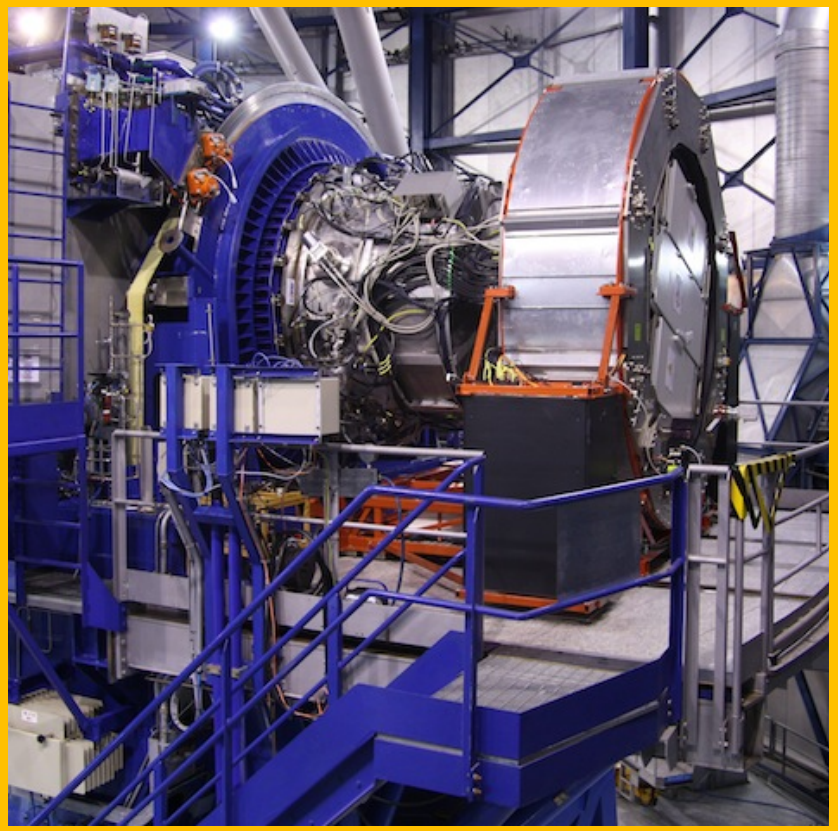


KMOS Pipeline Tutorial

Alex Agudo Berbel, Ric Davies, Erich Wiezorrek

24.07.2013

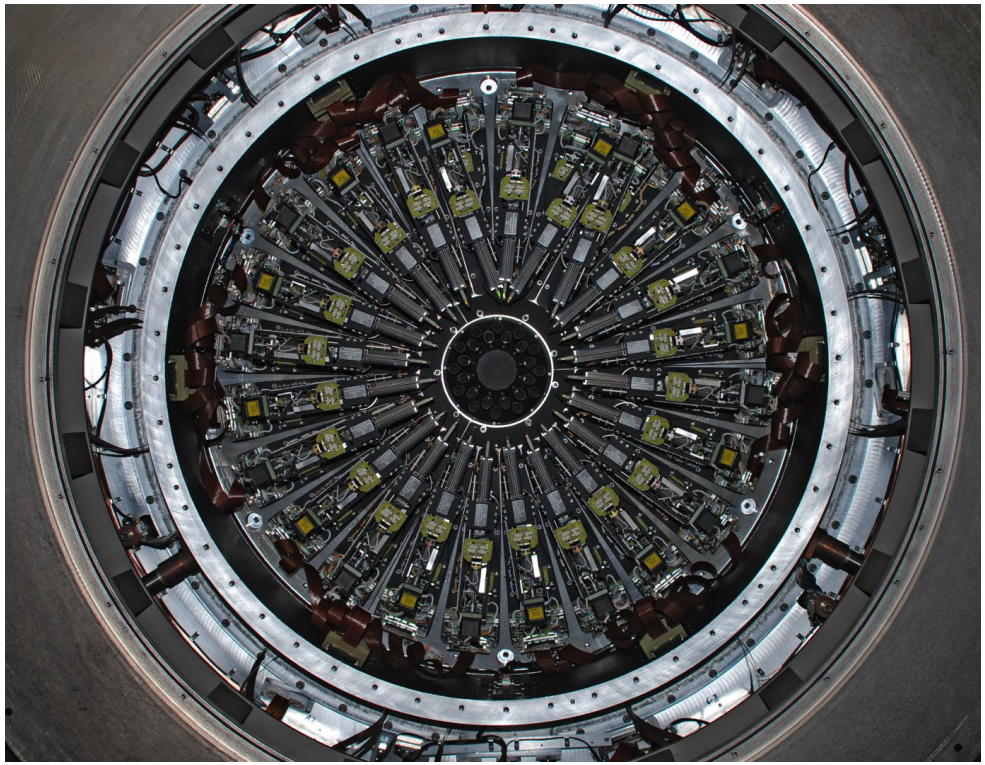
CONTENTS

- **KMOS: K**-band **M**ultiple-**O**bject cryogenic integral field **S**pectrograph designed for intermediate resolution spectroscopy in the 0.8-2.5μm range

- First of its kind at a 8m class telescope
  - Similar project: SINFONI (single IFU)

- 24 robotic pickoff arms patrol a 7.2 arcmin diameter field each of which feeds 2.8x2.8 arcsec FoV sampled at 0.2 arcsec to an image slicing IFU

- The IFUs are consolidated in groups of 8 which feed one of 3 identical spectrographs providing R~3500 spectra in the H, HK, IZ, K & YJ bands



Key Specifications

General

- Rotating Mass 2.4 t
- Total Mass 9.5 t
- Operating temperature -140 °C
- Optical Throughput ~30%

Hardware

- 24 robotic pick-off arms
  - arranged in 2 layers
  - divided into 3 sections
- 3 spectrographs
- 3 Hawaii-2RG detectors 2048 x 2048 pix

Field of View, Resolution

- Telescope Patrol Field 7.2 arcmin
- IFU
  - FoV 2.8 arcsec
  - Size 14 x 14 pix
  - Pixel size 0.2 arcsec

Timeline

- Kick-off: 04.2004
- Final Design Review 07.2007
- Prelim. Acceptance Europe 04.2012
- 1st commissioning 11.2012
- 2nd commissioning 01.2013
- 3rd commissioning 03.2013
- 1st science verification 06.2013
- 2nd science verification 09.2013

Wavelength

Total range **0.78 µm - 2.5 µm**

- H-band: 1.425 - 1.867 µm
- HK-band: 1.460 - 2.410 µm
- IZ-band: 0.780 - 1.090 µm
- K-band: 1.925 - 2.500 µm
- YJ-band: 1.000 - 1.359 µm

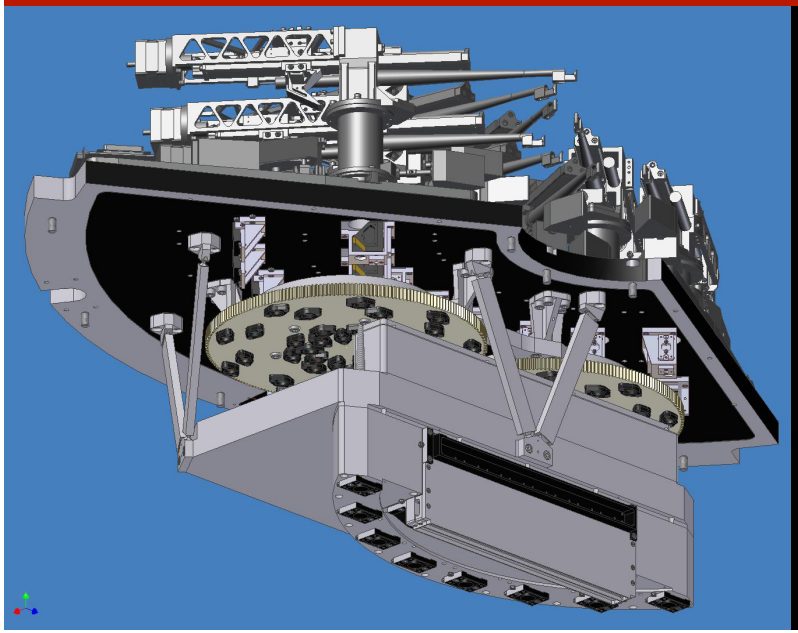
Spectral resolution

- H-band: R~4000
- HK-band: R~1900
- IZ-band: R~2800
- K-band: R~4100
- YJ-band: R~3400

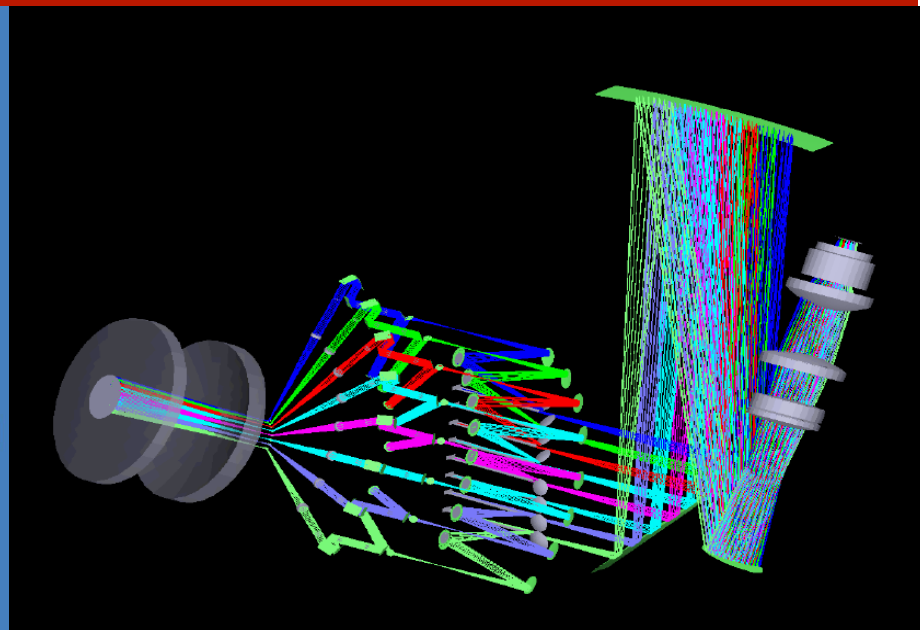
Optical throughput

	Hip039102	HIP054804
• K-band:	22 ± 1.5%	21.7%
• HK-band:	23 ± 1.4%	23.3%
• H-band:	23 ± 1.9%	22.9%
• YJ-band:	16 ± 1.3%	16.9%
• IZ-band*:	11 ± 1.0 %	9.1%

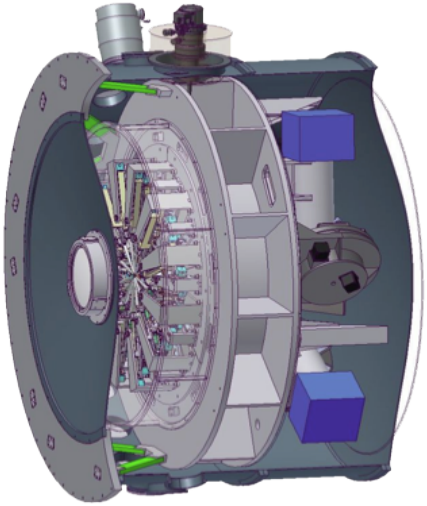
Inside KMOS



Pick-off arms, filter wheels, IFUs



Light path through the system (for 8 arms)

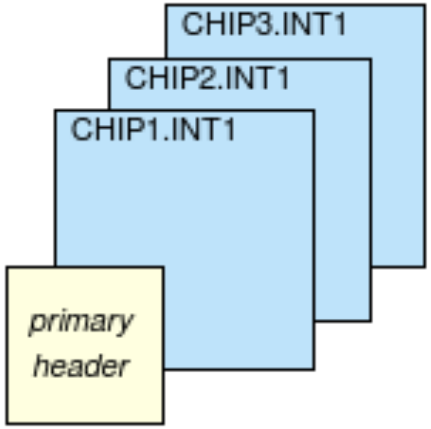


Pick-off arms, IFUs, spectrographs

Single pick-off arm

Set of mirrors (for 8 arms)

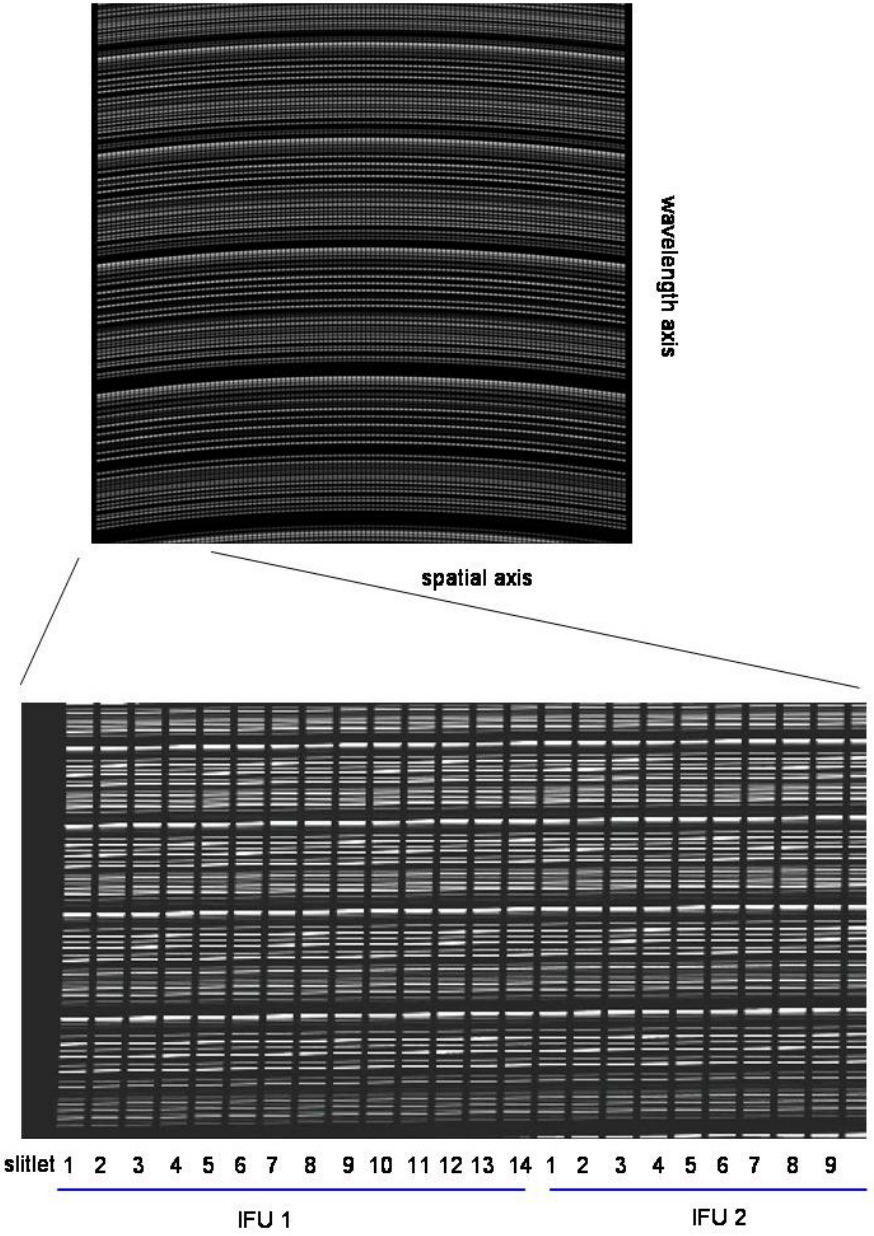
RAW detector frames



- Primary Header
  - Empty data section
- 3 data extensions

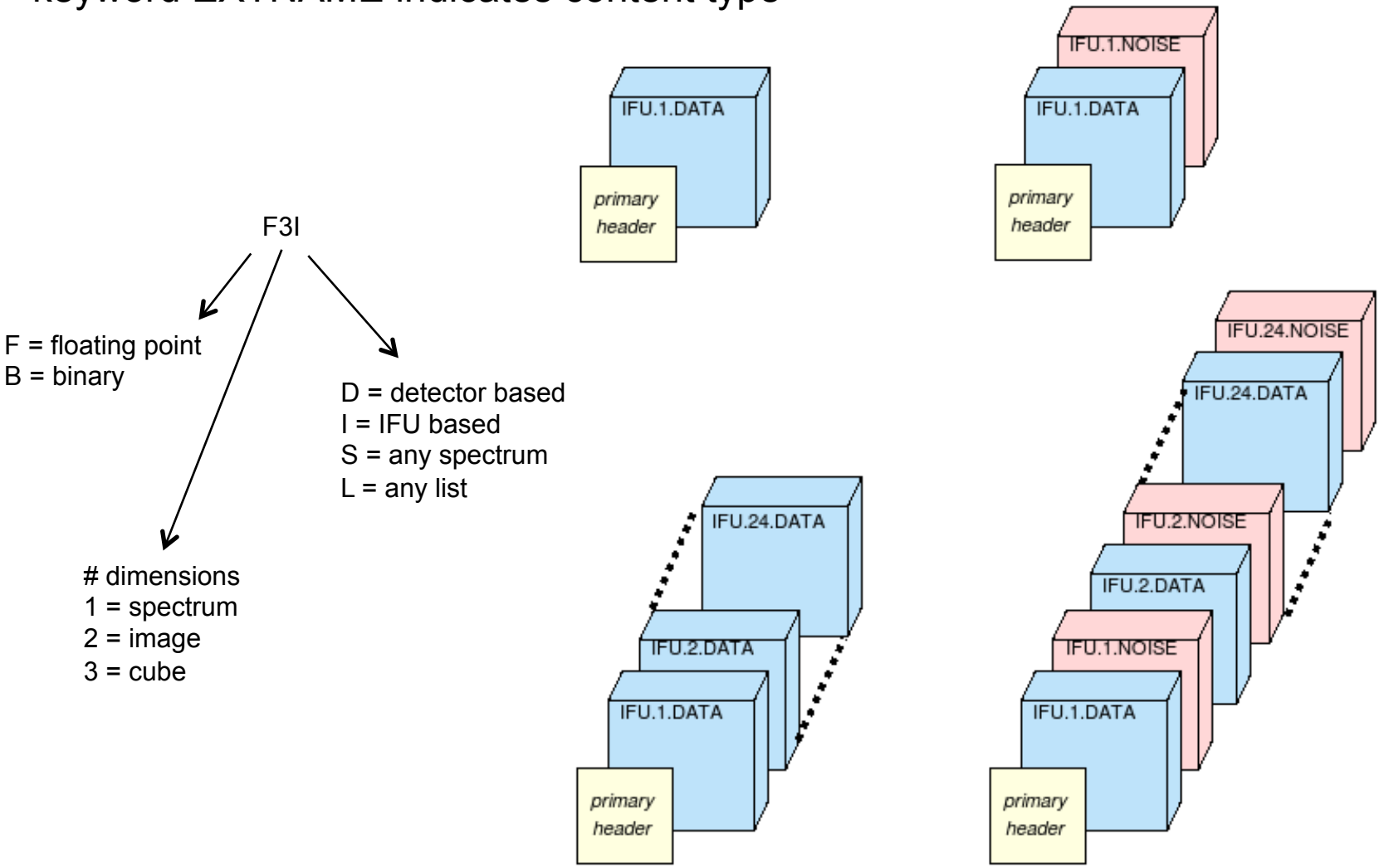
- 8 IFUs per detector
- Each IFU sliced into 14 slitlets, 14 pix width
- Each slitlet is a dispersed pseudo-longslit, 2040 pix length

- Exposure size: 48 MB
- 4 pix border around each frame reserved for detector readout electronics

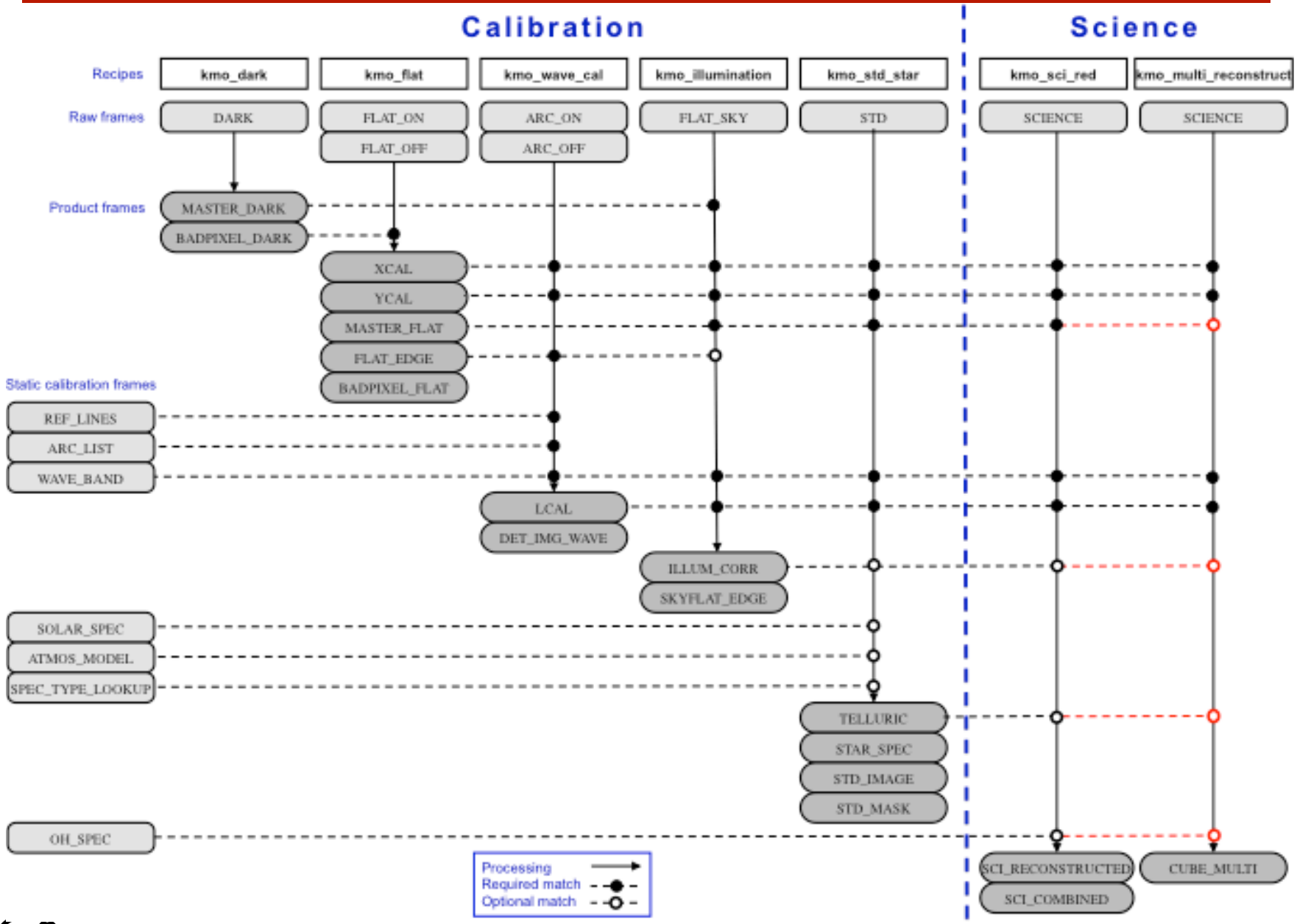


Processed frames

- Spectra, images, cubes are in extensions
- As a rule there are 1, 2, 24, or 48 extensions
- keyword EXTNAME indicates content type

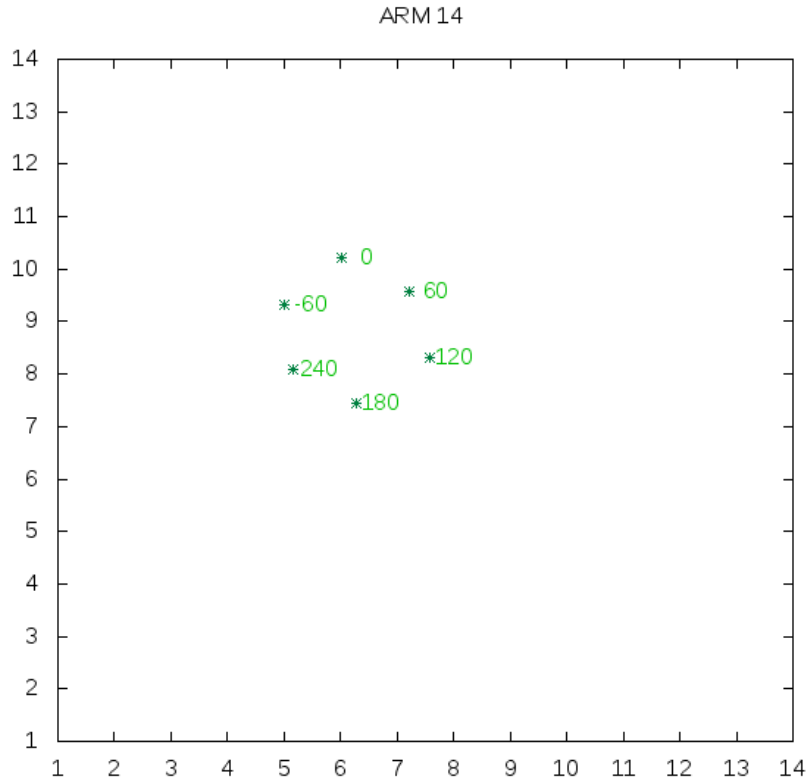


Calibration Cascade



Flexure

- Calibrations are done at 6 rotator angles (0, 60, 120, 180, 240, 300 deg)
- Experiment: Measuring Flexure
  - Place LED in the middle of the IFU
  - 6 exposures at different rotator angles
  - Reconstruct & measure centers



→ Whole instrument sags by a few microns wrt the optical axis

Calibration multitude

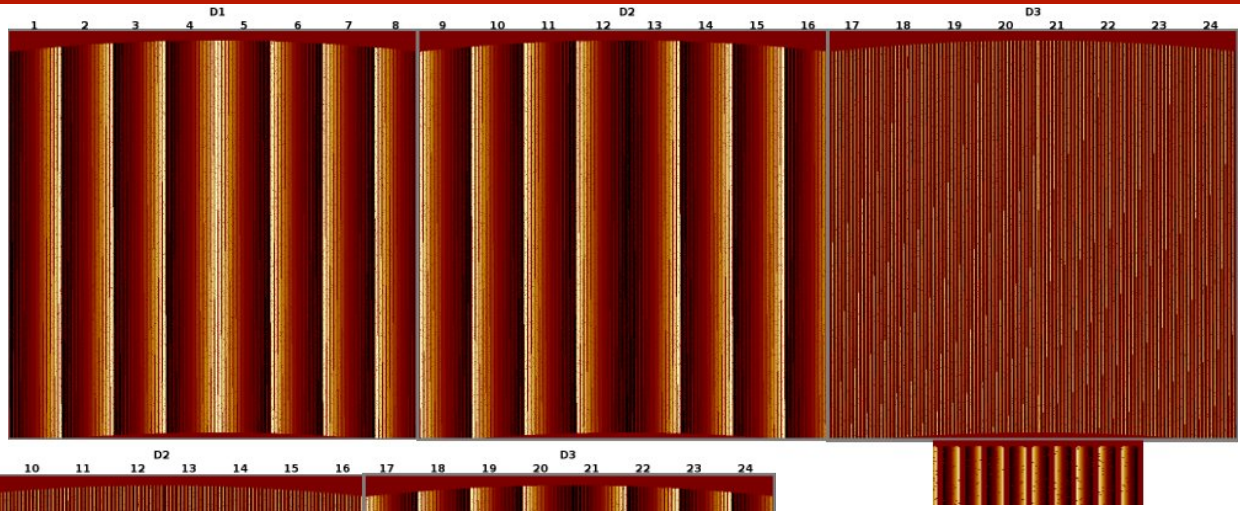
- 6 rotator angles @ 5 bands

→ 5 sets of dynamic calibration frames:
BADPIXEL_DARK
BADPIXEL_FLAT
FLAT_EDGE
LCAL
MASTER_DARK
MASTER_FLAT
XCAL
YCAL

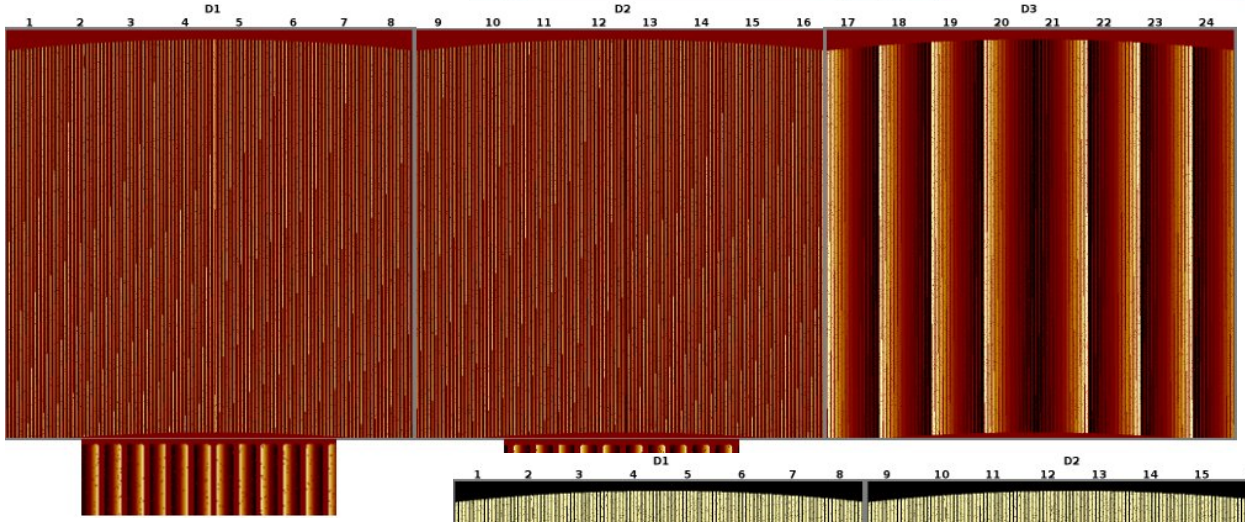
→ Static frames:
ARC_LIST
ATMOS_MODEL
OH_SPEC
REF_LINES
SOLAR_SPEC
SPEC_TYPE_LOOKUP
WAVE_BAND

→ 8.8 GB calibration data for 55 files

kmo_flat

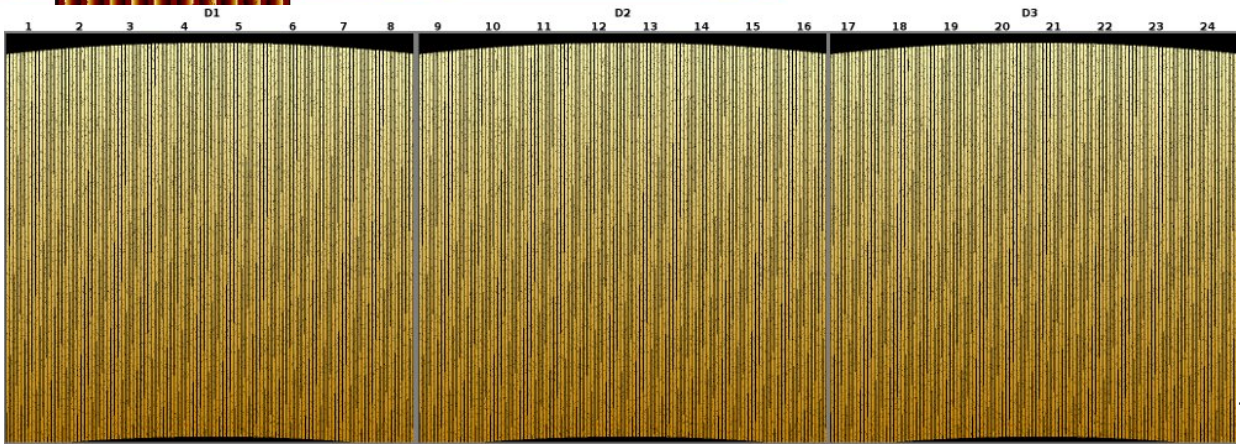


XCAL frame



YCAL frame

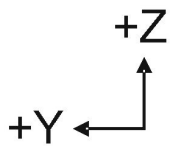
kmo_wave_cal



LCAL frame

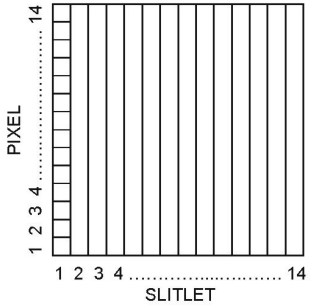
- Every 4 IFUs have a different orientation on the detector
- Calibration frames (as well raw frames) therefore miss a certain regularity

ON SKY

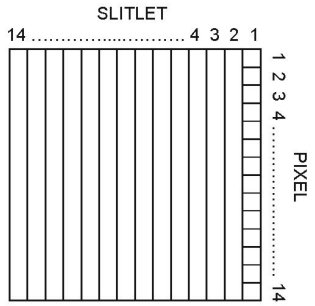


+Z corresponds to North and +Y to East when rotator offset angle is zero

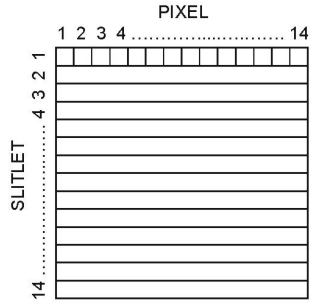
IFUs:
1, 2, 3, 4, 13, 14, 15, 16



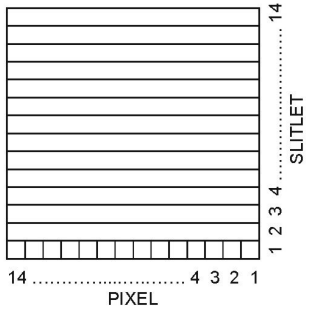
IFUs:
5, 6, 7, 8, 9, 10, 11, 12



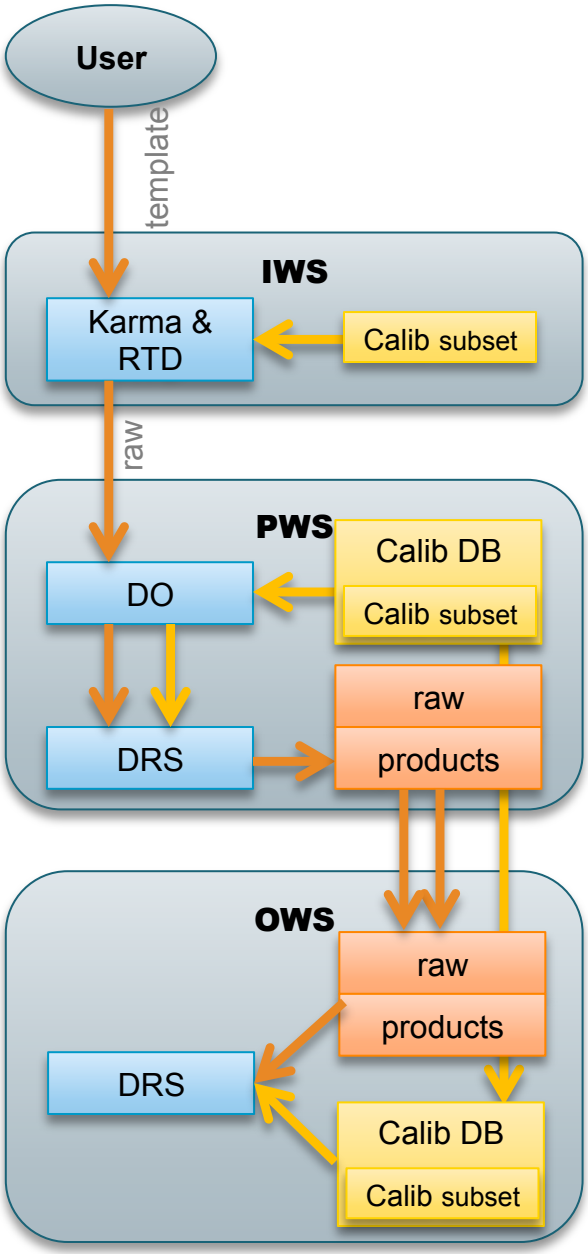
IFUs:
17, 18, 19, 20



IFUs:
21, 22, 23, 24



Observation workflow at VLT / Updating calibration frames



- User prepares OBs
- OBs are executed on IWS
- Exposures are sent to PWS
  - processed automatically with DO and static Calib DB
  - raw and product frames are archived (renamed):
    `master_flat.fits`
    will become
    `KMOS.2012-06-12T10:19:39.553.fits`
- Raw and product frames are copied to OWS
- On OWS observer can already do his own calculations or data reduction

Updating calibration data for KMOS

Standard workflow

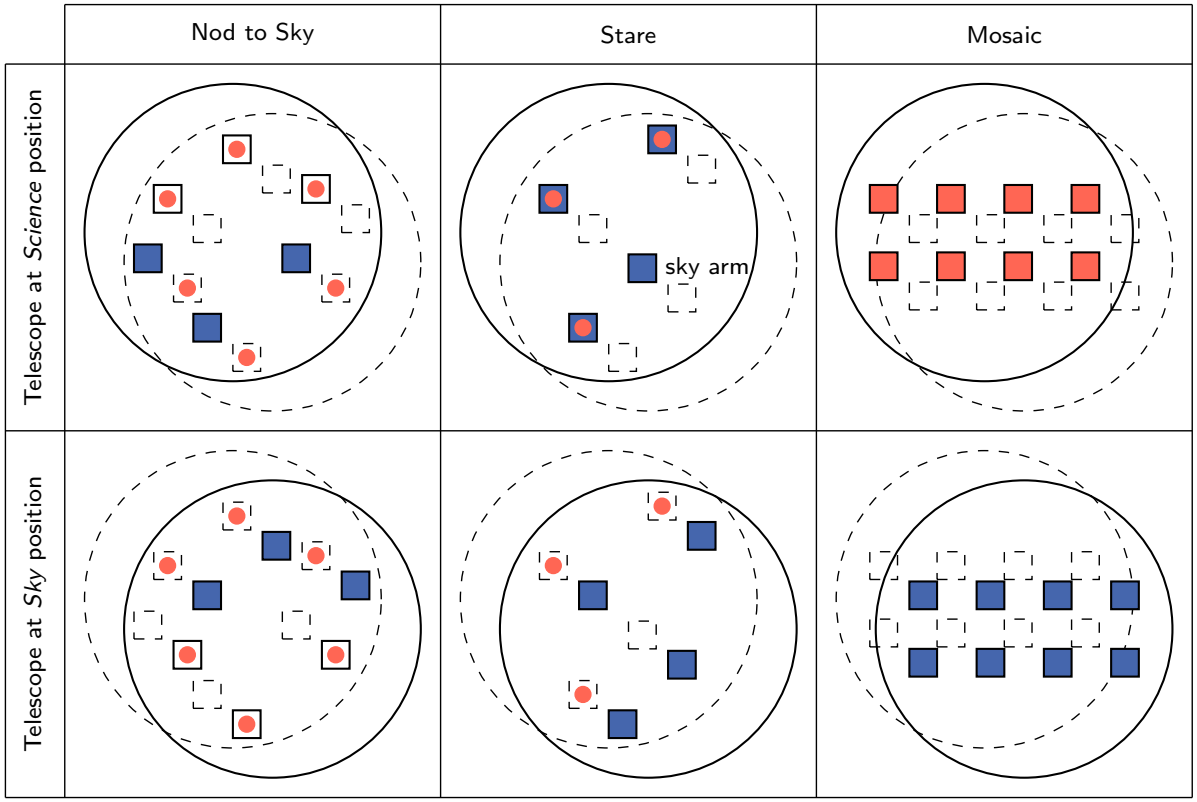
- Normally QC creates new calibration frames
- To be transferred and installed at Paranal

KMOS workflow

- Due to large size of calibration data, it is generated directly at Paranal (and therefore isn't part of the kmos-kit)

IWS:	Instrument Workstation
PWS:	Pipeline Workstation
OWS:	Offline Workstation
Karma:	OB Preparation Tool
RTD:	Real Time Display
DO:	Data Organizer
DRS:	Data Reduction Software
Calib DB:	contains line lists etc AND a static set of calibration files

3 Observation Modes



Nod to Sky

- Sky is obtained by moving telescope/rotating instrument
- Each IFU has its “own” sky
- Arm configuration remains unchanged
- Objects in Science AND Sky-Exposure

Stare

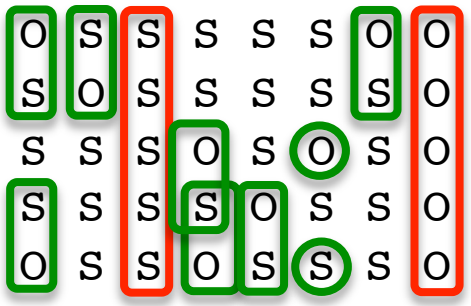
- Less frequent sky exposures (limit: One sky, many object exposures)
- May be possible to use Sky from dedicated IFUs

Mosaic

- Mapping 8 IFUs (4x2)
  - 9 exposures
  - 72 IFUs combined
  - 16x33 arcsec field
- Mapping 24 IFUs (6x4)
  - 16 exposures
  - 384 IFUs combined
  - 43x65 arcsec field
- Plus one sky exposure

The DO implemented in ESO software can't handle KMOS specific object/sky exposures objects and skies intermixed in one frame

Input frames



IFU #	1	2	3	4	5	6	7	8	Timestamp in "DATE-OBS" keyword
Frame 1	O	S	S	S	S	S	O	O	2011-01-13T01:00:00.0000
Frame 2	S	O	S	S	S	S	S	O	... 02 ...
Frame 3	S	S	S	O	S	O	S	O	... 10 ...
Frame 4	S	S	S	S	O	S	S	O	... 04 ...
Frame 5	O	S	S	O	S	S	S	O	... 05 ...

Output frames

Frame 1	X	.	.	.	.	.	X	.
Frame 2	.	X	.	.	.	.	.	.
Frame 3	.	.	.	X	.	X	.	.
Frame 4	.	.	.	.	X	.	.	.
Frame 5	X	.	.	X	.	.	.	.
IFU #	1	2	3	4	5	6	7	8
	X	X	.	X	X	X	X	.

To be implemented

- Write association table to disk
- Possibility to edit
- Read-in again

Data Handling

Problem:

Lots of exposures with different bands and rotator angles originating from different templates. How to find quickly the needed exposures?

Solutions:

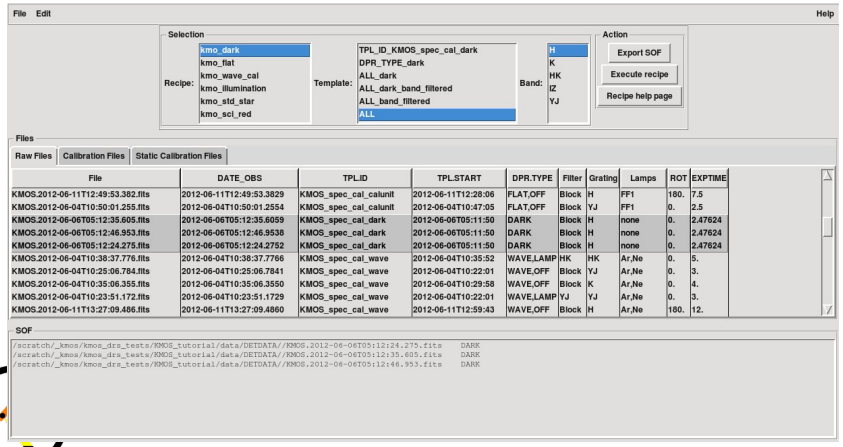
- Either make use of **dfits** and **fitsort**
- or use the **pipelineGUI-tool**
- or use the **easySPARK-scripts**
- or use **Reflex** from ESO → workflow GUI

Pipeline GUI

Aim:

Individual choice of frames to process → GUI

```
$ pipeline-GUI.pl \
                --raw=<data_dir> \
                --cal=<calib_dir> \
                --static=<static_calib_dir>
```



easySPARK-scripts

Aim:

Automated processing of Obs → console

- easySPARK_calibration.sh
  - easySPARK_dark.sh
  - easySPARK_flat.sh
  - easySPARK_wave_cal.sh
- easySPARK_illumination.sh
- easySPARK_std_star.sh
- easySPARK_reconstruct.sh
- easySPARK_sci_red.sh
- easySPARK_multi_reconstruct.sh (to come)

Environment variable KMOS_CALIB has to be defined

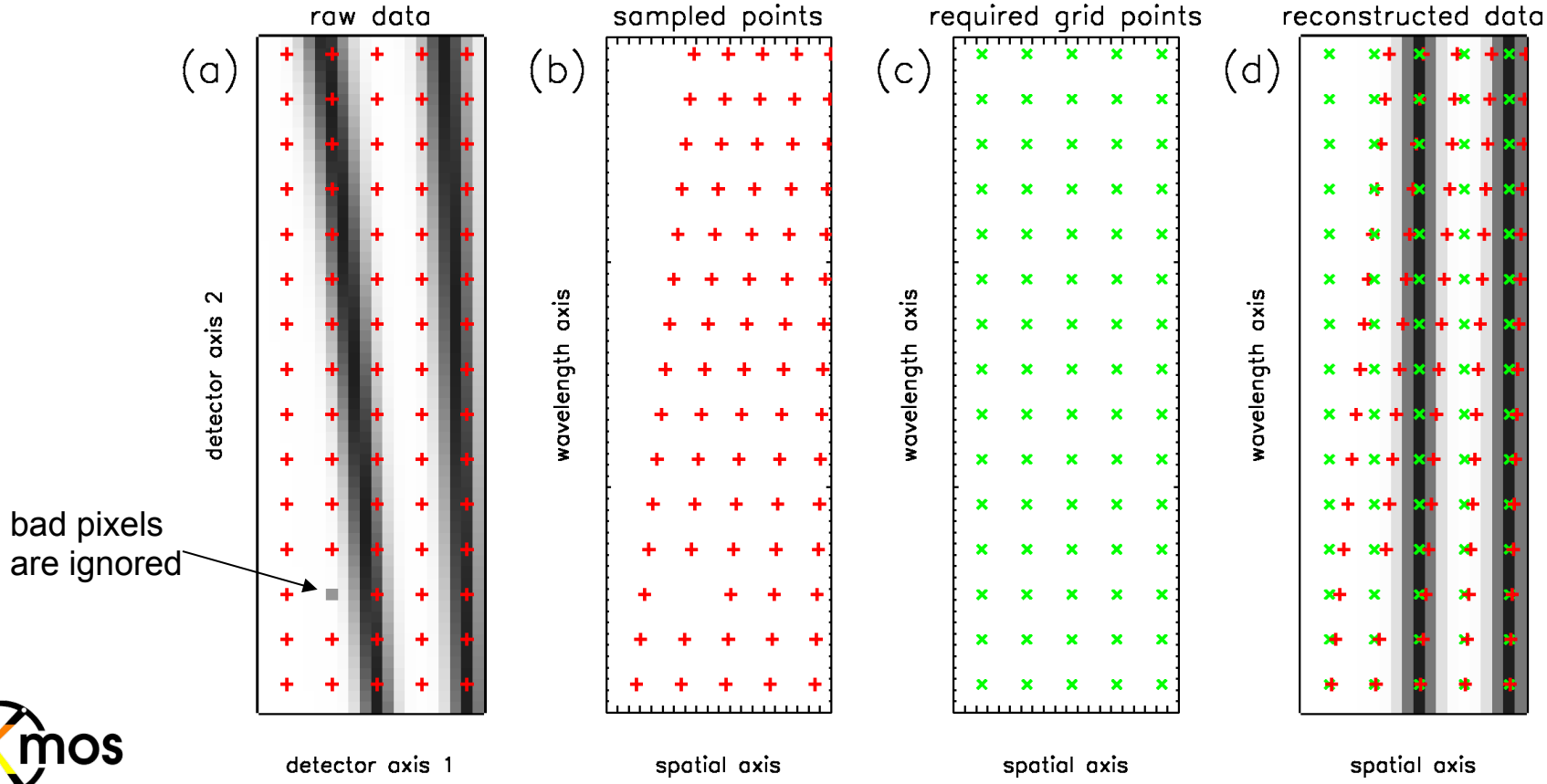
Final frame – *regularly* gridded x,y,λ positions where we want to know data values
Calibration frames – LUTs for *irregularly* spaced x,y,λ of each pixel on detector
Detector frame – data values for these *irregularly* spaced x,y,λ sampling positions

Create a list of sample points so that the data is dissociated totally from the detector frame.
i.e. the observations & calibrations simply give you: $value_0, x_0, y_0, \lambda_0$

...

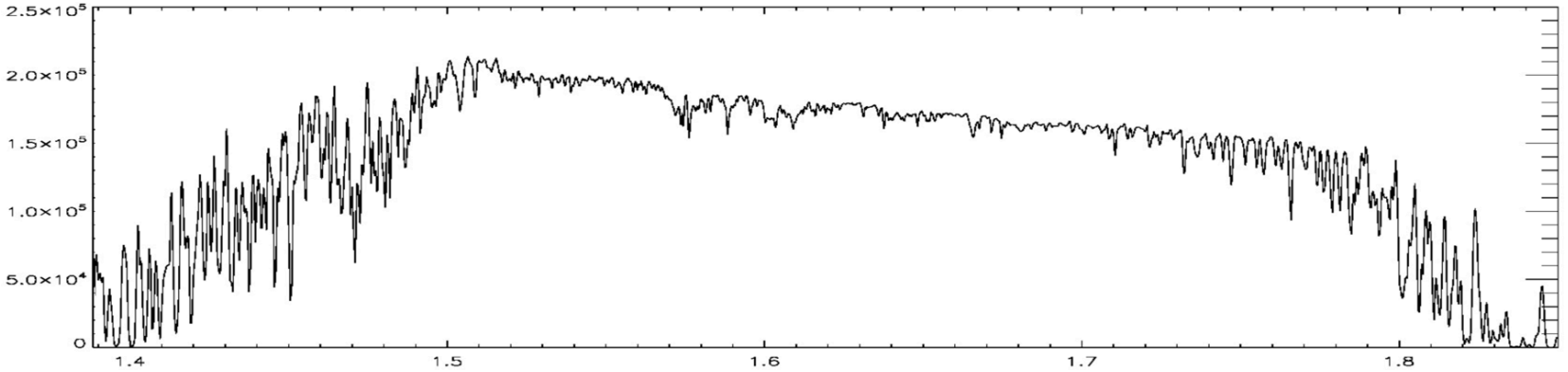
$value_n, x_n, y_n, \lambda_n$

Each point in final frame is interpolated from sampled points in its local neighbourhood

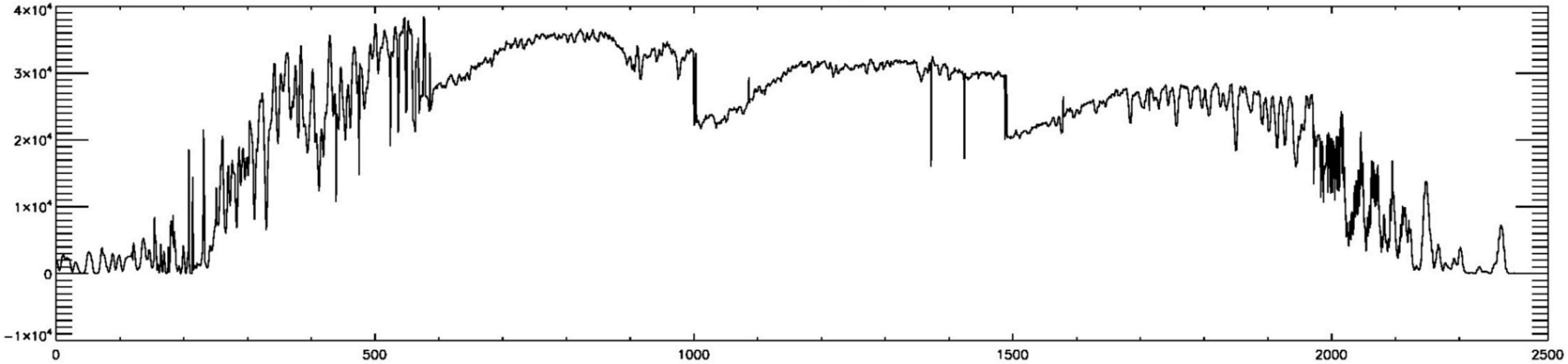


Comparison of Interpolation methods: Spectral Effects

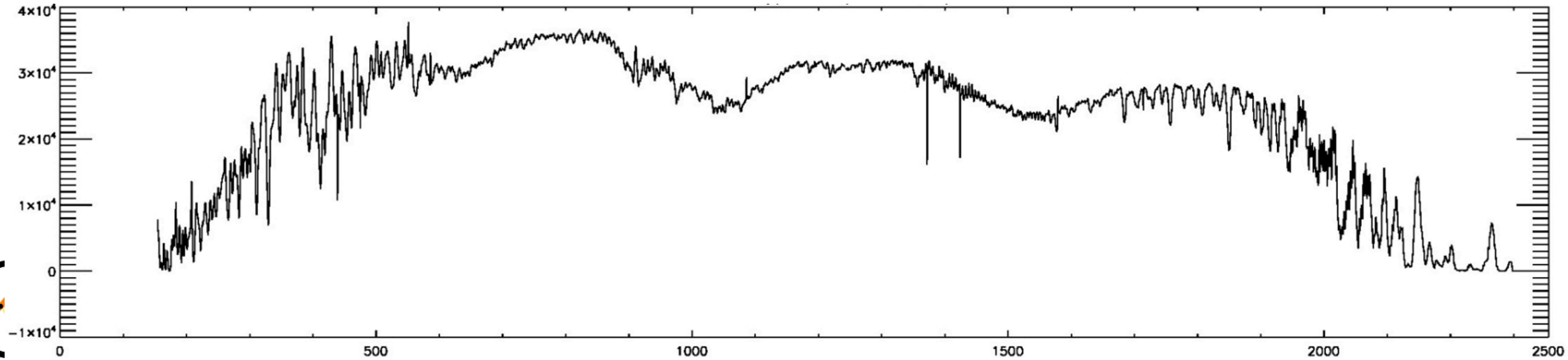
Original spectrum



Nearest Neighbour

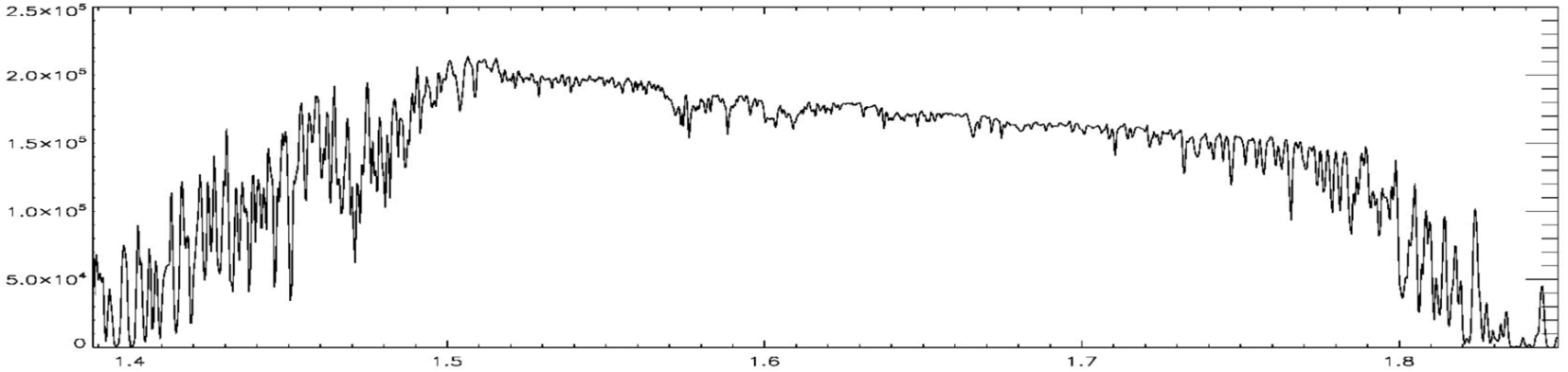


Modified Shepard‘s method

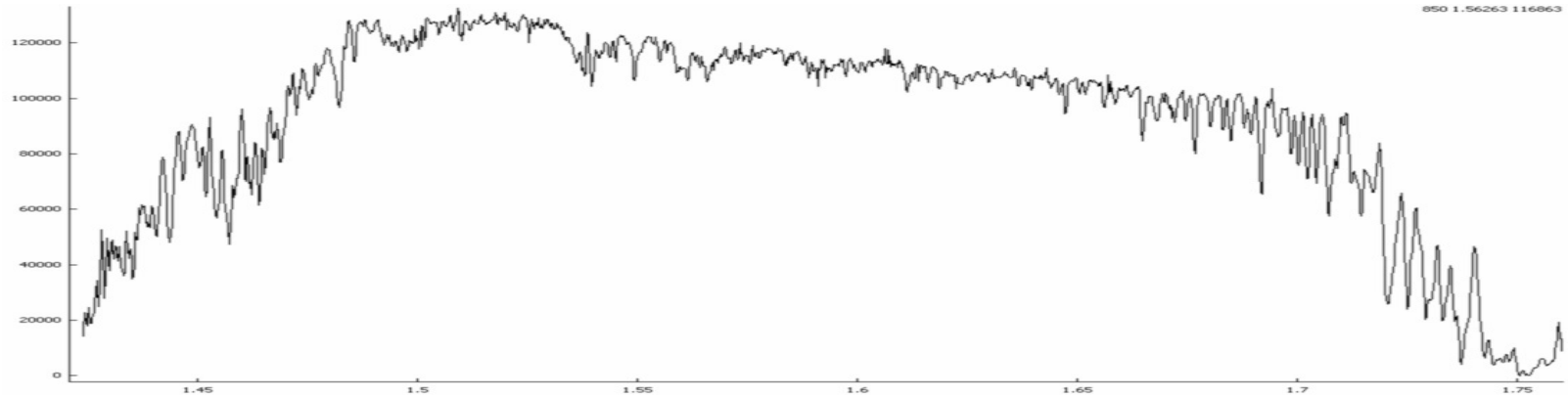


Comparison of Interpolation methods: Spectral Effects

Original spectrum



Cubic spline



Ripples introduced during reconstruction
With CS being less severe than with NN-methods

Can be avoided with better sampling, which provides the kmo_multi_reconstruct recipe

Simple two-step Reconstruction & Combination

- **kmo_sci_red**
  - **kmo_reconstruct**
    - Reconstruct every single IFU separately
    - For every IFU:
      sky-detection and –subtraction
    - Telluric and illumination correction
  - **kmo_combine**
    - All cubes combined together

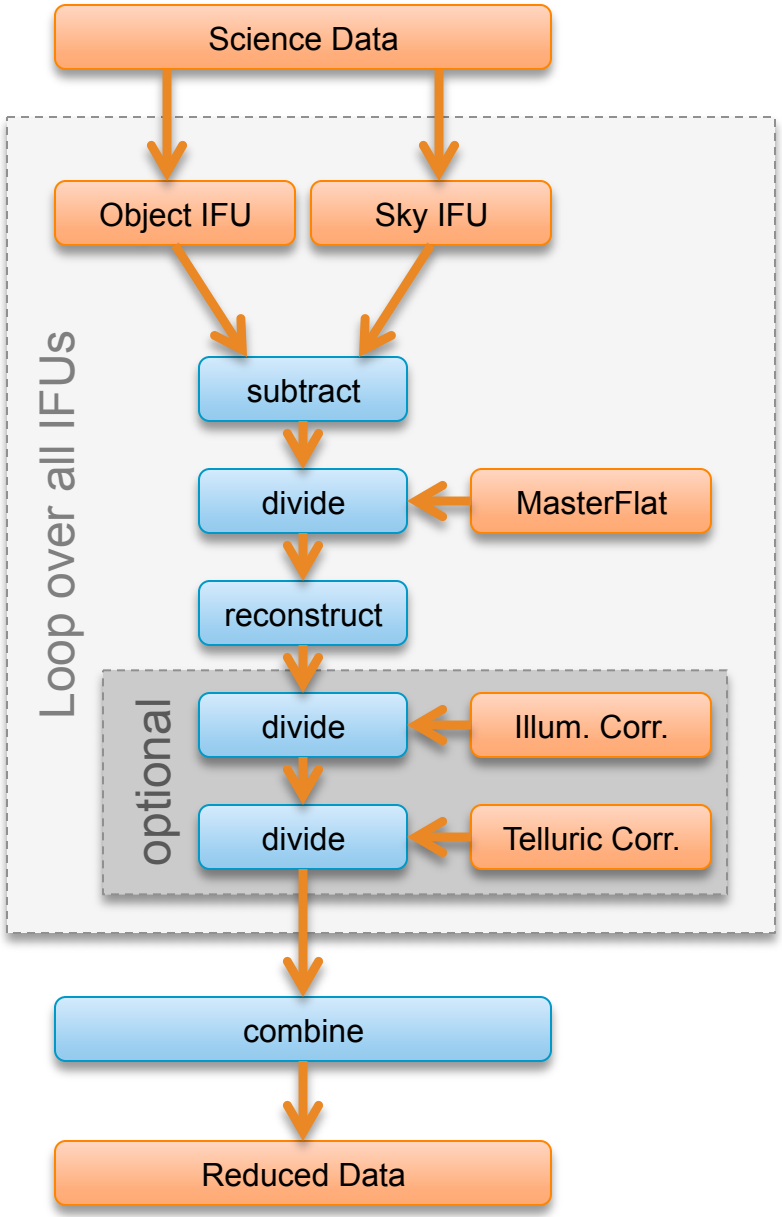
→ Problem: Data is interpolated twice

Advanced Reconstruction & Combination

- **kmo_multi_reconstruct**
  - Calculate shifts (evtl. reconstruct IFUs separately)
  - create Super-LUT
  - Reconstruct all data in one step

→ Solution: Data is interpolated once!

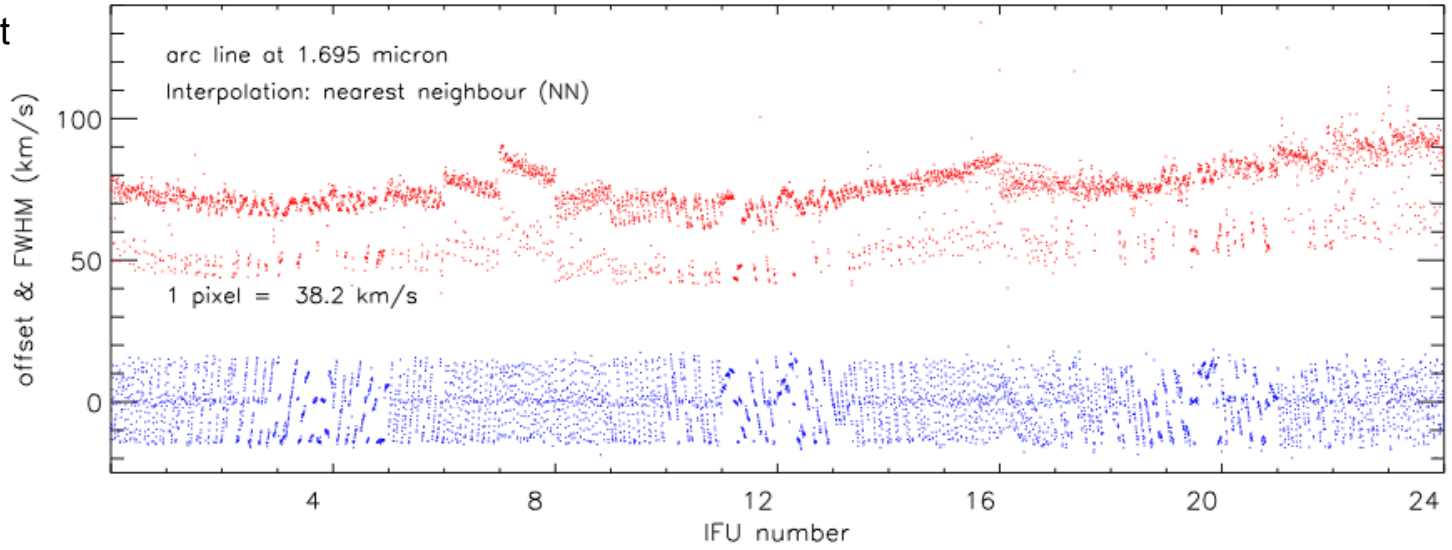
Note: originally this recipe was intended to provide an enhanced reconstruction method. But with angle multitude, angle interpolation etc. it will get the same interface as kmo_sci_red



Nearest neighbour:
Spectral fidelity of an arc-line in the H-band as function of a spatial position across all 24 IFUs

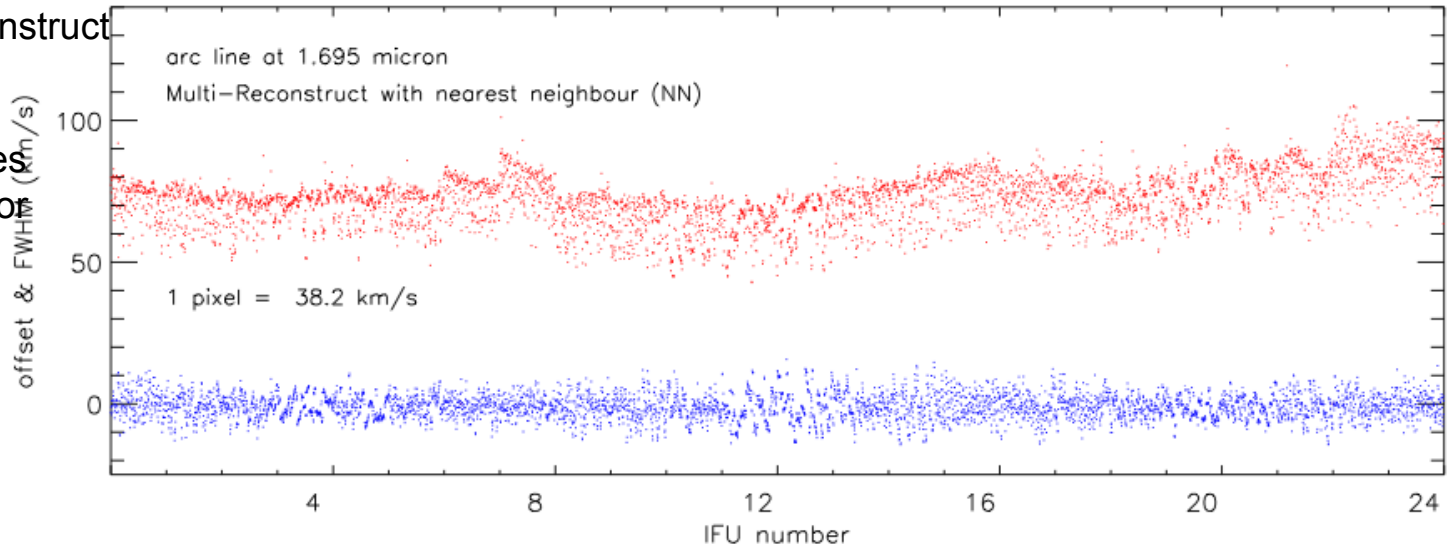
offset of the line from its nominal position (blue) and its FWHM (red)

kmo_reconstruct
RMS: 8.6 km/s



kmo_multi_reconstruct
RMS: 4.5 km/s

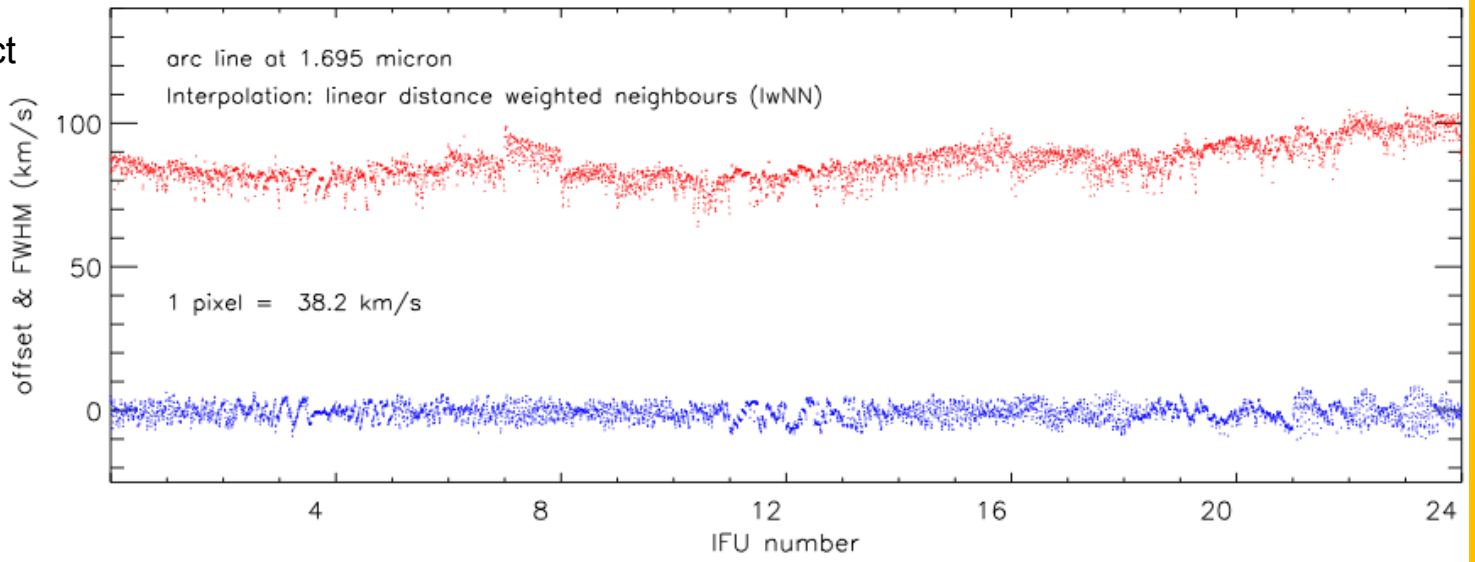
(with 6 exposures at different rotator angles)



Linear weighted Nearest neighbour:
Spectral fidelity of an arc-line in the H-band as function of a spatial position across all 24 IFUs

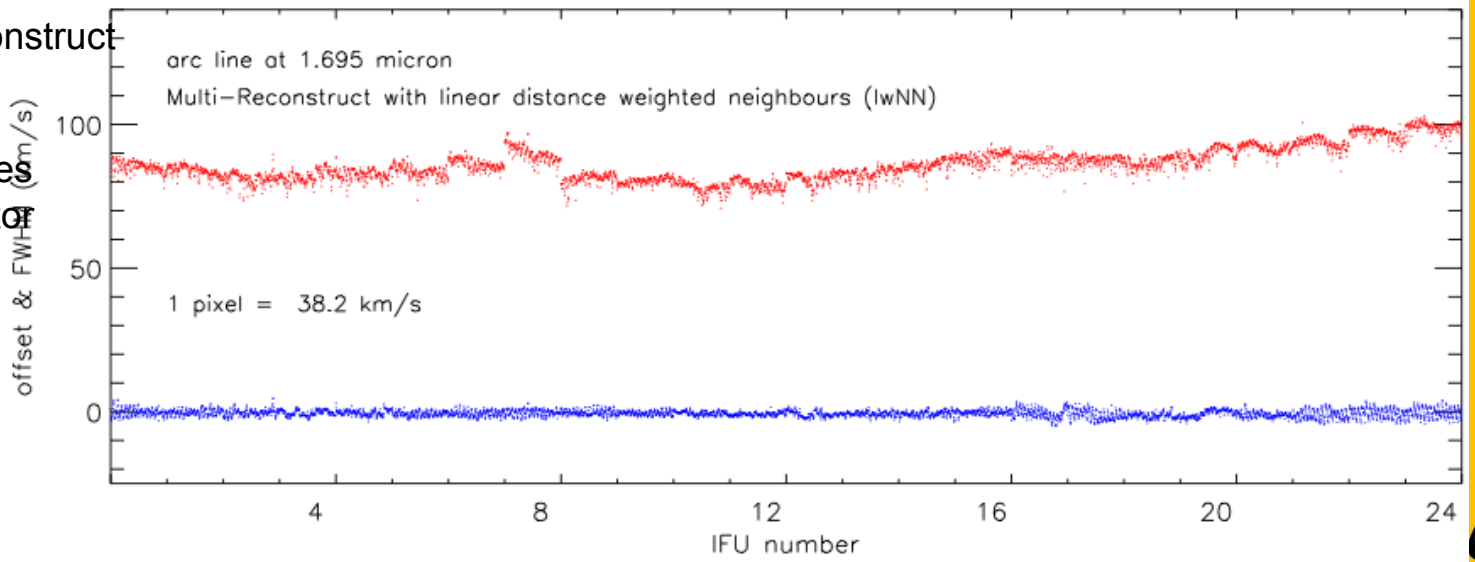
offset of the line from its nominal position (blue) and its FWHM (red)

kmo_reconstruct
RMS: 2.8 km/s



kmo_multi_reconstruct
RMS: 1.2 km/s

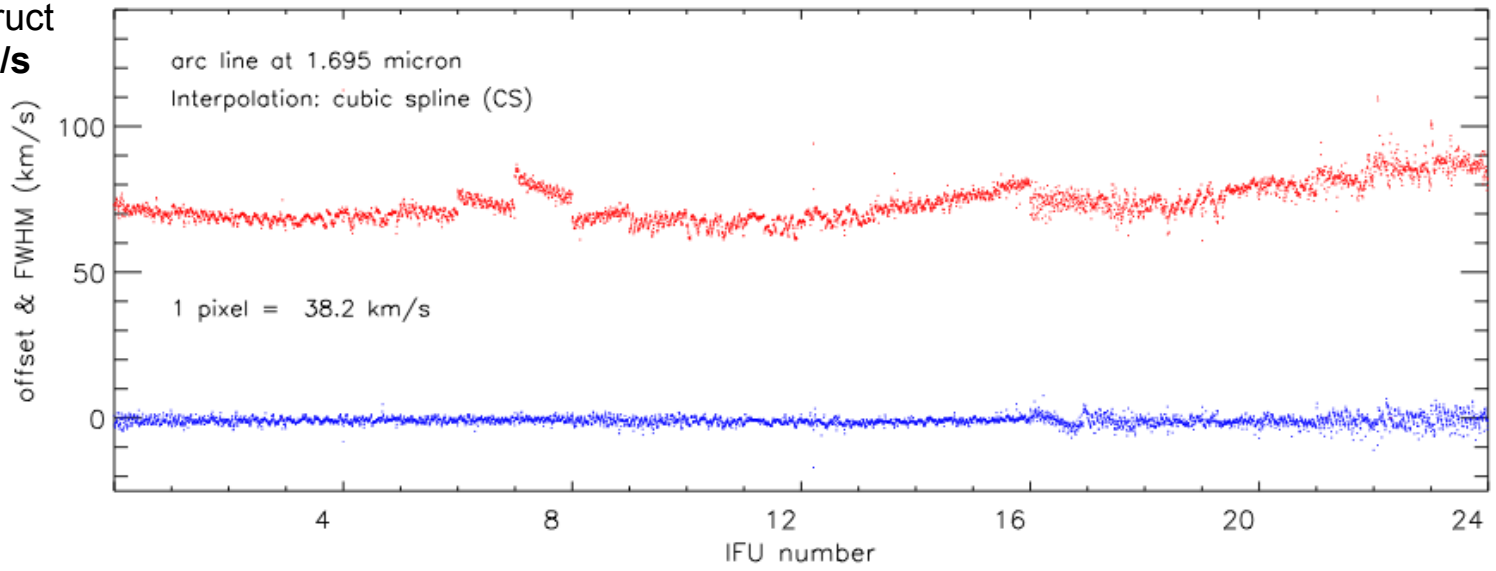
(with 6 exposures at different rotator angles)



Cubic Spline:
Spectral fidelity of an arc-line in the H-band as function of a spatial position across all 24 IFUs

offset of the line from its nominal position (blue) and its FWHM (red)

kmo_reconstruct
RMS: 1.5 km/s



kmo_multi_reconstruct
RMS: -

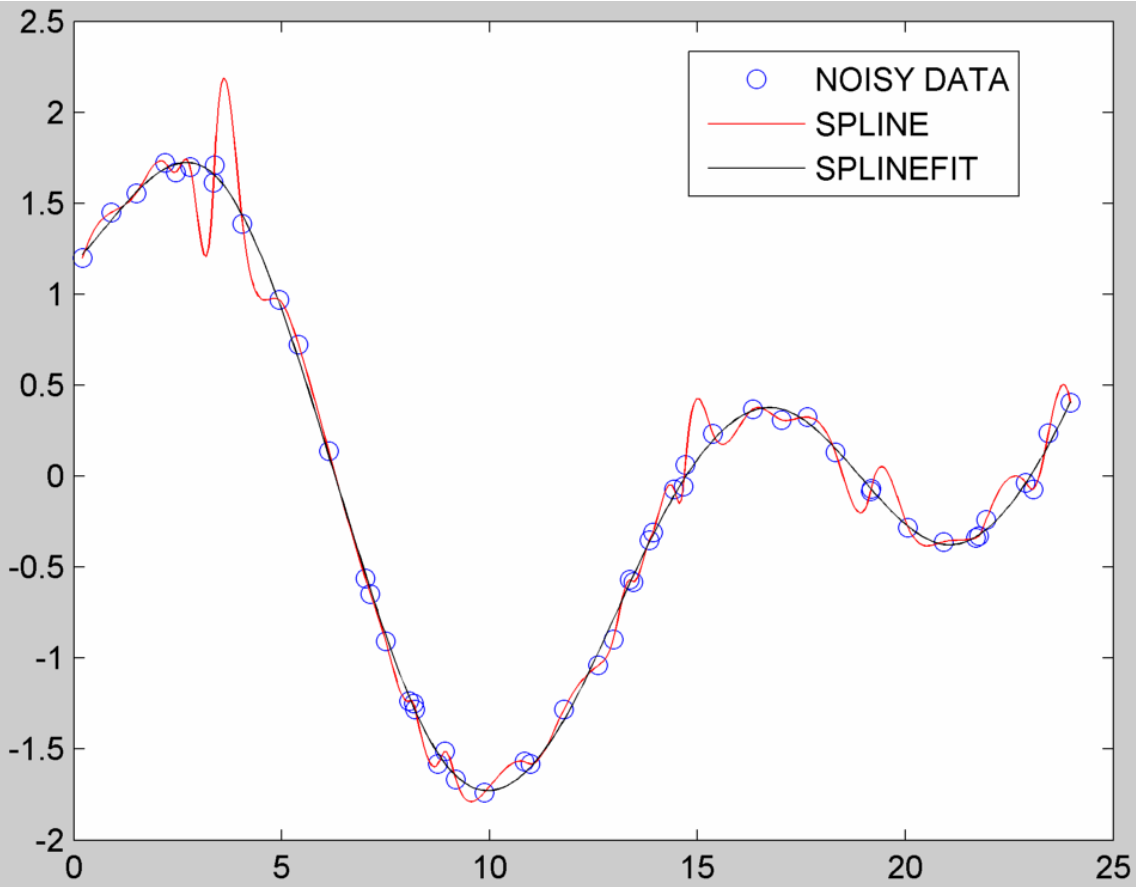
NOT AVAILABLE

Problem

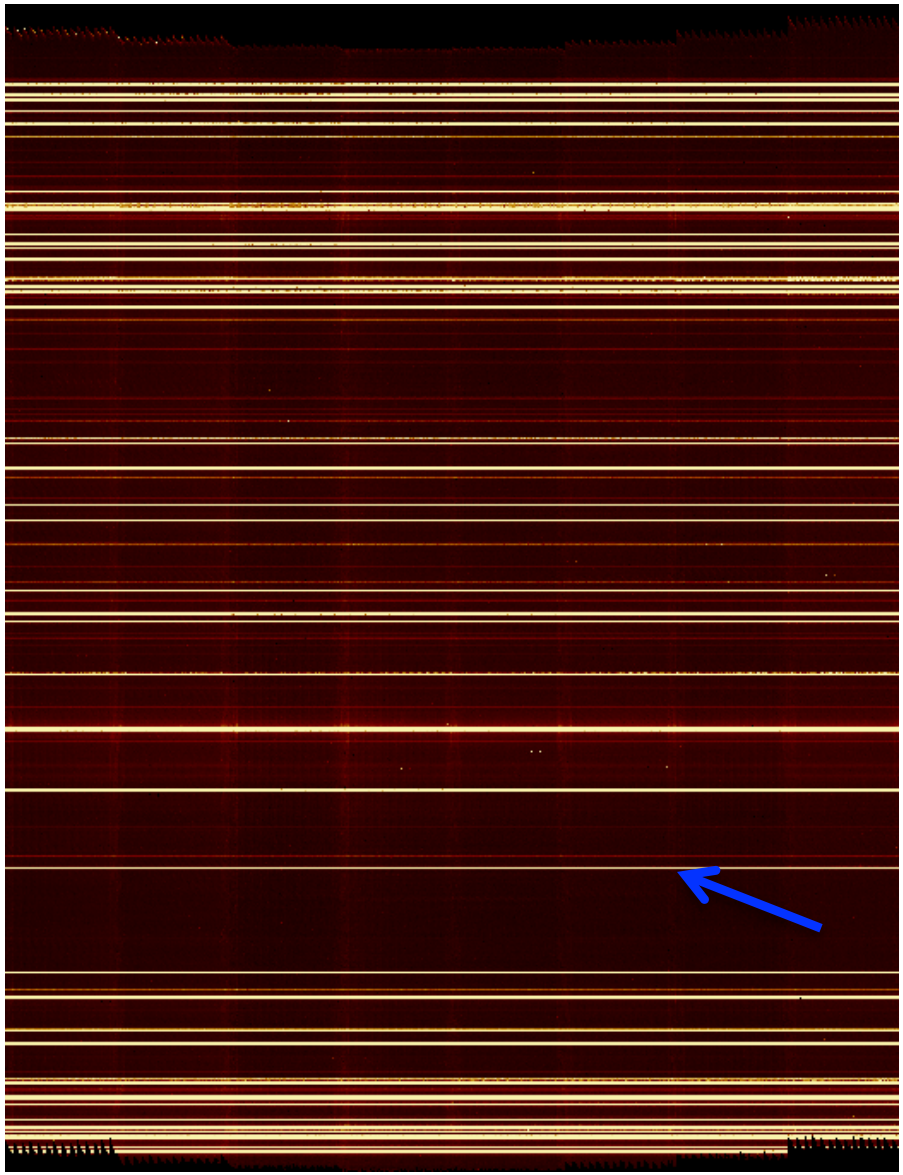
- Opposite to NN-methods, CS isn't weighting, but fitting the values
- If two differing values at same position, the fit will overshoot

Possible solution

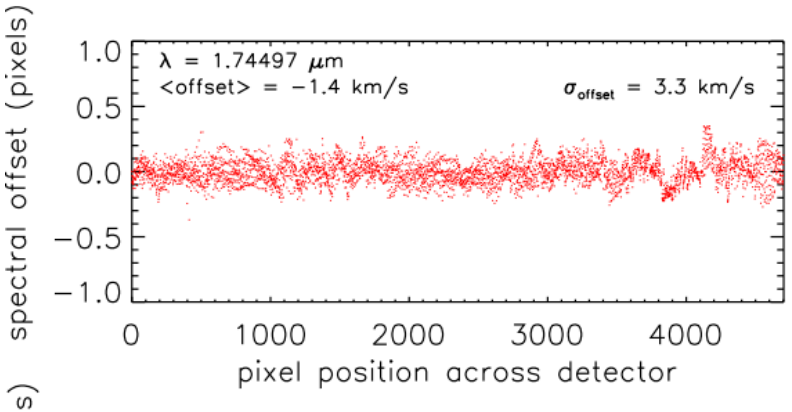
- Reduce degrees of freedom by adding least squares-method (splinefit)

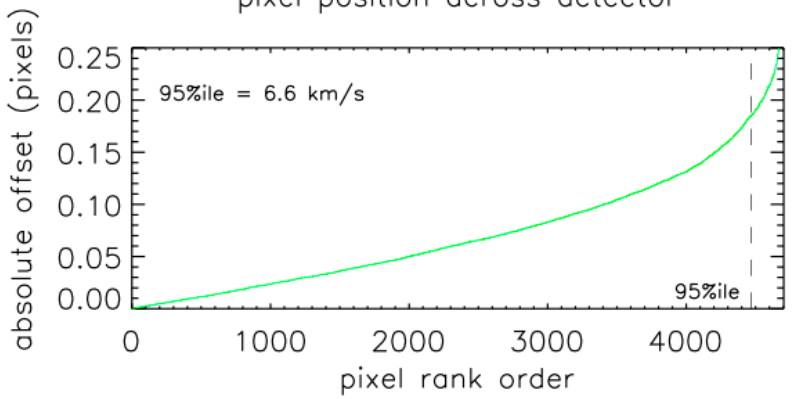


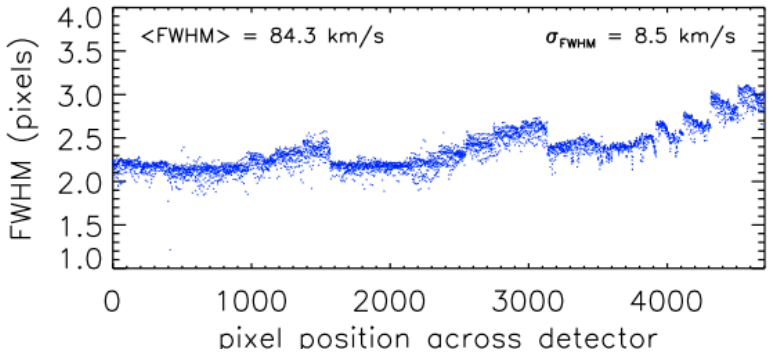
Calibration accuracy: DET_IMG_WAVE



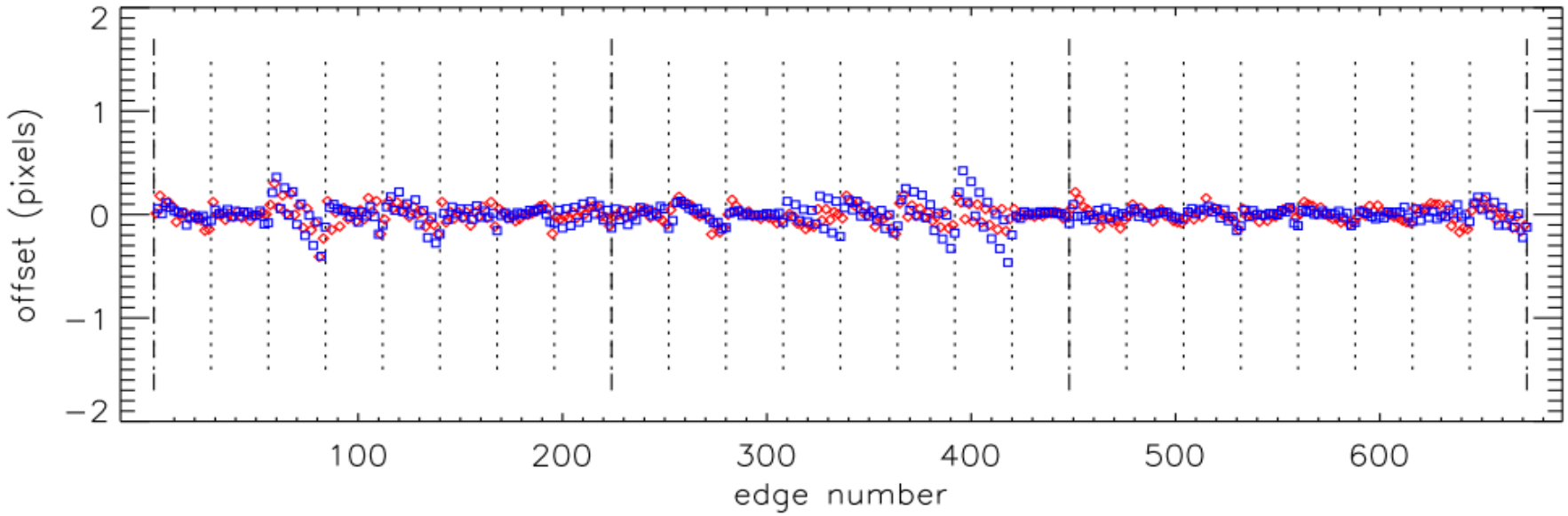
Reconstructed H-band arc frame (lwNN)







Edge Offsets



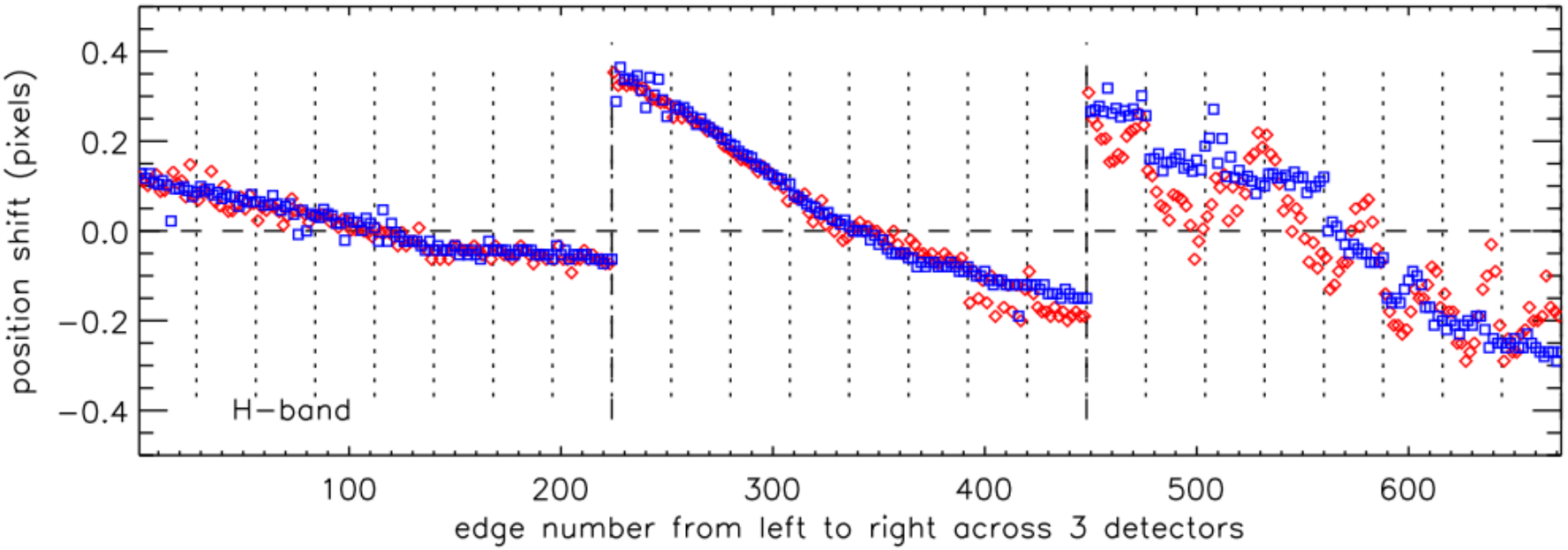
Offsets, derived for each IFU individually, between the measured location of each slitlet edge and its ideal position

(Left edge: red, right edge: blue
Dotted lines separate IFUs, dashed lines detectors)

An offset of 1 pixel is equivalent to 18 µm on the detector

The distinct pattern (e.g. IFU 3) is a direct imprint of the opto-mechanics

Calibration Stability

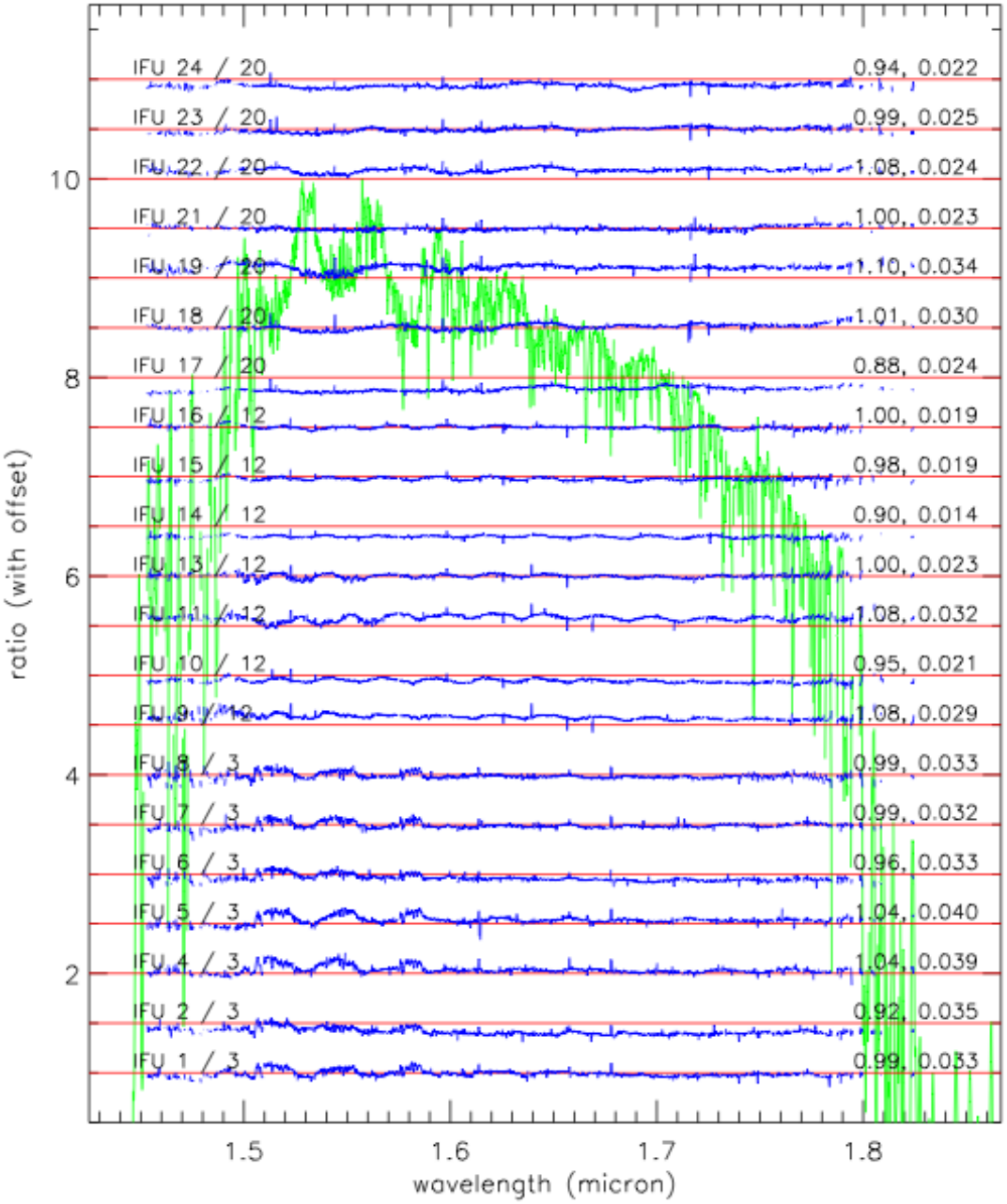


Shifts of slitlet edge positions when measured temperature in cryostat changed by 2 K
(Constant offsets have been removed)

Differential shift of ~0.2-0.4 pixels within a segment, corresponding to a stretch of 0.01-0,02% in the projected size of the pattern

Rule of thumb for calibration frames:
More important than stability in time: stability in temperature
(check e.g. ESO INS TEMP7 VAL)

Standard star templates



Comparison of H-band spectra of the same standard star measured just in IFUs 3, 12 and 20, to spectra of the same star measured in the other IFUs

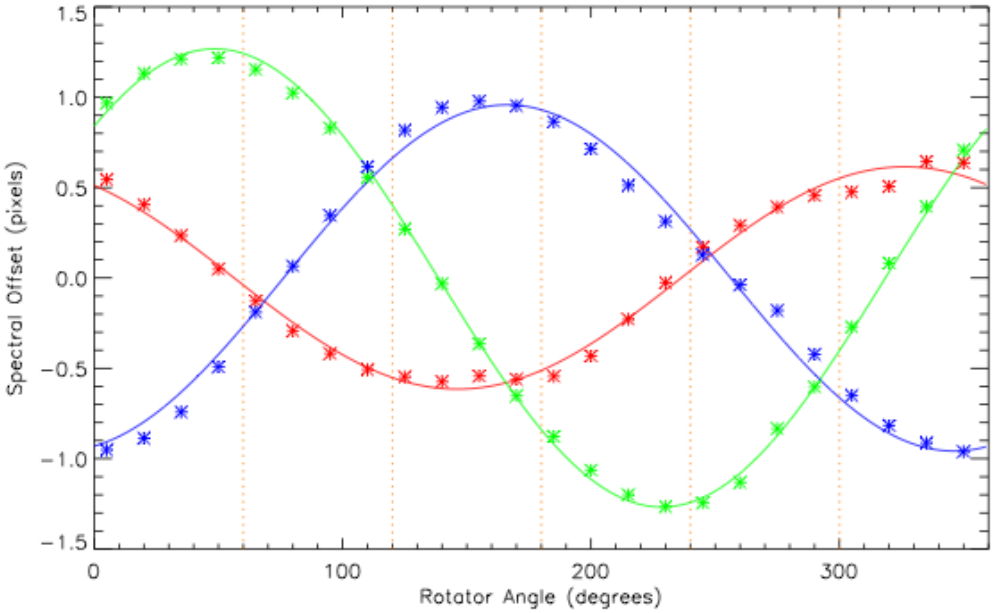
green: H-band spectrum
blue: ratio between 2 IFUs of same detector
red: ratio of 1 for reference

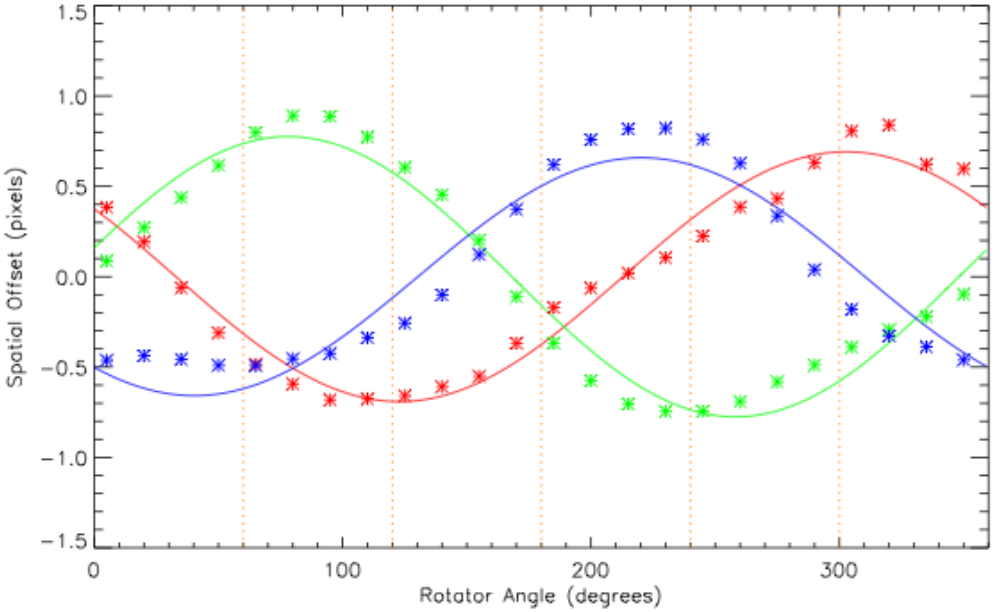
Numbers on the right: mean and stddev

Just using 3 arms to calibrate all IFUs sufficient at the level of precision of few percent

→ gain in time during calibration

Spectral and spatial flexure





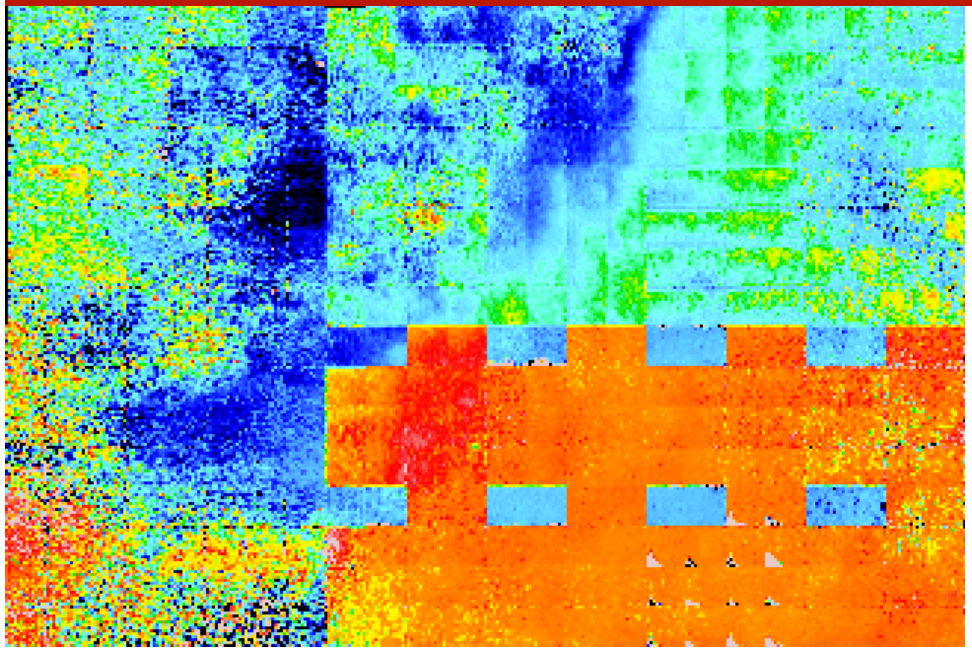
Spectral (top) and spatial (bottom) flexure measured from the location of an arcline (vertical shifts) and slitlet edges (horizontal shifts) repectively on raw detector frames, as a function of rotator angle

red/green/blue: detectors 1, 2, 3

Scale of shift is ~ ±1 pixel

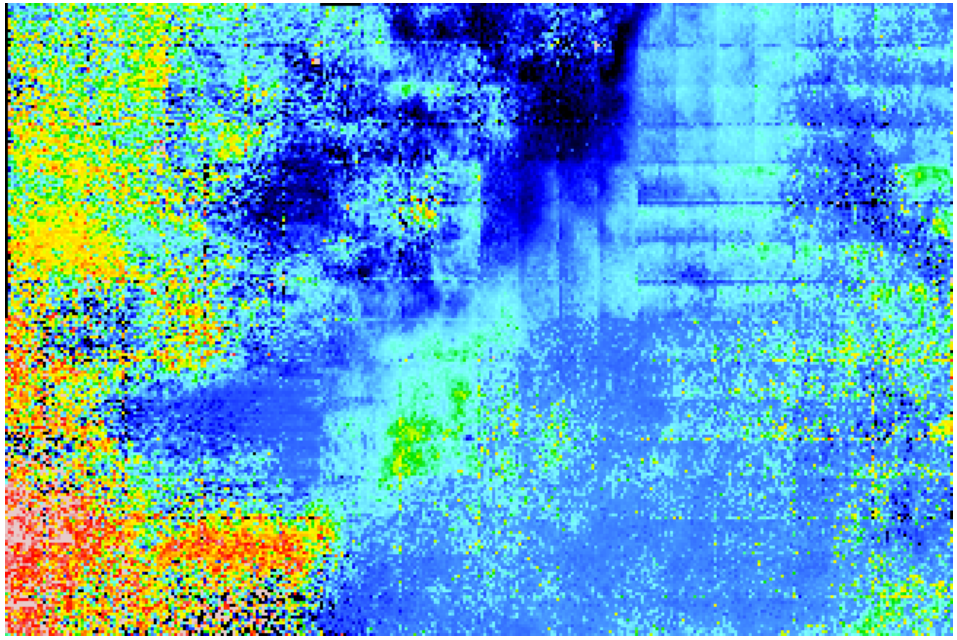
→ Good match for spatial flexure, approximative for spatial flexure

Example: Wavelength matching



before

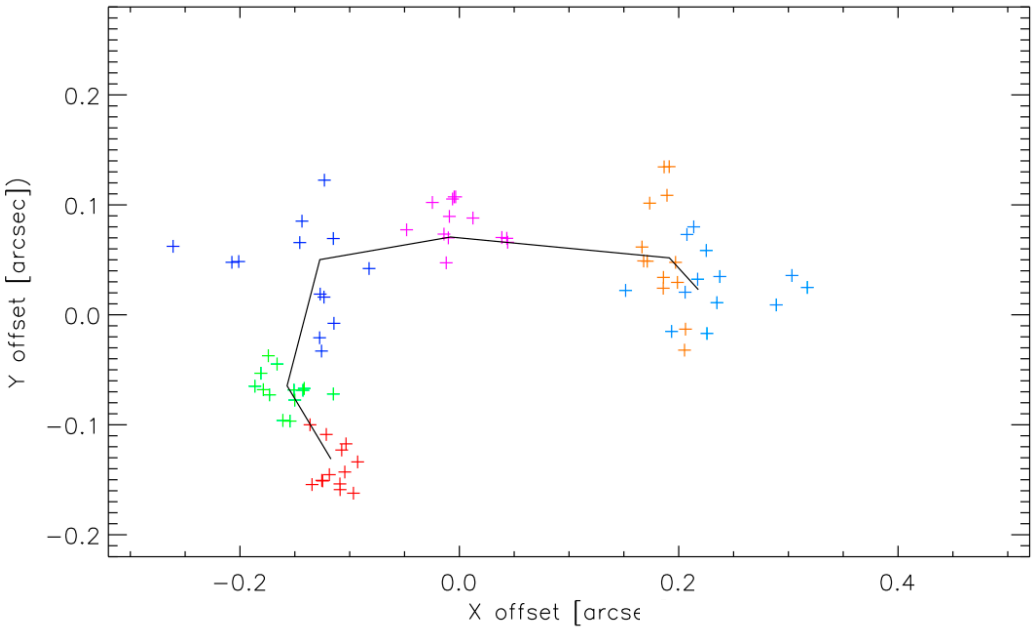
after



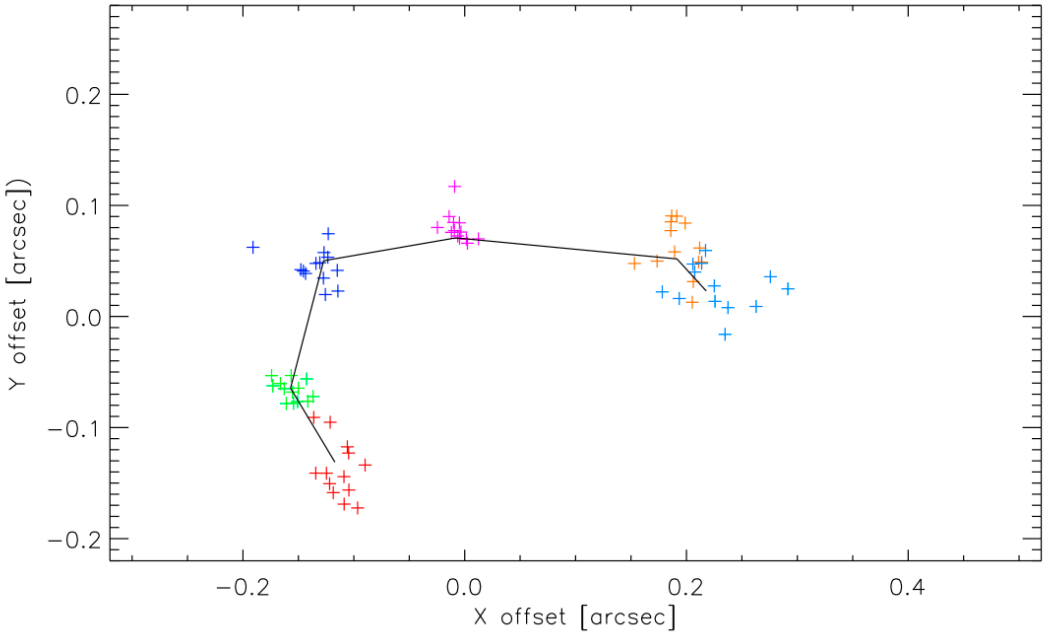
→ kmo_sci_red with
OH_SPEC frame provided

Example: interpolation of XCAL frames

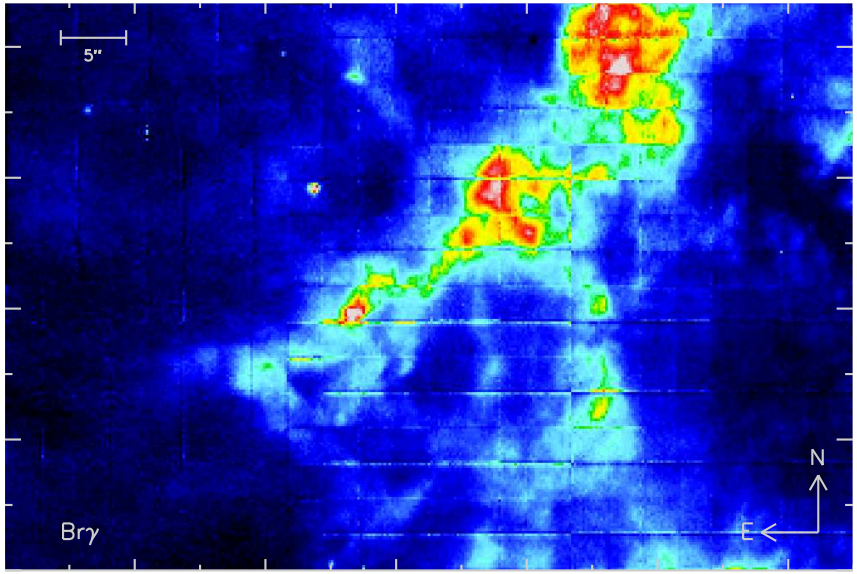
without XCAL interpolation

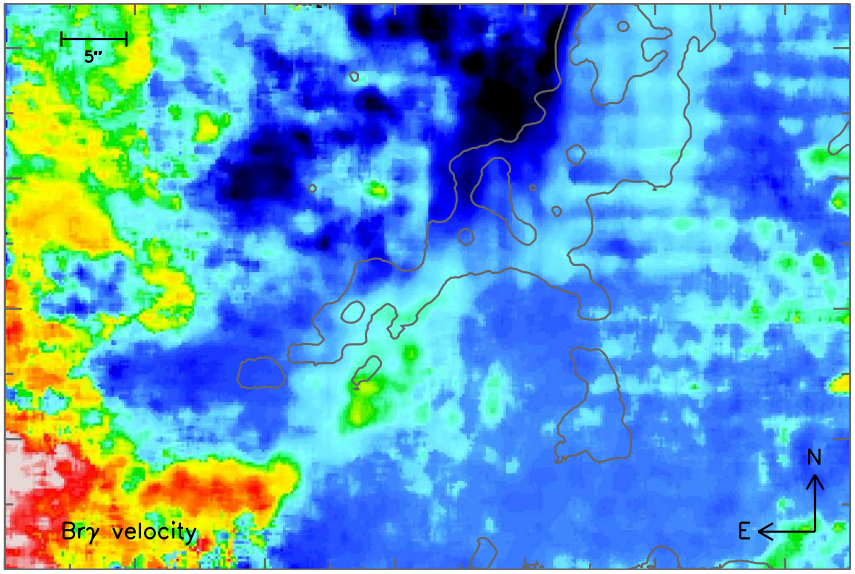


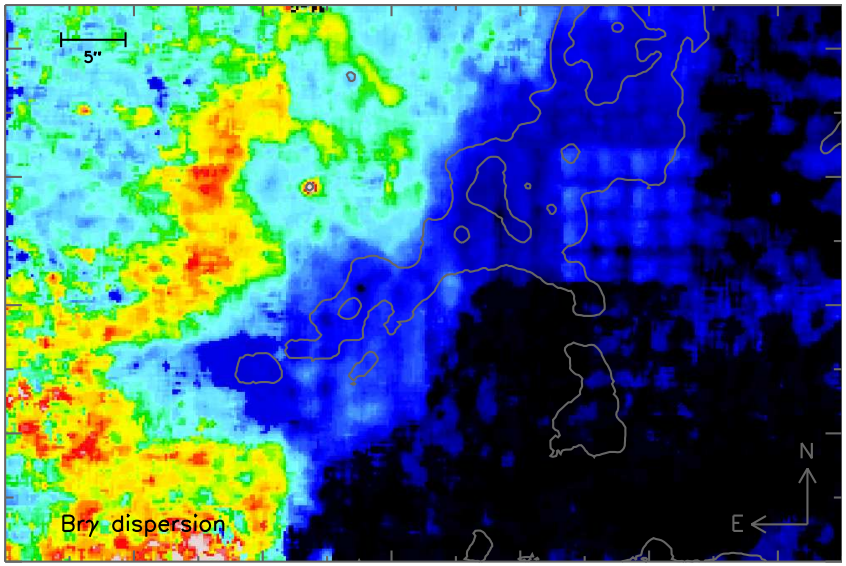
with XCAL interpolation



Example: Flux and background correction on mosaic of R136







Flux (top), velocity (top right) and dispersion (right) of the Brγ line extracted from the R136 mosaic.

The velocity is shown in the range 230–310 km/s and the dispersion in the range 0–70 km/s

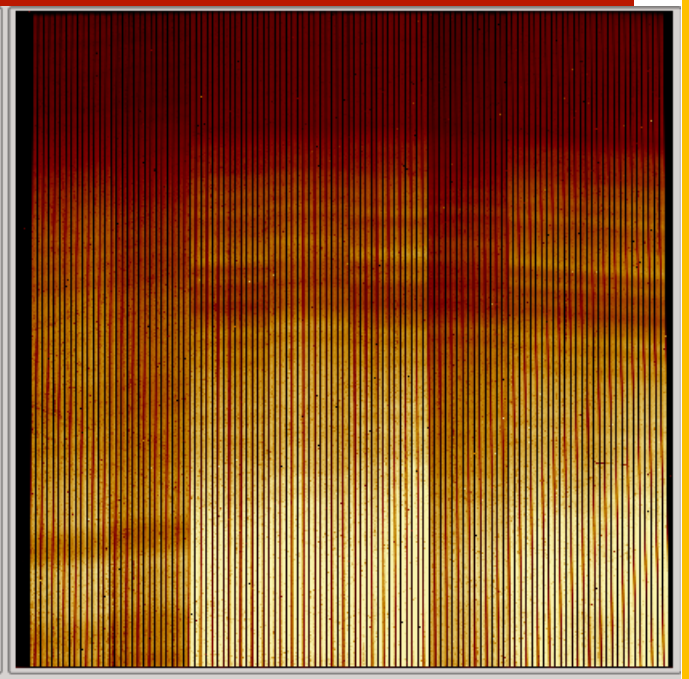
The 2 contours outline the location of the most prominent Brγ line emission for reference

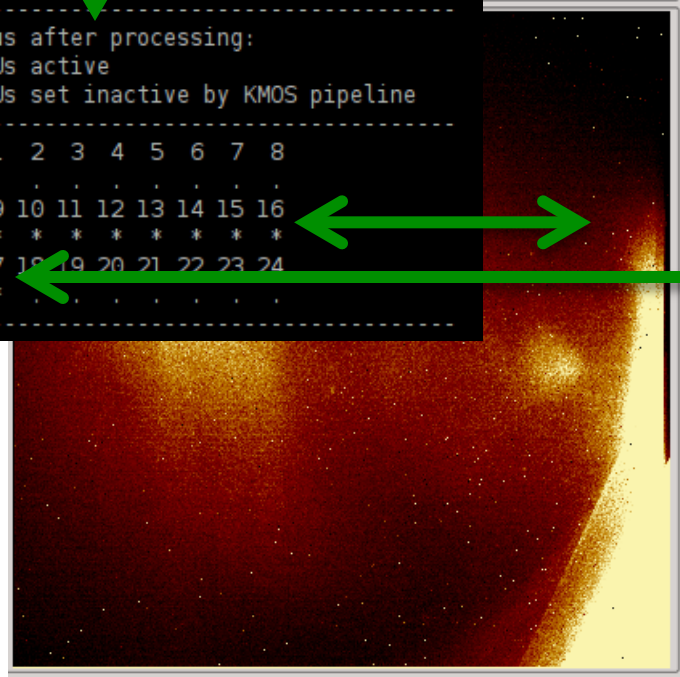
Flux and background calibration have been used for these images to reduce edge effects.
Can only be used for mosaics with small objects

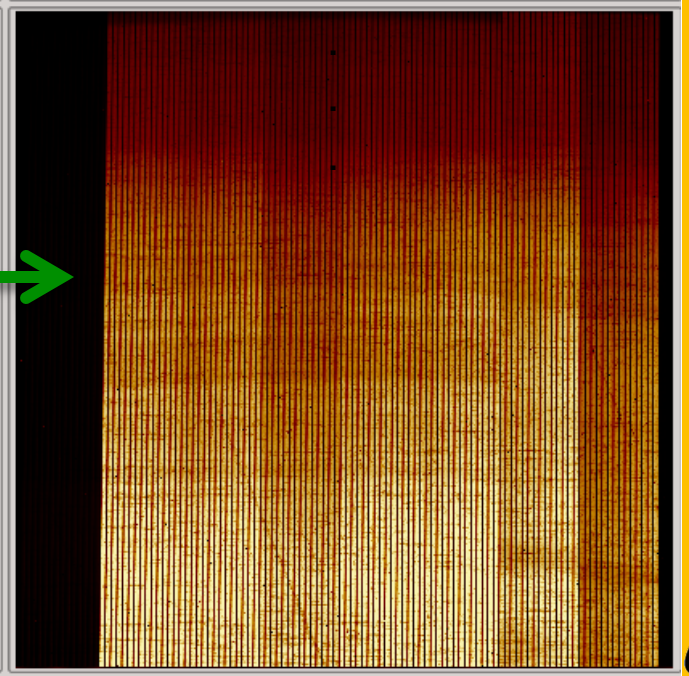
2013-06-26T04:11:07.405.fits, TPL ID: 2013-06-26T04:03:02

```
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: Detected instrument setup:   IZIZIZ
[ INFO  ] kmo_flat: (grating 1, 2 & 3)
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 0
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 60
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 120
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 180
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 240
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 300
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: IFU status before processing:
[ INFO  ] kmo_flat:    All IFUs are active
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: EXPTIME:  3 seconds
[ INFO  ] kmo_flat: NDIT: 1
[ INFO  ] kmo_flat: Detector readout mode: Nondest
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: Processing rotator angle 0 -> 0 degree
[ INFO  ] kmo_flat: Processing detector No. 1
```

```
[ INFO  ] kmo_flat: Readmode: NDR, # rejected pixels: 3 (Saturated
[ INFO  ] kmo_flat: Readmode: NDR, # rejected pixels: 23 (Saturate
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: IFU status after processing:
[ INFO  ] kmo_flat:    .: IFUs active
[ INFO  ] kmo_flat:    *: IFUs set inactive by KMOS pipeline
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat:    IFU  1  2  3  4  5  6  7  8
[ INFO  ] kmo_flat:         .  .  .  .  .  .  .  .
[ INFO  ] kmo_flat:    IFU  9 10 11 12 13 14 15 16
[ INFO  ] kmo_flat:         *  *  *  *  *  *  *  *
[ INFO  ] kmo_flat:    IFU 17 18 19 20 21 22 23 24
[ INFO  ] kmo_flat:         *  .  .  .  .  .  .  .
[ INFO  ] kmo_flat: ----------------------------------------
```





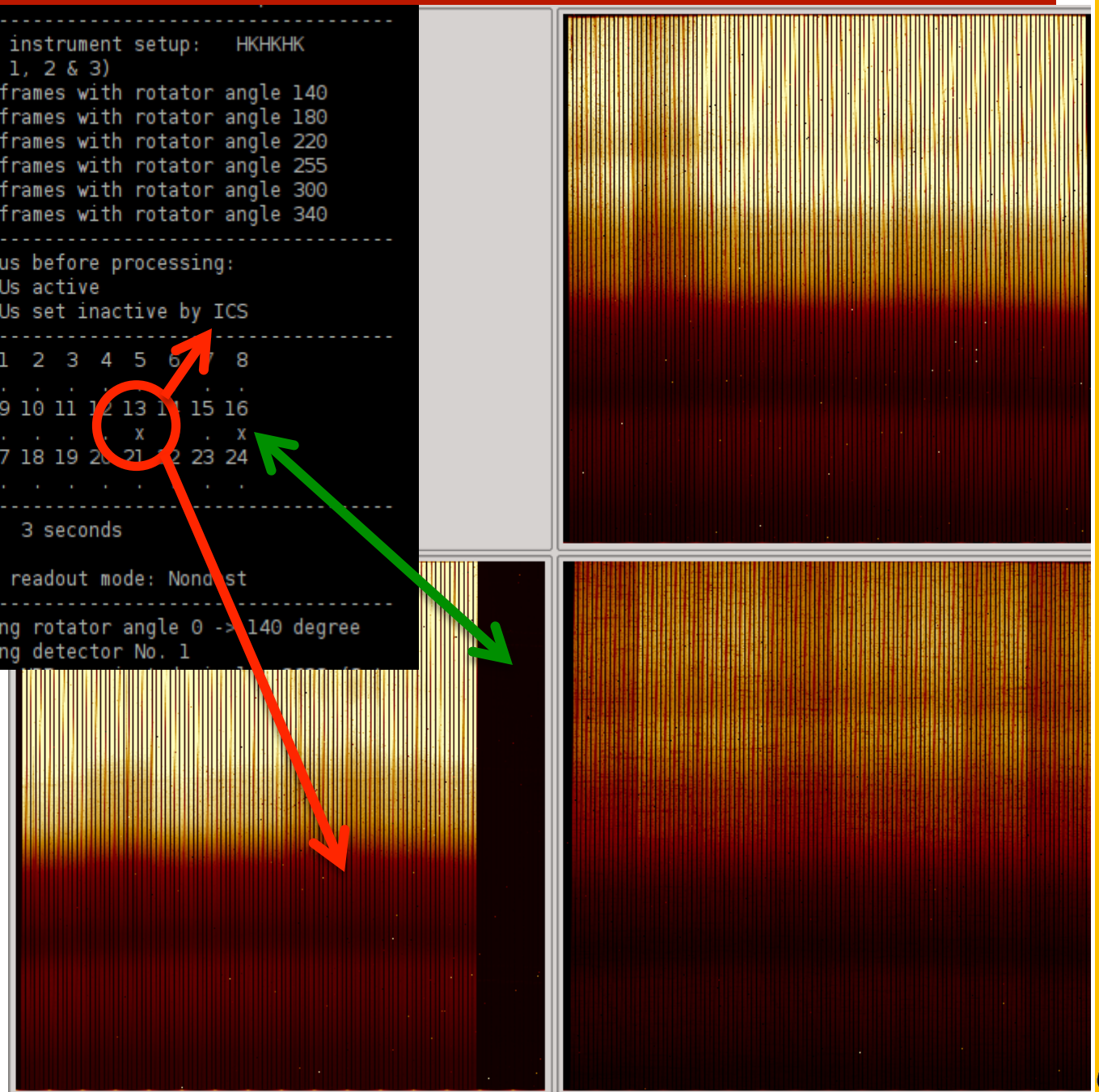


KMOS.2013-06-26T04:28:33.710.fits, TPL ID: 2013-06-26T04:23:39

```
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: Detected instrument setup:   HHH
[ INFO  ] kmo_flat: (grating 1, 2 & 3)
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 120
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: IFU status before processing:
[ INFO  ] kmo_flat:    All IFUs are active
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: EXPTIME:  7.5 seconds
[ INFO  ] kmo_flat: NDIT: 1
[ INFO  ] kmo_flat: Detector readout mode: Nondest
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: Processing rotator angle 0 -> 120 degree
[ INFO  ] kmo_flat: Processing detector No. 1
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 95 (Saturat
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 4415 (Satur
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 4482 (Satur
[ INFO  ] kmo_flat: Processing detector No. 2
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 16 (Saturat
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 9 (Saturate
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 24 (Saturat
[WARNING] kmo_flat: The number of identified slices is one! Appl
[WARNING] kmo_flat: IFU 16 is valid according to header keywords
[ INFO  ] kmo_flat: Processing detector No. 3
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 19 (Saturat
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 14 (Saturat
[ INFO  ] kmo_flat: Readmode: NDR, #rejected pixels: 39 (Saturat
[WARNING] kmo_flat: IFU 17 is valid according to header keywords
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: IFU status after processing:
[ INFO  ] kmo_flat:    .: IFUs active
[ INFO  ] kmo_flat:    *: IFUs set inactive by KMOS pipeline
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat:    IFU  1  2  3  4  5  6  7  8
[ INFO  ] kmo_flat:         .  .  .  .  .  .  .  .
[ INFO  ] kmo_flat:    IFU  9 10 11 12 13 14 15 16
[ INFO  ] kmo_flat:         .  .  .  .  .  .  .  *
[ INFO  ] kmo_flat:    IFU 17 18 19 20 21 22 23 24
[ INFO  ] kmo_flat:         *  .  .  .  .  .  .  .
[ INFO  ] kmo_flat: ----------------------------------------
```

KMOS.2013-06-29T17:06:57.569.fits, TPL ID: 2013-06-29T17:00:44

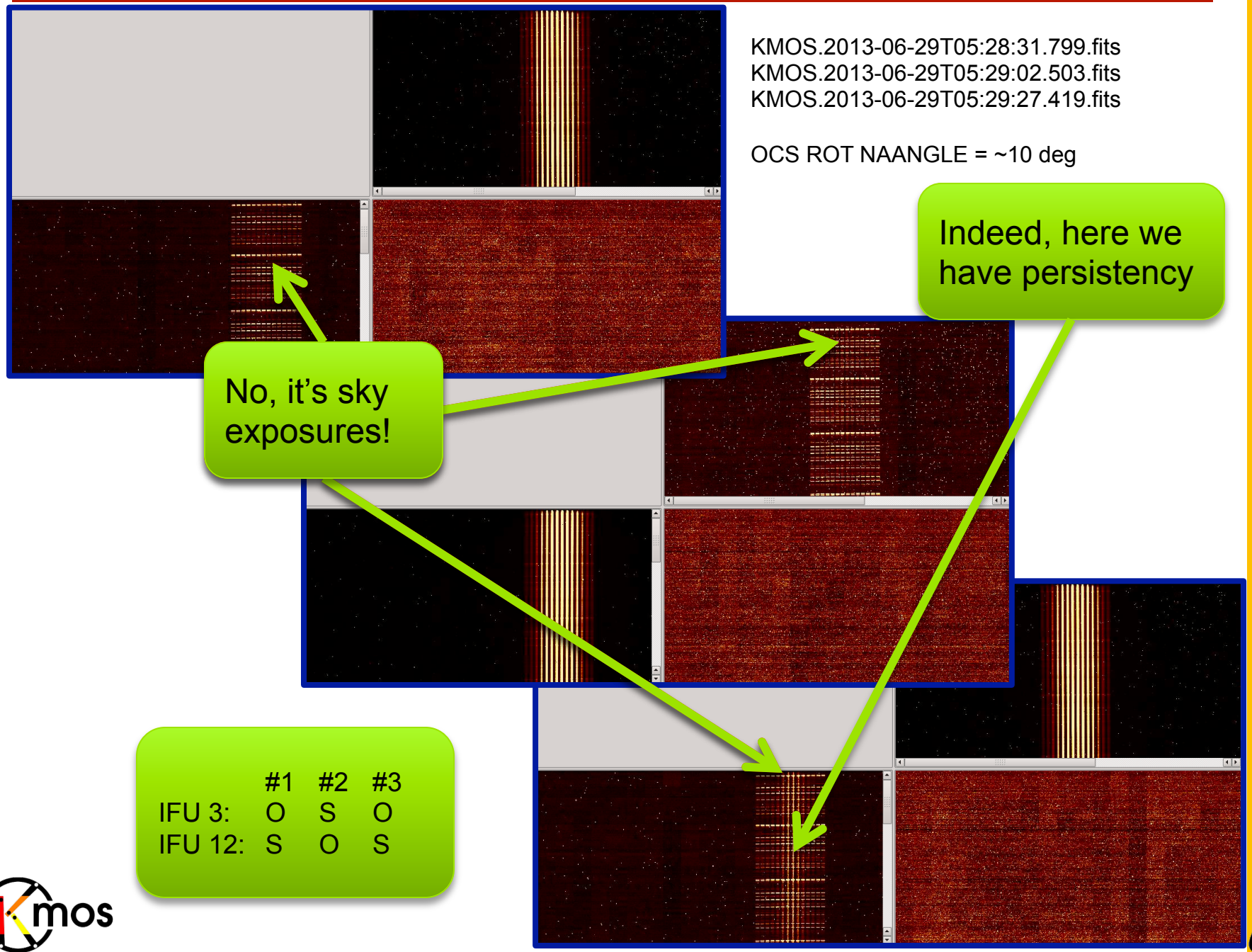
```
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: Detected instrument setup:   HKHKHK
[ INFO  ] kmo_flat: (grating 1, 2 & 3)
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 140
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 180
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 220
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 255
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 300
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 340
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: IFU status before processing:
[ INFO  ] kmo_flat:    .: IFUs active
[ INFO  ] kmo_flat:    x: IFUs set inactive by ICS
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat:    IFU  1  2  3  4  5  6  7  8
[ INFO  ] kmo_flat:         .  .  .  .  .  .  .  .
[ INFO  ] kmo_flat:    IFU  9 10 11 12 13 14 15 16
[ INFO  ] kmo_flat:         .  .  .  .  x  .  .  x
[ INFO  ] kmo_flat:    IFU 17 18 19 20 21 22 23 24
[ INFO  ] kmo_flat:         .  .  .  .  .  .  .  .
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: EXPTIME:  3 seconds
[ INFO  ] kmo_flat: NDIT: 1
[ INFO  ] kmo_flat: Detector readout mode: Nondest
[ INFO  ] kmo_flat: ----------------------------------------
[ INFO  ] kmo_flat: Processing rotator angle 0 -> 140 degree
[ INFO  ] kmo_flat: Processing detector No. 1
```



kmo_std_star: The RAW frames and their contents

KMOS.2013-06-29T05:28:31.799.fits
KMOS.2013-06-29T05:29:02.503.fits
KMOS.2013-06-29T05:29:27.419.fits

OCS ROT NAANGLE = ~10 deg



	#1	#2	#3
IFU 3:	O	S	O
IFU 12:	S	O	S

kmo_std_star: The RAW frames and their contents

- Normal IFU-setup of KMOS_spec_cal_stdstar-template:

IFUs	#3	#12	#20
Exp #1:	O	S	S
Exp #2:	S	O	S
Exp #3:	S	S	O
Exp #4:	O	S	S

- Standard star frames are taken in sets of 4, where all arms are deployed either on the star or on sky. One suitable set of frames is:
  KMOS.2013-06-30T02:00:18.548.fits
  KMOS.2013-06-30T02:00:48.044.fits
  KMOS.2013-06-30T02:01:14.064.fits
  KMOS.2013-06-30T02:01:40.858.fits

- The user can find suitable frame sets with the linux command

```
dfits KMOS.2013-06-*fits | \
                fitsort tpl.id dpr.type obs.name ins.filt1.id exptime | \
                grep HK | \
                grep stdstar
```

→ the pipeline only needs 3 frames, but taking 4 is a quirk of the observing software

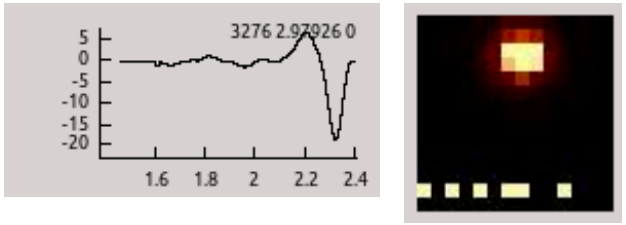
ATTENTION
It is important to have a standard star in every detector! When rotator optimization intervenes the IFUs can be reallocated (this is the case when the keyword ESO OCS OFFSET is present → check for ESO OCS ARMx ORIGNAME) (bug in v1.2.2: IFUs are hardcoded to 3,12, 20)

Reflex & CalSelector DOs

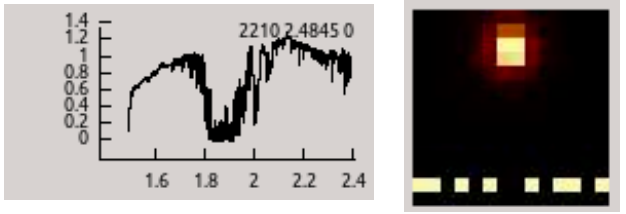
Problem

- Peculiar artifacts in products
- raw frames at 10deg

IFU 3



IFU 12



Reflex DO

- sof generated:
  angles at 140, 180, 220, 255, 300, 340 deg
- --xcal_interpolation between [-20, 140] deg!

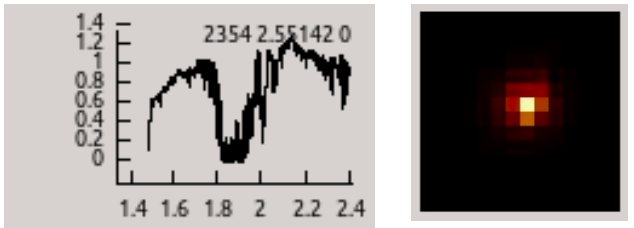
Solution

- Set --xcal_interpolation=FALSE
  340 deg chosen as closest angle
- (to come in v1.2.3) --xcal_interpolation switched off automatically when interval > 35 deg

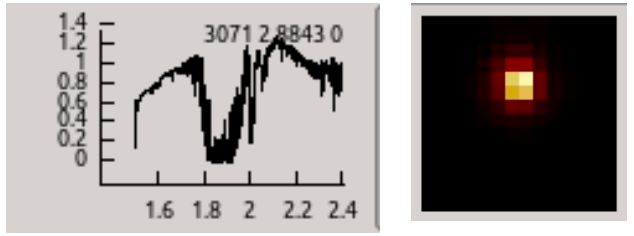
CalSelector

- sof generated:
  angles at 0, 60, 120, 180, 240, 300 deg
- --xcal-interpolation between [0,60 deg]
  no more than 30 deg difference

IFU 3



IFU 12



kmo_sci_red: noise / no noise

Problem

- sci_combined-products from kmo_sci_red sometimes with valid noise extension and sometimes with empty noise extension

Solution

- Products of size 14x14pix indicate, that just one object frame was to be combined
  - except for --method="none"
  - → sci_combined_xxx == sci_reconstructed_xx
- Default --imethod=CS **doesn't** generate noise extension, but empty noise extension generated (with --imethod=NN/lwNN/swNN noise is calculated
- Use kmo_fits_strip --noise to remove unwanted noise extensions (bug-fix in v1.2.3)

Potential solution

- Calculate anyway some noise with CS, but this isn't straightforward (interpolating splines over noise values?)
- e.g. same problem as with SINFONI / ERIS

kmo_sci_red: combining different angles

Problem

```
[ ERROR ] kmo_sci_red: Illegal input: Orientation of cube 1 (7.01671e-15deg) and cube 2 (90deg) differ! Align the orientation of this cube with kmo_rotate before applying this recipe.
```

Solution

- Combining cubes from different OBs, with different rotator offsets
  0deg and 90deg have to be derotated with kmo_rotate
- Look at
  - HIERARCH ESO OCS ROT OFFANGLE in RAW frames or
  - CD1_2 and CD2_1 in products, if these are zero → 0deg

Bug:

- Fixed rounding of values in error message to one decimal place (bug-fix in v1.2.3)

kmo_illumination

Problem

- kmo_illumination exited during processing of detector 2 without error message and any saved products

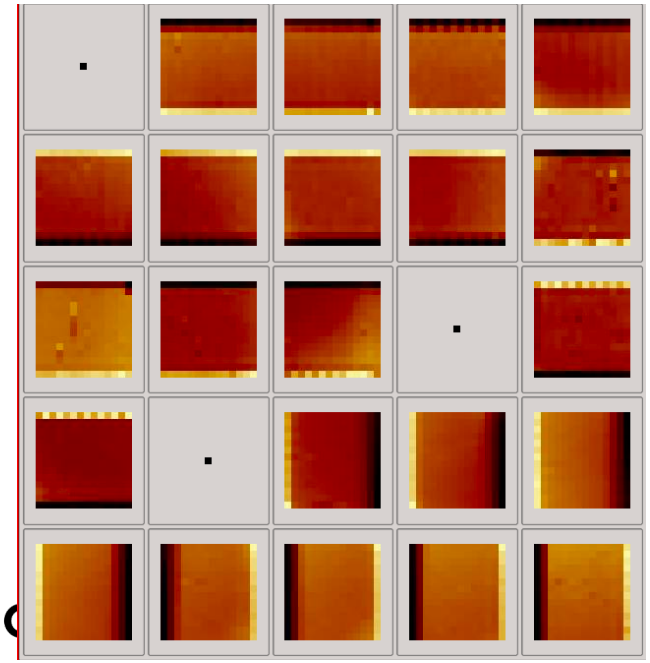
Solution

- Bug fix in v1.2.3: Added check on FLAT_EDGE for unused IFUs (to be compared with unused IFUS of FLAT_SKY frames)
- Quick Fix: Exclude FLAT_EDGE from sof file

Sub-optimal rotator angles

Problem

- Strong gradients on IFU edges
- Calibration data at 60, 105, 155, 205, 250, 305 deg
- FLAT_SKY is at 10 deg, closest calib. angle is 60 deg: Δ 50 deg

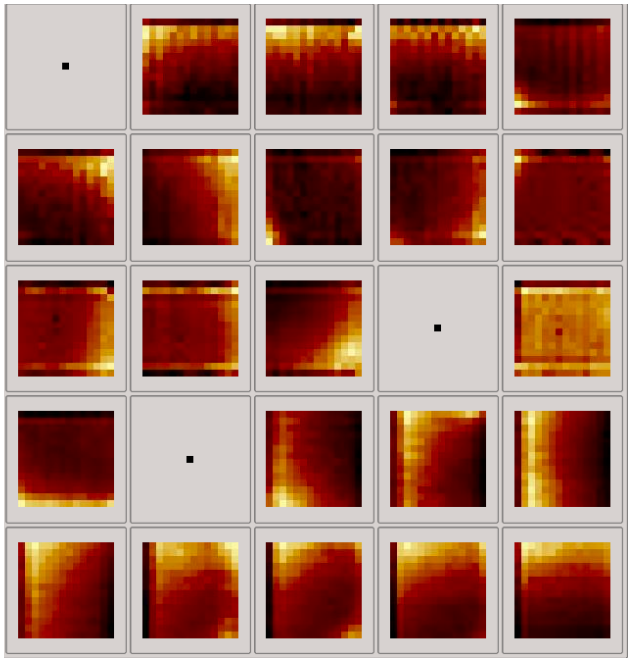


(noise has been stripped with kmo_fits_strip)

Optimal rotator angles

Solution

- With angles of 0, 60, 120, 180, 240, 300 deg effect is mimimised
- ESO OCS ROT NAANGLE matters when FLAT_EDGE supplied: SKYFLAT_EDGE shifted to match FLAT_EDGE



Overriding unused IFUs

Problem

- IFU has been wrongly defined as NOTUSED (data well visible on RAW frames)
- How to override ESO OCS ARMx NOTUSED keyword?

Solution

- Pipeline doesn't allow any overrides on this
- User can use a text editor or the program 'fv' to erase this keyword
  - In this case an appropriate ESO OCS ARMx TYPE = S or O or R (sky, object, reference) has to be defined

Long exposure time

Problem

- EXPTIME is 20 sec, but the time between exposures is about 1 min 30 sec?

Solution

- Reconstruction on RTD takes ~30 sec
- NDIT was 3
  → 3x 20 sec + 30 sec = 1 min 30 sec

Note

Normally only the 1st exposure of an OB is reconstructed, but there is a button in the KMOS Control Panel to switch reconstruction on/off during the OB

Defined wavelength ranges (WAVE_BAND)

- H-band: 1.425 - 1.867 µm
- HK-band: 1.460 - 2.410 µm
- IZ-band: 0.780 - 1.090 µm
- K-band: 1.925 - 2.500 µm
- YJ-band: 1.000 - 1.359 µm

ATMOS_MODEL

- H-band: 1.400 - 1.900 µm
- HK-band: 1.450 - 2.430 µm
- IZ-band: 0.800 - 1.200 µm
- K-band: 1.900 - 2.549 µm
- YJ-band: 0.925 - 1.379 µm

SOLAR_SPEC

- H-band: 1.403 - 1.802 µm
- HK-band: 1.403 - 2.501 µm
- IZ-band: –
- K-band: 1.932 - 2.501 µm
- YJ-band: –

STATIC CALIBRATIONS MISSING

Things to come

- Implement kmo_sky_tweak (advanced tool to match and remove OH lines)
- Update kmo_multi_reconstruct to provide same functionality as kmo_sci_red
- Additional illumination correction recipe (besides kmo_illumination) based on FLAT,LAMP frames
  - Reduce dependency on proper FLAT_SKY exposures
- Override for internal DO organiser (object/sky association)

Best practices

- Please choose equidistant rotator angles unless you know what you are doing
  - When observations have a nasmyth angle from 10 to 20 deg, it is ok to take calibrations at e.g. 5, 10, 15, 20, 25 deg
  - But then these calibrations are only suited for these specific SCIENCE frames!
  - Check ESO PRO NAANGLE keyword in extensions of calibration frames
- Check if there is a standard star in every detector
- Check
  https://wiki.mpe.mpg.de/KMOS-spark
  for newest SW-updates