# Populating the Gap in Dust-Formation History of Type II(P) Supernovae with JWST

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SUPERNOVA REMNANTS III
AN ODYSSEY IN SPACE AFTER STELLAR DEATH
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# JWST observations on dusty extragalactic SNe

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| MIRI Imaging | MIRI Spectr. | MIRI Spectr. + NIRSpec | MIRI Imaging & Spectr. + NIRSpec |
|---|---|---|---|

**Cycle 1:**

GO 1860 (PI: O. D. Fox)

GO 2348 (PI: S. Tinyanont)

GO 2666 (PI: O. D. Fox,
co-PI: T. Szalai)

**DD:** 4436, 4520 (PI: M. Shahbandeh)

**Cycle 2:**

SURVEY 3921 (PI: O. D. Fox)

GO 4217 (PI: M. Shahbandeh)

***Cycle 3:***

*GO 5290 (PI: C. Ashall)*

*GO 6049 (PI: T. Szalai)*

*GO 6213 (PI: M. Shahbandeh)*

*AR 6356 (PI: O. D. Fox)*

*GO 6583 (PI: M. Shahbandeh)*

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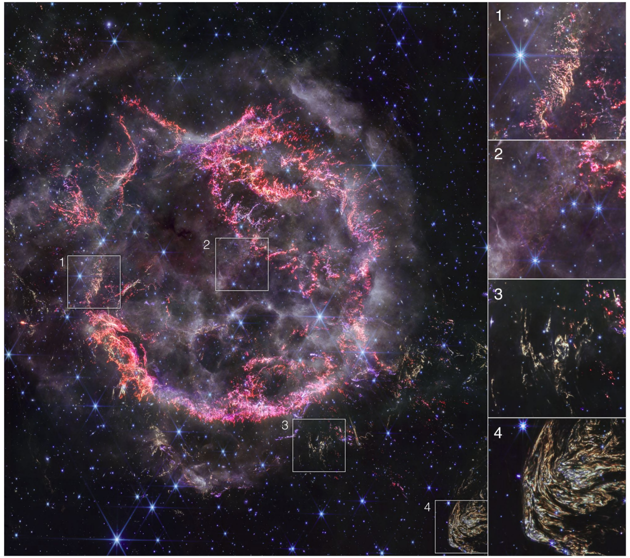
**Crab Nebula** (JWST MIRI + NIRCam)
*©NASA, ESA, CSA, STScI,*
*T. Temim (Princeton University)*



**Cassiopeia A** (JWST NIRCam)
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*T. Temim (Princeton University),*
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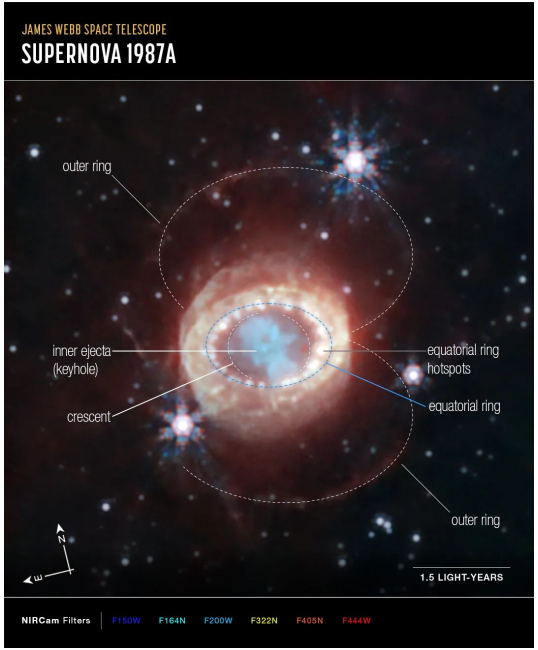


**SN 1987A** (JWST NIRCam)
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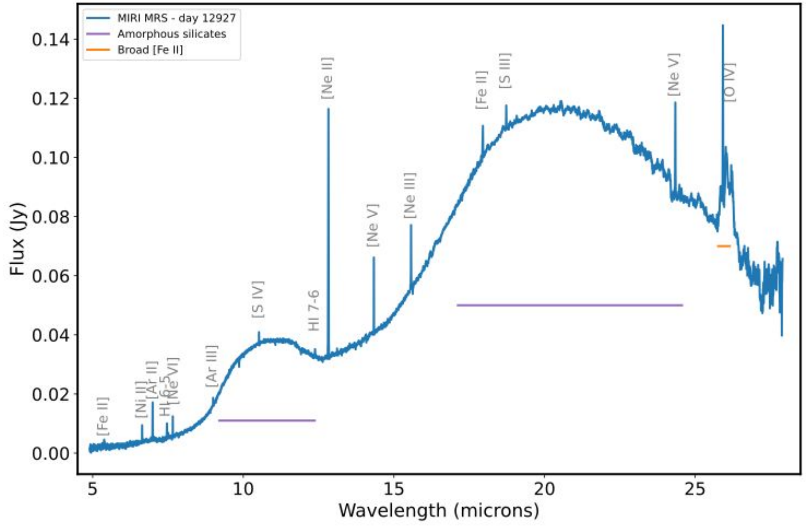
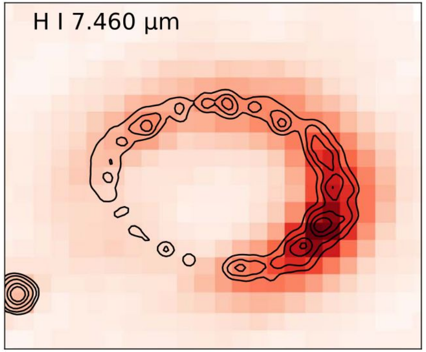
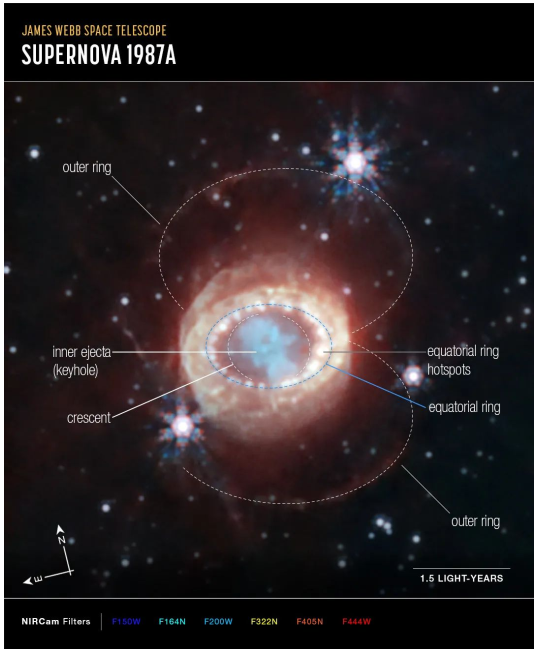
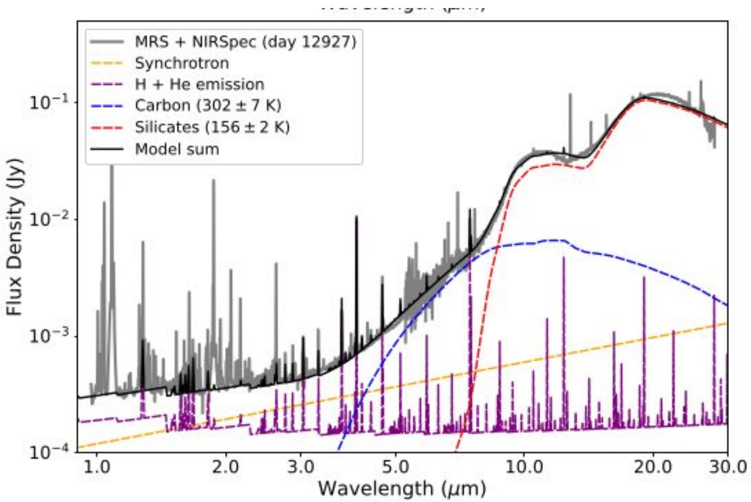


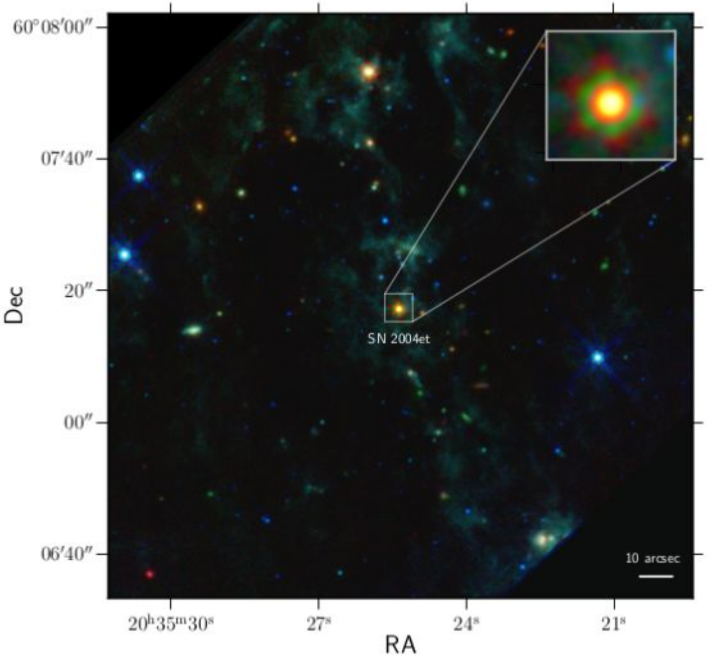



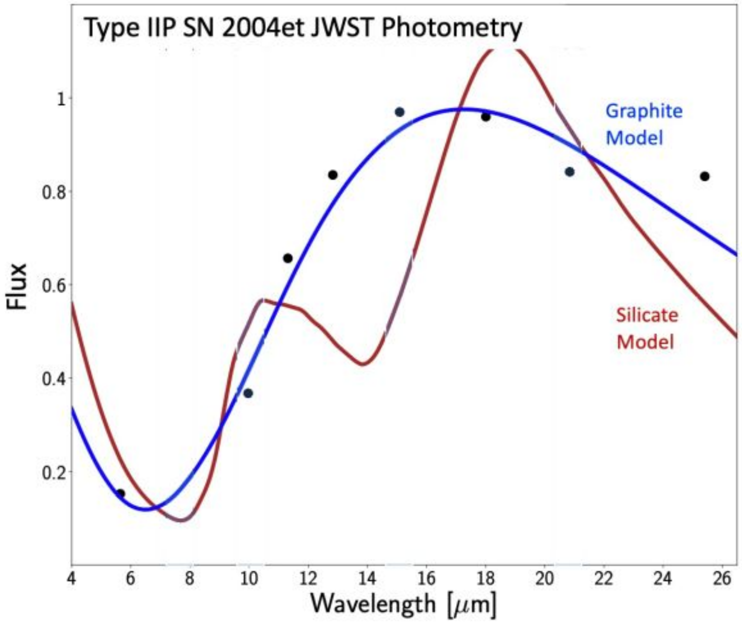




Jones+23

**SN 1987A** (JWST NIRCam)

# So… why do we need any JWST data on faint, distant point sources (i.e. extragalactic SNe)?




SN 2004et, JWST/MIRI (Shahbandeh+23)

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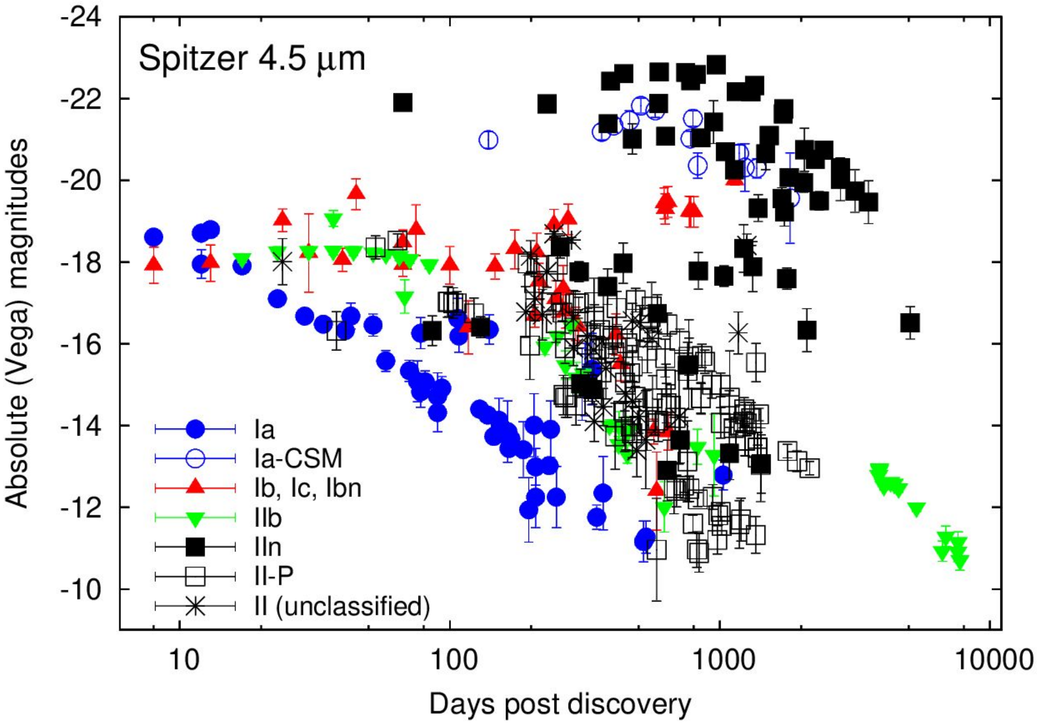
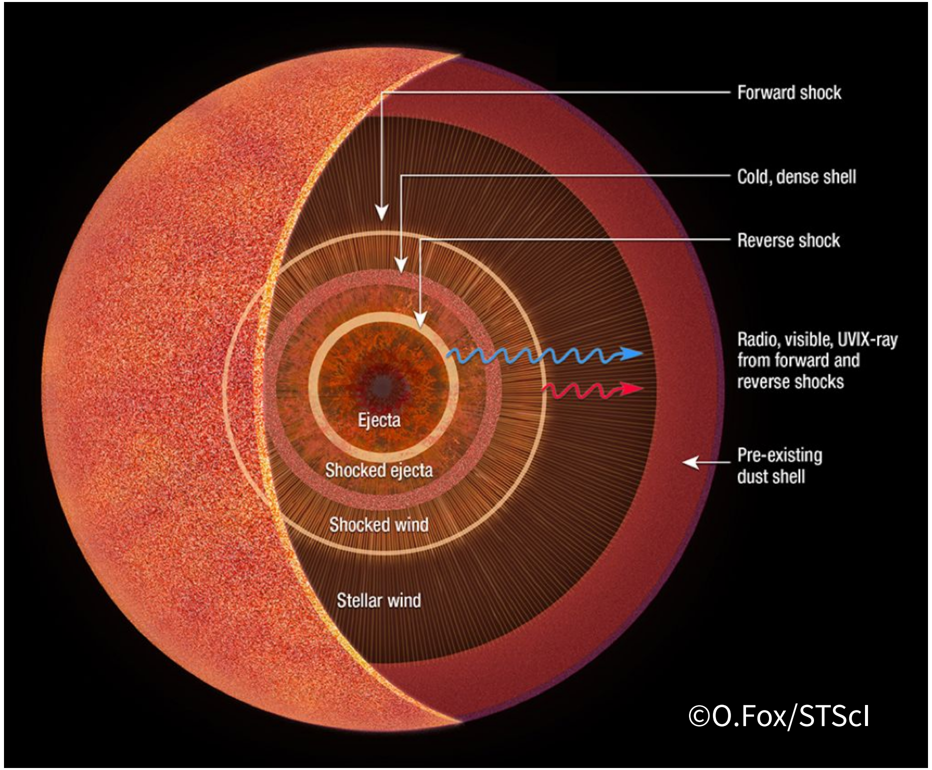



Szalai+19

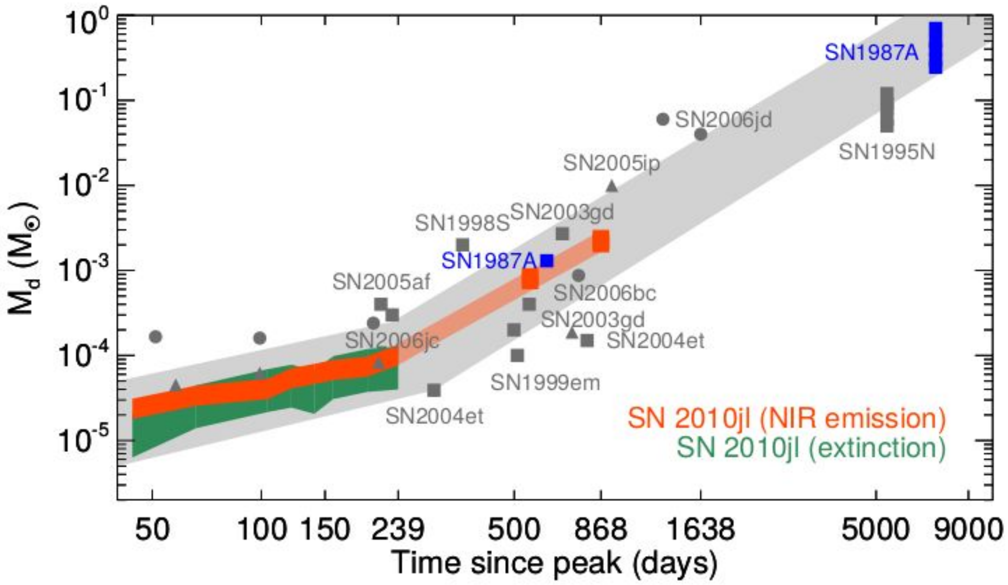
- A diversity in the long-term IR evolution of SNe

# So… why do we need any JWST data on faint, distant point sources (i.e. extragalactic SNe)?




- A diversity in the long-term IR evolution of SNe
- Disentangling the origin and heating mechanism of the dust
  - newly-formed dust in the inner (unshocked) ejecta or in the shocked region (cool dense shell)
  - pre-existing dust (radiative vs collisional heating)

# So… why do we need any JWST data on faint, distant point sources (i.e. extragalactic SNe)?




Gall+14

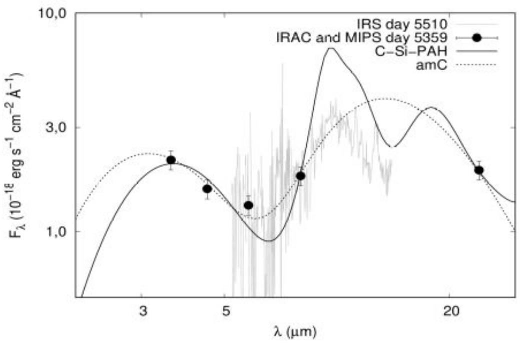
- A diversity in the long-term IR evolution of SNe
- Disentangling the origin and heating mechanism of the dust
    - newly-formed dust in the inner (unshocked) ejecta or in the shocked region (cool dense shell)
    - pre-existing dust (radiative vs collisional heating)
- (Post-explosion) Dust-formation history → dust mass vs time

# How to measure SN dust masses?

## Thermal (IR) radiation of dust grains

$$F_\nu = \frac{M_d B_\nu(T_d) \kappa_\nu(a)}{d^2}$$ (Hildebrand+83)

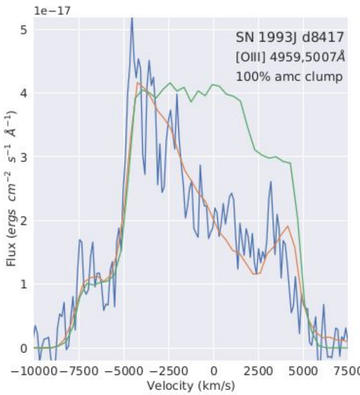
- Grain types: AC, Si, mixture
- Grain size (basically single-size)
- Spherical region
- Fitted parameters: $T_{dust}$ , $M_{dust}$
- Optical depth effects!



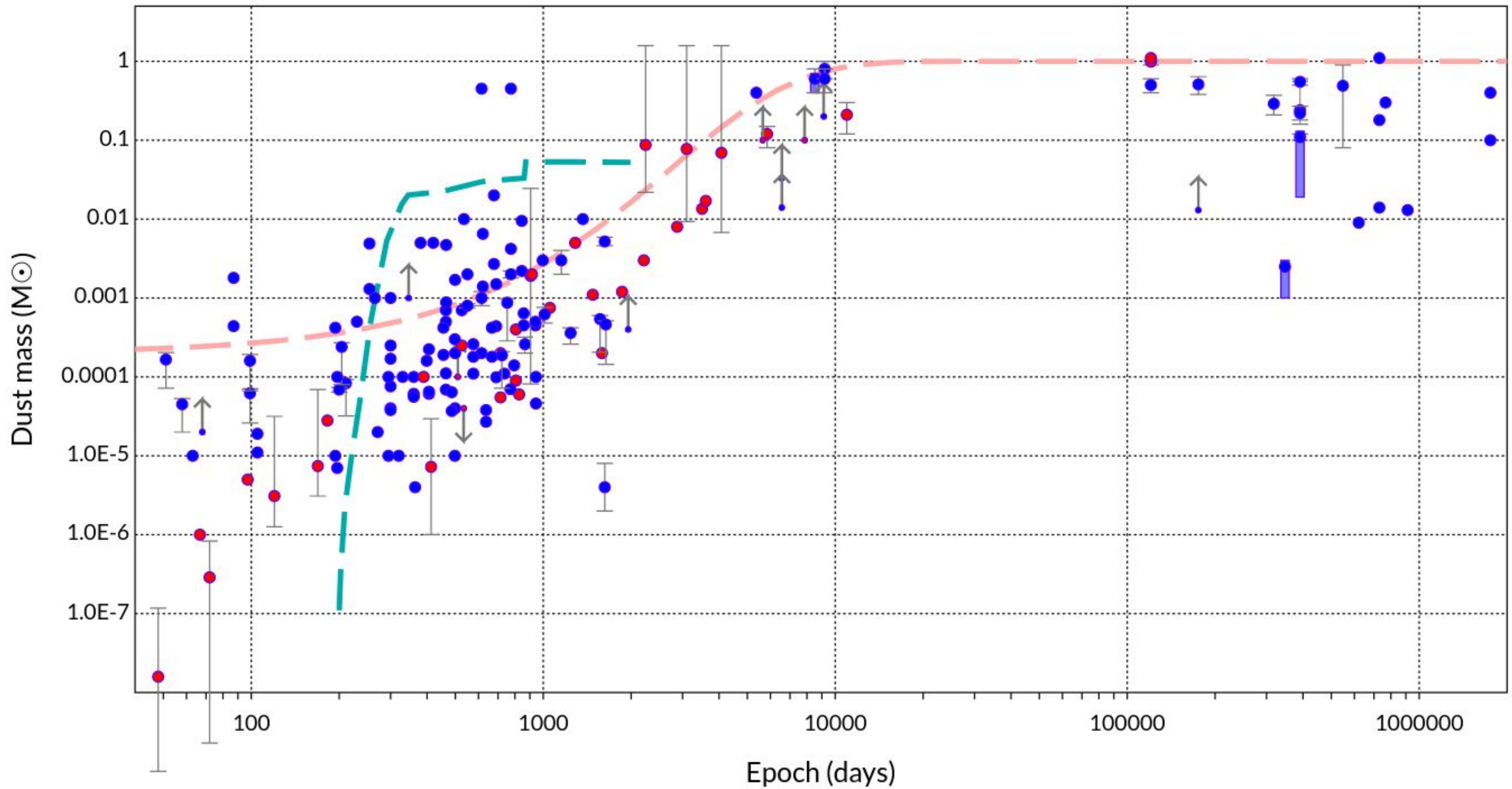

Zsíros+22

## Analysis of optical line profiles (red-blue asymmetry)

- Dust in the inner ejecta may result in an extended red wing and/or a blueshifted peak due to scattering and absorption effects (Lucy 89)
- DAMOCLES code for modeling (Bevan & Barlow 16, Bevan+17, Niculescu-Duvaz+22)




Parameters:
velocity
shell size & ratio
clumpiness (filling factor)
density profile
dust mass




IR SED (Spitzer)

Optical emission lines

https://nebulousresearch.org/dustmasses/
(©R. Wesson)

Theories on dust-formation timescale:

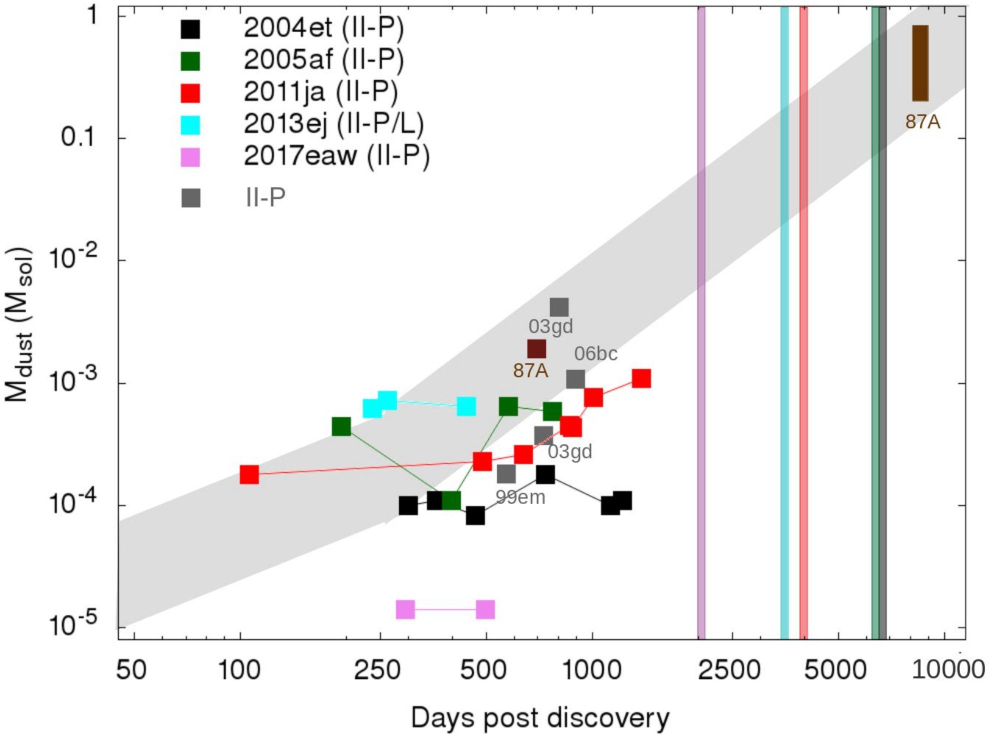
Rapid (Sarangi & Cherchneff 15, Dwek+19, Sarangi 22, …) vs.

continuous (Gall+14, Wesson+15, Bevan+19 …)

See more in Arka Sarangi's talk!

# JWST in action

## Cycle 1, GO 2666: Populating the Gap in Dust-Formation History of Type II(P) SNe





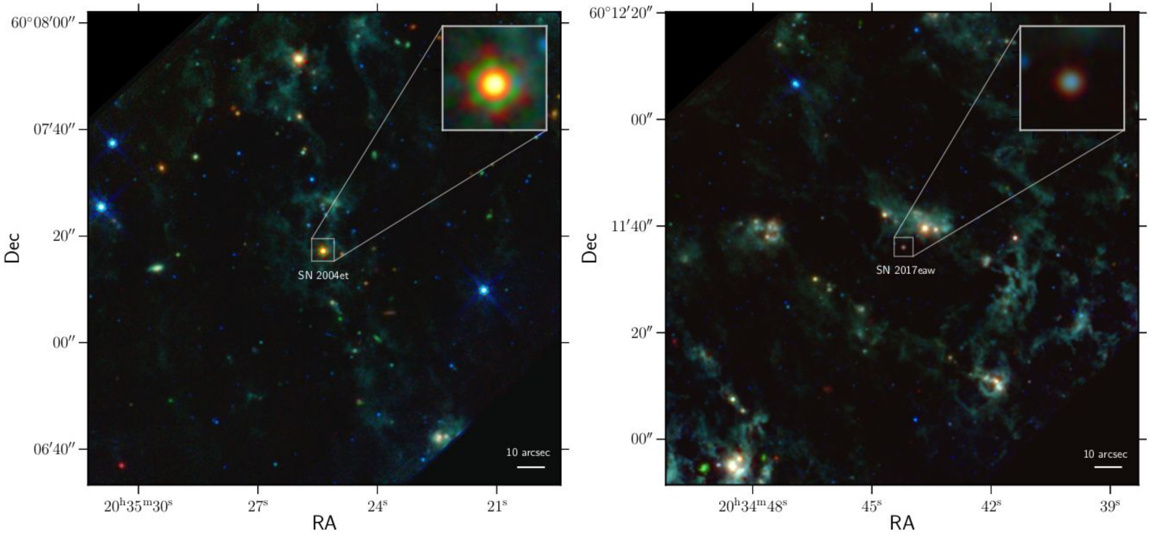

- Focusing on newly-formed ejecta dust in Type IIP SNe (= exploding RSG stars)
- Are they really able to form a large amount (~0.01-0.1 $M_\odot$) of dust? (Theory vs. pre-JWST observations)
- JWST is able to see cold (T<150K) dust at later epochs (>5 yr)
- Selecting 5 well-known targets for filling the gap
- MIRI imaging using 8 filters (F560W, F1000W, F1130W, F1280W, F1500W, F1800W, F2100W, F2550W)

# JWST GO 2066

- SN 2004et
- SN 2017eaw

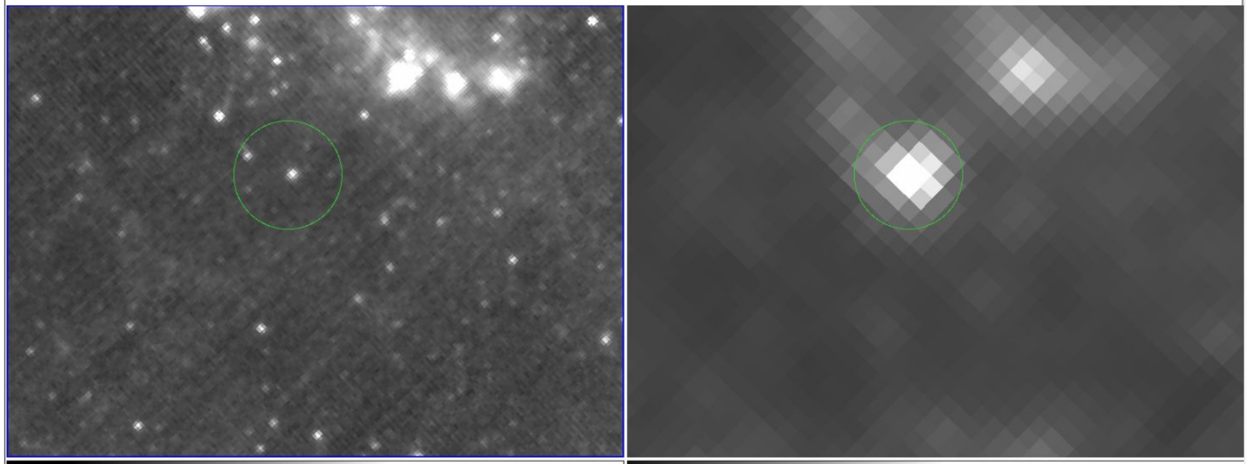
Published in Shahbandeh+23

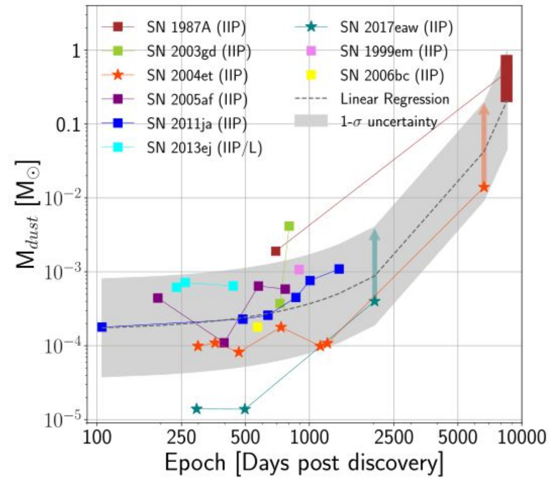
(Melissa Shahbandeh’s talk)




SN 2017eaw, 2022.09.22 (JWST, F560W)

SN 2017eaw, 2019.01.05 (Spitzer/IRAC CH2)





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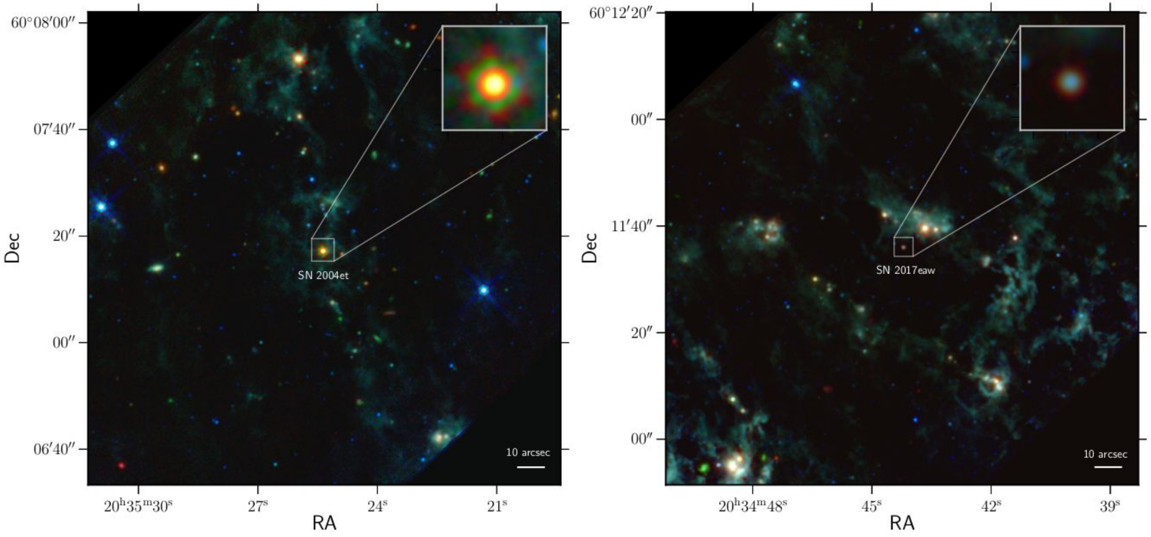
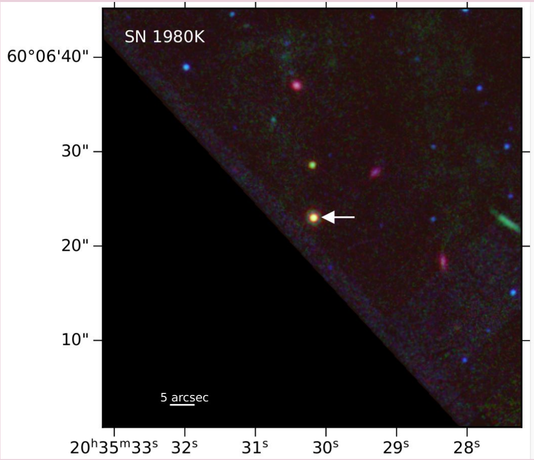
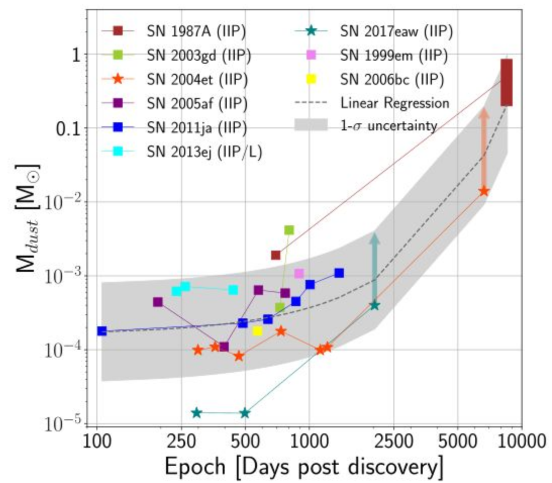



And a serendipitous detection of the Type IIL SN 1980K (in the 04et FOV) ~42 yrs after explosion!

(published in Zsíros+24)



# JWST GO 2066

## Optical depth effects

$$M_{\rm dust} = \frac{M_{\rm dust}^{\rm obs}}{P_{\rm esc}(\tau)},$$

where

$$M_{\rm dust}^{\rm obs} = \frac{F_\lambda^{\rm obs}(\lambda)\, d^2}{B_\lambda(\lambda, T_{\rm dust})\,\kappa(\lambda)}$$

(Dwek 19)

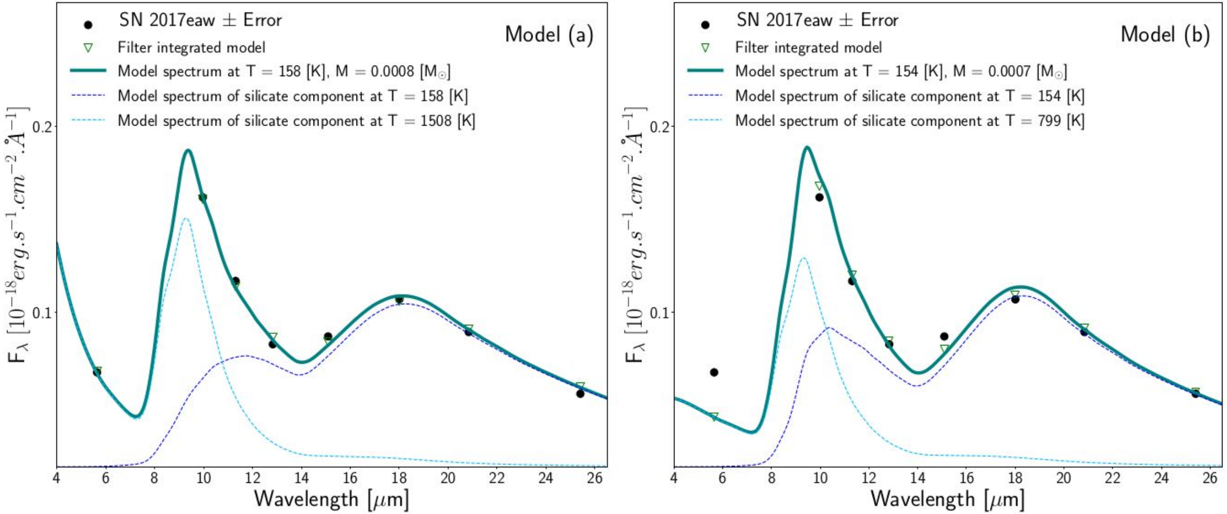



**Figure 5.** The MIR SED of SN 2017eaw obtained with *JWST*/MIRI on Sep. 21, 2022 fitted with two different models/assumptions. For both models, the solid line shows the model spectrum of silicates dust comprising two components. The dashed lines show the two components. The resulting parameters are listed in Table 3. **Model (a)** is assuming a dusty sphere of silicates using Equations 1 and 4, and **Model (b)** shows an optically thin silicate dust using Equation 1 with $P_{esc} \approx 1$.

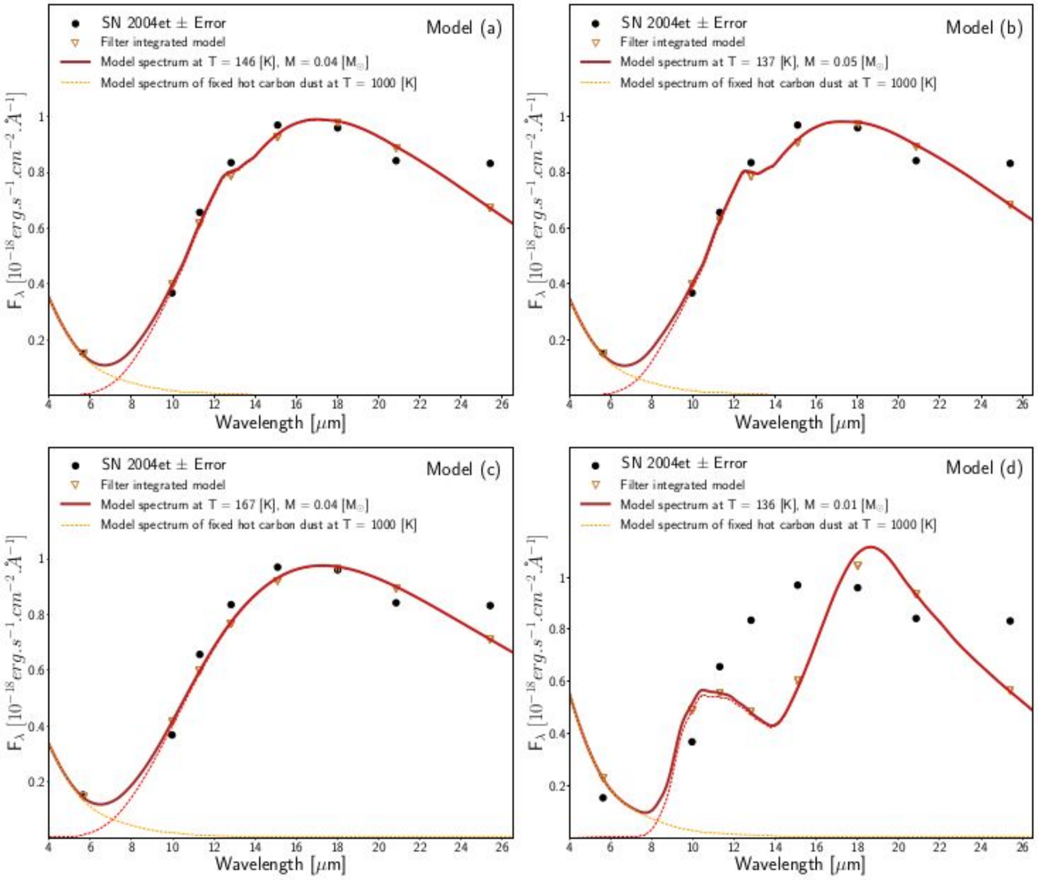
Shahbandeh+23

# JWST GO 2066

## Optical depth effects

**Table 2.** Best-fitting dust model parameters for SN 2004et.

| Model | $M^{a}_{dust}$ [$M_\odot$] | $T^{a}$ [K] | $\tau^{b}$ |
|---|---|---|---|
| (a) Dusty sphere (amorphous C) | $0.044^{+\dots}_{-0.007}$ | $146^{+20}_{-10}$ | $0 < \tau < 4.1$ |
| (b) Optically thin dust (amorphous C) | $0.047^{+0.007}_{-0.006}$ | $137^{+3}_{-3}$ | $<<1$ |
| (c) Dusty sphere (silicates) | $0.036^{+\dots}_{-0.012}$ | $167^{+5}_{-5}$ | $8.9 < \tau < 29.7$ |
| (d) Optically thin dust (silicates) | $0.012^{+0.008}_{-0.005}$ | $136^{+10}_{-10}$ | $<<1$ |




Shahbandeh+23

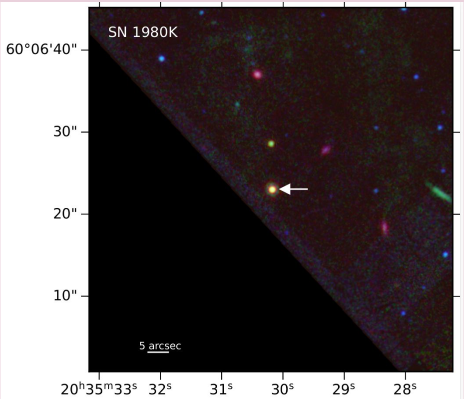
# JWST GO 2066

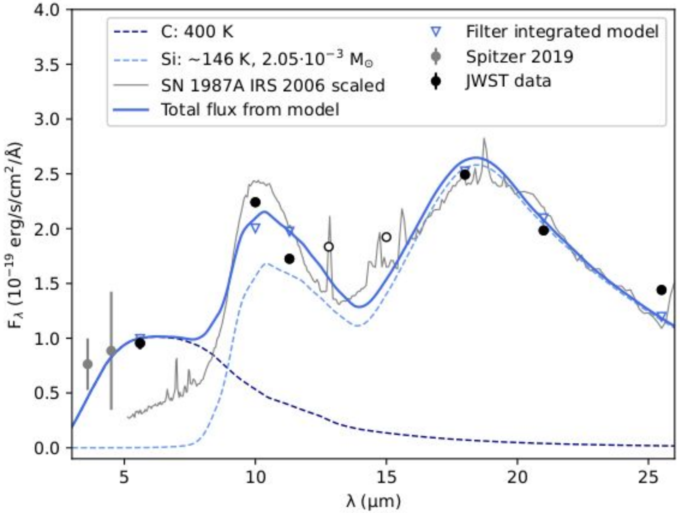
### SN 1980K

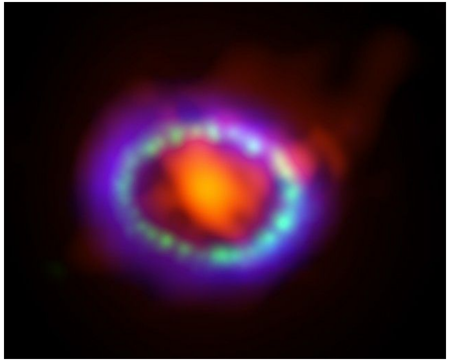
We see a very similar SED to that of 1987A, but with a much higher amount of mid-IR dust (0.002 vs. $10^{-6}$ $M_\odot$)

And a serendipitous detection of the Type IIL SN 1980K (in the 04et FOV) ~42 yrs after explosion!

(published in Zsíros+24)



SN 1987A composite image (HST & ALMA & Chandra) R. Indebetouw et. al, A. Angelich (NRAO/AUI/NSF)

# JWST GO 2066

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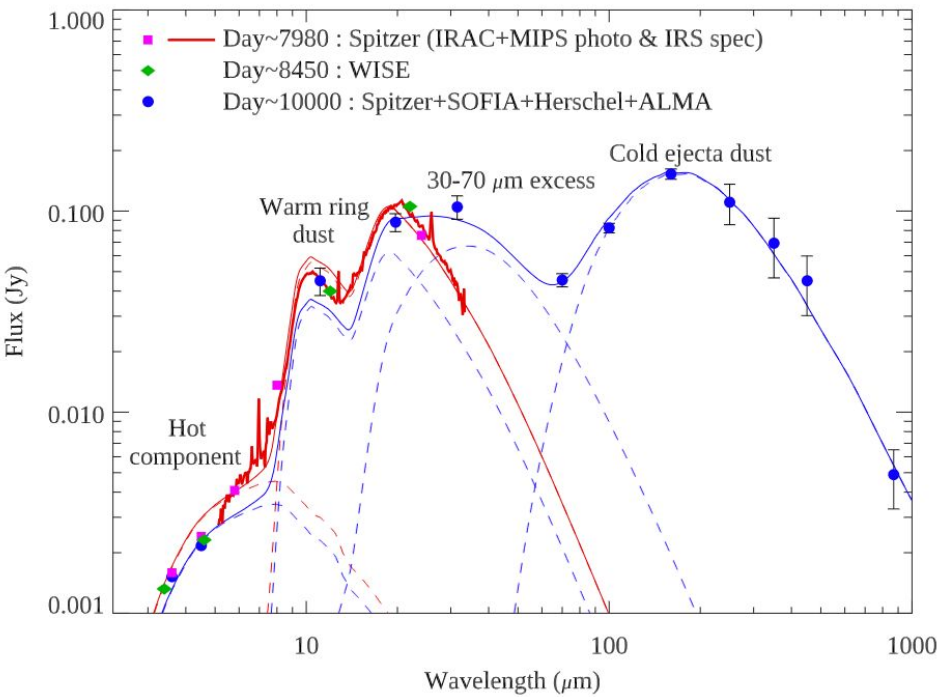
We see a very similar SED to that of 1987A, but with a much higher amount of mid-IR dust (0.002 vs. $10^{-6}$ $M_\odot$)




Matsuura+19

# JWST GO 2066

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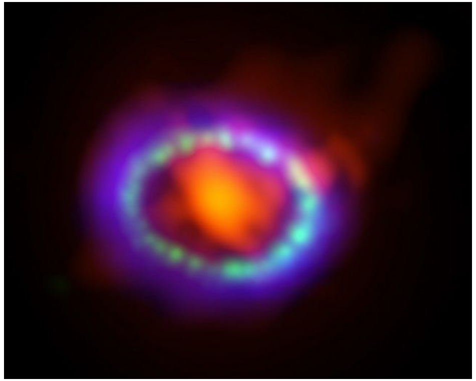
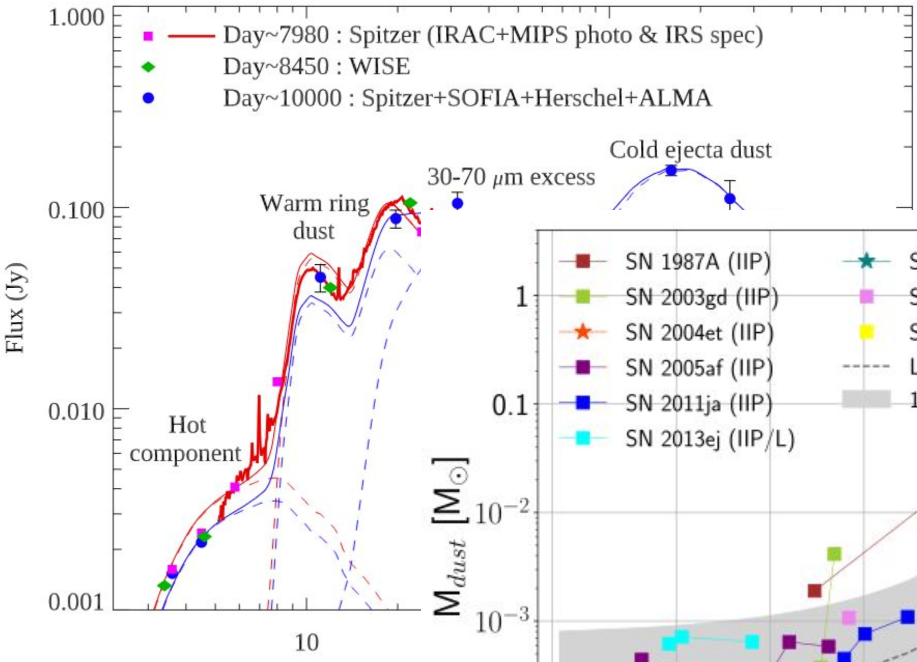
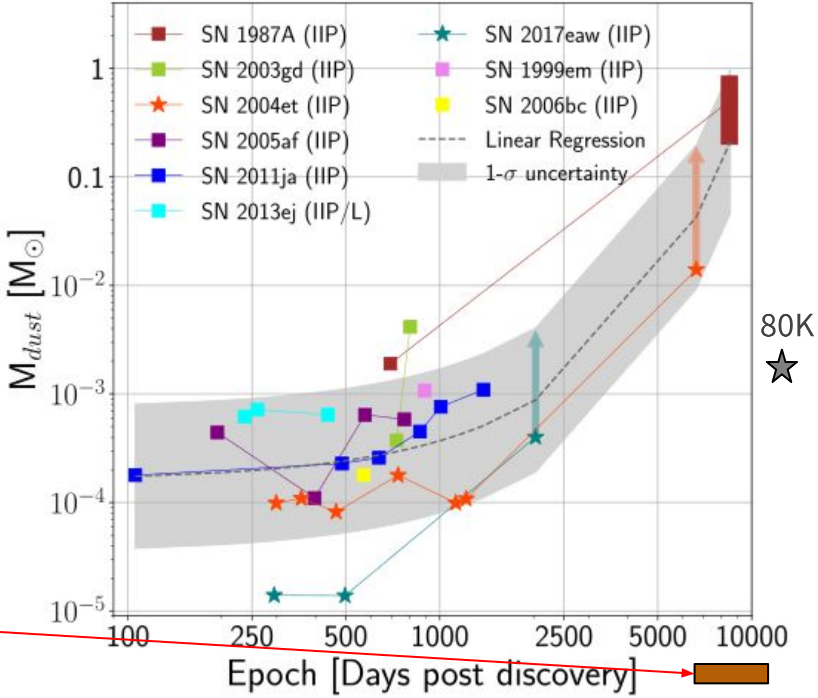





Mid-IR dust mass of SN 1987A!

# JWST GO 2066

## SN 1980K

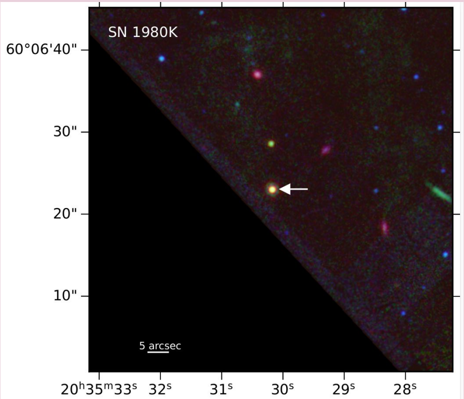
We see a very similar SED to that of 1987A, but with a much higher amount of mid-IR dust (0.002 vs. $10^{-6}$ $M_\odot$)

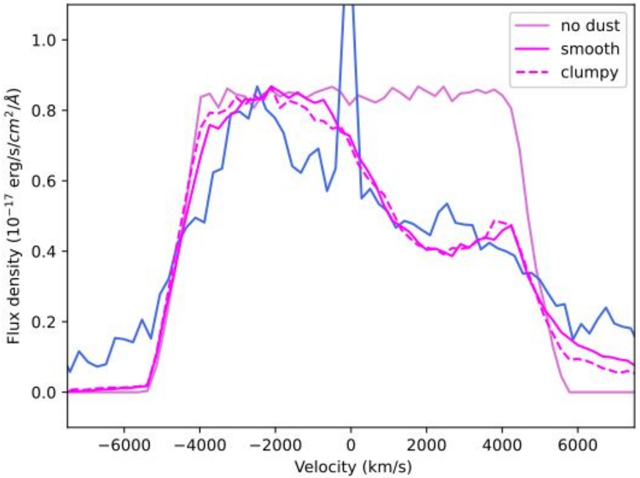
Optical line-profile analysis results in $M_{dust}$ ~0.2-0.6 $M_\odot$

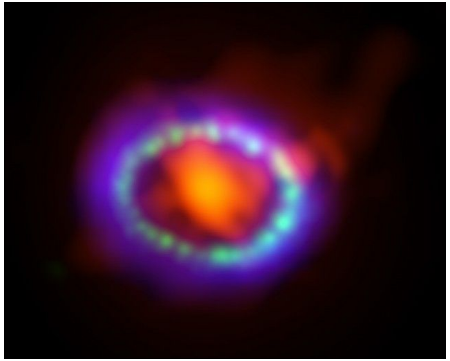
→ a „**super-ring**”, or **ejecta dust** („tip of the iceberg”)?

And a serendipitous detection of the Type IIL SN 1980K (in the 04et FOV) ~42 yrs after explosion!

(published in Zsíros+24)



SN 1987A composite image (HST & ALMA & Chandra)
R. Indebetouw et. al,
A. Angelich (NRAO/AUI/NSF)

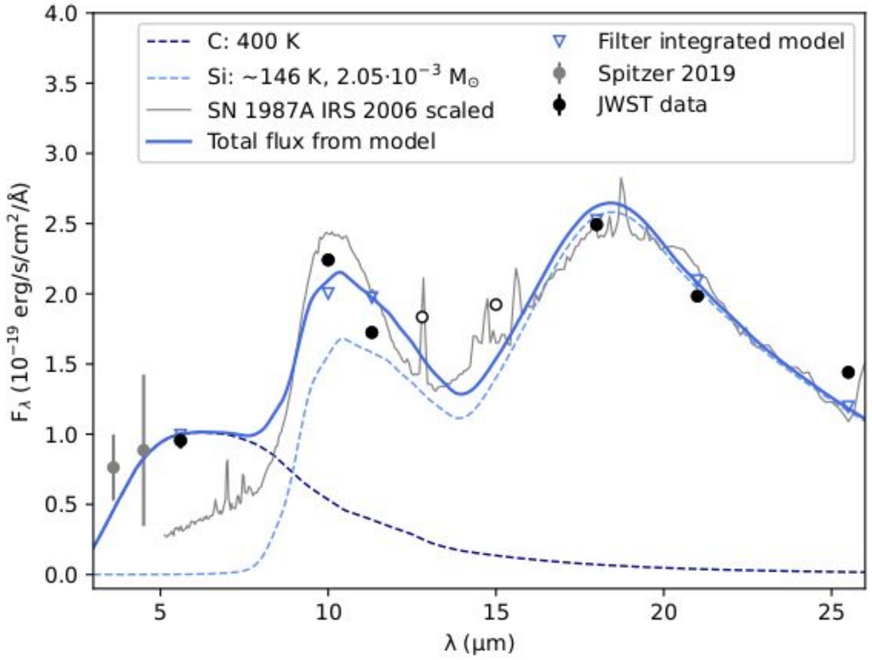
# JWST GO 2066

## Dust temperatures I: presence of a “hot” component

- Flux excess at F560W in all the three published cases (2004et, 2017eaw, 1980K)
- Similar findings in SN 1987A (Bouchet+06, Dwek+10, Jones+23)

→ CSM interaction? PWN?

→ contribution from the extrapolated long-wavelength synchrotron component and the H and He continuum emission in the near-IR? (Jones+23)

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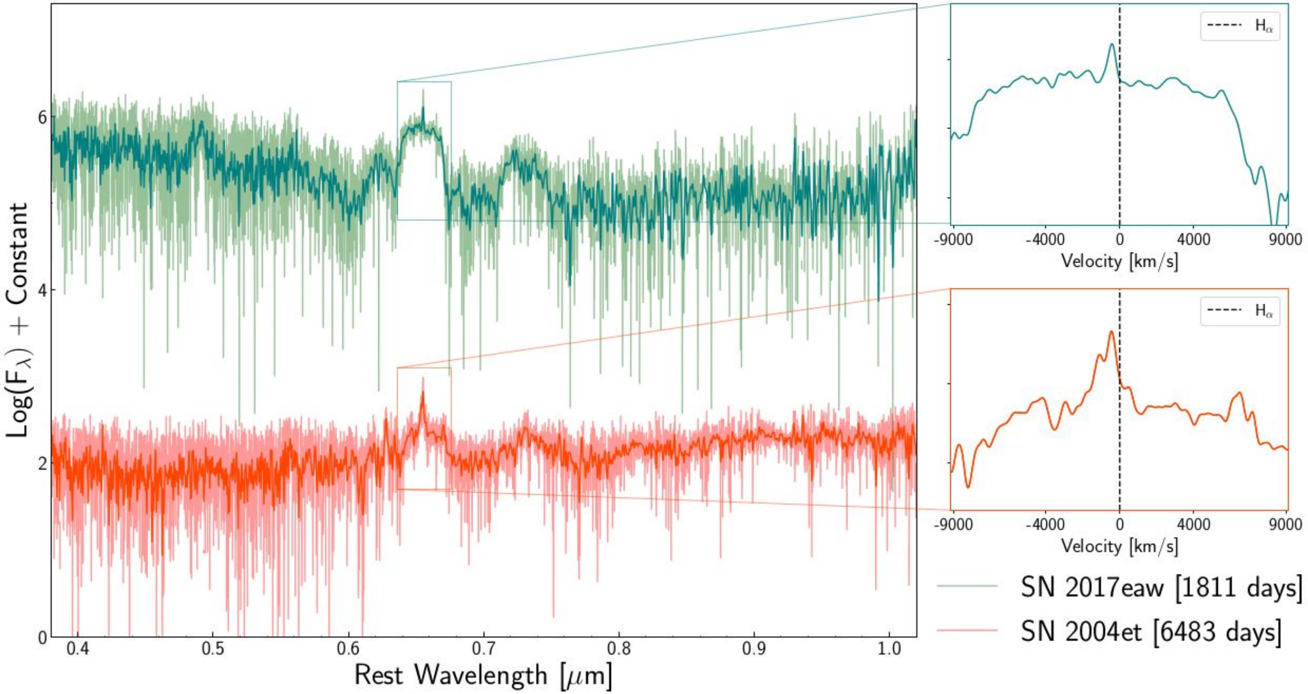
# JWST GO 2066

## Dust temperatures II: when the “cold” component is too “warm”

“Cold” dust masses agree with the expectations, but temperatures (~140-160K) are a bit high…

→ extra heating source even in the ejecta (e.g. back-scattered UV photons from CSM interaction)? (Dessart+22)

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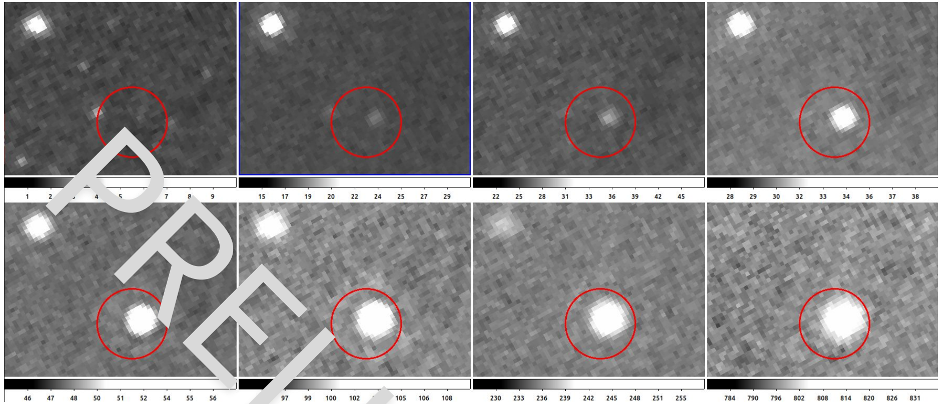
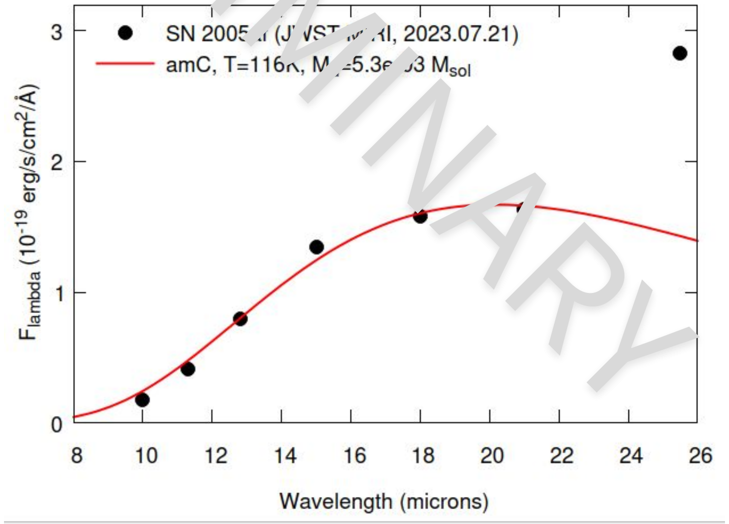
# JWST GO 2066

Preliminary results

- **SN 2005af**
- SN 2011ja
- SN 2013ej





# JWST GO 2066

Preliminary results

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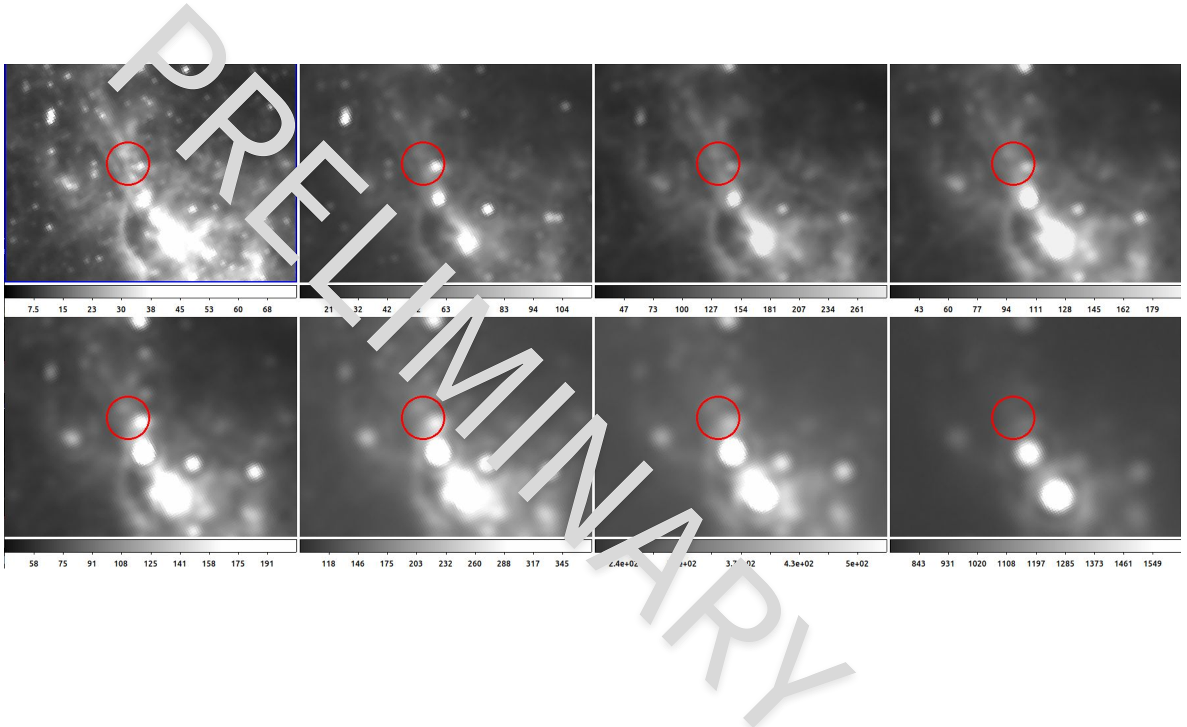

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Preliminary results

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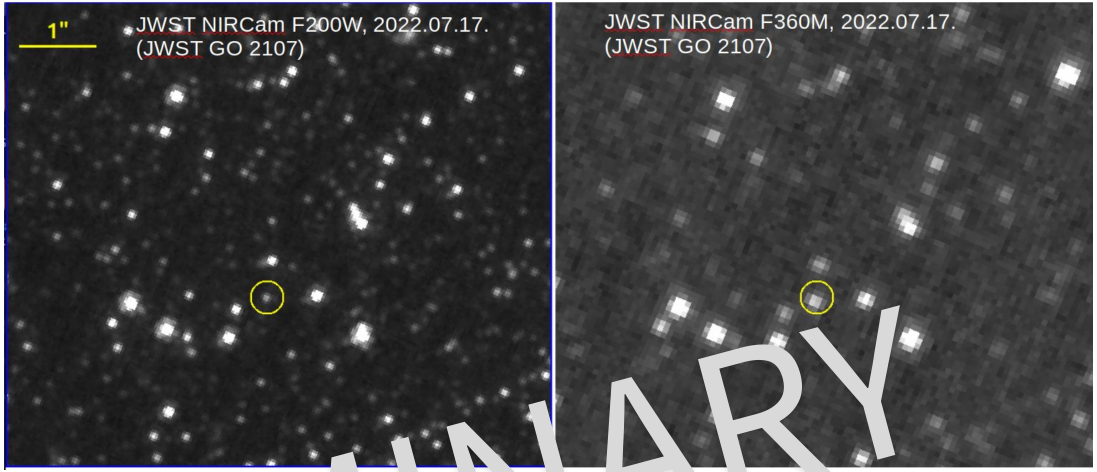
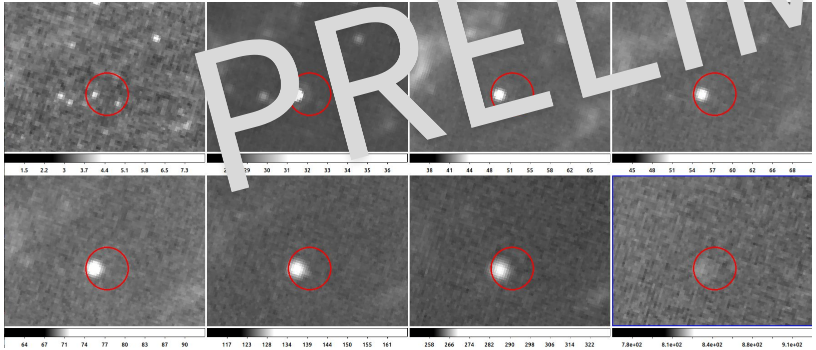
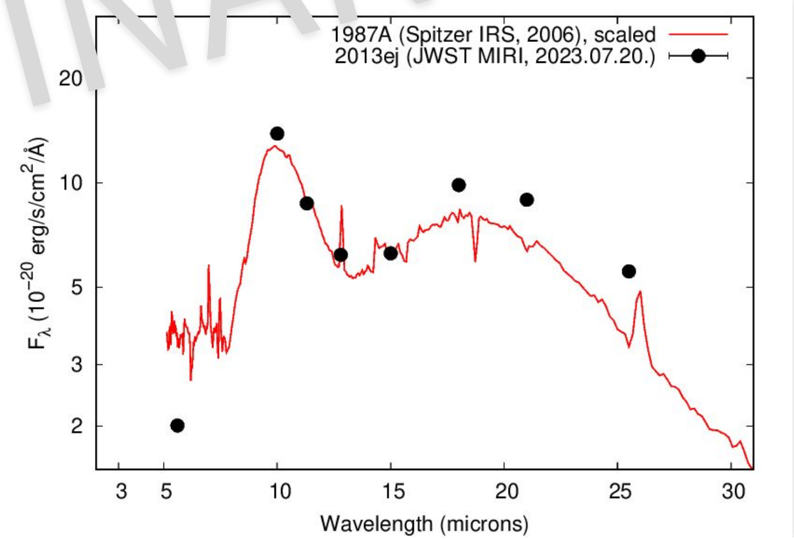
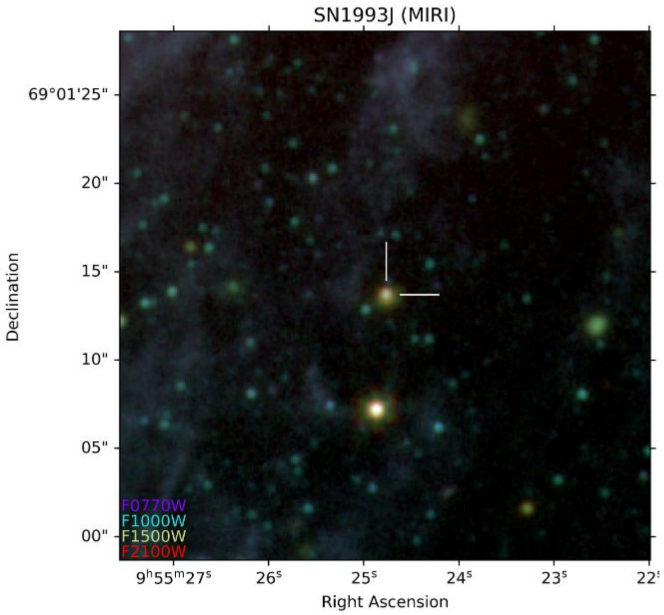




# JWST Cycle2, SURVEY 3921 (PI: O.D. Fox)

- 4-point SEDs from MIRI imaging (F770W, F1000W, F1500W, F21000W)
- Mid-IR bright SNe of various types and epochs (15 observed targets)
- First target: **SN 1993J**

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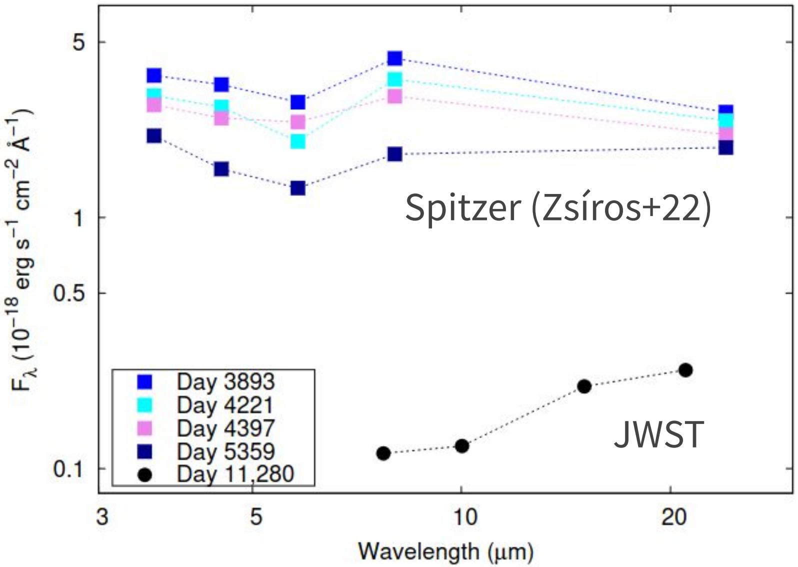
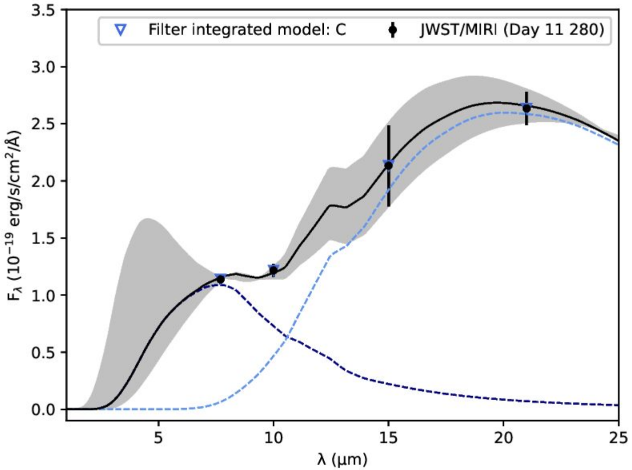


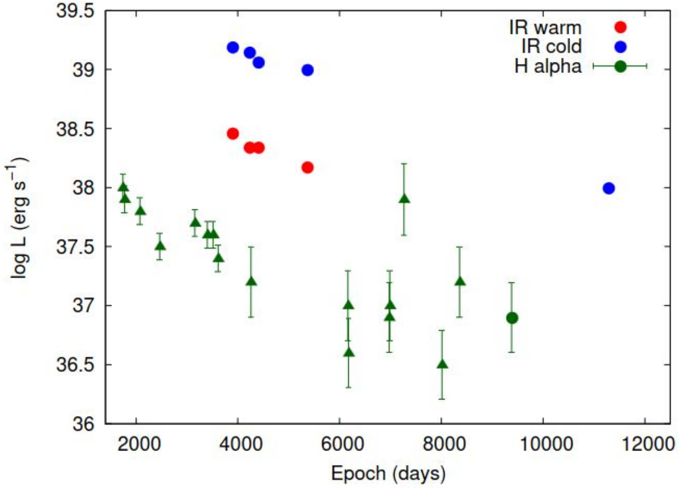

Szalai+ in prep.

## SN 1993J

- Still contains a significant amount (~ (4–6) ×$10^{-3}$ $M_\odot$) of dust ~30 yr after explosion → a similar amount to what was seen ~15 yrs ago, but at a lower temperature (~170 vs 125 K)
- Presence of a hot component → dust heating via UV/X-ray photons emerging from CSM interaction?
- Connect the dust evolution of 1993J to that of Type IIb Cas A

Szalai+ in prep.



# Conclusions & outlook

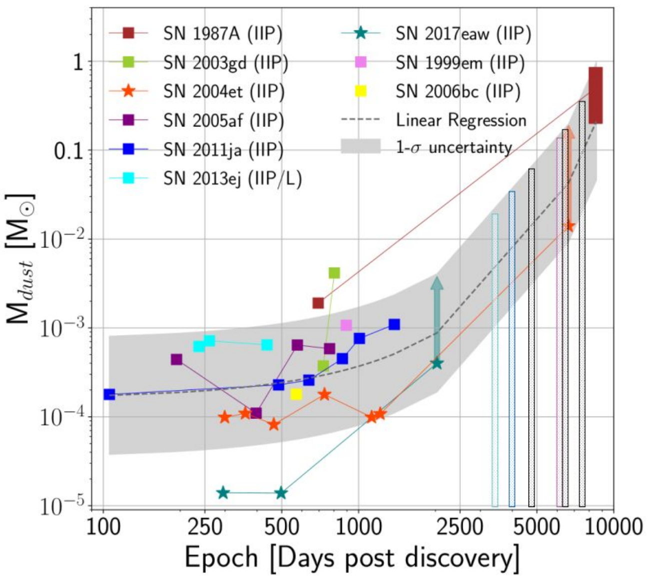
- JWST offers the opportunity to build a modern, ground-breaking sample of dusty SNe

  → a chance to get closer to understand dust-formation processes & timescales, as well as dust-heating mechanisms in SN environments

- First results from JWST GO 2666 program seem to support that Type II(P) SNe may be important contributors to the cosmic dust budget

- Further JWST programs are going to give clues on the dust content in other (mainly strongly interacting) SNe

Upcoming JWST Cycle 3 GO 6049 program:



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Nevertheless, there are further questions and challenges need to be solved

- "True" solutions of observed IR SEDs (optical depth effects, line emission contributions, …)
- Dust temperature problems (at both "cold" and "hot" components) → role of CSM interaction in *every* case?
- Handling of dust parameter correlations (optical depth vs. shell radii vs. dust mass)

  → contemporary IR & optical data, as well as advanced modeling methods (e.g. Bayesian modeling) are essential → see e.g. the poster of Szanna Zsíros

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**Thank you for your attention!**