Observing Needs for “Supernovae”

Anna Ho & Carla Frohlich

Panelists: Nayana AJ, Wynn Jacobson-Galan, Itai Sfaradi, Chris Fryer

Our focus: events…

- …for which, in our experience, “there are gaps in the existing proposal process that make it hard to do some of these things right” (Tom M.)
    - …that require fast response, multi-facility observations spanning a wide range of timescales and frequencies
    - …that are unusual opportunities, i.e., ~once per decade (or rarer)
    - …would have reasonably clear, widely agreed upon triggering criteria

Outline

- Two case studies
- Essential components of a follow-up program
- What has worked well
- What could be improved
- Other considerations for the future

Two case studies in white paper so far

1. A nearby (60 Mpc) fast blue optical transient: AT2018cow

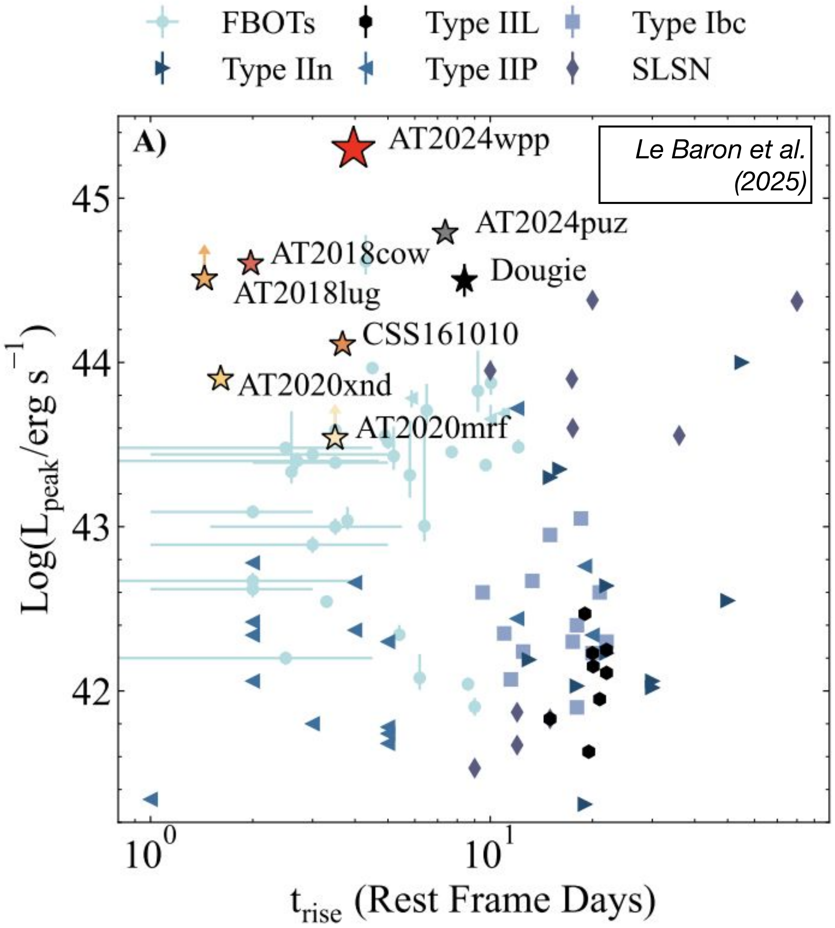
2. A nearby (7 Mpc) supernova: SN2023ixf

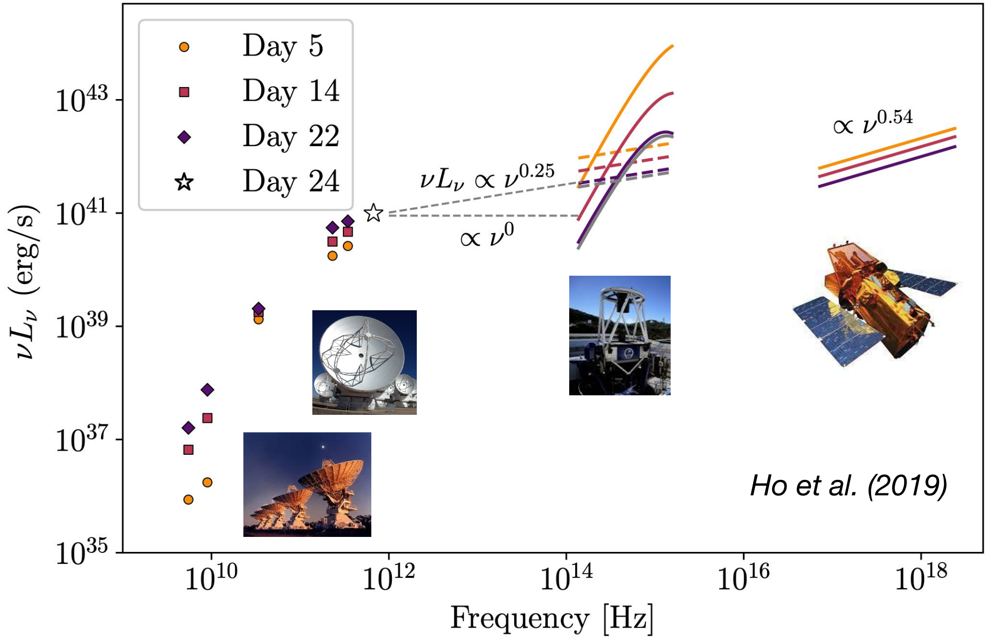
We should also think about something new/different (Galactic supernova? Unknown unknowns?)

Questions to consider:

- What infrastructure/policy changes would enable the best science to be done?
  - What is working well?
  - What are the current limitations?
- What facilities are needed and what are we concerned about losing?
- What is the line to trigger this process (which could be a community observing plan, “tiger team”)
  - 23ixf? 1987A? Milky Way?
    - And for that source class, what observations are most useful for determining the progenitors and understanding the relevant physical processes? What would be the triggering criteria?
- How to deal with something unexpected (like 18cow was at the time)?

Case Study #1: AT2018cow at 60 Mpc





Status of understanding

Ingredients: dense confined ambient matter, long-lived central engine & accretion disk, asymmetry, starforming galaxies (primarily non-nuclear), <0.1% of the CC SN rate

Models (typically black hole)

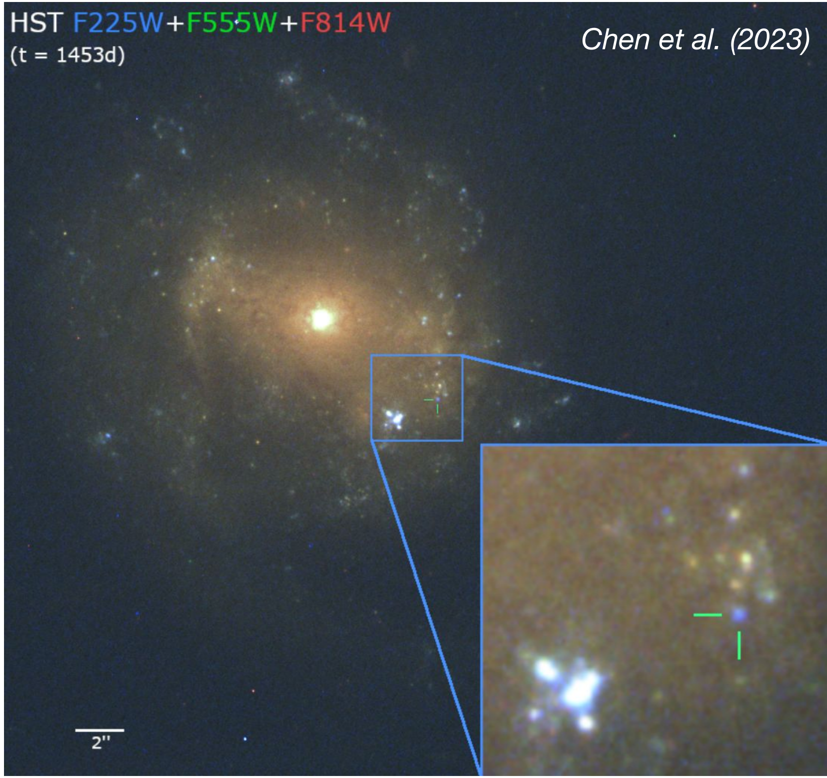
Stellar mass

Intermediate-mass

Failed supernova

TDE from merger

“Random” TDE

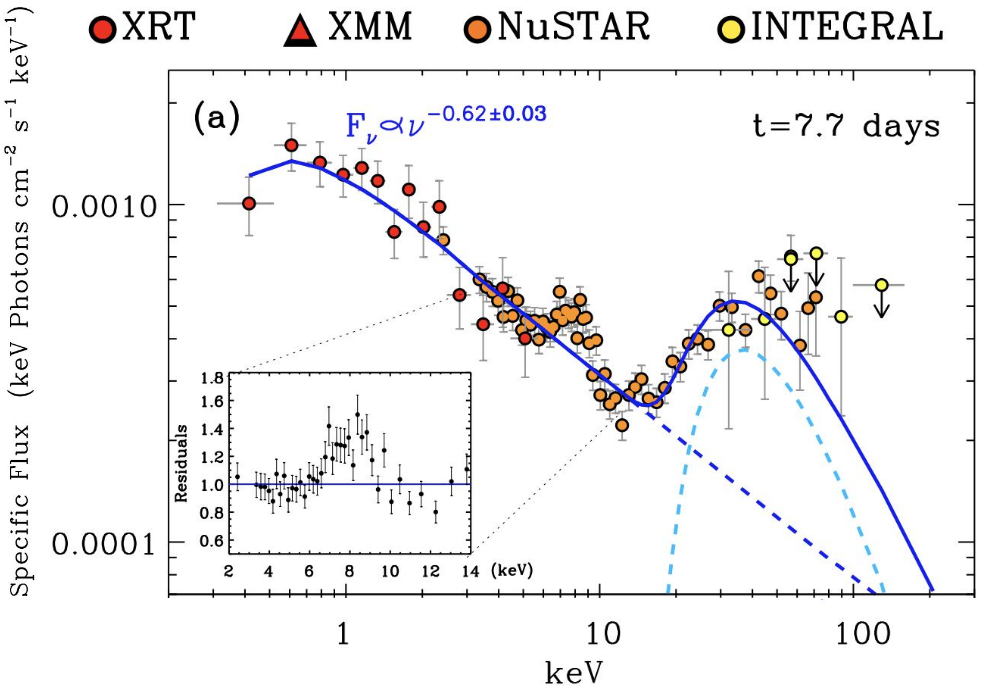


Chen et al. (2023)

Many contributions: Prentice et al. (2018), Perley et al. (2019), Fox & Smith (2019), Lyutikov & Tooonen (2019), Kuin et al. (2019), Margutti et al. (2019), Rivera Sandoval et al. (2018), Huang et al. (2019), Coppejans et al. (2020), Piro & Lu (2020), Mohan et al. (2020), Bietenholz et al. (2020), Uno & Maeda (2020), Leung et al. (2020), Nayana & Chandra (2021), Kremer et al. (2021), Margalit & Quataert (2021), Gottlieb et al. (2022), Metzger (2022), Pasham et al. (2022), Bright et al. (2022), Sun et al. (2022), Yao et al. (2022), Tuna & Metzger (2023), Ho et al. (2023), Chen et al. (2023), Maund et al. (2023), Migliori et al. (2024), Klencki & Metzger (2025), Chrimes et al. (2024), Inkenhaag et al. (2025)

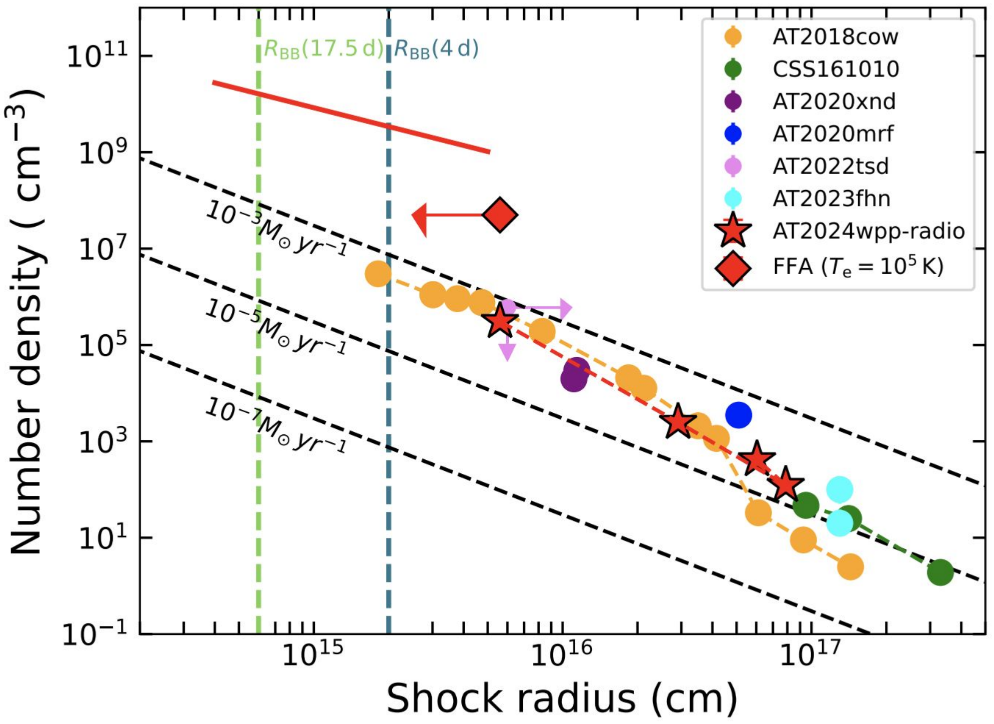
Role (so far) of specific facilities (unique contributions, capabilities)

- Swift: high cadence X-ray (variability)
- Broad-band X-rays: transient hard X-ray component
- HST photometry: luminous and fading late-time UV source (accretion disk)
- HST spectroscopy: ionization/composition
- Optical surveys: high-cadence LC, constraints on time of first light



Margutti et al. (2019)

- Optical/NIR photometric facilities: blackbody evolution, NIR excess, minutes-duration flares
- Optical spectroscopy: composition, velocity, evolution of spectral features
- ALMA, VLA, ATCA, NOEMA: inference of shockwave evolution, ambient density
- SMA: very high-cadence sub-mm monitoring, revealed variability



Nayana AJ et al. (2025)

What has worked well?

- Fast identification & announcement of something completely surprising
- Use of many major facilities
- Prompt analysis & publication
- Broad engagement of observers & theorists
- Facilities with flexibility (Swift, SMA)
- Basic observations of typical events (z=0.1-0.3)

ATEL #11727 ATEL #11727

Title: ATLAS18qqn (AT2018cow) - a bright transient spatially coincident with CGCG 137-068 (60 Mpc)

Author: S. J. Smartt, P. Clark K. W. Smith, O. McBrien, K. Maguire, D. O'Neil, M. Fulton, M. Magee, S. Prentice, C. Colin (Queen's University Belfast), J. Tonry, L. Denneau, B. Stalder, A. Heinze, H. Weiland, H. Flewelling (IfA, University of Hawaii), A. Rest (STScI),

Queries: s.smartt@qub.ac.uk

Posted: 17 Jun 2018; 22:22 UT

ATEL #11737 ATEL #11737

Title: Swift follow-up observations of the optical transient AT2018cow/ATLAS18qqn

Author: L. E. Rivera Sandoval, T. Maccarone (Texas Tech University)

Queries: liliana.rivera@ttu.edu

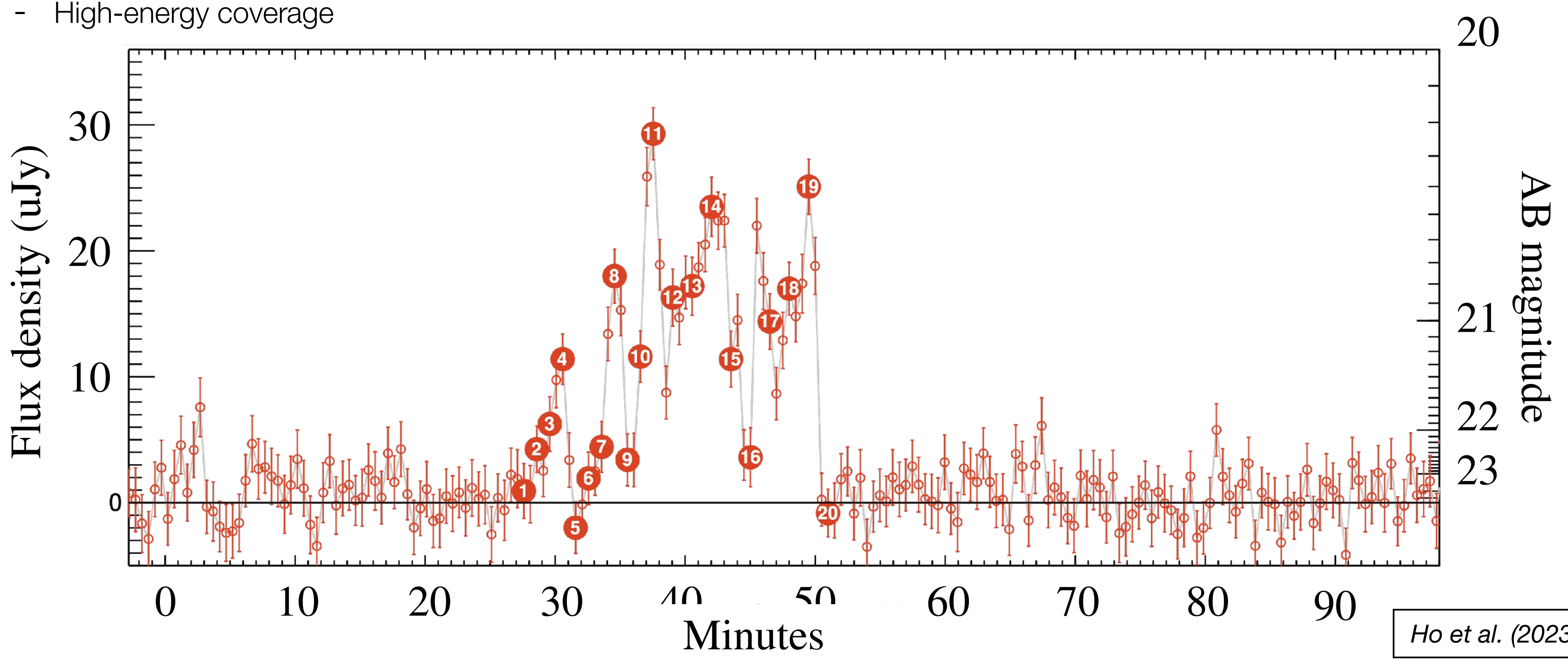
Posted: 19 Jun 2018; 22:54 UT

Subjects:Optical, Ultra-Violet, X-ray, Transient

We report on 0.5 ks Swift observations of the optical transient AT2018cow/ATLAS18qqn (ATel #11734, #11732, #11729, #11727). The observations were taken on 19 June 2018 using the XRT and UVOT instruments. Fitting an absorbed powerlaw model to the X-ray spectrum at z=0 we obtained nH= 6.8 +/- 0.08 e20 cm2, photon index = 1.48 +/- 0.2 and a flux of 3.4 +/- 0.5 e-11 ergs/cm2/s in

What could be improved?

- Coordination ***between*** facilities
    - Joint ToO (reciprocity, individual policies), simultaneous observation
- DDT for unexpected behavior—delays (e.g., 1-2 weeks to get ALMA response)
- Maybe infrastructure for tracking multiwavelength evolution?
- High-energy coverage



Ho et al. (2023)

Upcoming Changes to the Landscape

- Faster discovery and/or new information
  - Ability to discover a prompt transient (soft X-rays?) — Einstein Probe
  - High-cadence UV (ULTRASAT)
- New/expanded capabilities
  - UV spectroscopy (UVEX)
- Improved capabilities for multi-frequency coverage, e.g., dual-band observing mode with NOEMA (100 + 230 GHz simultaneously)
- …

Concerns about losses

- High-energy coverage (limits on gamma-ray emission)
- Swift for X-ray and UV monitoring, + rapid identification

Recommended observing timeline for a future event

Assume that the source is *identified* by a survey as a strong candidate at T0.

Triggering criteria: fast UV/optical light-curve evolution and a high luminosity + confirmed luminous X-rays and/or radio

Assume this would be within 24 hours of the time of first light

- T0 + 1-24 hr: X-ray broad-band SED (soft to hard X-rays). HST UV spectrum. Source would be very bright in optical, so small facilities would be sufficient. SMA + VLA observation to establish brightness.
- T0 + 1–7 days: Another epoch of X-ray SED, HST UV, VLA. ALMA SED. Continued intensive (~daily) X-ray, SMA monitoring. Small optical facilities can continue monitoring photometric and spectroscopic evolution.
- T0 + weeks–months: X-ray SED + HST UV + ALMA + VLA + Gemini/Keck spectroscopy on a logarithmic timescale. Total number of epochs could be 5 + 3 + 5 + 10.
    - Dedicated flaring search using a high-cadence facility (e.g., LAST) — upon detection, multi-observatory simultaneous observations
- T0 + months to years: On a logarithmic timescale, say 5-6 epochs. Gemini/Keck spectroscopy. HST UV + JWST NIR imaging. VLA SED monitoring, a few additional ALMA points (perhaps just at the lower frequencies).

Community coordination needs

- Rapid identification is essential
  - Optical/UV survey: discovering of a young, fast-brightening, likely luminous transient
  - Spectroscopy: confirmation of redshift and luminosity
  - Confirmation of luminous X-rays and/or radio
  - GCN, astronote, TDAMM Slack, etc
- Public data on source evolution (e.g., if the source becomes too faint at a certain wavelength)

What parameter space remains unexplored?

- Very early observations (first few days down to first few hours) at most wavelengths
- UV evolution
- Intermediate observations at many wavelengths (18cow went behind the Sun at dt~6 months)
- Late observations at certain wavelengths (e.g., NIR with JWST)
- …

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Questions to consider:

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- What is the line to trigger this process (which could be a community observing plan, “tiger team”)
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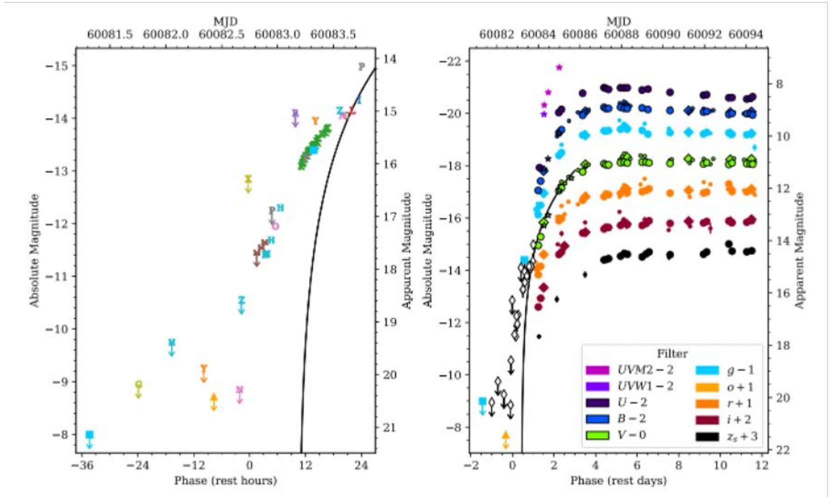
- How to deal with something unexpected (like 18cow was at the time)?

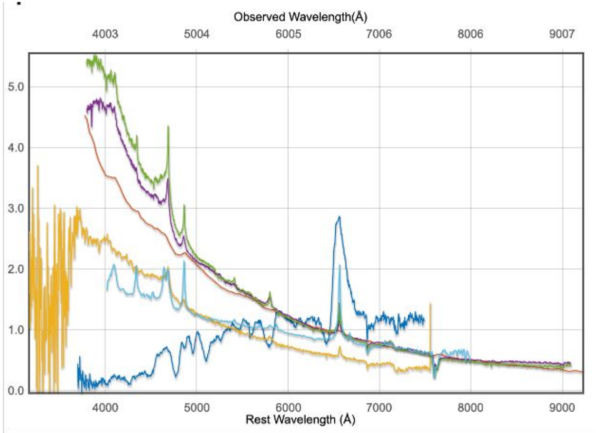
SN2023ixf: a nearby CCSN at 6.85 Mpc

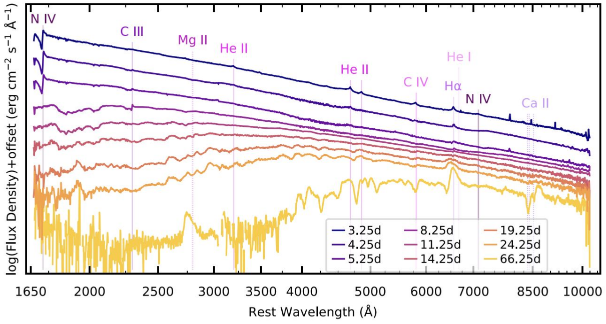
- Benefitted from many serendipitous observations (M101)
- Earliest detections of a CSM-interacting type-II SN to date
- Early photometry almost entirely from amateur astronomers



Lessons learned: What worked well

- First spectrum (at +1.1 days after first light) immediately reported to TNS
- Swift was immediately triggered
    - but first UV/X-ray photons did not come until >1.5 days
    - UVOT saturated
- HST STIS CCD got NUV spectrum by ~3.6 days + ~daily cadence
- X-rays: Use of most X-ray instruments (Chandra, XMM, NuSTAR, XRT).
- Radio: Use of multiple radio observatories (GMRT, VLA, NOEMA)





Lessons learned: What can be improved

- Responsiveness
  - First spectrum was at +1.1 days after first light (delayed because first TNS discovery report was ~1 day post-explosion)

- Wavelength coverage
  - Missed opportunity for Far-UV spectrum with HST
  - Most essential NUV information was missed at $t < 3.6$ days
  - First JWST spectrum only at ~33 days
  - Missed spectral coverage at mm and sub-mm bands

- Data latency
  - Better coordinated simultaneous observations (eg X-ray and radio facilities)
  - Needed many different DDTs. Should have been more of a community effort with open data access and full observational coverage across all space telescopes

Role of Specific Facilities

- Swift, Chandra, XMM, NuSTAR: Coordinated simultaneous observations
    - Cover soft (Swift, Chandra, XMM) to hard X-rays for broad band X-ray spectrum
    - XRT coverage out to late-times (>200 days) showed X-ray flattening

  Robust constraints on (i) the density of the X-ray emitting plasma, (ii) the line-of-sight neutral hydrogen column density, and (iii) the temperature of X-ray emitting plasma, which in turn reflects the shock velocity.

- GMRT, MeerKAT: Sample the low-frequency slope of the radio spectra

  Constraints on the dominant absorption processes (Free-free absorption and/or synchrotron self-absorption)

- VLA, ATCA: cm-band radio observations to trace peak of radio spectra

  Obtain shock radius, magnetic fields, and shock energy

- NOEMA, ALMA: Millimeter band observations

  (i) Probe the spectral peak at early times (a few days) --> constrain density of the immediate circumstellar environment; (ii) Measure the optically thin spectral index electron energy distribution; (iii) Identify signatures of electron cooling (synchrotron and/or Inverse Compton) that appear as spectral breaks in radio spectra

Recommended Timeline for Future Event

- See talk by Dave Sand
- See yesterday's discussion in the neutrino session

Triggering Criteria

- Very nearby supernova
  - Eg, survey detects source in a very nearby galaxy
- Galactic Supernovae (or Magellanic Clouds)
- Supernova detected via neutrinos or gravitational waves
  - Estimated time-delay between neutrino burst and SBO:
    ~30 minutes for a WR; 1-2 days for a RSG
  - GWs from non-rotating SNe detectable out to 6.9 kpc (~30kpc for extreme models) at FAR < 1 in 10 years --> may miss Galactic SN if non-rotating and beyond Galactic center

Community Coordination Needs

- Rapid announcement to community
- Rapid spectroscopy for identification
- Early observations (hours to few days)
  - Cover all wavelengths
  - But brightness of nearby object can be a challenge to instruments
- Coordinated observations between observatories
- Public data?

- Need a ‘Nearby Galaxy Broker’ for LSST

Overarching need: high scientific value events that are rare opportunities (once-in-a-decade or rarer) and require rapid response (including unknown unknowns)---need a way to get coordinated observations on most major observatories

Questions to consider:

- 10 mins: What infrastructure/policy changes would enable the best science to be done?
  - What is working well?
  - What are the current limitations?
- 5 mins: What facilities are needed and what are we concerned about losing?
- 10 mins: What is the line to trigger this process (which could be a community observing plan, "tiger team")
  - 23ixf? 1987A? Milky Way?
    - And for that source class, what observations are most useful for determining the progenitors and understanding the relevant physical processes? What would be the triggering criteria?
- 5 mins: Anything else?
  - How to deal with something unexpected (like 18cow was at the time)?