FISICA: The Florida image slicer for infrared cosmology and astrophysics

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Abstract

We report on the design and status of the Florida Image Slicer for Infrared Cosmology and Astrophysics (FISICA) – a fully-cryogenic all-reflective image-slicing integral field unit for the FLAMINGOS near-infrared spectrograph. Designed to accept input beams near f/15, FISICA with FLAMINGOS provides R/C24 = 1300 spectra over a 16 × 33 arcsec field-of-view on the Cassegrain f/15 focus of the KPNO 4-m telescope, or a 6 × 12 arcsec field-of-view on the Nasmyth or Bent Cassegrain foci of the Gran Telescopio Canarias 10.4-m telescope. FISICA accomplishes this using three sets of “monolithic” powered mirror arrays, each with 22 mirrored surfaces cut into a single piece of aluminum. We review the optical and opto-mechanical design, fabrication, laboratory test results, and on-telescope performance for FISICA. © 2006 Published by Elsevier B.V.

Keyword: Integral field units

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1. Introduction

Integral field capabilities have become a key contributor to many current spectroscopic research programs in optical and infrared astronomy. A particularly powerful approach is to use a segmented set of tilted mirrors at an image plane to “slice” the input 2-dimensional image and re-format it into a pseudo-longslit input to a spectrograph. Excellent descriptions of designs for such systems are provided by Content (1997, 1998).

Several previous image-slicing IFUs based on slicer mirrors have been built or are currently under construction, but
each has one or more significant drawbacks, such as: non-powered slicer mirrors; small fields of view (only a few square arcseconds on 8- to 10-m telescopes); multi-element mirror arrays (requiring painstaking alignment and mounting of a large number of mechanically-fragile elements); heterogeneous materials (causing differential misalignment from room to cryogenic temperatures). FISICA avoids or mitigates each of these problems, using monolithically-fabricated, all-aluminum powered mirror arrays to provide a >70-square-arcsecond field on the Gran Telescopio Canarias 10-m telescope, or a ~500-square-arcsecond field on the KPNO 4-m telescope.

FISICA is a 22-slice advanced slicer IFU design, incorporating three powered mirror arrays of 22 elements each at – the “slicer” mirror array, the “pupil” mirror array, and the “field” mirror array. It fits inside a clone of the multi-object spectroscopy (MOS) dewar of the FLAMINGOS instrument (Elston et al., 2002), slicing the input telescope focal plane and then replacing it in the outgoing beam such that the virtual sliced image appears at a virtual focus coincident with the input telescope focal plane. Thus, FLAMINGOS effectively “sees” a simple pseudo-longslit input coming as if from the telescope itself, requiring no modifications to the existing instrument. A description of the detailed design and preliminary lab test results from the FISICA IFU are presented in (Eikenberry et al., 2004; Glenn et al., 2004).

In Section 2 below, we describe the opto-mechanical concept for FISICA and fabrication results for the IFU. In Section 3, we show recent results from FISICA commissioning observations on the KPNO 4-m telescope and a comparison of FISICA with other currently-operating IFUs.

2. FISICA concept and fabrication

As noted above, the basic optical principle behind FISICA is to take an input 2-dimensional field-of-view at the telescope focal plane, divide it into 22 “slices”, orient these slices end-to-end to create a pseudo-longslit, and then place a virtual image of this pseudo-longslit in the optical beam so that it appears to originate from the output telescope focal plane. The basic design we used to accomplish this task is shown in Fig. 1.

In Fig. 1, light from the telescope enters from the left and forms an image at the telescope focal plane. The expanding beam encounters a 3-mirror re-imaging relay, which magnifies the image by x2, and comes to a focus at the surface of the 22-element “slicer” mirror. The slicer mirror has 22 slices, each powered, each tilted along both the “spatial” direction of the spectrograph (in order to separate the final images into a pseudo-longslit) and in the “dispersion” direction of the spectrograph (in order to separate pupil images into 2 rows of 11 each). The powered slicer mirror creates an image of the telescope exit pupil on the 22-element pupil mirror array. The pupil mirror array consists of 22 powered, offset, tilted mirrors arranged in two rows of 11 mirrors each. This 2 × 11 geometry was chosen in order to minimize field angles for the IFU, and thus reduce aberrations. The pupil mirrors create another relayed image of the telescope focal plane along a linear array of 22 field mirrors. This image is demagnified 2× from the original input beam (thus matching the f/15 telescope beam to the f/8 spectrograph beam of FLAMINGOS). We chose this geometry to allow the pupil mirrors to be significantly larger than the closely-spaced field mirrors, and for the field mirror array to correct telecentricity.

Fig. 1. Optical concept layout for FISICA.
Fig. 2. Fabricated FISICA mirror arrays: (a) slicer mirror array; (b) pupil mirror array; (c) field mirror array.

Fig. 3. FISICA IFU assembled with opto-mechanical support structure.
errors, and thus “offload” some tilt from the pupil mirror array. Two fold mirrors then relay the output “sliced” image to the FLAMINGOS spectrograph. The actual final rays proceed out of the figure to the right from the last fold mirror, while the figure shows them “reverse-traced” to the left to show that they do indeed appear to come from the output of the telescope focal plane.

In Fig. 2, we show the fabricated IFU mirror arrays for FISICA, diamond-turned from single pieces of aluminum. In Fig. 3, we show the final assembled FISICA IFU structure and its installation in the “MOS” dewar for FLAMINGOS.

Detailed tests show that FISICA meets essentially all specifications on optical quality and alignment without requiring any manual adjustments Glenn et al., 2004. The one notable exception to this is that the telecentricity performance of the FISICA IFU does not meet the goal of <5-mrad at all slice positions (Fig. 4). The primary impact of this is that the pupil image shifts on the cold pupil stop of the FLAMINGOS spectrograph in a position-dependent manner. This causes some slight (few percent) losses at some positions, but systematic effects of the position-dependent throughput of the system are removed through standard flatfielding techniques.

![Fig. 4. FISICA telecentricity performance across slices.](image)

![Fig. 5. FISICA “slice” images of a star: (a) “sliced” image seen at the FISICA detector focal plane; (b) software-reconstructed image of the star.](image)
3. FISICA telescope results and comparison to other IFUs

We commissioned FISICA in July 2004 on the KPNO 4-m telescope. We have had 2 additional observing runs since then, during which we have fully characterized FISICA’s performance. Fig. 5 shows an image through a J-band filter (no grism) of the FISICA field and a software-reconstructed 2-D image of the field. The star in the field has a FWHM of ~0.9", limited by the seeing at that time. Since then, we have seen images with ~0.7" (2 pixels) FWHM, again limited by the atmospheric seeing (evidenced by the smooth, round nature of the PSFs). These observations confirm that FISICA does not significantly degrade atmospheric seeing even at the 2-pixel Nyquist-limit specification for the instrument.

In Table 1, we compare the performance of the FISICA IFU to several other IFUs in operation. Generally speaking, FISICA significantly outperforms the competition, especially for surveys of extended regions (similar to or larger than the FISICA field of view). In the case of UIST and CIRPASS, this is due in part to the significantly higher throughput of FISICA. In all cases, FISICA offers a significantly larger “$A\Omega$” product than the other IFUs.

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References

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