Multimessenger Response to a SNEWS Alert

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On behalf of a larger collaboration

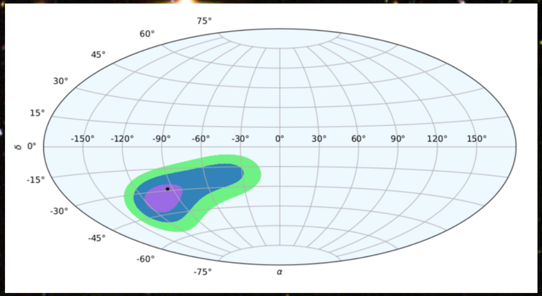
Information Observers Will Need

Phase 1: Immediate alert

Something is happening!

Phase 2: Shortly afterward…

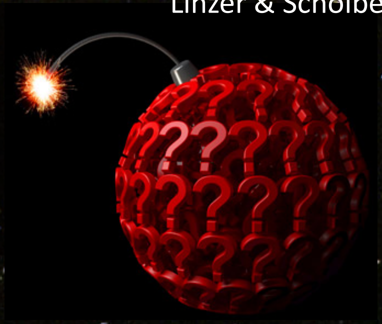
Localization



Linzer & Scholberg (2019)

Phase 3: A little while later…

Information about the nature of the explosion



Attitudes – Good and Bad

~~The next Galactic supernova will be so obvious that there is no need to plan follow up~~

We want to avoid a free-for-all…

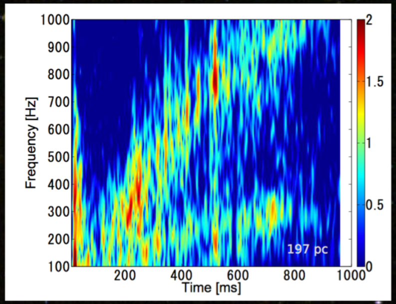
Rich scientific opportunities will be lost unless there is a world-wide cooperative effort to coordinate the complex array of multi-messenger resources needed fully characterize the next Galactic supernova.

Considerations for GW Follow up

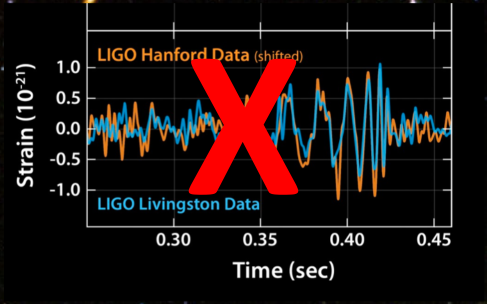
Neutrinos will provide timing window for GW search.

Lots of recent research into GW signatures of core-collapse supernovae, but much remains unknown.

See, e.g., Kotake+ (2013), Gossan+ (2015), Radice+ (2019), Andresen+ (2019), Westernacher-Schneider+ (2019)



Nakamura+ (2016)



Will not be able to perform *matched filtering*, thus excess power search centered around t=0 from SNEWS alert is likely approach.

Goal is to automate passing SNEWS information to GW facilities

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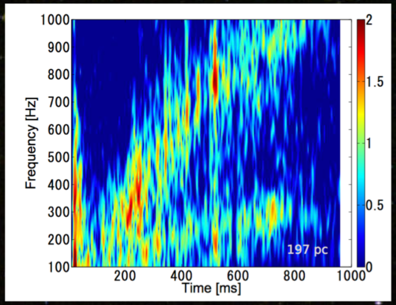
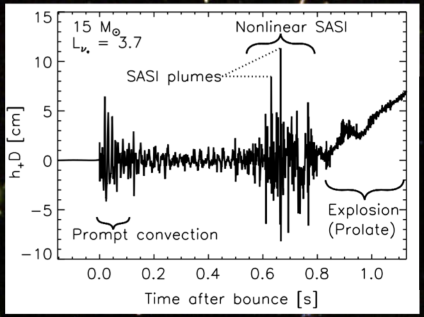


Nakamura+ (2016)



Murphy+ (2009)

Will not be able to perform *matched filtering*, thus excess power search centered around t=0 from SNEWS alert is likely approach.

Goal is to automate passing SNEWS information to GW facilities

Considerations for EM Follow up

Nature of event: SN with neutron star vs. black hole formation, SN Ia, pair instability supernova

Distance: challenges faced both near (and thus extremely bright) and far (dim)

Dust: heavy extinction increases priority of NIR monitoring

Location on sky: North vs. South, weather, etc.
Many obstacles if SN occurs at RA where local sidereal time is overhead

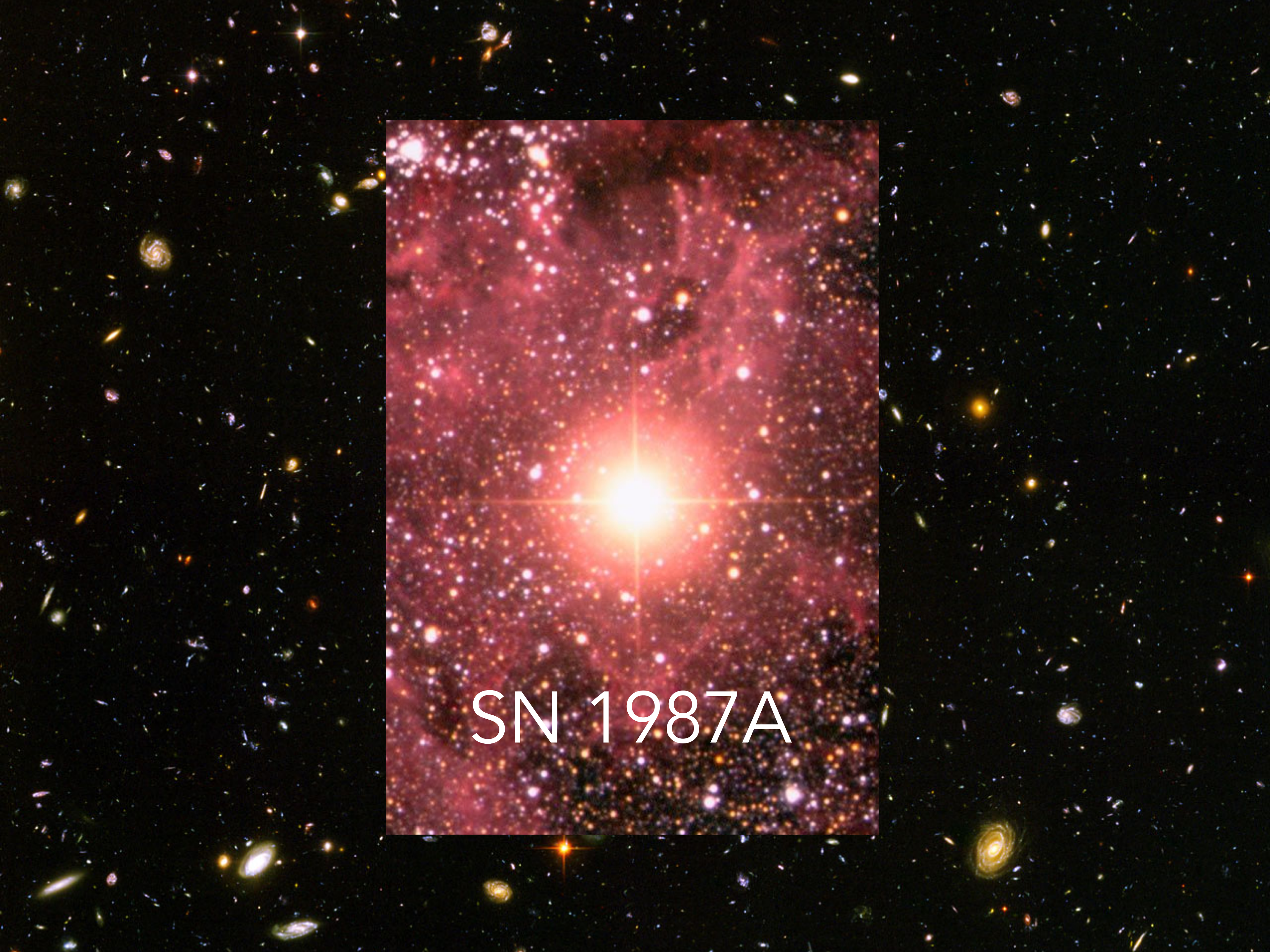
First priority is to locate progenitor star before shock breakout

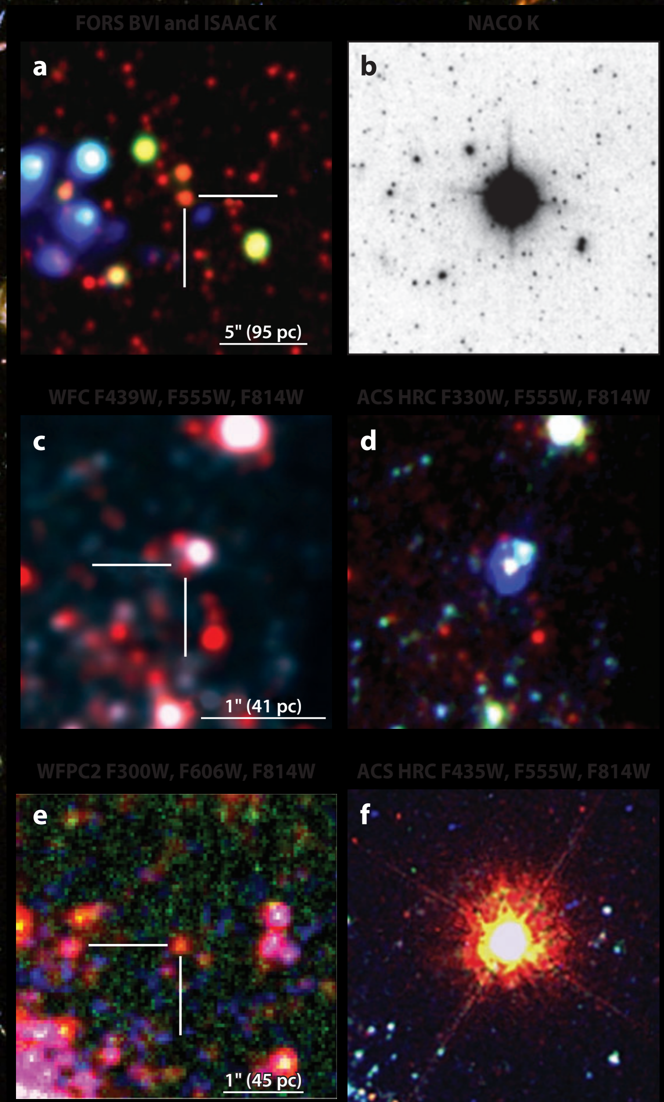
We will use ALL information to conduct an intelligent search and patrol likely candidates

Possible that we will not know which star will explode before shock breakout (SBO) in a large field (tens to hundreds of square degrees) thus intense monitoring is needed that can be analyzed afterwards.

Valuable information could be lost if not conducted properly!


Sk -69 202


SN 1987A

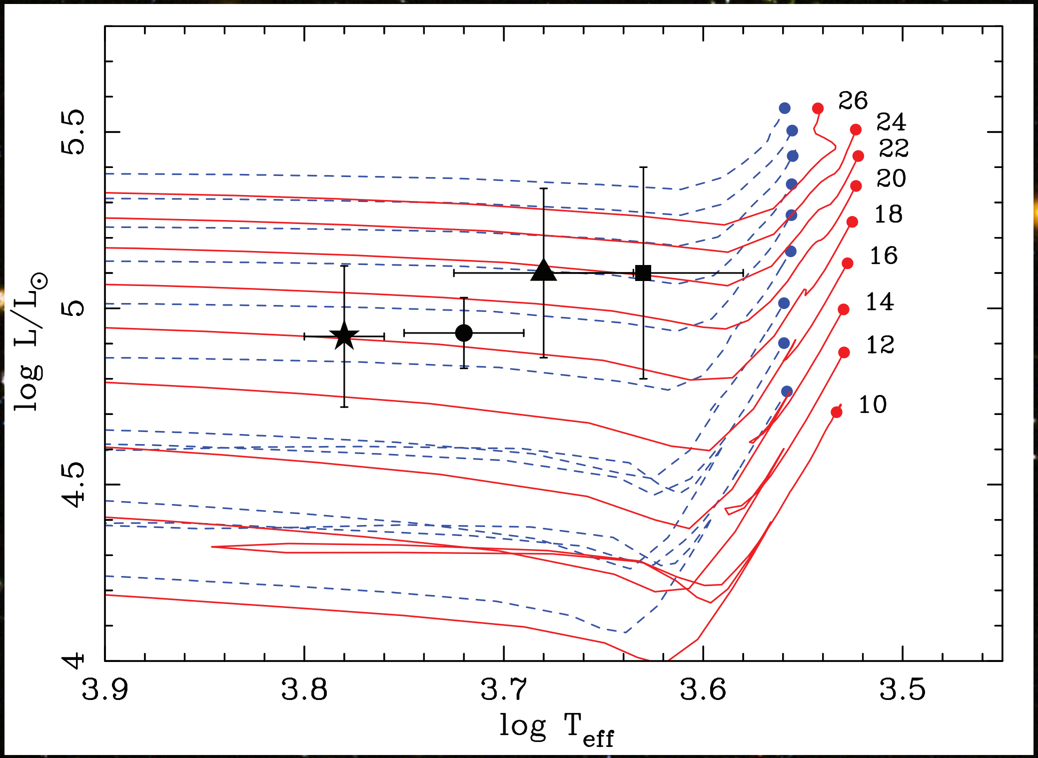


Smartt (2009)

Progenitor stars of *some* core-collapse supernovae have been detected in pre-explosion images.

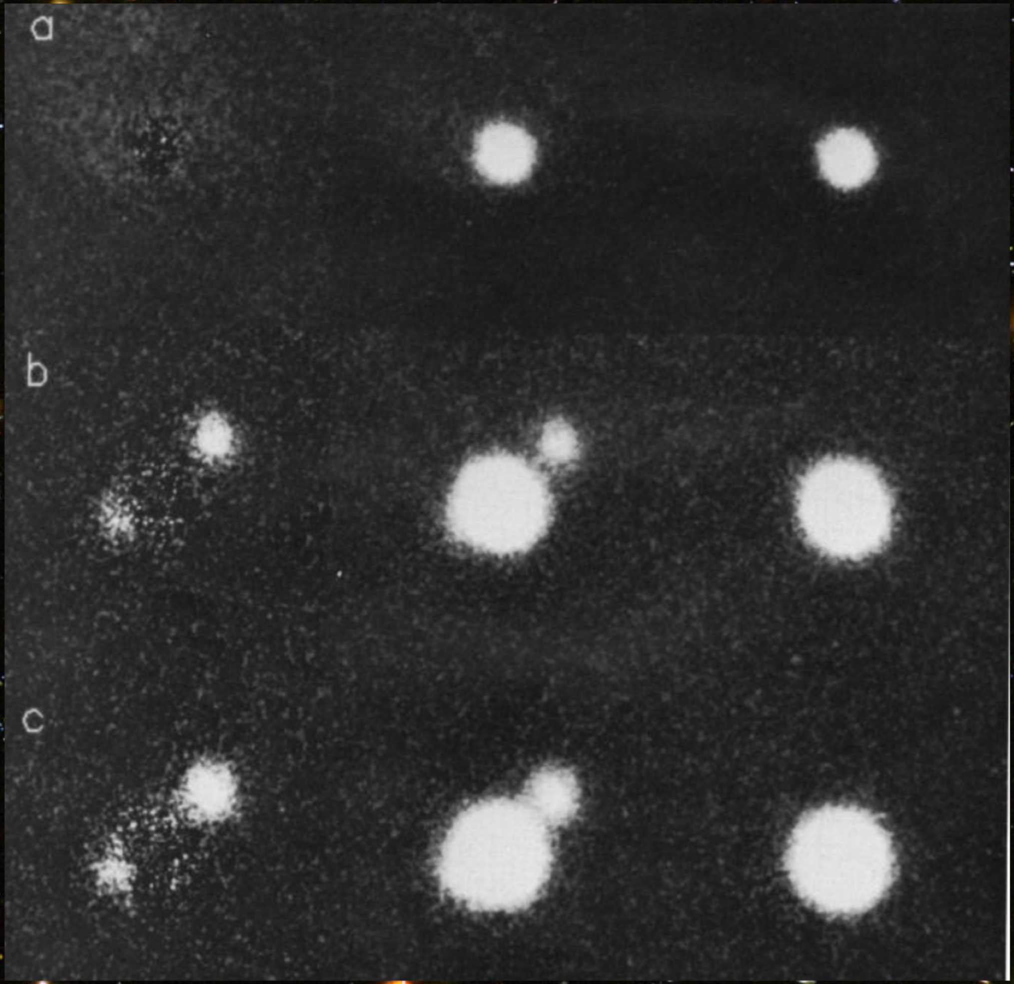
Type II come from red supergiants.

We compare observed properties with theoretical stellar tracks to derive the progenitor mass, but this is highly uncertain



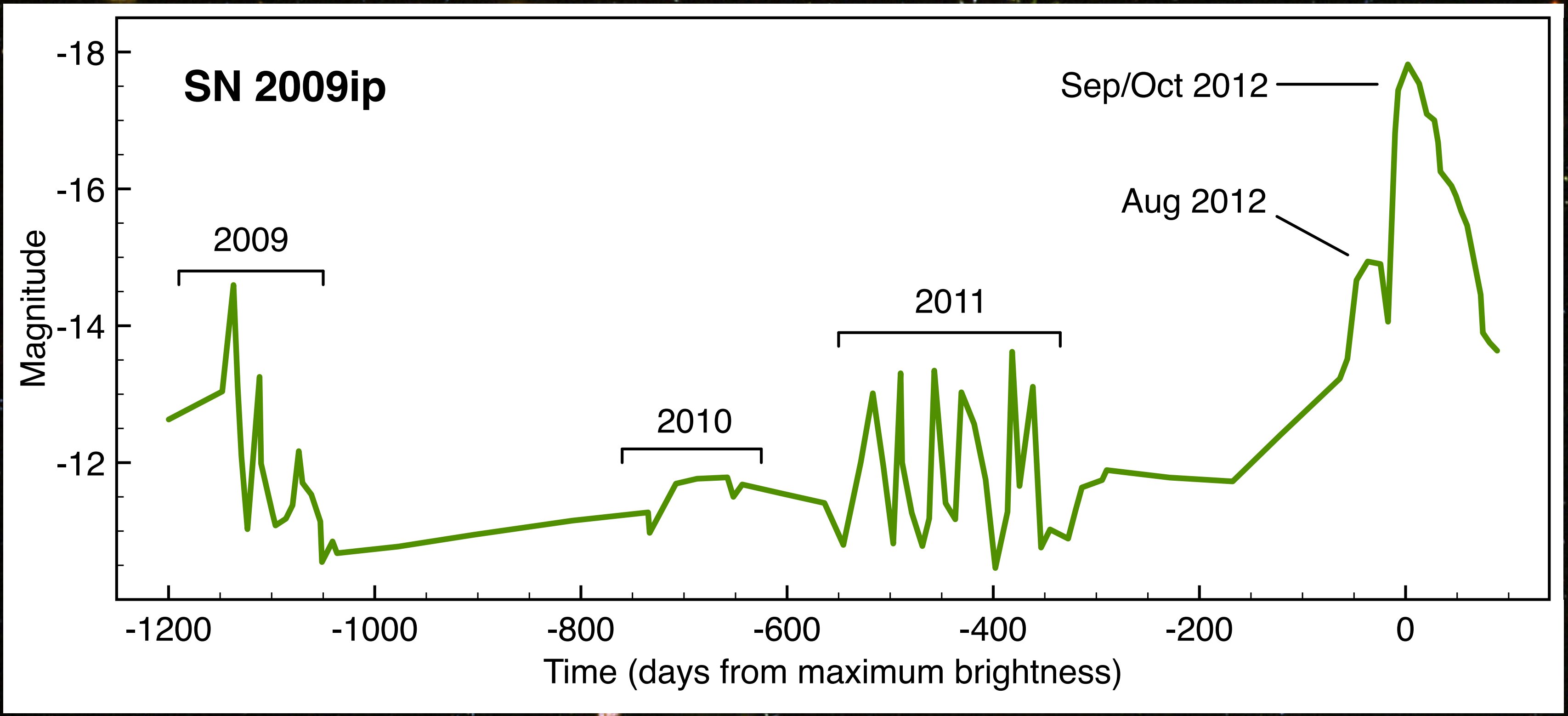
Maund et al. (2011)

Lesson from SN 1987A: expect the unexpected!
In this case, a blue supergiant progenitor



Walborn+ 1988

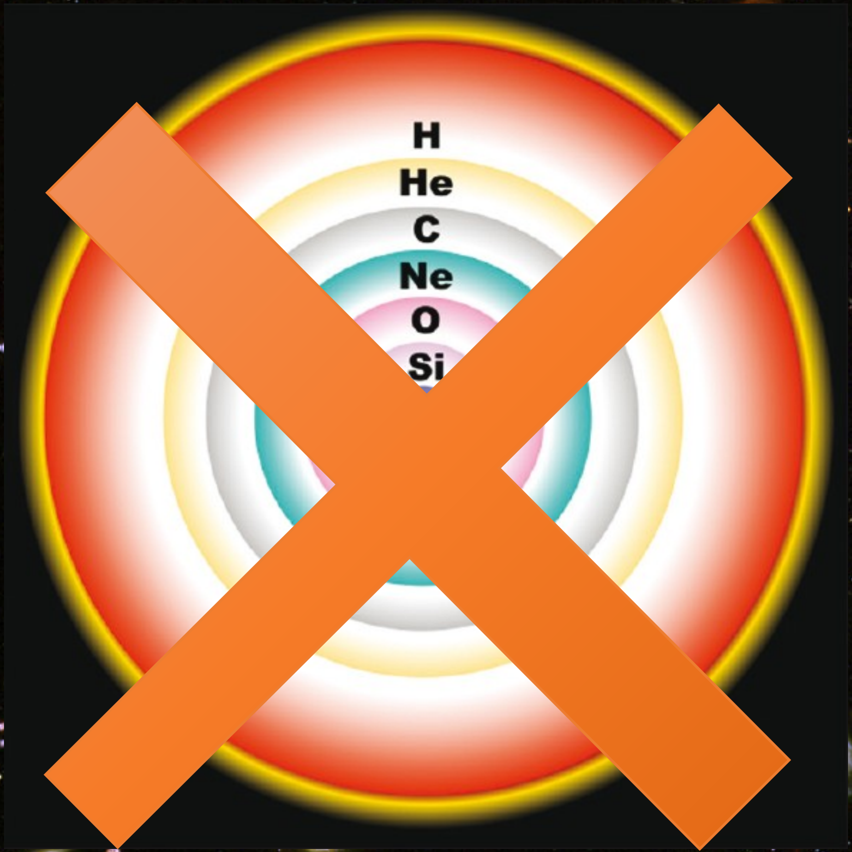
We've observed stars that undergo eruptions shortly before a supernova explosion

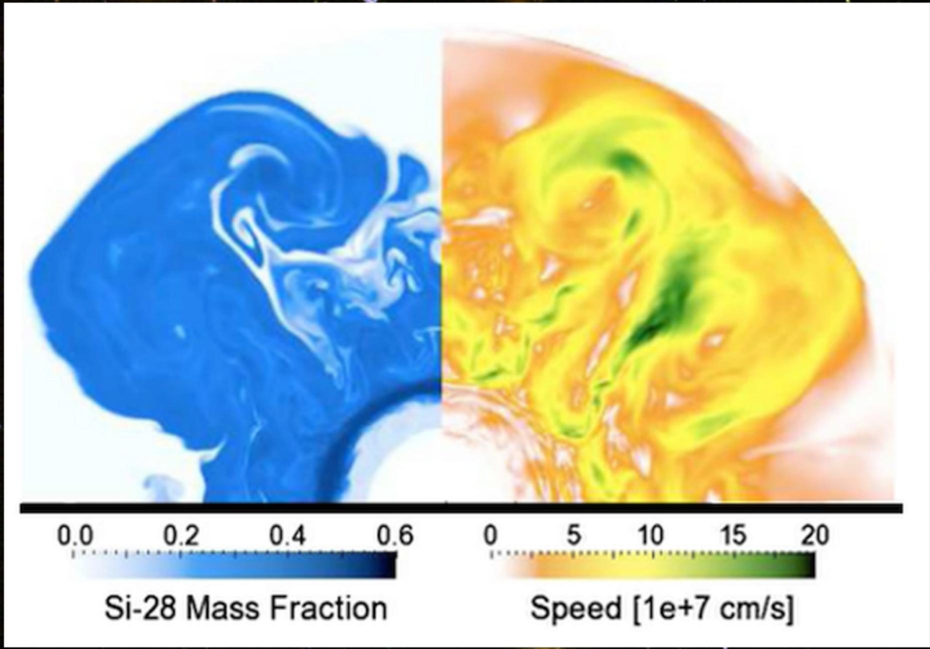


Data from Mauerhan+ 2013, Pastorello+ 2013 and Margutti, DM+2014

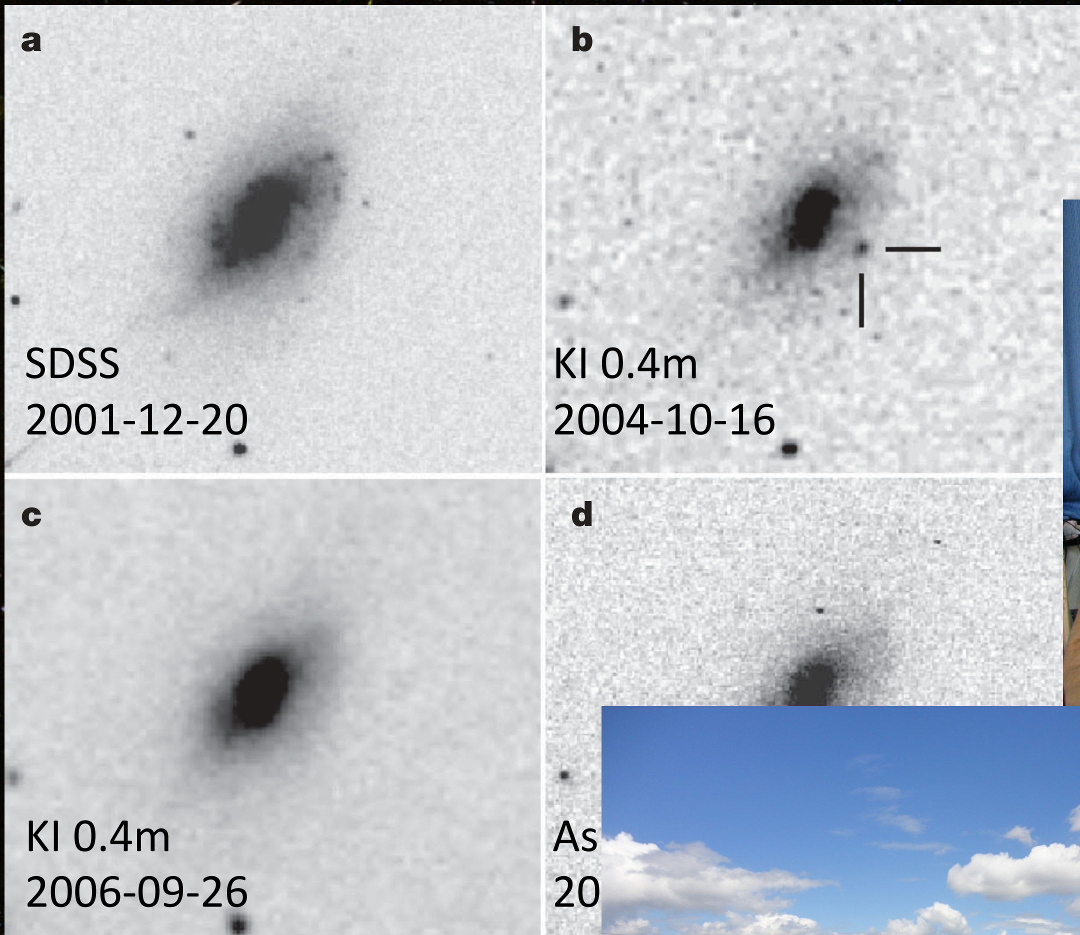
The close timing between outburst and core-collapse suggests a connection:

Interior structure of the progenitor star immediately prior to explosion may be very *turbulent* and *mixed*.



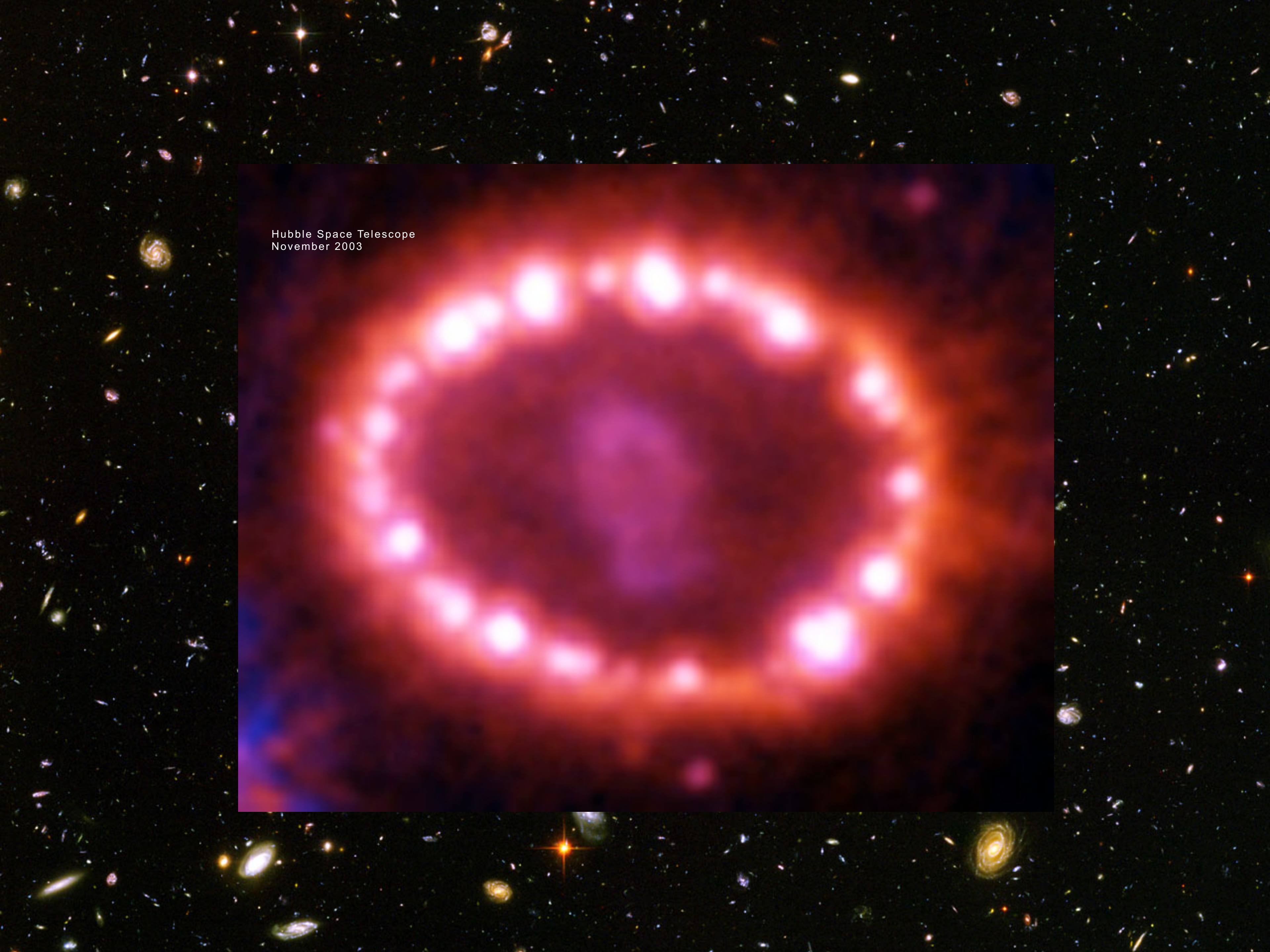


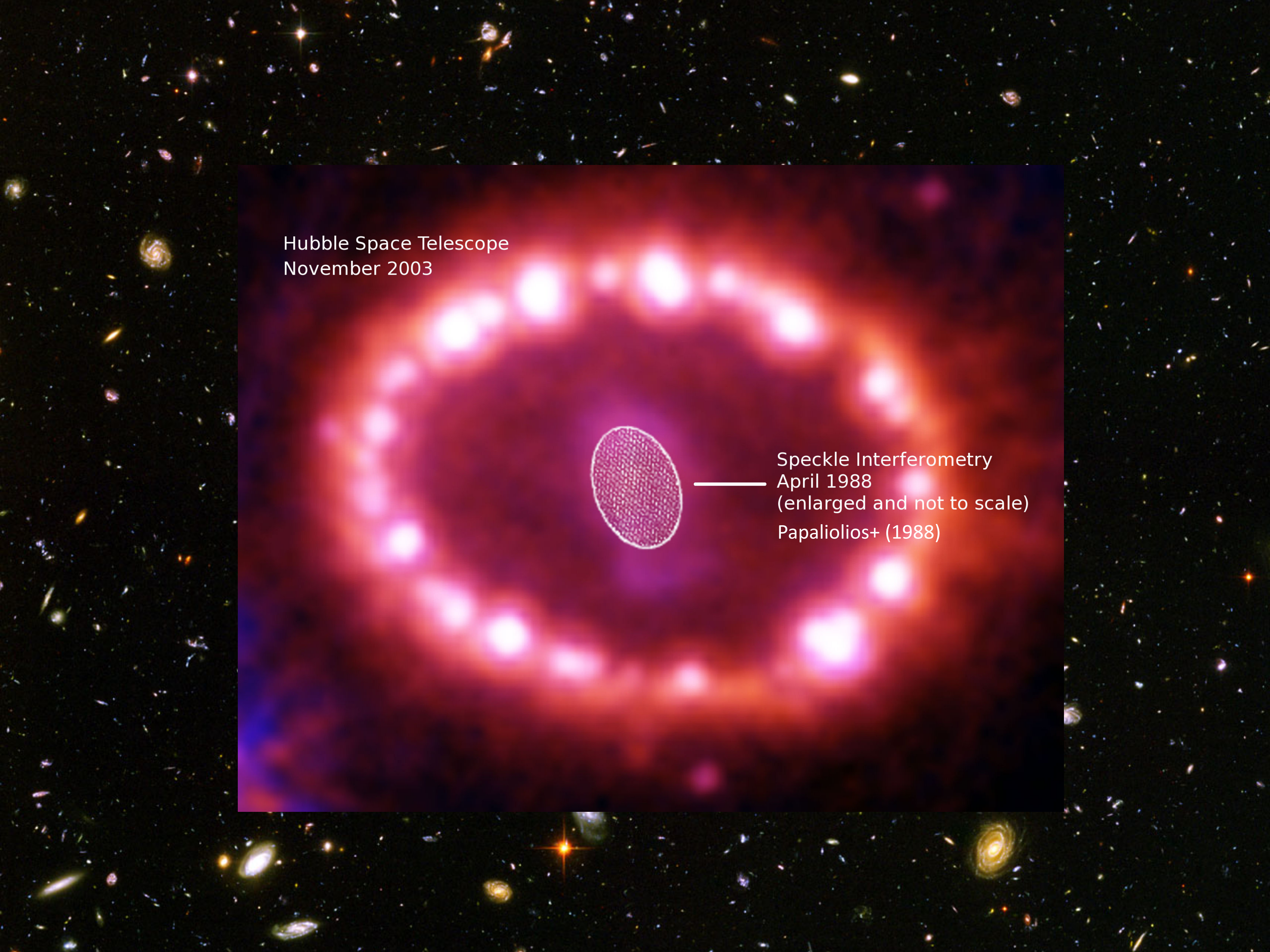
Arnett & Meakin (2011)



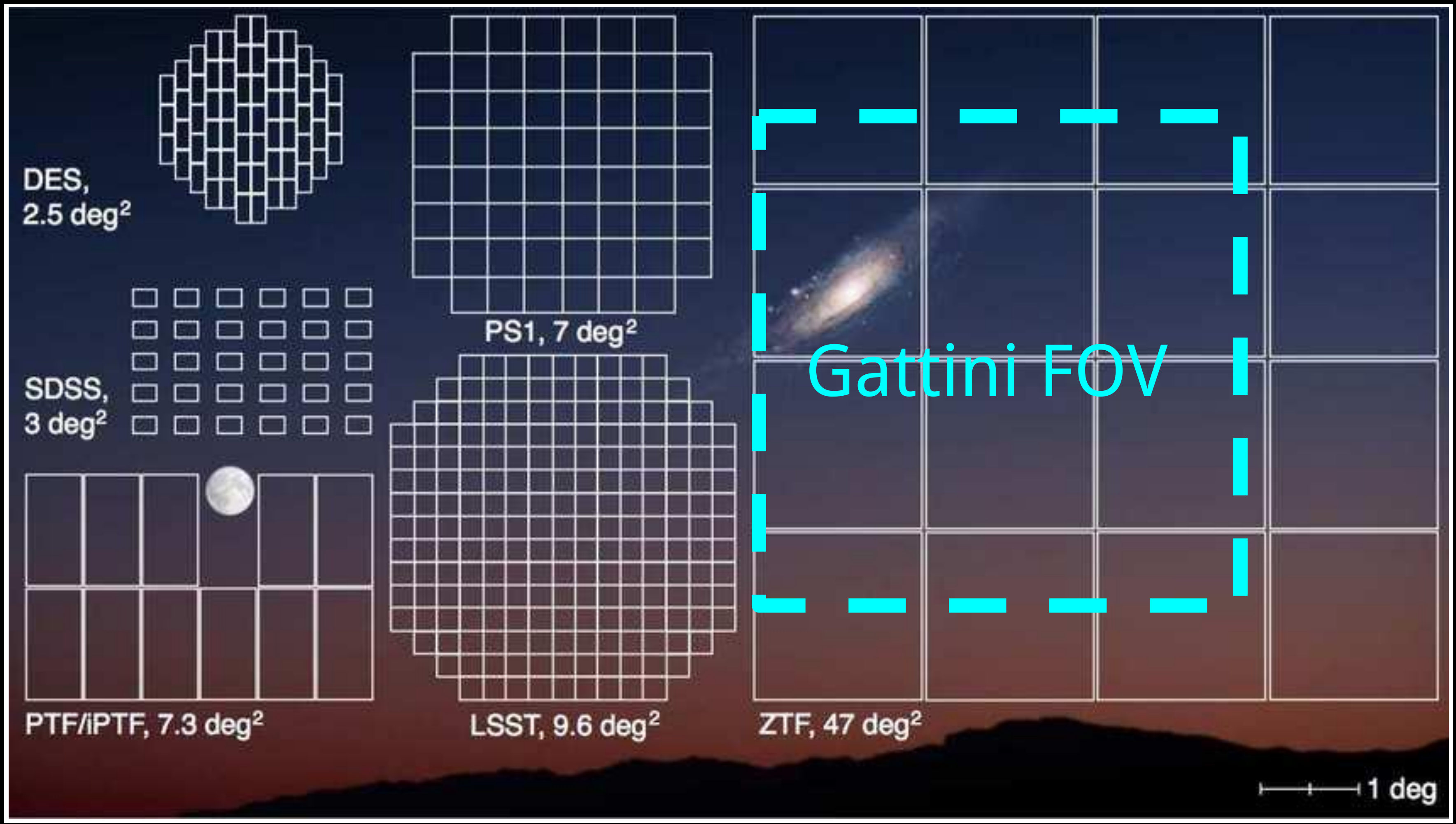
Pastorello et al. (2

Koichi Itagaki

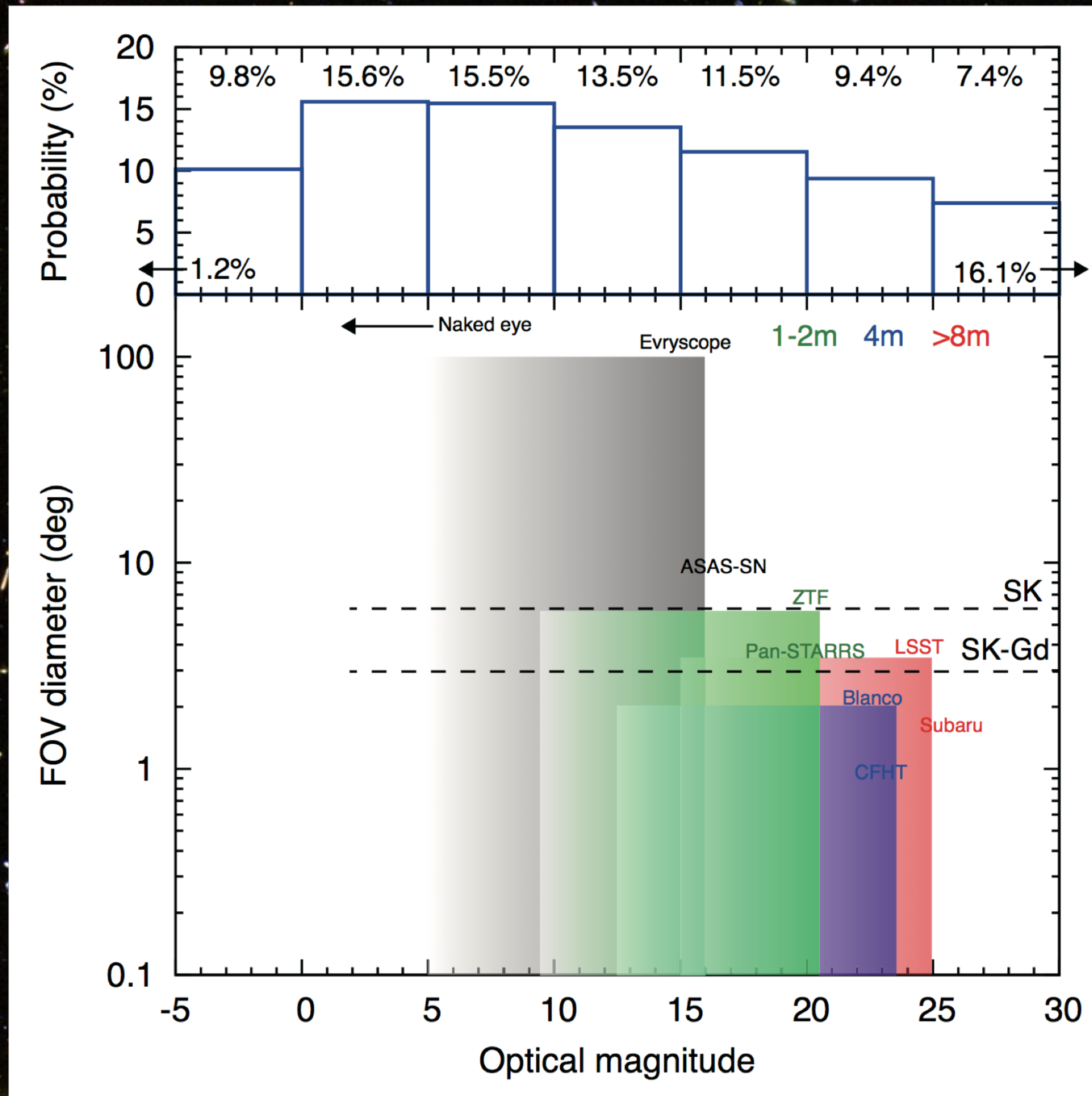

Hubble Space Telescope
November 2003


Hubble Space Telescope
November 2003
Speckle Interferometry
April 1988
(enlarged and not to scale)
Papaliolios+ (1988)

Large localizations are no longer intimidating



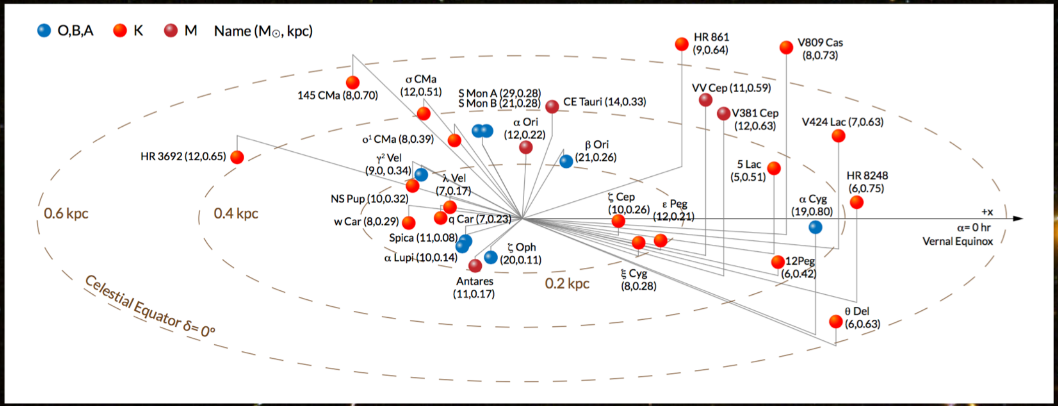
Credit M. Kasliwal



Nakamura+ 2016

An efficient search uses all information available

Pre-supernova detection



Mukhopadhyay+ 2020

Nearby

Table 4
Near-Earth Supernova Explosion Candidates

Star	Location	Dist. (pc)	Mass ⊙
IK Pegasi	Pegasus	46	1.65/1.15[a]
Spica	Virgo	80	10.25/7.0[a]
Alpha Lupi	Lupus	141	10.1
Antares	Scorpius	169	12.4/10[a]
Betelgeuse	Orion	197	7.7–20
Rigel	Orion	264	18[b]

Notes.
[a] Binary star system.
[b] Multiple star system.

Firestone+ 2014

"Dangerous"

Cullingham+ 2018

Red supergiants

Name	RA (J2000.0)	Dec (J2000.0)	Distance (kpc)	V mag	Spec. type	Note	Type ref[a]	Dist. reff[b]
BD+61 8	00:09:36.37	+62:40:04.1	2.40	9.49	M1ep Ib + B	KN Cas	1	2
BD+59 38	00:21:24.29	+59:57:11.2	2.09	9.67	M2 I	MZ Cas	1	1
HD 236446	00:31:25.47	+60:15:19.6	2.40	8.71	M0 Ib		1	3
TY Cas	00:36:59.42	+63:08:01.7	2.40	11.5 (*B*)	M6		1	3
V634 Cas	00:49:33.53	+64:46:59.1	2.51	10.46	M1 Iab		1	3
HD 4817	00:51:16.38	+61:48:19.8	1.05	6.18	K5 Ib	HR 237	4	4
HD 4842	00:51:26.00	+62:55:14.9	2.51	9.62	M6/7III	VY Cas	1	**
BD+62 190	01:03:15.35	+63:05:10.8	2.51	9.95	M5?		1	**
BD+62 207	01:08:19.93	+63:35:11.2	2.51	9.82	M4 Iab	HS Cas	1	2
HD 236697	01:19:53.62	+58:18:30.7	2.51	8.62	M1.5 I	V466 Cas	1	1

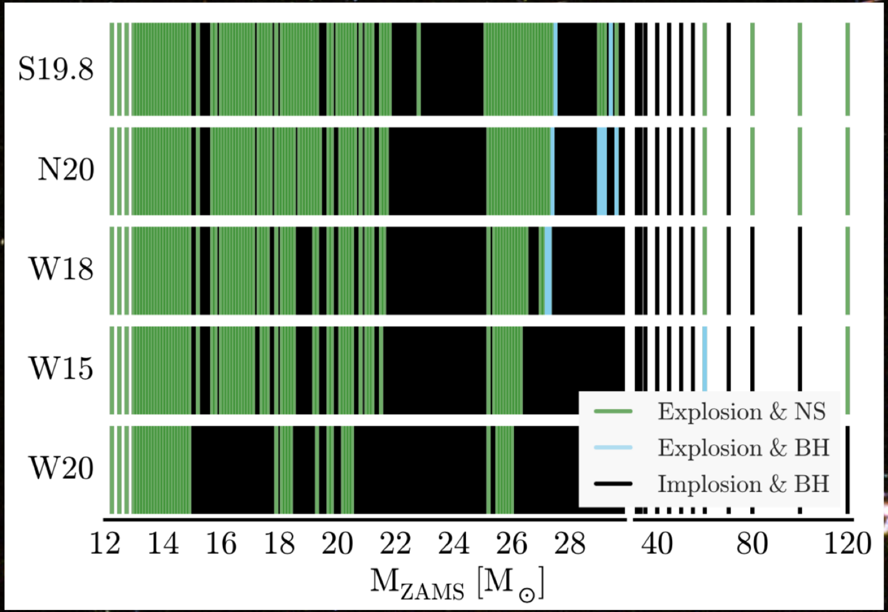
Only the first ten rows are shown in this table. The full list is available in online material.
http://th.nao.ac.jp/MEMBER/nakamura/2016multi/

Nakamura+ 2016

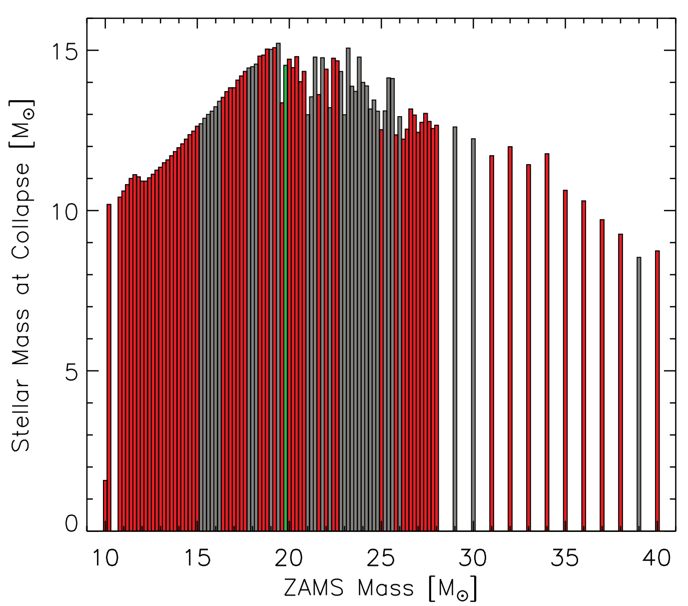
However, risk mitigation demands a strategy that combines

1) intensive monitoring of likely candidates with
2) wide and shallow monitoring to account for the unexpected

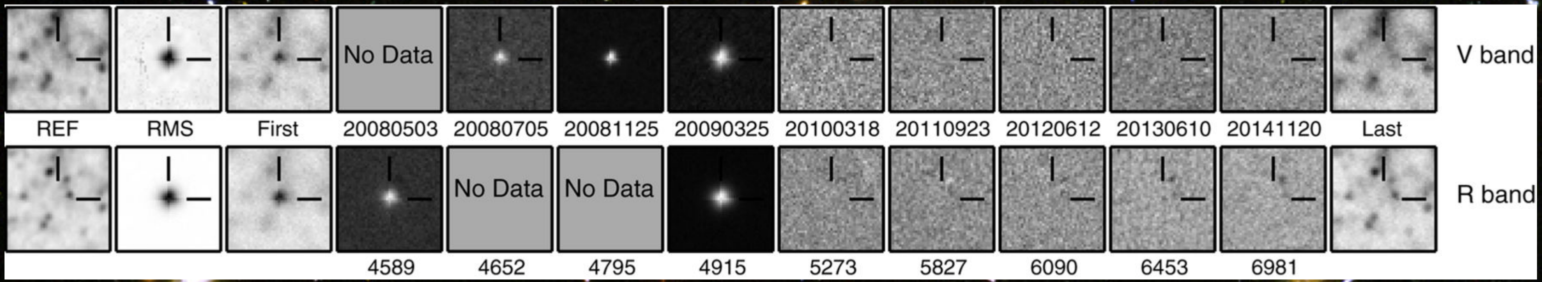
There is no specific cutoff mass between neutron star and black hole formation



Sukhbold+ (2016)

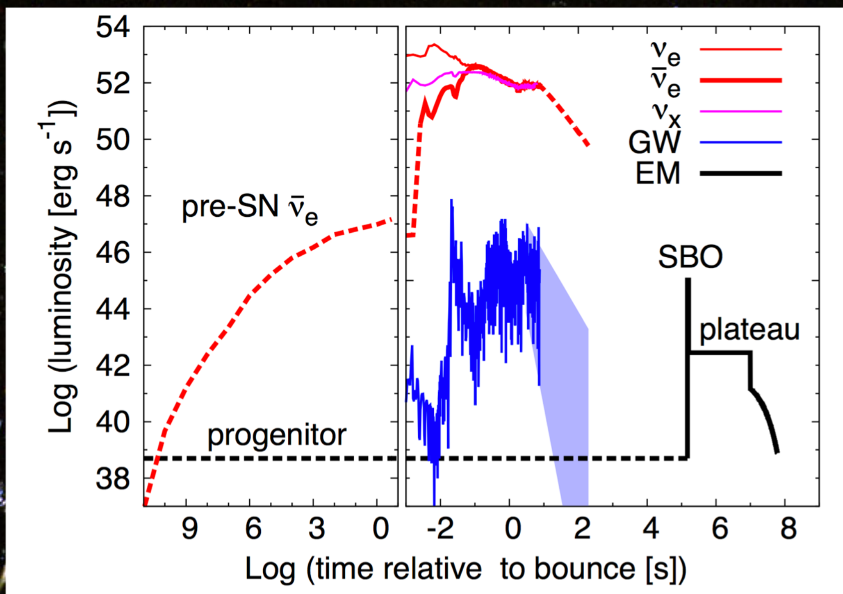


Ugliano+ (2012)



Adams+ (2016)

Observing Shock Breakout



Nakamura+ 2016

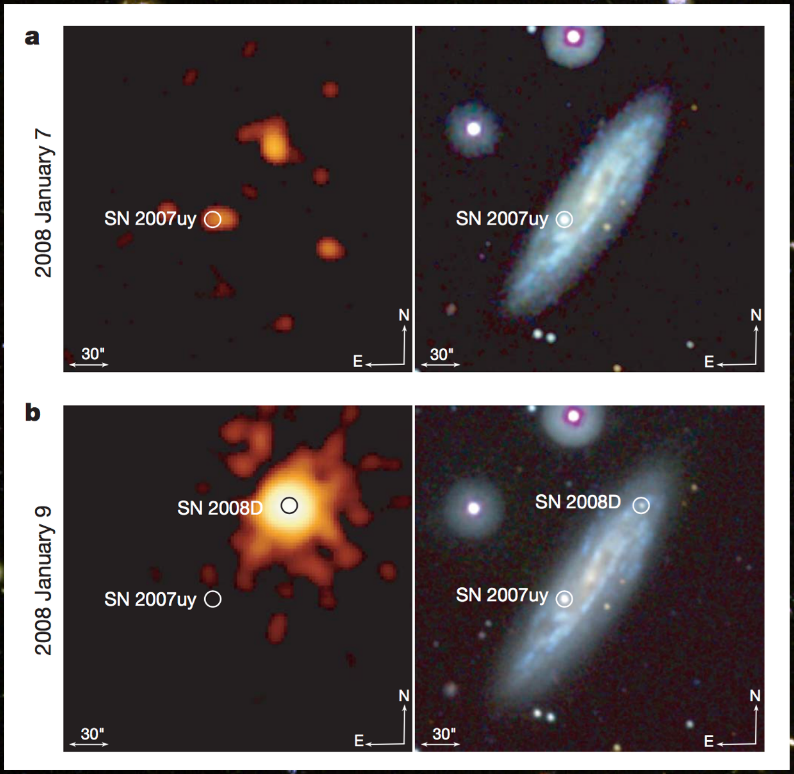
Shock breakout: Shock driving the ejection of the SN envelope, expands and reaches the edge of the star, producing a bright X-ray/UV flash on time scales of seconds to a fraction of an hour (see, e.g., Waxman & Katz 2017). This is followed by UV/optical emission from the expanding cooling envelope on a day time-scale.

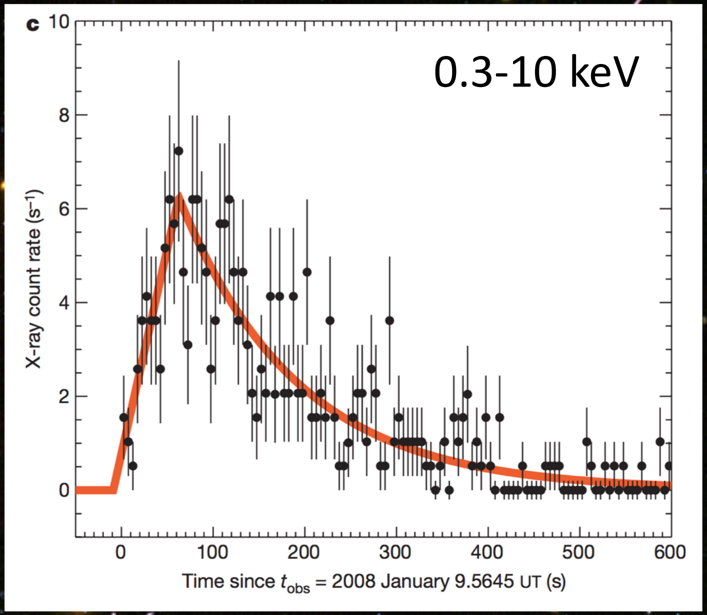
SBO can occur at larger radii within surrounding circumstellar material if significant mass loss prior to explosion (see Murase 2018).

Valuable information about the structure of the progenitor star (e.g. radius and surface composition) and of its mass-loss history is encoded in SBO.

IUE missed SBO in SN 1987A by approximately 35 hrs

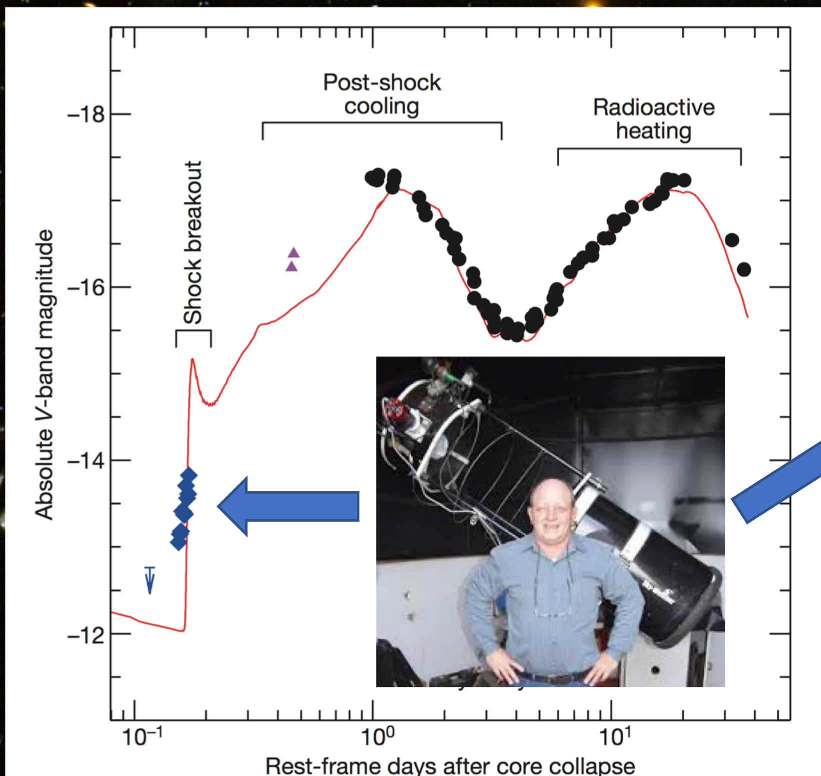
SN 2008D was observed serendipitously in X-ray as core collapse occurred and SBO was observed

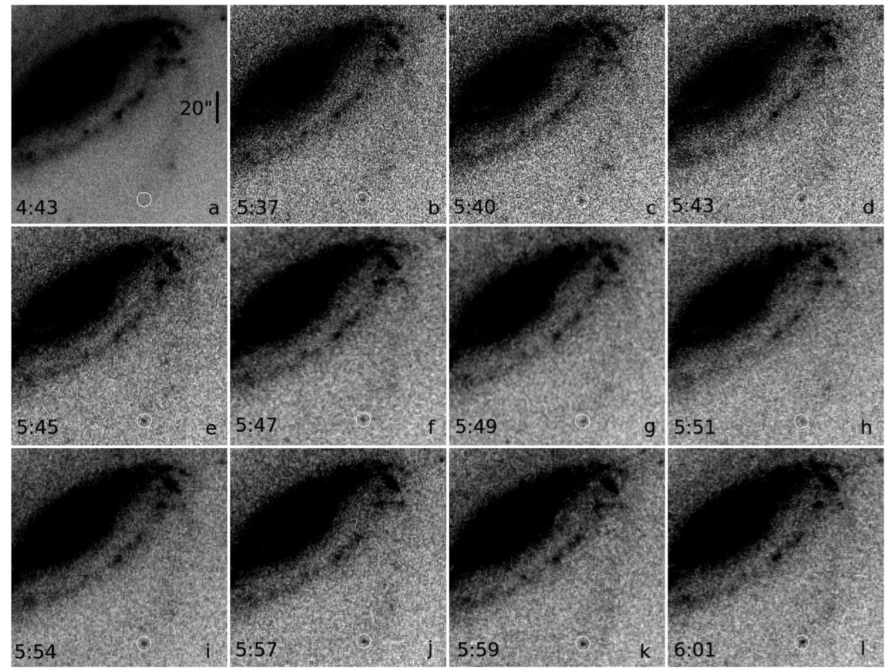




Soderberg+ (2008), but see also Mazzali+ (2008)

SN 2016gkg was observed serendipitously by amateur Victor Buso as core collapse occurred and SBO was observed

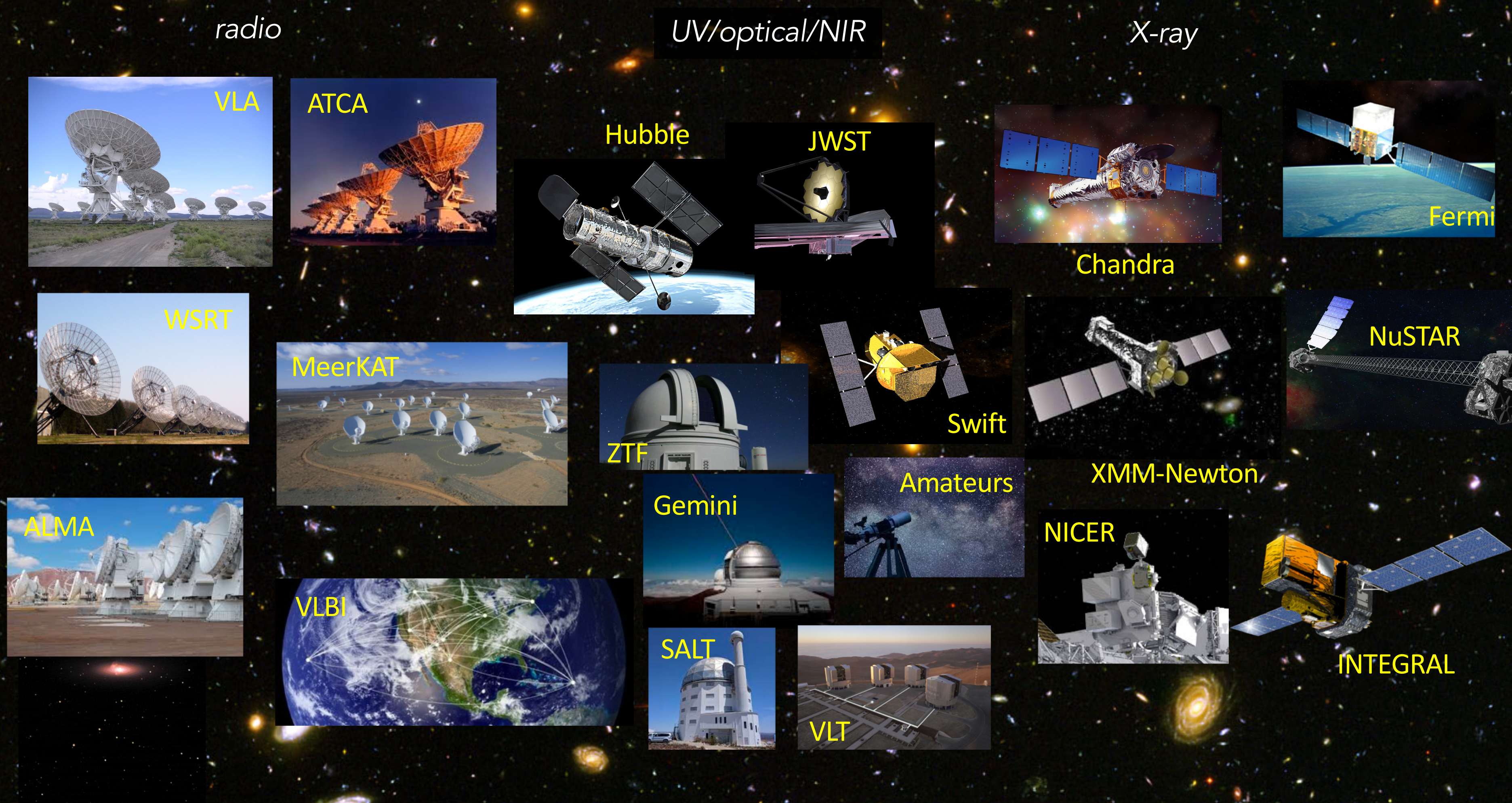




Extended Data Figure 2 | Series of discovery images of SN 2016gkg. The supernova location is indicated in all panels with a white circle. North is up and east is to the left. The bar in **a** indicates a scale of 20″. **a,** A combination of 40 exposures obtained before the detection of the supernova. **b–l,** Sequence of images obtained during the initial rise as combinations of five or six individual exposures. Labels on the lower left of each panel indicate the mean UT time of the images. Photometry from the latter set of images is shown with blue diamonds in Fig. 1. Images obtained by V.B.

Bersten+ (2018)

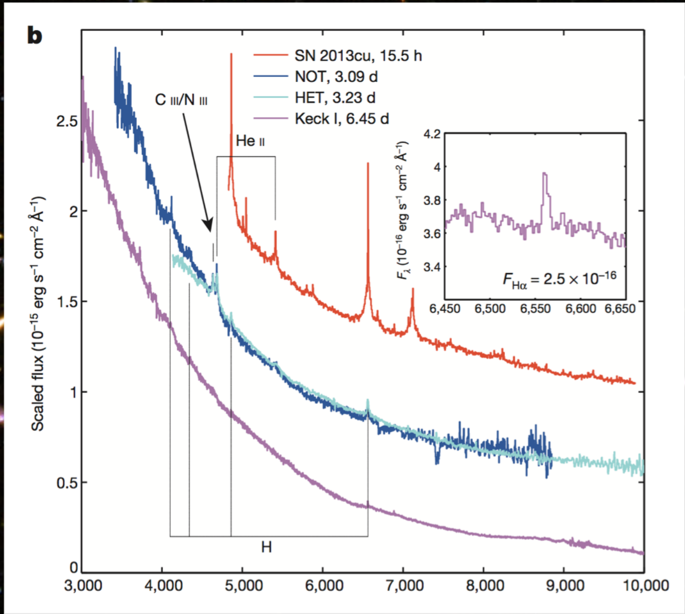
Second priority is to monitor across all electromagnetic wavelengths



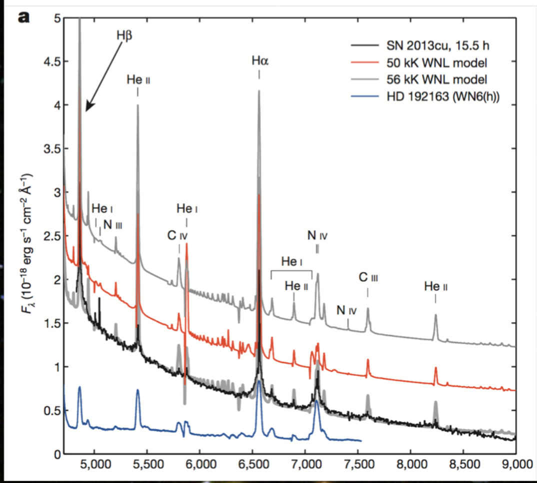
"Most likely" observing strategy for core collapse supernova

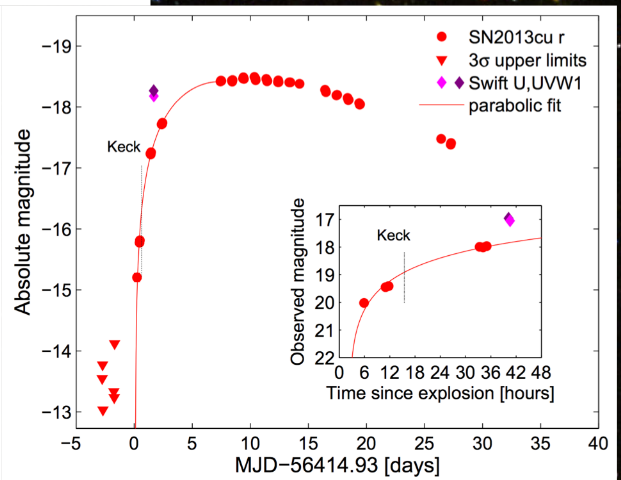
- High cadence photometry and spectroscopy of event as evolving. UV spectra is especially important but potentially challenging.
- Data will inform about the explosion and the immediate circumstellar environment of the progenitor.
- Spectropolarimetry at the highest resolution with high cadence. Early (hours) polarization data may show asphericity caused by the bipolar explosion.
- If nearby, AO observations to look for inner CSM that is illuminated by shock breakout or hit by the blast wave, or a companion star, or light echoes. An AO-fed slit spectrograph or IFU is ideal.

Probing pre-SN mass loss with “flash spectroscopy”



Extremely rapid spectroscopy (aka “flash spectroscopy”) obtained in the first hours to days after explosion shows emission lines that gradually fade. This is consistent with enhanced mass loss in SN progenitor systems that is overrun by the SN blast wave out to approximately 10^{15} cm.

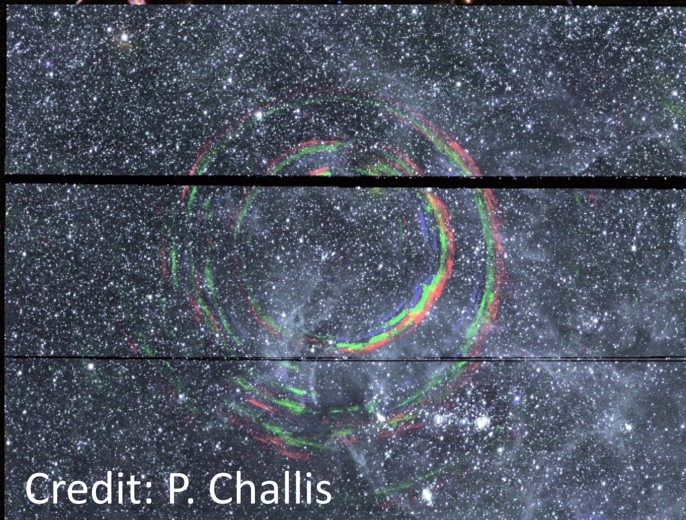




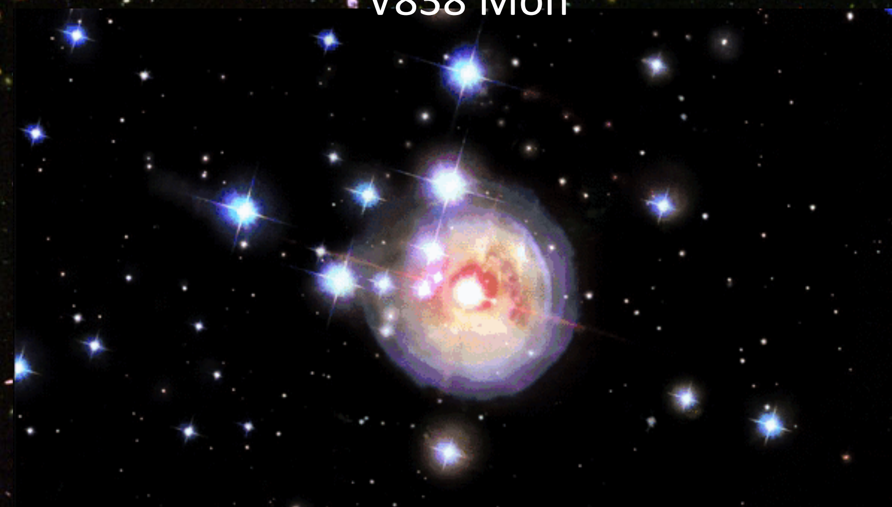
See also Groh (2014)
Terreran et al. (2017),
Yaron et al. (2017)

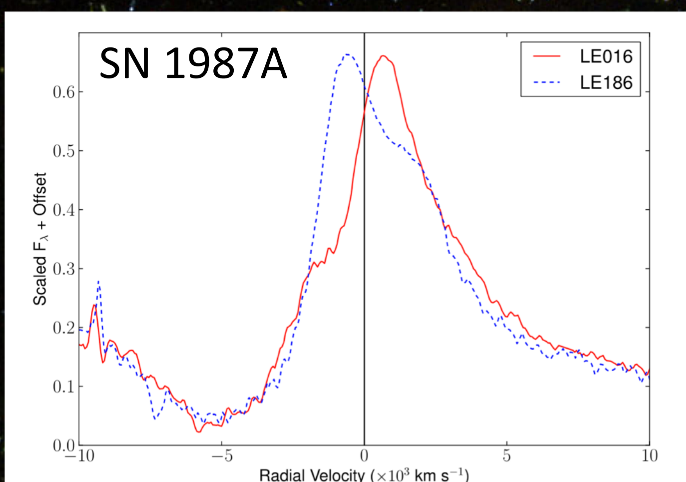
Gal-Yam et al. (2014)

Light echo spectroscopy can provide 3D information

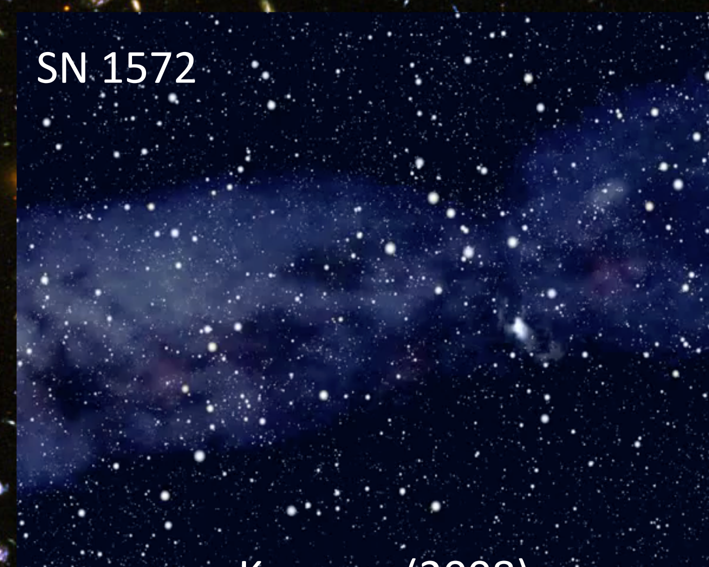


V838 Mon



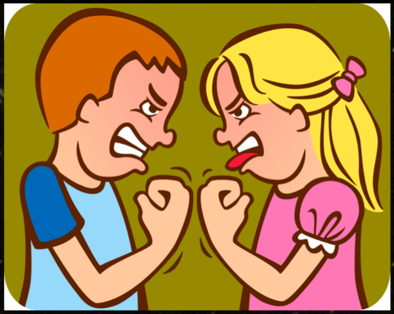


Sinnott+ (2013)



How to coordinate?

- Infrastructure exists to coordinate observations: Target and Observation Manager (Street+ 2018), GROWTH marshall (PI: Kasliwal), REFITT (Sravan+ 2020)
- At the very least participants can communicate planned and obtained observations (ATel, GCN) to limit duplication of effort leading to lost science opportunities
- Real challenge is to overcome competition for credit
- Goal is to have community alliance with agreed upon goals and shared data practices. Can be between individuals / groups / facilities.



"Recruiting from the human race"

Conclusions

We will use ALL information to conduct an intelligent search and patrol likely candidates

Observations of progenitor star *before* and *during* SBO is of high priority.

Widespread coordination motivated by shared community goals will vastly improve scientific return of this once-in-a-lifetime opportunity.

Thank You!