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FRIDA, the diffraction limited NIR imager and IFS for the GTC.

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Abstract

FRIDA (InFRared Imager and Dissector for the Adaptive optics system of GTC) is a near infrared, diffraction limited imager and integral field spectrograph that has been designed and is being built as a collaborative project between GTC partner institutions from México, Spain and the USA. FRIDA will operate with the adaptive optics system of GTC. Three different scales are provided in imaging mode, 0.010, 0.020 and 0.040 arcsec pixel^{-1}. The integral field unit is based on a monolithic image slicer that will slice up the field of view into 30 slices. The IFS spaxels have a 2:1 pixels aspect ratio (2 along the spectral axis an 1 along the spatial axis) and it will offer three different spectral resolutions, $R \sim 1000$, 5000 and 30,000, the latter over selectable regions in the H & K bands. Thus FRIDA will exploit the diffraction limit of a 10.4 m telescope with superb image quality and spectral resolutions suitable to tackle a large range of topical astrophysical problems. FRIDA has started systems integration and is scheduled to be ready for fully integrated system tests by the end of 2015 and be delivered to GTC shortly after. Here we present an overview of its design, current status and potential scientific applications.

1 Introduction

Why GTC needs FRIDA. The main two advantages of a big telescope are, first, its large photon gathering power that allow us to observe fainter objects and look further back into the past of the Universe, and second, their diffraction limit that provides high spatial resolution, this is usually blurred by the atmosphere but largely recovered by modern adaptive optics systems. When you combine both, large gathering power and high spatial resolution you are then fully exploiting the power of a big telescope, and with the right instruments you have at your disposal a very powerful tool for discoveries and top class astronomical research. GTC has come a long way into fulfilling these aims for its community. The telescope is now operating with better efficiency and the instruments in use are producing exciting science. GTC has recently transferred the responsibility of completing the adaptive optics system to the IAC, and with fresh funding for this task it shall become operational in the near future. FRIDA is the instrument designed to operate with GTCAO and thus finally exploit its diffraction limit in the near infrared and therefore the full power of GTC.

FRIDA will operate in the 0.9–2.5 μm wavelength range and will offer a large set of broad and narrow filters for imaging applications. Fine and medium selectable spatial scales of 0.010 and 0.020 arcsec pixel^{-1} provide fields of view of 20.48 $\times$ 20.48 arcsec and 40.96 $\times$ 40.96 arcsec, respectively. The fine scale provides adequate sampling for the nearly diffraction-limited core in the J and H bands and the medium scale provides adequate sampling in the K band. A third camera will provide a coarser scale of 0.040 arcsec pixel^{-1} to aid pointing in the IFS mode and for situations when the AO correction is poor.

2 Design Characteristics

The main design characteristics of FRIDA are shown in Table 1.

3 Optical and mechanical design

The FRIDA optical design is based of a classical refractive collimator-camera that images the GTC pupil into the pre-optics pupil and the GTCAO output image in the input object plane of the spectrograph. The pre-optics has four cameras (coarse, medium, fine and pupil) that provide the selectable spatial scales by performing a linear amplification. The spectrograph is a double-pass system that serves as a collimator and a camera and optimizes de diffraction gratings efficiency working at a near Littrow configuration. The imaging and IFS modes use the same Rockwell detector. In the imaging mode a switching mechanism sends the light beam directly to the detector. In the IFS mode the light beam is sent through the second focal plane to reach the IFU, where the beam is sliced up and arranged into an output pseudo-slit for the spectrograph. A grating carrousel holding 8 gratings and 2 mirrors receives the pseudo-slit image. The dispersed light beam then travels back through the double-pass spectrograph to the switching mechanism where it is finally redirected towards the detector. All the refractive components, collimator, cameras and the spectrograph are based on airspace doublets using

Table 1: General Design Characteristics of FRIDA

Working Location	Nasmyth B platform, after GTC AO
Wavelength Range	0.9 to 2.5 μm, optimized for 1.1 to 2.4 μm
Detector	Teledyne Hawaii II 2048 $\times$ 2048 HgCdTe, 18 μm pixel^{-1}
IMAGING MODE	
Scales	0.010, 0.020 arcsec pixel^{-1} ; 0.040 arcsec pixel^{-1}(coarse)
Fileds	20.48 $\times$ 20.48 and 40.96.48 $\times$ 40.96 arcsec (+ coarse for field ID)
Image Quality	SR $\geq$ 0.9, goal 0.95 in 1.1–2.4 μm and $\geq$ 0.8 in 0.9–2.5 μm
Field Distorsion	Less than 2 % (goal 1 %) over the whole field
Throughput	Better than 50 % (goal 70 %) excluding filters and detector
IFS MODE	
Scales	0.010 $\times$ 0.020 arcsec spaxel^{-1}, $\pm$5 % in the fine configuration 0.020 $\times$ 0.040 arcsec spaxel^{-1}, $\pm$5 % in the medium configuration 0.040 $\times$ 0.080 arcsec spaxel^{-1}, coarse, for fileld ID purposes only
Fileds	0.060 $\times$ 0.066 arcsec, 1.32 $\times$ 1.20 arcsec 2.64 $\times$ 2.40 arcsec
Spectral Resolutions	R$\sim$1500 for H & K and z & J $R \sim 4500$ over each z, J, H, K window $R \sim 30,000$ over selectable windows of $\lambda/30$ from 1.4 to 2.4 μm
Image Quality	Strehl degradation better 0.8 (goal 0.85) from 1.1 to 2.5

two cryogenic matching materials, namely, CAF2 and Ohara S-FTM16. The spectrograph also employ an Infrasil-301 lens. The optical bench and opto-mechanical layout of FRIDA are shown in Figs. 1 and 2.

Figure 1 shows a view from the top of the optical bench layout. The corrected beam from the GTCAO system enters from the right side of the figure. After entering the window it encounters, in progression: the focal plane wheel, the collimator, the filters and pupils wheel, the cameras wheel where the fine, coarse and pupil camera are located in a revolver holder. These cameras work in combination with the medium camera that sits still to perform the required amplifications. The beam then reaches the switching mechanism that either redirects the beam directly to the detector for imaging mode or lets it through to a second focal plane to enter the IFU. The beam is then sliced up and the slices are then rearranged to form an output pseudo slit image that leaves the IFU and is redirected to the double-pass spectrograph acting as a collimator and a camera. After the spectrograph the beam is sent to the gratings carrousel via a fold mirror. The dispersed light beam then travels back to meet the switching mechanism that redirects it to the detector. The beam in red in Fig. 1 corresponds to the full path in imaging mode and the beam in cyan to the full path in IFS mode. Fig. 2 shows a rendered image of FRIDA with the beam path of the IFS mode indicated in cyan.

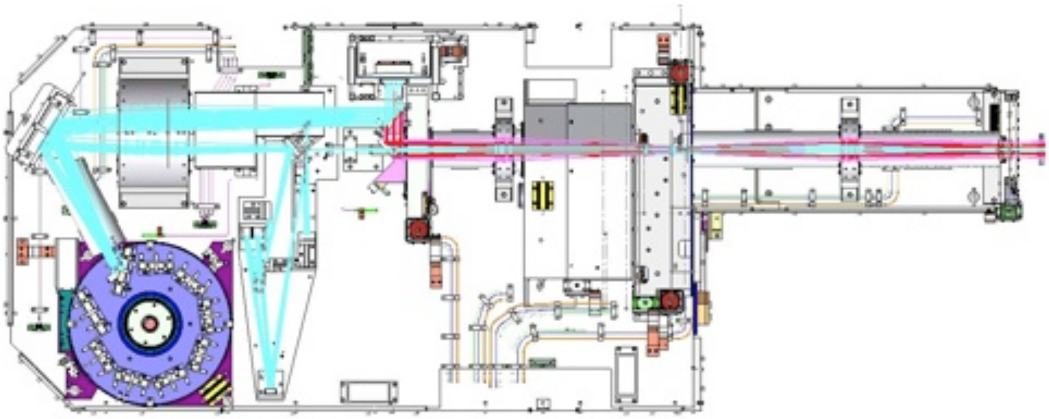


Figure 1: The optical bench lay-out of FRIDA. The red beam tracks the path in imaging mode and the cyan beam shows the path in IFS mode. The beam enters from the right.

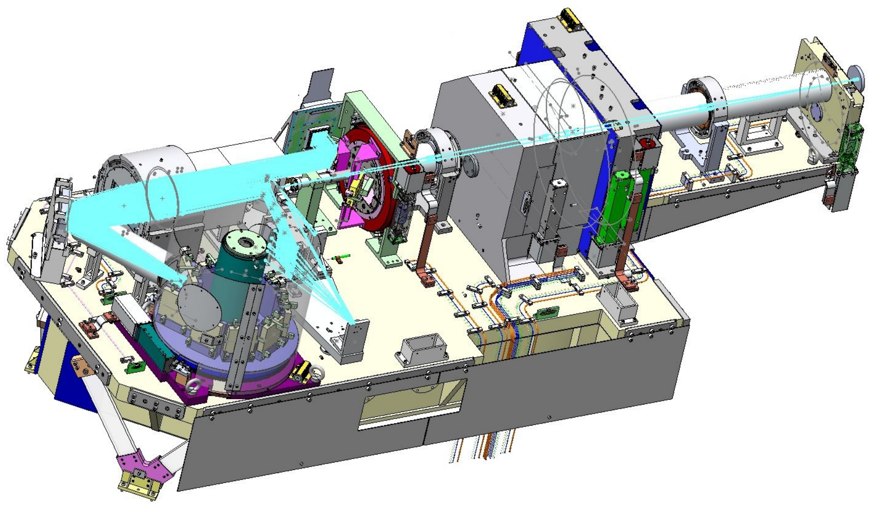


Figure 2: A rendered image of FRIDA with the beam path of the IFS mode indicated in cyan. The beam enters from the right.

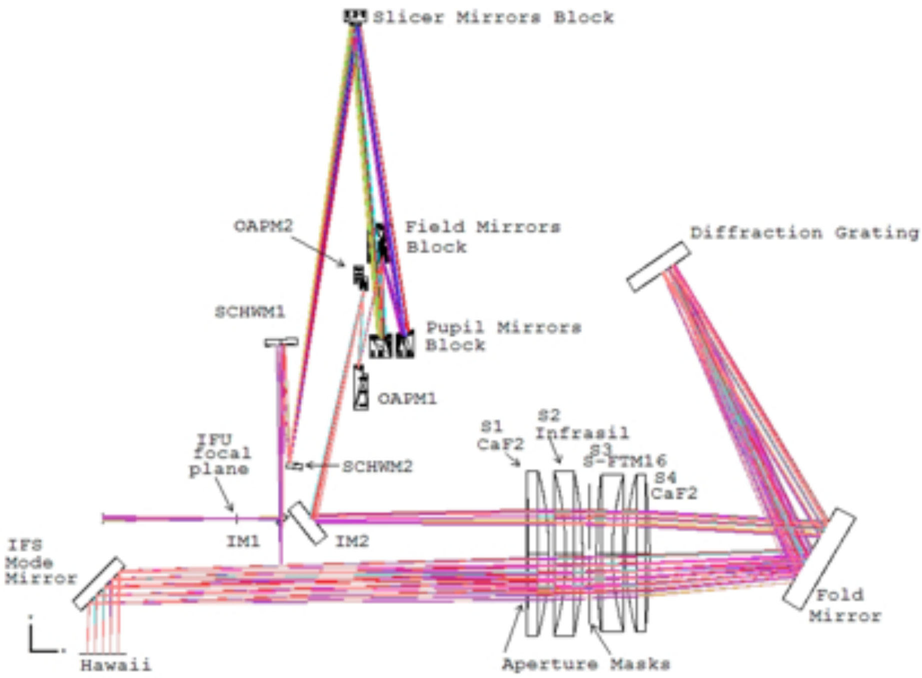


Figure 3: Optical lay-out of the integrak field unit and the spectrograph.

4 The integral field unit

A monolithic image slicer with 30 slices will provide integral field spectroscopy at three spectral resolutions, namely, low (~ 1500), medium (~ 4500) and high ($\sim 32,000$). Each slice will project to two pixels in the spectral direction. The corresponding fields of view with the fine, medium and coarse cameras are 0.65 x 0.60 arcsec, 1.30 x 1.20 arcsec and 2.60 x 2.40 arcsec, respectively. The combination of high spectral and spatial resolution will be a powerful capability of FRIDA. The design of the FRIDA IFU is based on the FISICA IFU. The diamond-turned mirrors of the IFU are coated with a Ni alloy to reduce scattering effects. Figure 3 shows in detail the optical layout for the integral field unit and the spectrograph.

In Fig. 3 the beam enters the IFU through the IFU focal plane, a Schwarzschild relay performs an amplification before the beam reaches the image slicer . The sliced image is sent to two sets of pupil mirrors blocks that redirect it to the field mirrors blocks. The slices are arranged into the output pseudo slit image. Two off-axis parabolic mirrors are used to de-magnify and extract the pseudo slit image form the IFU. The rest of the diagram shows the beams path through the spectrograph, the diffraction grating and back towards the detector. Figure 4 is a rendered image of the integral field unit and the spectrograph optics, with ray-tracing indicated. Notice that in this figure the beam enters from the right. the image slicer is located at the bottom of the figure and the spectrograph in the upper left. The beam tracing ends at the switching mechanism (IFS mode mirror in Fig. 3) where the beam is redirected towards the detector, close to the center of the figure.

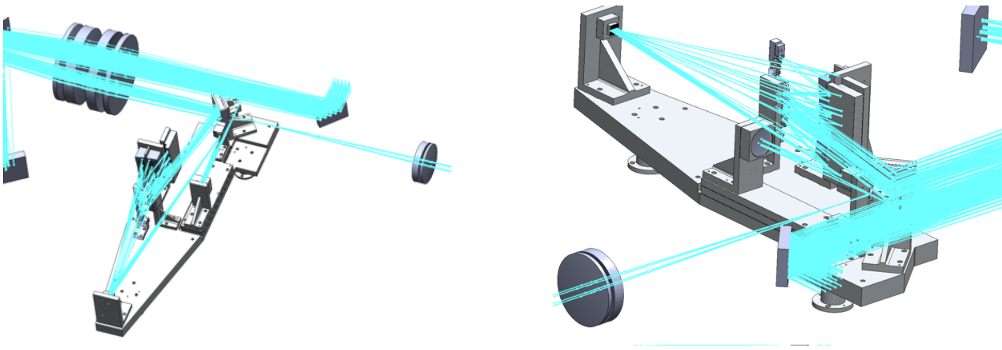


Figure 4: A rendered image of the IFU and the spectrographs optics, with ray tracing indicated.

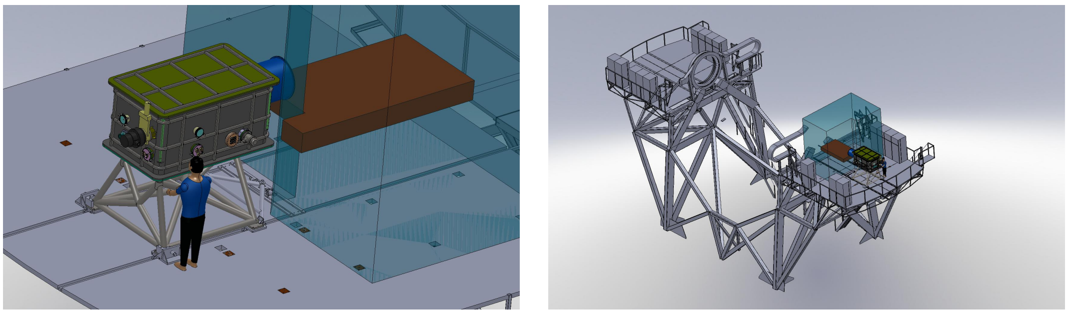


Figure 5: Rendered images of FRIDA at the Nasmyth platform showing the envelope of GTCAO.

5 FRIDA and the GTCAO

FRIDA will operate with the adaptive optics system of GTC, GTCAO. The development of GTCAO had been under the direct responsibility of GTC. This responsibility has been recently transferred to the IAC. Fresh funds have already been granted to speed up completion of the AO system. GTCAO will initially operate in the natural guide star mode and provisions are being taken to upgrade it to a laser guide system operation shortly after commissioning of the NGS mode. GTCAO is a single pupil-conjugate AO system with a Shack-Hartmann wave front sensor. The deformable mirror works with 21 x 21 actuators. GTCAO will be a fixed system at the Nasmyth platform with field de-rotator. GTCAO has a large envelope in the Nasmyth platform that the FRIDA design must comply with, imposing some severe restrictions at the interface between these instruments. The FRIDA group has no involvement in the design and development of GTCAO. Figure 5 shows rendered images of FRIDA and the GTCAO envelope at the Nasmyth platform.

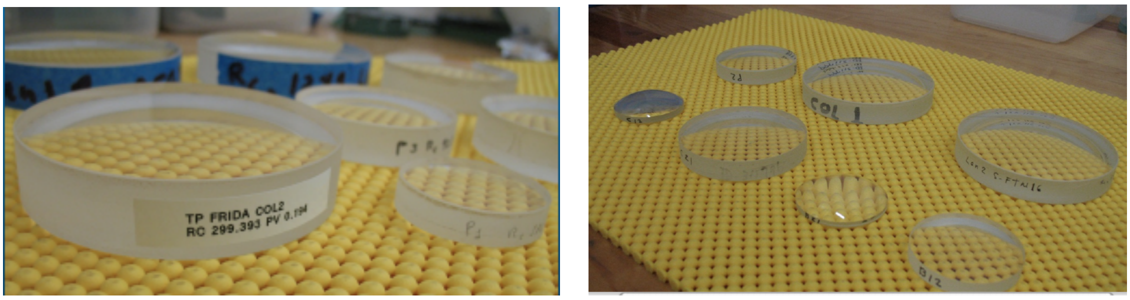


Figure 6: Examples of the finished lenses of FRIDA.

6 Current Status

The stage of proto-type testing and design optimization is finished. The design is closed. A substantial part of the optics and the mechanics has already been manufactured and FRIDA is now starting systems integration. We summarize below some of the progress made in the manufacture of several subsystems.

6.1 Optics

The optical design of FRIDA is based on achromatic doublets of CaF2 / SFTM16 lenses. Infrasil 301 is used on the cryostat window and the calibration unit, and quartz for the flat mirrors. FRIDA requires 30 optical elements in addition to the IFU. All these optical elements have been manufactured and tested at the IA-UNAM workshop with the exception of two flat mirrors. The manufacturing of these 28 optical elements has required the fabrication of 19 test plates and 200 tools. 90 surfaces have been polished in total. Only 3 surfaces or components have turned out of specifications and are being done again. Manufacturing has been done with three Strasbaugh polishing machines a Strasbaugh generating machine and a Satisloh rounding machine. Surface quality, curvature and rugosity evaluation have been performed with a Zygo 6 inches XP interferometer. Figure 6 shows some examples of the manufacturing process and finished lenses.

6.2 The integral field unit

The optical design of the IFU has been done between the IAUNAM and the University of Florida. This work package is responsibility of the UF. The manufacture of the IFU components has been contracted with CORNING and Durham Optics. All the components contracted with CORNING have arrived at UF. The IFU mage quality modeling has shown to comply and in many cases exceed the high level requirements. Preliminary tests on the IFU components now show that the average figure and roughness verification measurements show excellent quality, exceeding the original specifications. Figure 7 shows images of some of the finished components of the IFU. Alignment and mounting will be done at UF and the final assembly into FRIDA at the IA-UNAM. .

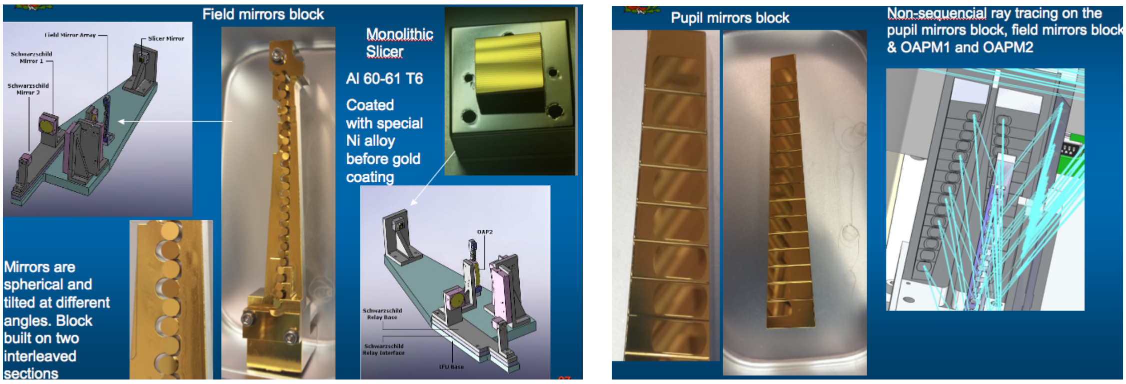


Figure 7: The finished and coated monolithic slicer, field mirrors block and pupil mirrors block are shown next to graphics that identify their location in the integral field unit.

6.3 Mechanics

The mechanical design, fabrication, welding and machining of FRIDA has been done at CIDESI in Queretaro, Mexico.The full mechanical design is finished and closed for all subsystems. Only validation of some elements is currently underway and verification has started for others. The following elements have the design complete and closed and many of them have already been manufactured: Focal plane wheel, Pupil wheels, Cameras wheel, Switching mechanism, Gratings carrousel, Collimator barrel, Medium camera barrel, Spectrograph, Cold shield, Adiabatic shield and supports, Cold plate, Optical bench, G10 supports, Baffles, Calibration unit, Support structure and cryostat. CIDESI is working now on thermal stabilization and cryogenic treatment of several elements such as wheels and carcasses and final validation of thermal links, CIDESI also manufactured several prototypes and two cryostats used for testing the prototypes. Figure 8 shows some of the progress made in this area. The focusing mechanism for the detector has been designed and is being manufactured by the University of Florida.

6.4 Control

The control work package is divided between the IAC and the IAUNAM. The IAC is in charge of the hardware and software for the high level control of mechanisms, the data acquisition system and the detector control (h/w and s/w). All these tasks are in an advanced stage. FRIDAs detector had been fully characterized but it has now been transferred to EMIR and we are waiting for delivery of a new detector for FRIDA. The tasks related to the Data Acquisition Software include implementation of the FRIDA GUI and Inspector Panels, the Sequencer, the FRIDA Observing Modes and the observing program management subsystem. The IAUNAM is developing the low level, embedded control of mechanisms and the housekeeping (h/w and s/w). These tasks have included development of control software for testing and validation of subsystems at room temperature and under cryogenic conditions. Tests on EMI and cross-talk. Control structure for the house-keeping based on PLC and redundancy

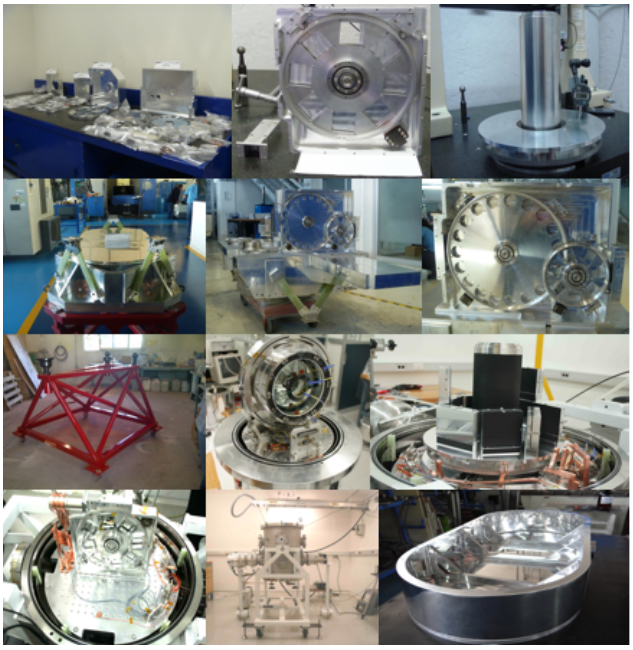


Figure 8: Examples of mechanical pieces fabricated by CIDESI. The image shows filter holders, the focal plane wheel and pupil wheels, the grating carrousel, the support structure, the collimator and FP wheel during cold tests, one of the large test dewars, FCTF, and the LN2 container of FRIDA

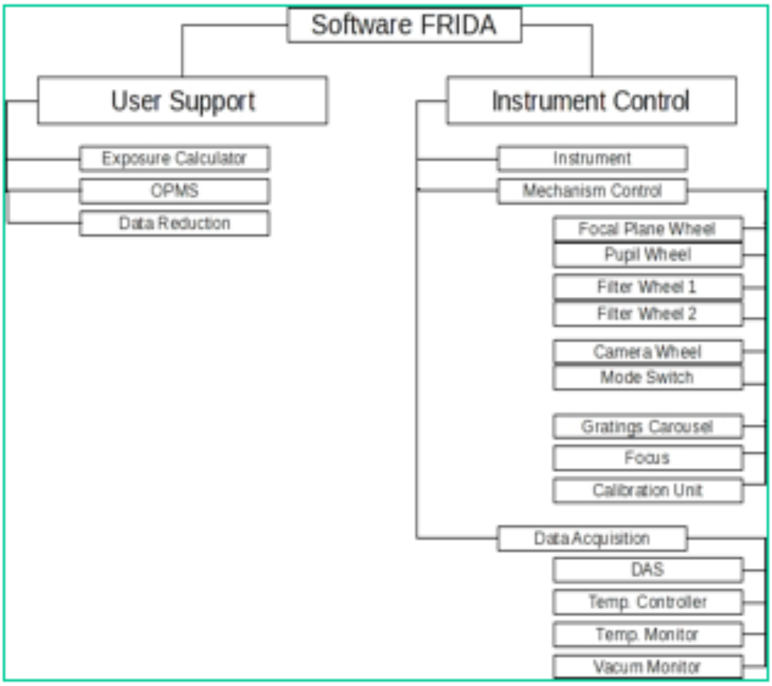


Figure 9: Tasks related to the high level software control and data acquisition of FRIDA

checks on the warming system. Heat dissipation related to electrical power (motors). Design of the electronics cabinet, electrical protection system, activation sequence, grounds system and trays distribution for cables under the Nasmyth platform, in addition to the routing design of cables, harnesses and location of connectors and temperature sensors on the cold base and for all the mechanisms. Figure 9 shows a diagram of tasks related to the high level software control and data acquisition of FRIDA.

6.5 Data factory pipeline

The data factory pipeline has been developed by the Universidad Complutense de Madrid, and its design is essentially complete. It consists of three main filter packages, namely, Data Reduction Filters, Calibration-related filters and Quality Control filters. In addition there is the DFP Use Cases Models that define a sequence of actions for the system to return an observable result or value and leads to the Reduction Recipes Packages. Figure 10 shows en example if the logical structure of the DFP.

7 Science with FRIDA

The combination of high spectral and spatial resolution combined with the light grasp of GTC will be a powerful capability of FRIDA. Since FRIDA will start operations with GTCAO in its NGS mode this will limit the observable realm of FRIDA in many instances to the local

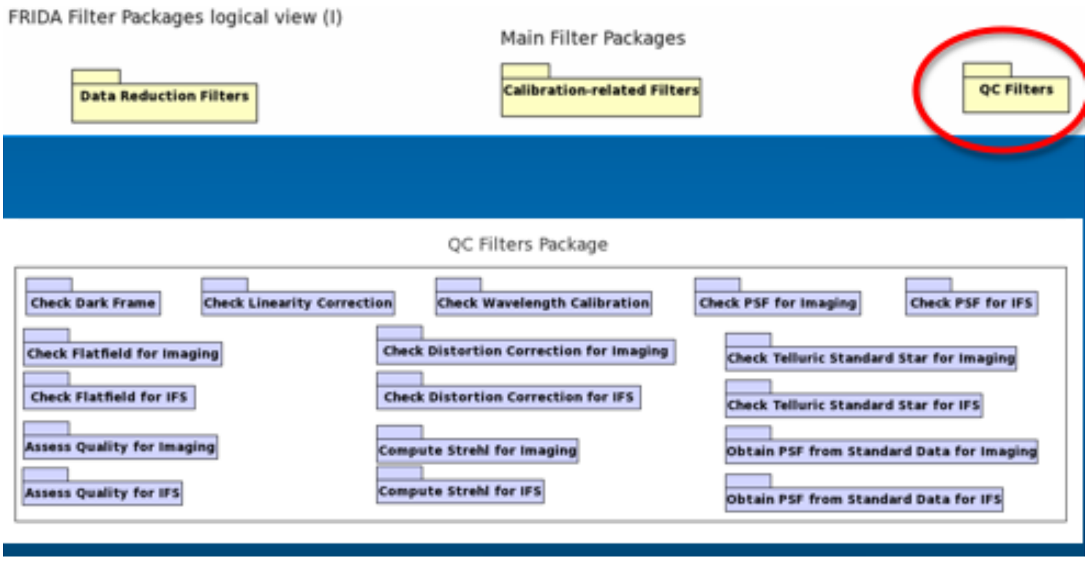
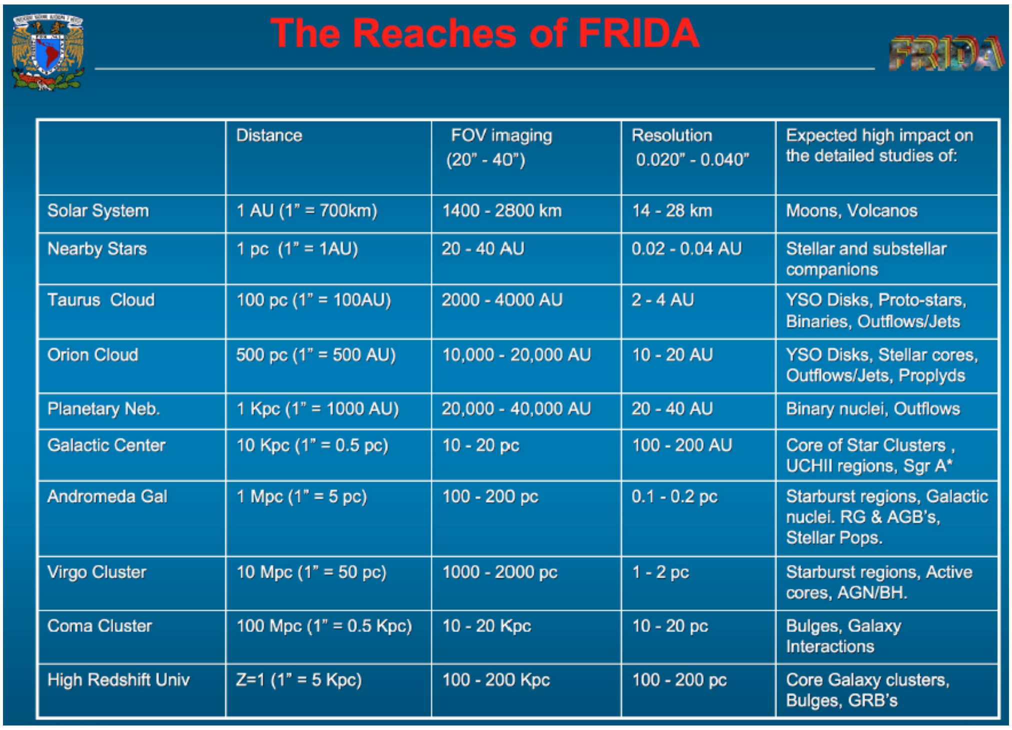


Figure 10: Example of the logical structure of the DFP of FRIDA


The Reaches of FRIDA

	Distance	FOV imaging (20" - 40")	Resolution 0.020" - 0.040"	Expected high impact on the detailed studies of:
Solar System	1 AU (1" = 700km)	1400 - 2800 km	14 - 28 km	Moons, Volcanos
Nearby Stars	1 pc (1" = 1AU)	20 - 40 AU	0.02 - 0.04 AU	Stellar and substellar companions
Taurus Cloud	100 pc (1" = 100AU)	2000 - 4000 AU	2 - 4 AU	YSO Disks, Proto-stars, Binaries, Outflows/Jets
Orion Cloud	500 pc (1" = 500 AU)	10,000 - 20,000 AU	10 - 20 AU	YSO Disks, Stellar cores, Outflows/Jets, Proplyds
Planetary Neb.	1 Kpc (1" = 1000 AU)	20,000 - 40,000 AU	20 - 40 AU	Binary nuclei, Outflows
Galactic Center	10 Kpc (1" = 0.5 pc)	10 - 20 pc	100 - 200 AU	Core of Star Clusters , UCHII regions, Sgr A*
Andromeda Gal	1 Mpc (1" = 5 pc)	100 - 200 pc	0.1 - 0.2 pc	Starburst regions, Galactic nuclei. RG & AGB's, Stellar Pops.
Virgo Cluster	10 Mpc (1" = 50 pc)	1000 - 2000 pc	1 - 2 pc	Starburst regions, Active cores, AGN/BH.
Coma Cluster	100 Mpc (1" = 0.5 Kpc)	10 - 20 Kpc	10 - 20 pc	Bulges, Galaxy Interactions
High Redshift Univ	Z=1 (1" = 5 Kpc)	100 - 200 Kpc	100 - 200 pc	Core Galaxy clusters, Bulges, GRB's

Figure 11: Examples of the reaches of FRIDA for some astronomical phenomena. The field of view and a range of spatial resolutions as a function of distance are listed according to the use of the fine or medium scale of FRIDA. This shows the high expected impact of FRIDA on the detailed study of these fields.

Universe, unless suitable guide stars are found available at larger zs in the field of view. However, the aggressive spatial scales and high spectral resolving power of FRIDA will make it uniquely suited to explore in detail the kinematics and structure of the innermost regions of complex phenomena such as active galactic nuclei, regions of star formation, X-ray binaries, micro-quasars, accretion disks at various scales, binary nuclei, etc.. Figure 11 shows some of the potential scientific reaches of FRIDA.

8 Conclusions

The FRIDA design is now closed and frozen. Approximately 70% of the instrument is already manufactured with similar proportions of software and electronics hardware ready. FRIDA is starting systems integrations and verification and it is scheduled to terminate its assembly, integration and verification of the whole system by the end of 2015. It will then be transferred to GTC to await verification on site and commissioning. FRIDA will allow GTC to exploit its full potential and provide an access for the local community to the realm of high spatial and spectral resolution astronomy.

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