Gravitational Wave Event Follow-up and Other Fast Transient Features

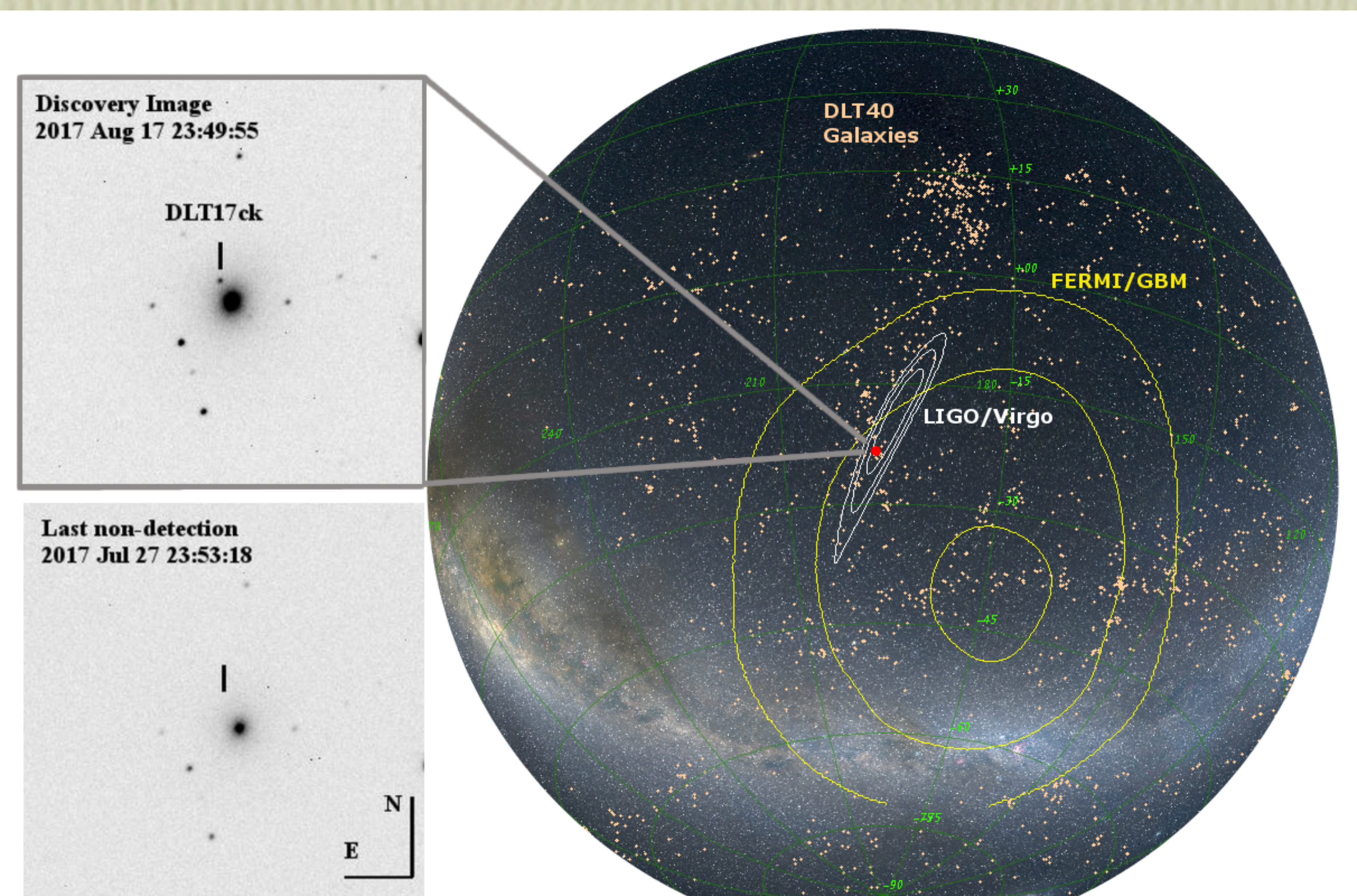
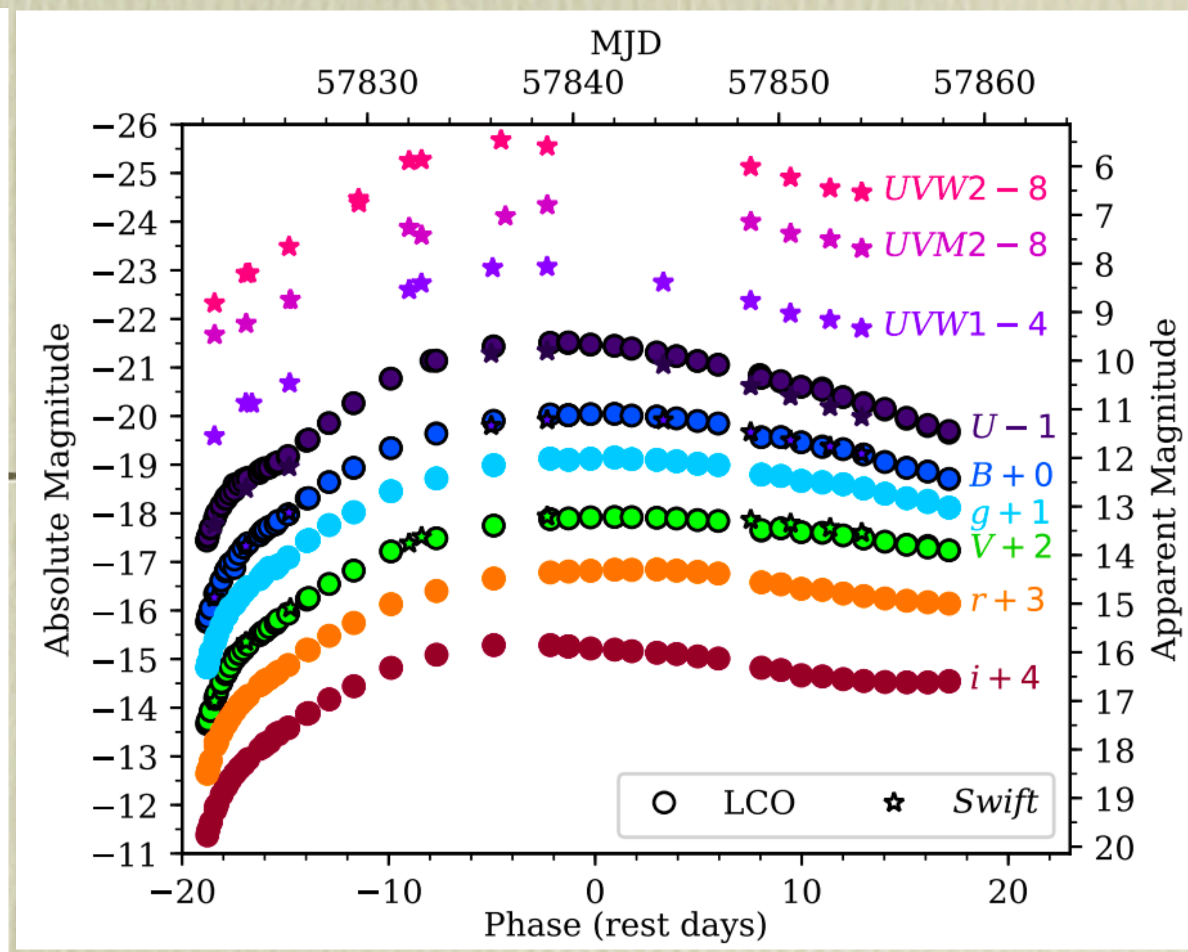


Image Credit: S Valenti



D. Sand (U of Arizona)

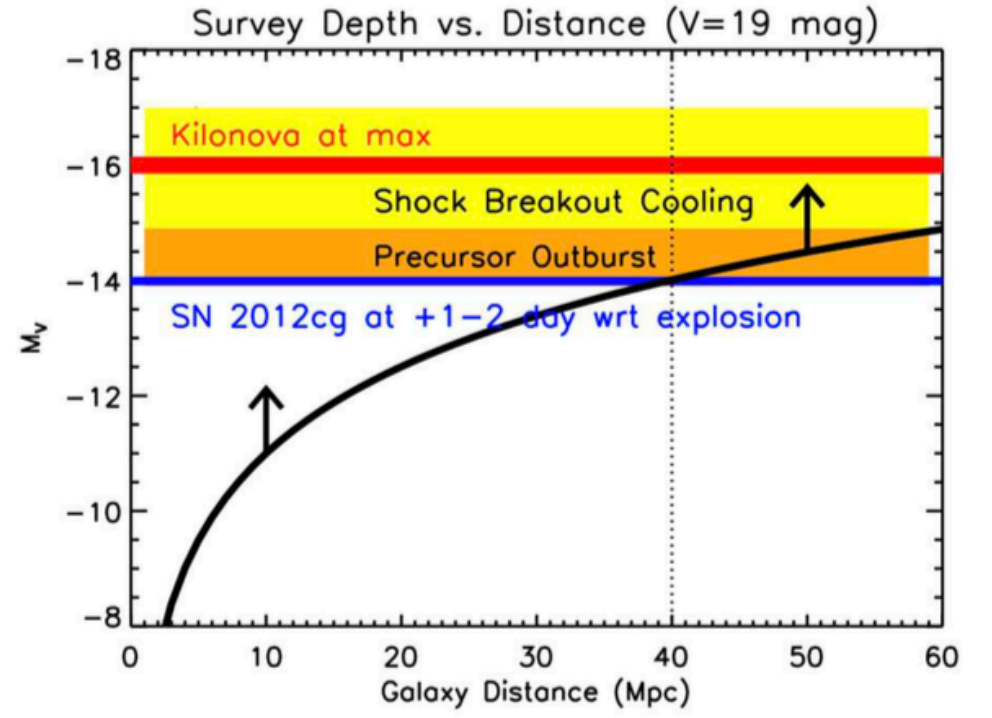
ARTN Workshop

Finding very young SNe to understand the progenitor/explosion

- Even the best transient searches aren't focused enough.

- A search of nearby galaxies could be done with ~0.5m telescopes. Looking at ~500 galaxies per night would find ~10 SNe per year, and could catch SNe within 1 day of explosion. Tied directly to FLOYDS, a pair of robotic spectrographs.

THE D < 40 MPC SURVEY



FLOYDS

PROMPT 0.4m

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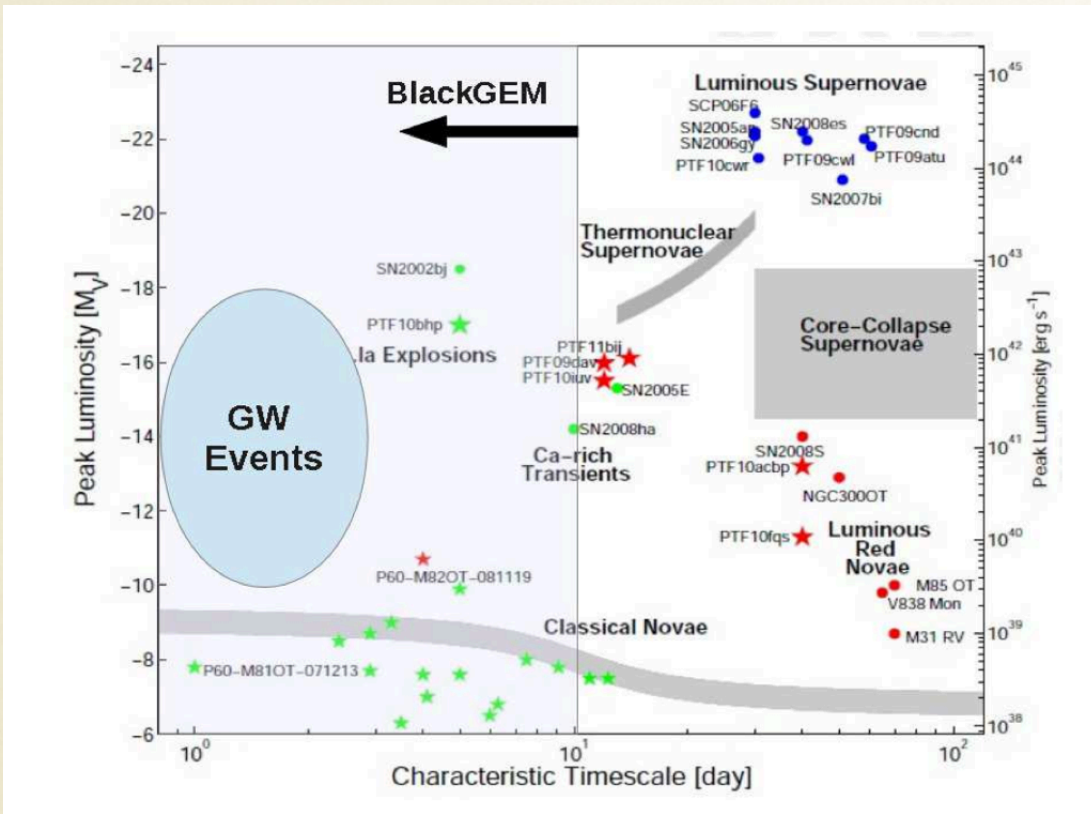

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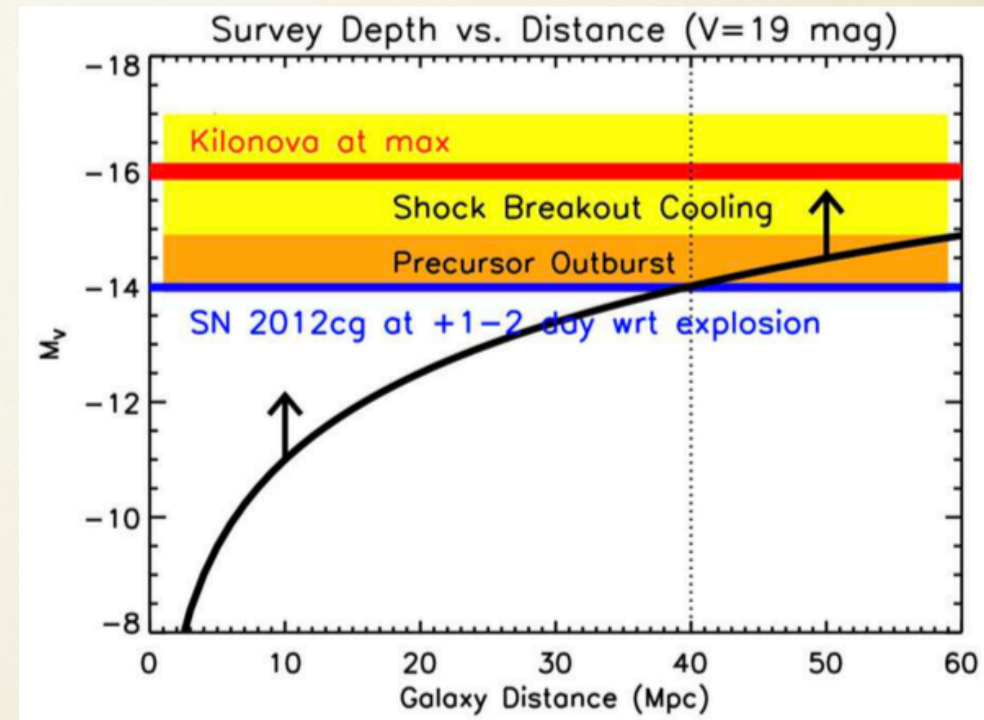

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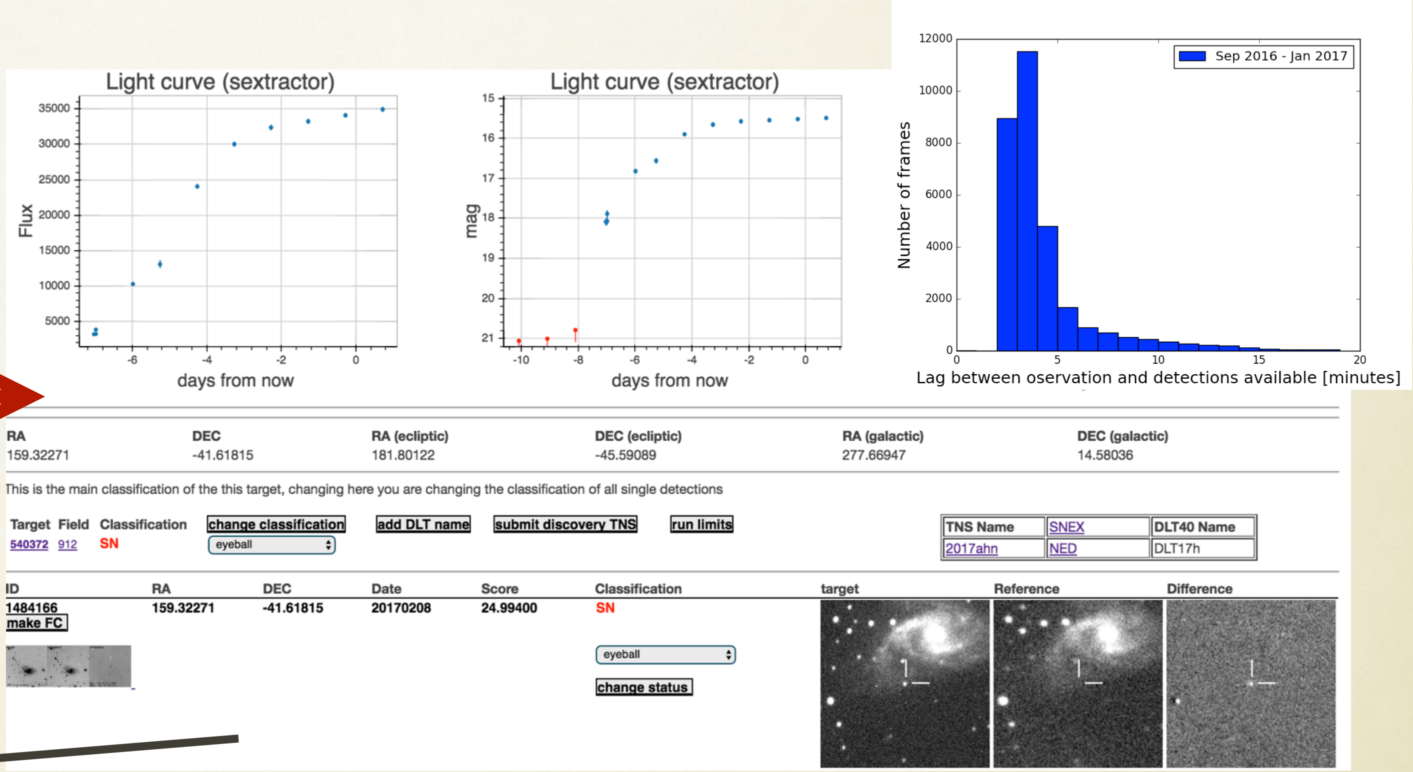
The DLT40 Survey: Fully Operational

PROMPT 0.4m



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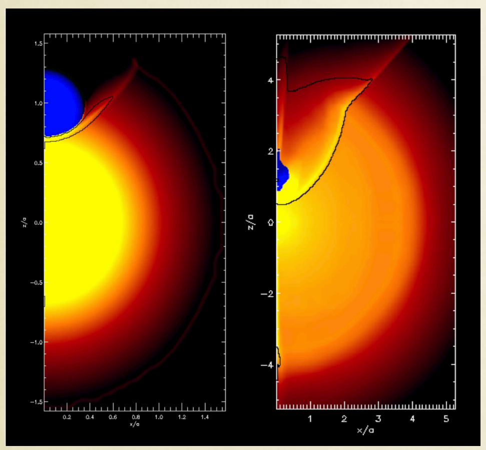
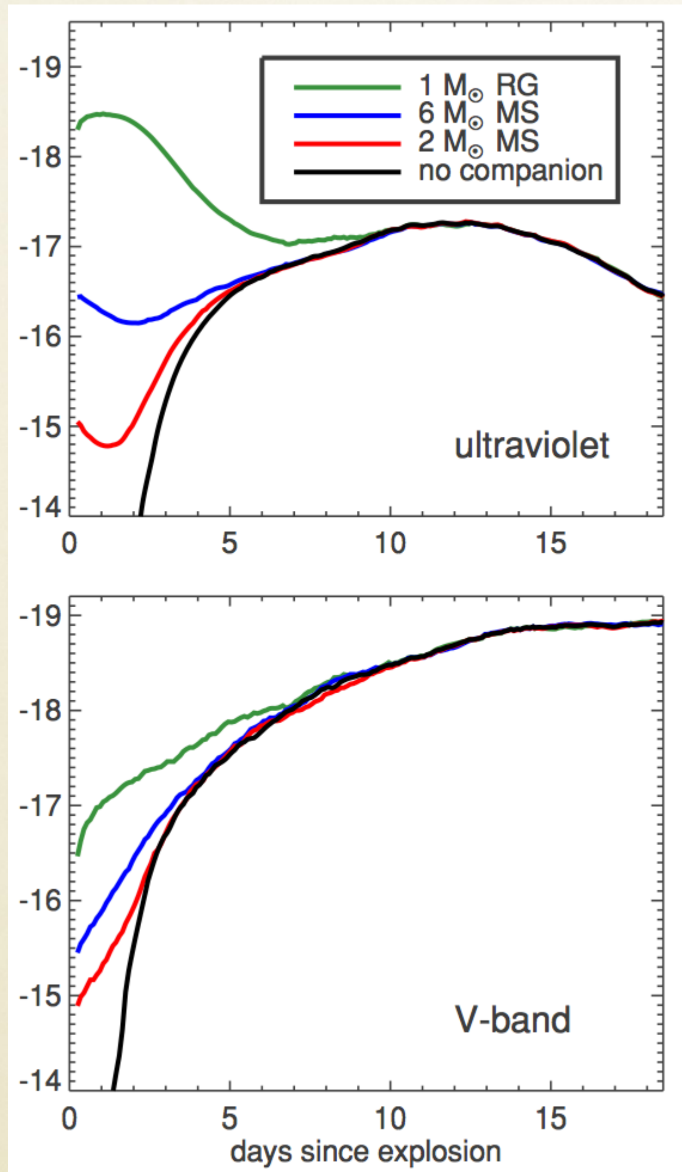
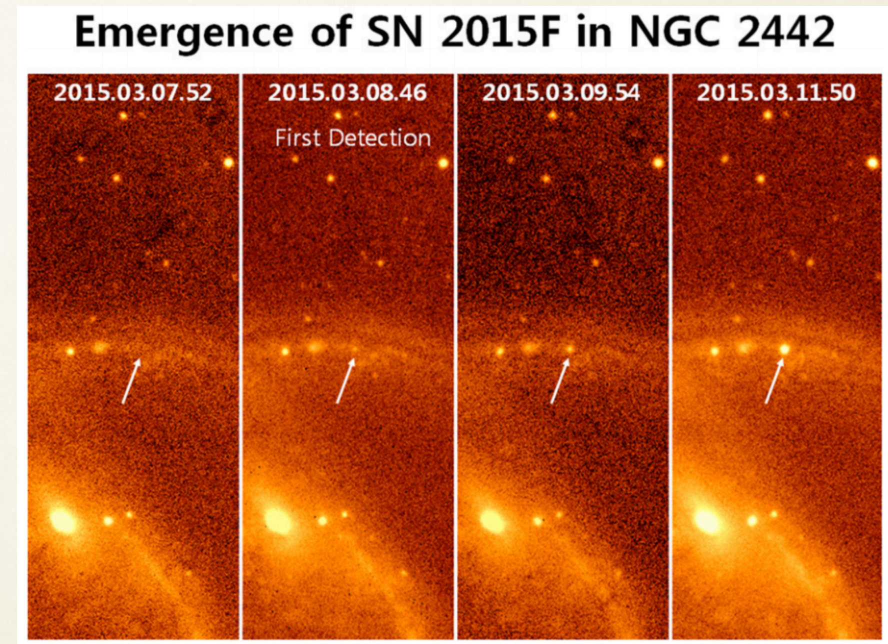
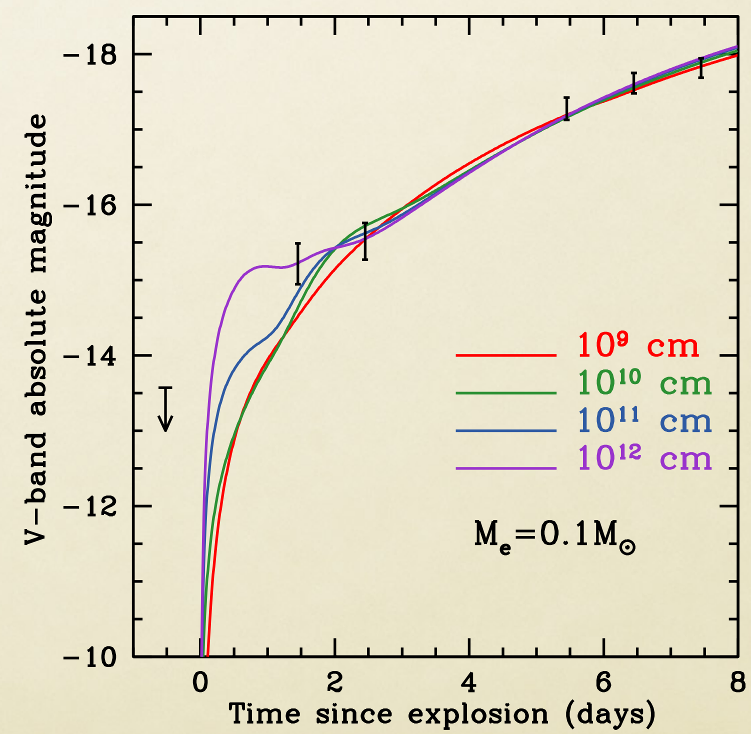


Kasen 2010





Piro & Morozova 2016



Non-degenerate companions and circumstellar material

DLT17u/SN2017cbv

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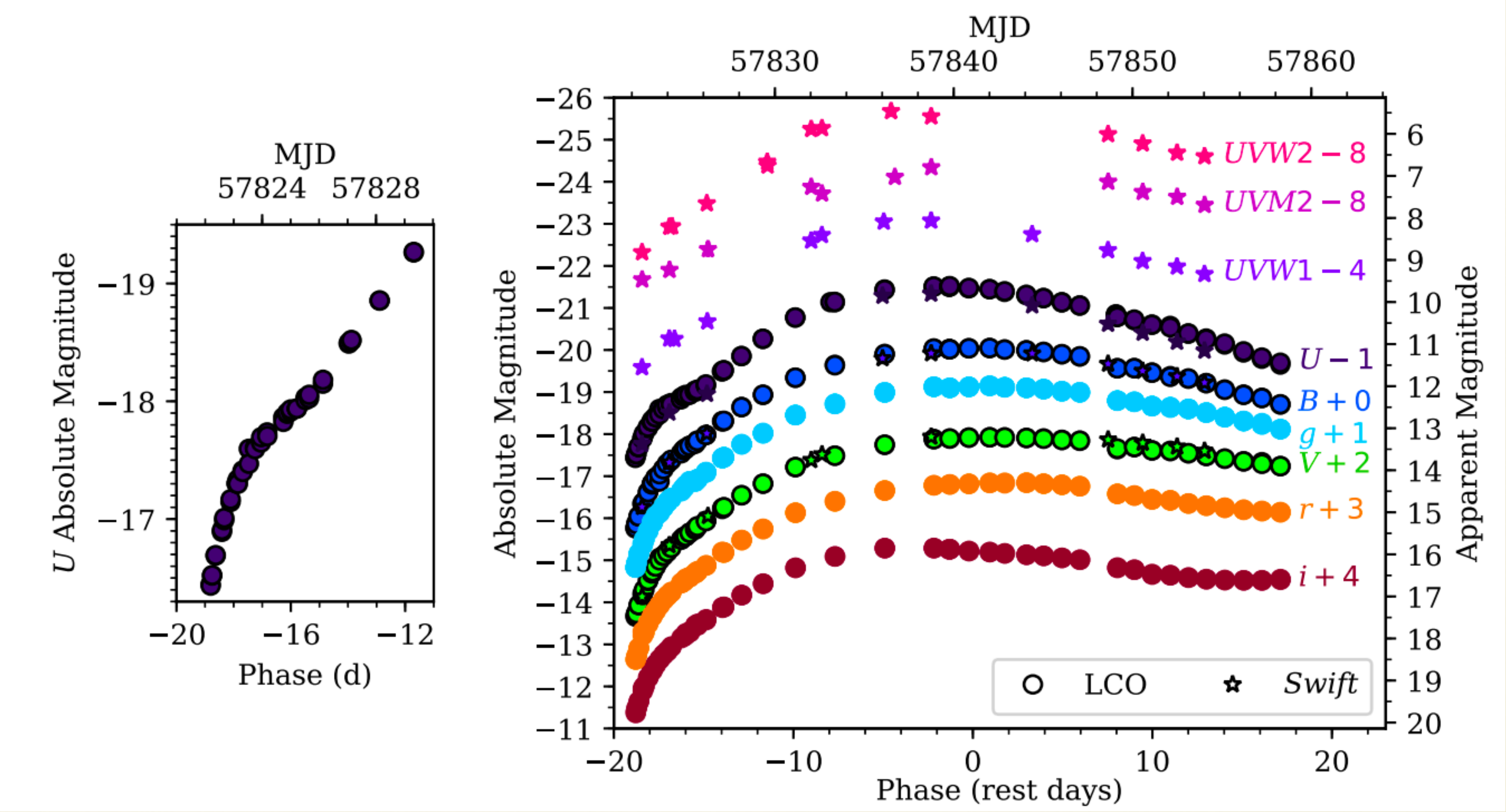
The light curve is sick. That is a ~5 hr cadence over ~6 days.



Hosseinzadeh et al. 2017

DLT17u/SN2017cbv

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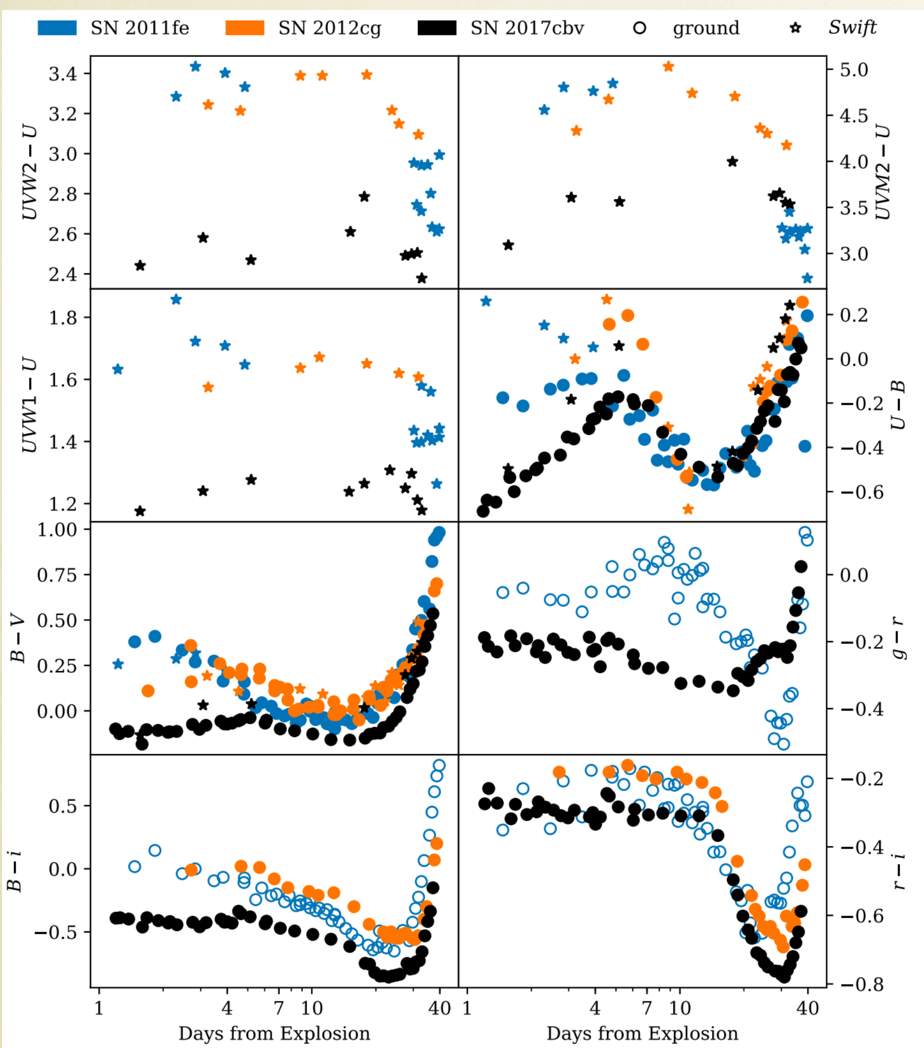
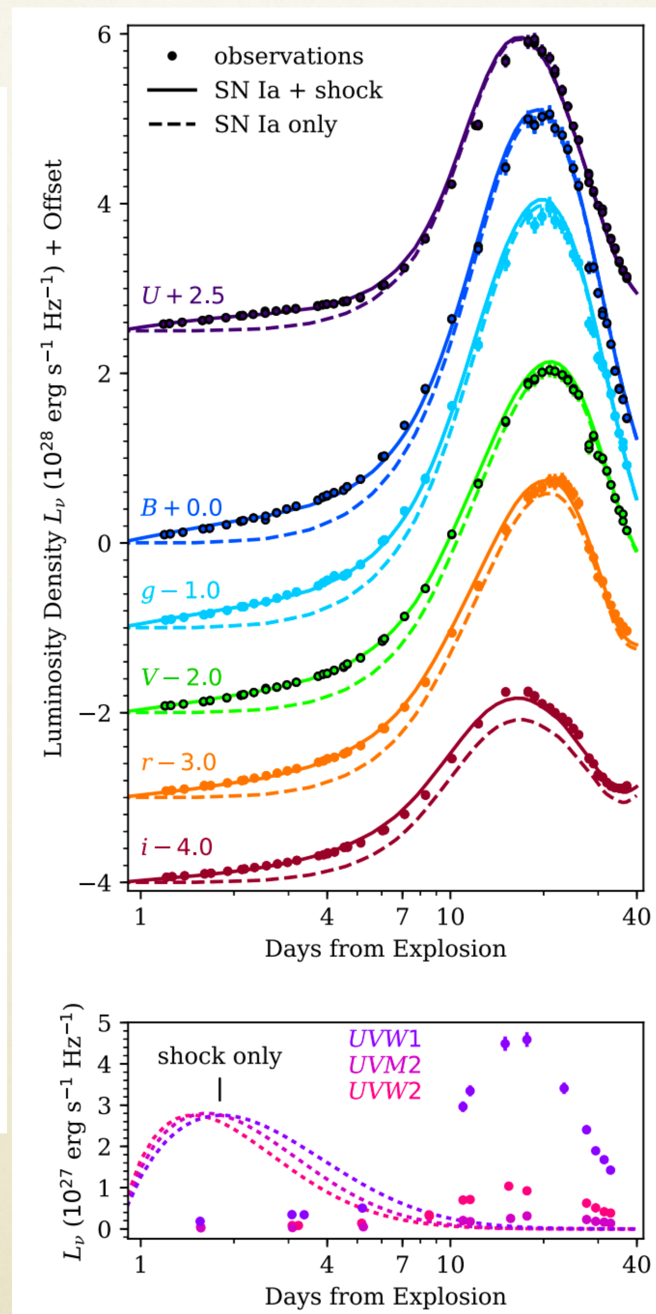
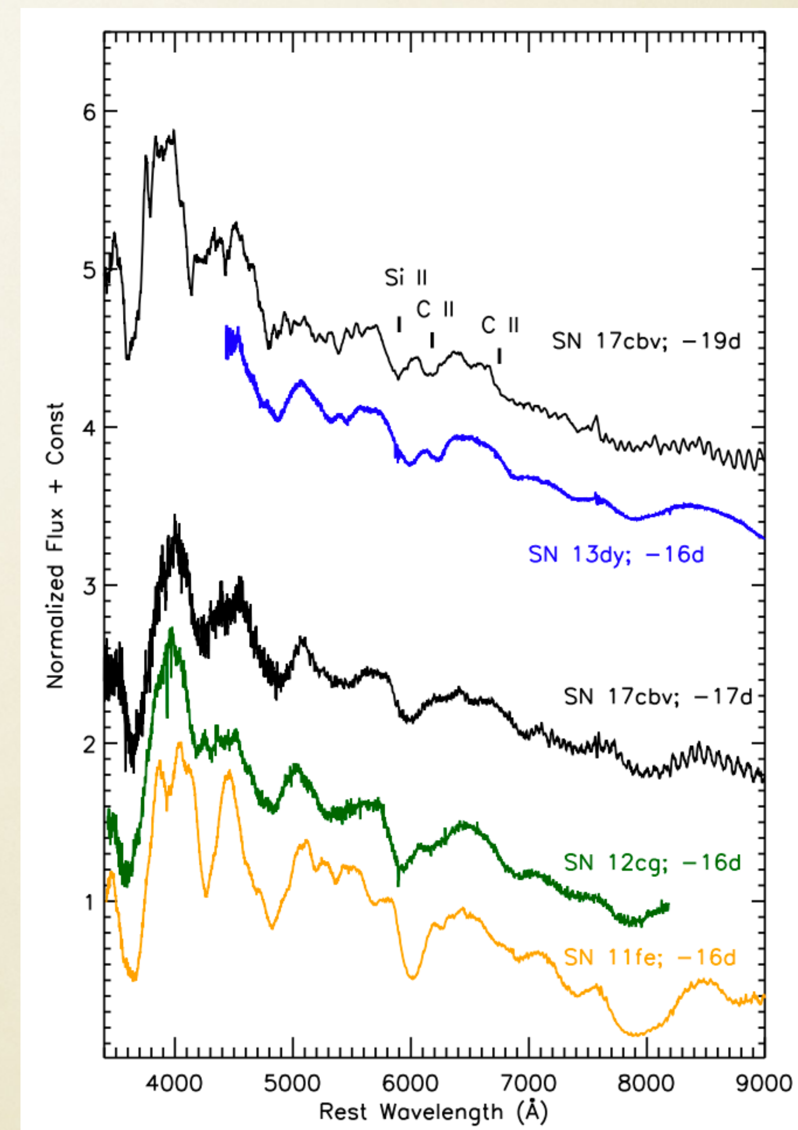


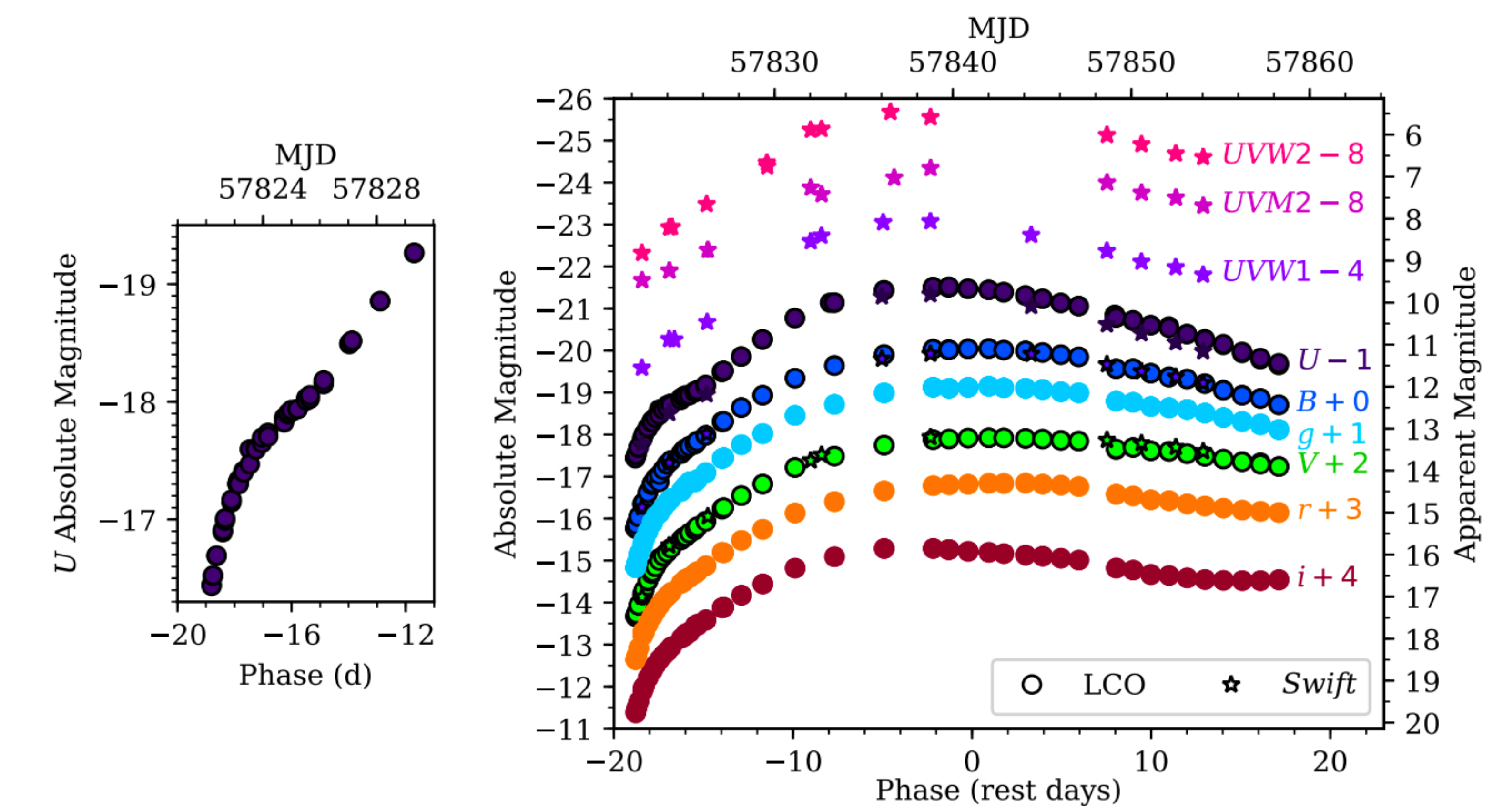




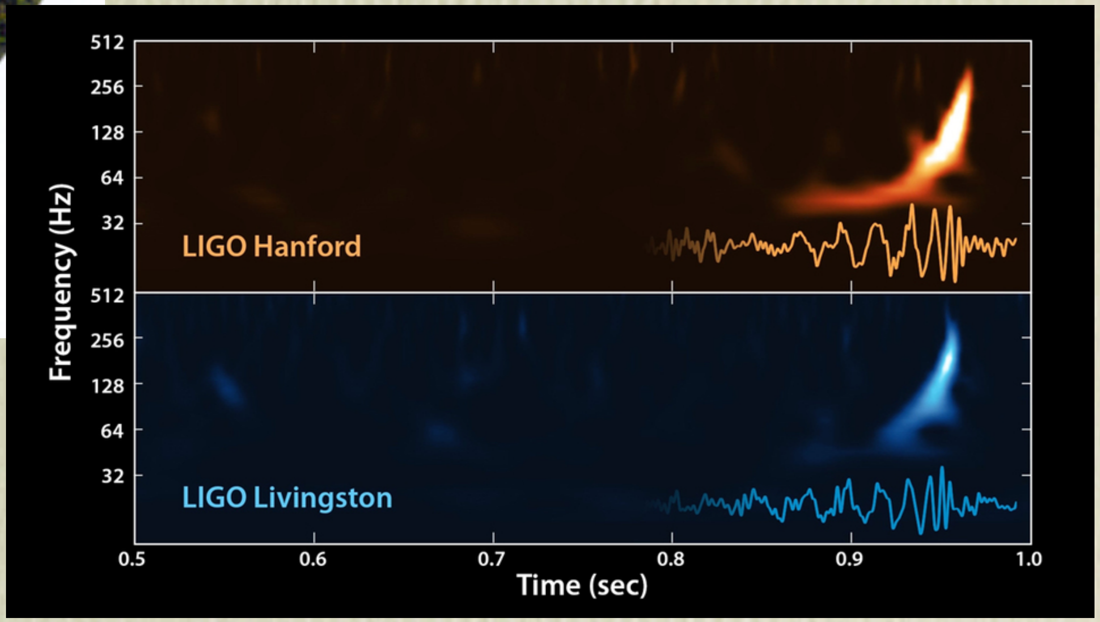
Hosseinzadeh et al. 2017

ARTN Bottom Line

- Fast follow-up of very young SN candidates — same night preferred. Any scheduler needs to be tied into an event broker, or similar.
- High cadence — multiple observations within a single day, sustained over one week, made this science possible. Do we want connections with other observatories to make this possible? [I say yes]
- Real time analysis and visualization lets you know if you have something special, so you can pour more resources in. [Onus on the scientist]

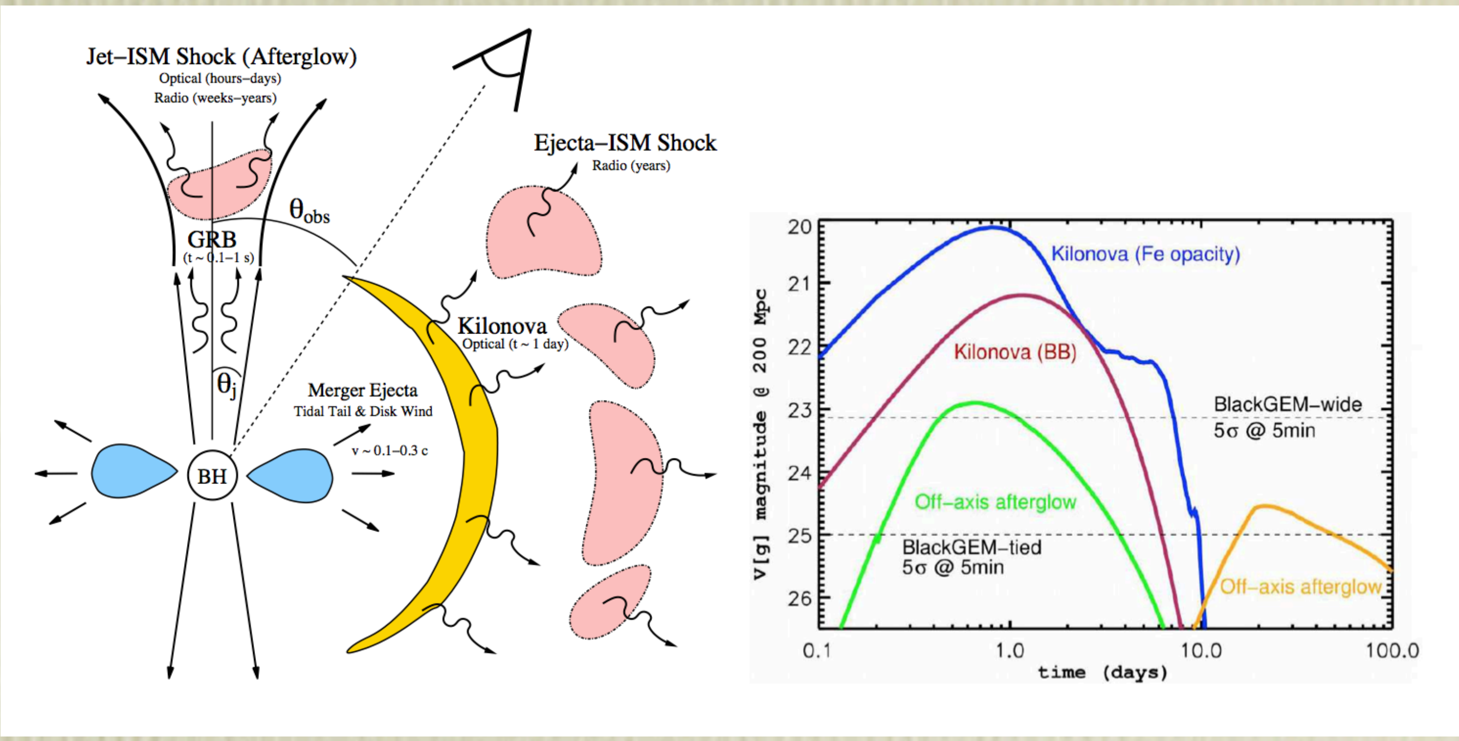


The gravitational wave era will demand fast response



The gravitational wave era will demand fast response

Neutron star material gets super-heated and ejected at ~0.2c.
Expanding and cooling photosphere should be observable in the optical/NIR



Adapted from Metzger & Berger 2012. See recent review by Metzger 2016. Predictions constantly refined.

The gravitational wave era will demand fast response

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Expanding a
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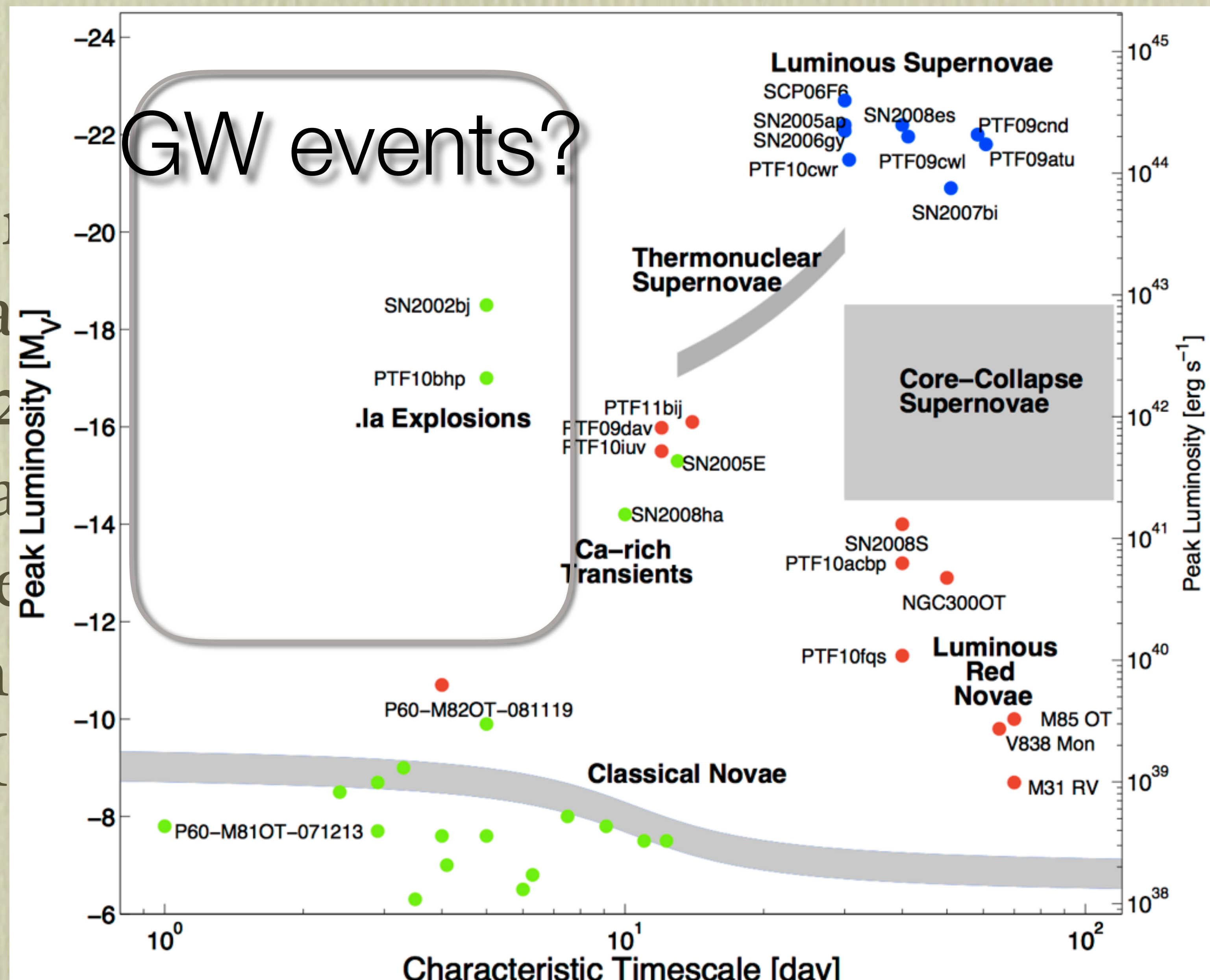

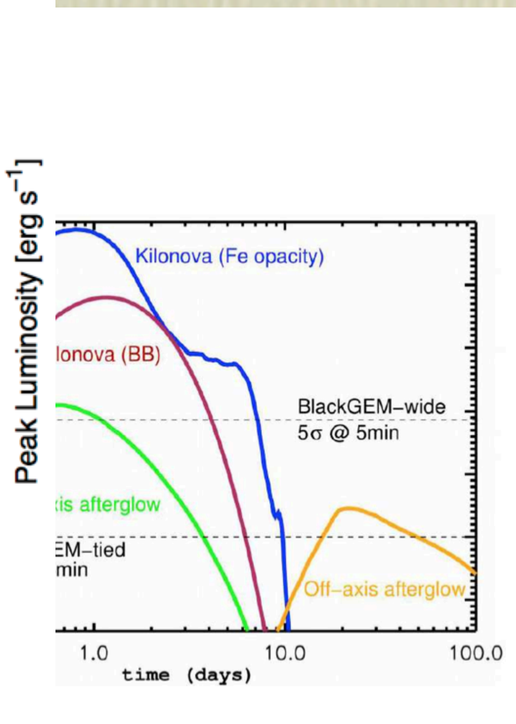

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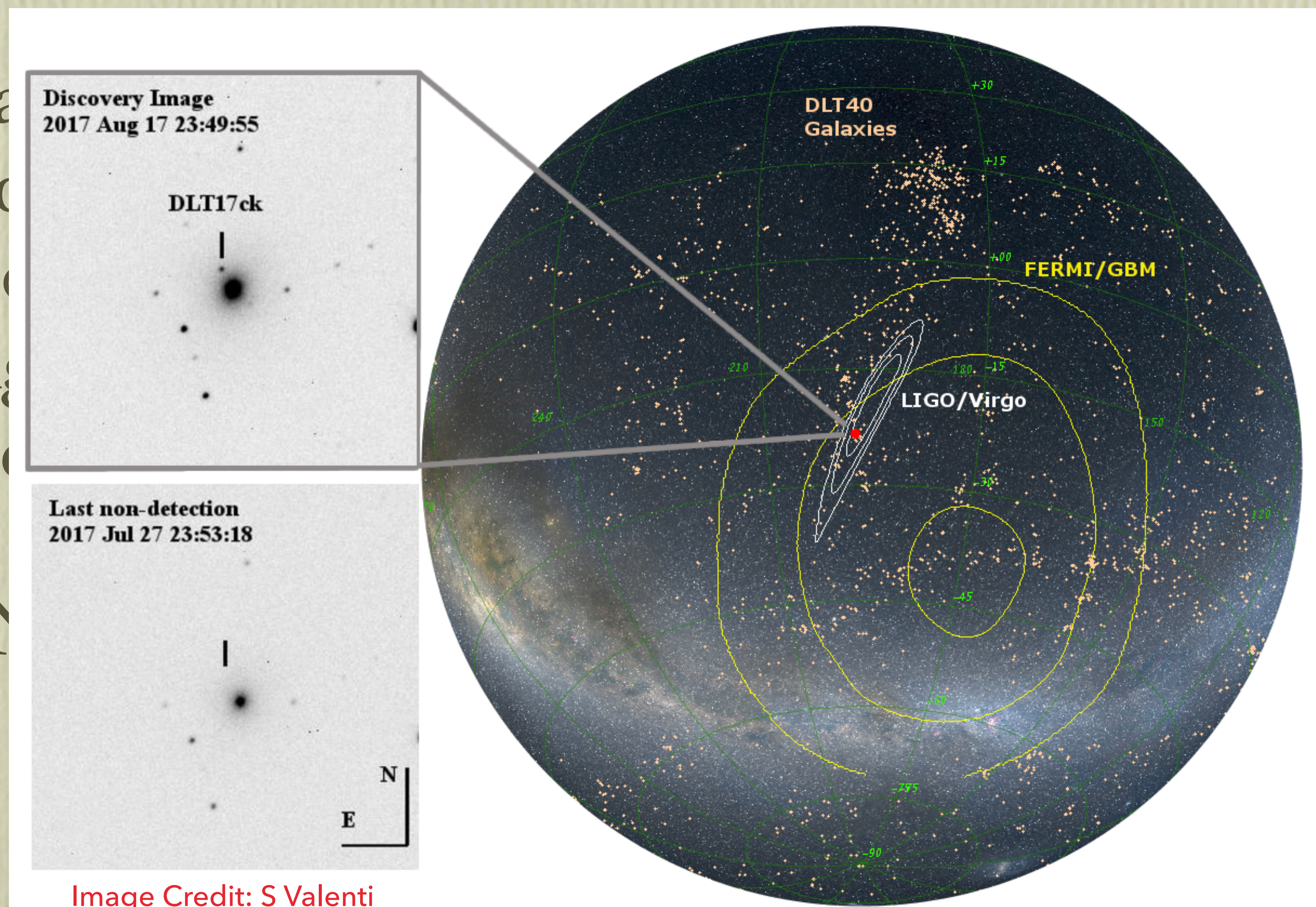

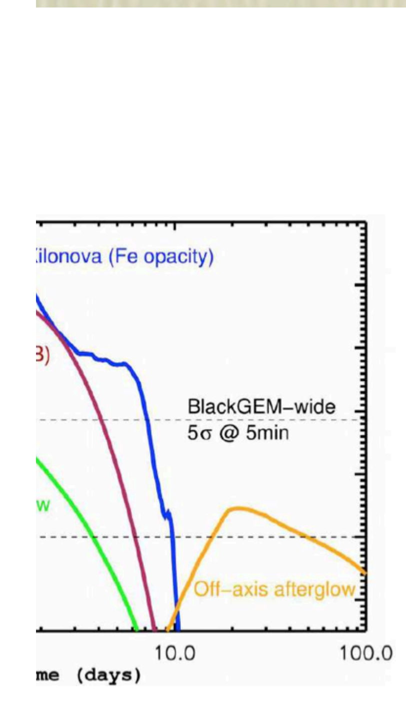

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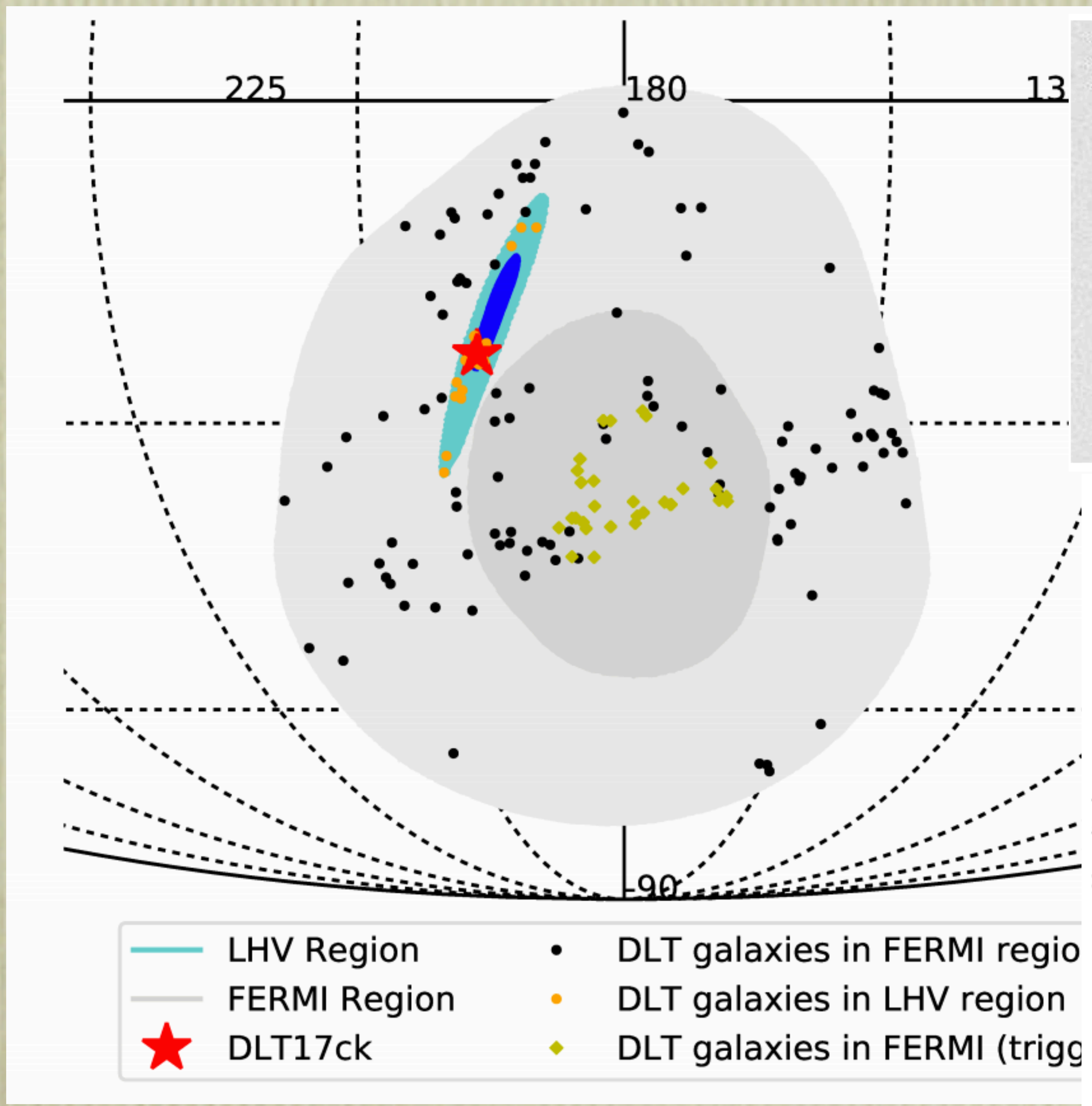
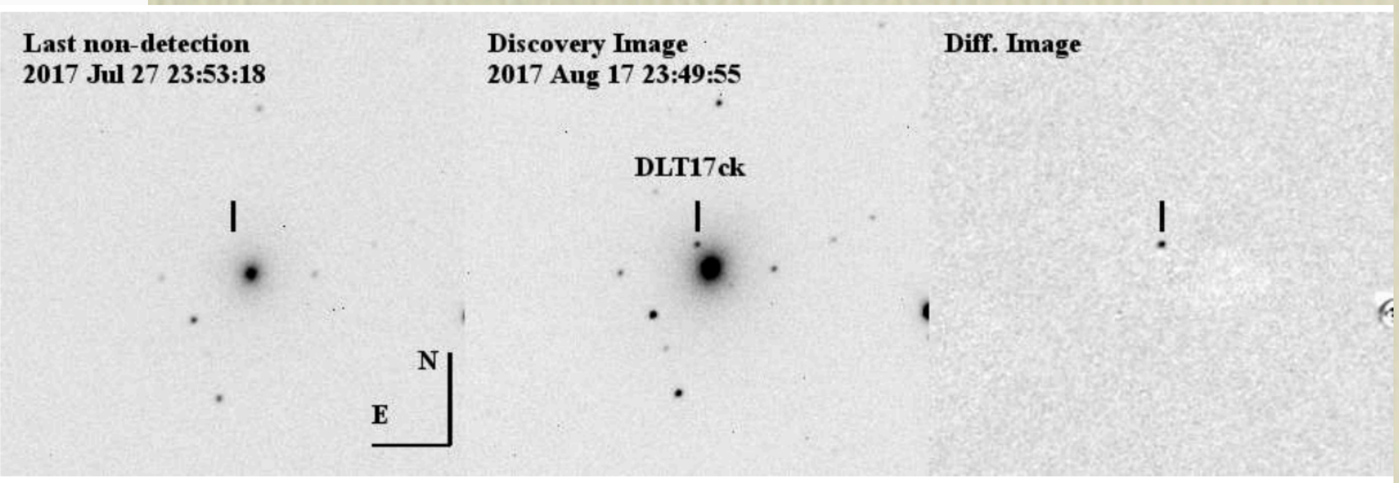
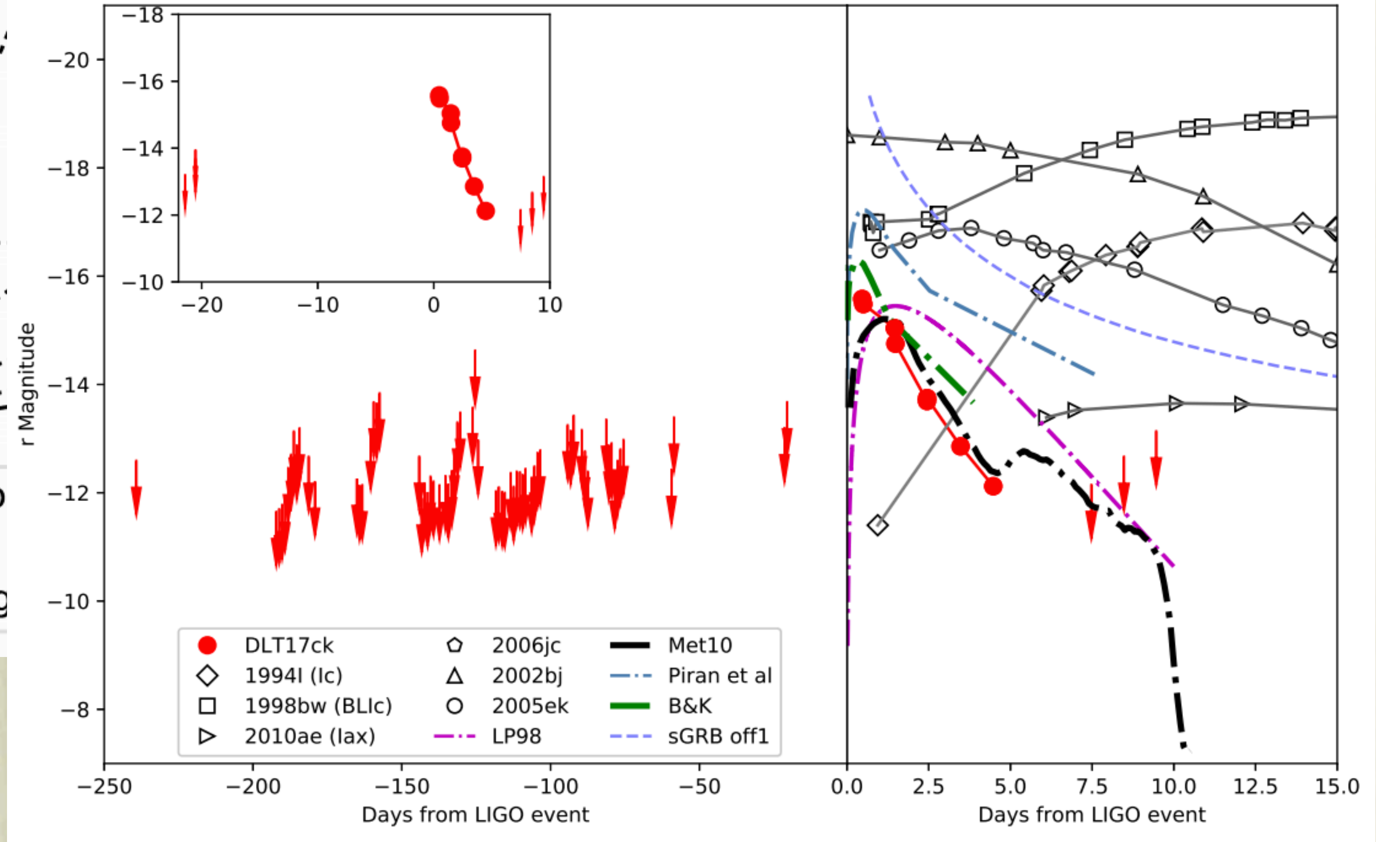
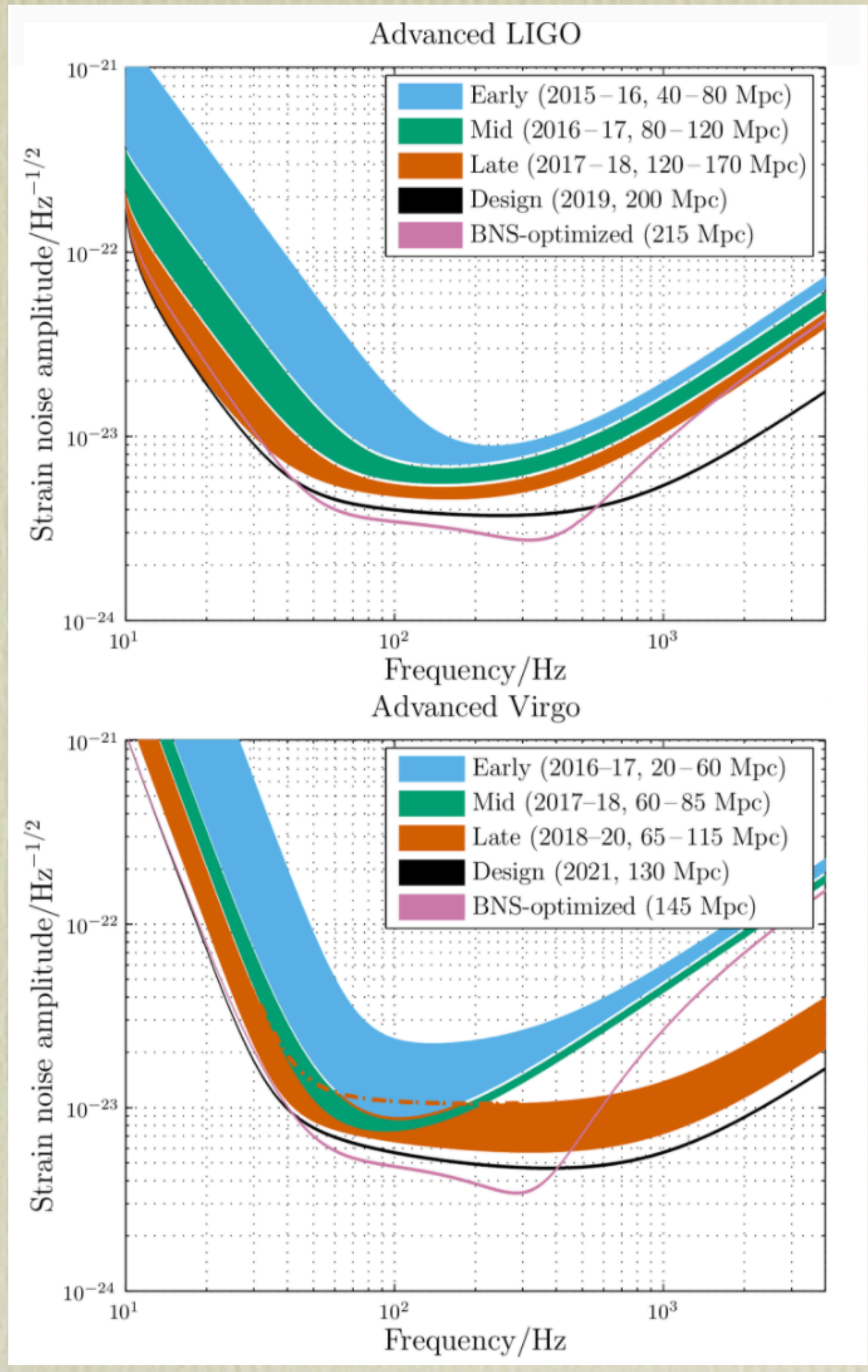






The years ahead

The three detector era, including LIGO+Virgo, will last until early 2020's. Design sensitivity in a few years will find NS-NS binaries out to 200+ Mpc, with ~10-100 sq deg error regions.



The years ahead

Steward can lead in discovery.

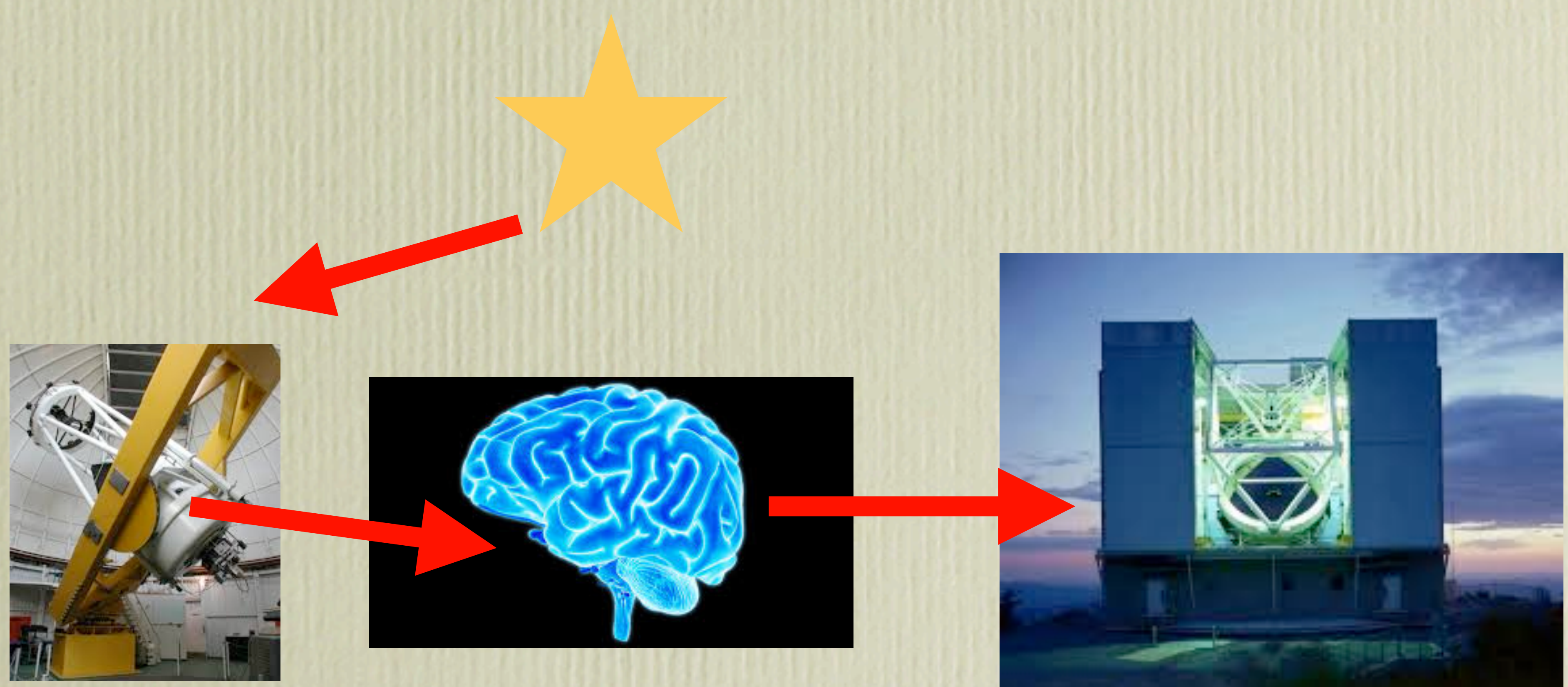
- Multi-pronged discovery ability:
  - 61-inch for pointed galaxy followup (D<100 Mpc)
  - 90Prime (1 deg^2) and Catalina 60-inch (5 deg^2) for more distant events.

Steward can lead in characterization.

- Sources discovered by us (or others) should be able to get same-night optical/NIR spectra from MMT+LBT, and photometry on all our facilities.

What we need in the years ahead

1. Adaptable schedule that can immediately insert high-priority targets/fields. [ARTN]
2. Software that can ID a new EM counterpart [Scientist]
3. Rapid ToO ability on big Steward facilities [bosses]



Las Cumbres Observatory
MANY EYES - ONE VISION

LCO Las Cumbres Observatory

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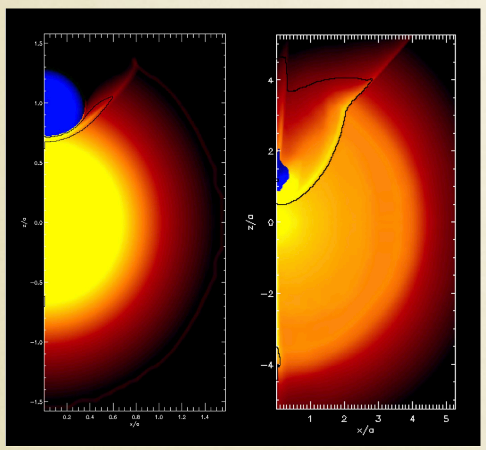

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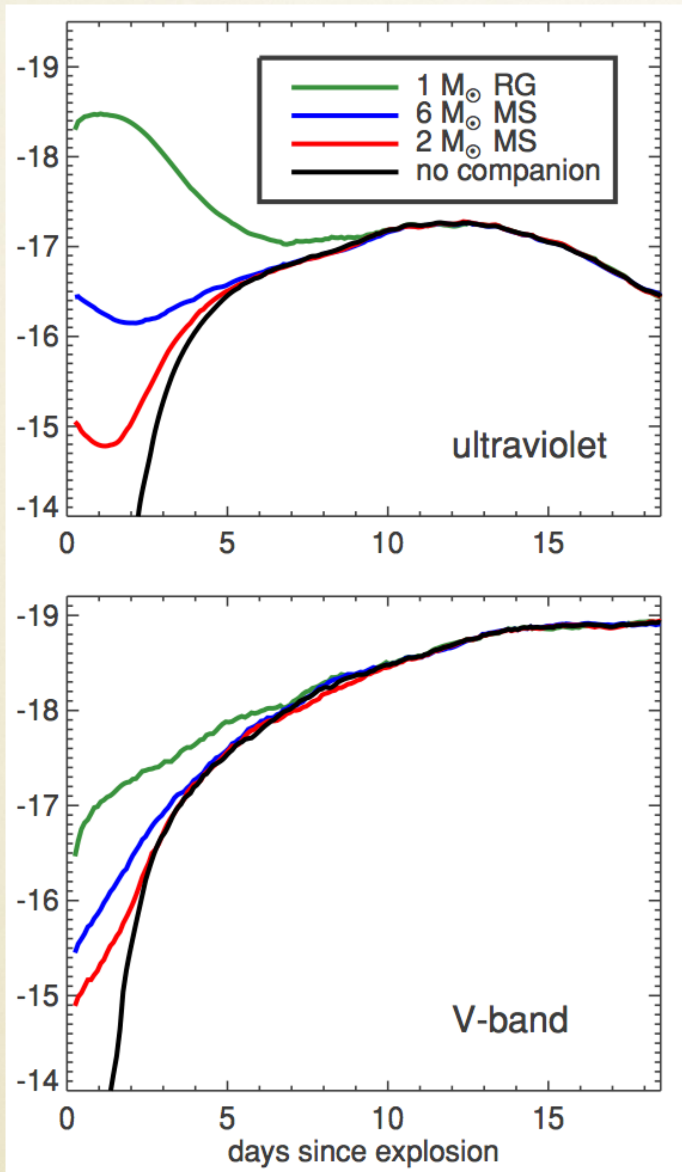

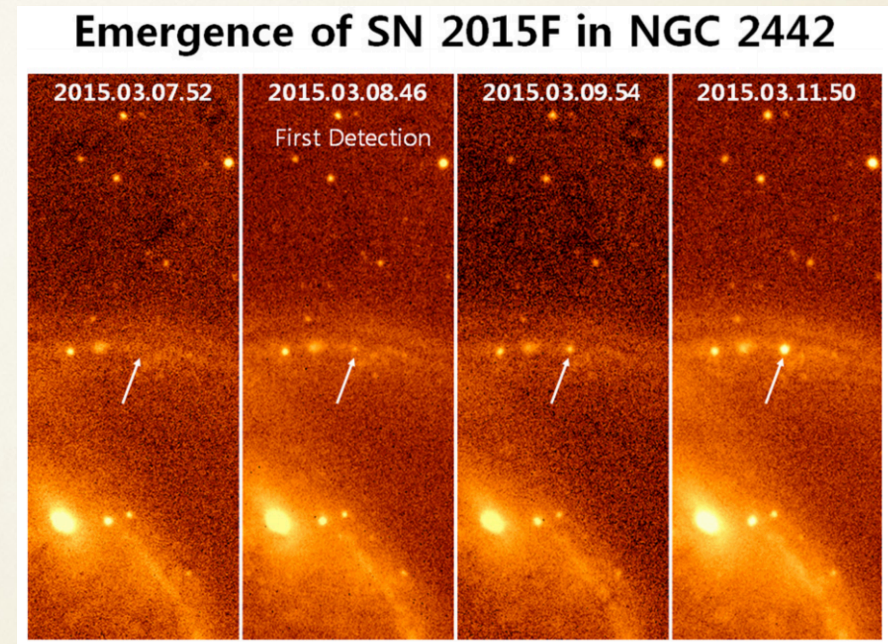

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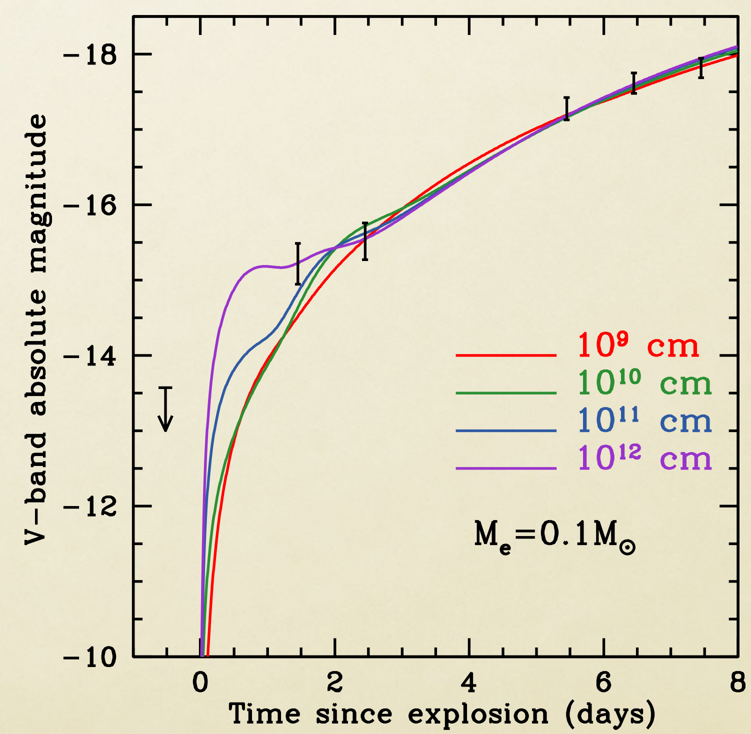

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Where are we going to get very young SNe from?

- Even the best transient searches aren't focused enough.
- A search of nearby galaxies could be done with ~0.5m telescopes. Looking at ~500 galaxies per night would find ~10 SNe per year, and could catch SNe within 1 day of explosion. Totally new capability if directly tied to FLOYDS.

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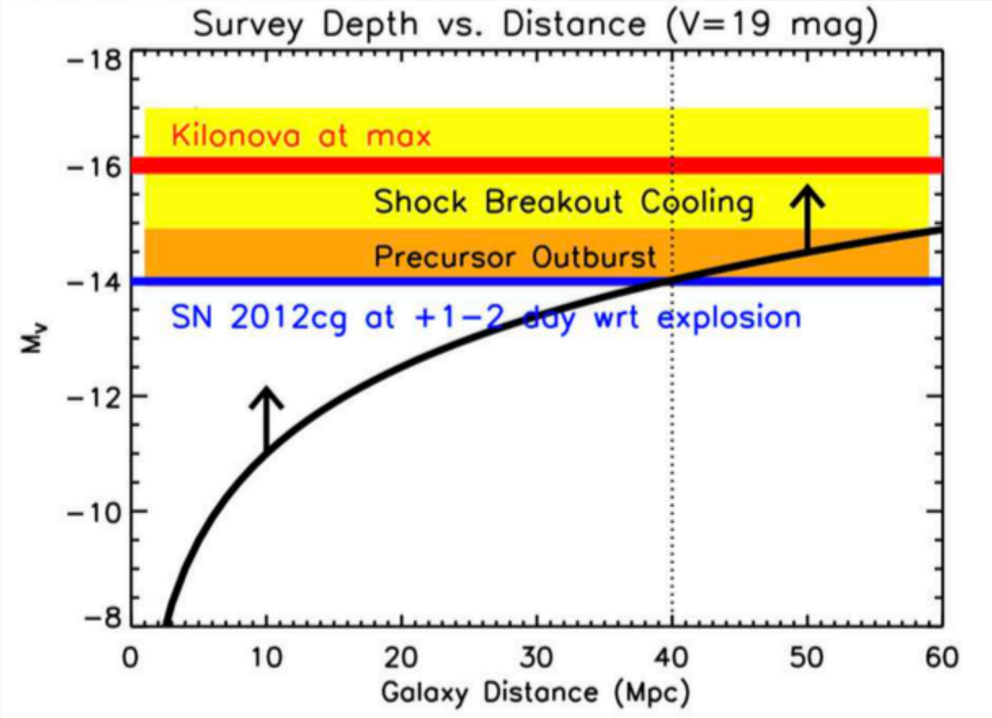

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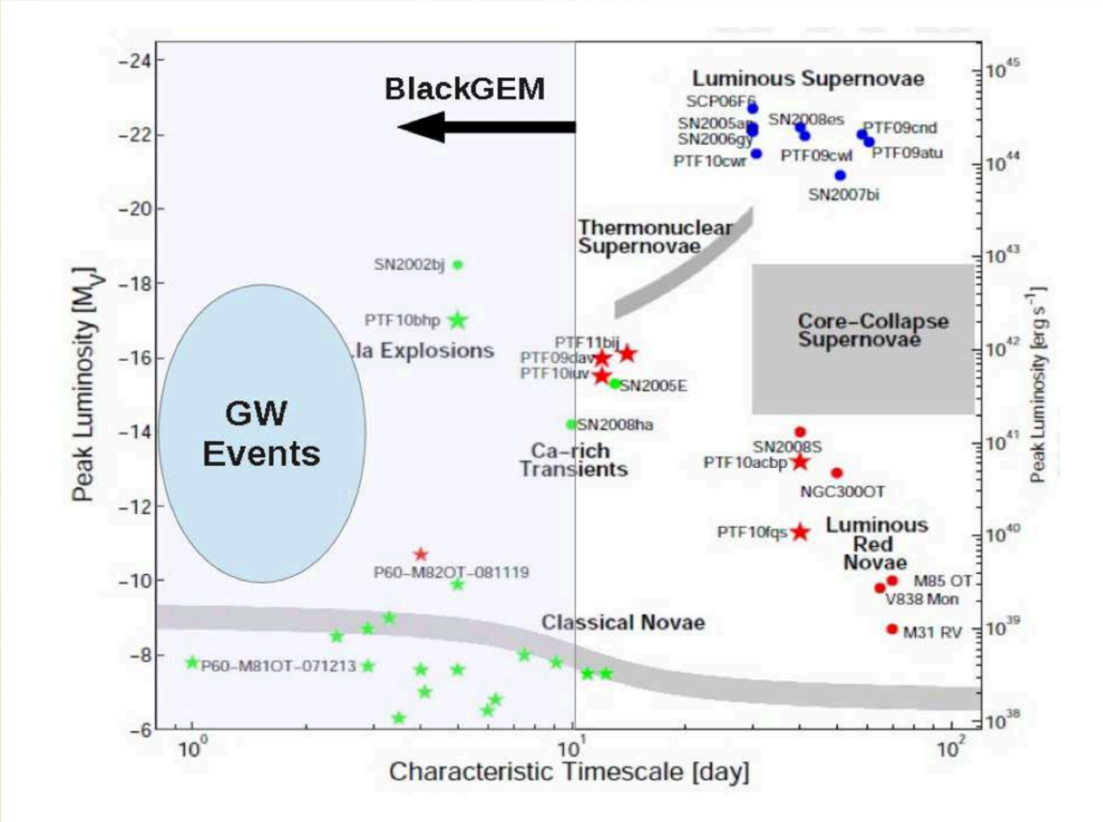

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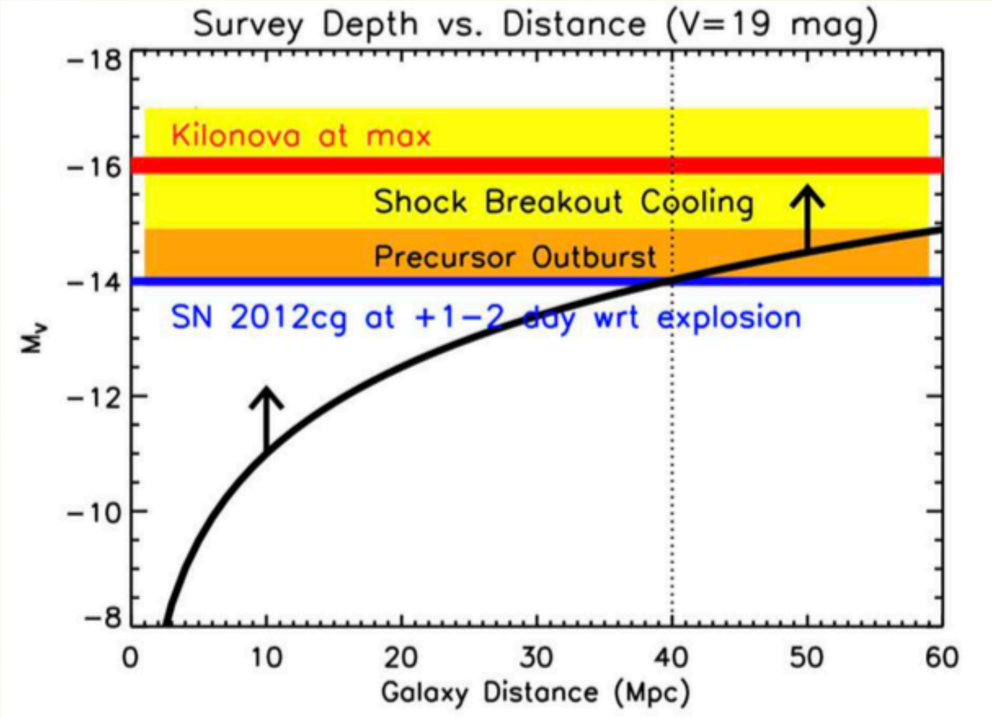

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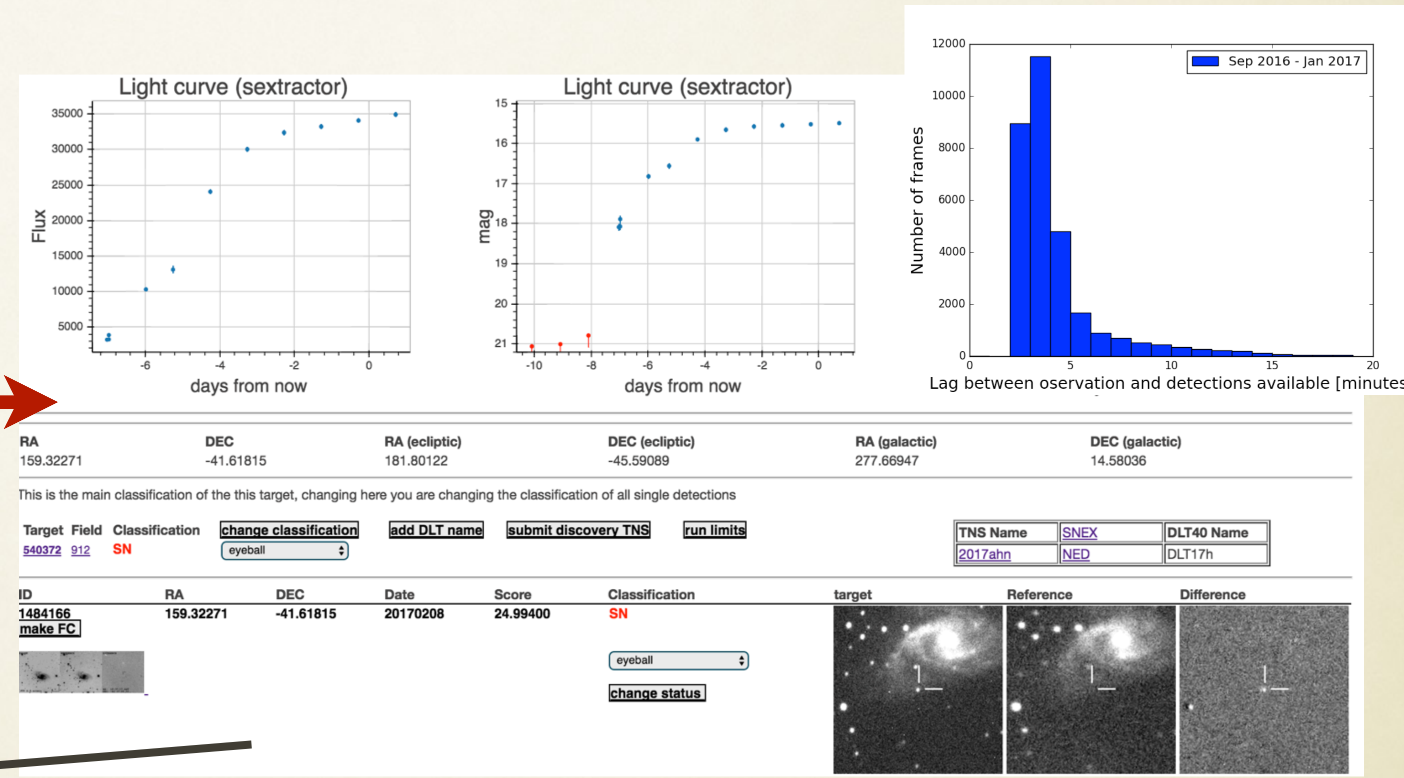

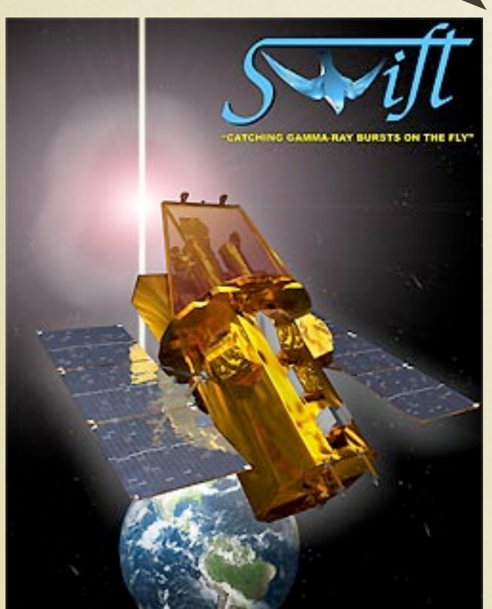

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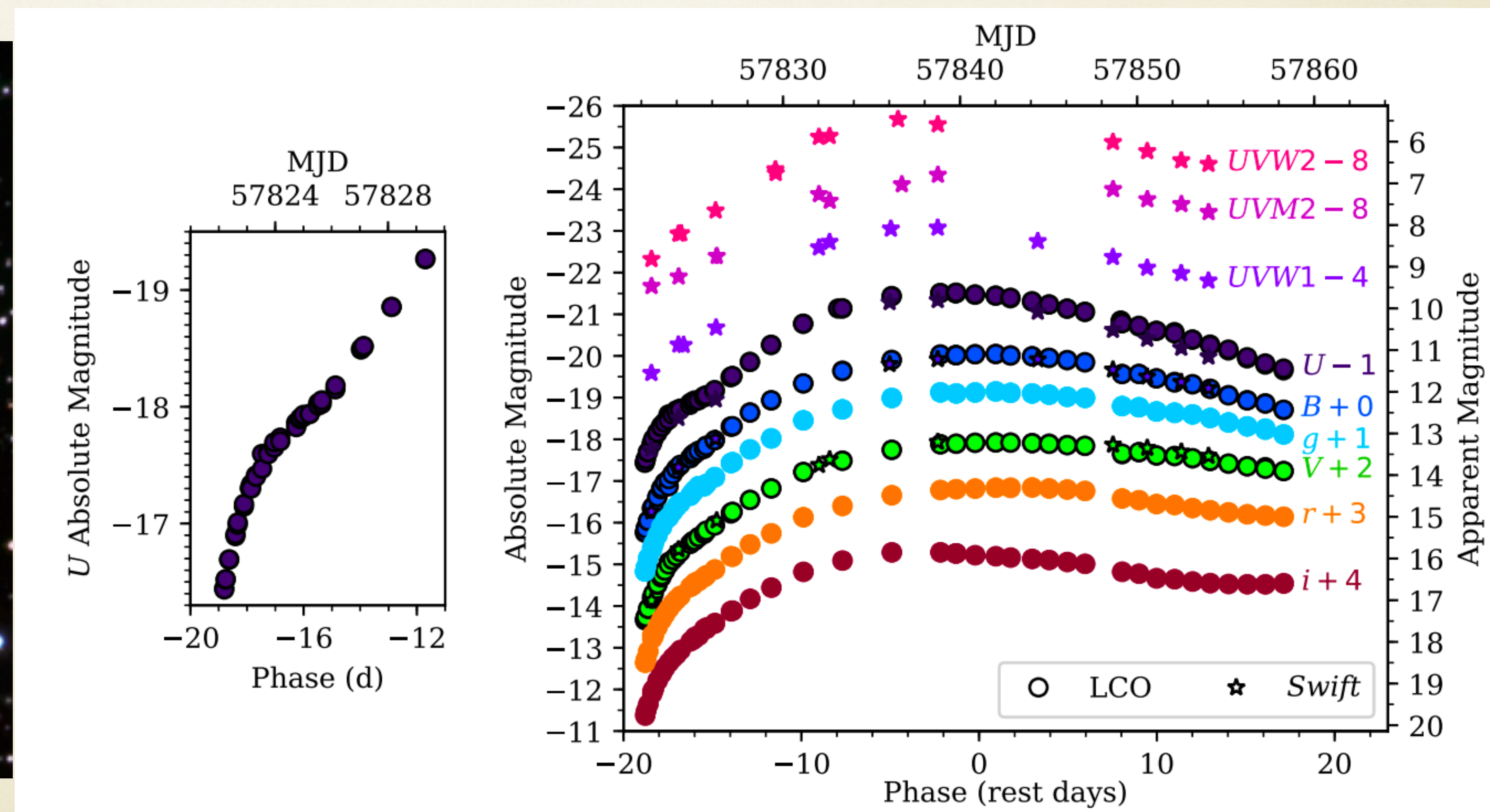

Hosseinzadeh et al. 2017

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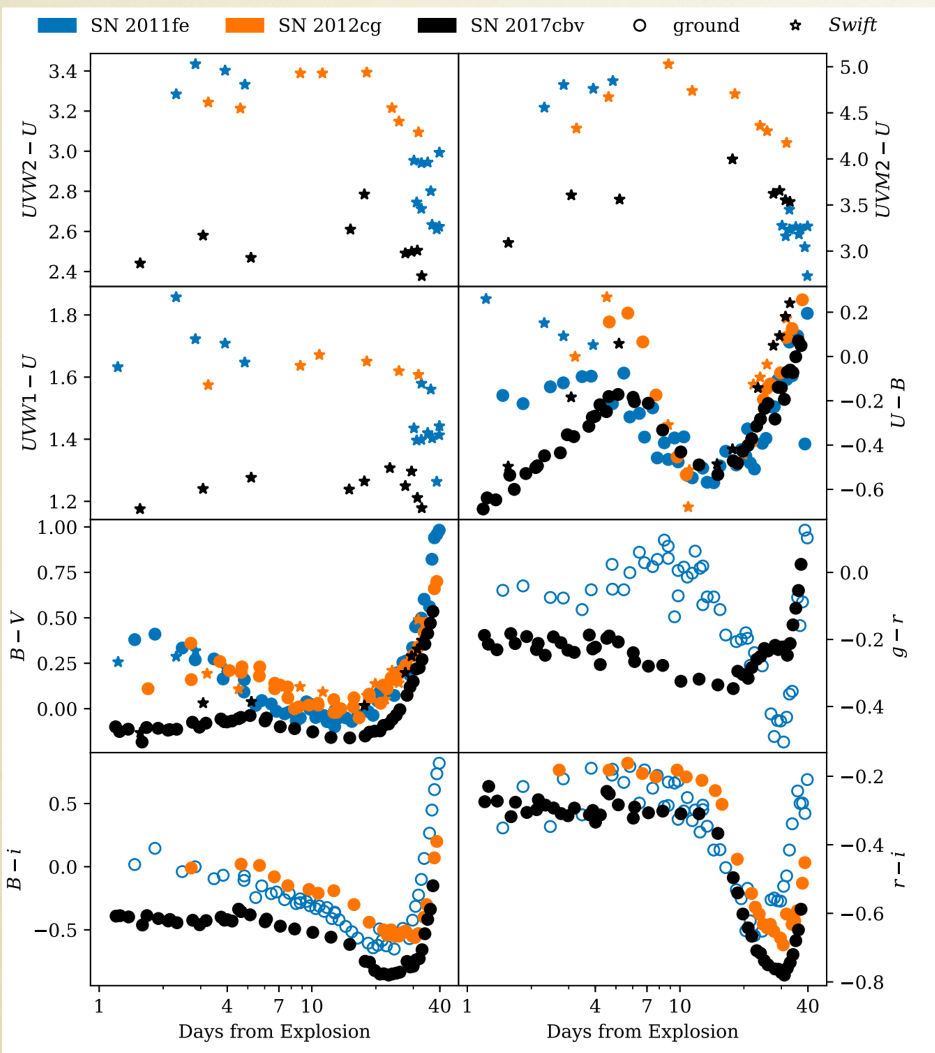
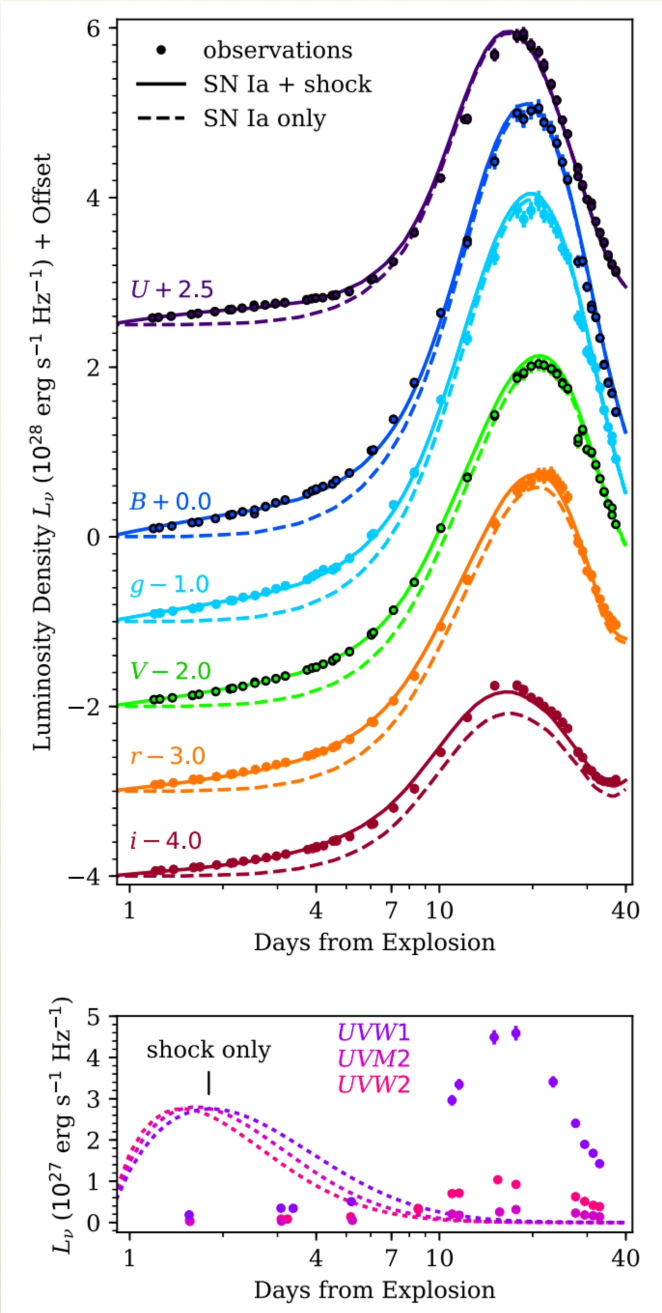
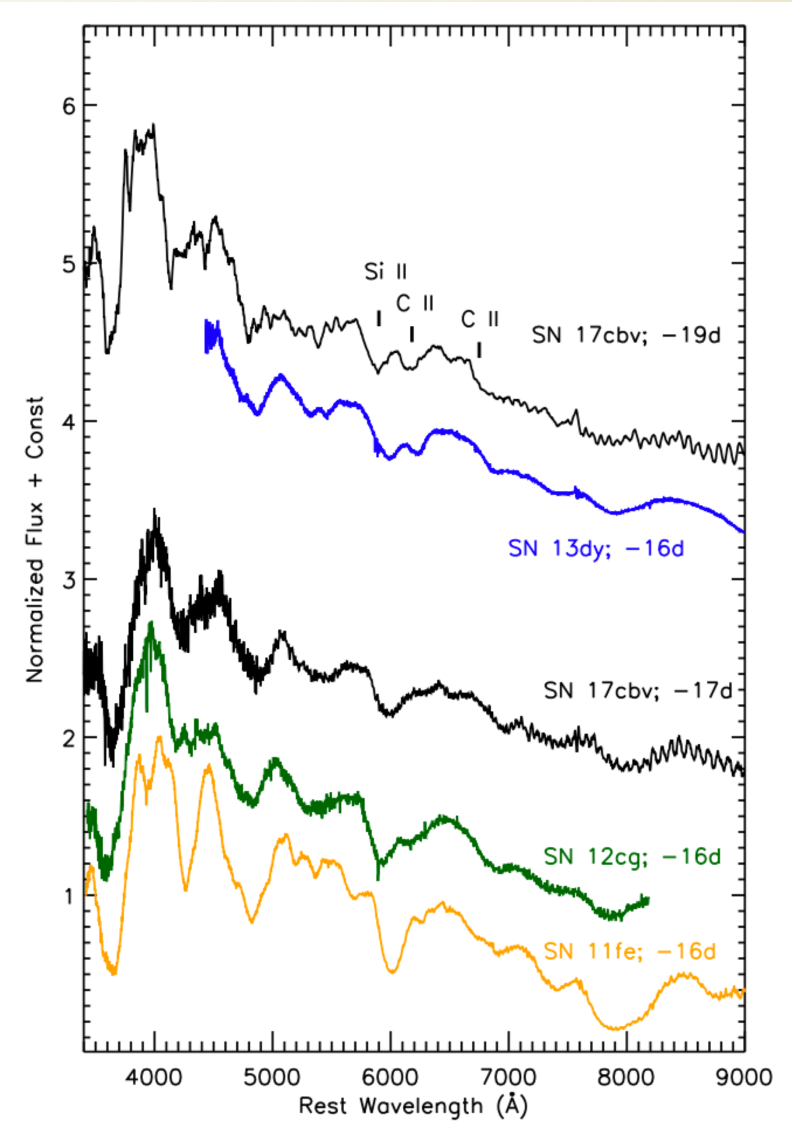






Hosseinzadeh et al. 2017

Looking Ahead for DLT40

- We discovered 10 SNe in our first year within a day of explosion (12 total).
- Northern hemisphere extension would include famous very nearby galaxies and give better coverage of the Virgo cluster.
- In the last month, we have added a second telescope in Australia. Meant for sub-day cadences!
- These events will be the nearest and most exciting SNe in the coming years -- very complementary to ASAS-SN & (soon) ZTF.
- Programs like this **do** have a life in the era of LSST, given its saturation limit.

Maximizing Science in the Era of LSST:
A Community-Based Study of Needed US OIR Capabilities

- Many important recommendations relevant for transient science, including alert brokers.
- Need telescopes/instruments at **all** aperture scales that can intelligently decide which transients are interesting, and then promptly observe them.

Full Report: https://www.noao.edu/meetings/lsst-oir-study/

Maximizing Science in the Era of LSST:
A Community-Based Study of Needed US OIR Capabilities

- 90Prime -- Excellent for wide area searches necessary for LIGO follow-up. Submitting proposal now for 18A; let me know if you are interested.

- Catalina Sky Survey — 60-in with 5 deg2 imager; workhorse for MMA.

- B&C Spectrograph -- update/roboticize for fast transient follow-up.

Maximizing Science in the Era of LSST:
A Community-Based Study of Needed US OIR Capabilities

Windows on the Universe: The Era of Multi-messenger Astrophysics



- Fast response light curves and fill in for appropriate cadences.


Maximizing Science in the Era of LSST:
A Community-Based Study of Needed US OIR Capabilities

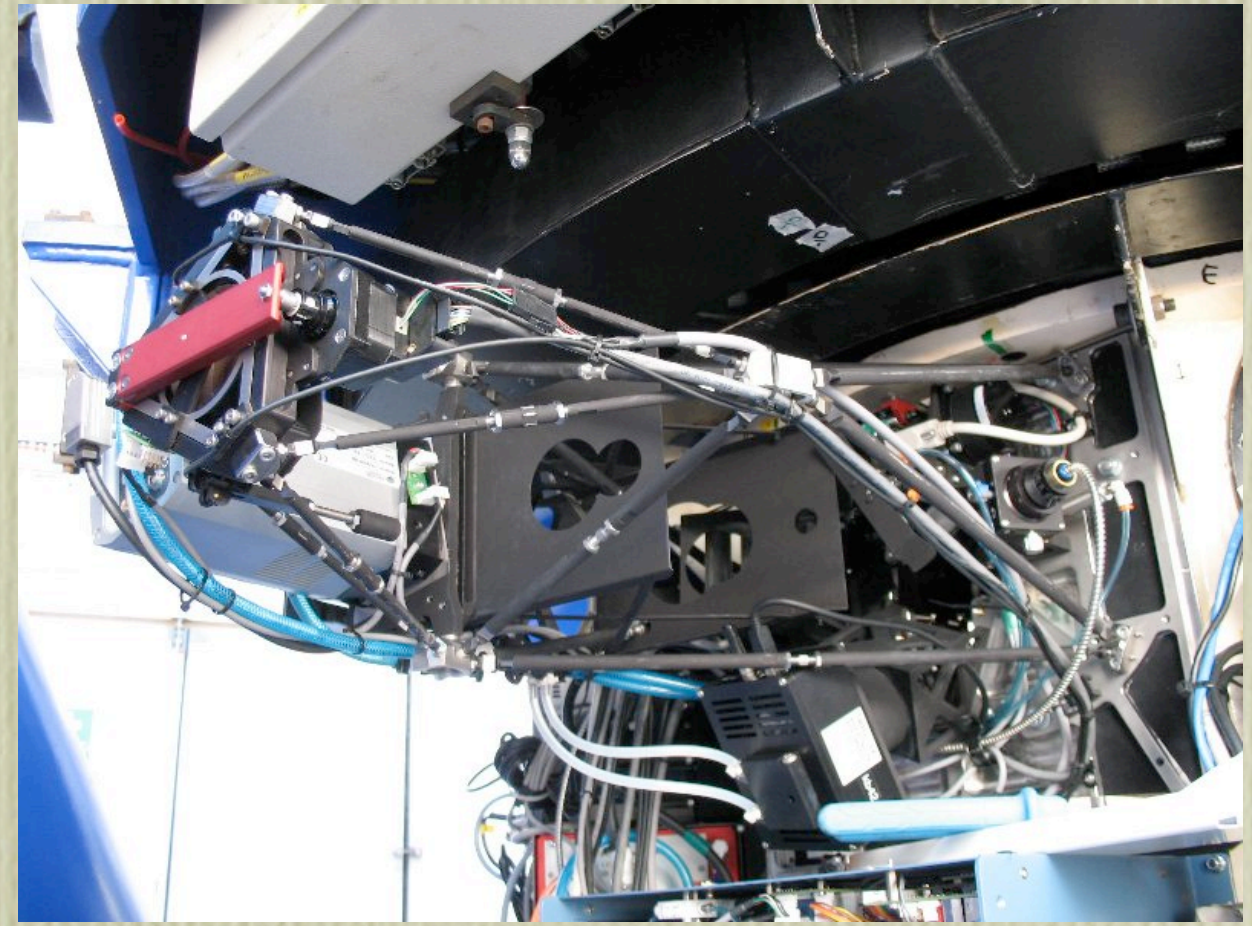
Windows on the Universe: The Era of Multi-messenger Astrophysics

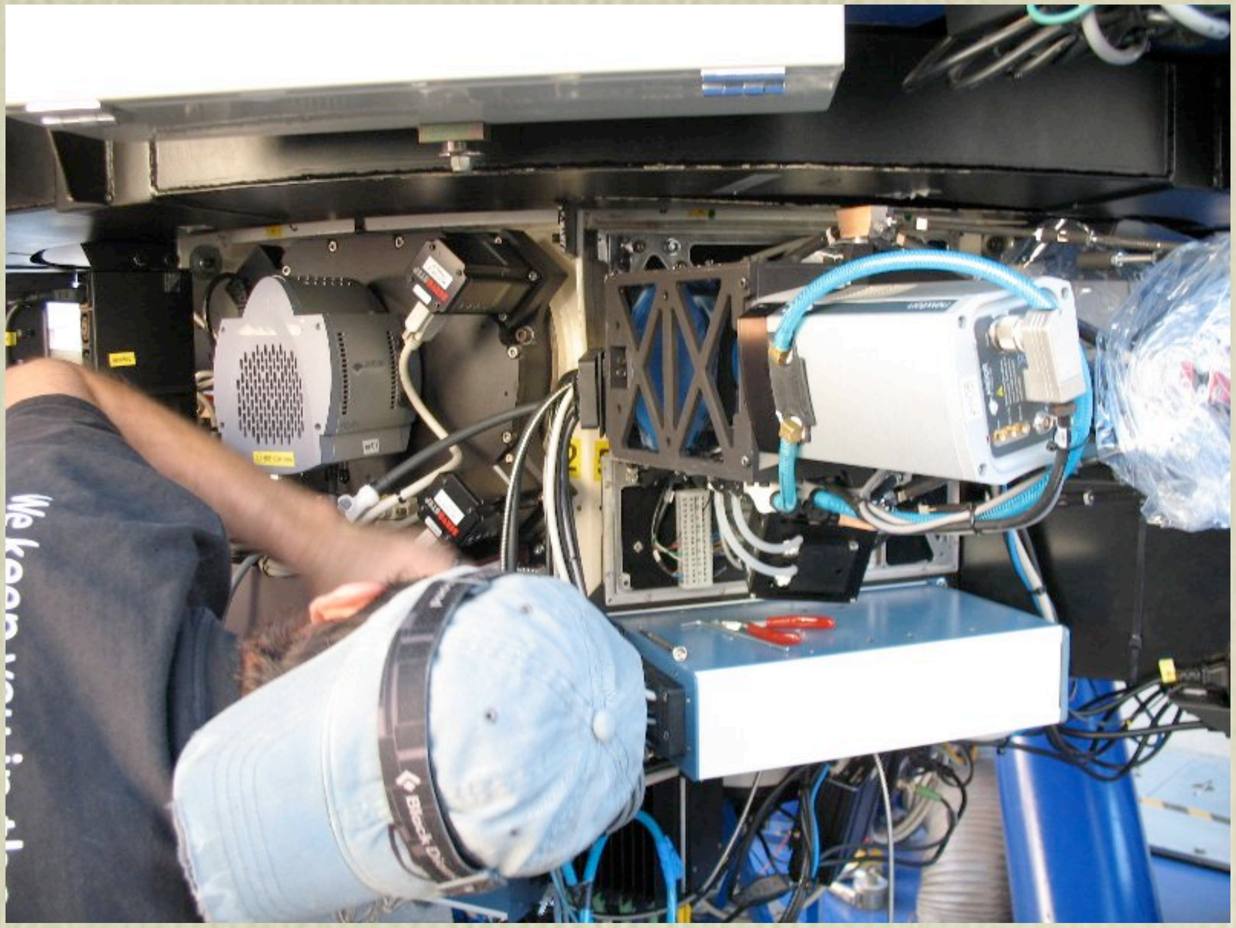
- Get the MMT/LBT transient broker ‘ready’ to respond to urgent alerts, with minimal interruption of normal operations.

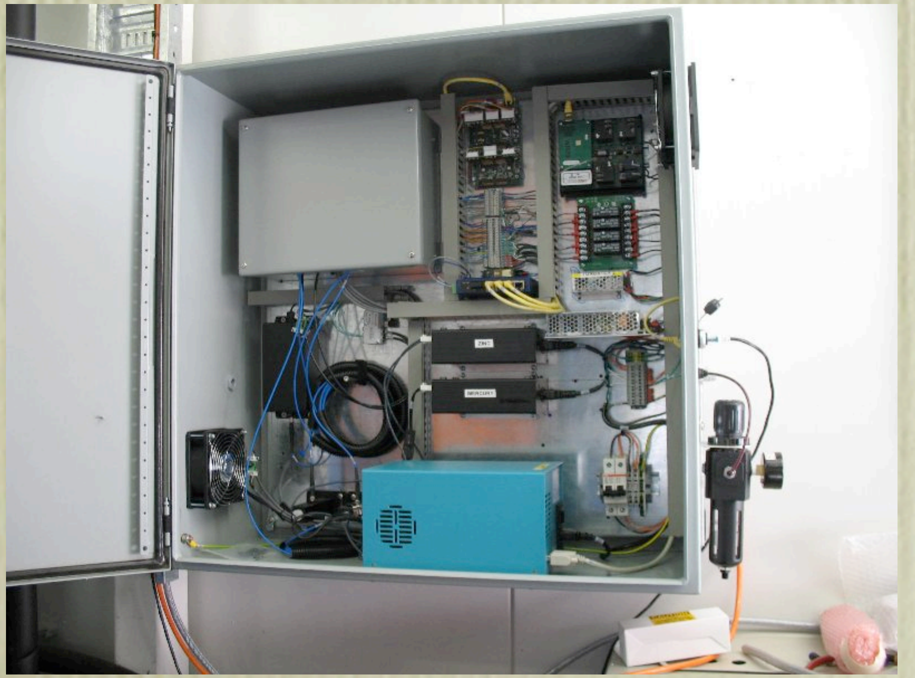
Summary

- We live in an exciting era of new time domain surveys. But there are infrastructure challenges now and on the horizon.
- Robotic spectroscopy can play a key role in current and upcoming time domain surveys to study transients in the moments after discovery.
- FLOYDS -- a pair of robotic spectrographs -- are now operating every day.
- A one-day cadence SN survey is now fully operational. Its focuses on the hints in the hours after explosion which shed light on the progenitor systems. We are expanding to Australia as we speak.
- Arizona will have the premier facilities for very fast time domain followup -- it is within reach!

Some pics





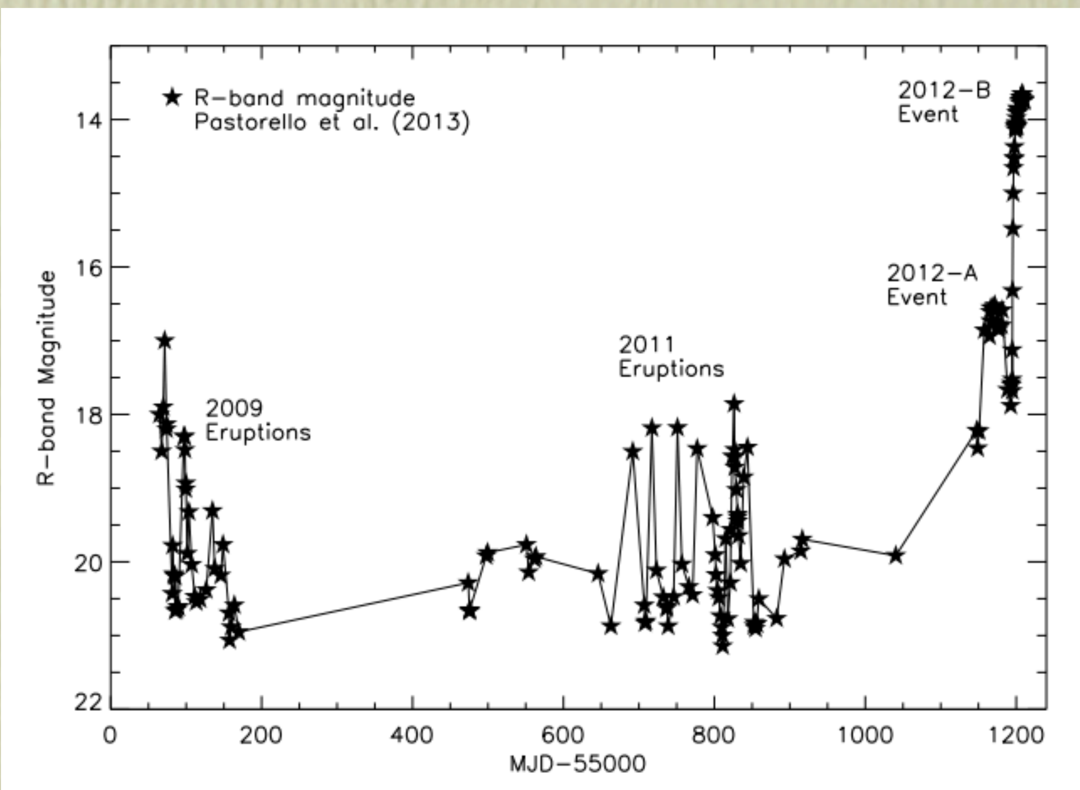


What needs to be done (an outsider's perspective)

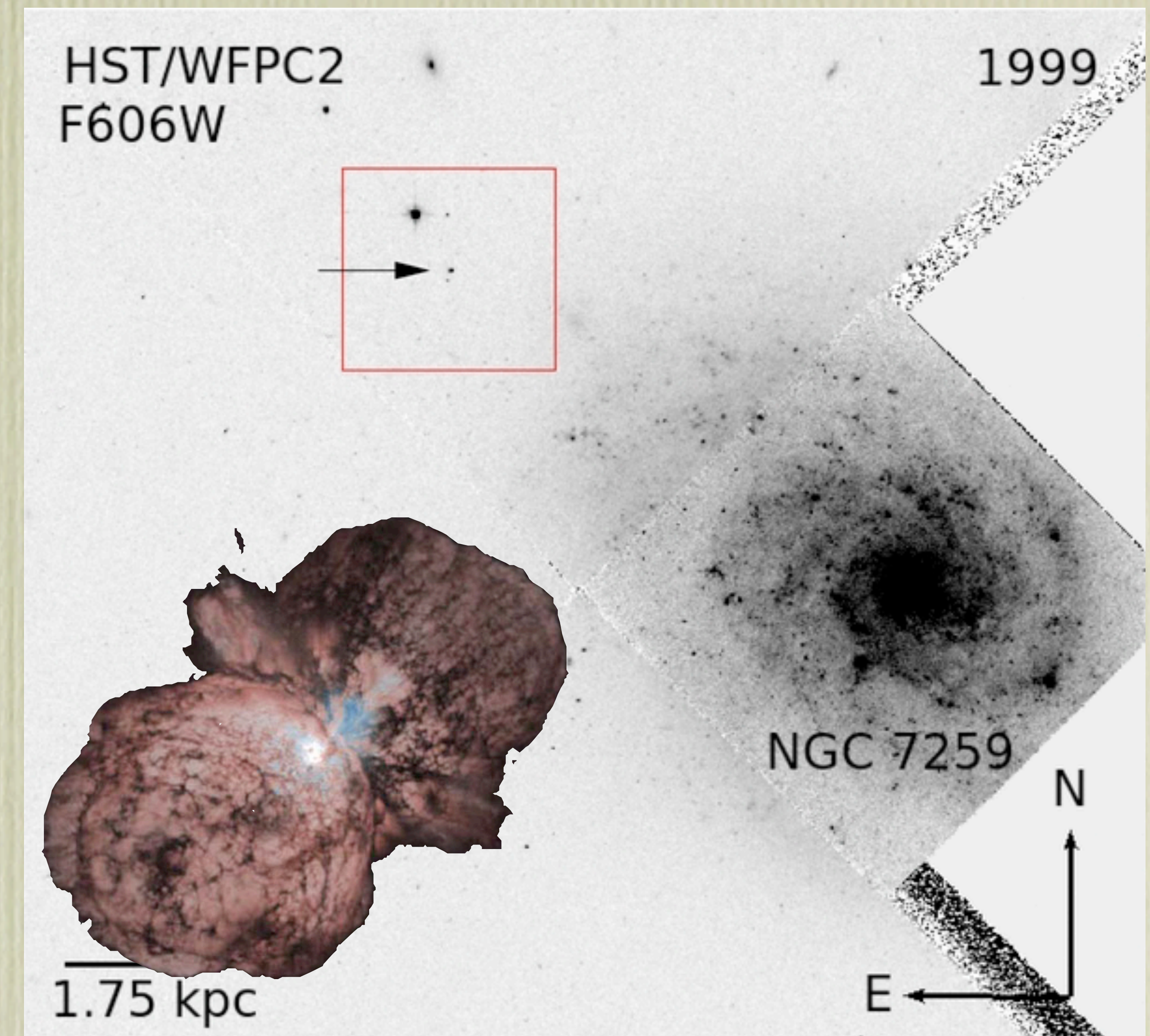
- Queue mode implementation (sometimes). The queue should be adaptable in real time and take inputs from transient brokers.
- Rapid Target of Opportunity.
- Fast reduction pipelines. Standard calibrations and monitoring.
- Augmentation of Goodman with a multiplexed VPH grating to get 3200-10000 A in a single shot?
- Wavefront Sensing.
- Fast/automated acquisition.

SN 2009ip

Graham, Sand, et al. 2014



Pastorello et al. 2013



Margutti et al. 2014

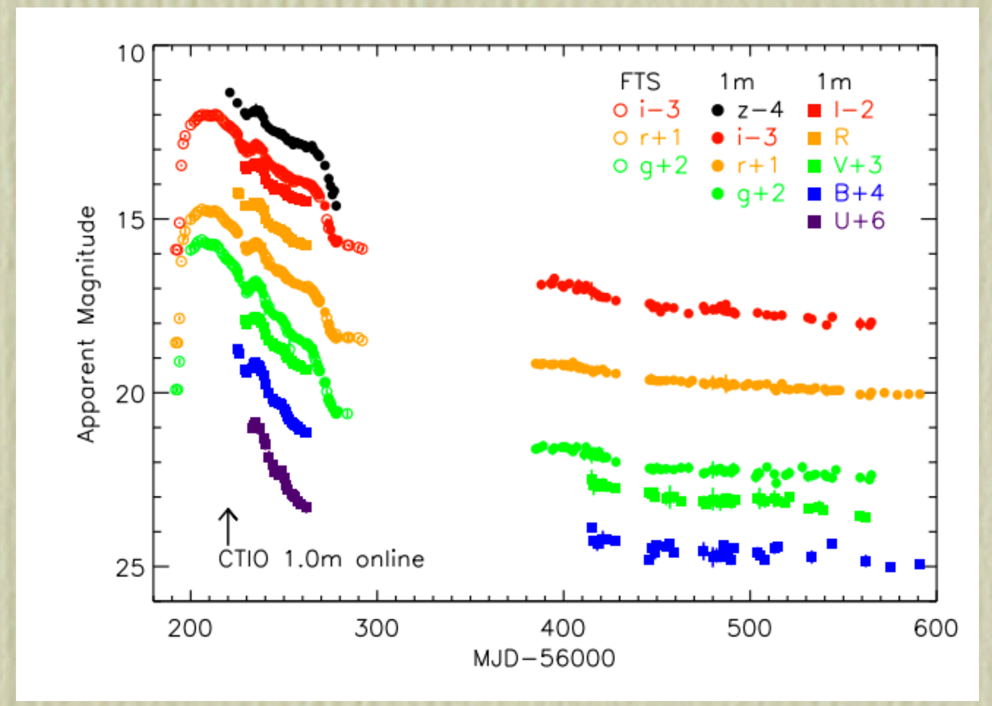
SN 2009ip: a “SN impostor” from 2009. Turned out to be an eruption from a Luminous Blue Variable like eta-Carinae.

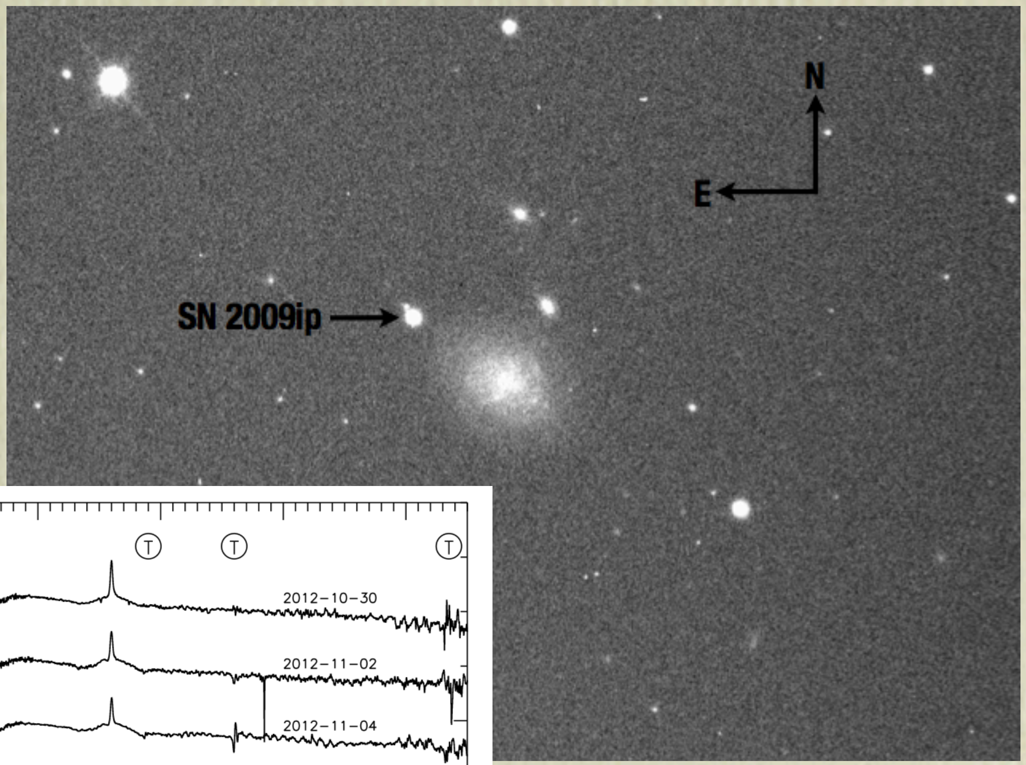
But then in 2012 it exploded as a real Type II supernova! (We think.)

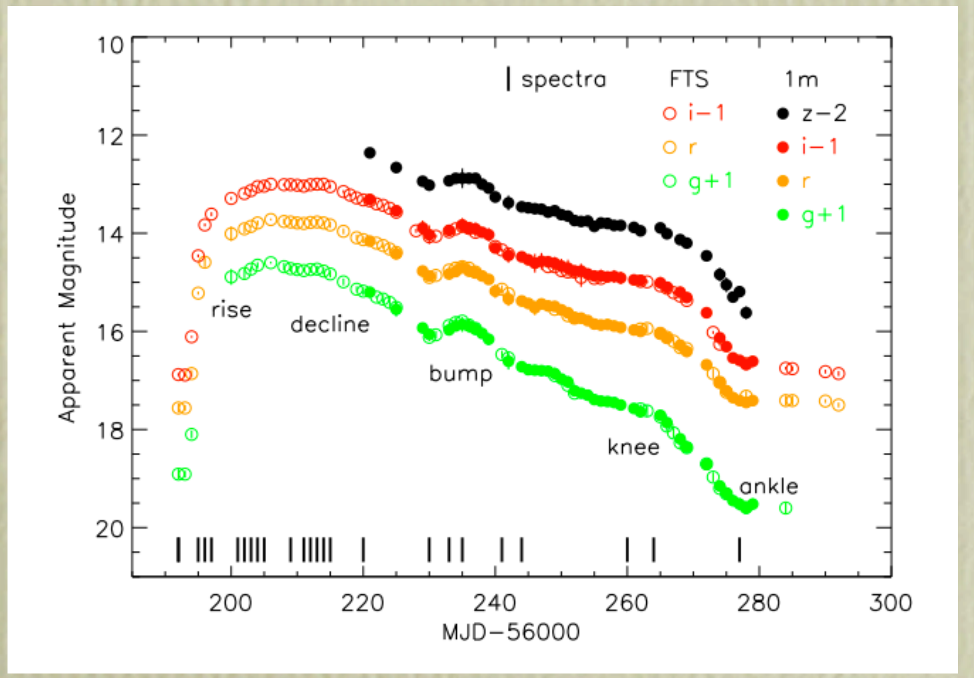
Many, many, many other papers about this event.

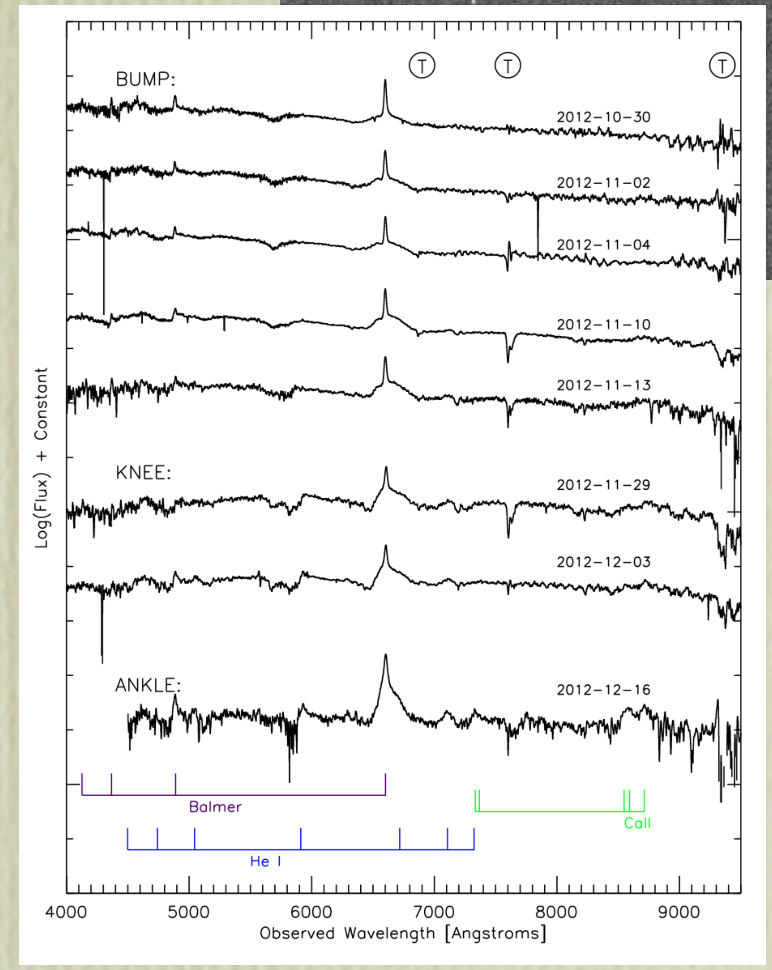
LCOGT light curve: SN 2009ip

Graham, Sand, et al. 2014



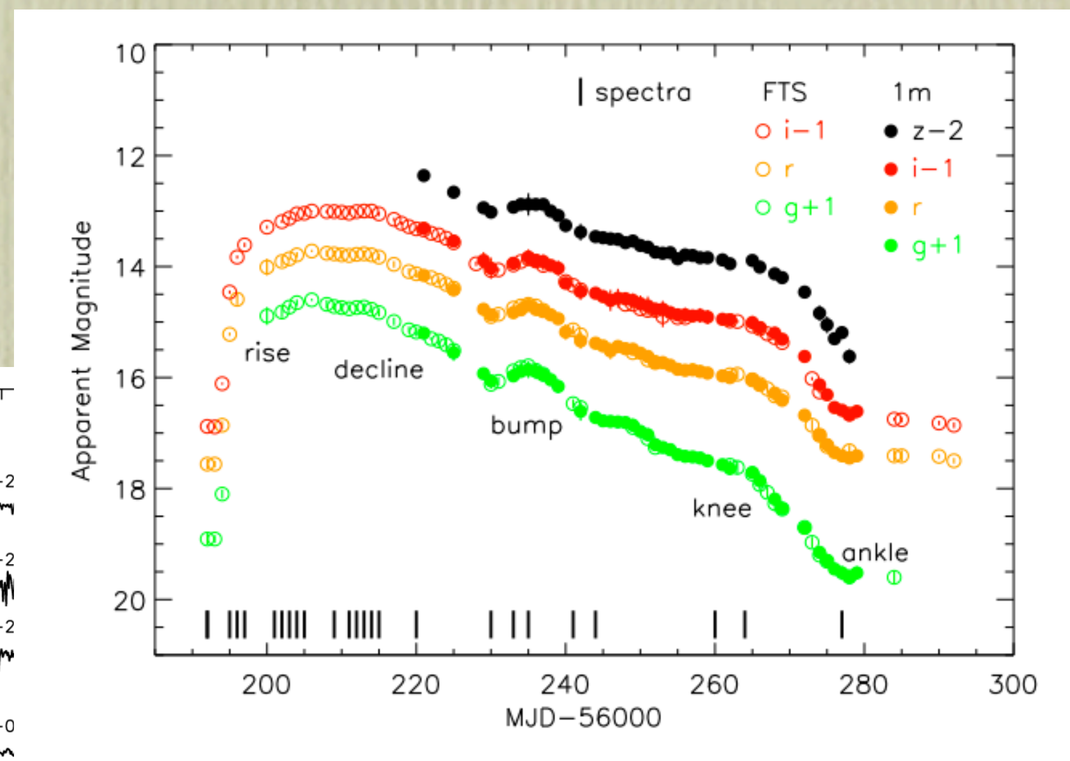


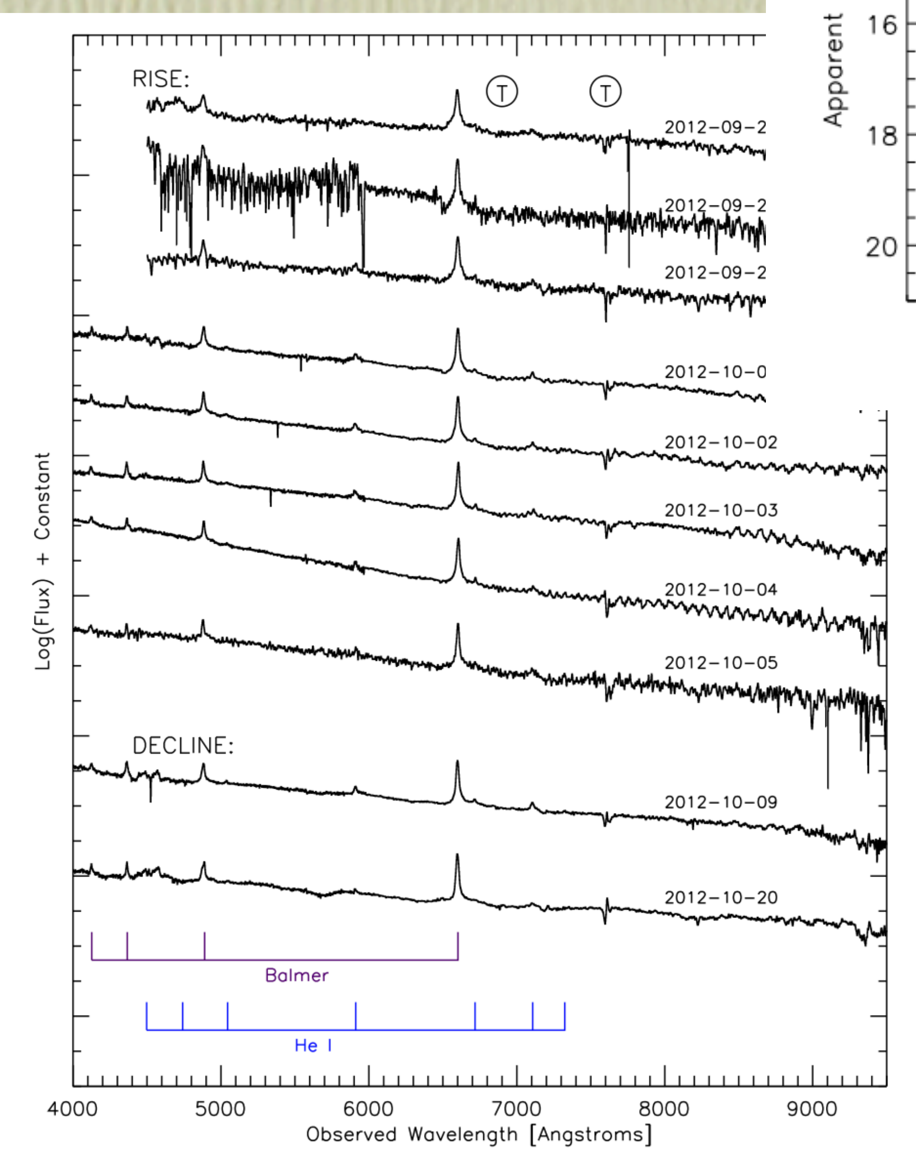


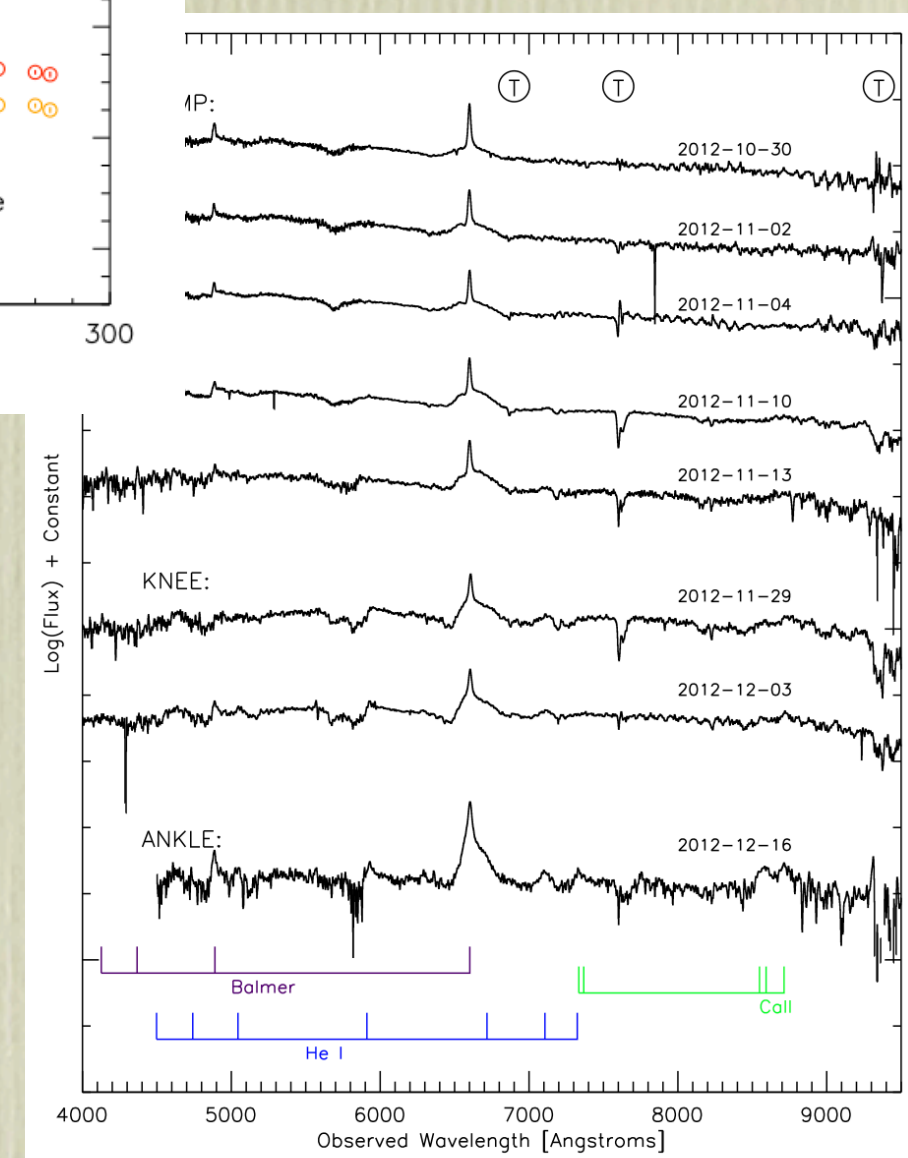


First FLOYDS results: SN 2009ip

Graham, Sand, et al.2014







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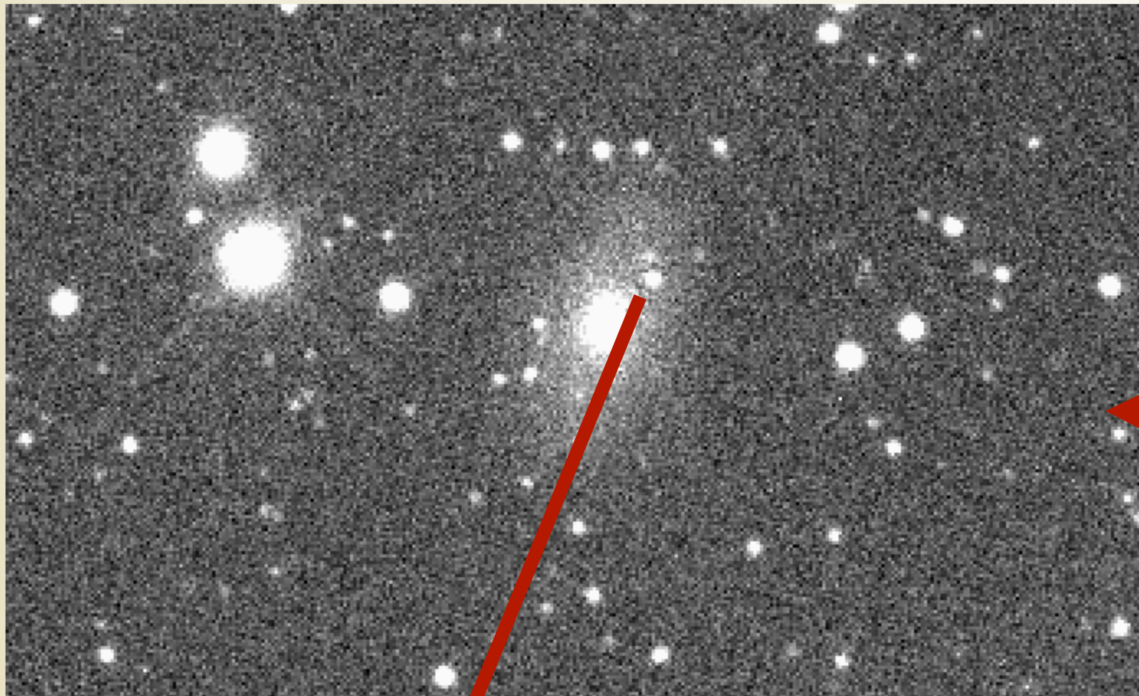
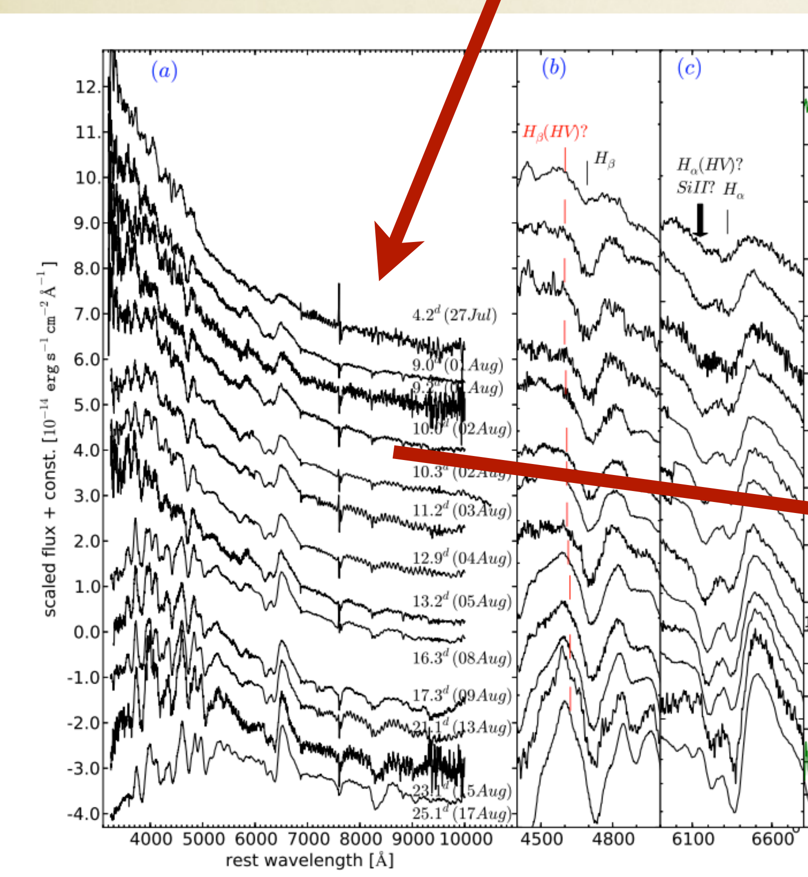
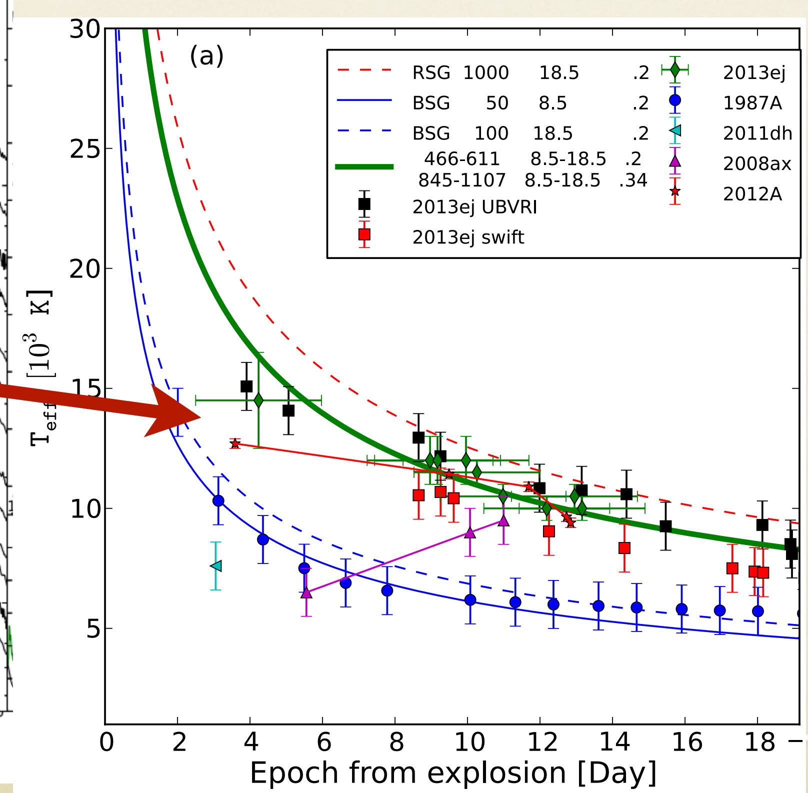
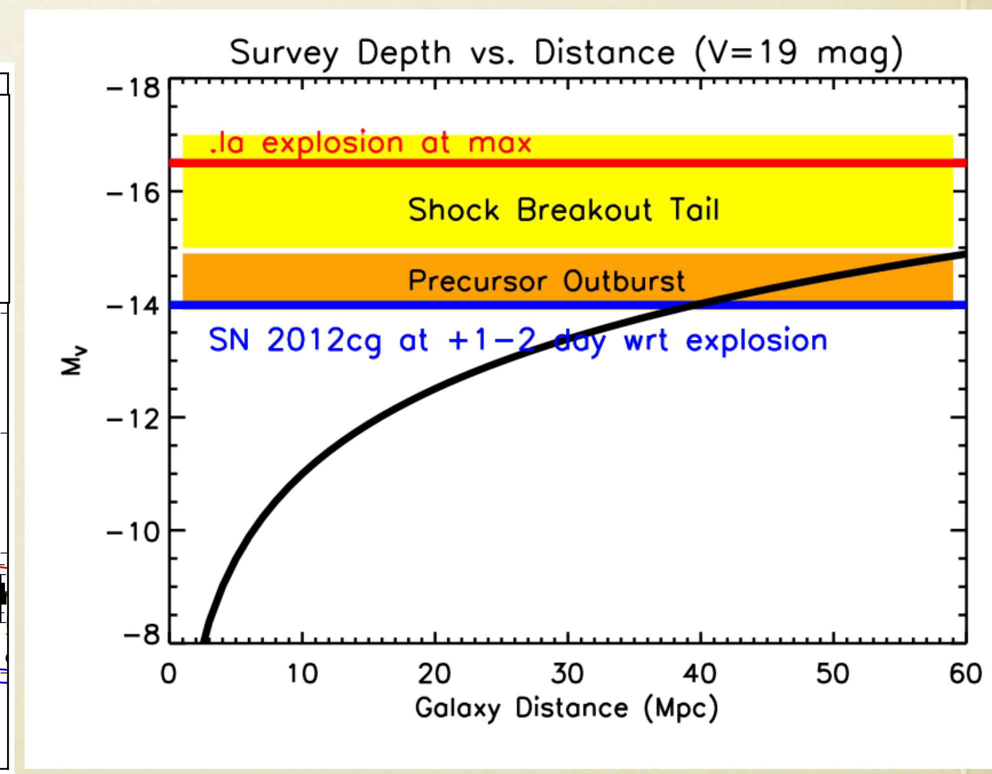
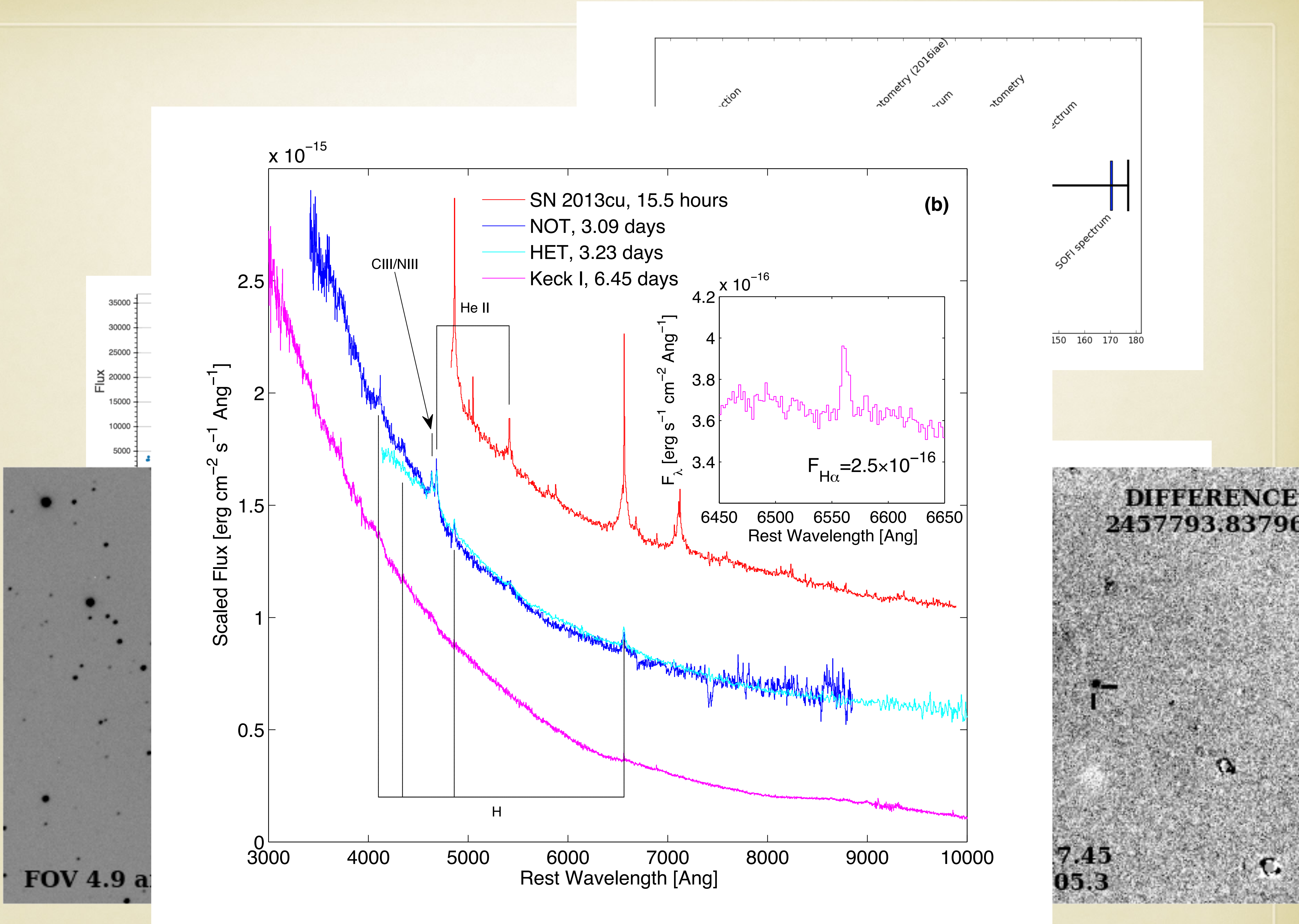


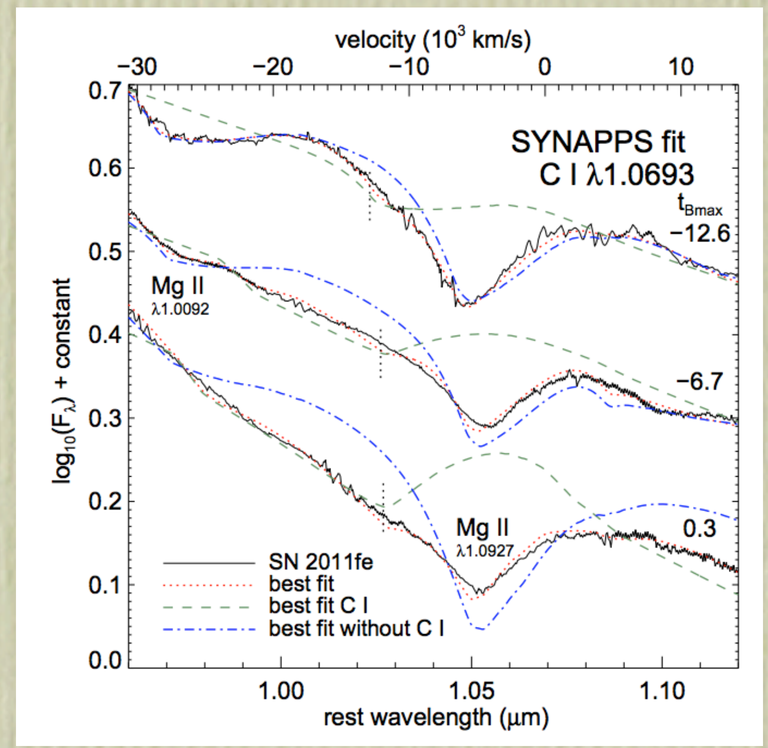




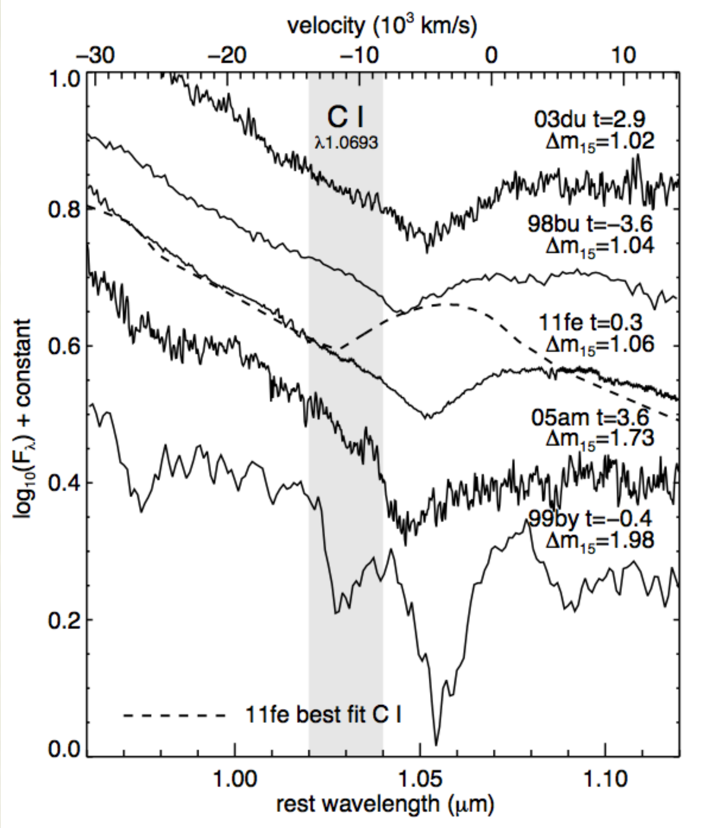


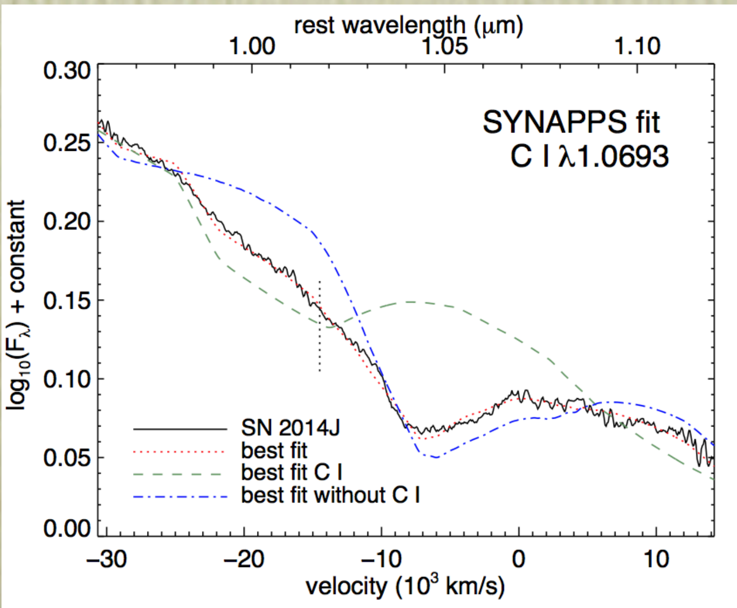

x 10^−15
SN 2013cu, 15.5 hours
NOT, 3.09 days
HET, 3.23 days
Keck I, 6.45 days
(b)
CIII/NIII
He II
H
Scaled Flux [erg cm^−2 s^−1 Ang^−1]
Rest Wavelength [Ang]
x 10^−16
F_λ [erg s^−1 cm^−2 Ang^−1]
F_Hα=2.5×10^−16
SOFI spectrum
Flux
DIFFERENCE
2457793.83796
FOV 4.9 a

The Signature of unburned material -- Carbon Maybe easier to see in NIR?



Hsiao et al. 2013



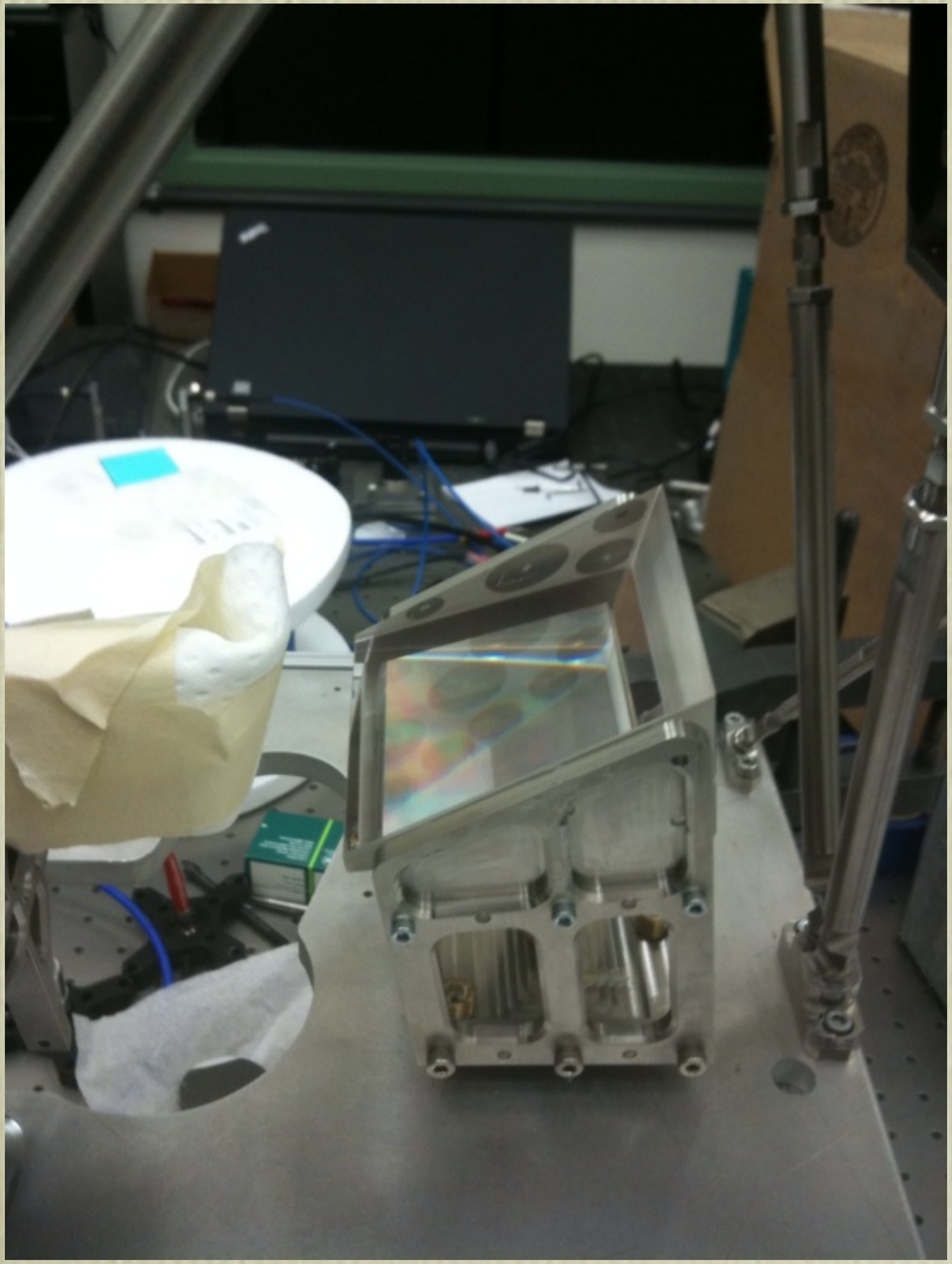


Marion, Sand et al. 2014

Neutral carbon recombines at lower temps/densities? Always discernible in NIR around max?

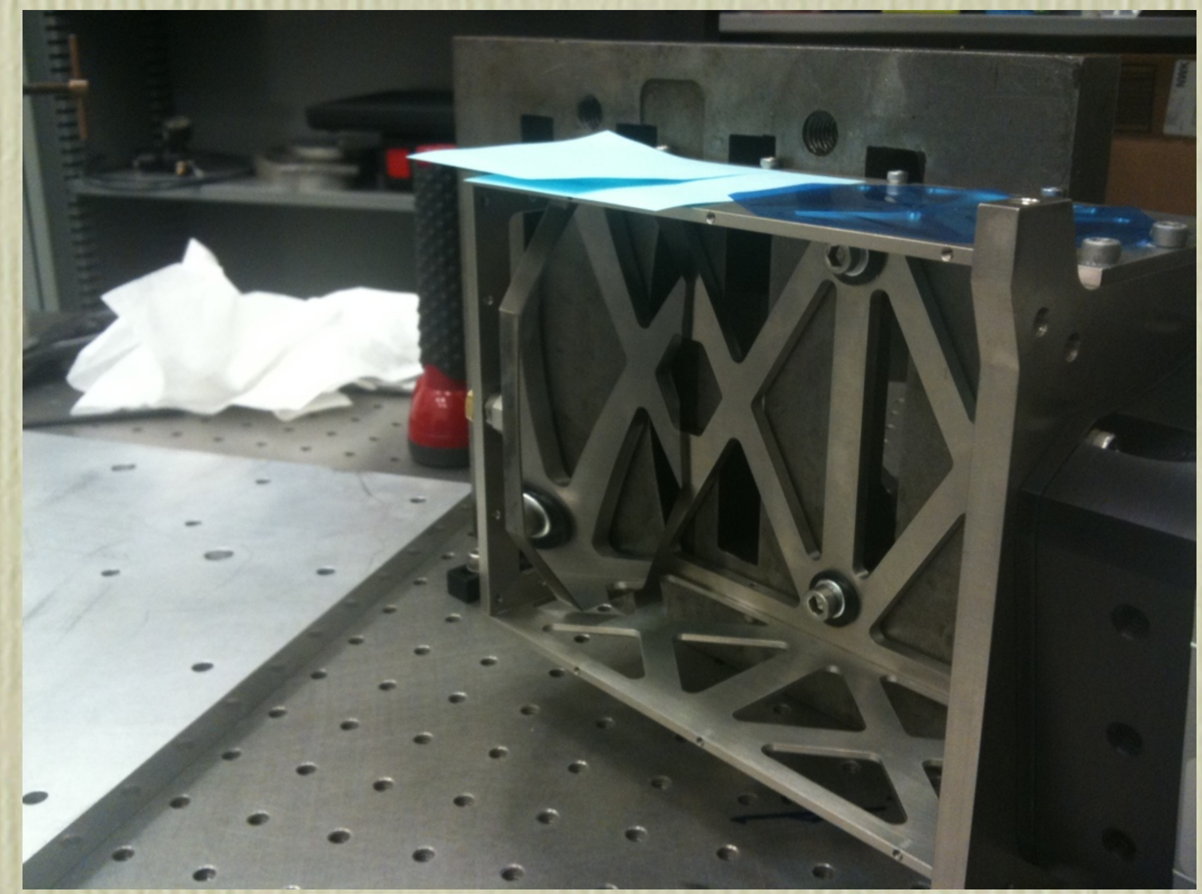
Collimator w/ linear stage (NEVER used)

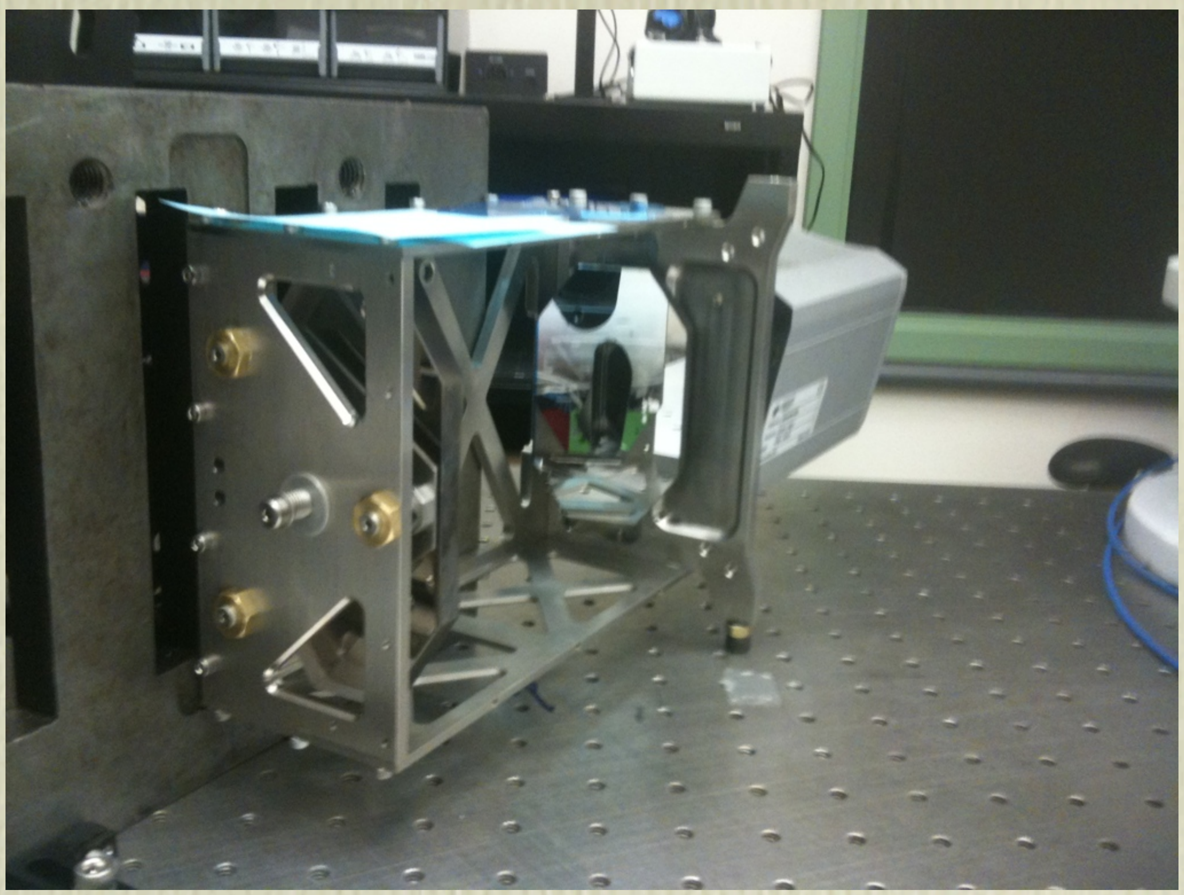
Calibration Cabinet (in other room)



- The 235 l/mm grating is the primary disperser, but the prism serves to separate orders.

Camera



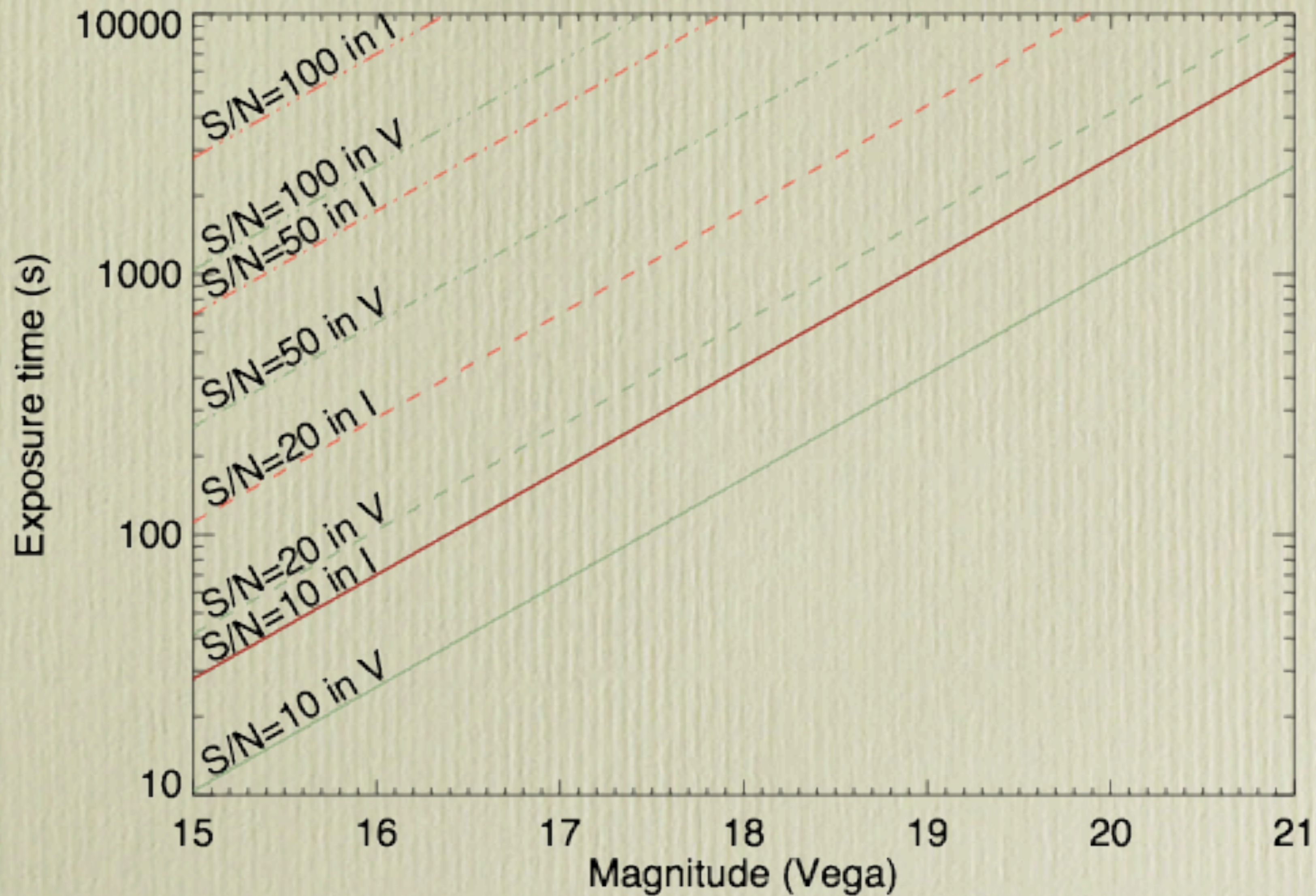


Simple folded 'Schmidt' design with spherical mirror. Corrector lens near CCD.

CCD

- 512x2048; 13.5 micron pixels
- Cooled to -70 C with TEC
- 20 sec readout
- UV & red sensitive (hit by fringing >700 nm)

Some sensitivity numbers



Numbers from standard star observations; thanks to Andy Howell for making plot.

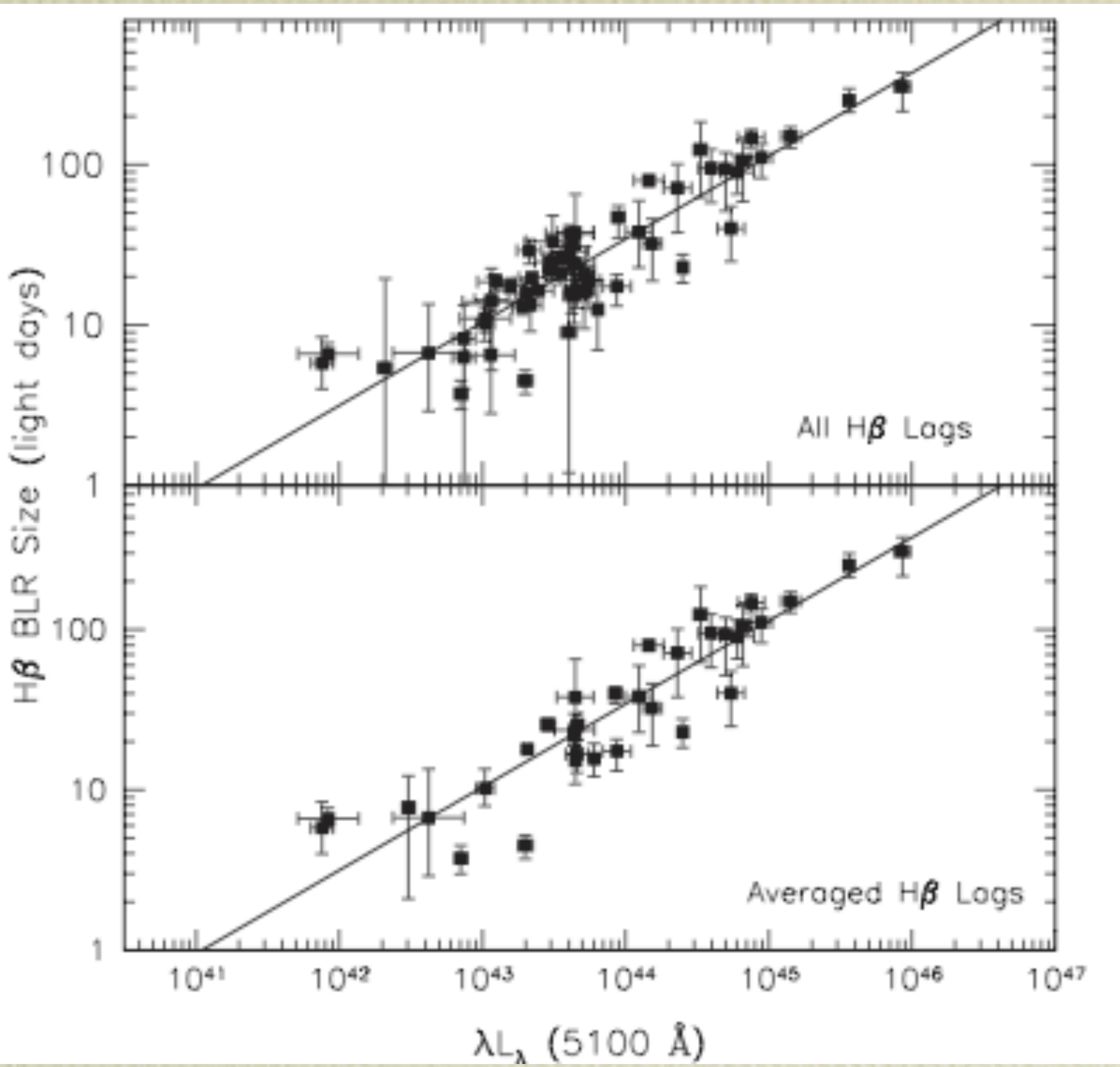
Standard Star field -- Just slam it into the slit.

Reverberation mapping of BHs -- pushing to high redshift

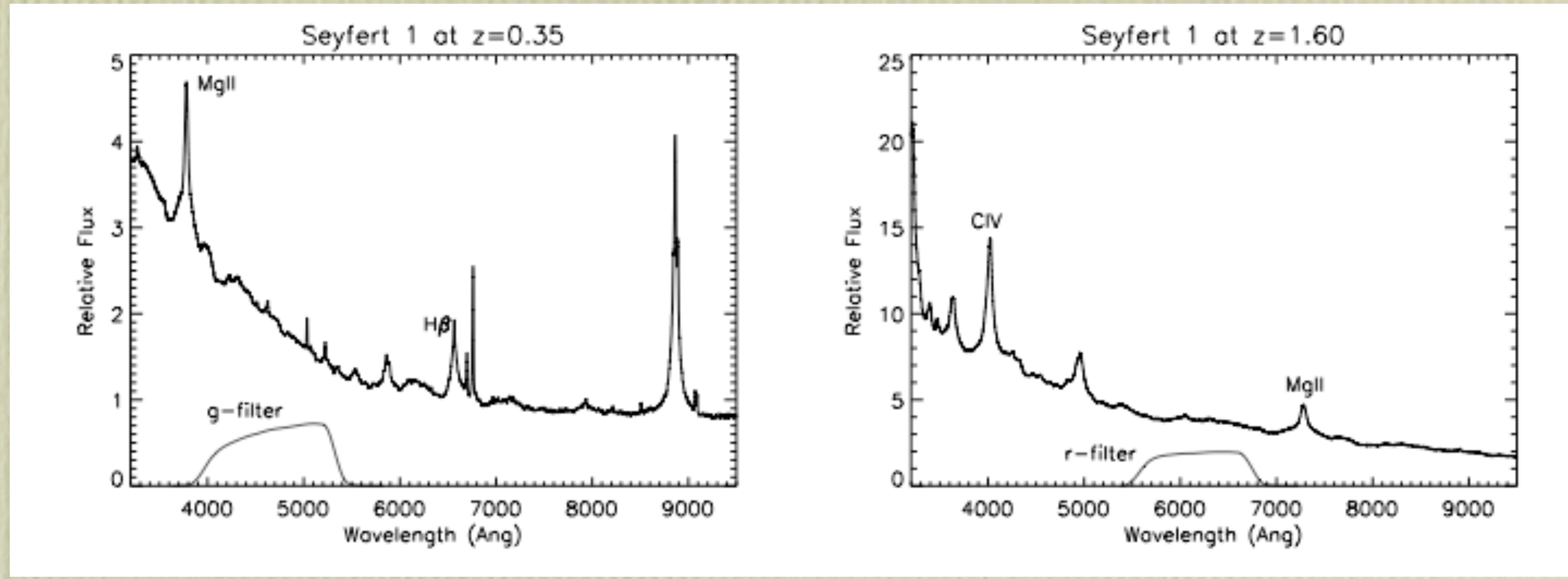
- M_{BH} vs σ relation -- how does it evolve with redshift? Uses 'single epoch' M_{BH} estimates based on local reverberation mapping results.

- Does the R_{BLR} vs. L_{AGN} relation evolve with redshift?

- Need direct R_{BLR} measurements via reverberation mapping at various z. Too hard to with classical observing, but is in LCOGT's wheelhouse

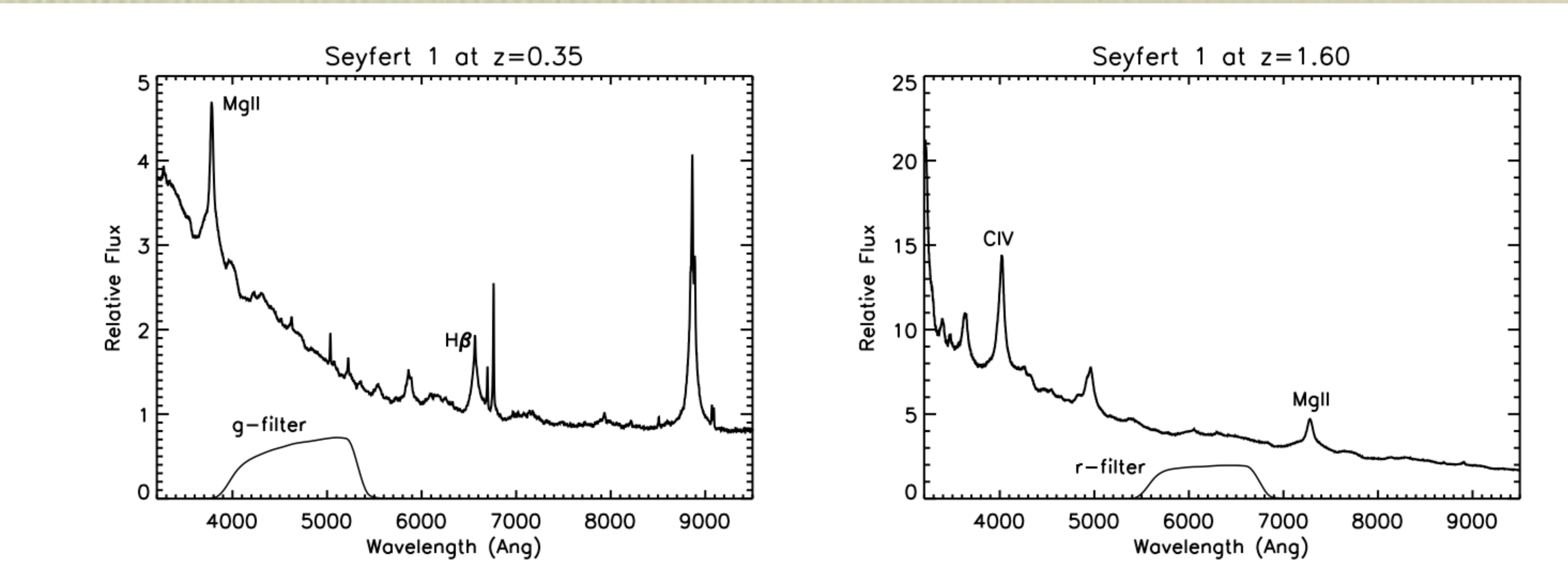


Reverberation mapping with FLOYDS: A three-pronged approach



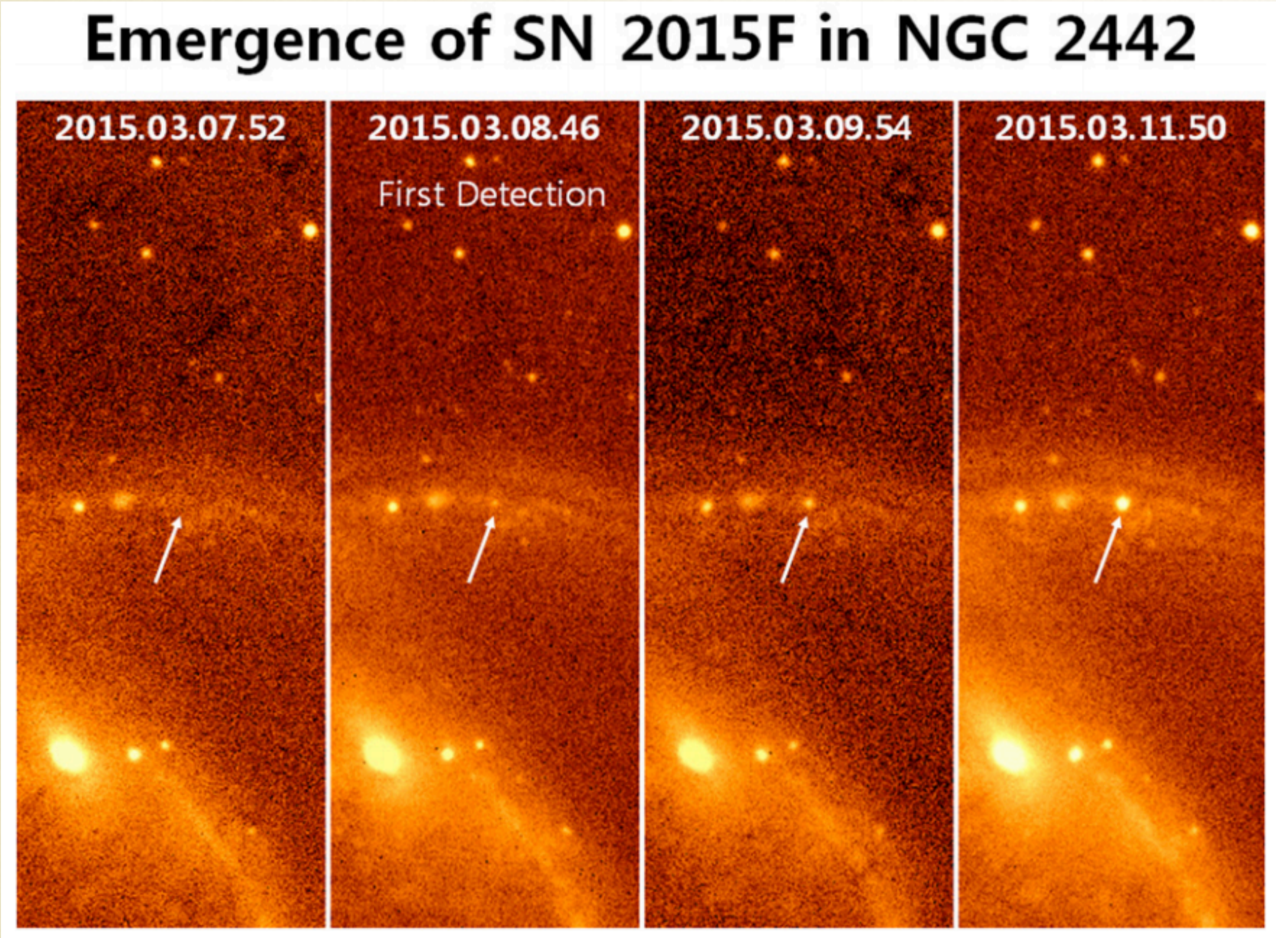
- Local sample to confirm utility of FLOYDS and obtain 1st robotic reverberation mapping result -- ~4-5 months.
- z~0.35 sample -- Measure RM signal in both MgII and Hbeta -- ~1 year
- z~1.6 sample -- Use CIV and MgII -- ~2 years.

Reverberation mapping (at z>0)

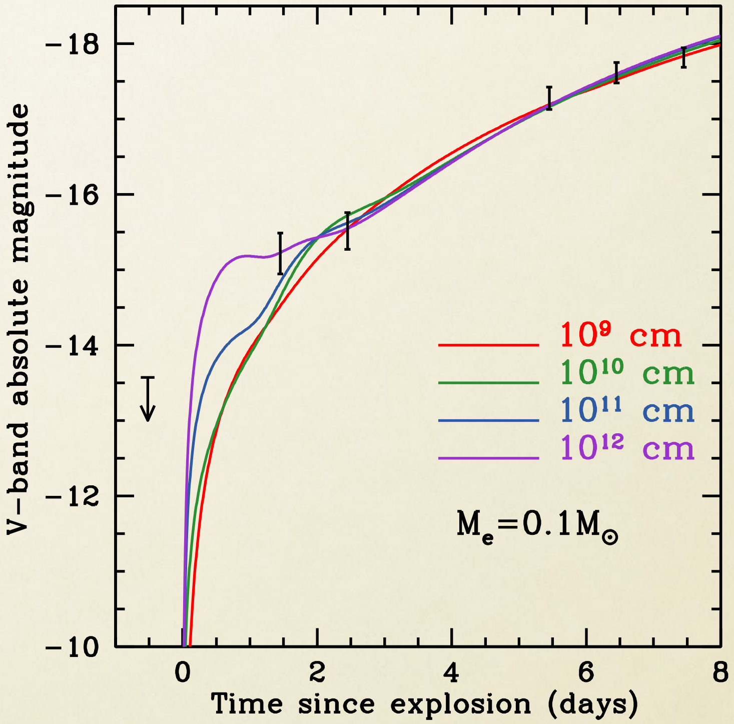


Need to establish a R_BLR vs. L relationship for MgII & CIV to bolster 'single epoch' black hole mass measurements. Extremely difficult for classically scheduled spectrographs.

Catching SN Ia early is another way to constrain their progenitor (but it has to be very early)



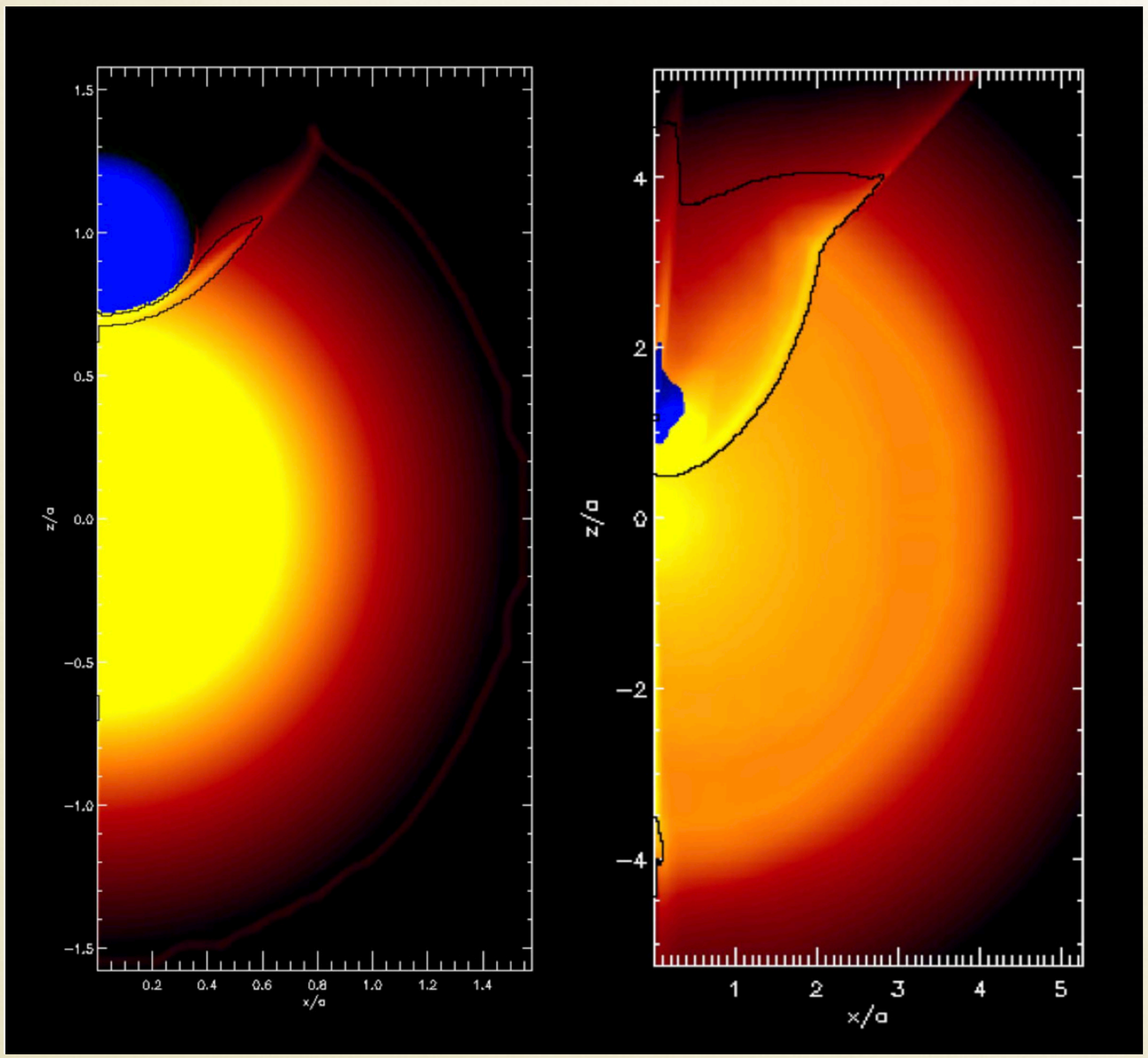
Im et al 2015

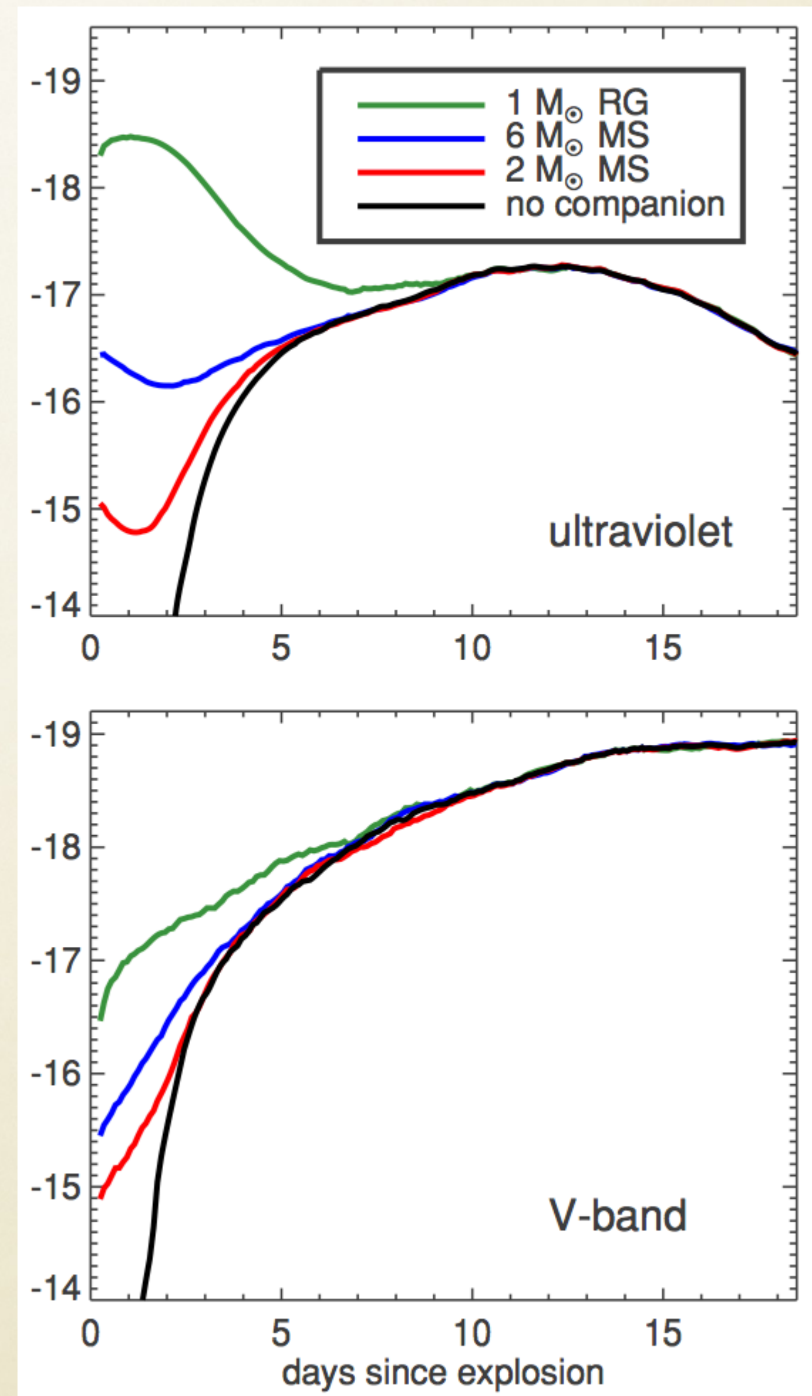


Piro & Morozova 2016

Can constrain amount of extended material around SNe Ia with very early light curve observations. Maybe need sub-day cadence?

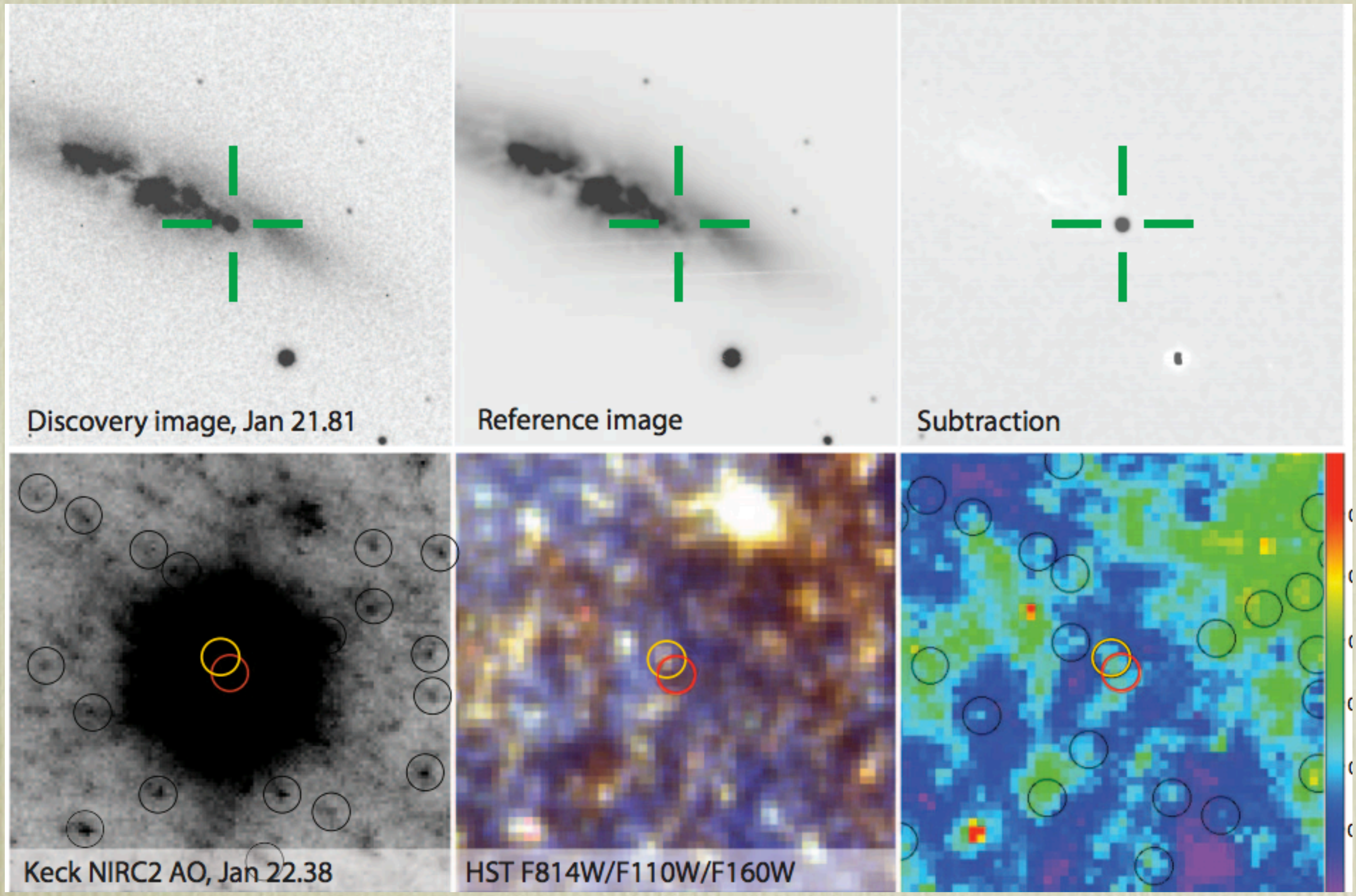
Catching SN Ia early is another way to constrain their progenitor (but it has to be very early)





Kasen 2010

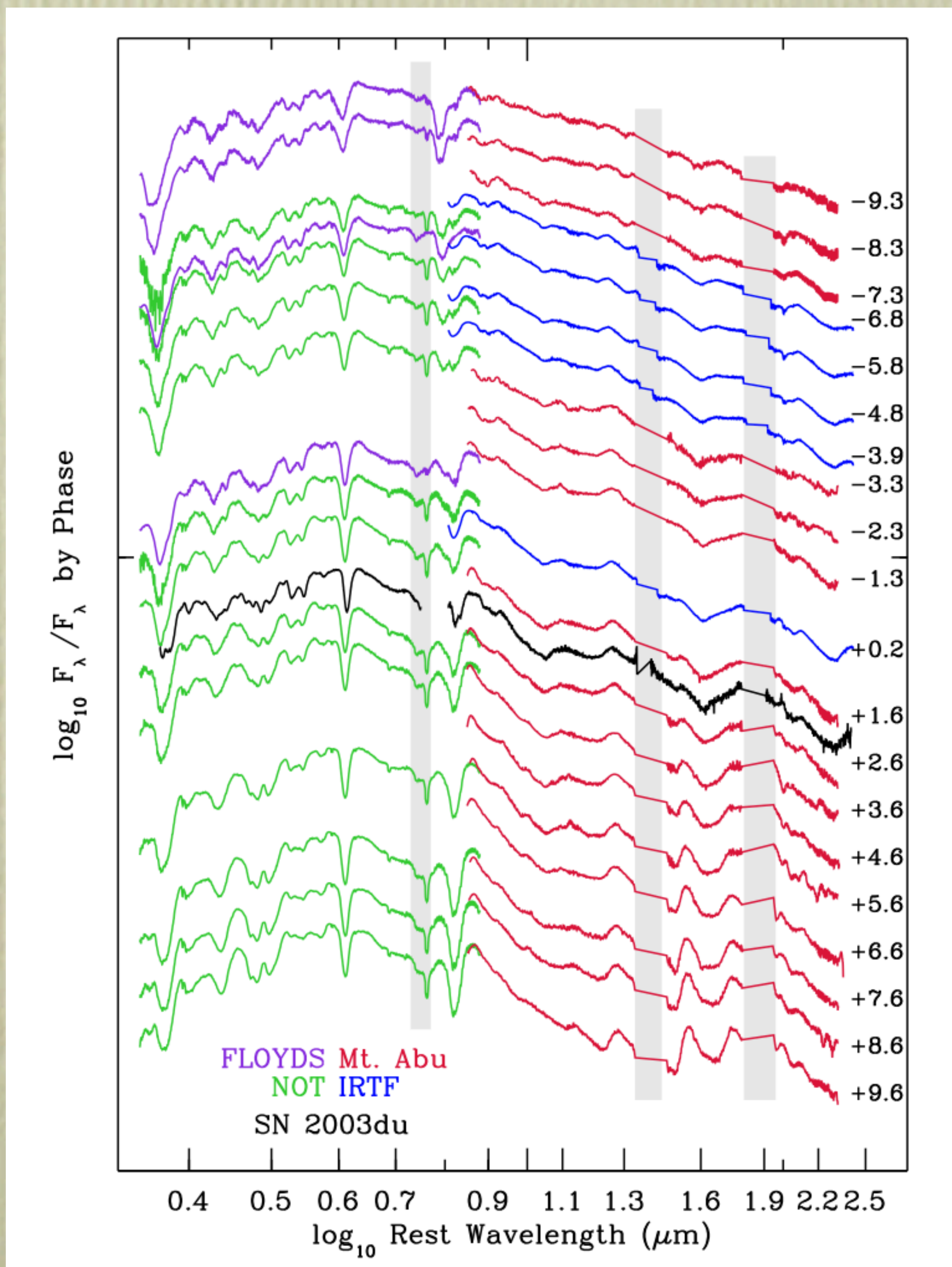
SN 2014J in M82!
Nearest SN Ia in a generation

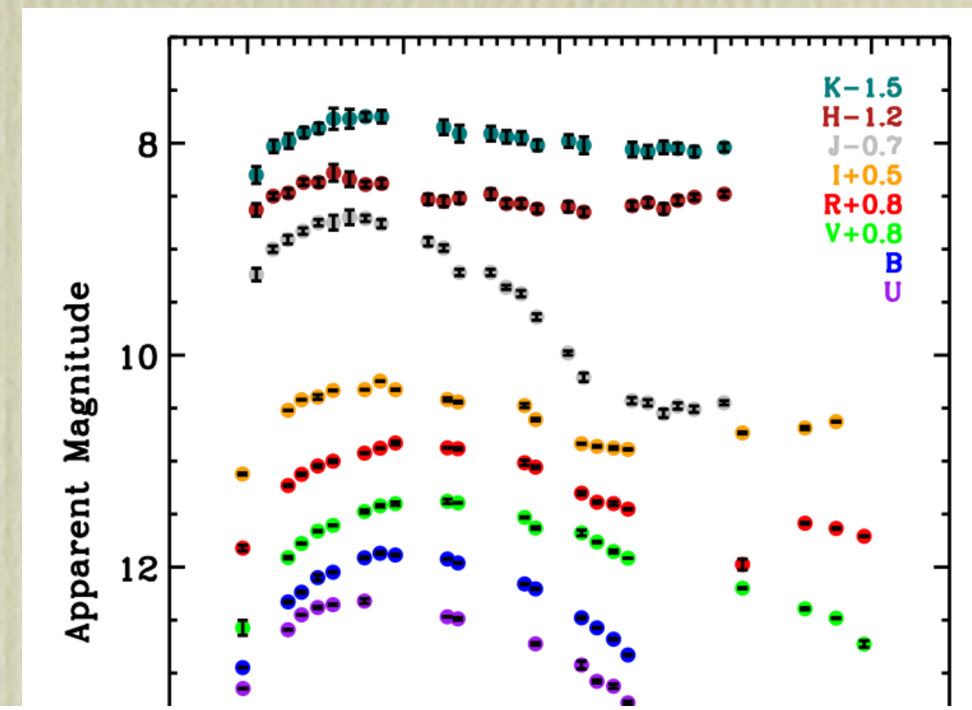


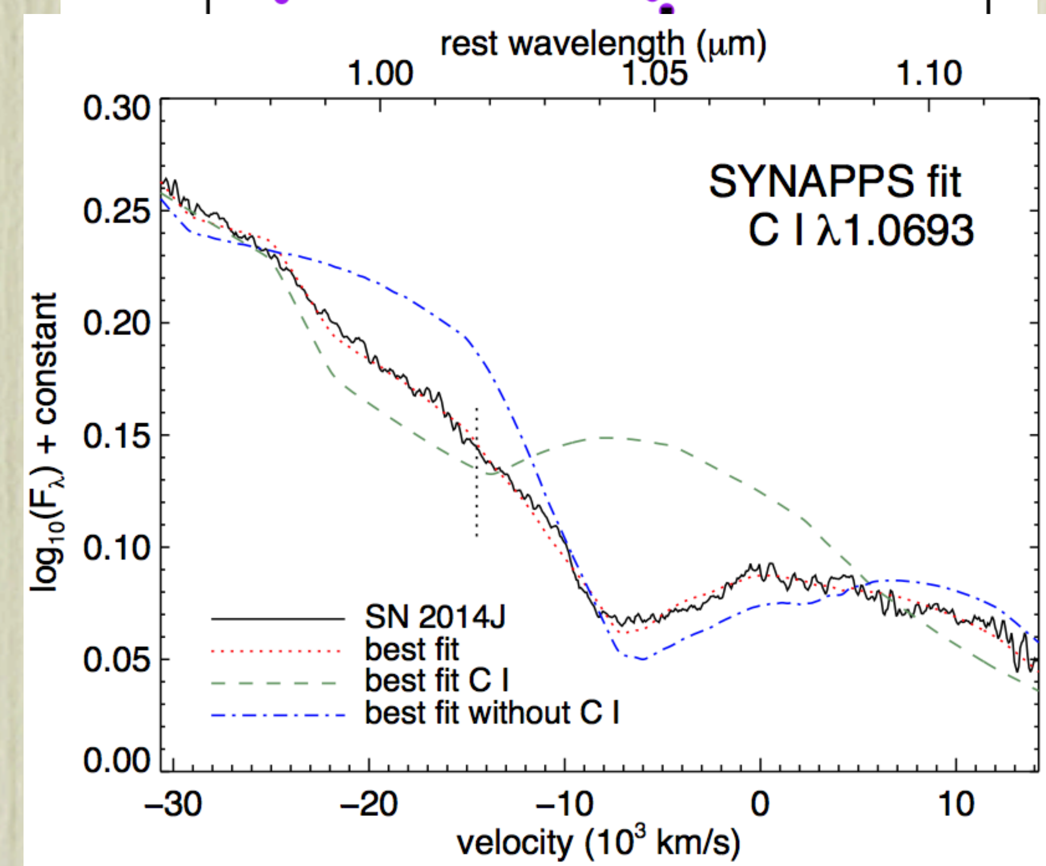
Goobar, ..., Sand et al. 2014

SN 2014J in M82

Optical/NIR followup and carbon detection



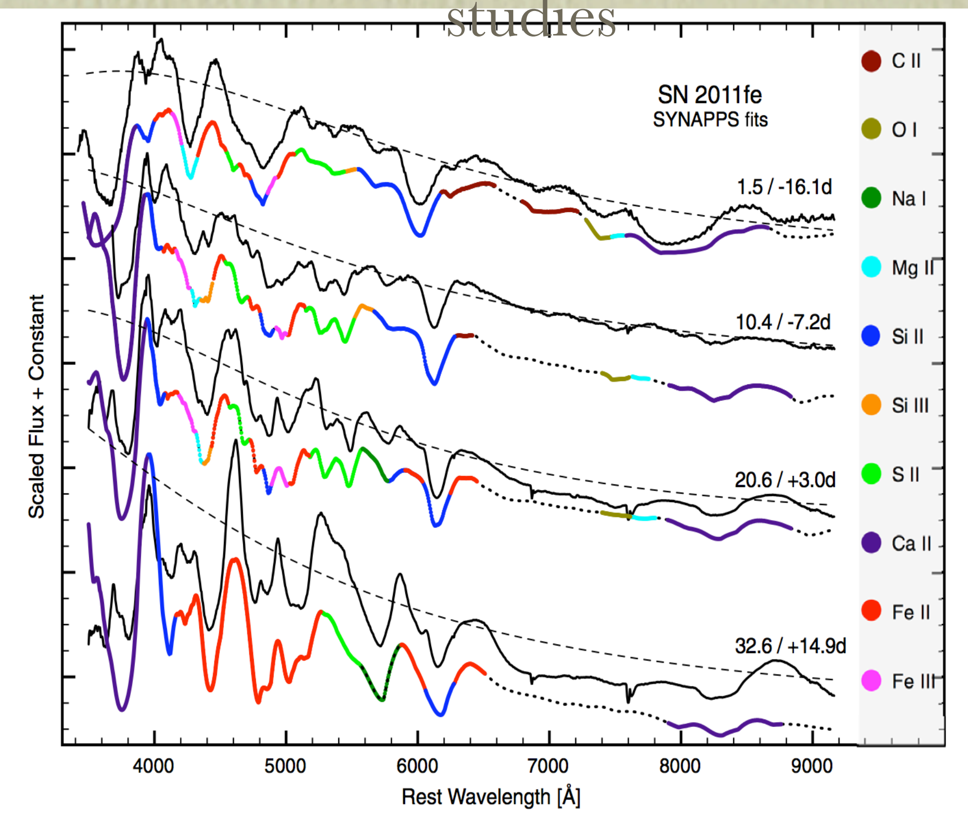


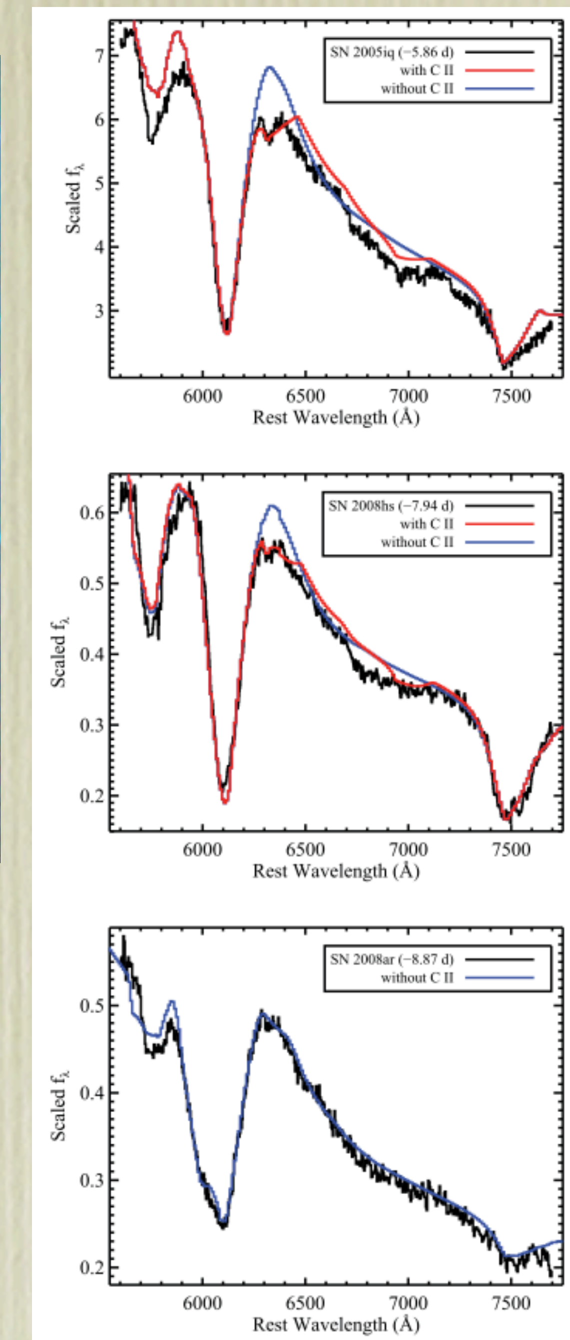


Marion, Sand et al. 2015

The Signature of unburned material -- Carbon

Parrent et al. 2012 + others for carbon studies





Carbon is a sign of original, unburned material from the C/O white dwarf. Frequency of carbon constrains various explosion scenarios.

Carbon seen only ~30% of the time, but the earlier you have data, the more likely you are to see it.