KMOS
The K band multi-IFU spectrograph

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European Southern Observatory

Outline of talk

- The science drivers for KMOS
- Derived instrument requirements
- The instrument as designed and built
- KMOS in use
  - Modes
  - Basic performance
  - Calibration of the arms
  - Sky subtraction
- Some results

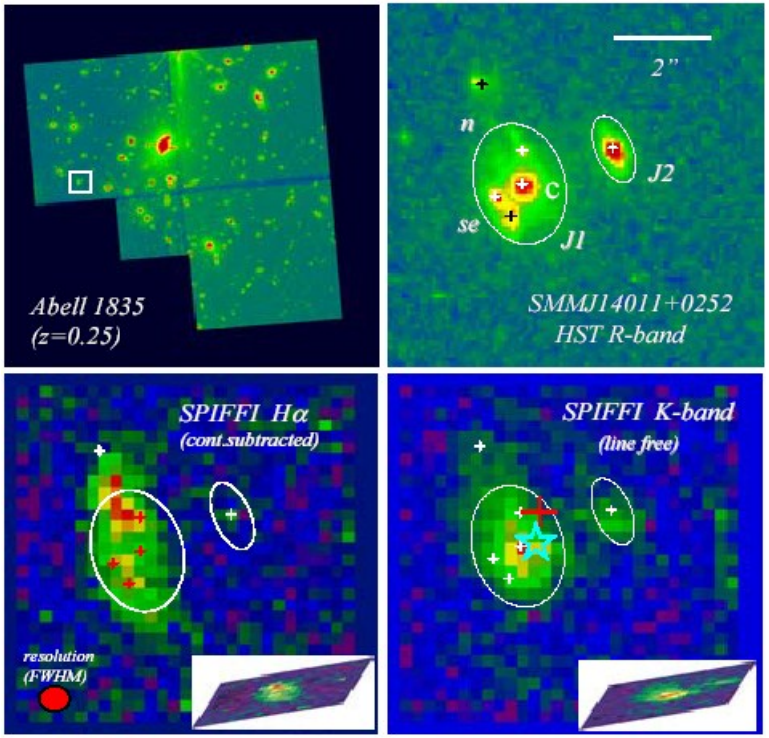
KMOS Consortium

- Universitäts-Sternwarte München
- MPI für Extraterrestrische Physik
- UK Astronomy Technology Centre
- University of Durham
- University of Oxford
- University of Bristol
- European Southern Observatory
- Co-PIs: Ray Sharples, Ralf Bender

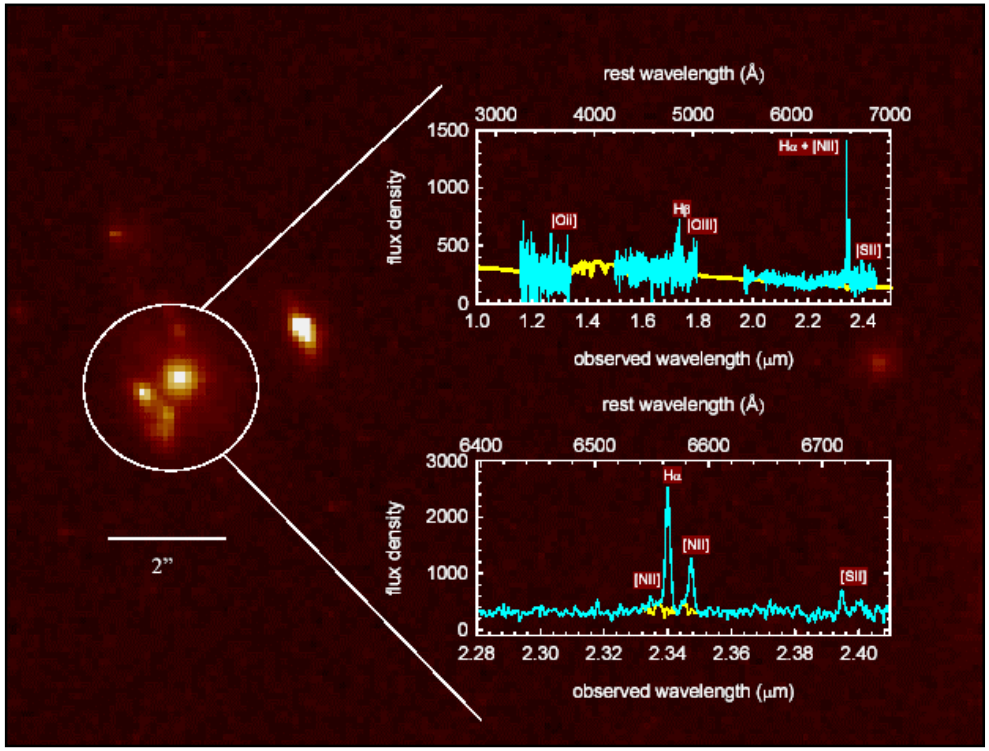
Top Level Science Drivers

- Investigate the physical processes which drive galaxy formation and evolution over redshift range $1<z<10$.
- Map the variations in star formation histories, spatially resolved star-formation properties, and merger rates
- Obtain dynamical masses of well-defined samples of galaxies across a wide range of environments at a series of progressively earlier epochs

The masses and growth of galaxies



SCUBA galaxy SMM J14011+0252 (z=2.565)

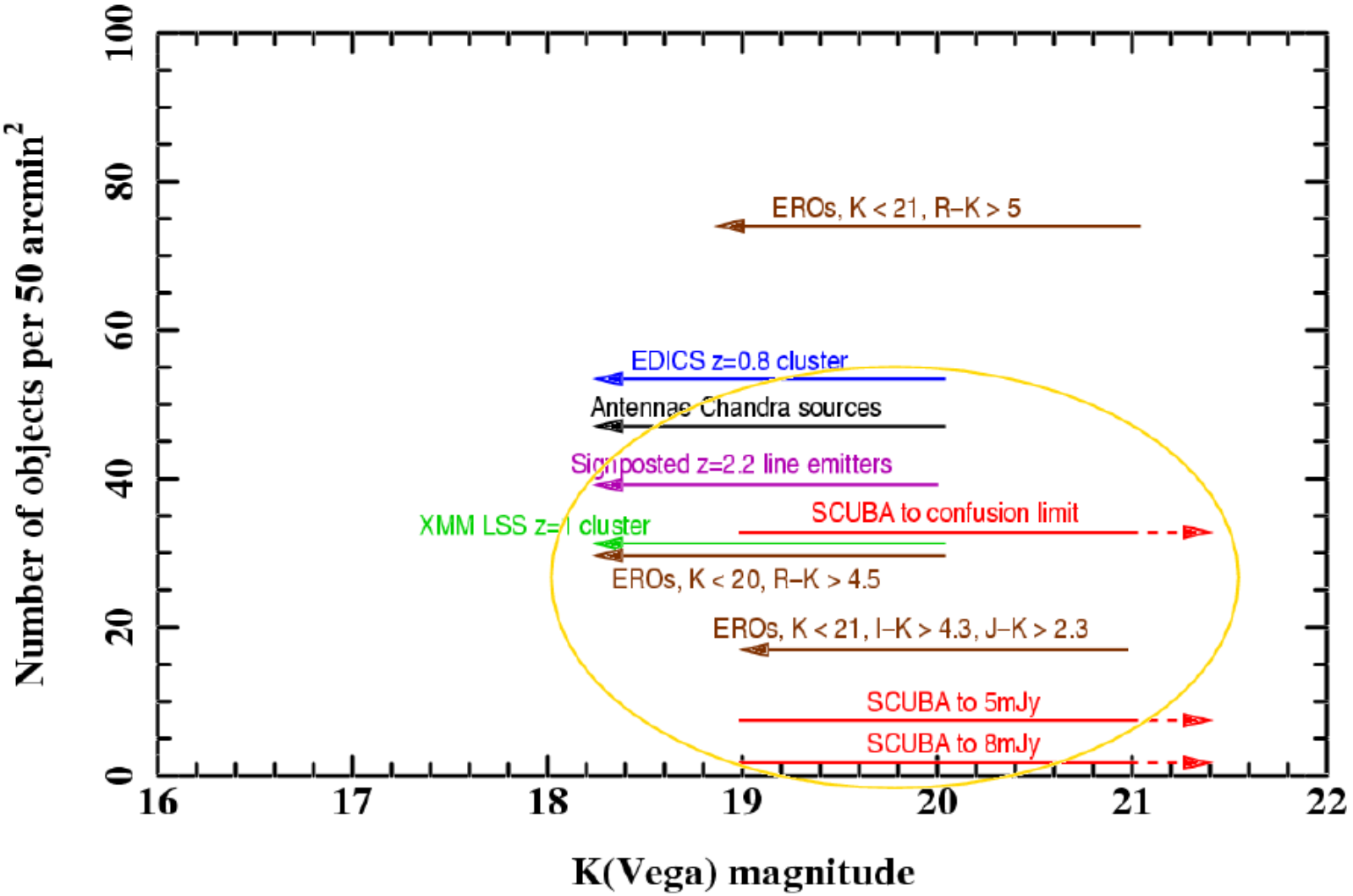


SPIFFI spectra of the central 2 arcsec of J1c indicates SMM J14011+0252 has been forming stars for several hundred Myrs

Basic requirements

- Target objects are at redshift z~1-2
  - Infrared wavelength coverage to 2.45μm
- Target objects are faint (K~18-21)
  - Good sensitivity on individual objects
  - Multi-object capability
- Patrol field set by
  - “infrared” / unvignetted field of the telescope – 7arcmin
  - Number density of targets implies ~20-30 objects

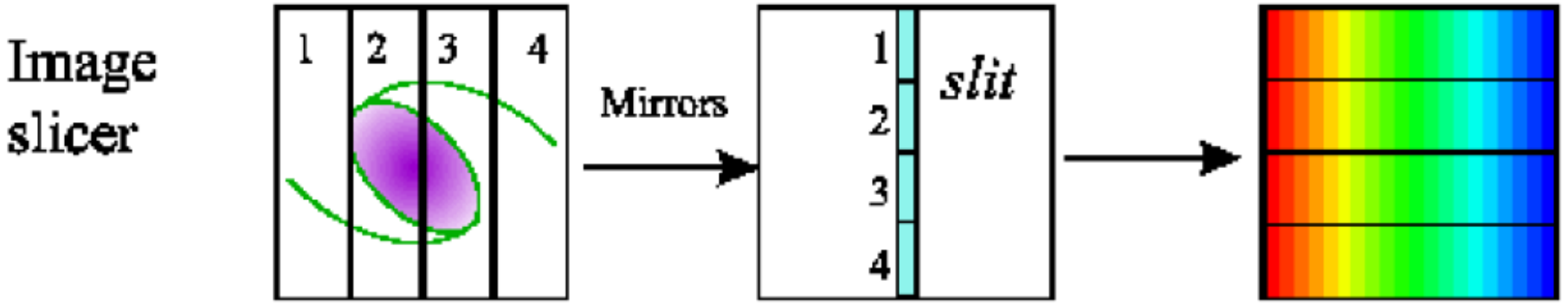
Basic requirements: multiplex



Basic requirements

- Target objects are at redshift z~1-2
  - Infrared wavelength coverage to 2.45μm
  - Find and insert plot of important lines versus redshift
- Target objects are faint (K~18-21)
- Patrol field set – 7arcmin, 20-30 objects
- Scale size of individual objects ~few arcsecs
  - Sets the individual fields of view
  - Spatially resolved information - scale set by seeing

Integral field spectroscopy



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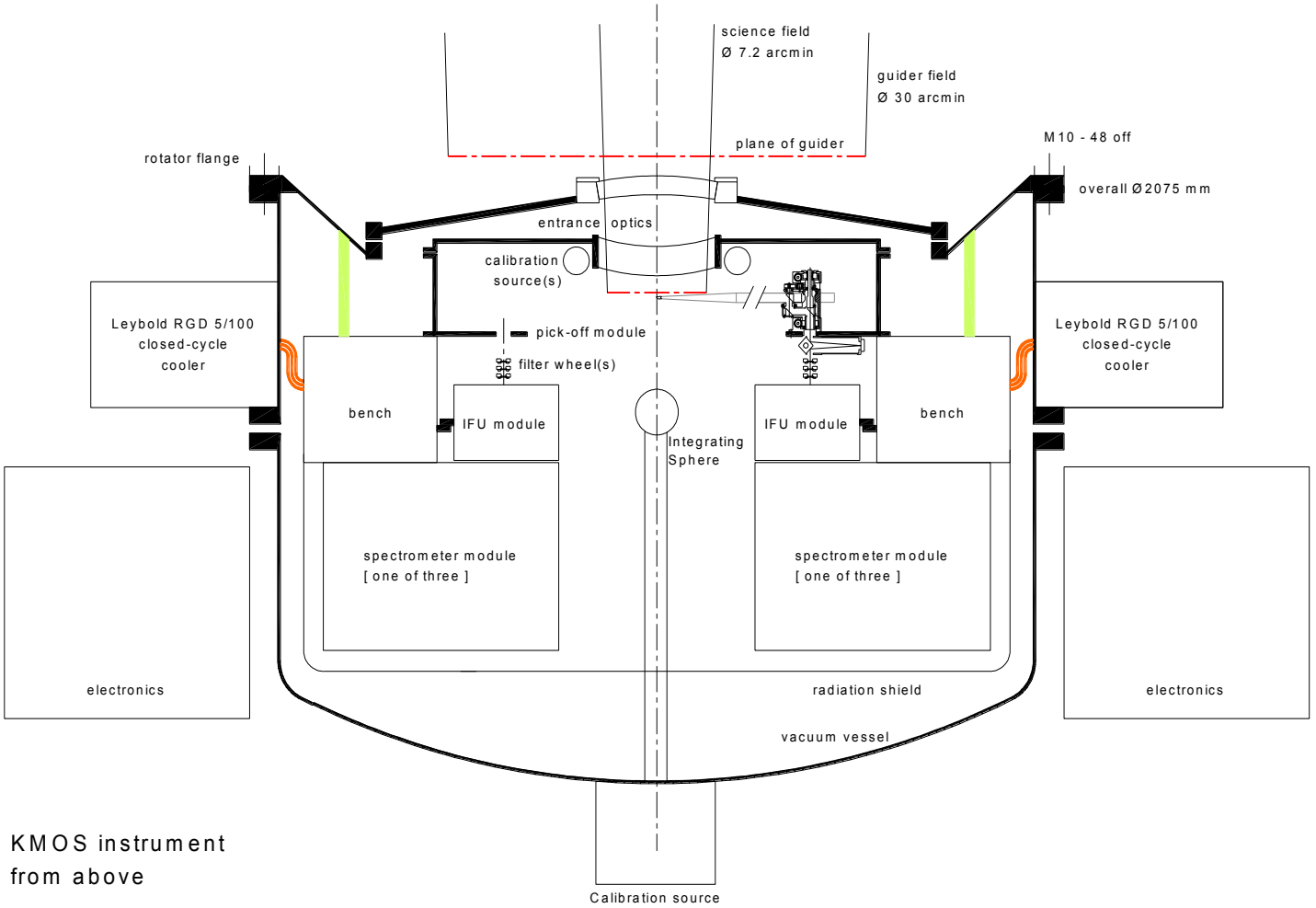
  - Spatially resolved information - scale set by seeing
- Ability to measure galaxy rotation curves
  - Velocity resolution ~10km/s
  - Spectral Resolving~ 3000-4000

Scientific Requirements

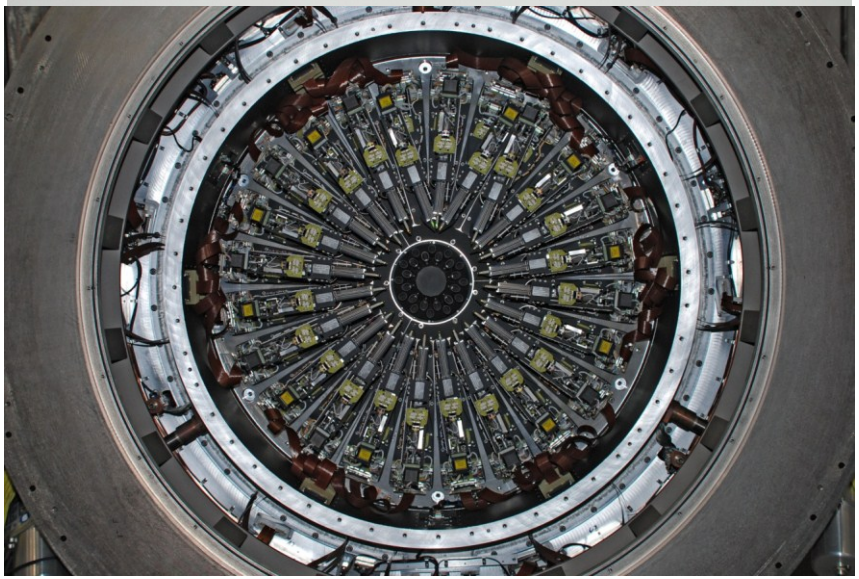
Requirement	Baseline Design
Throughput (excl tel/atm/det)	J=30%, H=40%, K=40%
Sensitivity (5σ 8hr)	YJ=22.0, H=21.0,K=20.5 + IZ
Wavelength coverage	1.0 to 2.45 μm
Spectral Resolution	R=3380,3800,3750 (J,H,K)
Number of IFUs	24
Extent of each IFU	2.8 x 2.8 sq. arc seconds
Spatial Sampling	0.2 arc seconds
Patrol field	7.2 arcmin diameter circle
Close packing of IFUs	≥3 within 1 sq arcmin
Closest approach of IFUs	≥3 pairs of IFUs separated by 6 arcsec

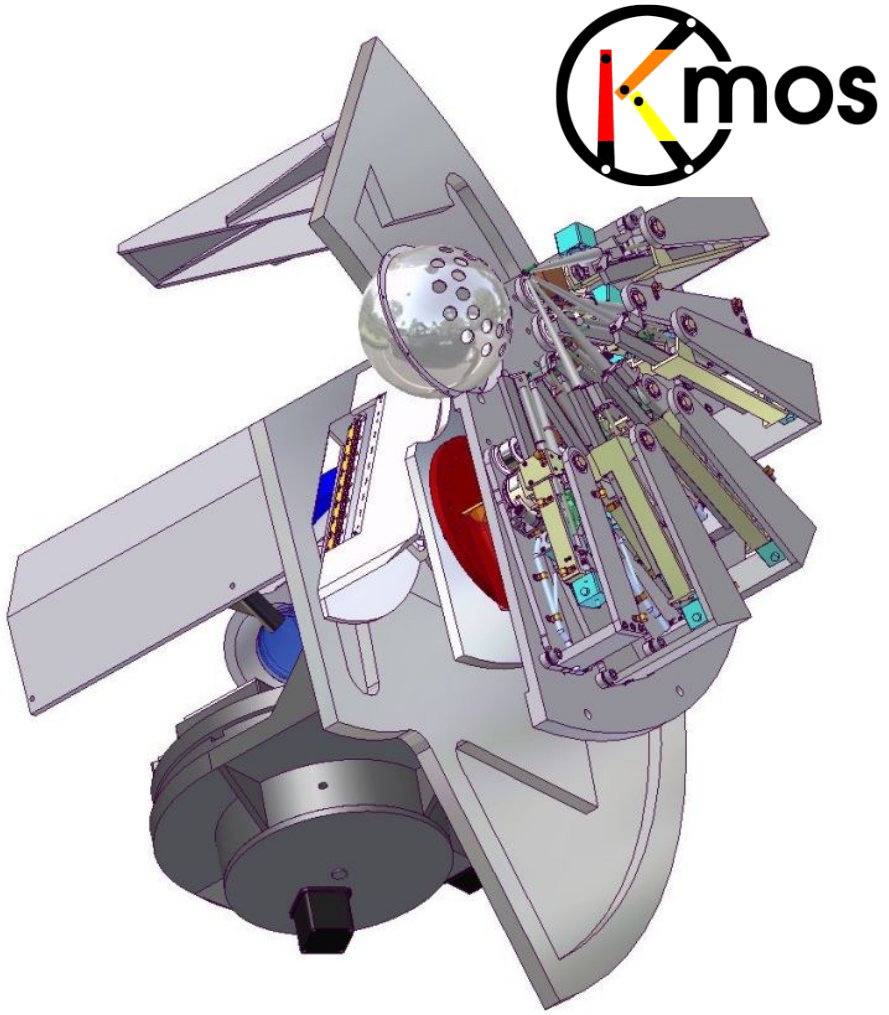
KMOS schematic



KMOS instrument
from above

Pick-off arms





Science & Technology Facilities Council
UK Astronomy Technology Centre

IFU module

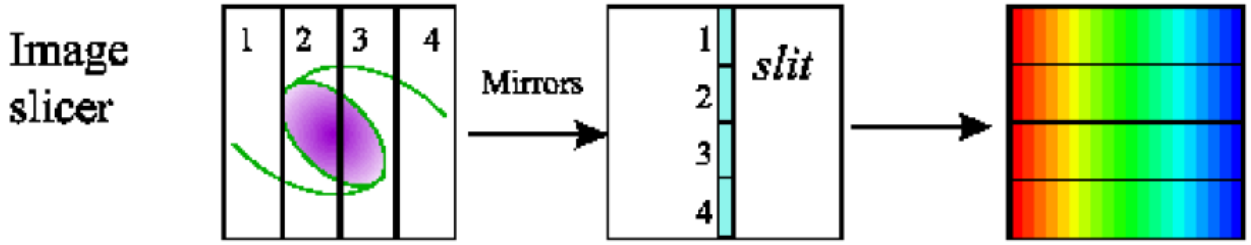
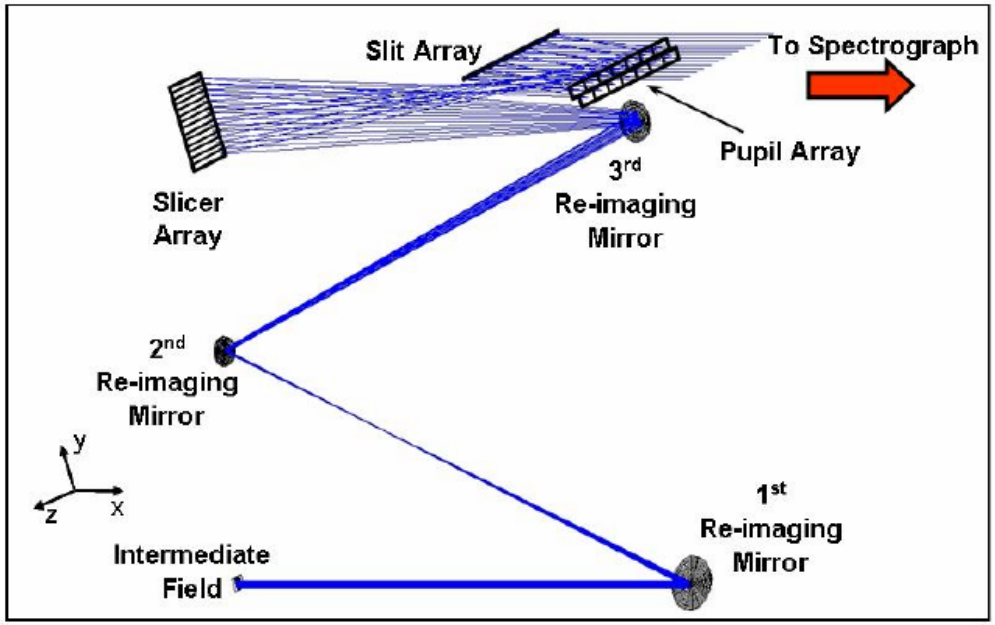
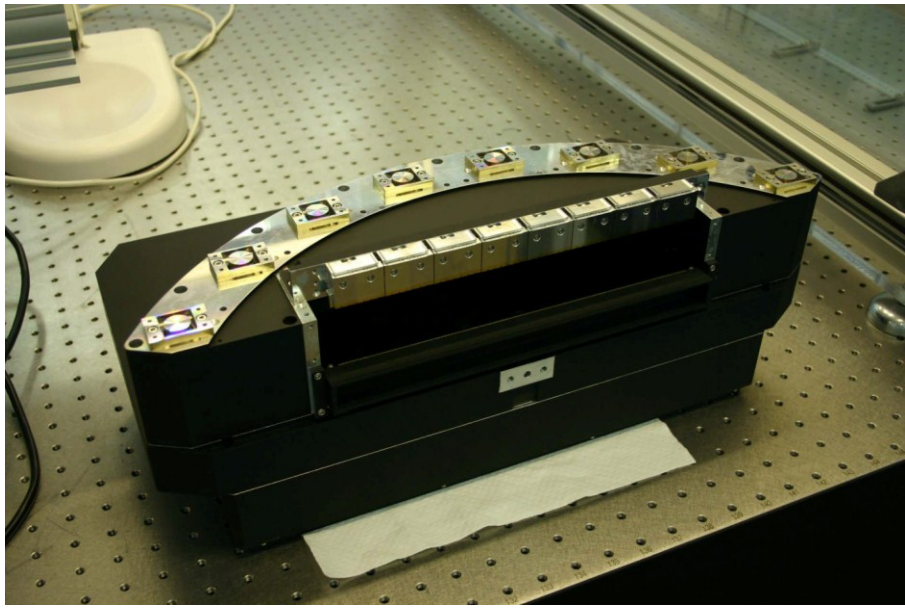
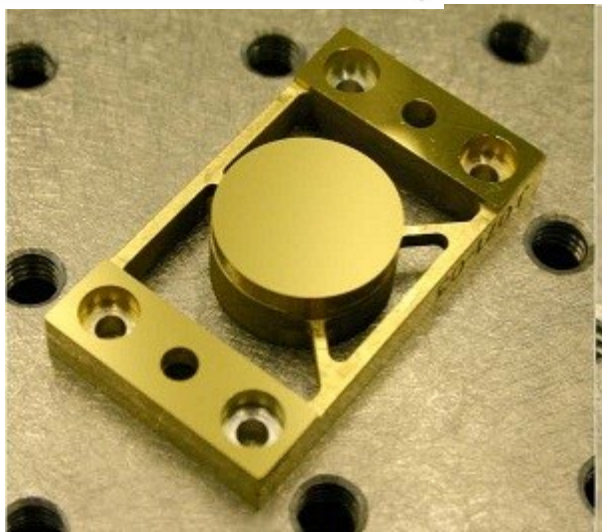


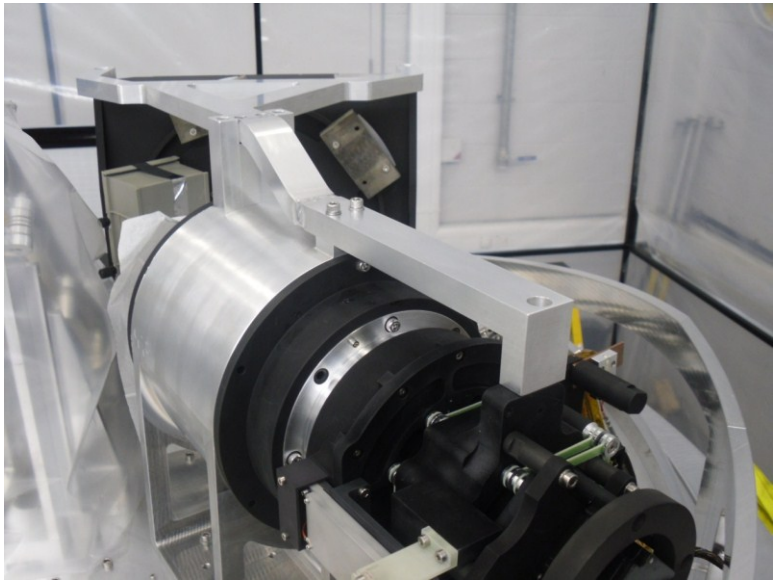
Image slicer
1
2
3
4
Mirrors
1
2
3
4
slit

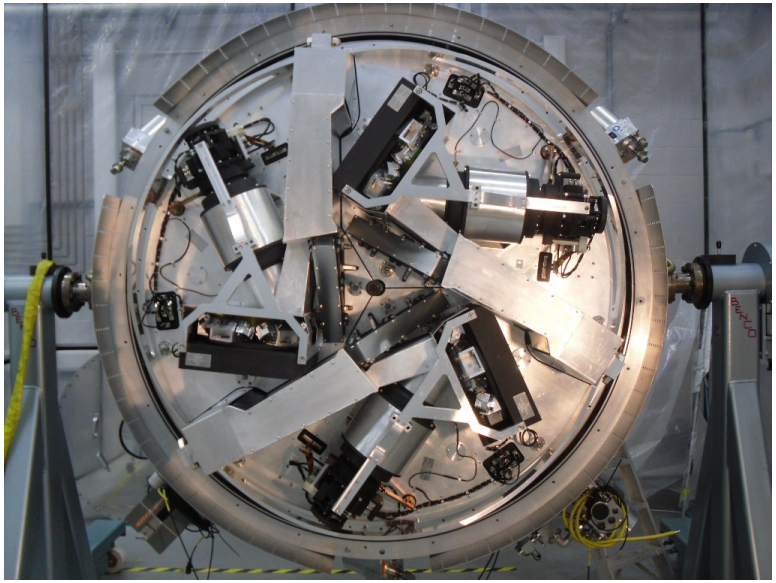

Slit Array
To Spectrograph
Pupil Array
3rd Re-imaging Mirror
Slicer Array
2nd Re-imaging Mirror
y
z
x
1st Re-imaging Mirror
Intermediate Field



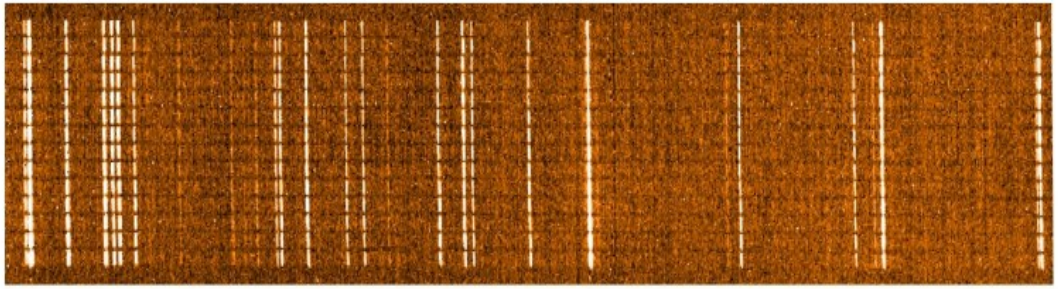


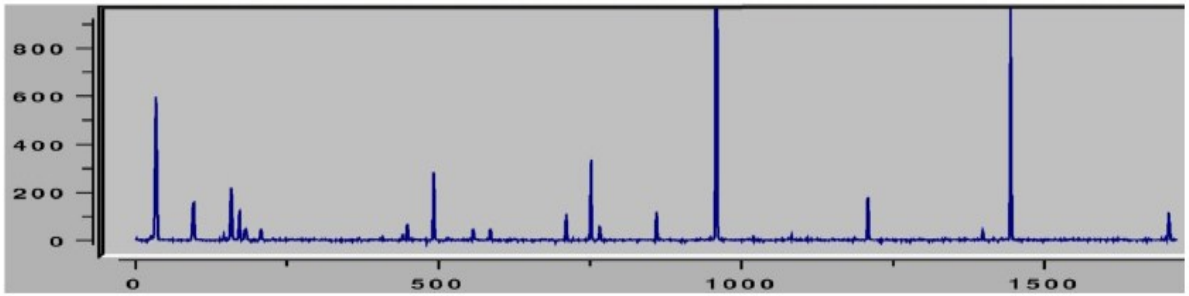
Spectrograph

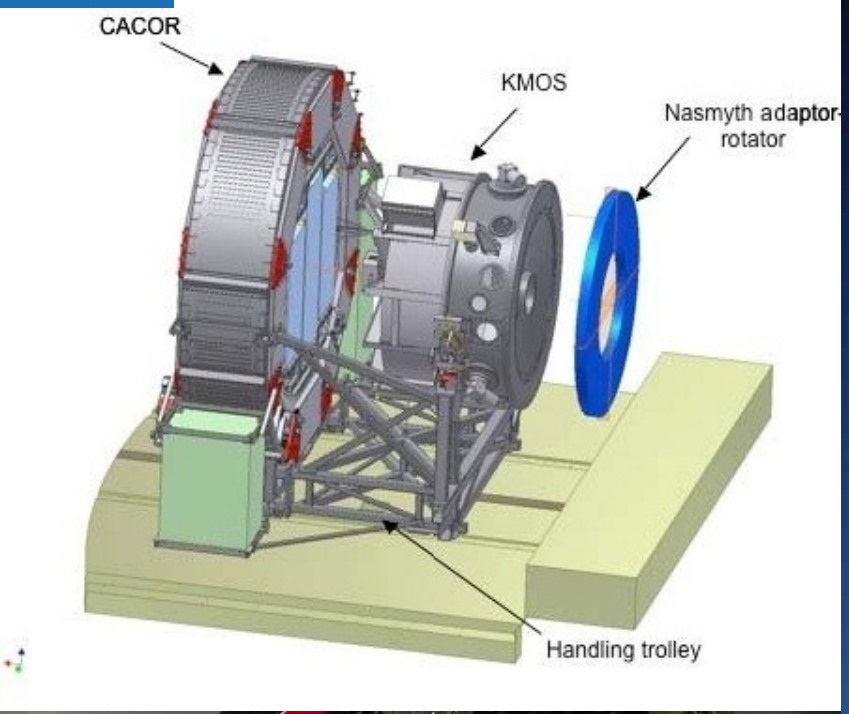


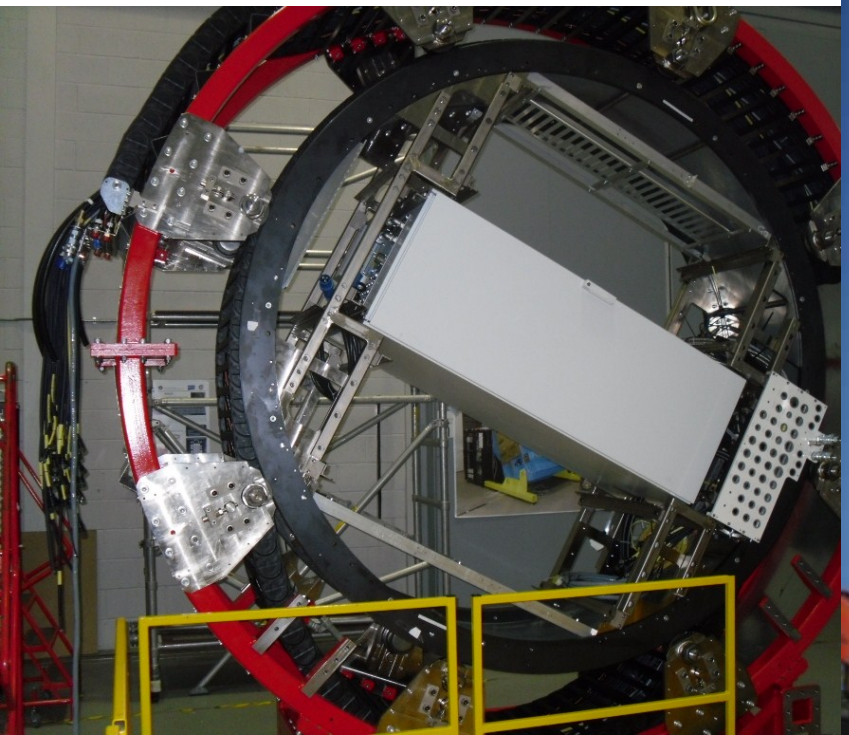


Laboratory ‘first light’ spectrum of an argon lamp in H band





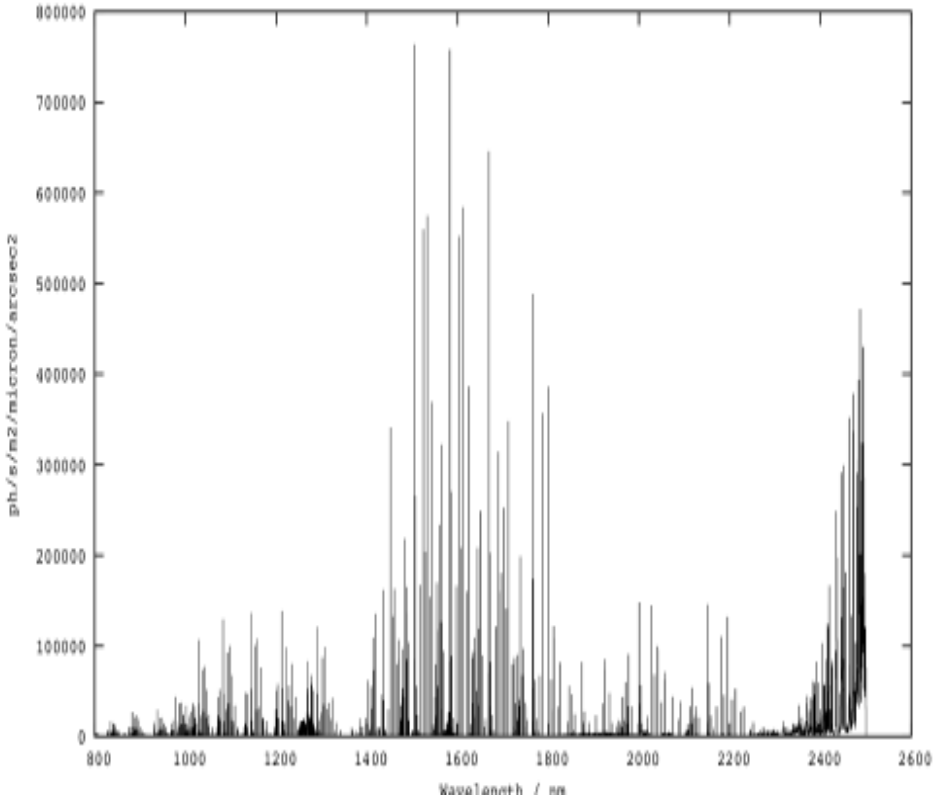

CACOR
KMOS
Nasmyth adaptor-rotator
Handling trolley




GROVE
GROVE

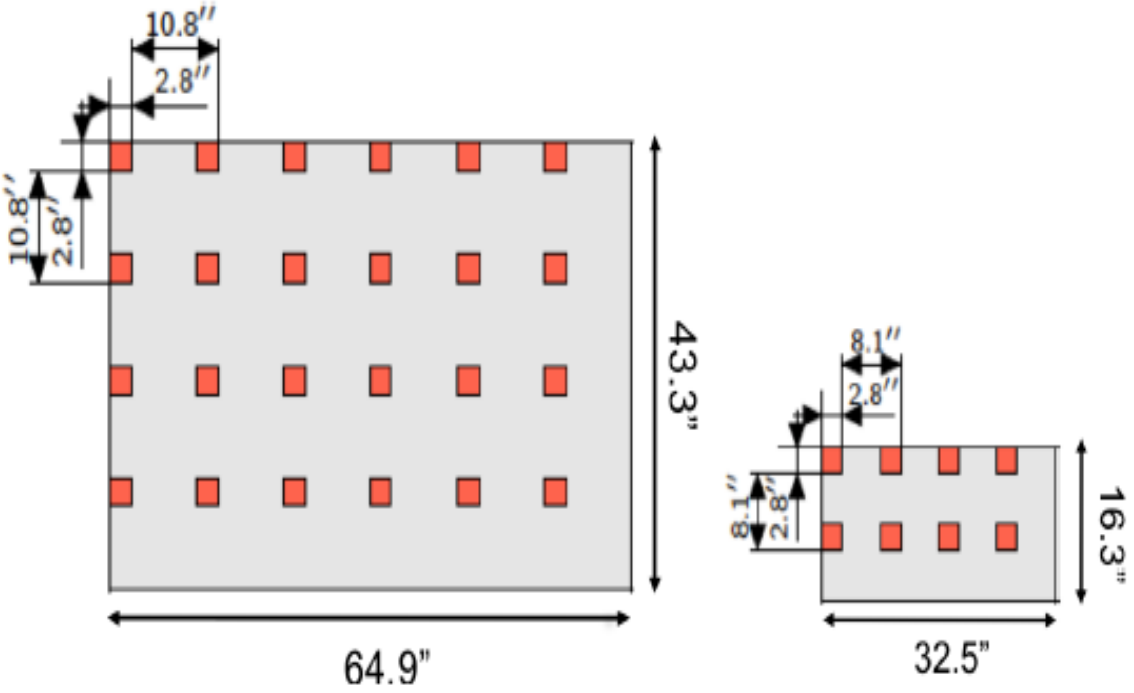
KMOS modes

- KMOS has two modes basic modes
- Multi-object
  - Arms placed on individual objects
  - Options for obtaining sky measurements

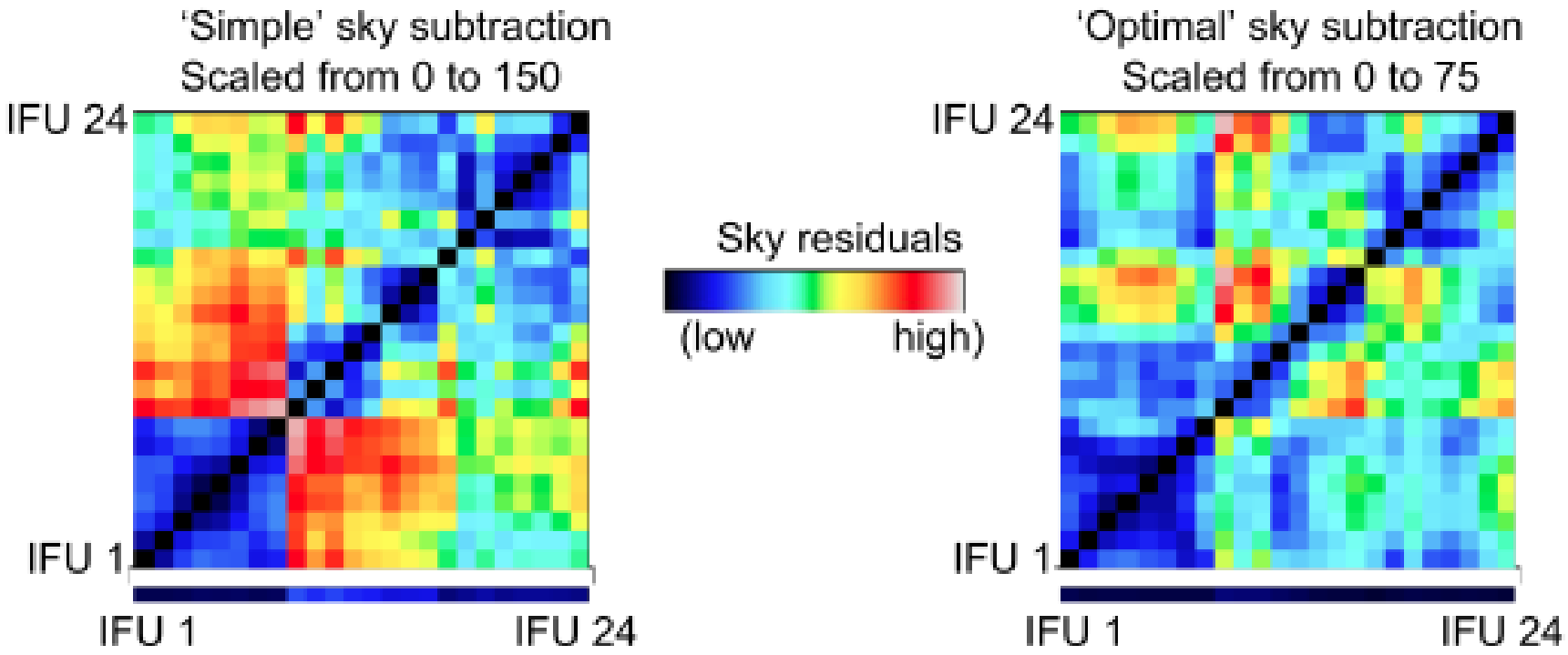


KMOS modes

- MOSAIC
  - Arms placed in a regular grid
  - Wide field spectral image obtained by offsetting the telescope



Sky subtraction strategies



- Simple sky subtraction – sky and source observed in the same arm
- Optimal sky subtraction – as above, with post-processing/'sky tweak
- Cross arm sky-subtraction – source in one arm, sky in another

Performance

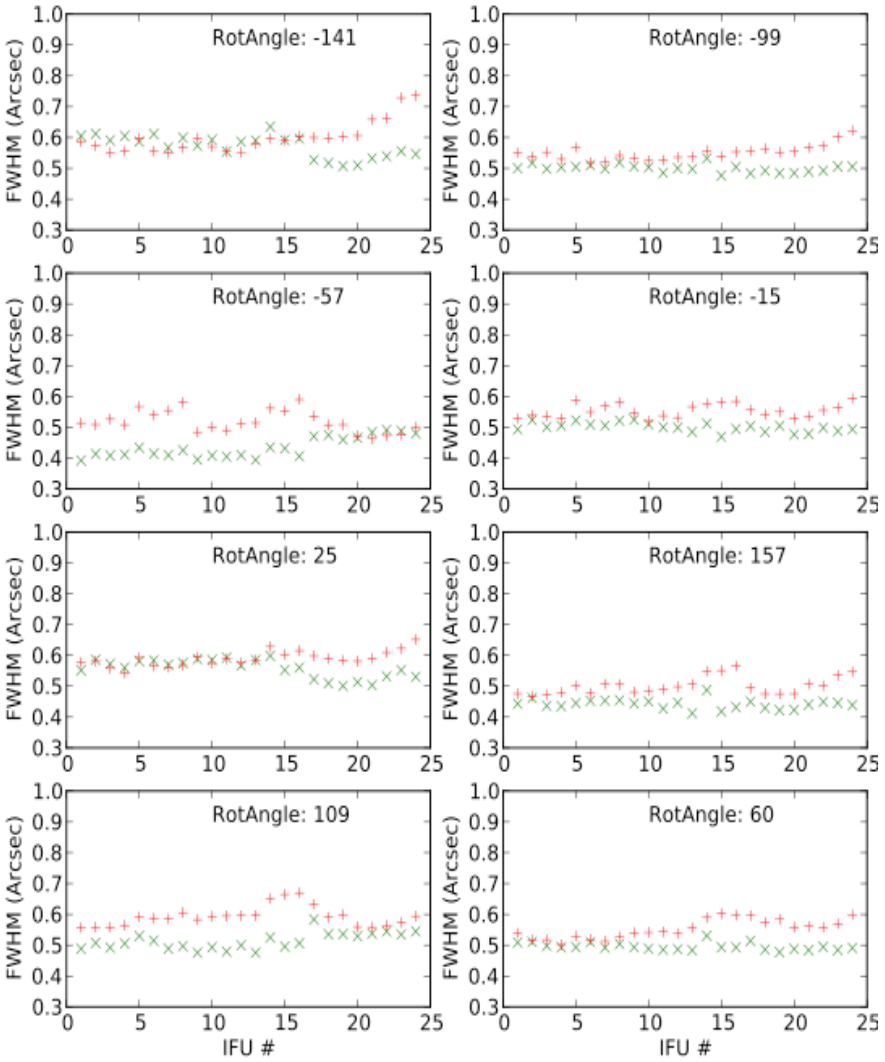
Throughput inc. telescope

K	22 %
HK	23 %
H	23 %
YJ	16 %
IZ*	11 %

5sigma 1h mag limits

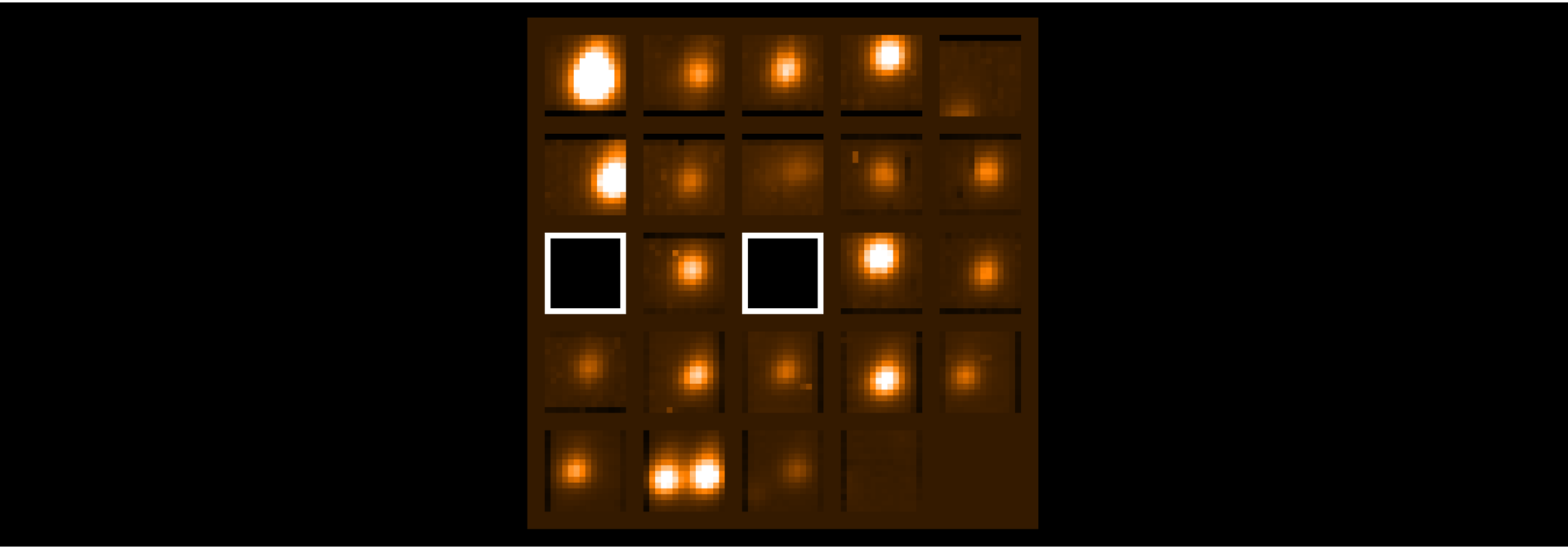
K	17.9
HK	19.8,17.9
H	19.8
YJ	20
IZ*	19

Image quality



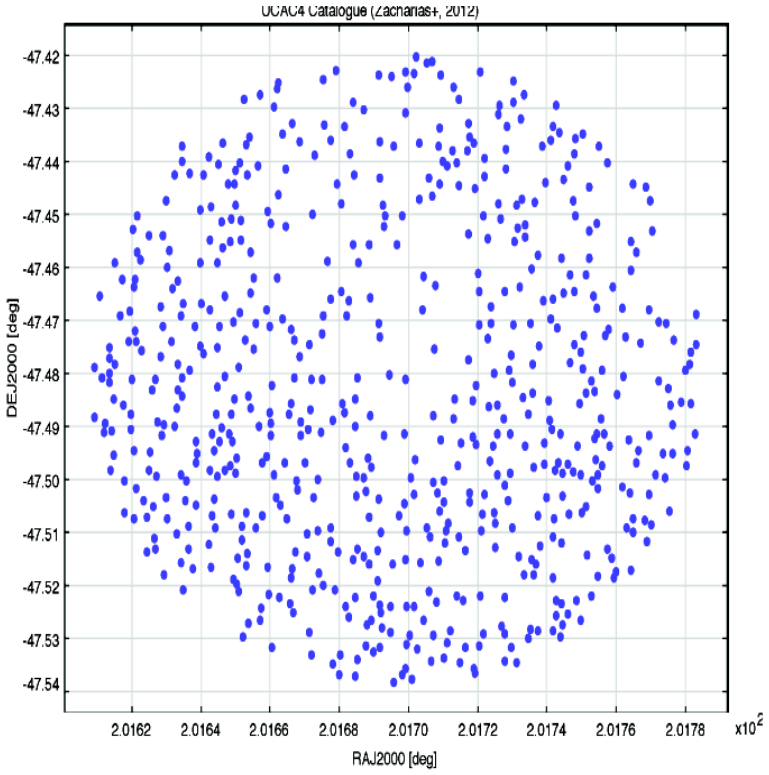
Acquisition

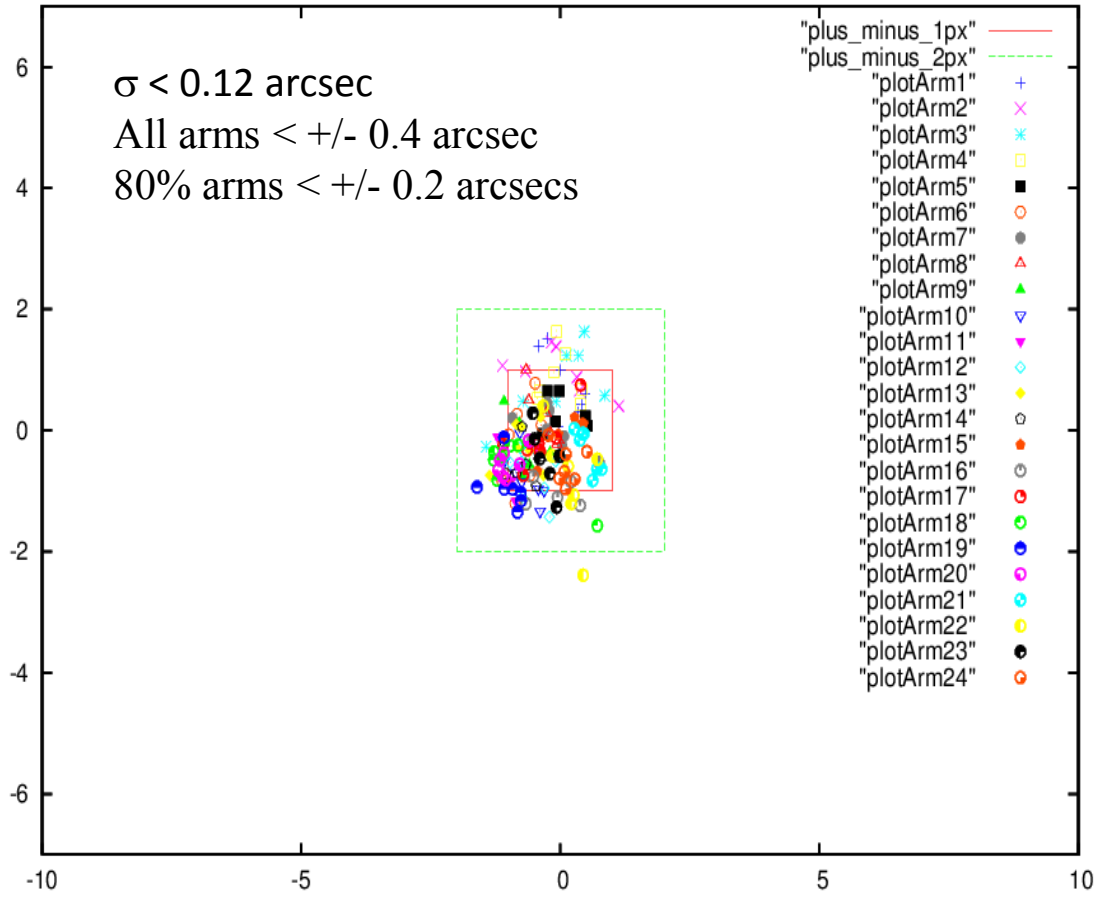
- Acquisition of objects onto the small KMOS fields relies on good astrometry from the user and good arm position calibration



Arm position calibration on-sky

Omega Centauri catalogue: 600 stars of suitable magnitude with accurately determined positions, low proper motion stars.





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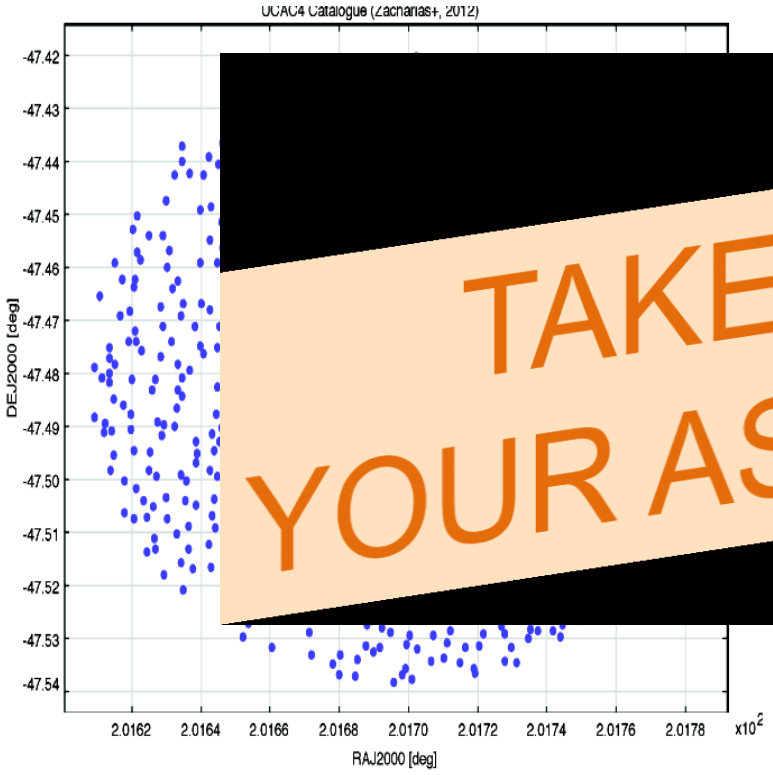
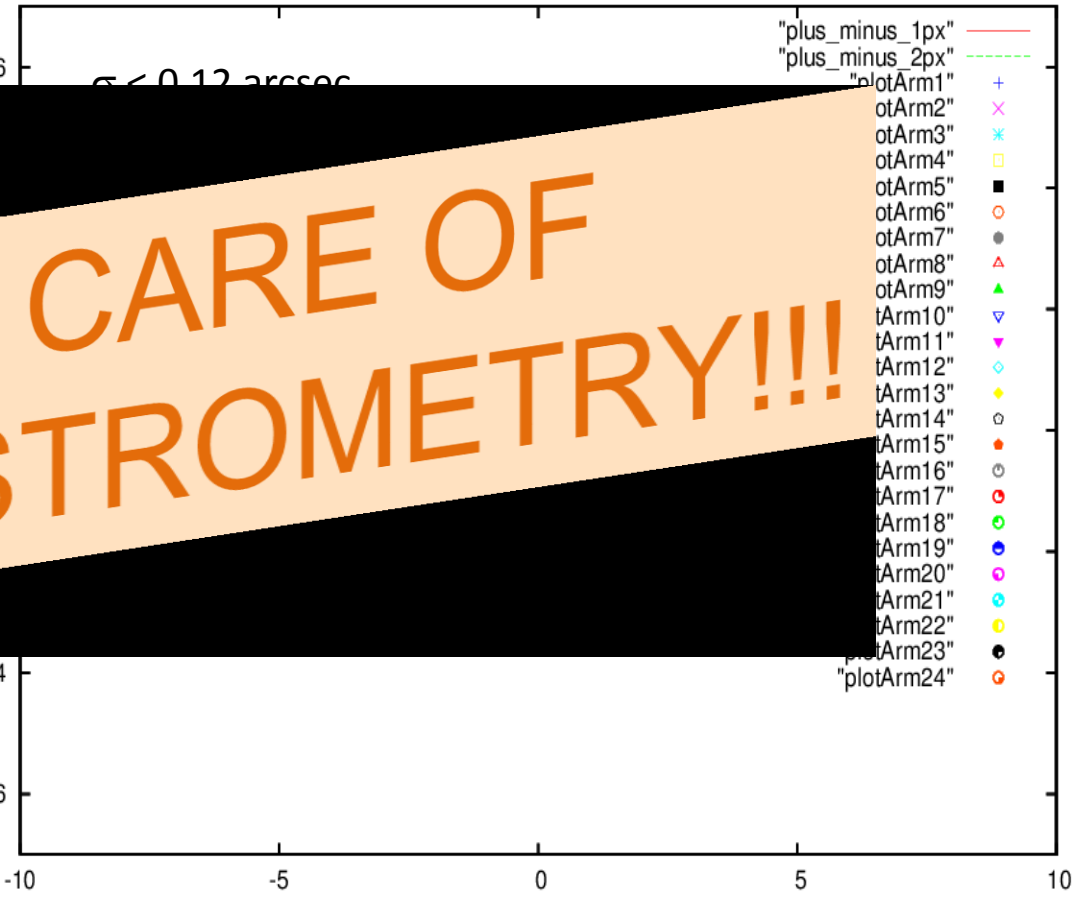
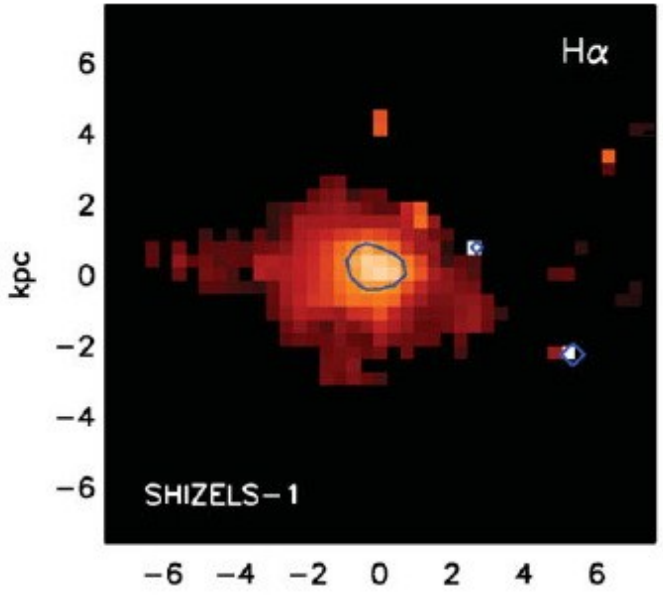


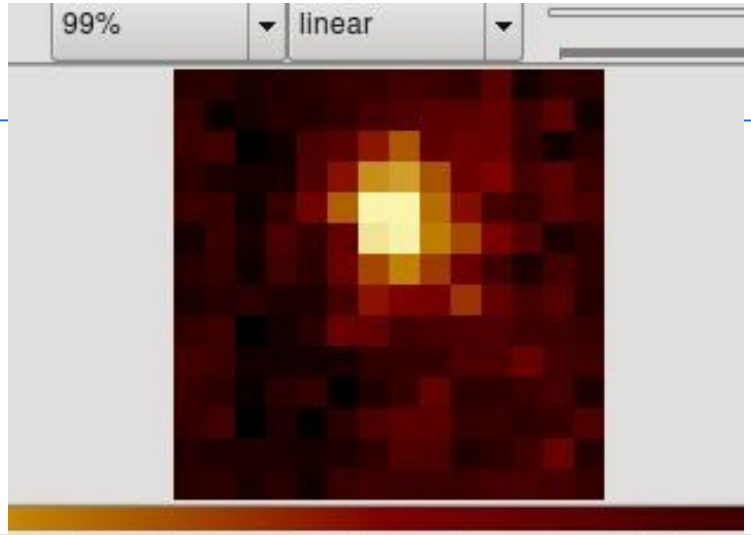


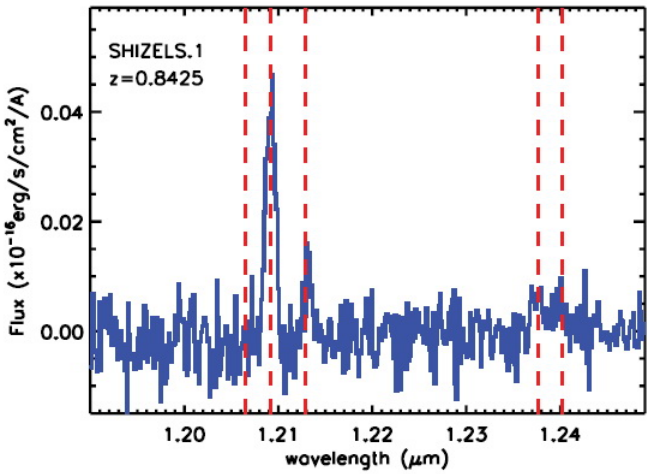
TAKE CARE OF YOUR ASTROMETRY!!!

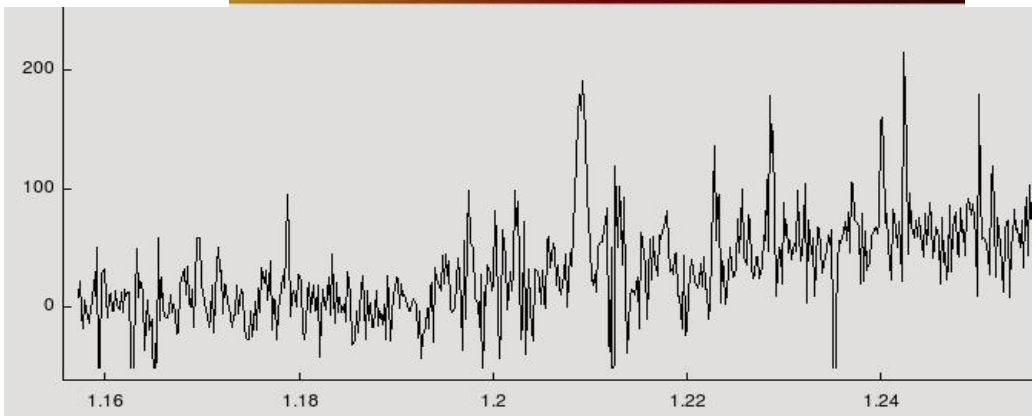
Dealing with Spectrograph flexure

- KMOS rotates on the Nasmyth rotator to track the field
- Flexure of the spectrographs result in two effects
  - Movement of the spectral lines
  - Movement of the slitlet pattern on the array
- Movement of the spectral lines
  - Compensated in the pipeline reduction by using the OH sky lines to correct the wavelength scale
- Movement of the slitlets on the array
  - Compensated by observing flat fields at 60degree separated rotation angles during daytime



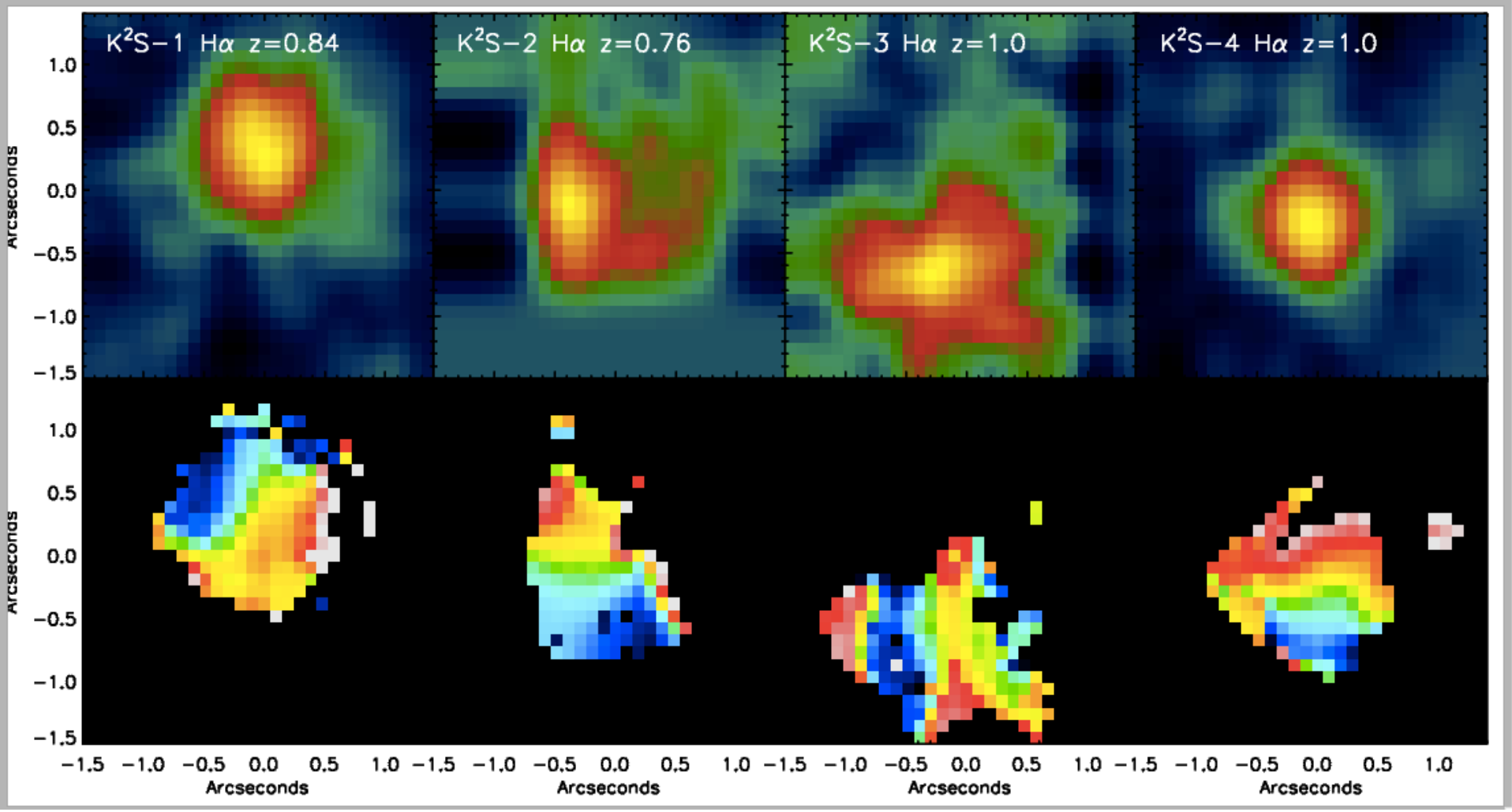






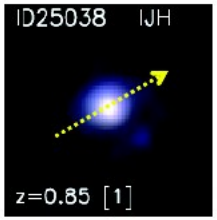
3hr integration of SHiZELS-1 at z=0.8425 with SINFONI (using AO), from Swinbank+ 12. The image and spectrum show the Hα line, which has a flux of 1.0e-16 erg/s/cm^2.

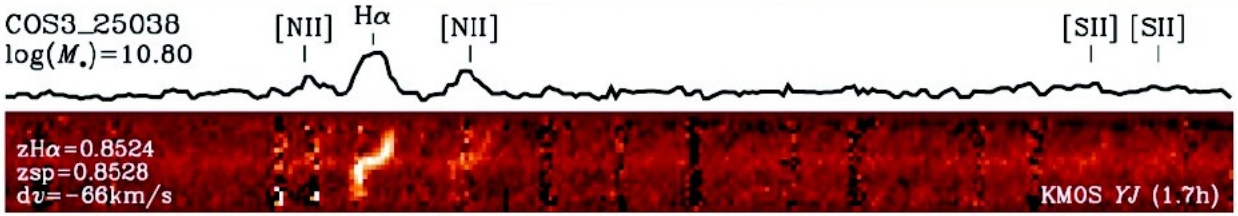
25min integration of the same object using KMOS. This could be seen in a single 5min exposure, confirming that KMOS is very sensitive.



H-alpha emission-line maps (top) and derived velocity fields (bottom) for a sample of faint z~1 emission-line galaxies in the GOOD-S field. The brightest targets have an observed integrated H-alpha flux of 1.0×10^{-16} ergs cm^{-2} s^{-1}. 30mins of on-source exposure.

See also Sharples et al. ESO Messenger, 151

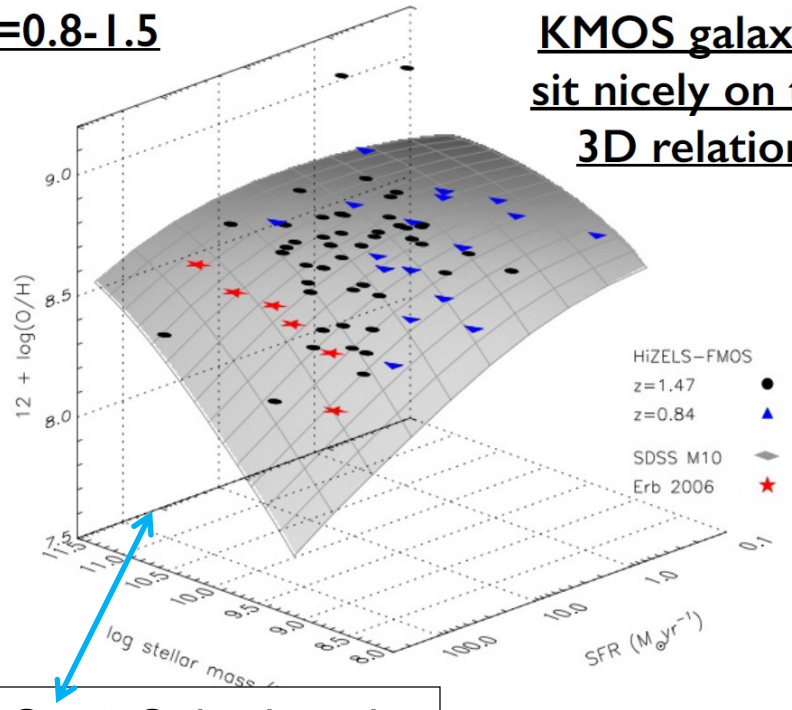


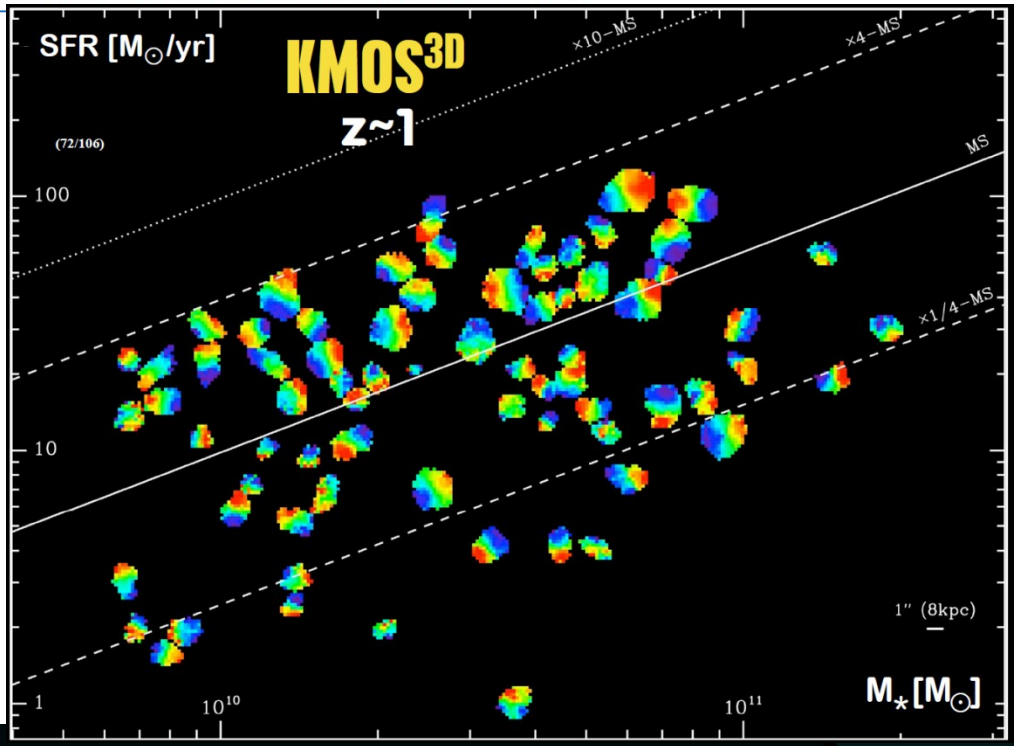


Wisnioski et al. 2015

z=0.8-1.5

KMOS galaxies sit nicely on the 3D relation



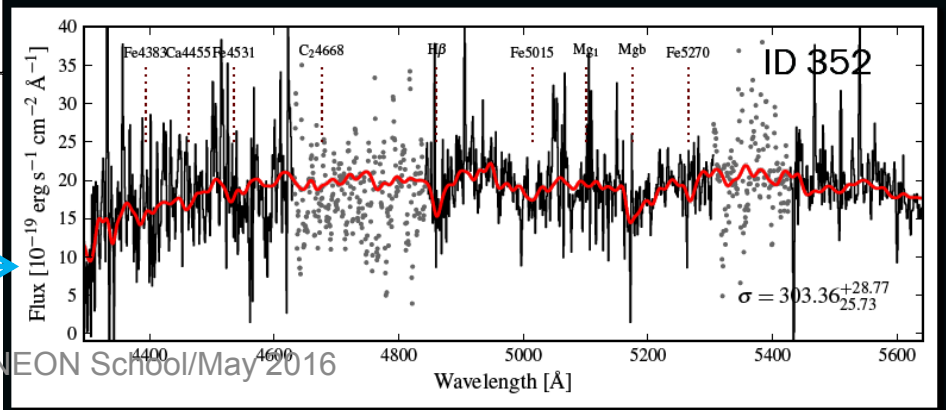


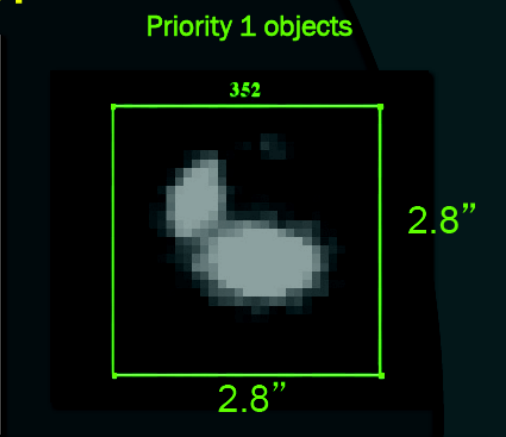
Stott, Sobral et al. 2013, 2014

Beifiori, Mendel et al. 2015 KMOS Clusters team

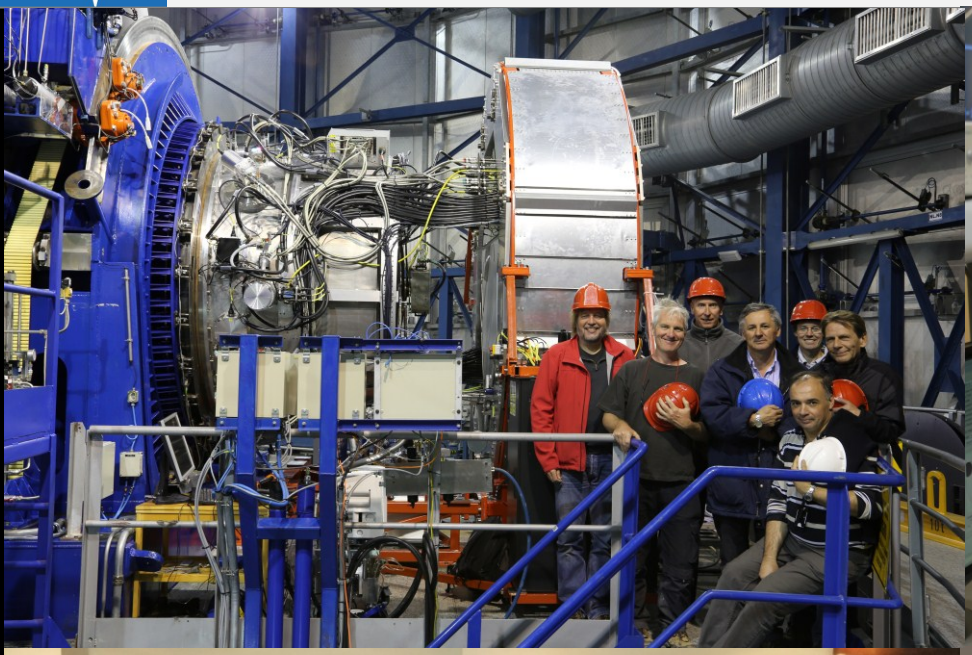
XMMU J2235-2557

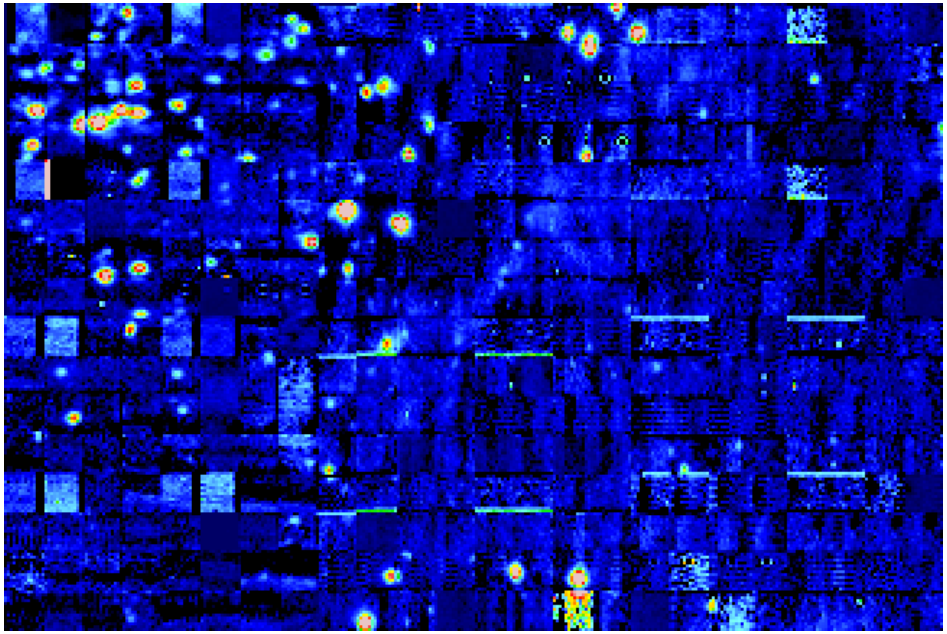
Exposure time=11.25 h

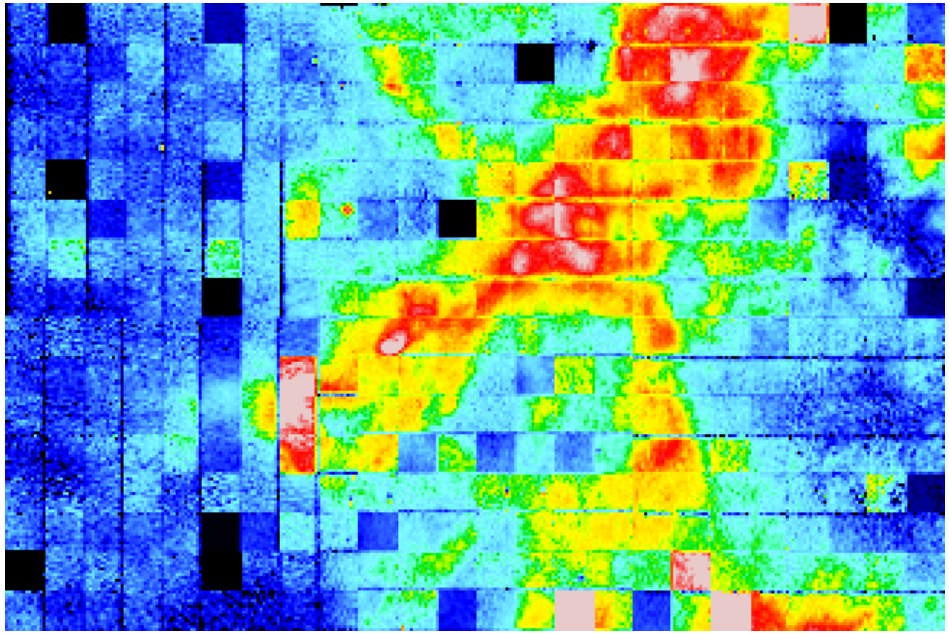


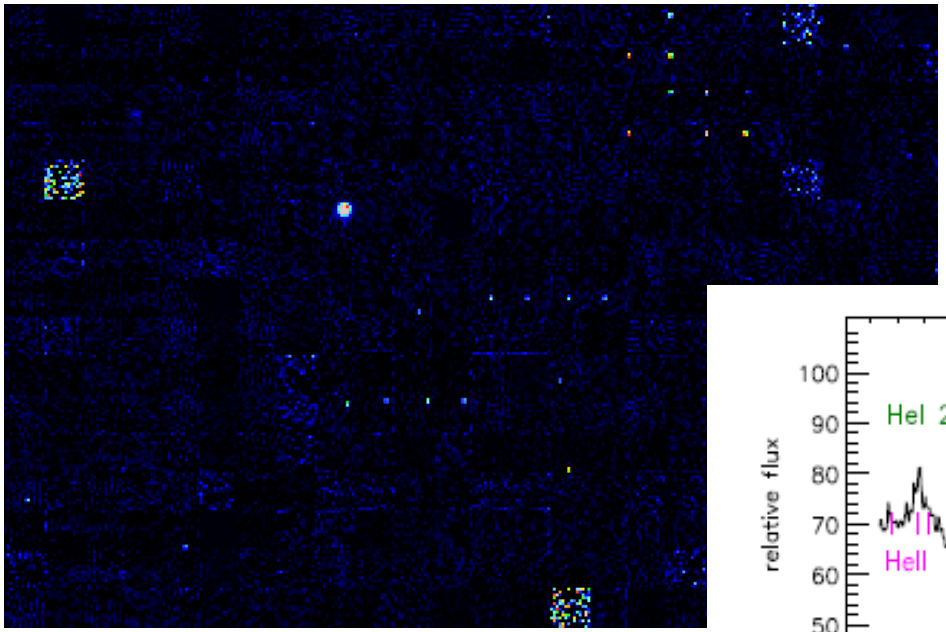


Thanks. Questions?

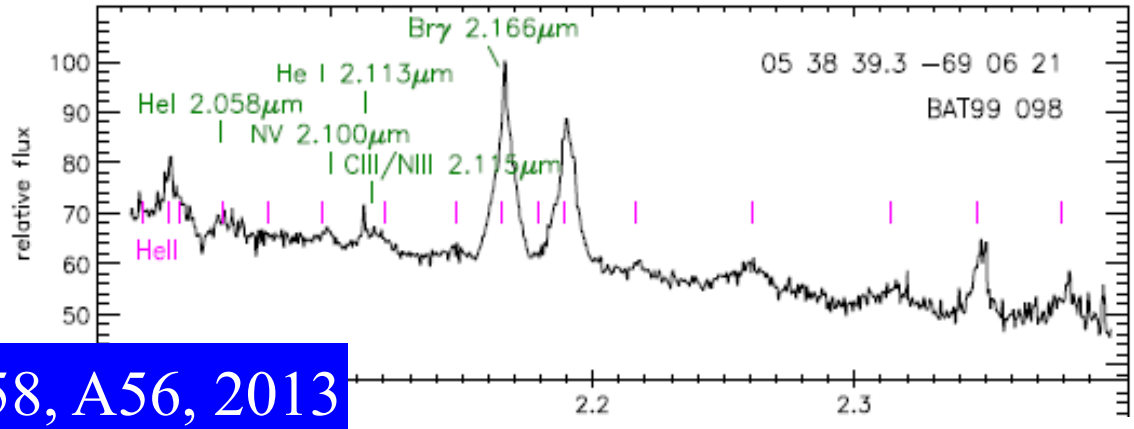






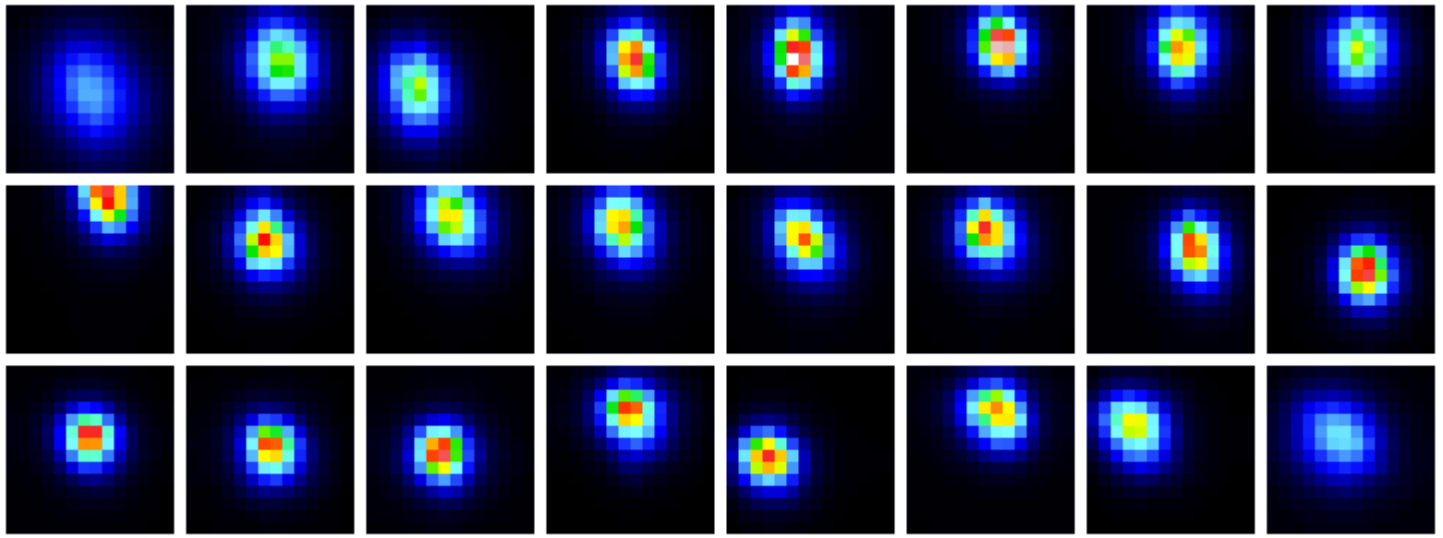


Mapping24 observation of R136.
Field is approx 40x60arcsec.
Top left: 2.1um continuum
Top right: Br-gamma
Bottom left: broad HeII in WR star.



See also Davies et al. A&A 558, A56, 2013

Nov 27



H-band spectrum of the emission-line B*III star Hip022112.