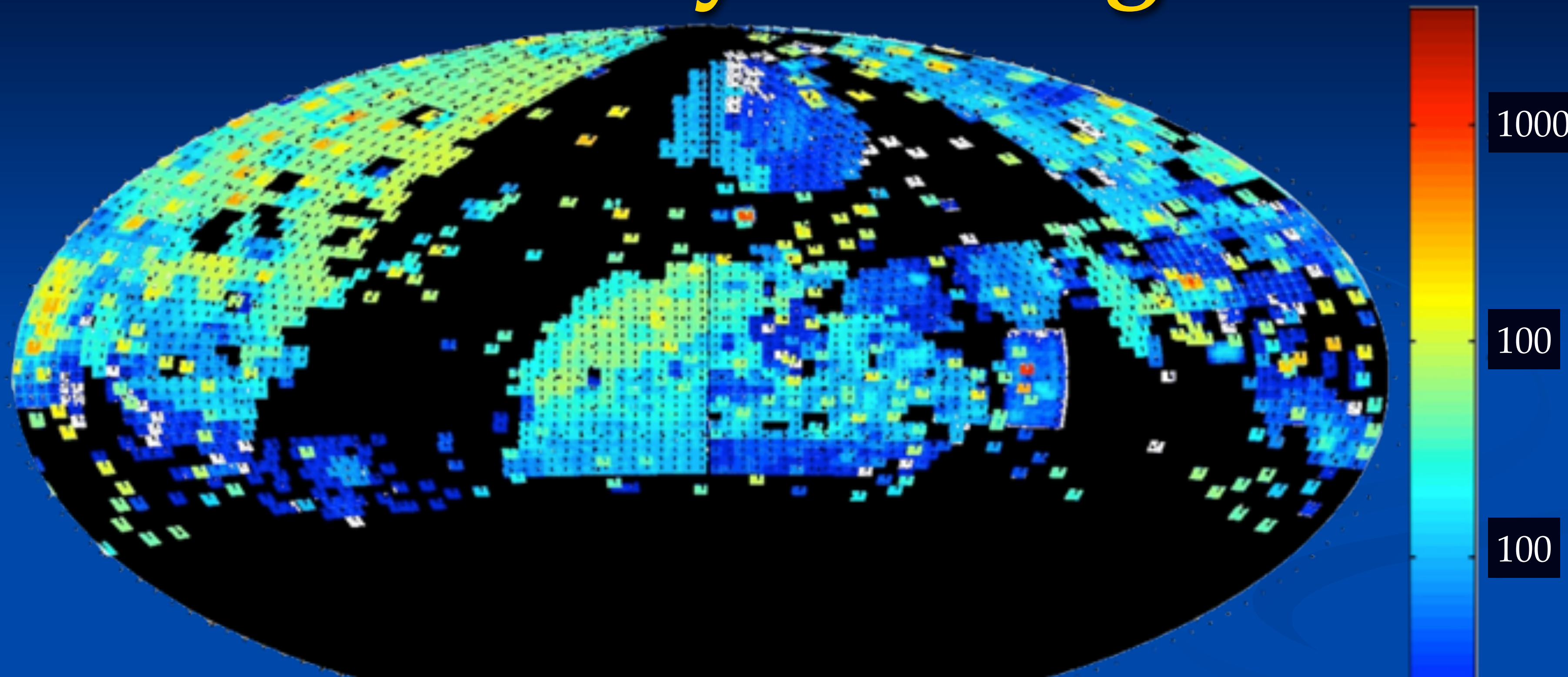
SN2011fe in M101 (Pinwheel Galaxy)

Peter Nugent (LBNL/UCB)

PTF Sky Coverage

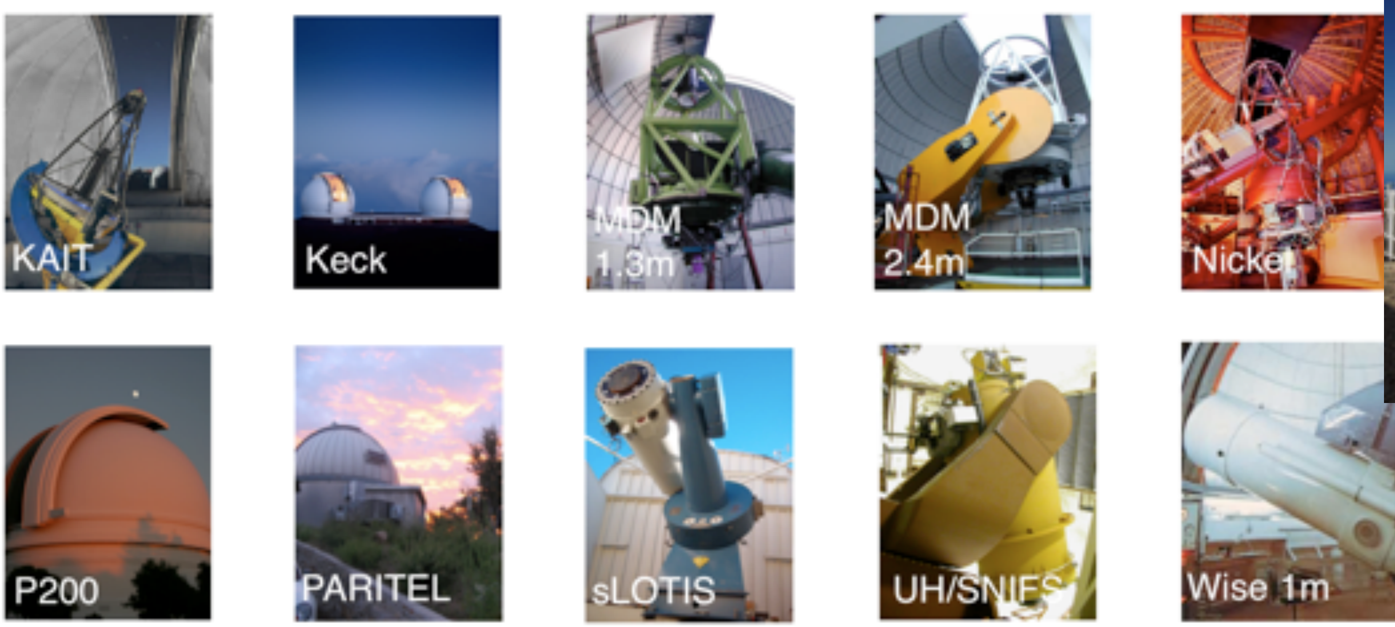


To date:

- 1500 Spectroscopically typed supernovae
- 10^5 Galactic Transients
- 10^4 Transients in M31

PTF Science

▼▶ Detected transients will be followed up using a wide variety of optical and IR, photometric and spectroscopic followup facilities.



Liverpool Telescope

The power of PTF resides in its diverse science goals and follow-up.

PTF Database

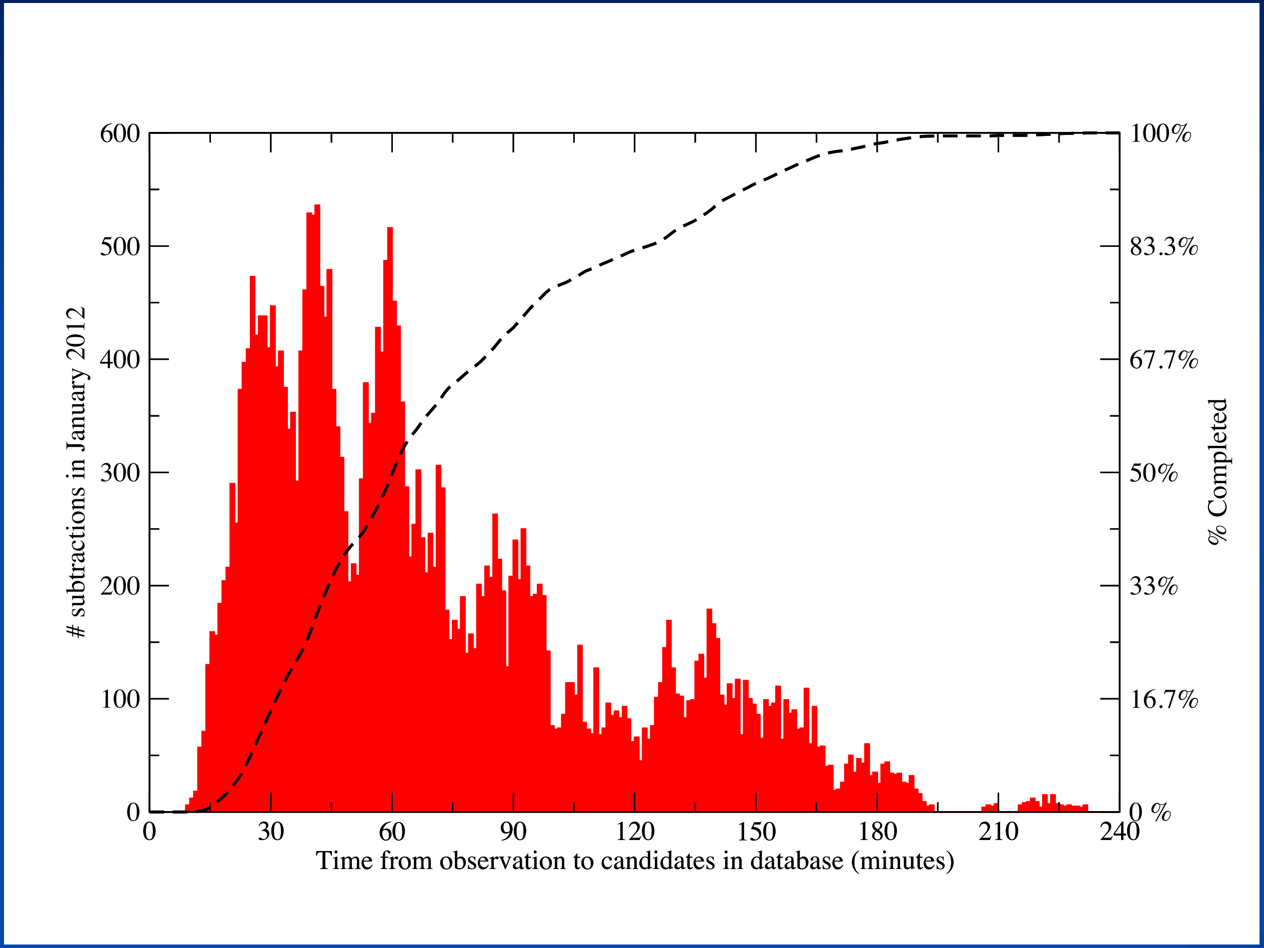
	R-band	g-band
images	1.37M	305k
subtractions	1.05M	146k
references	21.8k	6.3k
Candidates	684M	95M
Transients	39975	

All in 738 open nights (to Feb. 2, 2012).

An image is an individual chip (~0.7 sq. deg.)

The database is now 300GB.

Turn-around



What does "real-time" subtractions really mean?

Typically put half the candidates into the db in < 1hr and the other half in < 2hrs from the time the image was taken.

The majority of this lag is contention within the db (loading images, subs, cands, queries, checking new cands vs. old PTF names, etc.). It gets worse about half way through the night, and things slow down….

A New db will start next full moon.

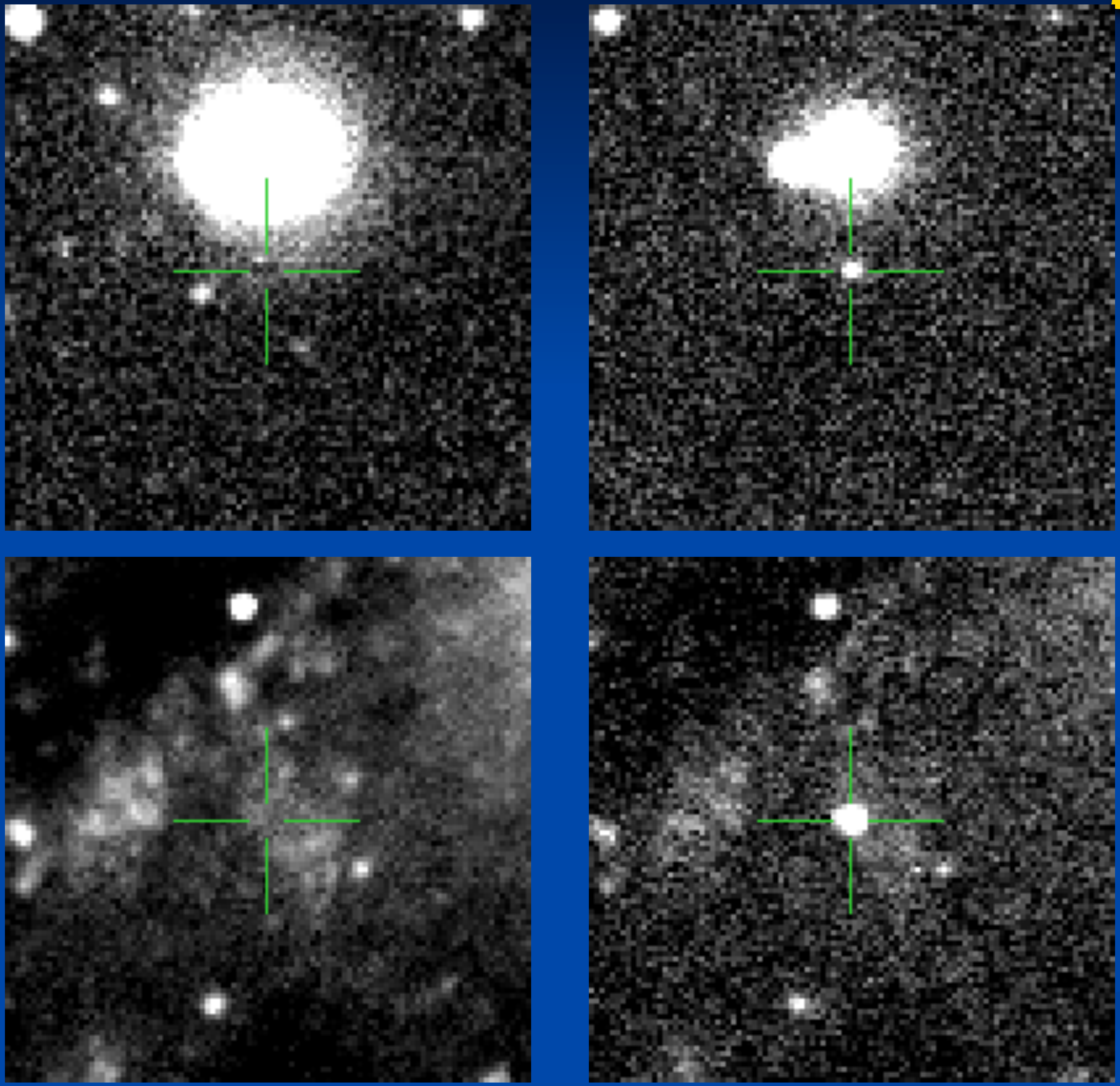
August 24, 2011

g-band run:

• ~500 sq. deg. hit twice during the night subtractions - rest went to new references
• 50-50 split between Dynamic and SN cadence
• 10 new transients found that night

• Pipeline was slow, running 6 hrs behind normal due to catching up from a kernel “update” on the NERSC machines.
• An IP address at Caltech had just been changed, thus we could only save things by hand….

Discovery



11klx - JSB @ UT 19:48

- response “I see your $20 and raise you $100”

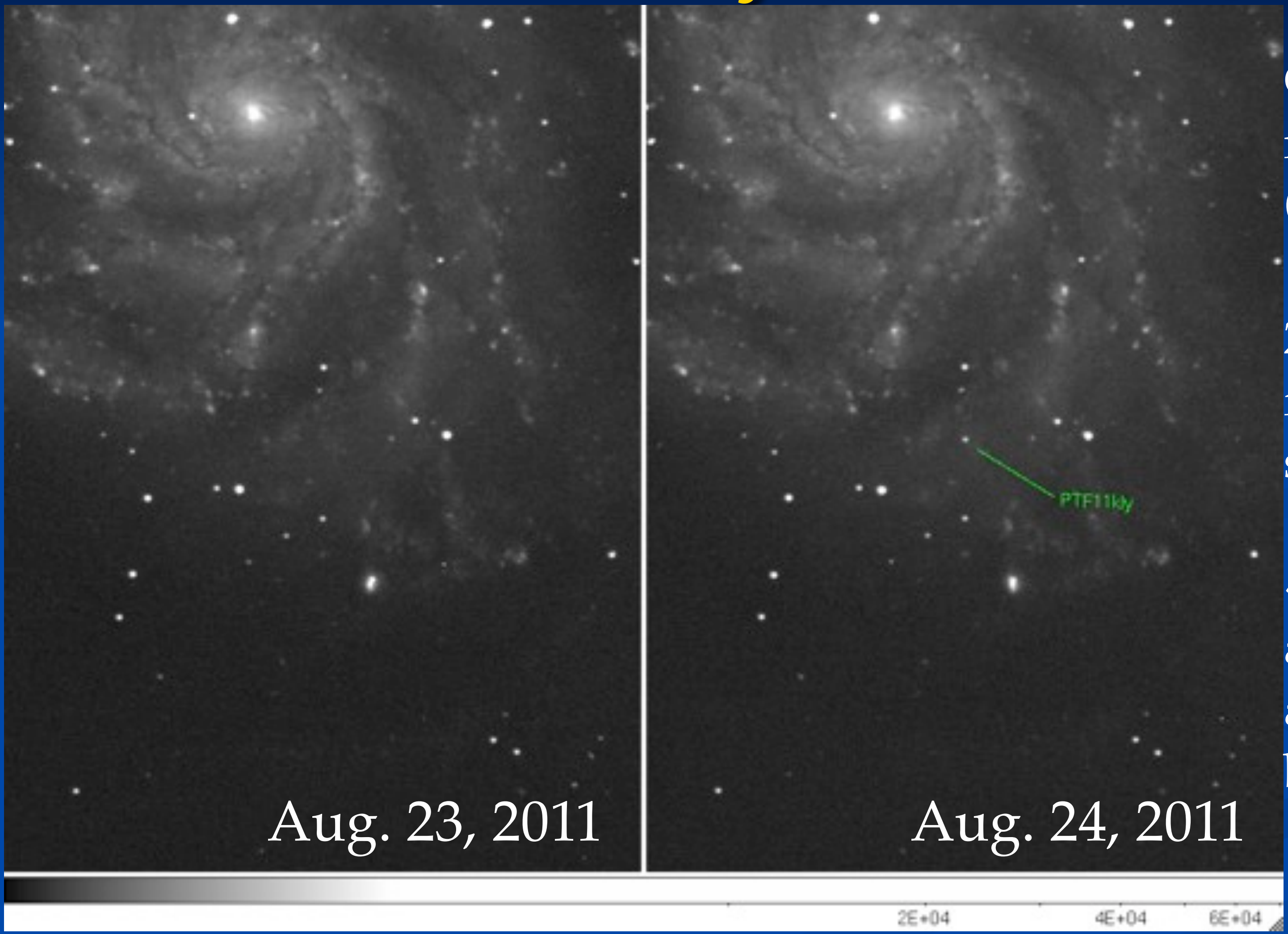
11kly - PEN @ UT 19:50

“Hi all,

M101 has given birth to 11kly

Check it out, alert the troops!!!”

PTF11kly (SN 2011fe)



Caught at magnitude ~17.4 (M_g = -11.7)

20% rise between first 2 detections separated by 1hr

~1/1000 as bright as the SN reached at peak brightness.

Discovery

20:04 Mark: reckon it's real?

20:05 me: it is
2 detections, not an asteroid but 1% chance it is a SN Ia

Mark: we can trigger LT or GTC
me: please do, it sets early

20:10 Mark: it's in the LT queue now. We shall see.
me: cool
Mark: LT trying it right now, gotta love robotic schedulers

21:05 PM Mark: I can see it in the acquisition images so it's definitely still there, now to see if I can get a sky-subtracted spectrum………

After this CARMA, EVLA, HST and Swift were triggered by PTF

Horesh *et al*. (ApJ 2012), Li *et al*. (Nature 2011)

SciDAC
Scientific Discovery through Advanced Computing

Discovery

Young Type Ia Supernova PTF11kly in M101

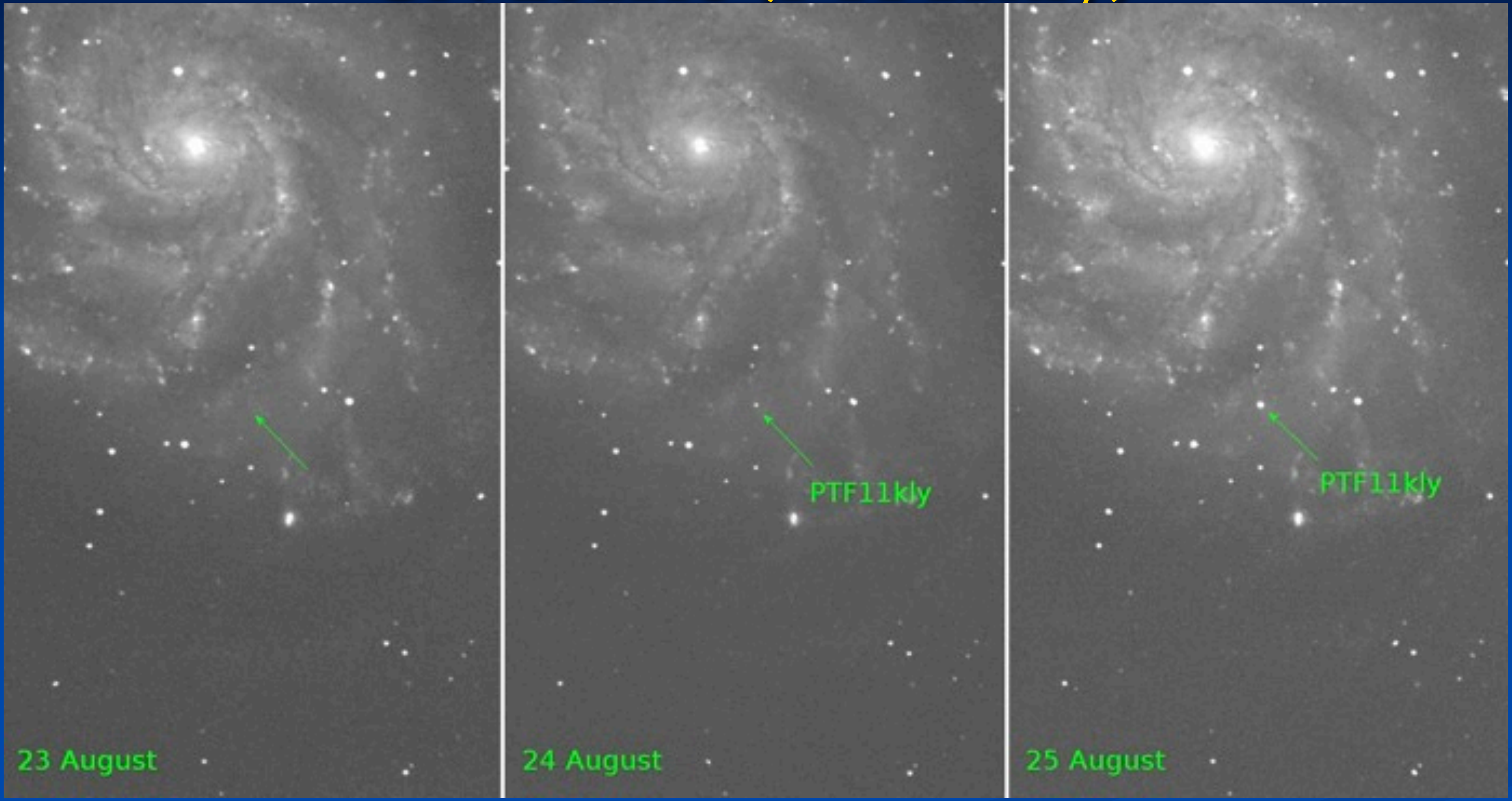
ATel #3581; *Peter Nugent (LBL/UCB), Mark Sullivan (Oxford), David Bersier (Liverpool John Moores), D.A. Howell (LCOGT/UCSB), Rollin Thomas (LBL), Phil James (Liverpool John Moores)*
on ***24 Aug 2011; 23:47 UT***
Distributed as an Instant Email Notice Supernovae
Credential Certification: R. C. Thomas (rcthomas@lbl.gov)

Subjects: Optical, Supernovae

Referred to by ATel #: 3582, 3583, 3584, 3588, 3589, 3590, 3592, 3594, 3597, 3598, 3602, 3605, 3607, 3620, 3623, 3642

The Type Ia supernova science working group of the Palomar Transient Factory (ATEL #1964) reports the discovery of the Type Ia supernova PTF11kly at RA=14:03:05.81, Dec=+54:16:25.4 (J2000) in the host galaxy M101. The supernova was discovered on Aug. 24 UT when it was at magnitude 17.2 in g-band (calibrated with respect to the USNO catalog). There was nothing at this location on Aug 23 UT to a limiting magnitude of 20.6. A preliminary spectrum obtained Aug 24 UT with FRODOSPEC on the Liverpool Telescope indicates that PTF11kly is probably a very young Type Ia supernova: Broad absorption lines (particularly Ca II IR triplet) are visible. The presence of an H-alpha feature is confidently rejected. STIS/UV spectroscopic observations on the Hubble Space Telescope are being triggered by the ToO program "Towards a Physical Understanding of the Diversity of Type Ia Supernovae" (PI: R. Ellis). Given that the supernova should brighten by 6 magnitudes, the strong age constraint, and the fact that the supernova will soon be behind the sun, we strongly encourage additional follow-up of this source at all wavelengths.

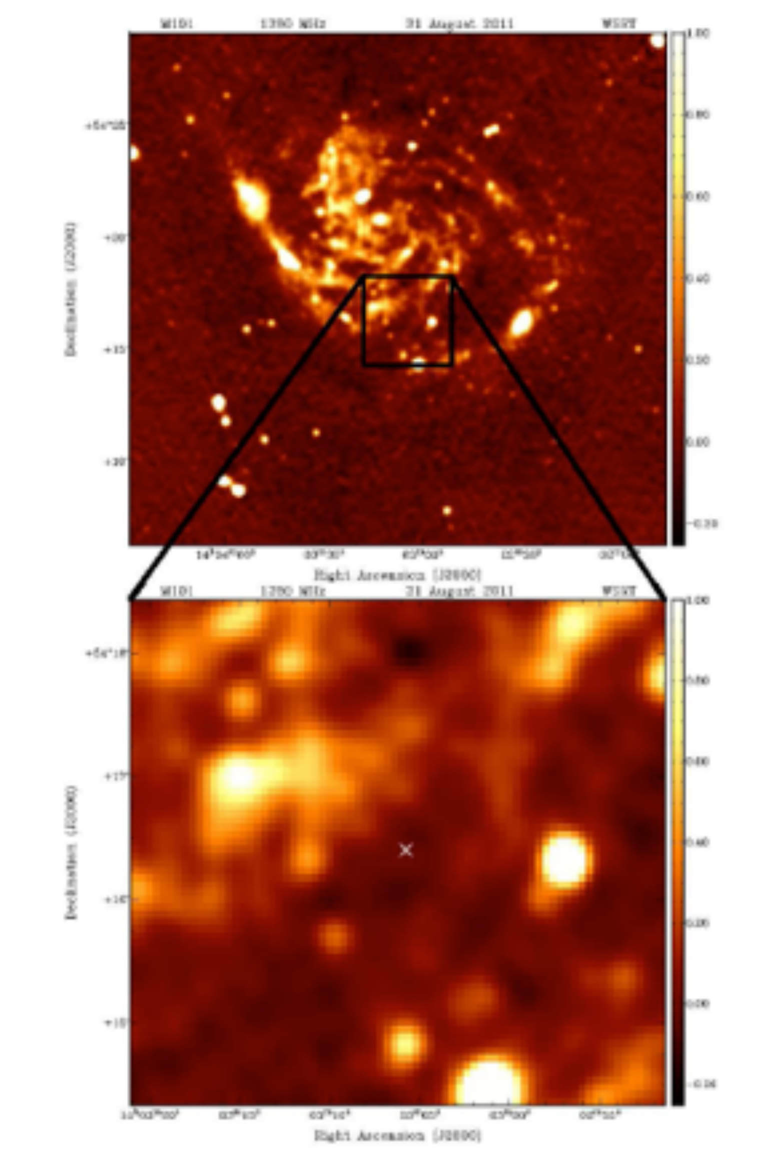
SN 2011fe (PTF11kly)



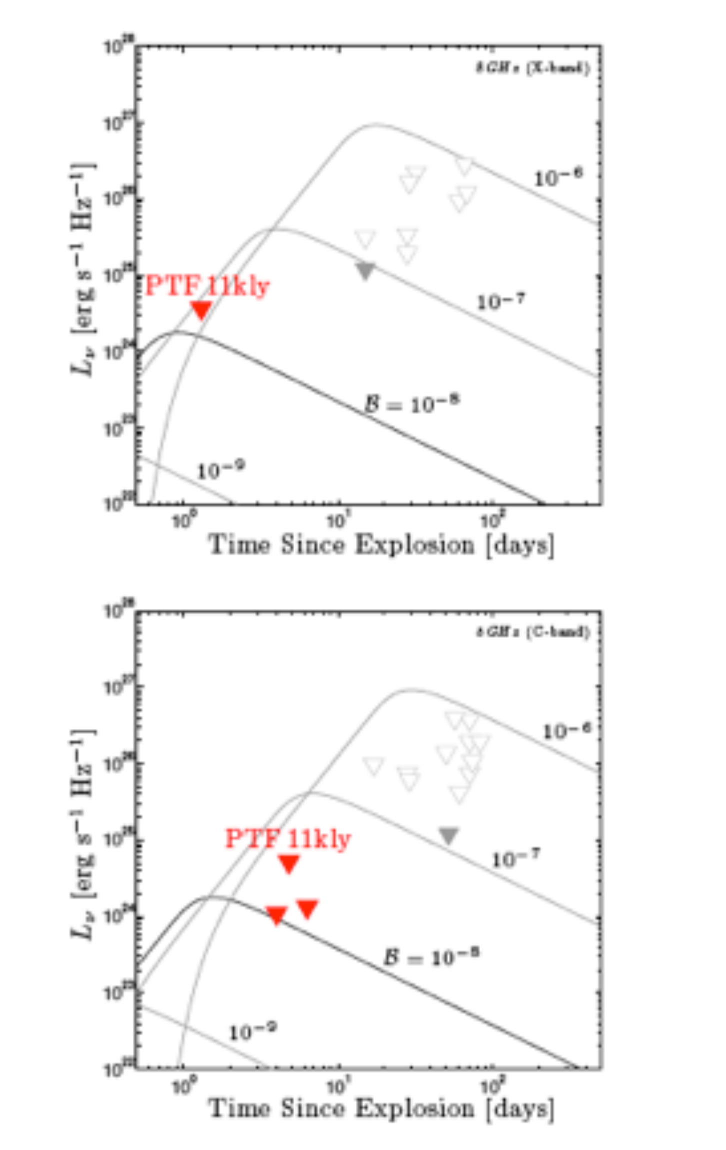
Aug 23: g < 21.5, Aug 24: g=17.4

Rose 20% in 1 hr. factor of 10 in first day.

Radio



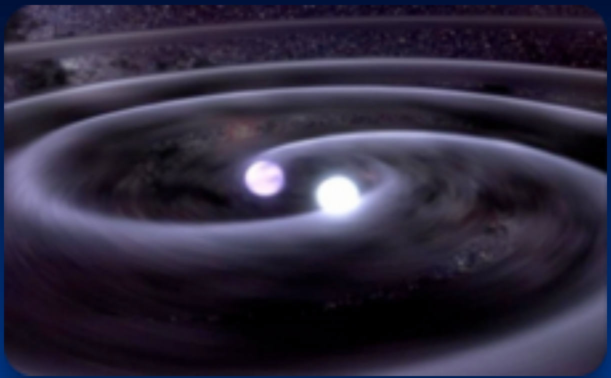
Horesh *et al.* (2011) present the earliest and most sensitive x-ray and radio data to date. Can not rule out MS or sub-giant SD donors.



Progenitors

Consensus: Thermonuclear explosion of accreting Carbon/Oxygen white dwarf (WD), nearing Chandrasekhar mass

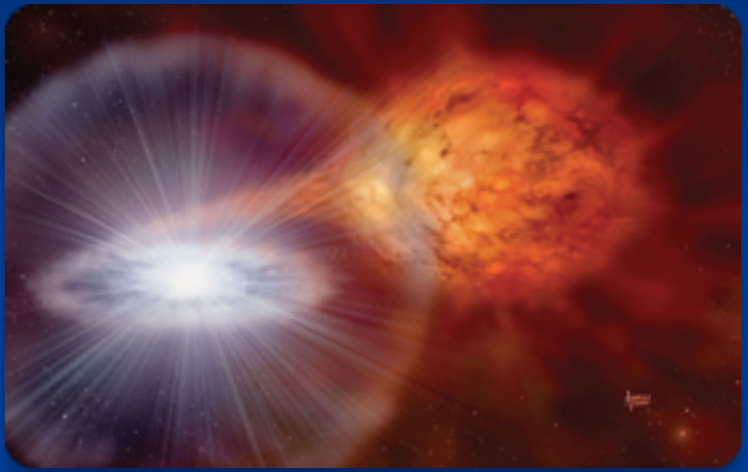
But… ***progenitor system(s)*** unknown



Double-degenerate channel (DD)

WD-WD ($M_{total} > 1.4\ M_\odot$) merger
(GW inspiral)

Iben & Tutukov 84; Webbink 84



Single-degenerate models

Accretion from non-degenerate star

Whelan, J. & Iben 73; Nomoto 82; Munari, U. & Renzini, A. 92

<u>supersoft channel</u> U Sco

MS or early RG donor
[$M \gtrsim 1.8\ M_\odot$, $P_{orbital} \lesssim$ day]

e.g., van den Heuvel+92, Han & Podsiadlowski 04

<u>Helium Star channel</u>

Liu+10 V445Pup

<u>Red Giant channel</u>

RLOF/Symbiotic wind accretion
[$P_{orbital} \sim 100$ day] RS Oph
T CrB

e.g., Nomoto, Umeda, ...; Han+95

Constraining SNe Progenitors

Most direct:
- detection preëxplosion (e.g., HST, Chandra imaging) + disappearance post-explosion
- outburst (e.g., novae) in historical time series

Core-collapse SNe:

93 within 28 Mpc/32 HST preëxplosion

3-4 slamdunk cases of red giant progenitor of IIP ($M_V \sim -4.5$; $M_I \sim -6.5$)

cf. Smartt 2009; Maund+05 de la Rosa & Van Dyk,, Li+06,Mattila+08....

SN Ia:

37 within 28 Mpc ... ~dozen HST preëxplosion

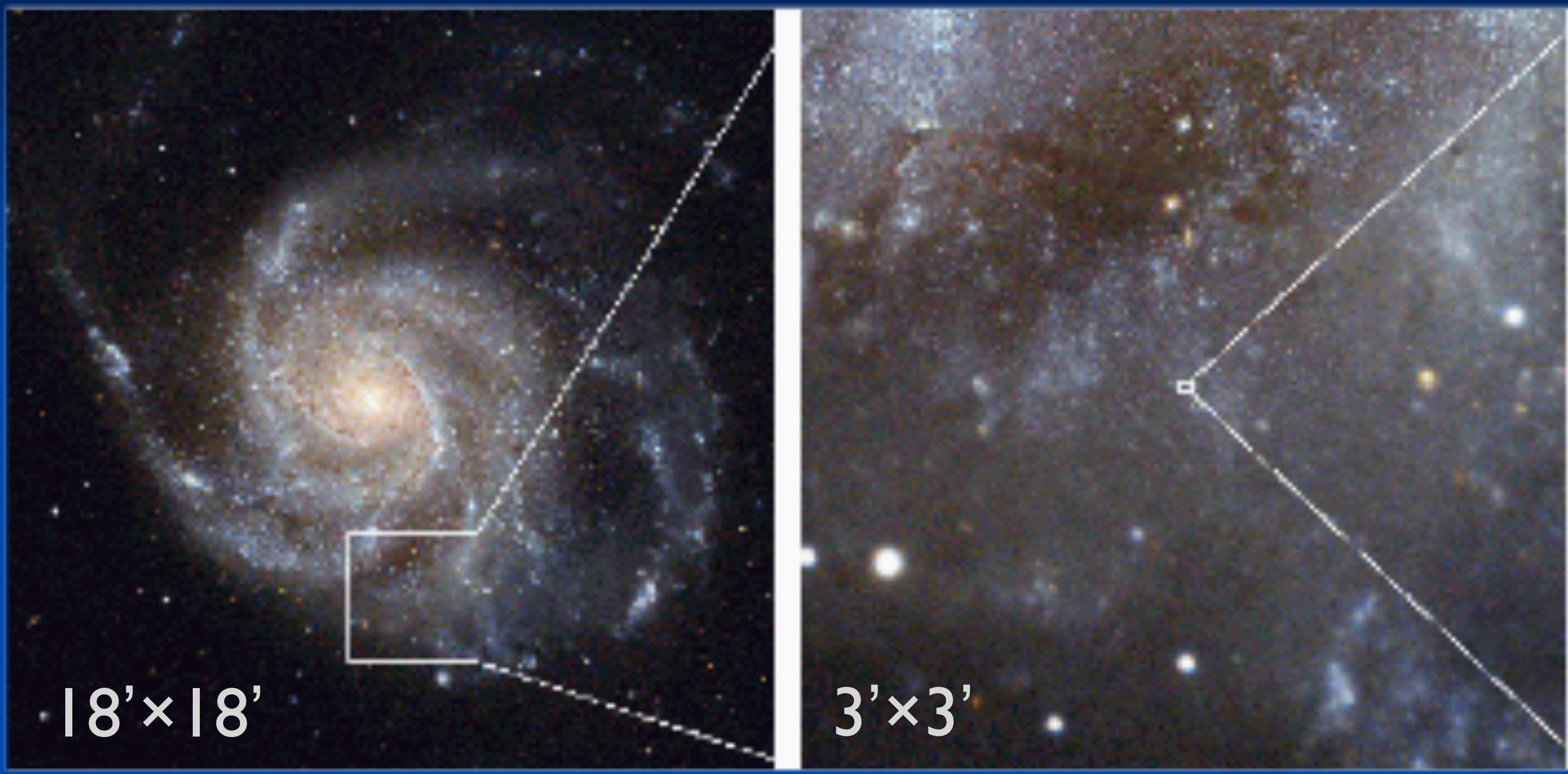
Smartt 2009

Constraining SNe Progenitors

Typical Ia progenitor system limits:
$M_I > -5$, $M_V > -6$

Smartt, Gibson 10
Maoz & Mannuci 08
Nelemans+08
Voss & Nelemans 08

PTF11kly/SN2011fe



DM=29.04 ± 0.23

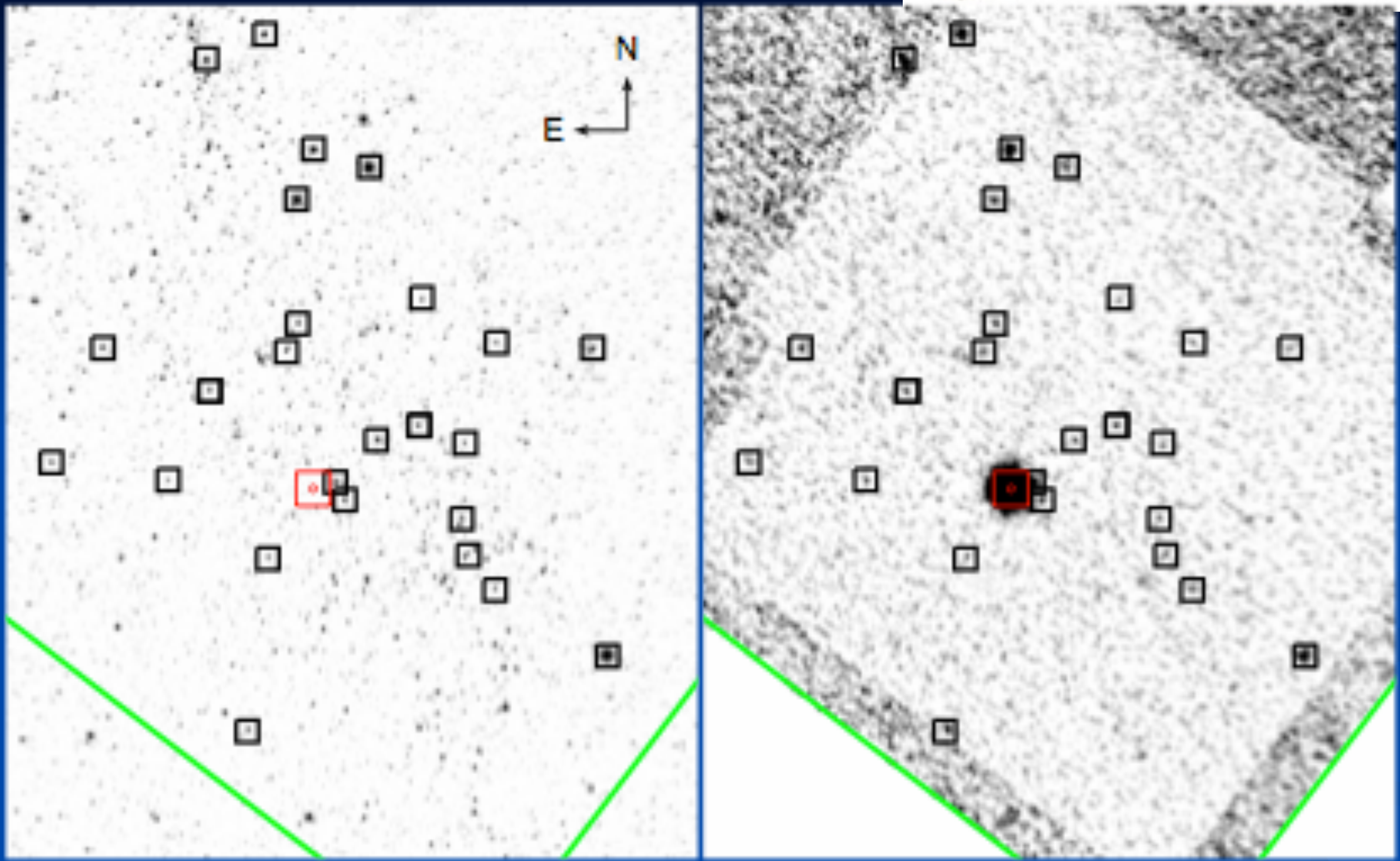
Shrappe,Stanek 11

Li+2011

DM=29.04 ± 0.23

Shrappe,Stanek 11

HST Pre-imaging of the field where SN 2011fe was found.
Li *et al*. (2011)



HST/ACS/F814W (~I band)

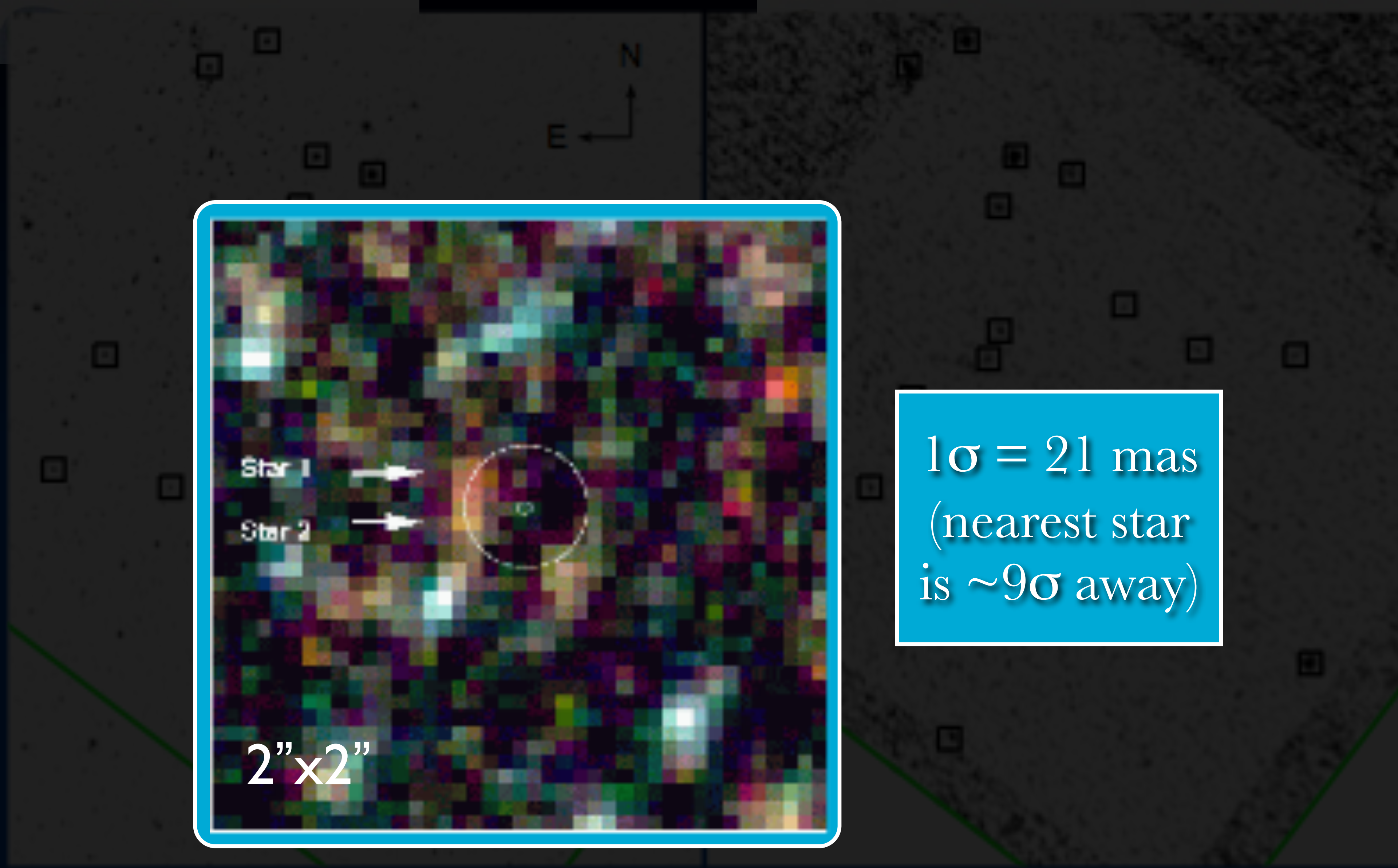
Nov 11, 2002

Keck/NIRC2/H-band

Aug 26, 2011 (t_0+3day)

Keck/NIRC2/H-band

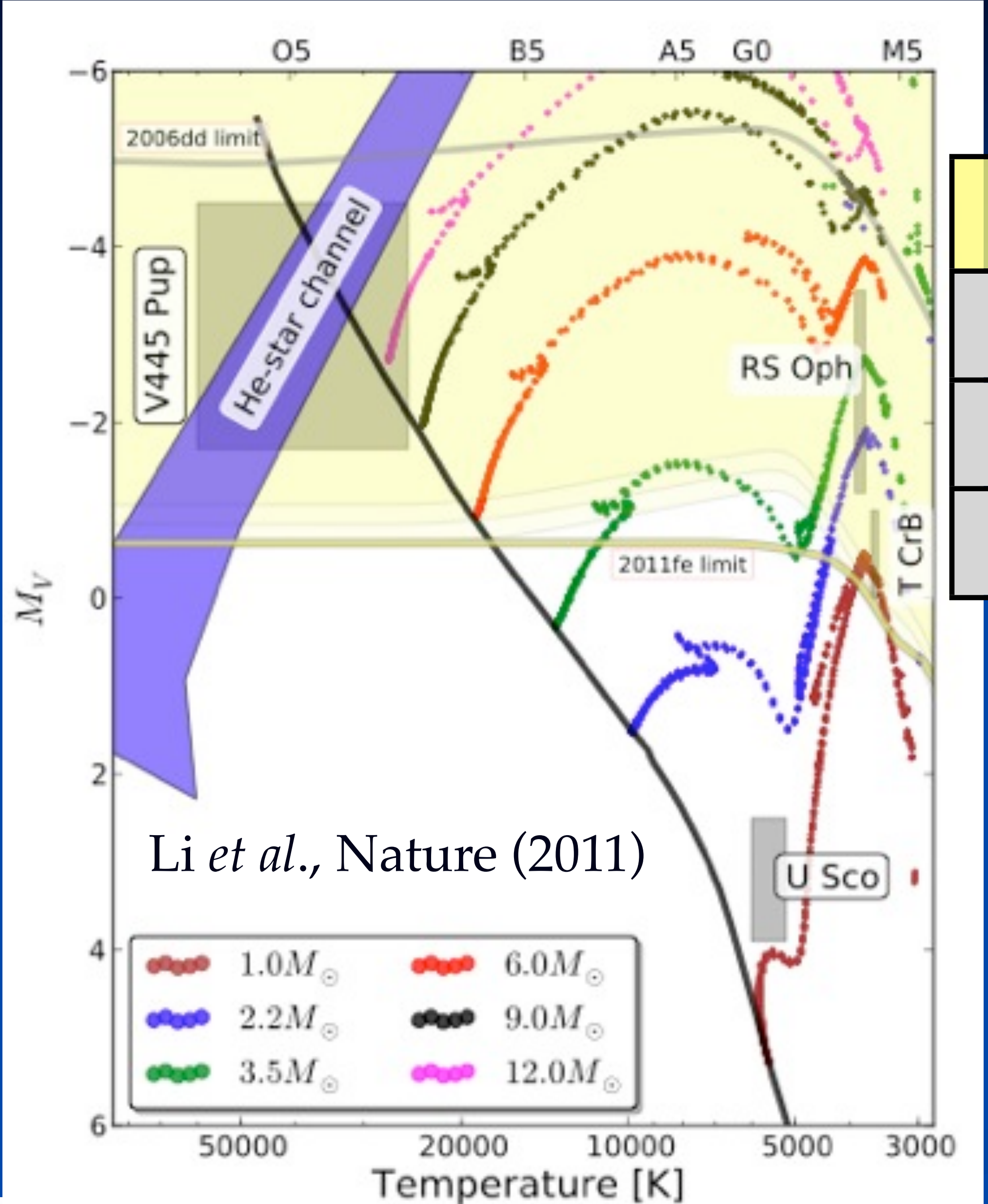
Aug 26, 2011 (t_0+3day)



$1\sigma = 21$ mas (nearest star is ~9σ away)

HST/ACS/F814W (~I band)
Nov 11, 2002

Keck/NIRC2/H-band
Aug 26, 2011 (t_0+3



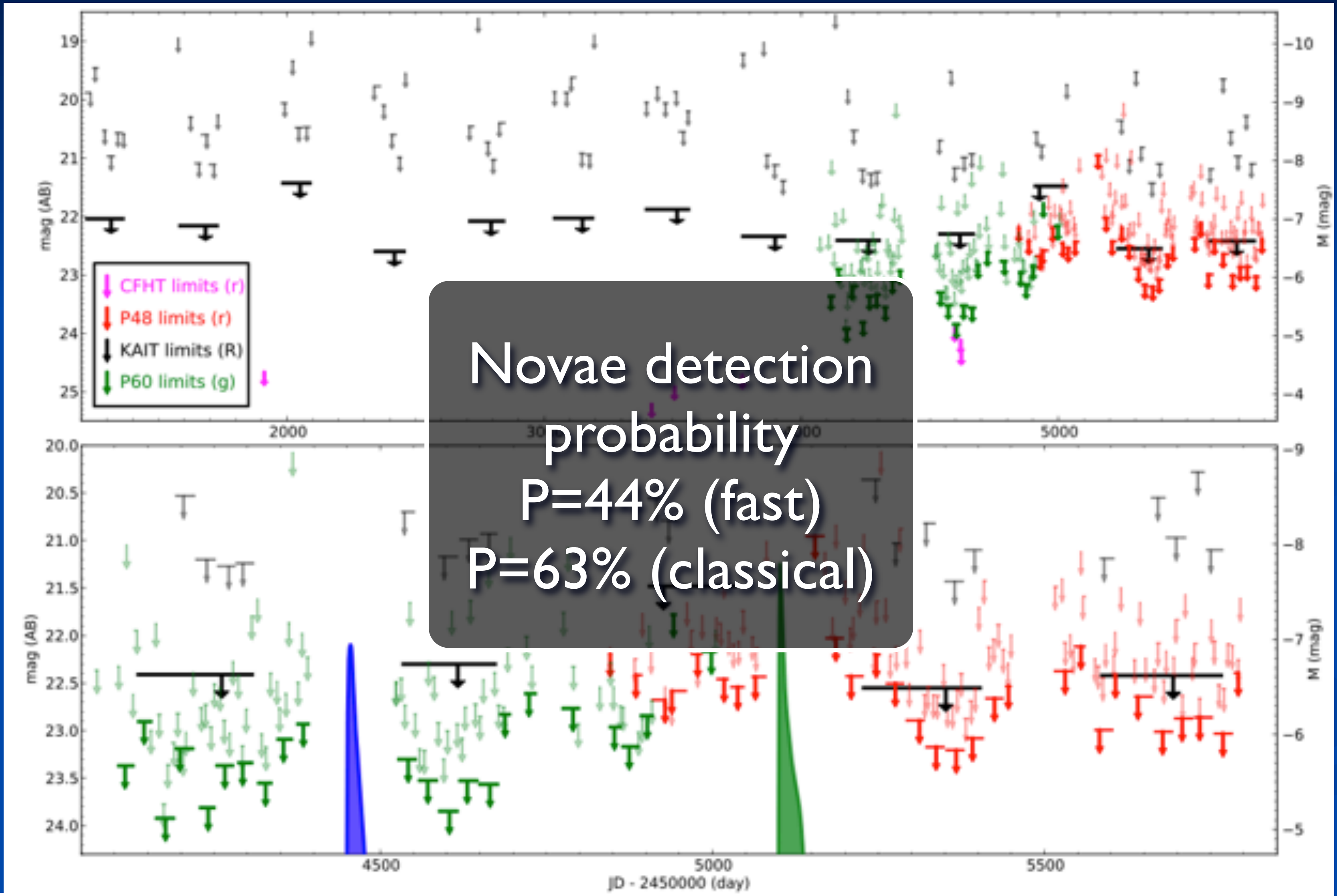
Li *et al.*, Nature (2011)

T_{eff}	M_V	Reff
3010	> 0.59 m	240 $R_\odot$
3490	> 0.24 m	63 $R_\odot$
4050	> -0.22 m	32 $R_\odot$

Constraints on the progenitor system.

Basically all we can have are a double degenerate system or a low mass main sequence companion.

12 years preceding SN2011fe … nothing



Novae detection probability
P=44% (fast)
P=63% (classical)

PTF11kly/SN2011fe pre-imaging

No indication of prior nova activity

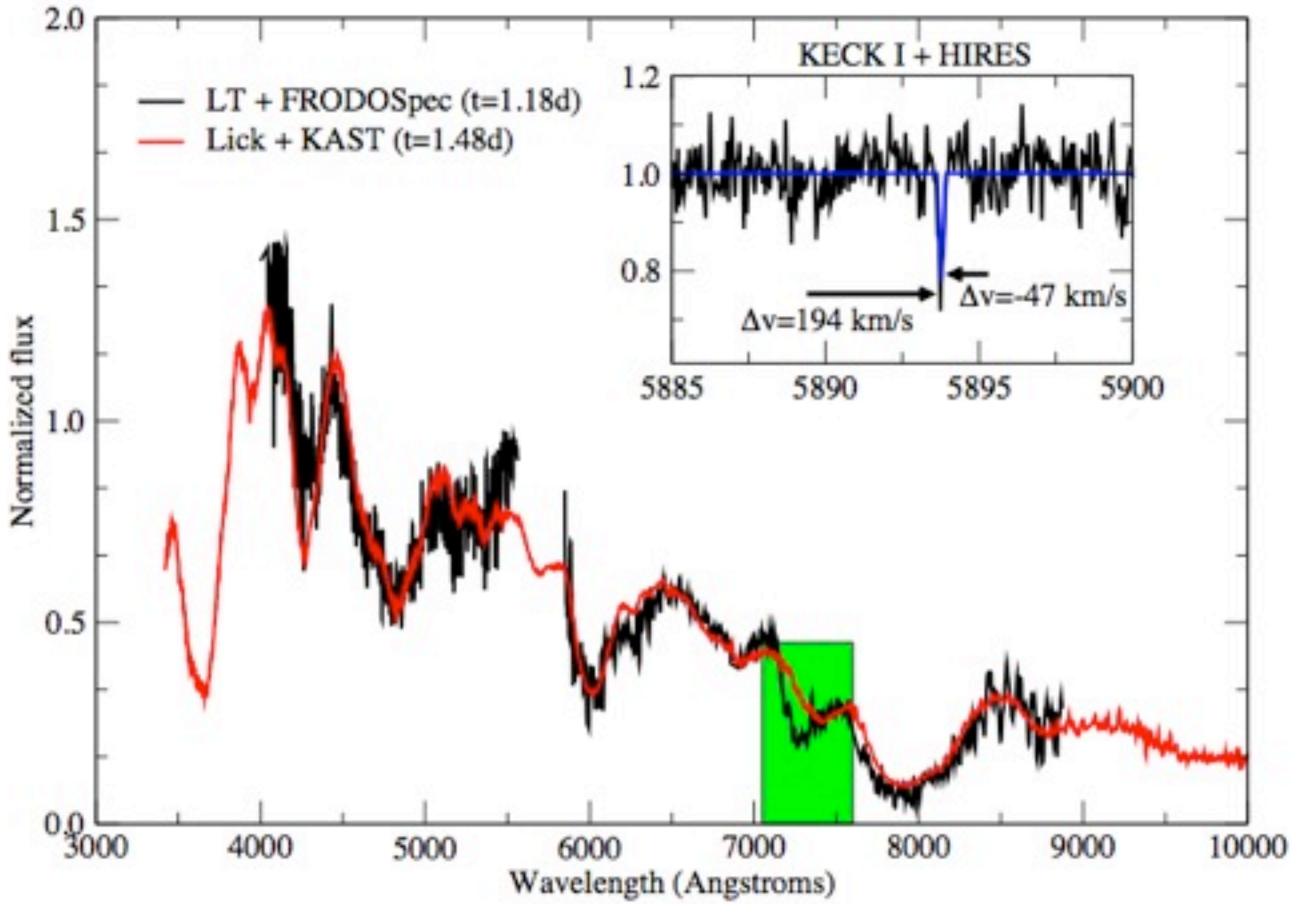
HST non-detection:

- M_V > 0.6 to -0.3 (red to blue)
- 100x deeper than previous limits on progenitor system

Single-degenerate, evolved redgiant progenitor system excluded

(RLOF from a subgiant or MS star allowed)

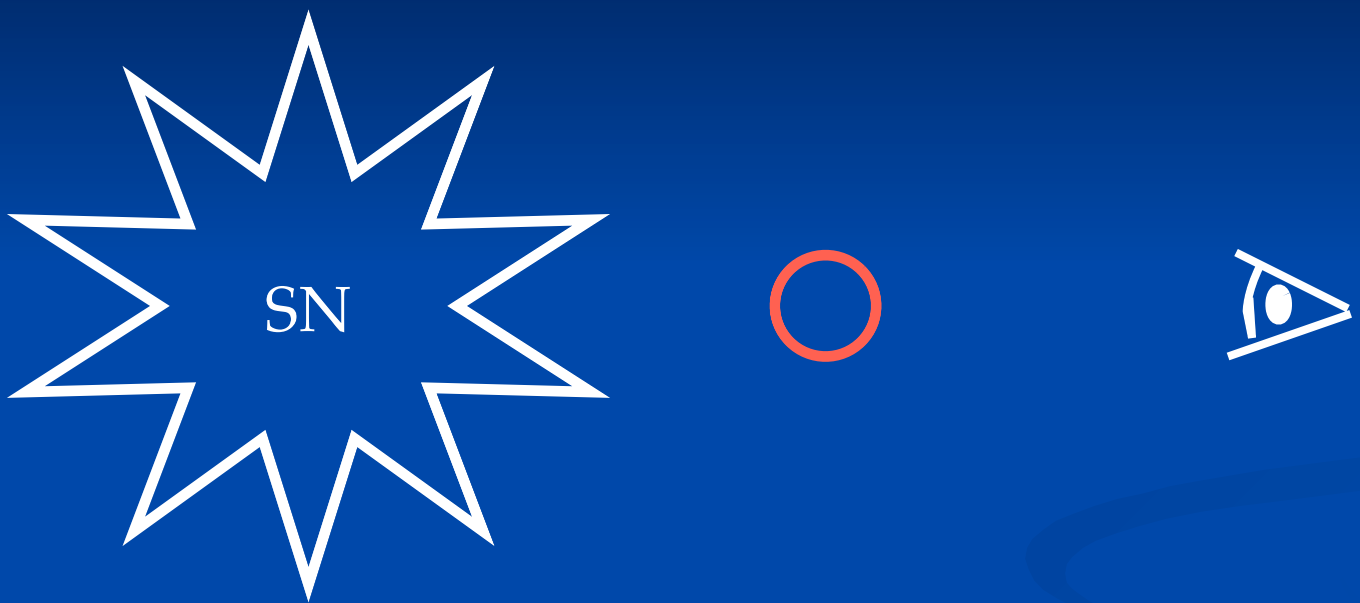
Nugent *et al.*, Nature (2011)



LT, Lick & Keck HIRES spectra.

Very little dust along the line of sight.

OI line evolution.



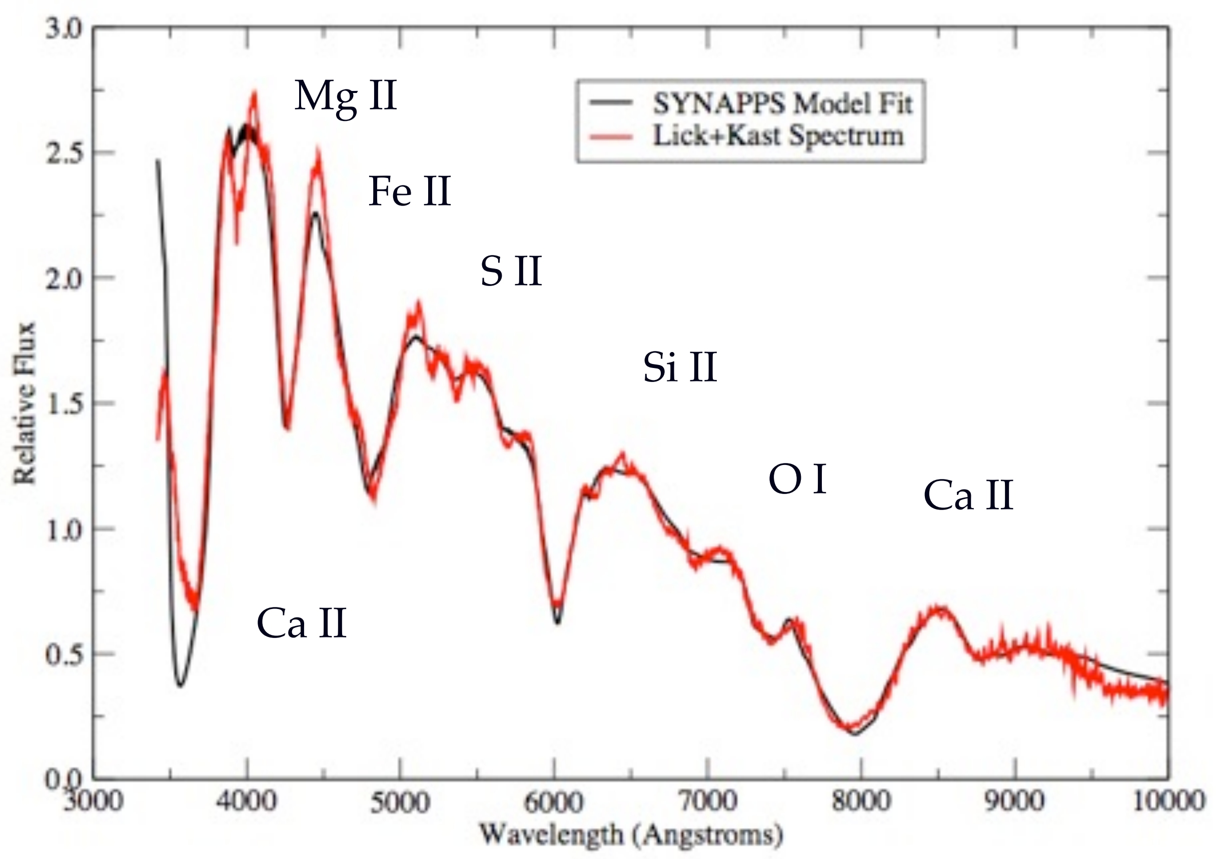
OI line evolution.

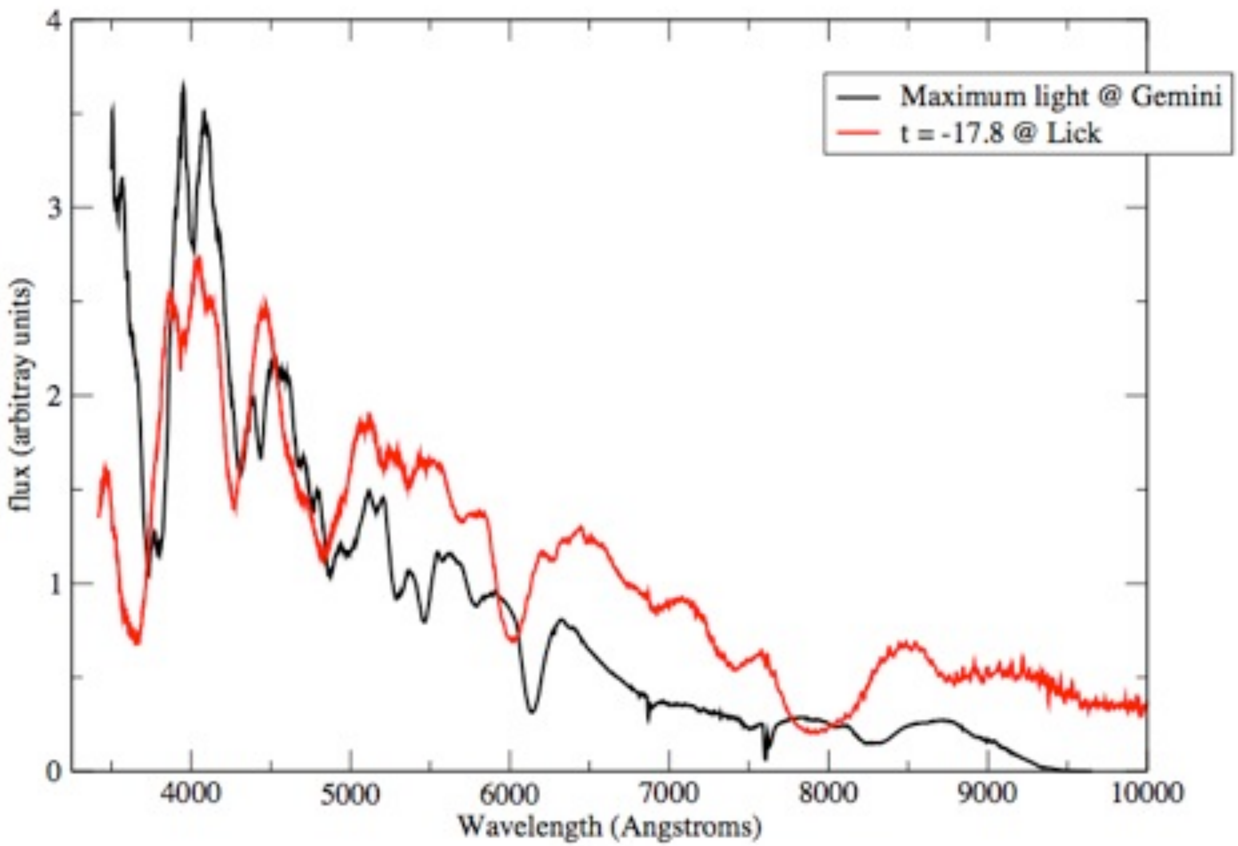
Just geometrical dilution.

SYNAPPS spectrum synthesis fits on NERSC's Hopper commenced 1 hour after first spectrum was reduced.

Finished analysis 30 hours after SN was first detected!

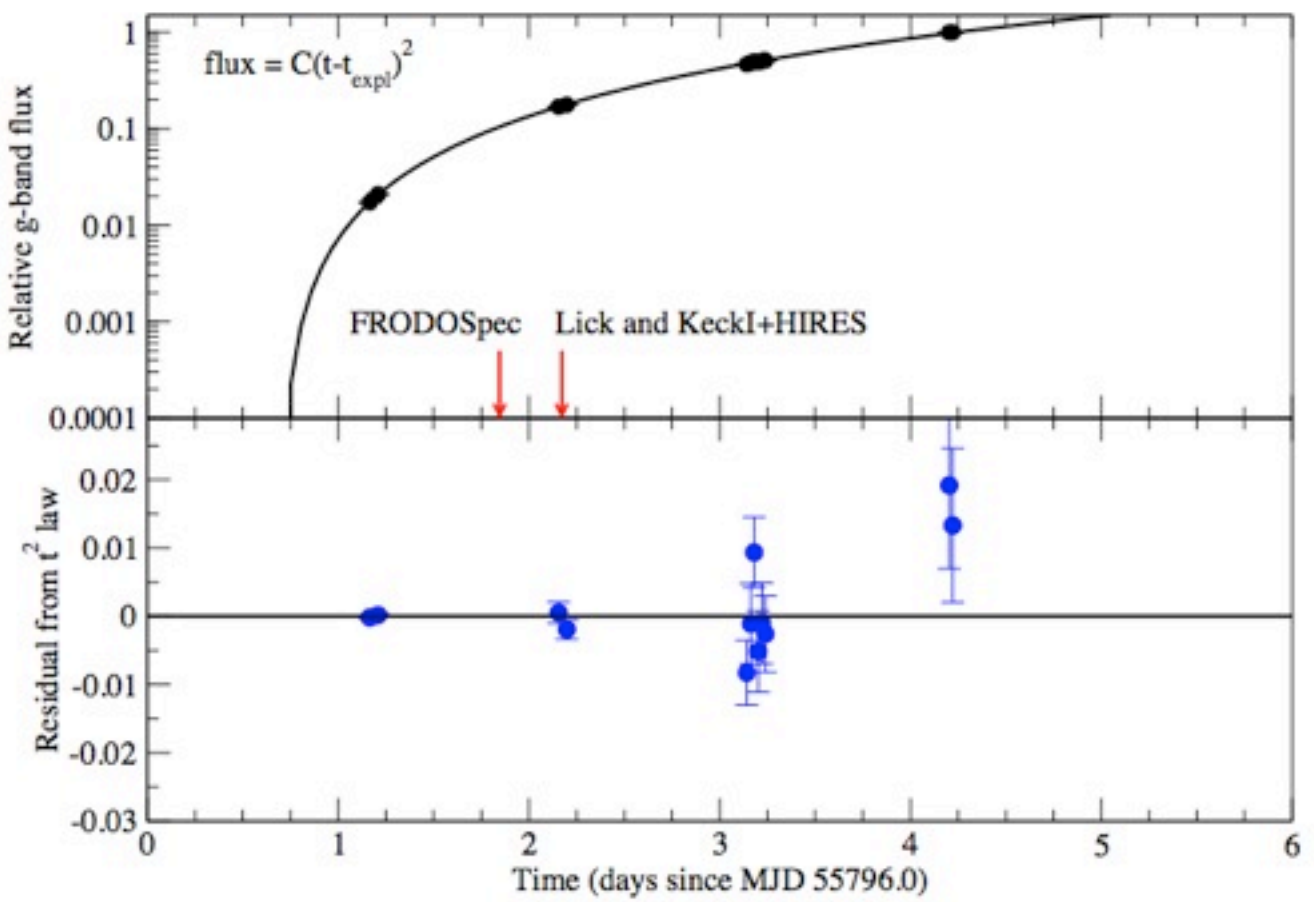
Nugent *et al.*, Nature (2011)





So similar to the maximum light spectrum abundance-wise that it is clear there is a lot of mixing in the SN explosion.

Nugent *et al.*, Nature (2011) *Swift* *HST*



SN 2011fe was caught within 11 hrs +/- 20 min. of explosion.

First spectra came in ~24 hr later.

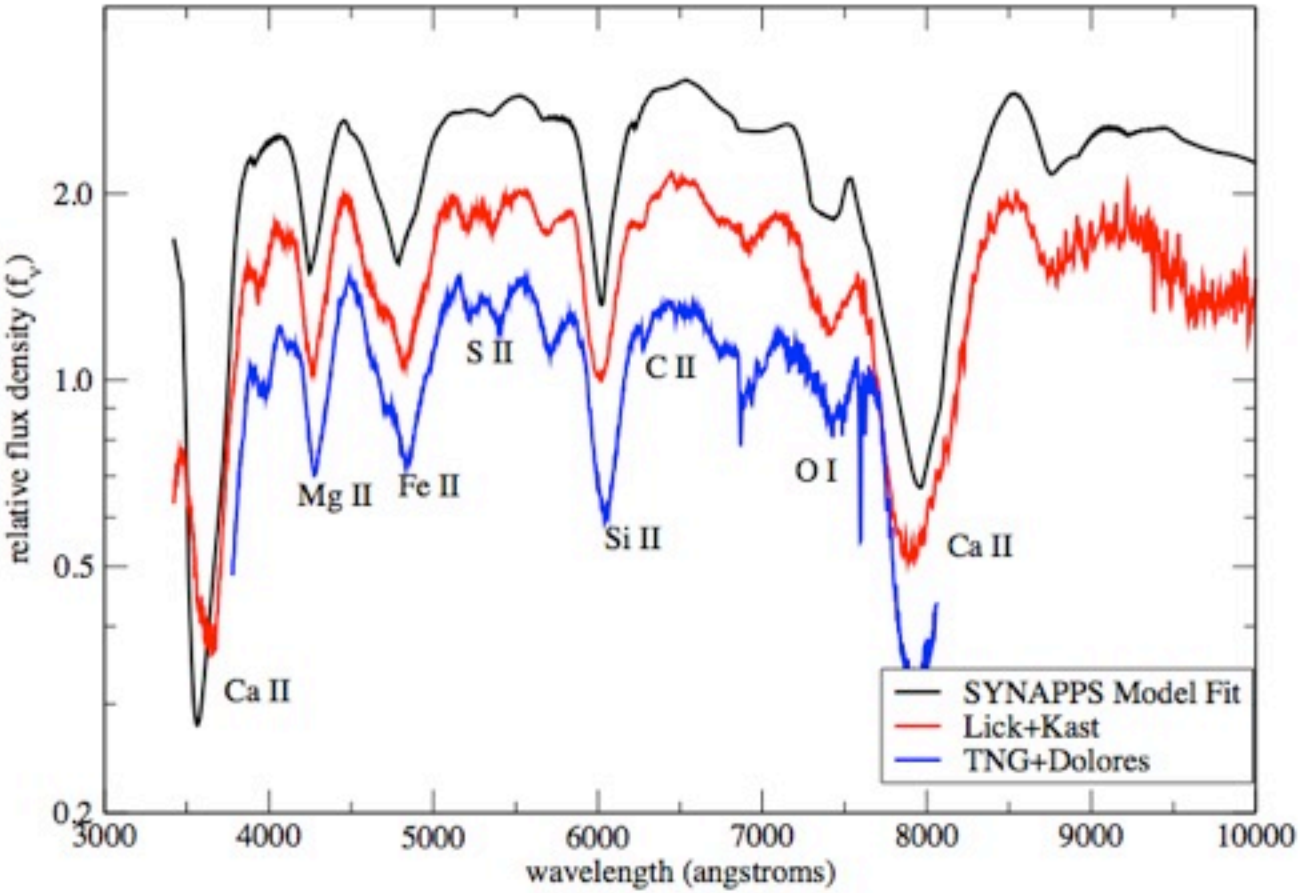
Peaked @ mag 9.9, making it the 5th brightest SN in last 100 years.

MJD	Telescope/Instrument	Filter	Exp. Time (s)	Magnitude
55795.199	P48	*g*	120.0	> 21.5
55797.166	P48	*g*	60.0	17.349 ± 0.011
55797.209	P48	*g*	60.0	17.155 ± 0.011
55797.923	*Swift*/UVOT	*uvw*1	314.49	18.90 ± 0.21
55797.925	*Swift*/UVOT	*u*	157.04	16.68 ± 0.05
55797.926	*Swift*/UVOT	*b*	157.02	15.42 ± 0.09
55797.927	*Swift*/UVOT	*uvw*2	629.48	20.96 ± 0.39
55797.930	*Swift*/UVOT	*v*	157.02	15.12 ± 0.09
55797.931	*Swift*/UVOT	*uvm*2	3264.03	> 21.0
55798.156	P48	*g*	60.0	14.886 ± 0.010
55798.199	P48	*g*	60.0	14.839 ± 0.009
55799.001	*Swift*/UVOT	*uvw*1	618.60	17.35 ± 0.08
55799.002	*Swift*/UVOT	*u*	206.69	15.11 ± 0.03
55799.003	*Swift*/UVOT	*b*	206.63	13.86 ± 0.06
55799.003	*Swift*/UVOT	*uvw*2	1037.48	19.02 ± 0.26
55799.006	*Swift*/UVOT	*v*	276.45	13.62 ± 0.06
55799.006	*Swift*/UVOT	*uvm*2	1387.15	20.04 ± 0.29
55799.142	P48	*g*	30.0	13.787 ± 0.011
55799.164	P48	*g*	30.0	13.751 ± 0.013
55799.181	P48	*g*	30.0	13.713 ± 0.011
55799.202	P48	*g*	30.0	13.726 ± 0.013
55799.221	P48	*g*	30.0	13.701 ± 0.013
55799.239	P48	*g*	30.0	13.689 ± 0.012
55800.203	P48	*g*	30.0	12.964 ± 0.013
55800.221	P48	*g*	30.0	12.959 ± 0.012

Supplementary Table 1 — UV/Optical Observations of SN 2011fe. P48 observations have been calibrated with respect to Sloan Digital Sky Survey *g*-band images of the field, and are on the PTF photometric system. *Swift*/UVOT images have been calibrated using standard recipes[39] and are reported on the AB system[40].

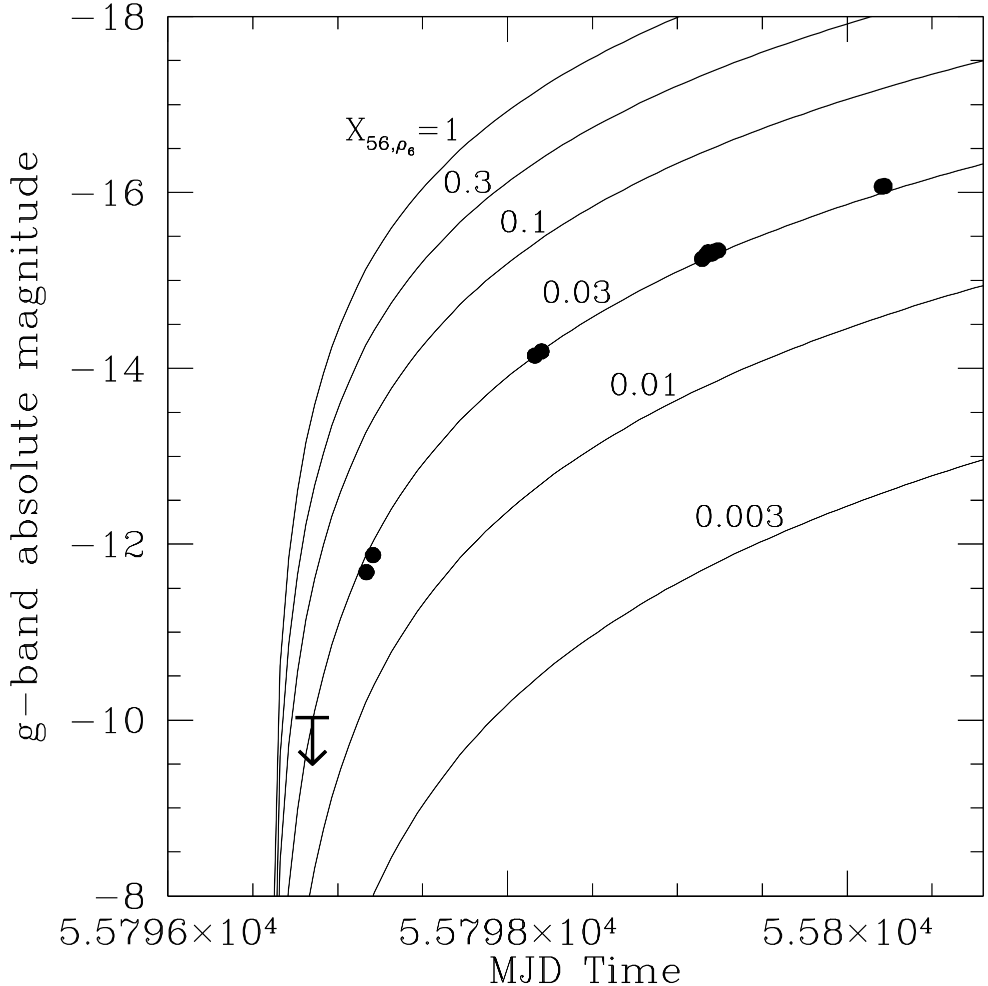
Temperature is cold (UV deficit) and roughly constant…

Nugent *et al.*, Nature (2011)



Why follow t^2 law?

Ni^{56} in outer layers, photosphere does not drop much in velocity space, temp constant - leads to luminosity increasing like surface area.



Piro *et al*. (2012)

Mixing to the outer layers of Ni^{56} or some other radioactive source is the only way to explain the early lightcurve – $M_{\odot} < 0.1$

Shock Breakout

detonation→ shock → early-time emission

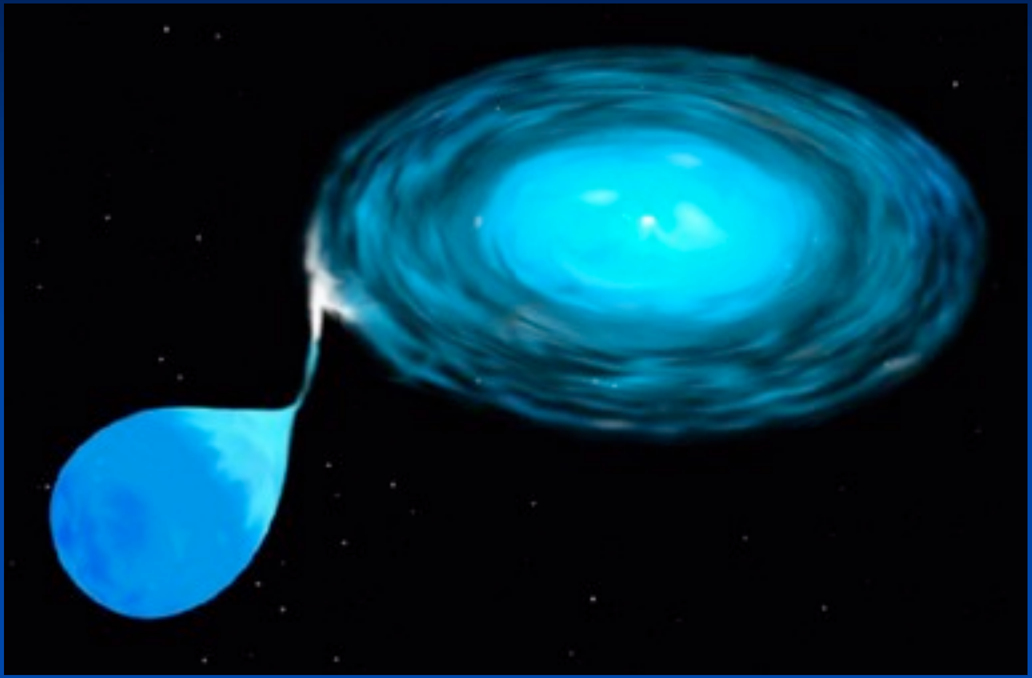
$L_{bol} \sim 10^{40}\,\text{erg} \times R_p\, t_{day}^{-1/3}$

$T(t) \sim 4000\,\text{K} \times \mathbf{R_p}^{1/4}\, t_{day}^{-1/2}$

Rabinak, Livne, Waxman (2011)

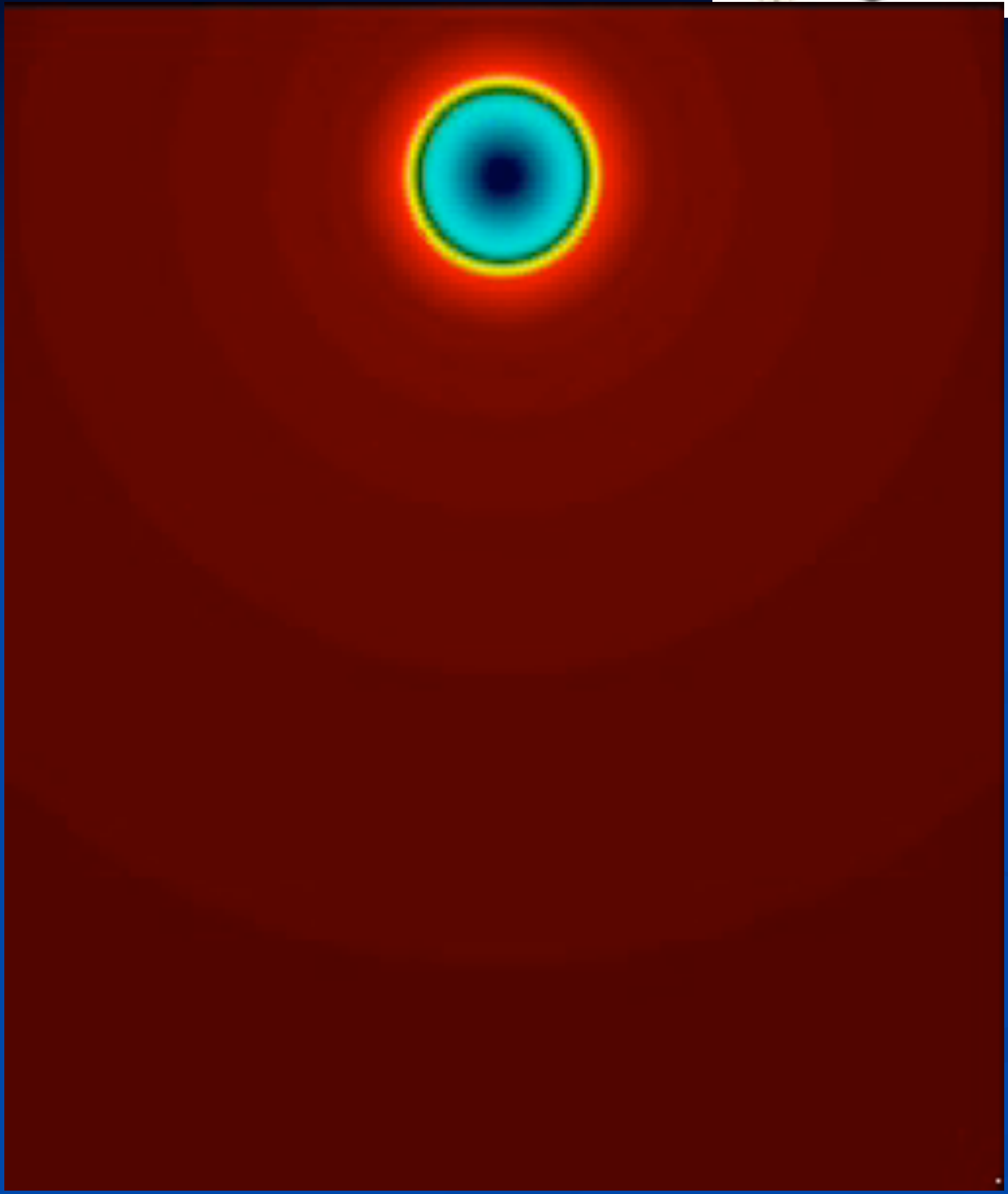
Piro, Chang & Weinberg (2010)

Companion

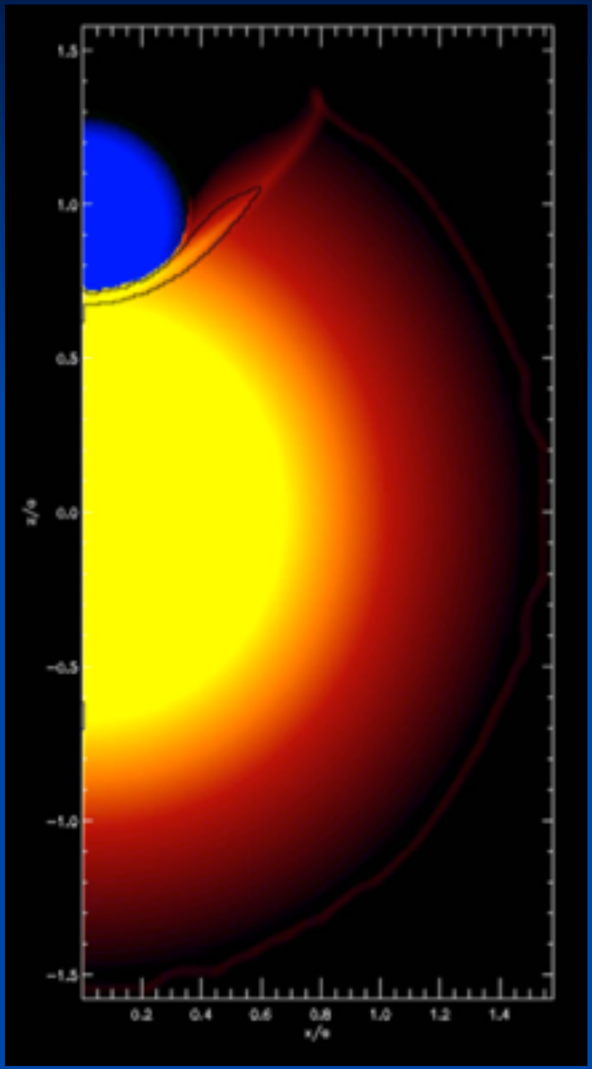


A White Dwarf accretes material from a companion star, either a main sequence Star or a Red Giant.

- The companion subtends an appreciable angle.
- After explosion, the SN ejecta runs over the companion star in a few minutes to hours.
- This may leave a ~40º hole in the SN ejecta . (Marietta *et. al.* 2000; c.f. Livne *et. al.* 1996)

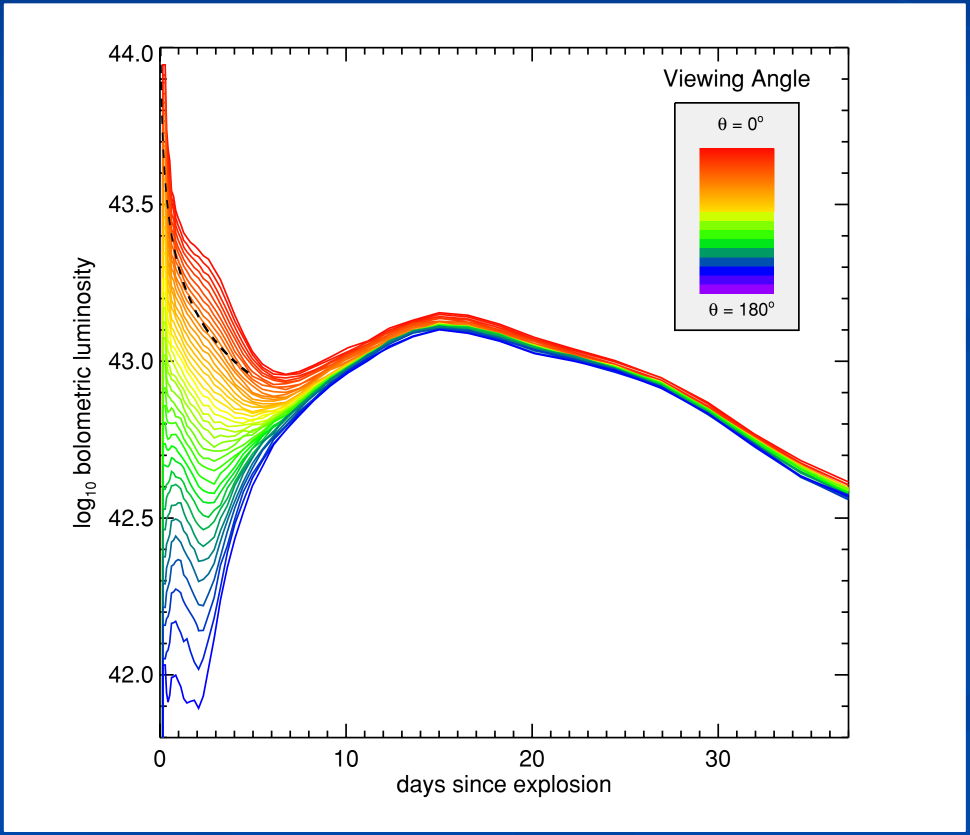


[*Marietta, Burrows, & Fryxel*](2000) (2000)

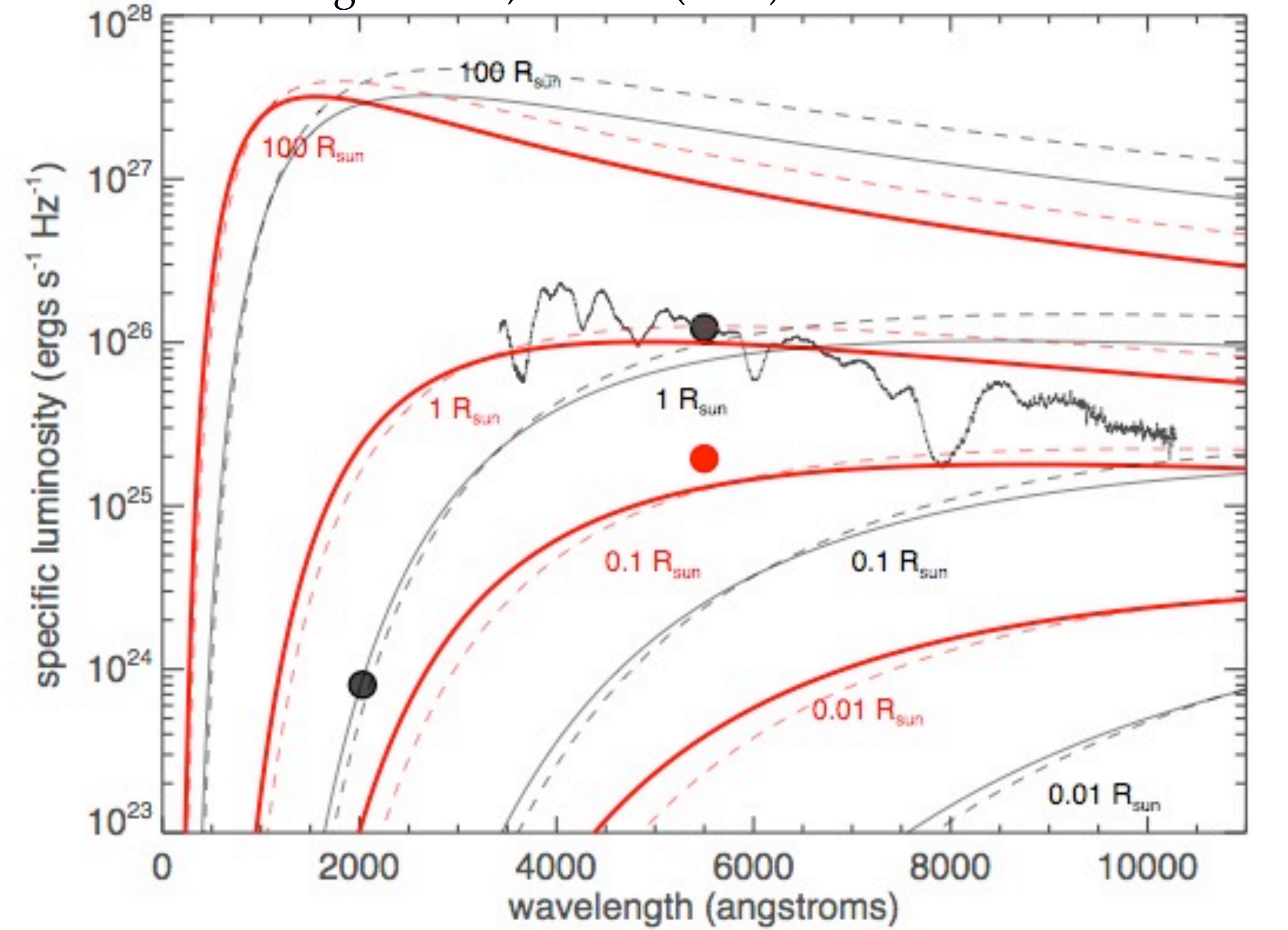


Kasen (2010)

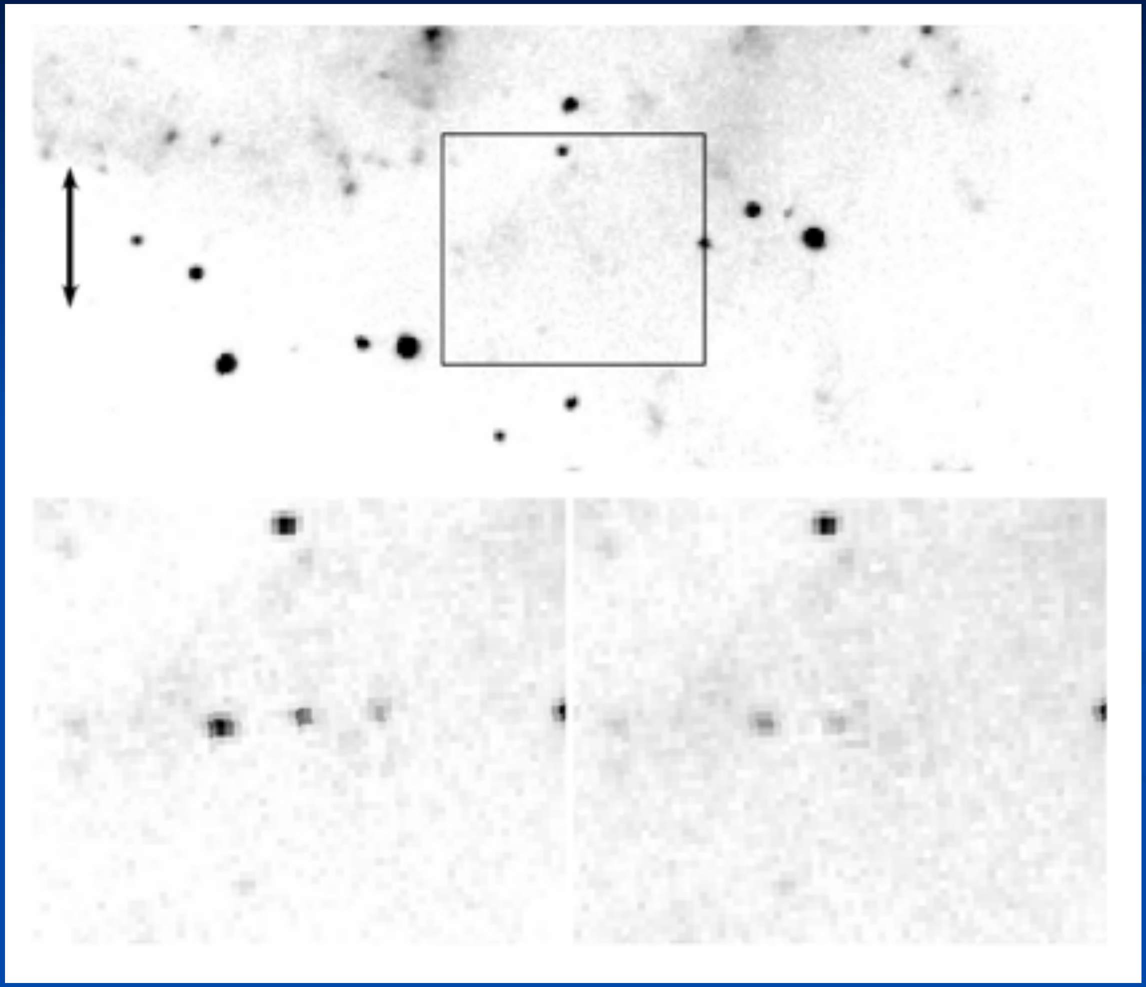
Doesn't matter if it is the initial WD or the system – the shock effects both almost equally.



Nugent *et al.*, Nature (2011)

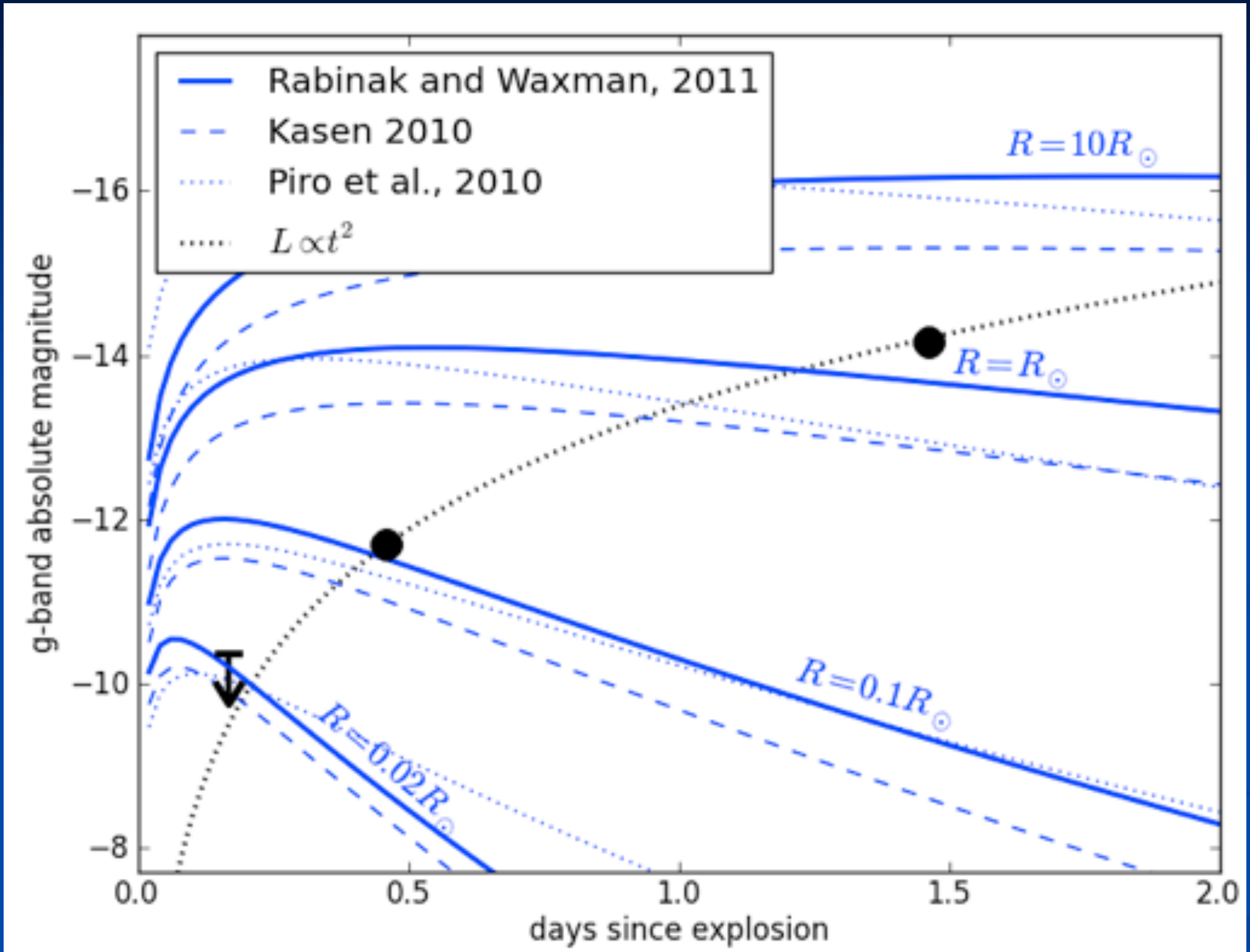


Assuming supernova energetics, a shock is produced that cools adiabatically and has a luminosity and temperature which is dependent on the initial radius of the system.



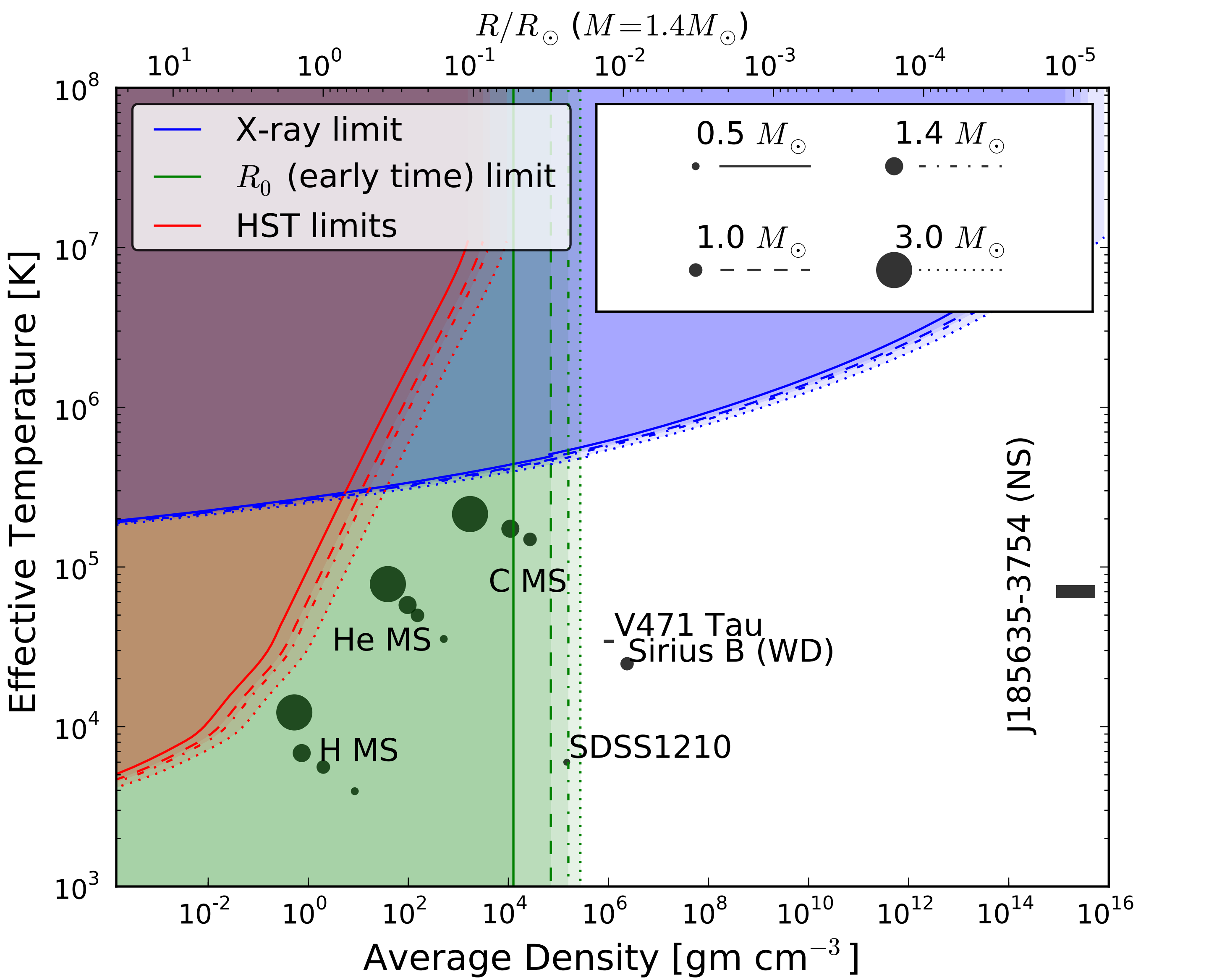
Open University observations on Mallorca only 4hrs after explosion.

Bloom *et al.*, ApJL (2012)



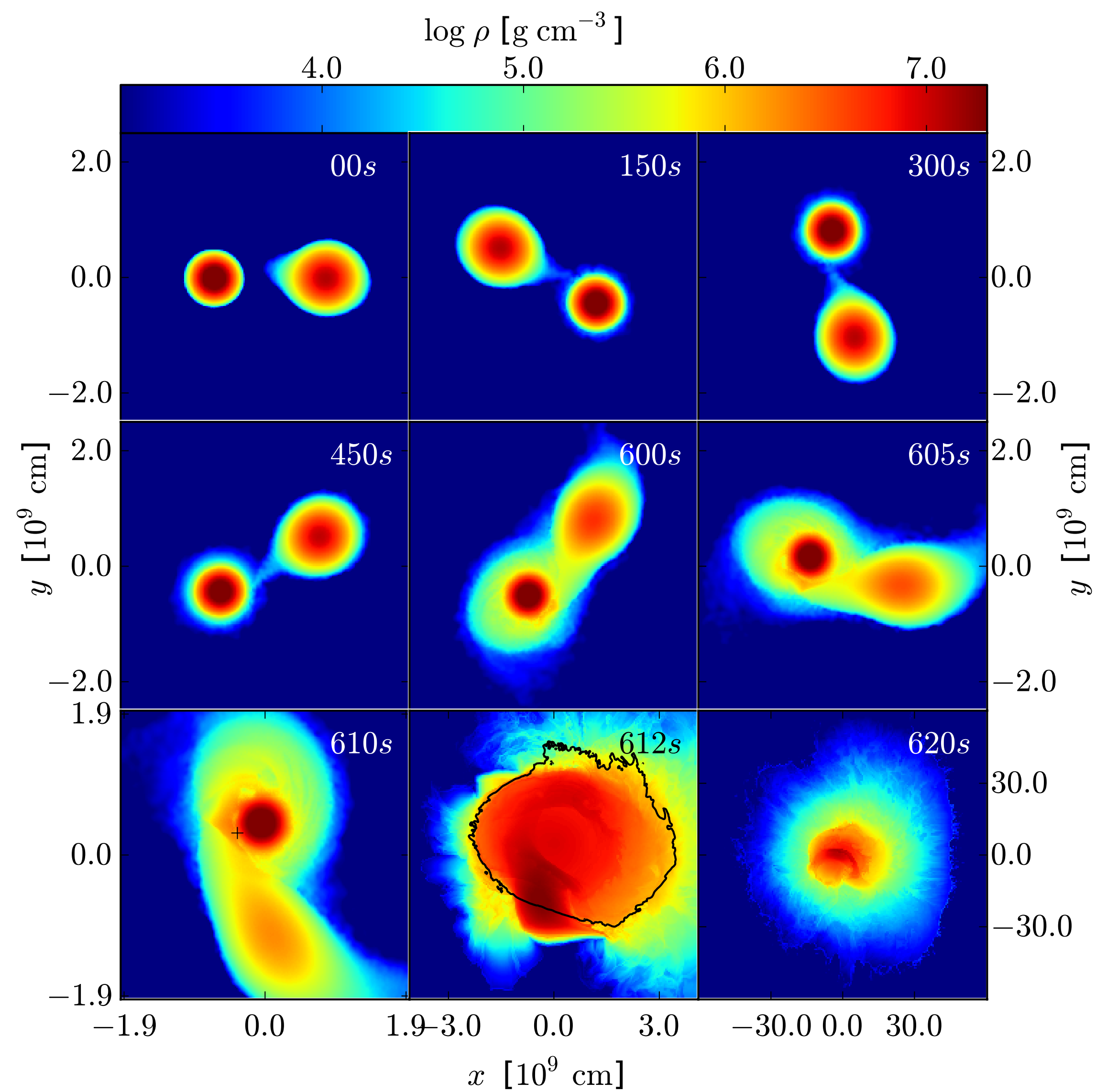
Constrains the explosion radius to R < 0.02 $R_\odot$

Bloom *et al.*, ApJL (2012)



Limits the progenitor to a WD or NS.

Bloom *et al.*, ApJL (2012)

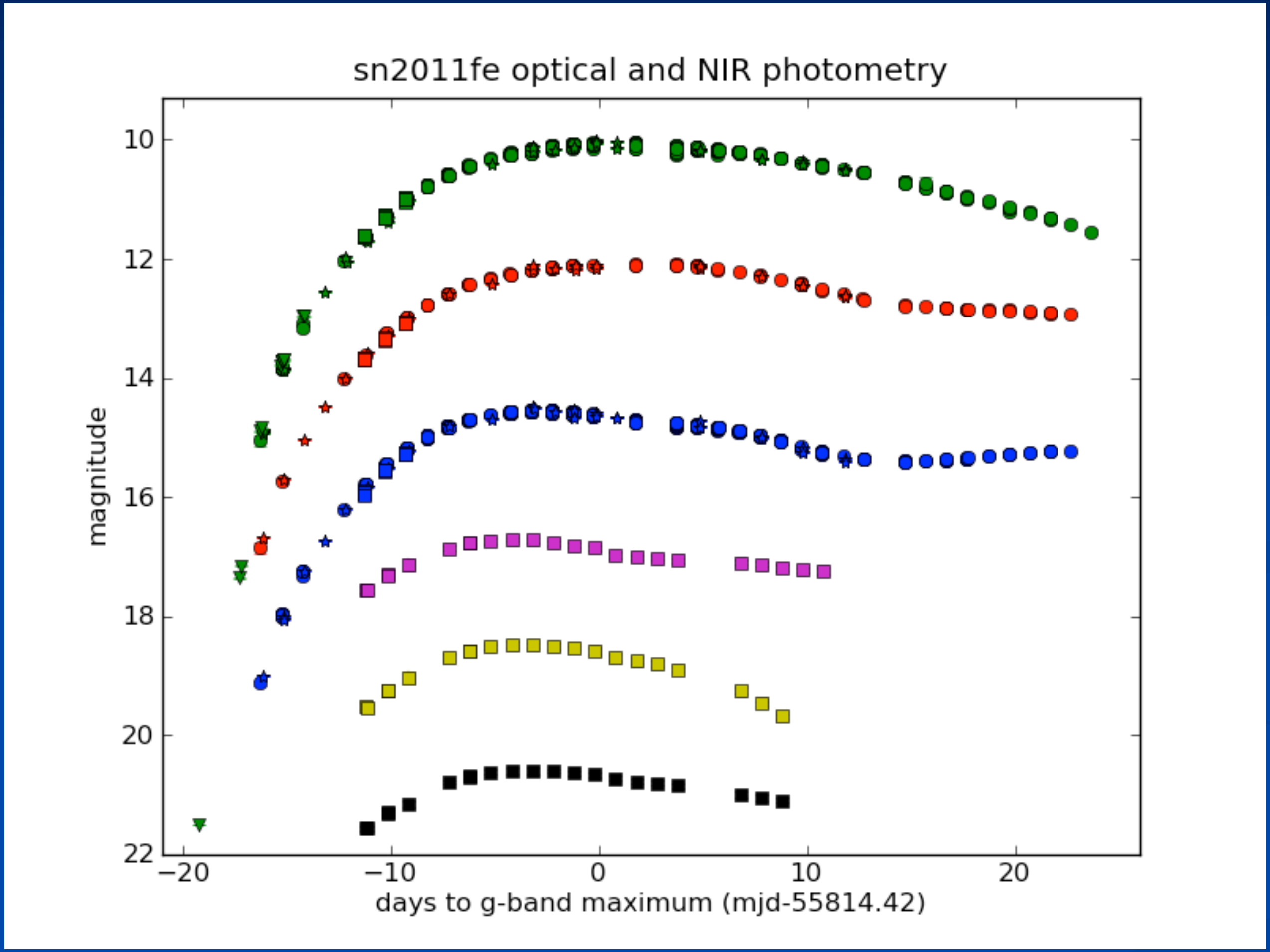


Companion from a WD+WD merger?

0.4 $R_{\odot}$ in size as the detonation makes its way out…

Pakmor *et al.*, (2012)

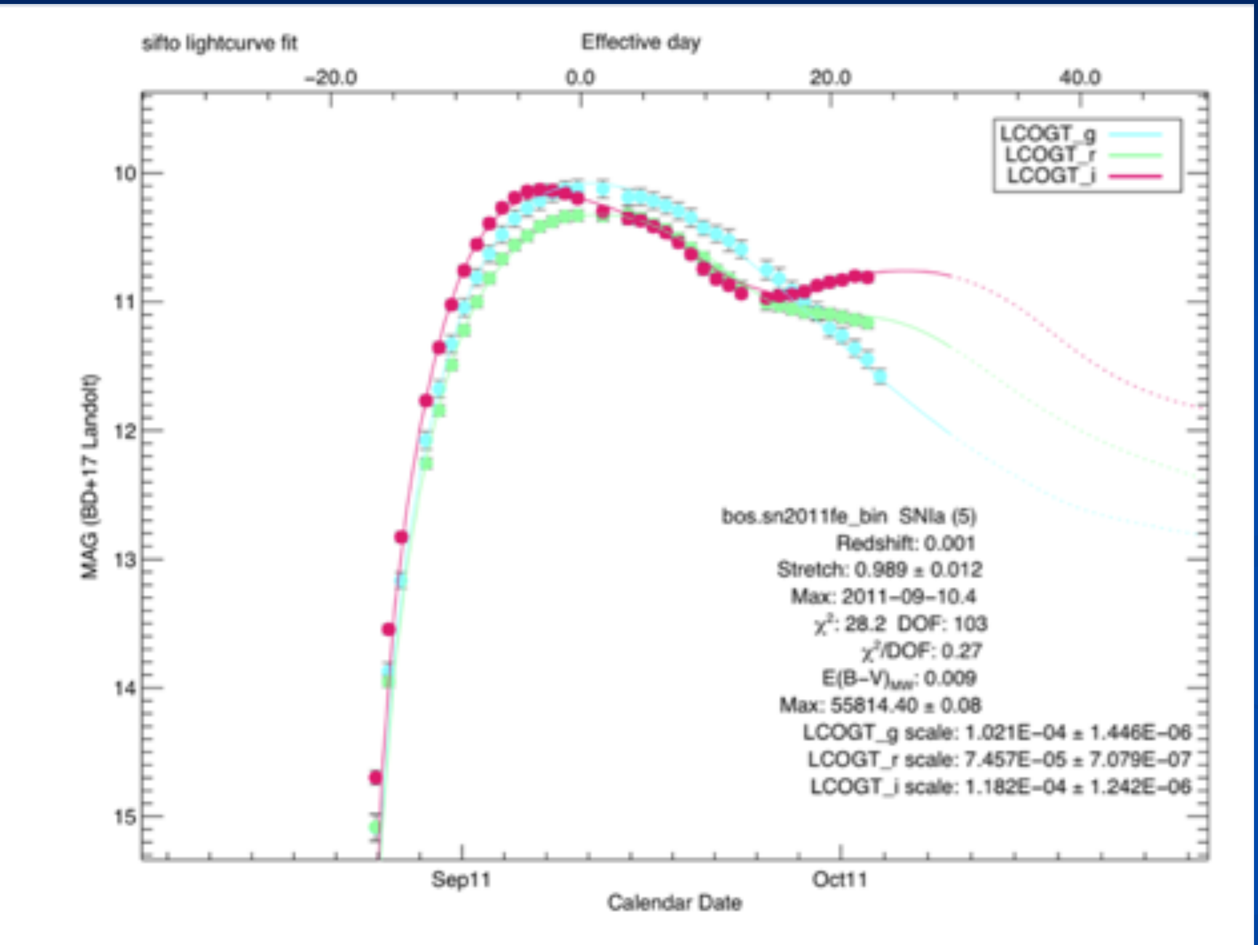
Photometric Follow-up



Follow-up from PTF in optical and NIR (FTN/LCOGT and UKIRT/Seoul University).

Bianco *et al*. (2012)

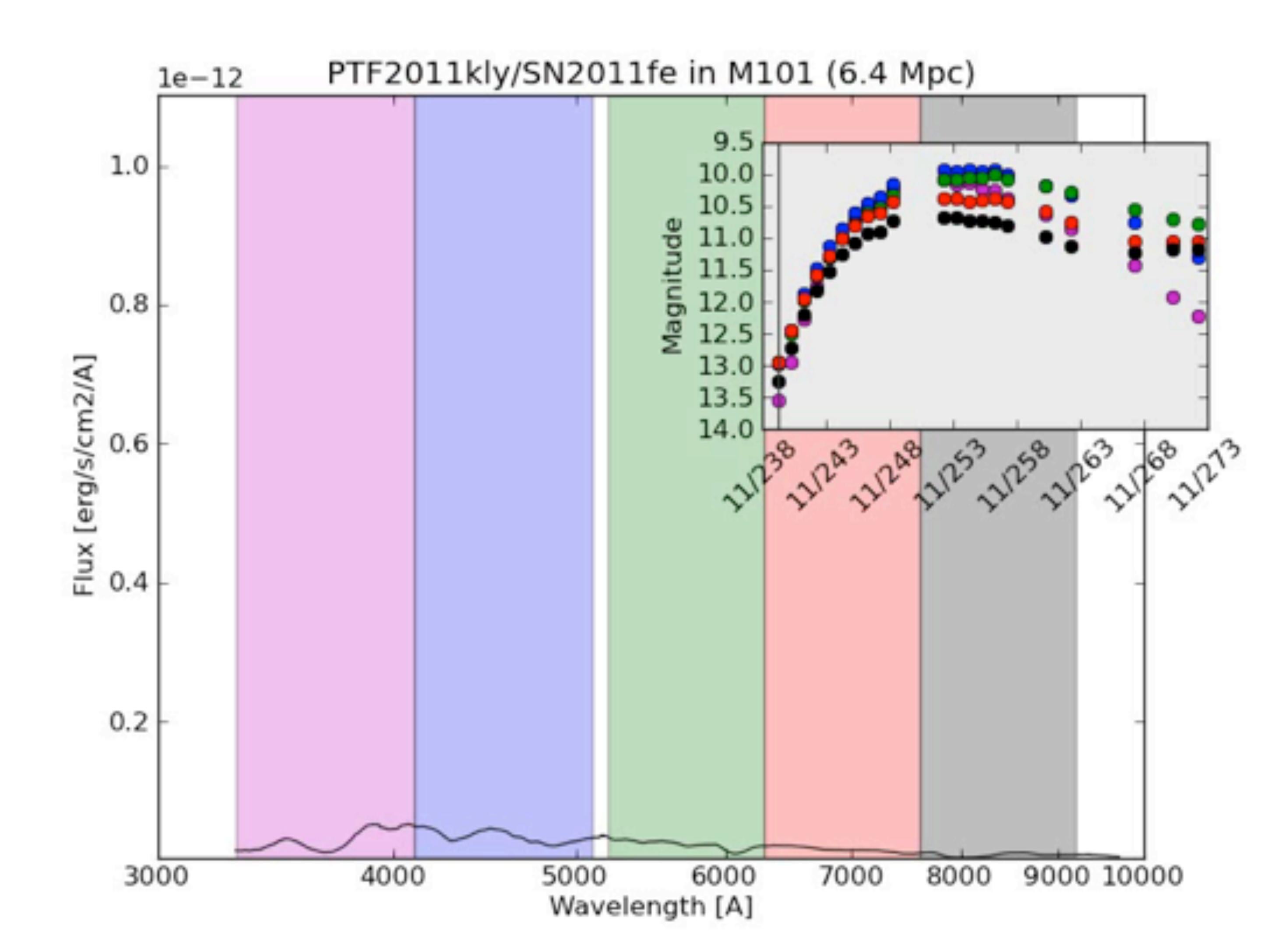
Photometric Follow-up



A SIFTO lightcurve fit shows that this is a completely normal Type Ia Supernova.

Bianco *et al*. (2012)

Spectroscopic Follow-up

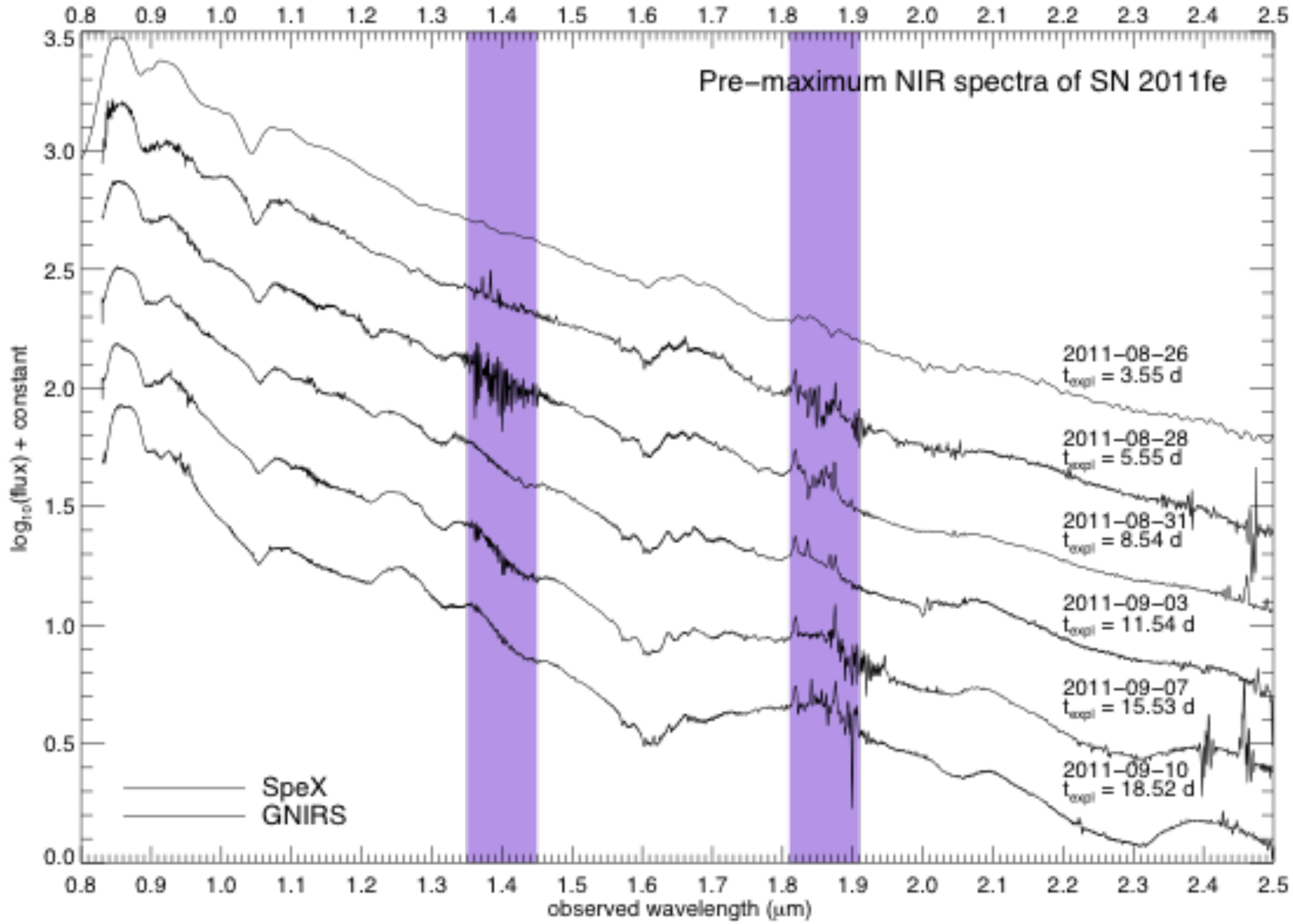


SNIFS follow-up starting the night after discovery.

Credit Y. Copin and SNfactory.

Pereira *et al*. (2012)

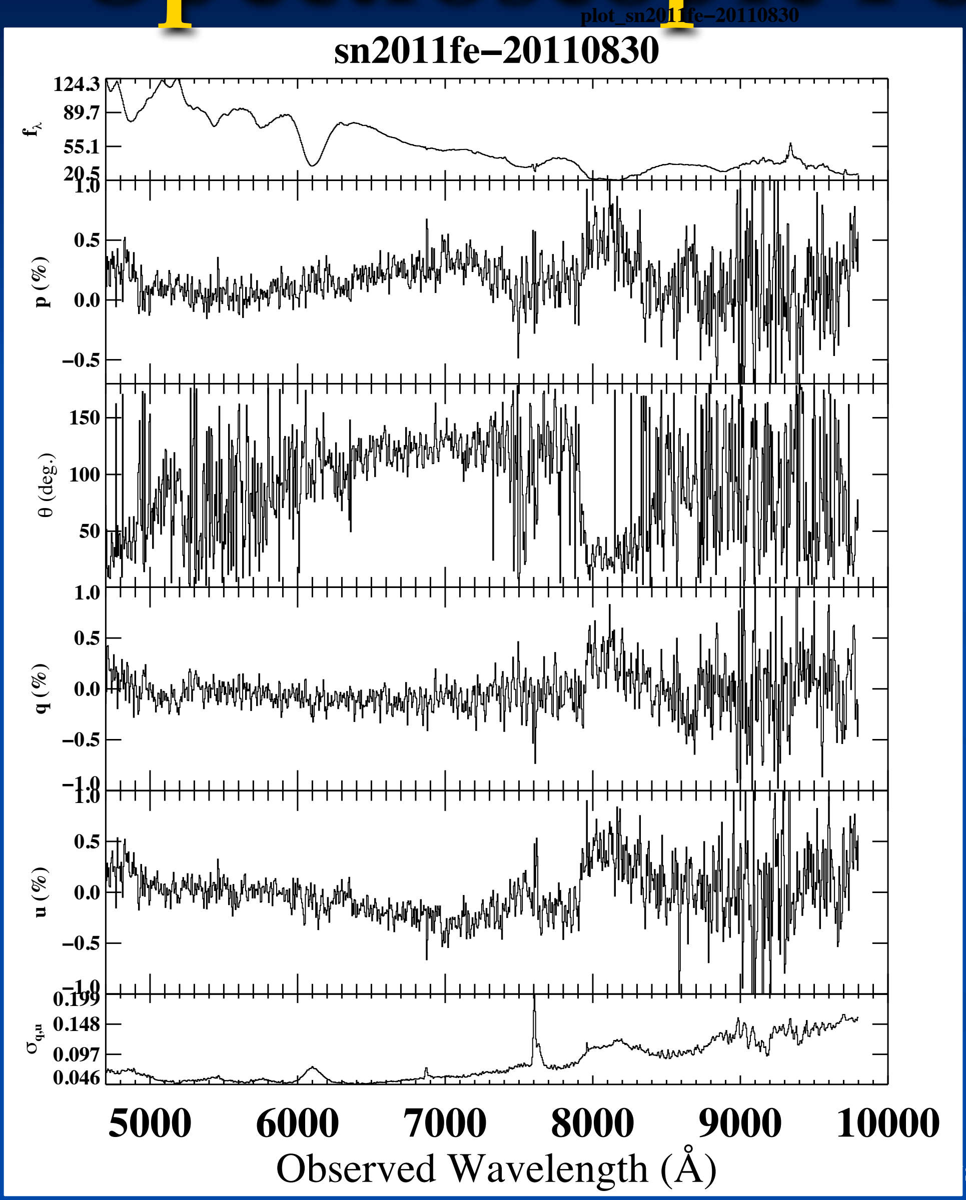
Spectroscopic Follow-up



IR follow-up starting 3 nights after discovery on Gemini North.

Hsiao, Phillips *et al*. (2012)

Spectroscopic Follow-up

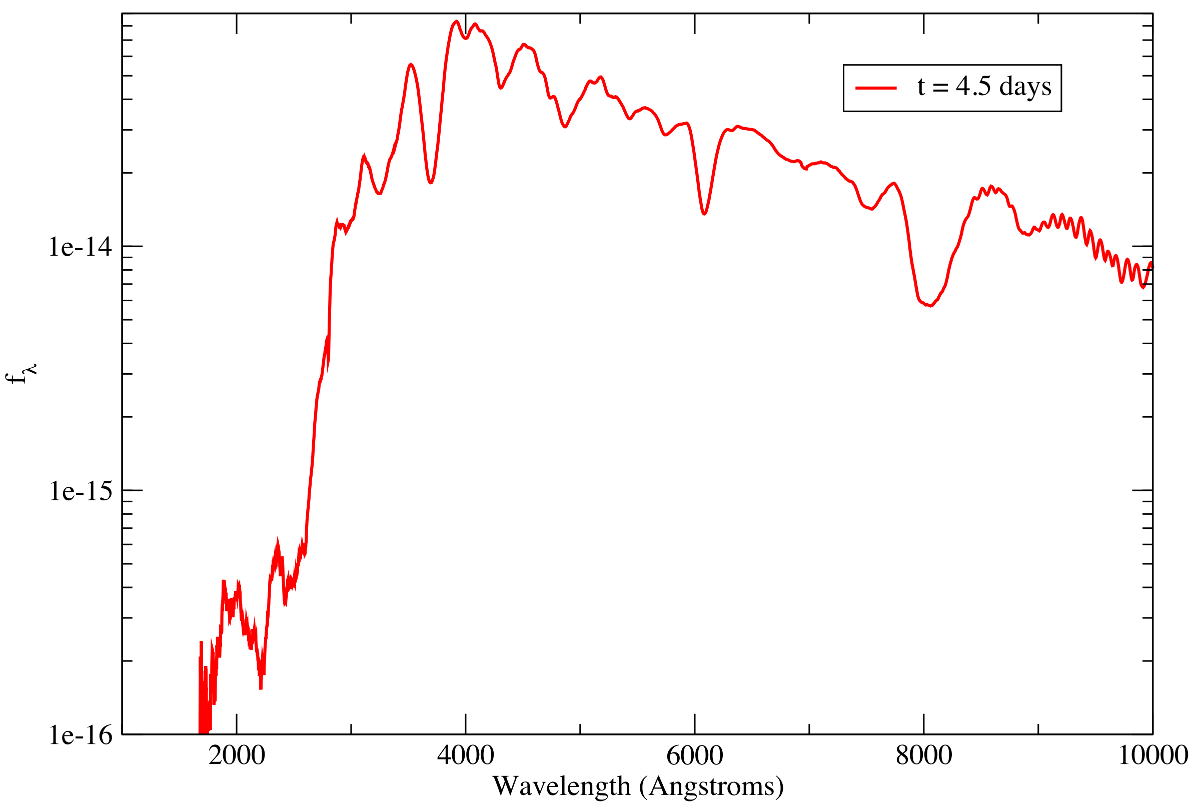


Spectrapolarimetry.
Leonard *et al*. (2012)

Preliminary analysis shows the SN is only moderately aspherical (0.2% polarization – axis ratio of ~0.9) but high-velocity Ca II is more significantly polarized.

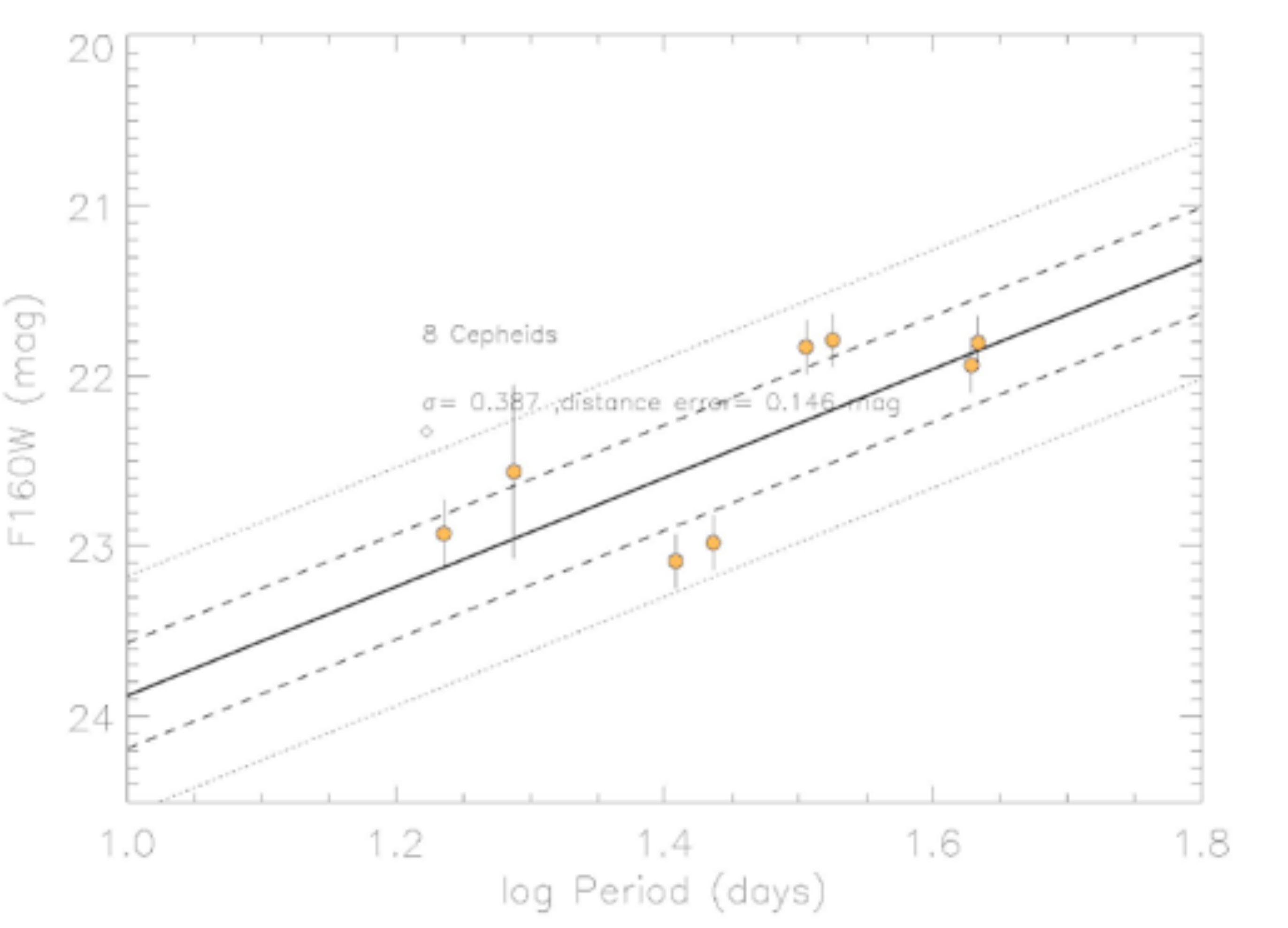
Modeling will be carried out by Botyanszki & Kasen.

HST UV Observations



As Part of the C18 program by R. Ellis *et al.*, observations were undertaken with HST+STIS. They start at just over 4 days after explosion and extend to 2 months.

HST IR Observations



Piggybacking off of the previously mentioned HST program, we were able to obtain simultaneous WFC3 IR imaging to improve the Cepheid distance. Analysis is ongoing.

Future

We will be able to see this supernova for 2 more years from small telescopes and perhaps another 5-10 years from the Hubble Space Telescope. Lots of opportunities for more science.

The modeling has just begun…