Calibration of KMOS

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Introduction

- Observing with KMOS and the implications for calibration
- One KMOS arm ≈ SINFONI
- Issues unique to KMOS
  - Calibration of the arm positions in the lab
  - Calibration of the arm positions on the sky
  - Flat fielding the multiple IFU fields
  - Details of the calunit design

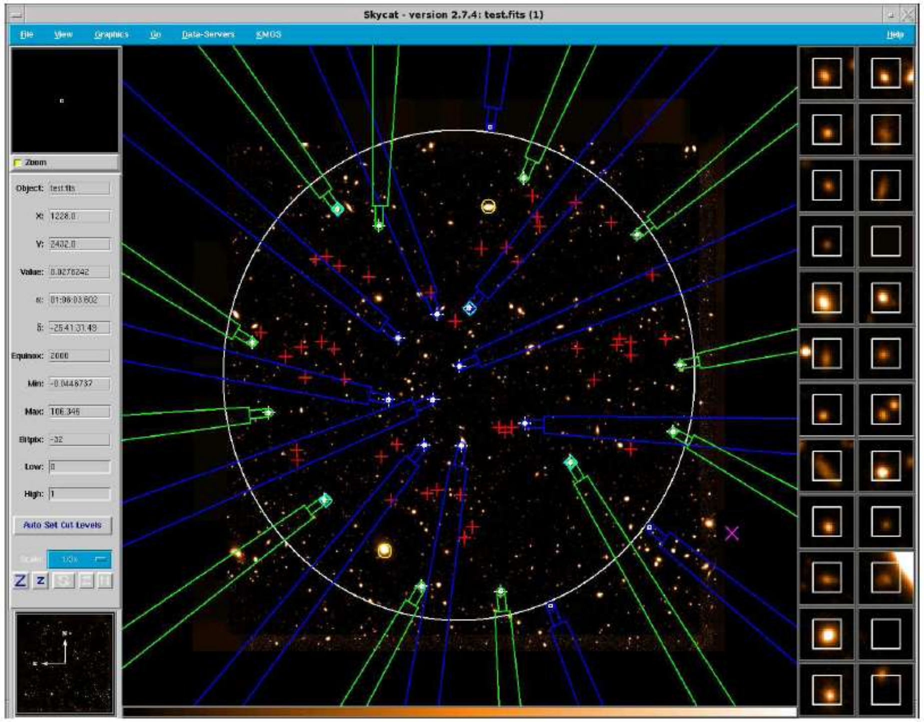
Multi-IFU spectroscopy

- Each single arm of KMOS can be calibrated as a single IFU spectrograph of moderate spectral resolution and so we may draw on experience with SINFONI, GNIRS, UIST
- However, the science cases call for deep observations (over many nights) which place constraints on stability and calibration
- Calibration of the arm positions is required to allow arm to be acquire sources blindly – relies upon relative positioning of the arms
- To exploit fully efficiencies of a multi-field system, should be able to calibrate (e.g. sky

Pre-observing with KMOS

- Allocation of the arms to sky positions based on user supplied positions for sources, reference stars on a common astrometric reference frame.
  - 0.1arcsec requirement

- Requires calibration of motor steps for two motors per arm into (RA, dec).

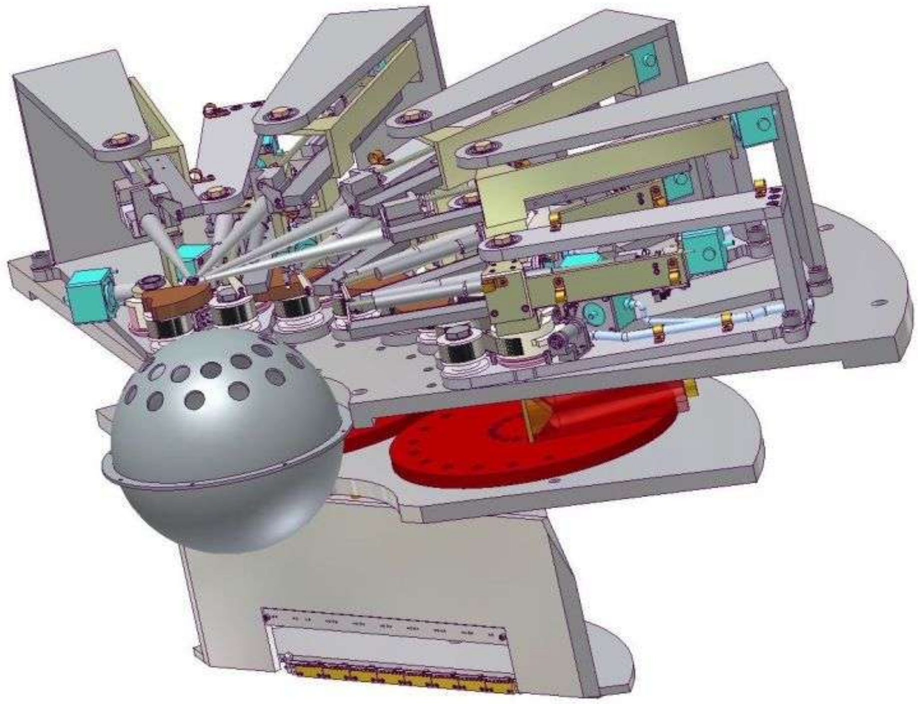


Karma tool under development at USM (Wegner, Muschielock).

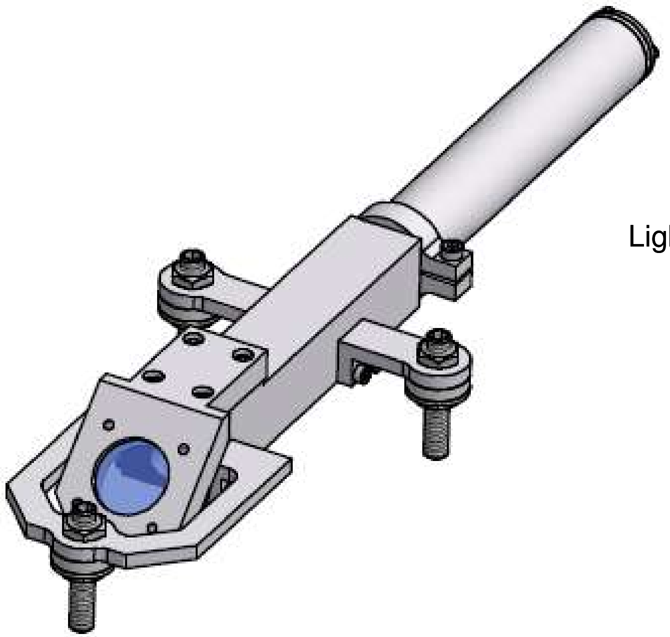
Calibration of motors steps to arm positions

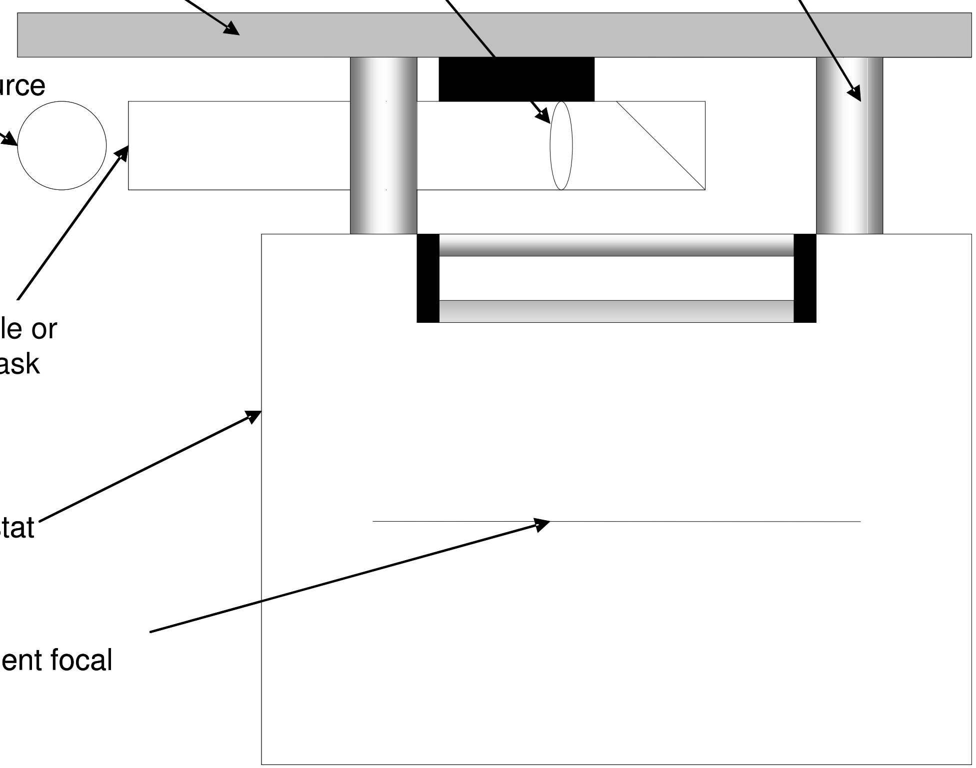
- Arms move in (R, theta) using motor step counting
- Initial calibration of individual arms
  - range of steps
  - steps to angle, radius
  - Geometrical transformation

  of R, theta to (X,Y)



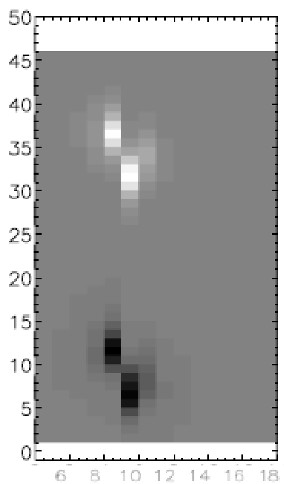
Lab calibration of the arm position



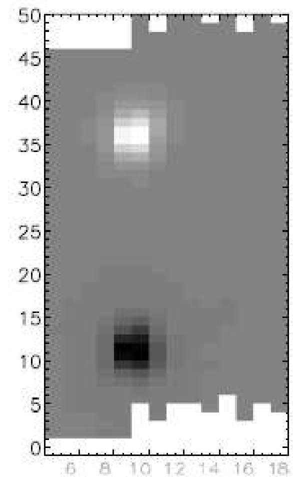


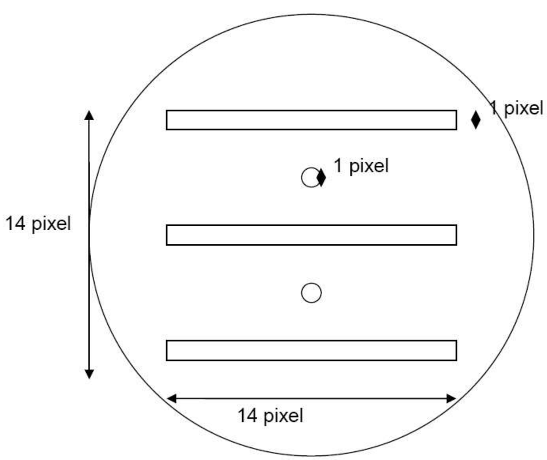
- F-15 source for lab calibration

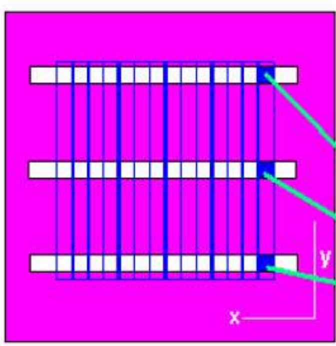
Calibration of spatial offsets



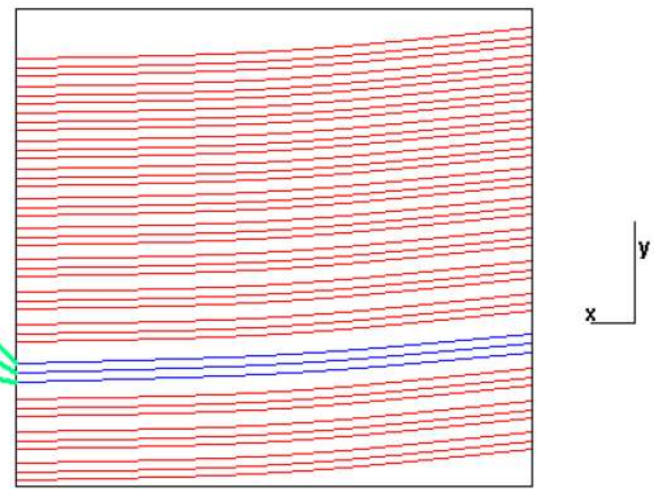
- Image reconstruction before and after arm the spatial offsets are calibrated
- Calibration of the spectral curvature
- Both obtained efficiently using a slit mask in the lab calibration system







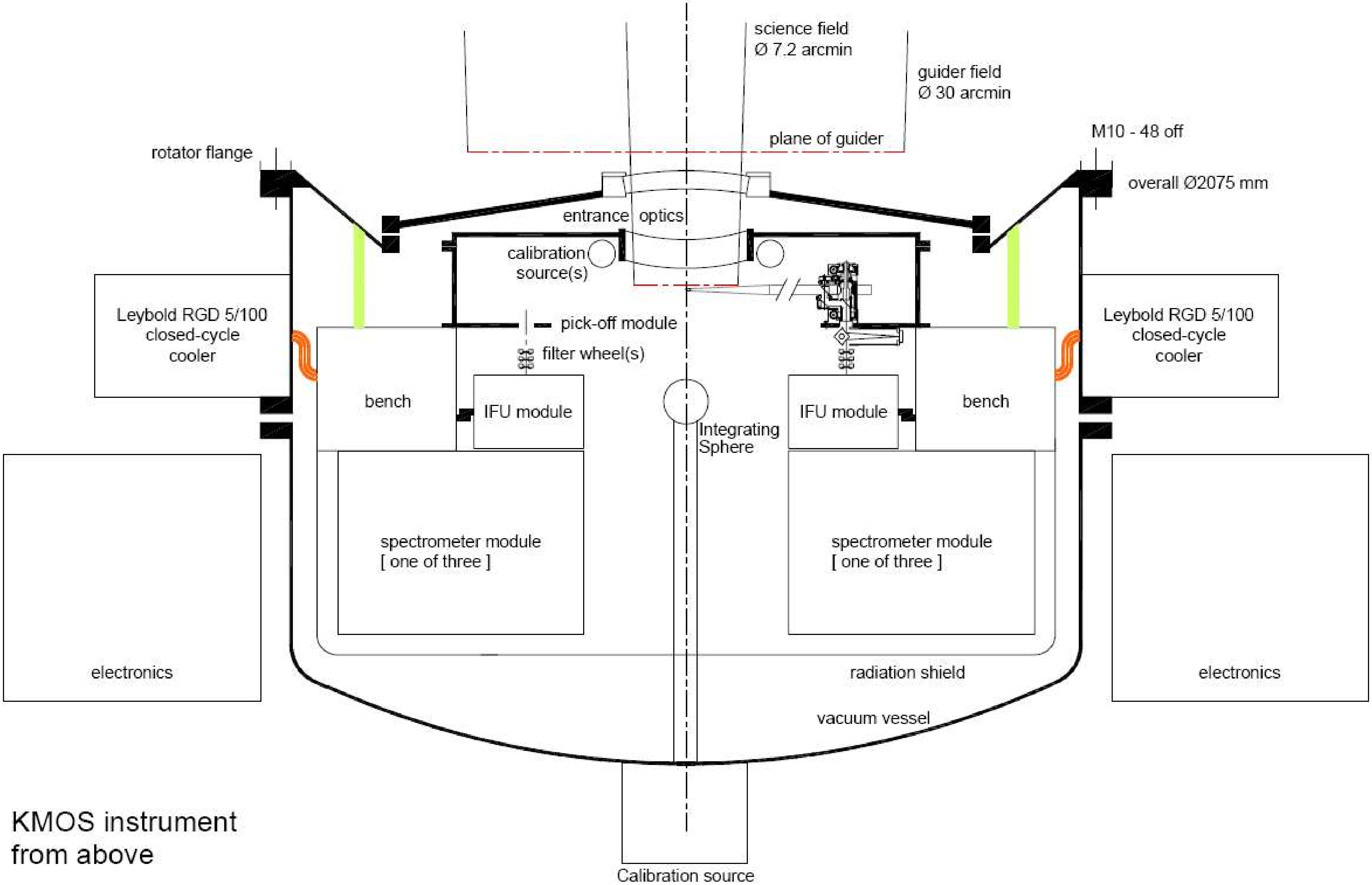
a) the slit mask and image slicer



b) the 'sliced' mask on the detector.

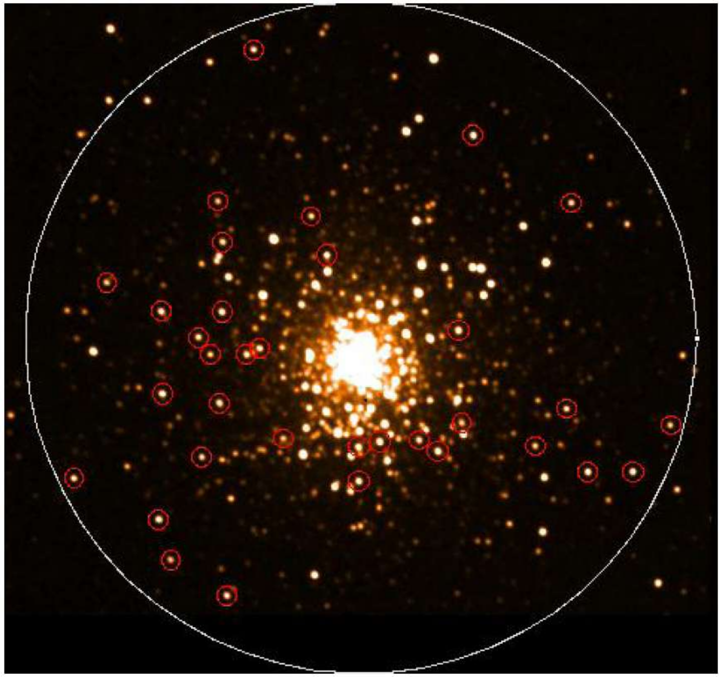
Calibration of sky coordinates to arm positions

- Mean (RA, Dec) to apparent place (Ra, Dec)
  - Input: atmospheric model of differential refraction
- (RA, Dec) to the tangent plane (ξ,η) in radians North and East
  - Input: field centre
- (ξ,η) to perfect (X,Y) mm
  - Inputs: telescope focal plane plate scale, rotation of the (ξ,η) plane relative to the instrument (X,Y) coordinate axis
- Perfect (X,Y) to real (X,Y) by correcting for residual field distortion (<3 pixels)
  - Inputs: Zemax model of the field corrector supplemented by on-sky calibrations



KMOS instrument from above

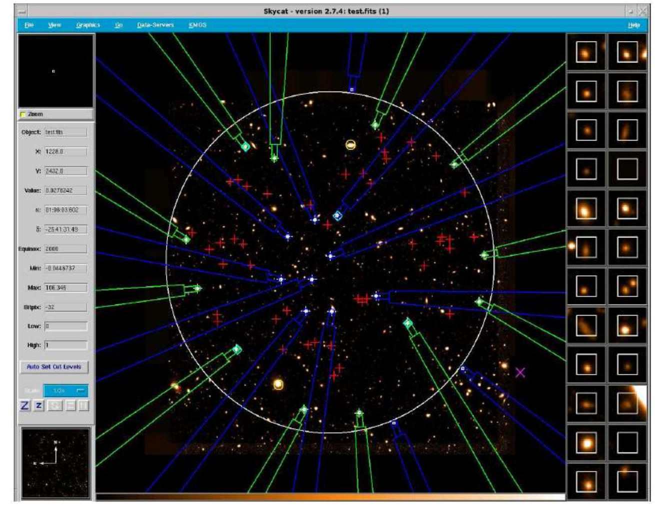
On sky calibration of the arm position



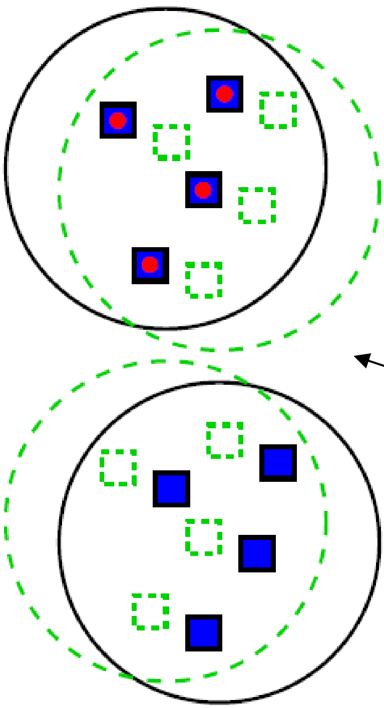
- Final calibration of the arm position obtained on sky using observation of globular clusters
- Stars with 13<H<11 are optimum for centroiding
- Final step confirms the model of the residual field distortion with the telescope+field flattener.
- Repeatable position of arms to ±0.2arcsec for acquisition of faint, invisible sources on several nights.

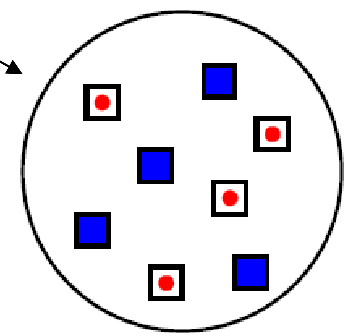
47 Tuc	00 24 05.2	-72 04 49	Jun-Nov
M5	15 18 33.7	+02 04 58	Feb-Aug
M4	16 23 35.4	-26 31 32	Feb-Sep
NGC6397	17 40 41.3	-53 40 25	Feb-Sep
M22	18 36 24.4	-23 54 12	Mar-Oct
Omega Cen (globular cluster)	03 26 45.8	-47 28 36	Jul-Mar
LMC (field stars – Smecker-Hane)	05 11 00.0	-70 00 00	Aug-Mar
NGC3603 (open cluster)	11 15 09.1	-61 16 17	Nov-Jul

Observing preparation with KMOS



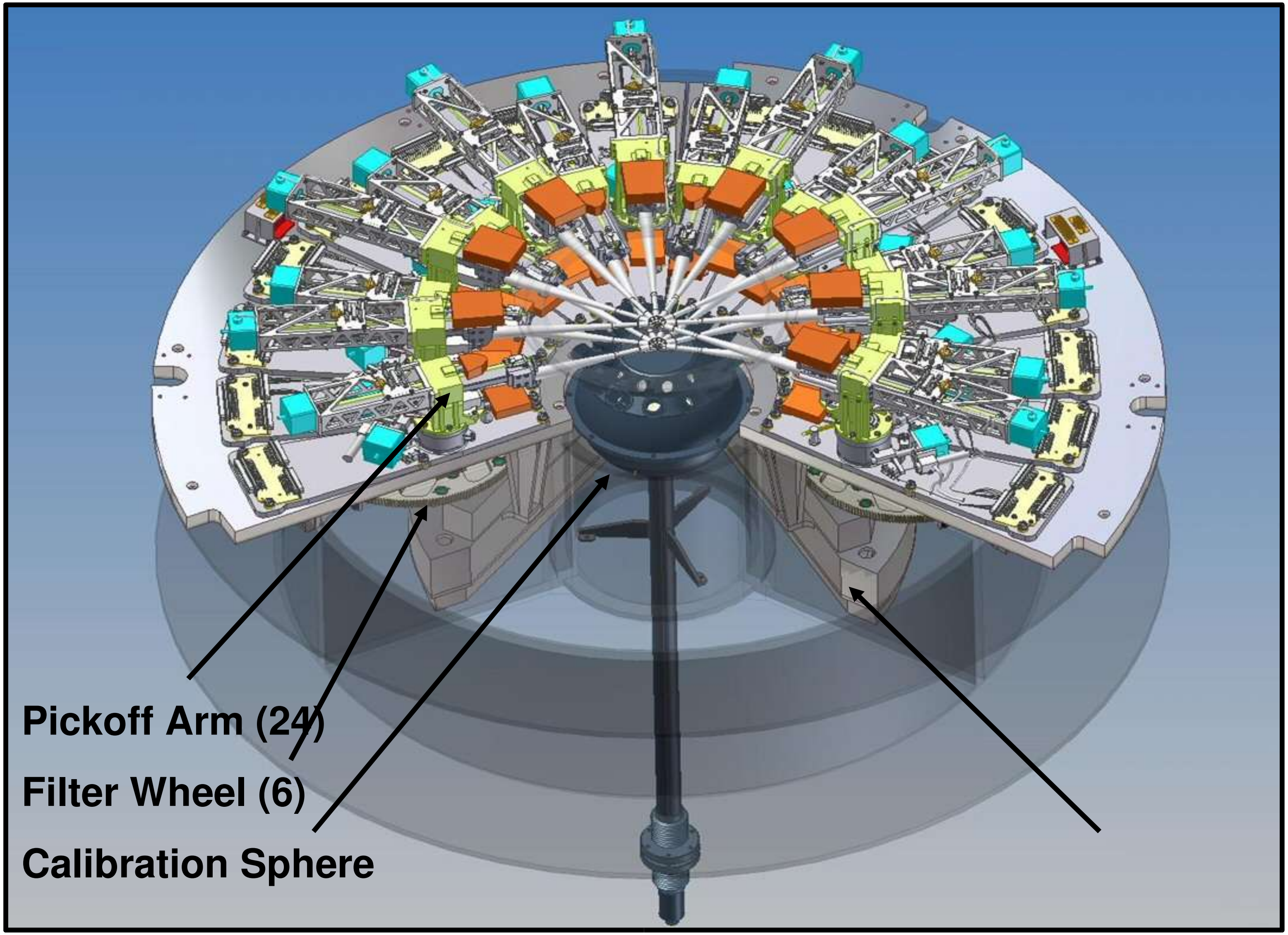
- Selection of the sky subtraction mode
- Baseline templates are
  - Obtain sky frames by offsetting the telescope
  - Obtain sky measurements from sky arms or around the IFU field
- Calibration requirements depend upon the mode chosen

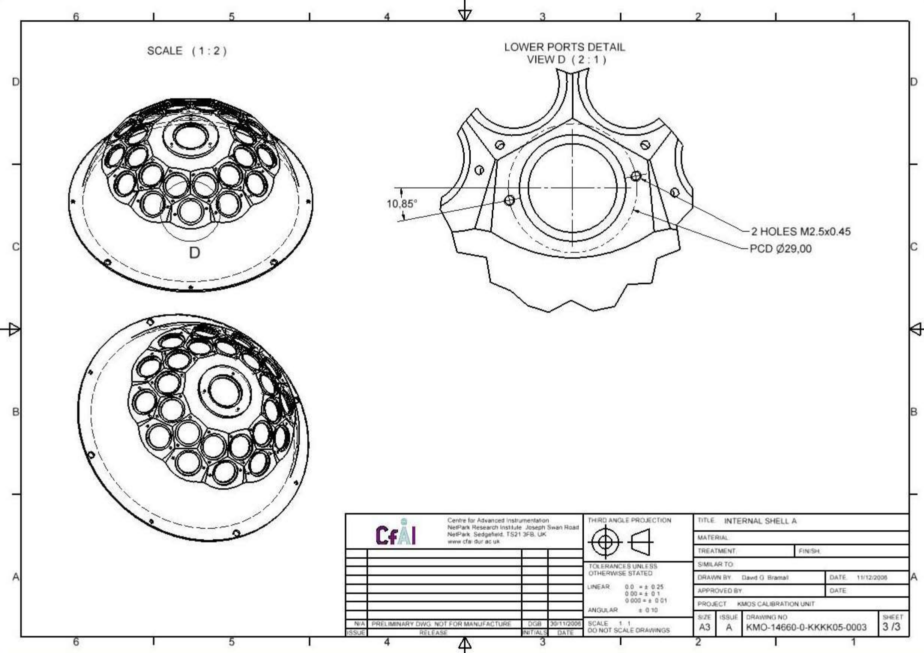


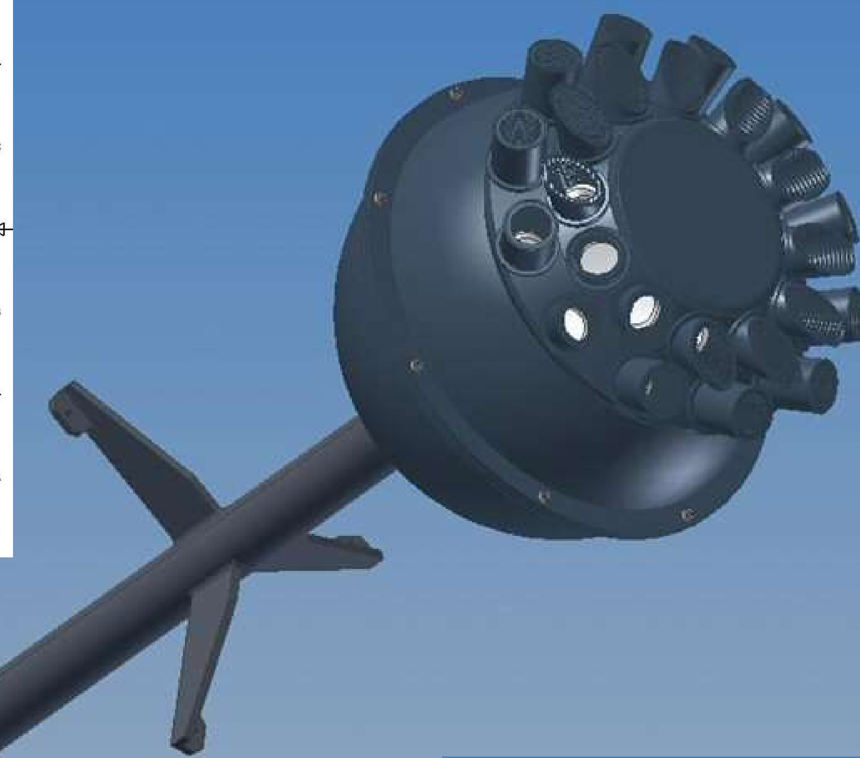


Calibration requirements with observing mode

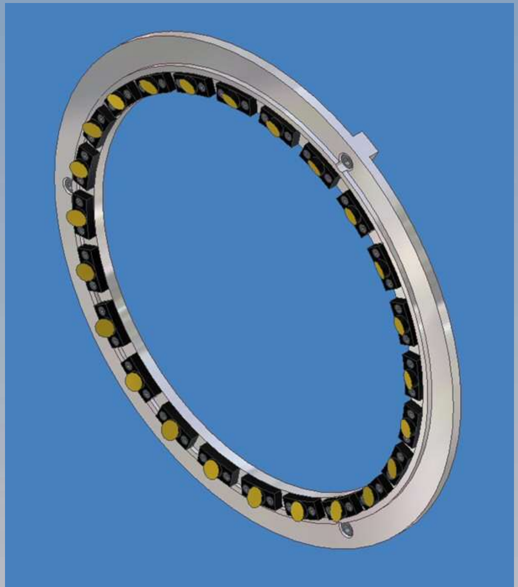
- Flat fielding requirements are set to ensure high quality sky subtraction
- For offsetting to sky, requirements are relaxed as the source and sky are observed along the same optical path
  - Flat field to 1%
  - But observations are inefficient
- Sky subtraction using a different arm or sky off source potentially highly efficient but requires 0.1% accuracy of sky subtraction


Pickoff Arm (24)
Filter Wheel (6)
Calibration Sphere





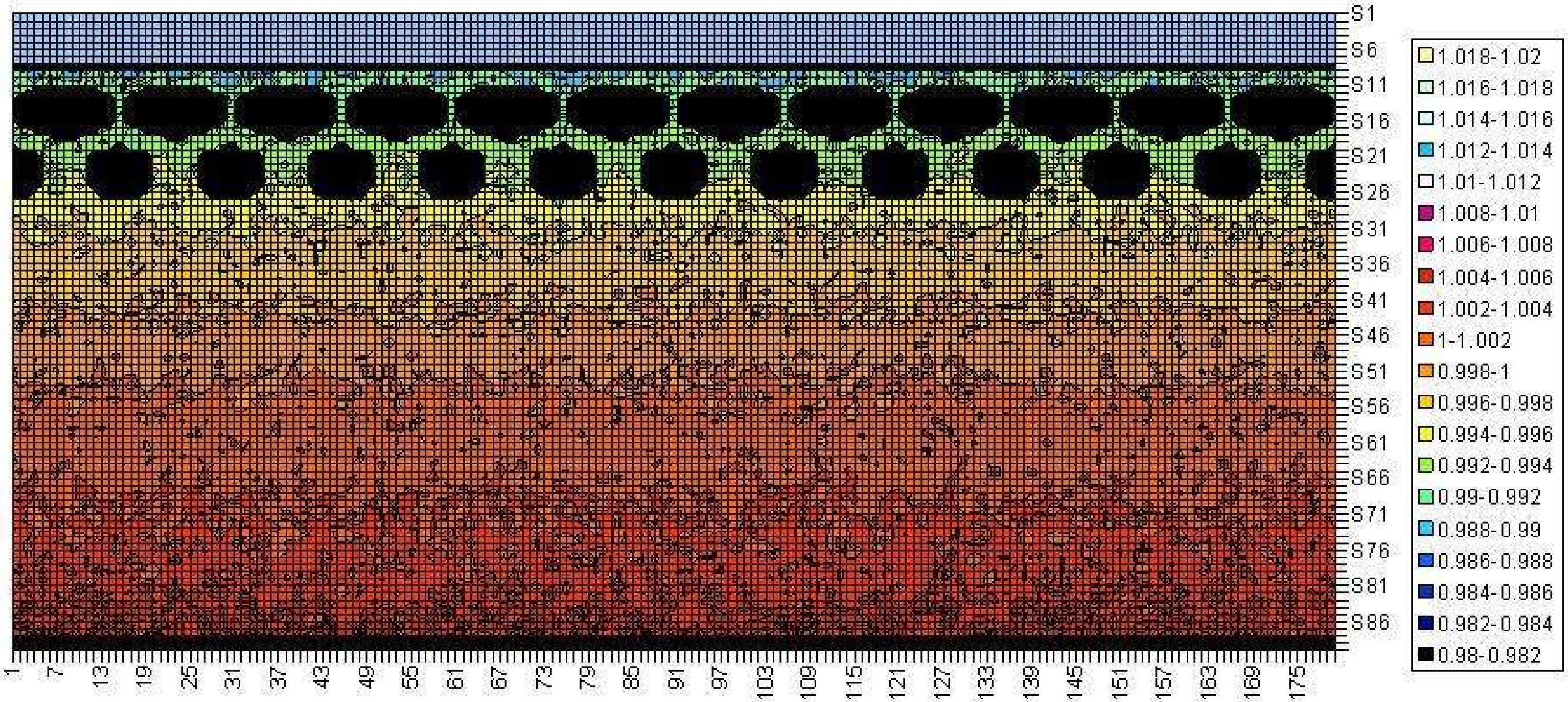

Calibration Source



Illumination at the output ports

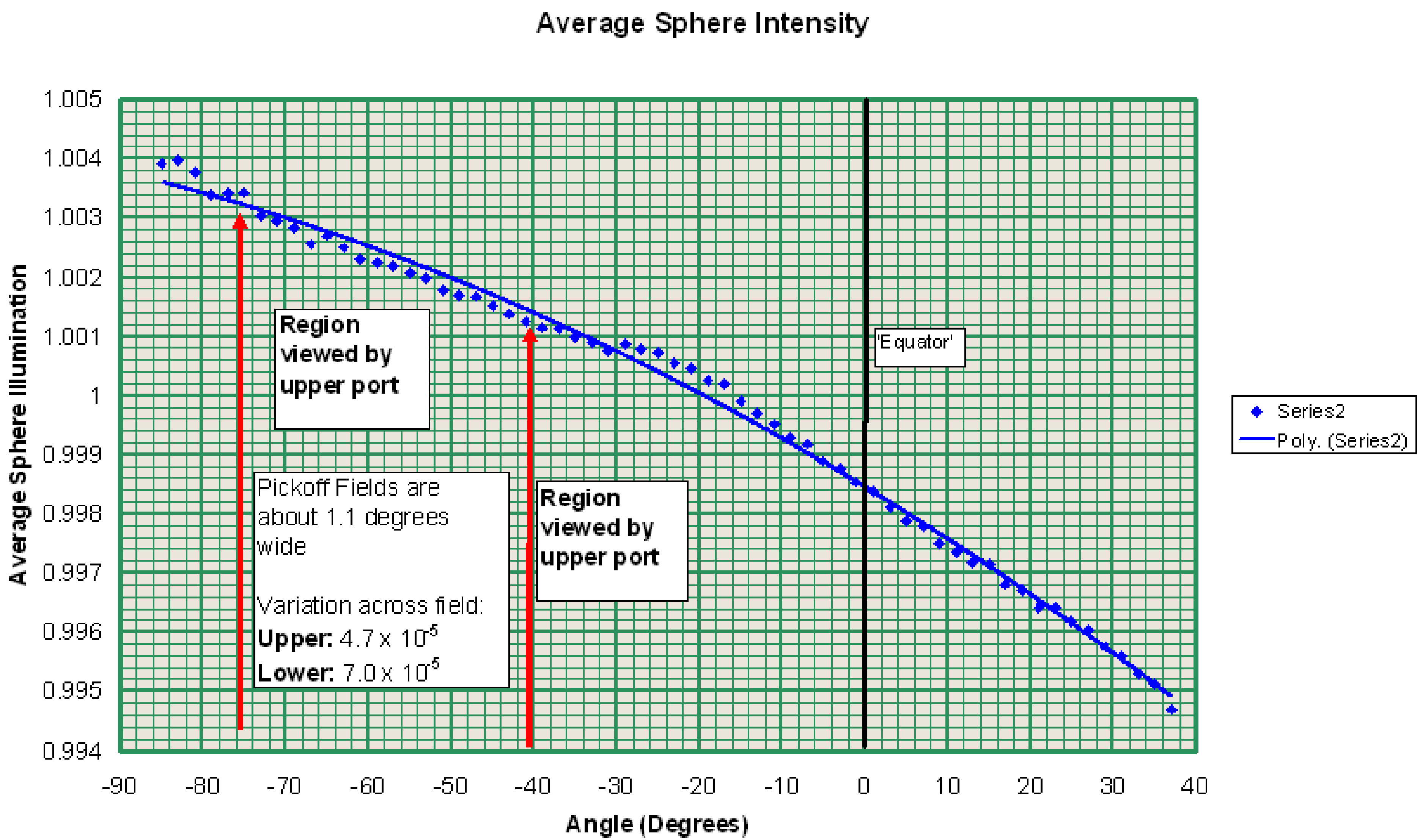
- modelled based on Spectralon coating data from JPL
- <0.01% variation across individual ports
- <0.1% from port to port

NORTH POLE

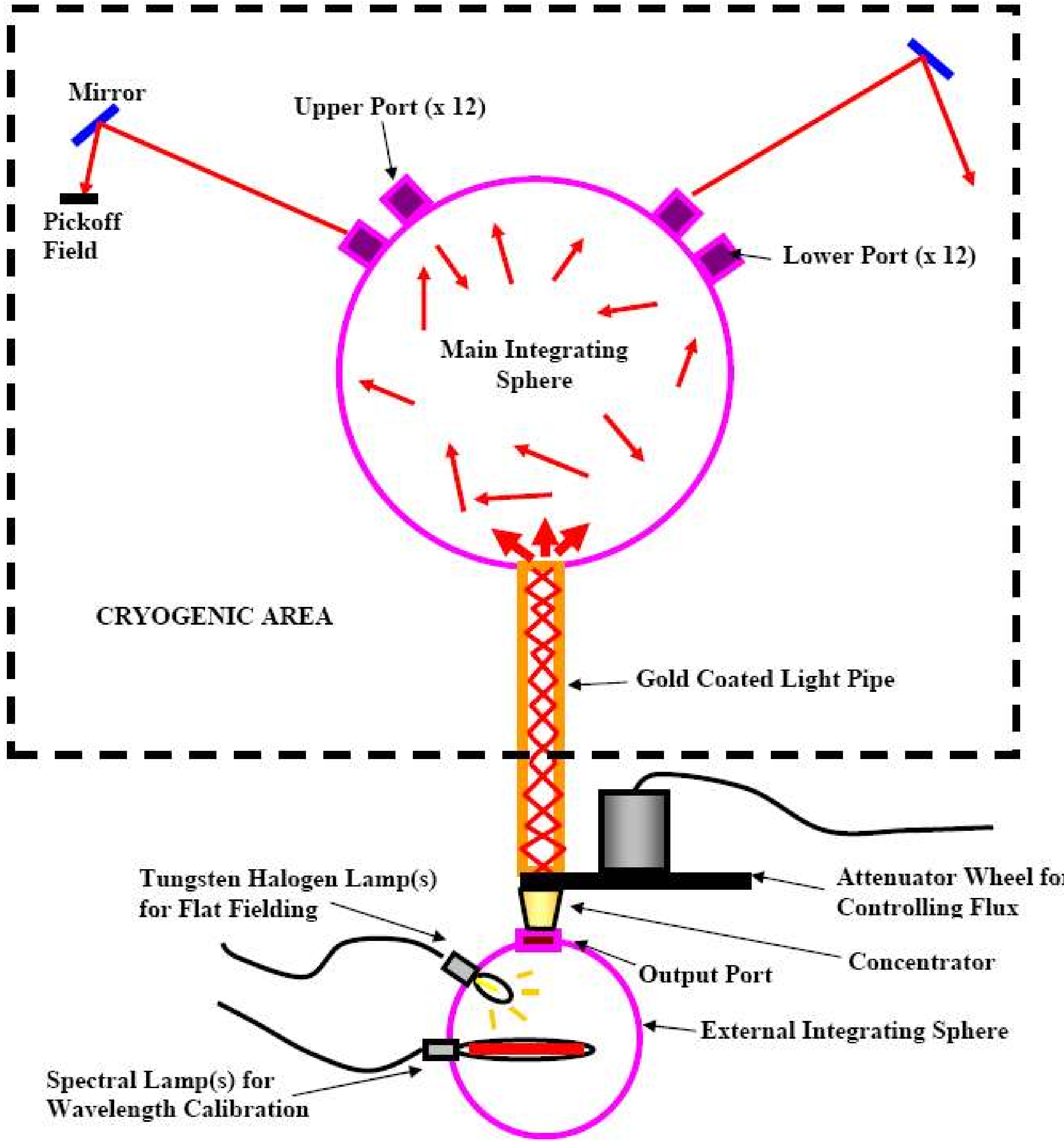


SOUTH POLE

Scale is ± 0.02%


Average Sphere Intensity
Average Sphere Illumination
1.005
1.004
1.003
1.002
1.001
1
0.999
0.998
0.997
0.996
0.995
0.994
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
Angle (Degrees)
Region viewed by upper port
Pickoff Fields are about 1.1 degrees wide
Variation across field:
Upper: 4.7 x 10-5
Lower: 7.0 x 10-5
Region viewed by upper port
'Equator'
Series2
Poly. (Series2)

Throughput >12% IJH
12%-6% 1.9um – 2.5um

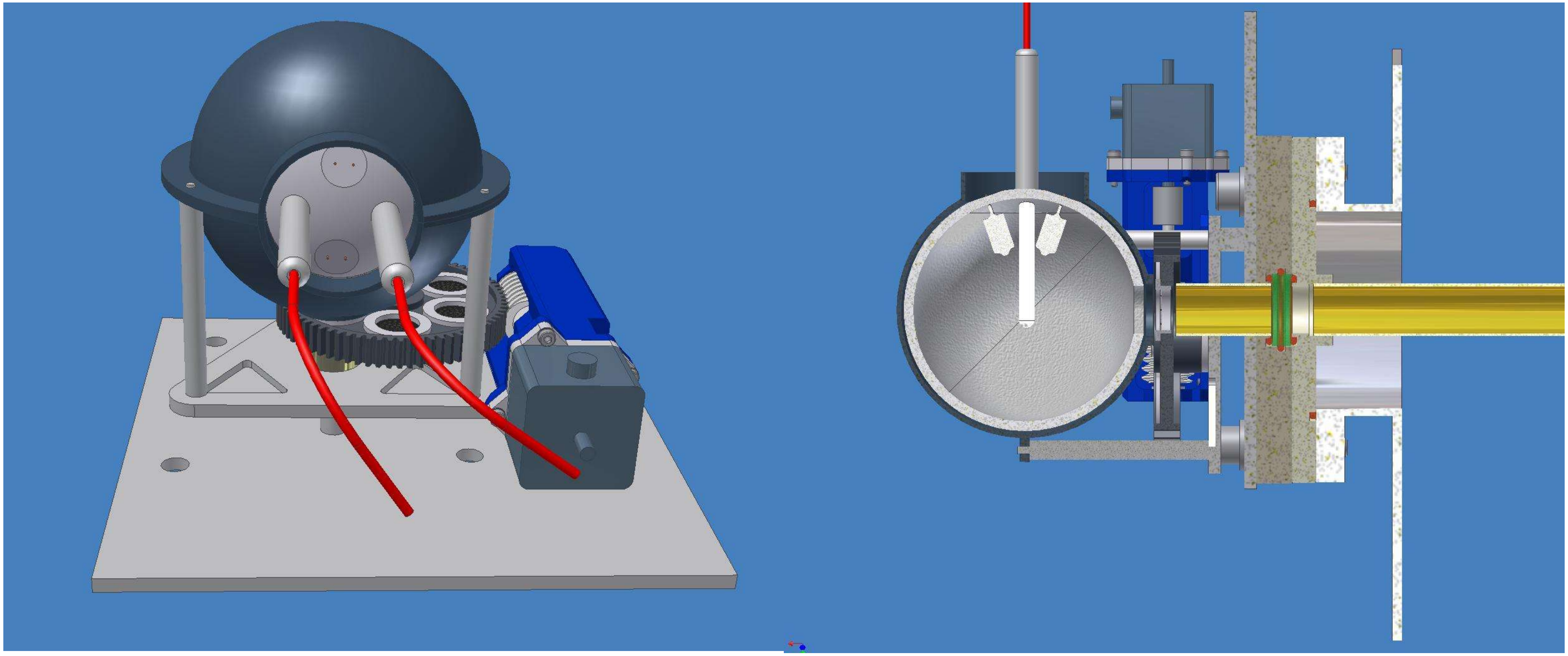


KMOS

Wavelength calibration: Spectral Line Count in K-Band

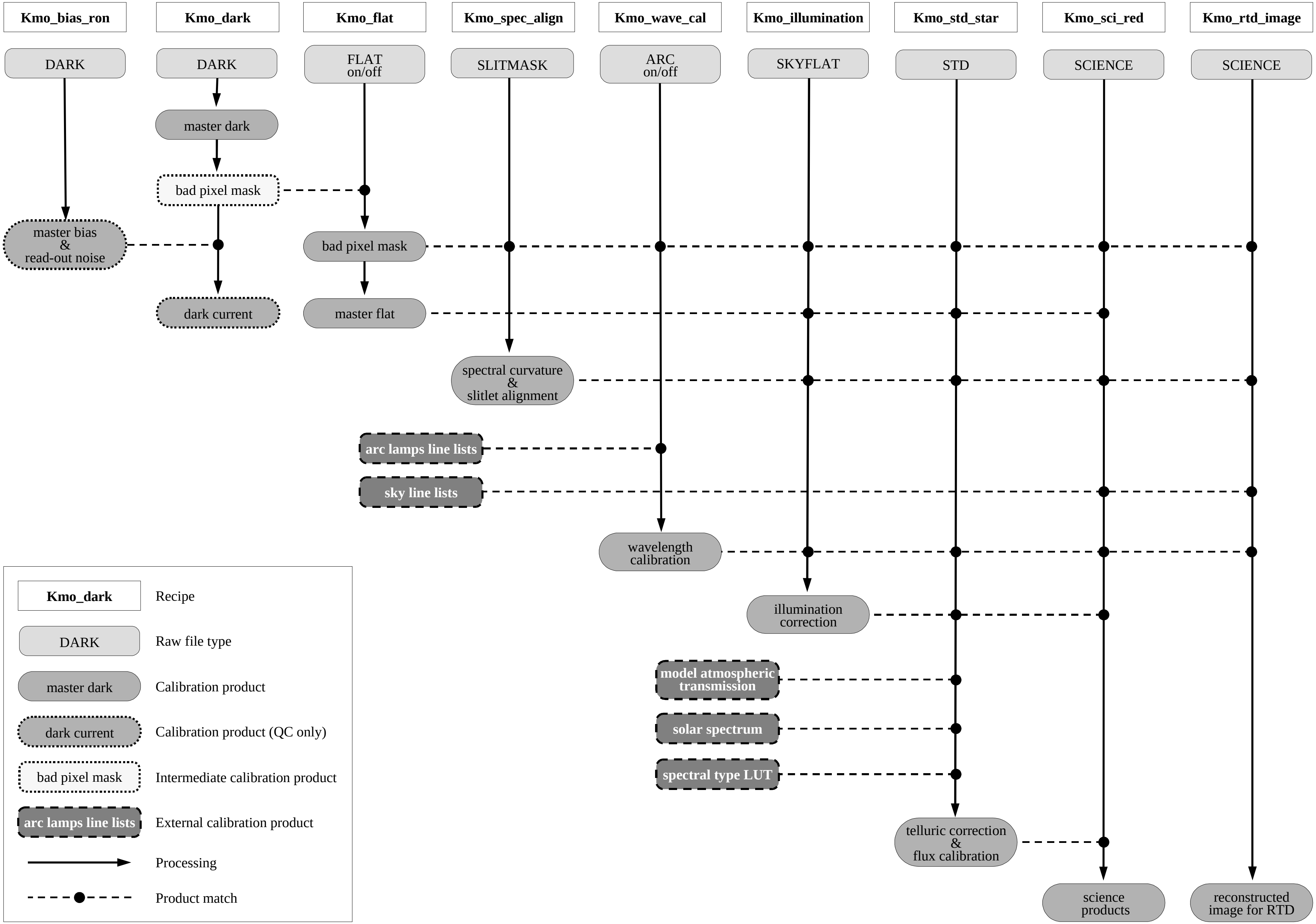
Argon		Neon	
Wavelength (πm)	Predicted Count	Wavelength (πm)	Predicted Count
1.98229	921	1.95771	170
1.99505	123	2.03602	139
1.99712	431	2.10413	213
2.00311	155	2.17061	343
2.03226	408	2.22473	296
2.06219	2177	2.24281	264
2.06528	222	2.23504	1748
2.07392	150	2.26818	166
2.08167	117	2.31005	581
2.09918	882	2.32603	520
2.13387	112	2.3373	1500
2.15401	626	2.35854	380
2.20456	200	2.36385	2709
2.20832	775	2.37077	1032
2.31395	624	2.39514	3002
2.38515	1153	2.40985	112
2.39731	453	2.41614	178
2.51321	655		

- Estimated count for 150 second integration
- >100 counts : 35 >400 counts : 18 >500 counts : 15 >1000 counts : 7



Calunit design

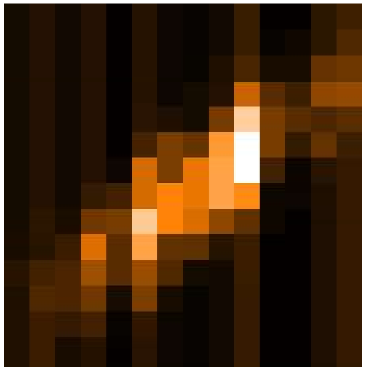
- The KMOS calunit allows efficient daytime calibration
- The uniformity pixel-to-pixel across the field is excellent at <0.1%
- Variation in illumination will occur with arm position
- Final calibration of KMOS will be from a combination calunit flats
  - illumination correction via sky flats
  - scaling of the OH lines to remove residuals (Davies 2007, in press)



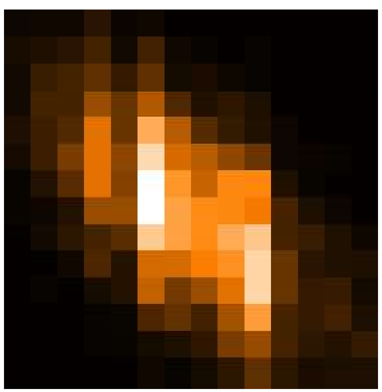
Kmo_bias_ron
Kmo_dark
Kmo_flat
Kmo_spec_align
Kmo_wave_cal
Kmo_illumination
Kmo_std_star
Kmo_sci_red
Kmo_rtd_image
DARK
DARK
FLAT on/off
SLITMASK
ARC on/off
SKYFLAT
STD
SCIENCE
SCIENCE
master dark
bad pixel mask
master bias & read-out noise
bad pixel mask
dark current
master flat
spectral curvature & slitlet alignment
arc lamps line lists
sky line lists
wavelength calibration
illumination correction
model atmospheric transmission
solar spectrum
spectral type LUT
telluric correction & flux calibration
science products
reconstructed image for RTD
Kmo_dark
Recipe
DARK
Raw file type
master dark
Calibration product
dark current
Calibration product (QC only)
bad pixel mask
Intermediate calibration product
arc lamps line lists
External calibration product
Processing
Product match

Testing the calibration scheme and pipeline: End-to-end modelling

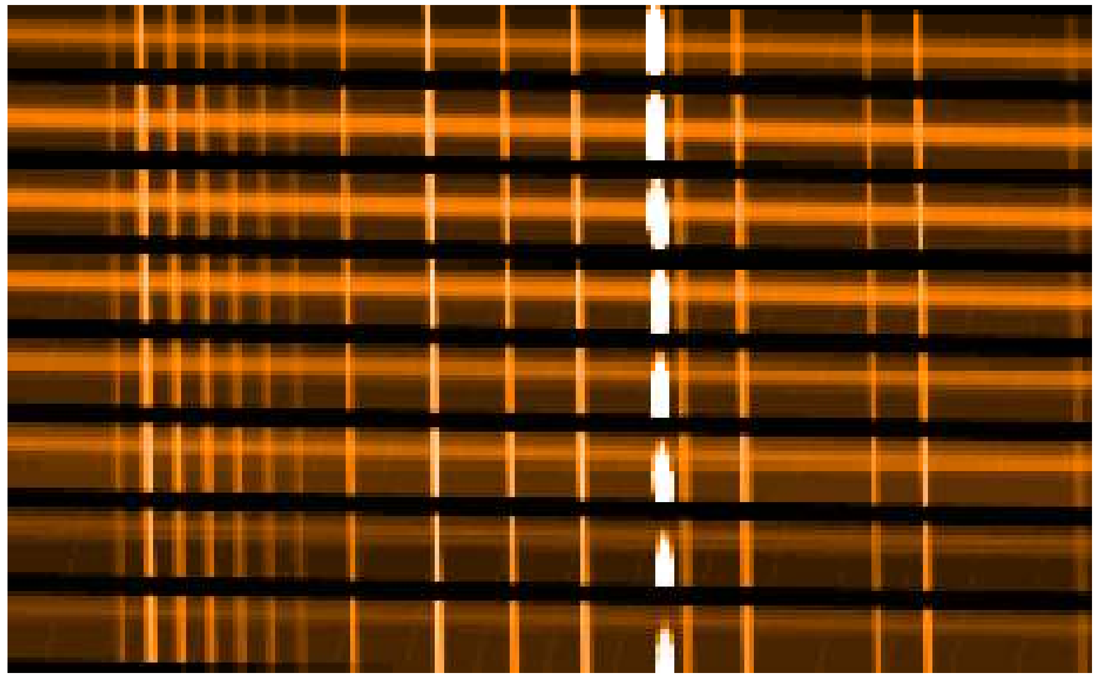
A development of SPECSIM for JWST-MIRI (Lorente)



- white light image



- emission line image



- Section of the spectral image