Probing early signatures of dust formation in core-collapse supernovae with ground based optical/NIR observations

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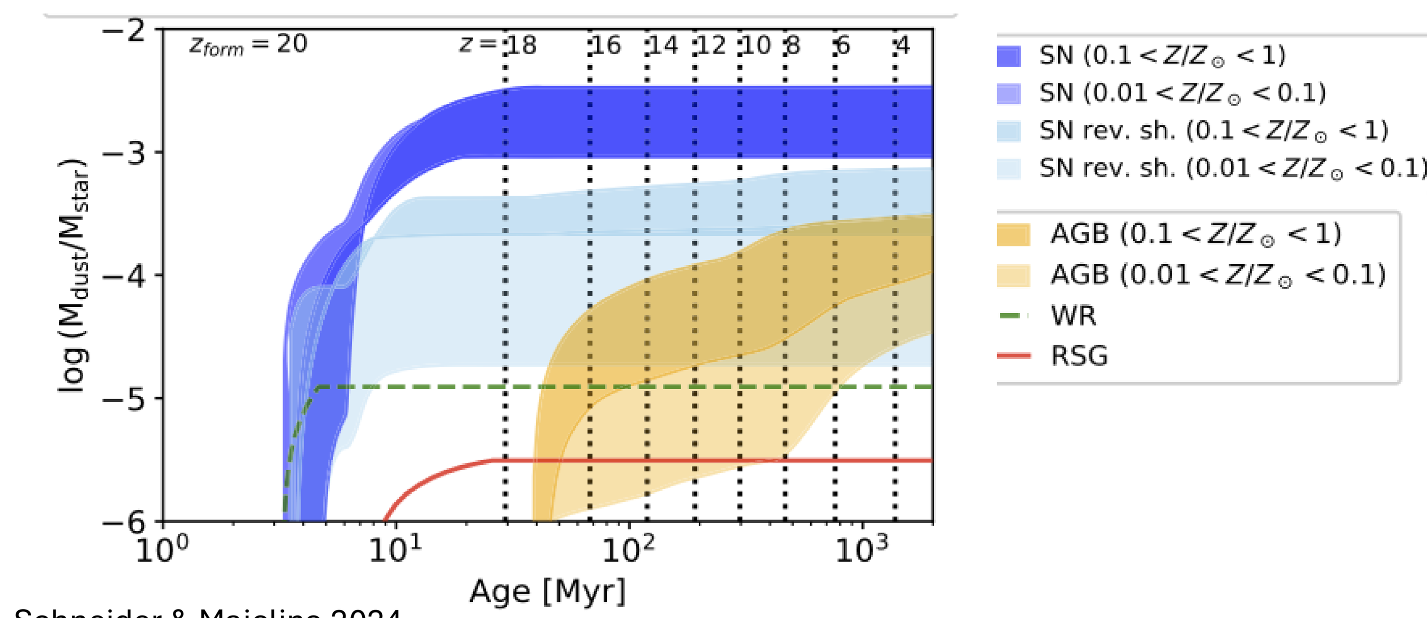
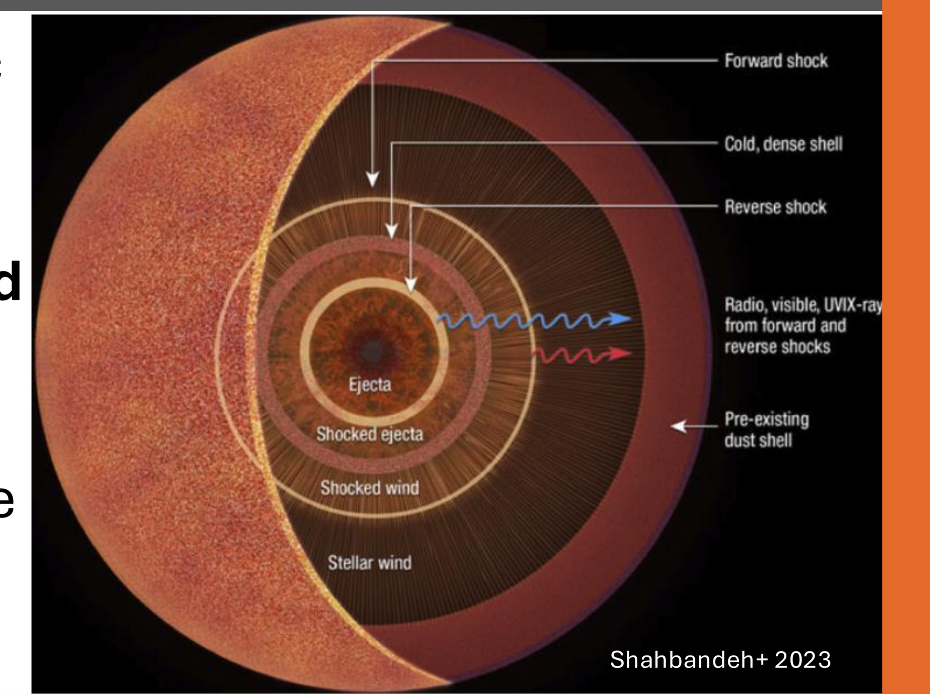
Where does dust come from?



Schneider & Maiolino 2024

Left: Relative contribution of different dust producers versus cosmic time. **It is very uncertain what the relative contribution of SNe versus AGB stars is to the cosmic dust budget. We need multi-epoch observations of large samples of SNe to better understand dust formation and destruction!**

Right: Schematic of a supernova which is producing dust at early times in the cold dense shell (CDS) between the forward and reverse shock. **We might expect to see the earliest signatures of dust formation in SNe with strong CSM interaction!**



The timeline of supernovae dust formation and where you see it

Very early times (0-50 days)

- UV flash spectroscopy shows early CSM interaction
- Optical spectroscopy probes ongoing CSM interaction
- Color evolution can indicate destruction of pre-SN CSM dust

Early times (50-300 days)

- Warm dust continuum emission probes dust mass
- NIR spectroscopic signatures of newly forming dust especially molecular CO

Late times (years)

- Warm dust continuum emission probes dust mass
- Dust features, including PAHs and silicate features, which provide information about dust composition

Very late times (years-decades)

- Cool dust continuum emission
- Shape of continuum depends on dust chemical composition
- Most of the dust mass at lates times is cold, allowing for good dust mass estimates

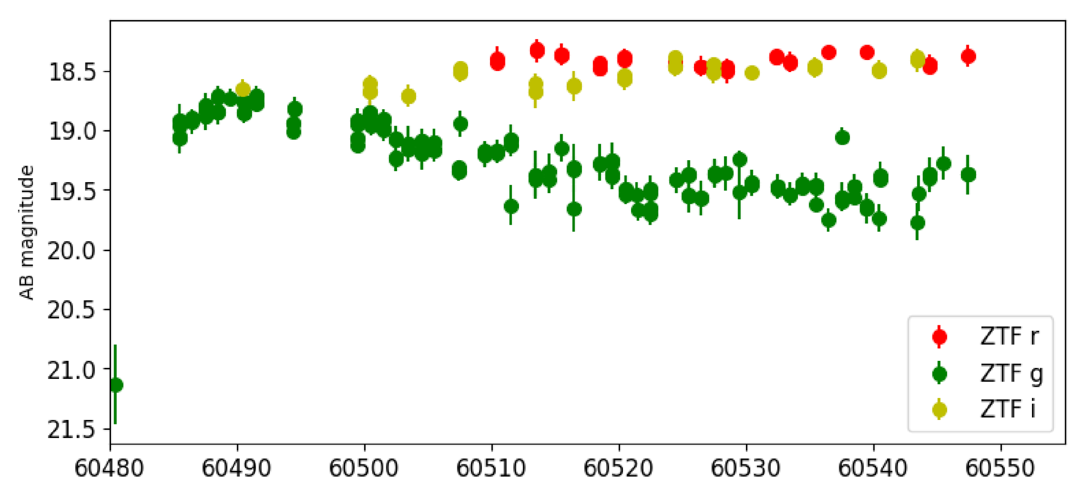
Can obtain large and complete samples with optical/NIR follow-up, especially the earliest signatures!

Can get the most detailed information about dust with MIR/FIR follow-up but only for a very limited number of objects.

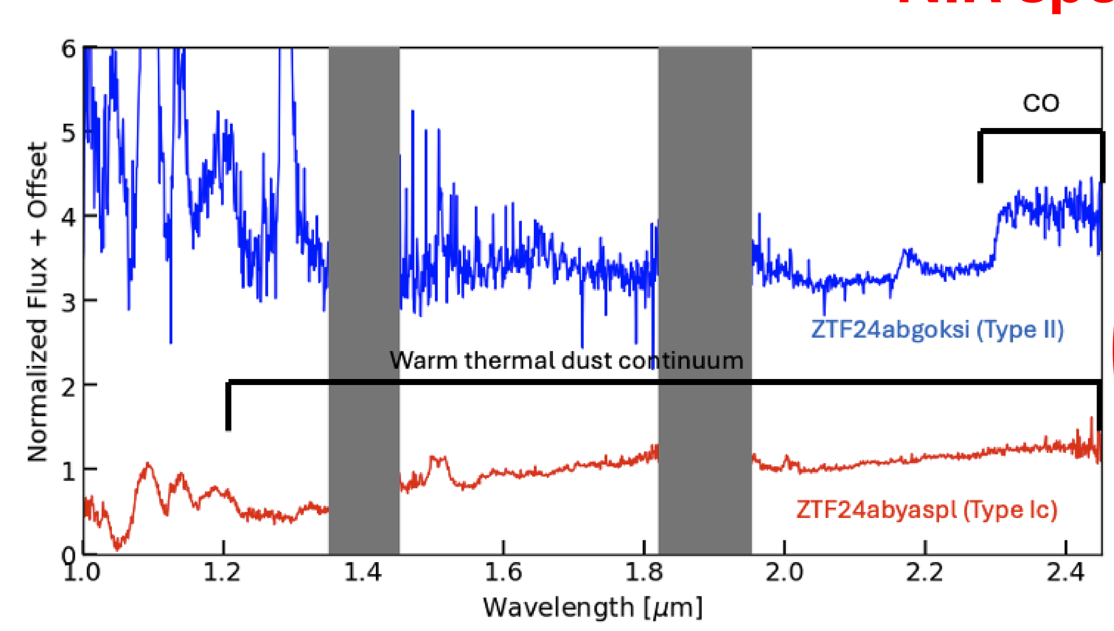
Here we present the largest sample of supernovae with systematic optical+NIR photometric and spectroscopic follow-up!

Discovery and optical light curves with ZTF

- The Zwicky Transient Facility (ZTF) collaboration discovers and classifies hundreds of supernovae each year
- The RAT survey sample includes core-collapse supernovae observed by ZTF brighter than 18.5 in r with colors g-r > 0.5 post-peak or g-r > 0.3 pre-peak to target supernovae which are starting to form dust and those that have large amounts of pre-existing CSM dust respectively

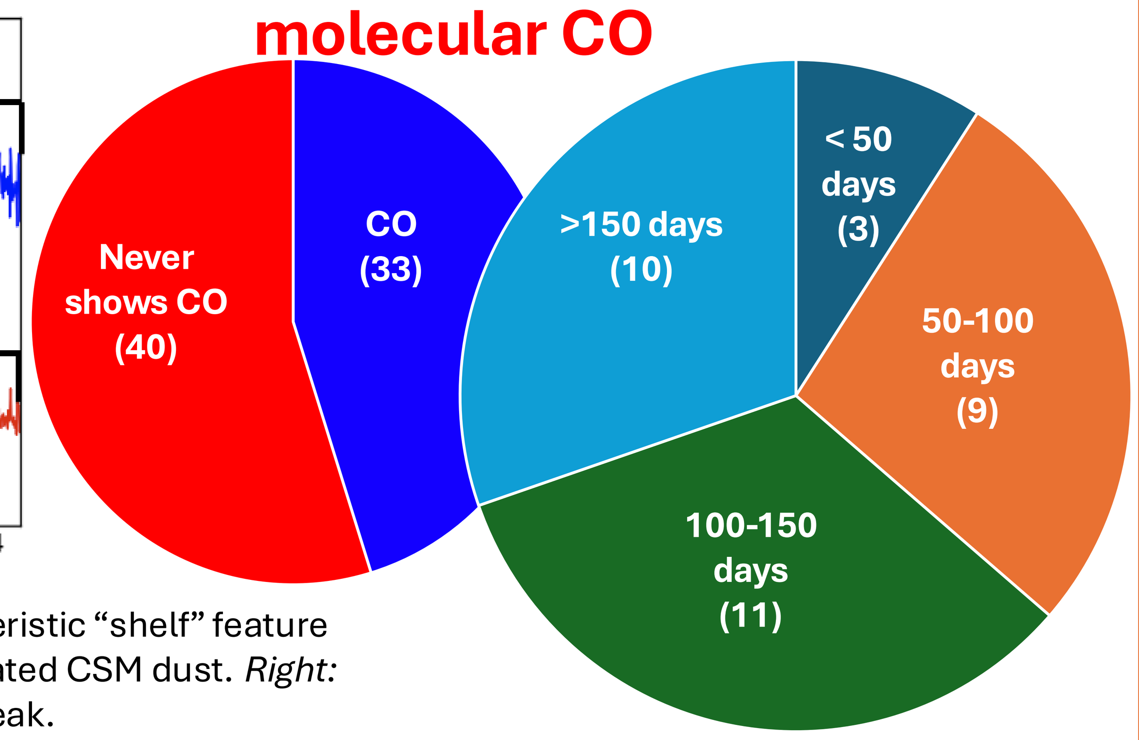


Top: The ZTF g r i lightcurve of the Type II SN 2024pcw. The atypical undulations are powered by interaction with the CSM. NIR photometric observations show an excess consistent with pre-existing CSM dust.

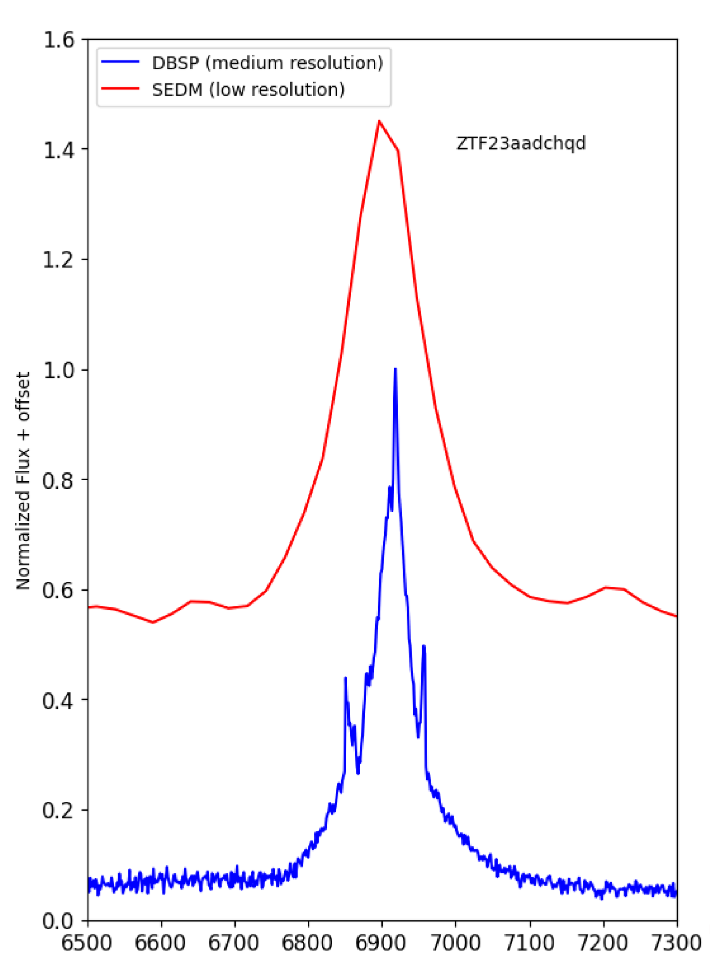


Left: Keck-II NIRES spectra of two RAT supernovae. ZTF24abgoksi shows the characteristic "shelf" feature of the CO first overtone, while ZTF24abyaspl shows an early NIR excess typical of heated CSM dust. *Right:* Statistics on the number of RAT supernovae which show CO by various times post-peak.

NIR spectroscopy with Keck II/NIRES probes molecular CO



Right: The complex Hα profile is resolved with medium resolution (R~2000) optical spectroscopy



Medium resolution optical spectroscopy also probes the CSM through narrow line interaction features

The Red Astronomical Transient (RAT) Survey

- The formation of CO is an essential step in the dust formation process as it cools the ejecta efficiently (e.g., Liljegren+ 2020)
- The RAT sample will nearly triple the existing sample size of core-collapse supernovae with CO detections!
- RAT supernovae which show signs of CSM interaction are no more likely to exhibit CO formation than those that don't, but they on average show CO signatures ~20 days earlier, suggesting early dust formation may take place in the cold dense shell (CDS)

References:

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Schneider R., Maiolino R., 2024, A&A Rev., 32, 2
Liljegren S., Jerkstrand A., Grumer J., 2020, A&A, 642, A135