

**Scientific Justification** *Be sure to include overall significance to astronomy; limit text to one page with figures, captions and references on no more than two additional pages.*

When massive stars end their lives in core-collapse supernova explosions, they are classed as either Type II if they show emission lines of hydrogen in their early optical spectra, or Type Ib/c if they do not. Nearly 10% of all Type II supernovae in the Padova-Asiago Supernova Catalog (<http://web.oa.pd.inaf.it/supern/>) show quite narrow emission features sitting atop the broad lines from the supernova ejecta. The narrow features in these so-called “Type IIn” supernovae are thought to arise from ionised circumstellar material which the expanding shock wave has not yet reached. This circumstellar material may be the last stages of mass-loss from a Wolf-Rayet or Luminous Blue Variable (LBV) progenitor star (Chu et al. 1999). As the expanding shock wave plows through this material, radio and X-ray emission is produced, the strength of which reflects the density. By watching how the radio, optical, UV, and X-ray fluxes evolve as the shock wave traverses earlier mass-loss material, we can in a sense replay in reverse the last few thousand years of stellar evolution.

The oldest known Type IIn supernova, SN 1978K in the late-type spiral galaxy NGC 1313, also happens to be one of the closest at just 4.13 Mpc (Mendez et al. 2002). However, it was only recognised as a supernova event when Ryder et al. (1993) pieced together evidence from optical spectroscopy, archival UKST imaging, ATCA and MOST radio maps, and ROSAT X-ray observations. Model fitting of the radio light curve suggested an explosion date of mid-1978, which subsequent monitoring has refined to late-May 1978. SN 1978K is also remarkable in that a possible progenitor object was identified at  $B \sim 22$ , which brightened by at least 6 magnitudes during the outburst, then returned to almost its pre-outburst brightness. This unusual optical behaviour in SN 1978K and some other Type IIn events has led some to suggest (e.g. Van Dyk 2005; Maund et al. 2006) that Type IIn events may in fact be “supernova imposters” in the form of a super-outburst of an LBV. Such a super-outburst however cannot account for the extreme radio and X-ray luminosity of SN 1978K.

In a recent paper Tanaka et al. (2012) report the results of a search for infrared emission from 6 core-collapse supernovae with ages 10–100 yrs and distances  $< 7$  Mpc that had been observed with the AKARI and *Spitzer* satellites. Only the youngest of these, SN 1978K was detected. They rule out the possibility of a light echo from dust formed in the ejecta or in the pre-supernova stellar wind since the observed IR luminosity is much higher than their model predicts. Instead, by fitting the spectral energy distribution which includes our ATCA radio fluxes they attribute this emission to shock heating of  $1.3 \times 10^{-3} M_{\odot}$  of silicate dust to a temperature of 230 K. However their model assumes a rapidly decaying SN outburst luminosity, even though the UV and X-ray emission has remained consistently strong throughout (Fig. 1; Smith et al. 2012).

We have been performing long-term multi-wavelength monitoring and spectroscopic studies of SN 1978K for almost two decades (Ryder et al. 1993; Schlegel et al. 1999; Smith et al. 2007, 2012). While the radio flux has steadily declined (with some possible chromatic variations), the X-ray emission has stayed remarkably bright and constant over the past decade. In XMM-Newton Cycle 11 (May 2012 – April 2013), we have been awarded 103 ksec of Priority C time to continue our detailed X-ray and UV studies of SN 1978K. In the same Cycle, 113 ksec of Priority B time was also awarded to another team to perform observations of the accreting Ultra-Luminous X-ray sources (ULXs) in NGC 1313 coordinated with the NuSTAR X-ray satellite; SN 1978K will also be in the field of view of these observations. Here we propose to complement these observations with contemporaneous optical photometry and spectroscopy using Gemini. Our program of radio monitoring is also ongoing. Since our understanding of the later-time evolution of Type IIn supernovae is limited, and no optical/UV observations have been made since 2009, it is important to not miss

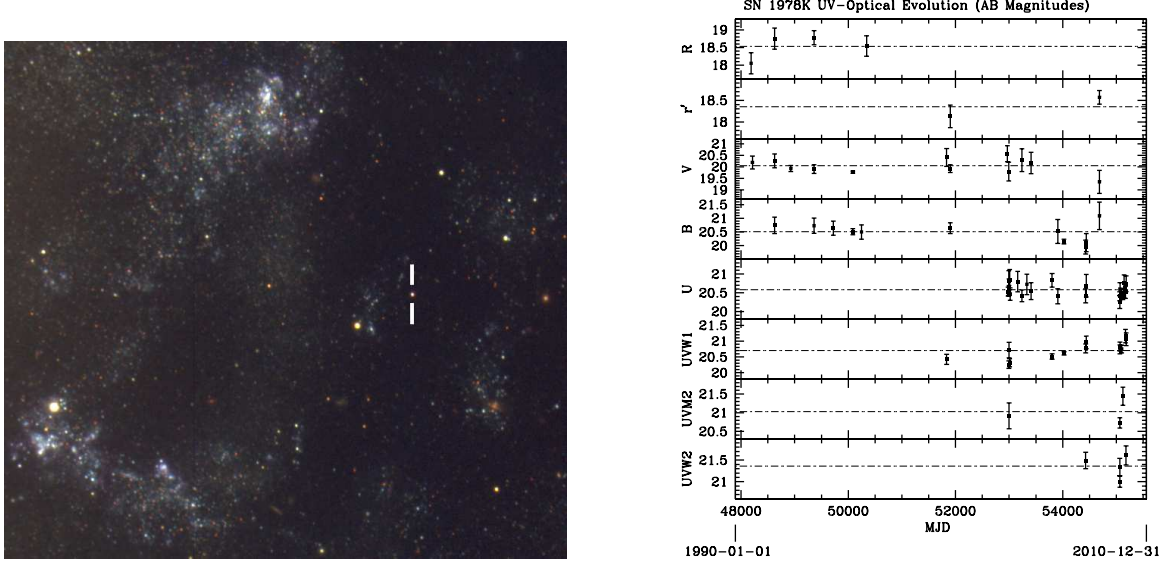


Figure 1: (left) A “true colour” image of SN 1978K (between vertical white bars) constructed from  $g'$ ,  $r'$ , and  $i'$  imaging with GMOS in August 2008. (right) The long-term evolution of the UV and optical brightness for SN 1978K from monitoring with the XMM/Newton and Swift satellites, the SSO 1.0m and 2.3m telescopes, the AAT, and Gemini (Smith et al. 2012).

any changes in the multi-wavelength emission.

In Semester 2008B we were allocated time for GMOS imaging and spectroscopy of SN 1978K. A “true colour” image of the environment around SN 1978K, and UV/optical light curves are shown in Figure 1. Surprisingly given the large amount of circumstellar dust inferred by Tanaka et al. (2012) there is little clear indication of significant fading or brightening of SN 1978K in the past 2 decades. However the optical magnitudes in particular come from a heterogeneous collection of telescopes, and require the use of transforms between filter systems (e.g.  $R$  and  $r'$ ) that are not ideal for emission line sources like SN 1978K. A new set of images in 2012B with the same filters and CCDs in GMOS-S as those used in 2008B will enable us to detect much more precisely any variation in the actual brightness. In addition a new spectrum (flux-calibrated using the imaging) will help confirm whether these changes are due purely to dust reddening, or to physical changes in the emission regions (and hence in the line ratios) themselves. From the line ratios and widths, we can learn how the mass-loss material currently being probed by the shock wave compares with that measured when the supernova was just half its present age. This can then serve as a pointer to what can be expected of younger Type II<sub>in</sub> objects in the future.

## References

- Chu, Y., et al. 1999, ApJ, 512, L51
- Gruendl, R., et al. 2002, AJ, 123, 2847
- Maund, J., et al. 2006, MNRAS, 369, 390
- Méndez, B., et al. 2002, AJ, 124, 213
- Ryder, S., et al. 1993, ApJ, 416, 167
- Schlegel, E., Ryder, S., Staveley-Smith, L., Petre, R., Colbert, E., & Dopita, M. 1999, AJ, 118, 2689

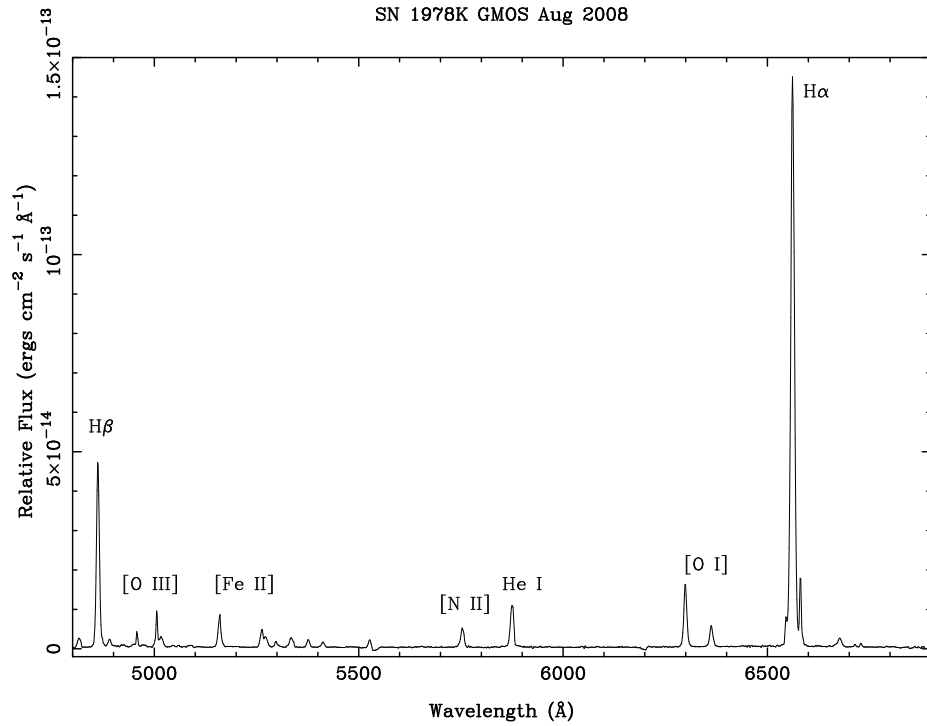


Figure 2: GMOS spectrum of SN 1978K from August 2008, with prominent lines marked. Most of the weaker features are shock-excited [Fe II] lines (from Smith et al. 2012).

Smith, I., Ryder, S., Böttcher, M., Tingay, S., Stacy, A., Pakull, M., & Liang, E. 2007, *ApJ*, 669, 1130

Smith, I., Ryder, S., Böttcher, M., Pakull, M., & Liang, E. 2012, in prep.

Tanaka, M., et al. 2012, *astro-ph/1202.4203*

Van Dyk, S. 2005, *ASP Conf. Ser.* 332, 449

**Technical Description**

*Justify the instrument configuration, the exposure times and the constraints requested (seeing, cloud cover, sky brightness and, if appropriate, water vapor and elevation). Limit text to one page with no additional figures or references.*

We propose to get new images under photometric conditions in SDSS  $u'$ ,  $g'$ ,  $r'$ , and  $i'$  of SN 1978K in order to check if it has faded (or even brightened) since our Aug 2008 images (Fig. 1). The closest spectral analog for SN 1978K available in the GMOS ITC is that of the H II region, which is a not unreasonable proxy as Fig. 2 shows. In Dec 2000, we measured B=20.8, V=20.0, R=17.6, and I=19.3 for SN 1978K. Assuming IQ=85%, CC=50%, SB=80%, and 4×4 binning, we find that 3×200 sec in  $u'$ , and 3×30 sec in each of  $g'$ ,  $r'$ , and  $i'$  yields a S/N of at least 50 in each filter. Allowing for 6 min acquisition, and readout time for 12 (heavily binned) exposures, we estimate a total time for the imaging of just 0.5 hr, so less integration time would be very inefficient.

For the relative spectrophotometry we assume IQ=70%, CC=70%, SB=80%, and 2×2 binning. With the R831 grating covering 480–690 nm, and a 1''0 slit giving a resolution  $R \sim 2200$ , three exposures of 1200 sec each would yield a  $S/N \gtrsim 100$  for most of the bright lines, enabling us to measure the current expansion velocity while picking out any of the weaker forbidden lines seen in earlier spectra. We repeat this with the B1200 grating to cover the 370–510 nm range, with an overlap that allows us to match the blue and red spectra using the  $H\beta$  and [O III]  $\lambda\lambda 4949, 5007$  lines. Including readouts and a 16 min acquisition, the spectroscopy component will require an additional 2.4 hrs, making our request a modest 2.9 hrs in total.

**Band 3 Plan** *If applying for queue time and it is acceptable for the proposal to be scheduled in Band 3, describe the changes to be made to allow it to be successful in Band 3 (limit text to half a page).*

Observing conditions specified also suitable for Band 3.

**Classical Backup Program** *If applying for classically scheduled time, describe the program you will pursue should the weather be worse than the requested observing conditions (limit text to half a page).*

This is not a classical request

**Justify Target Duplications** *If your targets have been previously observed by Gemini using similar setups to those proposed here, justify the duplication below.*

Last observed by us in August 2008. This request is to look for changes since then.

**Publications** *Enter a list of publications written by the PI and Co-Is that support this proposal.*

Kankare, E., Mattila, S., Ryder, S., et al. 2012, ApJ, 744, L19. “Discovery of Two Supernovae in the Nuclear Regions of the Luminous Infrared Galaxy IC 883”

Romero-Canizales, C., Mattila, S., Alberdi, A., Perez-Torres, M., Kankare, E., & Ryder, S. 2011, MNRAS, 415, 2688. “The core-collapse supernova rate in Arp 299 revisited”

Knapen, J., Sharp, R., Ryder, S., Falcon-Barroso, J., Fathi, K., & Gutierrez, L. 2010, MNRAS, 408, 797. “The central region of M83: Massive star formation, kinematics, and the location and origin of the nucleus”

Ryder, S., Sharp, R., Illingworth, S., & Farage, C. 2010, PASA, 27, 56. “The Nuclear Ring in the Barred Spiral Galaxy IC 4933”

Kankare, E., Ryder, S., Mattila, S., Romero-Canizales, C., Perez-Torres, M.-A., & Alberdi, A. 2011, CBET 2889. “Supernova 2011hi in IC 883 = PSN J13203538+3408222”

**Use of Other Facilities or Resources** *List any applications to non-Gemini facilities that are related to this proposal.*

XMM-Newton Cycle 11 (May 2012 – April 2013): Awarded 103 ksec of Priority C time to continue our detailed X-ray and UV studies of SN 1978K.

**Previous Use of Gemini** *List allocations of telescope time on Gemini to the PI during the last 2 years, together with the current status of the data.*

| Reference     | Allocation | % Useful | Status of previous data   |
|---------------|------------|----------|---|
| GN-2011A-Q-48 | 4.8h       | 100      | Discovered SN 2011hi in UGC 8387 (Kankare et al. 2011).                                 |
| GN-2011B-Q-73 | 3.2h       | 100      | Obtained reference imaging for SNe 2010O and 2010P in Arp 299, final paper now in prep. |
| GN-2012A-Q-56 | 5.8h       | 34       | <i>JH</i> reference images for SNe 2010cu and 2011hi in UGC 8387                        |