Coupling Instruments and Detectors at ESO : 1983-2009

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Abstract: The first installation of a 2D digital detector on a spectrograph at ESO (a CCD on CASPEC in 1983) and the latest (CCD and NIR arrays on the X-shooter spectrograph in 2009) are used to sketch changes in observational astronomy in the last quarter of the century and to stress the importance of an optimal coupling of detectors and instruments.

1. Introduction

In the very competitive world of observational astronomy a careful matching of an instrument with on one side the telescope and on the other with its detector is the key to performance and at the end of its success as a science producing machine. The astronomical community has very much the developments of telescopes and instrumentation in their hands, at least as far as they can raise the needed support and funding. In the case of detectors in the last quarter of century astronomy has largely made use of devices which had been originally developed for military or general use applications. The extra bit needed to produce "science grade" digital detectors has come from the collaboration of engineers in scientific institutes and industry. High quality detectors with unique performance has been the result of their dedicated efforts. The boost in limiting brightness of targets which can be observed and studied and the exquisite quality of the astronomical images now obtained at all wavelengths are to be attributed equally to the increase in size of the telescopes as to the progress in detector performance.

This contribution has no pretence to trace the history of detectors for astronomy in the last quarter of century at the ESO Observatories but just to present snapshots of two commissioning of ESO instruments with their digital detectors separated by 26 years: the CASPEC spectrograph at the 3.6m in 1983 and X-shooter at the VLT in 2009. These two examples are used to sketch the changes in the Observatory operation, in the technical capabilities and in the overall management in this quarter of century.

2. ESO instruments and detectors in the early 80's

ESO had been established in 1962 thanks to the persistence and vision of a few astronomers in Belgium, France, Germany, Holland and Sweden. The strategic choice was to join forces and to establish a modern observatory in the Atacama desert in Chile to explore the southern sky at a location where the observing conditions were optimal for astronomy. The ESO 3.6m telescope, the flagship of the La Silla ESO Observatory was finally inaugurated in 1978 . To establish a new observatory structure in a remote country, to erect telescopes there and to operate them efficiently had proven a difficult task. ESO in the early 80's was still son "of a lesser God" with respect to the large American Observatories and questioned in countries like the UK and France which had built their own national 4m class telescopes. The 3.6m was equipped with a prime focus for wide field imaging, a Cassegrain and a coudè for high resolution spectroscopy. Main instrument was a off-the shelves Boller & Chivens spectrograph with the 1D Image Dissector Scanner developed by Robinson and Wampler at Lick Observatory. Other detectors in use at La Silla telescopes in the early 80's were photographic plates, a Mc Mullan Camera for imaging (which had little impact on science), a reticon 1D array and ,as occasional visitor to the 3.6m, the Boxenberg's Image Photon Counting System, a bulky, complex to operate but efficient and successful device for spectroscopy of faint targets. The first CCD, a 512x320 RCA device, made its debut in 1981 in an imaging camera at the 1.5m Danish telescope. Near Infrared observations relied on "1 pixel" detector.

Fig.1: (a) The 3.6m telescope in la Silla (photo by Serge Brunner) and **(b)** the CASPEC spectrograph being tested in the laboratory by a young J.L. Lizon in 1982. The golden CCD cryostat is mounted on the left side of the instrument.

3. CASPEC: the first CCD-based spectrograph at ESO (1983)

ESO astronomers and engineers had been designing in Geneve where ESO was temporarily hosted by CERN two major instrument for the 3.6m: CES- the coudè echelle spectrometer- and CASPEC, an echelle spectrograph for the Cassegrain focus, intended for moderate-high resolution spectroscopy with wide spectral coverage. Both capability were of special interest to

Table 1: ESO CCD #2, the first detector of CASPEC

Type:	RCA SID 501 EX, thinned backside illuminated
Format	512x320 , 30x30mμ pixels
r.o.n.	40 e^- rms
Saturation	240000 e^-
Dark current	15 e^- /hr
QE:	50% at 400nm 70% at 550nm 50% at 700 nm
Defects	*strong fringing in the red, poor charge transfer efficiency at low light levels*

many European astronomers involved in the study of stellar properties and abundances and to the still relatively few interested in extragalactic astronomy. The CASPEC project had been delayed by the move of the headquarters of the organization from Geneve to the new building in Garching close to Munich in summer 1980. In 1982 the instrument was ready but on hold due to problems with the intended SEC Vidicon detector, one of the first digital 2D devices used in astronomy. The ESO CASPEC team was eager to go to the sky and made the proposal to use one CCD camera (at that time purchased by ESO from Princeton Scientific Instrument in the USA) with the fast optical camera for the first light at telescope. The configuration instrument+detector was well matched to the average seeing of the 3.6m- and turned out- after a successful commissioning- into a competitive machine for faint work at 20000 resolution, with 90nm of spectral coverage. The characteristic of that detector are given in Table 1. The RCA CCDs were characterized with a good cosmetic and good efficiency, but limited in their performance by high noise on chip amplifiers. The original plan to replace it with a photon counting device of the MAMA type (see Fig.2) did not succeed and CCDs – with improved properties- stayed as detector of the instrument until the end of its successful scientific life in 1998. RCA, the first supplier of high quality CCDs for astronomy, closed the production line for scientific CCDs in the late 80s. This opened a crisis in the procurement of detectors for the ESO instruments. While American observatories obtained from NASA TI chips which had been developed for the Space Telescope, ESO could just rely for new procurements on Thompson and GEC CCDS, which had good properties but were un-thinned devices with very low blue efficiency. This shortage of optimal scientific CCDs lasted for almost a decade, until Tektronix become in the mid 90s a reliable supplier of large, scientific quality devices for the astronomical community.

Extract from the ESO Annual Report 1982

The Cassegrain Echelle Spectrograph (CASPEC) was essentially completed. Extensive tests are being made, and a first use at La Silla is foreseen for mid-1983. The vidicon detector caused many problems which were partly due to magnet coils of improper construction. In order to speed up the project, it was decided to stop work on this detector and to replace it with a CCD. With the presently available CCD chips it will only be possible in the medium resolution mode (R=30,000) to cover the central part of 25 échelle orders. However, larger chips should become available in the future; in addition, a photon counting detector is being planned.

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ESO-CHILE
S. D'Odorico

June 22, 1983

Dear Lo:

this is a quick report on the test of CASPEC to give you a feeling on how things are proceeding.

I had so far four clear nights out of seven. The instrument performs well. We had to deal with minor software and hardware bugs, but actually these occurred during day time only. I have lost not a single hour of observation because of technical problems. I think this is quite a performance for a new,complex instrument and it comes as a compliment to the work of the technical staff which has set it up.

Now on the astronomical side. Again all of the exposures obtained so far are of good quality. I have observed several stars in the magnitude range 9-13 and 6 Seyfert nuclei and QSO between 13 and 15.5. The speed appears close to my predictions, when operating in good seeing conditions ($<$ 1.5 arcsec). We will be facing the known problems of CCD flat fielding and cosmetics. It will take months in Garching to test fully the data reduction procedure and to assess exactly the accuracy, but some observations are outstanding "in se" and I am quite happy.

In the interval between the two runs we will evaluate these first results more with an eye to the problems of data reduction and to see which gaps in the data base will have to be filled in the second run.

We had not the slightest difficulty in the interaction with the La Silla staff and I do not expect any in the future. Appenzeller has announced his arrival as discussed in Cargese. ....

Extract from the ESO Annual Report 1983

The Cassegrain Echelle Spectrograph CASPEC was installed at the 3.6m telescope with for the moment a CCD detector. A photon counting system with microchannel plate and multi-anode read-out has been ordered and should become available later in 1984. The first results show that the instrument fully lives up to expectations. Spectra have been obtained with a resolution of 20,000 and a signal-to-noise of 50 of stars of magnitude 13.5 in 1 hour. At a lower resolution and with lower S/N, useful spectra of the Mg II absorption lines in the quasar PKS 0454+039 with V magnitude 16.5 were obtained. With lower noise CCDs, an additional magnitude may be gained.

Fig.2: Snapshots on the installation of the first CCD spectrograph, CASPEC, on La Silla. The announcement at the beginning of 1983 (upper left). Commissioning took place in two runs over two months (D'Odorico et al.,1983, ESO Messenger 33,2). We travelled to Chile sleeping stretched on three seats in half-empty planes and went on to the Observatory by bus from Santiago. Contacts and reporting to the headquarters in Germany were mostly by telex and by letters forwarded by the diplomatic bag (upper right). The commissioning team consisted of five staff and two of us stayed over the all period of about 7 weeks, including a snow storm (lower left) which did cut power in the telescope for 2 days and forced the evacuation of most of the staff of the Observatory. The MAMA device announced in the Annual Report 83 (lower right) was never installed and the CCDs continued as detector of the instrument until its decommission in 1998.

4. ESO expansion from La Silla to the Paranal Observatory

The 3.5m New Technology Telescope- the NTT- , which saw first light in 1989, was a key milestone in the development of ESO. Made possible by the entry fees of two new ESO member states, Italy and Switzerland, the NTT was the first of the modern telescopes to employ active optics, a concept developed by the ESO engineer Ray Wilson. With the optical quality of the telescope actively kept at its best at every position of the telescope and reducing local turbulence with an innovative dome design, the NTT was able to exploit periods of optimal seeing of the site and inaugurated a new approach to ground-based astronomy. The success of the NTT gave ESO the confidence and the prestige to launch an even more ambitious project, the VLT, an array of four 8m telescope. A drier site in the same Atacama desert, the Paranal peak, was selected as location for the new Observatory. It is at this site that the most recent ESO instruments have been installed.

VLT and NTT

Some further studies of the Very Large Telescope were made. In the context of the membership of Italy and Switzerland, the possibility has arisen to construct a 3.5 m New Technology Telescope which would have two functions: to increase the amount of available observing time at La Silla and to serve as a test object for the newer technologies which will be required in the VLT.

Fig.3: A vision which came true. A first quotation of the VLT in the ESO Annual Report of 1980 (left). The VLT Paranal Observatory in 2008 (right).

5. X-SHOOTER at the VLT (2009)

X-shooter is the first of the second generation of VLT instruments and replaced at the Cassegrain focus of the Kueyen telescope (UT2) the workhorse-instrument FORS1, which has been successfully in use for more than a decade. The Consortium which has built X-shooter consists of 10 institutes in Denmark, France, Italy, The Netherlands and of ESO, which has delivered the detectors systems**.** X-shooter consists of a central structure (backbone), which supports three prism-cross-dispersed échelle spectrographs optimised for the UV-Blue, Visible and Near-IR wavelength ranges respectively. X-shooter simultaneously collects the full spectrum of the target from 300 to 2500 nm with an efficiency between 15% and 35% including the telescope and the atmosphere. The spectral resolution varies between 3,000 and 17,000 depending on the slit width and the wavelength. The optical image quality is between 1 and 2 pixels on the detector over the full range. In the first two commissioning runs of November 2008 and January 2009 the UV-B and Vis arms were first tested. Then the instrument was operated in its full three arm configuration from March 2009. Details on the instrument can be found at the web site http://www.eso.org/sci/facilities/paranal/instruments/xshooter.

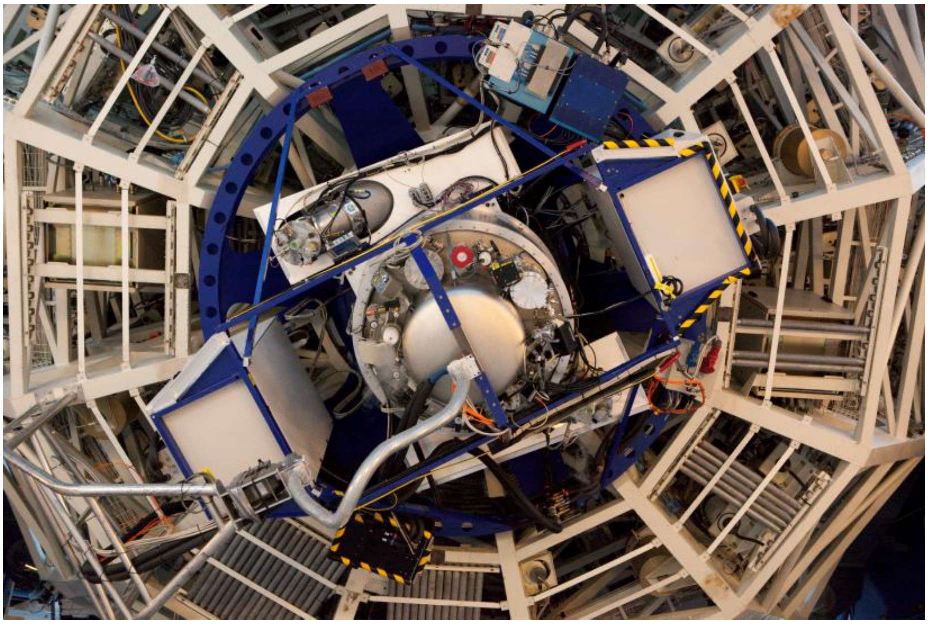

Fig.4: The three arm X-shooter instrument at the Cassegrain focus of the Kueyen telescope at the Paranal Observatory. At the center the NIR arm vessel, on the top the UV spectrograph with its CCD detector cryostat, at the bottom, partly hidden, the VIS spectrograph.

The X-shooter is the 12th instrument installed at the VLT on Paranal, ten years after the first light at the first 8m telescope , 25 after that first commissioning of CASPEC at the 3.6m. It comes in a fully operating structure, where most of the observing is done in service mode. Satellite link allows for easy connection to the Headquarters and other members of the project team in Europe. It is also used to transmit the data to the archive facility in Garching, for further processing and distribution.

Fig.5: A happy and fully staffed commissioning force pose in the comfortable control room of the VLT observatory, having just completed the first observation of the X-shooter in its full configuration in March 2009.

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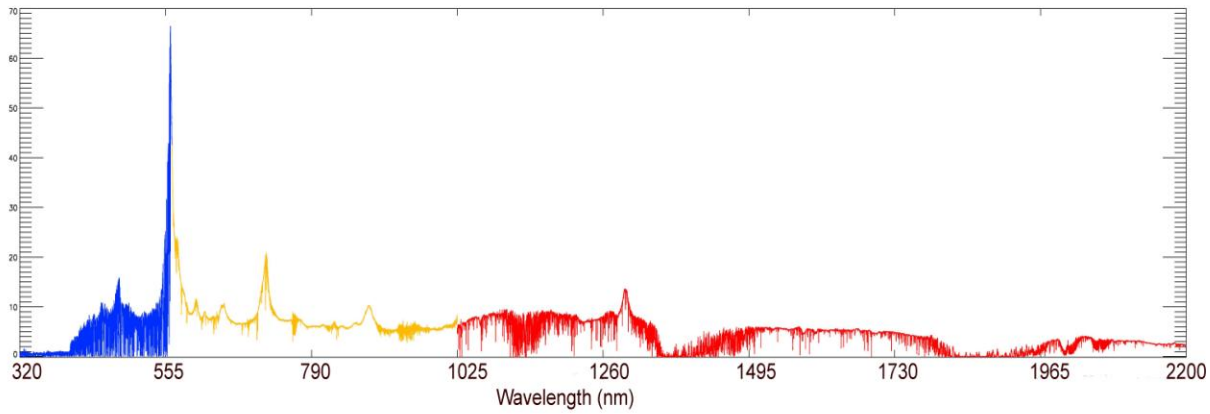

Fig. 6: Spectrum of the lensed QSO B1422+231 from the combination of four parallel 1200s exposures in the three arms of the instrument (Christensen and D'Odorico, in preparation). The blue part of the spectrum shows the UVB, the green the VIS, and the red the NIR data in relative flux units. The spectra are sky-subtracted but not corrected for telluric absorption. The resolving power is in 6200, 11000 and 8100 in the UVB, VIS and NIR arms respectively.

Table 2. Properties of the X-shooter detectors

	UVB	**VIS**	**NIR**
Detector type	E2V CCD44-82	MIT/LL CCID 20	substrate removed Hawaii 2RG
Operating temperature	153 K	135 K	81 K
QE	80% at 320 nm 88% at 400 nm 83% at 500 nm 81% at 540 nm	78% at 550 nm 91% at 700 nm 74% at 900 nm 23% at 1000 nm	~85% over the J, H, K bands
Number of pixels	2048×4096 (2048x3000 used)	2048×4096	2048×2048 (1024×2048 used)
Pixel size	15 µm	15µm	18µm
Gain (e^-/ADU)	High: 0.62 Low: 1.75	High: 0.595 Low: 1.4	2.12
Readout noise (e^- rms)	Slow: 2.5 Fast: 4.5	Slow: 3.1 Fast: 5.2	Short DIT: ~25 DIT>300s: ~8.0
Saturation (ADU)	65000	65000	45000 (for a single readout). TLI used for long DITs
Full frame read-out time (s)	1x1, slow-fast: 70-19 1x2, slow-fast: 38-12	1x1, slow-fast: 92-24 1x2, slow-fast: 48-14	0.665 (for a single readout)
Dark current	<0.2e-/pix/h (TBC)	<1.1e-/pix/h (TBC)	21 e-/pix/h
Fringing amplitude	-	~5% peak-to-valley	-
Non-linearity	Slow: 0.4%	Slow:0.8%	<1% up to 45000 ADUs

What makes X-shooter particularly interesting from the detector side is that it is the first spectrograph- at 8-10 m class telescope - and to my knowledge at any telescope so far - which permits parallel observations over the spectral range from the UV to the K band (Fig.6). The UV and V arms use as detectors 4k x 2k, 15 μm CCDs, the NIR arm a 2k x 2k Hawaii 2RG array. The properties of the detectors are summarized in Table 2. The parallel coverage of the two bands, optical and near infrared, was very much an unfeasible task until recently. X-shooter fulfills a long standing dream to eliminate the artificial separation around 1 μm between optical and NIR instruments, alias astronomers. This was more than anything else due to the different detectors used in the two spectral regions. CCDs- mostly used from the atmospheric cutoff to 1μm, where the sensitivity of silicon falls off, have been available in large format for more than two decades now. They can be used for long integrations due to their low dark current while NIR array have to be read at higher frequency to avoid saturation by the stronger sky lines. In the K band thermal emission requires cooling of the instrument and careful masking of the telescope pupil. With the availability of large NIR arrays with good cosmetics, reduced r.o.n and d.c. , the possibility to carry out parallel observations over the entire spectral range from the UV to the K band become real and was designed in the X-shooter concept. Still, the optimization of the operation of this unique instrument is an on-going process. “Staring” observation with the target on a fixed position on the slits appear possible with up to 20-30m integration. For fainter targets longer integration would be advantageous in the UV-B and VIS arms with the CCDs, while on slit offsetting is required in the NIR arm (Fig.7). In the X-shooter , it would be possible to implement an observing mode in which the target is moved a few arcsec on the NIR slit while it remains at a fixed position in the UVB and VIS arms.

6. Telescope, instruments and detectors

The advances in detector technology have been responsible for the larger fraction of the progress in astronomy and astrophysics in the last 25 years. The move from 4 to 8-10m telescopes, the space missions alone would not have had the same impact on so many fields of astrophysics without the fantastic, parallel development of detectors, both at optical and near-infrared wavelengths. The two examples sketched here tried to illustrate the progress which has taken place in the last 25 years and the importance of a careful coupling of detectors and instruments. Procurement of optimal detectors for astronomy remains a shaky business because the market of astronomical instrumentation is relatively small and cannot attract by itself alone the big investments which are needed for major technological steps in the field. If we like to maintain the rate of progress in astronomy that we have seen in the last decades it is necessary to continue to focus attention and resources as much on detectors as it is currently done on new extremely large telescopes and their instrumentation.

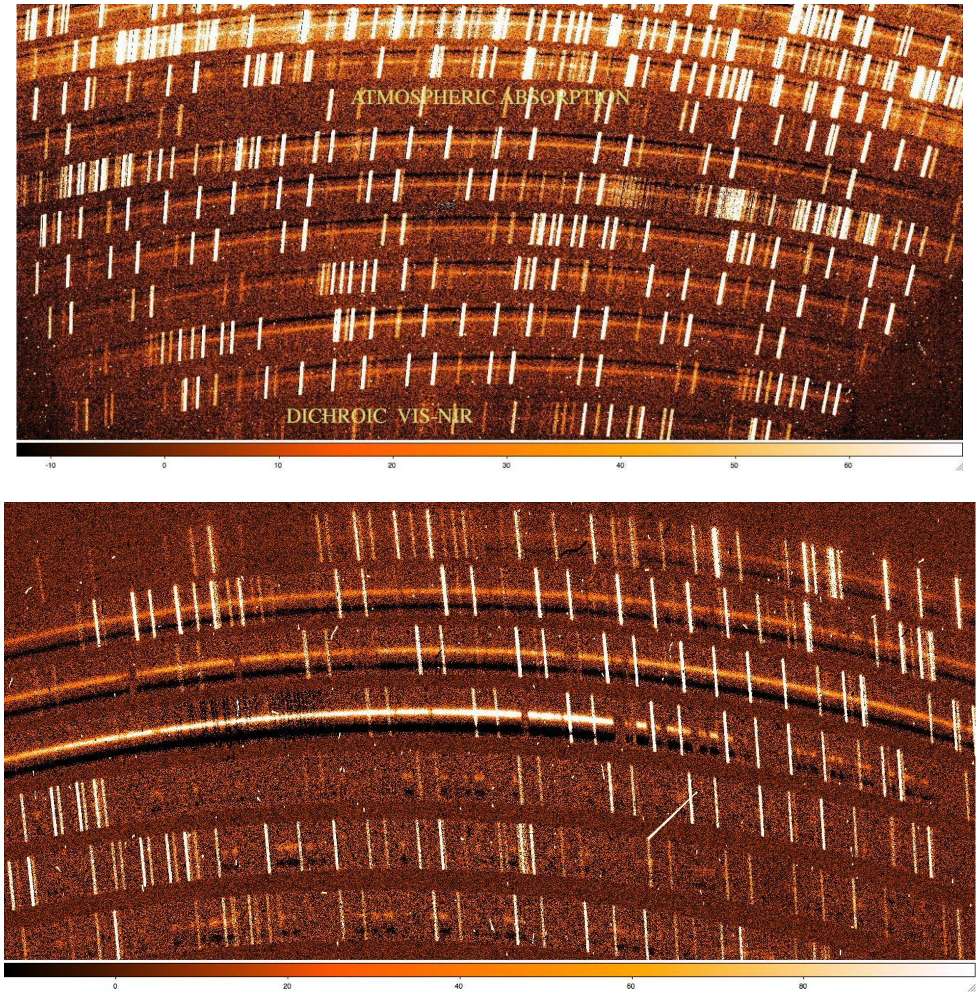

Fig.7: The two panels show part of 2D NIR (J and part of H band, upper panel) and VIS (700-1100nm region, lower panel) echelle spectra from X-shooter. They were obtained by subtracting two subsequent 30m exposures, with the target, a z=6 QSO, shifted along the slit between the two. The white vertical lines are residual of OH sky emission lines due to time variability and correspond to the full length of the slits (11”). Note the similar cosmetic quality of the CCD (a 4kx2k E2V thinned device) and NIR array (a 2kx2k Hawaii 2RG HgCdTe array) and the larger crowding of sky lines in the NIR region.

Acknowledgement

The instruments for ESO telescopes are built by astronomers, engineers and technicians at ESO and in various Institutes in the ESO member states. I would have achieved very little in my 30 years at ESO without their competent and dedicated efforts. I like here to acknowledge especially the contribution of J.L. Lizon, responsible at ESO of the Integration and Cryo-Vacuum Department, who played a key role in both the CASPEC and X-shooter and in many other ESO instrument projects we shared together.