Better Understanding Supernovae from the Kepler/K2 Mission

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KEGS – Kepler Extra-Galactic Survey
Better Understanding Supernovae from the Kepler/K2 Mission

- In the Beginning
- Physics of Supernovae
- Thermonuclear - Type Ia
- Core Collapse – Type II
- Other Transients
- The future - TESS

KEGS – Kepler Extra-Galactic Survey
Catching Supernovae on the Rise – Not Easy

SN 1998bu
In M96
Jha et al

SN Rise is the interesting part

Fading SN carry less information
A bright supernova is seen in a MW size galaxy about every 100 years

Kepler monitoring 100 large galaxies would catch a supernova once per year – on average

I aimed low and found nothing

U. Maryland asked to monitor 400 galaxies for AGN activity

6 supernovae in 3 years

Figure 1: Left: Combined light curves of 105 Type Ia supernovae from the SDSS-II Survey. The solid line shows a light curve with flux going as \( t^2 \) after explosion. Right: The simulated light curve of a single Type Ia observed with Kepler based on the signal-to-noise ratio measurements of faint cataclysmic variable stars observed by Kepler. The redshift of the simulated supernova is 0.05, the limit of the proposed search sample. No shock is simulated here, but shock emission lasting 12 hours or more would be easily detectable.

Plot from Cycle 2 proposal: Fastest ground-based cadence (at that time) versus simulated Kepler SN
The Kepler ExtraGalactic Survey (KEGS)

Rob Olling  Ed Shaya  Richard Mushostsky

Armin Rest  Peter Garnavich

Dan Kasen  Brad Tucker
The Physics of Supernovae

Thermonuclear
White Dwarf in Binary

Kinetic

Gravitational

Massive Stars

SN
The Physics of Supernovae

- Thermonuclear
  - 91T-like
  - 91bg-like
  - 02cx-like (lax)
- Kinetic
- Gravitational
- Massive Stars
- White Dwarf in Binary
- Supernova (SN)
- Pair-instability
- Increasing $^{56}$Ni
- Decreasing H/He Envelope
- Long GRB
  - broad-line
  - narrow-line
- Angular Mo?
- Magnetic+spin?
- Viewing angle
- Super-Luminous SN
- Ia
- Ic
- Ib
- IIb
- IIIL
- IIP
- Super-Chandra
- 02cx-like (Iax)
The Physics of Supernovae

Thermonuclear

Super-Chandra

91T-like

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02cx-like (lax)

White Dwarf in Binary

Kinetic

Circumstellar shock

Pair-instability

Increasing 56Ni

Decreasing H/He Envelope

Kinetic

NGC

02ic-like

Super-Chandra

Pair-instability

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Decreasing H/He Envelope

Gravitational

Circumstellar shock

SN

Long GRB

broad-line

narrow-line

Angular Mo?

Magnetic + spin?

Viewing angle

Super-Luminous SN

Ic

Ib

IIb

IIL

IIP

Decreasing H/He Envelope

Massive Stars

Gravity. It's not just a good idea. It's the Law.
Deflagration turns to Detonation – when? how?

Distribution of radioactive Ni – early rise? dark phase?

Simple early rise model (Arnett) – constant temperature => Flux~t^α where α=2

Progenitors – WD in binary, but
  – donor star uncertain
  – WD mass uncertain
  – trigger mechanism uncertain

If ^{56}\text{Ni} is deep, then energy takes a long time to diffuse out
Two Possible Progenitors

Degenerate white dwarf near $\sim 1.4 \, M_{\odot}$ can begin carbon burning in the center. But most WDs start out with lower mass. Need to raise mass of WD:

**Single Degenerate –** WD accretes from normal star

**Double Degenerate –** two WD merge
Early Shock Emission from SNIa?

Companion of single degenerate progenitor will shock ejecta. Test between DD & SD

Strong viewing angle dependence.

Shock brightness depends on size of secondary...Red Giants easy

Kasen shock light curves (B–band) added to normal SN Ia

Kasen 2010
Type Ia in the Kepler Field

KSN2012a $z=0.086$
KSN2011b $z=0.052$
KSN2011c $z=0.144$

MLCS2k2 fits consistent with type Ia

Second bump - SNIa

Bias toward fast-decliners (2MASS galaxy selection)

No color information, so no dust correction

Hubble scatter consistent with SDSS SNIa fit with red light curve

Olling+ (2015)
Early Light Curves – Test of Progenitor Models

30 Minute Cadence!!!
Continuous monitoring
Pre-Explosion
4000 Data Points per SN!
Search for “Kasen Shocks”
Degenerate companion – no shock expected
Large companion – possible shock lasting hours to days

Kepler Supernova 2011b

$F \propto (t-t_0)^{2.4}$

Days Since Explosion

 KEGS
Olling et al. 2015

6-hour average
Early Rise Shape

Fit flux function $F = C(t-t_0)^\alpha$

$t_0 => \text{“time of explosion” (assume no dark phase)}$

$\alpha=2$ is simple “fireball model”

Measured $\alpha$: 
- $2.12 \pm 0.14$
- $2.44 \pm 0.15$
- $2.58 \pm 0.33$

Simple model fits to 0.5% of peak on time scales of hours

Olling+ (2015)
A Second Chance: K2 Supernovae

Some Ground-base Follow-up, but it is hard with Sun angle.

22 extragalactic transients in K2 Campaigns 3-15

“K2 Supernova Experiment” C16 & C17

20000 Galaxies monitored—about 50 transients identified

Satellite reversed to allow simultaneous ground studies
Flashiest Result from the K2 Supernova Experiment

A Normal Type Ia at a redshift of 0.011 with an early bump

SN2018oh
(ASASSN-18bt)

Ed Shaya (Maryland)

Dimitriadis et al. 2019
+ talk this session

Shappee et al. 2019
+ Holoiien talk this session

Li, Wang, Vinko et al. 2019
Flashiest Result from the K2 Supernova Experiment

A Normal Type Ia at a redshift of 0.011 with an early bump

WD Companion?  Nickel Distribution?  Jet?

Dimitriadis et al. 2019
Shappee et al. 2019
Li, Wang, Vinko et al. 2019
Kepler “Core Collapse” Supernovae

Problems for Core-Collapse SN:

1) Shape of the rise? The rise is much faster than in Type Ia

3) Mass loss may cause range of circumstellar interaction strengths

3) Shock Break Out? After core-collapse it takes a day for the shock to reach the giant star surface: should make a detectable flash
Puzzles: Type II–P Shock Breakout

✧ Radius of RSG means breakout should be bright

✧ Breakout will be short ~ 1 day

✧ Circumstellar gas would modify early light curve

Predicted Shock Breakout light curves of Nakar & Sari (2010)
Kepler Type II-P – best defined II-P Light Curves

KSN 2011a – extremely fast rise

KSN2011d – rise consistent with simple photosphere model

Garnavich et al. 2016
KSN 2011d – Evidence for a Shock Breakout

Create simulation of light curve from Rabinak & Waxman model – no shock added
Smooth 30-minute cadence data to avoid binning bias
Detect 5-sigma deviation from simple model, $M = -15.6$ consistent with predictions for a RSG
Type II Caught by K2/Kepler

KSN2010A – IIln extremely long lasting => kinetic energy powered
KSN2016E – IIP z=0.083 rise missed
KSN2017M – IIb z=0.079 double peak => similar to SN 1993J

Shell around helium-rich envelop – interaction + radioactive decay

Bumps from varying circumstellar density?
The Power of Fast-Cadence, Wide-Field, Continuous Monitoring

Fast Extremely Luminous Transient (FELT)
KSN 2015K

Rest et al. 2018 (+talk at the end of this session)
On to TESS!

TESS light curve of the Asynchronous Polar CD Ind

Orbit - 112 min
WD spin - 111 min
Beat - 7 days

Littlefield et al. 2019
astro-ph today

Halaka, Ramsey et al. 2019
Poster 75
SN studies started small, but became a major science driver for K2 by the end.

Kepler/K2 have provided a unique look at supernova light curves on timescales and cadences never before possible.

Evidence for an early “extra” emission in some Type Ia events.

Diversity in SNII-P light curves – a shock breakout + circumstellar interaction.

Time to find another mission for SN to piggy-back on…