NASA/JPL Mission Design and Navigation (MD/Nav)

Jet Propulsion Laboratory
California Institute of Technology

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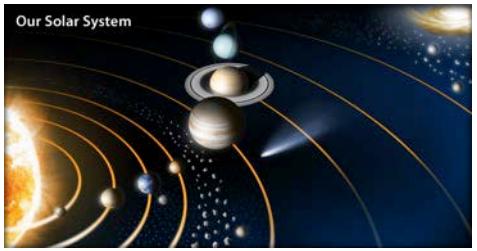
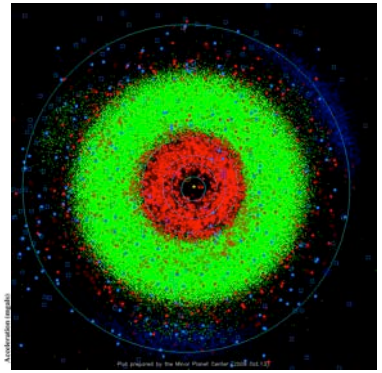
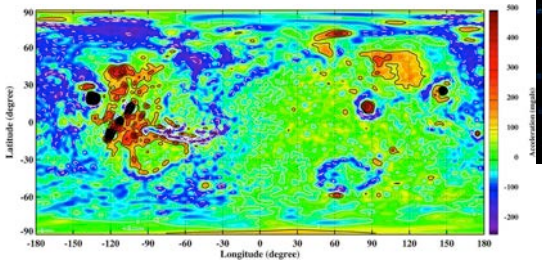
MD/Nav Section Manager
June 2016

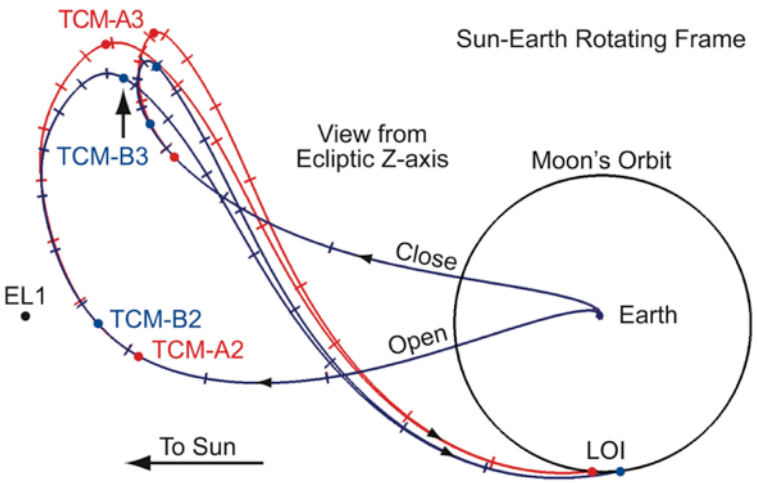
Deep Space Mission Design & Navigation

Build and maintain dynamical maps and software tools for interplanetary navigation



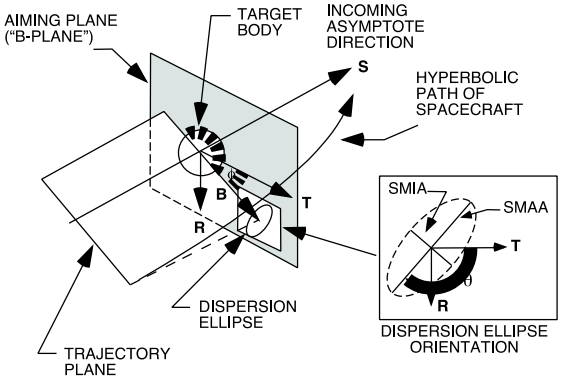






Design efficient routes for spacecraft to reach any remote Solar System location

Use deep space tracking measurements to safely pilot spacecraft to their ultimate destination

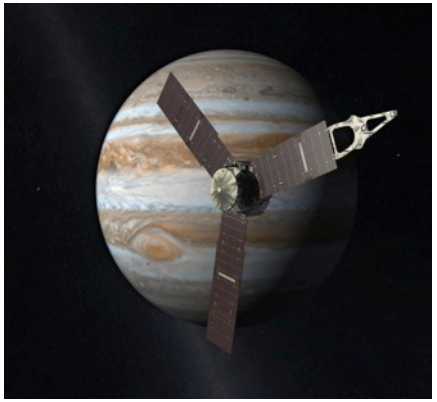


Selected Recent Accomplishments

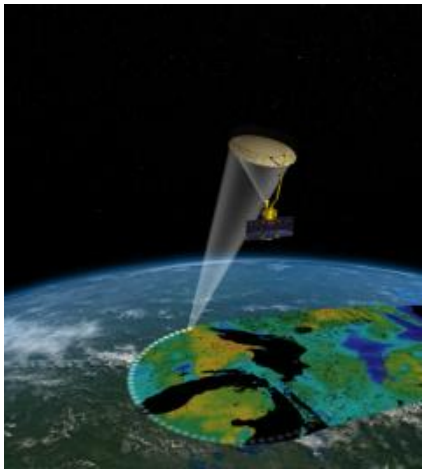
NASA/JPL Missions

Cassini

Dawn



Juno

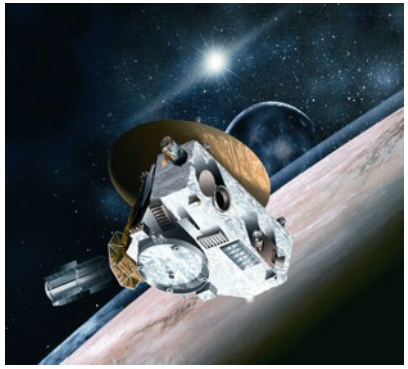


Soil Moisture Active Passive (SMAP)

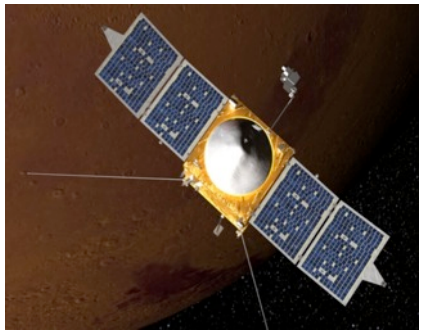
Partnership Missions

JAXA Hayabusa-2 Asteroid Sample Return

ESA Rosetta Comet Rendezvous/Landing



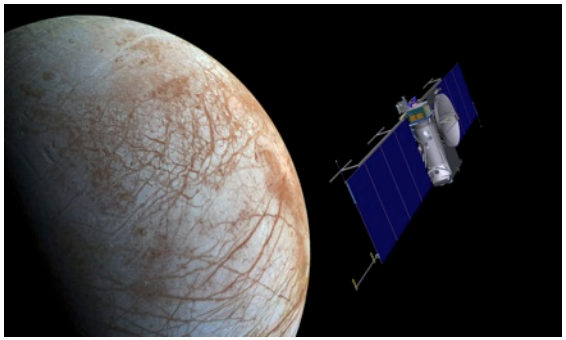
APL New Horizons Pluto



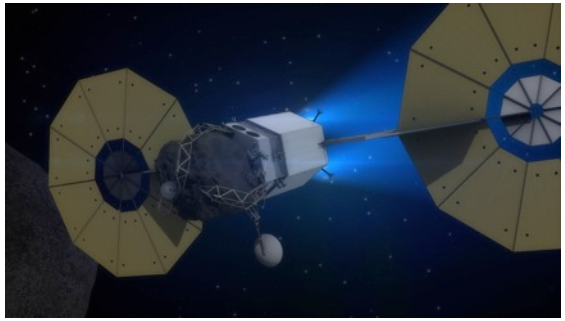
GSFC Maven Mars Orbiter

Selected Coming Attractions

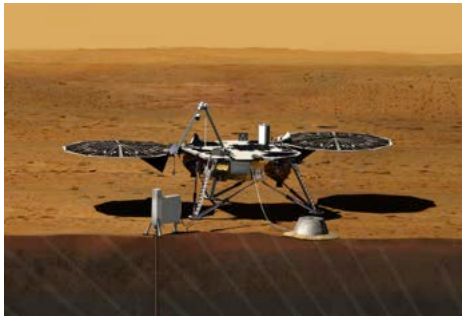
NASA/JPL Missions



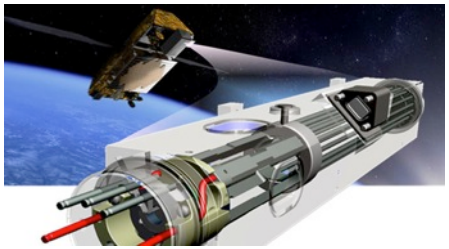
Europa Clipper (+Lander?)



Asteroid Robotic Redirect Mission (ARRM)



InSight



Deep Space Atomic Clock

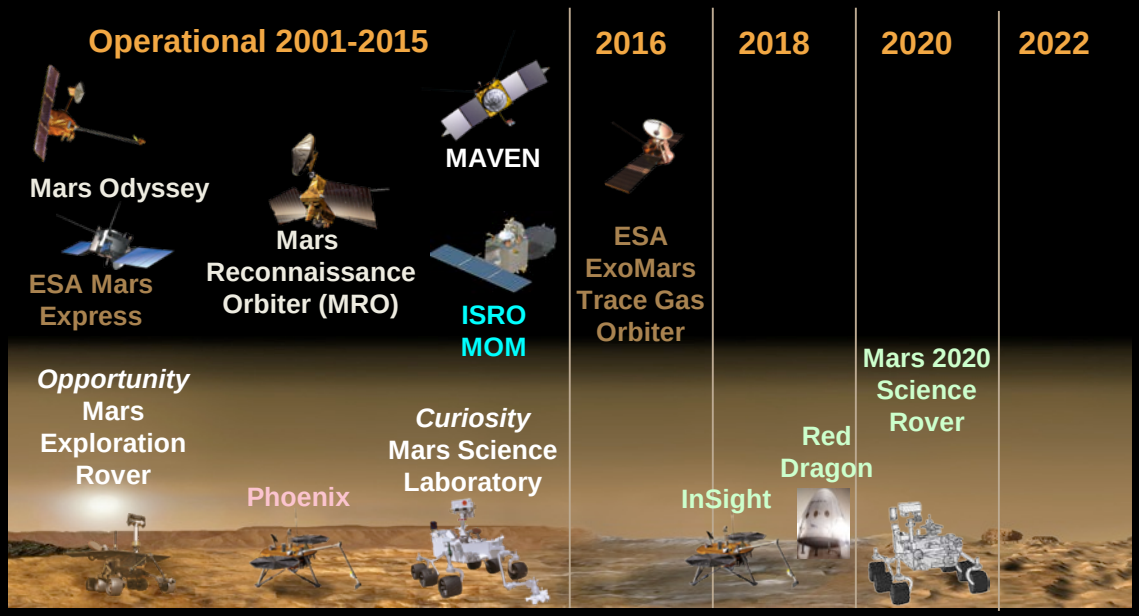
Partnership Missions

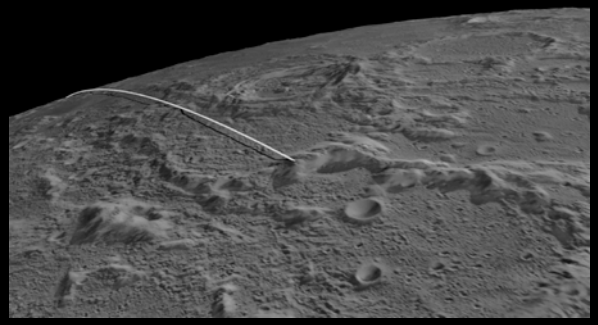
SpaceX Technology Demonstration (Mars EDL)

OSIRIS-REx

SLS EM-1

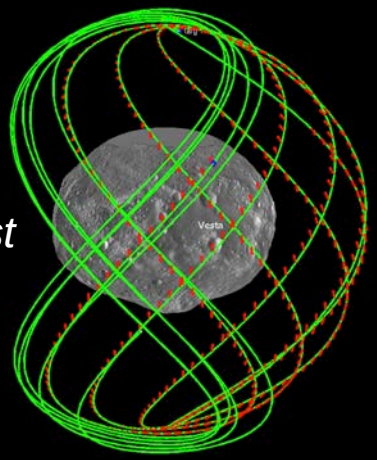
Mars, Lunar and Small Body Experience





GRAIL: Dual Spacecraft Formation (2011-2012)

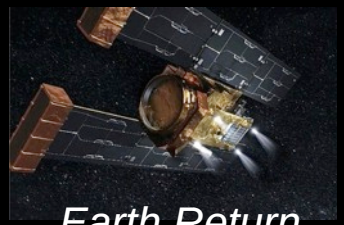
Dawn: Low Thrust Asteroid Orbiter



Deep Impact: Comet Tempel 1 Impactor (2005)

Re-Purposed as EPOXI: Hartley 2 Flyby (2010)

Stardust: Comet Coma Sample Return



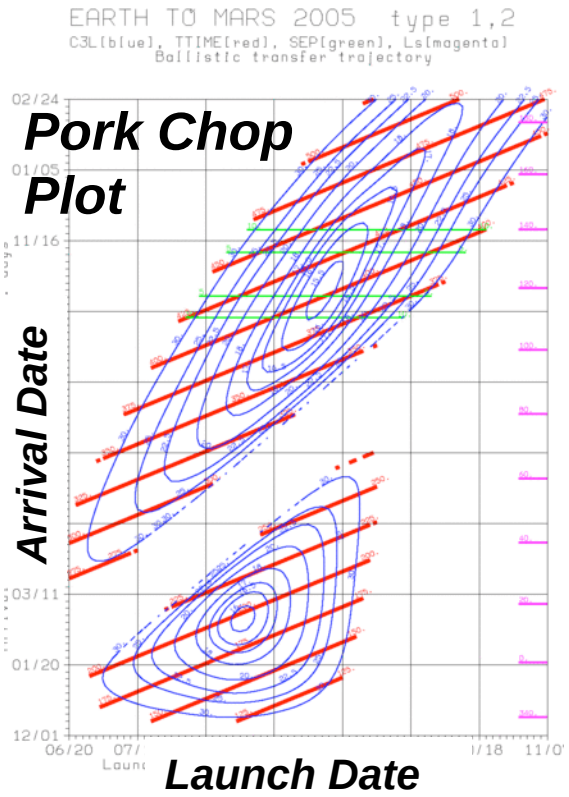
Earth Return (2006)

NASA/JPL Optimal Trajectory Design

For High/Low Thrust and Low Energy Missions

Finding ‘Global Minima’

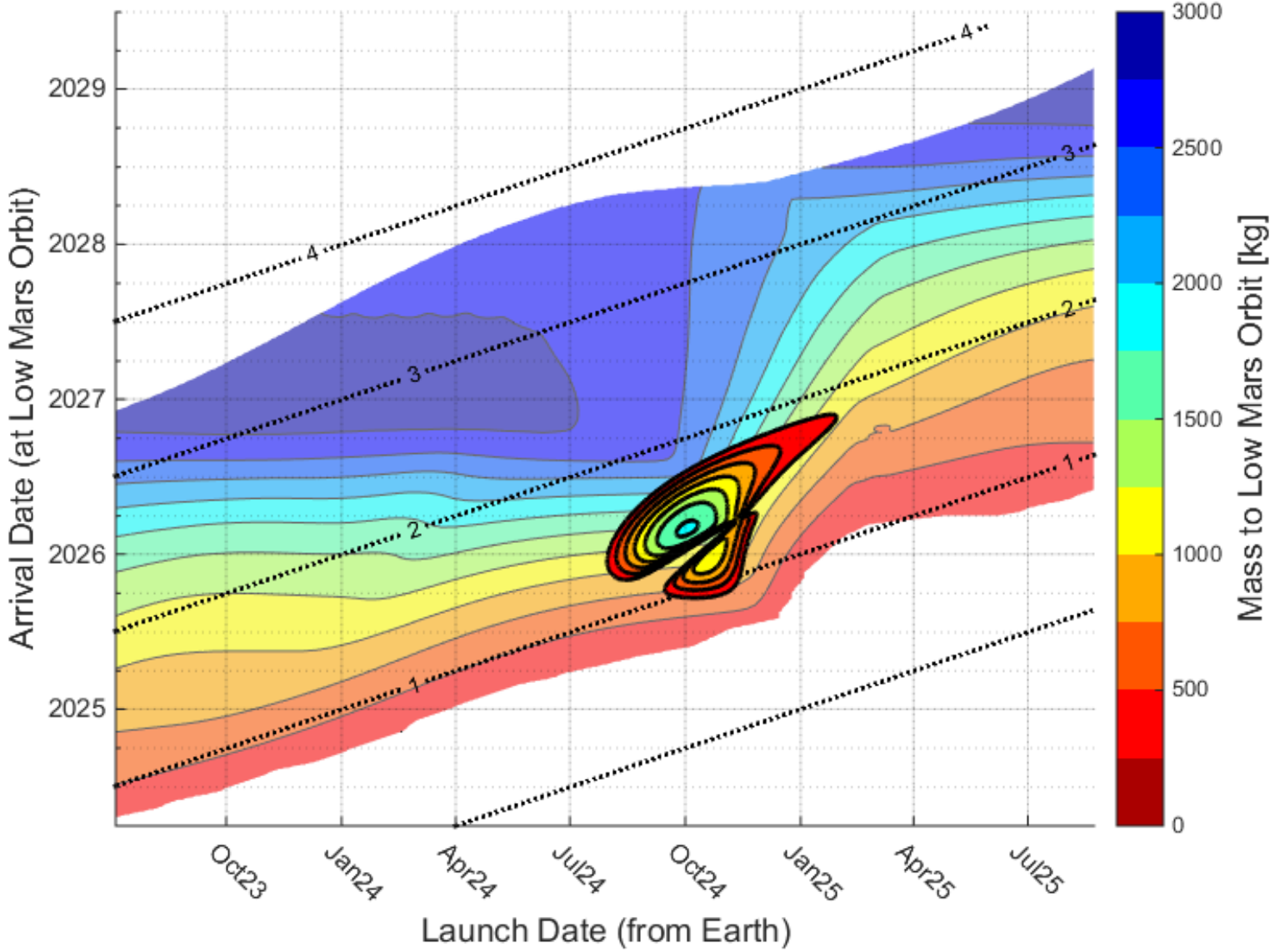
Not always straightforward



Complex constraints complicate the initial search…

State of the art techniques are used to uncover exceptionally strong trajectory solutions…

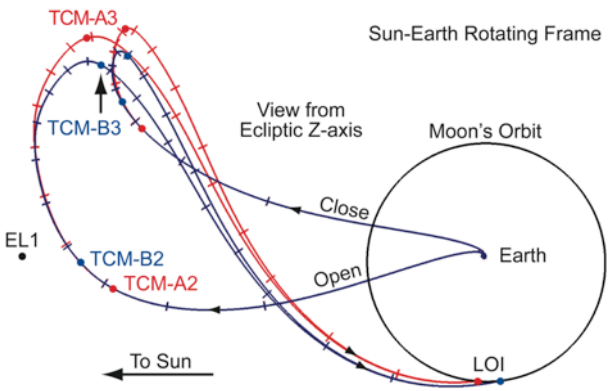
Bacon Plot


Arrival Date (at Low Mars Orbit)
2029
2028
2027
2026
2025
Launch Date (from Earth)
Oct23
Jan24
Apr24
Jul24
Oct24
Jan25
Apr25
Jul25
Mass to Low Mars Orbit [kg]
3000
2500
2000
1500
1000
500
0
1
2
3
4

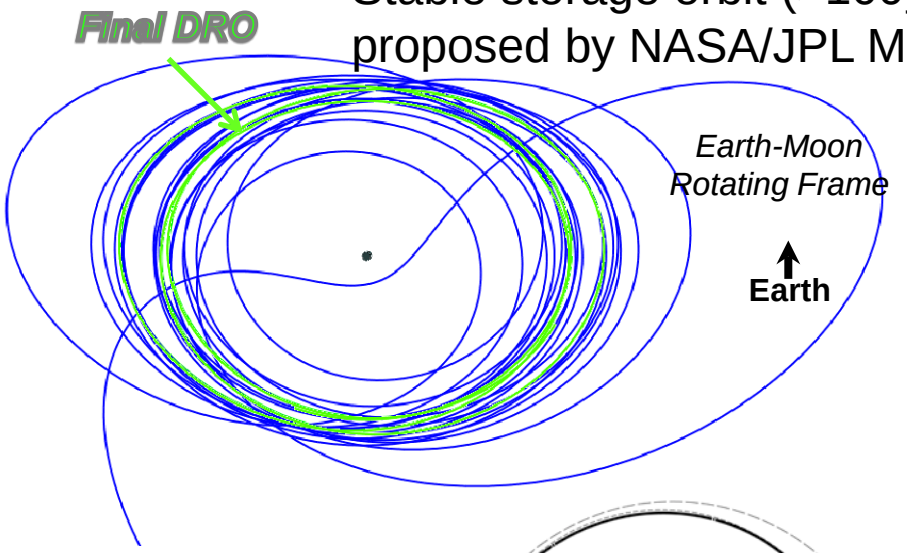
Low-Thrust & Low-Energy Trajectories

Ideal for robotic/human support missions

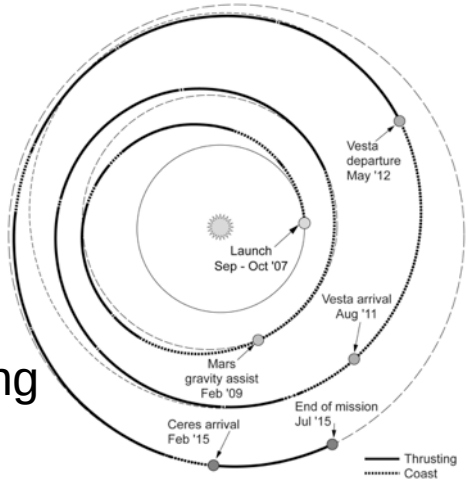
Proposed
Asteroid Retrieval Mission
Distant Retrograde Orbit (DRO)
Stable storage orbit (>100yrs)
proposed by NASA/JPL MD/Nav



GRAIL low-energy trajectory enabled the mission to reduce fuel requirements and the lunar arrival velocity



Dawn low-thrust trajectory has achieved a total delta-v over 10 km/s. Allows reaching both Vesta and Ceres.

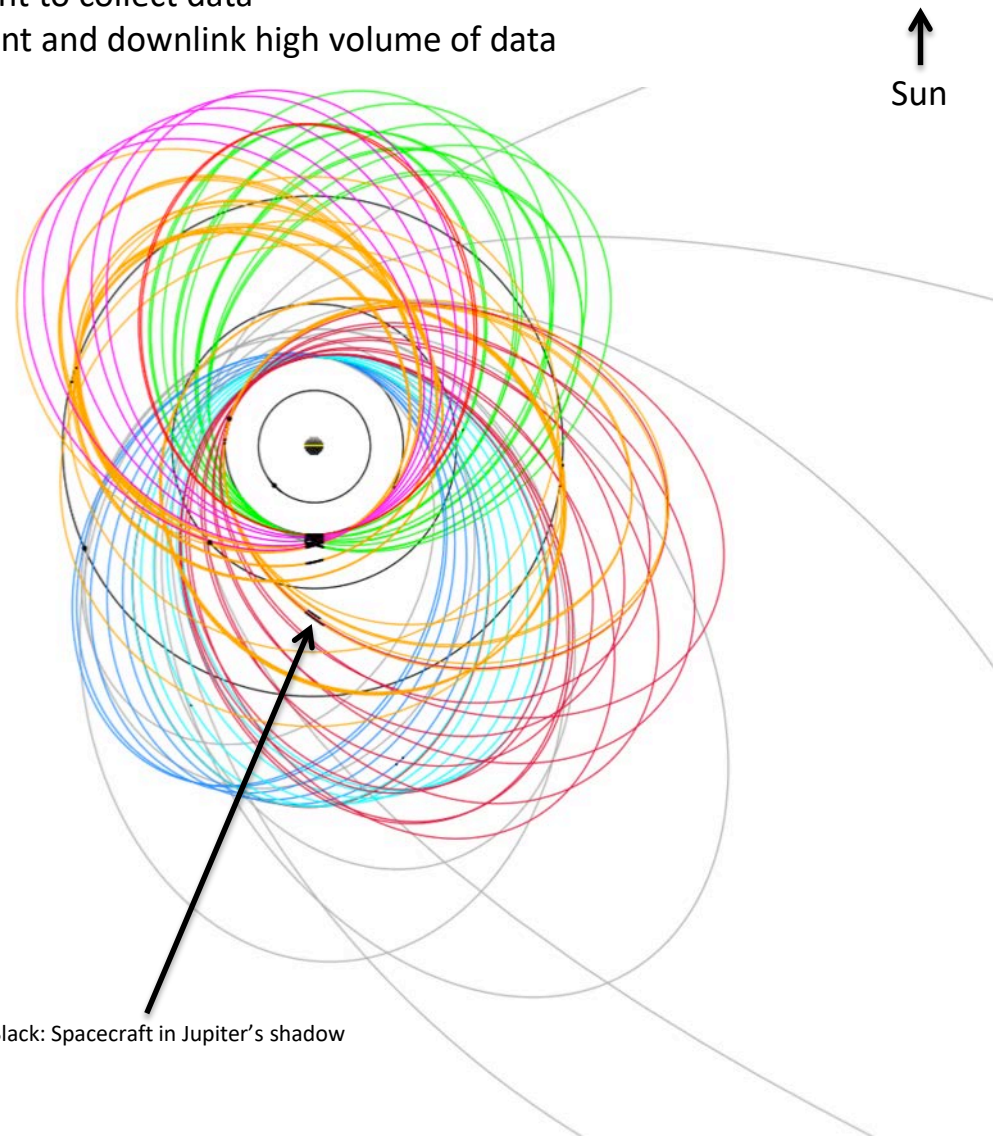


Europa Multiple Flyby Mission Concept

- Dip into the harsh radiation environment to collect data
- Get out of intense radiation environment and downlink high volume of data

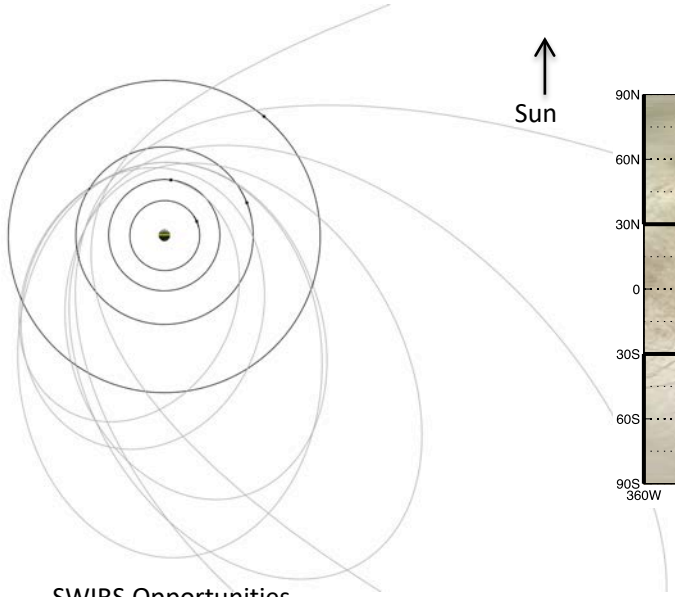
Key Statistics	13F7-A21
Tour Duration	3.5 years
Number of Flybys: Europa Ganymede Callisto	 45 5 9
Time between Flybys: Maximum* Minimum Mean*	 57.2 days 5.5 days 18.9 days
Maximum Inclination	20.1°
Maximum Eclipse Duration	4.5 hours
Total Ionizing Dose** (TID)	2.8 Mrad
Deterministic ΔV (post-PRM)	164 m/s
Statistical ΔV (99%)	223 m/s
Total Mission ΔV	1596 m/s

*Not including the 202-day capture orbit
**Si behind 100 mil Al, spherical shell (GIRE2)

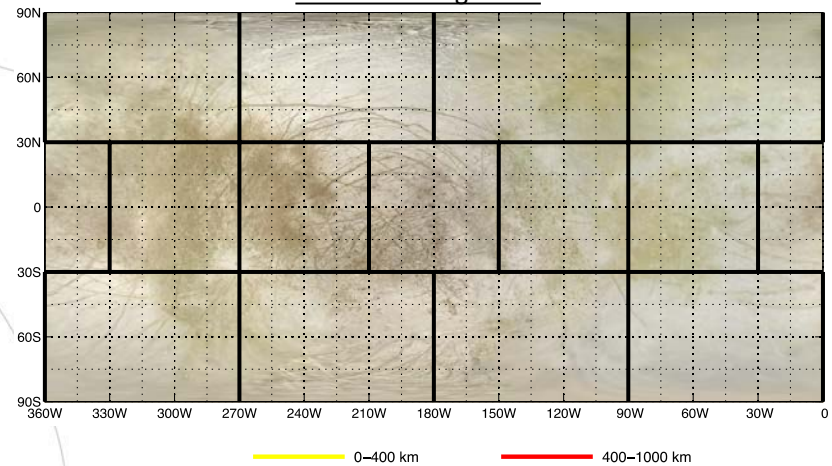


Coverage Build Up

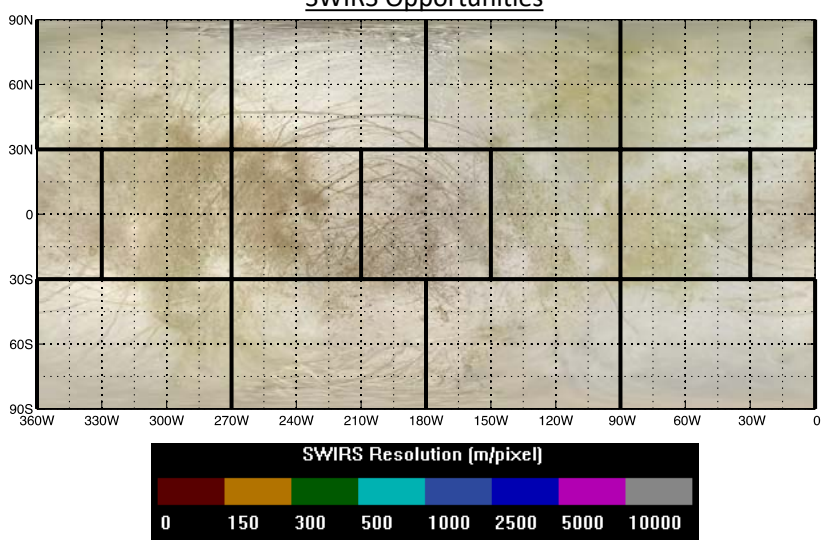
Tour Phases:
- Pump Down



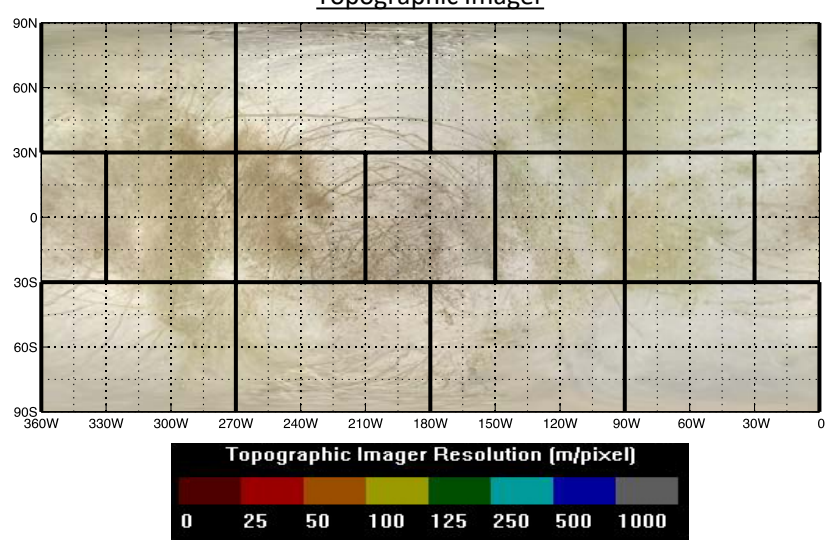
Ice Penetrating Radar



SWIRS Opportunities



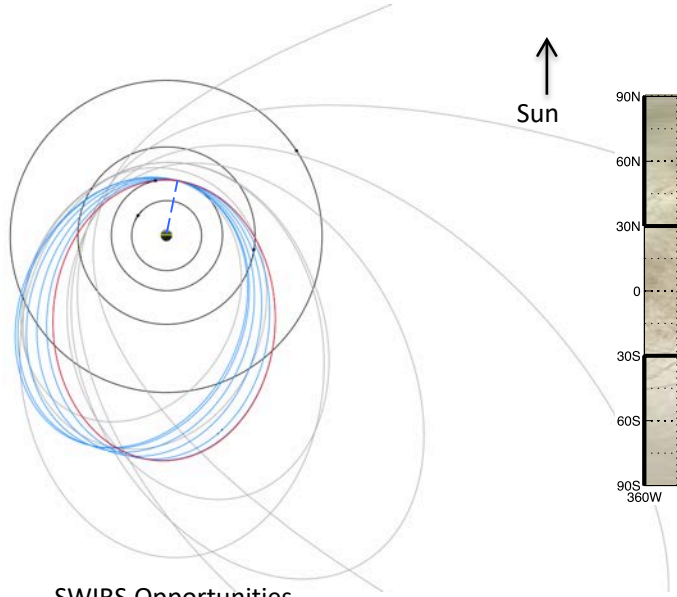
Topographic Imager



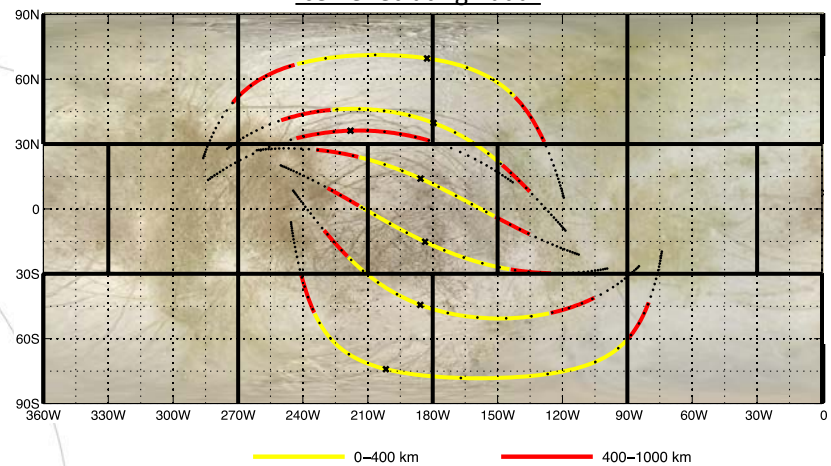
Coverage Build Up

[Through COT-1]

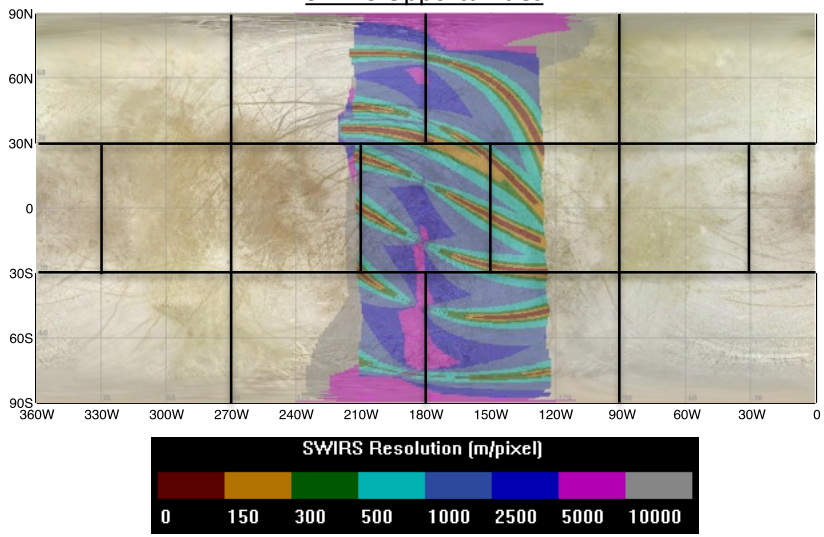
Tour Phases:
- Pump Down
- COT-1
- Non-Res



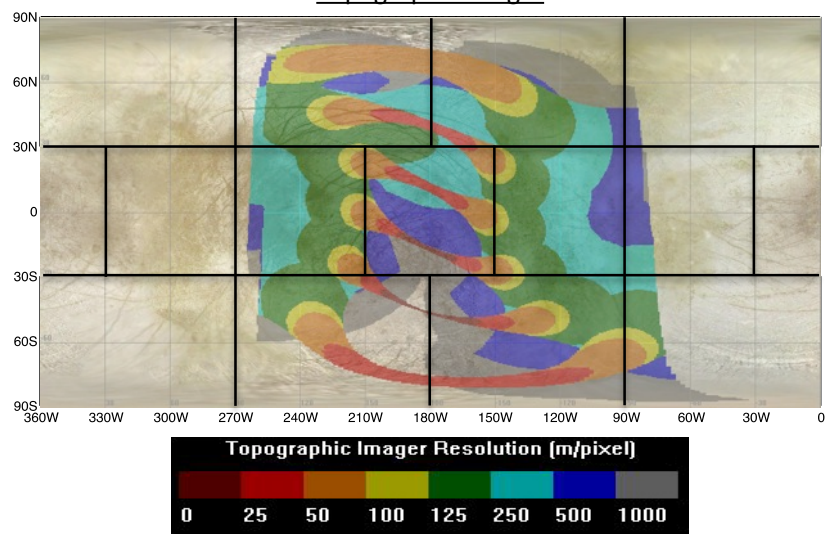
Ice Penetrating Radar



SWIRS Opportunities



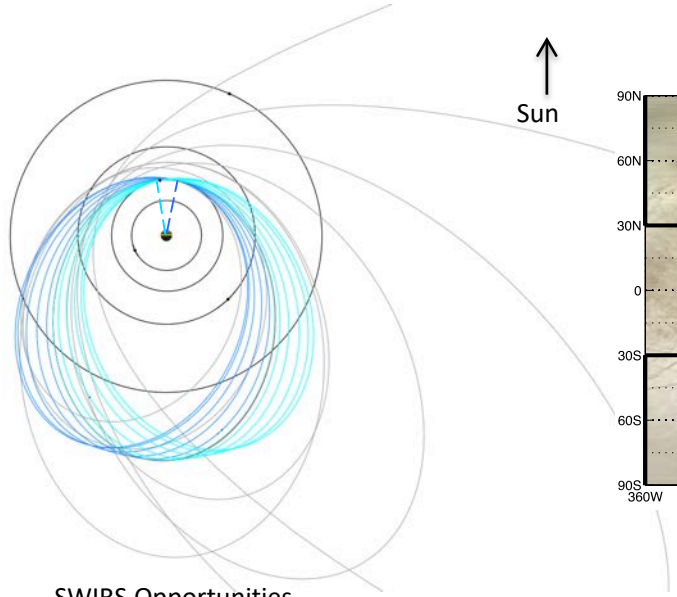
Topographic Imager



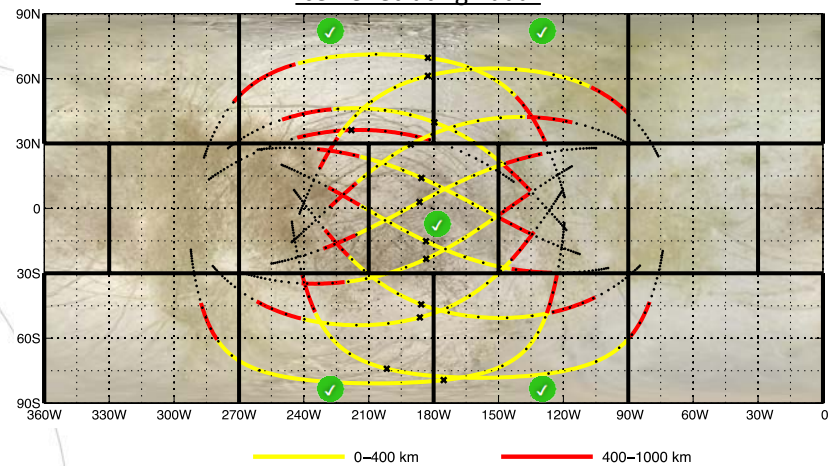
Coverage Build Up

[Through COT-2]

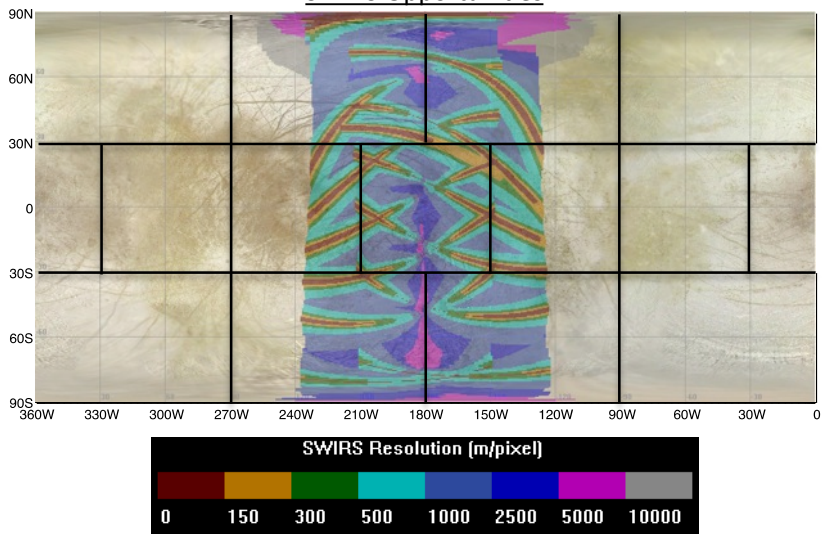
Tour Phases:
- Pump Down
- COT-1
- Non-Res
- COT-2



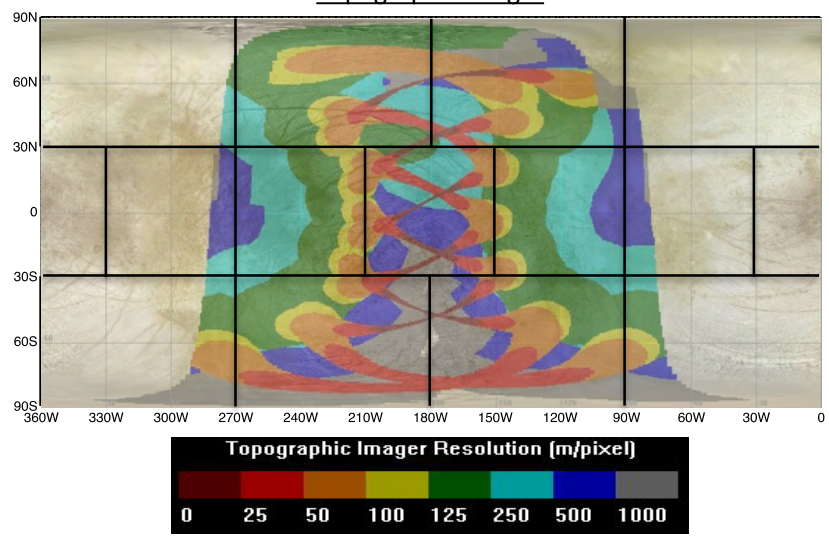
Ice Penetrating Radar



SWIRS Opportunities



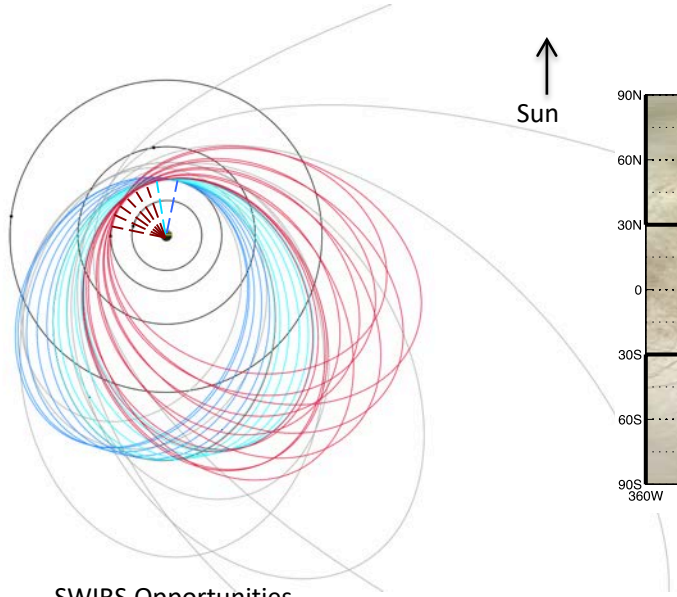
Topographic Imager



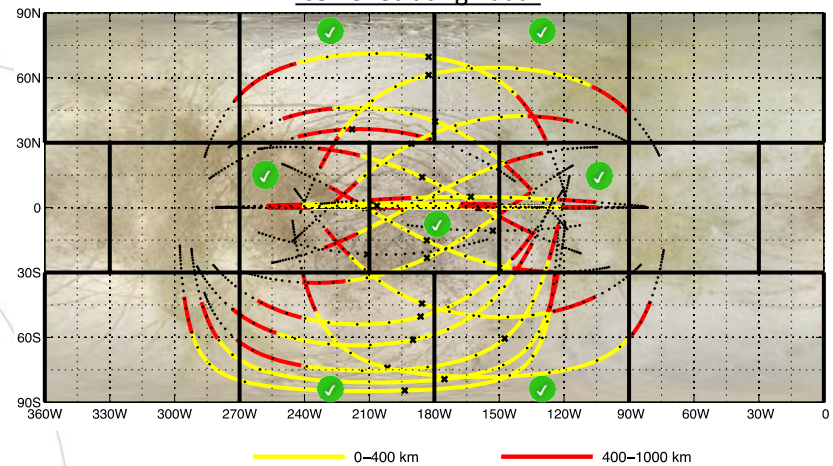
Coverage Build Up

[Through Petal Rotation]

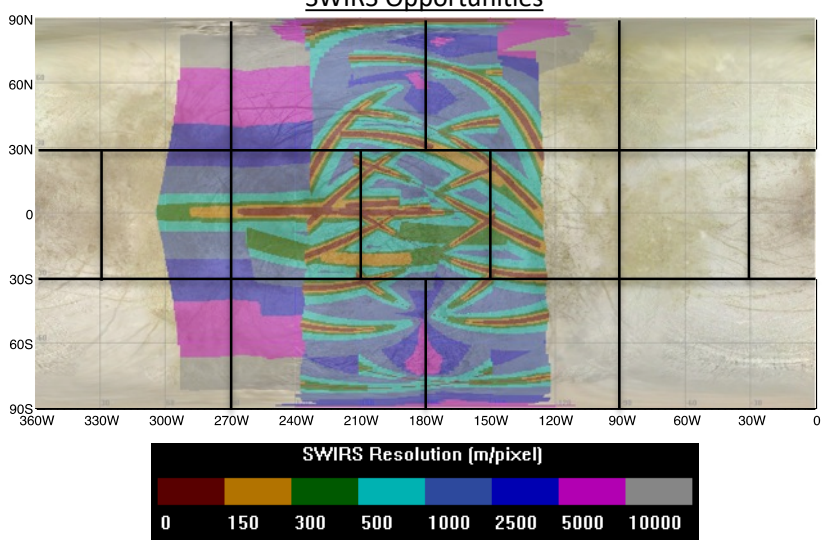
Tour Phases:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation



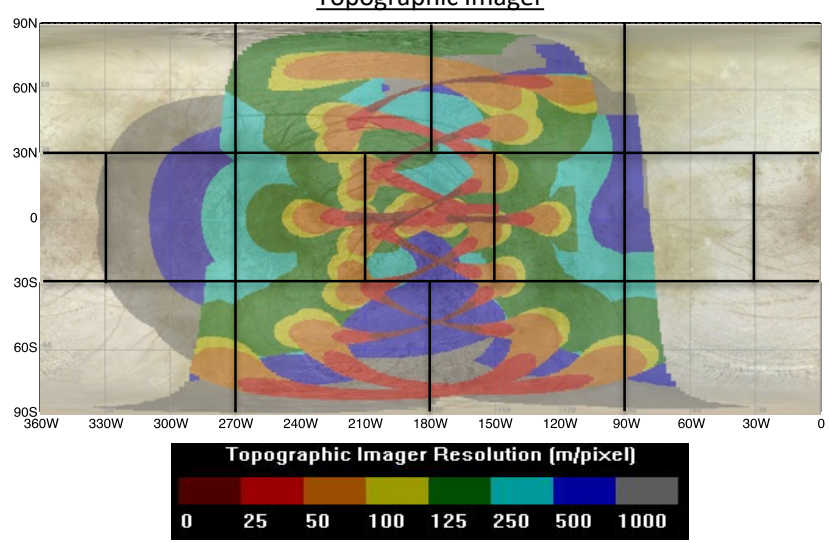
Ice Penetrating Radar



SWIRS Opportunities



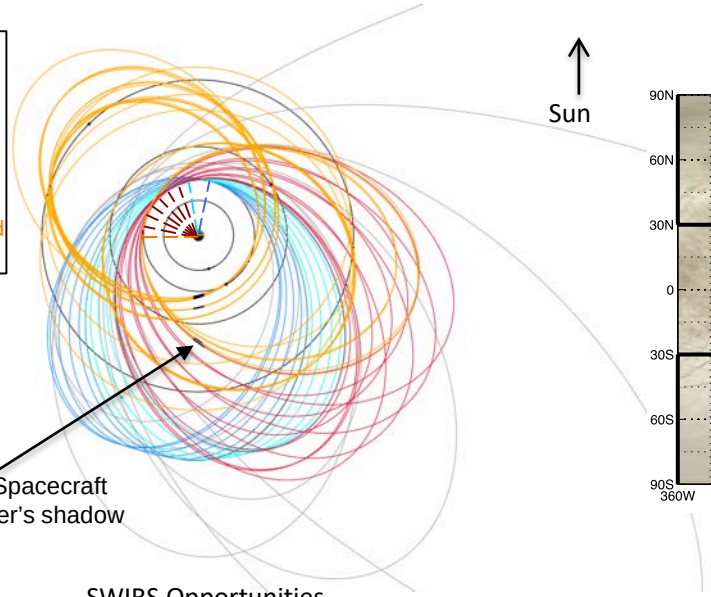
Topographic Imager



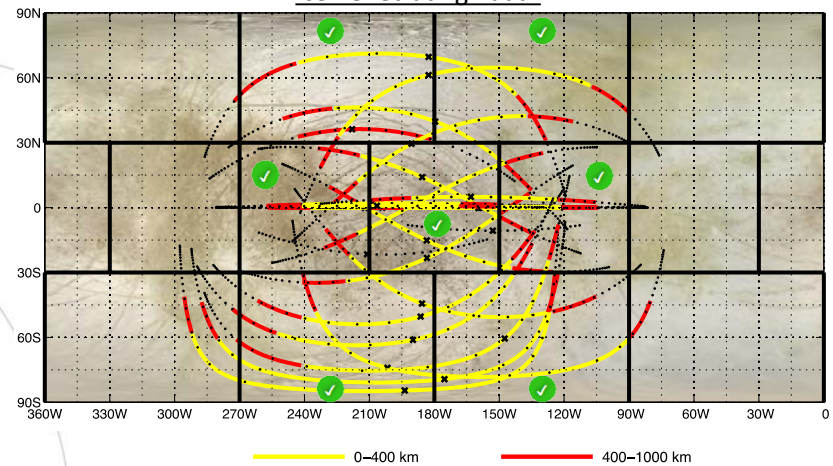
Coverage Build Up

[Through Switch-flip]

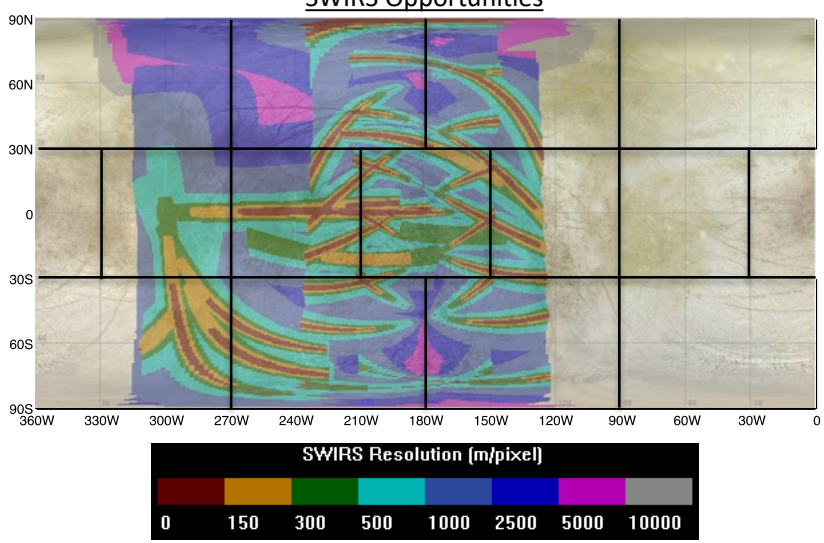
Tour Phases:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation
- Change Illuminated Hemisphere



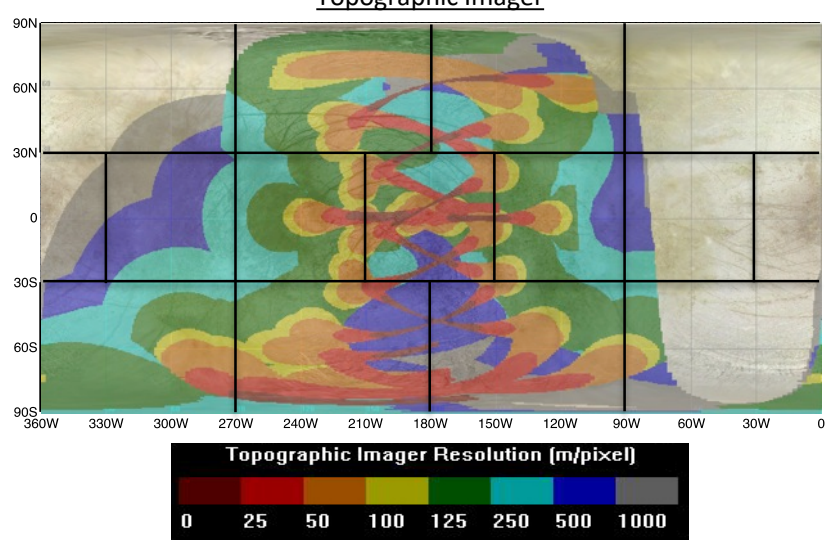
Ice Penetrating Radar



SWIRS Opportunities

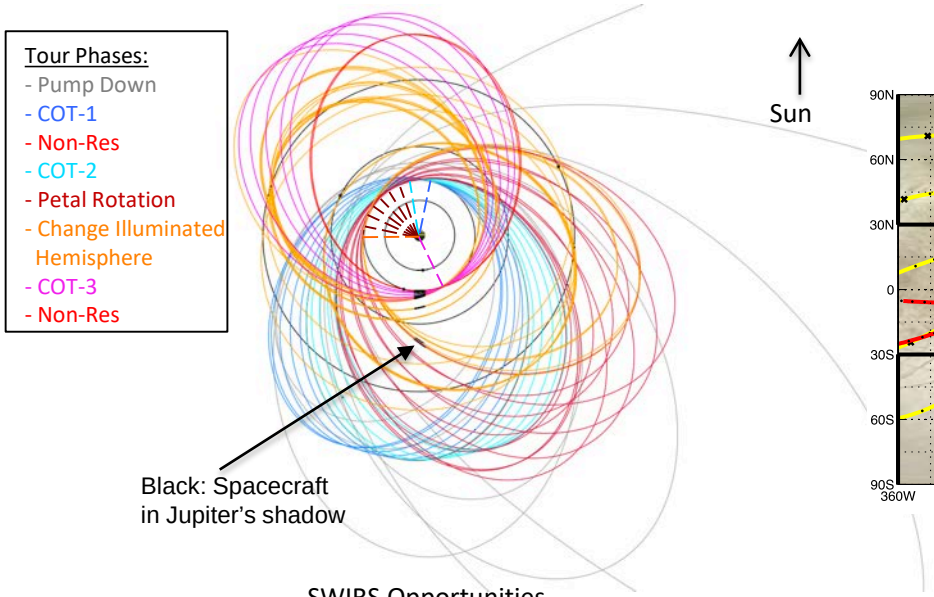


Topographic Imager

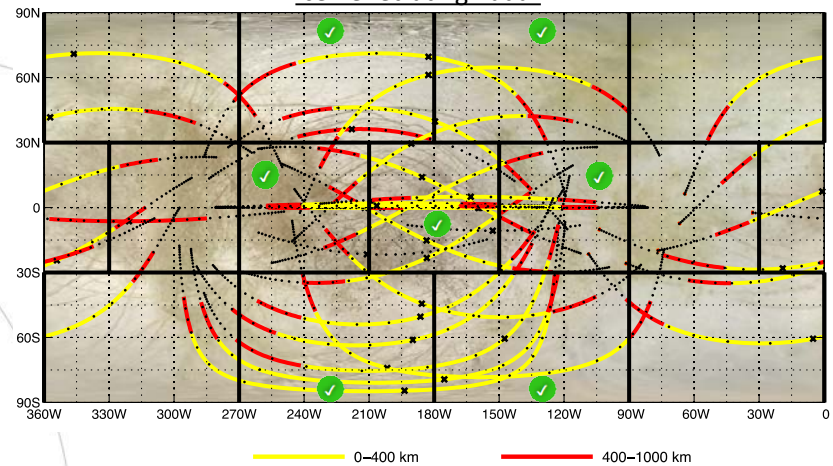


Coverage Build Up

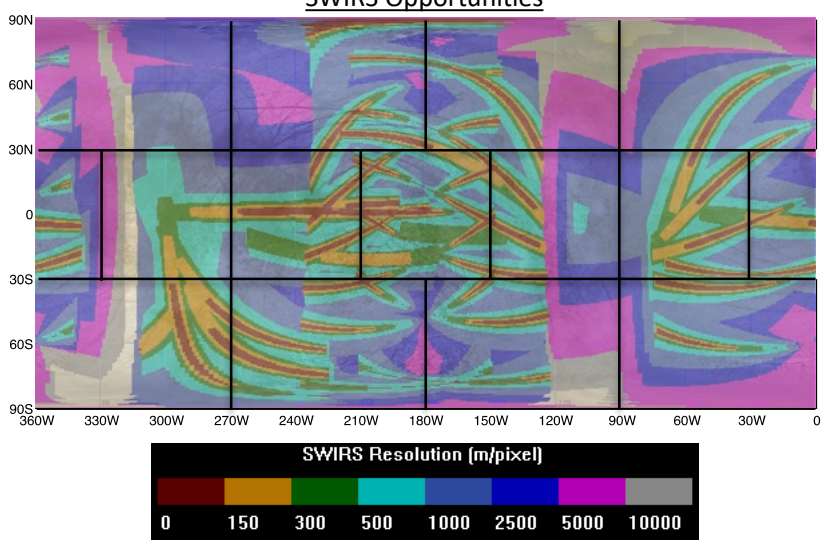
[Through COT-3]



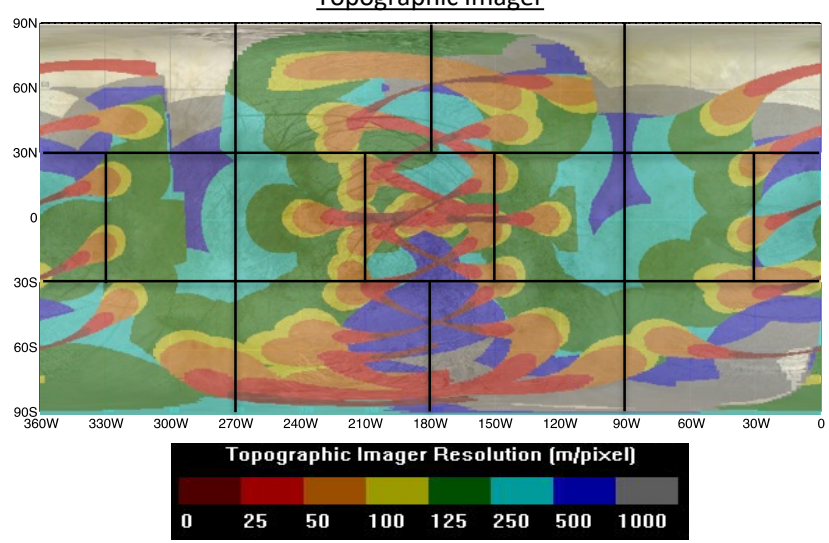
Ice Penetrating Radar



SWIRS Opportunities



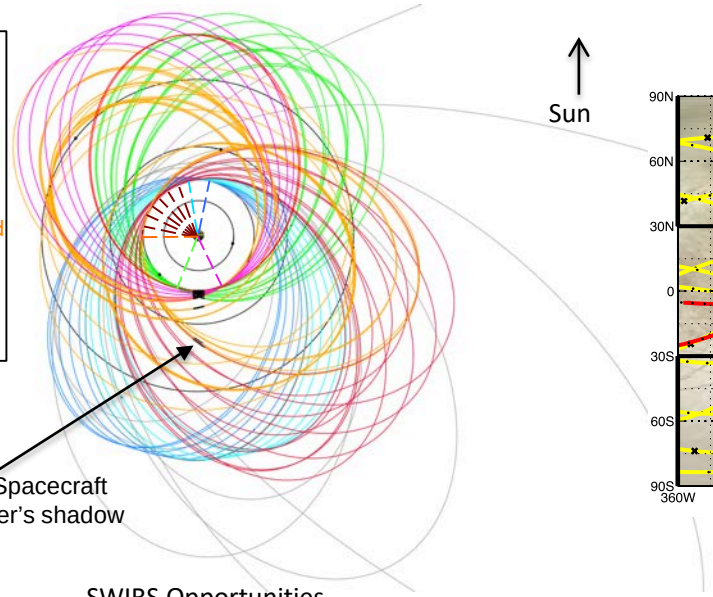
Topographic Imager



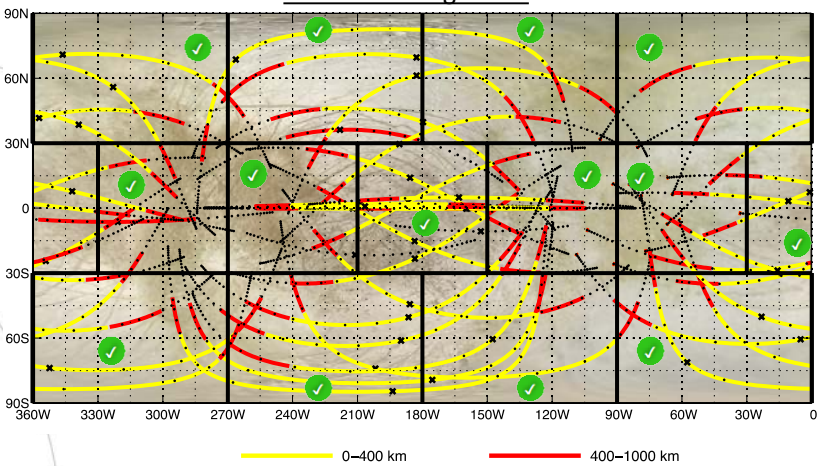
Coverage Build Up

[Through COT-4]

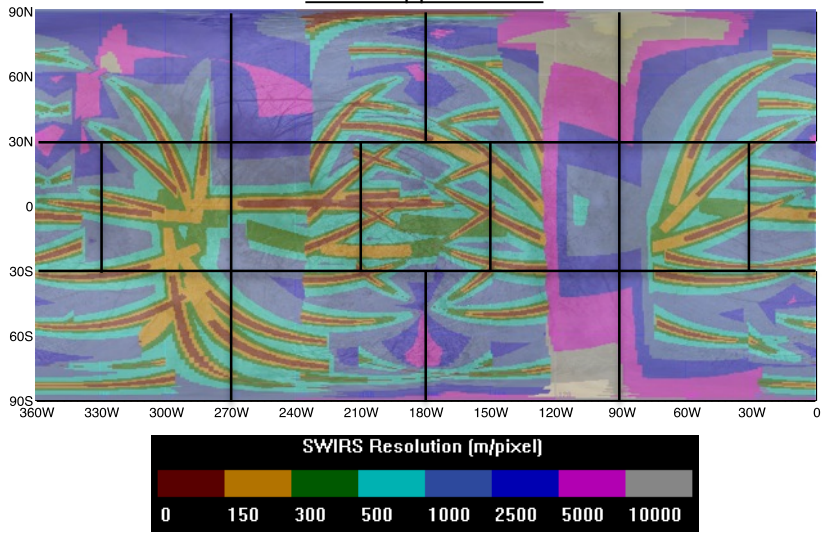
Tour Phases:
- Pump Down
- COT-1
- Non-Res
- COT-2
- Petal Rotation
- Change Illuminated Hemisphere
- COT-3
- Non-Res
- COT-4



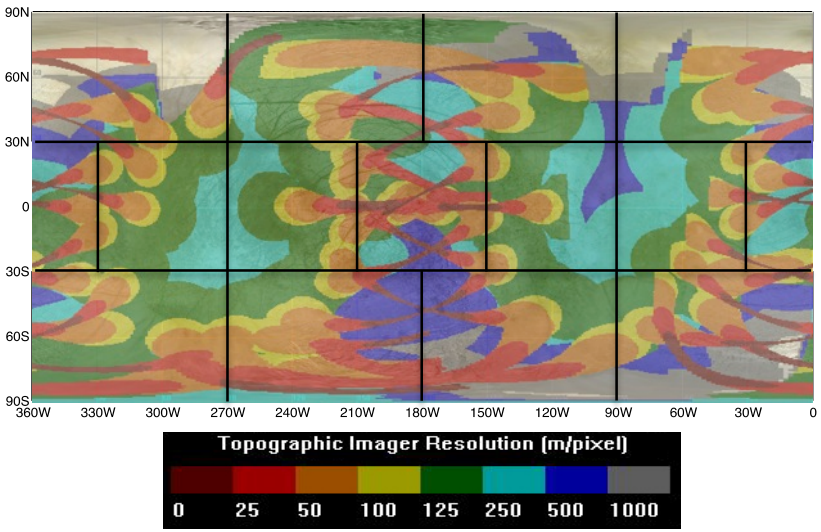
Ice Penetrating Radar



SWIRS Opportunities



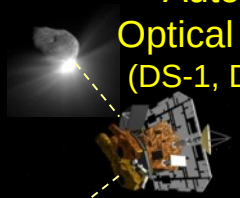
Topographic Imager



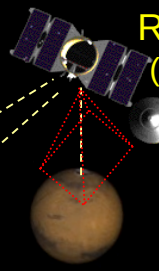
Navigation Measurements

Ground-based
Optical Navigation
(Voyager, Galileo, Cassini)

Autonomous
Optical Navigation
(DS-1, DI, Stardust)

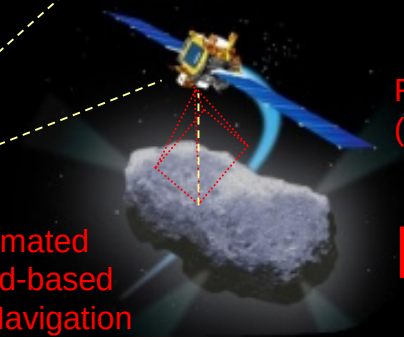


Ground-based
Radio Navigation
(MER, PHX, MSL)



In-Situ Radio
Beacons w/DSAC
(Pinpoint Landing)

Autonomous
Radio and Optical-based
(Rendezvous & Capture)



Automated
Ground-based
Radio Navigation

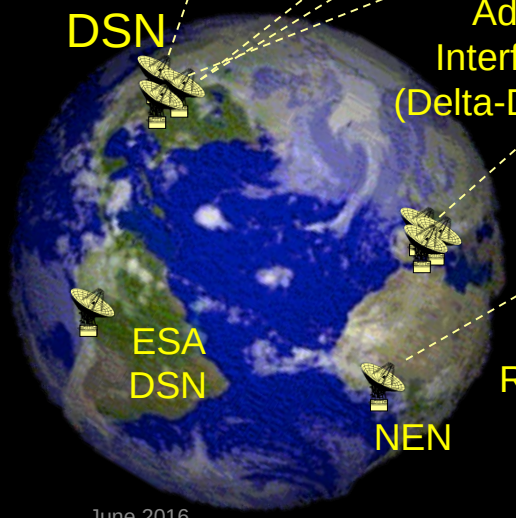
Radiometric
(Doppler and
Range)

State of the
Art

Future

DSN

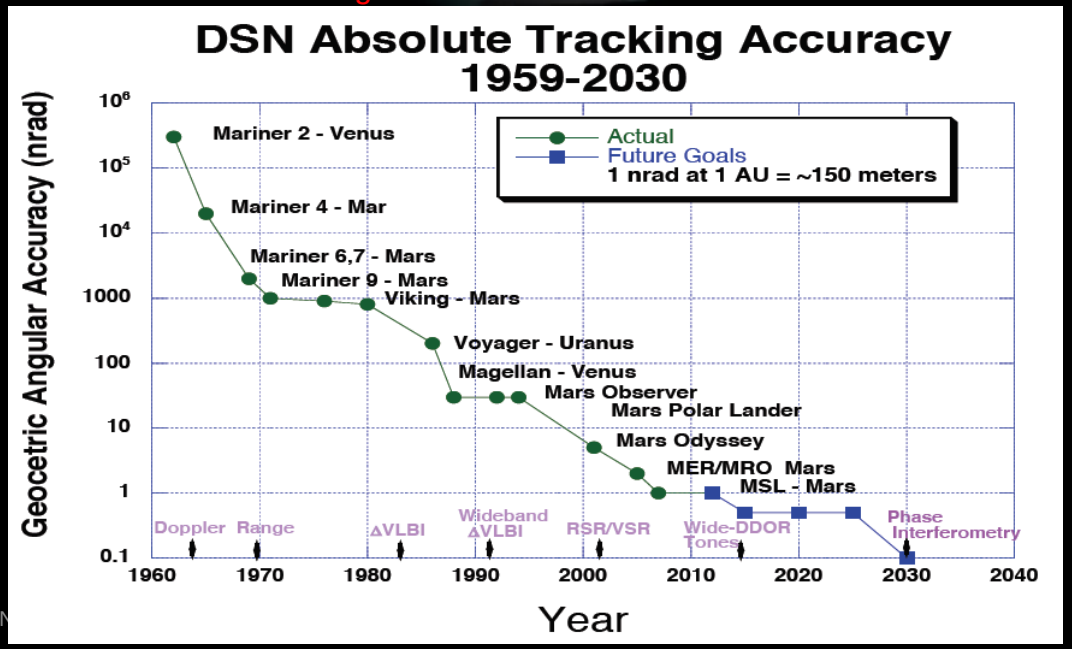
Advanced
Interferometric
(Delta-DOR, VLBA)



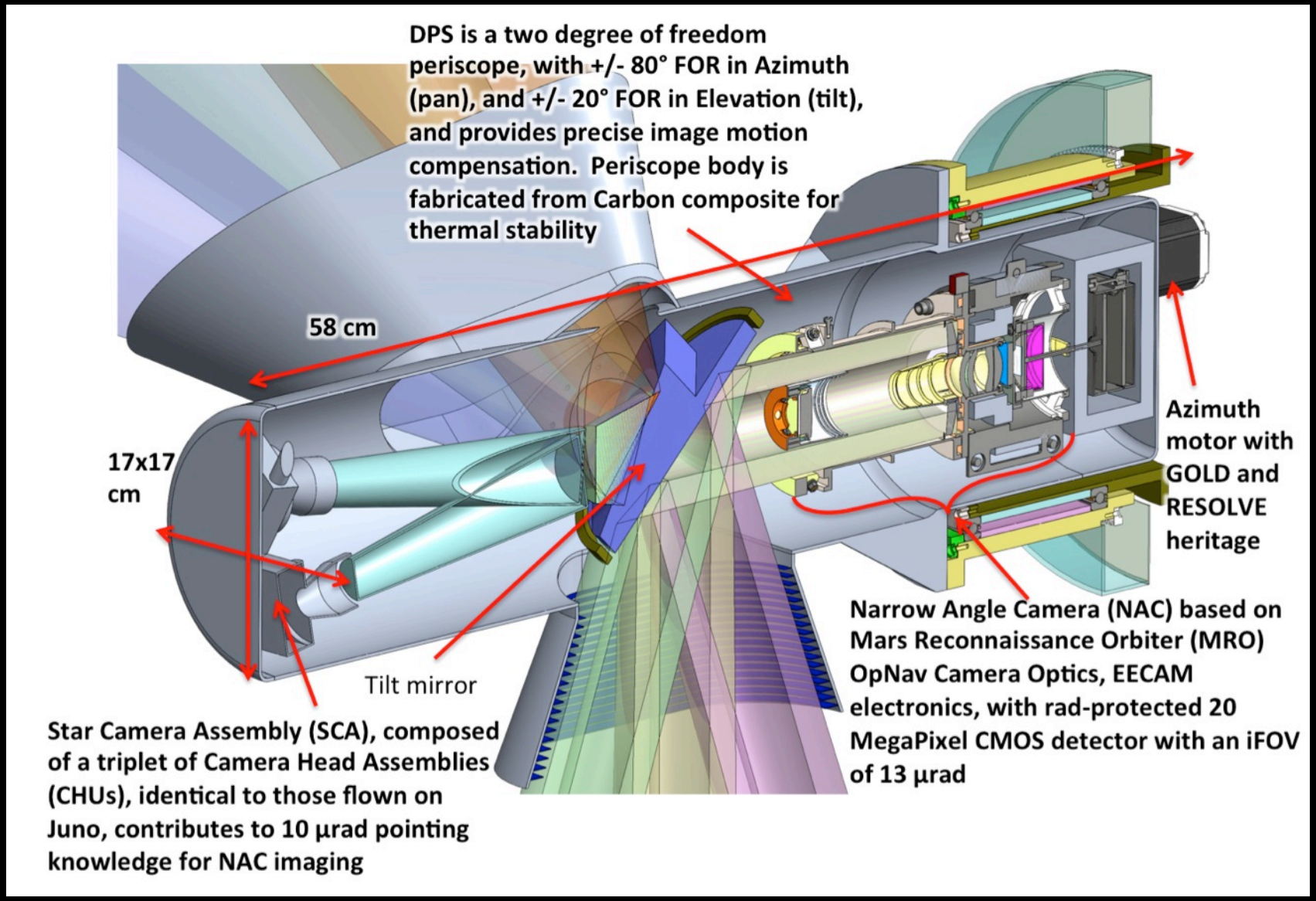
ESA
DSN

NEN

Automated
Ground-based
Radio Navigation
(SMAP)



Deep Space Positioning System (DPS) Concept



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