X-shooter Science Verification Proposal

Deep X-shooter spectroscopy of proplyds in diverse H II regions

Investigators	Institute	EMAIL
Y. G. Tsamis	IAA-CSIC	tsamis@iaa.es
J. R. Walsh	ESO	jwalsh@eso.org
J. M. Vílchez	IAA-CSIC	jvm@iaa.es
R. H. Rubin	NASA/Ames	rubin@cygnus.arc.nasa.gov
C. R. O'Dell	Vanderbilt Univ	cr.odell@vanderbilt.edu
M. van den Ancker	ESO	mvandena@eso.org

Abstract:

Protoplanetary disks (*proplyds*) embedded in H II regions are landmark objects in the study of how circumstellar disks and eventually planetary systems form in the vicinity of massive star forming areas. Analysis of their emission line spectra provides a window into their properties. Due to their intrinsically very high densities, bright collisionally-excited line (CEL) diagnostics are biased indicators of the physical conditions in proplyds. On the other hand, the much fainter metallic recombination lines (RLs) are excellent probes of clumpy, relatively low temperature plasmas, and can yield a direct unbiased measure of the temperature, density stratification, and metallicity of these sources. We propose to perform deep X-shooter IFU spectroscopy of four well-defined proplyds in NGC 3372, NGC 3603, M8 and M42 with a view to developing robust RL-based diagnostics of their properties. This project will provide template proplyd spectra from the near-UV to the near-IR covering a wide range of novel diagnostics in a variety of galactic H II environments.

Scientific Case:

Proplyds are variants of young stellar objects and in the early 1990s provided the first evidence of gaseous dusty disks around YSOs. They are thus landmark objects in the study of how circumstellar disks and eventually planetary systems form (O'Dell 2001, ARAA, 39). The archetypical proplyds detected in Orion (M42; O'Dell et al. 1993, APJ, 410) are dense objects surrounded by their parental gaseous cocoon; they are ionized and photoablated to various degrees depending on their position in the nebula, and on the distance from the Trapezium cluster. Similar objects have now been detected in more distant star-forming regions via their thermal dust emission in mid-IR *Spitzer* bands (Balog et al. 2006, APJL, 650), but also optically in M8 (Stecklum et al. 1998, AJ, 115) and in the giant nebulae NGC 3603 (Brandner et al. 2000, AJ, 119) and NGC 3372 (Smith et al. 2003, APJL, 587). NGC 3603 is a Galactic scaled-down analogue of 30 Dor but its proplyds are giant versions of those found in M42. The proplyds in NGC 3372, on the other hand, are intermediate in size between those in M42 and NGC 3603. It is thought that the very different far-UV/extreme-UV photon fluxes emitted from the ionizing stellar sources in each nebula may be responsible for this range in observed sizes as the $L_{\rm bol}$ of NGC 3603 is 100× that of M42 and 10% that of 30 Dor. However, systematic differences in the mass of the embedded protostellar sources may also contribute to the observed difference between sources in M42 and those in more massive star forming regions.

The chemical composition of proplyds is *virtually unknown.* It is difficult to obtain a direct estimate of their CNONe abundances relative to H from a classic analysis of their line spectra based solely on collisionally-excited lines (CELs). Due to their high densities ($\sim 10^6$ particles cm^{-3}) proplyds are relatively poor emitters of a number of important CEL diagnostics, especially of those that have low critical densities for de-excitation, such as e.g. [N II] 6584, [O II] 3729, [O III] 5007, [S II] 6717, 6730 Å, and others. As a result, standard diagnostics of electron densities ($N_{\rm e}$) and temperatures ($T_{\rm e}$) in photoionized nebular plasmas, for example the line ratios [S II] 6717/6730 and [O III] 4363/5007, break down when applied to proplyd spectra. Moreover, abundance determinations based on observed ratios of heavy-element CELs to H I Balmer recombination lines are intrinsically insecure since the emissivities of CELs have an exponential sensitivity to the electron temperature, and therefore depend crucially on an unbiased measure of $T_{\rm e}$. In stark contrast, faint recombination lines (RLs) from CNONe ions which have been used extensively in the past 15 years as probes of the metallicity of planetary nebulae and H II regions, are not quenched in high density regions and their ratios to H I RLs are largely ($T_{\rm e}$, $N_{\rm e}$) independent (Tsamis et al. 2008, MNRAS, 386 and references therein; Storey 1994, A&A, 282). They can thus supplant the classic CELs as diagnostics of the chemistry and properties of proplyds and their outflows. This is a novel approach as far as these sources are concerned. We have previously observed three M42 proplyds with FLAMES Argus and mapped their metallic RL spectra (Tsamis et al. in prep; Tsamis, Walsh, & Péquignot 2009, 'Science with the VLT in the ELT Era', p. 61). For the archetype Laques-Vidal 2 proplyd the O II and C II RLs have provided a more meaningful comparison of the ionic abundances between the proplyd and the background nebula. We wish to build upon the FLAMES results and extend this study to proplyds in NGC 3372, NGC 3603, and M8 where proplyds have been observed but which are subjected to different and in some cases much harsher ambient conditions.

Deep X-shooter IFU spectroscopy simultaneously covering the UBV, VIS, and NIR bands (300–2500 nm), yielding 55, 43, and 45% higher spectral resolution (R) than the instrument's 1″-wide long slit mode, will deliver spatially and spectrally resolved spectra of the targets over a 1.8″×4″ FoV. The resulting effective R will be ∼0.5, 0.6 and 2 Å FWHM in the three bands allowing to isolate the proplyds in velocity and gauge the interaction with their surroundings, separating any shocked gas. The wide wavelength range includes (i) extinction diagnostics of the dusty proplyd environment (H I Balmer, Paschen and Brackett lines); (ii) robust high $N_{\rm e}$ diagnostics (upper n>10 H I Balmer lines at ∼3650 Å and various [Fe III] 3d^6 lines at ∼4700 Å); (iii) $T_{\rm e}$ diagnostics of the proplyd ionized zones – the Balmer and Paschen discontinuities – and of the atom/molecule transition regions, [C I] λ9824+λ9850/λ8727; (iv) shock/temperature diagnostics of the proplyd molecular photodissociation regions – [Fe II] 1.64 μm, H_2 2.122 μm v= 1-0 S(1), 2.223 μm 1-0 S(0), 2.034 μm 2-1 S(1) lines; and (v) a host of abundance diagnostics for helium and heavier element ions, including the faint (10^{-3} of Hβ) optical and far-red metallic recombination lines, such as, C II $\lambda\lambda$4267, 6462, 8794, 9903, N I $\lambda\lambda$8680, 8683, N II $\lambda\lambda$5666, 5679, O I $\lambda\lambda$7772, 7775, O II $\lambda\lambda$3882, 4089, 4649 (plus other 3p-3d, 3d-4f and 3s-3p transitions), Ne II $\lambda\lambda$3218, 3694, 4392, Mg II λ4481 etc. This project will deliver template spectra of proplyds and of their ambient nebulae from the near-UV to the near-IR, sampling a wide range of novel diagnostics for dense photoevaporating knots projected against a strong emission line background.

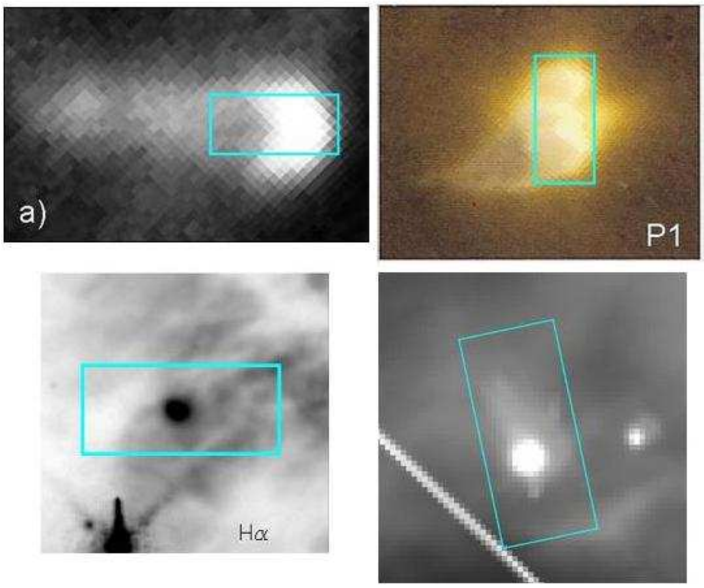

Figure 1: The proposed targets with the $4'' \times 1.8''$ IFU (cyan box) overlaid to scale. Top left: NGC 3372 in Hα (Smith et al. 2003, APJL, 587); Top right: NGC 3603 WFPC2 F656N+F658N composite (Brandner et al. 2000, AJ, 119); Bottom left: M8 in negative Hα WFPC2 (Stecklum et al. 1998, AJ, 115); Bottom right: LV2(M42) in Hα WFPC2 (O'Dell & Wong 1996, AJ, 111).

Calibration strategy:

Standard observations of one telluric standard per OB and one spectrophotometric standard per night are assumed.

Targets and number of visibility measurements

Target	**RA**	**DEC**	F**(H**α**)** erg s^{-1} cm^{-2} arcsec^{-2}	**Mode** (slit/IFU)	**Remarks**
NGC3372	10 45 14.2	-59 28 25	$\sim 3 \times 10^{-13}$	IFU	Equal priority
NGC3603	11 15 13.1	-61 15 50	$\sim 1 \times 10^{-13}$	IFU	
M8	18 03 40.5	-24 22 44	$\sim 2 \times 10^{-12}$	IFU	
M42-LV2	05 35 16.7	-05 23 17	8×10^{-12}	IFU	

Time Justification:

Using the X-shooter ETC and scaling from our FLAMES Argus observations for LV2 we estimate that a S/N ratio of $\sim$45 can be reached for the O II 4649 Å line in 3×270 s for the same target. An offset sky position close to the on-source position is requested for all targets to allow for nebular background subtraction. For LV2 an 'OS' cycle is sufficient [3×270 s (UBV), 3×260 s (VIS), 3×305 s (NIR)] in an OB of 2480 s with overheads included. For M8 an 'OSO' cycle of 3420 s would be needed to reach a similar S/N taking into account the expected difference in line surface brightness. For the more distant and fainter NGC 3372 and NGC 3603 'OSOO' cycles of roughly 4360 s per target are requested for anticipated S/N ratios of $\sim$10 in the 4649 Å line (they could be split in OBs of 3420 and 1540 s with overheads taken into account). The flexible 'generic offset' templates would be used. Bright nearby stars are present in all cases if blind offsets were necessary. Grey time could aid the detection of weak lines against the relatively bright target continua (nebular plus dust-scattered) especially in the NIR. The total time requested is therefore a maximum of 4.4 hr (or 5.8 hr if the night-time calibrations are included).