4MOST – 4m Multi-Object Spectroscopic Telescope

4MOST Project Overview
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4MOST PI

www.4MOST.eu
Overview

- Science drivers
- Instrument requirements and design
- Operations & simulations
- Schedule & team
Wide-field, high-multiplex optical spectroscopic survey facility for ESO

• Status:
  – Project approved by ESO
  – Preliminary design starts Jan 2015
  – Operations start on 4m-class VISTA telescope in end 2020 (2x 5 year)

• Science:
  – Cosmology, galaxy evolution, high-energy and Galactic science
  – Complement large-area space missions: Gaia, eROSITA, Euclid, PLATO
  – Complement ground-based surveys: VISTA, VST, DES, LSST, SKA, etc.

• Survey facility:
  – Instrument, science operations, data products, science
  – Run all-sky 5 year public surveys in parallel, with yearly data releases
  – Key surveys organized by consortium in coordination with community
  – Add-on surveys from community through ESO peer-reviewed applications
Background: EU strategic docs

• A Science Vision for European Astronomy (ASTRONET)
  – Extreme Universe (Dark Energy & Dark Matter, Black holes)
  – Galaxy Formation & Evolution
  – Origin of Stars and Planets
  – Solar System

• ASTRONET Infrastructure Roadmap
  „A smaller project, but again of high priority, is a wide-field spectrograph for massive surveys with large optical telescopes.“

• ESA-ESO Working Group on Galactic populations, chemistry and dynamics
  „Blue multiplexed spectrograph on 4 or 8m class telescope“

• Strategic Review on Europe’s 2-4m telescopes over the decade to 2020 (ASTRONET/OPTICON)
  „Optical wide-field spectrograph on 4m telescopes (N+S)“
Main science drivers
A 5 year 4MOST survey provides

Cosmology and galaxy evolution
- Euclid
- VST/VISTA/LSST/SKA (+other all-sky surveys)

High-energy sky
- eROSITA

Galactic Archeology
- Gaia
Main science drivers
A 5 year 4MOST survey provides

- Euclid/LSST/SKA (and other surveys) complement:
  - Dark Energy & Dark Matter (BAO, RSD, lensing, Ly forest)
  - Galaxy evolution (groups & clusters)
  - Transients (SNe Ia, GRB)
  - $>13 \times 10^6$ spectra of $m_V \sim 20-22.5$ mag LRGs & ELGs

- eROSITA complement:
  - Cosmology with x-ray clusters to $z \sim 0.8$
  - X-ray AGN/galaxy evolution and cosmology to $z \sim 5$
  - Galactic X-ray sources, resolving the Galactic edge
  - $2 \times 10^6$ spectra of AGN and galaxies in 50,000 clusters

- Gaia complement:
  - Chemo-dynamics of the Milky Way
  - Stellar radial velocities, parameters and abundances
  - $13 \times 10^6$ spectra @ $R \sim 5000$ of $m_V \sim 15-20$ mag stars
  - $2 \times 10^6$ spectra @ $R \sim 20,000$ of $m_V \sim 14-16$ mag stars

+ $\sim 15$ million spectra for community proposals
4MOST is a general purpose spectroscopic survey facility serving many astrophysical communities
Science Requirements

• 4MOST shall be able to obtain:
  – *Redshifts* of AGN and galaxies (also in clusters)
    • R~5000 spectra of 22 r-mag targets with S/N=5/Å with >3 targets in ø=2’
  – *Radial velocities* of ≤2 km/s accuracy and
    *Stellar parameters* of <0.15 dex accuracy of any Gaia star
    • R~5000 spectra of 20 r-mag stars with S/N=10 per Ångström
  – *Abundances* of up to 15 chemical elements
    • R~20000 spectra of 16 V-mag stars with S/N=140 per Ångström

• In a 5 year survey 4MOST shall obtain:
  – 15 (goal 30) million targets at R~5000
  – 1.0 (goal 3.0) million targets at R~20,000
  – 16,000 (goal 23,000) degree² area on the sky at least two times

Schnurr et al., Paper 9150-46
<table>
<thead>
<tr>
<th>Specification</th>
<th>Design value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field-of-View (hexagon)</td>
<td>&gt;4.0 degree² (ø&gt;2.5°)</td>
</tr>
<tr>
<td>Multiplex fiber positioner</td>
<td>~2400</td>
</tr>
<tr>
<td>Medium Resolution Spectrographs (2x)</td>
<td>R~5000–7000</td>
</tr>
<tr>
<td># Fibres</td>
<td>1600 fibres</td>
</tr>
<tr>
<td>Passband</td>
<td>390-930 nm</td>
</tr>
<tr>
<td>Velocity accuracy</td>
<td>&lt; 2 km/s</td>
</tr>
<tr>
<td>High Resolution Spectrograph (1x)</td>
<td>R~20,000</td>
</tr>
<tr>
<td># Fibres</td>
<td>800 fibres</td>
</tr>
<tr>
<td>Passband</td>
<td>392-437 &amp; 515-572 &amp; 605-675 nm</td>
</tr>
<tr>
<td>Velocity accuracy</td>
<td>&lt; 1 km/s</td>
</tr>
<tr>
<td># of fibers in ø=2’ circle</td>
<td>&gt;3</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>ø=1.4 arcsec</td>
</tr>
<tr>
<td>Area (first 5 year survey)</td>
<td>&gt;2h x 16,000 deg²</td>
</tr>
<tr>
<td>Number of science spectra (5 year)</td>
<td>~75 million of 20 min</td>
</tr>
</tbody>
</table>

Bellido et al., Paper 9150-45
Facility instrument overview

- New Wide-field Corrector, fibre positioner and three spectrographs
- Spectrographs mounted on telescope fork (gravitation invariant)
- Short fibre run (~15 m)

R. Haynes et al., Paper 9147-243
D. Haynes et al., Paper 9147-235
Wide-field corrector VISTA $\varnothing=2.5^\circ$
includes an ADC, A&G, and WFS

Design IoA, King, Parry, Sun, et al.

Design AAO, Gillingham et al., Paper 9151-230
Saunders et al., Paper 9151-56

ADC doublets  
401 kg

ADC lens  
310 kg
Wide-field corrector VISTA $\varnothing=2.5^\circ$ includes an ADC, A&G, and WFS.

Development AIP responsibility

- 1000nm Field-edge position
- Zenith Distance: 55 degree
- Seeing: 0.7 arcsec
- Fibre: 1.5 arcsec
- 380 nm

$\varnothing=1.5^\circ$
Tilting Spine (Echidna) positioner

- ~2400 fibres
- Large, overlapping patrol areas enables dense target packing and special high-resolution fibres
- Closest separation ~15 arcsec
- Reconfiguration time <2 min during science CCD readout

FMOS Echidna on Subaru

AAO, Sheinis et al., Paper 9151-67
Spectrograph optimisation ongoing

- Fixed configuration spectrographs, high throughput with VPH gratings
- 3-arm designs with 6k x 6k or 4k x 4k detectors for both high and low resolution are being considered

Implementation:
- HR: LSW
- LR: CRAL

Seifert, Xu (LSW)
Saunders (AAO), Paper 9147-223
Magnitude limits for typical science cases

- **2 hour limit**
  - Winkler et al., Paper 9150-28

- **20 min limit**

- **stochastic parameters**
  - abundances

- **radial velocities**

- **redshifts**

- **Wavelength [nm]**

4MOST | IAU S311, Galaxy Masses as Constraints on Formation Models, 25 July 2014 | Roelof de Jong
How are we going to run 4MOST?

• Unique operations for MOS instruments that allows observations for most science cases
• 4MOST program defined by Public Surveys of 5 years
• Surveys will be defined by Consortium and Community
• All Surveys will run in parallel
  – Surveys share fibres per exposure for increased efficiency
• Key Surveys will define observing strategy
  – Millions of targets all sky
• Add-on Surveys for smaller surveys
  – Small fraction fibers all sky
  – Dedicated small area
  – $10^3$ to $10^6$ targets
How are we going to run 4MOST?

- Consortium Surveys will ensure whole hemisphere covered with at least ~120 minutes total exposure time.
- Each exposure 20 minutes, repeats possible.
- Total exposures times per target between 20 and 120 min (and more) possible till required S/N.
- Areas with more targets get visited for more than 120 min.
Simulate throughput, fibre assignment, survey strategy and verify total survey quality

<table>
<thead>
<tr>
<th>Science case</th>
<th>S/N / Å</th>
<th>r_{AB}-mags</th>
<th># Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW halo HR</td>
<td>140</td>
<td>12–15.5</td>
<td>0.07M</td>
</tr>
<tr>
<td>MW halo LR</td>
<td>10</td>
<td>16–20.0</td>
<td>1.5M</td>
</tr>
<tr>
<td>MW disk/bulge HR</td>
<td>140</td>
<td>14–15.5</td>
<td>2.1M</td>
</tr>
<tr>
<td>MW disk/bulge LR</td>
<td>10–30</td>
<td>14–18.5</td>
<td>10.7M</td>
</tr>
<tr>
<td>X-ray galaxy clusters</td>
<td>4</td>
<td>18–22.0</td>
<td>1.4M</td>
</tr>
<tr>
<td>X-ray AGN</td>
<td>4</td>
<td>18–22.0</td>
<td>0.7M</td>
</tr>
<tr>
<td>BAO+RSD galaxies</td>
<td>4</td>
<td>20–22.5</td>
<td>12.8M</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>&gt;29M</strong></td>
</tr>
</tbody>
</table>

MPE, Garching, Boller, Dwelly et al.
GEPI, Paris, Sartoretti et al.
IoA, Walton et al.
Mass distributions of galaxies in the Milky Way system

- (Monday talks by van der Marel, Helmi)
- 3D potential Milky Way potential determination to much large radii than possible by Gaia alone
- Thin streams to larger radii, also from GCs
- Identify streams by abundances
- Full chemo-dynamics of Magellanic Cloud system and nearby satellites
- Detection of bar and spiral arm resonances throughout the Milky Way disk
Milky way bar creates moving groups in velocity distribution

- So far only done out to 200 pc with Hipparcos
- Gaia combined with 4MOST can do this to ~10 kpc, i.e. in almost half the Milky Way

Minchev et al. (2010)
Extra-galactic mass estimates

- RSD of the large scale structure
- Evolution of mass & energy budget for $z<1$
- Growth of structure on 1kpc-10Mpc scales for $z<1$
- Masses of 50,000 X-ray selected galaxy clusters with typically 40 redshifts/cluster
- Redshifts 1000s of strong lenses from Euclid
- Reverberation mapping of 100s of AGN
  - (and statistically of 100,000s with LSST)
• Concentrate on redshifts $z<\sim 1$ to complement Euclid, maximize area to increase total number of targets for 4m telescope
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- **Status:**
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- **Science:**
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  - Complement large area space missions: Gaia, eROSITA, Euclid, PLATO
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- **Survey facility:**
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  - Run all-sky 5 year *public* surveys in parallel with yearly data releases
  - Key surveys organized by consortium in coordination with community
  - Add-on surveys from community through ESO peer-reviewed applications
- **Instrument specifications:**
  - High multiplex: 1600 fibres to R~5000 + 800 fibres R~20,000 in parallel
  - Large field-of-view on VISTA, 4m-class telescope: φ=2.5°
Competitiveness: Low-Resolution

![Diagram showing the competitiveness of different observational projects based on resolution elements per year, area per year, and effective nights per year. The diagram includes labels for projects such as 4MOST, BigBOSS, GTC/GO-IRS, VIMOS, IMACS, FORS2, GIRAFFE, BOSS, WEAVE, DEspec, LAMOST, and 6dF.](image)
Competitiveness: High-Resolution

![Graph showing the relationship between area and information with different telescopes and their resolutions.](image-url)