Scientific Justification

Type Ia supernovae (SNe Ia) are thermonuclear explosions of a white dwarf in a binary system. They have been proven to be excellent distance indicators for constraining cosmological parameters, and are major contributors to the cosmic chemical enrichment. There remain, however, several open questions regarding the physics of the explosions that still need to be addressed, e.g. the mass at the time of white dwarf, the nature of the progenitor binary system, and the explosion physics. We propose to obtain a time-series of near-infrared (NIR) spectra of the closest SN Ia in four decades - 2014J - from 400 – 500 days past explosion. This will allow us to study the core of the exploded object, which in turn can be used to shed light on the progenitor white dwarf.

The power of nebular spectroscopy Most data on SNe Ia is collected during the photospheric phase. In contrast, the late time, nebular phase ($\gtrsim$ 100 days after maximum) has been observed much less frequently as most objects are too faint. 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 optical spectra at up to 400 days past maximum have been used to infer the 3-D abundance distribution in the ejecta (Maeda et al. [2010]).

Exploring the late time plasma state of SNe Ia Recent optical observations of the also very nearby SN2011fe (Taubenberger et al. [2015]) demonstrate a puzzling behaviour of this SN at very late epochs (>+1000d). The previously prominent [Fe III] feature at 4700 Å has completely faded. Instead, most of the emission is probably in [Fe II] lines. This suggests a significant change in the ionisation state. At the same time, the emission arises from relatively high-excitation lines, showing that the general evolution of the late-time plasma state in SNe Ia is very poorly understood. This becomes even more interesting if one compares the observed behaviour to theoretical predictions. At late epochs the ejecta begins to cool as the radioactive heating decreases whereas the cooling curve flattens. Once the ejecta temperature decreases below a critical threshold ($<$ 1500 K), the optical and NIR flux is expected to drop dramatically, which is known as the Infrared Catastrophe (IRC; Axelrod [1980]). Although theoretical models predict this IRC to happen around 500 d, it has never been observed in any of the few SNe that have been followed up photometrically to sufficiently late phases (Leloudas et al. [2009], Kerzendorf et al. [2014]; for an example see Figure 2). NIR spectra in the range of +400 - +500 days will provide valuable information on the ionisation and excitation state of the ejecta as well as the temperature in the core. This will allow us to judge how close SN2014J is to undergoing an IRC. One possible reason for the absence of an IRC might be clumping of ejecta which keeps the local temperature above the threshold. Line morphologies in high-S/N NIR spectra can provide evidence for clumping in the ejecta. Particularly suited for this endeavour is the unblended [Fe II] feature at 1.644 μm (see Figure 1).

Shifting lines in late time spectra Another puzzling feature seen in very late-time ($>$ 1000 days) spectra of SN 2011fe is a global shift of iron-group element features by 4000 km s^{-1} when compared to spectra at 300 days (Taubenberger et al. [2015]; see Figure 2). Normally, line shifts in nebular spectra are explained by asymmetries in the ejecta of the SN, which can provide powerful constraints on the progenitor system and explosion mechanism. However, in the case of SN2011fe the geometric interpretation is not straightforward, as neither the size of the shift nor its temporal evolution between 300 and 1000 days can be explained in this way. Hence, the origin of the phenomenon currently remains unknown. There are no published spectra of SN2011fe between +331 and +1034 d, hence one cannot constrain what the driving mechanism for this line shift is. Spectra of a normal SN Ia like SN2014J at regular intervals and at intermediate epochs can shed light onto whether this is a sudden or a gradual change.

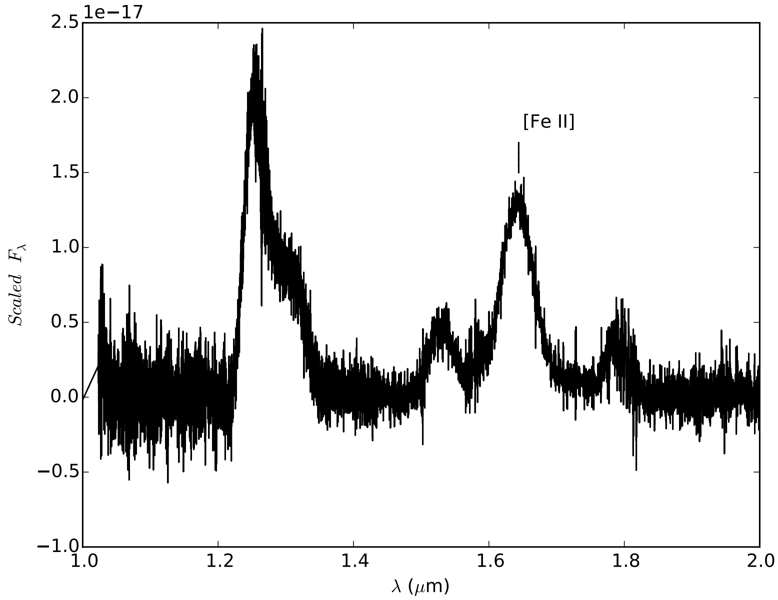

Figure 1: A nebular phase spectrum of SN2013aa (Maguire et al. in prep). The [Fe II] feature at 1.644 μm is marked.

References

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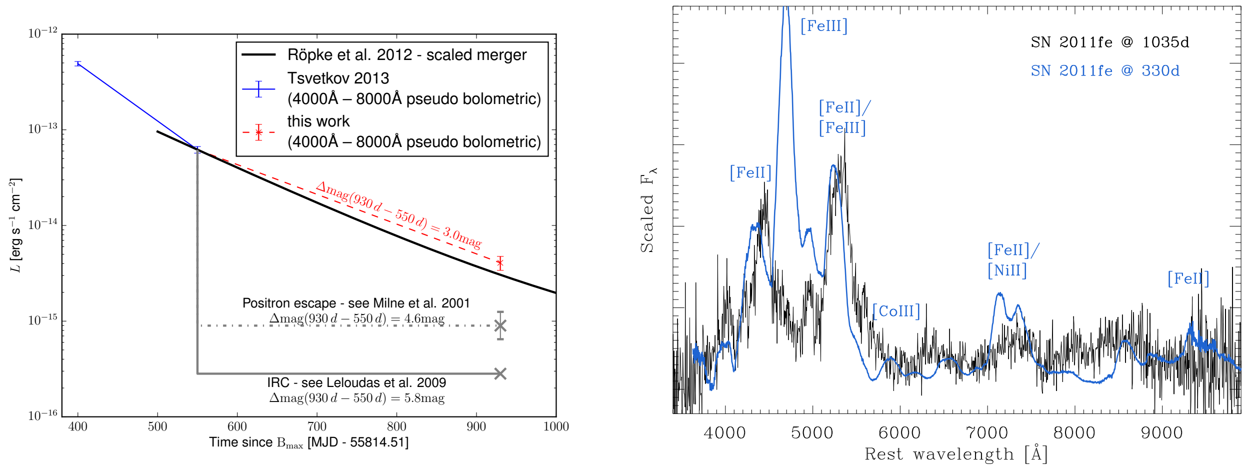

Figure 2: *Left*: The late time bolometric light curve of SN2011fe (Kerzendorf et al. [2014]). There is no evidence for an IRC *Right*: A comparison of the SN2011fe spectra at +331 and +1034 d showing the line shift at the later epoch.

Experimental Design

SN2011fe was another extremely close SN Ia (twice the distance as SN 2014J). This event has provided and is providing unique insights into SN Ia physics (e.g. Li et al. 2011, Chomiuk et al. 2012 Shappee et al. 2013 Mazzali et al. 2014 , Kerzendorf et al. 2014, Taubenberger et al. 2015), but also shows which observations are missing to complete some of the puzzles. Thus the closest SN Ia in more than four decades - SN 2014J - gives us the opportunity to make good for some of the missed observations. As some of these results were not available at the time of the last regular proposal deadline, we believe that the very modest request of time that we need to obtain a complete dataset for SN2014J justifies the FT mode application. Here, we propose a spectroscopic follow-up of SN2014J with regular cadence in the nebular phase in the near infrared (NIR; $0.8 - 2.2\mu$m) between +400 to +500 days with GNIRS.

This proposal is embedded in an observing campaign to get a comprehensive optical-NIR data set in order to study the late time properties of SN2014J. In addition to this experiment, we also propose 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. In addition, we will complete the dataset with optical spectroscopy obtained with the GTC Osiris instrument. Finally, an excellent dataset for the early time observations of SN2014J exists with a spectral time series in the UV, optical and NIR including multi-band photometry and polarimetry available publicly (Ashall et al. [2014], Foley et al. [2014], Marion et al. [2014], Patat et al. [2014]).

The proposed NIR GNIRS spectrum will allow us to verify the concepts outlined in the science justification. In particular, we intend to address the following questions:

- Measure emission line strengths and ratios to determine the ionisation and excitation state of the ejecta and the temperature of the electron gas.
- Measure line positions and profiles to infer the geometry of the emitting region (particularly using the unblended [Fe II] 1.644 μm line).

- Probe if there is any evolution in these quantities between 400 and 500 days.

The nebular spectra of SNe Ia are dominated by doppler-broadened ($\approx 5000\,\mathrm{km\,s^{-1}}$) forbidden emission lines. Thus we propose for a low-resolution (R=700-800) cross-dispersed spectra. For each individual spectrum, we aim to model the shapes of lines with a relatively high accuracy and thus require a S/N of ≈ 50 in the line peaks.

While many known processes in the nebular phase change over relatively long time scales (on the order of several 100 days), the infrared catastrophe (as one of our key science drivers) is believed to happen over a few weeks. To capture any change in the plasma state, we believe that a cadence of ~ 30 - 50 days is a good compromise. Hence, we propose to obtain 3 NIR spectra between the months of March and May.

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

This program is not suitable for band 3.

Classical Backup Program

This is not a classical request

Justify Target Duplications

The GSA contains observations of SN 2014J. However, as this is a transient event the existing can not be used to fulfill our science goals

Publications

References

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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

- Himalayan Chandra Telescope (HCT) - multi-epoch optical and NIR photometry of SN 2014J
- Gran Telescopio CANARIAS (GTC) - multi-epoch optical spectroscopy SN 2014J

Previous Use of Gemini

The PI does not have any previous Gemini time

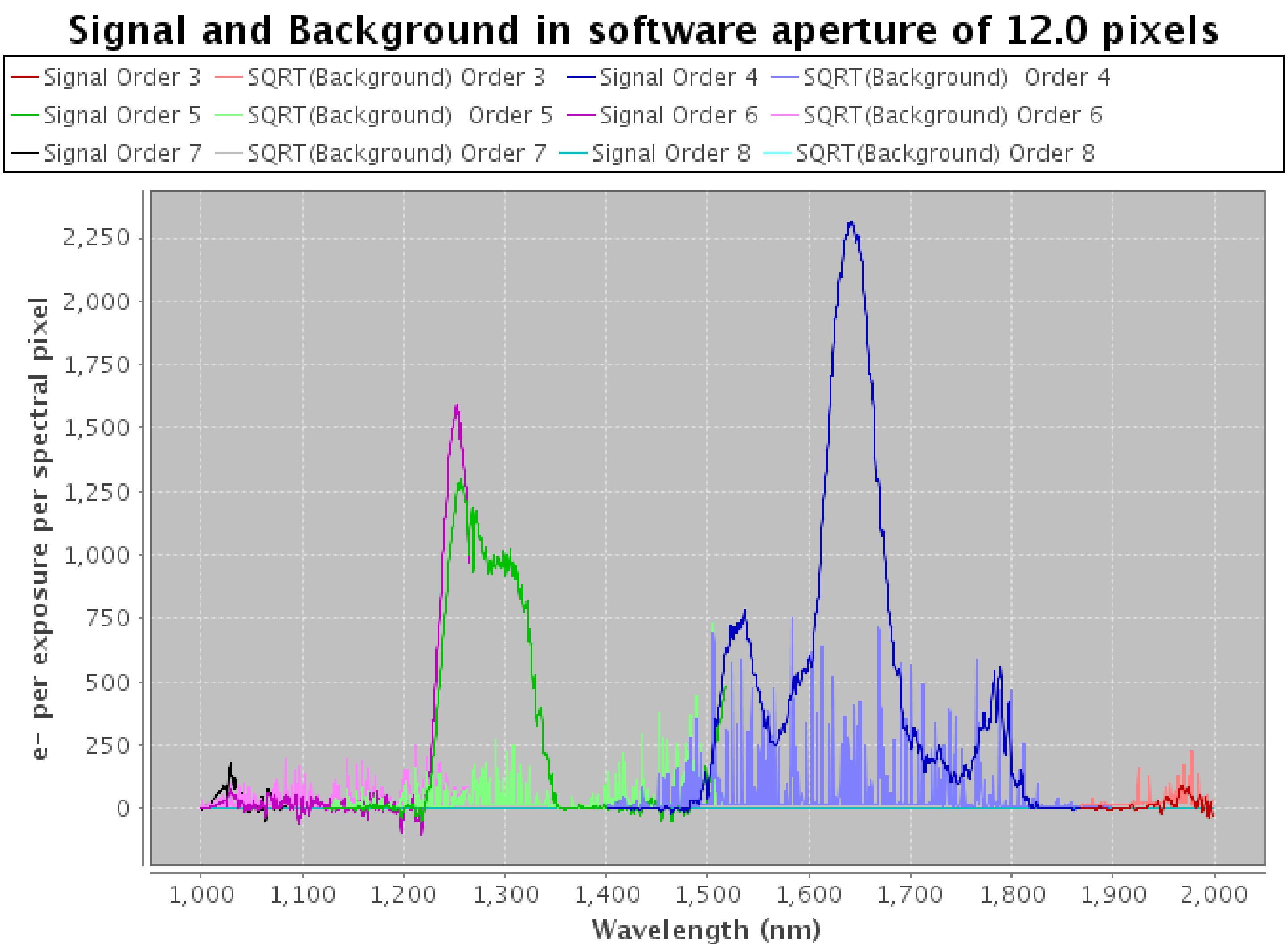
ITC Examples

Gemini Integration Time Calculator
GNIRS version 4.0

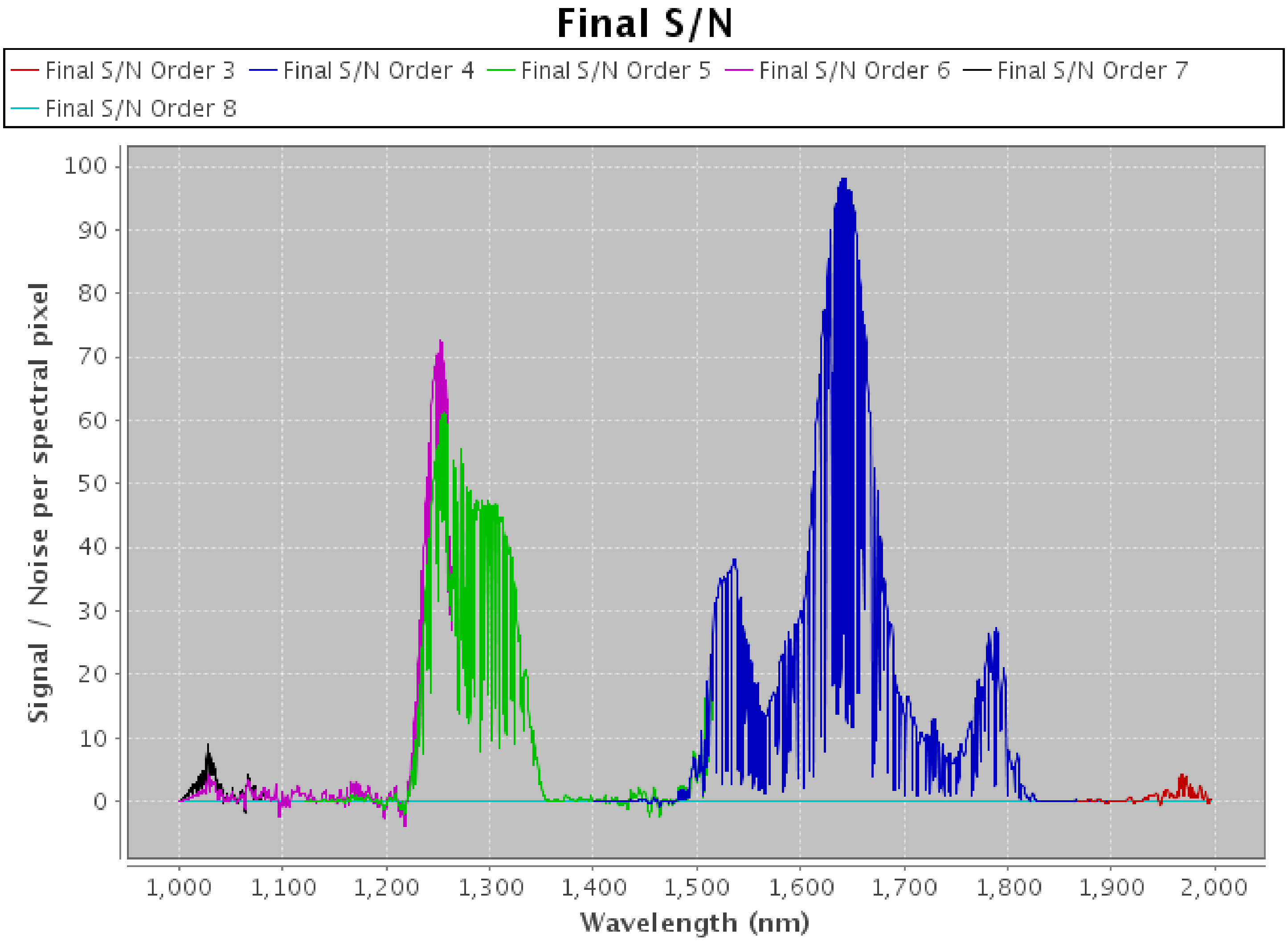
Click here for help with the results page.
software aperture extent along slit = 1.80 arcsec
fraction of source flux in aperture = 0.40
derived image size(FWHM) for a point source = 1.28arcsec

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.