# Project Prometheus
# and
# Future Entry Probe Missions


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# What Is Project Prometheus?

– Program to develop a broad range of nuclear power & propulsion techs
- Nuclear electric power & propulsion (NEPP)
  - Fission reactors with thermal-to-electric conversion systems
  - High-power ion propulsion systems
  - Advanced electric propulsion (e.g., magnetoplasmadynamic (MPD) systems?)
- Nuclear thermal propulsion (NTP)
  - Newly considered;  higher thrust at lower $I_{SP}$
- Radioisotope power systems (RPS)
  - RTGs, mini-RTGs
  - Milliwatt thermoelectric systems
  - Stirling power systems

–...for the Space Science & Space Exploration communities
- Anywhere in the solar system, regardless of solar energy availability
  - Outer solar system
  - Permanently shadowed regions
- Potential power source for human exploration programs

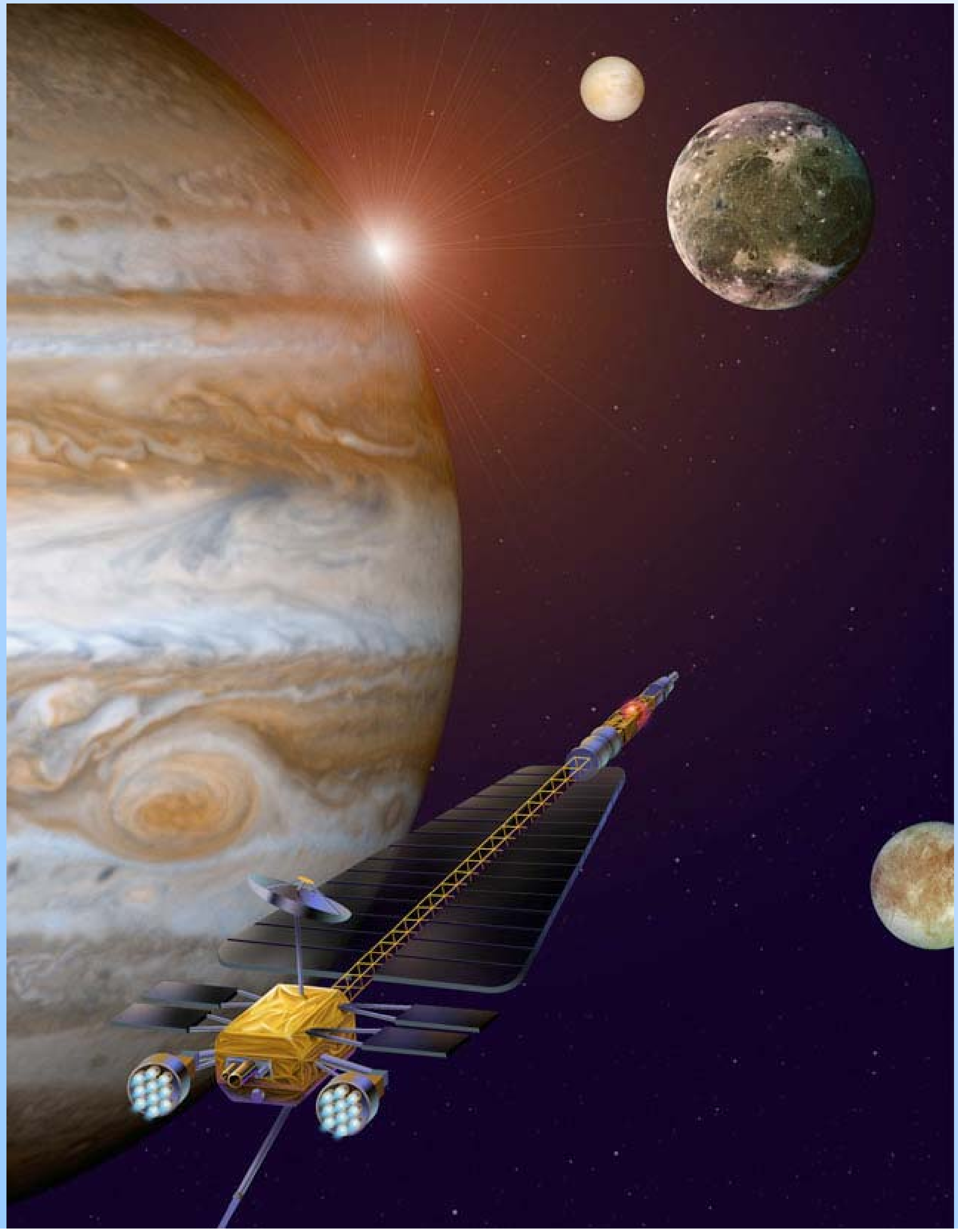
# What Capabilities Can Project Prometheus Offer? What Mission Types Are Being Considered?

– Capability: very high total energy from fission-based systems
  - High power (kW to MW) for long durations (> a decade)

– Capability: very high propulsive delta-V
  - Ion propulsion specific impulse (thousands of seconds)
  - Ion-propulsion-level accelerations ($\sim 10^{-4}$ m/s$^2$) for more than a decade
    - Anywhere in the solar system, independent of heliocentric distance

– Missions considered: ones making appropriate use of the technologies
  - Need very high post-launch delta-V (10's of km/s)
    - Chemical systems can provide up to a few km/s
    - Pushing a large payload to a relatively low delta-V is *not* efficient use of NEP
  - Need high power (10's of kWe or more), for years, at the destination
    - High power science instruments
    - High data rate telecommunications

# Jupiter Icy Moons Orbiter (JIMO)



## Fission-Powered Vehicle

- Turbine-generated electric power, ~100 kWe
- Ion propulsion (probably Xenon propellant)
  - $I_{SP}$ 6000 - 9000 s
  - Delta-V capability tens of km/s
- When propulsion system is not active, high power is available for science instruments
  - Extremely high data rates
- Launch 2011-2013?
- Some mission designs might allow delivering Jupiter entry probes
  - Significant impact to mission
    - Payload mass
    - Mission duration

*Never Mind!*

# How Are Mission Opportunities Changing?

– Decadal Survey priorities were based on Pre-Project Prometheus tech
  - Priorities for science objectives only partly influenced by technical feasibility
  - Flight schedule priorities heavily influenced by tech development schedules

– Project Prometheus re-arranges technical feasibility
  - Feasibility limitations by power or propulsion apply to fewer missions
  - Multiple ways this can affect mission schedules;  examples:
    - ♦ A mission's high-priority science is enabled sooner by NEPP
    - ♦ Earlier implementation of one mission pushes another mission later
    - ♦ Prospect of greater science return with NEPP implementation pushes it later

– Lower-priority missions steered to Discovery, New Frontiers Programs
  - Example:  Terrestrial-planet atmospheric entry missions
  - NASA faces a "mission size gap" between New Frontiers Program & Project Prometheus

# Missions Of Interest a Year Ago

–Some mission concepts directly involve atmospheric entry vehicles

- Venus In Situ Explorer (“VISE”;  New Frontiers candidate)
- Venus Sample Return
- Jupiter Polar Orbiter With Probes (“JPOP”;  New Frontiers candidate)
- Titan Explorer
- Neptune Orbiter With Probes (NASA Vision Mission concept)

–Other concepts might add entry probes, but then-current designs did not have them

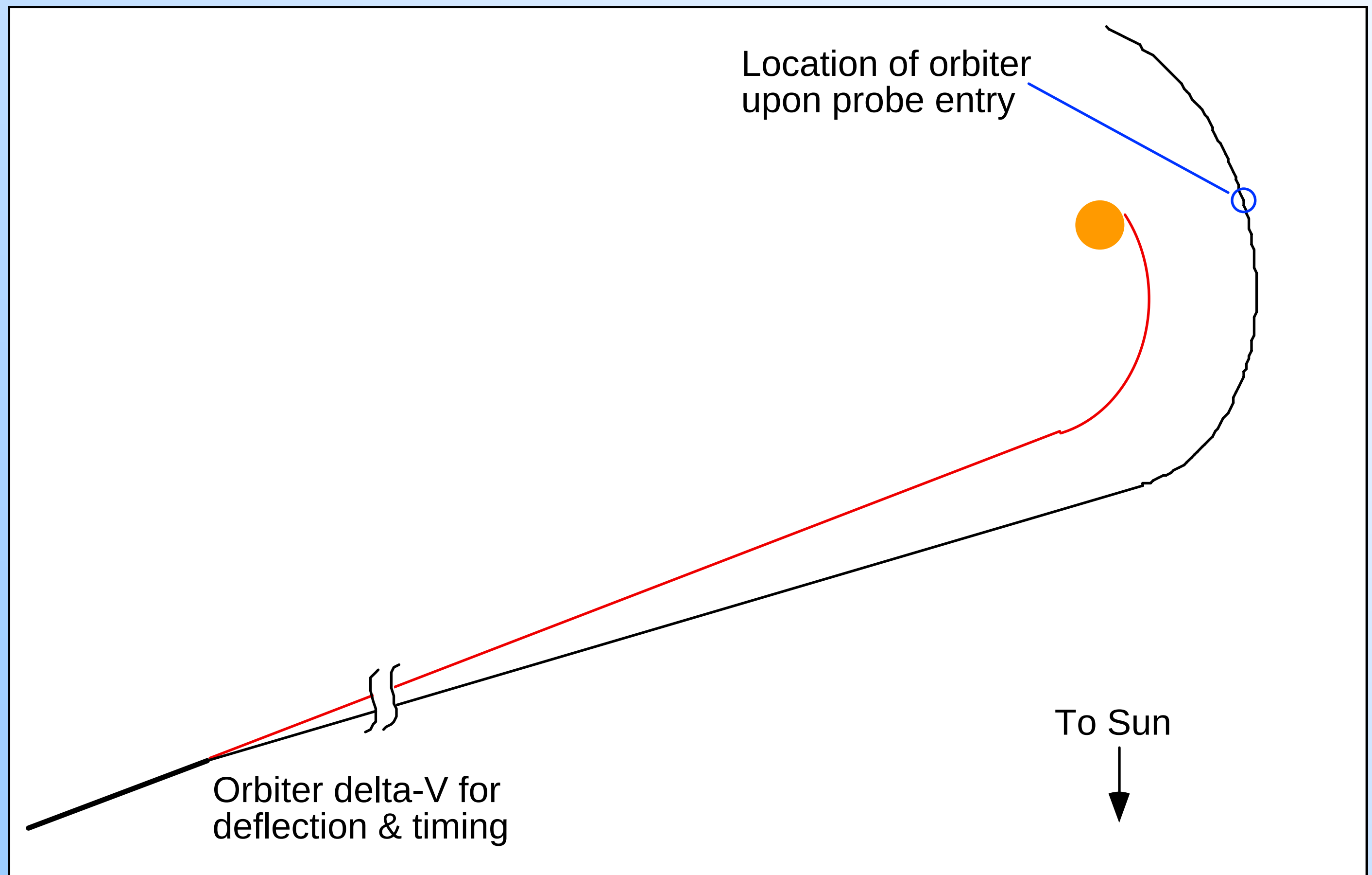
- Venus Aeronomy Probe
- Io Electrodynamics
- Saturn Ring Observer

# Missions Now Being Considered For Further Study

- Science direction from Decadal Surveys and NASA-convened groups
  - Example:  Second Outer Planets Forum held June 21-22, 2004
- Project Prometheus Advanced Missions Office is tasked with studies
  - Decisions about which missions to study are made at NASA HQ
  - Studies are performed by the multi-center “Team Prometheus” led by JPL
  - Missions deemed highest priority for near-term studies:
    - Saturn / Titan  (study largely completed)
    - Neptune / Triton (study just began;  considered directly applicable to Uranus)
    - Kuiper Belt (multiple objects)
    - Interstellar Precursor / Heliopause
    - Comet Cryogenic Sample Return
    - Multiple Asteroid Rendezvous and Sample Return
- Top two missions on the list potentially involve entry probes
  - <u>Saturn</u> entry probes;  <u>Titan</u> mobile surface/atmospheric platform (aerobot?)
  - <u>Neptune</u> (also, <u>Uranus</u>) entry probes;  <u>Triton</u> lander?

# Galileo-Style (Conventional) Probe Delivery

– Delivery from approach, several months before probe entry
– Orbiter on entry trajectory;  release, then small delta-V deflects & times
– Orbiter is overhead of probe during its descent



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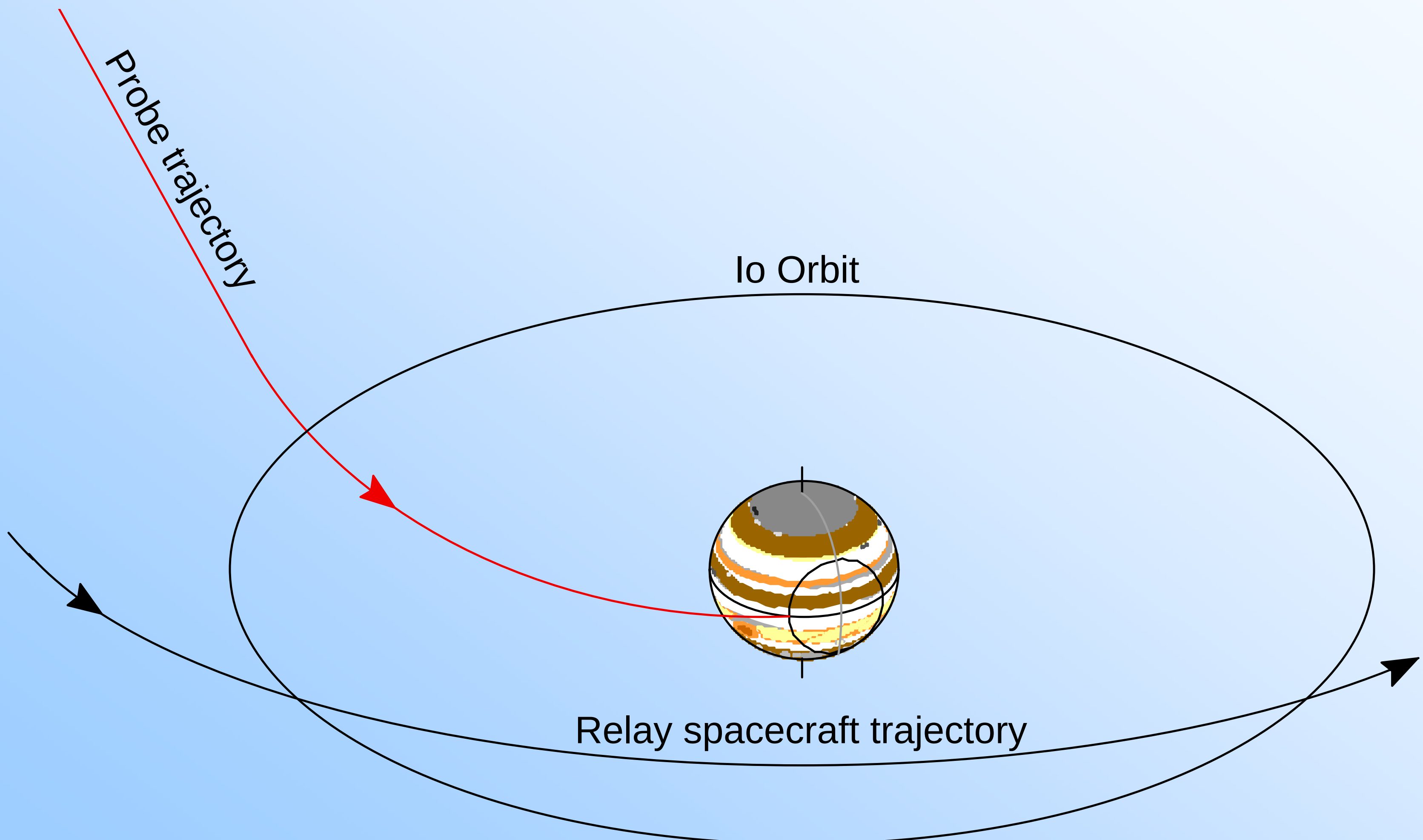
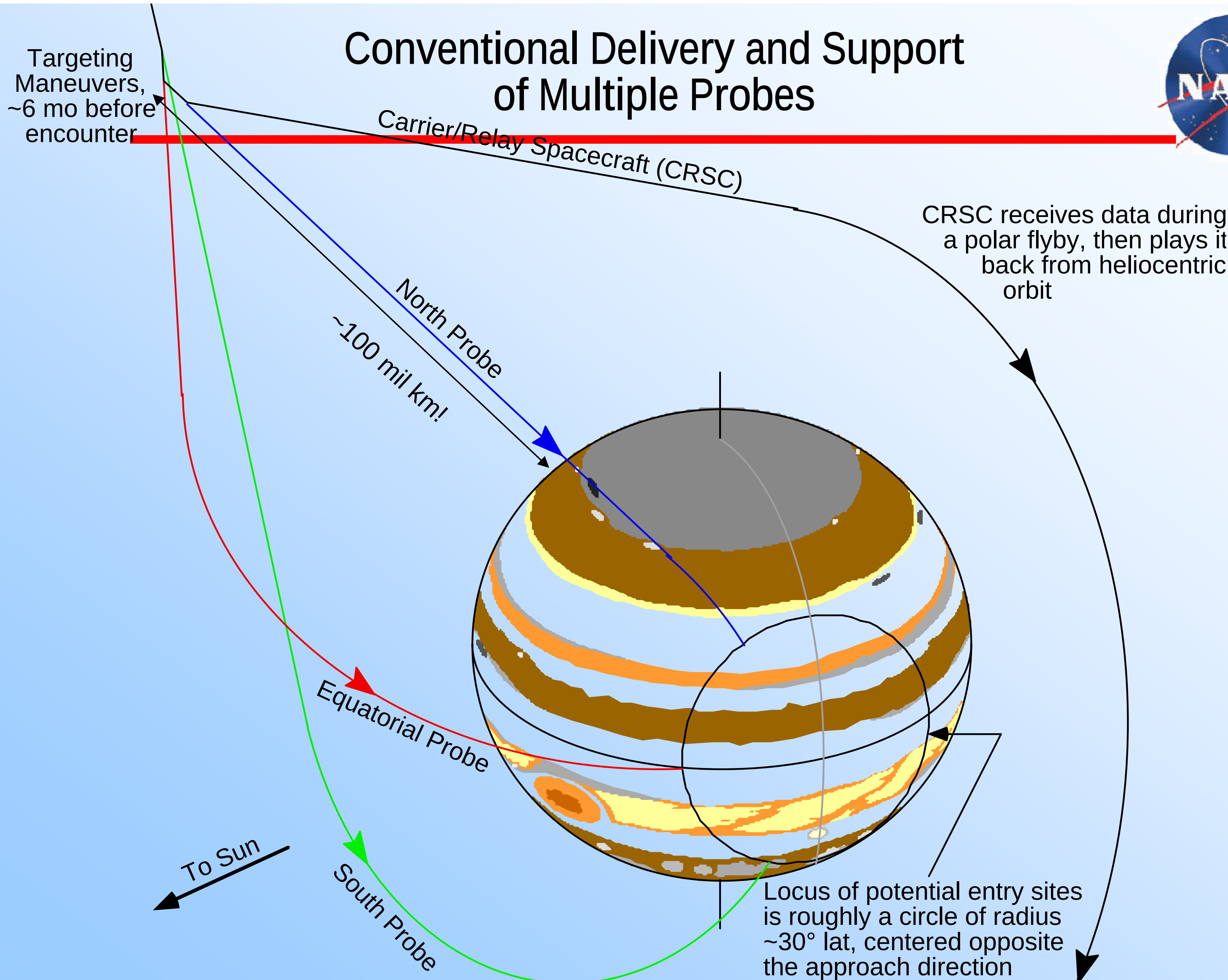
# Galileo-Style Probe Support



# Conventional Delivery and Support of Multiple Probes




Pre-Decisional -- For Discussion Purposes Only

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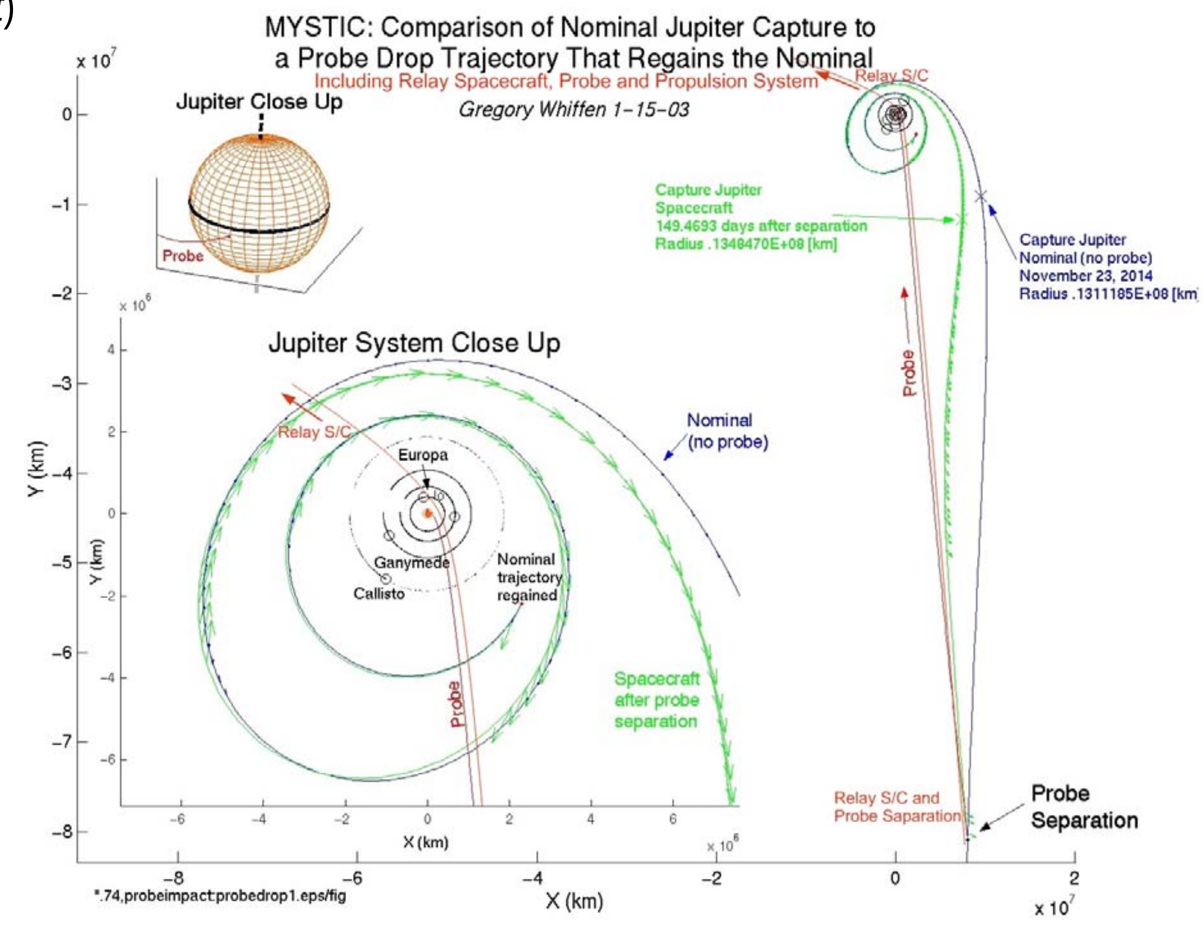
# How Entry Probe Delivery From an NEP Vehicle Is Different

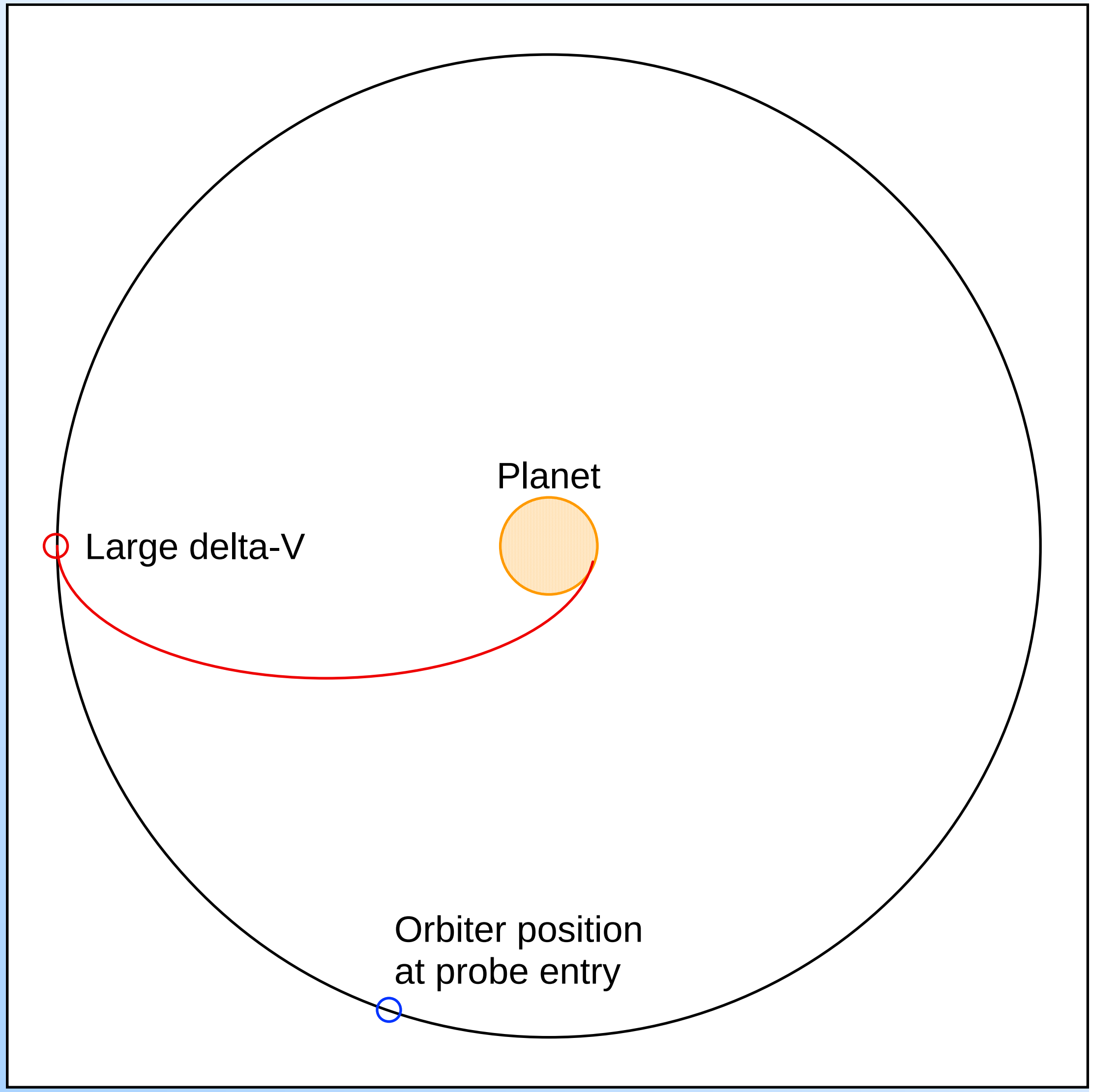
– Delivery from approach
- Delivery vehicle can (sometimes, *must*) accelerate continuously after release
  - E.g., to achieve capture into orbit
  - Can result in untenable data relay situations
    - – Large distances between probe and orbiter at entry
    - – Orbiter zenith angle (seen from probe) is too large for useful communications
  - Mitigating this problem can have large impacts on the orbiter
    - – Major changes in trajectory design, causing increases in required delta-V
    - – Adding a dedicated relay subsatellite, with a cost and complexity penalty




From Balint et al., 2003

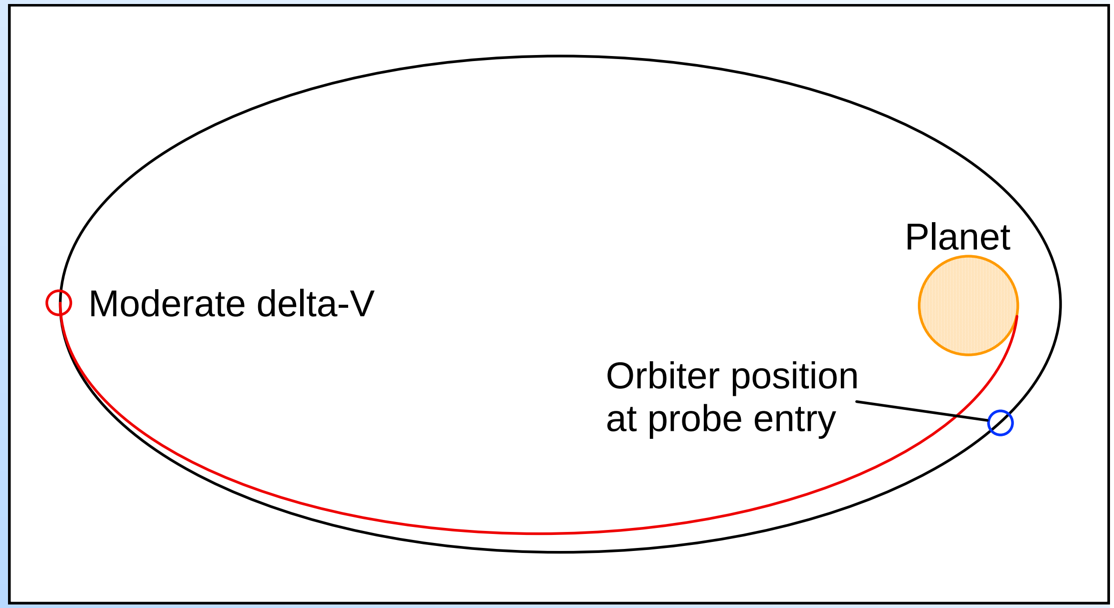
# How Entry Probe Delivery From an NEP Vehicle Is Different

– Delivery from near-circular orbit
- Orbiter must expend propellant to carry probe into orbit
- Imposes large delta-V require- ments *on the entry probe*
  - ♦ Large delta-V just for entry
  - ♦ Timing increases delta-V
  - ♦ For orbits larger than several planetary radii, entry speed may not be too different from “on-approach” situation
- Unless the orbit radius is the right size, angular rates can be quite different



# How Entry Probe Delivery From an NEP Vehicle Is Different

– Delivery from eccentric orbit
- Orbiter must expend propellant to carry probe into orbit
- Smaller delta-V requirements on the entry probe
  - Smaller timing penalty
  - Might be possible to perform the delta-Vs with the orbiter
    - Apoapse must be high for sufficient operations time
- Probe-orbiter distance smaller
- Overflight altitude must not be too low
  - Need reasonable overhead time
- Greatly increased flexibility in entry locations



# Concluding Remarks

Still, many future opportunities for entry probe missions

- Many science objectives at many potential destinations
- Available mechanisms for implementing missions have changed
  - Gap between New Frontiers and “Flagship”

Opportunities for methodological & technological innovation

- Design space for delivery and support has not been exhausted
  - Many avenues for new ideas
  - Old ideas are being “dusted off”
- Design of entry vehicles themselves is not significantly altered
  - One exception: possible addition of in-space delta-V capability

Realizing missions requires significant community consensus about mission objectives