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

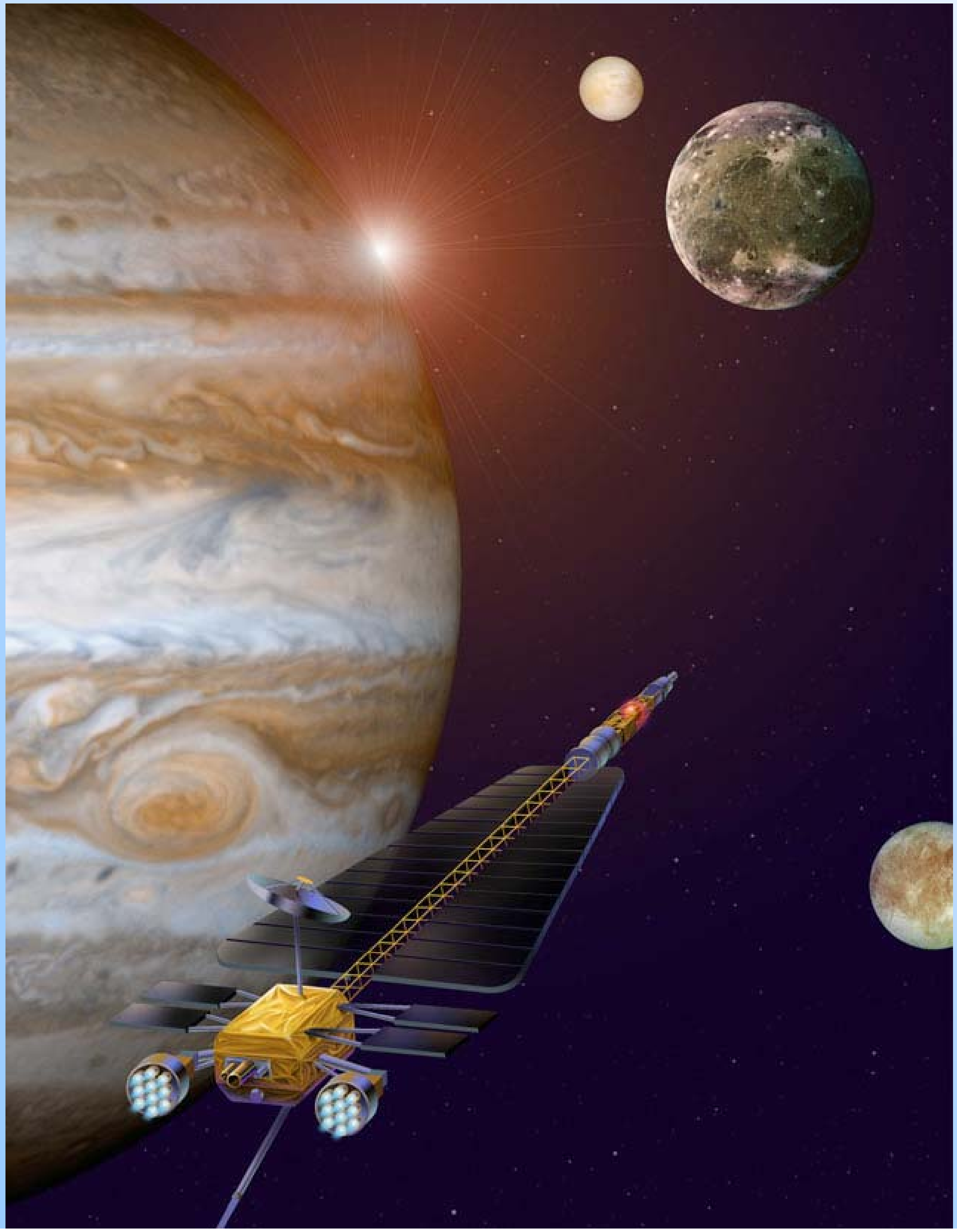
What Capabilities Can Project Prometheus Offer? What Mission Types Are Being Considered?

– 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 (~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

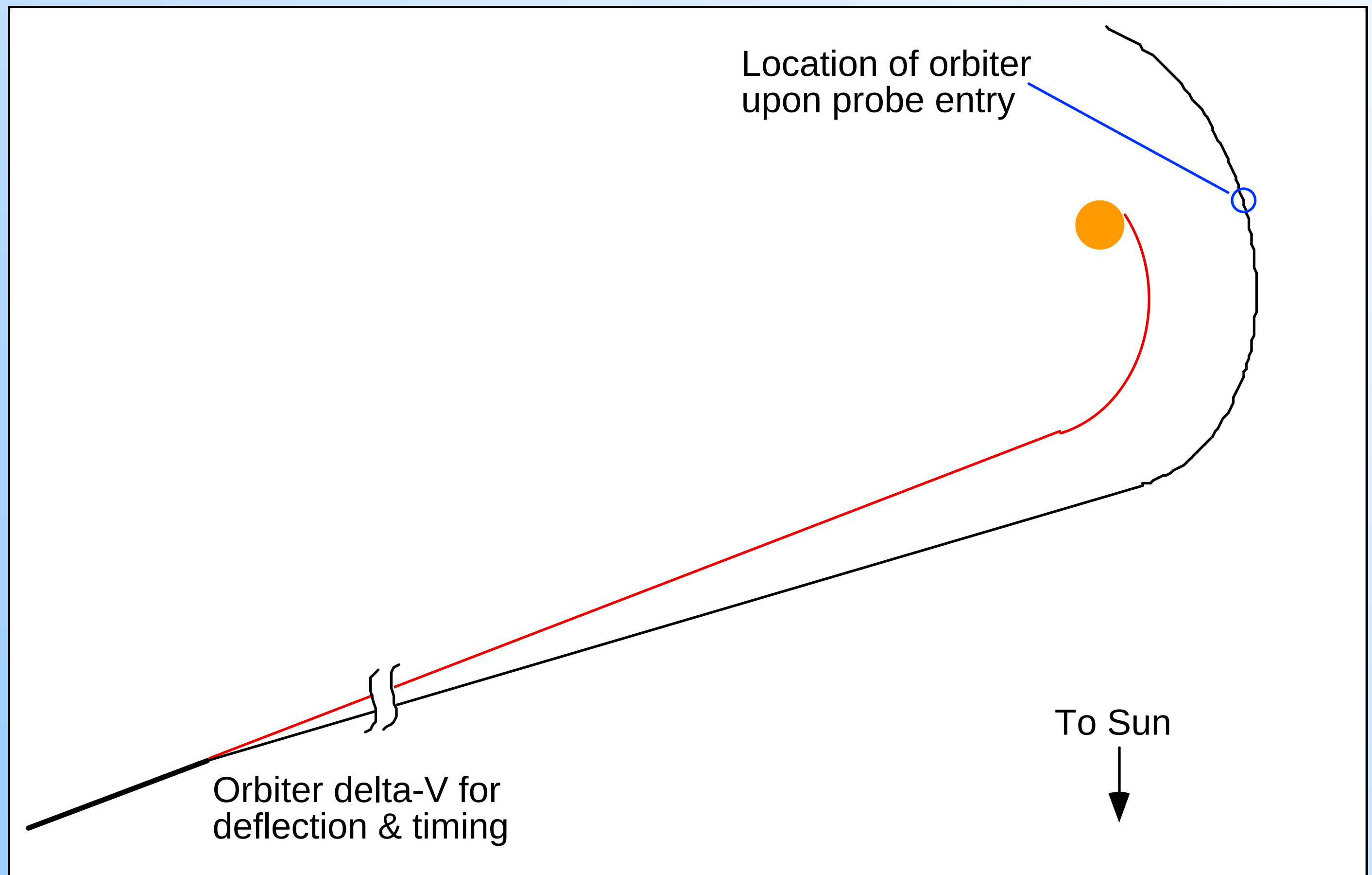
– Top two missions on the list potentially involve entry probes
  - <u>Saturn</u> entry probes; <u>Titan</u> mobile surface/atmospheric platform (aerobot?)
  - <u>Neptune</u> (also, <u>Uranus</u>) entry probes; <u>Triton</u> lander?

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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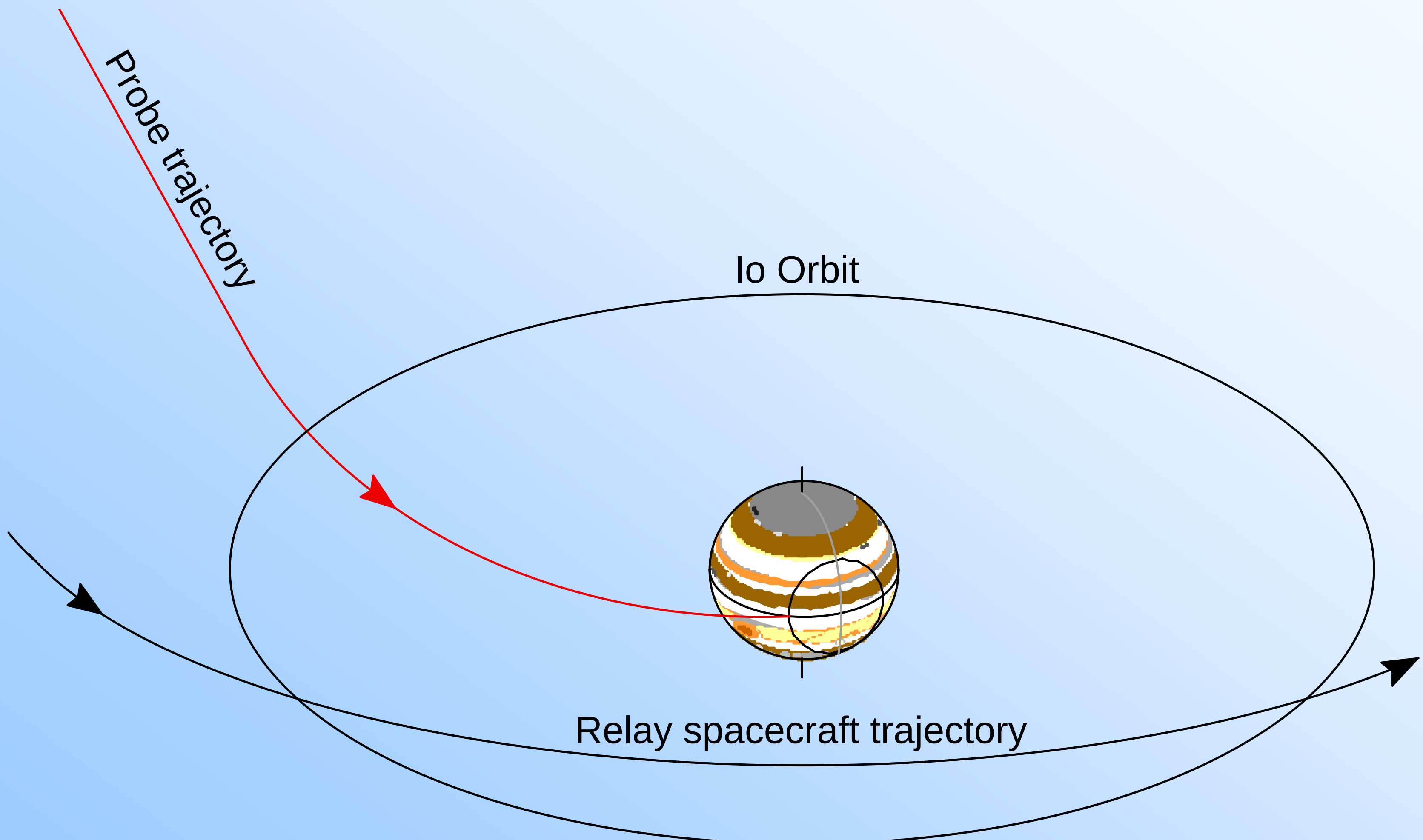
Galileo-Style Probe Support



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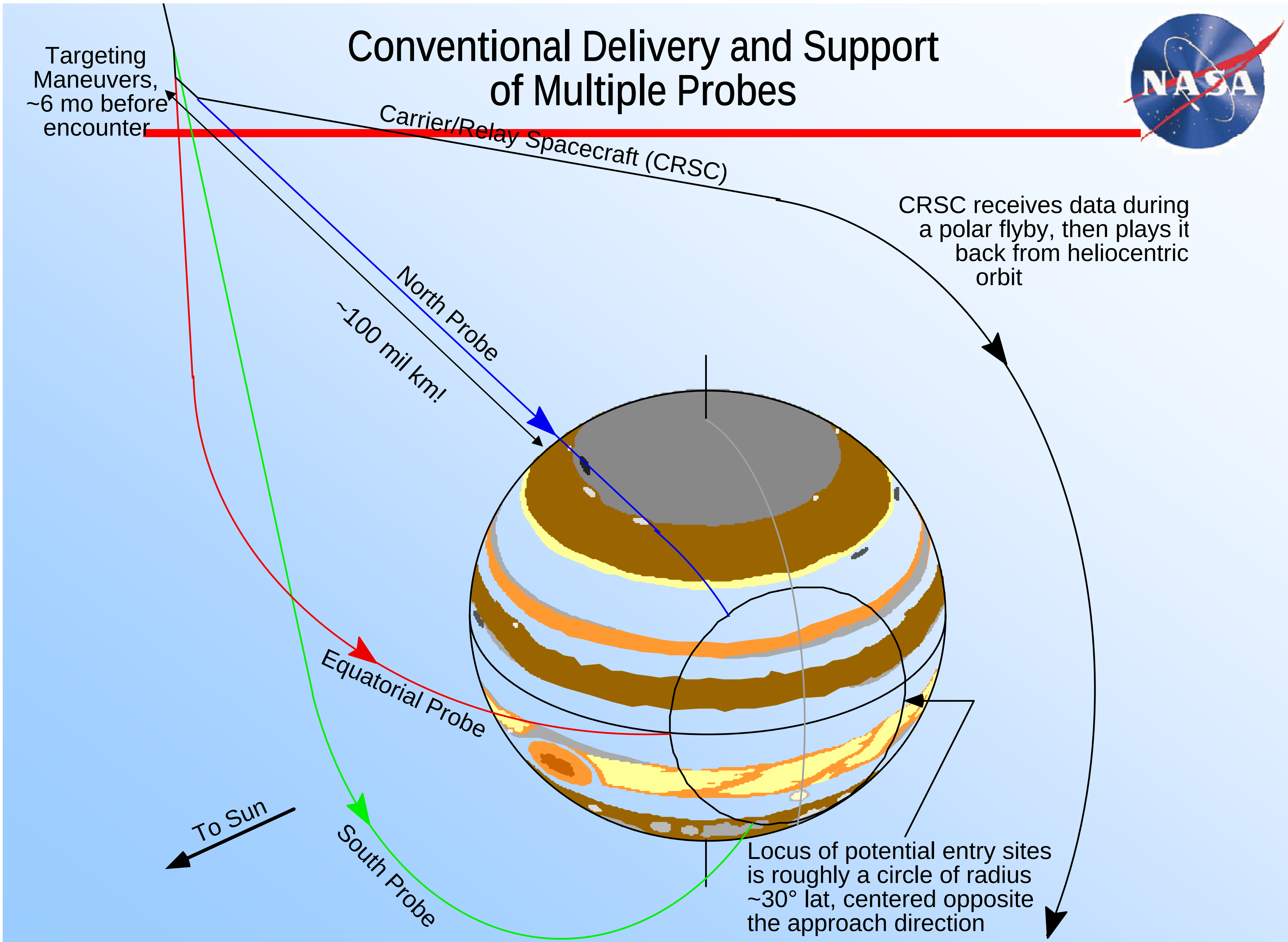
Conventional Delivery and Support of Multiple Probes



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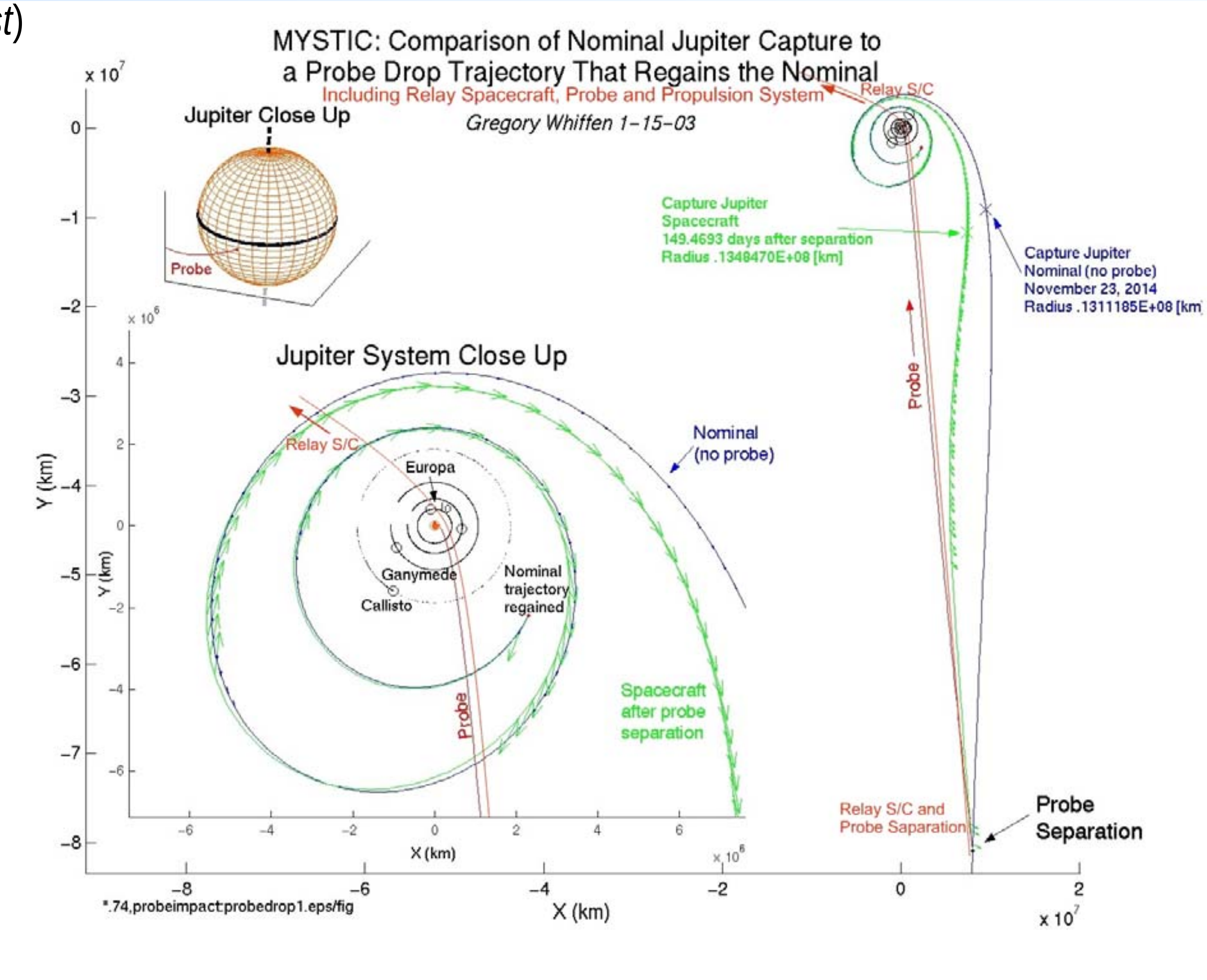
How Entry Probe Delivery From an NEP Vehicle Is Different

– 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

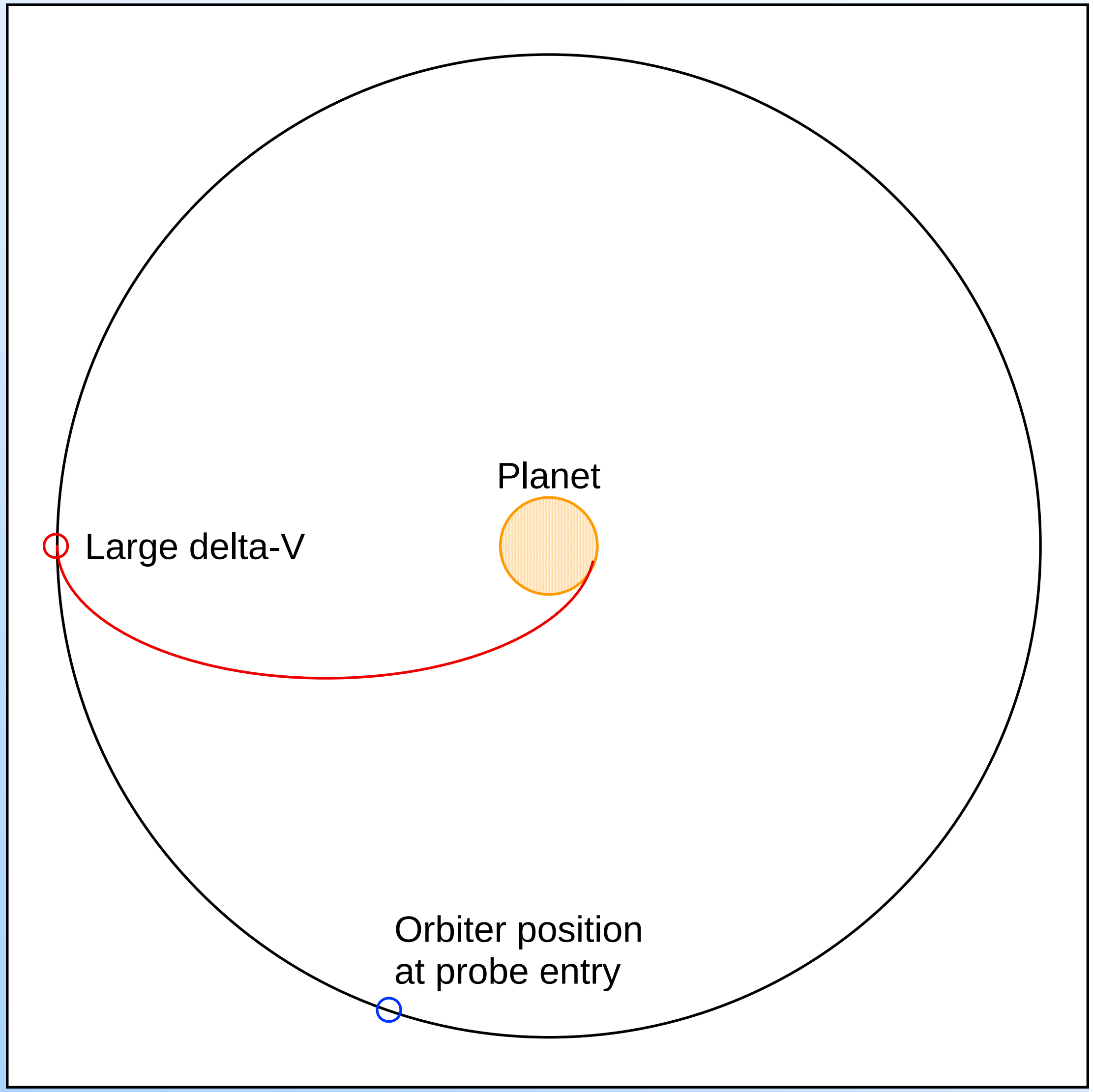


From Balint et al., 2003

How Entry Probe Delivery From an NEP Vehicle Is Different

–Delivery from near-circular orbit

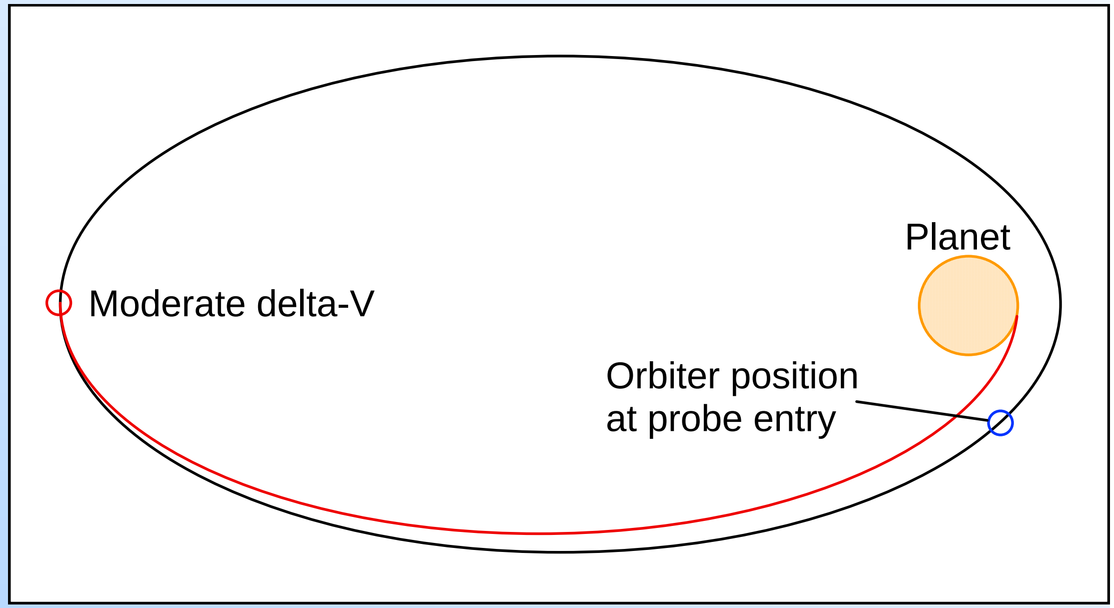
- Orbiter must expend propellant to carry probe into orbit
- Imposes large delta-V require- ments *on the entry probe*
  - Large delta-V just for entry
  - Timing increases delta-V
  - For orbits larger than several planetary radii, entry speed may not be too different from “on-approach” situation
- 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