中小口径望遠鏡による系外突発天体観測と多波長・多モード観測とのシナジー

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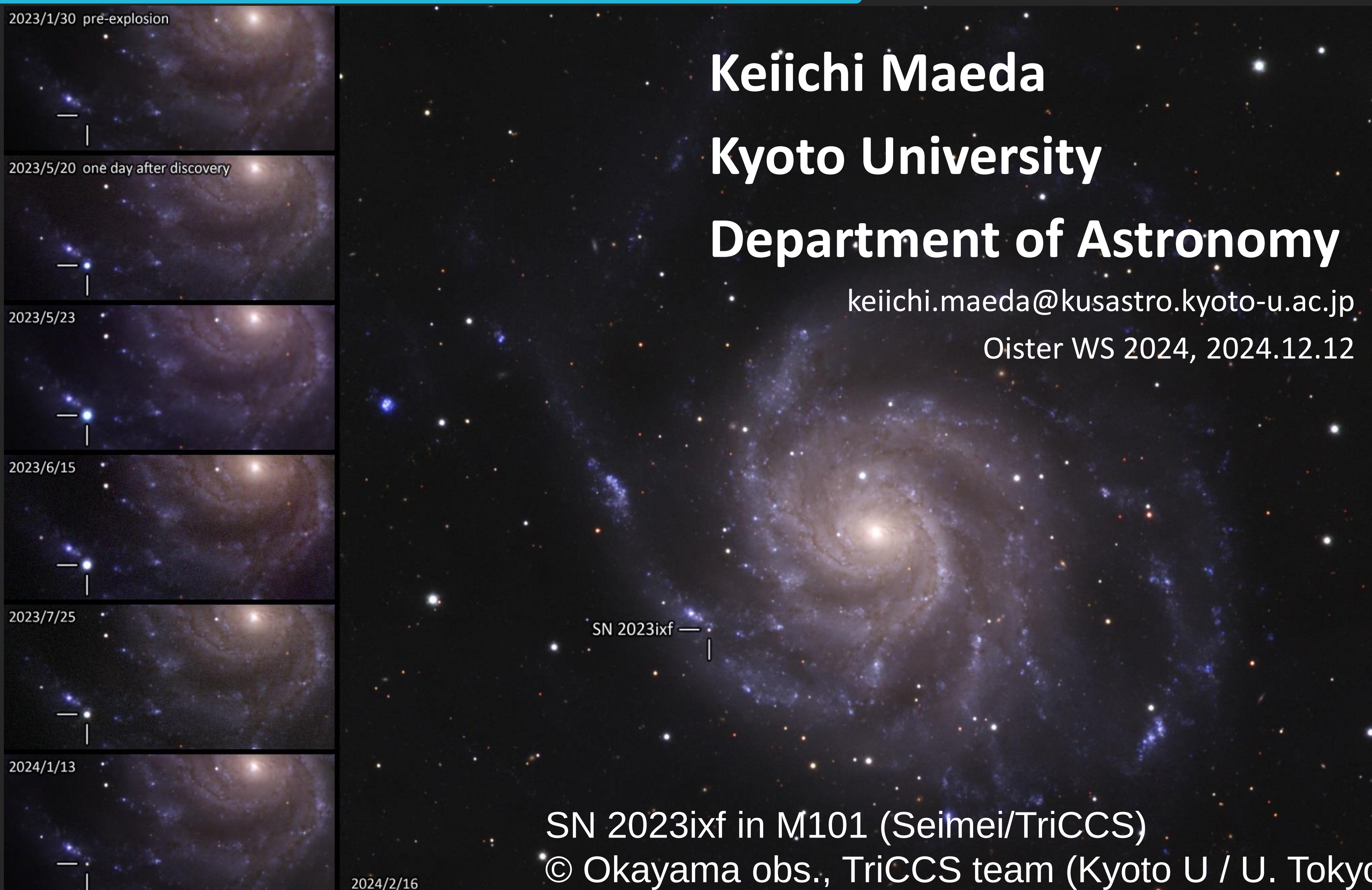
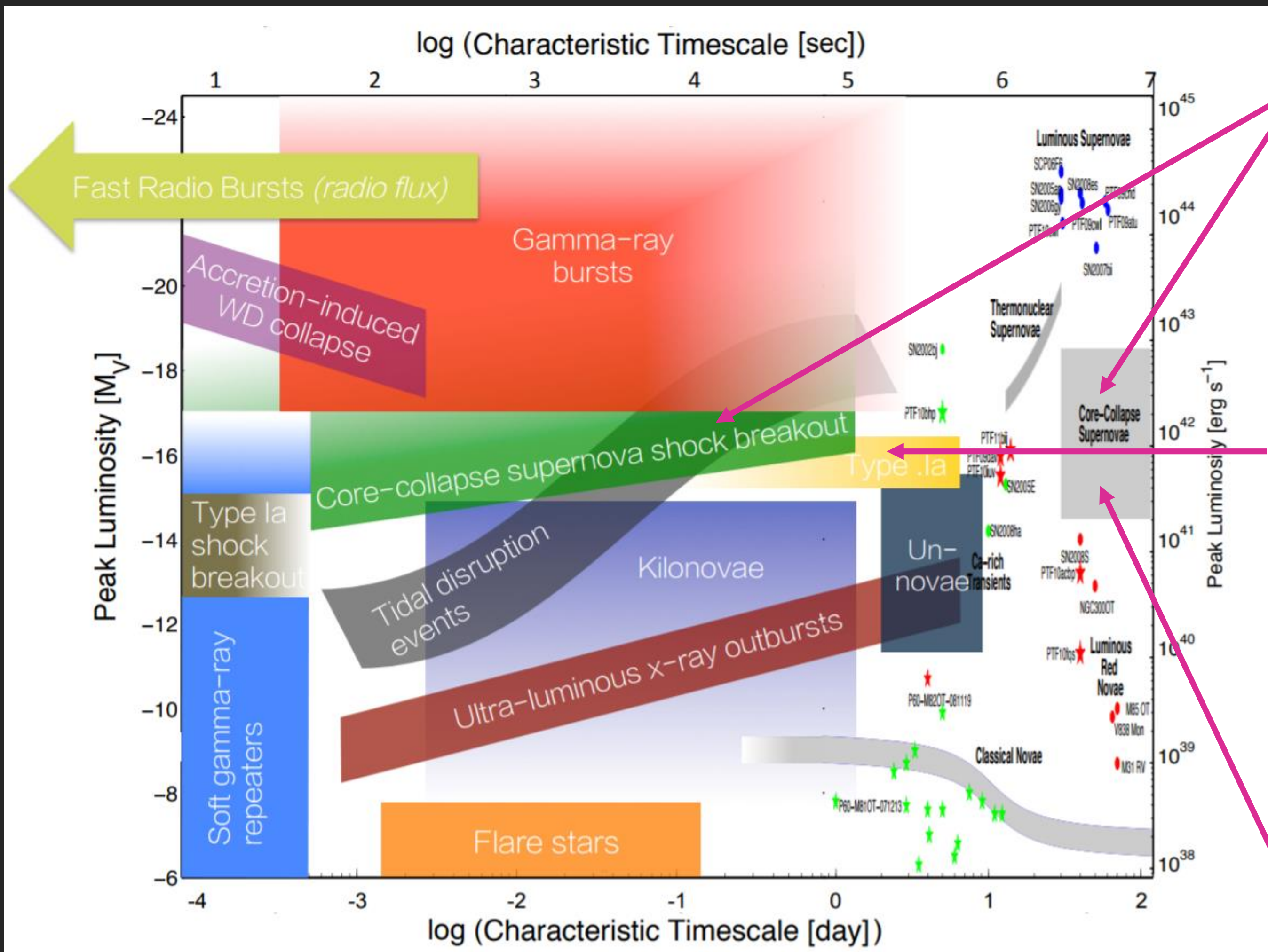
Oister WS 2024, 2024.12.12



SN 2023ixf in M101 (Seimei/TriCCS)

Frontiers in Transient Science



Cooke+ 2015

Higher cadence

Known transients, but from the beginning.

Unknown short-time scale objects.

Larger samples

Rare types of explosions.

New Time Domain Era

Survey	Depth (mag)	Area (deg²)	Cadence
BlackGEM	21.5	10,000	2 weeks
DES	23.5	5,000	1 week
KMTNet	~21	~6,000	1 day
MOA	~21	~1,000	1 day
TNTS	20.0	2,000	?
PTSS	20.5	4,000	1 day
HSC	25	800	1 day
Tomo-e	18/19	7,000	2 hr/1 day
ZTF	21	23,000	3 days
	21	2,000	1 day
	21	6,000	2 hr
ASAS-SN	17	40,000	1 day
DLT40	20	600 gal	1 dat

M. Tanaka

Ongoing surveys
+ Rubin/LSST to come

Catch transients/SNe even in the first day.

Discover rapidly-evolving transients/SNe.

Find unprecedented evolution (w/ monitoring).

SNe = Supernovae

Rapid follow-up observations as a key

- The survey information is very limited (only photometry, 1 or 2 bands in the optical).
- Need multi-bands, spec, multi-frequency, …

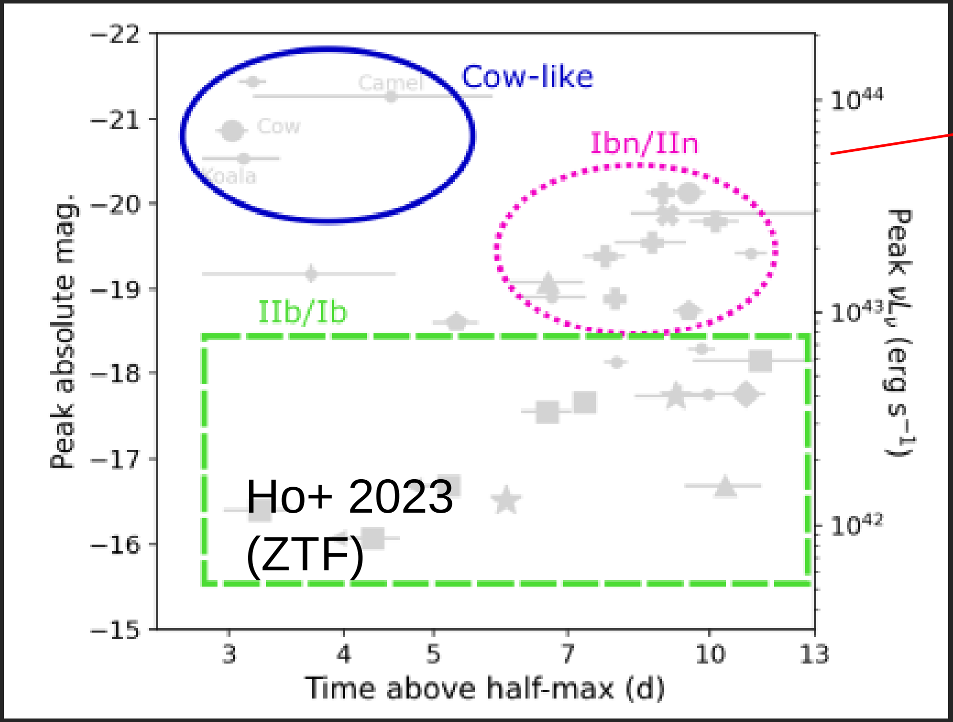
  ⇒ Need global collaborations.
- Our effort/contribution:
  - Model/interpretation.
  - Communication w/ surveys: Tomo-e, ZTF, WFST, …
  - Optical/NIR.
    - Seimei & Kanata telescopes as a "heavy user".
    - Subaru and Gemini telescopes through open-use slots.
    - Regular collaborations w/ Finnish & Indian groups.
    - Case-by-case collaborations w/ various groups.
  - Radio & X-rays.
    - ALMA as a PI; VLA, ATCA, GMRT, JVN, SWIFT, etc. as a Co-I.

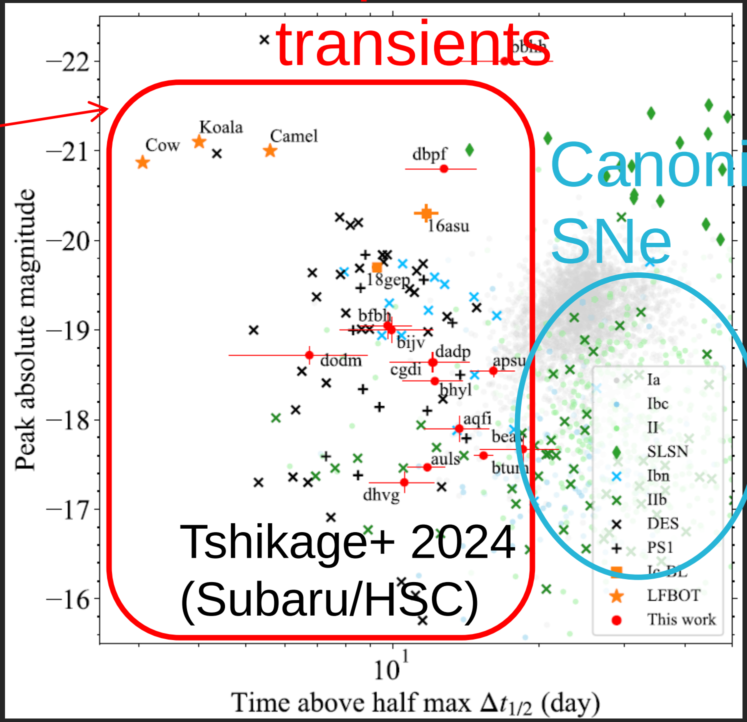
Topics (just a few among many)

- Power of multi-wavelength observation (example):
  - (H-poor) CSM-Interacting supernovae (SNe Ibn/Icn).

- Quick introduction for multi-mode (examples):
  - Luminous Fast-and-Blue Optical Transients (LFBOTs).
  - Tidal Disruption events.

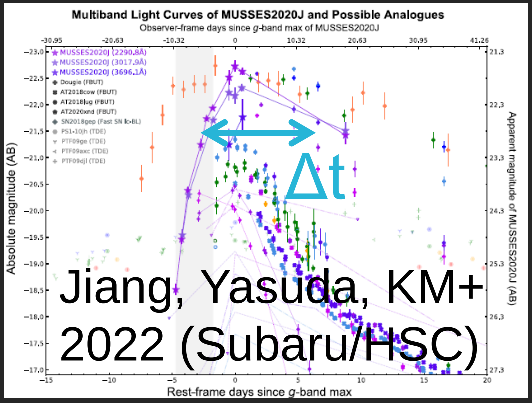
Rapidly-evolving transients





Newly discovered population(s) thanks to high-cadence surveys + rapid follow-up

- ○ faint IIb/Ib (c.f., prediction: Ouchi, KM+ 2021)
- ○ (H-poor) interacting SNe (IIn/Ibn/Icn, …)
- ○ Luminous-Fast-Optical-Transients (LFBOTs)



Mass loss as a key process:
A probe to (challenge for) stellar evolution theory

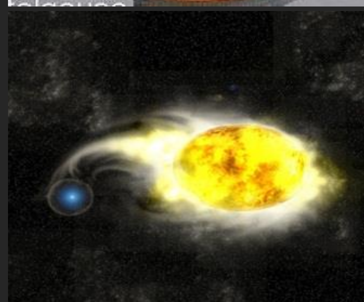
Progenitor

Mass loss

Main issue:
Progenitor evolution, mapping stars ⇔ SNe

IIP/L

RSG



YSG

IIb

BSG

WR

Ib

Ic

Decreasing radius

More CSM (where?)

Dense CSM in the vicinity

IIn

LBV?
CE?

Mass stripping sequence

Single star or binary?

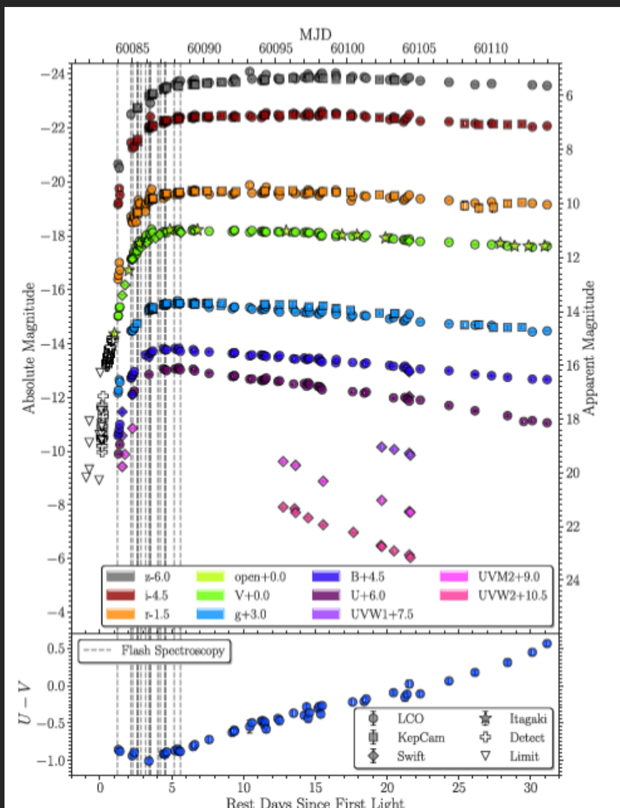
Timing?

Mass-loss mechanisms?

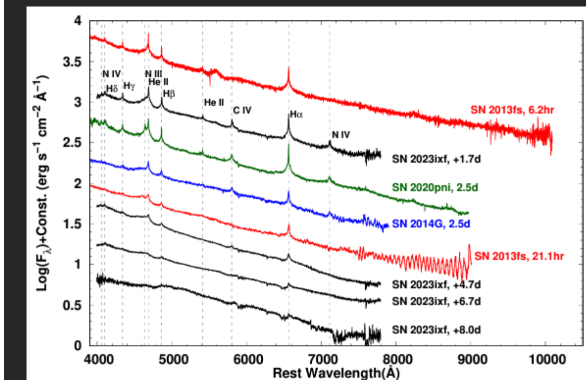
CSM – where and how much?

Multi-wavelength key to probing the CSM

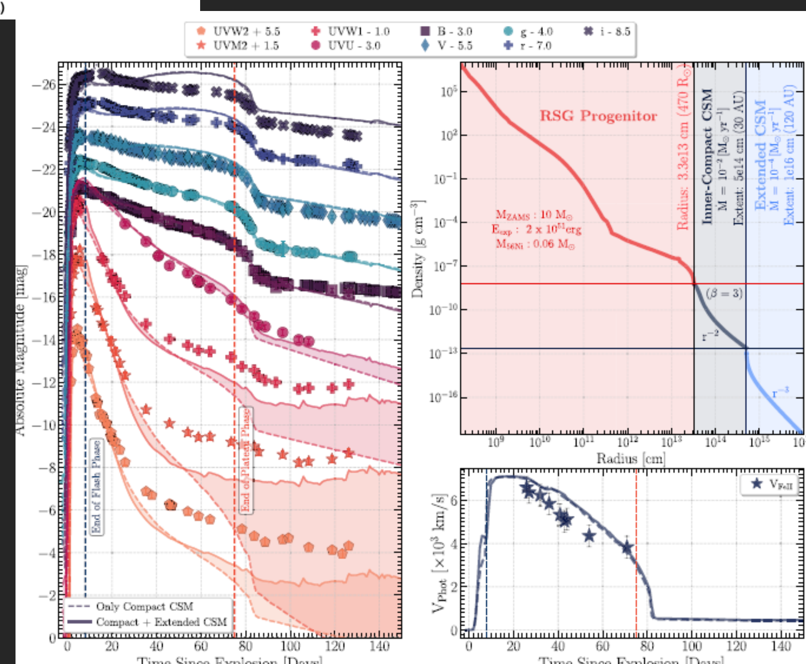
SN II 2023ixf as an example (M101, discovered by K. Itagaki)



Hiramatsu+ 2023 (LCO)



Yamanaka+ 2023



Singh+ 2024 (incl. Seimei)

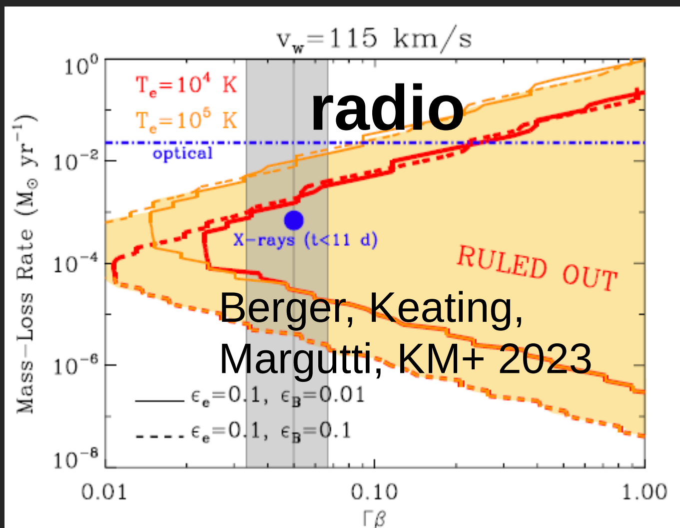
“Confined” CSM (<~10^{15}cm)

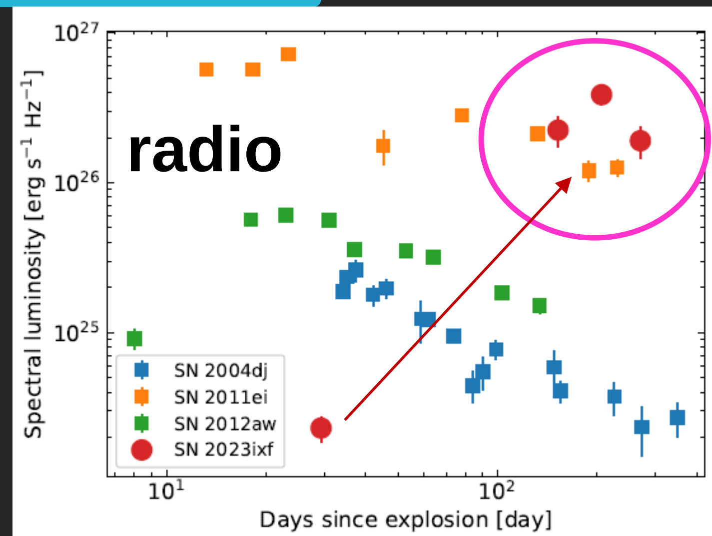
⇒“Final-decade” activity

SN 2023ixf as an example

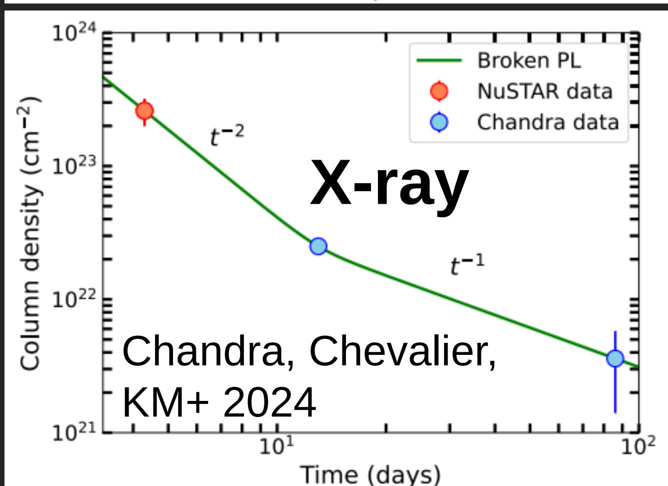
Multi-wavelength key to probing the CSM

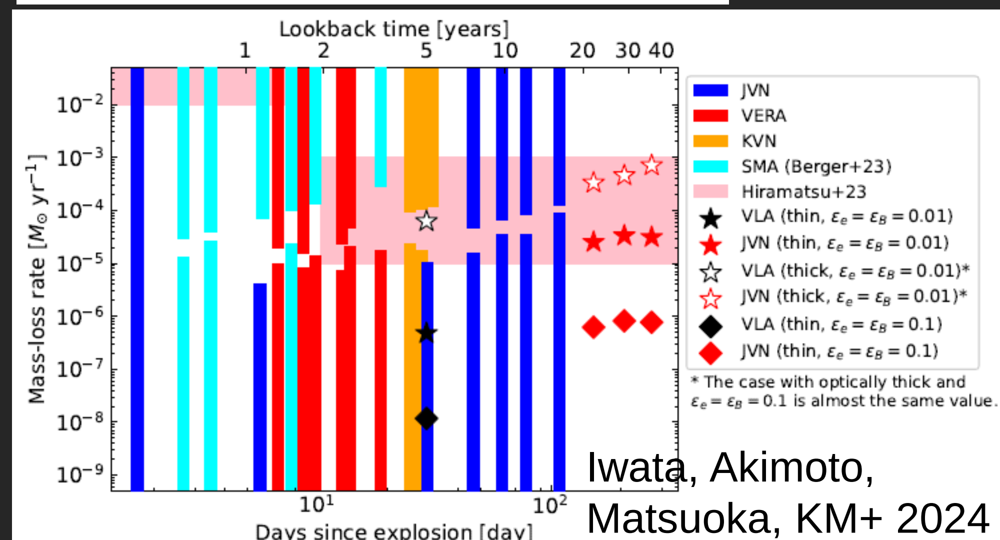
JVN detection





Delayed
→ dense
(outer) CSM





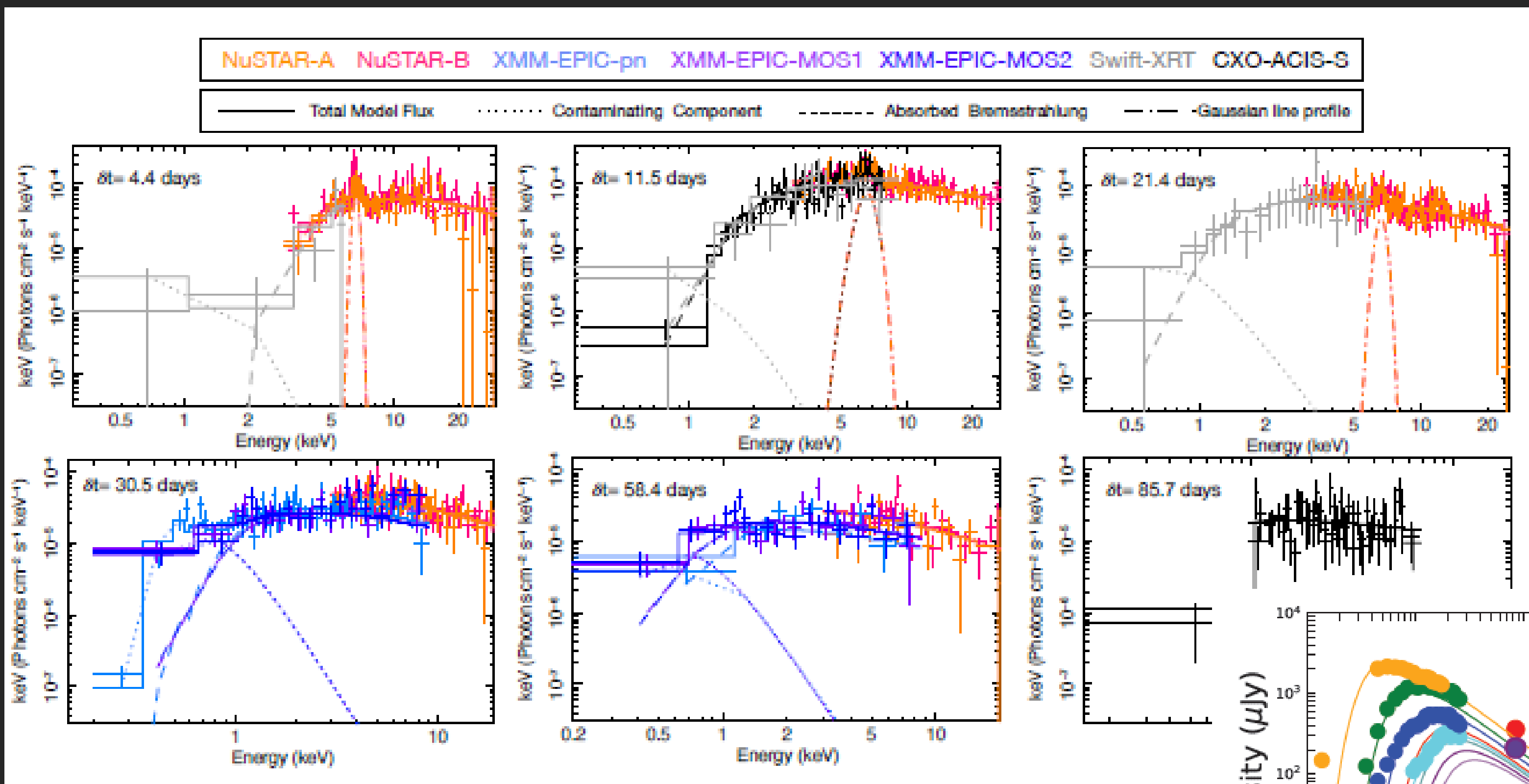
Confined CSM

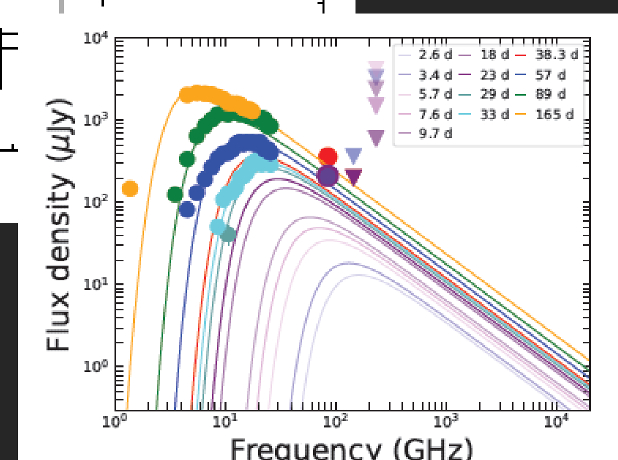
Consistent w/ Confined CSM + dense outer CSM

SN 2023ixf as an example

Multi-wavelength key to probing the CSM

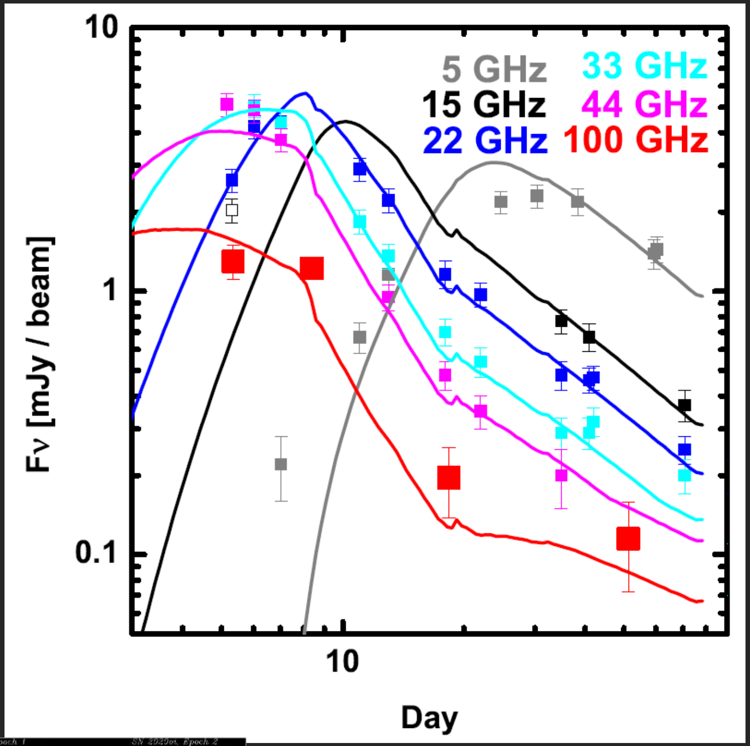
Nayana+ 2024



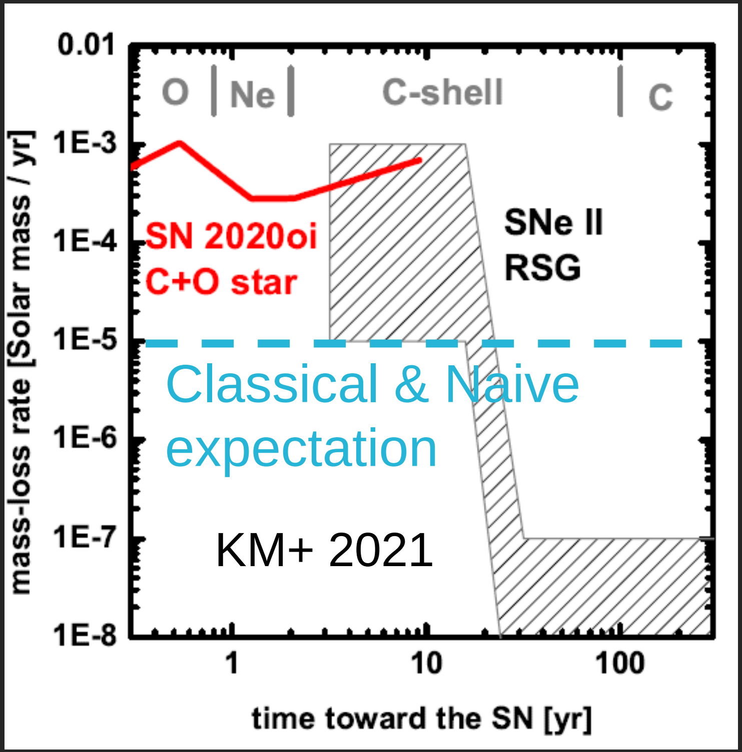


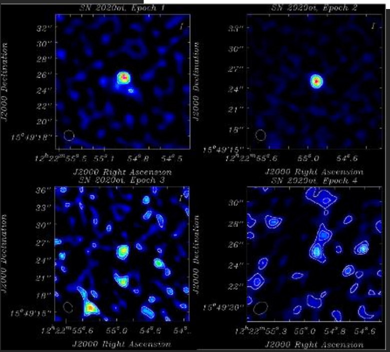
ALMA: “confined CSM” beyond type II

Multi-band LC



Derived mass-loss history



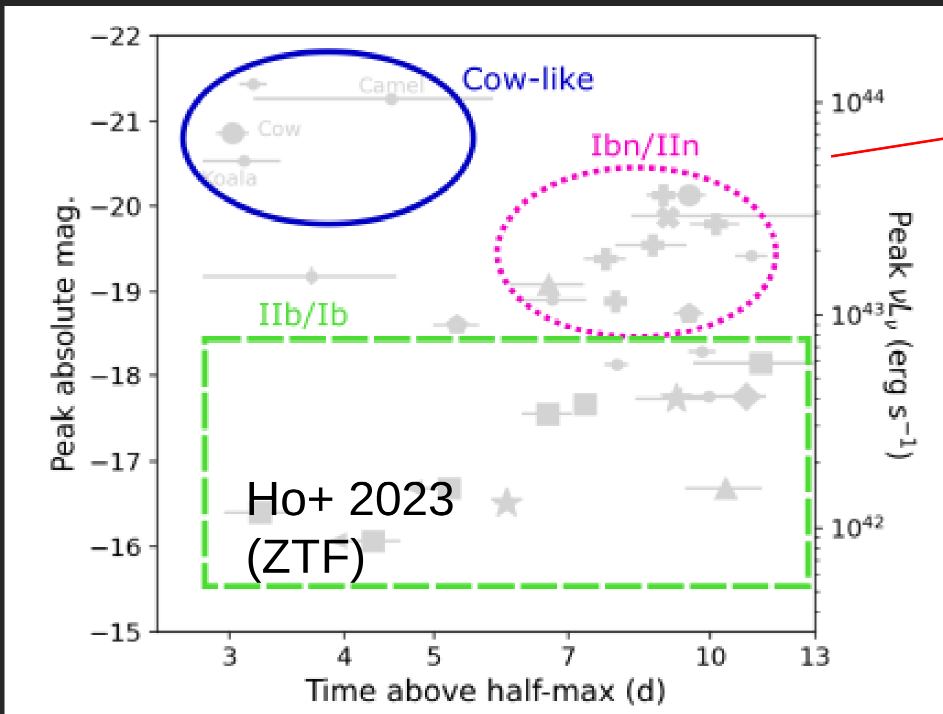


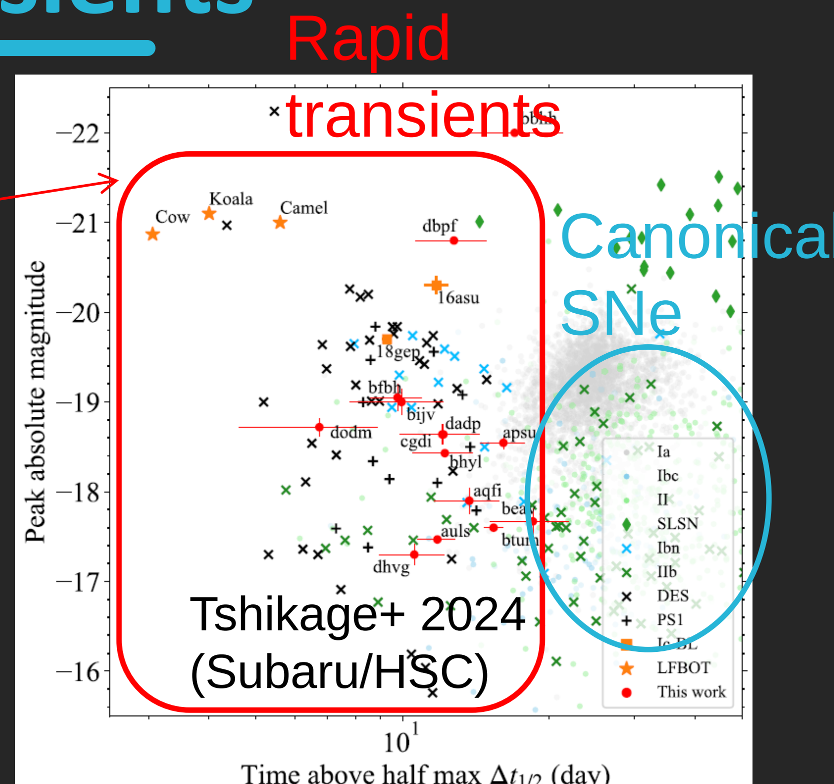
SN Ic = explosion of a C+O star (H/He stripped away)

Overall mass-loss rate in the final few yrs for SN Ic 2020oi
~ the (enhanced) mass-loss rate in the final decades for SN II.

Sub-year timescale variability toward the SN.

Rapidly-evolving transients



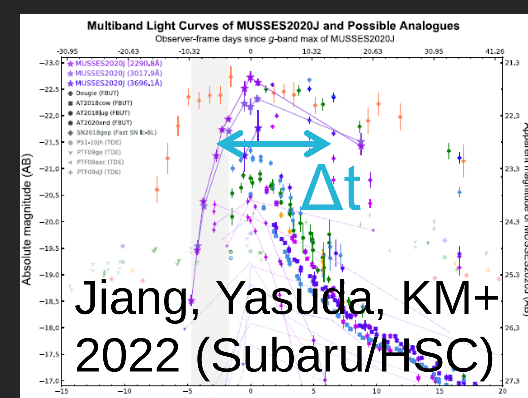


Newly discovered population(s) thanks to high-cadence surveys + rapid follow-up

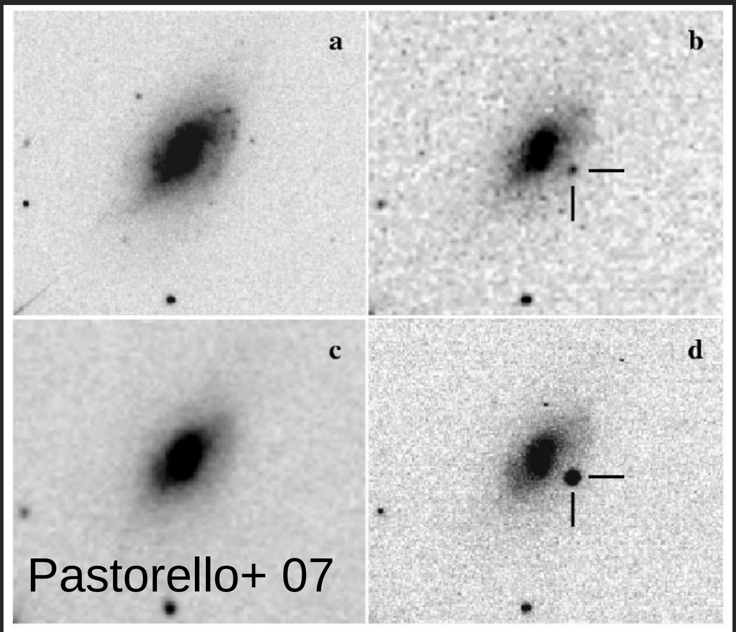
○ faint IIb/Ib (c.f., prediction: Ouchi, KM+ 2021)

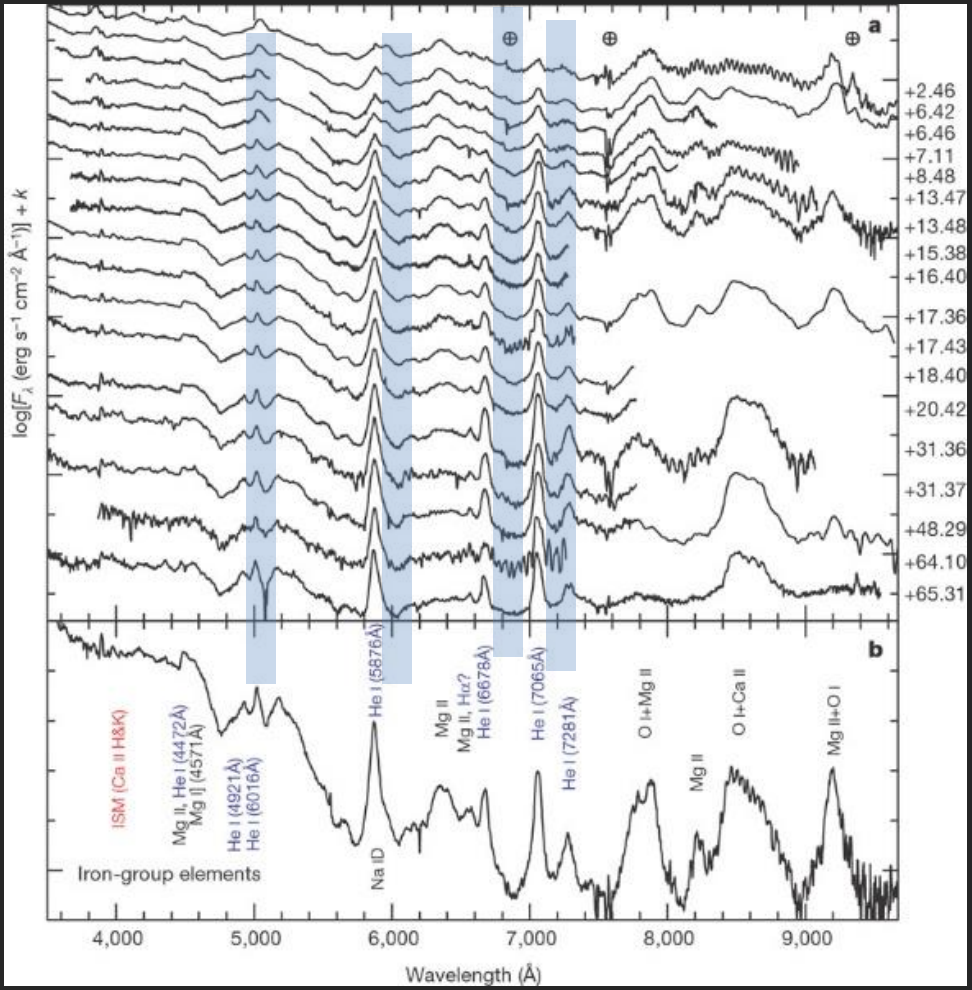
○ (H-poor) interacting SNe (IIn/Ibn/Icn, …)

○ Luminous-Fast-Optical-Transients (LFBOTs)



SNe Ibn: SNe interacting with He-rich CSM



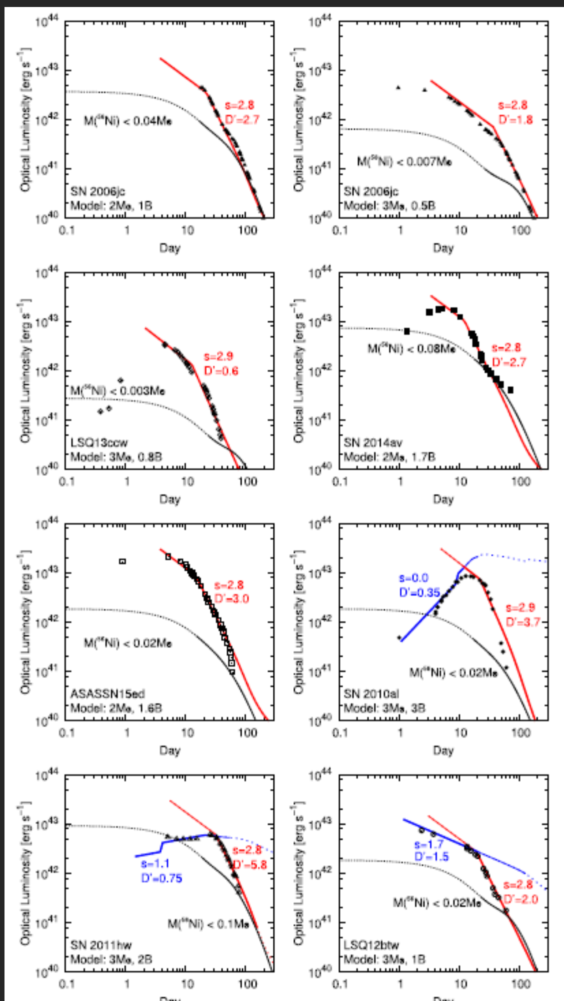


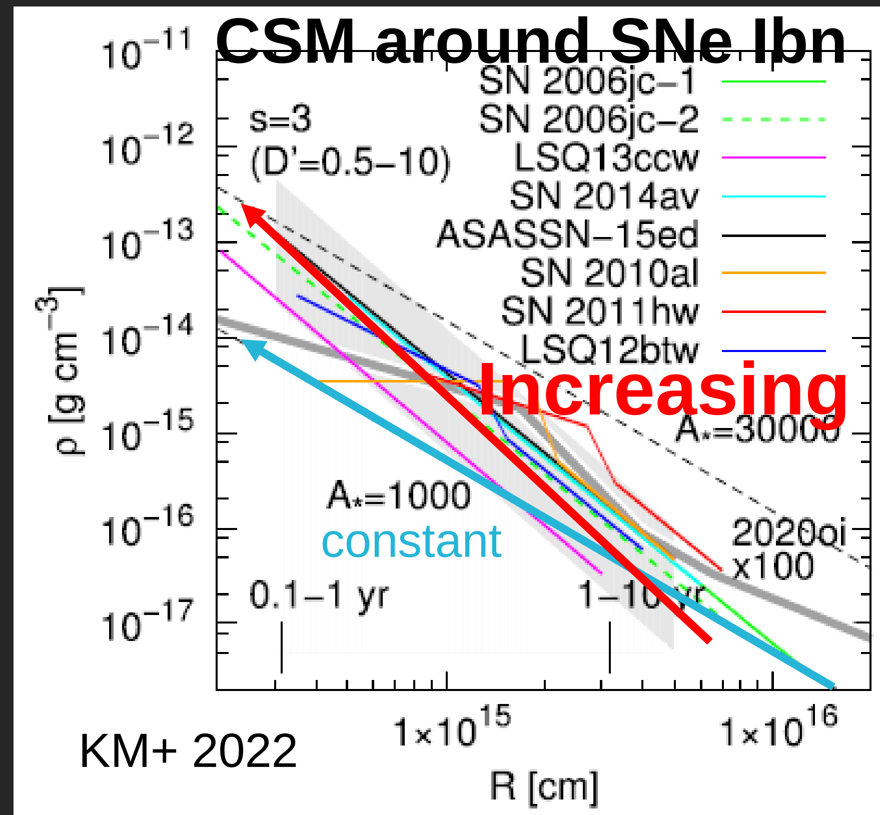
Pre-SN eruption (2 yrs ago).
He emission lines from the SN-CSM interaction.
No hydrogen.
Why different w/ canonical SNe Ib? Progenitor different?

\# New entries: SNe Ibn 2018jmt and 2019cj
Wang, Pastorello, KM+ 2024

Mass-loss history of SN Ibn progenitors

LC models (KM+Moriya 2022)





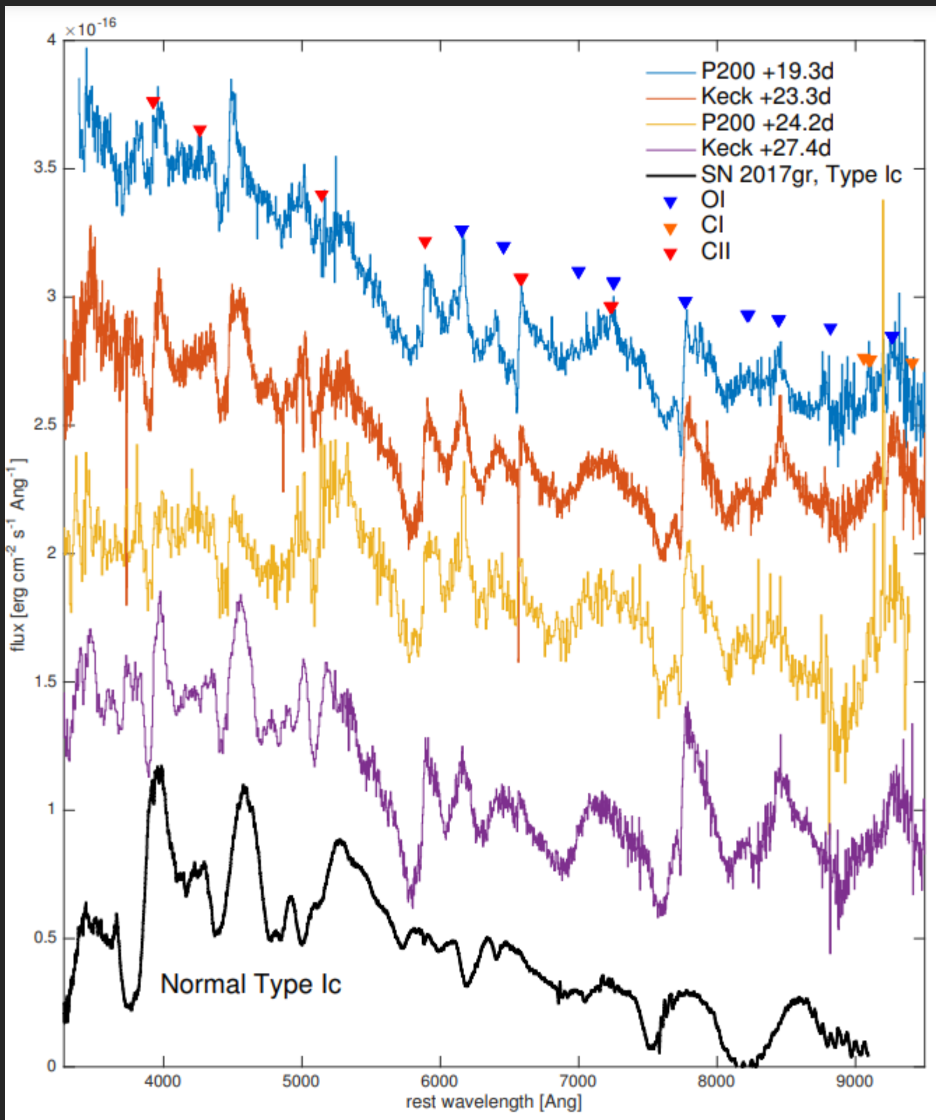
Mass-loss increasing in the final ~10 yrs.

Reaches to x1000 of canonical SNe Ib.

Something different than SNe Ib…

Single massive star (Ibn) vs. binary (Ib)?

SNe Icn: SNe interacting with C+O-rich CSM

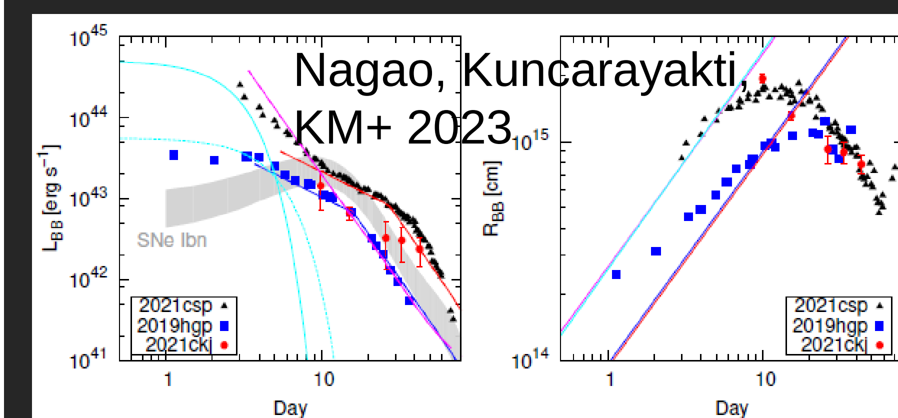


Gal-Yam et al. 2022, Nature

SN "Icn" 2019hgp

C+O emission lines originated in the CSM.
~ 5 examples so far.

C+O-rich dense CSM at the vicinity of the exploding star.

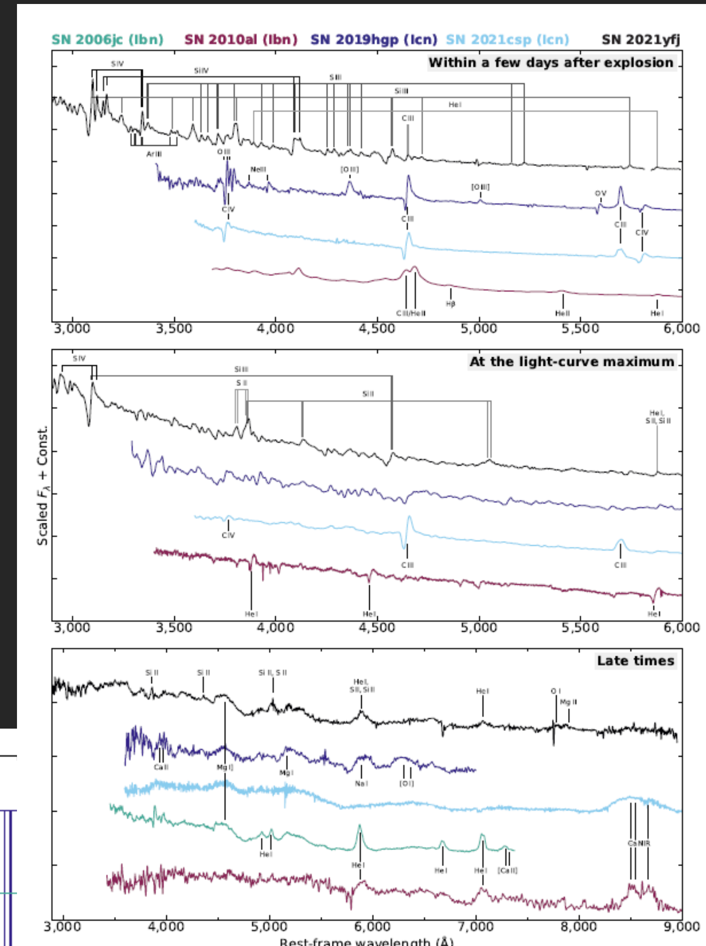


Nagao, Kuncarayakti, KM+ 2023

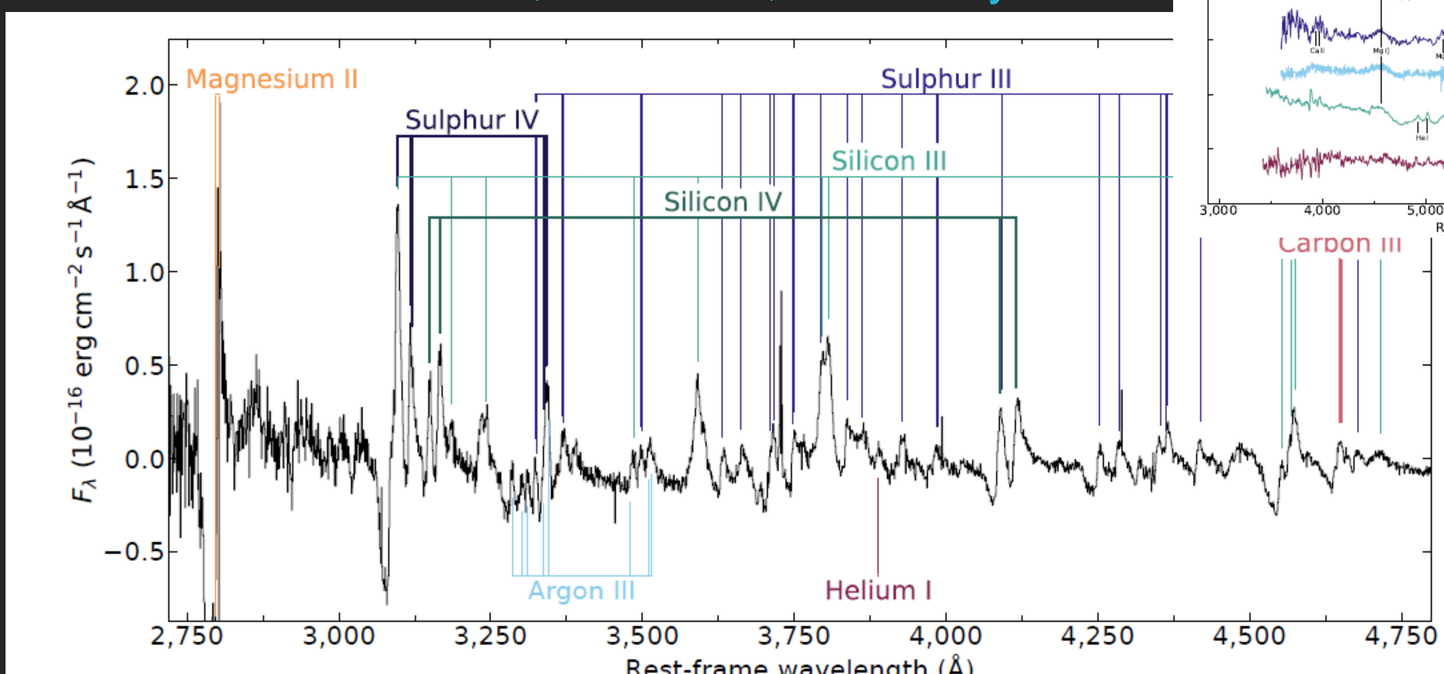
New Entry: Type Ien SN (Si/S-rich CSM)

Gal-Yam 2017, "prediction"

Ejecta composition	CSM composition	SN Type	SN Type[27]
H	H	SN IIn	SN 0 i0
He	He, (H)	SN Ibn	SN 1 i1
C/O	C/O	SN Icn	SN 2 i2
O/Ne/Mg	O/Ne/Mg	SN Idn	SN 3 i3
O/Si/S	**O/Si/S**	**SN Ien**	**SN 4 i4**



Schulze et al. 2024, submitted, "discovery"

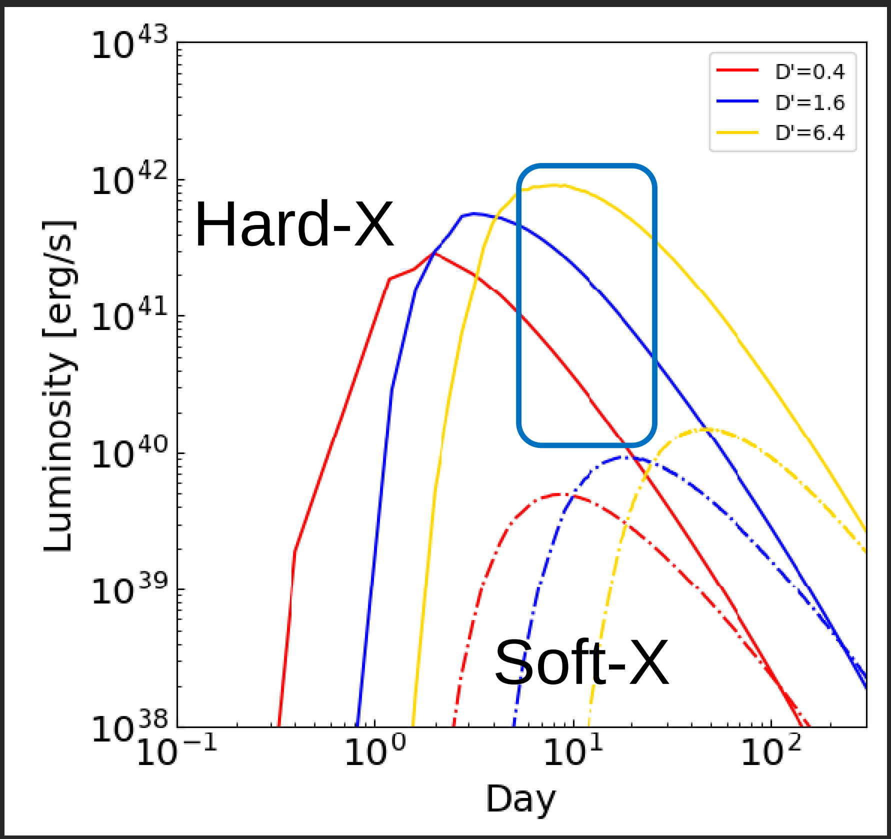


X(Si), X(S) > A few 0.01

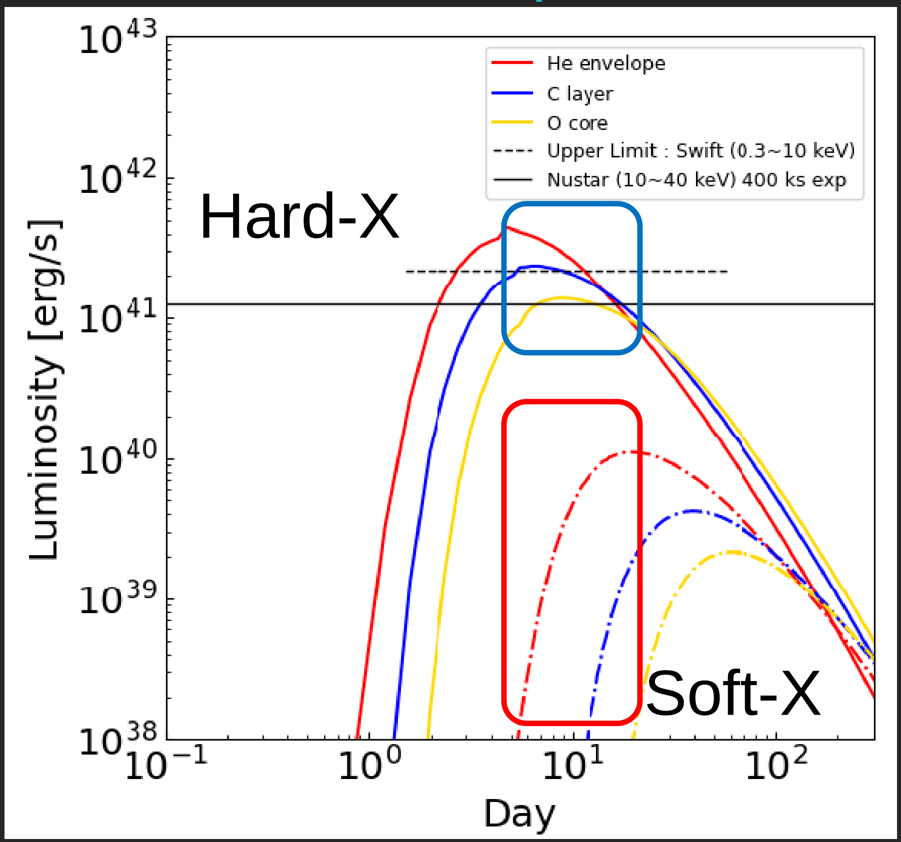
Inoue+KM 2024

Predicted X-rays for SNe Ibn/Icn

CSM density



CSM composition



~10 days (depending on the CSM density)

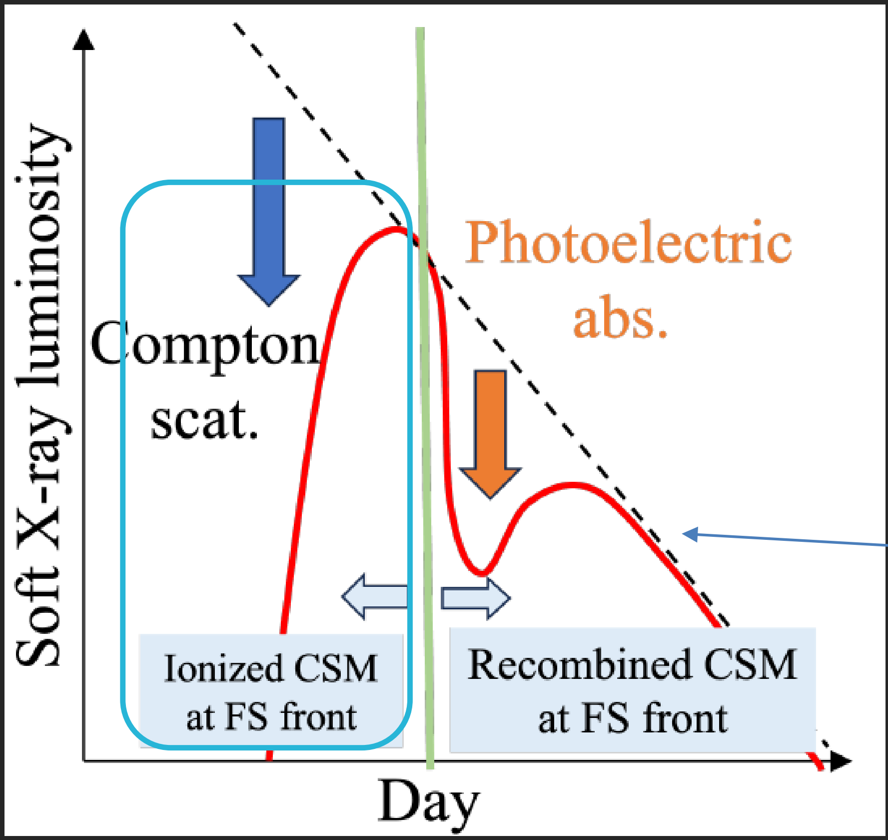
○ Hard-X decaying ⇒ CSM density

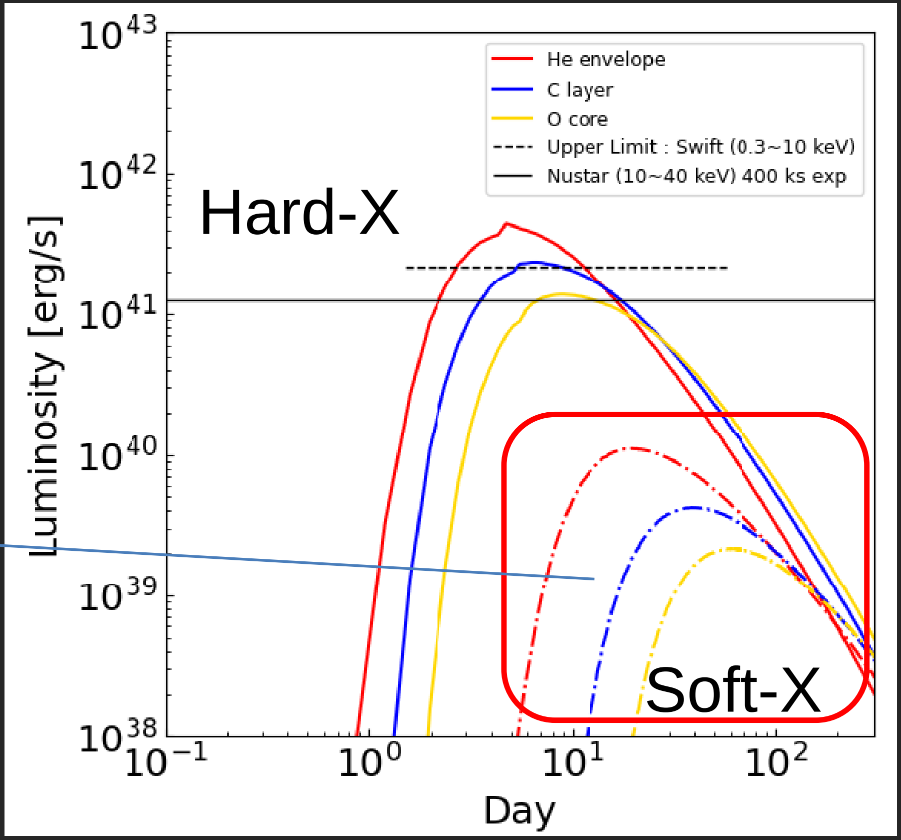
○ Soft-X rising ⇒ CSM composition

Inoue+KM 2024

Predicted X-rays for SNe Ibn/Icn

Taking into account the time-dependent ionization

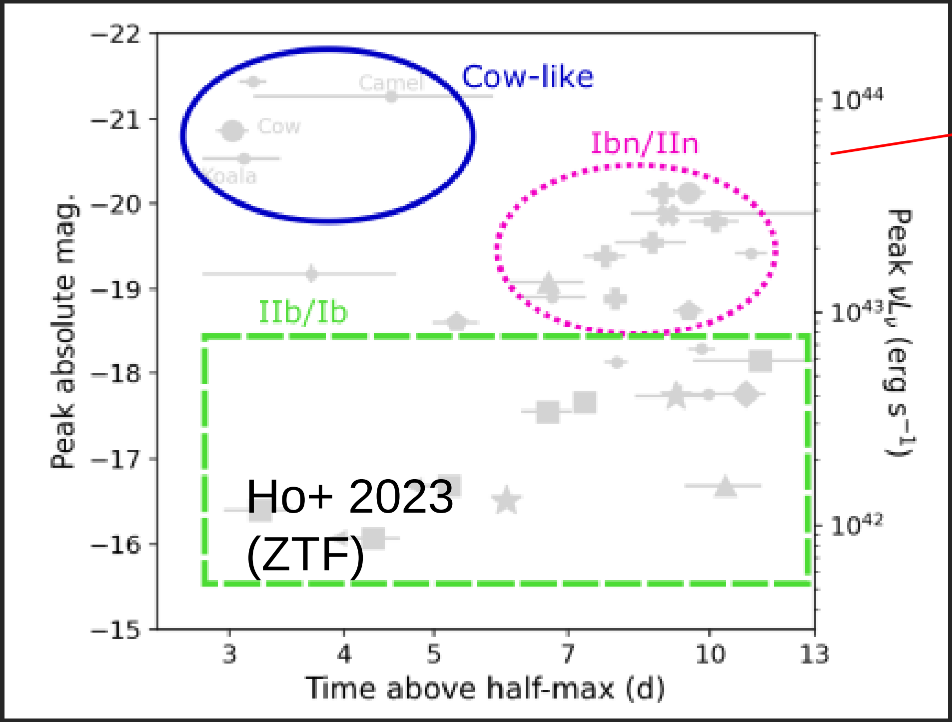


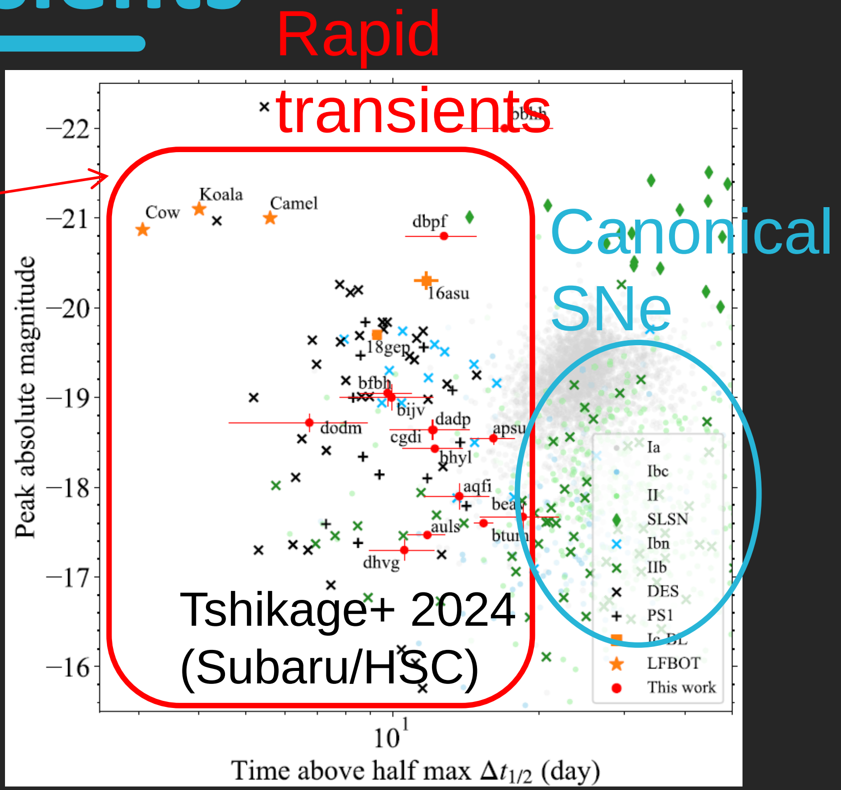


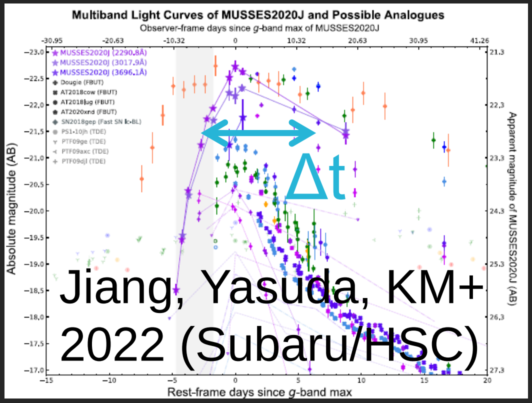
Additional “infant” component: ~ a few days: new probe

○ Further model constraints, ionization physics,…

Rapidly-evolving transients







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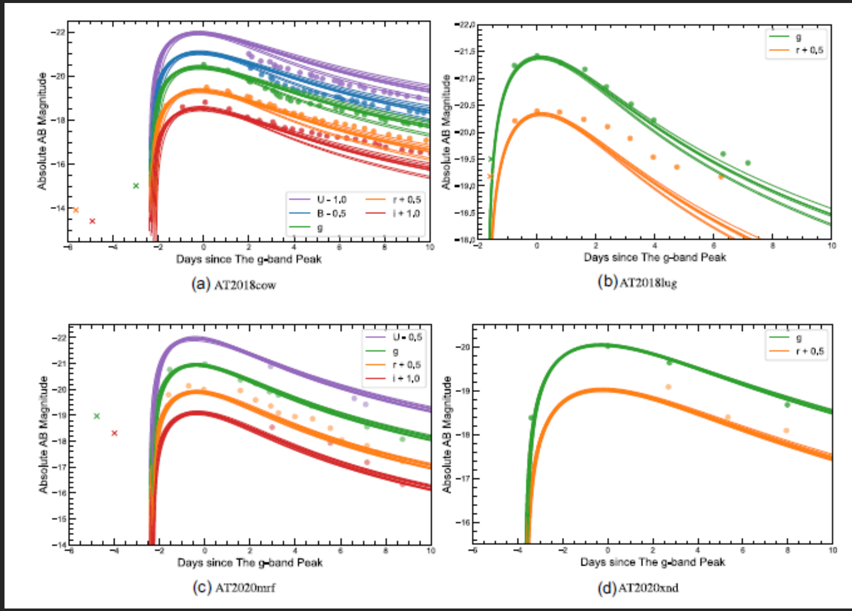
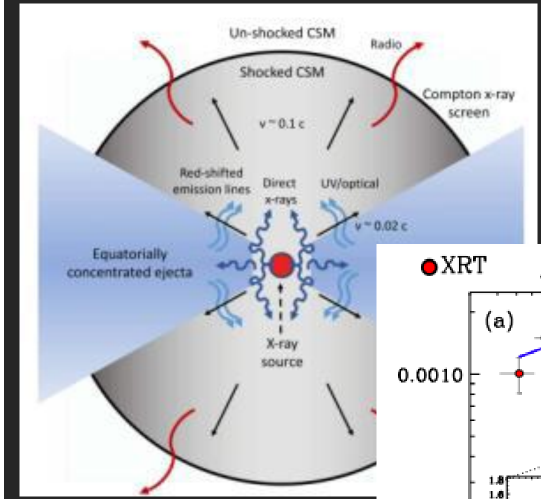
- ○ Luminous-Fast-Optical-Transients (LFBOTs)

LFBOTs (=2018cow-like)

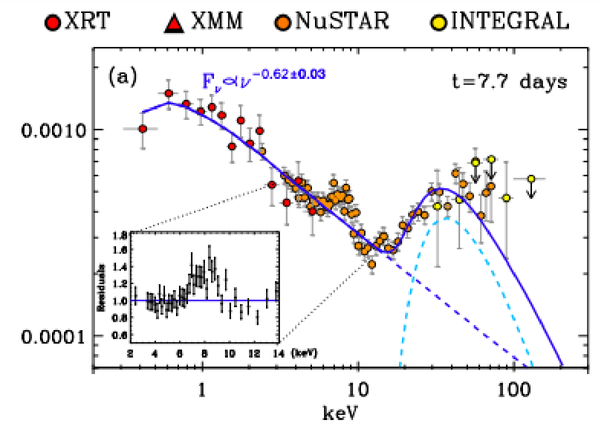
- Very bright & very fast… origin not identified.
  - BH formation? TDE by an IMBH?
- 2018cow (prototype, nearest so far):
  - Enigmatic X-ray and radio (especially mm).
  - Central engine? (trans-) Relativistic outflow?



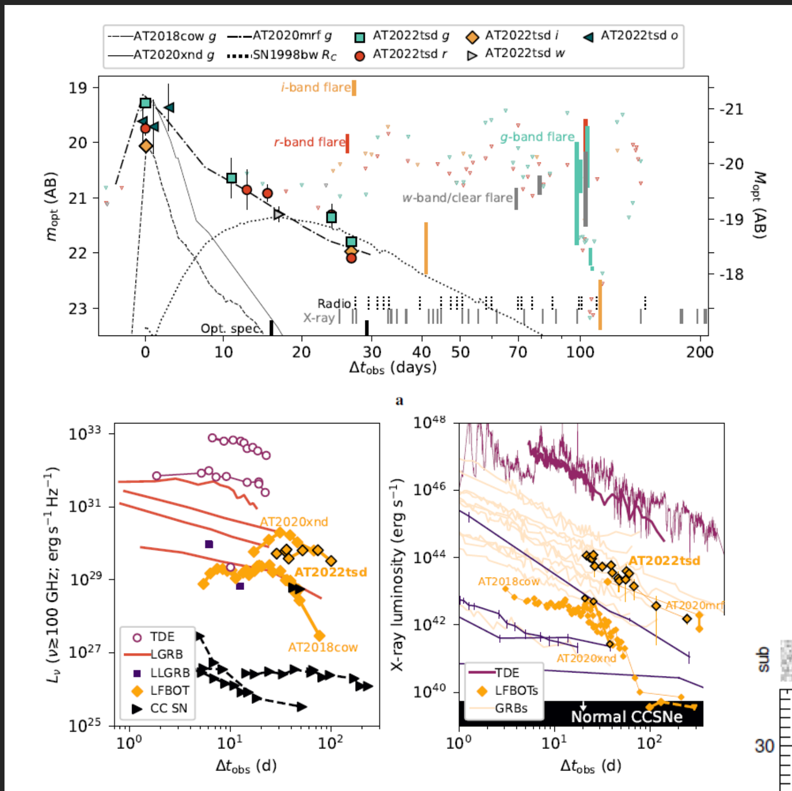
Uno & KM 2023 (optical LC model)



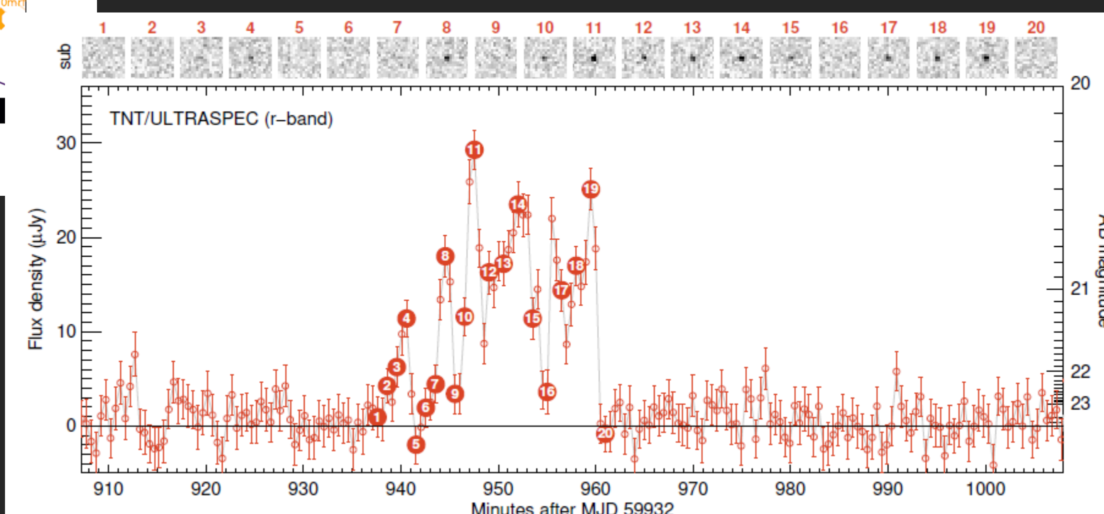
Margutti+ 2019



Luminous Fast & Blue Optical Transients
AT 2018cow and its cousins: recent news



- Suggested to be "central engine"-driven.
  - Black hole? (mass?)
  - Magnetar?
- Finally, < minute-scale variability reported in the optical for one object.



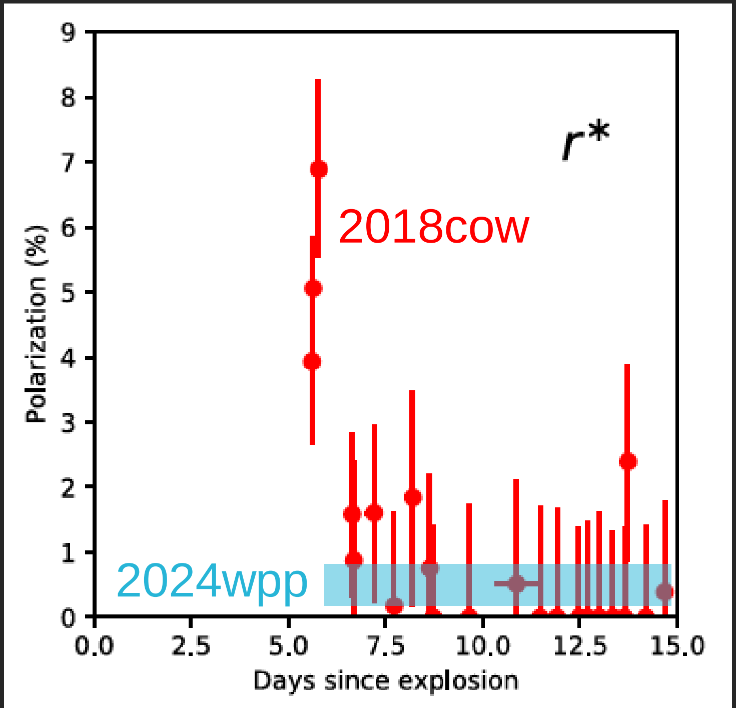
AT2022tsd

Ho+ 2023

LFBOT: ongoing efforts

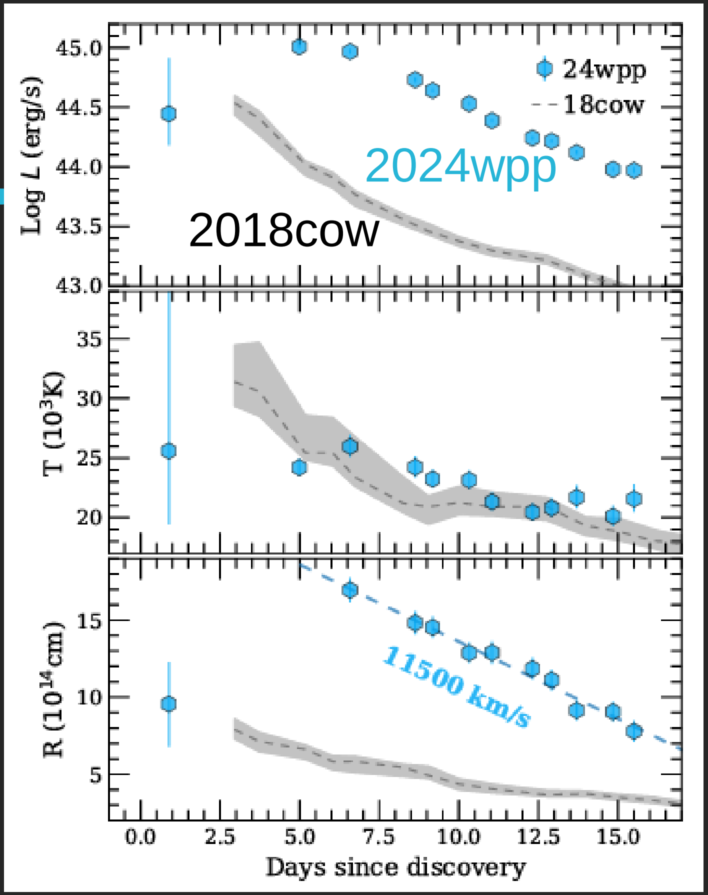
Example: AT2024wpp (nearest next to 2018cow)

Polarization



Sub-minute variability search

Seimei + Subaru/FOCAS (KM+)



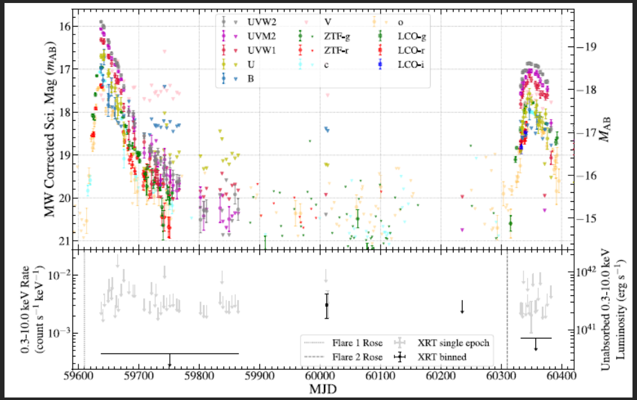
Pursiainen＋2024, submitted to A&A
discovery, polarization (jet?)

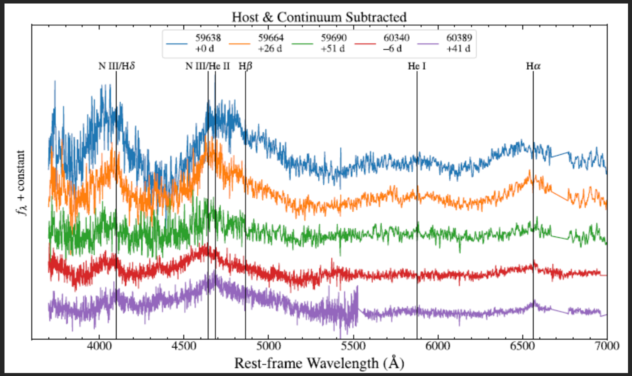
Multi-wavelength

VLA+ALMA (Ho+),
NICER (Komura+)

TDEs... diverse properties

Repeating TDE
(1st robust spec. identify)
partial disruption?

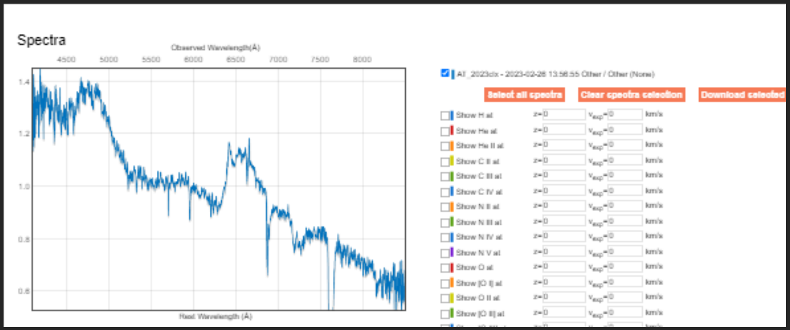




Lin+ 2024, ApJL

Nearest optical TDE
Classified/identified by Seimei
Best TDE pol data (Subaru/FOCAS)
Emission geometry (aspherical outflow)
Weak AGN (torus seen in pol, 1st time)

Taguchi+ 2023, TNS



Uno, KM+, submitted

Summary

- Transient science **rapidly expanding**.
  - Key = **rapid follow-up + multi-wavelengths/modes**.
    - X-ray, radio, polarization, short-time variability, …
  - Need global collaboration.

- Examples of key science
  - **Final** evolution of stars:
    - mass-loss history/mechanisms
  - **Enigmatic** transients:
    - LFBOTs
    - TDEs
    - +more and more