Dartmouth College
Dartmouth Digital Commons

Open Dartmouth: Faculty Open Access Articles

7-20-2010

SN 2010U: A Luminous Nova in NGC 4214

Roberta M. Humphreys
University of Minnesota

José L. Prieto
Carnegie Observatories

Philip Rosenfield
University of Washington

L. Andrew Helton
University of Minnesota

Christopher S. Kochanek
The Ohio State University

See next page for additional authors

Follow this and additional works at: https://digitalcommons.dartmouth.edu/facoa

Part of the Astrophysics and Astronomy Commons

Recommended Citation

Humphreys, Roberta M.; Prieto, José L.; Rosenfield, Philip; Helton, L. Andrew; Kochanek, Christopher S.; Stanek, K. Z.; Khan, Rubab; Szczygiel, Dorota; Mogren, Karen; and Fesen, Robert A., "SN 2010U: A Luminous Nova in NGC 4214" (2010). *Open Dartmouth: Faculty Open Access Articles*. 1800.
https://digitalcommons.dartmouth.edu/facoa/1800

This Article is brought to you for free and open access by Dartmouth Digital Commons. It has been accepted for inclusion in Open Dartmouth: Faculty Open Access Articles by an authorized administrator of Dartmouth Digital Commons. For more information, please contact dartmouthdigitalcommons@groups.dartmouth.edu.

Authors
Roberta M. Humphreys, José L. Prieto, Philip Rosenfield, L. Andrew Helton, Christopher S. Kochanek, K. Z. Stanek, Rubab Khan, Dorota Szczygiel, Karen Mogren, and Robert A. Fesen

This article is available at Dartmouth Digital Commons: https://digitalcommons.dartmouth.edu/facoa/1800

The Astrophysical Journal Letters, 718:L43–L47, 2010 July 20 doi:10.1088/2041-8205/718/1/L43
© 2010. The American Astronomical Society. All rights reserved. Printed in the U.S.A.

SN 2010U: A LUMINOUS NOVA IN NGC 4214*

Roberta M. Humphreys[1], José L. Prieto[2,6], Philip Rosenfield[3], L. Andrew Helton[1], Christopher S. Kochanek[4], K. Z. Stanek[4], Rubab Khan[4], Dorota Szczygiel[4], Karen Mogren[4], Robert A. Fesen[5], Dan Milisavljevic[5], Benjamin Williams[3], Jeremiah Murphy[3,7], Julianne Dalcanton[3], and Karoline Gilbert[3]
[1] Astronomy Department, University of Minnesota, Minneapolis, MN 55455, USA; roberta@umn.edu
[2] Carnegie Observatories, Pasadena, CA 91101, USA
[3] Astronomy Department, University of Washington, Seattle, WA 98195, USA
[4] Astronomy Department, The Ohio State University, Columbus, OH 43210, USA
[5] Department of Physics & Astronomy, Dartmouth College, Hanover, NH 03755, USA
Received 2010 May 23; accepted 2010 June 9; published 2010 July 2

ABSTRACT

The luminosity, light curve, post-maximum spectrum, and lack of a progenitor on deep pre-outburst images suggest that SN 2010U was a luminous, fast nova. Its outburst magnitude is consistent with that for a fast nova using the maximum magnitude–rate of decline relationship for classical novae.

Key words: novae, cataclysmic variables – stars: individual (SN 2010U) – supernovae: individual (SN 2010U)

1. INTRODUCTION

Episodic high mass loss events dominate the final stages of massive star evolution. The evidence for these events is observed across the upper H-R diagram ranging from giant eruptions like η Car, and the "LBV nebulae" associated with many of the luminous blue variables (LBVs) to the cool hypergiants and red supergiants like IRC +10420 and VY CMa with their complex circumstellar ejecta. Unfortunately, the observational record is sparse because these stars are rare and their importance has only been fully recognized in recent years.

Modern supernova surveys are finding a growing assortment of similar and related objects. These "impostors" are underluminous, have spectra with narrow emission lines and much slower ejection velocities. Some of these objects may be undergoing "giant" eruptions possibly similar to η Car but with much shorter durations (e.g., SN 2009ip; Smith et al. 2010). Others appear to be generically related to the normal LBV/S Dor variables like SN 2002 kg (Var 37 in NGC 2403; Weis & Bomans 2005; Van Dyk et al. 2006; Maund et al. 2006). A third subgroup including SN 2008S and the NGC 300 optical transient were heavily obscured prior to the outburst (Prieto et al. 2008; Prieto 2008); their progenitors may have recently evolved from a high mass losing stage such as an asymptotic giant branch (AGB) star or red supergiant (Smith et al. 2009; Bond et al. 2009; Berger et al. 2009; Botticella et al. 2009; Thompson et al. 2009; Prieto et al. 2009). We used to think that "eruptions" in which the star increased its total luminosity were primarily associated with the most massive stars, upward of 40–50 $M_\odot$, but the latter pair apparently originated from 10 to 20 $M_\odot$ stars (references above and Gogarten et al. 2009). It is thus increasingly apparent that these eruptions or outbursts may not all be the same phenomenon; the objects represent a range of stellar masses and may originate from stars in different evolutionary states.

Although discovery of these transient non-terminal eruptions are becoming more common, our information about them is still very incomplete. The most recent addition, SN 2010U in NGC 4214, was first reported in eruption on 2010 February 5 (Nakano 2010) at apparent magnitude ∼16 on unfiltered CCD frames. An early spectrum (Marion et al. 2010) with strong, narrow emission lines of hydrogen, Ca II, and Na I with P Cyg absorptions, quickly showed that it was not a true supernova, but possibly an eruptive variable or transient.

In this Letter, we present pre- and post-eruption observations of SN 2010U and a analysis of the associated stellar population in NGC 4214. Our discussion of its light curve, spectrum, and limitations on the mass and luminosity of its likely progenitor suggests that SN 2010U is a very luminous nova, not the eruption of a massive star.

2. PRE- AND POST-ERUPTION OBSERVATIONS

The discovery photometry for SN 2010U reported in Nakano (2010) listed magnitudes of 16.0 (Feb 5.6), 16.3 (Feb 5.7), 15.9 (Feb 6.5), and 16.3 (Feb 6.6) on unfiltered CCD frames from different observers. However, a fainter *R* magnitude of 17.3 was reported by Brimacombe also on 2010 February 6.[8] This difference of more than a magnitude in such a short time seemed too large to be realistic. At our request, the observers kindly provided their unfiltered CCD images. We determined the magnitude of SN 2010U relative to three Sloan Digital Sky Survey (SDSS) stars in the field with gri photometry converted to broadband *R* magnitudes. The photometry was done on galaxy-subtracted images, using an SDSS *r*-band image for the template galaxy (Freedman et al. 2009). The results yield an *R* band magnitude near 17 mag ± 0.2–0.3 mag. We also obtained post-eruption photometry of SN 2010U with Retrocam on the MDM[9] Hiltner 2.4 m telescope on Kitt Peak and the Large

* Some of the data presented in this Letter were obtained from the Multimission Archive at the Space Telescope Science Institute (MAST). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Support for MAST for non-HST data is provided by the NASA Office of Space Science via grant NNX09AF08G and by other grants and contracts.

[6] Hubble and Carnegie-Princeton Fellow.

[7] NSF Astronomy and Astrophysics Postdoctoral Fellow.

[8] http://www.rochesterastronomy.org/sn2010/index.html

[9] The MDM Observatory is owned and operated by a consortium of five universities: the University of Michigan, Dartmouth College, the Ohio State University, Columbia University, and Ohio University.

Table 1
Journal of Observations and Magnitudes

JD	Calendar Date	Magnitude	Filter	Observer or Telescope
2455233.1	2010 Feb 5	17.2	Unfiltered[a]	Itagaki
2455233.2	2010 Feb 5	16.9	Unfiltered[a]	Kadota
2455233.2	2010 Feb 5	17.2	Unfiltered[a]	Itagaki
2455233.8	2010 Feb 6	17.1	Unfiltered[a]	Yusa
2455234.1	2010 Feb 6	17.3	Unfiltered[a]	Itagaki
2455234.2	2010 Feb 6	16.9	Unfiltered[a]	Kadota
2455235.9	2010 Feb 8	18.53 ± 0.05	SDSS-g	MDM
2455235.9	2010 Feb 8	17.88 ± 0.02	SDSS-r	MDM
2455247.9	2010 Feb 20	19.64 ± 0.03	SDSS-r	MDM
2455252.8	2010 Feb 25	19.92 ± 0.11	SDSS-r	MDM
2455252.8	2010 Feb 25	20.63 ± 0.09	SDSS-i	MDM
2455273.9	2010 Mar 18	22.59 ± 0.17	Bessel-U	LBT
2455273.9	2010 Mar 18	23.20 ± 0.09	Bessel-B	LBT
2455273.9	2010 Mar 18	22.53 ± 0.05	Bessel-V	LBT
2455273.9	2010 Mar 18	21.35 ± 0.03	Bessel R	LBT

Note. [a]Approximate "*R*" band, see the text.

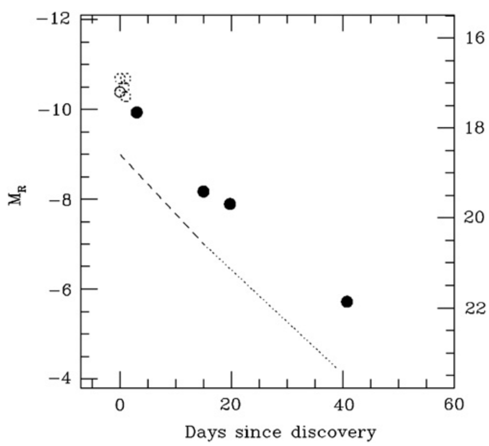

Figure 1. Light curve for SN 2010U showing the discovery photometry from CBET 2161 transformed to an approximate "*R*" band (see the text) and our CCD red photometry. The MDM *r*-band magnitudes have been converted to the Bessel *R*-band. The dashed lines show the t_2 (0–15 days) and t_3 (15–26 days) declines discussed in Section 3.

Binocular Camera (Giallongo et al. 2008) on the LBT[10] on Mt. Graham. The journal of observations and measured magnitudes for SN 2010U is included in Table 1 and the resulting light curve is shown in Figure 1.

Adopting an approximate "*R*-band" magnitude of 17.1 for maximum light yields a red absolute magnitude of ≈−10.5 at a mean distance of ≈3.2 Mpc for NGC 4214 from the NASA/IPAC Extragalactic Database[11] with $A_R = 0.06$ mag foreground Galactic reddening (Schlegel et al. 1998). SN 2010U was clearly sub-luminous for a supernova. Its maximum luminosity was more like the classical LBVs in their high mass loss or optically thick wind stage (Humphreys & Davidson 1994). However, SN 2010U's very rapid decline is not typical of LBVs.

We located the position of the transient on a deep, archival pre-outburst *HST*/*WFC3* F814W image of NGC 4214 (Proposal 11360; PI: R. O'Connell) obtained on 2009 December 23 and shown in Figure 2. To solve the relative astrometry between the post-outburst LBT *R*-band image obtained on 2010 March 18 and the pre-outburst WFC3 image, we used six bright, isolated point sources around the position of the transient identified in the WFC3 image. The astrometric solution was obtained using a second-order polynomial transformation with standard tasks in IRAF (*geotran* and *geomap*). The final rms of the solution is 0″.013 and 0″.021 in the *x* and *y* axes of the WFC3 image, respectively. As can be seen in Figure 2, there is no progenitor identified in the pre-outburst WFC3 image within the uncertainties of the relative astrometry. We obtained consistent results using shallower archival WFPC2 and LBT pre-outburst images.

The associated stellar population is shown on the color–magnitude diagram (CMD) in Figure 3(a). The *HST*/*WFPC2* $F555W$ and $F814W$ archival observations obtained on 1997 December 9 were reduced using the same procedure and with the same quality cuts as applied to the ANGST sample (see details in Dalcanton et al. 2009). The observations were calibrated and flat-fielded using the standard *HST* pipeline and the magnitudes were measured using HSTphot (Dolphin 2000). Only the highest quality photometry is used for the CMD. The color coding corresponds to the spatial distribution of the stars relative to the position of SN 2010U in the lower panel.

We find no visible star at the position of SN 2010U down to the 50% completeness limiting magnitudes of 24.4 and 23.5 of the $F555W$ and $F814W$ images, respectively, and thus no candidate precursor. At the distance of NGC 4214, these magnitude limits imply an upper limit of ∼−3.2 mag to the absolute visual magnitude of a possible progenitor. Most of the stars within ≈100 pc of SN 2010U are relatively faint and red, with $F555W$–$F814W$ colors of ∼1–2 mag, suggesting that the likely precursor is associated with an evolved population. The internal interstellar reddening is not known, consequently we show the reddening vector on the CMDs in Figure 3. Of course, it is possible that the progenitor star may have been heavily obscured by circumstellar dust prior to its eruption, similar to the NGC 300 OT (Prieto 2008) and SN 2008S (Prieto et al. 2008), and therefore be an intrinsically more luminous star. However, the spatial distribution (Figure 3(b)) of the younger and more

[10] The Large Binocular Telescope is an international collaboration among institutions in the United States, Italy, and Germany. The LBT Corporation partners are: the University of Arizona on behalf of the Arizona university system; the Istituto Nazionale di Astrofisica, Italy; the LBT Beteiligungsgesellschaft, Germany, representing the Max Planck Society, the Astrophysical Institute Potsdam, and Heidelberg University; the Ohio State University; and the Research Corporation, on behalf of the University of Minnesota, University of Notre Dame, and University of Virginia.
[11] http://nedwww.ipac.caltech.edu/

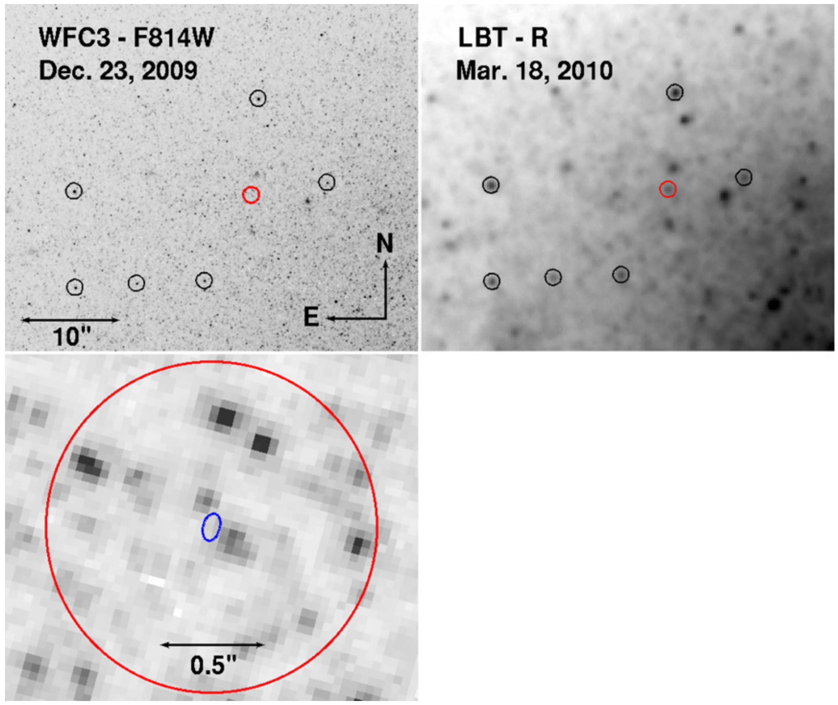

Figure 2. Top left: WFC3 I-band (F814W) image from 2009 December 23. The black circles mark the six stars used for the relative astrometry. The red circle marks the position of the transient after solving the relative astrometry between WFC3 and LBT image. All the circles have radius 0″.8. Top right: LBT image from 2010 March 18 showing SN 2010U and used to determine the relative astrometry. The same stars are marked here (circles have the same radius) and the red circle marks the position of the transient. Lower left: zoomed-in WFC3 F814W image around the position of the transient. The minor and major axes of the blue ellipse are three times the rms of the astrometric solution. The minor axis radius is 0″.04, and the major axis radius is 0″.06. The rms of the astrometric solution is 0″.013 in the x-axis and 0″.021 in the y-axis. The two closest stars to the position of the transient are 0″.132″ and 0″.120″ away, respectively, 5.3 and 4.9 times the rms of the astrometric solution.

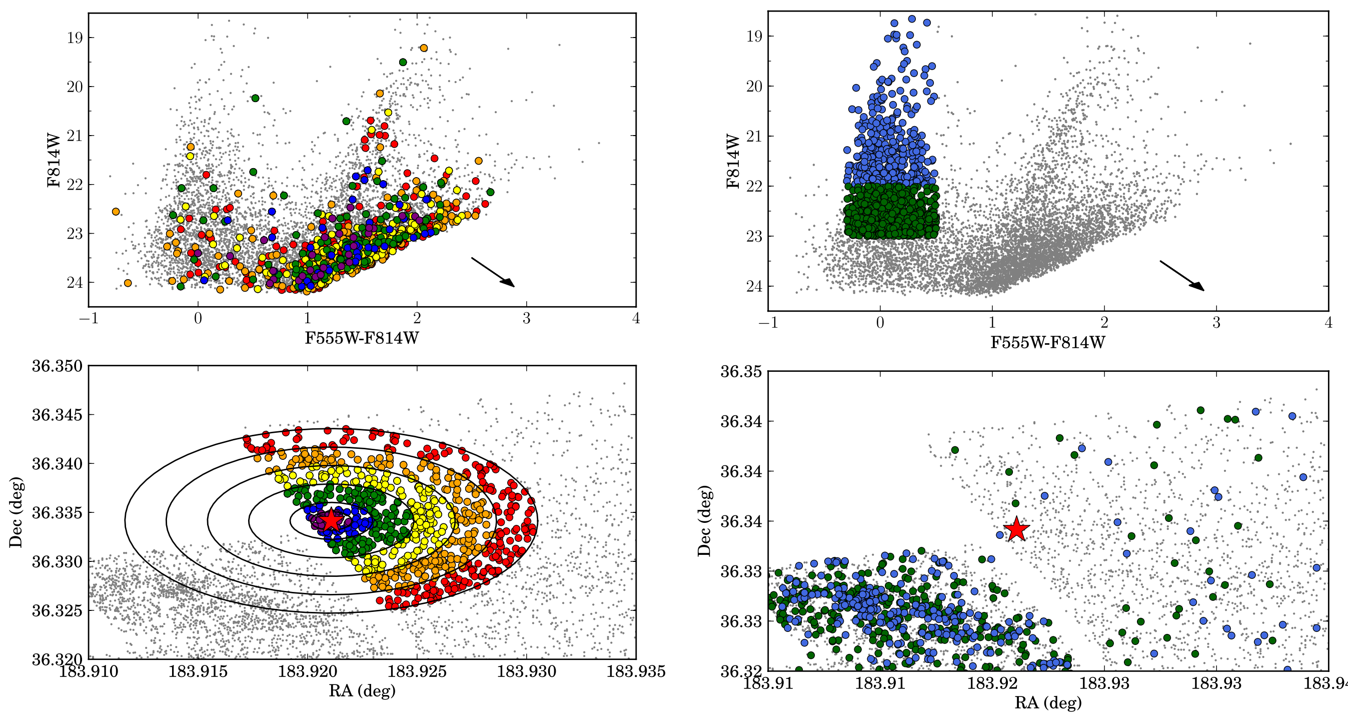

Figure 3. Top left: CMD from the archival data field (gray), the colors correspond to the spatial distribution in the lower panel. Bottom left: spatial distribution of the stars in the archival field (gray) with stars near SN 2010U color coded by projected distance, within 50 pc (purple), 100 pc (blue), 200 pc (green), 300 pc (yellow), 400 pc (orange), and 500 pc (red). The location of SN 2010U is marked with a red star. Top right: the CMD with the young main-sequence stars; $m_{F814W} < 22$ (blue) and $22 < m_{F814W} < 23$ (green). Bottom right: the spatial distribution of the stars in the above panel with the same color scheme. The reddening vector is shown in the upper panels.

luminous main sequence stars shows that the precursor star is not closely associated with a more massive young population. This, however, does not rule out an obscured, evolved star (AGB) of lower mass. Based on the CMDs, the characteristics of the

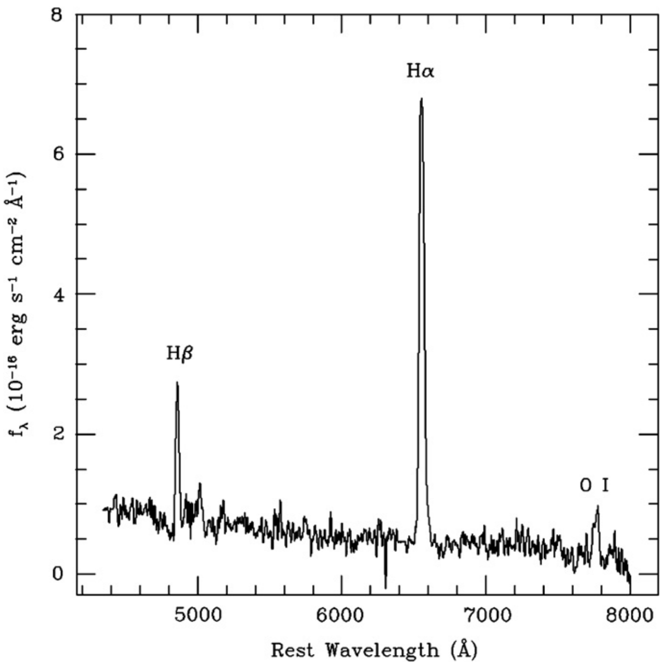

Figure 4. Flux calibrated post-maximum spectrum of SN 2010U.

associated stellar population, and the limiting magnitudes of the images, we suggest that the progenitor (or its companion) was most likely an evolved intermediate mass star, with an upper mass limit of 3–5 $M_\odot$.

This conclusion is supported by the post-maximum spectrum obtained on 2010 February 20, 14 days after the discovery. The CCDS spectrograph on the Hiltner 2.4 m MDM telescope was used with the 150*l* grating giving a resolution of ∼14 Å with a 2″ slit. The low-resolution spectrum is shown in Figure 4. The spectrum is dominated by strong emission lines of Hα and Hβ plus the O I blend at 7774 Å. This is not the spectrum of an LBV at maximum nor does it resemble the spectra of the less luminous transients such as SN 2008S and the NGC 300-OT. The strong O I emission indicates that it is most like a post-maximum nova. The lines are resolved with an FWHM of ∼1900 km s^{-1}, and the radial velocities of their line centers are 200–300 km s^{-1}. The Hα and Hβ line profiles are asymmetric to the red, and Hα has asymmetric wings extending to −2300 km s^{-1} and +3200 km s^{-1}. The asymmetry in the line profiles and the wings may be due to remnant P Cyg absorption. Hα and O I λ7774 also have split profiles possibly indicative of a bi-polar outflow or planar disk (Lynch et al. 2006). Similar profiles are often observed in classical novae (Lynch et al. 2006; Austin et al. 1996; Della Valle et al. 2002). The blue and red emission peaks in the O I line are shifted by −610 km s^{-1} and +460 km s^{-1}, respectively, relative to the line center. The corresponding shifts in Hα are less, −374 km s^{-1} and +150 km s^{-1}. Other weaker lines in the spectrum are identified with Fe II, [Fe II] and [O I]. The nebular [O III] lines may also be present, but they are blended with other lines.

3. DISCUSSION

The rapid decline of the light curve, the post-maximum spectrum, and the relatively low mass and luminosity inferred from the lack of a precursor on deep pre-eruption images and the associated stellar population, all suggest that SN 2010U was a luminous nova.

SN 2010U shares characteristics with the fast novae. If we adopt the observations by the amateur observers and assume that it was at or near maximum, then the time to decline by 2 mag (t_2) is 15 days and the time to decline by 3 mag (t_3) is 26 days. These decline rates are consistent with a fast nova. Classical novae obey the maximum magnitude–rate of decline (MMRD) relation of Della Valle & Livio (1995). Adopting M_r of −10.5 for maximum light and a $V-R$ color of 1.1–1.5 mag from V1500 Cyg, a classical nova a few days past-maximum light (Gallagher & Ney 1976), M_v is ≈−9 to −9.4 mag, near the upper luminosities observed for CNe. A t_2 of 15 days implies a maximum M_v of −8.7 mag (Downes & Duerbeck 2000), comparable to SN 2010U's maximum luminosity. Of course, it is possible that the maximum was missed and SN 2010U was more luminous, but the P Cyg profiles reported in Marion et al. (2010) indicate that it was not missed by more than a few days. Furthermore, a typical fast to moderately fast nova, with t_2 ∼ 15 days, has emission lines with FWHM from 2000 km s^{-1} up to as high as 6000 km s^{-1}. SN 2010U is on the low end but consistent with this range. Kasliwal et al. (2010) have recently described a group of fast and luminous novae that are apparently inconsistent with the MMRD relation. However, SN 2010U is at the upper end of luminosities expected from the MMRD relation for normal novae and was super-Eddington at maximum.

While not a high mass eruptive variable like most of the other "SN impostors," SN 2010U was indeed an impostor and is an excellent example of the need for post-maximum photometry and spectra, and a study of the stellar environment to determine the nature and evolutionary state of these objects.

We are especially grateful to the observers Syuichi Nakano, Koichi Itagaki, Ken-ichi Kadota, and Toru Yusa for forwarding their discovery images of SN 2010U. C.S.K. and K.Z.S. acknowledge support by the NSF grant AST-0908816; K.Z.S. is also supported by the NSF grant AST-0707982. J.L.P. acknowledges support from NASA through Hubble Fellowship grant HF-51261.01-A awarded by the STScI, which is operated by AURA, Inc., for NASA, under contract NAS 5-26555. J.W.M. is supported by an NSF Astronomy and Astrophysics Postdoctoral Fellowship under award AST-0802315. This work was also partially supported by AR-10905 from the Space Telescope Science Institute.

Facilities: LBT, Hiltner, HST(WFPC2, WFC3)

REFERENCES

Austin, S. J., Wagner, R. M., Starrfield, S., Shore, S. N., Sonneborn, G., & Bertram, R. 1996, AJ, 111, 869
Berger, E., et al. 2009, ApJ, 695, 310
Bond, H. E., Bedin, L. R., Bonanos, A. Z., Humphreys, R. M., Monard, L. A. G. B., Prieto, J. L., & Walter, F. M. 2009, ApJ, 695, 154
Botticella, M. T., et al. 2009, MNRAS, 398, 1041
Dalcanton, J. J., et al. 2009, ApJS, 183, 67
Della Valle, M., & Livio, M. 1995, ApJ, 452, 704
Della Valle, M., Pasquini, L., Daou, D., & Williams, R. E. 2002, A&A, 390, 155
Dolphin, A. E. 2000, PASP, 112, 1383
Downes, R. A., & Duerbeck, H. W. 2000, AJ, 120, 2007
Freedman, W. L., et al. 2009, ApJ, 704, 1036
Gallagher, J. S., & Ney, E. P. 1976, ApJ, 204, 35
Giallongo, E., et al. 2008, A&A, 482, 349
Gogarten, S. M., Dalcanton, J. J., Murphy, J. W., Williams, B. F., Gilbert, K., & Dolphin, A. 2009, ApJ, 703, 300
Humphreys, R. M., & Davidson, K. 1994, PASP, 196, 1025
Kasliwal, M. M., Cenko, S. B., Kulkarni, S. R., Ofek, E. O., Quimby, R., & Rau, A. 2010, arXiv:1003.1720
Lynch, D. K., et al. 2006, ApJ, 638, 987
Marion, G. H., Vinko, J., Wheeler, J. C., & Shetrone, M. 2010, CBET, 2163, 1

Maund, J. R., et al. 2006, MNRAS, 369, 390
Nakano, S. 2010, CBET, 2161, 1
Prieto, J. L. 2008, ATel, 1550, 1
Prieto, J. L., Sellgren, K., Thompson, T. A., & Kochanek, C. S. 2009, ApJ, 705, 1425
Prieto, J. L., et al. 2008, ApJ, 681, L9
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Smith, N. 2010, AJ, 139, 1451
Smith, N., et al. 2009, ApJ, 697, 49
Thompson, T. A., Prieto, J. L., Stanek, K. Z., Kistler, M. D., Beacom, J. F., & Kochanek, C. S. 2009, ApJ, 705, 1364
Van Dyk, S. D., Li, W., Filippenko, A. V., Humphreys, R. M., Chornock, R., Foley, R., & Challis, P. M. 2006, arXiv:astro-ph/0603025
Weis, K., & Bomans, D.J. 2005, A&A, 429, 13