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Italian contribution to the ESO instrumentation, from La Silla to the E-ELT

S. D'Odorico

European Southern Observatory – K.Schwarzschild Str. 2, 85748 Garching by Munich, Germany, e-mail: sdodoric@eso.org

Abstract. An overview is presented of the development of optical and infrared instrumentation at ESO from 1980 to 2012, a period which covers the build up of the La Silla and Paranal observatories and the plans for the E-ELT. The contributions by Italian institutes to the instrumentation projects at the different telescopes are described and the future prospects outlined.

Key words. Optical telescopes – Instrumentation

1. Introduction

In this paper the optical and infrared instrumentation built and planned by the European Southern Observatory (hereafter ESO) for the telescopes in its Chile Observatories are overviewed and the contributions by the Italian institutes presented. ESO was established as an European Institution in 1962 with the goal to build an optical astronomical observatory in the southern hemisphere. In 1963 Chile was selected as the country where to establish the Observatory with a first site developed starting in 1965 on the La Silla mountain ridge, in the Atacama desert, 85km northeast of the town of La Serena. A second ESO Atacama site, the Paranal peak, 110km south of Antofagasta, was chosen to host the Very Large Telescope (hereafter VLT). The Paranal Observatory started operation 1998 and includes 4x8.m telescopes + 4 1.5m positionable telescopes for interferometry. Two wide field survey telescopes, one for the infrared (VISTA) and one for the visual (VST) were added in 2009 and 2011 respectively.

Italy joined the organization as a member country in 1982. The development of ESO instrumentation for the La Silla larger telescopes, the 3.6m (1976), 2.2m (1982) and 3.5m New Technology Telescope (NTT, 1989) are summarized in section 2. The instrumentation built for the telescopes of Paranal Observatory are listed in section 3. The contribution on instrumentation by Italian institutes for the two observatories are described in these two sections. Section 4 presents the instrumentation studies carried out between 2006 and 2009 for the 42m European ELT project, for which construction on the Cerro Armazones close to Paranal should start in 2013. Final considerations on the Italian participation to the ESO instrumentation effort are presented in section 5. Detailed information on the technical properties of different instruments are not given here but can be easily retrieved from the ESO web pages.

Send offprint requests to: S. D'Odorico

2. Instrumentation development for the La Silla Observatory 1980-2000

2.1. Overview of the ESO La Silla instruments

The largest La Silla telescope, the 3.6m, saw first light in 1976 after a decade long design and construction time. Instrument planning and design for the 3.6m at ESO was started after the move to the CERN premises in 1970. The smaller telescopes which become operational before the 3.6m operated with instruments provided by European institutes. The operation efficiency suffered from the initial lack on the mountain of technical staff with knowledge and expertise in the instrumentation. The first ESO-built instrument for the 3.6m was the automatic camera at the prime-focus triplet corrector(1979)which operated still with photographic plates. With the move of ESO Headquarters to Garching in 1980, a detector group working on CCDs and infrared detectors was founded. As the photographic plates were being replaced by more efficient detectors, the procurement and installation of digital detector was a key step for a successful instrumentation program. The first spectroscopic device at the 3.6m was a commercial Boller & Chivens spectrograph equipped with a 1D Image Dissector Scanner and ,for a few visiting runs in the first years of operation of the telescope, with the Image Photon Counting System of the University College. The Echelle Cassegrain spectrograph with a CCD detector (CASPEC) was the first ESO-built spectrograph installed at the 3.6m. It was followed by another innovative ESO instrument, the Faint Object Spectrograph Camera (EFOSC) which combined the spectroscopic and imaging modes and the efficiency of the new CCD detectors to study the faintest galactic and extragalactic sources. The EFOSC concept was copied by several similar instruments at medium-large telescopes world-wide and was essentially duplicated for the 8-10m class telescopes.

It was also through the success of these home-made instruments in the first part of the 1980 decade that ESO gathered the consensus in the community to have the VLT project approved in 1987, before the new large telescope on La Silla, the NTT, saw first light in 1989. Table 1 summarizes the main instruments operating since 1980 at the three larger La Silla telescopes. The last two columns give the number of refereed papers using data from a given instrument (as derived from the data base of the ESO library) and the years of operations. The good quality of the instrumentation and of the maintenance and operation at the observatory can be appreciated by the very long lifetime of most instruments and by the large number of refereed papers.

While the larger fraction of the instruments for the La Silla Observatory was designed and built by ESO, a few projects were built by institutes in collaboration with ESO. The external technical and financial contributions were compensated with observing nights at the telescopes where the instruments were installed (the so-called guaranteed observing time- or in short GTO). In this category falls the two Adaptive Optics prototype instruments COME ON + and ADONIS and the multi arm field spectrograph MEFOS, all at the 3.6m, the FEROS echelle, fiber-fed spectrograph at the 1.5m (later moved to the 2.2m) and the Wide Field Camera at the 2.2m. This experience was useful to test at the telescope techniques like AO which were just being developed and to acquire instrumentation on a fast track when limited by ESO manpower or the available budget. The approach was followed more systematically for the VLT instrumentation program from 1990 on (see section 3). In the VLT era two other instruments built in collaboration with consortia of external institutes were installed at the 3.6m: TIMMI2 and HARPS. These collaborations opened to the ESO community a new spectral range, the mid infrared with TIMMI2 and a new observing technique, the highly accurate radial velocity spectroscopy, with HARPS.

2.2. The Italian contributions

Italy joined ESO as member state in May 1982. Its main contribution to the La Silla Observatory were the innovative mechanical structure and dome of the New Technology

TABLE 1. Main Instruments at the La Silla Telescopes

Instrument	Telescope	Type/ Spectral Range	Papers	Operation
CASPEC	3.6m	Echelle spectrograph, 340-1000nm	Not avail.	1984-1999
EFOSC1	3.6m	Imager/low resolution spectr., 350-1000nm	Not avail.	1985-1998
EMMI	NTT	Imager/ low-medium resol. spectr., 320-1000nm	593	1990-2008
SOFI	NTT	Imager/spectrograph, 950-2500 nm	607	1998-2012
SUSI2	NTT	Imager, 320-900 nm	117	1999-2008
EFOSC2	3.6m->NTT	Imager/low resolution spectr., 310-1000nm	315	1998-2012
WFI	2.2m	Wide Field Imager, 320-950 nm	409	2000-2012
FEROS	1.5m-> 2.2m	Fiber-fed, echelle spectr., 350-900nm	242 (2.2m)	1999-2004 2005-2012
TIMMI2	3.6m	MIR imager/spectrograph	95	2002-2006
HARPS	3.6m	Fiber-fed, echelle spectr., 378-691nm	270	2003-2012

Telescope which were built by Italian firms with the funds provided by the membership fees paid by Italy and Switzerland. As of collaborations on instrumentation, starting in the 80s, the Observatory of Trieste collaborated extensively (1985-1995, see the contribution by P. Santin in this volume) with ESO on the software for remote control of instruments and telescopes from Garching. The remote control become for several years an offered observing mode for the Coude Echelle Spectrograph at the CAT telescope and for instruments at the 2.2m and at the NTT. An experiment of remote control of EMMI at the NTT was successfully realized from the Trieste Observatory, via a link through the ESO Headquarter in Germany.

The Roma Observatory collaborated with ESO on the construction of SUSI2, an improved version of the NTT direct camera to be used in superb seeing conditions.It was build in a record time of two years, 1995-1997 (D'Odorico 1995). The contribution by the Roma Observatory was 320 kDM and 2 FTE, in exchange of 25 GTO nights. The camera was used by ESO and Roma astronomers to obtain the first ground-based, multicolor, high image quality deep field [1]. Figure 1 shows the combined deep image.

An additional contribution to the La Silla instrumentation was provided by the Osservatorio di Capodimonte for the construction of the CCD mosaic Wide Field Imager at the 2.2m. A cash contribution of 500kDM and 1 FTE was provided in exchange of 30 GTO nights.

[1] www.eso.org/sci/activities/garching/projects/ndf.html

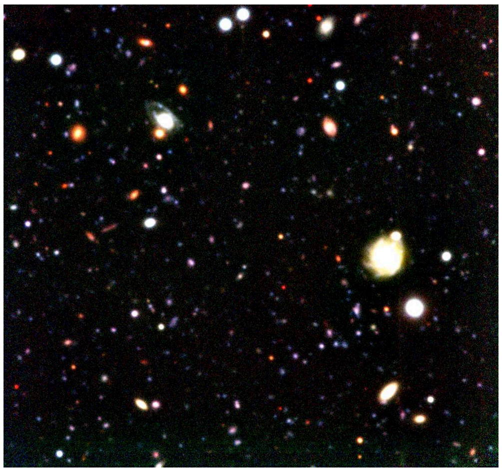

Fig. 1. BVri combined image of the NTT SUSI2 deep field , one of the first attempt of this type of deep imaging from the ground, chosen as NASA Picture of the day on September 15,1998. The image quality of the combined images is below 1 arc sec in all bands, the total exposure times vary from 54ksec (B) to 15ksec(i), see (Arnouts et al 2000), (Fontana et al. 2000).The camera project and the survey were the result of a collaboration between ESO and the Observatory of Roma

3. Instrumentation development for the Paranal Observatory

3.1. The 1st Generation VLT instruments

Long before the VLT first light, in 1989, ESO released an instrumentation plan where the first generation of instruments was outlined and the policy of instrument procurement in collaboration with the external institutes spelled out. 11 instruments were foreseen for the 12 focus positions at the 4 8m telescope (8 Nasmyth + 4 Cassegrain), with one position left free for visiting instruments. The largest fraction of instruments had to be built by consortia of institutes in the member states with the projects based on a set of agreed specifications, following strict standards in electronic components and in the control and acquisition software and subjected to a regular review process. ESO does contribute to the externally-led projects with cash for the hardware procurement and with selected subsystems. ESO does also take care of the procurement and testing of both state-of-the-art CCD devices and IR array and supplied the fully integrated and operational detector systems to all of the VLT instruments.

The plan contained an outline of the first instrument complement and was later updated based on the progress of the observing techniques and components and the changes in science priorities. At the completion of the first generation of instruments, of the 11 instruments 4 were built by ESO and 7 by Consortia led by external P.I.. The external contributions in cash and FTE were compensated by ESO with VLT GTO nights, at a rate of 1 night/50kEUR. This instrument procurement approach made possible the timely realization of the ambitious instrumentation program within budget. It favored the active participation of a large fraction of the scientific community to the project and permitted an early implementation at the VLT of advanced techniques like adaptive optics, the use of laser guide stars and image slicing for integral field spectroscopy. For the institutes the advantage was , and still is for the running and future projects, the possibility to build up a competent technical team around the project, with the support of the national agencies for the infrastructure costs. To the scientists in the consortium the GTO nights offer the great opportunity to carry out deep investigations which can have a major impact in their field of research.

Table 2 lists the current complement of instruments at the four 8m telescopes. They corresponds to the 1st generation of VLT instruments with the exception of the X-shooter, the first instrument of the second generation which replaced FORS1 in 2009. The table reports the current lifetime at the telescope of each instrument and the number of refereed papers using data from a given instrument (as derived from the data base of the ESO library). These numbers show that the first instruments exceeded the originally specified 10 years of operations and that the scientific production as measured by the number of published papers is very high.

An additional instrument used at the VLT is MAD, the Multi-conjugate Adaptive Optics Demonstrator. It is not listed in Table 2 because

TABLE 2. VLT instruments as of 2012, in order of installation date

Instrument	Start Date	λλ (nm)	Type*	Built by	Ref.
FORS2 (+FORS 1 till 2009)	1999 (1998)	V 330-1100	IM +LR SPE	Consortium + ESO	878 (870)
ISAAC	1998	IR 1-2.5, μm	IM +LR SPE	ESO	790
UVES	2000	V 310-1000	HR Echelle SPE	ESO	1069
NACO	2001	IR 450-2500	AO IM+SPE	Cons. + ESO	381
VIMOS	2002	V 360-1000	IM+LR MOS	Cons. + ESO	379
FLAMES	2003	V 370-950	MR+HR MOS	Cons + ESO	304
VISIR	2004	IR 8-13,16-24μm	IM+ LR SPE	Cons.+ ESO	118
SINFONI	2004	IR 1100-2450	AO+LGS IFS	Cons. + ESO	193
CRIRES	2006	IR 932-5200	HR SPE	ESO	78
HAWK-I	2007	IR 932-2100	WF IM	ESO	56
X-shooter	2009	V+IR 310-2500	MR Echelle SPE	Cons. + ESO	69

Note *: IM: imager; LR,MR, HR: low, medium and high resolution; SPE: spectrograph; MOS:multi-object spectrograph; AO: adaptive optics; LGS: laser guide star; IFS:integral field spectrograph; WF: wide field.

it was installed at the visitor focus for a few dedicated runs only during 2005 and 2006. It delivered for the first time on a large telescope successful observations of several astronomical targets with layer-oriented adaptive optics.

After completion of the four 8m , ESO did put in operation a coherent light combined focus for interferometry which can be fed by four auxiliary telescopes of 1.5m and the four 8m. The instrumentation for this focus was entirely provided by external consortia.

3.2. The Italian contribution to 1st Generation VLT instruments

The Observatory of Trieste provided for UVES, an instrument built by ESO and the third to be installed, important segments of the instrument control software, the secondary guiding software and the observing templates (Santin 2012). It was a technical collaboration and no GTO was involved.

VIMOS was build by a French-Italian consortium with an Italian coPI. INAF OA Capodimonte and IAFC Milano were responsible for the opto-mechanics, electronics, observing software, data reduction software and the mask manufacturing unit. The Consortium was compensated with 70 GTO nights, which were used in a coordinated way by the team.

FLAMES was an instrument built under ESO responsibility and in collaboration with French, Italian and Swiss institutes. The Italian contributions came from INAF OA Trieste and Bologna and covered the instrument control software and the observing templates. INAF received 11 GTO nights.

The INAF Observatories of Padova and Arcetri contributed to the MAD prototype with the wavefront sensors and the ICS, at a cost to INAF of 70kEUR and 3 FTE in exchange of 6 GTO nights.

Two important contributions were also provided on interferometry. In the same time frame than the VLT instruments, INAF OA Torino did build in collaboration with ESO FINITO (2004), a three beams fringe tracker operating in the H band. The INAF contribution was 300 kEUR and 8 FTE and was compensated with time at the small interferometry telescopes and 8 VLTI nights. The second interferometry project with Italian participation was AMBER (2008), a NIR spectrograph to be used with up to 3 beams. It was developed by a French, German, Italian consortium. INAF OA Arcetri did design and build the cryogenic spectrometer. The Italian share was 335 kEUR and 10 FTEs, or about 20%.

It is worth noting here that many INAF institutes (the observatories of Arcetri, Brera, Capodimonte, Catania, Padova, Roma and Trieste) at the time of the construction of the first generation of VLT instruments were strongly involved in the completion of the Galileo telescope and its instrumentation (DOLORES, SARG, NICS) and in the Large Binocular Telescope for which they provided the Prime Focus Cameras and the AO system.

3.3. The 2nd Generation VLT instruments

With a call for proposals issued in 2001, ESO launched a first batch of 2nd generation VLT instruments. Table 3 lists the currently approved projects. X-shooter, the first of the 2nd generation, was already included in Table 2 as an instrument in operation and it is not duplicated here. There are to this date four instruments approved for the 8m UT foci, one, ESPRESSO, for the incoherent light combined focus and two for the interferometry focus. The new instruments are not up-to-date versions of the instruments currently in operation but enable new observing techniques which will be used for the first time at the VLT.

3.4. The Italian contribution to 2nd Generation VLT instruments

The Italian participation is very significant on three of the new instruments. X-shooter is a three arms, intermediate resolution spectrograph designed to provide instantaneous coverage over the full spectral range from the UV to the K band. Among the five partners in the X-shooter project (Denmark, Italy, Holland, France and ESO) Italy contributed with 800 kEUR and 19 FTE, or about 25 % of the total effort. The institutes involved were the INAF Observatories of Brera, Trieste, Palermo and Catania. They provided the UV and VIS spectrographs and the instrument control software. The project was steered by a board of five coPI, one of them Italian. INAF received 45 GTO nights to compensate for the cash and FTE effort.

SPHERE, a planet detection instrument using extreme AO with three observing modes - imaging, IFS and polarimetry- is a six partners project (France, Germany, Italy, Switzerland, The Netherlands and ESO). The Project Scientist is Italian. The INAF Observatories of Padova, Catania, Capodimonte and IASF Milano are contributing with the IFS unit,the instrument control software and the scientific program. INAF's share of the effort is 500 kEUR and 28 FTEs, or about 20 % of the total. The consortium will receive 250 GTO nights which will be used mainly for a coordinated survey of the most promising planetary systems.

ESPRESSO, the counterpart of the 3.6m instrument HARPS at the VLT, will be the first instrument at the focus where the incoherent light beams of the four 8m telescopes are combined, close to the interferometry focus. It is being built by a consortium of institutes in four countries (Italy, Portugal, Spain and Switzerland) and ESO. Italy is represented by one coPI and provides the Project Scientist. The INAF Observatories of Brera and Trieste will be responsible for the delivery of the spectrograph front end unit,the exposimeter, the control electronics and software, the observation and data analysis software. INAF contribution amounts to 500 kEUR and 20 FTE, which represents about 25% of the total effort.

3.5. The Paranal Survey Telescopes

Two additional survey telescopes, the 2.5m VISTA -dedicated to a large field NIR observations- and the 2.2m VST- dedicated

TABLE 3. Future 2nd Generation VLT instruments +

Instrument	Date	λλ (nm)	Type*	Built by
KMOS	2012	IR 800-2500	Multi IFU SPE	Consortium + ESO
MUSE	2013	V 465-930	LR IFS (+AO)	Consortium + ESO
SPHERE	2013	IR 600-2300	XAO I ,SPE,POL	Consortium +ESO
ESPRESSO	2016	V 380-686	HR echelle SPE	Consortium + ESO
GRAVITY(VLTI)	2016	IR K band	I, Astrometry	Consortium + ESO
MATISSE (VLTI)	2016	IR L,M,N bands	I, LR SPE	Consortium + ESO
ERIS	2017	IR 1000-5000	AO I +IFS	ESO +Institutes (tbd)

Notes: +:X-shooter, the 1st of the 2nd generation instruments, is in operation since 2009 and listed in Table2; * XAO: high Strehl AO, for the others see notes in table 2 .

to wide field optical imaging- were added to Paranal operation in 2009 and 2011 respectively. The VST project was initiated by the Observatory of Capodimonte which carried out most of the telescope design and procurement and covered the cost. In the final phase INAF took care of the completion and the commissioning on Paranal. The Italian contribution is being compensated with about 15 % of the observing time with the telescope over the first 10 years. The Observatory of Capodimonte participated also to the Consortium which in collaboration with ESO did build the wide field CCD camera OmegaCam for the telescope.

4. The OWL and E-ELT instrument studies

Starting in 2004, in parallel with the study of the 100m OWL telescope, ESO launched 8 studies for instruments to be coupled with the new telescope. These were carried mainly by external institutes and explored for the first time the parameter space of the observations with a telescope of this size. Italian institutes were active in this phase, with INAF OA Trieste involved in CODEX, an ultrastable, high resolution spectrograph, the Department of Astronomy of the University of Padova in QuantEye, a high time resolution photometer, and the INAF Arcetri in ONIRICA, an infrared camera with high angular resolution. When the OWL telescope was scaled to 42m and become the European ELT in 2007, a new batch of instrument Phase A studies was carried out, to explore the full range of observing capabilities on a wide selection of scientific programs. These are listed in Table 4, together with the two post-focal adaptive optics modules which were studied in parallel. Numerous Italian institutes participated to the studies. They are identified in table 4.

5. Overview and future prospects

As described in the previous sections, the participation of external institutes to the construction of VLT and in the future to the E-ELT instruments has gained an increasing relevance since 1990. It has led to the establishment of strong instrumentation groups in different member states and to the development of successful scientific programs through the use of GTO. Italy joined ESO when most of the ESO effort on instrumentation for the telescope at the La Silla Observatory had been completed.

TABLE 4. E-ELT Instrument and AO Modules Studies

E-ELT Instrument Studies (2007-2010)		
EAGLE	Wide Field, Multi IFU NIR Spectrograph, MOAO assisted	LAM, OPM GEPI and LESIA, ONERA, UK-ATC, Univ. Durham
EPICS	Planet Imager and Spectrograph with XAO	ESO, LAOG, LESIA, FIZEAU UNSA-OCA.,LAM, ONERA, Univ. Oxford, **INAF OA Pd**, ETH Zurich, ASTRON-NOVA, Univ. Amsterdam & Utrecht
MICADO	Diffraction-limited NIR Camera- AO assisted	MPE, MPIA, US München, **INAF OA Padova**, NOVA -Univ. Leiden and Groningen
HARMONI	Single Field, Wide Band Spectrograph- AO assisted	Oxford University, CRA Lyon, DAMI Madrid, IAC, UK ATC
CODEX	High Spectral Resolution, High Stability Visual Spectrograph	ESO, **INAF OA Trieste & Brera**, IAC, IoA Cambridge, Obs. Geneve
METIS	Mid IR Imager & Spectrograph –AO assisted	NOVA-Leiden and ASTRON, MPIfA, CE Saclay DSM/IRFU/Sap, KU Leuven, ATC UK
OPTIMOS 1 & 2	Wide Field , Visual, MOS (1:fibre; 2:slit-based)	STCF RAL, Oxford, LAM, **IASF-MI**, OP-GEPI, NOVA-Univ. of Amsterdam and ASTRON, **INAF OA Brera and Trieste**, NBI.-Copenhagen University , IAC, ZAH, AIP
SIMPLE	High Spectral Resolution NIR Spectrograph –AO assisted	**INAF OA Bologna (P.I. L. Origlia), Arcetri, Roma,** UAO(S), TLS(G), PUC (Chile)
E-ELT AO Modules (2008-2010)		
MAORY	Multi Conjugate AO module (high Strehl, field up to 2')	**INAF-OABo (P.I. E. Diolaiti), OAA, OAPd; Univ.Bo**, ONERA
ATLAS	Laser Tomography AOModule (high Strehl, narrow field)	ONERA, OPM LESIA, GEPI

The participation in the first calls for VLT instruments, a process which was started at the end of the 80s, was still limited. Unlike other ESO member states (France, Germany) Italy had not developed a 4m class national telescope- the Galileo telescope started operation in 1998- and observatories and laboratories in Italy had therefore not acquired a specific expertise on instrumentation for large telescopes. It is with the second generation of VLT instruments only that Italy could take a share of the effort proportional to the strength of its scientific and engineering community. Three out of the 8 currently approved 2nd generation VLT instruments (X-shooter, Sphere and ESPRESSO) see a strong Italian partnership. The completion by INAF of the VST and the successful start of operation, even if delayed with respect to the original schedule, is now a very positive result. The Italian participation is even more promising for the E-ELT instruments and AO modules, where out of 11 studies, 7 include a significant Italian participation and 2 (SIMPLE, MAORY) are led by Italian P.I.. If the interest of the community will remain high and INAF will provide adequate support, this could lead to a strong Italian partnership in the E-ELT instrumentation construction and consequently to a significant share in the first exciting scientific programs carried out with the new telescope.

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