BATMAN @ Gemini: A Visiting DMD-based spectro-imager

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+ BATMAN French-Italian team

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Multi-object spectroscopy

Telescope’s field of view → Thousands of galaxies

Overlapping Spectra

Measured spectra

Telescope (ground or space) → Reflective surface → Spectrometer → CCD Camera
Multi-object spectroscopy

Telescope (ground or space) → Measured spectra

Telescope’s field of view → Thousands of galaxies

Hubble ultra deep field (HUDF), NASA, 3/9/2004

2D Micromirror array in the telescope focal plane

Spectrometer

CCD Camera

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SEGemini 2018, San Francisco, 22-26 July 2018
Most popular MOEMS devices available on the market.

- Micro-mirrors
  - 2048x1080 individually tiltable (> 2 millions mirrors)
  - 13.68µm pixel pitch,
  - Tilt angle of 12°
- Numerous applications
  - Prime use displaying images
  - No customization possible
- Space qualification tests (ESA contract, EUCLID)
  - -40°C in 10^-5 mbar vacuum
  - Micro-mirrors in position for > 1500s
  - DMD fully operational
  - 1038 hours life test, radiations, vibrations
  - No show-stopper for space application

Texas Instruments DMD
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field of view</strong></td>
<td>6.8 arcmin x 3.6 arcmin</td>
</tr>
<tr>
<td><strong>Focal ratio</strong></td>
<td>F/4 on DMD  &lt;br&gt;(scale = 0.2 arcsec per micromirror)</td>
</tr>
<tr>
<td><strong>Beams on DMD</strong></td>
<td>incoming light at normal incidence  &lt;br&gt;out-coming light at 24°  &lt;br&gt;DMD orientation at 45°</td>
</tr>
<tr>
<td><strong>Wavelength range</strong></td>
<td>400 - 800 nm</td>
</tr>
<tr>
<td><strong>Spectral resolution</strong></td>
<td><strong>R = 560</strong> for 1 arcsec slit to <strong>2000</strong> for 0.2 arcsec slit</td>
</tr>
<tr>
<td><strong>Two arms instrument</strong></td>
<td>one spectroscopic channel  &lt;br&gt;one imaging channel</td>
</tr>
<tr>
<td><strong>Detectors</strong></td>
<td>Two 2k x 4k CCDs</td>
</tr>
</tbody>
</table>
Optical design
Optical design
Simulated spectra (400 – 800 nm)
BATMAN: the opto-mechanics

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BATMAN
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Slit: 1 µM (13.68 µm)
Spectrum on 1.5 detector pixel (8.3 µm) in 500-600nm wavelength range
BATMAN is under construction

Slit: 1 μM (13.68 μm)
Spectrum on 1.5 detector pixel (8.3μm) in 500-600nm wavelength range

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Simu BATMAN : limiting magnitude

CT = SNR 10 ; CE = SNR 5 ; slit = 1.0"

Limit flux in ergs/cm²/A

Wavelength in um

et=1h TNG (CT) ; r_{SDSS} = 21.23
et=15h TNG (CT) ; r_{SDSS} = 22.72
et=1h GEMINI (CT) ; r_{SDSS} = 22.19
et=15h GEMINI (CT) ; r_{SDSS} = 23.67
et=1h TNG (CE) ; r_{SDSS} = 22.00
c=15h TNG (CE) ; r_{SDSS} = 23.48
et=1h GEMINI (CE) ; r_{SDSS} = 22.95
et=15h GEMINI (CE) ; r_{SDSS} = 24.43

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♦ **BATMAN @ TNG (2019 – 2021+)**
  - Italian telescope Ø3.6m
  - Seeing-limited
  - First Science Cases

♦ **BATMAN @ Gemini (2022 – 2025+)**
  - US telescope Ø8.2m
  - MCAO (GeMS)
  - 90 mas resolution

♦ **BATMAN @ VLT (2025 – 2030+)**
  - European telescope Ø8.2m
  - Visible MCAO (MAVIS)
  - 20 mas resolution

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BATMAN @ TNG

Telescope

Focal plane

MOEMS-DMD/MIRA

Focal plane

Pupil plane

Imager

FOV = 6.8 x 3.6 arcmin^2
BATMAN @ Gemini

Gemini + visible GeMs

FOV = 1.5 x 1.5 arcmin²
### Parameters (TNG / Gemini)

<table>
<thead>
<tr>
<th></th>
<th>Spatial resolution</th>
<th>Field of view</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNG (F/4) 3.6m</td>
<td>0.2”</td>
<td>6.8 x 3.6 arcmin²</td>
</tr>
<tr>
<td>Gemini + GeMS (F/4) 8.2m</td>
<td>0.088”</td>
<td>3 x 1.5 arcmin²</td>
</tr>
<tr>
<td>Gemini + GeMS (F/8) 8.2m</td>
<td>0.044”</td>
<td>1.5 x 0.8 arcmin²</td>
</tr>
</tbody>
</table>
Nearby galaxies physics

Nearby galaxies characterization (ex: XUV galaxies)

- Short time-scale star formation rate (Halpha), the dust distribution (Balmer ratio), the kinematics, the nucleus physics (AGN vs starburst), abundances
- For instance, study of NGC772
  - central part of gal. / nucleus
  - kinematics of the elongated spiral arms
  - star forming regions in the disk
  - star forming region in the XUV part of gal.
  - comparison with regular part of disk (metallicity, IMF, star forming history)

Instrument parameters

- Complete multiplexing of all regions in the FOV
- Optical spectroscopy (R 1000-1500)
Adaptable slit: following star formation regions

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Nearby galaxies physics

Sliding slit:
3D galaxy arm reconstruction

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Nearby galaxies physics

Gemini + GeMS + BATMAN = from nearby to remote galaxies

Sliding slit:
3D galaxy arm reconstruction
Stellar physics

Open clusters: characterization of the stellar content, especially the PDMF (present day mass function)

- Stellar physics and star formation in the Galactic center
- Clusters in the local group (Magellan clouds)
- Spectroscopic analysis of stars
  - distribution of stellar classes/types within the cluster (e.g. does the cluster core harbor the most massive stars?) \(\rightarrow\) constraints on IMF scenarios
  - physical distance of the cluster and location with respect to galactic arms (requires flux calibration) \(\rightarrow\) constraints on star formation
  - establish the evolutionary status of stars in the cluster (HR diagram) \(\rightarrow\) pinpoint empirical evolutionary links between different types of stars (e.g. massive dwarfs vs massive giants/supergiants, WRs) \(\rightarrow\) test whether single star evolutionary tracks can account for the observed stellar population

- Spectroscopic analysis of the diffuse matter in the cluster
  - derive ionization parameters, abundances, kinematics, selective extinction physics of HII regions etc)
Instrument parameters

- Complete multiplexing of stars in the FOV: MOS with 100s objects
- Requires flux calibration
- Spatial resolution 0.6” down to 0.08” with Gemini+GeMS (access to the core of the clusters)
- Optical spectroscopy, R 1500 (5000)
The EHB (Extreme Horizontal Branch) stars in globular clusters

- Faint blue stars (high Teff, lower luminosity, higher gravities)
- Physics of these objects
  - Variable surface abundance of He
  - Surface gravity
  - Fitting of Balmer lines profiles to Stark effect models

Instrument parameters

- Multiplexing of stars in the FOV
- Optical spectroscopy, R 1500
- Spatial resolution 0.6” to 0.08”
- Imagery for selection of objects (color-magnitude diagram det. by imagery in different bands)
Binaries: what is the fraction of Mdwarf – WhiteDwarf binaries? Is there a clue to the apparent deficit of isolated WD in cluster populations?

- Search of WD binaries
- Simultaneously check on normal main sequence binary pop.

Instrument parameters

- Multiplexing of stars in the FOV
- Optical spectroscopy R 500
- Spatial resolution 0.08"
- Very good photometry
Solar system objects

Near Earth Objects detection and characterization

- $V = 1.5$ arcmin / hour
- $\text{mag}_{\text{vis}} = 16 - 19$
- Simultaneous spectro of G2 stars
- Extension to asteroids

Instrument parameters

- Imagery: detection and trajectory determination
- Optical spectroscopy
  - $R = 300 - 500$
- Adjustable integration time
- Follow the object (imagery to spectroscopy in $1\text{ms}$ after alert)

Itokawa (Hayabusa)
BATMAN: the simulator

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BATMAN: the simulator
BATMAN: the simulator
Key numbers
- FOV 1.5 x 0.75 arcmin² (+)
- Spatial sampling 45mas / μM / detector pixel
- Imagery: multi-band filters
- Spectro: spectral resolution 500 – 2000 (+)
- Spectro MOS: 1 – several 100s objects
- Spectro IFU: FOV 1” up to 90” (sequential)

Unique abilities
- Imagery and spectroscopy in parallel (high accuracy photometry)
- Highly flexible (any combination of MOS, IFU, spectral resolution …)
- Transients (spatial, temporal), like SNe, NEO, AGN

Schedule
- BATMAN on Gemini in 2021-22