A Planet Finder Instrument for the VLT

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David Mouillet (PS), Pascal Puget (PM), Kjetil Dohlen (SE)
and numerous participants from 12 European institutes !

Institutes

LAOG, MPIA, LAM, ONERA, LESIA, INAF, Geneva Observatory, LUAN, ASTRON, ETH-Z, UvA, ESO

Co-Is:

T. Henning (MPIA, Heidelberg), C. Moutou (LAM, Marseille), A. Boccaletti (LESIA, Paris), S. Udry (Observatoire de Genève), M. Turrato (INAF, Padova), H.M. Schmid (ETH, Zurich), F. Vakili (LUAN, Nice), R. Waters (UvA, Amsterdam)

Data Reduction and Handling Software

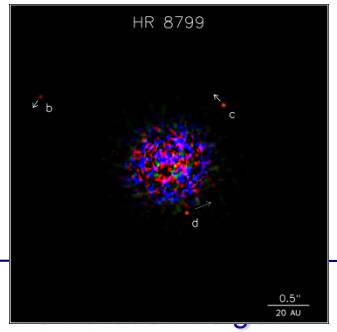
SPHERE

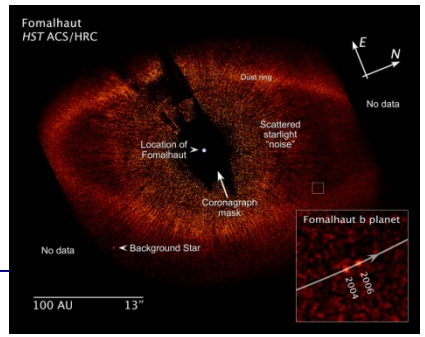
Spectro-Polarimetric High-contrast Exoplanet REsearch

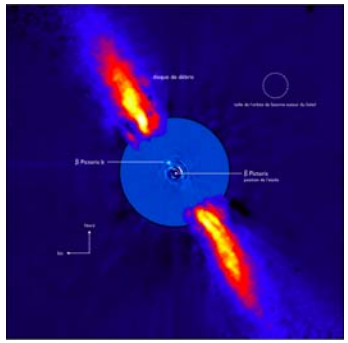
Science objectives

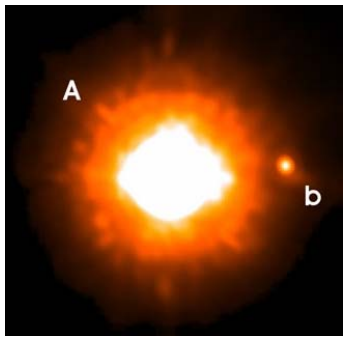
- High contrast imaging ⟶ **planetary masses**
- Large sample: **statistics**, variety of classes, evolutionary trends
- Complete accessible **mass / period** - diagram
- Characterization of **planet atmospheres**

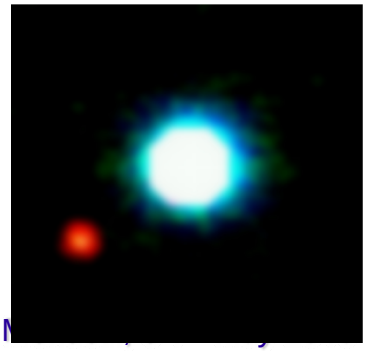
  (clouds, dust content, methane, water absorption, effective temperature, radius, dust polarization)



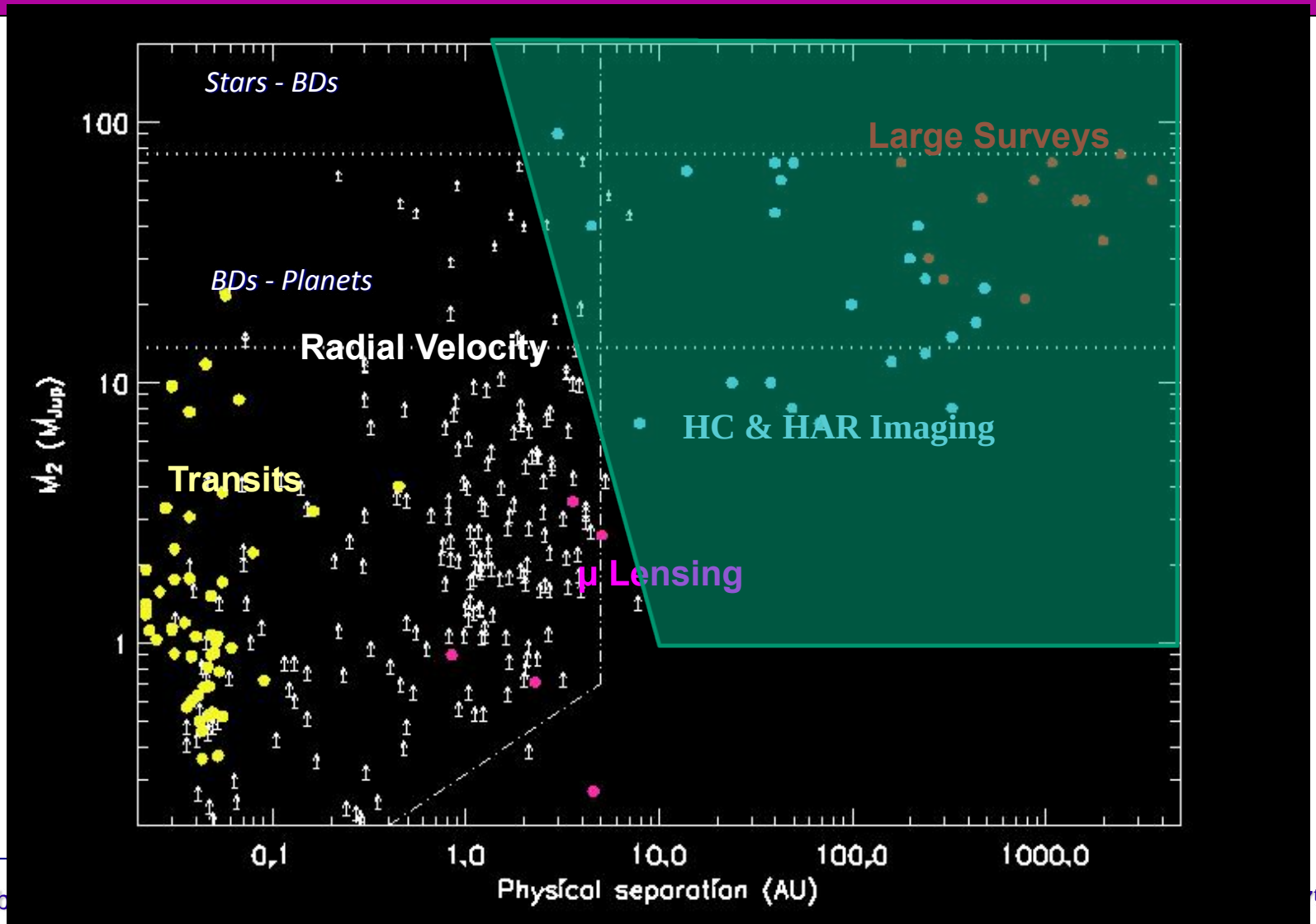








Mass-Period


Stars - BDs
BDs - Planets
Radial Velocity
Transits
Large Surveys
HC & HAR Imaging
μ Lensing
100
10
1
M2 (MJup)
0,1
1,0
10,0
100,0
1000,0
Physical separation (AU)

Targets

- Classes: several hundreds objects
  - Young nearby stars (5-50 Myr) (detection down to 0.5 M_J)
  - Young active F-K stars (0.1 – 1 Gyr)
  - Late type stars
  - Known planetary systems (from other techniques)
  - Closest stars (< 6 pc)

- Selection of individual targets
  - Known (proto) - planetary disks: physics, evolution, dynamics
  - Variety of high contrast targets: YSO gas environment, evolved stars, Solar System objects

Operation strategy

- Survey all accessible stars

- Follow-up observations for planet characterization

-> A few hundred nights required over several years

Data Reduction and Handling Software

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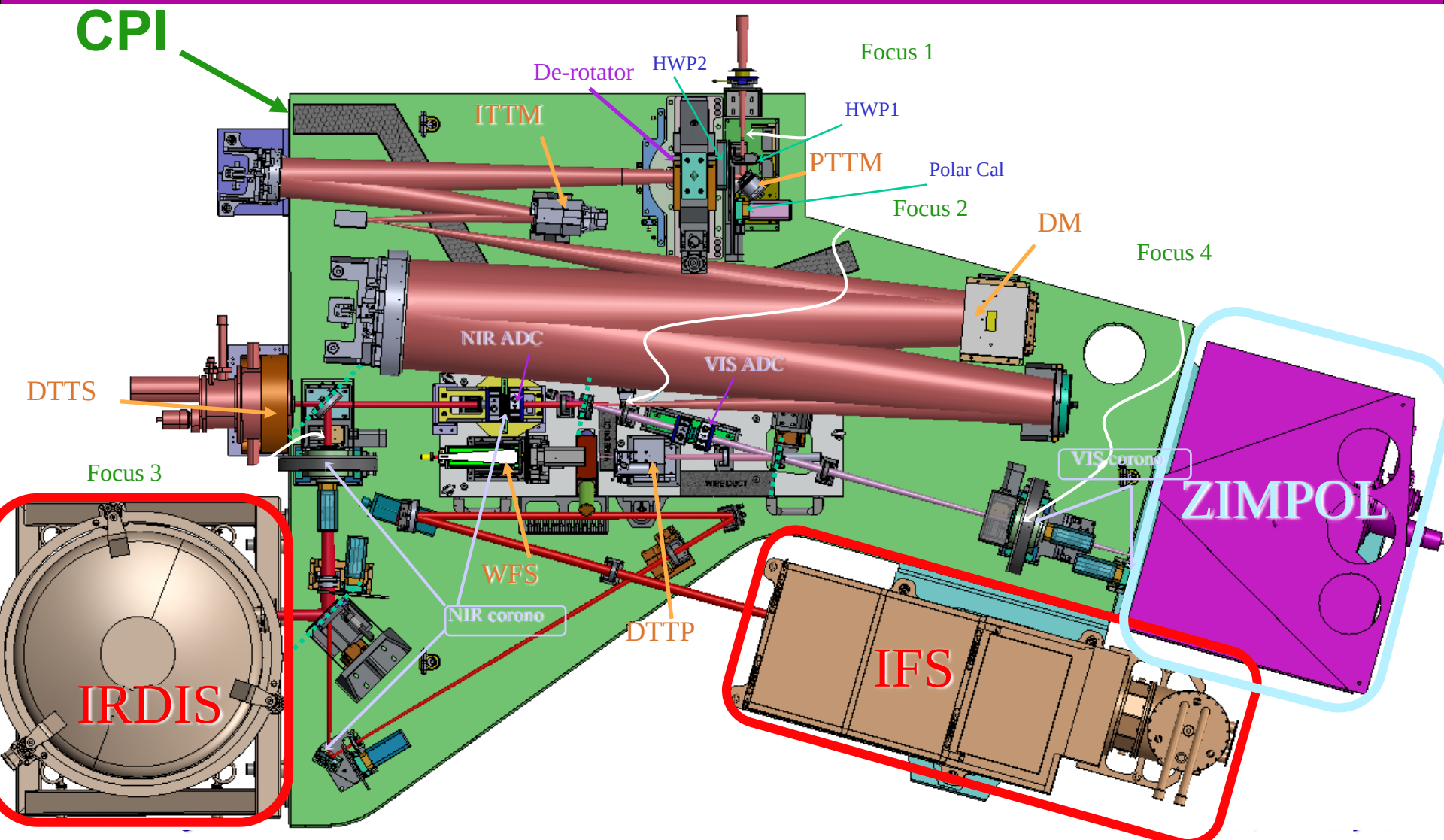
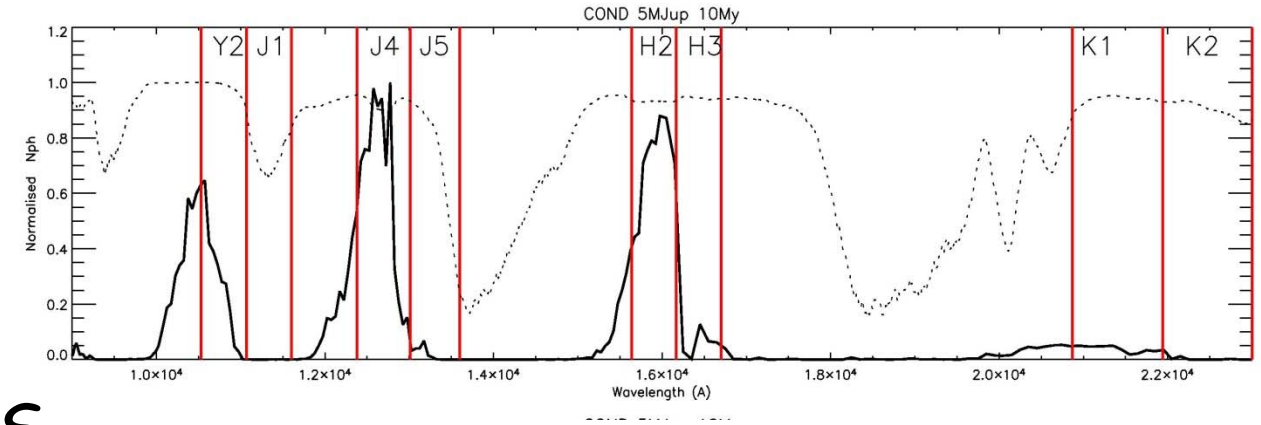
Design



Instrument modes

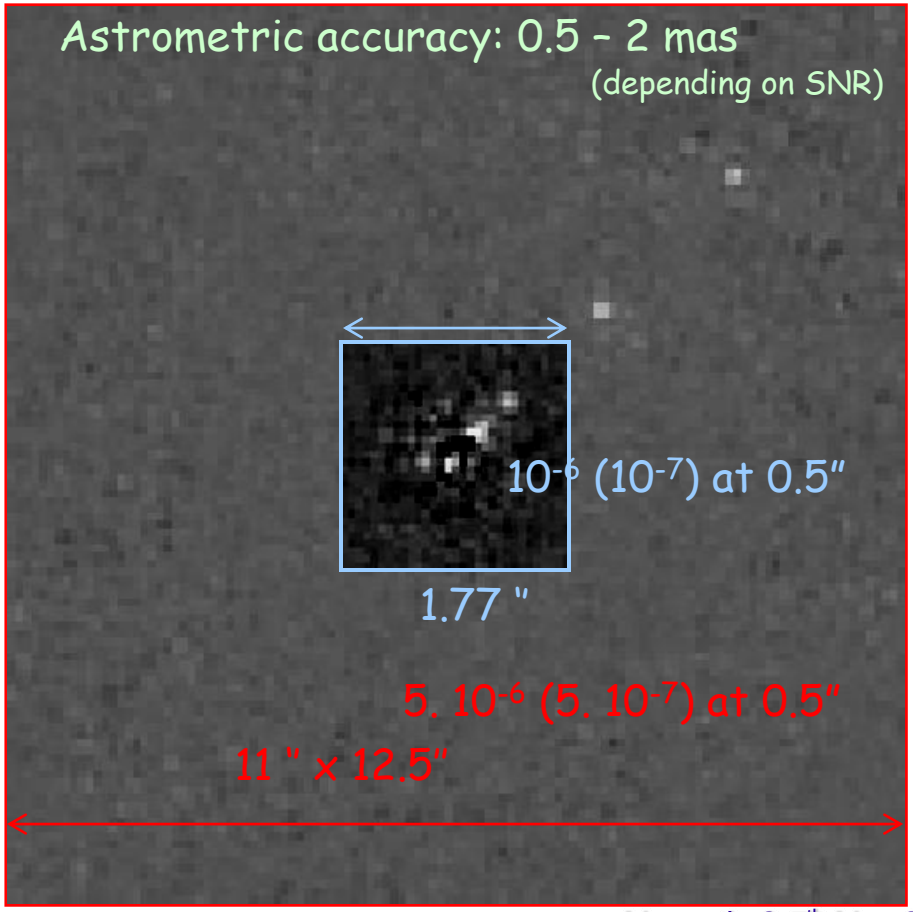
Science module	Modes
IRDIS	Dual Band Imaging (DBI)
	Long slit spectroscopy
	Classical imaging
	Dual Polarization imaging (DPI)
IFS	Imaging spectroscopy in Y to J
ZIMPOL	Very accurate relative polarimetry
	Classical imaging

IRDIS / DBI + IFS

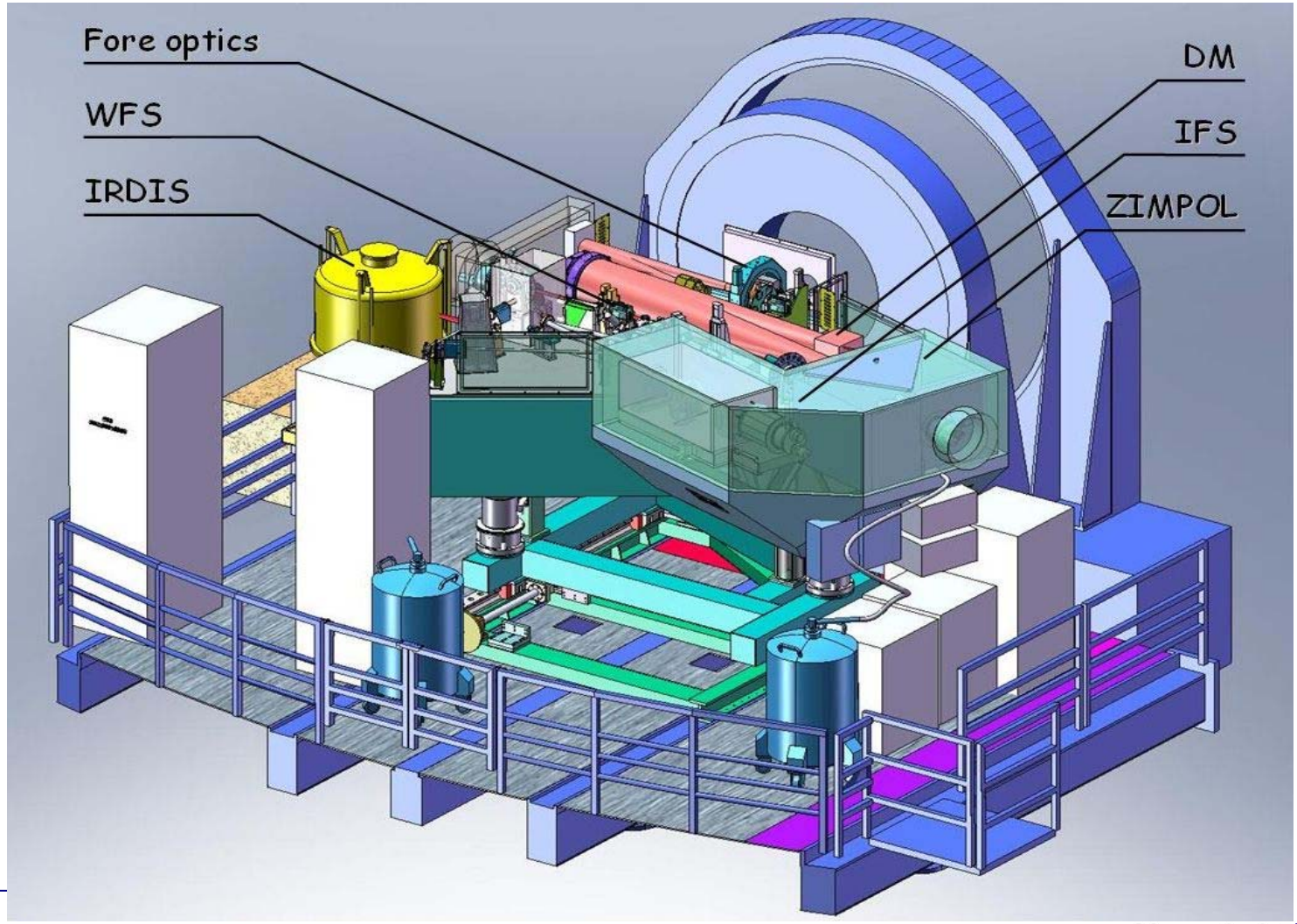


Y-J band with IFS
Dual imaging in H

- ✓ Multiplex advantage for field and spectral range
- ✓ false alarm reduction, operation, calibration
- ✓ early classification



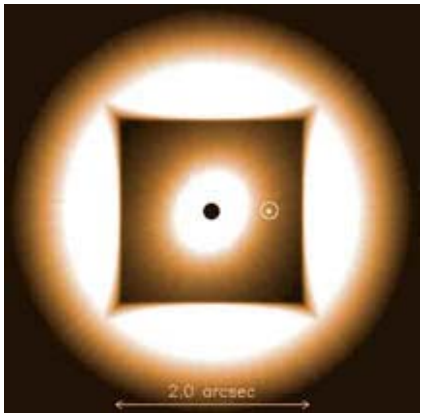
at the platform

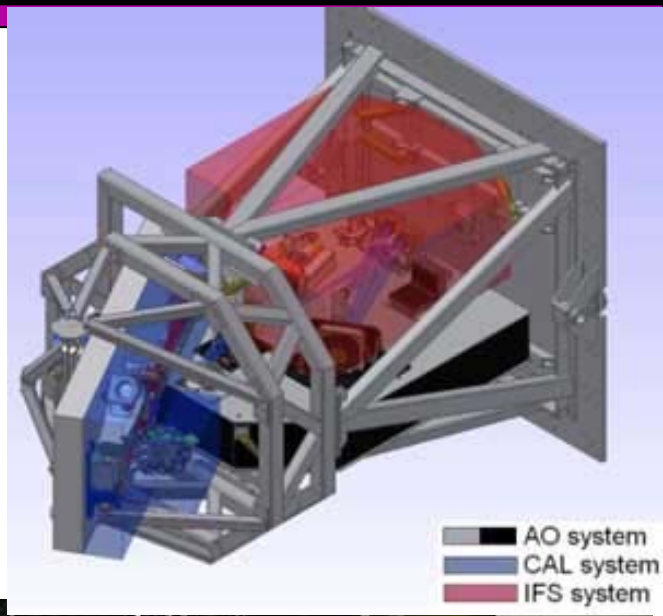


Cousins

GPI at Gemini South

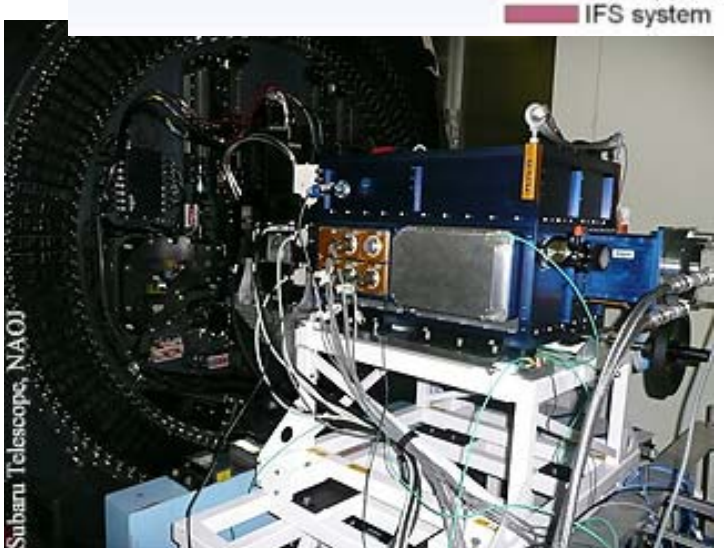
Macintosh et al.





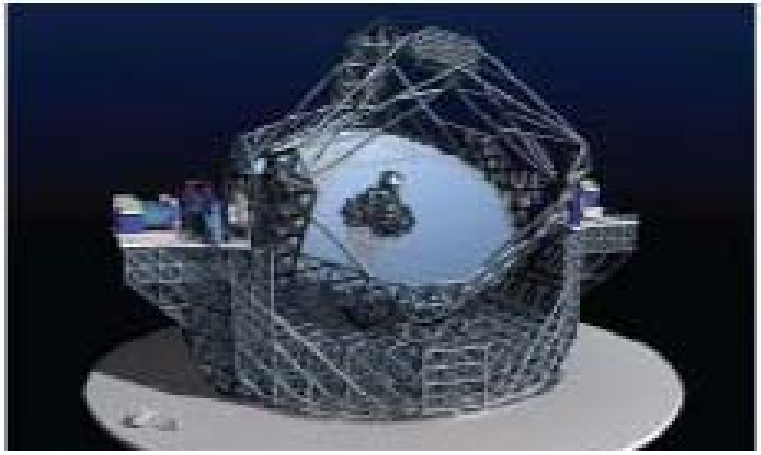
HiCIAO + SCExAO at Subaru

Tamura et al. & Guyon et al

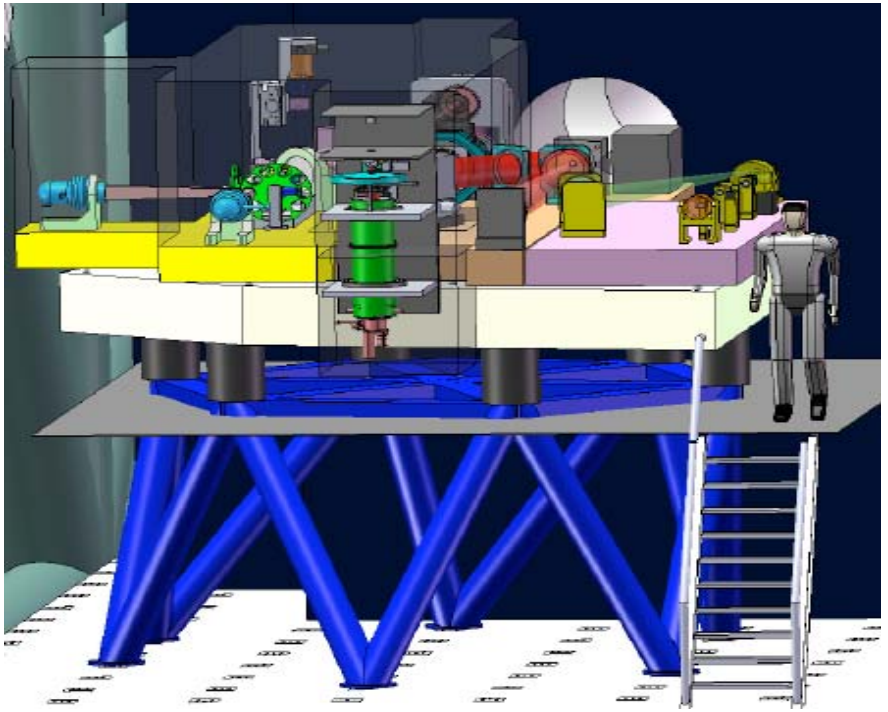


The future

E-ELT 42m



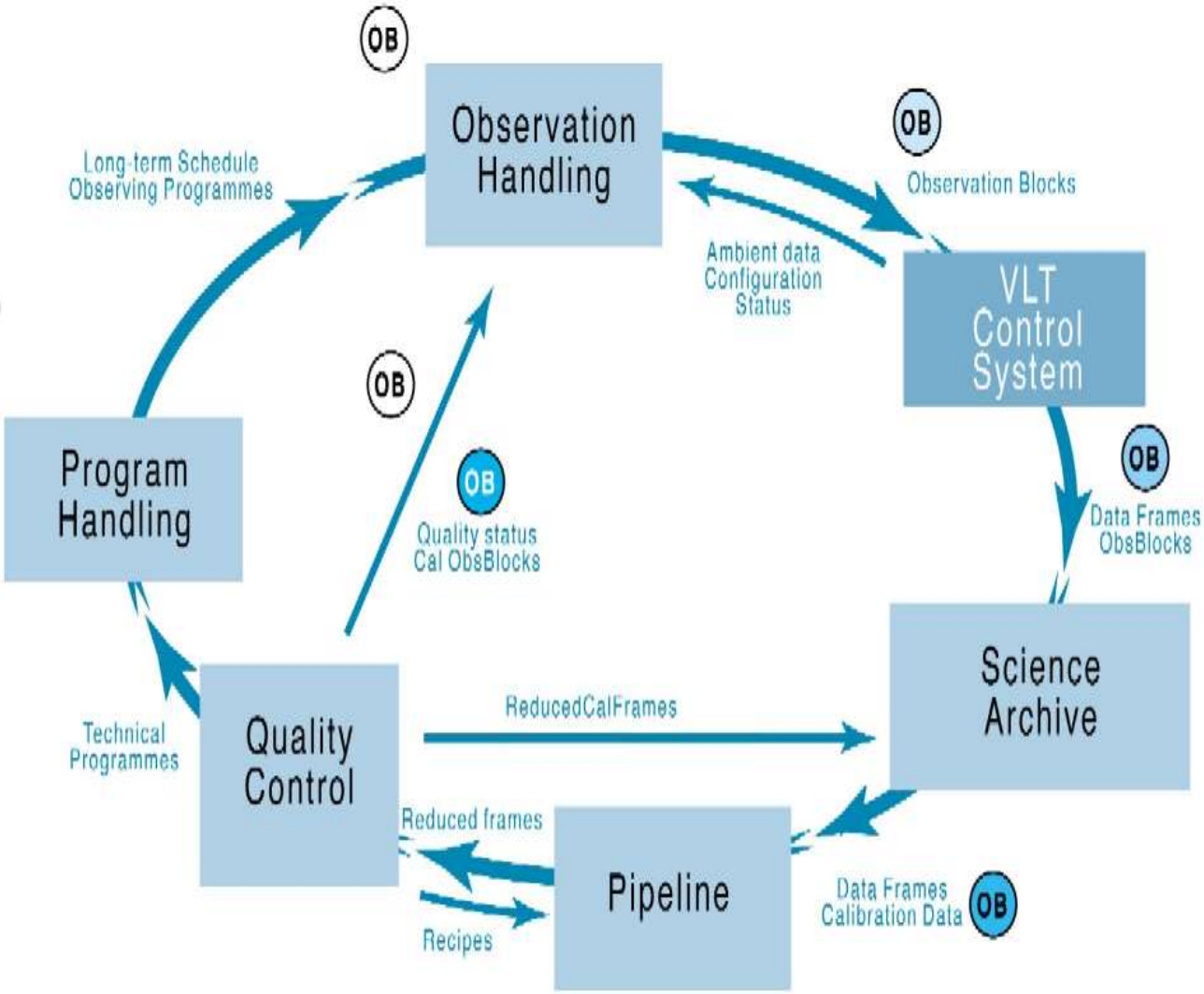
EPICS



Data Flow system

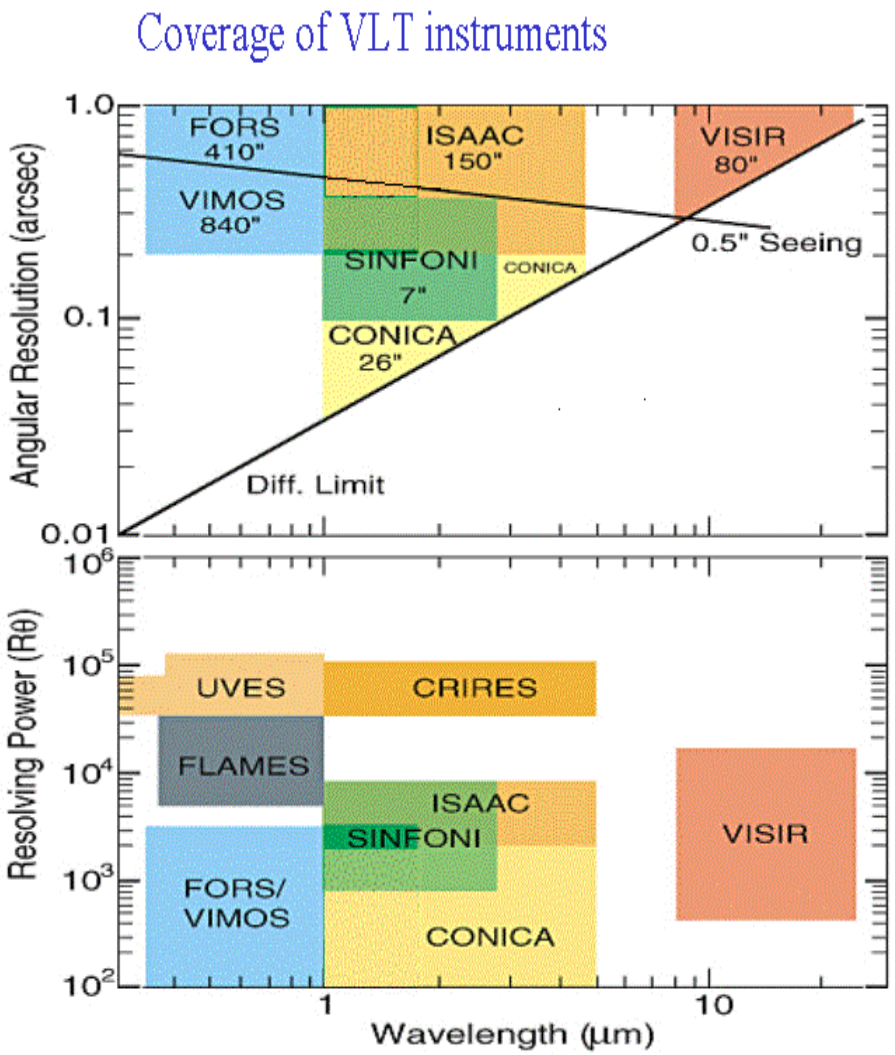
Customers:

- User Support Group
- Data Flow Operations Group
- Paranal Science Operations
- La Silla Science Operations
- ESO Community



Instrument Pipelines

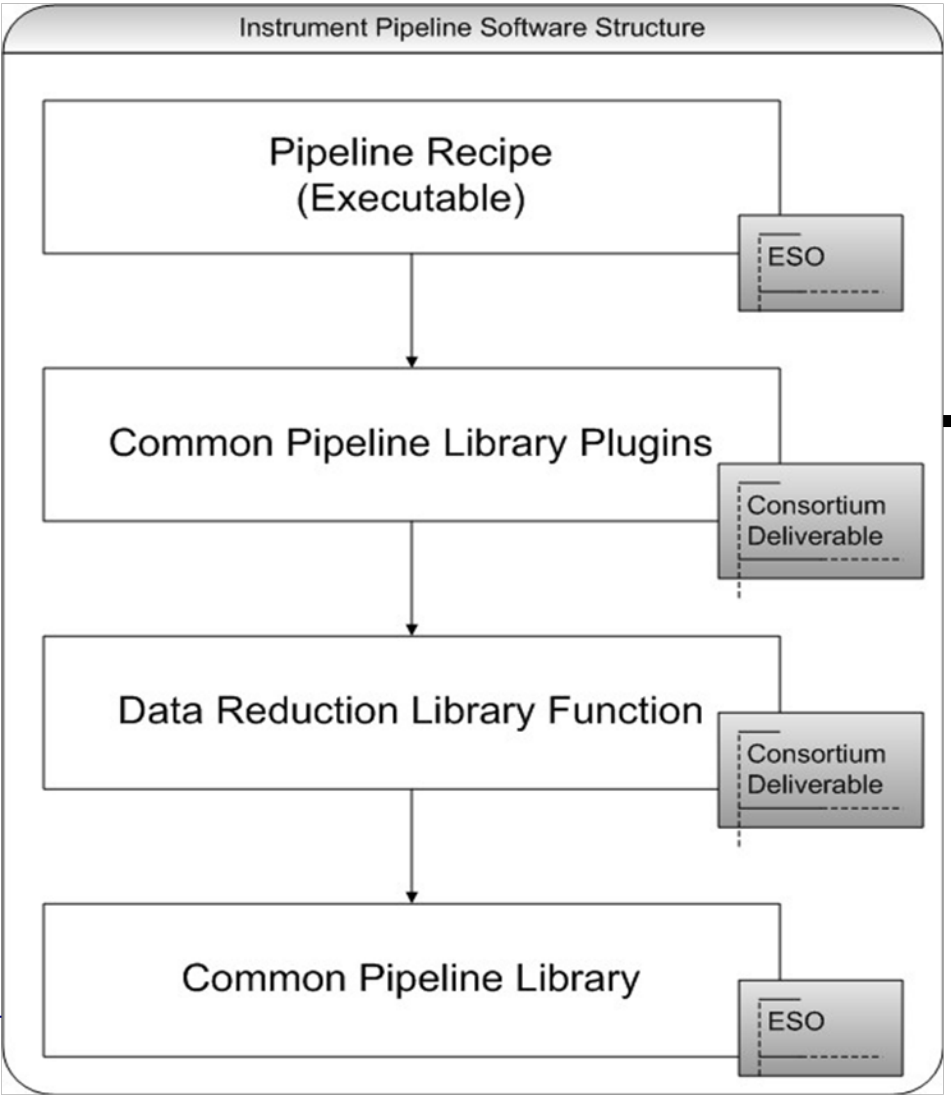
- Process raw and calibration frames
- Produce Quality Control for monitoring telescope, instrument and detector performance
- Process raw into science data
- Produce high level science grade data products (future)



Pipeline Fundamentals

- ESO pipeline run full automatic
- Implemented in ANSI C
- Architecture based on Calibration Plan
- Each calibration step needs a “Recipe”

Pipeline Integration



- DICB/Archive
- Data Flow Operations
- INS Commissioning Team
- Paranal Science Operations
- Public Release
- Reflex

EsoRex: command line tool

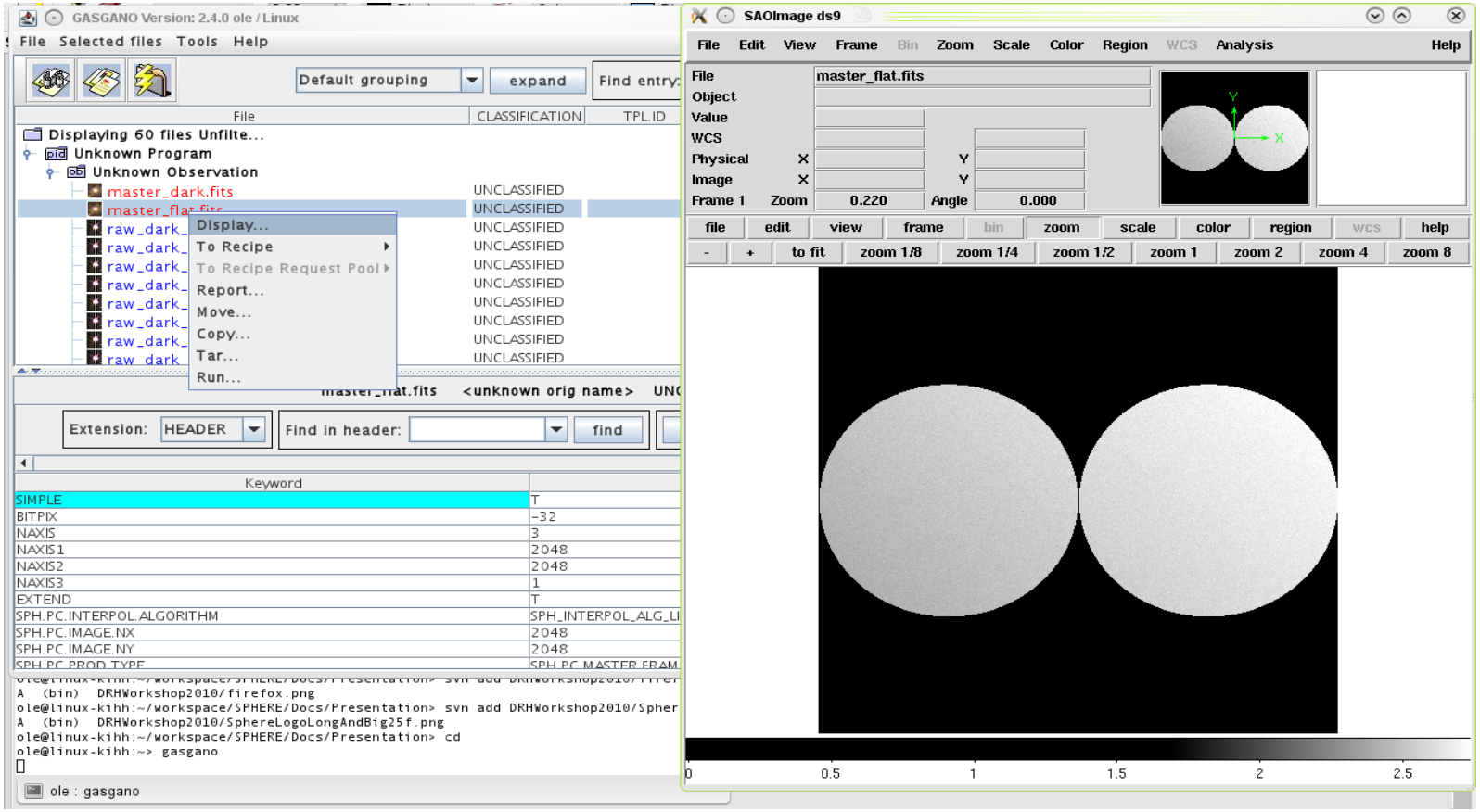
1. Edit the sof-file (set of frames)

```
File find_prectra.sof;
foo1.fits        IFS_FLAT_FIELD_RAW
foo2.fits        IFS_FLAT_FIELD_RAW
foo3.fits        IFS_FLAT_FIELD_RAW
det_flat.fits    SPH_IFS_MASTER_DTECTOR_FLAT
dark_frame.fits SPH_IFS_MASTER_DARK
```

2. Call esorex

```
esorex sph_ifs_spectra_positions \
--ifs.spectra_positions.dither_tolerance=0.01 find_spectra.sof
```

GASGANO: data organisation and executing recipes



Common Pipeline Library

- Data types: images, tables, matrices, strings, lists, ...
- Basic operators: arithmetic, statistic, file conversion
- Data access methods: FITS
- Keywords: handling and management
- Standards: interfaces, recipes
- Dynamic loading: recipes, modules.

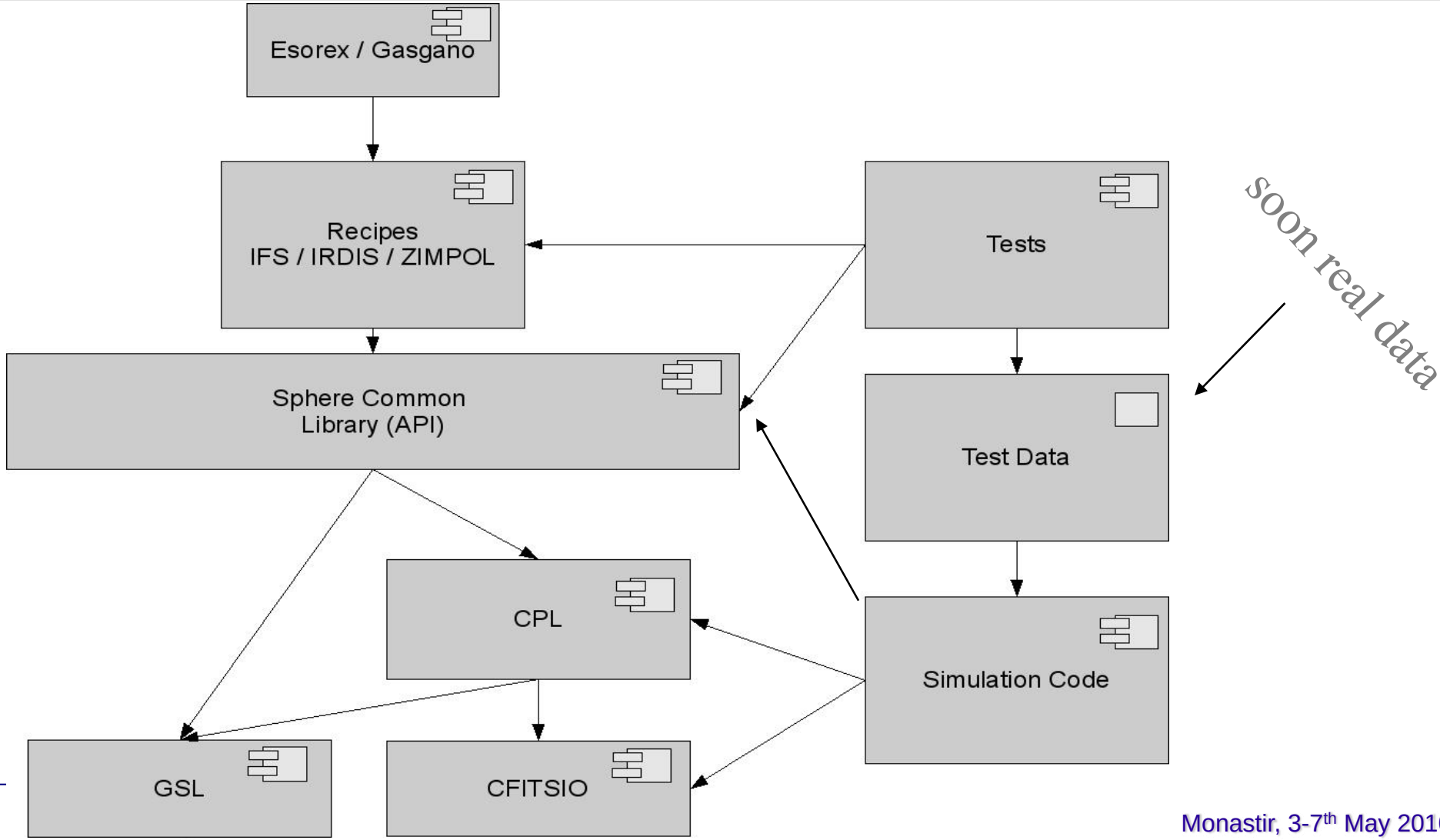
Data reduction

- Data formats
- Recipes
- NGC detector
- Instrument Control Software interface
- AIT support

Main developers:

- Ole Moeller-Nilsson
- Alexey Pavlov
- Markus Feldt

Architecture



Externals

* *Libraries*:

GSL

WCS

CFITSIO

* *ESO tools:*

Esorex

Gasgano

Distribution as single package

NO OTHER DEPENDENCIES

Data Formats

All products will be FITS

Currently some ASCII files

Depending on the recipe and execution mode formats may be complex

Data cubes

1 FITS = 4 Images + 1 Table of n- extensions

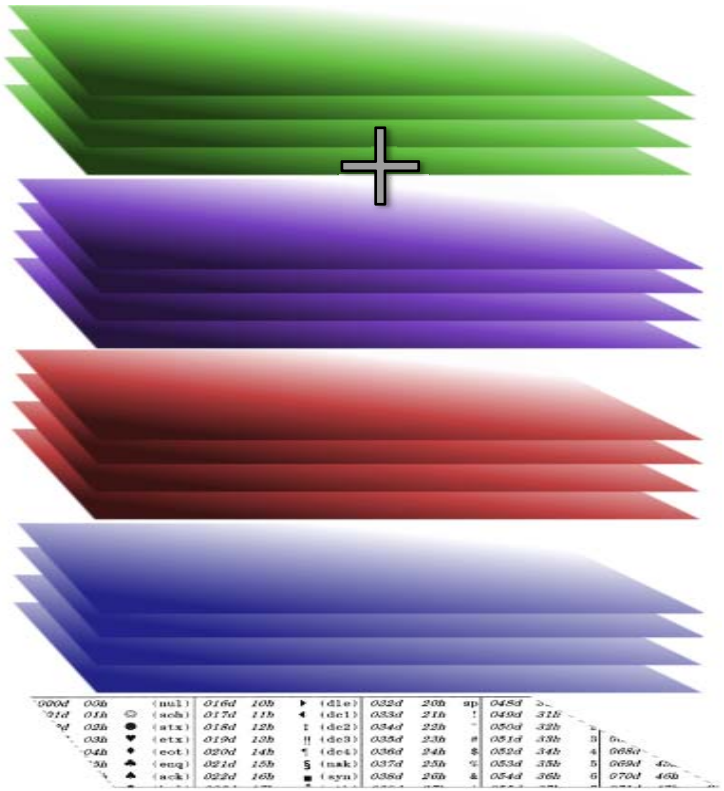
Image

Badpixel map

Weight map

RMS Error

Table



not a wavelength cube

Table contains information to interpret planes

Plane	EXPTIME	NREADOUTS	FILTER ID
1	1.3	1	1
2	1.3	1	2
3	1.3	2	2
4	2.6	1	1
5	2.6	1	1
6	2.6	2	1
7	2.6	2	2
8	5.2	1	1
9			

Always the same

Depends on recipe and “logic”

IFS Recipes

sph_ifs_master_dark
sph_ifs_master_detector_flat
sph_ifs_spectra_positions
sph_ifs_instrument_flat
sph_ifs_wave_calib
sph_ifs_science_dr
sph_ifs_astrometry
sph_ifs_atmospheric
sph_ifs_flux_calibration

sph_ifs_standard_photometry
sph_ifs_sky_cal
sph_ifs_psf_reference
sph_ifs_ron
sph_ifs_gain
sph_ifs_cal_background
sph_ifs_distortion_map
sph_ifs_detector_persistence
sph_ifs_sky_flat
sph_ifs_dithering_effects

ZIMPOL Recipes

sph_zpl_master_bias

bias.py

dark.py

intensity_flat.py

polarization_flat.py

modem.py

sph_zpl_aoc_offset

sph_zpl_aoc_crosstalk

sph_zpl_zimpol_crosstalk

sph_zpl_instrument_crosstalk

sph_zpl_instrument_offset

sph_zpl_instrument_zeropoint_angle

sph_zpl_distortion_map

sph_zpl_astrometry

sph_zpl_photometry

sph_zpl_science_int

sph_zpl_science_pol

sph_zpl_science_p2

science_p2.py

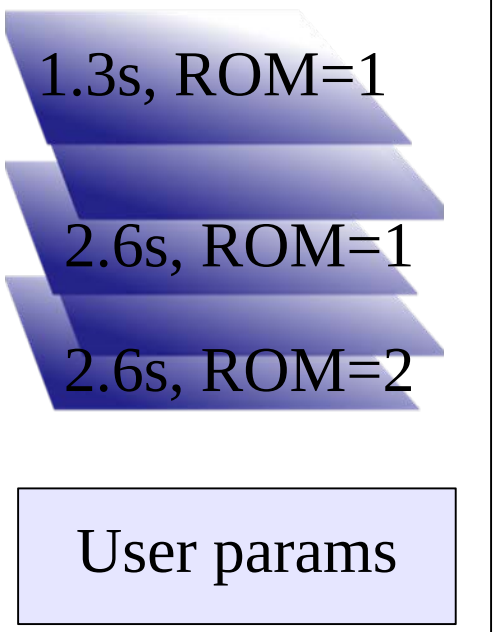
science_p3.py

IRDIS Recipes

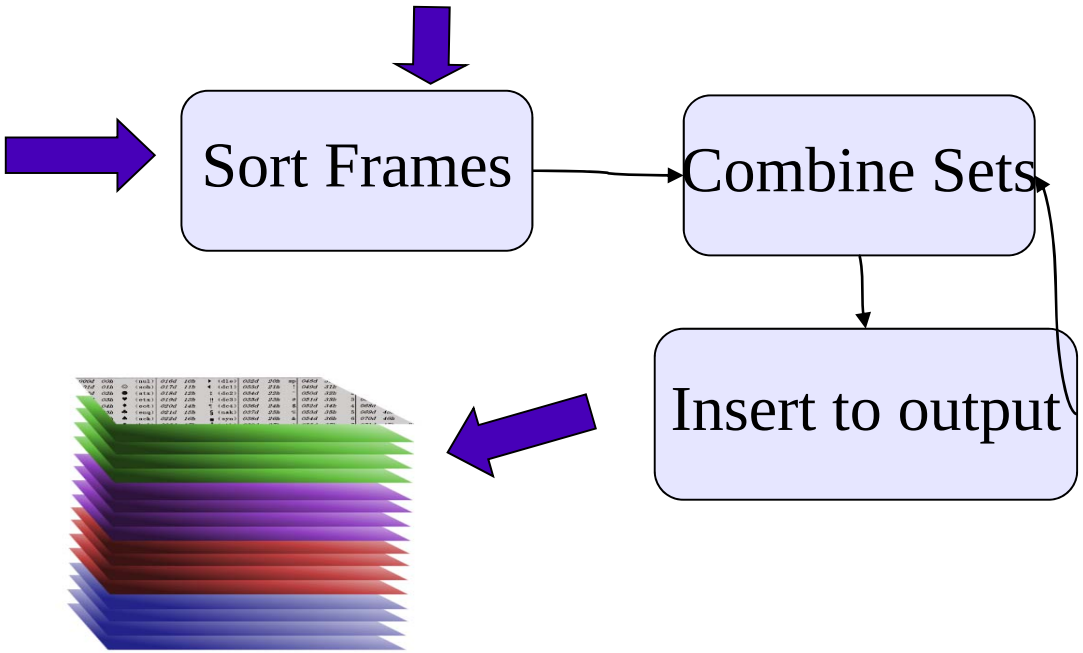
sph_ird_master_dark
sph_ird_instrument_flat
sph_ird_science_dbi
sph_ird_science_imaging
sph_ird_science_spectroscopy
sph_ird_wave_calib
sph_ird_science_dpi
sph_ird_astrometry
sph_ird_star_centre
sph_ird_atmospheric
sph_ird_flux_calib
sph_ird_ins_throughput
sph_ird_sky_bg
sph_ird_tff

sph_ird_psf_reference
sph_ird_pol_zpa_eff
sph_ird_tel_pol_offset
sph_ird_ron
sph_ird_gain
sph_ird_distortion_map
sph_ird_detector_persistence
sph_ird_spectra_resolution
sph_ird_ins_pol
sph_ird_ins_pol_eff
sph_ird_ins_pol_xtalk
(sph_ird_da_moods)
sph_ird_da_sandromeda

sph_ird_master_dark



DIT ID	Exp	ROM
1	1.3	1
2	2.6	1
3	2.6	2



sph_ifs_master_detector_flat

1.3s, BB lamp, bright

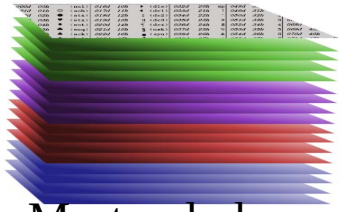
1.3s, BB lamp**, faint**

1.3s, **"blue"** lamp, faint

1.3s, "blue" lamp, bright

2.6s, "blue" lamp, faint

User params



Master dark

Subtract Dark

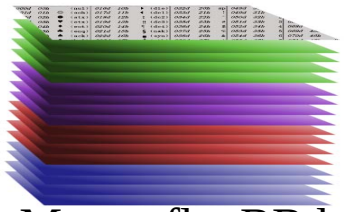
DIT ID	Exp	ROM
1	1.3	1
2	2.6	1
3	2.6	2

Sort Frames

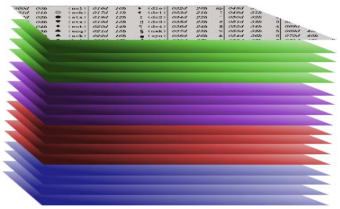
Combine sets with same mean count

Perform linear fit

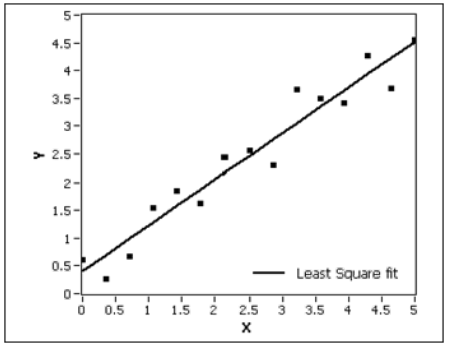
DIT ID on plane



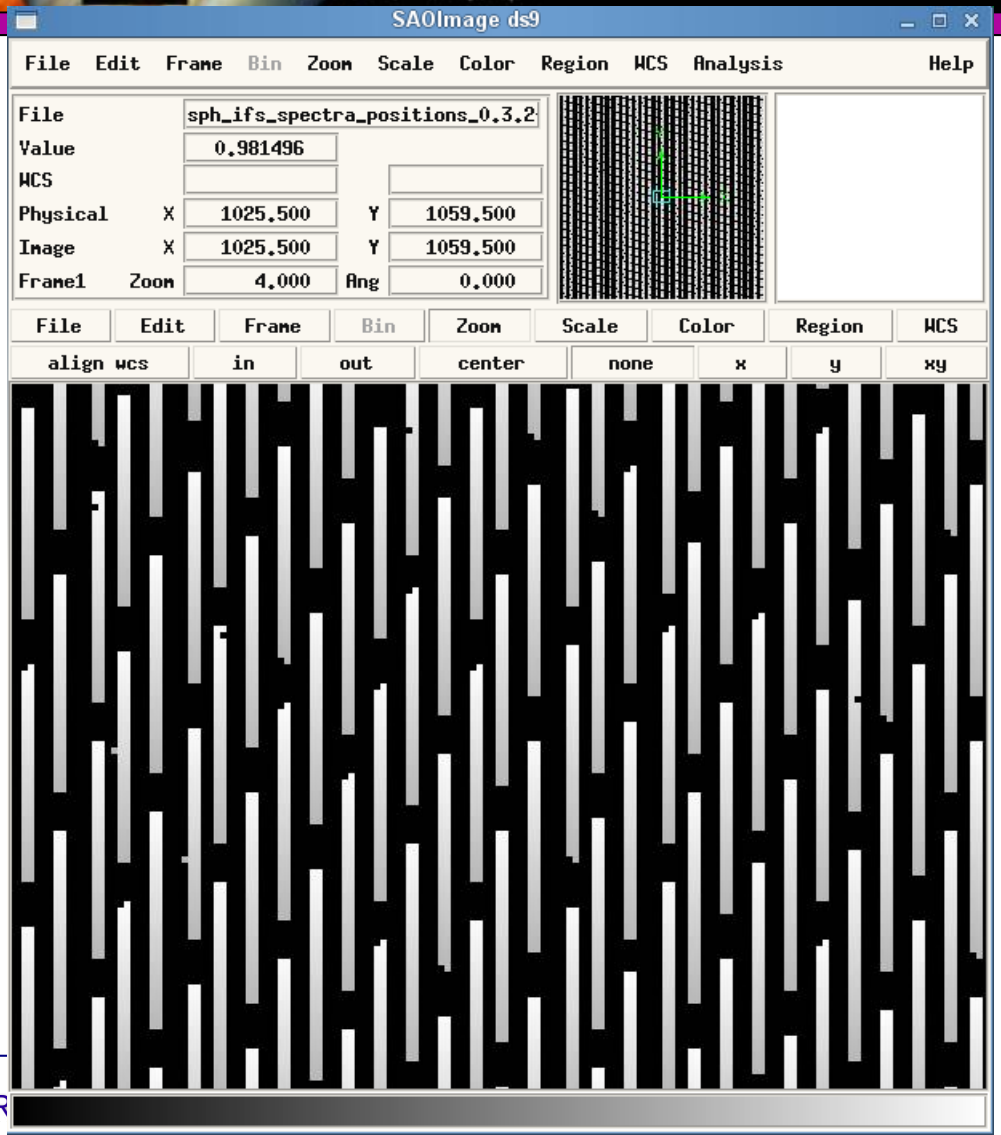
Master flat,BB lamp



Master flat, Blue lamp



sph_ifs_spectra_positions



About 60k pixels mis-identified

Averaging ~1 pixel / spectrum

Running a recipe

Methods provided:

- Esorex
- Gasgano
- New data organizer by ESO
- Python

Additional Methods:

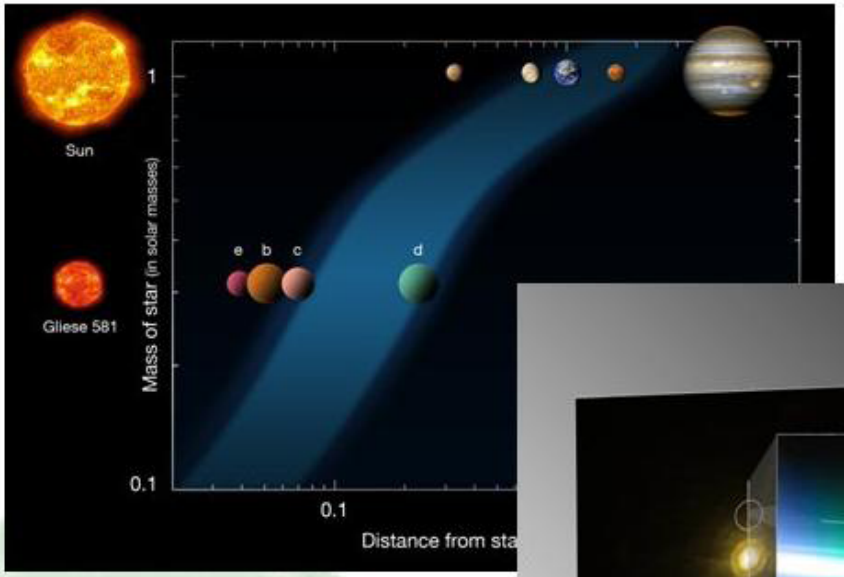
- C program
- Your own pipeline infrastructure…

Data Reduction and Handling Software

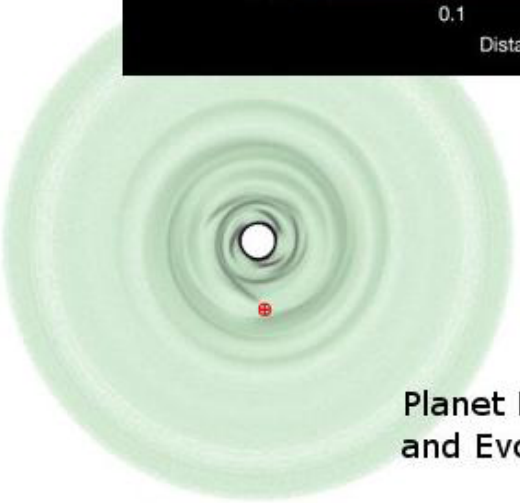
SPHERE

Spectro-Polarimetric High-contrast Exoplanet REsearch

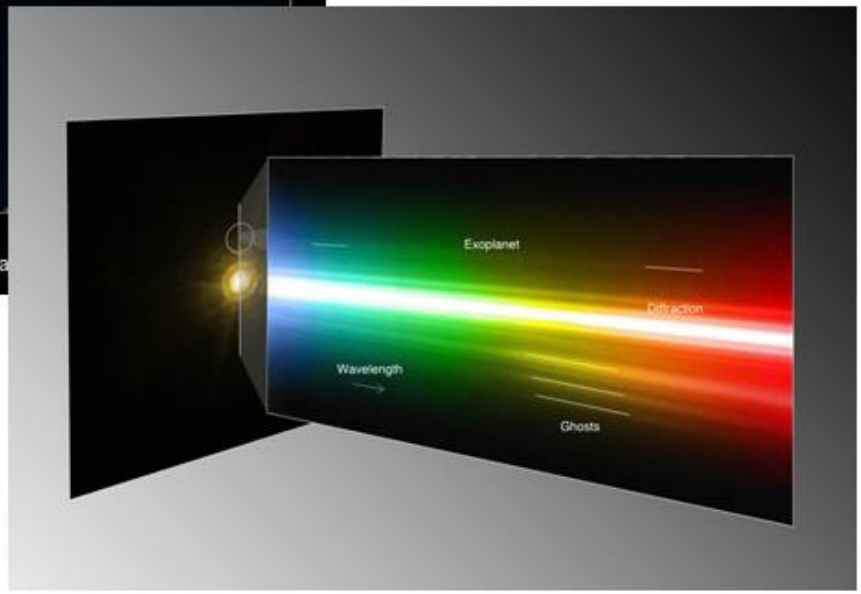
Pipeline development for Exo-Planets



Orbit architecture,
Low-mass planets



Planet Formation
and Evolution



Characterization of
Exoplanet atmospheres