Scientific Justification

Type Ia supernovae (SNIa) are thermonuclear explosions of a white dwarf (WD) in a binary system. They have been proven as excellent distance indicators for constraining cosmological parameters and are major contributors to chemical enrichment. There are,however, several open questions regarding the physics of the explosions that still need to be addressed, for eg. the distribution of the ejecta or the initial central density. Most data on SNIa is collected at the early photospheric phase. In contrast, the late time, nebular phase ($>\sim$ 100 days after maximum) has very little data. At these epochs the ejecta is optically thin at most wavelengths and no continuum is produced. Instead, the spectrum is dominated by forbidden line transitions of iron-group elements. The strength and shape of the lines provides information about the abundance stratification and density distribution in the core of the exploded object. High quality spectra at upto 400 days past maximum have been used to infer the 3-D abundance distribution in the ejecta (Maeda et al. [2010])

SN2014J is the closest SN is more than 4 decades. Hence, it stays bright even at late epochs. Due to their faintness, very few objects have been spectroscopically followed up in the NIR at epochs close to a year after maximum light. A very small fraction of those have spectra at more than one epoch. Thus, SN2014J, offers an opportunity to consistently follow-up an SN in the nebular phase. We would like to take Near Infrared (NIR; $0.8 - 2.2\mu$m) spectra between +400 to +500 days.

From observations of SN1998bu at +250 and +344 days, Spyromilio et al. [2004] (hereafter, S04) find that the line velocities are not the same (spectrum in figure 1), indicating a dependence of the nebular velocity on the epoch of observation. This is critical since nebular velocities have been used in studies to indicate a relation between the kinetic energy of the ejecta and the total energy from the ^{56}Ni decay (eg. Mazzali et al. [1998], Blondin et al. [2012]). An evolution in the line velocity would mean that these results need to be reconsidered. A series of late time spectra with high resolution are required to confirm whether this effect occurs and what is the physical mechanism that causes it.

Recent observations of SN2011fe (Taubenberger et al. [2015]) demonstrate a puzzling behaviour of the SN at very late epochs (>+1000d). The prominent Fe [III] feature at 4700 $\mathring{A}$ has almost completely faded away. Instead, most of the emission is probably in the Fe [II] lines. This suggests a significant change in the ionisation state. Moreover, the features in the +1034d are all collectively redshifted, a phenomenon which is currently unexplained. SN2011fe has no observations between +331 and +1034d, hence one cannot constrain what the driving mechanism for these changes is. Observations of a normal SNIa like SN2014J at intermediate epochs can shed light onto whether this is a sudden or a gradual change.

At late epochs, the flattening of the cooling curve and the exponential decline of the heating due to radioactivity combine to produce rapid cooling of the ejecta, which decreases the ejecta temperature to below a critical threshold. This leads to a sharp decrease in the optical and NIR flux and is known as the Infrared Catastrophe (IRC; Axelrod 1980). Although there are several theoretical models that predict this IRC, it hasn't been observed in any of the few SNe that have been followed up till late phases. For some SNe (eg. SN2001el) a lack of observations between +400 and +700 days makes it difficult to completely rule out the occurrence of an IRC. NIR spectra in the phase range of +400 - +500 days provide information on the ionisation and excitation of the ejecta as well as the temperature in the core. This allows us to deduce whether such an IRC has occurred in the ejecta or not. One possible reason for the absence of an IRC is the clumping of ejecta which keeps the local temperature above the threshold. Line morphologies in the NIR spectra can also provide evidence for clumping in the ejecta.

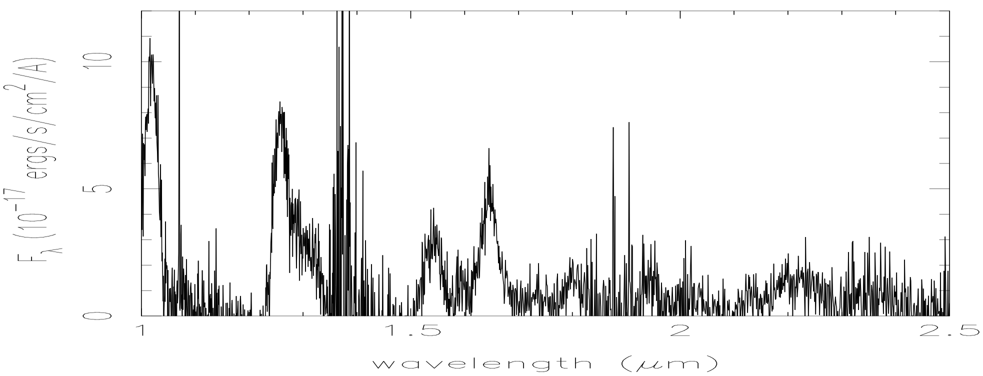


Figure 1: The NIR spectrum at +250 days for SN1998bu is shown from S04. We aim to improve upon the signal to noise and to observe the SN at later epochs.

References

[Axelrod1980] Axelrod T. S., 1980, PhDT

[Blondin et al.2012] Blondin S., et al., 2012, AJ, 143, 126

[Diamond, Hoeflich, & Gerardy2014] Diamond T., Hoeflich P., Gerardy C. L., 2014, arXiv, arXiv:1410.6759

[Leloudas et al.2009] Leloudas G., et al., 2009, A&A, 505, 265

[Maeda et al.2011] Maeda K., et al., 2011, MNRAS, 413, 3075

[Maeda et al.2010] Maeda K., et al., 2010, Natur, 466, 82

[Mazzali et al.1998] Mazzali P. A., Cappellaro E., Danziger I. J., Turatto M., Benetti S., 1998, ApJ, 499, L49

[Spyromilio et al.2004] Spyromilio J., Gilmozzi R., Sollerman J., Leibundgut B., Fransson C., Cuby J.-G., 2004, A&A, 426, 547

[Taubenberger et al.2015] Taubenberger S., et al., 2015, MNRAS, 448, L48

Experimental Design

SN2014J is the nearest SNIa in close to 4 decades. Due to its brightness high S/N late time NIR spectra between +400 and +500 days, which are not possible for other, more distant SNIa.

In order to constrain the ionisation evolution, we requires a spectral series with time sampling of $\sim$ 30 - 50 days. Hence, we propose to obtain 3 NIR spectra between the months of March and May.

In order to study the late time properties of SN2014J, we have also proposed for photometric observations in the optical and NIR on the Himalayan Chandra Telescope (HCT). This will allow us to get a late time (pseudo)-bolometric light curve which can elucidate the configuration of the magnetic field in the ejecta.

An excellent dataset for the early time observations of SN2014J exists with a spectral time series in the UV, optical and NIR. There is also multi-band photometry and polarimetry available publicly.

Technical Description

We would like 10 exposures of 120 seconds each per night. A total on source exposure time of 20 mins gives us an S/N of $\sim$ 30 in the line at $\sim 1.54\mu$m (see ITC pdf attached). We would require the same number of exposures for the same duration off source. Hence the total time on and off source is 40 mins.

For each such set of exposures, the acquisition time is 12 mins. The readout time for each exposure is 9 seconds. Hence for 10 X 2 exposures the total readout time is 180s. Hence, in total we request for 1 hour for each night (using a conservative estimate for overheads), and a total of 3 hours for the period of March to May.

We would like to use the cross-dispersed mode in order to obtain a complete spectrum from 0.8 to 2.5 μm. Recently published observations of SN2005df (Diamond et al. [2014]) using GNIRS have also used cross-dispersion mode to get a complete spectrum from 0.8-2.4 μm.

The observations can be carried out during any phase of the moon. Details of the ITC are attached.

Based on the fast turnaround schedule we would prefer observations in April on the 14th and in May on either 25th or 26th and on any of the nights scheduled in March. However, any other nights as well would be suitable.

Band 3 Plan

Classical Backup Program

Justify Target Duplications

Publications

Taubenberger S., et al., 2015, MNRAS, 448, L48

Kerzendorf W. E., Taubenberger S., Seitenzahl I. R., Ruiter A. J., 2014, ApJ, 796, LL26

Maguire K., et al., 2014, MNRAS, 444, 3258

Use of Other Facilities or Resources

Previous Use of Gemini

Reference	Allocation	% Useful	Status of previous data

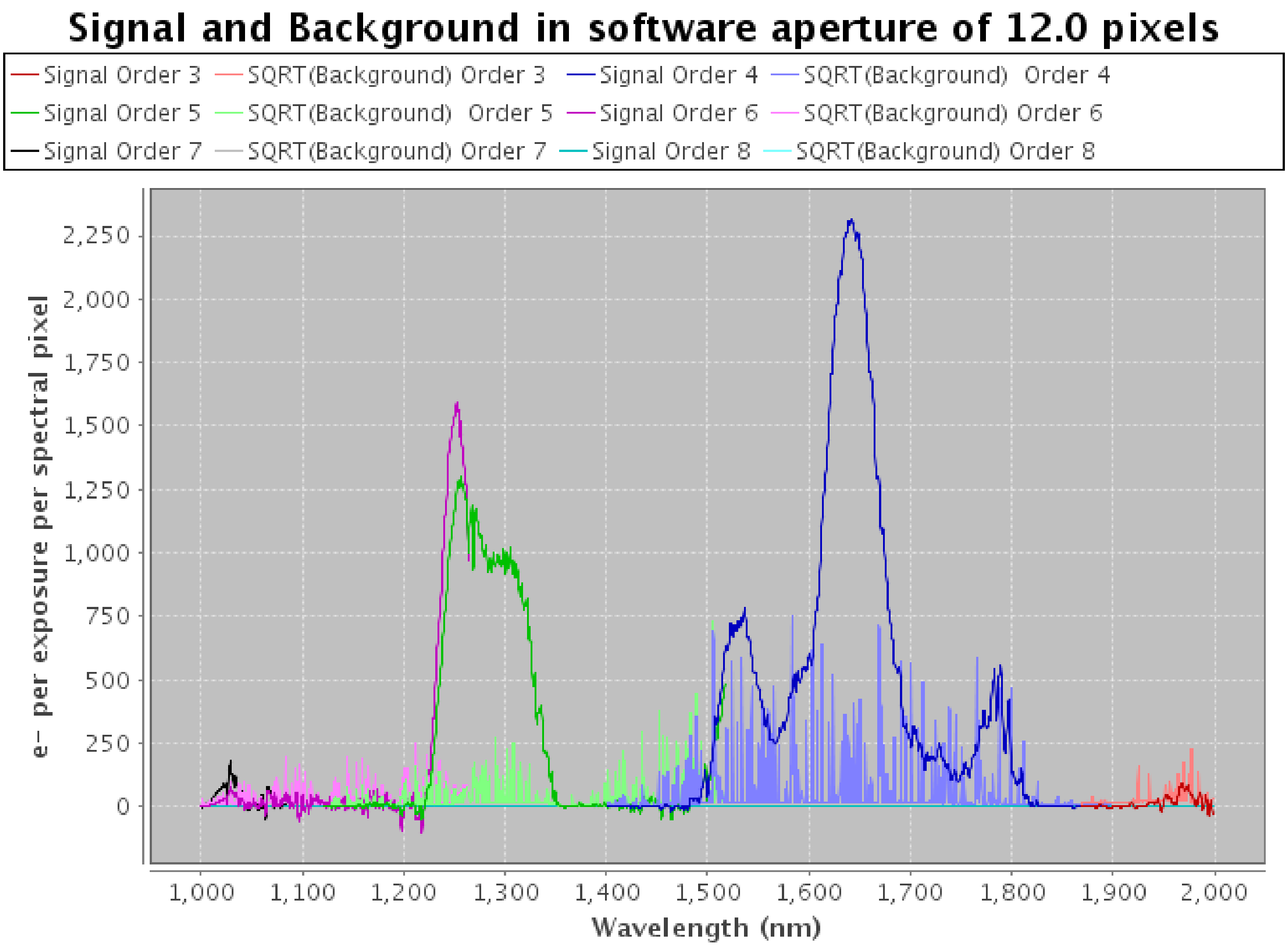
ITC Examples

Gemini Integration Time Calculator
GNIRS version 4.0

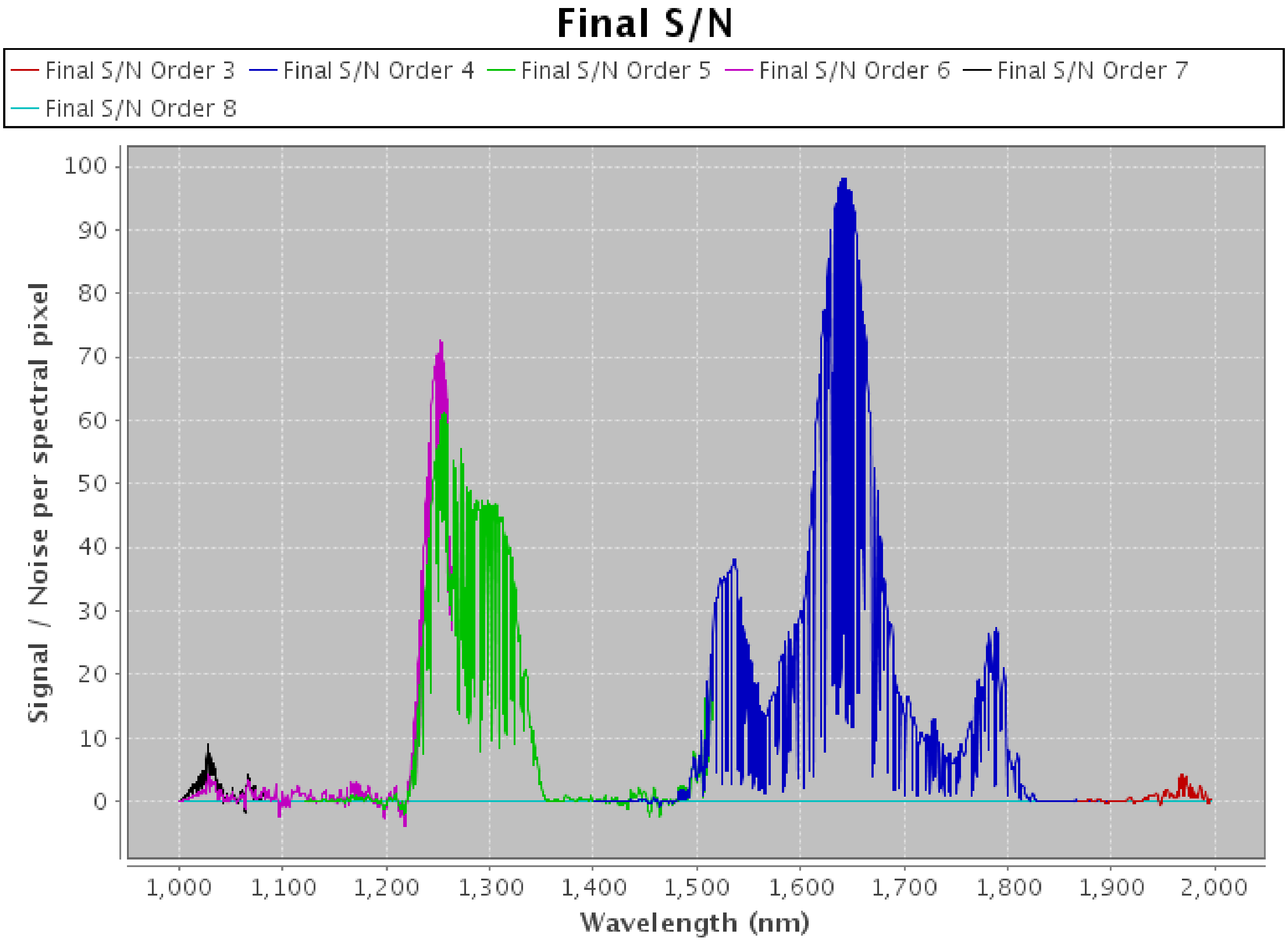
Click here for help with the results page.
software aperture extent along slit = 1.80 arcsec
fraction of source flux in aperture = 0.40
derived image size(FWHM) for a point source = 1.28arcsec

Sky subtraction aperture = 1.0 times the software aperture.

Requested total integration time = 1200.00 secs, of which 1200.00 secs is on source.



Click here for ASCII signal spectrum.
Click here for ASCII background spectrum.



[Click here for Final S/N ASCII data.]

Input Parameters:
Instrument: GNIRS

Source spatial profile, brightness, and spectral distribution:
The z = 0.0 point source is a a user defined spectrum with the name: ir_13aa.txt

Instrument configuration:
Optical Components:
- Filter: XD
- Cross-Dispersing Prism
- Fixed Optics
- Camera: 0.15arcsec/pix (Short Blue)
- Detector - 1K x 1K ALADDIN III InSb CCD
- Focal Plane Mask: slit0.675

- Grating: G32
- Read Noise: 10.0
- Well Depth: 90000.0

Central Wavelength: 1616.85 nm
Pixel Size in Spatial Direction: 0.15arcsec
Pixel Size in Spectral Direction(Order 3): 0.647nm
Pixel Size in Spectral Direction(Order 4): 0.485nm
Pixel Size in Spectral Direction(Order 5): 0.388nm
Pixel Size in Spectral Direction(Order 6): 0.323nm
Pixel Size in Spectral Direction(Order 7): 0.277nm
Pixel Size in Spectral Direction(Order 8): 0.242nm

Telescope configuration:
- silver mirror coating.
- side looking port.
- wavefront sensor: pwfs

Observing Conditions:
- Image Quality: 85.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 100.00%
- Airmass: 2.00

Frequency of occurrence of these conditions: 59.50%

Calculation and analysis methods:
- mode: spectroscopy
- Calculation of S/N ratio with 10 exposures of 120.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 1.00 times the target aperture.

Output:
- Spectra autoscaled.