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The Infrared grisms for ArNICa

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Abstract

In this report, we present the main characteristics of the grisms we have designed for ArNICa (Arcetri Near Infrared Camera) for the TIRGO Telescope and we show the results of the measurements and laboratory tests. The three designed grisms cover the J (1.25 μm), H (1.65 μm) and K (2.22 μm) bands at low (R ~ 300) resolution.

The tests in the laboratory and the first observation made with ArNICa as spectrograph instrument are in agreement with the optical simulation and are compliant with the scientific requests. We show the main characteristics of the grisms of ArNICa and present the performed laboratory tests: the first one to study the efficiency curves of the grisms and the second one to study the simulation of operative condition of ArNICa at the telescope by using an optical element that reproduces the telescope. At last, the first observation at Gornergrat Telescope obtained by Dr. G.P.Tozzi and Dr. M.Di Martino about the spectrum of the Asteroid 1588 is shown.

1 Introduction

The grism is a unique optical dispersive element formed by a prism and a transmission diffraction grating placed on the hypotenuse of the prism. It does not introduce further aberrations because the prism compensates the aberrations introduced by the grating. Moreover this element is characterised by an undeviated wave that coincides with the central wave of the spectral range that we need to observe on the detector. These peculiar characteristics of the grism permit, by inserting one of these elements, to turn an imaging camera into a low resolution spectrograph using the same optical scheme.

ArNICa is an imaging instrument for observing in near infrared bands at the Near Infrared Telescope of Gornergrat (diameter of primary mirror 1.52 m, f/20). Two parts compose it: a collimator and a focus group of lenses. The scale on the detector, NICMOS3 (HgCdTe, 256x256 pixels with 40 μm of pixel size), is about 1" per pixel and it is obtained by a suitable combination of the focal lengths of the optical parts (telescope – collimator – focus lens). The grisms are inserted between the collimator and the focus group of lenses, where the beam is collimated. In our case we optimized three grisms, the first for J band, the second for H band and the third one for K band.

2 The Grisms for ArNICa

Three grisms are projected and realized for ArNICa, one for each near infrared band J, H and K. The three spectral bands are dispersed independently and the area of detector covered by dispersion is the largest possible without changing the present optics of ArNICa. The resolution is about 300 for each band. The three bands are dispersed at the first order of the grisms.

In our case the grisms utilized are formed by three rectangular prisms and three different gratings placed on the oblique sides of the prisms. The Table 1 summarizes the top−level requirements for the nominal design of ArNICa with grisms.

Requirements
• Covering detector from J to K bands (1100 ÷ 2500 nm)
• Individual dispersion of the J band, H band and K band
• First Order grism
• Low (R ~ 300) resolution
• Don't change mechanics and optics elements existed
• Optical performance 80% of Encircled Energy in 1.5 pixel side (60 microns)

Table 1: requirements

The grisms selected among different solutions for the prism−grating combinations are listed in Table2: the prisms material is an infrared Schott glass, the IRGN6, whose index of refraction well matches the index of refraction of the resin used by Milton Roy to replicate the gratings limiting the reflection losses.

Main parameters of the grisms for ArNICa								
#	m	n_{pr} (~ n_{gr})	α_{pr} [deg]	λ_{min} [nm]	λ_o [nm]	λ_{max} [nm]	Res	Band
1	1	1.57	41	1100	1247	1450	320	J
2	1	1.57	39	1300	1495	1800	300	H
3	1	1.57	39	2000	2391	2500	320	K

Table 2: main parameters of grism for ArNICa. Where **#** is the identification number of the prism, **m** is the order of the grism, $\mathbf{n_{pr}}$ is the index of refraction of the glass of the prism, α_{pr} is the angle of the prism, λ_{min} the minimum wavelength dispersed on detector, λ_o the undeviated wavelength, λ_{max} the maximum wavelength dispersed on detector, **Res** the resolution and **Band** the band dispersed.

In Table 3 the parameters of the replicated gratings are given as taken from the Milton Roy catalogue.

Main parameters of the gratings for ArNICa				
#	Band	Milton Roy #	α_{gr}[deg]	Density[lines/mm]
1	J	35−53−*−440	36.8	300
2	H	35−53−*−825	34	240
3	K	35−53−*−890	36.8	150

Table 3: the main parameters of the replicated gratings are given as taken from the Milton Roy catalogue. Where **#** is the identification number of the grating, **Band** the dispersed band, Milton Roy **#** is the identification number of the grating in the catalogue, α**gr** is the blaze angle of the grating and the **Density** (lines/mm) at last.

The grism is a dispersive element that doesn't introduce new aberrations because the aberrations introduced by the grating are compensated by the prism (A.A.Hoag et al., 1970; D. J. Schoeder, 1970; J. M. Beckers et al.). But the incident collimated beam on the grism has residual aberrations that, in the case in which the grisms are not inserted into the optical path, are compensated by the optical system formed by the two focusing lenses. So to correct the residual aberrations and to be compliant with the initial scientific requirements together with the grisms, three different lens correctors that optimize the global performance have been projected and realized (D.Ferruzzi 1994−1995).

In table 4 the main characteristics of the lenses utilized are reported.

Main characteristics of the three lenses for ArNICa						
#	band	rdy s1	rdy s2	thinness	glass	diameter
1	J	19.00±0.01	16.01±0.01	5.59±0.01	ZnSe	15.0±0.1
2	H	18.30±0.01	15.20±0.01	5.90±0.01	ZnSe	15.3±0.1
3	K	21.80±0.01	18.75±0.01	6.30±0.01	ZnSe	16.0±0.1

Table 4: main characteristic of the three lenses for ArNIca. Where **#** is the identification number, **band** the spectral range in which the lens is optimized, **rdy s1** the ray of curvature of the first surface of the lens, **rdy s2** the ray of curvature of the second surface of the lens.

The Schott glass has been purchased directly from Schott through its Italian agent Italglass (Genova). Then the raw glasses have been optically worked into prisms by SILO and the lenses have been manufactured. Then, the prisms have been sent to the Milton Roy Company for the replication of the gratings.

According to the experience acquired with the efficiency measurements performed on the grisms of NICS for the GALILEO National Telescope (F. Vitali et al., July 1997), no difference is expected between the cooled and the room−temperature performances, so the measurements of efficiency have been performed at room−temperature.

3 Assembly of the grisms

In the filter wheel of ArNICa three new elements – each formed by filter, one corrector lens and grism – are inserted and three narrow filters removed. In Figure 1 there is a section of the filter wheel in which the two different prisms (with different α angle, see Table 2) of the three manufactured grisms are mounted into the filter wheel replacing two narrow filters. In the same figure the dimensions of the prisms and other important parameters are presented also. The grisms are selected by the rotation of the filters wheel.

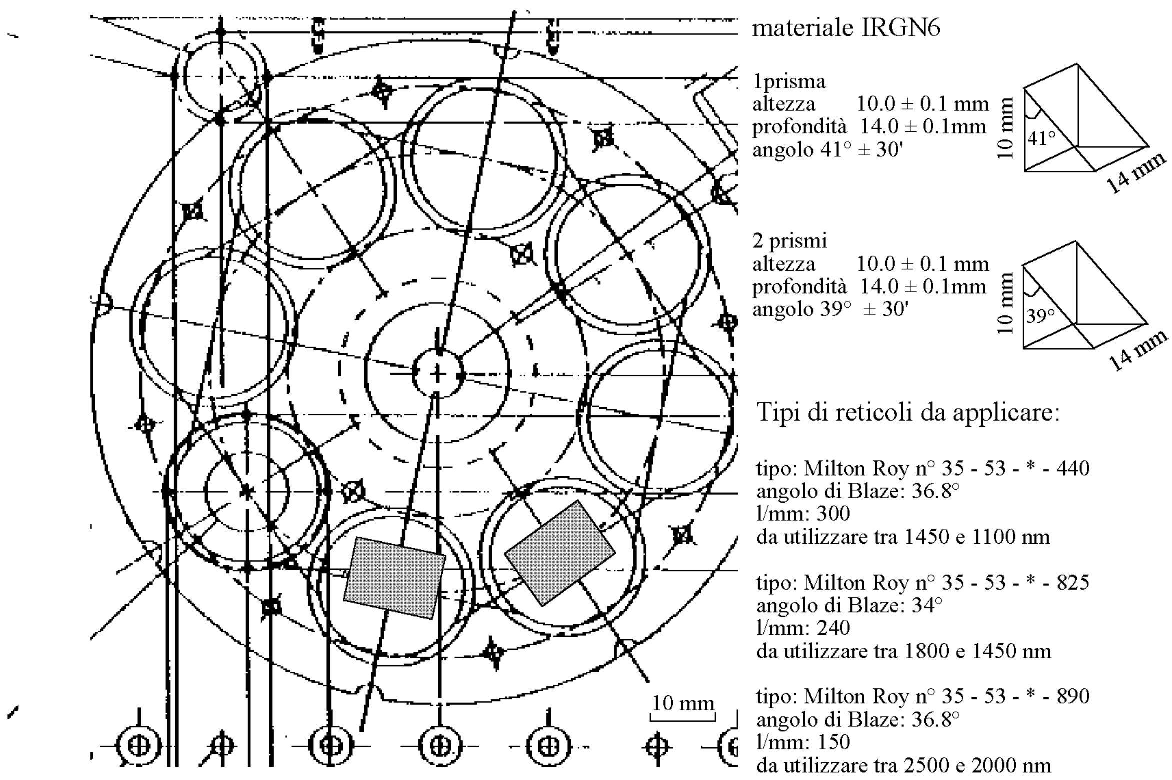


Figure 1 A section of filter wheel, two of the three grisms are inserted.

In Figure 2, the original optical design of ArNICa and of the grism with the new associated lens are reported into the filter box as new optical elements (grey coloured). The lens, the grism and the filter are all enclosed in a unique mechanical piece. Three pieces are made one for each spectral bands.

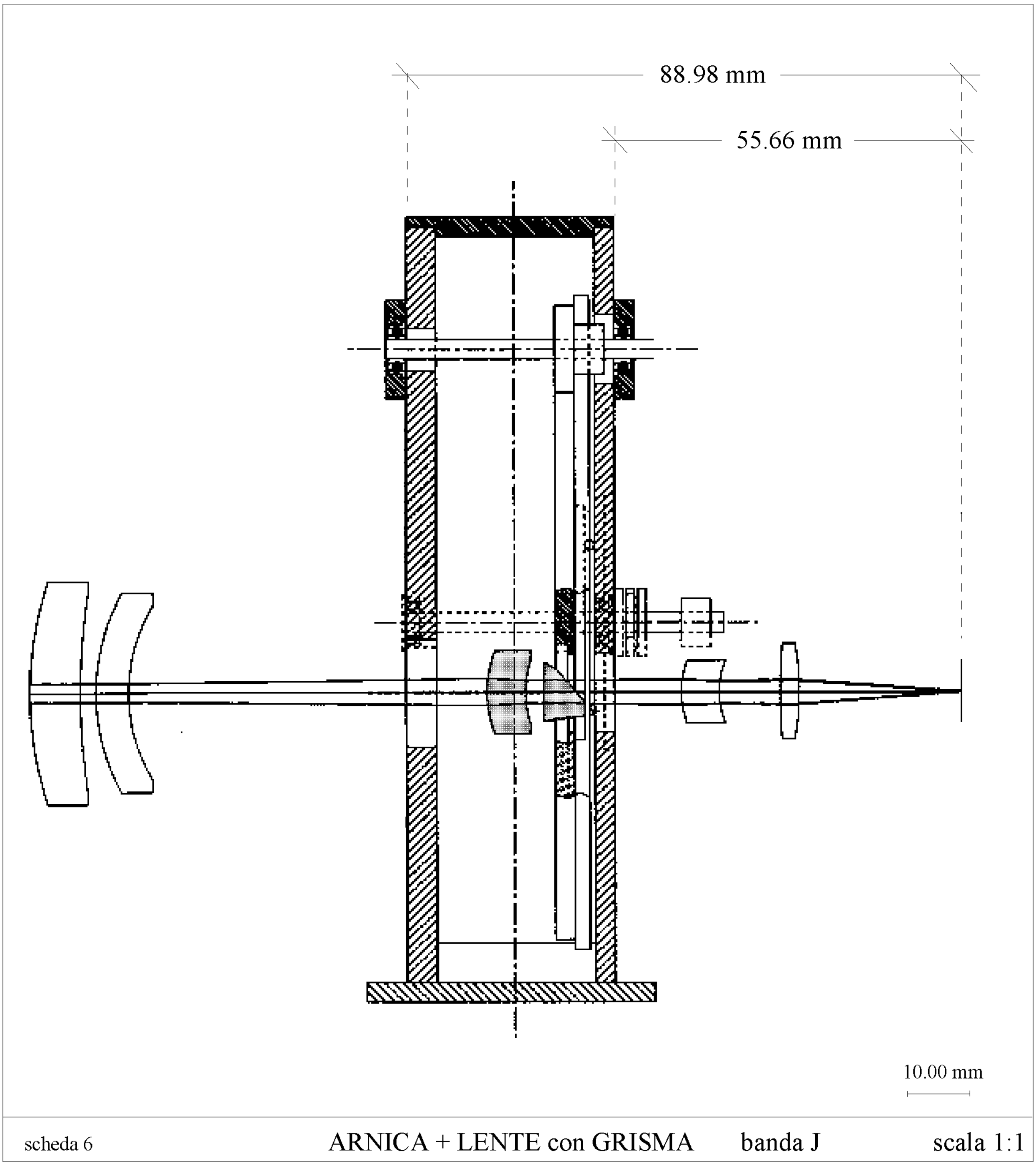


Figure 2 Simulation of inserting in the optical design of ArNICa the filter wheel and grism with lens corrector

4 Laboratory Tests

4.1 Efficiency curves of the grisms

Before the mounting of the three elements formed by filter, lens and grism in ArNICa, the efficiency curves of the grisms are found. The efficiency of the grisms is measured by a Perkin Elmer LAMDA9 spectrophotometer for transmission measurements on the spectral range UV−VIS−NIR (from 300 to 3000 nm) at the Istituto Nazionale di Ottica in Florence.

The relative efficiency of the grisms as a function of the wavelength, with an accuracy of about 0.1% in the range of interest, was measured.

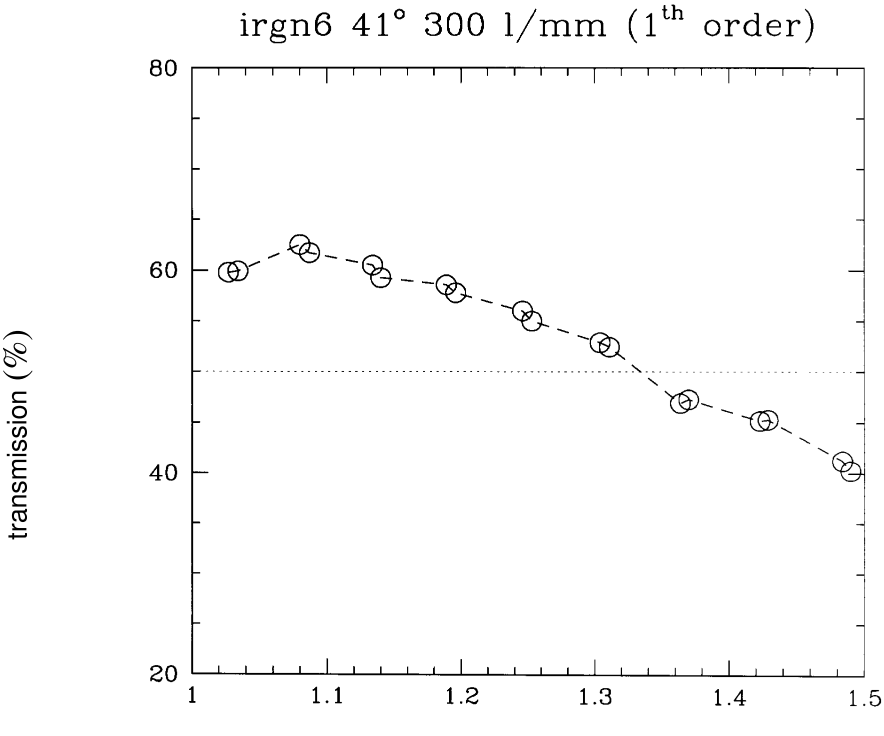
The detector of the Perkin Elmer has a fixed position. Therefore, to perform tests at wavelength far from the central undeviated wavelength, several combinations of the examined grism with one or two wedges of IRGN6 with 2.3° angle and a wedge of BK7 with 7.76° angle are used. The combinations are such that the central wavelength changes and covers the spectral range of the examined band, in this way some deviated λ to reach the detector. The values of transmission of the grism examined are given by the ratio between the total transmission of the combination and the transmission of the BK7 prism multiplied by the transmission of IRGN6 prism. The transmission of the IRGN6 prism as also the BK7 prism is about 0.91.

4.2 Results

First of all, the laboratory tests confirmed that the projected grisms cover the range of the desired wavelength and they are compliant with scientific requirements. The blaze wavelength, corresponding to the maximum efficiency is blue−shifted with respect to the value of the central undeviated wavelength calculated from the geometrical optics. One reason is the difference between the angle of the prism and the blaze angle of the grating. The maximum efficiency is at the central undeviated wavelength if the angle of prism and the blaze angle have the same value.

4.2.1 Grism J (#1)

In Figure 3, the transmission versus the wavelength in microns for the J near infrared band is reported. The circles show the errors in the measurement. The blaze wavelength is about 1100 nm, while the central undeviated wavelength calculated from geometrical optics should be 1247 nm (see Table 2).



wavelength (microns)

Figure 3 Efficiency curve for J grism, transmission (%) versus wavelength (microns)

4.2.2 Grism H (#2)

In Figure 4, the transmission versus the wavelength in microns for the H near infrared band is reported. The circles show the errors on the measurement.

The blaze wavelength is about 1300 nm, while the central undeviated wavelength calculated from geometrical optics should be 1495 nm (see Table 2).

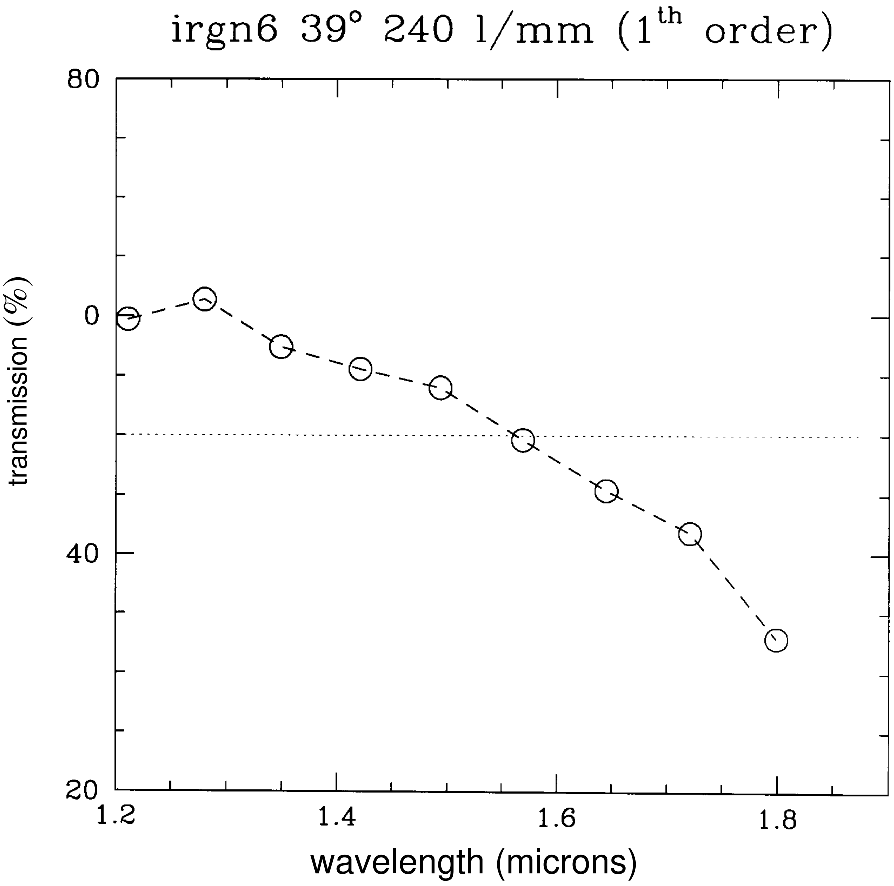


Figure 4 Efficiency curve for H grism, transmission (%) versus wavelength (microns)

4.2.3 Grism K (#3)

In Figure 5, the transmission versus the wavelength in microns for the K near infrared band is reported. The circles show the errors on the measurement.

The blaze wavelength is about 2025 nm, while the central undeviated wavelength calculated from geometrical optics should be 2391 nm (see Table 2).

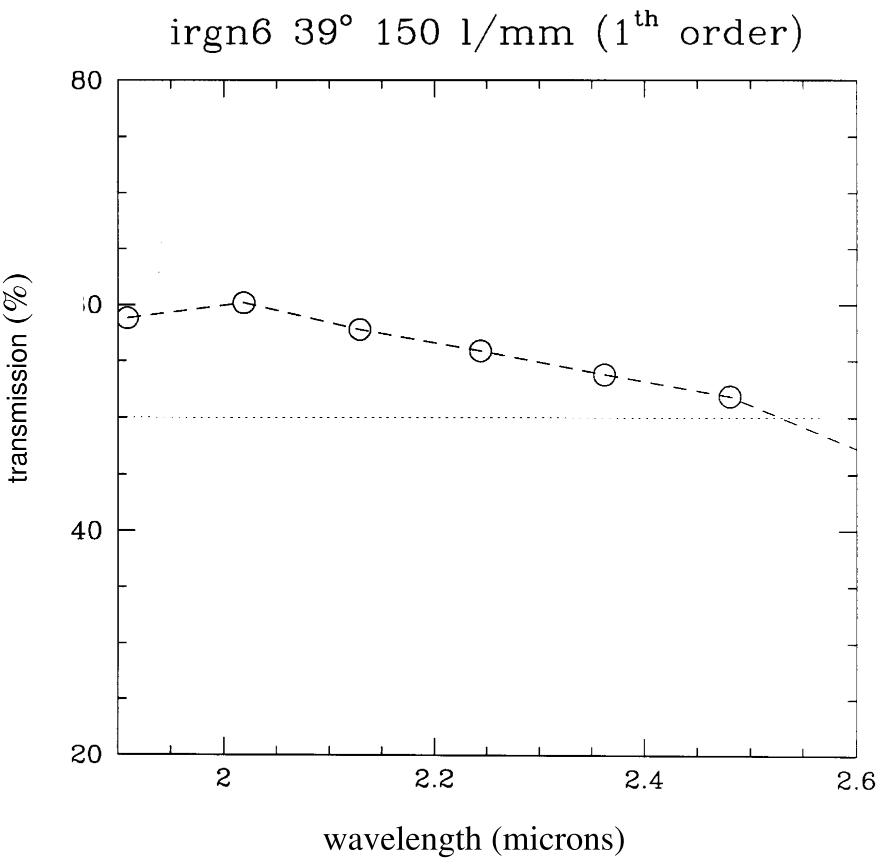


Figure 5 Efficiency curve for K grism, transmission (%) versus wavelength (microns)

4.4 ArNICa with grisms

The analysis of the alignment, of the spectral range, of the detector covering and of the aberrations of the three grisms are made with the complete instrument to check whether the quality of optics after the introduction of the three new elements is near to the quality calculated by the simulation with the optical design software. We analysed the spectrum of the argon lamp in J, H and K bands to measure the covering of all the grisms.

The spectrum obtained by the argon lamp, show that the alignment and the spectral range of the grisms are compliant with the initial requests. Moreover the covering of the detector for the three bands J, H and K and the curvature of the spectral lines are compliant with the optical design. The covering of detector is limited by the fixed dimensions of optical and mechanical elements of ArNICa and by requirements on resolution (see Table1).

In Figure 6, the spectrum of the Argon lamp produced by ArNICa with grism J is shown. The whole frame in the Figure 6 represents the whole detector (256X256 pixels).

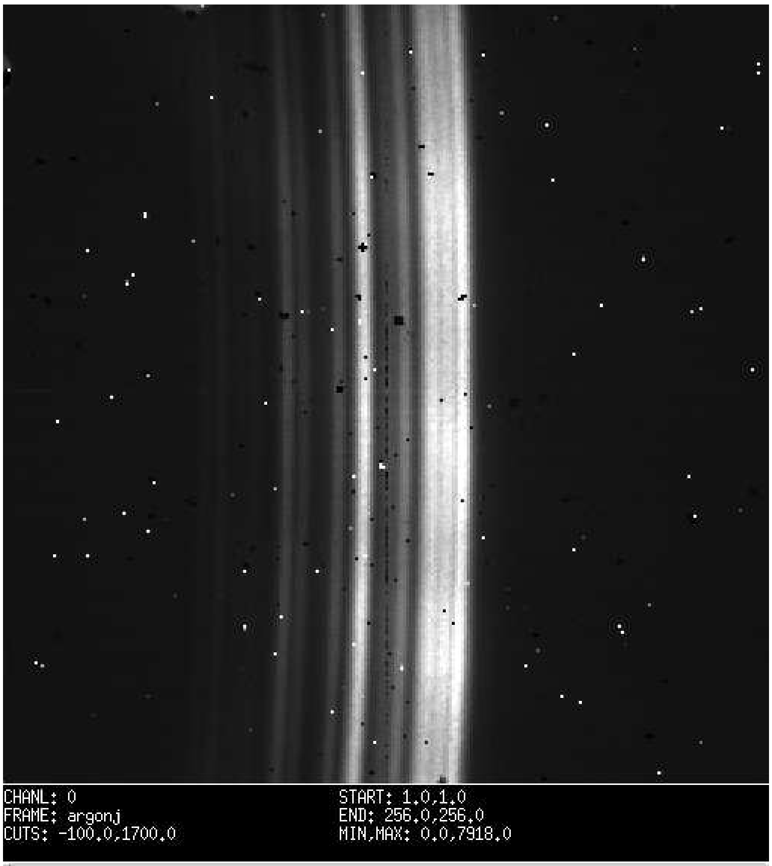


Figure 6Spectrum of the argon lamp in J band with ArNICA with grism

In Figure 7 and Figure 8, the spectrum of the Argon lamp produced by ArNICa with grism H and K respectively are shown

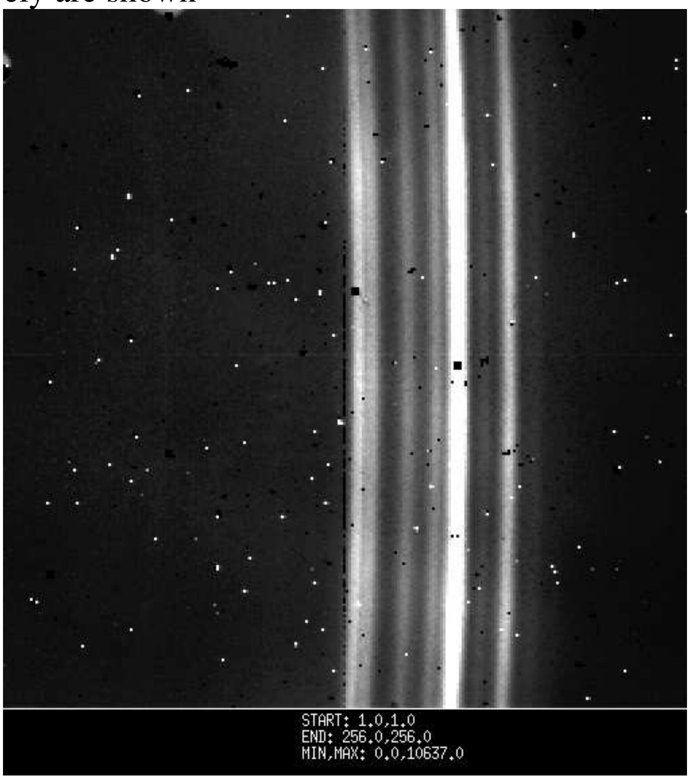


Figure 7Spectrum of the argon lamp in H band with ArNICA with grism

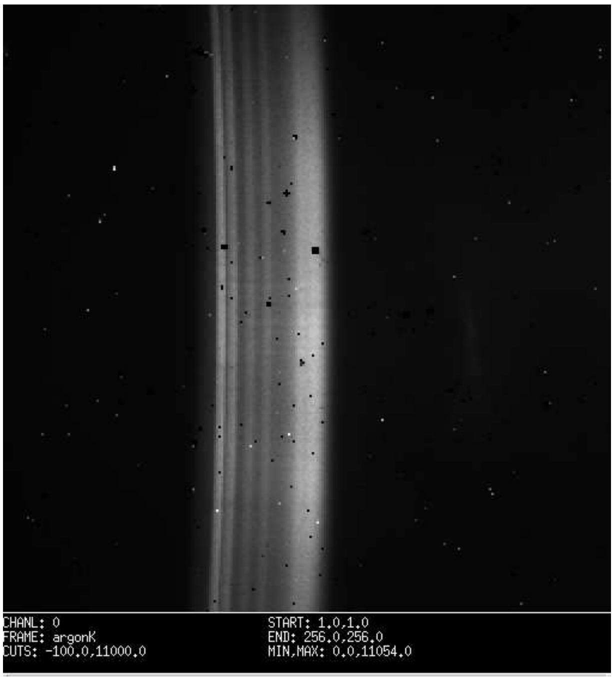


Figure 8Spectrum of the argon lamp in K band with ArNICA with grism

In Figure 9, we show a polychromatic point spread function for J grism. In Figure 10, the spot diagram for J grism is reported.

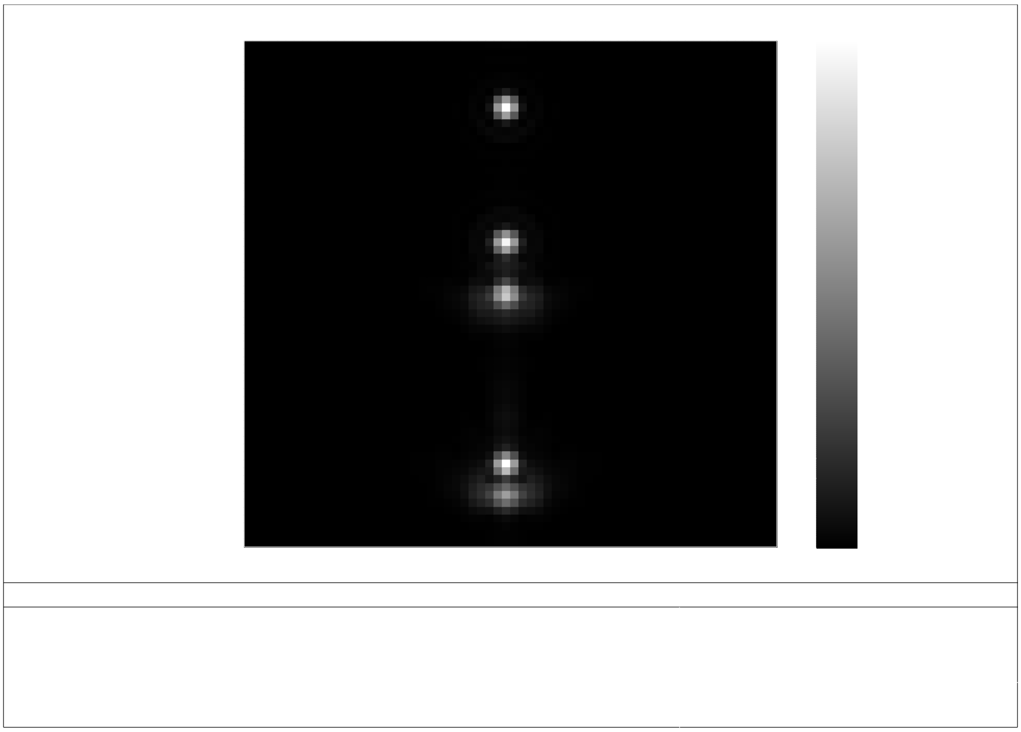


Figure 9 optical simulation GRISM J

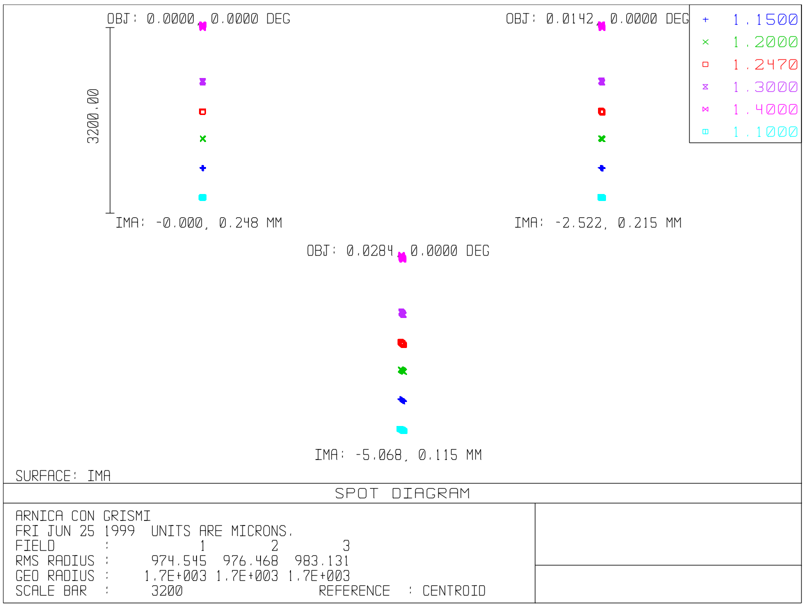


Figura 10 optical simulation GRISM J

A monochromatore with maximum wavelength reachable of 1500 nm is used to test the J grism and part of the H grism. Measurements have been performed at the central wavelength and at some wavelength in order to cover all the J band. The optical quality has been tested with ArNICa at the output of a lenses combination that reproduces the telescope in laboratory. A map of the imaging of an optical fibre on the detector is performed at difference position on the utilized slit.

The optical quality reachable is in agree with the optical simulation as we can see from Figure 11, Figure 12 and Figure 13 where we present the results of the laboratory test at 1100 nm at 1247 nm and at 1400 nm and the PSF optical simulation on 2x2.

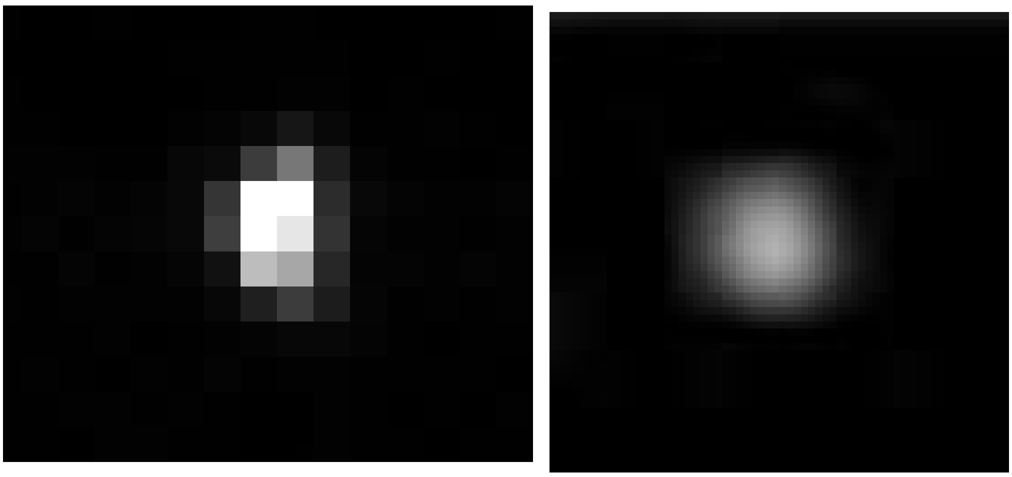


Figure 11, Grism J, at 1100 nm on ArNICa detector and PSF optical simulation 2x2 pixels

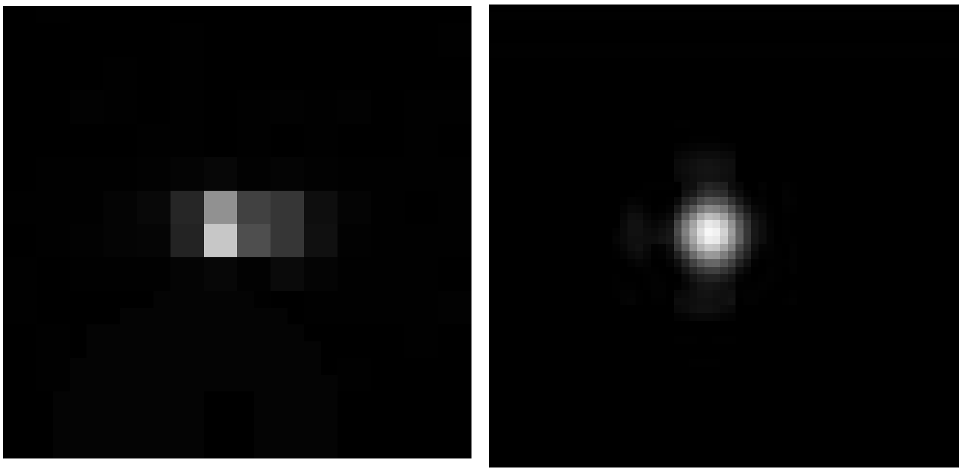


Figure 12, Grism J, at 1247 nm on ArNICa detector and PSF optical simulation on 2x2 pixels

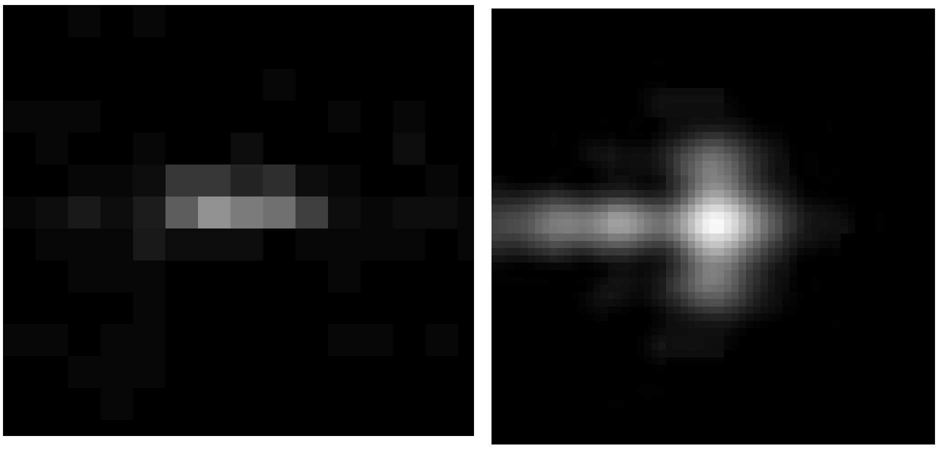


Figure 13, Grism J, at 1400 nm on ArNICa detector and PSF optical simulation on 2x2 pixels

5 First observation data at the Gornergrat Telescope

The first program of observation was dedicated to analysis of some asteroids. As example of observation we present the result of the reduction of the Asteroid 1588 spectrum obtained with J grism (Dr. G.P. Tozzi and Dr.M. Di Martino).
In Figure 14, the box reported is a portion of the 256X256 ArNICa detector's. The covering of the spectrum is in agreement with the spectrum of the Argon lamp in J band.

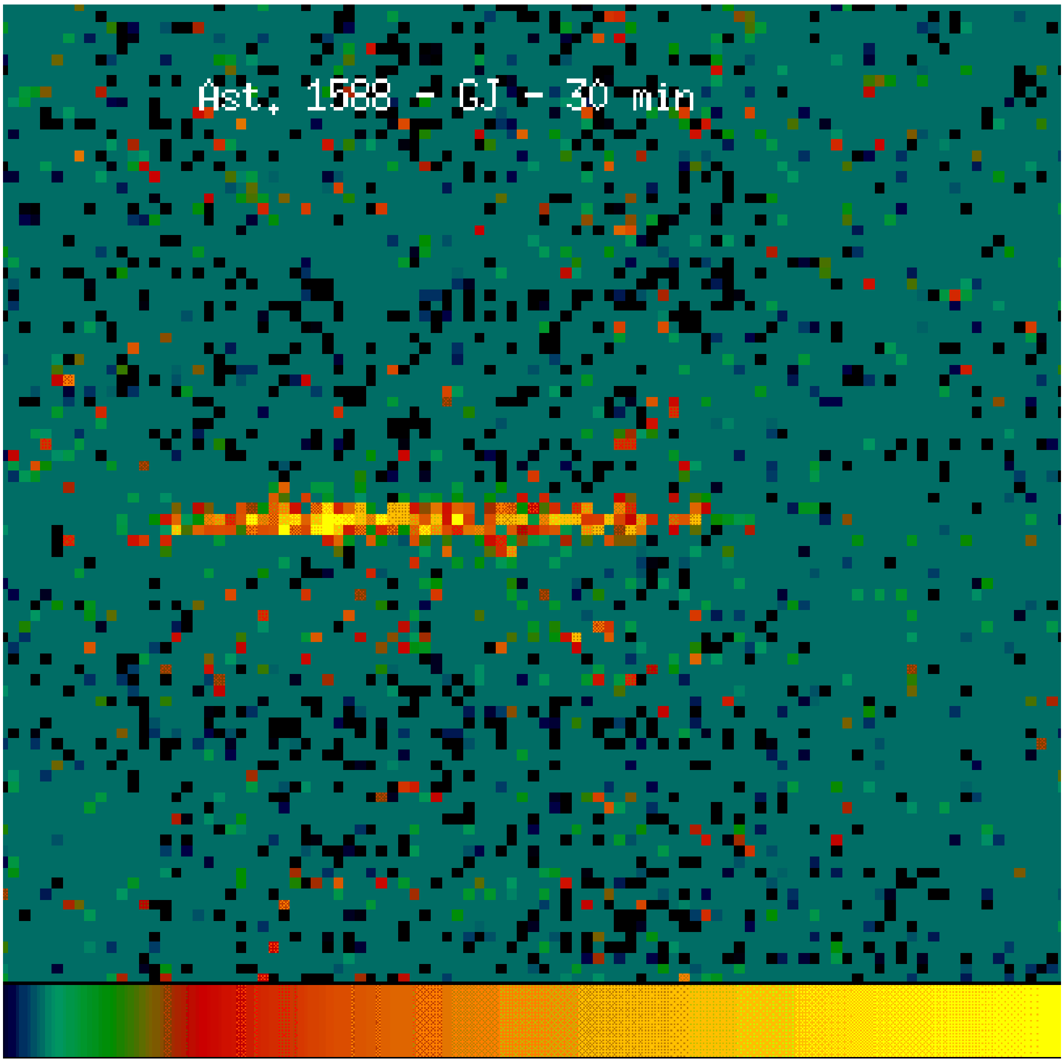


Figure 14 spectrum of asteroid 1588 in J band

In the Table 5, the main data of this asteroid are reported.

Name	m_v	m_J	m_H	m_K	exposition time
Ast. 1588 Descamizada	16.1	14.18	14.57	14.40	30 min

Table 5, main data of the asteroid 1588

In Figure 10, the spectrum of the Descamizada asteroid in J band, with the calibration in wavelength is shown. In the graphics the pixel value versus wavelength is reported.

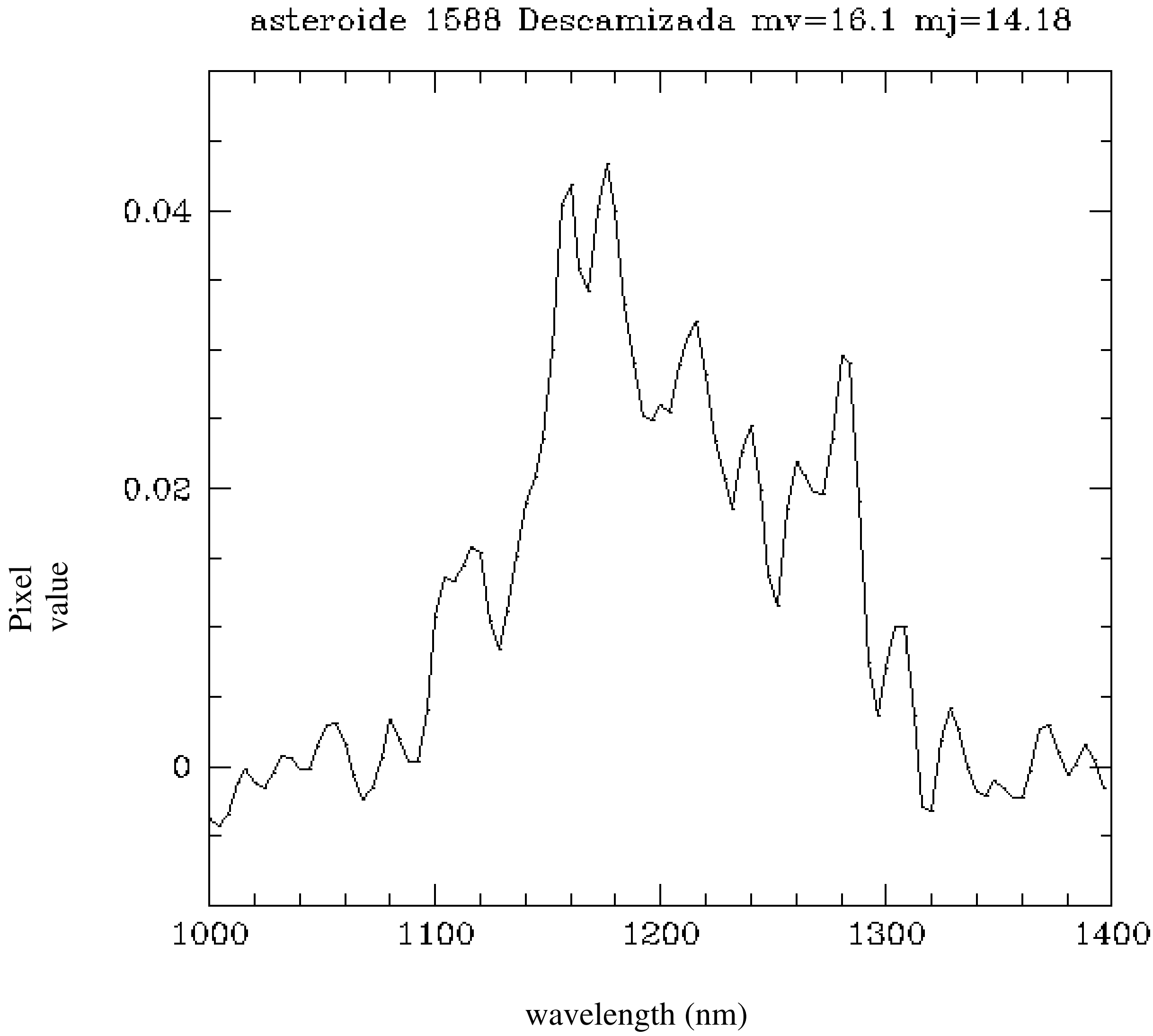


Figure 15 spectrum of asteroid Descamizada

The wavelength calibration has been performed with the laboratory references spectrum done with a monochromatore at 1100 nm, 1247 nm and at 1400 nm.

Acknowledgements

We would like to thank Dr Sandro Gennari for the suggestions about the grisms optical study and the measurements on ArNICa,. G.P.Tozzi and Dr. M. di Martino for the data on the asteroid 1588 Descamizada that they analysed at the TIRGO. Moreover Prof. C. Castellini for his kind hospitality at the Istituto Nazionale di Ottica (Firenze), where the optical tests on efficiency of the grisms have been carried out and Dr. Davide Jafrancesco for his assistance during the tests.

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