A Fast-Evolving, Luminous Transient Discovered by K2/Kepler

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KEGS: KEPLER EXTRA-GALACTIC SURVEY

BACKGROUND

For decades optical time-domain searches have been tuned to find ordinary supernovae, which rise and fall in brightness over a period of weeks. Recently, supernova searches have improved their cadences and a handful of fast-evolving luminous transients (FELTs) have been identified, e.g., SN2002bj (Poznanski+10), SN2010X (Kasliwal+10), SN2015U (Shivvers+16), PS1 sample (Drout+14), SNLS/PTF sample (Arcavi+16), HSC sample (Tanaka+16). FELTs have peak luminosities comparable to Type Ia supernovae, but rise to maximum in <10 days and fade from view in less than 30 days. The progenitors of FELTs and the energy source that powers the light curve have been debated, and members of the class could originate from more than one type of progenitor. Here we present KSN2015K, the most extreme example of this class thus far.

KSN 2015K

- KSN2015K was discovered Kepler K2 Campaign 6
- KSN2015K was detected in a single epoch with DECam, thus not triggered as a transient discovery.
- KSN2015K Lightcurve (see Figure 1):
  - Rises to peak in 2.2 days
  - Time above half-maximum of only 6.8 days
- Host is a star-forming spiral galaxy at z=0.090
- KSN2015K is blue, ground-based colors:
  - r-I = -0.15 $\pm$ 0.05 at peak
  - g-r = -0.17 $\pm$ 0.20 at +8 days

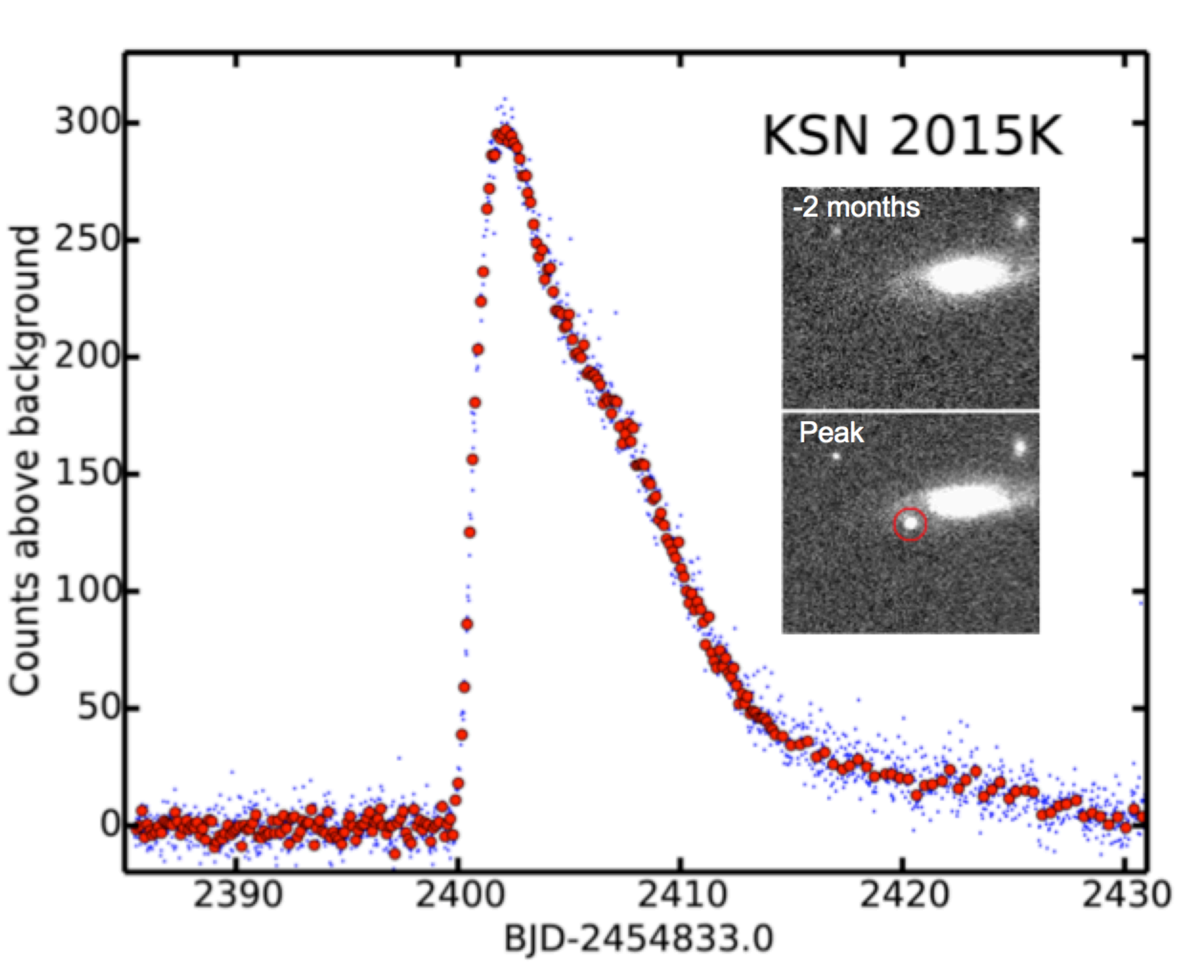

Fig. 1: **The K2 light curve of KSN2015K.** Blue dots are individual 30-minute cadence observations while the red points are median values made from 3-hour bins. The image cutouts in the inlet show DECam images from UT July 7th 2015 (2 months before peak) and August 1st 2015 (around peak) in the top and bottom panels, respectively. KSN 2015K is marked with a red circle in the bottom panel.

COMPARISON TO OTHER SNe

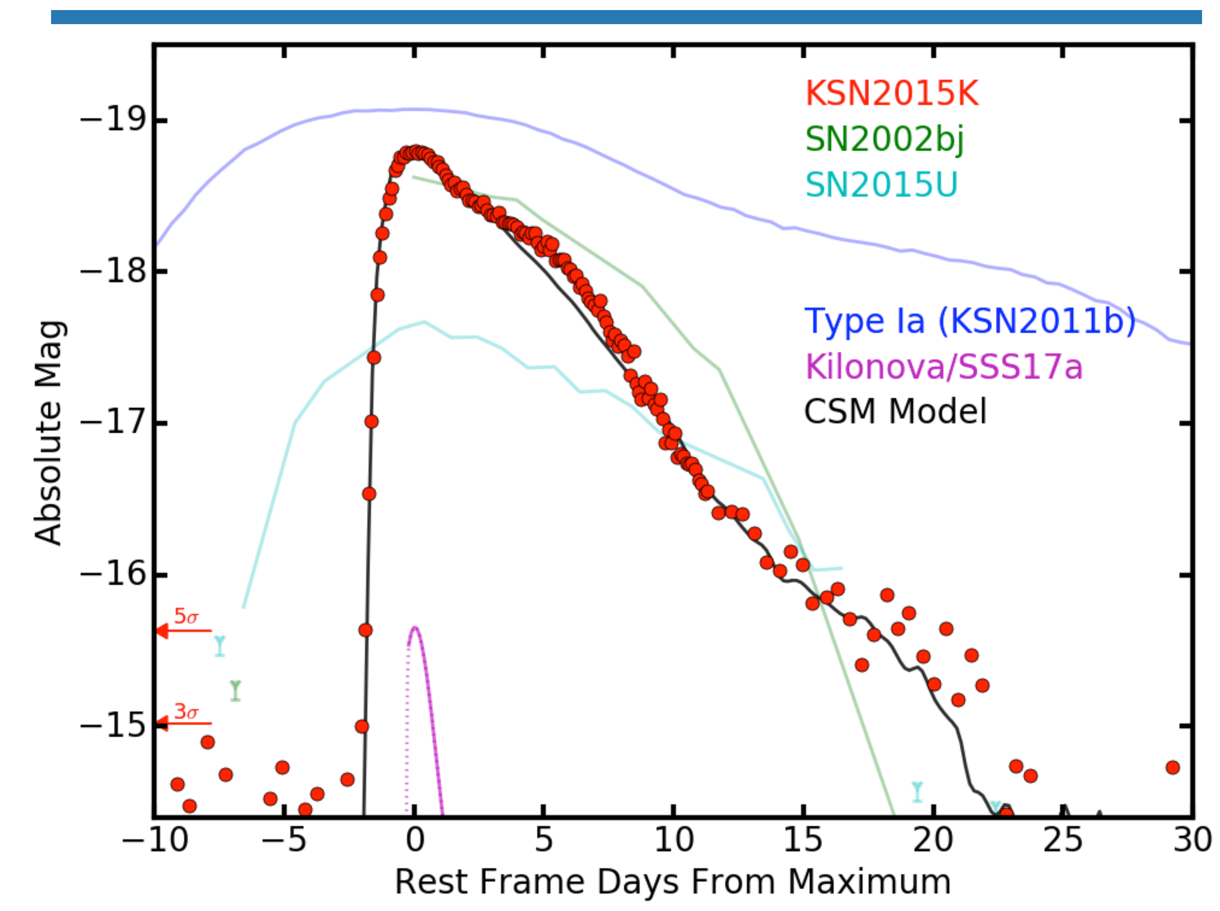

Fig. 2: **Light curve comparison.** The KSN2015K light curve assuming H_0=70, Milky Way extinction law, and A_V=0.10 mag. The light curve of a another Kepler type Ia supernova (blue line) is shown for comparison. Also shown are light curves of the fast transients SN2002bj and SN2015U, and the kilonova SSS17a/AT2017gfo. The black line shows the best fit shock breakout in circumstellar material model.

- SN2002bj (Poznanski+10): Similar to SN Ia but with Helium features, indicating a core-collapse SN interacting with a helium envelope.
- SN2010X (Kasliwal+10): low luminosity means it could be powered by nucleisynthesis.
- SN2015U (Shivvers+16): <10 days rise, $t_{1/2}$=15 days. Narrow Helium features indicate interaction with hydrogen-poor CSM.
- PS1 sample (Drout+14): 10 fast, blue transients with colors/luminosities similar to KSN 2015K.
- SNLS/PTF sample (4 transients, Arcavi+16), HSC sample (5 transients, Tanaka+16): brighter and longer timescales than KSN 2015K.

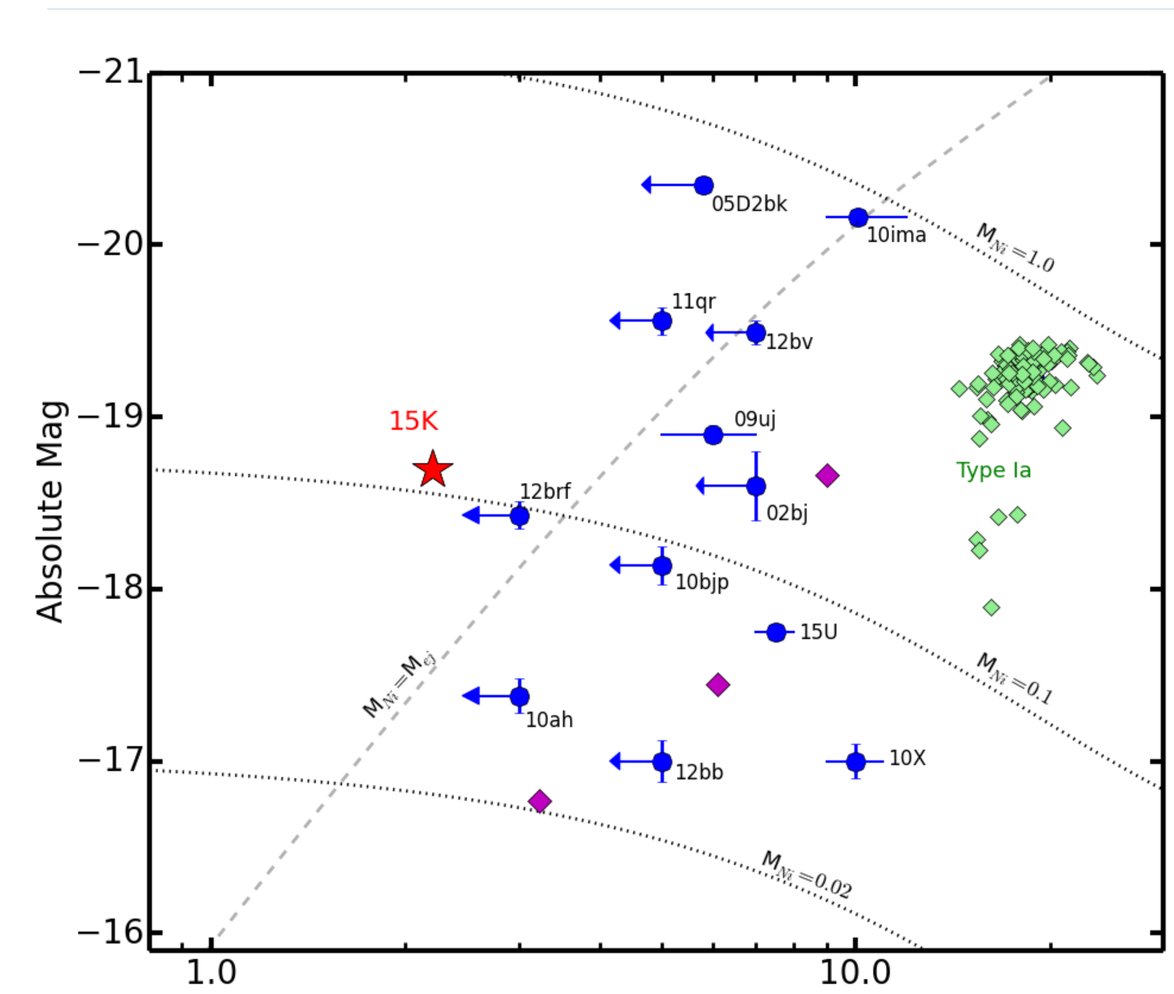

Fig. 3: **Peak luminosity versus rise time:** The peak luminosity versus rise time at optical wavelengths for fast transients (blue) and type Ia supernovae (green) from SDSS-II. The red star shows the position of KSN2015K and the errors are smaller than the size of the symbol. Purple diamonds show ".1a" models (Shen+10). Dotted lines show Arnett's rule for a range of synthesized ^{56}Ni masses. The dashed line is a thermonuclear scenario where a pure ^{56}Ni envelope is ejected at 10000 km s^{-1}. Events to the left of the dashed line cannot be fully powered with radioactive decay.

POSSIBLE EXPLOSION MECHANISMS

- Radioactive decay: Radioactive mass of 0.1$M_{\odot}$ is greater than total ejecta mass (see Fig. 3), excluded.
- ".Ia" model: KSN 2015K is too bright, excluded.
- Kilonova: KSN 2015K is too bright, excluded (see Fig. 2).
- Central engine (magnetar or accreting black hole): fine-tuning, and very rare. Unlikely.
- Orphan afterglow of LGRB: very rare, unlikely
- **Shock-breakout into CSM shell:**
  - **Models match light curve very well.**
  - **Suggested as explosion mechanism of PS1 fast transients (Drout+14).**
  - **Expect to find several in K2 Campaigns, based on PS1 sample rates.**

To test whether the shock breakout in CSM can explain the light curve of KSN2015K, we ran numerical radiation-hydrodynamical simulations of a supernova running into a circumstellar shell. Fig. 4 shows that for a model with CSM mass of 0.15$M_{\odot}$ and radii of roughly 4x10^{14} cm, the venting of the post-shock energy at breakout can explain KSN2015K's very rapid rise to a luminous peak. The post maximum luminosity is due to the diffusion of shock deposited energy from deeper layers. At later times (>10 days) the decline of the KSN2015k light curve becomes shallower and it is possible that radioactive ^{56}Ni decay contributes to the luminosity.

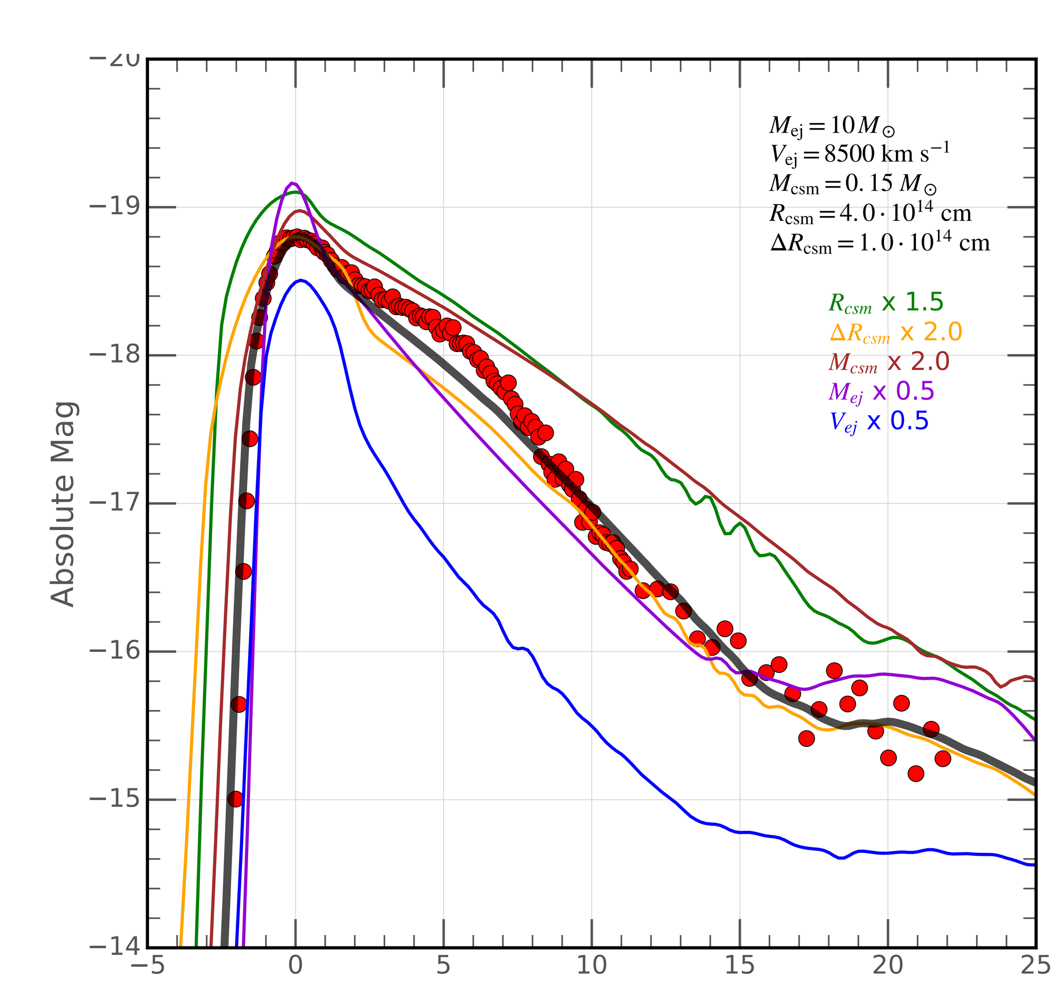

Fig. 4: **Light curve models.** The KSN2015K data (red points) compared to numerical radiation hydrodynamics simulations of the shock breakout in wind (SBW) models (lines). The best-fit model (black line, parameters shown inset) is able to capture the fast rise and peak magnitude of KSN2015K as well as the rapid decline due to cooling of the shock-heated CSM and ejecta.