

Integral Field Spectroscopy in the Near IR

Working with real data: NGC1068

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AÑOS



CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS



CENTRO DE ASTROBIOLOGÍA
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Overview of the session

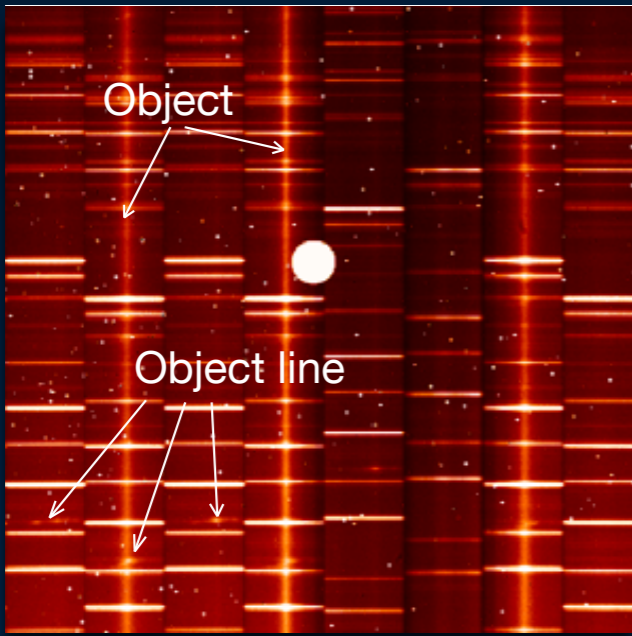
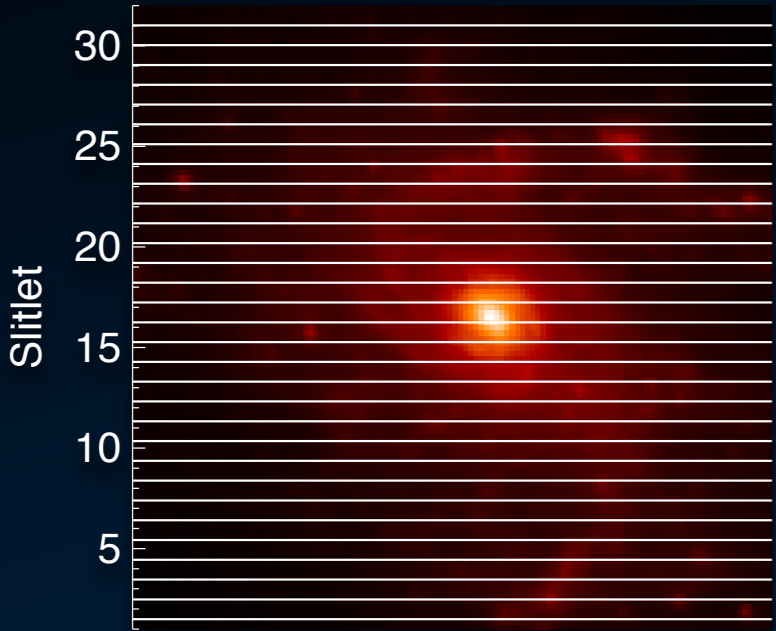
- SINFONI: the NIR IFU at the VLT
- A case study: NGC1068
 - NGC1068 in a nutshell
 - Observations
- Data reduction
 - ESOREX, Gasgano and Reflex
 - The dataset
 - Reduction process
- Calibration of the data
 - Atmospheric transmission
 - Absolute flux calibration

SINFONI: the NIR IFU at VLT

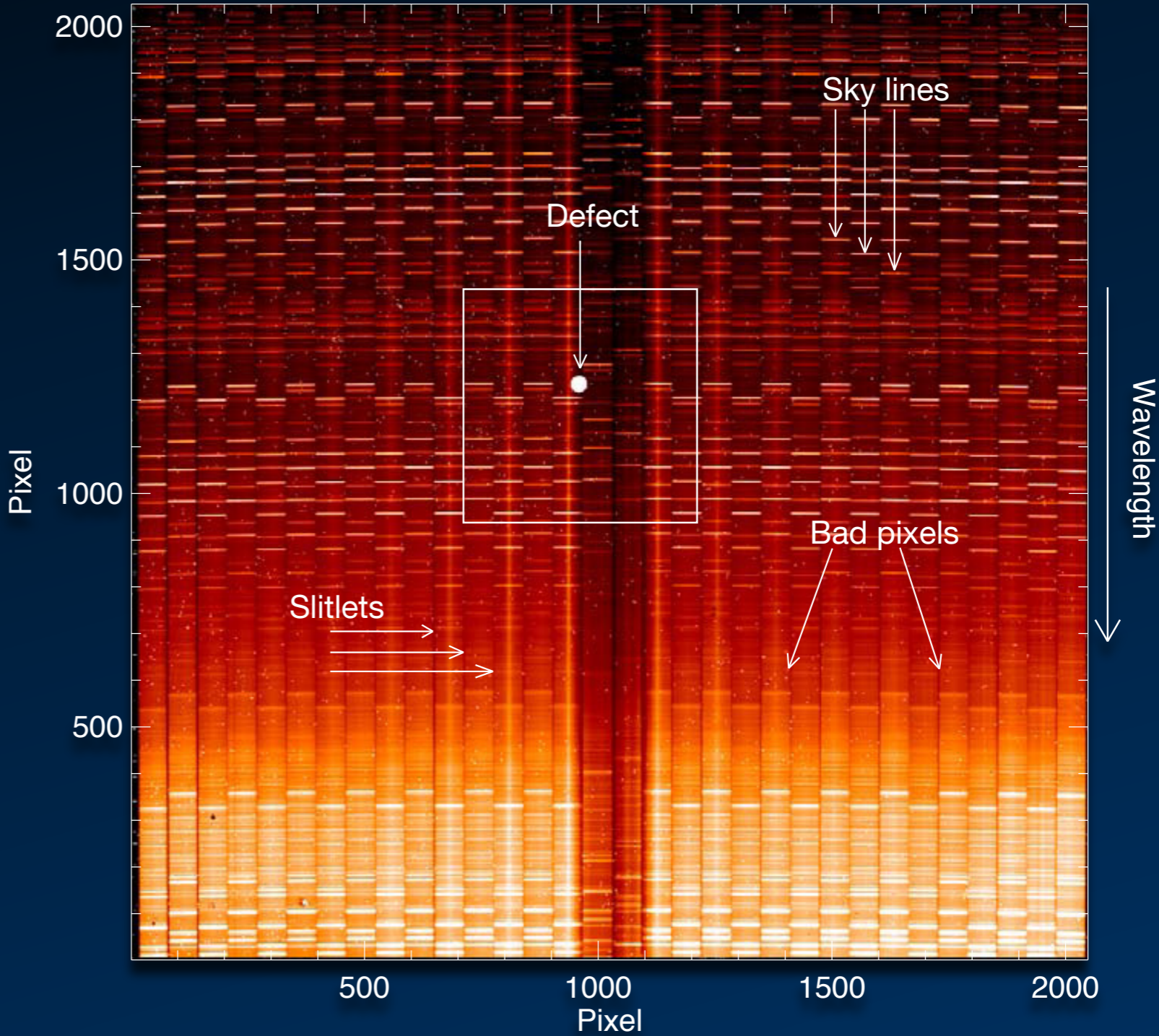
- ◉ Near-IR (1.1-2.45) integral field spectrograph at the Cassegrain focus of VLT-UT4 (*Eisenhauer et al. 2003, Bonnet et al 2004*)
- ◉ Seeing-limited and AO-assisted observations
- ◉ Four gratings: J, H, K and H+K
- ◉ Intermediate spectral resolution: R~2000- 4000 (J, H and K), R~1500 (H+K)
- ◉ Three plate scales: 0.025, 0.100 and 0.250 arcsec per spaxel yield FoV's of ~0.8"×0.8", 3"×3" and 8"×8"
- ◉ ~4000 individual spectra per data cube



SINFONI data: science raw frames

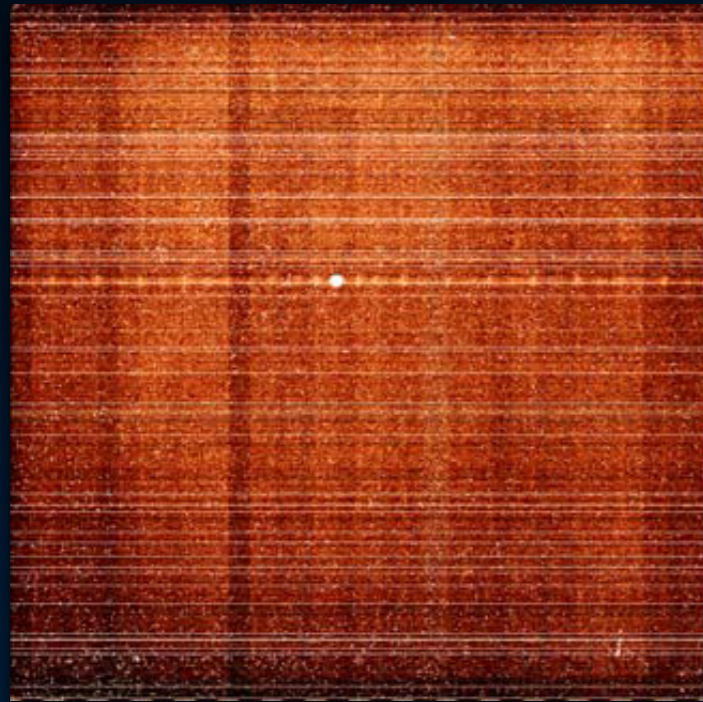


Piqueras López, J., 2014, PhD Thesis

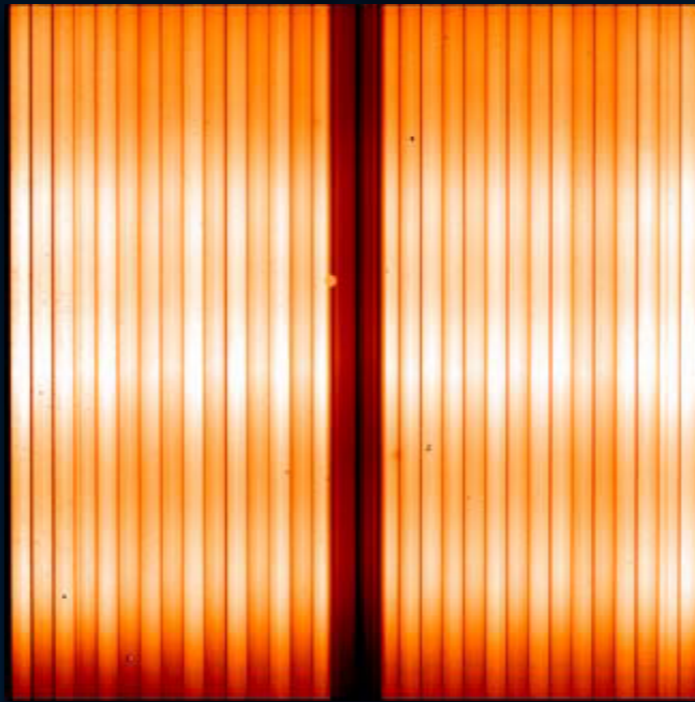


SINFONI data: calibration frames

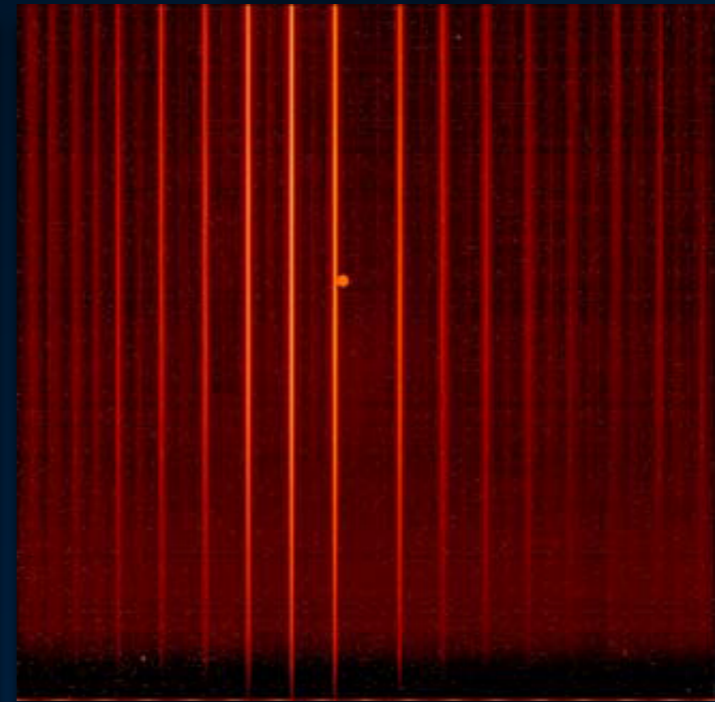
Dark frame



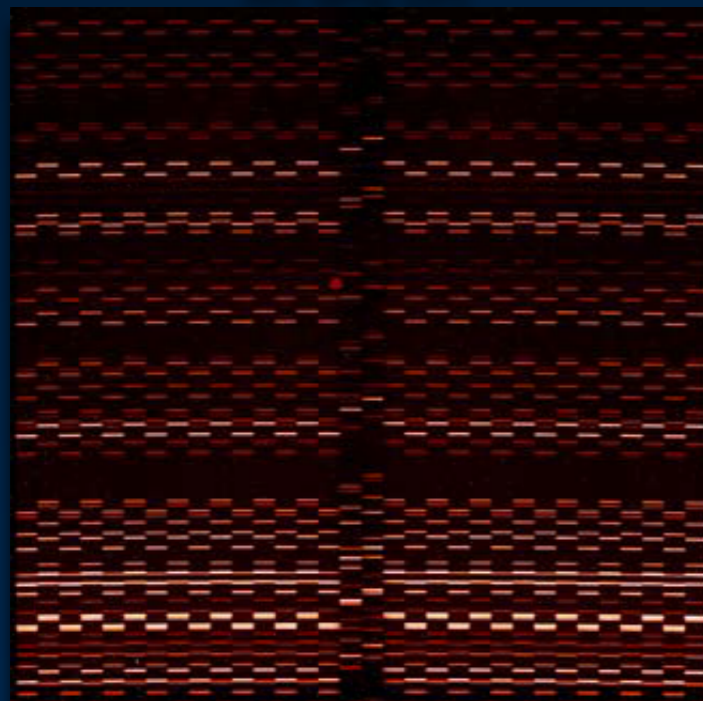
Flat field



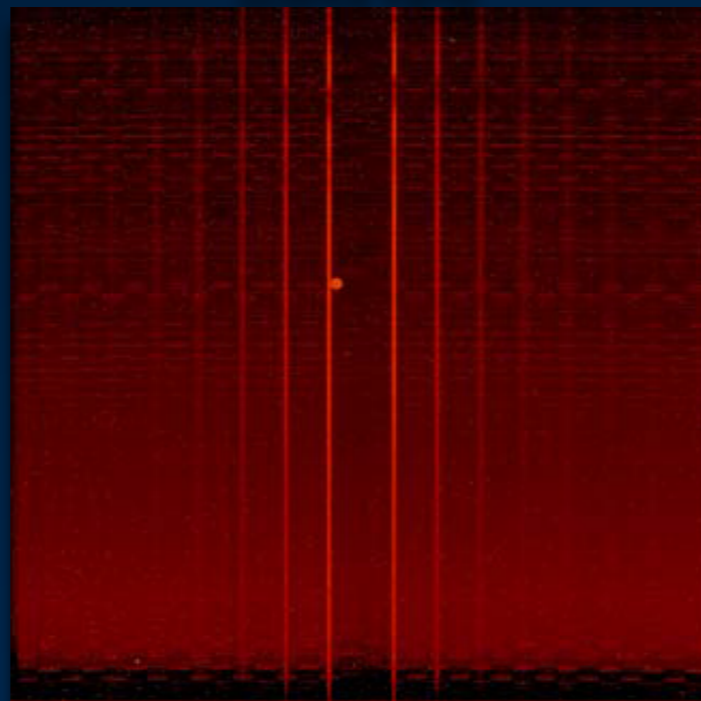
Distorsion frame



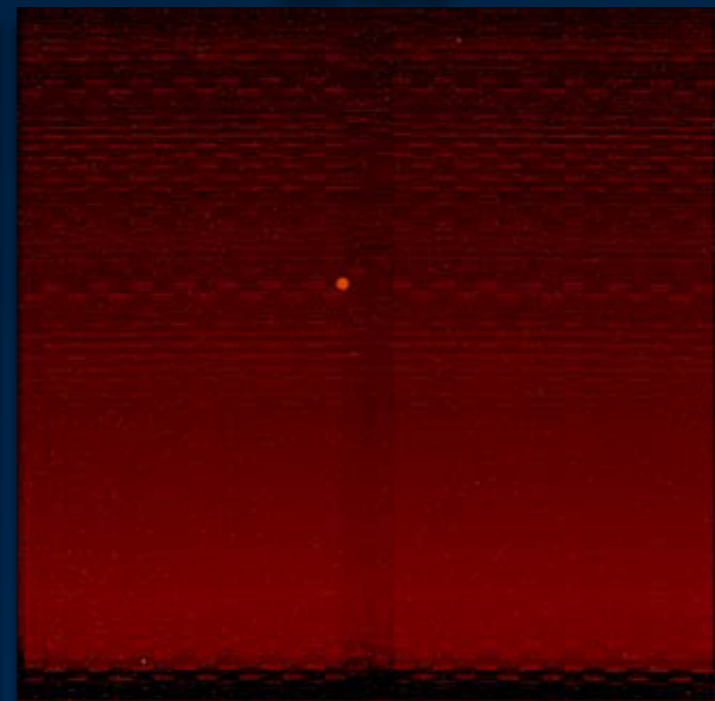
Arc lamp (on)



Science frame



Sky frame



A case study: NGC1068

- ◉ LIRG, Sy2
 - ◉ 15.2 Mpc, 74 pc/arcsec
- ◉ Extremely complex gas kinematics
- ◉ Papers based on these data:
Dasyra et al. (2007), Davies et al. (2007), Müller-Sánchez et al. (2009), Hicks et al. (2009), Davies et al. (2009), Müller-Sánchez et al. (2011), Hailey-Dunsheath et al. (2012)



A case study: NGC1068

- SINFONI AO observations
 - Program ID: 076.B-0098(A), PI Davies, R.
 - H+K, R~1500
 - Pixel scale ~0.05 arcsec, spatial resolution ~15 pc (FWHM)
 - FoV ~3"x3", inner ~700x700 pc
- Example dataset:
 - NGC1068
 - 8 on-source exposure + 4 sky frames (AABBAA pattern)
 - DIT = 50s
 - Standard star, Hip005607
 - 1 on-source exposure + 1 sky frame (AB pattern)
 - DIT = 2s
 - Calibration frames: dark, linearity, distortion, flat field and arc frames.

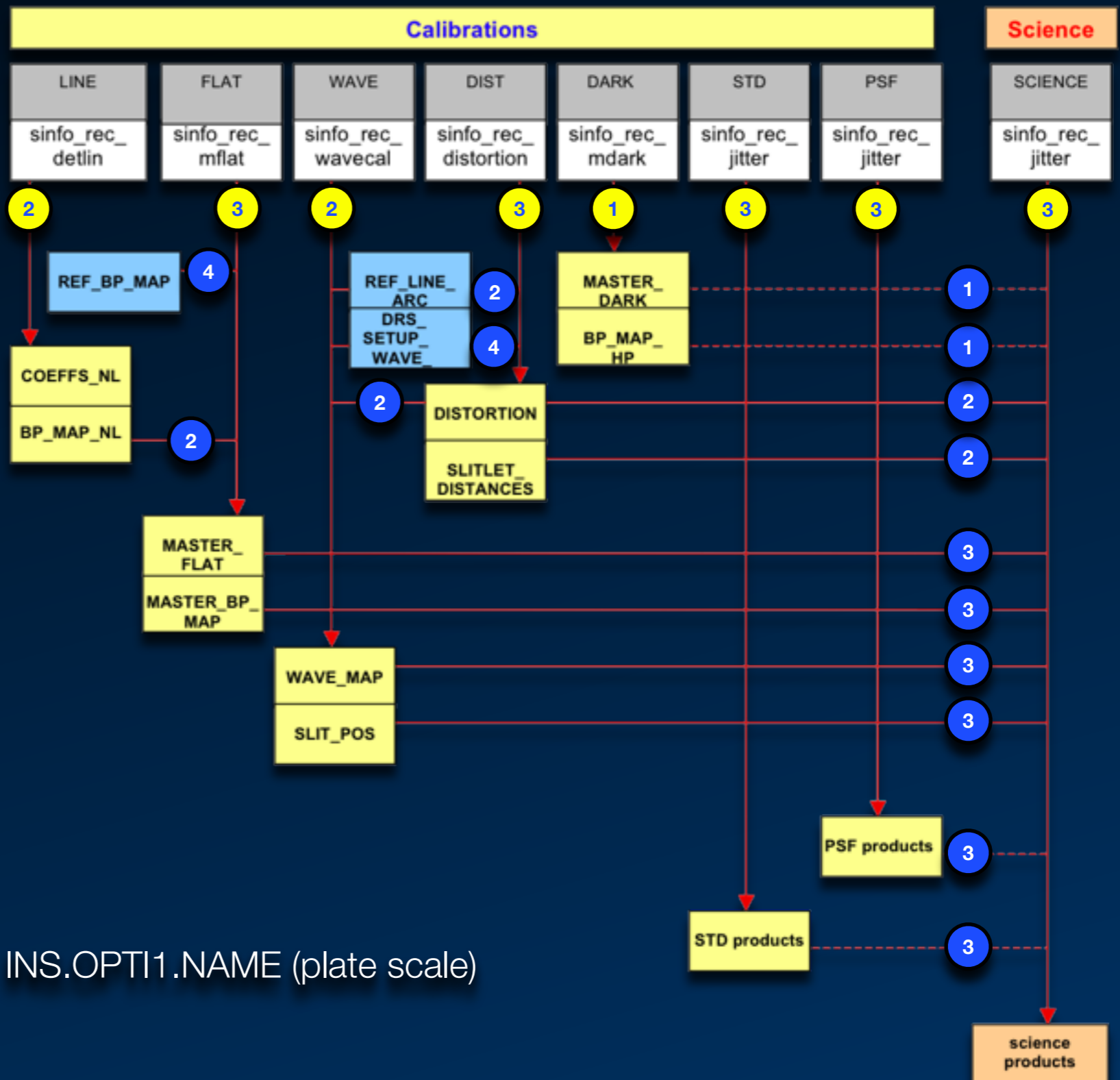
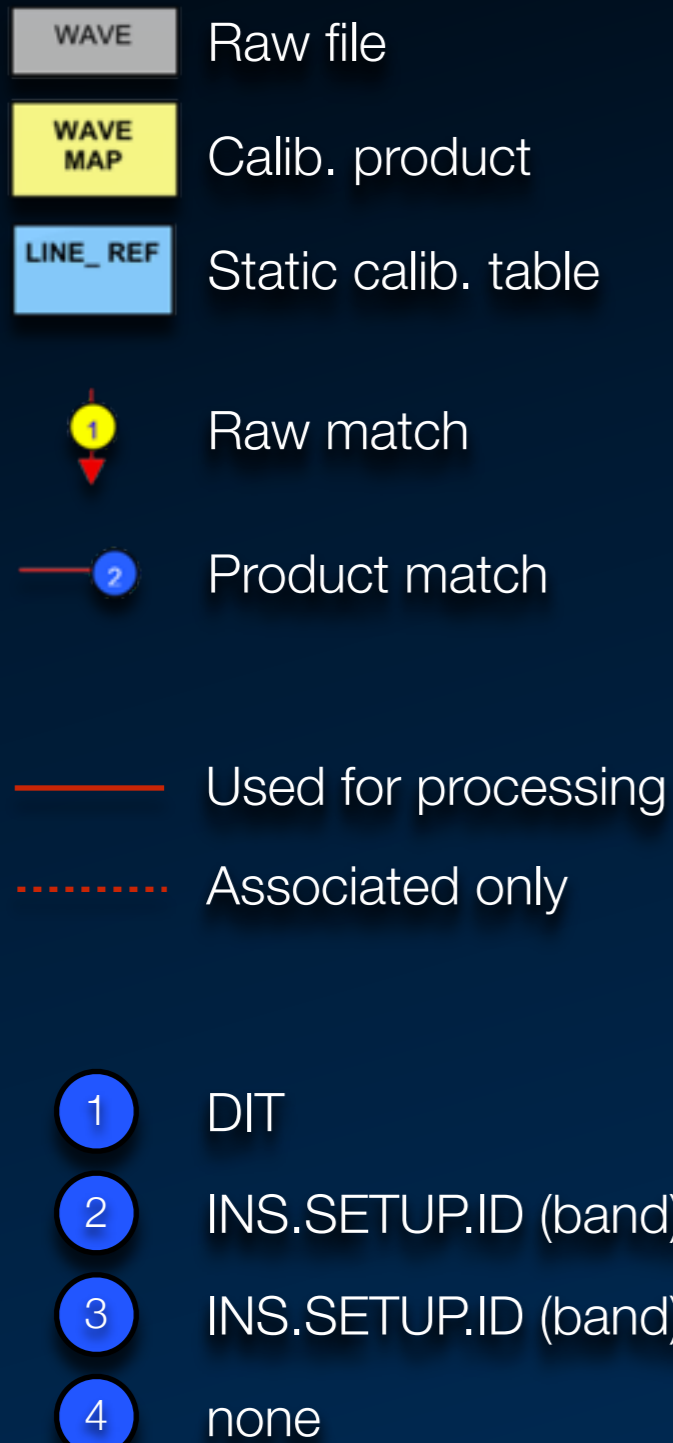
ESOREX, Gasgano and Reflex

- ◉ **ESOREX**: command line utility for running pipeline recipes
 - ◉ Easy to embed into data reduction scripts.
 - ◉ File classification and association ‘by hand’: set of files (SOF)
- ◉ **Gasgano** data management tool
 - ◉ Complete graphic interface: data browsing, file classification and association, display tools...
 - ◉ It allows the user to execute directly recipes on a set of selected files.
- ◉ **Reflex**: environment to reduce VLT science data using ESO pipelines (*Freudling et al. 2013*)
 - ◉ Based on workflow engine ‘Kepler’
 - ◉ It allows to graphically specify the sequence in which the data reduction steps are executed.
 - ◉ Easy to inspect the intermediate and final data products.
 - ◉ Plug-in user-defined modules and steps into the data reduction sequence.
 - ◉ Supports the development of data reduction workflows based on the ESO Common Pipeline Library.

The dataset

- ◉ A complete dataset should contain:
 - ◉ Science frames: on-source frames + sky frames [OBJECT, SKY]
 - ◉ Dark frames: ~3 frames per DIT [DARK]
 - ◉ Linearity frames: ~24 frames [LINEARITY_LAMP]
 - ◉ Distortion frames: ~75 fibre frames + 2 flat fields + 2 lamp frames [FIBRE_NS; FLAT_NS; WAVE_NS]
 - ◉ Lamp frames: ~2 frames, lamp on and off [WAVE_LAMP]
 - ◉ STD star frames: ~1 on-source + 1 sky (optional) [STD,SKY_STD]
- ◉ In addition, some static calibration tables are needed (provided with the pipeline)

SINFONI association map

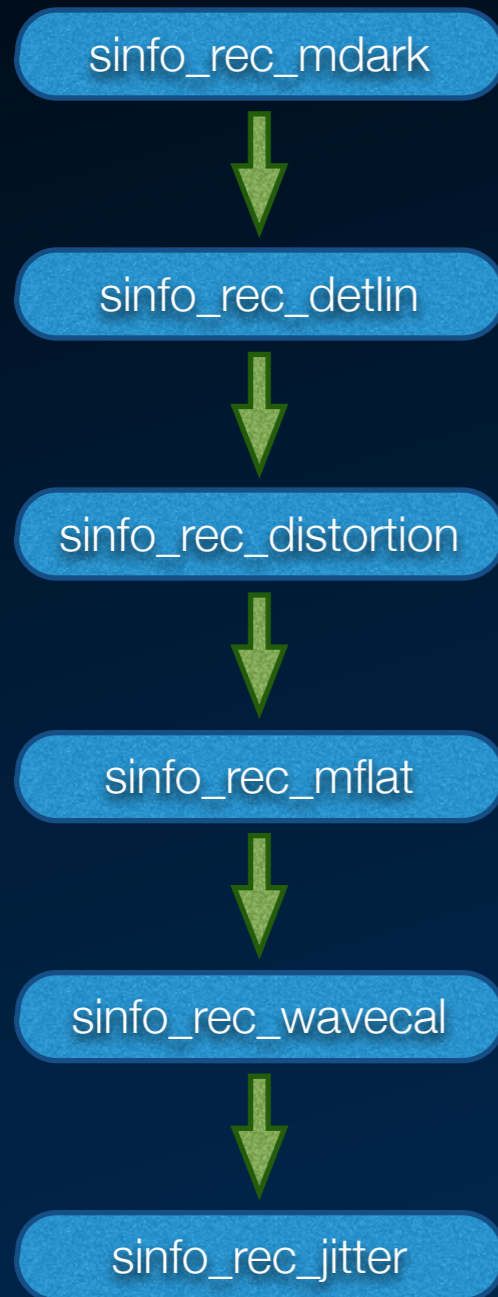


Reduction process

Main directory: `/file_path/SINFONI_hands_on/reduction`

1. Classify and organise raw frames: `./script.dprtype`
2. Run pipeline recipes: `./run.pipeline`

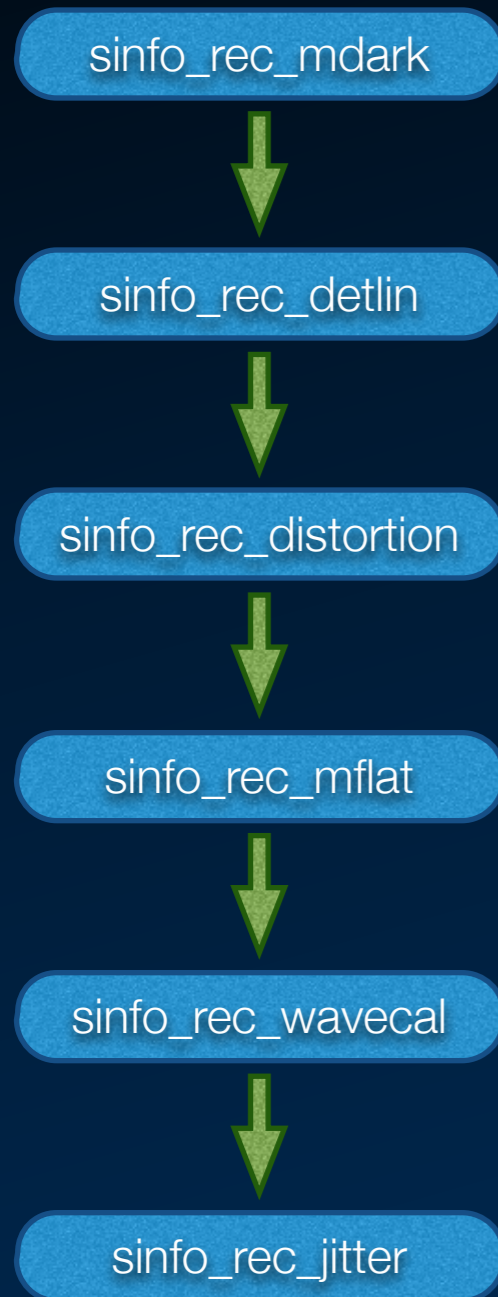
Reduction process



→ Master dark and bad pixel map

```
mdark_sof
./file_path/SINFO.2005-10-06T11_01_40.702.fits DARK
./file_path/SINFO.2005-10-06T11_02_47.803.fits DARK
./file_path/SINFO.2005-10-06T11_04_00.847.fits DARK
```

Reduction process

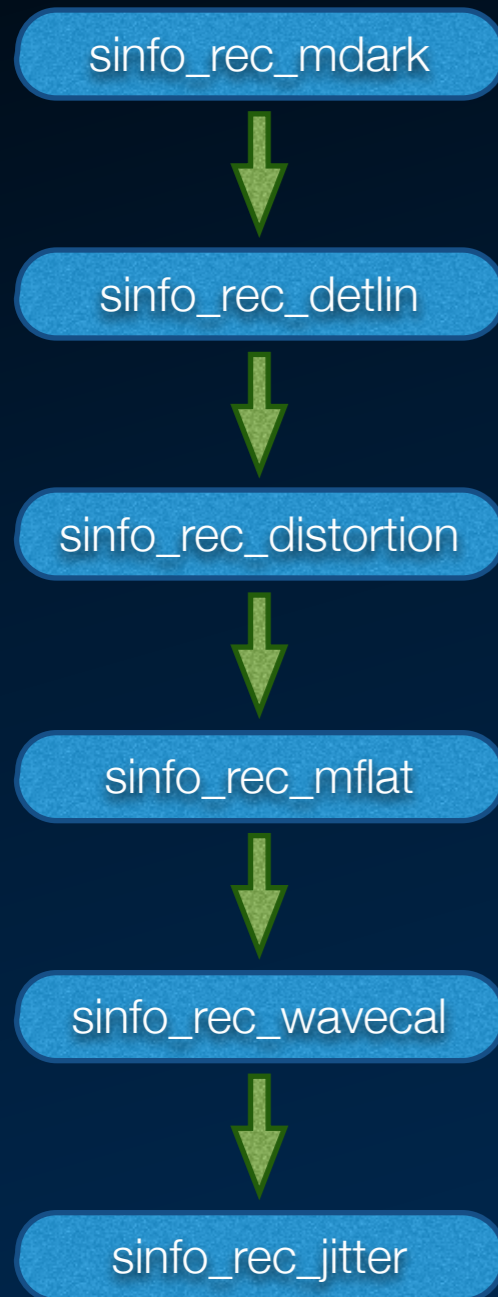


Response of the detector as a function of pixel intensity

```
linearity_sof

./file_path/SINFO.2005-10-06T12_03_54.533.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_04_21.865.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_04_39.139.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_05_43.390.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_06_48.441.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_07_53.993.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_09_02.725.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_10_55.655.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_12_43.634.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_13_17.729.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_13_44.215.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_15_01.968.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_16_14.341.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_17_14.982.fits LINEARITY_LAMP
./file_path/SINFO.2005-10-06T12_18_13.112.fits LINEARITY_LAMP
.
.
.
```

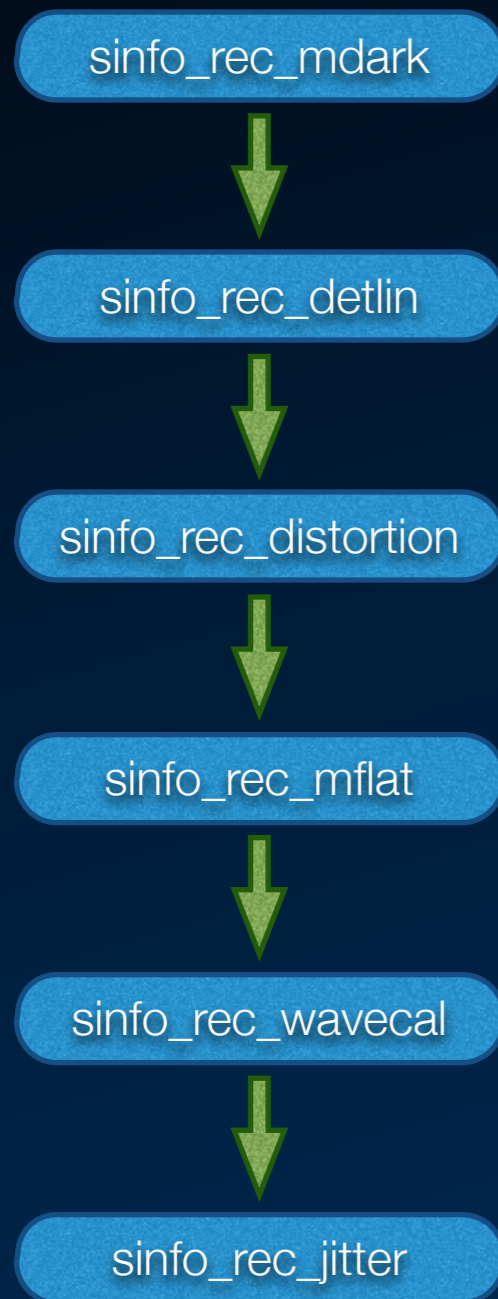
Reduction process



Optical distortion of the system
and relative distances of the slitlets

```
distortion_sof
.
.
./file_path/SINFO.2005-10-06T11_56_11.389.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_56_28.522.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_56_47.465.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_57_06.409.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_57_25.382.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_57_50.179.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_58_09.143.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_58_28.915.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_58_53.698.fits FIBRE_NS
./file_path/SINFO.2005-10-06T11_59_34.655.fits FLAT_NS
./file_path/SINFO.2005-10-06T12_00_02.020.fits FLAT_NS
./file_path/SINFO.2005-10-06T12_00_24.354.fits WAVE_NS
./file_path/SINFO.2005-10-06T12_01_18.933.fits WAVE_NS
./gen_calib/drs_setup_wave.fits DRS_SETUP_WAVE
./gen_calib/xenonHK.fits REF_LINE_ARC
```

Reduction process

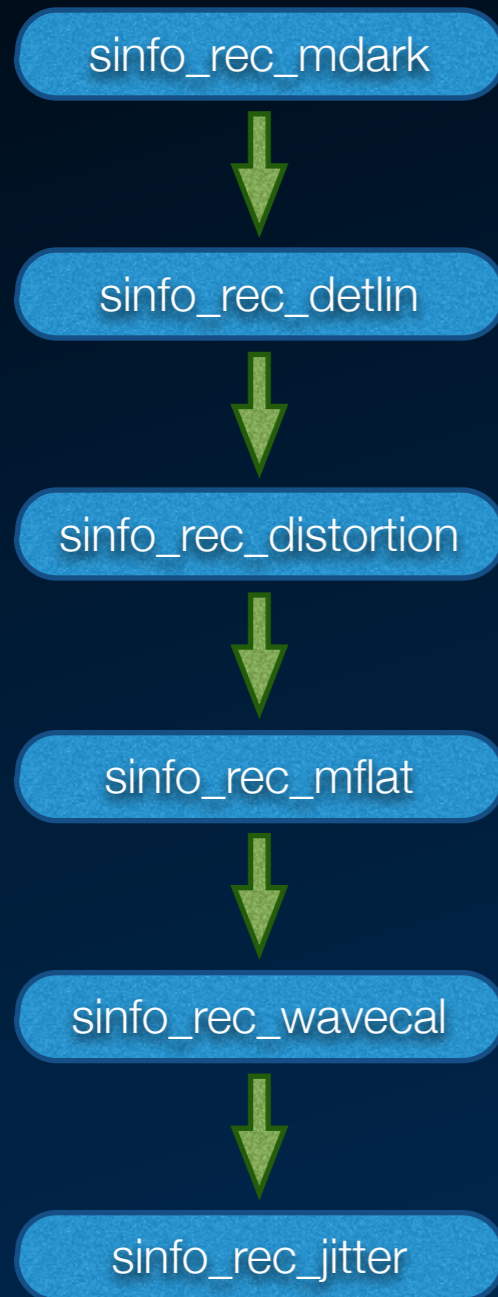


Master bad pixel map and master flat frame

```
mflat_sof

./file_path/SINFO.2005-10-06T12_31_17.960.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_31_45.095.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_32_01.808.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_33_08.670.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_34_17.192.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_34_36.466.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_34_54.898.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_35_58.570.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_37_07.082.fits FLAT_LAMP
./file_path/SINFO.2005-10-06T12_37_35.217.fits FLAT_LAMP
./gen_calib/REF_BP_MAP.fits REF_BP_MAP
./pro/BP_MAP_NL_HK.fits BP_MAP_NL
./pro/BP_MAP_HP.fits BP_MAP_HP
```

Reduction process

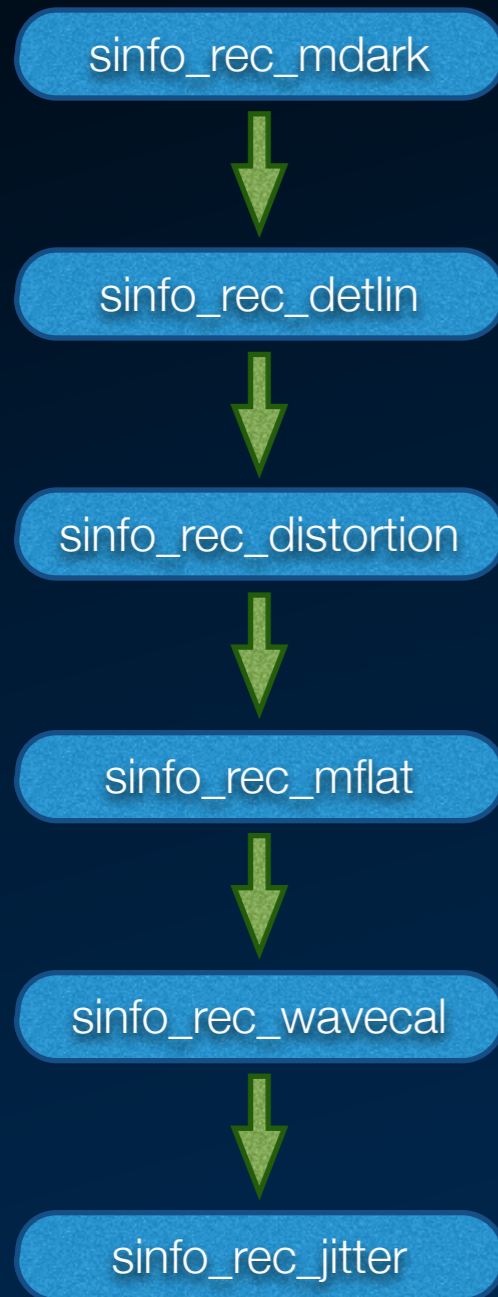


Wavelength calibration frames

```
wcal_sof

./file_path/SINFO.2005-10-06T12_39_31.918.fits  WAVE_LAMP
./file_path/SINFO.2005-10-06T12_40_16.096.fits  WAVE_LAMP
./gen_calib/xenonHK.fits                       REF_LINE_ARC
./gen_calib/drs_setup_wave.fits                 DRS_SETUP_WAVE
./gen_calib/SLIT_POS_HK_100.fits                SLIT_POS
./pro/MASTER_FLAT_LAMP_HK_100.fits             MASTER_FLAT_LAMP
./pro/MASTER_BP_MAP_HK_100.fits               MASTER_BP_MAP
./pro/DISTORTION_HK.fits                       DISTORTION
```

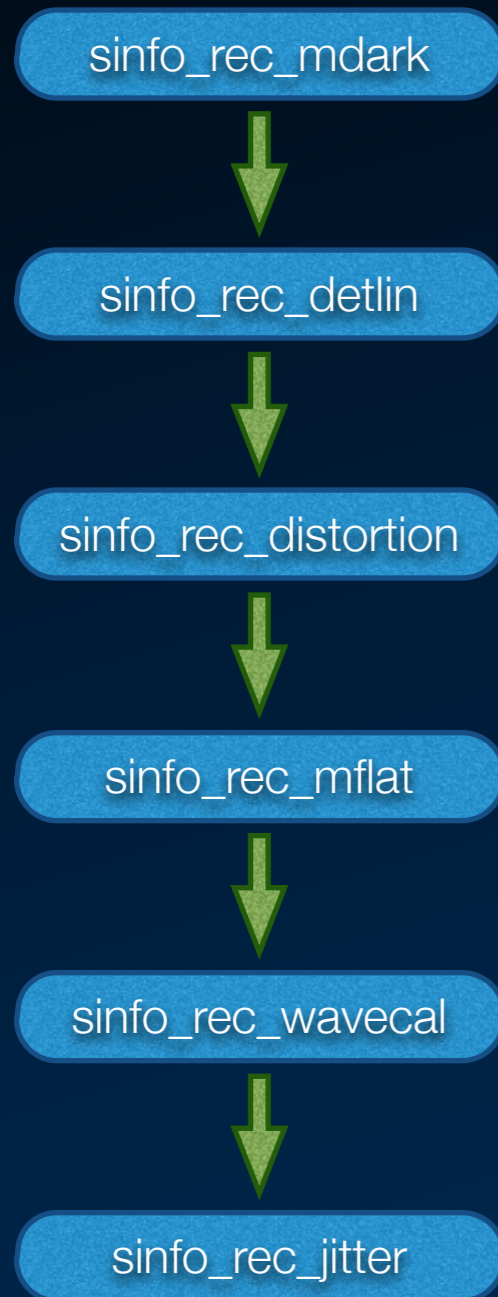

Reduction process



Science frames: corrects from sky emission and reconstructs final cube

```
sci_sof
./file_path/SINFO.2005-10-06T05_50_21.862.fits OBJECT_NODDING
./file_path/SINFO.2005-10-06T05_56_08.204.fits OBJECT_NODDING
./file_path/SINFO.2005-10-06T06_01_57.865.fits SKY_NODDING
./file_path/SINFO.2005-10-06T06_07_36.695.fits SKY_NODDING
./file_path/SINFO.2005-10-06T06_13_34.688.fits OBJECT_NODDING
./file_path/SINFO.2005-10-06T06_19_19.359.fits OBJECT_NODDING
./file_path/SINFO.2005-10-06T06_25_00.689.fits OBJECT_NODDING
./file_path/SINFO.2005-10-06T06_30_46.181.fits OBJECT_NODDING
./file_path/SINFO.2005-10-06T06_36_40.853.fits SKY_NODDING
./file_path/SINFO.2005-10-06T06_42_26.345.fits SKY_NODDING
./file_path/SINFO.2005-10-06T06_48_21.027.fits OBJECT_NODDING
./file_path/SINFO.2005-10-06T06_54_00.716.fits OBJECT_NODDING
./pro/MASTER_BP_MAP_HK_100.fits MASTER_BP_MAP
./pro/MASTER_FLAT_LAMP_HK_100.fits MASTER_FLAT_LAMP
./pro/WAVE_MAP_HK_100.fits WAVE_MAP
./pro/SLITLETS_DISTANCE_HK.fits SLITLETS_DISTANCE
./pro/SLIT_POS_HK_100.fits SLIT_POS
./pro/DISTORTION_HK.fits DISTORTION
```

Reduction process



STD star frames: corrects from sky emission and reconstructs final cube

```
std_sof

./file_path/SINFO.2005-10-06T07_06_02.984.fits STD
./file_path/SINFO.2005-10-06T07_07_00.134.fits SKY_STD
./pro/MASTER_BP_MAP_HK_100.fits MASTER_BP_MAP
./pro/MASTER_FLAT_LAMP_HK_100.fits MASTER_FLAT_LAMP
./pro/WAVE_MAP_HK_100.fits WAVE_MAP
./pro/SLITLETS_DISTANCE_HK.fits SLITLETS_DISTANCE
./pro/SLIT_POS_HK_100.fits SLIT_POS
./pro/DISTORTION_HK.fits DISTORTION
```

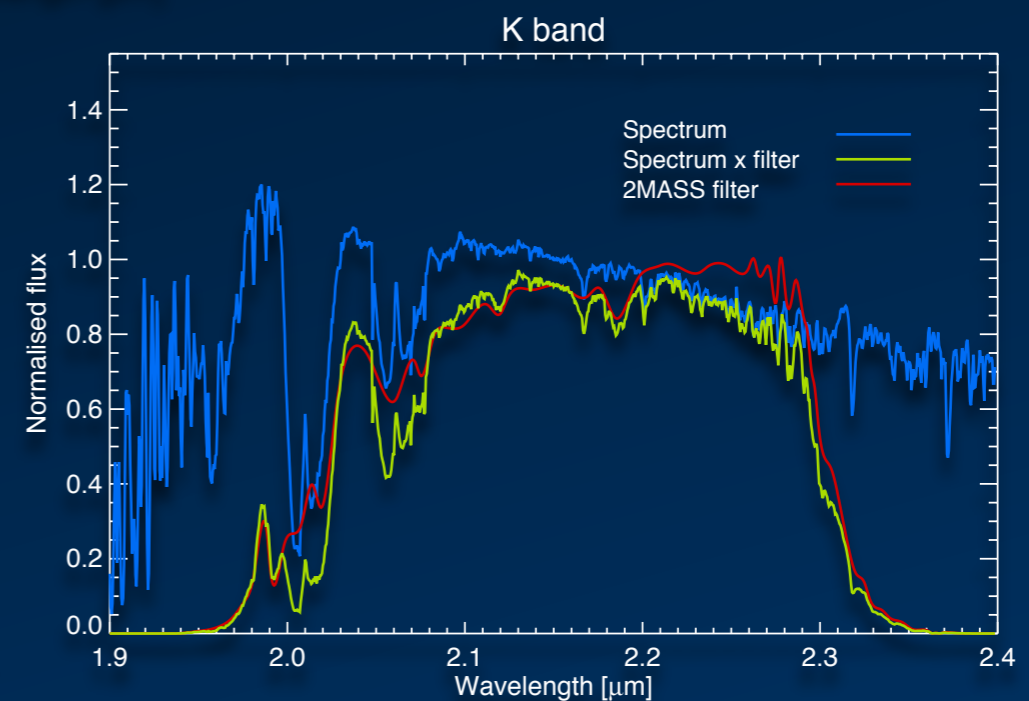
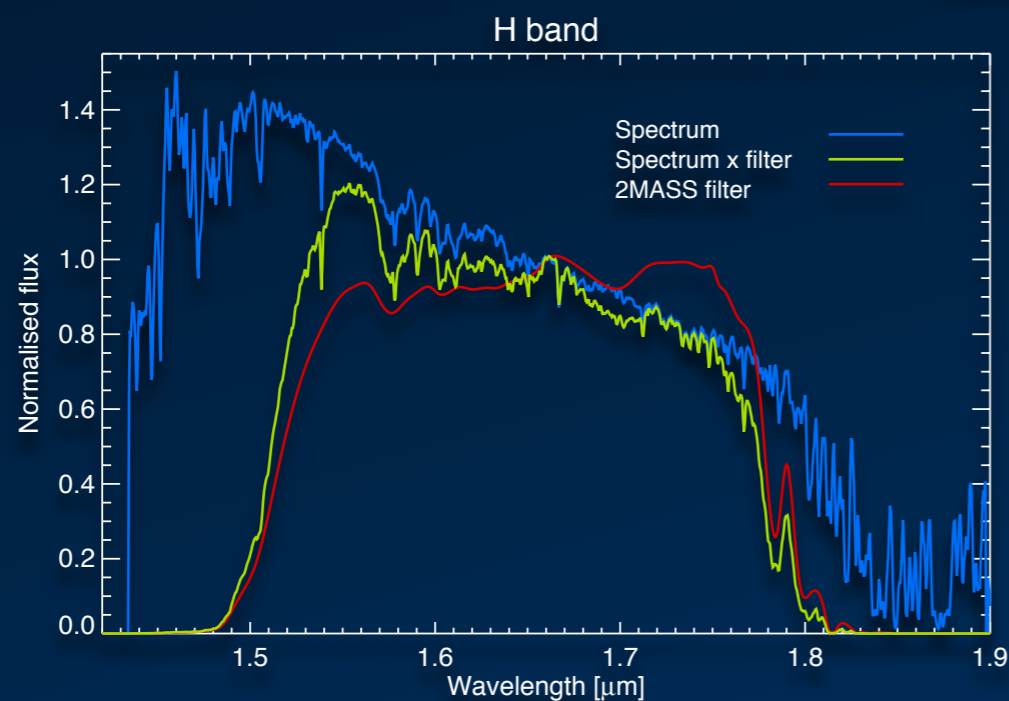
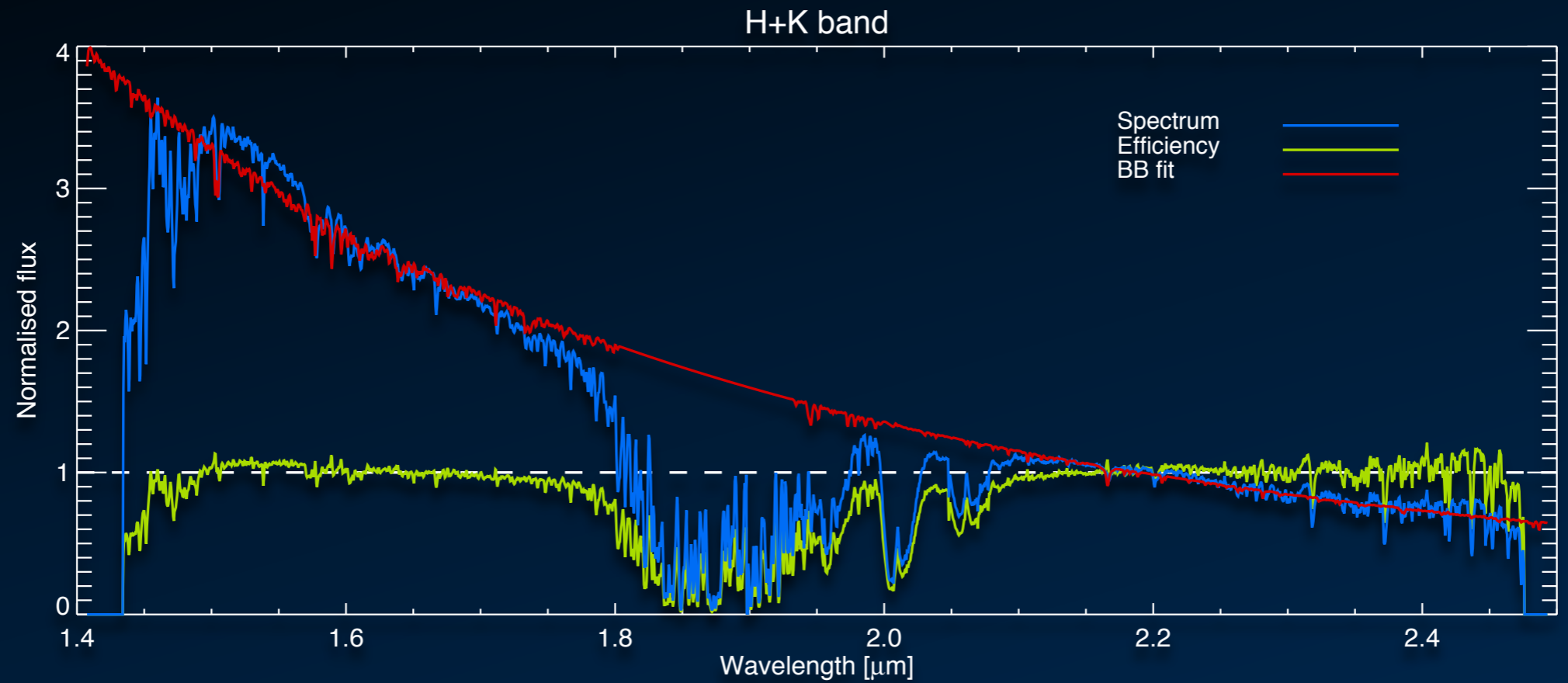
Reduction process

- Main products: combined, reconstructed data cubes (out_objnod.fits)
 - Science data
 - STD star
- Ancillary products:
 - Individual, reconstructed data cubes
 - Corrected from sky emission: out_cube_obj_cor##.fits
 - Non-corrected: out_cube_obj##.fits
 - Sky cubes: out_sky_cube##.fits
 - STD star spectrum: out_starspectrum.fits (optional)

Calibration of the data

- Efficiency curves
 - Characterization of the atmospheric transmission by its imprint on the spectrum of the standard star
- Absolute flux calibration: flux factors
- Inputs
 - Standard star spectrum
 - Effective temperature or spectral model (slope)
 - H- and K-band magnitudes (scaling)

Calibration of the data



Calibration of the data

Main directory: `/file_path/SINFONI_hands_on/flux_calibration`

1. Efficiency curve and flux factors:
 1. Go to `./STD`
 2. Run IDL
 3. Type: `IDL>@start_std_calibration`
2. Calibrate object data cube:
 1. Go to `../`
 2. Run IDL
 3. Type: `IDL>@start_flux_calibration`

Final product: `NGC1068_calibrated_cube_HK.fits`