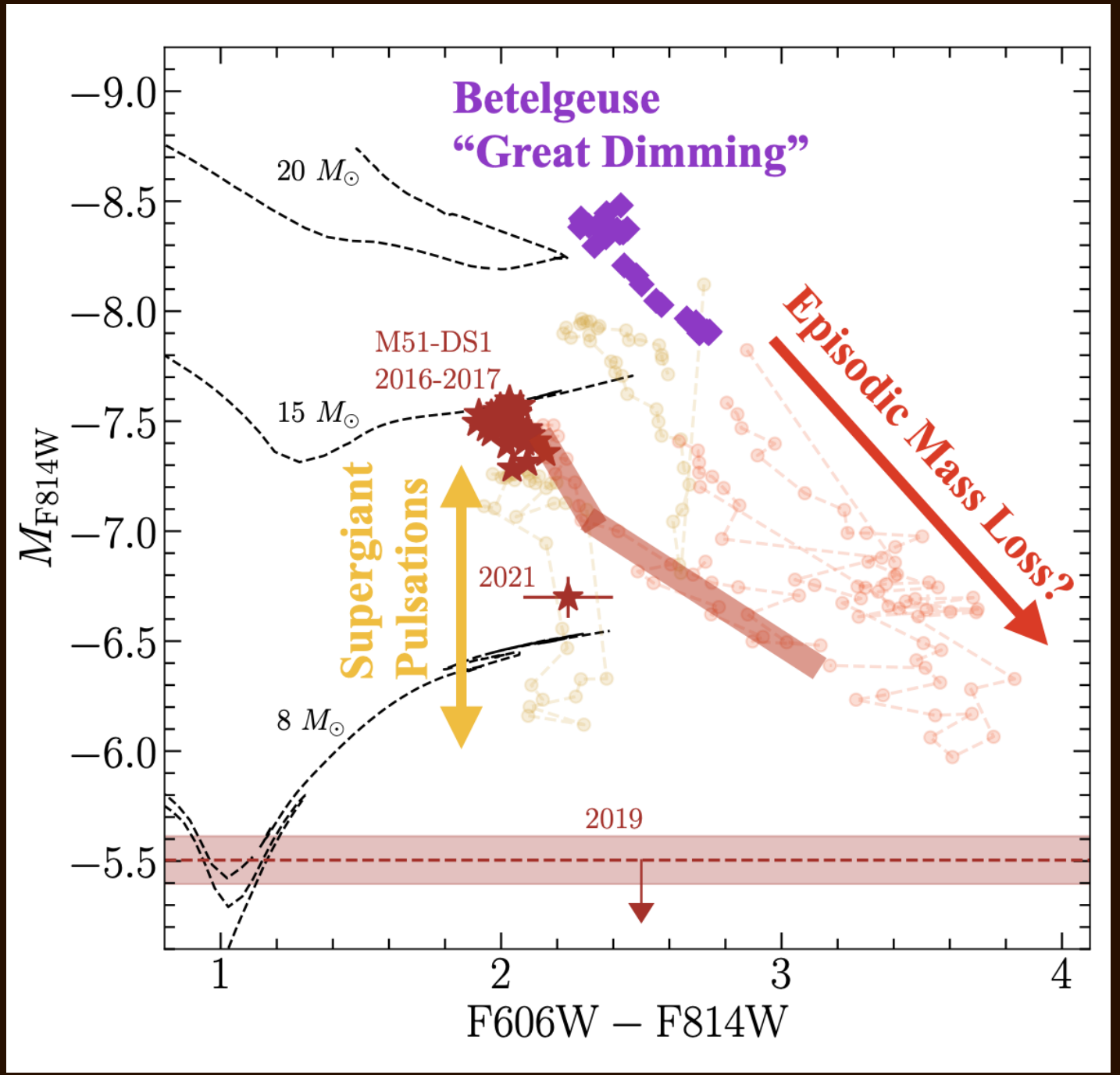
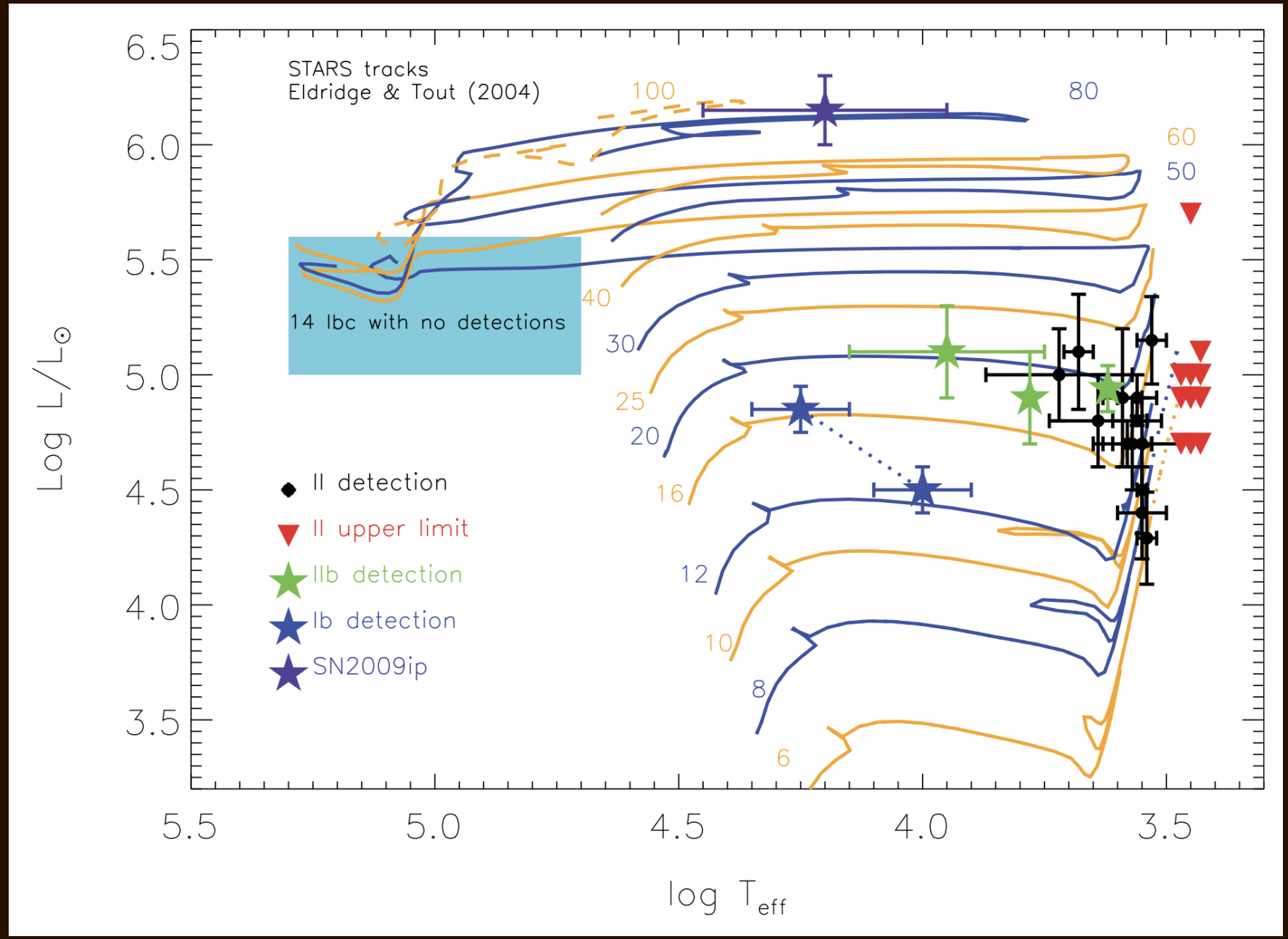
- Pros and cons of with doing this with HST
- Allows for resolving individual stars

- Challenges -> how do we do robust statistics to figure out a rate?
- Needs to be a targeted search
- Inhomogeneous sampling
  - Somewhat mitigated by additional archival data

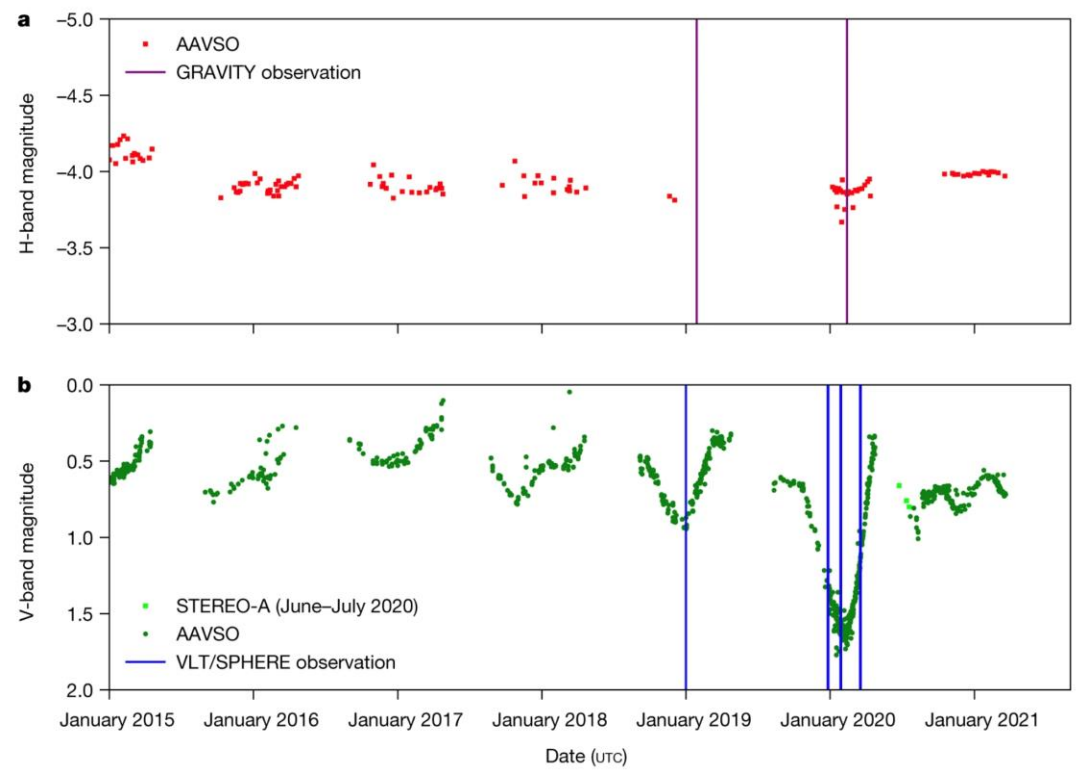


Jencson+2022


Betelgeuse
"Great Dimming"
Episodic Mass Loss?
M51-DS1
2016-2017
Supergiant
Pulsations
2021
2019
20 $M_\odot$
15 $M_\odot$
8 $M_\odot$
M_{F814W}
F606W − F814W
−9.0
−8.5
−8.0
−7.5
−7.0
−6.5
−6.0
−5.5
1
2
3
4


STARS tracks
Eldridge & Tout (2004)
100
80
60
50
40
30
25
20
16
12
10
8
6
14 Ibc with no detections
II detection
II upper limit
IIb detection
Ib detection
SN2009ip
Log L/L⊙
log T_eff
6.5
6.0
5.5
5.0
4.5
4.0
3.5
5.5
5.0
4.5
4.0
3.5

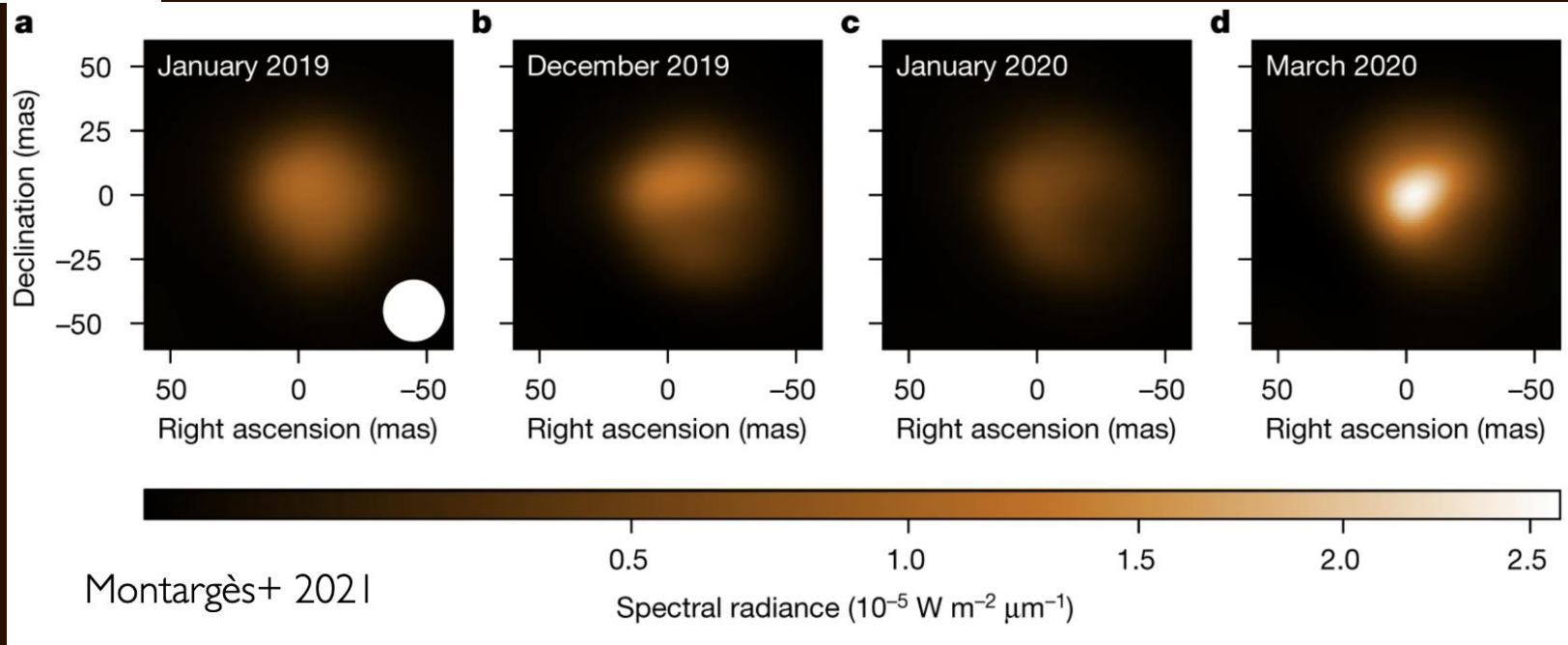
Smartt+2015



Favored model:

- Episode of mass loss that forms dust and obscures star. Coincides favorably with pulsation cycle and possibly the surfacing of a giant, cool convective cell.

The Great Dimming of Betelgeuse



Montargès+ 2021

- The most common class of core-collapse supernovae, SNe IIP, are the result of gravitational core collapse in red supergiants. Despite the existence of red supergiants with initial masses >18 solar masses, no SN IIP with a progenitor mass greater than ~18 solar masses has been observed. The apparent absence of high mass progenitors may indicate that massive red supergiants end their lives as failed supernovae, collapsing directly into black holes without producing a supernova. Proving the existence of failed supernovae, however, is a difficult observational challenge. Overcoming this requires frequent images of nearby galaxies to identify stars that disappear and remain absent in subsequent epochs. In this talk, I will discuss the ongoing effort to discover failed supernovae candidates in archival HST images of nearby star-forming galaxies. This sample enables strong observational constraints on the frequency of failed SNe, sheds light on the origins of black holes, and assembles one of the most comprehensive datasets to date of extreme variables. Entering the era of LSST, this methodology will be vital for discovering the rare cases of failed supernovae and exceptional variable stars amongst the millions of massive stars in nearby galaxies.