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The X-shooter Spectrograph for the VLT

F.M. Zerbi[1], R. Pallavicini[2], P. Conconi[1], R. Cosentino[3,4], V. De Caprio[1], A. de Ugarte Postigo[1,5], P. Di Marcantonio[6], M. Riva[1], P. Santin[6], P. Spanó[2], A. Zacchei[6]

[1] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Brera sede di Merate, Via Bianchi, 46, I-23807 Merate, Italy
[2] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, I-90134 Palermo, Italy
[3] Fundación Galileo Galilei INAF Calle Alvarez de Abreu, 70 , 38700 Santa Cruz de La Palma, TF - Spain
[4] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Catania, Via S.Sofia 78, 95123 Catania ITALY
[5] Instituto de Astrofísica de Andalucia – C/ Camino Bajo de Hutor, 50 18008 Granada - Spain
[6] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy

Abstract. X-shooter is a single target spectrograph for the Cassegrain focus of one of the VLT UTs. It covers in a single exposure the spectral range from the UV to the H band with a possible extension into part of the K band. In order to maximize the sensitivity in this spectral range the beam is splitted in three arms with optimized optics, coatings, dispersive elements and detectors. It operates at intermediate resolution (R=4000-14000) sufficient to address quantitatively a vast number of astrophysical applications. Approved as second generation instrument for the VLT, X-shooter will be available to the community in the first part of the year 2008

The X-shooter spectrograph has been proposed in response to the call for Proposals for a 2^{nd} generation VLT instruments issued by ESO on November 19, 2001, as the instrument to fill the gap in the capability of the current suite of VLT instruments in operation or under construction at ESO VLT (Fig. 1).

Many Astrophysical programs require a high efficiency fast response spectrograph covering a wide band (UV to IR) at intermediate resolutions mounted on an 8-10 mt class telescope. Such an instrument would allow to perform observations that are currently collected with multiple instruments on multiple UTs with an high cost in VLT time.

X-shooter is built by a Consortium of four Nations (Denmark, France, Italy and the Netherlands) and ESO. Each of the partners contributes in manpower and to the Hardware cost receiving in return guaranteed time. Each Nation expresses a Principal Investigator (P.K. Rasmussen, F. Hammer, R. Pallavicini, L. Kaper) and a Project Manager (P.K. Rasmussen, I. Guinouard, F.M. Zerbi, L. Venema). The board of PIs is coordinated by

Send offprint requests to: F.M. Zerbi

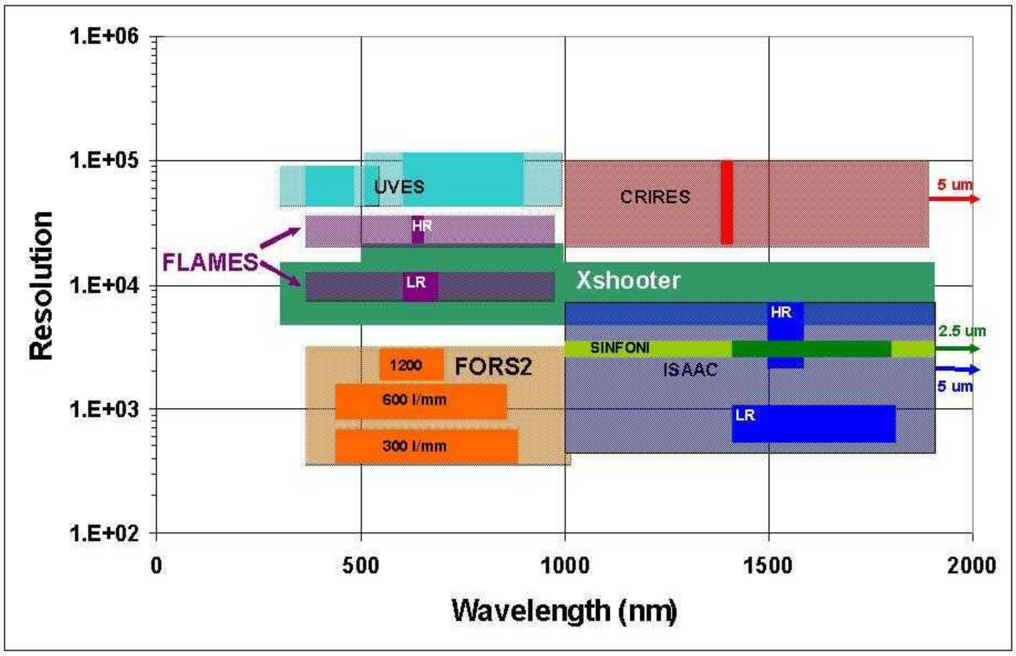

Fig. 1. Properties of VLT spectrographs in the resolving power versus wavelength plane U to H range). Note that by the time X-shooter will be in operation the FORSes and ISAAC will be beyond their guaranteed lifetime

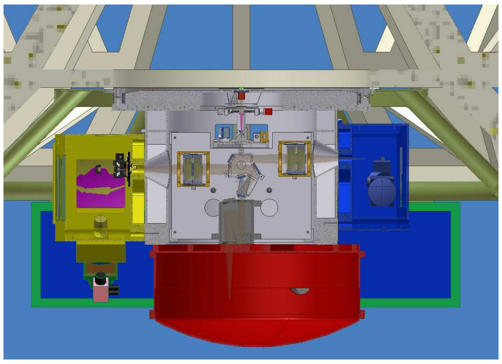

Fig. 2. X-shooter general layout. The backbone, shown attached to the Cassegrain focus of the VLT, contains the pre-slit optics pre-processing and despatching the light into the UV (left), the VIS (right) and the IR (bottom) arms.

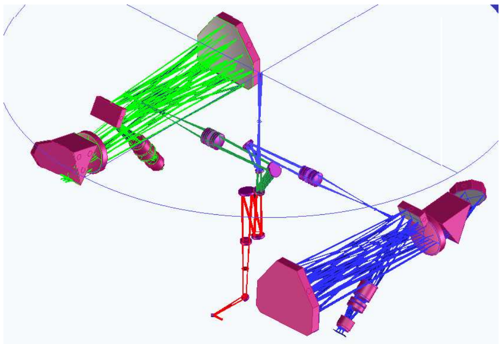

Fig. 3. X-shooter 4C Optical design (NIR arm not shown).

S. d'Odorico and the group of PMs by the Instrument Project Manager H. Dekker.

Presented in the final form in October 2003 and fully approved by ESO Scientific and Technical Committee in December 2003, X-shooter is proceeding at full pace. Having passed the Preliminary Design Review in December 2004 is now approaching the Final Design Review in schedule.

1. A Science Case for X-shooter

X-shooter is a multi-purpose instrument and can be used for innumerable astrophysical applications. Nevertheless a driving science case made of five key issues has been used to define the instrument requirements and are briefly reported below.

Brown Dwarfs. The goal is to understand the mechanism of formation of the population of these cold sub-stellar object and to explore through a statistically significant sample their properties versus those of giant planets and low mass stars. This requires simultaneous red and IR observations to study accretion-ejection rates, intermediate resolution to follow emission lines and high efficiency to study young and faint BDs in star formation regions.

Stellar Remnants in Compact Binaries. The goal is to study the physics of accretion disks, to measure abundances in secondary stars of mass-transferring binaries a clue to properties of the primaries. The above requires simultaneous UV-Visual-IR measurements and intermediate resolution to study evolution of narrow emission lines and to measure abundances from absorption lines.

Gamma Ray Burst Afterglows. The goals are to study the physics of these energetic events, to investigate the regions of star formation up to high z where they originate and to probe the IGM with unique possibility to do so in the redshift range $6 < z < 10$. The above requires UV to NIR coverage in a single exposure and with high efficiency. It requires as well intermediate resolution to allow for studies of the velocity structure of the absorption lines close to the source and in the intervening medium. In this case minimum operation overheads are required to address and follow timely rapidly decaying targets.

High z emission line galaxies. The goal is to collect spectroscopy of high redshift, low metallicity H II regions amplified by massive galaxy clusters to study the properties of the first stellar populations from the relative emission lin and continuum strengths. The above requires area spectroscopy capabilities and simultaneous coverage from UV to IR at $R \sim$ 5000 for accurate spectrophotometry of galaxies of small angular dimensions.

Fig. 4. Efficiency of the X-shooter dichroics

Line of sights to QSOs at moderate angular separation. By studying the Lyman α forest in lines-of-sights to QSOs separated by $< 5'$ one can determine the size and correlation scale of the clouds. Ultimately one can derive the cosmological constants Ω_Λ and Ω_m. The above requires high efficiency UV-Visual bands to obtain moderate resolution ($R \sim 5000 - 7000$) spectra of absorption lines in the line of sight to intrinsically faint targets ($m_b \sim 21 - 22$).

2. Instrument Description

A few keywords well summarize the specifications imposed on the instrument by the aforementioned Science Cases. These are a) Large (UV-VIS-NIR) simultaneous wavelength coverage, b) Intermediate (4000-15000) Resolutions c) High Efficiency, d) Easy to operate point-and-shoot philosophy.

X-shooter is a 3-arms Echelle Cross dispersed spectrograph (fig. 2). The 3 arms (UV-Vis and NIR) are needed to maximize the efficiency in such a large wavelength range, via optimizing the optics, the coatings and the detectors. The Cross dispersed Echelle configuration is instead the most straightforward technical solution for intermediate resolution in large wavelength ranges.

Nevertheless X-shooter is far from being an ordinary instrument. The optical design, named 4C (Camera Compensated Collimator Chromatism - Fig. 3), applied with some mod-

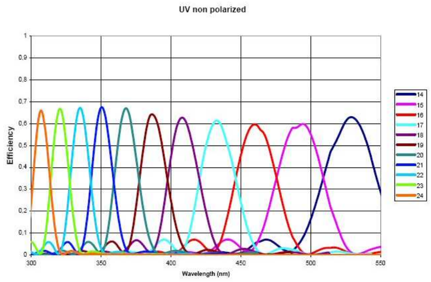

Fig. 5. Computed efficiency of the UV arm Echelle.

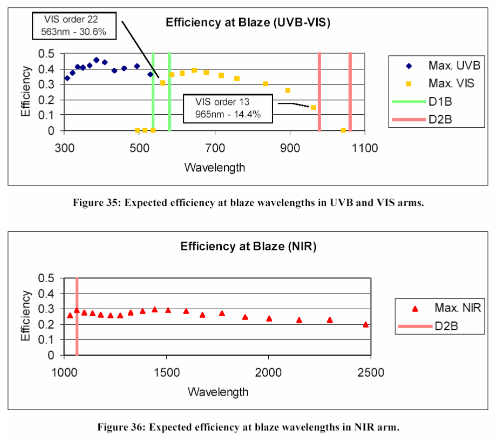

Fig. 6. Estimated efficiency throughout the wavelenght range covered by X-shooter

ification to each of the spectrograph arms, will be used for the first time in an Astronomical Instrument. This design introduces a controlled chromatism with the collimator which is then compensated by the camera, allowing smaller beam sizes and reduced weight with good performances. Efficiency is a goal that is being followed in the definition of each part of the instrument. The beam repartition is performed via a set of dichroics located in the pres-slit area. The Dichroics have been purposely selected for their efficiency (see fig. 4) so that they deliver most of the light to each of the science channels. The gratings are the most central element in any spectrograph. For the three X-shooter Echelles new ruling masters with specific ruling have been ordered. The ruling and the blaze angles selected are the results of detailed Rigorous Coupled Wave Theory (RCWA) simulations (fig. 6). The goal is to obtain grating delivering optimal spectral format on the detectors and with the highest possible average and peak efficiency. The detectors have been chosen as well with quantum efficiency maximized in the wavelength range covered by each arm.

The overall result of the selection operated on each component is a remarkably efficient instrument (fig. 6). X-shooter is expected to reach limiting magnitudes (1h, S/N=10, slit width=1) of U=21.9, B=22.0, V=21.7, R=21.7, I=21.3, Z=20.3, J=20.7, H=20.9, K=19, K=18.9. These numbers make X-shooter a good answer to the needs of the science cases that determined its characteristics and many others not reported or unknown.

3. The Italian Contribution to X-shooter

The Italian X-shooter team is composed by four INAF institutes, Catania, Milano-Brera, Palermo and Trieste, each providing their own specific expertise to the project. The Italian team has the following responsibilities in the Cnsortium:

- Optical design and optics procurement for the pre-slit, the UV and the Visible arm.
- Design and procurement of the Echelle gratings for the Visible and UV arm.
- Design, FEA and procurement of the mechanical supports for the optics of the Visible and UV spectrographs.
- Design and procurement of the Instrument Control Software
- Pre-integration of the UV and Visible arm at the Merate Observatory Integration facility

References

D'Odorico, S., et al. , 204, SPIE, 5492, 220