The commissioning of X-shooter: a new spectrograph @ VLT

P. Di Marcantonio – INAF-OAT (on behalf of the X-shooter consortium)
X-shooter has been built by a Consortium of European Institutes comprising:

- ESO (PI S. D’Odorico, PM H. Dekker)
- Denmark (PI/PM P. Kjærgaard-Rasmussen)
- France (PI F. Hammer, PM I. Guinouard)
- The Netherlands (PI L. Kaper, PM R. Navarro)
- Italy (PI R. Pallavicini, PM F. Zerbi)

**ATG has been responsible for the design, development, integration and commissioning for the control software of the whole instrument.**

People involved @ OAT:

- Paolo Di Marcantonio, Paolo Santin, Marzio Vidali (till end 2006)
- Andrea Zacchei, Claudio Zamberlan (thesis), Roberto Cirami
- continuous support of the OATs electronic group
The X-shooter Consortium

11 institutes in 5 countries
## X-shooter resources

<table>
<thead>
<tr>
<th></th>
<th>effort (FTE)</th>
<th>Cost (k€)</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>19</td>
<td>850</td>
<td>Control electronics, Backbone unit, FEA, system test of UVB spectrograph</td>
</tr>
<tr>
<td>ESO</td>
<td>15</td>
<td>1510</td>
<td>Overall ProjMan.&amp; SysEng, detectors, final system integration and commissioning, logistics</td>
</tr>
<tr>
<td>France</td>
<td>12</td>
<td>140</td>
<td>IFU, DRS</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td>19</td>
<td>800</td>
<td>Optomechanical design and integration of UVB and VIS, system test of VIS spectrograph, Control Software</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1.8</td>
<td>2044</td>
<td>NIR spectrograph, contribution to DRS</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>66.8</strong></td>
<td><strong>5344</strong></td>
<td></td>
</tr>
</tbody>
</table>
INAF-OATs (only) GTO involvement:

- Abundances and Dust in high redshift (z>4.0) Damped Lyman α galaxies (PI: Paolo M., CoI: Giovanni V., Valentina D’O. …)
- Optical-NIR spectra of quasars close to re-ionization (z~6) (PI: Valentina D’O., CoI: Paolo M., Stefano C., Matteo V., Giovanni V….)
- Extremely metal-poor stars in SDSS fields (PI: Piercarlo B., CoI: Paolo M., …)
- Tomography of the Intergalactic Medium with multiple QSO lines of sight (PI: Stefano C., CoI: F. Calura, E. Vanzella, V. D’Odorico, M. Viel, P. Monaco, …)
- A 100 burst X-Shooter/Swift GRB afterglow legacy survey (CoI: Elena P.)
- X-Shooting Supernovae (CoI: Elena P.)
- Study in situ of GRB progenitors and their host galaxies with X-Shooter : from z = 0.1 to 2.3 (CoI: Elena P.)
# X-shooter time schedule

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>STC 56</td>
<td>Dec 2003</td>
</tr>
<tr>
<td>PDR</td>
<td>Dec 2004</td>
</tr>
<tr>
<td>FDR</td>
<td>Feb – Jul 2006</td>
</tr>
<tr>
<td>Integration@ESO</td>
<td>2008</td>
</tr>
<tr>
<td>PAE</td>
<td>Sept 2008</td>
</tr>
<tr>
<td>Comm #1</td>
<td>Nov 2008</td>
</tr>
<tr>
<td>Comm #2</td>
<td>Jan 2009</td>
</tr>
<tr>
<td>Comm #3</td>
<td>Mar 2009</td>
</tr>
<tr>
<td>Comm #4</td>
<td>May 2009</td>
</tr>
<tr>
<td>SV or GTO (several periods)</td>
<td>Jul – Sept 2009</td>
</tr>
<tr>
<td><strong>Start of Operations</strong></td>
<td><strong>1.10.2009</strong></td>
</tr>
</tbody>
</table>
Instrument characteristics

- Wavelength range: three arms covering from 300 nm to 2500 nm
- Fixed prism cross-dispersed echelle format (slit length 11”)
- Detectors:
  - 2K x 4K 15μ CCDs (UVB and VIS arms)
  - 2K x 1K segment of a 2K x 2K 18μ Hawaii 2RG MBE (NIR arm)
- IFU (1.8” x 4”), ADC for UVB and VIS arms, calibration unit and A&G unit
- Spectral resolution: ~7000 to 12000 for 0.6” slit or IFU
- High Detective Quantum Efficiency
- Pipeline delivering sky-subtracted, wav cal 2D spectra and 3D data cube for the IFU
- High-redshift emission-line galaxies
- AGNs at intermediate and high redshifts
- Absorption lines in QSO spectra
- Tomography of the intergalactic medium
- Supernovae
- GRB afterglows
- Brown dwarfs and T-Tauri stars
- Stellar remnants and compact binaries

The instrument will be released on 01/10/09 and is already in high demand (120 proposals were received for P84 – for comparison: FORS 1+2: 180, UVES: 90).
Note: Widths of the darker strips identify the spectral coverage in a single exposure. VIMOS (not shown) approximately overlaps with FORS and both have poor response in the UV. FORSes and ISAAC are expected to be decommissioned by the time when X-shooter will become operational.
Arms observing capabilities

- **UV-blue arm Range: 300-550 nm in 12 orders**
  - Resolution: 5100 (1" slit)
  - Slit width: 0.5”, 0.8”, 1.0”, 1.3”, 1.6”, 5.0”
  - Detector: 4k x 2k E2V CCD

- **Visual-red arm Range: 550-1000 nm in 14 orders**
  - Resolution: 8800 (0.9" slit)
  - Slit width: 0.4”, 0.7”, 0.9”, 1.2”, 1.5”, 5.0”
  - Detector: 4k x 2k MIT/LL CCD

- **Near-IR arm Range: 1000-2500 nm in 16 orders**
  - Resolution: 5100 (0.9" slit)
  - Slit width: 0.4”, 0.6”, 0.9”, 1.2”, 1.5”, 5.0”
  - Detector: 2k x 1k Hawaii 2RG
UVB-VIS optical layout
NIR optical layout
Calibration unit

Figure 18 ISH & Calibration Lamps Unit, View from above

Figure 19 View from below
**ADCs & Piezo’s**

- UVB- Piezo Unit: centred 5mm
- 30 deg piece done by Alu.
- VIS- Piezo Unit
- NIR Piezo: Working perp. to the mirror
- New DC-Plates support Box
The vacuum containment as designed consists of three major elements, viz.

A stiff aluminum top plate (red part)
An aluminum cylindrical shell (green part)
A stainless steel cryogenic service unit (CSU) (blue part)
FDR CAD design
Eventually ...

Xshooter
UT3, Mar 09
UT3 integration

UVB, VIS&BB
MMB, Nov 08

UVB, VIS&BB
UT3, Nov 08

NIR
UT3, Mar 09

NIR
Garching, Feb 09
The ESO Control Software

ICS

TCS

Observation Software (OS)

DCS (TCCD/FIERA/IRACE)

ARCHIVE
ESO control software - full path

- User
- Obs. Block
- BOB
- On-line Midas
- Template
- RTD
- P2PP
- OS GUI

OS Server:
- WS ICS
- WS DCS
- tif
- TCS Telescope/Rotator
- Instrument
- Detectors
- Archive

ESO control software - full path
ESO Common software

- CCS: Basic common functions.
- ERR: Error reporting.
- LOG: Logging system.
- MSG: Message system.
- CMD: Command checking.
- DB: On Line Database.
- EVT: Event handling.
- TIMS: Time calculations & triggering.
- NTP: Clock synchronisation.
- SCAN: Data propagation.
- ALRM: Alarm reporting.
- BOOK: Security checks.
- PANEL: GUI development support.
- CCSEI: Engineering UIF.
- SAMP: Sampling/Plotting tools.
- DBL: Database generation.
- ECCS: CCS C++ API & Classes.
- EVH: C++ Event Handler template.

The main components of LCC are:

- Local database
- Interfaces with CCS
  - message system
  - logging system
  - error system
  - scan system
  - access control
- I/O system
- Time services
- Command Interpreter
- Start-up and shut-down procedures
- Simulation
- Drivers for ESO standards boards
- Motor Control module
- Engineering test tools
The X-shooter control sw design
**P2PP**

**ObsBlock: No Name: FLAMES**

**File**  |  **Edit**  |  **Synchronise**  |  **FindingCharts**
---|---|---|---
**Name:** No Name
**Status:** Partially Defined
**Execution Time:** 00:00:00.000
**User Priority:** 1
**User Comments:**

**Template Type:**
- Acquisition: FLAMES_calib.obs.exp
- Science: FLAMES_giraf.obs.exp
- Calibration: FLAMES_calib.obs.exp
- Test: FLAMES_uses.obs.exp

**Parameter:**
- **No. of Exp:** 1
- **Exposure time:** 10
- **Central wavelength:** 1.385.7
- **Simultaneous Th-Ar calib. lamp:**
  - L427.2
  - L479.7
  - L543.1
  - L614.2
  - L668.2
  - L733.4
  - L831.7

**Target**  |  **Constraint Set**  |  **Time Intervals**  |  **Sidereal Time**  |  **Calibration Requirements**
---|---|---|---|---
**Name:** No Name
**Right Ascension:** 00:00:00.000
**Declination:** 00:00:00.000
**Equinox:** 2000
**Epoch:** 2000.0

**Class:** Unknown
- proper motion RA: 0.0
- proper motion DEC: 0.0
- Diff RA: 0.0
- Diff DEC: 0.0
Sends a buffer of keywords to OS:

“DETi.WIN1.BINX 1 DETi.WIN1.BINY 1
DETi.WIN1.UIT1 5 INS.FILT1.NAME FREE
INS.LAMP1.ST F INS.LAMP2.ST F
TEL.TARG.ALPHA 00 TAL.TARG.DELTA 00 …”

Start Observation: sends START to OS
Observation software (OS)

Sends:
- TEL* to TCS
- INS* to ICS
- DETi* to DCS

After the exposure, OS collects all the FITS keywords from the various subsystems, merge them into the final FITS image and send it to the archive.
The ICS SW is split into a WS and an LCU part. Fig. 1 shows its general architecture.

Fig. 1 ICS process structure overview
### Instrument Control Software (ICS) II

#### Spectrogr. FE - Motors
- inch: ONLINE, SIM, 0
- cals: ONLINE, SIM, 0
- aags: ONLINE, SIM, 0
- afil: ONLINE, SIM, 0
- adc1: ONLINE, SIM, OFF, 0
- adc2: ONLINE, SIM, OFF, 2300
- adc3: ONLINE, SIM, OFF, 0
- adc4: ONLINE, SIM, OFF, 12739

#### Spectrogr. FE - Lamps

#### Spectrogr. FE - AFCS

#### TMS
- tms: ONLINE, SIM
- TGUC: N/A
- TSPF: N/A
- TMUE: N/A
- TSYC: N/A
- TKVF: N/A
- TKVE: N/A
- TUECR: N/A
- TUKCR: N/A
- TMNCP: N/A
- TMA: N/A
- TMADC: N/A

#### Command Feedback Window

#### Options
Instrument Control Software (II)
**Motors/Lamps/Sensors**

![Image of the components](image)

MAC4-INC Motion controller

Servo-drive unit

Function connector

Limit and Reference switches

VME4SA Servo-amplifier

4-chanr Backplia Cable

Manual Command Switch

LED Switch

Toggle Switch

STATUS LED

FAULT = YELLOW

LAMP ON = RED

LAMP OFF = GREEN

CONTROL

LAMP ON = RED

LAMP OFF = GREEN

Figure 20- CFC control electronics sub-rack
Local Control Unit (LCU)
Active Flexure Compensation

AFC executed during object acquisition, in parallel with telescope Active Optics, (but generally faster)

Correlation of two arc spectra taken with a pinhole in spectrograph and one in Cass focal plane

Popup window with correlation results, applied to the 3 Piezos
Why AFC?

Figure 58 NIR Spectrograph Slit Motion in the NIR slit plane. Combined Result from the 3 FEM analyses. From Zenith as zero position the maximum NIR slit motion is −52 μm in X direction and +131 μm in Y direction. This is just out of specification.
AFC mechanics

UVB- Piezo Unit
decentred 5mm

30 deg piece done
by Alu.

VIS- Piezo Unit

NIR Piezo
Working perp to
the mirror

Piezos

New DC-Plates
support Box
AFC electronics
- PARK – apply a fixed value corresponding to the middle position;
- STAT – maintain the current position;
- REF – moves the tables in a fixed position required for the alignment of the system with the telescope in zenith position;
- AUTO – activates the monitoring task which periodically calculates and applies the corrections. The corrections are calculated based on the current telescope/instrument position.
- INS.TILT AXISX – send a given correction
- INS.TILT AXISY – send a given correction

At sea level \((P = 760 \text{ mm Hg}, T = 15^\circ \text{C})\) the refractive index of dry air is given by (Edlén 1953; Coleman, Bozman, and Meggers 1960)

\[
(n(\lambda)_{15.760} - 1)10^6 = \frac{29498.1}{146 - (1/\lambda)^2} + \frac{255.4}{41 - (1/\lambda)^2},
\]

where \(\lambda\) is the wavelength of light in vacuo (microns). Since observatories are usually located at high altitudes, the index of refraction must be corrected for the lower ambient temperature and pressure (Barrell 1951):

\[
(n(\lambda)_{T,P} - 1) = (n(\lambda)_{15.760} - 1)
\]

\[
\times \frac{P [1 + (1.049 - 0.0157 T)10^{-6}P]}{720.883(1 + 0.003661 T)}
\]

In addition, the presence of water vapor in the atmosphere reduces \((n - 1)10^6\) by

\[
\frac{0.0624 - 0.000680/\lambda^2}{1 + 0.003661T} f,
\]
Object Acquisition

[Image of a software interface for object acquisition with a small window showing a magnified area of an image, and a larger window showing a broader view of the same image with various options for adjusting the view.]
Magnitude evaluation

Magnitude computation

xc: 70.2
yc: 310.2
Box dimension: 20.0
Obj cnts [ADU/s]:
Bck [ADU/pix/s]:
ZP:
Obj mag:

Pick Object  Cancel  Close

Bck. inner Rad. 8
Bck. outer Rad. 9

0 5 10 0 5 10 0 5 10

Pick object  Pick cursor

Compute magnitude
Allowed spectroscopic observations

- **staring** – each arm at a fixed position on sky;
- **staring synchronized** – exposures synchronized at their mid-time;
- **nodding**;
- **fixed offset**;
- **generic offset**;
Synchronized exposures

**Template**

- Tuvb: absolute starting time for UVB exposure
- Tvis: absolute starting time for UVB exposure
- DT: computed delay before sending START NIR command

**OS**

1: Get current time
2: Compute starting times and DT
3: START UVB - at shut Tuvb
4: START VIS - at shut Tvis
5: START UVB - at shut Tuvb
6: START VIS - at shut Tvis
7: Wait DT

**FIERA**

8: WIPE
9: WIPE

**IRACE**

10: START NIR
11: START
12: WAIT end of exposures
13: INTEGRATE
14: INTEGRATE
15: INTEGRATE

Exposure mid-point

**Shdetb**

**Shdetv**

**Shdett**
Sw complexity

Instruments

Lines of code

Adapt. optics
Miscellaneous
MS
Templates
OS
DCS LCU
DCS WS
ICS LCU
ICS WS
Some results from the three commissioning periods:

- nov 2008 and jan 2008- integration/installation of the UVB and VIS spectrograph with a dummy NIR;

Cited from a report sent to STC:

“... a total of 17 nights, no losses due to technical problems or weather. The overall efficiency and mechanical flexure are in spec. The hardware, software and operational interfaces with the telescope environment (A&G procedures, OBs, flexure compensation system, ADCs, IFU...) all work as expected in line with the desired “point and shoot” objectives for this instrument.”

- march 2009 – first light with the full instrument:

Excerpt from a report sent to STC: *March 14*

“... first light was achieved quite smoothly on. Commissioning continued until the morning of March 20 (6 nights, of which 0.75 lost due to VLT SW problems not directly related to the instrument and 1.75 due to weather). There were no significant losses due to problems with specific instrument hard- or software. NIR spectral resolution as a function of slit width was verified and found in agreement with predictions. Nodding and sky offset modes mostly used for the on sky observations. On faint targets, integration times of up to 25 minutes were used, also in the NIR. Classical A – B nodding was tested and works very well in the UVB and VIS arms.”
Expected Efficiency

Spec:
> 25% avg @ blaze 320 – 1800 nm. Goal 30%
> 10% min in FSR 300 – 1900 nm. Goal: 10%

Wavelength coverage:
> 95% 300-1800 nm; less than 60 nm lost in dichroic crossover ranges
Measured Efficiency UVB/VIS

X-shooter UVB efficiency – COMM1 night 324 – GD71

X-shooter VIS efficiency – COMM1 night 324 – GD71
Reduction of the observations of standard stars shows a peak blaze efficiency in U – H band which exceeds or is equal to predictions, except in J band. K band is still being analyzed.
First light 14/03/09 23:22 standard star, 10s

UVB (0.3–0.55 um)

VIS (0.55–1.0 um)

NIR (0.1–2.5 um)
X-shooter 1st night with NIR arm
14.3.2009
2m, R-5600

Unprocessed spectrum, Telluric Standard star
$4\times1200s$ exp. GRB host, starburst, emission line galaxy at $z=0.105$, $r=20.5$, $K=16.6$

UVB: 320-559nm, $R=5100$
VIS: 560-1040nm, $R=8800$
NIR: 1040-2300, $R=5600$
Observations of faint targets: a QSO at z=6 (2x30m, subtracted one from the other)

H and J Bands, R= 5900

N.B. Residual sky due to intensity variations in the night

VIS-RED above 700nm, R= 8800
QSO at $z=6.016$

VIS-R above 700nm,
R = 8800