X-shooter Science Verification Proposal

The Late Outburst Spectrum of the Eruptive Young Star V1647 Orionis

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Abstract:

On rare occasions, the accretion brightness in pre-main sequence stars is seen to increase by many orders of magnitude for a period of several months. These poorly understood eruptive phenomena profoundly alter the properties of the circumstellar disk and may to a large extent govern the final appearance of the planetary systems that are forming in these disks. The until then inconspicuous pre-main sequence star V1647 Ori started such a large-amplitude eruptive event in 2003, with a second eruption occurring in August 2008. Our team has performed detailed optical-infrared spectroscopic follow-up of the 2003 outburst (Fedele et al. 2007a, b; van den Ancker et al. 2008), and has obtained data last fall to study the 2008 outburst as well. However, data to trace the return to quiescence is still lacking. Obtaining a spectrum of the variable, eruptive YSO *simultaneously* from 350 nm to 2.2 μm would also be an enormous improvement over previous spectroscopic observations in which temporal variability hindered the comparison between UV-optical and near-IR data. We thus propose here to use X-shooter in the August 2009 Science Verification run to obtain a new ultraviolet-near-IR spectrum of V1647 Ori in its fading phase. This new spectrum will allow us to characterize the central star – something that has not been possible so far – and to trace the changes in the structure of the disk's planet-forming regions compared to the early stages of the 2003 and 2008 outbursts.

Scientific Case:

Outbursts of pre-main sequence (PMS) stars are spectacular phenomena that shed a unique light on the early evolution of the disk and the interface between the central source and the disk. Observationally, outbursts are characterized by a rapid increase of several magnitudes in the luminosity of the central source. Depending on their temporal duration and their strength, PMS stars experiencing an outburst are classified as FU Orionis-type stars (FUors) or EX Lupi-type stars (EXors). FUors display outbursts of 4 magnitudes and more, and last several decades. EXors exhibit somewhat smaller outbursts (2–3 magnitudes), have a shorter duration from months to a few years, and may exhibit periodic behaviour.

It is believed that these eruptive phenomena are due to the occurrence of an instability in the disk, causing a sudden increase of several orders of magnitude in the mass accretion rate of the disk on to the star from a pseudo-steady-state value of $\sim 10^{-9}$ $M_\odot$/yr in T Tauri stars, up to $\sim 10^{-4}$ $M_\odot$/yr in the case of FUors. Since a typical outburst can bring about 0.01 $M_\odot$ to the star, a significant amount of the stellar mass may be accreted through outbursts during the star's pre-main sequence lifetime. These events may also significantly alter the contents and structure of the disk and may ultimately be responsible for shaping the planetary systems that are forming in these disks. For example, FUOR and EXOR outbursts will push the snow line within the protoplanetary disk outwards, altering the location within which gas-giants may form (Pollack et al. 1996, Icarus 124, 72; Kennedy & Kenyon 2008, ApJ 682, 1264). Ábrahám et al. (2009, Nature 459, 224) found evidence for episodic formation of material with a composition similar to that found in comets in our solar system during EXOR outbursts. These changes in solid-state lattice structure induced by the outbursts will also alter the ease with which solids can grow in the disk, and may ultimately halt the planetesimal-formation process altogether.

In January 2004 a new eruptive pre-main-sequence star illuminating a cometary-shaped nebula was found in Orion by amateur astronomers: V1647 Ori (McNeil et al. 2004, IAU Circ. 8284, 1). Following an initial

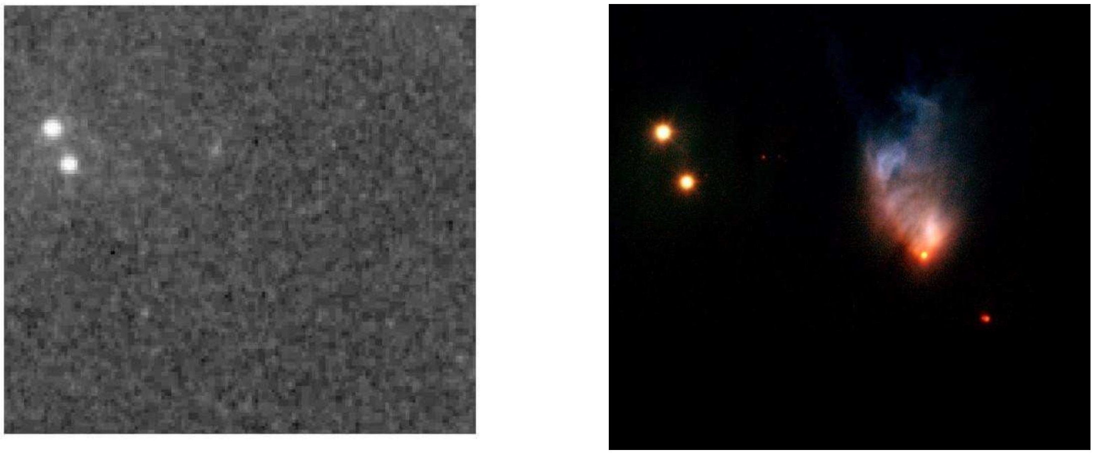

Figure 1: Optical images from the vicinity of V1647 Ori and its associated nebula before (left) and during (right) the 2003–2006 outburst. V1647 Ori is located at the apex of the cometary nebula.

brightening of approximately 4 magnitudes during a period of four months, this first V1647 Ori outburst lasted for about two years until October 2005 when the star started a rapid fading to the pre-outburst luminosity level. The V1647 Ori outburst was the largest amplitude eruptive phenomenon reported in a young star since 1984, and as such has generated quite a lot of attention within the YSO community (e.g. Briceño et al. 2004, ApJ 606, L123; Kastner et al. 2004, Nature 430, 429; Ojha et al. 2005, PASJ 57, 203; Ábrahám et al. 2006, A&A 449, L13). After the 2003–2006 outburst, V1647 Ori remained in quiescence for almost two years (Aspin et al. 2008, ApJ 135, 423), until August 2008, when a new outburst was reported (Itakagi et al. 2008, IAU Circ. 8968, 2). The star is currently fading from this new outburst, and is expected to be returning to its pre-outburst brightness level within the next year.

Our team has performed detailed optical-infrared spectroscopic follow-up of the 2003 outburst (Fedele et al. 2007a, A&A, 472, 199; Fedele et al. 2007b, A&A, 472, 207; van den Ancker et al. 2008, Messenger 131, 20), and has obtained FORS2 and CRIRES data last fall to trace the 2008 outburst as well. We found the optical spectrum of V1647 Ori during outburst to be characterized by Hα and Hβ with P-Cygni profiles and by many weak Fe I and Fe II emission lines. These emission lines are produced in the circumstellar disk and allow us to trace changes in the disk structure. Short timescale variability was detected in the continuum and line emission. In spectra taken during the last stages of the 2003–2006 outburst. we were the first to detect forbidden emission lines of [O I], [S II] and [Fe II], likely produced by a new Herbig-Haro object created during the outburst. We note that in our previous studies of the V1647 Ori system, optical and infrared spectroscopy had to be obtained non-simultaneously. This complicates an unambiguous reconstruction of the state of the system at any given time, since the system shows erratic variability on short timescales as well. Also, optical-near-infrared spectroscopic data to trace the return of the V1647 Ori system to quiescence after the August 2008 outburst is still lacking.

Here we propose to use the August 2009 X-shooter Science Verification run to obtain a new spectrum of V1647 Ori in the 350-2200 nm range. This new spectrum will allow us to (1) characterize the central star in the system by studying the absorption-line spectrum in the UV-optical range, (2) determine the current accretion rate by measuring the amount of veiling in the spectral region shortward of the Balmer jump, and (3) study the current state of the disk and outflow by studying the emission lines of H I, Fe I, Fe II, Ca II, [O I], [S II], [Fe II] and H_2 in the UV, optical, and near-infrared. We note that unlike our previous spectroscopic data taken with FORS2, X-shooter has the spectral resolution to distinguish kinematically between forbidden lines emanating from the disk and the outflow, greatly simplifying our analysis. With the data in hand for the 2003–2006 outburst and the data of the 2008 outburst obtained last fall, we will be able to trace the changes in the temperature and regions of the emitting gas in the V1647 Ori disk, setting new constraints on the mechanism responsible for the disk instability, and the initial conditions for planet formation in protoplanetary disks.

Targets and observing mode

Target	**RA**	**DEC**	**V** mag	**Mode** (slit/IFU)	**Remarks**
V1647 Ori	05 46 13.14	-00 06 04.8	17–19	slit	Grey time

Time Justification:

We want to take a spectrum of V1647 Ori during the August 2009 X-shooter Science Verification run. During quiescence, V1647 Ori can be as faint as V = 23. However, we expect V1647 Ori to have faded to a V-band magnitude between 17 and 19 (after its most recent outburst episode in August 2008. Using the X-shooter ETC, we find that we can get a S/N $>$ 10 over the 370-1000 nm wavelength range on a target of this brightness with an integration time (excluding overheads) of one hour. As V1647 Ori is considerably brighter in the near-IR than in the optical, the S/N in the near-IR arm will be better than 20 in this integration time. This spectrum will enable us to measure the absorption components in the optical spectrum with sufficient accuracy to characterize the spectrum of the underlying star. In addition this S/N will also allow us to study the emission-line spectrum of the circumstellar disk and the shocked gas in the outflow in exquisite detail in the ultraviolet, optical and near-infrared. Including overheads of 10 minutes for telescope pointing and target acquisition, and 3.5 minutes for detector read-outs and telescope offsets, we thus request a total of 73.5 minutes of observing time with X-shooter. This computation assumes that telluric and spectro-photometric standards will be taken as part of the normal X-shooter calibration plan (X-shooter User Manual, Sect. 4.1). If the time required to take these standards will be charged to our observing programme, a further 20 minutes per standard, or 40 minutes in total will have to be added to the requested 73.5 minutes of observing time.