Swift UVOT Observations of Core-Collapse SNe

Peter J. Brown*, Peter W. A. Roming*, Daniel E. Vanden Berk*, Stephen T. Holland†, Stefan Immler†,∗∗ and Peter Milne‡

*Pennsylvania State University, Dept of Astronomy & Astrophysics, University Park, PA 16802
†Astrophysics Science Division, X-Ray Astrophysics Branch, Code 662, NASA Goddard Space Flight Center, Greenbelt, MD 20771
∗∗Universities Space Research Association, 10211 Wincopin Circle, Columbia MD 21044
‡Dept of Astronomy and Steward Observatory, University of Arizona, Tucson, AZ 85721

Abstract. We review recent UV observations of core-collapse supernovae (SNe) with the Swift Ultra-violet/Optical Telescope (UVOT) during its first two years. Rest-frame UV photometry is useful for differentiating SN types by exploiting the UV-optical spectral shape and more subtle UV features. This is useful for the real-time classification of local and high-redshift SNe using only photometry. Two remarkable SNe Ib/c were observed with UVOT – SN2006jc was a UV bright SN Ib. Swift observations of GRB060218/SN2006aj began shortly after the explosion and show a UV-bright peak followed by a UV-faint SN bump. UV observations are also useful for constraining the temperature and ionization structure of SNe IIP. Rest-frame UV observations of all types are important for understanding the extinction, temperature, and bolometric luminosity of SNe and to interpret the observations of high redshift SNe observed at optical wavelengths.

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INTRODUCTION

In addition to the follow-up observations of Gamma Ray Bursts (GRBs), the Swift satellite [1] observes supernovae (SNe) discovered primarily from the ground. These observations capitalize on Swift’s rapid response capability, flexible short term scheduling, and multi-wavelength capabilities, particularly UV observations with the Ultra-Violet/Optical Telescope (UVOT; [2]) and X-ray observations with the X-Ray Telescope (XRT; [3]). The UV observations of SNe Ia and X-ray observations performed by Swift are discussed elsewhere in this volume [4,5]. Here we focus on the use of UV photometry to distinguish SN types, and describe UVOT observations of several core-collapse SNe. A list of the core-collapse SNe observed in the first two years of Swift UVOT (2005 and 2006) is given in Table 1.

| Type | Observations |
|------|--------------|
| Ib   | SN2006dn     |
|      | SN2006fc     |
| Ic   | SN2005cb     |
| IIP  | SN2005cs     |
| IIb  | SN2006T      |
| IIn  | SN2006bv     |

TABLE 1. Core-Collapse SNe observed by Swift in 2005-6.
FIGURE 1. UVOT grism spectra of SNe 2005am (Ia) and 2005cs (II) showing the difference in UV-optical shape of the spectral energy distribution [6,7]. The effective area curves of the UVOT filters are also shown (from Poole et al. in preparation.)

SN PHOTOTYPING WITH UV PHOTOMETRY

The UV properties of young SNe I and II are very different. Young SNe II have extremely high photospheric temperatures, resulting in a large quantity of UV photons. The atmospheres of SNe I (including the subtypes Ia, Ib, and Ic) are usually much cooler when observed. This creates a flux continuum that is severely depleted in the UV already, with many lines from iron peak elements blocking much of the remaining UV flux. The difference is well represented in Fig 1 which compares UV grism spectra obtained with Swift UVOT for the SN Ia 2005am [6] and the SN II 2005cs [7]. Also shown are the effective area curves of the Swift UVOT filters. The strong difference between the UV-optical flux distribution allows SNe II to be distinguished from SNe I without a spectrum [8,9], expanding the idea of phototyping which has been explored by several authors in the optical bands [10,11]. The UV-optical difference is especially important for classifying high redshift SNe observed in the optical [8,12].
FIGURE 2. Color-color plots showing the differentiation of different SN types using rest-frame UV and optical photometry. The colors are given in the UVOT’s Vega system (Poole et al. in preparation), but the u, b, and v colors are close to the Johnson system so that the lower right panel is comparable to the U-B vs. B-V plots in [11]. Extinction vectors in the UV depend on the spectral shape of the source and the extinction curve chosen, so are not plotted here.
UVOT’s 6 filters, spanning the UV and optical from 1700 Å to 6000 Å, provide excellent coverage of the bluer wavelengths where SNe are most clearly differentiated. Color-color plots using the 6 filters are displayed in Fig 2. They utilize the photometry of two SNe Ia (2005am and ke), two SNe Ic (2006aj and 2007Y), and two SNe II (2005cs and bp). One advancement with the UVOT photometry is the better time sampling out to later times than the generally sparse UV observations available for previous studies.

There is a high degree of overlap in the optical colors, as shown in the lower right hand panel of Fig. 2 (see equivalent plots in [11]). The general trend is that as more UV information is used, the SNe II become better separated from the SNe Ia. SNe II are in general bluer, though SNe Ia are extremely faint in the UVM2 filter [6], resulting in the UV colors of SNe Ia being very red in uvm2-uvw1 but blue in uvw2-uvm2. In all colors, however, the reddening of the SNII spectrum with time makes its colors more similar to a Ia as it becomes older. Milky Way extinction will also have a similar effect, though a full discussion of that is beyond the scope of this paper. Thus a SN II cannot be conclusively distinguished from a Ia without addition information on the age and reddening. The cadence of the SN search, behavior of light curve, or an approximate absolute magnitude might break the degeneracy.

Differentiating SNe Ib/c from SNe Ia is more difficult. The UV colors distinguish the Ic SN2006aj, which in the optical colors transitions from near the blue SNe II to the red SNe Ia but in the UV colors remains closer to the locus of SNe II. Another Ic SN2007Y, however, has a different color evolution that is harder to distinguish from SNe Ia. As both SNe Ic are peculiar it is not known what range of UV colors SNe Ib/c could have.

**SN 2006jc – Ib**

Spectral features from various SN types were identified in early spectra of SN2006jc which is perhaps best classified as a peculiar Ib, though from comparisons with Fig 2, its colors [13] would have led to it being confidently (but erroneously) phototyped as a young SN II. The blue optical continuum is attributed to Fe II emission lines blended into a pseudocontinuum [14]. UV grism spectra with UVOT also reveal emission from Mg II (Immler et al. 2007, in preparation) which suggests circumstellar matter interaction is also a contributor to the UV. X-ray emission was detected with Swift XRT and Chandra [15]. The blue colors persist and there is little color evolution as the SN fades. Light curves of SN2006jc in three filters are displayed in the left panel of Fig. 3. The full curves will be presented and discussed by Modjaz et al. (in preparation).

**GRB060218/SN 2006aj – Ic**

Swift triggered on GRB060218 and was able to observe the accompanying SN likely within minutes of core-collapse. The UVOT light curves exhibit a peculiar double peaked structure, as seen in the central panel of Fig 3. The first peak is UV-bright, likely from the shock breaking out of a wind-blown cocoon [16-18]. Self-absorbed synchrotron radiation has also been used to explain it [19]. The first peak is followed about ten days later by a second, broader peak driven by radioactive decay in the SN ejecta. The relative
FIGURE 3. Swift UVOT photometry of SN2006jc, a peculiar Ib (left panel), and SN2006aj, a SN Ic associated with GRB060218 (center panel), and SN2006at, a SN II (right panel). For clarity, only two UV filters (UVW2 and UVW1) are shown along with the V curves for comparison.

The strong UV flux at early times makes SNe II attractive targets for UV observations. Three SNe II have been well observed by Swift, namely SNe 2005cs, 2006at, and 2006bp. Current efforts have focused on modelling SNe 2005cs and 2006bp which had excellent optical spectroscopic coverage to accompany the Swift observations. Particularly at early times, UV observations put strong constraints on the line of sight extinction. As the photosphere cools, the UV flux drops dramatically due to the temperature and the subsequent line blanketing of iron-peak elements. Sample lightcurves of SN2006at are displayed in the right panel of Fig 3. The steeper decay at shorter wavelengths is a reflection of the rapid reddening of the SED. UV observations, which are a probe of the strength of the line blanketing, provide constraints on the temperature/ionization state of the ejecta. The observations and preliminary modelling for SNe 2005cs and 2006bp have been presented [7,20] with more detailed, quantitative results to be presented by Dessart et al. (2007 in prep).
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