

KMOS @ VLT Overview and first results

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KMOS Near-IR multi-object IFU for VLT

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"
Spatial sampling	0.2" x 0.2"
Patrol field	7.2 arcmin diameter circle
Close packing of IFUs	≥ 3 within 1 sq. arcmin
Closest approach of IFUs	\ge 2 pairs of IFU separated by ~6 arcsec centre to centre of the IFU, depending on the details of the configuration.

3 spectrographs

Pick-off system 24 arms

> Integral Field Units

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24 pick off arms





24 pick off arms





Integral Field Units





Built by Durham University

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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



On the way to the telescope...



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Some example of KMOS observations









KMOS mosaic mode

Jupiter methane bands





30 Dorado Davies et al. 2015



Total System Throughput



Green line: Throughput measured across all *IFUs including telescope and atmosphere* Red dotted line: Requirements from the technical specifications



Sensitivity: emission lines at z =0.8

SINFONI





3hr integration with **SINFONI** (using AO), from Swinbank+ 12. The image and spectrum show the H α line, which has a flux of 1.0e-16 erg/s/cm².

25min integration of the same object using **KMOS**.



Spatial resolution



- In good seeing and S/N the PSF in reconstructed cubes are wellbehaved.
- FWHM along the slice (red) is slightly broader (0".05) due to the additional aberrations in spectrograph.

Spectral resolution



- Resolution is close to two pixels FWHM over all spatial channels.
- Segment #3 seems slightly better than Segment #1



Detector Persistence





Science cases

- [1] Cluster Formation and Morphology-Density Relation
- [2] The Masses and Growth of Field Galaxies
- [3] Extremely High-Redshift Galaxies and Re-ionisation
- [4] The AGN-Galaxy Formation Connection
- [5] Age-Dating Ellipticals at z=2 to 3
- [6] Stellar Populations in Nearby Galaxies
- [7] Galactic Astronomy

September 2003

Scientific motivation





Near-IR IFU spectroscopy

Physics of galaxy evolution:

- Spatially resolved SFR
- Chemical composition
- Metal enrichment and gradients
- Kinematics and structure build-up
- Excitation mechanisms
- Gas inflows and outflows
- Feedback





Near-IR IFU spectroscopy

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Surveys with Opt/NIR IFUs

Glazebrook et al. 2014 (review)

SINS/zC-SINF: Förster Schreiber +09/15,Mancini+11,Newman+13; MASSIV: Épinat+09a/12,Contini+12,Sanchez-Lopez+12; AMAZE/LSD: Gnerucci+10/11; OSIRIS: Law+09/12,Wright+09; WiggleZ: Wisnioski+11,12; HiZELs: Swinbank+12a/12b; IMAGES: Flores+06, Yang+08, Puech+12; LBAs: Basu-Zych+09,Gonçalves+10; DYNAMO: Green+10; GHASP: Épinat+09b/10 Lensed objects: Stark+08, Jones+10/12, Yuan+11/12, E.Wuyts+13, Livermore+15, Leethochawalit+15



What is changing with KMOS

A GTO view:

- KROSS
- KASHz
- KMOS^{3D}
- VIRIAL
- KMOS-CLUSTERS
- KMOS Deep Survey





The KMOS Redshift One Spectroscopic Survey *PI: Sharples (30 nights GTO Durham + Oxford + Edinburgh)*

- 750 galaxies at z = 0.75-1.15 in best-studied extra-galactic fields (COSMOS, ECDFS, UDS).
- Simple mass selection (complete to stellar mass $M^* = 10^{9.5} M_{sun}$; K < 22.5).
- Exposure: 4.5 hrs integrations with KMOS in JY-filter.



K R

KROSS

S S



KROSS

Galaxies at z~1:

- Ordered rotation in 83% of galaxies
- Turbulent discs and marginally unstable (Toomre Q~1)
- High baryonic mass fraction ~30%

Sobral et al. 2014 Stott et al. 2015, submitted







KMOS AGN Survey at High redshift

PI: Alexander (GTO Durham)

- 89 galaxies at 0.6 < z < 1.7
- AGNs: $L_{\chi} = 10^{42-45}$ erg/s.
- Observations in YJ to detect $\mbox{H}\alpha$ and [OIII]





Harrison et al. 2015 (1511.00008)





KMOS^{3D}

PI: Förster Schreiber (75 nights MPE/USM)

- Mass limited sample of ~600 galaxies @ z~0.7-2.7
- 75 nights GTO programme
- Exposure: 4hr YJ, 6hrs H, 8-10hrs K
- Selection: 3D-HST
- Targeting: Hα, [NII], [SII]







Disc Kinematics

- 83% of of z=1-2 galaxies are "rotation-dominated"
- ~70% of z=1-2 galaxies are "disk-like"
- Possible mild evolution in disk fraction from z=2 to z=1



Wisnioski et al. 2015, Wuyts et al. 2014, Genzel et al. 2014





Evolution of Dispersion

- Average dispersion in outer disc at z~2 is 2x higher than at z~1
- Discs are unsettled and thick at high-z
- v/σ evolves with gas fraction



Wisnioski et al. 2015, Wuyts et al. 2014, Genzel et al. 2014





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See also: Genzel+ 2015, *Förster Schreiber*+ 2015 for Outflows

Burkert+ 2015 for Angular Momentum





VIRIAL

VIRIAL

PI: Mendel (GTO MPE/USM)

- 135 passive galaxies at 1.4<z<2
- m_{140} < 22.5 (corresponding to M>10^{9.5} M_{\odot}







 cm^{-2} Å⁻¹]

Flux $[10^{-19} \text{ erg s}^{-1}]$

35

30

25

20

KMOS - Cluster

KMOS - Clusters

Pls: Bender – Davies (MPE/USM – Oxford)

- Deep spectroscopy of passive galaxies in known X-ray selected clusters at 1<z<2
- 20 galaxies in each clusters with available spectroscopic redshifts and HST imaging.
- Total: sample of > 80 galaxies at z>1 (IZ, YJ), exposures > 10hrs





KMOS Deep Survey

KMOS Deep Survey

PI: Cirasuolo

- 30 nights GTO programme to observe the high-z Universe (3 < z < 10)
 - Formation of the first discs and bulges at z>3
 - Tentative detection of CIII] at z>5
 - Galaxies at z > 7 and the epoch of reionization
- Faint targets require long integrations: >10hrs on source
- Fields
 - CANDELS (field galaxies)
 - SSA-22 (proto-cluster at $z \sim 3$)
 - Hubble Ultra-Deep Field and Parallels



KMOS Deep Survey (I) 3 < z < 5

Target selection and observing strategy

- Originally ~200 galaxies in the redshift range 3<z<5
- Mostly spectroscopic redshifts + some with photo-z to test selection bias.
- Wide range in mass and SFR
- Observing bands: H+K to detect OII, Hβ, OIII

Aims:

- Spatially resolved Metallicity and SFR
- Mass-metallicity-SFR relation
- Dynamics and Tully-Fisher relation





Cresci et al. 2010



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KMOS Deep Survey (I) 3 < z < 5



PRELIMINARY RESULTS (Most of the work done by Owen Turner and Fergus Cullen)

- Lost ~ half of the observing time due to bad weather conditions
- 80 objects observed with >10hrs onsource in H and K band
- For 59 galaxies possible to determine velocity maps
- ~50% of galaxies at z>3 are rotation-dominated







KMOS Deep Survey (I) 3 < z < 5

PRELIMINARY RESULTS (Most of the work done by Owen Turner and Fergus Cullen)



Using OII, Hβ and OIII



KMOS Deep Survey (III) z > 7





KMOS Deep Survey (III) z > 7

TARGET SELECTION

- From McLure et al. 2013
- CANDELS + ERS: $25 < J_{AB} < 28$
- HUDF12: J_{AB} < 29.5
- Photoz: 7.5 < z < 9.5
- Targeted 24 galaxies
- YJ band
- Exposure time: ~12-14 hrs on source



λ/μm McLure et al. 2013



KMOS Deep Survey (III) z > 7

NO Lyα detection !!

Constraints from upper-limits is ongoing



Treu et al (2013) – Keck MOSFIRE + BoRG z~8 Curtis-Lake et al. 2012 – VLT z~6 Finkelstein et al (2013) – Keck MOSFIRE + CANDELS z > 7 Pentericci et al (2014) – VLT FORS 6<z<7.3 amongst others...



Next ...

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KMOS Large Programme

PI: Fontana

Exploit lensing magnification (Frontier Fields and GLASS)

- Candidates at z>7
- *Kinematics of galaxies at 1<z<3*

See talks on Thursday







KMOS Large Programme

PI: Cirasuolo

- 216 hrs approved from P98
- 200 galaxies at 1<z<2.5
- Both lensed in FF and unlensed in CANDELS
- Full wavelength coverage (YJ,H,K) to have simultaneously all key diagnostics: [OII]3727, Hβ, [OIII]5007, Hα, [NII]5684, [SII]6717,6731, [SIII]9060,9532



Pilot programme



Summary

- KMOS long awaited near-IR multi-object IFU at the VLT
- Essential to understand how the physical conditions across the galaxy evolve with cosmic time.
- Unveil the interplay between:
 - Metal enrichment
 - Excitation mechanisms
 - Structural evolution
 - Inflow and outflow
 - Feedback
- Large statistical samples





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Much more to come !!













ELT HARMONI and MOSAIC

