From MOONS@VLT to MOSAIC@E-ELT:

Spectroscopic follow-up for WISH

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MOONS Multi-Object Optical and Near-infrared Spectrograph for the VLT

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MOONS

✓ **Competitive Phase A with 4MOST completed in April 2013**

✓ **Top-ranked and selected by ESO as 3rd generation instrument for VLT**

From the ESO Phase A report:

"The STC is therefore asked to recommend that the MOONS and 4MOST projects can proceed to design and construction phase.

STC is asked as well to recommend that MOONS can start this phase immediately with full financing (6M Euro), while 4MOST can proceed with a delay of about 1 year (with reduced financing 5M Euros) that is compatible with the resources available at ESO."

✓ **MoU (Septembre 2014)**

✓ **Operational by early 2019**


European Organisation for Astronomical Research in the Southern Hemisphere
Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

Dr Adrian Russell
Director of Programmes
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28 May 2013

Dr. Michele Cirasuolo
UK Astronomy Technology Center
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Edinburgh EH9 3HJ

Dear Dr. Cirasuolo

MOONS

The MOONS proposal for detailed design and construction was discussed at the 80th meeting of the ESO Scientific Technical Committee on April 23.

The committee has subsequently recommended that ESO proceed with the detailed design and construction of instrument.

In the coming weeks we will therefore commence good faith negotiations towards achieving requirements definition, scope of work and the formal ESO-consortium agreement.

We will also need to agree the guaranteed-time return for the consortium and submit this to ESO Council for approval.

I look forward to working with you on the delivery of this important project.

Best wishes,

Adrian Russell,
ESO Director of Programmes

Cc Tim de Zeeuw
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MOONS in a nutshell

Field of view: 500 sq. arcmin at the 8.2m VLT

Multiplex: 1024 fibers, with the possibility to deploy them in pairs

Medium resolution:

Simultaneously 0.8-1.8µm

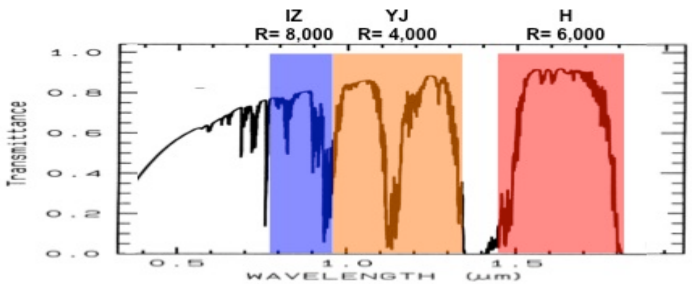
at

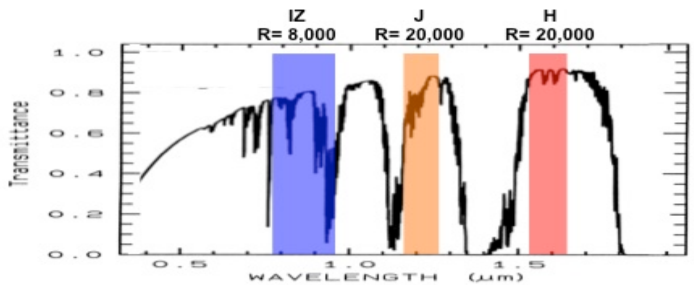
R=4,000 – 6,000

High resolution:

Simultaneously 3 bands:

- 0.8-0.95µm at R = 8,000
- 1.17-1.26µm at R=20,000
- 1.52-1.63µm at R=20,000





Throughput: ~ 30 %

MOONS Surveys

300 nights GTO programs

Negotiating with ESO extension to a Legacy Survey led by consortium

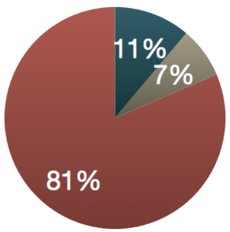
Galactic Archaeology
> 3M stars in Bulge, Disc and Halo

SDSS-like at z>1
~1M galaxies with full spectral diagnostics

Cosmology
~ 2M redshifts for a *complete* galaxy sample

LESSON from SDSS: Out of 834 "official" SDSS journal papers

Area	# papers	Percentage
Cosmology	93	11.2%
Supernovae	62	7.4%
Legacy	679	81.4%



But many more (>4500) papers have been written using SDSS data !!

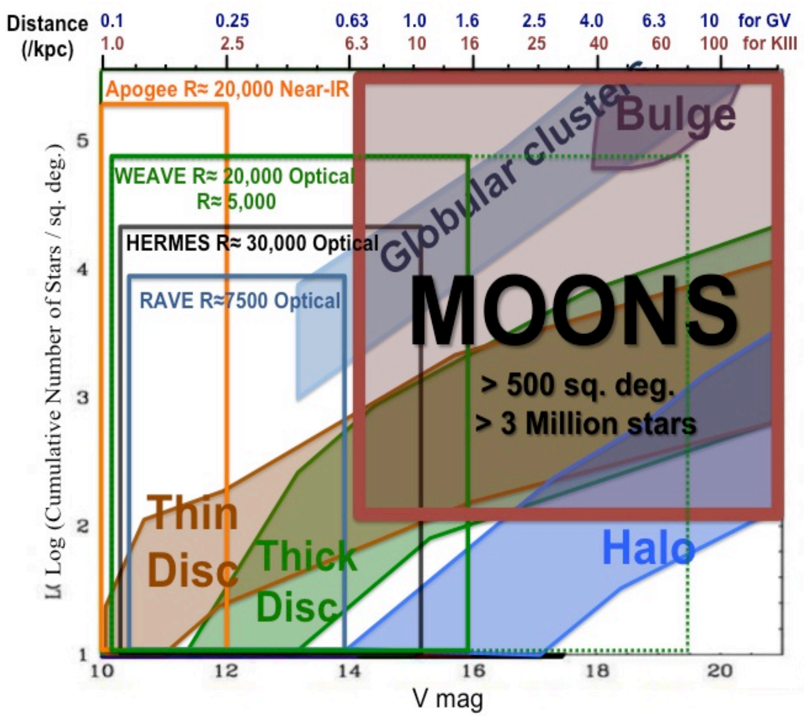
MOONS Legacy Surveys

Inner Galaxy + Gaia Legacies

Radial velocities and chemical abundances
for > 3M stars over >500 sq. deg.

CaT @R=8,000   I < 21
+
[M/H] (via Fe,Si,Ti,Mg) @R=4000-6000 JH_{Vega} < 17-18

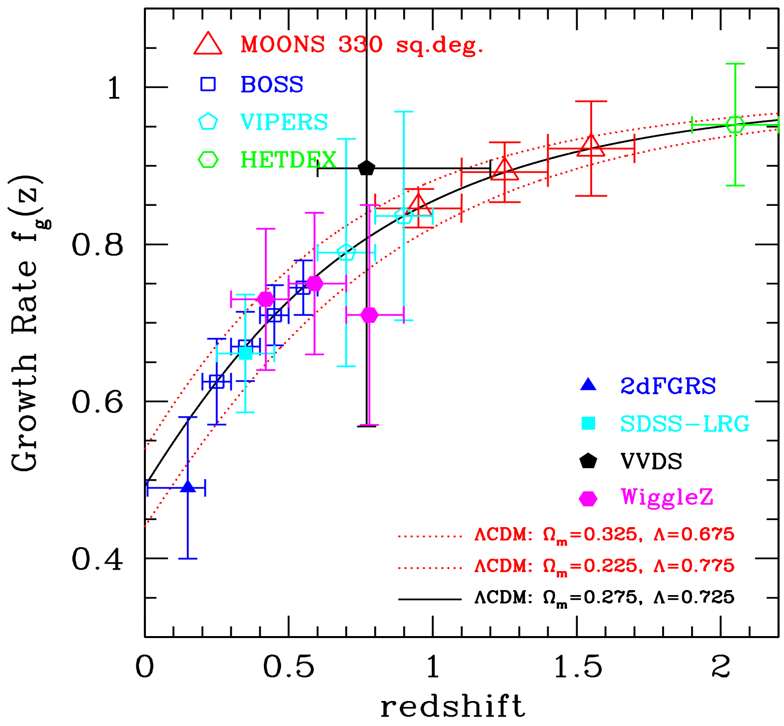
(Si, Ca, Ti, Mg, Fe, Cr, Mn, CNO …) @R=20,000
JH_{Vega} < 15.5-16
+
CaT @R=8,000



MOONS cosmological survey

Spectroscopic redshift for EUCLID, WISH, BOSS, PFS, BigBOSS
target just star-forming or LRG

Survey with MOONS can provide
a complete sample to $H_{AB} < 22$



- Statistical precision on the growth rate f_g to better than 4% at z>1.

- More importantly, a complete sample and not just star-forming or LRG can be used to eliminate potential systematic effects dependent on the galaxy population considered.

MOSAIC

MOSAIC@E-ELT: a MOS for Astrophysics, IGM & Cosmology

Science Team

Jose Afonso, David Alexander, Omar Almaini, Beatriz Barbuy, Nate Bastian, Xavier Bonfils, Piercarlo Bonifacio, Nicolas Bouche, Enzo Brocato, Andy Bunker, Elisabetta Caffau, Karina Caputi, Andrea Cimatti, Michele Cirasuolo, Christopher Conselice, Thierry Contini, Jean-Gabriel Cuby, Katia Cunha, Massimo Dall'Ora, Gavin Dalton, Ben Davies, Reinaldo de Carvalho, Alex de Koter, Karen Disseau, James Dunlop, Benoit Epinat, Chris Evans, Michele Fabrizio, Annette Ferguson, Fabrizio Fiore, Hector Flores, Adriano Fontana, Emanuele Giallongo, Eike Guenther, Francois Hammer, Vanessa Hill, Marc Huertas-Company, Lex Kaper, Thierry Lanz, Soeren Larsen, Bertrand Lemasle, Claudia Maraston, Ross McLure, Simona Mei, Simon Morris, Goran Ostlin, Roser Pello, Laura Pentericci, Celine Peroux, Rolf-Peter Kudritzki, Patrick Petitjean, Henri Plana, Mathieu Puech, Myriam Rodrigues, Emmanuel Rollinde de Beaumont, Hugues Sana, Daniel Schaerer, Mark Swinbank, William Taylor, Eduardo Telles, Goncalves Thiago, Scott Trager, Niraj Welikala, Yanbin Yang, Stefano Zibetti, Bodo Ziegler

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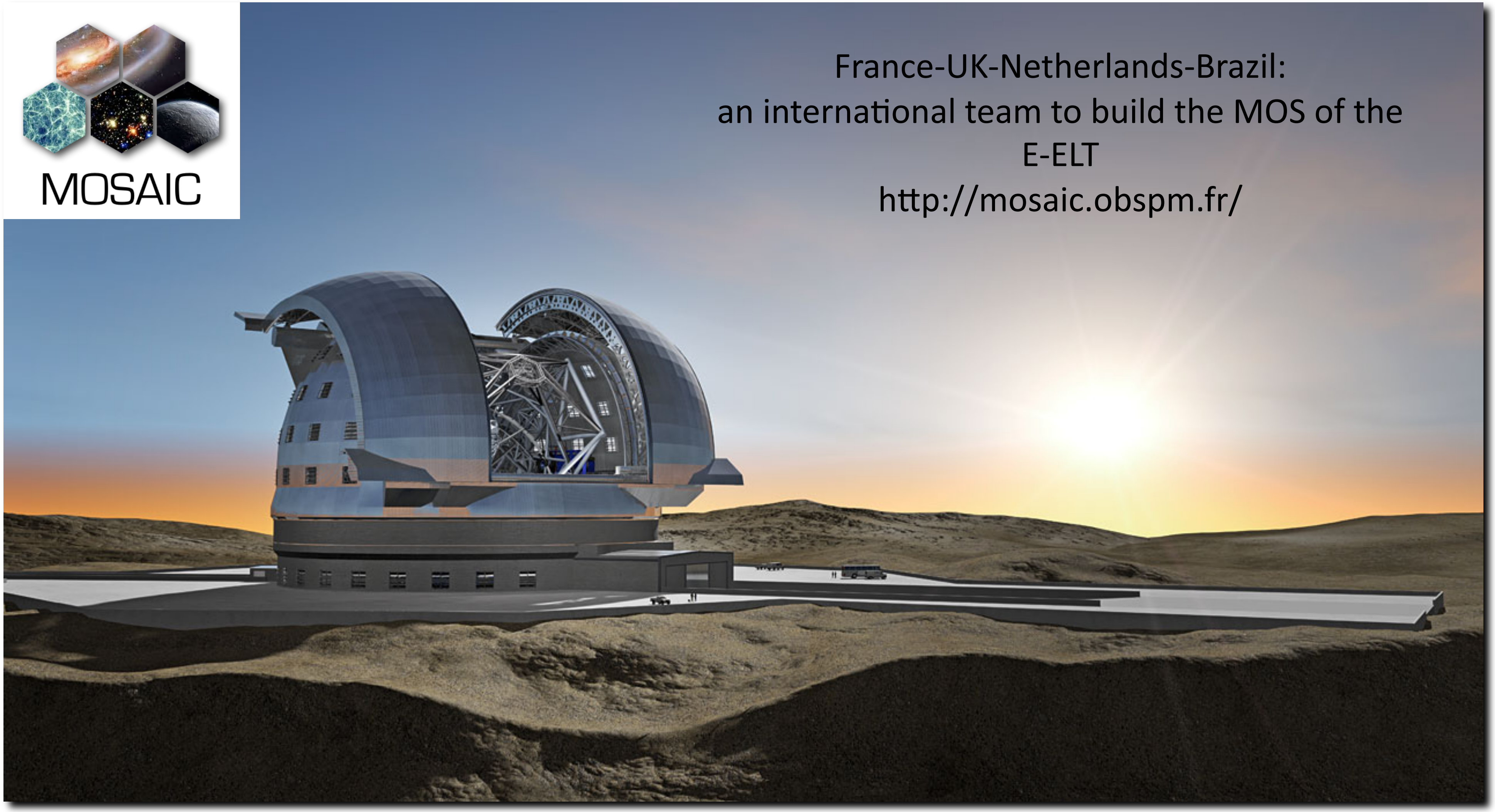
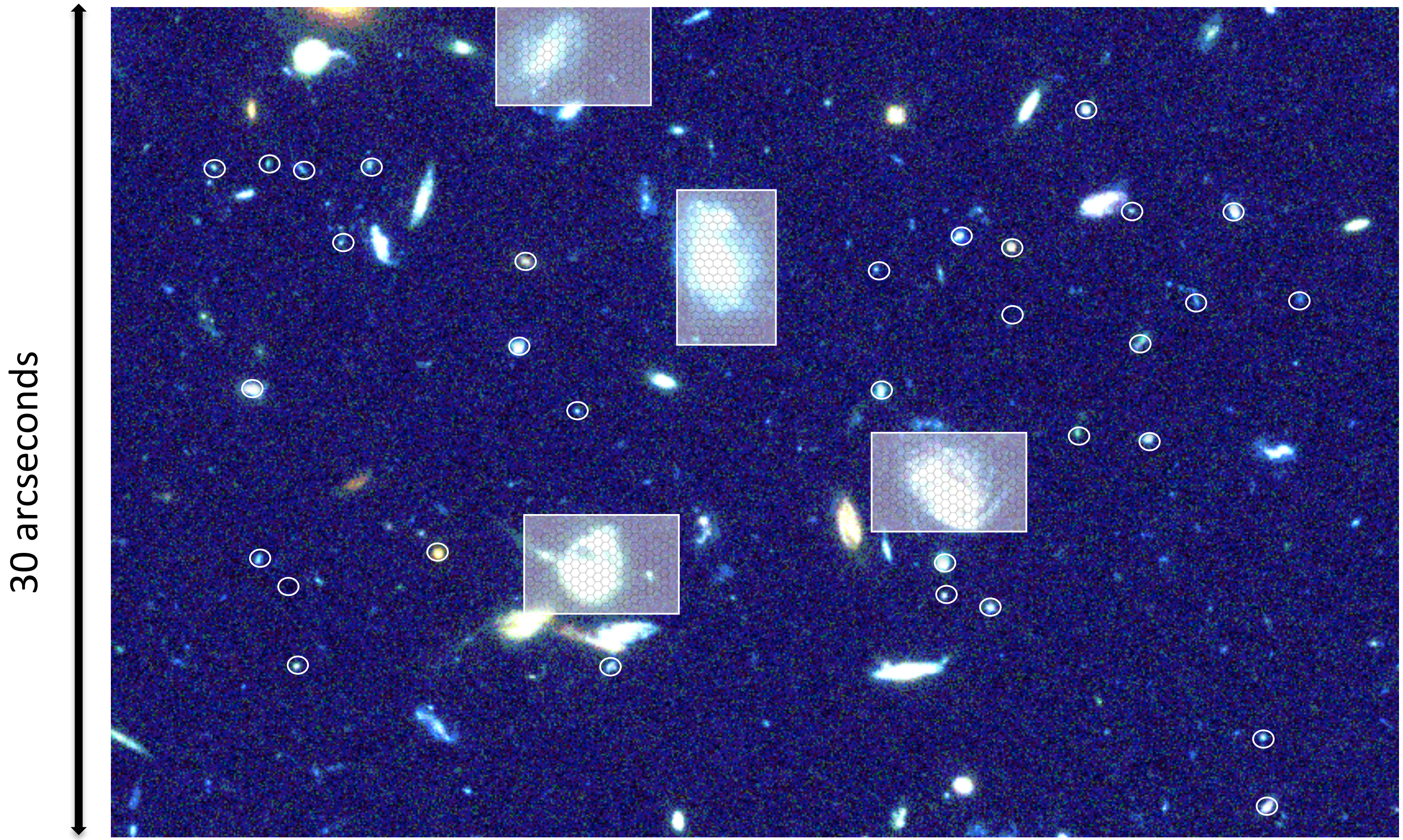


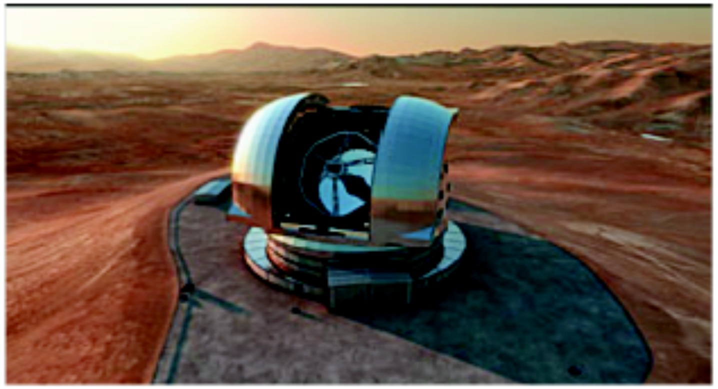
MOSAIC team have developed then implemented:
GIRAFFE/FLAMES - NACO - X-SHOOTER - KMOS

A CENSUS for z >> 1 galaxies



- spatially resolved kinematics of z>>1 massive galaxies
- spectroscopy of dwarfs and their link to massive galaxies

A good description of science cases: ELT-MOS White Paper



Document Title	ELT-MOS White Paper: Science Overview & Requirements
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Editors	Chris Evans (UK ATC) & Mathieu Puech (GEPI)

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Issue 1.0 : ArXiv:1303.0029
Issue 2.0 : 2014

ELT-MOS Science Cases

- SC1: First light - spectroscopy of the most distant galaxies
- SC2: Spatially-resolved spectroscopy of high-z galaxies
- SC3: Role of high-z dwarf galaxies in galaxy evolution
- SC4: Tomography of the IGM
- SC5: Resolved stellar populations beyond the Local Group
- SC6: Galaxy archaeology with metal-poor stars

& more...

Need for imagery & photometry

- Both instruments need deep images (blind instruments).

- Spectroscopy with higher multiplex (500-1000/VLT & 100-200/ELT fov), (Multi-band) photometry to catch very high-z sources low spatial resolution images are OK:
  WISH + Ground based telescopes

- For the E-ELT: Imagery for comparing with kinematics 3D-spectroscopy, with small multiplex (10-20/ELT fov), requires high spatial resolution images: JWST / ELT-CAM

1 MOONS FoV~500 arcmin^2 ; 1 E-ELT FoV ~ 40-50 arcmin^2

Future existing galaxy imagery

(excerpt from Hervé Aussel)

Table A1: Number of sources detected per 40 arcmin² ELT-MOS field per bin of redshift, for Euclid deep survey, WISH survey and for 1 hour exposure with JWST and ELT-CAM. All quoted depths are 5σ point source. For survey instruments (Euclid and WISH), the quoted depths are for the deep surveys. For JWST and ELT-CAM, the quoted depths are for 1-hour integration time. Note that the number for Euclid in J and H are identical except for the last redshift bin, as the Lyman break enters the J band at z=8.

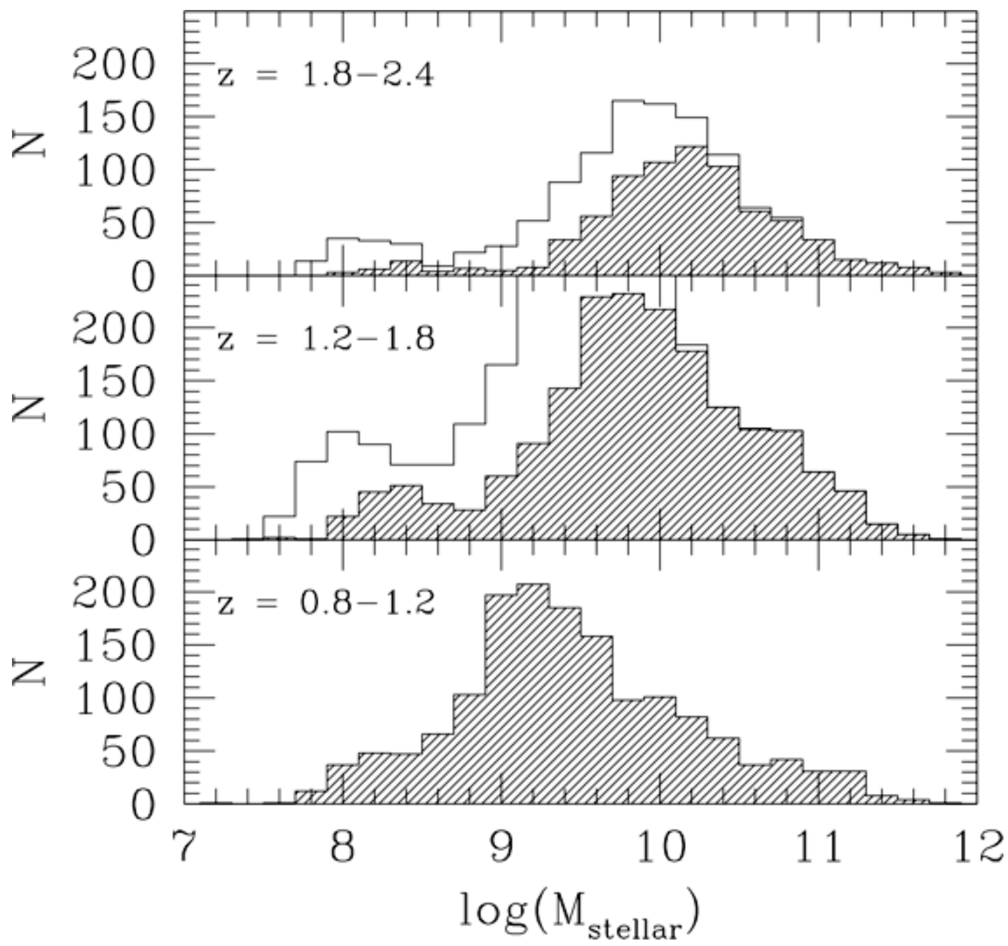
		$5 < z \leq 6$	$6 < z \leq 7$	$7 < z \leq 8$	$8 < z \leq 9$
Euclid	$J_{AB} \leq 26$	13.68	3.14	0.45	0.16
Euclid	$H_{AB} \leq 26$	13.68	3.14	0.45	0.21
WISH	$H_{AB} \leq 27.4$	127	60	21	12
JWST	$H_{AB} \leq 29.0$	640	439	225	148
ELT-CAM	$H_{AB} \leq 29.9$	1371	1083	640	452

MOS will be able to detect/study highest z galaxies from JWST/ELT-CAM imagery & photometry

SC3: Study the numerous distant galaxy population

1600 galaxies at z> 1.5 in an E-ELT FoV (mostly dwarfs)

- Origin of dwarves: primordial galaxies or tidal dwarfs?
- Low surface brightness galaxies in the gaseous-rich Universe
- Test of curvature (Λ using HII galaxies)



m_J(AB)<26

Based on CANDEL counts & Dahlen photo'z

Optical imagery/photometry for searching very high z sources

•WISH will probe deep imagery in additional FoVs (at large depths, cosmic variance has to be tested);

•with its Extreme Survey (AB ~ 29-30, 0.25 sq deg.) it will bring a very important addition to the "single cosmological field" problem (e.g., the 3hr field -GOODS- with the VLT);

•For z ~ 7-8, it is necessary to have imagery I_{AB} ~ 28+2=30 to warrant Lyman break detection

•Other needs are mostly for (larger) survey modes (galaxy statistics, ids of large scale structures)

Expected Numbers with WISH Ultra-deep Survey

- 100 sq. deg survey with 5 filters from 1.0μm to 3.0μm
  - Limiting magnitudes 28AB (point source, 3σ)
  - Total 1,500 days

	z=8-9	z=10-12	z=13-17
Empirical Ev.	169,000	10,420	72
SAM	63,120	4,970	107

Iwata et al 2011

Synergy

E-ELT & MOONS: MOONS will be an ideal science path-finder for the MOSAIC@E-ELT instrument.

Spectrograph:
Cooling of fibers and design of the shutter (vacuum, vibrations, etc)

Fibers:
Cooling the fibers between the front-end and the spectrograph

DRS:
Test all the algorithms and observational strategy to subtract the sky.

Science: The two surveys (stellar and extragalactic) can be used to generate samples to be observed with the ELT/MOSAIC)

Synergy

WISH: MOONS can be the first for the brightest sources and then in the future MOSAIC.

The two MOONS surveys (stellar and extragalactic) will need near mid IR photometry.

Wavelength coverage: 0.7-0.8µm – 1.8µm: three WISH filters (0 1 2)

Large aperture telescope: 8.2m diameter

High spectral resolving power: R~ 4,000 – 6,000

Crucial to reduce contamination from OH sky lines and
Resolve spectral features

Conclusions

- WISH with the wavelength coverage could provide mass determination for all the galaxies of the SDSS-like MOONS survey
- Preliminary spectroscopic follow up with MOONS@VLT (for the bright high z candidates)
- An E-ELT FoV contains 8000 $H_{AB}<27$ sources, 1600 $z > 1.5$ galaxies

  High multiplex & high definition modes needed: this is MOONS + MOSAIC
- MOSAIC@E-ELT with multi-IFUs can detect the first light, solve the re-ionisation problem & probe the galaxy mass assembly, WISH can provide targets

Synergy with other facilities

Gaia: MOONS will be the only instrument to provide the necessary radial velocities and especially chemical abundances for faint stars and the inner Bulge and Disc.

Both PIs of of ESO-Gaia survey are part of the MOONS science team (G. Gilmore and S. Randich)

VISTA: MOONS will be the best-suited instrument to provide follow-up of the VISTA near-IR imaging surveys: **Ultra-VISTA, VIDEO, VIKING, VVV, VMC**.

5 PIs of the VISTA Public Surveys are also part of the MOONS science team
(J. Dunlop, J. Fynbo, M. Jarvis, M-R. Cioni, D. Minniti).

Radio and X-ray surveys: MOONS will be essential to follow-up faint radio galaxies and AGN selected in X-ray. The most interesting high-z obscured AGNs (e.g. selected by ***eRosita***) are typically faint in optical R>25 but relatively bright in the near-IR (H<24) and therefore only accessible with near-IR spectroscopy on an 8m telescope.

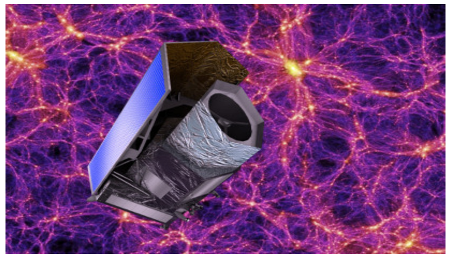
Synergy with other facilities

Euclid: ESA cosmology mission (2020-21) to address the nature of Dark Energy, Dark Matter and Gravity via Baryonic Acoustic Oscillations and Weak Lensing.

MOONS will provide the necessary deep spectroscopic control sample needed to calibrate the photometric redshifts and slitless-spectroscopic redshifts, essential for Euclid primary science cases.

Many Euclid team members are also part of the MOONS science team.

(see recent workshop: Synergies between large-area surveys, MOONS and Euclid, 5-6th November 2012, http://www.roe.ac.uk/roe/workshop/).



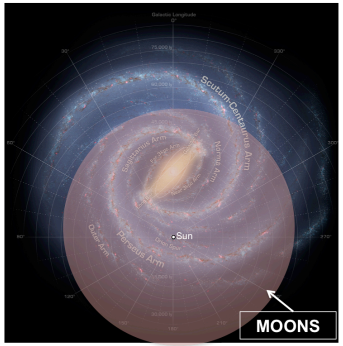
Summary

MOONS is the long-awaited near-IR MOS for the VLT
Operational 2019

FoV	500 sq. arcmin
Simultaneous λ	0.8μm – 1.8μm
Multiplex	1000 or 500 pairs
Resolution	5000 or 20,000

Galactic Archaeology

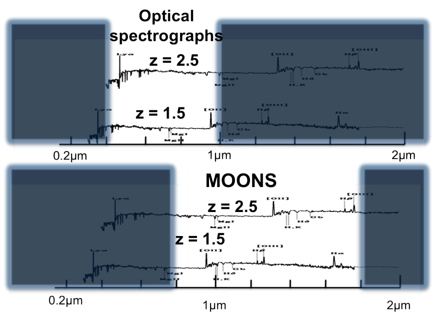
- ✓ Radial velocities and detailed chemical abundances for **several million stars** over **>500 sq. deg**.
- ✓ Best instrument to study the inner Bulge and Disk
- ✓ Possibility to target stream, clusters in the Halo and nearby galaxies



Chemistry and dynamics for all components of the Milky Way (Bulge, Disc and Halo)

A formidable SDSS-like survey at z > 1

- ✓ Fundamental insights into galaxy formation and evolution over cosmic time from **~1M galaxies at z>1**.
- ✓ Follow-up of the very first galaxies at z>7 into the **epoch of re-ionization**.
- ✓ Follow-up of large-area imaging surveys: VISTA, Herschel, DES, UKIDSS, eRosita, LSS, etc.
- ✓ Strong synergies with Euclid and SKA1 and SKA pathfinders.



MOONS for Galactic studies

MOONS will be able to observe all the main components of our Galaxy

Gaia + VISTA imaging

- Position
- Transverse velocities
- Photometry

→

MOONS Spectra

- Radial velocities
- Global metallicity
- Detailed chemistry

→

MOONS + Gaia + VISTA

- Positions & velocities
- Dynamics
- Abundances
- iron-peak, alpha, CNO
- Astrophysics (ages, histories, etc)

- Formation and evolution of the Bulge.
- Origin of the thick Disc.
- Structure and evolution of the thin Disc.
- Quantitative studies of Halo sub-structure, dark matter, and rare stars.
- Kinematic multi-element distribution function in the Solar Neighbourhood.

Galactic Archaeology

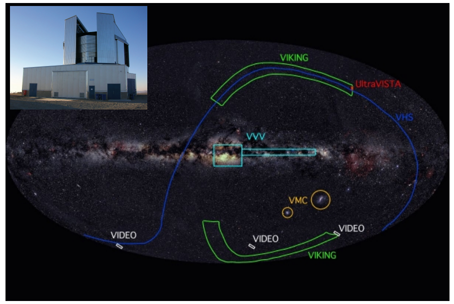
Gaia - ESA cornerstone mission:

Imaging to measure proper motion (for V<20)

On board spectroscopy is limited to bright objects:

V < 17 for radial velocity

V < 13 for detailed chemical abundances



VISTA public surveys

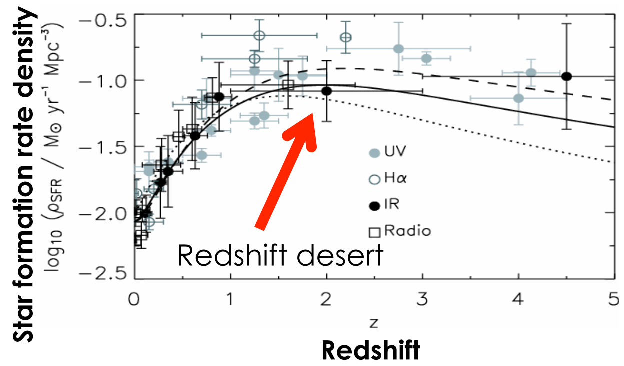
Ground-based spectroscopic follow-up is essential

MOONS will provide

Medium resolution mode	**High resolution mode**
Radial velocities via CaT @R=8,000 for I<21 + [M/H] (via Fe,Si,Ti,Mg) @R=4000-6000 (J+H)	Detailed chemical abundances (Si, Ca, Ti, Mg, Fe, Cr, Mn, CNO …) @R=20,000 for H<15.5 + CaT @R=8,000

Extra Galactic Science Case

1M galaxies at z>1 across the peak of star-formation and black hole accretion, up to the very first galaxies at z>7-8



Galaxy Evolution: Diagnostics for passive and star-forming galaxies

- ***Metallicity (R_{23},N_2)***
- ***SFR (Hα, Hβ, [OII])***
- ***AGN power (BPT)***
- ***Dust extinction (Hα/Hβ)***
- ***Galaxy mass (σ_v)***
- ***BH mass (BLR)***