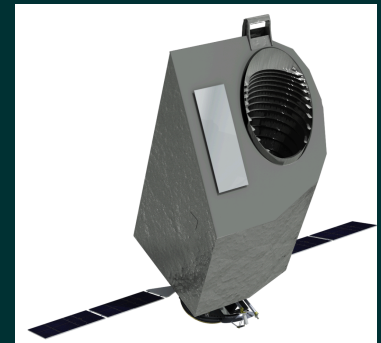


The Core Collapse SN Landscape: Infrastructure and Science Opportunities



UVEX



Einstein
Probe

I. Andreoni



SVOM



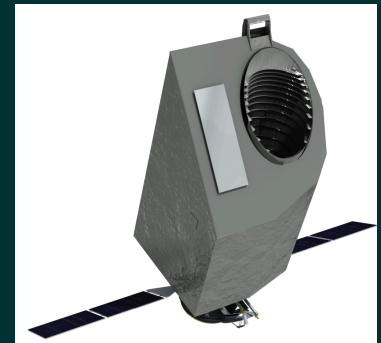
ULTRASAT

D. Sand (U of Arizona)
Hot-Wiring and RAPID

The Core-Collapse SN Landscape: Infrastructure and Science Opportunities



UVEX



Einstein
Probe

I. Andreoni



SVOM



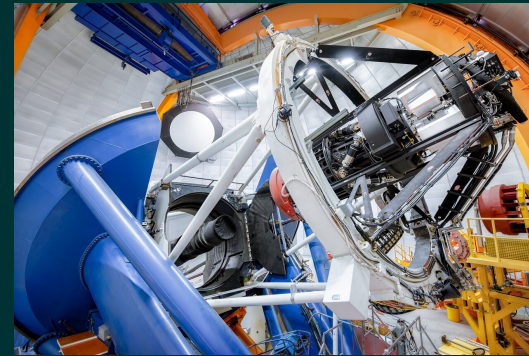
ULTRASAT

D. Sand (U of Arizona)
Hot-Wiring and RAPID

Current and Future State of Supernova Observations

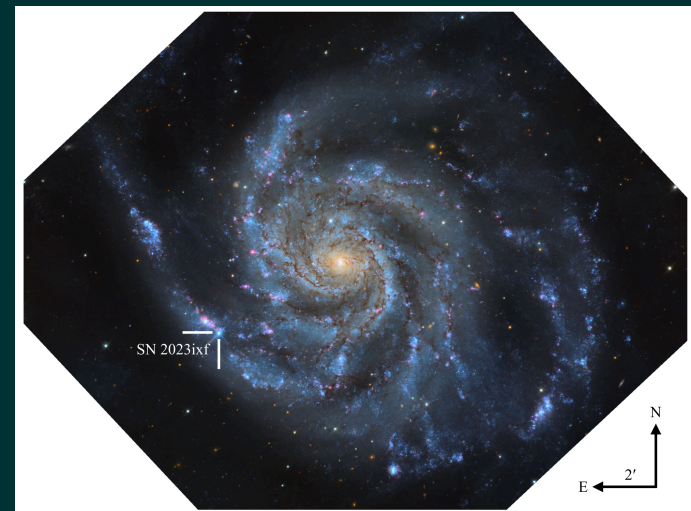
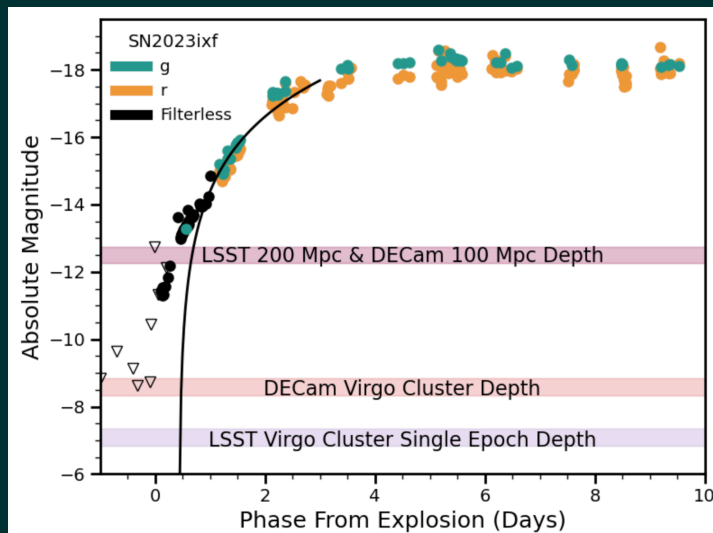


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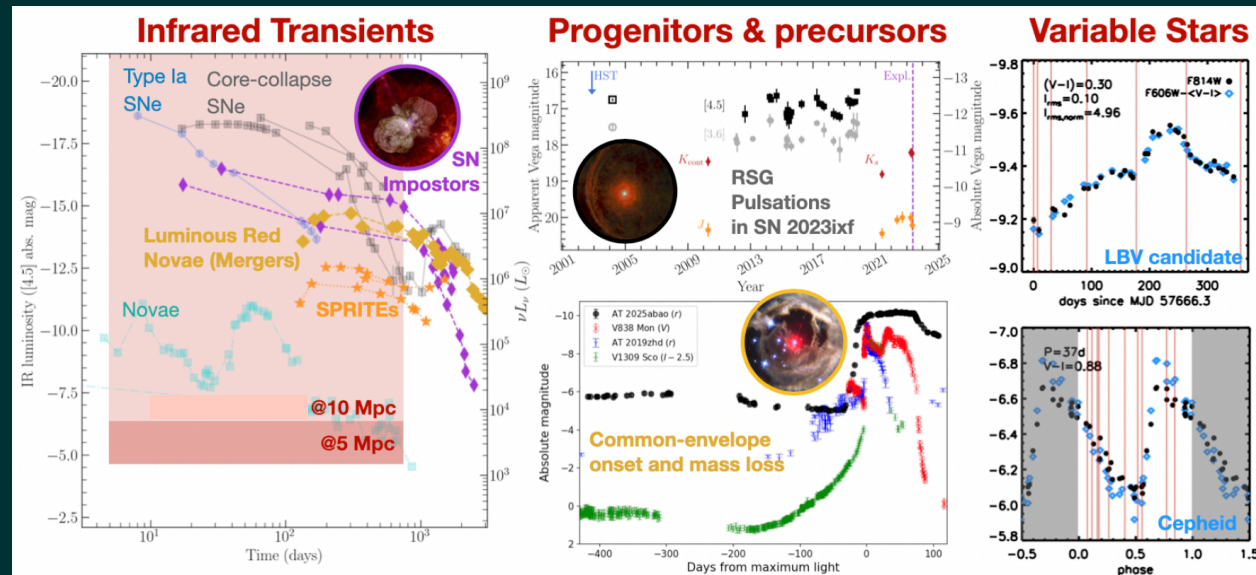
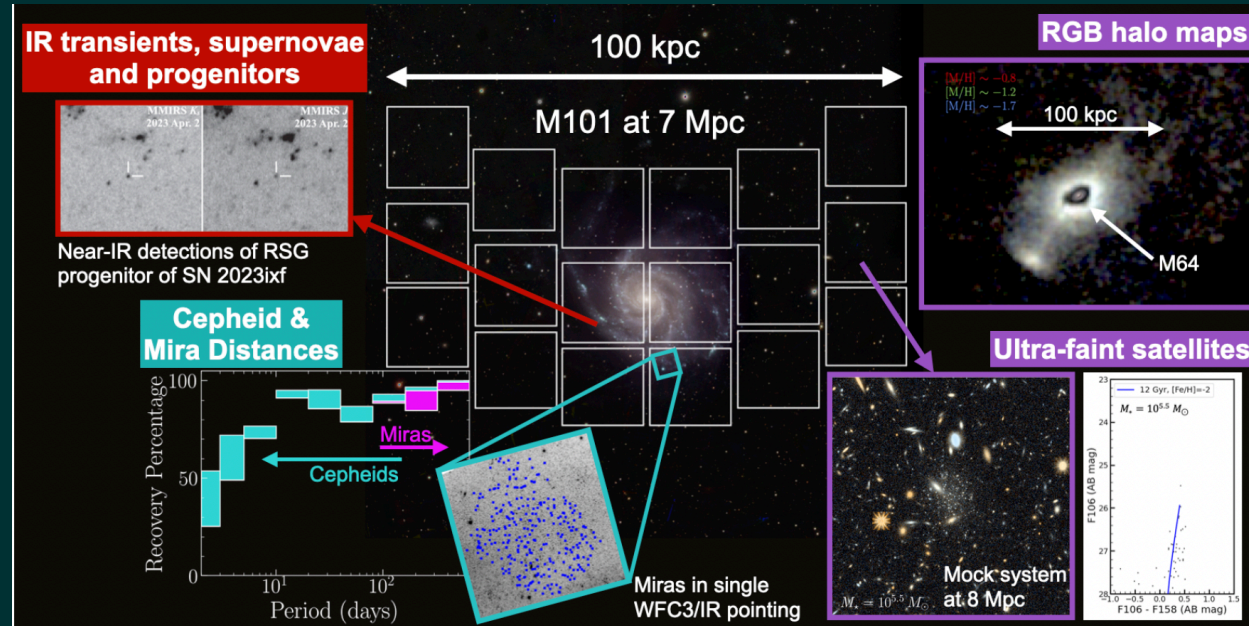


=

Hosseinzadeh+23

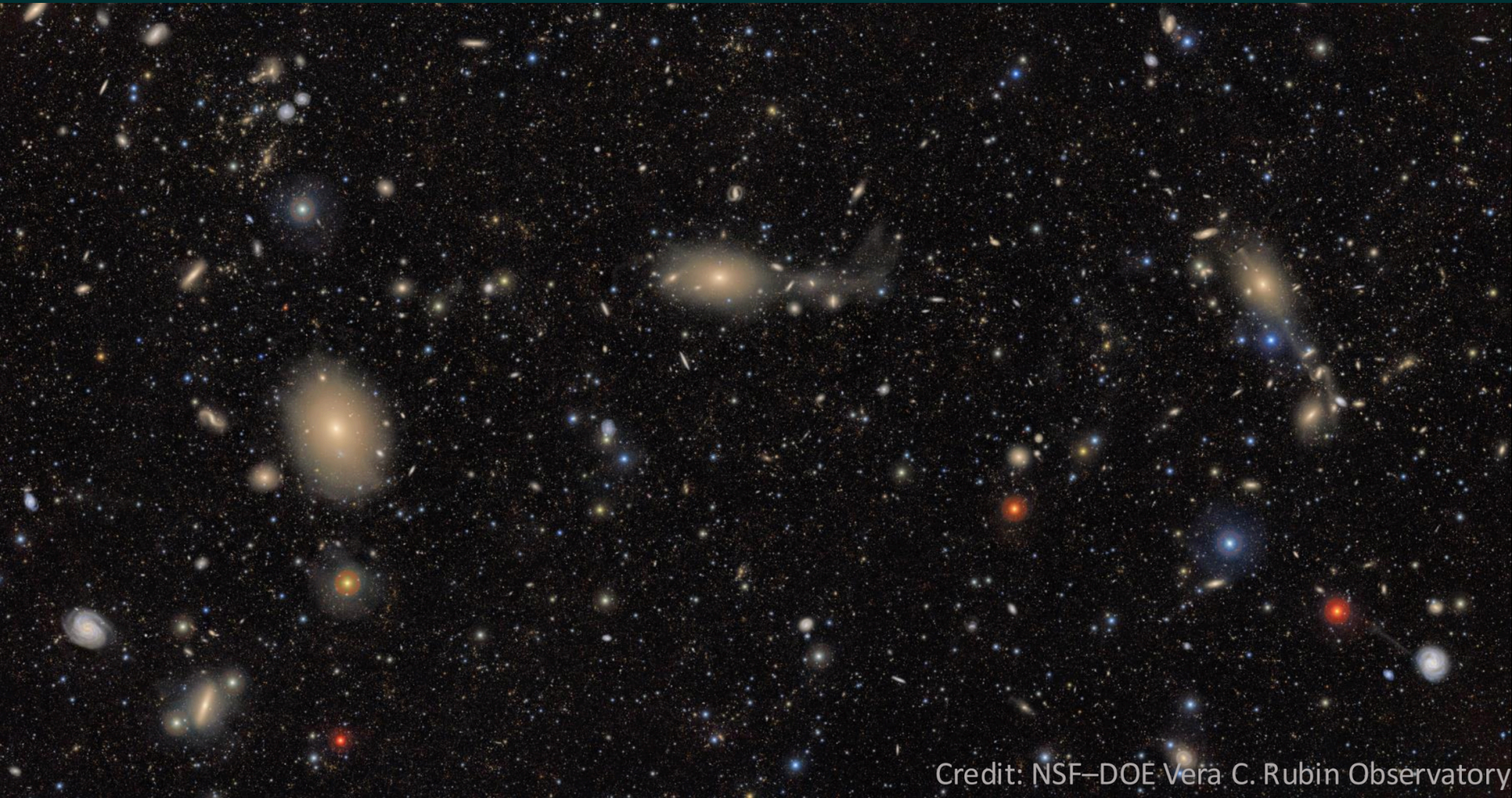


Roman Needs Some Kind of Nearby Galaxy Transient Survey



Ready for LSST Alerts?

10^6 - 10^7 alerts per night



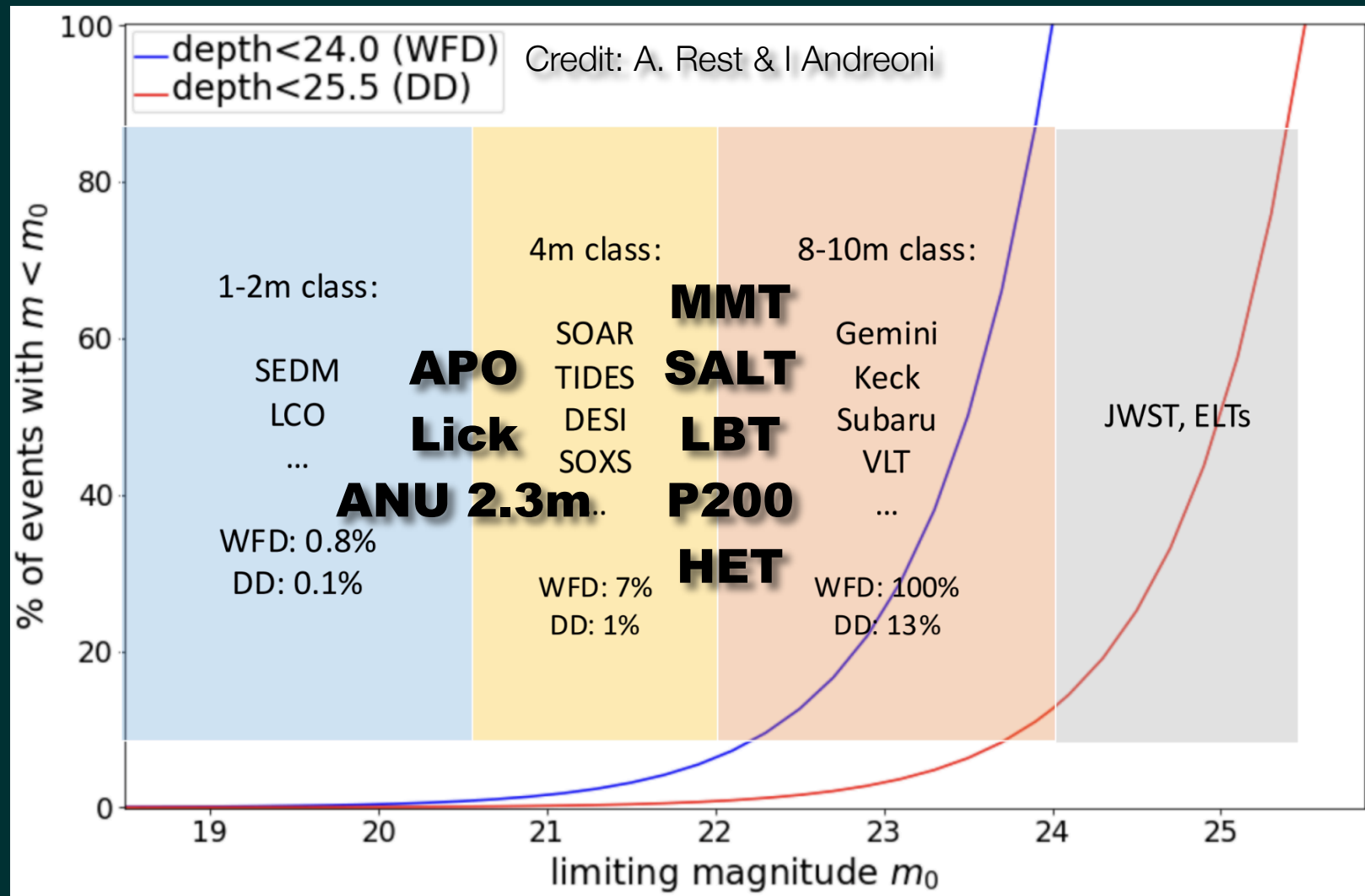
Credit: NSF-DOE Vera C. Rubin Observatory

LSSTCam: 3.2 Gigapixel, $0.2''/\text{pixel}$
9.6 deg² field of view
u,g,r,i,z,y

Wide-Fast-Deep Survey
3 day cadence, 3 filter/visit, 100 visits
18,000 deg²

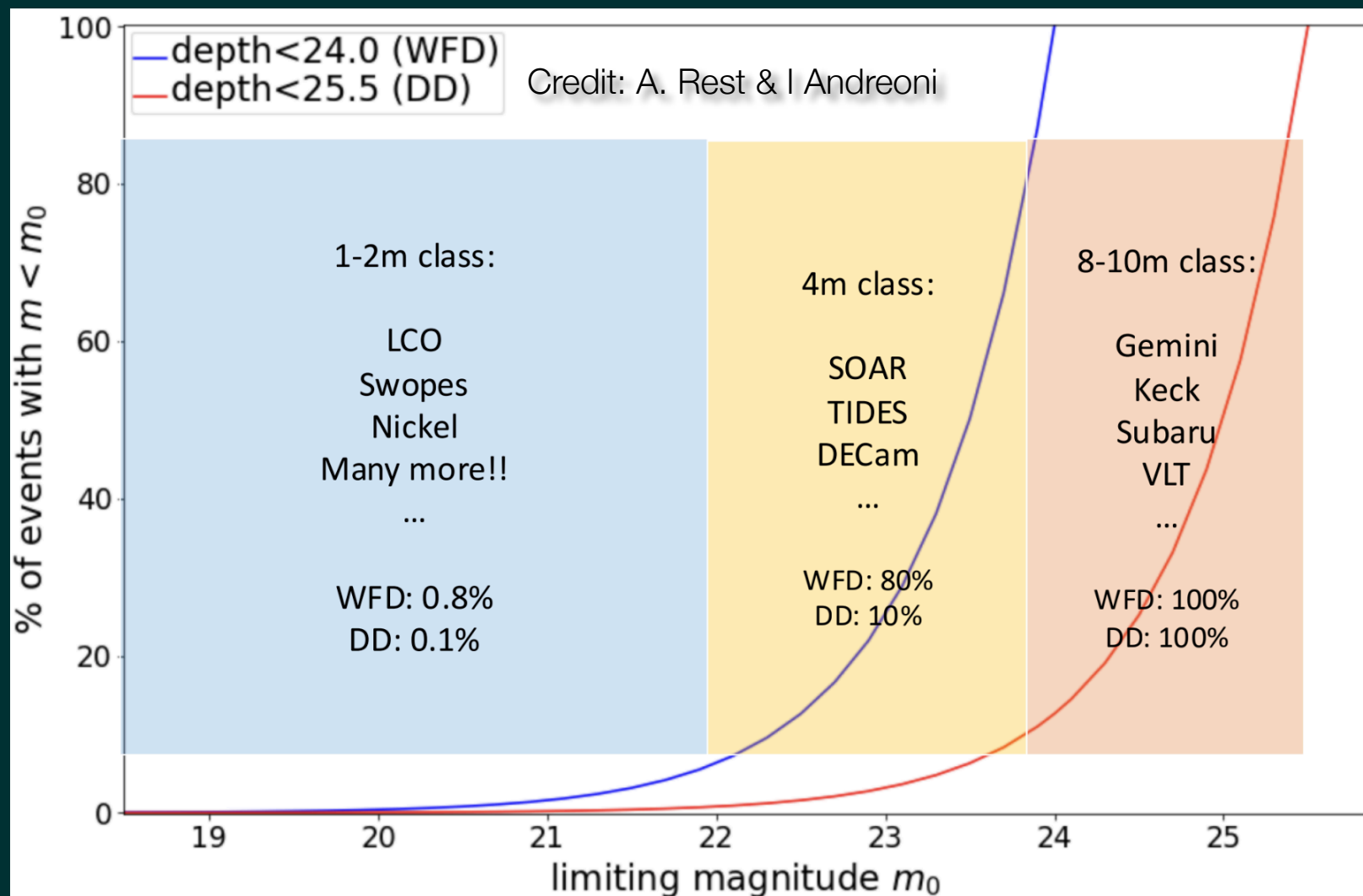
$(u,g,r,i,z,y)=(23.9,25.0,24.7,24.0,23.3,22.1)$

The LSST Data On Its Own will be Nice, but Supernova Scientists Want Follow-up Data



Spectroscopic Follow-up Resources
(Not complete)

The LSST Data On Its Own will be Nice, but Supernova Scientists Want Follow-up Data

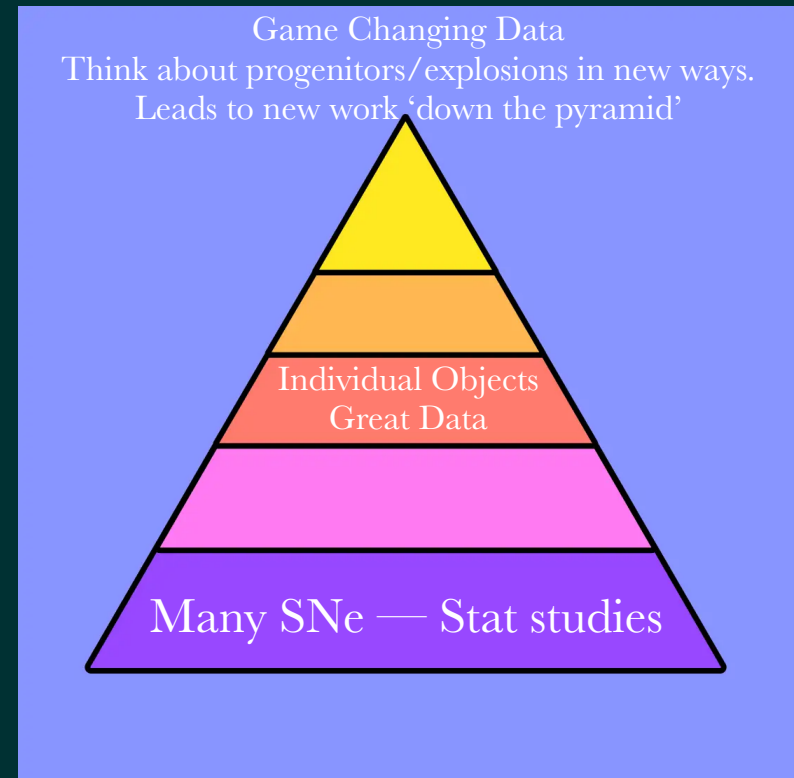


Photometric Follow-up Resources
(Not complete)

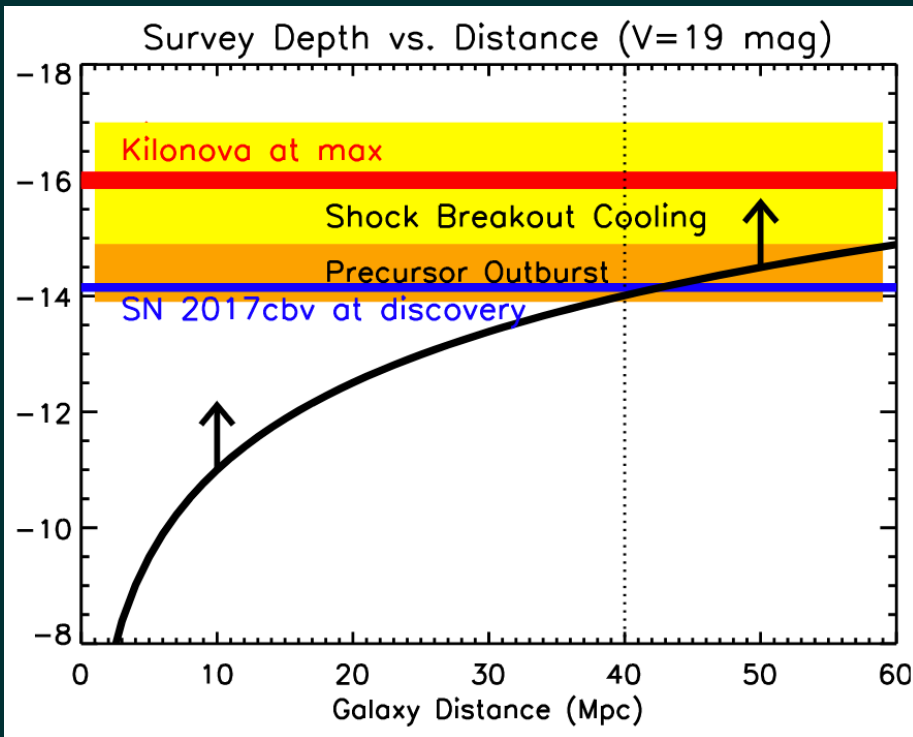
Top of Pyramid or Tip of the Spear

Intensive Study of Individual Supernovae Drive the Field

- Disclaimer: This is Dave's limited view in era of big surveys.
- ‘Golden Age’ of time domain transient science. Many surveys, array of follow-up, plethora of targets.
- Base of pyramid: For many SNe, only a limited amount of data is taken for statistical studies.
- Middle pyramid: Near and bright, good data. Or new/exotic. Worthy of single object paper.
- Pinnacle of pyramid: Extraordinary data, some new clue about explosion/progenitor. Drives/tests theory, further experiments, statistical studies, etc.



DLT40 Survey as Pathfinder



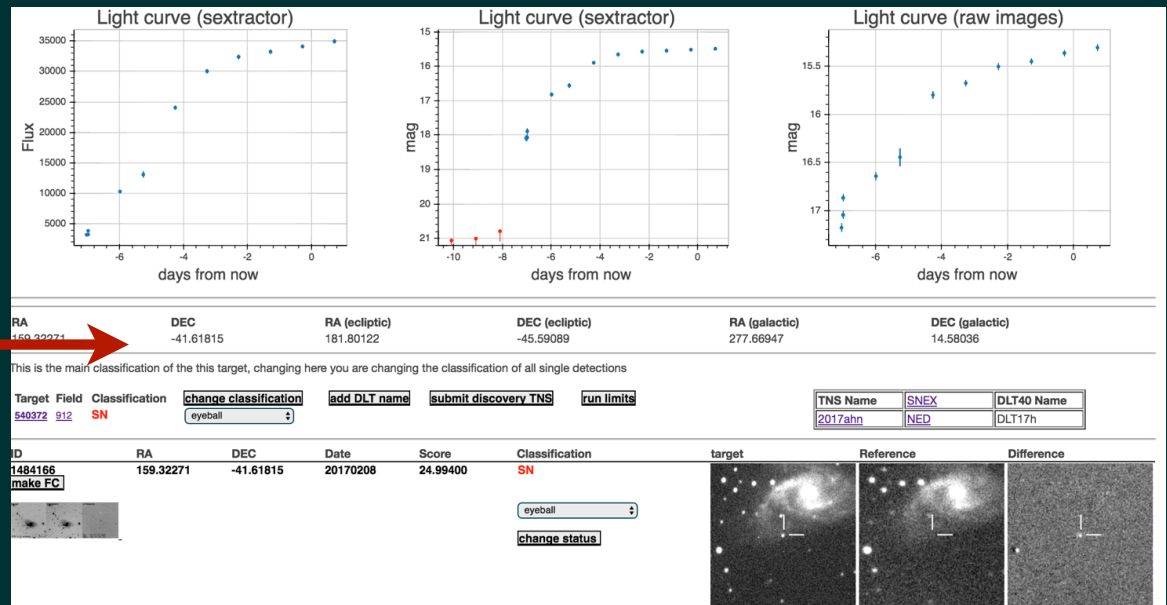
Early and Fast Time Scale Supernova Features

Supernova Feature	Time Scale	Brightness (mag)	Probe of?
Core Collapse SNe			
Shock Breakout Cooling	$\lesssim 3$ days	$-17 < M_V < -11$	Progenitor Radius & Energy/Ejecta Mass CSM Comp/Extent
Flash Spectroscopy	$\lesssim 3$ days	$-17 < M_V < -12$	CSM Comp/Extent
Pre-Explosion Outburst	Days to years	$M_V > -15$	Massive Star Evol. Explosion Physics CSM Comp/Extent
Type IIn		$-15 < M_V < -12$	
Type Ibn		$-15 < M_V < -12$	
Type II		$M_V > -12?$	
Thermonuclear			
Light Curve Shocking	< 5 days (Red Giant)	$-17 < M_V < -16$	Nondegenerate
	$\lesssim 1$ day (MS)	$-16 < M_V < -15$	Companion & CSM
Early light curve shape	< 3 days	$M_V > -14$	Nickel Dist. Progenitor Radius
Carbon	Early as possible	NA	Expl Mechanism/Mixing
Very High Velocities ($> 25,000 \text{ km s}^{-1}$)	$\lesssim 1$ day	NA	Expl Mechanism/Mixing Asymmetries/Shells?

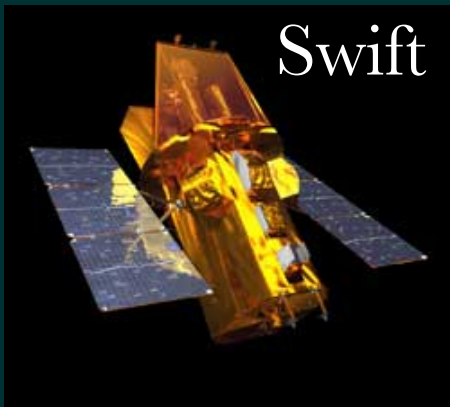
- Even in the era of big transient surveys, early discovery with excellent multi-band & spectroscopic data on the nearest SNe is not easy
- Hybrid approach of discovery + incorporating other survey data in real time. Coupled to real-time facilities.

DLT40 MECHANICS IN A NUTSHELL

PROMPT 0.4m
Chile, Canada & Australia



Swift



- Many friends: Global Supernova Project, SALT, Gemini, other collaborations.
- HST, and now JWST
- Release all young discoveries immediately



SOFTWARE & TECHNOLOGY

This is the main classification of the this target, changing here you are changing the classification of all single detections

Target Field Classification **change** **add** Submit **run** **run_atlas** **run ztf** **fast** **fast** **fast** **fast** **submit to**
classification **DLT** TNS **limits** **check ztf** **Prompt5** **PROMPT-** **PROMPT-** **PROMPT-** **PROMPT-** **MMT**
name **limits** **check ztf** **Prompt5** **PROMPT-** **PROMPT-** **PROMPT-** **PROMPT-** **(beta)**

7542987 335 SN eyeball 20 59935-59955 59935-59955 45 45 45 45 Longslit
 Open Open Open Clear 45

TNS Name SNEX DLT40 Name
 2022xkq NED DLT22r

ID	RA	DEC	Telescope	Filter	ML Score	Score	Date	Classification	target	Reference	Difference
31227126 make FC	76.34879	-11.88226	PROMPT-MO-1	Open	0.51	23.08890	20221231	SN	eyeball		

change status

- Real-time ML-based alerts to team. Automated follow-up with DLT40 telescopes and beyond.
- Real-time alerts from other surveys when they discover transients in nearby galaxies. Automated follow-up with DLT40 telescopes.
- Immediate triggering of Las Cumbres. We are also immediately triggering FLOYDS spectroscopy (no human in loop).
- Gather limits from ATLAS, ZTF immediately. Agnostic to discovery, just want to do early time science.
- Immediate triggering of spectroscopy from the MMT (Binospec & MMIRS). Also SALT, Gemini, Las Cumbres FLOYDS, etc.
- Release all young discoveries immediately. ‘TNS button’

AUTOMATED FOLLOW-UP

DLT40 DISCOVERY OR TNS ANNOUNCED

- 5 min: DLT40 data reduced and objects detected.
- 5-10 min: ML Score high, Image clean. Automatic follow-up image.
- 10 min: Automated clear image has high ML score. Trigger continuous multiband sequence.
- 15 min: Continued strong detections. Trigger FLOYDS. @ the channel.

Big assist from Aidan Martas —
undergrad at UC Davis



DLT40 BOT APP 8:14 PM

SN₂₀₂₄pxg discovery sequence

43010270.diff.fits Prompt5

Trigger confirmation image for object 9261299 in galaxy 1915

schedule submitted Prompt5 9261299 NGC6221 just triggered

filter = Open exptime = 45.0

triggered by = dave.j.sand@gmail.com

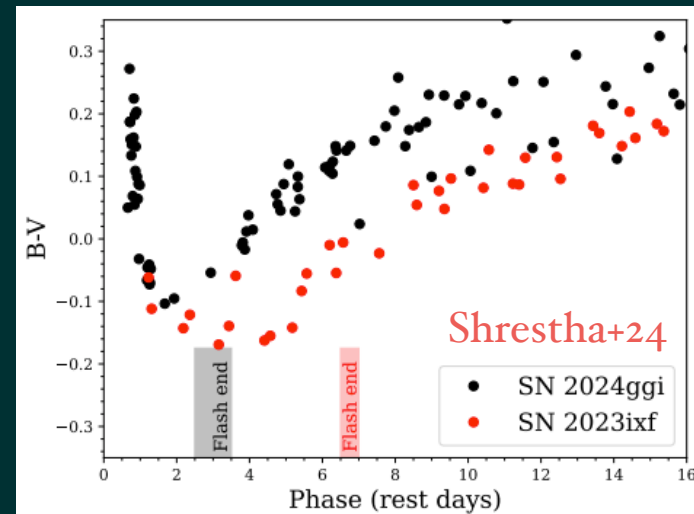
43010873.diff.fits Prompt5

@here Trigger Multiband photometry and Clear for object 9261299 in galaxy 1915

43010874.diff.fits Prompt5

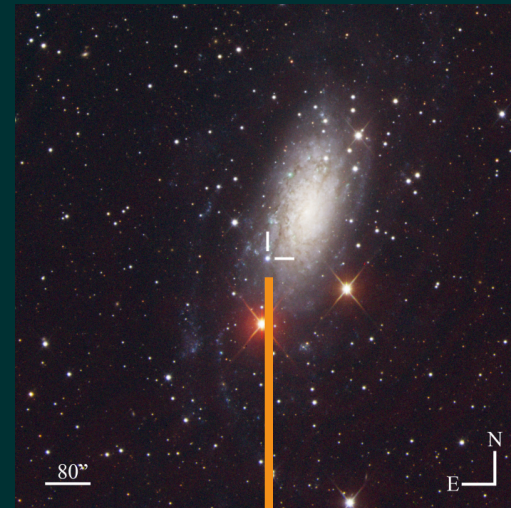
@channel TRIGGERING SPECTRUM for object 9261299 in galaxy 1915

triggerid= 2011753



SAME-NIGHT TRIGGERING OF MMT

- MMT has Binospec (optical) and MMIRS (NIR) operated in a queue. Perfect for real time follow-up.
- Built API that can be plugged into your TOM. Can have it tied to your favorite filter on a broker. This is READY for LSST.
- Imagine getting 30-40 rapid ToOs per year, rather than a handful from Gemini.

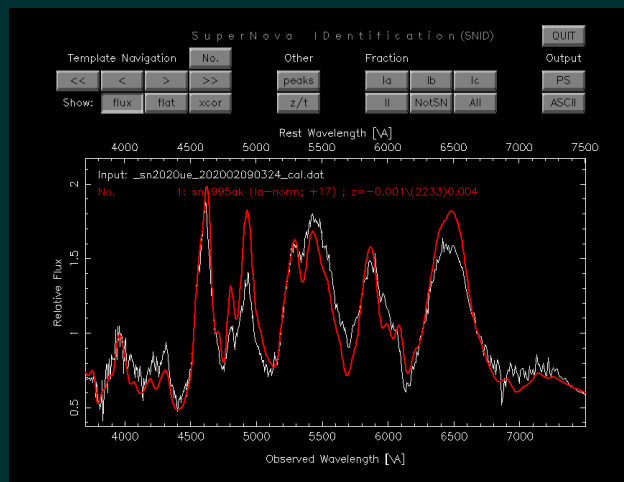


Shrestha+24b

Binospec Imaging Binospec Spectroscopy MMIRS Imaging

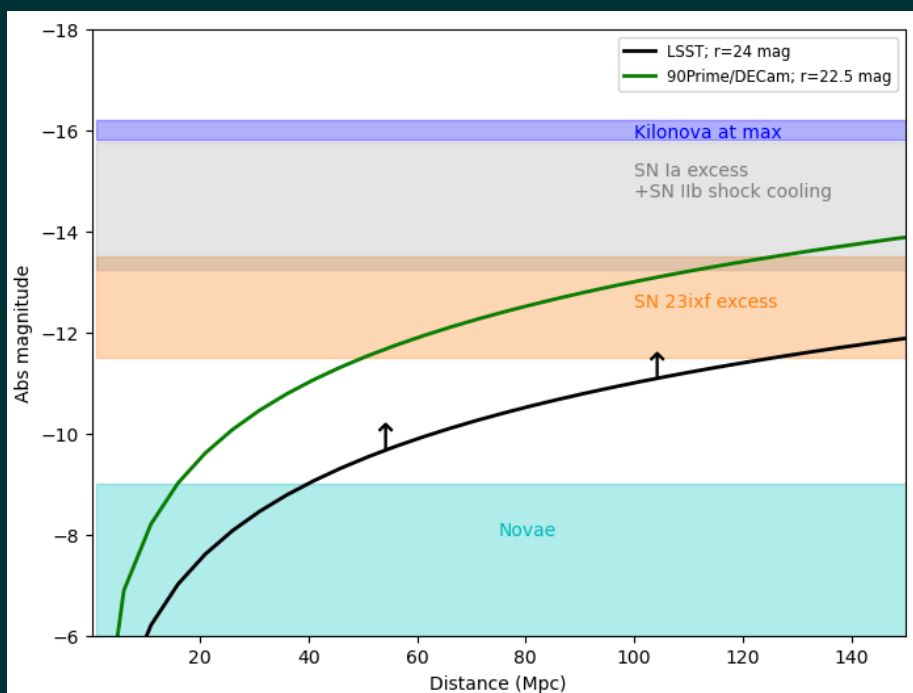
MMIRS Spectroscopy

Magnitude*	Exposure time*	Filter*
18.98571586608	100 s	g
Visits*	Number of exposures*	Priority*
1	5	low
Program*		
Rapid Spectroscopic Follow-up of Very Young SNe		



LSST + Time Domain Ecosystem

Early and Fast Time Scale Supernova Features

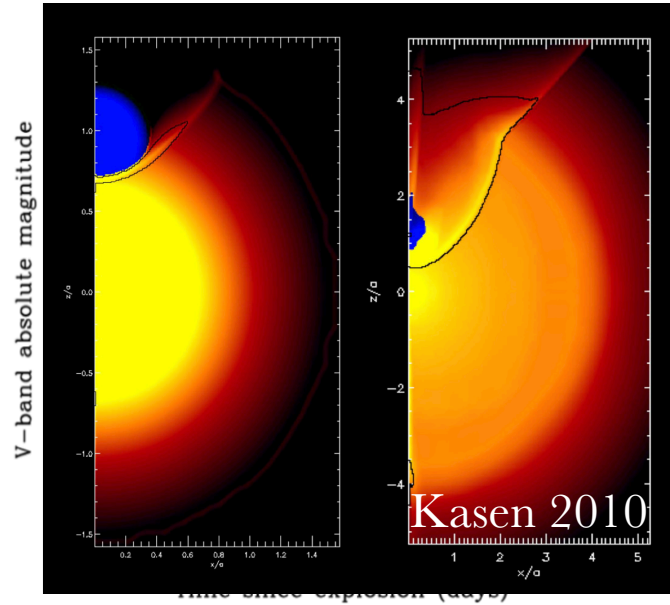
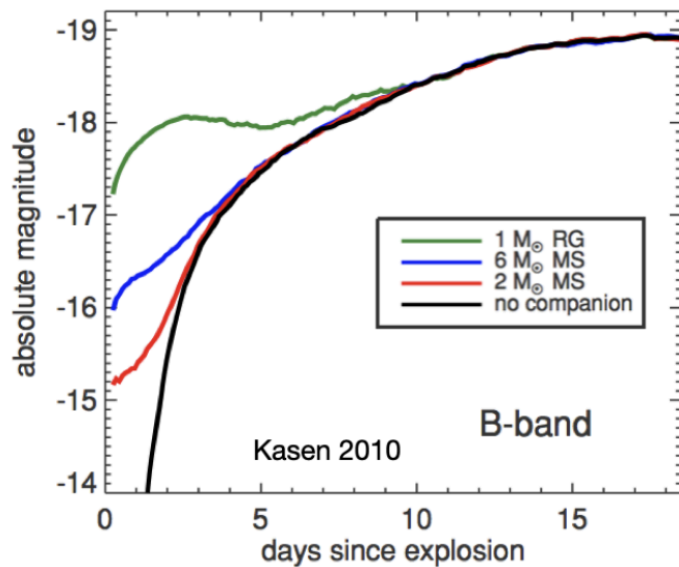


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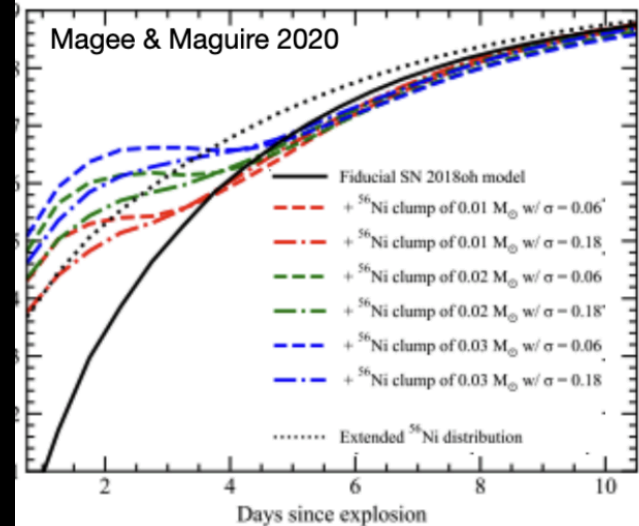
- The LSST WFD cadence is **not** good enough to do this science, BUT it does offer the opportunity to make discovering such features much easier.
- Even in the era of big transient surveys, early discovery with excellent multi-band & spectroscopic data on the nearest SNe is not easy
- Hybrid approach of discovery + incorporating other survey data in real time. Coupled to real-time facilities.

Type Ia SN: Early Light Curves Shed Light on Progenitor & Explosion

Shock interaction with a companion star

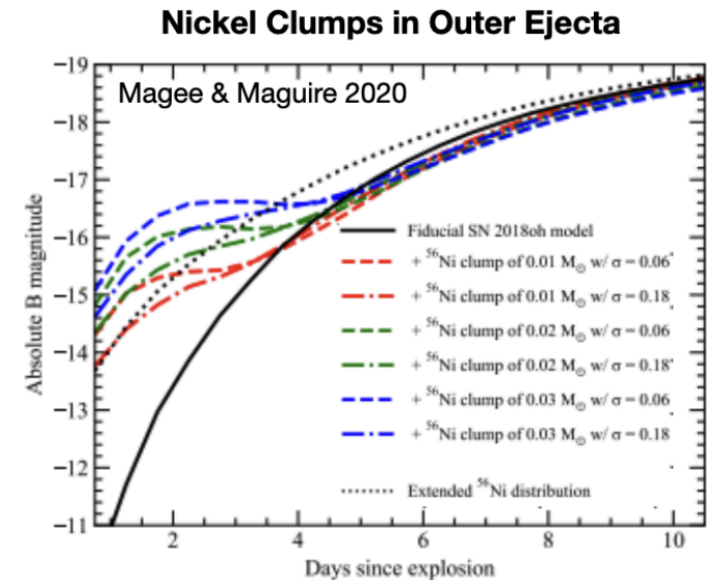
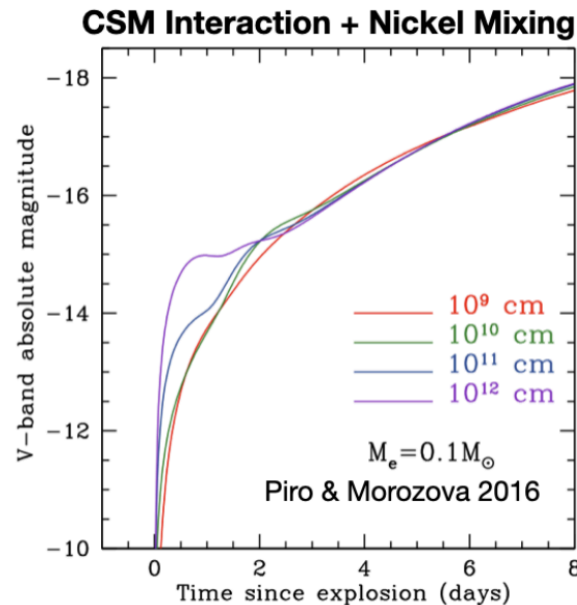
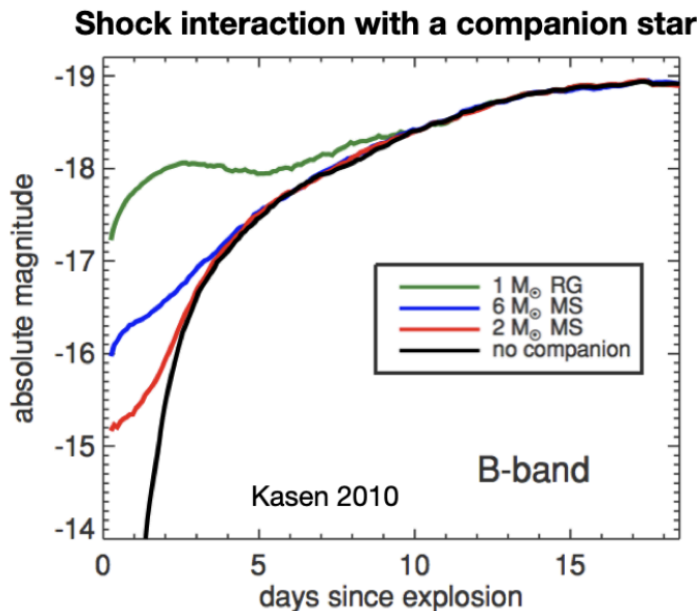


Nickel Clumps in Outer Ejecta



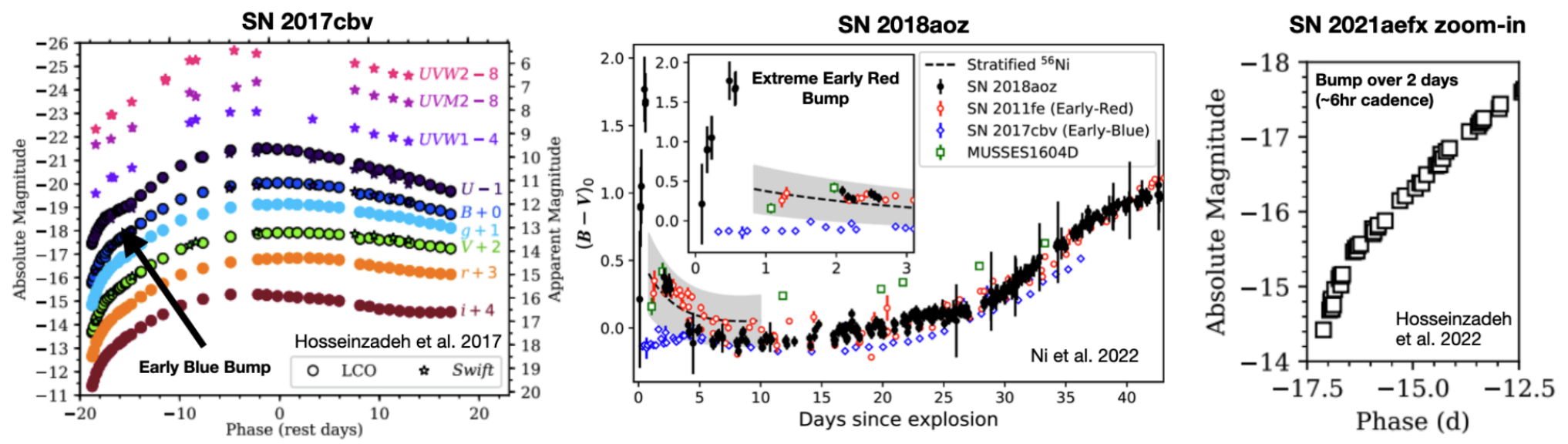
- All expected features that deviate from a smooth early rise occur on < 2 day time scales.
- Need early discovery *and* follow-up on < 1 day time scales to sample these features.

Type Ia SN: Early Light Curves Shed Light on Progenitor & Explosion



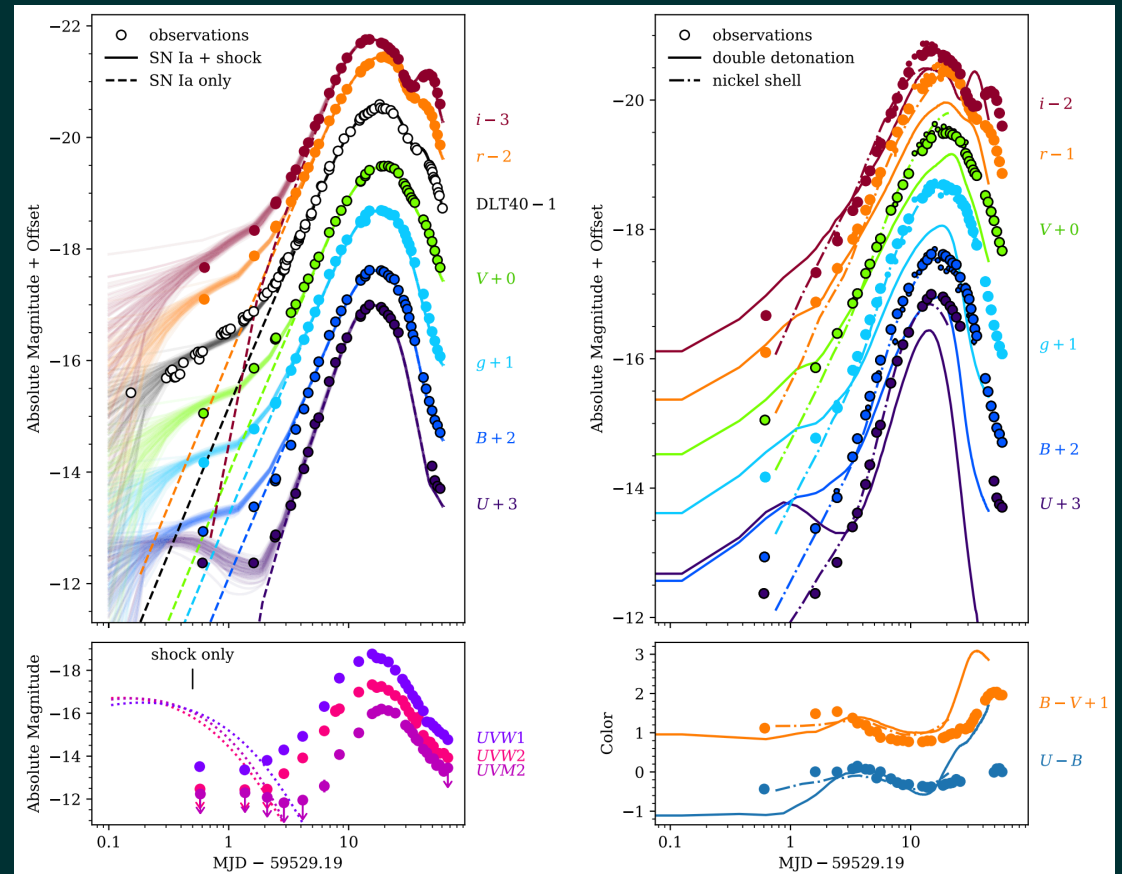
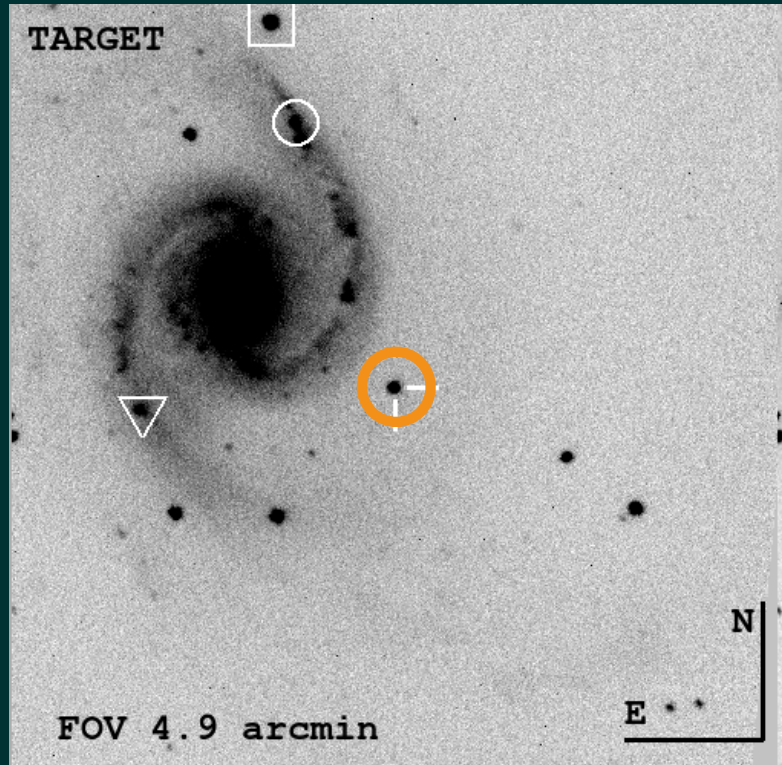
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Type Ia SN: Early Light Curves Shed Light on Progenitor & Explosion



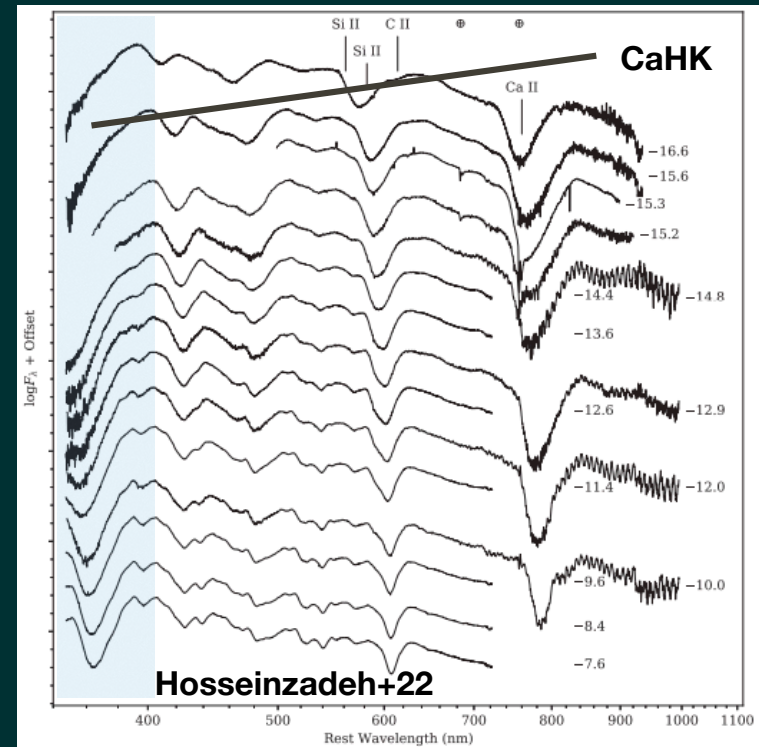
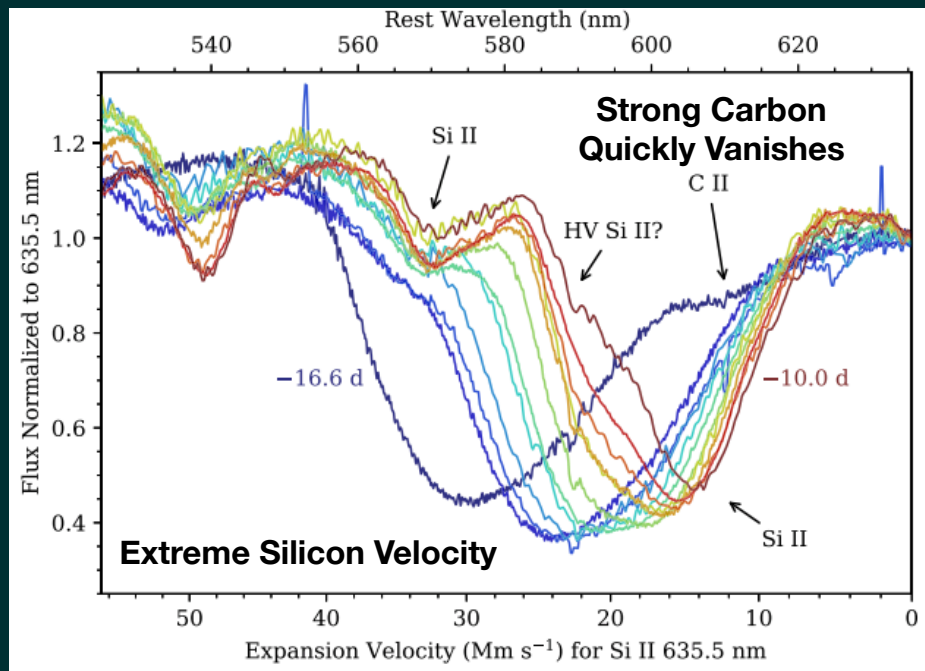
-Direct connection to multi-band photometry & spectroscopy is the key. Allows direct testing of models.

SN2021aefx in Spotlight NGC 1566; D=18 Mpc



No light curve model can perfectly explain the early light curve of SN2021aefx. Early Swift data does not match expectations from shocks from a companion star, etc.

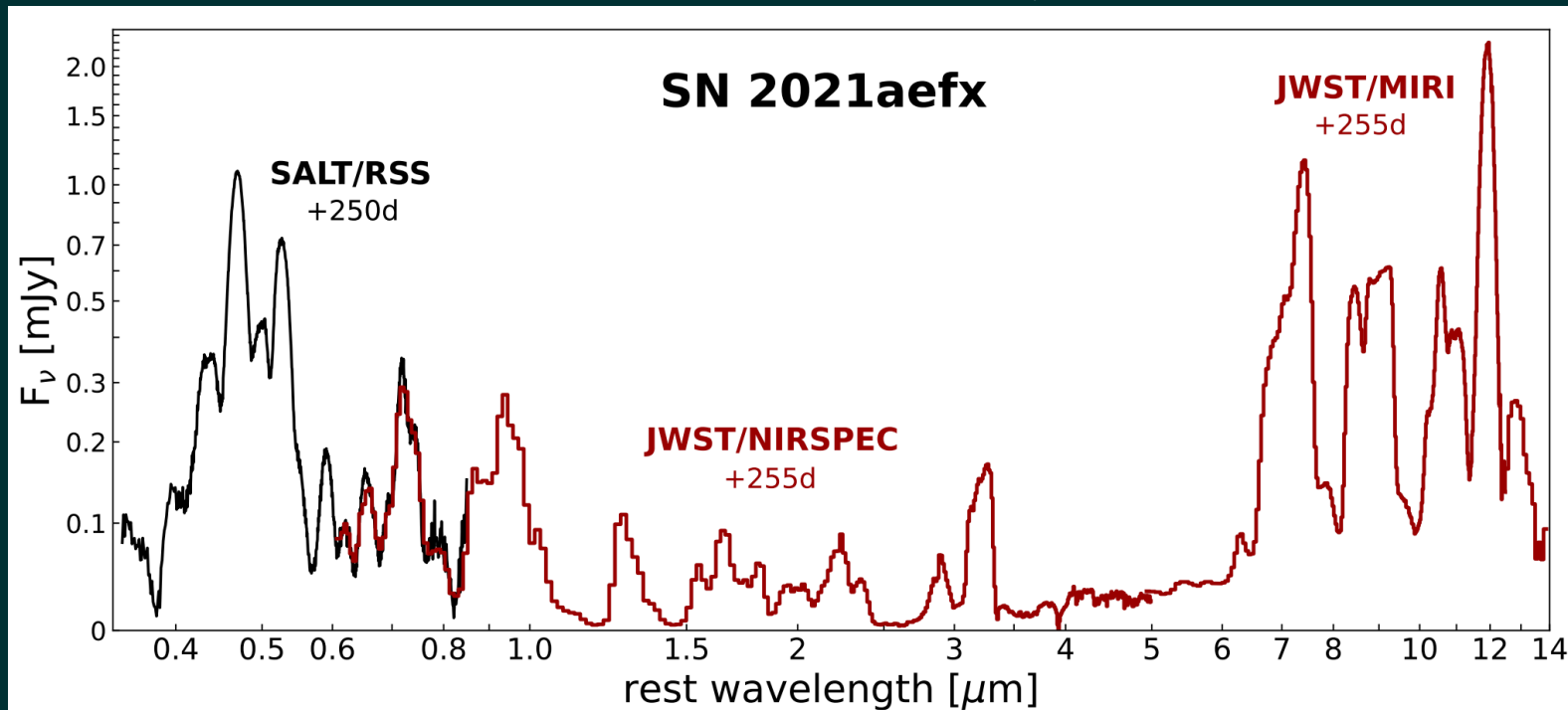
Type Ia Early Spectra Still Need Exploration: SN2021aefx



- Early features vanish on ~ 1 day time scales.
- Incidence of carbon can constrain explosion models. Must get sample with extremely early data.
- Extreme velocities only seen in a couple systems so far. 'Bullet' of material coming towards us?

SN2021aefx and JWST

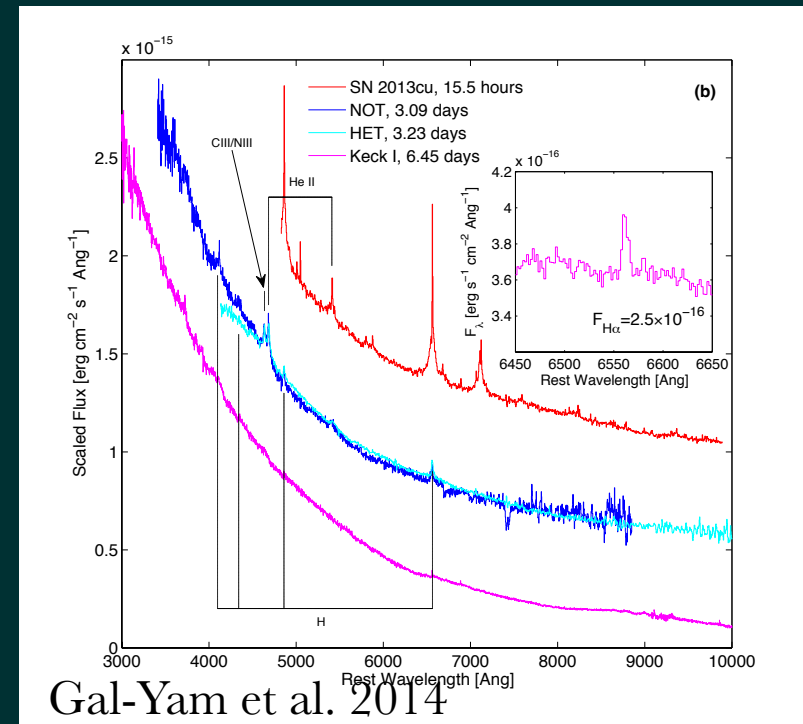
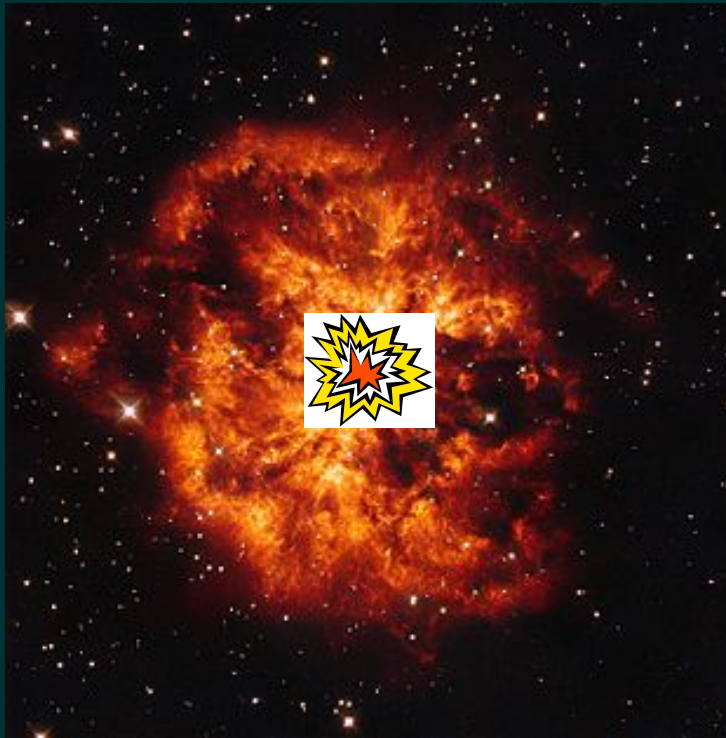
(Kwok et al. 2023; PI: Saurabh Jha. See also: DerKacy+23, Blondin+23, Ashall+24)



- First spectrum from 2.5-5 microns, ever! Iron and stable nickel.
- New line identifications of iron group elements.
- Insights into emission geometry, ionization structure, density, temperature; ultimately constrain explosion models.

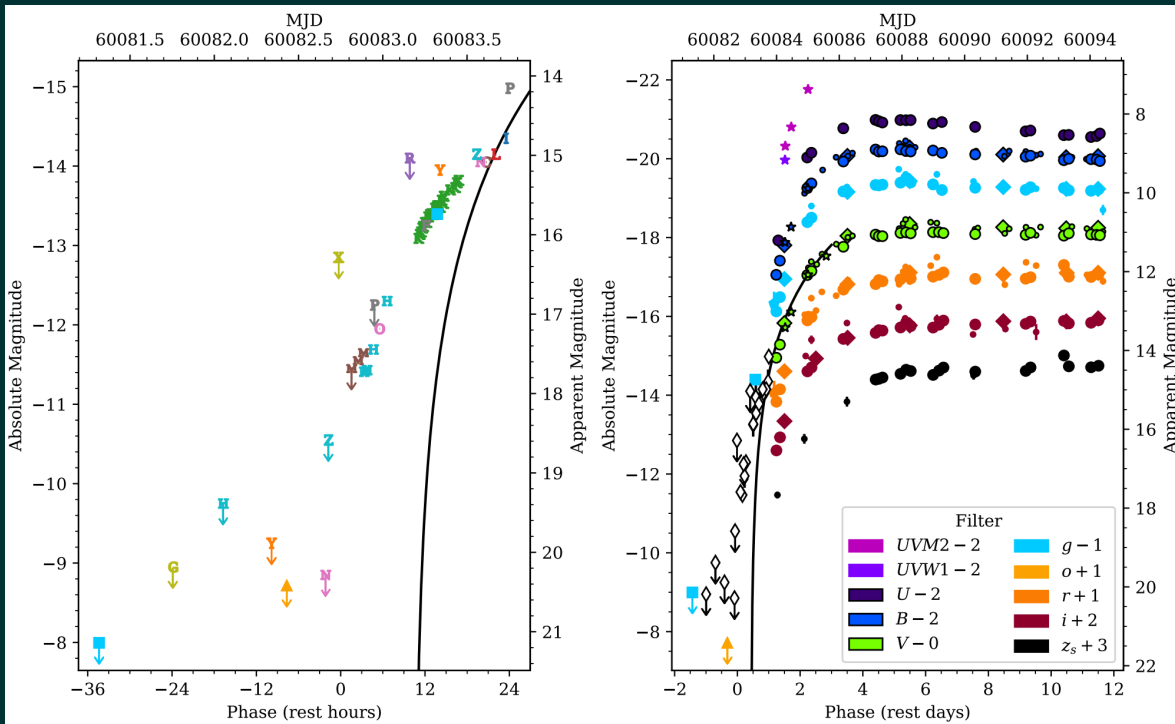
Core Collapse SNe

Flash Spectroscopy as Example



Shock breakout or ejecta interaction can ionize material surrounding the progenitor star -- learn about its composition, velocity structure and extent from recombination spectrum and its evolution

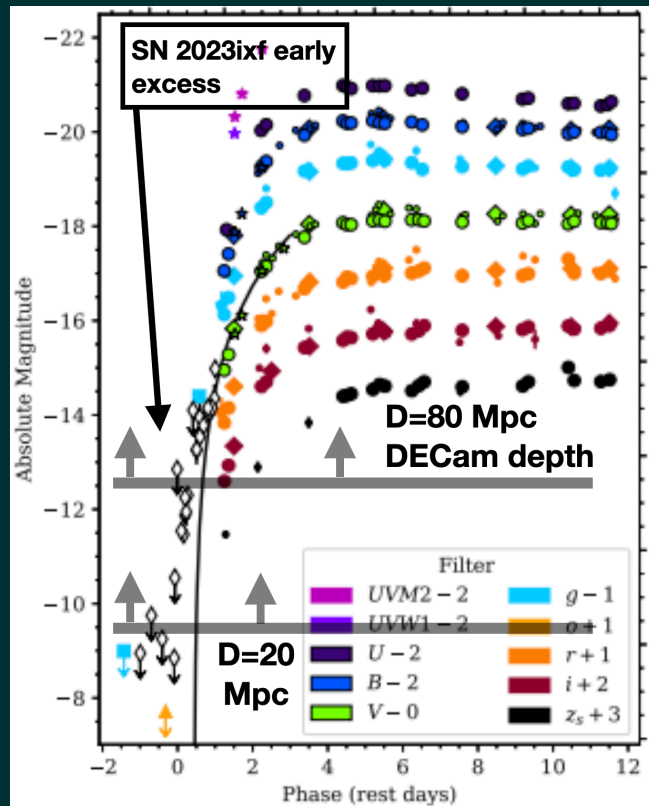
SN2023ixf



Hosseinzadeh+23

- Never before seen ‘early excess’ compared to smooth rise, seen in compilation of amateur data. Shock breakout cooling? CSM interaction?
- This kind of excess should be visible out to ~ 80 Mpc in a DECam shadowing program.

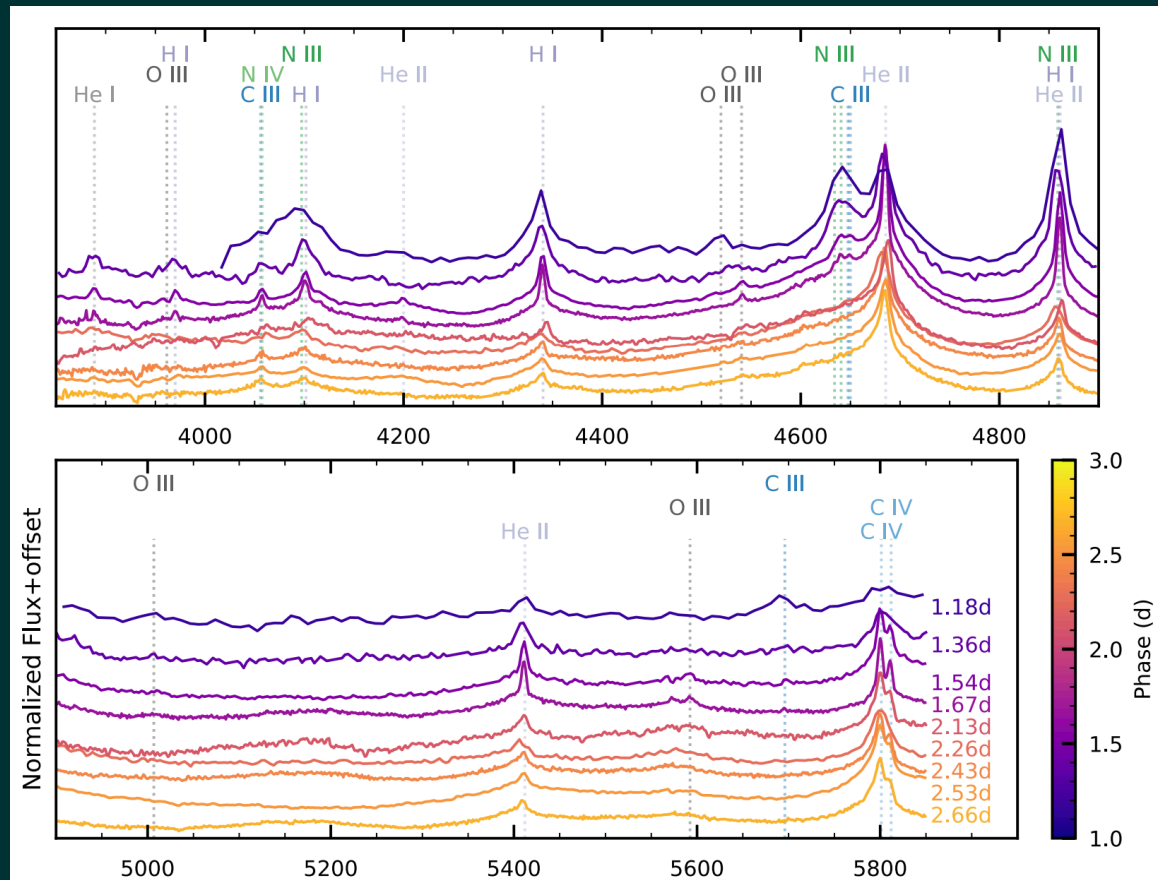
SN2023ixf



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SN2023ixf

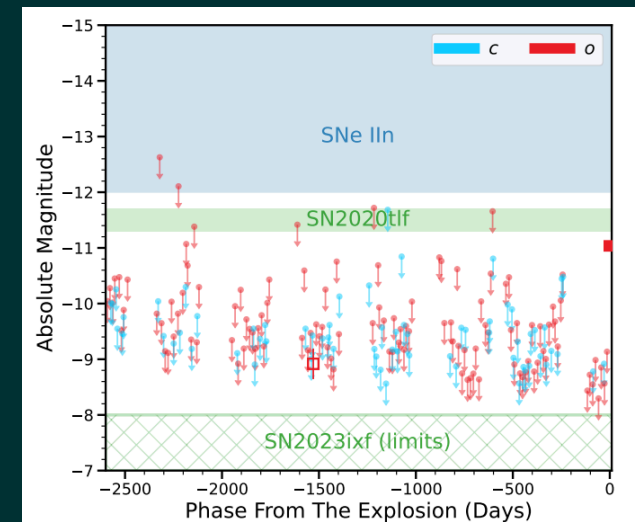
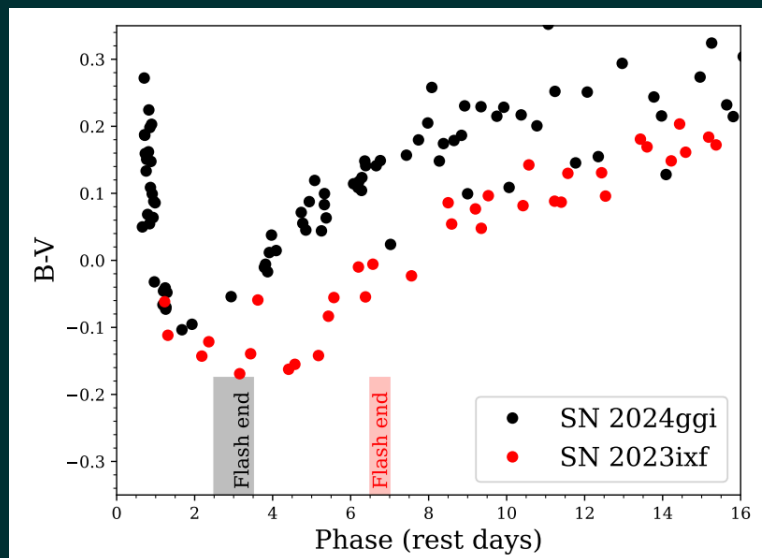
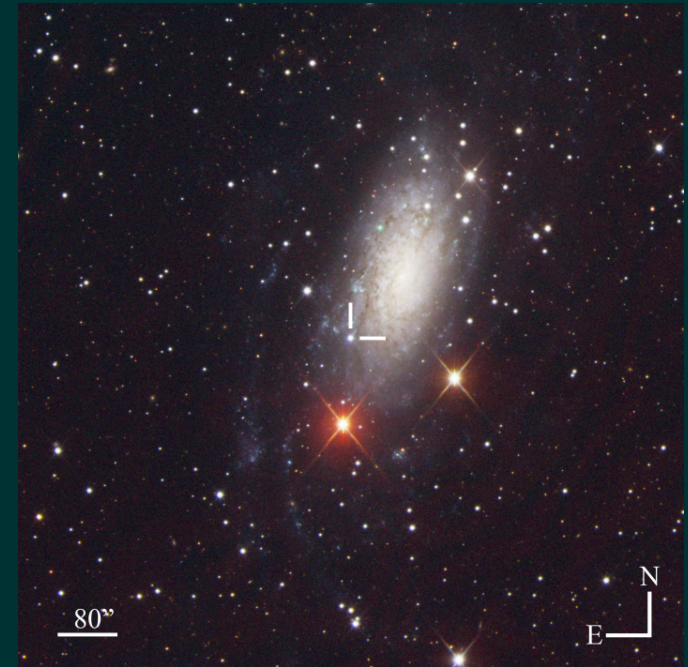
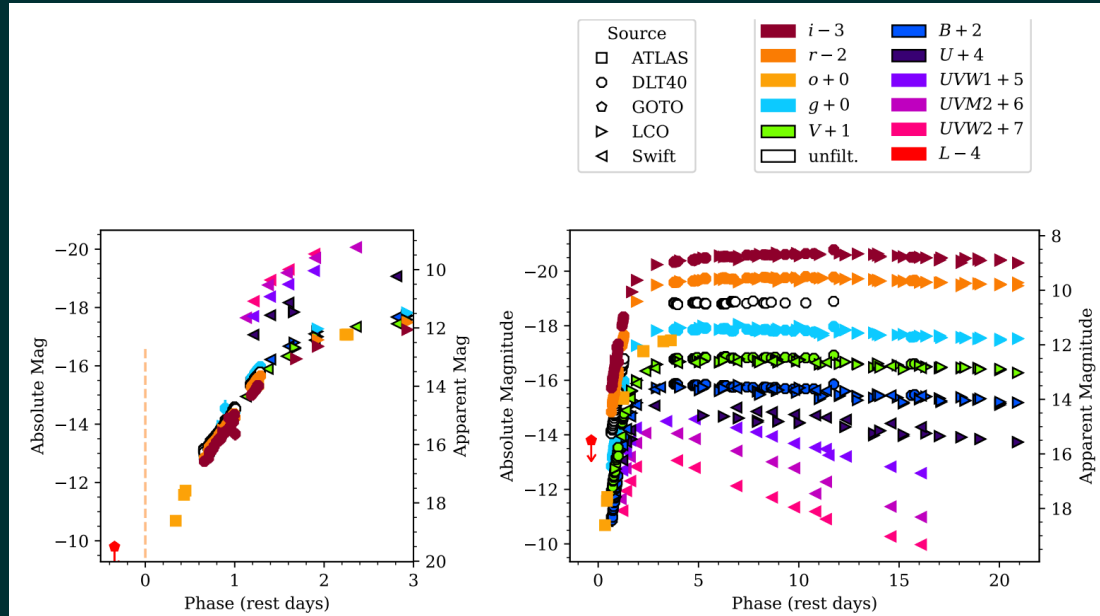


Bostroem+23
[of course many
other SN23ixf flash
spectra as well]

- 3-4 spectra per night traced evolution of 'flash' features and change in ionization. One of a kind data set.

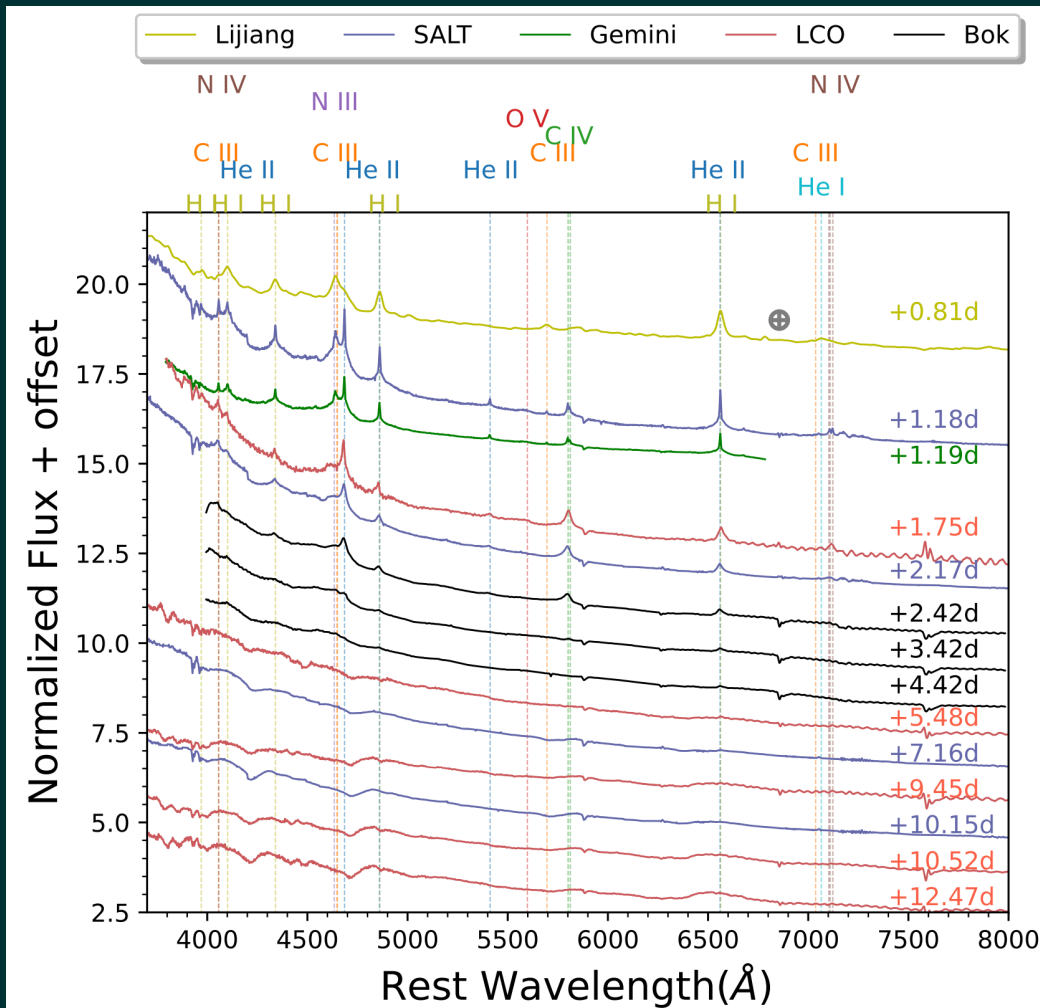
SN2024ggi

Shrestha+24

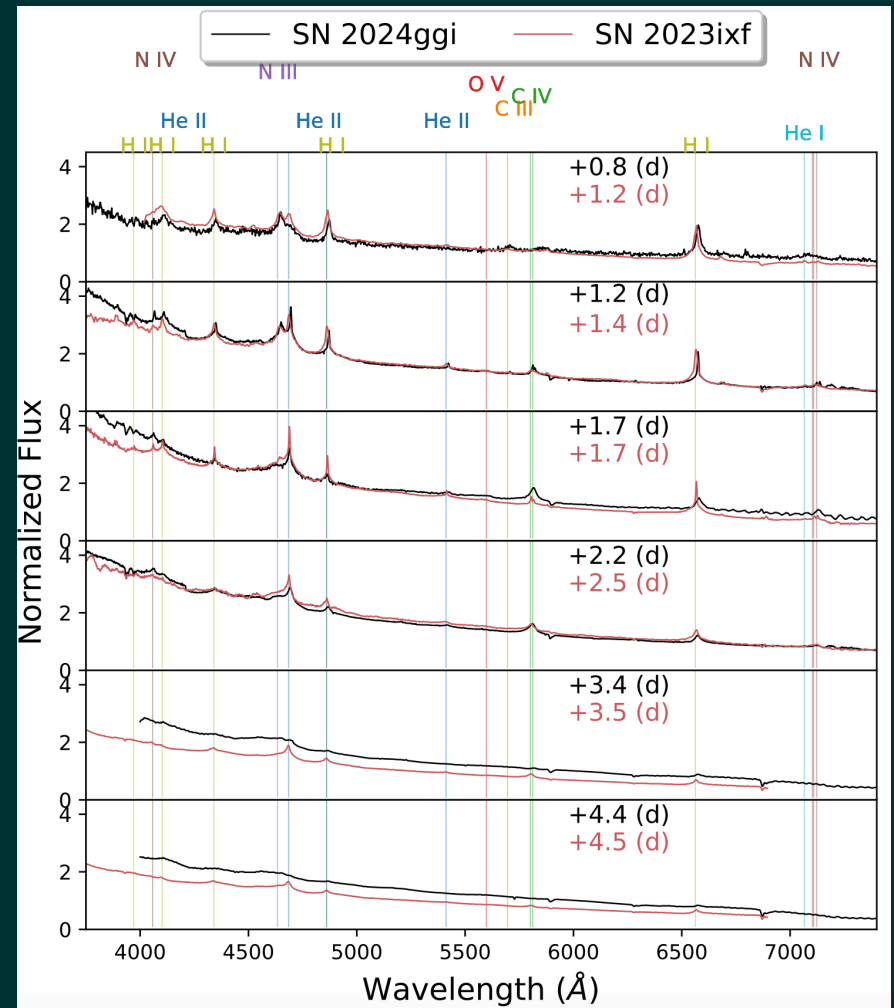


SN2024ggi

Shrestha+24

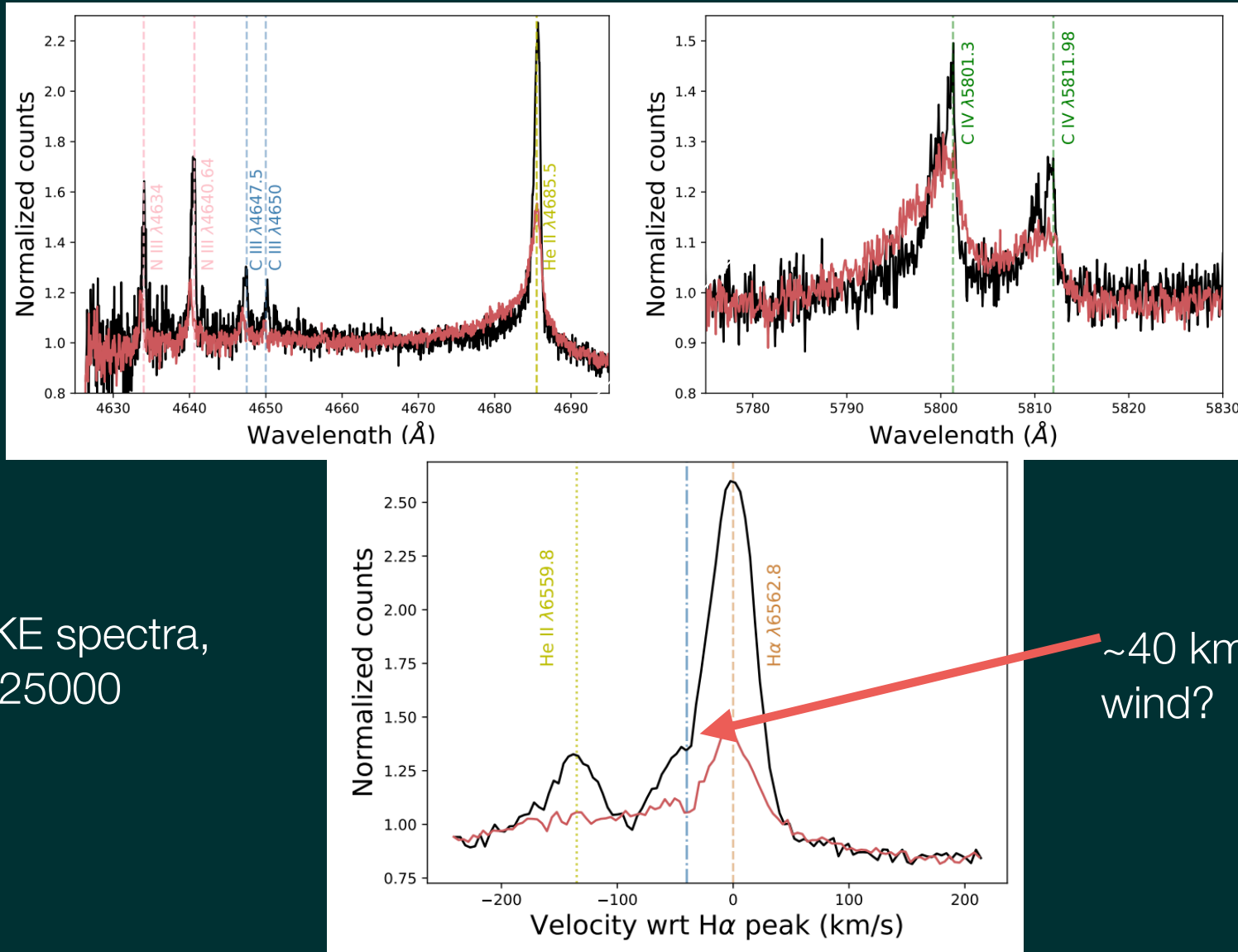


Comparison to SN23ixf



SN2024ggi — Narrow line evolution over ~8 hours (1.22 & 1.49d)

Shrestha+24; see also Pessi+24

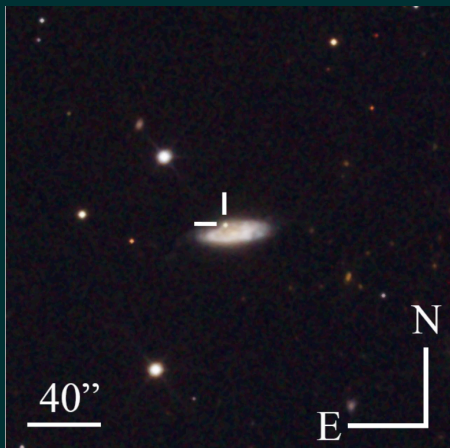
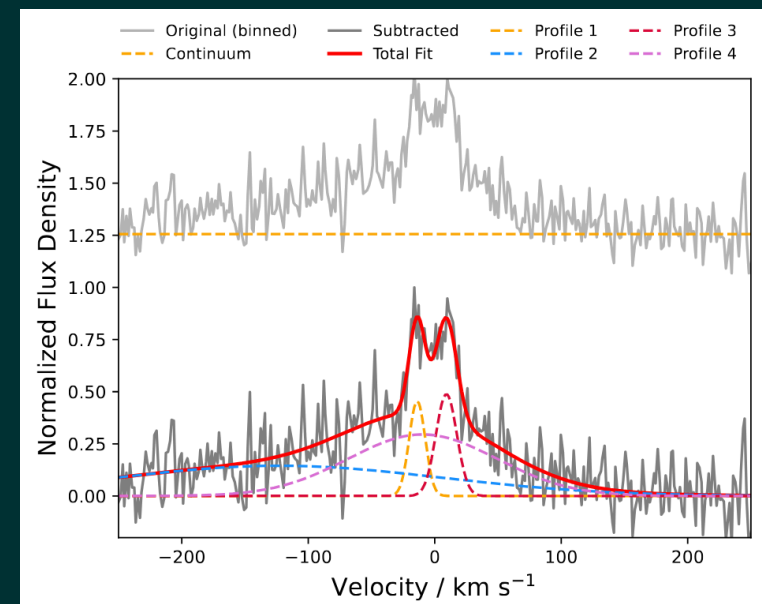
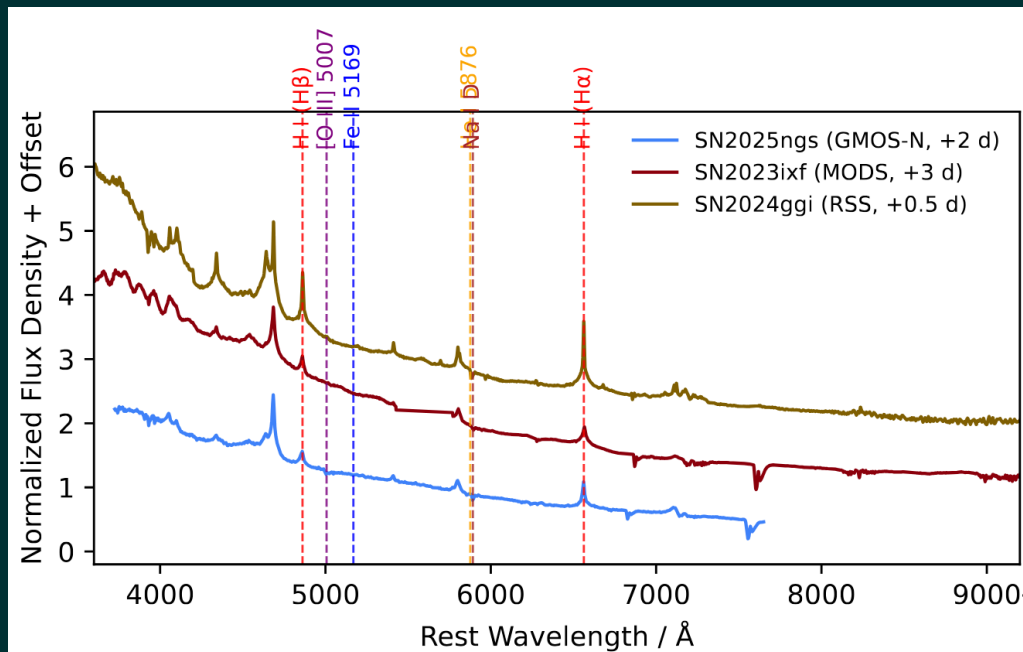


MIKE spectra,
R~25000

~40 km/s; RSG
wind?

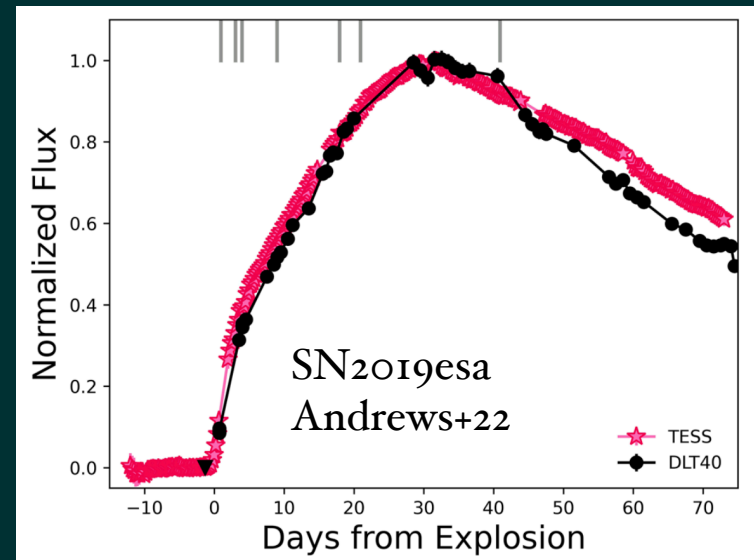
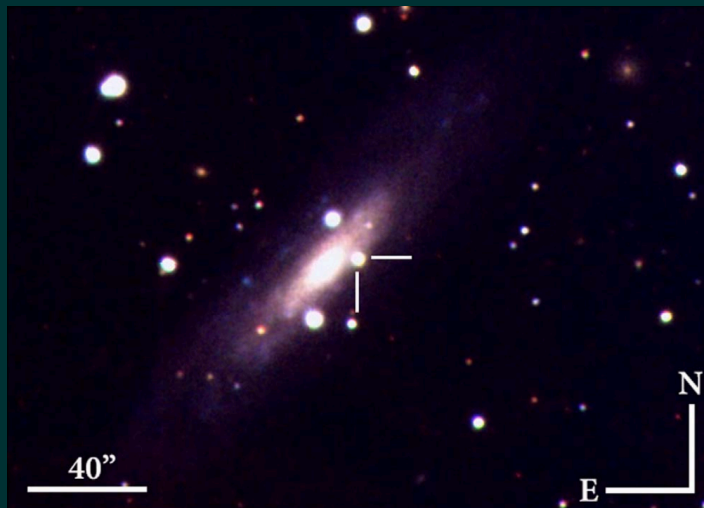
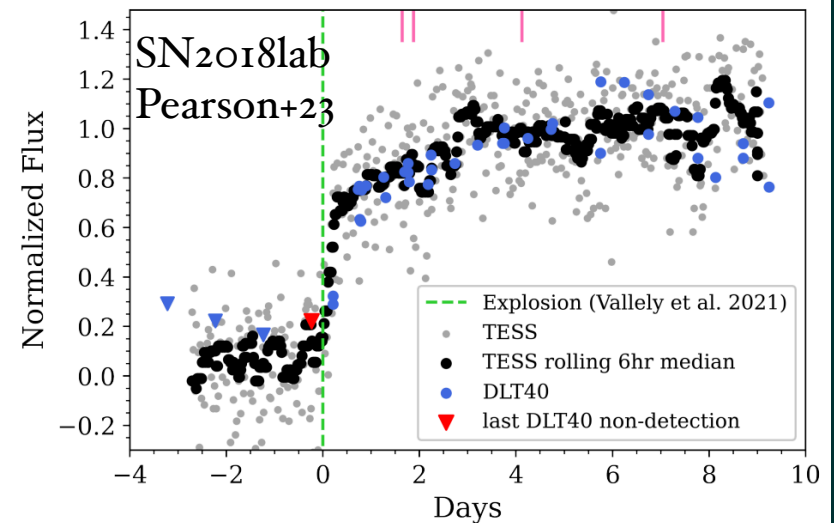
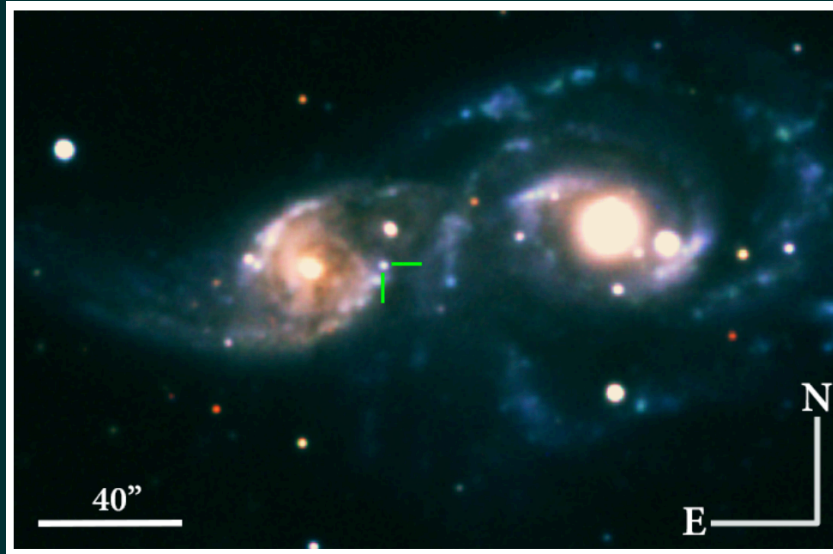
One last thing: SN2025ngs high resolution spectra

Ransome+26....any day now.



Gemini MAROON-X — clear sign of disk CSM structure in earliest flash data. ~20 km/s, and is gone the next day.

Early Discovery + TESS

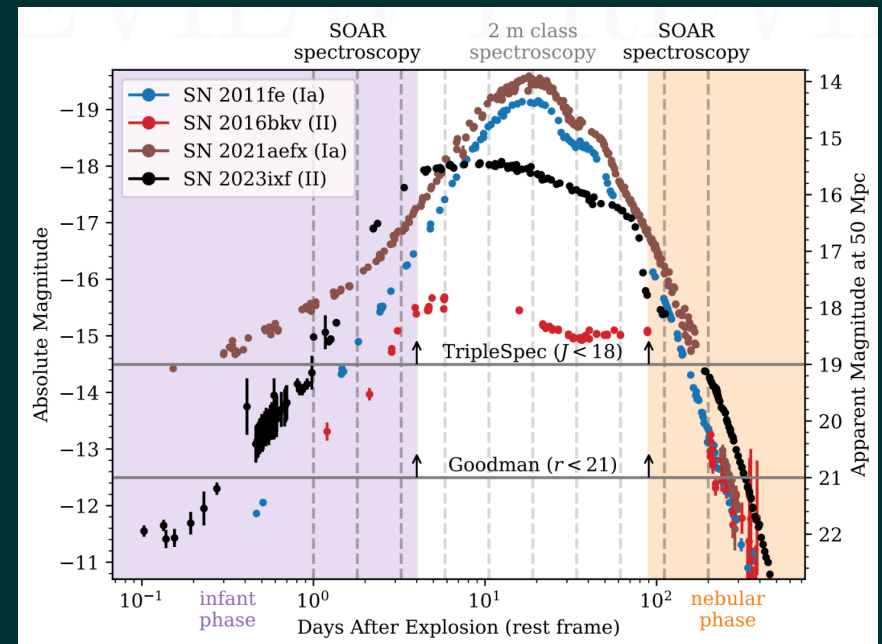


TESS can pinpoint explosion epoch. Can also search for subtle light curve features due to CSM interaction, etc. High cadence SN searches in ULTRASAT fields could pay dividends.

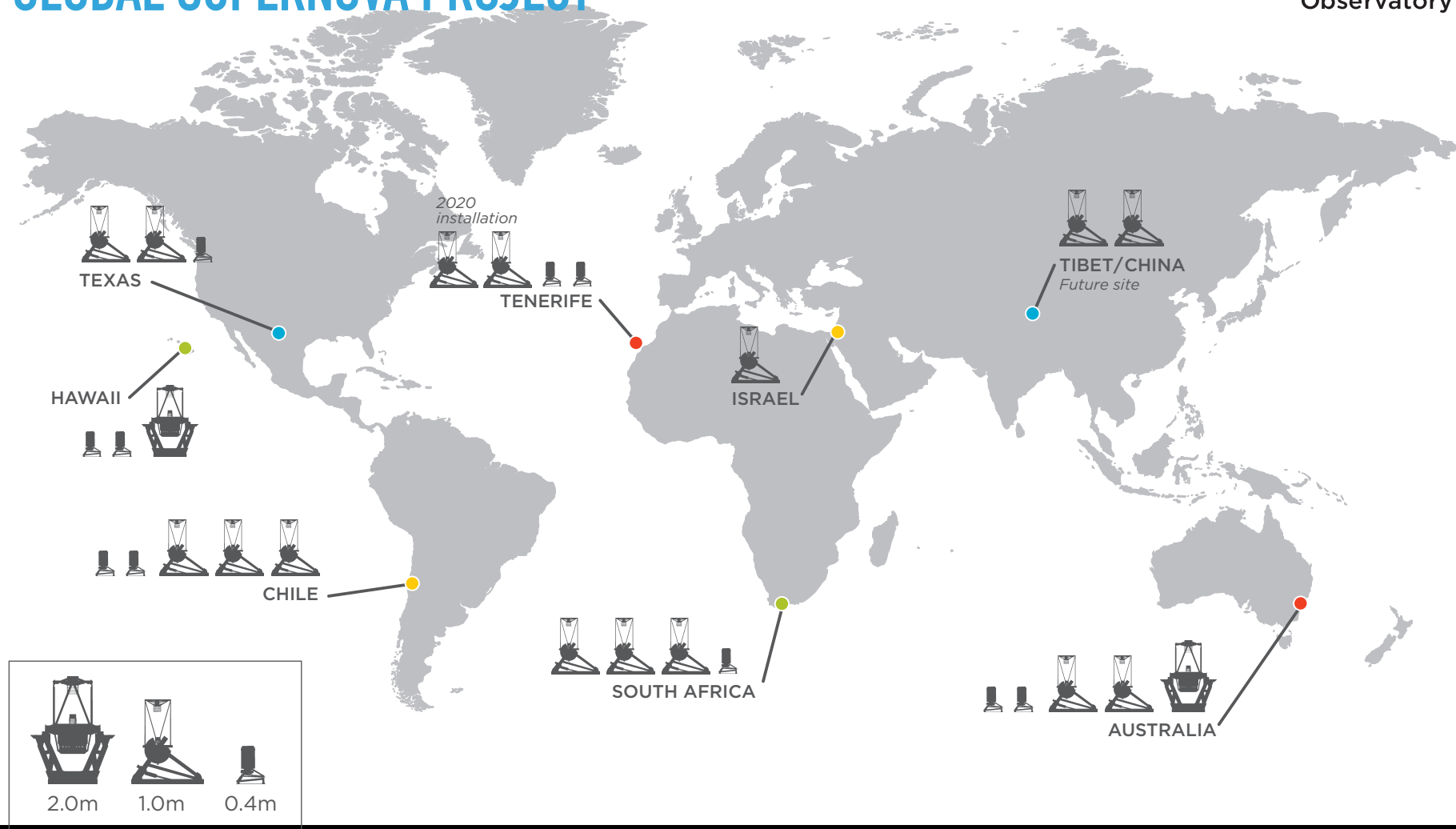
PASSTA: The Public AEON Spectroscopic Survey for Transient Astronomy

PI: Hosseinzadeh

- 25B through 28A. ~60 SOAR nights with ToOs. Focus on SNe within ~50 Mpc discovered young.
- Coupled to ‘large and long programs’ on Gemini for both optical+NIR spectroscopy (PI Sand, Andrews) and GHOST high res spectroscopy (PI Andrews)
- Goodman Optical spectrograph + TripleSpec NIR spectrograph. Full wavelength coverage.
- World-wide collaboration with resources in Chile, South Africa, Hawaii, Arizona, Australia, etc etc.
- All spectra public on Wiserep and TNS within ~24 hours.

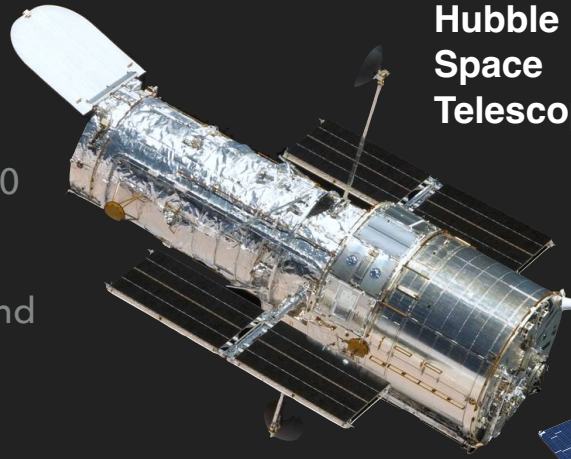


GLOBAL TELESCOPE NETWORK GLOBAL SUPERNOVA PROJECT



GLOBAL SUPERNOVA PROJECT

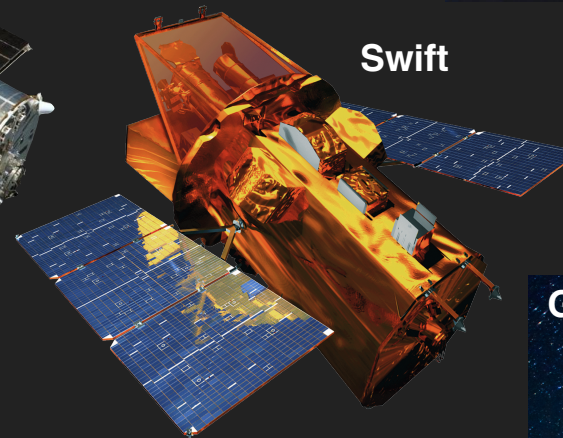
- ▶ A large fraction of the worldwide supernova community working together – more than 200 members.
- ▶ We obtain light curves and spectra using LCO's 25 robotic telescopes, and combine them with data from another ~30 facilities on Earth and in space.
- ▶ This is the 4th iteration, after 2 successful 3 year Key Projects 2014-2017, 2017-2020, and 2020-2023
- ▶ We have already studied more than 1000 SNe
- ▶ More than 250 publications



Hubble
Space
Telescope



Keck



Swift



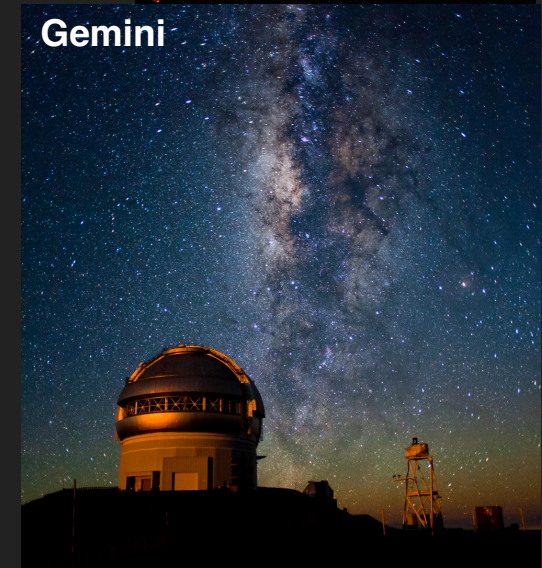
IRTF



NTT
ePESSTO



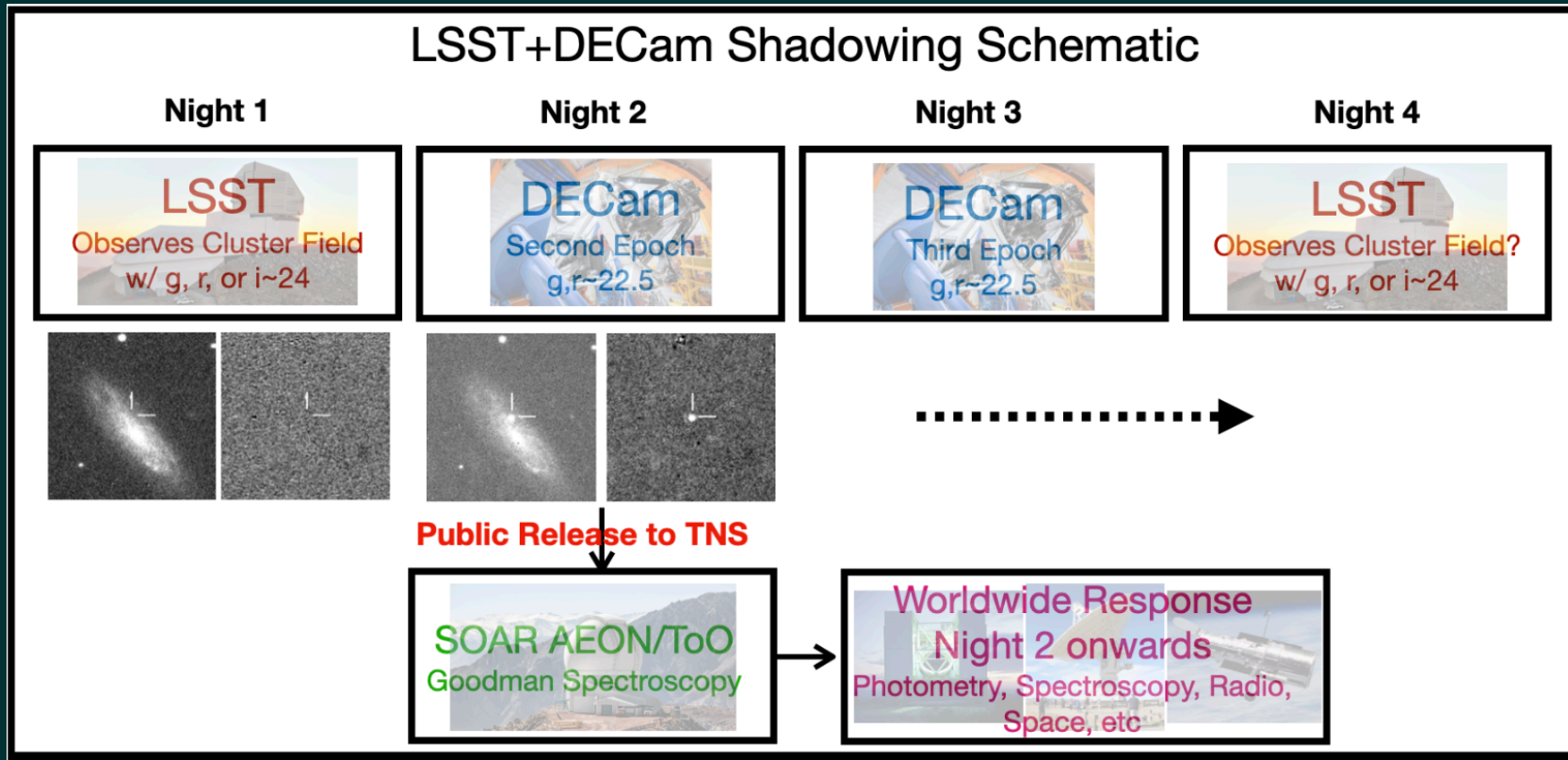
VLA



Gemini

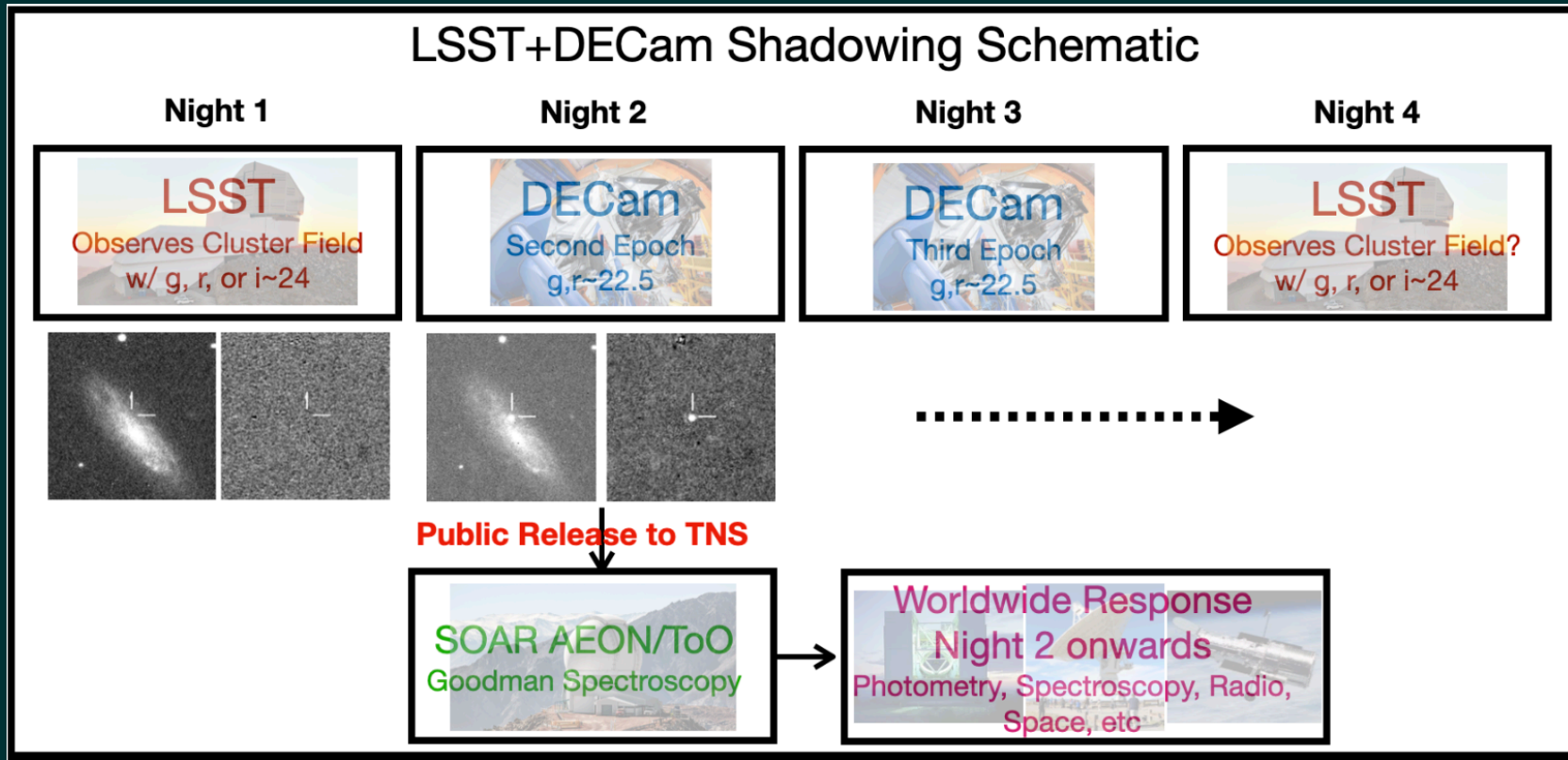
Contact PI A. Howell if interested in joining

Shadowing LSST: Approved NOIRLab Survey Program



- 25B through 28A. ~80 DECam nights. 7 nights of SOAR ToO. Paired with another SOAR survey program (PASSTA), the GSP and Gemini.
- 25 SNe in total, roughly evenly split between thermonuclear and core collapse. Each one with world class data.
- World-wide collaboration with resources in Chile, South Africa, Hawaii, Arizona, Australia, etc etc.

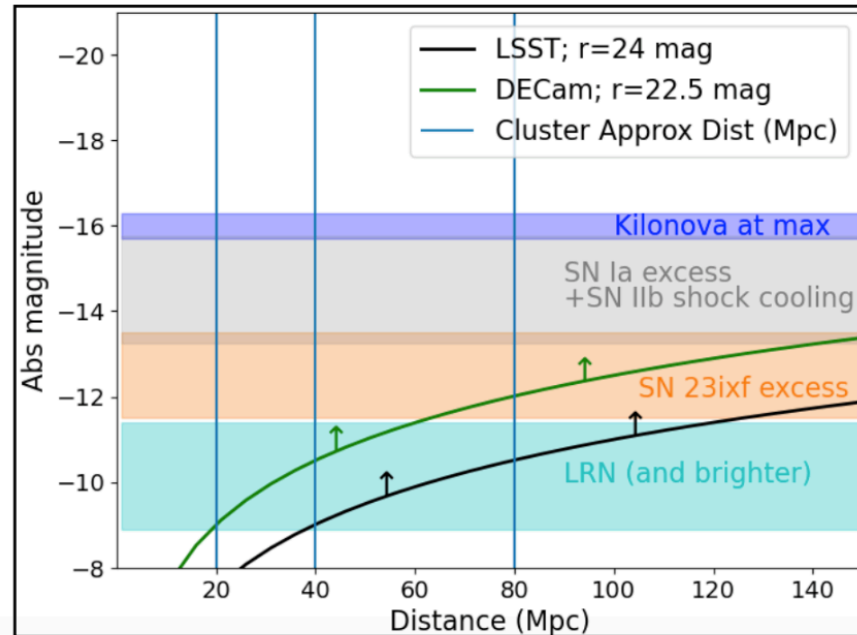
Shadowing LSST: Approved NOIRLab Survey Program



Target	RA (HH:MM)	Dec (DD:MM)	Distance (Mpc)	Area (deg ²)	M_r Depth (mag)	# of DECam fields	On-sky Time per Visit (hr)
Fornax Cluster	03:38	-35:27	21	45	-9.1	15	1
Eridanus Cluster	03:28	-20:44	25	45	-9.5	15	1
Dorado Cloud	04:17	-56:06	20	10	-9.0	5	0.33
Antlia Cluster	10:30	-35:20	40	3	-10.5	1	0.1
Hydra Cluster	10:36	-27:31	80	9	-12.0	3	0.2
Virgo Cluster	12:30	+12:20	18	90	-8.8	30	2

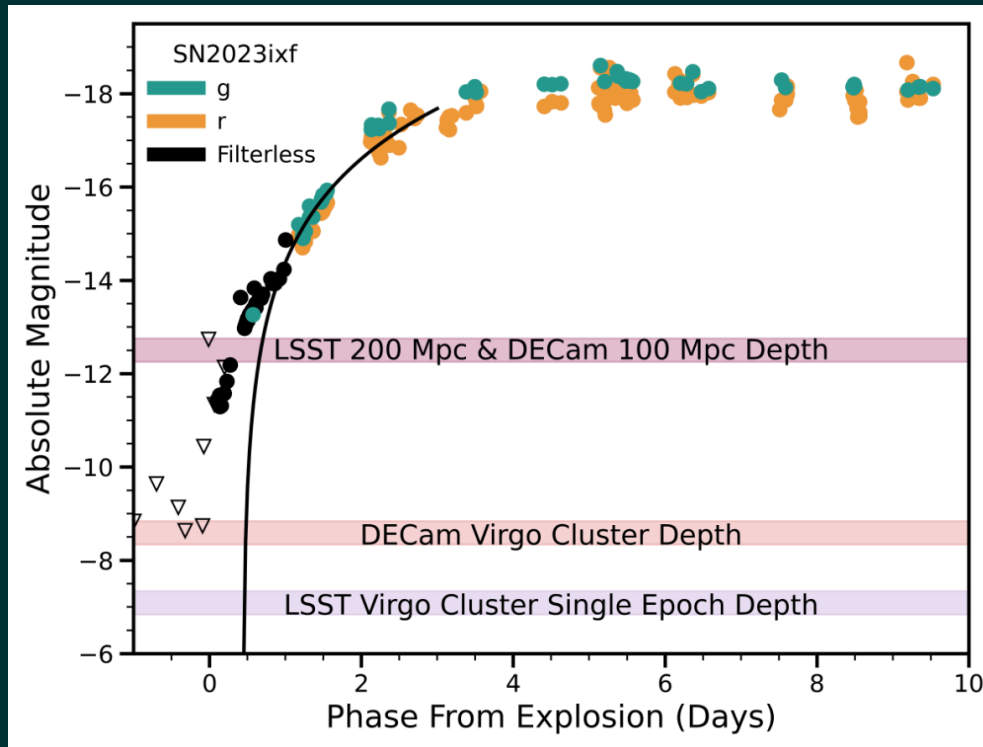
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Early SN Signatures vs.
Distance



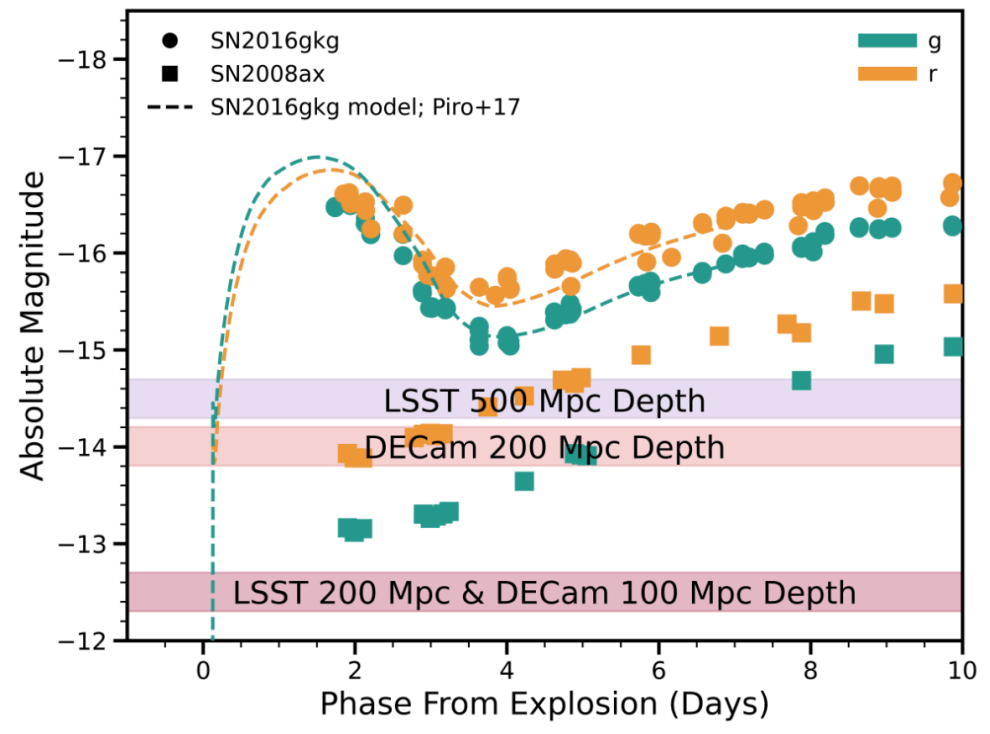
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Early Core Collapse Light Curve Signatures



Normal Core Collapse
(type II)

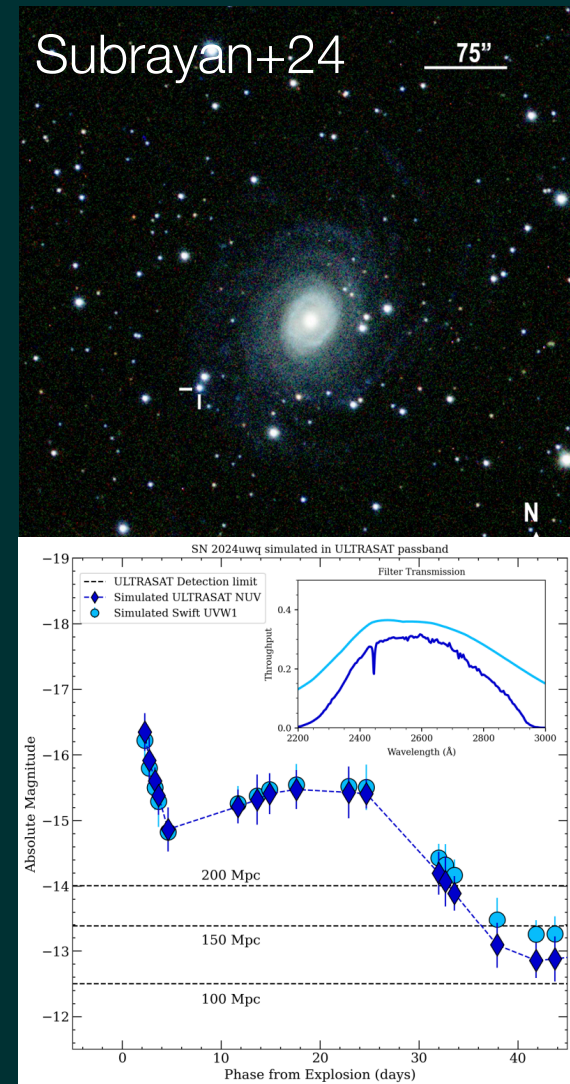
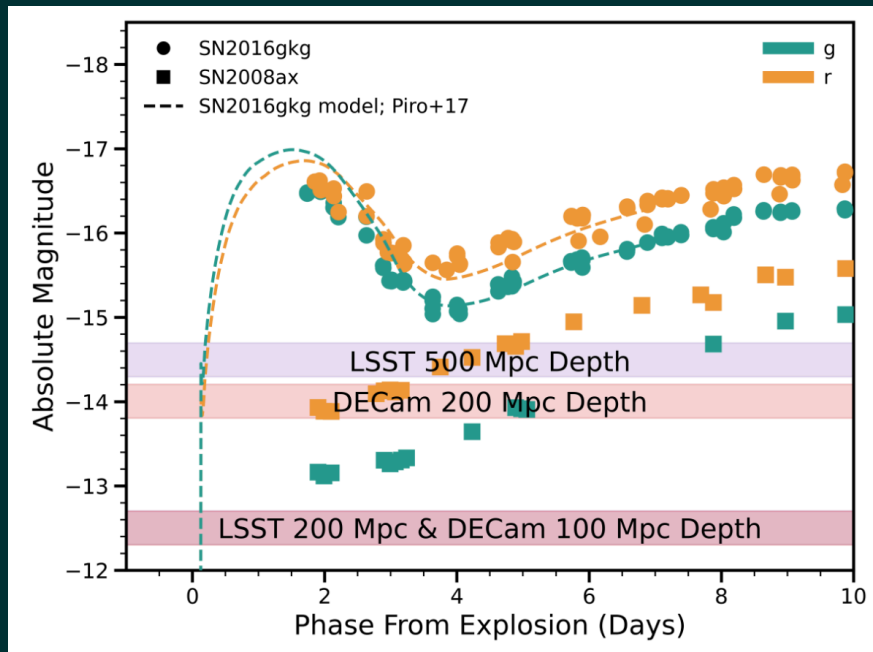
~75 SN23ixf-like excesses per year



Type IIb's

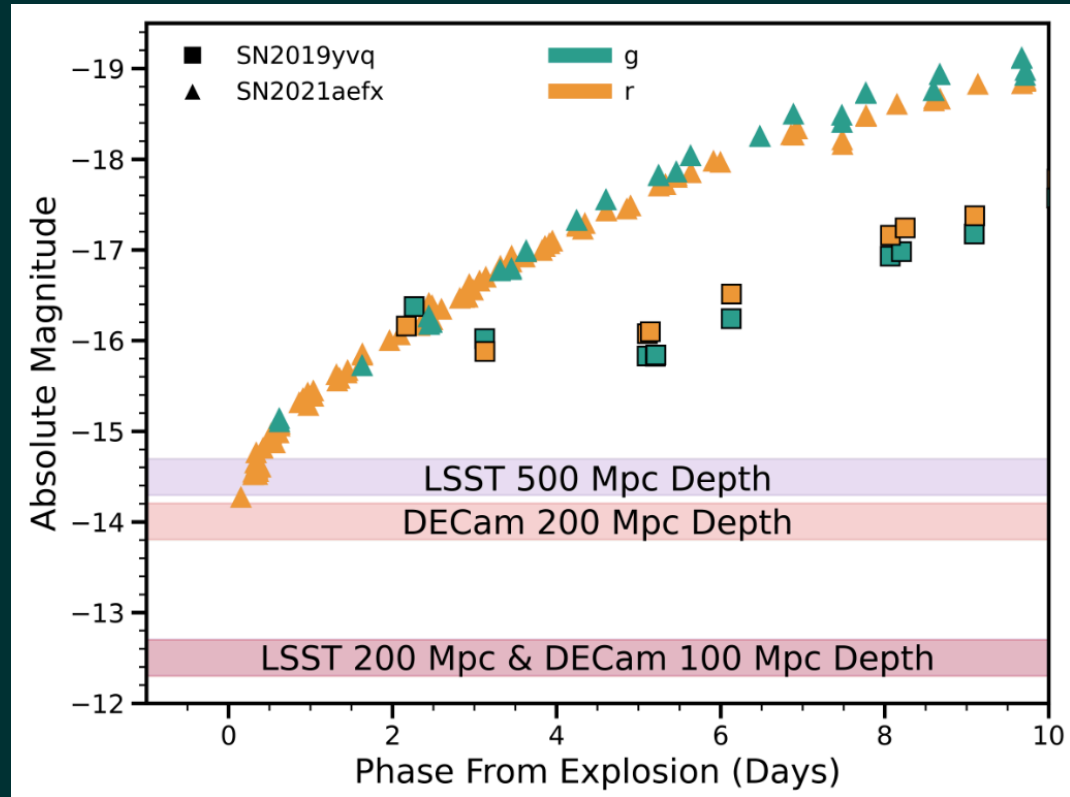
~15 SNIib excesses per year
(conservative)

Type IIb Early Discovery + ULTRASAT



ULTRASAT high-cadence field (200 deg²) will find 2-3 type IIb SNe each year to characterize their shock cooling phase in the UV.

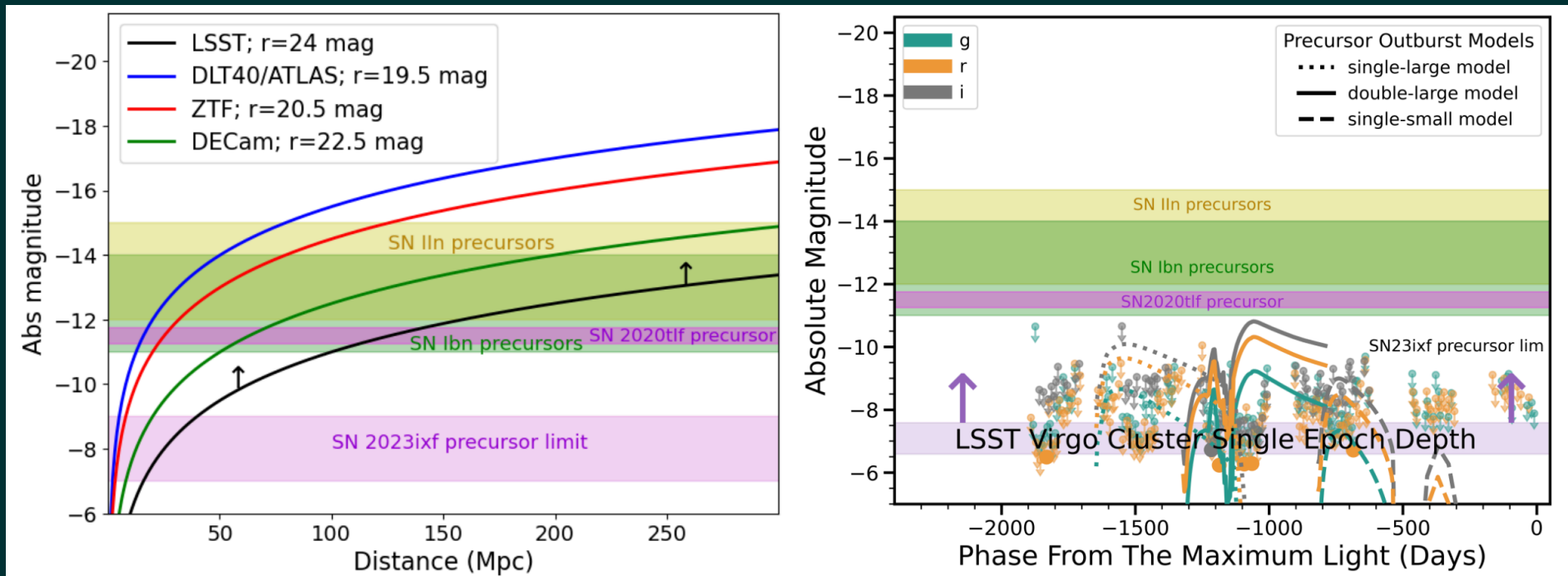
Early SN Ia Light Curve Signatures



SN Ia

~250 per year

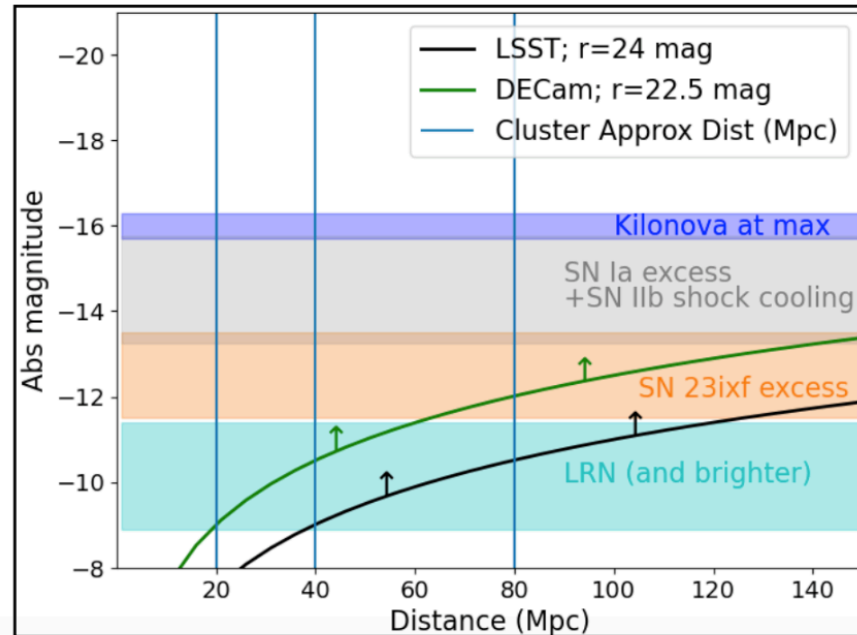
Precursor Outbursts with LSST & Related Facilities



- ~ 1 SN Ibn precursors per year.
- ~ 15 SN IIn precursors per year.
- ~ 75 SN II per year where we can look for SN20tlf-like outbursts
- ~ 5 SN II per year where we could be sensitive to SN23ixf-like precursor limit.

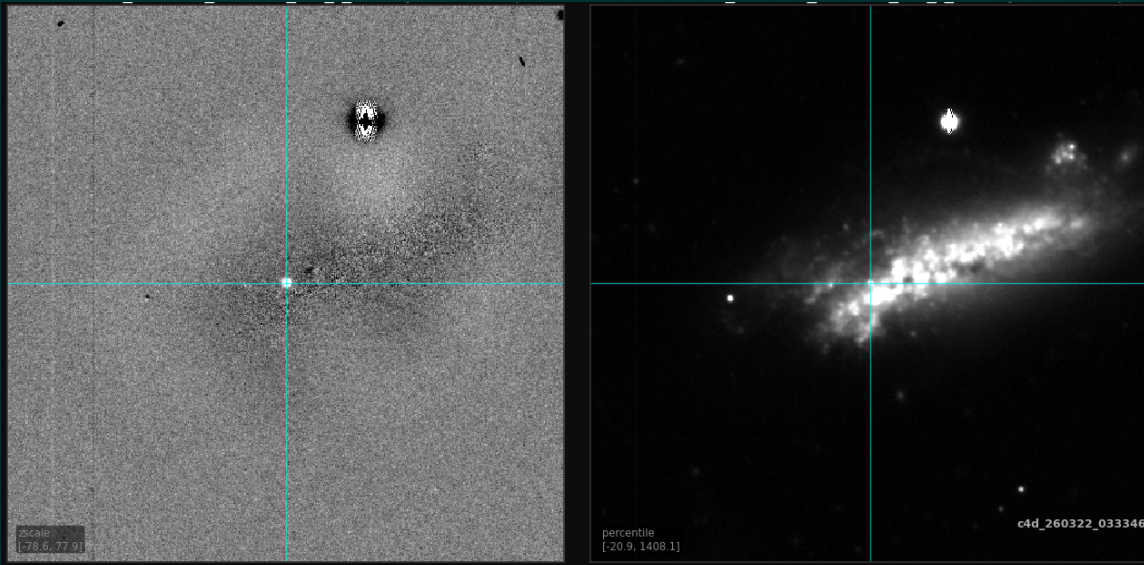
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Early SN Signatures vs. Distance



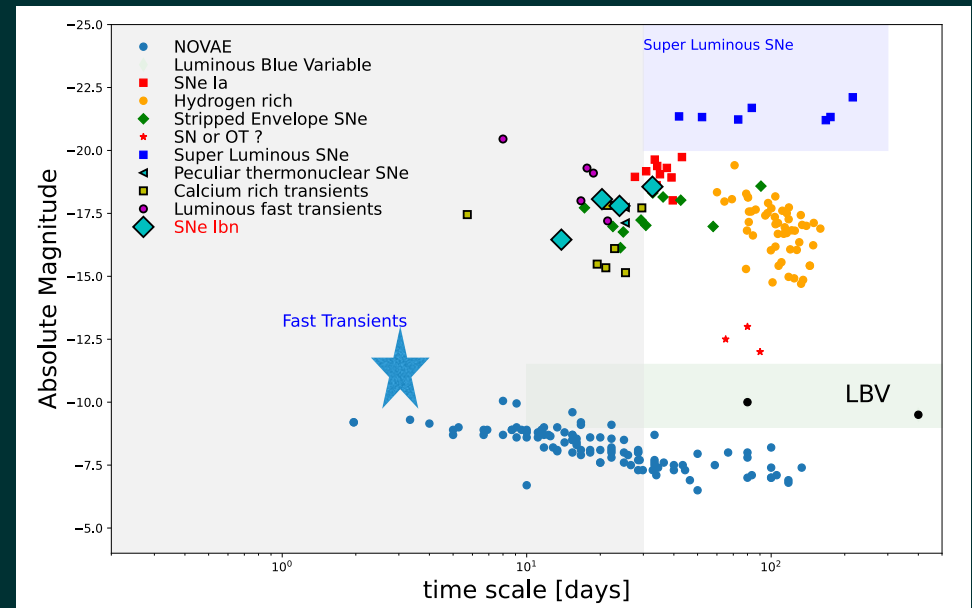
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Shadowing LSST: Not much LSST yet, but plenty of transients

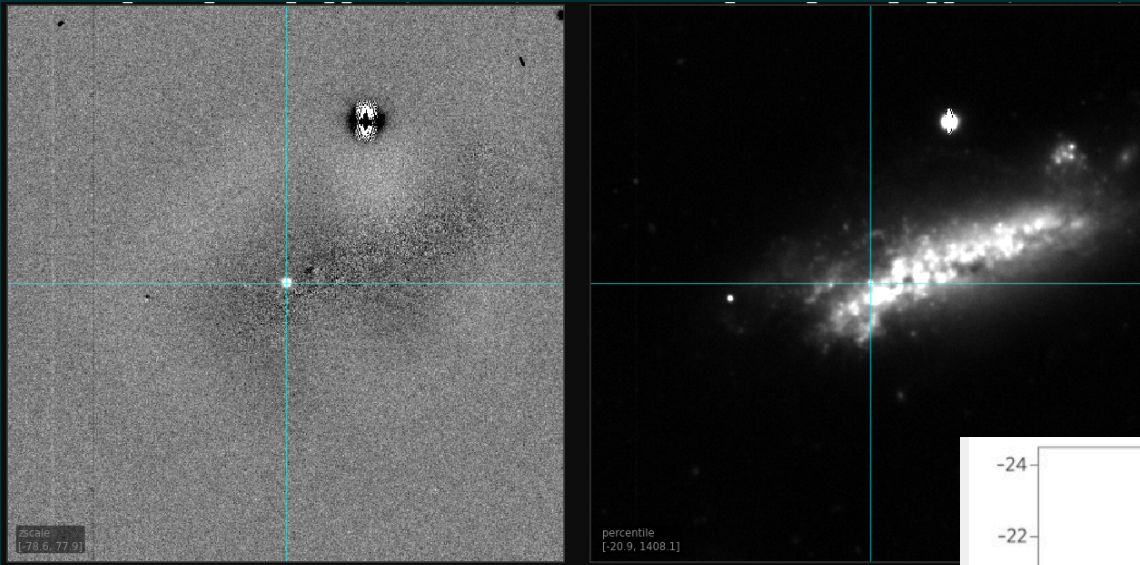


AT2017des now in eruption

~25 transients in TNS
Several M49/Virgo novae

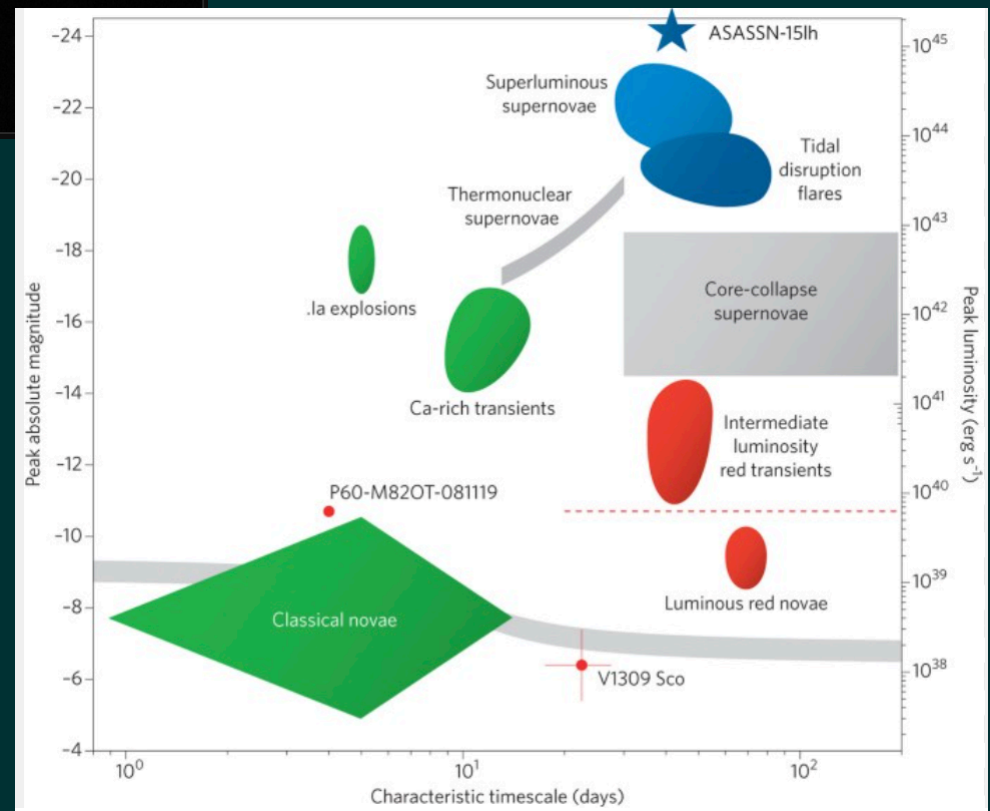


Shadowing LSST: Not much LSST yet, but plenty of transients

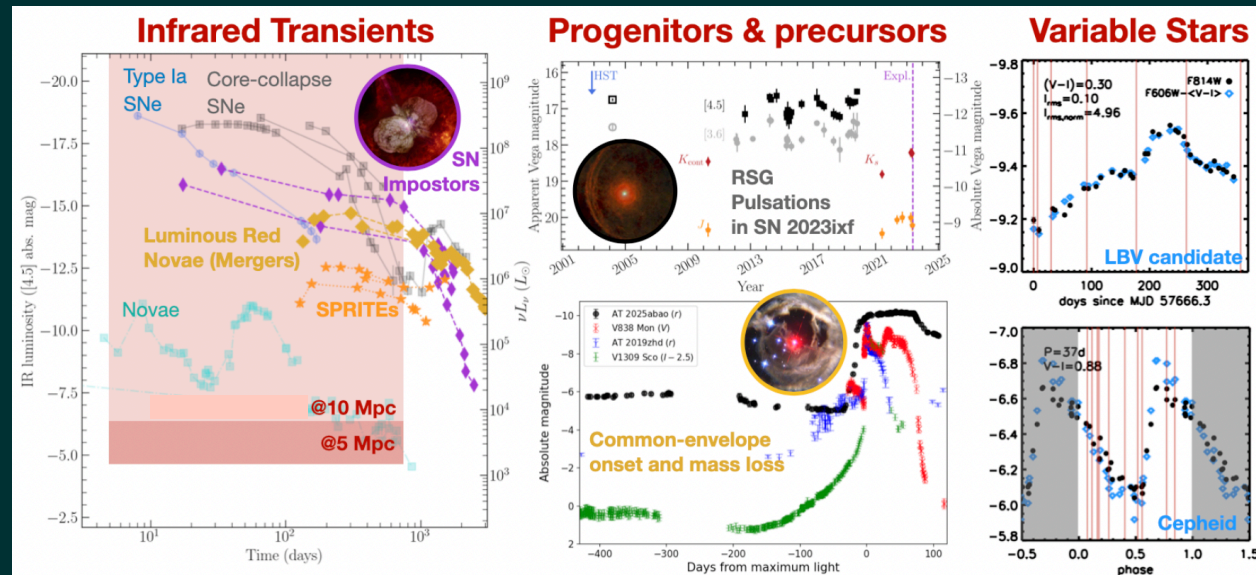
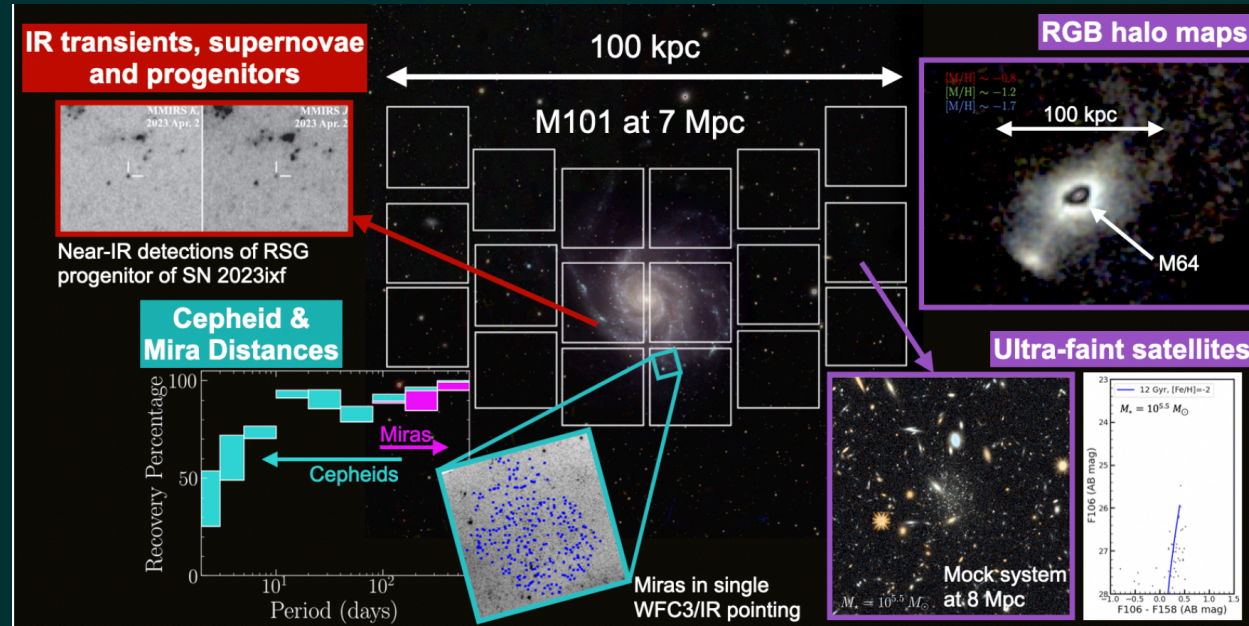


AT2017des now in eruption

A zoo of dusty/embedded/
merging transients in star
forming regions



Roman Needs Some Kind of Nearby Galaxy Transient Survey

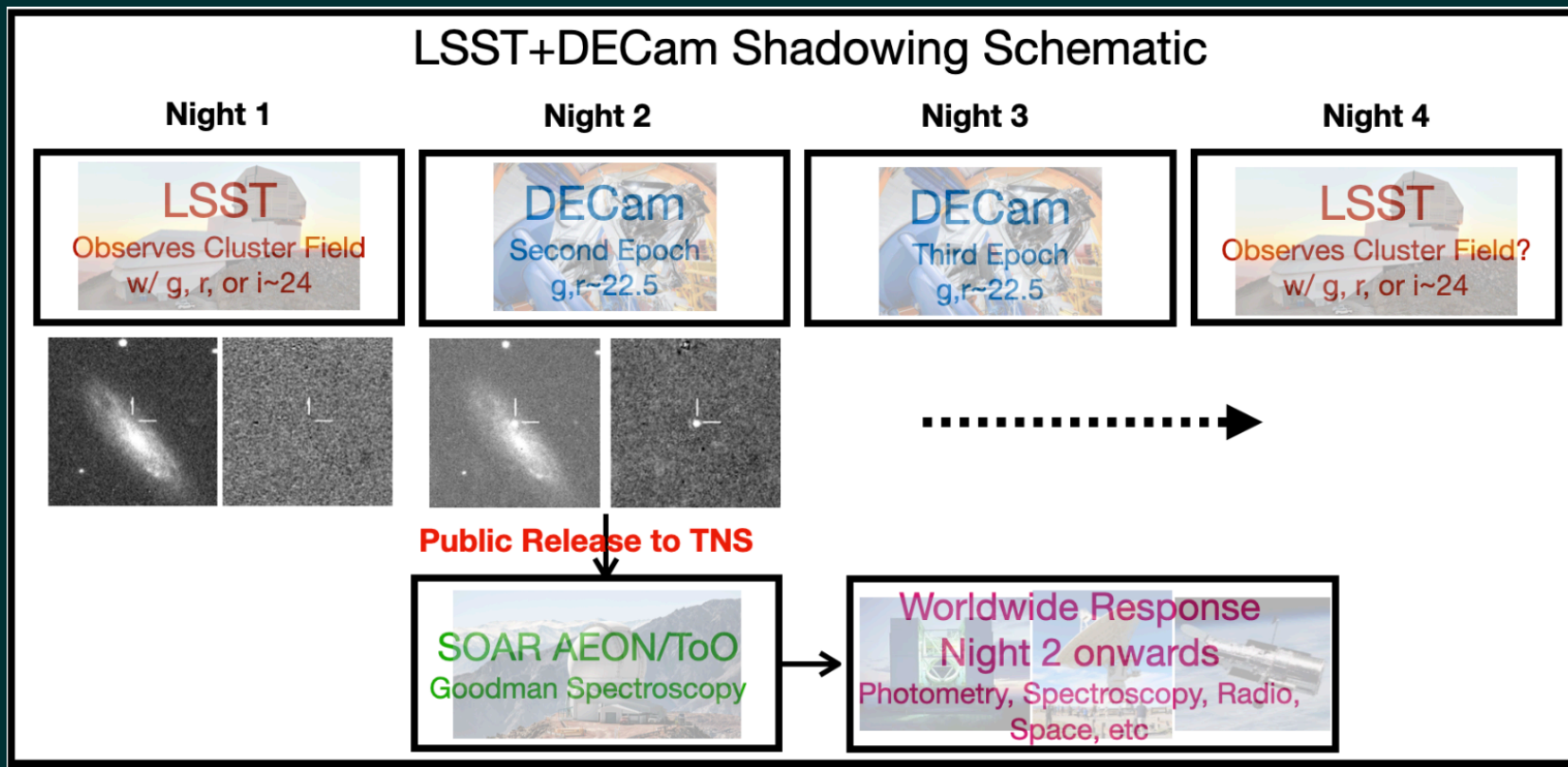


FUTURE NEEDS

- Merge the Streams!!! And let's keep merging them in the future. Even if just for nearby galaxies. <100-200 Mpc? There is a deep need for a 'Nearby Galaxy Broker'.
 - The '80 hour' rule for images from LSST is not ideal...
- More Automation. Be brave and automate your triggers, get higher cadence data, push the wavelength resolution. You will find new things. Swift is a good model for NASA.
- Coordinate more. Join a collaboration and get a world-class data set.

PUNCHLINE #I

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