

Opportunities with ESO optical and infrared telescopes

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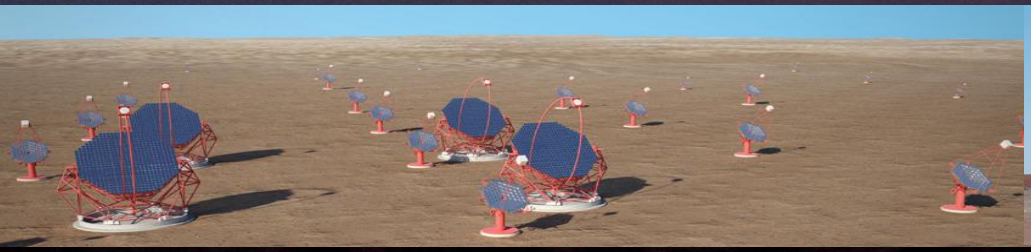
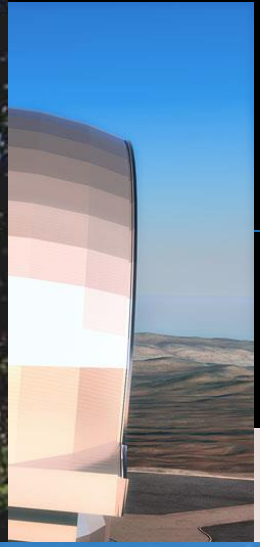
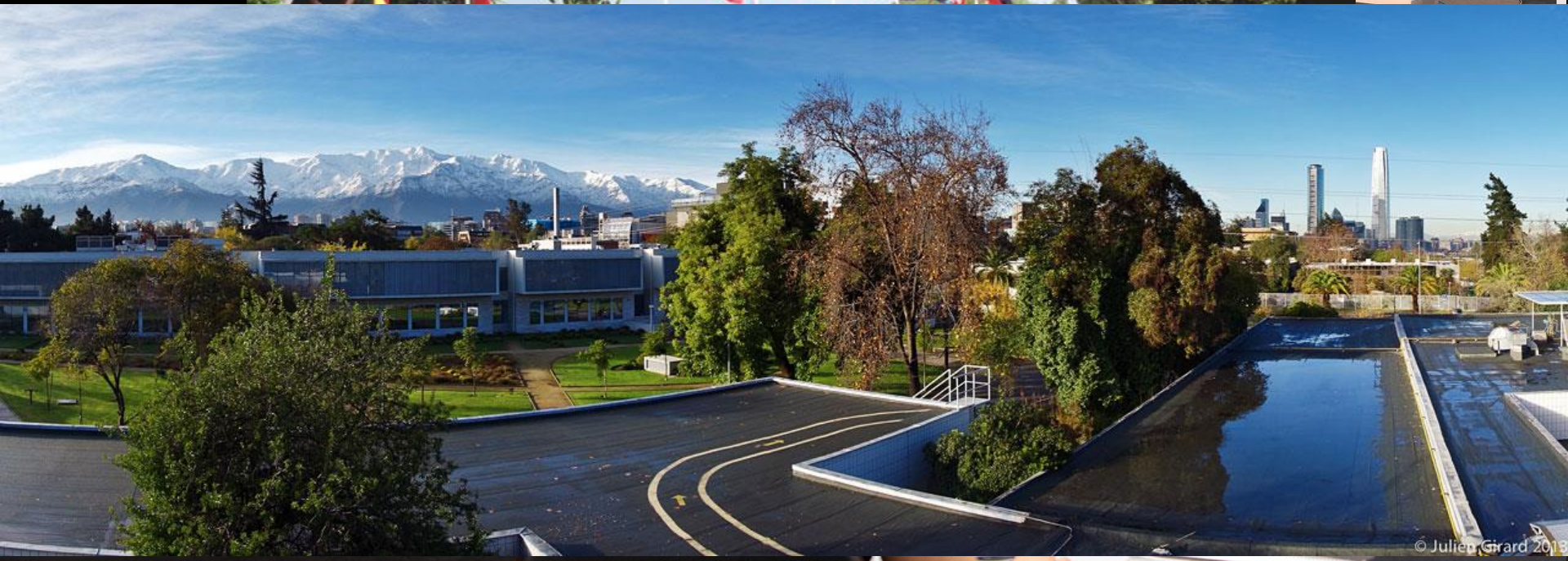


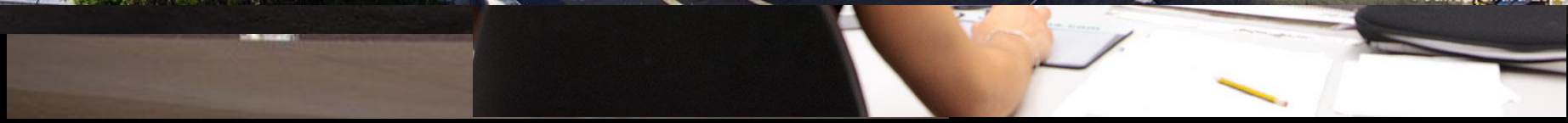

Observa

8 Tel

APEX ir







Overall strategy

- ALMA mm/sub-mm flagship facility
- ELT future O/IR flagship facility
  - faint, high-angular resolution, near-infrared
- VLT/I current O/IR flagship facility
  - multi-purpose instrumentation
  - focus on unique capabilities
    - optical/ultraviolet, versatility, flexibility, angular resolution
- 4m telescopes dedicated to specific topics
  - VISTA → surveys (VIRCAM → 4MOST)
  - 3.6m → radial velocity studies (HARPS, NIRPS)
  - NTT → transient spectroscopy (EFOSC2 → SOXS)

VLT/I Opportunities

- Four 8m telescopes
  - flexibility
  - scientific throughput
    - 1200 observing nights/year
- Successful operational model
  - expand existing model to allow new modes
    - high time resolution photometry and spectroscopy
    - faster turnaround (currently DDT)
    - closer interaction with user, e.g. remote observing
- Telescope system
  - spatial resolution from 1 degree to 2 mas
  - wavelength coverage from 320nm to 20μm
  - spectral resolutions from a few to 100000

Multi-Wavelength Astrophysics

- ESO offers access to optical, infrared and sub-mm wavelength ranges
- VLT/I provides many resolution scales
- Operational model adapted to fast reactions/transient targets

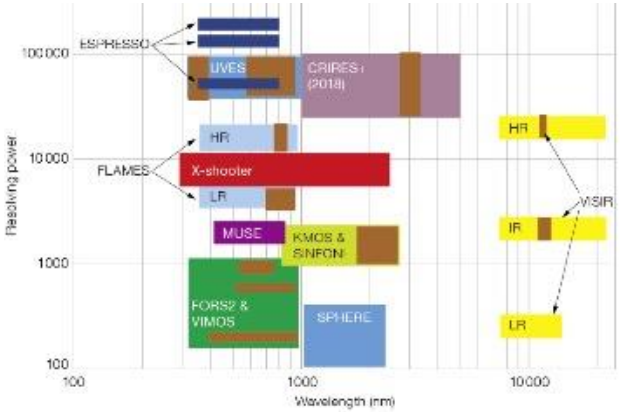


Figure 1: **Wavelength-Spectral Resolving power diagram for the VLT instruments of 1st and 2nd generation.**

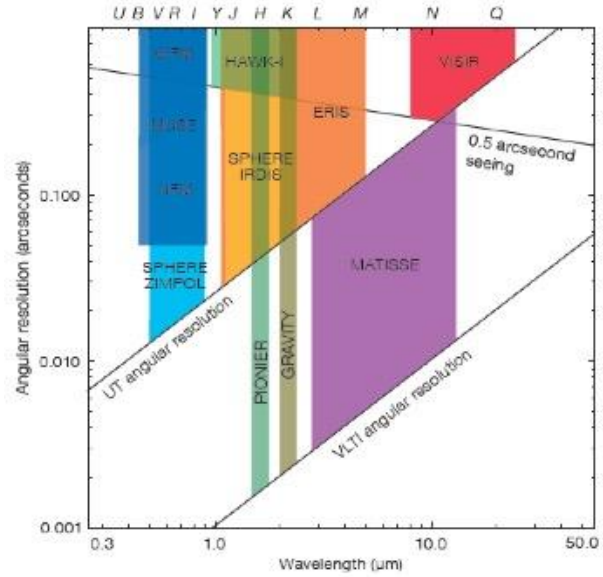


Figure 2: **Wavelength-angular resolution diagram for the VLT/I instruments of 1st and 2nd generation.**

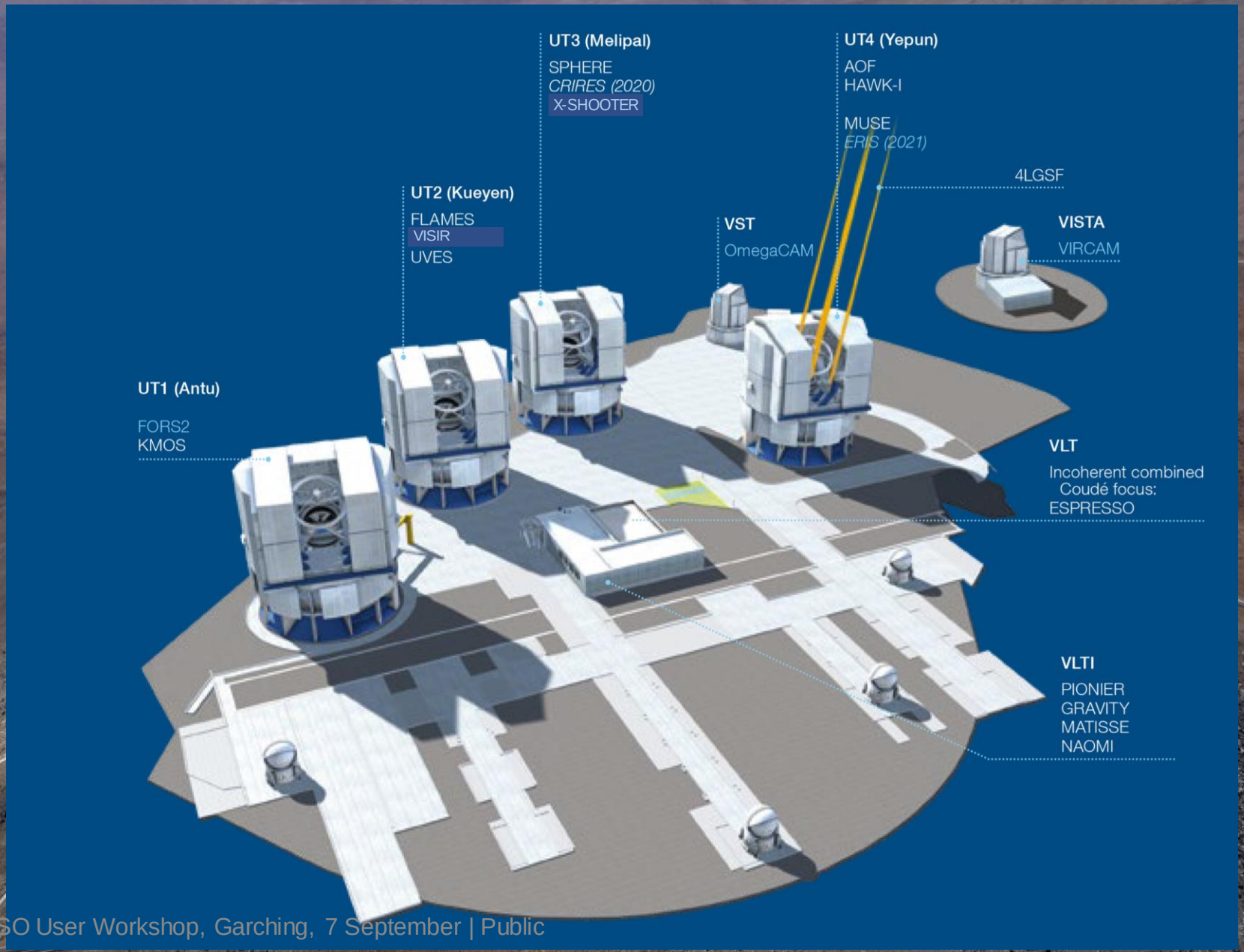
Current VLT instruments

- Spectrographs:
  - High: UVES, ESPRESSO, CRIRES
  - Mid: XSHOOTER
  - Low: FORS2, ERIS, VISIR
- Imagers:
  - Visible: FORS2
  - Near IR: HAWK-I, ERIS
  - Mid-IR: VISIR
- MOS:
  - FLAMES (fibers)
  - FORS2 (slitlets)
  - KMOS (mini-IFUs)
- IFU:
  - ERIS
  - MUSE
- Interferometric:
  - PIONIER
  - GRAVITY
  - MATISSE

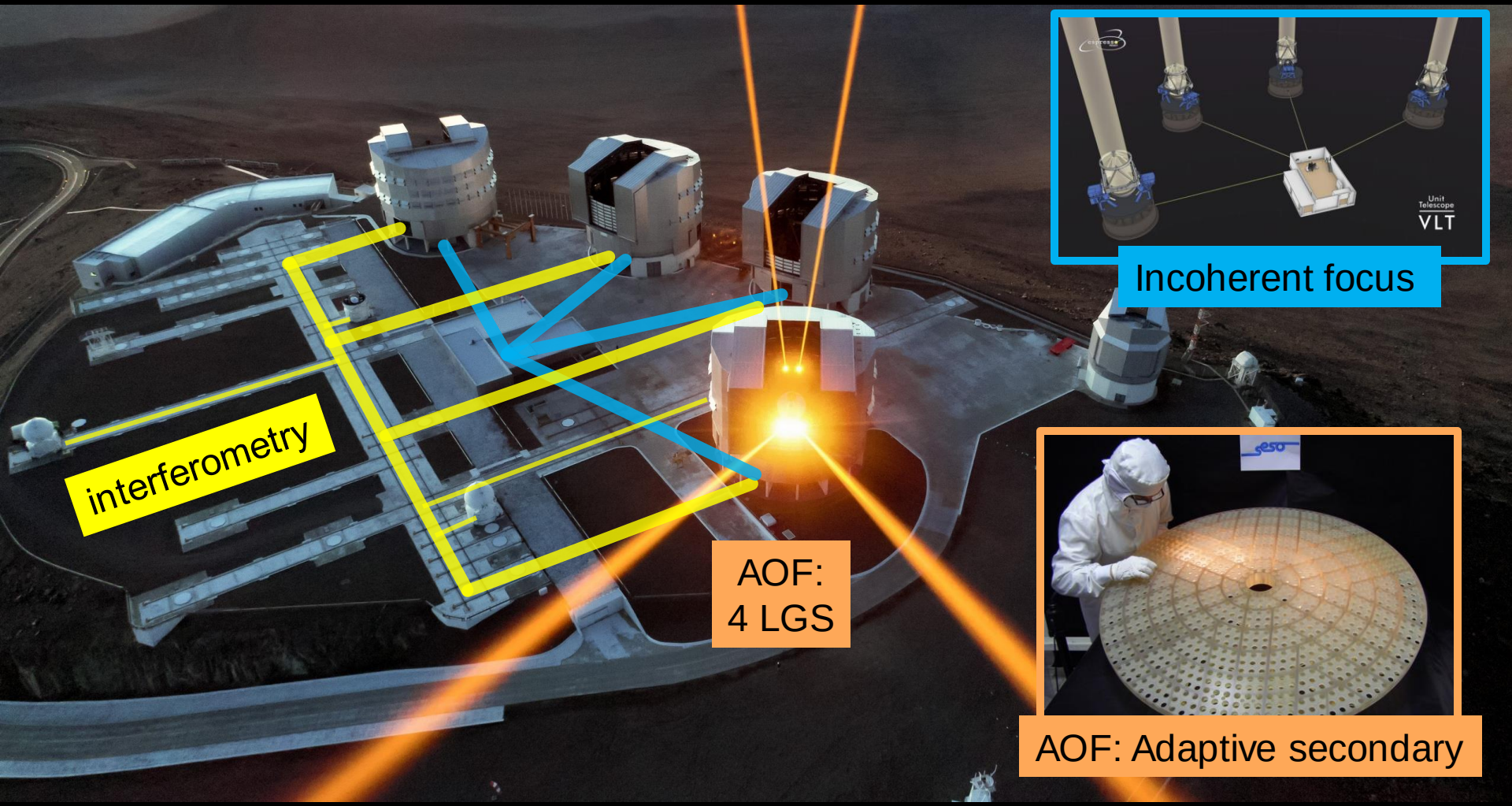
Paranal Facilities

- VLT
  - Instrumentation operating, in assembly and planned
    - Covers the available optical infrared wavelengths 300nm to 20µm
    - Angular resolution from seeing limit to 50 µ-arcseconds
    - FORS2, UVES, FLAMES, VISIR, HAWK-I, X-Shooter, laser guide star facility, KMOS, MUSE, SPHERE, Adaptive Optics Facility, ESPRESSO, CRIRES+, ERIS, MOONS, CUBES, MAVIS
- VLTI
  - PIONIER, GRAVITY, MATISSE
- VISTA
  - VIRCAM, 4MOST
- VST
  - ΩCam

Paranal 2020

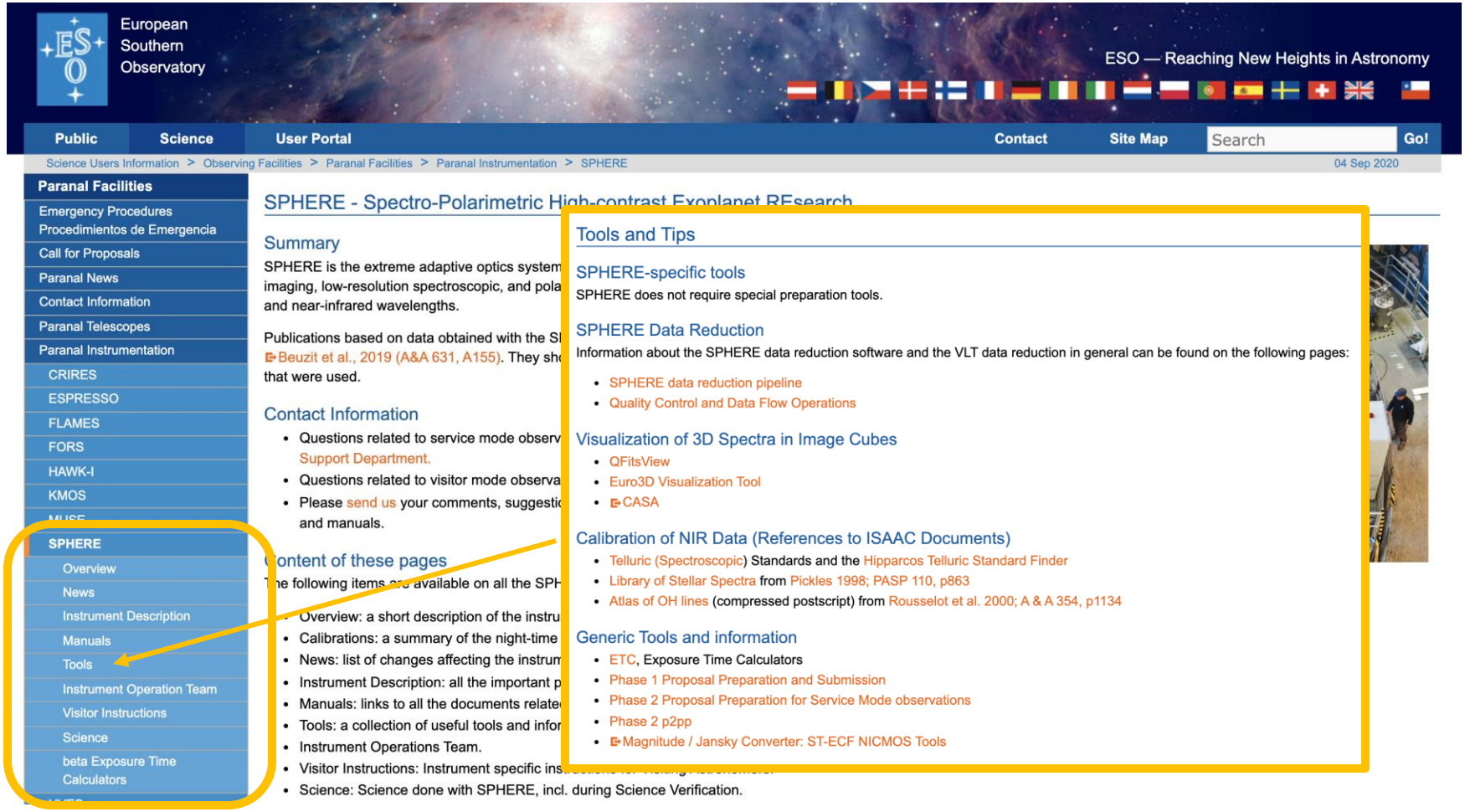


VLT unique capabilities



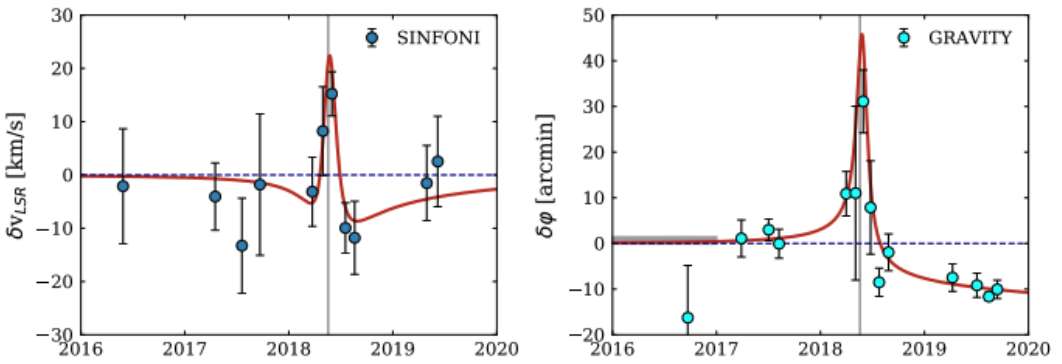
Everything about instruments

https://www.eso.org/sci/facilities/paranal/instruments.html

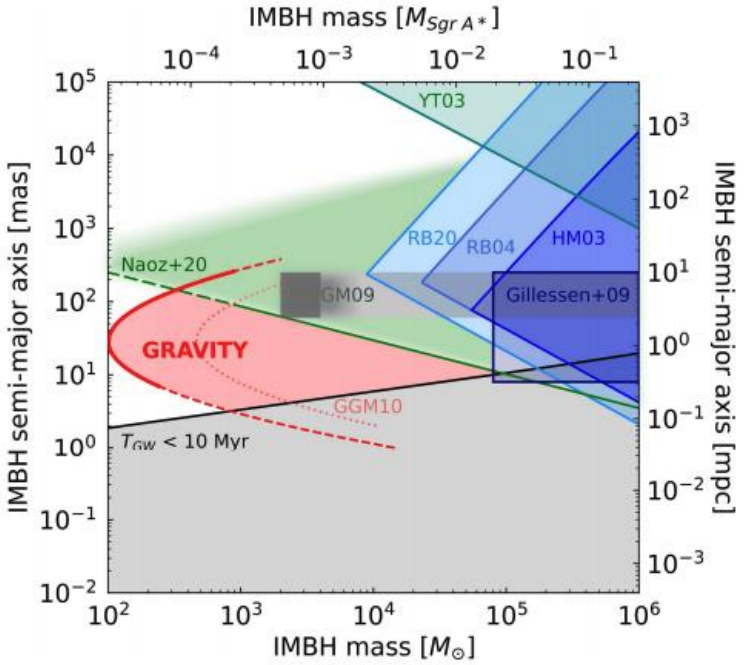


Schwarzschild precession around Sgr A*

- SINFONI and GRAVITY culminate 30 years of observation of star S2 using ESO facilities



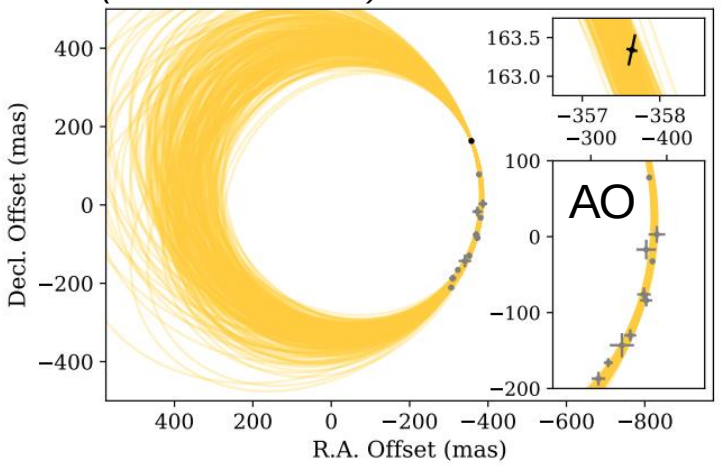
- New S2 orbit nearly excludes all possible additional intermediate mass black hole around Sgr A*



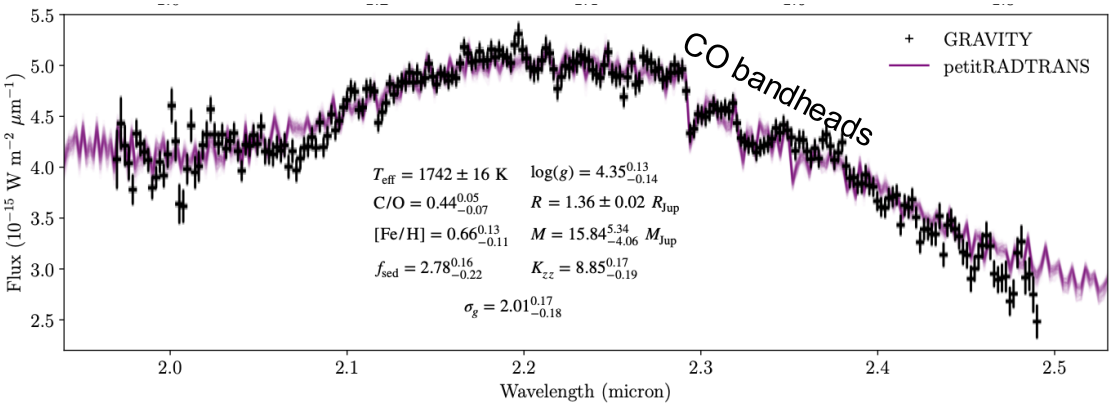
VLTI observes exoplanets

- GRAVITY astrometry of HR8799e (x10 better than AO) disproves co-planar hypothesis for HR8799b-e orbits.
- Carbon to oxygen ratio measurement for β Pic c favours core-accretion formation scenario

GRAVITY Collaboration, (Lacour et al. 2019)

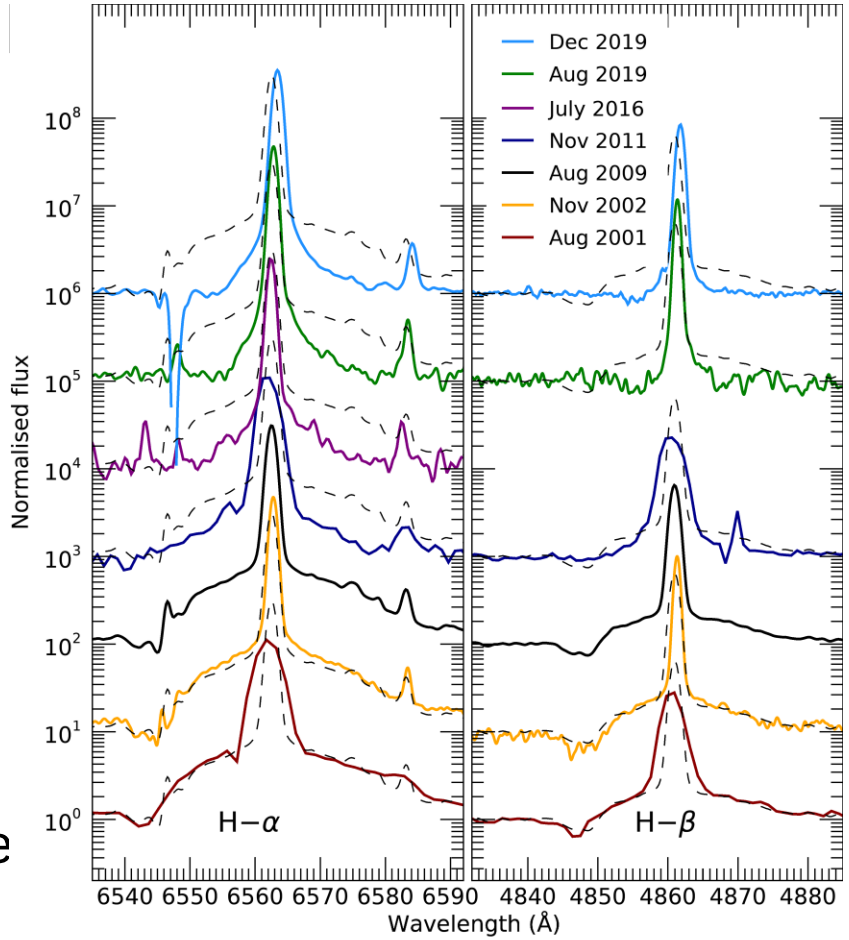


GRAVITY Collaboration (Nowak et al. 2020)



Disappearance of a star

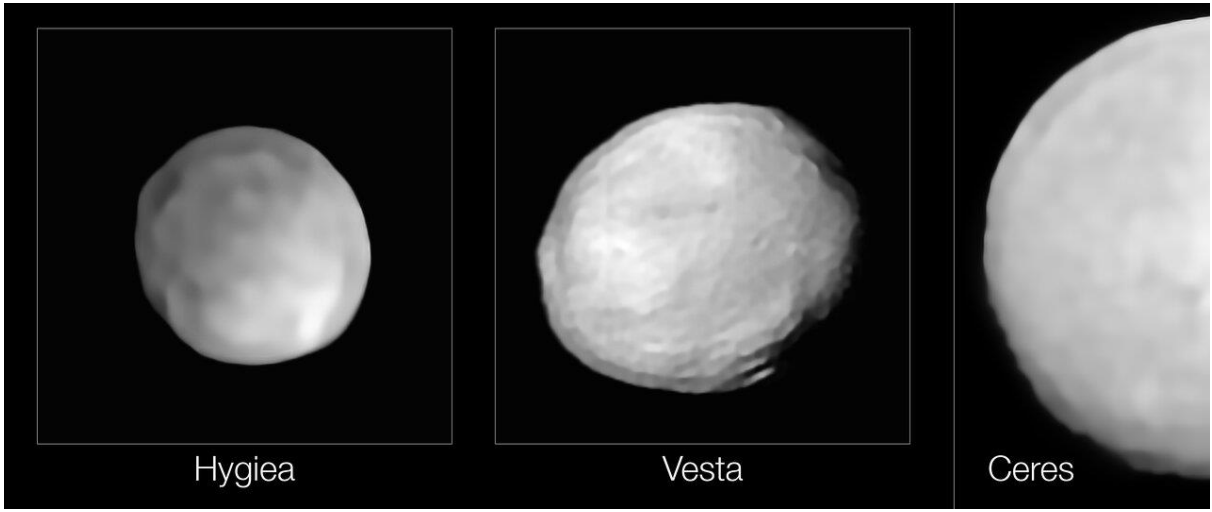
- Long-term observations of an LBV in the dwarf galaxy PHL293B
  - Combination of new and archival data from
    - ESPRESSO, X-shooter, UVES, HST/COS, INT/IDS, WHT/ISIS
  - Disappearance of the broad wings in the H lines after 2009
    - LBV changed from active state
  - Either star dropped in luminosity and increased temperature (plus some dust)
  - Or LBV collapsed to a black hole without a supernova



Allan et al. 2020

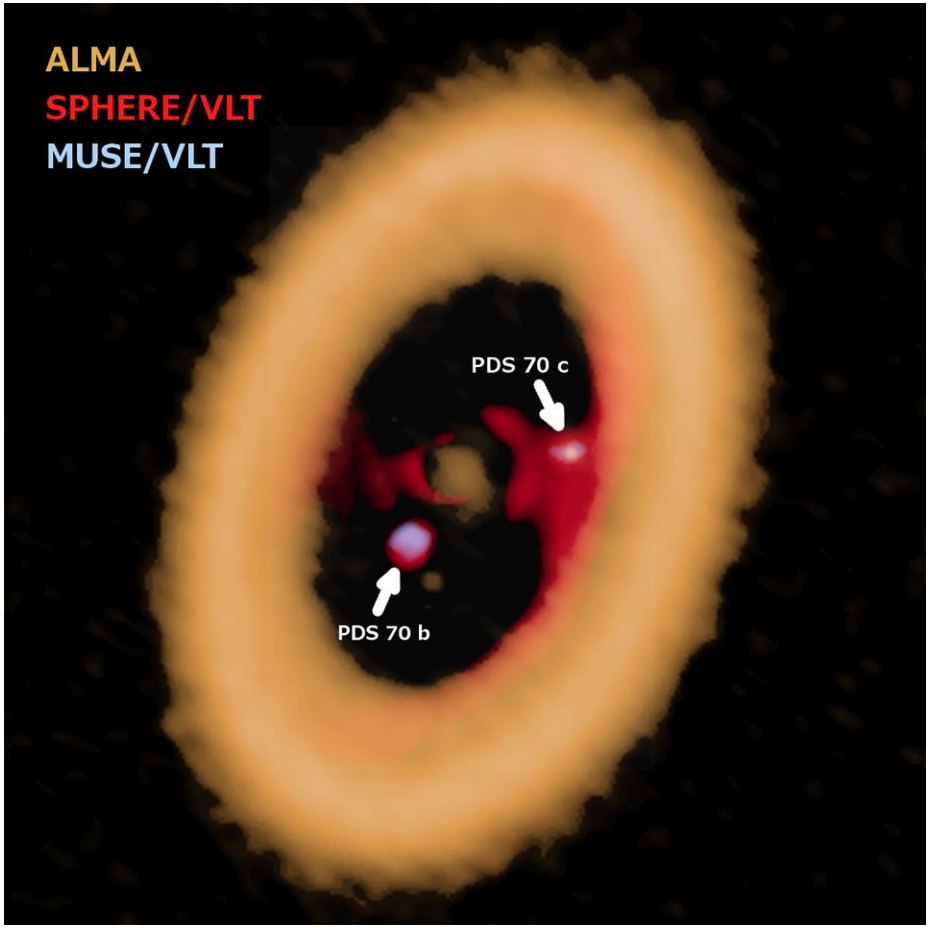
Shapes of Asteroids

- Origin of asteroids → collisional debris?
- SPHERE observations of (10)Hygiea
- Shape nearly spherical and surface without major craters
  - contrary to, e.g., (4)VESTA
  - diameter 440km
  - density 2000kg/m^3
- Formation
  - possibly after a major impact
  - reformed from the debris under self gravity
  - signatures of a minor planet



Vernazza et al. 2019

An exomoon in formation



- Synergy between ALMA and VLT
- PDS 70: T Tauri star with a VLT/SPHERE-discovered companion PDS 70 b (Müller et al. 2018)
- Hα emission (VLT/MUSE) at location of two planets indicates accretion onto these planets (Haffert et al. 2019)
- Initial analysis of ALMA data show a highly structured disk (Keppler et al. 2019), with an upper limit of circumplanetary material around PDS 70 b of 0.01 M_{Earth}
- Further analysis of the ALMA continuum emission at the location of PDS 70 c constrains this to the presence of 2-4 x 10^{-3} M_{Earth} in the form of dust, enough to form an exomoon (Isella et al. 2019), assuming typical dust-to-gas ratios

The ESO exo-planet machinery

- HARPS at 3.6m telescope (in the future also NIRPS)
  - best radial velocity machine at a 4m telescope
  - extremely stable spectrograph
  - ESPRESSO at VLT
- SPHERE
  - adaptive optics supported imaging and spectroscopy
- VLTI/GRAVITY
  - highest spatial resolution for follow-up observations of known systems
- FORS2/ERIS
  - transit measurements, atmospheres of exo-planets
- CRIRES+
  - spectroscopy of atmospheres

Science with Paranal/La Silla telescopes

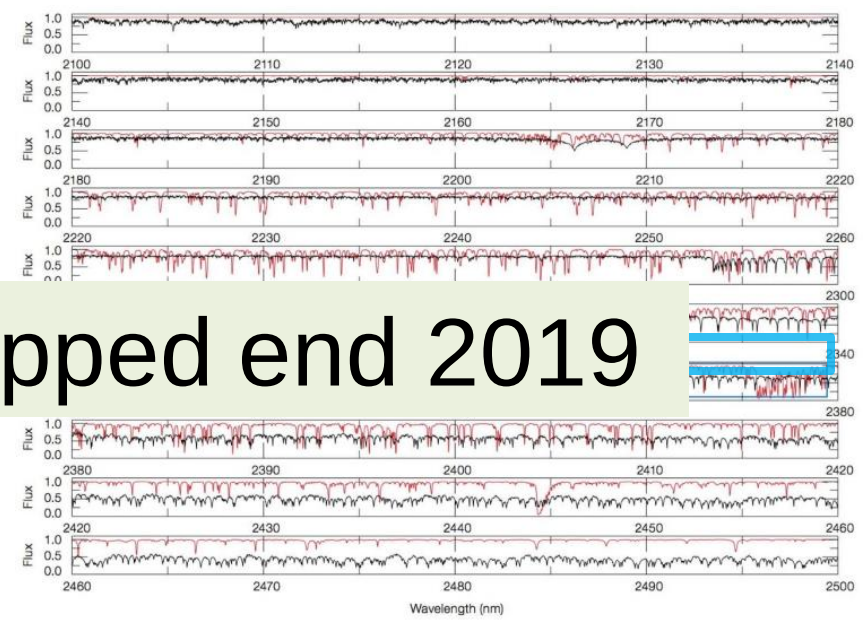
- Contributions to nearly all of astrophysics
  - Solar system
    - Trans-Neptunian Objects, asteroids, comets
  - Exo-planets
    - direct imaging, temperate planets, planetary systems
  - Stellar physics
    - metal-poor stars, supernovae, neutron star mergers
  - Milky Way structure
    - galactic centre, distances
  - Galaxy evolution
    - redshift surveys, rotation curves, absorption studies
  - Cosmology
    - accelerating universe, background temperature, chemical evolution

Current Status of VLT/I instrumentation development

- GRAVITY for MATISSE commissioned and offered
- CRIRES mounted on UT3
  - Commissioning pending
- ERIS nearly completely integrated
  - PAE expected towards the end of 2020
- MOONS integration progressing
- 4MOST in construction phase
- FORS Upgrade project started
- MAVIS Phase A finished
- CUBES Phase A started
- NIRPS/3.6m and SOXS/NTT in integration phase

CRyogenic InfraRed Echelle Spectrograph

- Upgrade of exisiting AO-assisted high resolution spectrograph at 1-5μm (R=100,000)
- Use Hawai 2RG up to 5μm: wavelength coverage x10
  - exoplanets velocimetry and atmosphere
- Polarimetry
  - Stellar magnetism

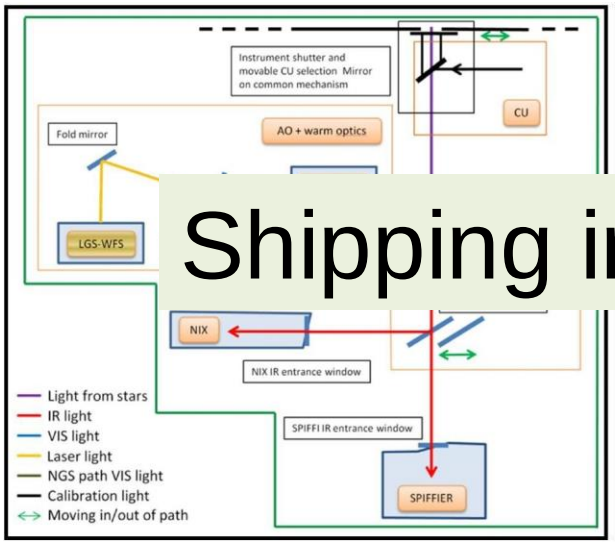


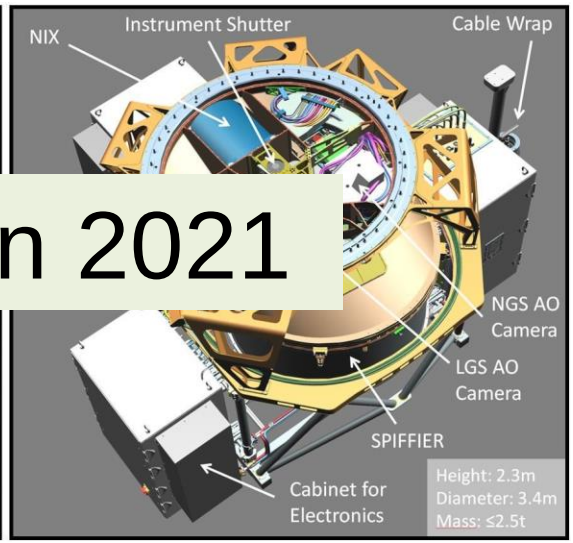
Shipped end 2019

https://www.eso.org/sci/facilities/paranal/instruments/crires/overview.html

Enhanced Resolution Imager and Spectrograph

- Near IR 1-5 μm with 4LGS and adaptive secondary
- Replaces NACO and SINFONI
- Imager, coronagraph, sparse mask, IFU 1-2.5μm, LSS 3-5μm
- Exoplanets, GC, resolved stellar pops, high-z, …



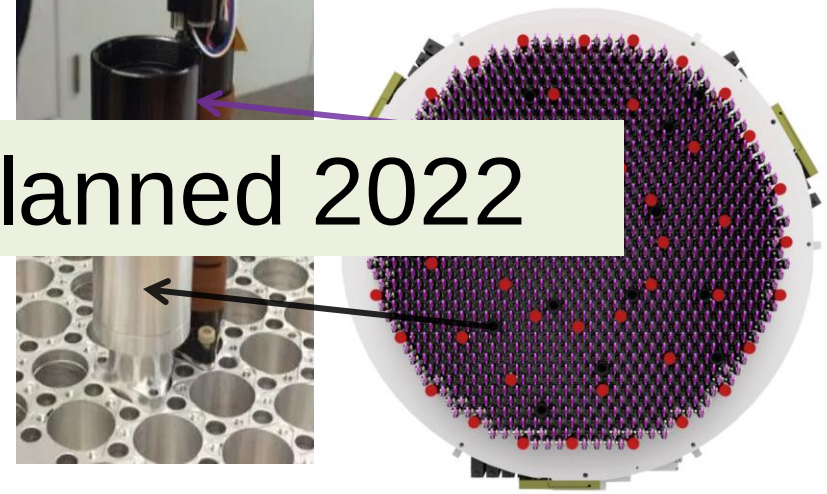


Shipping in 2021

http://www.eso.org/sci/facilities/develop/instruments/eris.html

Multi Object Optical and Near-infrared Spectrograph

- 1001 fibres over 500 arcmin^2
- 0.65-1.8μm at R=4000-18000
- Science cases:
  - Galactic archeology
  - Growth of galaxies: million objects at z>1
  - First Galaxies (z>7)

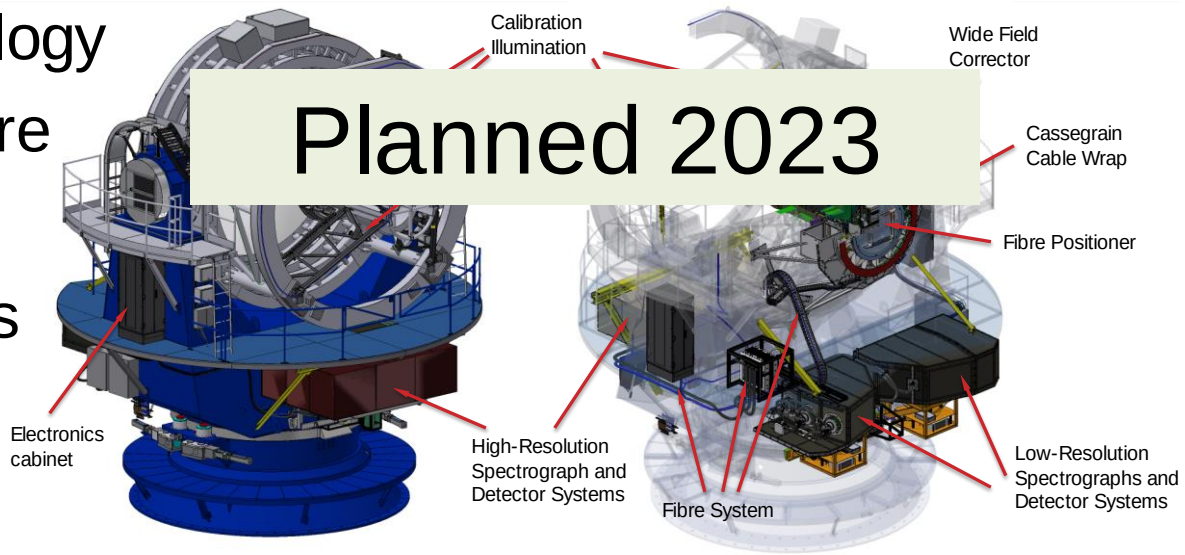


Planned 2022

https://www.eso.org/sci/facilities/develop/instruments/MOONS.html

4MOST

- Wide-field MOS on VISTA
  - FoV ~4.1 deg^2
  - 2436 fibres observed simultaneously
    - 812 fibres with R~20000; $400nm < \lambda < 680nm$ (three settings)
    - 1624 fibres with R~5000; $370nm < \lambda < 950nm$
- Surveys only
  - Galactic archeology
  - Galactic structure
  - Galaxy surveys
  - Redshift surveys

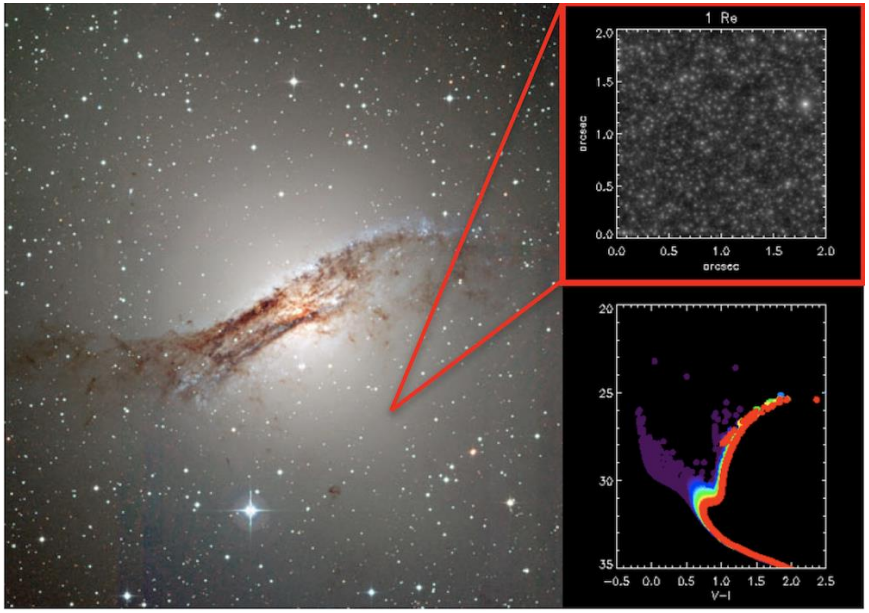


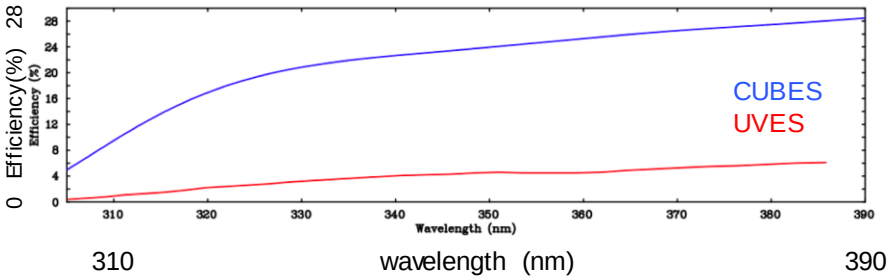
Planned 2023

https://www.4most.eu/

Instruments in development

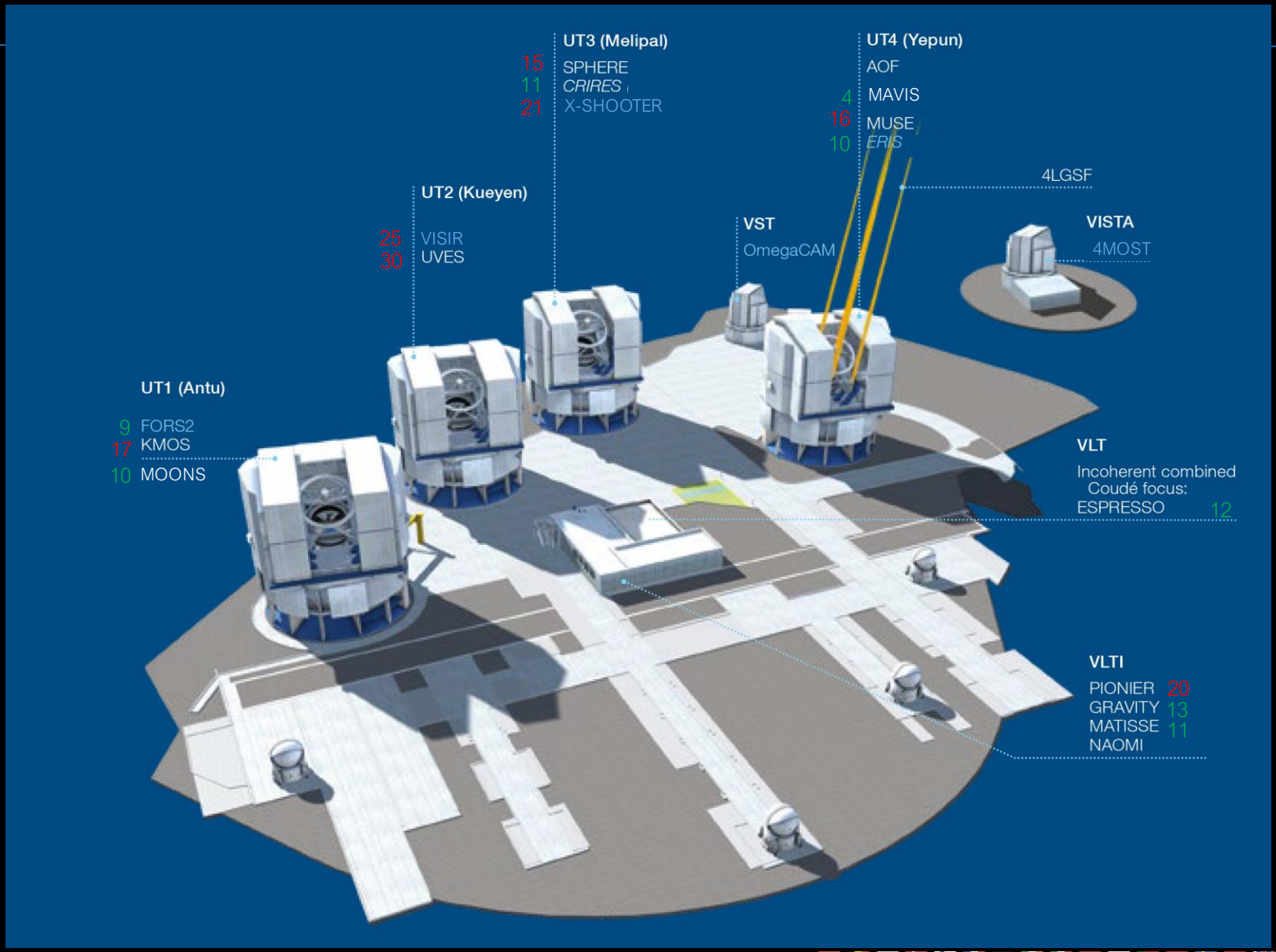
- MAVIS:
  - MCAO in the visible: imager and spectrograph
  - Phase A finished
  - http://mavis-ao.org/mavis/
- Near-UV high-resolution spectrograph
  - New instrument (CUBES)
  - Phase A started
  - https://cubes.inaf.it





310 wavelength (nm) 390

VLT in 2030


UT3 (Melipal)
15 SPHERE
11 CRIRES
21 X-SHOOTER
UT4 (Yepun)
AOF
4 MAVIS
16 MUSE
10 ERIS
4LGSF
UT2 (Kueyen)
25 VISIR
30 UVES
VST
OmegaCAM
VISTA
4MOST
UT1 (Antu)
9 FORS2
17 KMOS
10 MOONS
VLT
Incoherent combined Coudé focus:
ESPRESSO 12
VLTI
PIONIER 20
GRAVITY 13
MATISSE 11
NAOMI

VLT/I in 2030

- Kicked-off at a Workshop in June 2019
  - Well attended, largely by instrument builders
- Science prioritization exercise explicitly polled the scientific community about science drive of the evolution of VLT/I, outcome injected into exercise
- White Papers delivered by 3 teams
- Reviewed at the 16-17 April 2020 STC meeting, clear priorities established:
  - GRAVITY+ https://zenodo.org/record/3356274
  - BlueMUSE https://arxiv.org/abs/1906.01657
- Teams informed in June
- Phase A planning started

Stay involved

- Student- and Fellowship programmes
  - https://www.eso.org/sci/activities/FeSt-overview/ESOstudentship.html
  - https://www.eso.org/sci/activities/FeSt-overview/fellowship_programme.html
- Visitor programme
- Workshops and conferences
- ESO Messenger
  - https://www.eso.org/sci/publications/messenger/
- Science Newsletter
  - https://www.eso.org/sci/publications/newsletter.html
- Web pages: www.eso.org