The GIANO spectrometer: towards its first light at the TNG

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ABSTRACT

GIANO is a high resolution (R~50,000) IR spectrograph which provides a quasi-complete coverage of the 0.95-2.5\textmu m wavelengths range in a single exposure. The instrument was integrated and tested in Arcetri-INAF (Florence, Italy) and will be commissioned at the 3.58m TNG Italian telescope in La Palma. The major scientific goals include the search for rocky planets with habitable conditions around low-mass stars, quantitative spectroscopy of brown dwarfs, accurate chemical abundances of high metallicity stars and stellar clusters.

This presentation describes the status of the instrument and presents the first results obtained in laboratory during the acceptance tests.

Keywords: Ground based infrared instrumentation, infrared spectrometers

1. INTRODUCTION

GIANO is an optimized near infrared echelle spectrograph which can yield, in a single exposure, 0.9-2.5 micron spectra at a resolution R~50,000.

This project is part of the Second Generation Instrumentation Plan of the Telescopio Nazionale Galileo (TNG) located at Roque de Los Muchachos Observatory (ORM), La Palma, Spain and it has been entirely funded by the Italian Istituto Nazionale di Astrofisica (INAF).

GIANO can provide high resolution spectra for accurate radial velocity measurements of exo-planets and for chemical and dynamical studies of stellar or extragalactic objects down to a magnitude limit comparable to that of 2MASS. The main science targets of GIANO are as follows.

- Exo-planets - The capability of GIANO to simultaneously measure a huge number of near-IR features at high spectral resolution will make it the optimal tool in the search for low-mass rocky planets around cool, low-mass stars.

- Brown dwarfs - A wide, continuous spectral coverage in the near-IR is the optimal tool for the classification of very low mass stars and brown dwarfs. The high spectral resolution capabilities of GIANO will allow to perform quantitative spectroscopy to study the chemical composition of their atmosphere and their circumstellar activity.

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• Star-forming regions - By studying the velocity structure of suitable emission lines in star-forming regions it will be possible to obtain fundamental information on accretion/ejection mechanisms in active protostars and on how the activity of low mass young stars evolves from the embedded to the pre-main sequence phase.

• Cool stellar atmospheres - The unique combination of high spectral resolution and wide spectral coverage will allow us to derive very accurate abundances of many atomic and molecular species, to measure magnetic fields and mass loss activity in any class of cool stars. This information is crucial for our understanding of the stellar physics, evolution and chemical enrichment.

• Extragalactic stellar clusters - GIANO can provide near-IR integrated spectra of stellar clusters in the local Group and beyond, allowing to determine both their chemical composition and dynamical mass, and constrain the star formation history and chemical enrichment of their host galaxies.

• Initial Mass Function (IMF) in starburst galaxies - By resolving the width of absorption and emission features in dust embedded Super Star Clusters (found in starburst galaxies) it will be possible to tightly constrain their dynamical mass and IMF and its dependence on the level of activity and metallicity of these systems.

• Damped Ly-alpha systems - GIANO will allow to determine the metallicity of high-z Damped Ly-alpha systems illuminated by bright/lensed QSO and GRBs, by measuring the equivalent width of the associated absorption by various atomic lines, which are shifted into the near-IR.

2. INSTRUMENT DESCRIPTION AND STATUS
The spectrometer optical design is based on a three mirrors anastigmat (TMA) combination used in double-pass, which acts both as collimator and camera. The collimated beam is 100mm and the system focal length is 420mm. The dispersing element is a commercial 23.2 ll/mm R2 echelle working at a fixed position in a quasi-Littrow configuration with an off-axis angle along the slit of a ~5 degrees. A system of prisms from high dispersing IR optical materials acts as cross-disperser. As the entrance image of this system lies close to the detector, we also included a 2-mirrors system which re-images the slit at a convenient place, far from any critical element.

The entrance slit is the first optical element at cryogenic temperatures. It is illuminated by the beam from the pre-slit optics, which feeds two conic mirrors. These re-image the focal plane at a focal aperture of F/4.2 on a side of the detector. The light then enters into the TMA which creates a 100mm collimated beam feeding the cross-dispersing prisms and the grating. The rays reflected from the grating pass again through the prisms and are focused onto the array by the same three mirrors. Two flat mirrors are added to conveniently position the array, the input slit and the slit reimaging mirrors. The optical performances of the system are excellent, with >80% en-squared energy within one pixel over most of the array area. Fig. 1 shows the spectrometer optical bench.

The two main mechanical components of GIANO are the spectrometer cryostat, the tank for liquid nitrogen and the optical bench, which are both machined out of a block of Al-6082, whose thermal expansion coefficient was accurately measured and found to be equal to that of Al-6061, the alloy used to manufacture the mirrors. The bench is fixed in one point and elastically pressed onto the tank. Thin Pb foils are inserted to improve the thermal contact. The aluminum liquid nitrogen tank is isostatically mounted on a hexapod system. The hexapod arms and joints are made of stainless steel to achieve a reasonably low heat conduction, while maintaining a rigid and easy to manufacture system.

With respect to its initial design the current baseline of the spectrometer has been simplified and optimized for its high resolution (HR) mode. Major changes can be summarized as follows.

• GIANO is now a single-face spectrometer since the low resolution (LR) has been eliminated. This follows from the choice of moving the instrument to the TNG Nas-A platform, where the only way to get light from the telescope is via fibers, which are inadequate for observing faint objects at low resolution.
The IMA mode is not included. It was foreseen to have imaging for centering the object in the slit. It is not necessary because the slit is illuminated from a fiber at a fixed position. Object centering is done in the pre-slit, at the other end of the fiber.

The SHR mode, used to observe the portion of the K band outside the standard echellogram configuration, was also eliminated because reflections from the thin SHR prism inserted before the echelle produced strong ghosts of white-light.

Long-slit (spectro-astrometry) observations are not possible, because all spatial information are lost once the light from the telescope enters into the fiber.

The HCl/HBr/HI gas cell and the polarimetric module could not be implemented because of the very limited space available at the telescope focal plane in the Nas-A, before the fibers entrance.

A HRup/HRdown has been added. It moves the detector in order to dither the image by ~6 pixels in the Y direction. This is necessary to correct for the large number of bad pixels of the spare detector which is currently used in the instrument.

The optical bench and the holders of the mirrors have been rebuilt because the special system previously developed was later on found to be exceedingly sensitive to mechanical vibrations.
3. PRESLIT AND TELESCOPE INTERFACE

The spectrometer is fed through a bundle of 2 ZBLAN fibers (manufactured by IR-photonics) connected to the TNG straight focus at the Nasmyth-A. These fibers are standard off-the-shelf products with a core of 85 µm, which corresponds to a sky-projected angle of 1 arcsec, and a cladding of 125 µm. The two fibers are aligned and mounted inside a custom connector. The cores are at a distance of 0.25 mm, equivalent to a sky projected angle of 3 arcsec. The bundle is inside a steel jacket, in order to protect these fragile fibers from bending and breaking.

The fibers entrance is mounted at the straight Nasmyth-A focus. The layout of the fibers-telescope interface is shown in the left panel of Fig. 2. The F/11 beam from the telescope is focused onto the fibers at F/5 by a singlet CaF$_2$ lens positioned 6 cm before the TNG focus. A pellicle beam-splitter, positioned just before the lens, deviates ~8% of the light to the guider channel working in the Z-band. The autoguide channel consists of a 4-lenses camera feeding a commercial CCD 512x512 array through a RG850 filter. Since the relative positions of the fiber and the image on the guiding camera is fixed, acquisition and guiding simply consists of centering and maintaining the image at a given (fixed) X,Y position on the guiding camera.

The pre-slit system also includes a calibration channel which re-images, onto the science fibers, the light from the $\varnothing 0.6$ mm calibration fiber. This is connected to the calibration unit which includes a U-Ne lamp for wavelengths calibration and a halogen lamp for flat-fielding.

To avoid mechanical stress on the fiber and simplify telescope operations when GIANO is not observing, the fiber pre-slit module is mounted on a bearing structure which maintains a fixed orientation relative to gravity, independently of the position of the Nasmyth de-rotator. Fig. 2 shows the layout and a picture of the pre-slit fibers-telescope interface mounted at the telescope.

On the opposite end the ZBLAN fibers are mounted at a fixed position 53 cm before the warm lens system which was originally designed and manufactured to take the light directly from the telescope. A CaF$_2$-infrasil doublet is added to adapt the focal aperture from F/4.5 (fiber exit) to F/11 (entrance of the spectrometer).

4. MEASURED/EXPECTED PERFORMANCES

Laboratory and sky tests in Arcetri have provided preliminary measurements of noise and efficiencies. These can be summarized as follows.

- The read-out noise is very low: 5 e$^-$ for a single double-correlated exposure. For most applications the noise performances are dominated by the dark-current (0.05 e/sec).
- By comparing stacked flat-field exposures spaced by 5-10 minutes we obtain pixel-to-pixel rms noise compatible with the photon-noise and overall signal-to-noise ratios larger than 300.
• The spectrometer efficiency (without fiber) measured from thermal background at room temperature turns out to be \(\approx 21\%\) in K (2.1-2.4 micron). Efficiencies at shorter wavelengths have been roughly estimated from observation of scattered sun light and ratios of airglow OH lines from the same upper levels. Preliminary values indicate that they slightly drops in H (by less than 10%) and J (by an amount ranging between 20 and 40%). More firm estimates of these efficiencies will be obtained during the commissioning and science verification at the telescope in the forthcoming months.

• The overall efficiency of the fibers, provisionally estimated from the absolute surface brightness of OH airglow lines, turns out to be about 40%. This value is significantly lower than the 73% measured during laboratory tests with the same type of fibers. This discrepancy may reflect the presence of micro-fractures produced during the connectoring of the fibers at the manufacturing company.

A first version of the Exposure Time Calculator is already available and provides the following limiting magnitudes (Vega units).

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These performances indicate that GIANO could virtually observe all objects detected by 2MASS and to observe late M4-M6 dwarfs (e.g. for exo-planet searching purposes) out to a distance of 20-30 pc.

5. SPECTRAL FORMAT AND FIRST RESULTS
The GIANO echellogram includes the orders from 31 to 80, corresponding to the 0.95-2.47\(\mu\)m wavelength range. It has a full spectral coverage up to 1.8 \(\mu\)m, while at the longest wavelengths the spectral coverage is about 75%.

Fig. 3 shows the echellogram of the halogen lamp for flat-field purposes, while Fig. 4 shows the echellogram of the U-Ne lamp.\(^{11}\) It is worth noticing the spectacular richness of U lines at \(\lambda < 2\ \mu\)m. However, at longer wavelengths the line density is much lower and disturbed by the thermal emission of the lamp.

During the laboratory tests in Arcetri, a number of spectra of the Sun scattered light during daytime were also acquired, an example is shown in Fig. 6.

6. ACKNOWLEDGMENTS
The GIANO Team wishes to dedicate this project to the memory of Sandro Gennari who prematurely passed away on July 30th 2007. We all thank Sandro for his great work on astronomical technologies and GIANO as well as for his immense courage and humanity. We deeply miss him.

REFERENCES
Figure 3. GIANO echellogram of an halogen lamp used for flat-field purposes.
Figure 4. GIANO echellogram of the U-Ne lamp for wavelength calibration.
Figure 5. Details of the GIANO echellogram of the U-Ne lamp showing the width of the lines.
Figure 6. GIANO echellogram of the Sun scattered light.