Fast and Furious:
Analysis of the Luminous and Rapidly-Evolving Type Ic-BL Supernova iPTF16asu

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Assessing the Scene: Data and context of iPTF16asu

Context

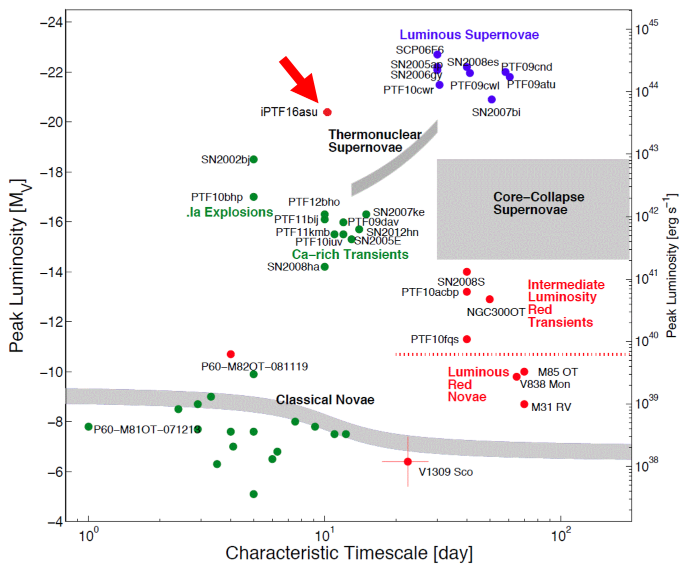

Figure 1: Luminosity versus timescale for a variety of different astrophysical transients. Location of iPTF16asu marked with arrow.

iPTF16asu is a **rare event** in a unique part of transient phase-space.

Photometry

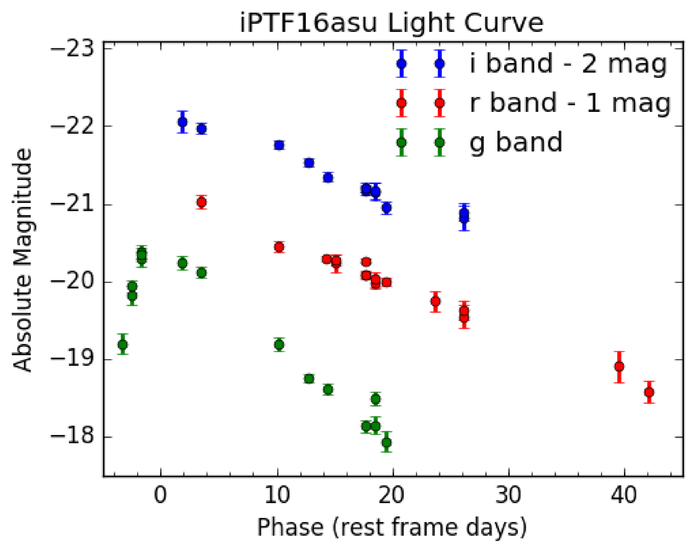

Figure 2: Light curve of iPTF16asu in g, r, and i bands. Data from P48 and P60. Filters offset for clarity.

Rest-frame rise time (τ_g): 4.0 days!
Peak luminosity (M_g): -20.4 mag

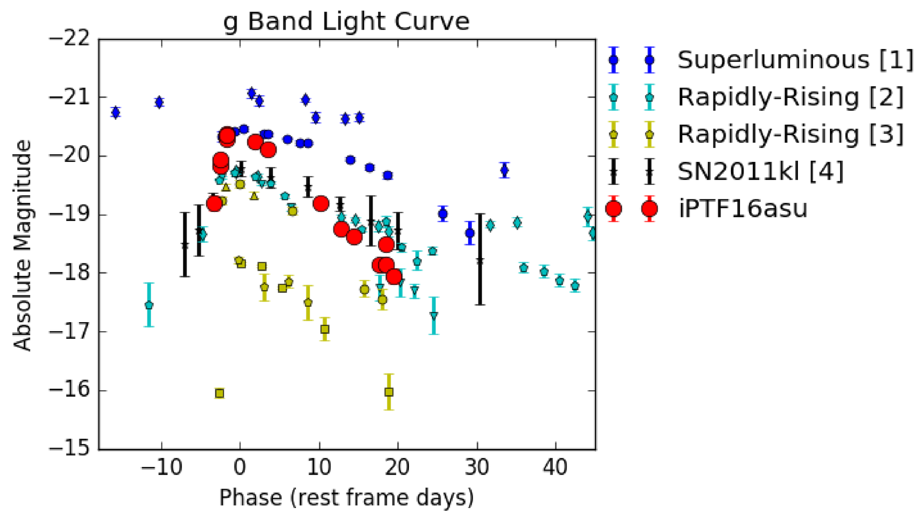

Figure 3: Comparison of iPTF16asu's light curve to similar transients: superluminous supernovae (SLSN) [1]; rapidly-rising transients in SN/SLSN gap [2]; rapidly-rising Pan-STARRS1 objects [3]; and SN2011kl [4], which was associated with an ultra-long gamma-ray burst.

More luminous and rapidly-evolving than other similar transients.

Spectroscopy

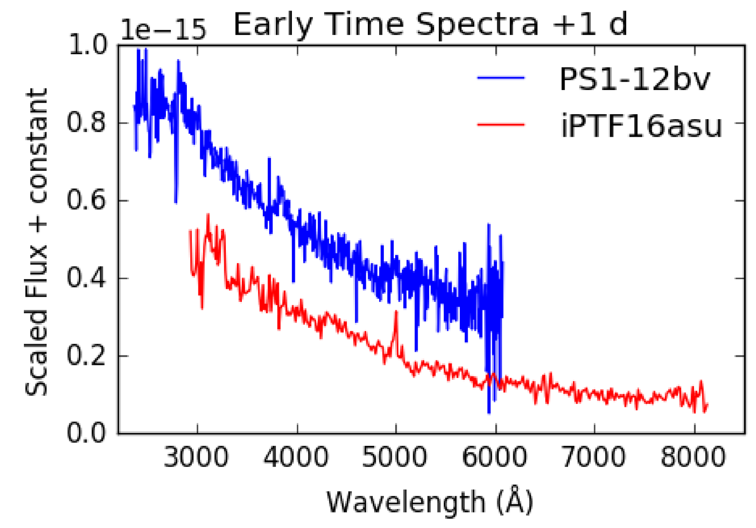

Figure 4: Spectra of PS1-12bv [2] at +2 d compared to iPTF16asu at +1 d. iPTF16asu spectra from NOT.

Featureless, blue continuum, similar to [3].
From host galaxy narrow emission lines:
z = 0.1874

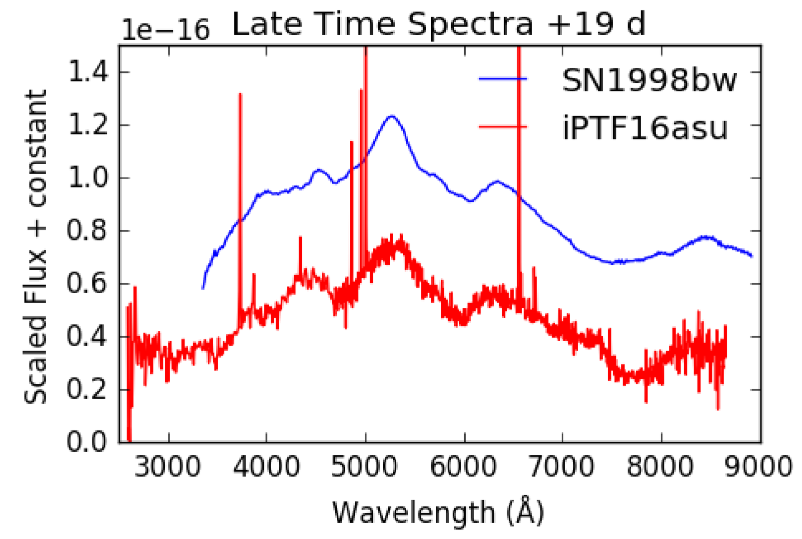

Figure 5: Spectra of 1998bw [5] at +6 d compared with iPTF16asu at +19 d. iPTF16asu spectrum from Keck1+LRIS.

Broad-lines, H/He-poor, similar to SN1998bw, a typical SN Ic-BL + GRB [5].

Investigating the Explosion: Analysis of physical properties

Bolometric Light Curve & Radiated Energy

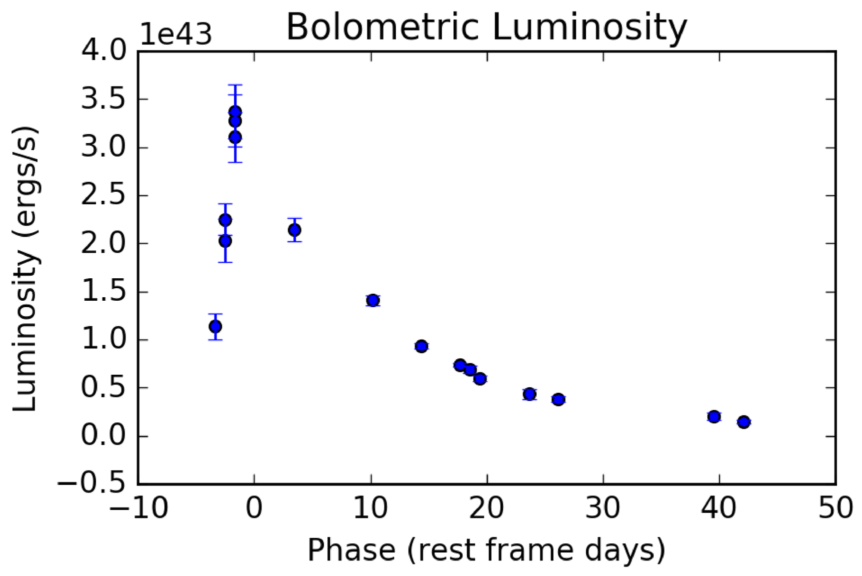

Figure 6: Bolometric light curve constructed by summing flux over wavelength bands. Energy computed by integrating bolometric light curve. Note the rapid rise and decay.

Total Radiated Energy:
$4.0\times10^{49} \pm 6.3\times10^{48}$ ergs

Peak Bolometric Luminosity:
$3.4\times10^{43} \pm 2.8\times10^{42}$ ergs/s

Bolometric light curve used to compare to physical models.

Temperature & Radius

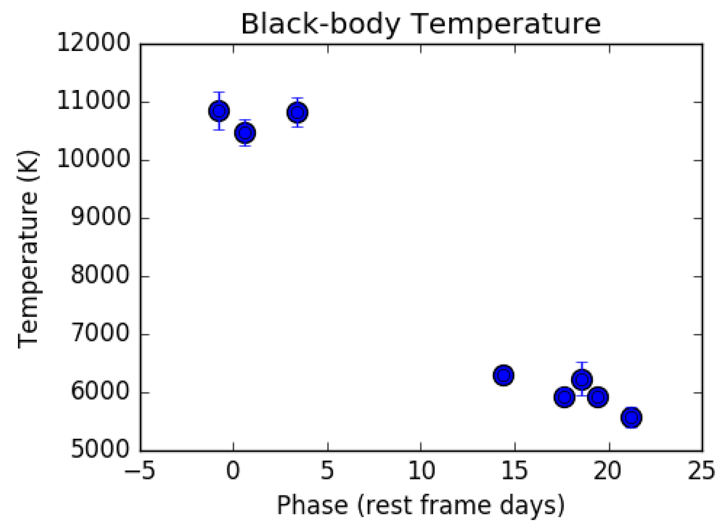

Figure 7: Black-body temperature as a function of time. Fit black-body curves to days with observations in 3+ filters and the earliest 2 spectra.

Starts hot and cools rapidly.
Large peak velocity and radius!

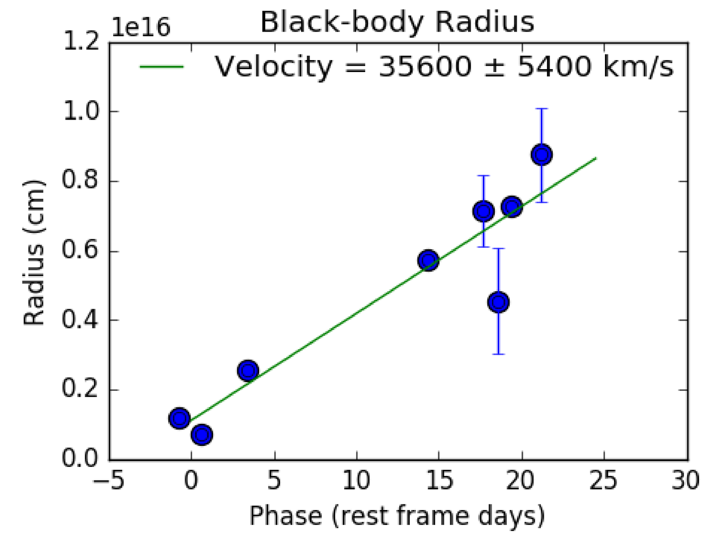

Figure 8: Like Figure 7 but showing black-body radius.

Peak Parameters:
T = 10820 ± 520 K
R = $2.6\times10^{15} \pm 1.9\times10^{14}$ cm

Velocity

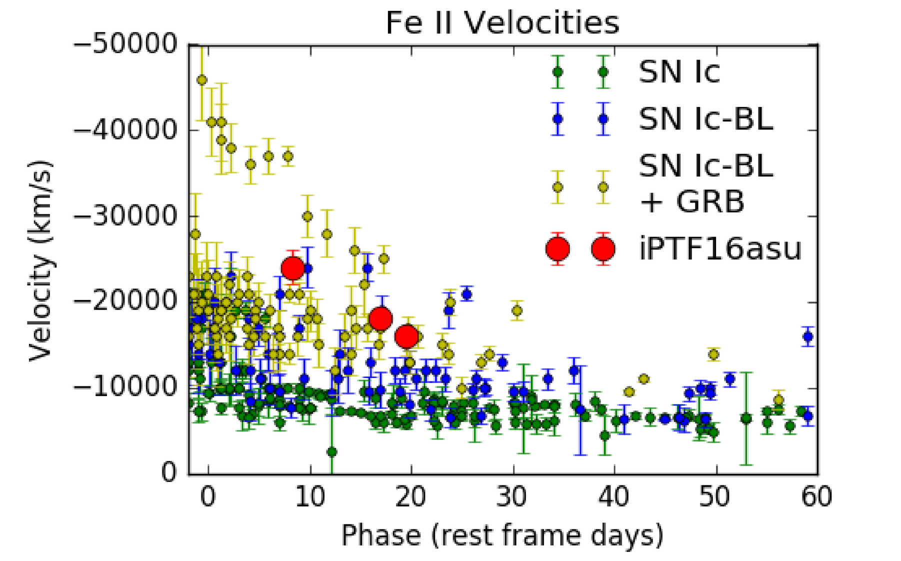

Figure 9: Velocity measured from Fe II lines using method in [6]. Compared to a compilation of SN Ic, Ic-BL, and Ic-BL + GRB Fe II velocity data from [6].

Radio non-detection (VLA) → upper limit on relativistic ejecta.

Velocities comparable to SN Ic-BL + GRB.

Unraveling the Mystery: Testing various explosion models

Nickel-56 Decay?

Normal Type Ic supernovae powered by radioactive decay of ^{56}Ni:

$^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co} + \gamma$ $\quad$ $^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe} + \gamma$

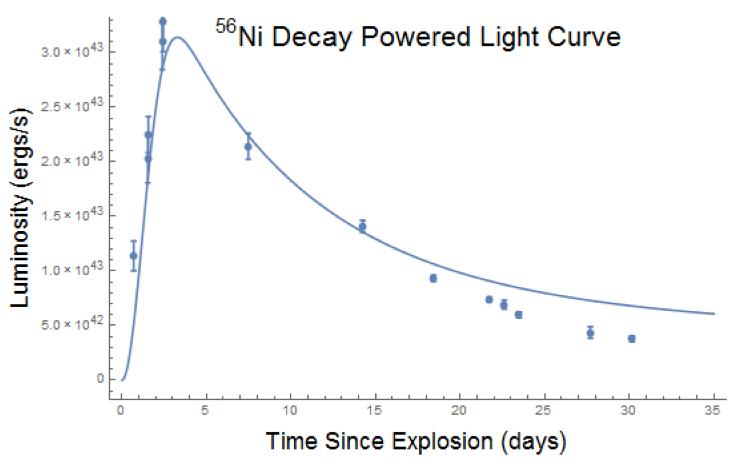

Figure 10: Fit bolometric light curve to ^{56}Ni decay model [7].

- High ^{56}Ni mass due to high luminosity: 0.55 $M_\odot$
- Low ejecta mass due to short time-scales: 0.095 $M_\odot$
- Model unphysical

✗ Nickel Mass > Ejecta Mass!

Not feasible

Magnetar?

Rapidly-spinning neutron star generates extreme magnetic fields. Energy is released to the supernova as magnetar spins down.

✓

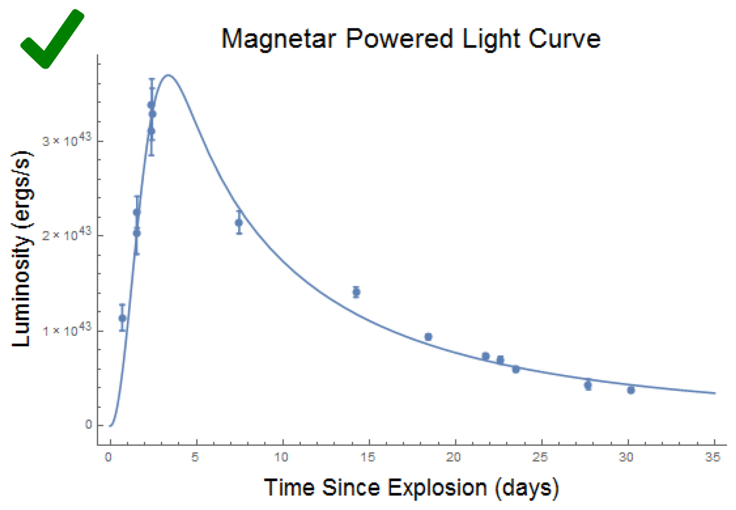

Figure 11: Fit bolometric light curve to magnetar model [8].

Magnetar Energy ∝ $1/P^2$
Diffusion Time ∝ $M_{ej}^{1/2}$
Spin-down Time ∝ P^2/B^2

Magnetic field: 6.5×10^{14} G
Ejecta Mass: 0.13 $M_\odot$
Period: 18.5 ms

? Requires very low ejecta mass to fit rise.

Possible

Off-Axis GRB?

- ✓ Velocities comparable to other SN Ic-BL + GRB.
- ✓ Featureless blue spectra at early times.
- ✗ No reported GRB consistent with location and explosion time.
- ✗ No radio detection with VLA.
- ✗ No X-ray detection with Swift/XRT.

Unlikely

Shock Cooling?

- ✓ Early blue spectra, luminous, and short-lived.
- ✗ Peak radius of 4×10^4 $R_\odot$ is larger than any star, requiring circumstellar material.

Analysis in progress.

Possible?

References [1] Lunnan, R., et al. 2013, ApJ, 771; Inserra, C., et al. 2013, ApJ, 770; [2] Arcavi, I., et al. 2016, ApJ, 819; [3] Drout, M. R., et al. 2014, ApJ, 794; [4] Greiner, J., et al. 2015, Nature 523; [5] Patat, F., et al. 2001, ApJ, 555; [6] Modjaz, M., et al. 2016, ApJ, 832; [7] Arnett, W. D. et al. 1982, ApJ, 253; [8] Wang, S. Q. et al. 2015, ApJ, 799