The next generation of near-IR spectrographs KMOS and MOONS

Michele Cirasuolo
Royal Observatory Edinburgh

on behalf of *KMOS* and *MOONS* Consortia

Outline

- Why near-IR spectroscopy
- KMOS
  - Unique features
  - Science
  - Latest news
- MOONS
  - Status
  - Major science cases

The need for near-IR spectroscopy

The need for near-IR spectroscopy

1. Less affected by dust obscuration
   (e.g. Bulge of the Galaxy or dusty starbursts)

Visible Near-IR

The need for near-IR spectroscopy

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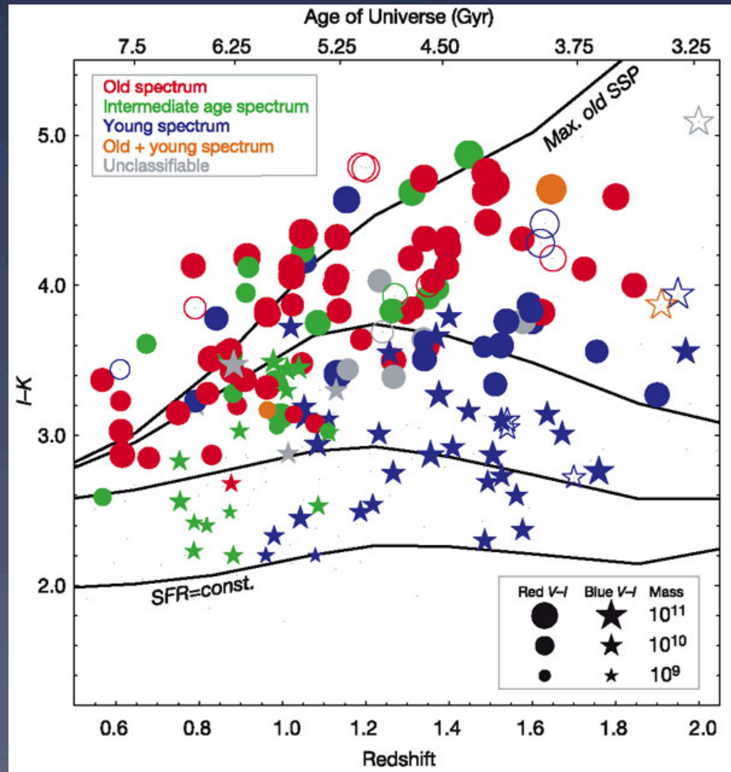
   (e.g. Bulge of the Galaxy or dusty starbursts)

2. Objects are intrinsically red
   (low-mass stars in the Milky Way and galaxies)



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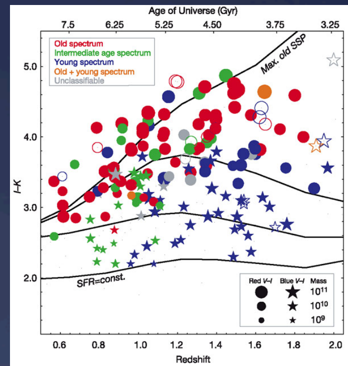

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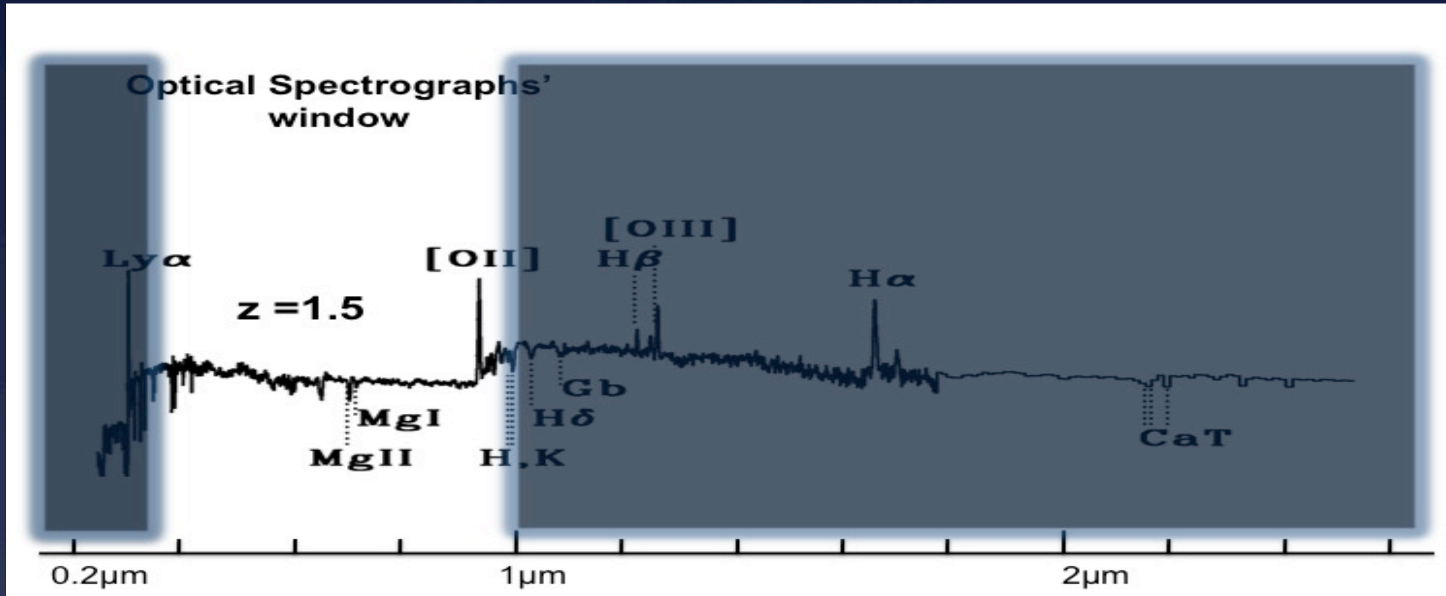
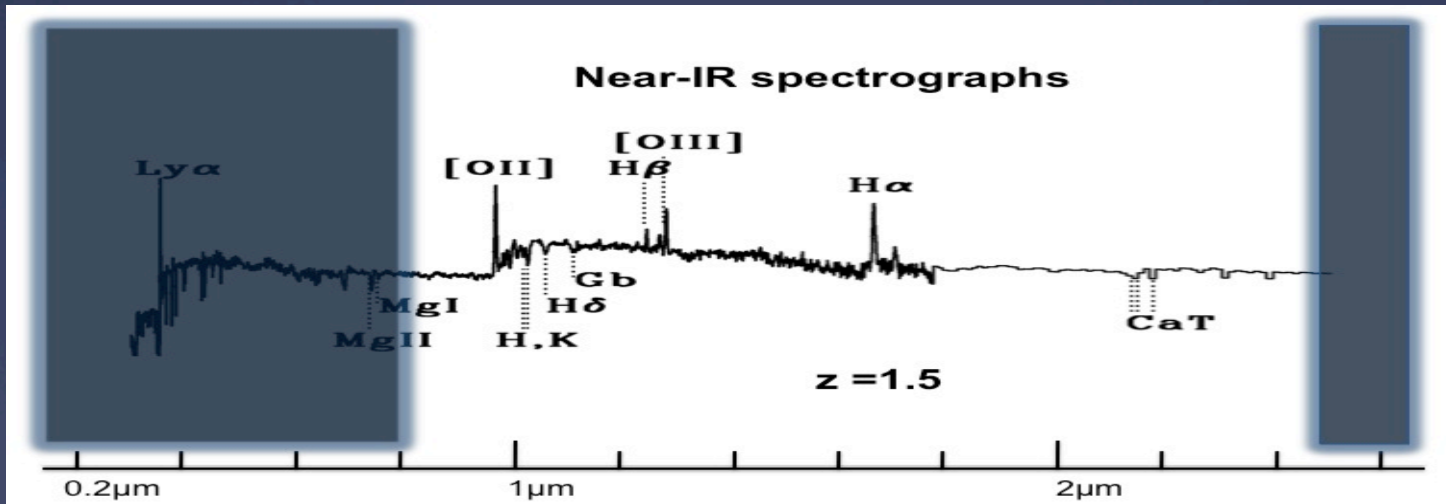
3. At z > 1 most of the key spectral features are
   reshifted in the near-IR

The need for near-IR spectroscopy



Observed wavelength λ



Observed wavelength λ

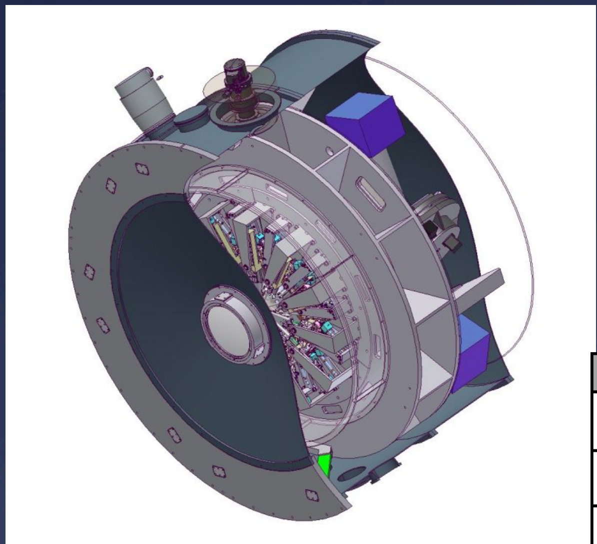
Ground-based Near-Infrared spectroscopy

Kmos

2013 — 2017-18 — 2020+

KMOS Near-IR multi-object IFU for VLT

First commissioning on sky in November 2012



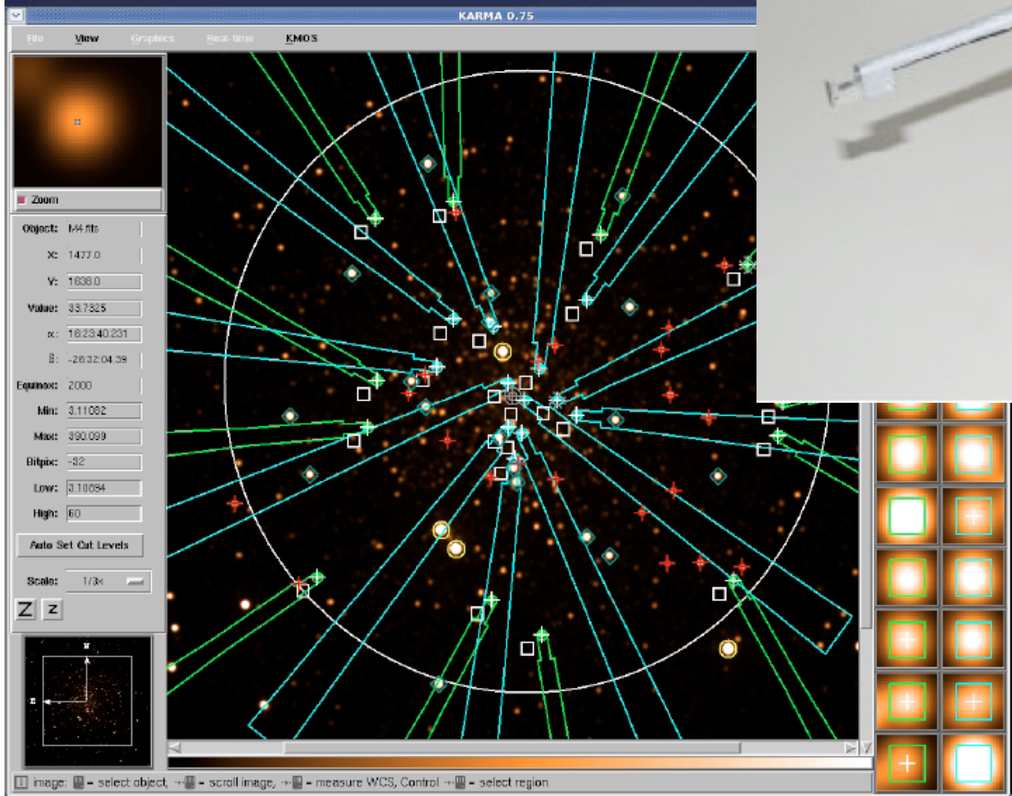
PI: R. Sharples

Consortium: UK, Germany and ESO
Instrument scientist: Cirasuolo

Wavelength coverage	0.8μm to 2.5μm
Spectral bands	IZ, YJ, H, K, H+K
Spectral resolving power	R = 3400, 3600, 4000, 4200, 2000 (IZ, YJ, H, K, H+K)
Number of IFUs	24
Extent of each IFU	2.8” x 2.8” (14 x 14)
Spatial sampling	0.2” x 0.2”
Patrol field	7.2 arcmin diameter circle
Close packing of IFUs	≥ 3 withing 1 sq. arcmin
Closest approach of IFUs	≥ 2 pairs of IFU separated by 6 arcsec

24 pick off arms

7 arcmin diameter FoV



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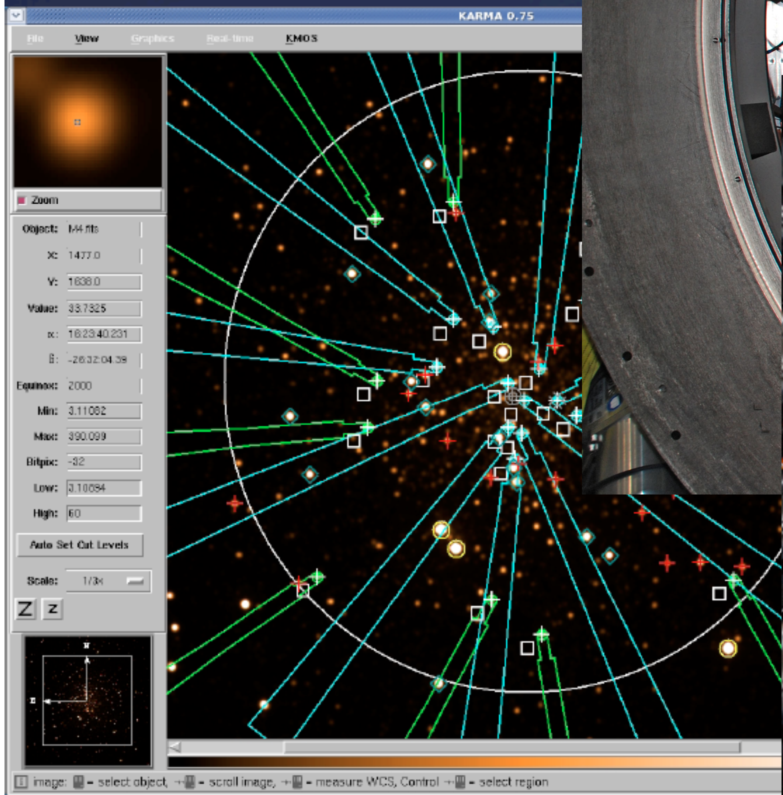
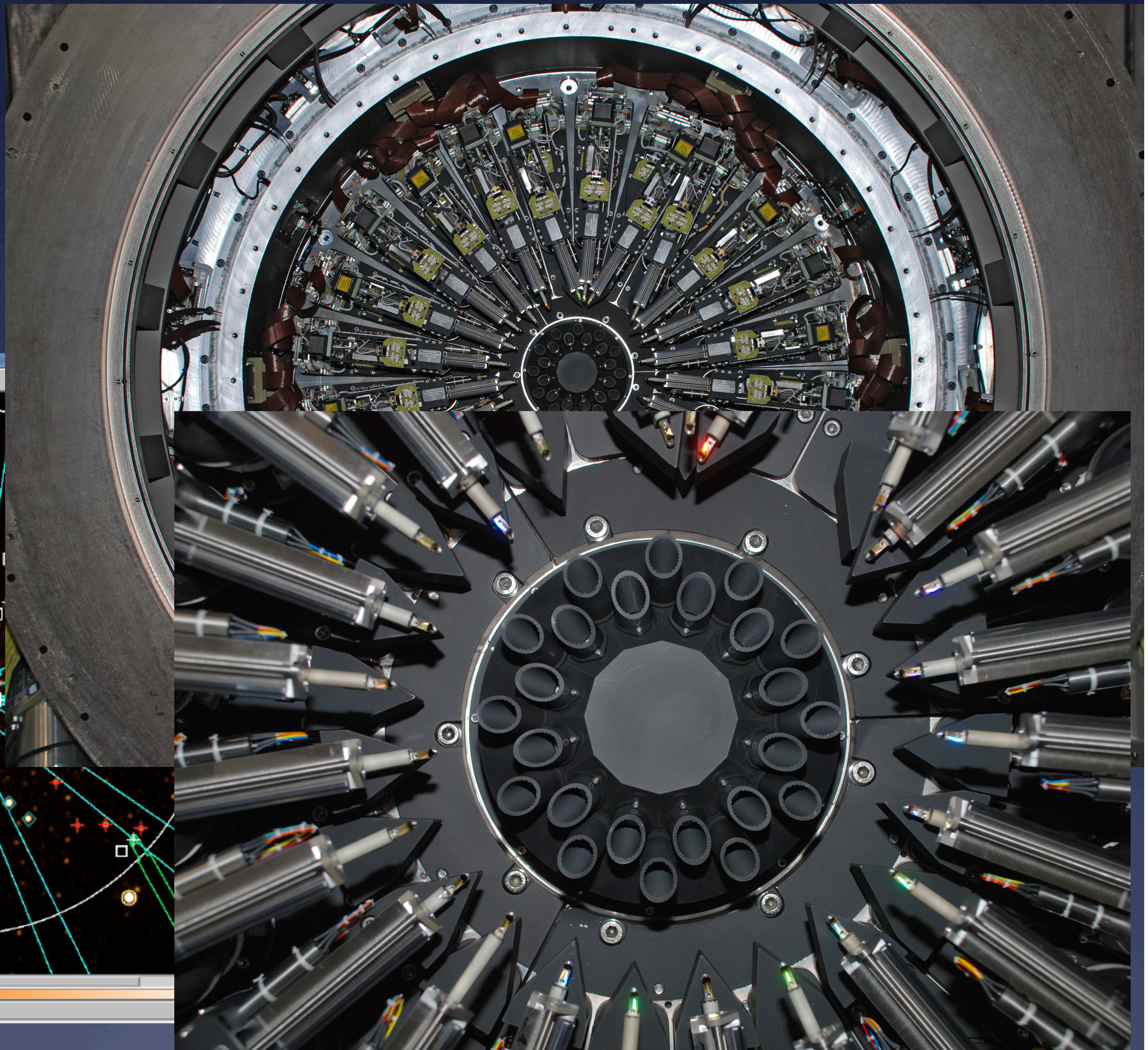
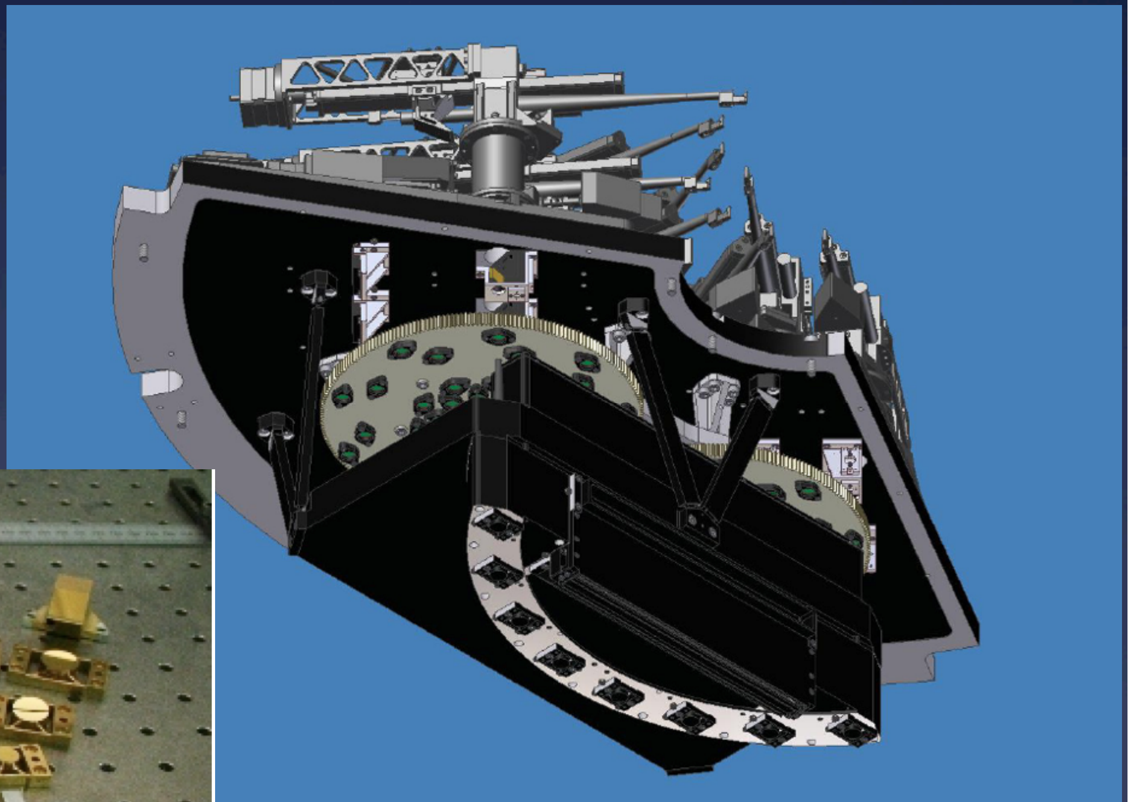
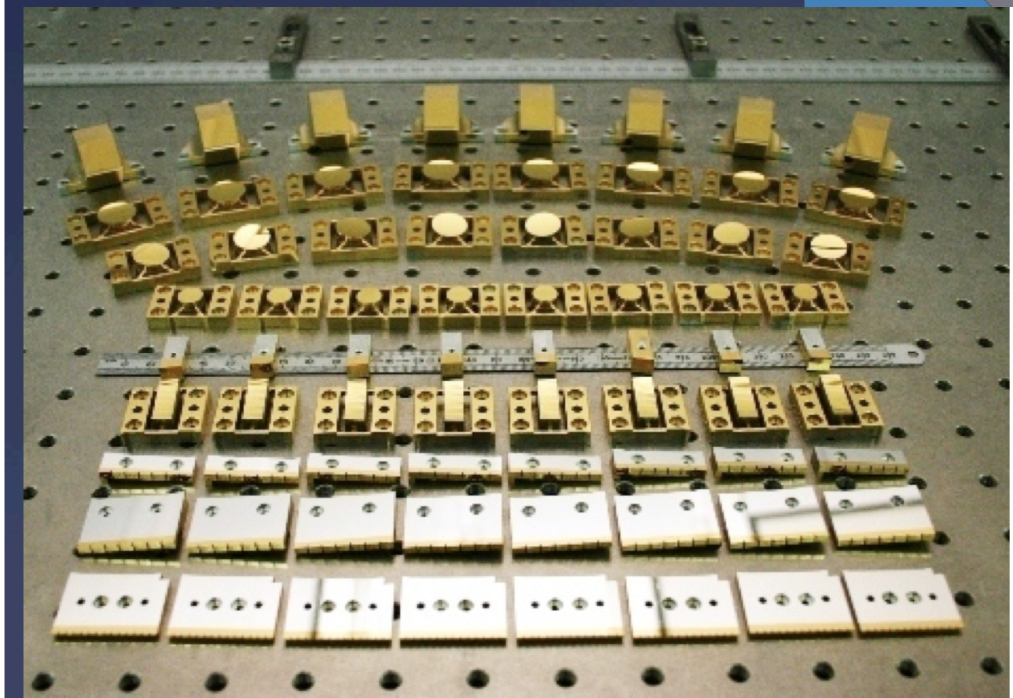




Integral Field Units

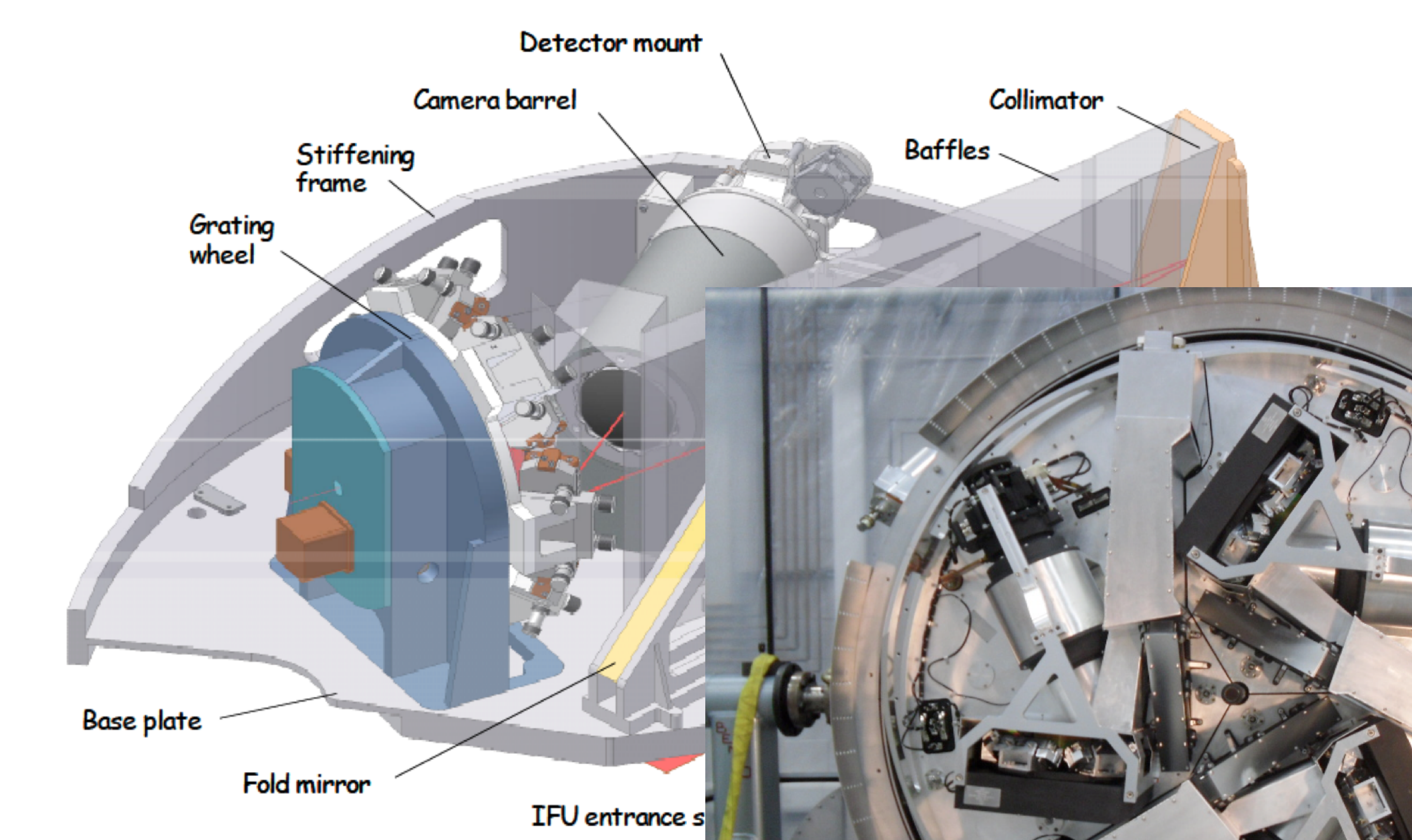
The light from 8 pick-off arms
is sliced and reformatted into a
pseudo long slit and
injected into
1 spectrograph

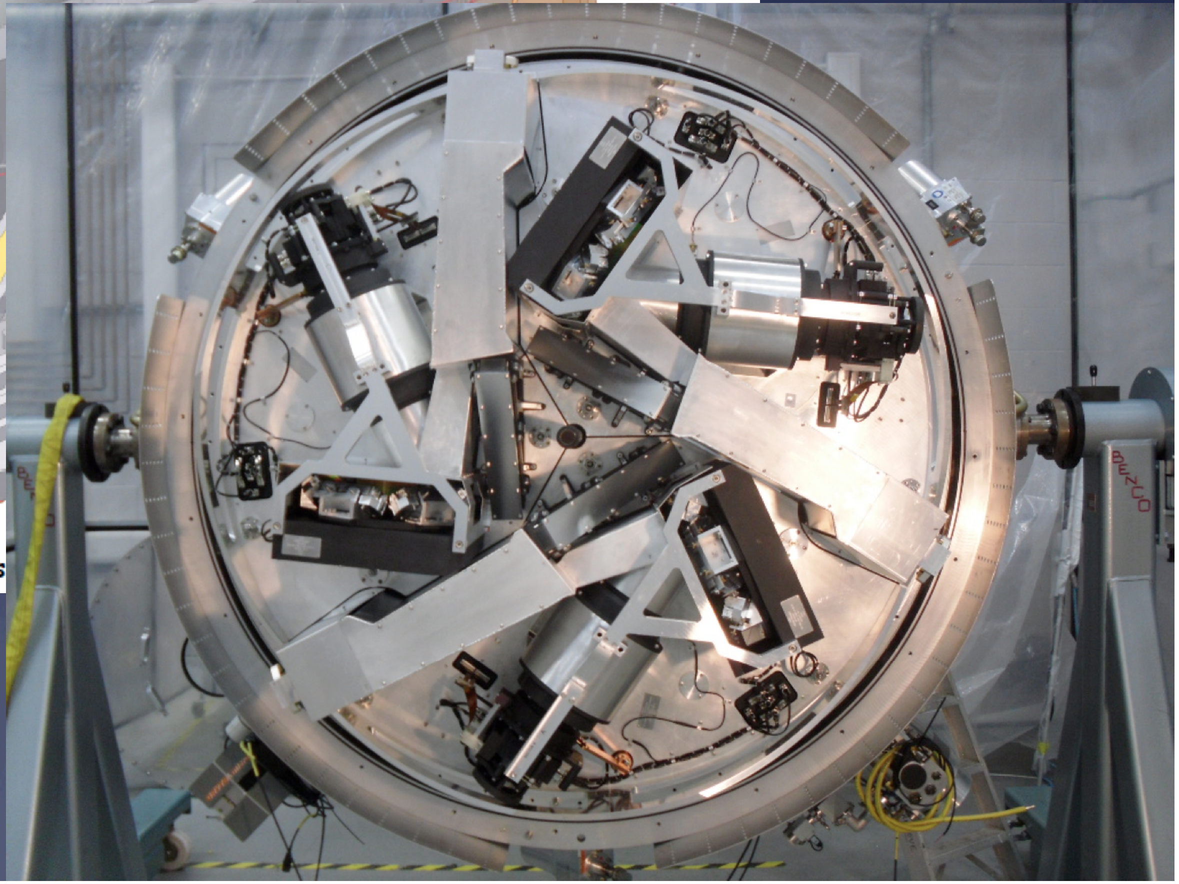




Built by Durham University

3 identical spectrographs



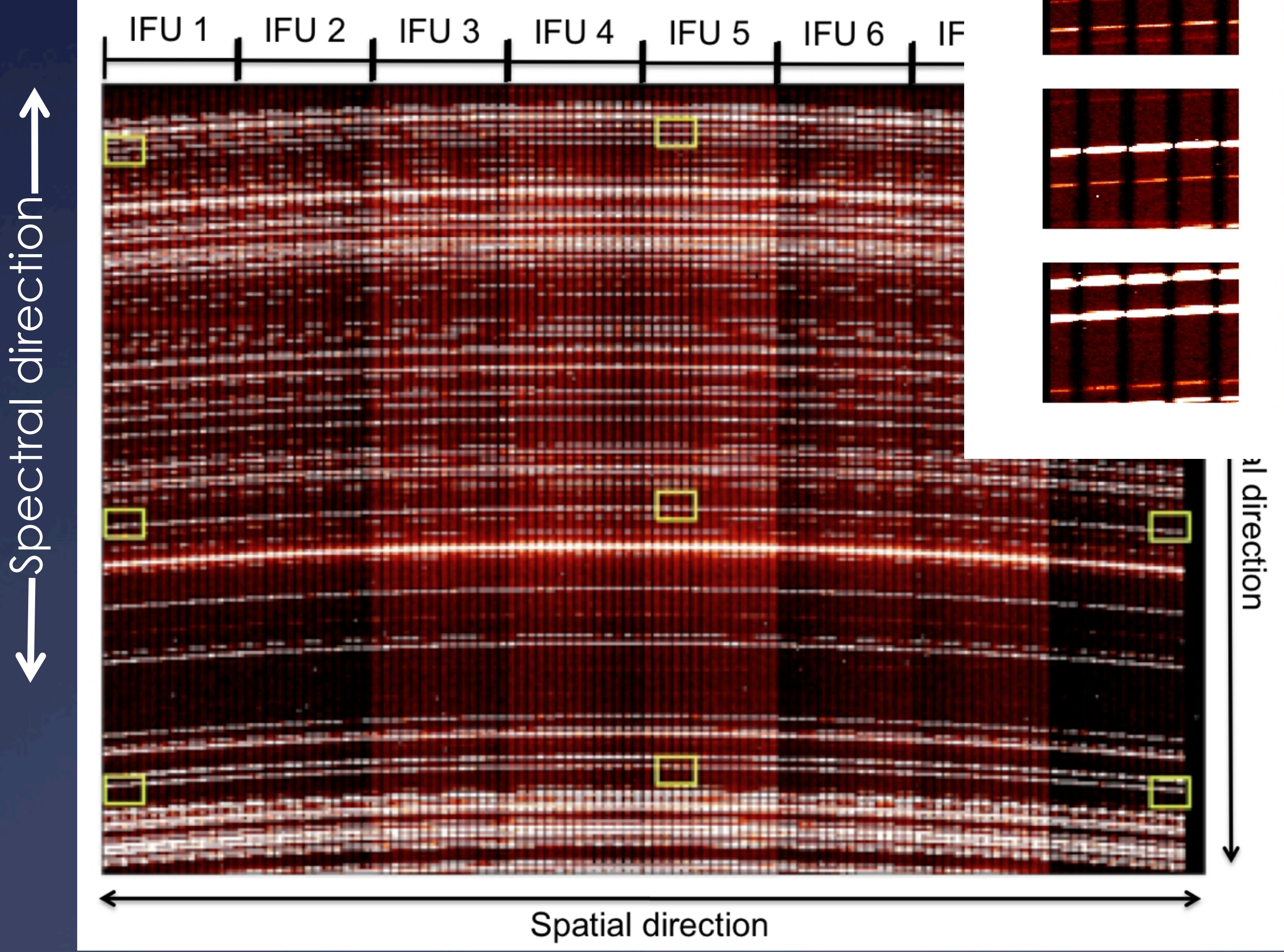


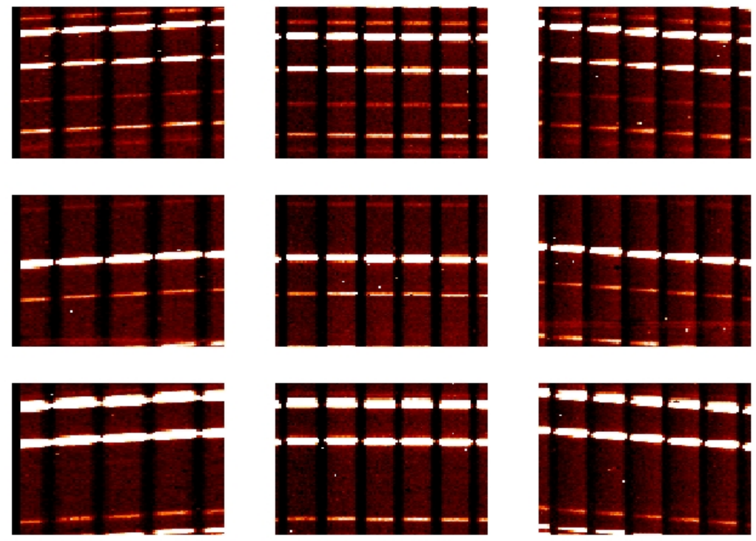
Built by Oxford University

KMOS data

ARGON lamp

1 detector, 8 IFUs





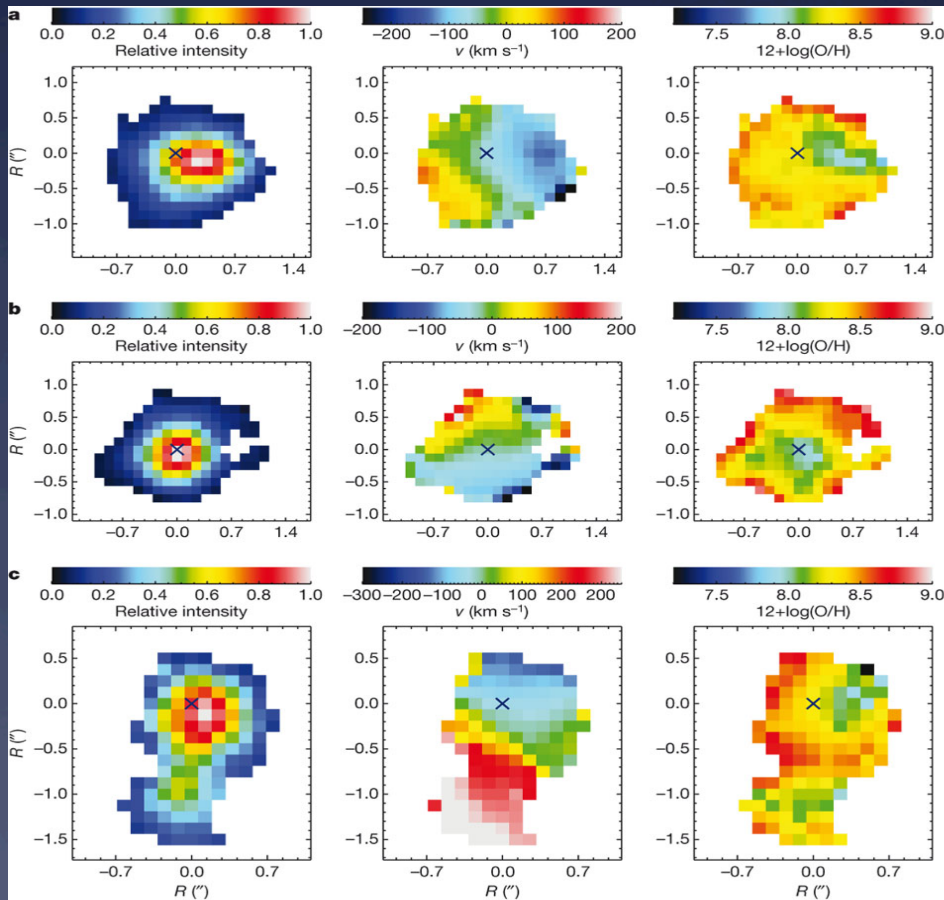
Spatial image quality
0.2 arcsec

Spectral image quality
2 pixels

Science with KMOS

Spatially resolved spectroscopy on kpc scales:

- Star formation history
- Dynamics
- Extinction
- Metallicity
- Mergers



Latest news

- Passes PAE and shipped from Edinburgh in July/August
- Arrived at Paranal beginning of September
- Reassembled and tested in the assembly hall

All is OK and working …. with great relief of the team !!!!

- First commissioning on sky: 21st November

Stay tuned …

One more step forward…

MOONS

Multi-Object Optical and Near-infrared Spectrograph for VLT

MOONS

- PI: M. Cirasuolo
- Consortium: UK, France, Germany, Italy, Netherlands, Portugal, Chile, Switzerland, Sweden, ESO

M. Cirasuolo[1,2*], J. Afonso[3], R. Bender[4,5], P. Bonifacio[6], C. Evans[1], L. Kaper[7], E. Oliva[8], L. Vanzi[9], M. Abreu[10], E. Atad-Ettedgui[1], C. Babusiaux[6], F. Bauer[9], P. Best[2], N. Bezawada[1], I. Bryson[1], A. Cabral[10], K. Caputi[2], M. Centrone[15], F. Chemla[6], A. Cimatti[11], M-R. Cioni[12], G. Clementini[20], J. Coelho[10], E. Daddi[13], J. Dunlop[2], S. Feltzing[14], A. Ferguson[2], H. Flores[6], A. Fontana[15], J. Fynbo[16], B. Garilli[23], A. Glauser[17], I. Guinouard[6], F. Hammer[6], P. Hastings[1], A. Hess[4], R. Ivison[1], P. Jagourel[6], M. Jarvis[12], G. Kauffman[18], A. Lawrence[2], D. Lee[1], G. Licausi[15], S. Lilly[17], D. Lorenzetti[15], R. Maiolino[15], F. Mannucci[8], R. McLure[2], D. Minniti[9], D. Montgomery[1], B. Muschielok[4], K. Nandra[5], R. Navarro[19], P. Norberg[2], L. Origlia[20], N. Padilla[9], J. Peacock[2], F. Pedicini[15], L. Pentericci[15], J. Pragt[19], M. Puech[6], S. Randich[8], A. Renzini[21], N. Ryde[14], M. Rodrigues[24], F. Royer[6], R. Saglia[4,5], A. Sanchez[5], H. Schnetler[1], D. Sobral[2], R. Speziali[15], S. Todd[1], E. Tolstoy[22], M. Torres[9], L. Venema[22], F. Vitali[15], M. Wegner[4], M. Wells[1], V. Wild[2], G. Wright[1]

[1]STFC UK Astronomy Technology Centre, Edinburgh, UK; [2]Institute for Astronomy, Edinburgh, UK; [3]Observatorio Astronomico de Lisboa, Portugal; [4]Universitaets-Sternwarte, Munchen, Germany; [5]Max-Planck-Institut fuer Extraterrestrische Physik, Munchen, Germany; [6]GEPI, Observatoire de Paris, CNRS, Univ. Paris Diderot, France; [7]Astronomical Institute Anton Pannekoer, Amsterdam, The Netherlands; [8]INAF-Osservatorio Astrofisico di Arcetri, Italy; [9]Centre for Astro-Engineering at Universidad Catolica, Santiago, Chile, [10]Centre for Astronomy and Astrophysics of University of Lisboa, Portugal; [11]Università di Bologna - Dipartimento di Astronomia, Italy; [12]University of Hertfordshire, UK; [13]CEA-Saclay, France; [14]Lund Observatory, Sweden; [15]INAF-Osservatorio Astronomico Roma, Italy; [16]Dark Cosmology Centre, Copenhagen, Denmark; [17]ETH Zürich, Switzerland; [18]Max-Planck-Institut für Astrophysik, Garching, Germany; [19]NOVA-ASTRON, The Netherlands; [20]INAF-Osservatorio Astronomico Bologna, Italy; [21]INAF-Osservatorio Astronoomico Padova, Italy; [22]Kapteyn Astronomical Institute, Groningen, The Netherlands; [23]IASF-INAF, Milano, Italy; [24] European Southern Observatory, Santiago, Chile.

MOONS

- PI: M. Cirasuolo
- Consortium: UK, France, Germany, Italy, Netherlands, Portugal, Chile, Switzerland, Sweden, ESO

Selected by ESO for a Phase A study as
a wide field MOS in combination with 4MOST

The aim for MOONS is to be operational on sky by 2017-18

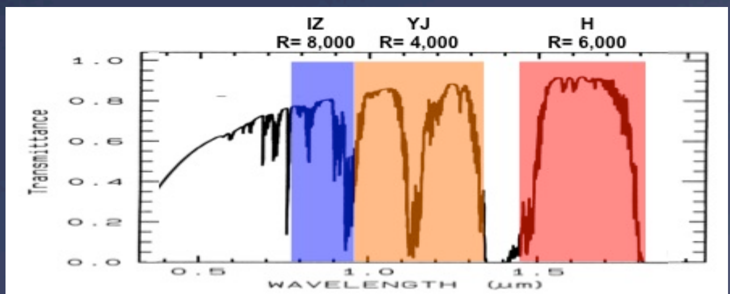
MOONS in a nutshell

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

Multiplex: 1000 fibers, with the possibility to deploy them in pairs

Medium resolution:

Simultaneously 0.8-1.8 μm
at
R=4,000 – 6,000

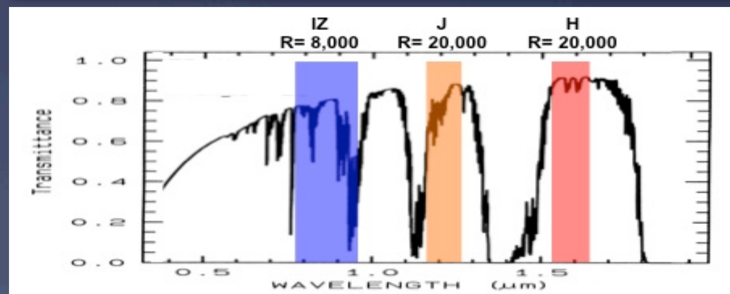


+

High resolution:

Simultaneously 3 bands:

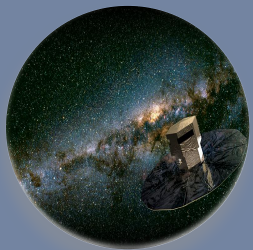
- 0.8-0.95 μm at R = 8,000
- 1.17-1.26 μm at R=20,000
- 1.52-1.63 μm at R=20,000



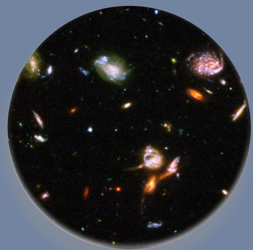
Throughput: 20-30 %

MOONS

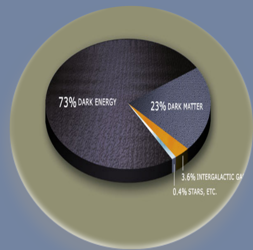
Offers unique features and versatility for a variety of studies



Galactic Archaeology



Galaxy Evolution



Cosmology

MOONS
Multi Object Optical and Near-infrared Spectrograph

Galactic Archaeology

MOONS Multi Object Optical and Near-infrared Spectrograph

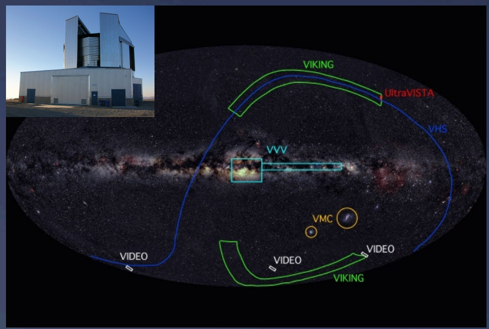
Galactic Archaeology

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 and
V < 13 for detailed chemical abundances

VISTA public surveys



Ground-based spectroscopic follow-up is essential

MOONS wil provide

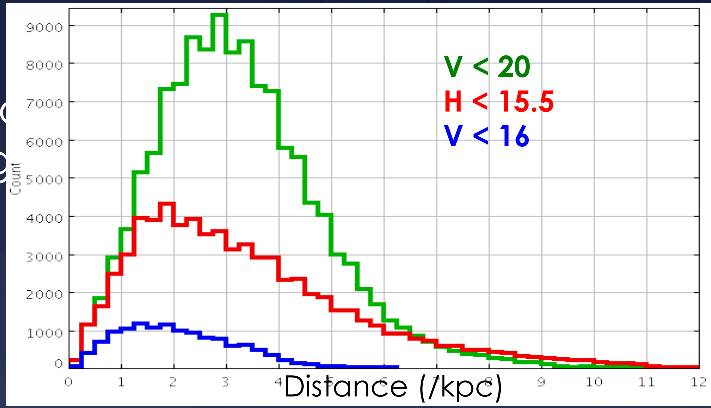
- Radial velocities by observing the CaT at resolution R = 8,000 for V< 20
- Detailed chemical abundances at R=20,000 in (J+H) for H < 15.5

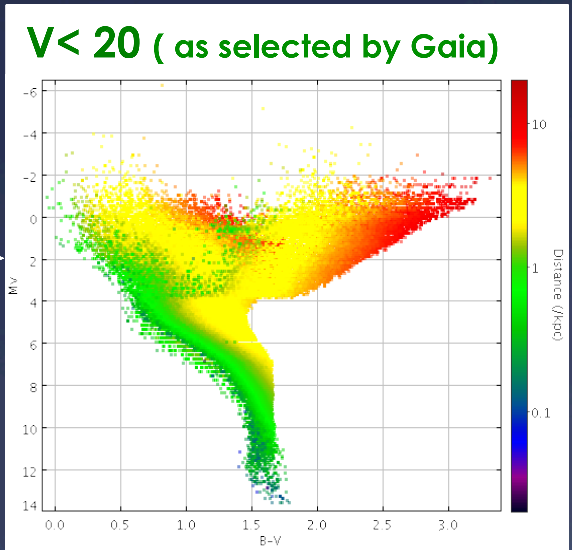
Galactic Archaeology

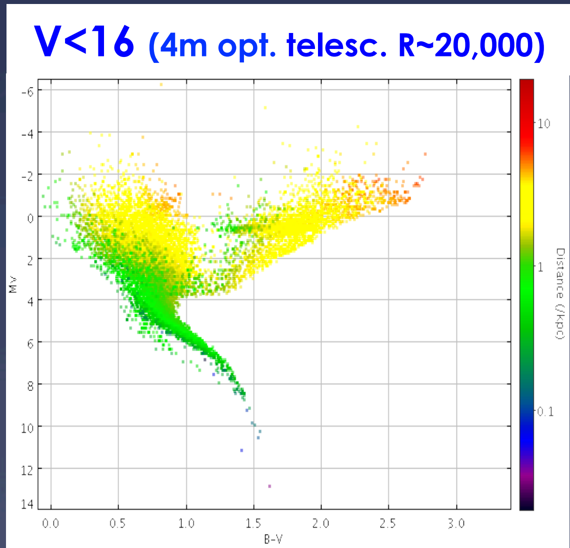
Disk and bulge

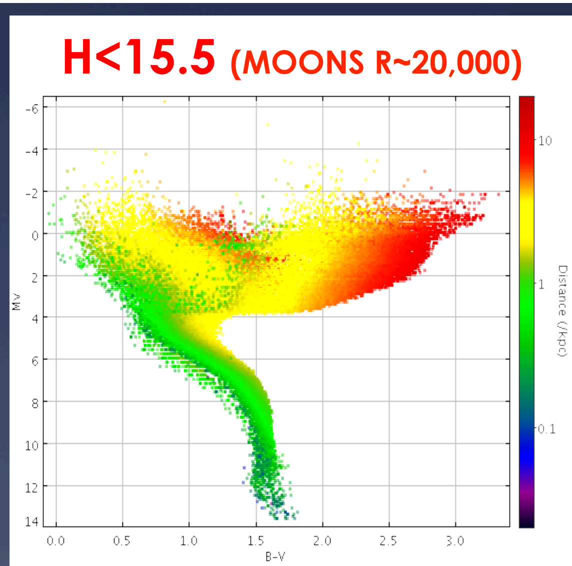
Near-IR is less sensitive to dust obscuration and combinec
VLT can reach a distance of ~12 kpc, essentially looking

CMD for the Disc from Besancon Models (l=90, b=0, Av=0.7mag/kpc)









M_V B-V   Distance (/kpc)

Medium resolution: 30min - 1hr
I < 20 + J&H <17
CaT @R~8,000 +
Fe, Na, Al, Mn, S, K @R~5,000
Radial velocities and metallicity

In the Bulge even higher extinction
Av > 20-30

High resolution: 1hr integration
I < 20 + J&H <15.5
CaT @R~8,000 +
Fe, CNO, Ca, Si, Ti, Mg, Cr
@R~20,000
RV + detailed chemical abundances

Galactic Archaeology

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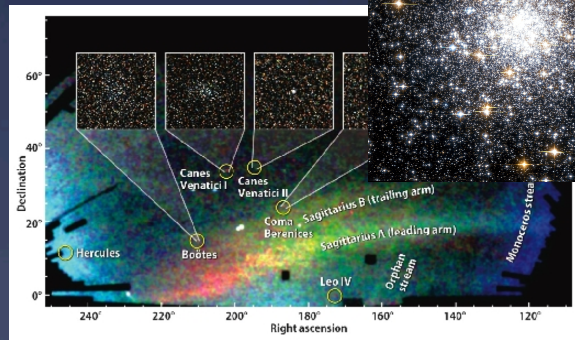
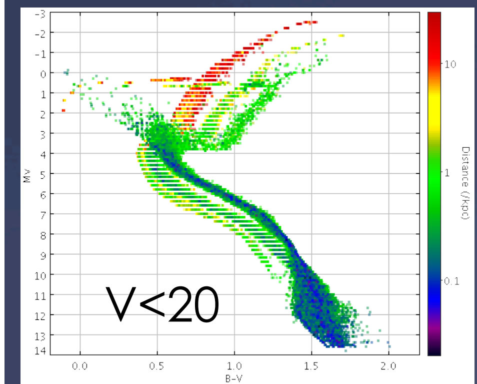
Near-IR is less sensitive to dust obscuration and combined with collective power of 8.2m VLT can
reach a distance of ~12 kpc,
essentially looking through the Bulge and disc.

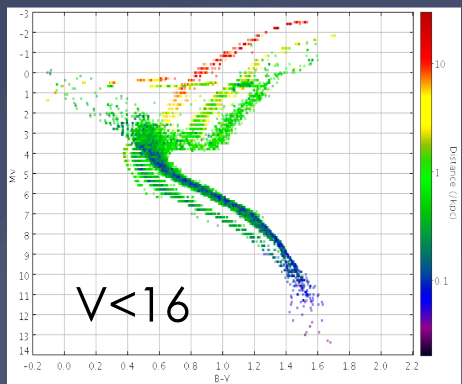


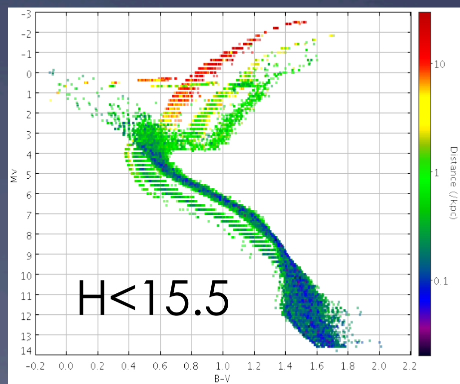
Streams in the Halo and clusters

Photometrically selected with Gaia, SDSS, Pan-STARRS, VISTA, UKIDSS, LSST etc.

CMD for the Halo from Besancon Models (l=90, b=60, Av=0)







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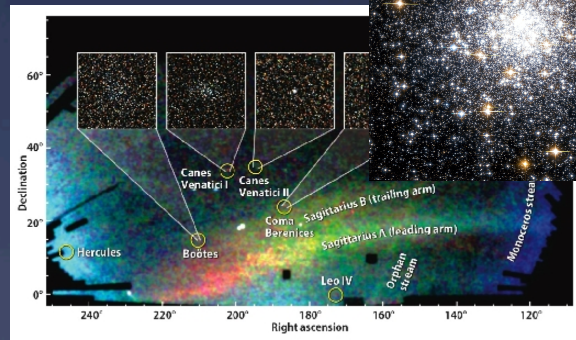


Resolved stellar population in external galaxies

Magellanic clouds, Nearby galaxies, follow-up of VISTA and UKIDSS

MOONS for Galactic studies

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

Gaia + VISTA imaging →
- Position
- Transverse velocities
- Photometry + colours

MOONS Spectra →
- Radial velocities
- Global metallicity
- Detailed chemistry

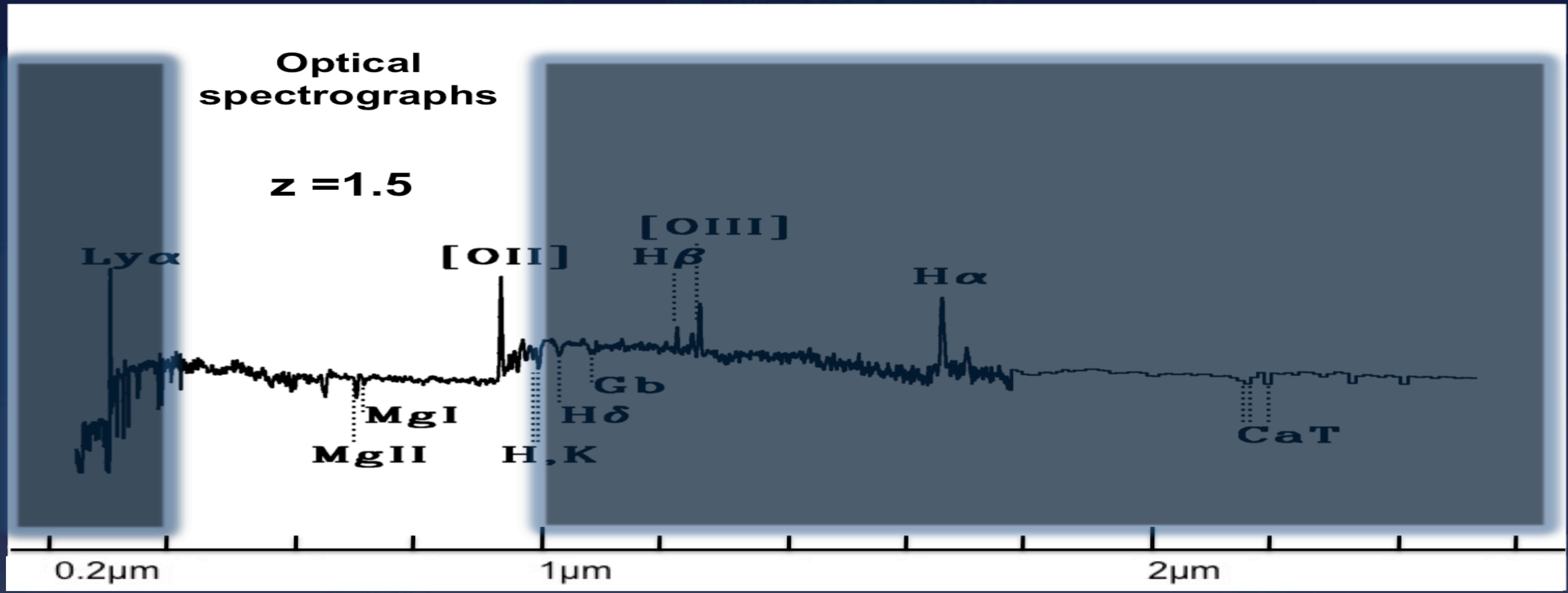
MOONS + Gaia 12+ D
- Position + vel.
- Dynamics
- Abundances
  - Si, Ca, Ti, Mg,
  - Fe, Cr, Mn, CNO
- Astrophysics
  (ages, histories, etc)

In 100 nights a year for 5 years => 8 Million stars over > 1000 sq. deg.

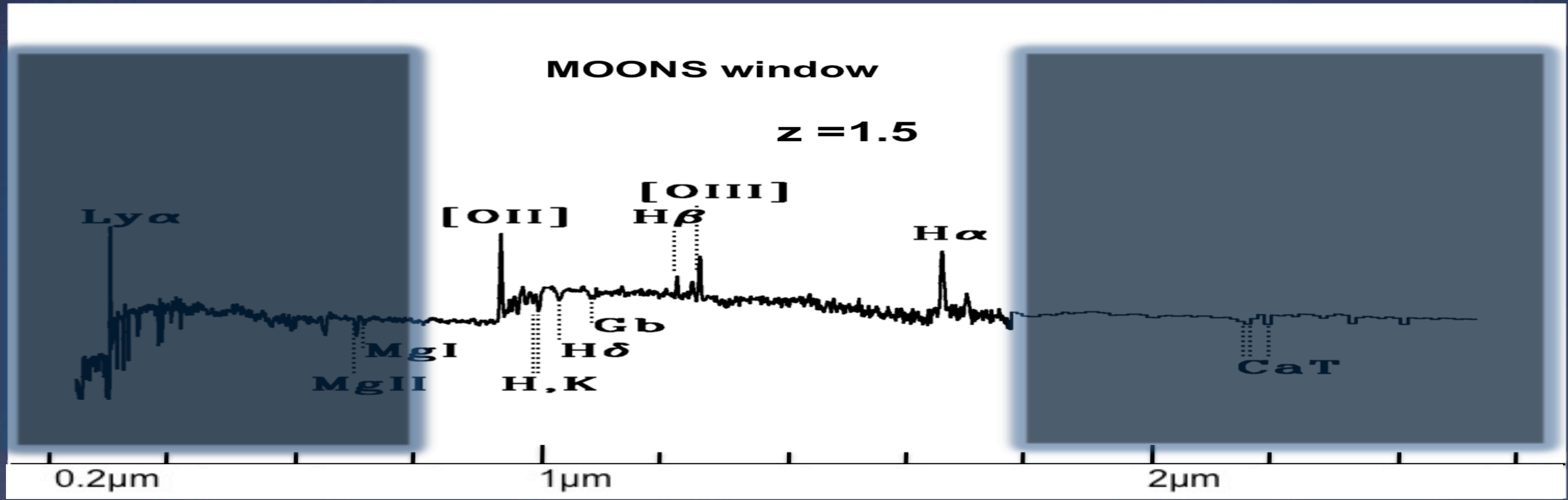
- Nature of the Bulge
- Origin of the thick Disc
- Evolution and structure of the thin Disc
- Kinematic multi-element distribution function in the Solar Neighbourhood.
- Open cluster formation and disruption
- Complex physics affecting stellar evolution
- Quantitative studies of Halo substructure, dark matter, and rare stars

Galaxy evolution at high z

Need near-IR to study galaxy evolution at high-z

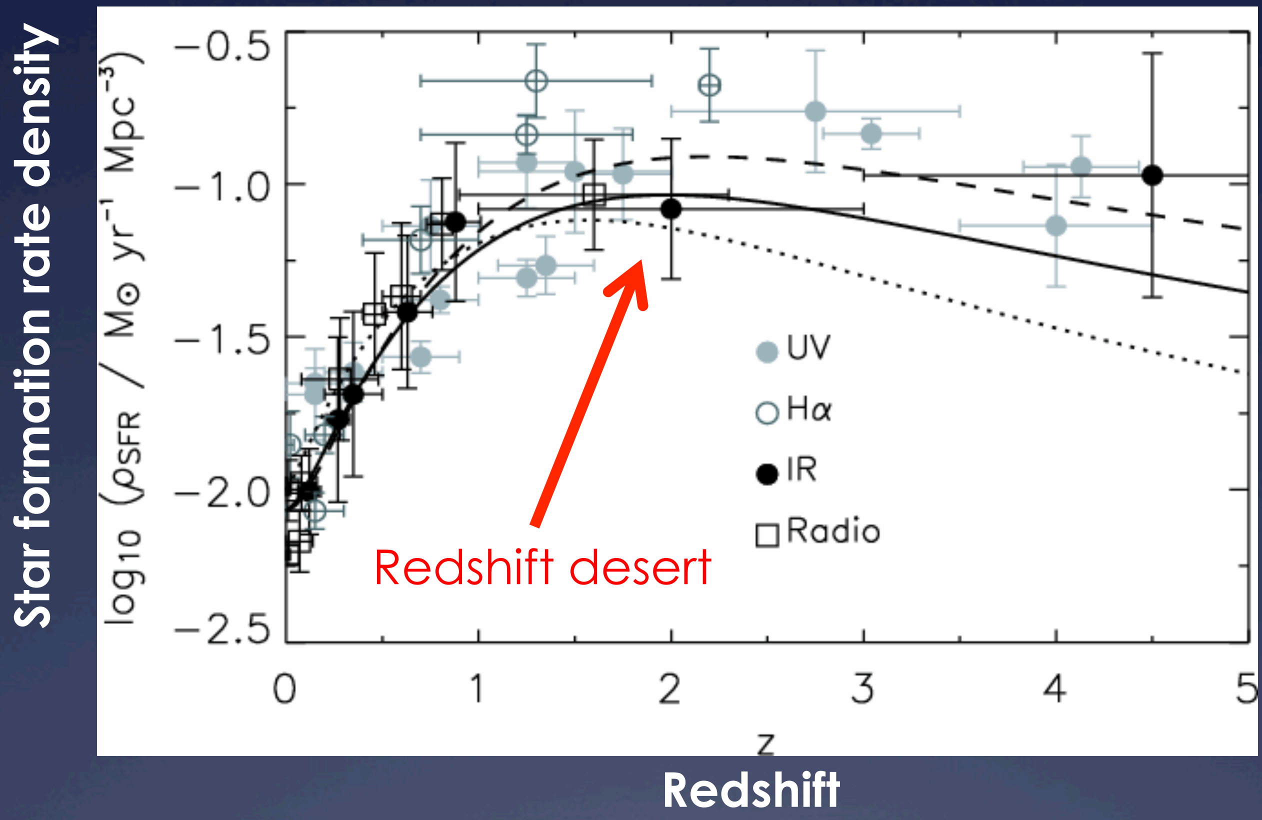


Observed wavelength λ



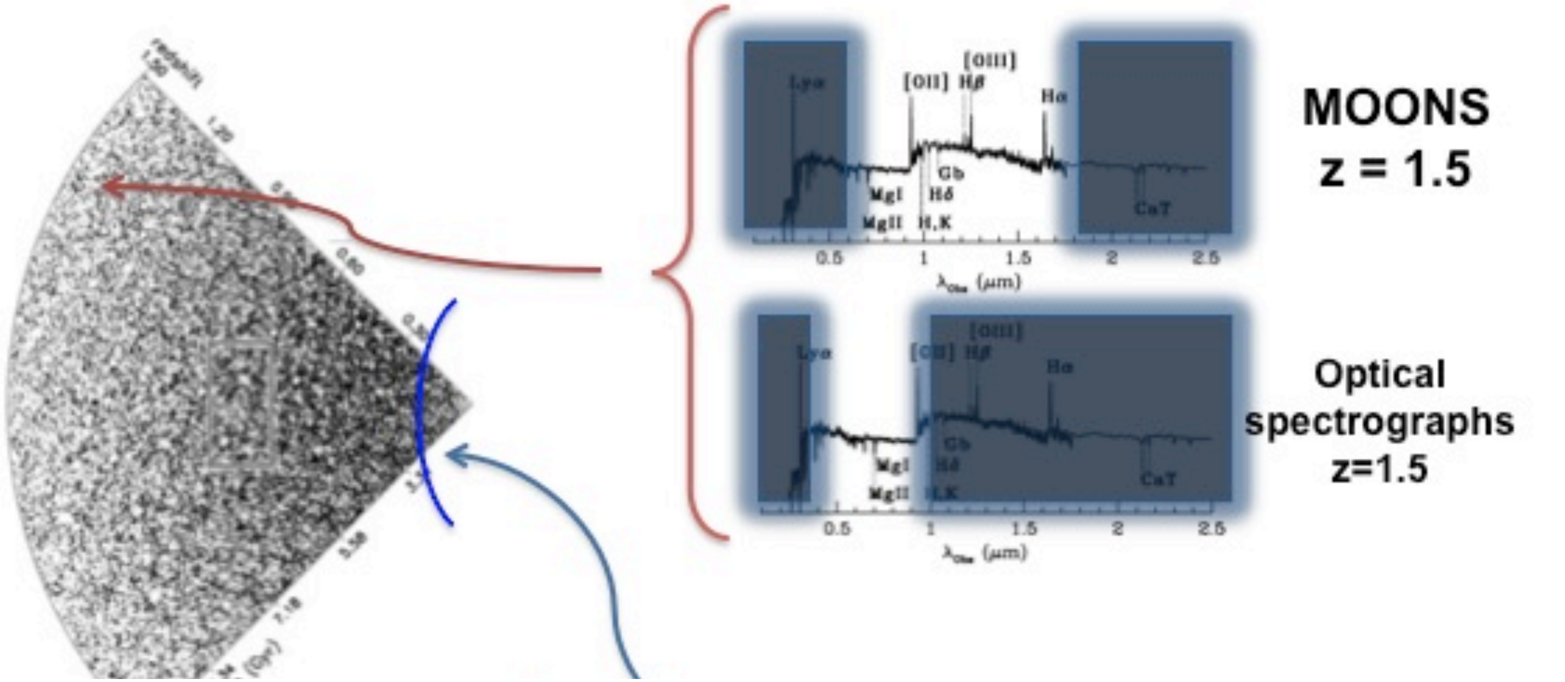
Observed wavelength λ

The peak epoch of star-formation and mass assembly



Needed for follow-up of major imaging surveys/facilities: VISTA, UKIDSS, Herschel, DES, ALMA, eRosita, Euclid etc

An SDSS-like survey at z ≈ 1-2



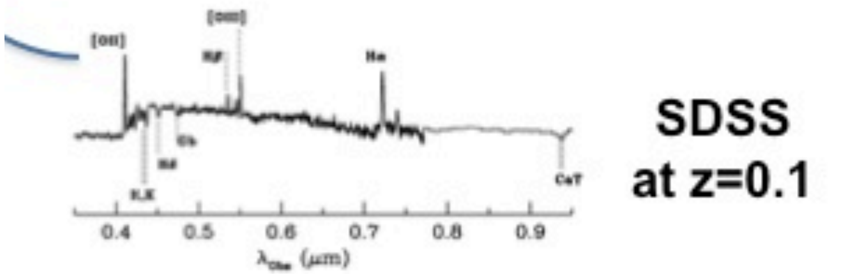
2-3h integration per pointing

500 nights survey

1 Million galaxies at z>1

Continuum: AB ≈ 23 (5σ)

Lines: F ≈ 1 × 10^{-17} erg/s/cm^2



Possibility for a multi-layer strategy with deeper pointings (10-30hr)

Legacy value

Unique, large samples of **~ 1M galaxies at z>1** to achieve robust measurements of inter-dependence of key physical parameters.

• Accurately determine the critical relation between stellar mass, star-formation and metalllicity and the role of feedback.

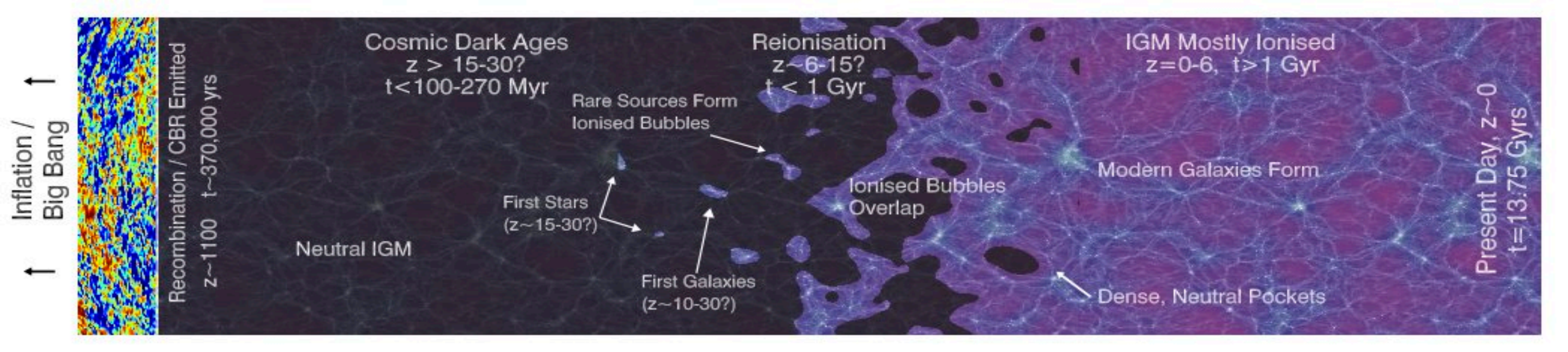
• Study the crucial effect of the environment

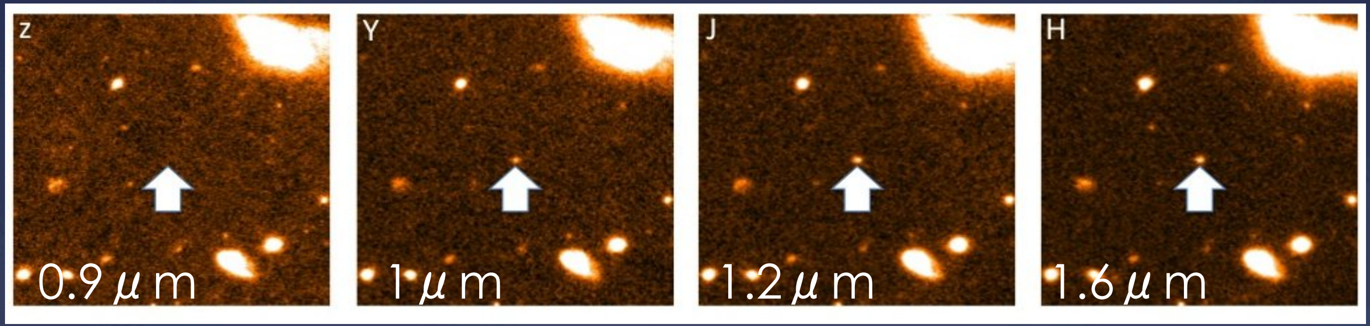
• Unveil the link between mass accretion and central black hole growth

• Determine the Dark Matter halo mass function via galaxy groups as a fundamental test of the Cold Dark Matter paradigm.

• Allow precise clustering measurements and unprecedented estimation of mass and luminosity function at z>1.

The first galaxies and the epoch of reionization





- ✓ Spectroscopic confirmation of the most distant galaxies.
- ✓ Establish the Lyman-α escape fraction and unveil the physics of re-ionization.
- ✓ Measure star-formation and mass assembly of primeval galaxies.
- ✓ Clustering of high-z galaxies and constrain how re-ionization processes.

MOONS
Multi Object Optical and Near-infrared Spectrograph

Summary

MOONS is the long-awaited near-IR work-horse MOS for the VLT

Galactic studies: essential follow-up of Gaia and VISTA

- ✓ Radial velocities and detailed chemical abundances for **several million stars** over **>1000 sq. deg**.
- ✓ Best instrument to study the Bulge and Disk
- ✓ Possibility to target stream, clusters in the Halo and nearby galaxies

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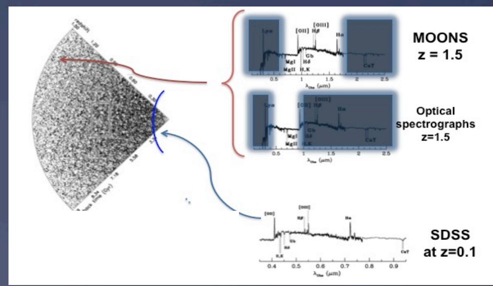
A formidable **SDSS-like survey at z > 1**

- ✓ 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, LOFAR, eRosita, Euclid etc.
- ✓ Pathfinder for E-ELT and ALMA.



ROE workshop 2012

Synergies between large-area infrared surveys, VLT-MOONS and Euclid

Royal Observatory Edinburgh, 5-6th November 2012

http://www.roe.ac.uk/roe/workshop/

Deadline for abstract and registration: 19th October

More information on MOONS at: www.roe.ac.uk/~ciras/MOONS.html

MOONS: a world leading facility

Instrument	Number of objects	Filter/wavelength	Resolutions	Field of View	Survey speed (nights)
KMOS	24 IFUs	Iz, YJ,H, K	3500	7' diameter	400
Flamingos II	Up to 80 slits	JH & HK	1200 or 3000	6' x 2'	500
EMIR	Up to 50 slits	z, J, H, K	4000	6' x 4'	200
MOSFIRE	Up to 45 slits	Y, J, H, K	3300	6.1' x 6.1'	220
LUCIFER	Up to 20 slits	z, J, H, K	7000-8000	4' x 3'	500
MOIRCS	Up to 40 slits	z, J, H, K	600 - 1500	7' x 4'	250
FMOS	200 obj + 200 sky fibers	0.9 – 1.8μm zY, J, H	500 2200	30' diameter	50 †
MOONS	**500 objects + 500 sky fibres**	**0.8(0.5)μm-1.8μm** **In bands λ~0.1μm**	**3000 – 5000** **20,000**	**25' diameter**	**20**

High resolution (R>20,000) in the optical for Galactic Archaeology:

- FLAMES on VLT will provide cutting-edge work at optical wavelengths and the first Gaia follow-up via upcoming large public spectroscopic surveys.
- AAT-HERMES is on a 4m telescope and not ideal to study the obscure Disc and Bulge

High resolution (R>20,000) in the near-IR:

- The Apogee survey is carried out with a small 2.5m telescope and it is the North.