Multi-Object Spectroscopy in the Next Decade: Big Questions, Large Surveys, and Wide Fields
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BATMAN: MOS Spectroscopy on Demand

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Abstract. Multi-Object Spectrographs (MOS) are the major instruments for studying primary galaxies and remote and faint objects. Current object selection systems are limited and/or difficult to implement in next generation MOS for space and ground-based telescopes. A promising solution is the use of MOEMS devices such as micromirror arrays, which allow the remote control of the multi-slit configuration in real time. TNG is hosting a novelty project for real-time, on-demand MOS masks based on MOEMS programmable slits. We are developing a 2048 × 1080 Digital-Micromirror-Device-based (DMD) MOS instrument to be mounted on the Galileo telescope, called BATMAN. It is a two-arm instrument designed for providing in parallel imaging and spectroscopic capabilities. With a field of view of 6.8 × 3.6 arcmin and a plate scale of 0.2 arcsec per micromirror, this astronomical setup can be used to investigate the formation and evolution of galaxies. The wavelength range is in the visible and the spectral resolution is R=560 for a 1 arcsec object, and the two arms will have 2k × 4k CCD detectors. ROBIN, a BATMAN demonstrator, has been designed, realized and integrated. We plan to have BATMAN first light by mid-2016.

1. Introduction

Next generation Multi-Object Spectrographs (MOS) for space such as the Near Infrared Multi-Object Spectrograph (NIRSpec) for the James Webb Space Telescope (JWST) require a programmable multi-slit mask. MOEMS programmable slit masks could be next-generation devices for selecting objects in real time. MOEMS devices such as micromirror arrays (MMA) (Burg et al. 1998; Zamkotsian et al. 1999) or micro-shutter arrays (MSA) (Li et al. 2010) are promising solutions. MMAs are designed for generating reflecting slits, while MSAs generate transmissive slits. At LAM effort is currently under way to develop micromirror arrays for infrared multi-object spectroscopy (Canonica et al. 2013). By placing the programmable slit mask in the focal plane of the telescope, the light from selected objects is directed toward the spectrograph, while the light from other objects and from the sky background is blocked. To get more than two million independent micromirrors, the only available component is a Digital Micromirror Device (DMD) chip from Texas Instruments (TI) that features 2048 × 1080 mirrors and a 13.68 μm pixel pitch. DMDs have been tested in a space-like environment (-40°C, vacuum, radiation) by LAM and no showstoppers have been revealed (Zamkotsian et al. 2011).

In this paper we present a DMD-based spectrograph called BATMAN which includes two arms, a spectroscopic channel and an imaging channel. BATMAN will be placed on the Nasmyth focus of Telescopio Nazionale Galileo (TNG) during 2016. ROBIN, a BATMAN demonstrator, has been designed, realized and integrated.

2. BATMAN concept and opto-mechanical design

BATMAN is a compact spectro-imager with two arms in parallel, a spectroscopic channel and an imaging channel. Both arms are fed by using the DMD mirrors two stable positions, Fig. 1 (Zamkotsian et al. 2012, 2014). Our goal is to make a robust and

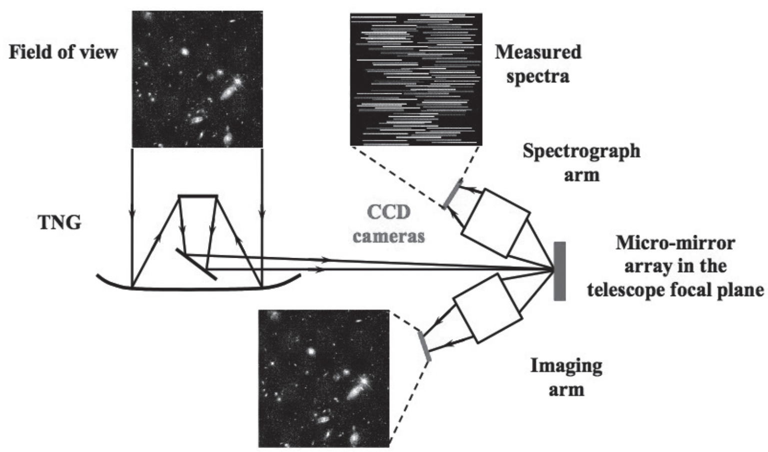

Figure 1. Principle of BATMAN spectro-imager

efficient instrument for a space mission, focusing on large areas and fixing some constraints:

- focal ratios feeding the DMD should be close to F/4, thus allowing relatively easy decoupling from the incoming and outcoming beams on the DMD surface
- the incoming beam must hit the DMD surface at normal incidence everywhere on the DMD chip; a simple relay system should not introduce tilted image planes and should be telecentric
- both spectroscopy and imaging modes should be available
- all optical components should lie in a plane for easy integration and alignment

- plane and spherical optics should be used as much as possible to reduce cost and delivery time

The BATMAN baseline is summarized in Table 1.

Table 1. Baseline parameters of BATMAN

Primary mirror diameter	3.6 m
Field of view	6.8 arcmin x 3.6 arcmin
Focal ratio	F/4 on DMD (with 2048 - 1080 micro-mirrors)
Plate scale	0.2 arcsec per micromirror
Beams on DMD	incoming light at normal incidence; outgoing light at 24°; DMD orientation at 45°
Wavelength range	400 - 800 nm
Spectral resolution	R=560 for 1arcsec object (typical slit size)
Two arms instrument	one spectroscopic channel and one imaging channel
Detectors	Two 2k × 4k CCDs

Digital Micromirror Devices (DMD) from Texas Instruments could act as an objects' selection reconfigurable mask. The largest DMD chip developed by TI features 2048 × 1080 mirrors on a 13.68 μm pitch, where each mirror can be independently switched between an ON (+12°) position and an OFF (-12°) position. Specialized driving electronics and a cold temperature test set-up have been developed and tested in different environmental conditions. *These results do not reveal any concerns regarding the ability of the DMD to meet environmental space requirements* (Zamkotsian et al. 2011).
In Europe effort is currently under way to develop single-crystalline silicon micromirror arrays for future generation infrared multi-object spectroscopy (collaboration between LAM and EPFL-CSEM). First arrays with 2048 micro-mirrors have been successfully designed, realized and tested at 160K (Canonica et al. 2013). On a longer time scale these arrays could be used in the BATMAN concept.

Fig. 2 shows the optical layout of BATMAN. The entrance beam is adapted in F-number by the fore-optics and is split by the DMD into two arms, the spectrograph arm and the imaging arm. BATMAN is based on a double Offner relay system with a 1:1 magnification between the DMD and the detector pixels. The general mechanical design of BATMAN consists of a main optical bench supporting all optical elements except the detectors, which are mounted on a second bench above, and attached to, the main bench (Fig. 2). The main bench supports the two arms: the entrance beam is adapted by the fore-optics and is split by the DMD into the spectrograph arm and the imaging arm.

3. ROBIN: a BATMAN demonstrator

Before developing BATMAN, we built a demonstrator named ROBIN. The design of the demonstrator is identical to the instrument design in being fully representative, with

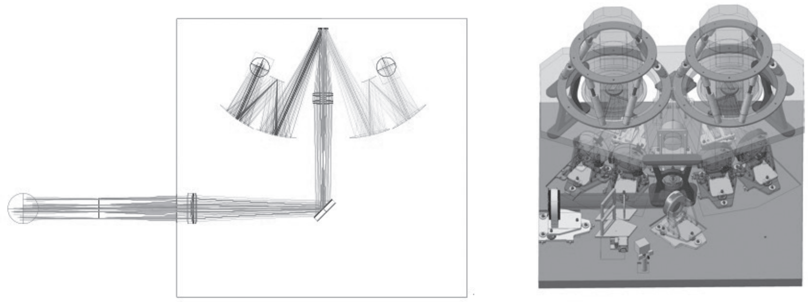

Figure 2. Optical layout of BATMAN (left); light coming from the telescope is split by the DMD into two arms, a spectrograph arm and an imaging arm (both are Offner relays). The BATMAN opto-mechanical design overall view (right)

a global reduced size, for mirrors as well as for the grating. The general mechanical design of ROBIN consists of a main optical bench supporting two arms: a spectrograph arm and an imaging arm. The detectors are located on both sides of the bench. A picture of ROBIN is shown in Fig. 3.

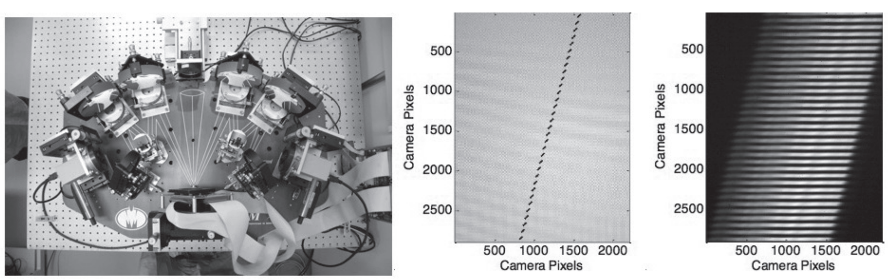

Figure 3. Integrated ROBIN picture (left), image of the slit mask in the imaging channel (center) and the corresponding spectra in the spectral channel (right)

First images and first spectra have been recorded (Fig. 3). A series of slits, 5 micromirrors wide and 15 micromirrors long are set on the DMD; in the imaging arm they appear black because the light located on these slits is sent towards the spectrograph. In the spectroscopic arm the slits generate spectra for each, and all spectra are aligned on the detector due to the dispersion orientation of the grating.

4. Conclusion

BATMAN is a 2048 × 1080 Digital-Micromirror-Device-based (DMD) MOS instrument to be mounted on the 3.6 m Galileo telescope. A two-arm instrument, it has been designed for providing in parallel imaging and spectroscopic capabilities. The field of view (FOV) is 6.8 × 3.6 arcmin with a plate scale of 0.2 arcsec per micromirror. The wavelength range is in the visible, and the spectral resolution is R=560 for a 1 arcsec object (typical slit size). The two arms will have 2k × 4k CCD detectors.

ROBIN, a BATMAN demonstrator, has been designed, realized and integrated. BATMAN will be placed on the Telescopio Nazionale Galileo mid-2016.

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