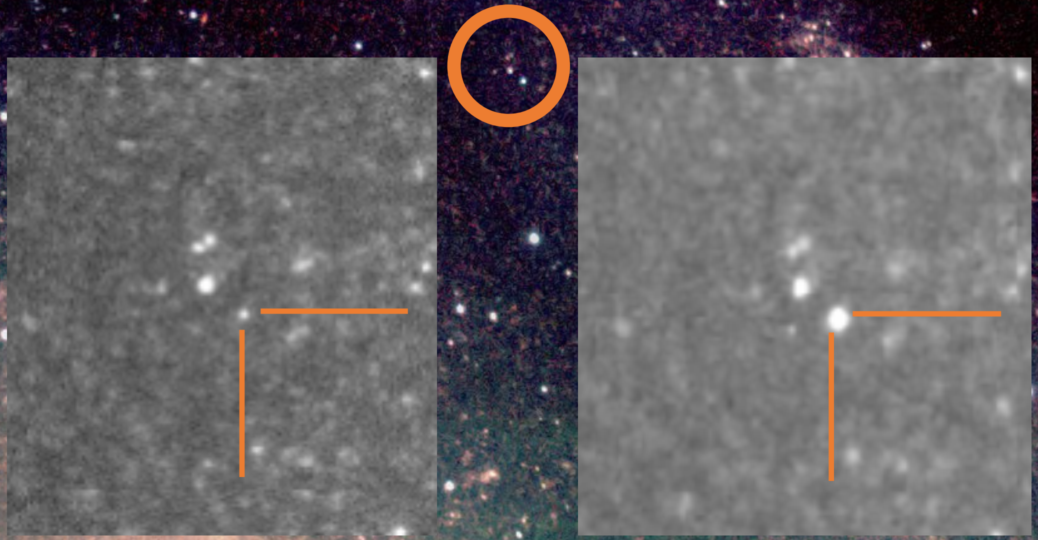
Insights into Stellar Explosions from Infrared Light



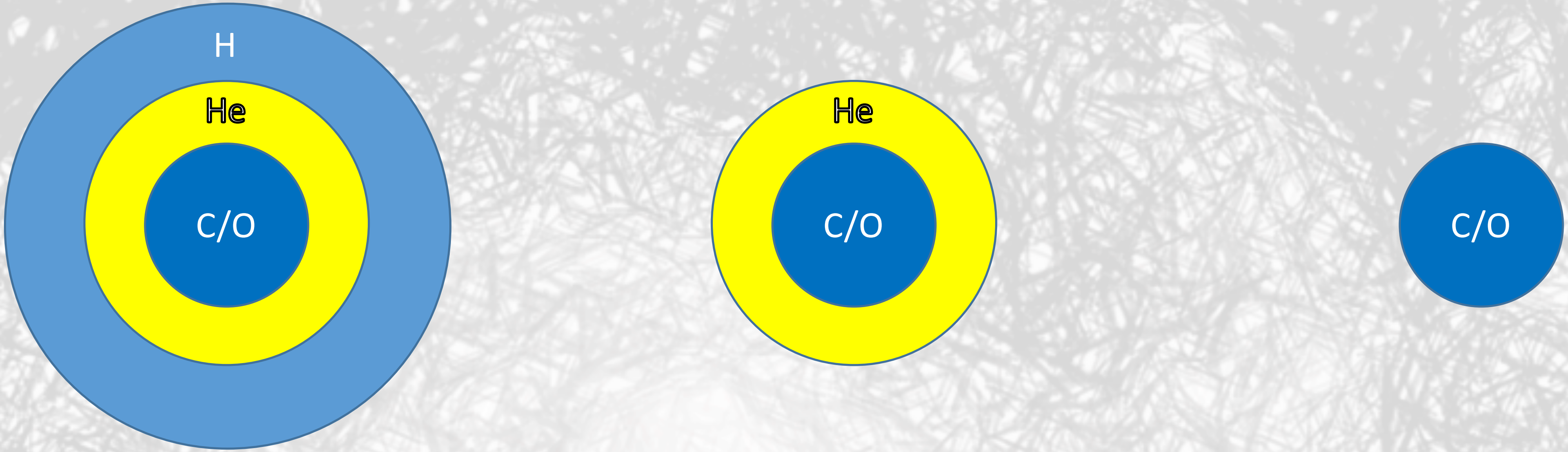
Kavli IPMU
2019 April 2

Kaew Tinyanont (Caltech)
Ryan Lau (ISAS), Mansi Kasliwal (Caltech)
SPIRITS team

Outline

- Scientific goal: how massive stars, and their supernovae, enrich the interstellar medium (ISM)
  - What can infrared observations tell us?
- Supernova with **molecule and dust formation**: SN 2017eaw
- Supernova with **interaction with circumstellar medium**: SN 2014C
- Outlook for future of supernova IR observations

Basic flavors of core-collapse SNe



Type II-Plateau
~60%

Type Ib
~10%

Type Ic
~20%

Transitional (II-L, IIb), **interacting (IIn), ~10%**

Basic flavors of core-collapse SNe

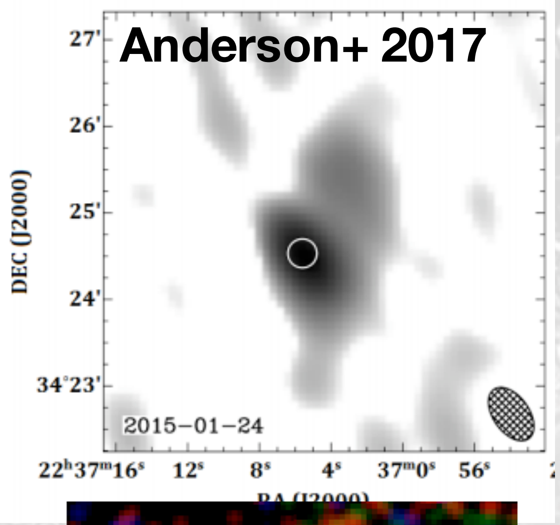
Outstanding Questions: What processes strip the envelope of Type Ib/c progenitors? What do these stars look like pre-explosion?

To answer: Observe SNe at late times and look at the circumstellar material around the SN!

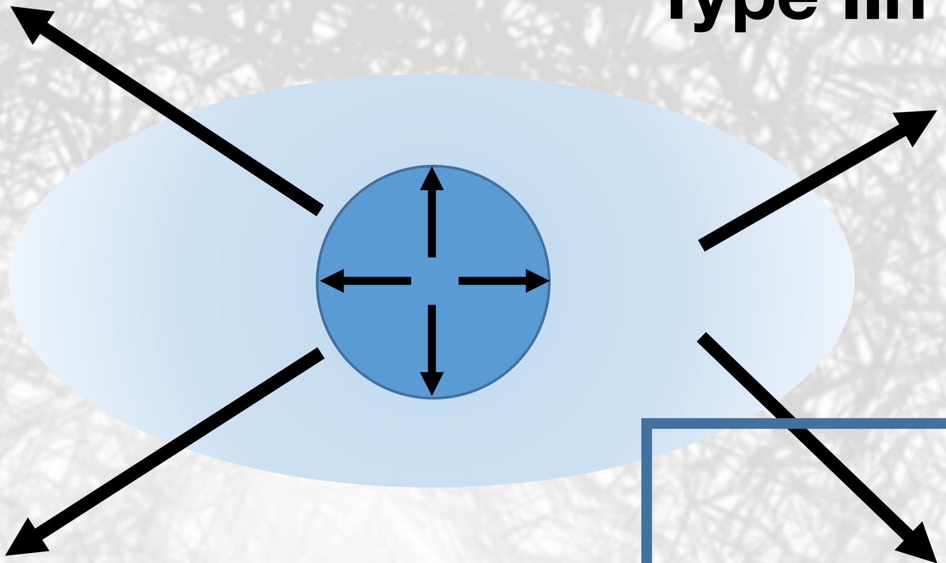
Type II-Plateau	**Type Ib**	**Type Ic**
~60%	**~10%**	**~20%**

Transitional (II-L, IIb), **interacting (IIn), ~10%**

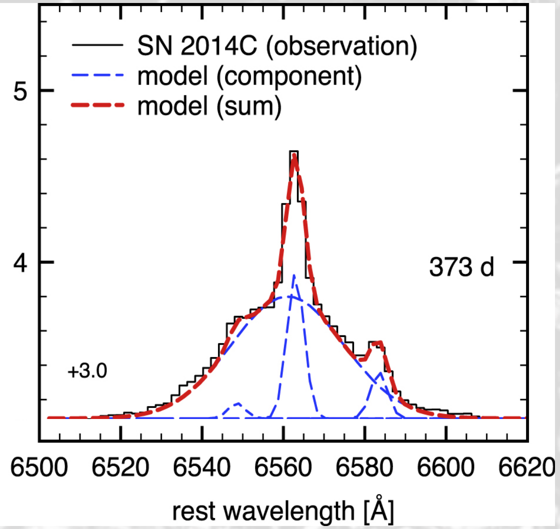
Signs of SN interactions with CSM



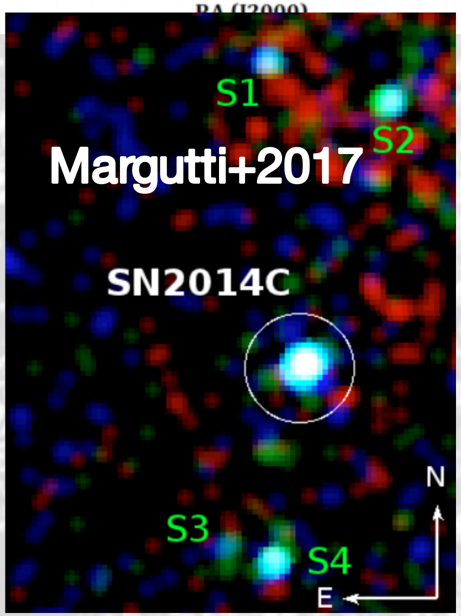
Radio



Optical
“Type IIn”

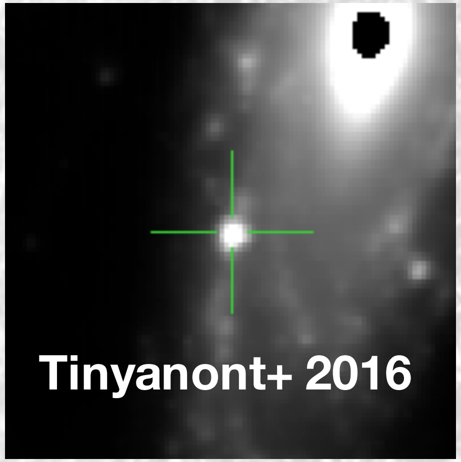


Milisavljevic+ 2015

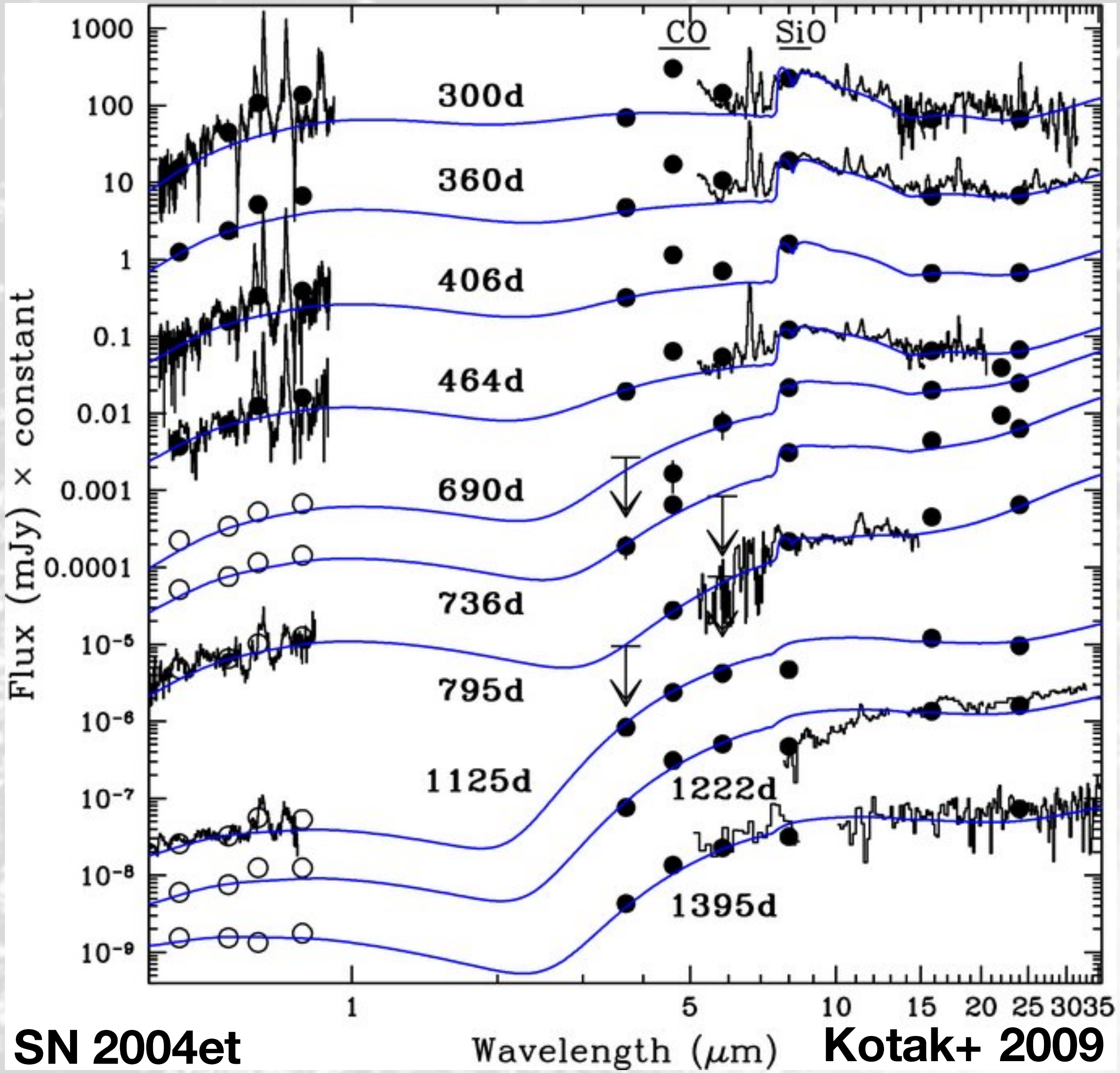


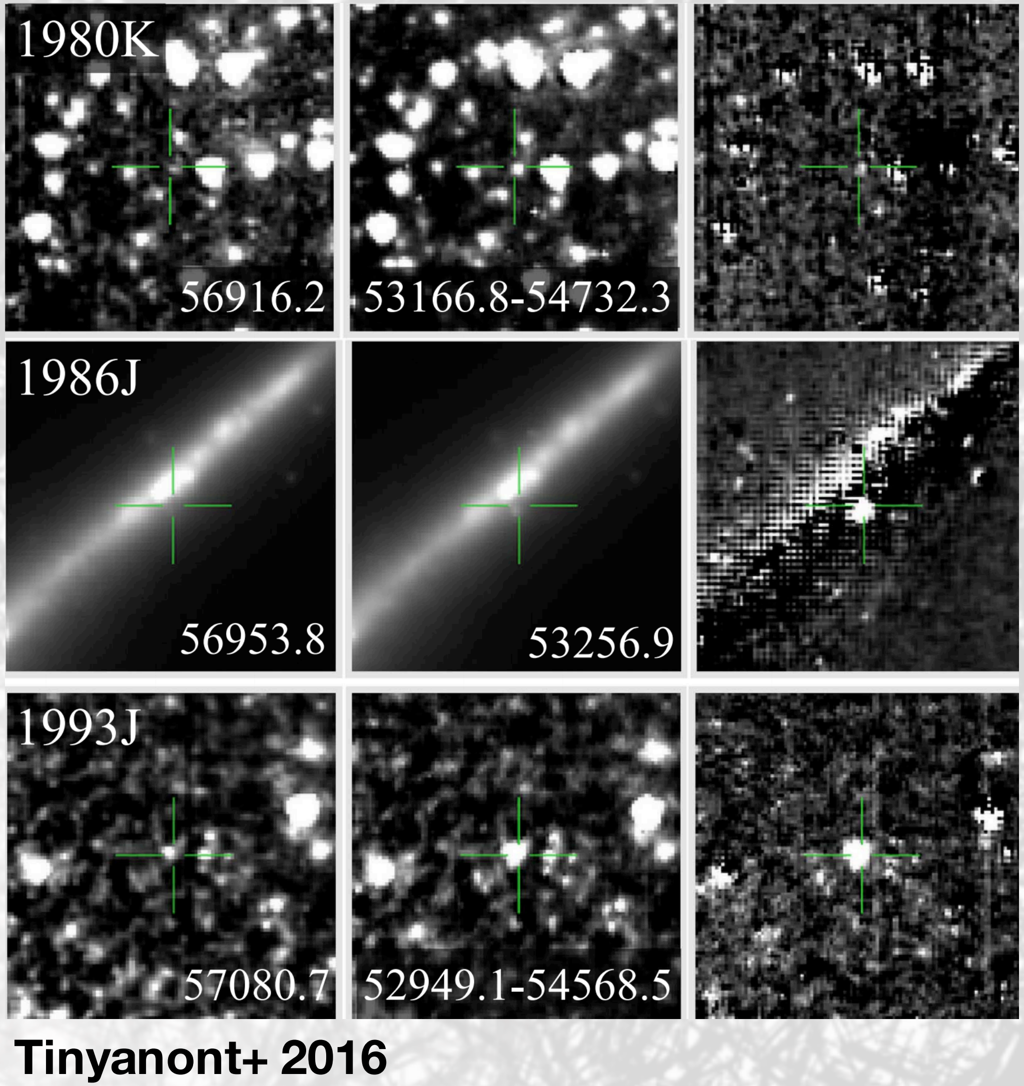
X-ray

IR dust



Why Infrared?

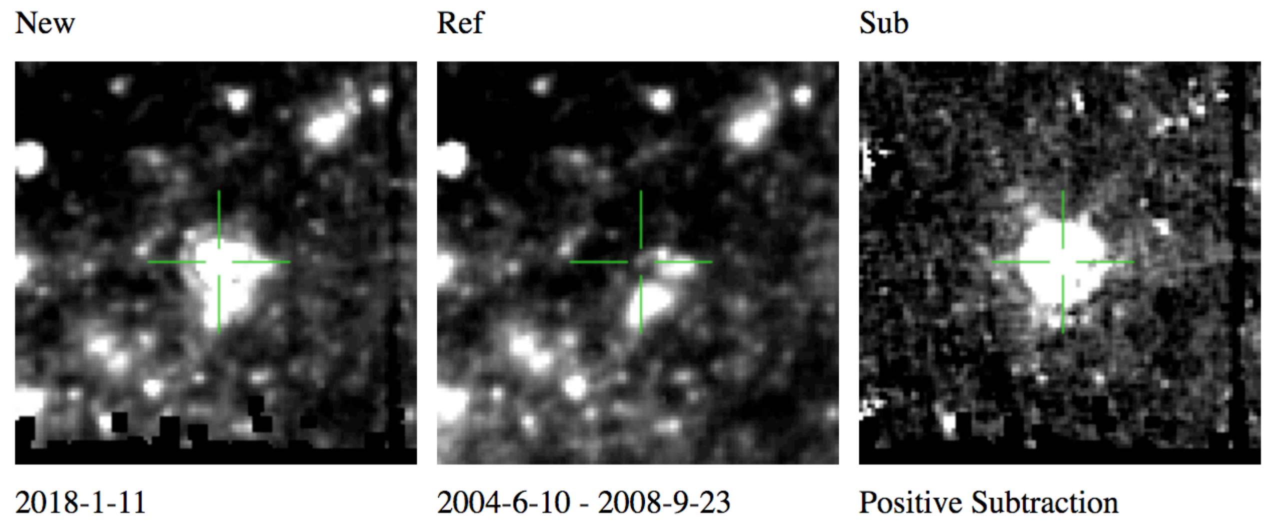


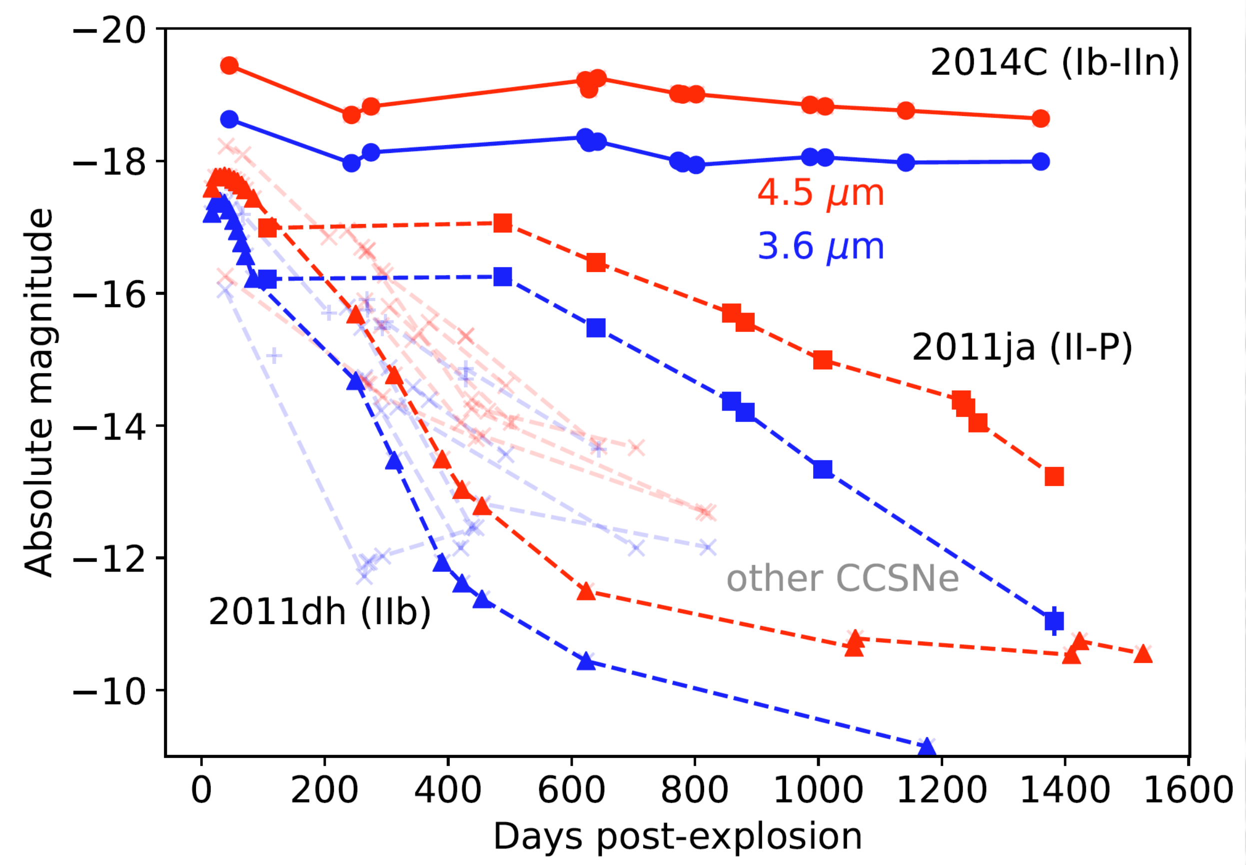


SPitzer InfraRed Transients Survey (SPIRITS)

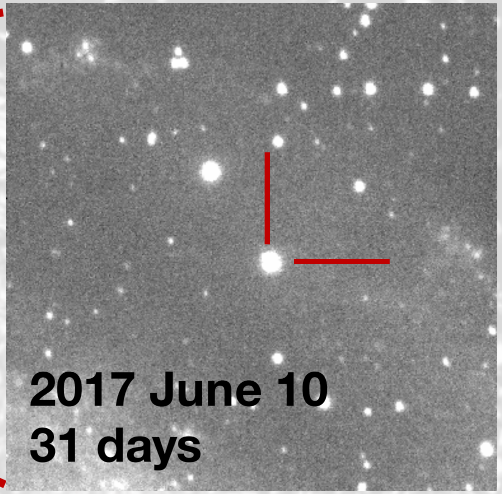
- 3.6 and 4.5 μm
- 190 galaxies, 141 nearby SNe
- See e.g. Kasliwal, Jencson

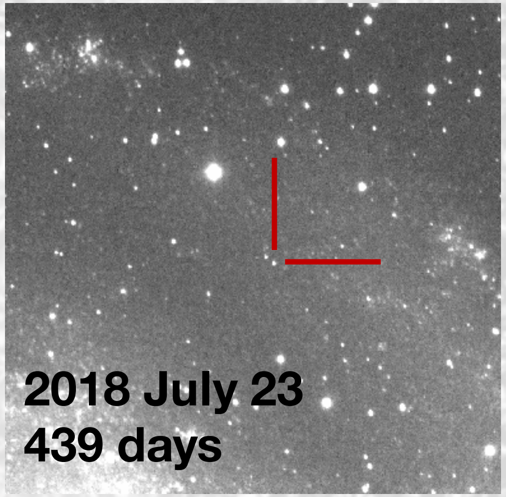
Modified from Tinyanont+ 2016





SN 2017eaw: bright & nearby normal Type II



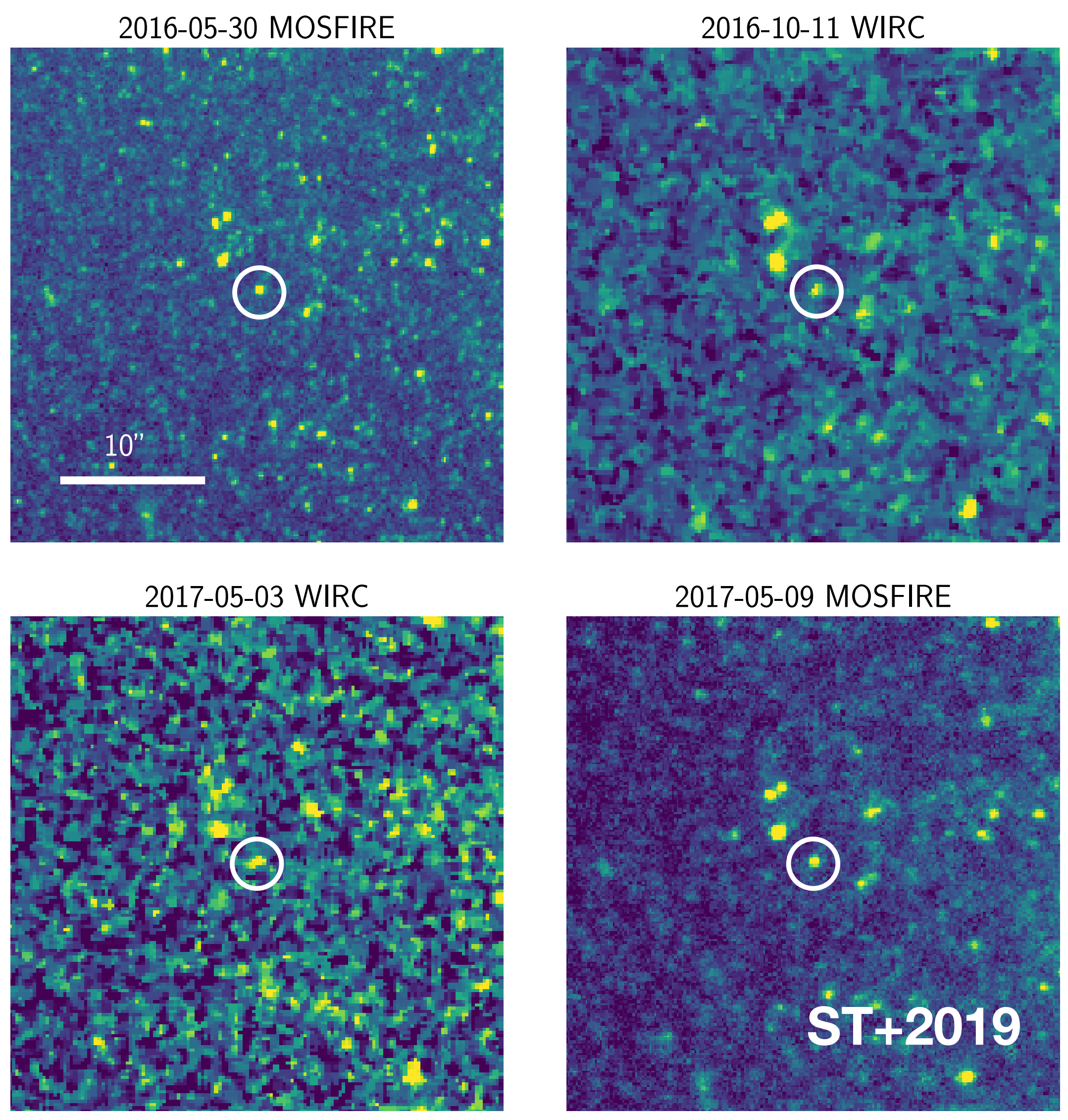


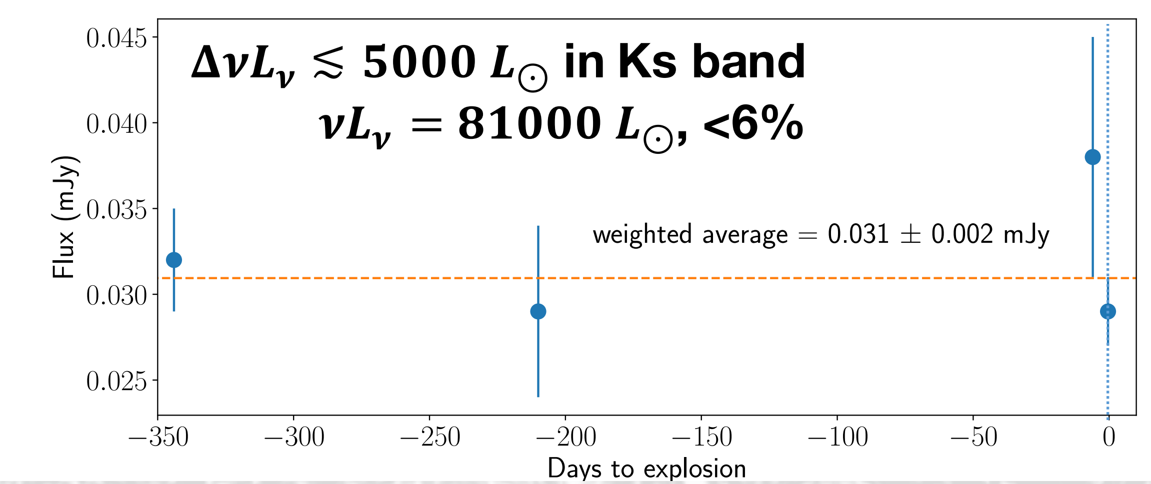
NGC6946
“Fireworks Galaxy”
P200/WIRC JHKs bands
2018 July 23

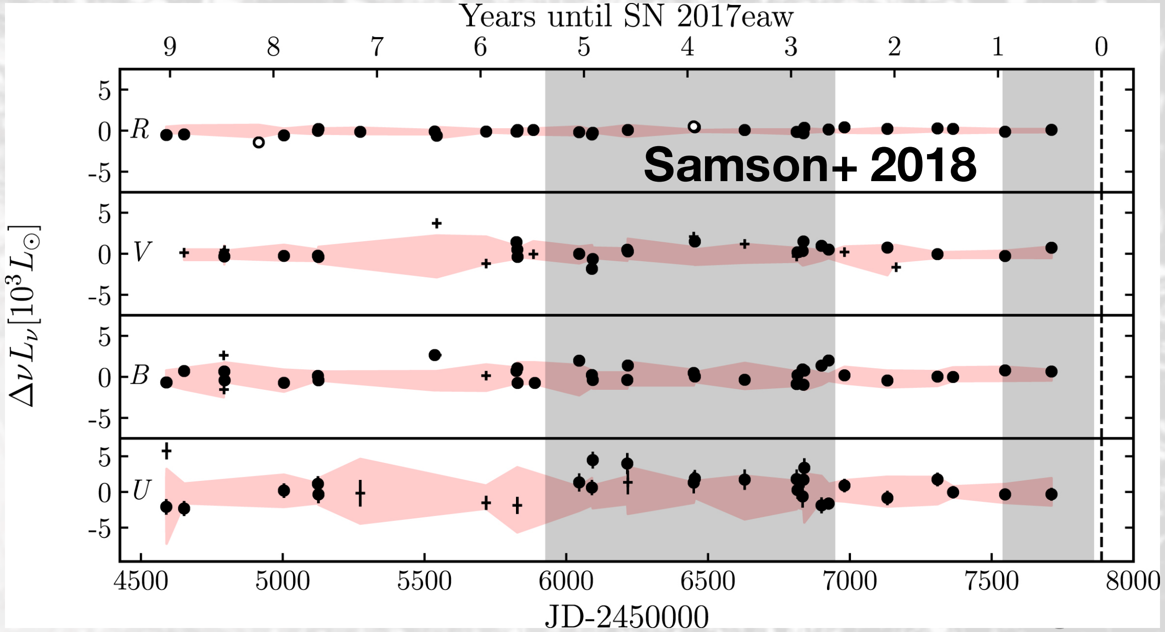
P200/WIRC
J band

RSG progenitor, no mass ejection*

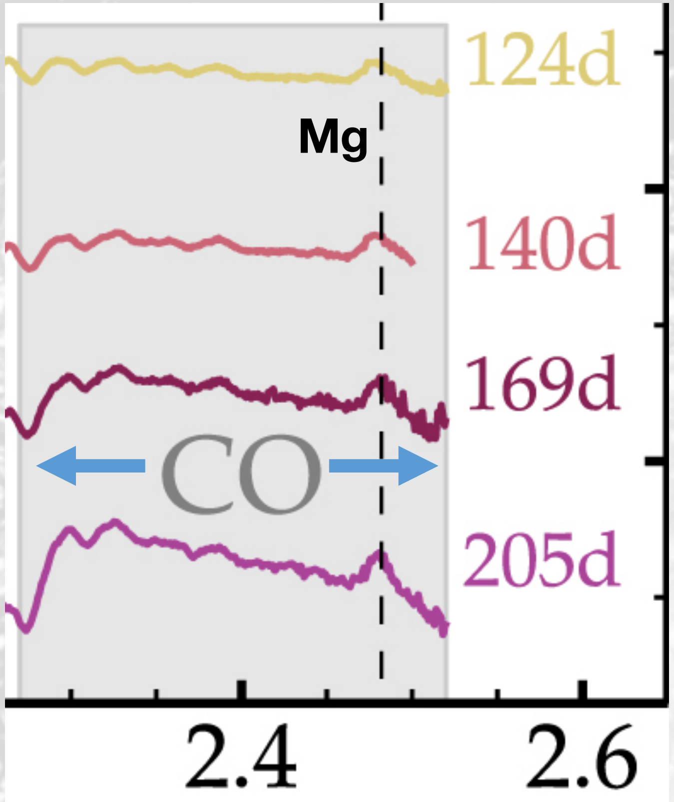
*See Kilpatrick & Foley 2018, van Dyk+2019



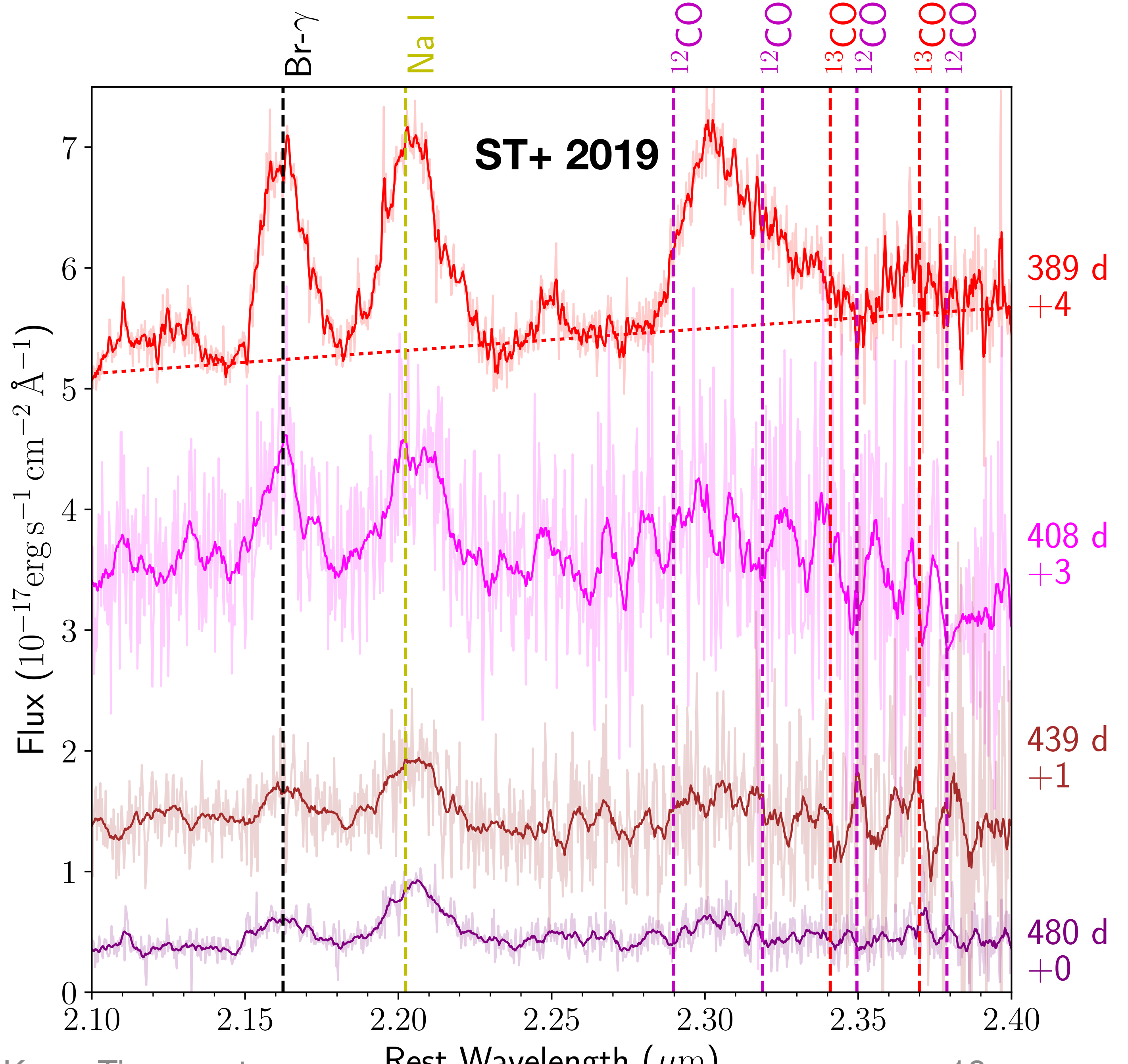




Formation of Carbon Monoxide

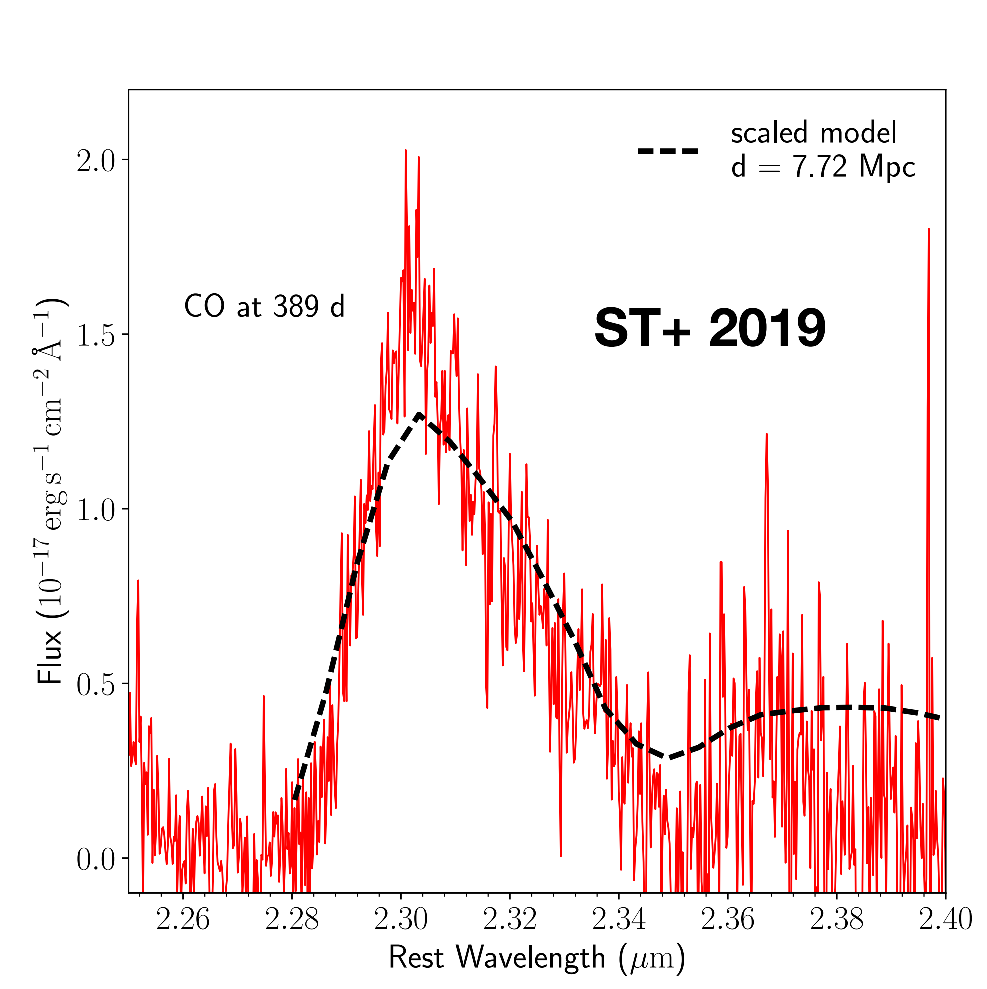


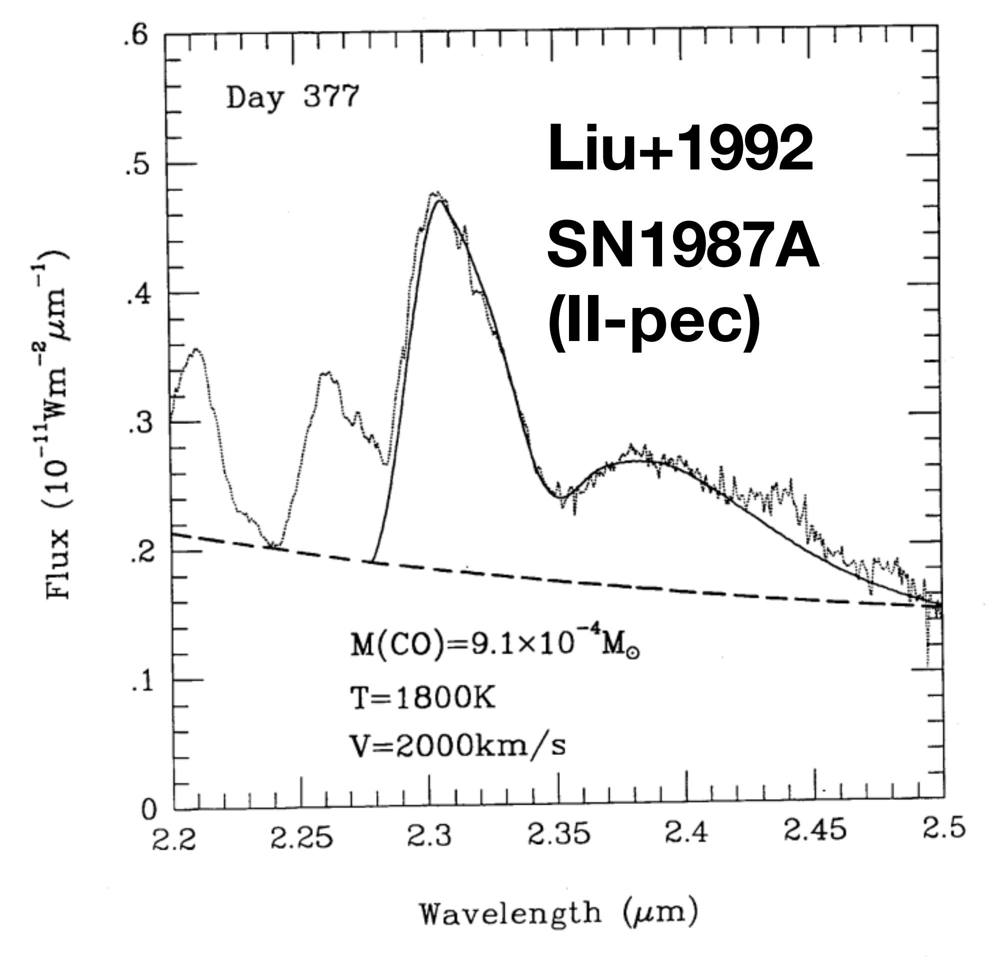
Rho+ 2018
CO first overtone at ~120 d



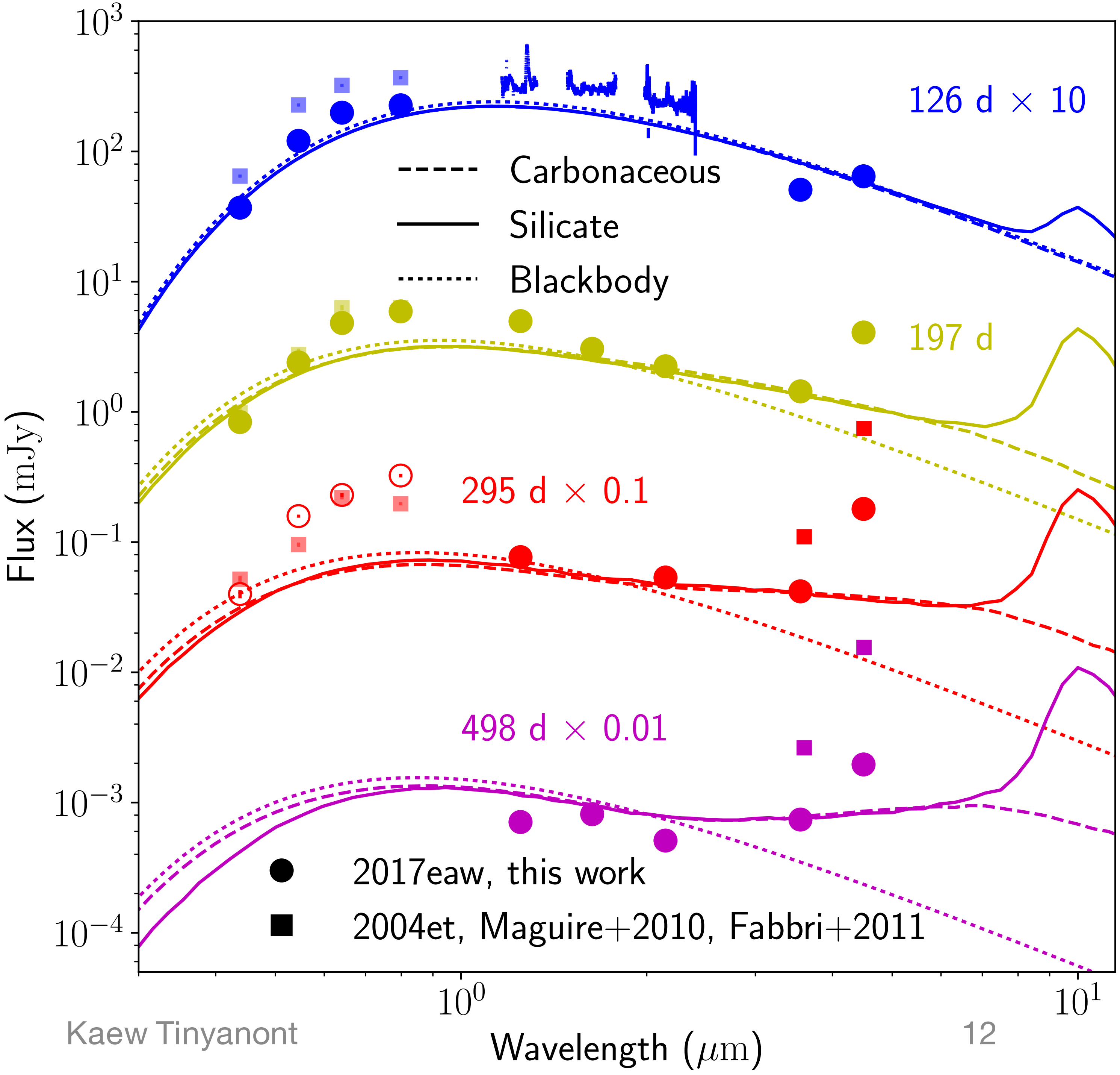
Kaew Tinyanont

CO looks like in SN 1987A!

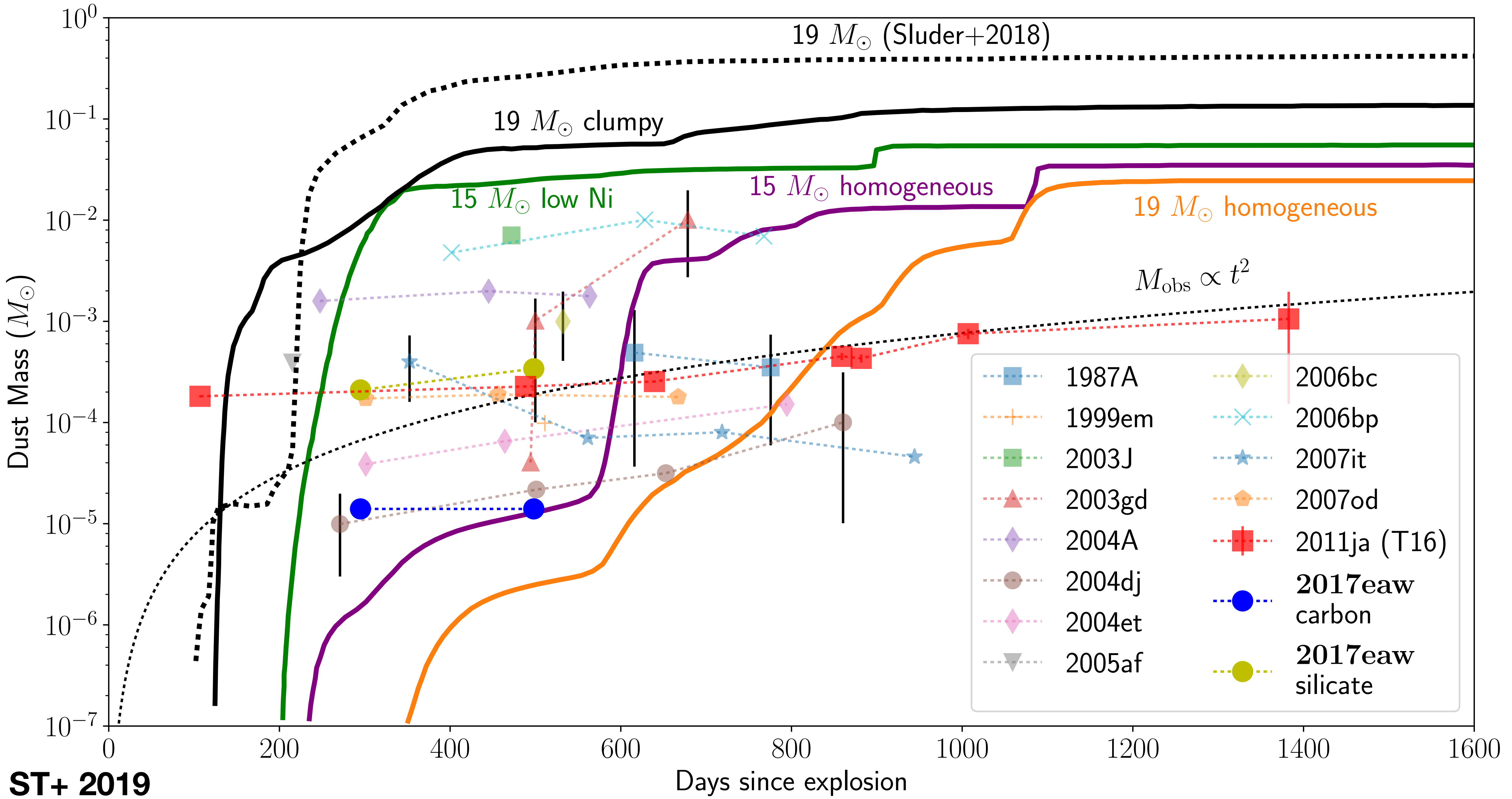




Dust formation

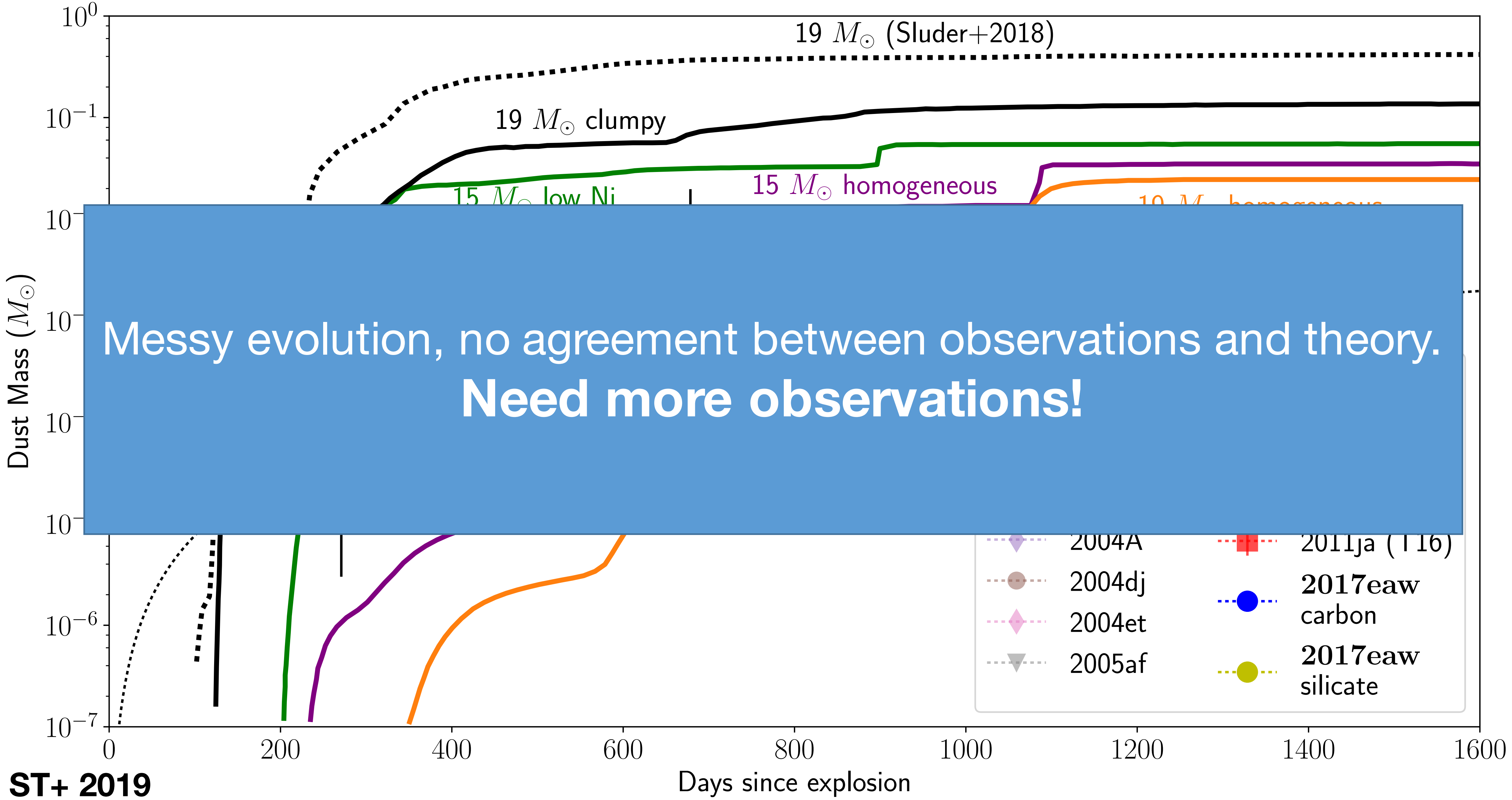


ST+ 2019



19 $M_\odot$ (Sluder+2018)
19 $M_\odot$ clumpy
15 $M_\odot$ low Ni
15 $M_\odot$ homogeneous
19 $M_\odot$ homogeneous
$M_{\rm obs} \propto t^2$
Dust Mass ($M_\odot$)
Days since explosion
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
200
400
600
800
1000
1200
1400
1600
1987A
1999em
2003J
2003gd
2004A
2004dj
2004et
2005af
2006bc
2006bp
2007it
2007od
2011ja (T16)
2017eaw carbon
2017eaw silicate

ST+ 2019

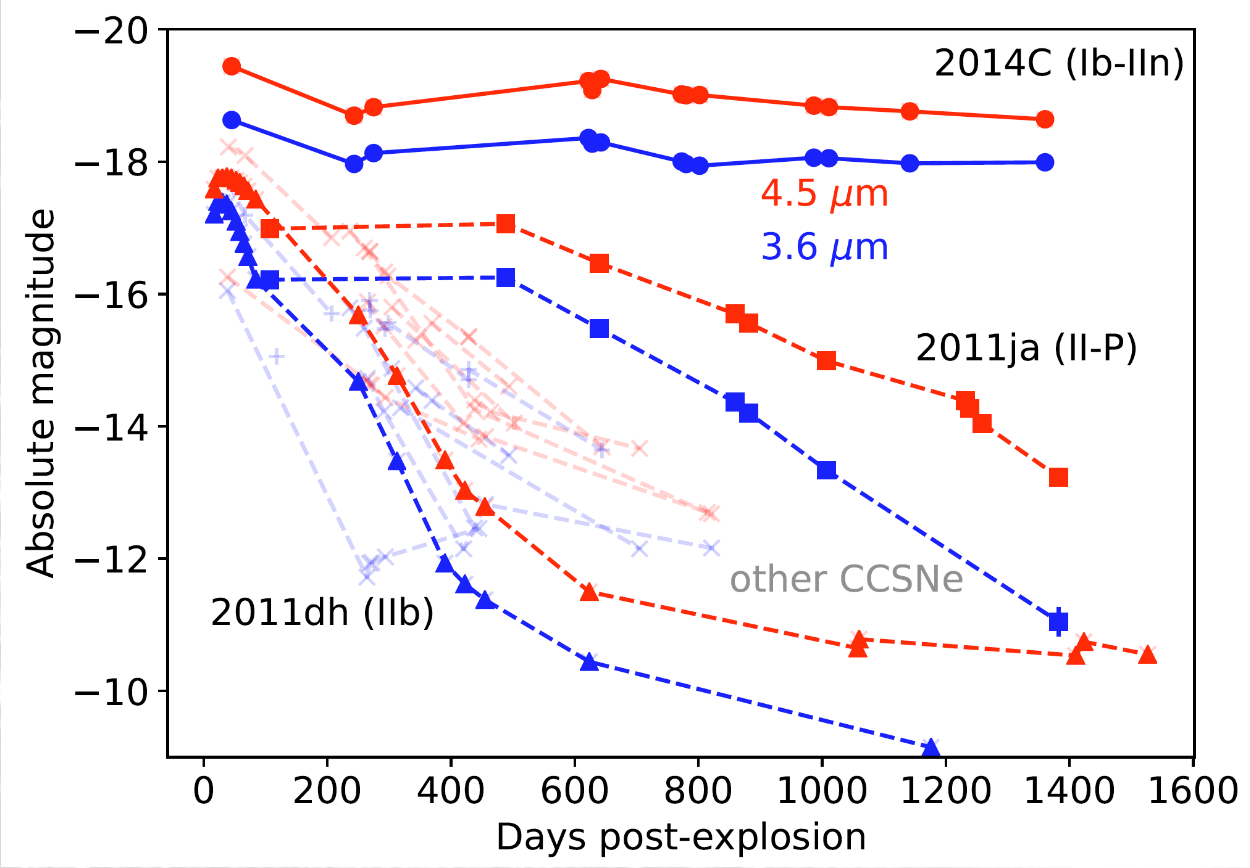


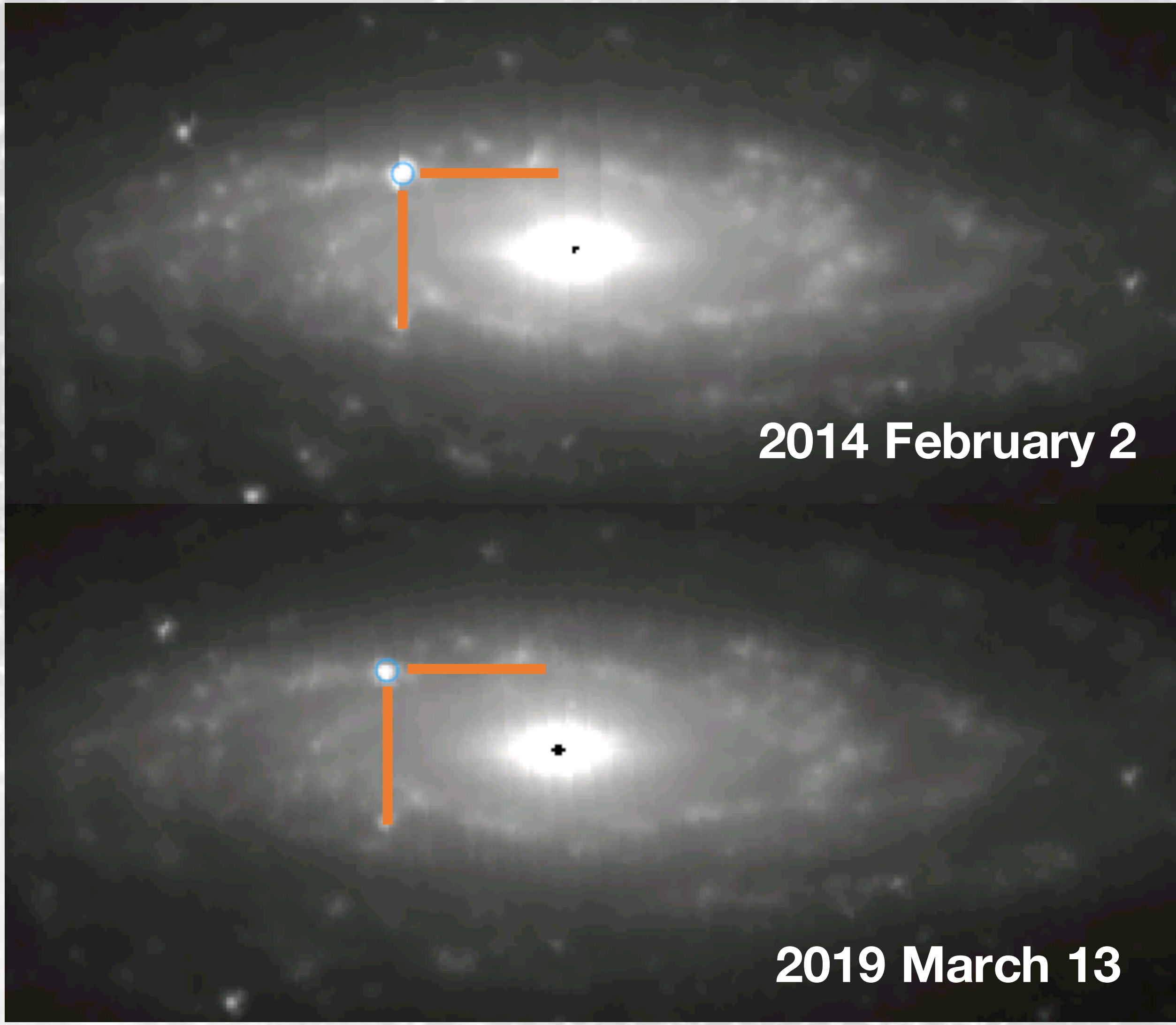
Messy evolution, no agreement between observations and theory.

Need more observations!

ST+ 2019

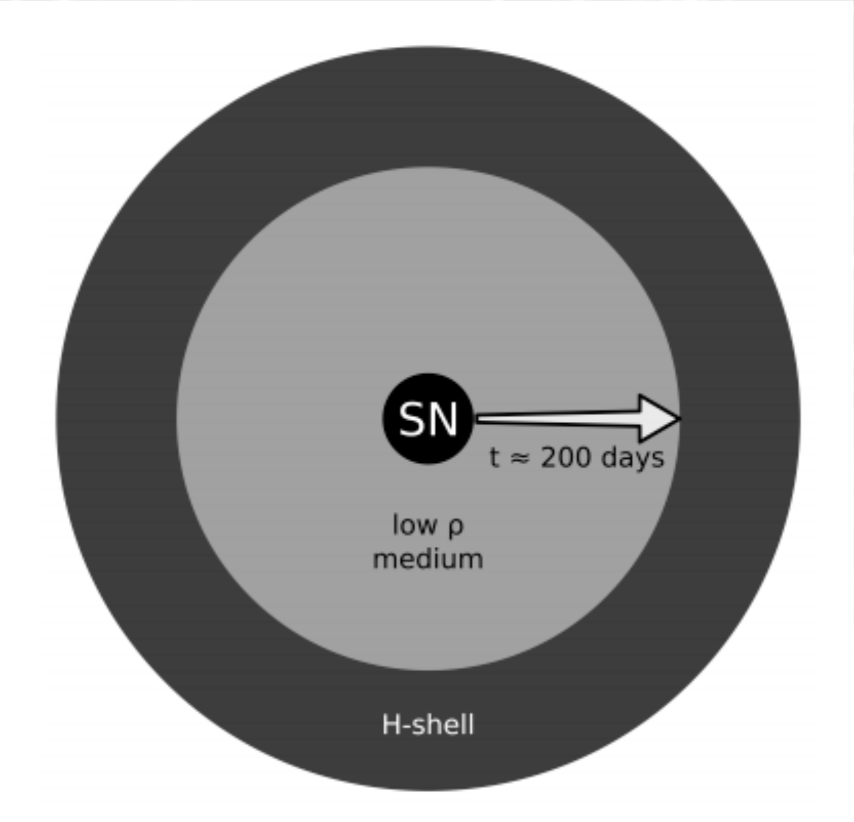
Interacting supernova in the IR
SN 2014C

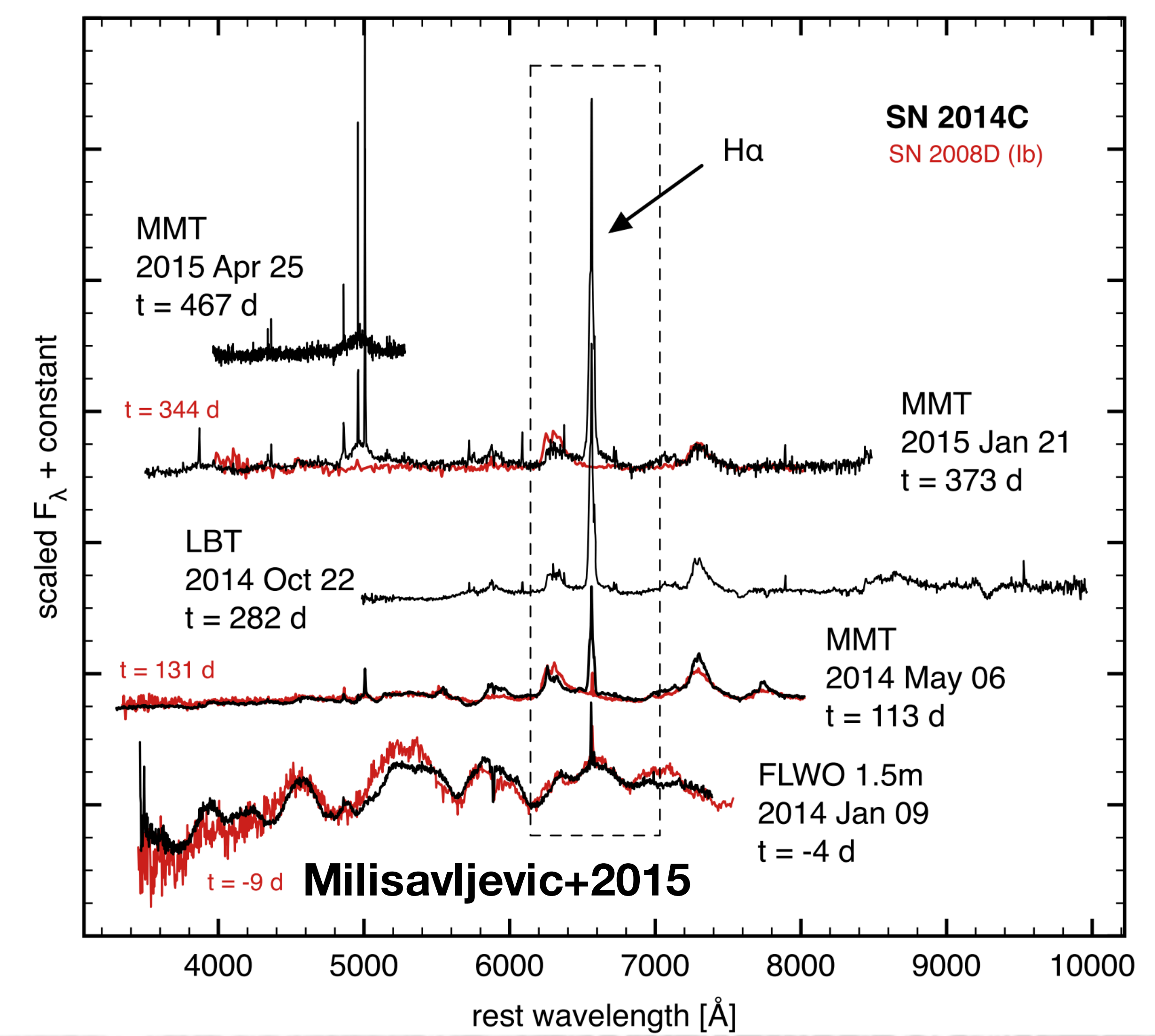




The "Chameleon" SN Ib → IIn

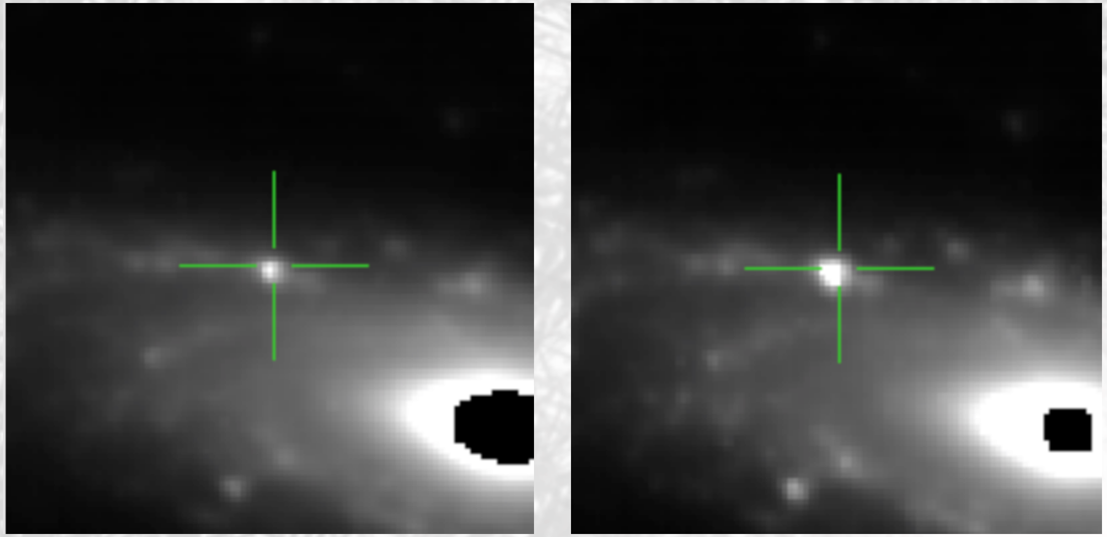
Anderson+2017



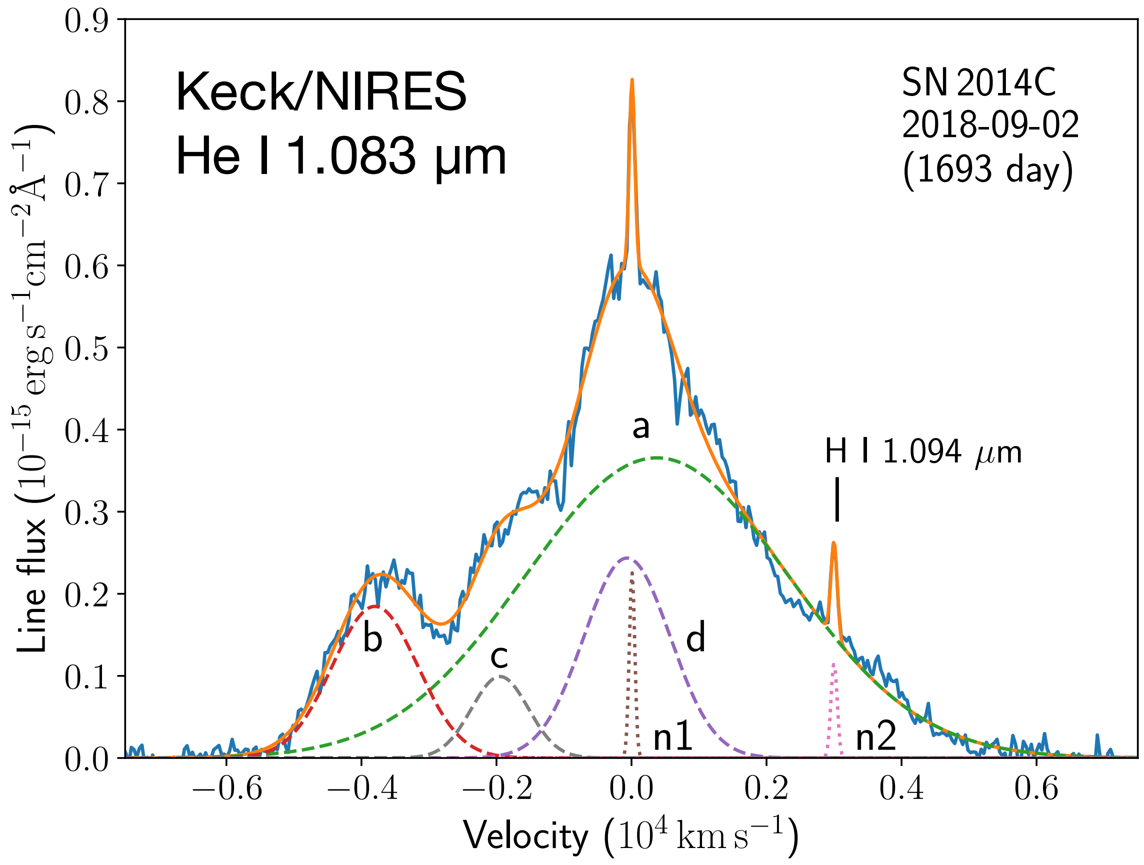


Long lasting CSM interactions

Spitzer 3.6 and 4.5 μm
2019 March 13, ~1900 days!

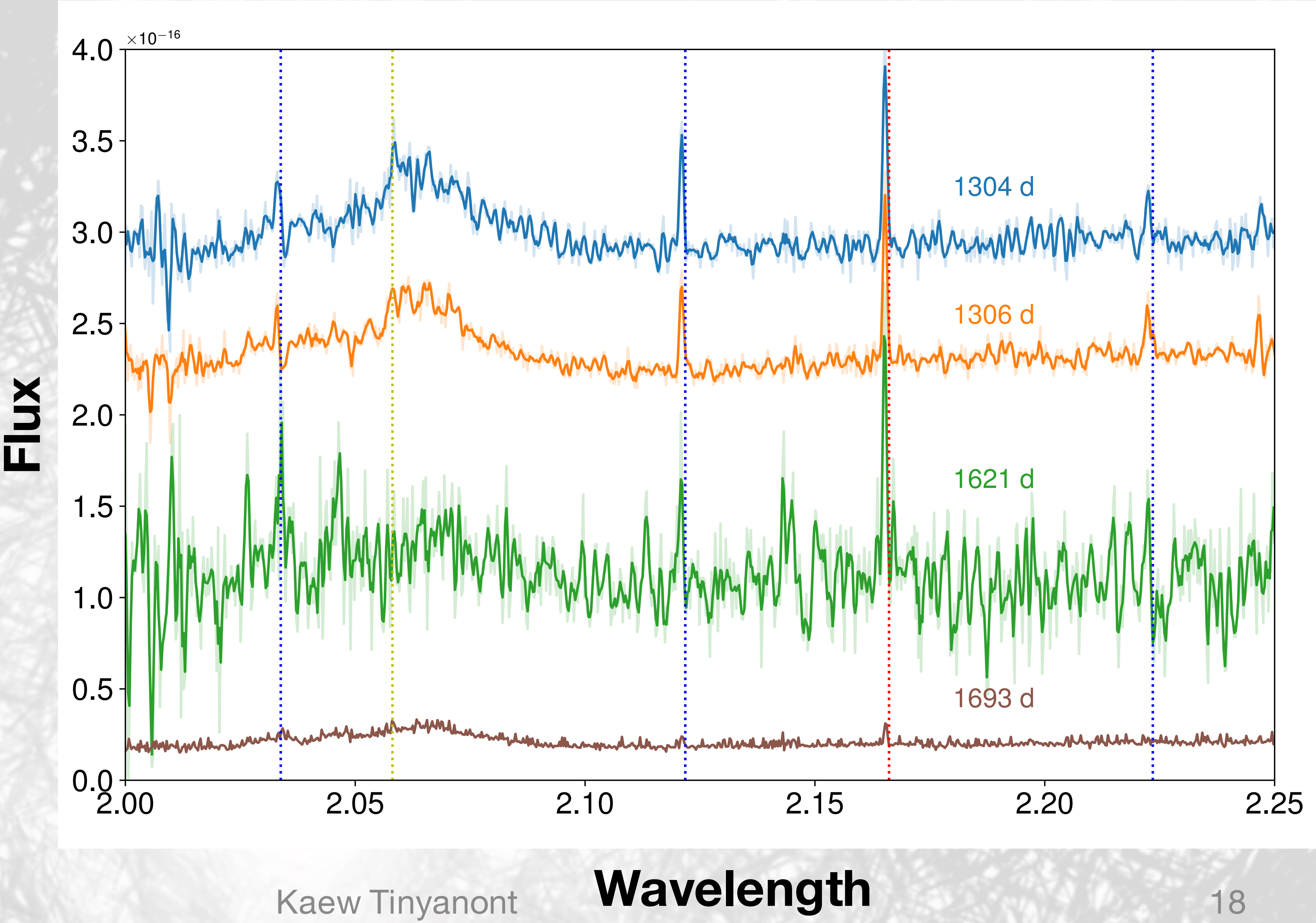


Tinyanont, Lau,+ 2019 in prep.

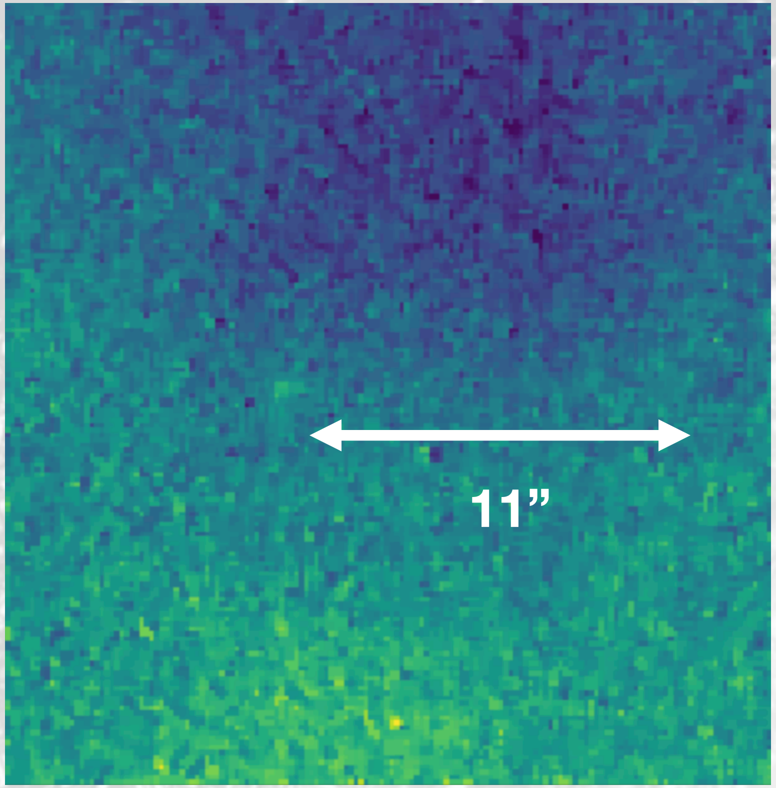


Molecular Hydrogen!

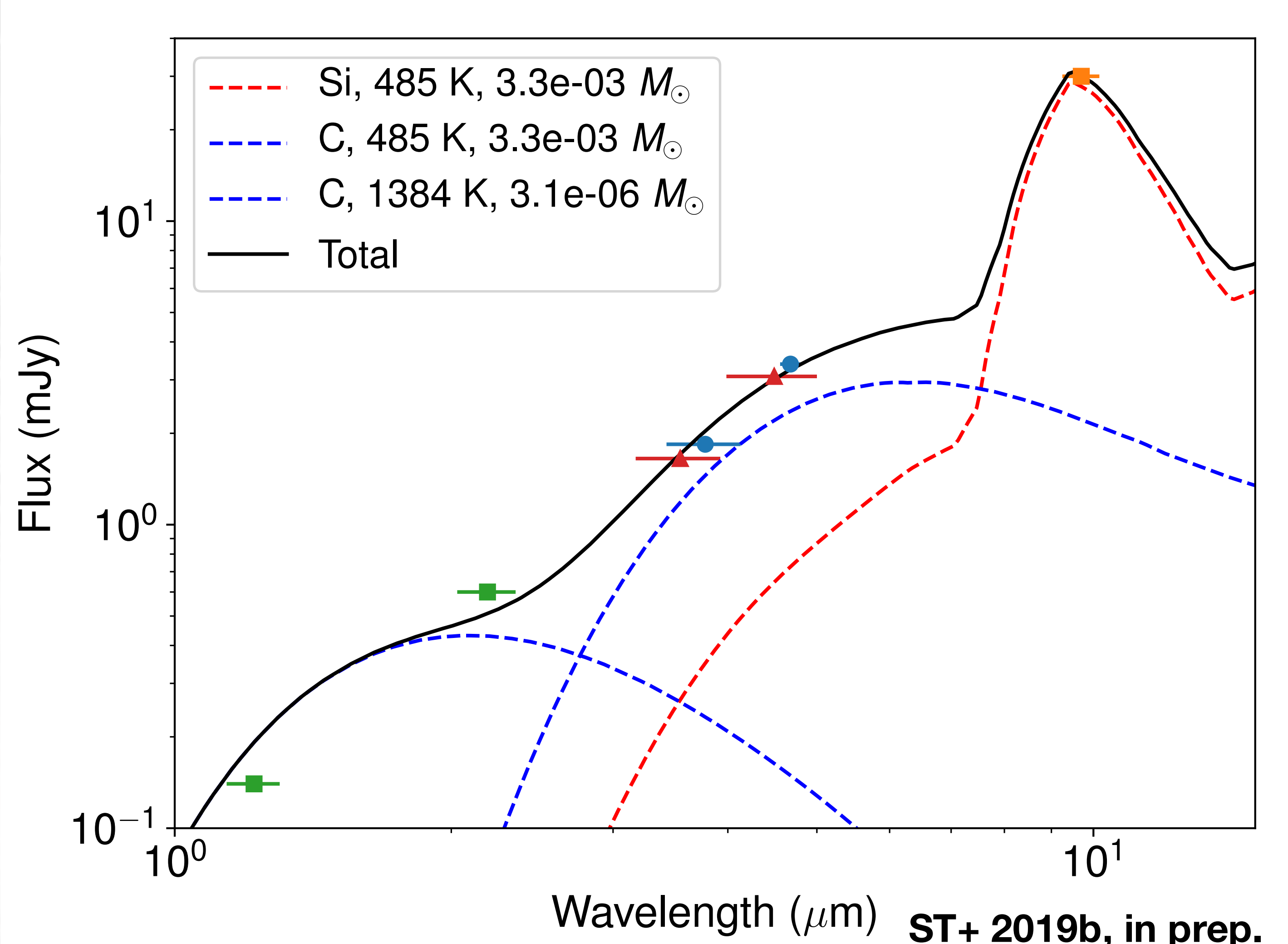
ST+ 2019b, in prep.



IR SED shows silicate features

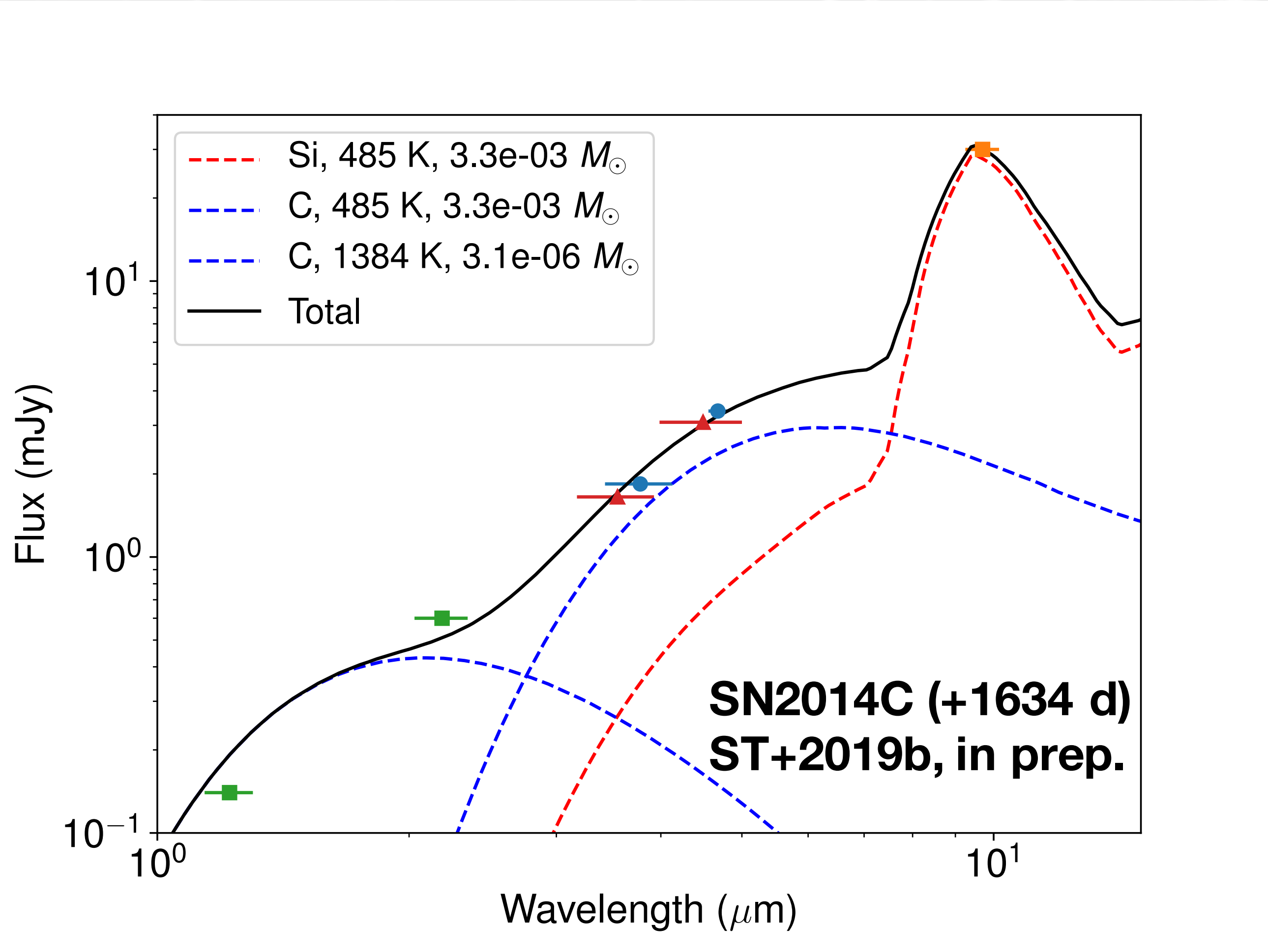


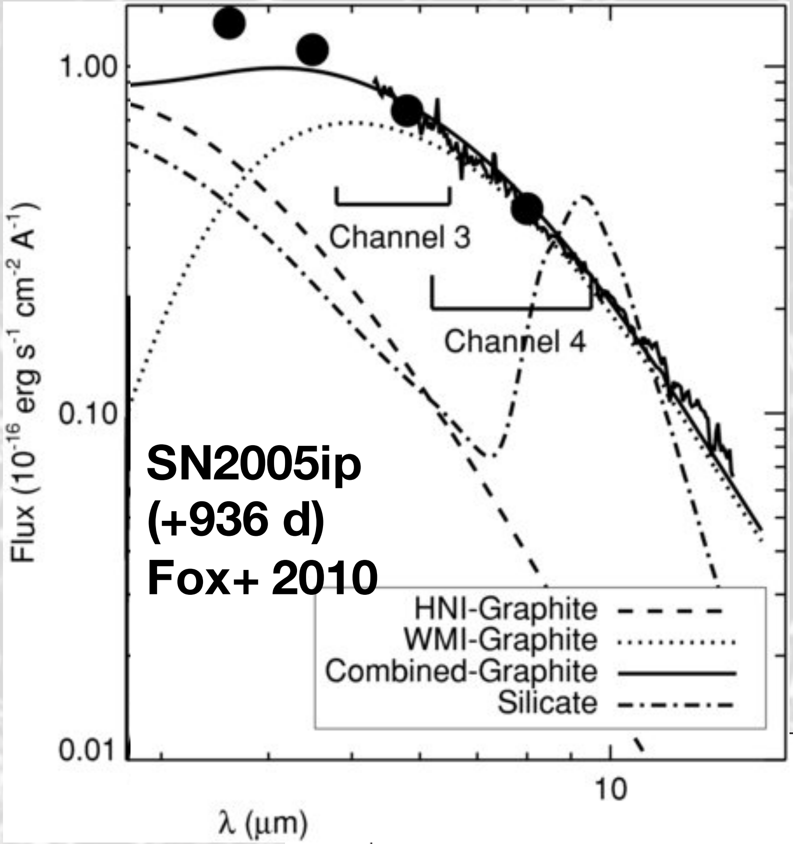
Subaru/COMICS
9.7 µm (PI R. Lau)

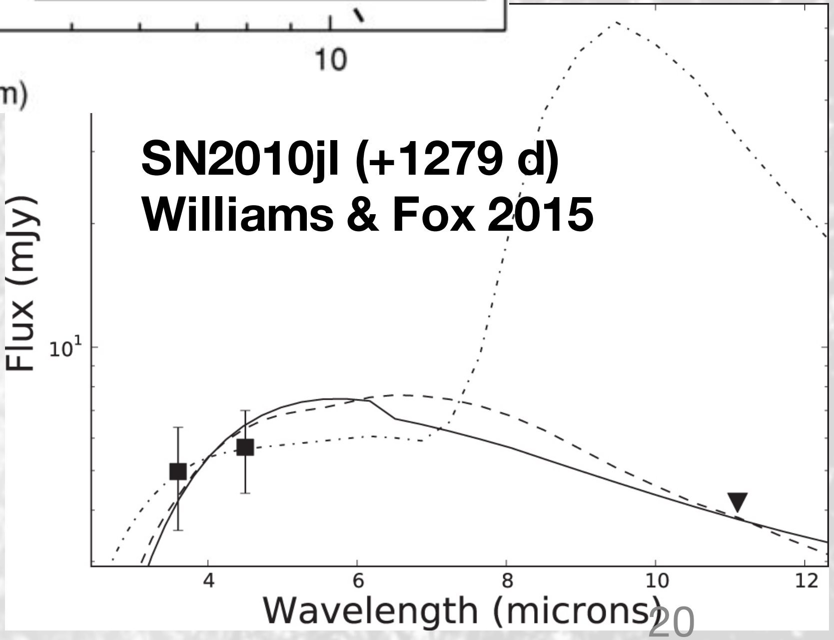


ST+ 2019b, in prep.

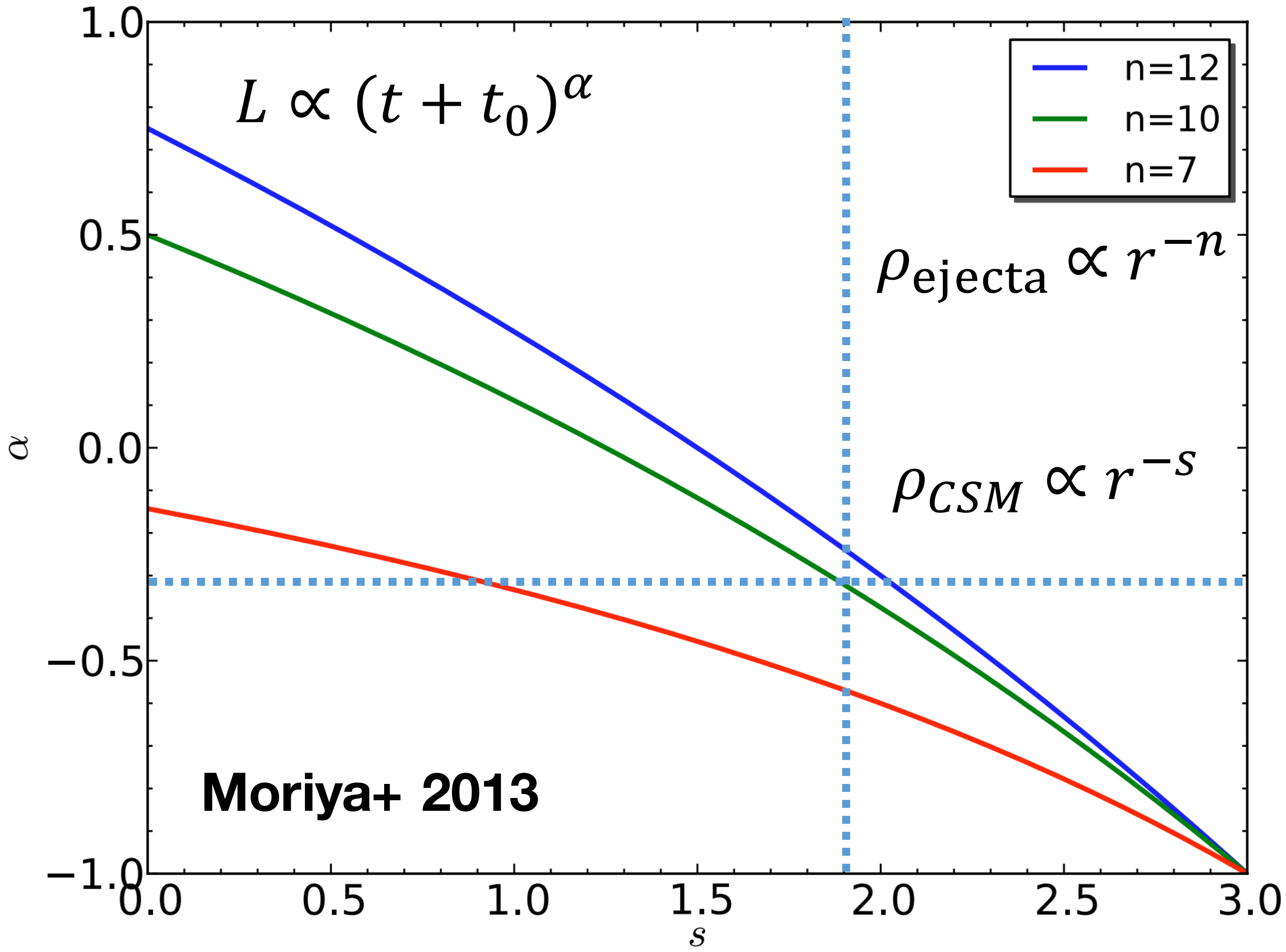
First silicate detection in interacting SN

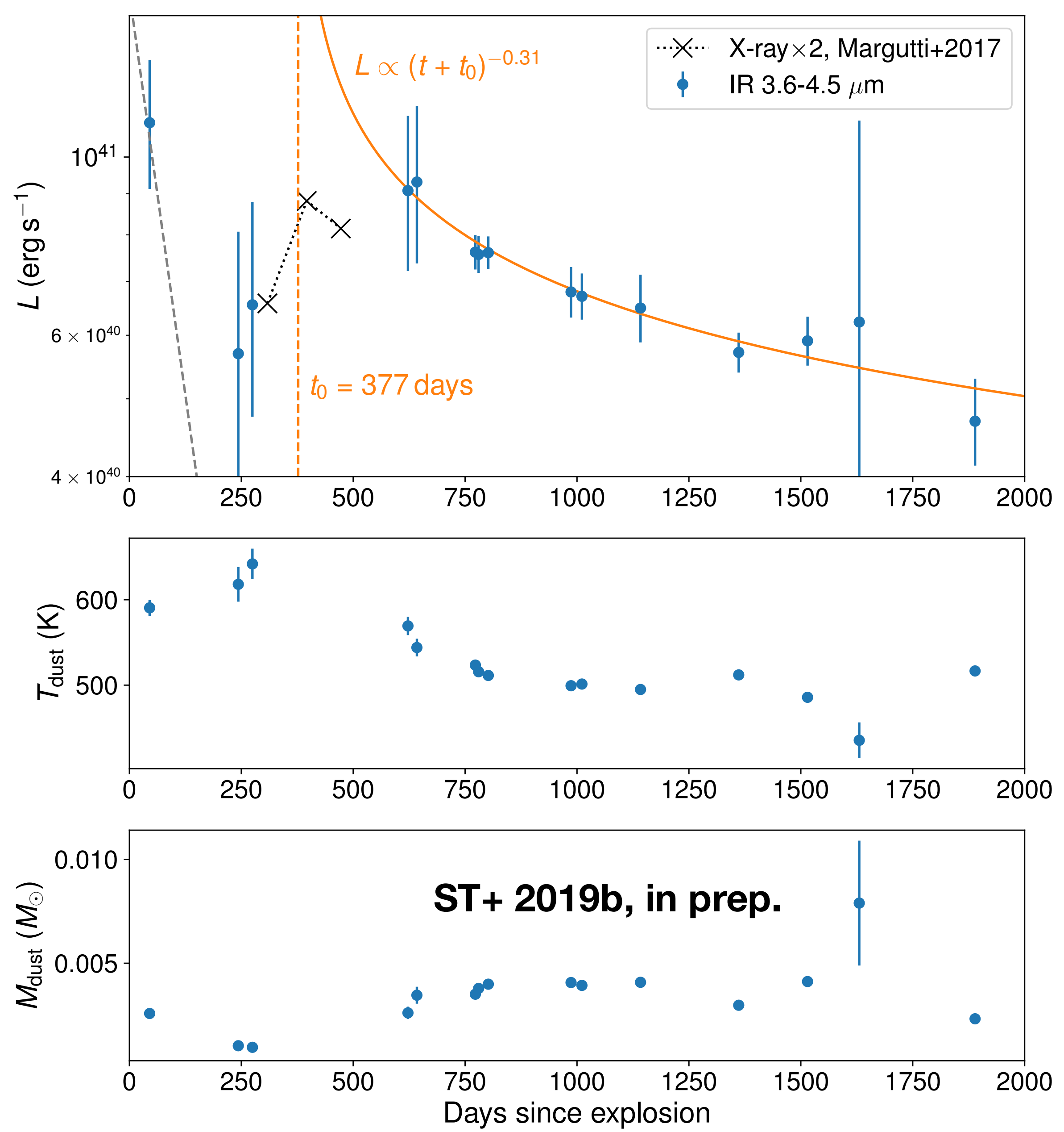






IR evolution consistent to steady wind

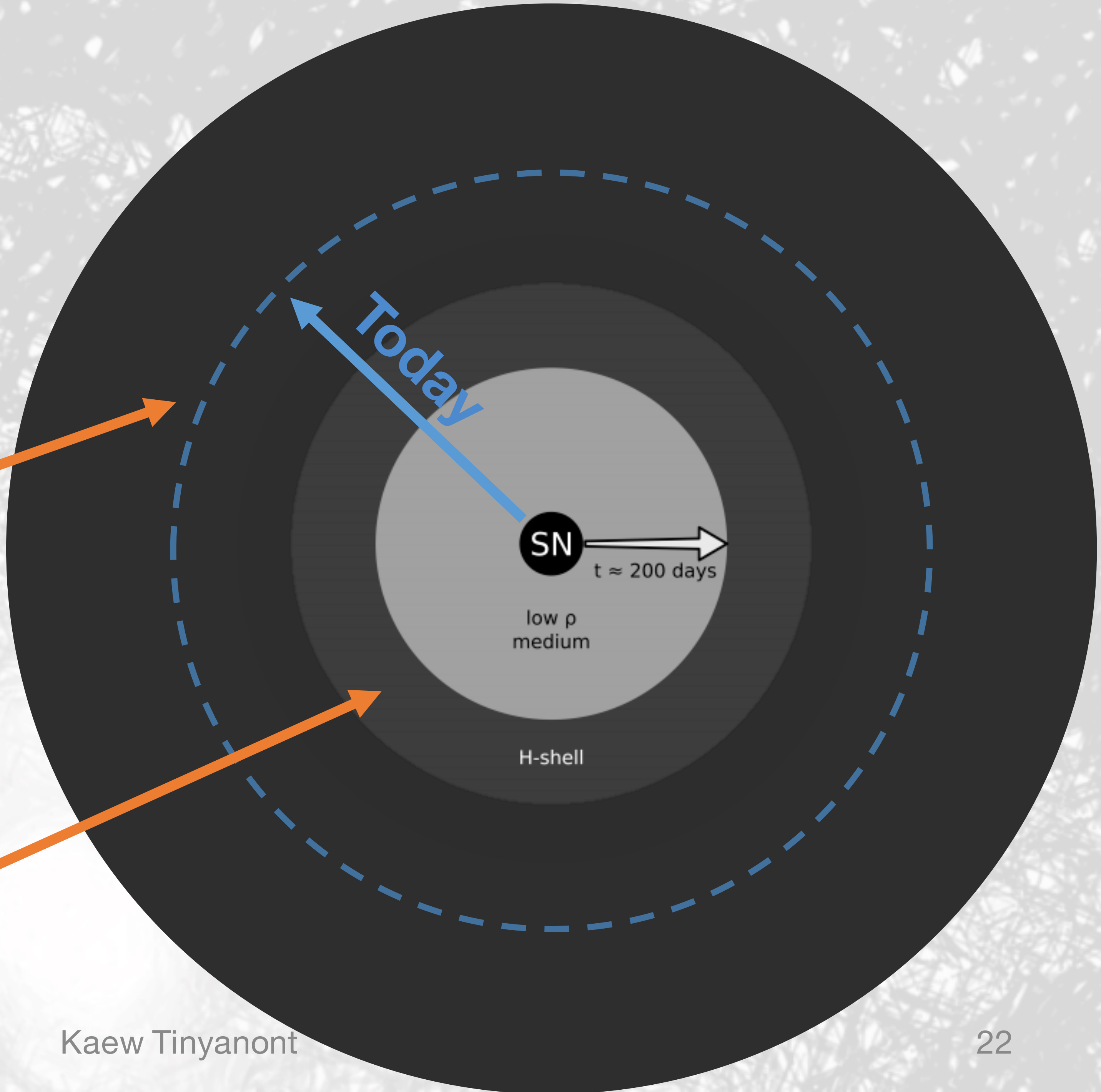




Dense shell with fuzzy exterior

Steady wind CSM
Silicate rich, cold enough for molecular hydrogen

Dense shell from eruptive mass loss



Future of IR observations of SNe

2021

JWST

20??

WFIRST

Deep 1-20 μm **spectroscopy** of more SNe
Better consensus on molecule & dust formation

Statistics of SNe near-IR light curves
Revolutionize progenitor search

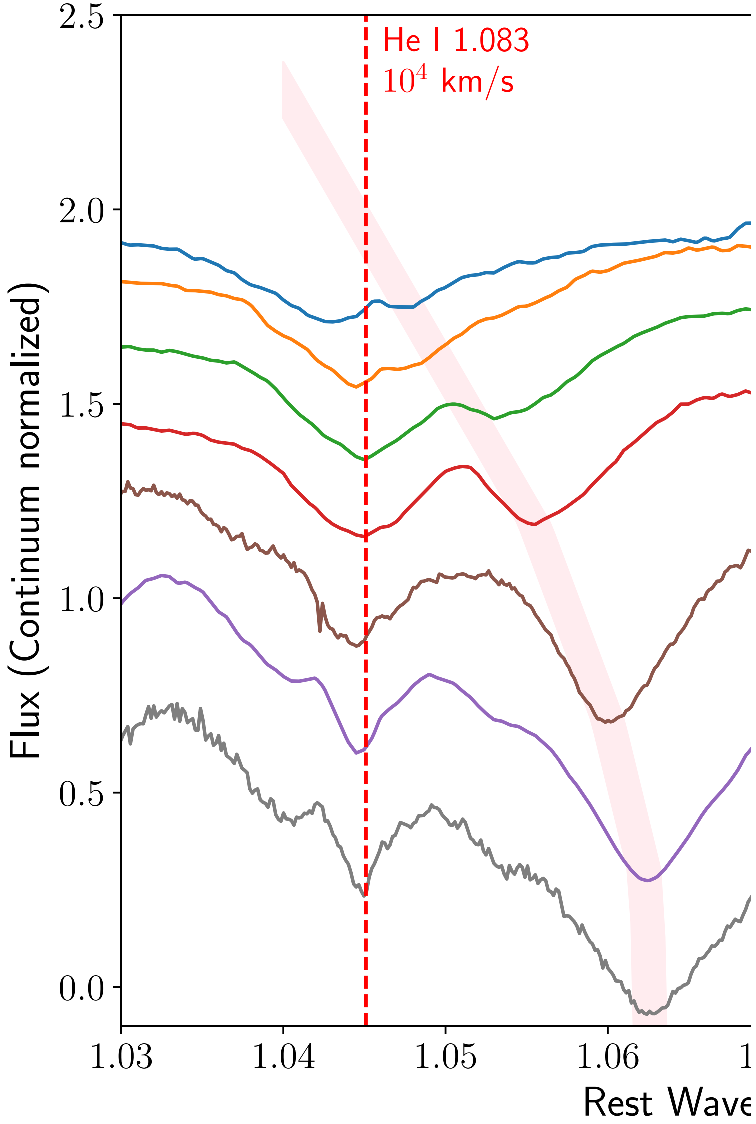
Conclusion

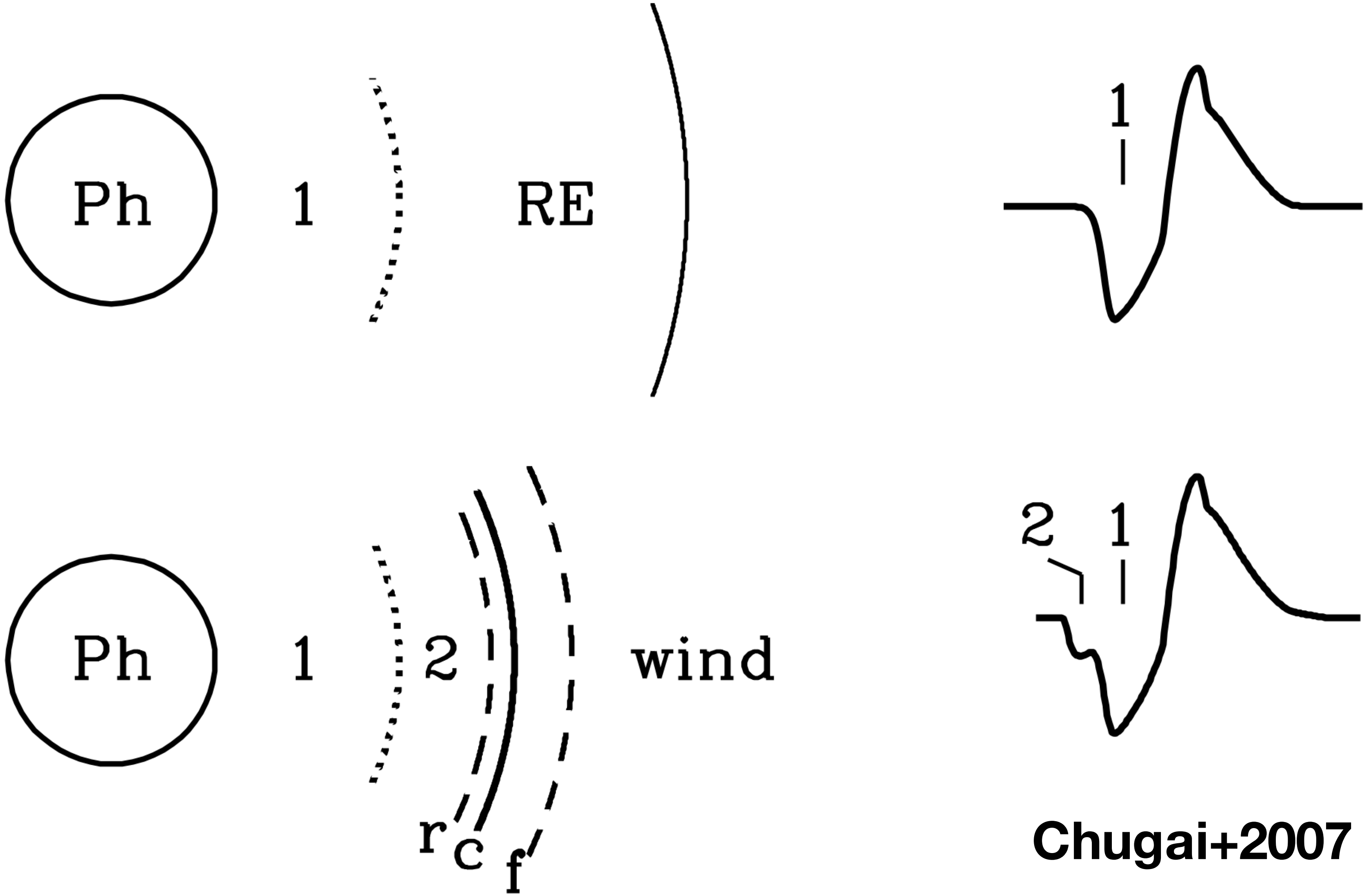
- Infrared holds important information about supernovae, but not yet well studied
- IR tells us about dust and molecule formation (2017eaw)
- IR tells us about mass loss history from CSM interaction (2014C)
- Upcoming missions can provide key observations needed to better understand the last phase of massive star evolution

WIRC+Pol: IR Spectropolarimeter

- R ~ 100 in J and H band on the 5.1-meter at Palomar Observatory
- Liquid crystal-based design, high throughput
- ~0.05% accuracy for bright sources ($J < 12$), characterization underway for faint sources.

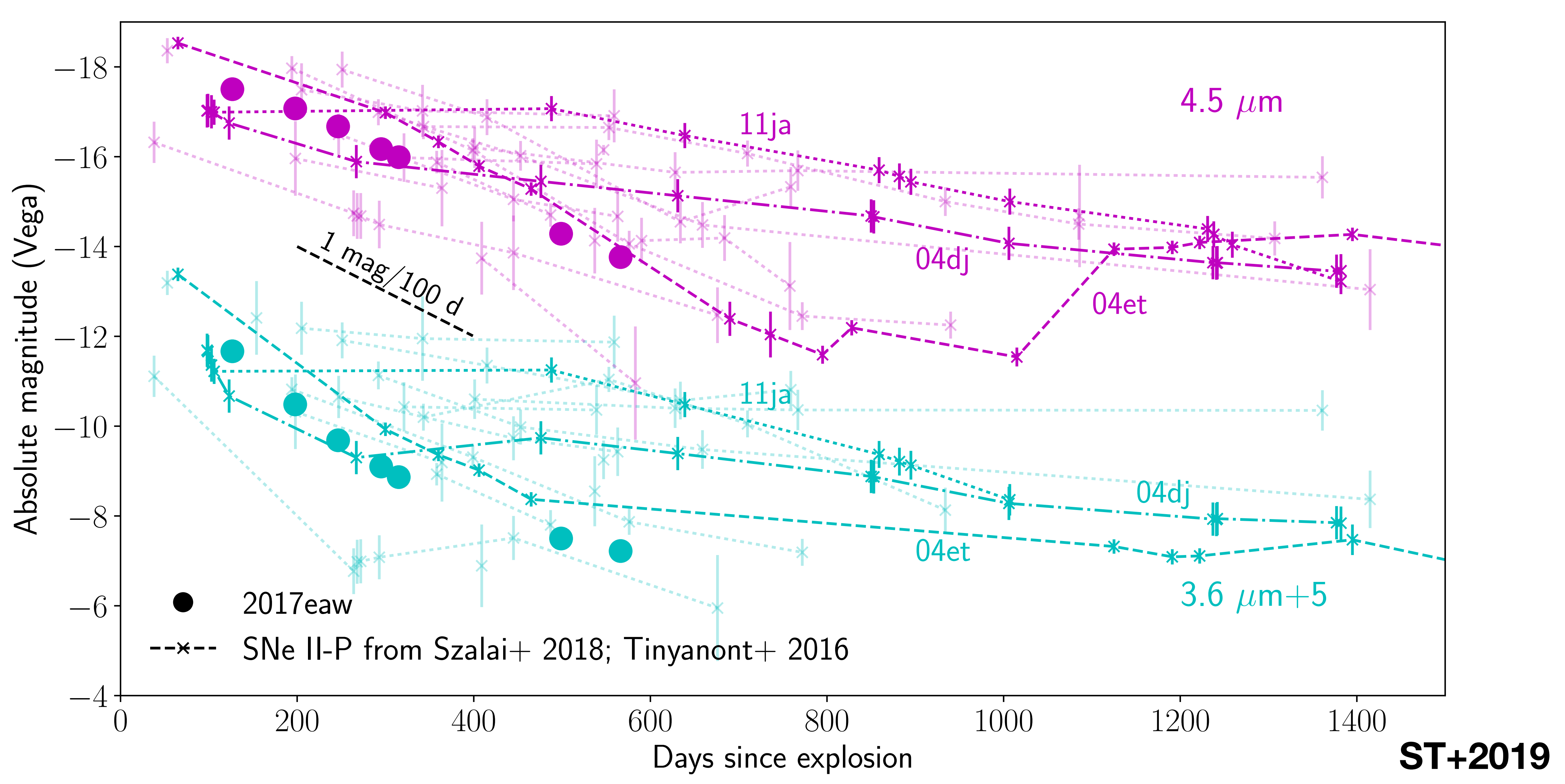
High-velocity helium: CSM interaction





Chugai+2007

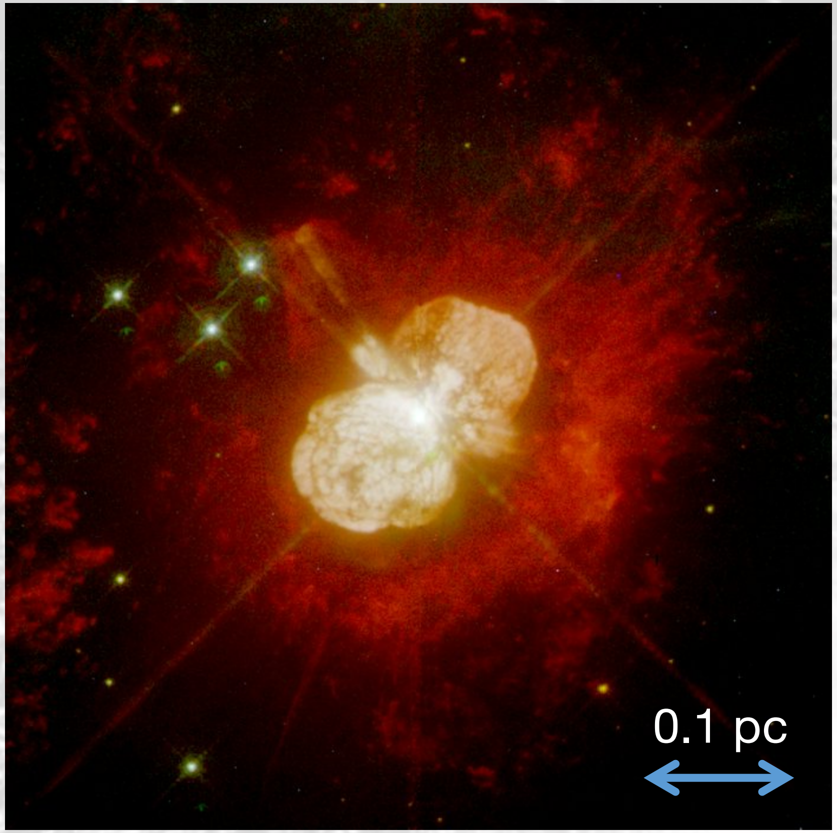
SN 2017eaw's upcoming interaction?



ST+2019

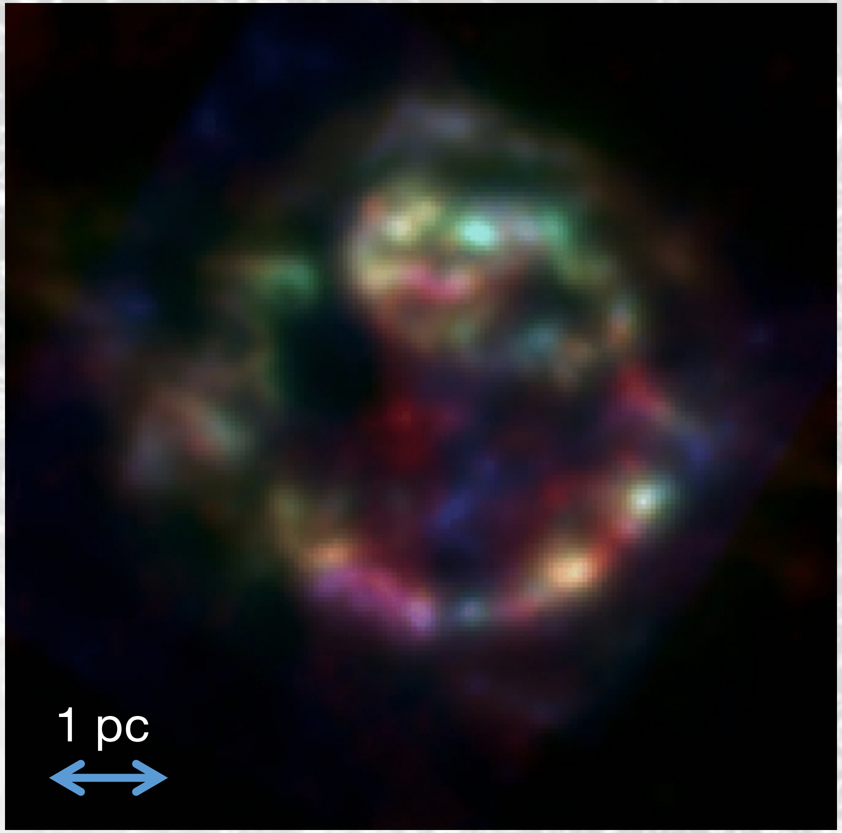
Massive star's legacy

Mass loss and circumstellar materials (CSM)



η Car (Luminous Blue Variable)
HST, J. Hester

Molecule and dust formation in supernova (SN) ejecta

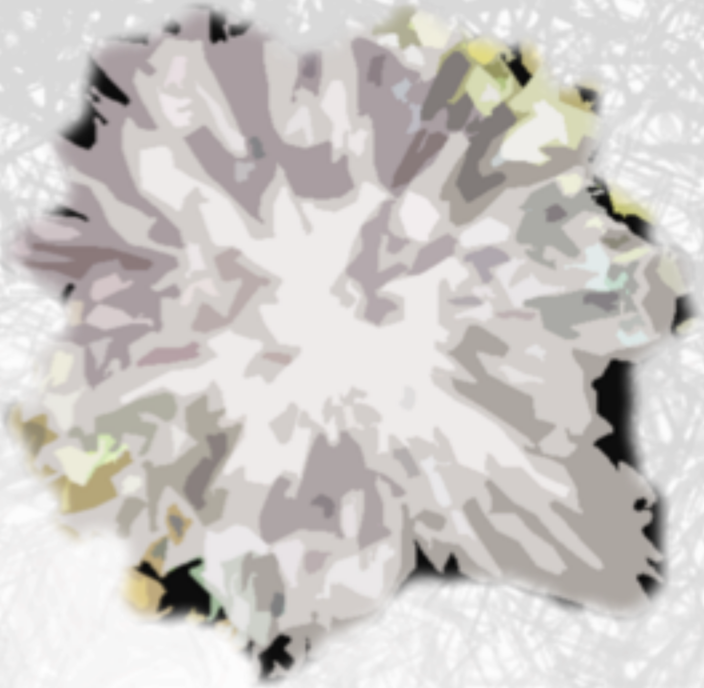


Cassiopeia A (SN remnant)
Herschel dust continuum, Arendt+ 2014

Textbook massive star evolution

Blue star
$M > 8\ M_\odot$

Red Supergiant



Core-collapse supernova

Supernova remnant