IPPW2019 - Trajectories for Ice Giant Entry Probes

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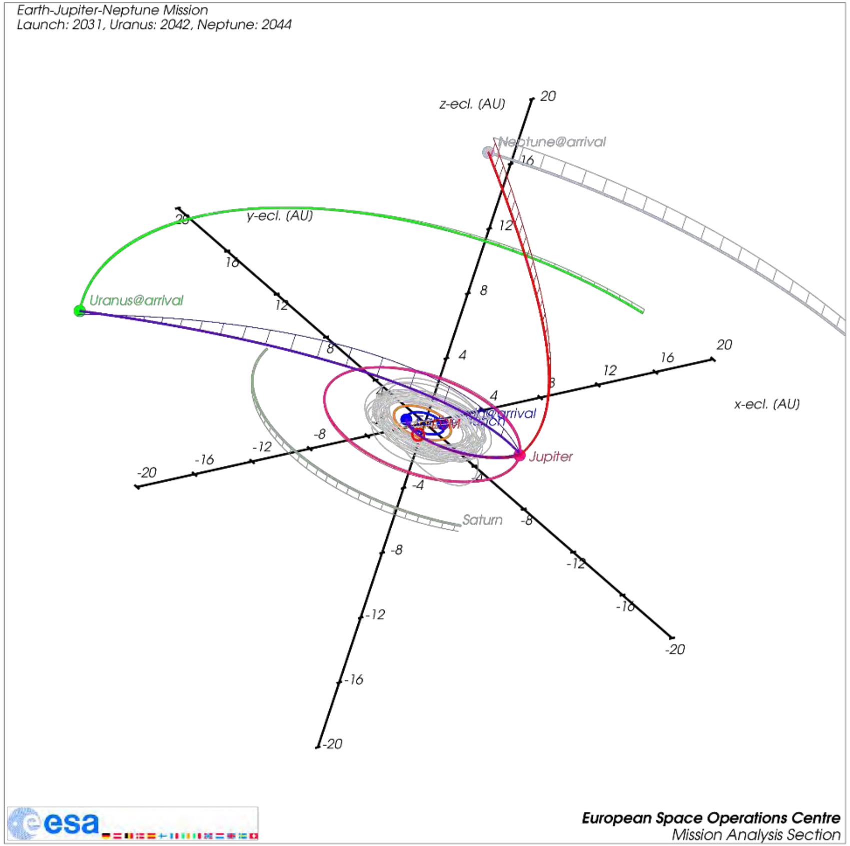
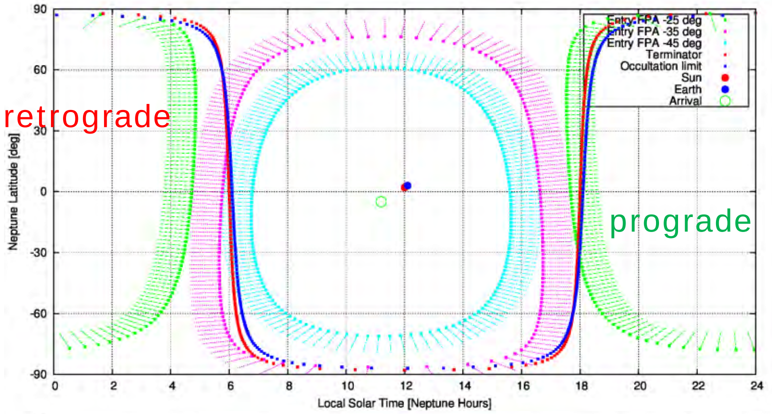
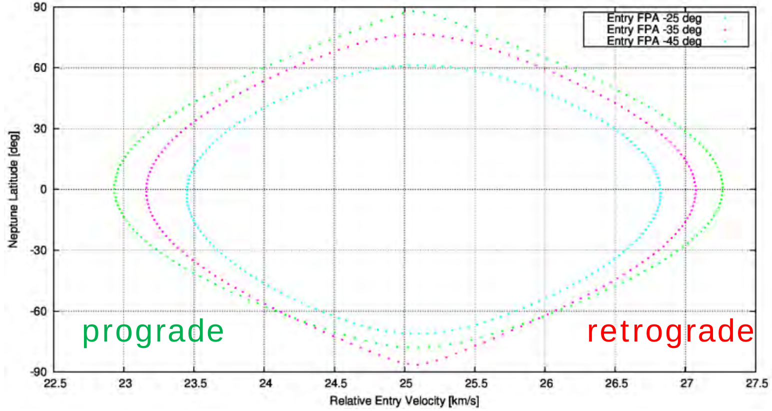
The Transfer Drives it all



- The mission always originates from the Earth
- Its transfer to the target ice giant is driven by a plethora of constraints and requirements
  - Launch window
  - Maximum transfer duration
  - Jupiter Gravity Assist radiation loads (count on a JGA)
  - Absence of superior conjunction prior to or after entry
  - Character of mother ship (carrier vs. orbiter)
  - Joint missions possible (single launch, separated by JGA, entry probes at Uranus and Neptune)
- For a given launch window, the arrival conditions are near-unchangeable
  - Another factor is the low orbit speed of the ice giants.
  - Months or years later, the target will still be almost at the same location in the solar system
- Entry probe mission duration
  - ~10 to 90 minutes

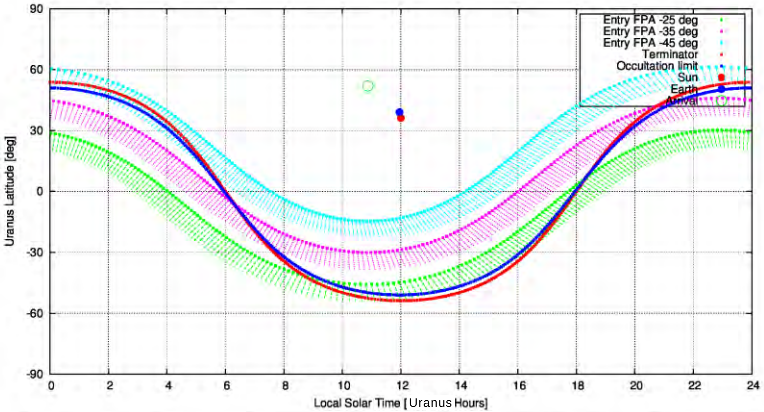
The Entry Diagram – a “diagram of everything”

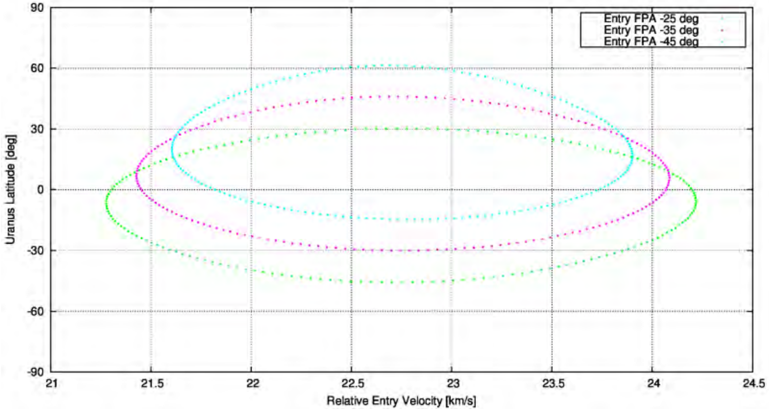




- The “diagram of (almost) everything” shows, as function of local solar time and latitude:
  - the limits of Sun and Earth visibility
  - the possible entry points for any entry flight path angle
  - The direction of flight at the entry interface point
- Given here is an example for Neptune
  - Every transfer scenario yields its own, distinct diagram
- The relative entry velocity as function of entry latitude and FPA is directly linked to the entry diagram
  - Due to the ice giants’ fast rotation, the difference between prograde and retrograde entry is massive
  - Entry flight path angle and velocity drive peak heat flux, peak deceleration and total heat load, as is shown in a later lecture
- This diagram contributes to selection of entry conditions
  - Consistency with TPS, mother ship, data relay must be studied

Uranus is weirder than Neptune





- Shown here is a sample entry diagram for a specific case
- Tilt of the rotation axis and retrograde rotation
- Limited range of reachable entry latitudes
- Atmospheric rotation deflects the entry probe sideways, carrying it away from the mother ship’s path

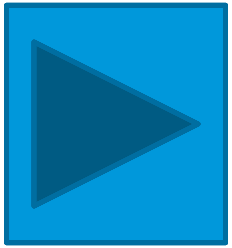
Approach Operations

- The mother ship deploys the entry probe on the entry trajectory
- Typically, the mother ship is still needed afterwards
  - Even if it is just a carrier with no further mission, it will likely be needed for data relay of the entry probe data
  - If the mother ship is an orbiter that will embark on a tour of the target ice giant, it will likely also perform probe data relay plus an orbit insertion manoeuvre during the entry probe’s atmospheric phase
  - *In the future, added microsatellites might be used to enhance data relay performance*
  - In all cases an orbiter deflection manoeuvre will be needed to raise closest approach of the mother ship’s trajectory to a safe altitude
  - The mother ship might try to image the departing probe
  - A second, phasing manoeuvre might also be needed for optimal timing of closest approach
  - The mother ship then prepares for data relay (plus insertion manoeuvre?) and enters a quiet phase
  - Foresee sufficient time between probe separation and entry (5-30 days), allowing backup opportunities for all manoeuvres and critical operations

Approach Navigation

- Months before entry and tens of million km from the target body, the pre-targeting navigation campaign will start
  - The campaign will ramp up as the day of separation draws close
  - Measurement types:
    - Radiometric (Doppler and Delta-DOR)
      - Delta-DOR loses precision at range of 19 AU (Uranus) or 30 AU (Neptune)
    - Optical Navigation, likely indispensable for accurate probe targeting (and tour?)

Examples

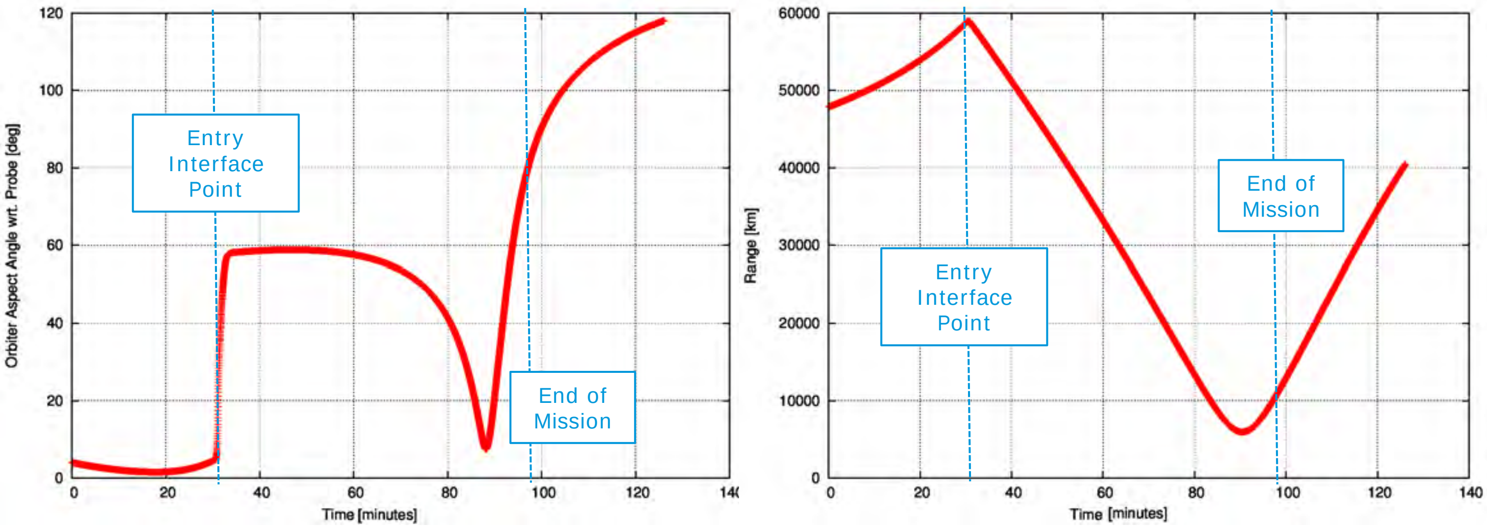


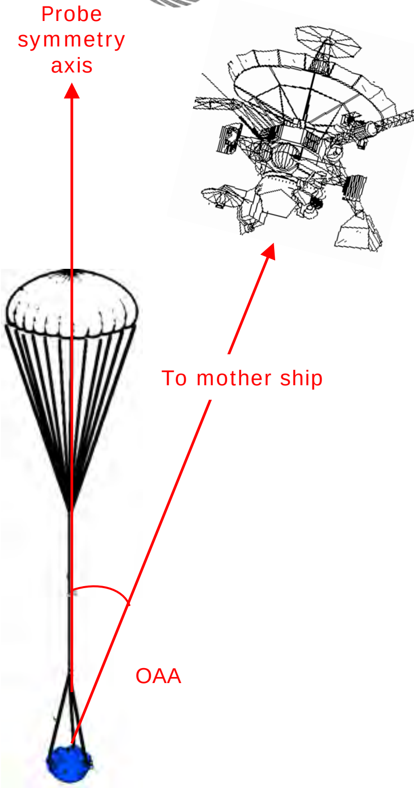
Example 1: Neptune Entry probe and mother ship

Example 2: Uranus Entry probe and mother ship

Animations courtesy of David de la Torre Sangrá

Probe-Mother Ship Comms: OAA





- Orbiter Aspect Angle (OAA): see diagram →
  - Even with a near-hemispherical antenna characteristics on probe, OAA cannot exceed ~80 deg or comms will fail
- Excessive range: reduced bit rate, valuable data cannot be transmitted
- No data, no science!

Thank you for your attention