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Preparing Solar System object observations with the ELT MICADO/MORFEO

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and the MORFEO team.



First light of a Giant

at Cerro Armazones (Chile)

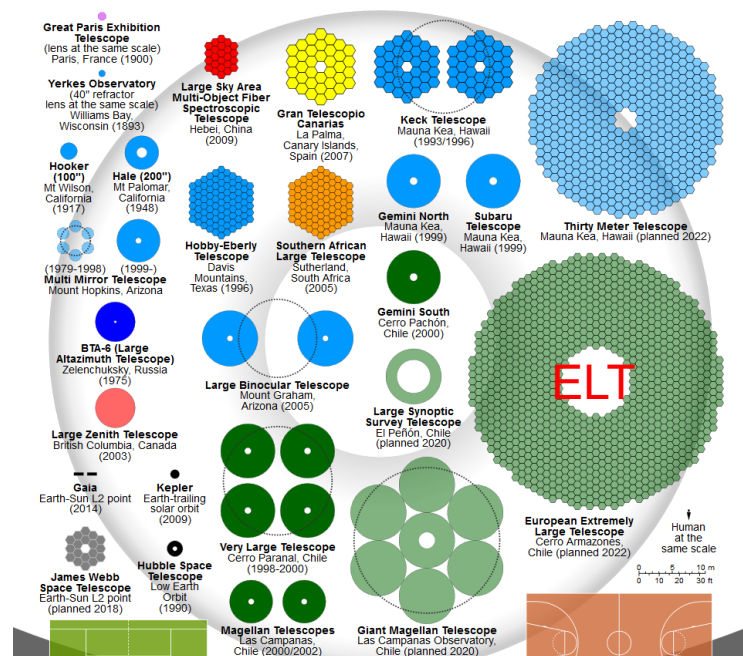
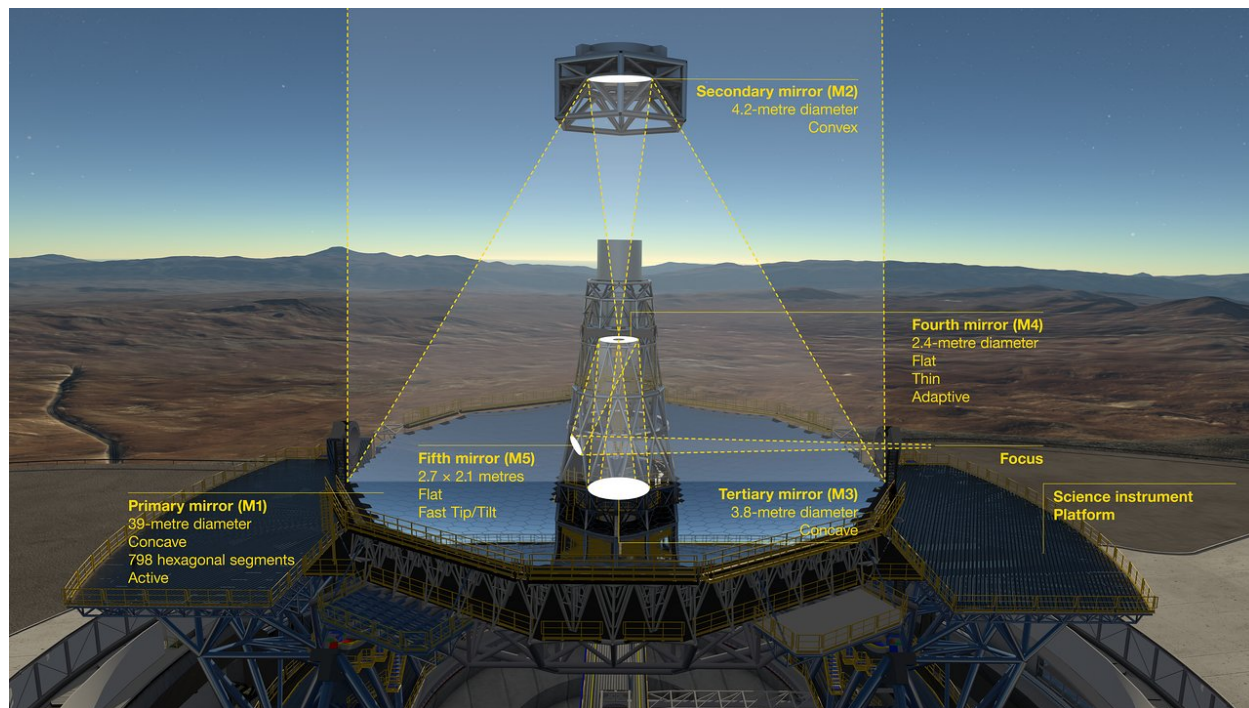


developed by the European Southern Observatory (ESO).



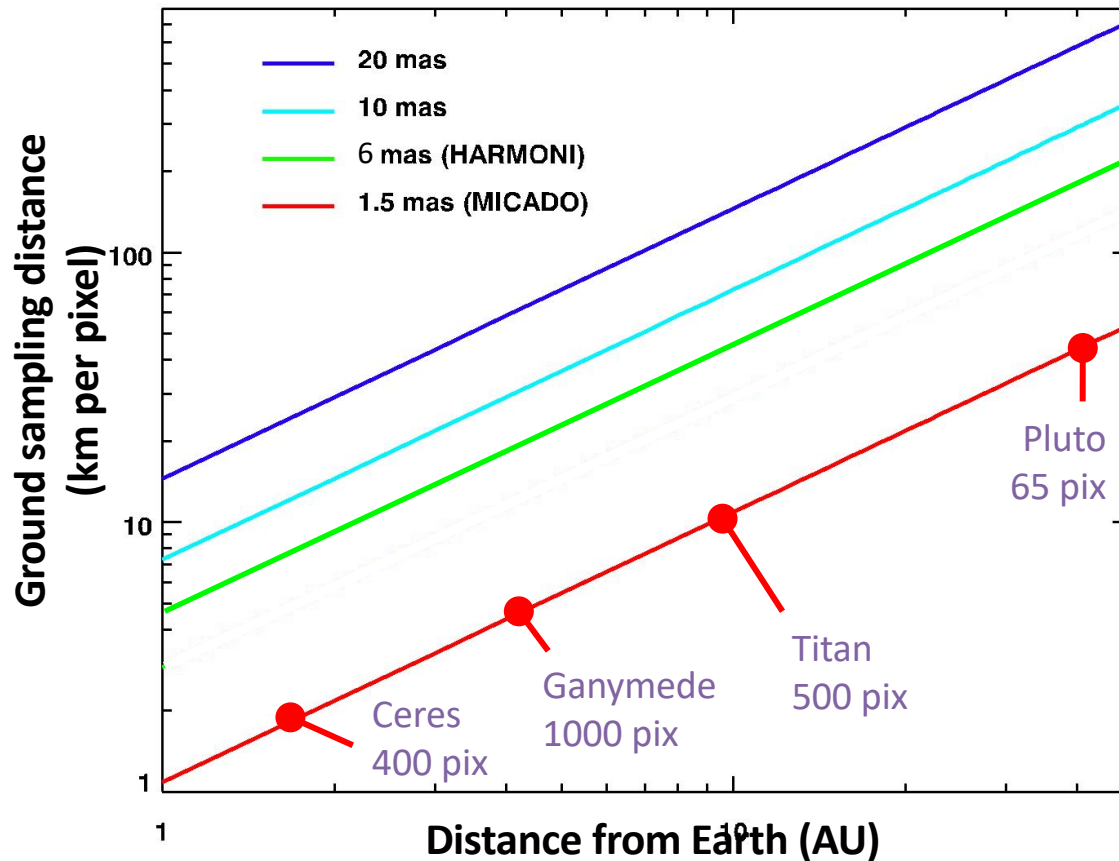


A 39m telescope with 5 mirrors and built-in adaptive optics.

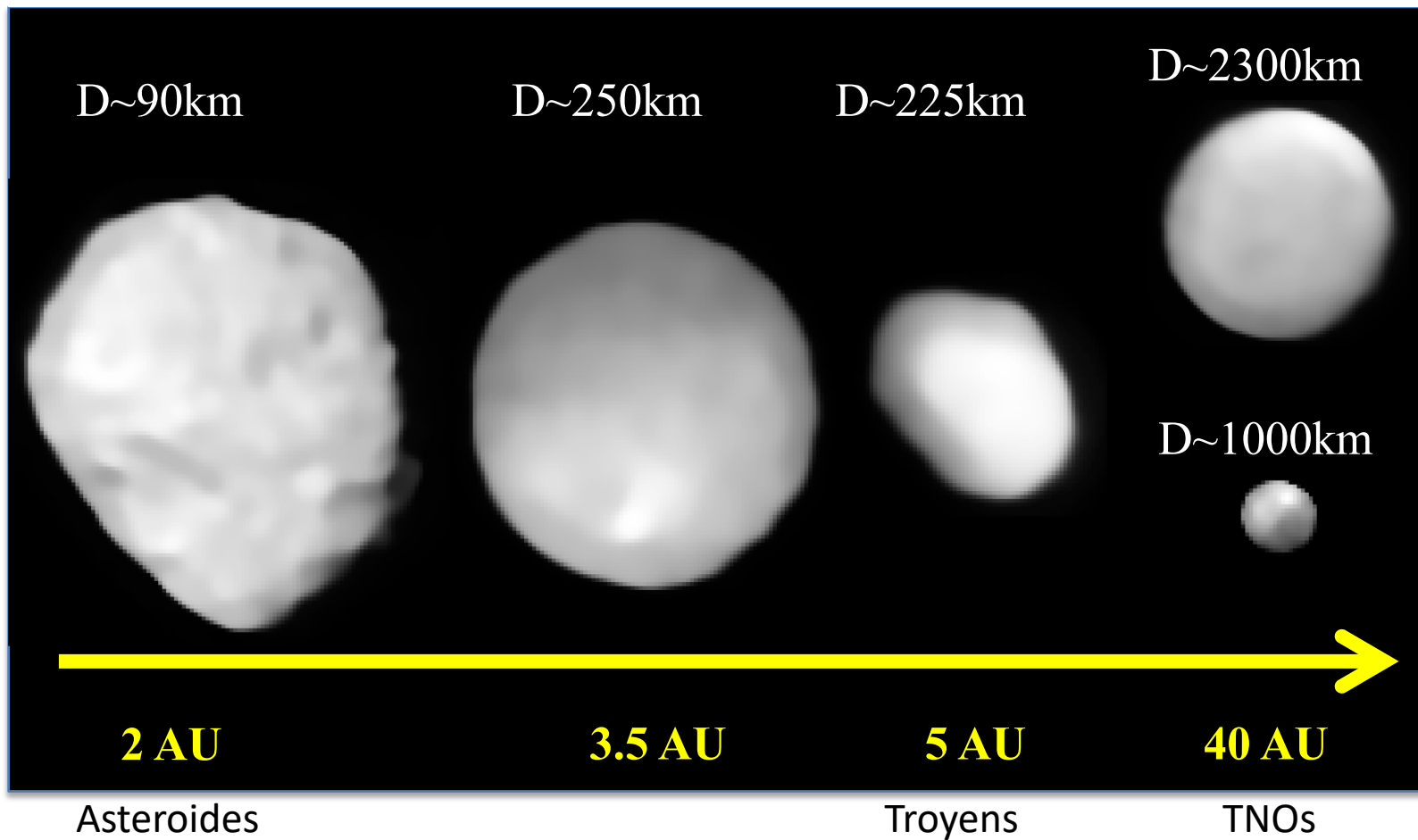


Breakthrough with the ELT in Planetary science

Fainter magnitude + better spatial resolution

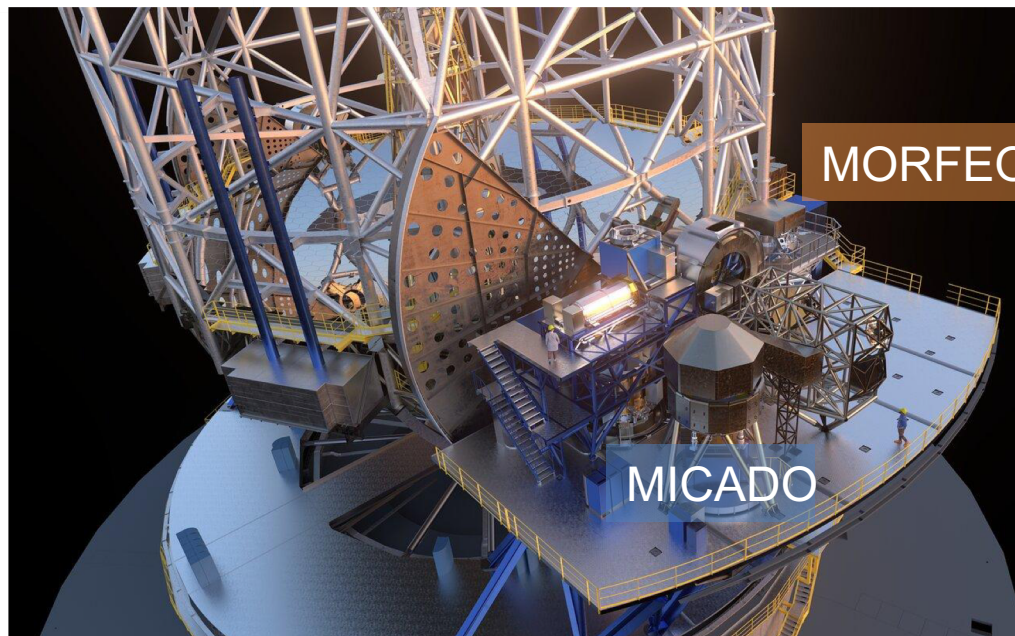


Current VLT/SPHERE survey helps estimating what to expect from ELT





First light instruments



MICADO with MORFEO on Nasmyth Platform

- MORFEO is the Multi-Conjugate Adaptive Optics (MCAO) module of the ELT
 - MICADO & HARMONI.

- The MICADO camera will provide imaging:
 - ✓ with 27 broad/narrow filters in the near-infrared ($0.8\text{--}2.4\ \mu\text{m}$),
 - ✓ 1.5 & 4 mas pixels for $19''$ & $50.5''$ FoV at $6\text{--}12$ mas diffraction limit.
- slit spectroscopy:
 - ✓ Slits $3'' \times 16$ mas (narrow), $3'' \times 48$ mas (wide),
 - ✓ HK ($1.52\text{--}2.45\ \mu\text{m}$) ~ 20000 for point sources, $R \sim 10000$ across slit.
- astrometry, and coronagraphy.





Observing non sidereal objects with AO

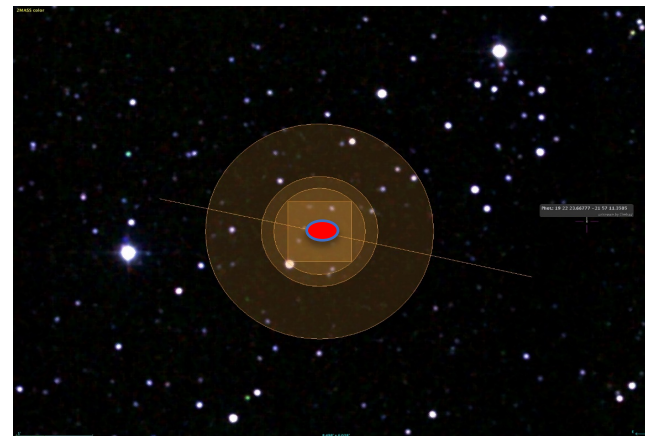
Point like ($\emptyset < 2''$) bright ($16 < \text{mag} < 7$) science target

- ✓ MORFEO will support **SCAO mode** over a small $\sim 10''$ field of view
- Strehl ratio ≈ 0.6 on axis, 0.3 at $10''$ in H band

Targets

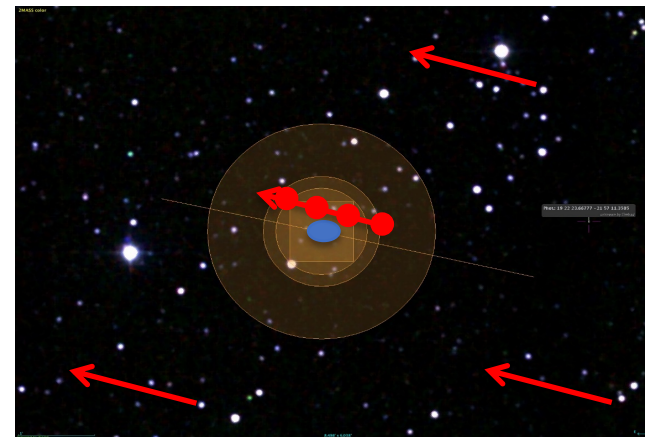
Guide object

SCAO



Star passing close to a faint target (coincidence)

SCAO



SCAO

1 NGS ($R < 16$) ★



Slit spectroscopy non available



Observing non sidereal objects with AO

Faint ($24 < \text{mag} < 16$) slow (motion < 8 mas/sec) objects

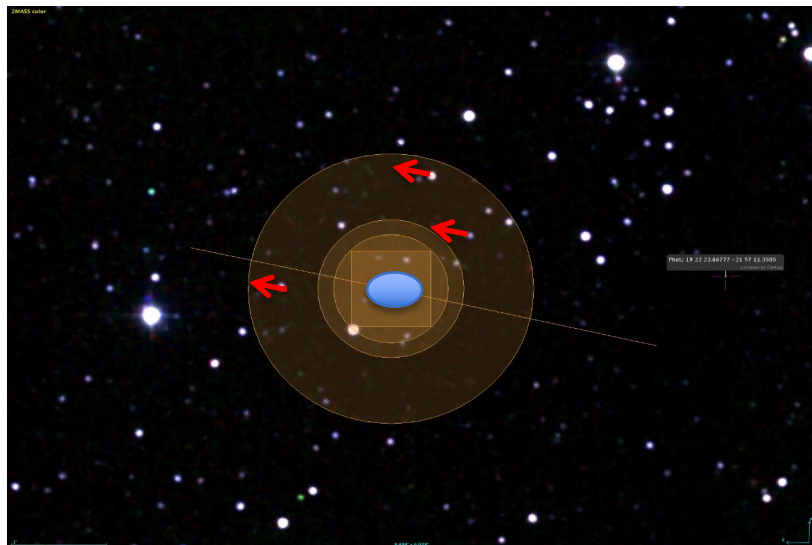
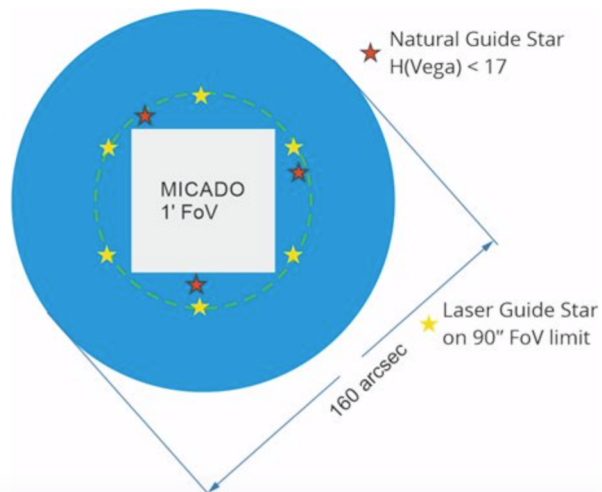
- ✓ MORFEO will provide a **diffraction-limited correction for atmospheric turbulence** over the entire ~ 1 arcmin² MICADO field of view plus **large sky coverage** (MCAO mode)

Targets

Guide object

MCAO

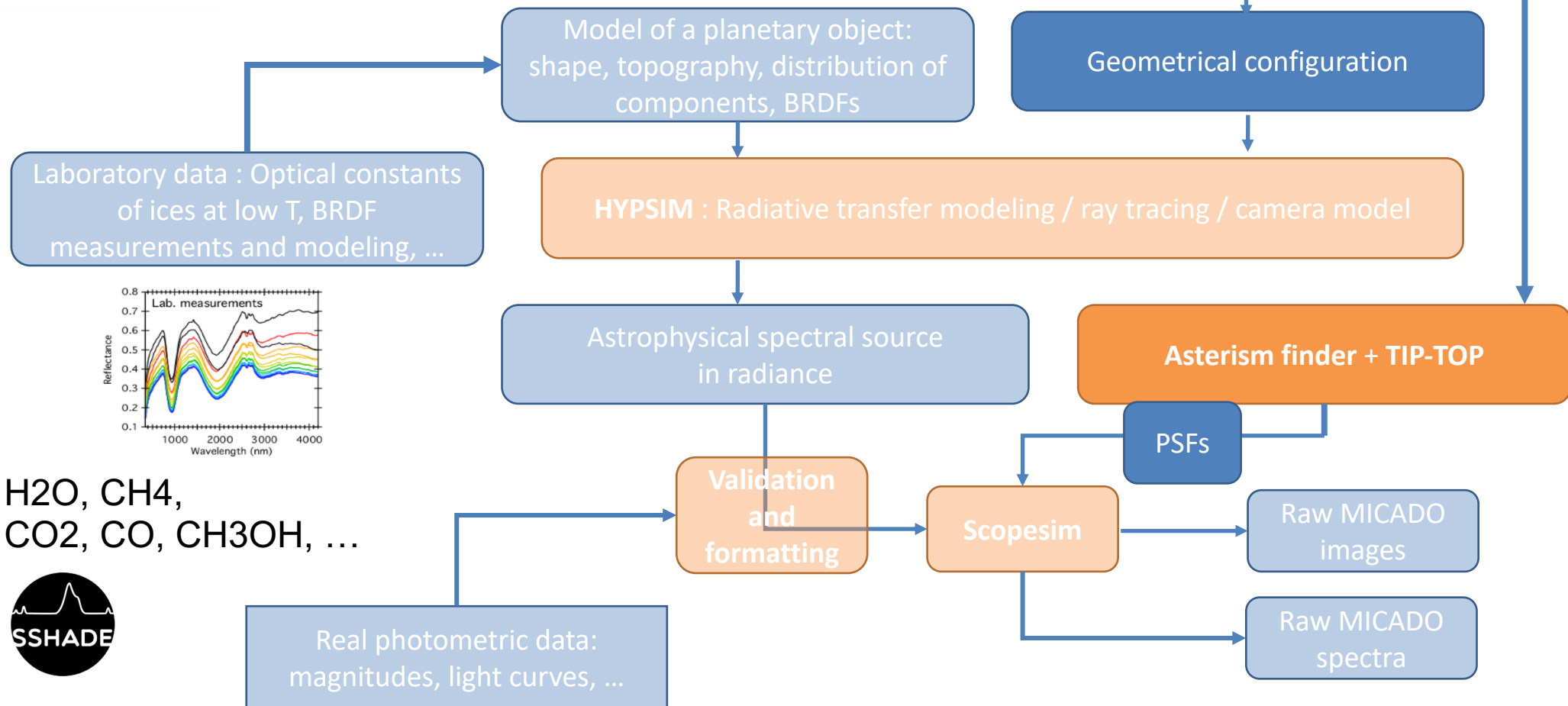
3 NGSs (R<24, H<21) ★
6 LGSs ★



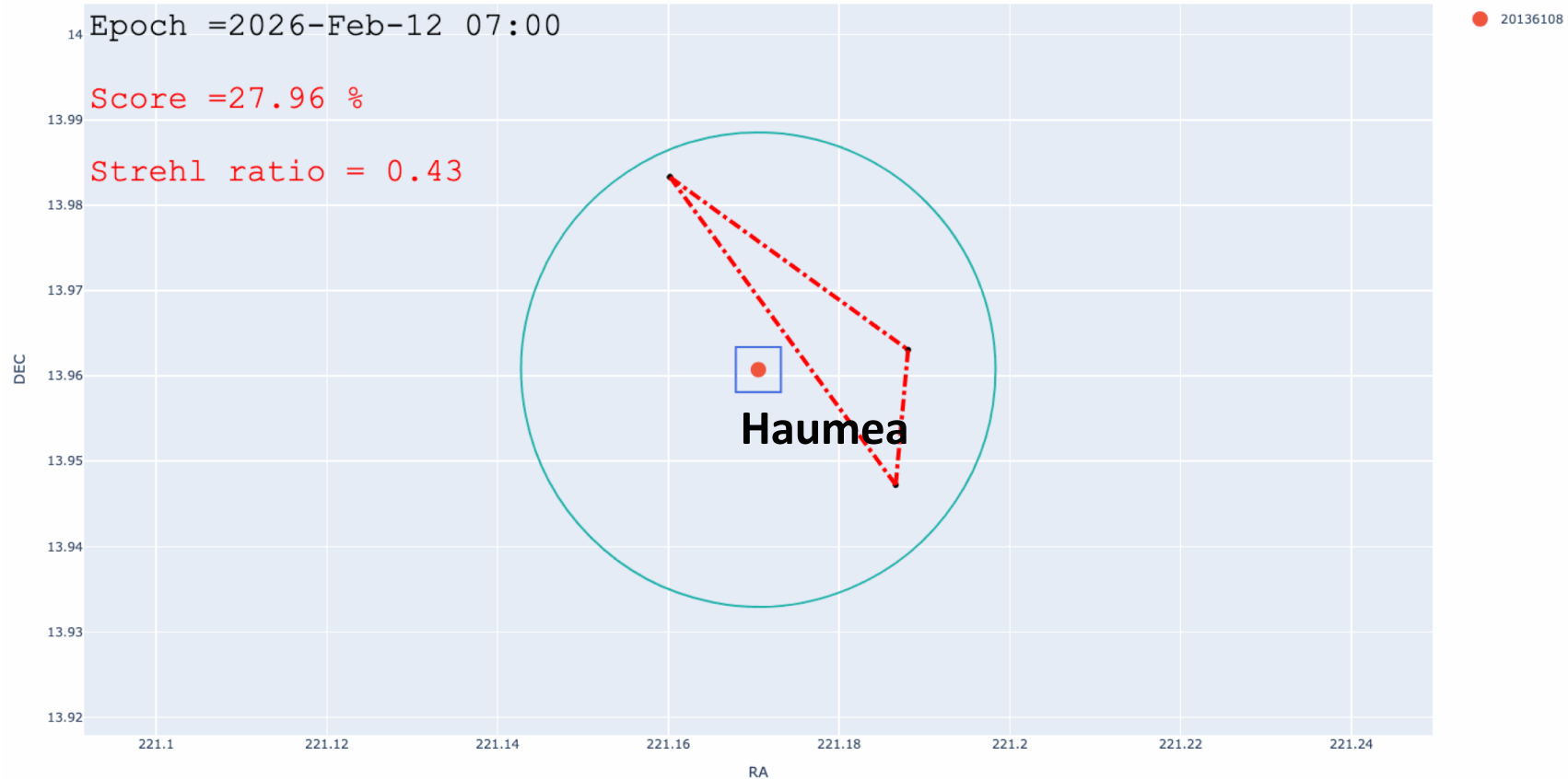
Strehl ratio = 0.44 in K band for 50% of the sky



Preparation tools



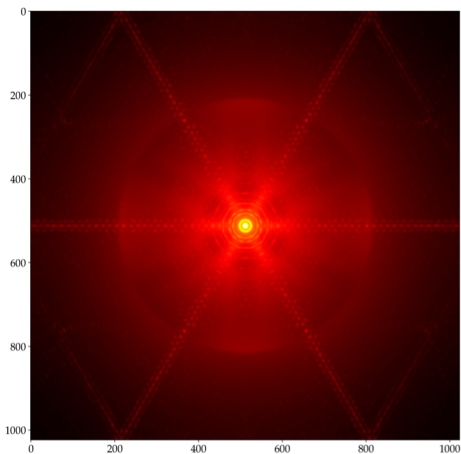
Coincidence statistics : results (semester)



Coincidences are pretty rare when the object is not in the galactic plane:

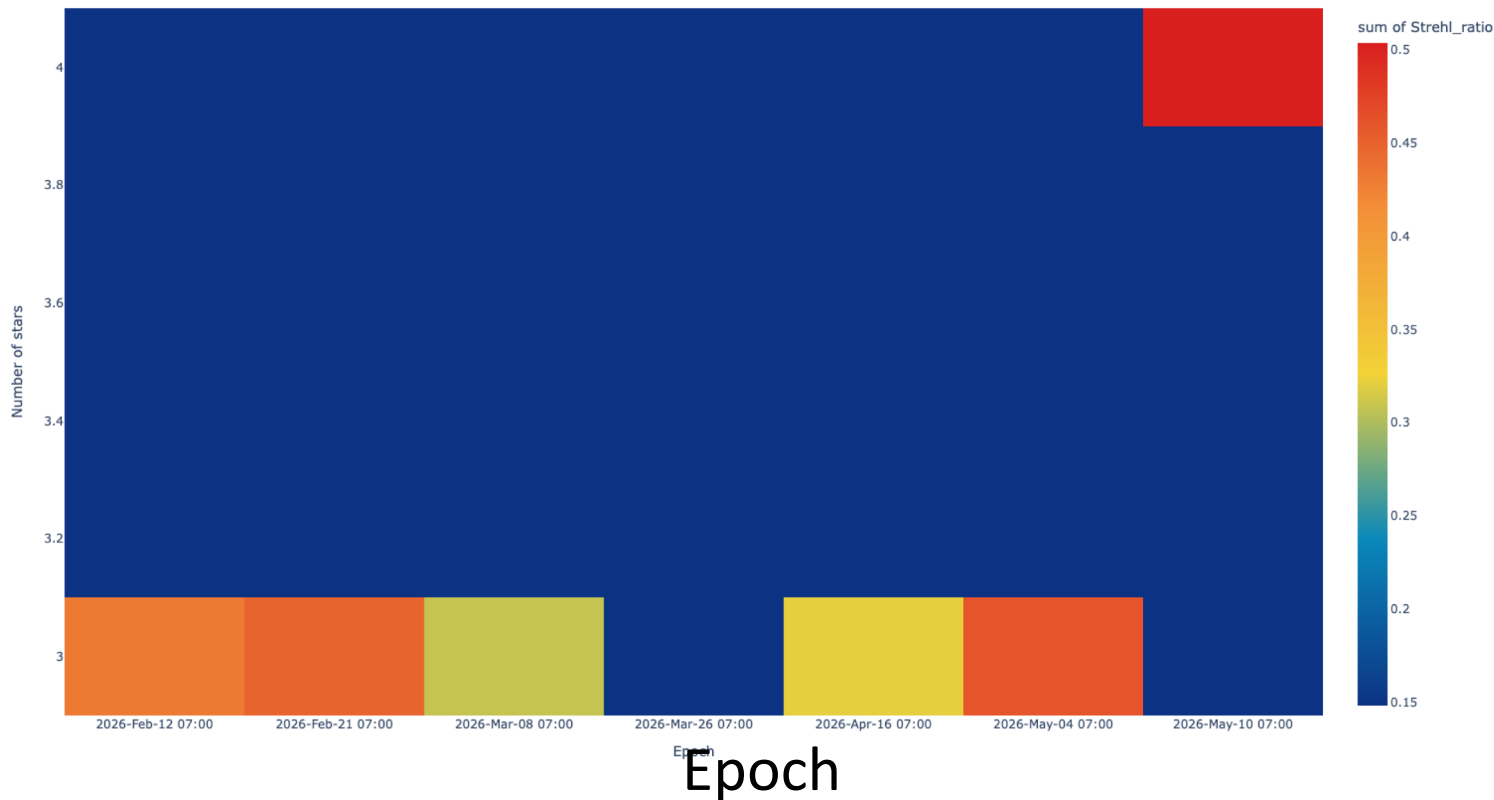


~1-2 coincidence per month



PSF delivered by MORFEO

Number of stars



Haumea coincidence coverage for a over 6 month period

MORFEO science cases: Icy worlds

Understanding their origins, geology, activity, and evolution.

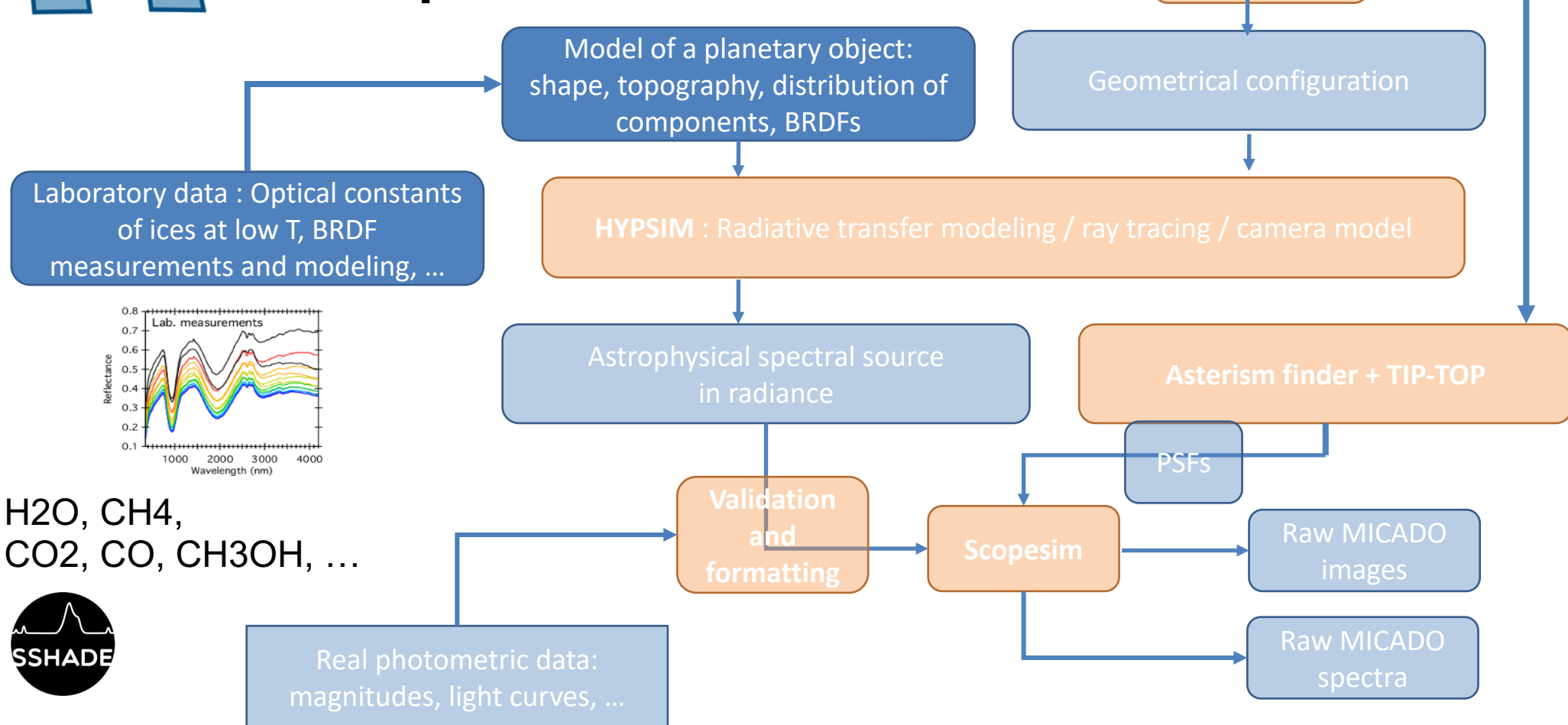
- **Spatially resolved observations**

- **Shape** models (and **density** determination).
- **Large scale geology & compositional** heterogeneities:
 - Europa and Enceladus plumes
 - Europa and Ganymede non icy components
 - Triton icy and non icy components
- **physical properties** (T of ices)
- **Exosphere and atmosphere**
 - Titan clouds, Pluto and Triton seasons.



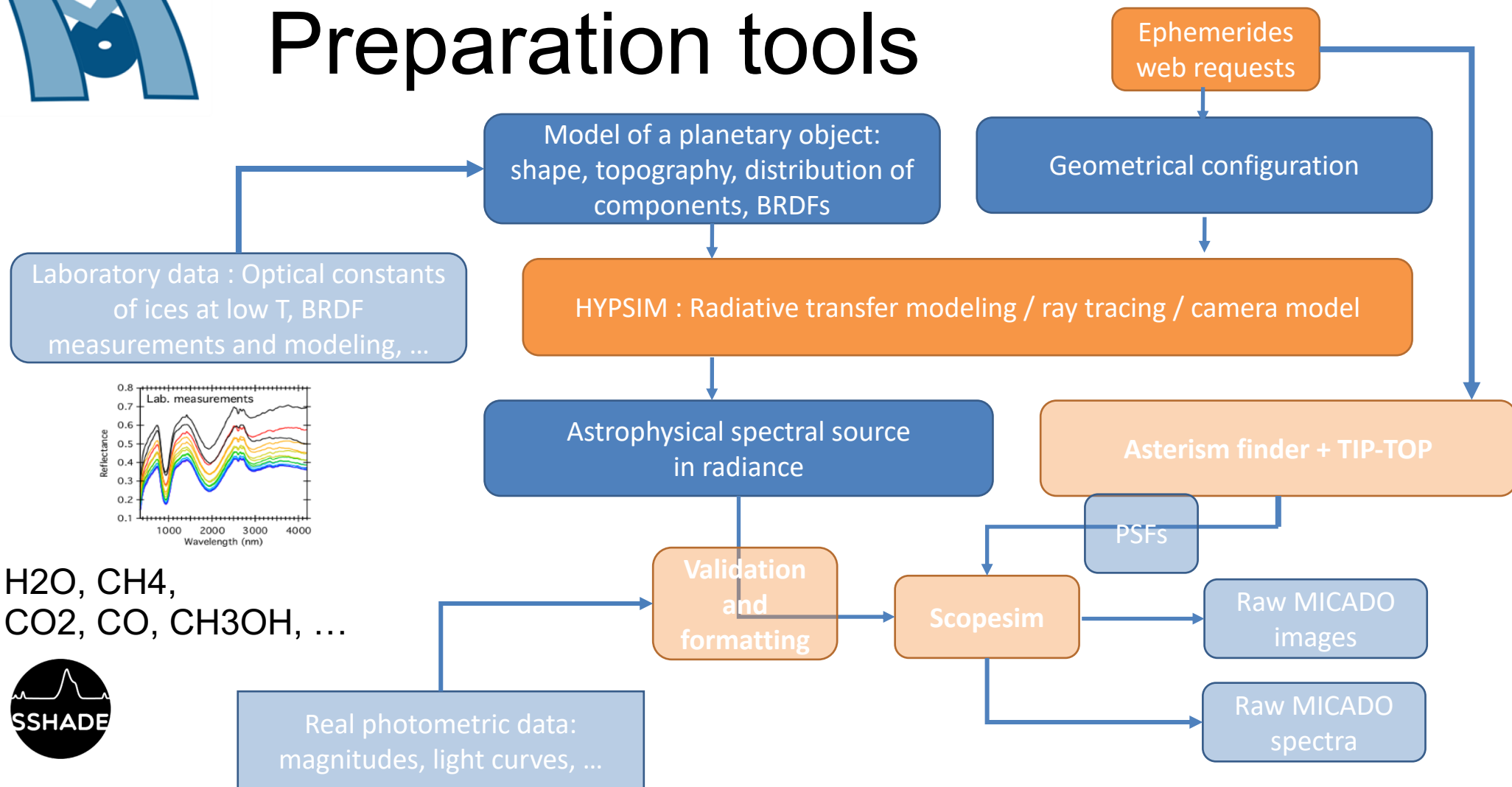


Preparation tools



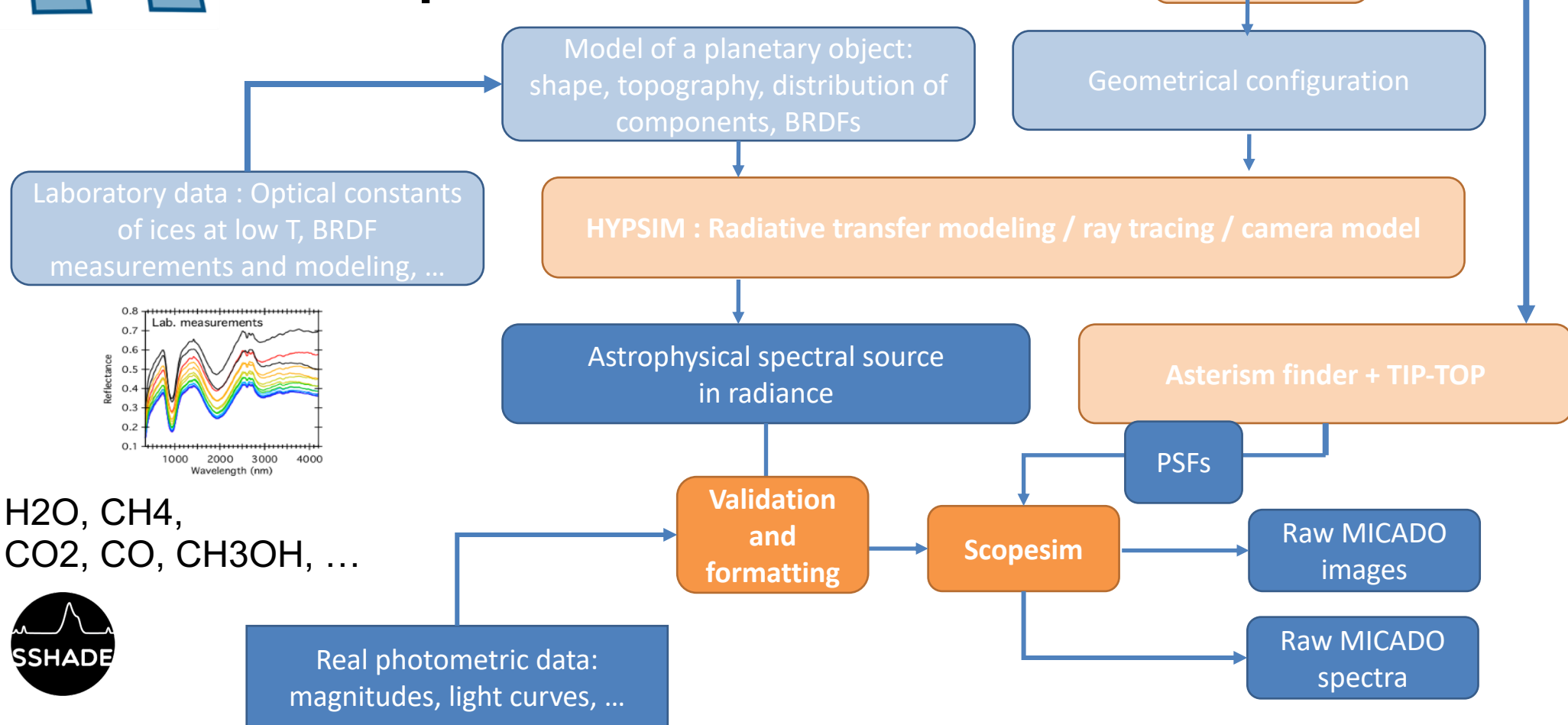


Preparation tools





Preparation tools

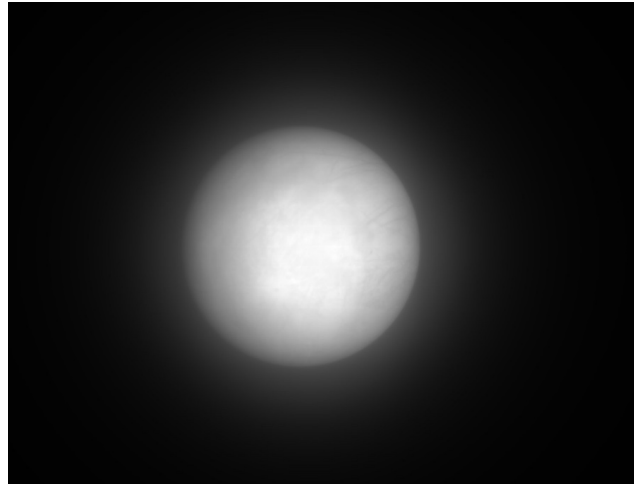


Giant planets and their satellites

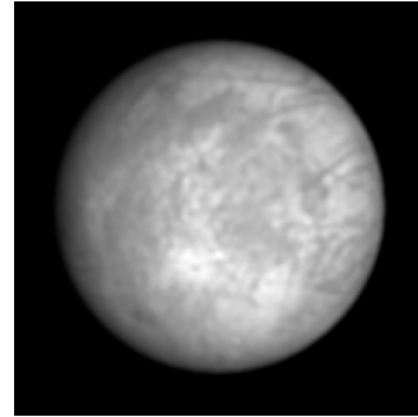
Simulation of deconvolved
images



Europa spectral source in radiance represented in true colors. Calculated from a very realistic spectro-photometric model of Europa surface (NIMS+SSI/Galileo).



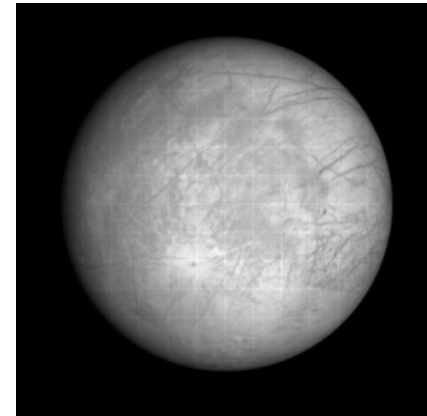
Simulation of a raw image acquired by the MICADO instrument in band I during an ELT observation of Europa.



SPHERE@VLT

Effective spatial resolution:

$\sim 35 \text{ km.pixel}^{-1}$



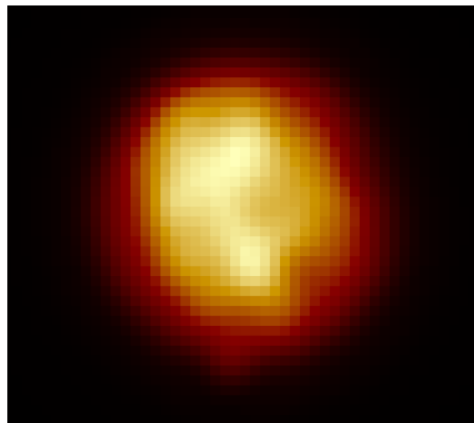
MICADO@ELT

$\sim 15 \text{ km.pixel}^{-1}$

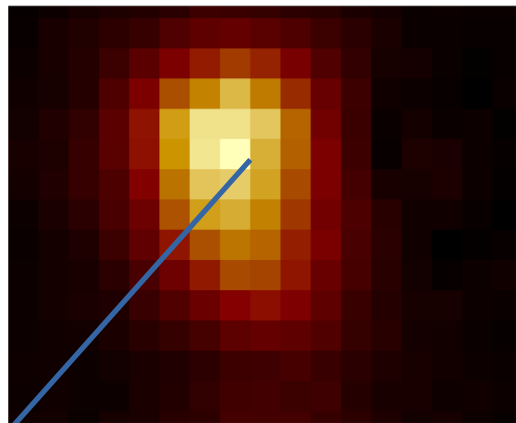
Multi-instrumental investigation: Charon

rh=35AU; d=1200 km
apparent $\emptyset$ 47 mas
V mag.= 17

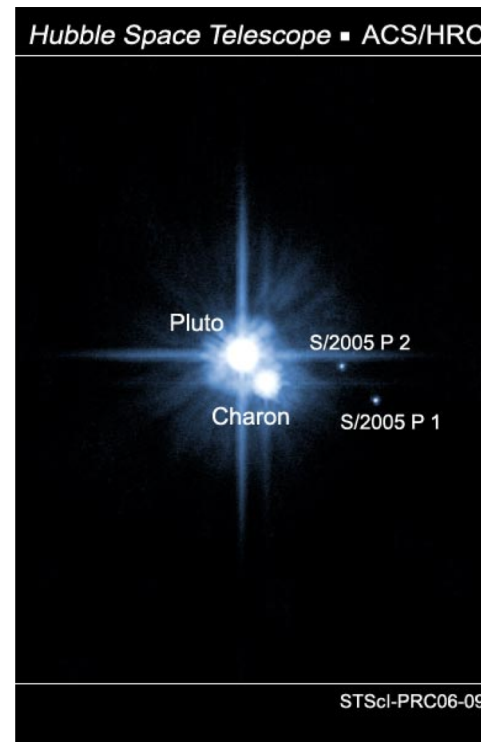
Harmoni H+K band t=300s
6x6 mas



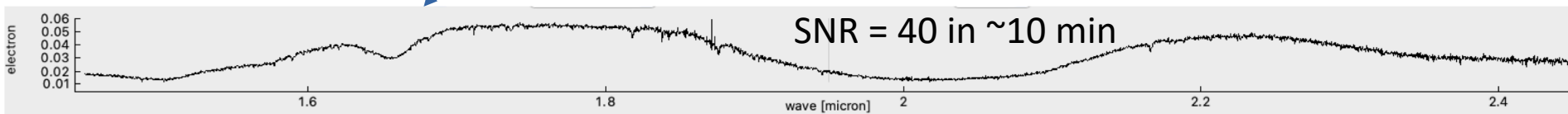
Icy satellite Charon by MICADO
in H band filter



Icy satellite Charon (HARMONI
in H+K band (reduced cube)



Pluto system in 2006 by HST

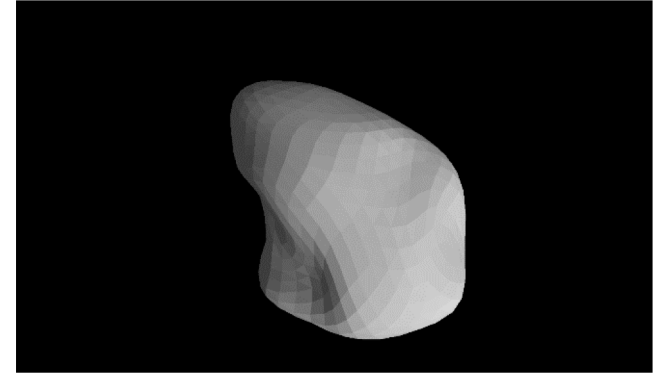


Simulation of images for shape and topography reconstruction

Original Shape Model
(DeepImpact Stardust, 2013)



Reconstructed Shape model from Lightcurves



Error on the volume:

- Lightcurves ~ 18%
- Lightcurves +ELT/Micado ~ 3,7%

Haumea-like KBO

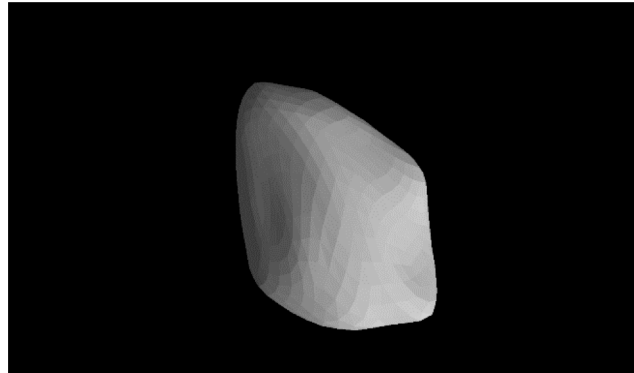
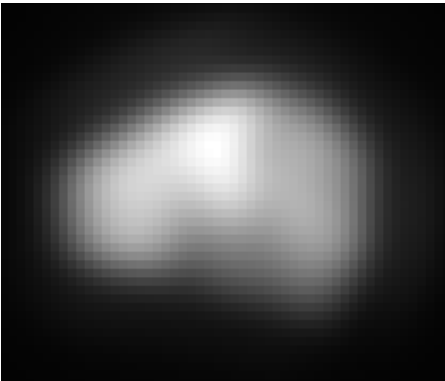
rh=50AU; d=1500 km

apparent $\emptyset$ 28 mas

V mag.= 17

Micado Observation (RAW image)

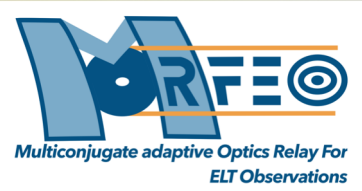
MCAO mode with H Filter (2/03/2033)



Reconstructed Shape model from micado AO images

Conclusions: the ELT preparation, a work in progress

- **Task 0 definition of Solar System reference cases:**
science and technical justification
coordination of the MSSWG for the writing of the Solar System chapter in the MORFEO WB
- **Task 1 AO operations for non sidereal planetary objects:**
 - appulse/asterism statistics,
 - performance statistics (SR, EE, PSF, etc...).
- Task 2 Observation strategy in relation to planetary configurations (distance, phase angle, apparent speed, orbital plane projection, SEP, SSP etc...).
- **Task 3 Compilation of existing laboratory, space, and ground based astronomy data.**
- **Task 4 Simulation of realistic raw data (MICADO, HARMONI).**
- Task 5 **Image processing and calibration**, deconvolution.
- Task 6 high-precision relative astrometry on mutual orbits with MICADO/MORFEO.
- Task 7 Photometry of extended objects.



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Thank you



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MORFEO science cases: Small bodies

Asteroids, Trojans, Centaures, TNOs, comets as witnesses of the early Solar System formation and dynamics

- **Spatially resolved observations**
(size >10 km for asteroids, >500 km for TNOs)
 - **Shape** models (and **density** determination).
 - **Geological** & **compositional** heterogeneities.
 - **Nucleus and Coma** of comets.
 - **Spatially unresolved observations**
Detection and characterization of binaries :
 - orbital and internal properties (**density**),
 - Surface composition.
- Insights into birth place, migration, collisional history, surface aging, space weathering, large scale brecciation, connection with meteorites and dust.



Atmospheres of giant planets

A laboratory to investigate large-scale fluid dynamics and physicochemical phenomena.

- **Spatially resolved observations:**
 - variability of minor gas abundances (CH_4 , NH_3 , H_2S),
 - atmospheric structures (clouds, hazes),
 - winds and weather,
 - giant storms, vortex,
 - aurora.
- **Time variability from yearly to monthly scale.**

