MOSAIC: the E-ELT MOS

By Jesús Gallego

Thanks to:
Á. Castillo-Morales, J. Iglesias, F. Hammer & the overall MOSAIC team
MOSAIC concept

MOSAIC core team has developed, then implemented: GIRAFFE - NACO – VIMOS - X-SHOOTER - KMOS

Includes also: AIP Potsdam, Nice, Toulouse, Vienna, Stockholm/Lund, Helsinki, Roma, Arcetri, UCM-Madrid, IAA-Granada & Geneva
2 main different observing modes in the optical and nIR J,H within 5-7 arcmin FoV

- High definition (HDM, 80 mas/pix) with ≥10 MOAO IFUs
  **EAGLE science cases**
  e.g., first objects & detailed kinematics of galaxies up to z=5, R=5000

- High multiplex (HMM, 100-250), GLAO/seeing resolution
  **OPTIMOS-EVE science cases**
  e.g., stars & z > 1.5 galaxies in an E-ELT FoV, R=5000-20000
High definition & high multiplex modes

≥ 200 fibers with natural seeing or GLAO
≥ 10 IFUs with MOAO
Timeline: MOS requirements

- Workshop in Amsterdam
- Initial science team assembled
- Meetings in UK, Italy, Brazil, NL
- New science simulations
- ELT-MOS White Paper
- Ismaning conference

Huge number of science cases!!

see Evans et al., 2013, arXiv1303.002E
& Evans et al. 2015 arXiv150104726E
See MOSAIC White Paper, Evans et al., arXiv150104726E
TODAY: $z \sim 1$ galaxies

GIRAFFE
SINFONI
X-SHOOTER
KMOS
MUSE
The reionisation of the Universe: first objects

Robertson et al. Nature 468, 49, 2010
TOMORROW: first galaxies with E-ELT + JWST

Multiplex is a key issue for studies of galaxy evolution & formation
See ELT-MOS white paper by Evans, Puech et al.
Deepest galaxy surveys

CANDLES
Area: 0.25 deg$^2$
Groging+11
Keokemoer+11

$H_{AB} = 27$:

- 8000 galaxies in an E-ELT FoV (~40 arcmin$^2$)
- 1600 $z > 1.5$ galaxies

A MOS can already detect highest $z$ galaxies from existing photometry
A needle in a haystack!

8000 galaxies in an E-ELT FoV: Requires a MOS for spectral ID and confirmation

Hubble Ultra Deep Field

z=10 candidate galaxy

Bouwens+ 2011
End-to-end simulations, see K. Disseau et al.

IFUs: essential for the best sky subtraction
Sky subtraction with fibers demonstrated with FLAMES (I-band) on sky

Expected in J-band: 0.6% of the sky-continuum & at the theoretical limit (~ 0.2-0.3%) with IFUs (Yang et al., Messenger, 2013; Rodrigues et al. 2012)
See MOSAIC White Paper
See MOSAIC White Paper
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See MOSAIC White Paper
Exo-planets, Galactic Center

See MOSAIC White Paper
From the 2\textsuperscript{nd} version of the MOS-white paper (Evans et al., arXiv150104726E)

- 100 scientists from all Europe
- SC1: first galaxies, reionisation
- SC2: Large scale structures
- SC3: Galaxies mass assembly
- SC4: AGN/Galaxy coevolution
- SC5: Resolved stars beyond the LG
- SC6: Galaxy archaeology
- SC7: Galactic centre
- SC8: Planet formation in clusters

ALL SCs tested or to be tested through an ‘end-to’end’ simulator

**Deployable fov: $\Phi = 5$-7 arcmin**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Working assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Definition Mode (HDM)</strong></td>
<td></td>
</tr>
<tr>
<td>IFU field of view</td>
<td>2.0 x 2.0 arcsec</td>
</tr>
<tr>
<td>Multiplex</td>
<td>10 IFUs</td>
</tr>
<tr>
<td>Spatial pixel size</td>
<td>75 mas</td>
</tr>
<tr>
<td>Ensquared Energy</td>
<td>$\geq 25%$ EE</td>
</tr>
<tr>
<td>Spectral Res. Power®</td>
<td>5,000</td>
</tr>
<tr>
<td>$\lambda$ coverage (not simult.)</td>
<td>0.8 - 1.8 $\mu$m</td>
</tr>
<tr>
<td><strong>High Multiplex Mode (HMM)</strong></td>
<td></td>
</tr>
<tr>
<td>On Sky Aperture</td>
<td>0.9 arcsec</td>
</tr>
<tr>
<td>Multiplex</td>
<td>200</td>
</tr>
<tr>
<td>Spectral Res. Power®</td>
<td>5,000 &amp; 15,000</td>
</tr>
<tr>
<td>$\lambda$ coverage</td>
<td>0.4 - 1.8 $\mu$m</td>
</tr>
<tr>
<td><strong>InterGalactic Medium (IGM)</strong></td>
<td></td>
</tr>
<tr>
<td>IFU field of view</td>
<td>2.0 x 2.0 arcsec</td>
</tr>
<tr>
<td>Multiplex</td>
<td>10 IFUs</td>
</tr>
<tr>
<td>Spatial pixel size</td>
<td>0.3 arcsec</td>
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<tr>
<td>Spectral Res. Power®</td>
<td>5,000</td>
</tr>
<tr>
<td>$\lambda$ coverage (not simult.)</td>
<td>0.4 - 1.0 $\mu$m</td>
</tr>
</tbody>
</table>
ESO & community context:

• End 2011: MOSAIC gathers EAGLE & EVE teams

• Oct. 2012 & Febr. 2013: 1st MOS meeting in Amsterdam (80 participants) & MOS/HIRES meeting with $\geq 250$ participants

• March 2014: community has chosen MOSAIC as a 1st MOS & a 2nd MOS (large scale structures) is required later

• MOS will be the 4 or 5th E-ELT instrument
MOSAIC: A Multi-Object Spectrograph for Astrophysics, Intergalactic medium and Cosmology

The Universe includes hundreds of billions of galaxies, each of them being populated by hundreds of billions of stars. Astrophysics aims to understand the complexity of an almost incommensurable number of stars, stellar clusters and galaxies, including their spatial distribution, their formation and their current interactions with the interstellar and intergalactic media. A considerable fraction of discoveries in astrophysics require statistics, which can only be addressed by a Multi-Object Spectrograph (MOS). A visible/near-Infra-Red MOS with capacities adapted from stellar physics to cosmology is technically feasible as recent studies have demonstrated that key issues like sky background subtraction and multi-object Adaptive Optics can be solved.

The E-ELT(*), which will be the world's largest optical/IR telescope in the 2020s, has to be equipped as soon as possible with a MOS that allows the largest discovery space. The MOS at the E-ELT will be unique to probe the sources of reionisation, to investigate their physics, to study the galaxy mass-assembly history including high-z dwarves, to describe the distribution of the Intergalactic medium, as well as probing resolved stars at unprecedented distances, from the outskirts of the Local Group for main sequence stars, to a significant volume including nearby galaxy clusters for luminous red supergiants.
CEFALU meeting 2015:
Science with MOS towards the ELT Era

7 - 11 September 2015

**SOC**: Barbuy, Bonifacio, Charlot, Contini, Cuby, Dickinson, Dunlop, Evans, Fiore (co-chair), Fontana, Garilli, Genzel, Giallongo, Hammer (co-chair), Kaper, Le Fèvre, Morris, Randich, Zamorani
Notice that the costing includes the instrument and its Adaptive Optics. As such, within the E-ELT instrumentation plan, it can be compared with (MICADO+MAORY) and with (HARMONI+LTAO)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (M€)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Optics</td>
<td>10,4</td>
<td>2015 Quotes</td>
</tr>
<tr>
<td>Spectrographs</td>
<td>10,1</td>
<td>Assumes E2V (6kx6k) for VIS and HAWAII (4kx4k) for NIR are used. 2015 Quotes</td>
</tr>
<tr>
<td>Fibres</td>
<td>3,3</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>3,8</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>27,6</strong></td>
<td>18 proposed by ESO</td>
</tr>
</tbody>
</table>
Baseline: 10 years to get MOSAIC on sky!
But the consortium is eager to fast-track development to ensure time lineness cf. JWST, GMT, TMT
Strategy for Phase A

- **One baseline** + one backup (Board conclusions, 16-10-2015)
- **Baseline** includes the nominal MOSAIC

  *Baseline is already a significant de-scoping versus ESO TLRs (HMM: 200 vs 400; HDM: 10 vs 40; no K-band)*

- Back-up: requires first 6 months of work by the Science Team to elaborate further trade-off

- Also to be investigated in Phase A:
  - Financial plan including the overall Consortium
  - Elaboration of the MOU and of the steering committee
  - How to be compensated (which GTO policy)? Surveys?
Spanish Contribution

- Spanish representative to the Steering committee
- To exploit MEGARA legacy
- UCM + IAA MEGARA control groups contribution to the Control WorkPackage

- Still under negotiation

- No major contribution planned until Phase A is finished
Conclusions

- E-ELT coupled with MOSAIC would benefit of an overwhelming number of SCs revolutionizing cosmology to planets, since individual studies are limited.
- Multi-IFUs with MOAO are unbeatable for sky-subtraction, light concentration & no aperture losses.
- E-ELT/MOSAIC is very competitive vs TMT/MOS.
- MOSAIC is relatively low risk, using existing technology and on-the-shelf components (fibres, AO etc.).
- Could still be one of the first MOS on sky to follow JWST, if necessary using simplified modes.