Alma Mater Studiorum – Università di Bologna

DOTTORATO DI RICERCA

ASTRONOMIA

Ciclo XXII

FIS/05

Development and optimization of graphic user interfaces (GUIs) for infrared spectrometers at the Telescopio Nazionale Galileo

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Esame finale anno 2009

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Introduction

Astronomical instruments require suitable interfaces to be properly operated and maintained and for an optimized acquisition of astronomical data. The latter aspect is crucial to optimize data reduction and maximize the scientific output from the acquired data.

The aim of this PhD thesis has been the design and development of an optimized graphical user interface (GUI) for the near infrared camera spectrometer (NICS) installed on the Nasmyth A of the TNG (Telescopio Nazionale Galileo, La Palma, Canary Island). The thesis work has been entirely undertaken at the TNG.

The thesis work deals with either the very low-level control software (for technical connections and communications with sensors, detectors, motors, database and so on) and the high-level software (users interaction windows), providing a number of important tools for observations, and implementing them in a Graphical User Interface.

The first and second Chapters are an introduction to infrared astronomy and astronomical software.

The third Chapter describes what is a GUI and the adopted software language and environment (Tcl/tk) to develop the GUI for NICS.

The fourth Chapter describes the Telescopio Nazionale Galileo and the details of all mechanical components of NICS in its imaging and spectroscopic modes: motors, detectors, optics etc.

The fifth Chapter deals with the GUI for NICS, describing the three windows to manage observations, the tools implemented, structures and functions.

The sixth Chapter introduces the protocol and main device communications. Indeed, a spectrometer as NICS is not a stand alone instrument but it is connected to many other devices: temperature and pressure sensors, calibration lamps etc.

The seventh Chapter deals with a warning system implemented for NICS as for the other instruments at TNG. This software constantly monitors the temperature and pressure of the instruments and in case of unusual values, sends an email and an SMS to the responsible to notify the problem.

The eighth Chapter describes a scientific application with the twofold goal of checking the correct functioning of the new GUI and of studying the atmospheric extinction at the Roque de Los Muchachos. During some engineering time, two telluric standard stars have been observed with the AMICI prisms and the JH and HK grisms. Data have been analyzed and some information of the trend of atmospheric extinction as a function of the air mass have been obtained.

Finally the last Chapter contains a summary of the results and conclusions.

Chapter 1

Infrared observations

Astronomy is a continuously evolving science. Whereas since antiquity and until the 19th century, the observations were made in the visible domain, the celestial vault is now studied in the whole electromagnetic spectrum wavelengths: Gamma rays, X rays, Ultraviolet (UV), Visible, Infrared (IR), Millimeter and sub-millimeter domain, Radio, etc....

Actually, the Universe sends us light at all wavelengths of the electromagnetic spectrum. However, most of this light does not reach us at ground level because the atmosphere blocks out many types of radiation while letting other types through (see *Figure 1*). Fortunately for life on Earth, our atmosphere blocks out harmful, high energy radiation like X-rays, gamma rays and most of the ultraviolet rays. It also blocks out most infrared radiation, as well as very low energy radio waves. On the other hand, our atmosphere lets visible light, most radio waves, and small wavelength ranges of infrared (IR) light through, allowing astronomers to study the Universe at these wavelengths.

Most of the IR light coming from the Universe is absorbed by water vapor and carbon dioxide in the Earth's atmosphere. Only in a few narrow wavelength ranges, infrared light can make it through (at least partially) to a ground based IR telescopes.

The best view of the IR universe, from ground based telescopes, is at infrared wavelengths which can pass through the Earth's atmosphere and at which the atmosphere is dim in the IR. Ground based IR observatories are usually placed near the summit of high, dry mountains to get the lowest content of water vapor and to stay well above the inversion layer. Even so, most IR wavelengths are completely absorbed by the atmosphere and never make it to the ground. The IR windows, where atmospheric transparency is good enough, are mainly at wavelengths below 5 microns and around 10 micron.

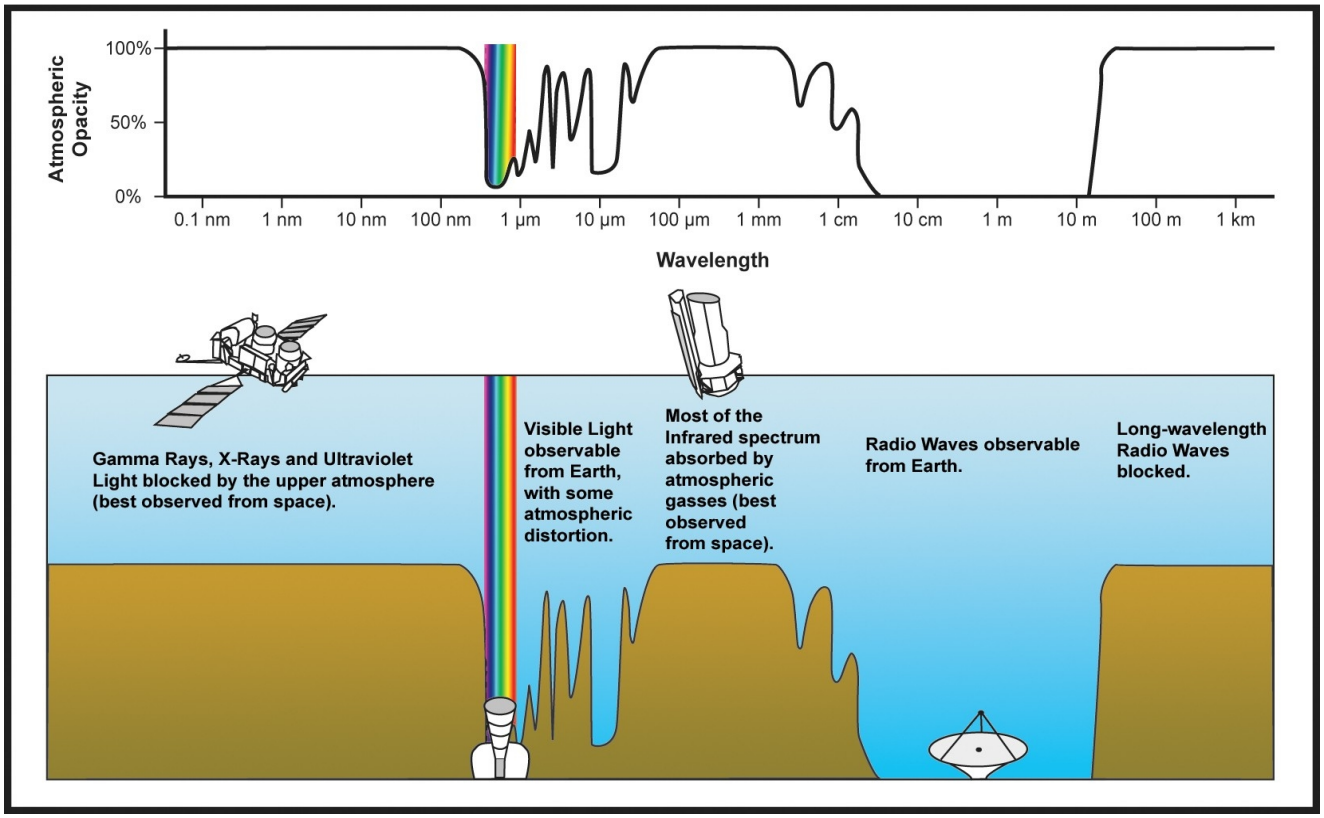


Figure 1 – Atmospheric opacity as function of electromagnetic wavelengths.

Infrared Windows in the Atmosphere

Wavelength Range	Band	Sky Transparency	Sky Brightness
1.1 – 1.4 µm	J	high	low at night
1.5 - 1.8 µm	H	high	very low
2.0 - 2.4 µm	K	high	very low
3.0 - 4.0 µm	L	3.0 - 3.5 µm: fair 3.5 - 4.0 µm: high	low
4.6 - 5.0 µm	M	low	high
7.5 - 14.5 µm	N	8 - 9 µm and 10 -12 µm: fair others: low	very high
17 - 40 µm	17 - 25 µm: Q 28 - 40 µm: Z	very low	very high
330 - 370 µm		very low	low

IR is usually divided into 3 spectral regions: near, mid and far-IR. The boundaries between the near, mid and far-IR regions can vary depending on the type of detector technology used for gathering IR light[1] .

1 *http://coolcosmos.ipac.caltech.edu/*

SPECTRAL REGION	WAVELENGTH RANGE (microns)	TEMPERATURE RANGE (degrees Kelvin)	WHAT WE SEE
Near-Infrared	(0.7-1) to 5	740 to (3,000-5,200)	Cooler red stars Red giants Dust is transparent
Mid-Infrared	5 to (25-40)	(92.5-140) to 740	Planets, comets and asteroids Dust warmed by starlight Protoplanetary disks
Far-Infrared	(25-40) to (200-350)	(10.6-18.5) to (92.5-140)	Emission from cold dust Central regions of galaxies Very cold molecular clouds

Near-IR imaging and spectroscopy are much more difficult / different than in optical[2] .

- The sky background is dominated by night sky emission lines, and especially in the K-bands by the temperature of the atmosphere. The IR detectors usually get saturated after 10-20 seconds of exposure time in K, which leads to a very large number of images with rather short exposure times.

- Although IR instruments are usually cooled down to about 60-70 K in order to suppress heat radiation, the telescope and surrounding dome remain at ambient temperature. Their heat radiation has to be carefully kept out of the instrument in order to minimize the background noise.
- Background subtraction is a critical step since very often the target sources are significantly fainter than the background noise. IR array detectors are intrinsically unstable, their response depends on illumination (hence a mere subtraction of a dark frame as for optical CCDs it is not sufficient) and can vary on typical timescales of minutes. This requires a periodic acquisition of background frames (the so-called sky-frames). Sky frames can be acquired by dithering techniques and/or by telescope nodding.
- The read-out of IR detectors is also different from CCDs. Each pixel is read independently, so for example, there are no blooming effects, and during an exposure the array can be read several times (*multiple non-destructive read* mode, *MNDR*) in order to reduce the readout noise (especially useful for spectroscopy).

2 *http://www.ing.iac.es/Astronomy/instruments/liris/liris_obs_tech.html*

In the recent years, many of the 4-8m class ground-based telescopes have been equipped with Adaptive Optics (AO) capabilities to improve the overall image quality. An AO system can potentially remove the effects of the atmospheric turbulence and other optical distortions by using a suitable wavefront sensor to monitor them and a deformable mirror to compensate for them.

Chapter 2

Overall structure for astronomical software

All wavelength regions are, nowadays, studied by specific instruments and telescopes:

- ***Optical astronomy*** is the part of astronomy that uses optical components (mirrors, lenses and solid-state detectors) to observe light from near infrared to near ultraviolet wavelengths. Visible range falls in the middle of this range.

- ***Infrared astronomy*** deals with the detection and analysis of infrared radiation (this typically refers to wavelength longer than the detection limit of silicon solid-state detectors, about 1 μm wavelength).

- ***Radio astronomy*** detects radiation from millimeter to tens of meters wavelength. The receivers are similar to those used in radio broadcast transmission but much more sensitive.

- ***High-energy astronomy*** includes X-ray, gamma-ray and extreme UV astronomy as well as studies of neutrinos and cosmic rays.

The instruments to study each spectral range are very different in concept, kind of arrays and optic systems but in its general structure the software to manage these devices and to do the observation is very similar and can be subdivided into 4 main levels (*Rossetti, 2008*):

- the ***low-level software***. This level is designed to handle all hardware related functions and detector controls. It is physically split in two

locations: one inside the NICS PC and the other into the embedded processor (FASTI) located at the focal plane electronics.

- the ***middle-level software.*** This level works like a bridge between the high-level software and the low-level software managing all commands, messages and errors.

- the ***high-level software***. This level is intended to fulfill all astronomy-related tasks and also to act as an interface between the low-level software and the astronomer. Hence, it includes several GUI to provide a full control of all sub-systems.

- the ***scientific software***. It includes the observing block preparation tools and the off-line data reduction pipeline.

The goal of the *low-level software* is to interact directly with the hardware, and to provide an easy-to-use interface between the electrical devices and the high level software. The low-level software typically manages directly electronic devices like: array, temperature/pressure sensors, motors, calibration lamps etc. Usually it is equipped with a command line interface which allows to communicate using a serial or socket connection to the external world.

The *middle-level software* is very useful when we have to communicate with the array. It is very important to provide a secure and clean communication to prevent damages of these delicate devices. The middle-level software provides to do that, managing the errors before their arrival to the low-level software and ensuring a good quality communication checking all commands sent to the array.

The *high-level software* provides an interface between the users and the low/middle-level software. It manages all human errors allowing the interaction with all instruments and devices. It allows to monitor and have a full control of all sub-systems such as the telemetry, the calibration lamps status, the motors status and the setting up of all the observational parameters.

The *scientific software* is composed by packages of facilities tools dedicated to simplify the data reduction and the planning of the observations. Usually includes a quick-look software which ensures a wide displayer for the images visualization comprehending the possibility of:

- making a field zoom
- creating a box around the object to do statistics
- estimating some important parameters like Full Width Half Maximum (FWHM) and relatives *sigma* in x and y, the peak of the intensity, the background value etc...

These criteria ensure a stable, complete and user-friendly GUI; for these reasons the GUI for NICS at the TNG, has been developed following this structure (*see Chapter 4*).

Chapter 3

Graphical User Interface

A Graphical User Interface (GUI) is a type of user interface which allows people to interact with electronic devices like computers, hand-held devices, household appliances and office equipment. A GUI offers graphical icons, and visual indicators as opposed to text-based interfaces. The actions are usually performed through direct manipulation of the graphical elements. The term came into existence because the first interactive user interfaces to computers were not graphical; they were text-and-keyboard oriented and usually consisted of commands you had to remember and computer responses that were infamously brief. The command interface of the DOS (Disk Operating System) is an example of the typical user-computer interface before GUI arrived. An intermediate step in user interfaces between the command line interface and the GUI was the non-graphical *menu-based interface*, which let you interact by using a mouse rather than by having to type in keyboard commands. Elements of a GUI include such things as: windows, pull-down menus, buttons, scroll bars, iconic images, wizards, mouse pointer etc.

A major advantage of GUI is that they make computer operation more intuitive, and thus easier to learn and use.

The GUI allows users to take full advantage of the powerful *multitasking* (the ability for multiple programs and/or multiple instances of single programs to run simultaneously) capabilities of modern operating system by allowing such multiple programs and/or instances to be displayed simultaneously. The result is a large increase in the flexibility of computer and devices use with a consequent rise in user productivity. The GUI has become much more than a mere convenience. It has also become the standard in human-devices interaction. Moreover, it has led to the development of new types of applications and entire new industries.

3.1 Why a new NICS GUI

The necessity of a new GUI for NICS is due to the hardware evolution. The hardware evolution normally leads up to the necessity of a software update in order to fully exploit new technology. A GUI to properly work, needs to be based on libraries. A library is a collection of subroutines or classes used to develop software. Libraries contain code and data that provide services to independent programs.

Some operative systems and libraries may not be compatibles with the oldest softwares. For this reason, usually, the PC dedicated to an instrument is updated with care to the latest software versions to avoid the problems due to the incompatibility risks. Year after year the software/hardware update necessity becomes more and more important until it becomes essential. The best solution is to develop a new GUI based on the newest software and libraries to exploit the new hardware resources.

3.2 Tcl/Tk language for GUI developing

Nowadays, there are a lot of different languages for GUI developing; some of the most used are: *Perl*, *Java*, *Python*, *C++, HTML*, *PHP*, *IDL* and *Tcl*.

For the new NICS GUI developing I used *Tcl* for the follow reasons:

- All data types can be manipulated as strings, including code.
- Everything can be dynamically redefined and overridden.
- Everything is a command, including language structures.
- Extremely simple syntactic rules.
- Event-driven interface to sockets and files. Time-based and user-defined events are also possible.
- Simple exception handling using exception code returned by all command executions.
- All commands defined by Tcl itself generate informative error messages on incorrect usage.
- Readily extensible, via C, C++, Java, and Tcl.
- Interpreted language using byte-code for improved speed whilst maintaining dynamic modifiability.

Tcl stands for ***Tool Command Language***[3]. Tcl is a scripting language, and an interpreter for that language that is designed to be easy to embed into the applications. Tcl and its associated graphical user-interface toolkit, Tk, were designed and crafted by Professor John Ousterhout of the Berkeley University of California and provides a “virtual machine” that is portable across UNIX, Windows, and Macintosh environments.

The Tcl interpreter has been ported from UNIX to DOS, Windows, OS/2, NT, and Macintosh environments. The Tk toolkit has been ported from the X window system to Windows and Macintosh.

As a scripting language, Tcl is similar to other UNIX shell languages such as the Bourne

3 *http://www.tcl.tk/about/index.html*

Shell (sh), the C Shell (csh), the Korn Shell (ksh), and Perl. Shell programs let you execute other programs. They provide enough programmability (variables, control flow, and procedures) to let you build complex scripts that assemble existing programs into a new tool tailored for your needs.

It is the ability to easily add a Tcl interpreter to your application that sets it apart from other shells. Tcl fills the role of an extension language that is used to configure and customize applications.

The Tcl C library has clean interfaces and it is simple to use. The library implements the basic interpreter and a set of core scripting commands that implement variables, flow control, and procedures. There is also a set of commands that access operating system services to run other programs, access the file system, and use network sockets.

There are many Tcl extensions freely available on the Internet. Most extensions include a C library that provides some new functionality, and a Tcl interface to the library. The script-based approach to user interface programming has three benefits:

- Development is fast because of the rapid turnaround: there is no waiting for long compilations.
- The Tcl commands provide a higher-level interface than most standard C library user-interface toolkits. Simple user interfaces require just a handful of commands to define them.
- The user interface can be factored out from the rest of your application. The developer can concentrate on the implementation of the application core and then fairly painlessly works up a user interface. The core set of Tk widgets is often sufficient for all your user interface needs. However, it is also possible to write custom Tk widgets in C, and again there are many contributed Tk widgets available on the network.

Moreover, Tcl/Tk is largely used for developing specific astronomical tools and applications like:

- DS9 SAOImage[4] (HEA Harvard-Smithsonian Center for Astrophysics)
- Skycat[5] (ESO, communication with astronomical archives and catalogs date)
- Fv[6] (NASA, fits viewer)
- RAC[7] (NASA, radio astronomy controller)
- BOB[8] (ESO, manage Observation Blocks at VLT)
- COBRA[9] (Jodrell Bank Observatory).

4 http://hea-www.harvard.edu/RD/ds9/
5 http://archive.eso.org/cms/tools-documentation/skycat
6 http://heasarc.nasa.gov/docs/software/ftools/fv/
7 http://dsnra.jpl.nasa.gov/development/rac/
8 http://www.eso.org/sci/facilities/lasilla/sciops/observing/bob.html
9 http://www.jb.man.ac.uk/research/pulsar/tech03/

Chapter 4

TNG and NICS

The TNG (*Figure 2*) is a new concept telescope located in the Roque de Los Muchachos, La Palma (Canary Islands). To take full advantage of the seeing quality in this site (*Milian M., 1996*), the TNG is furnished with an active optical correction system which allows to minimize the errors due to the mechanical components: micro bend effects, thermal dilatation etc... The air flux inside the telescope dome is constantly monitored and regulated to improve the seeing near the incoming optical beam.

The optical design is a Ritchey-Chretien type with two hyperbolic mirrors: the principal mirror called M1 is concave with a diameter D = 3.6 m and the second one (M2) is a convex mirror which provides a focus at *F/11*. The third mirror is plane (M3) and provides two Nasmyth focus (named A and B). The TNG is provided with an alt-azimuth mount. For this reason the telescope needs a field derotator for each Nasmyth.

The TNG is equipped with a mechanic derotator which consists in a flange ring with a diameter D = 1.7 m in which are mounted the scientific instruments. These flange rings can rotate to 295 degrees in both directions around the elevation axes of the telescope. Each of those are equipped with an optical pointing system, the auto-guide and a Shack-Hartmann wavefront sensor (WFS) for the optic active corrections, performed on M1 through 78 actuators.

TNG (Barbieri C., 1989), with its instruments, allows astronomers to investigate optical and Near-Infrared (NIR) wavelengths. In particular to study the NIR ranges, TNG is equipped with NICS and in the near future will be equipped also with GIANO (*Oliva E., 2006*).

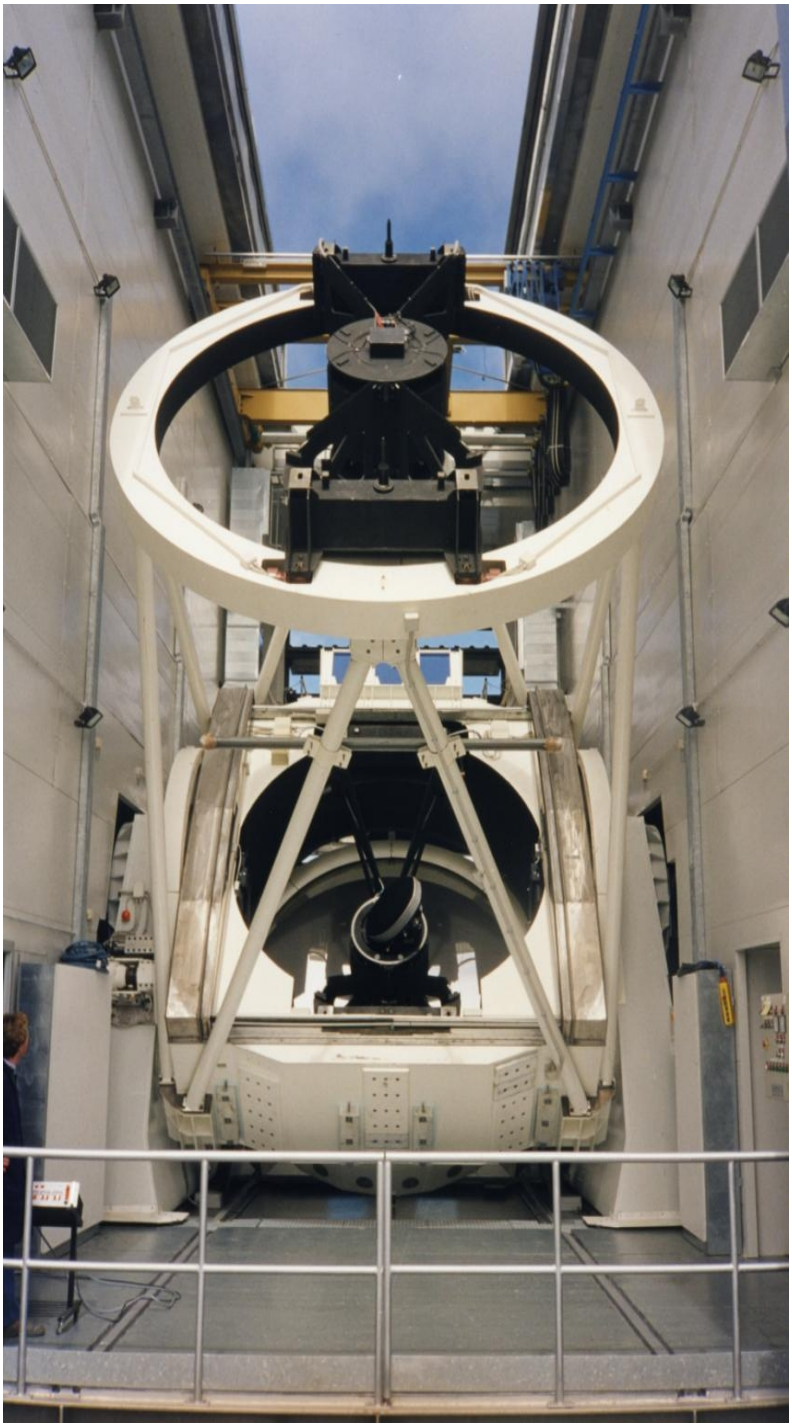


Figure 2 – The Telescopio Nazionale Galileo.

NICS is the TNG infrared (0.9-2.5 μm) multi-mode instrument which is based on a HgCdTe Hawaii 1024x1024 array. It was designed and built for the TNG by the infrared group at the Arcetri Observatory in Firenze (Italy) and placed in Nasmyth A as shown in the following image (*Baffa C., 2001*).

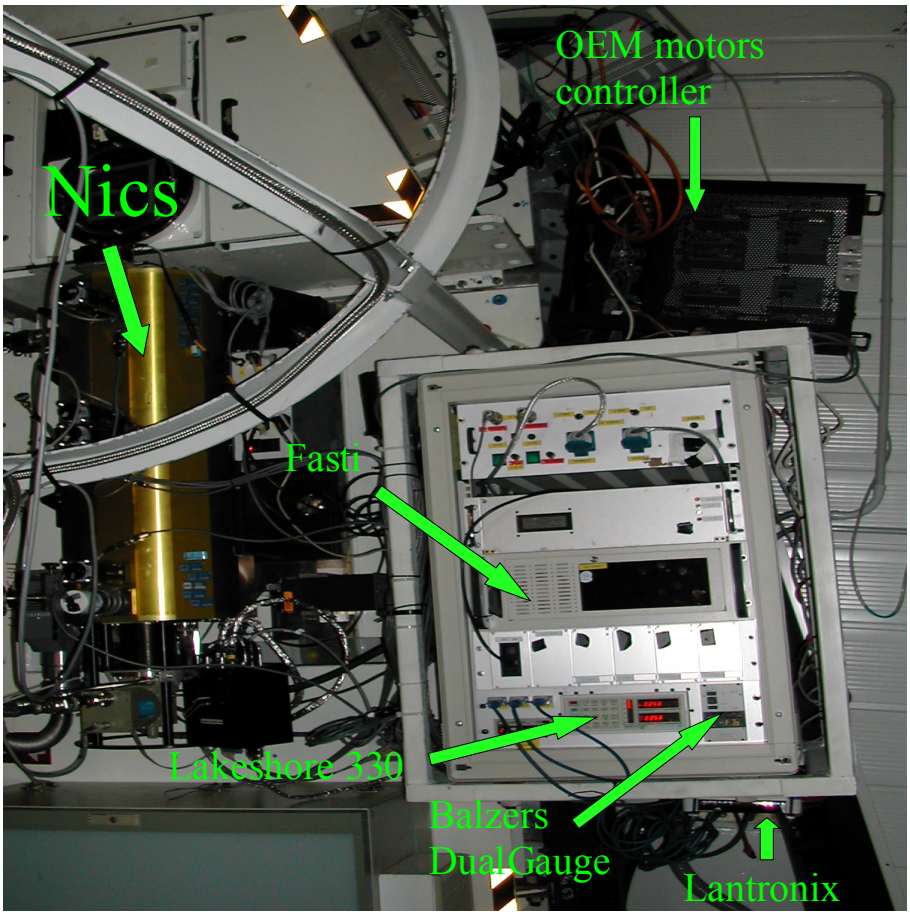


Figure 3 – NICS and the electronic devices mounted in Nasmyth A.

The instrument provides the following imaging and spectroscopic observing modes:

- ***wide-field imaging*** with a plate scale of 0.25"/pixel and a total field, as projected on the sky, of 4.2'x4.2' field of view (FOV). Narrow-band filters are available for photometry and in-line imaging;

- ***small-field imaging*** with a plate scale of 0.13"/pixel (2.1'x2.1' FOV), for better sampling under excellent seeing conditions;

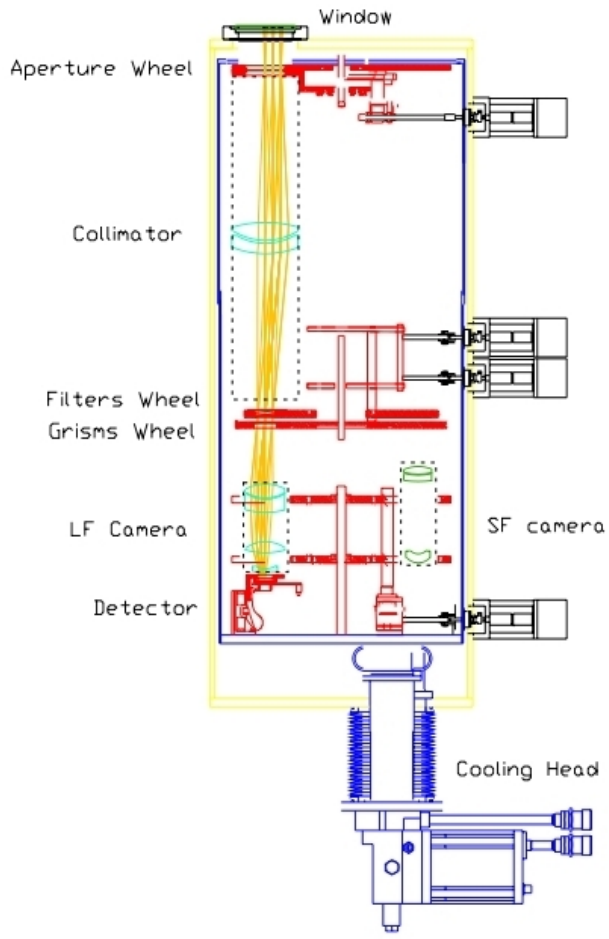
- ***medium to low-dispersion long-slit*** (4' slit) grism spectroscopy with a resolving power between 300 and 1300;

- ***very low-dispersion long-slit*** (4' slit) spectroscopy with a resolving power ~50, by means of an Amici prism;

- ***imaging polarimetry*** for both wide and small-field imaging mode. Polarimetry imaging is performed on only 1/4 of the FOV, but simultaneously on four directions of polarization angle (0, 45, 90, and 135 degrees), with a clear gain of relative sensitivity;

- ***spectro-polarimetry*** with a reduced (25%) slit length, but with four directions of polarization angle (0, 45, 90, and 135 degrees) measured simultaneously.

Three of these modes: low-dispersion, long-slit, spectroscopy and simultaneous angle polarimetry/spectro-polarimetry are unique to NICS (*Baffa C., 2001*), and provide, the possibility to reliably perform these measurements in the infrared.



NICS is mounted at the same focal station as the optical CCD camera. A plane mirror (M4), mounted on a remotely-operated sliding bench, deflects the beam from the telescope to the entrance of the IR camera, that has its optical axes perpendicular respect to the telescope beam.

The optical scheme comprises the single collimator and the two cameras. All the optical components reside in a vacuum at a temperature of about 80 K, inside a suitable cryostat (*see Figure 4* for details). The focal plane masks (field stops and slits) are mounted on a wheel. Immediately after the focal plane, a further removable field stop makes polarimetric measurements possible.

The collimator is an achromatic doublet lens, which images the entrance pupil of the TNG and provides a parallel beam at the pupil plane where Lyot stops can be placed. Immediately after the pupil plane, two adjacent wheels carry filters and grisms. Two interchangeable optical systems relay the image of the focal plane on the detector with the desired magnification.

Figure 4 – Mechanical Layout of NICS cryostat.

A third optical system images the entrance pupil on the detector, for the purpose of an accurate alignment of the telescope with the instrument pupil, and is not normally used in routine observations. A short discussion can be found in *Gennari et al (1995)*.

The spectroscopic mode makes use of the wide–field camera by inserting one of the grisms, located on the second filter wheel, into the parallel beam after the pupil.

The rejection of stray and thermal light is left to the TNG baffles in J, H, and K bands. At longer wavelengths, where the thermal radiation could prevail, it is possible to insert a cold stop precisely positioned at the pupil image. The sensitive element of NICS has a 18.5 μm/pixel pitch and is sensitive to radiation at wavelengths between ~0.90 μm and ~2.5 μm. Its

performance in term of dark current, efficiency, and read noise, is comparable or better than the 256 × 256 NICMOS 3 (*e.g. Lisi et al.,1996*). The electronic noise is dominated by the detector and by the first cold amplifier and is ~25 e^- , if a suitable number of detector resets (more than 32) is performed at each integration.

4.1 NICS in imaging mode

The LF offers a 4.2'x 4.2' FOV and a pixel scale of 0.25" /pixel. The LF images are, on the other way, characterized by a significant pin-cushion distortion which is intrinsic to the optics design and amounts to 1% at the edges and 3% at the array corners. This effect is wavelength independent and can be accurately modeled and corrected for during the image reduction.

The small field camera (SF), with its 2.1'x2.1' FOV and a pixel scale of 0.13" /pixel, is primarily intended for imaging programs, requiring a fine sampling of the point spread function. LF and SF main characteristics are shown in *Table 1*.

Camera	Image scale	Field of view
LF	0.25"/pix	4.2' x 4.2'
SF	0.13"/pix	2.2' x 2.2'
LF+Adopt	0.08"/pix	1.4' x 1.4'
SF+Adopt	0.04"/pix	0.7' x 0.7'

Table 1 - Main characteristics of LF and SF camera.

The instrument is equipped with a number of broad and narrow band filters which are listed in *Table 2*.

Filter	Center wl (μm)	FWHM (μm)
K	2.20	0.34
K'	2.12	0.35
H	1.63	0.30
J	1.27	0.30
Js	1.25	0.16
1mic	1.02	0.13
Kcont	2.275	0.039
Brgamma	2.169	0.035
H2	2.122	0.032
FeII	1.644	0.027
Hcont	1.570	0.023
CH4s	1.60	0.12
CH4l	1.68	0.12
SW	Cut-off 1.75	Cut-off 1.75

Table 2 - Filters characteristics.

Figure 5 shows the spectral response and the efficiency of the wide band filters which are presently available. Besides the standard filters for J, H, and K bands, NICS offers the 1 μm filter centered at 1.030 μm in correspondence with a fair atmospheric window, the Jn filter as defined by the Gemini project, the K' filter which cuts the K band portion where the thermal emission dominates the background flux.

There is also a band pass filter (labeled SW) for general purpose observations and pointing and a high–pass filter (labeled LW) which, along with the spectral response of the detector, acts as a band pass for longer wavelengths.

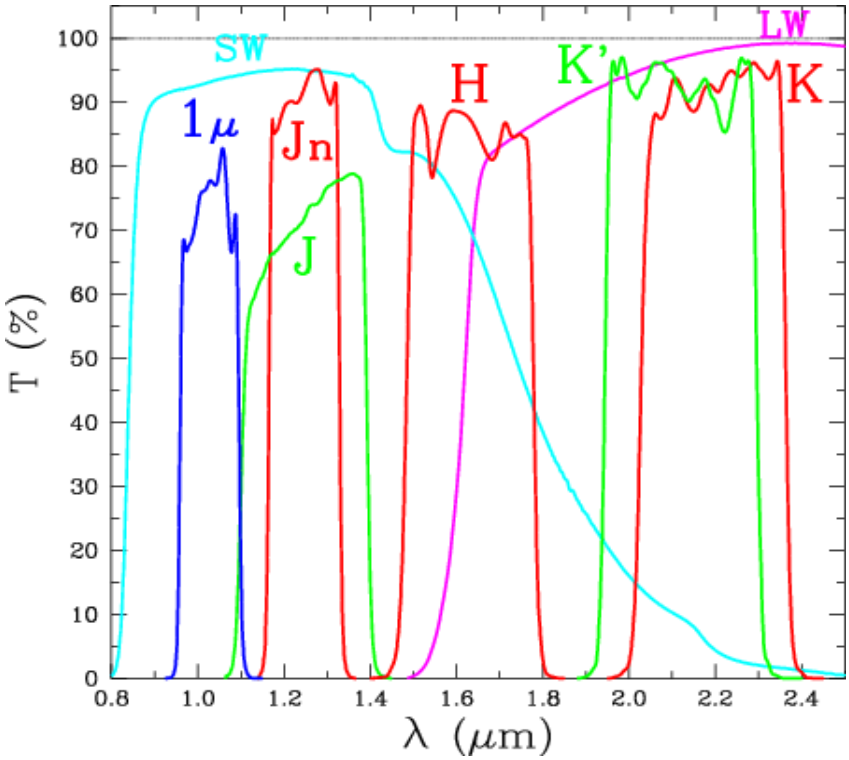


Figure 5: Spectral response and efficiency of NICS wide-band filters.

Wavelength	Attenuation (mag)

(μm)	gray5	gray10
1.03	4.8	~9.5
1.25	5.1	~10.0
1.65	5.5	~10.5
2.15	5.7	~11

Table 3 – Attenuators characteristics.

NICS is also equipped with two attenuators (gray filters) which can be used in combination with any of the broad and narrow band filters whenever observing bright objects which would otherwise saturate the detector. The main characteristics of the gray filters are

summarized in Table 3.

The background flux beyond 2.15 μm is dominated by thermal emission from the mirrors which strongly depends on the ambient temperature and on the cleanness of the mirrors.

The background at shorter wavelengths is mainly due to airglow emission which may vary by up to about a magnitude on time scales of hours. A list of typical values of zero points and background sky emission is shown in Table 4.

Filter	Zero point (mag per 1 ADU/sec)	Background (mag/sq-arcsec)
K	21.8	12.5-13.0
K'	21.9	13.1-13.6
H	22.3	13.4-14.7
J	22.1	15.0-16.0
Js	22.1	15.0-16.0
1mic	22.5	16.0-17.0
Kcont	18.8	12.5-13.0
Brgamma	18.8	13.0-13.5
H2	18.8	13.5-14.0
FeII	19.2	13.4-14.7
Hcont	19.1	13.6-14.9
SW	~23	13.5-14.5

Table 4 - Typical values of zero points and background sky emission.

4.2 NICS in spectroscopic modes

Long slit spectroscopic observations are performed by inserting a slit (*see Table 5*) at the entrance focal plane and a disperser (grism or prism) in the collimated beam. All spectroscopic modes make use of the LF camera with a scale of 0.25"/pixel.

NICS slits		
Name	Width	Length
0.5	0.5" = 2 pix	4'
0.75	0.75" = 3 pix	4'
1.0	1.0" = 4 pix	4'
1.5	1.5" = 6 pix	4'
2.0	2.0" = 8 pix	4'

Table 5 – Slits available in NICS.

The instrument is equipped with one prism and a number of grism dispersers whose main characteristics are listed in the *Table 6*. The grisms have a fairly constant dispersion

(Å/pix) throughout the spectrum and, therefore, their resolving power increases going towards the red. The Amici prism, on the contrary, delivers a spectrum with a quasi-constant resolving power and its dispersion varies by more than a factor of 3 over its spectral range. All the low resolution dispersers can be used in combination with the gray filters to take spectra of very bright objects which would otherwise saturate the array.

Figure 6 shows the resolving power (associated to the 1" slit) and the efficiency of the available grisms which are resin–replicated Milton-Roy gratings on IRGn6 prisms (*Vitali et al., 2000*).

NICS dispersers			
Low resolution			
Name	wl-range (μm)	dispersion (Å/pix)	Res.power with 1" slit
Amici	0.8-2.5	30-100	50
IJ	0.9-1.45	5.5	500
JH	1.15-1.75	6.6	500
JK'	1.15-2.23	11.6	350
HK	1.40-2.50	11.2	500
High resolution			
1mic	0.96-1.09	2.0	1250
Js	1.17-1.33	2.5	1200
J	1.12-1.40	2.5	1200
H	1.48-1.78	3.5	1150
KB	1.95-2.34	4.3	1250

Table 6 – NICS grism dispensers and main characteristics.

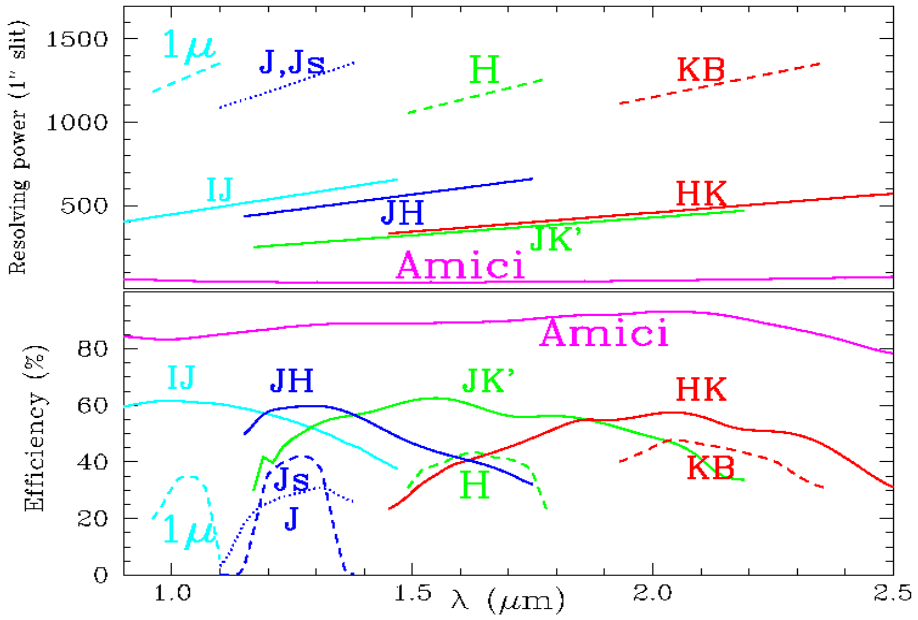


Figure 6 – Resolving power and efficiency of NICS grisms.

4.3 NICS detector

The detector is a Rockwell 1024x1024 HgCdTe Hawaii array which, alike other devices used in various astronomical instruments, has some peculiar characteristics.

Data acquisition and control system are based on the controller developed by the CCD Working Group of TNG, suitably modified to adapt it to the architecture of infrared arrays (*Baffa, C., 2001*). The controller is based on a set of Transputer processors, which are responsible for handling data and sending commands, and on a DSP Motorola 56001, which generates the synchronized clock pattern needed for accessing and reading the array multiplexer.

The analog signal read on each pixel of the four quadrants is buffered by four FET amplifiers located on the same board that hosts the detector. After that stage, there is a set of four 16-bit A/D converters, which convert the pixel intensity of the four quadrants in parallel. The parallel outputs from the converters are translated to the Transputer serial protocol using a dedicated programmable logic chip from Xilinx.

The Transputer stage sends the digital data to a Linux PC by means of a fiber link which exploits the fast serial connection capability built into each Transputer. The controller takes care of telemetry and stepper motors by means of dedicated RS–232 serial ports.

The array multiplexer has a stubborn attitude to remember whatever strong signal was recorded in the previous frame(s). This ghost image will also persist in the subsequent frames with intensity slowly fading down to below the noise level (see *Figure 7*).

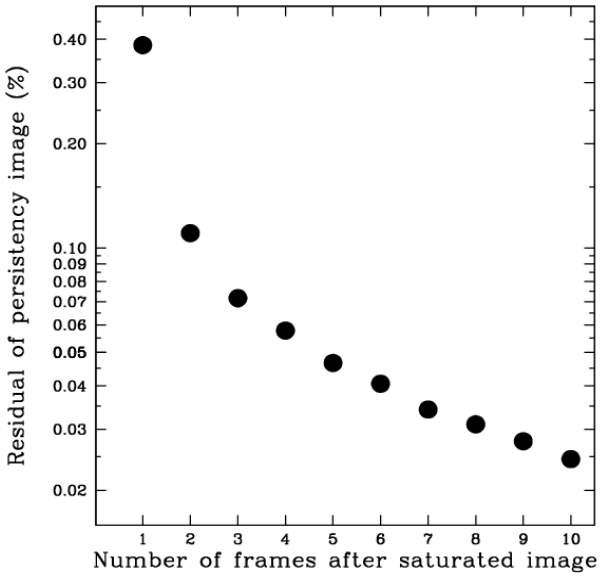


Figure 7 - Evolution of the level of persistency signal (ghost) after a strongly saturated frame. The level of persistency has decreased about a factor of 3 after the new acquisition electronics (FASTI- NICS).

Contrary to standard CCD devices, the "bias" of this detector is not uniform over the array, but has a distinct horizontal pattern with pronounced maximum at rows Y=1 and Y=513.

Moreover its level is not constant along a row but increases with X (see for example *Figure 8*).

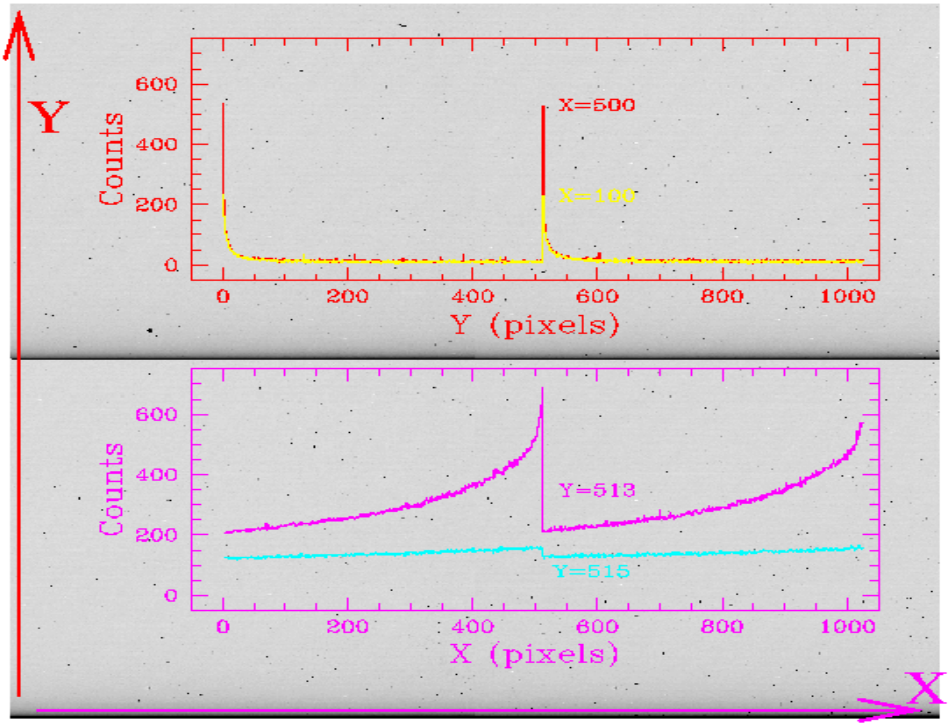


Figure 8 – NICS array quantum efficiency function of the wavelength.

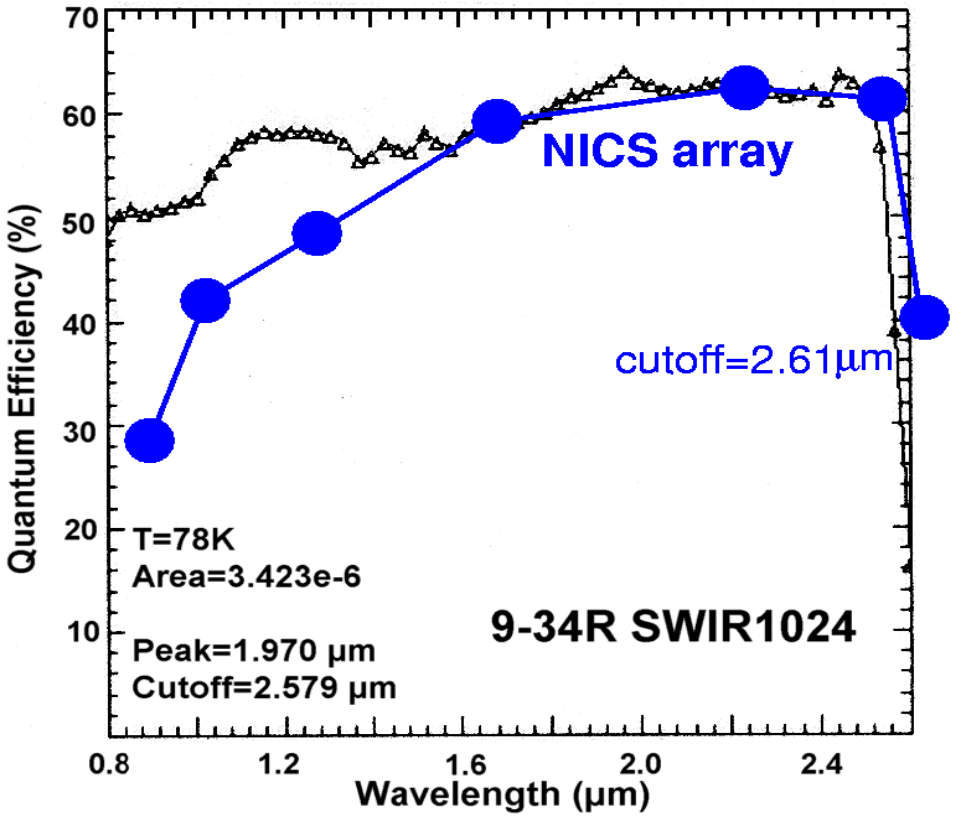


Figure 9 - A typical 60s dark frame with cuts along the two axes shows the NICS detector bias.

The amplitude of the peaks and their slopes are not constant but strongly vary with the level of the signal. In dark exposures, the pattern is characterized by a prominent maximum with quite gentle slopes, while at higher levels of illumination, the peaks become progressively narrower. This effect could produce annoying features when subtracting images/spectra taken under variable sky conditions.

The values displayed in *Figure 9* (blue dots) were determined from measurements of standard stars both in imaging and low resolution spectroscopy (prism).

The data were corrected for the transmission of the optics, filters and prism and normalized to the value at 2.2 micron given in the typical efficiency curve (black triangles). Evident and somewhat unexpected is the quite rapid decrease of efficiency below 1.4 microns which translates into a significant loss of sensitivity in the J and 1micron bands.

4.4 NICS electronics

The infrared detector control is named FASTI. FASTI meant to be a "light" electronic system, which is modular, flexible, extendible, and avoids obsolescence as much as possible. The design does not constrain the downhill controlling computer: FASTI is seen as a peripheral through a network connection.

FASTI contains a central controller for start-up, general housekeeping, global control of operations (start integrations for example), data collection, formatting and buffering, or for data pre-processing when needed. That is realized with a disk-less embedded computer, using an Intel or Alpha family CPU and a number of commercial boards.

There are many advantages in this choice:

- it is very flexible and its behavior can be easily changed
- it is fast and capable of substantial data pre-processing
- it has plenty of built-in or easily available interfaces
- it is much cheaper compared to alternate solutions based on custom interface adapters
- it is seen by the instrument controller computer as a socket in a standard (or fast) Ethernet connection, giving no constraints on it
- it is scalable and can be replaced with similar models (hopefully more powerful) without big modifications to the existing software

The global characteristics are:

- standard interfaces and bus: a serial port, a parallel port, Ethernet, PCI bus
- no moving part (such as hard or floppy disk drivers)
- very fast parallel interface (described later)
- it can be used as an embedded system, with no external human interaction

The *FASTI* control electronics, continuously takes short dummy frames during the idle time for cleaning the array.

The "clear-array" procedure, which was formerly mandatory when switching from imaging to spectroscopy, should be now used only in very extreme cases, e.g. when starting a very long spectroscopic integration after having centered the target using images of a field with one or more saturated objects.

Table 7 summarizes the values of detector integration times (the minimum on-chip integration time is 3 seconds) which should guarantee good performances for observations of faint objects. Entries marked with a "*" indicate that the maximum value of DIT (Detector Integration Time) is not sufficient to guarantee background-limited performances.

The imaging with the SF should require integration times a factor of 4 longer than those with the LF. In spectroscopy, the data taken with low and medium resolution grisms are read-out noise limited at all the wavelengths where the sky emission is low.

The only mode which achieves background limited performances at most wavelengths is low-R spectroscopy with the Amici prism. However, this requires a careful tuning of the value of DIT to obtain a reasonably high signal in the blue without saturating the red part of the spectrum.

The value given in *Table 7* guarantees good performances in the blue with saturation starting at about 2.4 microns.

Observing mode	***Suggested DIT (sec)***	
Imaging J/Js/1mic	*60 (LF)*	*240 (SF/pol)*
Imaging H/K'/K	*25 (LF)*	*100 (SF/pol)*
Ima narrow band	*150 (LF)*	*600 (SF/pol)*
Ima+AdOpt J/Js/1mic	*600 (LF)*	*600*(SF)*
Ima+AdOpt H/K'/K	*240 (LF)*	*600*(SF)*
Ima+AdOpt N.B.	*600*(LF)*	*600*(SF)*
Spectroscopy Amici	*120 x (1"/slit-width)*	
Spectroscopy	*600-900**	

Table 7- Suggested integrations time for observing modes.

Chapter 5

The NICS interface

In its general structure the NICS software system can be subdivided into 4 main levels as already described in *Chapter 2* and here summarized:

- the ***low-level software***. This level is designed to handle all hardware related functions and detector controls. It is physically split in two locations: one inside the NICS PC and the other into the embedded processor located at the focal plane electronics.

- the ***middle-level software.*** This level works like a bridge between the high-level software and the low-level software managing all commands, messages and errors.

- the ***high-level software***. This level is intended to fulfill all astronomy-related tasks and also to act as an interface between the low-level software and the astronomer. Hence, it includes several GUIs to provide a full control of all sub-systems.

- the ***scientific software***. It includes the pre-reduction facilities and some useful tools for the observations.

Figure 10 shows the main architecture of the NICS Control Software.

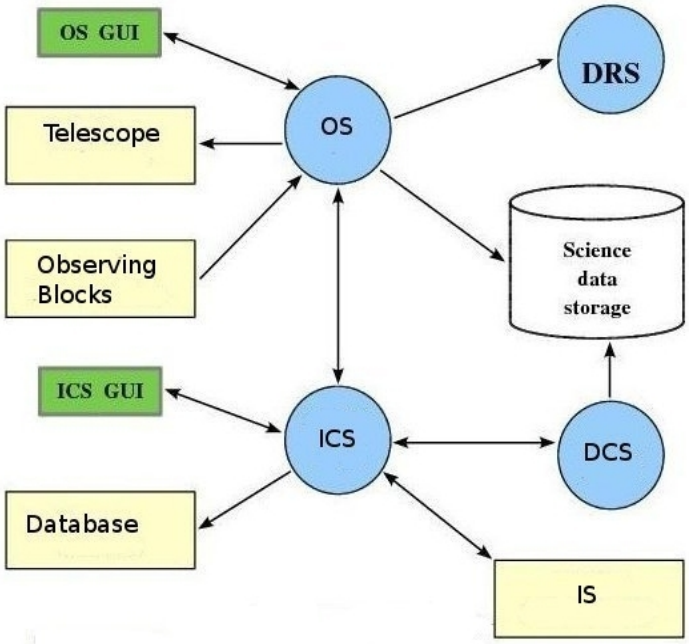


Figure 10 - Main architecture blocks for the high-level software.

Each software level deals with different aspects of the instrument functionality and includes several blocks, which can be conveniently grouped as follows (*Rossetti et al., 2008*):

- ***Detector Control Software*** (DCS): it manages the array controllers. It is directly interfaced to the hardware and is responsible for the initial handling of scientific data in real time.

- ***Instrument Control Software*** (ICS): this block manages the instrument status. It provides a list of FITS keywords describing the instrument status (IS). A permanent connection with ORACLE database allows to retrieve all NICS low-level telemetry.

- ***Observation Software*** (OS): this branch coordinates telescope telemetry command variables. It controls all the parameters needed to perform scientific exposures: instrument setup, initializations, calibration units, setting and exposure time count-down. This block is responsible for frame storage and visualization using the Quick-look task.

- ***Data Pre-Reduction software*** (DRS): it provides a high-level interface necessary to make fast analysis (pre-reduction) on all the NICS acquired frames like a sky subtraction, apply a cross-talk correction etc...

The NICS interface communicates with the array control system via socket through a

dedicated “bridge” program running on the same PC (*see Chapter. 6.1*). The DCS consists of two different parts: the first resides inside the PC-Linux and the second runs on the embedded processor at the focal plane electronics and has direct access to the hardware. The two branches are interfaced by means of a standard Ethernet connection, on which data and commands are sent to Unix-like sockets. The software portion inside the embedded processor manages the data flow controls and can handle special observing modes such as multiple starts and stops. More specifically, it can perform any of the following tasks:

- setting the array read-out mode and detector integration time (DIT)
- starting an integration and, at its end, transferring the resulting frame to the instrument workstation
- averaging a NDIT number of individual DITs before transferring the image
- executing a sequence of dummy images (useful to clean the array from persistence effects)

A typical observation with NICS consists of a mosaic of exposures taken with the telescope pointing at different positions (coordinates) in the sky. Informations on the mosaic positions are saved in the header fits files where the images are stored (*see Chapter 5.1.5***)**. Each exposure produces and writes on disks a number of frames characterized by the DIT, NDIT parameters. These parameters are saved in the header of the fits files where the images are stored.

The interface includes separate buttons to start/stop the various acquisition modes foreseen by the system. A running acquisition can always be stopped or aborted by the user as described in *Chapter 5.1*.
The last acquired integration is always displayed using a Ds9 window integrated within the interface.

Besides the standard buttons available in the Ds9 window (some of which are deactivated by the program), the interface also includes a few buttons which can be used to modify the display and to perform a few analysis on the image. The latter includes measurements of the FWHM of the stellar profile, the possibility of selecting an object and move it to a certain position of the field by offsetting the telescope (*see Chapter 5.3.1***)** and the procedure to compute and execute the telescope offsets necessary for centering the object in the slit **(***see Chapter 5.3.2***)**.

The Observing GUI is divided in three main windows:

- ***Acquisition window*** manages everything which concerns the single frames or mosaics acquisitions. It allows the observing mode selection and setting acquisitions parameters like: DIT, NDIT, NINT, calibration lamps etc.. Also provides detailed and useful informations on telemetry parameters, telescope and NICS status.

- ***Maintenance window*** is dedicated to the motors management allowing operations like positioning, Stop and Reset of each motor. This window also checks all engineering parameters allowing the users to have a complete motors control and monitoring the overall status of them. Also it manages potential blocks of the motors allowing the superuser to restore the normal work conditions.

- ***Quick-look and pre-reduction window*** provides a wide display for the images visualizations and a package of tools acts to: setting up the instruments for observations, showing the seeing and radial profiles informations.

To optimize the space on the desktop and to avoid its saturation, opening many different windows in the same virtual desktop, a light software called *Devilspie*[10] has been implemented. This software allows to automatically redirect applications to a specific virtual desktop. At the startup, *Devilspie* looks for scripts ending with "*.ds*" in a "*.devilspie*" directory in the home directory. The "*.ds*" files have been opportunely configured to organize the windows in three virtual desktops: the workspace 1 is reserved for the Observing window, the second one for the Quick-look window and the third one is used for the maintenance window. In this way, the user, has at hand all the instruments in separated windows avoiding confusions due to their overlapping.

5.1 Acquisition window

NICS observational modes require selecting a given combination of the elements mounted on the 7 movable axis existing inside the cryostat.

For example, large field imaging in *K* requires selecting: the "*LF*" camera in the camera wheel, the *K* filter in the filter wheel, the "*open*" position in the grism, slit and mask wheels, the "*in*" position in the *Lyot-stop slide* and a suitable position of the *focusing slide*.

To simplify the interface and avoid the user to work manually selecting the position of all the wheels, a system of "observing modes" has been defined. The user can choose among 4 different observing modes: imaging (IMA), imaging polarimetry (IMAPOL), spectroscopy (SPE) and spectro-polarimetry (SPEPOL).

For each observing mode up to three parameters can be selected. The interfaces handles the observing modes and relative parameters as groups of 2, 3 or 4 keywords which summarize the requested setup as in the following examples :

IMA K LF G0	**:**	Imaging in K with LF objective
IMA K LF G5	**:**	as above but with a 5-mag gray filter
IMAPOL J	**:**	Imaging polarimetry in J
SPE IJ 1.0 G0	**:**	Spectroscopy with IJ grism and 1.0" slit
SPE IJ 1.0 G10	**:**	as above but with 10-mag gray filter
SPEPOL HK 1.5	**:**	Spectropolarimetry with a HK grism and 1.5" slit

10 http://burtonini.com/blog/computers/devilspie

The general structure of the observing modes is shown in the following:

IMA	*[Filter]*	*[Camera]*	*[Attenuator]*
IMAPOL	*[Filter]*	---	---
SPE	*[Grism]*	*[Slit]*	*[Attenuator]*
SPEPOL	*[Grism]*	*[Slit]*	---

The keywords (parameters) are defined in external files which can be edited by the (super)user:

IMA_1_menu.nics : defines the names of the Filter
IMA_2_menu.nics : defines the names of the Camera
IMA_3_menu.nics : defines the names of the Attenuator
IMAPOL_1 menu.nics : defines the names of the Filter
SPE_1_menu.nics : defines the names of the Grism
SPE_2_menu.nics : defines the names of the Slit
SPE_3_menu.nics : defines the names of the Attenuator

SPEPOL_1_menu.nics : defines the names of the Grism
SPEPOL_2_menu.nics : defines the names of the Slit

The correspondence between observing mode setup and positions of the 7 axis (motors) is defined within the text file "*obsmodes_tab.nics*" which can be edited by the (super)user for maintenance purposes.
This file contains comments (records starting with "#") and one record per observing setup as in the following examples :

Obsmode.setup				*Position of motors*						
				#1	*#2*	*#3*	*#4*	*#5*	*#6*	*#7*
IMA	*H*	*LF*	*G5*	*LF*	*LF1*	*in*	*H*	*gray5*	*LF*	*open*
SPE	*Amici*	*0.75*	*G0*	*LFS*	*LF1*	*in*	*open*	*Amici*	*0.75*	*open*
SPE	*Dark*	*1.00*	*G0*	*LFS*	*any*	*any*	*any*	*close*	*any*	*any*

The first setup corresponds to imaging with H filter, large field camera and 5-magnitude attenuator. It is obtained by positioning *motor#1* at its *LF* position, *motor#2* at its "*LF1"* position, *motor#3* at its "*in"* position, *motor#4* at its *H* position, *motor#5* at its "*gray5"* position, *motor#6* at its "*LF"* position and *motor#7* at its "*open"* position.

The second setup corresponds to spectroscopy with the Amici-prism disperser, 0.75" slit and without attenuator, it is obtained by positioning *motor#1* at its "*LFS"* position, *motor#2* at its "*LF1"* position, *motor#3* at its "*in"* position, *motor#4* at its "*open"* position, *motor#5* at its "*AMICI"* position, *motor#6* at its *0.75"* position and *motor#7* at its "*open"* position.

The third setup corresponds to a dark measurement in spectroscopic mode and is obtained by positioning *motor#1* at its "*LFS"* position, *motor#5* at its "*close"* position, and

leaving the other motors at the current position (keyword *any*).
The translation between motor position keywords and physical positions (i.e. encoder steps) is performed using the information contained in the text files "*motor1_pos.nics*" through "*motor7_pos.nics*" which can be edited by the (super)user for maintenance purposes. The structure of these files is described in the header and comment lines of each file.

The acquisition window (*Figure 11*) allows the users to have a full control of NICS, show the overall NICS status, telemetry variables and allows users to manage acquisitions. Users can introduce the observing setting, can start a single/multiple frame or mosaic acquisition, monitor the motors status and all telemetry parameters, manage the calibration lamps and the connection with the telescope (obviously if there is no connection with the telescope the mosaic tools will be disabled). This window is also equipped with a detailed log window act to provide an historical observations log and giving moreover, the possibility to the users, to manually add personal comments.

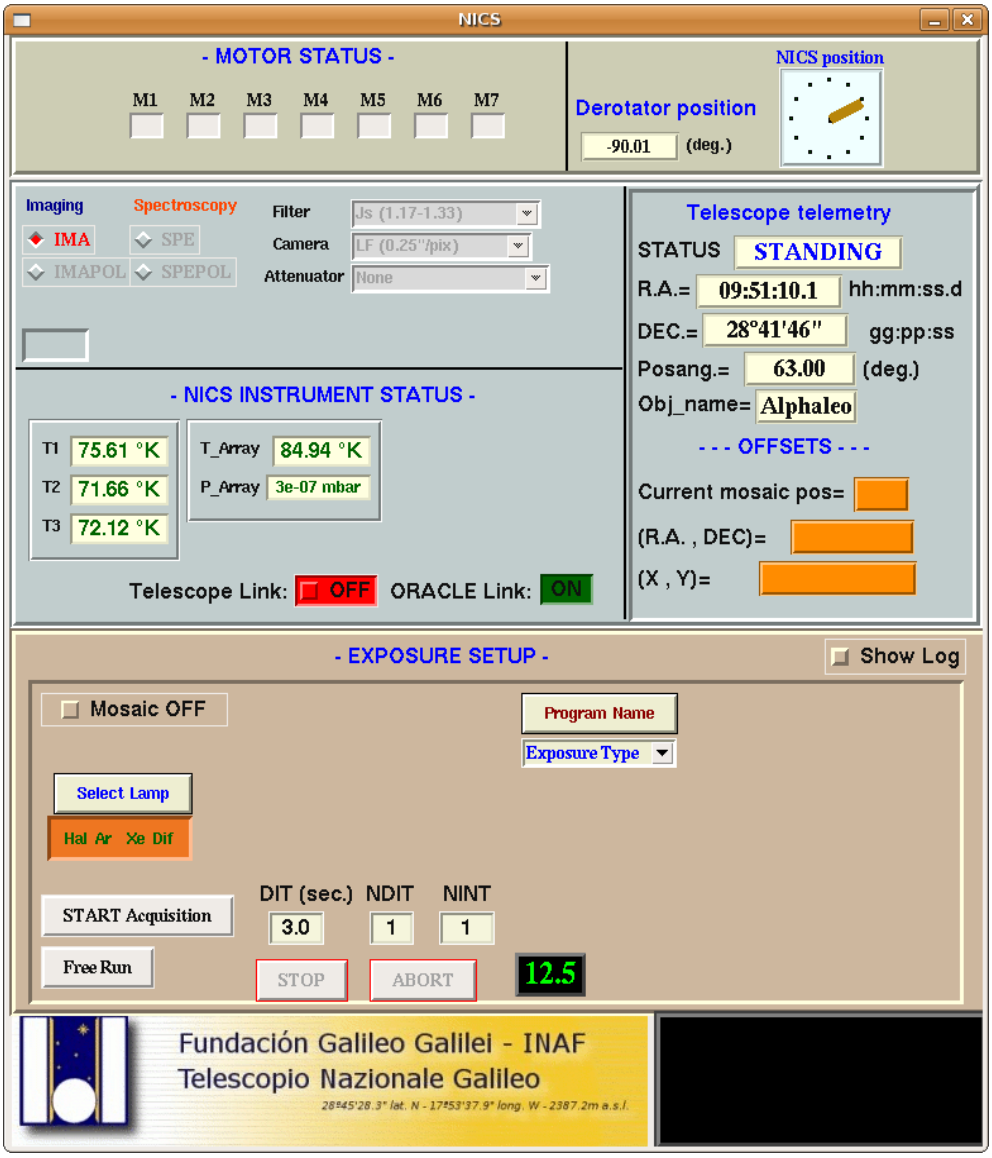


Figure 11 – Acquisition window.

The ***Motors Status*** display uses different color to show the status of each motor:

Color	Status
Green	In position
Blue	Moving
Red	Error
Grey	Not set
Yellow	Not in position

NICS Instrument Status panel allows the users to have a quick-look of the dewar status, showing temperatures and pressure values. The text color changes when the temperature/pressure increase over the normal ranges as shown in the following:

Green	Orange	Red
$T_n <= 80$ (K)	$80 < T_n < 100$ (K)	$T_n >= 100$ (K)
$T_{Array} <= 87$ (K)	$87 < T_{Array} < 95$ (K)	$T_{Array} >= 95$ (K)
$P_{Array} <= 0.000005$ (mbar)	$0.000005 < P_{Array} < 0.0005$ (mbar)	$P_{Array} >= 0.0005$ (mbar)

Where T_n are the three temperature along the dewar, P_{Array} and T_{array} are respectively, the pressure and the temperatures inside the dewar.
It also allows to manage the connection with the telescope and have a look on the connection status through the ORACLE database.

The ***Telescope telemetry*** panel shows all the telescope telemetry parameters retrieved from the ORACLE database (*see Chapter 6.6*).
Instrument setups for the observations are defined in the exposure setup panel which include the “Start acquisition” and the “FreeRun”.

START Acquisition procedure allows to start the acquisition in MOSAIC or NINT mode. The MOSAIC mode is available only when the telescope connection is active. It's granted by setting the MOSAIC checkbutton in the status ON. Setting the MOSAIC checkbutton in the status OFF the user performs NINT integrations. The frames generated are saved into the archive. Each exposure is characterized by the following parameters:

- ***DIT***, is the on-chip integration time or, equivalently, the time elapsed between the “start” and “end” read-outs of the detector. The value of DIT is given in seconds and can vary between 3 to 9999. There is no default value for this parameter.

- ***NDIT***, is the number of single frames which are averaged before writing the image on the disk. The average is performed by the lower level software. The value of NDIT can vary between 1 and 100. The default value is 1.

- ***NINT***, is the number of (averaged) frames to be written the disk. The value of NINT can vary between 1 and 9999. The default value is 1.

Examples:

- DIT=20, NDIT=2, NINT=4 : take and save on disk 4 frames each of them containing the average of 2 images of ~20 sec on-chip integration time.

- DIT=900, NDIT=1, NINT=1 : take and save on disk 1 frame containing 1 image of ~900 sec on-chip integration time.

When an Acquisition is started the interface check the status of the motors and moves them in case they are not at the position defined by the observing mode. Then, simultaneously, it activates the STOP and ABORT buttons, and deactivates all set-up buttons (observing mode, array parameters, mosaic definition, maintenance controls etc.). EXIT button always remains active.

FreeRun procedure continuously acquires frames of ~3 seconds exposure time and displays the results without saving the images into the archive. The images are nevertheless available on disk as temporary fits files and may be used for quick on-line analysis (e.g. display subtracted frames, display images divided by reference-flat frames, compute FWHM of stellar images, perform statistics of sub-areas). This mode can only be terminated by an ABORT command.

When a Free-Run is started the interface checks the status of the motors simultaneously and move them in case they are not at the position defined by the observing mode. Then activates the ABORT button and deactivate the set-up buttons relative to the array parameters. All the other set-up buttons are left active. This implies e.g. that the user can change the observing mode and move the motors using the maintenance panel while the free-run is running, which could be useful to verify directly if and how a given motor is moving.
The buttons used to interact with the image display remain active during the integration, but is be deactivated when a new image is loaded.

The user can STOP or ABORT a running exposure or mosaic by selecting a suitable key. This command pops-up a "*Please confirm the stop (or abort)*" window which blocks all other buttons until the user answer.

In case the STOP is confirmed, the interface saves the on-going exposure frame on disk and stops the other exposures. In case a mosaic is running, the interface sends a "move to origin" command to the telescope and terminates the mosaic.

In case the ABORT is confirmed the interface aborts the on-going integration of the detector and completes the the on-going exposure. In case a mosaic is running, the interface sends a "move to origin" command to the telescope and stops the mosaic.

The Exposure Setup Panel also allows to manage the calibration lamps. NICS is equipped with three different calibration lamps: Halogen, Xenon, Argon and a diffusor.
The procedure to manage the calibration lamps allows the user to put the diffusor in position ON/OFF and switch ON/OFF one or more lamps at a time.

The connection between the GUI and the lamps is guaranteed by the port number 5 on the Lantronix. Using this connection the following list of commands allows to manage the calibration lamps.

Command	Description
#5 / #6	Halogen ON / OFF
#7 / #8	Argon ON / OFF
#9 / #0	Xenon ON / OFF
#r	read all lamps status
#a	put diffusor in ON/OFF state

When the GUI is starting up, an "*#r*" command is sent to the lamps and their actual status is shown into the GUI.
The user must wait approximately 20 seconds, while the diffusor is positioning. During this time the acquisition buttons are disabled but the user can continue working on the current or latest image.
During the diffusor positioning the label "*Dif*" (*Figure 12*) is shown in blue color to notify that diffusor is moving. The color become light green when the diffusor is in "*close*" position.

Figure 12 - All lamps OFF and the diffusor in Close position (left)
Halogen and Xeno lamps ON (right).

Finally, the GUI shutdown procedure checks the status of the lamps before close the GUI and notifies, when necessary, if some lamps are ON or if the diffusor is in "open" position allowing the user to switch OFF.

5.1.1 Defining and performing the telescope movements (mosaic)

A typical IR observations consist of several frames taken with the telescope pointing at different positions. The instructions on how the telescope should be moved are contained in the "mosaic files". They are simple text files (extension .txt mandatory) structured as follows:

```
[MODE]
X_offset1  Y_offset1
X_offset2  Y_offset2
X_offset3  Y_offset3
X_offset4  Y_offset4
X_offset5  Y_offset5
....
```

The header MODE is optional and specifies how the offsets must be interpreted. Four modes are feasible:

- *REL2SOURCE_AD*: offsets are in arcsec. The first column contains the RA offset and the second the Declination offsets. The origin (0,0) is the position of the telescope before starting the mosaic. Offsets are absolute with respect to this position. This is the default mode. A mosaic without an header will be interpreted and executed in this way.

- *REL2LAST_AD*: also in this case units are arcsec and the columns contain RA and Dec offsets, but now they are relative to the previous mosaic position.

- *REL2SOURCE_XY*: offsets are in pixels for the LF camera and are defined along rows (X) and columns (Y) of the array. They are absolute offsets with respect to the origin (0,0), i.e. the position of the telescope before starting the mosaic.

- *REL2LAST_XY*: the same as *REL2SOURCE_XY* except that the offsets are relative to the last mosaic position.

The GUI executes the mosaic command according to the following steps:

1. Reads the mosaic file, determines the offsets and stores the offsets values

2. Moves the telescope to the first mosaic position and waits for telescope settling. Obviously, this operation is skipped in case the offset amplitudes are both = 0.

3. Acquires frame

4. Moves telescope to next mosaic position and waits for telescope setting

5. Repeats steps 3-4 until the mosaic ends

6. Moves to the origin, i.e. moves the telescope back to the original position of the mosaic and waits for telescope settling before reactivating the START button.

In case of a STOP or ABORT command the GUI sends the telescope directly to the step 6.

5.1.2 Offsetting the telescope

The interface can move the telescope sending to the tracking the command *GDOFFS* in the following format:

GDOFFS dAR dDEC

This command is issued to the telescope tracking system through the *WSS-bridge* (*see Chapter 6.5*). The parameters dAR and dDEC are the α and δ offsets, in arcsec, to give to the telescope.

Everytime this command is used, the interface must wait for the telescope to settle: first of all the time necessary for the tracking system to accept the command (about 4 seconds), thus periodically (every second), check the value of the telemetry variable *TRKOK*.

The telescope is settled when *TRKOK*=1. During this waiting the interface blocks the image acquisition, but allows other operations, e.g. handling of the display etc.
In case the waiting lasts more than 30 seconds (parameter to be stored and read from the configuration file *overall_config.nics)* the interface times-out produces an error message. If a mosaic is running the interface suspends the mosaic leaving the telescope in the current position and informs the user of the amplitude of the α, δ offsets which must be (manually) applied to return to the origin position of the mosaic.

5.1.3 Computing the offsets of a mosaic

Depending on the mosaic mode the telescope offsets are determined as follows:

- Let θ_p be the position angle of the frame
- Let X(i) , Y(i) be the entries of the *i-th* line of the mosaic file
- Let X(0)=0.0 and Y(0)=0.0

- ***REL2SOURCE_AD***

  Move to the next *i-th* position: $dAR(i)=X(i)-X(i-1)$

  $$dDEC(i)=Y(i)-Y(i-1)$$

  Move to origin from current *m-th* position: $dAR=-X(m)$; $dDEC=-Y(m)$

- ***REL2LAST_AD***

  Move to the next *i-th* position: $dAR(i)=X(i)$; $dDEC(i)=Y(i)$

Move to origin from current *m-th* position: $dAR=-\sum_{J=1}^{m} X(j)$; $dDEC=-\sum_{J=1}^{m} Y(j)$

- ***REL2SOURCE_XY***

  Move to the next *i-th* position:

$$dAR(i)=Scale*\{-[X(i)-X(i-1)]*\cos(\theta p)+[Y(i)-Y(i-1)*\sin(\theta p)]\}$$
$$dDEC(i)=Scale*\{[X(i)-X(i-1)]*\sin(\theta p)-[Y(i)-Y(i-1)*\cos(\theta p)]\}$$

Move to origin from current *m-th* position:

$$dAR = Scale * [X(m)\cos(\theta_P) - Y(m)\sin(\theta_P)]$$
$$dDEC = Scale * [-X(m)\sin(\theta_P) - Y(m)\cos(\theta_P)]$$

- ***REL2LAST_XY***
  Move to the next *i-th* position:

$$dAR = Scale * [-X(i)\cos(\theta_P) + Y(i)\sin(\theta_P)]$$
$$dDEC = Scale * [X(i)\sin(\theta_P) + Y(i)\cos(\theta_P)]$$

Move to origin from current *m-th* position:

$$dAR = Scale * \left\{ \left[\sum_{J=1}^{m} X(j) \right] \cos(\theta_P) - \left[\sum_{J=1}^{m} Y(j)\sin(\theta_P) \right] \right\}$$
$$dDEC = Scale * \left\{ \left[-\sum_{J=1}^{m} X(j) \right] \sin(\theta_P) - \left[\sum_{J=1}^{m} Y(j)\cos(\theta_P) \right] \right\}$$

Where *Scale* is the pixel scale (in arcsec/pix) which depends on observing mode as follows :

IMA-LF	*0.25*
SPE/POL	*0.25*
IMA-SF	*0.13*
IMA-LF-AdOpt	*0.086*
IMA-SF-AdOpt	*0.043*

The angle θ_p is the position angle of the frame, defined as the angle between the detector Y-axis and the North direction. The angle increases going from North to East. This parameter is computed as follows:

$$\boldsymbol{\theta_p = RPAOFF + NICS\_DEROFF}$$

where *RPAOFF* is a telemetry variable generated by the telescope tracking system, while *NICS_DEROFF* is a constant which must be stored and read from the configuration file *overall_config.nic*s.

During a mosaic the values of *DEL_RA*, *DEL_DEC* are shown in green if the mosaic is of type *REL2SOURCE_AD* or *REL2LAST_AD*, otherwise in default color (gray) for *REL2SOURCE_XY* or *REL2LAST_XY*.
The values of *DEL_X*, *DEL_Y* are shown in green if the mosaic is of type *REL2SOURCE_XY* or *REL2LAST_XY*, otherwise in default color (gray) for *REL2SOURCE_AD* or *REL2LAST_AD*.

5.1.4 Structure of the fits files

The images are stored in *I*2* fits files. The name of the each file is *XXXZiiii.fts*, where *XXX* is the session name which is create by the telescope tracking and read from the database. It is a unique 3 letter counter which is normally updated every 24 hr.

- *Z* is the label identifying NICS
- *iiii* is an integer number (1...9999) which counts the images within a given session. This counter is updated everytime a new frame is stored. Its value is saved (also in the telemetry database) to make sure that image names are never duplicated

Fits files also contain a lot of useful informations about the NICS state, calibration lamps, motors positions, acquisition time, etc... (an examples of fits file is shown in *Appendix A*).
The GUI manages the header fits using a specific Tcl library named *fitsTcl 2.2*.This library is an extension to the script language Tcl/Tk, which uses the CFITSIO library and provides general users with a simple interface to read/write FITS file.

5.1.5 Mosaic offsets in the header fits

During a mosaic the values of the offsets, relative to the origin, are also stored in the header file of the image in the keywords *DEL_RA*, *DEL_DEC*, *DEL_X*, *DEL_Y*. These values differ from that sent to the tracking because in that case they are always referred at the REL2LAST_AD mosaic (*see Chapter 5.2.3* for details), while the offset values stored in the header fits are computed as follows.

Let θ_p be the position angle of the frame, *m* be the current position of the mosaic.

- ***REL2SOURCE_AD*** $DEL\_RA = X(m)$; $DEL\_DEC = Y(m)$

While the keywords DEL_X and DEL_Y are not saved.

- ***REL2LAST_AD*** $DEL\_RA = \sum_{J=1}^{m} X(j)$; $DEL\_DEC = \sum_{J=1}^{m} Y(j)$

While the keywords DEL_X and DEL_Y are not saved.

- ***REL2SOURCE_XY*** $DEL\_X = X(m)$; $DEL\_Y = Y(m)$

$$dAR = Scale * [-X(m)\cos(\theta_p) + Y(m)\sin(\theta_p)]$$
$$dDEC = Scale * [X(m)\sin(\theta_p) + Y(m)\cos(\theta_p)]$$

- ***REL2LAST_XY***: $DEL\_X = \sum_{J=1}^{m} X(j)$; $DEL\_Y = \sum_{J=1}^{m} Y(j)$

$$DEL\_RA \quad Scale * \left\{ -\left[\sum_{J=1}^{m} X(j) \right] \cos(\theta_P) + \left[\sum_{J=1}^{m} Y(j) \sin(\theta_P) \right] \right\}$$

$$DEL\_DEC = \quad Scale * \left\{ \left[\sum_{J=1}^{m} X(j) \right] \sin(\theta_P) + \left[\sum_{J=1}^{m} Y(j) \cos(\theta_P) \right] \right\}$$

Where *Scale* is the pixel scale (in arcsec/pix) which depends on the observing mode.

5.2 Maintenance window

The maintenance window is the interface which allows the control of the NICS motors (*see Figure 13*).
The NICS instrument includes 7 axis driven by stepper motors. Each of the stepper motors is controlled by a OEM300 Power Module (*Chapter 6.3*) which, among other operations, keeps track of all the movements performed (steps) and updates a "step-encoder" value which, in practice corresponds, to the absolute position of the axis, unless some mechanical problem occurs.

The controller holds the value of the step-encoder only as long as it is powered, i.e. the information is lost when the system is switched off. Consequently, a "reset" operation is needed whenever the system is turned-off and on and it is also useful to check and correct for mechanical problems.
The 7 axis/movements perform the following operations:

- ***Motor #1*** rotates the "*cameras wheel*" which houses 3 cameras (LF, SF, PR) and one "close" position. The step-encoders corresponding to the cameras positions are listed in the text file *motor1_pos.nics* which can be edited for maintenance purposes. The wheel can rotate freely (no mechanical blocks) and has one home-switch used to define the zero-position. A complete 360˚ turn requires about 100,000 motor steps, the exact value is stored in the configuration file *motors_config.nic*s.

- ***Motor #2*** drives the "*focus slide*" which moves the array detector perpendicularly to the optical axis. The step-encoders corresponding to the optimal focus positions in the various observing modes are listed in the text file *motor2_pos.nics* which can be edited for maintenance purposes. The slide has two limit-switches, limiting the movement from 0 to about +9000 steps. Besides these hardware limits, the interface also foresees “software limits” which are defined in the configuration file *motors_config.nic*s and are used to avoid approaching the limit switches during normal operations. A home switch is also present but, in practice, is not used.

- ***Motor #3*** drives the "*pupil stop slide*" used to insert or remove a Lyot pupil stop. The step-encoders corresponding to the "in" and "out" positions are listed in the text file *motor3_pos.nics* which can be edited for maintenance purposes. The slide has two limit-switches, limiting the movement from 0 to about +33000 steps. Besides these hardware limits, the interface also foresees “software limits” which are defined in the configuration file *motors_config.nics* and are used to avoid approaching the limit switches during normal operations. A home switch is also present but, in practice, is not used.

- ***Motor #4*** rotates the "*filters wheel*" which can house up to 21 optical elements. The step-encoders corresponding to the "filters" positions are listed in the text file *motor4_pos.nics* which can be edited for maintenance purposes. The wheel can rotate freely (no mechanical blocks) and has one home-switch used to define the zero-position. A complete 360˚ turn requires about 60,000 motor steps, the exact value is stored in the configuration file *motors_config.nics*.

- ***Motor #5*** rotates the "*grisms wheel*" which can house up to 18 optical elements. The step-encoders corresponding to the "grisms" positions are listed in the text file *motor5_pos.nics* which can be edited for maintenance purposes. The wheel can rotate freely (no mechanical blocks) and has one home-switch used to define the zero-position. A complete 360˚ turn requires about 60,000 motor steps, the exact value is stored in the configuration file *motors_config.nics*.

- ***Motor #6*** rotates the "*apertures wheel*" which can houses up to 15 optical elements. The step-encoders corresponding to the "apertures" positions are listed in the text file *motor5_pos.nics* which can be edited for maintenance purposes. The wheel can rotate freely (no mechanical blocks) and has one home-switch used to define the zero-position. A complete 360˚ turn requires about 200,000 motor steps, the exact value is stored in the configuration file *motors_config.nics*.

- ***Motor #7*** rotates the "*mask wheel sector*" housing up to 3 masks useful for polarimetric observations. The step-encoders corresponding to the masks positions are listed in the text file *motor7_pos.nics* which can be edited for maintenance purposes. The wheel sector cannot rotate freely and has two limit-switches limiting the movement from about 0 steps to about +50,000 steps. Besides these hardware limits, the interface also foresees “software limits” which are defined in the configuration file *motors_config.nics* and are used to avoid approaching the limit switches during normal operations. Due to a manufacturing error, the two limit-switches are connected in parallel, i.e. the controller cannot recognize which of the two is activated. Consequently, this motor requires ad-hoc operations for defining the zero position and for the initialization.

The motors which activates rotation movements (#1, #4, #5 and #6) can rotate freely (both clockwise and/or anticlockwise) and have only a home switch defining their "zero points". The number of step corresponding to a complete 360° turn, varies from 60 000 to 200 000 steps depending on the motor. Of course it is convenient to make the motor move in the rotational direction that minimize the motion and, consequently, the time needed to accomplish it. This implies that the step encoder may have positive or negative values, depending on the rotational direction.

However the "step encoder" may have values which can be extremely large depending on the number of rotations performed by the wheel along the same direction, while the "real position" must range between 0 and the maximum motor elongations (i.e. the correspondence to 360°). The conversion "step encoder" to "real position" is automatically done by the interface.

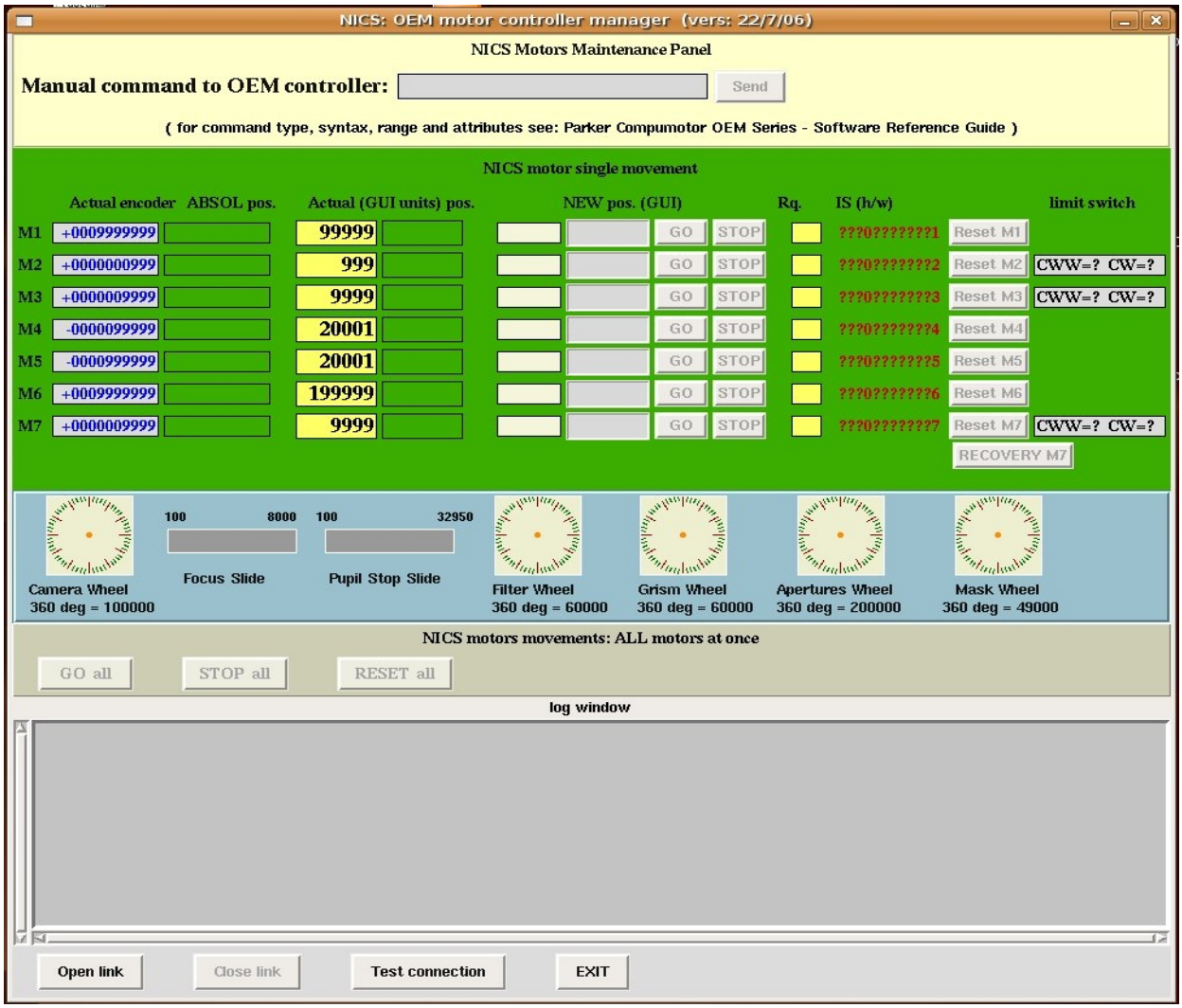


Figure 13 – Maintenance window.

Motors controlling translation movement (#2, #3 and #7) instead, have a limited range of movements from about 0 to a few thousands of steps. These values are always positive and for these motors "step encoders" and "real position" coincide. For these motors the new NICS

interface also has a set of “software limits” which are defined in the configuration file and are used to avoid approaching the limit switches during normal operations.

The valid “real positions” for all NICS motors are defined in a hidden configuration file which can be modified only for maintenance purposes. This file allows the logical translation between “real position” (at low-level) and instrumental setup (at high-level).

The maintenance window allows all low-level remote operations related to the motion of different motors. This panel has been designed and tested to work as:

- an *entry-command*. The NICS superuser can type and send command directly to the controller without any “filtering” by the interface. In this case the log window reports detailed informations of what is happening during the execution of the command.

- a *single-motor movement* manager. The position of every motor is codified both in terms of “*encoder absolute and actual position*” (the latter is named GUI units in the panel). The difference between the two units has been explained above for rotational motors and depends, on the number of times that a given wheel performs a complete turn. To move a motor one has to fill the corresponding entry “NEW pos.” with the value expressed in “GUI units”. The entering of wrong values, either out of possible range or mistyped, do not produce any movement and generate an error message.
- a *motion-display* for each motor. To the right side of each “encoder absolute position” and “GUI position” there is a transparent label which becomes active as soon as the corresponding motor is starting. These labels display the motor position, every one in its own units, and are active until the end of motion. As soon as the motor stops the new final position are updated in the corresponding labels.

- a *hardware status* display. The interface reports, for each motor, an 11 character string made of 10 ASCII digits (0 or 1) and a device address (1-8), which is not a software status but the report of the actual hardware status (response) on the inputs. This information is used to verify the limit switches, trigger inputs and home switches are working correctly. Furthermore the “Rq.” label indicates the status of each motor: “R” stands for ready, “B” for busy.

- a *resetting motors* utility. For every motor it is possible to launch a reset procedure, which is rather simple for the rotating wheels and more complicated for the translational movements (especially for #7). The resetting is mandatory in case of switching ON of the controller and when a failure of the system in suspected. Test on all NICS motors give a maximum value of resetting time (starting from the worst conditions) from about 20 sec (motors #4 and #5) to abouts 2.5 min (motor #7).

- a *recovery system* (only for motor #7). Due to technical problems, motor #7 requires an additional procedure of initialization, which must be run at starting and generally in case of problems (*see Chapter 5.2.3*).

- a *multi-motions* procedure. More than one motor can be moved at the same time. The command "GO all" is able to perform this action provided that the "NEW pos." entries have been filled with right values. If only one new entry position is entered the command "GO all" is equivalent to the "GO" command for that motor.

The new low-level NICS motor interface is able to communicate with the *OEM750X* controller (*see Chapter 6.3*) in two different ways: through a direct serial connection (when the controller is linked directly with the serial port of NICS workstation) or by means of an IP socket (when the controller is linked to a port of the terminal server *ETS8PS see Chapter 6.2*). The interface also has an internal queue manager, which activates when the resetting procedures are launched.

This algorithm is extremely useful when dealing with motor #7 whose resetting and/or recovering proceeds through a series of logical conditions.
Finally each operation done using this new NICS motor interface is recorded in a local (rotational) log file (Rossetti E., 2008).

5.2.1 Interface encoder, absolute counter and historic log

When the wheels are moving, the step-encoders from the controller may have negative values or values larger then N, the number of steps corresponding to a complete 360° round. This occurs for example, when passing through the zero position. To avoid confusion, the program uses the "interface encoders" X defined as:

$$X = x + i * N$$

$$0 \leq X < N$$

where x is the "step encoder" read from the controller and i is an integer number which is updated by the interface whenever necessary. The GUI should only display the value of X.

All the positions stored in the configuration files *motor*_pos.nics* are measured in interface encoder units, i.e. are ≥ 0 and $< N$. When targeting a new position the program reads the value X from the configuration file and computes the target value in step-encoders as $x = X - i * N$.
In parallel to the step-encoders information available from the controller, the interface should keep track of the total number of steps moved by each motor since the last reset, and update the "absolute step counter"'.

This is useful for instance when deciding if it is convenient to perform a reset during a "passing through zero" operation. Its value should be displayed on the GUI.

The interface also updates for each movement an historical log-file where minimal information of all the movements performed are stored. It could be also useful to maintain/update an historical step-counter which is the sum of all the movements performed since the first time the interface has been used.

5.2.2 Interface startup

The interface sends, first of all, the initialization commands to the controllers. Then reads the actual positions of the motors (step-encoders) which are not explicitly excluded, checks if motor #7 is in a critical position, and recovers it, if necessary. Obviously, the latter test must not be performed if motor#7 is explicitly excluded.
The controllers are mounted inside a single rack and connected to the same power-supply. The motor-rack is normally kept powered and, therefore, the controllers keep memory of the step-encoder positions even when the interface is not operative.

If the motor-rack is switched-OFF and ON again, all the controllers restart with the step-encoder counters set to zero. Since the useful motor positions never correspond to the zero position of the step-encoder, the startup procedure for the step-encoders can be easily performed as follows.

- if all the active motors have step-encoders $\neq 0$ simply takes the values and displays them on the panel

- If all the active motors have step-encoders $=0$ the interface opens a window saying *"motors controllers have been most likely switched off, ready to reset all motors"*, and executes the reset operation after the user confirms it.

- If some of the active motors have step-encoders $=0$ the interface issues warning message(s) but does not perform any reset.

After that, the interface searches if the current positions of the active motors corresponds to an observing mode. This is performed by searching, for each motor and in the *motor**_pos.nics* files, the keyword corresponding to the actual position, within the positional error defined in *motors_config.nics*. If no correspondence is found the keyword "*any*" is used.

The program then checks if the combination of keywords thus produced is present in the *obsmodes_tab.nics* configuration file. In case it exists the program takes the strings describing the observing mode from the corresponding "*_menu.nics"* files and updates the GUI accordingly. Otherwise the GUI displays *"Not Set"* in the observing mode window.

5.2.3 Recovery of motor #7 when stuck at initialization

Due to a manufacturing error, the limit switches of this motor are mounted in parallel, i.e. when one of the two is activated the controller sees both limit switches as active. Consequently, if the limit switches are active the motor is stuck (i.e. cannot move in any direction) and one cannot know at which of the two edges the axis is positioned.

The *"motor-stuck"* condition can be recognized using the status command *7IS* which, under stuck conditions, answers "*????11?????"* where *"?"* means that the digit is unimportant for this limit-switch status control.

If the interface detects this condition it operates as follows:

- Check if at negative end

Serial command	*Comment*
7PZ	Reset step-encoder
7OSA1	Define inverted status of limit-switch
7D300	Prepare a small positive movement
7G	Start movement (will stop almost immediately)
7IS	Check limit switch status if answer = ?????00???7 Unlock and reset

- Check if at positive end

7D-600	Prepare a small negative movement
7G	Start movement (will stop almost immediately)
7IS	Check limit switch status if answer = ?????00???7 Unlock and reset

- Surrender and abort

7OSA0	Define normal status of limit-switch then abort program/interface with an alarm message

- Unlock and reset

7OSA0	Define normal status of limit-switch then reset motor

Obviously, these operations must not be performed if motor#7 is explicitly excluded.

5.2.4 Mechanical problems

Each stepper motor operates at room temperature and atmospheric pressure and is connected, through a quite complex mechanical system, to the moving axis which lies in vacuum and at cryogenic temperatures. No encoder exists on the moving axis and the only information available relative to the movement is the number of steps issued by the controller to the motor. Noticeably, these steps are counted even when the motor is mechanically blocked.

In case a mechanical problem occurs, the axis may not respond correctly to the motor impulse or may even not move at all. In such a case the system "looses steps" and the step-encoders recorded by the controller do not any longer correspond to the position of the axis.
Even when the mechanics works properly it may occur that the system looses a few steps every once in while.

The only way to recover the correct step-encoders value is to reset the axis. During this operation it is also possible to quantify the number of steps lost.

In case mechanicals problems prevent the movement of a given motor, this can be excluded by all setup procedures. In such a case the interface ignores any setup, movement or telemetric command related to the motor and display *"excluded"* in the engineering status panel.

The parameter defining if a motor is "*active*" or "*excluded*" is contained in the configuration file *motors_config.nics* which can be edited by the (super)user for maintenance purposes into the Maintenance GUI which allows the user to modify the "*active*" motors column contained in *motors_config.nics* file, simply using a checkbutton.
All motors have a relative checkbutton which allows superuser to include/exclude it for the movements. The format of this text file is described in the header and comment lines of the file itself.

The most obvious problem is when the controllers do not respond to the serial commands, in such a case the interface should exit issuing a suitable message.
It may also occur that the serial communication works correctly but one or more of the controllers do not work properly. These faults can be detected using the command ***nIS*** and checking the status of the first, second, third and fifth digit which are =1 when everything works fine and =0 otherwise. In other words, the controller is OK only as long as the ***nIP*** command answers with 111?1?????n. Different situations must be reported as "fault" by the interface.

5.2.5 Resetting the motors

The rotating wheels (i.e. motors #1, #4, #5 and #6) are equipped with an electro-mechanical switch ("home-switch") which is activated by a shaft when the system is at a given mechanical position. The reset procedure consists therefore of moving the motor in a given direction until the controllers detects a change of state of the signal connected to the home-switch. To guarantee the maximum precision and repeatability of this positioning the axis should always approach the home-switch from the same direction and with the same speed.

The motor controller foresees a specific command ***GH*** to perform the reset operation. The parameters to be set are the direction and the speed. This command also sets to zero the step-encoder at the end of the operation. The resets of NICS wheels are all performed in the negative direction and with different speeds for the different motors.

In case of mechanical problems with the axis (e.g. stuck) or electrical problems with the home-switch (e.g. disconnected), the reset command would result in a never-ending rotation of the motor driving the wheel. This must be prevented using the following strategy.

Using the command ***W3*** the interface can monitor the reset process and count the number of steps moved since command has been issued. If this number largely exceeds the number of steps corresponding to a 360° turn (N, defined in *motors_config.nics)*, the interface stops the movement (command ***nS***) and displays an error message.

Due to a manufacturing error, the negative limit switch of axis #2 and #3 are mounted very close to the home-switch. Consequently, the ***GH*** procedure cannot be performed in a self-consistent way and the resetting of the motor must rely on the information provided by the limit switch.

The procedure in this case is as follows:

Motor 2

Serial Command	***Comment***
2MPI	Set incremental moving mode
2D-9500	Prepare movement toward negative limit-switch (number = total length of the slide + 500)
2G	Start movement
wait/count	Follow movement until motor stops
2MPA	Set absolute moving mode
2IS	Check limit switch status (should be ?????10????2)
2PZ	Reset step-encoder

Motor 3

Serial Command	***Comment***
3MPI	Set incremental moving mode
3V0.3	Set a slow velocity for the motor
3D-3350	Prepare movement toward negative limit-switch (number = total length of the slide +500)
3G	Start movement
wait/count	Follow movement until motor stops
3MPA	Set absolute moving mode
3IS	Check limit switch status (should be ????10????3)
3PZ	Reset step-encoder
3V1	Set normal velocity for the motor

Due to a manufacturing error, the seventh axis does not have a home-switch. Moreover, the limit switches are mounted in parallel, i.e. when one of the two is activated, the controller sees both limit switches as active.

Hence the reset of the axis must be performed using the information available from the limit-switch as follows:

Motor 7

Serial command	*Comment*
7IS	Check limit switch status, must be ?????00???? if not follow emergency recovery
7V0.3	Set a slow velocity for the motor
7MPI	Set incremental moving mod
7D-60000	Prepare movement toward negative limit-switch (number = total length of sector + 500)
7G	Start movement
wait/count	Follow movement until motor stops
7IS	Check limit switch status, it should be ?????11????
7OSA1	Define inverted status of limit-switch
7D1000	Prepare movement to a positive target to open limit-switch
7G	Start movement (will stop almost immediately)
7MPA	Set absolute moving mode
7IS	Check limit switch status (must be ?????00????)
7PZ	Reset step-encoder
7OSA0	Define normal status of limit-switch
7V2	Set normal velocity for the motor

The reset of the slides (motors #2, #3) and wheel sector (motor #7) are performed by moving the motor toward the negative limit-switch by a number of steps equivalent to the maximum allowed range .
Under normal circumstances the movement will be prematurely stopped by the activation of the limit switch. In case of mechanical problems with the axis (e.g. stuck) or electrical problems with the limit-switch (e.g. disconnected), the limit switch would remain inactive even after movement is completed. If this occurs the interface displays an error message: “Limit switch of *motor#n* not found. Please resend reset command and visually check if motor is moving. If this does not work contact instrument responsible.”

Using the command *W3* the interface can monitor the reset process and compute the number of steps which the axis has moved since the reset command has been issued. Once the command is terminated the interface can compare the total number of steps moved with the step-encoder position prior to the reset command.

5.2.6 Optimizing wheels movement (passing through zero)

As described above, motors #1, #4, #5 and #6 drive wheels which can rotate freely. The same position ***x*** (encoder steps from controller) can be therefore reached by moving the motor to the complementary positions ***N+x*** or ***x-N***, ***N*** being the number of steps corresponding to a complete 360° round.
The value of ***N*** is defined inside the configuration file *motors_config.nic*s which can be edited

by the (super)user for maintenance purposes.

It may therefore happen that a new setup position can be more effectively performed by moving the motor to the ***N+x*** or ***x-N*** complementary positions, i.e. passing through the zero position. In such a circumstance it is convenient to adopt the following procedures. Please note that ***x***, ***y*** are encoder steps which are computed from the interface encoder values.

- ***Case 1:*** the target position (*x*) is larger than the actual (y) position and $(x-y) \gg N/2$ The program moves to the (negative) $x-N$ position and updates the interface encoder *X*.

- ***Case 1R:*** the target position (*x*) is larger than the actual (*y*) position and $(x-y) \gg N/2$. The absolute step encoder (i.e. the number of steps since the last reset), is larger than, $1*10^6$. The program, first sends a reset command and, once terminated, moves the motor to the (negative) $x-N$ position and updates the interface encoder *X*.

- ***Case 2:*** the target position (*x*) is smaller than the actual (*y*) position and $(y-x) \gg N/2$. The program moves the motor to the $x+N$ position and updates the interface encoder *X*.

- ***Case 2R:*** the target position (*x*) is smaller than the actual (*y*) position and $(y-x) \gg N/2$. The absolute step encoder (i.e. the number of steps since the last reset) is larger than, $1*10^6$. The program, first moves the motor to position $N+3000$ then sends a reset command and, finally, moves the motor to the *x* position.

5.2.7 Commands to serial

The program communicates with the drivers through a single serial channel and using a relatively simple protocol of string (ASCII) commands. Although the drivers always respond to the command, however, the answer is sometimes "*queued*" and issued only when the motor has terminated the movement (see e.g. the PR command below).

During this time the controller accepts other commands. Consequently, the program must be designed to handle "*delayed answe*r" or, alternatively, to issue "*dangerous commands*", only when the system is ready to answer promptly.

The maintenance panel must also foresee a terminal-like interface where the (super)user can type the commands to send to the controllers without any "*filtering*" by the interface.
In the following there is a list of the serial commands used to control/move the NICS motors.

Reset motor #1	*1GH-2*
Reset motor #2	*see Chapter 5.2.5*
Reset motor #3	*see Chapter 5.2.5*
Reset motor #4	*4GH-2*
Reset motor #5	*5GH-2*
Reset motor #6	*6GH-2*
Reset motor #7	*see Chapter 5.2.5*

Set step-encoder of motor *n* to zero	*nPZ*
Prepare motor *n* to move to *xxx* step-encoders	*nDxxx*
Start movement of motor *n*	*nG*
Start movement of all motors at once	*G*
Send message when movement has terminated (where *message* is a <17 characters string)	*n"message*
Get step-encoder value for motor *n* (WARNING: responds only when motor is not moving)	*nPR*
Get indexer status of motor *n*	*nR*
Get hardware status of motor *n* (returns limit switches status and general status of the hardware)	*nIS*
Get steps moved since last G command (useful to get telemetry when motor is moving)	*nW3*
Stop movement of motor *n*	*nS*
Stop all movements	*S*
Switch-off motor #n	*nST1*
Switch-off all motors	*ST1*

Whenever a change of the setup is requested, all the motors involved are moved at the same time. The interface must follow the evolution of the movement (command W3, used only for relatively long movements) and define the motor as "ready" once the trajectory is completed. This last condition can be checked using the command R or, more simply, just waiting for the message-string which can be requested just after the beginning of the movement.

Note that the motors may stop at a position slightly (1-2 steps typically) different than the target value. This error is accepted as long as it remains below the threshold defined in the configuration file *motors_config.nics*.
Initialization commands, have to be sent whenever a new connection with the controller is established (i.e. at interface startup). These commands are stored in a text file (*motors_iniseq.nics*) which can be edited by the (super)user for maintenance purposes.

Set mode normal for all motors	*MN*
Set step resolution for all motors & MR1000	
Set absolute step-encoder mode for all motors	*MPA*
Set acceleration for all motors	*A1.5*
Set acceleration for motor#2	*2A0.5*
Set acceleration for motor#3	*3A1.5*

Set velocity for all motors	*V2*
Set velocity for motor#2	*2V0.3*
Set velocity for motor#3	*3V1.5*
Set active state of home switch for all motors	*OSC1*
Set active state of limit switches for all motors	*OSA0*
Set "back to home" option for all motors	*OSB0*
Set power-on to all motors	*ST0*

The Maintenance window also manages the calibration lamps allowing the superuser to exclude, via software, one or more motors. The checkbutton in red means that the motor is active. If a checkbutton is pressed, the procedure modifies the status of the motor into the file *motors_config.nics* passing from 1 (active) to 0 (disabled).
Only the motors with status 1 are implied in the positioning motor procedures. An examples of *motors_config.nics* file is shown in *Appendix B*.

5.3 Quicklook and pre-reduction window

The Quick-look procedure is performed by a modified version of *SAOImage DS9*.
The *Ds9* is the next version of the popular *SAOtng* display program. It is a *Tk/Tcl* application which utilizes the *SAOtk* widget set. It also incorporates the new X Public Access[11] *(XPA)* mechanism to allow external processes to access and control its data, GUI functions, and algorithms. *DS9* supports the direct display of FITS images and binary tables, multiple frame buffers, region cursor manipulation, many scale algorithms and colormaps, and easy communication with external analysis tasks. It is highly configurable and extensible to meet the evolving needs of the astronomical community.

In particular, *SAOImage XPA* messaging system provides an easy communication between *DS9* and other *Unix/Linux* tasks, including *X* programs and a few scripting languages. It also provides an easy way for users to communicate with *DS9* by executing *XPA* client commands in the shell or by using such commands in scripts. Because *XPA* works at the programming as well as shell levels, it is a powerful tool to interface different environment packages.

In order to make *Ds9* a suitable tool only for a quick-look during the observation, the source code has been modified. To avoid undesiderable activities on the GUI (i.e. data reduction) the user can only perform a few essential actions: set the zoom, change scale and color display, enable horizontal/vertical cut graph. Manual loading of fits files is disabled: only images present in the NICS archieve may be loaded.

Figure 14 compares the standard *Ds9* (on the left) and the modifed *Ds9* version (on the right).

The toolbar on the top has been disabled to avoid operations not strictly tied up with the observations. Two information boxes for automatic visualization of the mean and the standard deviation in a box of 9x9 pixel around the mouse position have been implemented.

11 http://hea-www.harvard.edu/RD/xpa/

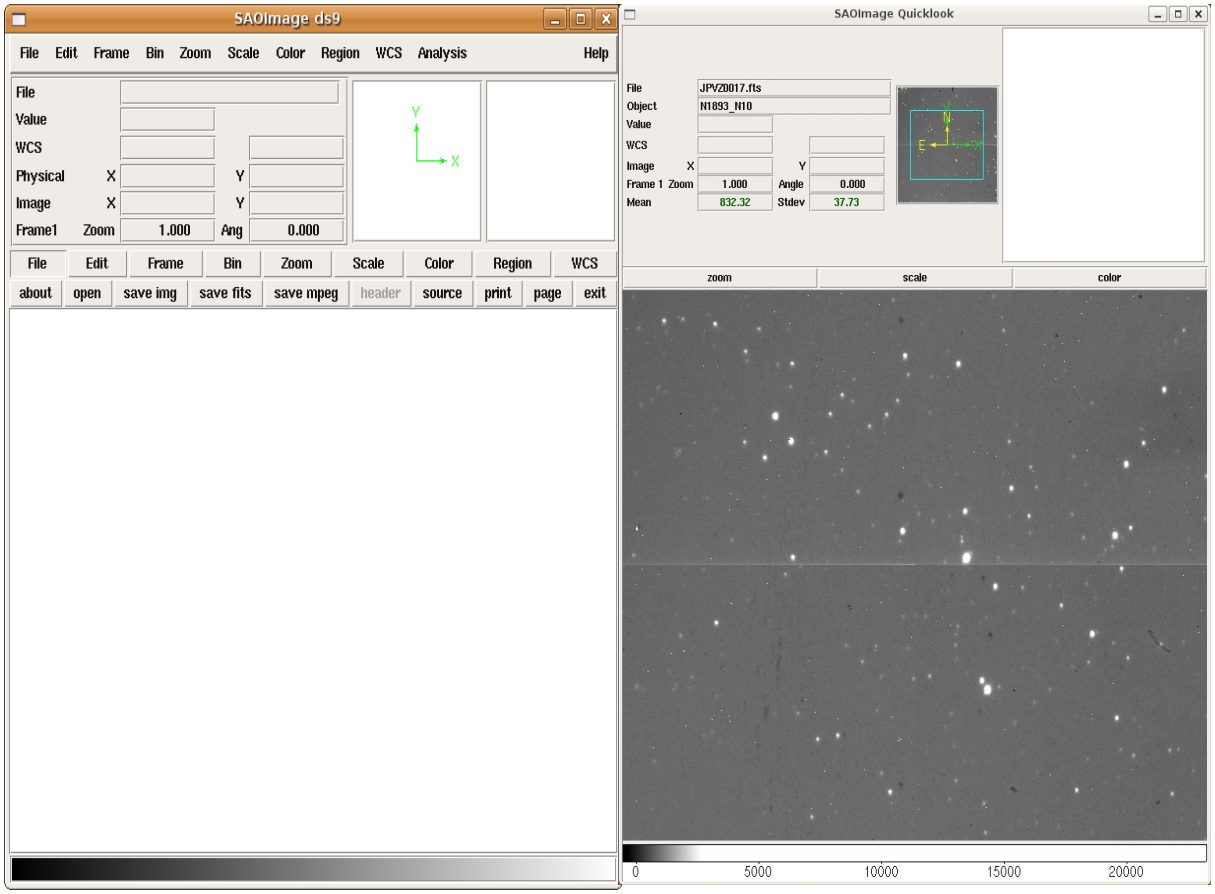


Figure 14 – Standard Ds9 (on the left side) and modified Ds9 (on the right side).

The magnifier has been enlarged to double the standard size and finally, only few buttons have been leaved available.

The new Ds9 version for the GUI shows as default a cross-talk corrected image.

The cross-talk is an interference due to a spurious coupling between the electronic channels which simultaneously read the 4 sections of the array. Every saturated object detected in a given quadrant produces negative ghost images in the other 3 ones (*see Figure 15*).
The green circles put in evidence the ghosts due to the cross-talk

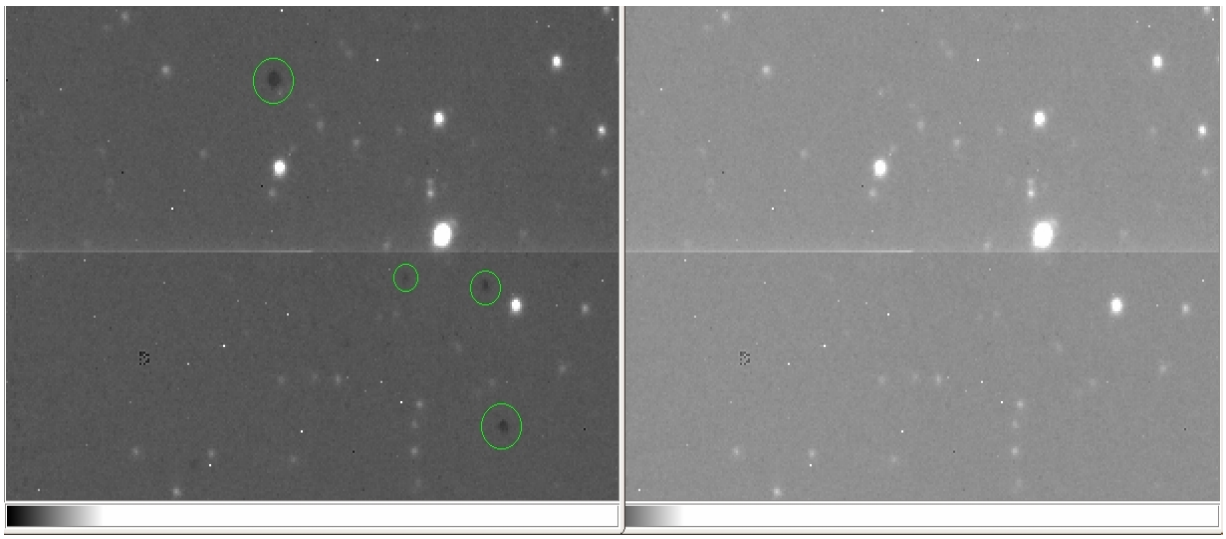


Figure 15 - Comparison between a non crosstalk corrected image (on the left) and a crosstalk corrected image (on the right).

In the GUI this effect is compensated via software using a specific FORTRAN script "*crt_nics*".
As shown in *Figure 16*, the Quicklook and pre-reduction window is divided into three main blocks:

- Move object in the field
- Center object on slit
- The pre-reduction tools

The procedure "*Move object in field*" and "*Center object on slit*" are very useful to automatically put an object into the center of a selected slit or to move an object into a specific position of the array, chosen by the astronomer. These procedures are described more in details in the *paragraphs 5.3.1* and *5.3.2*.

The "Tools" procedure (*see paragraph 5.3.3* for more details) contains a large number of useful tools which allow the astronomers to retrieve important informations on the objects and simplify the finding procedure.

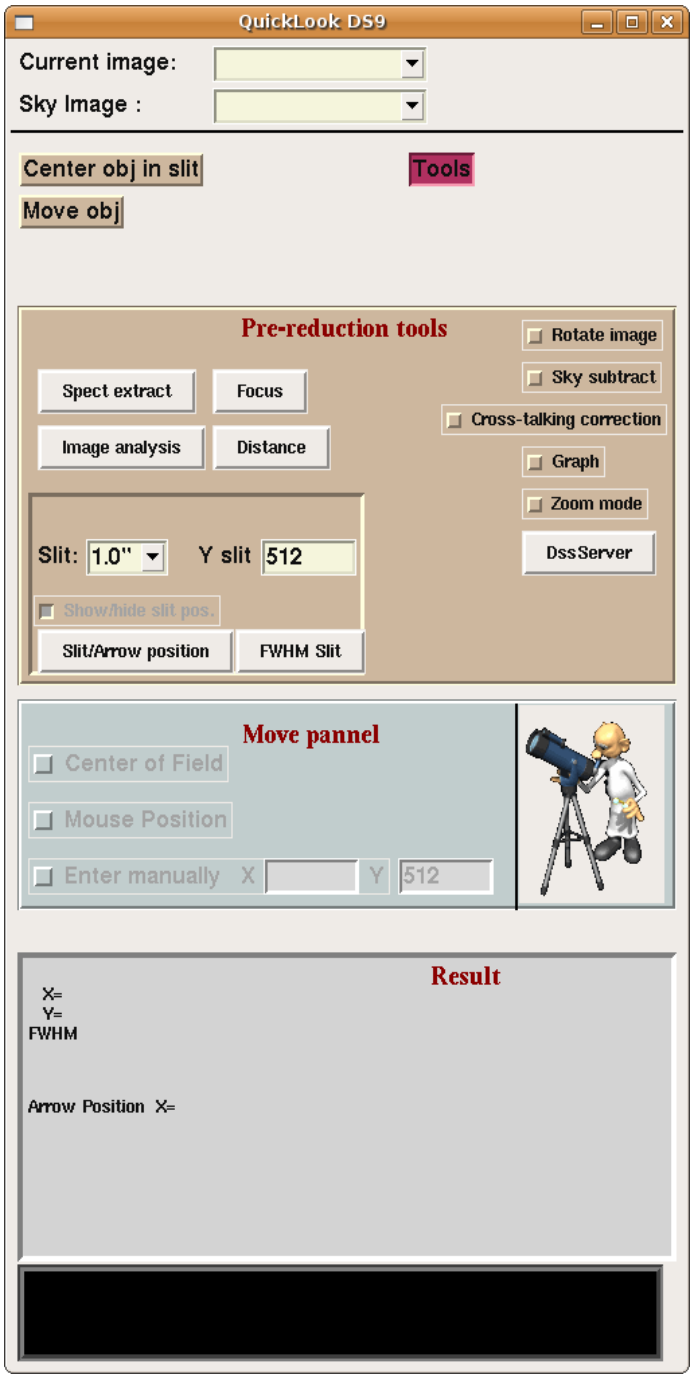


Figure 16 – The Quicklook and pre-reduction window.

In the follow the tools available on the GUI:

- ***Rotate image:*** This is a tools which allows user to rotate the images and provides a suitable tools for the object seeking.

- ***Sky subtract:*** Allows the subtraction between the images selected in the combobox[12] "Current image" and "Sky image". Default subtraction is made between the last two images taken, but the user can choose different images.

- ***Cross-talking corrections:*** Allows the correction for the crosstalk. The default is ON but for test or maintenance it is possible to switch OFF the correction and see the original image.

- ***Graph:*** Shows a plot of a horizontal and a vertical cut of the region of the image centered into the mouse position.

- ***Zoom mode:*** Allows the user to zoom IN or OUT simply clicking into the image

- ***DSS server*** *(Digital Sky Survey server)*[13]*:* Displays an image retrieved from DSS server, at the current coordinates of the telescope position angles after a radiation corresponding to the target position angle.

- ***Image/Spectrum analysis:*** Shows the most important informations of the selected object: coordinates of the centroid, value of the ellipticity, Flux, FWHM, etc...

- ***Focus:*** Automatically calculates the correction for the M2 mirror to optimize the focus.

- ***Distance:*** Calculates the distance in arcsecond between two objects.

Every tools which needs the object selection like the "Image analysis", "Center object on slit" or "Move object in field" uses SExtractor to automatically recognize the objects present in the field and allowing to choose one of those. A layout of the Sextractor procedure is shown in *Figure 17*.

12 http://en.wikipedia.org/wiki/Combo_box
13 http://archive.eso.org/dss/dss

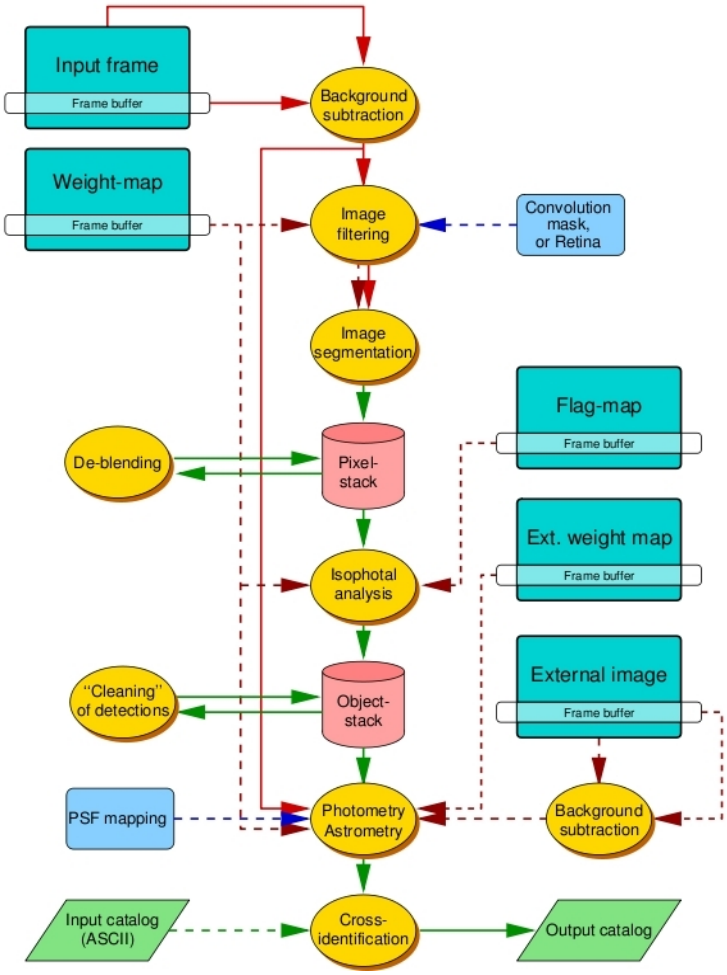


Figure 17- Layout of the main SExtractor procedures. Dashed arrows represent optional inputs.

Usually SExtractor is oriented towards reduction of large scale galaxy-survey data, but it also can work on moderately crowded star fields. Its main features are:

- Support for multi-extension FITS
- Speed: typically 1 Mpixel/s with a 2GHz processor.
- Ability to work with very large images (up to 65k × 65k pixels on 32 bit machines, or 2G × 2G pixels on 64 bit machines), thanks to buffered image access.
- Robust deblending of overlapping extended objects.
- Real-time filtering of images to improve detectability.
- Neural-Network-based star/galaxy classifier.
- Flexible catalog output of desired parameters only.
- Pixel-to-pixel photometry in dual-image mode.
- Handling of weight-maps and flag-maps.
- Optimum handling of images with variable S/N.
- Special mode for photographic scans.
- XML VOTable-compliant catalog output.

The purpose of *SExtractor* is to find a compromise between refinement in both detection, photometry of the objects, and computational speed.

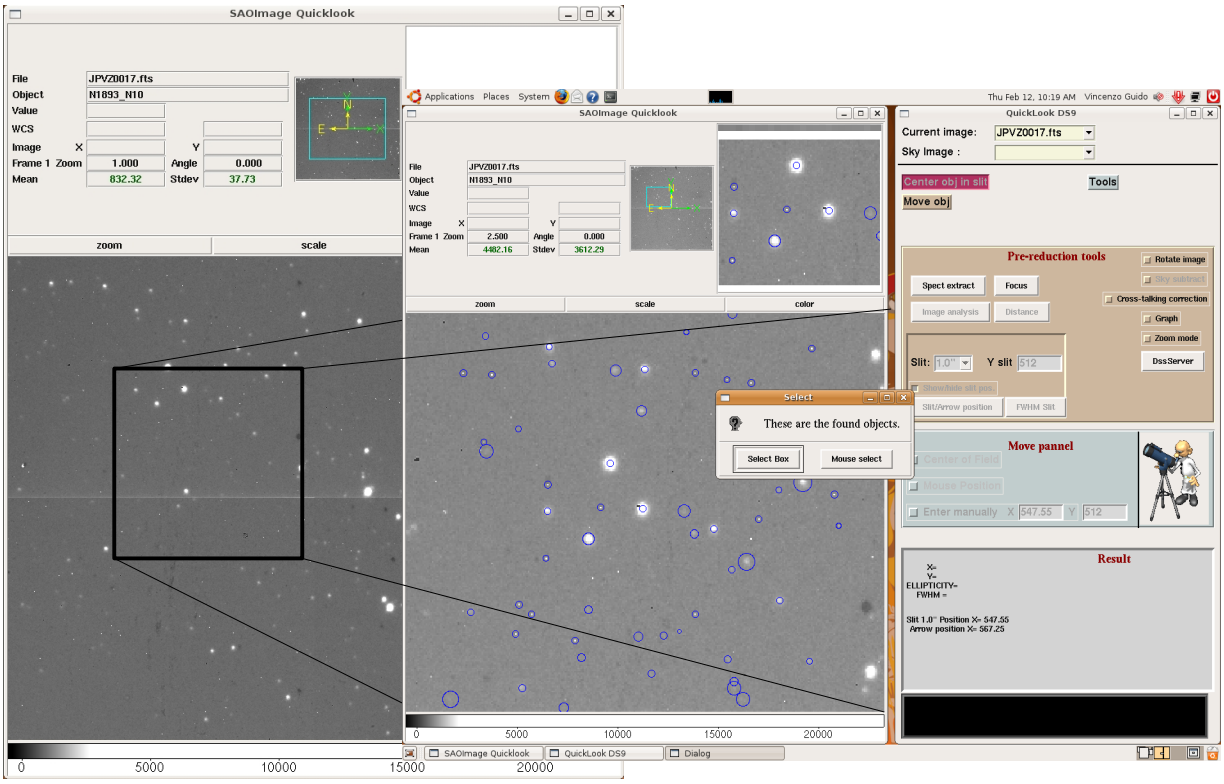


Figure 18 – Stars selection procedure: blue circles in the zoomed portion of the image are the objects found by the procedure using SExtractor.

The star selection procedure works as follow: the interface automatically zooms the portion of the image centered on the click of mouse while *SExtractor* routine analyzes the image finding the objects as shown in *Figure 18*.

The blue circles evidence the objects found by the procedures: the dimension of the circles are adaptive. It change with the FWHM of the objects to minimize the overlap problems due to objects very close. Then the user can select a given object simply clicking into the blue circle corresponding to the target.

A red cross shows the selected object; than the user can decide if changes the object or continues in the analysis on the selected one.

If the object is not recognize by *SExtractor* the user can decide to manually select it. In this case information like FWHM, ellipticity, flux etc. is not available.

5.3.1 Moving an object in the field

The "*Moving an object in the field*" procedure (*see Figure 19*) is executed as follows:

- The interface verifies that the current observing mode is IMA or IMAPOL and takes an image with the current DIT, NDIT combination.
- The user selects an object on the display. The interface determines the centroids x_c, y_c of the object using SExtractor. If SExtractor does not properly work (e.g. error in fitting, center values outside the box), the interface takes the mouse position as the object position.

- The user selects/defines the position to which the object should be moved. For example: center of field, mouse position, X-Y coordinates entered manually.

- The program computes the distortion-corrected distance in pixels, ΔX and ΔY, from the target position and transforms them in α, δ offsets:

$$dAR(i) = Scale \cdot \left[-\Delta X \cos(\theta p) + \Delta Y \sin(\theta p) \right]$$
$$dDEC(i) = Scale \cdot \left[\Delta X \sin(\theta p) + \Delta Y \cos(\theta p) \right]$$

  where θ_p is the position angle and *Scale* is the pixel scale in arcsec/pix (*see Chapter 5.1.3* for details). The *Scale* parameter is stored in the configuration file *overall_config.nics*.

- The interface transmits the offsets to the telescope and waits for telescope settling

- The interface acquires a new frame, displays it and asks if the user wants to repeat the centering procedure. If not, it exits from the procedure.

Into the *Ds9* are shown the current object position (red cross), the final object position the user choiseand the distance between the two positions in arcsecond. A pop-up informs the user about the values of the offset and permits the user to decide if it is necessary move again the telescope or not.
Note that the LF images are affected by pin-cushion distortion which amounts to ≈ 1 % and ≈ 3 % at the array edges and corners, respectively. Any measurement of pixel coordinates must then be corrected for this effect using the following algorithm.

Let x and y be the measured pixel coordinates (x,y= {1:1024}).
Let R_{obs} be the normalized distance from the frame center:

$$R_{obs} = \sqrt{(x-512)^2 + (y-512)^2} \Big/ 512$$

The distortion-corrected pixel coordinates X,Y are given by:

$$X = x * \left(1 - 0.0055 \cdot Robs^2 - 0.0072 \cdot Robs^4 + 0.0021 \cdot Robs^6\right)$$

$$Y = y * \left(1 - 0.0055 \cdot Robs^2 - 0.0072 \cdot Robs^4 + 0.0021 \cdot Robs^6\right)$$

The SF images are not affected by distortion, i.e. X=x and Y=y;

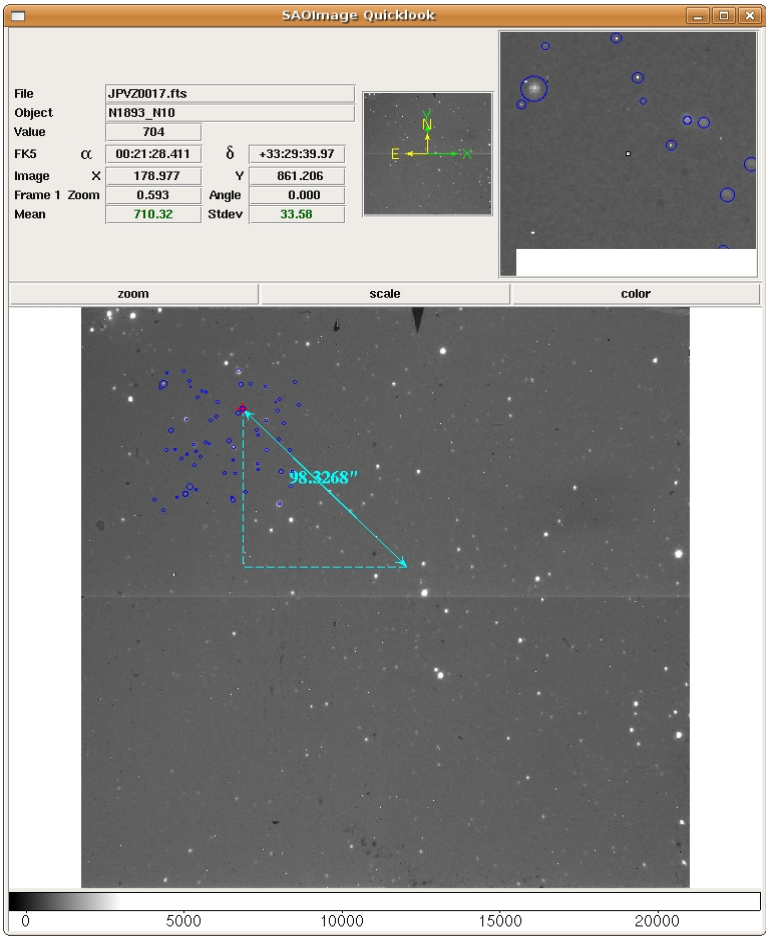


Figure 19 - Move procedure as an example of the moving object in the field procedure.

5.3.2 Centering the object in the slit

Due to mechanical inflections, the image of the slit on the array may move by a few pixels depending on the angle of the derotator where NICS is mounted. To guarantee that the object is properly centered in the slit the interface can take advantage of a small arrow inserted at the top-center of the mask for LF imaging.

This arrow is clearly visible as a shadow in all LF frames taken with broad-band filters and typical integration times.

This slit-centering procedure (*see Figure 20*) is executed as follows:

1. The interface verifies that the current observing mode is "IMA" with objective "LF" and takes an image with the current DIT, NDIT combination. The image is displayed on the screen and ready for the typical image processing options (e.g. subtract another image, divide by flat).
2. The interface selects a small area of the frame around the arrow position, from x=500--590 and y=990--1024, verifies if the arrow is visible and determines x_a, its central position along the x axis. In case the arrow in not visible the program exits with an error message which includes some wise suggestions.

3. The user selects the slit among the list in the configuration file (the default is the previous slit used) and the y_t position at which the object must be positioned (default is y_t=560). The X-target position, x_t, is derived from the fitted arrow central position, x_a, as follows:

$$x_t = x_a + \text{SLIT\_DX}$$

   where SLIT_DX depends on the selected slit and is tabulated in the configuration file *overall_config.nic*s.

4. The user selects the object with the mouse on the image display and defines if a centering algorithm should be performed (default is "*yes"*). An option for exiting from the procedure is also available.

5. If the centering is requested, the interface determines the centroids X_c , Y_c of the object using a suitable centering algorithm. If the algorithm does not properly work (e.g. error in fitting, center values outside the box), the interface issues an error message and return to step 4. If no centering algorithm is requested, the parameters X_c , Y_c are set equal to the mouse position.

6. The program computes the distortion-corrected distance in pixels, ΔX and ΔY, from the target position and transforms them in α , δ offsets:

$$dAR(i) = Scale \cdot \left[-\Delta X \cos(\theta p) + \Delta Y \sin(\theta p) \right]$$
$$dDEC(i) = Scale \cdot \left[\Delta X \sin(\theta p) + \Delta Y \cos(\theta p) \right]$$

   where θ_p is the position angle and *Scale* is the pixel scale (arcsec/pix) correspondent to the LF objective (0.25"/pix).

7. The interface offsets the telescope by the computed amounts and waits for telescope settling.

8. The interface acquires a new frame, displays it and asks if the user wants to repeat the centering procedure. If not, it exits from the procedure.

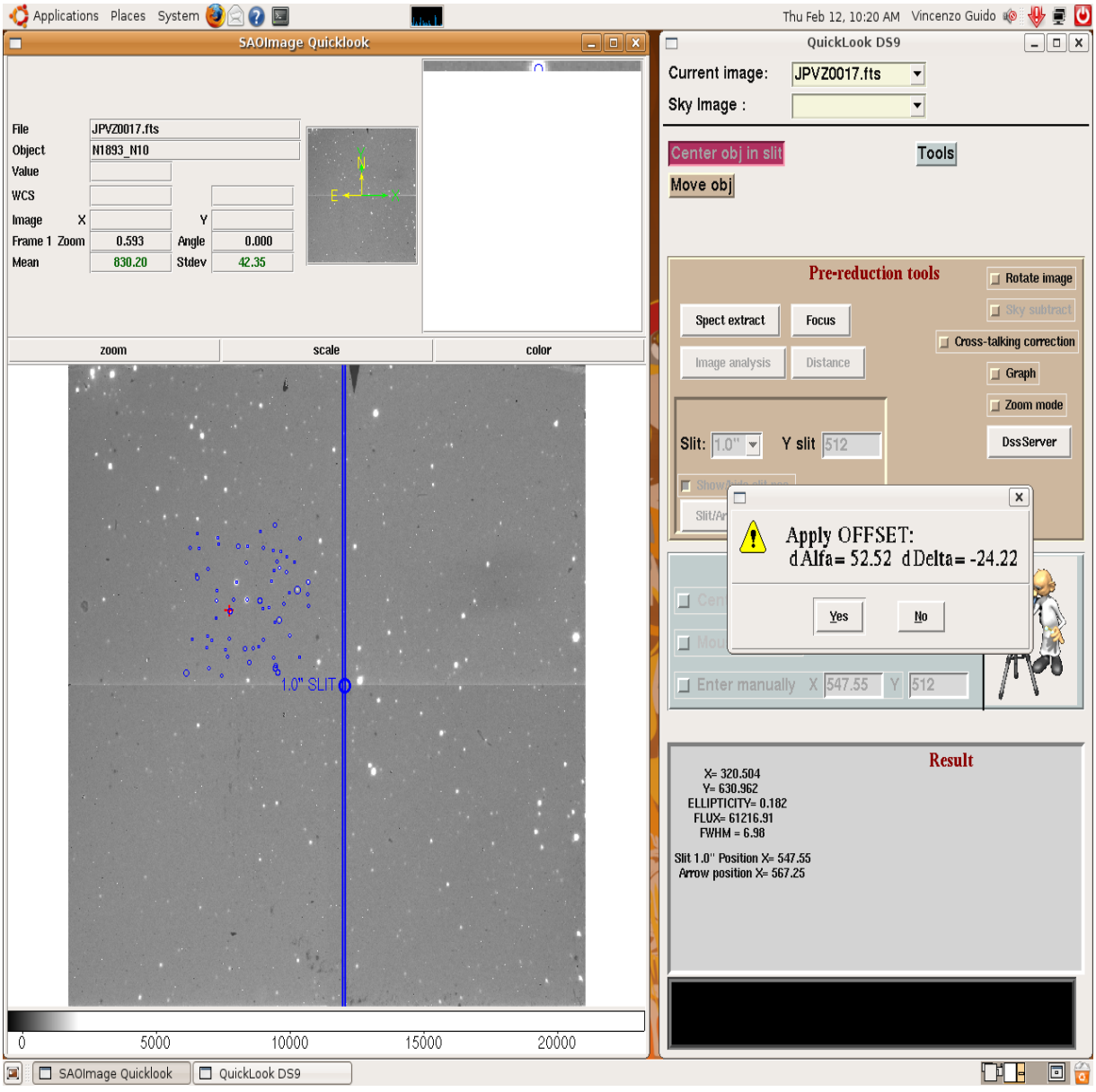


Figure 20 – Example of the "Center object on slit" procedure.

5.3.3 Tools for observations

One of the most important tools for observation is the ***Focus procedure*** (*see Figure 21*).

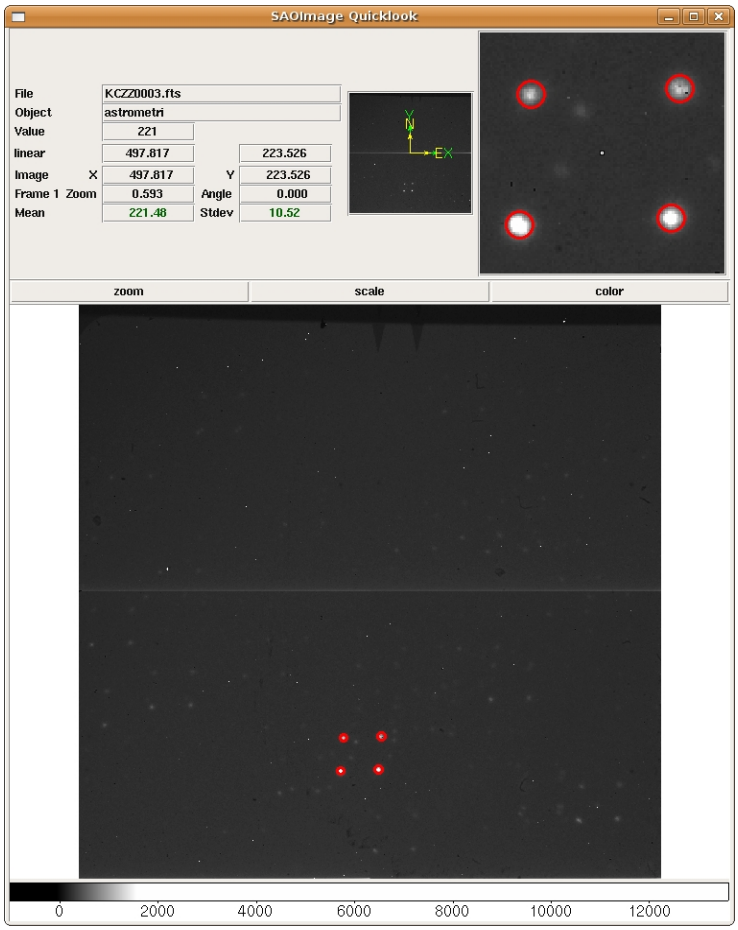
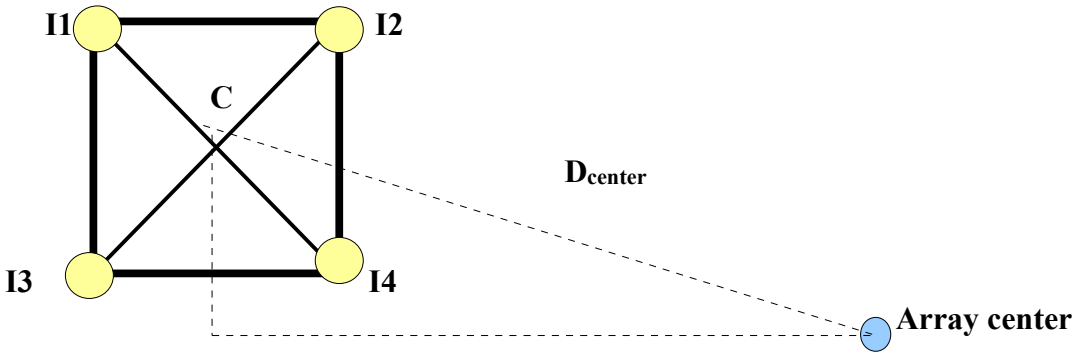


Figure 21 – Focus procedure: useful to calculate the correction to send to M2 mirror for optimizing the focus of the telescope.

The focus is performed acquiring an image using a focus pyramid on the light beam.
The pyramid splits the image in four different beams (I1, I2, I3, I4) as shown in the following:



The focus procedure calculates the distance of the center ***C*** from the center of the array (*512,512*) where X_n , Y_n are the center of every beams (I_n):

$$X_{mead} = -512 + (\sum_{i=1}^{4} X_n)/4$$

$$Y_{mead} = -512 + (\sum_{j=1}^{4} Y_n)/4$$

$$D_{center} = \sqrt{(X_{mead})^2 + (Y_{mead})^2}$$

than, calculates the distance of each of the four centroid (I_n) from the center C:

$$I_n C = (\sum_{n=1}^{4} \sqrt{(\left|(X_c - X_{mean})^2\right| + \left|(Y_c - Y_{mean})^2\right|)})$$

and the mean of I_n distance normalized at 1:

$$I_{(Nmean)} = (\sum_{n=1}^{4} I_n C)/4 \qquad\qquad D_{norm} = D_{center}/512$$

the D_{norm} is used to calculate the correction (Z_{corr}) to send to the M2 mirror for adjusting the focus :

$$Ratio = (1 - 0.0066 * 2 * D_{norm}) - (0.0076 * 4 * (D_{norm})^3) + (0.0016 * 6 * (D_{norm})^5)$$

$$Z_{corr} = (I_{(Nmean)} - (45.1/Ratio))/28$$

The ***image analysis*** procedure (*see Figure 22*) allows users to retrieve important informations on the selected object in image mode. When the object is selected *SExtractor* analyzes the image and the results are shown into a popup window.

The user can then retrieve informations as: the centroid coordinates, the ellipticity, the flux and the *FWHM* of the object. Moreover a 3D graph automatically pops up to make easier to have a look on the object characteristics. For the 3D graph the interface includes a really powerful software: *Gnuplot*.

Gnuplot[14] is a portable command-line driven interactive data and function plotting utility for *UNIX, IBM OS/2, MS Windows, DOS, Macintosh, VMS, Atari* and many other

14 http://www.gnuplot.info/

platforms. *Gnuplot* supports many types of plots in either 2D and 3D. It can draw lines, points, boxes, contours, vector fields, surfaces, and various associated texts. It also supports various specialized plot types and many different types of output: interactive screen terminals (with mouse and hotkey functionality), direct output to pen plotters or modern printers, and output to many file formats (*eps, fig, jpeg, LaTeX, metafont, pbm, pdf, png, postscript, svg*, ...).

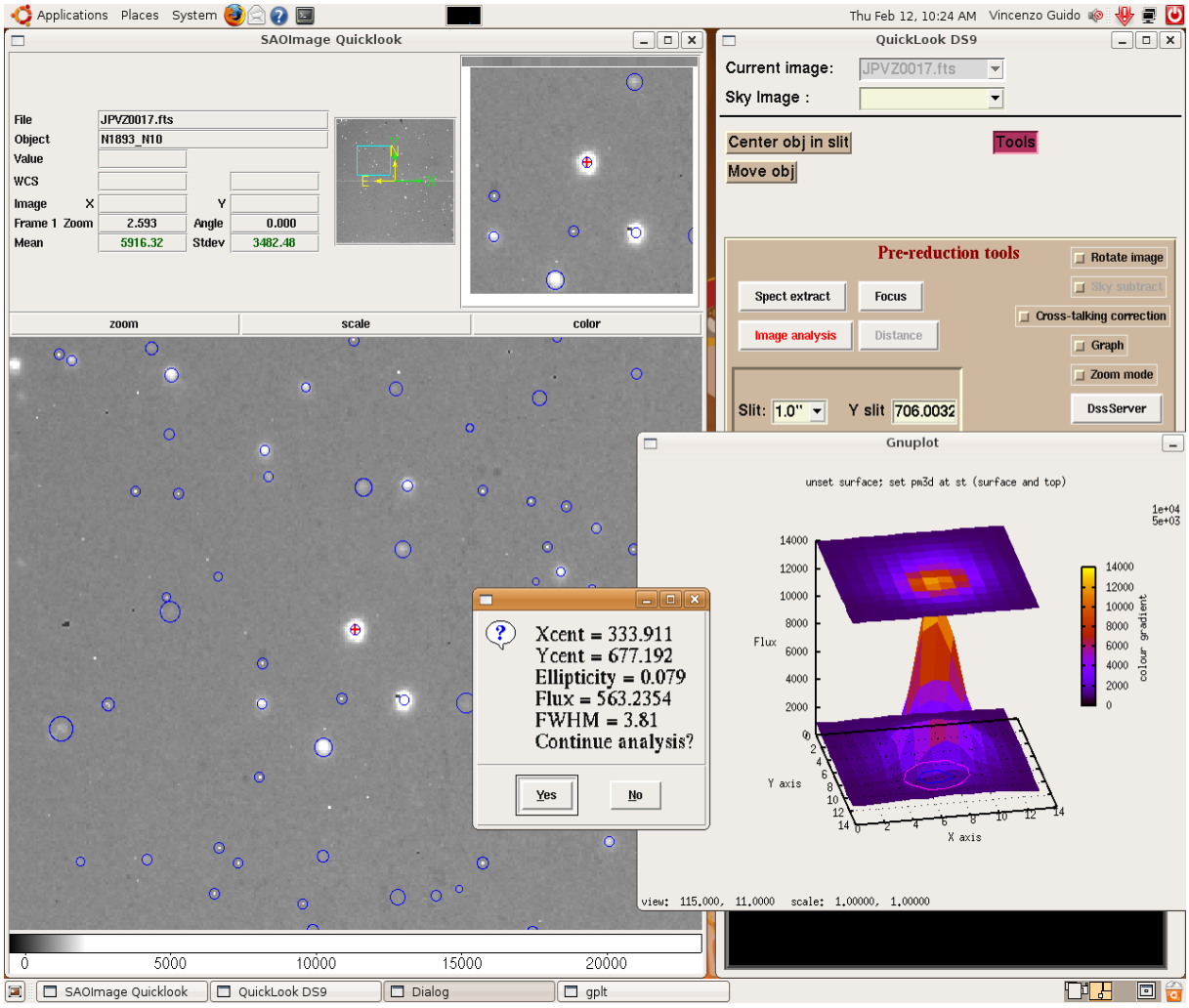


Figure 22 – "Object analysis" procedure: allows user to know the most important parameters of the selected object and shows a 3D graph of it.

For the ***spectrum analysis*** the interface implements the *Eclipse*[15] software. The "Spectrum extraction" procedure asks to the user to select, with a click of the mouse, an upper and a lower limit containing the spectrum and the position of the spectrum into the array. These values are sent to the Eclipse software which extracts the spectrum and shows the graph into a *Gnuplot* window.

Eclipse is a library offering numerous services related to astronomical image processing: FITS data access, various image and cube loading methods, binary image handling

15 www.eso.org/shi/data-processing/*software/eclipse/eug/eug/eug.ps.gz*

and filtering (including convolution and morphological filters), 2-D cross-correlation, connected components, cube and image arithmetic, dead pixel detection and correction, object detection, data extraction, flat-fielding with robust fit, image generation, statistics, photometry, image-space resampling, image combination, and cube stacking.

It also contains support for mathematical tools like random number generation, FFT, curve fitting, matrices, fast median computation, and point-pattern matching. The main feature of this library is its ability to handle large amounts of input data (up to 2GB in the current version) regardless of the amount of memory and swap available on the local machine. Another feature is the very high speed allowed by optimized C, making it an ideal base tool for programming efficient number-crunching applications.

The user only have to select, by the click of mouse, the position of the spectrum, than the upper and lower limits. Once the limits are set the "*extract_spec*" command of eclipse is invoked and the Gnuplot is called to print out a first look at the spectrum (*see Figure 23*).

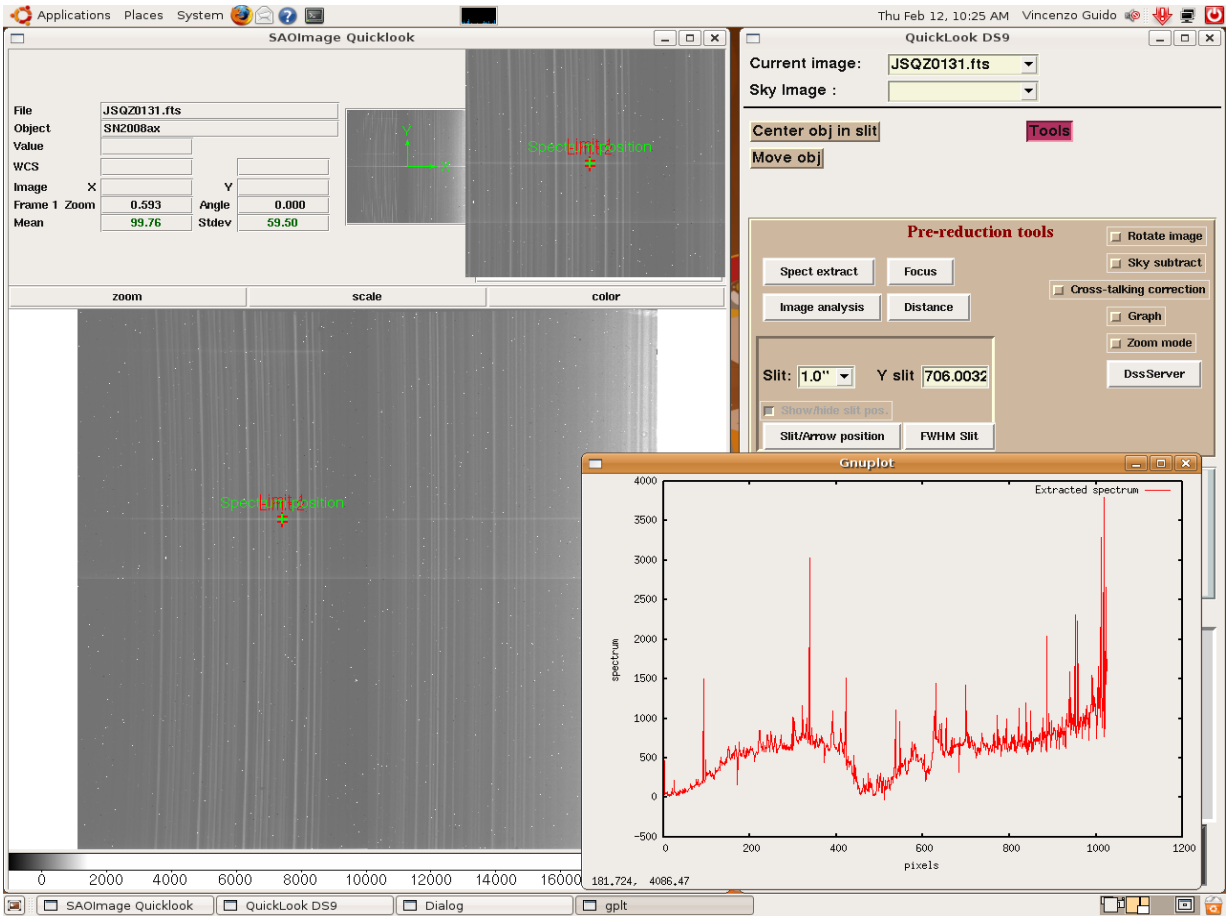


Figure 23 - "Spectrum extraction" procedure allows user to have a first look on the spectrum.

Chapter 6

Protocols and devices communication

A protocol is a convention or standard that controls or enables the connection, communication, and transfer between two computing endpoints. The term "protocol" is very generic and is used for hundreds of different communications methods. A protocol may define the packet structure of the data transmitted or the control commands that manage the session, or both.

In its simplest form, a protocol can be defined as the rules governing the syntax, semantics, and synchronization of communication. Protocols may be implemented by hardware, software, or a combination of the two. At the lowest level, a protocol defines the behavior of a hardware connection.

It is difficult to generalize about protocols because they vary so greatly in purpose and sophistication. Most protocols specify one or more of the following properties:

- Detection of the underlying physical connection (wired or wireless), or the existence of the other endpoint or node
- Handshaking
- Negotiation of various connection characteristics
- How to start and end a message
- How to format a message
- What to do with corrupted or improperly formatted messages (error correction)
- How to detect unexpected loss of the connection, and what to do next
- Termination of the session and or connection.

Computers have no way of learning protocols, so network engineers have written rules for communication that must be strictly followed for successful host-to-host communication.

6.1 FASTI-NBRIDGE

The acquisition controller device is managed by a dedicated *PC* named *PC104* in which runs a control software called *server104*.
The *server104* manages the acquisition system settings and acts like an interface for the array. These tasks are executed under the total control of the low-level software (*Nbridge*) running on the *Pc-embed* (*Fasti*).

The *Nbridge* application interacts also with the high-level software (NICS GUI) which allows the users to manage NICS and starts the acquisitions.
We can image *Nbridge* as a "bridge" between the high-level software (NICS GUI) and the middleware-level software as the array control software. Through *Nbridge* pass all the commands, messages and errors to/from the NICS GUI and server104 applications.

The communications between NICS GUI and *Nbridge* takes place by a socket. This socket can be a local socket (socket *UNIX*) or an Internet socket. The protocol used is structured in packages as suggested by the standard protocols used in Internet. These communication packages have a standard format: they are composed by an header formed by 8 words of 16 bits each and followed by 1400 bytes, as maximum length, of data field. The structure of the header is described as follows:

Word	***Description***	***Value examples***
1	*Magic-number*	*0xA50F*
2	*Destination*	*NICS GUI, Fasti*
3	*Type*	*command/data/message/ack ..*
4	*Command*	*DUMMYREAD, RUN, ...*
5	*Data length*	*form 0 to 1400*
6	*Restricted*	
7	*Package number*	*form 1 to 65535*
8	*Checksum*	*from 0 to 65535*

1. ***Magic-number***. This value contains a start package mask. It's composed by a pattern of characteristic bits (10100101 00001111) making easier the protocol synchronization. It accepts only the 0xA50F value.

2. ***Destination***. Contains the pointer to the destination process for the package.

Description	***Value***
server104	*0x1001*
nbridge	*0x1004*

3. ***Type***. Contains informations about the package type. CMD if is a command, ACK if is a receiving check, etc.

Description	***Value***
COMMAND	*0x0010*
MESSAGE	*0x0020*
ACK	*0x0006*
ERROR	*0xFF00*

4. ***Command***. Contains the real operation. For example if the package type is CMD contains the effective command, if the package is MSG contains the priority level etc.

The values of the commands has been subdivided as follow:

- sequence generator commands from 0x0100 to 0x01ff
- integration parameter commands from 0x0200 to 0x02ff
- acquisition commands from 0x0300 to 0x03ff
- state commands and debug from 0x0400 to 0x04ff

The defined command at a time are:

Name	***Value***	***Comment***
LOADWAVE	*0x0109*	*Select a wave form*
DOUBLE	*0x0202*	*Single or double acquisition*
QUADRANTS	*0x0203*	*Number of quadrants to use*
ONDISK	*0x0204*	*Enable/disable write on disk*
STOP	*0x0302*	*Stop the acquisition*
ABORT	*0x0303*	*Abort the acquisition*
INTEGRA	*0x0304*	*Start the integration*
FREERUN	*0x0305*	*Free-run*
SOCKDS9	*0x0306*	*Set the socket name for Ds9*
REINIT	*0x0310*	*Reinitialize*
STATUS	*0x0400*	*Show the variable status*
READLOG	*0x0410*	*Print a log*
KILLTERM	*0x0445*	*Close connection socket*

5. ***Data length***. Contains the value of the data length. Due to efficiency reasons this value can't exceed 1400.

6. ***Reserved.*** This value is reserved for future expansion.

7. ***Number of package***. Contains the value of the number package. It is used by the ACK package.

8. ***Checksum***. Controls mask for the package integrity. Calculates as the 16 bits sum of value from 1 to 7 of the header.

The communication protocol includes the possibility of a ACK received check. Every CMD packages sent from the GUI to the *server104* or to the *Nbridge* will be confirmed by the receiving process with a ACK type package built as follows:

Position in header	***Sent package***	***ACK package***
1	*0xA50F*	*0xA50F*
2	*0x1001*	*0x1003*
3	*0x0010 (COMMAND)*	*0x0006 (ACK)*
4	*0x0400 (STATUS)*	*0x0400 (STATUS)*
5	*0*	---
6	---	---
7	*11*	*11*
8	*Checksum*	*Checksum*

6.2 LANTRONIX

The Lantronix[16] ETS8p is a Multiport Device Servers that provides shared network access to terminals, devices, console ports, and printers for a variety of network protocols and operating systems. The ETS supports the TCP/IP, IPX (NetWare), Local Area Transport (LAT), AppleTalk (EtherTalk), and Microsoft LAN Manager protocols.

This device is used to communicate and manage the OEM Compumotor devices, calibration lamps and pressure/temperature devices. *Figure 24* shows a connection scheme between Pc Fasti and the other devices using a Lantronix ETS8P.
The management of all NICS sensors and controls of the mechanical movements are a crucial point that must be handled by dedicated functions called Instrument Status (IS).

The more practical solution to build IS block is to use a socket transmission protocol between the PC and the related hardware controller. In case of serial controllers it is possible to use a "serial-Ethernet" transceiver like e.g. the commercial Lantronix multi-port devices. Each

16 http://www.lantronix.com/

IS input/output command is driven and addressed to a specific IP number.

The spectrometer is equipped with 5 sensors positioned throughout the cryostat to monitor the temporal and spatial variation of the temperature during the instrument cooling/warming processes and during normal operations. These are commercial temperature sensors and controllers (Lakeshore 330 and Balzers DualGauge) which communicate directly with the PC-control system using their dedicated serial protocol. These serial communications are re-routed on the Ethernet by a commercial terminal server (Lantronix ETS8P).

The temperature and pressure monitor program (IS) reads every few seconds the temperatures of all sensors inside the cryostat and the dewar pressures and sent the values immediately to the TNG database by the ICS.

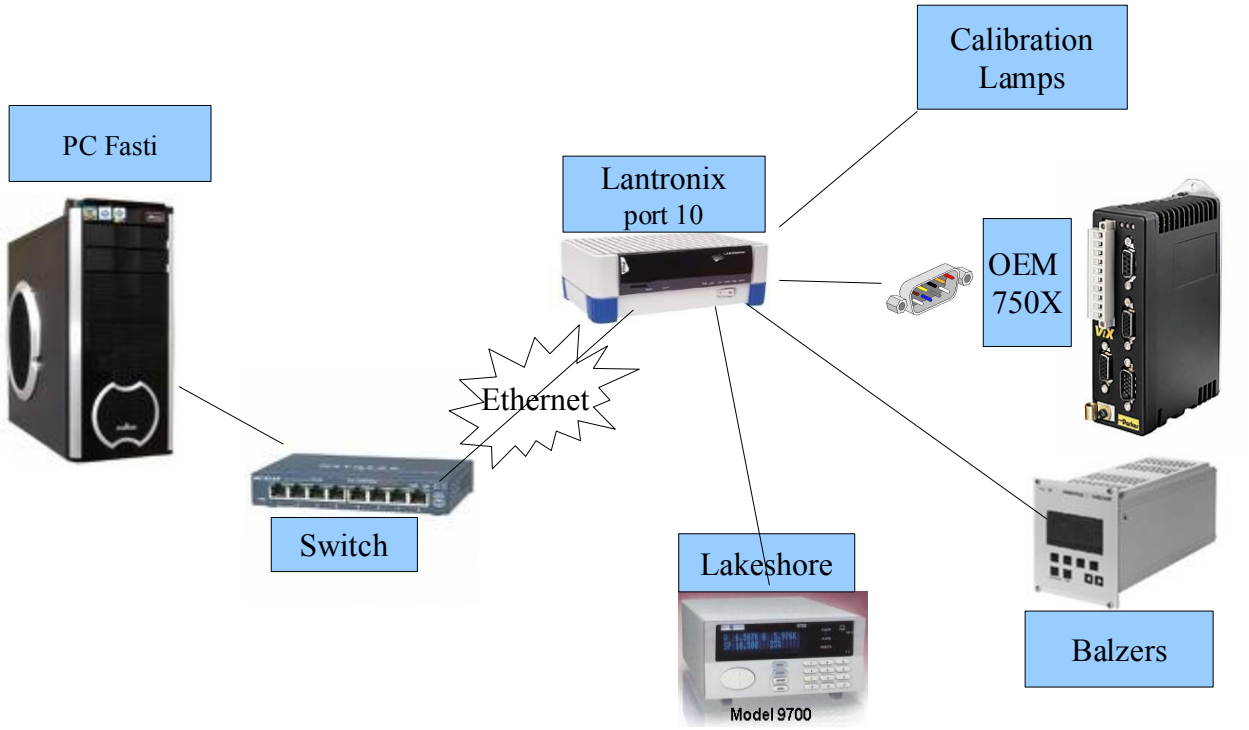


Figure 24 – Schematic connection between Fasti pc and NICS devices.

6.2.1 Troubleshot in communication with the Lantronix device

During the motors communication tests at the telescope, some different kinds of errors occured. The communication between the Compumotor OEM300 and Lantronix was affected by overlap in reply packages and by hexadecimal values incoming.

Since the first test the appearance of various kind of different and casual errors in communication between the two devices leaded to a very frequent interface crash. A specific and depth study acts to solve these problems was started analyzing, first of all, the software procedure that, delays time in receive/send communication packages and the socket parameters.

There are two typical and correct answers depending by the motors:

<---------- head ----------> <----------- res------------->
1) "valid input"<CR><LF>"valid answer"<CR><LF> (for the motors M1,M4,M5,M6,M7)

2) "valid input"<CR>"*valid answer"<CR><LF><LF> (for the motors M2 and M3)
<----------------- string ------------------>

After some tests I have subdivided the class of errors in tree main groups:

1. ***Wrong command:*** the received command was not the sent command. In the example the sent command was 7IS (request status for the motor number 7) but the OEM device received 7IW (this command does not exist)

16/03/07 12:06:12
SENT: 7IS
06:12 6 bytes
received:
7IW<CR><LF><LF>

Reply ERROR: 7IW
7IS

2. ***Answer overlapping:*** frequently the OEM sent the answer packages with a considerable delay producing the following kind of errors.

28/03/07 17:51:39 SENT: 7IS
51:39 18 bytes received:
7IS<CR><LF>11111111118<CR><LF>
11111111118
28/03/07 17:51:39 Input Status info:
motor 8 OK
28/03/07 17:51:39 SENT: 7R
28/03/07 17:51:40 SENT: 7IS
28/03/07 17:51:40 SENT: 7R
51:40 19 bytes received
7R<CR><LF>S<CR><LF>7IS<CR><LF><LF>7R<CR><
LF><LF><CR>S7IS7R

3. ***Hexadecimal values:*** the packages was frequently affected by some control character as : ^M, ^Z, ^L, ^O, ^E, ^H, ^N (corresponding to *Carriage return*, *Substitute*, *Formfeed, Shift in, Enquiry, Backspace* and *Shift out*).

Finally, the solution of the overlap packages were found in some Lantronix port settings:

```
ETS8P Version V3.6/4(000712)        Uptime:              0:41:35
  Hardware Addr: 00-xx-xx-xx-xx-xx     Name/Nodenum:     ETS_66AABE/ 0
  Ident String: ETS Terminal Server

LAT  Circuit Timer (msec):      80        Password Limit:          3
       Inactive Timer (min):    30        Console Port:            1
      Queue Limit:              32        Retrans Limit:           25
      Keepalive Timer (sec):    30        Session Limit:           4
     Multicast Timer (sec):     30        Node/Host Limits:        50/(none)

     TCP/IP Address:      161.xx.xx.xxx    Subnet Mask:          255.255.255.0
     Nameserver:           161.xx.xx.xx    Backup Nameserver: xxx.xx.xx.xxx
     TCP/IP Gateway:      161.xx.xx.x      Backup Gateway:       (undefined)
     Domain Name:         tng.iac.es       IP Time:              Daytime
                                           TCP Keepalives:       Enabled
     DHCP Server:         161.72.52.38     Lease Time:           0:08:51

  Serial Delay (msec):       30           Network Buffering:    2048
  Prompt:            Local_%n%P>
  Groups: 0

  Characteristics:  Announce  Broadcast  Lock
 Incoming logins: LAN Telnet (No password Required)
```

The settings responsible in answer overlaps are evidenced in red color; the ***IP time*** allows Lantronix to send a request package to the server for the date and time updated, the ***Lease Time*** allows Lantronix to update, every specific time, the IP address when the DHCP protocol is enabled. The overlap in answer occured when the Lantronix was busy for this kind of communications. Disabling the ***lease time*** and setting static IP for the Lantronix the overlap packages problems are solved.

The problem of the hexadecimal values was due to a wrong pin connection cable. Initially I used a serial cable for the Lantronix/OEM communication. This allowed to communicate with Lantronix but not in the best way.

The Lantronix output is provided by a RJ45 cable and the input of OEM is provided by a DB9 connector. An ad hoc connector has been created to ensure a good communication between these two devices as schematized in *Figure 25*:

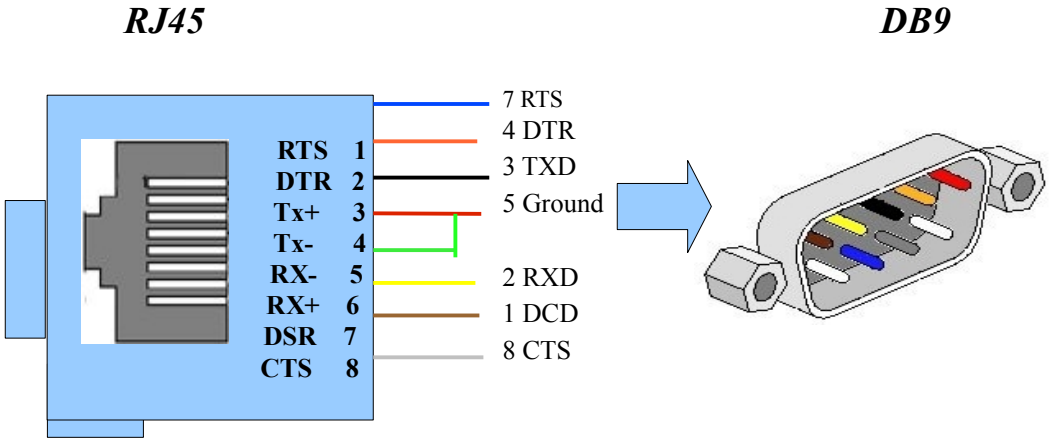


Figure 25 – Pin out of special connector used for connecting the Lantronix to the motors controller.

6.3 OEM300 Compumotor

The Compumotor OEM300 (Original Equipment Manufacturer) is an high performance motion control modules.
It is composed by a OEM Series Drivers and a Power Module and Motors. The devices connection is described in *Figure 26*.

The OEM300 (PM) Power Module provide power to Compumotor's OEM Series of microstepping drivers and servo. It contains a dual range power supply which can operate at 120VAC or 240VAC, at 50/60 Hz.

The voltage output of the OEM300 is fixed at 75VDC. It can produce 2.7A continuous and 4.0A peak, and provides power for drivers and motors.
The OEM PM is a compact device. It occupies the space of two OEM drivers, and mounts similarly to the drivers. Its small footprint conserves space in equipment cabinets.

Several circuits in the OEM300 automatically provide protection for the PM and the equipment it powers:

- OVER-TEMPERATURE. The PM monitors the temperature of its heat plate, and will automatically shut down if the heat plate temperature exceeds 60°C.
- SHORT CIRCUIT PROTECTION. The PM monitors current going to the drive, and will shut down its output if it detects a short circuit in the drive.
- INTERNAL POWER DUMP. The PM has an internal power dump circuit which can dissipate excess energy during load regeneration conditions.
- OVERVOLTAGE. The PM will shut down if there is excessive voltage at its output terminals.

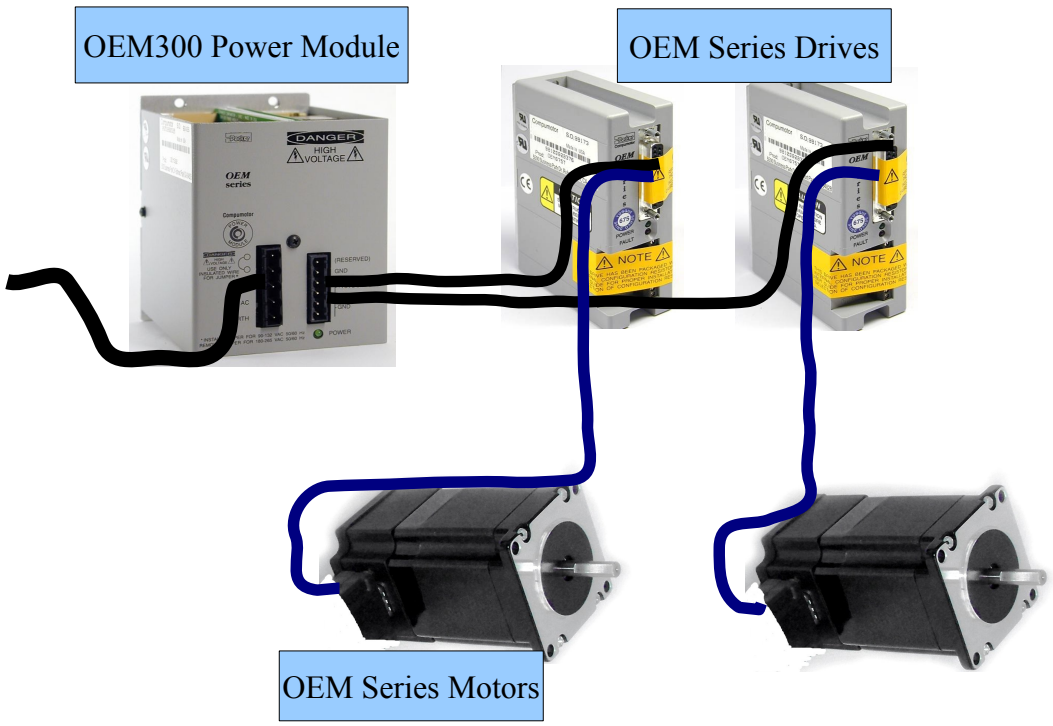


Figure 26 – Internal OEM connection.

6.4 LAKESHORE & BALZERS (Temperature & Pressure monitor devices)

The temperature and pressure are measured by the Lakeshore and Balzers controllers. The *Lakeshore Model 330* is a microcontroller-based Autotunning temperature controller. This model accommodates three of the most common cryogenic temperature sensors with the flip of a switch. These are field selectable, without calibration. Isolated excitation currents allow true four-lead measurement of the sensors signals. High resolution A/D converters digitalize the signal at both inputs simultaneously for use in thermometry, control and autotuning.

Precision thermometry is the most basic building block of any digital controller and is necessary for stable, accurate control. Careful analog design and ground isolation provide the Model 330 with stable and repeatable measurement.

Software in the Model 330 compares the measured value of the control sensor to the desired control setpoint and acts with the three term (PID) control function to minimize the difference. Control parameters can be entered manually or by the autotuning algorithm.

Up to 50 watts of heater power is available to control a variety of cryogenic cooling systems. The power output of the Model 330 is a quiet, variable DC current to ensure as little noise coupling as possible between the heater and experiment. Two lower heater ranges allow for a variety of cooling systems.

The Model 330 allows up to ten user defined temperature zones to be entered over the interface. The setpoint ramp, settable from 0.1 to 99.9 K/min, allows the user to set the rate at which the setpoint increases or decreases when changed. IEEE-488 and serial interface

provide remote access to data and stored parameters in the Model 330 and allow setting of most front panel functions.

The Pfeiffer Balzer DualGauge TPG 262 is a dual-channel measurement and control unit for compact gauges. It is allowed to measure pressure from 1.000 mbar up to $5*10^{-9}$ mbar. These two devices are connected to the Lantronix ETS8P device with a standard serial connection RS232C and send to the archive ORACLE the T/P status every few seconds.

6.5 WSS-BRIDGE (middleware-level software for the telescope tracking)

WSS Bridge (*see Figure 27*) is a software solution that provides a bridge between the outside world and the WSS Telescope Control System. The principle is very simple: there is a server process which provides two connection pools, one for the outside processes and another one for the different native Ancillary Processes (AP); in essence, it works like a switch.
The BRG (or BGE) ancillary process accepts commands, settings, and telemetry calls from the outside via socket from the remote bridge server.

It accepts 3 WSS Command: START, STOP, EXIT. The START command opens a socket connection to the WSS-bridge server, while the STOP command closes the socket.
The EXIT command is called internally by WSS once the system is shutting down.

Once the connection to the WSS-bridge server is active, the AP will check every second if data arrive through the socket. If something has arrived it will be parsed and the appropriate WSS function will be called.

It accepts 3 type of actions, getting telemetry, setting telemetry and sending commands; 2 kinds of command are available, one waits for completion and the other one returns without waiting.
If any problem happens with the socket, an alarm will be shown on the screen where the AP is executing; at the same time, if there's sent any actions that doesn't exist inside the WSS system, an alarm window will be shown.

The AP is written in C99, so it works under the HP-UX workstation; the logging information will be shown on the standard output and on a log file.

The WSS Bridge Server is a daemon process. The WSS Bridge Server is an Event Driven Multitasking Server running some Components. It has 2 Connection Pools components, and a logging component.
One connection pool listen on the port *9000*. This is the port the outside clients connect to, in order to talk with the WSS Telescope Control System. The other port, *9001* is the port used by the native AP from WSS.

The WSS Bridge Server uses a configuration file in order to know which AP should perform the requested action from an outside client. This also permits to have a setup where one AP is responsible for executing actions for different units, so you get an easy mechanism for load balancing.

The logging facilities also uses a separate configuration file, so that you don't need to change the main configuration to add for example a new logging dispatcher.
The WSS Bridge Server uses a simple mechanism to know to which outside client belongs an action. It attachs the client unique ID to the message sent to the BRG AP, then the BRG AP uses this ID only to compose the response message which then will be parsed again by the WSS Bridge Server to send the response coming from the BRG AP back to the correct client.
The WSS Bridge Server parses all the messages going through so that it checks if a message coming from an outside client is malformed, before sending it to a BRG AP.

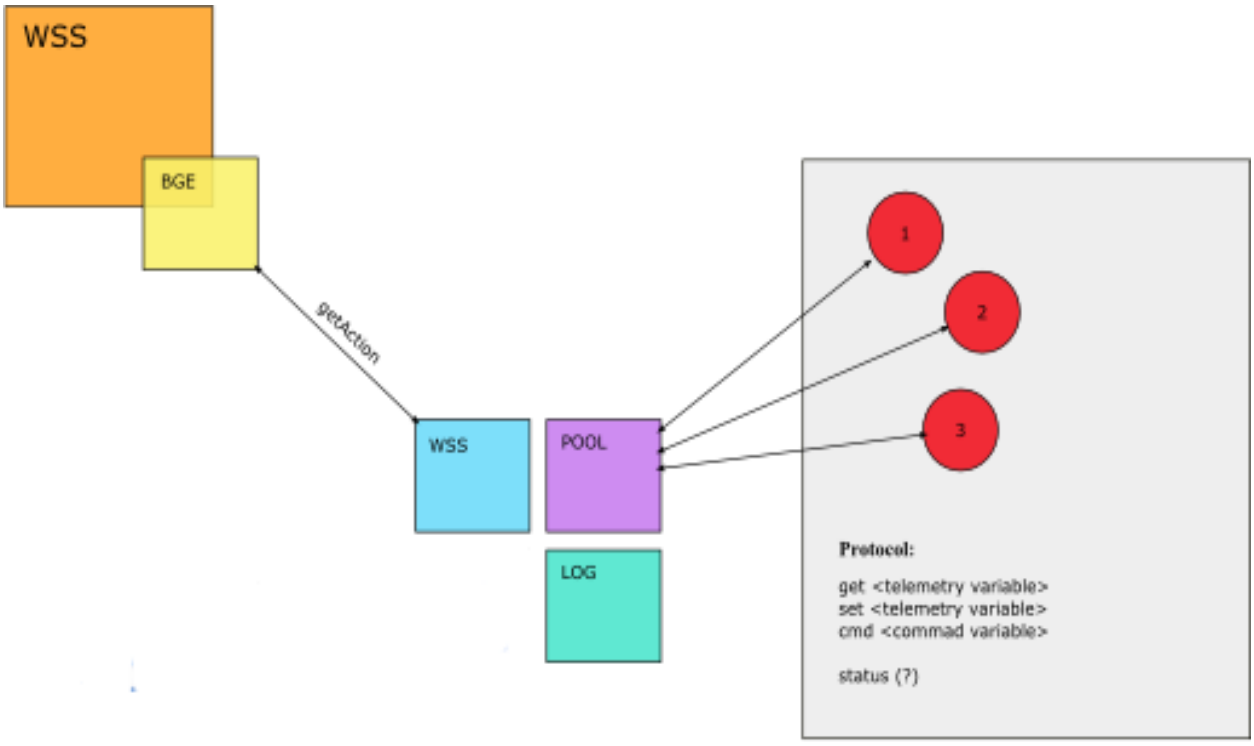


Figure 27 - Schematic representation of WSS-bridge/Tracking connection.

6.6 ORACLE (instruments variables archive)

An Oracle database[17] is a collection of data treated as a unit. The purpose of a database is to store and retrieve related information. A database server is the key for solving the problems of information management. In general, a server reliably manages a large amount of data in a multiuser environment, so that, many users can concurrently access the same data. All this is accomplished while delivering high performance. A database server also prevents unauthorized access and provides efficient solutions for failure recovery.

Oracle Database is the first database designed for enterprise grid computing, the most flexible and cost effective way to manage information and applications. Enterprise grid computing creates large pools of industry-standard, modular storage and servers. With this architecture, each new system can be rapidly provisioned from the pool of components. There is no need for peak workloads, because capacity can be easily added or reallocated from the

17 http://www.oracle.com/lang/it/database/index.html

resource pools as needed.

The database has logical structures and physical structures. Because the physical and logical structures are separate, the physical storage of data can be managed without affecting the access to logical storage structures.

One of the most powerful tools to communicate with ORACLE is the SQL[18] language.

SQL means **Structured Query Language.** That is a database computer language designed for the retrieval and management of data in relational database management systems (RDBMS), database schema creation and modification, and database object access control management.

SQL is a standard interactive and programming language for querying and modifying data and managing databases. Although SQL is both an ANSI and an ISO standard, many database products support SQL with proprietary extensions to the standard language. The core of SQL is formed by a command language that allows the retrieval, insertion, updating, and deletion of data, and performing management and administrative functions. SQL also includes a Call Level Interface (SQL/CLI) for accessing and managing data and databases remotely.

The strengths of SQL provide benefits for all types of users, including application programmers, database administrators, managers, and end users. Technically speaking, SQL is a data sub-language. The purpose of SQL is to provide an interface to a relational database such as Oracle Database, and all SQL statements are instructions to the database. In this SQL differs from general-purpose programming languages like C and BASIC. Among the features of SQL are the following:

- It processes sets of data as groups rather than as individual units.
- It provides automatic navigation to the data.
- It uses statements that are complex and powerful individually, and that therefore stand alone. Flow-control statements are commonly known as "persistent stored modules" (PSM), and the PL/SQL extension to Oracle SQL is similar to PSM.

SQL lets you work with data at the logical level. You need to be concerned with the implementation details only when you want to manipulate the data. For example, to retrieve a set of rows from a table, you define a condition used to filter the rows. All rows satisfying the condition are retrieved in a single step and can be passed as a unit to the user, to another SQL statement, or to an application. You need not deal with the rows one by one, nor do you have to worry about how they are physically stored or retrieved. All SQL statements use the optimizer, a part of Oracle Database that determines the most efficient means of accessing the specified data. Oracle also provides techniques that you can use to make the optimizer perform its job better.

18 www.sql.org

SQL provides statements for a variety of tasks, including:

- Querying data
- Inserting, updating, and deleting rows in a table
- Creating, replacing, altering, and dropping objects
- Controlling access to the database and its objects
- Guaranteeing database consistency and integrity

SQL unifies all of the preceding tasks in one consistent language.

In the ORACLE database, the telemetry variables of all TNG instruments are stored. Using the SQL standard language to communicate with the ORACLE, the most important telemetry variables are retrieved by the interface, allowing the user to exactly know the telescope position; moreover the temperature and pressure variable are updated every 3 seconds allowing a complete monitoring of NICS status.

An example of SQL code acts to retrieve the temperature and pressure from ORACLE is shown below:

```
select variable_name name,
        to_char( to_date('19700101','YYYYMMDD') + data/86400, 'YYYY-MM-DD
HH24:MI:SS')
        data, num_value value
    from current_telemetry
        inner join hashtable using (id)
where id between 150 and 154
order by id asc
```

Chapter 7

Notify NICS status via SMS for instrument responsible

To simplify the instrument responsibles life and avoid troubleshoots due to anomalous level of pressure and temperature, an additional facilities for NICS has been implemented. The *NICS Status Monitor (NicSM)* is a useful utility which constantly and regularly watchs the instruments status and reports the problems sending an immediate notification to the responsibles by sending email and an SMS[19].

An example of the typical *Status Email* structure is:

Subject: NICS Report Status – GOOD -

Body:

```
#NICS HEALT REPORT STATUS                          DELAY
#=================================================
Date.............:          2009-09-17 UPDATE
Time(U.T.).......:          08:50:27
Pressure.........:          7e-07 mbar
Temperature_Array.....:     85.00 °K
Temperature_1.........:     68.86 °K
Temperature_2.........:     64.65 °K
Temperature_3.........:     64.99 °K
#=================================================
Link: Nics Internal Telemetry
```

The *NicSM* is based on a similar connection with ORACLE database, used by the interface, to retrieve the values of the parameters. The software, continuously monitors the

19 http://en.wikipedia.org/wiki/SMS

temperatures and pressures of NICS every 30 minutes, reading them from ORACLE, checking if the values are normal or not and sending via email and SMS the informations regarding the dewar status if the parameters exceed the normal values. If the temperature or pressure reach a particular "warning" values (described in *Table 8*), the "Subject" in the next email changes in:

Subject: NICS Report Status – CHECK ME -

and the color in the body changes from GREEN to YELLOW. In the worst case it changes in:

Subject: NICS Report Status – WARNING !!!

and the value color in the body changes in RED. Moreover, to avoid the reading of obsolete values, due for example to a defective cable/contact or on a sensor malfunction an additional check on date is performed and a warning situation will be produced if the values are oldest than 30 min. The column *DELAY* will report how old is the variable.

The values used for establishing the different kind of emails are:

Value	***Label***
$5*10^{-6} < Pressure < 5*10^{-4}$	***YELLOW***
$Pressure \geq 5*10^{-4}$	***RED***
$95°K < Temperature\,Detector < 8$	***YELLOW***
$Temperature\,Detector \geq 95°K$	***RED***
$100°K < Temperature\,1 < 80°K$	***YELLOW***
$Temperature\,1 \geq 100°K$	***RED***
$100°K < Temperature\,2 < 80°K$	***YELLOW***
$Temperature\,2 \geq 100°K$	***RED***
$100°K < Temperature\,3 < 80°K$	***YELLOW***
$Temperature\,3 \geq 100°K$	***RED***

Table 8 – Ranges of internal pressures and temperatures of NICS.

The web link allows the responsible to connect automatically to the internal TNG web page dedicate to NICS. In that way the responsible can check the dewar graphs and retrieve most accurate informations on the problem.

For increasing the safety, in case of warning status detections, the software sends, in addiction to the warning email, an SMS (Short Message Service) to the responsible trough an SMS gateway.

SMS (*see Appendix C*) is a communication service which is a text message up to 160 characters long, no matter what method is used. Typically used on mobile telephone handsets, utilizing the GSM, it is now available on a wide range of networks, including 3G, and can be used with VOIP systems, and from your desktop computer.

A SMS gateway provider facilitates the SMS traffic between subscribers, acting as the server or network hub for the individual messages, much like a service provider for Internet or websites. The SMS Gateway provides the path so that the SMS messages can be sent directly to and from recipients, avoiding delays and message loss, through optimized routing, and is frequently used for communications.

Due to the total length limitation in number of characters (no more than 160) and the row length limitation (approximatively 40 characters), the SMS must be much more compact than emails but its must include all the informations to the responsibles and must be easy to understand. To create an exhaustive but compact SMS I have studied a structure as described in the following table:

Subject:	*NICS Warning*
Text:	Time 15:14:58 2009-09-16 OK Press GREEN OK ***Tdewar RED NO*** T1 GREEN OK T2 GREEN OK T3 GREEN OK

The labels (GREEN,YELLOW,RED), as in the emails, change in base of the wrong values. The second column shows if the values are updated or not. In the case above, I show an example of the dewar temperature (*Tdewar*) fault and the reasons is that it's obsolete (the second column report a “NO”).

Chapter 8

GUI tests: Atmospheric extinction

Although some astronomical spectroscopy today is done using space-based telescopes, much is still done in ground-based observatories. Ground-based astronomical spectroscopy is plagued by absorption/extinction within the atmosphere. Absorption features that originate in the Earth's atmosphere are referred to as telluric features and are prevalent in the IR and visible regions of the spectrum.

There is significant atmospheric transmission across the entire 1 to 2.5 μm wavelength region, but large sections of it are strongly affected by molecular absorption.

The main absorbers are CO_2 and H_2O with weaker features of CH_4 and O_2 etc (s*ee Figure 27*). These features must be removed from spectra observed with ground-based telescopes to derive the true spectrum of the astronomical source.

The telluric absorption in the NIR varies as a function of air mass and of the time. Ideally, in spectral regions of strong telluric absorption, a standard star and a science target should be observed through identical atmospheric paths at the same time, allowing the atmospheric absorption to be canceled out. In this ideal case, a reference star would be within a few arcseconds of a science target, and placing the spectrograph slit across both objects in a position suitable for beam switching would give the highest observing efficiency and accuracy (Kenworthy Matthew A., 2004).

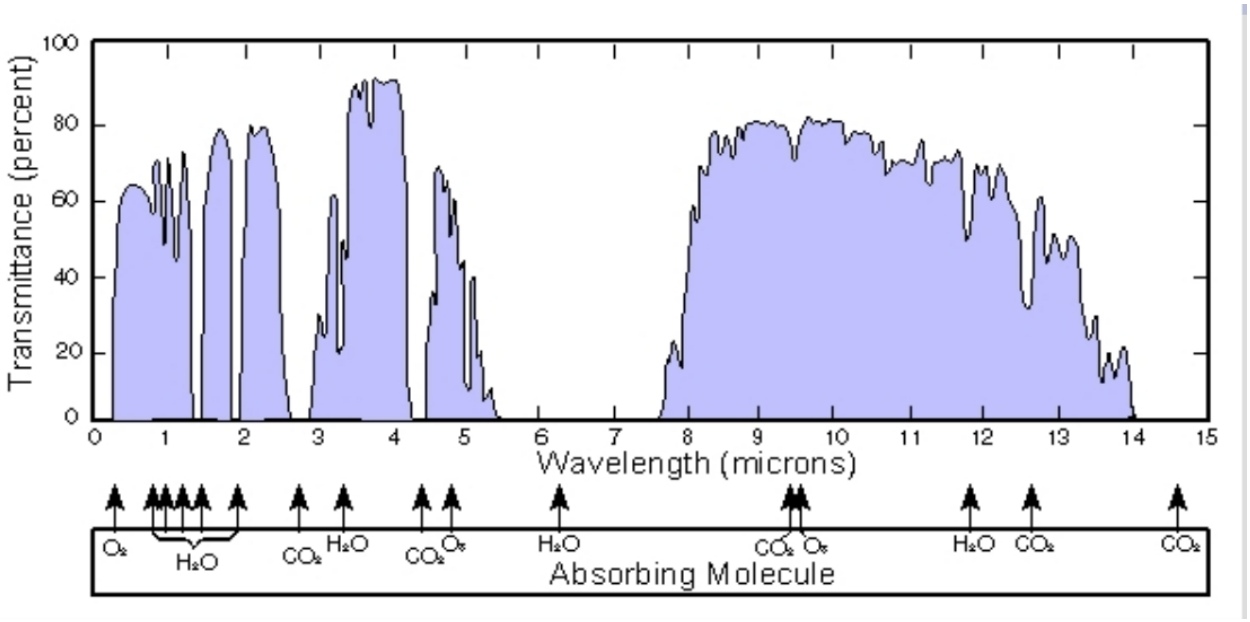


Figure 27 - Atmospheric absorption of electromagnetic radiation.

8.1 Telluric Features

Telluric features are atmospheric absorption lines of the Earth's atmosphere. When an astronomer observes something from the Earth, such as a star, the starlight passes through the atmosphere and these telluric absorption features appear superimposed with the stellar spectrum. Telluric features in the IR region of the spectrum are mainly the result of absorption by ozone (O_3), gaseous oxygen (O_2), and water vapor (H_2O). Other lines include the sodium-D lines and Carbon dioxide (CO_2). Of these lines, H_2O proves the most problematic, varying not only with air mass but with humidity levels within the atmosphere as well. Water vapor lines are also abundant within the IR region of the spectrum. When the spectrum of the object is taken in several different exposures, the telluric features will not be identical in each spectrum.

Atmospheric lines may be modeled by Doppler or Lorentz profiles or with a combination of the two, called a Voigt profile. A Lorentz profile is used to characterize pressure broadening which is caused by collisions between molecules. Pressure broadening is dominant in the lower atmosphere where pressures are high. A Doppler profile is used to model molecular motions in the atmosphere which broaden the lines.

In the upper atmosphere where the pressure is much lower, Doppler broadening becomes dominant, and a Doppler profile is used to model the absorption lines. Most observatories are at high altitudes to avoid looking through so much atmosphere. At these altitudes (20-50 km), a convolution of the Doppler and Lorentz profiles is used:

$$f_{voight}(\nu-\nu_0)=\frac{\alpha_L}{\alpha_D\pi^{3/2}}\int_{-\infty}^{\infty}\frac{1}{(\nu'-\nu_0')^2+\alpha^2}\exp\left[-\left(\frac{\nu-\nu'}{\alpha_D}\right)^2\right]d\nu'$$

where α_D is the Doppler line width defined by:

$$\alpha_D = \frac{\nu_0}{c}(2k_B T/m)^{1/2}$$

where *c* is the speed of light, *k* is the Boltzmann's constant, and *m* is the mass of the molecule.
α_L is the half-width of the Lorentz line shape defined by:

$$\alpha_L(P,T) = \alpha_0 \frac{P}{P_0}\left(\frac{T_0}{T}\right)^n$$

where P is the pressure and T is the temperature.
α_0 is the reference half-width at T_0 = 273 °K, P_0 = 1013 mbar. n = 1/2 for most gases. Line widths are subject to changes due to varying wind speeds, and pressure and temperature changes. The central wavelength of the lines may also shift due to high winds as a result of the Doppler Effect. Water lines are affected by altitude at which the observations are made, air mass related to the secant of the zenith angle, and humidity at the time of the observations. Seasonal variations also occur. All of these things must be taken into account before removal of the lines can take place (Wood E., 2003).

8.2 Observation and telluric standards

By observing from the ground, strong OH sky lines in emissions are also present in the spectra of any astronomical source.

The standard procedure to remove them consists in observing a target along two slit positions (A & B) through an ABBA cycle, as sketched in *Figure 28*.

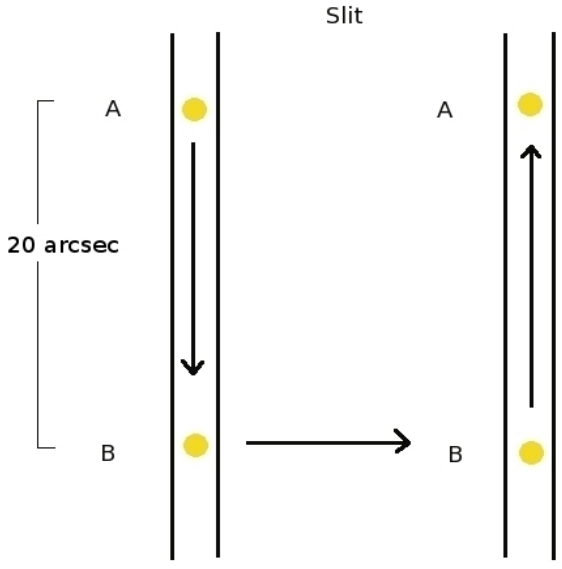


Figure 28 – Examples of a nodding on slit technique using a mosaic ABBA.

The main steps for a spectrum reduction are as follows:

- Crosstalk correction
- A-B and B-A pairs
- Flat fielding
- Spectra co-adding
- 1-D Extraction
- Telluric line correction
- Flux calibration

The first step in data reduction consists in the correction of the spectra for the crosstalk.

Then one computes A-B, B-A pairs and applies a shift to match the median values, in order to properly cancel out the OH sky lines.

In case of no dithering between different A-B, B-A pairs, a 2-D co-adding of the various pairs can be applied and then the final 2-D spectrum will be divided by the flat field.

The coadding spectra is a technique in which the spectra are combined to increase the signal to noise ratio.

In case of dithering, each A-B, B-A pair will be divided by the flat field, then the corresponding 1-D spectra will be extracted and co-added.

Flat fields are obtained by taking many exposures of an halogen lamp switched on and off thus, computing the difference on-off and normalizing the final 2-D frame.

As emphasized at the beginning of this chapter, the most prominent absorption features in the near IR spectra are the telluric features due to the Earth's Atmosphere.

Correction for telluric lines is computed by observing suitable telluric standard stars. Such "telluric standards" are not standards in the classical sense at all; they are simply bright stars of known spectral type for which the intrinsic stellar features are either negligible or easily recognized and separated from features introduced by the Earth's atmosphere.

Normally the telluric lines do not scale linearly with air mass, so it is necessary to observe a star, which we call a telluric standard, at an air mass as close as possible to that of the target and with the same instrumental setup.

The choice of the “best” telluric standard depends on the spectral resolution and on the wavelength regime of interest.

Stars of spectral type O and early B are the most featureless in the near IR (they only show a few HeII and/or HeI lines), but they are also relatively rare and so it may be hard to find at a good air mass match with the target.

The photospheric emission of such hot stars, can be approximated by a blackbody curve. The spectral type of the star and its photometric colors can provide an estimate of its temperature. The blackbody curve is then multiplied into the object spectrum to recover the intrinsic spectral shape of the scientific target.

Early to mid-A and late B dwarfs have primarily hydrogen recombination lines, which are quite strong and highly pressure broadened. However, these lines can be fit and removed in a fairly straight-forward way and techniques and software exist to do this (*Matthew A. et al., 2003*), so these are the spectral types most commonly used. If one is interested specifically in measuring hydrogen lines in the science target, they may not be the best choice.

IN G0V stars, the hydrogen lines are considerably weaker (and many of the weaker lines seen in A dwarfs are essentially negligible); however, lines of Mg, Si, Fe and other elements are strong. Intrinsic lines in G2V spectra can be fit using high-resolution, high signal-to-noise solar spectra. At early-mid F many of the hydrogen lines still are intermediate in strength and width and almost all of the lines of other atomic species are not yet very noticeable. Hence these spectral types may offer a reasonable compromise, particularly at low to moderate resolution.

Later spectral types (late G, K and M) have too many intrinsic features to be generally useful for telluric corrections.

The final step of the spectral reduction is the flux calibration if scientifically relevant.
Flux calibration of spectroscopic data in IR is not trivial since suitable spectrophotometric standards with tabulated spectroscopic fluxes in the wavelength range of interest are still rare and the available compilation have been mainly intended to support space based missions, hence they are not optimized to calibrate ground based data.
Hence, normally the most common procedure to (roughly) flux-calibrate IR spectra is to use the broad band magnitudes of the target. The filter band passes are then convolved with the spectrum to determine the appropriate scaling factor. Alternatively, one can use a standard stars , which is measured through both the 2" slit and the slit used for the science target, to set the absolute scale.

8.3 Spectral analisys

With the twofold goal of testing the new GUI of NICS and studying the atmospheric absorption at the Roque de los Muchachos (La Palma, Canary islands), a number of spectroscopic observations of telluric standard stars have been performed during the TNG engineering time on 22 and 23 March 2009.
For the tests, I chose two O8 telluric standard stars: Hip031567 ($06^h36^m25^s.89$; $06^h04^m59^s.50$ J2000.0, V= 6.87) and Hip031303 ($06^h33^m50^s.96$: $04^h31^m31^s.60$ J2000.0, V= 8.27), observed at different air masses.

The data were acquired using the JH (R~1000), HK (R~1000) grisms and the AMICI prism at very low resolution (R~100), with a 0.5" slit in LF mode (0.25 arcsec/pixel) .

For each star and each instrumental setup a standard ABBA mosaic has been used (i.e. a 4 points mosaic with a separation of 20" between the points as shown in *Figure 28*). Different

exposure times have been adopted for different instrumental configurations, as shown in *Table 9*.

Filter	***Dit (sec.)***	***Ndit***
Amici	*7*	*1*
JH	*40*	*1*
HK	*60*	*1*

Table 9 – Observational exposure times.

Table 10 shows for each stars and each instrumental setup the air mass values for the observations taken during the photometric night 22/03/2009.

Hip031303

JH	1,21	1,7	2,07
HK	1.13	1,35	1,62
AMICI	1,2	1,32	2,12

Hip031567

JH	1,16	1,42	1,92
HK	1,1	1,41	1,83
AMICI	1,1	1.16	1,57

Table 10 – Air mass values for each telluric standard star at the different instrumental setups.

Data reduction has been performed by using IRAF[20] tasks with the support of SAOImage Ds9 for the visualization. The spectra obtained by using the ABBA mosaic have been subtracted (A-B, B-A) and combined using a IRAF macro (*sp_comb*) (Maiolino, private communications), to obtain a mean of all the spectra and to subtract the sky contribution. The spectra have been extracted using the APALL task and thus calibrated in wavelengths.
In particular for the spectra AMICI a lookup table has been used for the wavelength calibration because the AMICI spectra have a too much low resolution for using calibration lamps.
The resulting spectra have been normalized dividing every counts by the mean.

8.3.1 Relative flux versus air mass

In the following I show some results obtained comparing the spectra observed at different air masses.

Figure 29 and *Figure 30* show two AMICI spectra for the standard stars Hip031303 and Hip031567 respectively, taken at different air masses after a normalization at the same flux value, corresponding to a mean of the fluxes in a wavelengths range values around 1.1 m.
As expected, systematic deeper absorption features at higher air masses are observed, together with a decrease of the relative flux. The corresponding observational conditions are shown in *Table 11* and *12*.

20 http://iraf.noao.edu/

Graph	Air mass	Seeing
Yellow	*1,57*	*1.5”*
Black	*2.12*	*1.5”*

Table 11 – Data parameters for the standard Hip031303

Graph	Air mass	Seeing
Red	*1,1*	*1.0”*
Cyan	*1.57*	*1.0”*

Table 12– Data parameters for the standard Hip031567

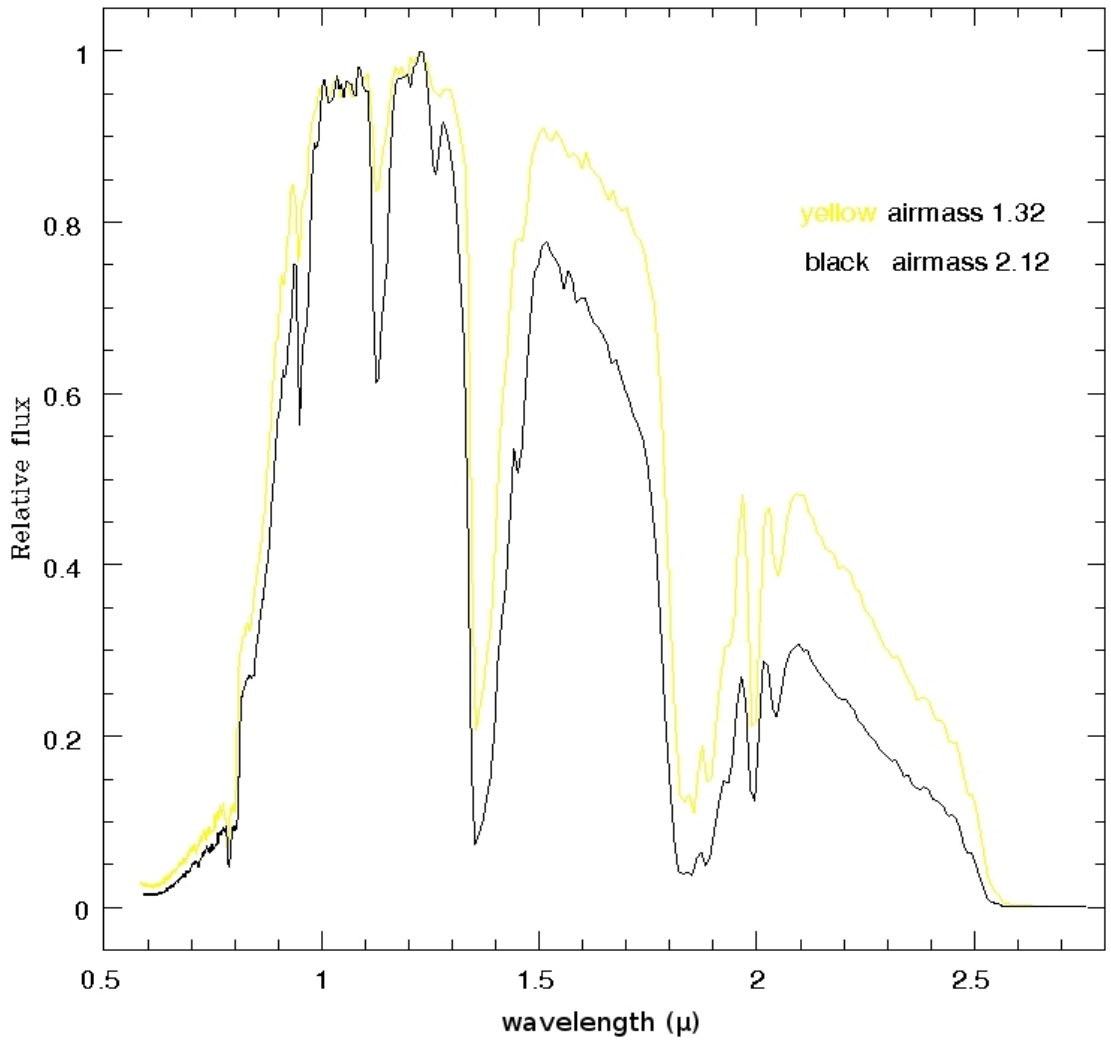


Figure 29 – Comparison of two AMICI spectra taken at different air masses for the star Hip031303.

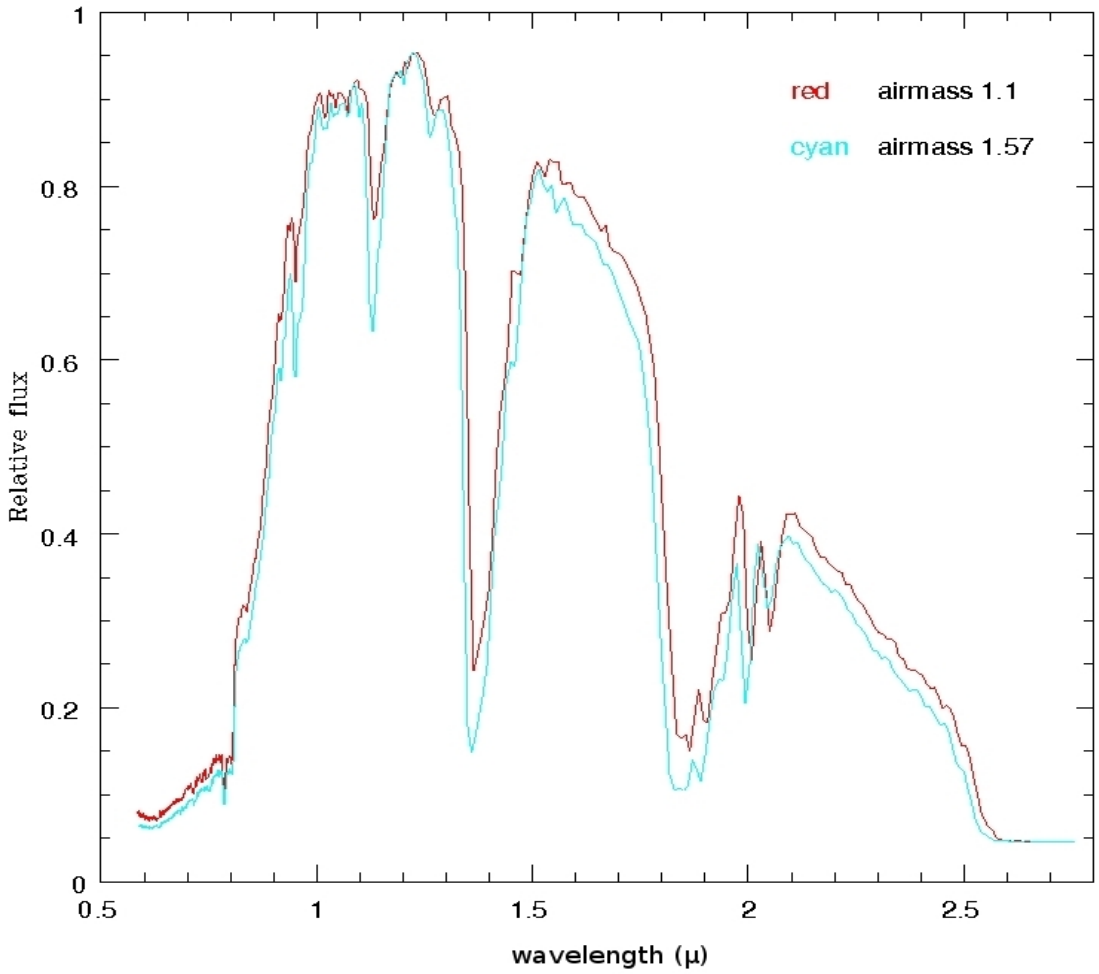


Figure 30 – Comparison of two AMICI spectra taken at different air masses for the star Hip031567.

Figure 31 shows two spectra for the star Hip031303 taken at different air masses with the HK (on the left) and JH grism (on the right). Thanks to the higher spectral resolution of these grisms compared to the AMICI prism (*Figure 29*), the absorption features of CO_2 are somewhat better defined.

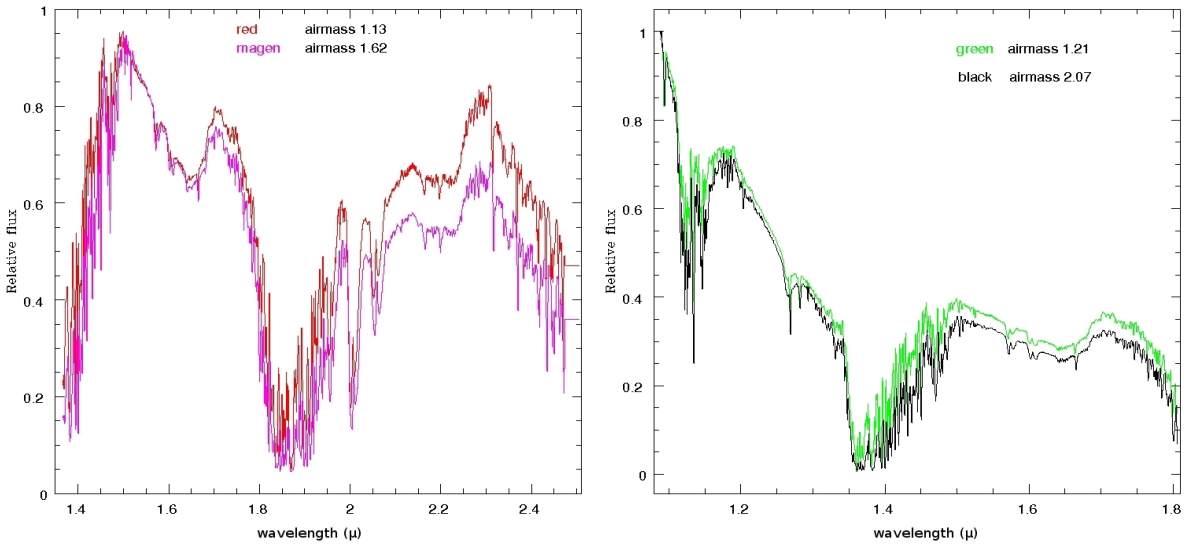


Figure 31 – Comparison of two HK (on the left) and JH spectra (on the right) taken at different air masses for the star Hip031303.

It is interesting to check the effects of the atmospheric extinction with varying the air mass in each of the photometric J ,H ,K bands.

In order to do that, the AMICI spectra at the different air masses of the telluric standard star Hip031303 have been convolved with the J,H,K filter transmission profiles.

Figure 32 shows an example of the results of such computation, while *Figure 33* compares relatives fluxes of four spectra taken at different airmasses and convolved with the J, H, K band profiles.

It was not possible to do the same test for the standard stars Hip031567 due to lack of data.

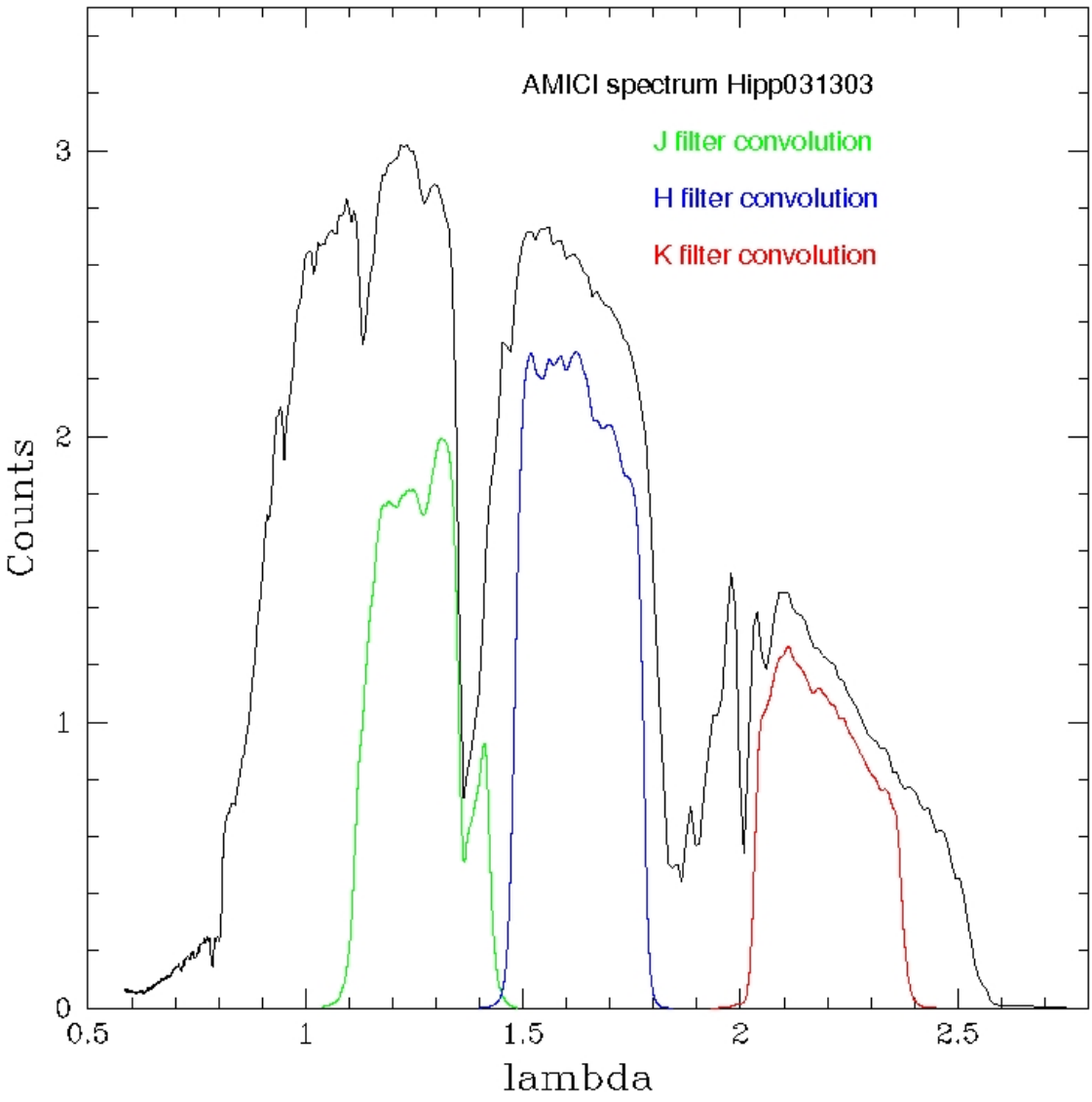


Figure 32 – The observed AMICI spectrum of Hip031303 (black line) and the same spectrum convolved with the J (green line), H (blue line), K (red line) filter profiles.

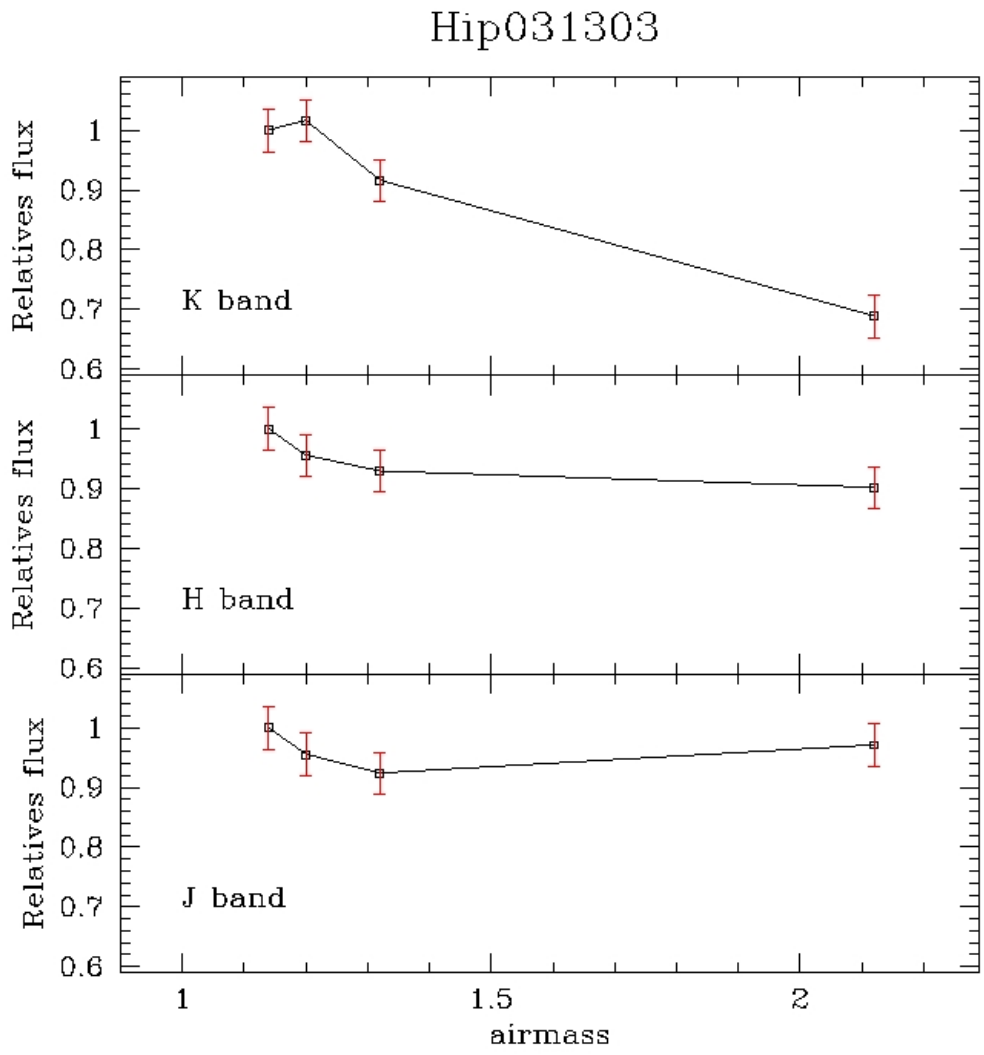


Figure 33 – Comparison of four AMICI spectra taken at different air masses for the star Hip031303, convolved with the filters profile J, H, K.

In particular, the graphs in *Figure 33* show that: i) as already emphasized by the *Figure 29* and *30*, the flux decreases with the increasing of the air mass and ii) the atmospheric extinction is strongest in the K band rather than in others filters. In particular, the effect, estimated as loss of relative flux, is about 10% in the filter J and H and 30% in K.

As already found for AMICI spectra observed at different air masses, a systematic deeper absorption features at higher air masses are observed, together with a decrease of the relative flux.

8.3.2 Molecular absorption bands and features

As the main features and bands are the same for the spectra obtained from the two standard stars, in the following, I only show the results obtained for the star Hip031303.

Figures 34 evidences the molecular absorption features and bands of an AMICI spectrum for the star Hip031303. *Figures 35* to *37* show different zoomed regions for the same spectrum: the most important molecular atmospheric absorption features and bands are emphasized.

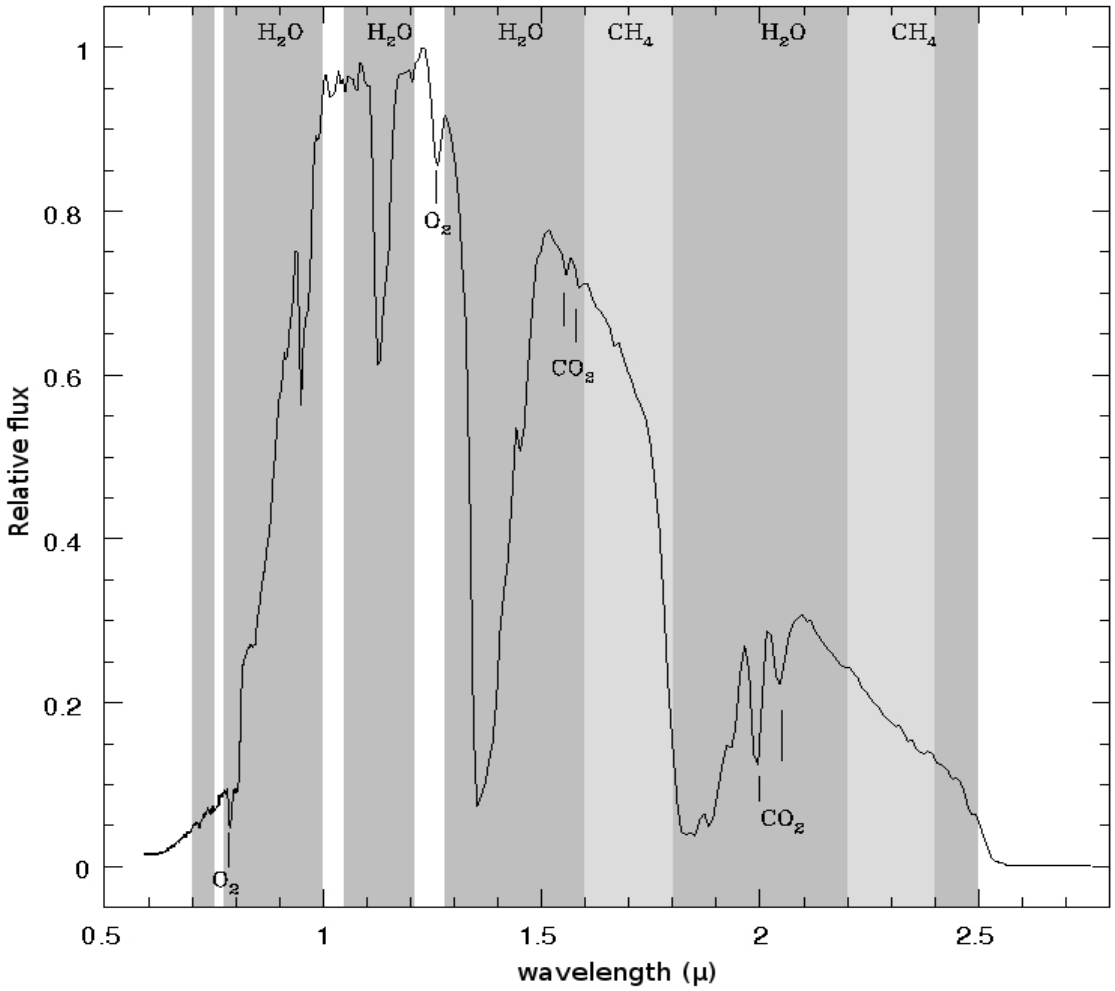


Figure 34 – Absorption features in an AMICI spectrum for the star Hip031303.

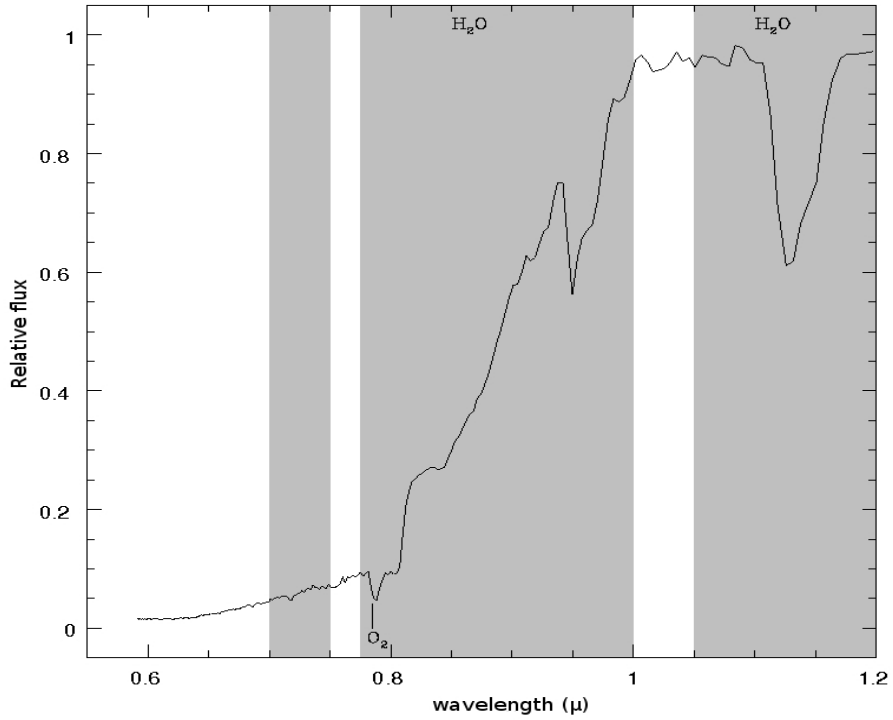


Figure 35 – Absorption features in the 0.6 - 1.2 μm region in an AMICI spectrum for the star Hip031303.

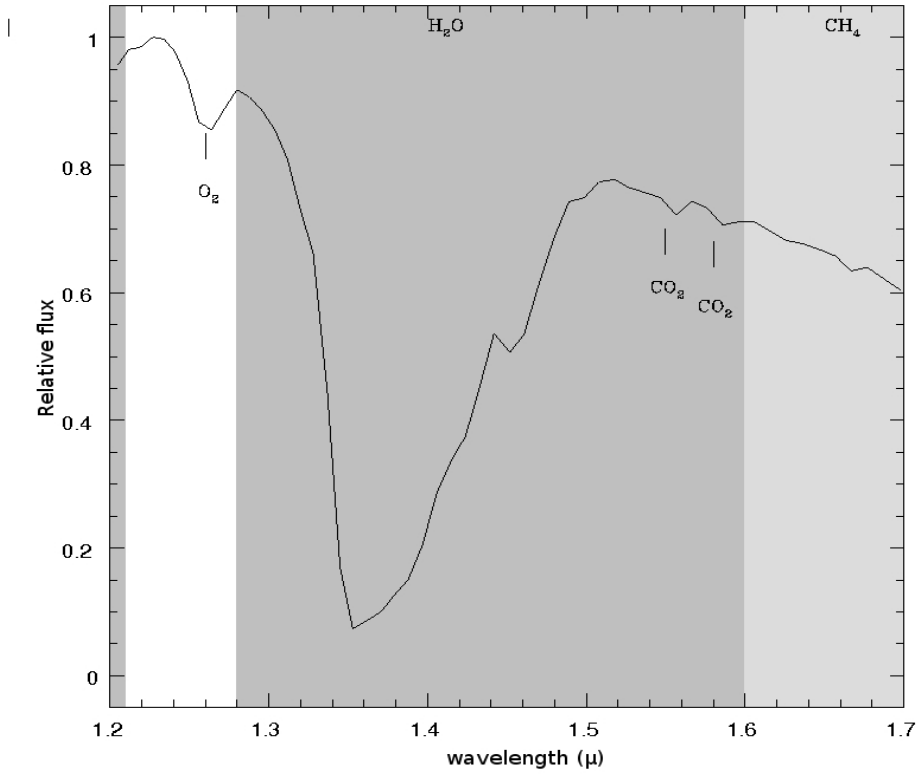


Figure 36 - Absorption features in the 1.2 - 1.7 μm region in an AMICI spectrum for the star Hip031303.

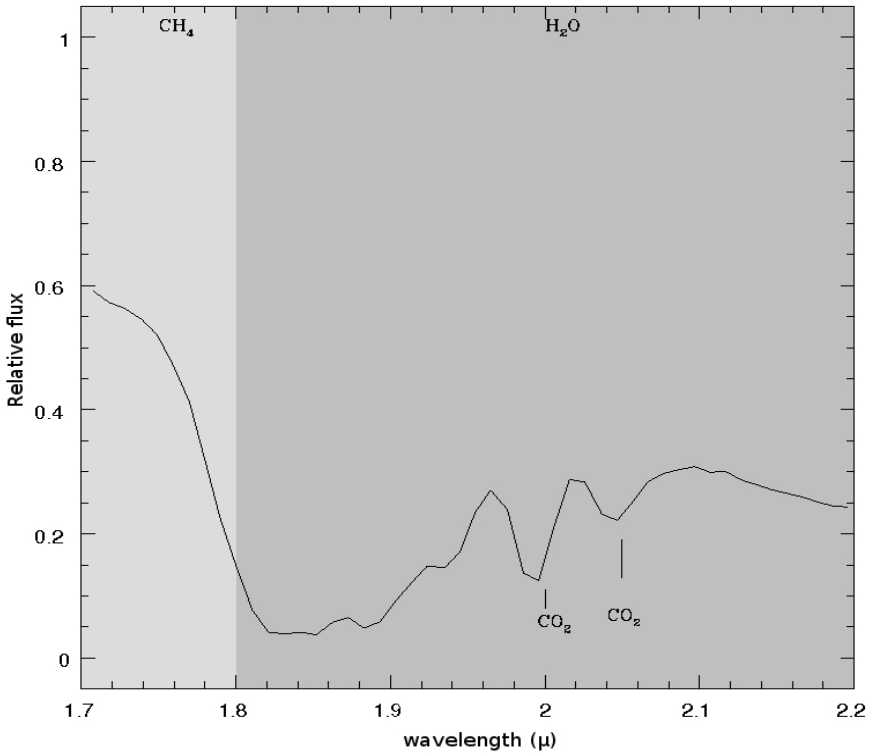


Figure 37 – Absorption features in the 1.7 - 2.2 μm region in an AMICI spectrum for the star Hip031303.

As shown in *Figure 34*, one of the most common and important constituents of our atmosphere is the water vapour. Its importance is due not only to its determining effects on the weather development within the troposphere, but also to the role, as an important partner, in the photochemical reactions and important agent of the heat exchange and of atmospheric motions.

Due to the bent structure of its molecule, water vapour exhibits a very large number of absorption lines along whole the spectra.

The Earth presents strong absorption features at 0.8 m and 1.26 μm, bands likely produced by molecular oxygen (O_2), and oxygen collision complexes, including collisions between O_2 and N_2.

Oxygen is supplied to the atmosphere from formation of sedimentary rocks and as a result of photodisintegration of water vapour in the upper atmosphere layers.
In the 1.6 micron region CH_4 and $C0_2$, have significant absorption features.

Figure 38 shows an HK spectrum for the star Hip031303 with marked the most important telluric features, while *Figures 39* to *41* show some zoomed regions of such a spectrum.

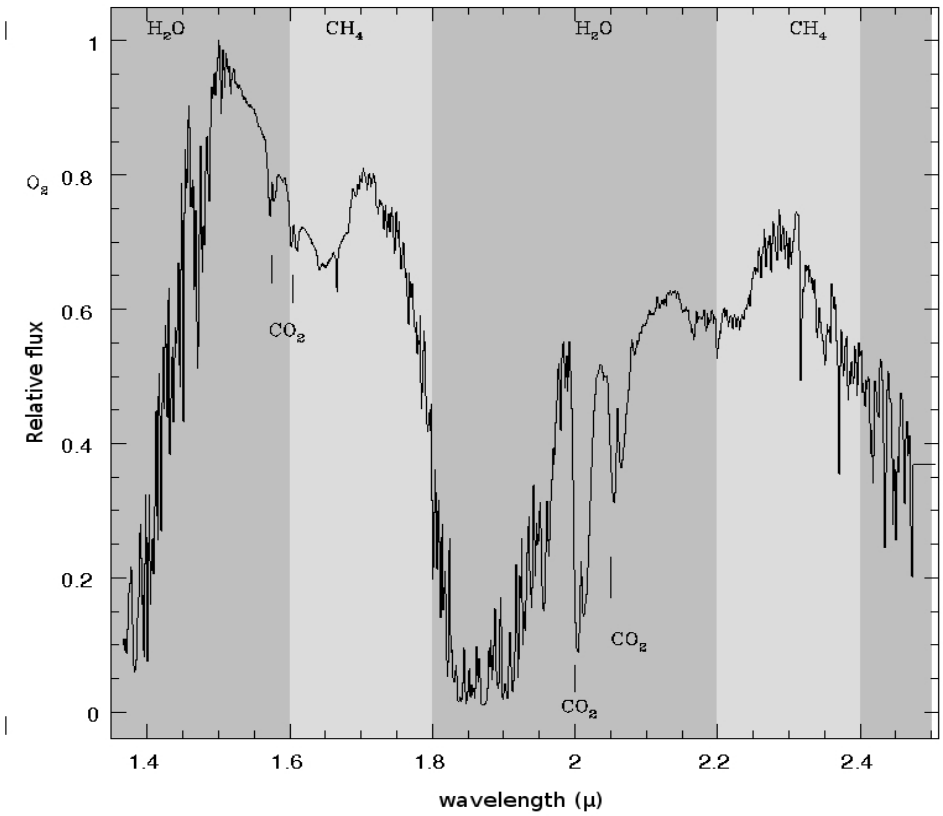


Figure 38 – Absorption features in an HK spectrum for the star Hip031303.

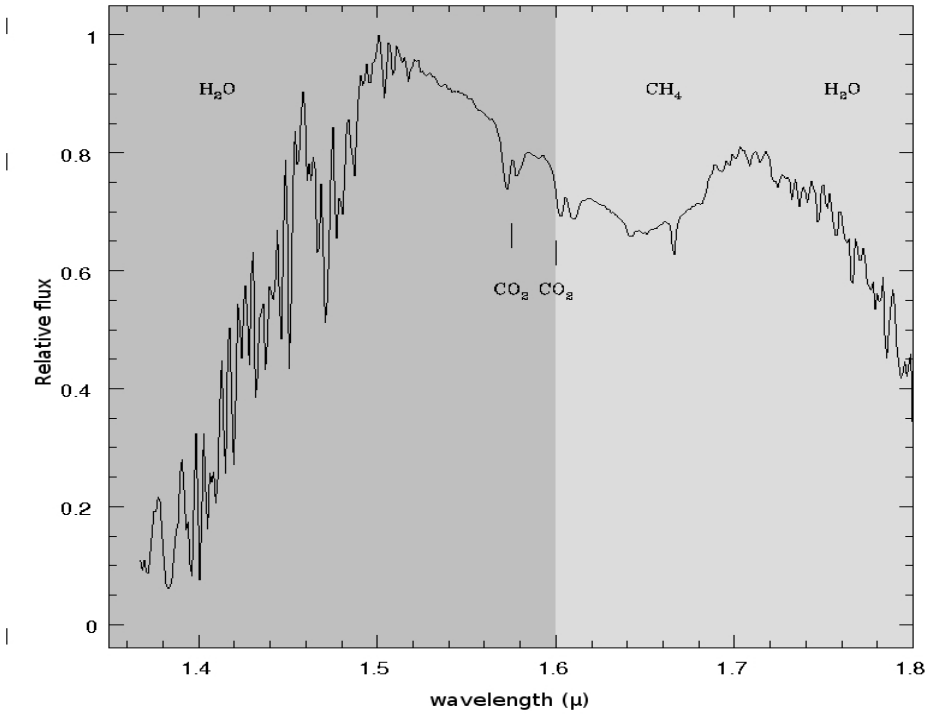


Figure 39 – Absorption features in the 1.35 to 1.8 μm region of an HK spectrum for the star Hip031303.

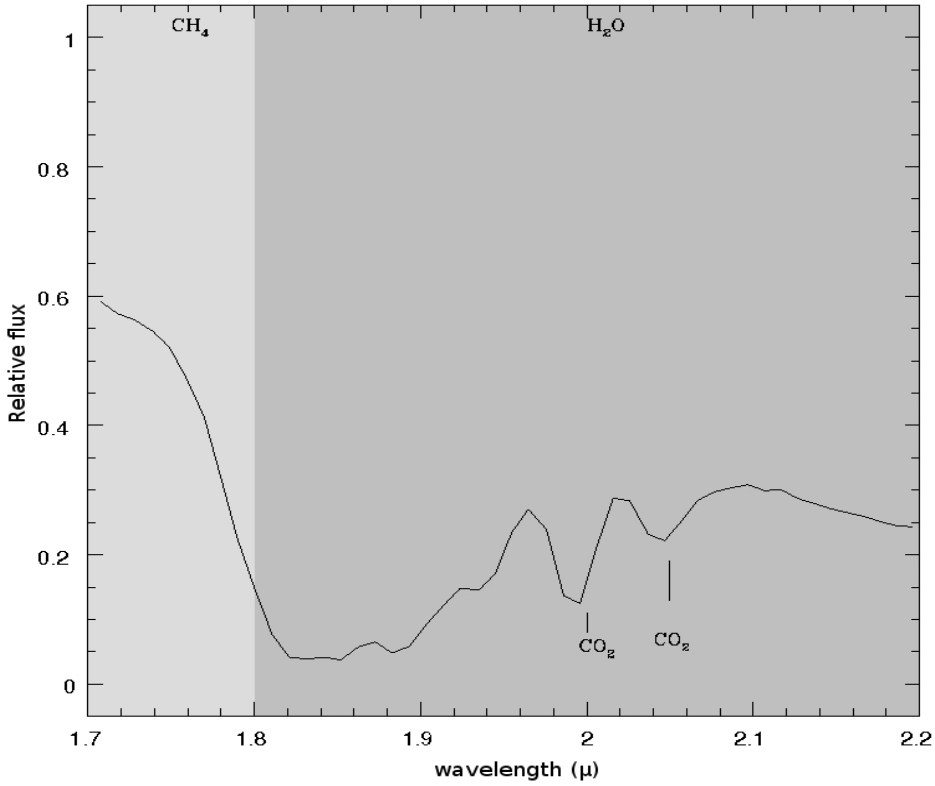


Figure 40 – Absorption features in the 1.7 to 2.1 μm region of a HK spectrum for the star Hip031303.

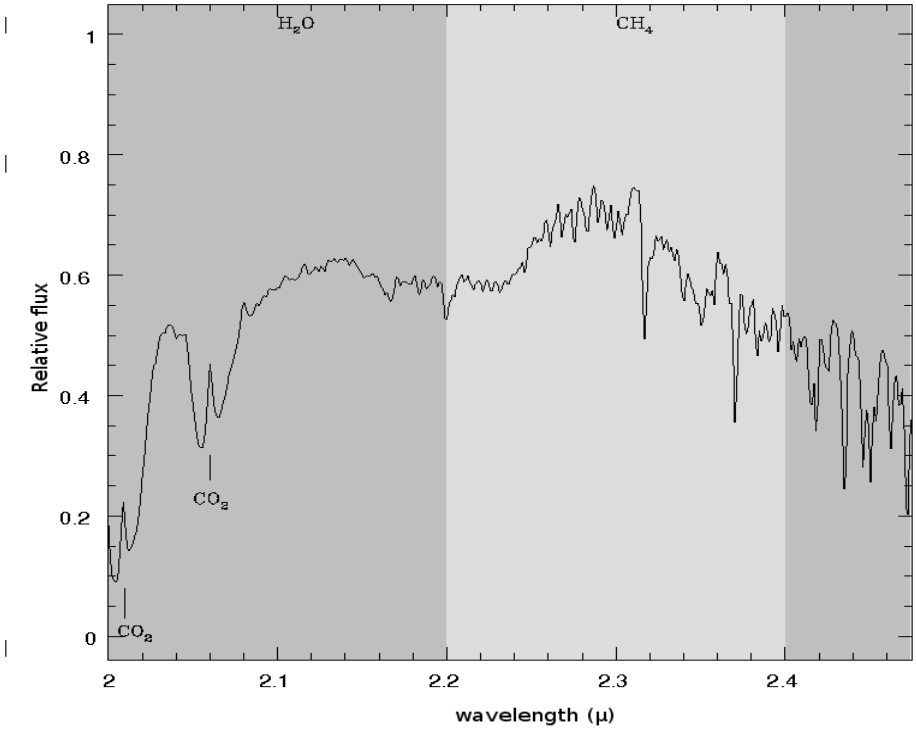


Figure 41 – Absorption features in the 2.0 to 2.5 μm region of an HK spectrum for the Hip031303.

Figure 42 shows an JH spectrum for the star Hip031303 with emphasized the most important telluric features, while *Figures 43* to *45* show some zoomed regions of such a spectrum.

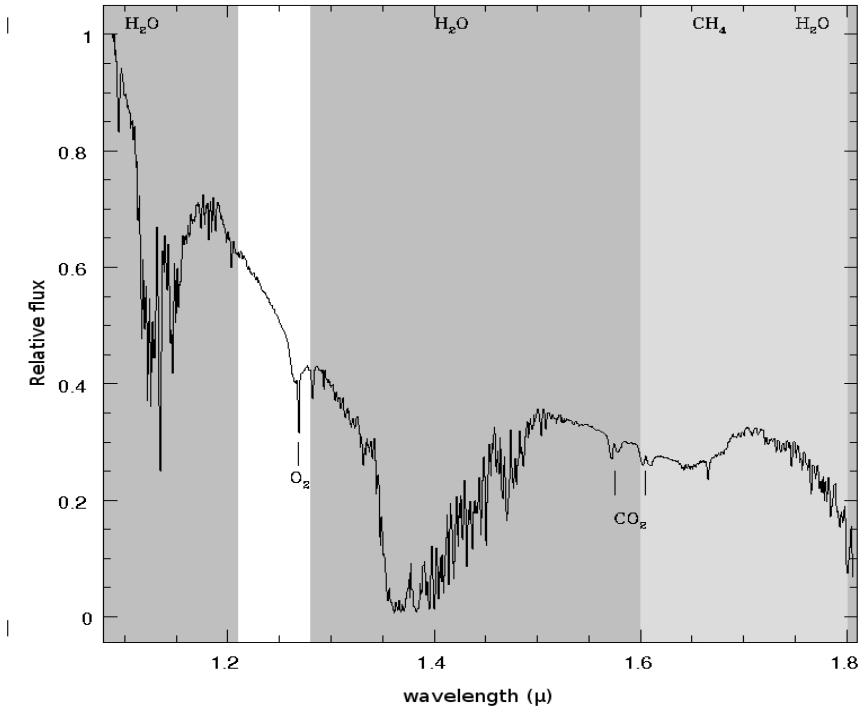


Figure 42 – Absorption features in a JH spectrum for the star Hip031303.

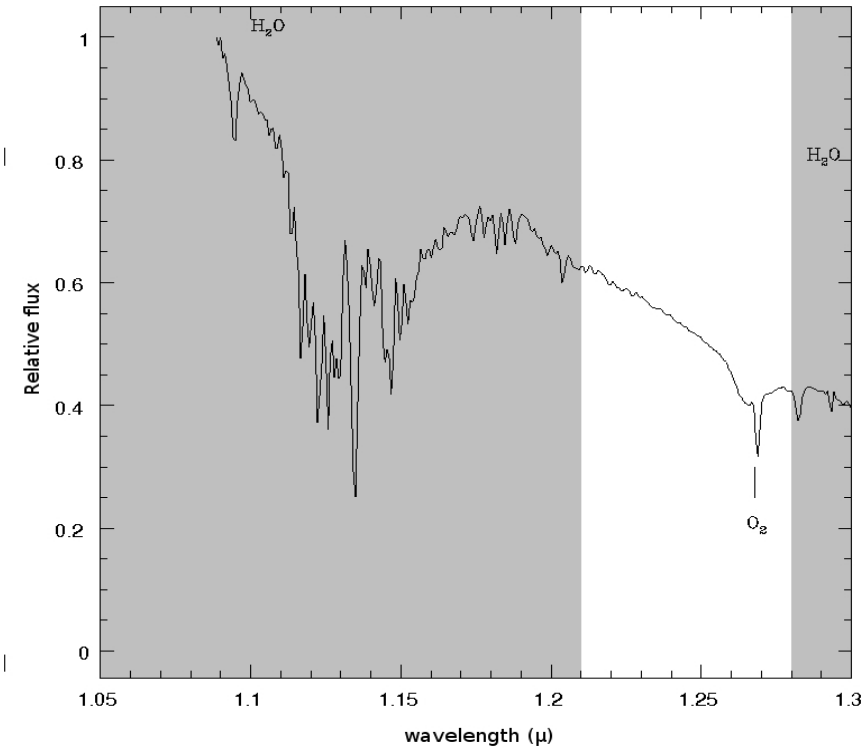


Figure 43 – Absorption features in the 1.05 to 1.3 μm region of a JH spectrum for the star Hip031303.

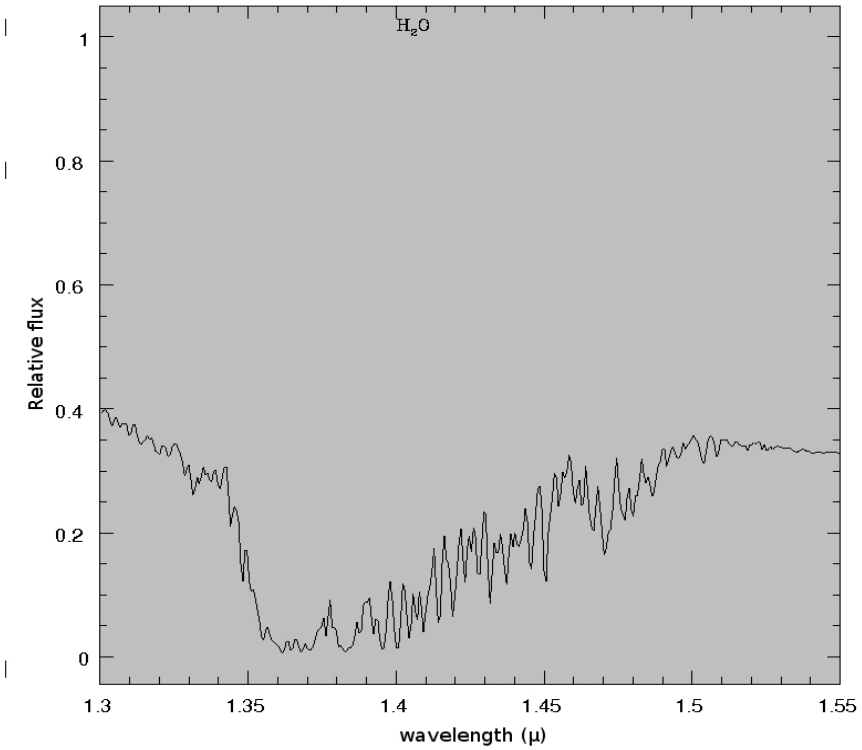


Figure 44 - Absorption features in the 1.3 to 1.55 μm region of a JH spectrum for the star Hip031303.

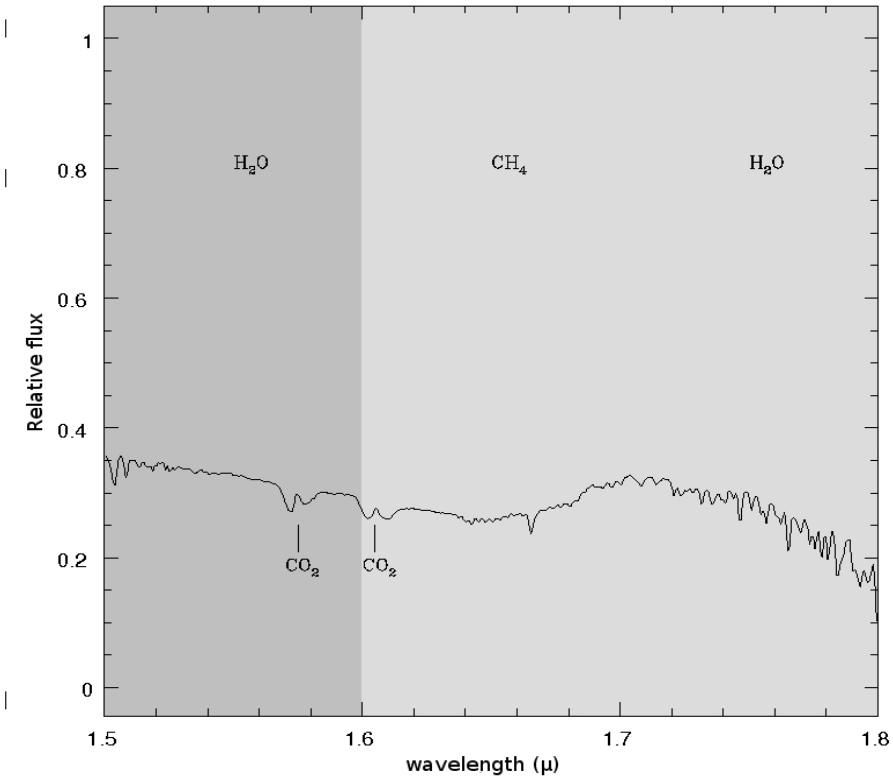


Figure 45 – Absorption features in the 1.5 to 1.8 μm region of a JH spectrum for the star Hip031303.

Thanks to the higher spectral resolution of these grisms compared to the AMICI prism (*see Figure 29*), the absorption features of O_2 and CO_2 are somewhat better defined.

8.3.3 Features depth versus air mass from the AMICI spectra

This section shows the behavior of some selected absorption features with varying the air mass from the AMICI spectra of both telluric standards.

Table 13 shows the wavelength ranges in which the selected molecular features fall together with the corresponding percentages of the absorption.

Atmospheric species	Wavelength range (m)	Absorption difference betwwe 1.2 and 2 airmasses
O_2	*0.758 – 0.768*	*95,87%*
H_2O	*0.930 – 0.940*	*55,55%*
H_2O	*1.120 – 1.130*	*37,50%*
H_2O	*1.350 – 1.360*	*78,95%*
O_2	*1.254 – 1.264*	*86,67%*
$C0_2$	*2.060 – 2.070*	*56,82%*

Table 13 – List of the visible features in the AMICI, JH, HK spectra.

The quoted depths are the observed ones, not necessarily the intrinsic ones.

Figure 46, Figure 47 and Figure 48 show the depth trend respectively of: O2 (~0.8μm and 1.25μm), CO2 (~2μm) and H2O (~0.9, ~1.12 and ~1.35 μm) versus the air mass, for the star Hip031303. The most relevant result of this study is that the depth of the features increases with the airmass as already emphasized at the beginning of this chapter.
The last column of *Table 13* reports the differences of the absorption percentage at air mass 1.2 and 2 respectively.

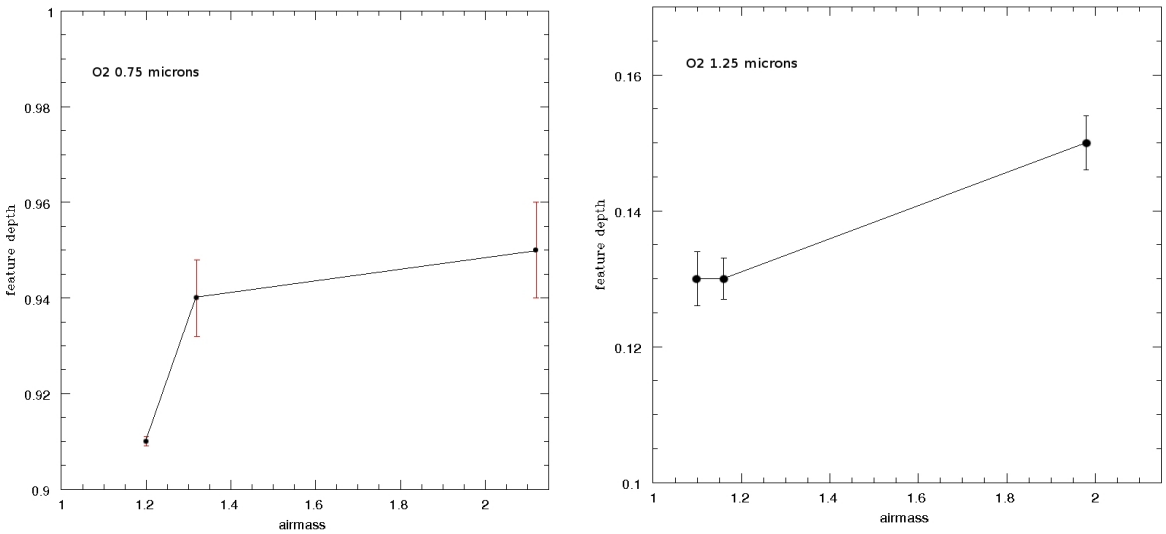


Figure 46 – Observed depth of the O_2 features at 0.75 μm and 1.25 μm versus the air mass for the star Hip031303.

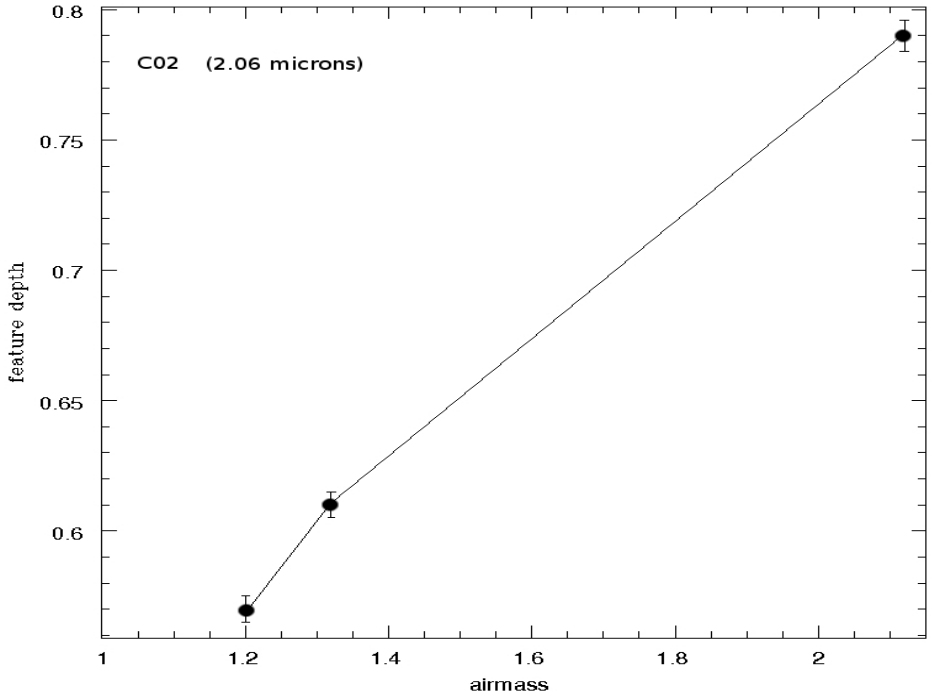


Figure 47 – Observed depth of the CO_2 features at 2.05 µm versus the air mass for the star Hip031303.

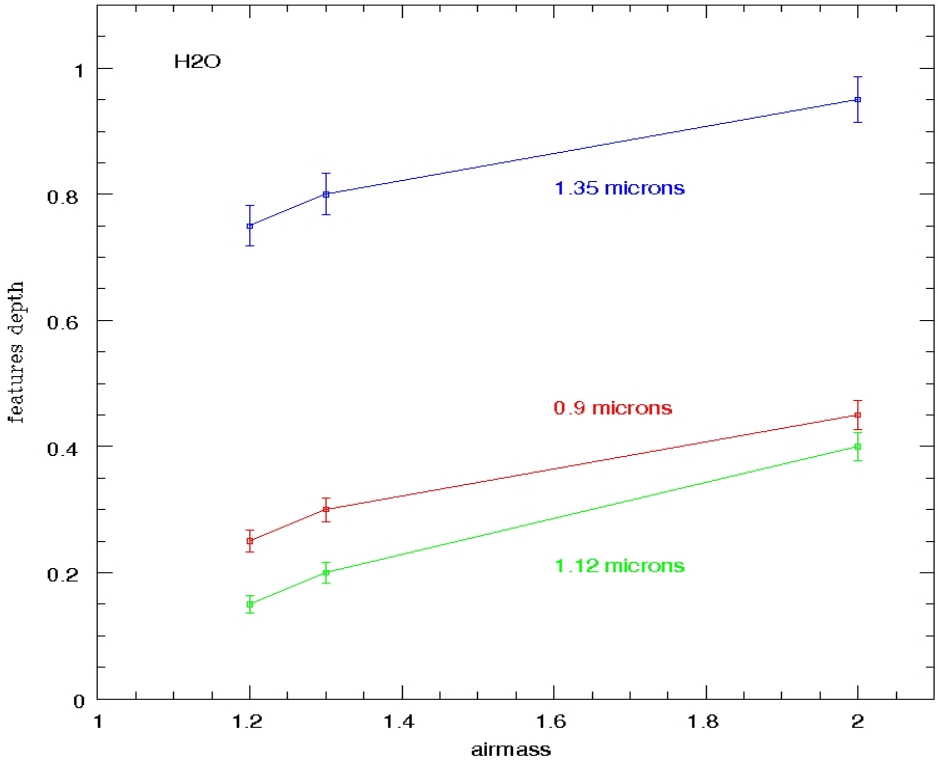


Figure 48 - Observed depth of the H_2O features at 0.9, 1.12 and 1.35 µm versus the air mass for the star Hip031303.

Conclusion

This Phd thesis was entirely developed at the Telescopio Nazionale Galileo (TNG, Roque de los Muchachos, La Palma Canary Islands) with the aim of designing, developing and implementing a new Graphical User Interface (GUI) for the Near Infrared Camera Spectrometer (NICS) installed on the Nasmyth A of the telescope.

The idea of a new GUI for NICS has risen for optimizing the astronomers work through a set of powerful tools not present in the existing GUI, such as the possibility to move automatically, an object on the slit or do a very preliminary images analysis and spectra extraction. The new GUI also provides a wide and versatile image display, an automatic procedure to find out the astronomical objects and a facility for the automatic image crosstalk correction.

Moreover, some other improvements regarding the technical aspect of the GUI has been implemented, such as the time for the startup has been optimized in comparison to the existing version, the serial motors connection have been replaced by an ethernet connection making easier the relocation of the control room to the downstairs floor as planned by the director of the TNG.

Special care was taken to simplify the mosaic procedure, for examples, the return to the origin position of the telescope (0,0) when the exposure ends or is aborted.

Within the project of progressively automatizing the telescope (planned for the next years) the new interface will allows easy communications with a new system of observing blocks manager for the execution of sequences of exposures in a fully automatic way, that should become available in near feature.

In order to test the overall correct functioning of the new GUI for NICS, and providing some information on the atmospheric extinction at the TNG site, two telluric standard stars have been spectroscopically observed within some engineering time, namely Hip031303 and Hip031567. The used NICS set-up is as follows: Large Field (0.25" /pixel) mode, 0.5" slit and spectral dispersion through the AMICI prism (R~100), and the higher resolution (R~1000) JH and HK grisms.

Such observations provide: *i)* a successful testing of the GUI, including mosaic procedures, the general connection with motors and detectors, the FITS creator procedures; *ii)* a preliminary study of the atmospheric extinction in the near IR spectral range at the Roque de Los Muchachos. The variation of the observed depth of the most important absorbers like water, CO_2 and oxygen, with varying the air mass has been also investigated as well has their integrating contribution in the J, H and K photometric bands. Air mass is a critical parameter when estimating the overall attenuation of the IR flux by the atmosphere, particularly in the K band: by changing air mass from 1 to 2, the overall attenuation factor increases by ~30%, while is only within ~10% in the J and H bands.

APPENDIX A (fits file examples)

```
SIMPLE  =           T                   / file does conform to FITS standard
BITPIX  =           16                  / number of bits per data pixel
NAXIS   =           2                   / number of data axes
NAXIS1  =           1024                / length of data axis 1
NAXIS2  =           1024                / length of data axis 2
EXTEND  =           T                   / FITS dataset may contain extensions
TELESCOP=          ' TNG '              /  Observatory
INSTRUME=          'NICS  '             / Instrument name
BSCALE  =           1.                  / real_value = tape_value * BSCALE + BZERO
BZERO   =           0.                  / real_value = tape_value * BSCALE + BZERO
BUNIT   =            ' COUNTS '         / Each count is about 8  electrons
EXP_ID  =            ' JRZZ0052 '       / exposure identifier
OBS-TYPE=            ' science '        / exposure type
FILENAME=            ' JRZZ0052.fts '   / FITS file name
NUMBER  =           52                  / Incremental acquisition number
DATE-OBS=            ' 2008-03-01 '     / UT date of data acquisition
DATE    =            ' 2008-03-01 '     / UT date when the file was written
TIME    =            ' 06:31:13 '       / UT Time file was written
EXPSTART=            ' 06:29:58 '       / UT Time exposure was started
ORIGIN  =            ' CGG     '        /  file written at CGG
J-DAY   =            4526.77167824097   / Julian date of acquisition minus 2450000
PROGRAM =           'A17TAC_9 '         / Program name
OBJECT  =            ' GRB080229 '      / Identifier of source
OBJCAT  =            ' GRB080229 '      / Identifier of source
RA-RAD  =           3.983067            / Telescope Right ascension (rad)
DEC-RAD =          -0.2564538           / Telescope Declination (rad)
RA-HOURS=           15.21419            / Telescope Right ascension (hours)
DEC-DEG =           -14.69372           / Telescope Declination  (deg)
DEL_RA  =           -10.                / current AR offset from source (arcsec)
DEL_DEC =            10.                / current DEC offset from source (arcsec)
RA      =            15.2144            / RA of catalog hours
DEC     =           -14.7018            / DEC of catalog deg
LST     =            15.9545            / Local Siderial Time
PARANG  =            0.2396734          / Parallatic Angle (rad)
EQX-OBS =            2000.              / equinox of telescope coordinates
EQUINOX =            2000.              / equinox of catalog coordinate
AIRMASS =            1.404435           / Airmass when acquisition started
AZ      =            0.2655523          / starting azimuth (rad)
EL      =           0.7923853           / starting elevation (rad)
POSANG  =          -3.814697E-06        / Position angle (deg)
ROT-POS =            2.594846           / Derotator position (rad)
ROT-OFF =           -1.099558           / Derotator offset  angle (rad)
CRPIX1  =            1                  / reference X pixel
CRPIX2  =            1                  / reference Y pixel
CRDELT1 =            1                  / binning (X axis)
CRDELT2 =            1                  / binning (Y axis)
DETOFF1 =            0                  / X offset on detector
DETOFF2 =          0                    / Y offset on detector
DETSIZ1 =          1024                 / detector size (X axis)
DETSIZ2 =          1024                 / detector size (Y axis)
```

```
OBSMODE =      " IMA '                  / Observation Mode
FILTER  =      'K '                     / Filter name
FLT_ID  =      'K       '               / Filter name
OBJECTIV=      'LF      '               / Objective
PIXSCALE=      '0.25    '               / arcsec per pixel
GRAY    =      'G0      '               / Attenuator
MOTOR1  =      'LF      57950'          / Camera Wheel
MOTOR2  =      'LF1       3000'         / Array Focus
MOTOR3  =      'in      32800'          / Lyot Slide
MOTOR4  =      'K       14108'          / Filter Wheel
MOTOR5  =      'open       4800'        / Grism Wheel
MOTOR6  =      'LF      72780'          / Aperture Wheel
MOTOR7  =      'open        300'        / Aperture Sector Paddle
TIME-INT=      30.00115                 / Integration time on detector 30.0 * 2
DIT     =      30.00115                 / Same as TIME-INT
COADDS  =      2                        / Number of frames added together
NDIT    =      2                        / Same as COADDS
MOSAIC  =      'grb080229_mos#2'        / Name of mosaic file & position in it
BQ1     =      0                        / Bias quadrant 1
BQ2     =      0                        / Bias quadrant 2
BQ3     =      0                        / Bias quadrant 3
BQ4     =      0                        / Bias quadrant 4
POLTEN1 =      0                        / Polarimeter tension 1
POLTEN2 =      0                        / Polarimeter tension 2
DUMMYR  =      0                        / Dummy read =1 set 0 not
NRESETS =      255                      / number of resets before integration
SAMPLING=      2                        / =1 single integration =2 standard
DINTEGR =      0                        / =1 dummy integration before real, =0 not
HAL_LAMP=      0                        / HAL lamp =1 on, =0 off
AR_LAMP =      0                        / Ar lamp =1 on, =0 off
XE_LAMP =      0                        / Xe lamp =1 on, =0 off
DIFFUS  =      0                        / Diffusor =1 on, =0 off
END
```

APPENDIX B (*motor_config.nics* file)

```
#
# Files containing configuration information for the 7 motors of NICS
#
#  Motor#    active?     max_err      steps/round                 software limiting positions
#              >0 yes       (a)        (<=0 for slides)              (+/-1e10 = none)
#             <=0 no
#
     1         1             2             100000                      -1e10  1e10
     2         1             2                0                         100    8000
     3         0             3                0                         100   32950
     4         1             2              60000                      -1e10  1e10
     5         1             2              60000                      -1e10  1e10
     6         1             2             200000                      -1e10   1e10
     7         1             4             200000                       100   49000
#
# (a) Maximum positioning error (step encoders)
#
```

APPENDIX C - *Short Message Service (SMS) and Gateway SMS*

SMS is a communication service standardized in the GSM mobile communication system, using standardized communications protocols allowing the interchange of short text messages between mobile telephone devices. SMS text messaging is the most widely used data application on the planet.

SMS as used on modern handsets, was originally defined as part of the GSM series of standards in 1985 as a means of sending messages of up to 160 characters (including spaces), to and from GSM mobile handsets.

SMS gateway providers facilitate the SMS traffic between businesses and mobile subscribers, being mainly responsible for carrying mission-critical messages, SMS for enterprises, content delivery and entertainment services involving SMS, e.g. TV voting. Considering SMS messaging performance and cost, as well as the level of messaging services, SMS gateway providers can be classified as aggregators or *Signaling System 7* (SS7) providers.

The SS7 protocol is used in the public switched telephone system (the "intelligent network" or "advanced intelligent network") for setting up calls and providing services.

The aggregator model is based on multiple agreements with mobile carriers to exchange 2-way SMS traffic into and out of the operator's SMS platform, also known as *local termination model*. Aggregators lack direct access into the SS7 protocol, which is the protocol where the *SMS* messages are exchanged. SMS messages are delivered in the operator's SMS-C, but not the subscriber's handset, the SMS-C takes care of further handling of the message through the SS7 network.

Another type of SMS gateway provider is based on SS7 connectivity to route SMS messages, also known as *international termination model*. The advantage of this model is the ability to route data directly through SS7, which gives the provider total control and visibility of the complete path during the SMS routing. This means SMS messages can be sent directly to and from recipients without having to go through the SMS-Centers of other mobile operators. Therefore, it's possible to avoid delays and message losses, offering full delivery guarantees of messages and optimized routing. This model is particularly efficient when used in mission-critical messaging and SMS used in corporate communications.

Message Service Centers communicate with the Public Land Mobile Network (PLMN) or PSTN via Interworking and Gateway MSCs.

Subscriber-originated messages are transported from a handset to a Service Center, and may be destined for mobile users, subscribers on a fixed network, or Value-Added Service Providers (VASPs), also known as application-terminated.

Subscriber-terminated messages are transported from the Service Center to the destination handset, and may originate from mobile users, from fixed network subscribers, or from other sources such as VASPs. It is also possible, on some carriers, for non-subscribers to send messages to a subscriber's phone using an E-Mail to SMS gateway. Additionally, many carriers, offer the ability to do this through their respective websites. For example an AT&T subscriber whose phone number was 555-555-5555 would receive e-mails to 5555555555@txt.att.net as text messages. Sending a message this way is free but subject to the normal length limit.

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