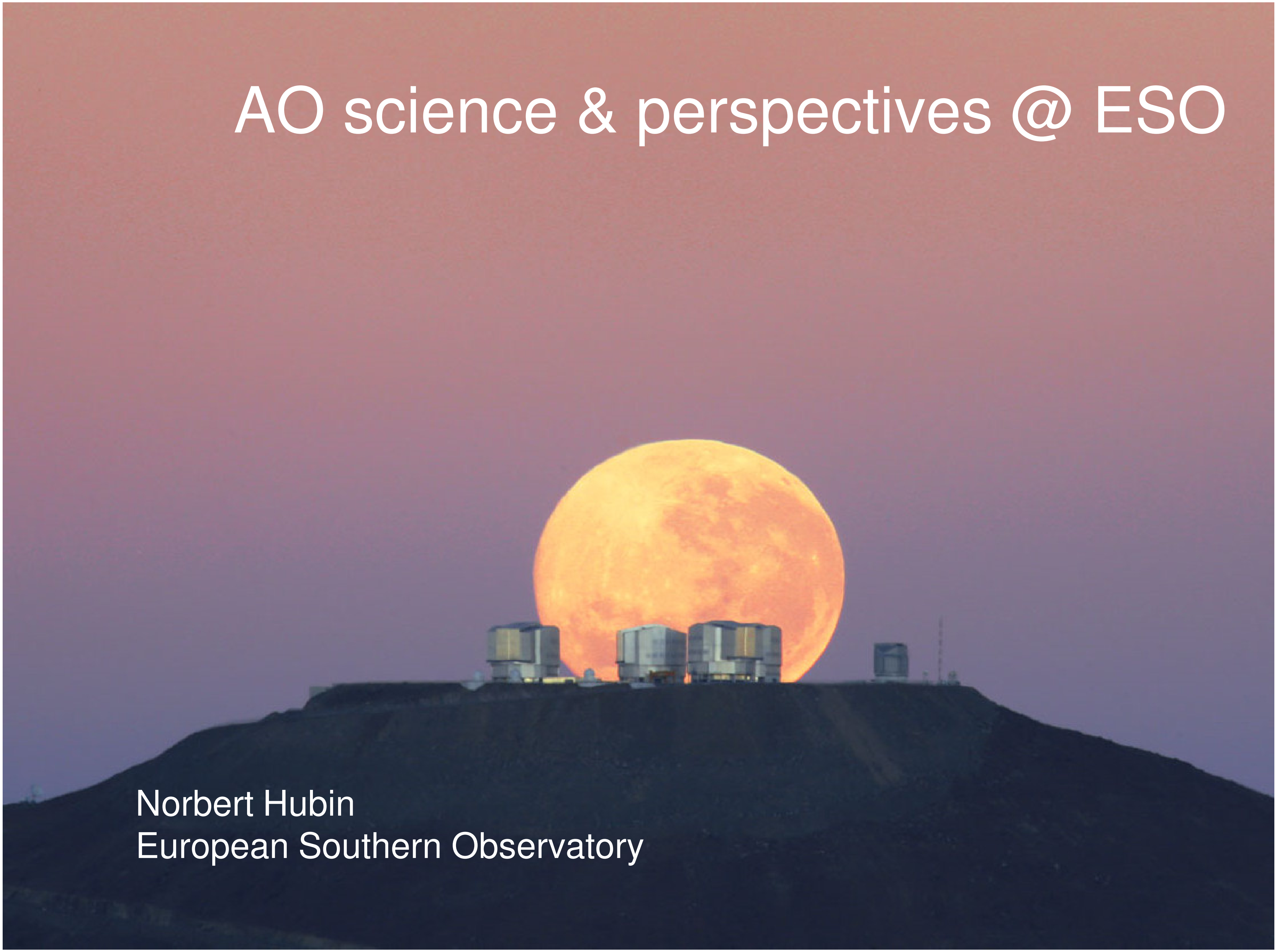
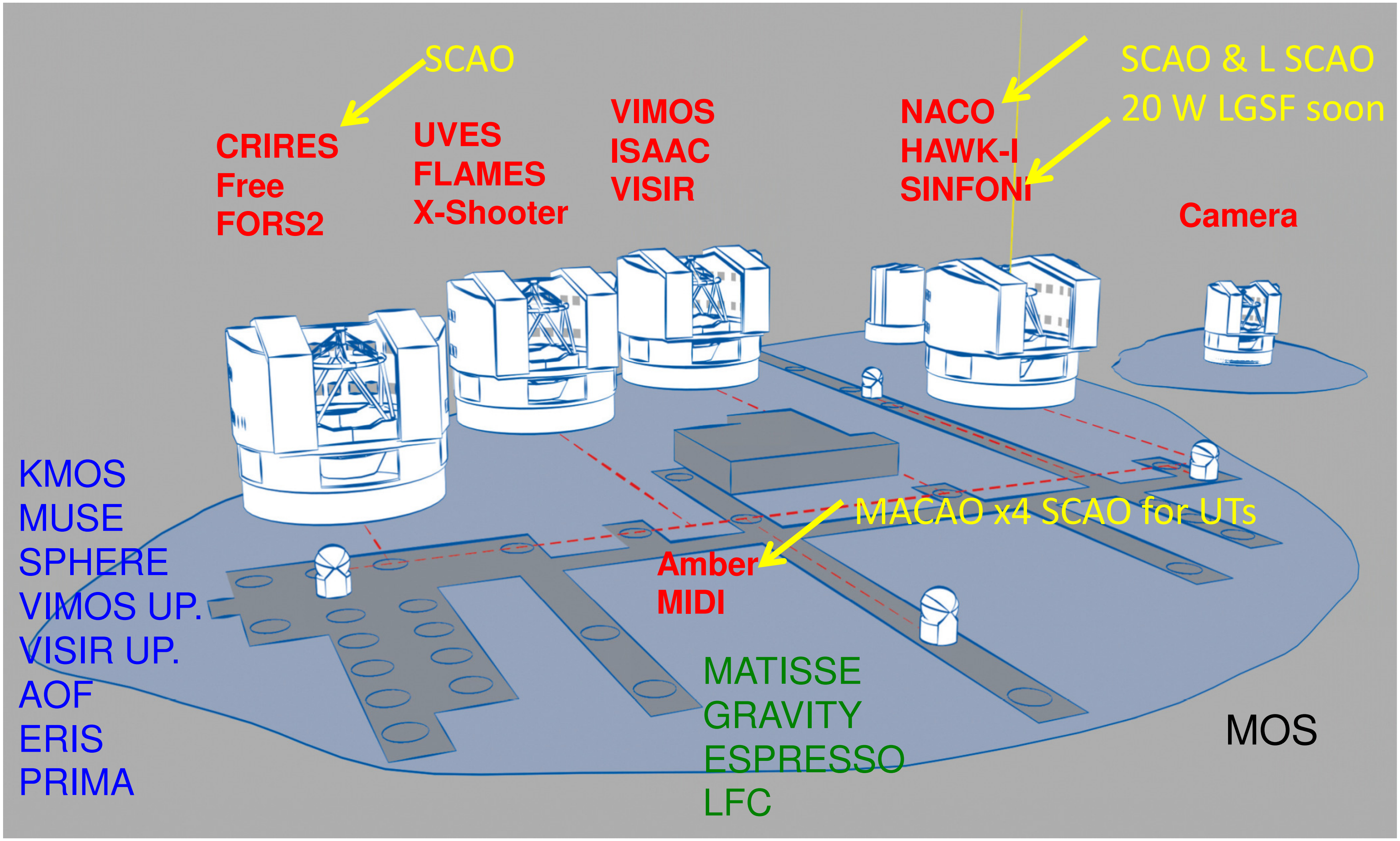
AO science & perspectives @ ESO



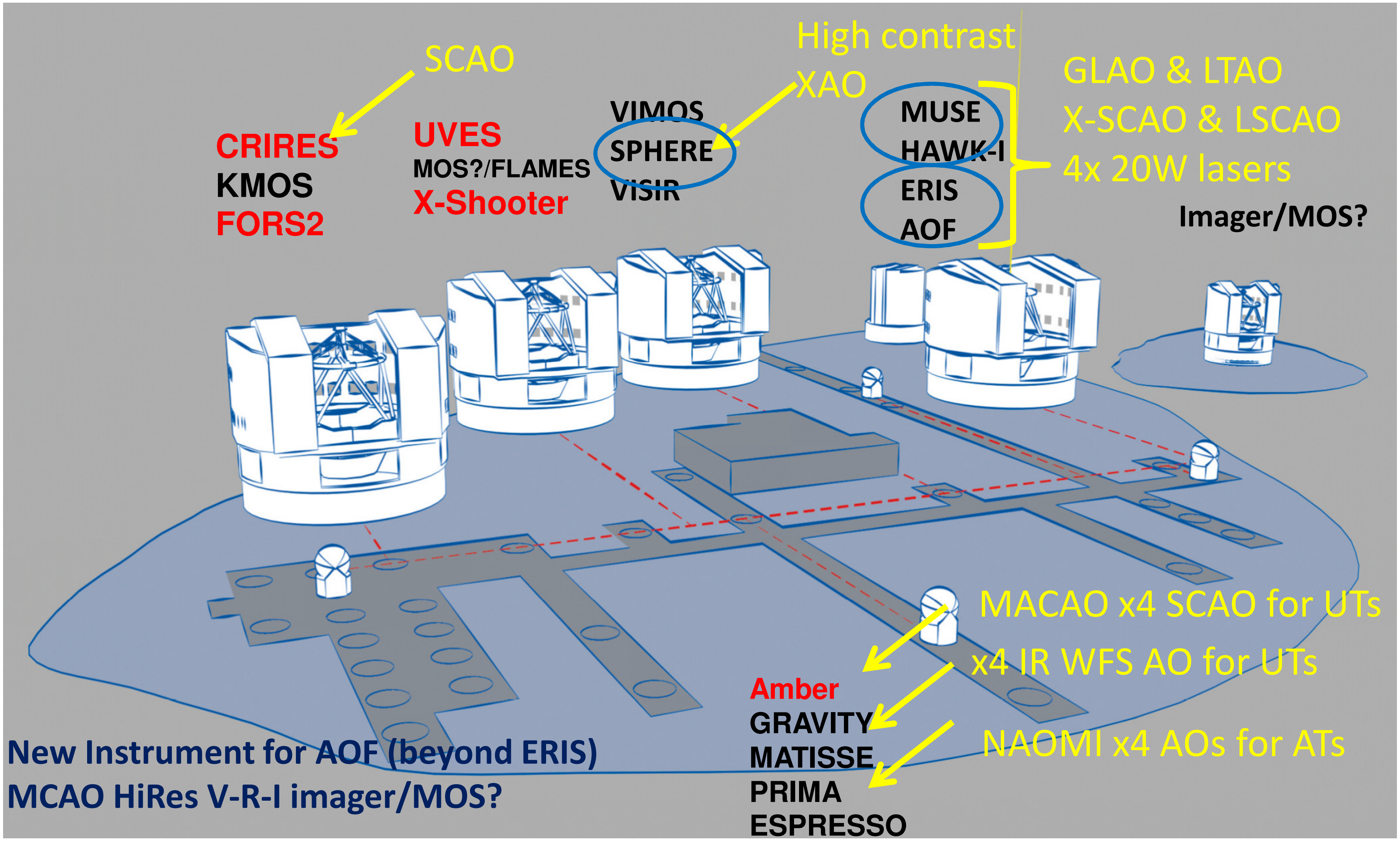
Norbert Hubin
European Southern Observatory

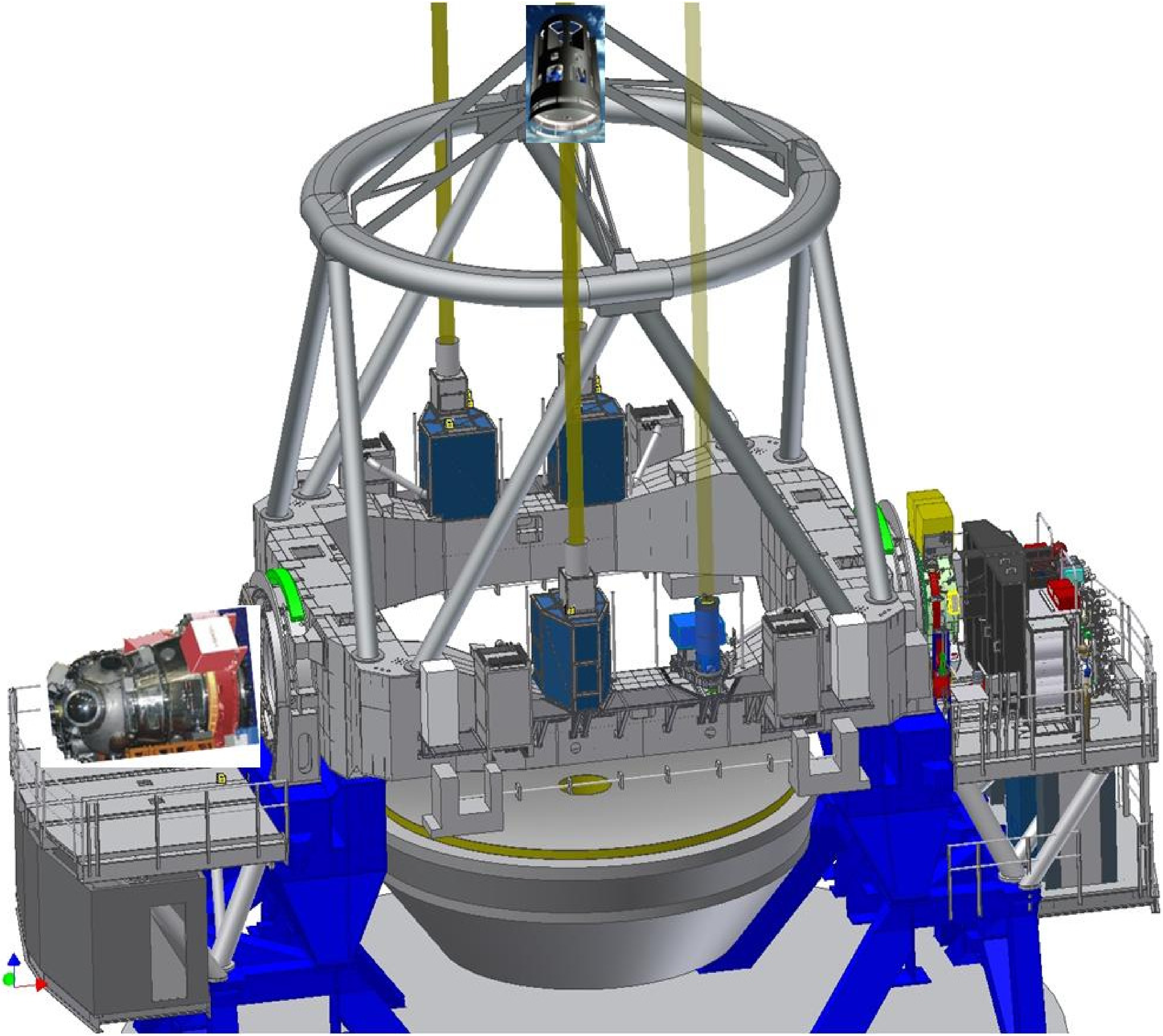
VLT AO instruments in 2012



KMOS
MUSE
SPHERE
VIMOS UP.
VISIR UP.
AOF
ERIS
PRIMA

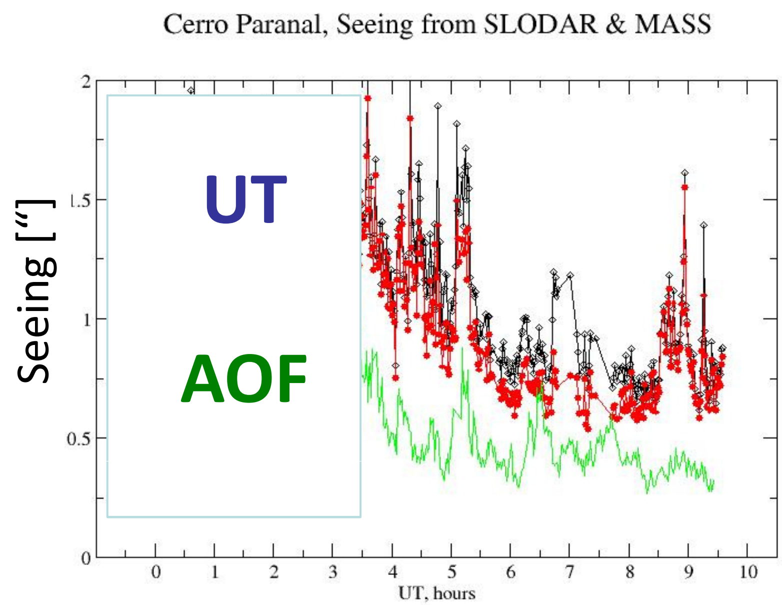
VLT AO instruments in 2013-2018





Science with the AOF
<u>in ground layer mode</u>

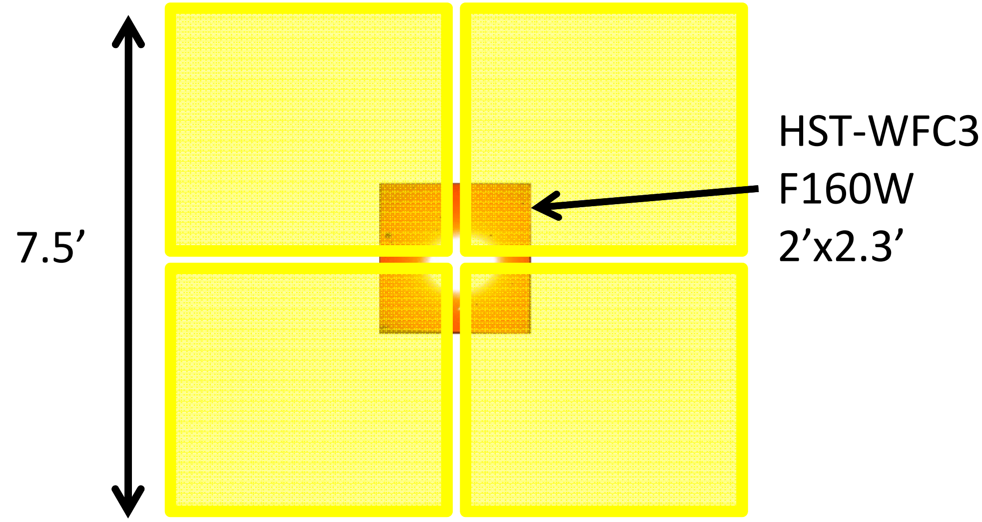
- Enable **more** observations anc specifically surveys in ***good tc best seeing conditions***



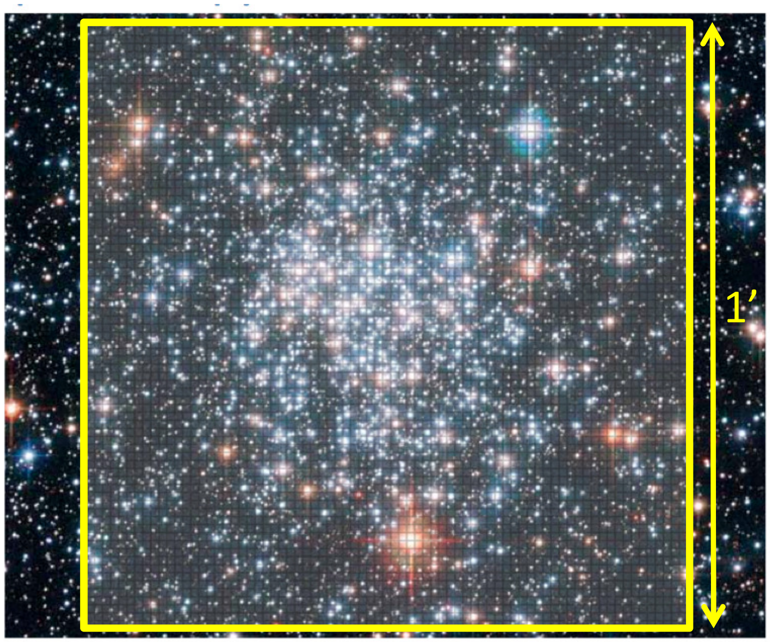
- AOF will provide
  - For MUSE: 50% ≤ 0.45” at 750nm (EE-gain ≈ 2)
  - For Hawk-I: 50% ≤ 0.3” at K-band (EE-gain ≈ 1.7)
  - Fainter magnitude limits for point sources
  - Better spatial resolution for extended sources

AOF science examples

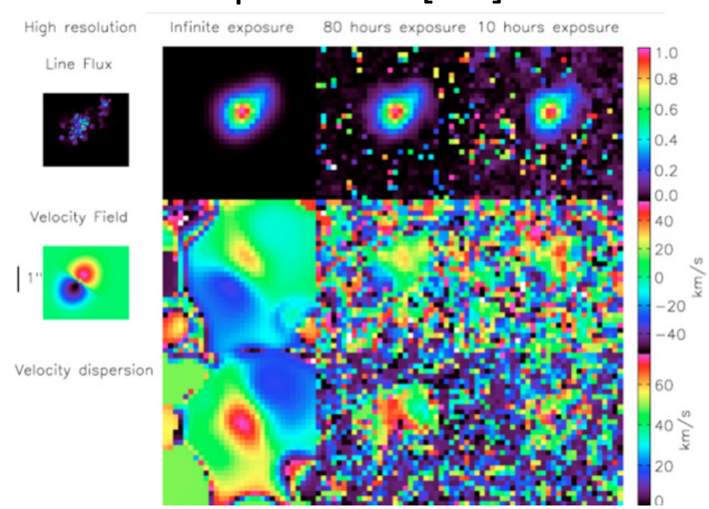
Complementing HST - Hawk-I K-band globular clusters around NGC1399



MUSE-WFM spectroscopy in crowded stellar fields "DAOPHOT in 3D"



MUSE-WFM galaxy v-maps in deep fields – [OII] at z≈1

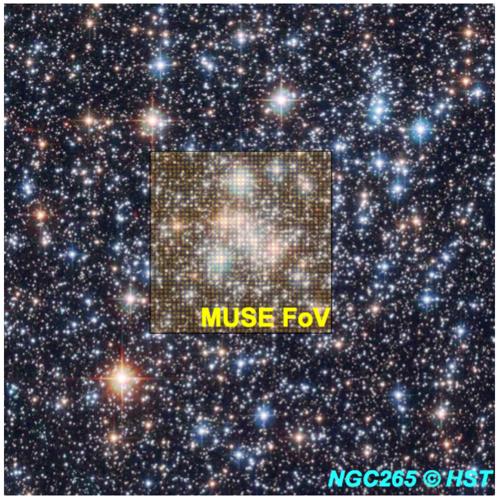


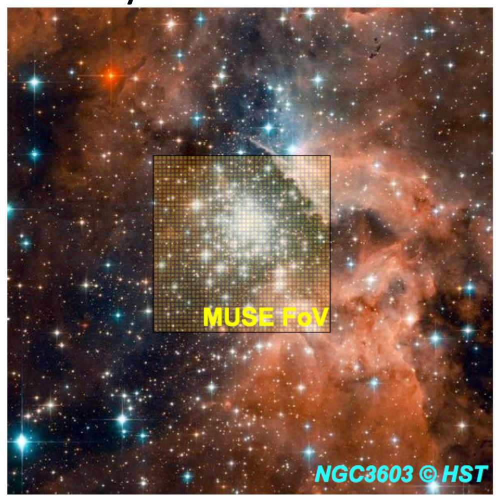
Courtesy MUSE consortium

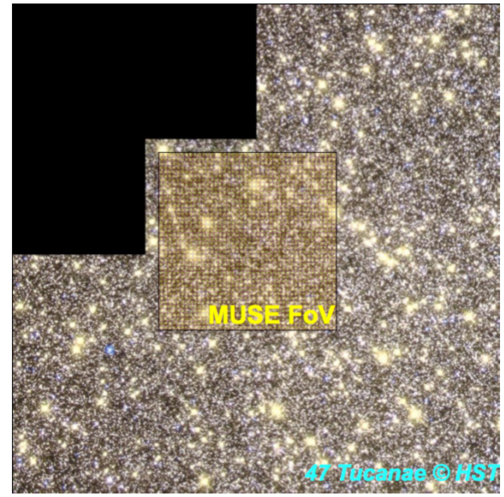
MUSE + AOF science potential

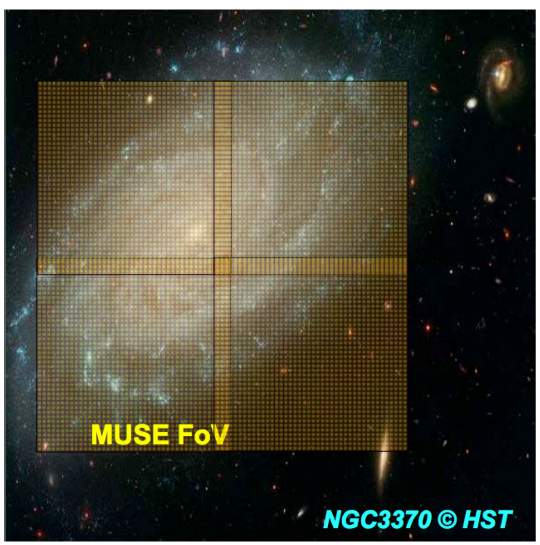
Courtesy MUSE consortium

Study of crowded stellar field

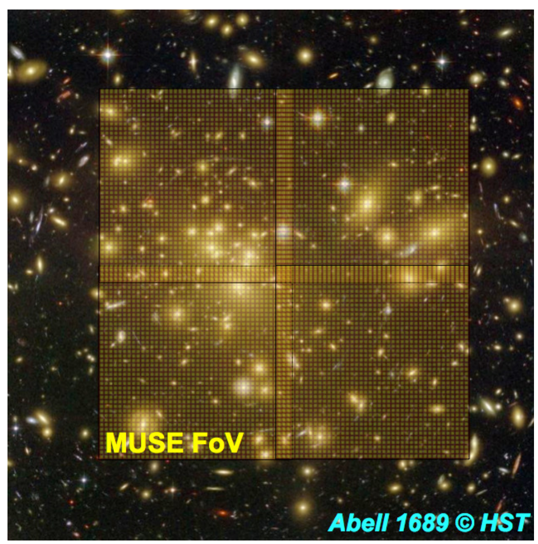




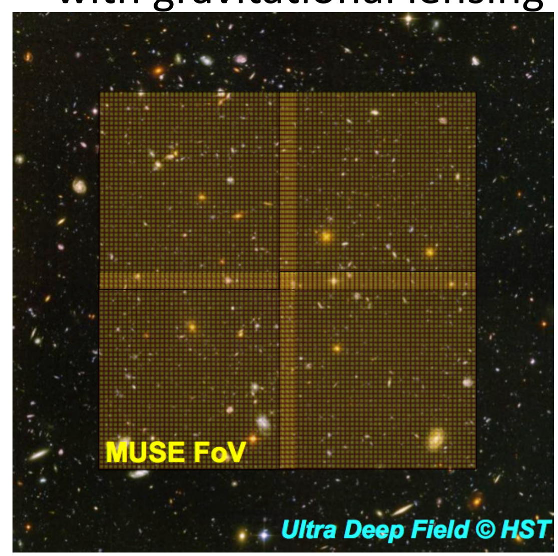




Lyman α emission from high-z galaxies

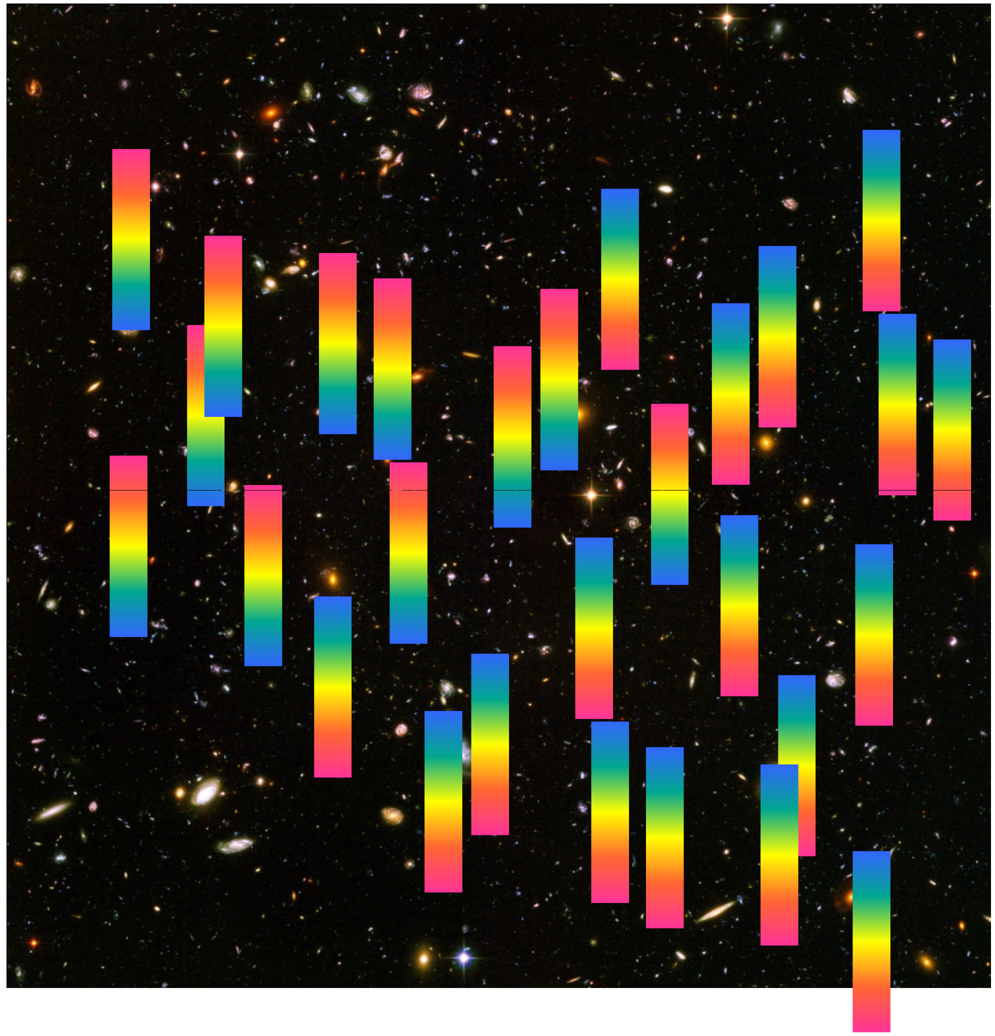


Ultra deep field combined with gravitational lensing



Multi-Object Spectroscopy

- Need pre imaging
- Need pre selection
- Limited discovery space

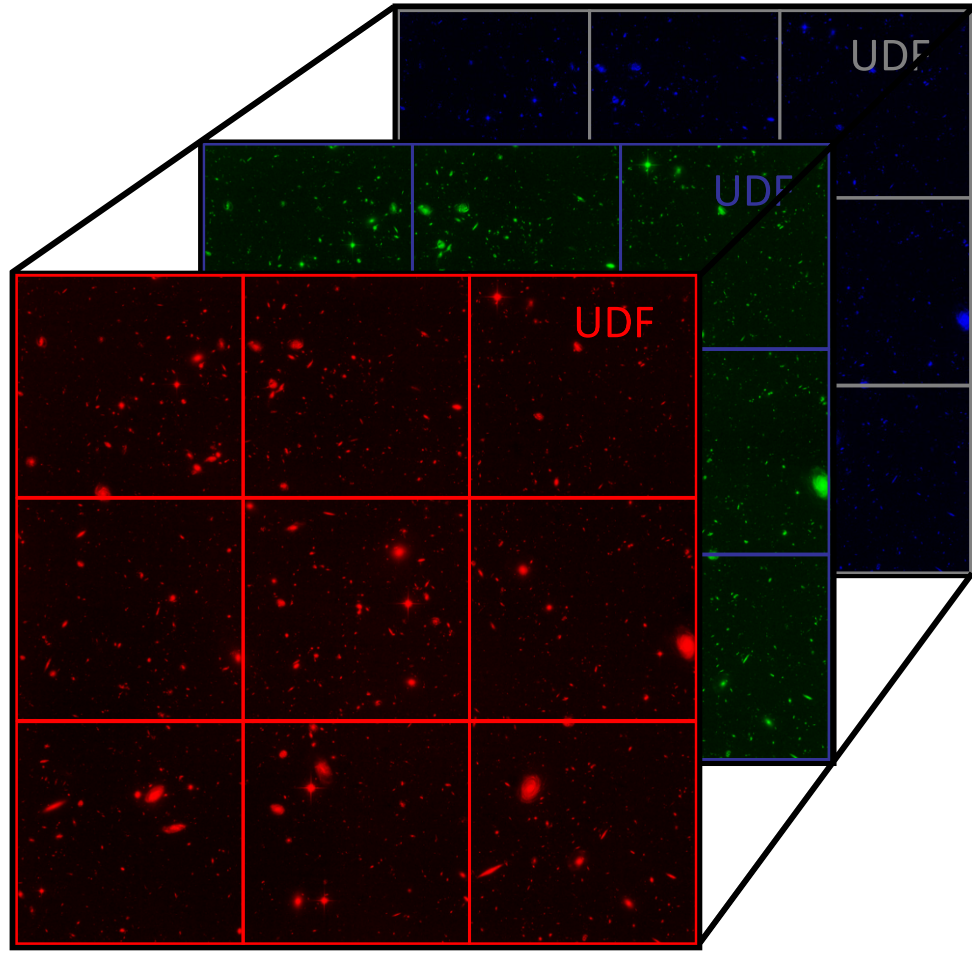


Courtesy MUSE consortium

MUSE 3D Deep Fields

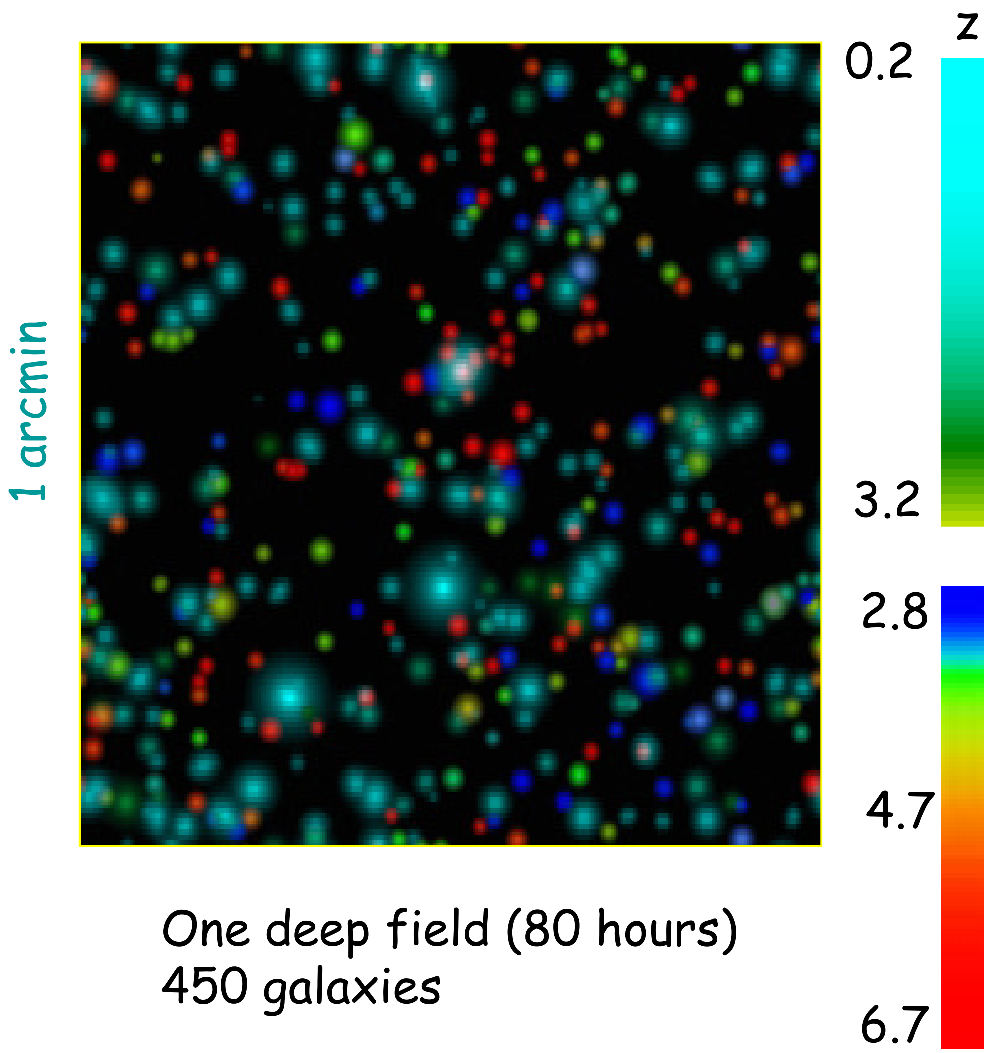
Get everything!

- Eliminates pre-imaging
- Eliminates pre-selection
- Observe only once
- Attack multiple science topics simultaneously
- Large discovery space for serendipitous sources



Courtesy MUSE consortium

MUSE 3D deep field



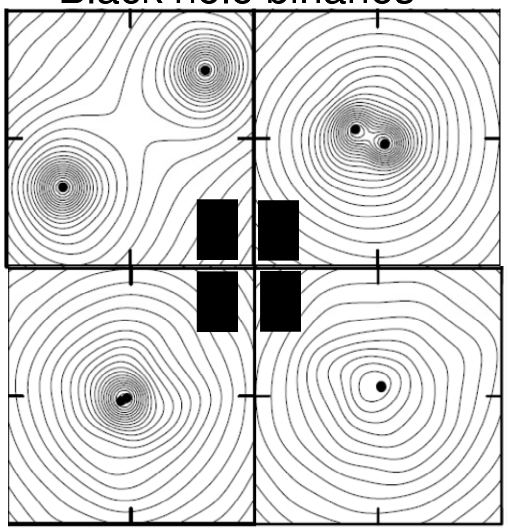
One deep field (80 hours)
450 galaxies

- High z Lyα emitters
- Reionization
- Intermediate z galaxies
- Fluorescent emission
- Feedback processes
- Gravitational lensing
- Spatially resolved spectroscopy
- Late forming pop III
- Active galactic nuclei
- Merger rate
- Development of dark halo

Courtesy MUSE consortium

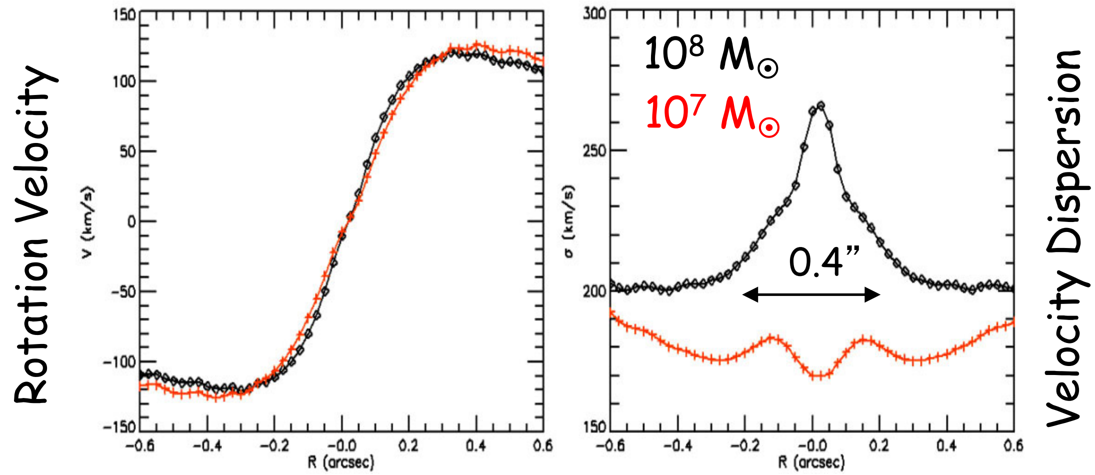
NFM Science: Black Holes

Black hole binaries



Milosavljevic & Merritt, 2001, AJ, 563, 34

Courtesy MUSE consortium



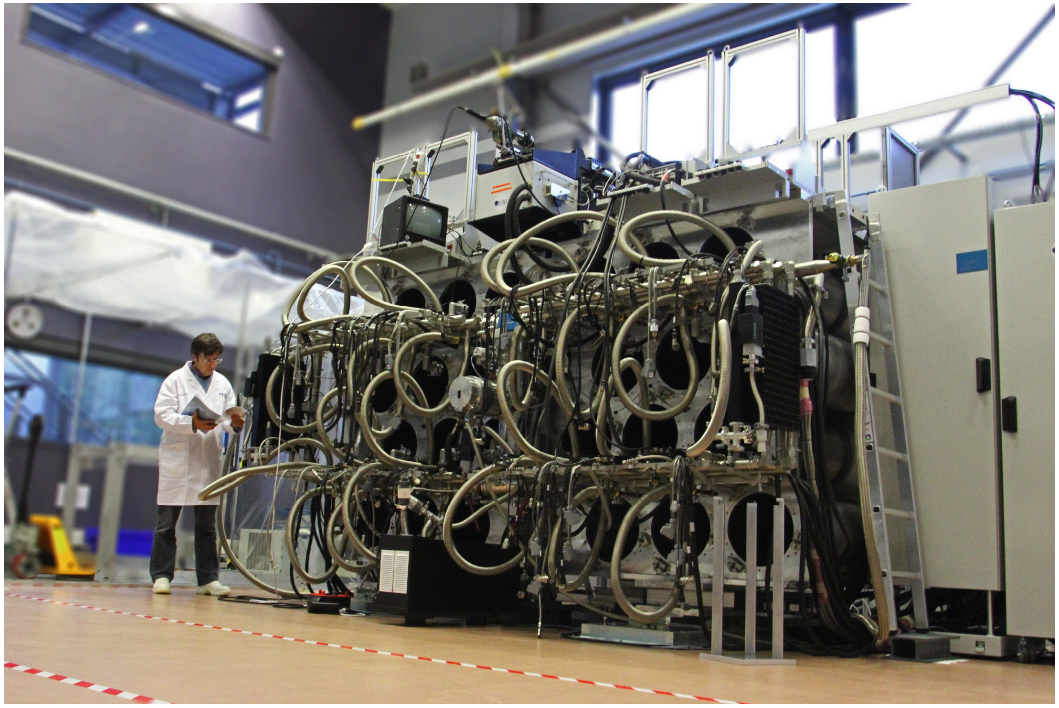
- Stellar dynamics at 0.05” scales – black hole masses & formation scenarios
- Optical spectra give stellar populations and gas properties ‘for free’
- Low background allows low-surf. brightness objects

MUSE Instrument Overview

- Integral Field Spectrograph
- Optimized for ESO AO Facility
  - but can run without AO
- Two modes only
  - WFM: Wide Field Mode
    - 0.2 arcsec, 1x1 $arcmin^2$
    - Spatial resolution
      - Non AO: seeing
      - AO: 0.3-0.4 arcsec
  - NFM: Narrow Field Mode
    - only with AO
    - 0.025 arcsec, 7x7 arcsec2
    - Spatial resolution
      - 10-20% Strehl ratio

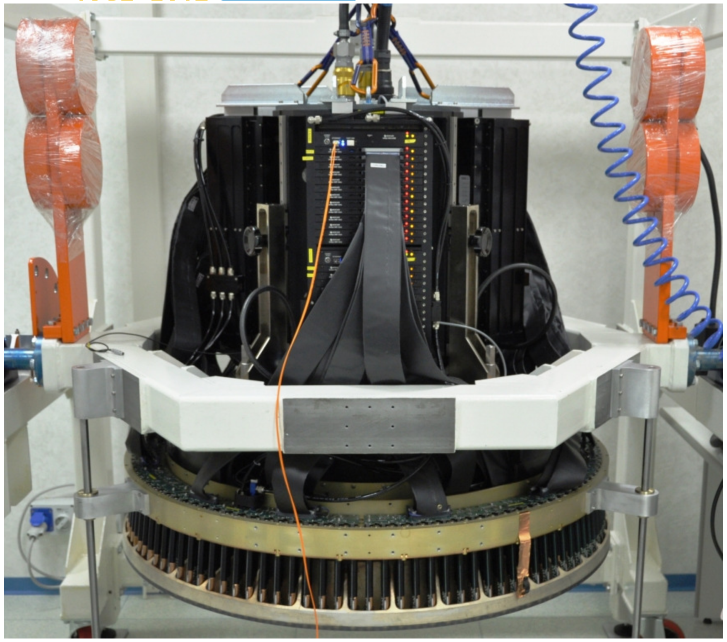
- Spectral characteristics
  - 465-930 nm simultaneous
  - R~3000
- Data volume
  - 400 10^6 pixels
  - 90,000 spectra in one exposure

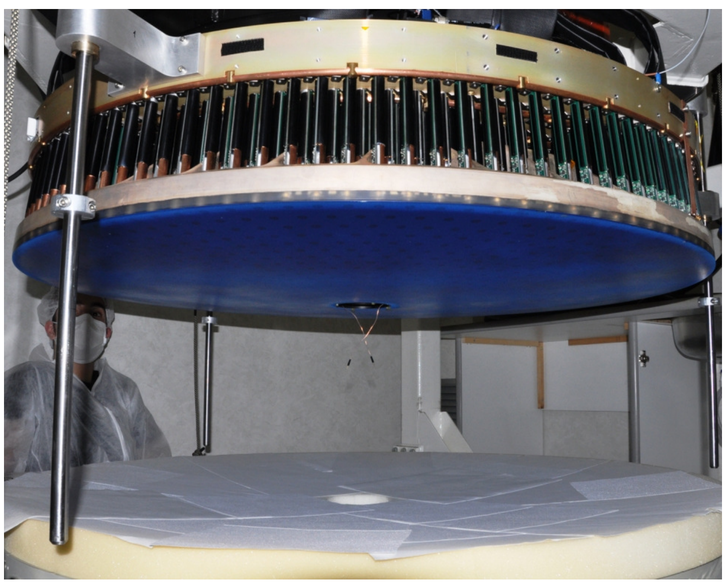
MUSE and HAWK-I status

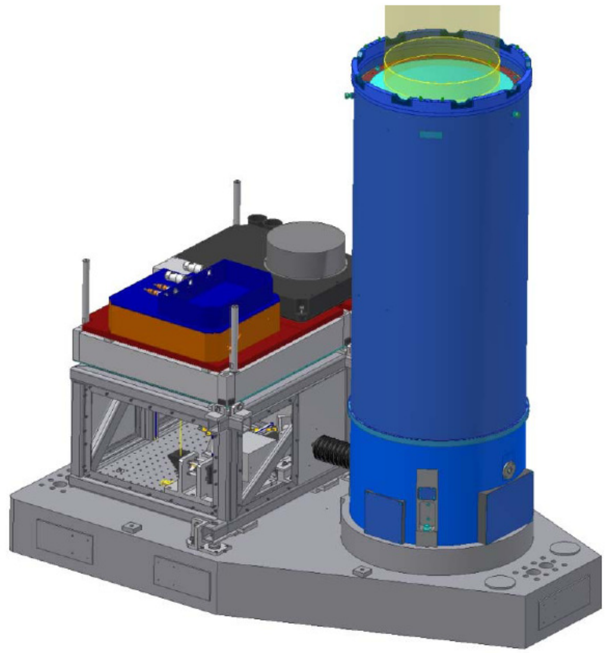


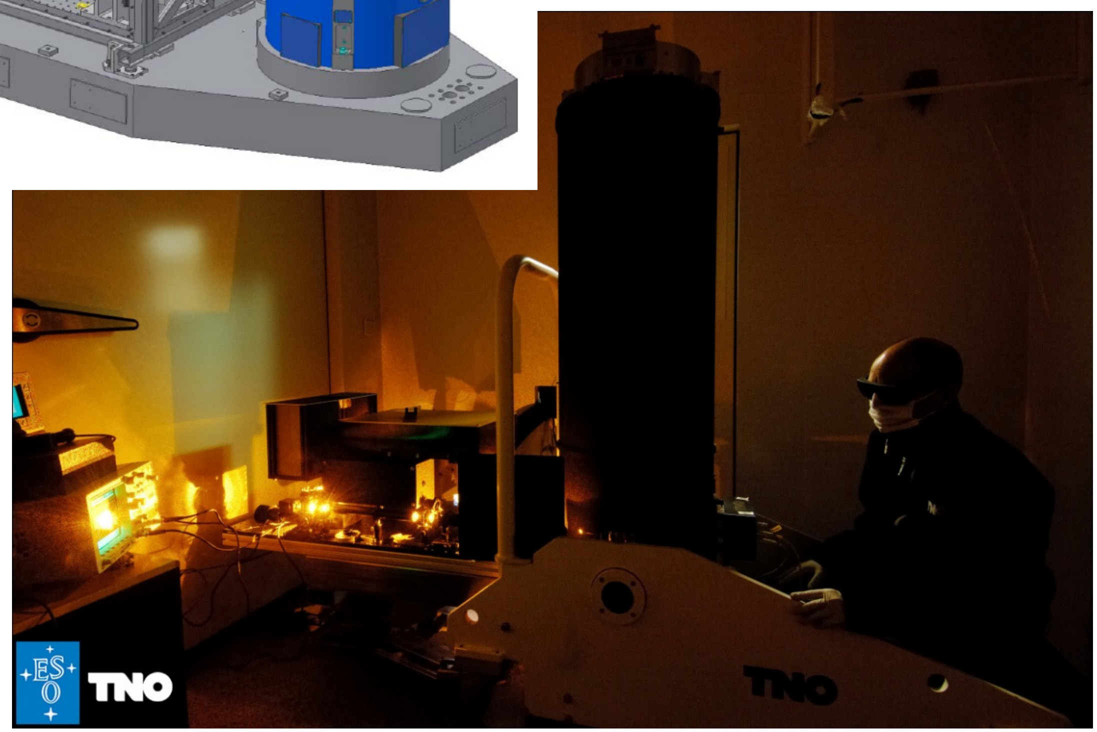
Expected 1st light without AO in 2013

AOF status: DSM & Lasers & LTS

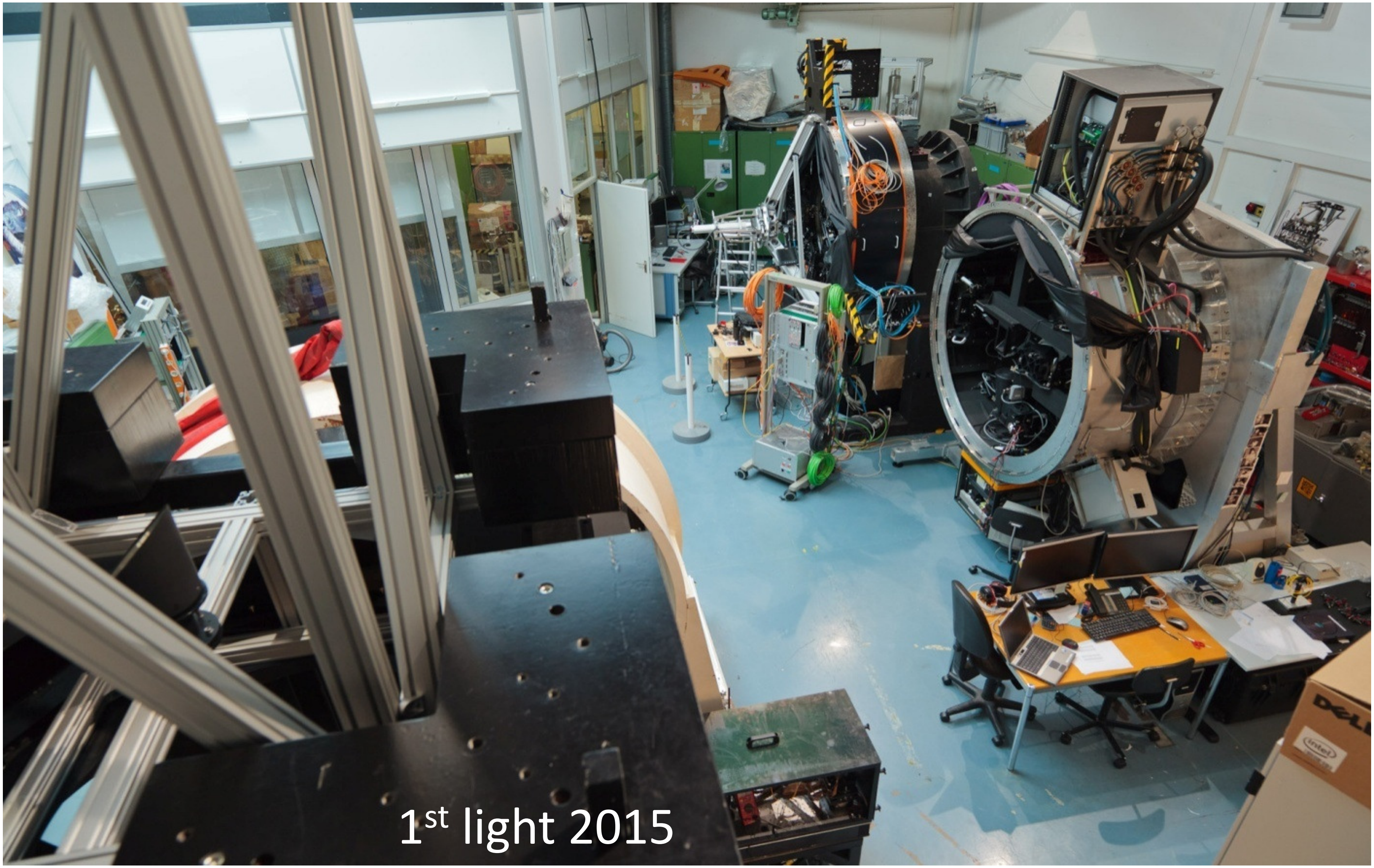






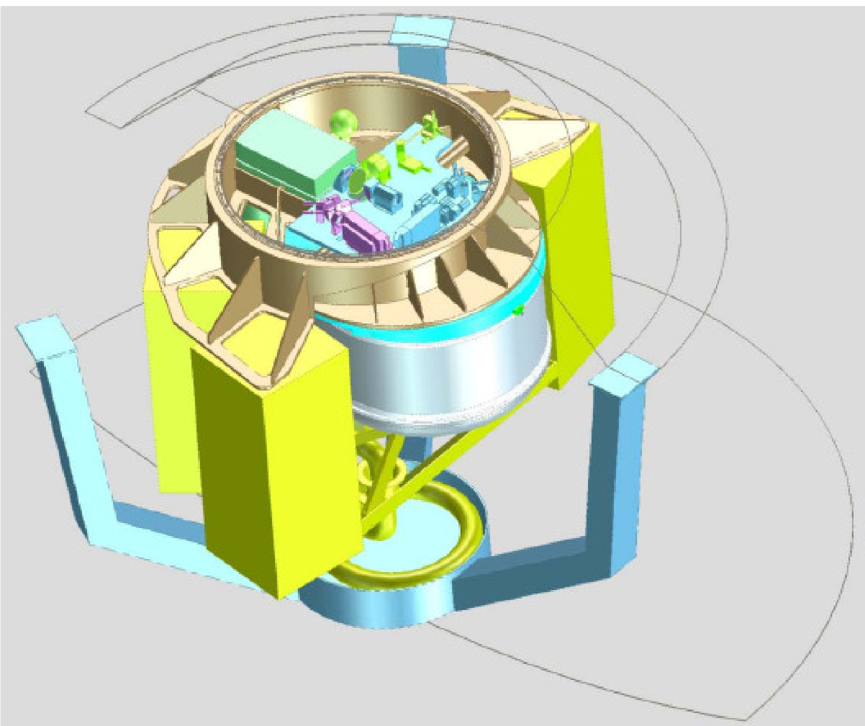


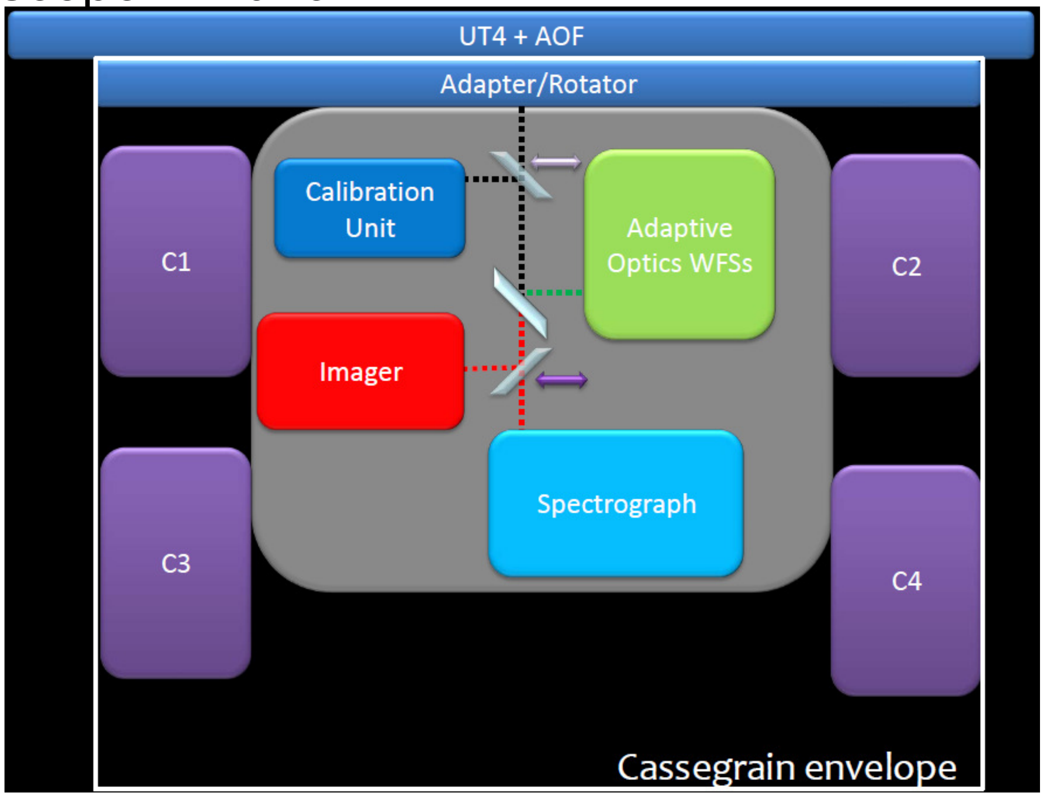
AOF status: GRAAL & GALACSI



ERIS:
Enhanced Resolution Imager & Spectrograph

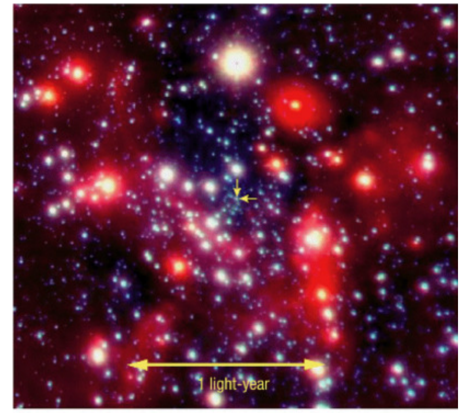
- New AO fed instrument for VLT, replacing NACO
- Integrated with VLT AOF at Cassegrain: DSM + Laser Guide star
- Two science instruments:
  - Integral Field Unit Spectrograph (upgraded SPIFFI)
  - New infrared imager (taking over NACO)
- High Strehl AO system at the telescope in 2016



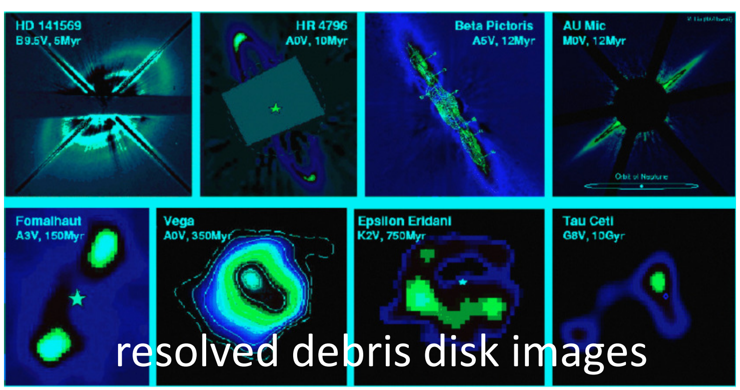


ERIS Science cases

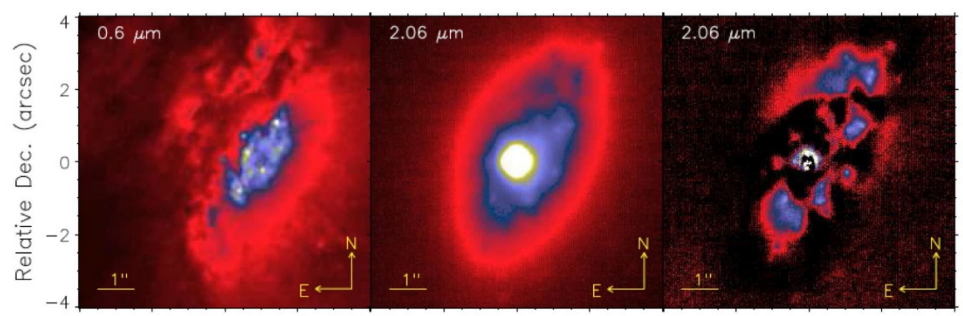
- Disk Science: NIR SCAO imager with LGS + IR WFS
  - Low- and intermediate-mass young stellar objects➔ High contrast
  - Massive star formation: disk or no disk?
  - Debris disks
- Exoplanets: Thermal infrared SCAO imager & R=500 spectro (complement of SPHERE)
- Starburst Clusters & Initial Mass Function: high order NIR SCAO imager with LGS & IR WFS
- Solar System: Thermal infrared SCAO imager with LGS
  - Asteroids and their multiplicity
  - Satellites of Giant Planets
  - Atmospheres and rings of Giant Planets
- Galactic Center: NIR SCAO imager+ spectro with LGS+ IRWFS
- AGN & Super Massive Black Holes: SCAO imager & spectro with LGS + IRWFS
- Distant (high-z) galaxies: NIR SCAO imager & spectro with LGS
  - Galaxy morphology - resolved structure and colors



The Centre of the Milky Way
(VLT YEPUN + NACO)



resolved debris disk images

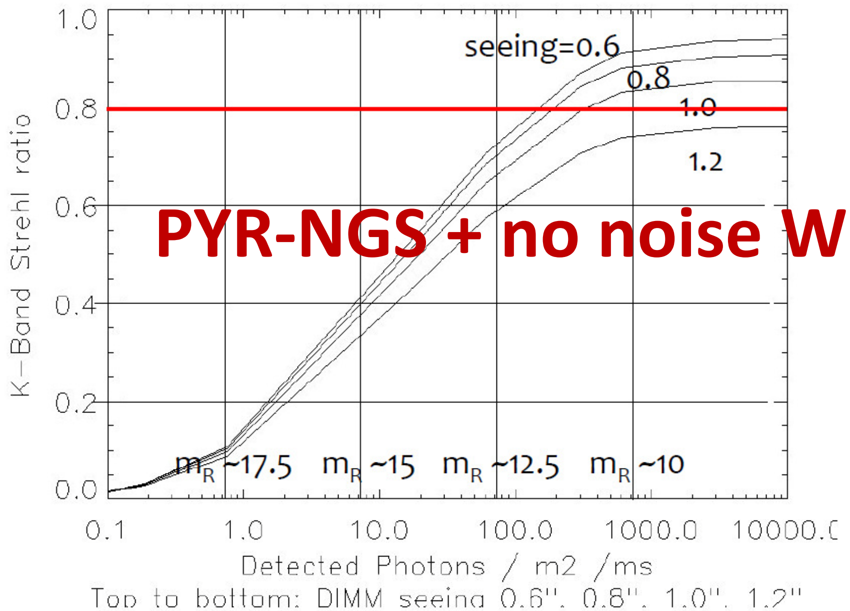


Central 300300 pc of the active nucleus in NGC 7582

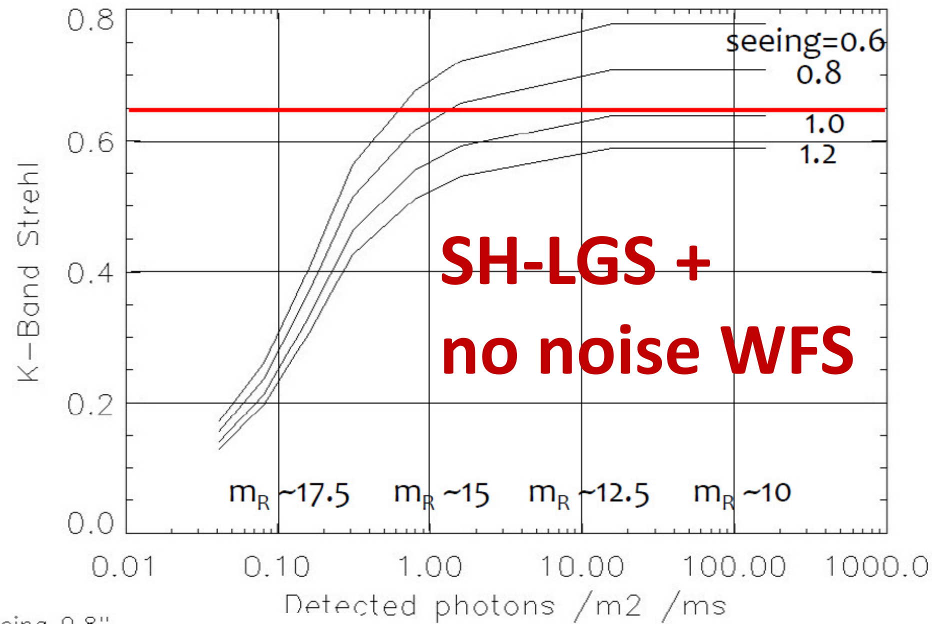
ERIS Top level requirements

UT4 + AOF + Cassegrain +SPIFFI + NACO-like	
AO modes	NGS, LGS + LO sensor, SE, noAO
AO performance	SR (NGS>80%, LGS >65%) Sky Coverage >30% at GP Max 5% SR loss due to instrument (flexures)
IR Camera modes	Imaging J-K (13-27 mas/pix) Imaging L-M (27 mas/pix) Pupil plane coronagraphy (L-M) SAM J-M > 24 filters
IR Camera Performance	FoV >45" ∅ Low distortion: < 1.5mas on 7"x7" FoV Low emissivity: $0.5*(\varepsilon_t+\varepsilon_s)$ High transmission; >65% in J-K Low noise: DC Noise=0.3 Total Noise
"Re-use" SPIFFI	Minimize changes
ERIS-SPIFFI Performance	Maintain or improve transmission Maintain or improve open-shutter time

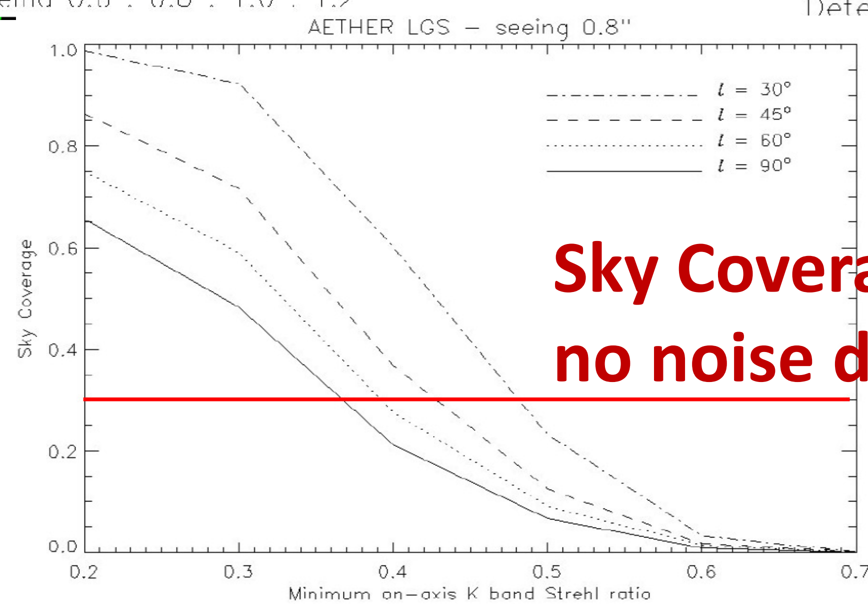
ERIS preliminary performances



PYR-NGS + no noise WFS



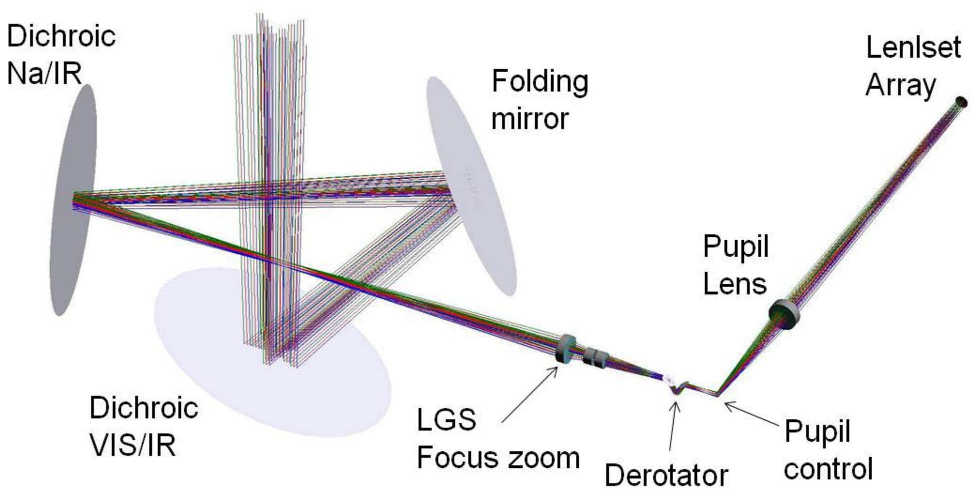
SH-LGS +
no noise WFS

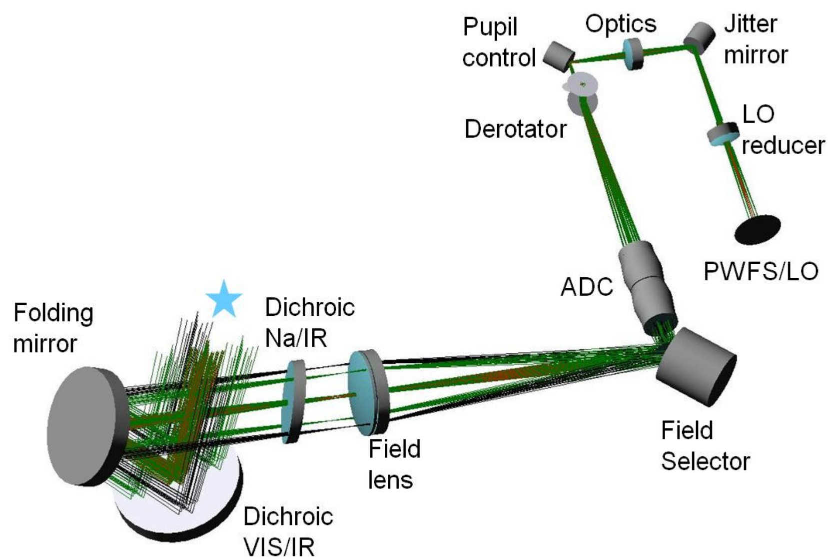


Sky Coverage LGS + PYR NGS +
no noise detector

ERIS Overview

- LGS WFS arm
  - SH 40x40, CCD220 assembly, up to 1.2kHz
  - LGS focus & pupil control, pupil derotation
  - Low order Visible sensor (T/T+Foc)
- NGS WFS arm
  - Pyramid based visible λ 40x40 → 8x8 sub-ap., CCD220 1.2kHz
  - Serving also as low order sensor for LGS
  - Field selecting, pupil control, ADC, pupil derotation

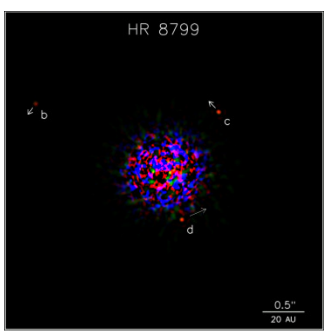


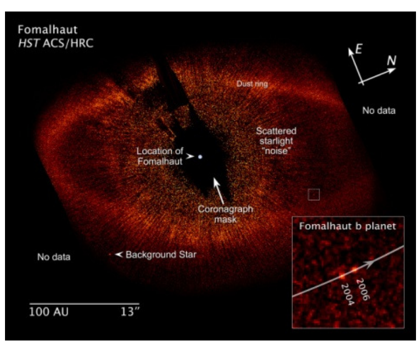


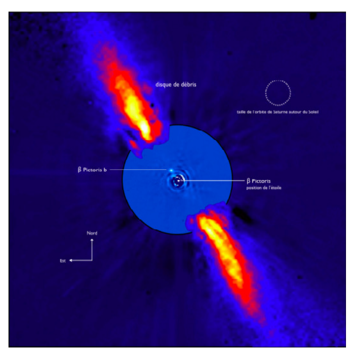
SPHERE Science objectives

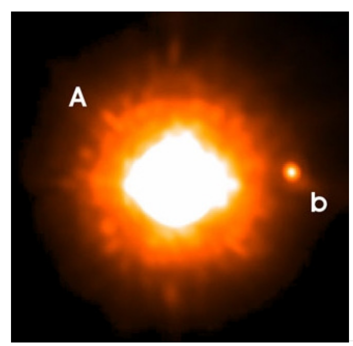
- High contrast imaging down to planetary masses
- Investigate large target sample: statistics, variety of stellar classes, evolutionary trends
- Complete the accessible period window
- First order characterization of the atmosphere (clouds, dust content, Methane, water absorption, effective temperature, radius, dust polarization)

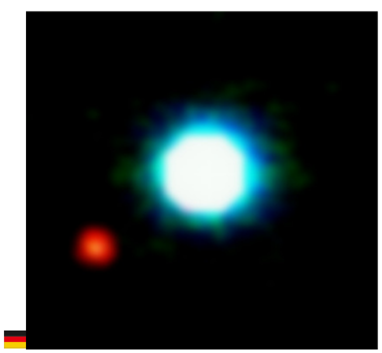
➔ Understand the **planetary system origins**



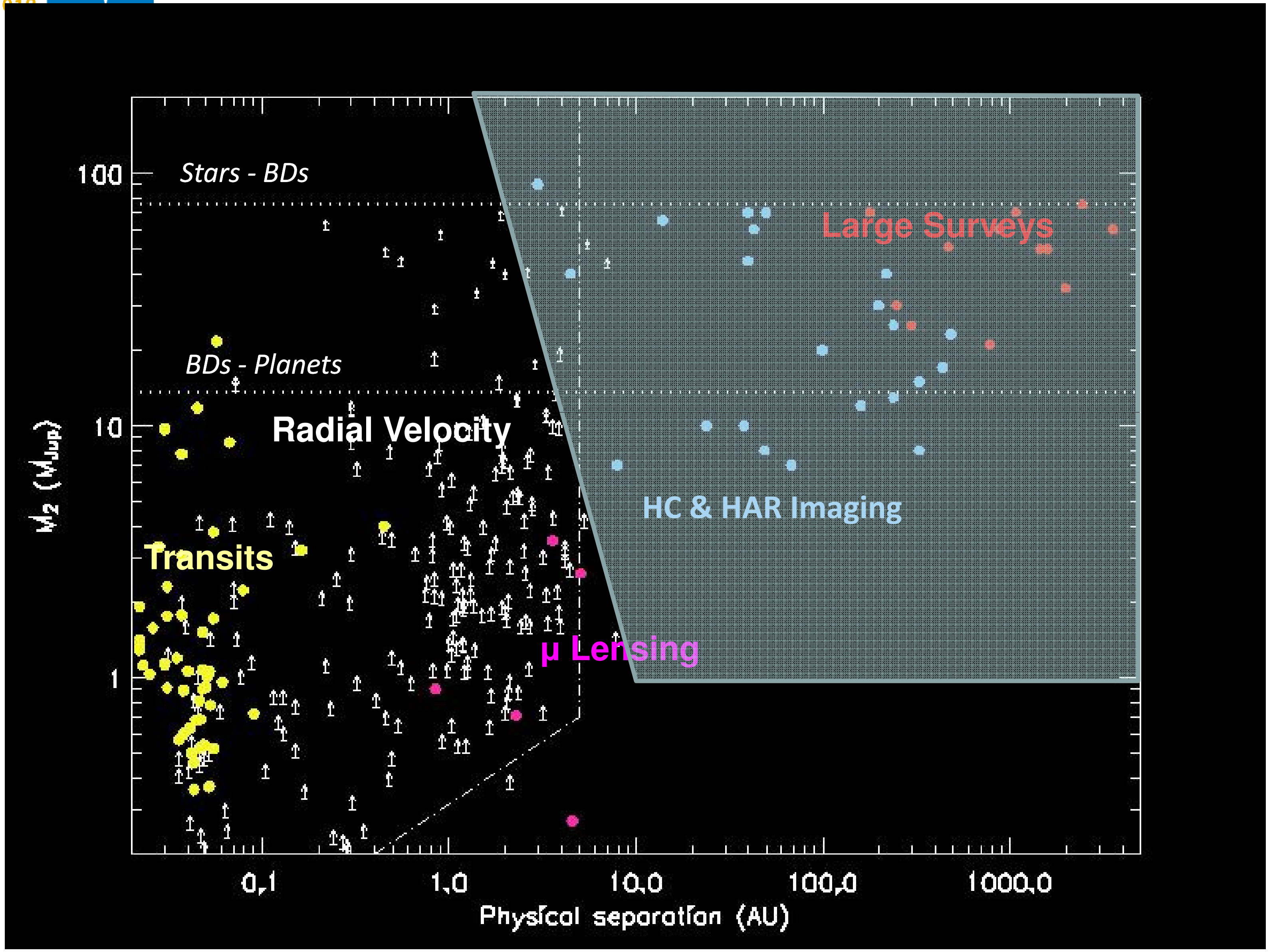






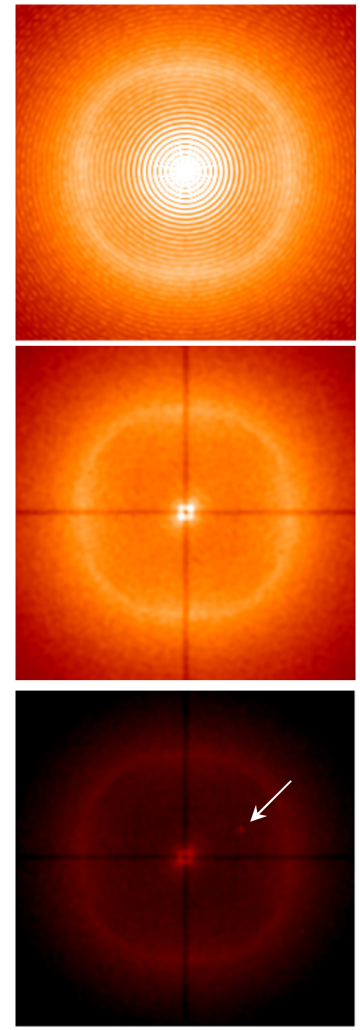


SPHERE Science objectives

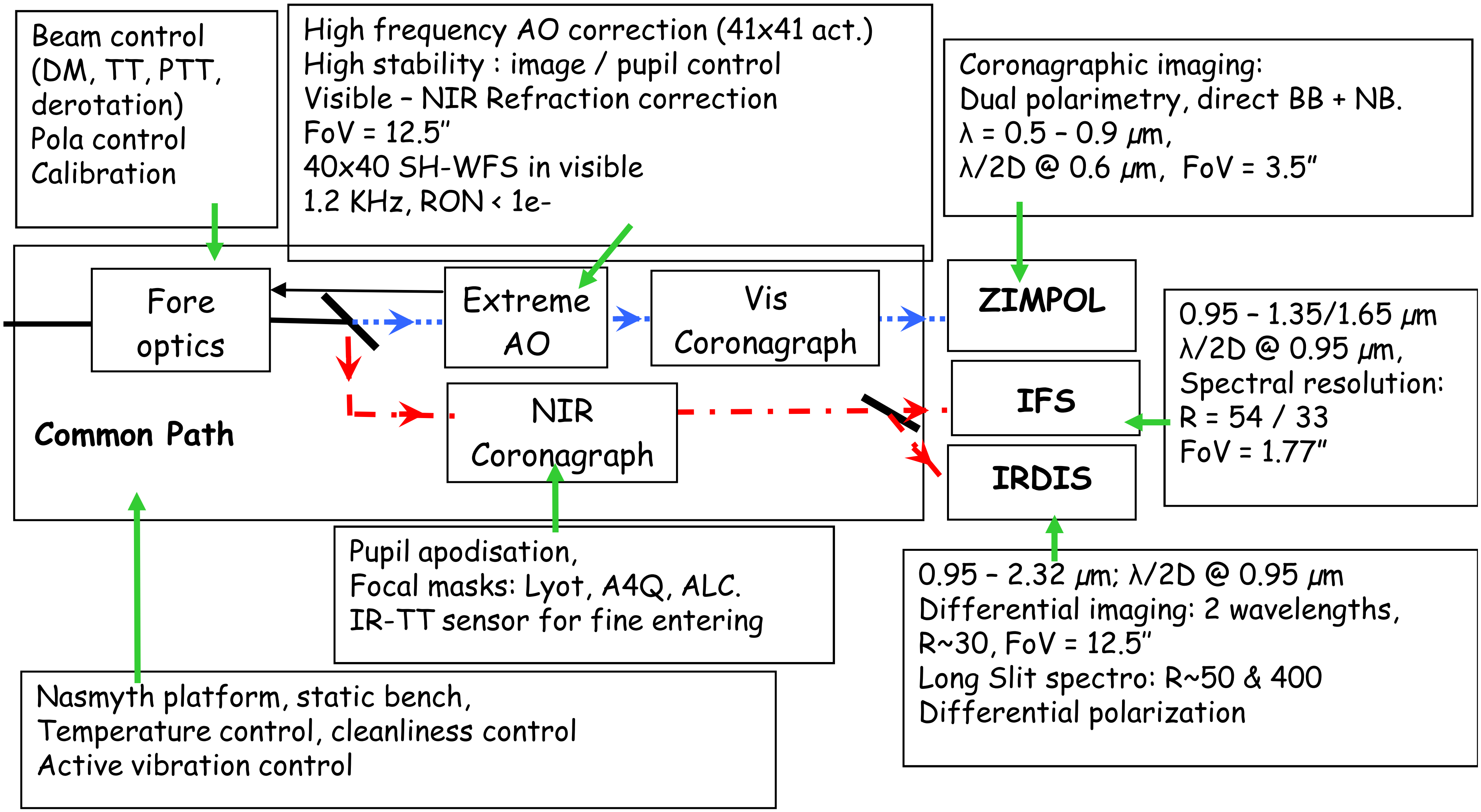


SPHERE High level requirements

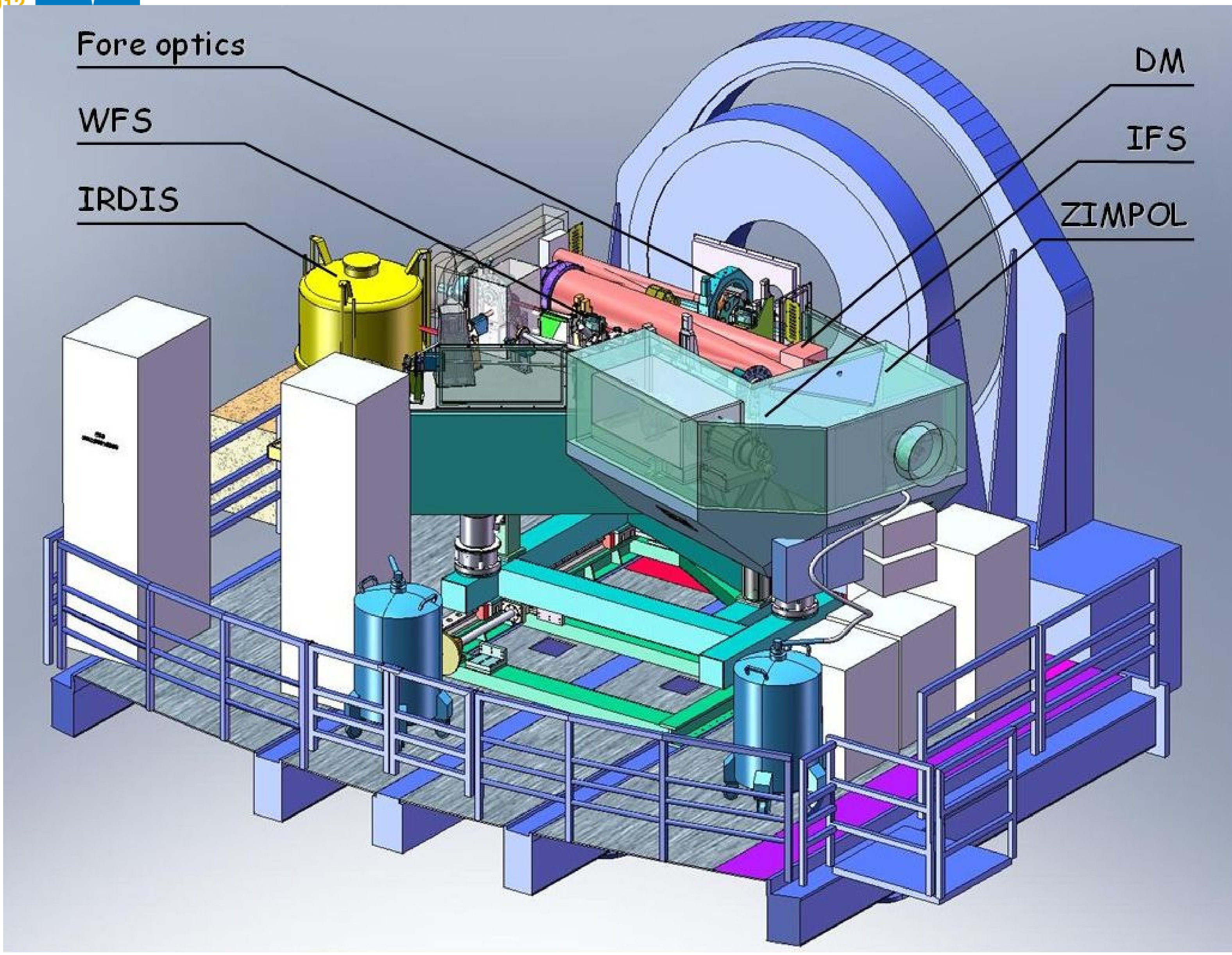
- Scientific requirements
  - ✓ Gain up to 2 orders of magnitude in contrast as compared to current instrumentation
  - ✓ Reach short separations: 0.1" – 3" (1- 100AU)
  - ✓ Survey a large number of targets
- High contrast detection capability
  - ✓ Extreme AO (turbulence correction)
    - ✓ feed coronagraph with well corrected WF
    - ✓ SR ~ 90% in H-band
  - ✓ Coronagraphy (removal of diffraction pattern)
    - ✓ high dynamics at short separations
  - ✓ Differential detection (removal of residual defects)
    - ✓ calibration of non common path aberrations
    - ✓ pupil and field stability
    - ✓ smart post processing tools
- High sensitivity
  - ✓ optimal correction up to V ~ 9-10



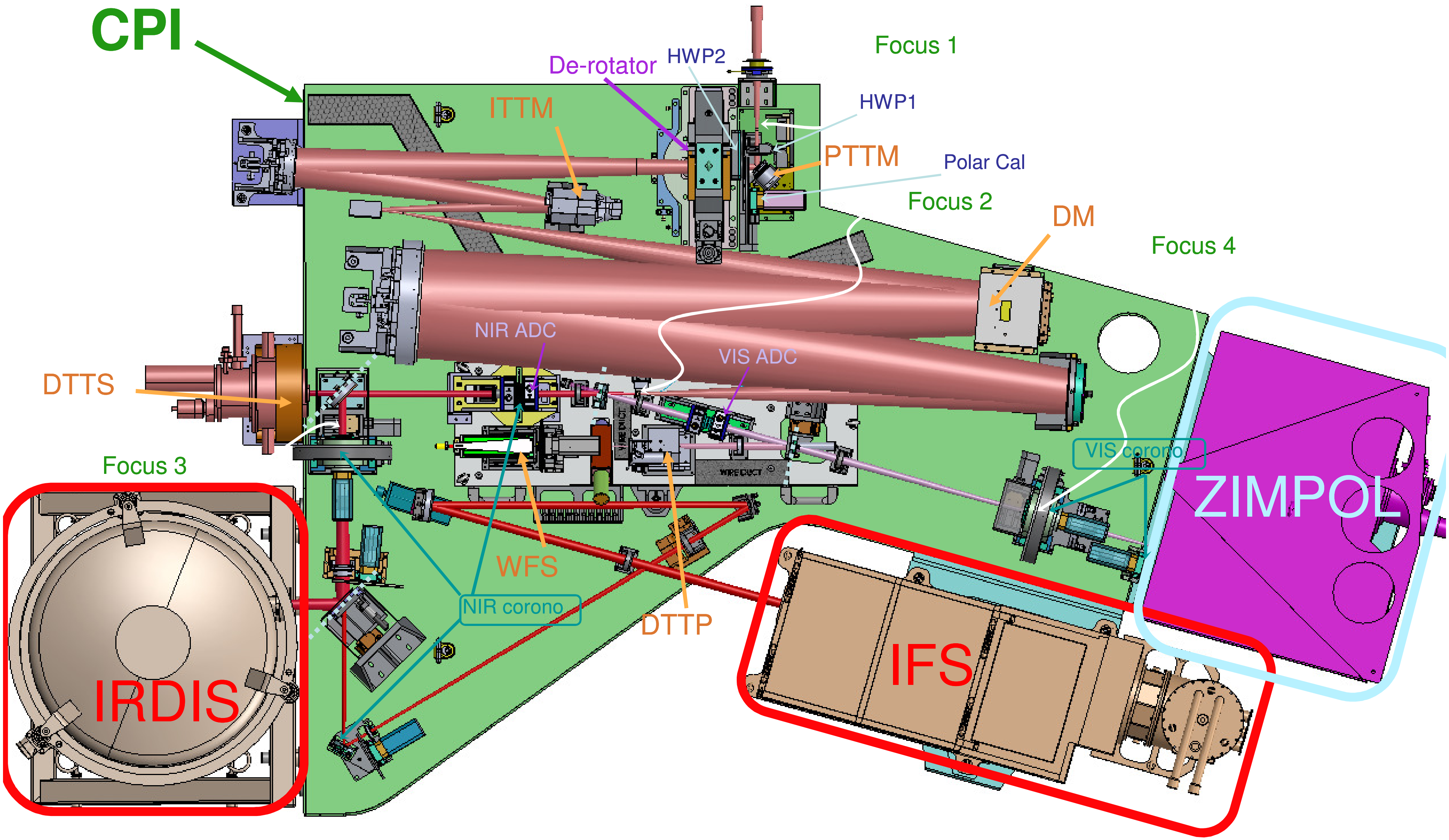
SPHERE Concept overview



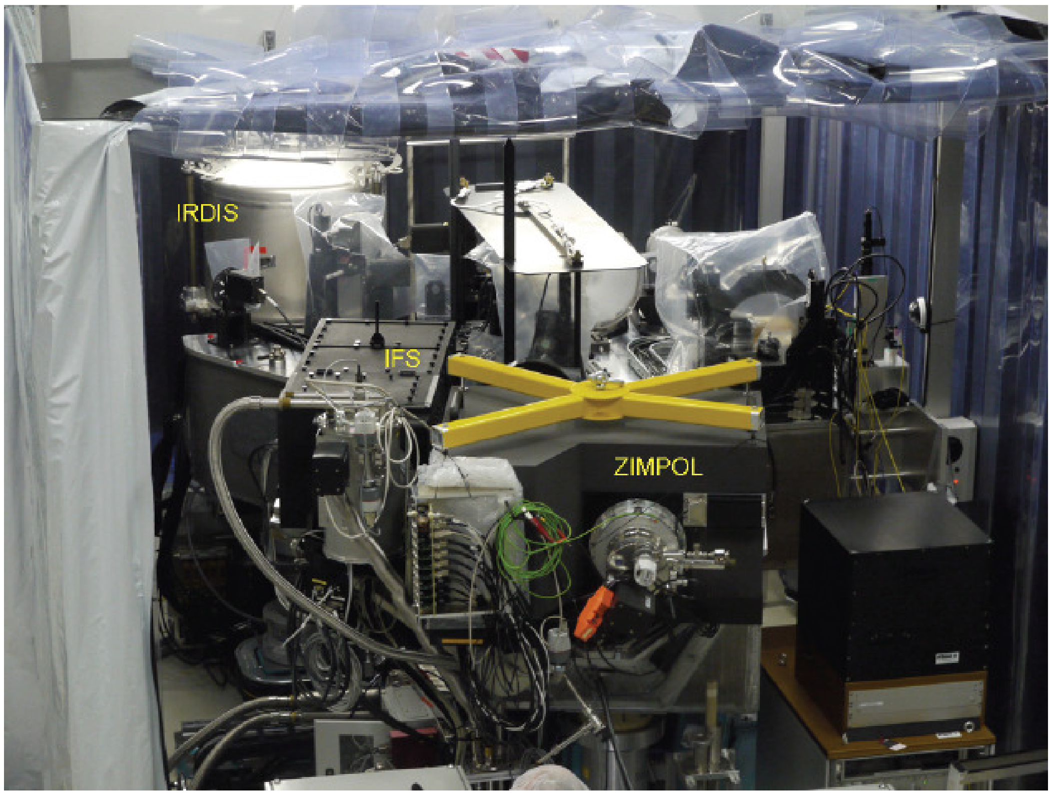
SPHERE DESIGN



SPHERE DESIGN

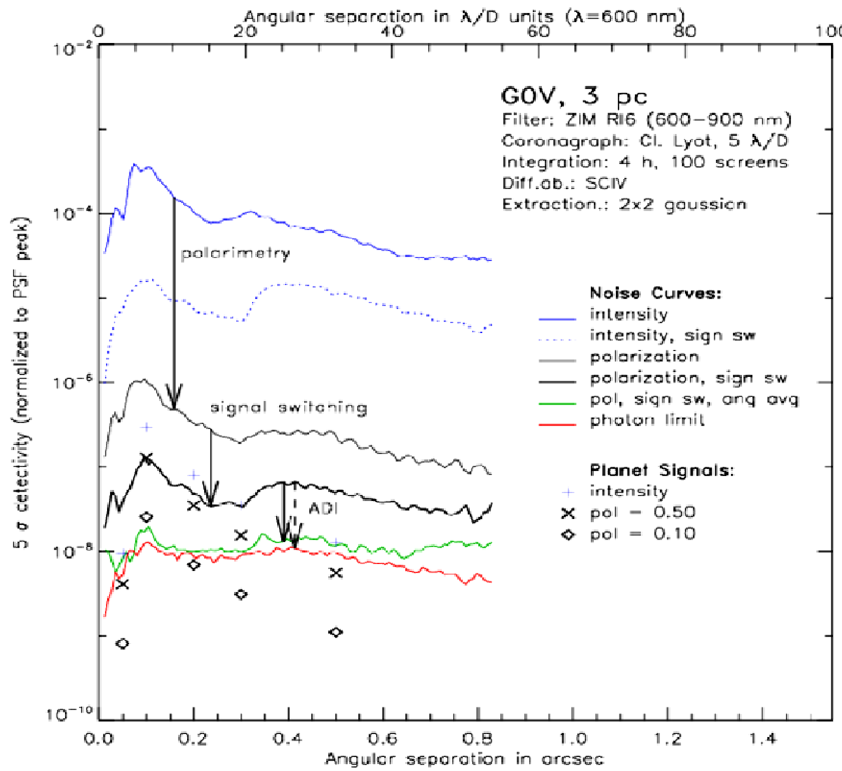


SPHERE status

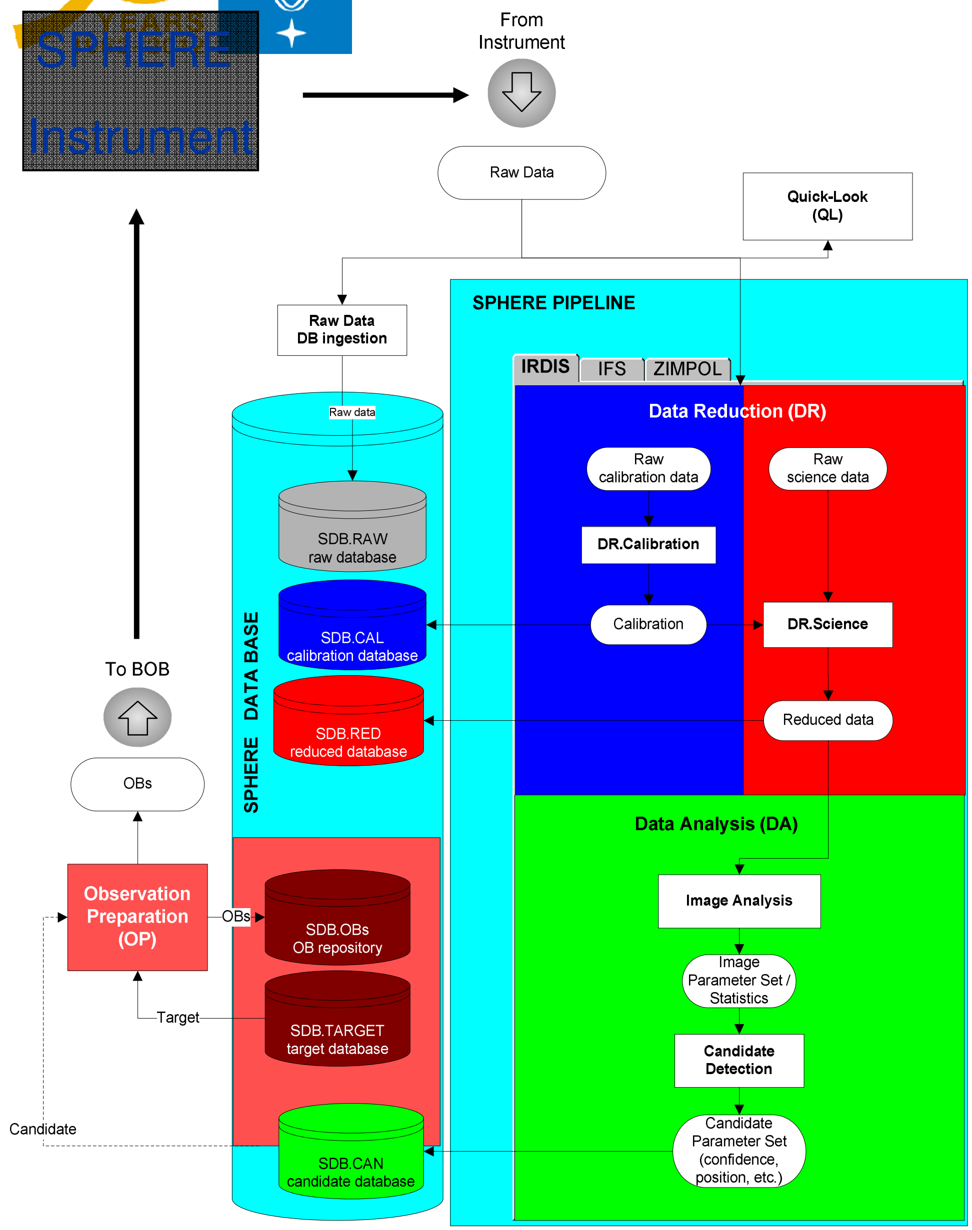


1st light early 2013

Unique but challenging
ZIMPOL capability



SPHERE Data Reduction & Handling



- DRH = Data Reduction and Handling
- Organizes data flow of the SPHERE Survey(s)
- From target lists via observing blocks, raw and reduced data, and search algorithms to candidate data bases
- More than just “data reduction“

Conclusions

- VLT AO capabilities in construction cover a large range of science requirements and instrument capabilities:
  - GLAO Large FoV NIR imaging, small FoV visible 3D spectroscopy
  - Laser Tomography AO in the visible for 3D spectroscopy
  - High Strehl ratio & High contrast Mid-NIR imaging & 3D spectroscopy
  - High contrast both in the NIR and in the visible for bright objects
  - Missing: Medium FoV, diffraction limited MCAO instrument… for now...
- Science cases calls for challenging AO concepts & techno.
  - Better Sky coverage and higher performance availability (LGS!)
  - Larger FoV & better PSF uniformity (photometry & astrometry)
  - Better performance at shorter wavelength➔ HST replacement?
  - Higher contrast at small separation for large set of objects
  - Well focused science cases allow for AO design compromises to converge to more affordable & less risky instruments….