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UNIVERSITÀ DEGLI STUDI DI PADOVA

Characterization and calibrations of VIS cameras for space applications – JANUS and HYPSOS systems

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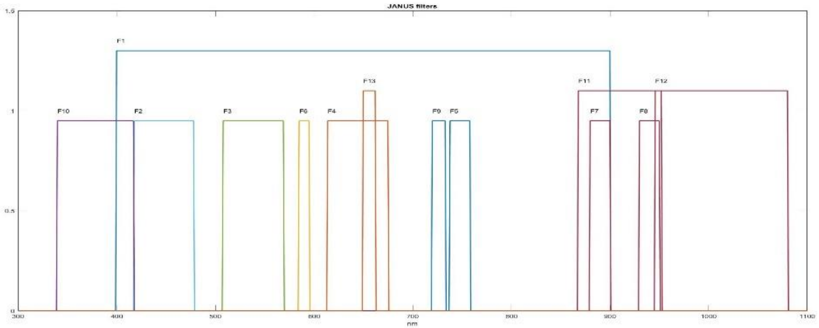
JANUS on board JUICE



JANUS (Jovis Amorum ac Natorum Undique Scrutator) is the high-resolution camera on board the ESA JUICE (JUpiter Icy Moons Explorer), the first Large mission of the framework of the Cosmic Vision 2015-2025.

The main scientifical objective is the study of the emergence of habitable worlds, with focus on Ganymede and the Jovian system (the icy moons host subcrustal liquid water oceans). JANUS has a very broad range of scientifical goals both as lead instrument and as context for the other one in a fully synergistic way.

The instrument is composed by three main parts: the Main Electronics (MEU), the Proximity Electronics (PEU) and the Optical Head Unit (OHU). The telescope features a modified Ritchie-Chretien telescope with dioptric corrector.
Thanks to a Filter Wheel with 13 filters, it can provide multispectral imaging with an overall range from 350 nm to 1080 nm

Detector's features (1/2)

- Selected sessions has been included for the analysis of the detector's properties such as Dark current generation rate, Offset, DSNU, Readout noise (RoN) and related dependencies from temperature.

- The various analyses has been performed considering the tiled structure of the detector/electronic readout. Each tile has its own readout chain which includes both a reference and signal path to perform a Correlated Double Sampling (CDS) acquisition.

- As it possible to see from the figures, the variation with temperature is negligible with a generation of less than 6 DN at 100s
  The RoN is about 2.5 DN in median (about 5 e-).

Detector’s features (2/2)

Radiometric calibration

The radiometric calibration objectives is to provide a mapping between the digital output of the instrument and some physical (radiometric) quantity of interest.

The calibration sessions have two types of measurements: fixed radiance level with varying integration time (ITFvsTexpo) and fixed integration time with varying radiance level (ITFvsRad). In the analysis are also included when possible different temperature setpoints, different integration time range and radiance level spanning a broader parameter's space (see for example F9).

To perform a preliminary evaluation the spatial average value (on each tile) has been plotted wrt the product of radiance and integration time. The radiance is evaluated using the monitoring photodiode and used to generate the x-axis and as input of the radiometric model developed.

Geometrical calibration (1/2)

The objective of the geometrical calibration is to provide a mapping between the 3D coordinates of the space and the 2D coordinates on the detector. This translates into the determination of a set of parameters such as: focal length, FOV, IFOV, distortion map, boresight direction and stability of this parameters with the temperature

Two different types of measurements are available: boresight (BS) and Line Of Sight (LOS)

The analysis of this two types of measurement provides different information. From the BS an evaluation of “dispersion” induced by using different filters and a response of the system to different temperature (BS) is possible in principle. From the LOS a more extended set of parameters are obtainable. They have been thought to be complementary and, in the meantime, optimize the schedule.

Geometrical calibration (2/2)

Geometrical calibration (2/2)

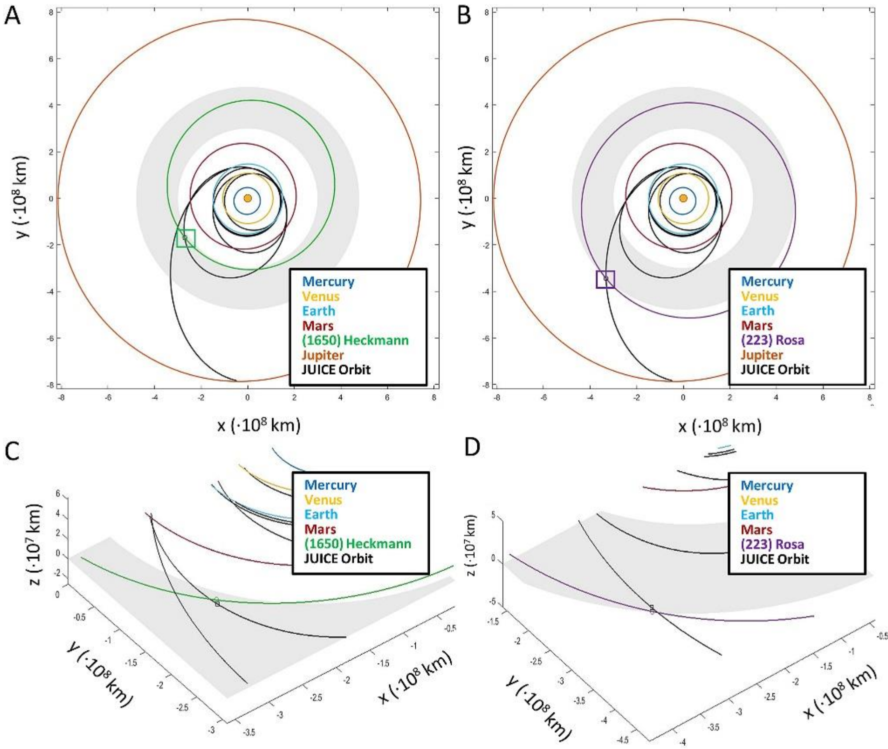
Spectral calibration

The Spectral Response Function (SRF) describes how the instrument (each filter) spectrally responds to the sources. This measure aims to provides indications on the relative SRF shape and to verify the bandpass and central wavelength of each filter

The dataset is generated with a pinhole on the focal plane of a collimator. The pinhole is illuminated by a small Teflon integrating sphere fed by a monochromator. The filter edge and the plateau are illuminated with different integration times and with different sampling.

Each image is background-subtracted and normalized by the integration time and a preliminary flat-field image. After that a centroid algorithm identify the center of the spot and the sum of the DN over a radius of 4 pixel is calculated. Finally, the curve is normalized over the lamp input and then to the maximum value to highlight the shape. From the radiometric model the ITF is normalized to 1 for comparison

Targets of opportunity



JUICE will spend about 8.5 years in the interplanetary cruise before reaching the Jovian system.
The possibility to observe some targets of opportunity has been analyzed (in particular asteroids). The idea is that the celestial bodies closer to the nominal trajectory will be also easier to reach with a dedicated flyby. Asteroids are in fact fundamental blocks of our comprehension of the Solar System formation. Observing a minor body will maximize the scientific return of the whole mission.

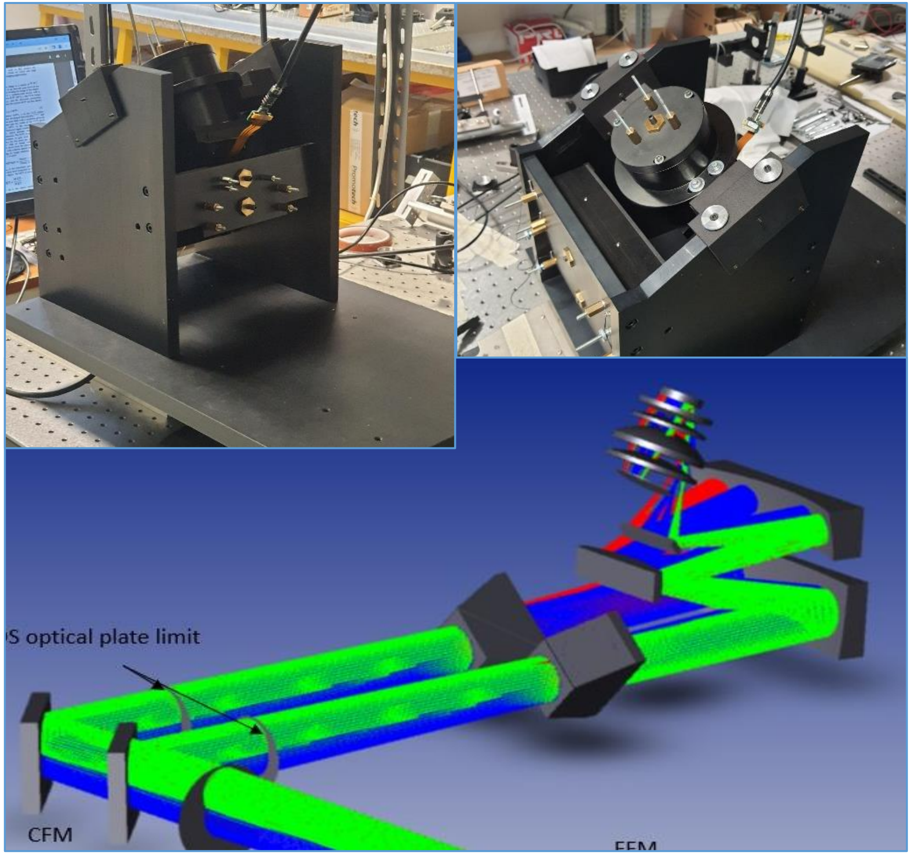
About 140000 asteroids has been analyzed

A dedicated software has been developed to analyze the trajectory of the spacecraft and the asteroids (based on SPICE and MatLab). The analysis has carried out using the meta-kernel *juice_crema_5_0b23_1.tm.* The SPK kernels for asteroids retrieved from NASA HORIZONS systems.

A list of 71 possible targets has been provided to the scientific community and in particular to ESA as input. Two interesting targets has been considered, on which ESA performed an analysis of feasibility.
Publications:

- Agostini et al. 2022, doi.org/10.1016/j.pss.2022.105476)
- Advellidou et al, 2021 doi.org/10.1051/0004-6361/202142600

HYPSOS (HYPerspectral Spectral Observing System)



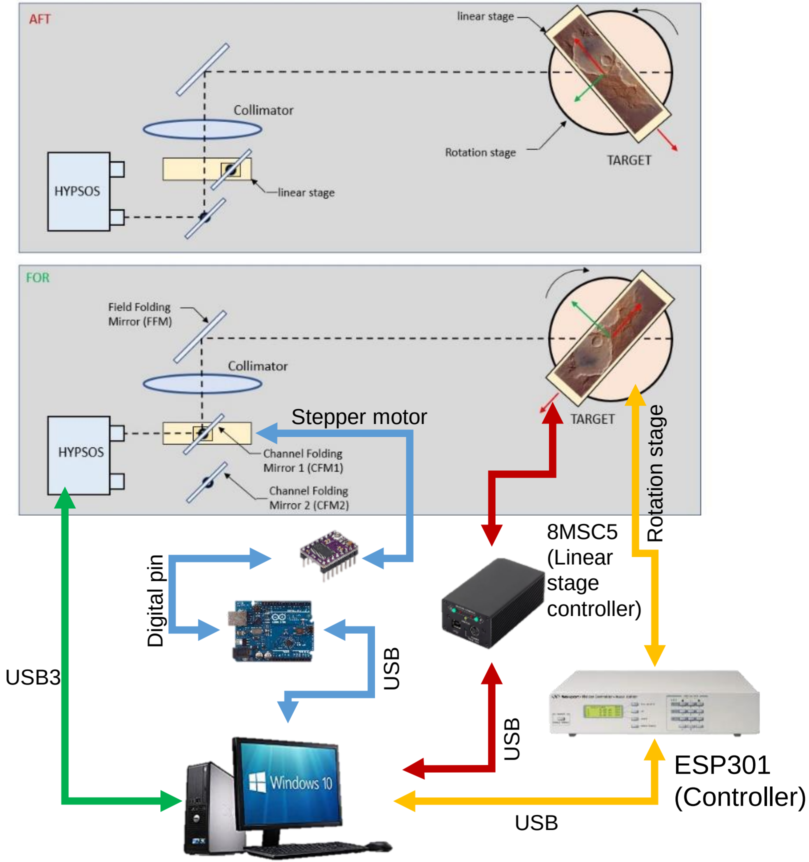
HYPSOS is a novel optical instrument designed to generate hyperspectral Digital Terrain Models (4D) with a fully passive approach.

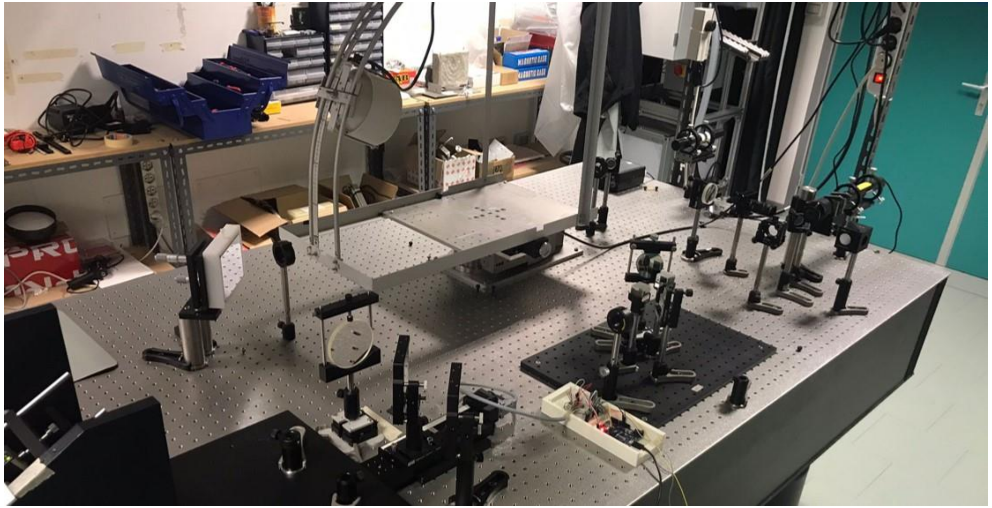
Combining a stereo camera with an imaging spectrometer in the way HYPSOS does (the channels share the same optical elements and the same detector) allows to strongly reduce the problems of data fusion required to create the same type of data.

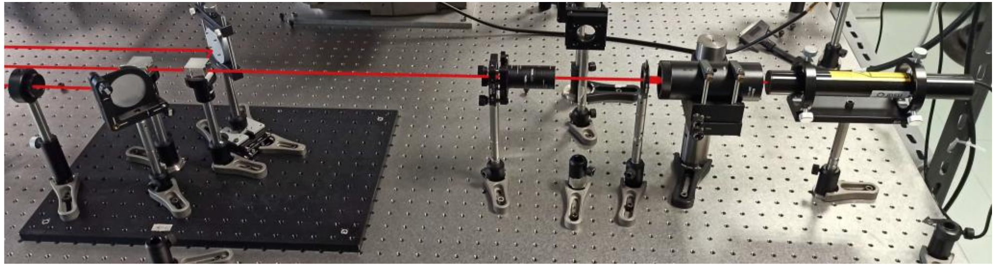
The instrument couples a Three Mirror Anastigmat (TMA) telescope with a Dyson spectrometer in a pushbroom configuration. A key component of the current optical design is a couple of Pechan prisms which allows to rotate the fields from the two channels on the same slit

A laboratory prototype is under development founded by contract ASI-INAF-2018-16-HH.0

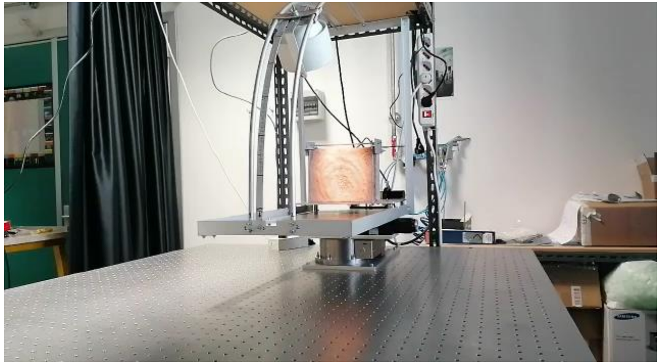
Setup development







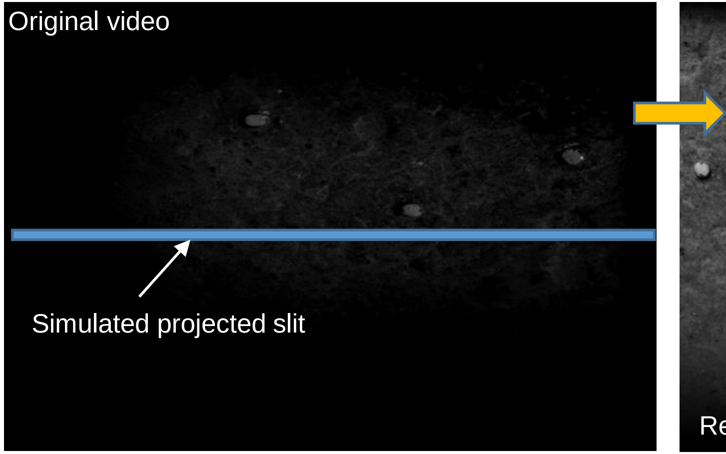
Acquisition software

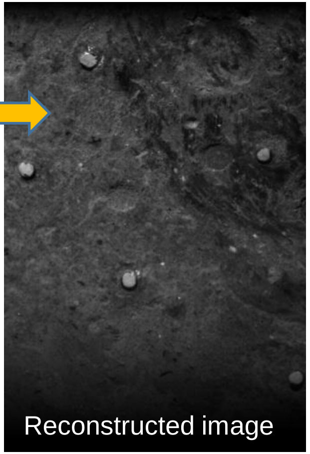


A dedicated control software is required to manage all the hardware and in general to acquisition sequence. In fact, HYPSOS works in a pushbroom mode, meaning that to generate a 2D spatial image suitable for a photogrammetric code a high number of frames should be acquired → difficult to manually manage

A set of libraries has been developed to interface the control software with the hardware. The overall code is highly flexible and stable and thanks to a modular approach it is possible to substitute some libraries with other for specific test also during the assembly and verification of the instrument (see video and image).

The software manages a *dynamical* acquisition, in which the frame rate is suitably coupled to the linear stage velocity.



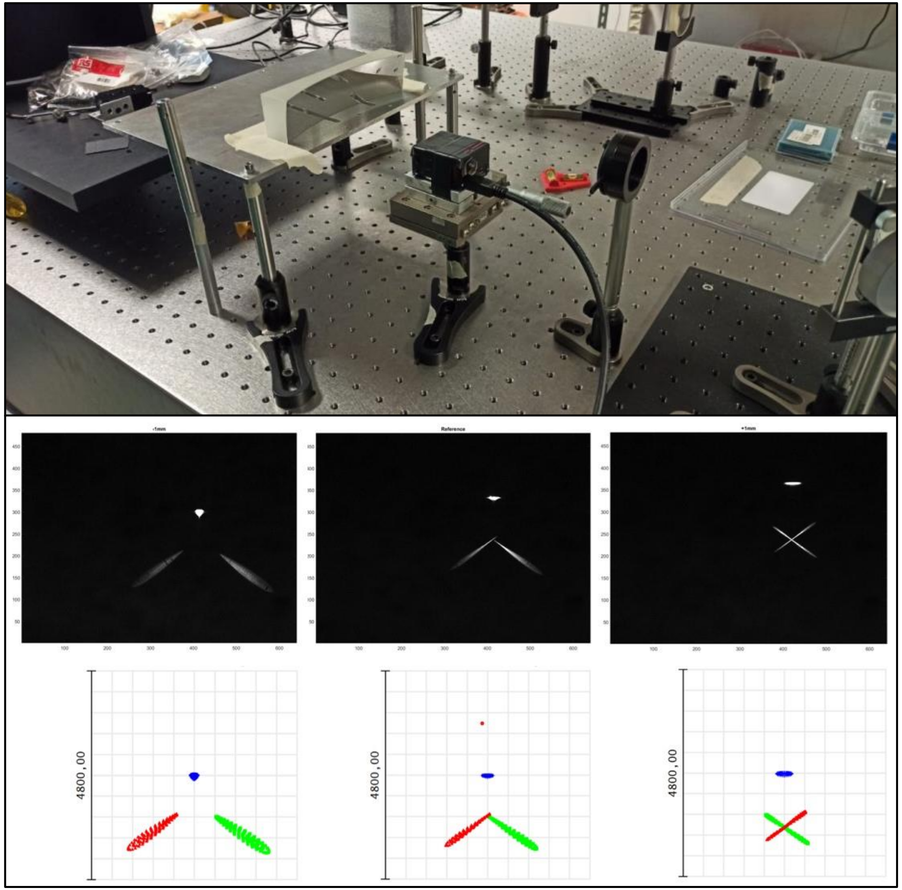


Each one the code is launched it performs a sequence to generate the required actions to generate the Spectral DTM:

- Initialize the communication with hardware
- Execute home procedure for all moving parts
- Rotation (ϑ) and translation
- Rotation (-ϑ) and translation

The code has been tested in laboratory providing reliable results. A preliminary test on image generation from pushbroom acquisition has been made during the integration/alignment phase of the whole instrument using a service camera (a dedicated library was used instead of the default one) with good results.

Components characterization (1/2)

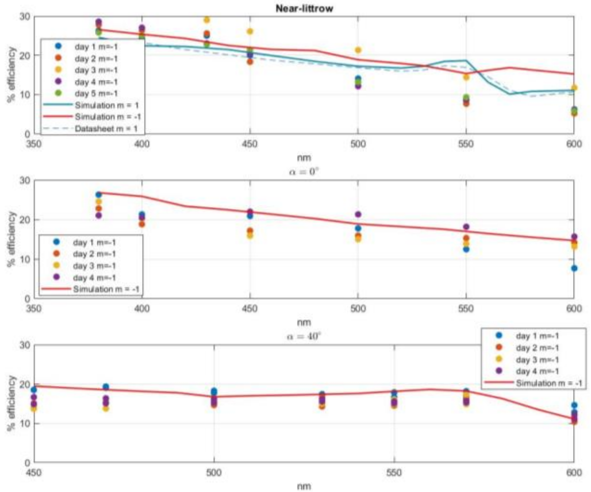


Before the integration and alignment phase of the instrument a slot in the instrument development schedule has been dedicated to characterization of the components in order to verify the nominal behavior. In particular, a qualitative control of the mirrors shape (M1 & M3) has been performed and an evaluation of the diffraction grating efficiency

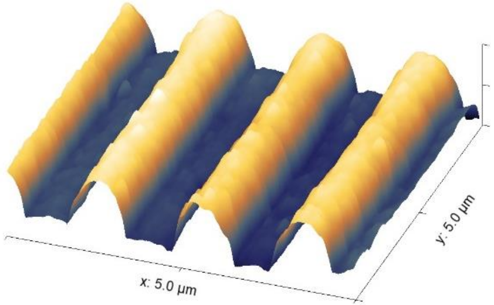
To characterize the mirrors, the alignment tool has been used. The mirror has been located on a platform (or on HYPSOS in the case of M1), aligned and a camera is located on a manual precision linear stage in order to provide through focus images. The images taken at different positions wrt a reference has been compared with a Zemax simulation of the setup.

The images show a good agreement with the simulation providing indication that the mirrors are as required in terms of curvature radius and conic constant

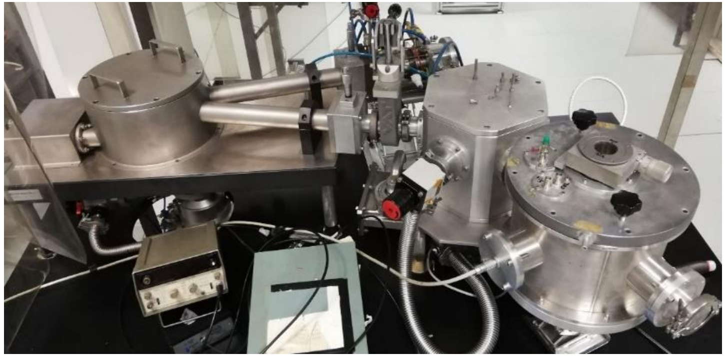
Components characterization (2/2)



The Atomic Force Microscope (at CNR-IFN Padua) has been used to characterized the topography of the gratings at two levels of resolution. A verification of the groove density has been performed and the shape too. The shape parameters has been used to perform a simulation with PCGrate Demo software of the diffraction efficiency. In order to evaluate experimentally the efficiency, a double-monochromator setup has been used where the monochromatic input is provided by the Johnson-Onaka monochromator of the reflectometer facility at CNR-IFN Padua. The efficiency is evaluated as the ratio of the currents after/before the lightpath is elaborated by the gratings.

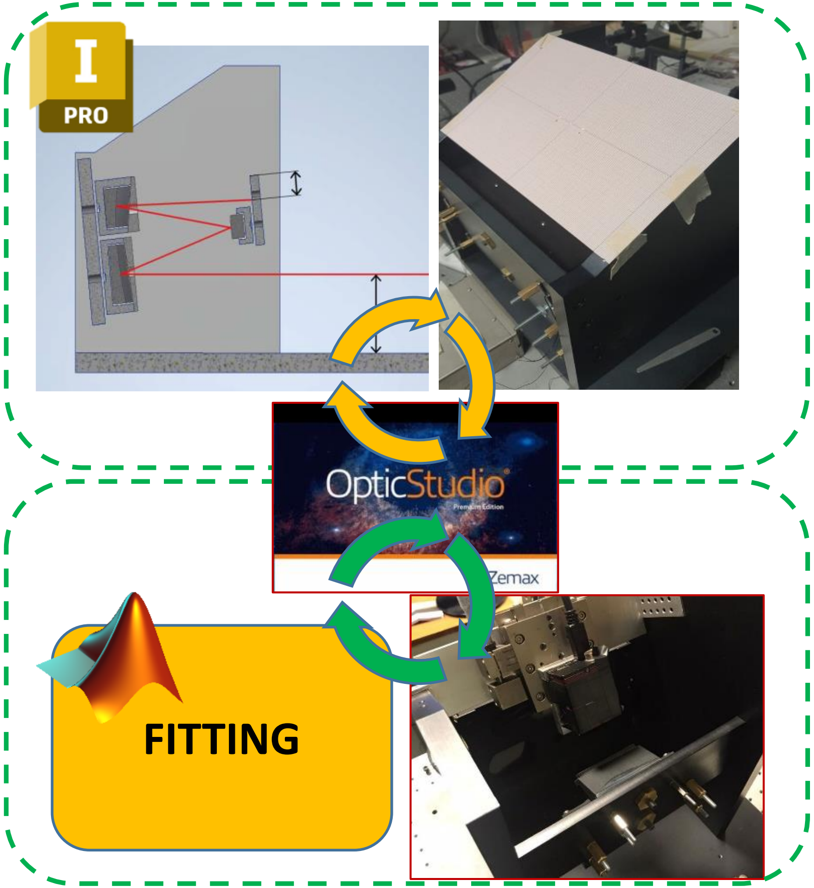


The surface seems to show a good quality with a limited number of cosmetic defects. A preliminary estimation of the groove density is in agreement with the prescription (678 g/mm nominal wrt 680+/-20 g/mm calculated).



The efficiency evaluated experimentally Seems to have a good agreement with the simulation in particular for incidence angle of 0° and 40°. The near-Littrow case shows higher differences although the overall quality seems good considering the difficulty of the measurement. The simulation captured also some specific trend

Telescope alignment



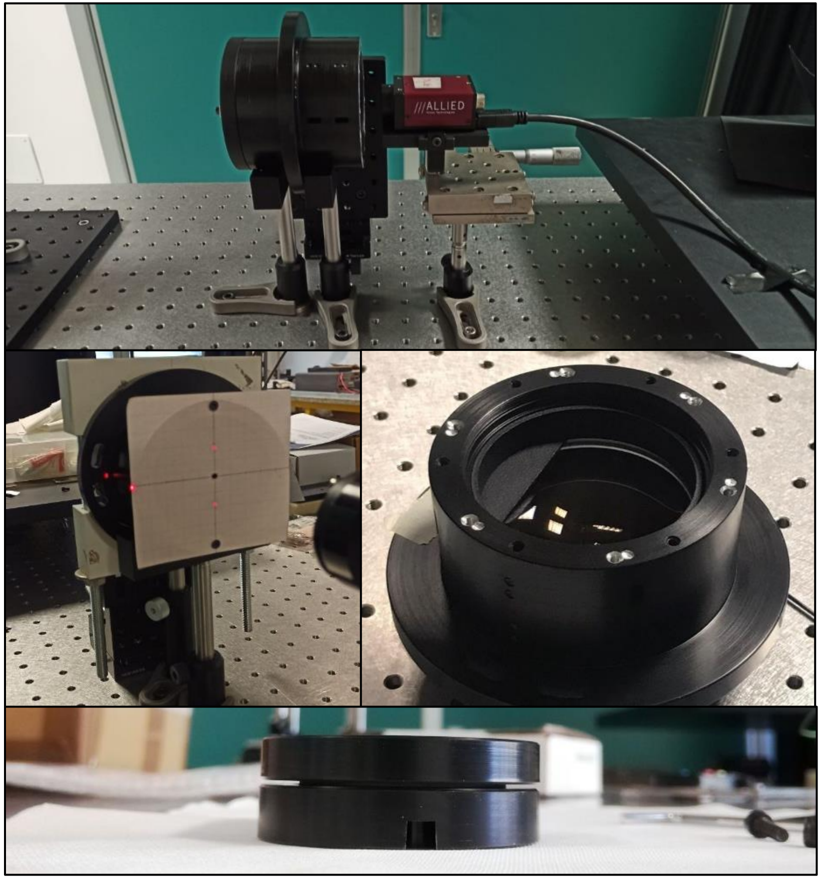
The telescope requires 4 mirrors should be aligned in order to correctly work. They are 2 off-axis aspherical surfaces (M1 & M3), 1 spherical mirror (M2) and 1 plane mirror (FM).

The alignment procedure made use of the already cited alignment tool, which provides 3 parallel laser beams. Before each session started a check of the ray parallelism has been performed using dedicated procedure. The alignment strategy has been divided into two main phases:

- Coarse alignment. Using combination of Zemax/Inventor models and graph papers
- Fine alignment: Using spots, relative positions and specifically developed Zemax merit function (optimization)

The procedure is relatively fast, and the fine alignment make reliable results in the movement of the spots towards the desired configurations. Anyway, in general, it seems to provide good but suboptimal results in terms of global alignment, probably due to a dependance from the starting point.
For not well understood reasons, the focal points of the two channels are on a different position along the optical axis.

Spectrometer assembly and verification, diffraction grating alignment

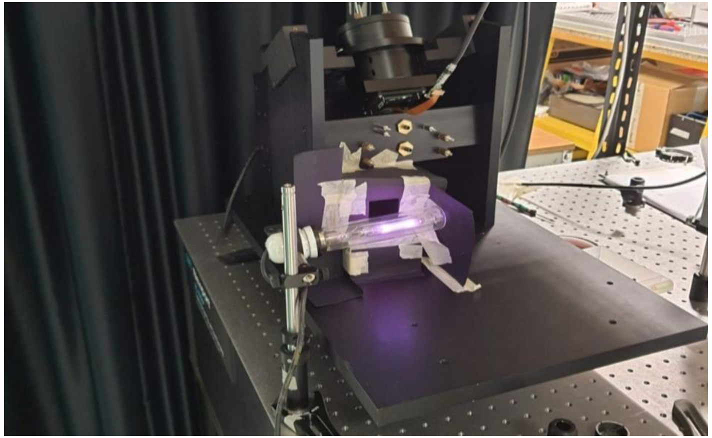


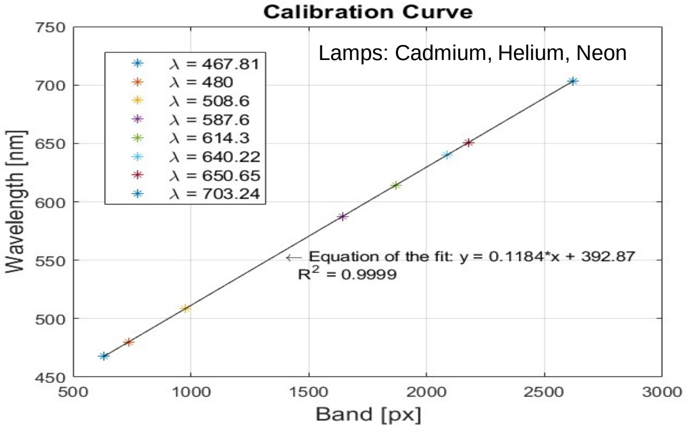
The spectrometer has been assembled in laboratory and several activities has been performed to verify the status of the assembly. After that, the diffraction grating (inside its support) has been mounted and aligned.

The barrel has been aligned to a laser beam using the back-reflection method. After that a camera has been located on a precision manual linear stage and used to very the focal extraction. This allows to very the focal length estimated with the Zemax simulation. Moving the camera through focus allows to verify the spot dimension is coherent with the expected.
The alignment of the diffraction grating is performed taking advantage of the reflected +/- 1 orders. A graph paper aligned mounted on the barrel holes is used to verify the symmetry of the orders with respect to the center. The diffraction grating can be moved thank to 3 threaded rods for tip/tilt, a central rod for piston and the rotation around the optical axis with three buttonholes on the cap.

The measured focal length is 36.5 mm wrt to 36.482 mm of simulation. The diffraction grating has been correctly aligned.

Spectral calibration





The objective of the spectral calibration is to provide a correspondence between the band number (aka pixel index on the detector) and the wavelength, in order to correctly relate the monochromatic image of the slit with the related wavelength

In order to retrieve this relation a set of spectral lamps has been used to illuminate the system. This gas lamps produce emission spectra with very narrow peaks. This peaks are fitted to determine the coordinates on the detector. The spectral registration is possible thanks to information retrieved by NIST curves. After that the spectral calibration is performed fitting a linear curve. This allows to determine the first wavelength detected and the spectral sampling (SSI). This measure has been repeated several times during the alignment phase.

The results seem very reliable and provide a dispersion of 34.32 nm/mm very consistent with the optical design (34.7 nm/mm).

Thanks for the attention

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