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THE MICRO-MIRROR TECHNOLOGY APPLIED TO ASTRONOMY : ANIS ADAPTIVE-SLIT NEAR INFRARED SPECTROGRAPH

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ABSTRACT - This poster presents a very promising application of the micro-mirror technology to space (and remote ground-based) astronomy. Multi-object spectrographs are the most efficient way of carrying out spectroscopic studies on a large field of view and a large number of targets. However, for the time being, it would be very difficult to operate a multi-object spectrograph in space. A project called MIROS (P.I. : J. Mackenty, STScI) was based on Texas Instrument Digital Micro-mirror Device (DMD) and proposed to NASA to be installed on the HST in 2002. This poster describes a Near InfraRed spectro-imager called ANIS which would fly with NGST pathfinder 3. Although a very versatile instrument, the combined performances of this telescope and ANIS would allow to carry out a deep and large field of view spectro-imaging survey with a first-rate scientific return on the high redshift universe.

1 - INTRODUCTION

Multi Object Spectrographs (MOS) have undergone an important development in the last decade and, nowadays they appear as a major tool in ground-based astronomy. Their advanced capabilities will allow to secure tens to several hundreds of spectra simultaneously in a wide field of view.

Large ground-based telescopes can, very efficiently, observe in the visible range and take advantage of the multiplexing gain of MOS. That is the reason why the wavelength range is essentially limited to the visible but the next generation of ground-based MOS will extend their capabilities in the Near Infra Red (NIR) up to 1.7 μm (see for instance VIRMOS on the ESO Very Large Telescope). Unfortunately, due to the high atmospheric absorption and the OH emission lines, the performances are limited in the NIR.

To address this problem, we proposed to develop an instrument called MIROS (Multi-object InfraRed Optical Spectrometer, P.I. : John Mackenty, STScI) for the Hubble Space Telescope (HST). Thanks to the HST location in space, the sky background seen in the 1.0 - 1.7 μm range is much fainter than from the ground. But the thermal component due to the emission from the HST dominates beyond 2μm and the HST background exceeds the ground one at these wavelengths. A very good way to decrease the IR background is to put the telescopes in a place farther away from the Earth and to cool it down. The telescope temperature reachable at 1 astronomical unit (AU) from the Sun is of the order of T ≈ 50 °K and the thermal emission only takes over the zodiacal light at wavelengths > 18 μm.

However, if on ground-based MOS, objects are selected by mechanically positioning optical fibers or cutting slits, these ways of working are hardly transportable to space and an important step is now to "export" these instruments to space. A recent breakthrough was the application of the micro-mirror technology to design a new generation of MOS (this type of MOS will certainly be used on the Next Generation Space Telescope and was also used in the HST project MIROS).

This poster presents a space MOS using the micro-mirror technology that would be launch to the L2 point and carry out a spectroscopic plus imaging wide field survey in the 1 - 5 μm range.

2 - THE MICRO-MIRROR TECHNOLOGY AND APPLICATION TO ASTRONOMY

Texas Instrument developed a Digital Micro-mirror Device ™ (DMD™) microchip consisting in an array of 16 × 16 μm² aluminum micro-mirrors with a 1-μm spacing between each of them (Hornbeck 1995, SPIE Thematic Applied Science and Engineering Series, Austin, Texas). From their rest-position, each micro-mirror can rotate by +10 or -10 degrees to two stable equilibrium positions. The DMD pixel is a monolithically integrated micro-electromechanical system superstructure fabricated over a CMOS static random access memory (SRAM) cell. Each mirror is connected to an underlying yoke which, in turn is suspended by two thin torsion hinges to support posts. When a mirror is electrostatically attracted, it rotates until the yoke reaches the mechanical stops. The position of these stops limits the rotation angle to the +10 or -10 degrees. The high homogeneity of the mirror angles guarantees a good uniformity of the DMD.

When a micro-mirror is on the ON position (say +10 degrees), the light reflected by each micro-mirror is sent to a spectrograph while OFF micro-mirror (-10 degrees) light is sent to another direction (which can be an imaging detector). Therefore, this device would be very useful to design MOS. The selection of the areas in the field that we would like to study spectroscopically can be performed by the optical switching of the selected micro-mirrors very quickly (< 20 μs). The crucial advantage of this device resides in the fact that this operation can be performed remotely and the selection can be sent out to the telescope either at a remote place on Earth or in space. One can also define complex slits to follow the shape of the objects or image an area without bright pixels (coronography). The present generation of Texas Instrument micro-mirrors contains about 1 million of micro-mirrors.

3 - INTERNATIONAL CONTEXT

The Next Generation Space Telescope (NGST) will be a large 6-8 space telescope optimized to work in the NIR (with a possible extension in the mid IR). Three possible precursor missions are planned to test and validate the state-of-the-art technologies that would be used to build a light, efficient and relatively cheap NGST (Stockman 1997, The Next Generation Space Telescope, Visiting a Time When Galaxies Were Young). The third of them, Pathfinder 3 (PF3) would be launched 3-5 years before the NGST launch (presently ~2007) and while only a technological flight is planned, such a telescope would be very useful to carry out a deep spectro-imaging survey in the 1-5 μm NIR range. Apart for the technical testing of such an instrument for the NGST, we propose to put a wide-field spectro-imager using the micro-mirror technology (Adaptive-slit Near Infrared Spectrograph = ANIS) that would provide an extremely efficient way of harvesting first-rate scientific data out of reach for present ground-based and space planned instruments.

4 - ANIS MISSION CONCEPT

The goal of PF3 would be to demonstrate precision deployment of the optics and test the optics. In the following we assume these characteristics for PF3 + ANIS :

- 1m / 2m primary mirror, diffraction limited at 5 µm that is a resolution of 1.3 / 0.6 arcsec
- one 2k $\times$ 2k InSb detector covering a field of view of 0.4 $\times$ 0.4 / 0.2 $\times$ 0.2 square degrees with a pixel scale of 0.7 / 0.3 arcsec / pixel
- spectral resolutions $R = \lambda / \Delta\lambda = 100$ and 1000 in spectroscopy plus imagery
- orbit L2 at 1 AU to reach a temperature $T \approx 50$ °K
- A first spectroscopic and imaging 1-year science mission would survey approximately 10 square degrees with exposure times of 1h in imagery (4 passbands), 1h in low spectral resolution spectroscopy (R=100) and in a second run after a field and/or target selection, a second survey with 5h in medium spectral resolution spectroscopy (R=1000) for a typical field would allow to reach the performances plotted in the following Figs. 1-3.

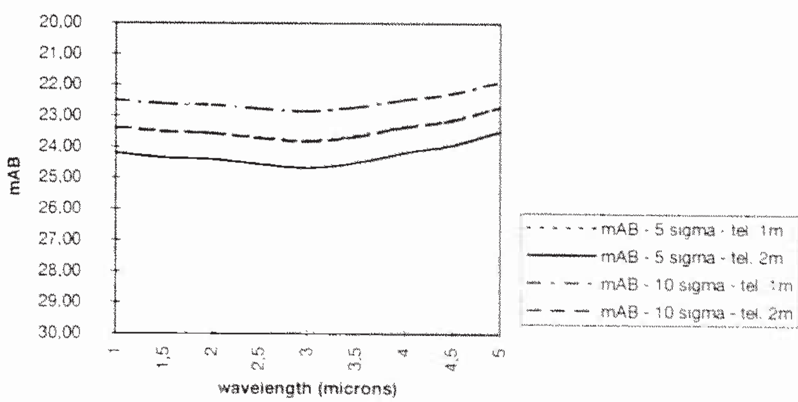

Fig. 1 - Performances of ANIS in medium resolution spectroscopy (R=1000) in 5h. As a reminder, mAB = -2.5 Log (f_η (erg/cm^2 s A)) - 48.6.

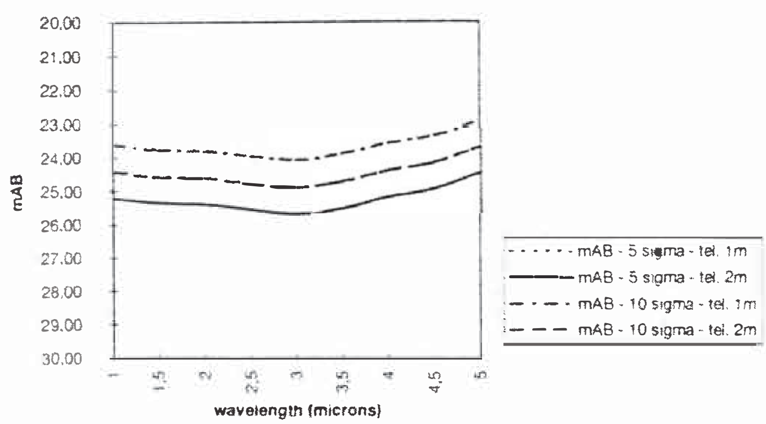

Fig. 2 - Performances of ANIS in low resolution spectroscopy (R=100) in 1h.

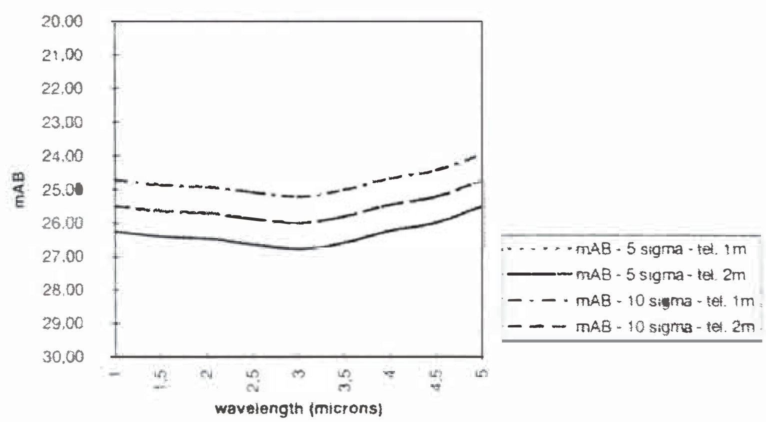

Fig. 3 - Performances of ANIS in imagery (R=5) in 1h.

5 - ASTRONOMICAL OBJECTIVES

All astronomical topics can take advantage of this type of device but this technology will have major consequences on topics where the density of objects is high (more than a few unities per observed field of view) : Galactic center, Galactic globular clusters, extragalactic globular cluster systems and deep extragalactic fields. Very promising fields are deep spectroscopic and imaging NIR surveys.

The deepest K-band survey (Djorgovski et al. 1995, ApJ 438, L13; Gardner et al. 1997, ApJ 480, L99) suggests than the cumulative surface density reach ≈ 5×10^{5} galaxies / deg^2 down to a magnitude K=24 which translates in > 5×10^{6} galaxies in our photometric survey and about 8×10^{4} galaxies / deg^2 down to a magnitude K=22, which means that about 10^{6} galaxies can be observed in the high spectral resolution survey. The apparent K magnitude for an Sb galaxy with L = 3L* is at z≈5 and L=0.1L* is z≈2 (Cowie et al. 1996, AJ 112, 839). The number of galaxies at z>2 in the Hubble Deep Field is about 4 galaxies / arcmin^2, we should observe more than 2000 galaxies in this survey which would be a very valuable way of probing the high redshift universe and provide us a continuous z-coverage unavailable from Earth.

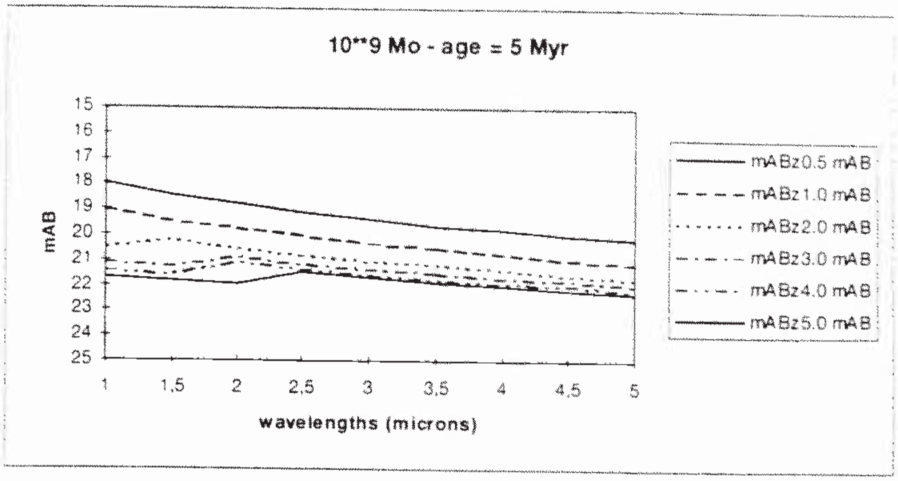

Fig. 4 - Spectral Energy Distributions in the redshifted 1-5 μm range from Leitherer & Heckman's models for an instantaneous burst with 10^9 M_o and an age of 5 Myr.

The Hα line (656.3 nm) which is the main star formation tracer is redshifted beyond λ = 1.3 μm at z > 1 and beyond λ = 2 μm for z > 2 ($\lambda_{observed} = \lambda_0 (1+z)$). Therefore the NIR range becomes crucial when studying high redshift objects. From the Hα line, we would be able to estimate the star formation of high redshift galaxies accurately (Kennicut 1992, ApJ 388, 310) and study the evolution of this star formation with time (Van der Werf 1997, astro-ph/9706130).

Obviously, it is not possible to be exhaustive in this poster but such a wide-angle survey would also bring a significant contribution to a number of other important fields in astronomy (dark matter, solar system objects, etc.).

6 - CONCLUSION

The micro-mirror technology presents a major interest for ground-based and space astronomy. It will allow an important simplification and therefore an enhanced safety in the operations and selection of objects that we would like to analyze spectroscopically. Indeed, one of the limitations for remote astronomy (either in space or in ground-based telescopes) resides in the mask-cutting or the positioning of optical fibers. Although this technology is recent, we proposed to NASA a HST instrument (MIROS) based on this concept and the NGST MOS baseline also uses this technology. Using the micro-mirror technology will allow to develop MOS in space. A wide-field spectroscopic plus imaging NIR (1 - 5 μm) deep survey would be a first-order scientific use of NGST pathfinder 3 and its 1m to 2m primary mirror telescope.