X-shooter Science Verification Proposal

Quantitative spectroscopy of the most massive stars beyond the Local Group

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Abstract:

Massive stars are key players in the Universe: they emit strong winds and energetic photons throughout their lifetime and they provide most of the chemical elements when they explode as supernovae or gamma-ray bursts, leaving a neutron star or a black hole. Important questions remain regarding the formation, evolution and fate of massive stars, e.g. (i) how massive is the most massive star? (ii) how does a massive star shed a large fraction of its mass before exploding as a supernova or a gamma-ray burst, and (iii) what determines whether a neutron star or a black hole is formed? Recently, significant progress in addressing these questions has been obtained from studying massive stars in different environments, i.e. in Local Group galaxies. We now want to take the next step, i.e. studying massive stars outside the Local Group. We have selected the **three candidate most massive stars in NGC 55, one of the brightest galaxies in the Sculptor Group**. With this science verification proposal we want **to demonstrate that VLT/X-shooter is capable of providing high quality spectra of massive stars in a distant galaxy**, enabling to derive key stellar parameters ($T_{\rm eff}$, $L_{\rm bol}$, M, $\dot{M}$, metallicity, rotation rate, etc.) of massive stars in an extragalactic environment.

Scientific Case:

The evolution of low-metallicity massive stars is of key importance to understand the early evolution of the universe, including its re-ionization, galaxy formation, and chemical evolution of young galaxies and of the intra-galaxy medium. Also, low-metallicity massive stars have been proposed to be progenitors of long-duration gamma ray bursts.

To be able to predict the properties and evolution of massive stars at cosmological distances it is fundamental to understand how global properties (e.g. luminosity, mass and rotation rate) and atmospheric properties (e.g. surface temperature and chemical composition) of massive stars determine the strength of their stellar winds and amount of ionizing radiation. Using this empirical information, theoretical predictions towards extremely low metal contents may be calibrated.

For progress towards this goal, massive OB, LBV and WR stars in the Large and Small Magellanic Clouds have been studied intensively in the past decades (e.g., Hunter et al. 2007, Mokiem et al. 2007, Trundle et al. 2007). With the latest generation of 8-10m class telescopes massive stars in more distant dwarf galaxies can now be studied, allowing us to probe a wider span in environmental properties, albeit *so far* at a low spectral resolution $R < 1000$ and mostly within the Local Group (e.g., Bresolin et al. 2007, Evans et al. 2007). Though quite a number of exiting objects have been identified, detailed quantitative spectroscopic analysis have remained cumbersome for obvious reasons: low S/N and modest spectral resolution, complicating (or preventing) among others the correction for nebular emission.

To demonstrate the breakthrough capabilities of X-shooter in this field of research, we propose to perform quantitative spectroscopy of three of the most massive early-type stars in the dwarf galaxy NGC 55. At about 2 Mpc, NGC 55 is one of the largest galaxies of the Sculptor group (see Fig. 1). Low resolution ($R = 780$) MXU spectroscopy with FORS2 allowed Castro et al. (2008) to recently identify the largest most distant individually resolved early-type population known so far, among which over a dozen O-type supergiants. Two of the three stars that we have selected from this census have spectral type Of/WN (C1_51 and B_12) and one is an early OI (C2_35) star, and, in view of their brightness are spectral types likely among the most massive stars known with masses in the range of 50 to 100 $M_\odot$.

While by selecting **a host-galaxy beyond the Local Group** we are clearly aiming at **breaking records**, these stars will yield important information about the **physics and evolution of the most massive stars**. Their brightness and spectral type are indicative for extremely dense winds and provide a valuable test of our theoretical understanding of stellar mass loss in a part of parameter space that has barely been studied. The evolutionary state of the Of/WN targets is intriguing and spectral analysis has to reveal whether these stars are main sequence objects with extremely dense winds due to their high luminosity, or whether they are evolved objects in transition to the WR stage (de Koter et al. 1997).

We will analyse the spectra using **a unique combination of state-of-the-art NLTE model atmospheres** accounting for the outflow of gas (FASTWIND, Puls et al. 2005) and **a genetic algorithm fitting** approach as developed at the University of Amsterdam (Mokiem et al. 2005). This will provide detailed information about the stars physical parameters (M, L, $T_{\rm eff}$, $v \sin i$), its chemical composition (X,Y) and its wind properties (${\rm d}M/{\rm d}t$, v_∞). This will **pinpoint the mass and evolutionary status of the objects**, and will provide **tests for the theory of radiation driven winds** (e.g., Kudritzki & Puls 2000, Vink et al. 2001), allowing us to address the question whether or not Of/WN stars have radiation driven winds like normal O stars have.

X-shooter offers two critical advantages compared to previous instrumentation: i) a spectra resolution R = 6000-10000, needed to securely disentangle the stellar signature from nebular emission, and ii) the full UV-Visible-NIR wavelength coverage, giving access to an unprecedentedly large number of diagnostic lines.

As a summary, we propose to perform quantitative spectroscopy of some of the most massive stars known beyond the Local Group. Using the unprecedented spectral resolution and wavelength coverage offered by X-shooter, the current project will allow us to pinpoint the physical properties and evolutionary status of the objects and to test the theory of radiation driven winds. Upon completion, this project will indeed prove the capability of X-shooter for extragalactic stellar astronomy.

References:

Bresolin et al. 2007, ApJ 671, 2028
Castro et al. 2008, A&A 485, 41
de Koter, Heap & Hubeny 1997, ApJ 477, 792
Evans et al. 2007, ApJ 659, 1198
Kudritzki & Puls 2000, ARA&A 38, 613
Hunter et al. 2007, A&A 466, 277
Mokiem, de Koter et al. 2005, A&A 441, 711
Mokiem, de Koter et al. 2007, A&A 465, 1003
Puls et al. 2005, A&A 435, 669
Vink, de Koter & Lamers 2001, A&A 369, 574

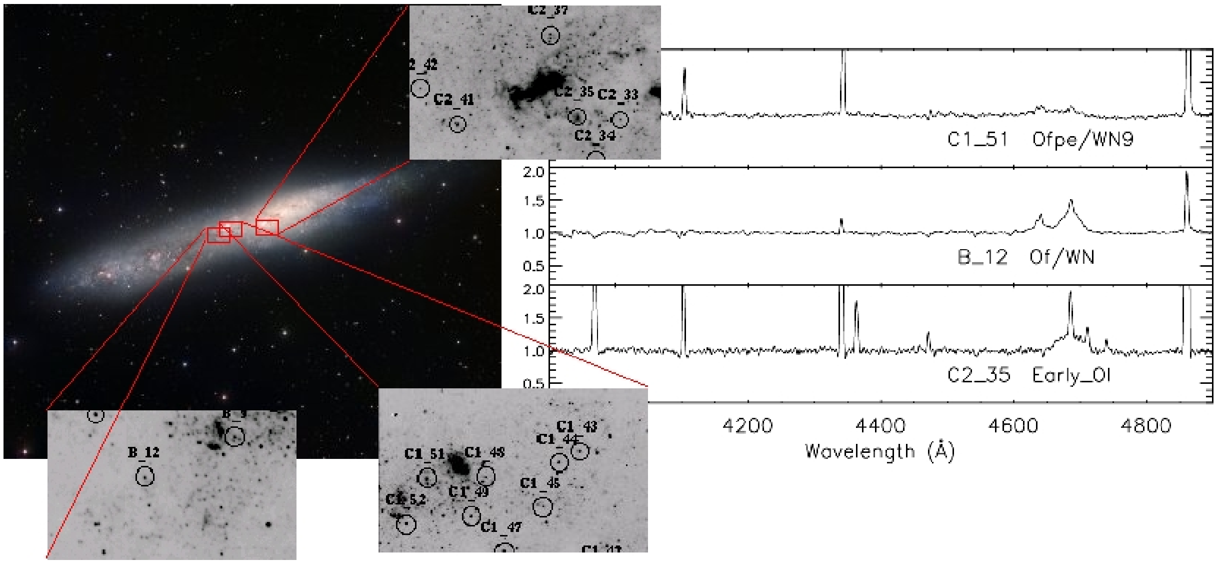

Fig. 1: *Left:* WFI three color image (B, V, Hα) of the NGC 55 galaxy in the Sculptor Group. North is up, East to the left. The field-of-view is 30' wide. Close up show FORS2 pre-imaging in the surroundings of the selected targets. *Right:* Low-resolution ($R = 780$) blue spectra of the selected targets (Castro et al. 2008)

Targets and observing mode

Target	RA	DEC	V mag	Mode (slit/IFU)	Remarks
C1_51	00 15 14.7	-39 12 54.4	18.3	slit	Ofpe/WN9
B_12	00 15 16.8	-39 13 26.4	19.1	slit	Of/WN
C2_35	00 14 59.7	-39 12 42.8	18.2	slit	early OI

Time Justification:

Typical SNR of 30-40 is needed for accurate atmosphere model fitting, which can be reached in a total integration time of 5400 sec for a typical magnitude of V=18.5 (adopted slitwidths are 0.8/0.9/0.7" for the UBV/VIS/NIR arm respectively, ETC v.3.2.8). In the NIR, the objects are expected to be even brighter, which will compensate the lower efficiency of the instrument in the H and K band. The total observing time will be split in 3 AB cycles, with a DIT of 900sec at each position to allow for sky-subtraction. The time for readout will be dominated by the VIS detector, so that the total time per object is : Pointing / acquisition / slit / 6x(DIT+offset+readout) = 360s / 180s / 30s / 6x(900+15+91) = 6612sec, equivalent to 1.84h. The total time requested for the three objects is thus 5.5 hours.

If less time should be allocated to this project, we note that valuable science could already be done with only one or two objects, although one would increase the risk of picking the one non-representative object in NGC 55.

Note on the calibrations: If possible, observation of a spectrophotometric standard star is particularly relevant for us as the change of slope of the spectrum from VIS to NIR contains important information on the stellar wind.