CSIRO PUBLISHING
Publications of the Astronomical Society of Australia
http://dx.doi.org/10.1071/AS11061
Review

Systematically Bridging the Gap Between Novae and Supernovae

M. M. Kasliwal

Department of Astronomy, California Institute of Technology, 1200 E. California Blvd,
M/C 249-17, Pasadena, CA 91125, USA, and
Carnegie Institution for Science, 813 Santa Barbara St, Pasadena, CA 91101, USA
Email: mansi@obs.carnegiescience.edu

Abstract: The venerable study of cosmic explosions is over a century old. However, until recently, there has existed a glaring six-magnitude luminosity gap between the brightest novae and faintest supernovae. Serendipitous discoveries, archival searches and ongoing systematic surveys are yielding optical transients that are fainter, faster and rarer than supernovae. Theorists predict a variety of mechanisms to produce transients in the gap and observers have the best chance of finding them in the local Universe. Here I review the discoveries and the unique physics of cosmic explosions that bridge this gap between novae and supernovae.

Keywords: surveys — novae, cataclysmic variables — supernovae: general

Received 2011 October 18, accepted 2012 June 15, published online 2012 July 12

1 Introduction

The venerable field of cosmic explosions has a rich history. Since the discovery of the first supernova in AD 185 and the first nova in AD 1670, we have discovered ≈ 6600 supernovae and ≈ 1000 novae. In the past century, explosions have unveiled the synthesis of elements heavier than iron, the acceleration of the Universe's expansion, and dark energy. However, our studies have been limited to thermonuclear supernovae (white dwarf detonation), core-collapse supernovae (massive star death), and classical novae (accretion-driven burning on a white dwarf).

Two fundamental parameters that describe an explosion are the peak luminosity and the duration. Using these two parameters to characterize transient events, we present a graphical summary of the framework of optical transients in Figure 1. Thousands of supernovae and novae could be neatly squared away into the three gray regions. However, until recently, there was a wide 'gap' spanning nearly three orders of magnitude in luminosity between novae and supernovae, particularly on short time-scales. This was no surprise and simply a product of observational bias towards finding the most luminous (supernovae) and most populous (novae) events first. Here, I discuss the theoretical predictions of transients in this gap and then recent progress in discovering at least four new classes of transient in this gap. This rapid progress has been made possible by three channels: systematic surveys, serendipitous discoveries, and archival searches.

This short review has a specific focus on explosive optical transients in the luminosity gap between novae and supernovae. Ultraviolet/X-ray transients, variable stars (e.g. luminous blue variables), and extremely luminous supernovae are not discussed here.

2 Theoretically Predicted Transients in the Gap

Theoretically, a wide variety of fundamental stellar outcomes are expected to result in transients in the gap. Recent discoveries have motivated detailed modeling to predict the explosion signatures of several of these outcomes.

2.1 Compact Binaries

First, let us take a closer look at accretion-powered thermonuclear runaways on the surfaces of white dwarfs. Both classical novae and supernovae of Type Ia (SN Ia) are outcomes of this process. A key difference between them is that classical novae have an ejecta mass of only 10^{-4}–$10^{-5}\,M_\odot$ and SN Ia undergo a complete detonation with an ejecta mass of 10^{-1}–$1\,M_\odot$.

Naturally, the question arises as to whether there are explosions in which the ejecta mass is intermediate. One scenario that gives ejecta between 10^{-2}–$10^{1}\,M_\odot$ is a '.Ia' explosion (Bildsten et al. 2007; Shen et al. 2010). In an ultra-compact white dwarf–white dwarf system, with a period shorter than an hour, suppose that mass is transferred from the lower mass helium white dwarf to the higher mass carbon–oxygen white dwarf. A series of novae will result. If the final helium flash is such that the nuclear time-scale is shorter than the hydrodynamical one, then the entire shell could detonate, resulting in a '.Ia' explosion. The name '.Ia' is drawn from characteristics that are a tenth of those seen in SN Ia, specifically

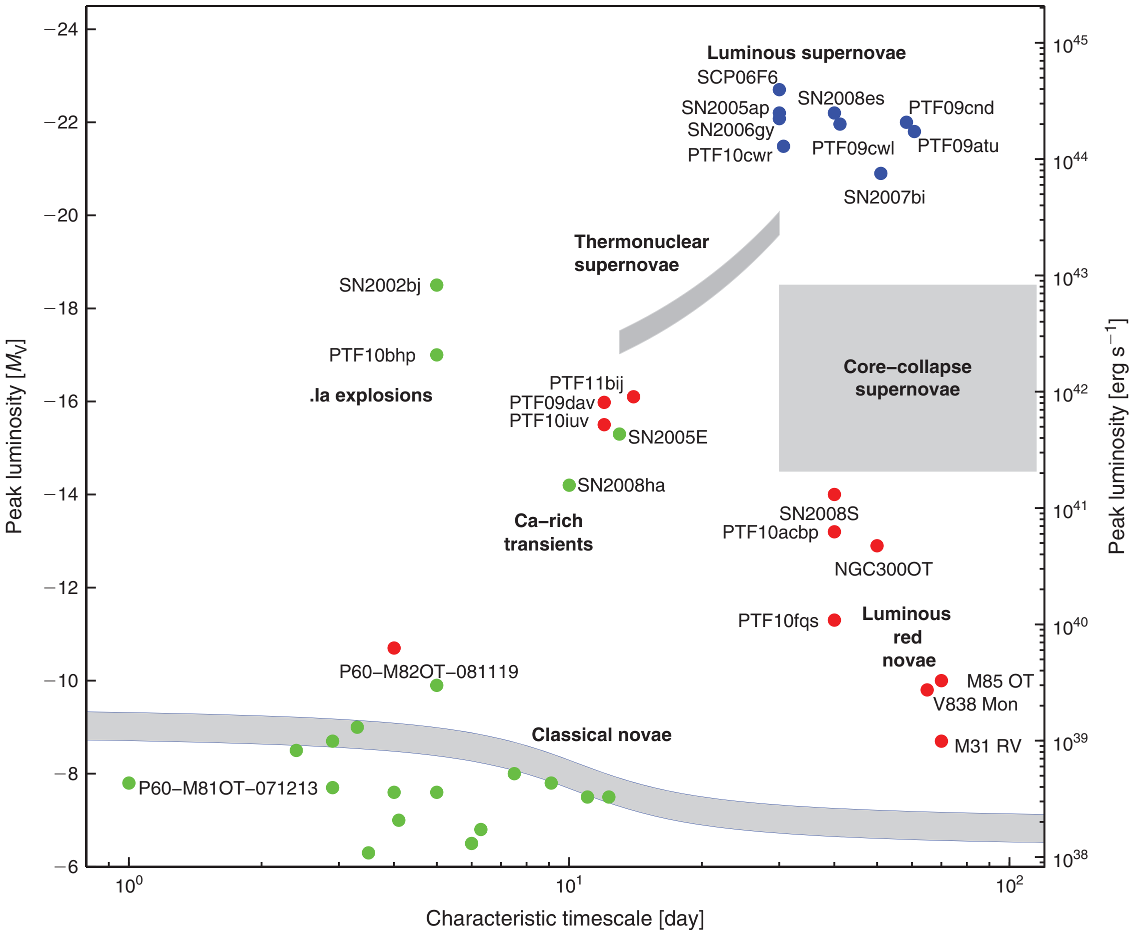

Figure 1 Framework of optical transients in the year 2011. Note that until 2005 we only knew about three classes (denoted by gray bands). In the past six years, systematic searches, serendipitous discoveries, and archival searches have uncovered a plethora of novel, rare transients. Several new classes are emerging and the governing physics is being widely debated: luminous red novae (electron-capture induced collapse of rapidly rotating O–Ne–Mg white dwarfs?), luminous supernovae (magnetars or pair-instability explosions?), .Ia explosions (helium detonations in ultra-compact white dwarf binaries), and calcium-rich halo transients (helium deflagrations?). (See Kasliwal 2011.)

the explosion mass, the characteristic time-scale, and the peak luminosity. Whether or not the shock wave also detonates the core is an open question (Waldman et al. 2011).

Next, we consider a scenario involving a total ejecta mass between 10^{-3}–$10^{-2}\,\mathrm{M}_\odot$: the accretion-induced collapse (AIC) of a rapidly rotating O–Ne–Mg white dwarf into a neutron star before ignition in the core (Metzger et al. 2009; Darbha et al. 2010). O–Ne–Mg white dwarfs require a relatively lower density for electron captures than C–O white dwarfs and thus are more likely to undergo AIC. As the white dwarf accretes mass, it also accretes angular momentum, leading to rapid rotation. After AIC, to conserve angular momentum, the proto-neutron star is expected to have a centrifugally supported disk. As this disk spreads to larger radii and cools, heavy nucleons form, causing the disk to become unbound. Although initially neutron-rich ($Y_\mathrm{e} \equiv n_\mathrm{p}/(n_\mathrm{p}+n_\mathrm{n}) \approx 0.1$), the irradiation of electron neutrinos by the proto-neutron star evens out the neutron-to-proton ratio ($Y_\mathrm{e} \approx 0.5$). Thus, nickel-56 is synthesized and a radioactivity-powered explosion follows. The characteristics of this explosion are a short lifetime, low luminosity, very high ejecta velocities approaching $0.1c$, and the absence of intermediate-mass elements.

Next, consider another situation in which the powerhouse of a radioactivity-powered explosion is not nickel-56. Specifically, in the case of neutron star–neutron star coalescence, the abundance of free neutrons allows significant quantities of very neutron-rich material (e.g. iodine-135, antimony-129, tellurium-129, xenon-135, tin-127) to be built up by the *r* process (Li & Paczyński 1998; Kulkarni 2005; Metzger et al. 2010). The half-life of these elements is only a few hours and consequently the explosion is also ephemeral. The peak luminosity is predicted to be in the range of 10^{40}–10^{42} erg s^{-1}. This class of objects has been referred to as mini-supernovae (Li & Paczyński 1998) or macronovae (Kulkarni 2005) or kilonovae (Metzger et al. 2010).

2.2 Massive Stars

Let us first review the current understanding of the core collapse of massive stars. The detailed underpinning of how the gravitational potential energy of the collapsing

Table 1. Theoretically predicted rates of transients

Scenario	Peak luminosity (Abs. mag.)	Time-scale (Days)	Universal rate ($\mathrm{Mpc^{-3}\,yr^{-1}}$)	Reference
.Ia explosion	-15 to -18	2–7	$0.6\text{–}2 \times 10^{-6}$	Shen et al. (2010); Bildsten et al. (2007)
Macronovae	-12 to -16	0.1–1	$10^{-5}\text{–}10^{-7}$	Metzger et al. (2010); Kulkarni (2005)
AIC	-13 to -16	0.1–4	$10^{-6}\text{–}10^{-8}$	Darbha et al. (2010)
Fallback SN	-4 to -21	0.5–2	5×10^{-6}	Fryer 2008, private communication
Type Ia SN	-17 to -20	20–40	3.0×10^{-5}	Li et al. (2011)
Core-collapse SN	-15 to -20	30–300	7.1×10^{-5}	Li et al. (2011)

iron core is converted into a shock-induced explosion is still being ironed out. Several mechanisms, including neutrino-heating-driven, magnetohydrodynamic, acoustic, and phase-transition-induced explosions, are being simulated. Recent three-dimensional simulations have finally been able to reproduce an explosion (Nordhaus et al. 2010).

Observationally, the different flavors of core collapse appear to be related to the envelope mass. The more massive the envelope, the lower the peak luminosity and slower the evolution (hence the subclasses of Type IIB, Type IIL, and Type IIP, from least massive to most massive envelope). Core-collapse supernovae that have expelled their hydrogen shell are called Type Ib and those with neither hydrogen nor helium are called Type Ic.

Unambiguous identification of eight progenitor stars in deep imaging prior to the explosions has directly shown that Type IIP supernovae come from red supergiants in the mass range $8.5\text{–}16.5 \pm 1.5\,\mathrm{M}_\odot$ (see the recent review by Smartt (2009) and references therein). It is expected that red supergiants in the mass range $15\text{–}25\,\mathrm{M}_\odot$ result in Type IIL supernovae, but this has not yet been observationally demonstrated. Two peculiar Type II supernovae have been seen from blue supergiants (SN1987A, SN2000cb: Kleiser et al. 2011).

We currently have very little direct evidence for the fate of more massive progenitors. The three cases in which we have seen a $>25\,\mathrm{M}_\odot$ progenitor star (or precursor eruption) resulted in three different types of supernovae (Type Ic SN2005gl, Gal-Yam & Leonard 2009; Type IIn SN2006jc, Pastorello et al. 2007; Type IIB SN2008ax, Crockett et al. 2008). Thus, the fate of stars more massive than $>25\,\mathrm{M}_\odot$ and stars in the transition range of $8\text{–}10\,\mathrm{M}_\odot$ is an open question.

Stars $>25\,\mathrm{M}_\odot$ may undergo black hole formation at the time of collapse. More massive stars have larger regions in the mantle that have increasing ρr^3 such that the shock wave slows and significant material falls back on to the core (Woosley & Weaver 1995; Heger et al. 2003). Such fallback can result in the formation of a black hole instead of a neutron star. Depending on the amount of fallback, the observed explosion is expected to be of lower luminosity and lower velocity and lack a radioactive tail in the light curve. In extreme cases, the shock wave may not be revived at all and the star would simply disappear into a black hole without any electromagnetic signature (Fryer 1999; O'Connor & Ott 2011). The lower the metallicity, the lower the mass loss due to winds and the larger the probability of black hole formation (Heger et al. 2003).

Stars in the $8\text{–}10\,\mathrm{M}_\odot$ range are expected to have O–Ne–Mg cores. Neutrinos produced by electron capture on neon-20 and magnesium-24 nuclei efficiently carry away the energy produced by nuclear burning. The core can collapse to form a neutron star; neutrino heating and the neutrino-driven wind can power an explosion. Such an explosion is expected to have low energy, produce little nickel-56, have an extended plateau phase, and eject very little oxygen (Kitaura, Janka & Hillebrandt 2006).

Thus, there are at least five stellar outcomes that motivate a search for transients in the gap. Additional ideas for unusual transients occuring earlier in stellar evolution include the merger of main sequence stars (Soker & Tylenda 2003) and planets being swallowed by their host star (Retter & Marom 2003). I summarize theoretically predicted rates (albeit uncertain) and compare them with rates of supernovae in Table 1.

3 Observed New Classes of Transients in the Gap

Recently, serendipitous discoveries (e.g. SN 2008ha) and archival searches (e.g. SN 2005E and SN 2002bj) have yielded novel transients in the gap. We undertook a systematic search for these transients with the synoptic survey 'the Palomar Transient Factory' (Law et al. 2009; Rau et al. 2009; Rahmer et al. 2008). Since these transients were expected to be fainter, faster, and rarer than supernovae, our search was designed to be deeper, higher cadence, and focus on the local Universe. Leveraging the clumpiness of the local Universe by searching nearby galaxy light concentrations, we were able to increase the odds of finding these rare events by a factor of four relative to blind pointings. Next, we summarize the distinct classes of transients in the gap (Figure 1).

3.1 Luminous Red Novae

The defining characteristics of the emerging class of luminous red novae (LRN; Figure 2) are large amplitude (>7 mag), peak luminosity intermediate between novae and supernovae (-6 to -14 mag), very red colors, and long-lived infrared emission. When the first extragalactic LRN was identified as such (Kulkarni et al. 2007), the

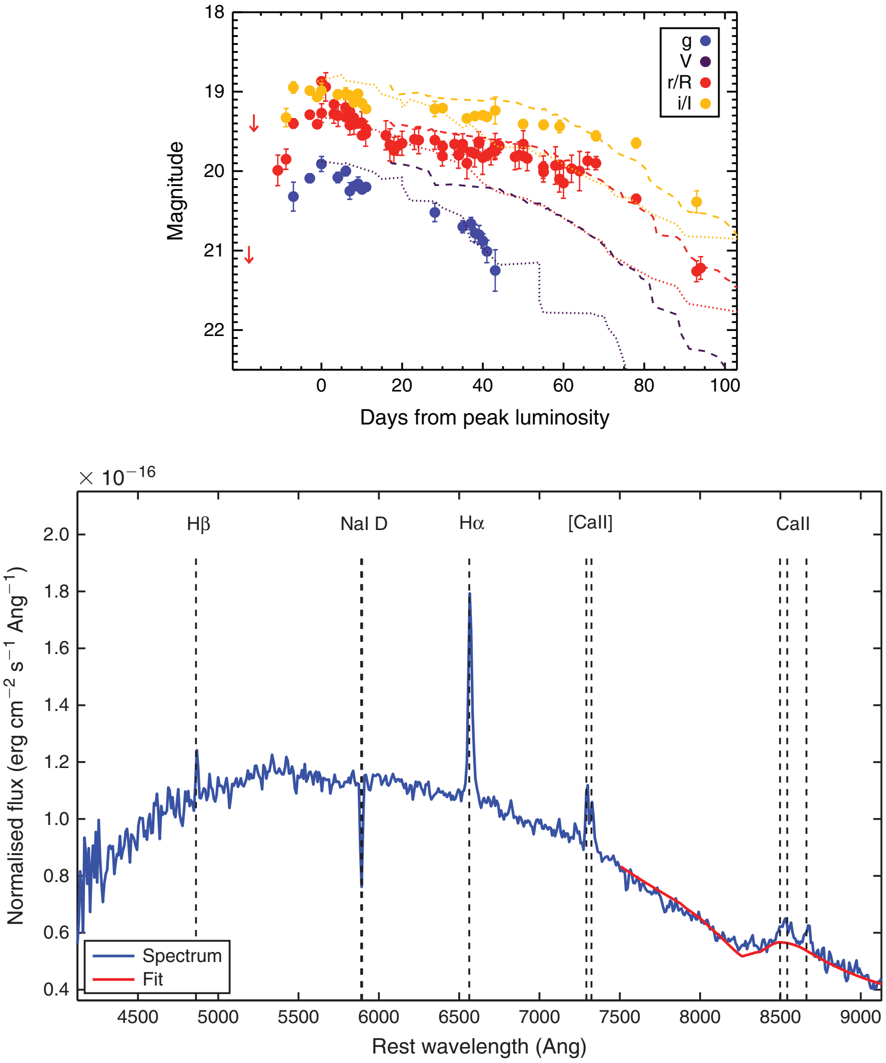

Figure 2 Light curve (top) and spectra (bottom) of PTF10fqs. PTF10fqs (solid symbols) is a member of the emerging class of LRN where the light curves evolve significantly more slowly in the redder bands. Also shown are light curves of SN2008S (dotted, shifted by +3 mag; Botticella et al. 2009) and NGC300-OT (dashed, shifted by +5.2 mag; Bond et al. 2009). On the spectra, note that in addition to the primarily narrow Balmer and calcium emission features there is a wide 10 000 km s^{-1} feature around 8600 Å, suggesting an explosive origin. (See Kasliwal et al. 2011b.)

similarities to three previously known Galactic explosions suggested a common origin. Since then, five more extragalactic and one more Galactic LRN have been discovered. Recent developments suggest there are at least two progenitor channels.

First, a less luminous but likely more prolific channel is the merger of main sequence stars. In particular, the well-sampled ten-year baseline of V1309 Sco showed clear evidence of a decaying orbital period prior to eruption (Tylenda et al. 2011). As the orbital period decayed, the second maximum in the light curve became weaker as the secondary was engulfed by the primary. This suggests that it was a mergeburst of a K-type main sequence star and a lower mass companion. The distance estimate is uncertain and the peak luminosity is ≈ -6 mag. It is plausible that other Galactic events also have similar origin, with higher luminosity corresponding to higher masses of the stars in the binary. However, this channel cannot be arbitrarily scaled up in luminosity beyond -10 mag.

Second, a more luminous but rarer channel is electron-capture supernovae in extreme asymptotic giant branch (eAGB) stars. In the year 2008, two serendipitous discoveries yielded the two nearest extragalactic LRN: NGC300-OT and SN 2008S. Their mid-infrared progenitor has been identified to be at the extremely luminous and red end of the AGB branch (Prieto et al. 2008; Thompson et al. 2009). In the year 2010, PTF discovered two extragalactic LRN: PTF 10fqs (Kasliwal et al. 2011b) and PTF 10acbp (Kasliwal et al. 2010a). We estimate a lower limit on the rate of $>7 \times 10^{-5}$ Mpc^{-3} (based on finding 2 LRN in the same volume as 13 core-collapse supernovae). The fundamental differences between the extragalactic and Galactic populations are higher peak luminosity range (-10 to -14 mag), higher velocities (10 000 km s^{-1}), and an infrared progenitor versus an

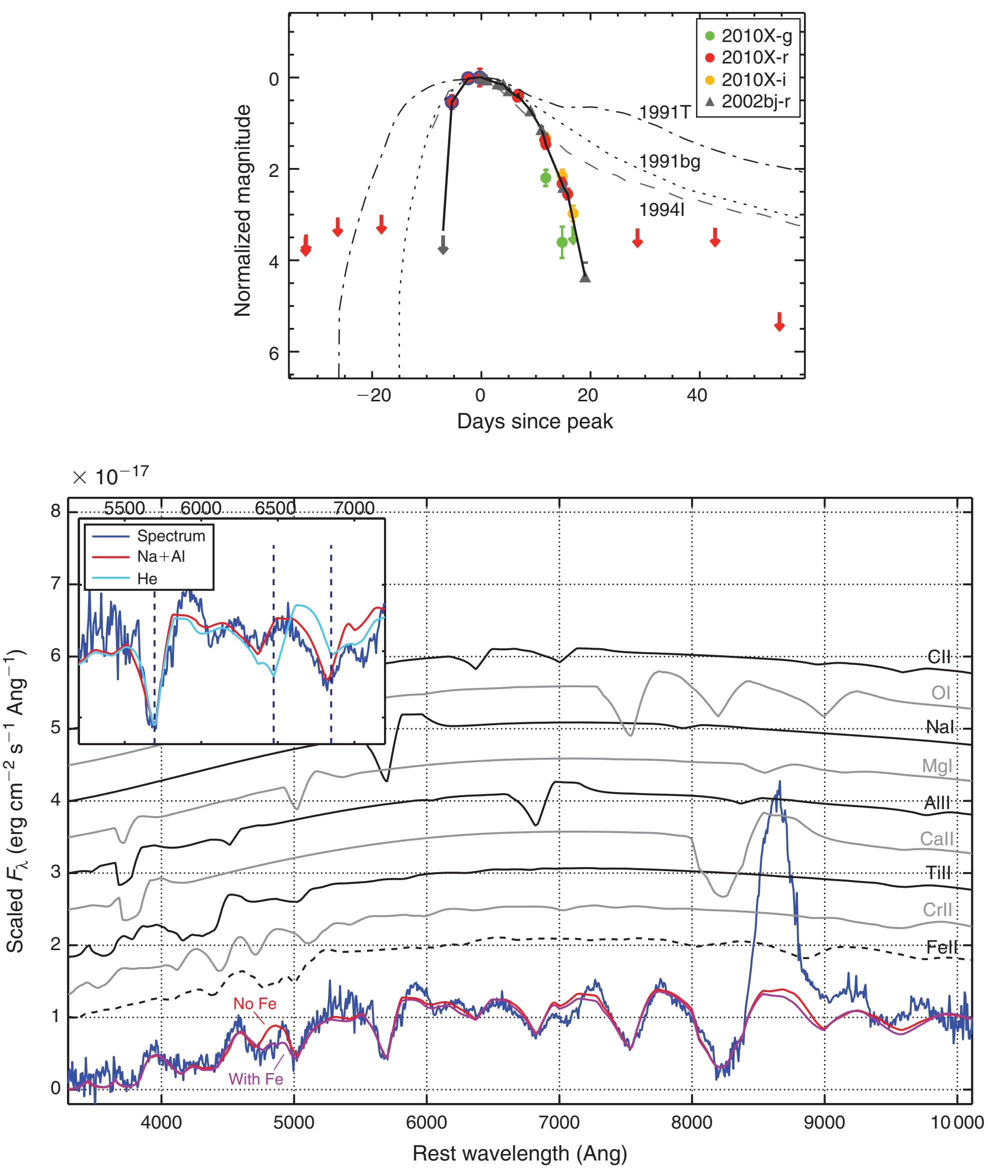

Figure 3 Light curve (top) and spectra (bottom) of PTF10bhp. This supernova rose in six days and then decayed exponentially on a timescale of five days. All observables are consistent with it being a '.Ia' explosion (He-shell detonation) in an ultra-compact AMCVn system. (See Kasliwal et al. 2010b.)

optical one. Thermal pulses could result in significant dust formation and are consistent with the deep limits on an optical progenitor. The luminosities, velocities and longevity in the redder bands are all consistent with electron capture in an O–Ne–Mg core of an eAGB star.

We note here that only two channels for the origin of LRN are presented here. There is a wider set of proposed scenarios for the origin of these transients in the literature (e.g. Berger et al. 2009; Botticella et al. 2009; Smith et al. 2009): luminous blue variable eruptions, an asteroid crashing into a white dwarf, accretion-induced collapse, peculiar core-collapse supernovae, and peculiar classical novae.

3.2 *'.Ia' Explosions*

All observables of PTF 10bhp (Kasliwal et al. 2010b) point towards it being a protypical '.Ia' explosion: short rise time of 6 days, exponential decline of 5 days, peak luminosity of −17 mag, velocities of 9000 km s^{-1}, and ejecta composition of Ca II, Ti II and He I (Figure 3). These properties are consistent with a helium detonation in an ultra-compact white dwarf (AMCVn) system. The only other supernova with as fast a photospheric evolution is SN 2002bj (identified as such an object eight years after explosion by an archive search: Poznanski et al. 2010). However, the lower velocities (4000 km s^{-1}) and higher peak luminosity (−18.5 mag) make the case for SN 2002bj as a '.Ia' explosion less clear. An unfortunate circumstance with PTF 10bhp was that it was too close to the Sun at the time of discovery. With future events, efforts to quantify the late-time photometric evolution and the late-time nebular spectrum better in order to measure ejecta masses directly will be undertaken. There has been steady progress on constraining the Galactic

AMCVn population (Roelofs, Nelemans & Groot 2007; Nelemans et al. 2001) and, recently, candidates that will merge within the Hubble time have also been identified (Kilic et al. 2011). Further progress here requires a larger sample to constrain the rates and hence, constrain the fraction of AMCVn (Brown et al. 2011) that undergo such an explosion.

3.3 Calcium-Rich Halo Transients

Recently, Perets et al. (2010) presented the mystery of SN 2005E, found by an archival search of the Lick Observatory Supernova Survey. Since then, PTF 09dav, PTF 10iuv, PTF 11bij, and SN 2007ke have also been identified to constitute a family of transients in the far-flung outskirts of their hosts with the following characteristics: peak luminosity lower than supernovae (-14 to -16 mag), rise time of 12 days, large photospheric velocities ($\approx 10\,000\,\mathrm{km\,s^{-1}}$), early spectroscopic evolution into the nebular phase (3 months), and nebular spectra dominated by calcium emission (Kasliwal et al. 2012). The nature of this class remains mysterious due to contradictory lines of evidence. While the halo location and lack of evidence of in situ star formation to deep limits suggest a white dwarf origin, the presence of hydrogen emission at late time suggests a massive star. There are two possible resolutions. One possibility is that the white dwarf explosion shock front ran into a previously ejected hydrogen-rich shell of a nova-like eruption. Another possibility is that the fates of massive stars formed in low-metallicity environments are entirely different, with a larger fraction undergoing significant fallback on to the core to form black holes. Progress here requires statistics to address whether or not the remote location is the key to explain this class or simply a red herring.

3.4 Low Velocity Gap Transients

Another curious transient in the luminosity gap is SN 2008ha (-14 mag: Foley et al. 2009; Valenti et al. 2009), discovered by a 14-yr-old amateur Caroline Moore (CBET#1567). In addition to the low velocity and the fast evolution, spectroscopically it is characterized by very low velocities ($2000\,\mathrm{km\,s^{-1}}$). Whether this is a white dwarf deflagration (Foley et al. 2009) or a massive core collapse (Valenti et al. 2009; Moriya et al. 2010) is questionable, and the membership of SN 2008ha in the SN 2002cx family of supernovae is also being debated.

4 Summary

In summary, we are at the brink of an explosion of new explosions (Figure 1). A handful of discoveries bridging the gap between novae and supernovae already suggests a diversity of physics. Systematic surveys are well poised to characterize the phase space of transients, especially on time-scales longer than a day. The 'hours to one day' regime remains the charter for next-generation synoptic surveys. With the advent of the Large Synoptic Survey Telescope at the beginning of the next decade, it will be trivial to discover even rarer transients. The challenge then would be in rapid identification and follow-up of the elusive events amidst the fire hose of other transients.

This decade is also expected to witness a network of advanced gravitational-wave detectors (advanced LIGO, advanced VIRGO, LCGT, INDIGO) coming online. Detecting gravitational waves from neutron star mergers every month is expected to become routine. A basic commonality between gravitational-wave searches and the electromagnetic search described above is that both are limited to the local Universe (say, $d < 200$ Mpc). A known challenge will be the poor sky localizations of the gravitational wave signal and consequent large false positive rate of electromagnetic candidates (Kulkarni & Kasliwal 2009). Therefore, prior to the ambitious search for an electromagnetic counterpart to a gravitational-wave signal, it would only be prudent to build this complete inventory of transients in the local Universe.

Acknowledgments

MMK acknowledges support from NASA's Hubble Fellowship and the Carnegie–Princeton Fellowship. The Palomar Transient Factory is a fully automated, wide-field survey aimed at a systematic exploration of explosions and variable phenomena in optical wavelengths. The program is centered on a 12K × 8K, 7.8 square degree CCD array (CFH12K) re-engineered for the 1.2-m Oschin Telescope at the Palomar Observatory by Caltech Optical Observatories. Photometric follow-up is undertaken by the automated Palomar 1.5-m telescope and other telescopes provided by consortium members including UC Berkeley, Weizman Institute, Israel, LCOGT, and the University of Oxford. For more information, see `http://www.astro.caltech.edu/ptf`.

References

Berger, E., et al., 2009, ApJ, 699, 1850
Bildsten, L., Shen, K. J., Weinberg, N. N. & Nelemans, G., 2007, ApJL, 662, L95
Bond, H. E., Bedin, L. R., Bonanos, A. Z., Humphreys, R. M., Monard, L. A. G. B., Prieto, J. L. & Walter, F. M., 2009, ApJL, 695, L154
Botticella, M. T., et al., 2009, MNRAS, 398, 1041
Brown, W. R., Kilic, M., Allende Prieto, C. & Kenyon, S. J., 2011, MNRAS, 411, L31
Crockett, R. M., et al., 2008, MNRAS, 391, L5
Darbha, S., et al., 2010, MNRAS, 409, 846
Foley, R. J., et al., 2009, AJ, 138, 376
Fryer, C. L., 1999, ApJ, 522, 413
Gal-Yam, A. & Leonard, D. C., 2009, Natur, 458, 865
Heger, A., Fryer, C. L., Woosley, S. E., Langer, N. & Hartmann, D. H., 2003, ApJ, 591, 288
Kasliwal, M. M., 2011, PhD Thesis, California Institute of Technology
Kasliwal, M. M., et al., 2010a, ATel, 3094, 1
Kasliwal, M. M., et al., 2010b, ApJL, 723, L98
Kasliwal, M. M., Cenko, S. B., Kulkarni, S. R., Ofek, E. O., Quimby, R. & Rau, A., 2011a, ApJ, 735, 94
Kasliwal, M. M., et al., 2011b, ApJ, 730, 134
Kasliwal, M. M., et al., 2012, ApJ, in press

Kilic, M., Brown, W. R., Allende Prieto, C., Agüeros, M. A., Heinke, C. & Kenyon, S. J., 2011, ApJ, 727, 3

Kitaura, F. S., Janka, H. & Hillebrandt, W., 2006, A&A, 450, 345

Kleiser, I., et al., 2011, MNRAS, 415, 372

Kulkarni, S. R., 2005, ArXiv astrophysics e-print (arXiv:0510256)

Kulkarni, S. & Kasliwal, M. M., 2009, in Astrophysics with All-Sky X-Ray Observations, Proceedings of the RIKEN Symposium, ed. N. Kawai, T. Mihara, M. Kohama & M. Suzuki (Wako, Saitama: RIKEN and JAXA), 312.

Kulkarni, S. R., et al., 2007, Natur, 447, 458

Law, N. M., et al., PASP, 121, 1395

Li, L. & Paczyński, B., 1998, ApJL, 507, L59

Li, W., Chornock, R., Leaman, J., Filippenko, A. V., Poznanski, D., Wang, X., Ganeshalingam, M. & Mannucci, F., 2011, MNRAS, 412, 1473

Metzger, B. D., Piro, A. L., Quataert, E. & Thompson, T. A., 2009, ArXiv e-print (arXiv:0908.1127)

Metzger, B. D., et al., 2010, MNRAS, 406, 2650

Moriya, T., Tominaga, N., Tanaka, M., Nomoto, K., Sauer, D. N., Mazzali, P. A., Maeda, K. & Suzuki, T., 2010, ApJ, 719, 1445

Nelemans, G., Portegies Zwart, S. F., Verbunt, F. & Yungelson, L. R., 2001, A&A, 368, 939

Nordhaus, J., Burrows, A., Almgren, A. & Bell, J., 2010, ApJ, 720, 694

O'Connor, E. & Ott, C. D., 2011, ApJ, 730, 70

Pastorello, A., et al., 2007, Natur, 447, 829

Perets, H. B., et al., 2010, Natur, 465, 322

Poznanski, D., et al., 2010, Sci, 327, 58

Prieto, J. L., et al., 2008, ApJL, 681, L9

Rahmer, G., Smith, R., Velur, V., Hale, D., Law, N., Bui, K., Petrie, H. & Dekany, R., 2008, in Ground-Based and Airborne Instrumentation for Astronomy II, Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE), ed. I. S. McLean & M. M. Casali, Vol. 7014 (Bellingham: SPIE), 70144Y

Rau, A., et al., 2009, PASP, 121, 1334

Retter, A. & Marom, A., 2003, MNRAS, 345, L25

Roelofs, G. H. A., Nelemans, G. & Groot, P. J., 2007, MNRAS, 382, 685

Shen, K. J., Kasen, D., Weinberg, N. N., Bildsten, L. & Scannapieco, E., 2010, ApJ, 715, 767

Smartt, S. J., 2009, ARA&A, 47, 63

Smith, N., et al., 2009, ApJL, 697, L49

Soker, N. & Tylenda, R., 2003, ApJL, 582, L105

Thompson, T. A., Prieto, J. L., Stanek, K. Z., Kistler, M. D., Beacom, J. F. & Kochanek, C. S., 2009, ApJ, 705, 1364

Tylenda, R., et al., 2011, A&A, 528, A114

Valenti, S., et al., 2009, Natur, 459, 674

Waldman, R., Sauer, D., Livne, E., Perets, H., Glasner, A., Mazzali, P., Truran, J. W. & Gal-Yam, A., 2011, ApJ, 738, 21

Woosley, S. E. & Weaver, T. A., 1995, ApJS, 101, 181