Ecole Evry Schatzman 2024

The Synergy VLT(I)-ELT-JWST

Lucas Labadie

Institute for Astrophysics – University of Cologne

The Synergy VLT(I)-ELT-JWST

Lucas Labadie

Institute for Astrophysics – University of Cologne

Lecture outline

I. Description and specificities of the ELT and VLT(I)

- Observing techniques
- Performances
- Observational challenges

➢ II. Complementary science with the ELT/VLT(I)

- Structure and evolution of protoplanetary disks
- Composition of planet forming material and its evolution
- The inner regions of protoplanetary disks

Science drivers

Witnessing planet formation in disks

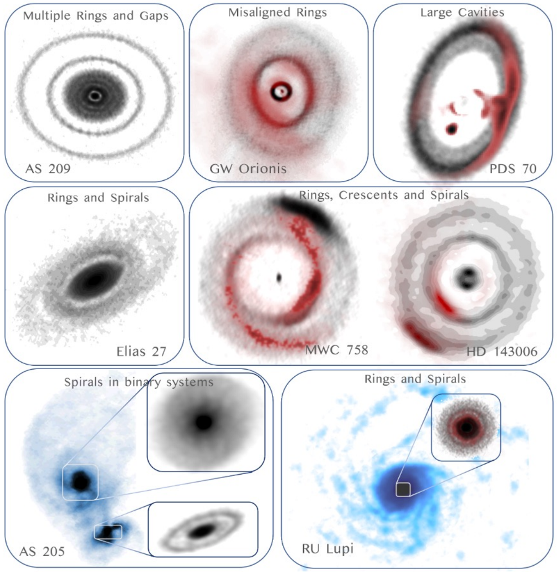
Disk mineralogy and chemistry

Star/disk interactions

Disk structures “at all scales”

Influence of the environment

Disk evolutionary phases



[Bae+2023]

Disks identification and classification

Science drivers

Inner planet formation and disk dispersal

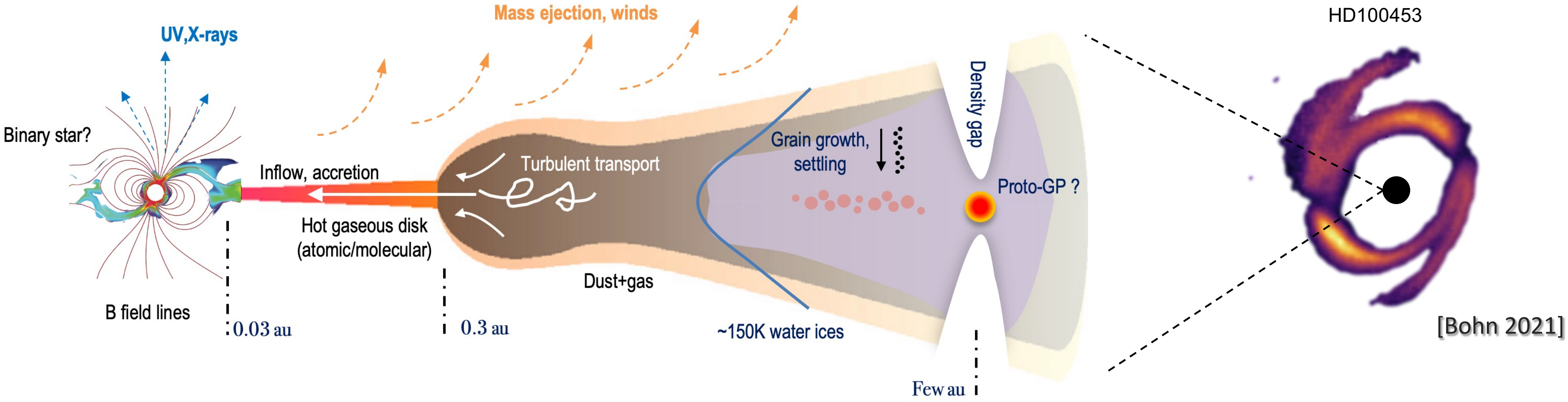
Grain growth, trapping, dust mineralogy

Mass Accretion/Ejection, gas kinematics

Host star properties (B-field, Spin, Period)

Disk turbulence

Disk chemical composition



[adapted from Henning 2013]

Observational approach

Inner planet formation and disk dispersal

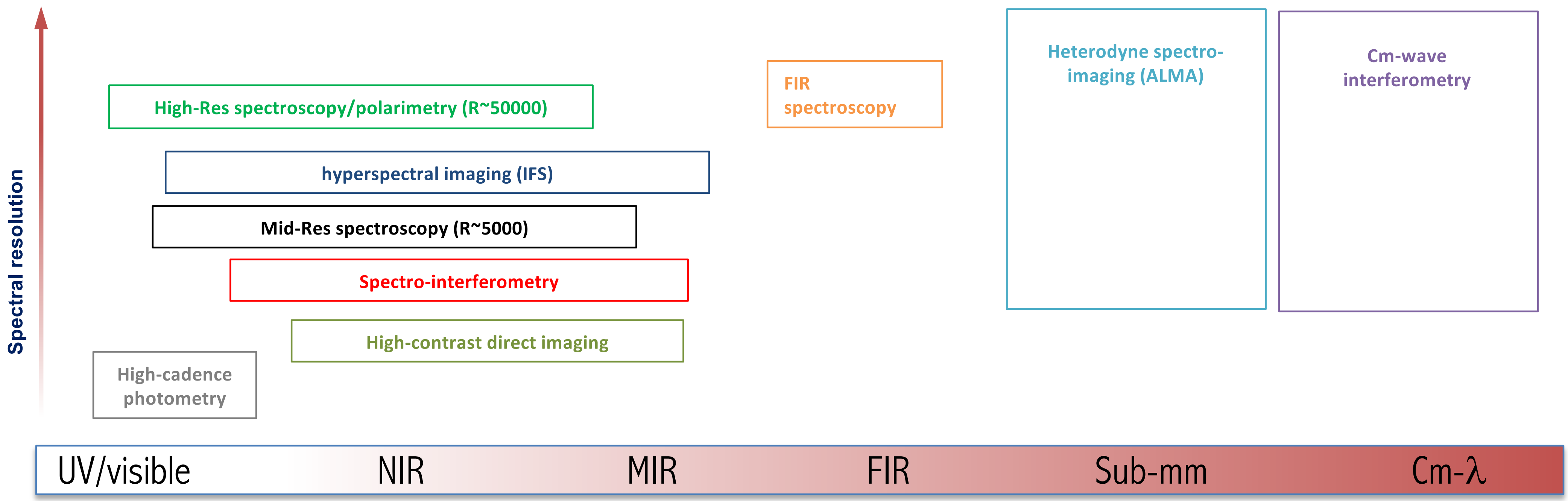
Grain growth, trapping, dust mineralogy

Mass Accretion/Ejection, gas kinematics

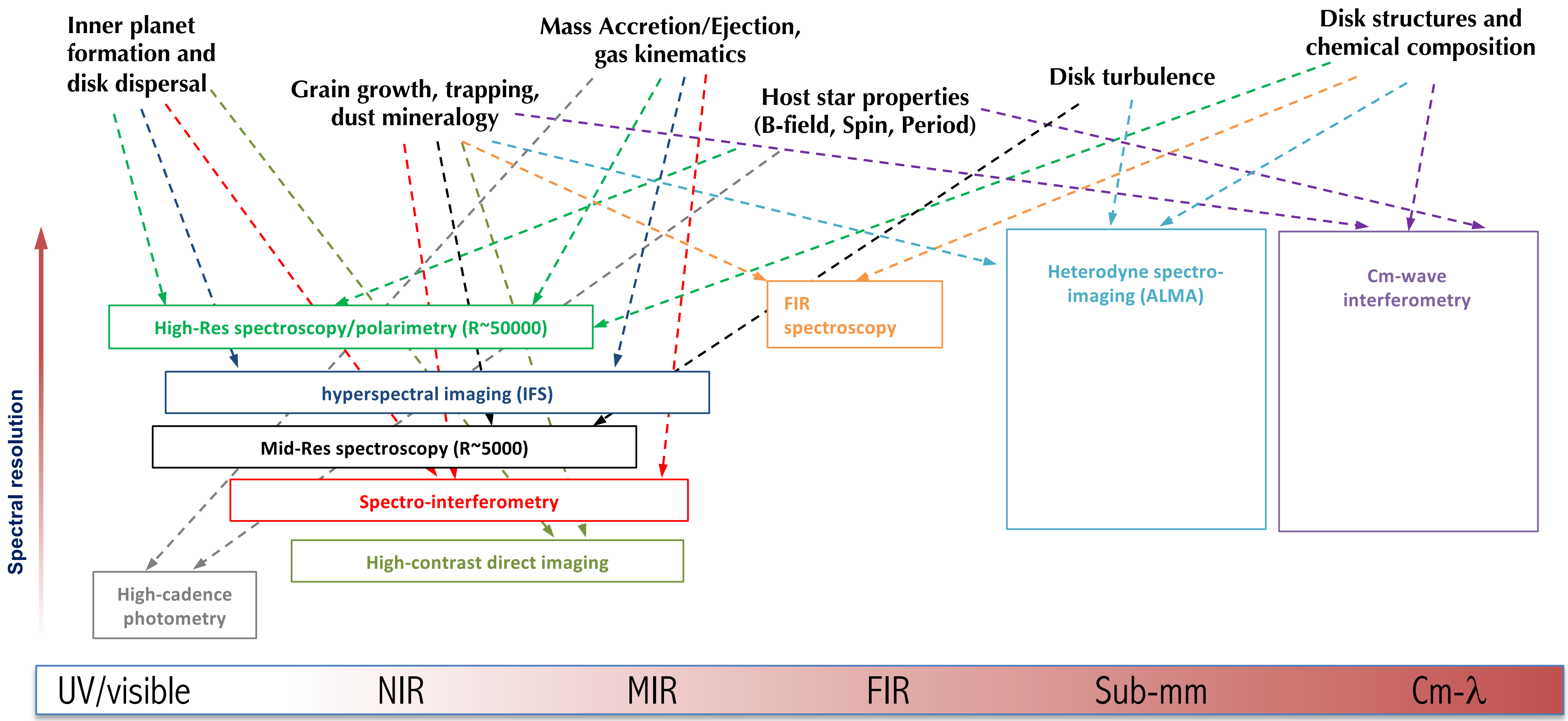
Host star properties (B-field, Spin, Period)

Disk turbulence

Disk structures and chemical composition



Observational approach



Instrumentation landscape

Mid-size telescopes

HARPS

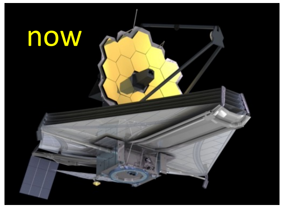
SPIRou

now

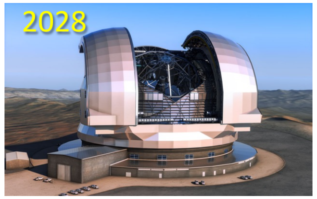
High temporal resolution

High angular resolution

High spectral resolution



NIRCAM
NIRSPEC
MIRI
NIRISS



MICADO
METIS
HARMONI

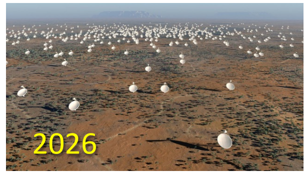
GRAVITY(+)
MATISSE
ERIS
CRIRES+
(Visitors)

Rubin/LSST
2024

>2030

ngVLA

MID-SKA



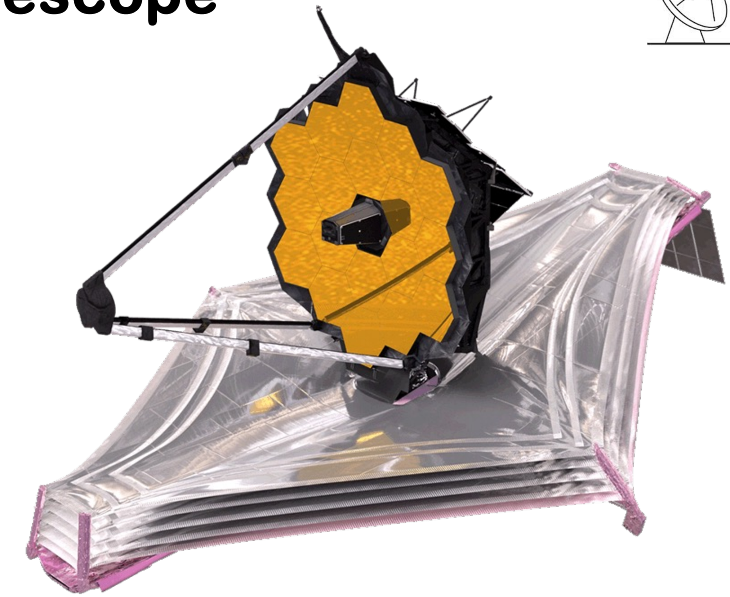
OST/PRIMA

ALMA (Band 1+2)
PdB, SMA

UV/visible — NIR — MIR — FIR — Sub-mm — Cm-λ

Facilities

James Webb Space Telescope



Key figures (https://jwst-docs.stsci.edu)

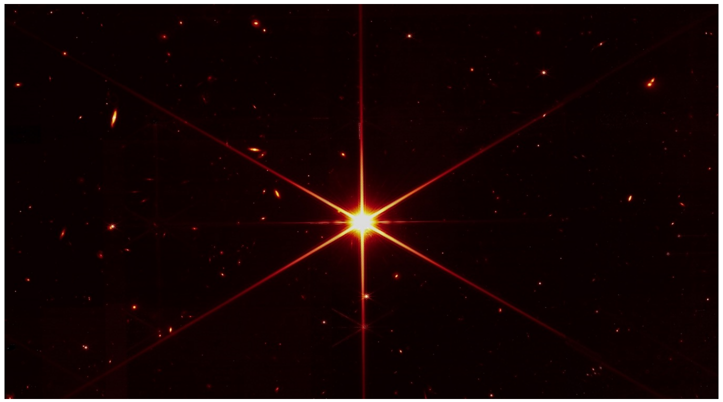
- 6.5-m primary mirror with 18 1.3-m segments (Keck has 36 segments) and ~25m^2 collecting area

- Orbits at gravitationally and thermally stable Lagrange point L2

- Passive cooling to 40K

- **Launched on 25/12/2021**

- Four scientific instruments: NIRCam, NIRSpec, MIRI, NIRISS



European ELT

Key figures (https://elt.eso.org)

- 39-m primary mirror with 798 1.4-m segments and 978m^2 collecting area

- At Cerro Armazones, 30 km from Paranal; VLT control room to be used

- Active Mirrors part of the telescope (Adaptive M4 & tip-tilt M5)

- **First technical light in 2028**

- Three first-light scientific instruments: MICADO, METIS, HARMONI

European ELT

Key figures (https://elt.eso.org)

- 39-m primary mirror with 798 1.4-m segments (Keck has 36 segments) and 978m^2 collecting area (VLT=52m^2)
- At Cerro Armazones, 30 km from Paranal; VLT control room to be used
- Active Mirrors part of the telescope (Adaptive M4 & tip-tilt M5)
- **First technical light in 2028**
- Three first-light scientific instruments: MICADO, METIS, HARMONI

https://elt.eso.org/about/webcams/

European ELT

<u>Key figures</u> (https://elt.eso.org)

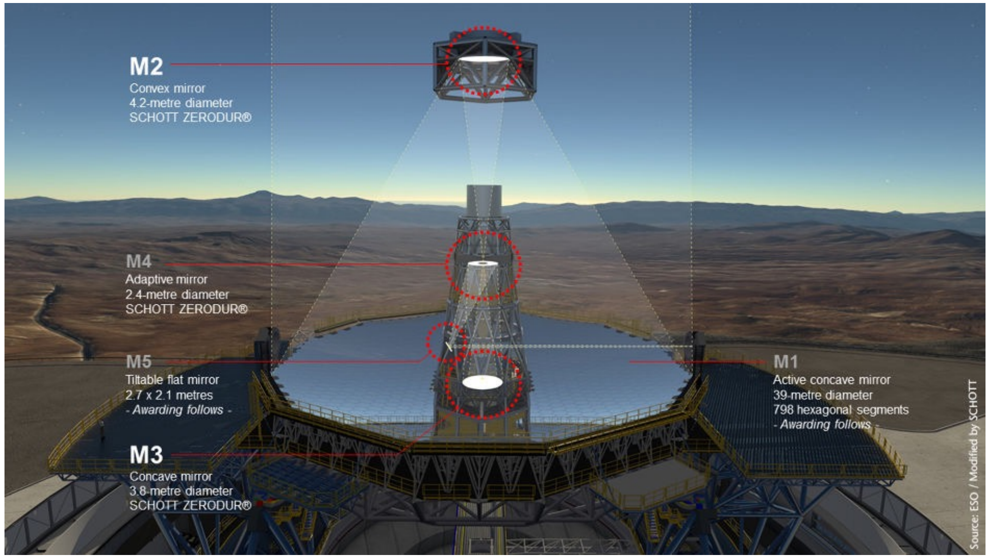
- 39-m primary mirror with 798 1.4-m segments (Keck has 36 segments) and 978m² collecting area (VLT=52m²)

- At Cerro Armazones, 30 km from Paranal; VLT control room to be used

- Active Mirrors part of the telescope (Adaptive M4 & tip-tilt M5)

- **First technical light in 2028**

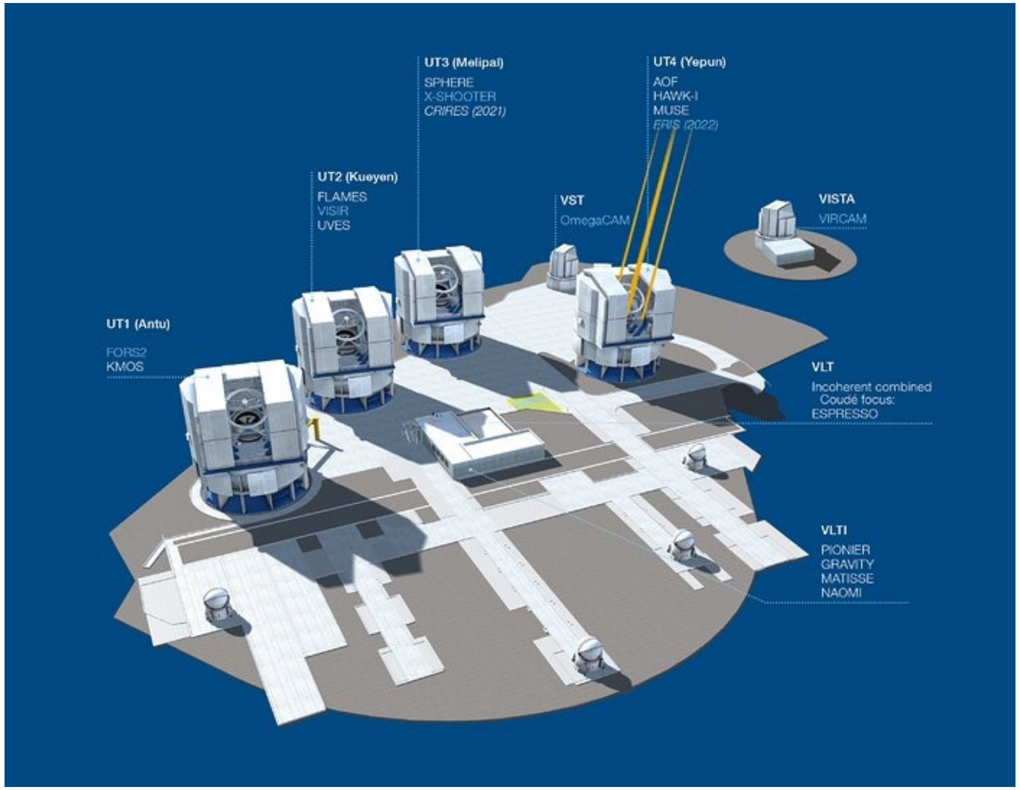
- Three first-light scientific instruments: MICADO, METIS, HARMONI



ESO VLT(I)

<u>Key figures</u> (https://www.eso.org/paranal/)

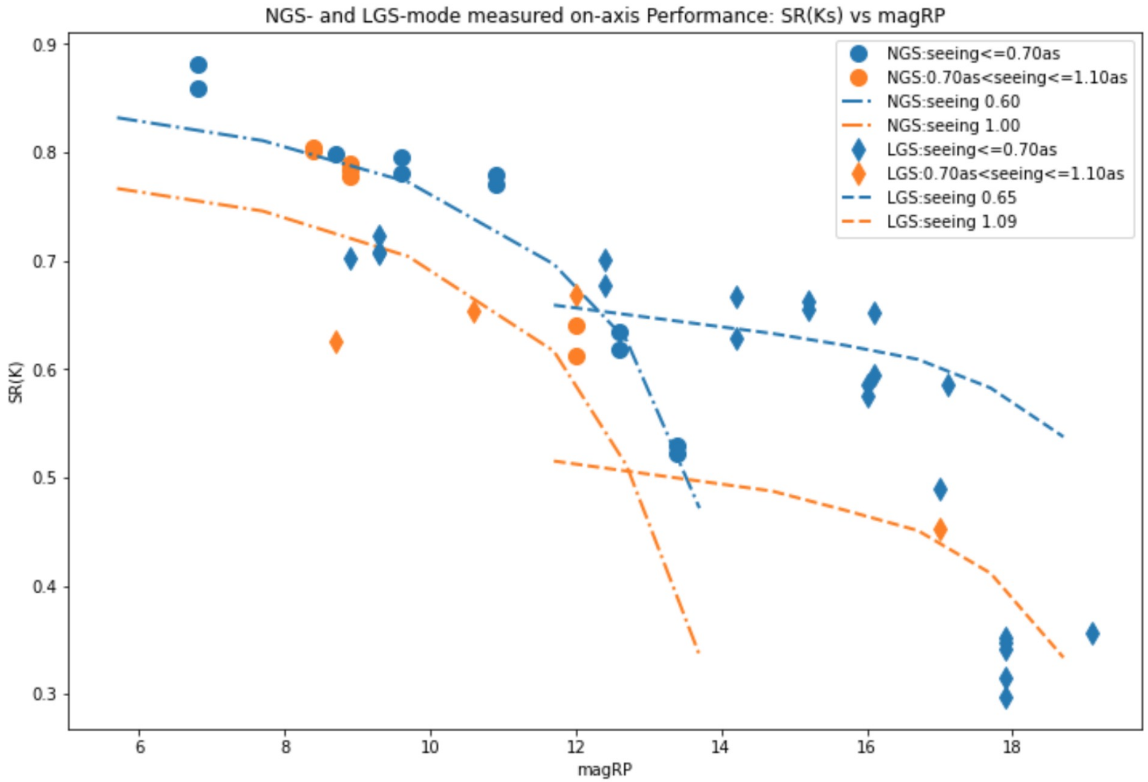
- 8.2-m primary monolithic mirror with $52 m^2$ collecting area each
- 4x UT operating as the VLTI at Paranal
- **First light in 1998**
- Host single-telescope and interferometric instruments
- **Laser Guide Star** for increased sky coverage



ESO VLT(I)

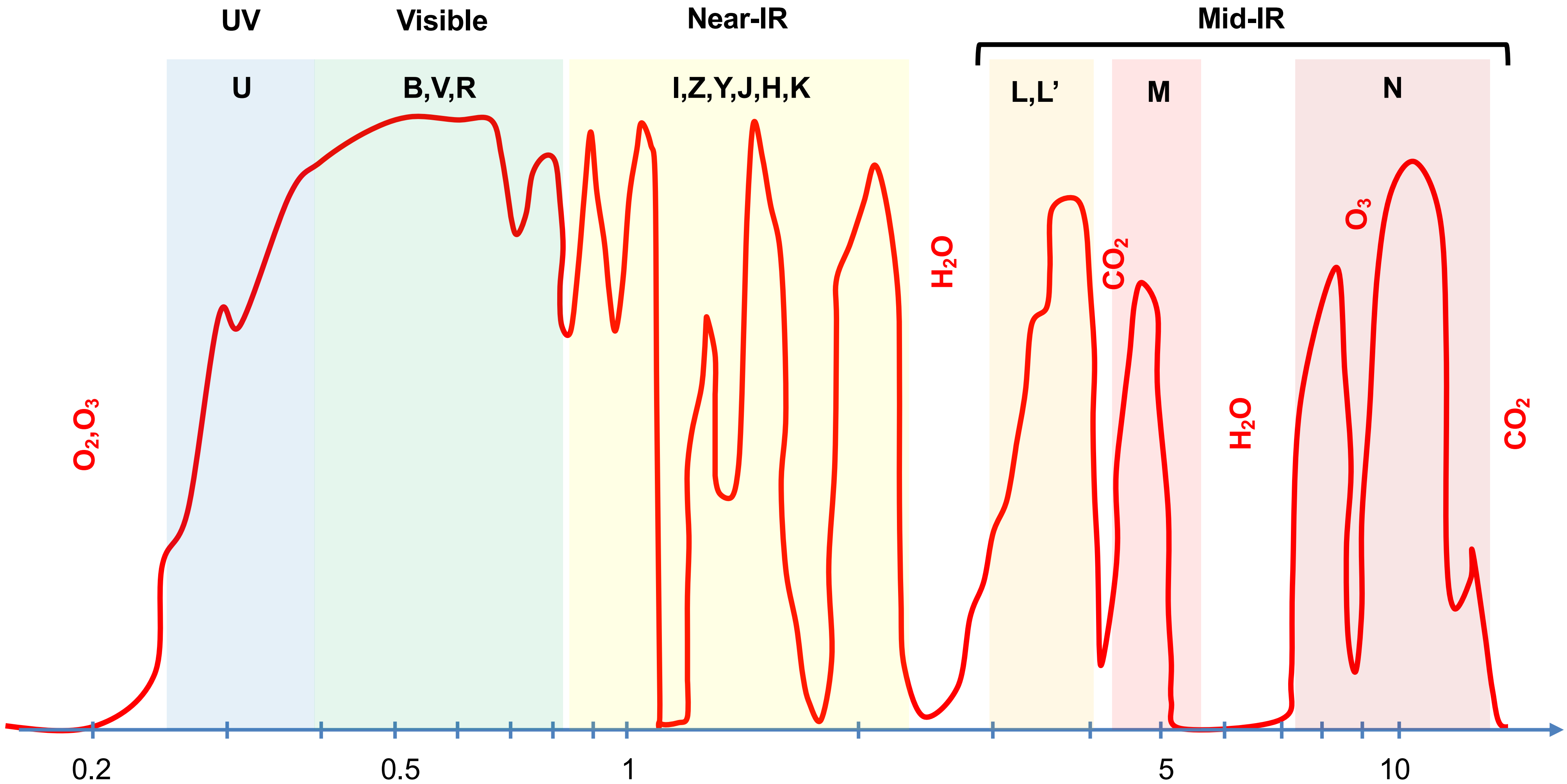
Key figures (https://www.eso.org/paranal/)

- 8.2-m primary monolithic mirror with 52m² collecting area each
- 4x UT operating as the VLTI at Paranal
- **First light in 1998**
- Host single-telescope and interferometric instruments
- **Laser Guide Star** for increased sky coverage



Basics of observational techniques

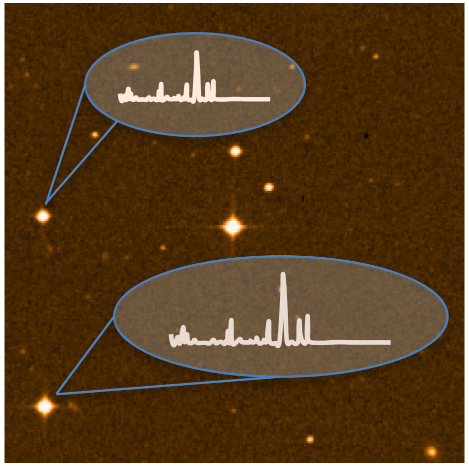
Atmosphere transparency



Basic observing modes

Imaging: spatial structures and properties, (time-resolved) photometry, astrometry

- Field of view
  - $\gtrsim$ 1' (wide field), $\lesssim$ 1' (narrow field) in the VLT/ELT context
  - VISTA delivers **~1.5 deg** diameter FoV (f/3.5 focus), LBT cameras
- Angular resolution λ/D: diffraction (AO) vs. seeing-limited (~0.8")
  - @ λ~2µm, **VLT ~ 50 mas** and **ELT ~ 10 mas**
- Wavelength range with broad- and narrow-band filters



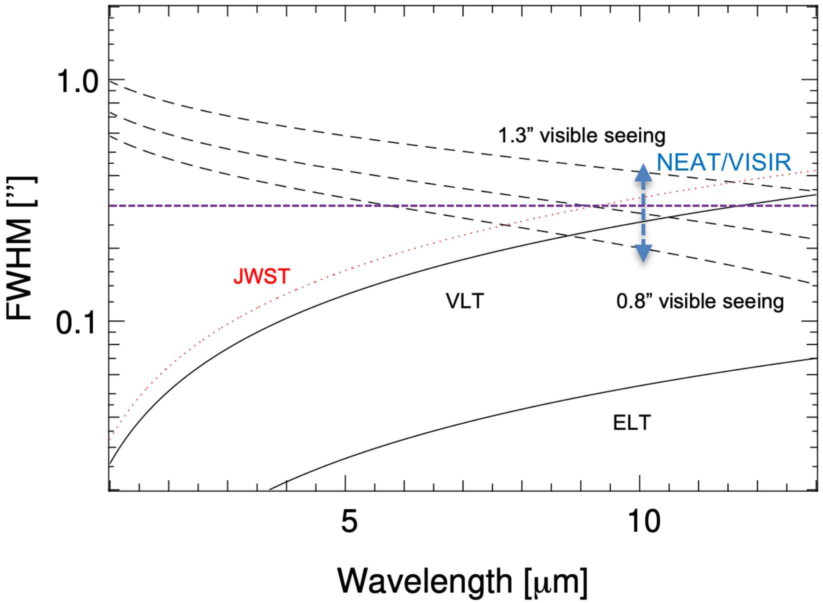
Spectroscopy: composition, gas kinematics, magnetic field

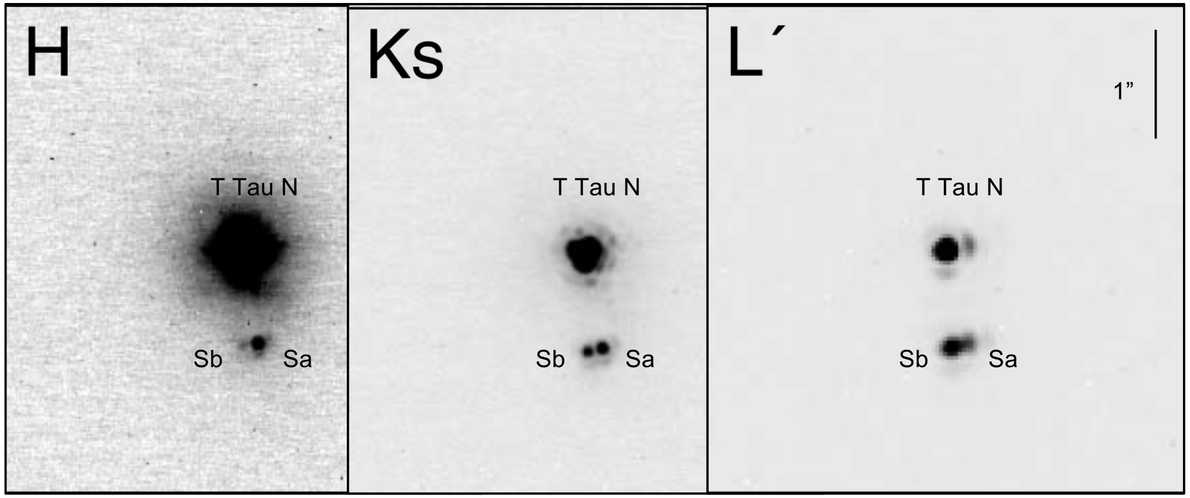
- Spectral resolution
  - low- (R~10^2-10^3), medium- (R~ 10^3 -10^4) high-resolution (R~10^5)
  - Impacts the size of the instrument as R $\propto$ d/D
- Instantaneous spectral coverage
- Spatial multiplexing

Imaging

Diffraction-limited imaging:

- Investigate the close environment of young, e.g., through adaptive optics
- Improve the SNR with DL imaging



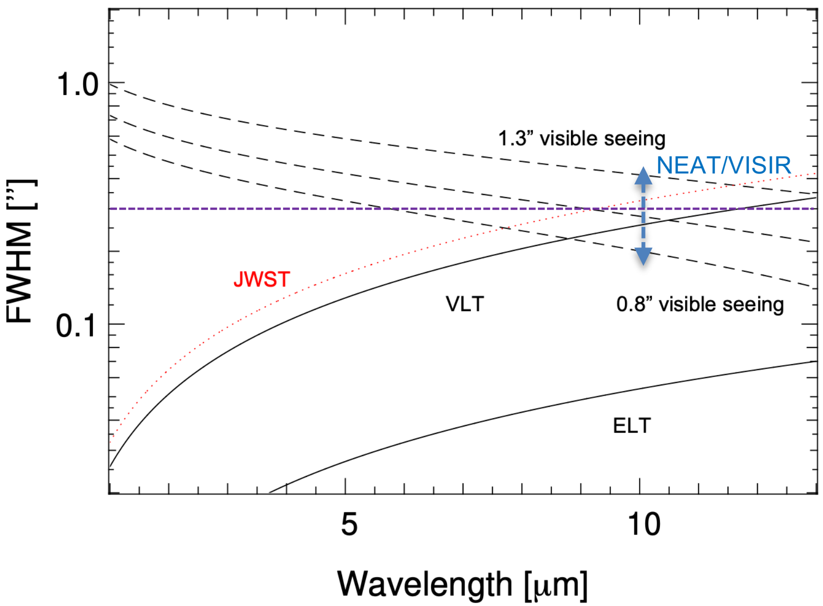


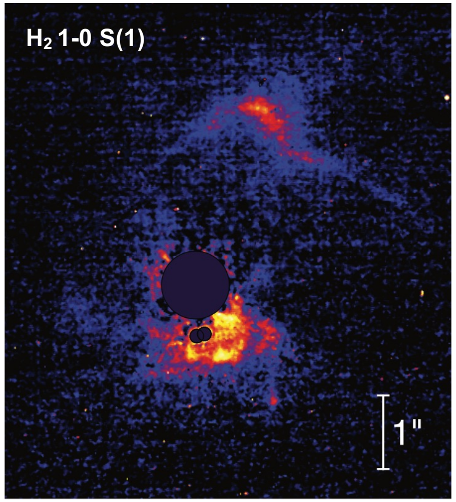
[Herbst 2007]

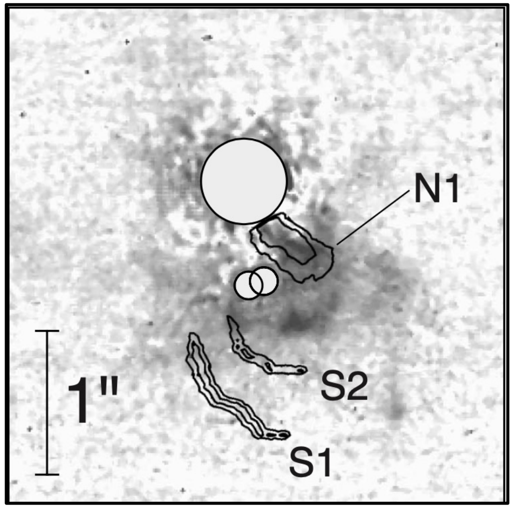
Imaging

Diffraction-limited imaging:

- Investigate the close environment of young, e.g., through adaptive optics
- Improve the SNR with DL imaging





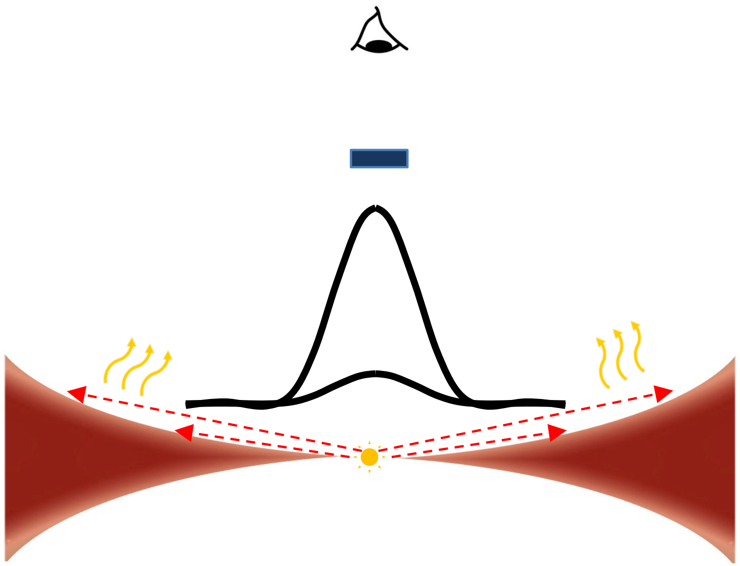


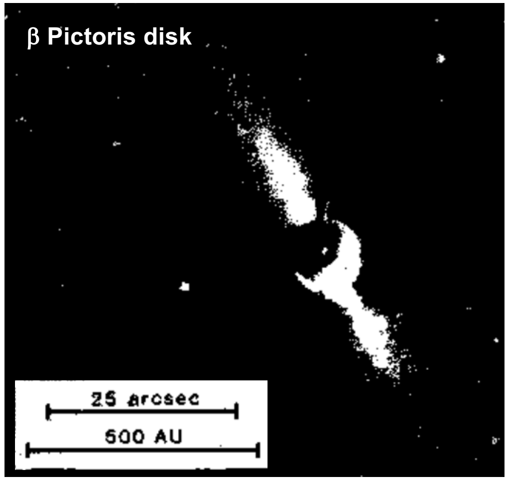
[Herbst 2007]

Imaging

High-contrast imaging:

- Scattered-light imaging of circumstellar disk
- Probing the spatial distribution of small grains in the disk atmosphere



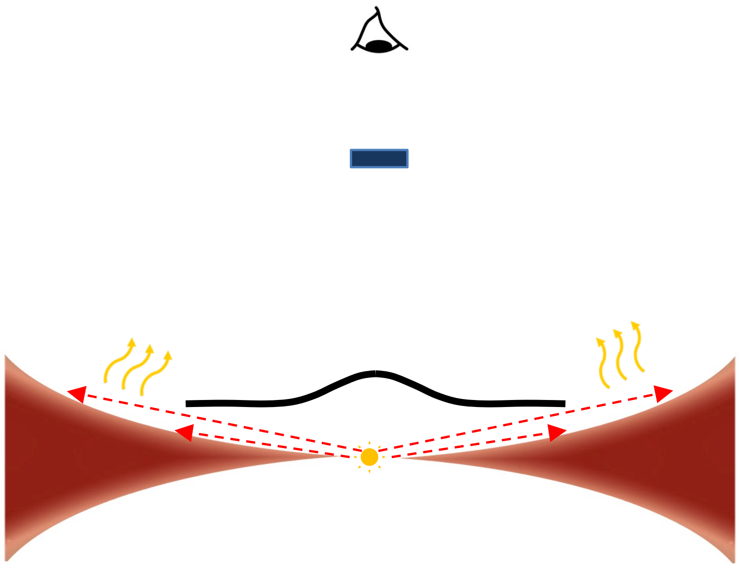


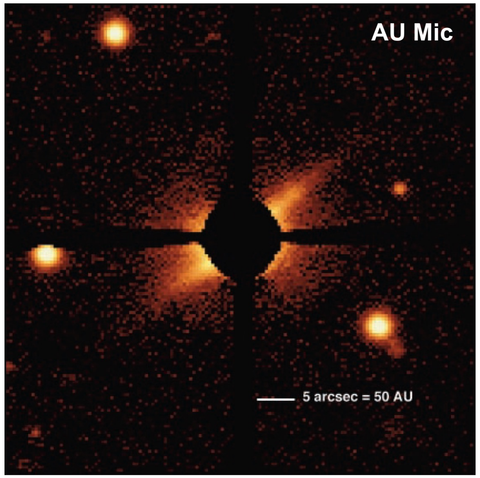
[Smith and Terrile 1984]

Imaging

High-contrast imaging:

- Scattered-light imaging of circumstellar disk
- Probing the spatial distribution of small grains in the disk atmosphere



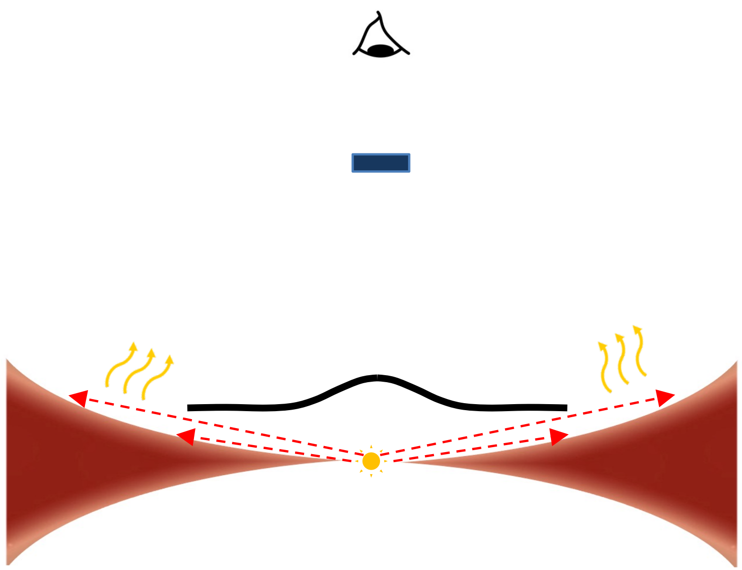


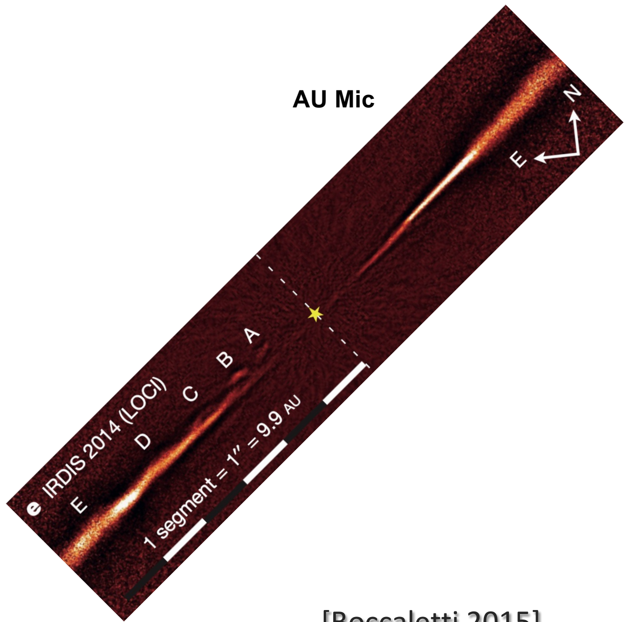
[Kalas 2004]

Imaging

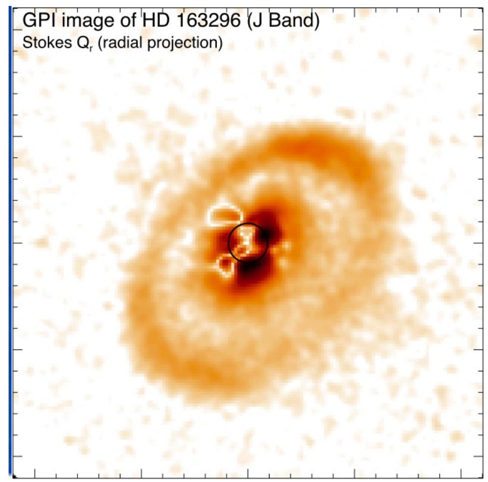
High-contrast imaging:

- Scattered-light imaging of circumstellar disk
- Probing the spatial distribution of small grains in the disk atmosphere





[Boccaletti 2015]

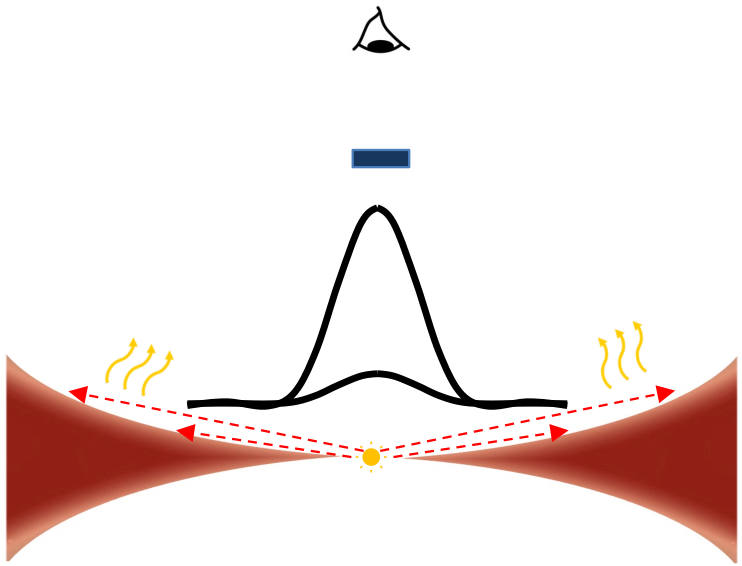


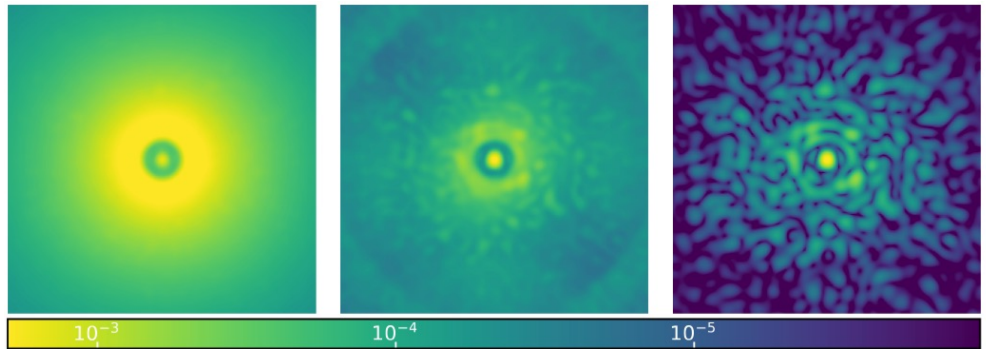
[Wahhaj 2015]

Imaging

High-contrast imaging:

- Scattered-light imaging of circumstellar disk
- Probing the spatial distribution of small grains in the disk atmosphere



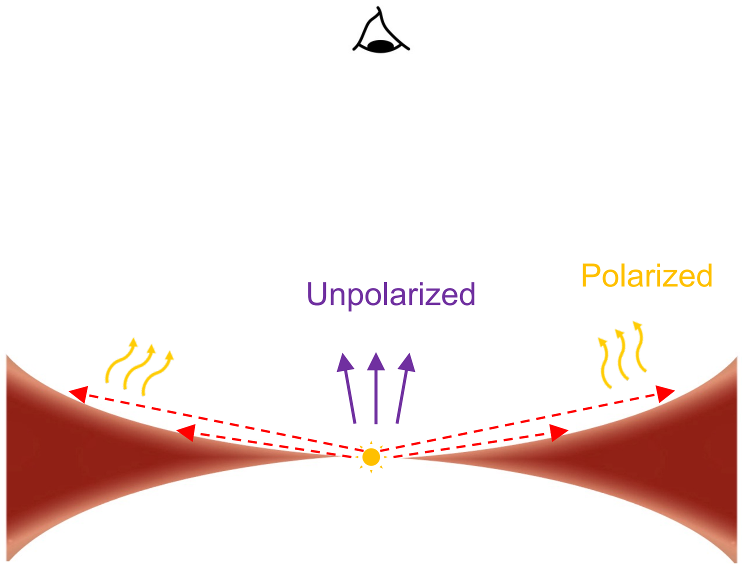


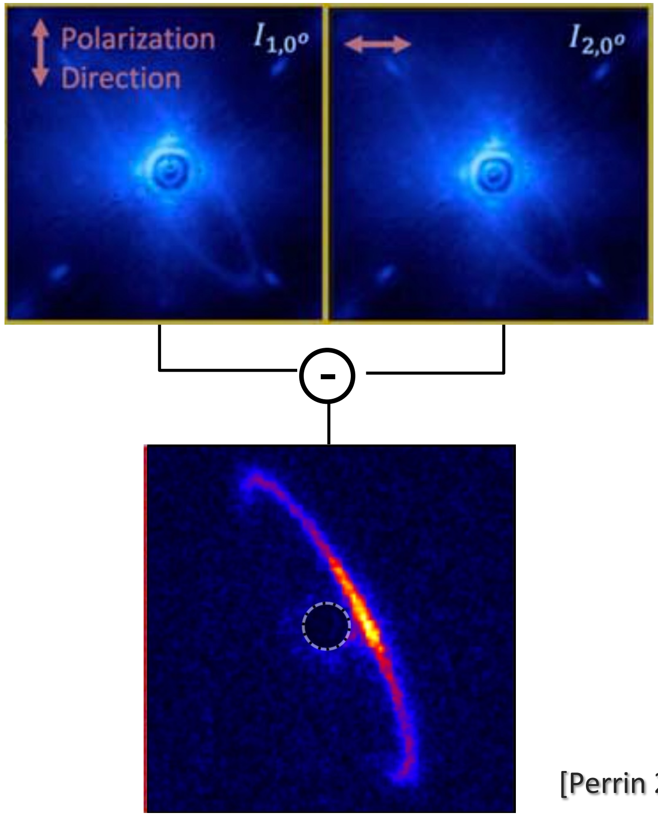
[Galicher 2023]

Imaging

High-contrast imaging:

- Combination with **polarimetry** and **pupil-tracking**
- Polarimetric differential imaging, angular differential imaging, spectral differential imaging





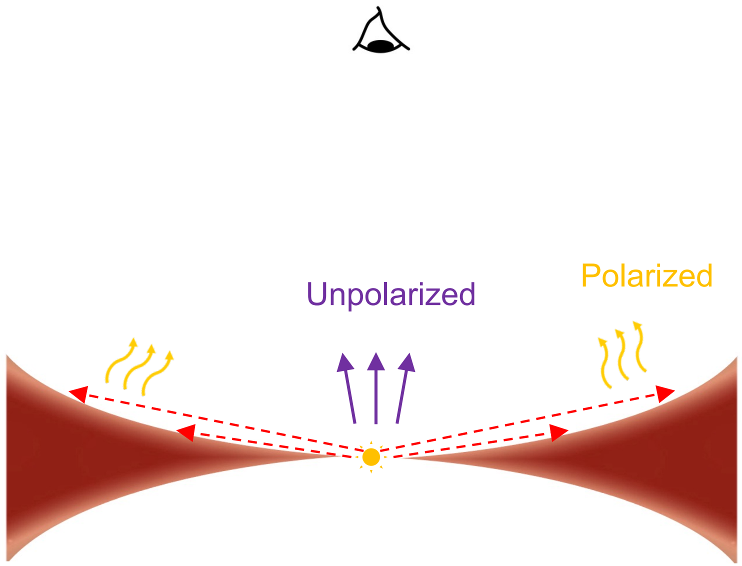
[Follette 2023]

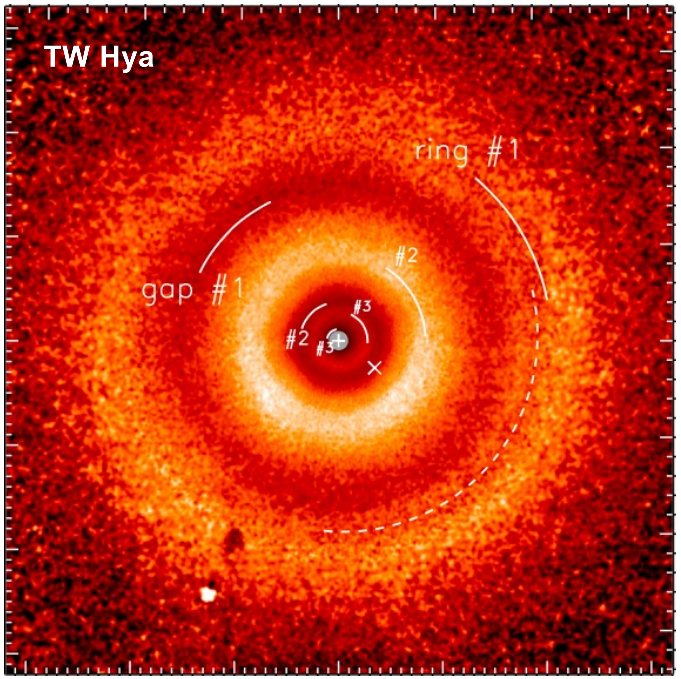
[Perrin 2015]

Imaging

High-contrast imaging:

- Combination with **polarimetry** and **pupil-tracking**
- Polarimetric-differential imaging, angular differential imaging, spectral differential imaging



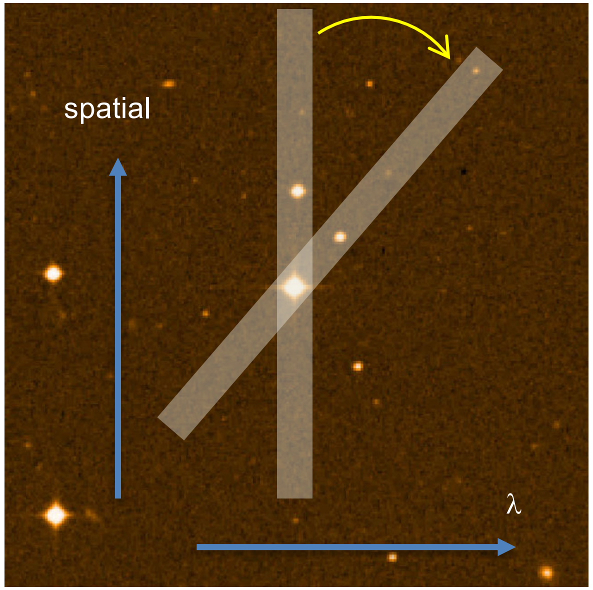


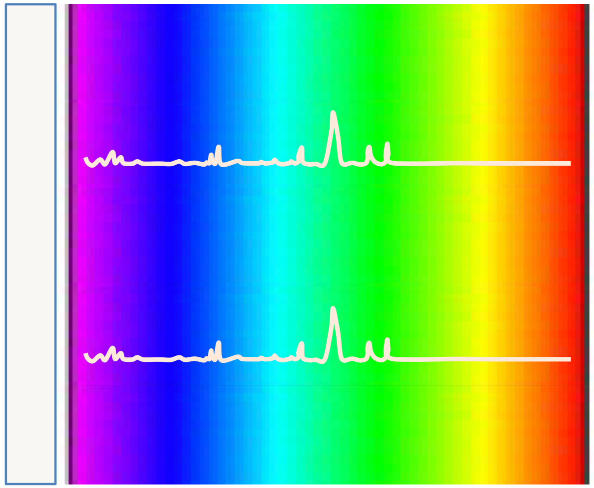
[Van Boekel 2017]

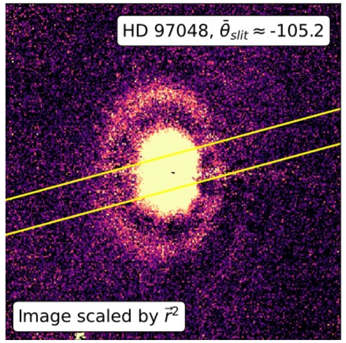
Spectroscopy

Slit spectroscopy:

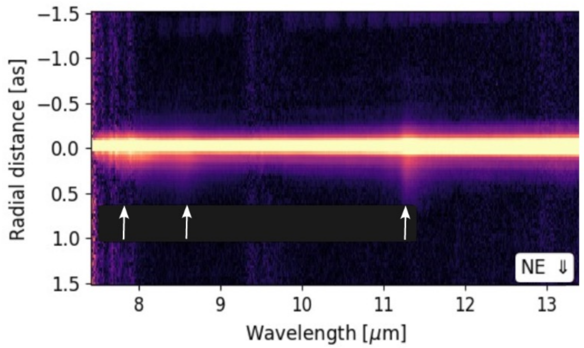
- Spatial information along the slit ("spatially resolved spectroscopy")
- In the mid-infrared, one can "*chop*" **in** or **out** of the slit to remove the thermal background
- Slit width: compromise between SNR and spectral resolution







Solid state bands

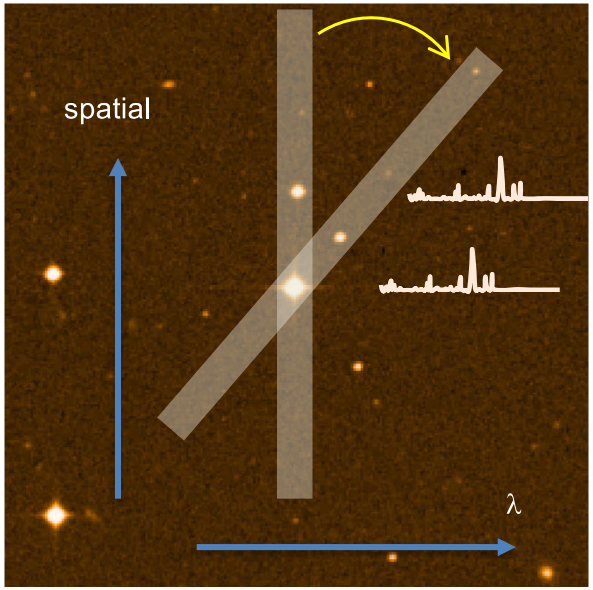


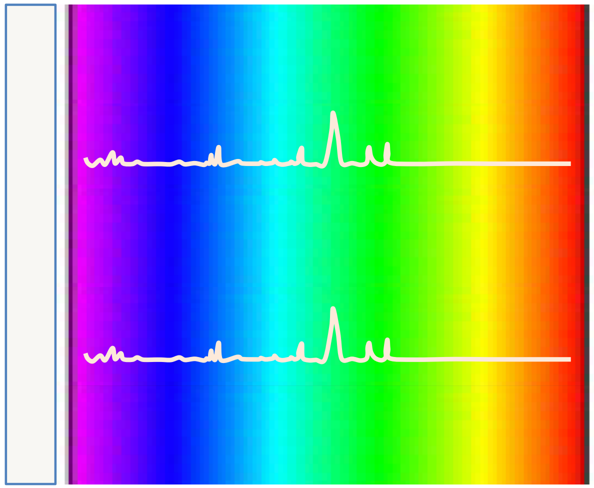
[Yoffe 2023]

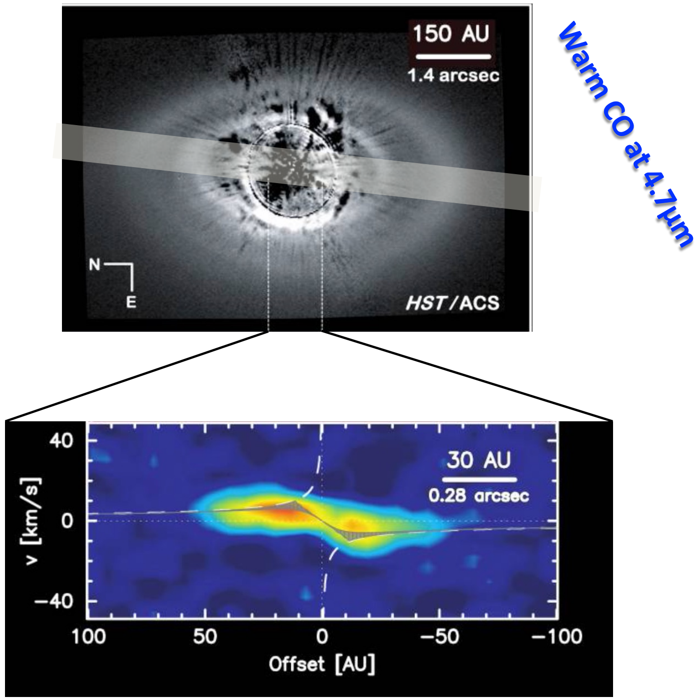
Spectroscopy

Slit spectroscopy:

- Spatial information along the slit ("spatially resolved spectroscopy")
- In the mid-infrared, one can "*chop*" **in** or **out** of the slit to remove the thermal background
- Slit width: compromise between SNR and spectral resolution





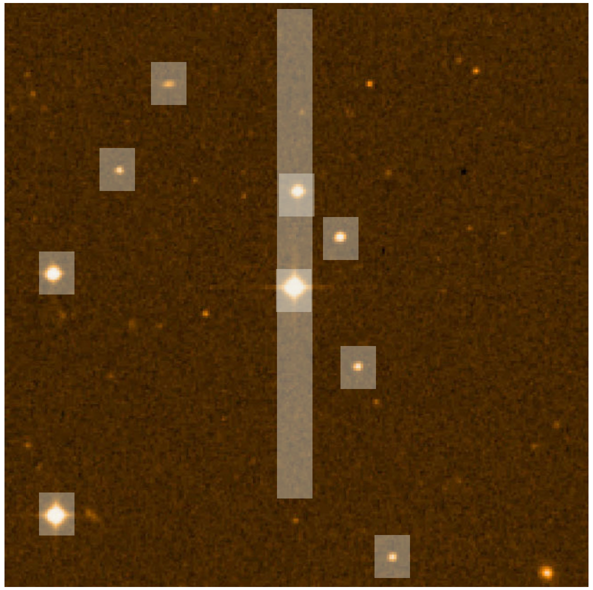


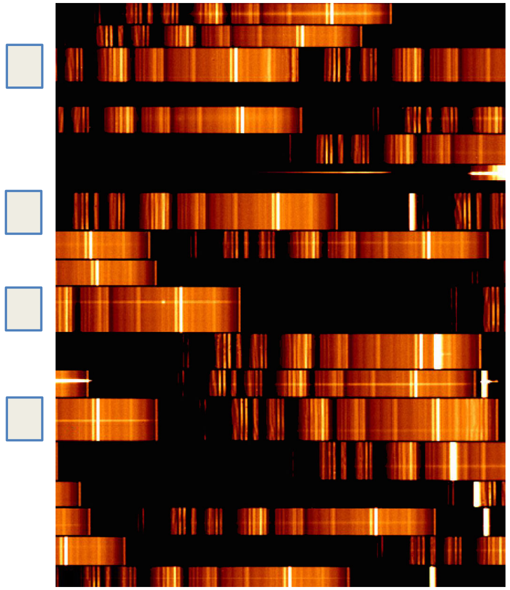
[Goto 2006]

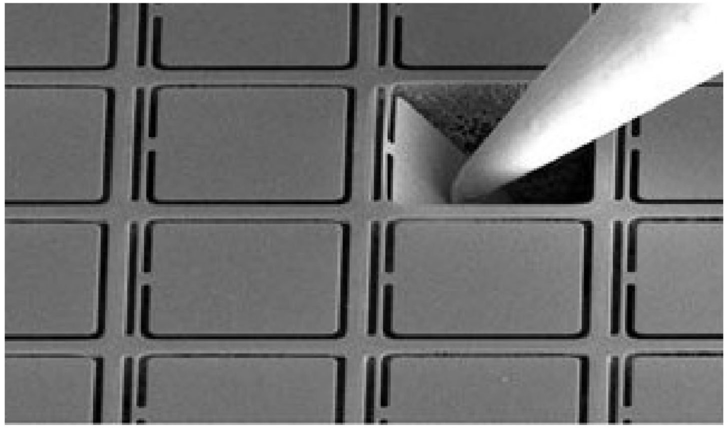
Spectroscopy

Multiplexed spectroscopy

- Spatially multiplexed long-slit spectroscopy
  - Multi-slit spectrograph
  - Fiber multi-object spectrographs
  - Slitless spectrographs





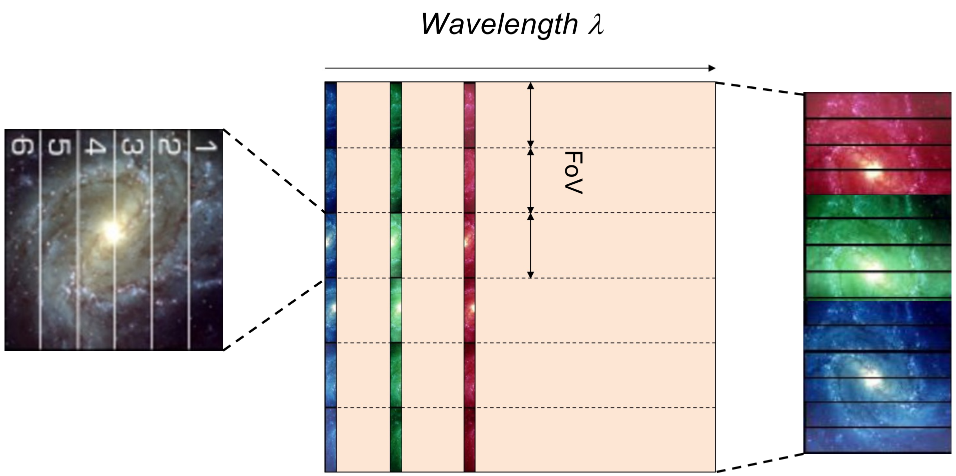


Microshutter array on NIRSpec ©ESA/NASA/JPL

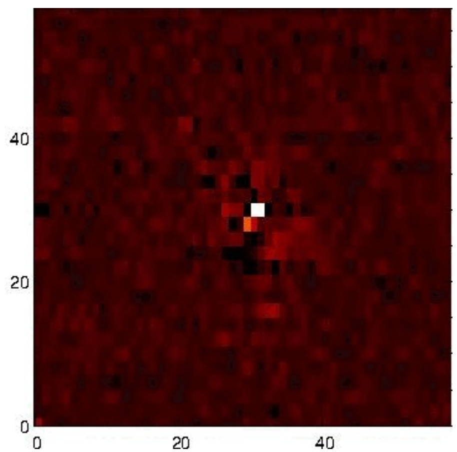
Spectroscopy

3D Imaging spectroscopy

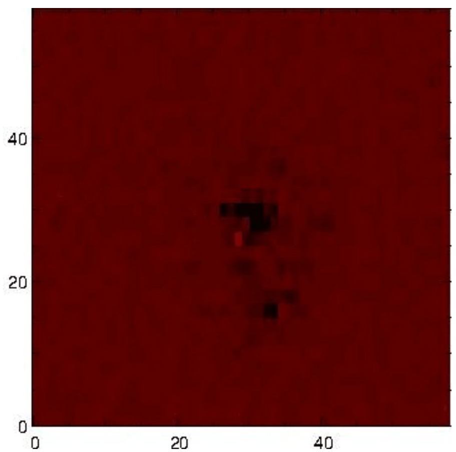
- 2D to 3D **data cube** reformatting: “image vs wavelength”, Spatial **multiplexing** (spectral structures, extended sources)
- Typically, **slicer-based IFUs** have smaller **field of view** due to **slicing**
  - E.g., NACO imager has ~28x28” FoV - SINFONI 0.8”x0.8”
- Different flavors of Integral Field Spectrographs (slicers, lenslet arrays, fibres)



T Tau, H_2 outflow, 2.12 μm



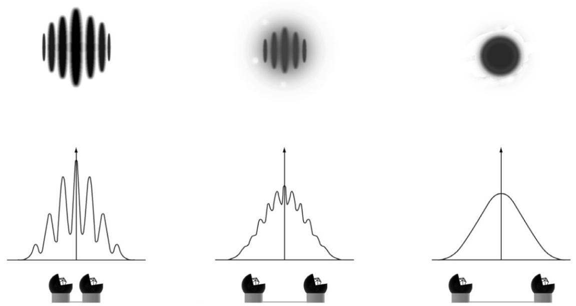
T Tau, Brg line, 2.16 μm

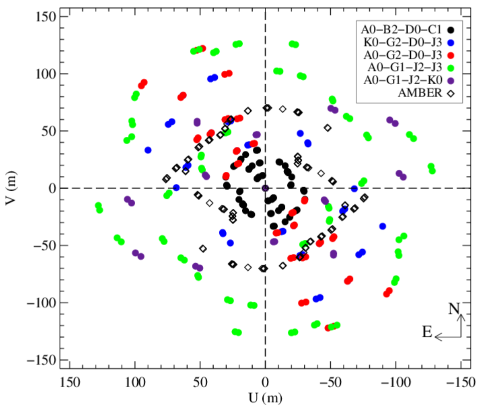


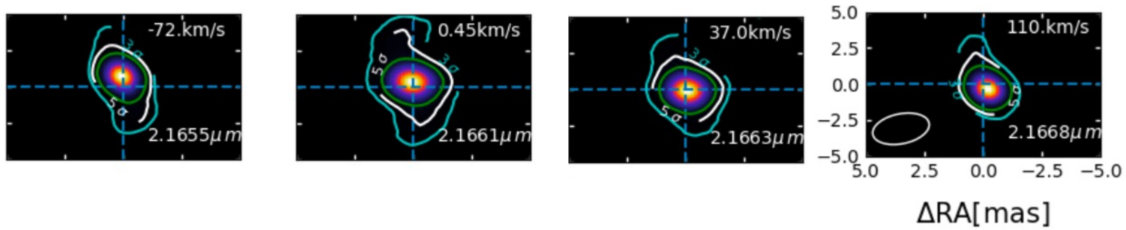
Spectro-interferometry

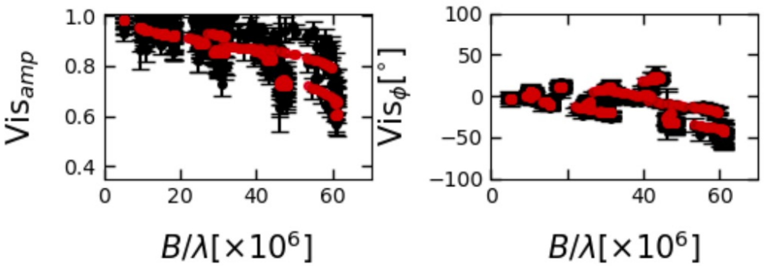
IR long-baseline interferometric spectro-imaging:

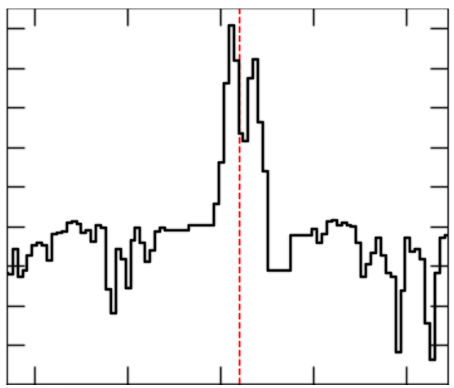
- Angular resolution set by telescope separation (principle of ALMA, VLA, VLBI)
- Measures the spatial coherence of the source
- Mostly “no-field” technique: effective FoV is the point-spread function of the single-dish telescope







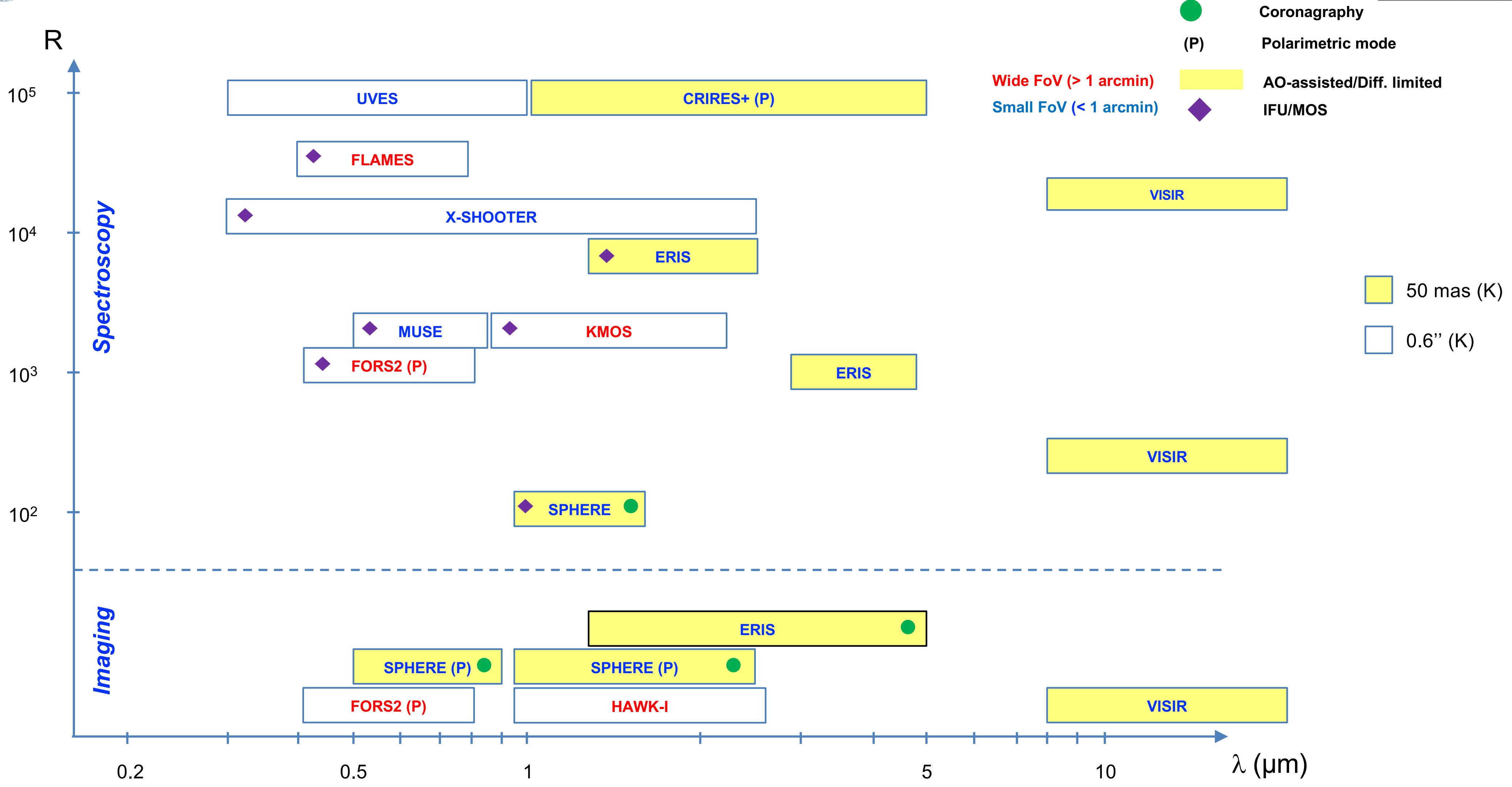




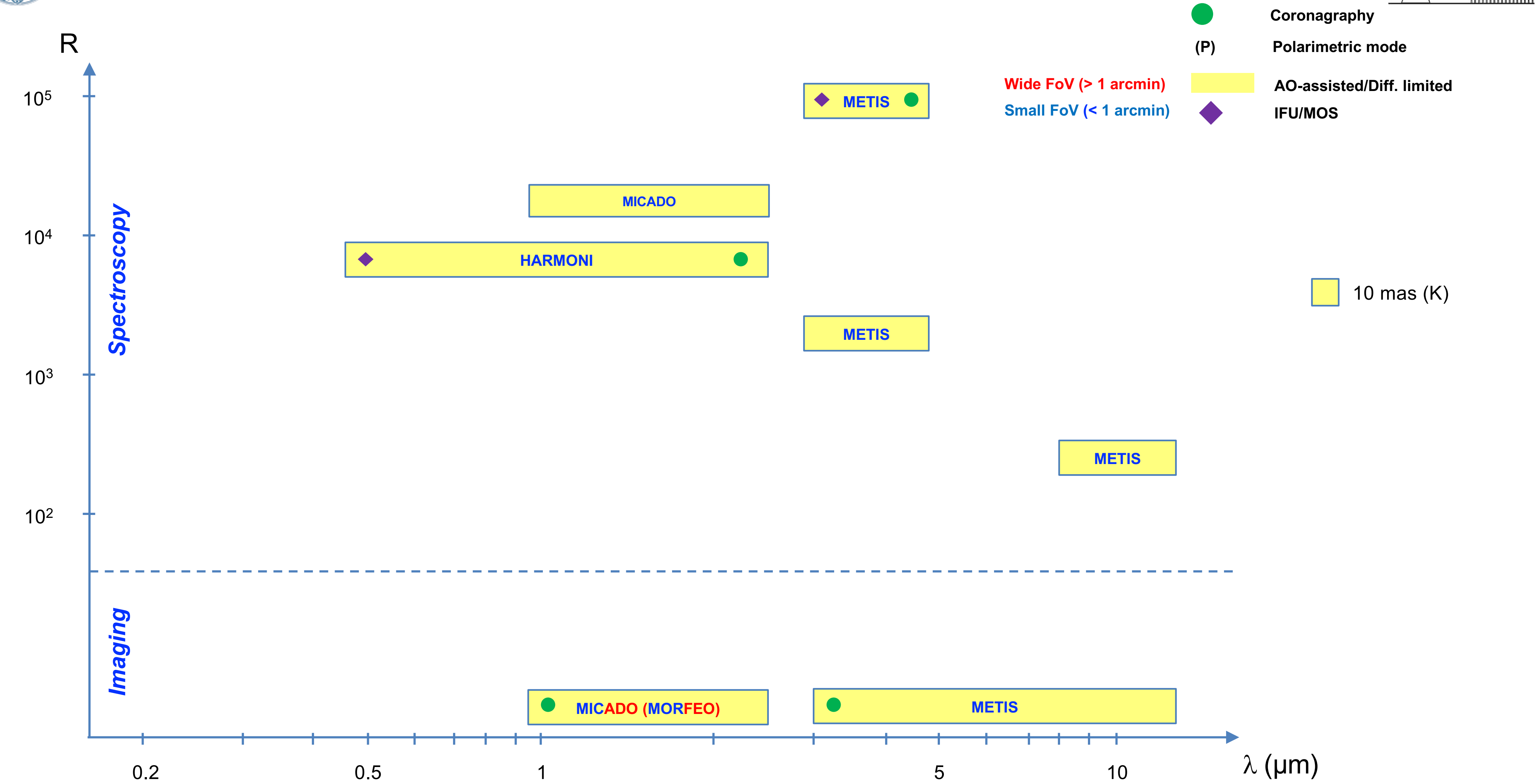
[Bouarour 2024]

Comparative contribution of infrastructures

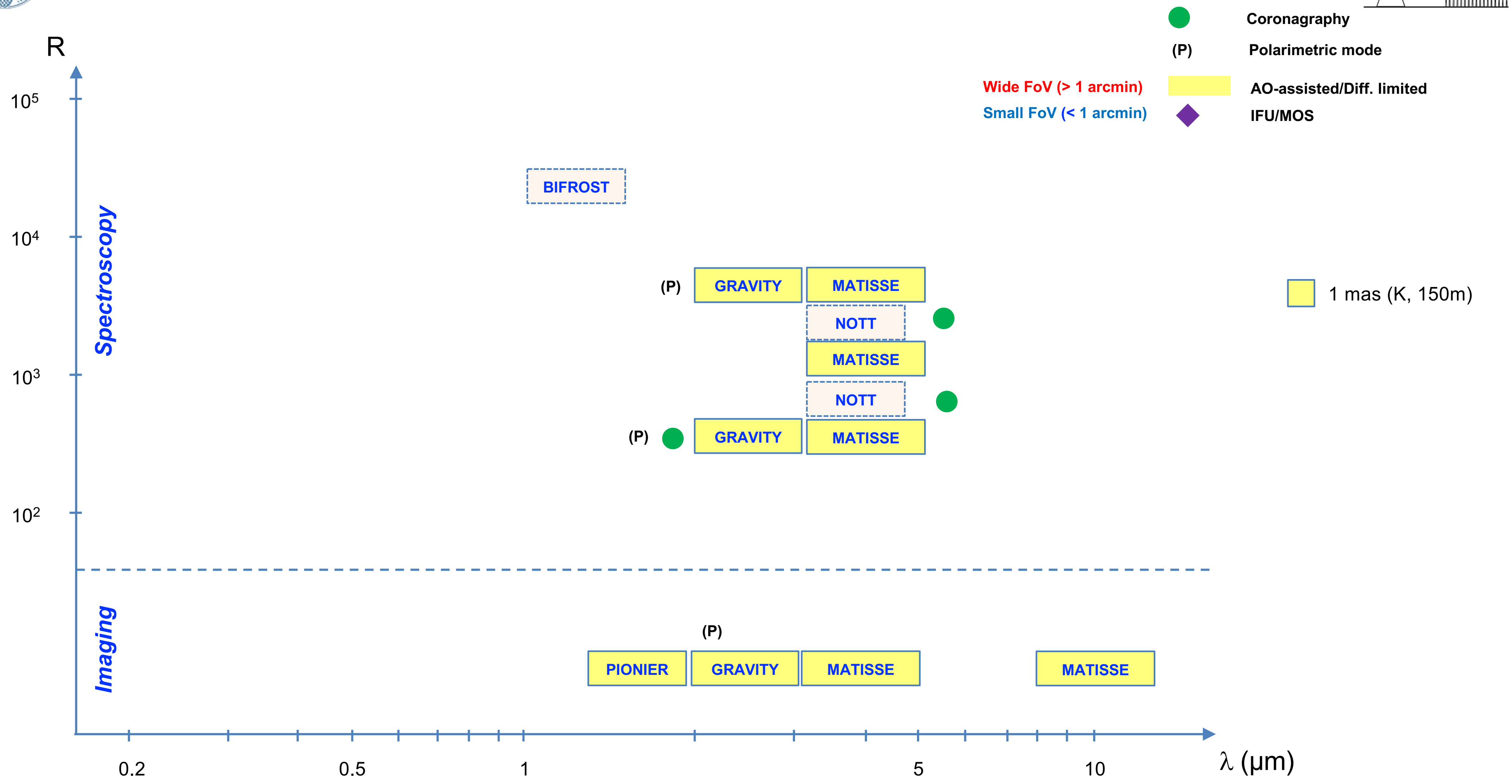
Overview of Paranal instrumentation



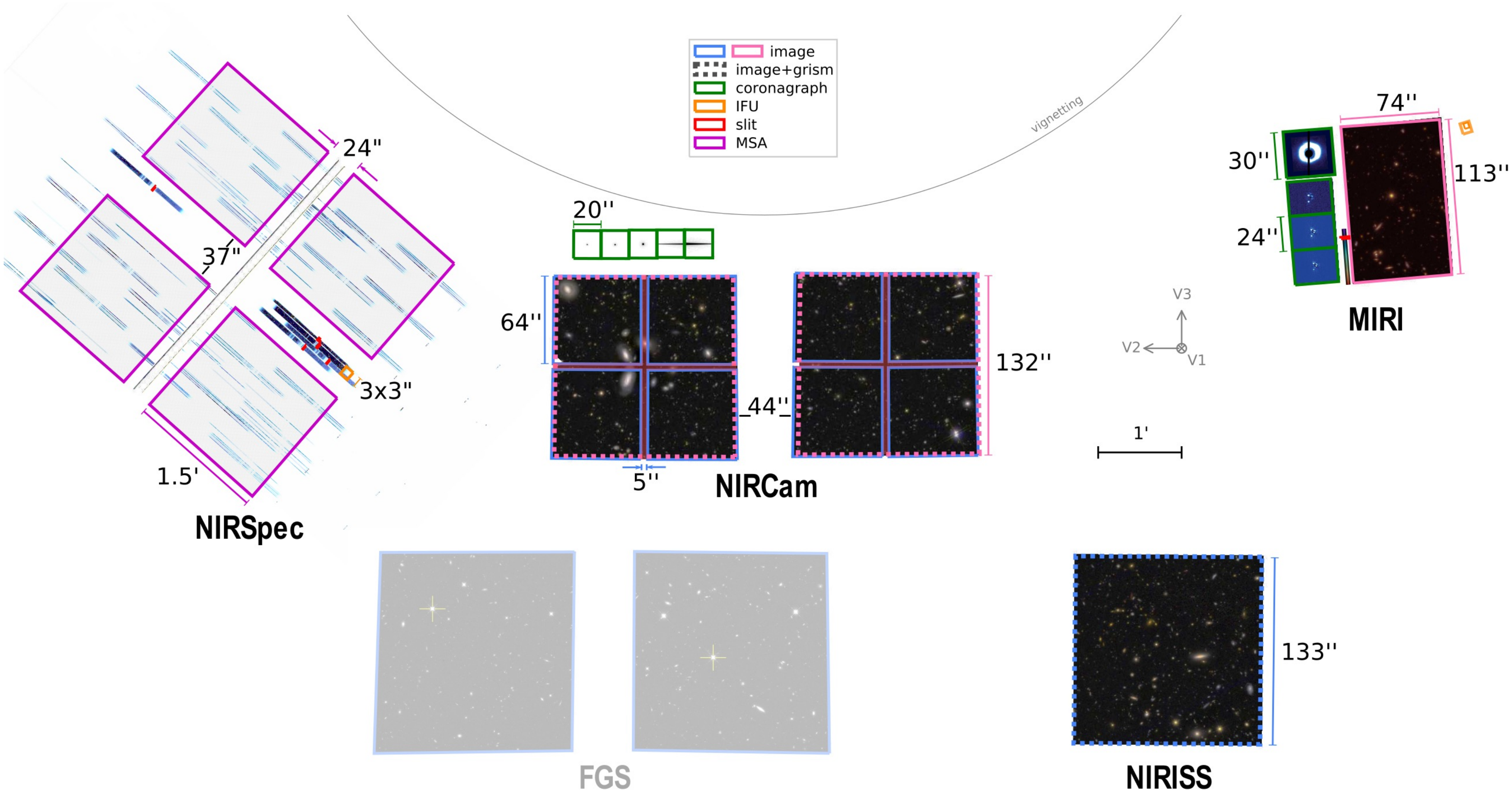
Extremely Large Telescope



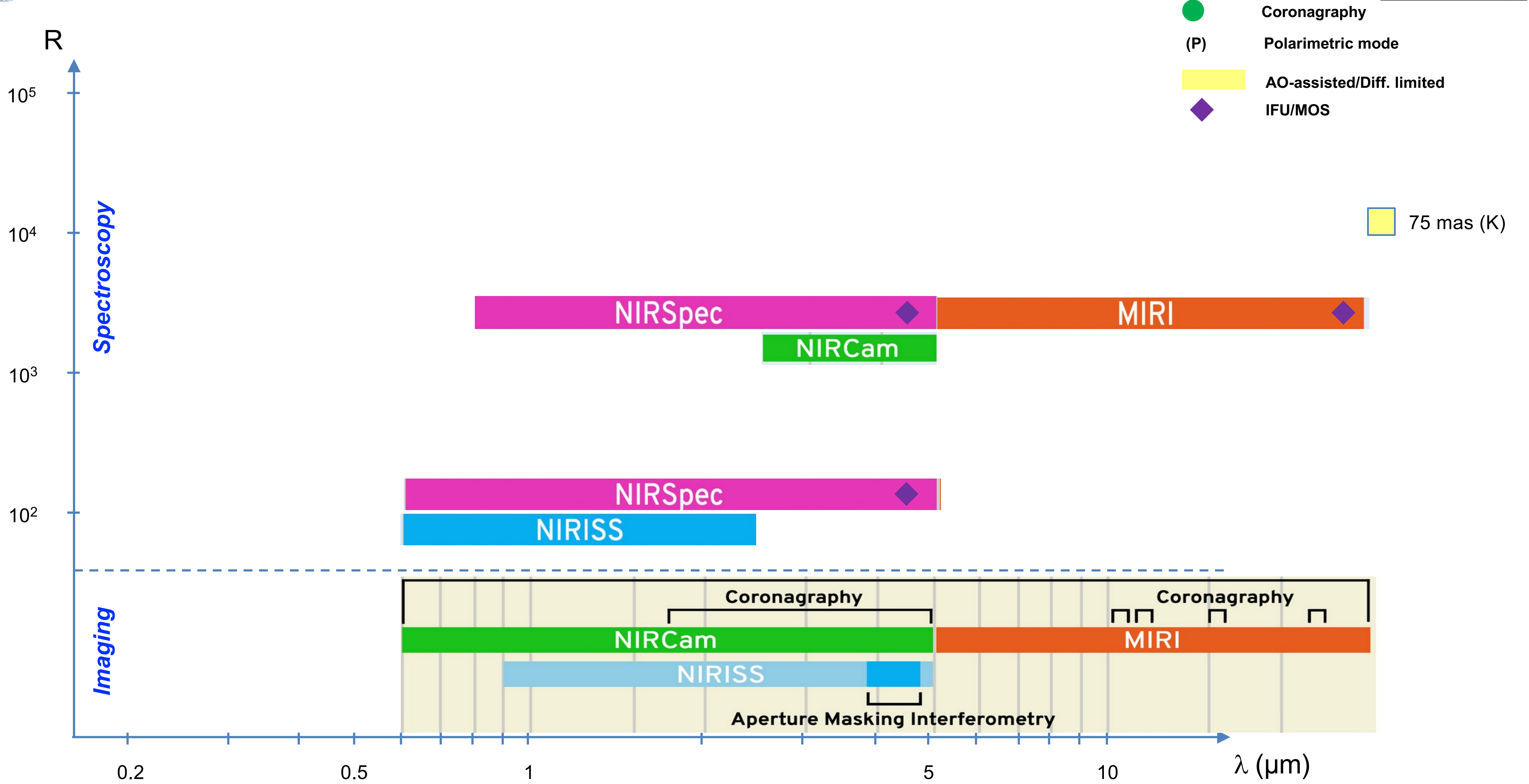
Very Large Telescope Interferometer



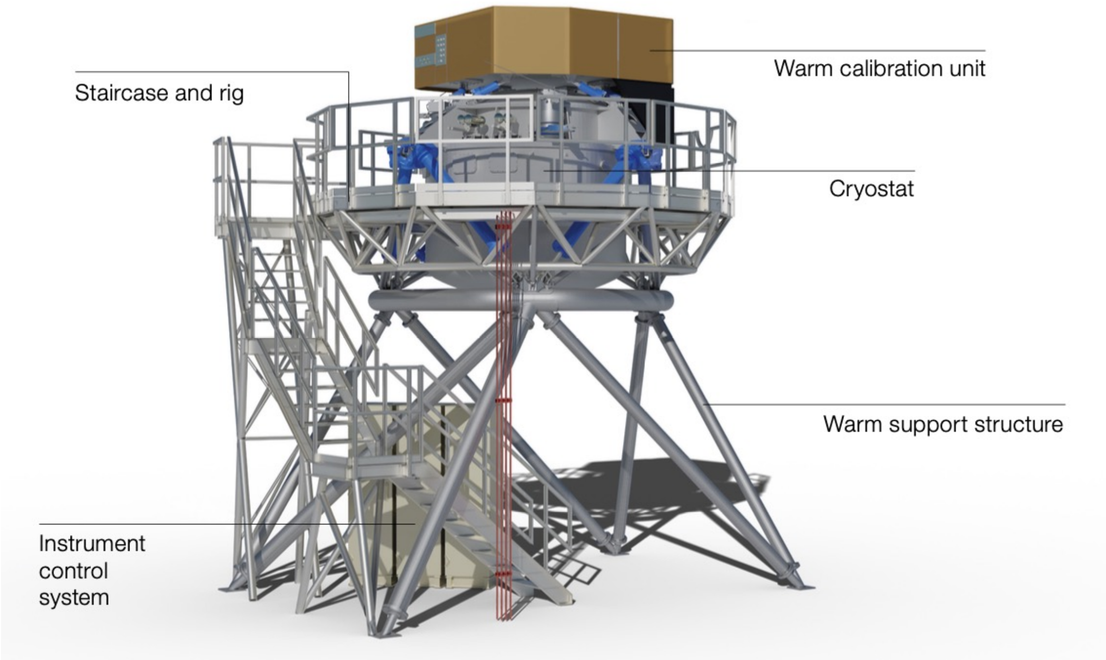
JWST instrumentation

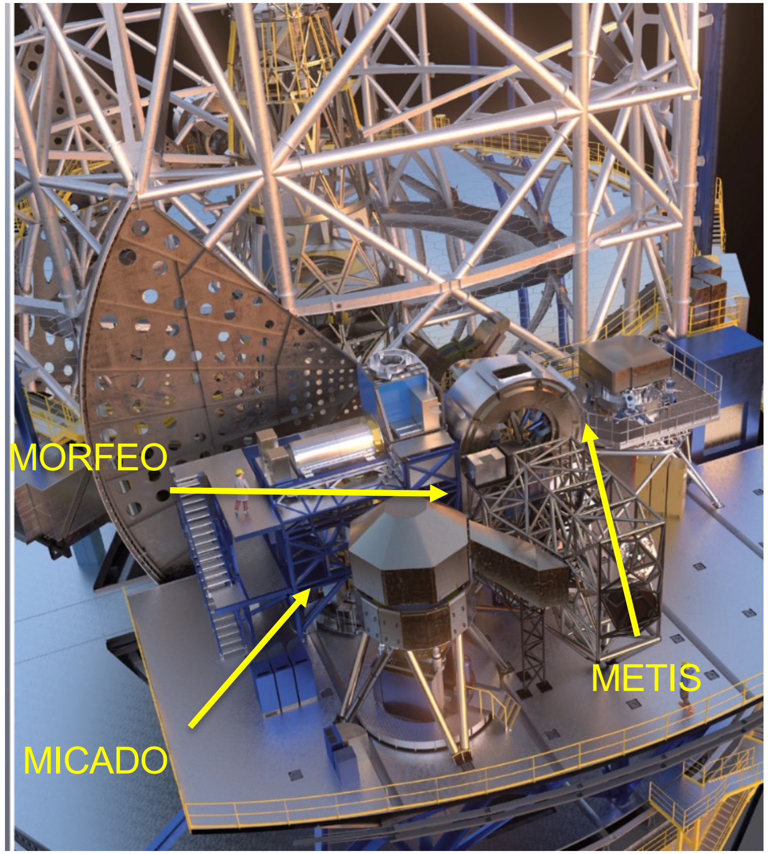


JWST instrumentation



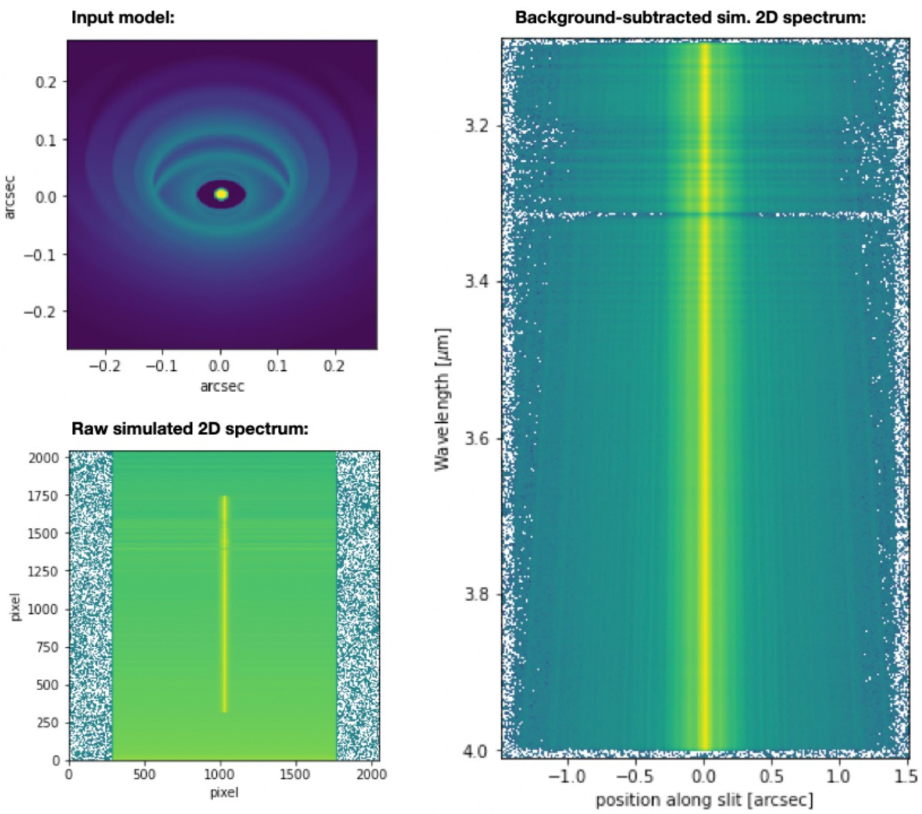
The example of METIS/ELT





Synthetic observations

SimMETIS



Instrument Reference Database

Navigation

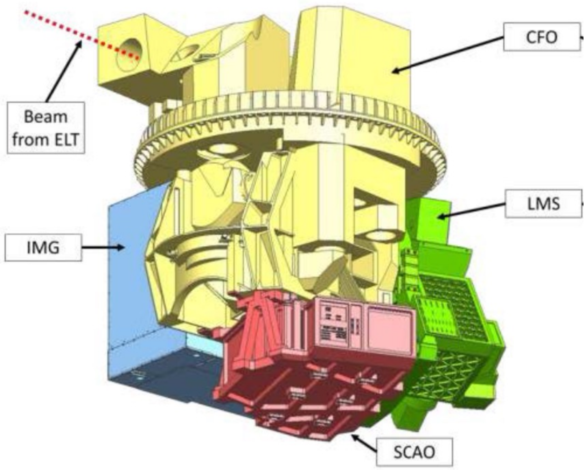
Quick search

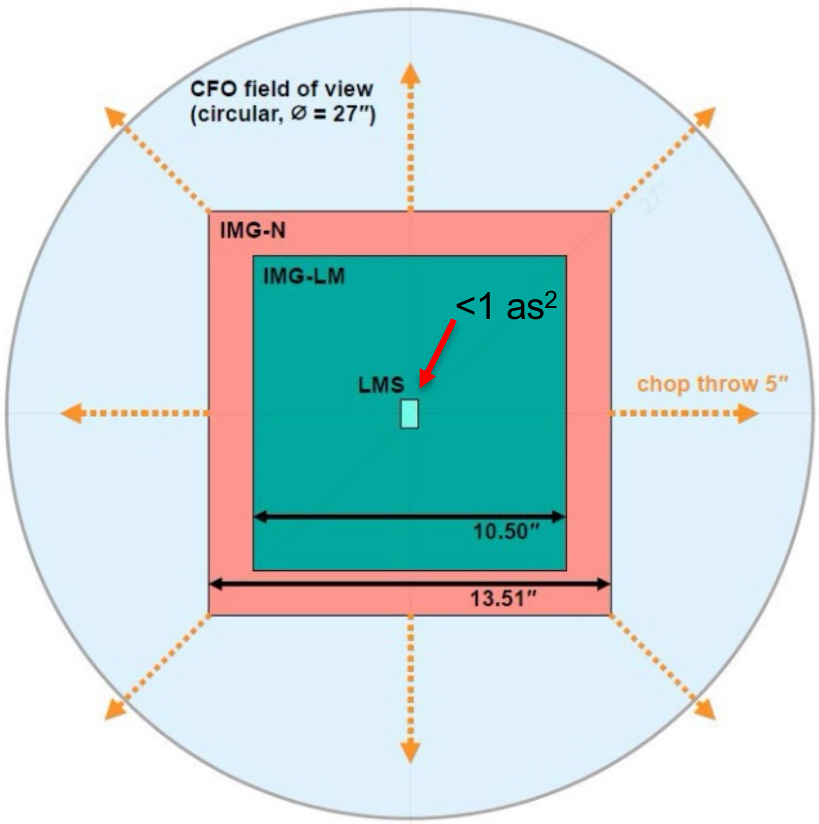
Go

Introduction

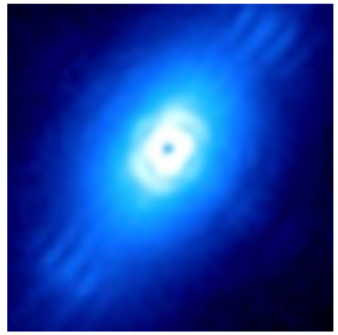
The METIS data simulator is based on the generic simulator software Scopesim, a descendant of the older SimCado/SimMETIS interface. METIS itself is handled as an instrument package that contains configuration files for the various instrument modes as well as data files describing the components of the instruments. The new METIS data simulator currently supports the imaging and long-slit modes. The LM-band high-resolution IFU (LMS) mode will be offered soon.

The example of METIS/ELT





Fomalhaut @ 15 μm

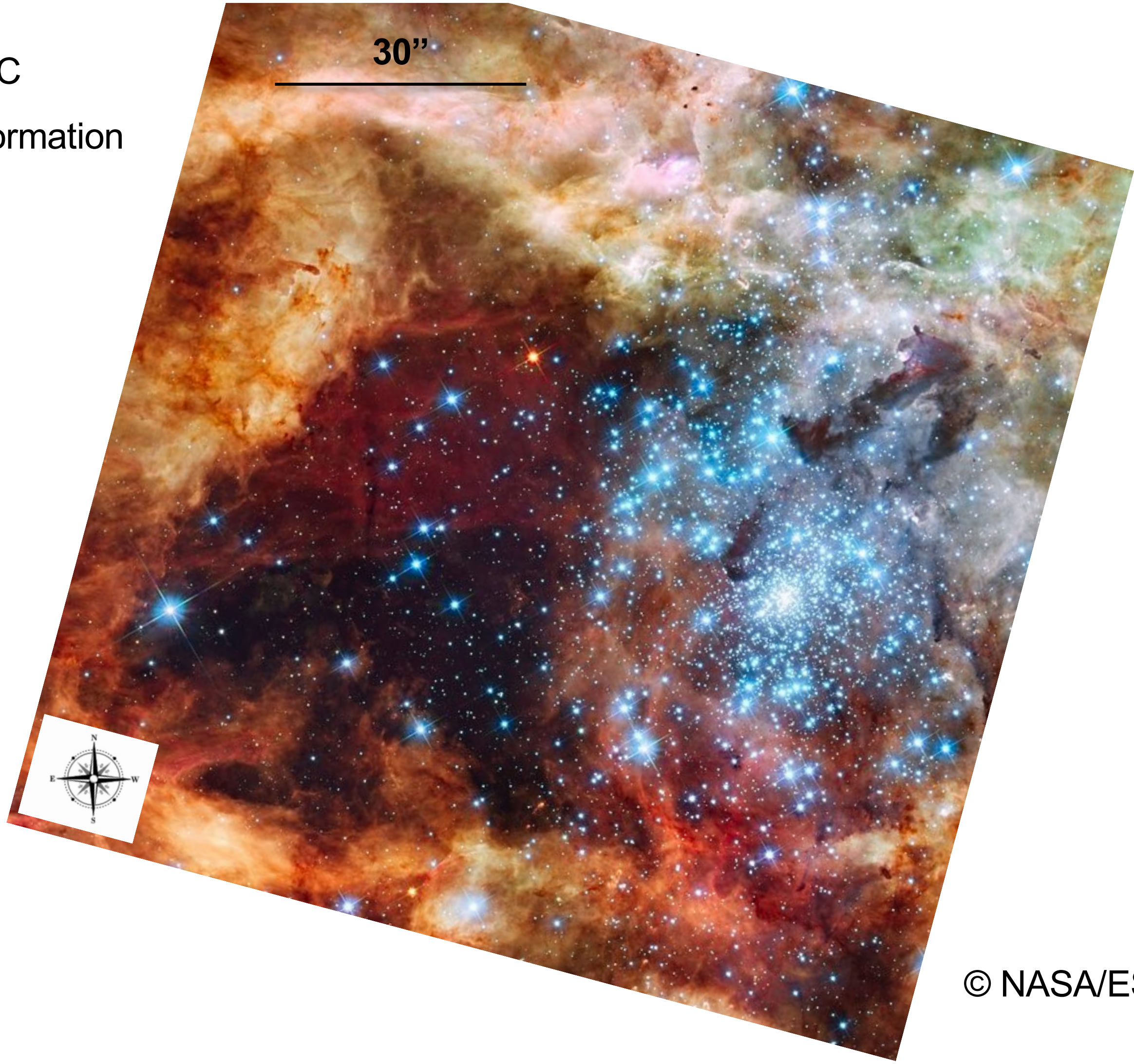


[Gaspar 2022]

Comparative performances: sensitivity and resolution

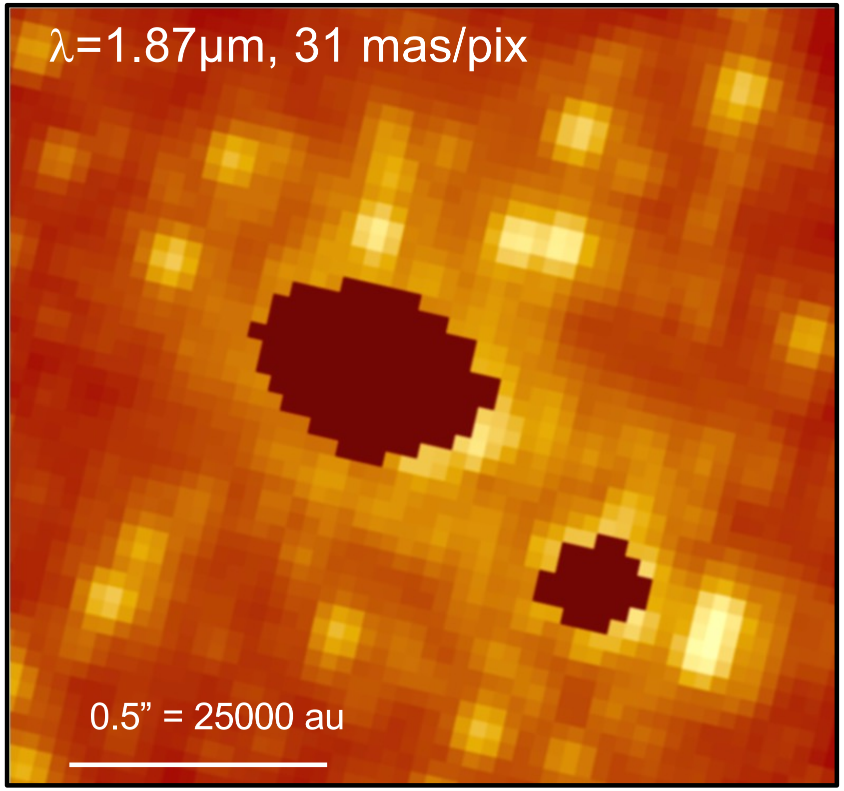
Example: JWST and VLT resolution

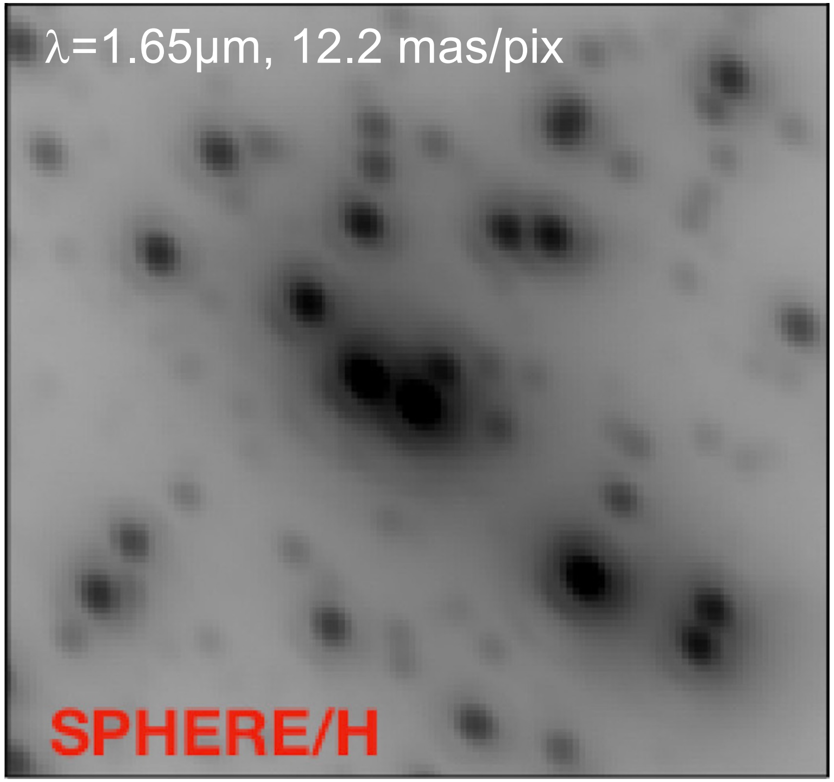
- 30 Doradus in the LMC
- Site of massive star formation



Example: JWST and VLT resolution

- SPHERE/IRDIS in the H band (PSF FWHM ~ 55 mas)
- JWST/NIRCAM in ~H band





[Khorrami 2017]