X-shooter Science Verification Proposal

Title: The extraordinary return of two core-collapse supernovae

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Abstract: With the very recent report of the reappearance of two core-collapse supernovae at X-ray and radio wavelengths, we wish to obtain optical-near-IR spectroscopy to a) confirm interaction between the supernova ejecta and circumstellar material; b) to use a number of line diagnostics to derive the properties of the interaction (temperature, density etc.); c) use the shapes and widths of the line profiles as a probe of the circumstellar geometry. This behaviour i.e., redetection years after fading away, is unprecedented for supernovae. The proposed observations are for a small, self-contained data-set that should not only lead to rapid publication, but are also likely to push X-Shooter to the extreme ends of its capabilities.

Scientific Case: Core-collapse supernovae (CCSNe) are the end points of all stars more massive than about $8M_{\odot}$. The collision between SN ejecta and any surrounding material results in shocks. These shocks give rise to X-rays which heat and ionize the medium, giving rise to line-emission in the UV and optical regions. X-ray emission is probably the clearest signature of circumstellar (CS) interaction (Nyman et al. 2006, A&A, 449, 171), but X-ray studies are only feasible for nearby, bright events. Many studies of CS-ejecta interaction have focussed on radio observations which are sensitive to the amount and density of the CS. However, interpreting radio emission is subject to assumptions relating to the magnetic field, particle acceleration efficiencies, and the temperature of the gas. With UV, optical, and near-IR spectroscopy, however, one can measure relative abundances and obtain important line diagnostics in a relatively robust way. There also exists a close correlation between the late-time optical luminosity and the CS density. In March this year, came the report of x-ray and radio detections of two core-collapse supernovae, SN 2004dk and SN 1996aq, both of which were thought to have faded beyond observability, a long time ago (CBET 1714; http://www.cfa.harvard.edu/iau/cbet/001700/CBET001714.txt). Both are of type Ib/c (i.e. contain no hydrogen, but have shown possible signatures of helium). This is the first ever re-surfacing of SNe that were previously thought to have faded away. In contrast there is a small handful ($\lesssim 6$) of objects that have shown a very slow evolution in their lightcurves over a long period of time; an example of this class is SN 1979C.

Proposed Observations: Now the key to understanding the nature of the stars that gave rise to these SNe, is through understanding the type and nature of the interaction. The timely advent of X-Shooter will allow us to do just this and we request one full spectrum per SN. The shocked material will provide a host of diagnostic lines in the optical region e.g. lines of [OI] and [OIII] near 6300, and 5000 Å, respectively. The near-IR [FeII] lines, in combination with especially the optical [FeII] 7155 Å line, are temperature and density indicators. We will model the spectra along the lines of Fransson et al. 2002. The shapes and velocities of the line profiles will provide information on the extent and nature of the surrounding material e.g. double-peaked would imply a shell-like geometry. The urgency of our request is underlined by the fact that the interaction is transient, and that we would be unwise to wait for a whole year to propose observations via the usual channels. Early-time observations of CCSNe are abundant, as are observations of SN remnants (hundreds of years old). However, observations of CCSNe at epochs of a few years to 20 years post-explosion are non-existent for type Ib/c SNe. It may well be that this peek into the previous evolutionary phase of Ib/c SNe might provide a vital clue to the path leading up to the core-collapse of presumably very massive ($\gtrsim 20\,M_{\odot}$) stars.

Targets and observing mode

Target	**RA**	**DEC**	**V** mag	**Mode** (slit/IFU)	**Remarks**
SN 2004dk	16 21 48.87	-02 16 17.6	21.	slit	No moon
SN 1996aq	14 22 22.71	-00 23 23.7	21.	slit	No moon

Time Justification: The reported behaviour of our targets is unprecedented, so we based our time estimates on a spectrum of SN 1979C taken in 2008 (Milisavljevic et al. 2009). Such late-time observations are likely to be representative for our targets. The request for dark/grey time is based on the faintness of the targets in the V and R bands, which host lines of interest. Using v3.2.8 of the ETC, we find that three 1800s exposures in the VIS arm, will give us a S/N $\gtrsim 10$. We will use integrations of 200 s in ABBA fashion for the near-IR arm. We expect lines in emission, which will boost our S/N. Including overheads, our total time request comes to 4hrs. We will require standard calibrations.