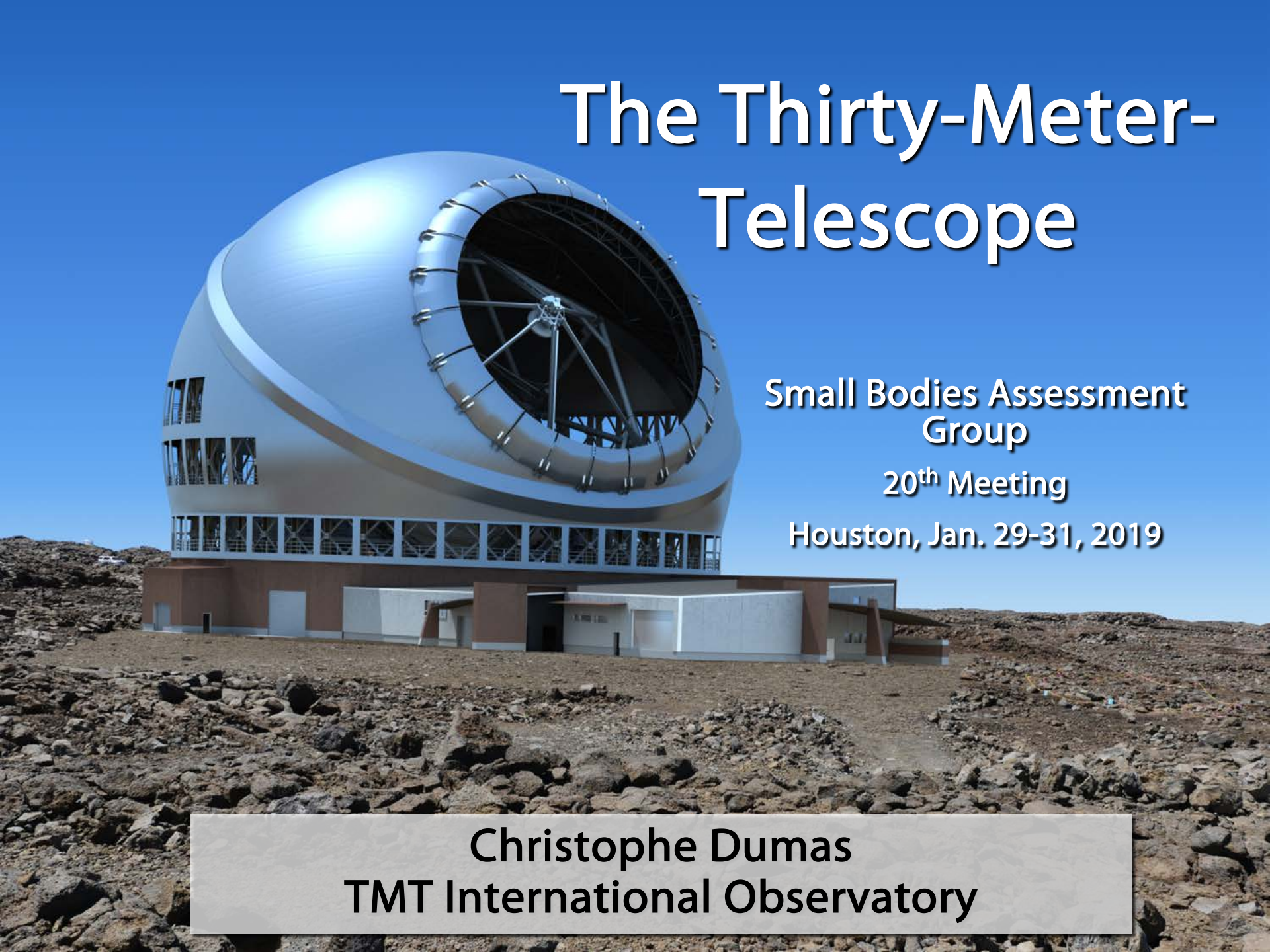
The Thirty-Meter-Telescope



Small Bodies Assessment Group

20th Meeting

Houston, Jan. 29-31, 2019

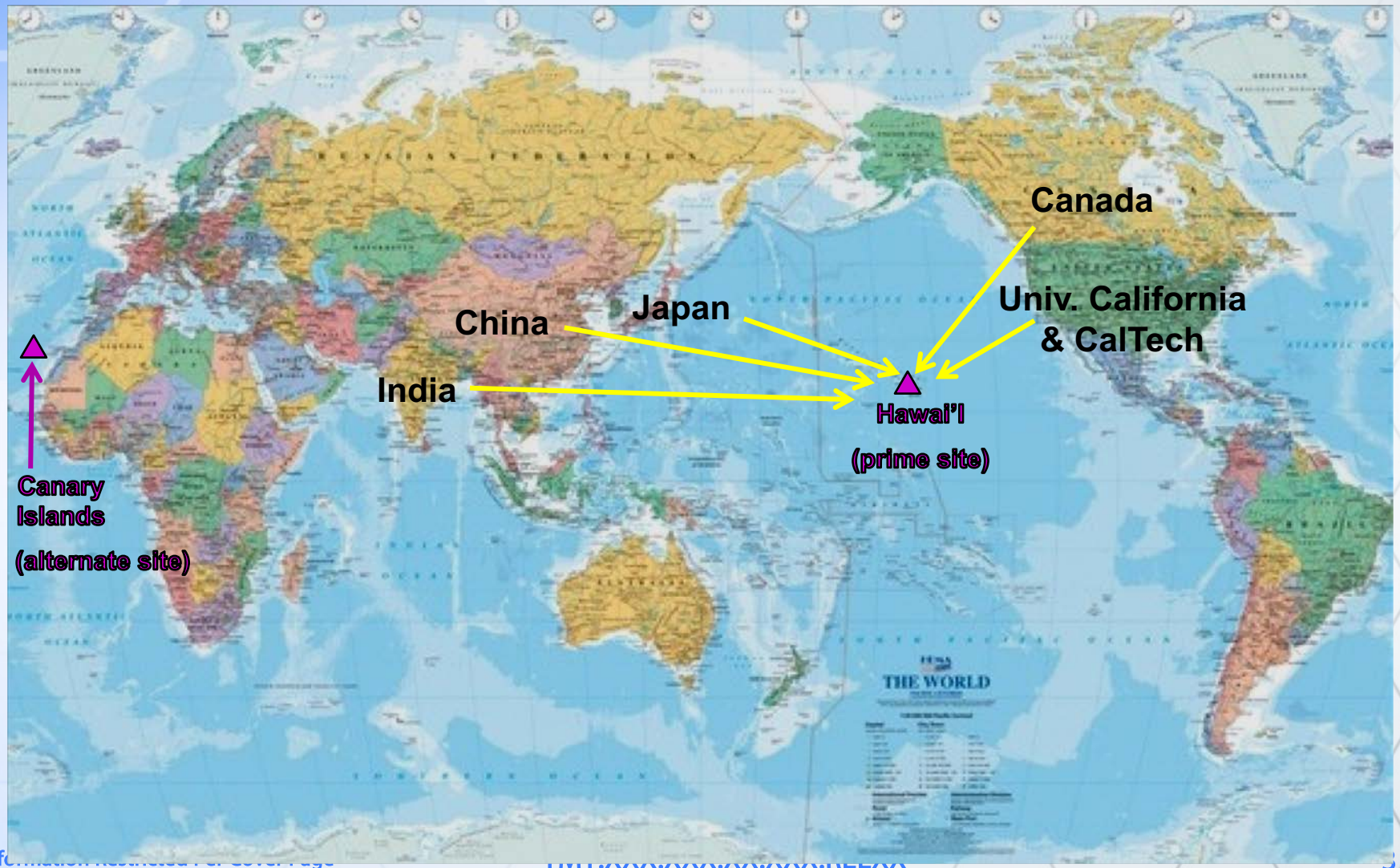
Christophe Dumas
TMT International Observatory

Plan

- Introduction to TMT & project update
- Capabilities for studying the Small Bodies of our Solar System

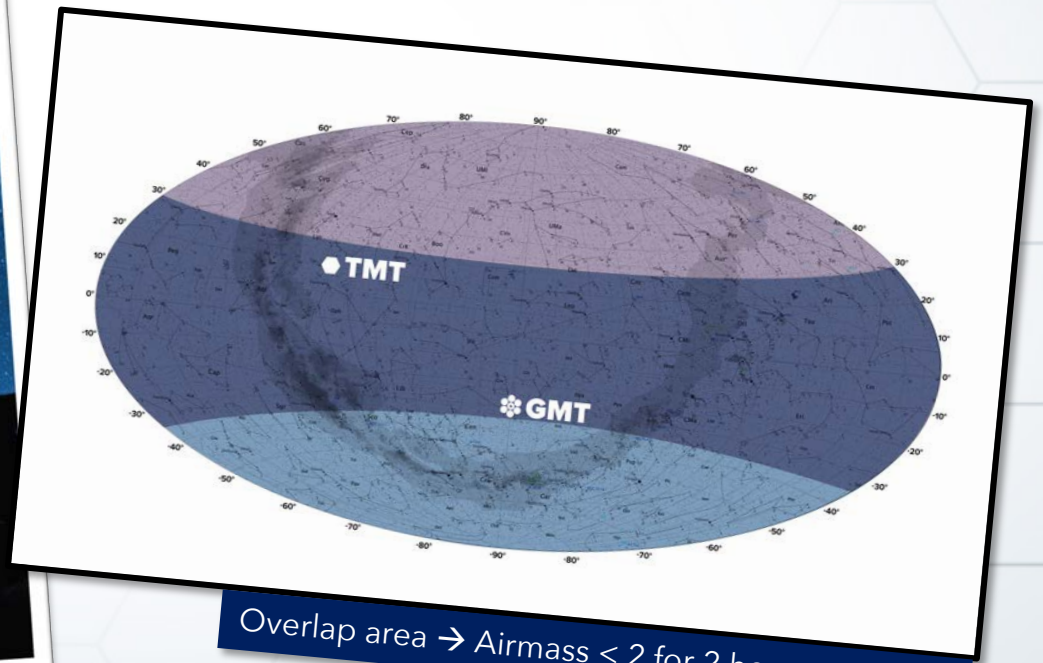
TMT
Thirty Meter Telescope

International Partnership and construction site(s)



US-ELT Program

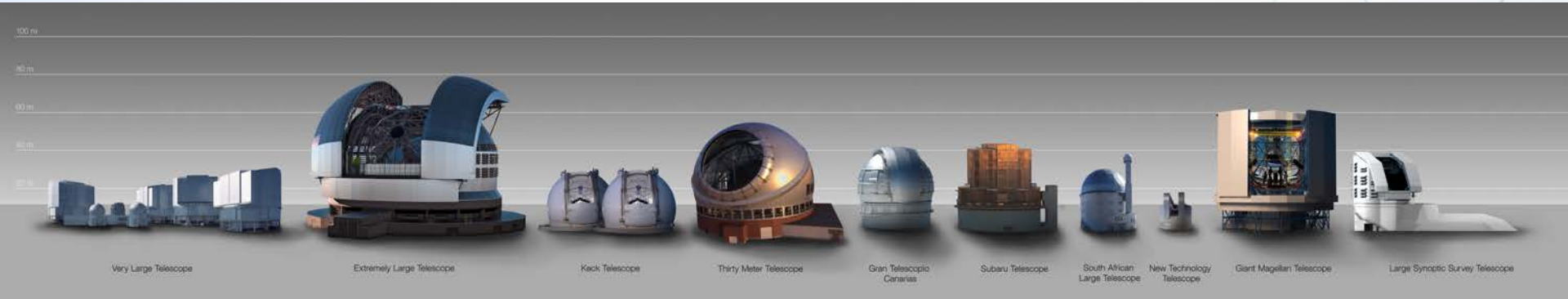
2 telescopes, 2 hemispheres, 1 system
All-sky coverage
Broad instrument suite
US-led Key Science Programs



Overlap area → Airmass < 2 for 2 hours or more

TMT in a nutshell

- Wide-field, Alt-Az Ritchey-Chretien telescope
- 30 meter diameter primary mirror (**492 hexagonal segments**, 1.44m across corners)
- Can **swap instrument/targets in ~ 10 minutes**
- Can track **fast non-sidereal targets** (e.g. NEOs)
- **Up to 8 instruments** on two Nasmyth platforms
- **First-light AO system (NFIRAOS):**
  - Laser Guide Star Facility (LGSF) Multi-Conjugate-AO (MCAO)
  - Diffraction-limit at J, H, and K bands, can feed 3 instruments.
- Expected (re-)start of construction: 2019. First-light: 2027/28



TMT's science operations model
(work in progress . . .)

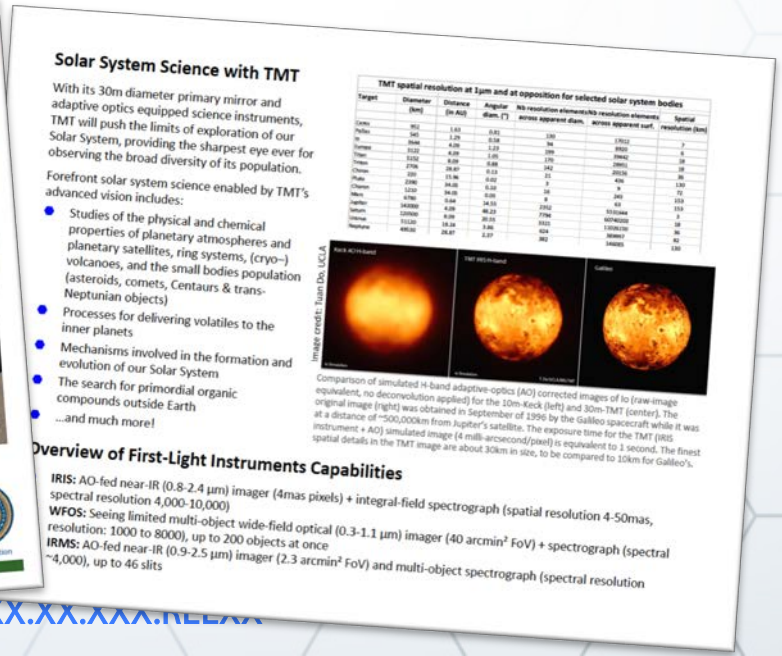
- TMT will support **visitor** (PI-mode) & **service** (queue) **observing modes** (inc. ToOs, eavesdropping)
  - Visitor mode: All observations done remotely from HQs
- TMT **operations staff will support all science operations activities**
  - Proposal submission, observing preparation/execution, instrument performance-monitoring/upgrades, quality control, data-reduction
- Proposal cycle of 12 months with **fast-turnaround**
- **All data archived**: Raw, calibrations, metadata, possibly reduced-data (proprietary period ~ 18months)

Current construction timeline

- **Today:** Access granted in Hawaii and La Palma (*only a few admin steps away in Hawaii*)
- **2019:** Start of construction in Hawaii (*La Palma is backup site*)
- **2020 -2022:** Enclosure assembly
  - End 2023: End construction of all summit buildings
- **2022-2024:** Telescope structure integration
- **2024 -2027:** AIV, commissioning
- **2028: "First-light"**

Science / instruments capabilities

- Dynamical and compositional monitoring & mapping of planetary surfaces & atmospheres
  - Support of space missions
- Study of the most primitive bodies in our solar system
  - Transport of volatiles across solar-system, search for organics
- Observing time-variable events (quick operational response-time)



Solar System Science with TMT

With its 30m diameter primary mirror and adaptive optics equipped science instruments, TMT will push the limits of exploration of our Solar System, providing the sharpest eye ever for observing the broad diversity of its population.

Forefront solar system science enabled by TMT's advanced vision includes:

- Studies of the physical and chemical properties of planetary atmospheres and planetary satellites, ring systems, (cryo–) volcanoes, and the small bodies population (asteroids, comets, Centaurs & trans-Neptunian objects)
- Processes for delivering volatiles to the inner planets
- Mechanisms involved in the formation and evolution of our Solar System
- The search for primordial organic compounds outside Earth
- ...and much more!

TMT spatial resolution at 1μm and at opposition for selected solar system bodies

Target	Diameter (km)	Distance (in AU)	Angular diam. (")	No resolution elements across apparent diam.	No resolution elements across apparent surf.	Spatial resolution (km)
Ceres	952	1.63	0.91	130		
Pallas	545	1.29	0.58	94	17512	7
Io	3640	4.20	1.23	199	8920	9
Europa	3122	4.20	1.05	170	28442	9
Titan	5152	9.19	0.88	142	20491	18
Triton	2706	28.87	0.13	21	20155	36
Charon	590	15.96	0.02	3	426	130
Pluto	2390	34.10	0.10	16	9	71
Ceres	1210	34.19	0.04	7	241	153
Vesta	4760	3.04	1.57	254	64	153
Jupiter	143000	4.28	23.12	3748	55310444	3
Saturn	120500	8.39	8.23	1335	60740224	18
Uranus	51120	18.14	2.31	374	13026150	36
Neptune	49530	28.87	1.17	190	308957	62
					344885	130

Image credit: Juan Ds. UCLA

Comparison of simulated H-band adaptive-optics (AO) corrected images of Io (raw-image equivalent, no deconvolution applied) for the 10m-Keck (left) and 30m-TMT (center). The original image (right) was obtained in September of 1996 by the Galileo spacecraft while it was at a distance of ~500,000km from Jupiter's satellite. The exposure time for the TMT (IRIS instrument + AO) simulated image (4 milli-arcsecond/pixel) is equivalent to 1 second. The finest spatial details in the TMT image are about 30km in size, to be compared to 10km for Galileo's.

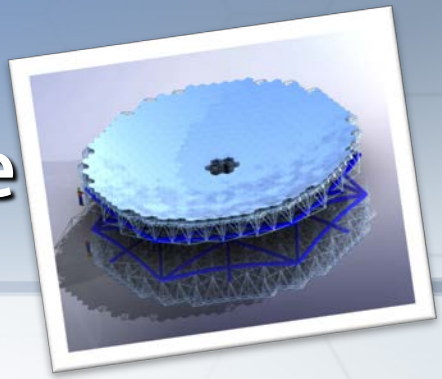
Overview of First-Light Instruments Capabilities

IRIS: AO-fed near-IR (0.8-2.4 μm) imager (4mas pixels) + integral-field spectrograph (spatial resolution 4-50mas, spectral resolution 4,000-10,000)

WFOS: Seeing limited multi-object wide-field optical (0.3-1.1 μm) imager (40 arcmin² FoV) + spectrograph (spectral resolution: 1000 to 8000), up to 200 objects at once

IRMS: AO-fed near-IR (0.9-2.5 μm) imager (2.3 arcmin² FoV) and multi-object spectrograph (spectral resolution ~4,000), up to 46 slits

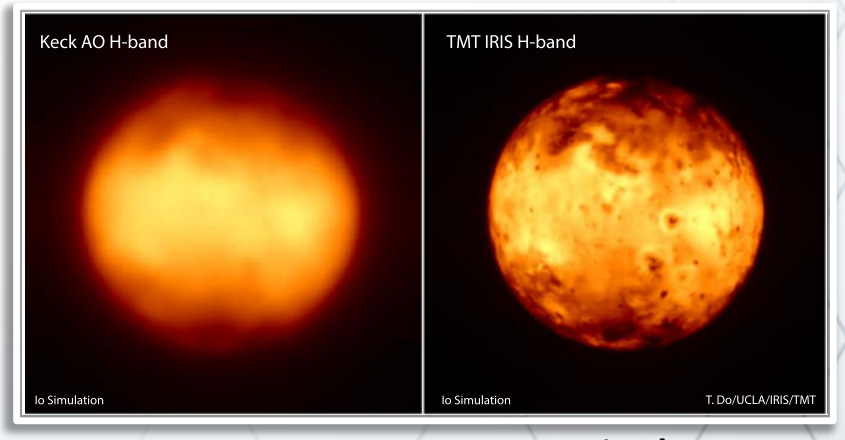
Expected boost in performance



- SENSITIVITY: $S \sim D^2$
  - **~10 times the collecting area of Keck, or ~150 times that of the HST**
    - For AO on point sources: **$S \sim D^4$, i.e. ~200 times better than current VLTs**

Pluto-Charon

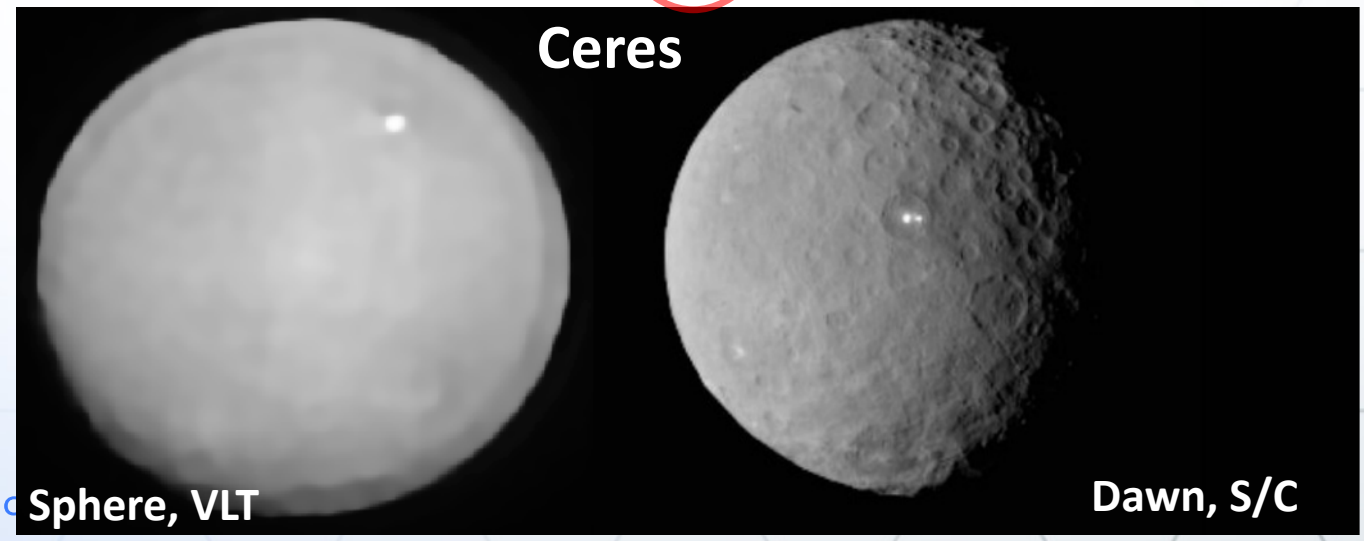
- ANGULAR RESOLUTION:
  - **12 times better HST**
  - **3-4 times better than current VLTs**



Jupiter's moon - Io

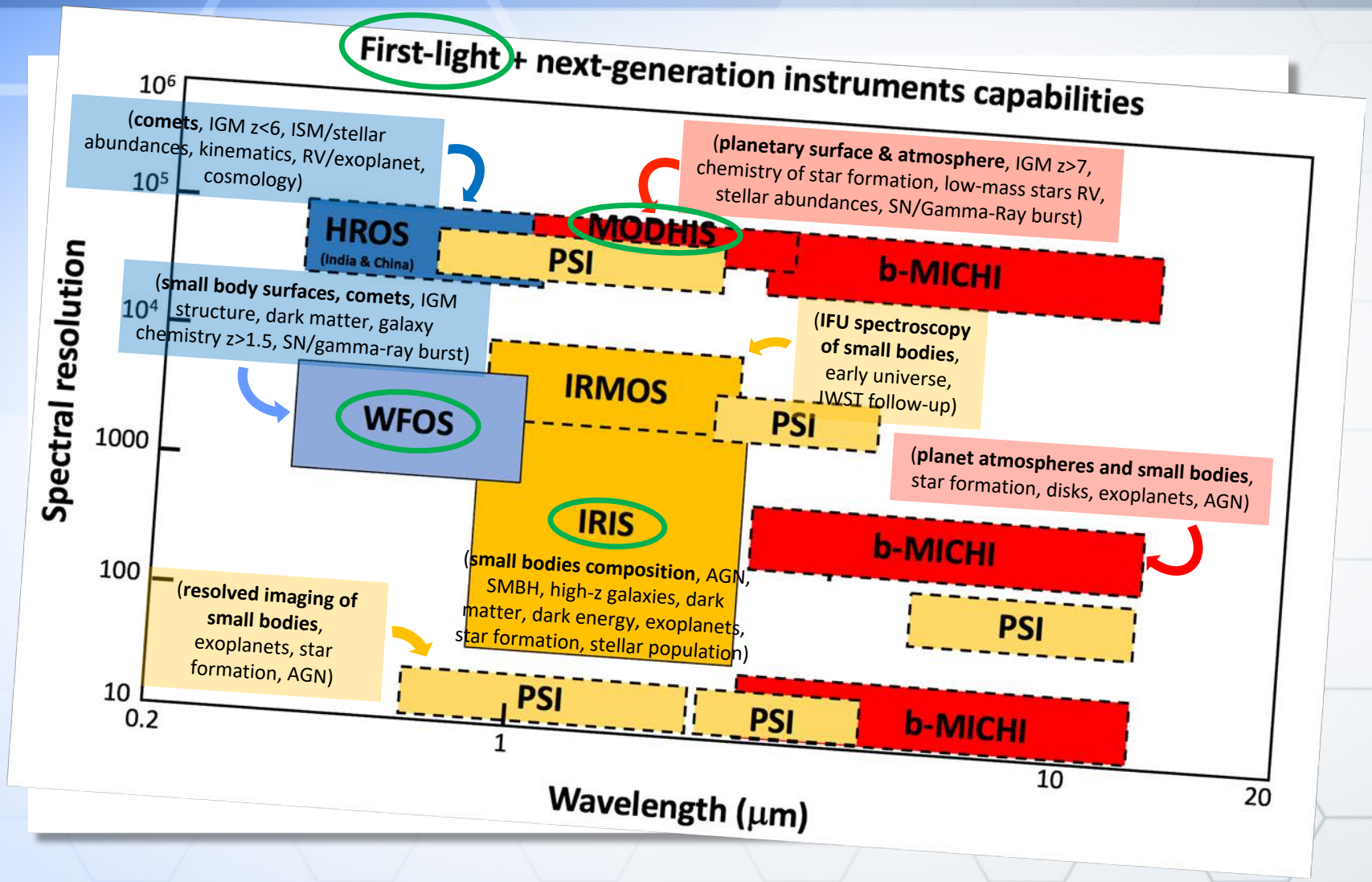
TMT spatial resolution at 1µm and at opposition for selected solar system bodies

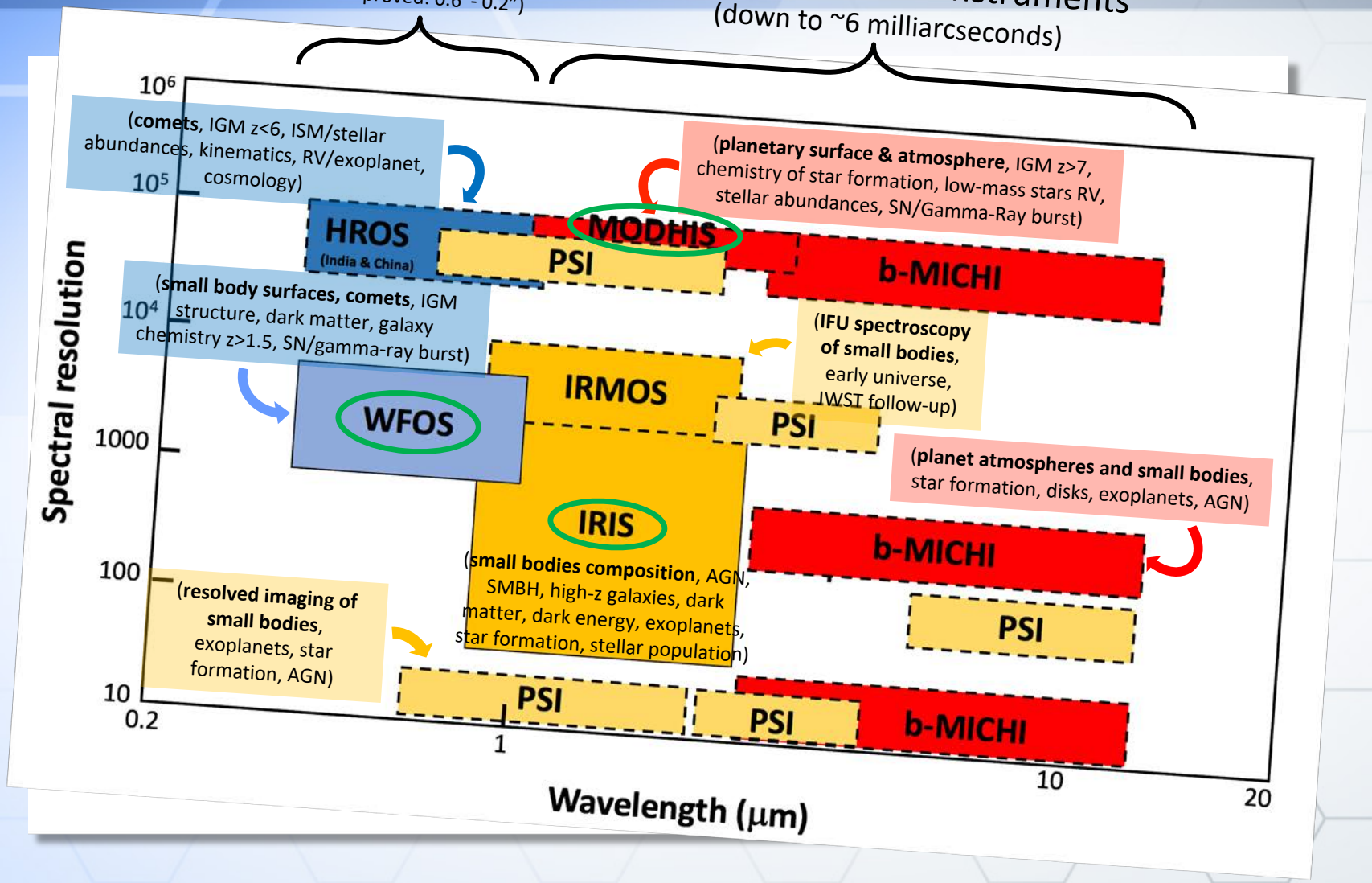
Target	Diameter (km)	Distance (in AU)	Angular diam. (")	Nb resolution elements across apparent diam.	Nb resolution elements across apparent surf.	Spatial resolution (km)
Ceres	952	1.63	0.81	130 (~30 with VLT)	17012	7
Pallas	545	1.29	0.58	94	8920	6
Io	3644	4.09	1.23	199	39442	18
Europa	3122	4.09	1.05	170	28951	18
Titan	5152	8.09	0.88	142	20156	36
Triton	2706	28.87	0.13	21	436	130
Chiron	220	15.96	0.02	3	9	72
Pluto	2390	34.05	0.10	16	245	153
Charon	1210	34.05	0.05	8	63	153
Mars	6780	0.64	14.55	2352	5531644	3
Jupiter	143000	4.09	48.23	7794	60740203	18
Saturn	120500	8.09	20.55	3321	11026150	36
Uranus	51120	18.24	3.86	624	389997	82
Neptune	49530	28.87	2.37	382	146085	130



TMT instruments

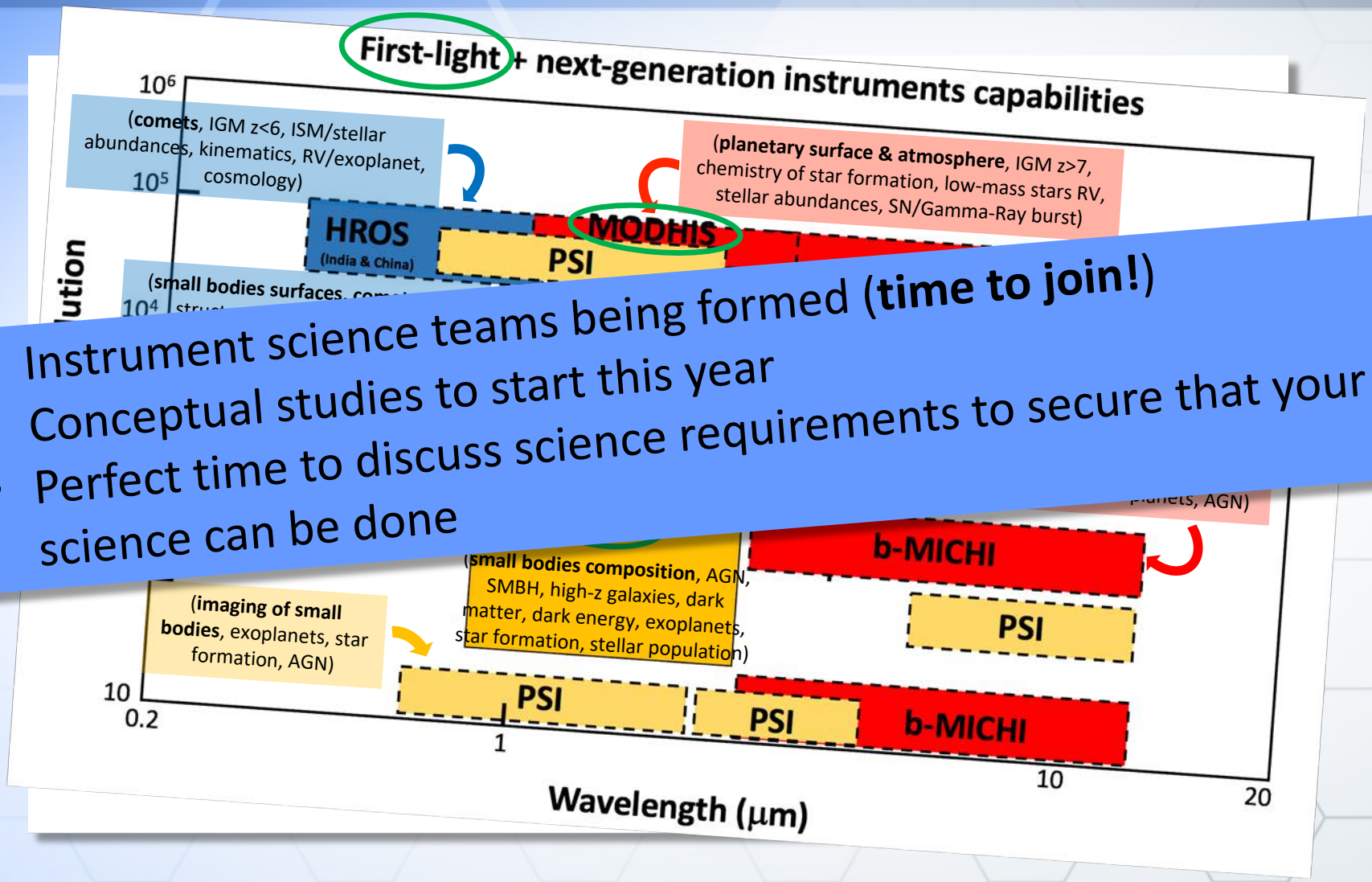
Discovery space




Seeing-limited
(or improved: 0.6”- 0.2”)
Diffraction-limited instruments
(down to ~6 milliarcseconds)
(comets, IGM z<6, ISM/stellar abundances, kinematics, RV/exoplanet, cosmology)
(planetary surface & atmosphere, IGM z>7, chemistry of star formation, low-mass stars RV, stellar abundances, SN/Gamma-Ray burst)
HROS
(India & China)
MODHIS
PSI
b-MICHI
(small body surfaces, comets, IGM structure, dark matter, galaxy chemistry z>1.5, SN/gamma-ray burst)
(IFU spectroscopy of small bodies, early universe, JWST follow-up)
IRMOS
WFOS
PSI
(planet atmospheres and small bodies, star formation, disks, exoplanets, AGN)
IRIS
b-MICHI
(small bodies composition, AGN, SMBH, high-z galaxies, dark matter, dark energy, exoplanets, star formation, stellar population)
(resolved imaging of small bodies, exoplanets, star formation, AGN)
PSI
PSI
PSI
b-MICHI
Spectral resolution
10^6
10^5
10^4
1000
100
10
0.2
1
10
20
Wavelength (μm)

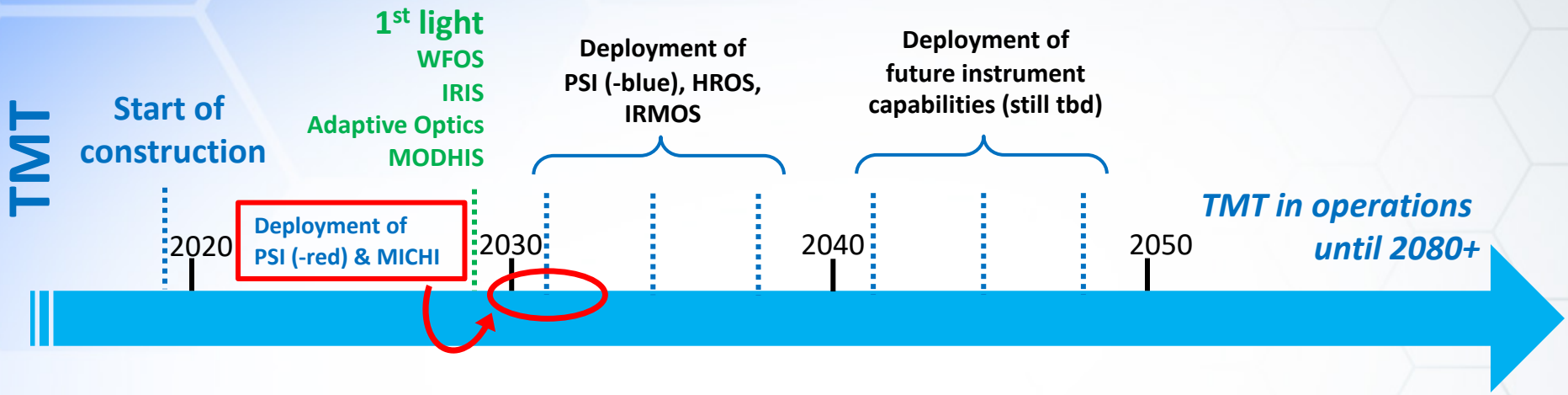
TMT instruments

Discovery space



- Instrument science teams being formed (**time to join!**)
- Conceptual studies to start this year
- Perfect time to discuss science requirements to secure that your science can be done

Possible timeline of instrument deployment 1st light and "next-generation"



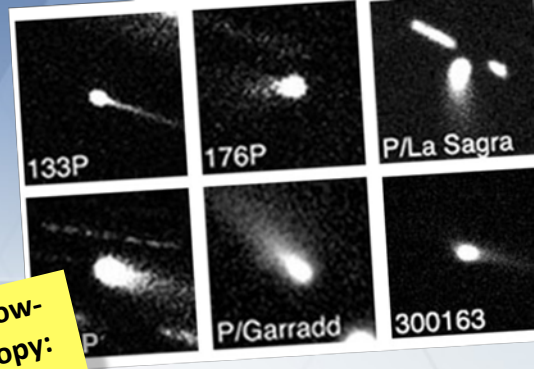
Recommendation: The National Science Foundation (NSF) should invest in both the GMT and TMT and their exoplanet instrumentation to provide all-sky access to the U.S. community. (Chapter 4)

From "Exoplanet science strategy", 2018, National Academy Press

Recommendation: NASA should implement high-contrast starlight suppression technologies in near-term space- and ground-based direct imaging missions. (Chapter 5)

From "Astrobiology strategy to search for life in the universe", 2018, National Academy Press

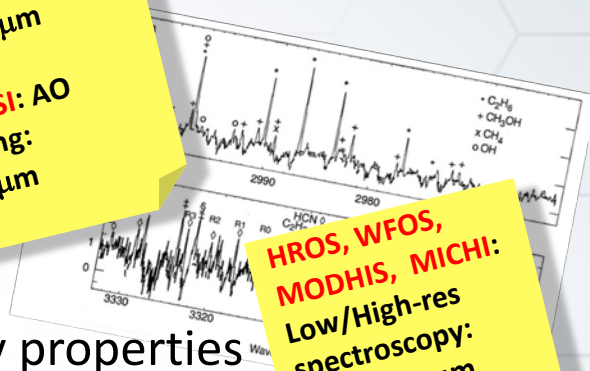
Small bodies



- Asteroids (dry, "wet", main-belt comets)
  - Satellites/rings: Search and characterization
  - 3-D shape and collision history
  - Surface composition (search for ices, organics)
- Comets
  - Near-IR and infrared regions are fundamental to study properties of released molecules
    - D/H ratio, nuclear spin temperatures of some species (e.g. NH_3, H_2O and dissociated products). Organic and prebiotic chemistry
  - Spectroscopy in the blue/UV (λ<0.4μm)
- Centaurs & Trans-Neptunians are faint, BUT brightest can be observed with AO/LGS (directly or w/ star appulse)
  - cryo-volcanism activity, ring structures, satellites
    - e.g. Chariklo, Chiron?, Haumea

IRIS, MICHI: Low-res spectroscopy: λ= 1-15 μm

IRIS, PSI: AO imaging: 0.8-2μm



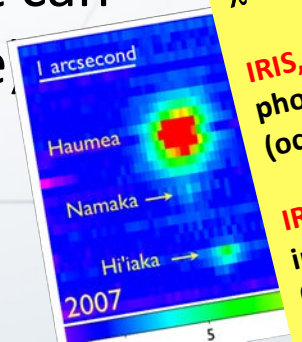
HROS, WFOS, MODHIS, MICHI: Low/High-res spectroscopy: λ= 0.5-15 μm

IRIS: Vis/near-IR imaging (MCAO)

IRIS: Low-res spectroscopy: λ= 1-2.5 μm

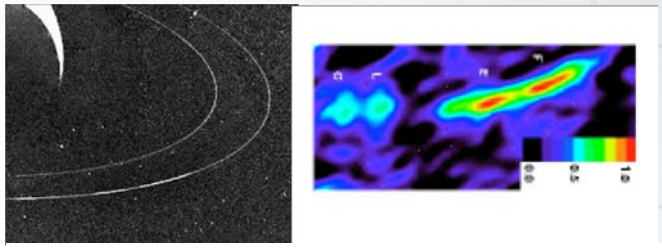
IRIS, WFOS: Fast photometry (occultations)

IRIS, PSI: AO imaging: 0.8-2μm

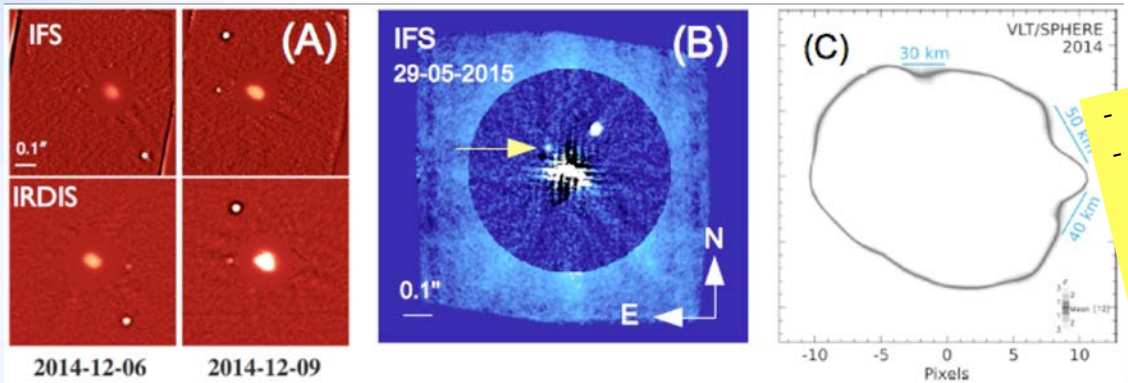


Small bodies: Shape models, moons and rings

- Moons and rings observations to study solar system dynamics and collisions (via direct imaging or occultations)



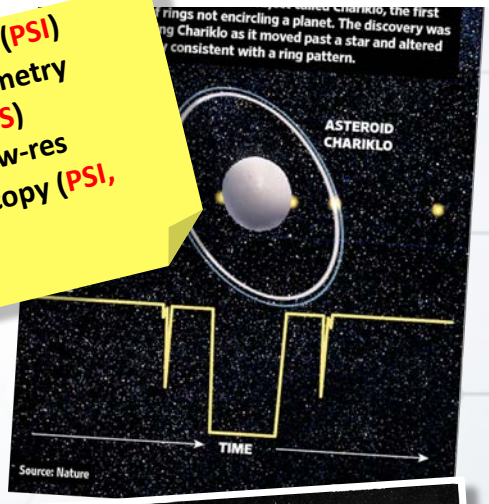
Neptune's ring arcs. Voyager and HST/Nicmos

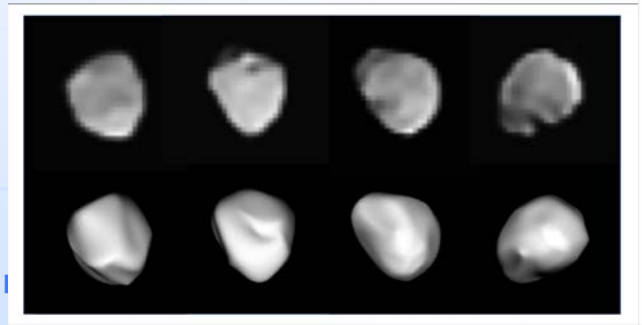


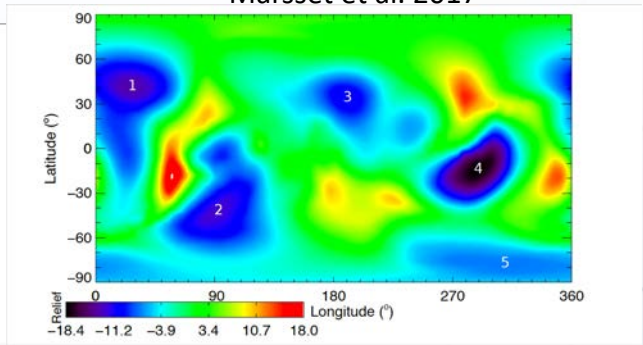
Triple asteroid Elektra and Minerva. Yang et al. 2017

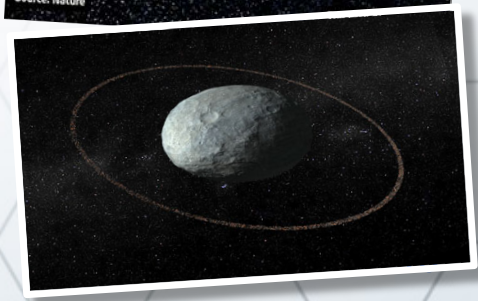
Asteroid Hebe
Marsset et al. 2017

- AO imaging (PSI)
- Fast photometry (WFOS, IRIS)
- near-IR low-res spectroscopy (PSI, IRIS)





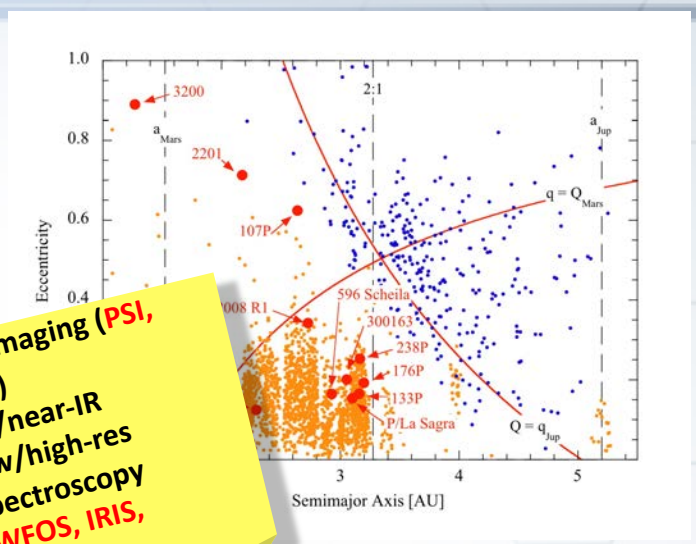




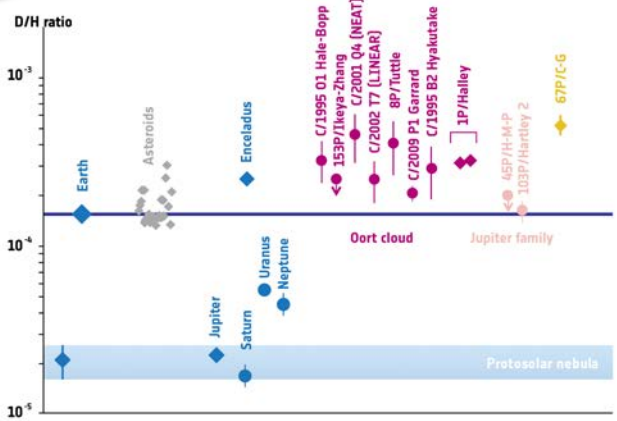
Origin / transport of water to inner solar system

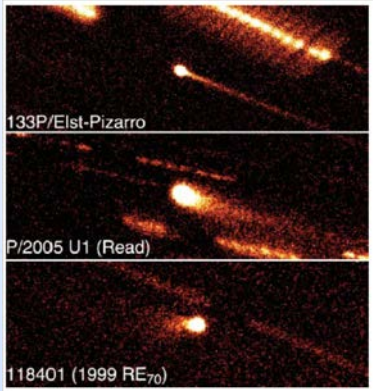
- Terrestrial planets got their water via transport of small, hydrated, solar system bodies such as asteroids, comets, trans-Neptunian objects

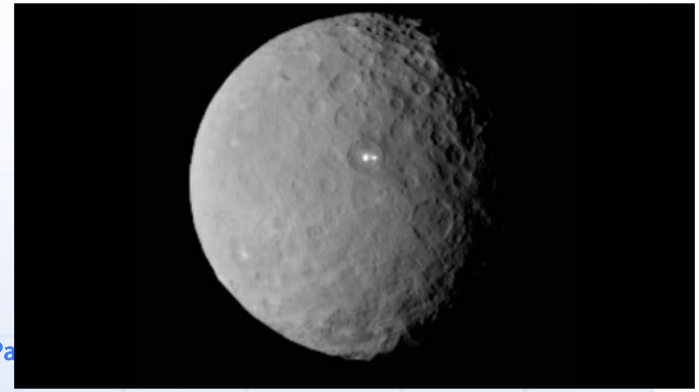
- A compositional of the most primitive/icy objects of our solar system (comets, asteroids) will help better constrain the origin of Earth's water



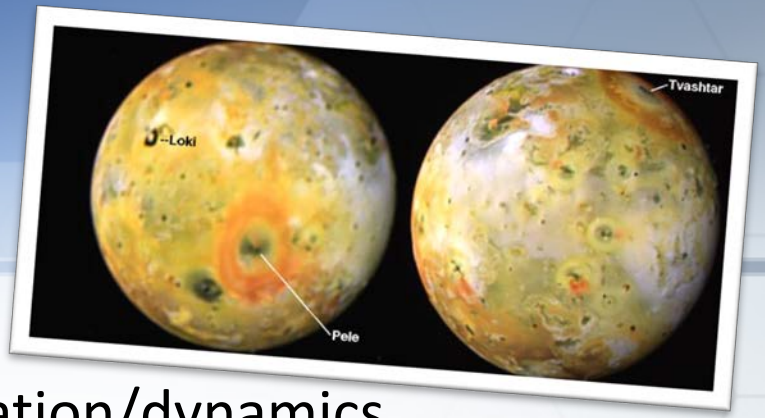
- AO imaging (PSI, IRIS)
- UV/near-IR low/high-res spectroscopy (WFOS, IRIS, MODHIS)



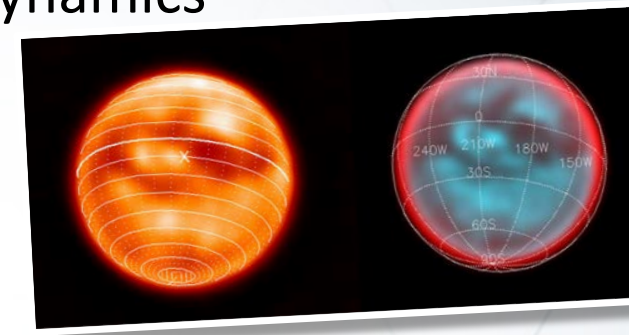




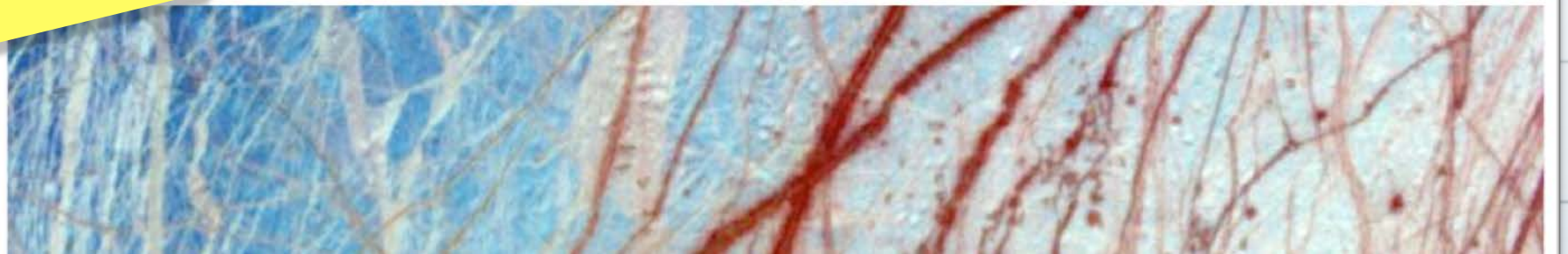
Giant planets and satellites



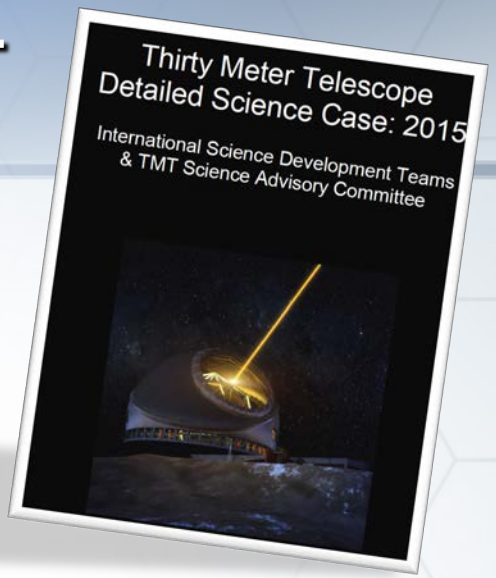
- Atmosphere composition, circulation/dynamics
- Energy budget
- Isotopic ratios and abundances
- Satellites
  - (cryo-)volcanism (e.g. Enceladus, Triton, Pluto)
  - surface/atmosphere composition and boundary conditions
    - Titan: Lake formation and surface/atmosphere interaction
    - Monitoring of Io's volcanoes and Europa's surface
    - Mapping of Europa and search for bio-signatures of organic material



AO imaging (IRIS, PSI)
near-IR low/high-res spectroscopy (IRIS, MODHIS, MICHI)



International Science Development Teams - ISDT



- ISDTs provide a unique opportunity to:
  - Build bridges between the TMT project and the international science community
  - **Shape the future science capabilities of TMT**
    - Definition of science cases and science/instrument requirements
    - Definition of 'Key-programs' (large, long-term observing programs)
  - **Get involved in defining TMT's operations capabilities to maximize science outputs of TMT**
    - Telescope time proposal process, data need, data-reduction pipelines, etc
  - **Organize topical meeting** on specific science domains
    - E.g. Annual TMT Forum, TownHall meetings at AAS/DPS, science workshops, etc

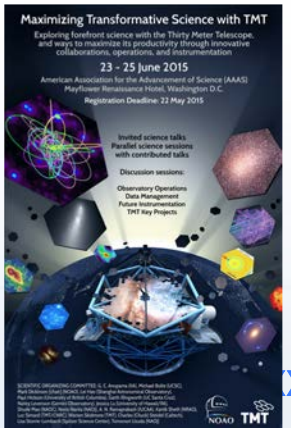
International Science Development Teams – ISDT (Cont'd)

- **ISDT membership renewed yearly**
  - Ongoing open call for 2019 **(isdt@tmt.org).** Deadline: Feb. 08
- More than 200 scientists worldwide for 9 ISDTs:
  - Early universe/galaxy formation, Exoplanets, Star-Planet formation, **Solar system**, Physics and cosmology, Milky-way & nearby galaxies, Stellar physics & the ISM, Supermassive black-holes, Time domain science

2013

2014

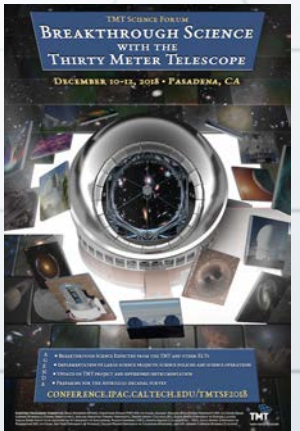
2015



2016

2017

2018



… while waiting for real construction images

Thank you!