Ice Giant System Architectures:

Ramifications for Probe Mission Architectures

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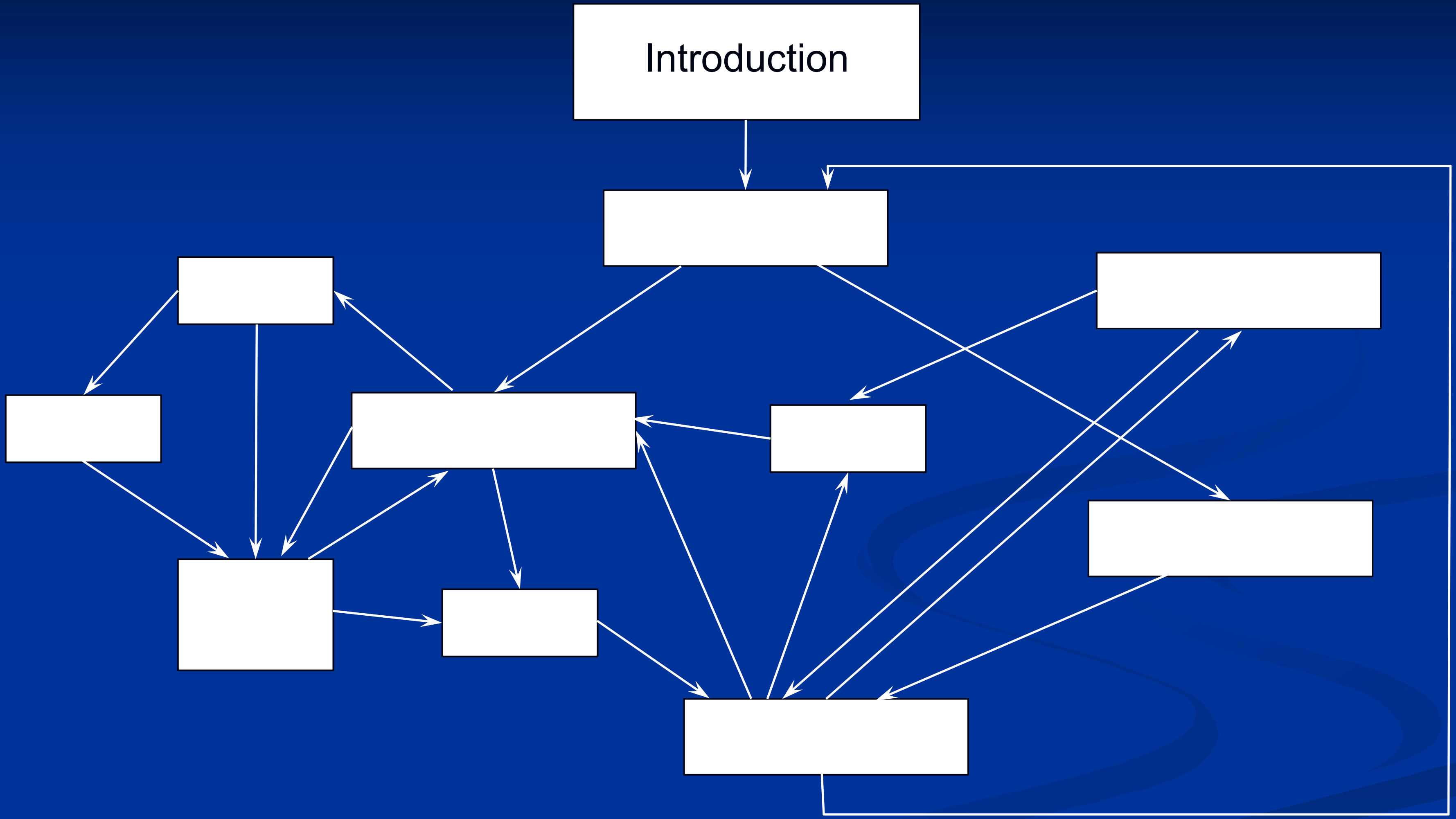
Organization



For Missions and Planetary Systems, What Is “Architecture”?

- For planetary systems, architecture is a high-level description of the system’s major components and characteristics, such as:
  - Planetary mass, radius, composition, rotation rate, pole orientation
  - Heliocentric orbit radius, eccentricity, inclination
  - Satellite system
  - Ring system
  - Magnetic field

- For missions, architecture is a high-level description of the mission’s major components and characteristics, such as:
  - Science objectives
  - Type(s) of spacecraft involved: orbiter, entry probe, lander, etc.
  - High-level characteristics of the trajectories
  - Rough ΔV required
  - Communications approach

Nuances of Uranian System Architecture

- URANUS'S ORBIT IS NOT CIRCULAR
- URANUS'S ORBIT IS NOT COPLANAR WITH EARTH'S
- (NEITHER IS NEPTUNE'S)
- URANUS'S ROTATION AXIS IS NOT PERPENDICULAR TO ITS ORBIT PLANE

Bounds on Entry Velocities

"Escape Velocity" (V_{esc}) at the entry interface radius

=

Entry velocity from a V_∞ of *zero*

(spherical planet approximation)

$$V_{esc} = \sqrt{\frac{2GM}{r}}$$

At Uranus, V_{esc} is ~21.2 km/s

Uranus's equatorial rotation rate is ~2.6 km/s

Under *ideal* circumstances (equatorial entry, shallow EFPA, parallel to equator, & $V_\infty = 0$,

~18.6 km/s is the <u>best</u> (slowest) you'll ever get

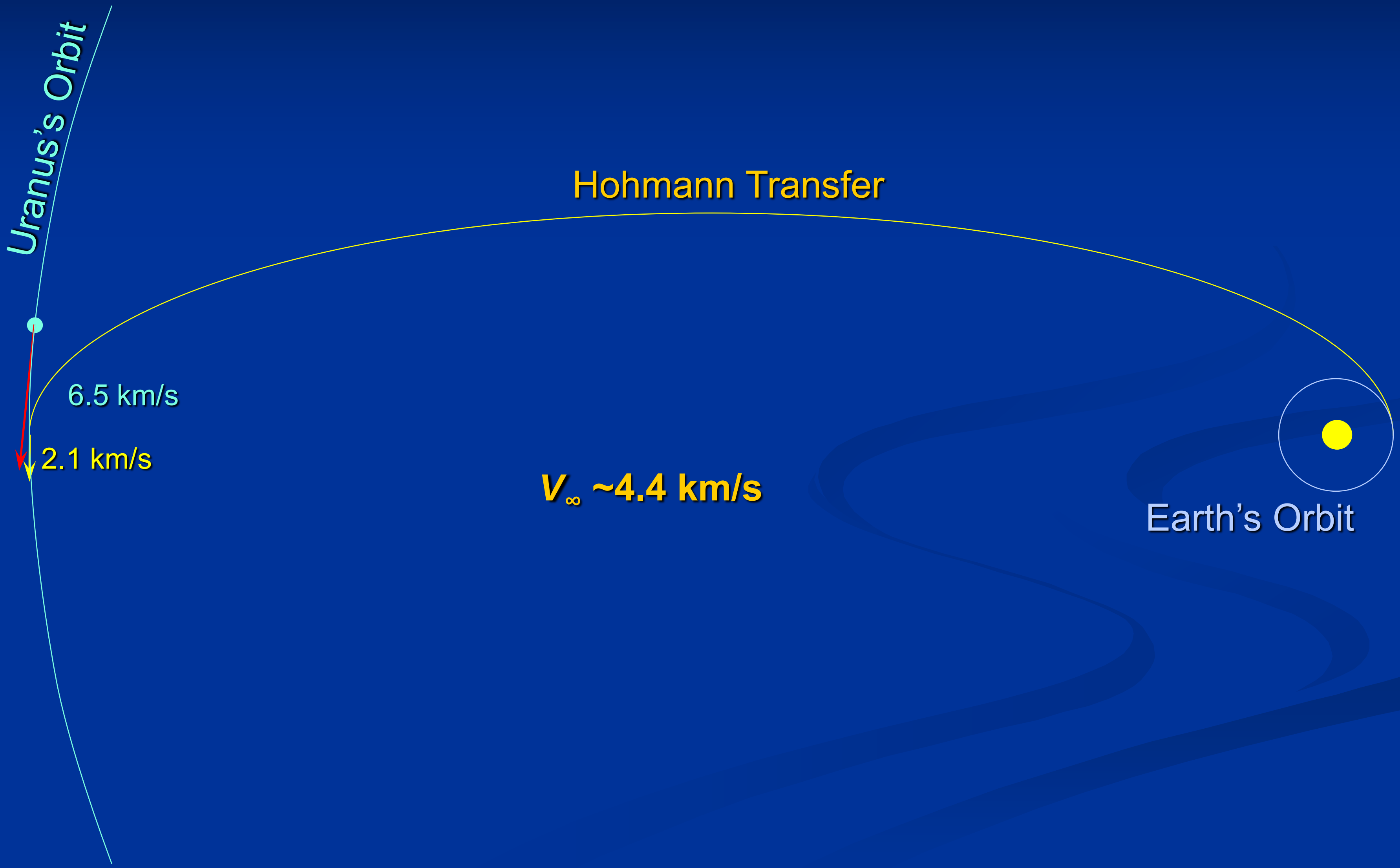
Bounds on Entry Velocities

But the approaching spacecraft won't have a V_∞ of *zero* and that V_∞ affects the entry speed:

$$V_{ent} = \sqrt{V_{esc}^2 + V_\infty^2}$$

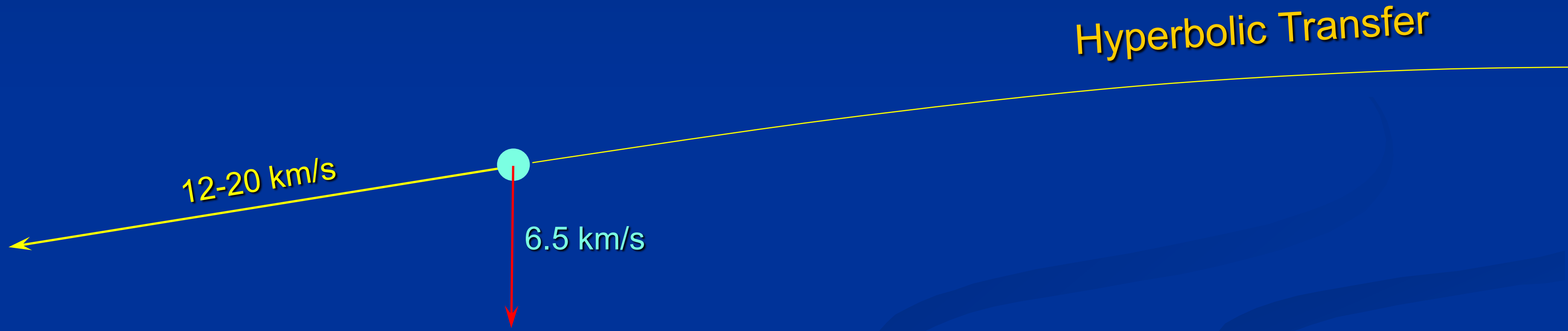
- What are the bounds on V_∞?

Simple Transfer Orbits to Uranus



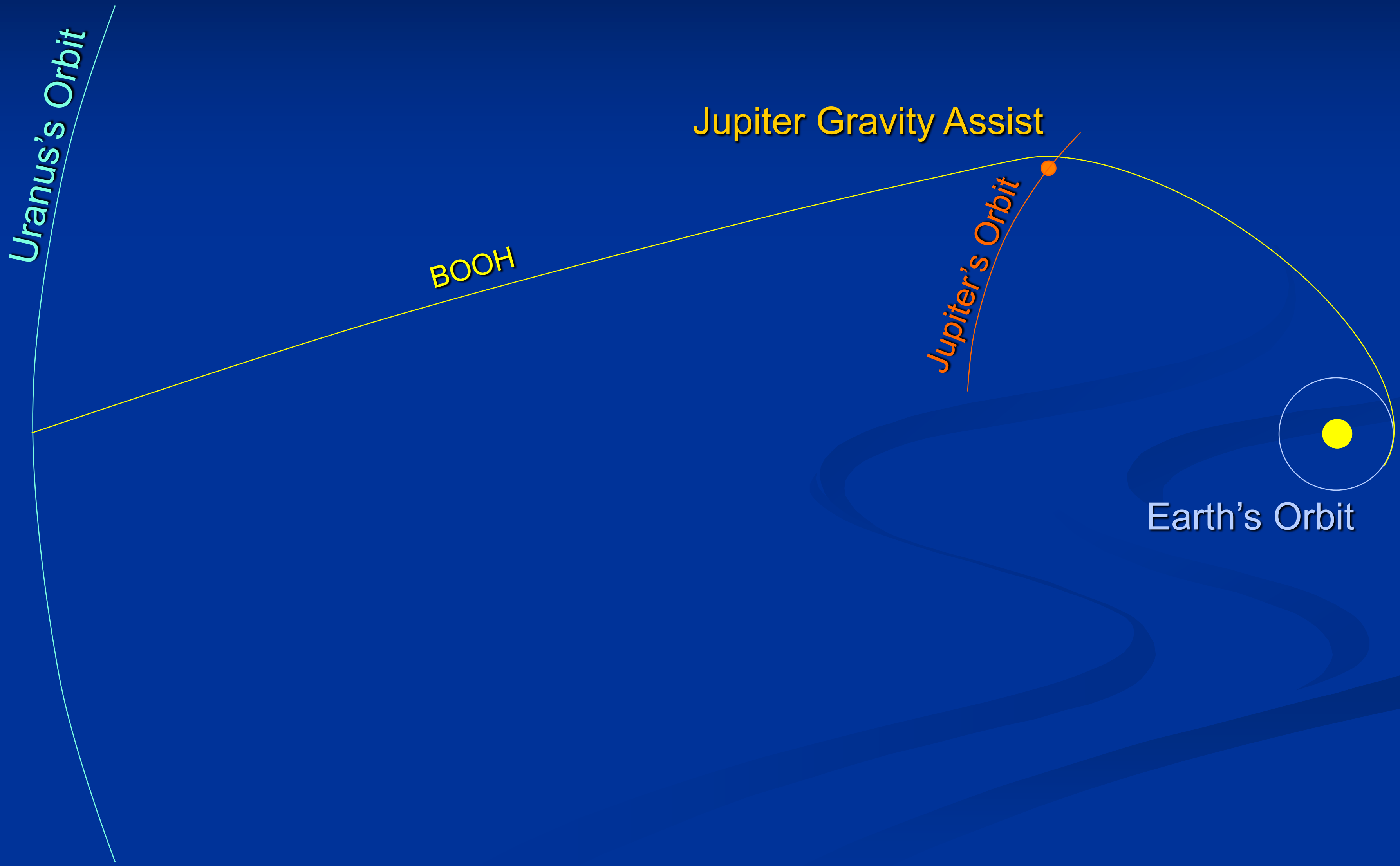
Simple Transfer Orbits to Uranus

Simple Transfer Orbits to Uranus



V_{ent} (assuming ideal orientation wrt rotation) is now 21.6 – 26.7 km/s

Gravity Assist Transfer Orbits to Uranus



Bounds on Entry Velocities

at Neptune

$$V_{esc} = \sqrt{\frac{2GM}{r}}$$

Neptune has a *smaller radius* …

… and a *larger GM*

Neptune entry speeds tend to be *higher* than for Uranus

Typical Atm-Relative Entry Speeds At the Giant Planets

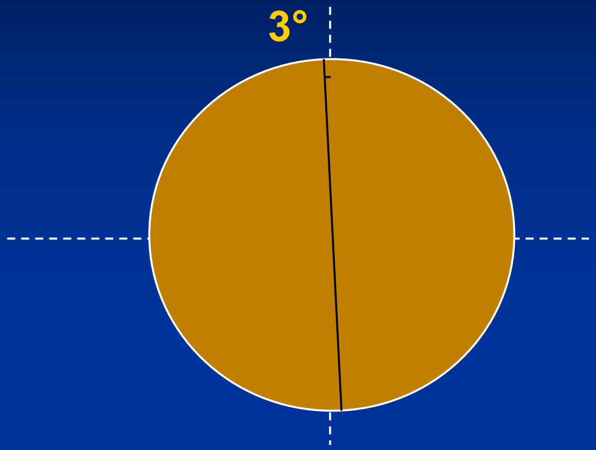
Speeds in km/s; assume "typical" hyperbolic approach V_∞

Entry Orbit Inclination / Destination	0° (prograde)	90° (polar)	180° (retrograde)
Jupiter	47.4	61.1	72.2
Saturn	26.5	37.5	46.2
Uranus	21.6	24.1	26.7
Neptune	25.4	28.2	30.8

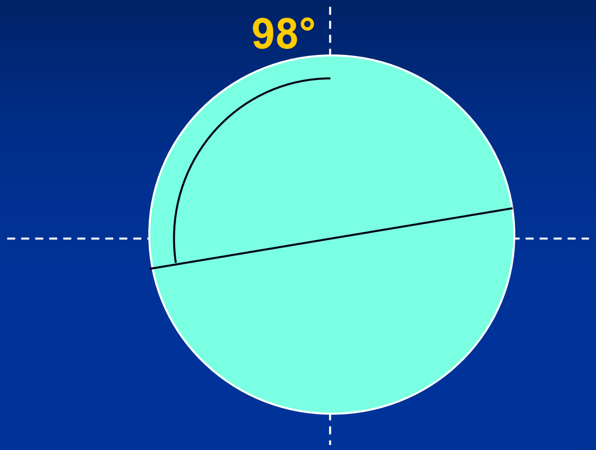
Color-coded entry velocity indicators assume shallow entry angle

CRITICAL TECHNOLOGY: HIGH-PERFORMANCE TPS MATERIALS

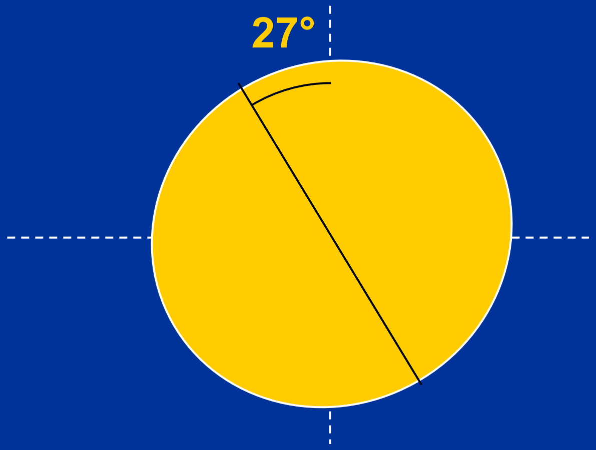
Obliquities of the Giant Planets



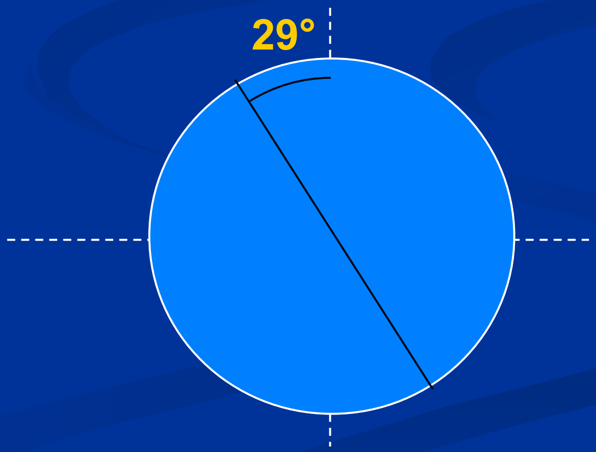
Jupiter



Uranus



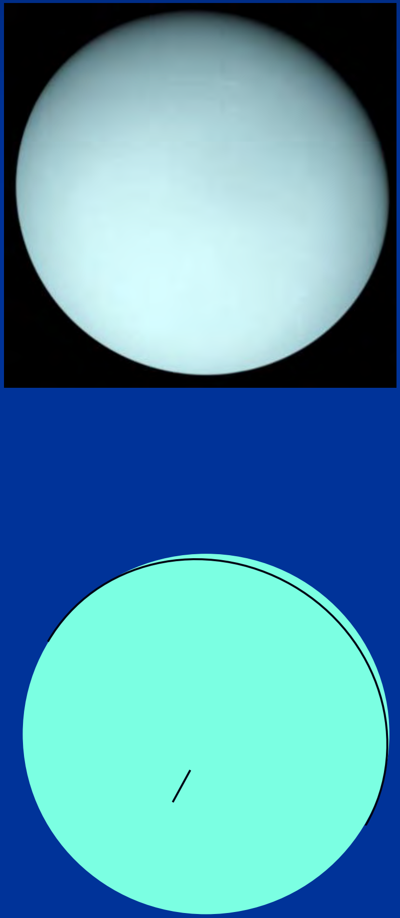
Saturn



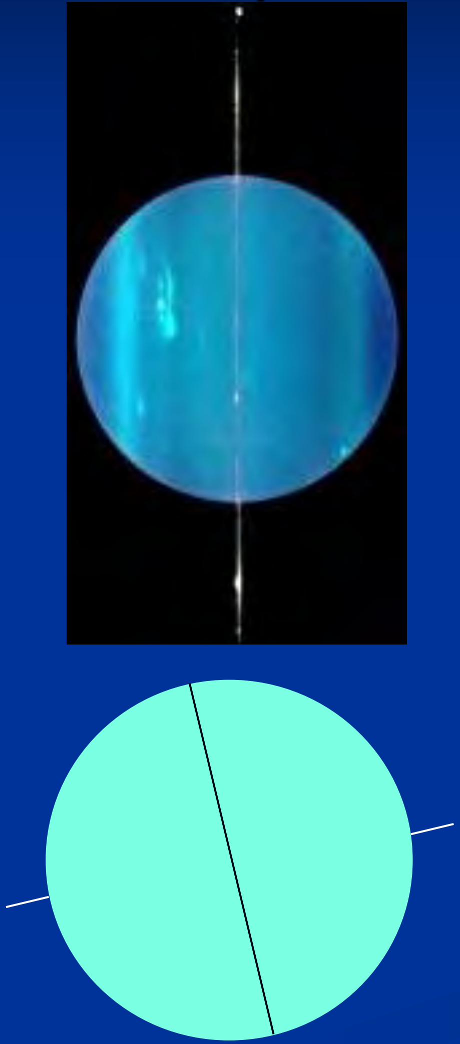
Neptune

Uranus Heliocentric Views With Time

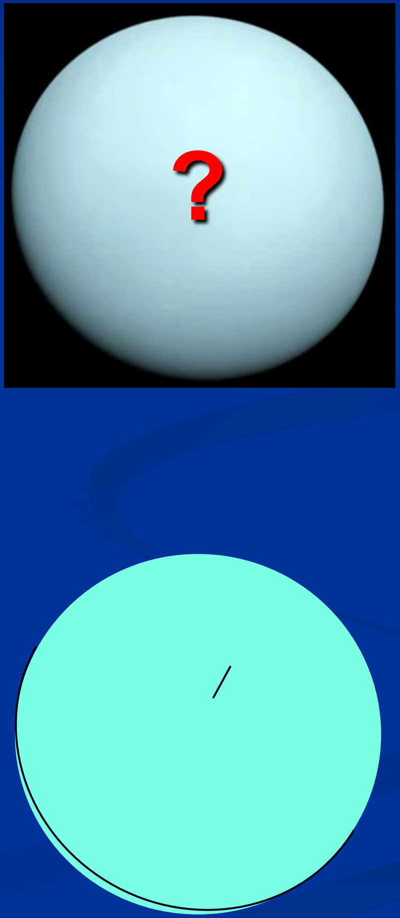
1986: *Voyager 2* View



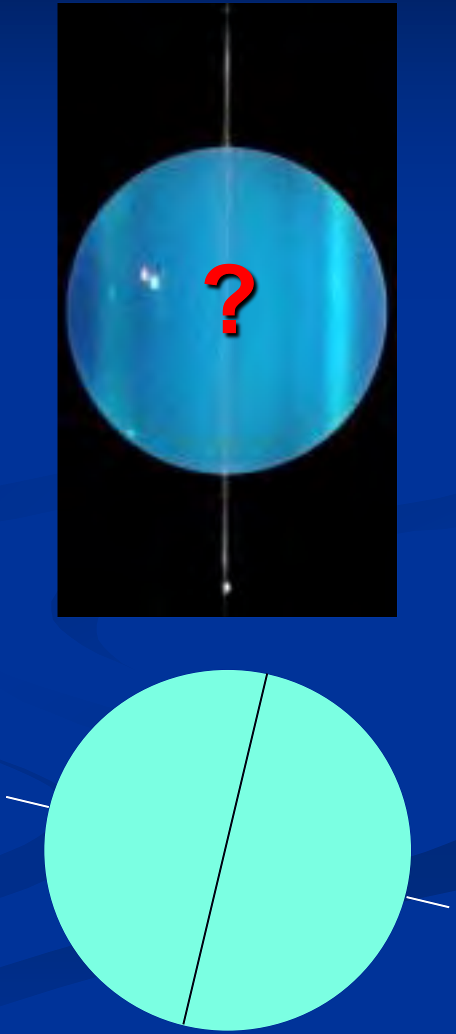
2007: Equinox



2028



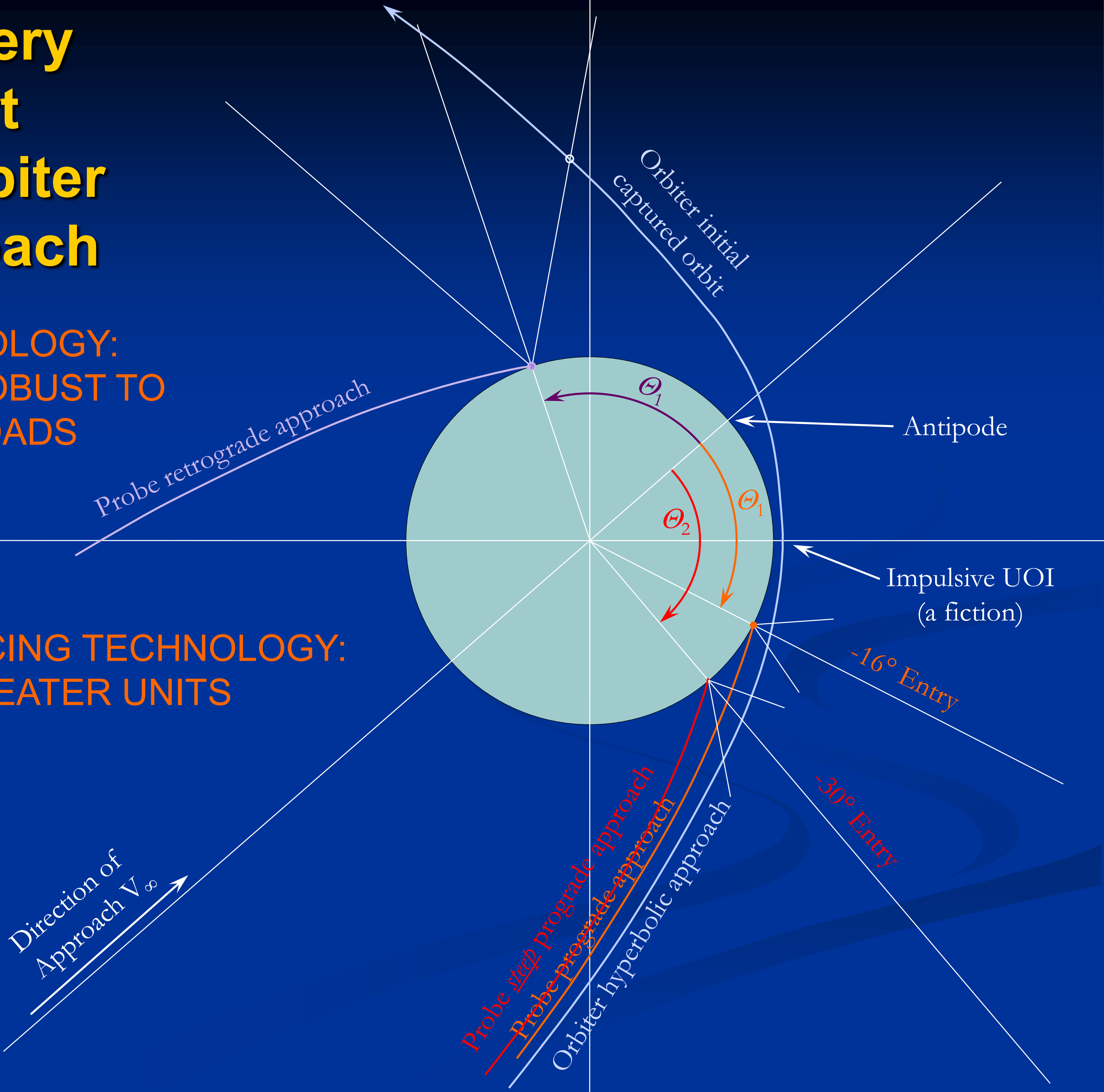
2049: Equinox



Probe Delivery And Support From an Orbiter Upon Approach

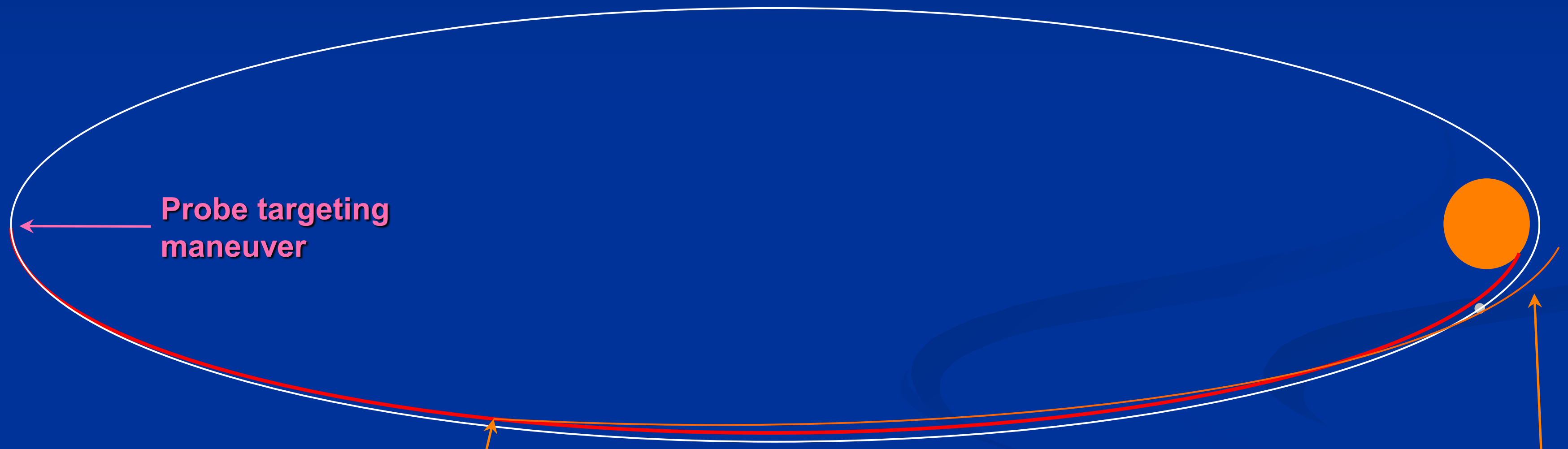
CRITICAL TECHNOLOGY:
INSTRUMENTS ROBUST TO
HIGH INERTIAL LOADS

GREATLY ENHANCING TECHNOLOGY:
RADIOISOTOPE HEATER UNITS



Probe Delivery And Support From Orbit

Highly eccentric orbit

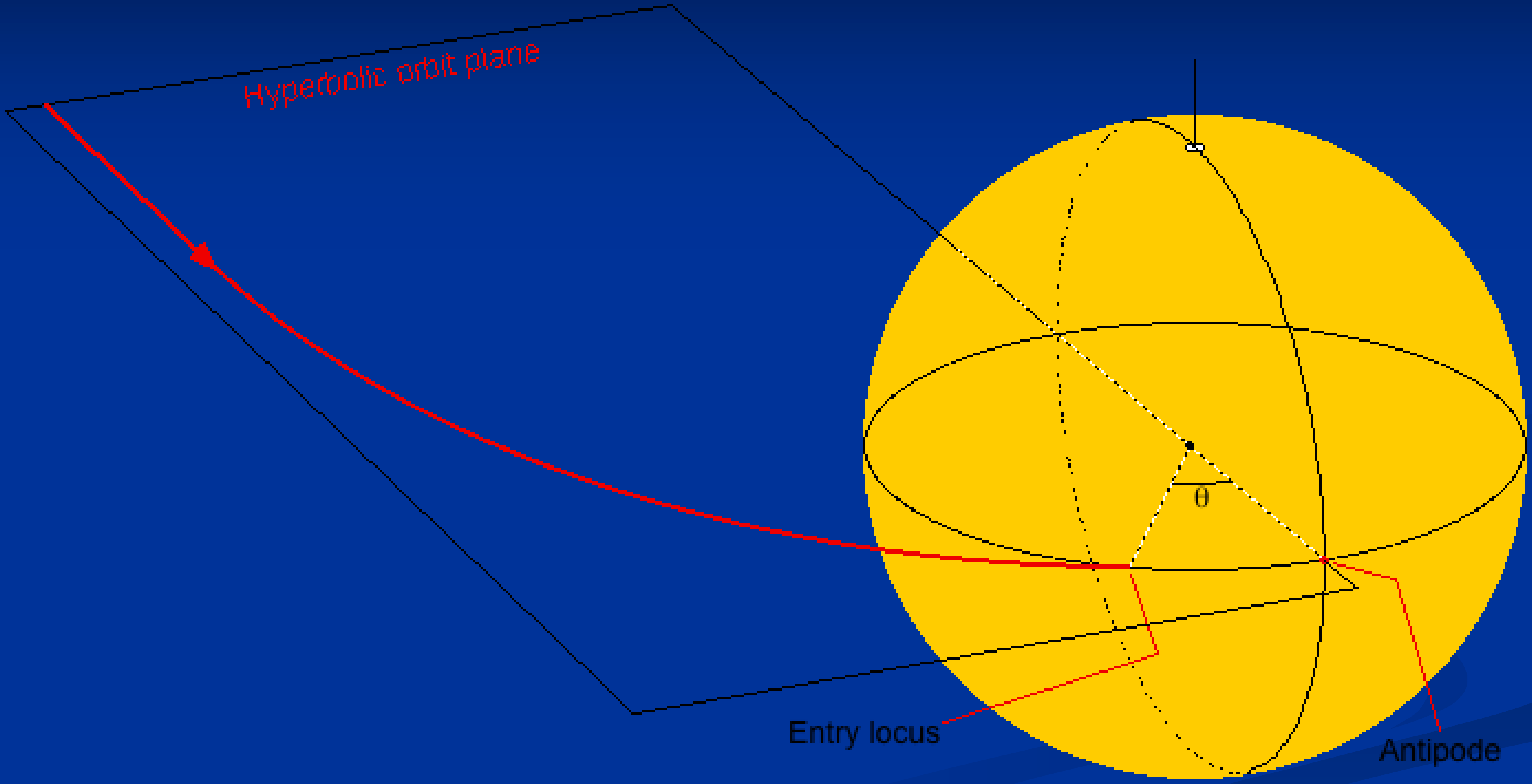


Probe targeting maneuver

CRSC phasing maneuver

Potential problem: *this orbit is very different from the original pre-phasing orbit, and might even be an escape orbit!*

Feasible Probe Entry Locations



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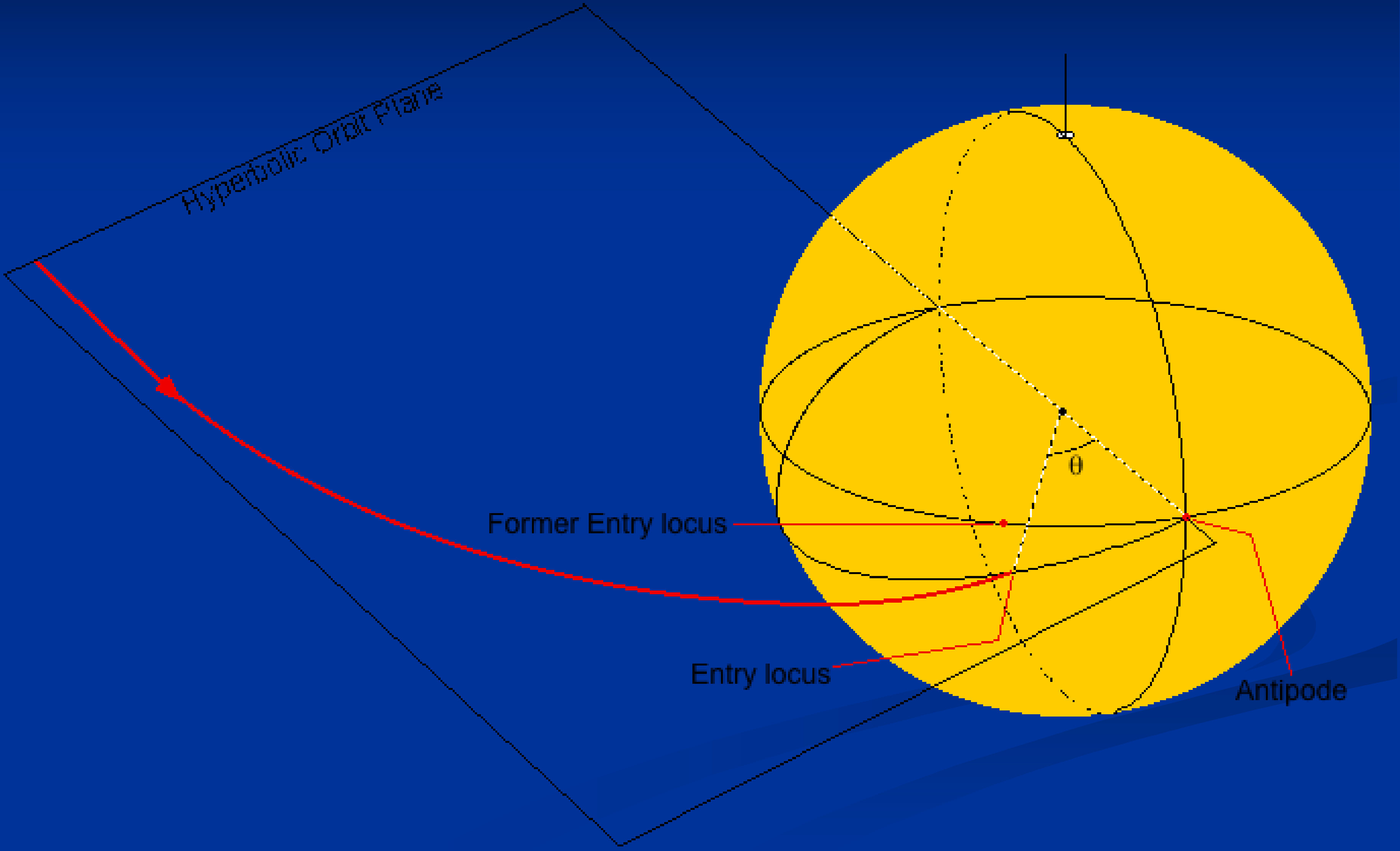
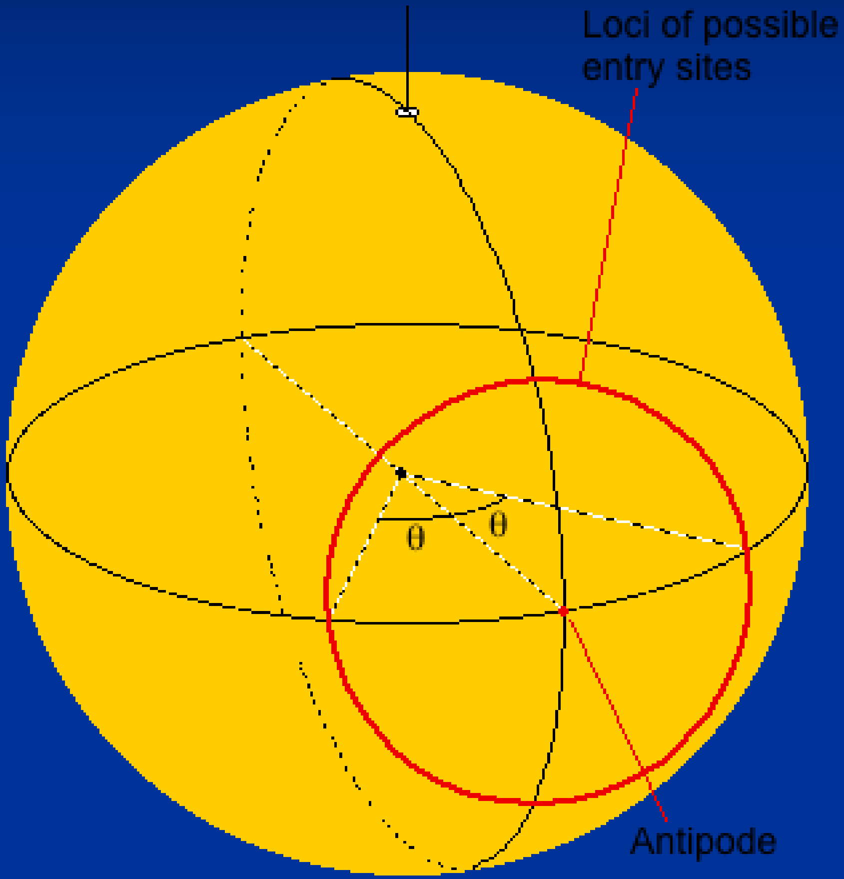


Feasible Probe Entry Locations



The loci of entry sites with the proper entry flight path angle define (roughly) a circle centered on the antipode with central angle θ.

Various characteristics of the planet cause deviations of this set of loci from circular

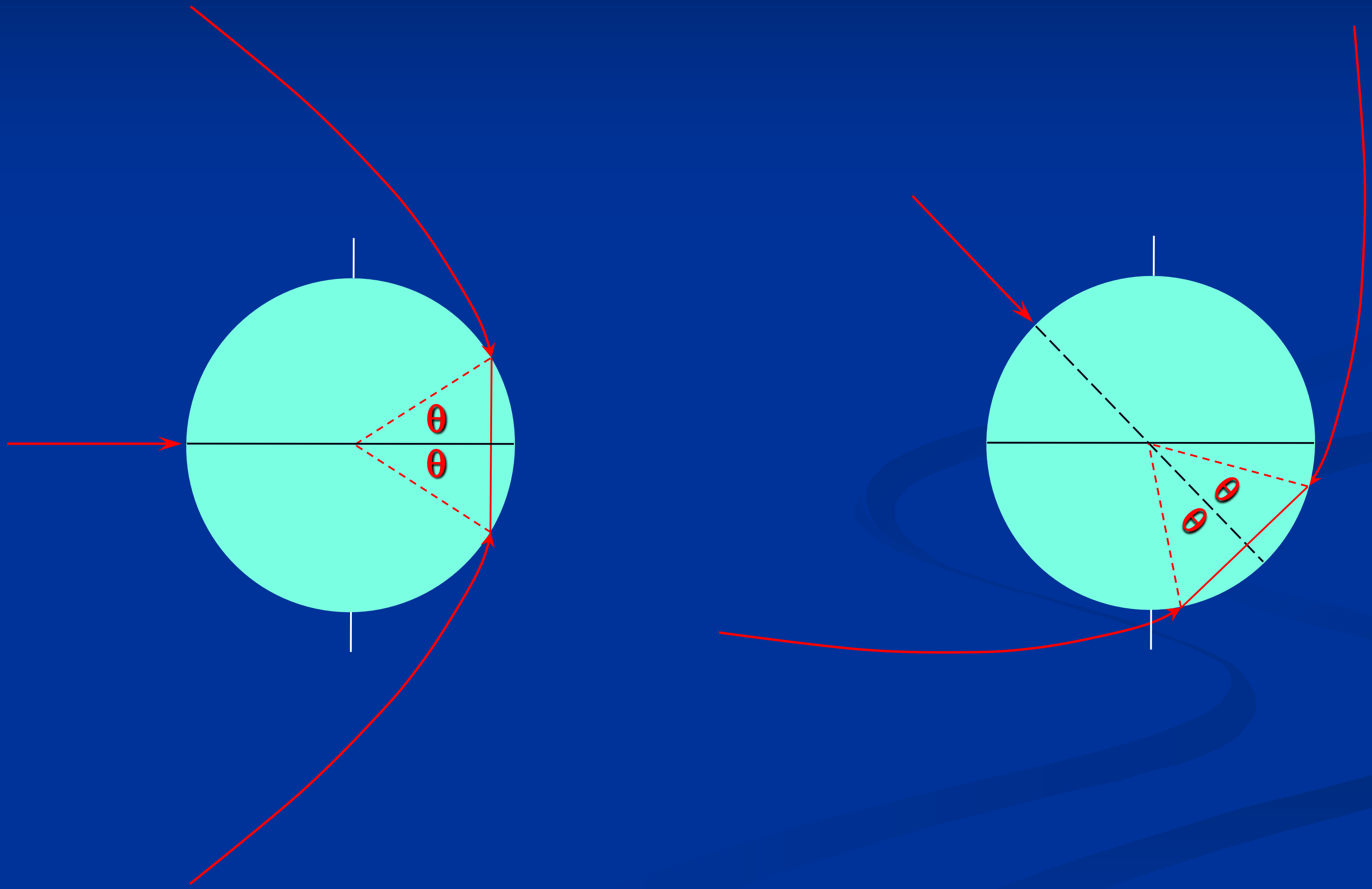
- Planetary rotation
- Planetary shape (such as oblateness)

Fast planetary rotation can cause some or most of the circle to be unusable due to high entry speeds

Obstacles such as rings and moons can also make parts of the circle unusable

In general, the antipode will *not* be at the planet's equator.

Equatorial Region Might Not Be Accessible

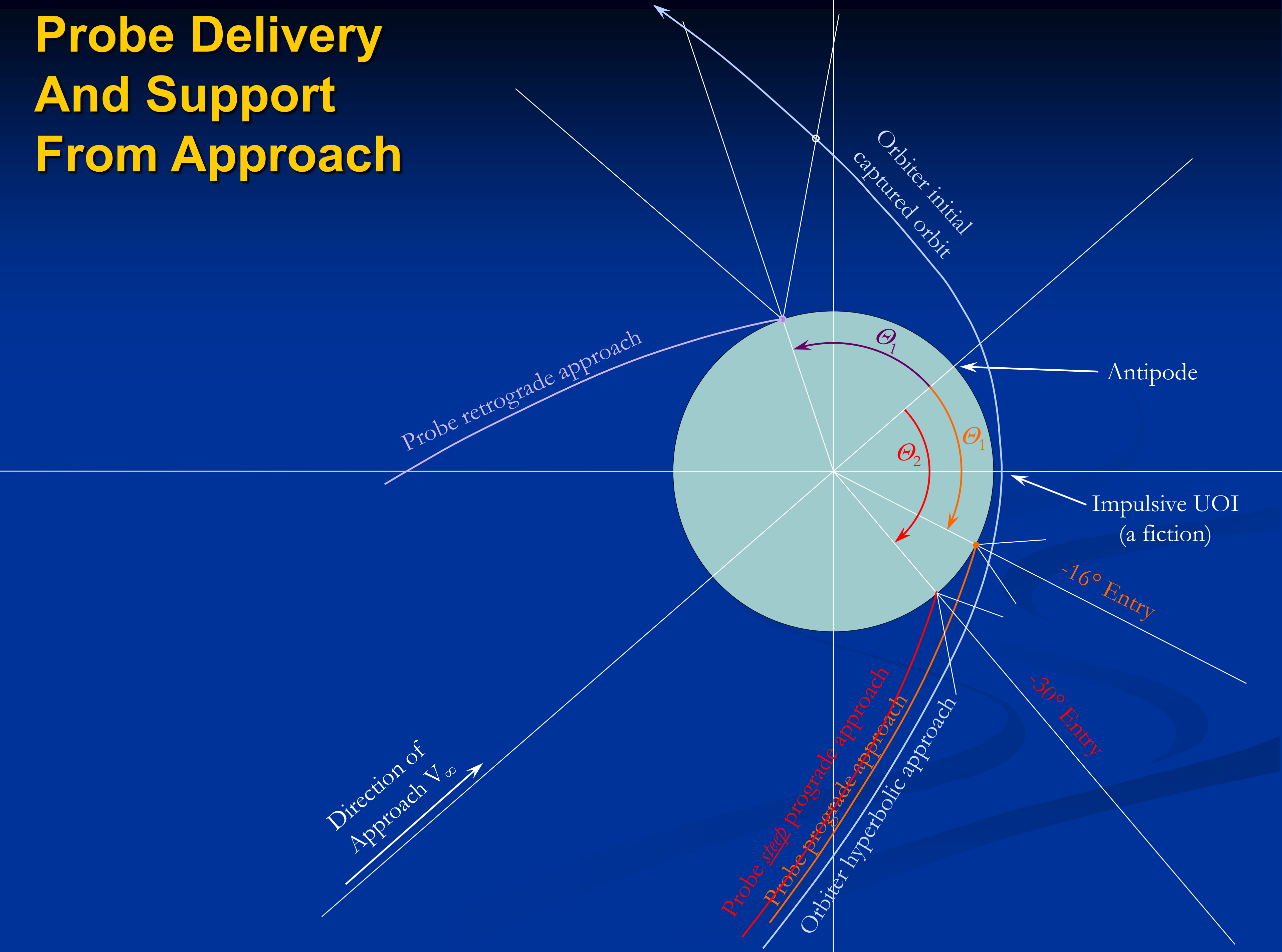


Architectures Under Consideration

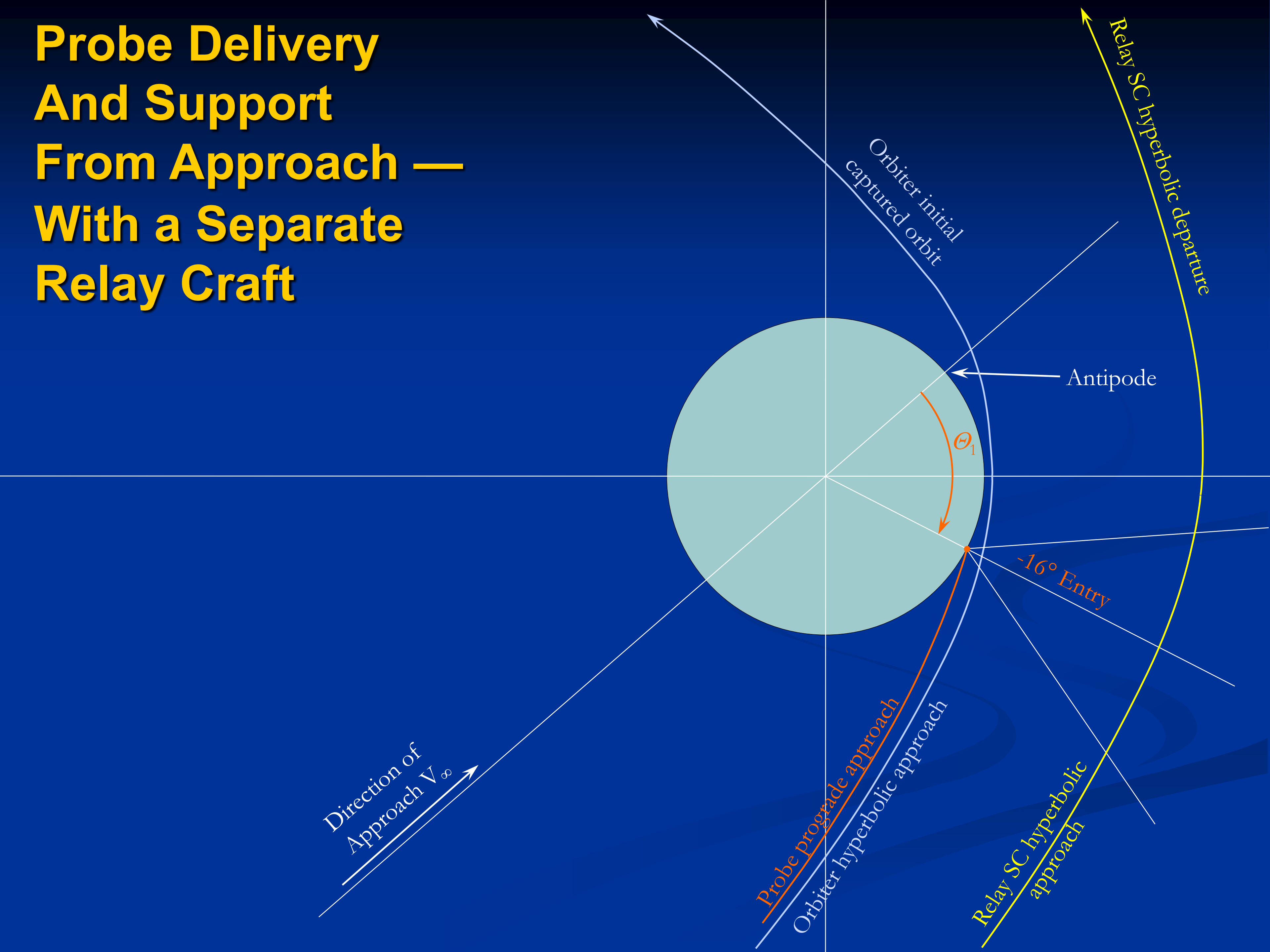
- From the NASA Ice Giants Study
  - Flyby without probe
  - Orbiter without probe
  - Flyby with probe
  - Orbiter with probe
  - Dual orbiters
  - Chemical propulsive orbit insertion, with and without SEP

- Other architectural elements to consider
  - Possible roles of small sub-satellites (such as CubeSats)
  - More in-depth analysis of approach trajectory trade space
  - Aerocapture

Probe Delivery And Support From Approach

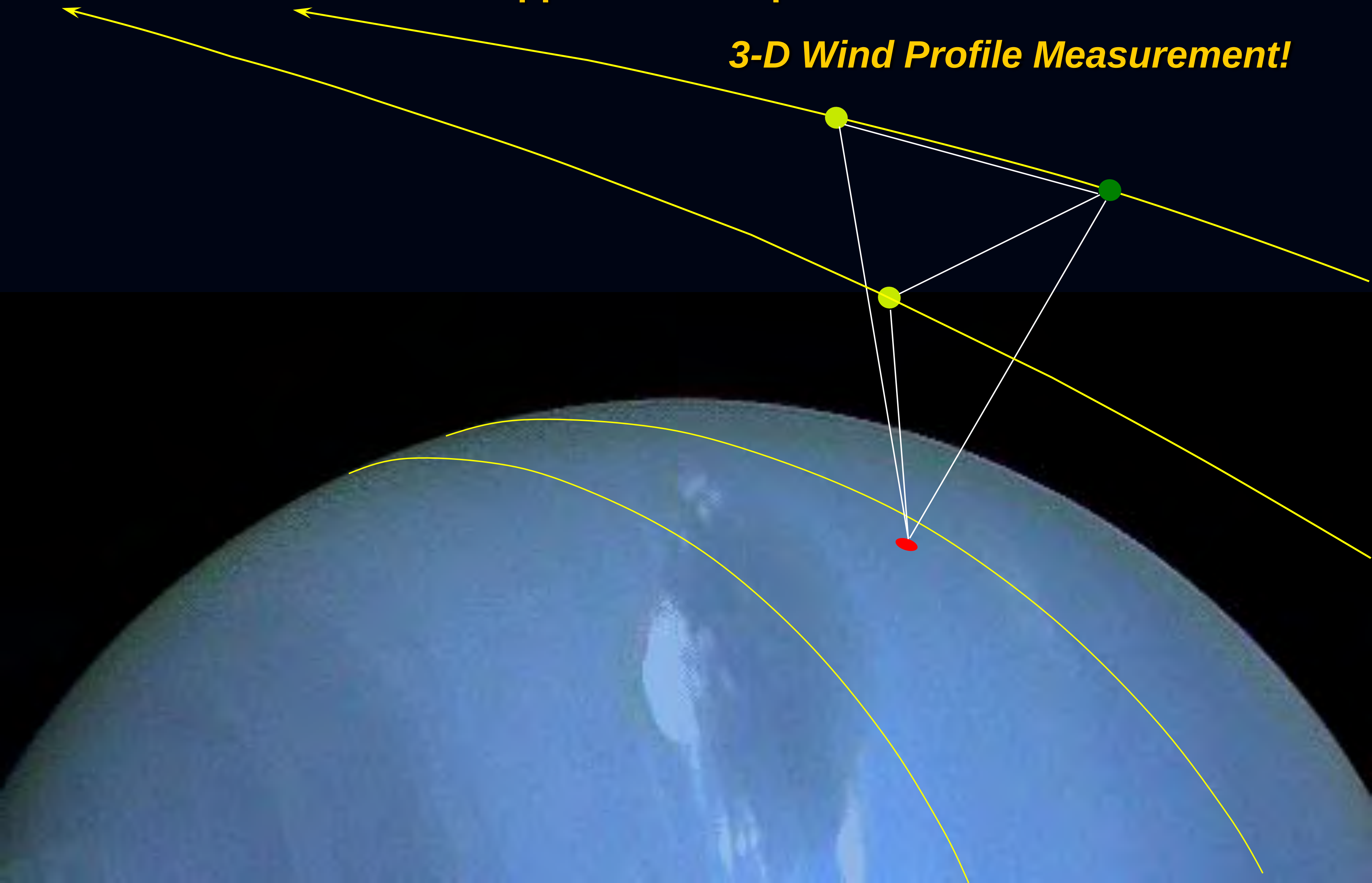


Probe Delivery And Support From Approach — With a Separate Relay Craft

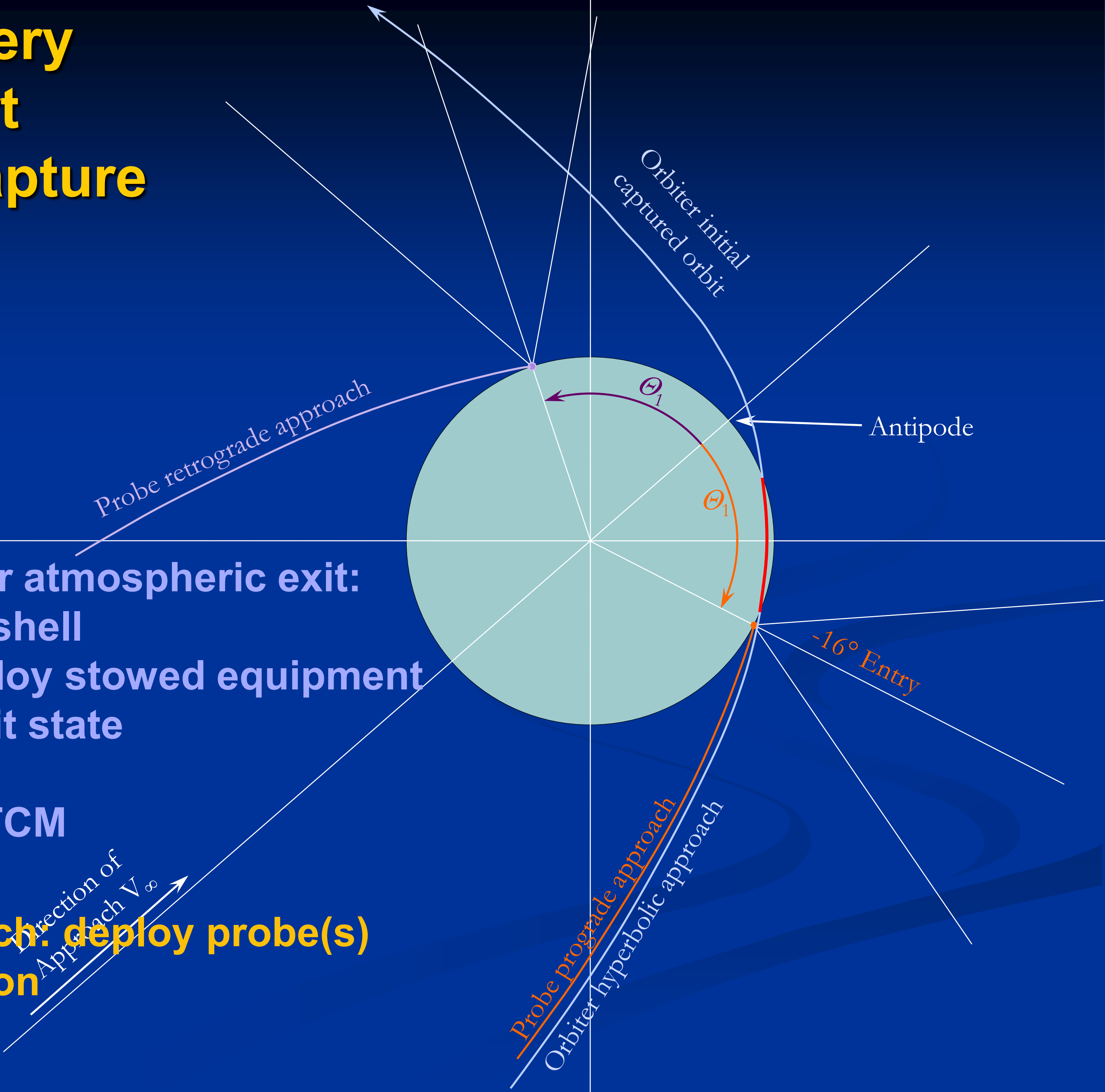


Example Architecture Using Secondary Spacecraft

Multi-Element Doppler Wind Experiment Architecture


3-D Wind Profile Measurement!

Probe Delivery And Support With Aerocapture



Orbiter tasks after atmospheric exit:

- Jettison aeroshell
- Deploy/redeploy stowed equipment
- Determine exit state
- Design TCM
- Reorient for TCM
- Execute TCM

Alternate approach: deploy probe(s) *after* orbit insertion

Important Technologies

- Critical Technologies
  - Instruments robust to high inertial loads
    - Level depends on entry trajectory specifics
  - High-performance TPS materials
    - Materials available in US; under development in Europe
    - Must *maintain* availability

- Greatly Enhancing Technologies
  - Radioisotope heater units
    - Reduces probe battery mass
    - Reduces orbiter divert maneuver ΔV (thus propellant mass)
  - Low-mass survey composition instruments (e.g., mass spec)
    - Significant effect on probe total mass
    - "Front-end" (inlets, valves, enrichment cells) currently is most massive subsystem

Questions?

Bulk Characteristics of the Giant Planets

Characteristic / Planet	Mass (Earth masses)	Equatorial radius (km)	Mean mass density (gm/cm^3)
Jupiter	317	71490	1.32
Saturn	95	60330	0.68
Uranus	14.5	25500	1.27
Neptune	17.1	24770	1.64

Bulk Characteristics of the Giant Planets

Characteristic / Planet	Atmospheric Helium Abundance	Icy Element Abundance (x Solar)	Tropopause Temperature (K)
Jupiter	11-12%	3-6	110
Saturn	13±5%	5-10?	90
Uranus	18%?	20-50?	50
Neptune	18%?	20-50?	50