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## SolSysELTs2022 part I: METIS

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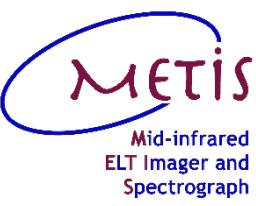
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# METIS

Mid-infrared  
ELT Imager and  
Spectrograph

Bernhard Brandl  
(U Leiden / TU Delft) – April 28<sup>th</sup>, 2022

# 1<sup>st</sup> Generation scientific Instruments on the ELT

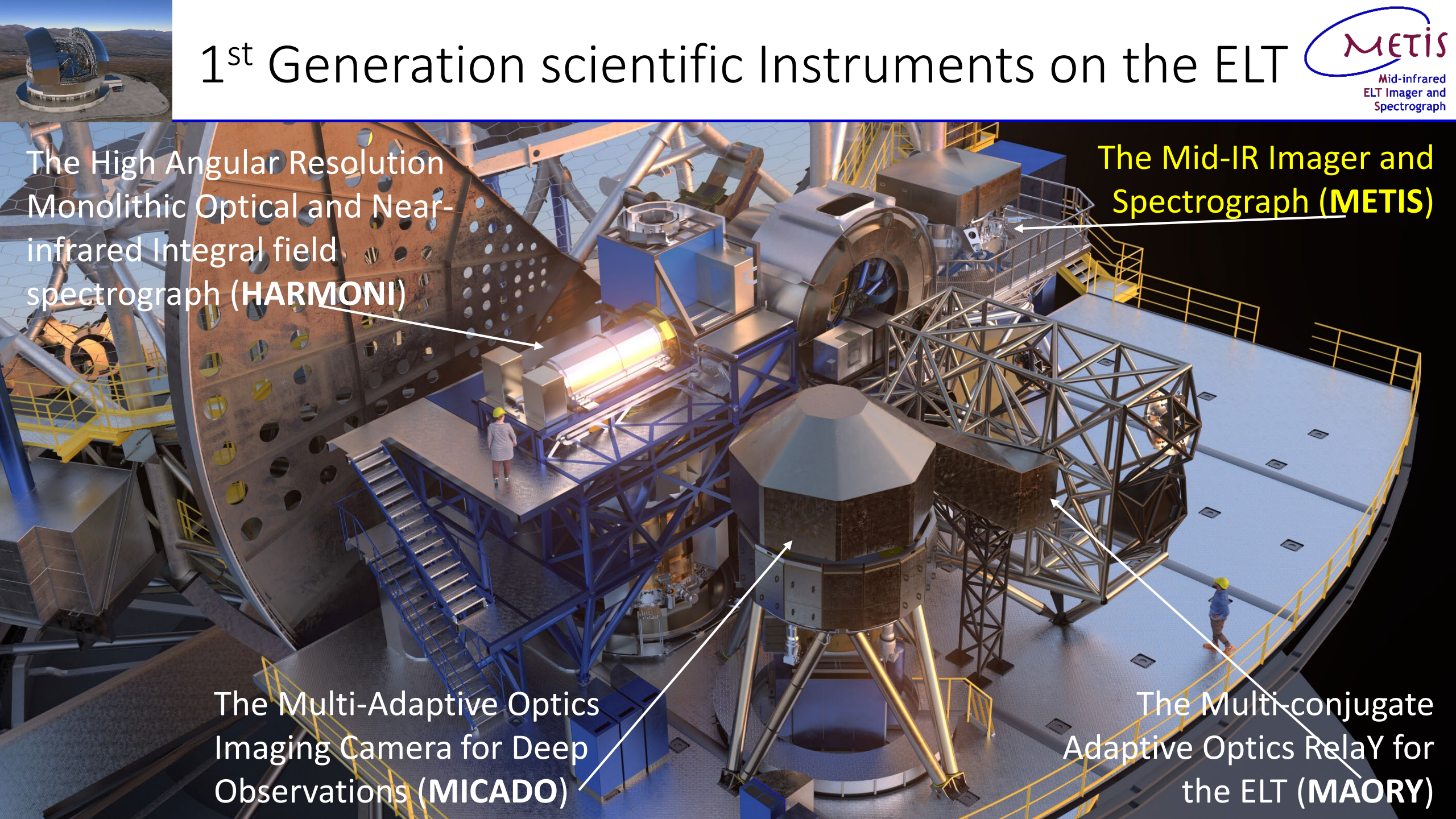


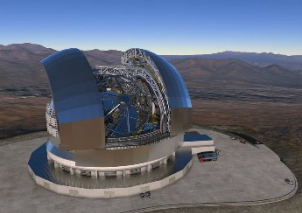
The High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (**HARMONI**)

The Mid-IR Imager and Spectrograph (**METIS**)

The Multi-Adaptive Optics Imaging Camera for Deep Observations (**MICADO**)

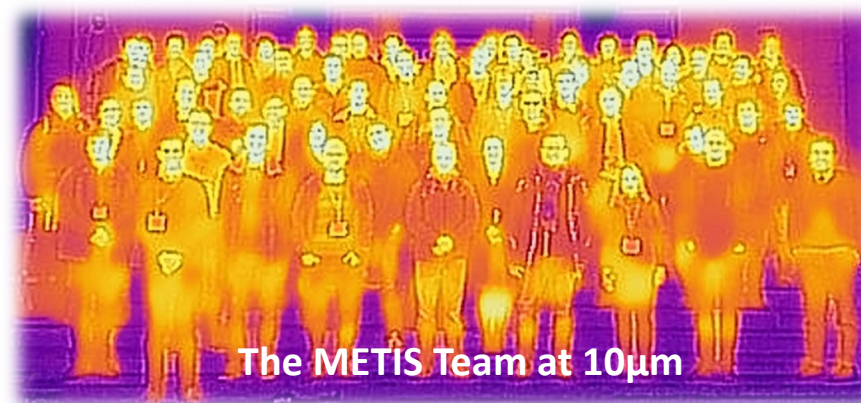
The Multi-conjugate Adaptive Optics Relay for the ELT (**MAORY**)





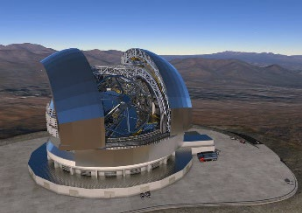
# Project Overview

- One of three 1<sup>st</sup>-generation ELT science instruments → 1<sup>st</sup>-light ~2028
- Consortium of **12 international partner institutions** (10 European, 1 US, 1 Taiwan) + ESO
- Project milestones:
  - Kick-off 2015
  - PDR 2019
  - FDR (2021 & 2022)
  - AIT 2024–27

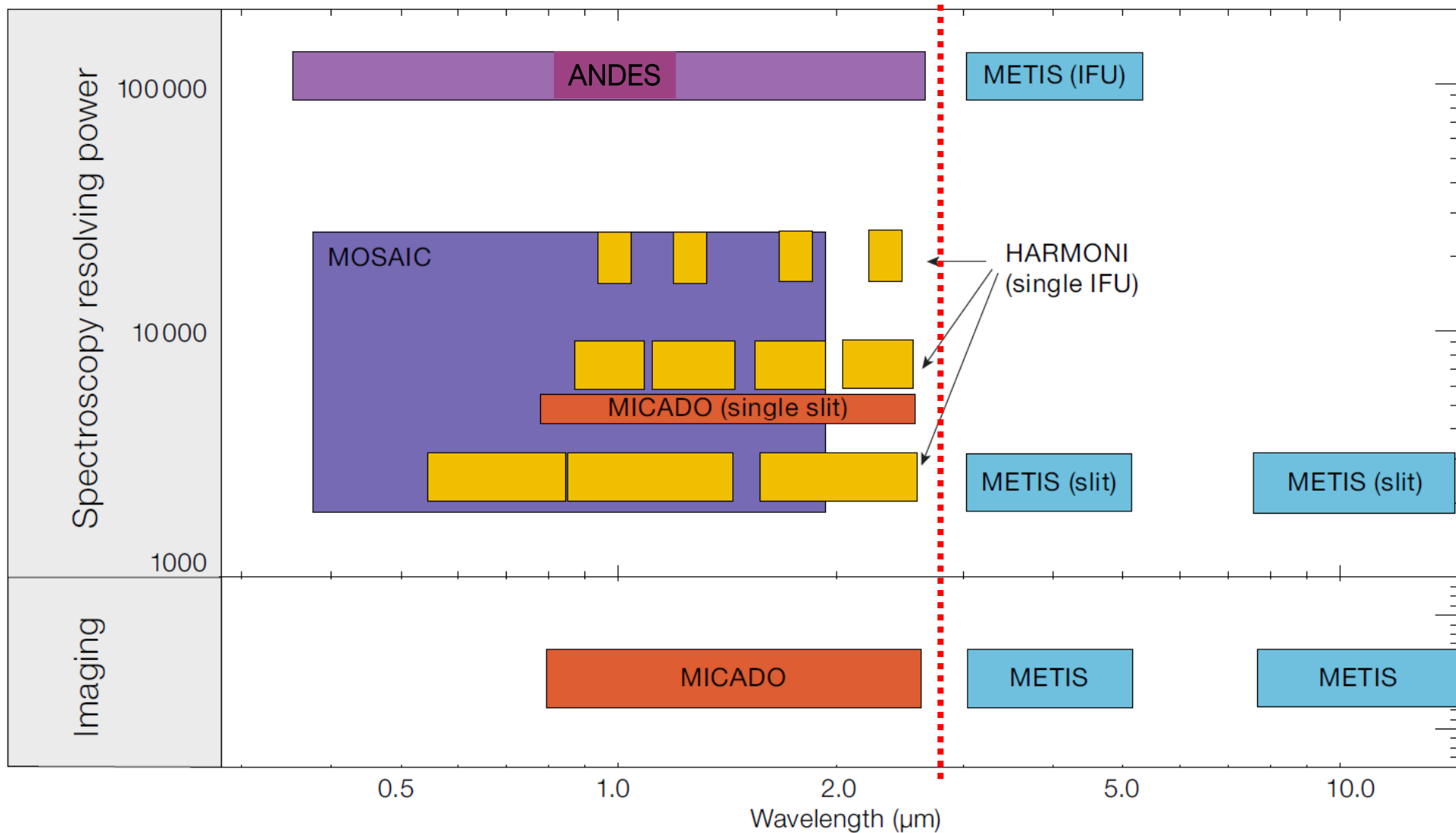


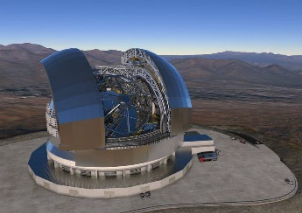
The METIS Team at 10μm





# METIS' unique Parameter Space





# Instrument Overview

❑ **Imaging** over a field of view of  $10.5'' \times 10.5''$  ( $3 - 5 \mu\text{m}$ ) and  $13.5'' \times 13.5''$  ( $8 - 13 \mu\text{m}$ ), including:

- medium resolution ( $R \sim 1400$  @LM;  $R \sim 400$  @N) **long-slit spectroscopy**
- **coronagraphy** for high contrast imaging

❑ **High resolution** ( $R \sim 100,000$ ) **integral-field spectroscopy** at  $3 - 5 \mu\text{m}$ , over a field of view of  $\sim 0.93'' \times 0.58''$ , including:

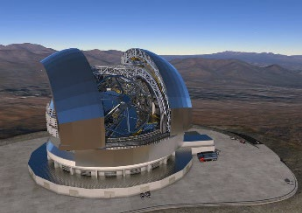
- a mode with extended  $\Delta\lambda_{\text{instant}} \sim 300 \text{ nm}$
- **coronagraphy** for high contrast IFU spectroscopy

❑ *All observing modes **work at the diffraction limit** of the 39m ELT with a single conjugate **Adaptive Optics** system.*

## PS Sensitivities:

(10- $\sigma$ , 1 hr)

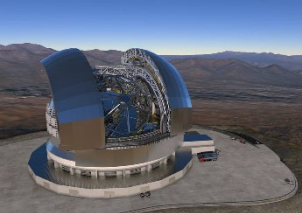
| $\lambda$ | F                  | mag  |
|-----------|--------------------|------|
| L         | 1 $\mu\text{Jy}$   | 21.2 |
| M         | 10 $\mu\text{Jy}$  | 18   |
| N         | 100 $\mu\text{Jy}$ | 14   |



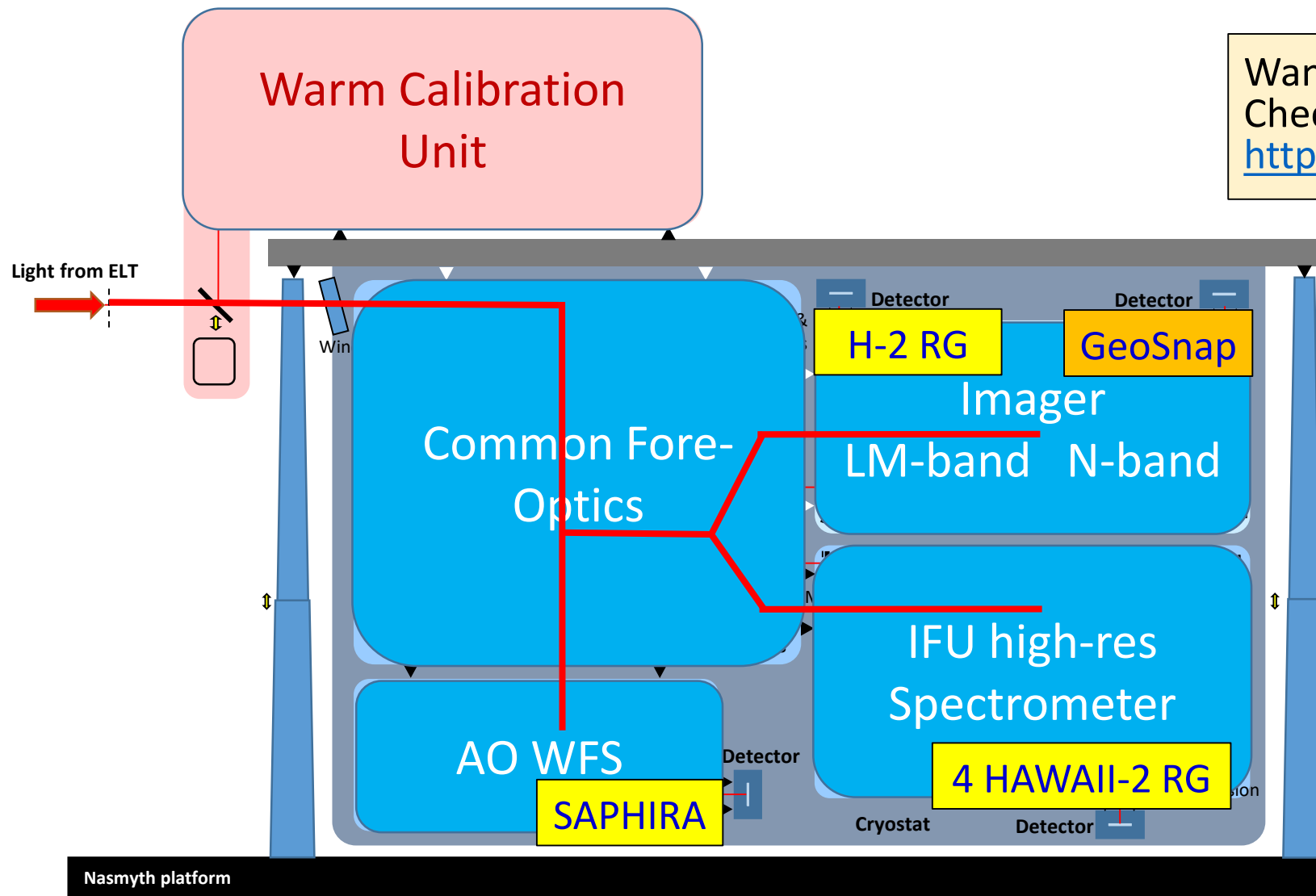
# Observing Modes and Configurations

| Science Observing Mode | Instrument Configuration |      |                                               |          |        |        | Science Driver                                                                                |
|------------------------|--------------------------|------|-----------------------------------------------|----------|--------|--------|-----------------------------------------------------------------------------------------------|
|                        | Sub-Syst.                | Band | IFS Setting                                   | HCI Mask | P<br>T | F<br>T |                                                                                               |
| Direct Imaging         | IMG                      | L,M  | N/A                                           | N/A      | •      | •      | circum-stellar (YSOs) and circum-nuclear (AGN) structures, star clusters                      |
|                        | IMG                      | N    | N/A                                           | N/A      | •      | •      | circum-stellar (YSOs) and circum-nuclear (AGN) structures                                     |
| High Contrast Imaging  | IMG                      | L,M  | N/A                                           | RAVC/CVC | •      | •      | exoplanets (detection + characterization)                                                     |
|                        | IMG                      | N    | N/A                                           | APP      | •      | •      | exoplanets (detection + characterization)                                                     |
| Longslit spectroscopy  | IMG                      | L,M  | N/A                                           | N/A      | •      | •      | ices in comets and star forming regions                                                       |
|                        | IMG                      | N    | N/A                                           | N/A      | •      | •      | physics of circum-stellar and circum-nuclear environments; solid-state chemistry & mineralogy |
| IFU spectroscopy       | LMS                      | L,M  | full IFU field                                | N/A      | •      | •      | kinematics and chemistry of circum-stellar environments                                       |
|                        | LMS                      | L,M  | spectral IFU $\Delta\lambda\sim 300\text{nm}$ | N/A      | •      | •      | chemical studies of the interstellar medium                                                   |
| IFU+HCI spectroscopy   | LMS                      | L,M  | full IFU field                                | APP      | •      | •      | exoplanetary atmospheres at $\theta > 3\lambda/D$ , pp-disks                                  |
|                        | LMS                      | L,M  | full IFU field                                | RAVC/CVC | •      | •      | exoplanetary atmospheres at $\theta \sim 2\lambda/D$ , pp-disks                               |
|                        | LMS                      | L,M  | spectral IFU $\Delta\lambda\sim 300\text{nm}$ | APP      | •      | •      | exoplanetary atmospheres at $\theta > 3\lambda/D$                                             |
|                        | LMS                      | L,M  | spectral IFU $\Delta\lambda\sim 300\text{nm}$ | RAVC/CVC | •      | •      | exoplanetary atmospheres at $\theta \sim 2\lambda/D$                                          |

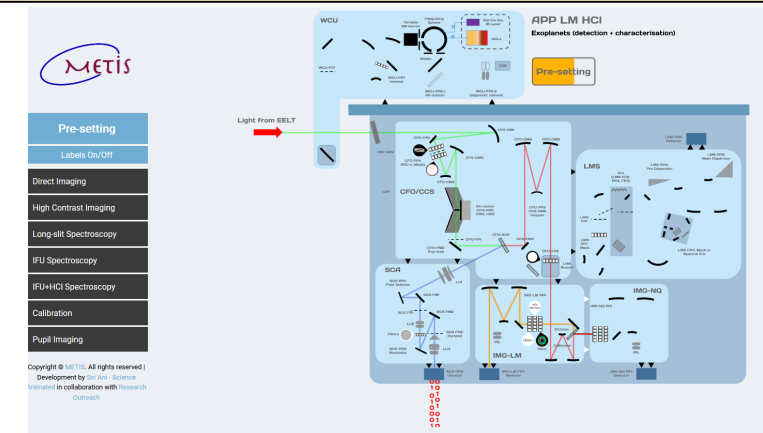
See ESO Messenger 182 (2021)

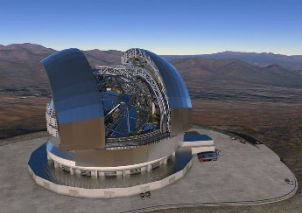


# Optical Concept

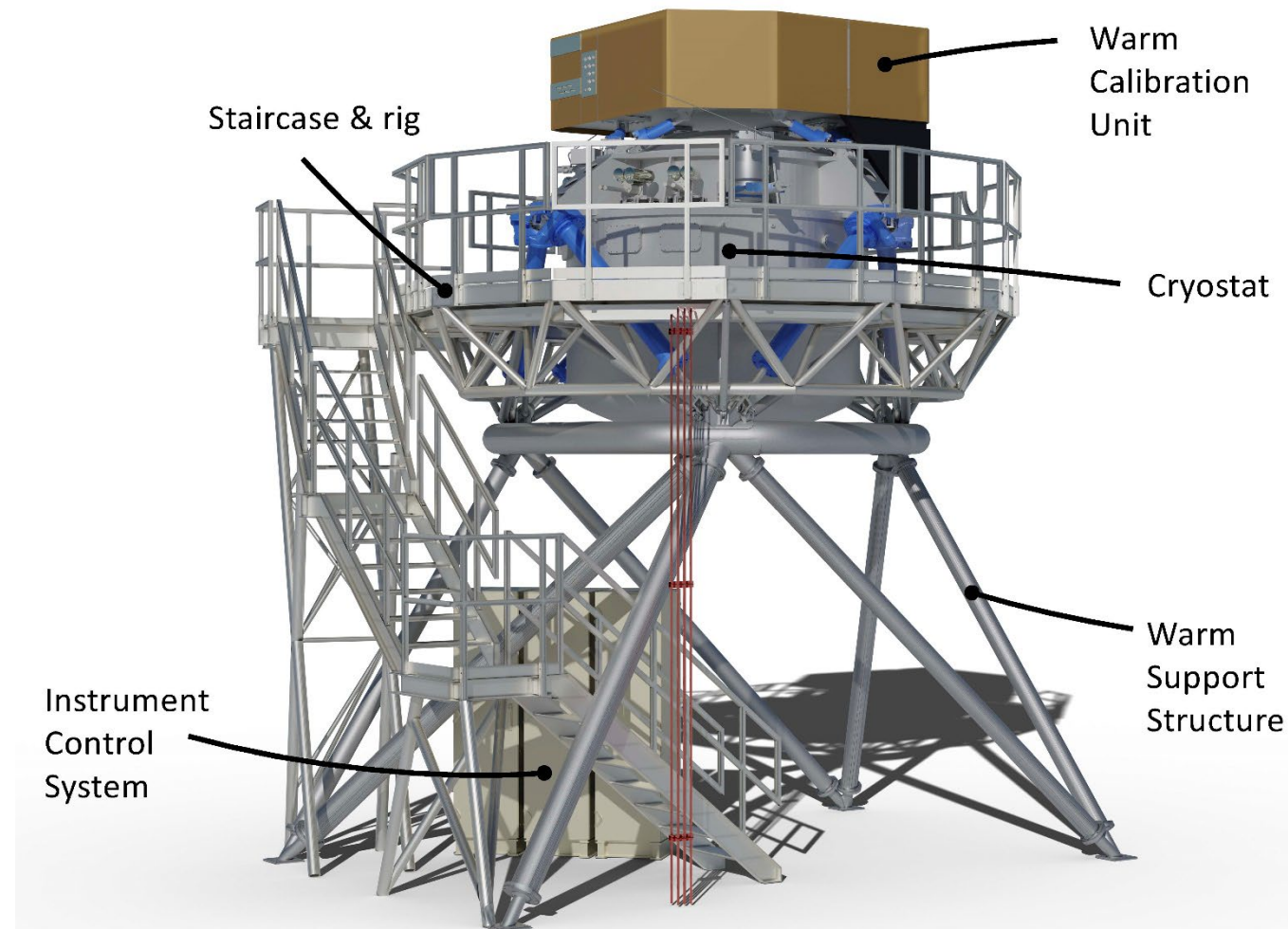
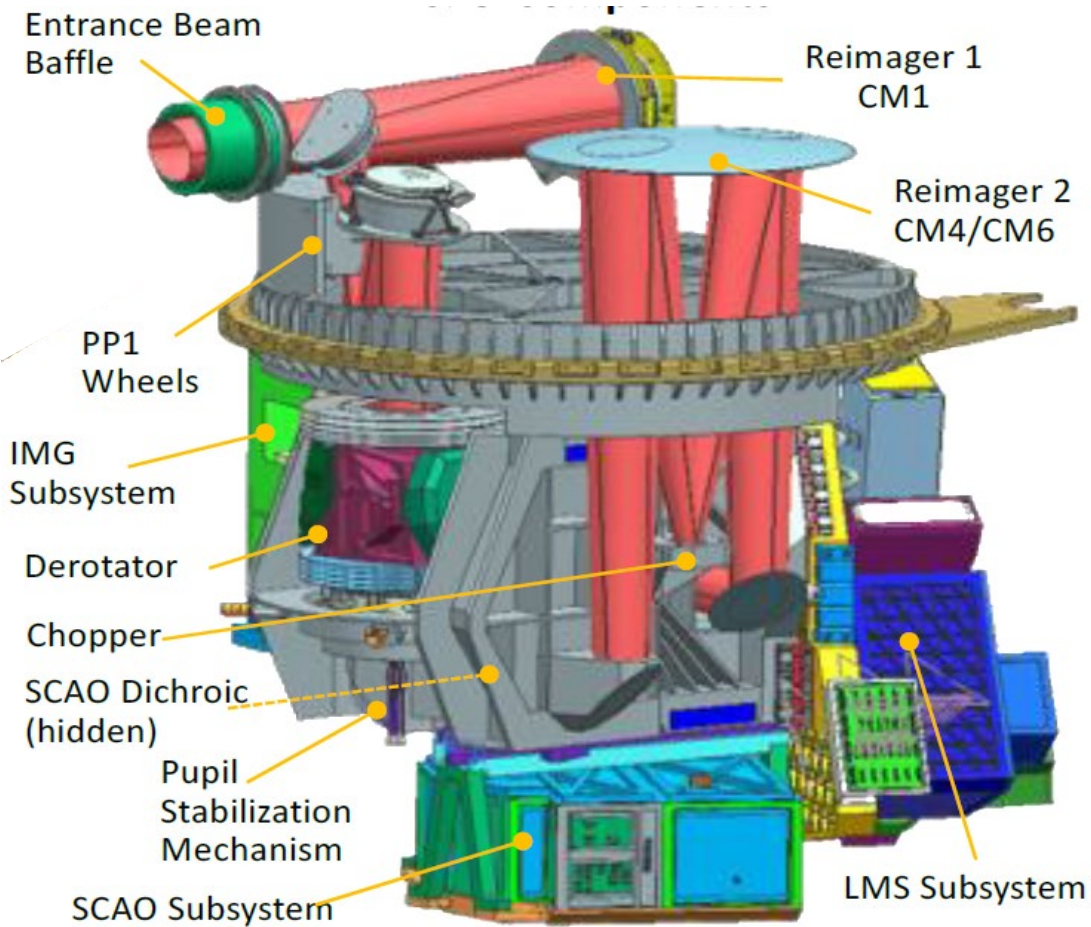


Want to understand how METIS works?  
Check out the METIS App:  
<http://metis-app.strw.leidenuniv.nl/>

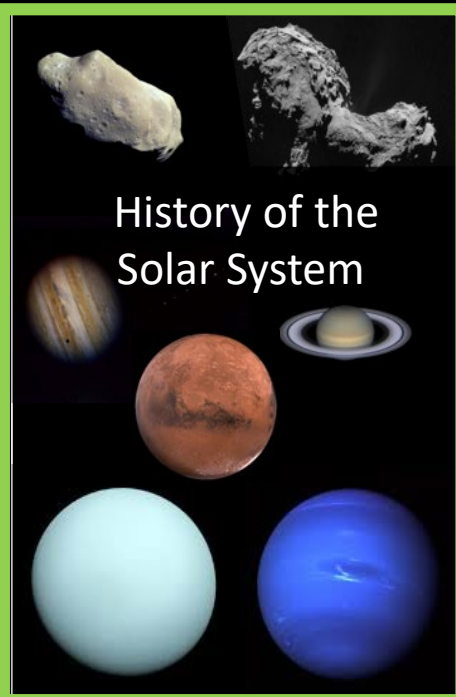
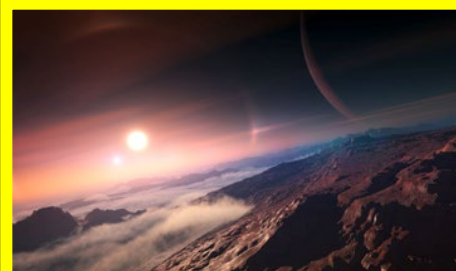
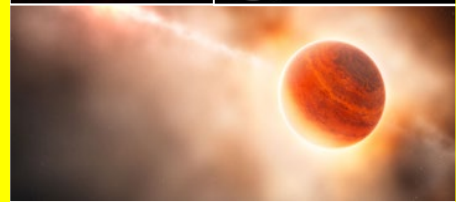
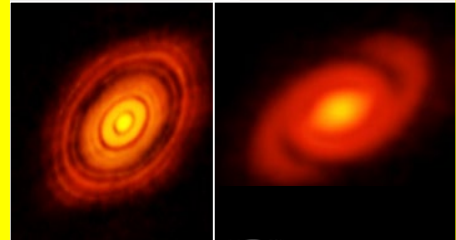




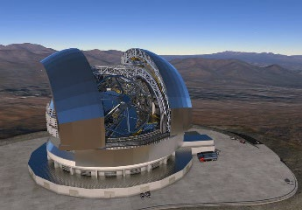
# Opto-mechanical Realization



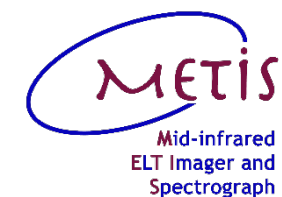
# Science Case Overview



# Main drivers: Exoplanets & proto-planetary Disks



# METIS Science Areas in our Solar System

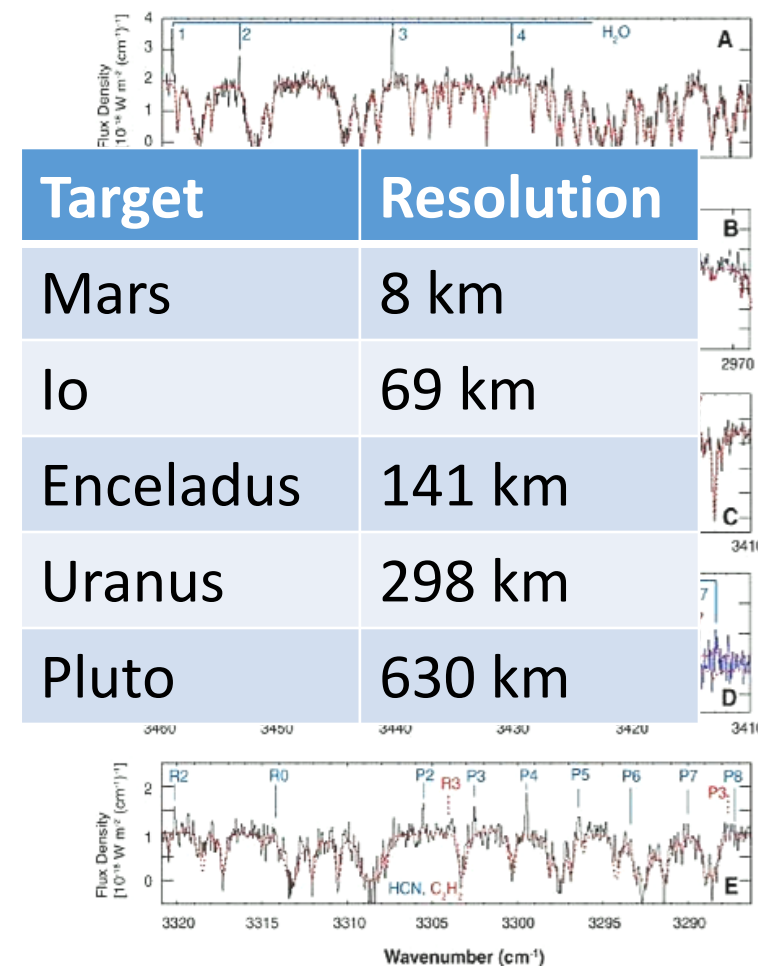


Key: METIS IFU **high-res spectroscopy** (L/M bands)

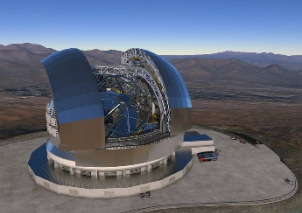
- Chemical composition of the outer disk & formation temperature of the **ices**
- Origin of **water** and other **isotopic** enrichment processes in comets
- Composition of **asteroid** surfaces & **comet** comae
- Long-term monitoring of **volcanic activity**

**NASA decadal survey** → Uranus mission & **ESA** will contribute ← ground-based preparation & follow-ups

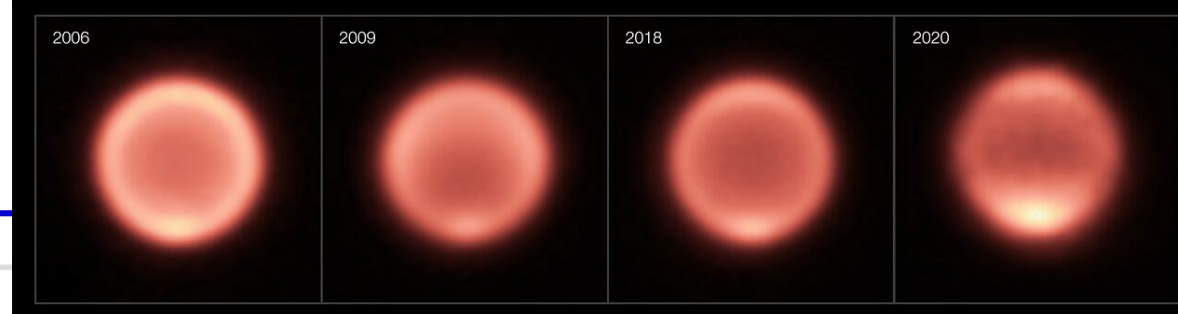
**→ Ice Giants and their moons will become an increasingly hot topic.**



3-5μm spectroscopy of parent species from volatile ices in cometary nuclei (Mumma et al. 2003)

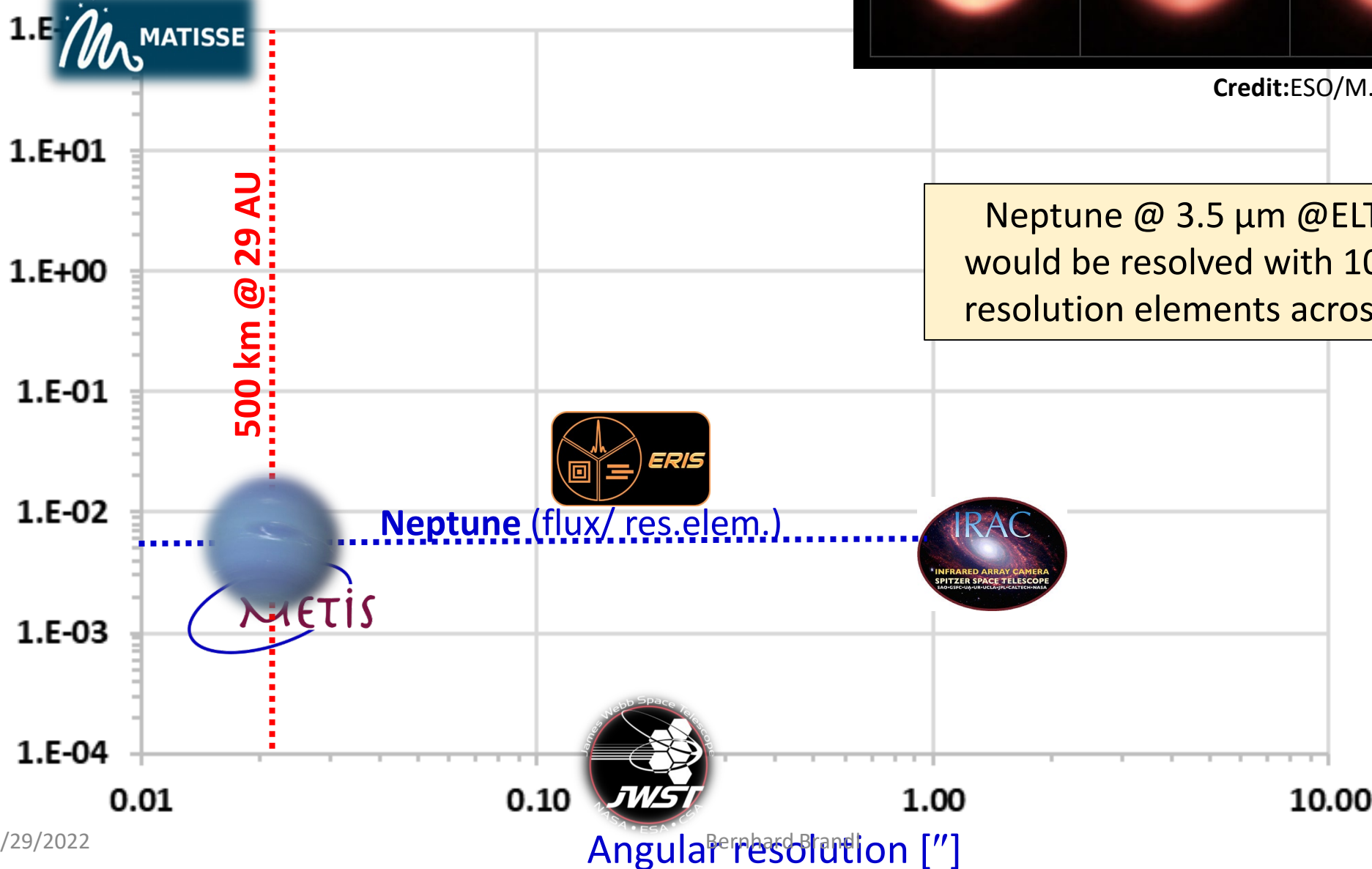


# Prime Example: Neptune

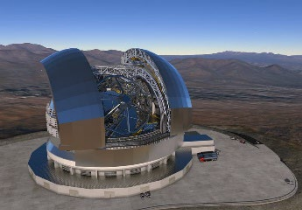


Credit:ESO/M. Roman, NAOJ/Subaru/COMICS

Point-Source (res.elem.) Sensitivity [mJy]  
(10σ, 1hr at 3.5μm)



Neptune @ 3.5 μm @ELT would be resolved with 100 resolution elements across!

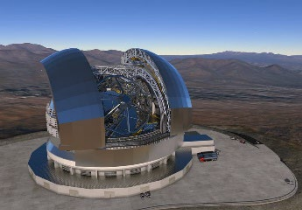


# Bummer!

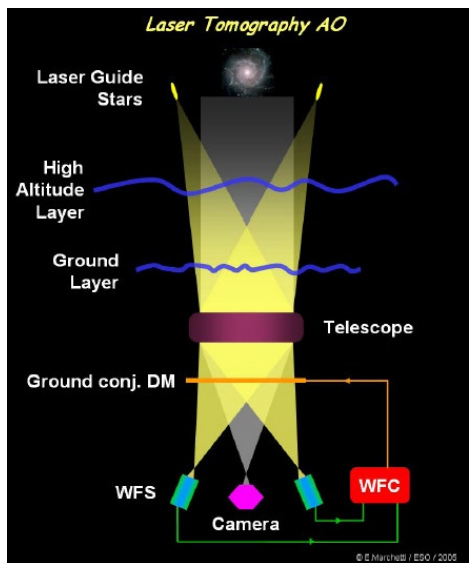
All of this assumes that we are able to run adaptive optics to reach the diffraction-limit of the ELT



- For most science targets, METIS can use the science target as “guide star”
- For most Solar System objects, we need a laser guide star
- Such a laser guide star system is not (yet) part of the METIS baseline!



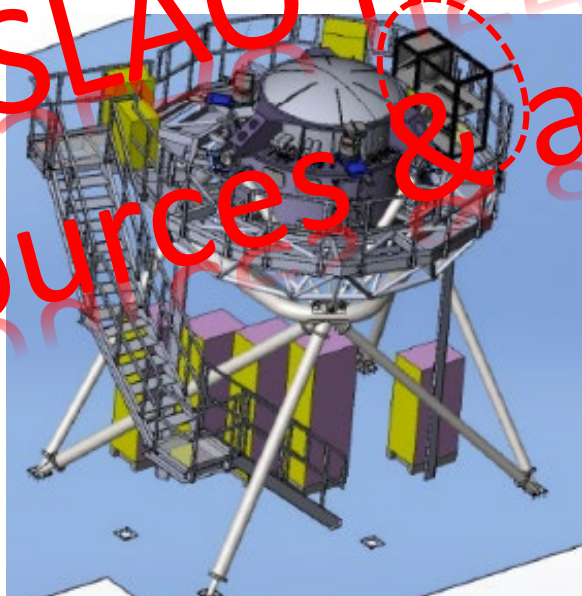
# Laser Adaptive Optics for METIS



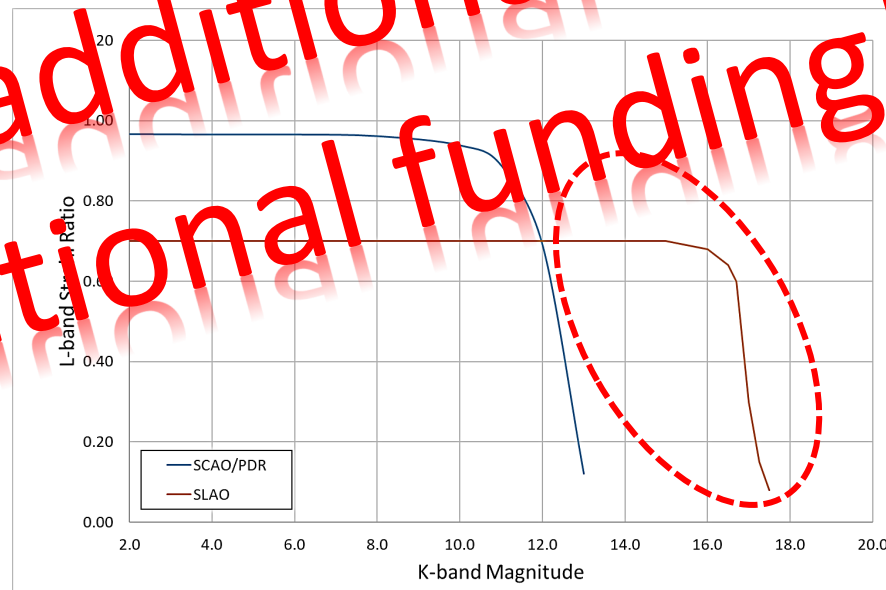
ELTs require 4 – 6 laser guide stars to reduce the cone effect → “LTAO”, which are complex and expensive systems ← not part of METIS!

We investigated the performance of a **single on-axis LGS (SLAO)** at  $\lambda > 3 \mu\text{m}$  on the ELT, and use existing internal SCAO WFS to provide tip/tilt and truth sensing.

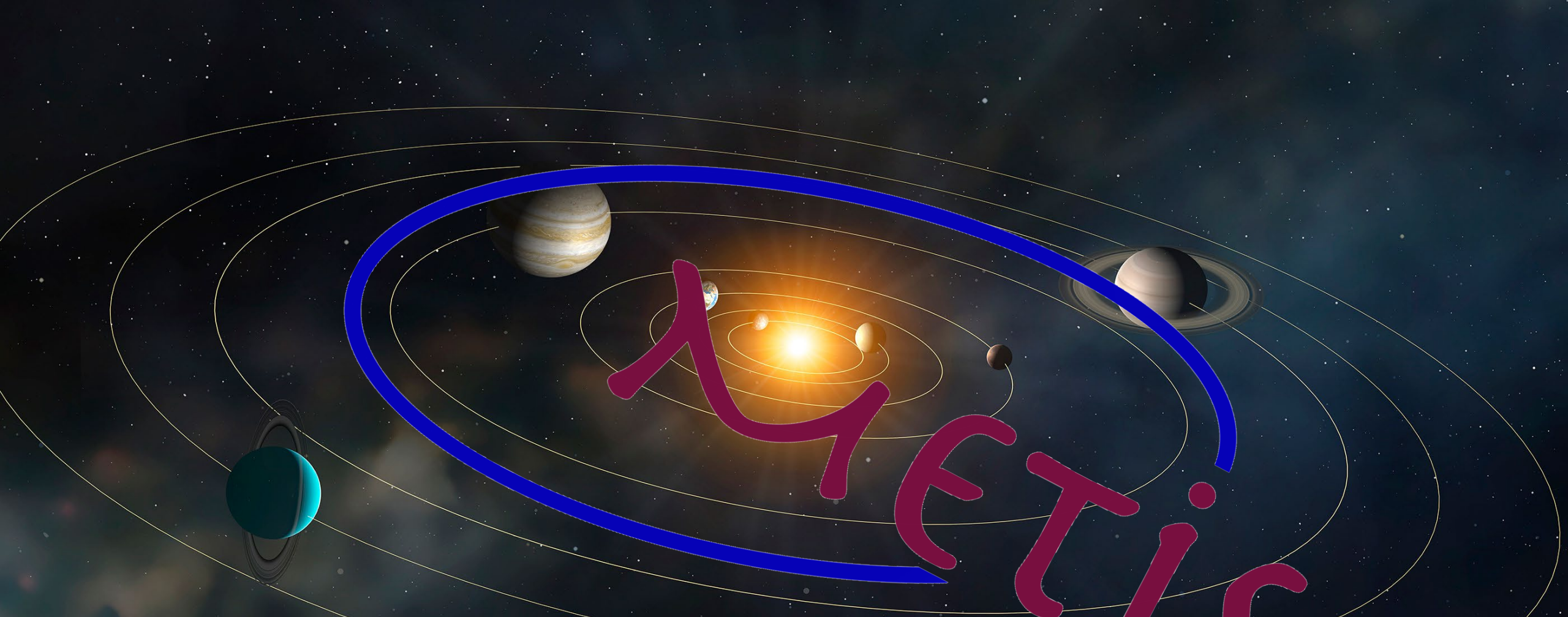
SLAO



SLAO needs additional resources & additional funding!



- Limiting magnitude allows for 100× fainter sources
- Quite good correction at  $K > 12$



**METIS** science talks at *Solar System Science with the ELTs – part II:*

- Bertrand Bonfond [Liège] – “*Observing the Outer Planets' Systems with METIS*”
- Emmanuel Jehin [Liège] – “*METIS and the small Bodies of the Solar System*”
- Ravit Helled [ETH Zürich] – TBC
- ...and many more