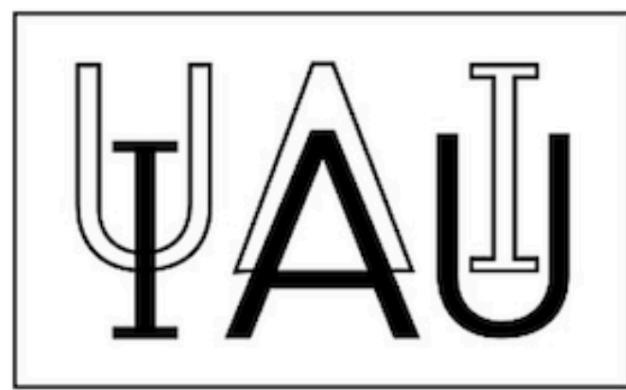




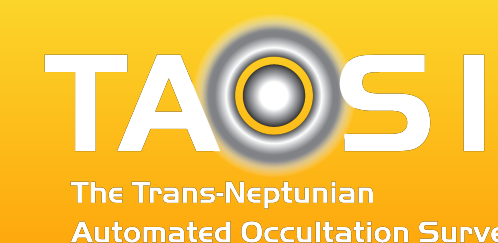
Kavli-IAU Global Coordination Workshop (GCW) 22-26 June 2026 in
Görlitz, Germany

Core-collapse Supernovae: The Diverse Deaths of Massive Stars

Janet Ting-Wan Chen 陳婷琬
National Central University
Yushan Young Fellow



國立中央大學
National Central University



Why CCSNe matter for this workshop

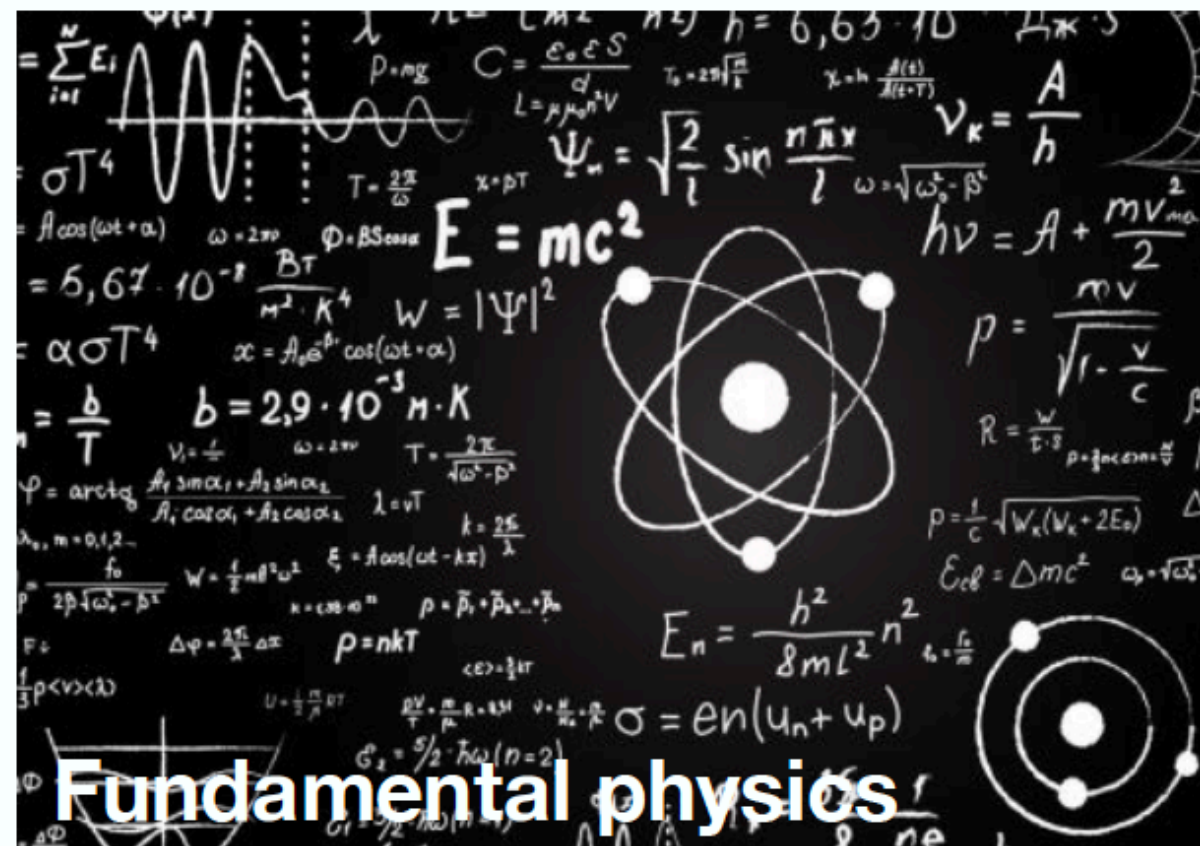
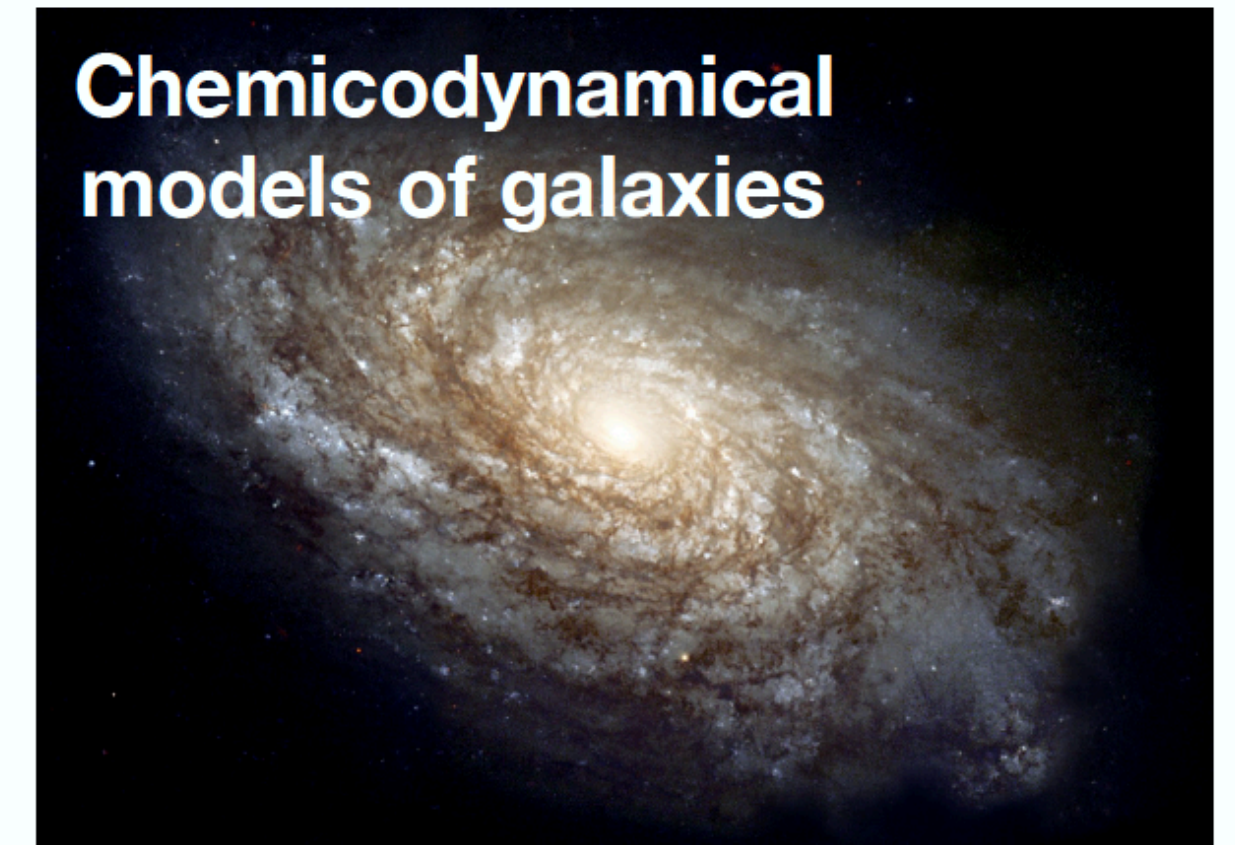
Core-collapse supernovae are central to:

- the death of massive stars
- neutron-star and black-hole formation
- chemical enrichment
- dust formation
- feedback in galaxies
- cosmic-ray acceleration
- multi-messenger astrophysics

**Missing processes
for stellar evolution**



**Chemicodynamical
models of galaxies**



Fundamental physics



Credit: Morgan Fraser

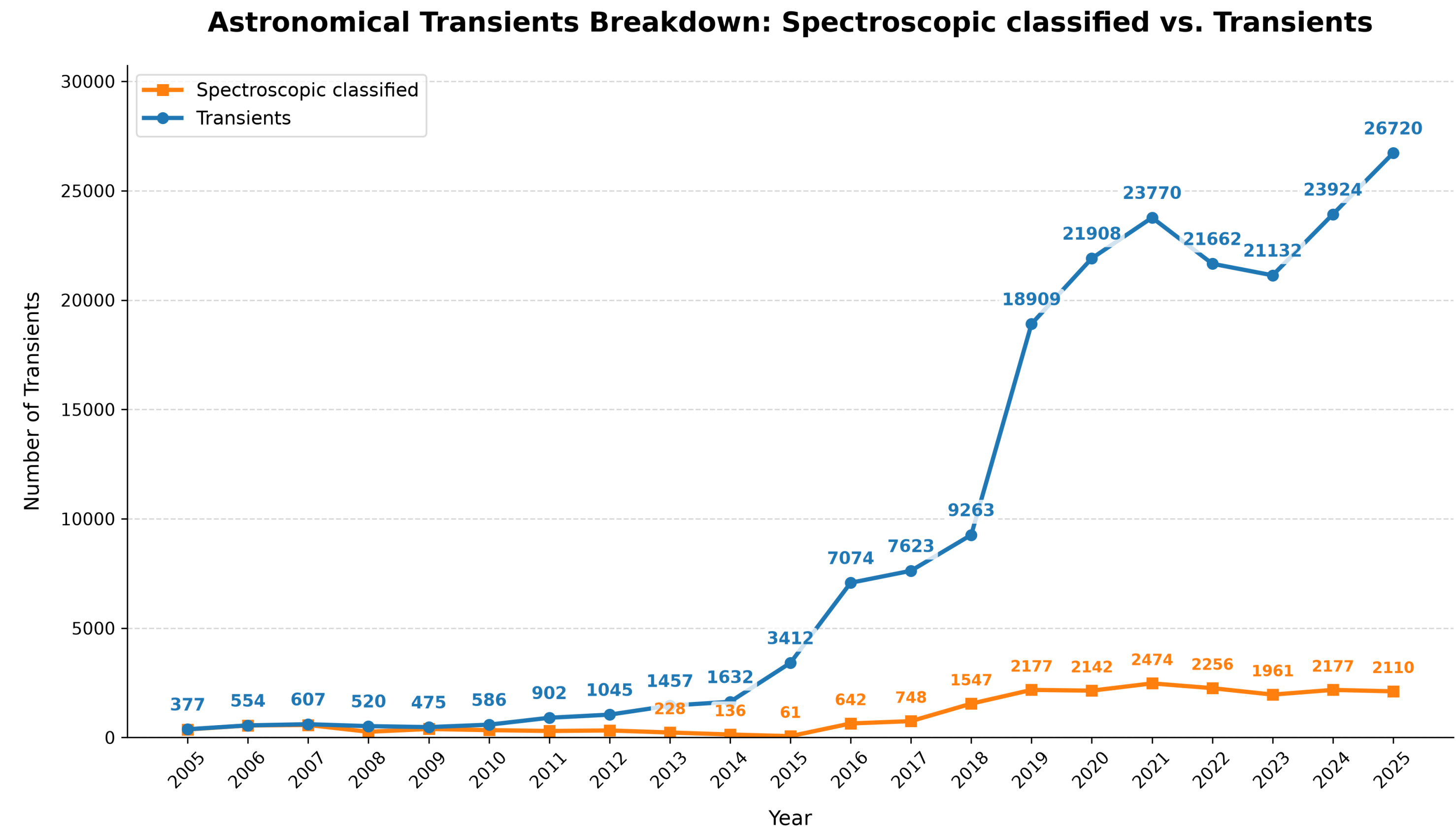
From discovery-limited to follow-up-limited science

Wide-field discovery and alert streams: Rubin/LSST, ATLAS, ZTF, BlackGEM, Einstein Probe, ULTRASAT, UVEX, Roman, Euclid

Follow-up and physical characterisation: SKA/SKAO, CTAO, ELT, JWST, VLT, Gemini, ALMA, MeerKAT, Swift, Chandra, XMM-Newton

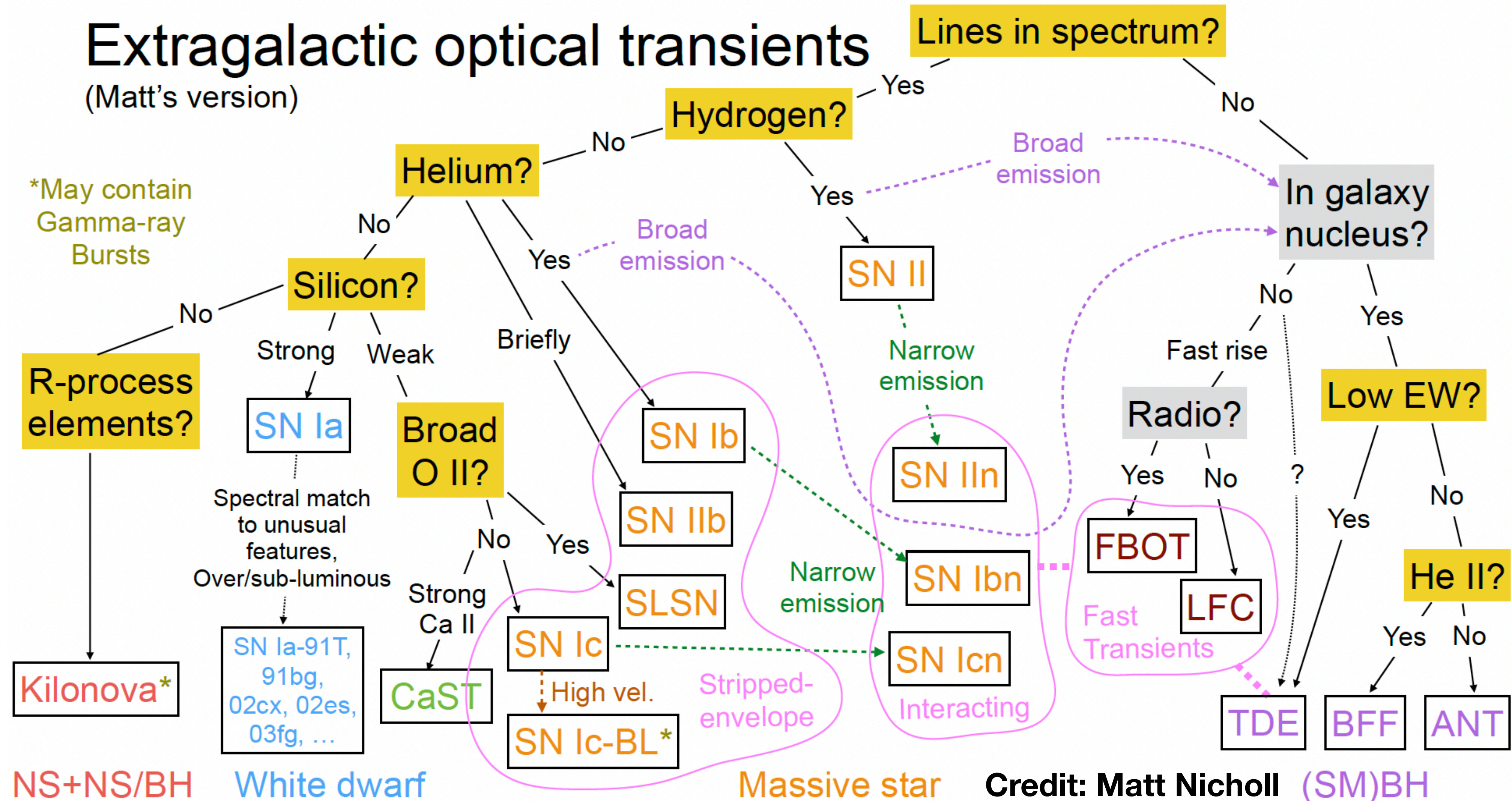
The coming challenge:

- millions of alerts
- many young transients
- limited spectroscopy
- limited UV/X-ray/radio access
- limited human attention



(data from Yamaoka 2016 based on IAUCs/CBETs, and TNS)

CCSNe classification: observational types vs physical channels



New interacting subclasses – Ibn, Icn, and the proposed Ien

AstroNote 2021-76

AstroNotes

Stats

2021-02-23 11:00:13

Type: Object/s-Discovery/Classification

Bibcode: 2021TNSAN..76....1G

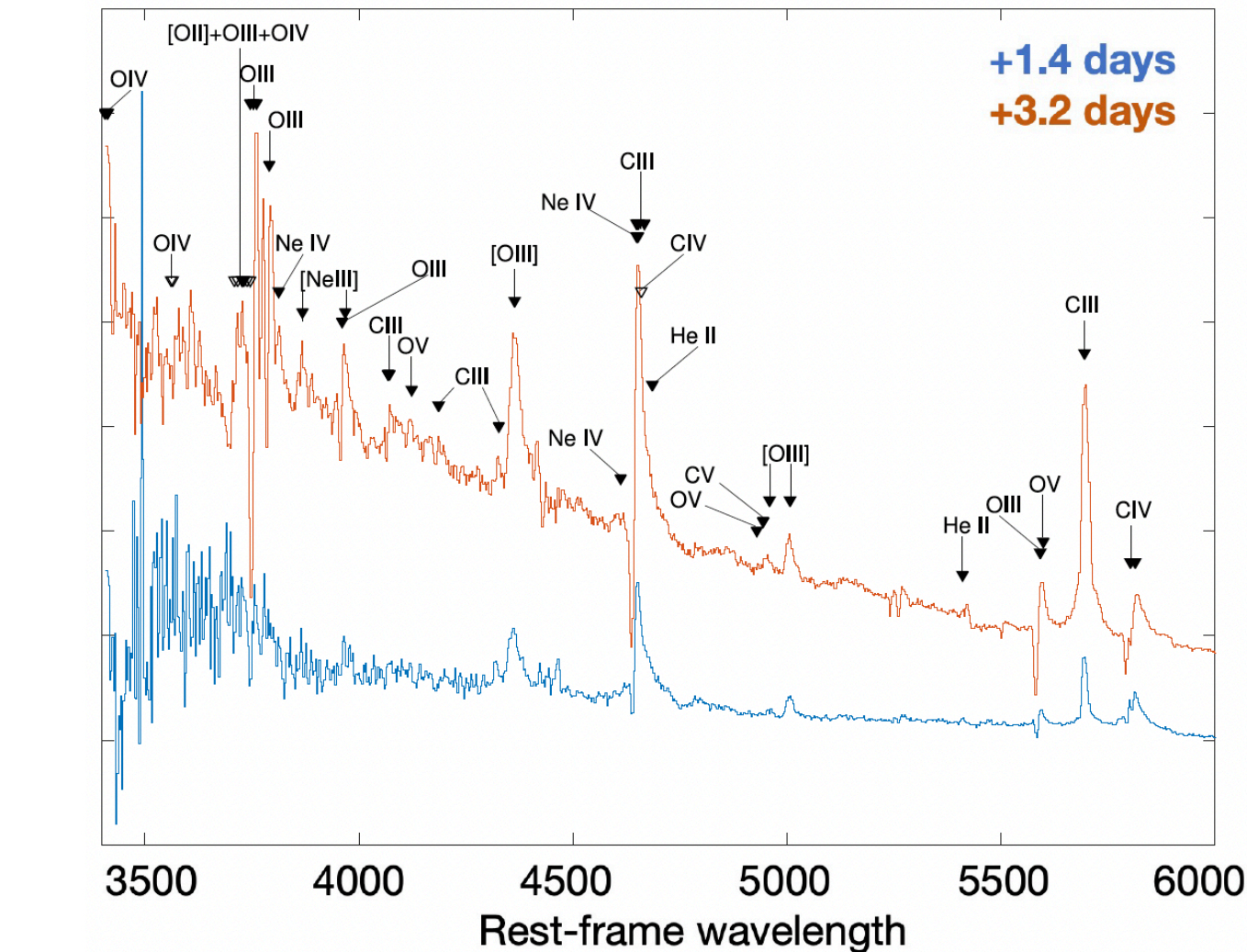
Introducing a new Supernova classification type: SN Icn

Authors: Avishay Gal-Yam, Ofer Yaron (WIS), Andrea Pastorello (INAF), Stefan Taubenberger (MPA), Morgan Fraser (UCD), Daniel Perley (LJMU)

Keywords: Supernova

Abstract: Motivated by recent discovery and classification reports of transients with spectra showing prominent narrow emission lines of carbon and/or oxygen, but lacking lines of hydrogen and helium, we propose to use a new spectroscopic SN type - SN Icn - to refer to such objects.

SN 2026obc
SN 2026ezk
SN 2024abvb
SN 2023emq
SN 2022ann
SN 2021csp
SN 2021ckj
SN 2019hgp
SN 2019jc
SN 2018erx



Gal-Yam et al. (2022)

AstroNote 2024-239

AstroNotes

Stats

2024-09-03 14:05:38

Type: Object/s-Discovery/Classification

Bibcode: 2024TNSAN.239....1G

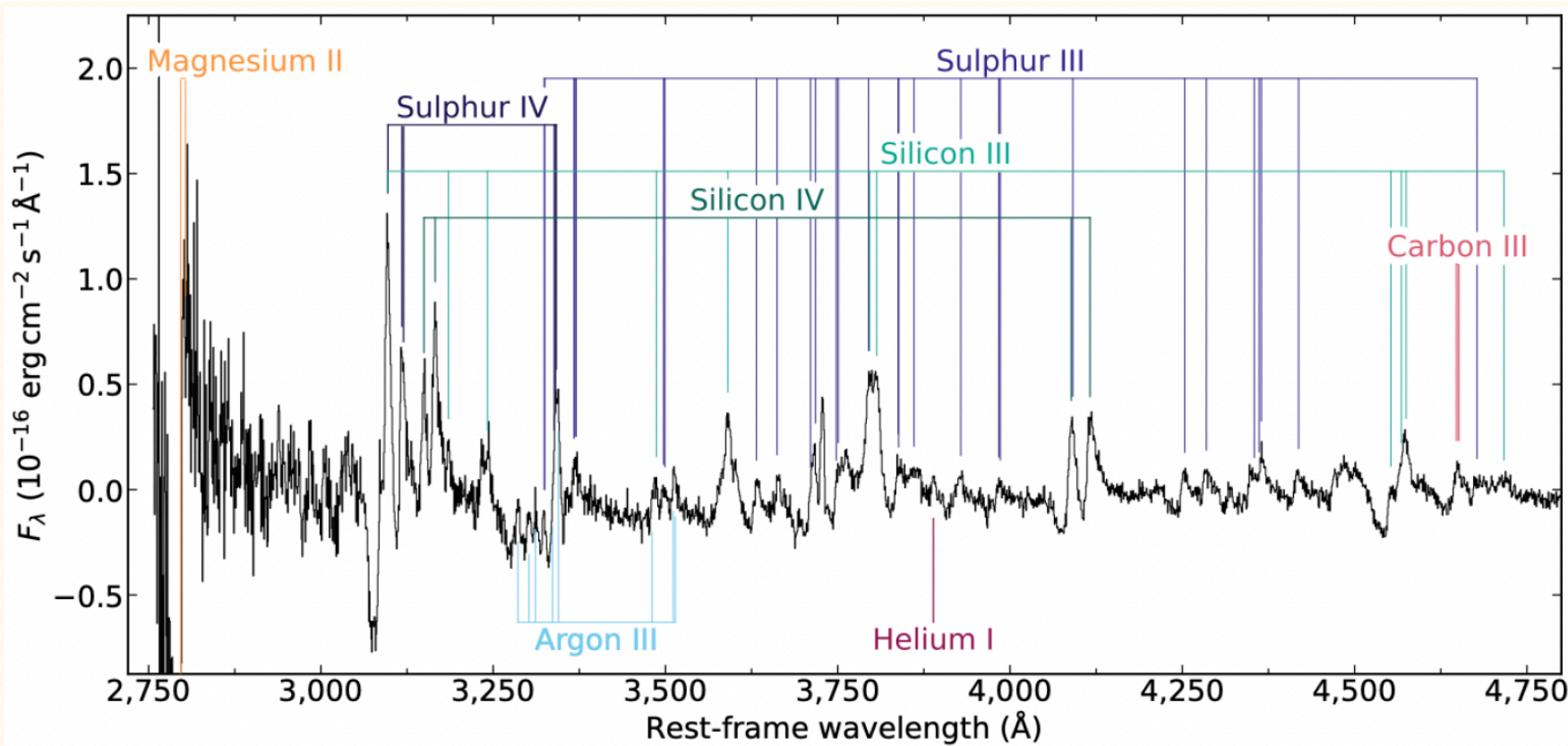
Introducing a new supernova classification type: SN Ien

Authors: Avishay Gal-Yam, Ofer Yaron (WIS), Steve Schulze (CIERA/NU)

Keywords: Supernova , Spectroscopy

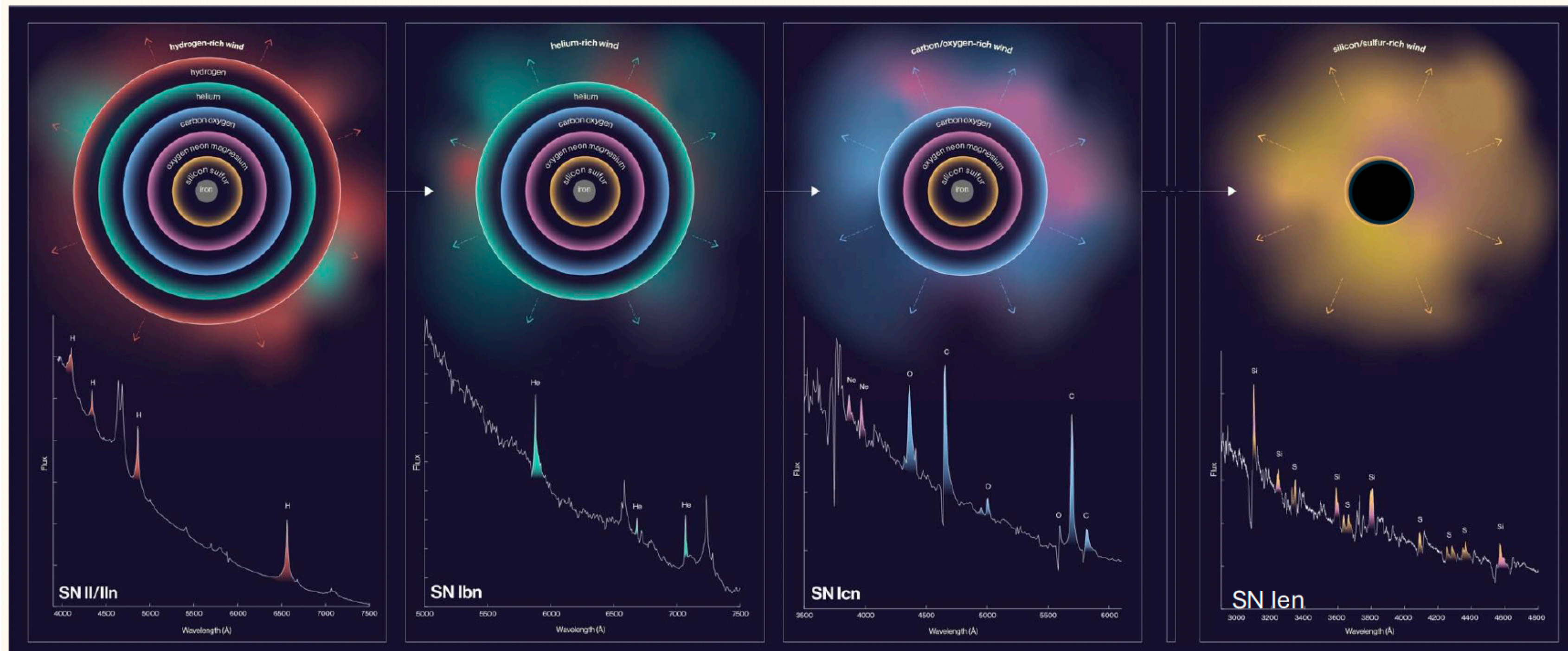
Abstract: Following the discovery and classification of SN 2021yfi whose unique early spectra are completely dominated by prominent emission lines of highly ionized silicon, sulphur and argon, lacking prominent features from carbon, oxygen, helium and hydrogen, we propose to tentatively introduce a new spectroscopic SN type - SN Ien; leaving a "placeholder" for a potential intermediate class -- Idn -- whose spectra would be dominated by oxygen/neon/magnesium. This issue can be re-examined once additional relevant examples are found.

SN 2021yfi



S. Schulze et al. 2025

New interacting subclasses – Ibn, Icn, and the proposed Ien

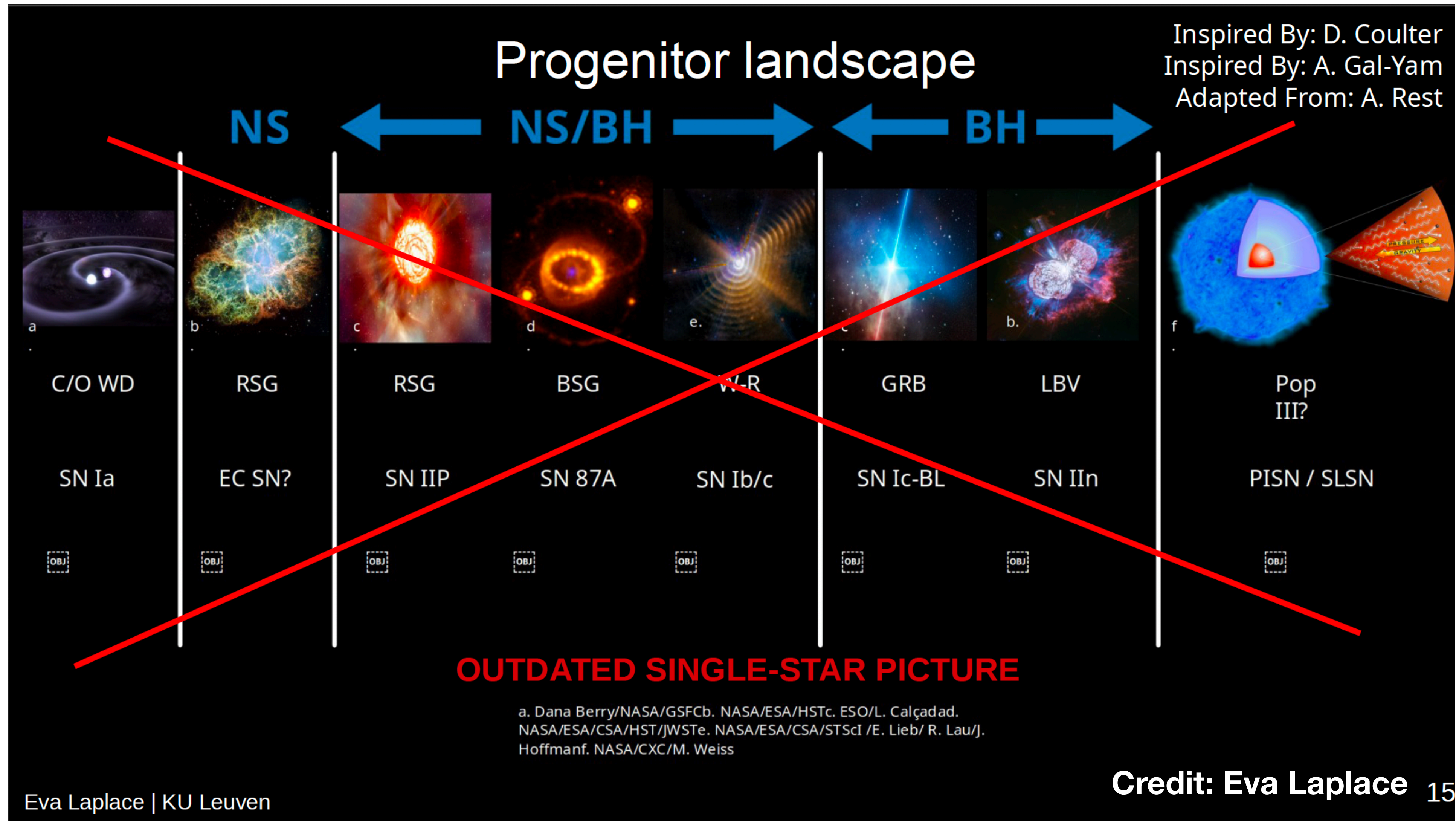


Weizmann Institute of Science

Ejecta composition	CSM composition	SN Type
H	H	SN IIIn
He	He (, H)	SN Ibn
C/O	C/O	SN Icn
O/Ne/Mg	O/Ne/Mg	...
O/Si/S	O/Si/S	SN Ien

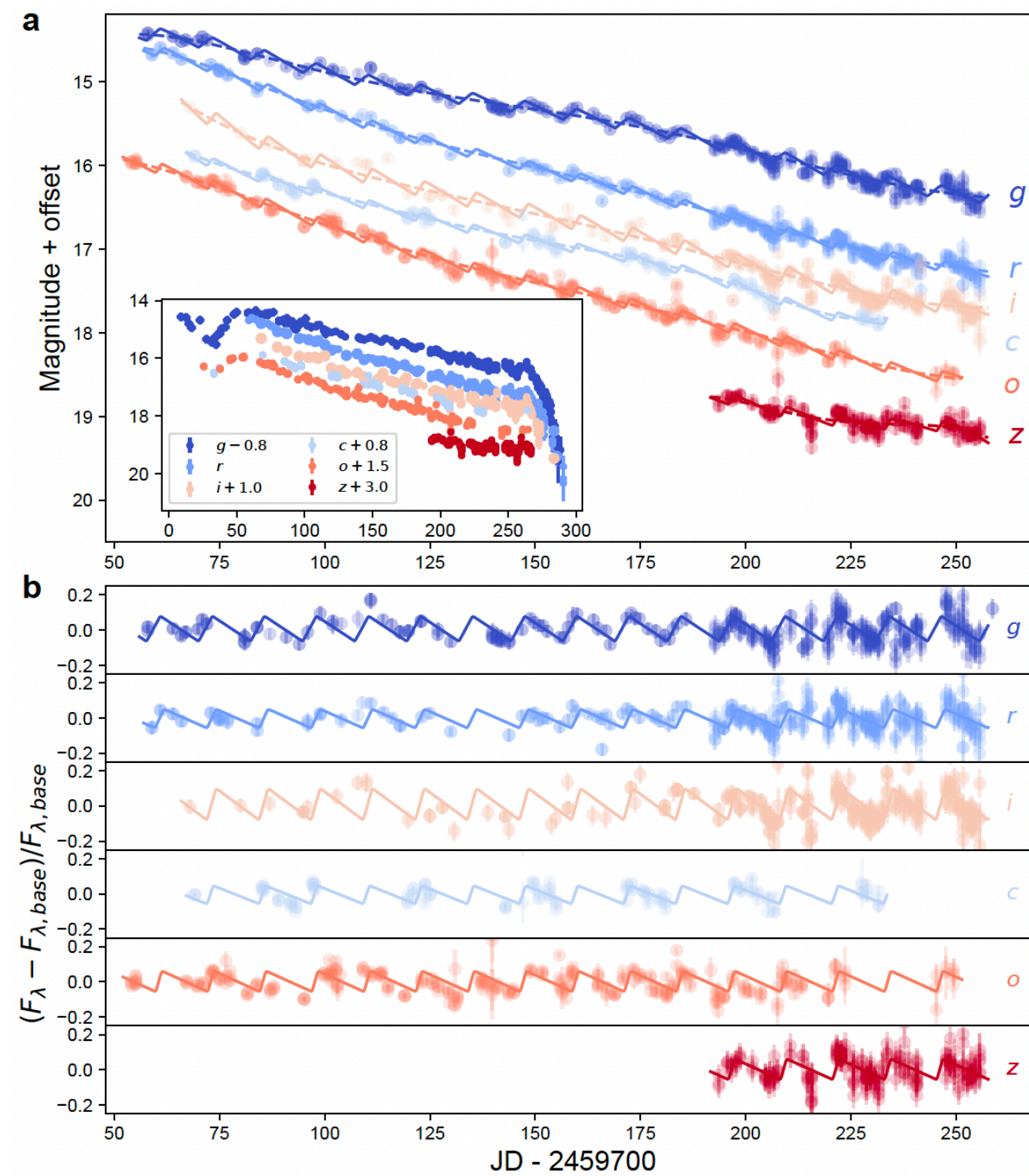
Credit: Steve Schulze

Almost everything is binary

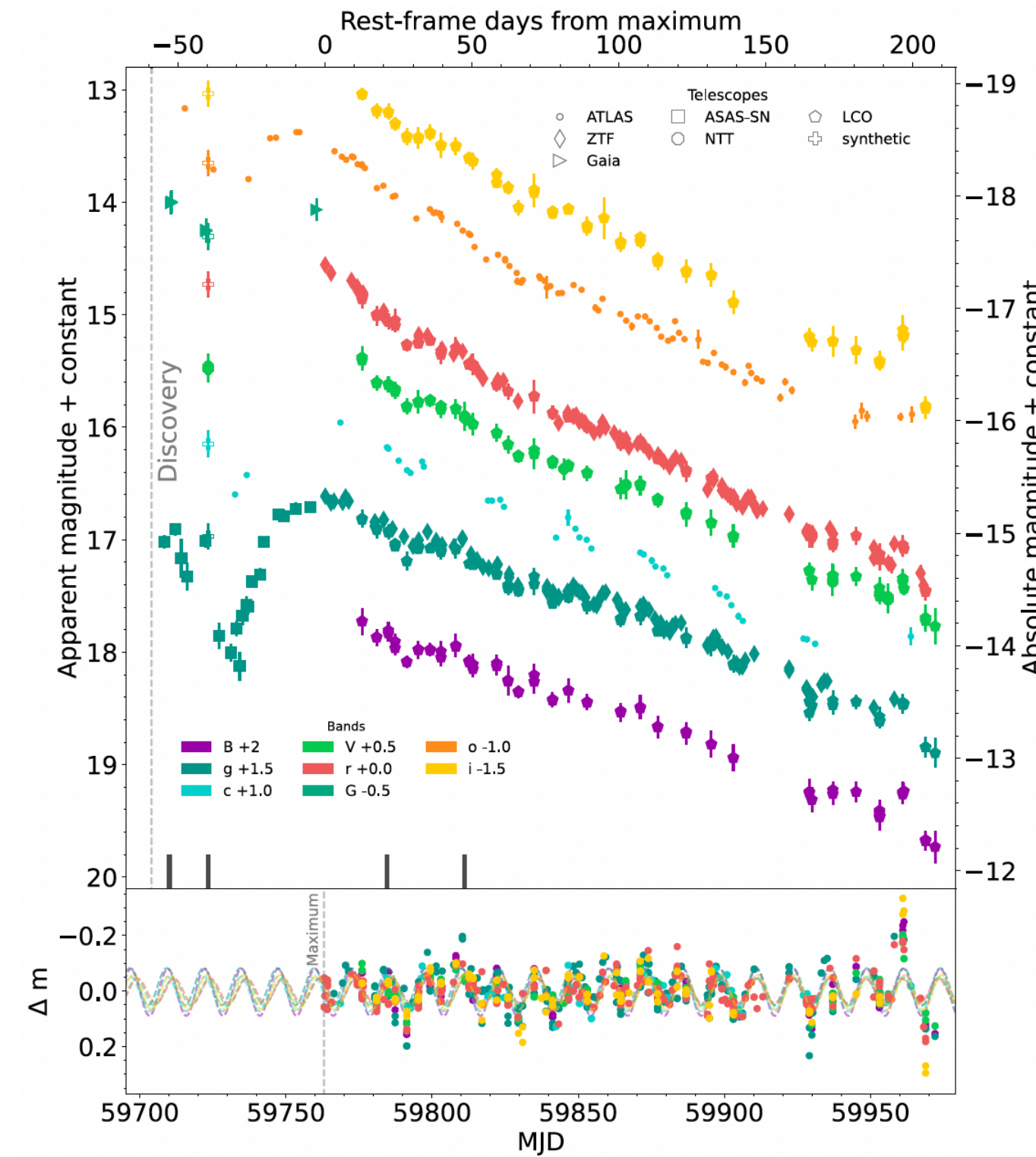


Periodic Modulation in the Light Curve

SN 2022jli; period 12.4 d

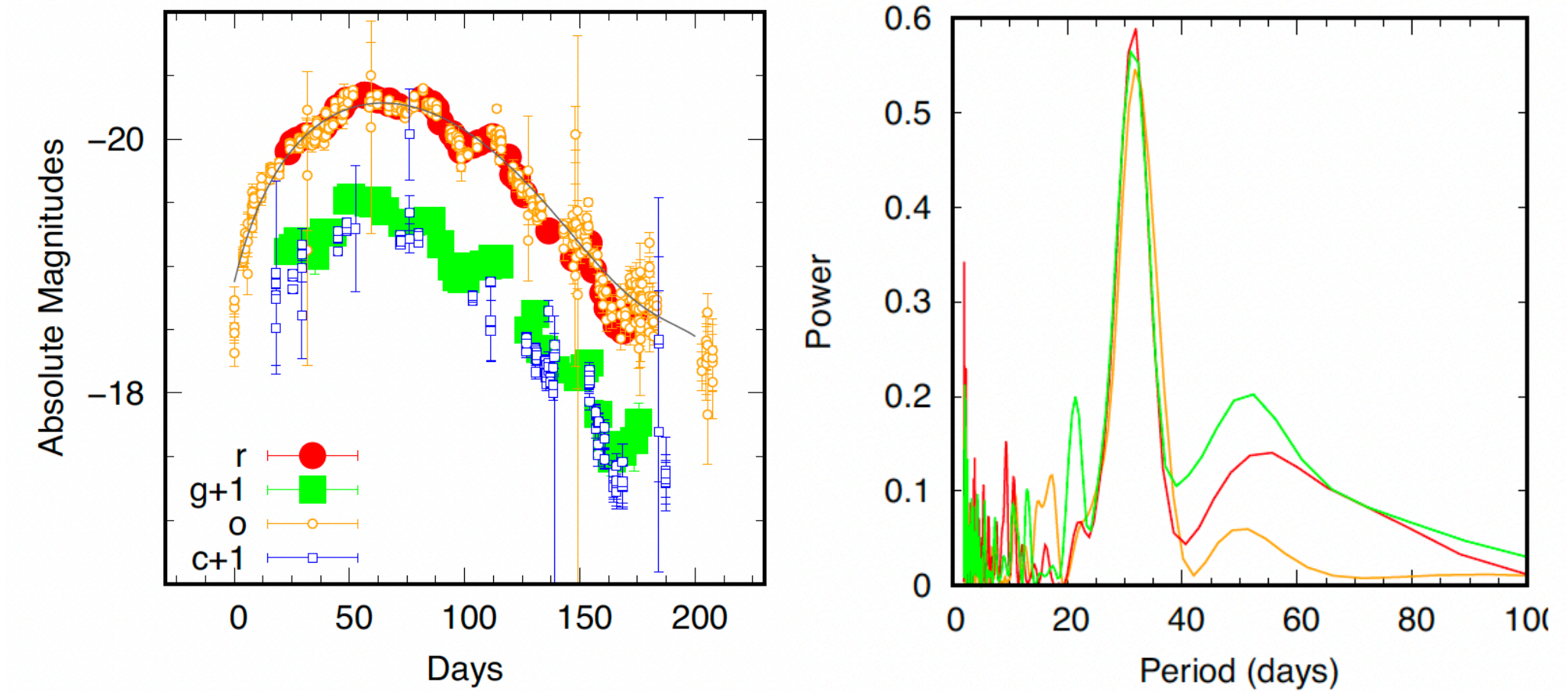


P. Chen et al. 2023



T. Moore et al. 2023

SN 2022esa; period ~ 32 d



K. Maeda et al. 2026

What happens in the final years before core collapse?

Massive stars do not always die quietly

Evidence for enhanced pre-SN mass loss comes from:

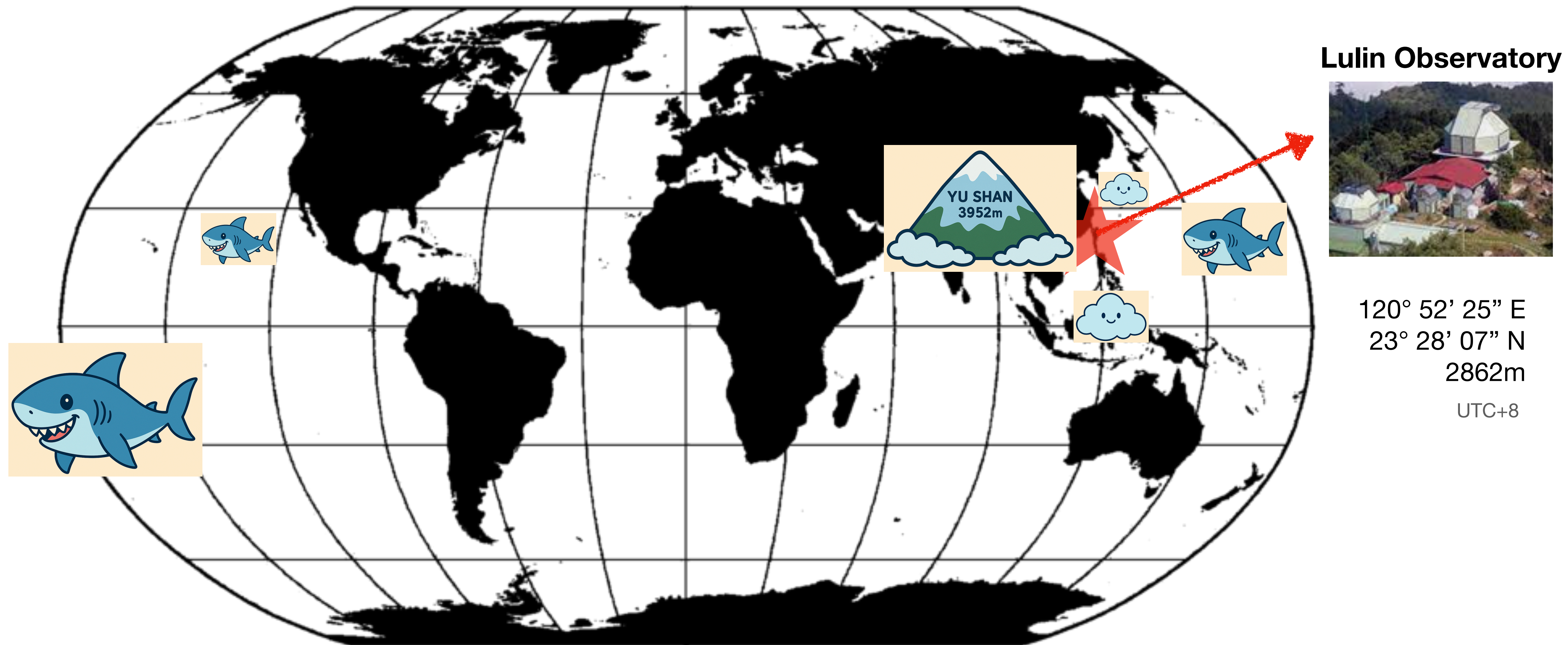
- flash-ionised spectral features
- early optical / UV excesses
- narrow emission lines
- radio and X-ray interaction
- precursor variability
- dense CSM inferred from light-curve modelling

Nearby young CCSNe are high-priority global events

A well-observed first day can provide:

- explosion epoch to within hours
- early color temperature
- shock-cooling constraints
- evidence for confined CSM
- first spectral signatures before they disappear
- a trigger for UV, X-ray, and radio follow-up

Taiwan's unique location makes it ideal for time-domain astronomy

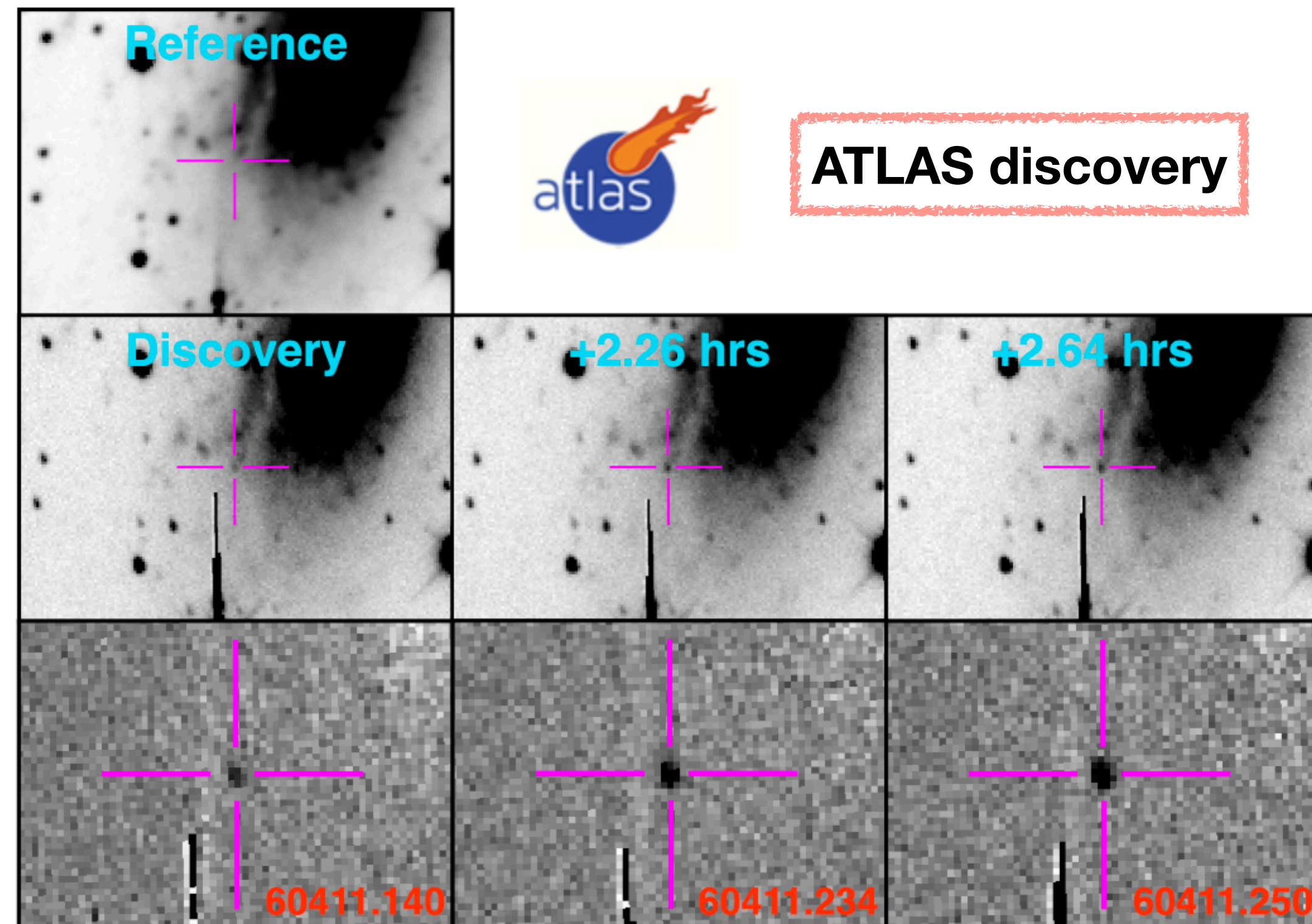


Facing the Pacific Ocean and at low latitude, Taiwan has access to large area of the sky, making it well suited for fast, flexible transient follow-up.

First-day CCSN science, e.g. SN 2024ggi

On the 11th April 2024...

A new transient, SN 2024ggi, was discovered in NGC 3621 at ~6.7 Mpc, making it among the nearest core-collapse SNe discovered in recent years.



A rapid intra-night rise of 1.03 mag over a span of 2.64 hours

Discussions in *Slack*

Shubham Srivastav 11:04 AM
<https://star.pst.qub.ac.uk/sne/atlas4/candidate/1111822090325015200/>
fast track object at 7 Mpc

Stephen Smartt 1:28 PM
Maybe pause on sending until we see it in the SLT ? Is this minutes Janet ??



Shubham Srivastav 1:43 PM
<https://www.wis-tns.org/astronotes/astronote/2024-100>
Posted

(posted with permission)

Confirmation image from a 40cm SLT



T.-W. Chen et al. 2025
ApJ, 983, 86

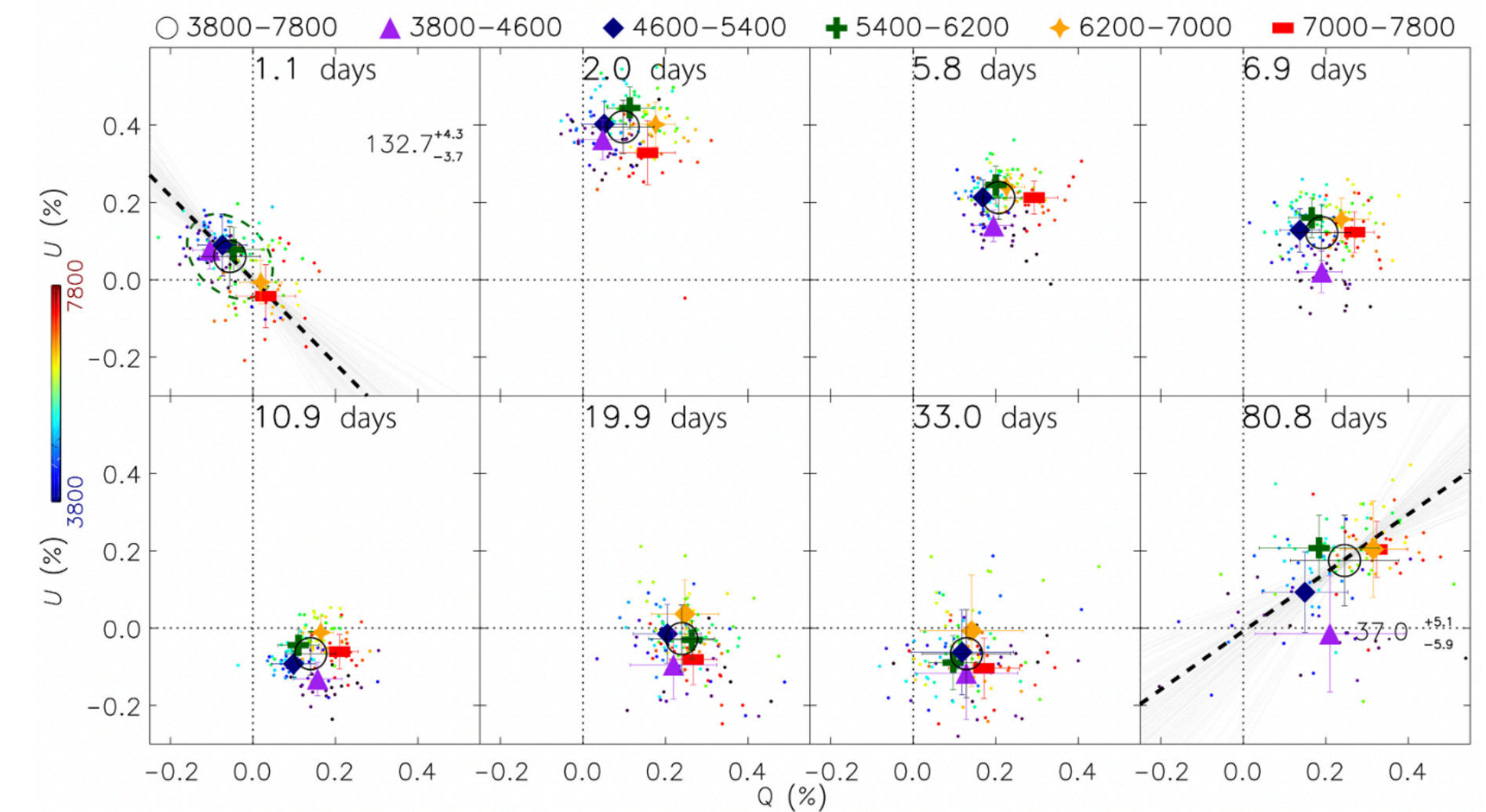
First-day CCSN science, e.g. SN 2024ggi

A social media post triggered a rapid response

VLT/FORS2 was triggered!

Citizen scientists joined the effort

Spectropolarimetry of SN 2024ggi



Y. Yang et al. 2026



Six AstroNotes at one night!

2024-04-11 11:43:14 Type: Object/s-Discovery/Classification Bibcode: [2024TNSAN.100....1S](#)

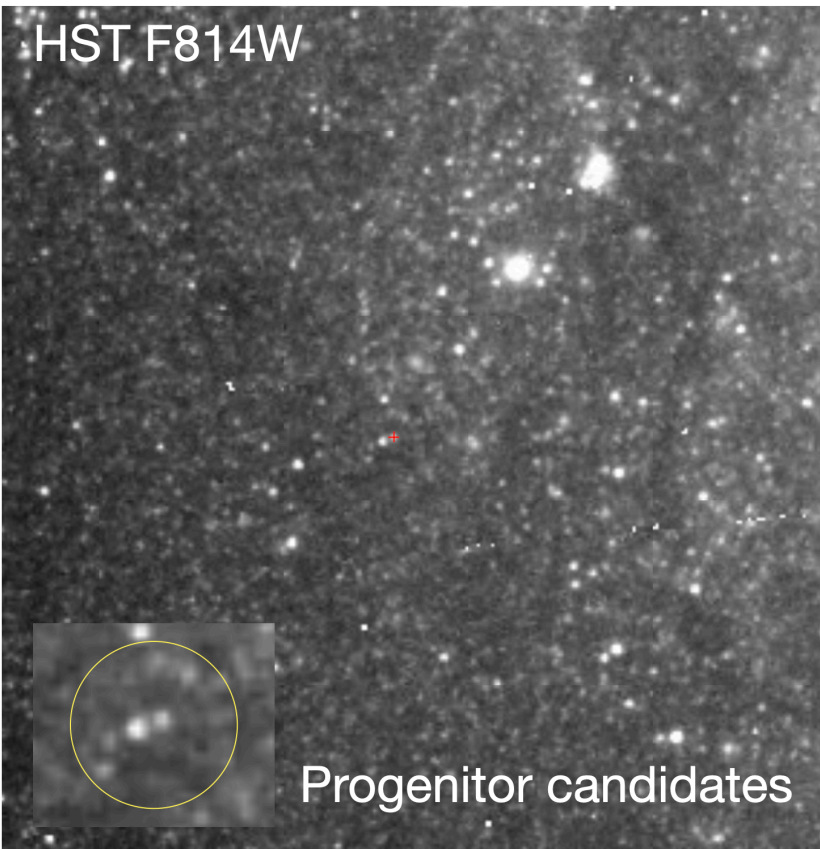
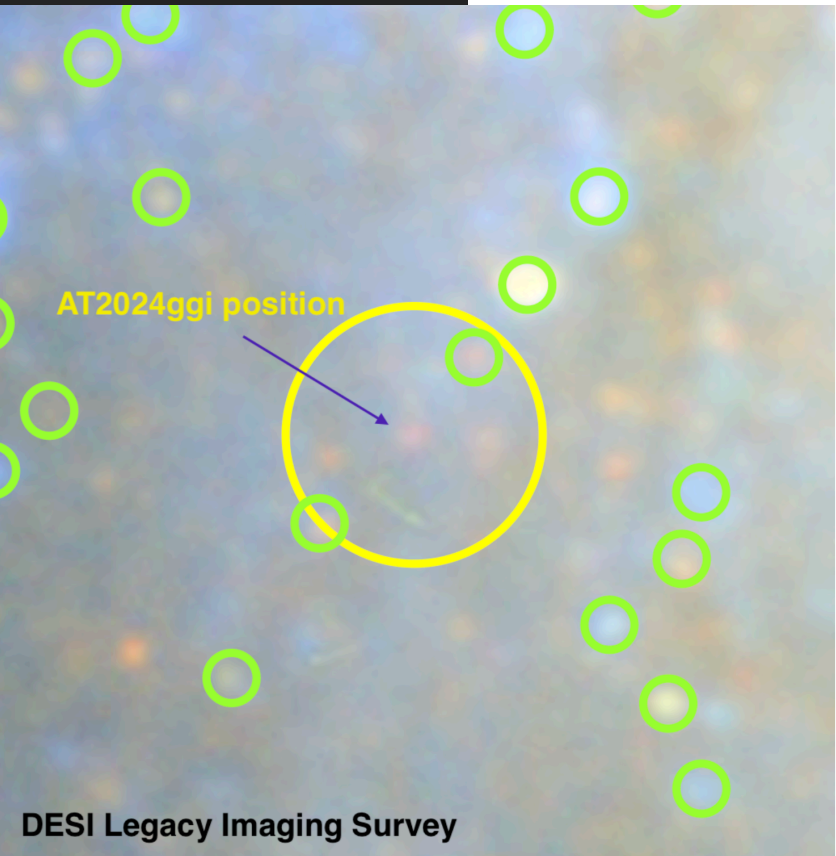
ATLAS24fsk (AT2024ggi): discovery of a nearby candidate SN in NGC 3621 at 7 Mpc with a possible progenitor detection

Authors: S. Srivastav (Oxford), T.-W. Chen (NCU), S. J. Smartt (Oxford/QUB), M. Nicholl, K. W. Smith, D. R. Young, M. Fulton, M. McCollum, T. Moore, J. West, Aamer, C. R. Angus (QUB), P. Ramsden (QUB/Birmingham), L. Shingles (GSI/QUB), J. Gillanders, L. Rhodes, A. Andersson, H. Stevance (Oxford), L. Dennehy, Weiland, A. Lawrence, R. Siverd (IfA, University of Hawaii), N. Erasmus, W. Koorts (South African Astronomical Observatory), A. Jordan, V. Suc (UAI, Obstechn), Stubbs (Harvard), J. Sommer (LMU/QUB)

2024-04-11 13:34:05 Type: Object/s-Discovery/Classification Bibcode: [2024TNSAN.102....1C](#)

Kinder follow-up observations of AT 2024ggi (ATLAS24fsk)

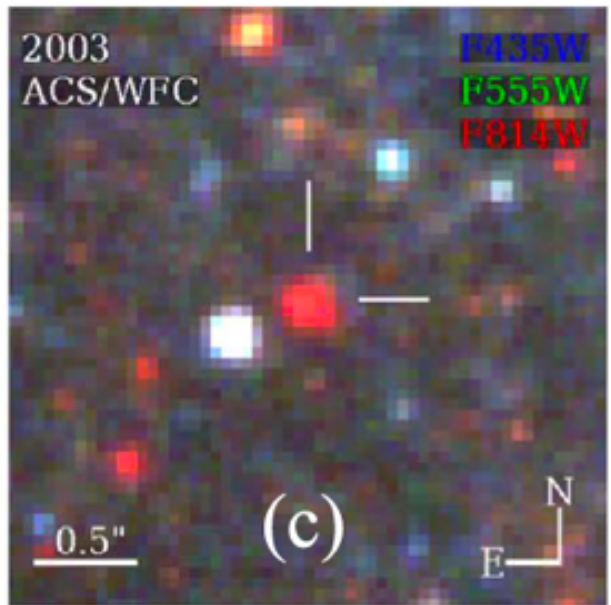
Authors: T.-W. Chen, A. Sankar.K (both NCUIA), S. Yang (HNAS), S. Srivastav (Oxford), S. J. Smartt (Oxford/QUB), W.-J. Hou, C.-S. Lin (both NCUIA), S. Lee, C.-H. Lai, A. Aryan, H.-Y. Hsiao, Y.-C. Pan, C.-C. Ngeow, H.-C. Lin, J.-K. Guo (NCUIA), H. Stevance, J. Gillanders (Oxford), K. W. Smith, M. Fulton, Aamer (all QUB)



2024-04-11 17:35:13 Type: Object/s-Data/Analysis Bibcode: [2024TNSAN.105....1Y](#)

Maximum luminosity of the progenitor of SN 2024ggi (ATLAS24fsk) from the Legacy Survey images

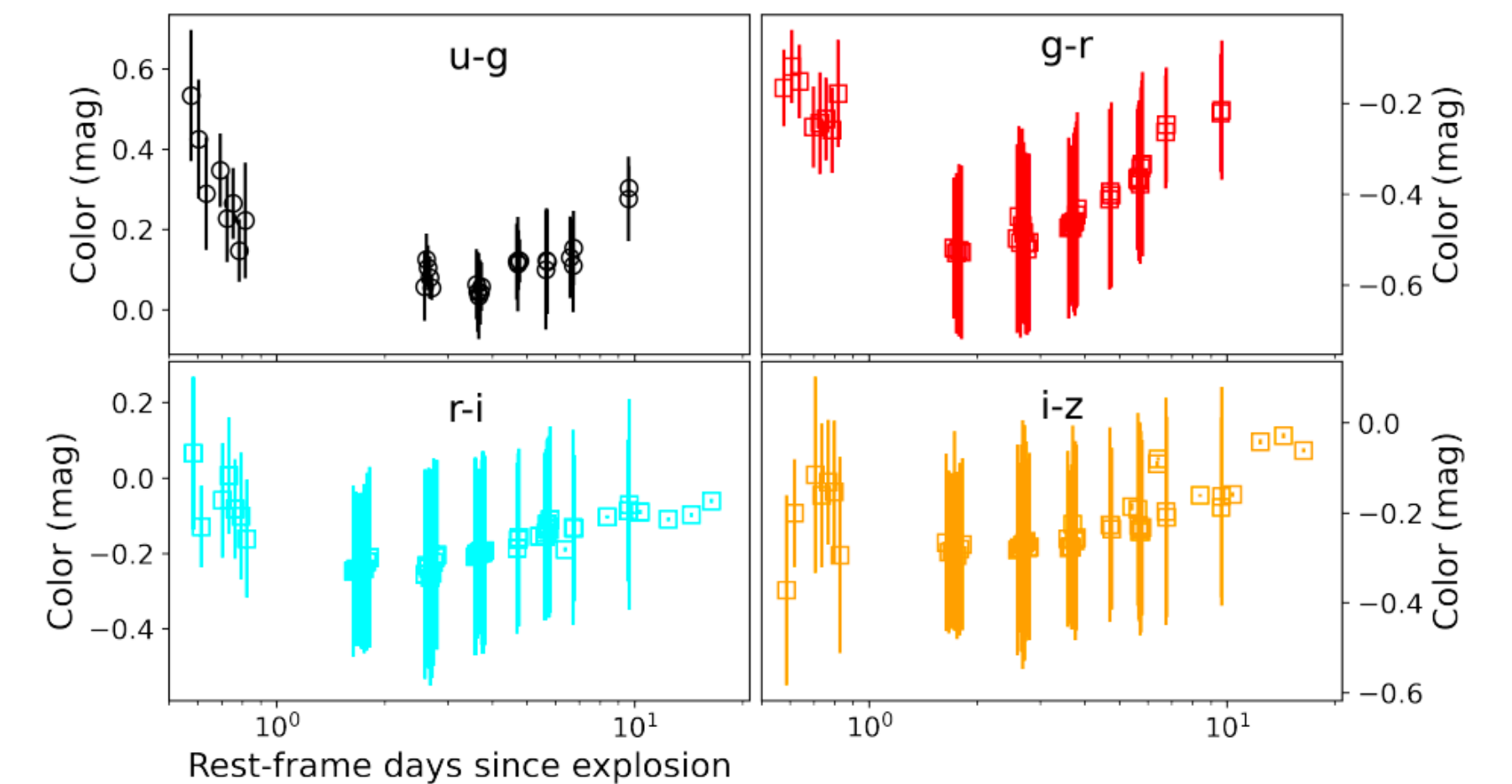
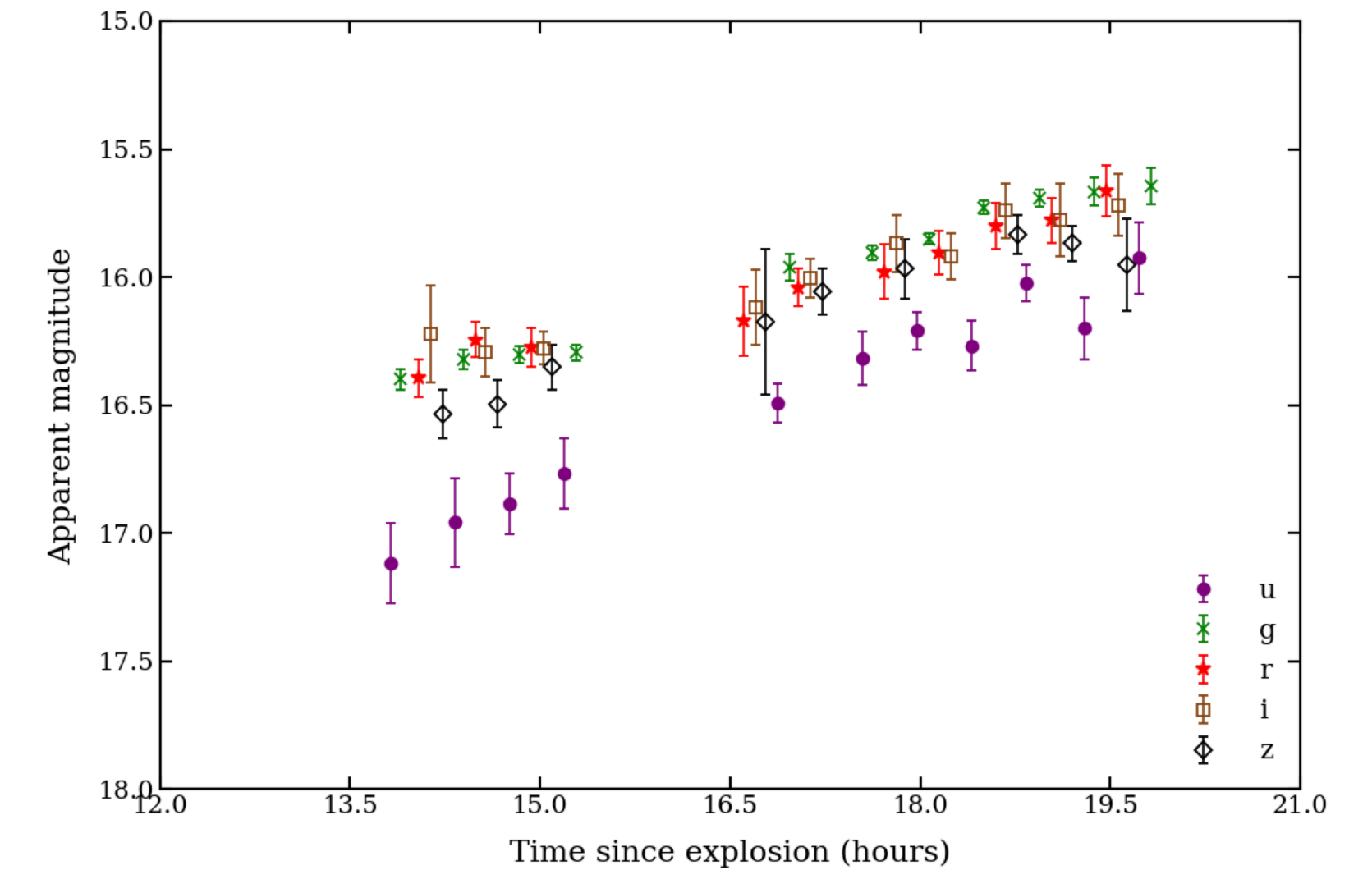
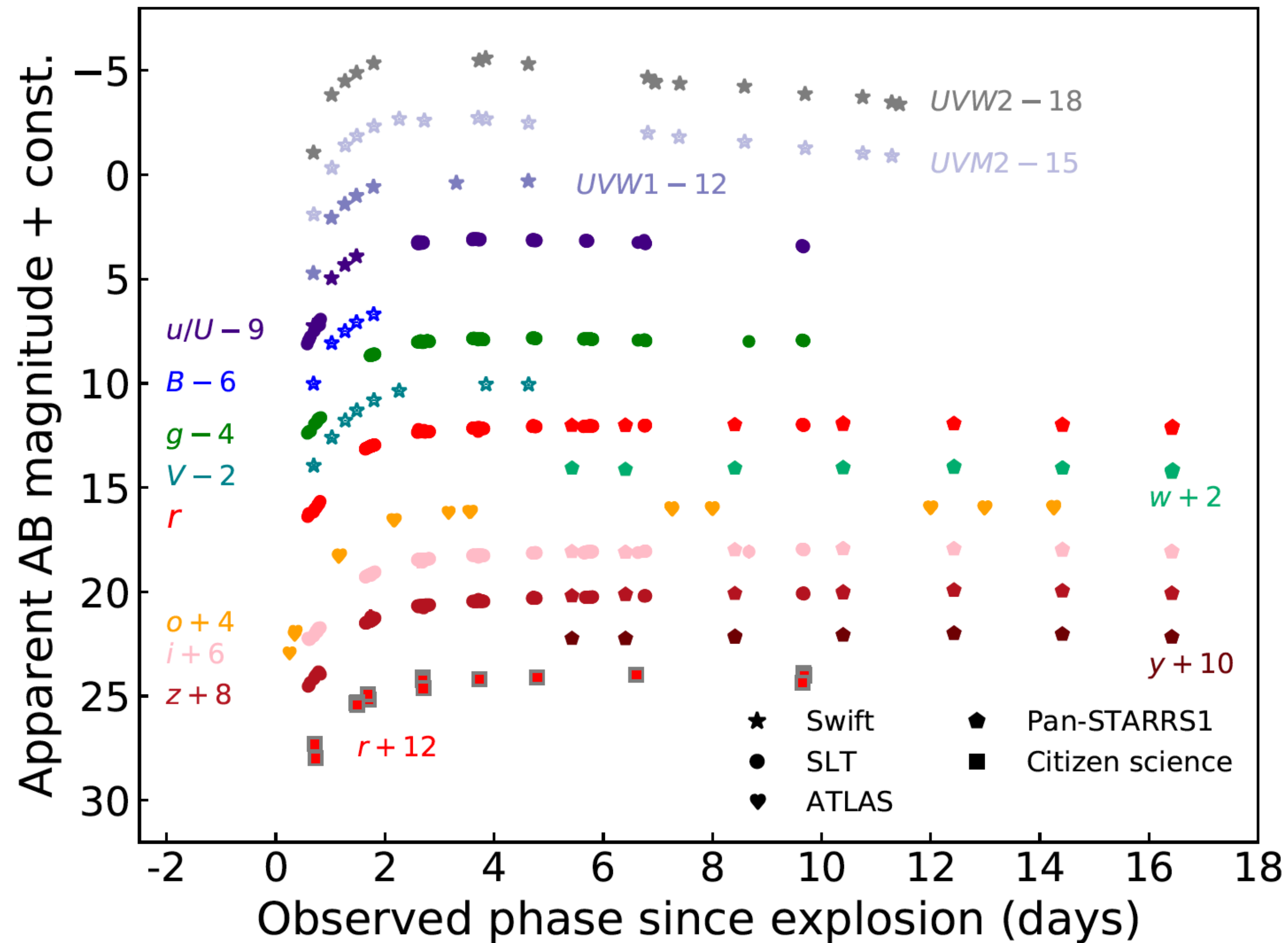
Authors: S. Yang (HNAS), T.-W. Chen (NCUIA), H.F. Stevance (Oxford/QUB), S. J. Smartt (Oxford/QUB), S. Srivastav (Oxford), J. Gillanders (Oxford), M. Fulton (QUB), T. Moore (QUB), K. W. Smith (QUB)



see also Killestein et al., AstroNote 2024-101; Hoogendam et al., AstroNote 2024-103; Zhai et al., AstroNote 2024-104, all posted on 2024-04-11

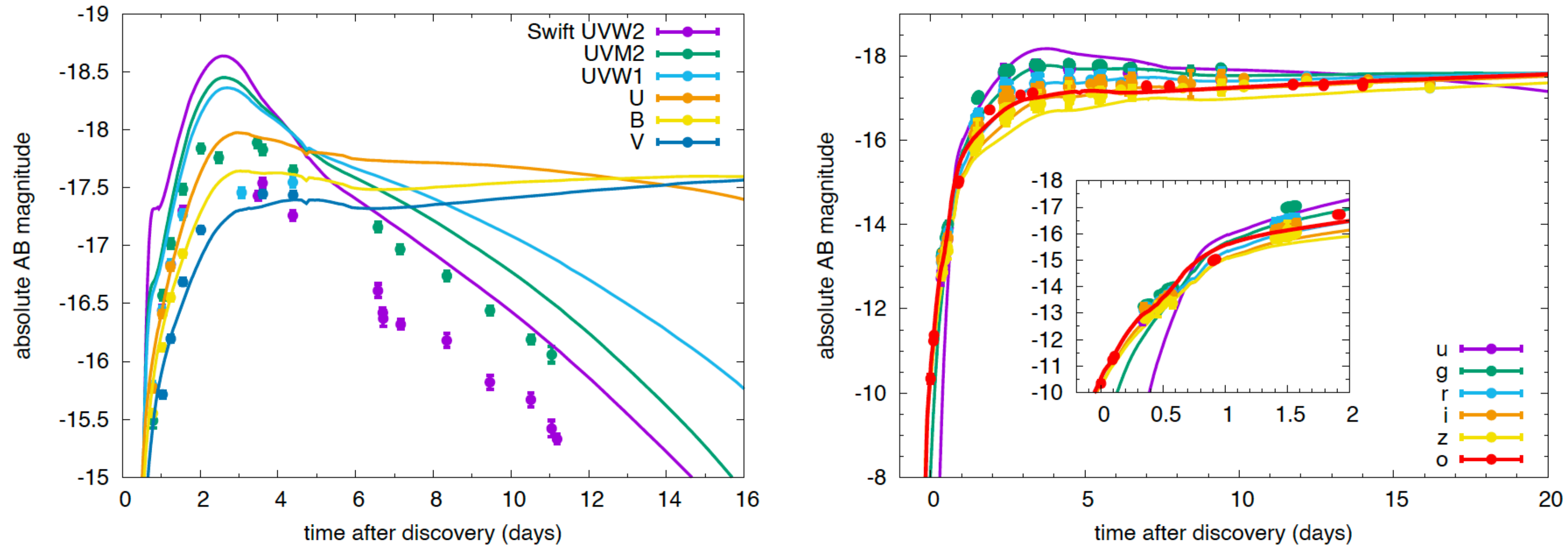
Xiang et al. 2024
initial mass of $\sim 13 M_{\odot}$

First-day CCSN science, e.g. SN 2024ggi



T.-W. Chen et al. 2025, ApJ, 983, 86

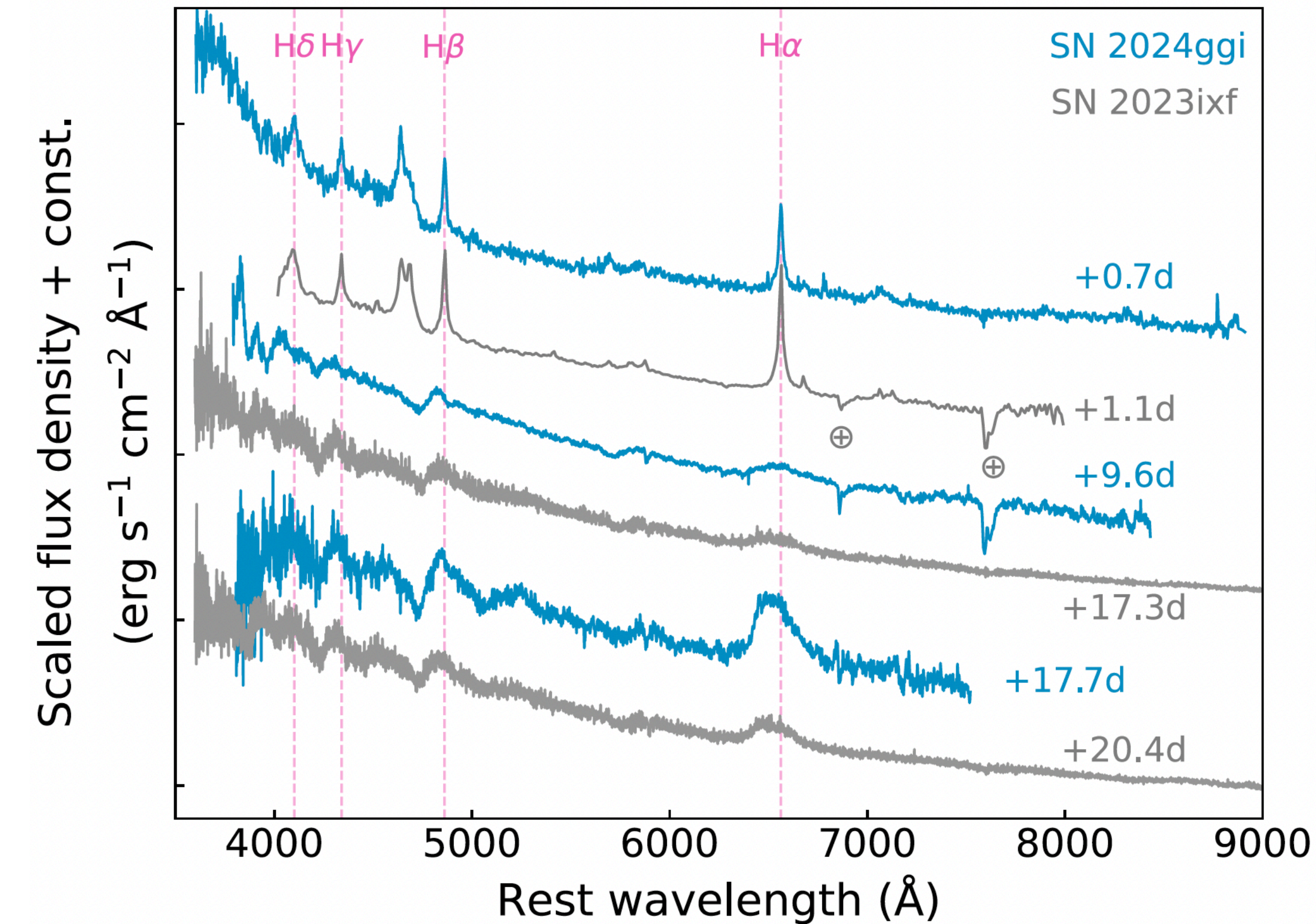
Light curve modelling



To constrain the confined CSM properties based on the early phase light curves, we searched for the best matching models from the pre-computed light-curve library presented in Moriya et al. (2023).

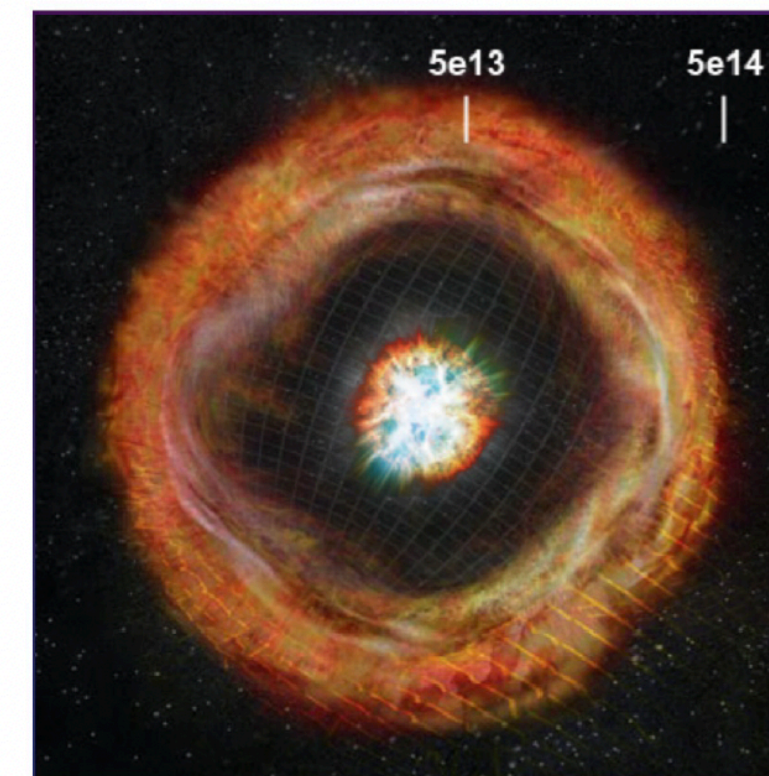
- The model has a explosion energy of 2×10^{51} erg, a mass-loss rate of $10^{-3} M_{\odot} \text{ yr}^{-1}$ (with the assumed 10 km s^{-1} wind), a confined CSM radius of $6 \times 10^{14} \text{ cm}$, and $\beta = 4.0$. The corresponding **CSM mass is $0.4 M_{\odot}$** .

First-day CCSN science, e.g. SN 2024ggi

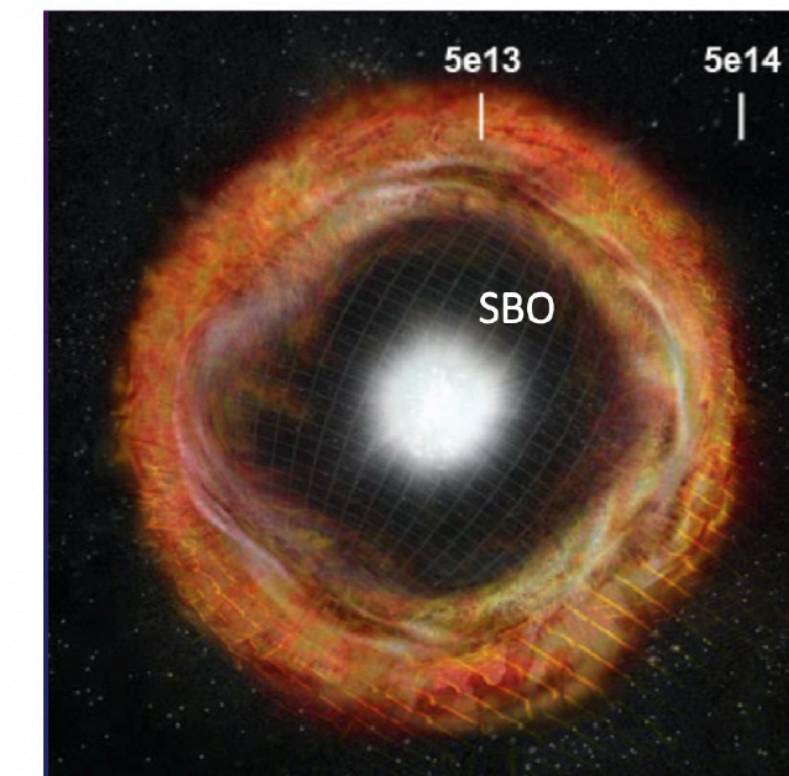


T.-W. Chen et al. 2025, ApJ, 983, 86

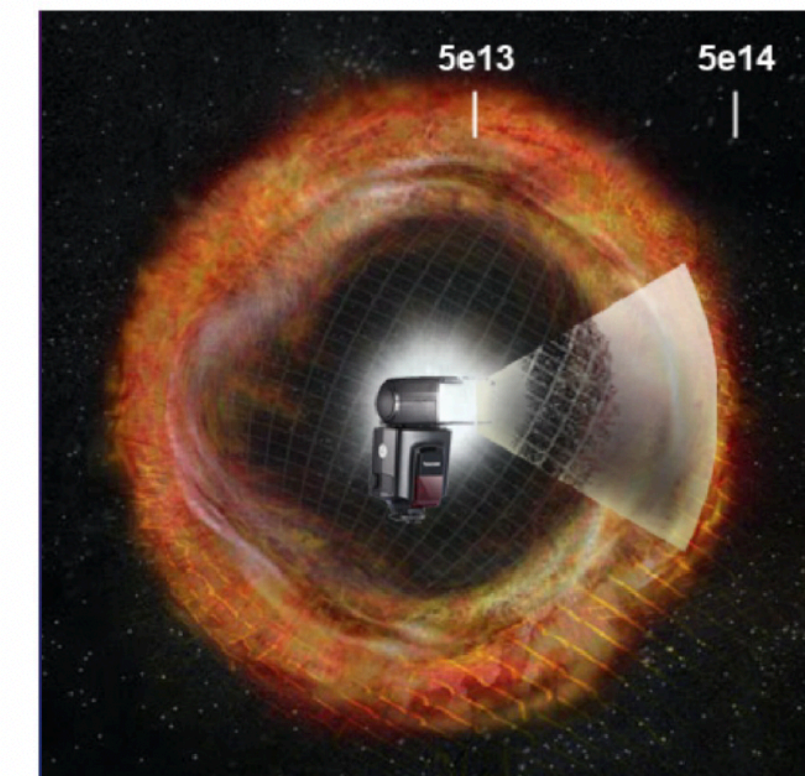
Evidence for pre-SN mass-loss: Flash spectroscopy



Progenitor is embedded in circumstellar material or optically thick wind



SN shock break-out illuminates and ionizes circumstellar material



Circumstellar material reacts immediately and produces a series of recombination emission lines of H, He, C, N, O + their ions

Credit: Ofer Yaron

Infant SN project within ZTF:
6/10 SNe II with spectra obtained <48 hours after explosion show flash features. (R. J. Bruch et al. 2021)

How do massive stars lose their envelopes?

Can we connect observed SN classes to physical progenitor channels?

The stripped-envelope sequence:

Type II → IIb → Ib → Ic → Ic-BL

This sequence encodes:

- hydrogen-envelope loss
- helium-envelope loss
- metallicity-dependent winds
- binary stripping
- explosion energy
- viewing angle and asymmetry
- possible central engines

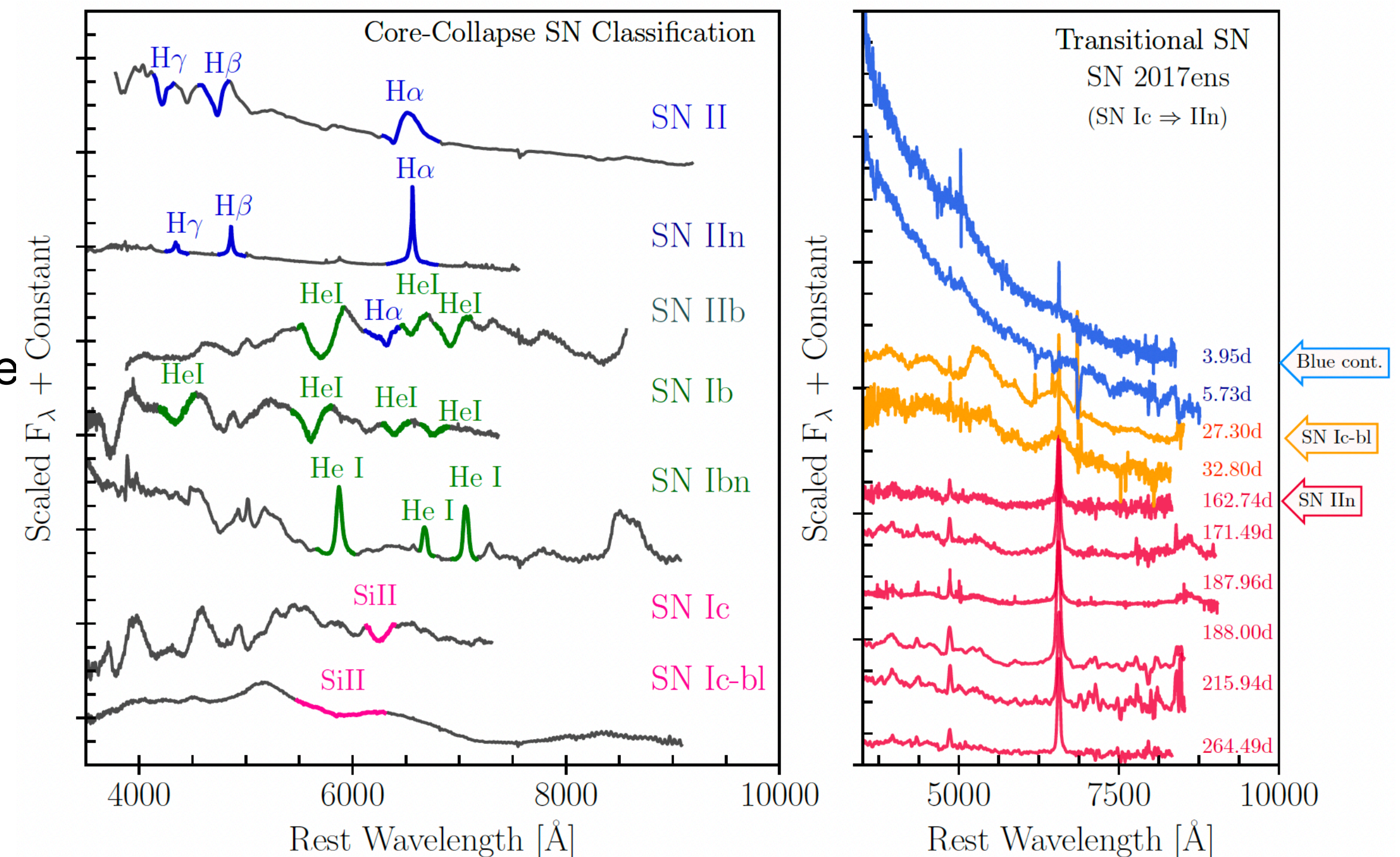
Spectroscopy beyond classification

Classification spectra are not enough

A complete CCSN spectroscopic strategy needs:

- very early spectra: flash features and CSM composition
- photospheric spectra: velocities, line evolution, envelope structure
- nebular spectra: core composition, asymmetry, nucleosynthesis
- NIR spectra: He, C/O, dust, molecules
- spectropolarimetry: geometry and asymmetry

The same object requires different spectra at different phases for different science.



Modjaz, Gutiérrez & Arcavi 2019

Spectroscopic metamorphosis, e.g. SN 2017ens

*I asked for help —
and the community answered!*

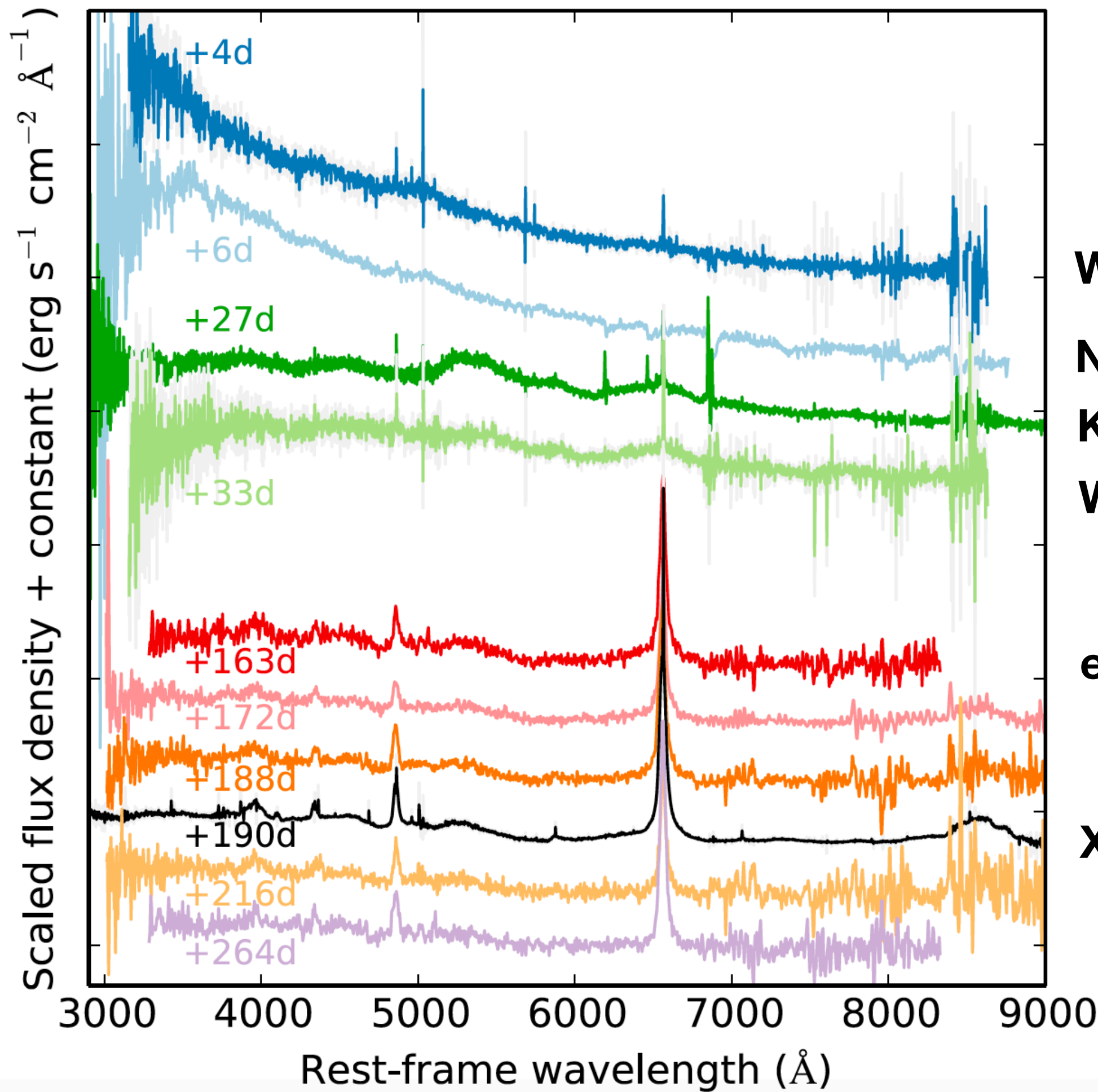
**ATLAS17gqa/AT2017ens GREAT followup: a
spectroscopic classification of superluminous
supernova candidate encouraged**

ATel #10583; *T.-W. Chen, T. Schweyer and P. Schady (MPE Garching)*
on 19 Jul 2017; 14:21 UT
Distributed as an Instant Email Notice Supernovae
Credential Certification: Ting-Wan Chen (jchen@mpe.mpg.de)

Subjects: Infra-Red, Optical, Supernovae, Transient, Tidal Disruption Event

Referred to by ATel #: [10587](#)

**SN 2017ens at $z=0.1086 \rightarrow M_g=-21.1$ mag
the regime of superluminous supernovae**



WiFeS Ivo, Ashley

NOT Jesper, Francesco

Keck Alex, Dan

WiFeS Ivo

CTIO Sean attempted +45d

ePESSTO

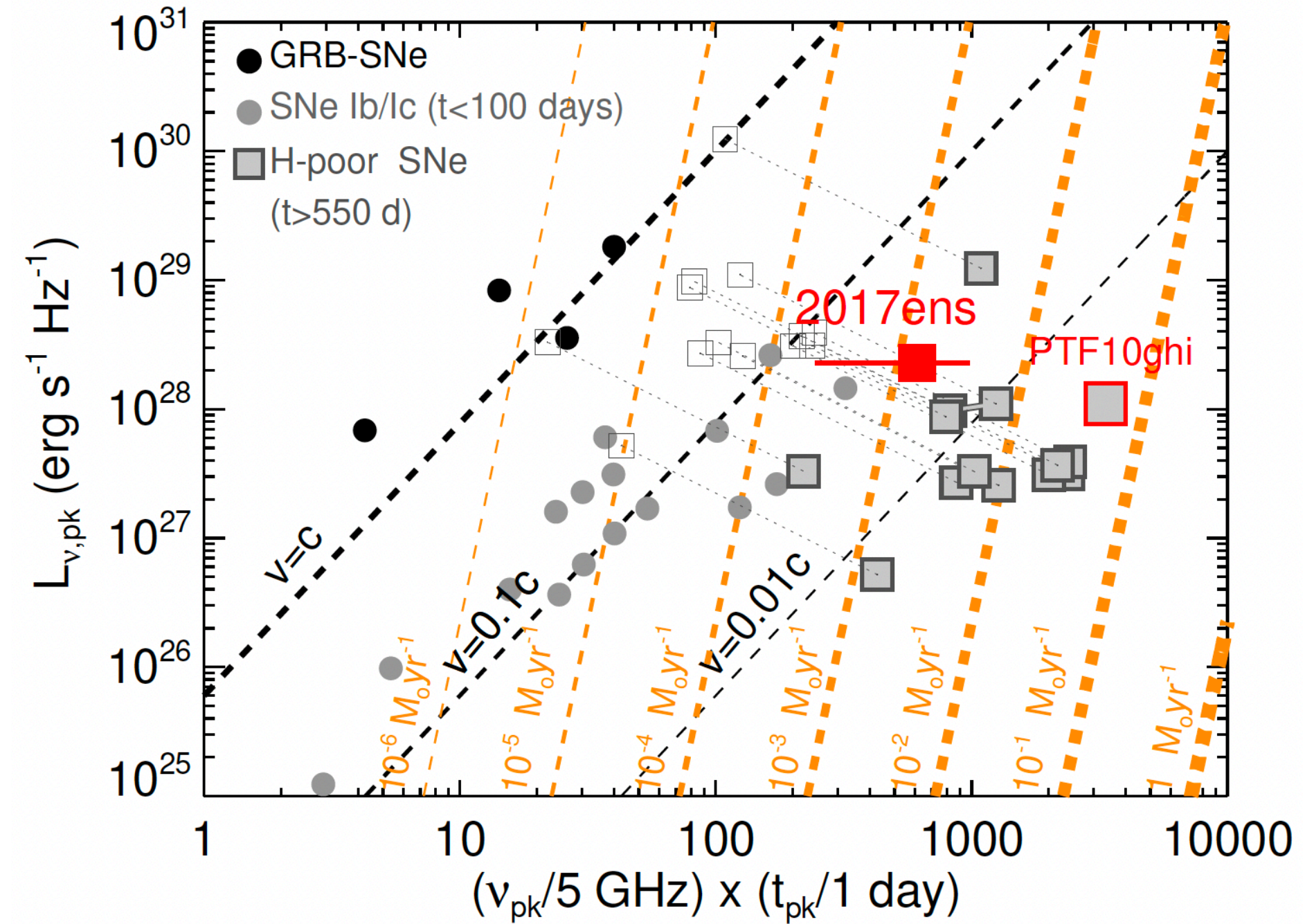
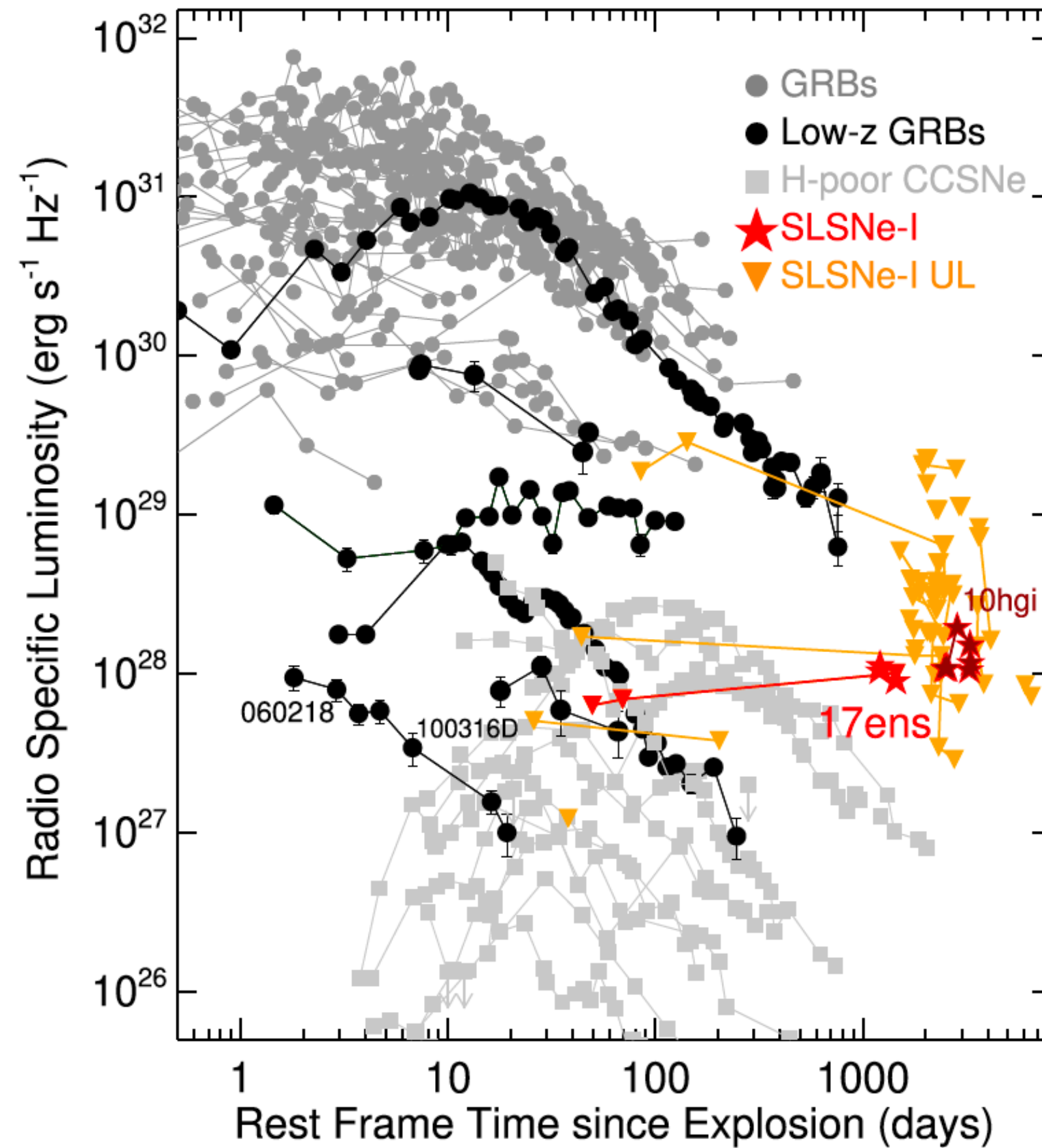
X-Shooter

Coronal lines detected!
[Fe X], [Fe XI], [Ne V], [Ca V], [Ar X], etc.

Wind velocity $\sim 50\text{--}60$ km/s measured from
the blueshift of P-Cygni of Balmer and
He I lines

T.-W. Chen et al. 2018, ApJ, 867L, 31

Spectroscopic metamorphosis, e.g. SN 2017ens



R. Margutti et al. 2023

SN 2017ens radio detection:

- Initially not detected in radio frequencies for about 300 days
- Reached $L_{\nu} \approx 10^{28} \text{ erg s}^{-1} \text{ cm}^{-2}$ at $\nu \sim 6 \text{ GHz}$, ~ 1250 days post-explosion
- Similar to interacting H-stripped SNe at late times ($t > 550$ days)

- Synchrotron radiation from SN shock and CSM interaction
- Inferred effective mass-loss rate: $\dot{m} \approx 10^{-4} M_{\odot} \text{yr}^{-1}$ at $r \sim 10^{17} \text{ cm}$
- Implies **CSM mass up to $0.5 M_{\odot}$**
- Binary interactions (common envelope evolution and envelope ejection) play a key role in shaping SLSNe progenitor evolution in $\lesssim 500$ years prior to core collapse.

Which CCSNe launch engines or relativistic outflows?

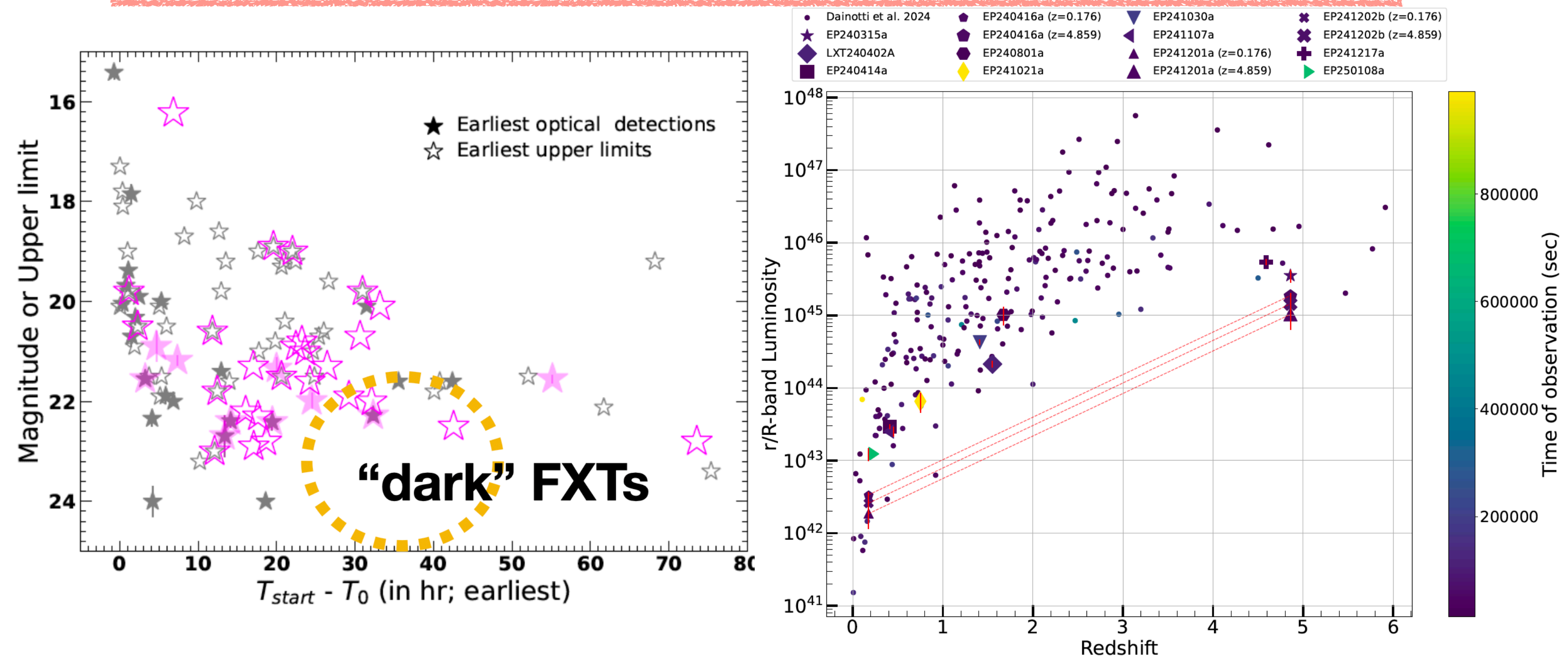
Are these separate classes, or different observational windows on a continuum of engine activity?

- GRB-SNe
- low-luminosity GRBs
- Type Ic-BL SNe
- engine-driven explosions
- FBOT-like events
- X-ray transients
- radio-bright CCSNe

partly determined by how quickly
and how extensively we observe?

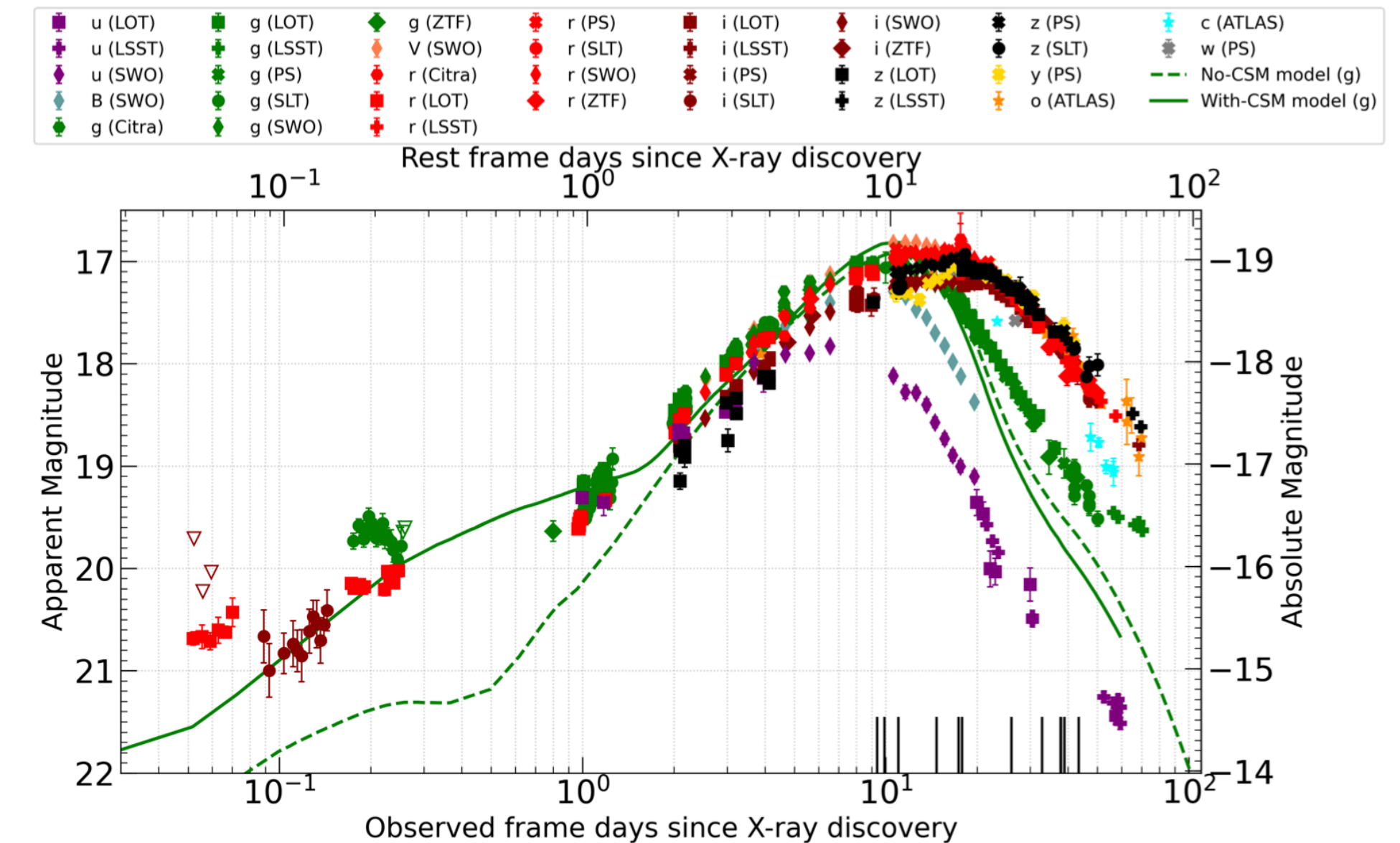
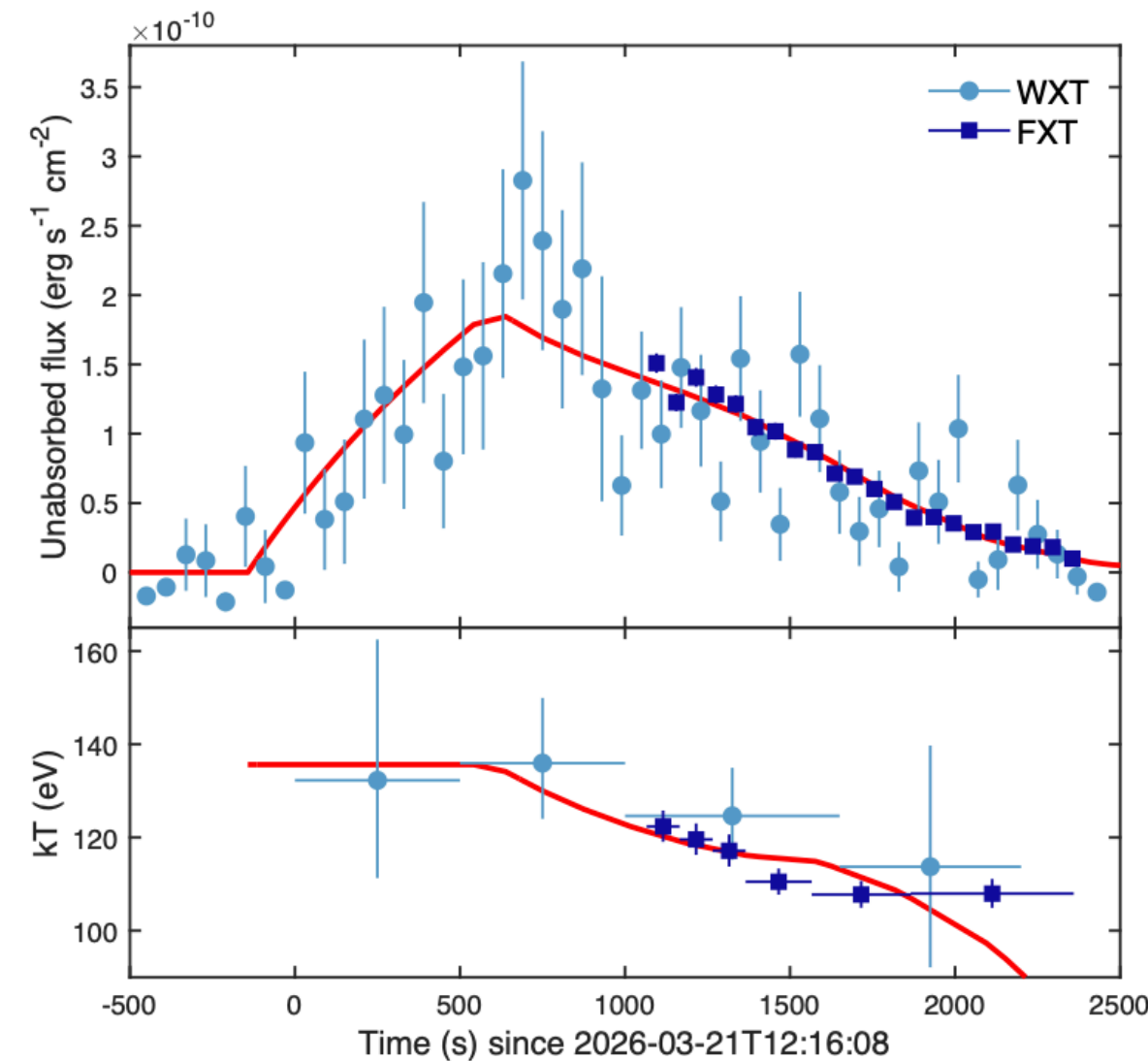
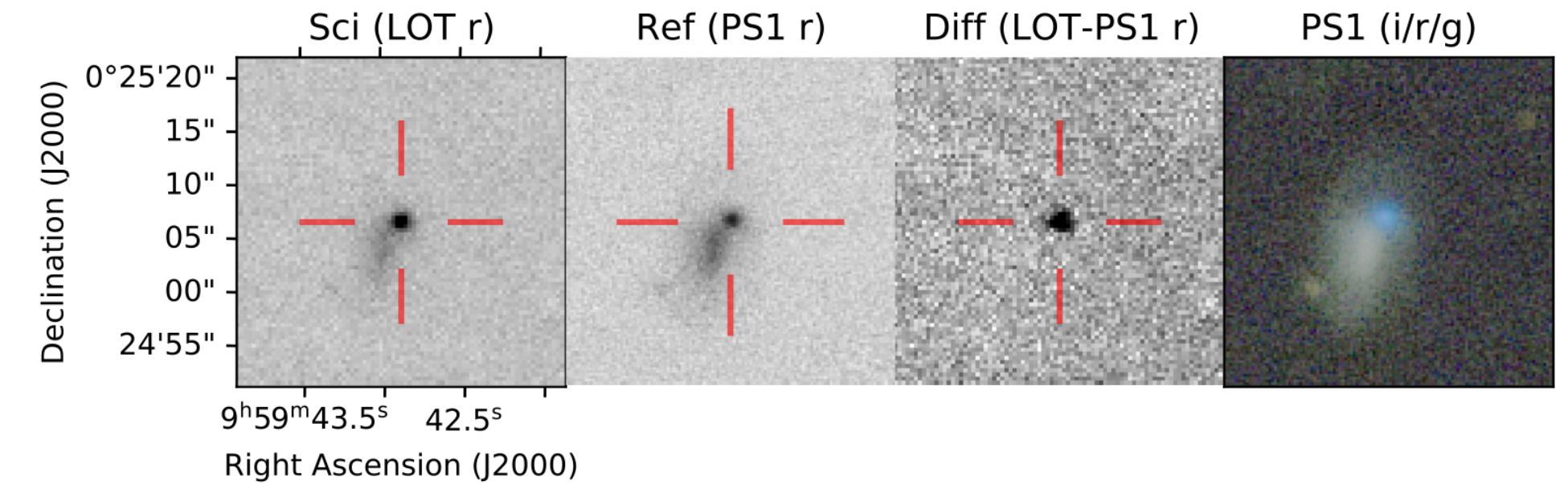
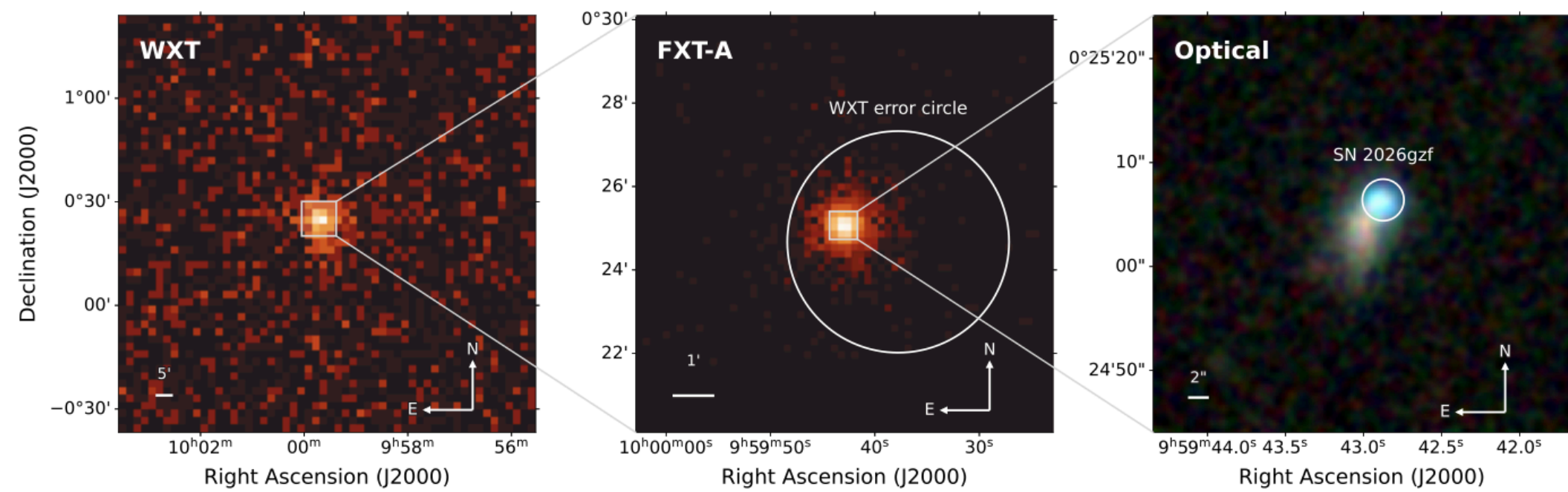
9 EP OTs discovered by Kinder!
including:
EP240414a / SN 2024gsa
EP260321a / SN 2026gzf

Kinder optical counterpart search for Einstein Probe X-ray transients



A. Aryan, T.-W. Chen et al. 2025, ApJS, 281, 20

X-ray connection, e.g. SN 2026gzf

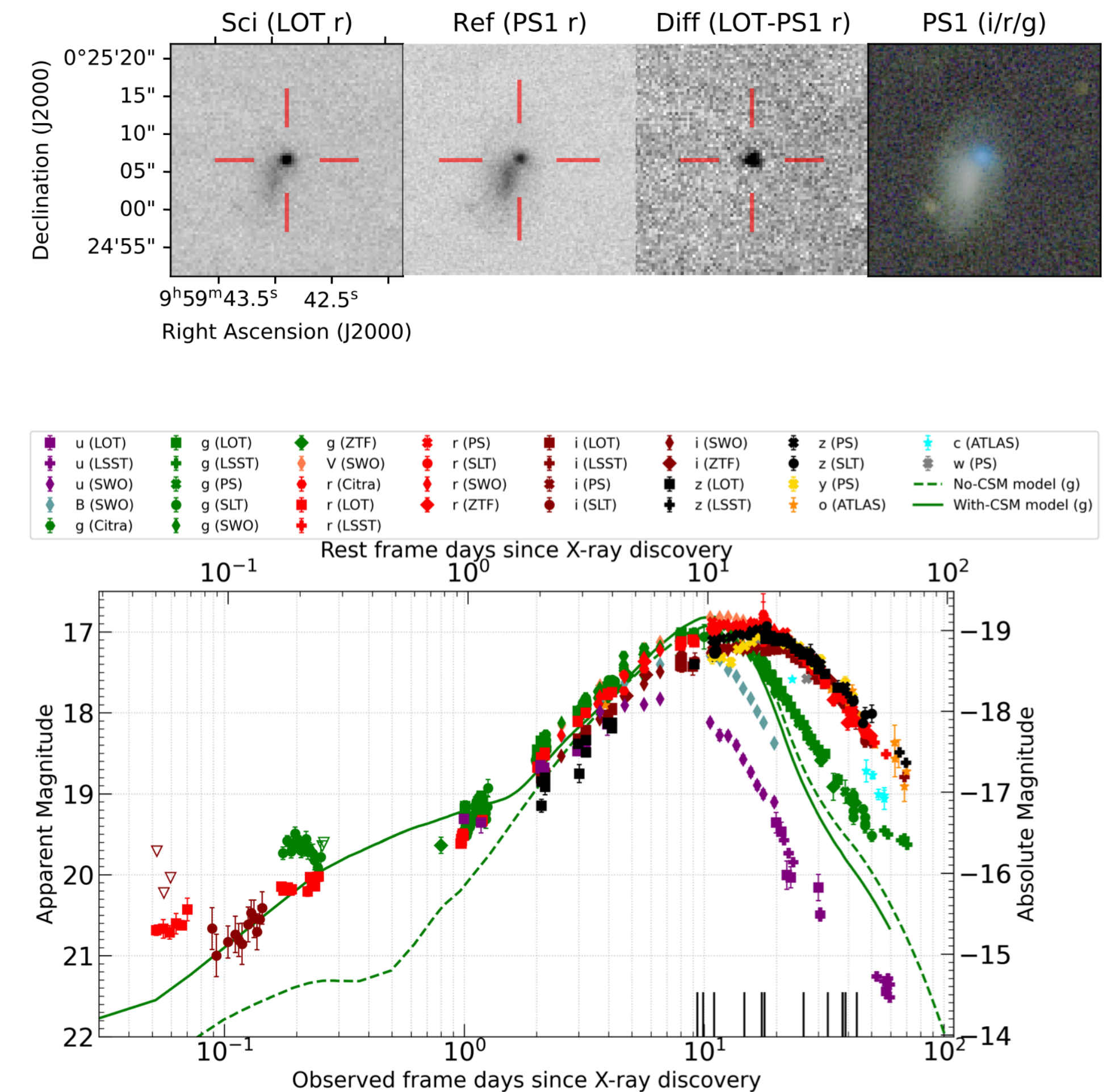
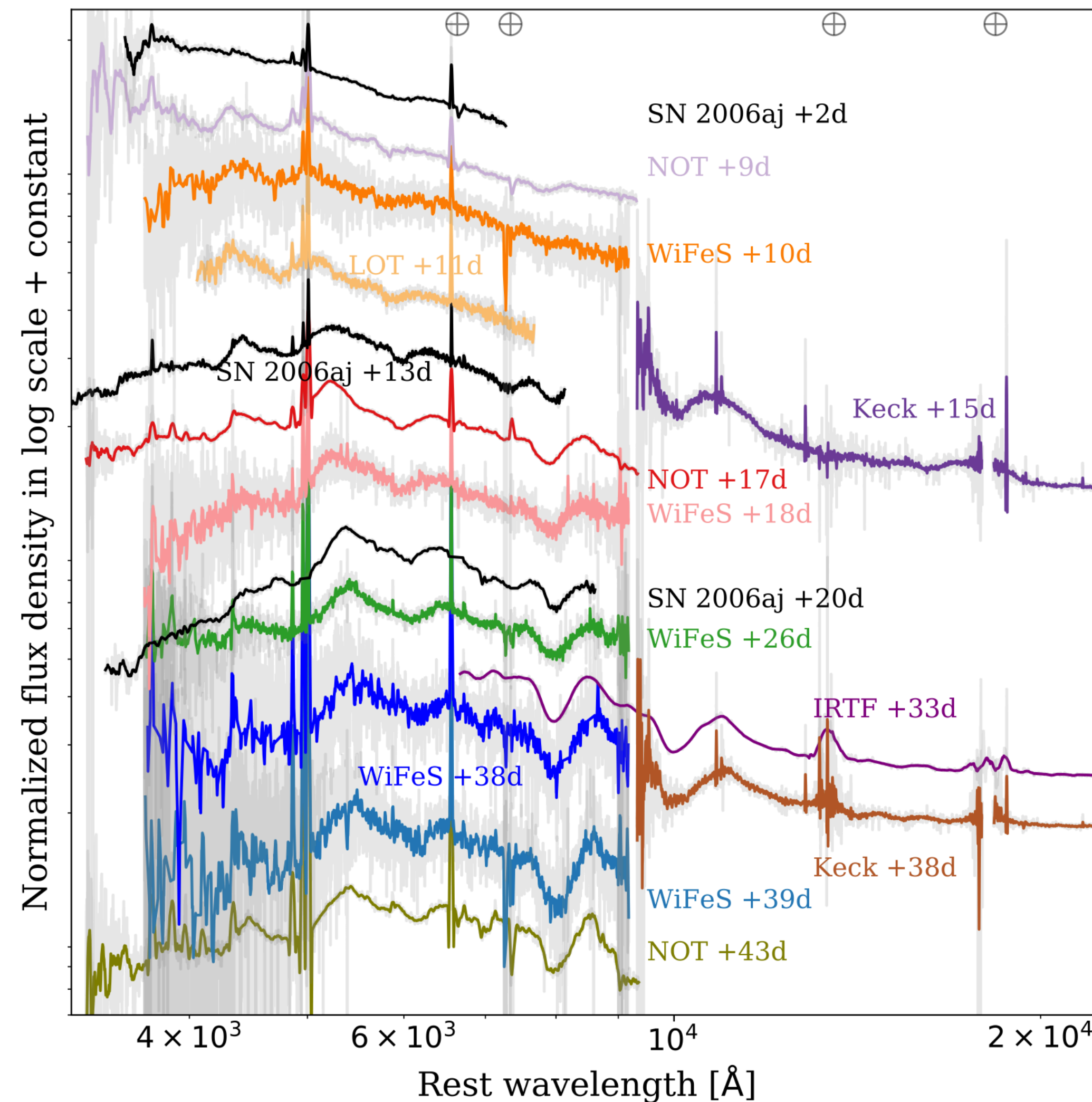


W. Yuan et al. 2026, arXiv:2606.10014

T.-W. Chen et al. 2026, arXiv:2606.10009

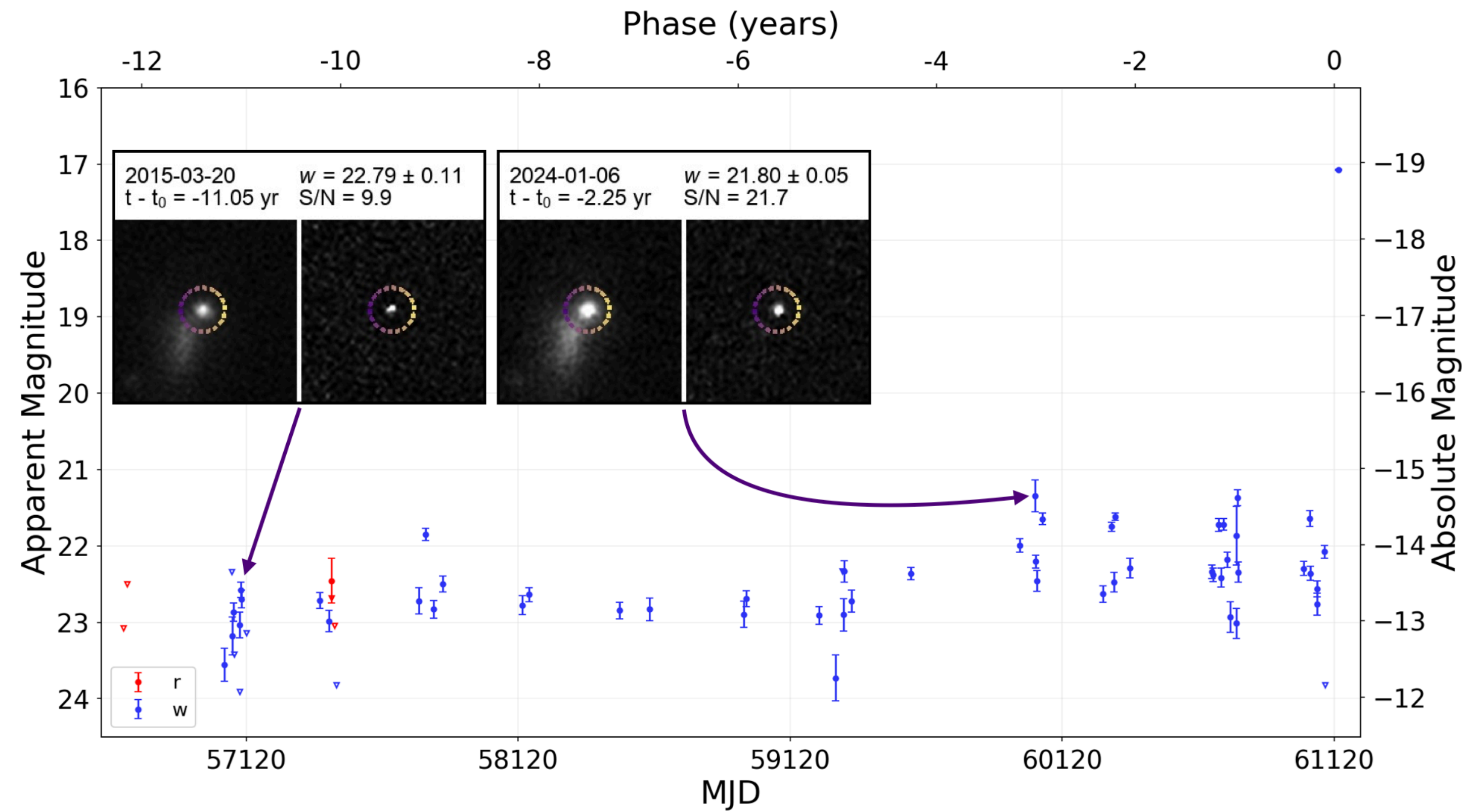
see more: A. Martin-Carrillo+26; J. C. Rastinejad+26; B. O'Connor+26; all coordinated to post on arXiv on the same day!

SN Ic-BL connection, e.g. SN 2026gzf



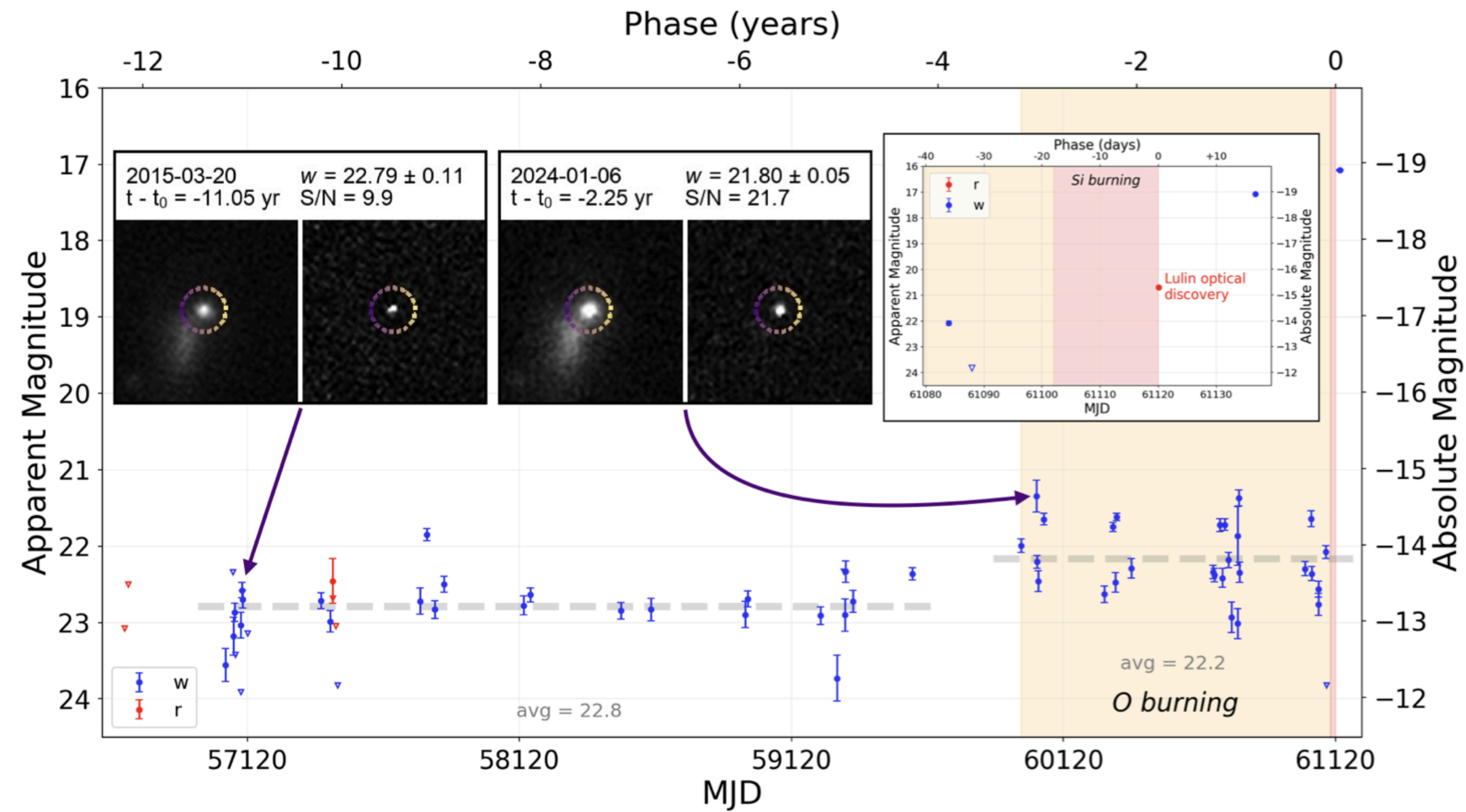
T.-W. Chen et al. 2026, arXiv:2606.10009

Precursor connection, e.g. SN 2026gzf



T.-W. Chen et al. 2026, arXiv:2606.10009

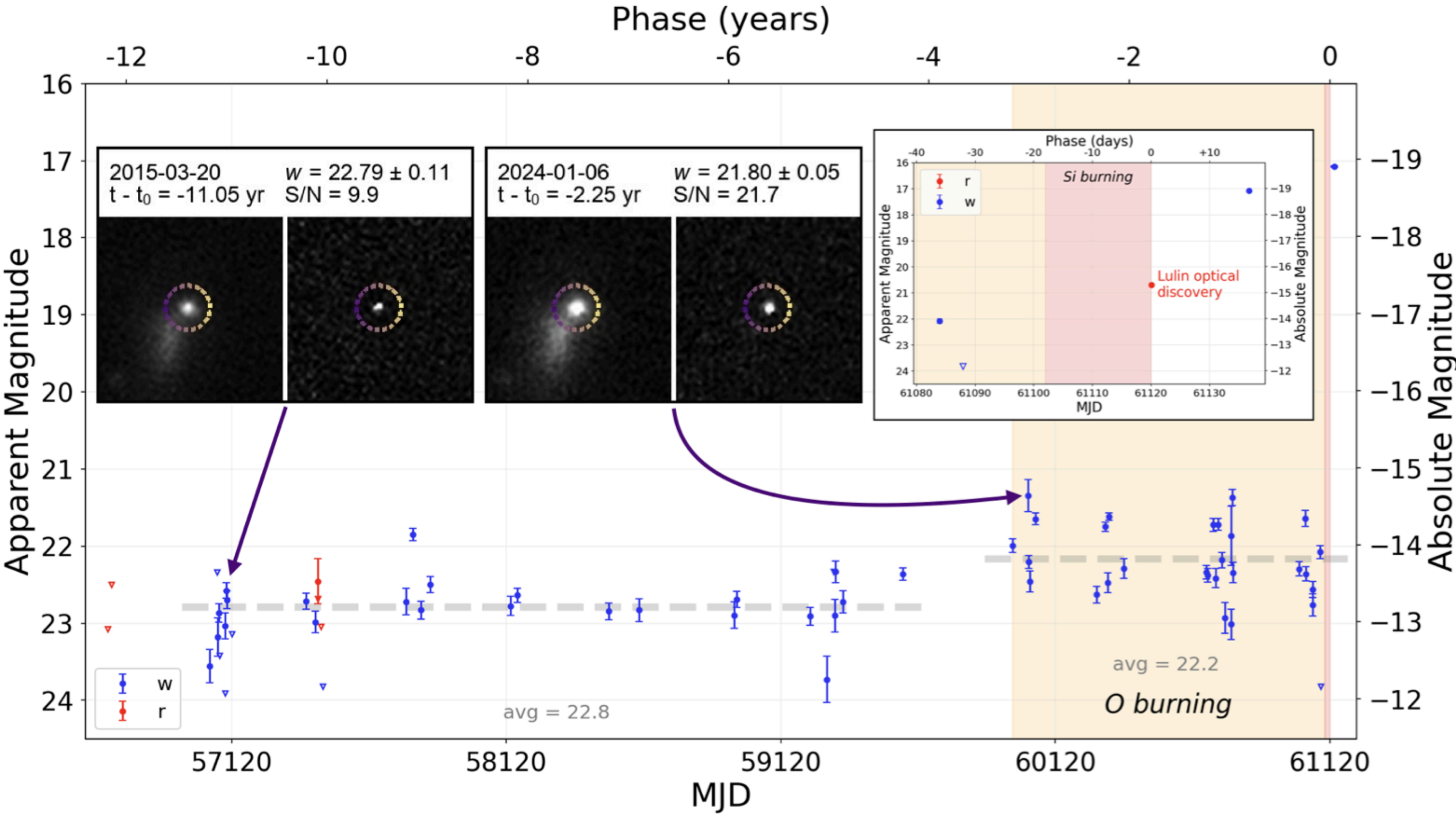
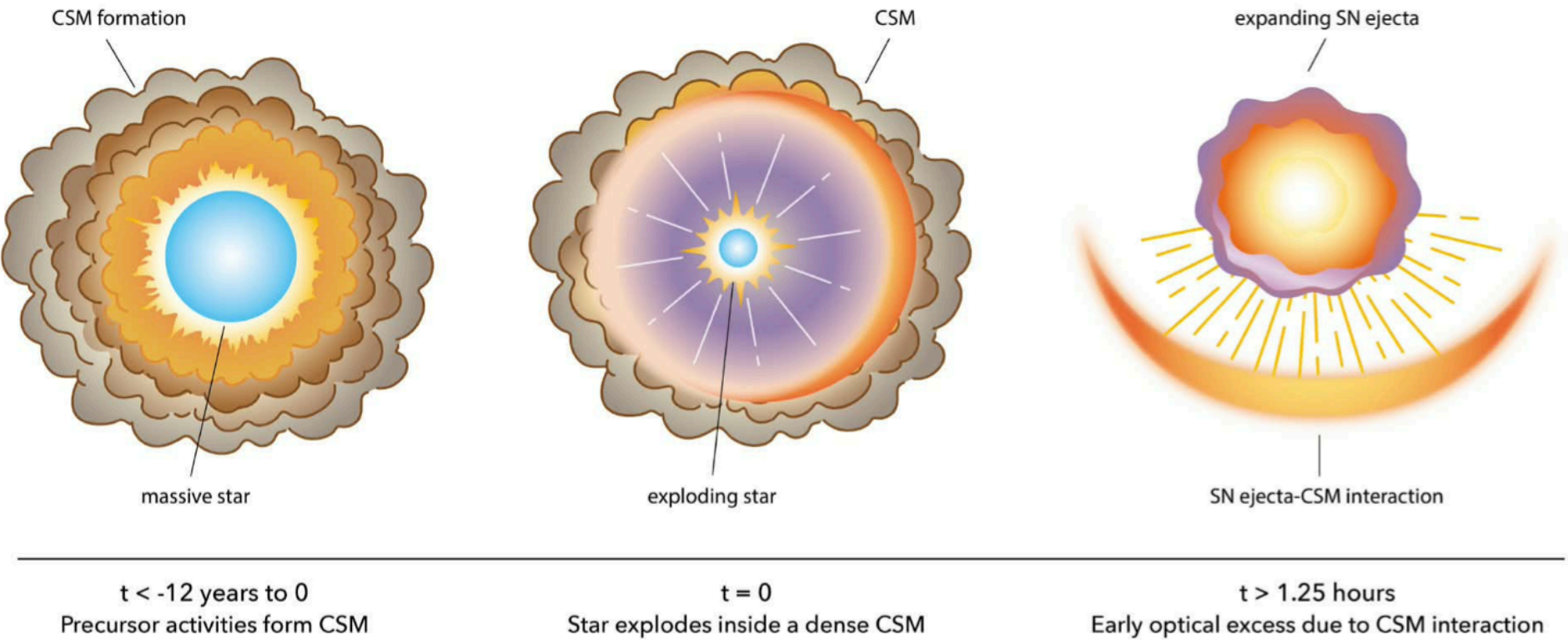
Precursor connection, e.g. SN 2026gzf



T.-W. Chen et al. 2026, arXiv:2606.10009

CSM connection, e.g. SN 2026gzf

A precursor and early CSM interaction in the Type Ic-BL SN associated with EP260321a



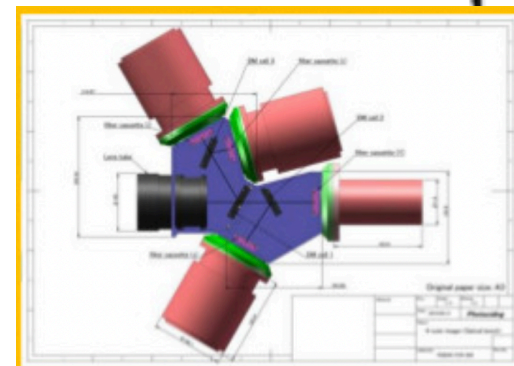
T.-W. Chen et al. 2026, arXiv:2606.10009

The Trans-Pacific Two-Meter Telescope

2-m telescope UT-6

@San Pedro Mártir Observatory
first light 2024

115° 27' 49" W
31° 02' 39" N



- First instruments:
 - long-slit spectrograph
 - 4-colour imager (r' , i' , z' , y)
- Future instruments:
 - NIR Camera
 - IFU

0.4m, 1m telescopes
@Lulin Observatory



UT+8

120° 52' 25" E
23° 28' 07" N

- Current instruments:
 - imager (UBVRI, $u'g'r'i'z'$, narrow filters)
 - luminous slit-based spectrograph (LISA)
 - TRI-color imaging POLarimeter (TRIPOL)
 - Spectroscope - UVEX

CCSNe in the time-domain era

New surveys are changing CCSN science:

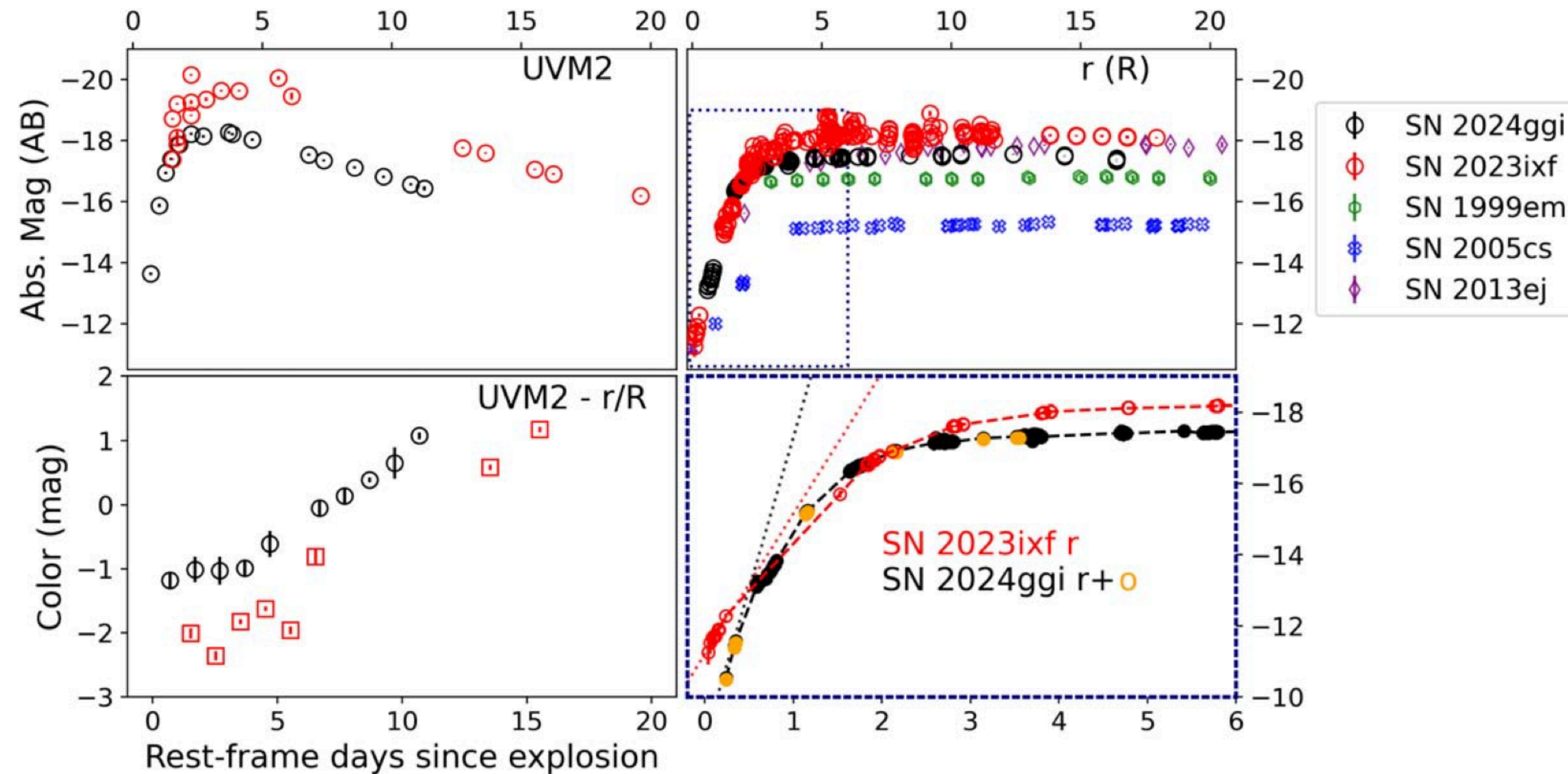
- **earlier discovery**
- **larger samples**
- **better pre-explosion limits**
- **more rare subclasses**
- **statistical progenitor constraints**
- **high-redshift CCSNe**
- **automated alert streams**

But the science still requires physical interpretation.

- **CCSNe are diverse because massive stars die in many different ways.**
- **The first hours reveal the star's surface and immediate environment; the late phases reveal the core.**
- **The time-domain era is turning CCSNe from individual discoveries into a systematic experiment in massive-star death.**

backup

Comparison between SN 2024ggi & SN 2023ixf



- SN 2024ggi is significantly dimmer in the UV. Relative to standard SNe II, early-time flashers are generally very bright in the UV (Irani et al. 2023; Jacobson-Gal'an et al. 2024b).
- SN 2024ggi exhibited a much faster rise (black dotted line) compared to SN 2023ixf (red dotted line) in the bottom right panel.
- This indicates that the CSM of SN 2024ggi is less dense than that of SN 2023ixf, although the CSM density is still high enough to affect their light curves and spectra in the early phases.