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SolSysELTs2022 part I: METIS

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METIS

Mid-infrared
ELT Imager and
Spectrograph

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

4/29/2022

Bernhard Brandl

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1st Generation scientific Instruments on the ELT

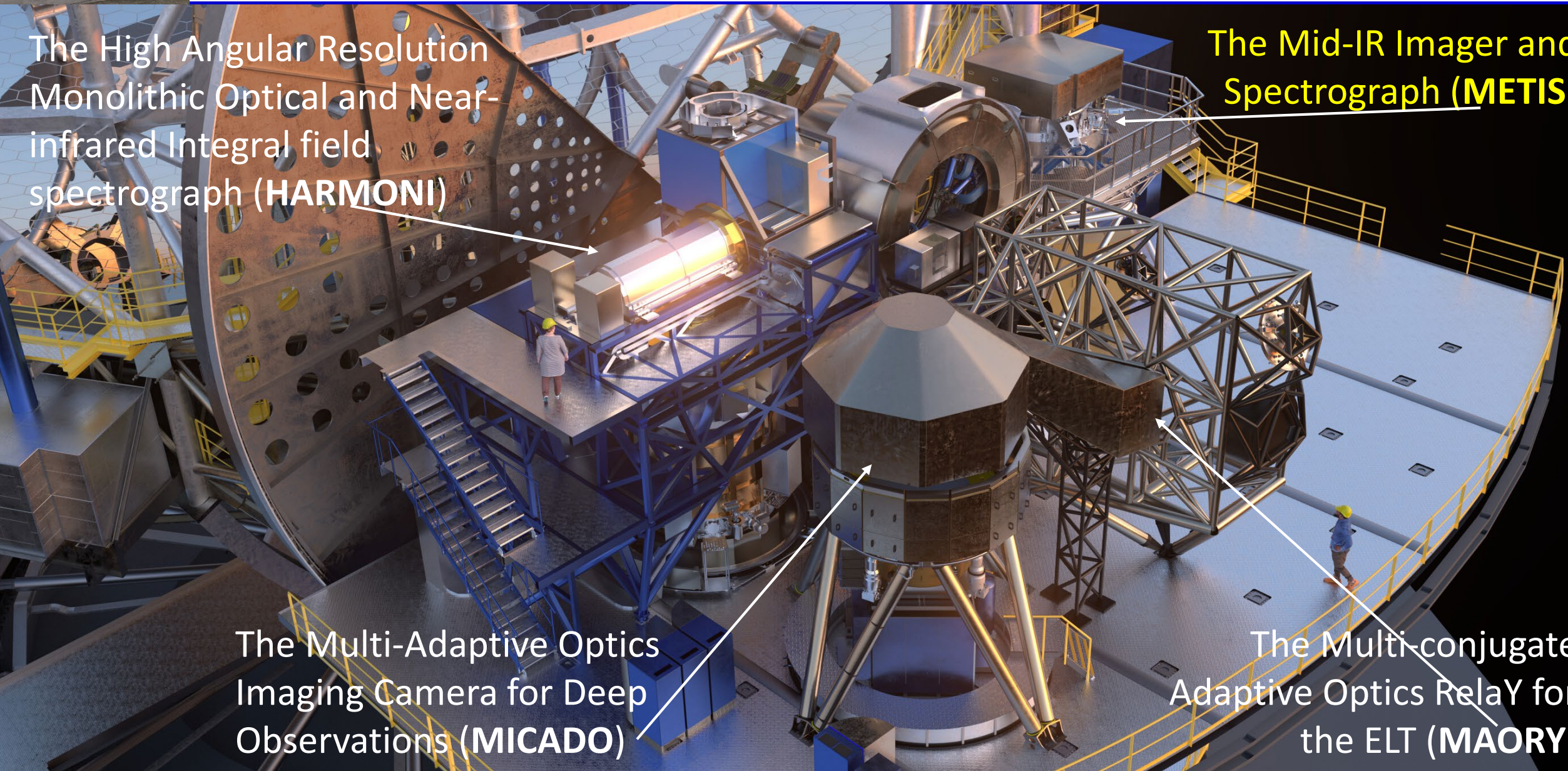


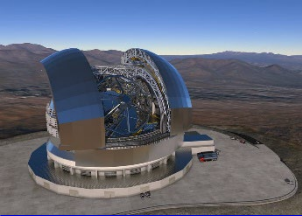
The High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (**HARMONI**)

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

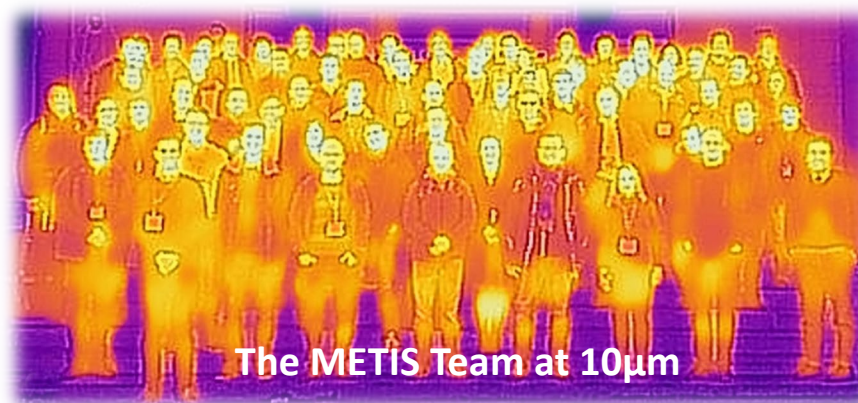
- One of three 1st-generation ELT science instruments → 1st-light ~2028
- Consortium of **12 international partner institutions** (10 European, 1 US, 1 Taiwan) + ESO
- Project milestones:
 - Kick-off 2015
 - PDR 2019
 - FDR (2021 & 2022)
 - AIT 2024–27



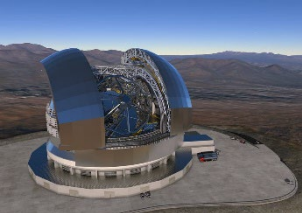
UK Astronomy Technology Centre



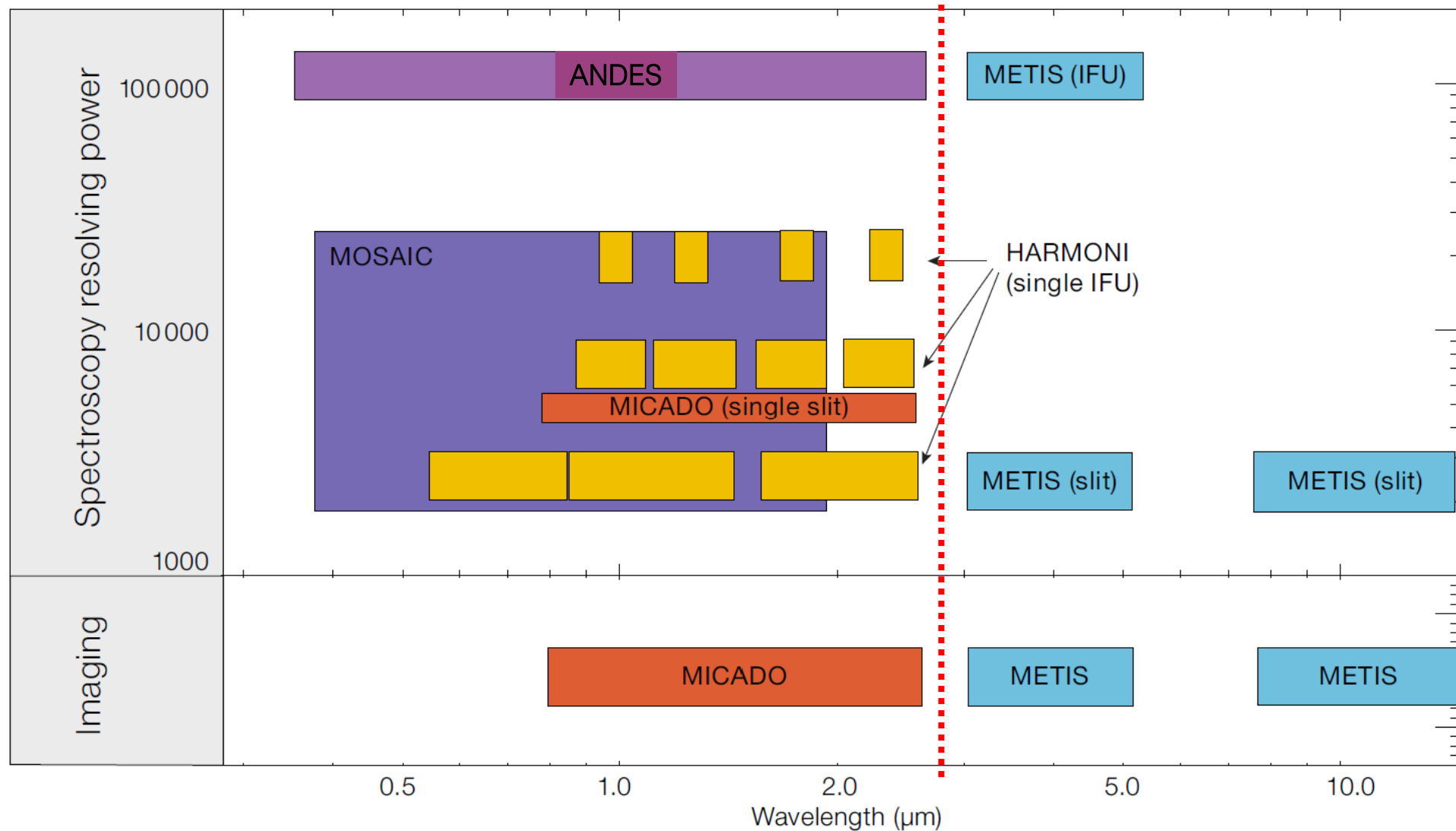
centra
center for astrophysics and gravitation

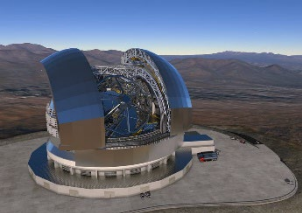


The METIS Team at 10μm



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:

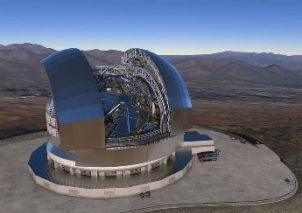
- a mode with extended $\Delta\lambda_{\text{instant}} \sim 300 \text{ nm}$
- **coronagraphy** for high contrast IFU spectroscopy

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

PS Sensitivities:

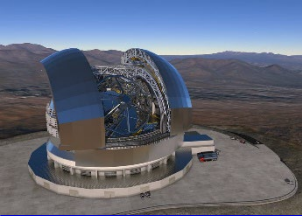
(10- σ , 1 hr)

λ	F	mag
L	1 μJy	21.2
M	10 μJy	18
N	100 μJy	14

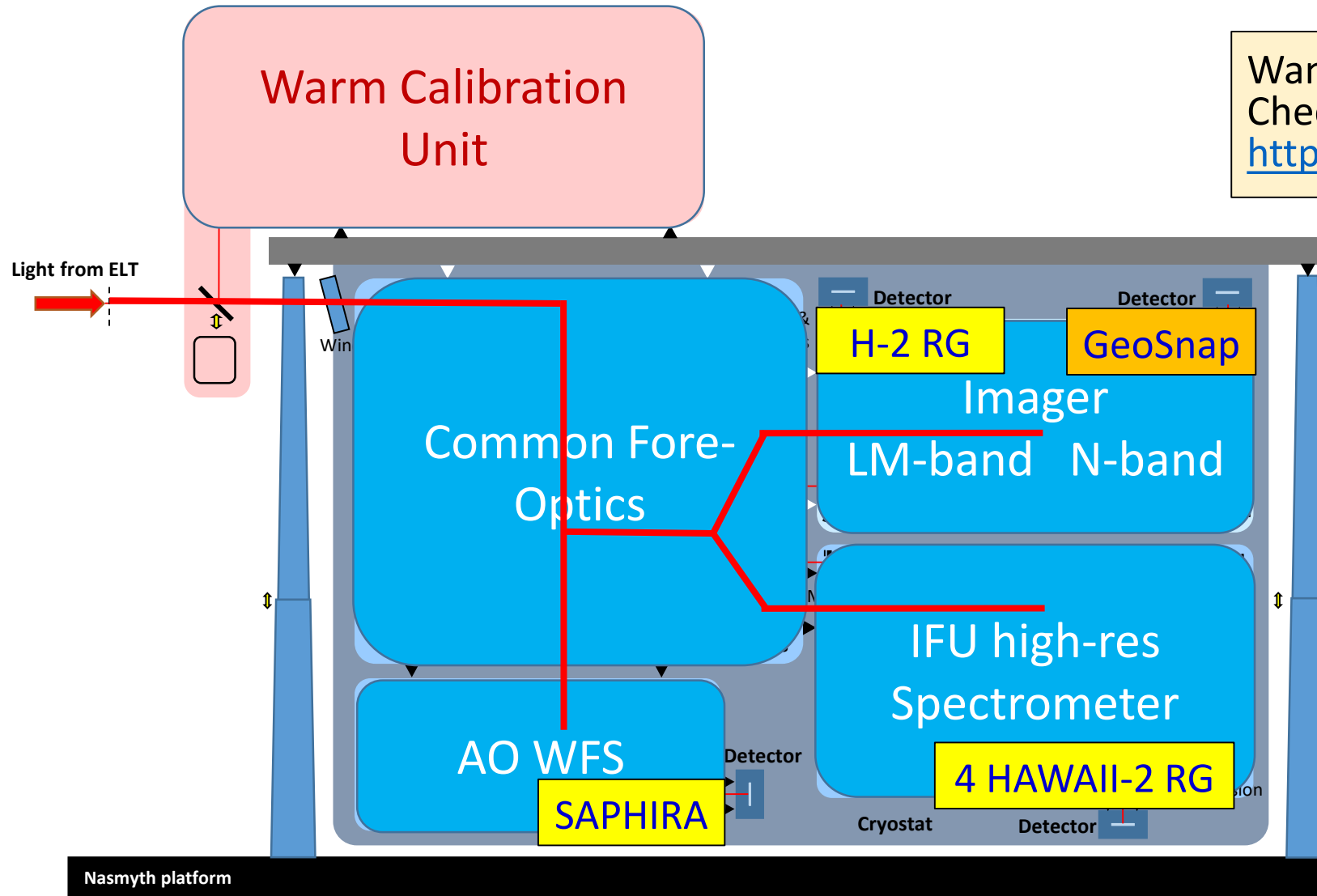


Observing Modes and Configurations

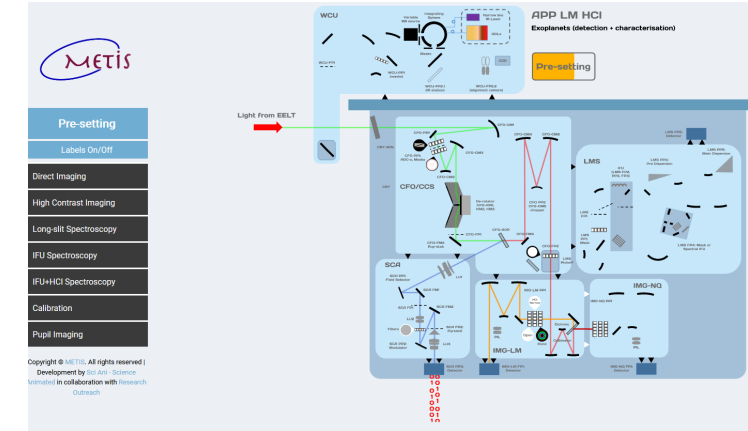
Science Observing Mode	Instrument Configuration						Science Driver
	Sub-Syst.	Band	IFS Setting	HCI Mask	P T	F T	
Direct Imaging	IMG	L,M	N/A	N/A	•	•	circum-stellar (YSOs) and circum-nuclear (AGN) structures, star clusters
	IMG	N	N/A	N/A	•	•	circum-stellar (YSOs) and circum-nuclear (AGN) structures
High Contrast Imaging	IMG	L,M	N/A	RAVC/CVC	•	•	exoplanets (detection + characterization)
			N/A	APP	•	•	exoplanets (detection + characterization)
	IMG	N	N/A	CVC	•	•	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
				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 $\theta > 3\lambda/D$
				RAVC/CVC	•	•	exoplanetary atmospheres at $\theta \sim 2\lambda/D$

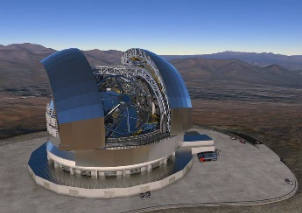


Optical Concept

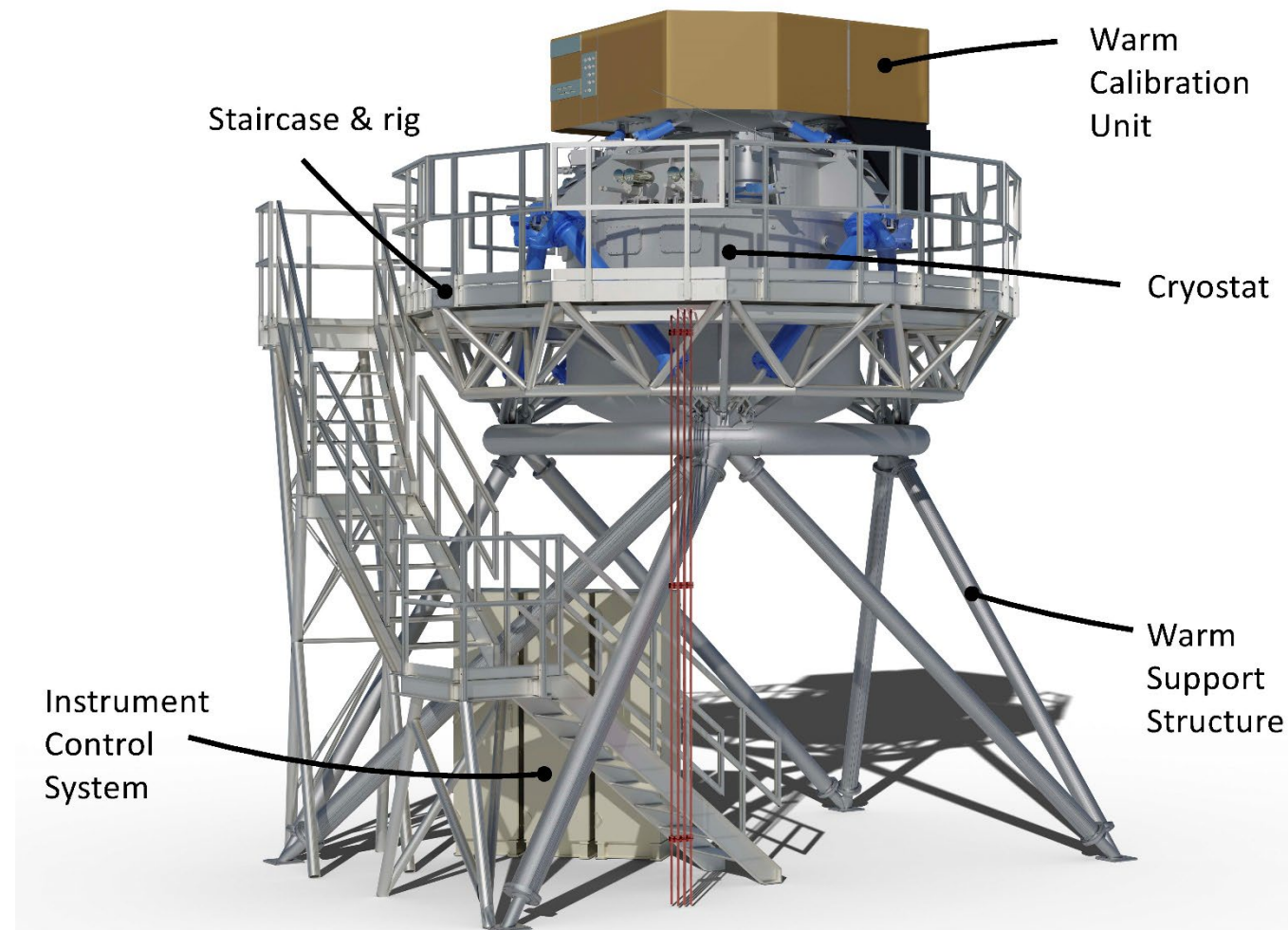
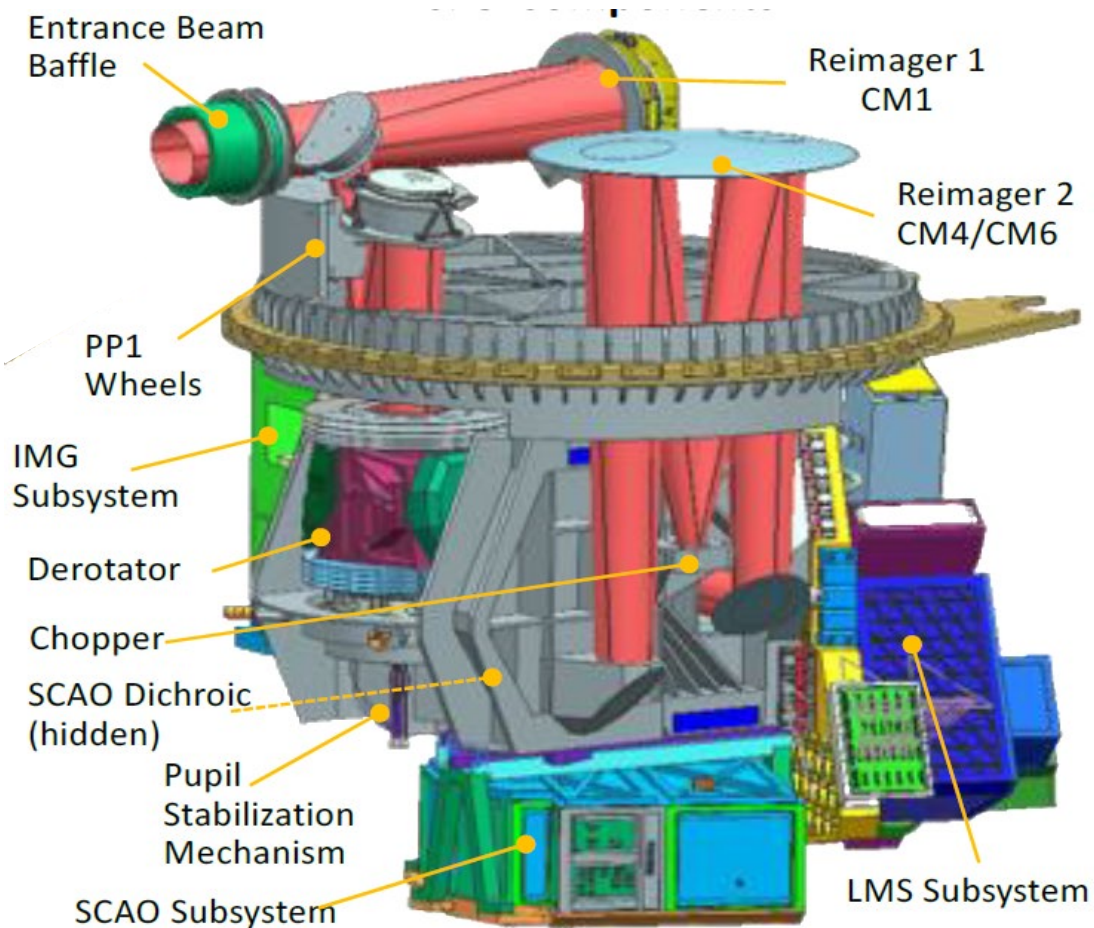


Want to understand how METIS works?
Check out the METIS App:
<http://metis-app.strw.leidenuniv.nl/>

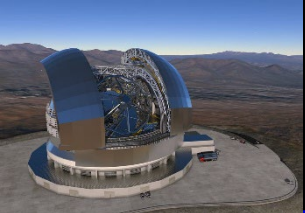




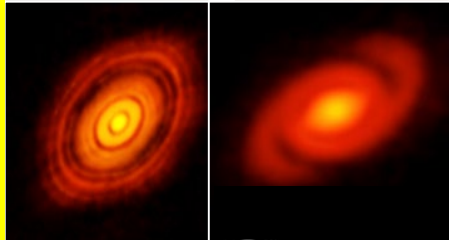
Opto-mechanical Realization



Science Case Overview



Circumstellar
Disks



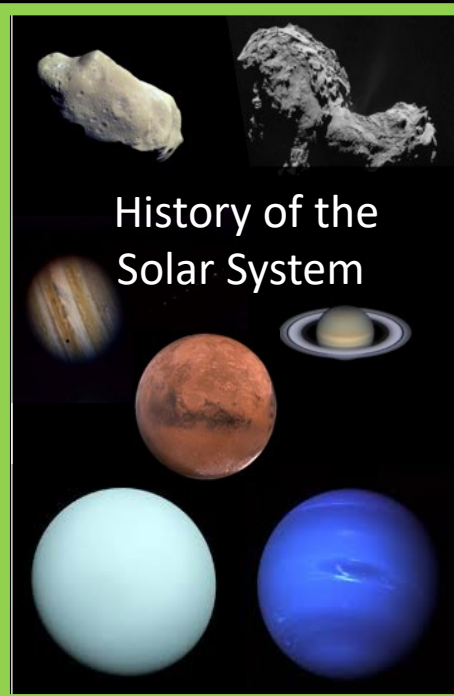
Exoplanets



Star Formation &
Stellar Clusters



The Physics
of Galaxies



History of the
Solar System



Active
Galactic Nuclei

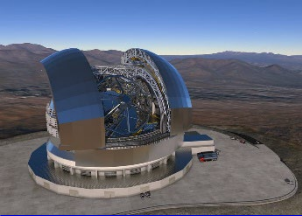


Evolved
Stars



The Galactic
Center

Main drivers: Exoplanets
& proto-planetary Disks



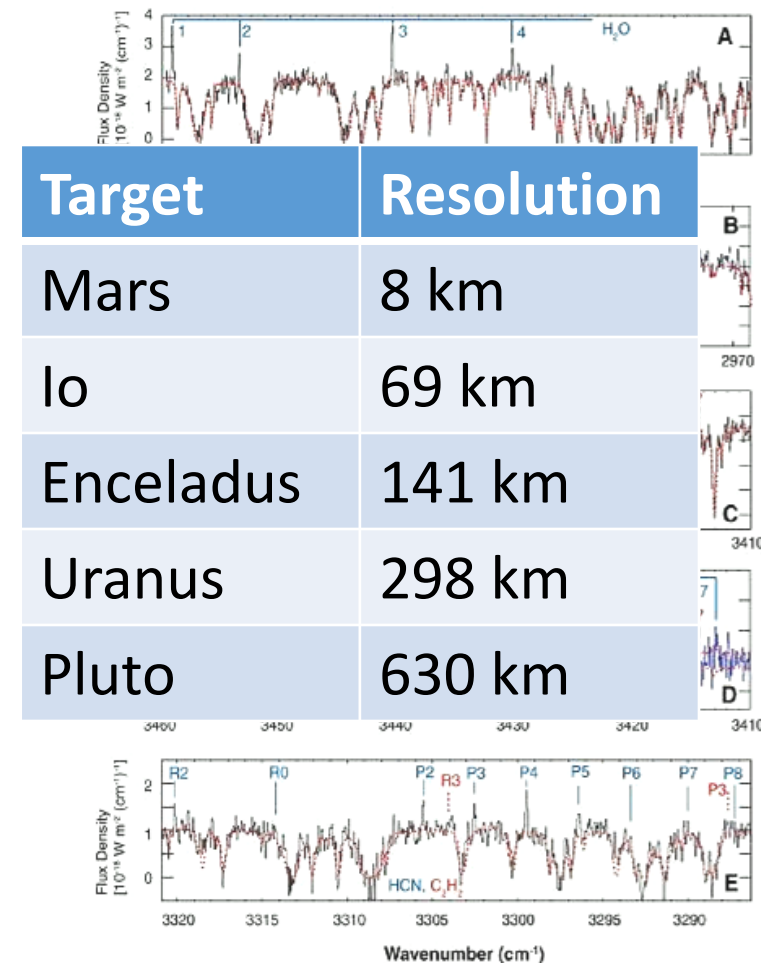
METIS Science Areas in our Solar System

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

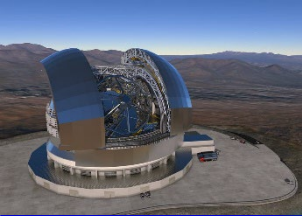
- Chemical composition of the outer disk & formation temperature of the **ices**
- Origin of **water** and other **isotopic** enrichment processes in comets
- Composition of **asteroid** surfaces & **comet** comae
- Long-term monitoring of **volcanic activity**

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

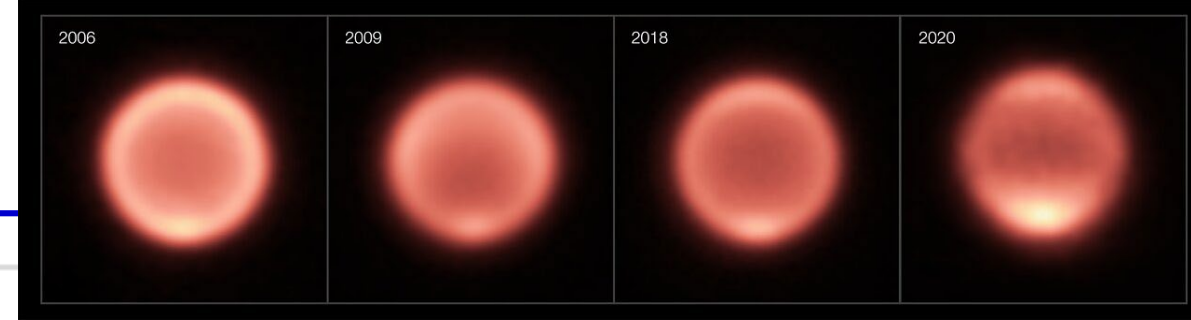
→ *Ice Giants and their moons will become an increasingly hot topic.*



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

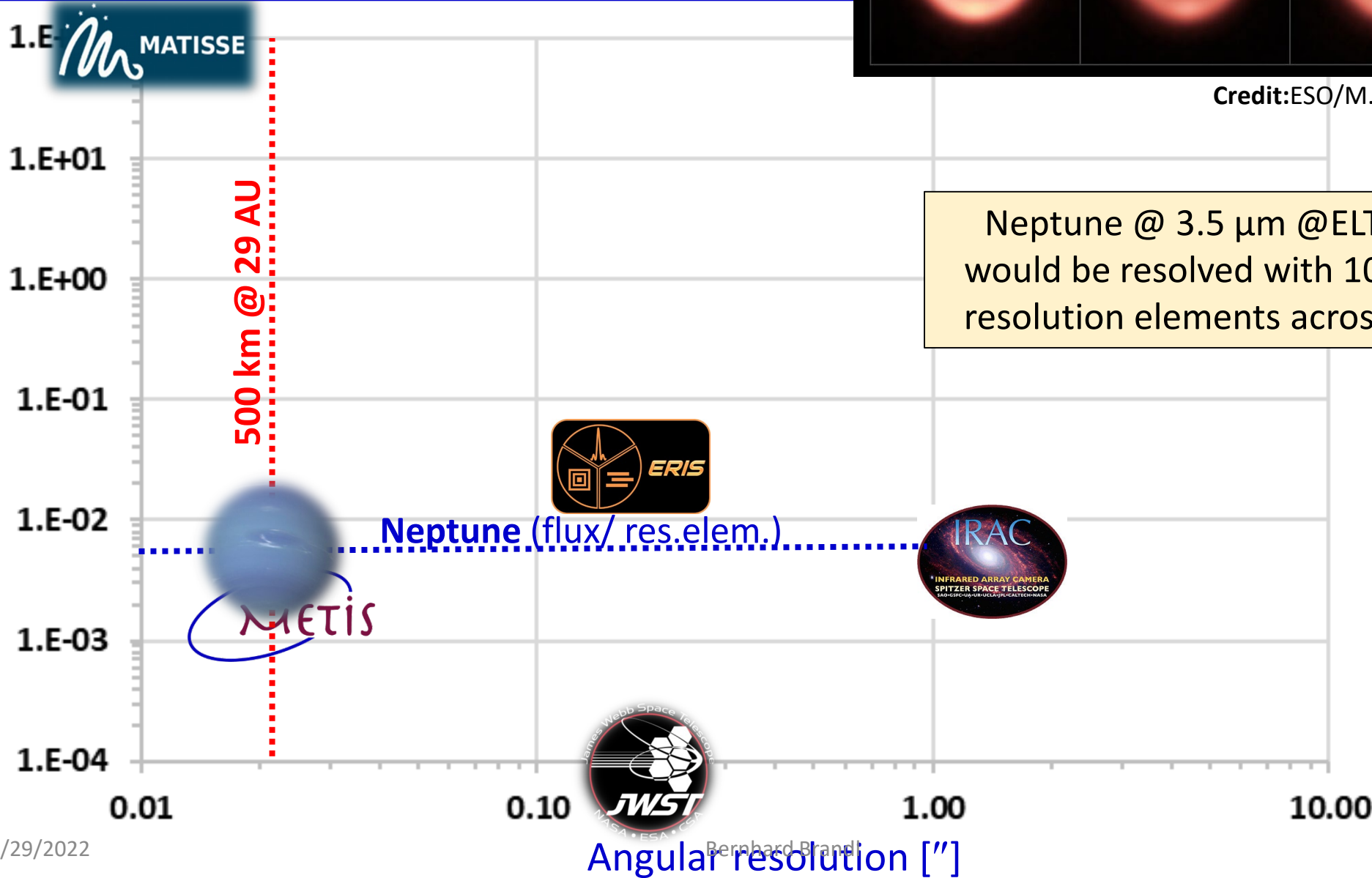


Prime Example: Neptune

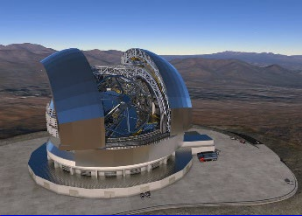


Credit:ESO/M. Roman, NAOJ/Subaru/COMICS

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



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

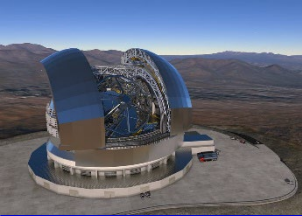


Bummer!

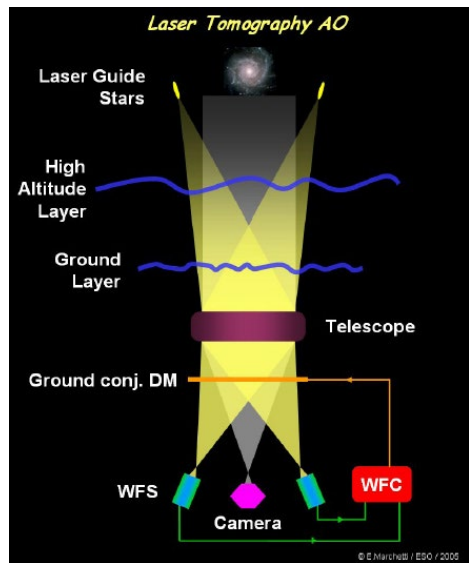
All of this assumes that we are able to run adaptive optics to reach the diffraction-limit of the ELT



- 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!



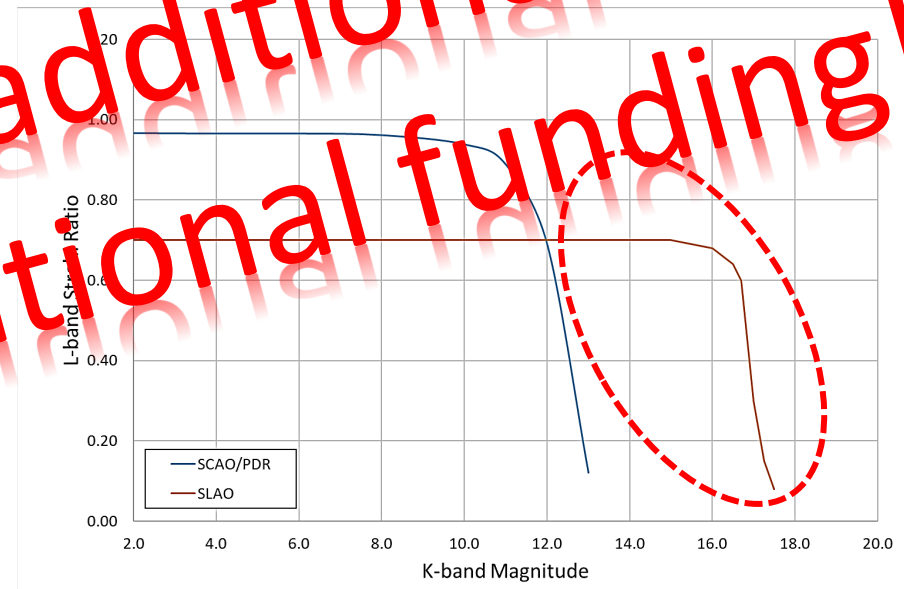
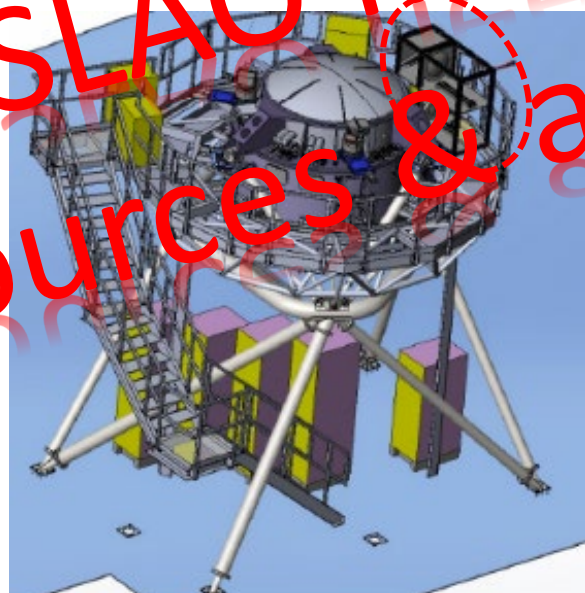
Laser Adaptive Optics for METIS



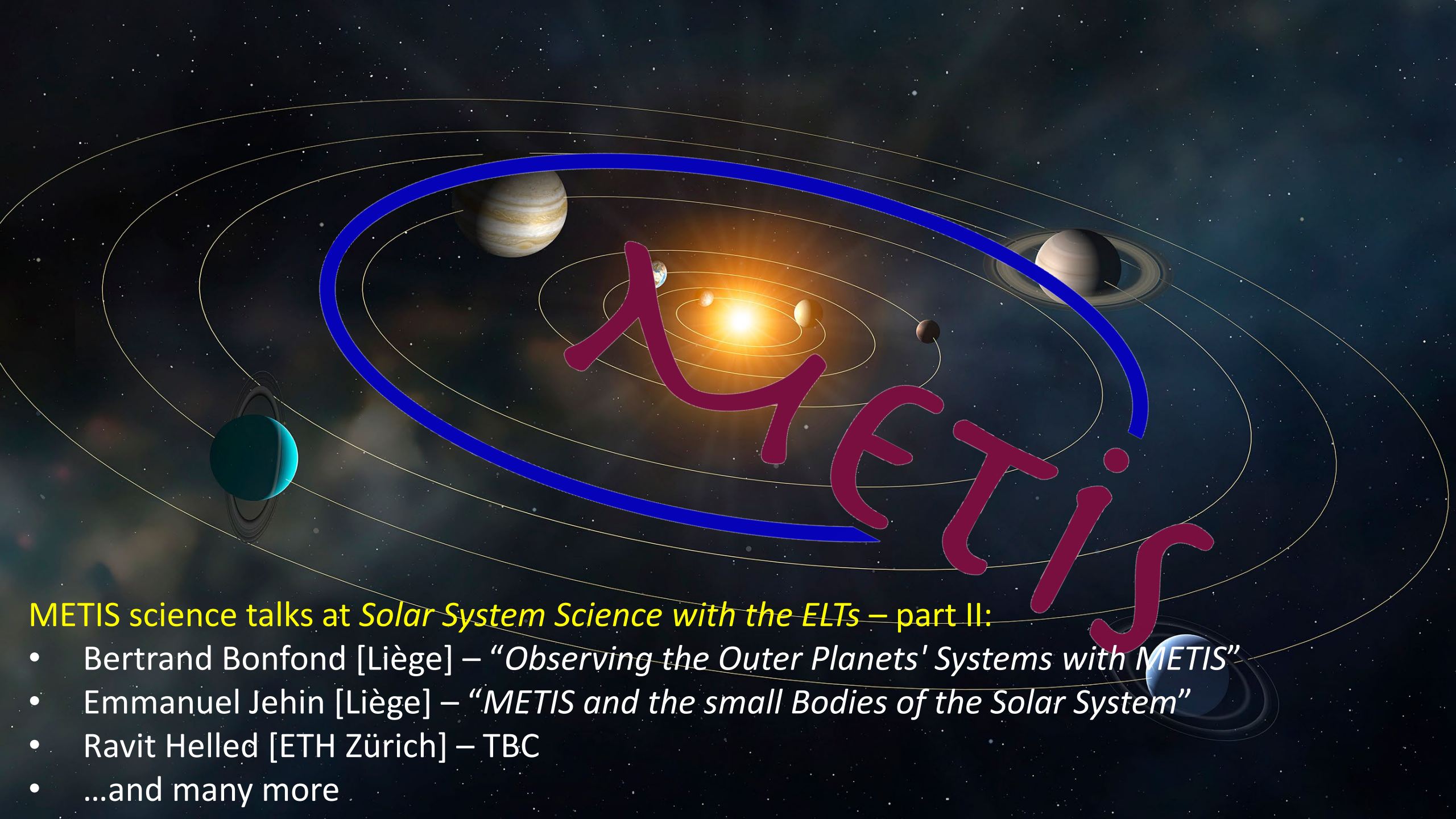
ELTs require 4 – 6 laser guide stars to reduce the cone effect → “LTAO”, which are complex and expensive systems ← not part of METIS!

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



- 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