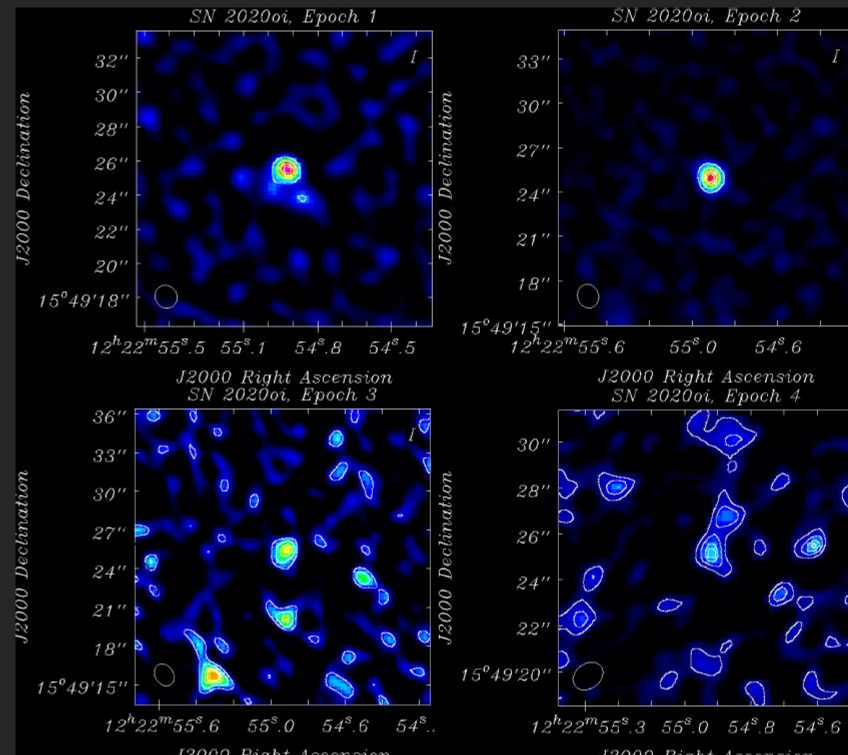
超新星イジェクタ・星周物質衝突の痕跡から探る大質量星終末期進化の性質とその多様性

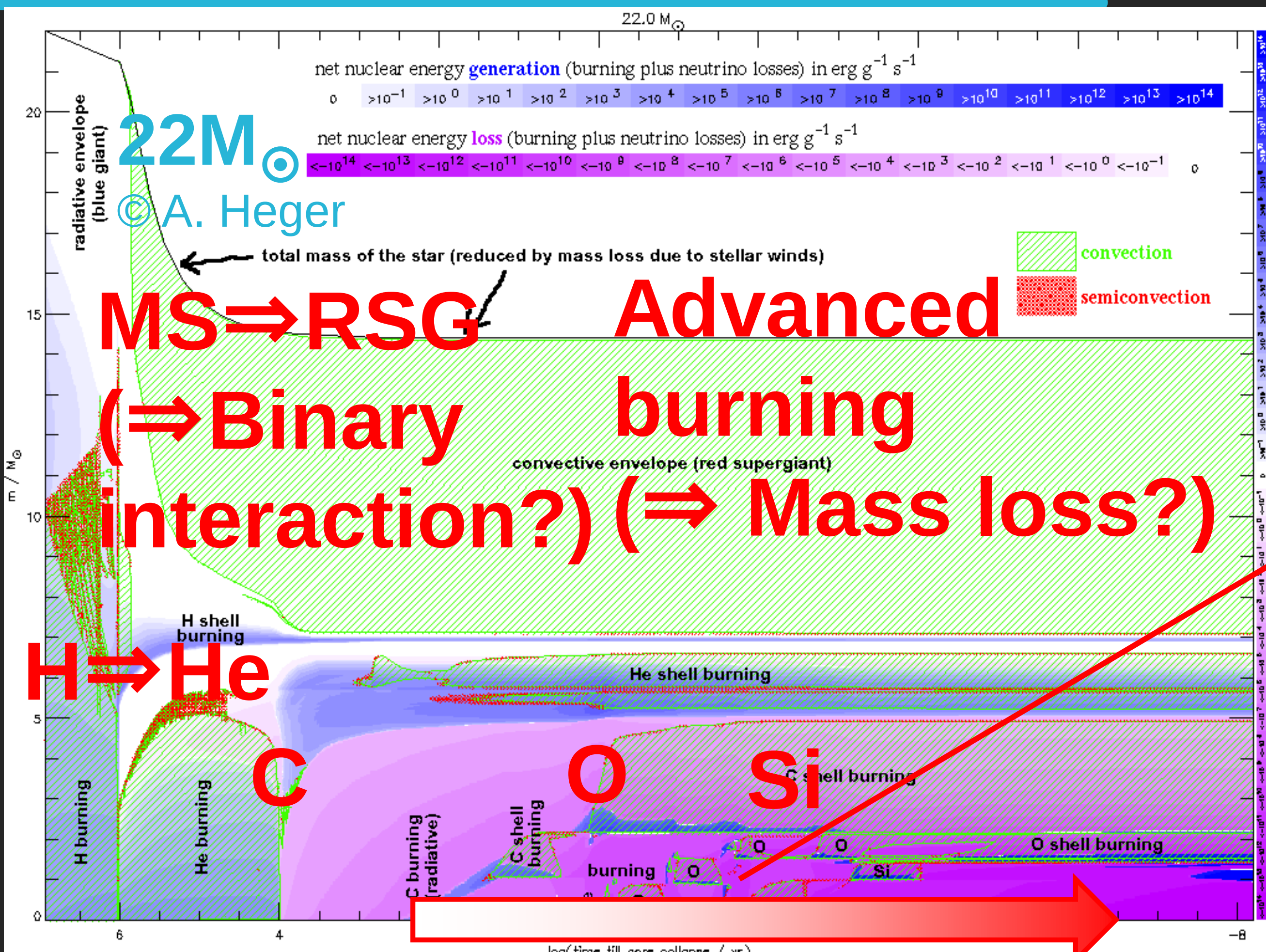


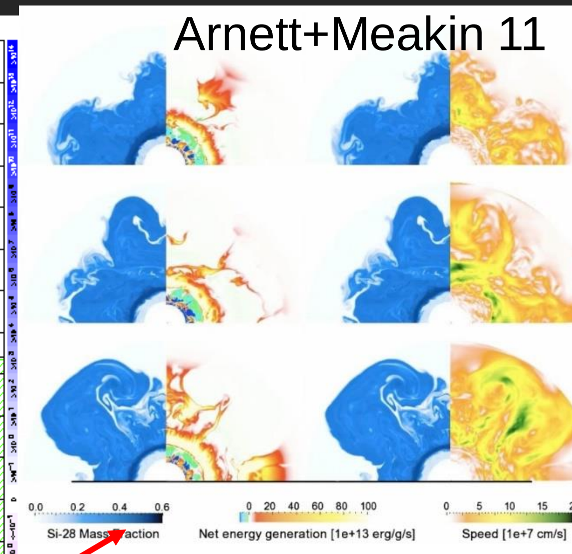
Keiichi Maeda（Kyoto University）

YITP WS on Extreme Outflows in Astrophysical Transients

August 23-27, 2021

Massive stars in the final phase: unresolved





Uncertain both in theory and observations

10^6 10^4 100 1 yr 1 day Supernova (SN)

Confined CSM?

“**Flash** spectroscopy” within a day to a few days of explosion. Recombination from the massive CSM near the SN???

→ New probe of CSM (Circumstellar Medium).

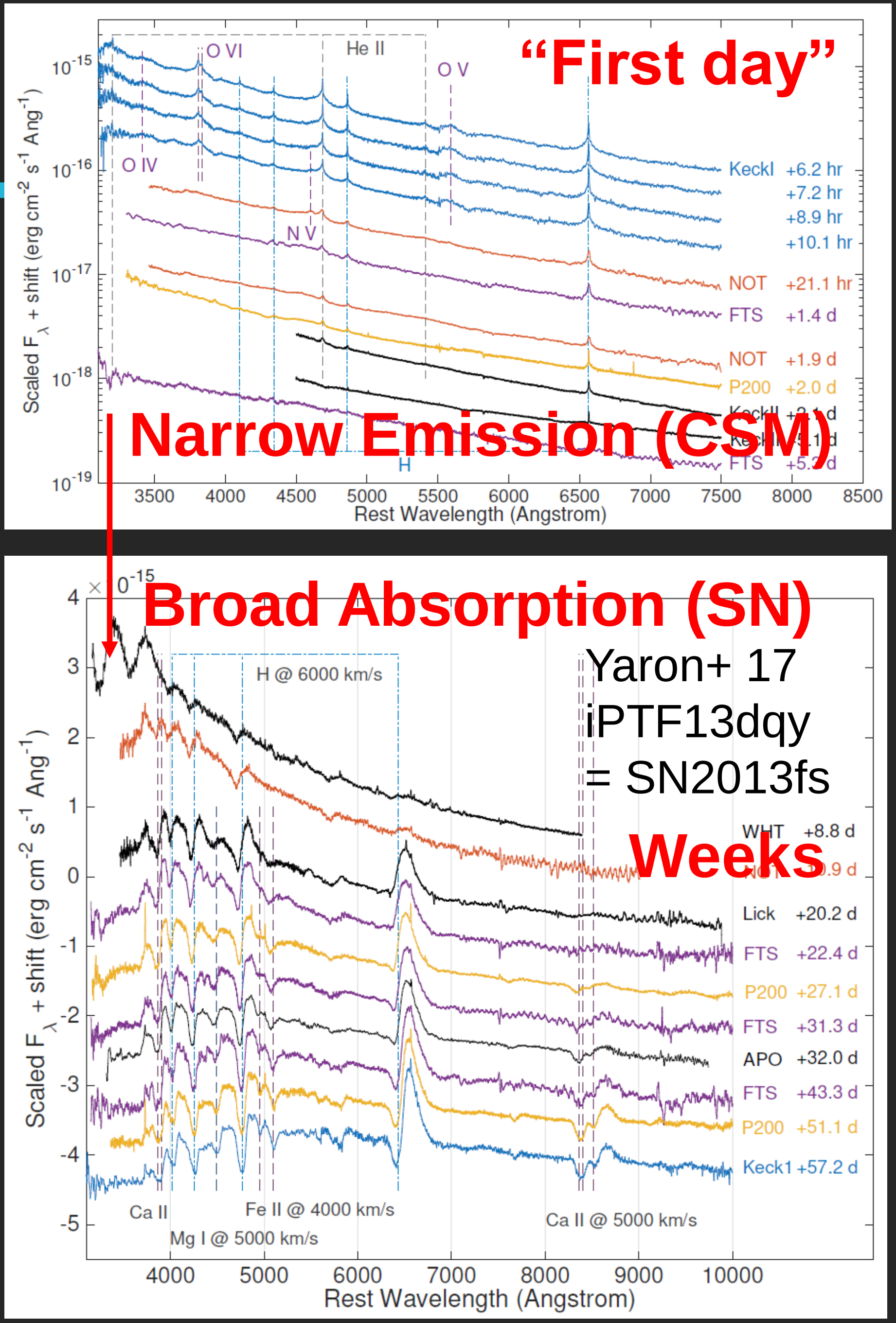
CSM @ <10^{15}cm:

Mass loss in the final phase.

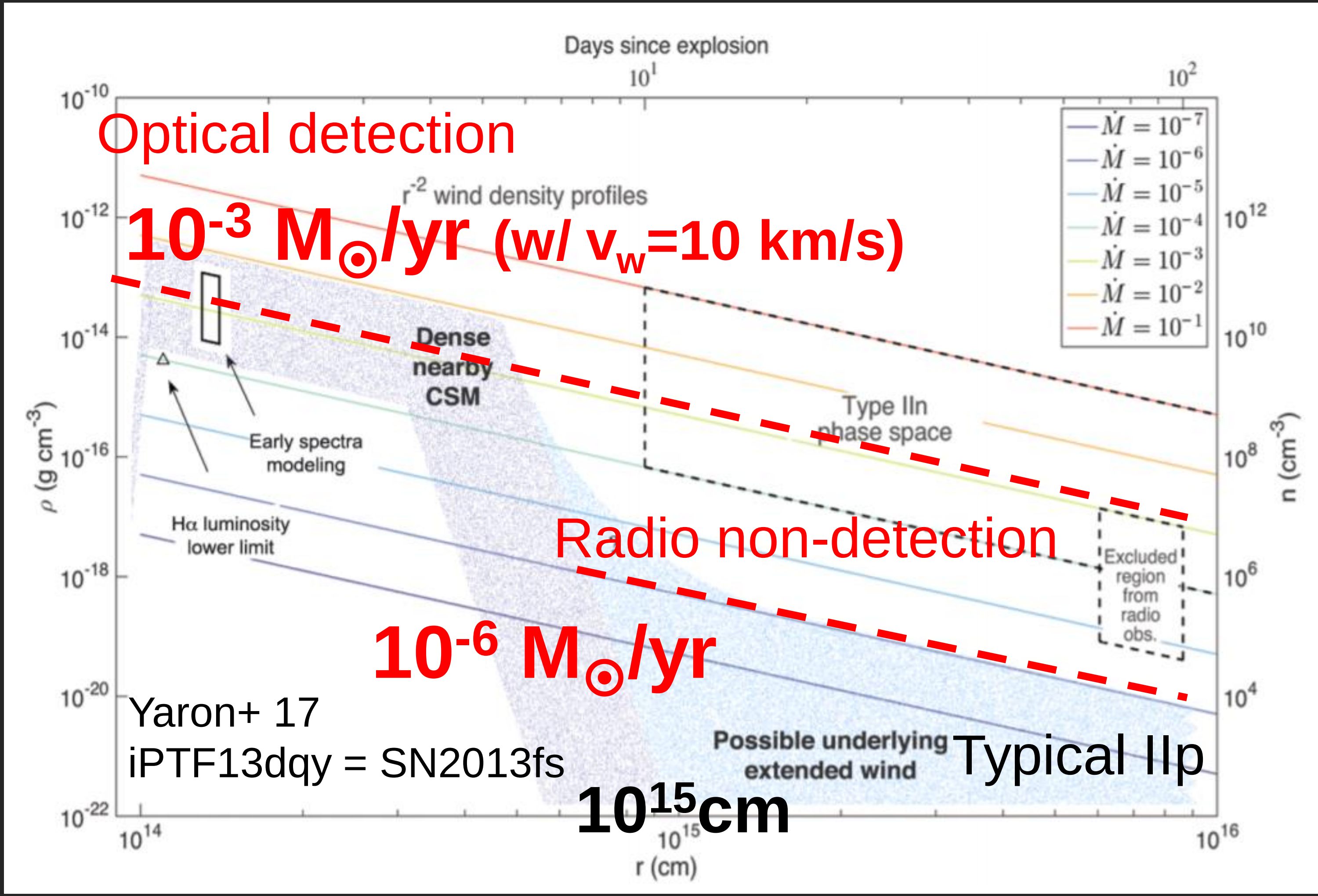
If v_w ~ 10 km/s, ~ 30 yrs.

If v_w ~ 1000 km/s, < 1 yr.

v_w = mass-loss velocity from the progenitor star.



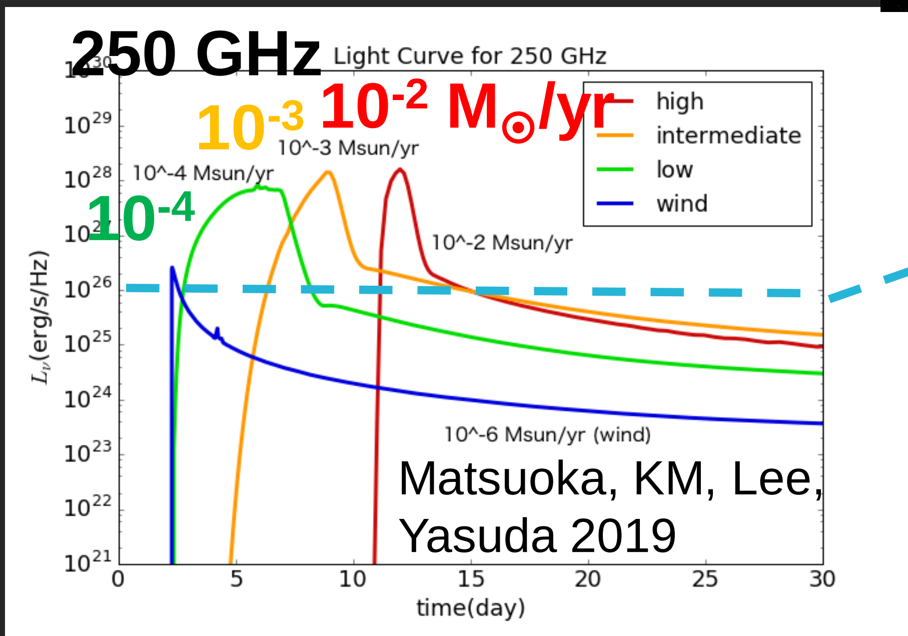
Mass loss in the final days to decades (< 10^{15}cm)

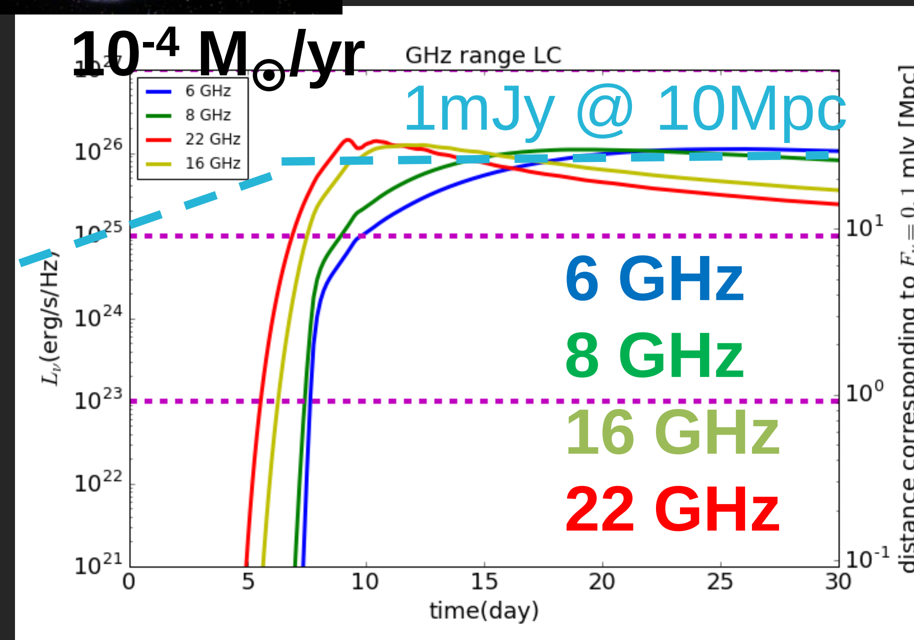


Dense CSM within 10^{15}cm (Type II SN = RSG progenitor)

Radio (High freq.) within 10 days of SN

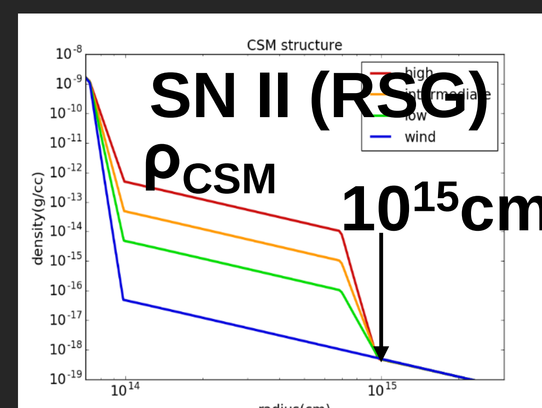
SN-CSM interaction
⇒ Synchrotron





Issues in the "optical" diagnostics:

- Interpretation complicated.
- Bias toward the dense(st) CSM.
- Probable bias toward SNe II (RSG).



Radio overwhelms these difficulties:
ALMA cycles 5-7 (KM+) + ATCA/GMRT

100 + 250 GHz to detect the optically thin emission.

Going closer to the moment of explosion

CSM @ <10^{15}cm (first 10 days):

Mass loss in the final phase.

If v_w ~ 10 km/s, ~ 30 yrs.

If v_w ~ 1000 km/s, < 1 yr.

But CSM density $\times$0.01: For 10^{-3} $M_\odot$/yr,
Kin. power ~ 10^{43} erg/s (v_w = 10 km/s) but 10^{41} erg/s (1000 km/s).
τ (100 keV) ~1 (v_w = 10 km/s) but 0.01 (v_w=1000 km/s) at 10^{14} cm.

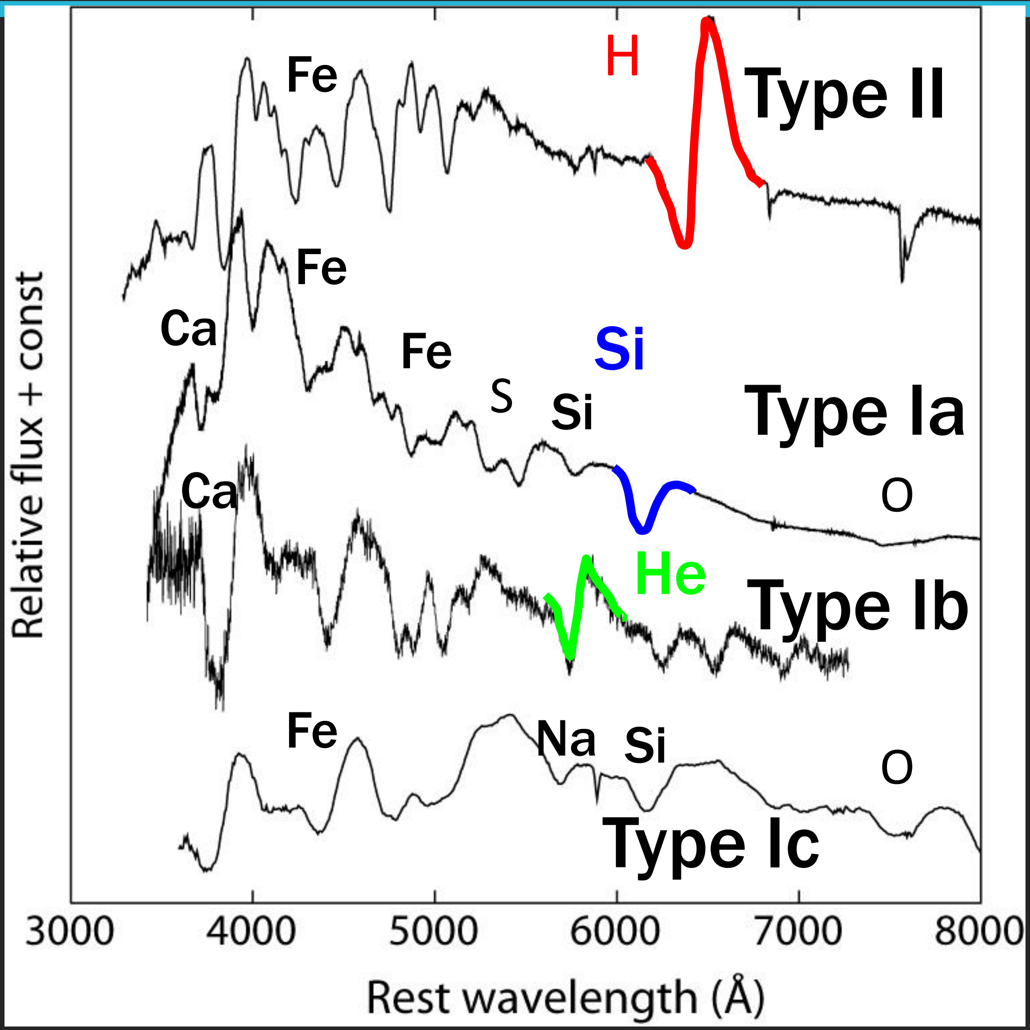
v_w=10 km/s

Synchrotron
+ (bright) optical

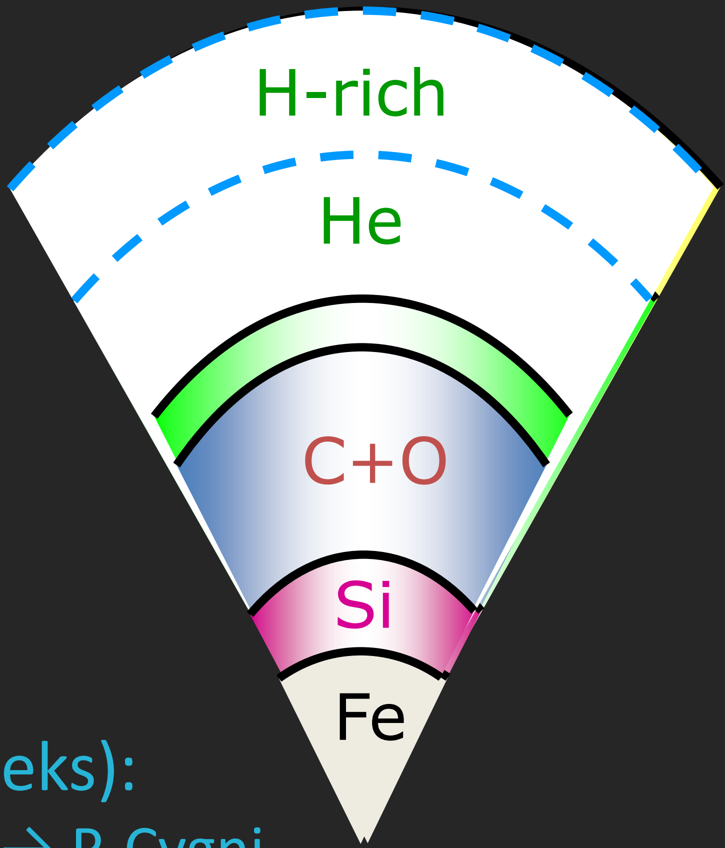
v_w=1000 km/s

Synchrotron
+ (faint) hard X
+ little trace in optical

Stripped-Envelope SNe (SESNe: SNe IIb/Ib/Ic)

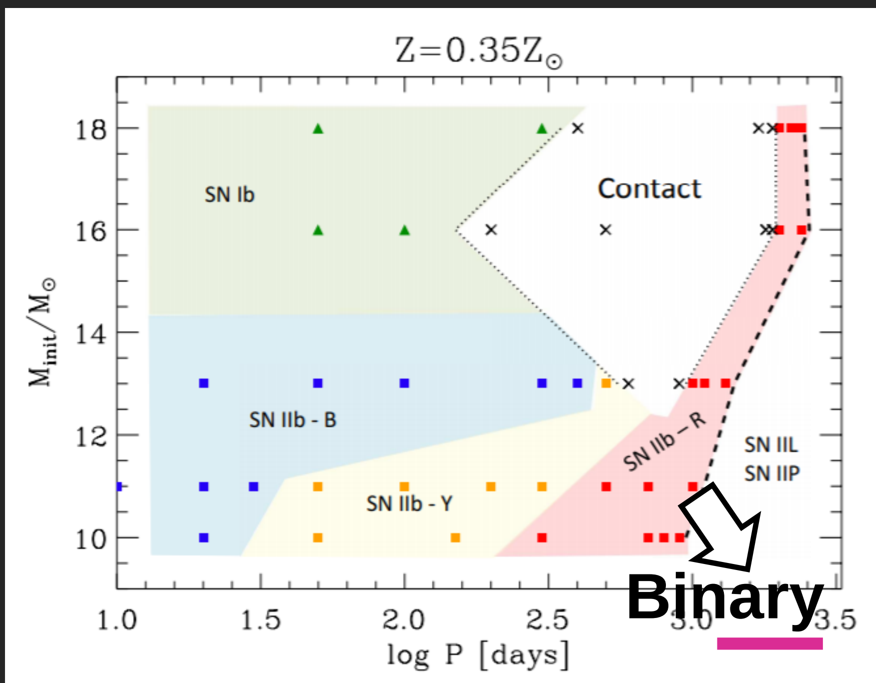


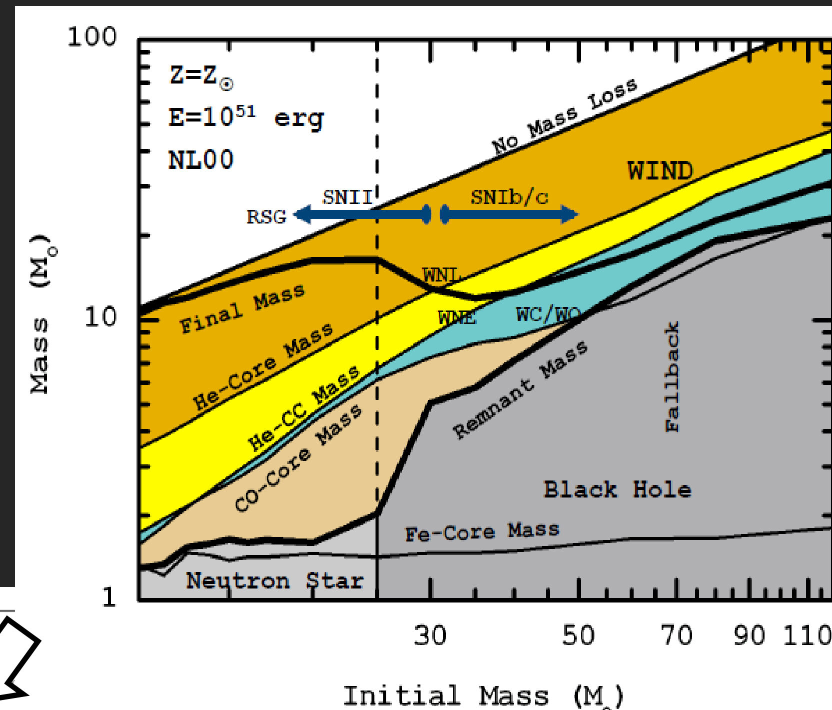
II (but for IIn)
Red Supergiant
IIb/Ib/Ic (Stripped Envelope SNe, SESNe)
Wolf-Rayet-like star

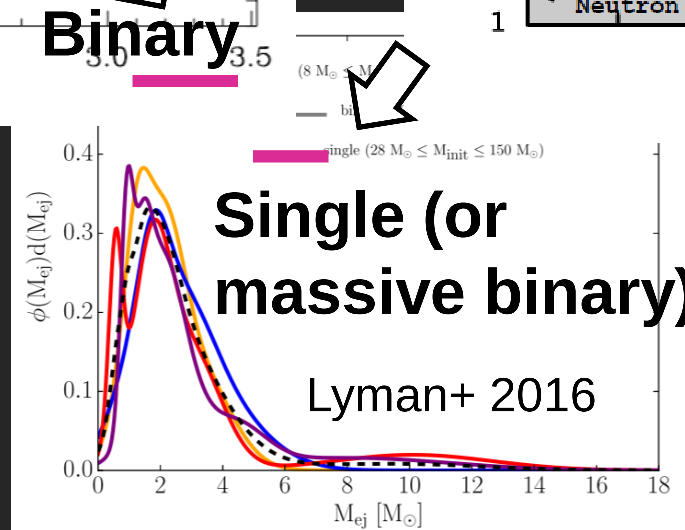


- @ maximum brightness (~ a few weeks):
  - Expanding optically thick medium → P-Cygni.

Evolution toward SESN progenitors?



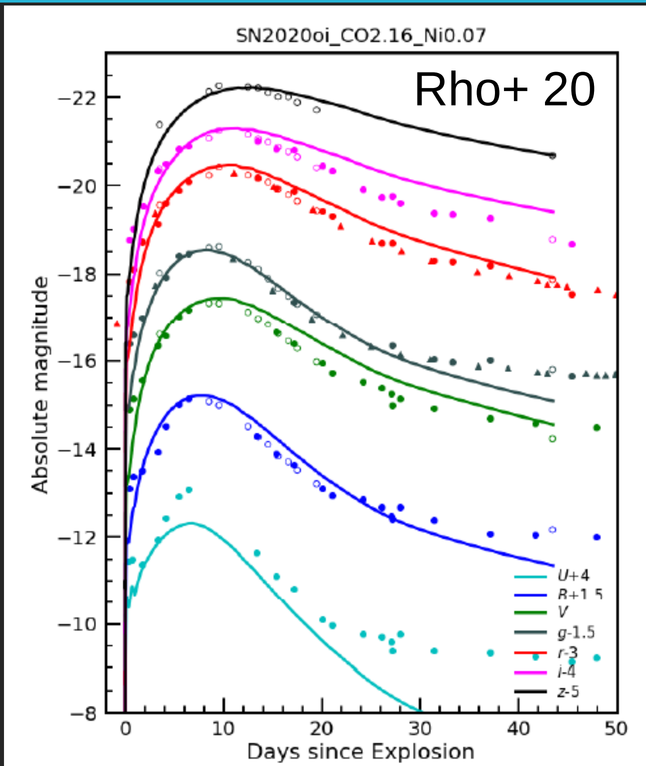


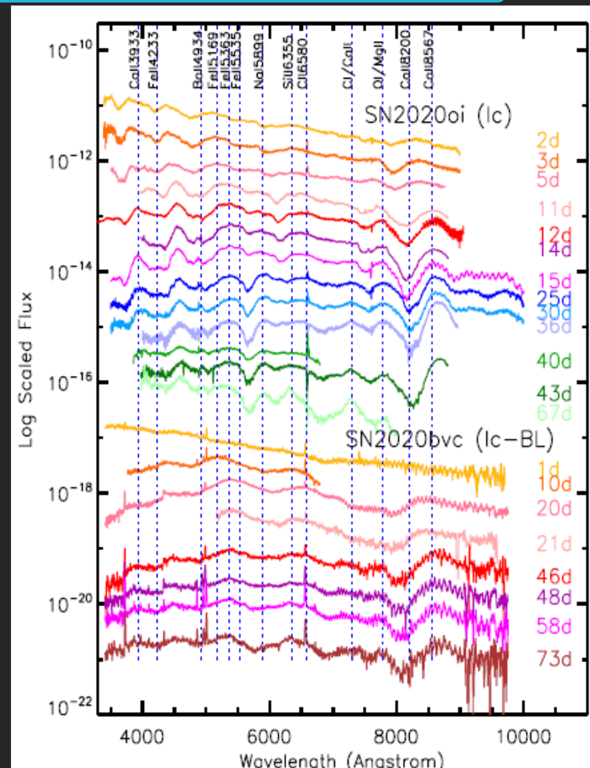


Normal SESNe are likely dominated by the binary evolution of $M_{ms} < 20M_{\odot}$

Progenitors: SESNe ~ SNe II Core evolution should be similar.

A nearby SN Ic 2020oi @ M100 (~ 14 Mpc)





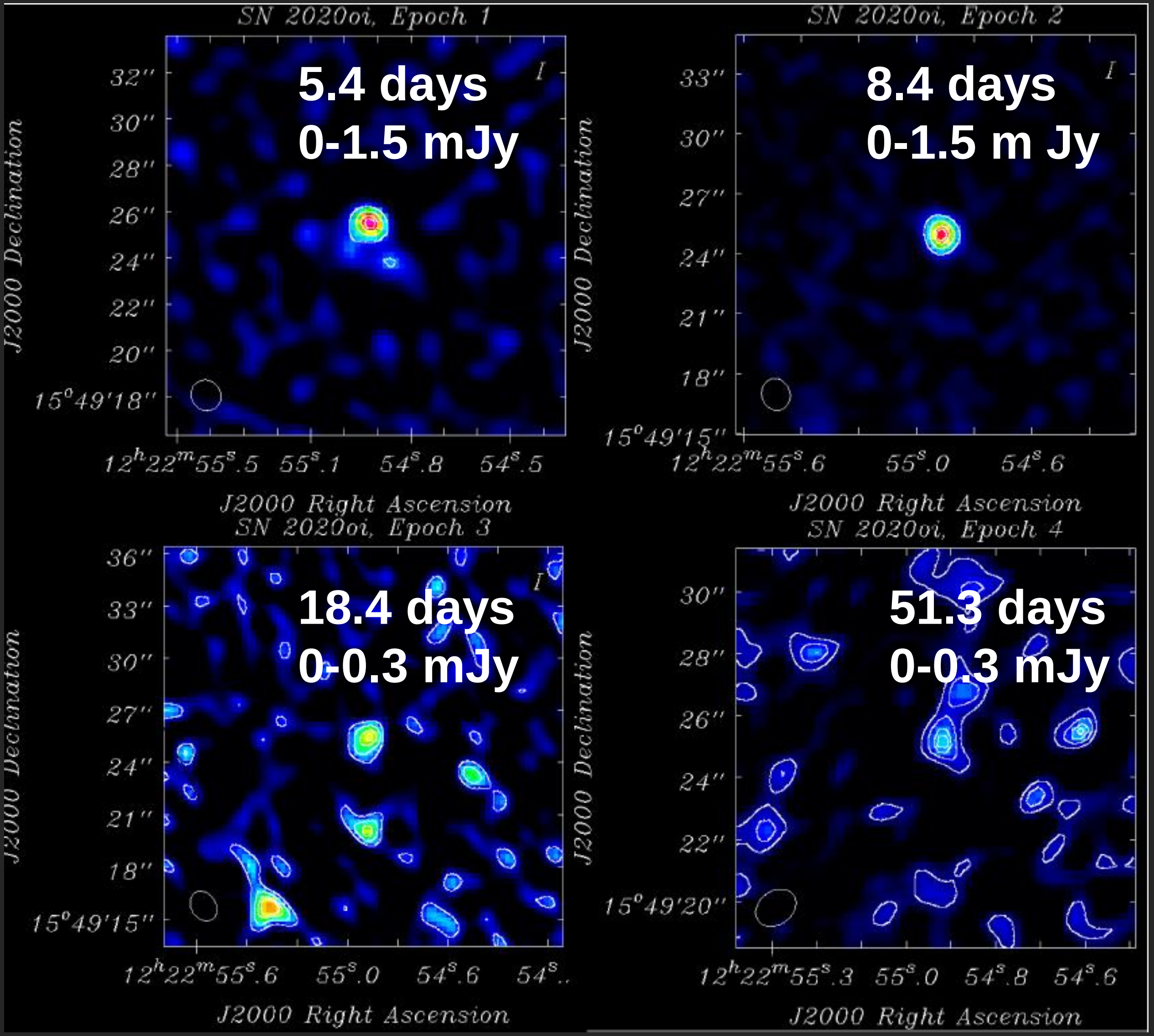
Discovery on 7 Jan 2020 @ ~ 1 day of explosion.

Discover within a few days of SN explosion is now common ⇒ quick follow-up possible. ALMA ToO triggered (@ 100 GHz).

SN Ic = Compact C+O star, v_w ~ 1000 km/s:

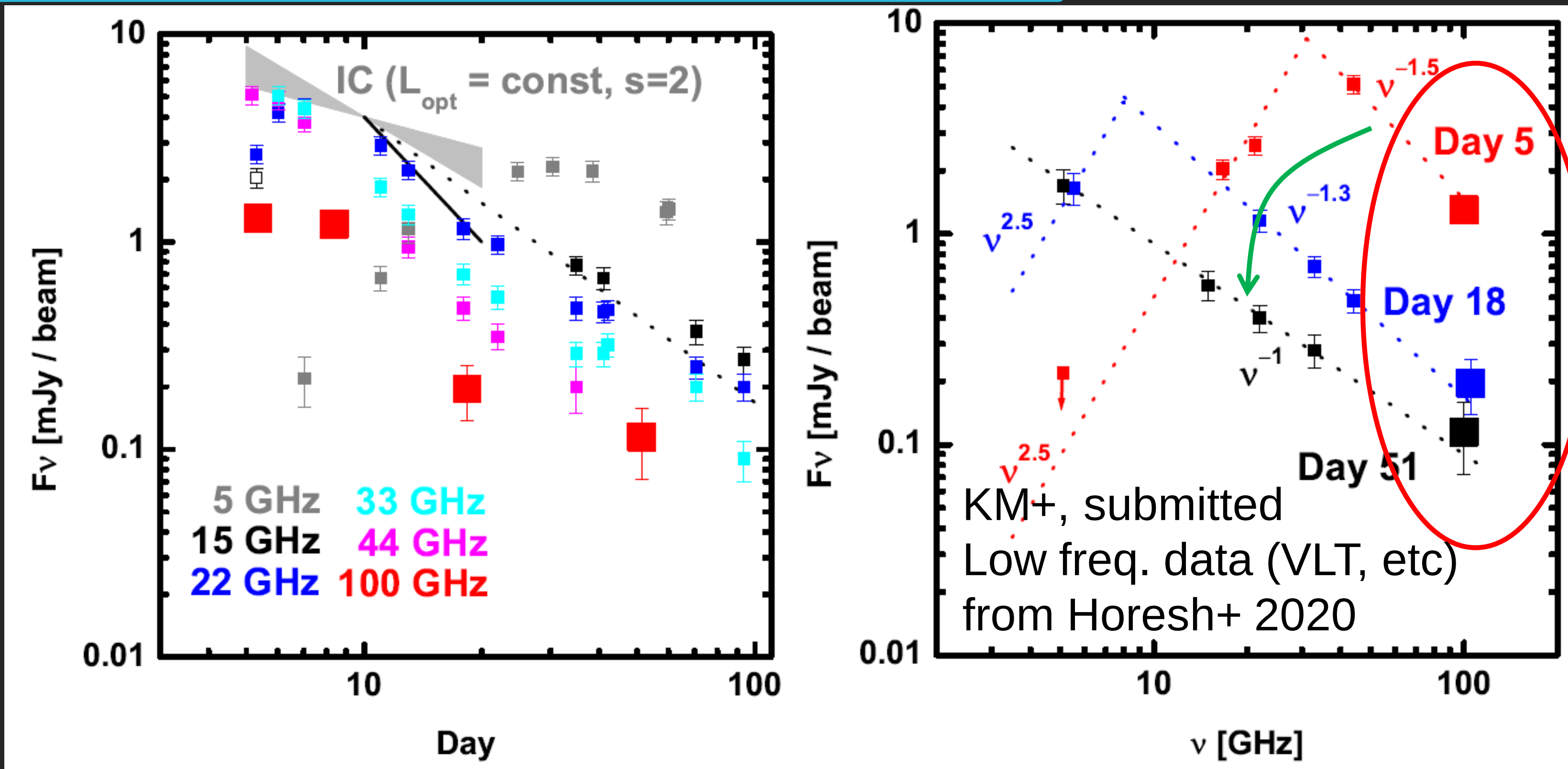
CSM @ < 10^{15}cm ⇒ mass loss @ <1 yr before SN.

ALMA ToO obs. at 100 GHz (band 3)



KM+, 2021

SN 2020oi in the optically thin limit



Optically thin @ 100 GHz from the beginning.

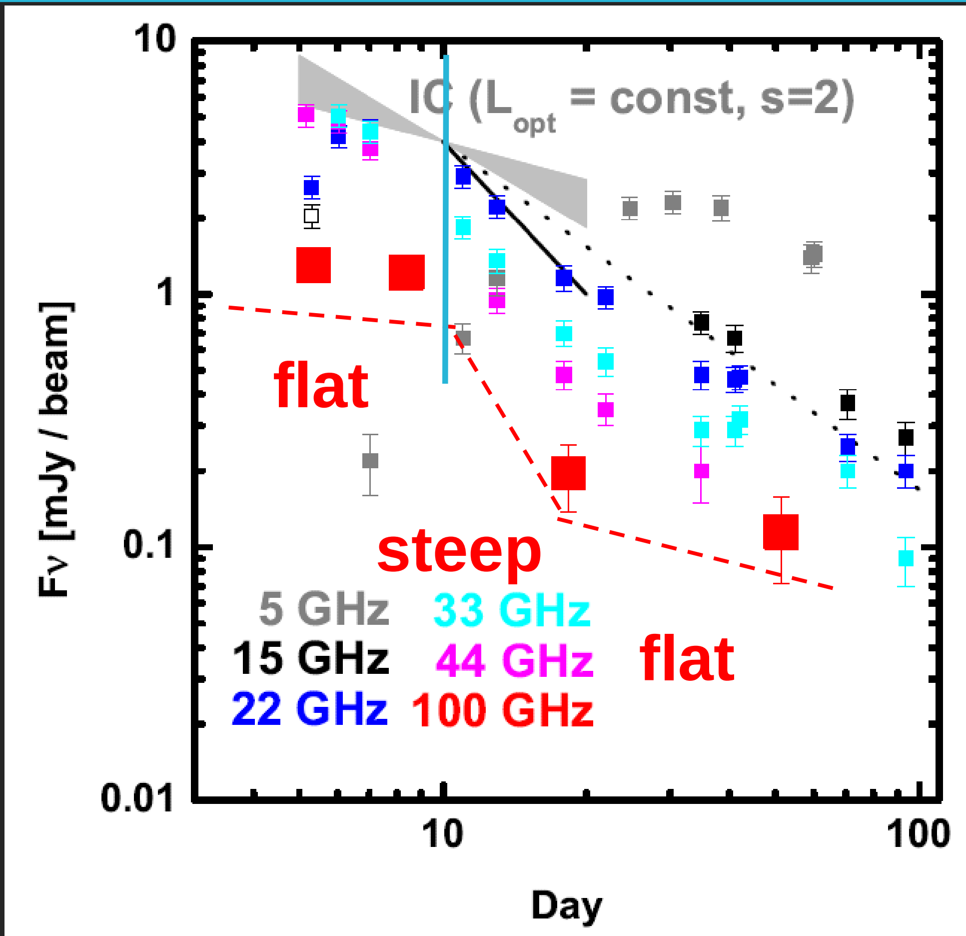
Spectral fattening: Inverse Compton (IC) cooling to adiabatic.

Optically thin & cooling effect well understood

⇒ reconstruction of the CSM density distribution.

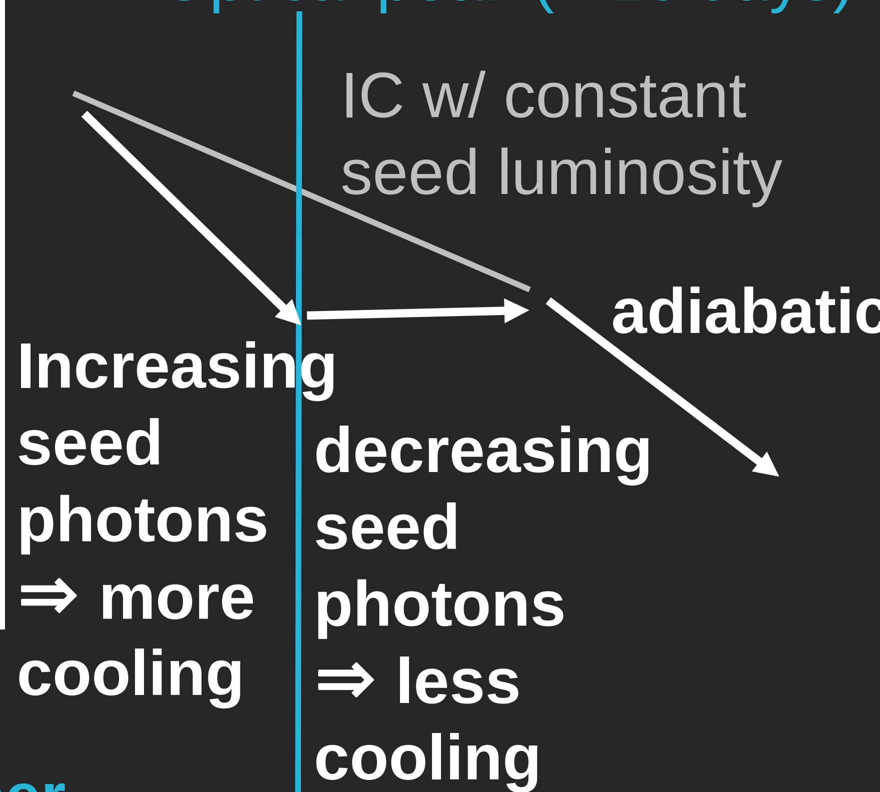
KM+ 2021

A need for the non-smooth CSM



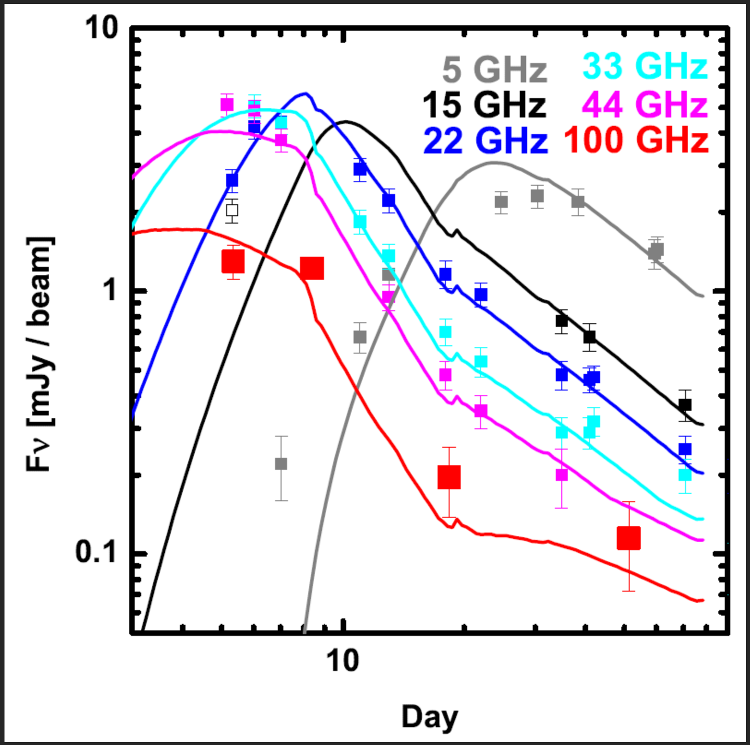
The prediction if the CSM is smooth (single power):
steep-flat-steep evolution.

Optical peak (~ 10 days)

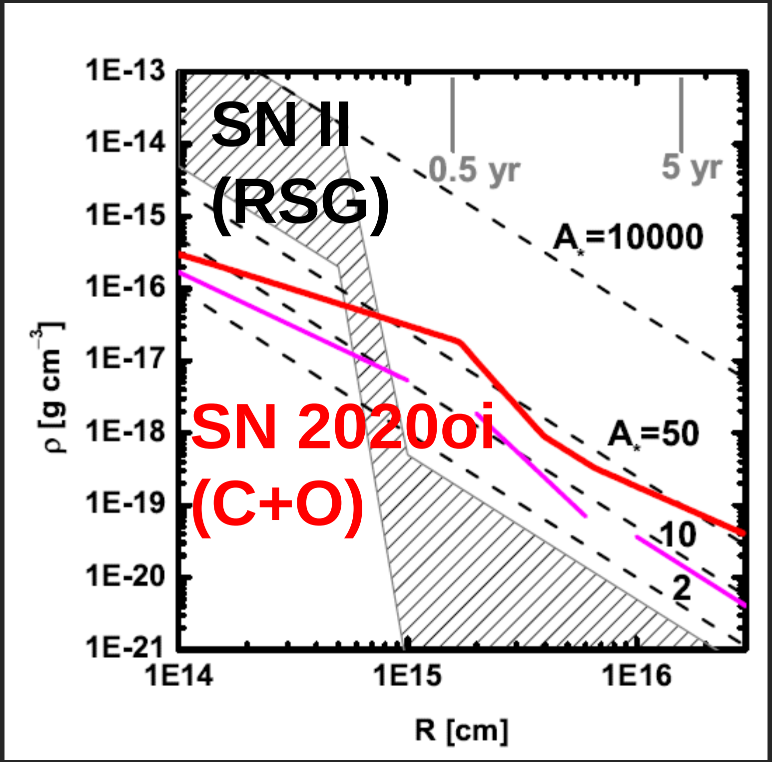


Inferred CSM structure:
flat – steep – flat from the inner.

Multi-band radio modeling



Derived CSM distribution



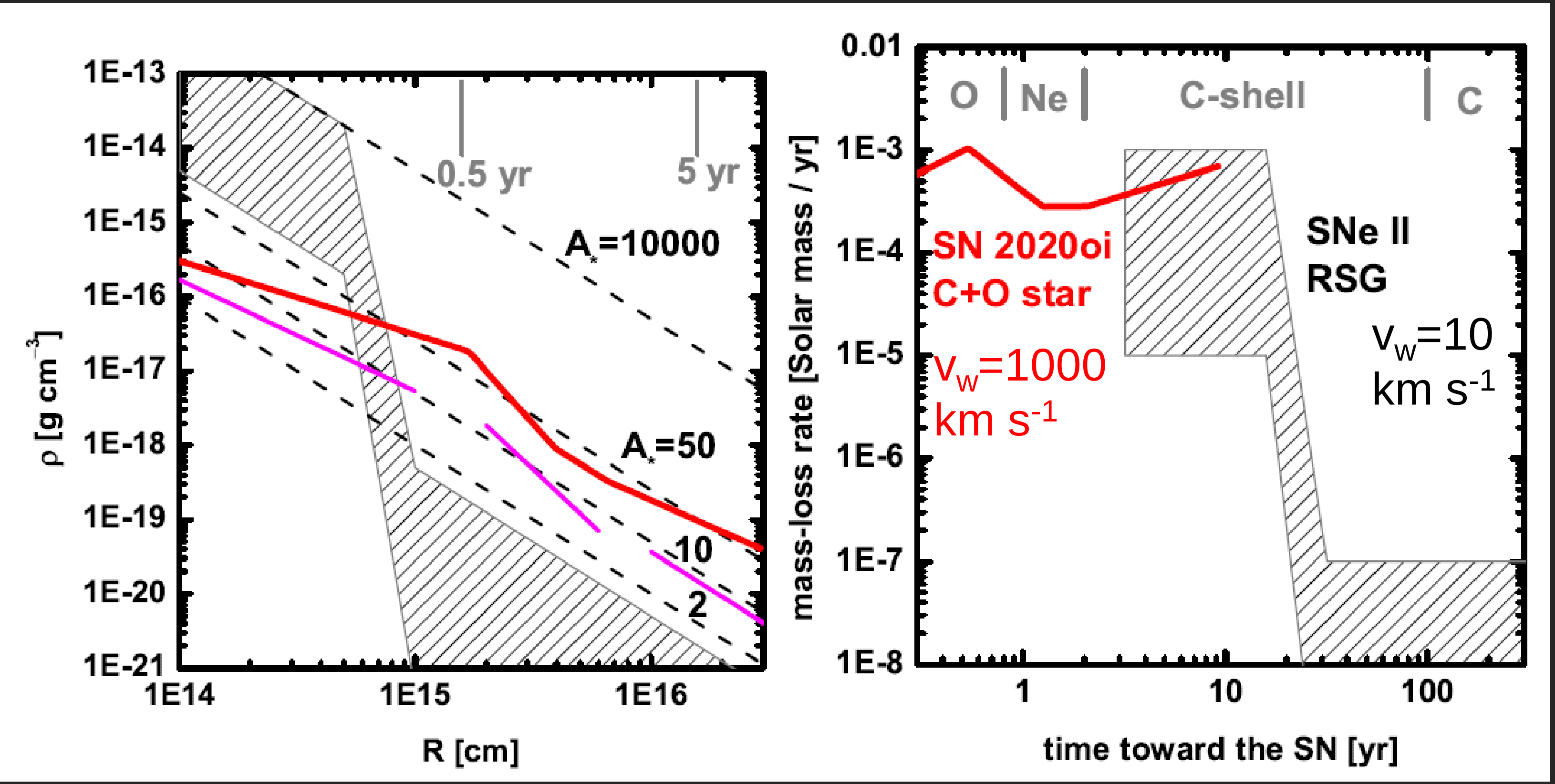
Enhancement of the CSM density @ ~ 10^{15} cm, but much less significant than seen in SNe II.

⇒ Should leave no trace in the optical.

The sub-year timescale variability toward the SN.

KM+ 2021

Implications for the final activity



Change in the mass-loss properties roughly coincident with the change in the nuclear burning stage.

The final activity driven by the increasing nuclear energy generation (+dynamical response)?

Summary

ALMA (+ VLA etc) observations of SN Ic 2020oi + theoretical interpretation and modeling:

The first case to trace the mass-loss property down to the final sub-year scale.

Nuclear burning as an origin of the final activity?

The slides on unpublished works are omitted here.
Contact KM for further discussion on these works.