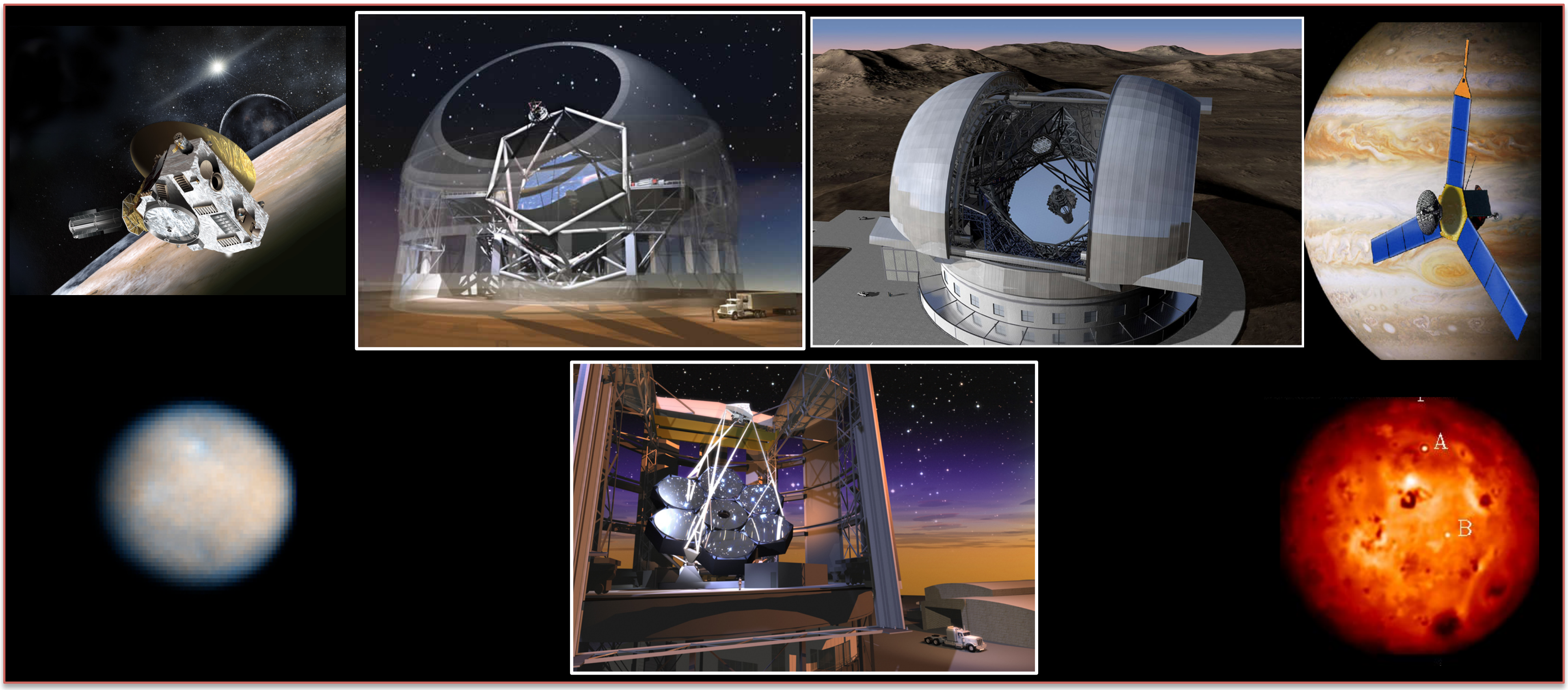
Planetary Science in the Eyes of Giant Telescopes



Franck Marchis (Carl Sagan Center at the SETI Institute)

Feeding the Giants Workshop, Ischia, Italy, August 30 2011,

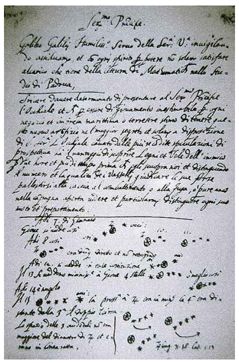
Outline

ELTs = Extremely Large Telescopes (E-ELT, TMT, GMT)

- Solar System Exploration
  - Why Exploring the Solar System with ELTs
  - Space Mission Programs: Why, Who, Where, When?
- Potential of the ELTs for Solar System Science
  - High Angular imaging coupled with spectroscopy in the NIR to explore Io, Titan, and TNOs
  - Low res UV-NIR spectroscopic combined with All-sky surveys

402 Years of Telescopes

Why Planetary Science and the ELTs?



- Long heritage of telescopic observations for the study of the Solar System
- Started in 1609 with Galileo Galilei
  - First publication in modern astronomy based on telescope data
  - Discoveries in the field of Planetary Science
    - Galilean Moons
    - Roughness of the Moon surface
    - Disk appearance of planets & phase of Venus
- In 2009, 40% of Keck PR and 25% of Keck AO publications are based on Planetary Science results
- Strong Public Interest for Planetary Science

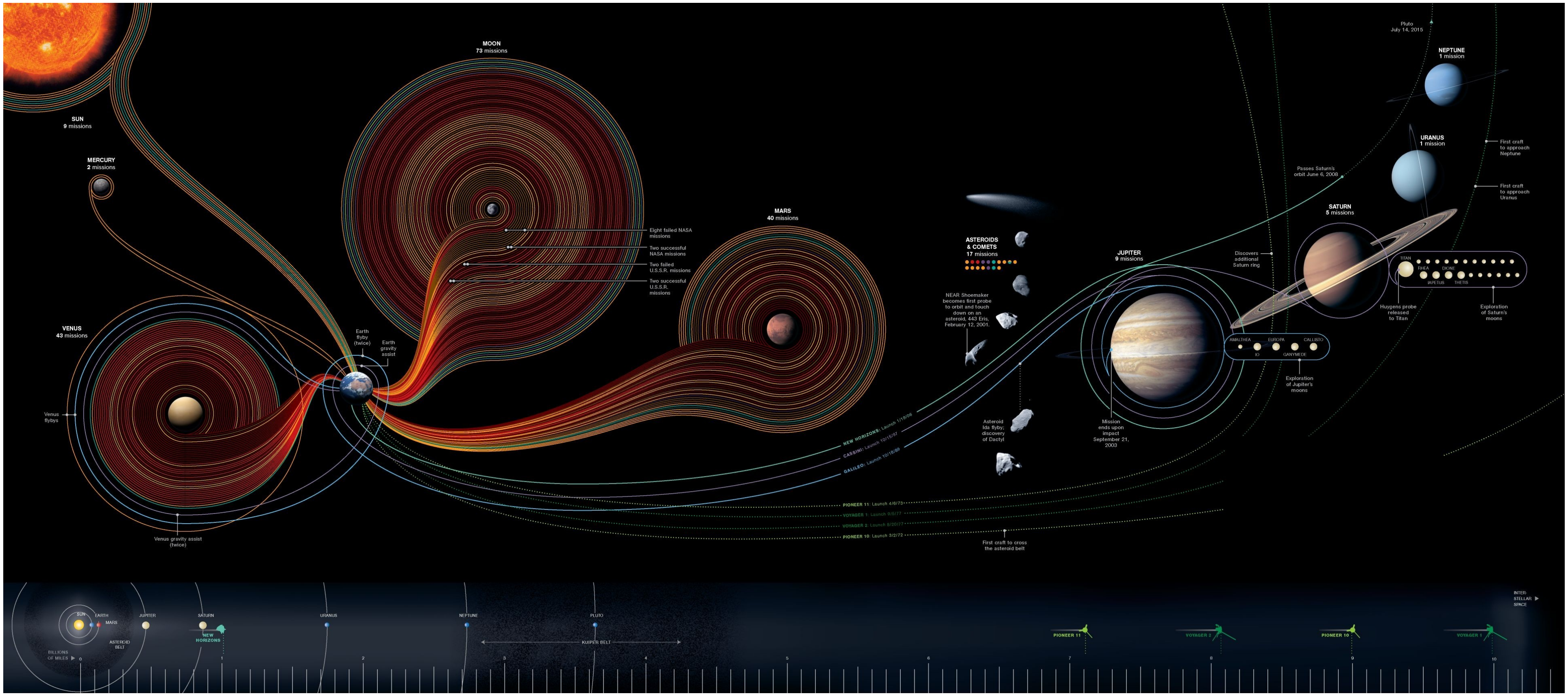
Pluto protests

Toys in Japan

51 Years of Space Missions

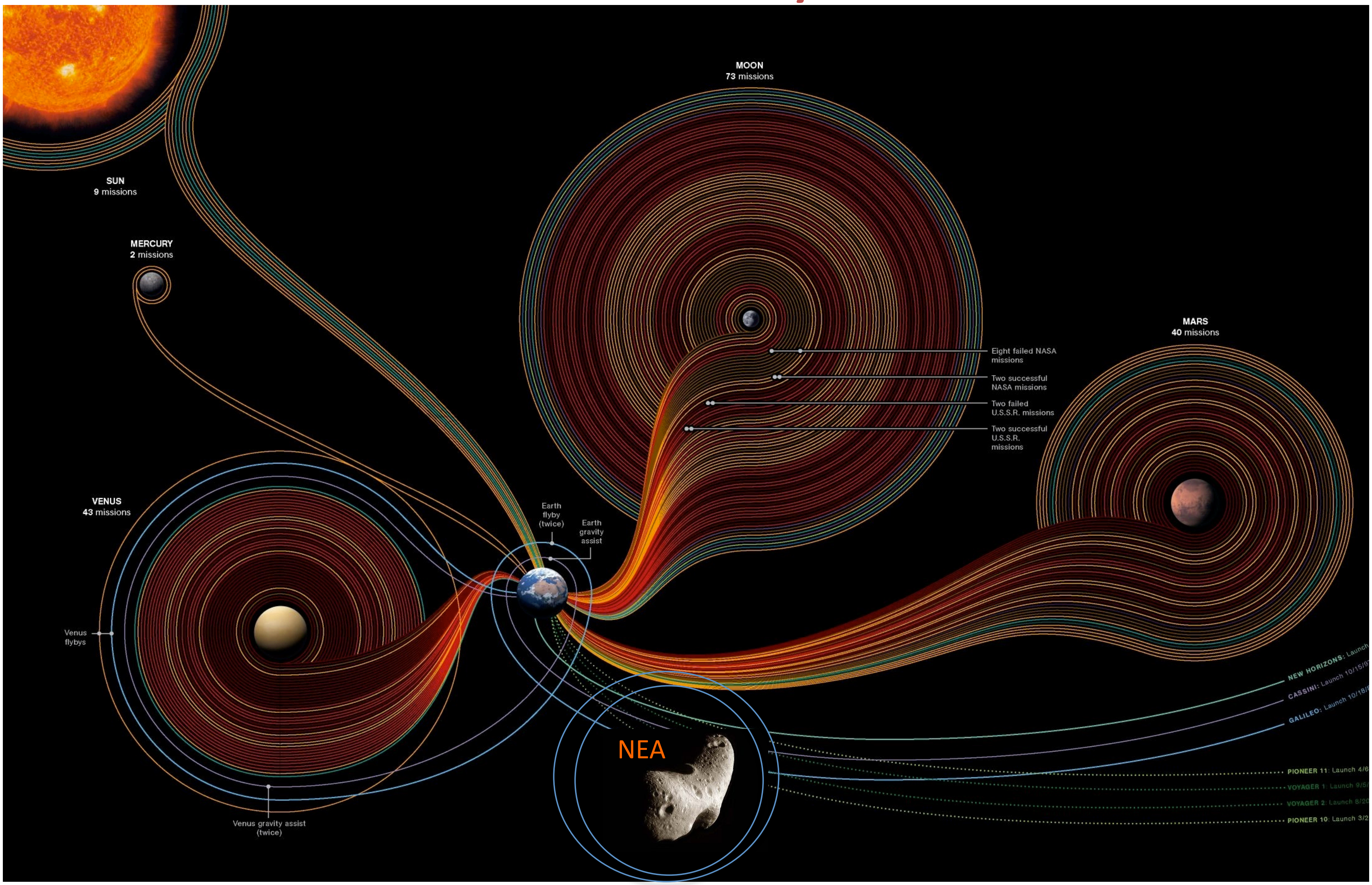
- First attempts to reach Mars (1960) and Venus (1961)
- ~200 solar, lunar and interplanetary missions
- More reliable technologies -> more space missions
- More accessible technologies -> more countries have access to space (e.g. Japan, China, India,…)
- Could the ELTs contribute to Planetary Science in this context?

51 Years of Space Missions

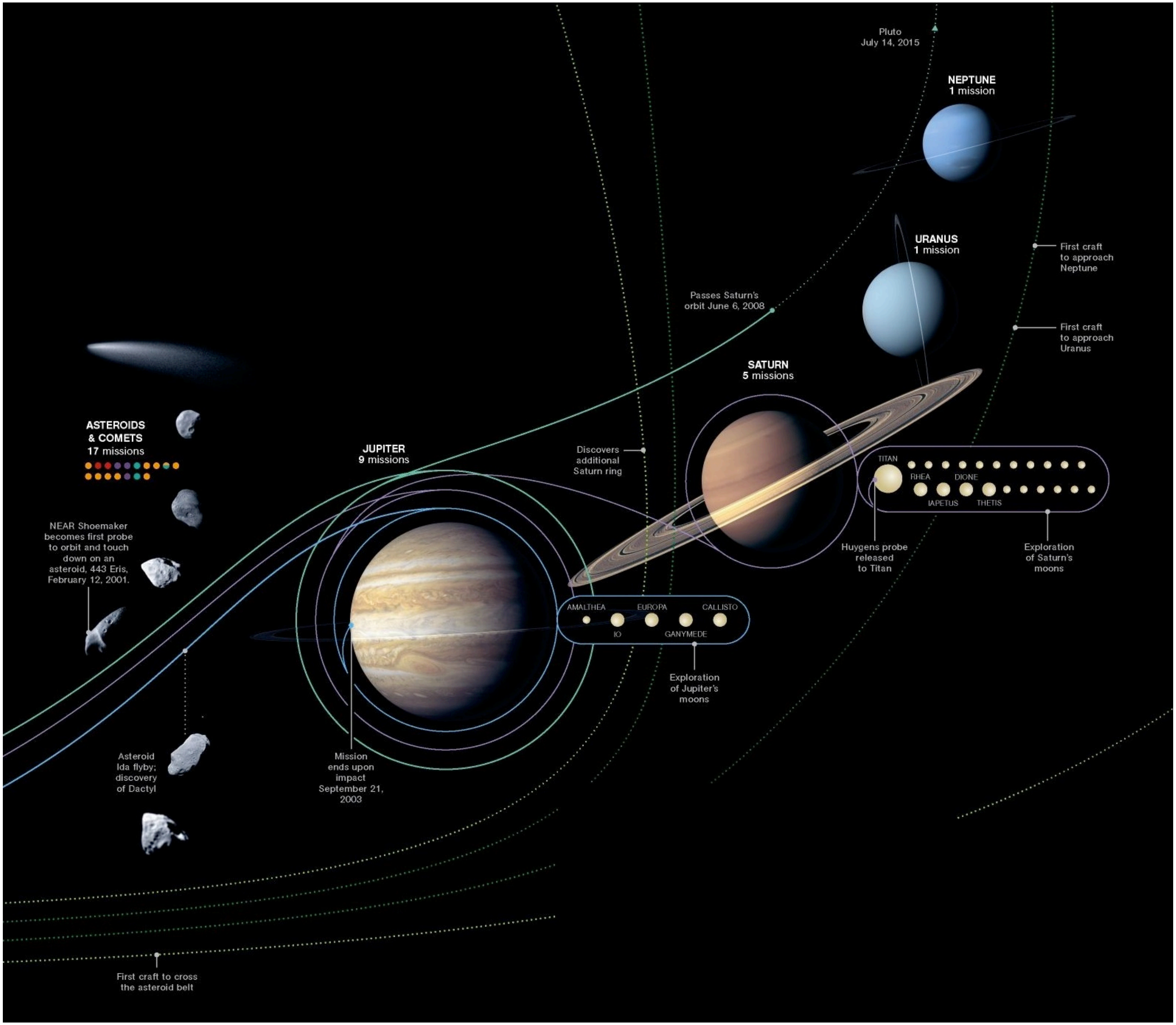


(2009) National Geographic

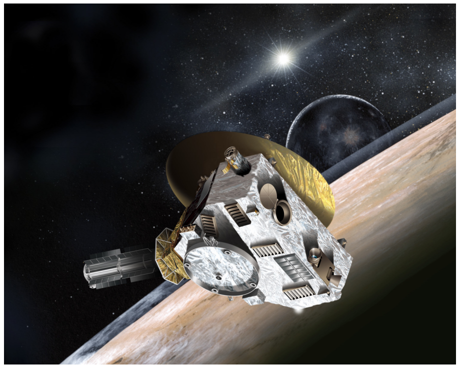
51 Years of Space Missions
Inner Solar System

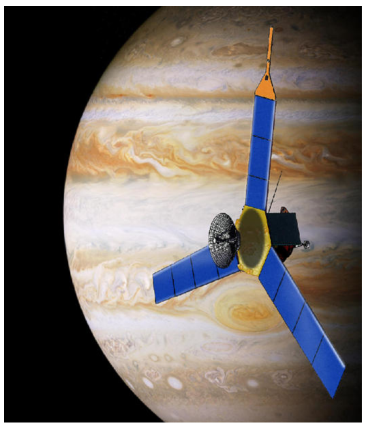


51 Years of Space Missions
Outer Solar System



NASA Future Space Missions





- Missions in progress
  - **Mars Program missions**
  - **Low $ Discovery missions: Messenger** in orbit around Mercury **(2011), Dawn** (Vesta & Ceres), **Grail** (Moon)
  - **New Frontier** (“medium $) NF-1 **New Horizons** (Pluto in 2015)
  - NF-2 **Juno** (Jupiter interior in 2016)
- Decadal Survey (2013-2022) for Planetary Science
  - Recommendation for NF-4 & NF-5: Comet sample Return, Lunar south pole lander, Saturn Probe, Trojan tour, Venus in Situ Explorer, *Io Explorer, Lunar Network*
  - **Flagship Missions (high $)**: 1. Mars Sample Return 2. Jupiter Europa Orbiter 3. Ice Giant Planet (Uranus) 4. Enceladus Orbiter or Venus Climate Mission
  - **Discovery and Mars Scout Missions** (**low $**) No listed priorities, but vigorous and regularly scheduled missions

<u>The most likely scenario:</u>

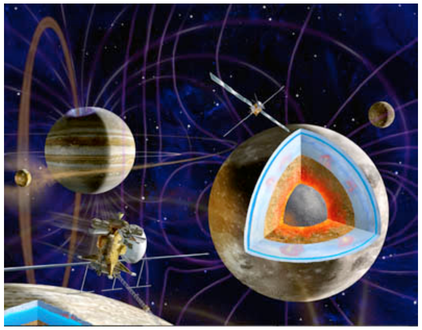
If no $$$ -> delay Flagship missions, focus on small and medium size missions

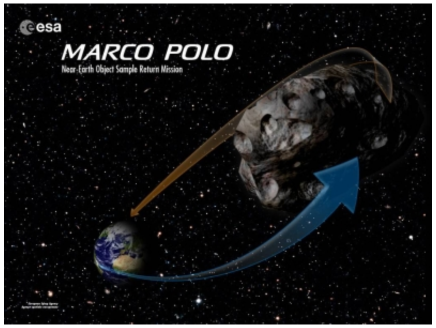
CSA Space Mission Program

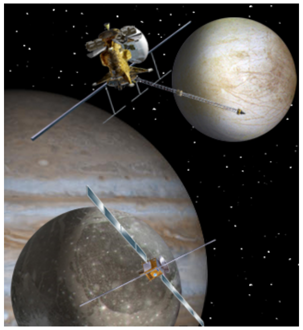
- The Canadian Space Agency is mostly oriented to Human Space Exploration (ISS)
- Mostly linked to NASA STS & ISS programs
- No space mission program

Space Mission Program

- One fully-funded mission to Mercury in collaboration with JAXA (Bepi-Colombo)
- COSMIC Vision 2015-2025
  - Preselected M2-class: No interplanetary mission (2017)
  - Preselected M3-class: MarcoPolo-R (asteroid sample return)
  - Preselected L-Class: LISA, IXO, and EJSM-Laplace (lost NASA Partnership). Decision postponed to Feb 2012







Recent Spacefaring Countries

"Spacefaring" is to be capable of and active in the art of space travel (wikipedia)

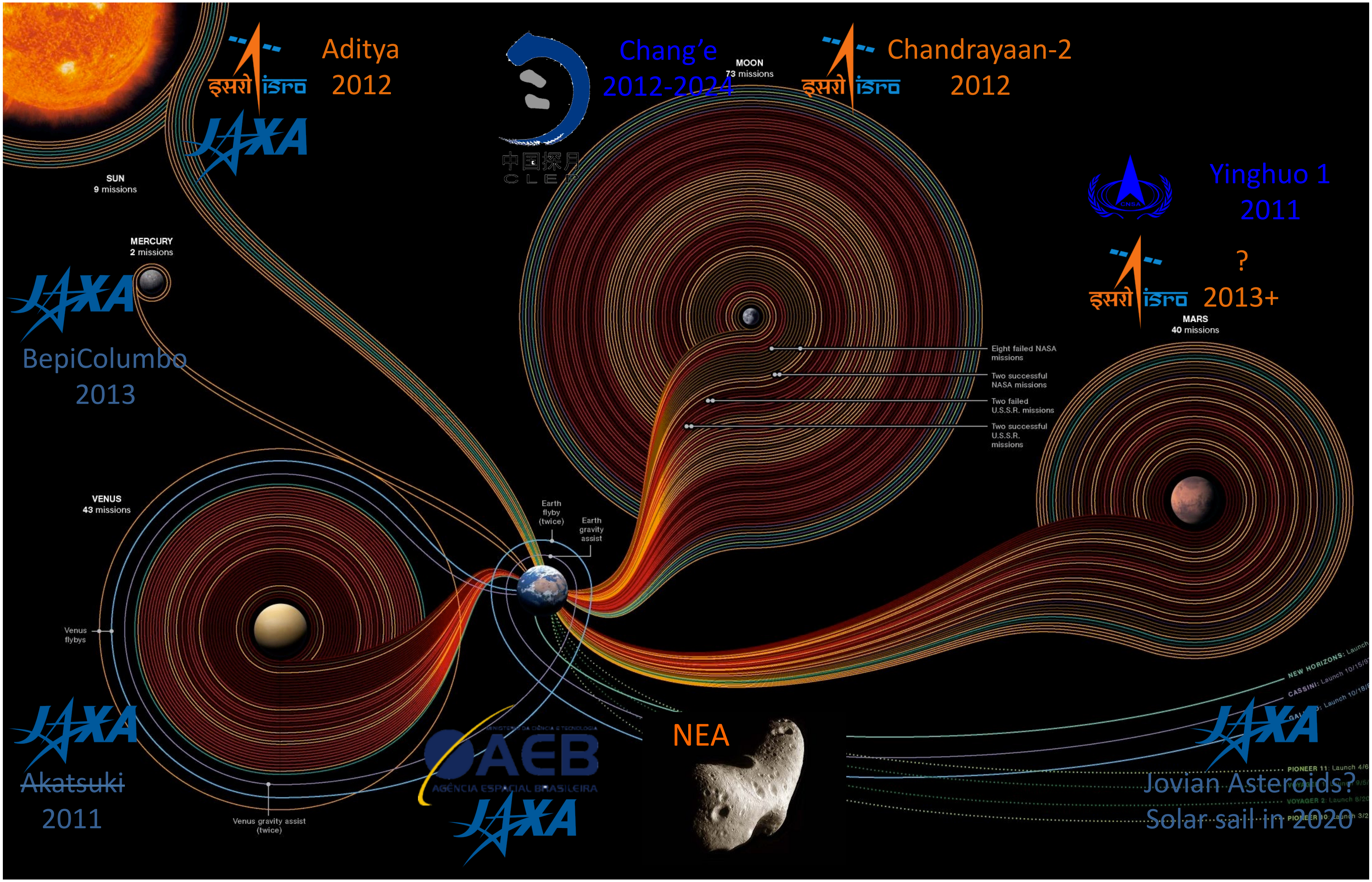
Uncrewed spacefaring nations:
USSR (1957), USA (1958), France (1965), Japan (1970), China (1970), UK (1971), EU (1979), India (1980), Israel (1988), Ukraine (1991), Russia (1992), Iran (2009), North Korea (2009), Brazil (2010)

But a few of them have a **Planetary Mission Programs**:

- **Japan Aerospace Exploration Agency (JAXA)**
  Hayabusa (Near-Earth asteroid Itokawa in 2003), SELENE in 2007, Akatsuki in 2010, BepiColombo in 2013, Hayabusa 2 in 2014
- **Indian Space Research Organisation (ISRO)**
  Chandrayaan-1 (lunar probe in 2008), Chandrayaan-2 (lunar rover in 2013), Aditya (solar probe), Mars after 2013
- **China National Space Administration (CNSA)**
  Lunar Exploration program (Chang'e 1-5 2009-2024), Yinghuo-1 (Mars orbiter 2011)
- **Brazilian Space Agency (AEB)**
  ASTER in 2015

National Astronomical Observatory of Japan is a collaborating Institution of the TMT
National Astronomical Observatories of the Chinese Academy of Sciences & **Department of Science and Technology of India** are Observers in the TMT

Recent Spacefaring Countries
Future Solar System Exploration



Context of Space Mission Exploration During the ELTs Era

"Prediction is very difficult, especially if it's about the future. " *Niels Bohr*

- No space mission toward outer solar system for recent spacefaring countries
- One NASA mission toward a TNO (New Horizons 2015)
- One NASA mission toward Jupiter (JUNO 2016)
- Then the future is unclear and gloomy…

BUT

- ELTs will give access to the outer part of our solar system with an unprecedented angular resolution and sensitivity.

The Potential of the ELTs for Planetary Science

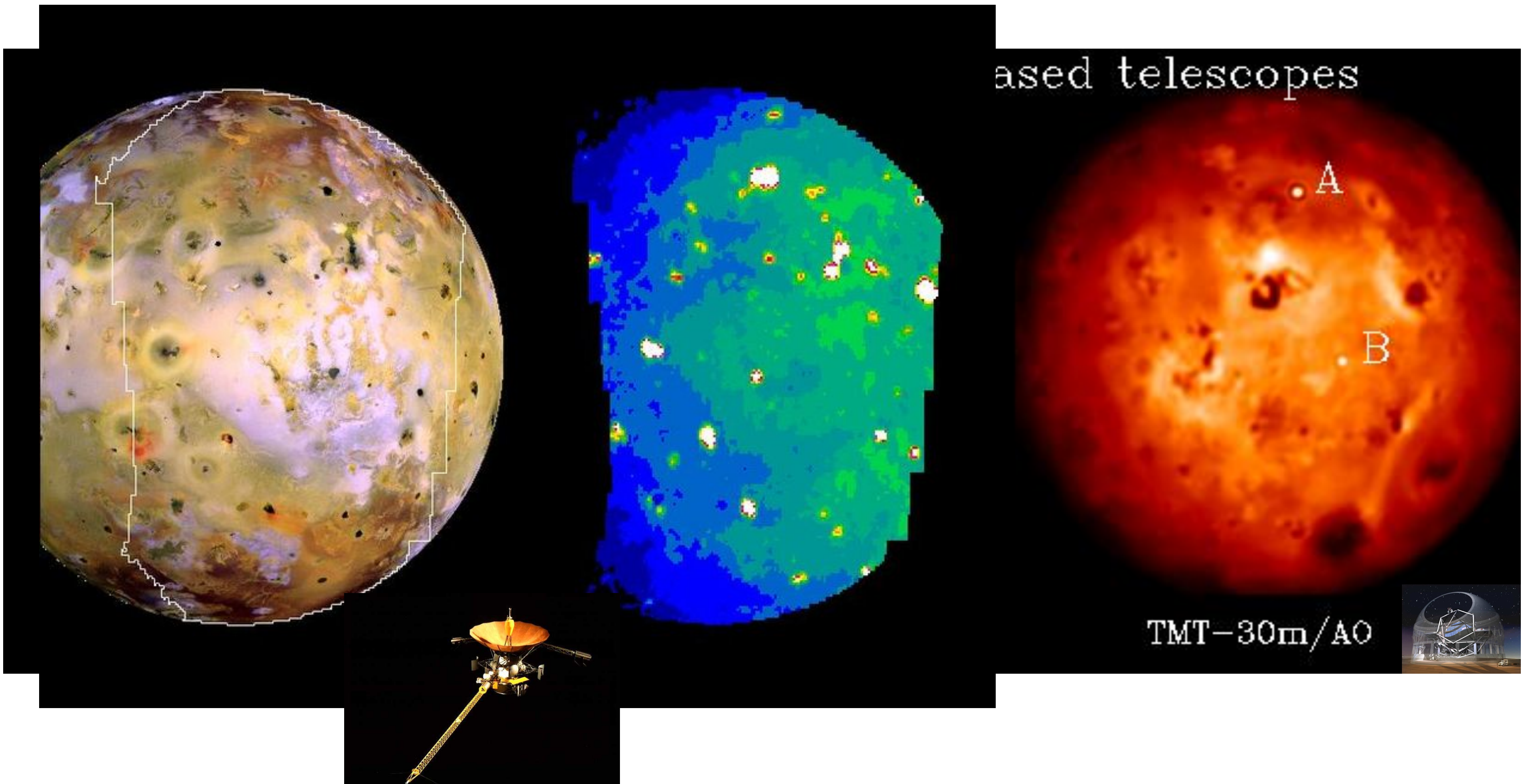
- High Angular Resolution Imaging and Spectro in NIR
  - Surface Composition of Jovian and Kronian Satellites
  - Monitor atmospheric, volcanic, geological changes

- visible-NIR Reflectance Spectroscopy
  - Surface composition of small and distant minor planets

- *mid-IR spectroscopy*
  - *Molecular species in atmospheres of Titan, Uranus & Neptune, and volcanic outgassing on Enceladus & Triton, Atmospheres of TNOs*
  - *Surface composition of minor planets (asteroids)*

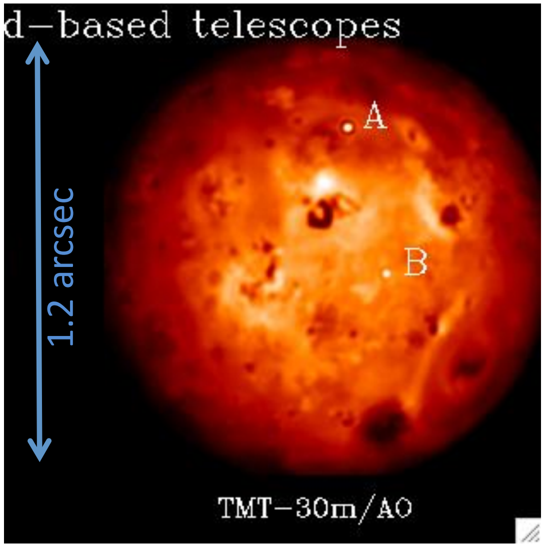
Potential of Imaging & Spectro in NIR

- Angular resolution provided by ELT-AOs
  - TMT/IRIS (0.8-2.5 um) 7 mas at 1 um
  - GMT AO 10 mas at 1 um, 20-40” FOV (Hinz et al.)
- Keck angular resolution ~40 mas at 1 um

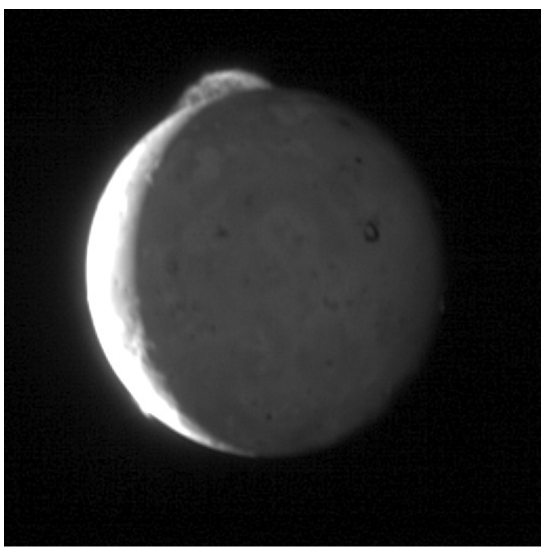


Potential of Imaging & Spectro in NIR Study of Io Volcanism

Simulated TMT/IRIS obs



New Horizons obs in 2007



Io in a nutshell: V~5, ang size=1.2”, innermost Galilean satellite, most volcanic place due to resonance with other Galilean satellites

->ELTs Spatial resolution on Io ~ 20 km (at 7 mas)

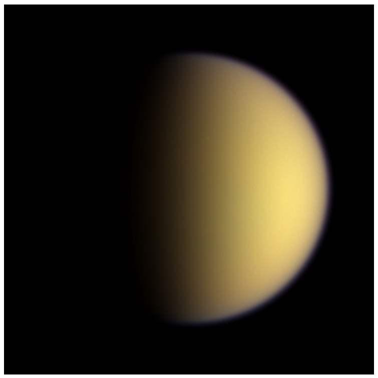
Scientific Objectives:

- Monitoring of individual volcanoes
- Temperature and type of volcanic activities (fire fountaining, lava lake, lava field)
- Thermal Output of Io and its evolution

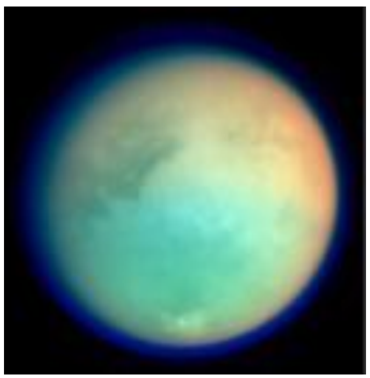
Outstanding Questions:

- Highest temperature of lava (sulfuric T<1000K, mafic T<1450K, ultra-mafic T>1500 K?) & Interior of Io (Ocean of magma, partially differentiated?)
- Understanding the evolution of Io into the Laplace resonance
- Potential for life in Europa and around exomoons (Exovolcanism)

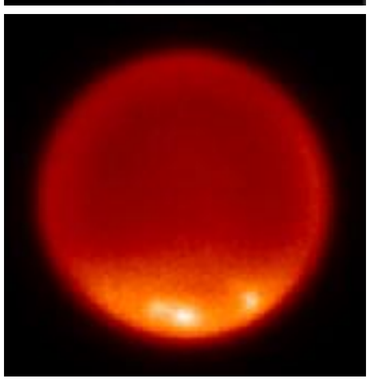
Potential of Imaging & Spectro in NIR
Weather on Titan and Its impact



1981 Voyager 1 visible
Boring



2004 Cassini IR data
Surface + Atm



2001 Keck AO IR
Clouds

Titan in a nutshell: largest satellite of Saturn, V~8, ang. Diam=0.9", atmosphere of prebiotic material, channels and lakes on surface

-> ELTs spatial resolution ~ 45 km at 1 um on Titan

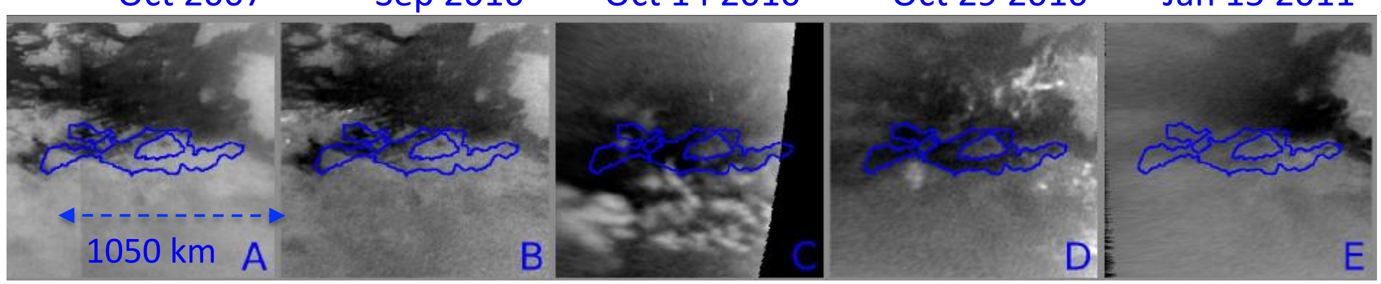
Science Objective: Monitor Titan Atmosphere and detect Surface Change

An Earth-like weather with methane cycle?

Cassini Radar Observations (Turtle et al. 2011)

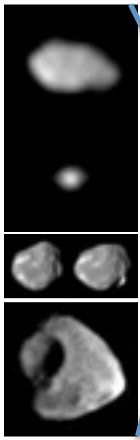
Storm → Surface Change → Drying

Oct 2007 | Sep 2010 | Oct 14 2010 | Oct 29 2010 | Jan 15 2011



Potential of Imaging & Spectro in NIR

Surface Mapping of Jovian and Kronian Satellites



Moons	D in km	# of elts	Dist to Jupiter in km	
Metis	60	3	127700	inner
Adrastea	20	1		
Amalthea	250	12		
Thebe	116	5		
Io	3660	171	421700	Galilean
Europa	3122	146		
Ganymede	5262	247		
Callisto	4820	225		
Leda	16	~1		irregular
Himalia	170	8		
Lysithea	36	2		
Elara	86	4		
Ananke	28	1		
Carme	46	2		
Pasiphae	60	3		
Sinope	38	2	2.40E+07	

Moons	D in km	# of elts	Dist2Saturn in km
Pan	35	~2	
Atlas	46	1	
Prometheus	119	3	139E3km
Pandora	103	2	
Epimetheus	113	3	
Janus	193	4	
Mimas	415	9	
Enceladus	513	11	
Tethys	1081	24	
Telesco	29	~1	
Calypso	30	~1	
Dione	1128	25	
Helene	36	~1	
Rhea	1529	34	
Titan	5151	114	
Hyperion	360	8	
Iapetus	1472	33	
Phoebe	230	5	
Siarnak	~40	~1	

Scientific Objectives:

-Map the surface and distribution of material

-Determine their size and shape

-Detect of surface changes by comparison with Galileo or Cassini Missions

Outstanding Questions:

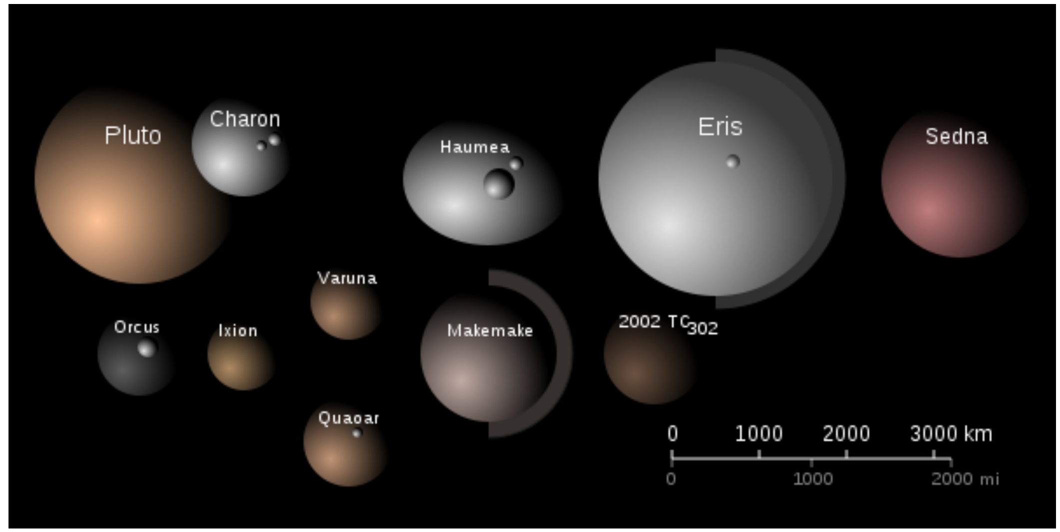
- Captured or formed in-situ?
- Cryovolcanism on Enceladus and elsewhere?

Potential of Imaging & Spectro in NIR

Size, Shape, Surface Mapping, Atmosphere of TNOs

Population of 1,000 Minor planets orbiting at 30+ AU made of mixture of ices and rock. vis/NIR spectra of the surface -> water ice, amorphous carbon, organic, and silicates.

Name	Diameter km	semi-major AU	ang size in mas	# of elt
Pluto	2320	39.4	81	11
Makemake	1500	80.0	26	4
Haumea	1150	84.0	19	3
Charon	1205	39.4	42	6
Orcus	950	39.4	33	5
Quaoar	844	43.5	27	4
Ixion	650	39.6	23	3
2002AW197	730	47.4	21	3
2002UX25	681	42.5	22	3
Varuna	500	43.0	16	2
2002MS4	762	42.0	25	4
2003AZ84	685	39.6	24	3



Scientific Objectives:

-Map the surface of TNOs (distribution of ices)

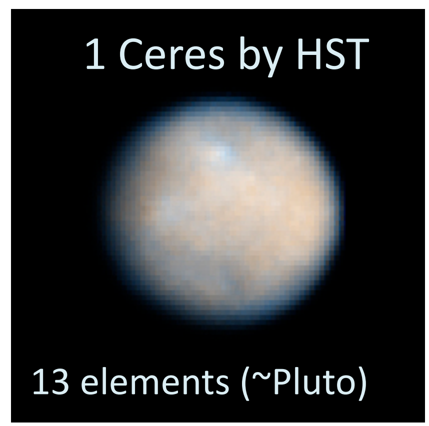
-Determine their size and shape

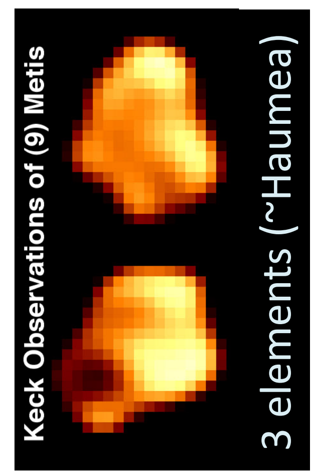
-Detect small satellites and follow up their orbits

-Detect of surface changes

Outstanding Questions (Pre-New Horizons):

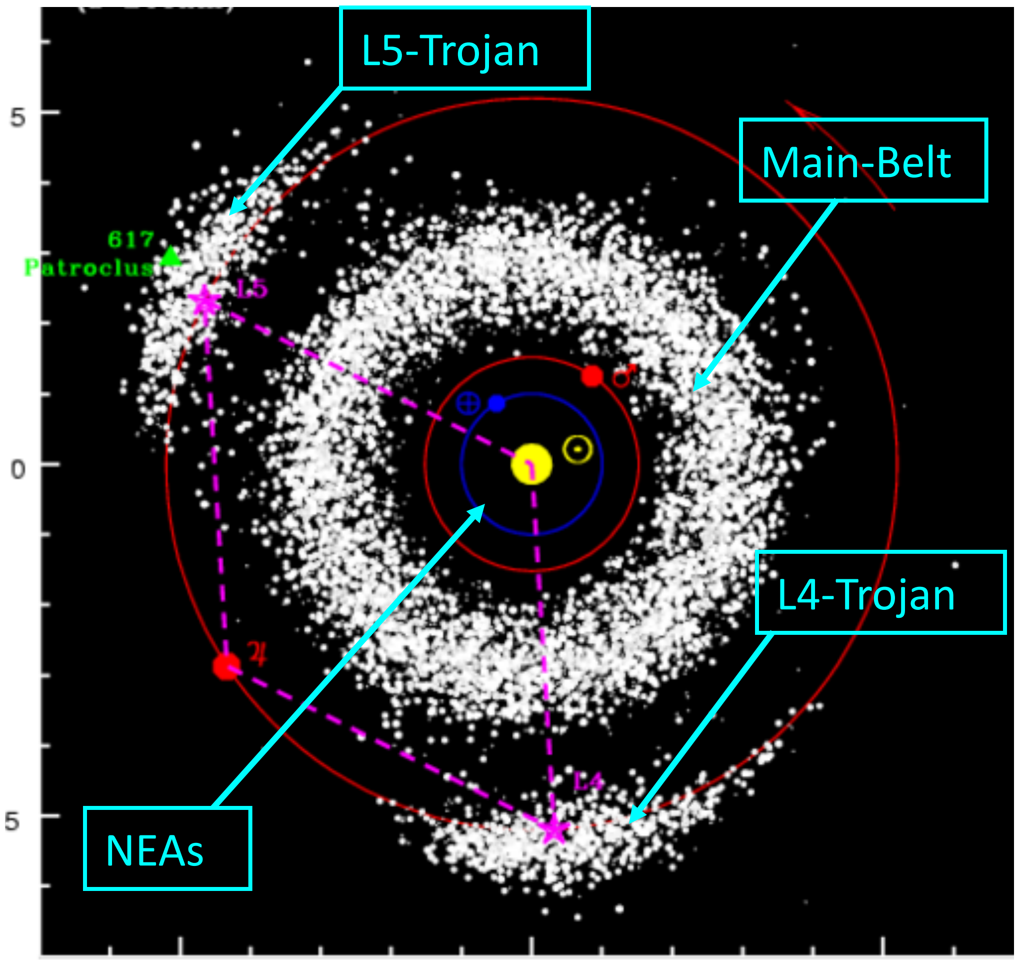
- Cryovolcanism on TNOs
- Bulk density and interior structure of the most primitive planetesimals

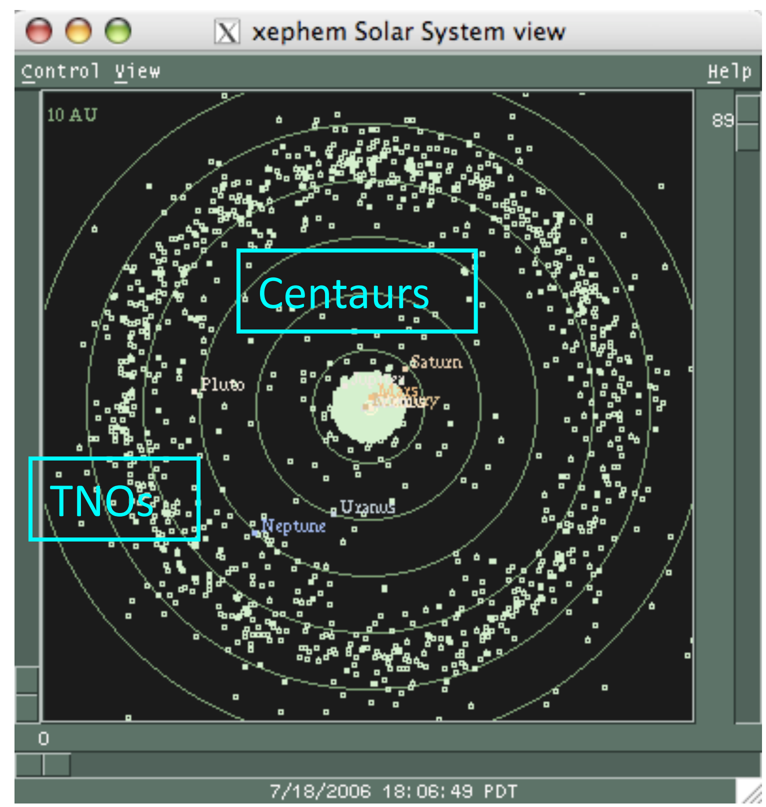




Small Solar System Bodies

- On Aug 26 2011, **560,714** registered SSSBs. They are "Small but Numerous"
- Statistical analysis by surveys is necessary to understand their formation, origin and evolution
- Small apparent size (largest MB-> 1 Ceres D_{app}=0.7arcsec <-> "seeing" limit
- Building blocks of the Solar System linked to its formation





SSSBs: Outstanding Questions

From "**Asteroids**" White paper for the US Decadal survey:

•What was the compositional gradient of the asteroid belt at the time of initial protoplanetary accretion?

•What fragments originated from the same primordial parent bodies, and what was the original distribution of those parent bodies?

•What do asteroids tell us about the early steps in planet formation and evolution?

•What are the characteristics of asteroids as individual worlds?

From NEAs White paper for the US Decadal survey:

•What is the Compositional Distribution of NEOs?

•What is the Range of NEO Physical Properties and How do they Evolve?

•What are the Specific NEO Source Regions and Sinks?

•How can NEOs be used as resources?

From "Goals and Priorities for the Study of Centaurs and TNOs" A community white paper for the US Decadal Survey

•What are the Physical Properties of TNOs?

•What are the Compositions of TNOs?

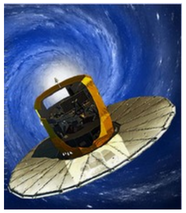
•What Physical and Chemical Processes affect TNOs, and How?

What is the Dynamical Structure of the Trans-Neptunian Region?

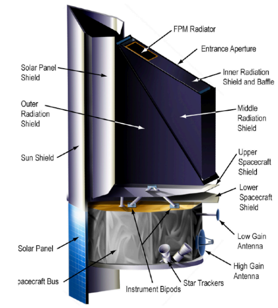
NASA Authorization act of 2005

The U.S. Congress has declared that the general welfare and security of the United States require that the unique competence of NASA be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth. The NASA Administrator shall plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near- Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90% completion of its near-Earth object catalogue (based on statistically predicted populations of near-Earth objects) within 15 years after the date of enactment of this Act.

Keywords are "Physical properties", "Surface Composition", "Orbits/Dynamical structure"



SSSBs: Future Surveys

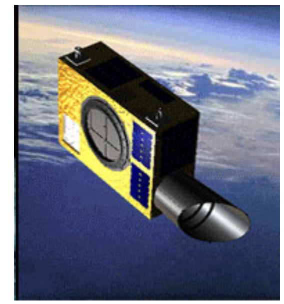


- **In Space**

• **GAIA** Mass determination of 100s large Main-Belt Asteroids by perturbations

• **NEOSSAT** NEO Surveillance SATellite Canadian micro-satellite 15-cm telescope to search for Interior-Earth-Orbit (IEO) asteroids (to be launched in 2011)

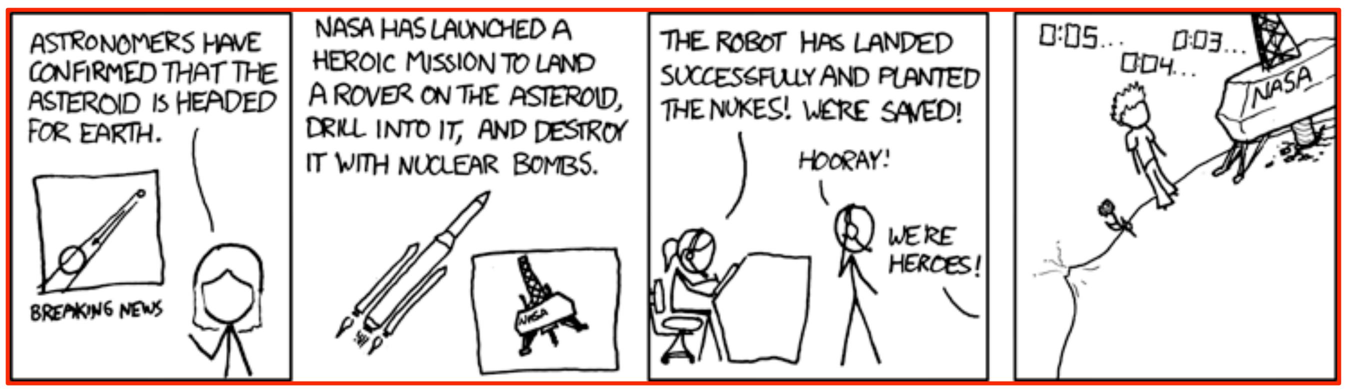
• **NEOCAM** The Near-Earth Object CAMera: NASA Discovery (low $) class 50cm cryogenic mid-IR Space telescope to be launched in 2016 (not yet funded)



•With p_v=0.05, V_{lim} = 25.4 so NEOCAM will find:

- 1×10^6 new Mainbelt Asteroids
- 90% of all Potentially Hazardous Objects (PHOs) in 15 years

-> “Physical properties”, “Orbits/Dynamical structure””



- **On the ground**

• **PAN-STARRS** 4 x 1.8m telescopes in Hawaii with a FOV of 7 deg^2, V_{lim}=24, PS1 is working

• **Large Synoptic Survey Telescope (LSST)** large FOV (9 deg^2) 8m class telescope in Chile g_{lim}=25, survey to start in 2020 -> “Detection/Orbits/Dynamical structure”

SSSBS: Low-Res UV-NIR Spectroscopy

LSST

8.2m in Chile

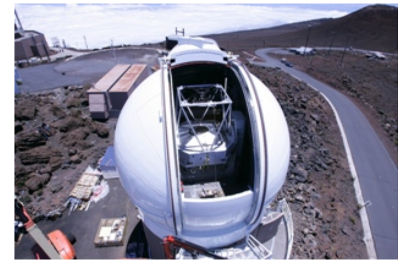
1st Priority of the 2011 Decadal Astronomy survey

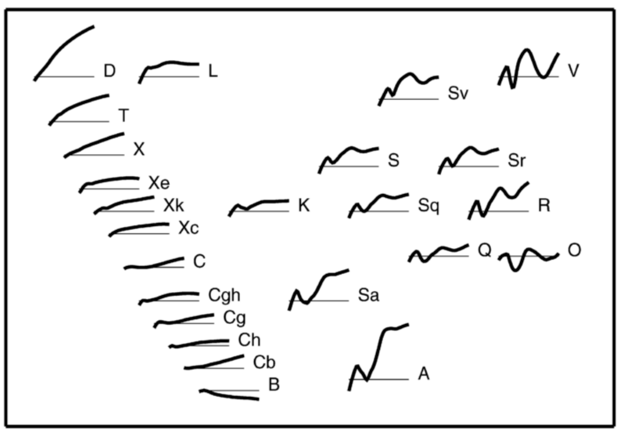
- Today, 460,000 asteroids and comets are known
- X 12 times more soon thanks to ground-based and space surveys
- Including 100,000 Near-Earth Asteroids, 40,000 TNOs, and unexpected "interstellar interlopers"?

Need for low-res R<1000 spectroscopic follow-up

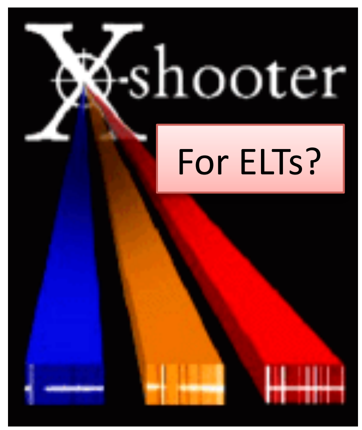
Pan-Starrs

4x1.8m in Hawaii

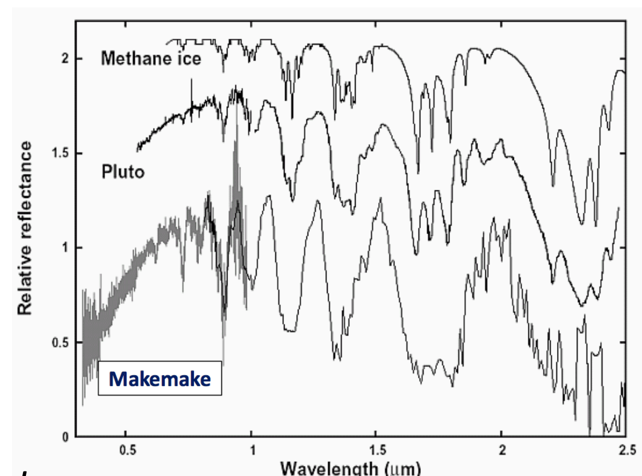




Taxonomic classes of asteroids



A seeing-limited UV-NIR spectrograph



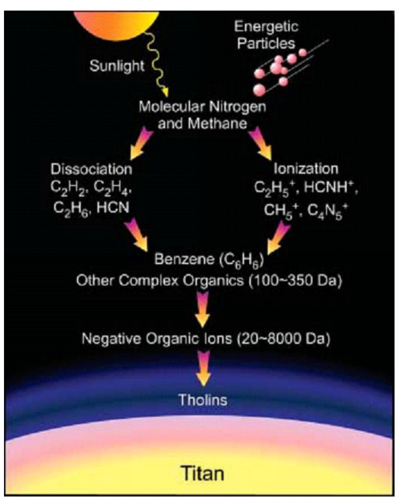
Ices on TNOs

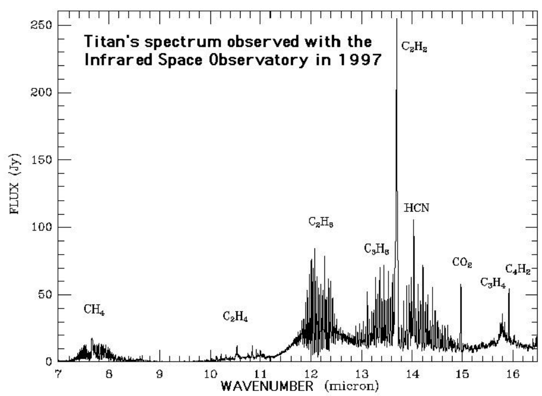
Science Objectives:

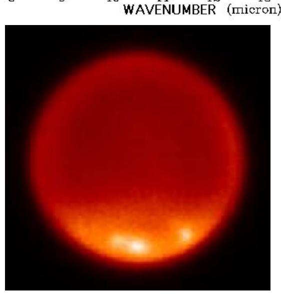
- Taxonomic Classification from Vis+NIR of minor planets
- Surface composition by reflectance spectroscopy from UV to NIR

Mid-IR Spectroscopy

- Titan prebiotic atmosphere (also Uranus, Neptune)
- Molecular species and their distribution -> astro-chemistry
- mid-IR spectrograph with R=10,0000- 100,000 (MIRES/TMT)
- Instruments prioritized during mediocre seeing conditions?
- Synergic activity with SOFIA



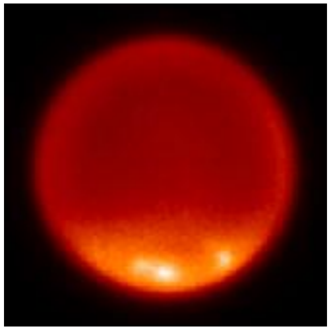
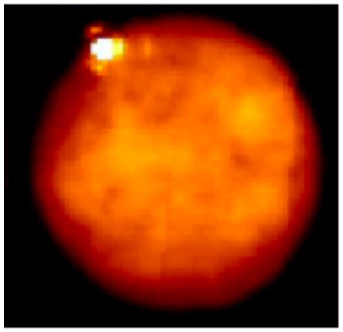
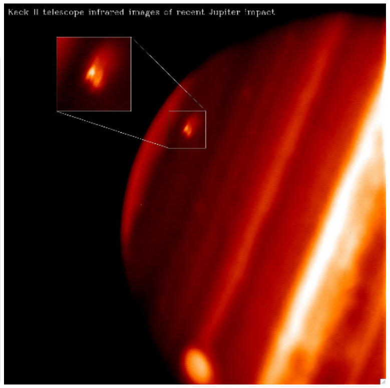




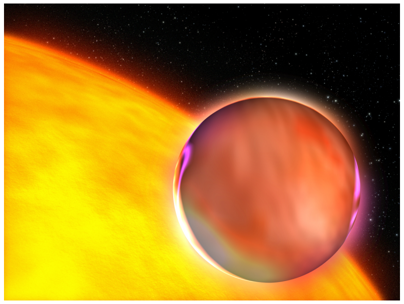
Continuous monitoring, rare events and the future…

Ground-based astronomy is key to study and understand the "Planets"

- Good temporal monitoring needed to observe variable/seasonal phenomena (atmosphere and surface)
  - Clouds on Titan
  - Volcanism on Io
- Short time scale to respond to transit and unpredictable events
  - Comets impact (SL9, Jupiter-2009)
  - Energetic explosion on Io

- In the last 15 years an entire new field was born "Exoplanetary Science" => Planetary Science



ELT instruments must be designed in the framework of current science objectives but also be flexible enough to address future needs

Conclusion

- ELTs have an enormous potential for the exploration of the Outer Solar System (TNOs, satellites of Giant Planets)
  - Very bright targets (up to V~5)
  - Moving target (up to 100”/h)
- TMT & E-ELT have a 1st generation AO Instrument - best choice for planetary science and to promote their capabilities to the public
- Low res UV-vis-NIR spectrograph are synergetic with wide telescope surveys
- Versatile instrument suite will be needed to address key new science results from surveys (e.g. LSST, SKA). The future “exoplanetary-equivalent” field is still unknown.