Hypersonic Interplanetary Flight: Aero Gravity Assist

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Cal Poly Pomona
31 Oct 2006


OFF
MAIN MOM
TALK

Gravity Assist

Al Bowers & Dan Banks

Mission

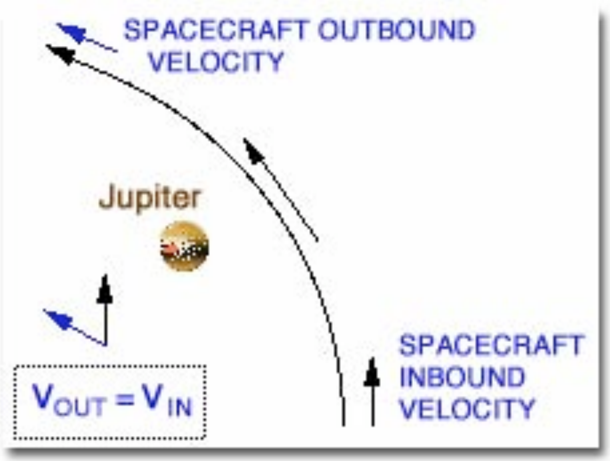
- NASA's Mission
  To understand our home planet
  To explore the Universe & search for life
  To inspire the next generation of explorers
- Dryden's Mission
  To fly what others can only imagine

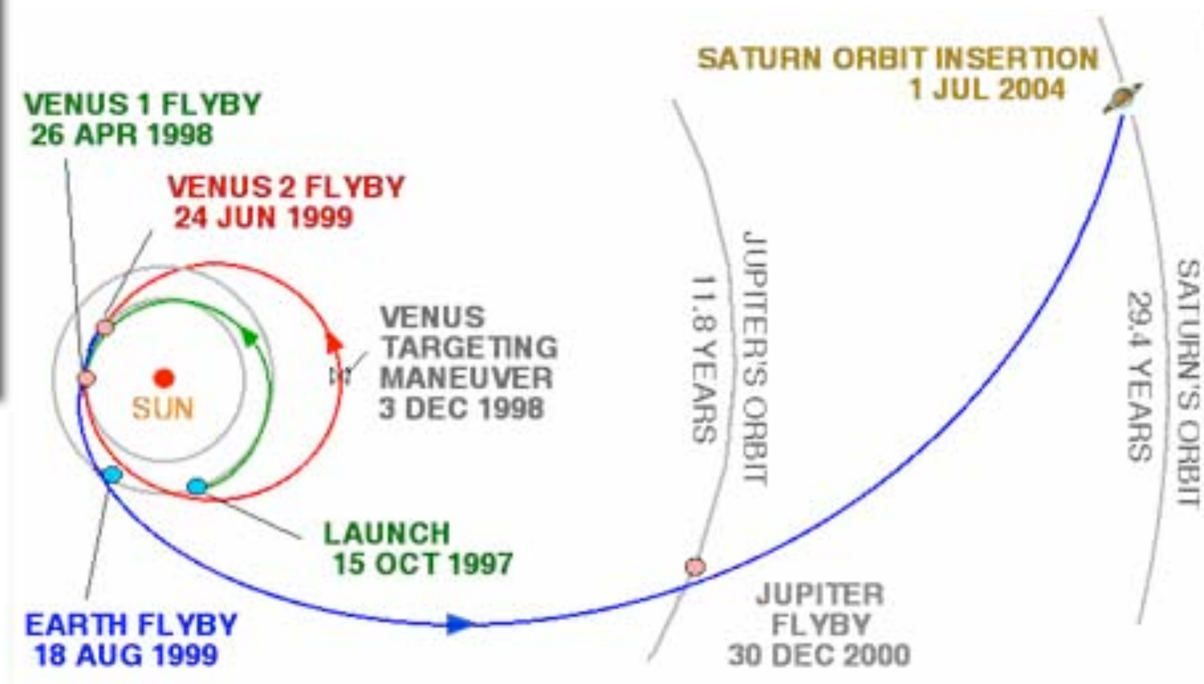
Gravity Assist & Aero Gravity Assist

- The Past: Gravity Assist
  - the idea
  - Grand Tour of the Planets: Pioneer 10/11 & Voyager 1/2
- The Future: Aero Gravity Assist
  - large v small planets for gravity assist
  - AGA trajectories
  - launch opportunities
  - planetary waverider performance

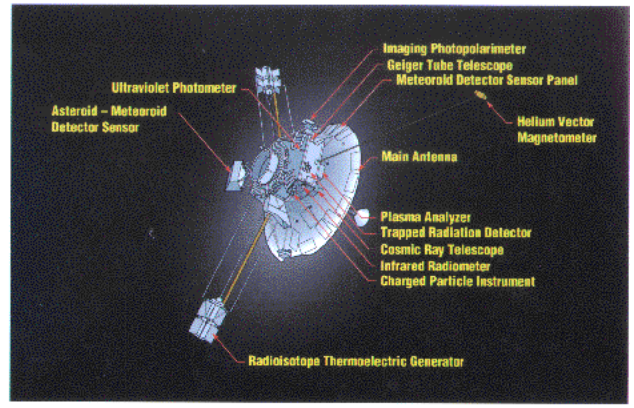
Gravity Assist - The Idea

- Planet-centric speed doesn't change, only direction
- Heliocentric radial speed does change, boost to a higher orbit

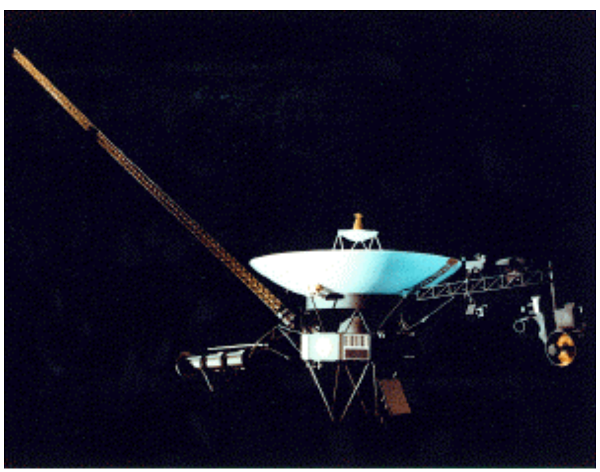




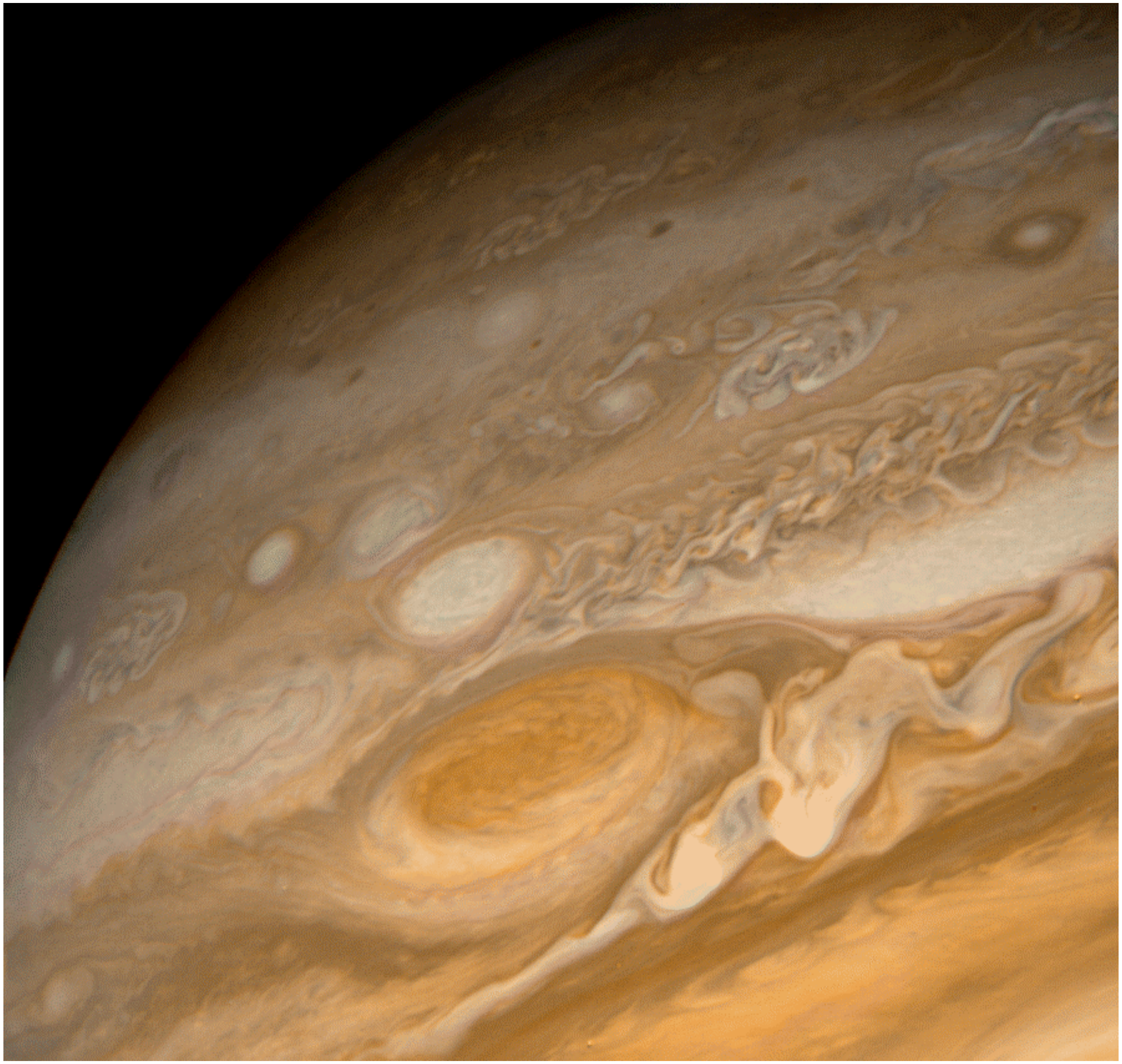
Pioneer 10/11 & Voyager 1/2

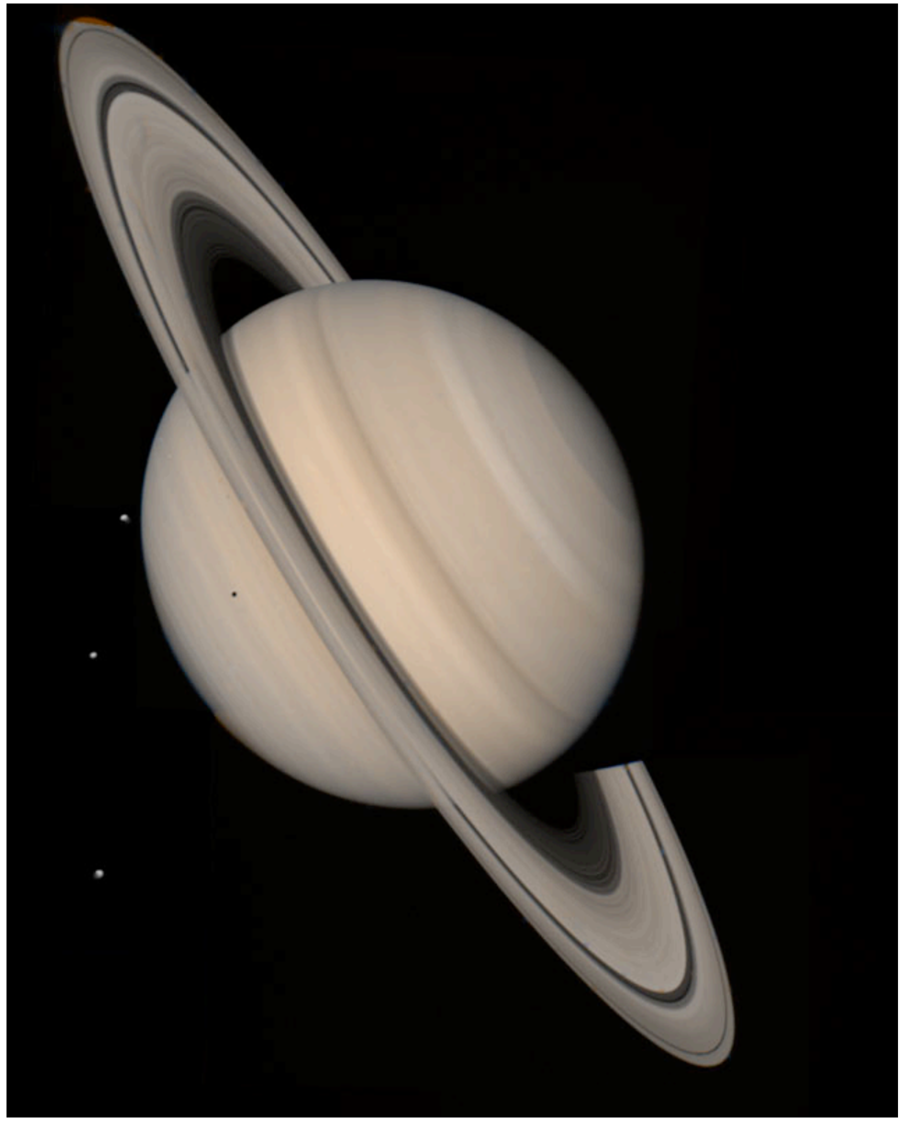


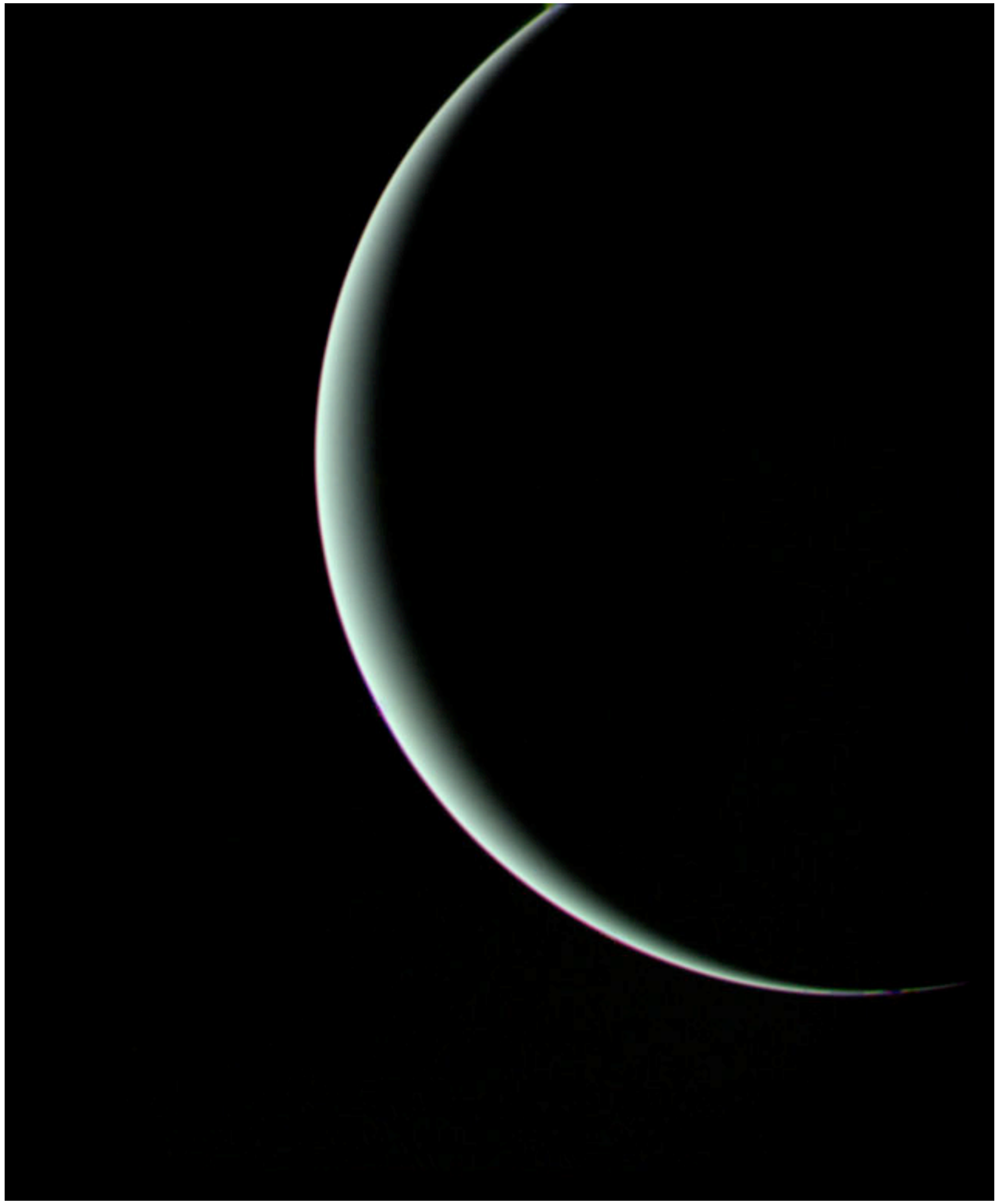
- Pioneer 10/11
  - Pioneer 10 to Jupiter
    launched 02 Mar 72
    Jupiter 03 Dec 73
  - Pioneer 11 to Jupiter & Saturn
    launched 05 Apr 73
    Jupiter 02 Dec 74
    Saturn 01 Sep 79

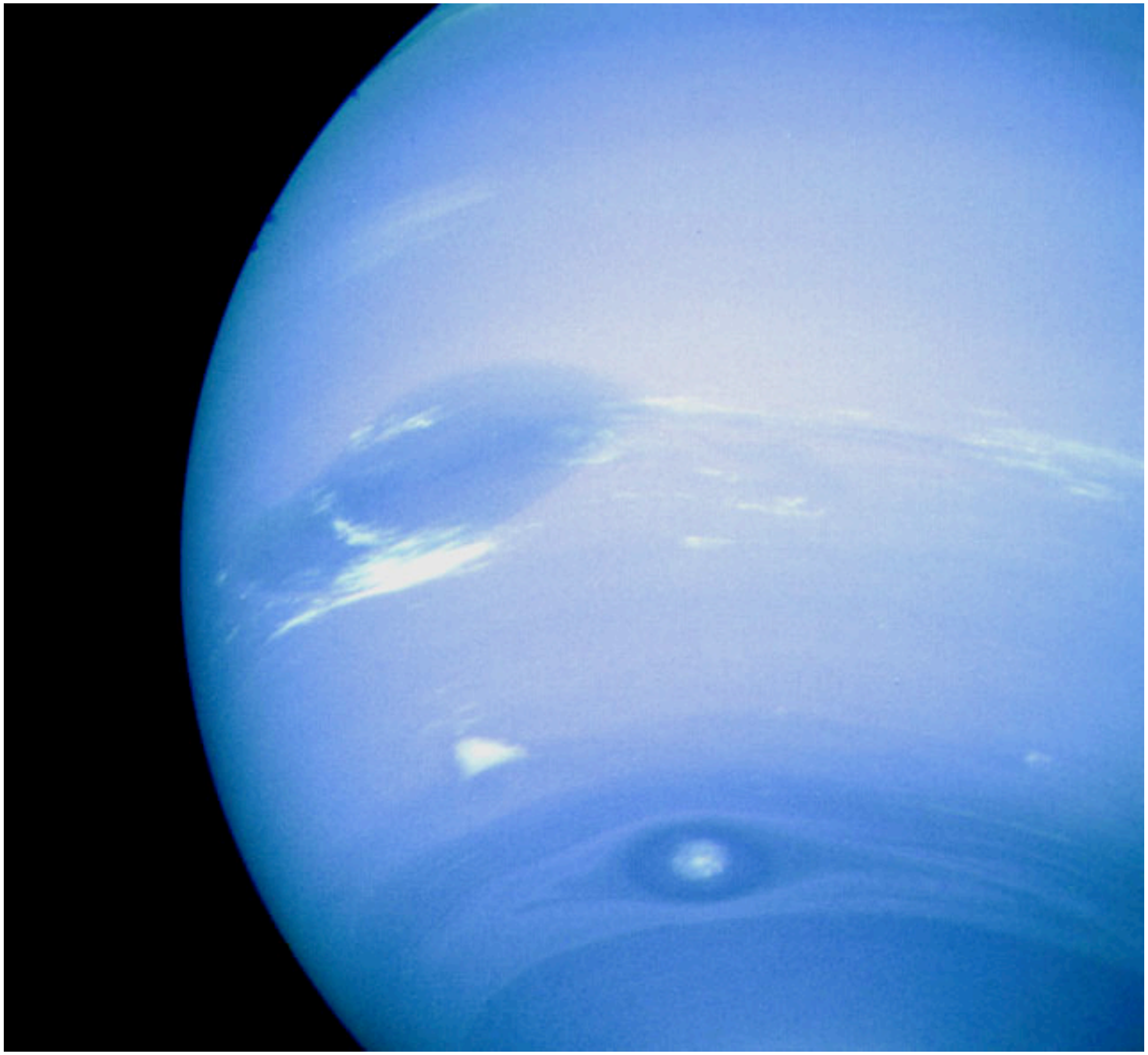


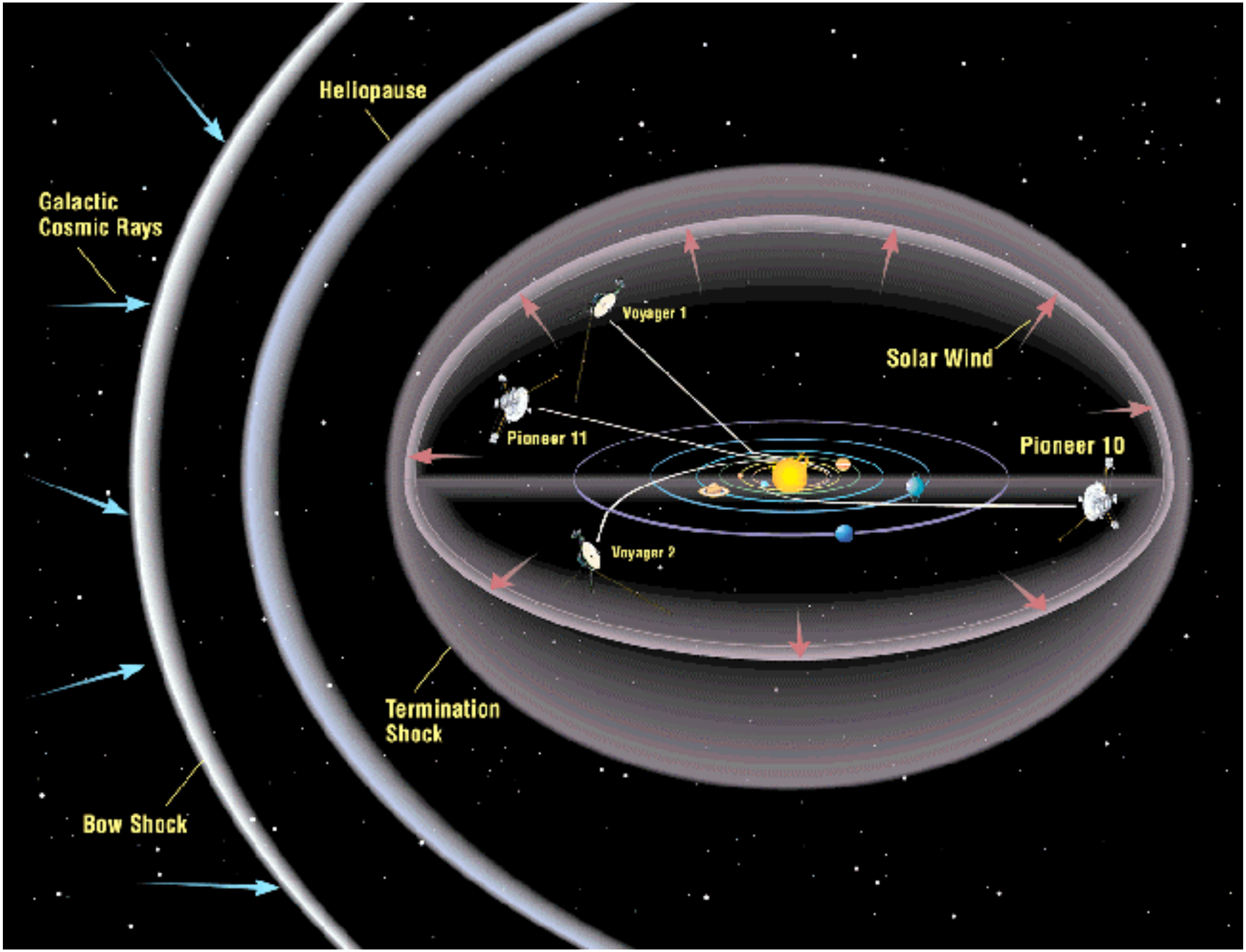
- Voyager 1/2
  - Voyager 1 to Jupiter & Saturn
    launched 05 Sep 77
    Jupiter 05 Mar 79
    Saturn 12 Nov 80
  - Voyager 2 to Jupiter, Saturn, Uranus & Neptune
    launched 20 Aug 77
    Jupiter 09 Jul 79
    Saturn 25 Aug 81
    Uranus 24 Jan 86 & Neptune 25 Aug 89

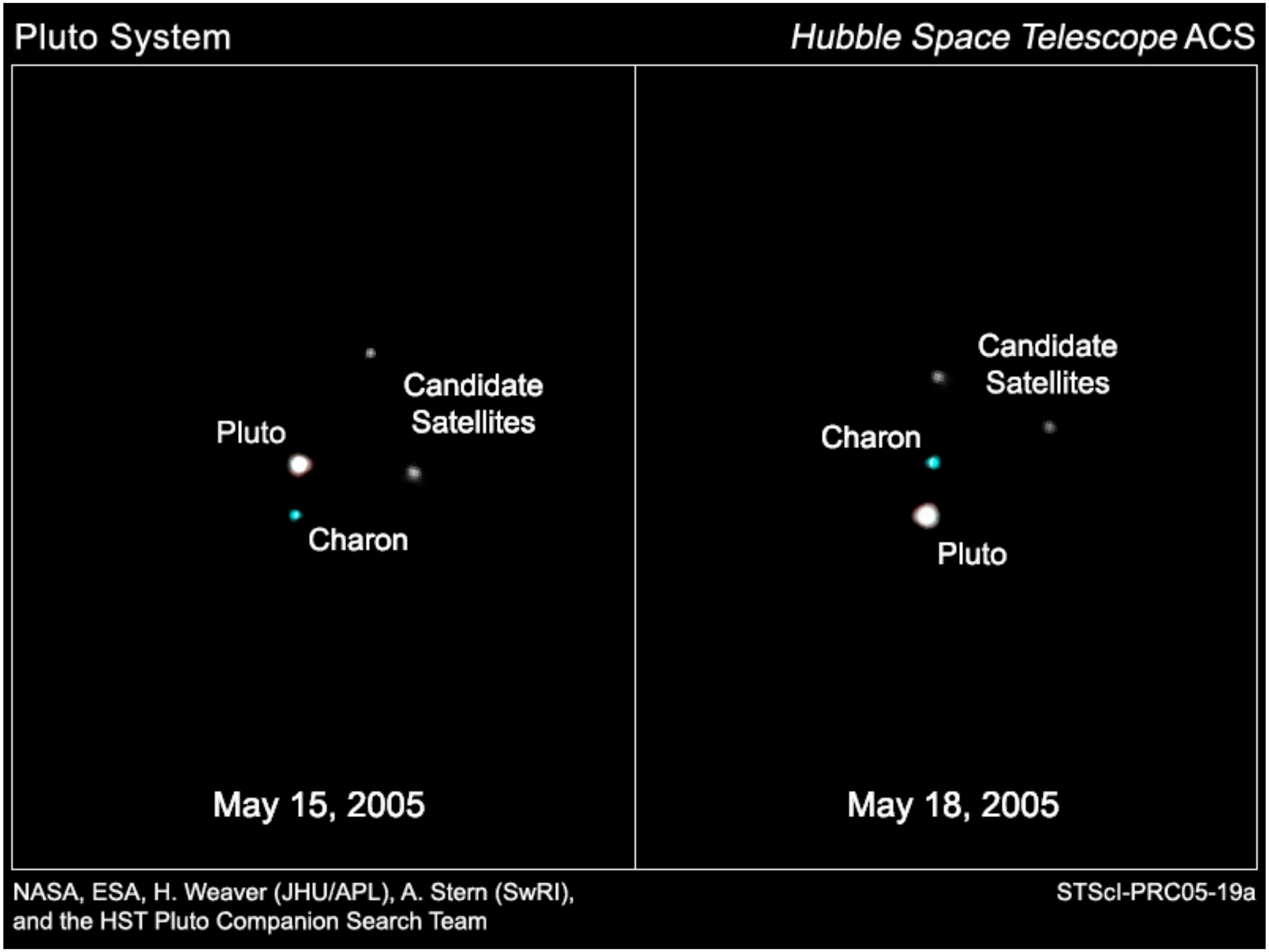









Heliopause
Galactic Cosmic Rays
Voyager 1
Solar Wind
Pioneer 11
Pioneer 10
Voyager 2
Termination Shock
Bow Shock


Pluto System
Hubble Space Telescope ACS
Candidate
Satellites
Pluto
Charon
May 15, 2005
Candidate
Satellites
Charon
Pluto
May 18, 2005
NASA, ESA, H. Weaver (JHU/APL), A. Stern (SwRI),
and the HST Pluto Companion Search Team
STScI-PRC05-19a

TYPICAL PLANETARY GRAVITY-ASSIST TRAJECTORIES

· USING LARGE OUTER PLANETS

LARGE **G** , LARGE BENDING ANGLES**, LARGE ΔV**

HIGH LAUNCH ENERGY (C_3 = 80 - 120 km^2/sec^2)

LONG DURATION TO THE CLOSEST PLANET (e.g. JUPITER)

RADIATION DANGER IN THE MAGNETOSPHERES OF GAS GIANTS

· USING SMALL TERRESTRIAL PLANETS

SMALL **G**, SMALL BENDING ANGLES, **SMALL ΔV**

LOW LAUNCH ENERGY (C_3 = 10 - 30 km^2/sec^2)

LOW INTERPLANETARY VELOCITIES (<10 km/sec)

LONG DURATION : MULTIPLE FLYBYS TO GET REASONABLE VELOCITIES

AERO-GRAVITY ASSIST (AGA) TRAJECTORIES

- **TERRESTRIAL PLANETS FOR AGA MANEUVERS**

  USING ATMOSPHERE TO INCREASE BENDING ANGLE AND ΔV

  SMALL LAUNCH ENERGY (C_3 ~ 10 - 30 km2/sec2)

  AGA RESULTS IN HIGH INTERPLANETARY VELOCITIES (>> 10 km/sec)

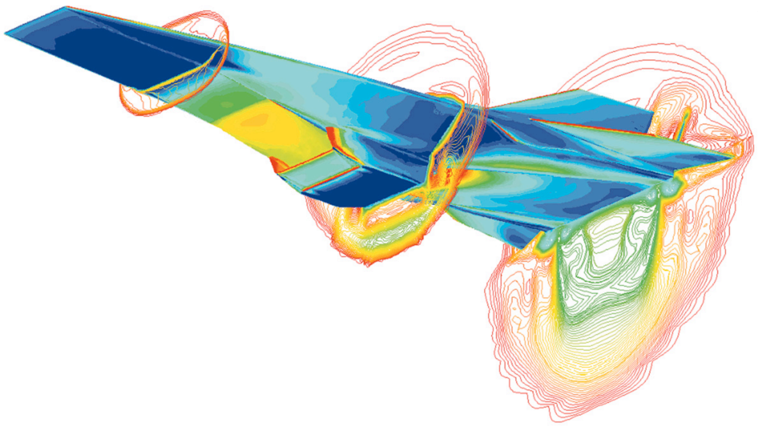
  SHORTENED MISSION DURATIONS TO DISTANT TARGETS

- **WAVERIDER APPLICATION**

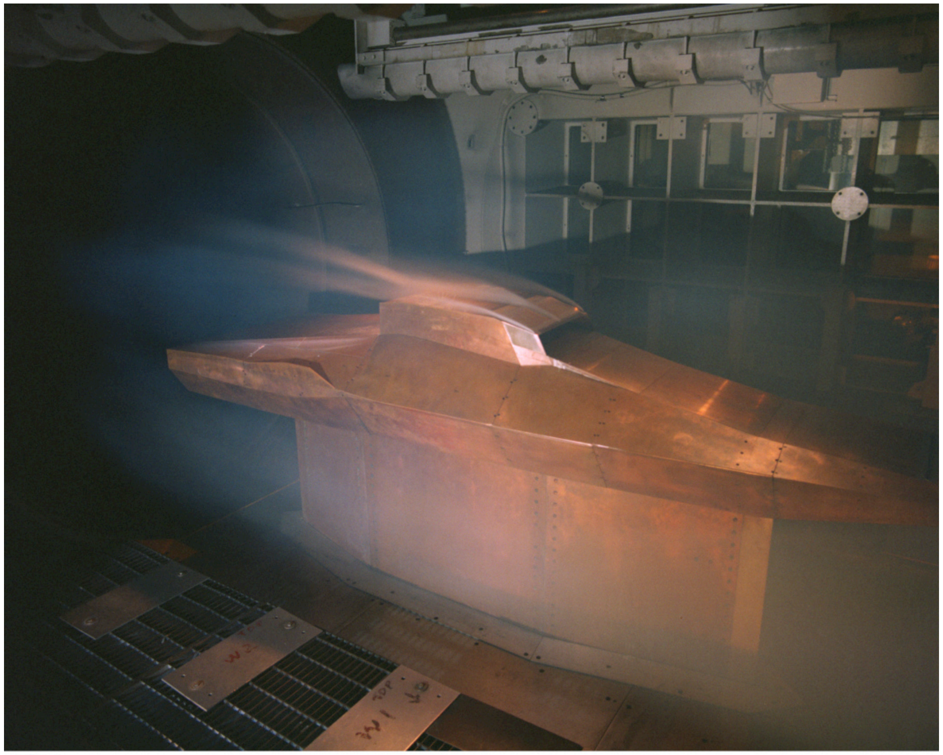
  AEROASSIST VEHICLE WITH HIGH LIFT/DRAG AT HIGH MACH NUMBERS

  MINIMUM DRAG LOSS DURING THE ATMOSPHERIC PASS

  LARGE AERODYNAMIC CONTROL AUTHORITY FOR PRECISE NAVIGATION

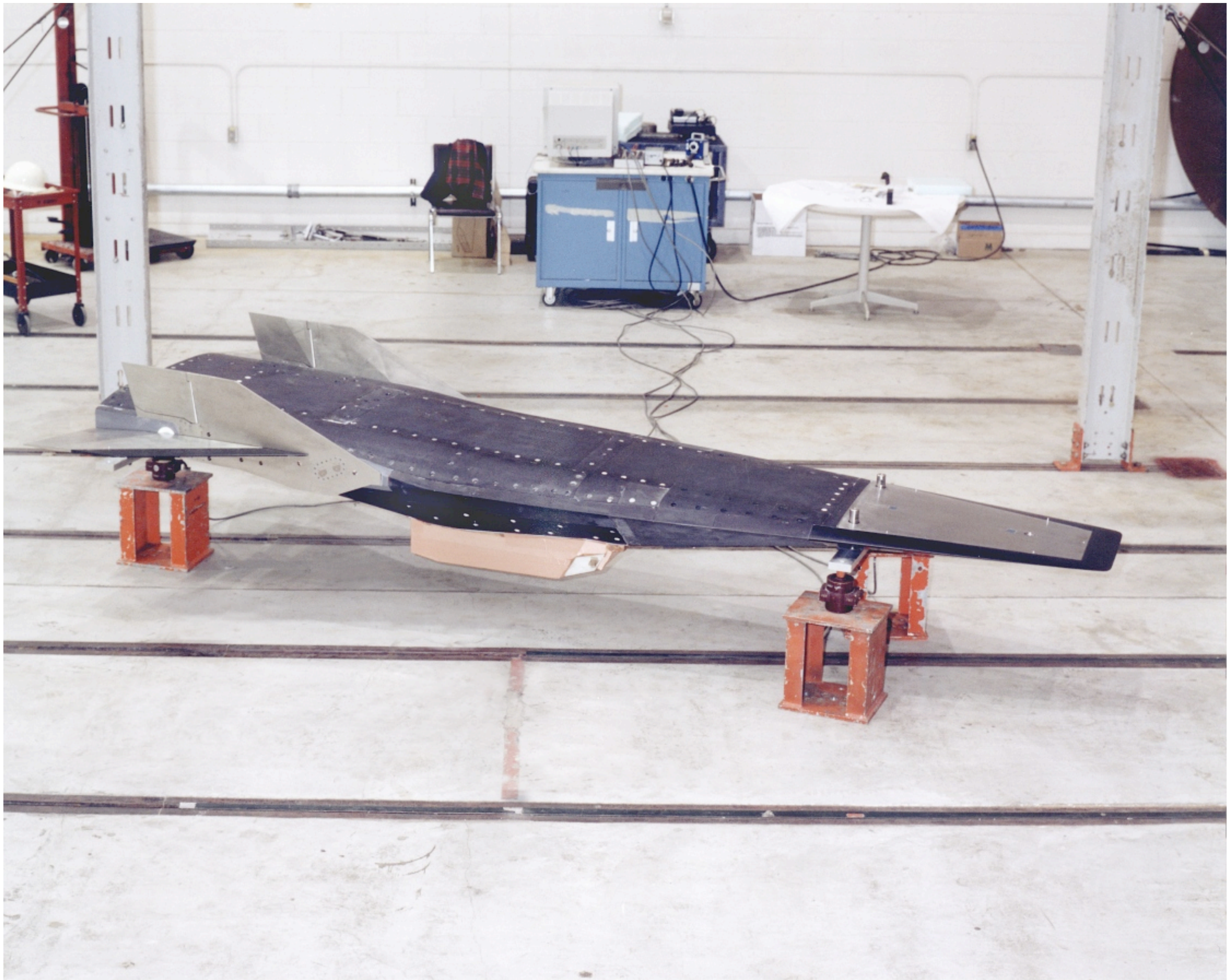


Dryden Flight Research Center ED97 43968-01
HYPER-X AT MACH 7: This computational fluid dynamic (CFD) image is of the Hyper-X vehicle at the Mach 7 test condition with the engine operating.



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: ED04-0082-2

Mach 7 wind tunnel test of the full-scale X-43A model with spare flight engine in Langley's 8-Foot High Temperature Tunnel.



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC99-45265-23 Date: December 1999 Photo by: Tom Tschida

X-43A Vehicle During Ground Testing

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC04-0091-39 Date: March 26, 2004 Photo By: Tony Landis

NASA's B-52B launch aircraft at sunset with the second X-43A hypersonic research vehicle attached to a modified Pegasus rocket under its right wing.

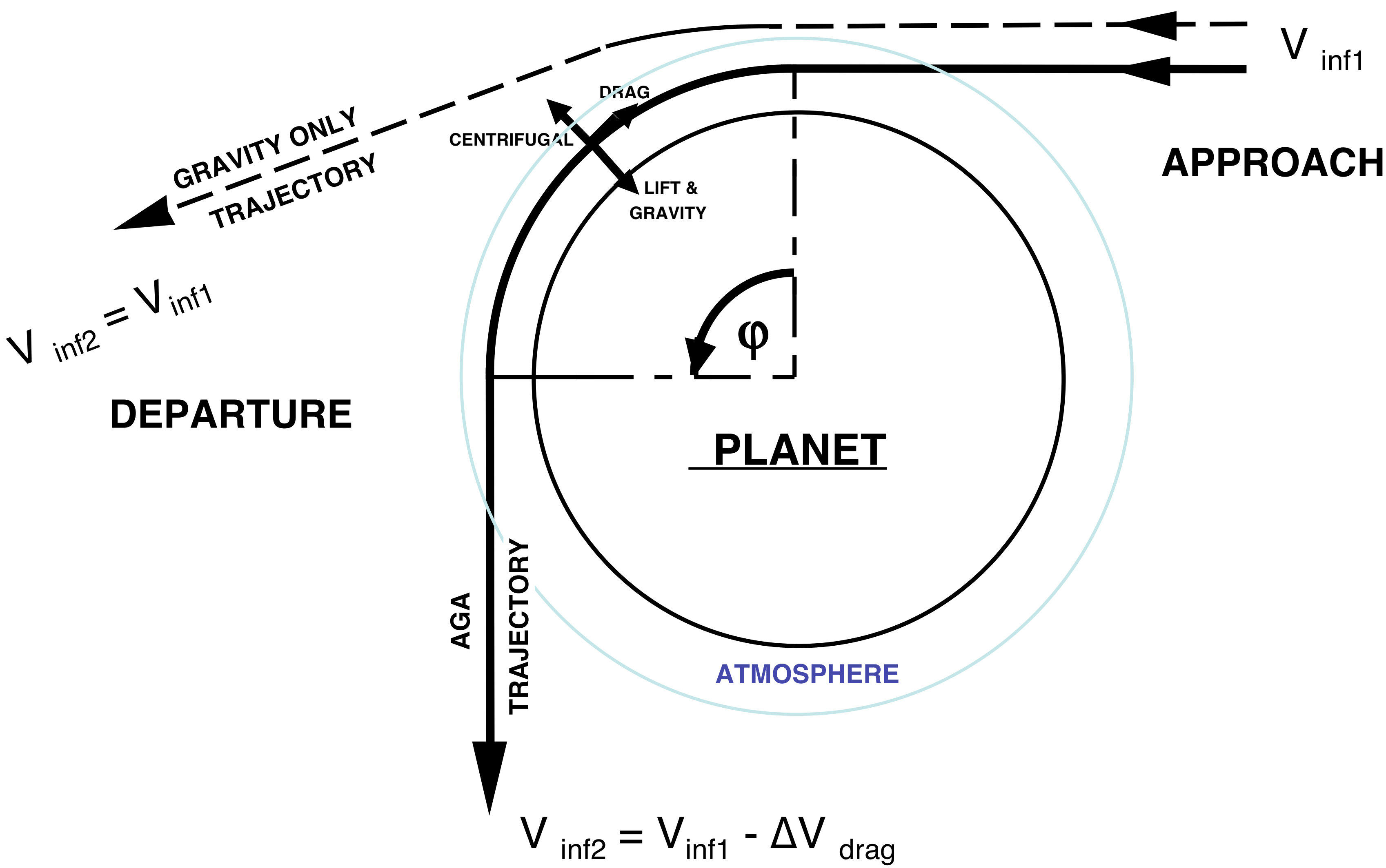
NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC04−0325−32 Date: November 16, 2004 Photo By: Carla Thomas

A modified Pegasus rocket drops away after release from NASA's B−52B before accelerating the X−43A over a Pacific Ocean test range on Nov. 16, 2004.

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC04−0092−39 Date: March 27, 2004 Photo By: Jim Ross

The second X−43A and its modified Pegasus booster rocket accelerate after launch from NASA's B−52B launch aircraft over the Pacific Ocean.

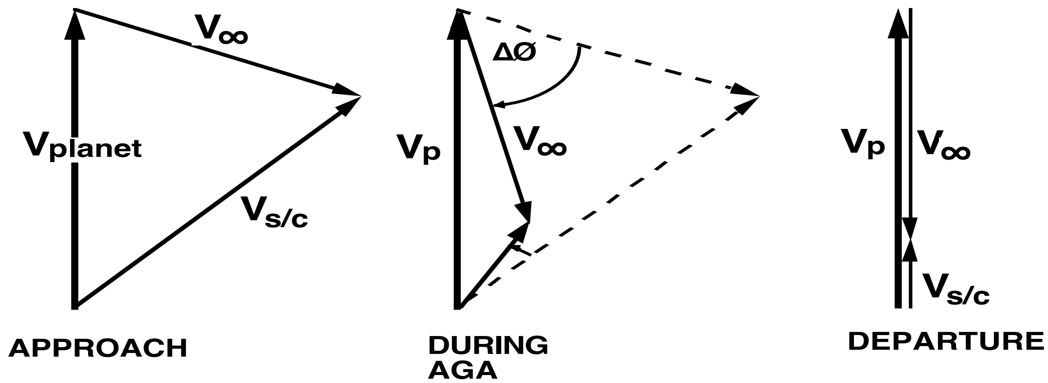
PLANET CENTERED TRAJECTORY COMPARISON



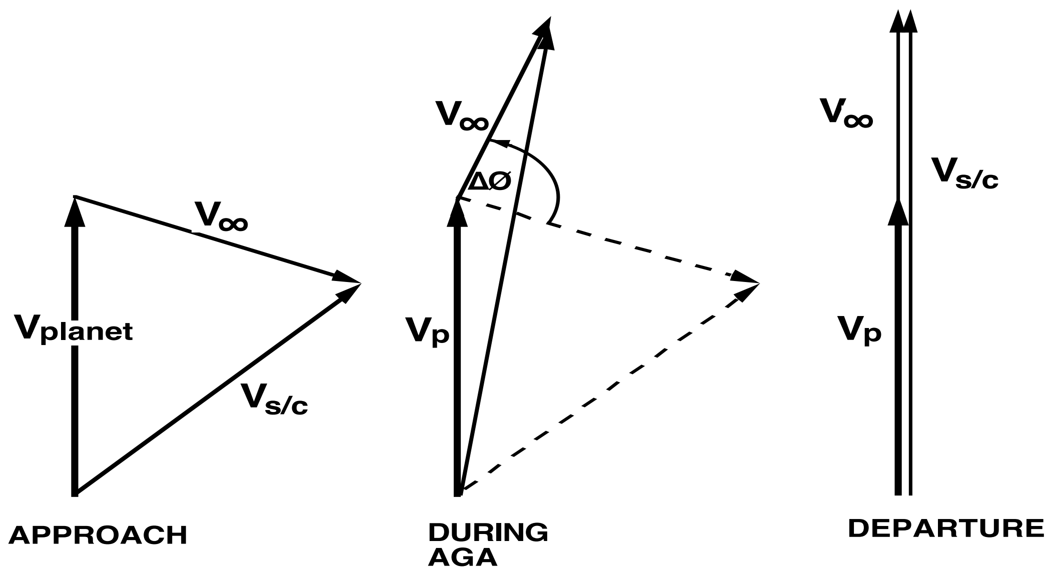
AGA Velocity Triangles

$$V_{S/C} = V_{PLANET} \;\vec{+}\; V_{\infty}$$

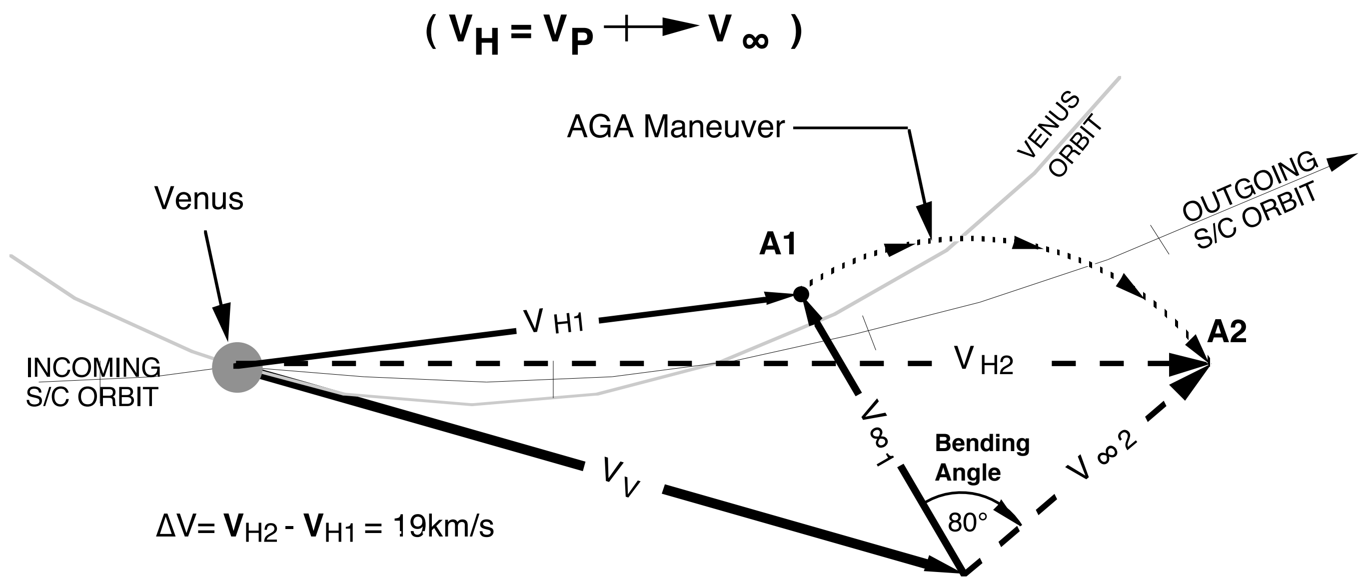
a. DECREASE VELOCITY (e.g. SOLAR PROBE)



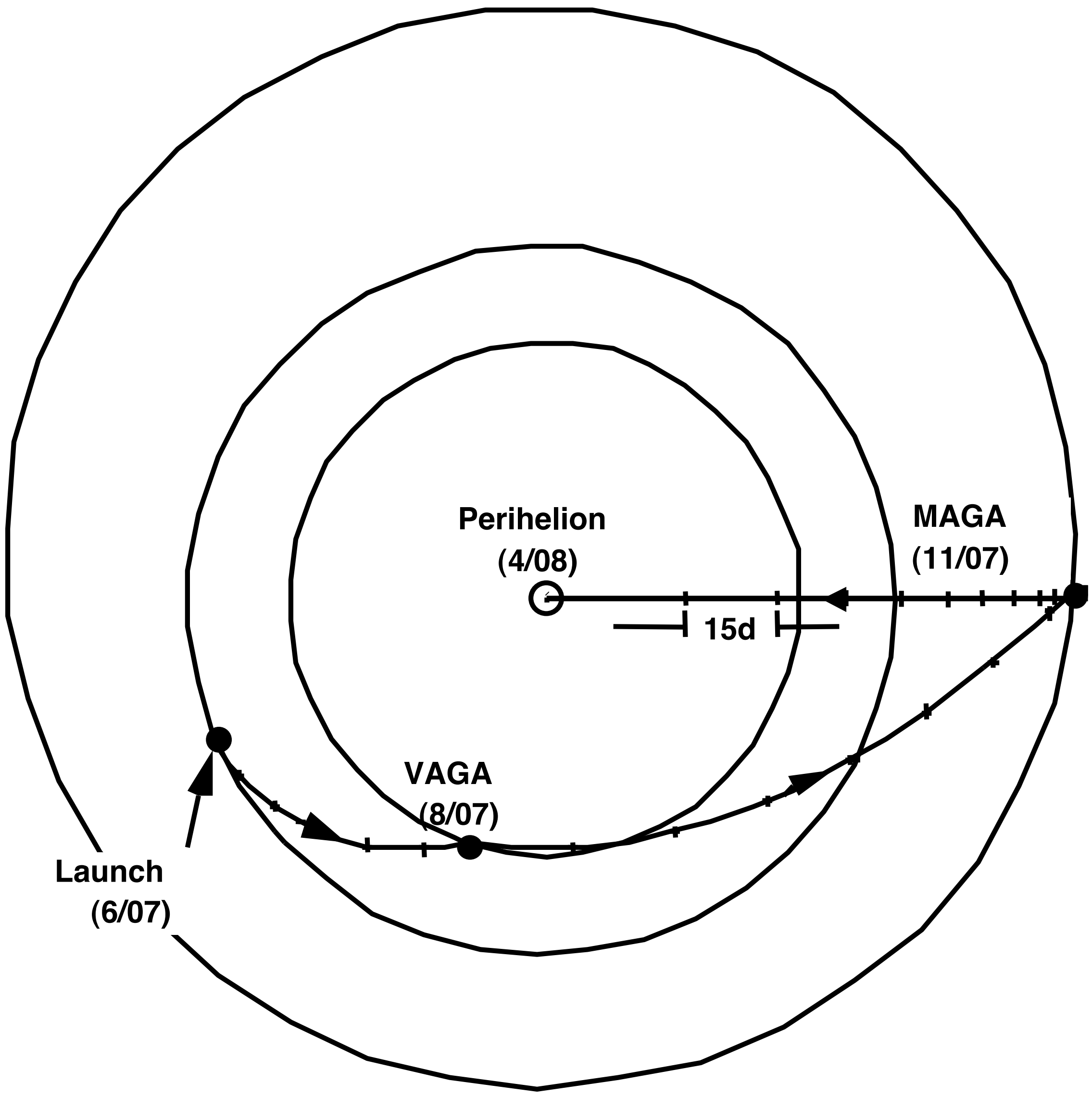
b. INCREASE VELOCITY (e.g. OUTER PLANETS MISSION)



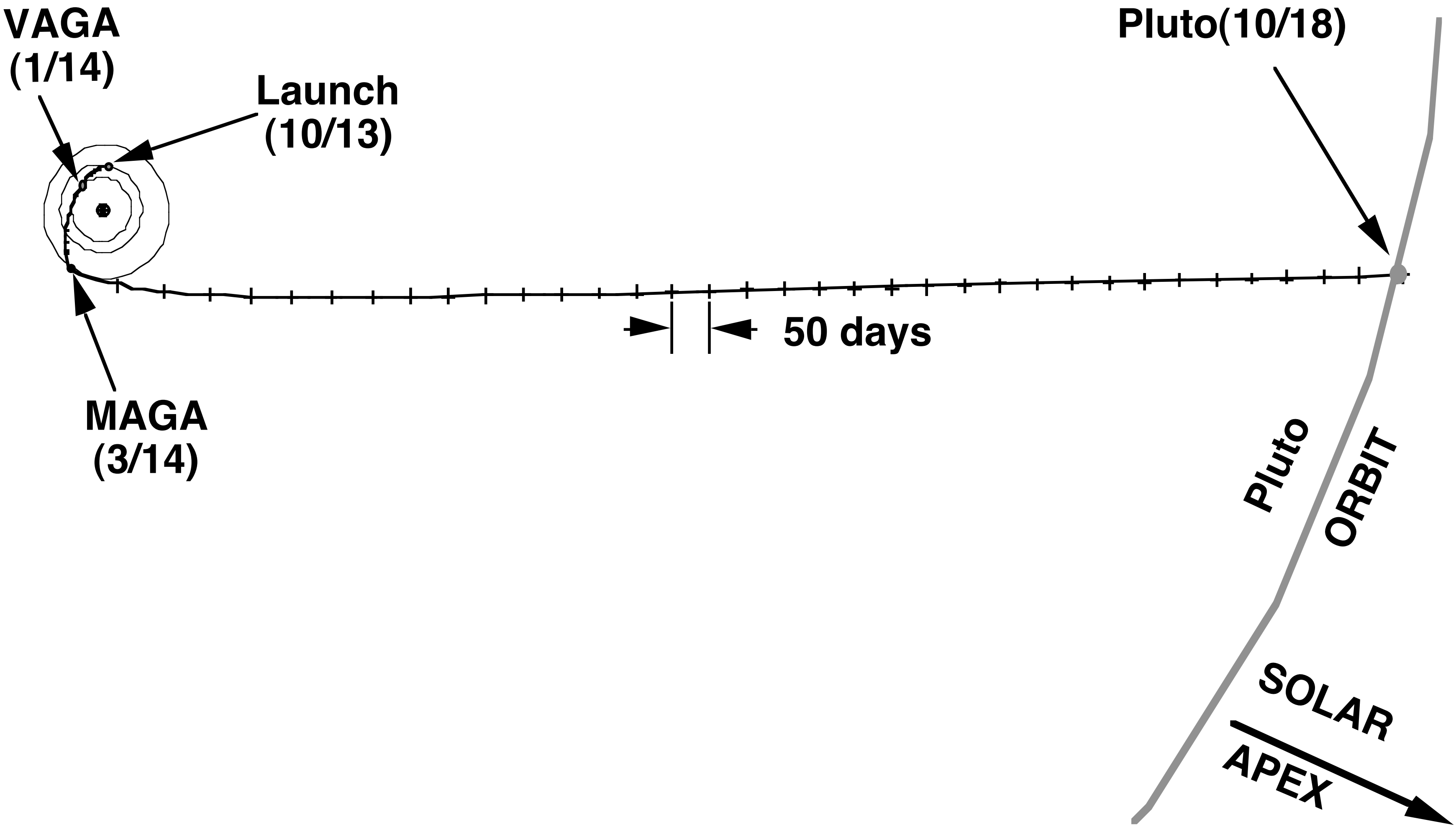
VENUS AGA Maneuver



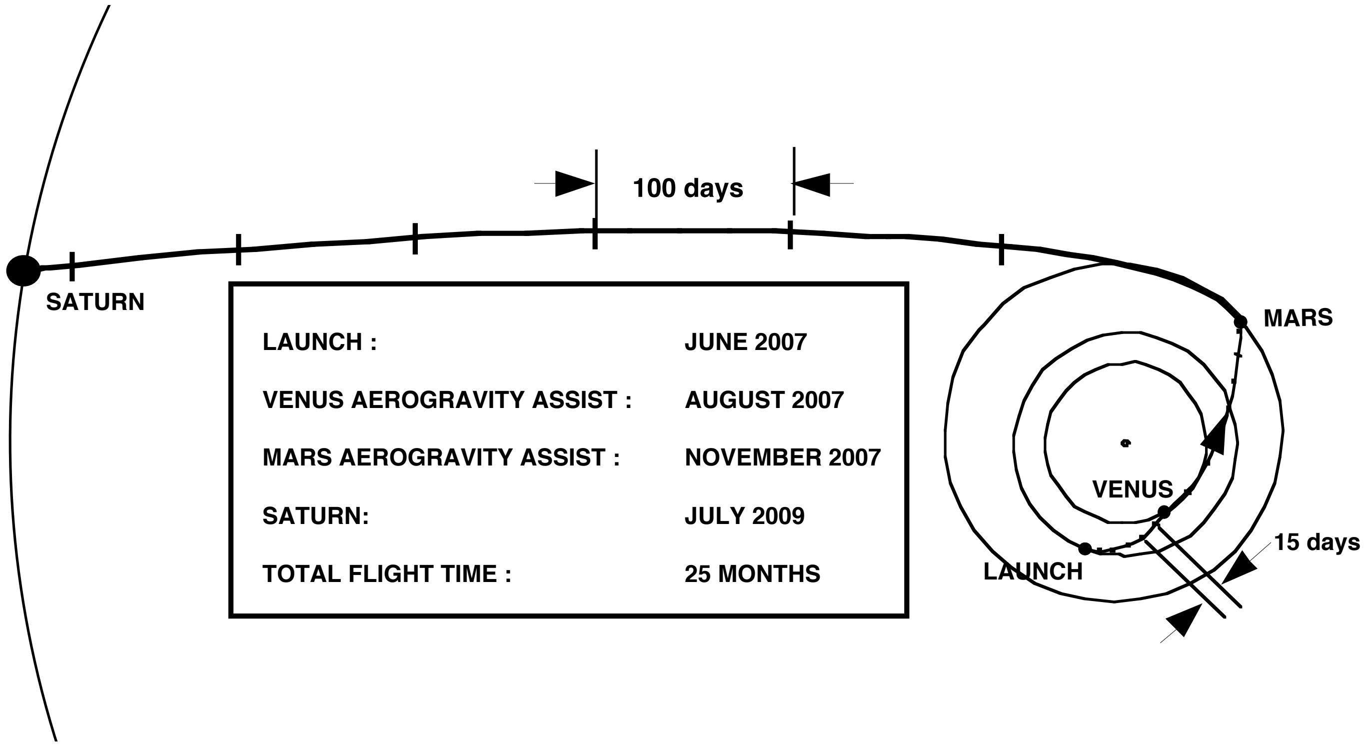
VENUS - MARS AGA TRAJECTORY TO THE SUN



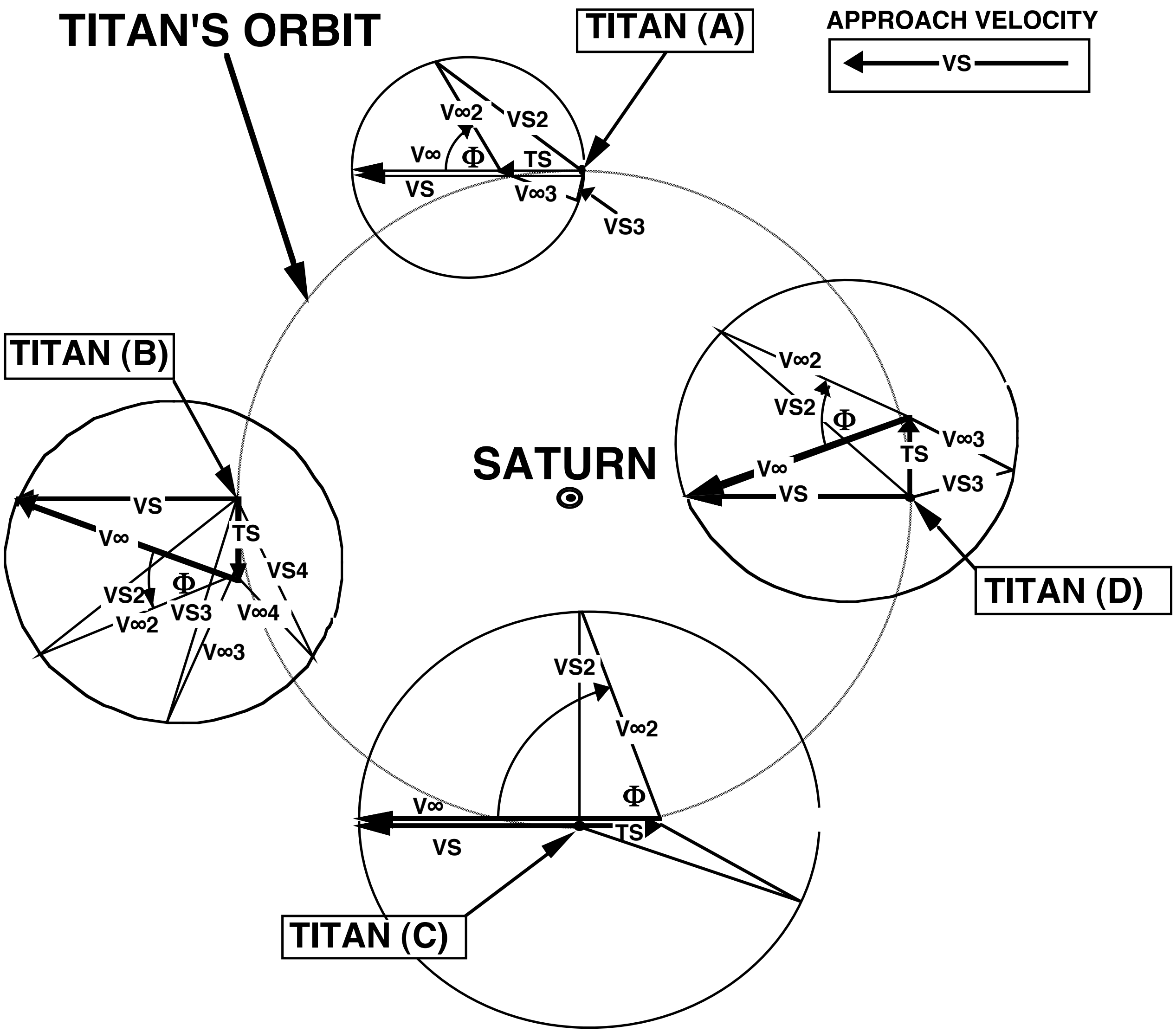
VAGAMAGA Trajectory to Pluto



VAGAMAGA Trajectory to Saturn



TITAN AGA OPTIONS



LEGEND

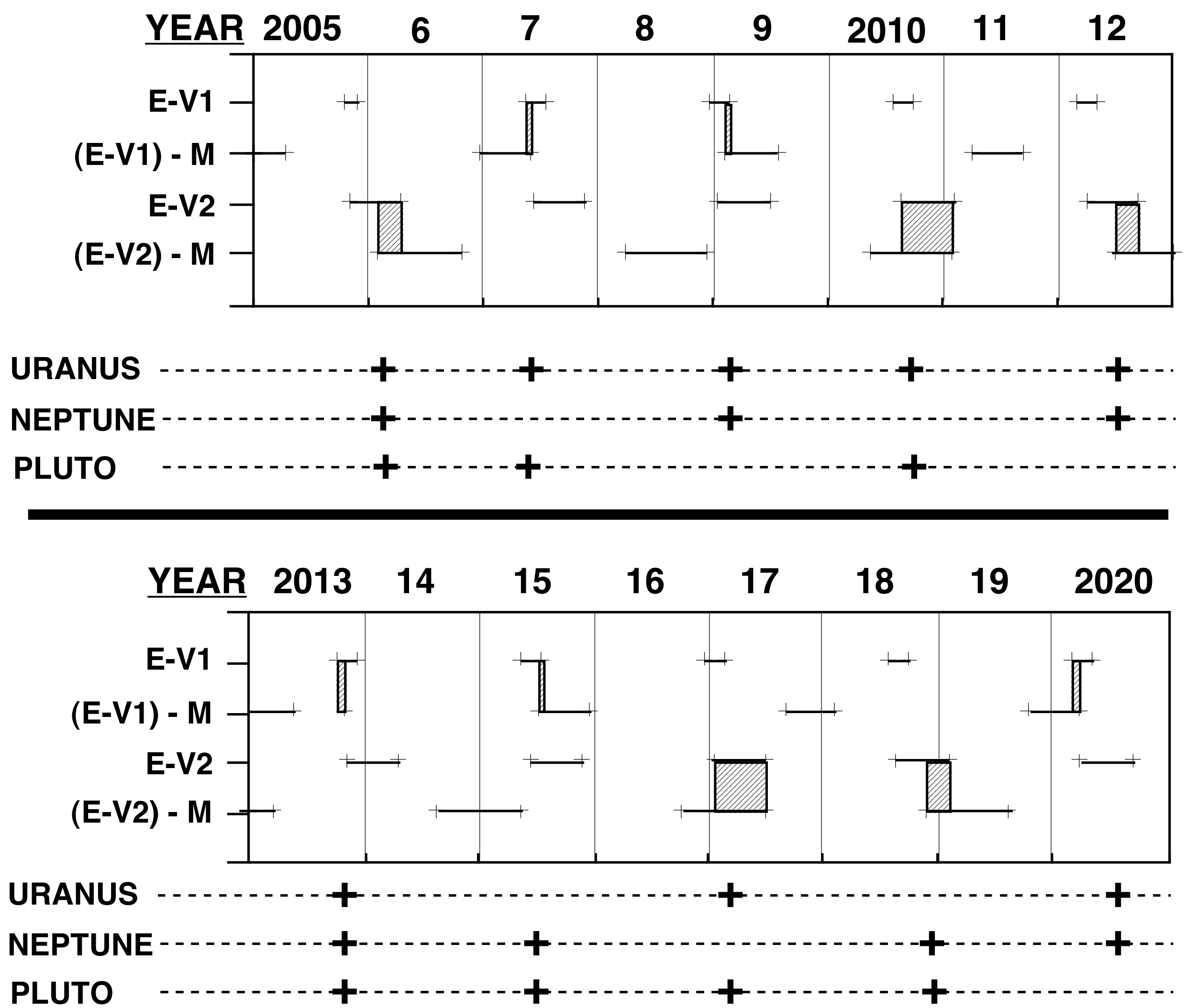
TITAN A:
Stop S/C, VS3 ~0

TITAN B:
Escape at "posigrade" direction

TITAN C:
Polar trajectory

TITAN D:
Escape in retrograde direction

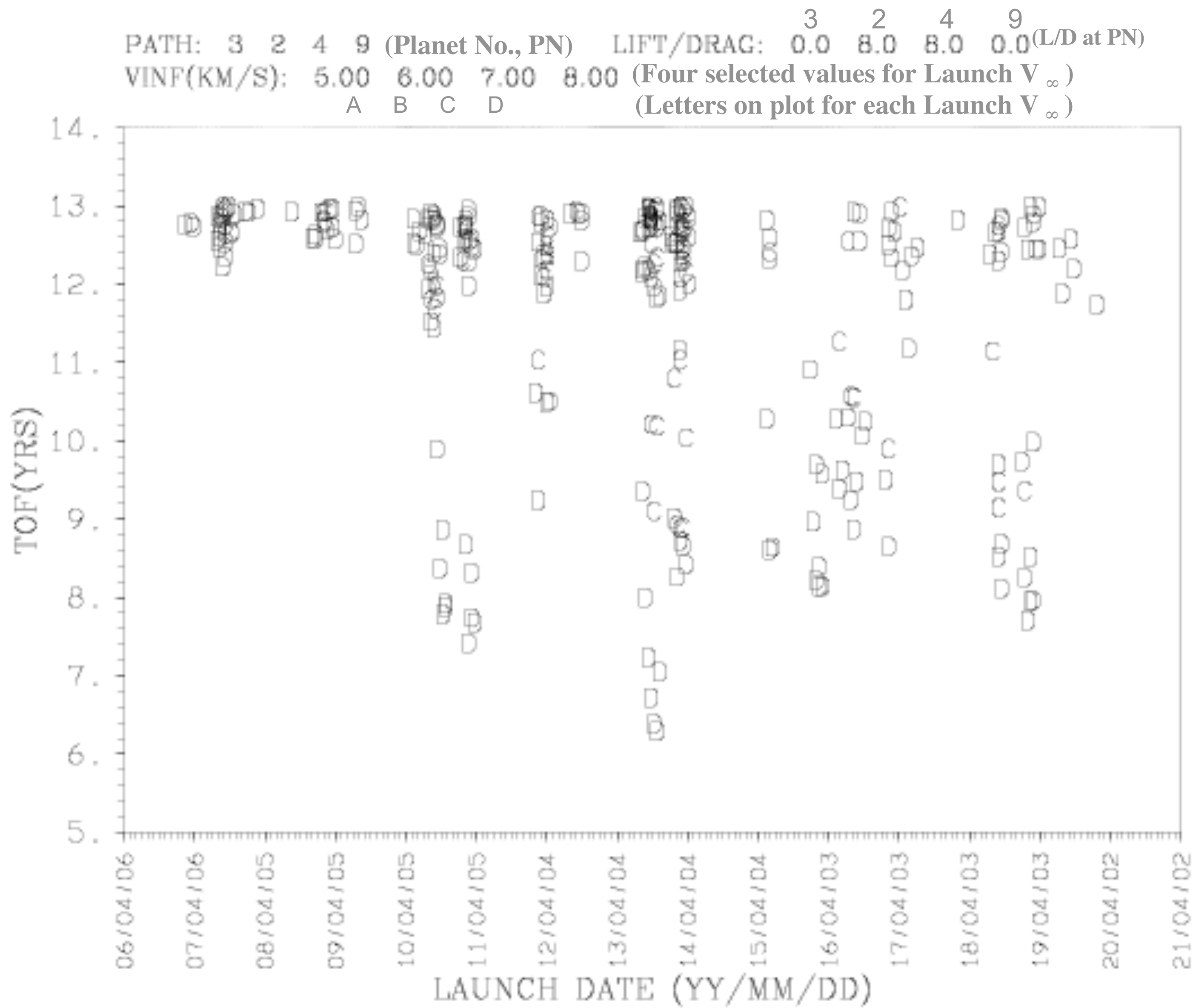
Terrestrial Planets Trajectories and OP Launch opportunities from 2005 to 2020



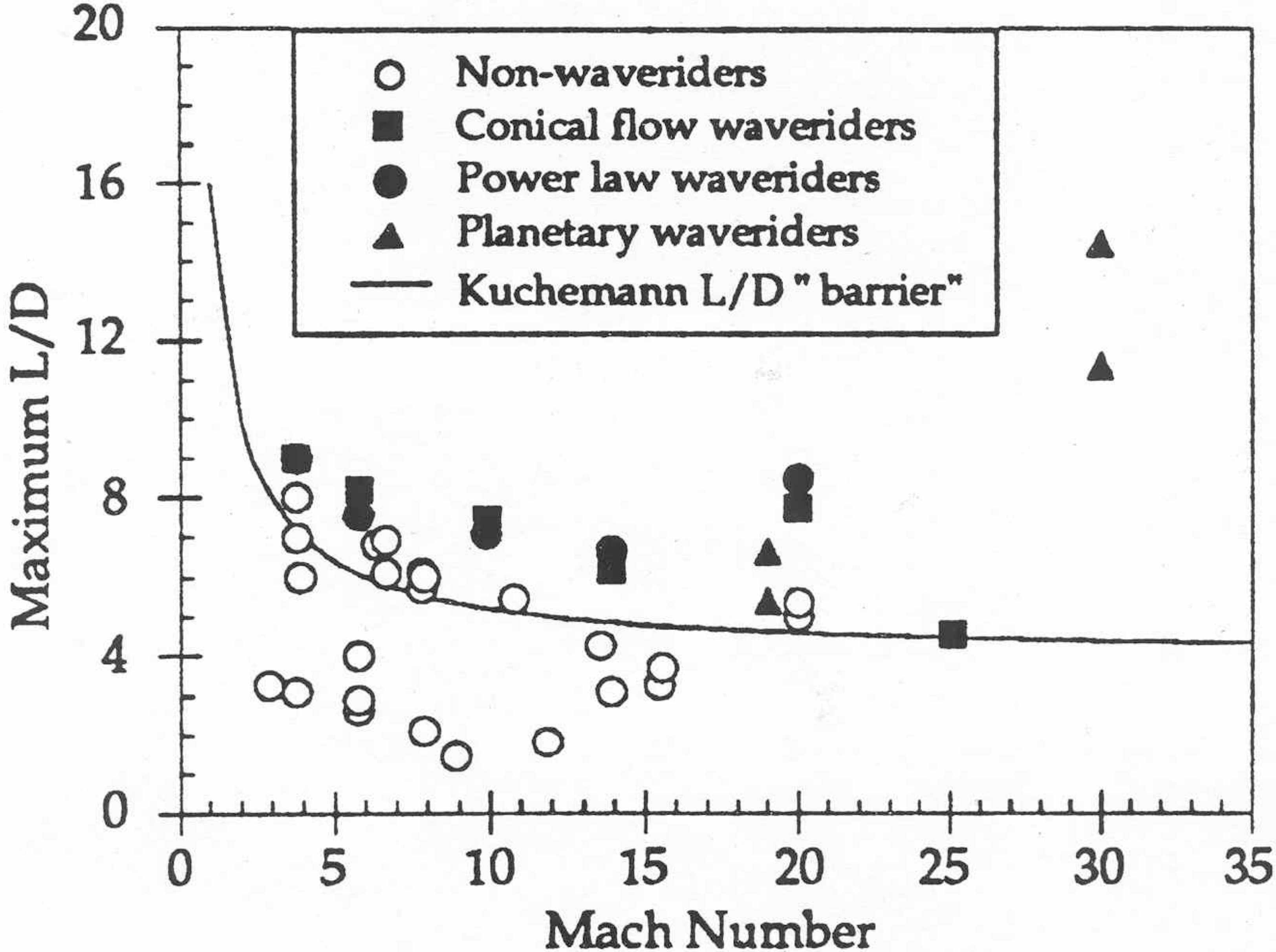
= Viable Opportunity to the Outer Planet Shown Below Box

Time of Flight for Pluto opportunities 2006 to 2020

(using Venus and Mars AGA maneuvers)

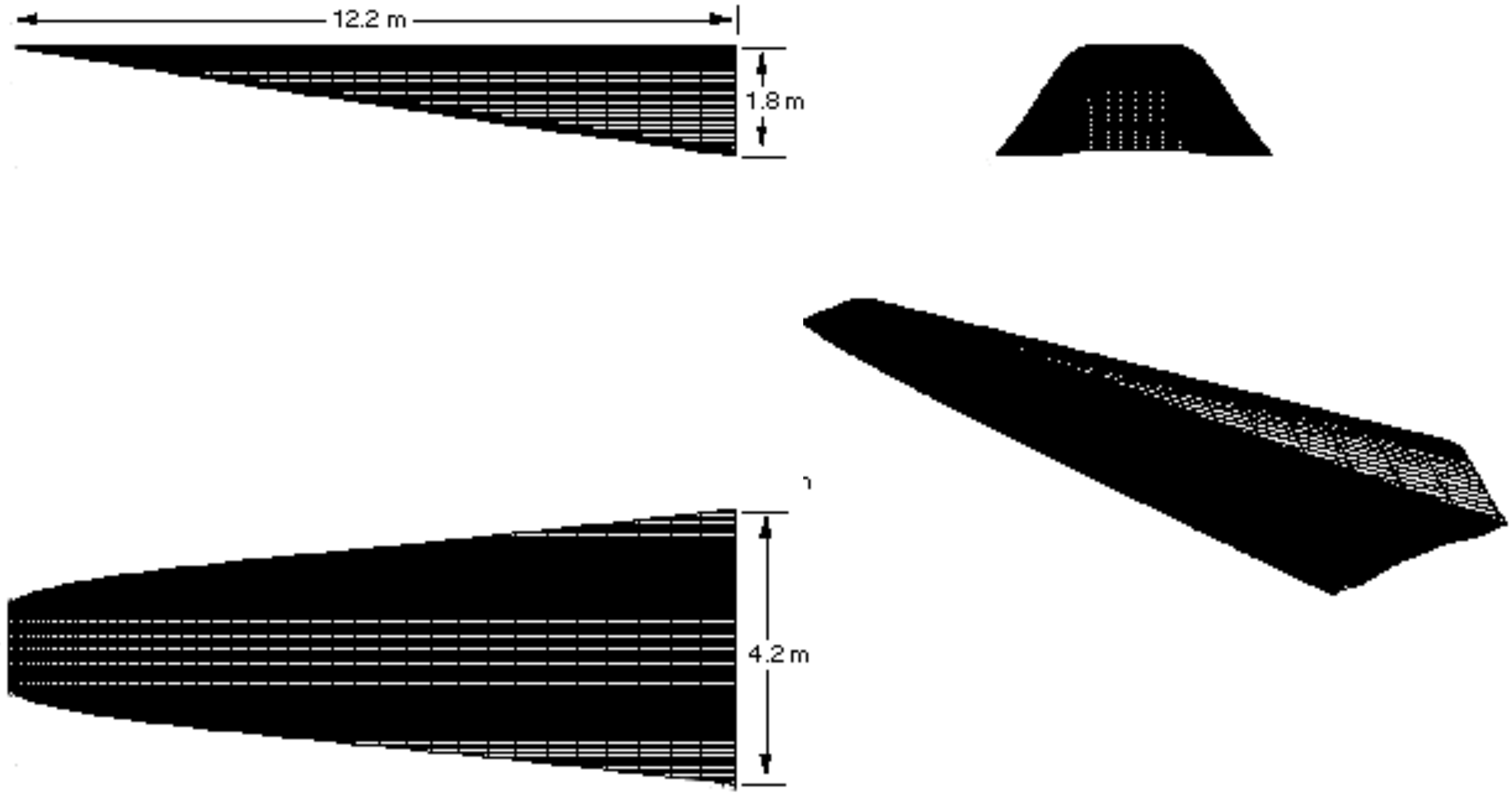


Planetary Waverider Performance Comparison*

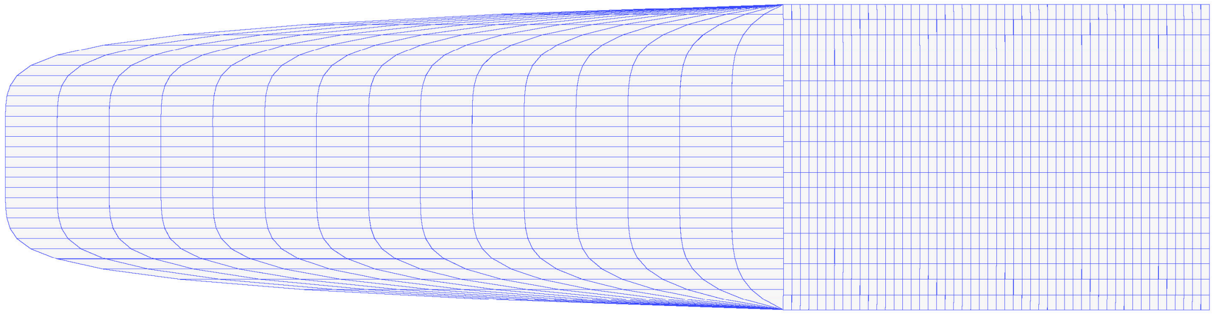


* From Lewis & McRonald, AIAA #91-0053, 1/7/91

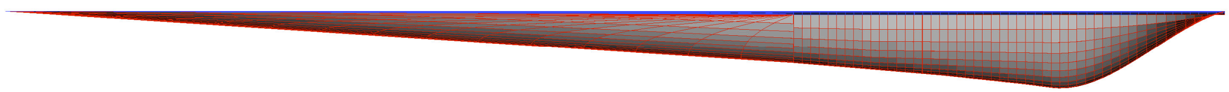
University of Maryland Waverider Concept



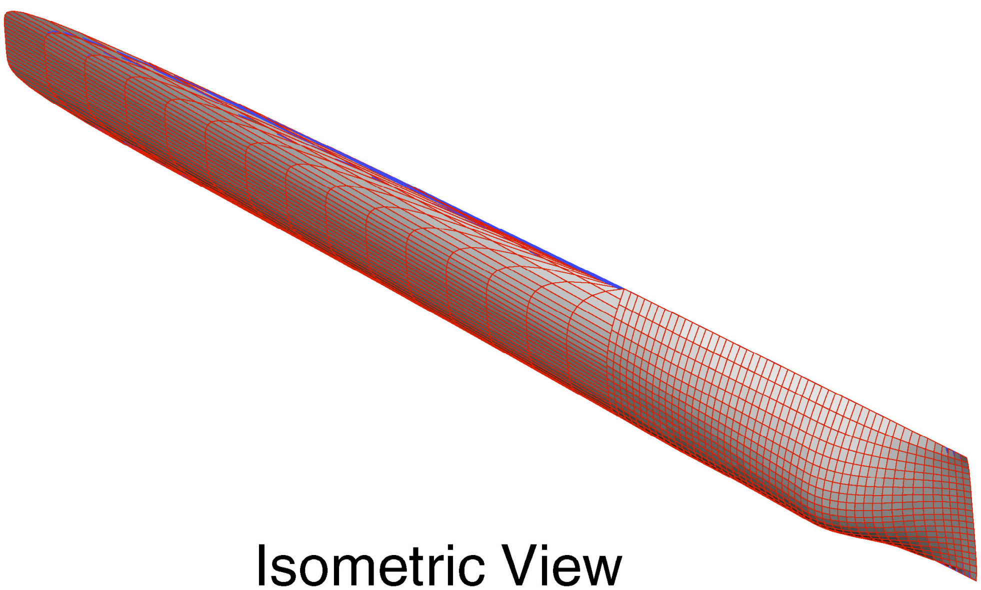
Waverider shape for a turbulent (CO_2) boundary layer (From the CVD design code at the U of Maryland)



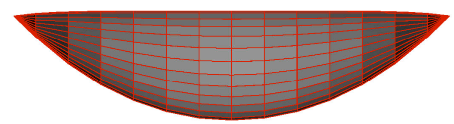
Planform View



Side View

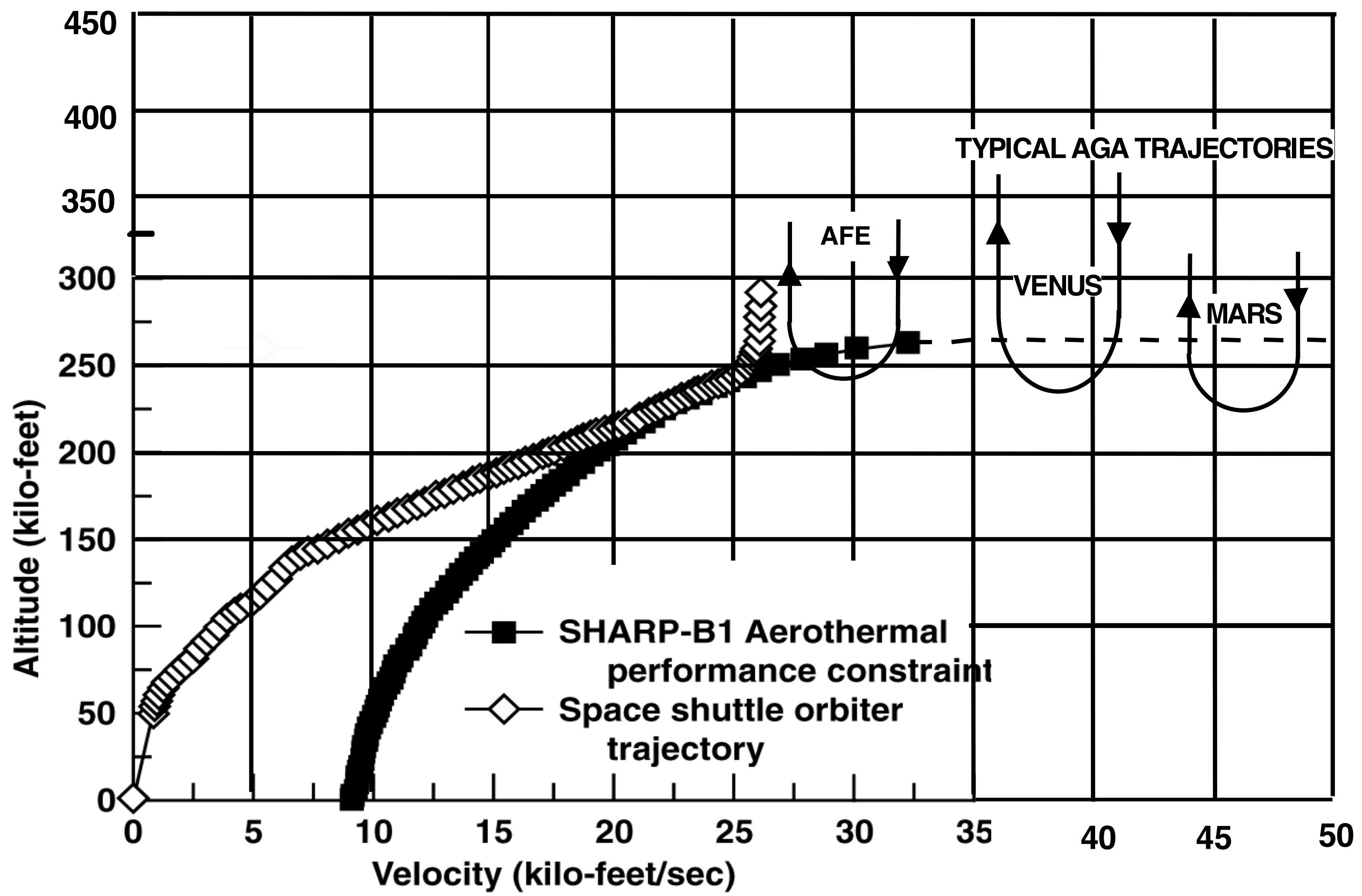


Isometric View



Base View

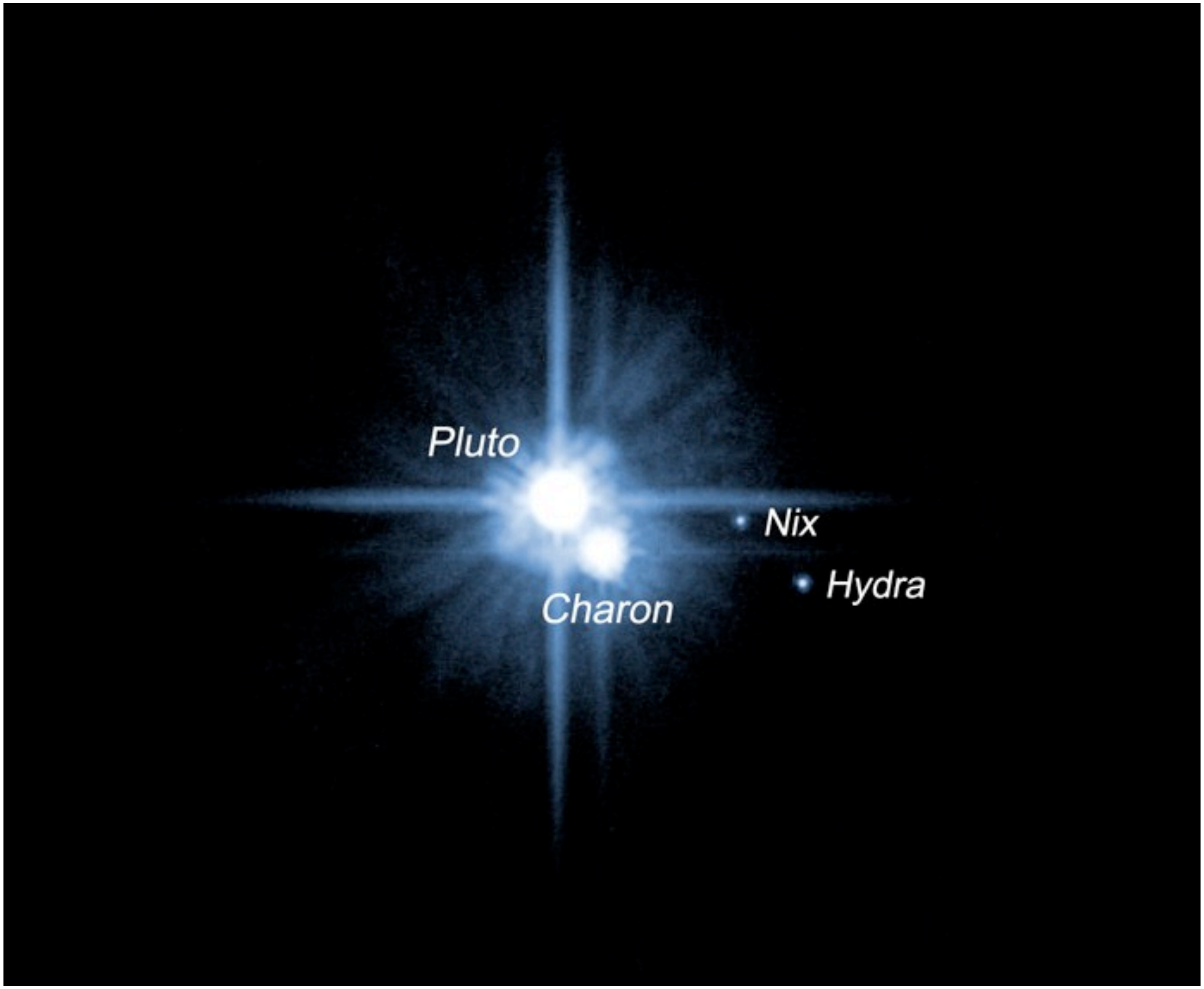
Aerothermal Performance Constraint (APC) Regimes*



* From Kolodziez, et al, NASA ARC

SOME WAVERIDER AGA ISSUES

- ACTUAL L/D PERFORMANCE
- HEATING
- NAVIGATION ERRORS
- GUIDANCE AND CONTROL
- SCIENCE ACCOMMODATION


Pluto
Nix
Hydra
Charon

References

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