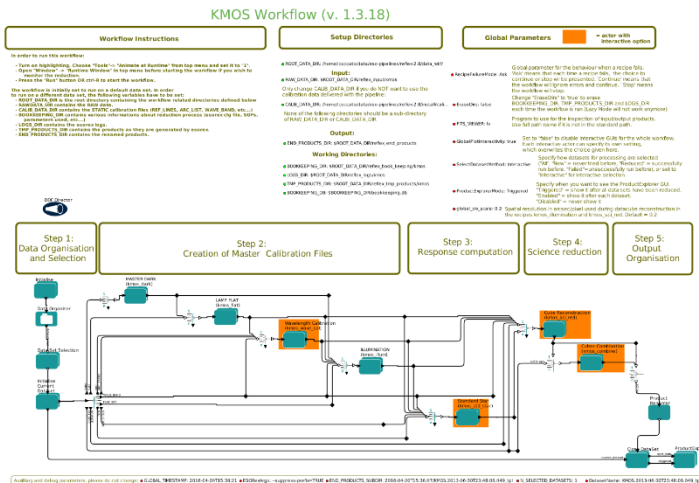
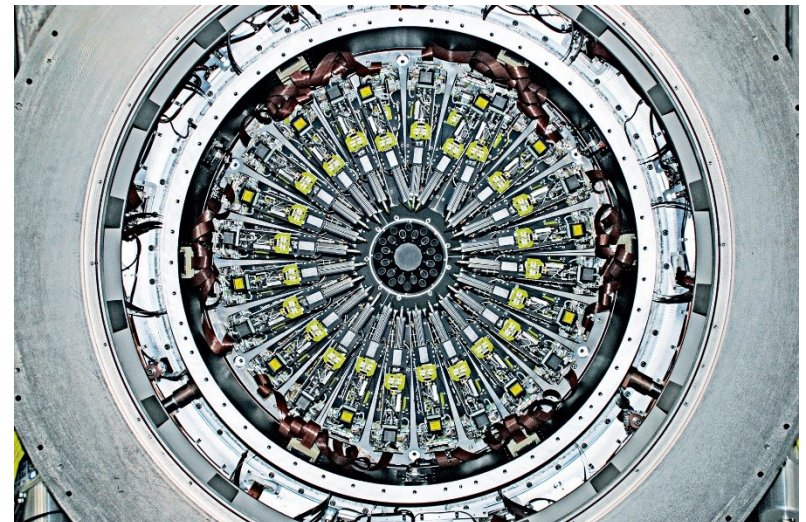
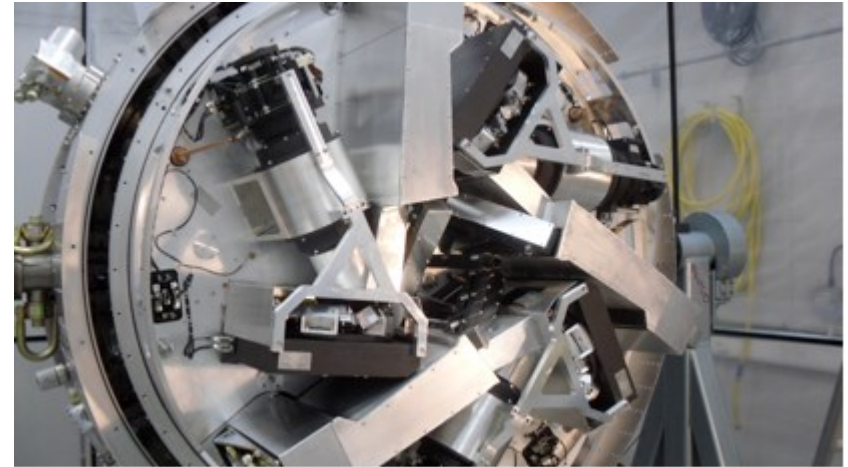


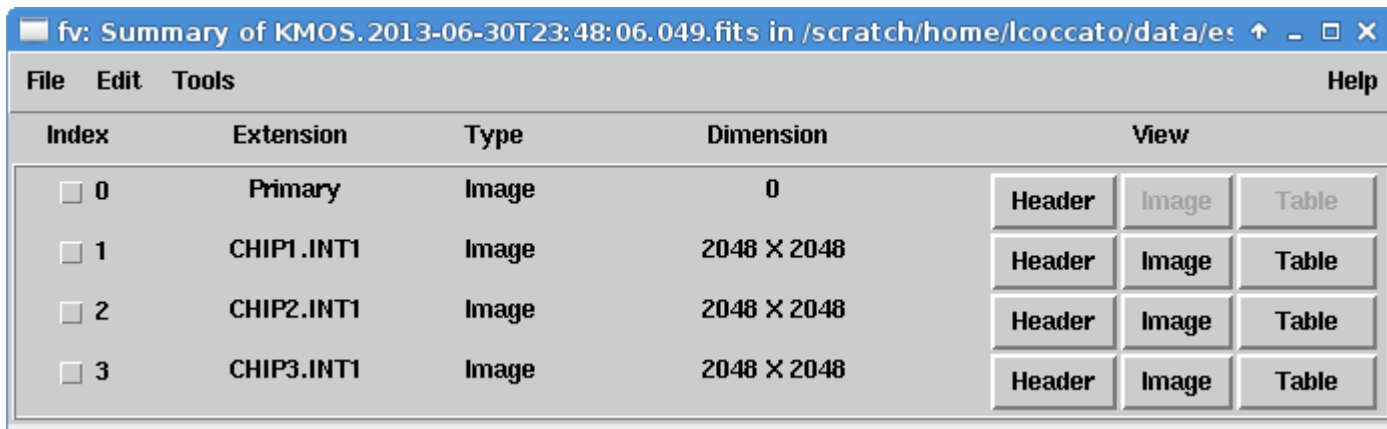


# KMOS: K-band Multi Object Spectrograph data reduction overview



# Data reduction

Structure of a single RAW science frame



Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	0	Header Image Table
<input type="checkbox"/> 1	CHIP1.INT1	Image	2048 X 2048	Header Image Table
<input type="checkbox"/> 2	CHIP2.INT1	Image	2048 X 2048	Header Image Table
<input type="checkbox"/> 3	CHIP3.INT1	Image	2048 X 2048	Header Image Table

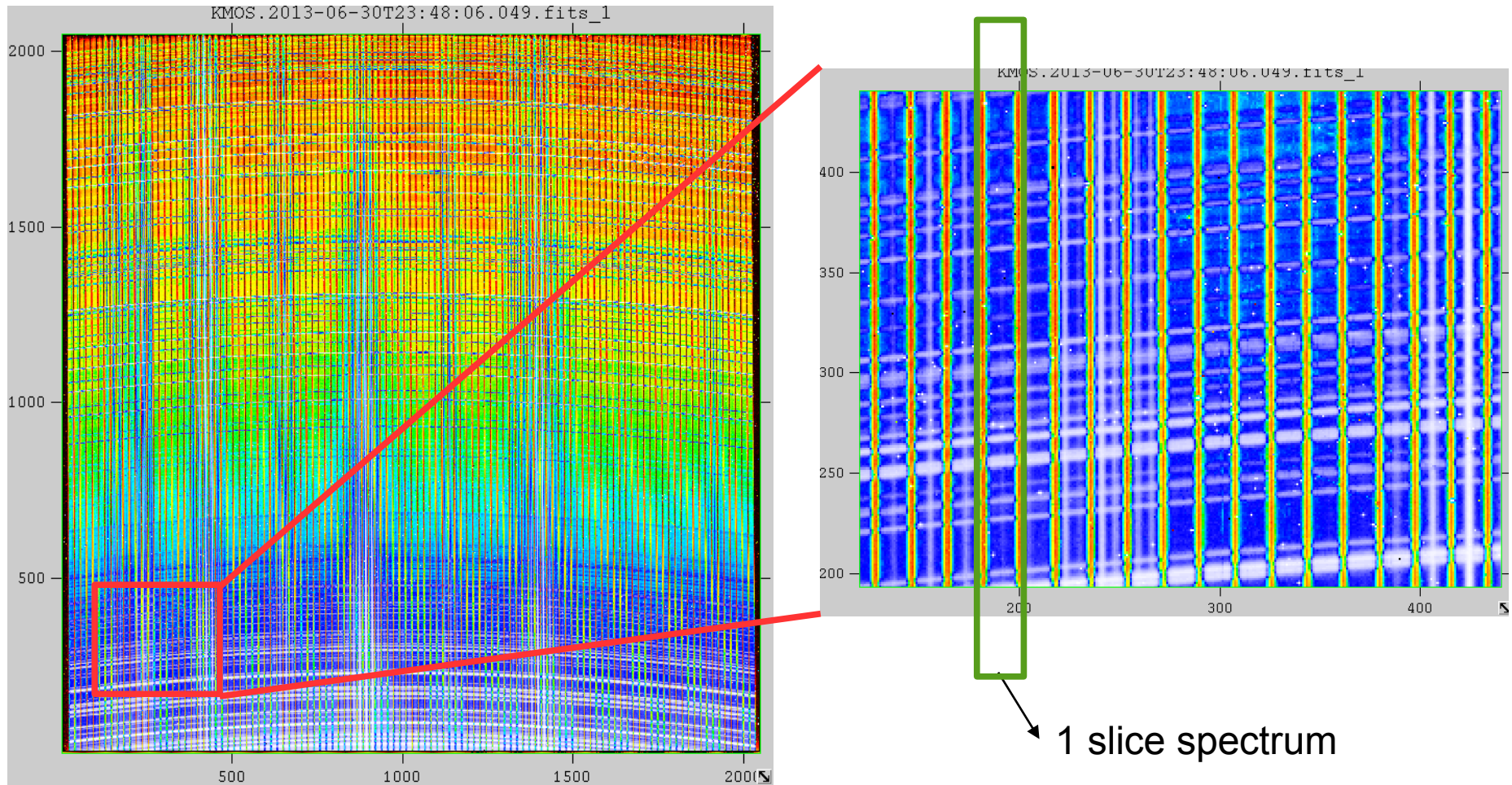
Each observational dataset consists of a set of Science frames plus calibration frames.

Header contains some key arm-related information for data reduction, such as pointing coordinates, type (object or sky), object name.

# Data reduction

How do you go from 3 collections of photons...

Content of 1 extension of a single RAW science frame





# Data reduction

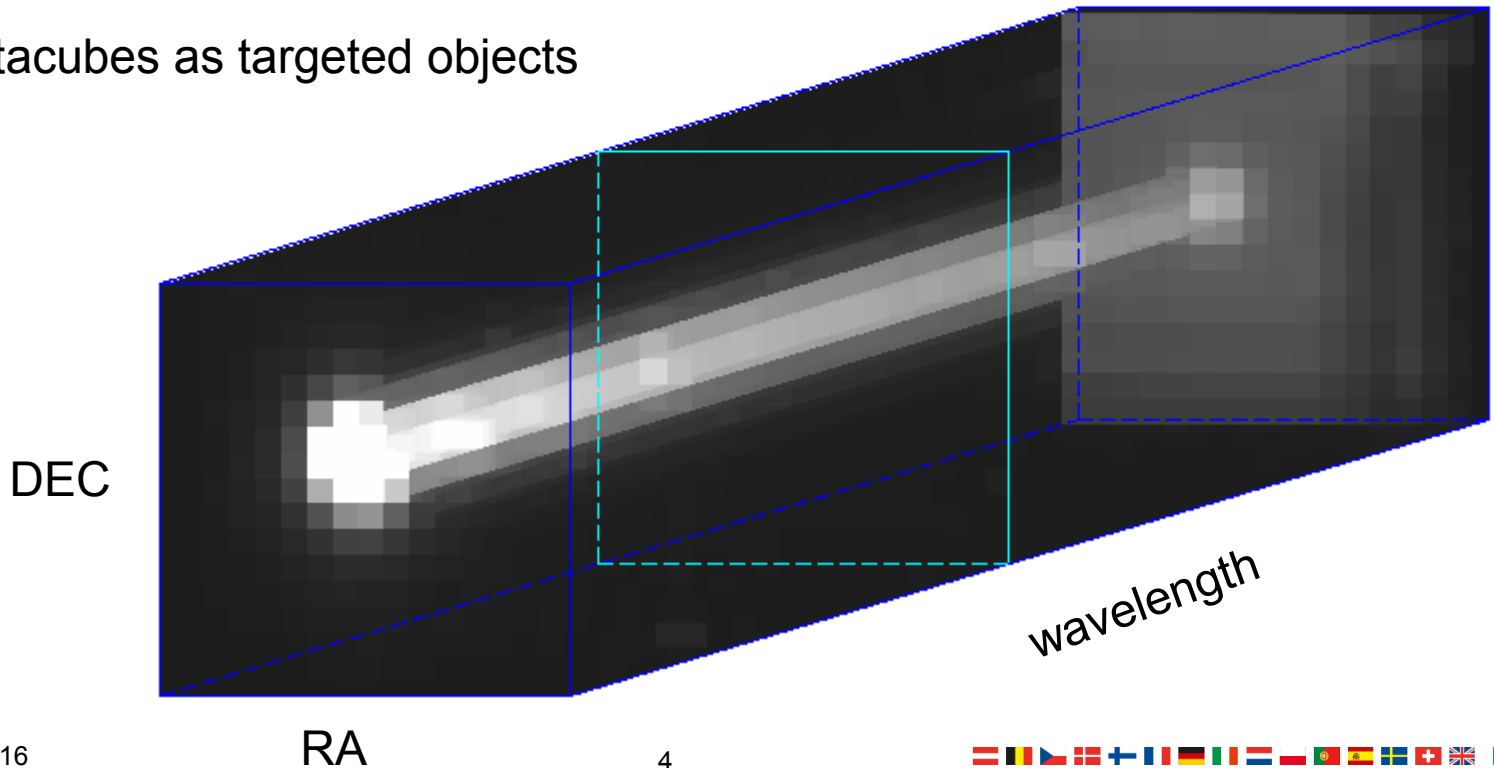
... to the final datacube(s) ?

fv: Summary of SCI-GUM43\_COMBINE\_SCI\_RECONSTRUCTED\_058.fits in /run/media

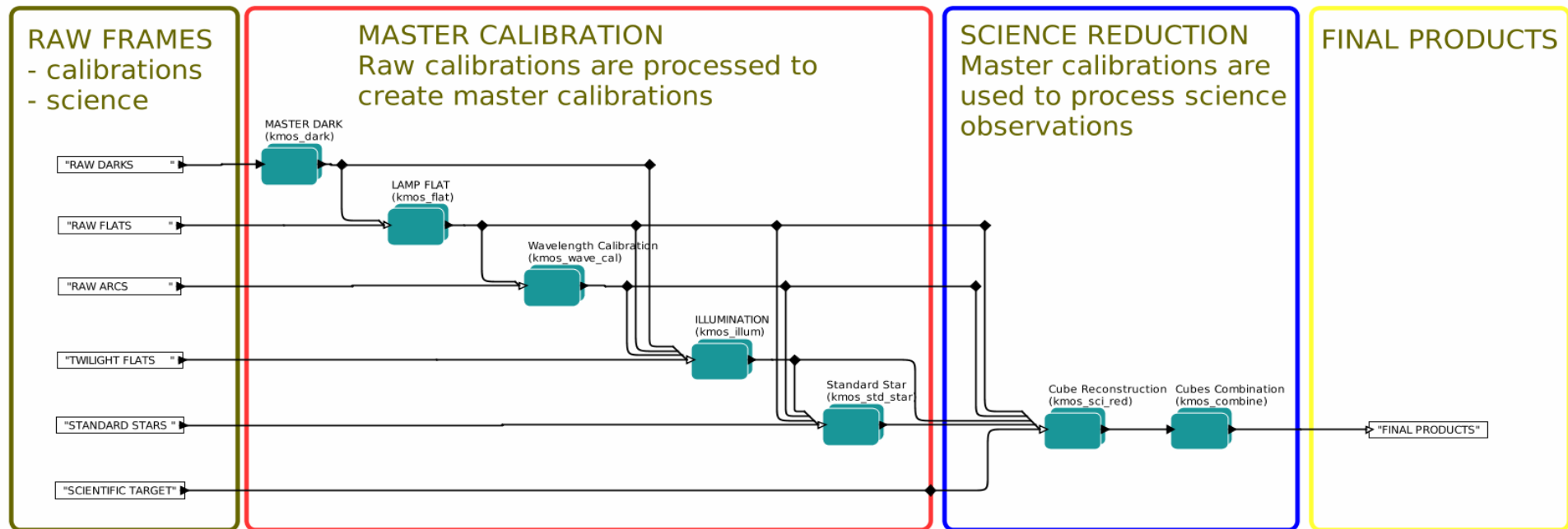
Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	0	Header Image Table
<input type="checkbox"/> 1	058.DATA	Image	16 X 16 X 2048	Header Image Table
<input type="checkbox"/> 2	058.NOISE	Image	16 X 16 X 2048	Header Image Table

Final DATACUBE(s)

As many datacubes as targeted objects



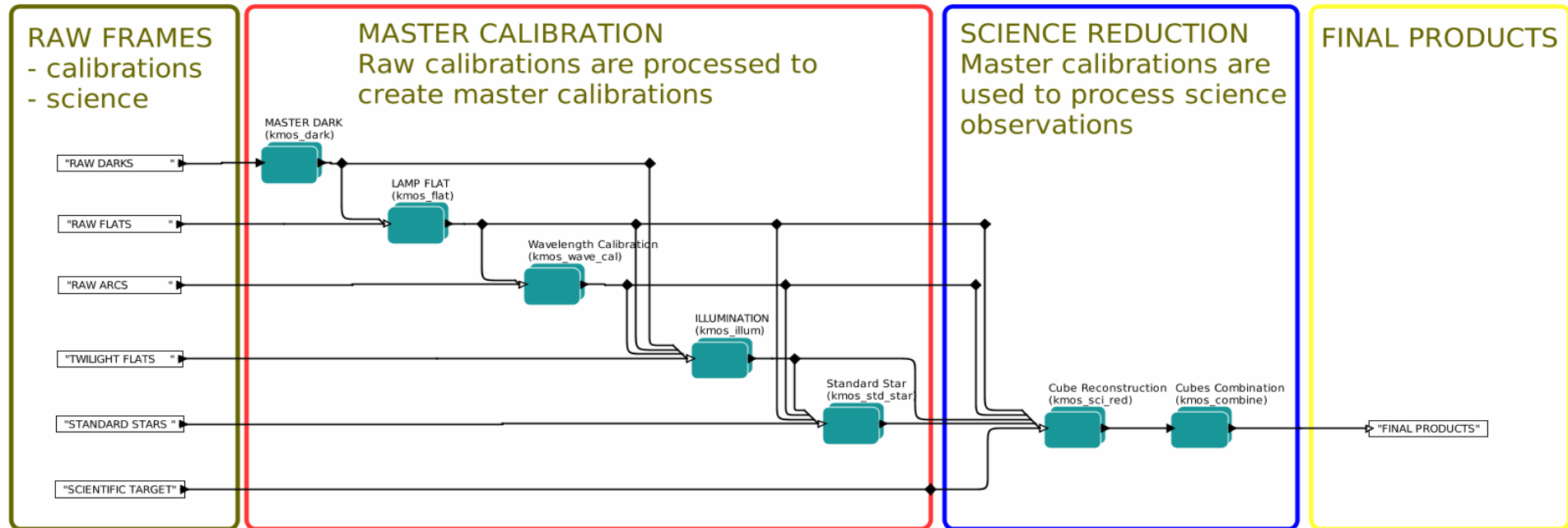
# KMOS DATA REDUCTION CASCADE



Raw calibration (e.g., darks, flats) plus static calibration files (e.g. arc line list) are processed to create MASTER CALIBRATIONS.

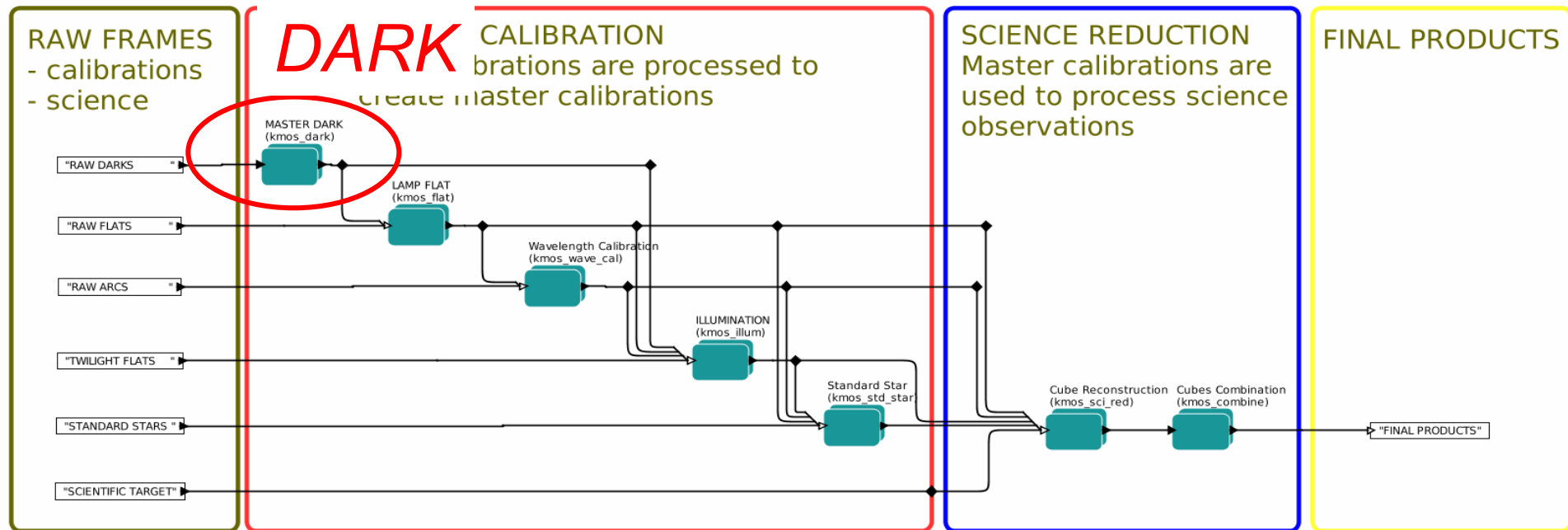
MASTER CALIBRATIONS are used to reduce the raw science exposures (collection of photon signal onto 2D detectors) to get the final products (datacubes), which are fully calibrated in astrometric, wavelength, and flux units.

# KMOS DATA REDUCTION CASCADE



Each step of the data reduction cascade triggers a pipeline **recipe**. Each recipe is designed to process a set of frames and provide the inputs to the next recipes. The process is automatic from the raw data till the final products. It can be customized by setting the recipe parameters.

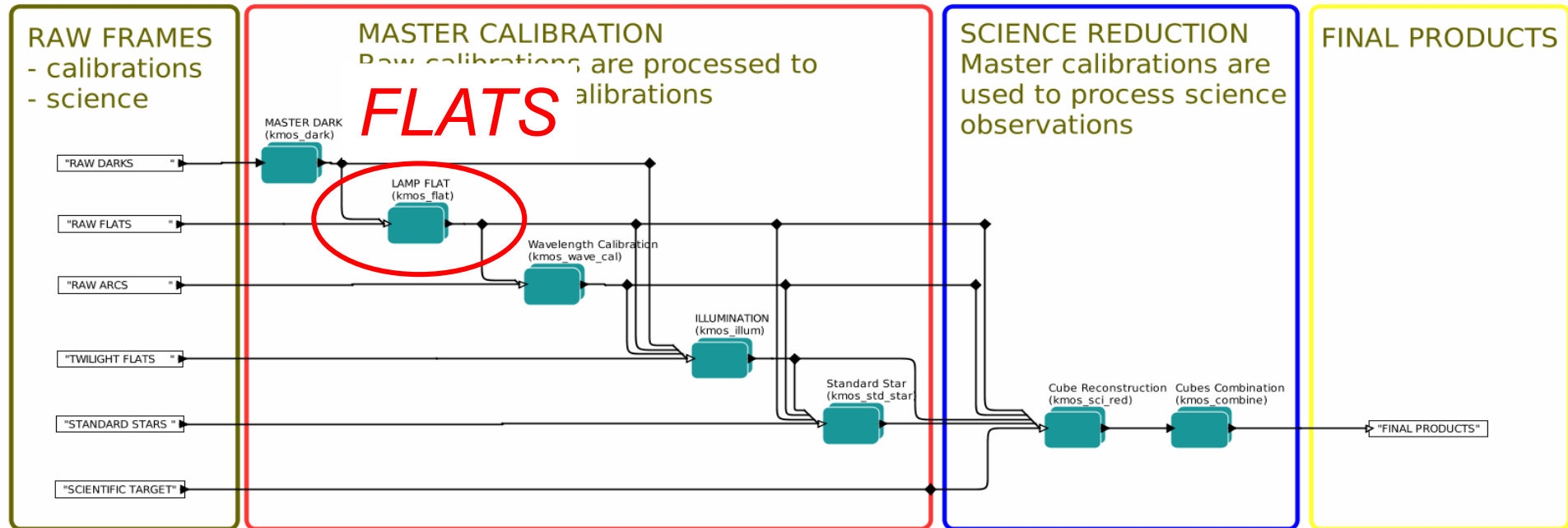
# KMOS DATA REDUCTION CASCADE



Dark frames are exposures taken with 0 sec integration time. They are used to map the bad pixels in the detector.

Main products: MASTER\_DARK; BADPIXEL\_DARK

# KMOS DATA REDUCTION CASCADE

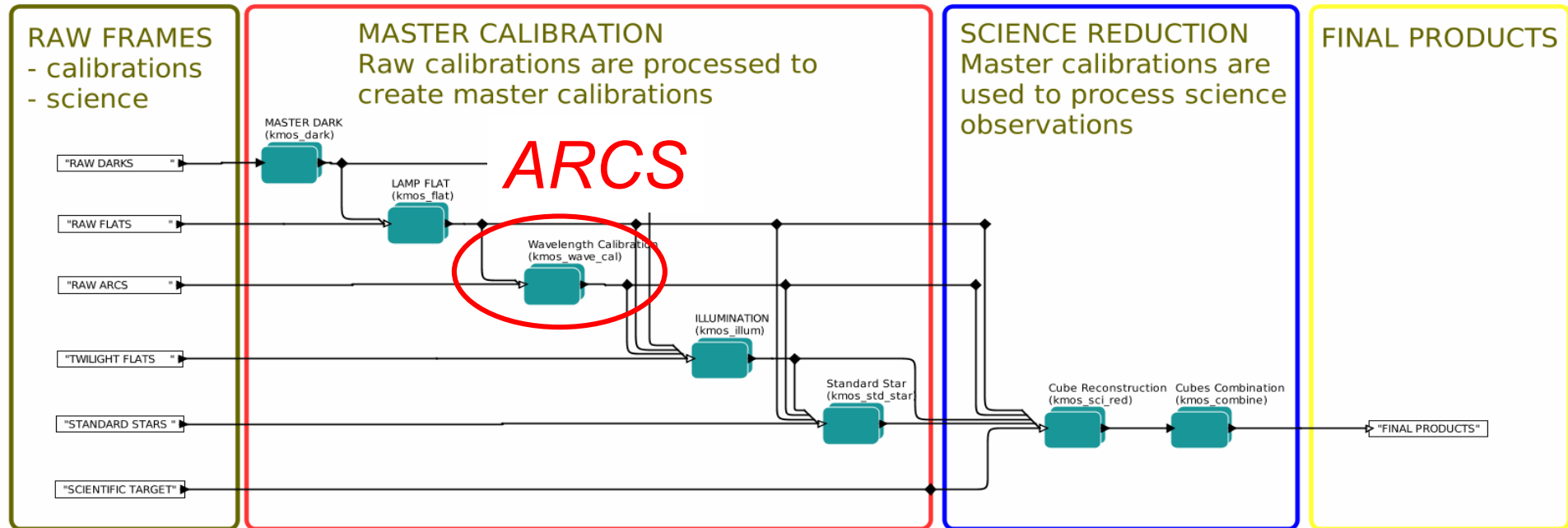


Flat fields are used to:

- Map the pixel-to-pixel sensitivity variation through the detector (FLAT\_EDGE)
- Detect bad pixels additional to that of dark frames (BADPIXEL\_FLAT)
- Identify the position of the slices in the detector → to which position on the sky each spectrum belongs (XCAL, YCAL).



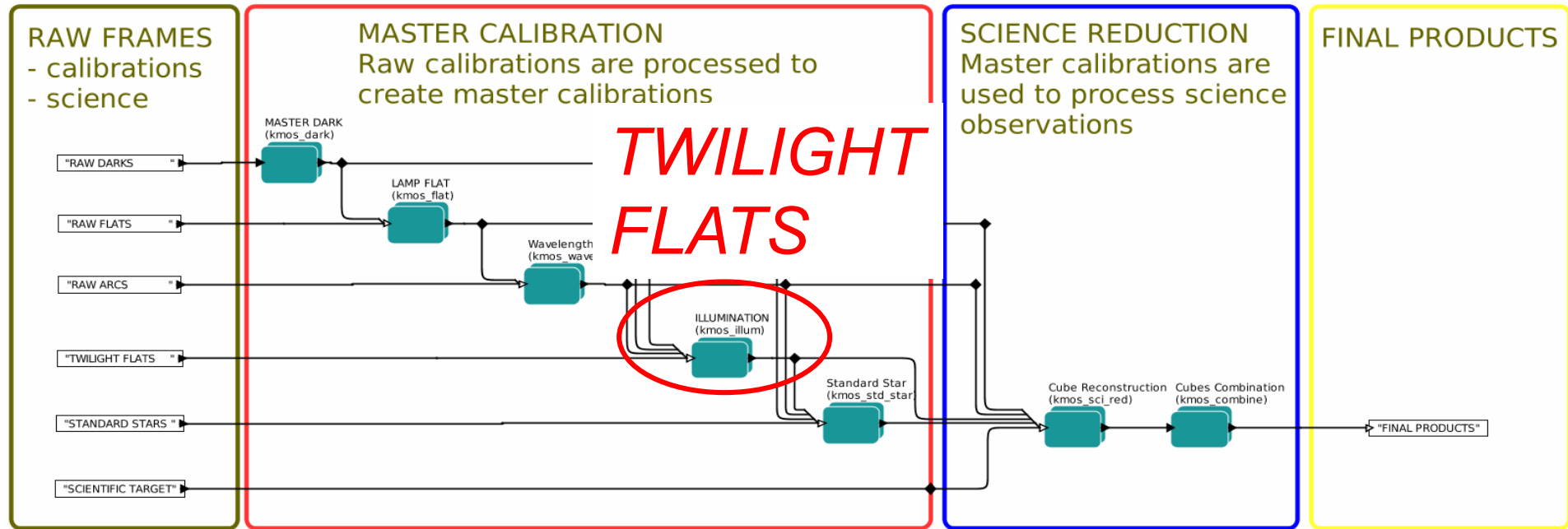
# KMOS DATA REDUCTION CASCADE



Comparison arcs are used to map each pixel in the detector to a precise wavelength. The transformation is computed by comparing the detected emission lines to a reference list.

Main products: LCAL (tells the wavelength for each pixel of the detector)

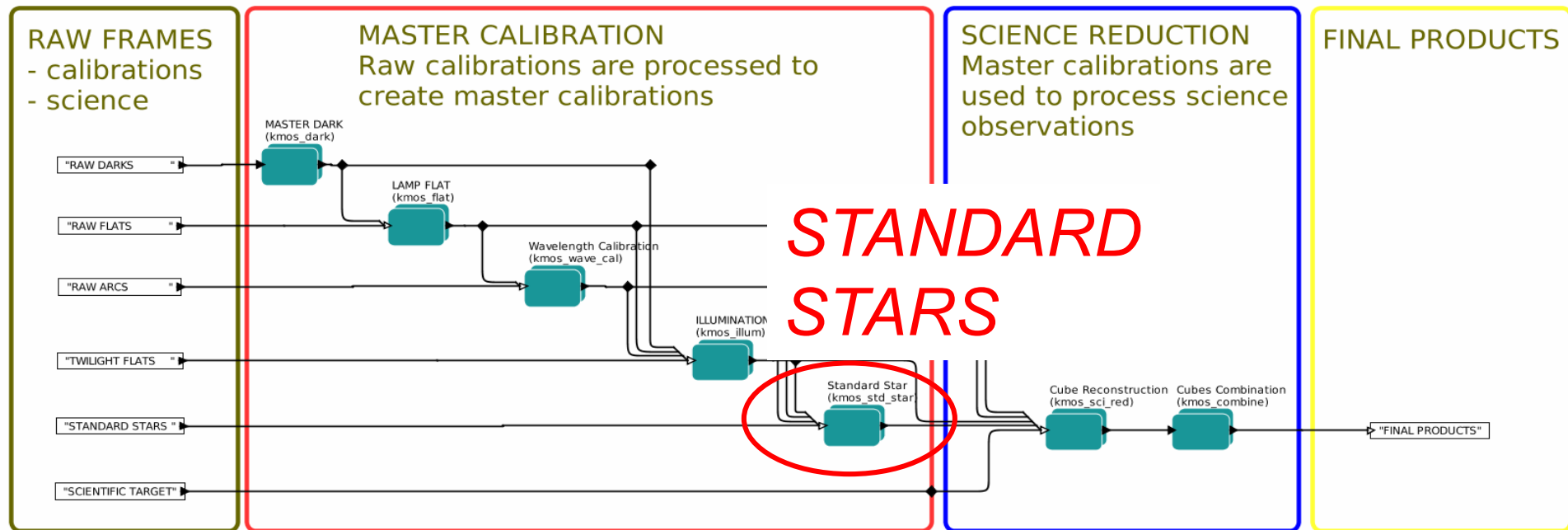
# KMOS DATA REDUCTION CASCADE



Twilight flats are used to correct for the non-homogeneous illumination of the field of view.

Main product: ILLUM\_CORR

# KMOS DATA REDUCTION CASCADE



Standard stars are used to:

- Flux calibration (convert photon counts into physical units such as  $\text{ergs}/\text{sec}/\text{cm}^2/\text{\AA}$ )
- Derive the telluric correction to account for atmospheric extinction.

Main product: TELLURIC



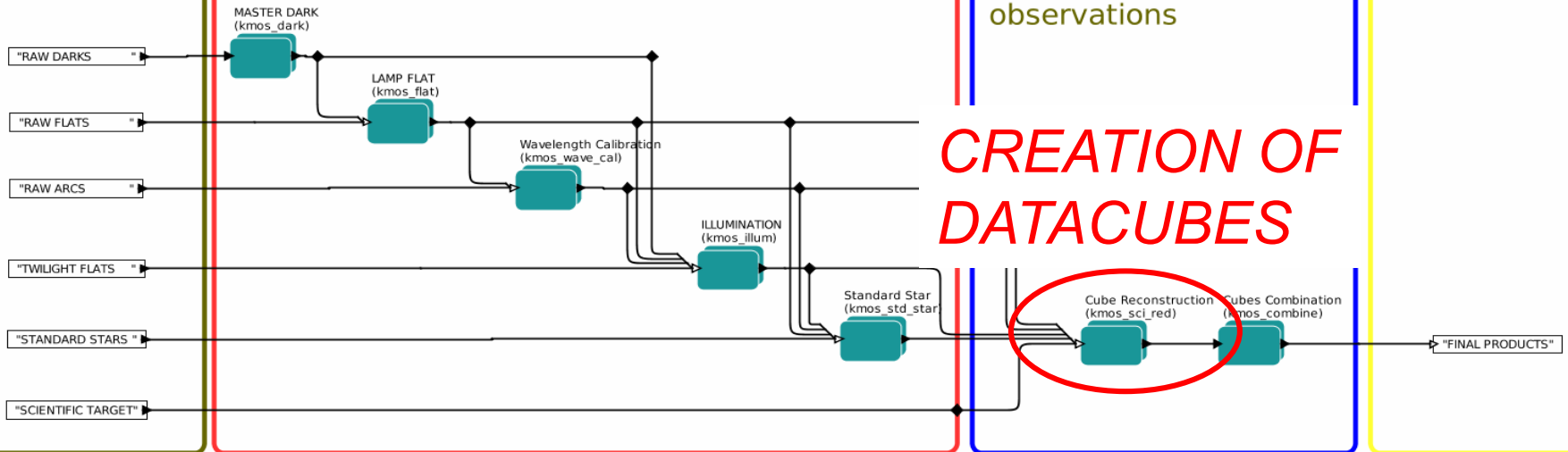
# KMOS DATA REDUCTION CASCADE

RAW FRAMES  
- calibrations  
- science

MASTER CALIBRATION  
Raw calibrations are processed to create master calibrations

SCIENCE REDUCTION  
Master calibrations are used to process science observations

FINAL PRODUCTS



Each exposure will be calibrated using the master calibrations. The reduced exposure contains 24 extensions (one per IFU). Each extension contains a reduced datacube. Main product: SCI\_RECONSTRUCTED

IFUs targeting empty sky regions will be used to subtract the sky from IFU targeting objects.

# KMOS DATA REDUCTION CASCADE

## Datacube reconstruction

**Raw science (3 extensions)**

**Calibrations**

- xcal, ycal, ycal
- flat\_fields, illumination
- Telluric and response



**Datacubes. Calibrated and sky subtracted.**

1 file per exposure with 24 extensions.

*Calibrations*

*Calibration A (multi extension fits)*

1. Rot angle 0
2. Rot angle 60
3. Rot angle 120
4. Rot angle 180
5. Rot angle 240
6. Rot angle 300

*Raw science*

- Science exposure 1 (rot angle 50)
- Science exposure 2 (rot angle 80)
- Science exposure 3 (rot angle 110)
- ...
- Science exposure N (rot angle 220)

*Products*

- Datacube 1
- Datacube 2
- Datacube 3
- ...
- Datacube N

*Calibration B (multi extension fits)*

1. Rot angle 0
2. Rot angle 60
3. Rot angle 120
4. Rot angle 180
5. Rot angle 240
6. Rot angle 300

Instrument behavior depends on the rotator angle. The raw calibrations are taken at different rotator angles to map the instrument response. The pipeline recipes are able to associate each file with the calibration taken at the closest matching rotator angle.



# KMOS DATA REDUCTION CASCADE

## Datacube reconstruction

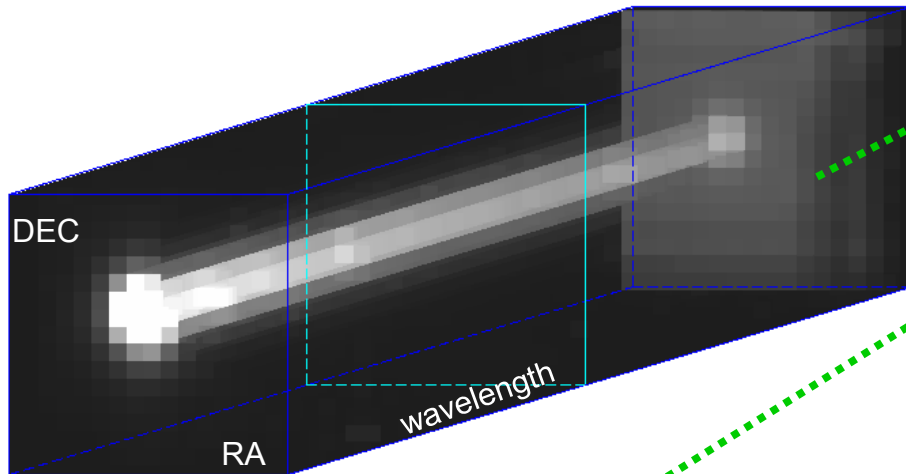
Raw science (3 extensions)

Calibrations

- xcal, ycal, ycal
- flat\_fields, illumination
- Telluric and response



Datacubes. Calibrated and sky subtracted.  
1 file per exposure with 24 extensions.



Empty arm (sky or not active)

fv: Summary of sci\_reconstructed\_KMOS.2014-02-21T02:45:45.986.fits in /scratch/home/lcc

Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	0	Header Image Table
<input type="checkbox"/> 1	IFU.1.DATA	Image	0	Header Image Table
<input type="checkbox"/> 2	IFU.2.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 3	IFU.3.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 4	IFU.4.DATA	Image	0	Header Image Table
<input type="checkbox"/> 5	IFU.5.DATA	Image	0	Header Image Table
<input type="checkbox"/> 6	IFU.6.DATA	Image	0	Header Image Table
<input type="checkbox"/> 7	IFU.7.DATA	Image	0	Header Image Table
<input type="checkbox"/> 8	IFU.8.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 9	IFU.9.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 10	IFU.10.DATA	Image	0	Header Image Table
<input type="checkbox"/> 11	IFU.11.DATA	Image	0	Header Image Table
<input type="checkbox"/> 12	IFU.12.DATA	Image	0	Header Image Table
<input type="checkbox"/> 13	IFU.13.DATA	Image	0	Header Image Table
<input type="checkbox"/> 14	IFU.14.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 15	IFU.15.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 16	IFU.16.DATA	Image	0	Header Image Table
<input type="checkbox"/> 17	IFU.17.DATA	Image	0	Header Image Table
<input type="checkbox"/> 18	IFU.18.DATA	Image	0	Header Image Table
<input type="checkbox"/> 19	IFU.19.DATA	Image	0	Header Image Table
<input type="checkbox"/> 20	IFU.20.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 21	IFU.21.DATA	Image	14 X 14 X 2048	Header Image Table
<input type="checkbox"/> 22	IFU.22.DATA	Image	0	Header Image Table
<input type="checkbox"/> 23	IFU.23.DATA	Image	0	Header Image Table
<input type="checkbox"/> 24	IFU.24.DATA	Image	0	Header Image Table



# KMOS DATA REDUCTION CASCADE

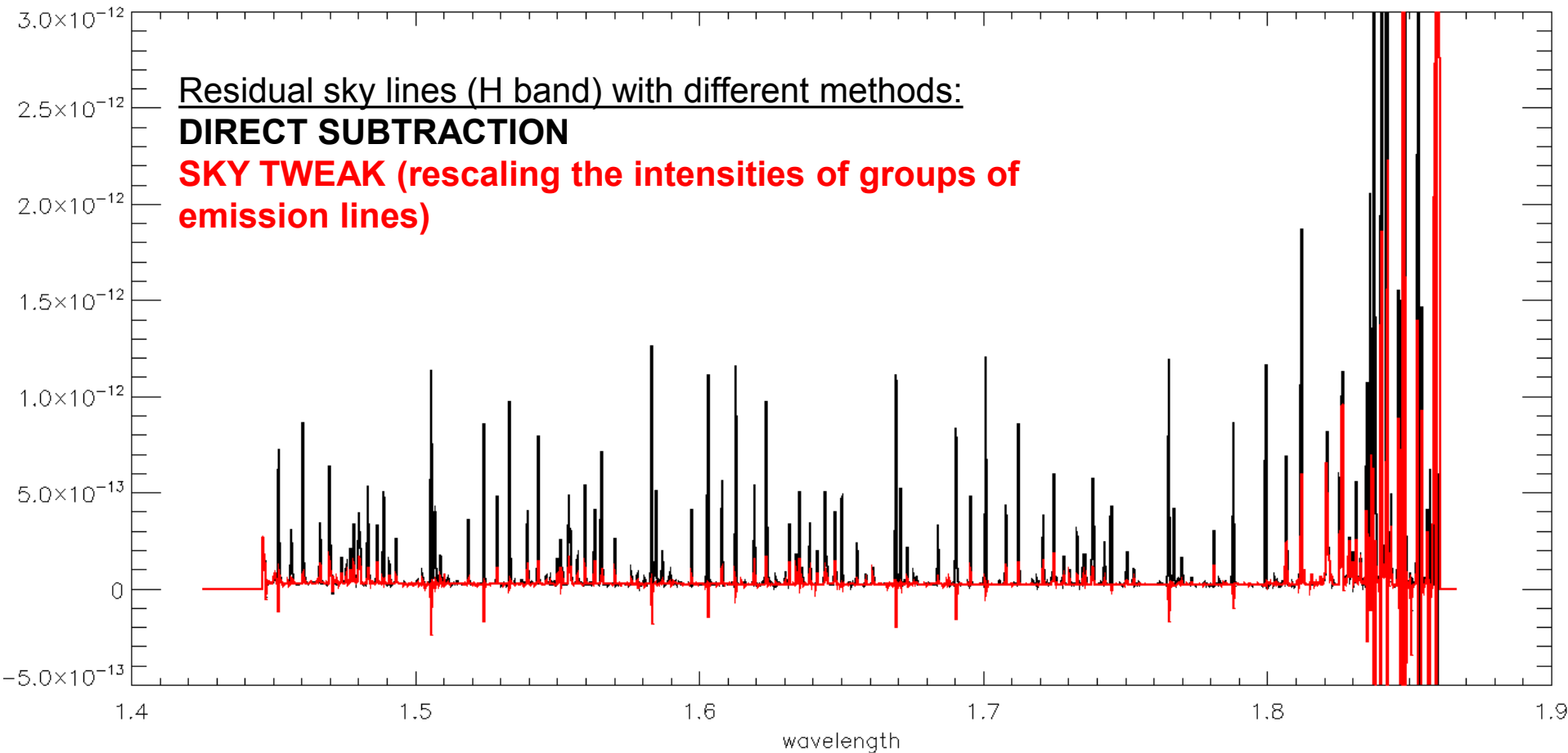
## *Sky subtraction*

- It is performed during the datacube reconstruction step.
- The pipeline associates to each ARM the most appropriate SKY exposure. Override is possible.
- Best results are seen if object-sky association is for the same arm. Arm consistency is important than time variations.
- Several algorithms for sky subtraction
  - Direct subtraction – a sky spectrum is constructed from the arm pointing to the sky, and the subtracted from the corresponding science.
  - Sky tweaking method (Davies 2007, MNRAS, 375, 1099). Groups of emission lines are defined on the sky spectrum. Each group has a scaling factor which is applied before subtraction.
  - Stretching of wavelength solution for the sky spectrum (either with or without sky tweak) to minimize residuals (implementation on-going).

# KMOS DATA REDUCTION CASCADE

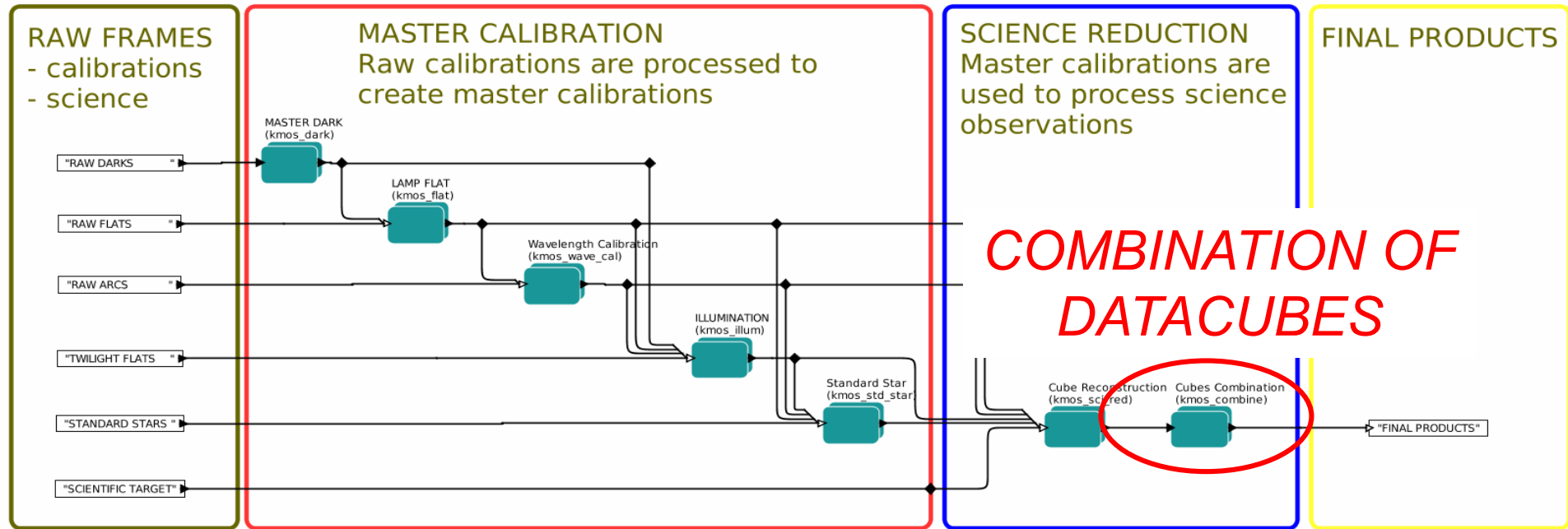
## Sky subtraction

In some cases, sky tweaking makes really a substantial improvement





# KMOS DATA REDUCTION CASCADE



All the extensions (datacubes) of all the exposures that target the same object on the sky will be combined together to create a single datacube.

One datacube per targeted object will be produced.

Main products: COMBINED\_SCI\_RECONSTRUCTED

# KMOS DATA REDUCTION CASCADE

## Datacube combination

### RECONSTRUCTED CUBES

INDIVIDUAL EXPOSURES (each file has 24 extensions)

```
sci_reconstructed_KMOS.2013-06-30T23:48:06.049.fits
sci_reconstructed_KMOS.2013-06-30T23:59:09.586.fits
sci_reconstructed_KMOS.2013-07-01T00:04:22.390.fits
sci_reconstructed_KMOS.2013-07-01T00:09:35.560.fits
sci_reconstructed_KMOS.2013-07-01T00:20:10.285.fits
sci_reconstructed_KMOS.2013-07-01T00:25:24.507.fits
sci_reconstructed_KMOS.2013-07-01T00:30:37.274.fits
sci_reconstructed_KMOS.2013-07-01T00:41:13.785.fits
sci_reconstructed_KMOS.2013-07-01T00:46:26.588.fits
```

*Exposure identification*

### FINAL PRODUCTS

DATACUBE (1 cube per object)

```
combine_sci_reconstructed_001.fits
combine_sci_reconstructed_002.fits
combine_sci_reconstructed_003.fits
combine_sci_reconstructed_004.fits
combine_sci_reconstructed_007.fits
combine_sci_reconstructed_010.fits
combine_sci_reconstructed_014.fits
combine_sci_reconstructed_018.fits
combine_sci_reconstructed_020.fits
combine_sci_reconstructed_021.fits
combine_sci_reconstructed_027.fits
combine_sci_reconstructed_029.fits
combine_sci_reconstructed_030.fits
combine_sci_reconstructed_048.fits
combine_sci_reconstructed_058.fits
combine_sci_reconstructed_069.fits
combine_sci_reconstructed_100.fits
combine_sci_reconstructed_101.fits
combine_sci_reconstructed_103.fits
```

*Object name*



# KMOS DATA REDUCTION WORKFLOW

## The easiest way to reduce KMOS data

### KMOS Workflow (v. 1.3.16)

#### Workflow Instructions

In order to run this workflow:

- Turn on highlighting. Choose "Tools" -> "Animate at Runtime" from top menu and set it to "1".
- Open "Window" -> "Runtime Window" in top menu before starting the workflow if you wish to monitor the reduction.
- Press the "Run" button OR ctrl-R to start the workflow.

The workflow is initially set to run on a default data set. In order to run on a different data set, the following variables have to be set:

- ROOT\_DATA\_DIR is the root directory containing the workflow related directories defined below
- RAW\_DATA\_DIR contains the RAW data.
- CALIB\_DATA\_DIR contains the STATIC calibration files (REF\_LINES, ARC\_LIST, WAVE\_BAND, etc...)
- BOOKKEEPING\_DIR contains various informations about reduction process (esorex.cfg file, SOfs, parameters used, etc...)
- LOGS\_DIR contains the esorex logs.
- TMP\_PRODUCTS\_DIR contains the products as they are generated by esorex.
- END\_PRODUCTS\_DIR contains the renamed products.



#### Setup Directories

● ROOT\_DATA\_DIR: /home/reflex/install

#### Input:

● RAW\_DATA\_DIR: \$ROOT\_DATA\_DIR/reflex\_input/kmos  
Only change CALIB\_DATA\_DIR if you do NOT want to use the calibration data delivered with the pipeline:

● CALIB\_DATA\_DIR: /home/reflex/install/calib/kmos-1.3.16/cal

None of the following directories should be a sub-directory of RAW\_DATA\_DIR or CALIB\_DATA\_DIR

#### Output:

● END\_PRODUCTS\_DIR: \$ROOT\_DATA\_DIR/reflex\_end\_products

#### Working Directories:

- BOOKKEEPING\_DIR: \$ROOT\_DATA\_DIR/reflex\_book\_keeping/kmos
- LOGS\_DIR: \$ROOT\_DATA\_DIR/reflex\_logs/kmos
- TMP\_PRODUCTS\_DIR: \$ROOT\_DATA\_DIR/reflex\_tmp\_products/kmos
- BOOKKEEPING\_DB: \$BOOKKEEPING\_DIR/bookkeeping.db

#### Global Parameters

■ = actor with interactive option

● RecipeFailureMode: Ask

Global parameter for the behaviour when a recipe fails. 'Ask' means that each time a recipe fails, the choice to continue or stop will be presented. 'Continue' means that the workflow will ignore errors and continue. 'Stop' means the workflow will stop.

● EraseDirs: false

Change "EraseDirs" to "true" to erase BOOKKEEPING\_DIR, TMP\_PRODUCTS\_DIR and LOGS\_DIR each time the workflow is run (Lazy Mode will not work anymore)

● FITS\_VIEWER: N

Program to use for the inspection of input/output products. Use full path name if it is not in the standard path.

● GlobalPktInteractivity: true

Set to "false" to disable interactive GUIs for the whole workflow. Each interactive actor can specify its own setting, which overwrites the choice given here.

● SelectDataSetMethod: Interactive

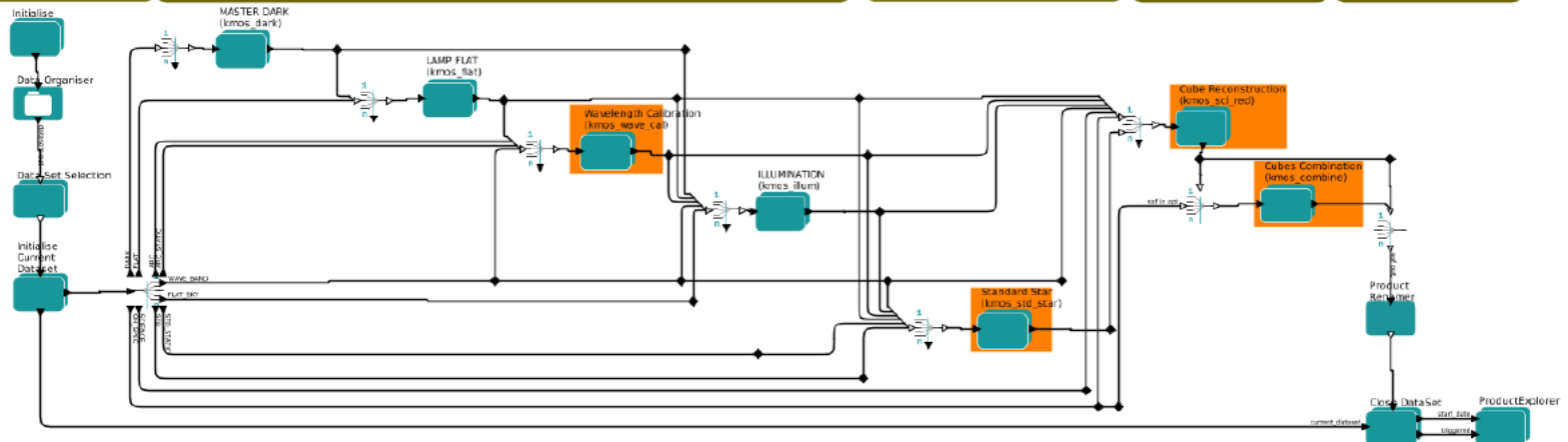
Specify how datasets for processing are selected ("AF", "New" = never tried before, "Reduced" = successfully run before, "Failed" = unsuccessfully run before), or set to "Interactive" for interactive selection.

● ProductExplorerMode: Triggered

Specify when you want to see the ProductExplorer GUI. "Triggered" = show it after all data sets have been reduced. "Enabled" = show it after each dataset. "Disabled" = never show it

● Global\_pix\_scale: 0.2

Spatial resolution in arcsec/pixel used during datacube reconstruction in the recipes kmos\_illumination and kmos\_sci\_red. Default = 0.2



Auxiliary and debug parameters, please do not change: ● GLOBAL\_TIMESTAMP: 2015-12-08T16:54:34 ● ESORExArgs: --suppress-prefix=TRUE ● END\_PRODUCTS\_SUBDIR: 2015-12-08T16:54:34/KMOS-2014-02-21T02:45:45.986\_tel ● RL\_SELECTED\_DATASETS: 2 ● DataSetName: KMOS-2014-02-21T02:45:45.986\_tel

