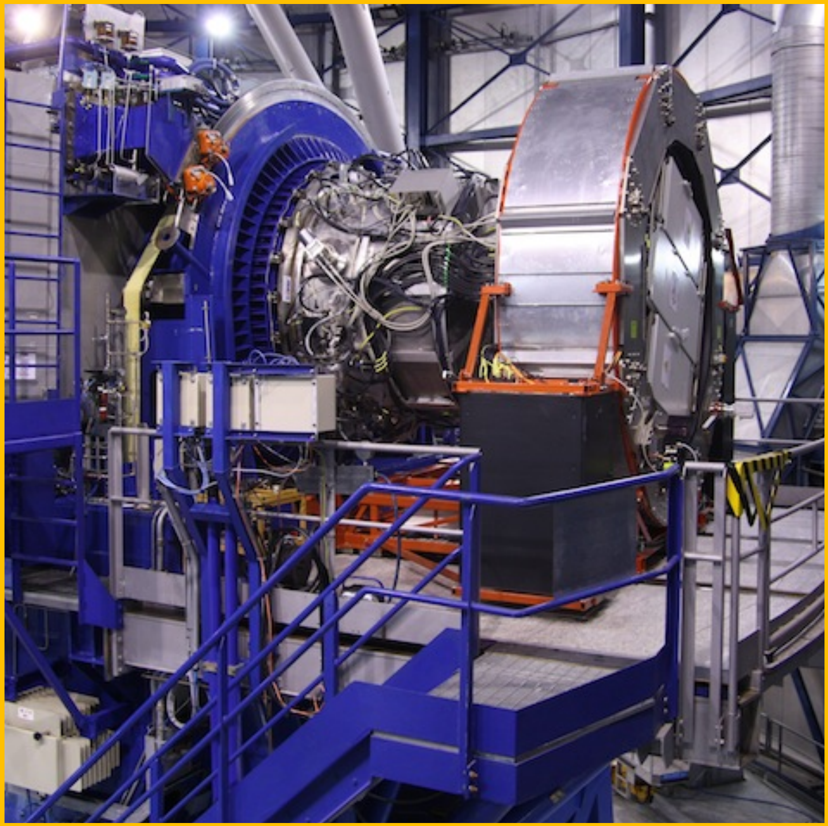


KMOS Pipeline Tutorial

Alex Agudo Berbel

kmos

11.+13..03.2014

kmos

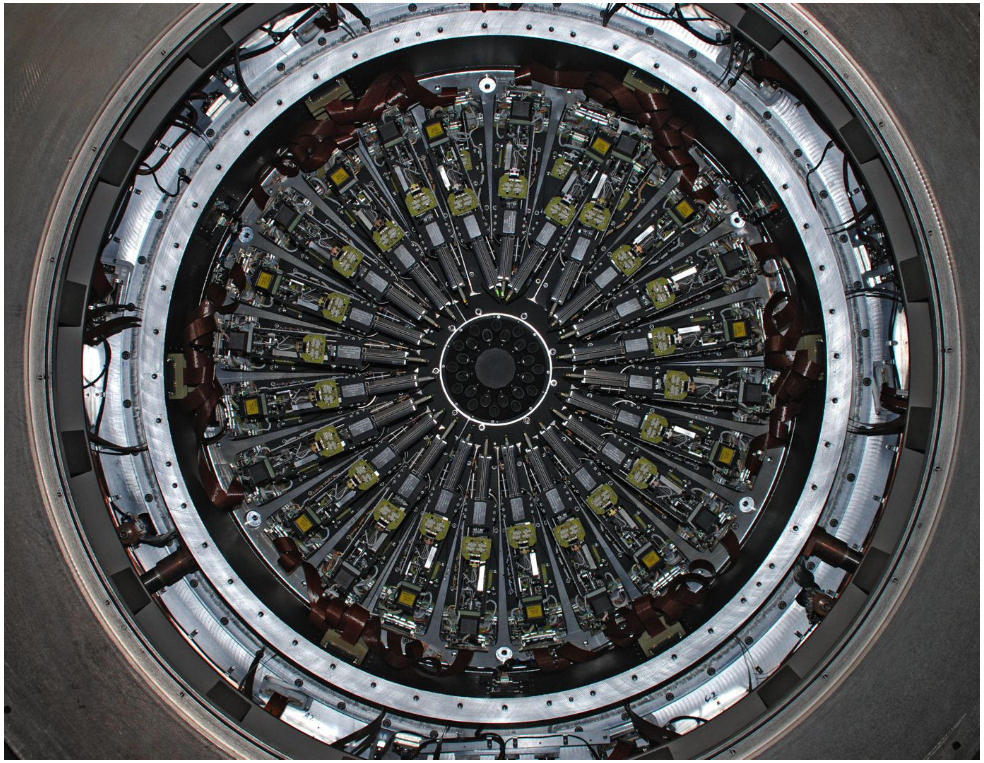
MPE

- **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

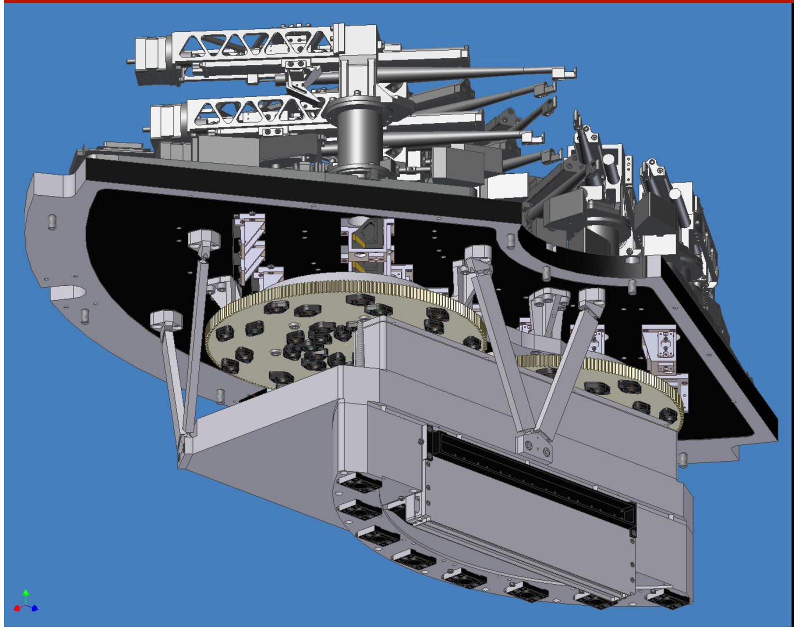
- H-band: R~4000
- HK-band: R~1900
- IZ-band: R~2800
- K-band: R~4100
- YJ-band: R~3400

Optical throughput

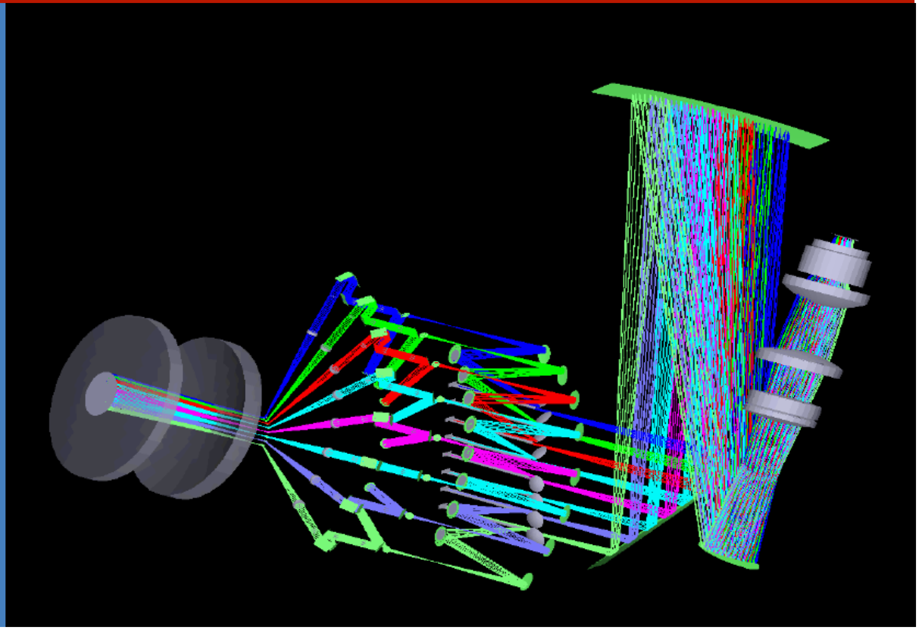
	Hip039102	HIP054804
K-band:	22 ± 1.5%	21.7%
HK-band:	23 ± 1.4%	23.3%
H-band:	23 ± 1.9%	22.9%
YJ-band:	16 ± 1.3%	16.9%
IZ-band*:	11 ± 1.0 %	9.1%

Inside KMOS

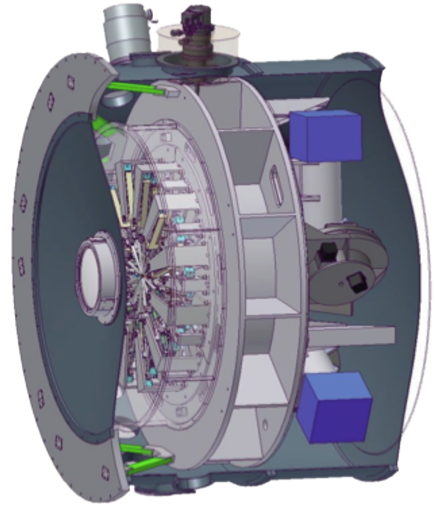
SPECIFICATIONS



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)

Actual pipeline release

- v1.3.0 released on 07.03.2014
- Problem installing on MacOSX (CPL 6.4?) → kmos-kit-1.2.8.tar.gz

Where to get the newest pipeline releases?

- see KMOS Wiki

KMOS Wiki

- Resources, manuals, papers, downloads, etc.:
  wiki.mpe.mpg.de/KMOS-spark

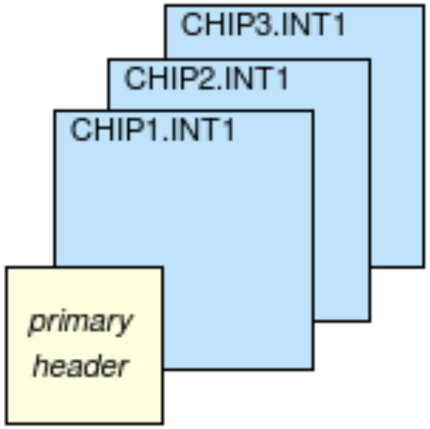
Resources for a quick start:

- **SPARKING Guide:** SPARK Instructional Guide for KMOS data (contained in the pipeline release or as well from the KMOS Wiki)
- ***The Software Package for Astronomical Reductions with KMOS: SPARK***
  [Davies R., Agudo Berbel A., Wiezorrek E., Cirasuolo M., Förster Schreiber N.M., Jung Y., Muschielok B., Ott T., Ramsay S., Schlichter J., Sharples R., Wegner M., 2013, A&A, 558, A56]

Tutorial test data:

- see KMOS Wiki
  - tutorial_working.tar.gz
  - tutorial_data.tar.gz
  - (Optional) tutorial_products.tar.gz

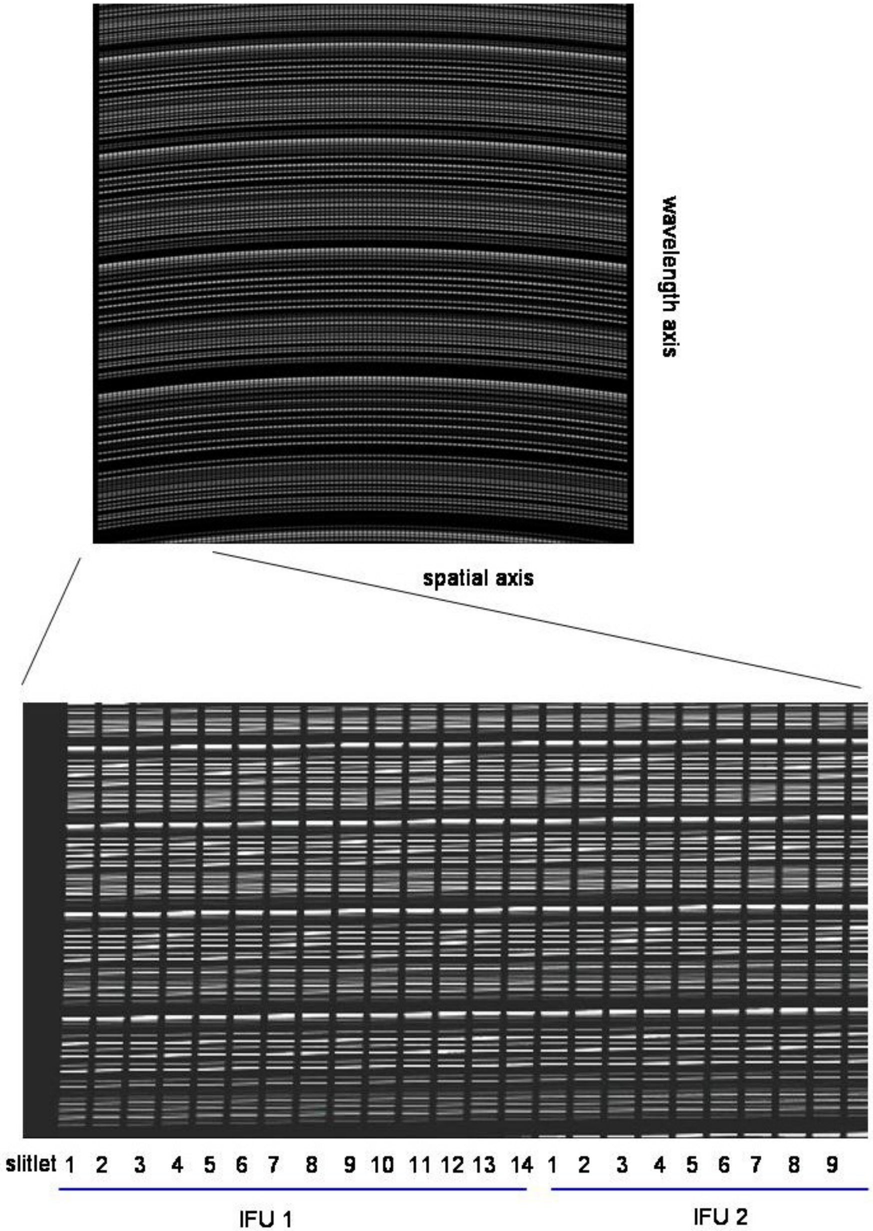
RAW detector frames



- 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



KMOS MPE

Processed frames

- Spectra, images, cubes are in extensions
- As a rule there are 1, 2, 24, or 48 extensions

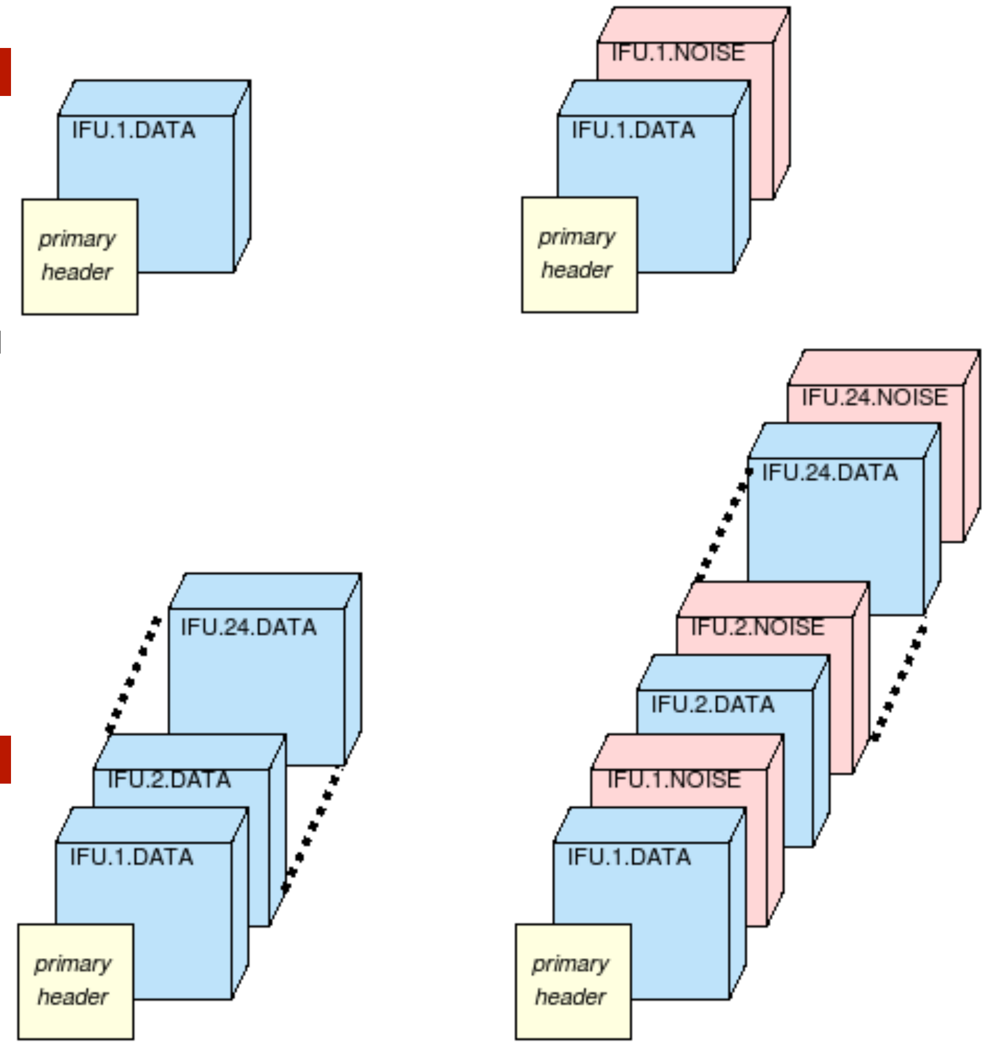
Frame Types

F3I

F = floating point
B = binary

D = detector based
I = IFU based
S = any spectrum
L = any list

# dimensions
1 = spectrum
2 = image
3 = cube



EXTNAME

keyword EXTNAME indicates content type e.g.
IFU.4.DATA or DET.1.NOISE

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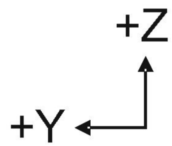
MPE

IFU orientation

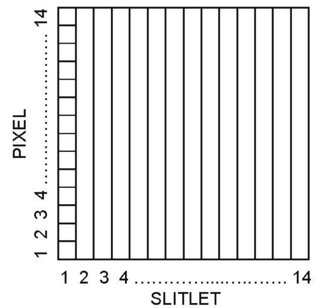
- Every 4 IFUs have a different orientation on the detector
- Exposures therefore miss a certain regularity

ON SKY

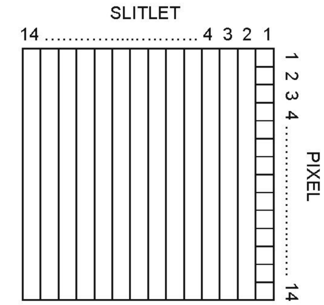


+Z corresponds to North and +Y to East when rotator offset angle is zero

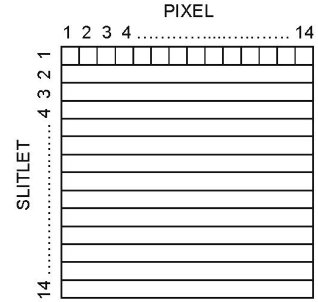
IFUs:
1, 2, 3, 4, 13, 14, 15, 16



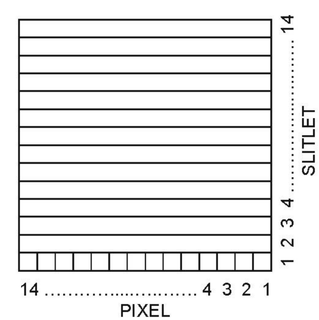
IFUs:
5, 6, 7, 8, 9, 10, 11, 12



IFUs:
17, 18, 19, 20



IFUs:
21, 22, 23, 24



FRAME FORMAT

Calibration Recipes

- kmo_dark
- kmo_flat
- kmo_wave_cal
- kmo_illumination
  or
  kmo_illumination_flat
- kmo_std_star

Science Recipes

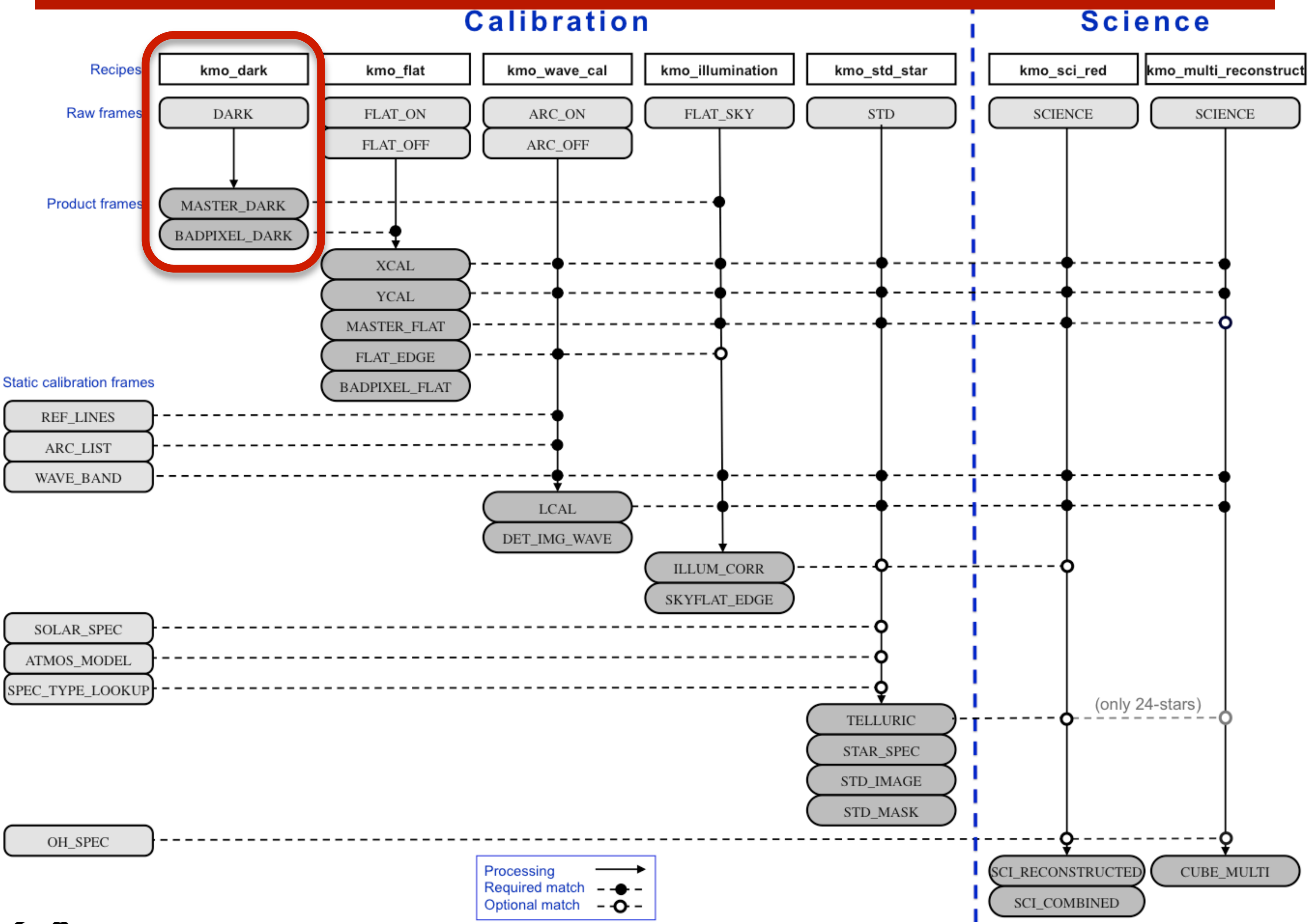
- kmo_sci_red
- kmo_multi_reconstruct

- kmo_reconstruct
- kmo_combine

Basic tools

- kmo_arithmetic
- kmo_copy
- kmo_extract_spec
- kmo_fit_profile
- kmo_fits_check
- kmo_fits_strip
- kmo_make_image
- kmo_noise_map
- kmo_rotate
- kmo_shift
- kmo_sky_mask
- kmo_sky_tweak
- kmo_stats

Calibration Cascade



CALIBRATION RECIPES

Dark Frames

Recipe: **kmo_dark**

Purpose:

Combine individual dark frames into a MasterDark frame and create a preliminary bad pixel mask.

Main Parameters:

--cmethod="ksigma" (default), "min_max", "median", "average", "sum" *
[others for rejection thresholds, number of iterations, etc.]

Example:

```
esorex   kmo_dark   dark.sof
```

with dark.sof containing:

```
dark_001.fits   DARK
dark_002.fits   DARK
dark_003.fits   DARK
```

It is recommended to supply at least 3 DARK frames

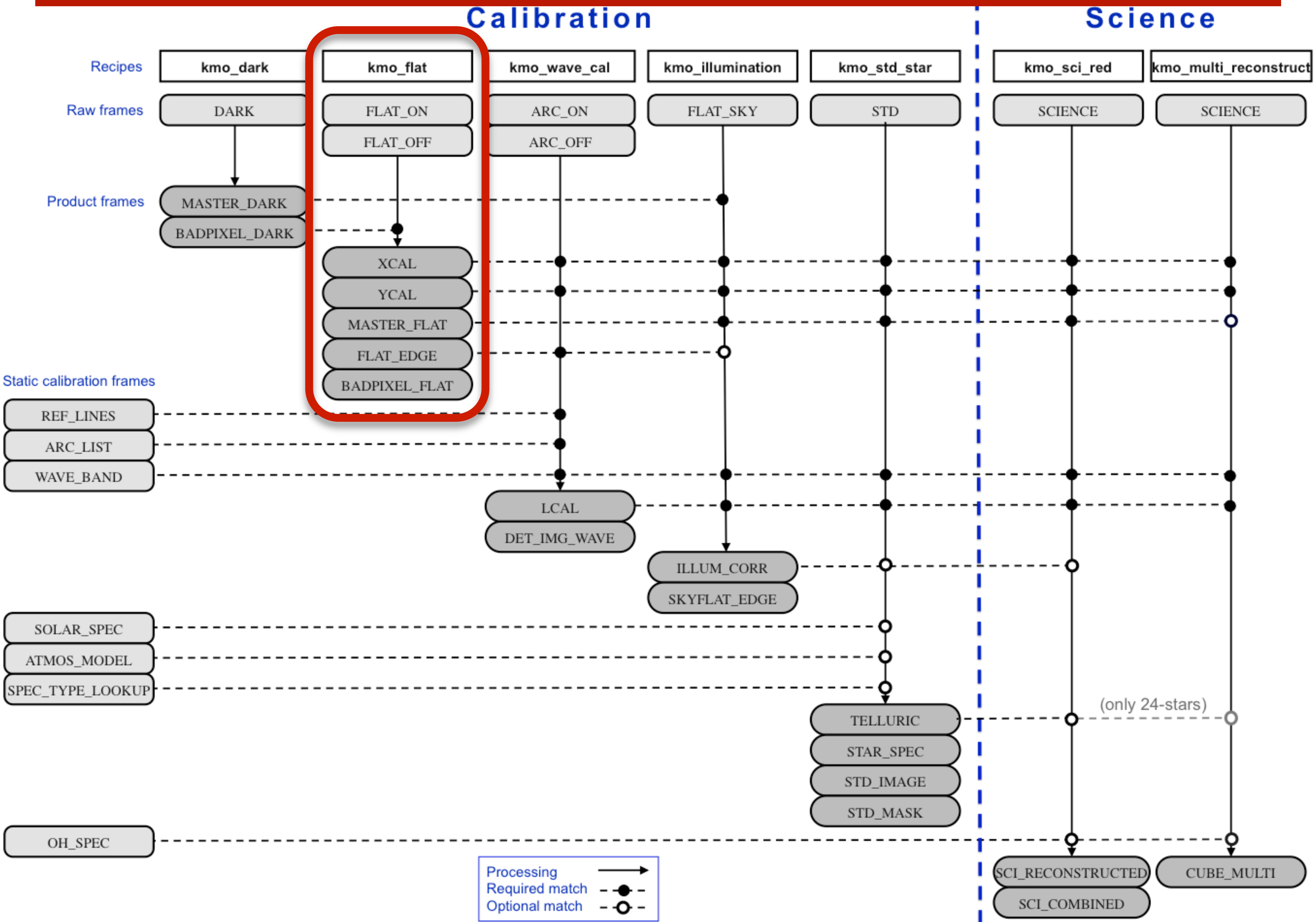
Output frames:

MASTER_DARK, BADPIXEL_DARK

Getting help on recipes

```
esorex  -man <recipe name>
```

Calibration Cascade



Recipe: **kmo_flat**

Purpose:

Combine individual flat frames into a MasterFlat frame, create the XCAL and YCAL spatial calibration frames and create the final bad pixel mask.

Main Parameters:

--surrounding_pixels

The amount of bad pixels to surround a specific pixel, to let it be marked bad as well.

Example:

```
esorex kmo_flat flat.sof
```

with flat.sof containing:

```
flat_001.fits        FLAT_ON
flat_002.fits        FLAT_ON
flat_003.fits        FLAT_ON
flat_004.fits        FLAT_OFF
flat_005.fits        FLAT_OFF
flat_006.fits        FLAT_OFF
badpixel_dark.fits   BADPIXEL_DARK
```

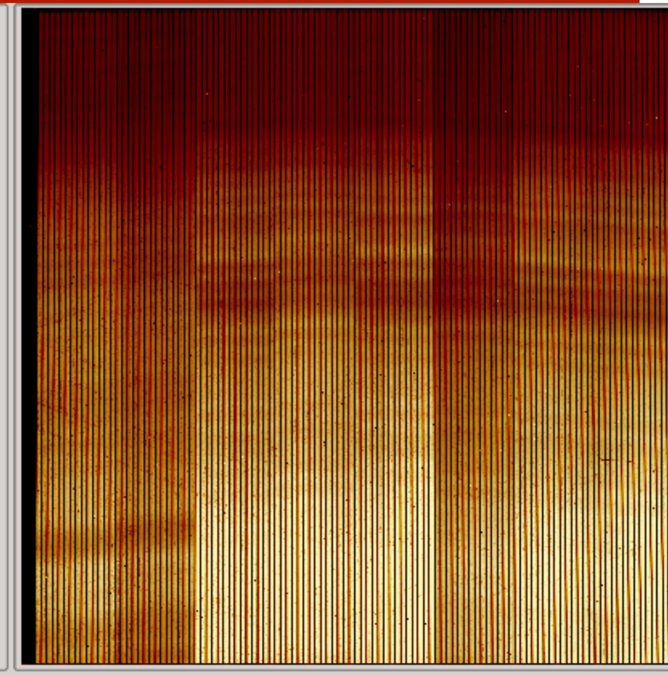
It is recommended to supply at least 3 FLAT_ON and FLAT_OFF frames

Output frames:

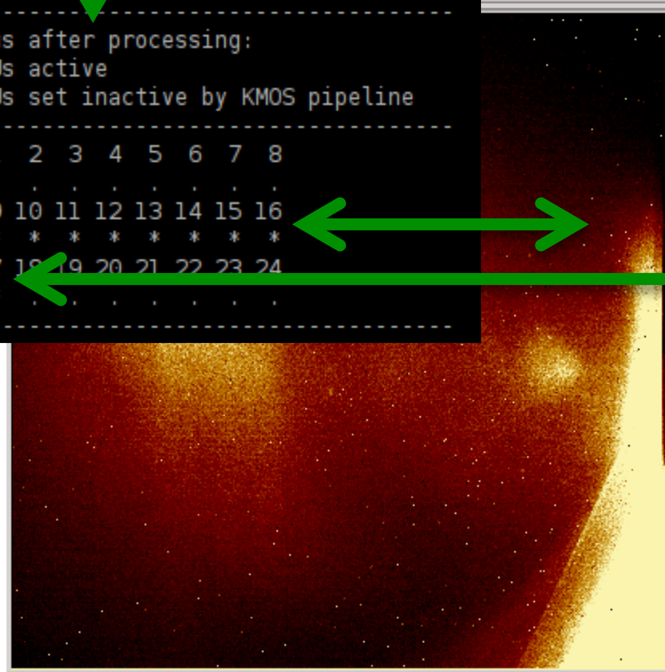
MASTER_FLAT, BADPIXEL_FLAT, XCAL, YCAL, FLAT_EDGE

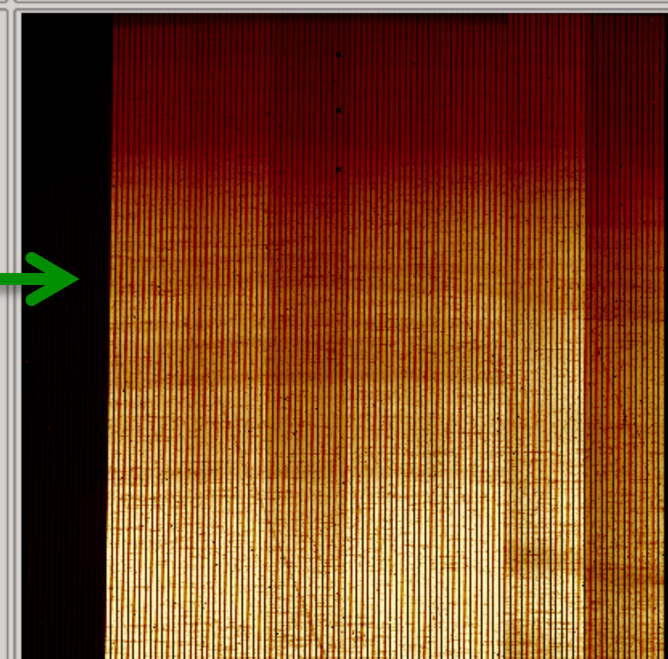
Example #1: kmo_flat

```
[ 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: -------------------------------------------
```

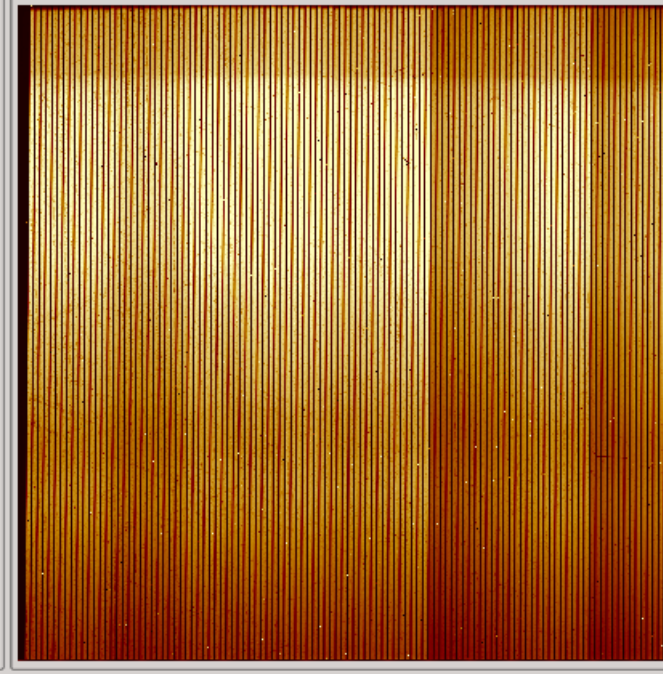


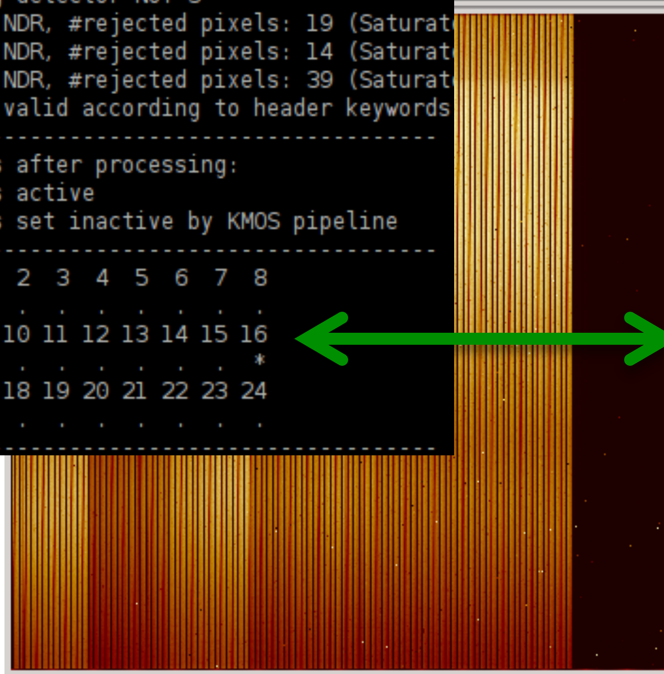


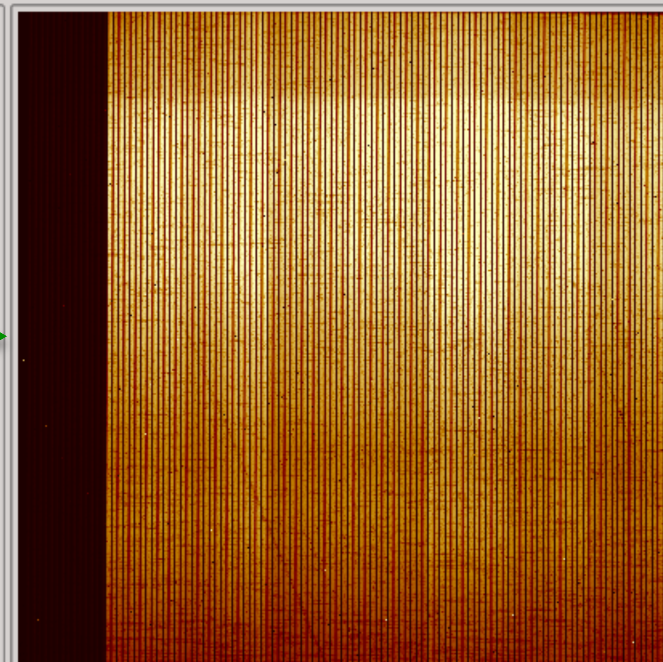
kmos

Example #2: kmo_flat

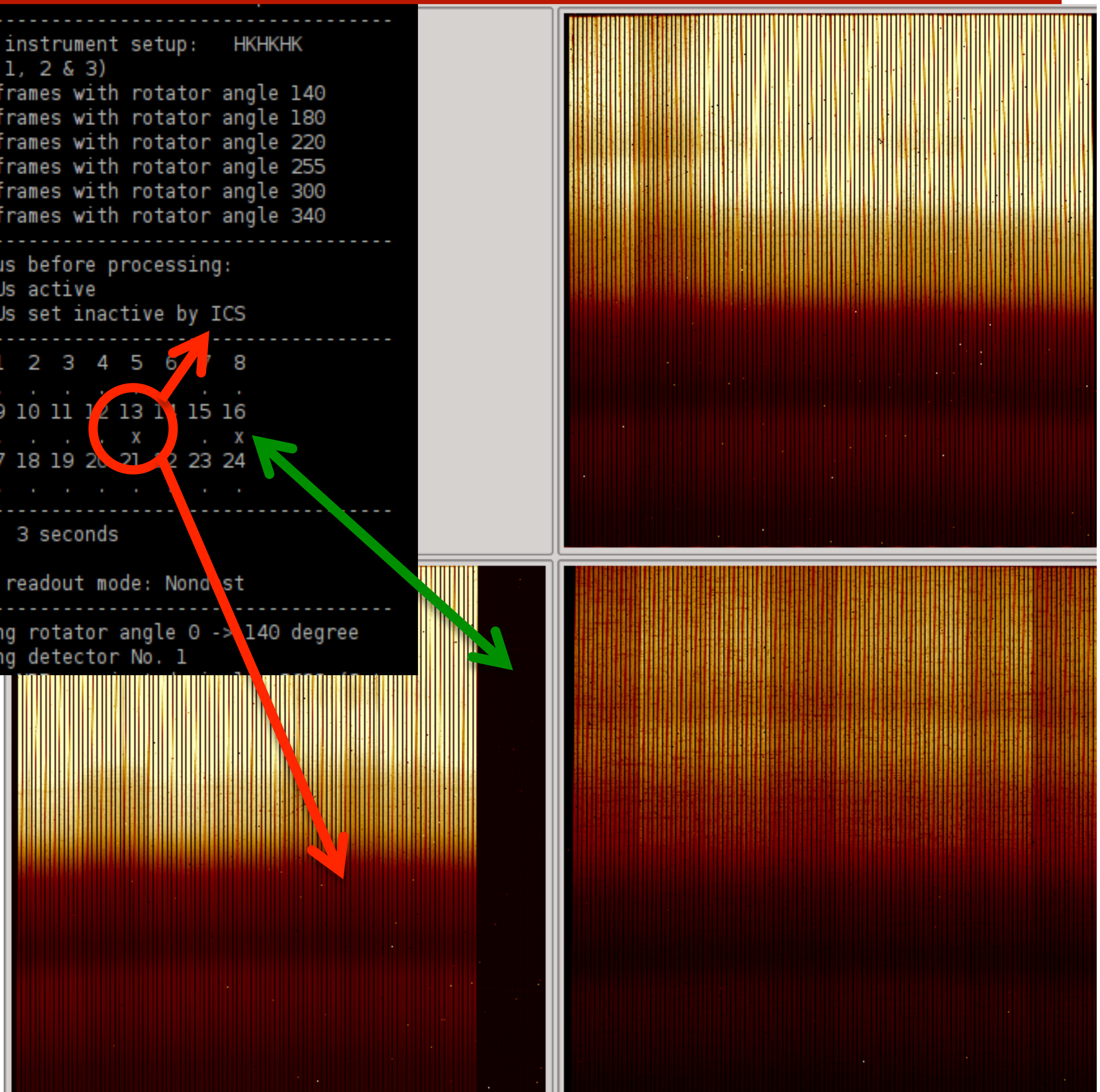
```
[ INFO  ] kmo_flat: -----------------------------------------
[ INFO  ] kmo_flat: Detected instrument setup:   HHH
[ INFO  ] kmo_flat: (grating 1, 2 & 3)
[ INFO  ] kmo_flat: Found 3 frames with rotator angle 120
[ INFO  ] kmo_flat: -----------------------------------------
[ INFO  ] kmo_flat: IFU 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: -----------------------------------------
```





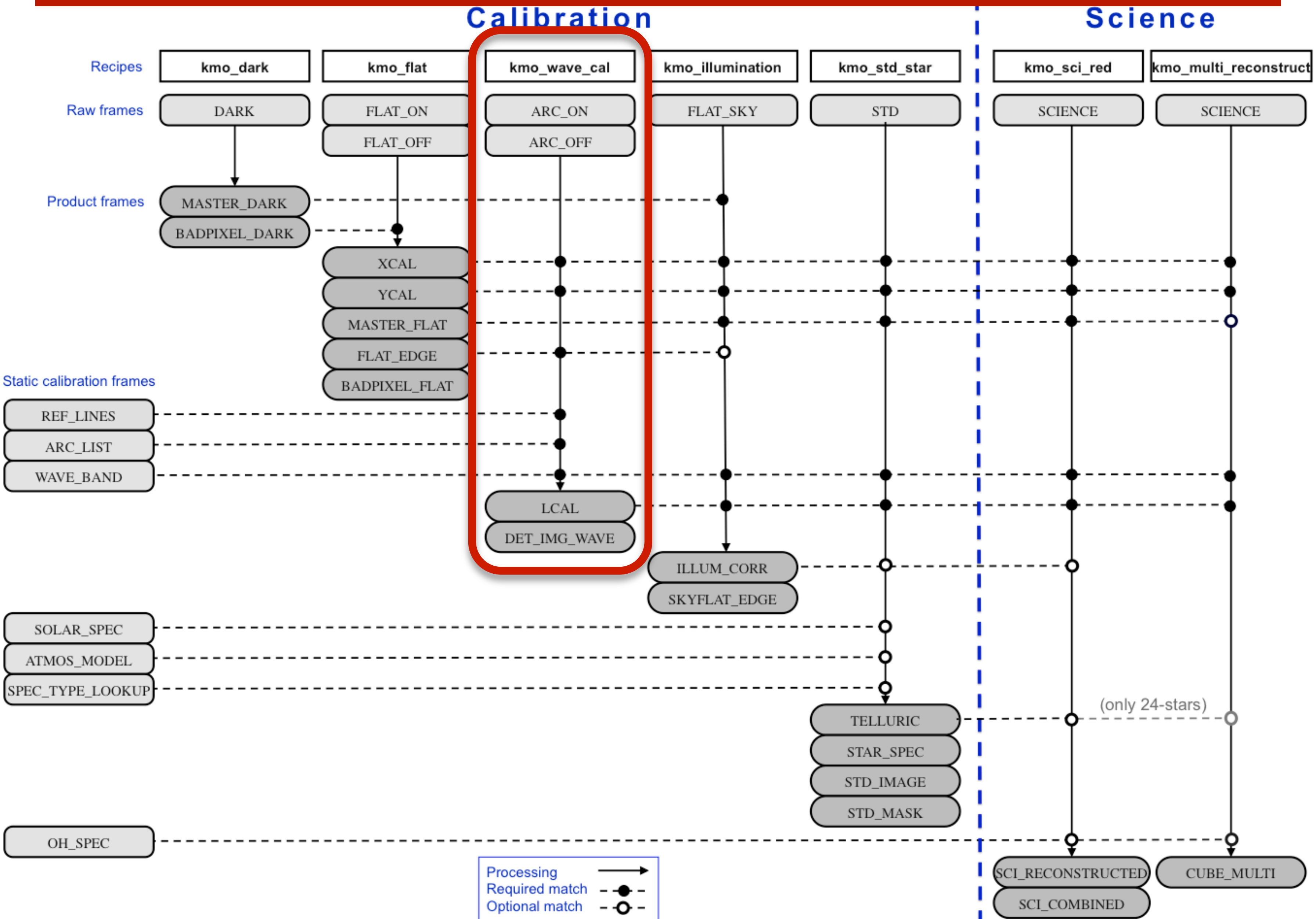


Example #3: kmo_flat



```
[ 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
```

Calibration Cascade



CALIBRATION RECIPES

Recipe: **kmo_wave_cal**

Purpose:

Create the LCAL wavelength calibration frame.

Main Parameters:

none

Example:

`esorex kmo_wave_cal arc.sof` with arc.sof containing:

```
frame_001.fits                ARC_ON
frame_002.fits                ARC_OFF
master_flat.fits              MASTER_FLAT
badpixel_flat.fits            BADPIXEL_FLAT
xcal.fits                     XCAL
ycal.fits                     YCAL
flat_edge.fits                FLAT_EDGE
kmos_wave_ref_table.fits      REF_LINES
kmos_wave_band.fits           WAVE_BAND
```

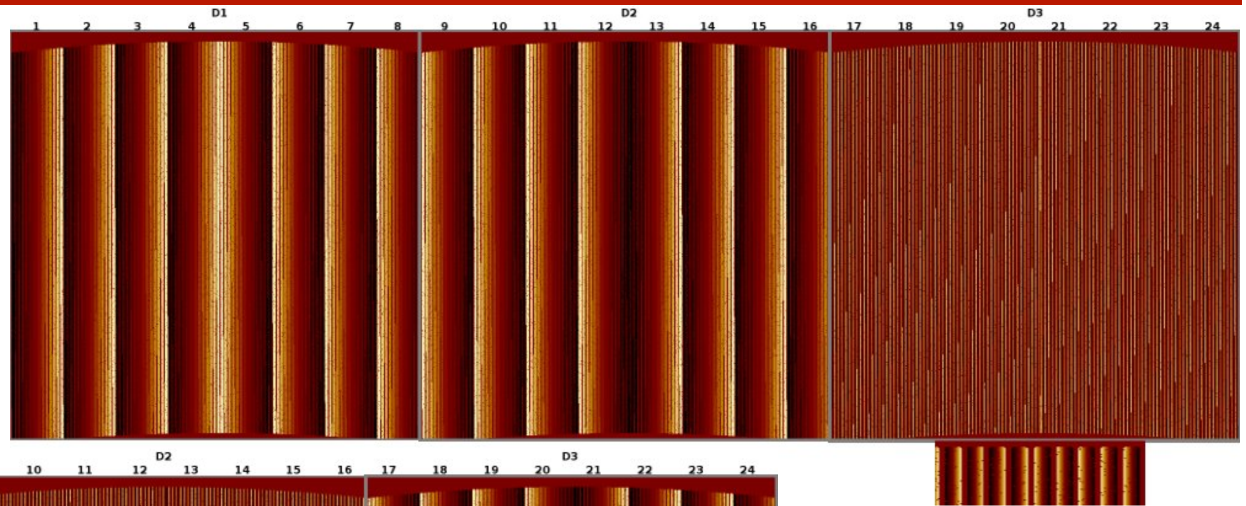
Output frames:

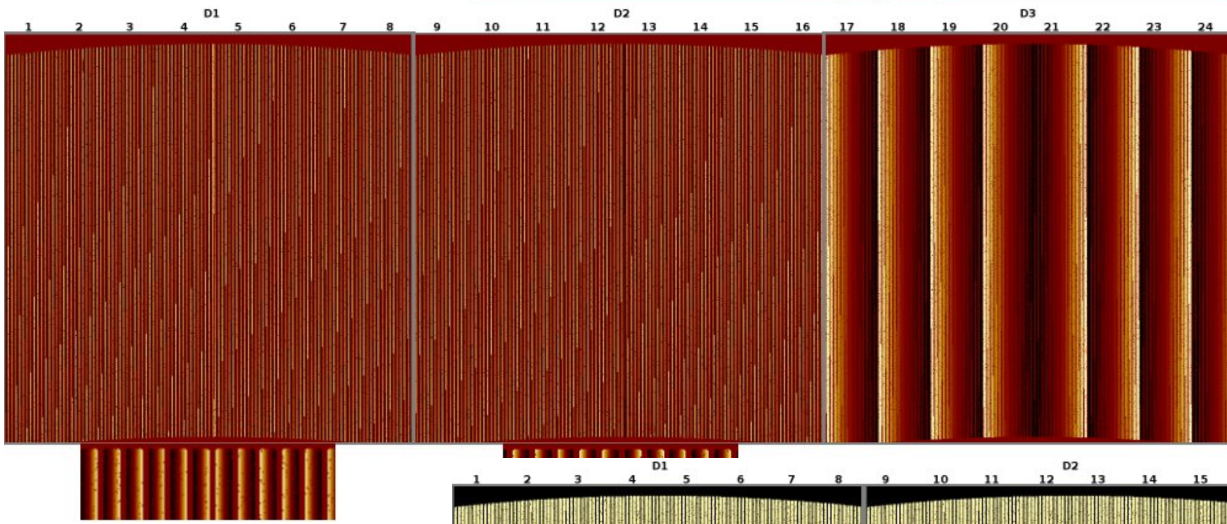
LCAL, DET_IMG_WAVE

Calibration Concept: Spatial & Spectral Frames act as Lookup Tables (LUTs)

kmo_flat

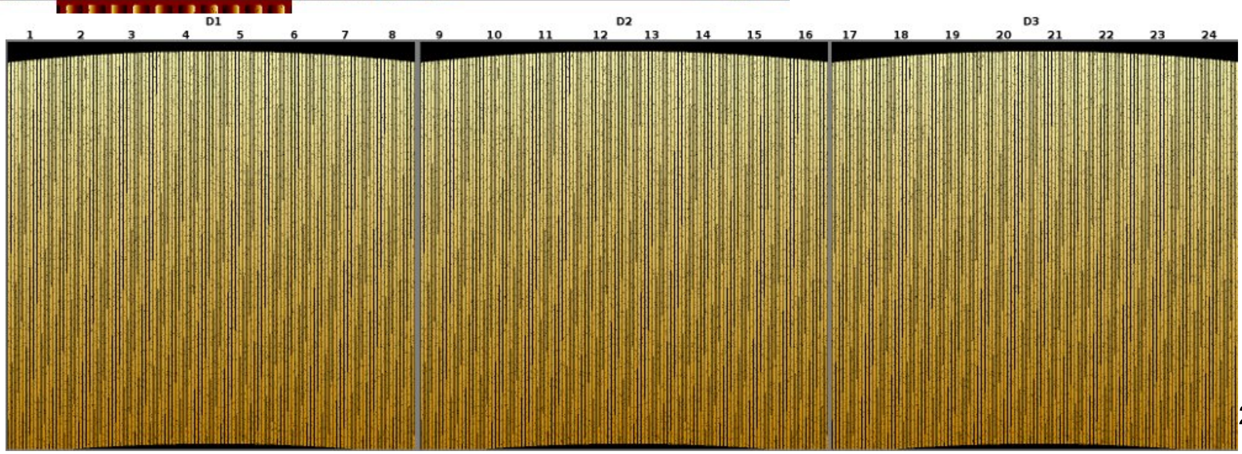
XCAL frame





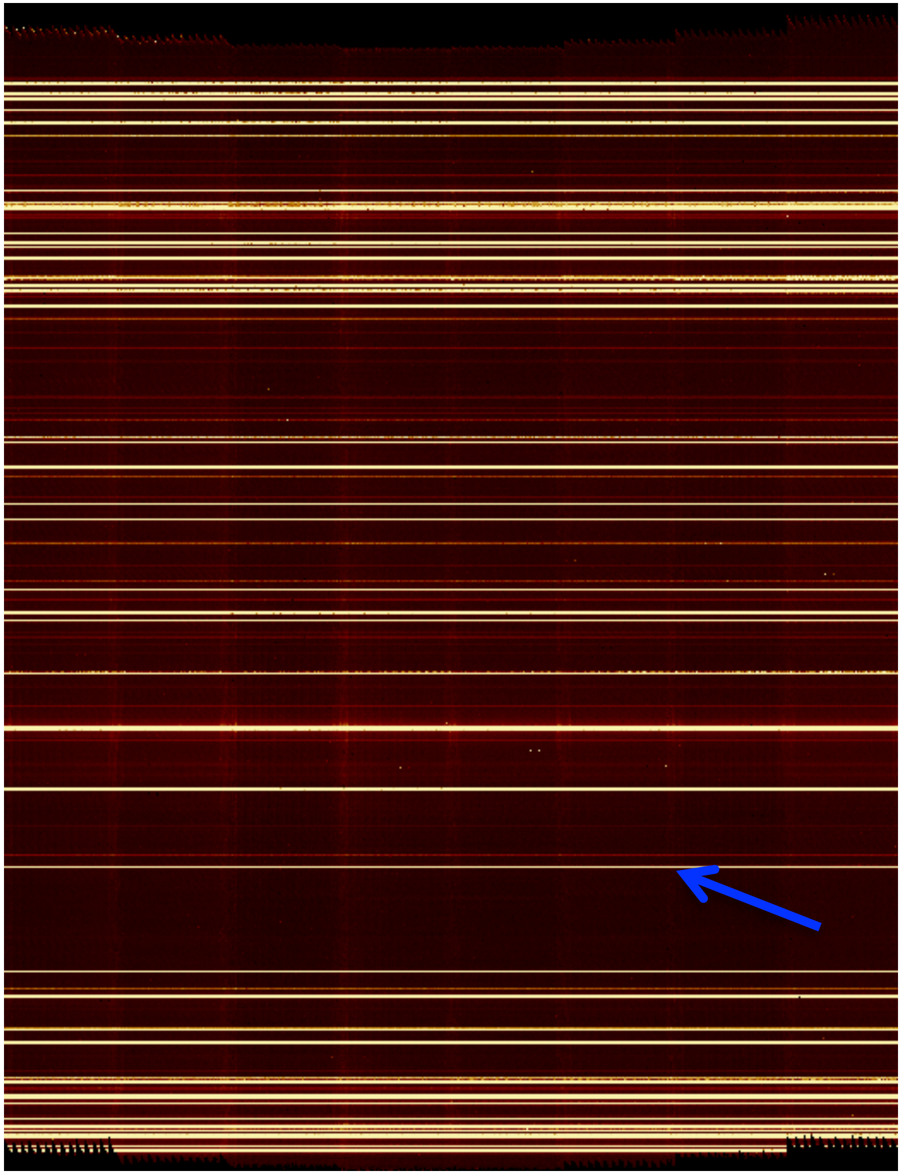
YCAL frame

kmo_wave_cal

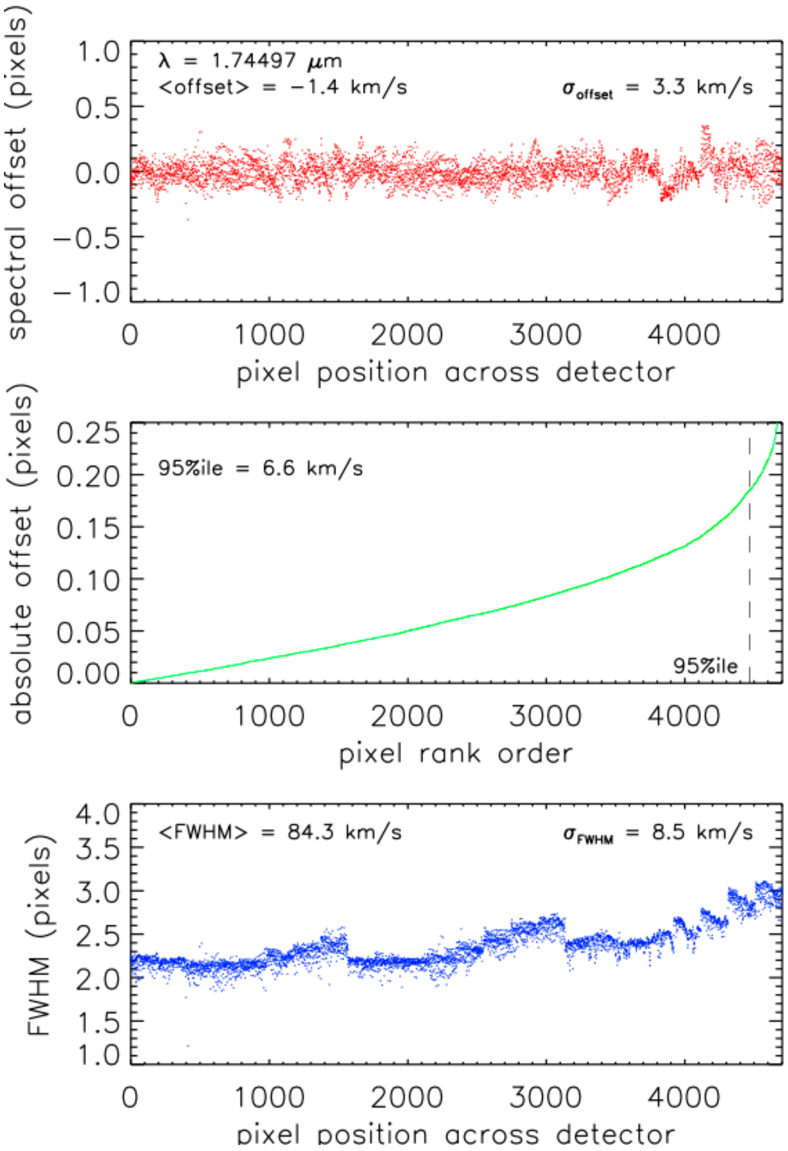


LCAL frame

Calibration accuracy: DET_IMG_WAVE



Reconstructed H-band arc frame (lwNN)



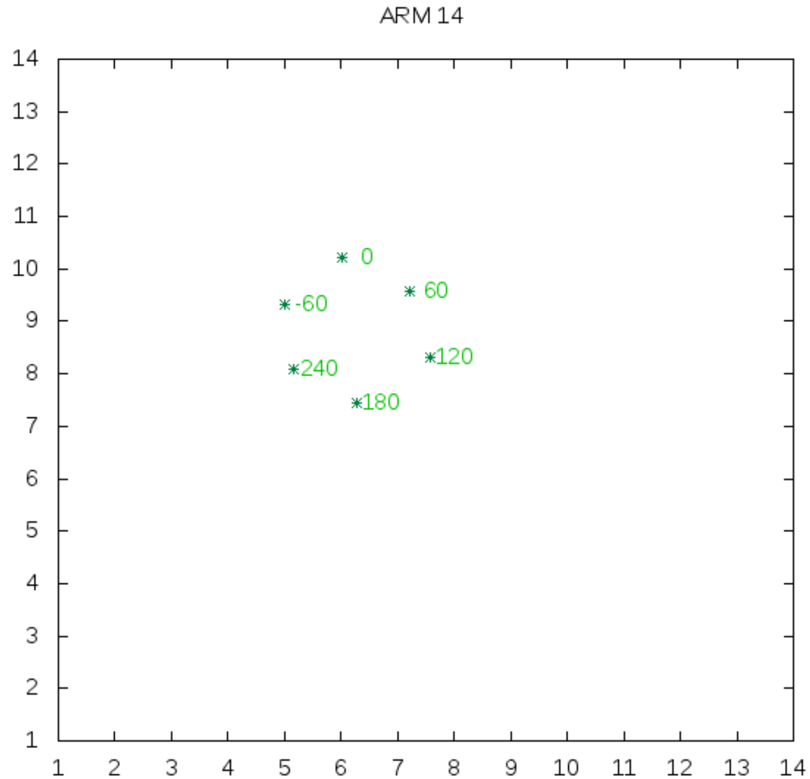
CALIBRATION RECIPES

KMOS

MPE

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

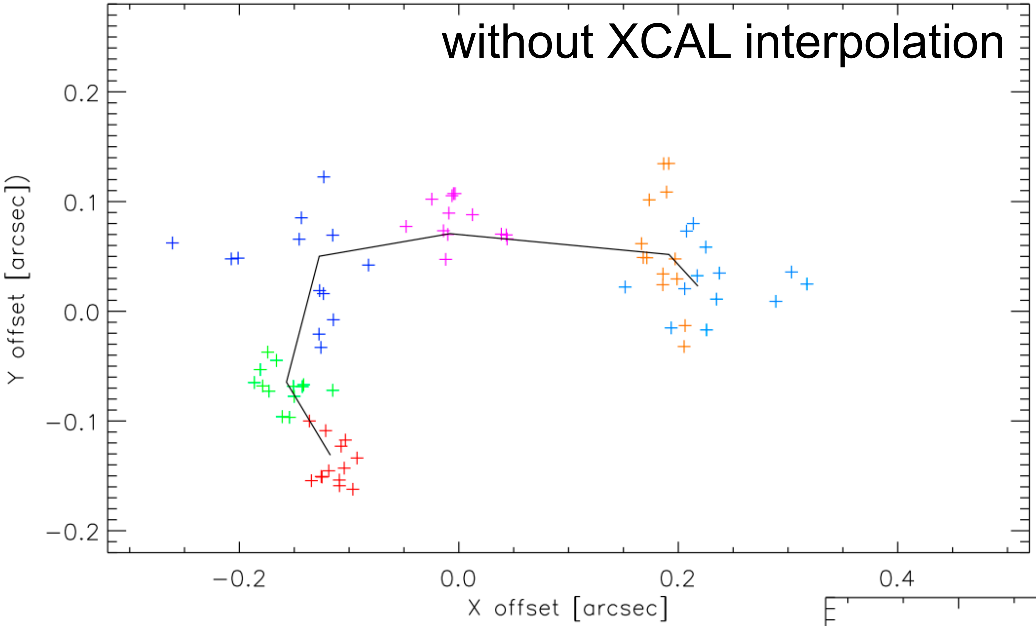
- 6 rotator angles @ 5 bands

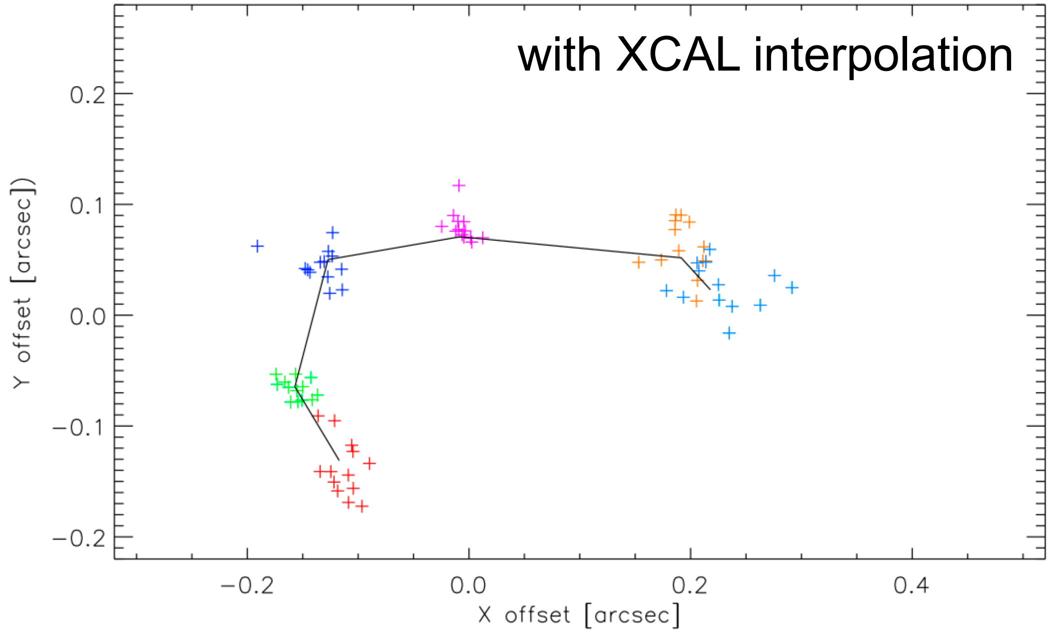
→ 5 sets of dynamic calibration frames:
BADPIXEL_DARK
BADPIXEL_FLAT
FLAT_EDGE
LCAL
MASTER_DARK
MASTER_FLAT
XCAL
YCAL

→ 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

Example: interpolation of XCAL frames

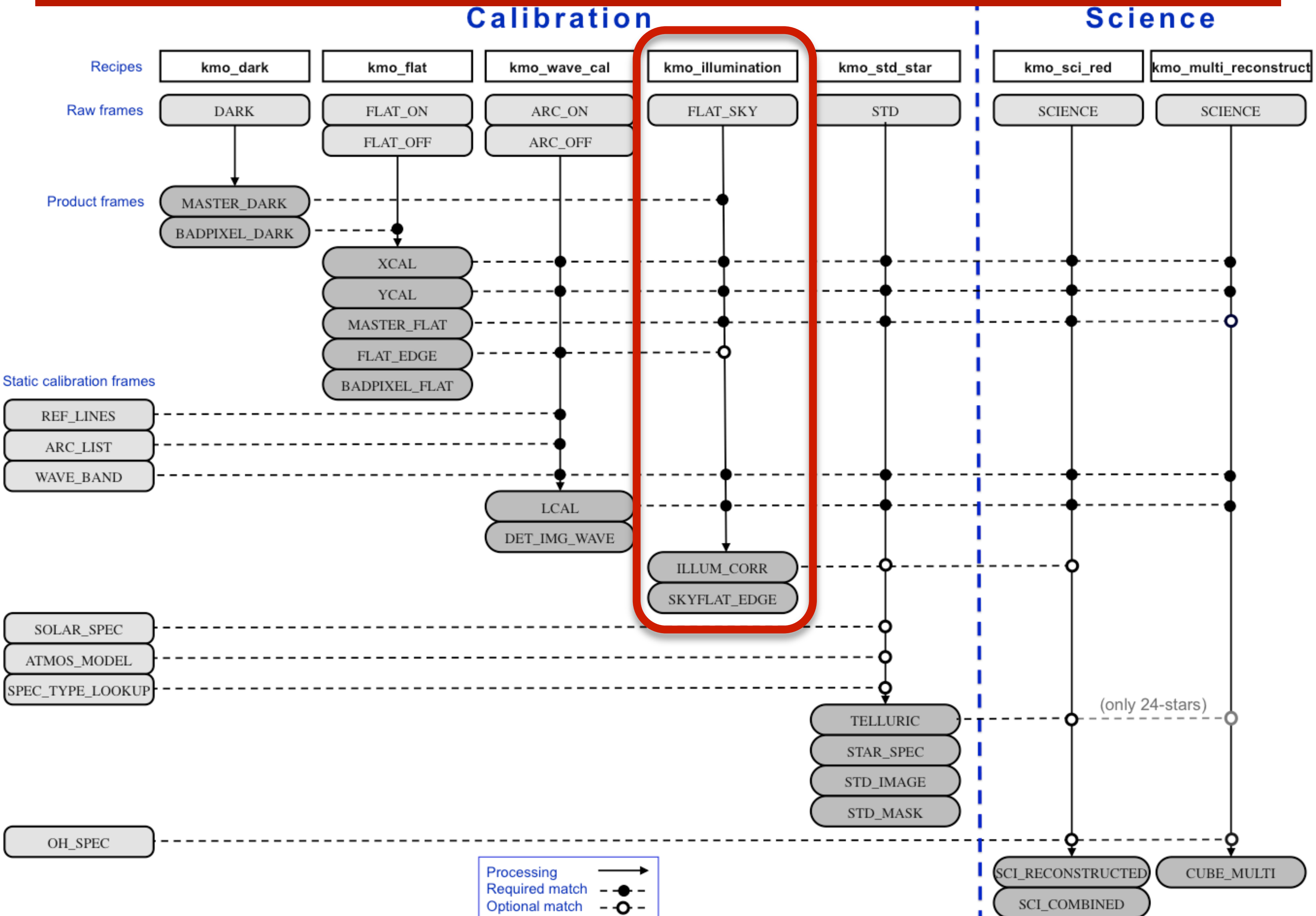




Calibration frames drift in time and with temperature!

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

Calibration Cascade



CALIBRATION RECIPES

Recipe: **kmo_illumination**

Purpose:
Create a calibration frame to correct spatial non-uniformity of flatfield.

Main Parameters:
--imethod="NN", "lwNN", "swNN", „MS", „CS"
--flux=TRUE (apply flux conservation)

Example:

`esorex kmo_illumination illum.sof`

with illum.sof containing:

```
frame_001.fits       FLAT_SKY
frame_002.fits       FLAT_SKY
frame_003.fits       FLAT_SKY
master_dark.fits     MASTER_DARK
master_flat.fits     MASTER_FLAT
xcal.fits            XCAL
ycal.fits            YCAL
lcal.fits            LCAL
kmos_wave_band.fits  WAVE_BAND
```

It is recommended to supply at least 3 FLAT_SKY frames

Output frames:
ILLUM_CORR

kmo_illumination

Sub-optimal rotator angles

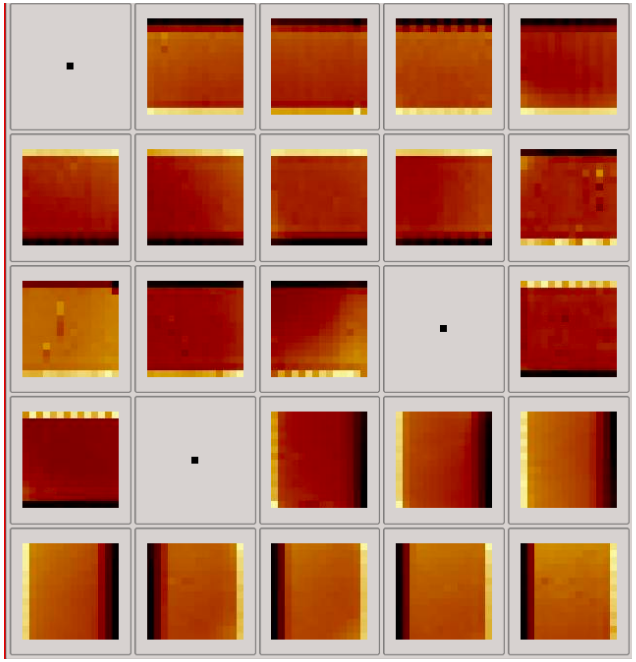
Problem

- 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

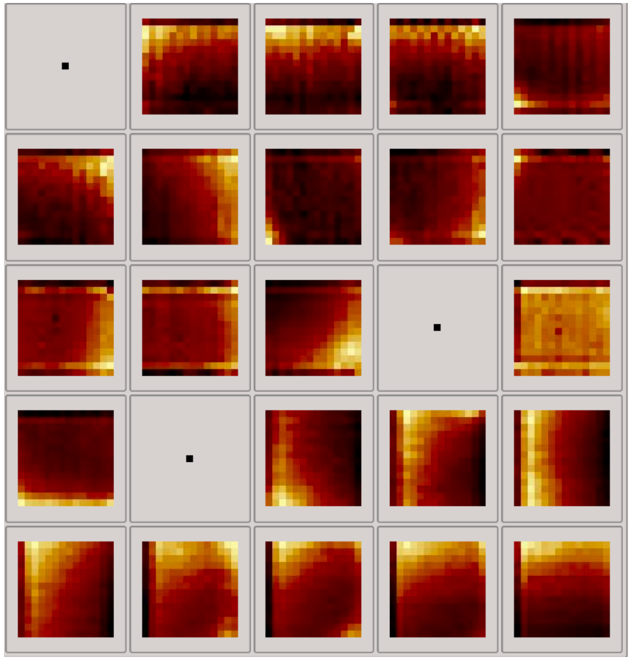
Optimal rotator angles

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



(noise has been stripped with kmo_fits_strip)



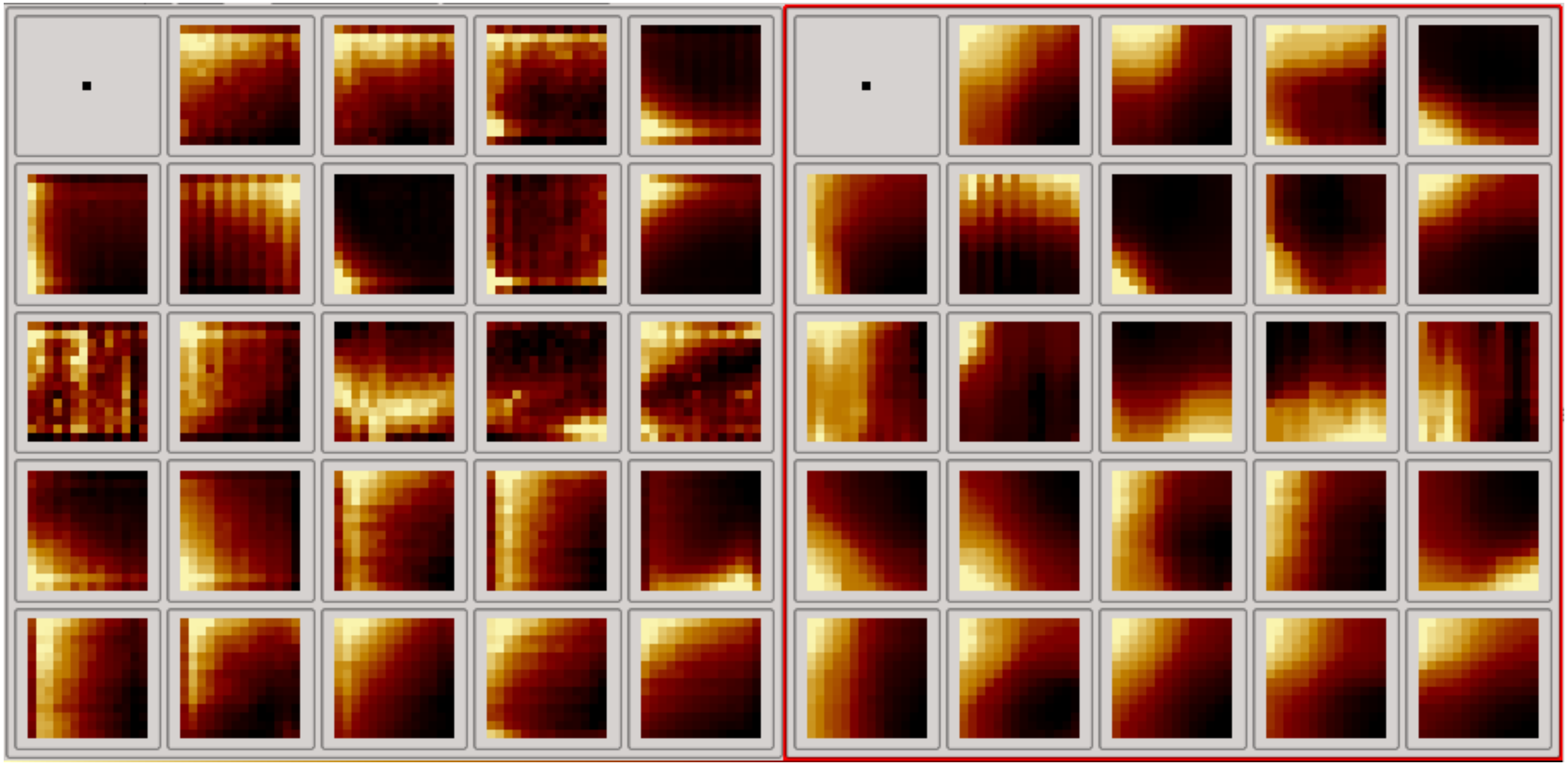
kmo_illumination vs. kmo_illumination_flat

kmo_illumination
- several FLAT_SKY frames

Pro:
Real sky exposures
Con:
Edge effects due to flexure (FLAT_SKY and MASTER_FLAT not matching exactly)

kmo_illumination_flat
- Using FLAT_ON frames

Pro:
No edge effects



Recipe: **kmo_illumination_flat**

Purpose:

Create a calibration frame to correct spatial non-uniformity of flatfield.

Main Parameters:

--imethod="NN", "lwNN", "swNN", „MS", „CS"

--flux=TRUE (apply flux conservation)

Example:

```
esorex kmo_illumination_flat illum_flat.sof
```

with illum_flat.sof containing:

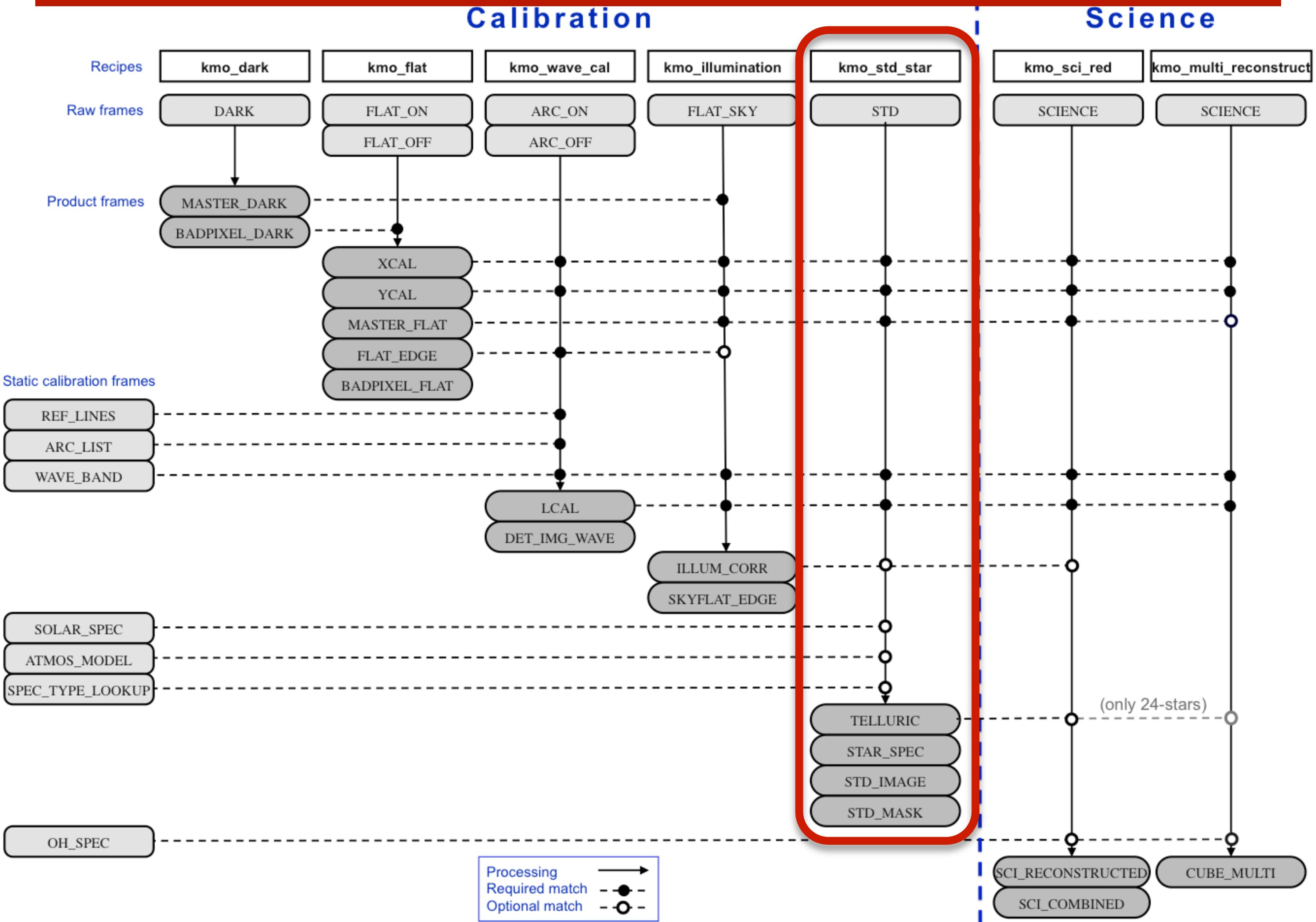
```
flat_001.fits            FLAT_SKY_FLAT
flat_002.fits            FLAT_SKY_FLAT
flat_003.fits            FLAT_SKY_FLAT
xcal.fits                XCAL
ycal.fits                YCAL
lcal.fits                LCAL
kmos_wave_band.fits      WAVE_BAND
```

It is recommended to supply at least 3 FLAT_SKY_FLAT frames

Output frames:

ILLUM_CORR

Calibration Cascade



Recipe: **kmo_std_star**

Purpose:
Create the telluric correction frame

Main Parameters:
--imethod=“NN”, “lwNN”, “swNN”, „MS“, „CS“
--startype=“B7III“
--magnitude=7

Common 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

Example:

```
esorex kmo_std_star std.sof
```

with std.sof containing:

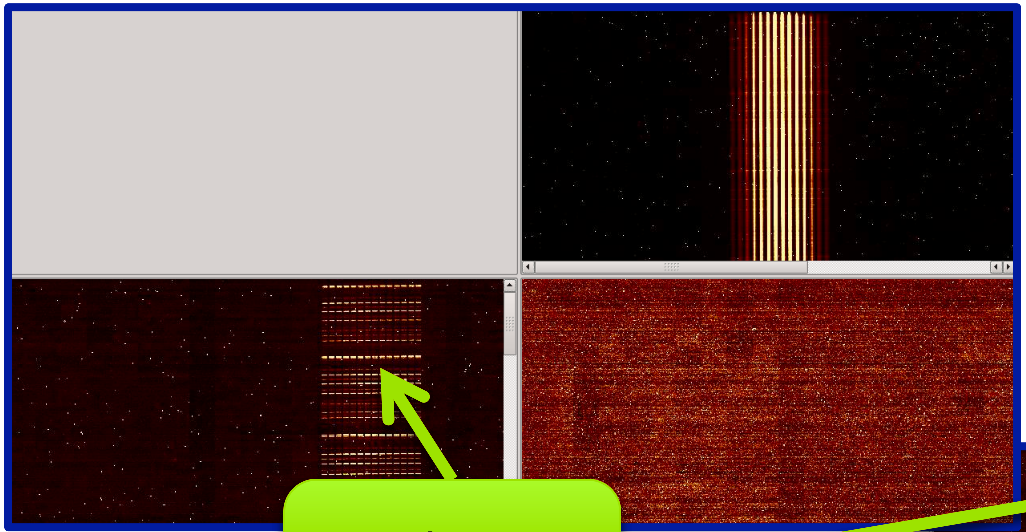
```
frame_001.fits          STD
frame_002.fits          STD
frame_003.fits          STD
master_flat.fits        MASTER_FLAT
xcal.fits               XCAL
ycal.fits               YCAL
lcal.fits               LCAL
kmos_wave_band.fits     WAVE_BAND
illum_corr.fits         ILLUM_CORR
kmos_solar_h_2400.fits  SOLAR_SPEC
kmos_atmos_h.fits       ATMOS_MODEL
kmos_spec_type.fits     SPEC_TYPE_LOOKUP
```

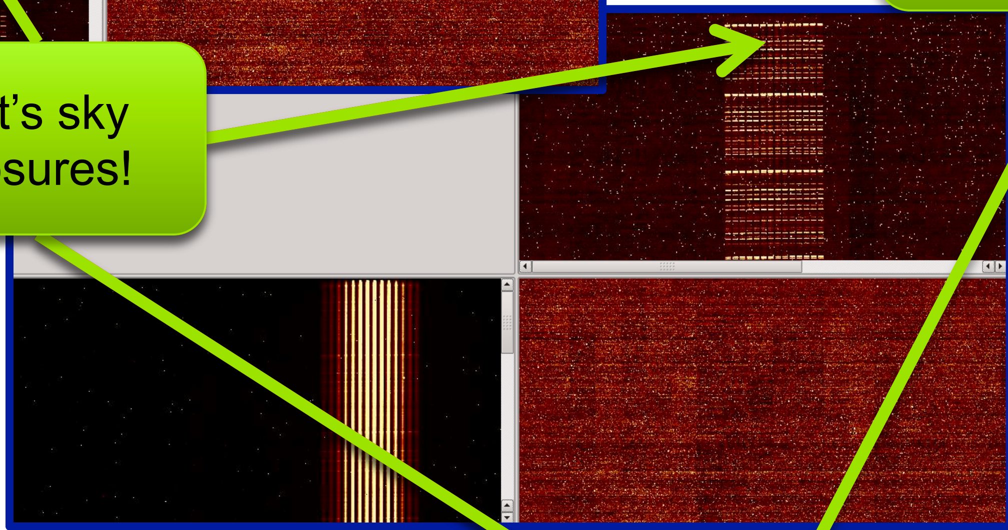
Output frames:
TELLURIC, STD_IMAGE

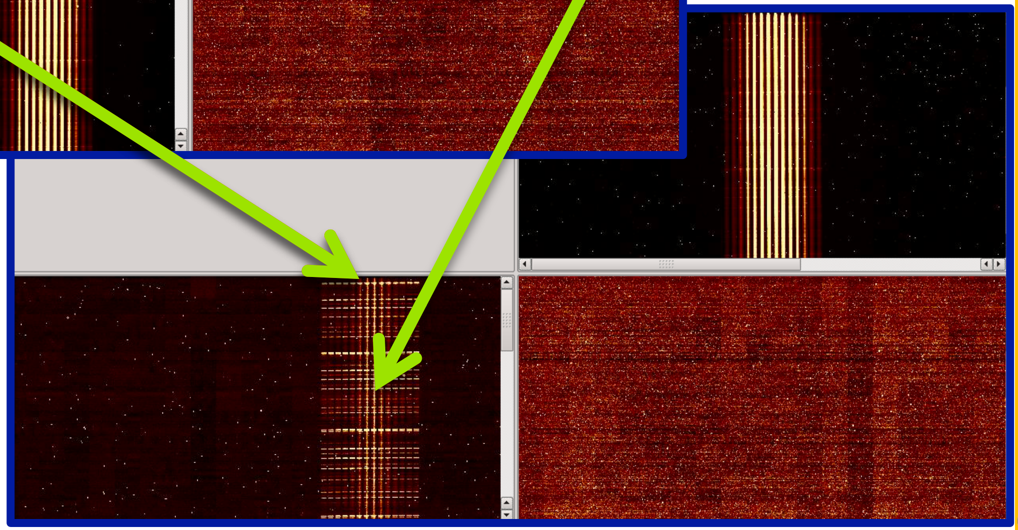
kmo_std_star: The RAW frames and their contents

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





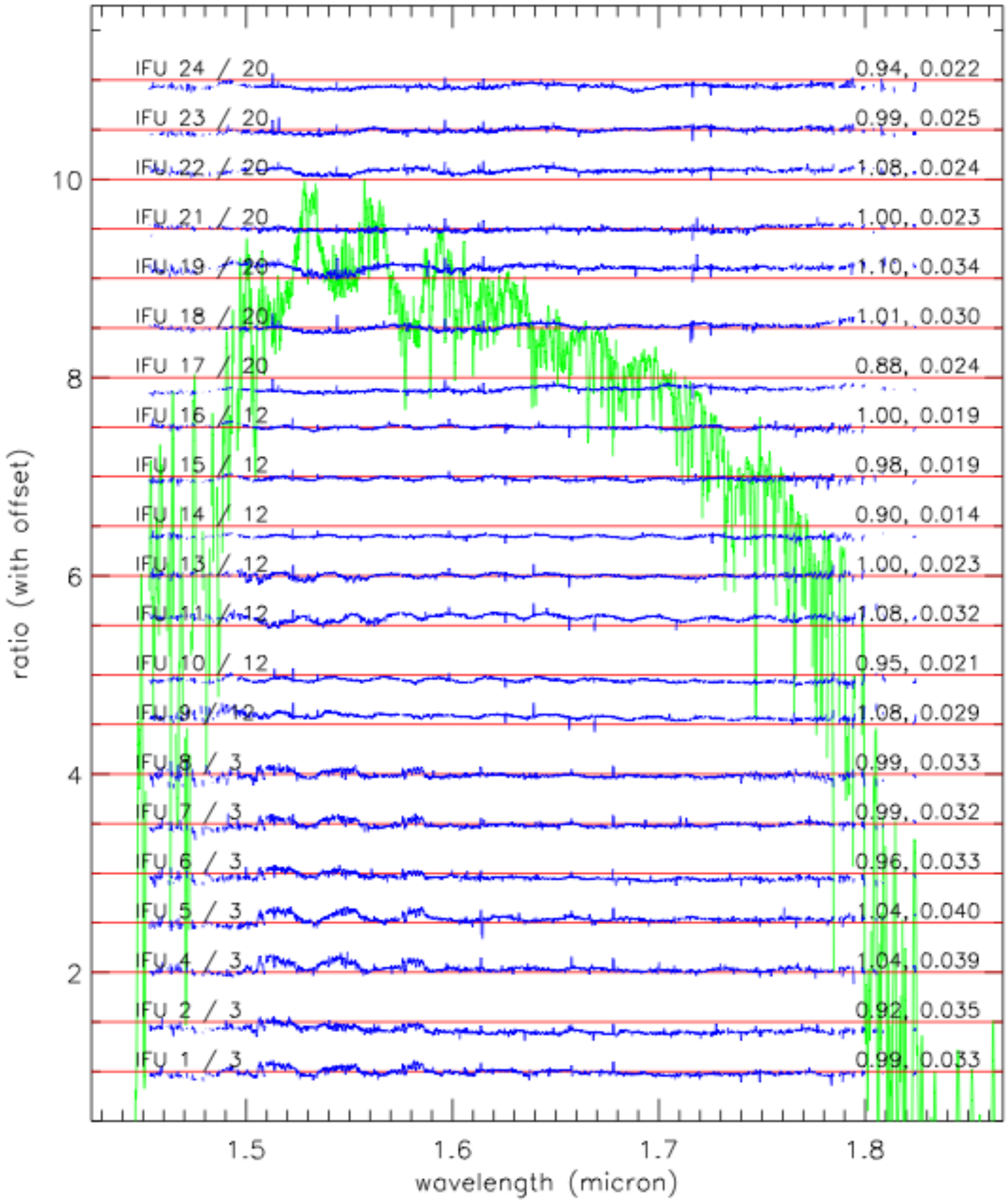


No, it's sky exposures!

Indeed, here we have persistency

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

Standard star templates: 3-star vs. 24-star template



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

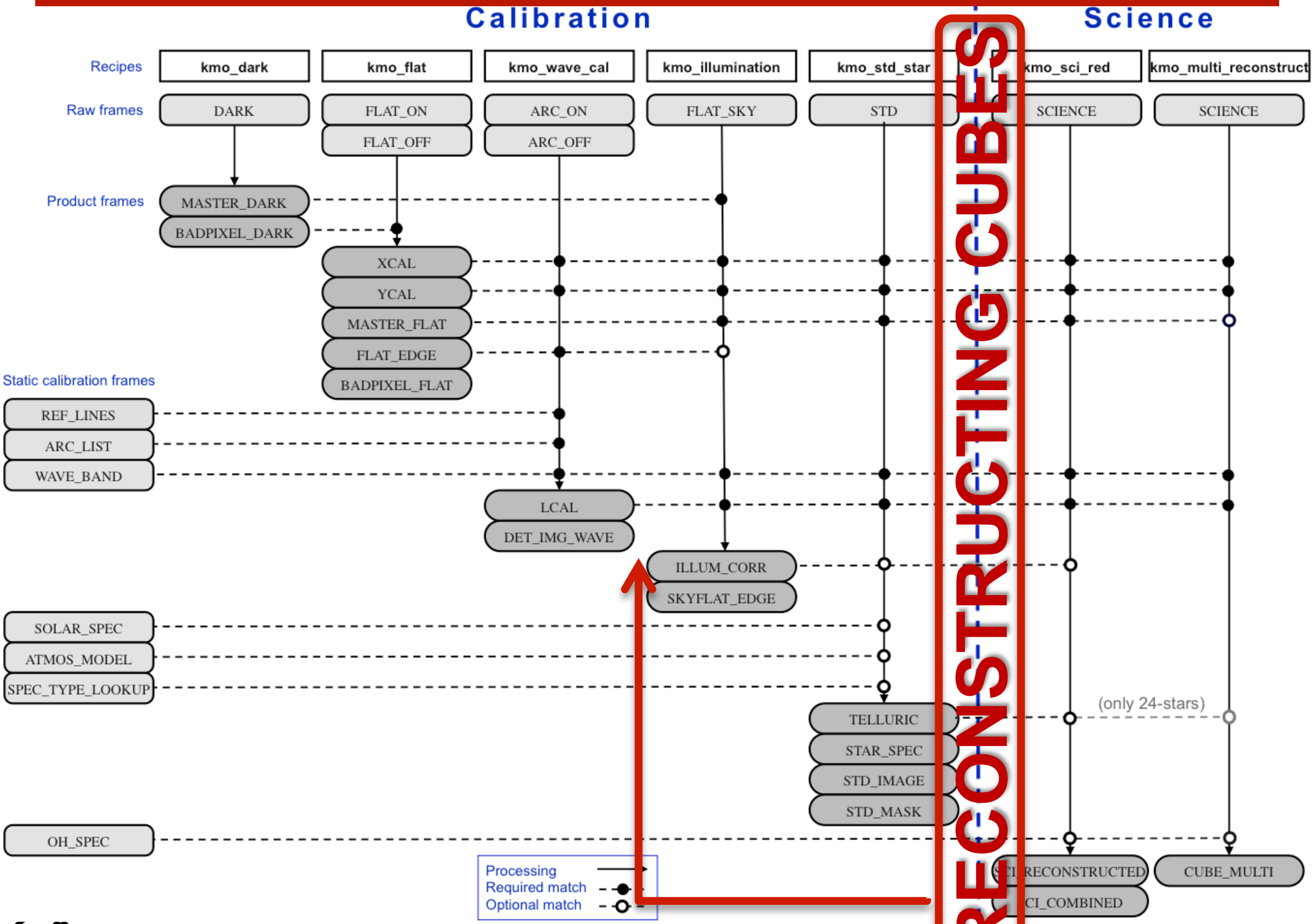
Just using 3 arms to calibrate all IFUs sufficient at the level of precision of few percent

→ gain in time during calibration

→ **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)

Calibration Cascade



Recipe: **kmo_reconstruct**

Purpose:

Reconstruct the 24 cubes of a single exposure.
Note that **no separate bad pixel mask is required** because it is already encoded in the calibration frames.

Main Parameters:

--imethod="NN", "lwNN", "swNN", „MS", „CS"
--flux=TRUE (apply flux conservation)

Example:

```
esorex kmo_reconstruct reconstruct.sof
```

with reconstruct.sof containing:

```
frame_001.fits       OBJECT
xcal.fits            XCAL
ycal.fits            YCAL
lcal.fits            LCAL
kmos_wave_band.fits  WAVE_BAND
```

Instead of OBJECT as well DARK, FLAT_ON, ARC_ON, STD or SCIENCE can be provided

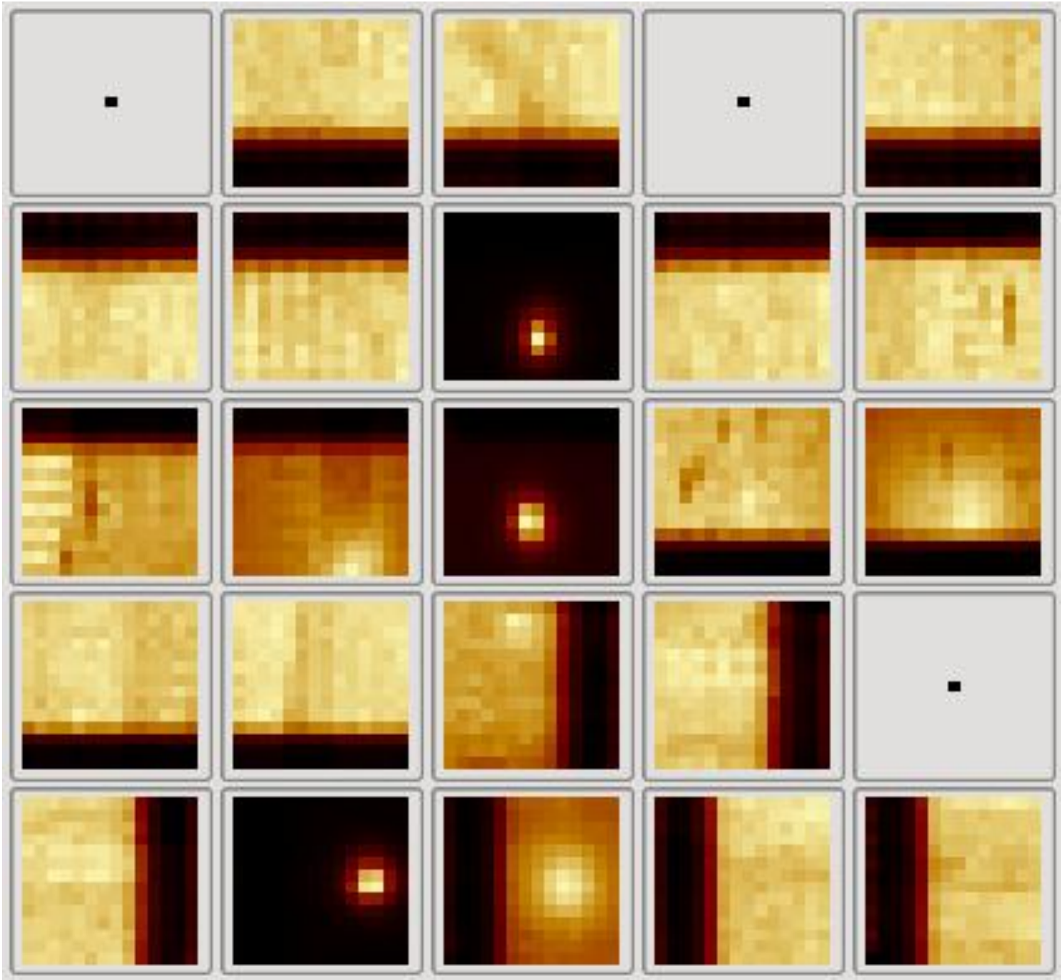
Output frames:

CUBE_DARK, CUBE_FLAT, CUBE_ARC, CUBE_OBJECT, CUBE_STD or CUBE_SCIENCE
DET_IMG_WAVE (optional)

Example of bad reconstruction

Issue:
Big stripes at IFU borders

- Reconstruction has been executed
- But calibrations don't match the data frames
- e.g. gratings slightly in a different position

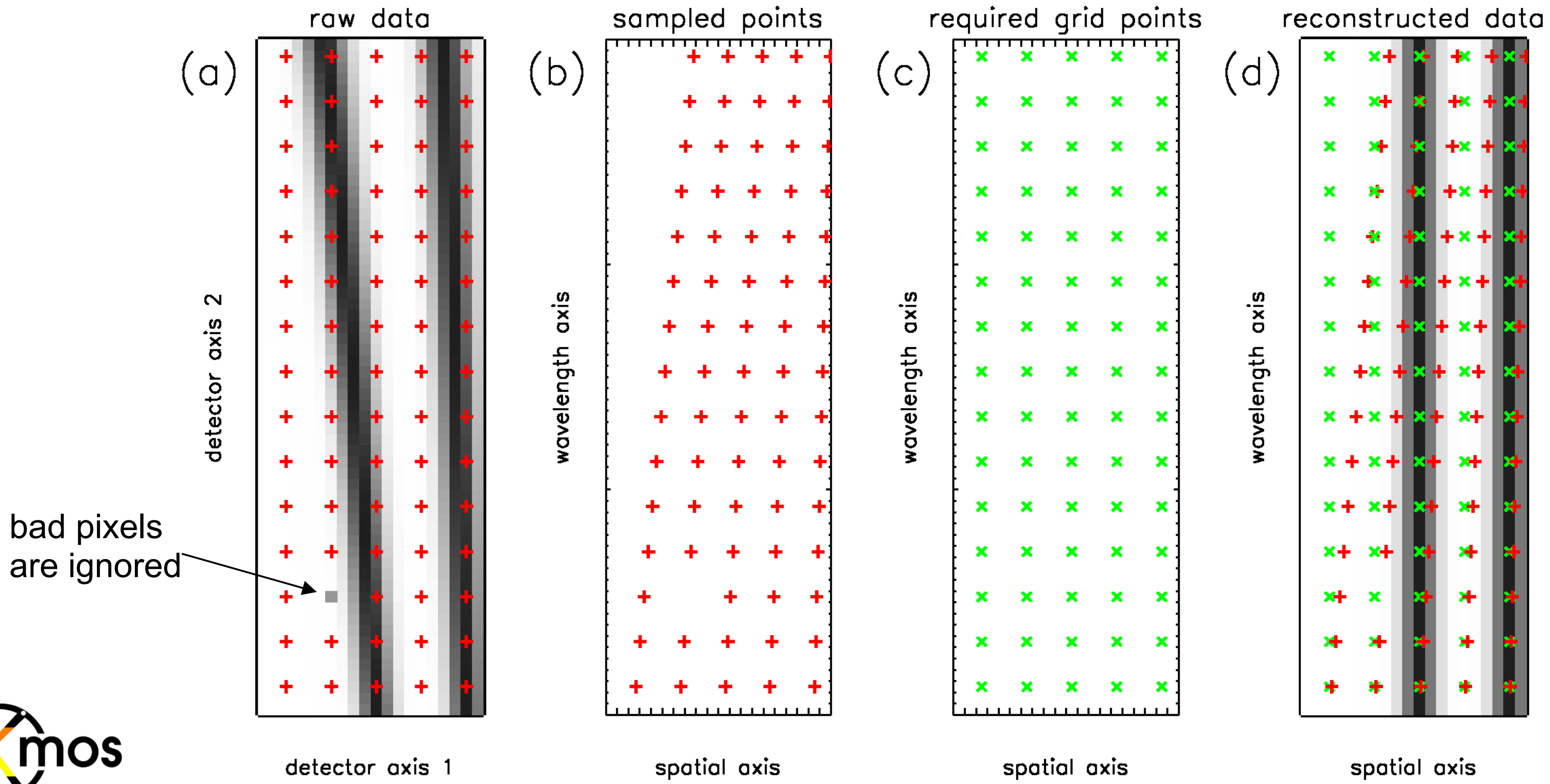


Solution:
Take new calibration frames

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, λ_0
...
value$_n$, x_n, y_n, λ_n

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

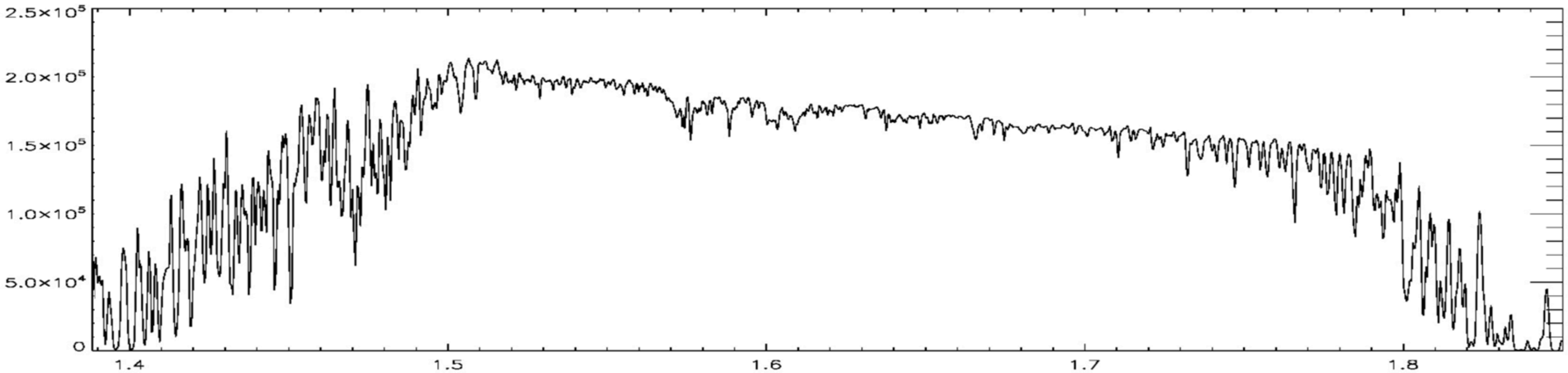


KMOS

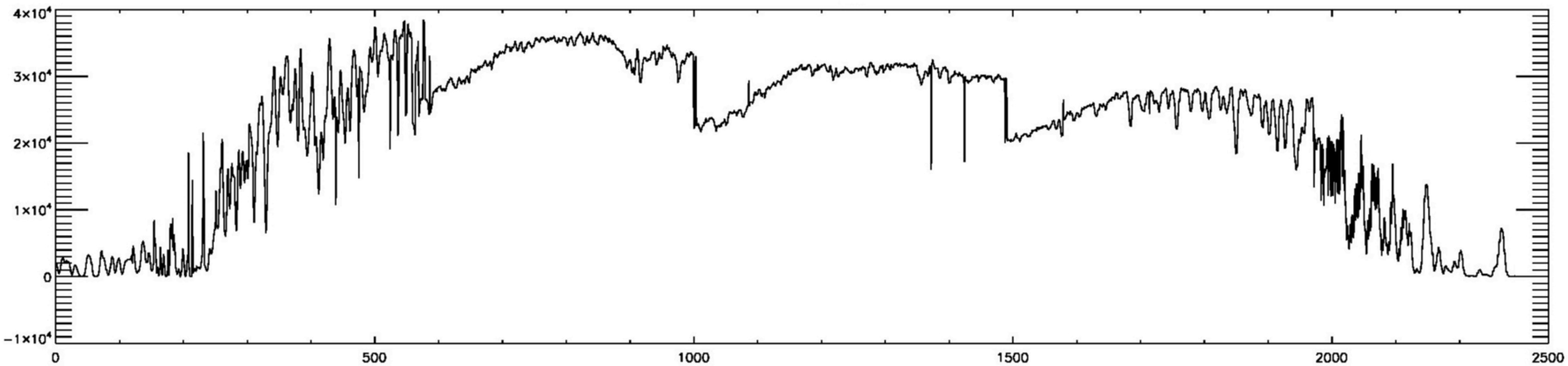
MPE

Comparison of Interpolation methods: Spectral Effects

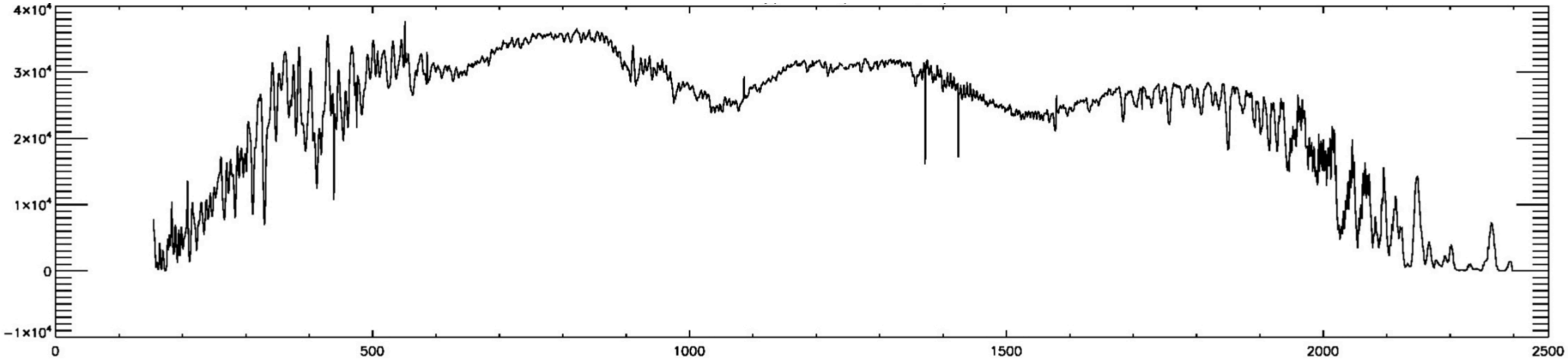
Original spectrum



Nearest Neighbour

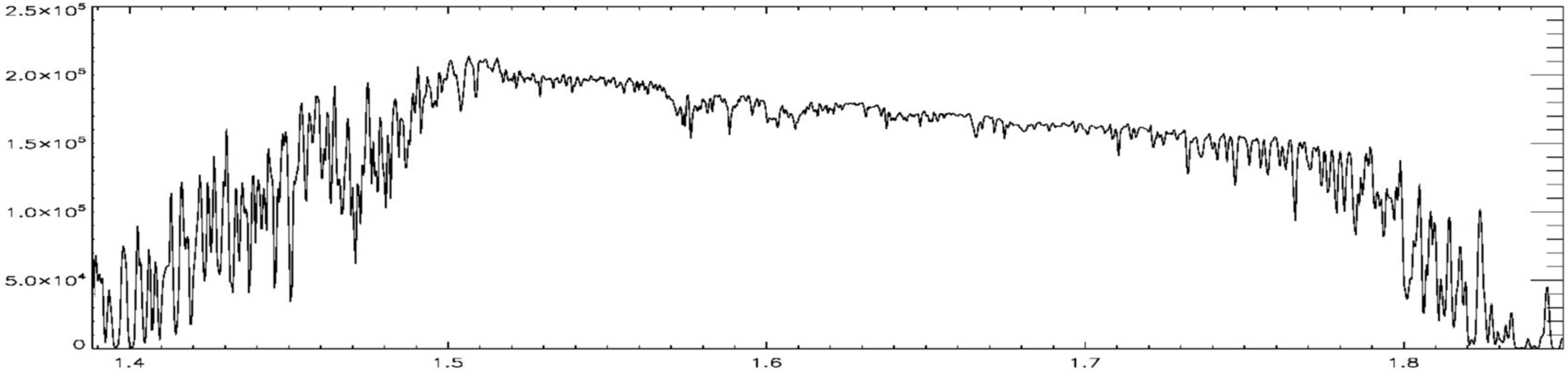


Modified Shepard's method

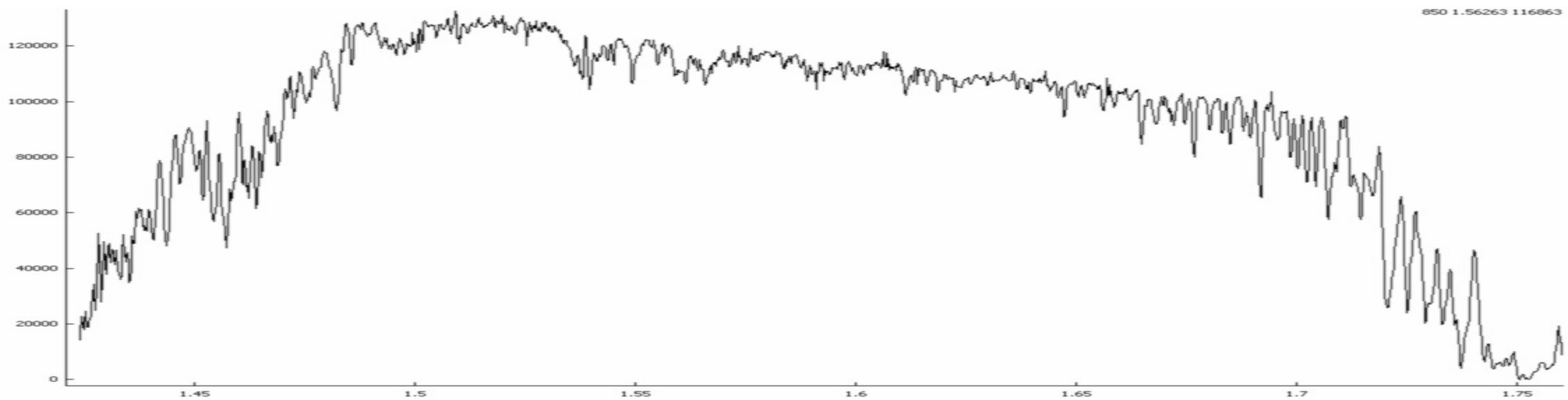


Comparison of Interpolation methods: Spectral Effects

Original spectrum



Cubic spline

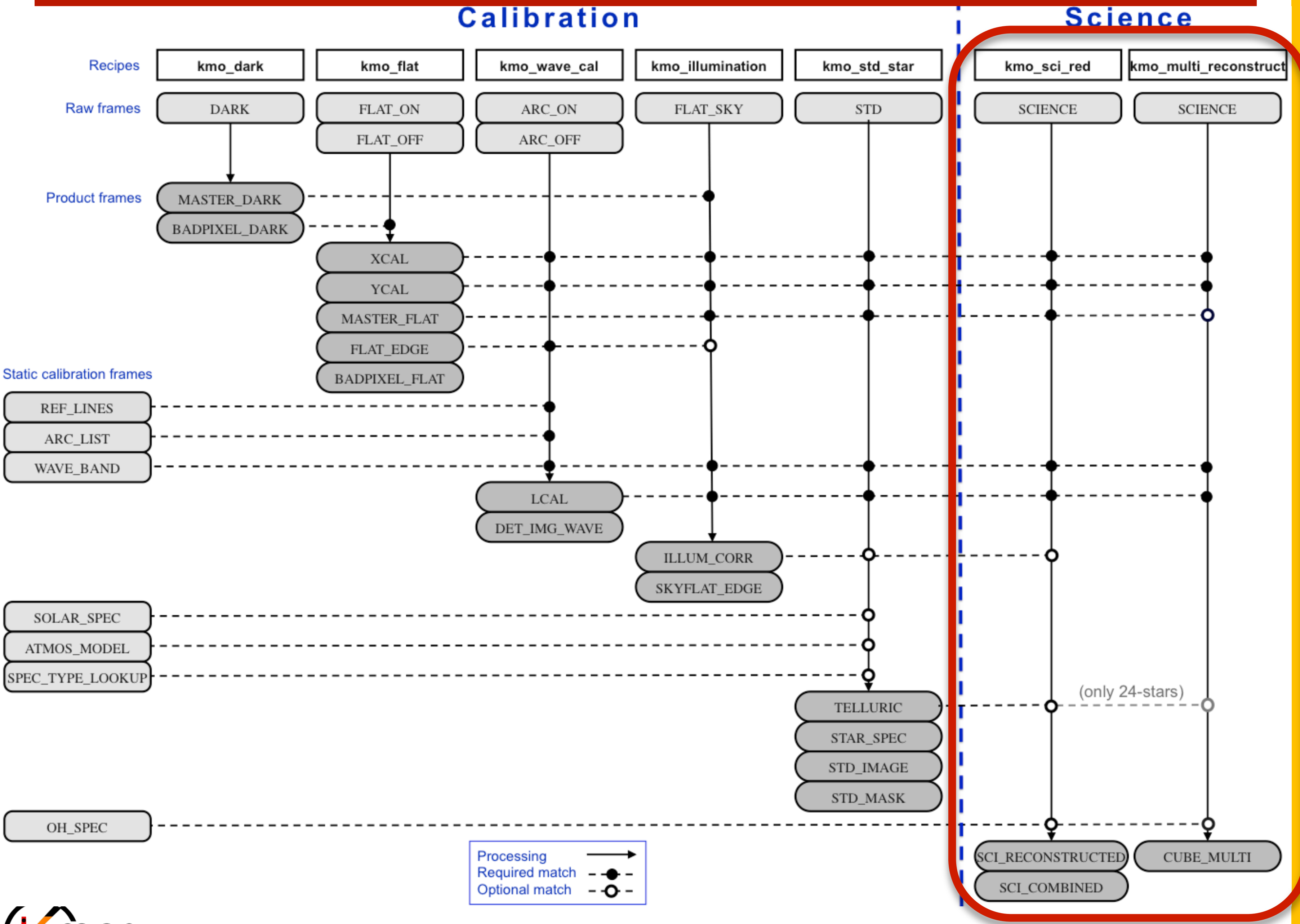


Ripples introduced during reconstruction
With CS being less severe than with NN-methods

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

kmos MPE

Calibration Cascade



SCIENCE REDUCTION RECIPES

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

→ **Poor:** Data is interpolated twice

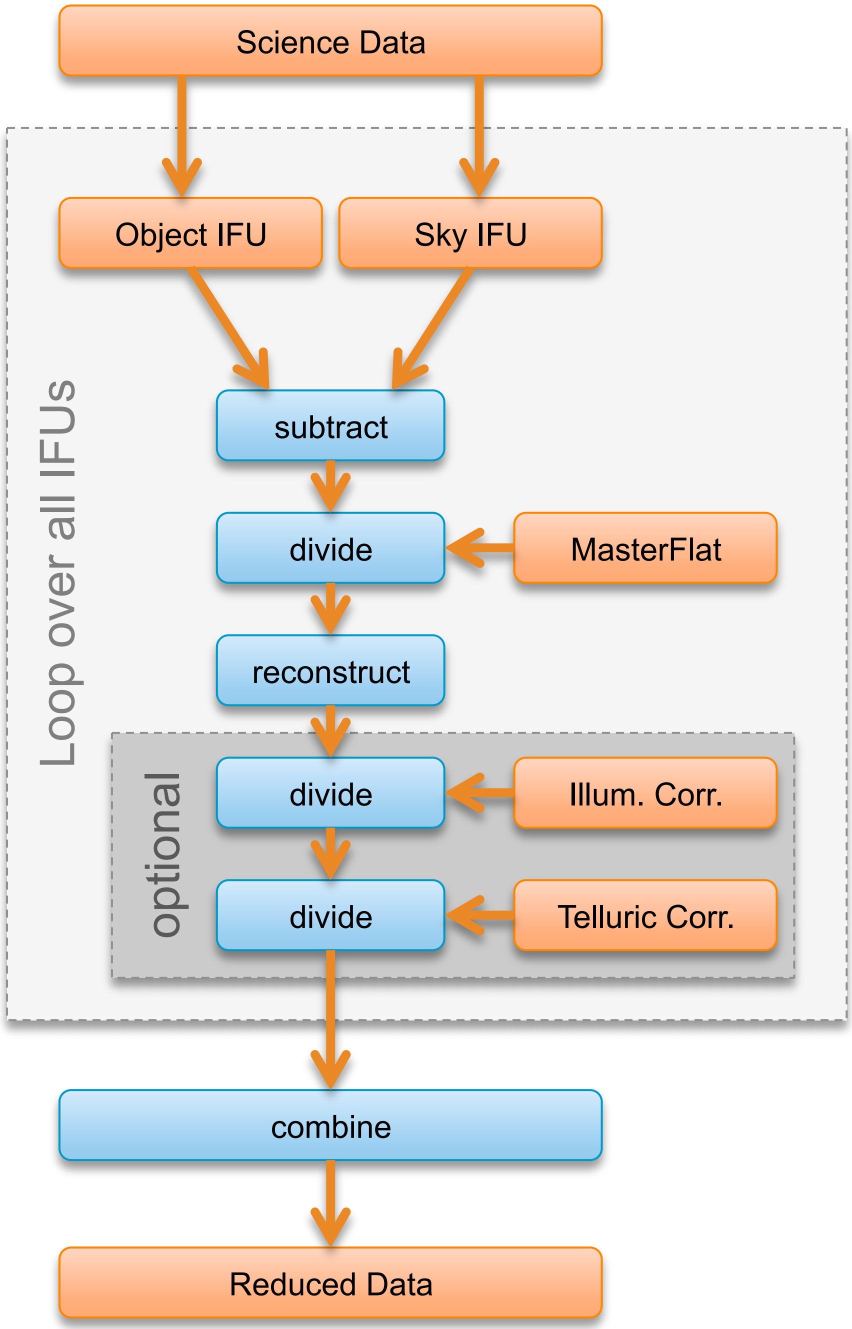
Advanced Reconstruction & Combination

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

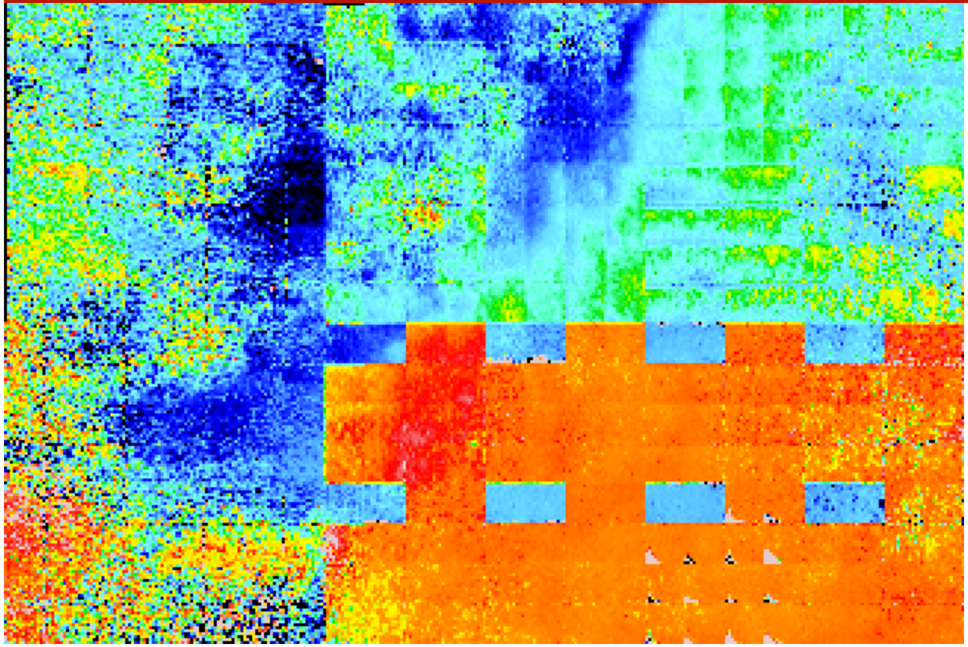
→ **Pretty:** Data is interpolated once!

→ **BUT:**

- Advanced recipe for expert users
- Doesn't provide all features kmo_sci_red does!
  e.g. ILLUM_CORR would have to be mapped back to RAW image space and is therefore not supported
- TELLURIC only supported with 24-star template

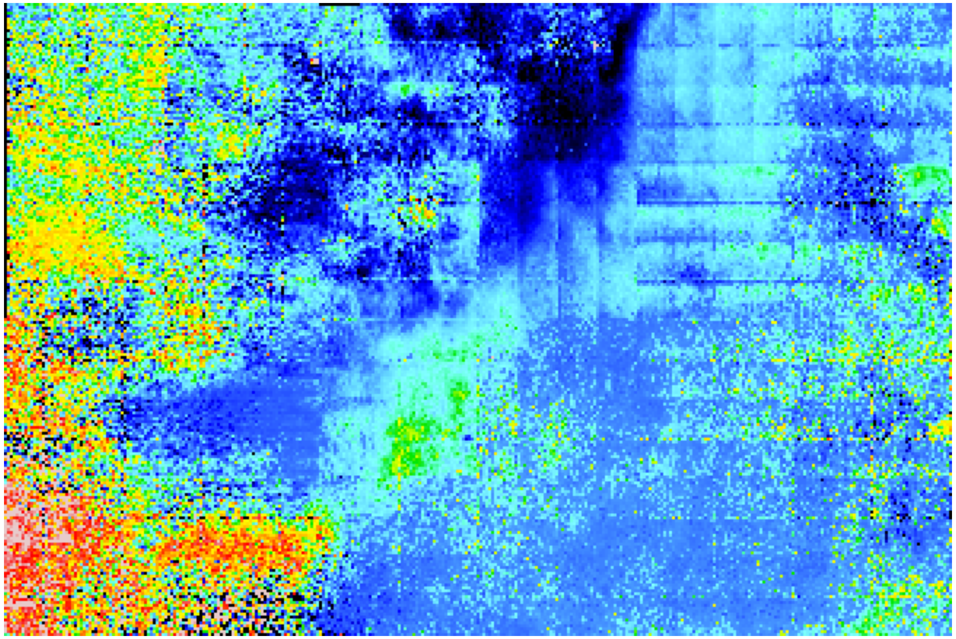


Example: Wavelength matching



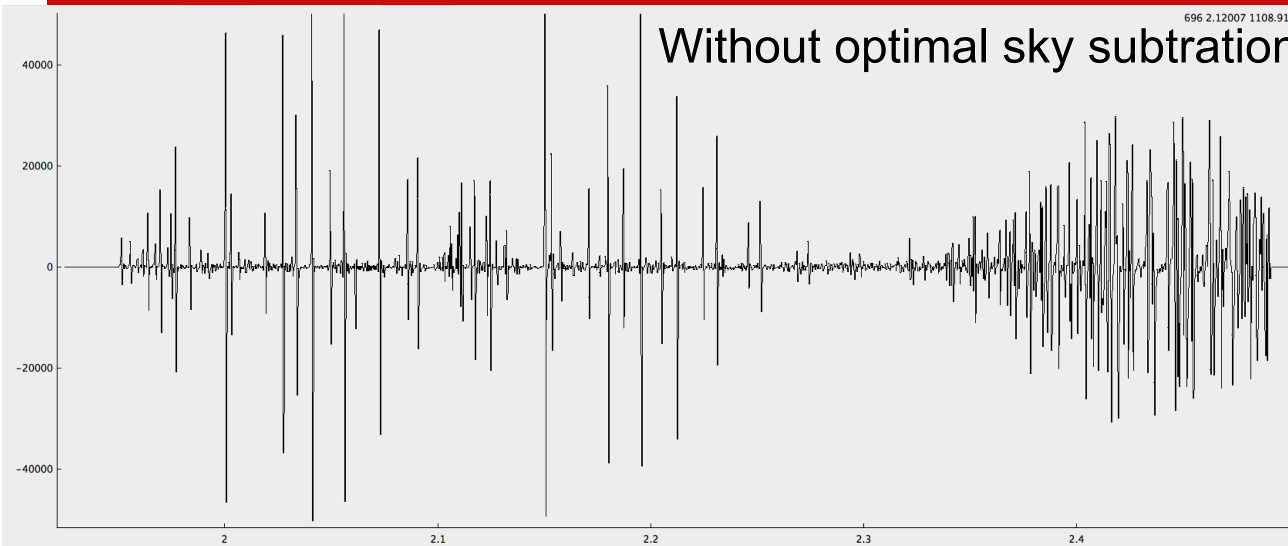
before

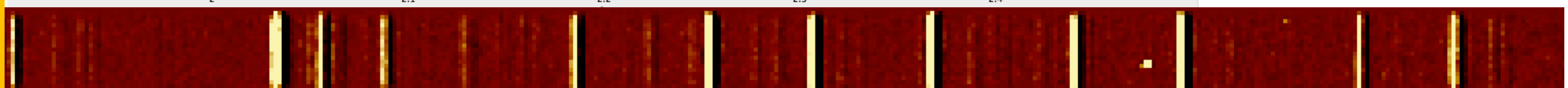
after

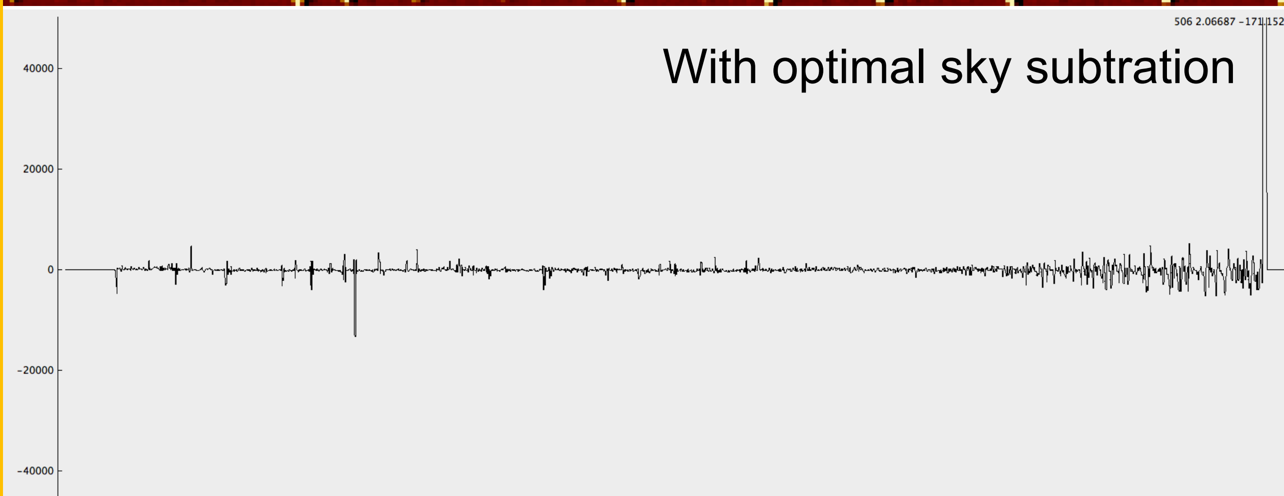


→ kmo_sci_red with OH_SPEC frame provided

Example: Optimal sky subtraction

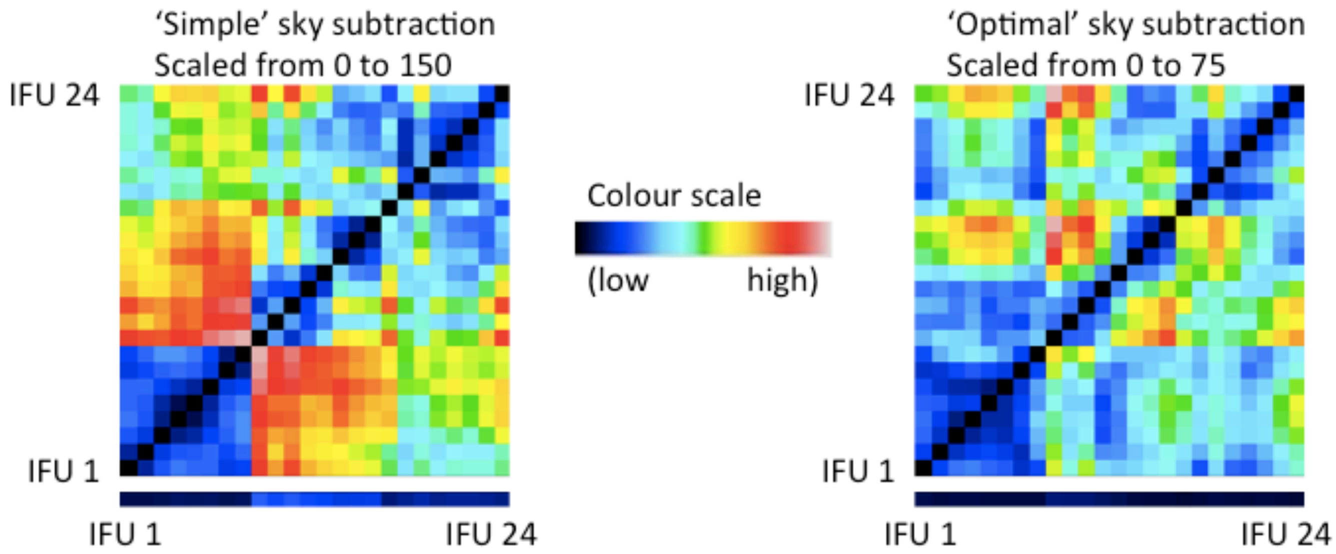






- Available as
  - opt. parameter in kmo_sci_red --sky_tweak (off by default!)
  - Standalone recipe kmo_sky_tweak (e.g. in combination with kmo_sci_red --no_subtract)
- Visual difference best seen in H- and K-band

A method to remove residual OH emission from near infrared spectra
[Davies R., 2007, MNRAS, 375, 1009]

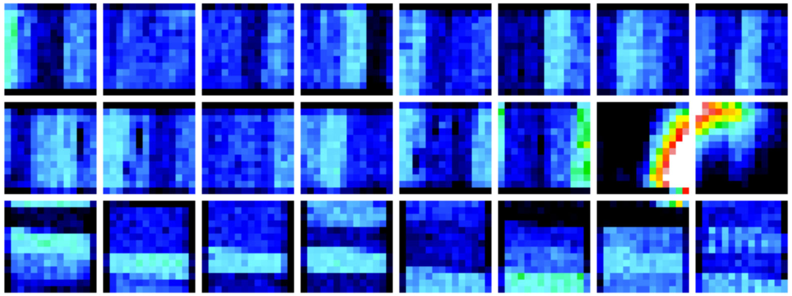


An illustration of the quality of sky subtraction, on the left for the "simple" sky subtraction method, and on the right using the "optimal" sky subtraction method following the algorithm presented in Davies et al. (2007). The matrix shows arm-to-arm subtraction in the same exposure, e.g. the sky residual in IFU j using IFU k to do sky subtraction in the same exposure. For comparison, the vector at the bottom shows the sky residual when the sky is subtracted from the same IFU, but from the subsequent exposure, e.g. IFU j – IFU j in the classical A-B sequence.

Recipes: **kmo_reconstruct, kmo_sci_red, kmo_multi_reconstruct**

Issue:

Do your reconstructed data have stripes like those?



- Due to temporally variable levels in the read-out channels of the detectors
- The effect is only ~1 count but is an issue when observing very faint sources.

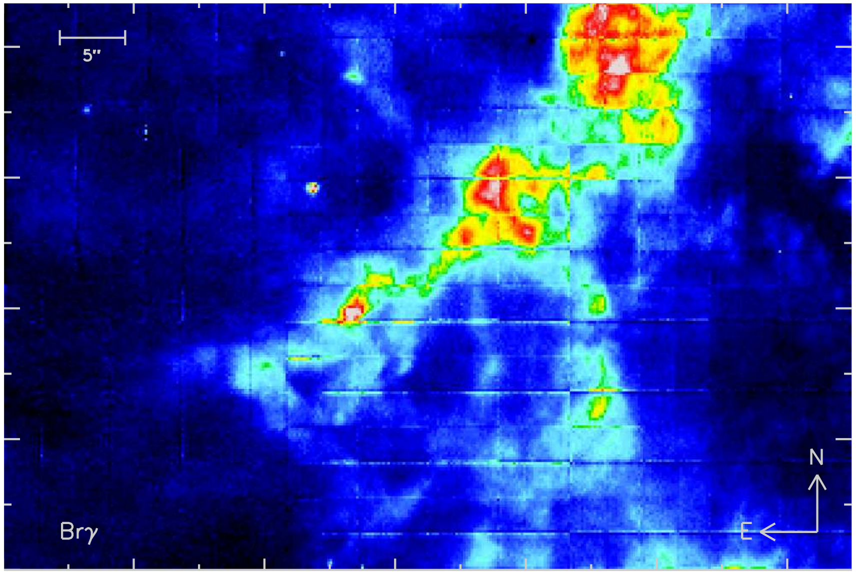
Solution:

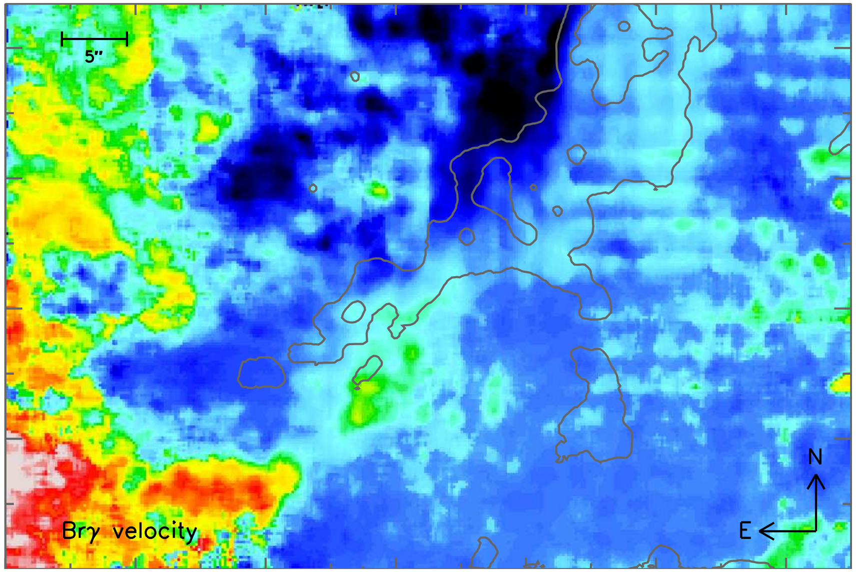
Perhaps ESO can determine a better setting for the detector readout mode

Workaround:

- Download and apply experimental IDL-toolchain **dark_channel_correction.tar.gz** from KMOS Wiki

Example: Flux and background correction on mosaic of R136



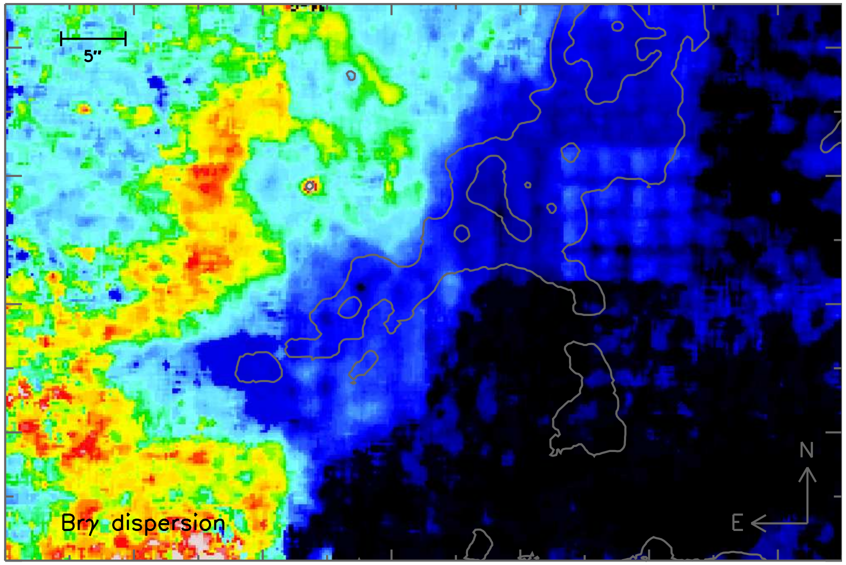


Flux (top), velocity (top right) and dispersion (right) of the Brγ line extracted from the R136 mosaic.

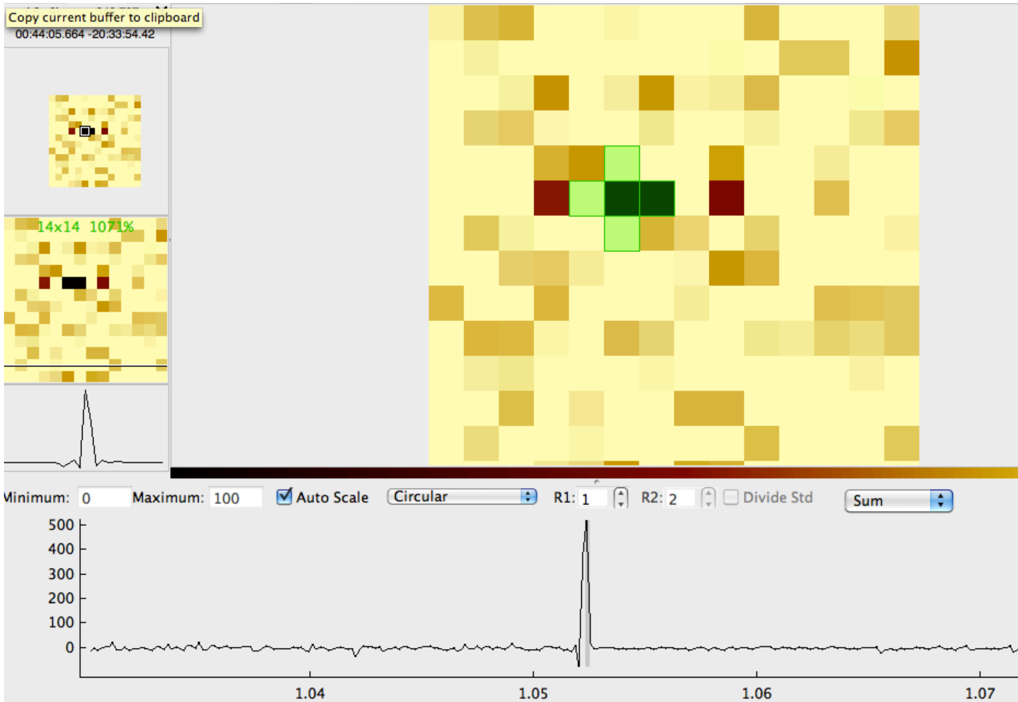
The velocity is shown in the range 230–310 km/s and the dispersion in the range 0–70 km/s

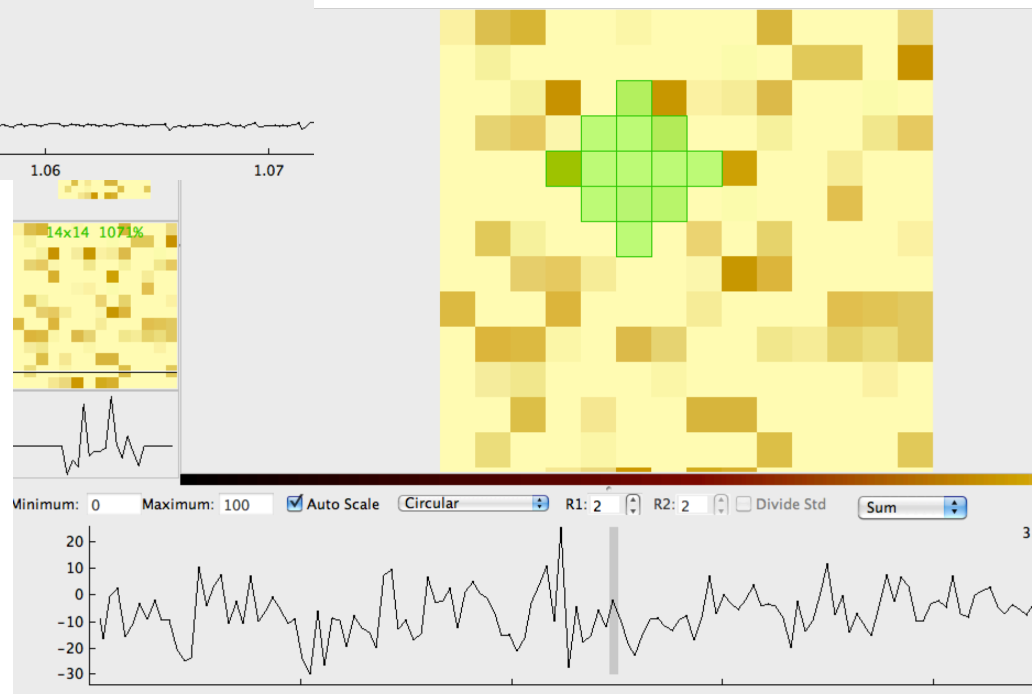
The 2 contours outline the location of the most prominent Brγ line emission for reference

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



Cosmic hits





Get IDL script from KMOS Wiki:
L.A. Cosmic

[van Dokkum P., 2001, PASP, 113, 1420]

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	.

- Association table written to disk obj_sky_table.txt
- 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 **easySPARK-scripts**
- or use **Reflex** from ESO → workflow GUI

easySPARK-scripts

- easySPARK_calibration.sh
  - easySPARK_dark.sh
  - easySPARK_flat.sh
  - easySPARK_wave_cal.sh
- easySPARK_illumination.sh
- easySPARK_illumination_flat.sh
- easySPARK_std_star.sh
- easySPARK_reconstruct.sh
- easySPARK_sci_red.sh
- easySPARK_multi_reconstruct.sh

Environment variable KMOS_CALIB has to be defined

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

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

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: –

- Please **choose equidistant rotator angles** unless you know what you are doing
  - When observations have a nasmyth angle from 10 to 20deg (ESO PRO NAANGLE keyword), it is valid to take calibrations at e.g. 5, 10, 15, 20, 25deg
  - But then these calibrations are only suited for these specific SCIENCE frames!
- Check if there is a **standard star in every detector!**
- Assure that you always have a **sky exposure in every IFU!**
- Consider strongly to **provide OH_SPEC frame** for wavelength matching!
- **Use sky_tweak wherever possible** (as parameter in kmo_sci_red or standalone with kmo_sky_tweak)!
- Consider using parameter **--edge_nan** in kmo_sci_red when dithering. Dark edges will be cut off.
- When experienceing offsets in pointing, respect following sources:
  - LUTs for arm positioning on instrument workstation could be outdated
    → nothing you can do afterwards
  - Calibration frames differing too much in time from science exposures
    → check for newer calibration frames (normally done during daytime after observation)
  - Calibration frames differing too much in temperature from science exposures
    → check for better matching calibration frames
- And still ther can be shifts up to 1pix…