Report on the Workshop

The First Year of Science with X-shooter

held at the Palace Hotel and Centro Congressi, Como, Italy, 19–22 October 2010

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The workshop was held with the aim of bringing together X-shooter users to discuss scientific results, performance and technical aspects, after the first year of successful operations of the instrument. The workshop was also organised to commemorate Roberto Pallavicini, whose scientific and human contribution to the development of X-shooter was invaluable and a source of continuous inspiration for all of us. A touching presentation focusing on the scientific personality of Roberto was given by Luca Pasquini on the second day of the workshop.

About 50 people attended the workshop, including several young researchers. A variety of preliminary and more advanced results from the first year of X-shooter activities was reported. In spite of the natural need of the community to become well acquainted with a new and sophisticated instrument and its analysis tools, the first results are, already, truly exciting, spanning a wide range of different scientific fields, covering virtually all classes of astrophysical objects, and demonstrating the high flexibility and throughput of X-shooter. The scientific programme was put together thanks to the dedicated work of the Scientific Organising Committee (S. Covino, Co-Chair; S. D'Odorico; J. Fynbo; P. Groot; F. Hammer; J. Hjorth; L. Kaper; S. Randich, Co-Chair; P. Rasmussen; and F. Zerbi).

The first session of the workshop was dedicated to talks related to the instrument itself, including a description of its history, characteristics, performance and a science overview, with particular focus on the Guaranteed Time Observer (GTO) programme (presentations by S. D'Odorico; F. Zerbi et al.; C. Martayan et al.; P. Bristow et al.; M. Andersen; P. Groot). A programme aimed at setting up an X-shooter spectral library was also presented (S. Trager). The second session was devoted to star formation, while during the third session the potential of X-shooter for studies of stars and stellar populations was discussed. The fourth and fifth sessions focused on supernovae and gamma-ray bursts (GRB); speakers in the last session presented X-shooter results on the physics of galaxies and the intergalactic medium (IGM) in the low- and high-*z* Universe. The full programme of the meeting and selected presentations are available on the conference web page[1].

We present here a selection of the topics presented. Proceedings will be published in a dedicated volume of *Astronomische Nachrichten* and most of the quoted contributions will soon be available there.

Stellar spectroscopy

X-shooter offers a unique instrument combination for studies of star formation, from the lowest mass brown dwarfs (BDs), to the most massive young stellar objects (YSOs).

A set of spectra of very low-mass members of nearby star-forming regions (SFRs), shown in Figure 1, represents a spectacular example of the capabilities of X-shooter in this field. The large and simultaneous spectral coverage, from the *U*- to the *K*-band, allows the characteristics of these objects, such as their spectral types, lithium abundances, the accretion and wind properties and the physical conditions of the gas accreting from the circumstellar disc onto the star (J. Alcalà et al.; E. Rigliaco et al.), to

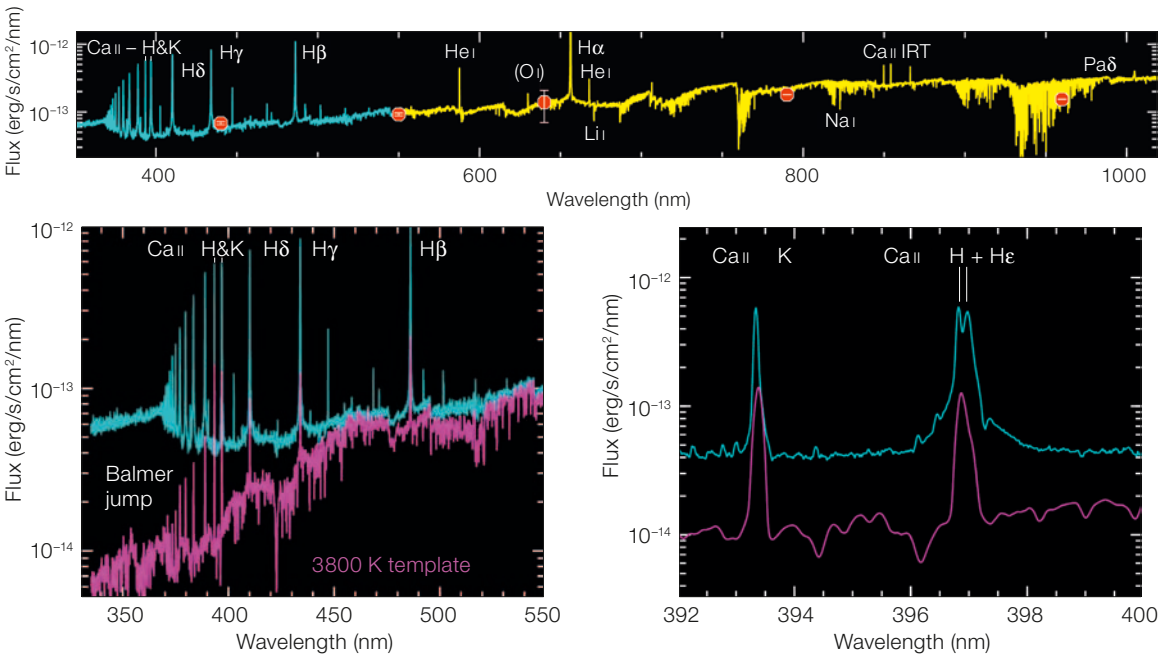

Figure 1. Example of the flux-calibrated UVB (blue) and VIS (red) X-shooter spectrum of the young, low-mass (M = 0.6 $M_{\odot}$) star Sz130 in the Lupus--- cloud. The good match between the flux of the UVB and VIS spectra is noticeable. The emission lines of the Balmer series (up to ~ H24), as well as the HeI and CaII (H&K and the infrared triplet), are evidence of strong accretion. There is also a very good agreement between the flux derived from the *B*, *V*, *R*, *I*, *Z* photometry (red dots) and the continuum flux of the spectrum. Adapted from Alcalà et al. (2011).

be studied with unprecedented reliability. A large survey of low-mass stars in different SFRs is being carried out as part of the Italian GTO and the first results were presented at the workshop. A survey of older BDs outside star-forming regions is also being carried out (B. Goldmann), which will, for the first time, allow a complete characterisation of these objects and constraints to be put on model atmospheres.

Both for low-mass pre-main sequence (PMS) stars, or T Tauri stars, and for Herbig Ae/Be stars, which are intermediate mass stars still in the PMS phase, X-shooter makes it possible to cover several accretion diagnostics. In this upper mass range, the active star-forming mechanism switches from magnetically controlled accretion to an, as yet, unknown mechanism, but which is likely to be direct disc accretion onto the star. An X-shooter study of a large sample of Herbig Ae/Be stars has started, with the main aim of mapping the differences between the accretion characteristics of low- and higher-mass stars and eventually to put constraints on the formation mechanism of the latter (R. Oudmaijer et al.).

At the highest mass end, X-shooter has the unique potential to probe the spectra of rare massive YSOs in the optical wavelength range. This, in turn, is critical to better determine their photospheric properties, to study the onset of the stellar wind, and to characterise the physical structure of the circumstellar disc. Very interesting and promising results were also obtained thanks to X-shooter observations of two massive YSO candidates. Both spectra are characterised by several emission lines, including the CO first overtone emission, Hα and Ca II IR triplet; these features are indeed consistent with the presence of infall and outflow and are similar to those observed in lower-mass stars (L. Kaper et al.).

Moving to older stars, X-shooter has, in spite of the modest resolution, but thanks to the wide spectral coverage and high efficiency, allowed the determination of abundances of extremely metal-poor stars in the outer Galactic Halo — revealing, in all likelihood, the most distant dwarf stars studied in detail to date — and of two turn-off stars in the globular cluster

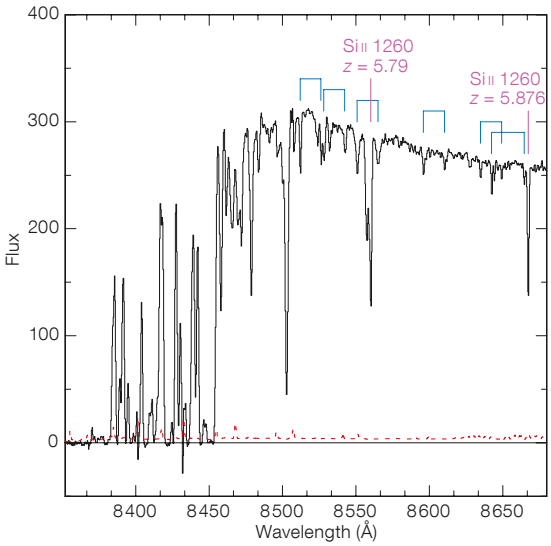

Figure 2. The region of the Lyα emission in the X-shooter spectrum of the QSO SDSS J0818+1722 (z_{em} = 6.00). The detected weak C IV doublets are marked in blue and the two prominent Si II 1260 Å absorption features of the systems at z = 5.79 and z = 5.876 in magenta (for details see V. D’Odorico et al., 2011).

NGC 2808 (P. Bonifacio et al.; A. Bragaglia et al.). The chemical composition of the two halo stars has been derived, showing that they are less metal-poor than expected from the initial selection, and presenting evidence of an anomalous composition (namely an underabundance of α-elements) for one of the two objects. As for the two stars belonging to NGC 2808, they are characterised by significant differences in their abundance patterns, confirming that they likely are representative of two different generations of stars. Remarkably, these results would have not been possible with other spectrographs, except with an unrealistically huge investment of observing time.

X-shooter is also proving to be a very efficient instrument for carrying out intermediate resolution studies of Solar System objects (e.g., asteroids; A. Alvarez-Candal) and for mysterious interacting binary stars. Indeed observations of one of the most well-known recurrent novae and of a candidate black hole have revealed totally unexpected results and spectral features (E. Mason & P. Gandhi).

Extragalactic spectroscopy

The efficiency of X-shooter has allowed D. Bettoni et al. to study the faintest galaxies in nearby clusters and to explore the galaxy scaling relations of early-type galaxies over a broad mass range. The star formation in galaxies at low and high redshifts has been investigated (by L. Christensen), providing a wealth of new data. Results on the gravitationally lensed galaxy “the 8 o’clock arc” have also been reported (by M. Dessauges-Zavadsky et al.) making it possible to dissect the physical properties of a z ~ 3 galaxy.

Studies of the intergalactic medium at high redshift are a *pièce de resistance* for X-shooter and quasars have always been a preferential target (G. Cupani; P. Petitjean). Spectacular results have been obtained for the QSO J0818+1722, as shown in Figure 2, where a tiny subset of the wavelengths covered by X-shooter gives a flavour of the richness of information that can be derived about the processes leading to the cosmological reionisation and the IGM metal pollution (V. D’Odorico et al.).

Gamma-ray bursts and supernovae

Cosmological objects, in particular if rapidly varying, such as GRBs, are definitely a natural core target for X-shooter, and indeed during the first year of X-shooter observations, GRB afterglows (PI J. Fynbo) and GRB host galaxies were frequently targeted. The management of the X-shooter GTO programme has also been an opportunity for research fields with a traditionally high level of international competition to define and establish multinational collaborations, which, in turn, have also allowed young people to immediately begin their research work within this most stimulating environment.

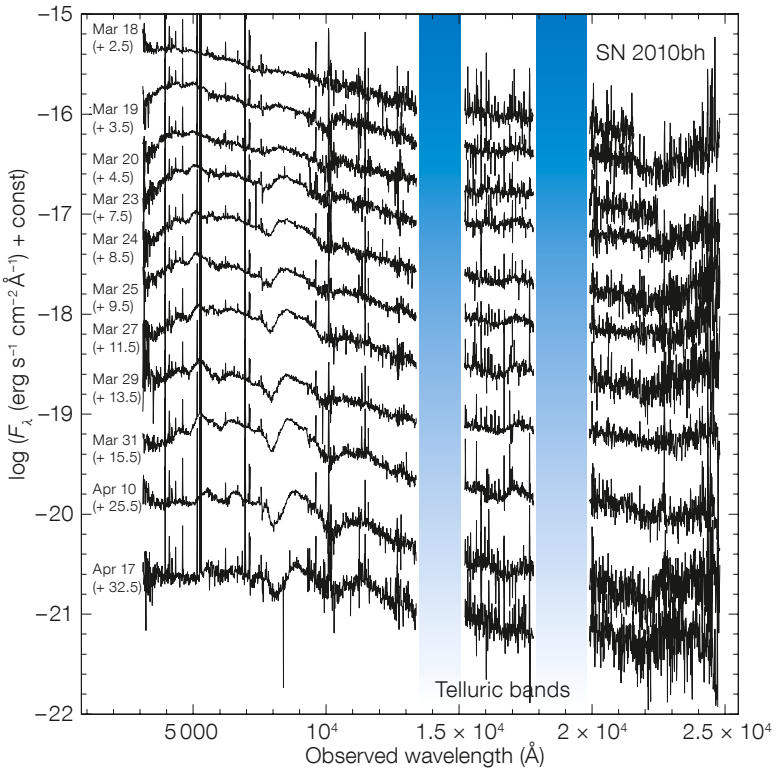

Figure 3. Spectral evolution of SN 2010bh over a period of about two months obtained with VLT + X-shooter. Phases are reported in the observed frame from the Swift/BAT trigger (2010 Mar 16.53). Spectra have been vertically displaced by an arbitrary quantity for clarity of the plot (see Bufano et al., 2011).

The large X-shooter wavelength coverage allows quick and unprecedentedly reliable derivations of redshifts for GRBs crossing the so-called redshift desert ($1.4 < z < 3$). Moreover, the availability of large sets of emission and absorption lines opens up the possibility of substantially improving the knowledge of the chemical features of the environment of these remote objects (V. D'Elia; P. Jakobsson et al.; S. Piranomonte et al.; C. Thöne et al.; S. Vergani et al.) and, when possible, to perform time-resolved analyses (A. de Ugarte Postigo et al.). Integral field unit observations with X-shooter (H. Flores et al.) allowed spatially resolved chemical and dynamical information to be derived, while the extinction properties of high-redshift galaxies are explored with emission line diagnostics provided by the large wavelength range (K. Wieserma).

The supernovae and GRB communities had the opportunity to join efforts, when, in March 2010, one of the still rare SNIb/c objects associated to a GRB (SN2010bh/GRB100316D) occurred. Spectra were taken immediately and the evolution of this event was followed for months (F. Bufano et al., see Figure 3).

M. Strintzinger reviewed the state of the art of observations of type I SNe, putting X-shooter in context, while A. Pastorello et al. presented preliminary results about the impressive efficiency of X-shooter in delivering information about the interaction of SNe with their circumstellar media.

Future prospects

X-shooter is definitely not an instrument designed for high-resolution studies. Nevertheless, with good signal-to-noise, it is possible to derive reliable information about line profiles as carried out by several studies, where, for instance, the profile of Lyman-α was successfully modelled. In this case the large wavelength range of X-shooter makes it easier to find lines to study without being limited to a specific spectral range, and the high efficiency of the spectrograph allows one to deal with fainter objects not reachable at intermediate resolution in previous studies.

It is clear that, in order to cope with the impressive data flow provided by the three X-shooter arms, it is mandatory to employ reliable software tools. The X-shooter pipeline is, of course, still under intense development; nevertheless, it is already mature enough to allow routine reduction and analysis of X-shooter data (P. Goldoni). During the conference a very profitable open session led by A. Modigliani, on behalf of the software development team, was devoted to feedback from the users in order to better drive the future development of the reduction package.

From extended discussions, a number of proposals for further improving the impressive capabilities of X-shooter emerged: the introduction of a cold filter in the infrared to reduce the background; upgrade of the acquisition CCD in order to provide *BVRz* photometry as a scientific and calibration added value, the possibility of infrared-only nodding; the suggestion to move X-shooter to another VLT Unit Telescope with lower time oversubscription. The action of studying an IR sensitive acquisition camera, important for high redshift work and IR flux calibration, was also taken.

Summing up, within the limits of just one year of observations with a young instrument, the wealth of data is impressive and researchers have learnt how to deal with information which, in the recent past, was (occasionally) available only through time-consuming, multi-instrument observational campaigns. X-shooter now defines the state of the art for this category of spectrographs. Not by chance it has been among the most requested instruments at ESO since the very first observational period that it was offered to the community.

References

Proceedings will be published in *Astronomische Nachrichten* in 2011.

Links

[1] Conference web page: http://www.brera.inaf.it/xshooter2010/