Science Goals

Addressed via Entry Probes

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The Giant Planet Entry Probes Team

represented by

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The Team

Entry Probe Missions to the Giant Planets

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A mix of >50 Scientists, Engineers, & Technologists

Topics Addressed

- History of the effort
- High-level “Key Science Questions” from previous committees
- Science objectives that address the high-level goals
  - Focus on *achievable* objectives
  - Those best done using atmospheric entry probes
- Why entry probes?
- Priority destinations in the outer solar system
- Practical considerations - implementation options

History: Where Have We Delivered Entry Probes?

- Venus
  - Pioneer Venus Probes (1 large, 3 small)
  - Many Soviet Venera probes with brief (~1 hr) landed operations
  - Two Soviet Vega balloons
- Mars
  - NASA Mars landers/rovers
    - Viking, Mars Pathfinder, Mars Exploration Rovers (Spirit/Opportunity), Phoenix
- Jupiter
  - Galileo Probe
    - Only outer planet probe so far
- Titan
  - ESA Huygens probe, delivered by NASA's Cassini Saturn orbiter

History: Outer Planets Efforts Since Galileo

- Concerted effort over the past ~15 years
  - Multidisciplinary group of scientists, engineers, & technologists
  - Science objectives fairly well defined
    - Atreya's "Multiple Probes to Multiple Worlds" presentations
  - Engineers working on standard probe mission design issues (transfer & delivery trajectories, entry & descent, comm, power, etc.)
  - Technologies available -- trying to use them while they last
  - Technologists available -- trying to use them while they're still around
  - International Planetary Probe Workshops, annually since 2003
    - Bringing together the scientists, engineers, technologists, managers, ...
- Notable incremental successes ... but notable failures
  - Capability to manufacture feedstock for OP heat shields is gone
    - Stock in stores for only two Galileo Probe heat shields
  - Facilities for testing OP heat shields are gone, mothballed at Ames

High-Level Key Science Questions From Previous Committees

General questions

- From what material, and by what processes, did the solar system form?
- How have the planets of our solar system evolved since their initial formation, and how will their evolution continue?
- What processes are responsible for the observed characters of the planets?

High-Level Key Science Questions From Previous Committees

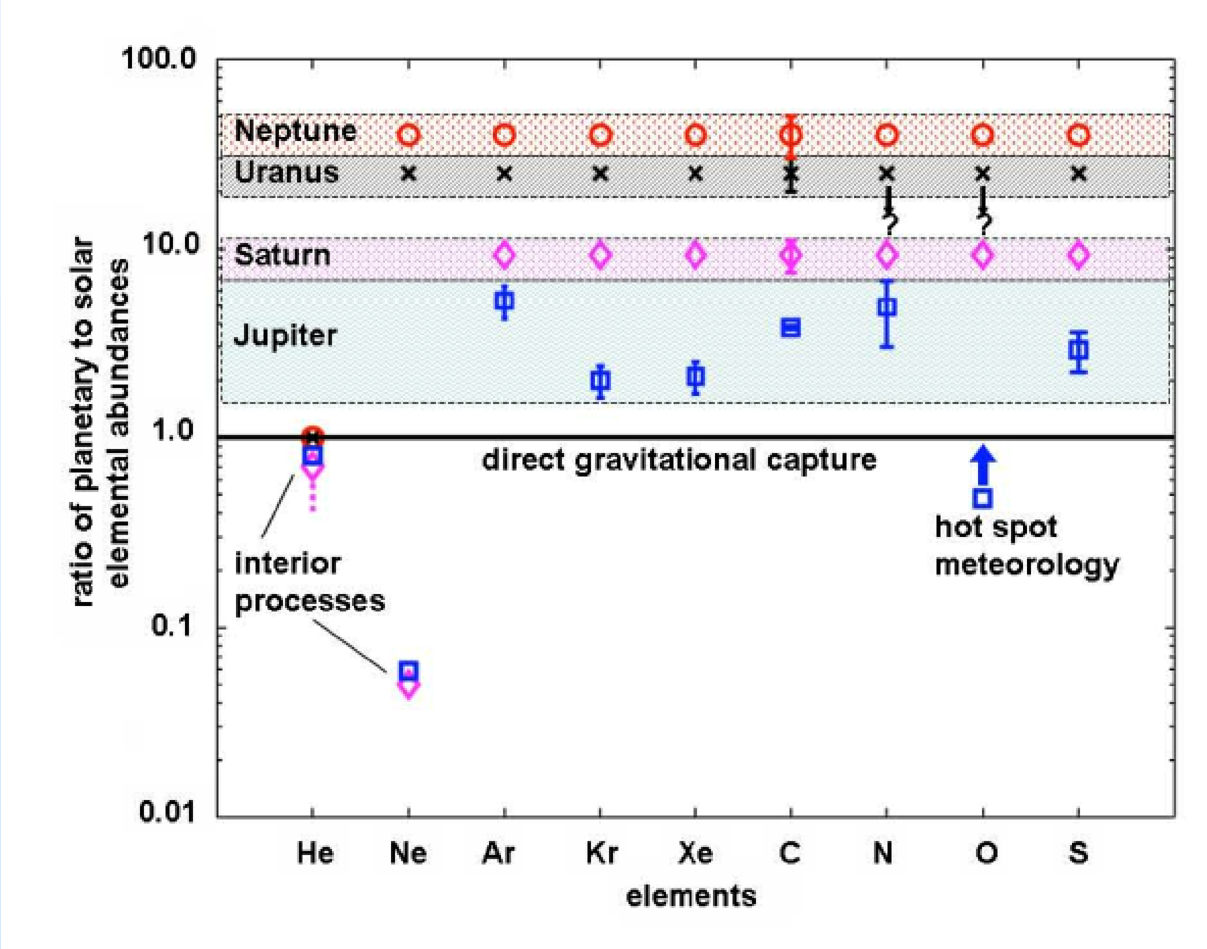
Questions more focused on giant planets

- What was the time scale over which the giant planets formed, and how did the formation process of the ice giants differ from that of the gas giants?
- What is the history of water and other volatiles throughout the solar system?
- What are the processes that have and continue to shape the character of the outer planets, and how do they work?
- What can we learn about giant exoplanets by observing the giant planets of our solar system?

Giant Planet Formation

- Multiple theories address how solar-composition materials produce giant planets with heavy-element enrichments of varying degrees
  - Most deal with the mechanism of transport of those heavies
  - Detailed *composition* measurements allow discrimination
- Core accretion models
  - Accrete 10-15 Earth-mass refractory cores, hydrodynamic collapse of disk material follows
- Nucleated instability models
  - Local density increase due to disk flow instability leads to hydrodynamic collapse of disk material without a refractory core
- Models of subsequent enrichment
  - SCIPs: solar-composition icy planetesimals
    - *N*SCIPs - *e.g.*, some heavies trapped in clathrate-hydrate cages
  - Disk material fractionation

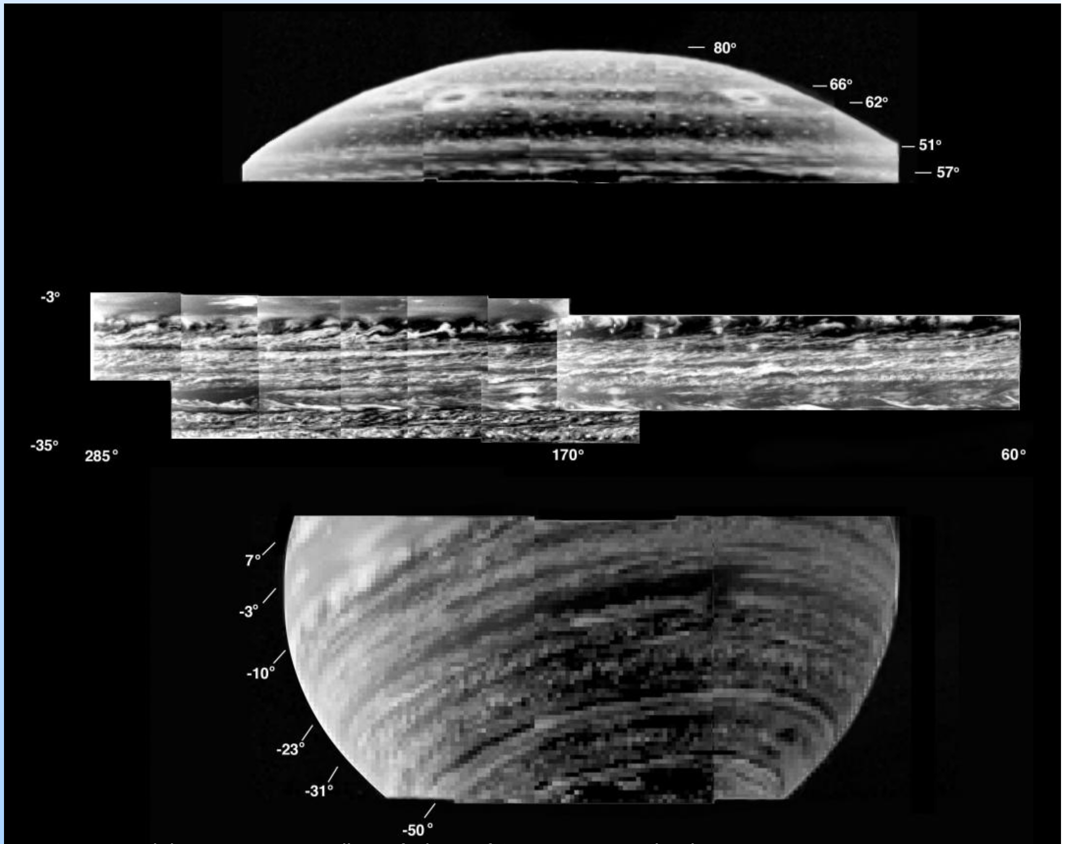
Measurements and Example Predictions



- Galileo Probe results at Jupiter; Voyager/Cassini carbon at S, U, & N
- Model predictions for other heavies at S, U, & N

Atmospheric Structure & Dynamics

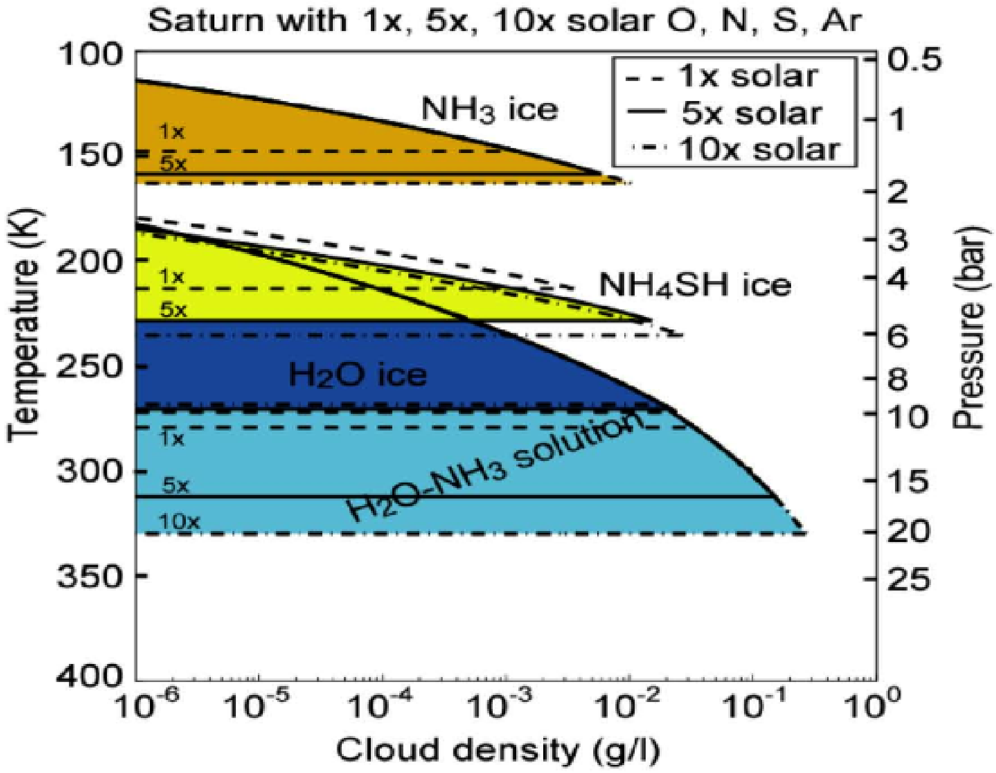
- Thermal Structure
  - Temperature, pressure, & density vs. altitude
  - Closely tied to atmospheric stability, convection, & mixing
  - Spatial variation of structure ties to regional- & global-scale winds
- Dynamics
  - All giant planets exhibit zonal flows of varying complexity
  - Galileo Probe & other evidence suggest vertical movement as well
  - Moves atmospheric constituents through the thermal structure, producing *atmospheric compositional structure*



NASA – Cassini: PIA03560: A Gallery of Views of Saturn's Deep Clouds

Atmospheric *Compositional* Structure

- Condensation; gives rise to clouds
  - Changing temperature, pressure of an air parcel
  - Differential transport can lead to fractionation
  - Clouds affect insolation at deeper levels, can modulate winds
- Chemical
  - Chemical equilibria can change
    - *E.g.*: $NH_3 + H_2S <=> NH_4SH$
  - Disequilibrium species, indicators of processes in unseen regions (and mixing rates), can be dredged up from deeper levels



Atreya, 2006

Science Objectives That Address the High-Level Goals

- Fundamental composition measurements
  - Abundances, relative to hydrogen, of:
    - Heavy elements O, N, C, & S
    - Noble gases He, Ne, Ar, Kr, Xe
  - Key isotopic ratios, relative to solar:
    - D/H, $^{3}He/^{4}He$, $^{14}N/^{15}N$, $^{12}C/^{13}C$, $^{16}O/^{18}O$
  - Disequilibrium species diagnostic of interior processes and deep circulation:
    - PH_3, CO, AsH_3, GeH_4, SiH_4
  - All in the *deep, well-mixed* regions of the atmosphere

Science Objectives That Address the High-Level Goals

- Structure measurements
  - Pressure and temperature, or density, as a function of altitude
  - Cloud altitudes, compositions, particle sizes & densities
  - Heat balance
    - Net local radiative divergence (heating) and opacity
  - Radiant energy net flux, as a function of altitude and wavelength
- Dynamics measurements
  - Lateral & vertical winds
  - Waves, turbulence
- Core size & mass
  - Not an entry probe measurement
    - Probably best done via gravity & magnetic field measurements
  - Does *not* need to be measured simultaneously with entry probe measurements
    - Could be done decades before or after a probe mission

Why Entry Probes?

- Some critical measurements are not feasible using remote sensing techniques
  - Spectrally inactive processes or constituents
    - E.g., noble gases
  - Processes or constituents whose electromagnetic signatures are buried beneath an optical depth >>1
    - Commonly encountered in the deep, well-mixed regions
- *In situ* measurements do not rely on long-distance propagation

Priority Destinations

1. Saturn
   - Shallow (10-20 bar) probe(s) with MWR on a flyby carrier
     - Highest priority and most feasible near-term mission
     - *Possibly* a New Frontiers Program candidate
   - For comparison to Jupiter
2. Neptune
   - Polar orbiter with probes (similar to NASA Vision Mission concept)
     - Second priority, following a Saturn probe mission
   - Likely a flagship-class mission
3. Return to Jupiter
   - Multiple probes to sample spatial variation
   - Probe targeting and specific measurements depend on Juno results

Practical Considerations

- Transfer trajectories, Earth to destination
  - Arrival & delivery geometries
- Entry & descent
  - Entry systems, descent systems and timing
- Communications
  - Intervening atmosphere(s)
  - Link geometries
    - Trajectories
- ... and there’s a lot more

Earth-to-Saturn Trajectory Options

- Direct trajectory
  - Delivered mass too low (less than 100 kg)

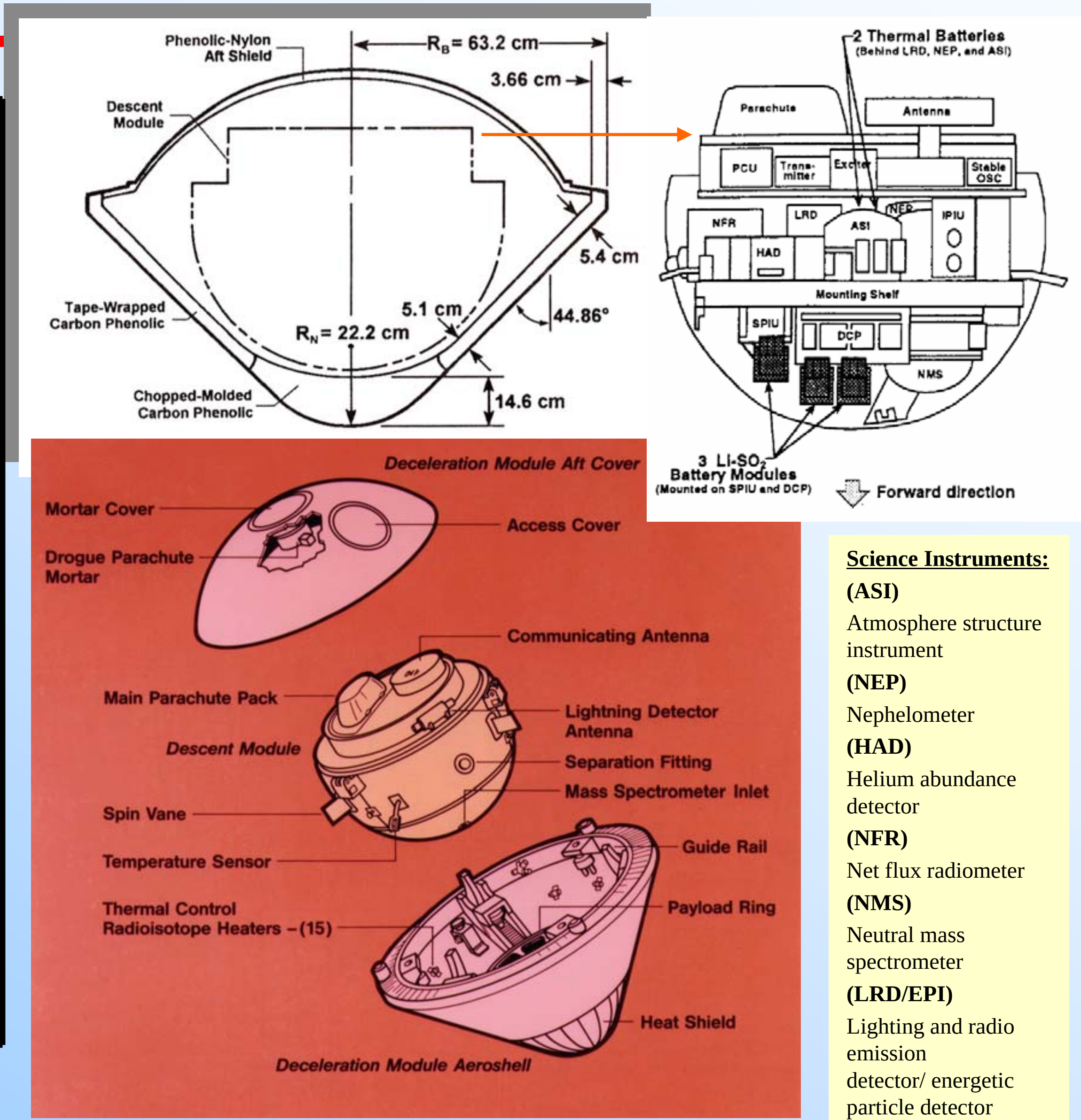
- Gravity Assists
  - Inner planets Gravity Assist
    - Earth & Venus
    - With or without deep space maneuvers (ΔV)

  - Jupiter GA + inner planet(s) GA + ΔV
    - Jupiter & Saturn: alignment every 19-20 years
      - 1977 – 1997 – 2016 – 2035
        Voyager Cassini
      - After Jan. 2017, next opportunity for JGA to Saturn: 2034

Ref: Theresa Kowalkowski, JPL, FY06

Practical Considerations: Galileo Probe

Item / Subsystem	Mass (kg)	Mass Subtotals (kg)
Deceleration Module		221.8
Forebody heat shield	152.1	
Afterbody heat shield	16.7	
Structure	29.2	
Parachute	8.2	
Separation hardware	6.9	
Harness	4.3	
Thermal control	4.4	
Descent module		117.1
Communications	13.0	
C&DH subsystem	18.4	
Power subsystem	13.5	
Structure	30.0	
Harness	9.1	
Thermal control	4.3	
Science instruments	28.0	
Separation hardware	0.9	
Probe Total		338.9



Science Instruments:

(ASI)
Atmosphere structure instrument

(NEP)
Nephelometer

(HAD)
Helium abundance detector

(NFR)
Net flux radiometer

(NMS)
Neutral mass spectrometer

(LRD/EPI)
Lighting and radio emission detector/ energetic particle detector

Ref: Galileo Probe Deceleration Module Final Report, Doc No. 84SDS2020, General Electric Re-entry Systems Operations, 1984
AIAA,"Project Galileo Mission and Spacecraft Design", Proc. 21st Aerospace Science Meeting, Reno, NV, January 10-13, 1983

After T. Balint

Probe Entry / Aeroshell / TPS

Entry direct.	Latitude deg	Rel. entry V, km/s	Max diameter,m	Entry mass, kg	Max. heat rate*, kW/cm^2	Forebody TPS mass fraction	Est. total TPS mass fraction$^+$ (+ zero margins)	Max. decel., g
Pro.	6.5°	26.8	1.265	335	2.66	23.5%	25.8%	43.6
Pro.	-45°	29.6	1.265	335	3.67	24.8%	27.3%	47.9
Retro.	6.5°	46.4	1.265	335	21.5	35.2%	38.7%	76.4

- TPS availability for Galileo size probes H/S were confirmed by NASA ARC
  - C-P for prograde entry can be supported (heating rate about 10% of Galileo's)
  - Retrograde heat flux might be too high to support with current testing facilities

- TPS requirement at Saturn is less demanding than at Jupiter

- TPS mass-fraction for prograde entry is about 30% less than Galileo's
- Max. heating rates and max. g load about 35% of Galileo's
- Heating pulse about 2.5 times longer due to scale height difference
- Saturn probes have less ablation, but need more insulation

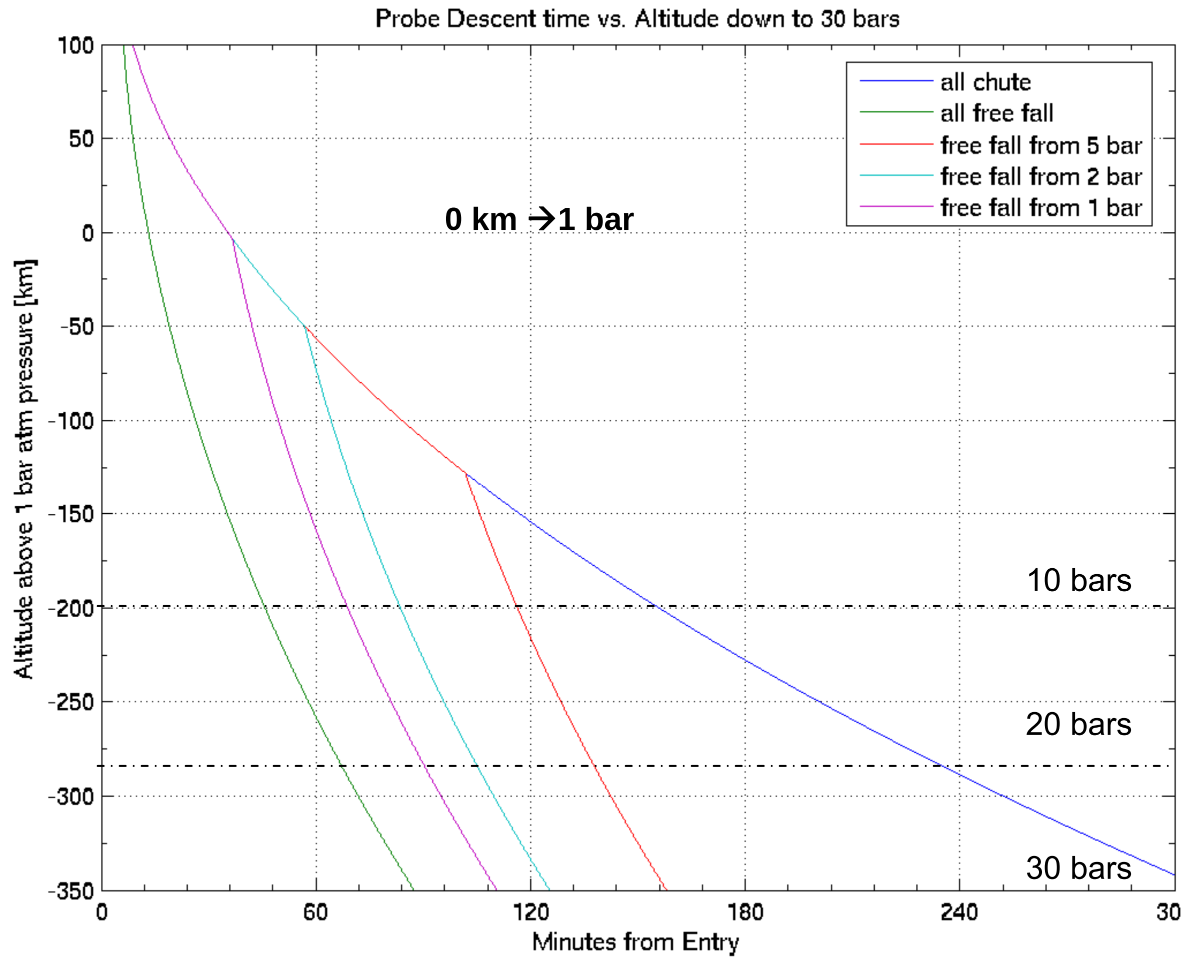
- Time to parachute deployment is about 5 minutes

After T. Balint

Ref: Mike Tauber, Gary A. Allen, Jr. and Lily Yang

Ames Research Center

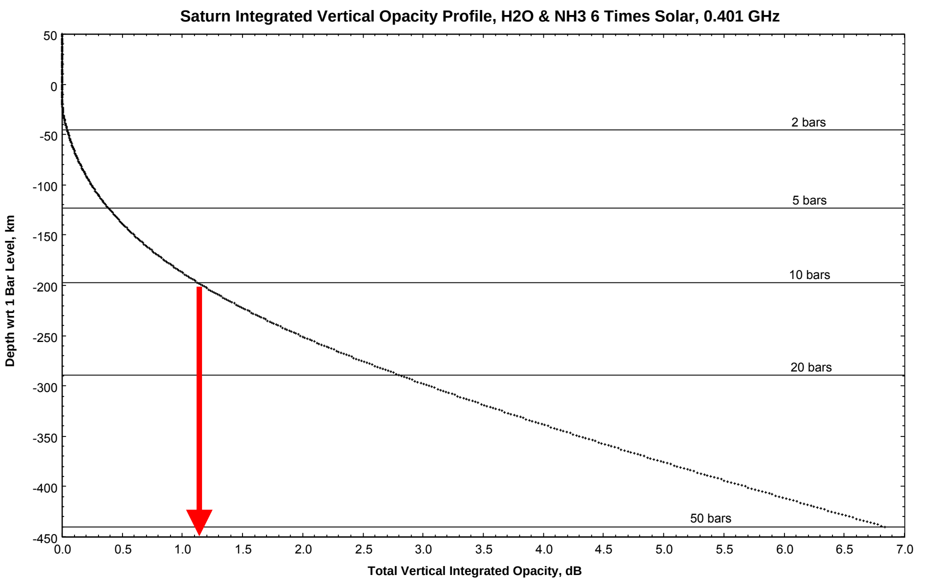
Probe Descent Time

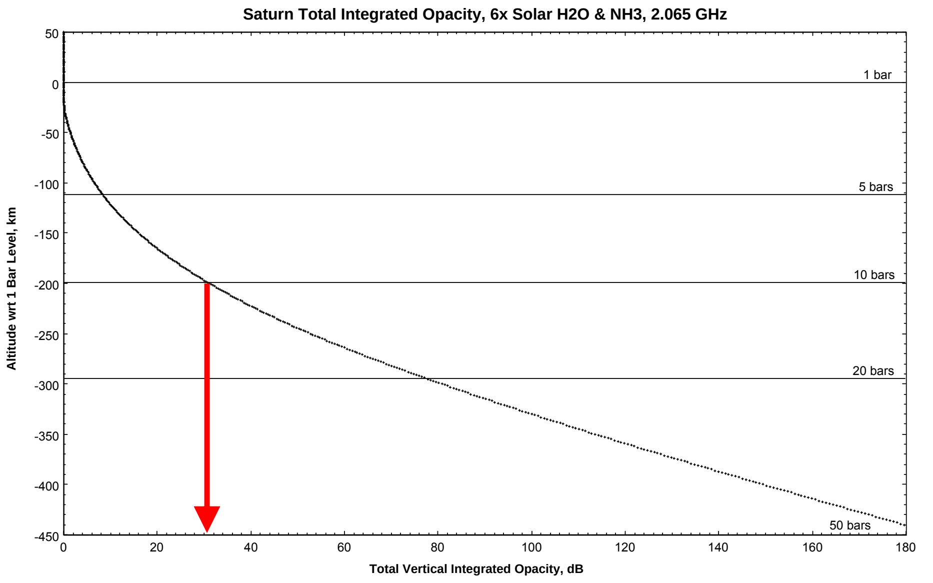


- If free fall begins at pressure of 1 bar, it will take ~70 minutes from entry to reach 10 bars
- *For better probe stability, the freefall phase could be replaced with descent with a drogue parachute (This requires further analysis)*
- If the descent is entirely on the parachute, it will take ~2.5 hours to reach 10 bars

Ref: Bill Strauss / Independently confirmed by both Gary Allen and Tom Spilker (all using a Saturn Atmosphere Model by G. Orton)

Communications: Zenith Radio Opacity


Saturn Integrated Vertical Opacity Profile, H2O & NH3 6 Times Solar, 0.401 GHz


Saturn Total Integrated Opacity, 6x Solar H2O & NH3, 2.065 GHz

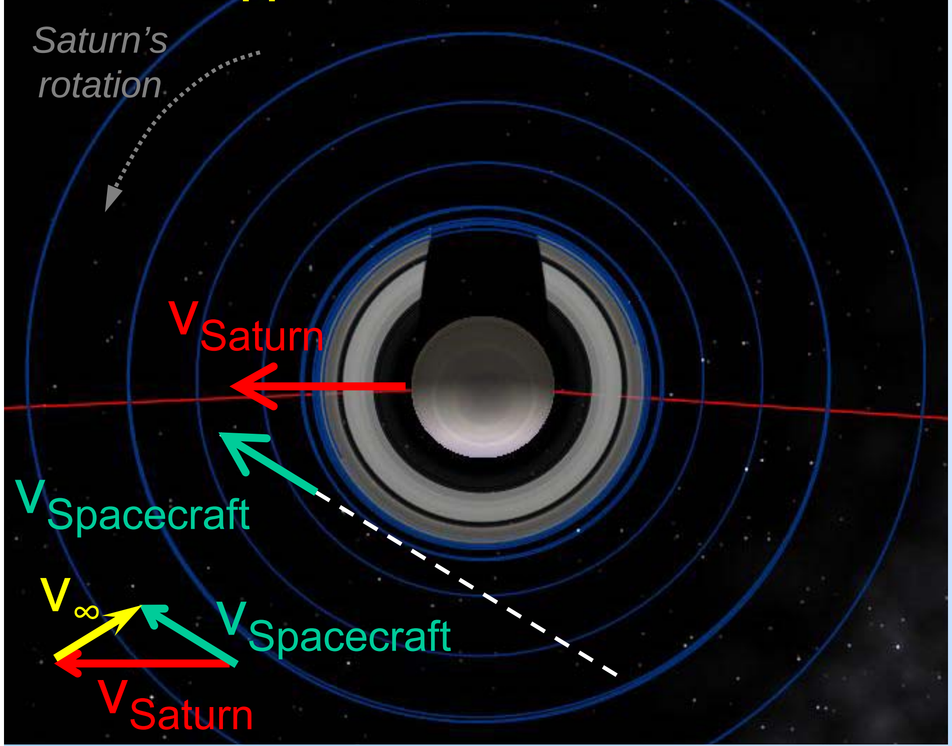
Ref: Tom Spilker, JPL, 2006

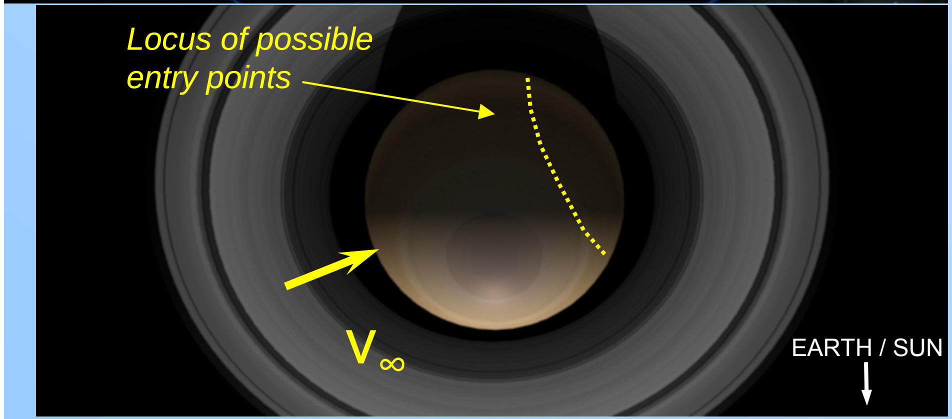
- Saturn's scale height is
  - ~2x that of Jupiter's
  - ~45 km at the pressures of interest
- Saturn has a far less intense radiation field than Jupiter
  - Little synchrotron radiation, thus low (UHF) frequencies are useful
- Zenith attenuation of radio signal as a function of probe depth (measured by atmospheric pressure), based on H_2O & NH_3 abundances 6 times solar

Attenuation (w/o margin) at 10 bars
UHF (400 MHz): ~1.2 dB
S-band (2 GHz): ~31 dB

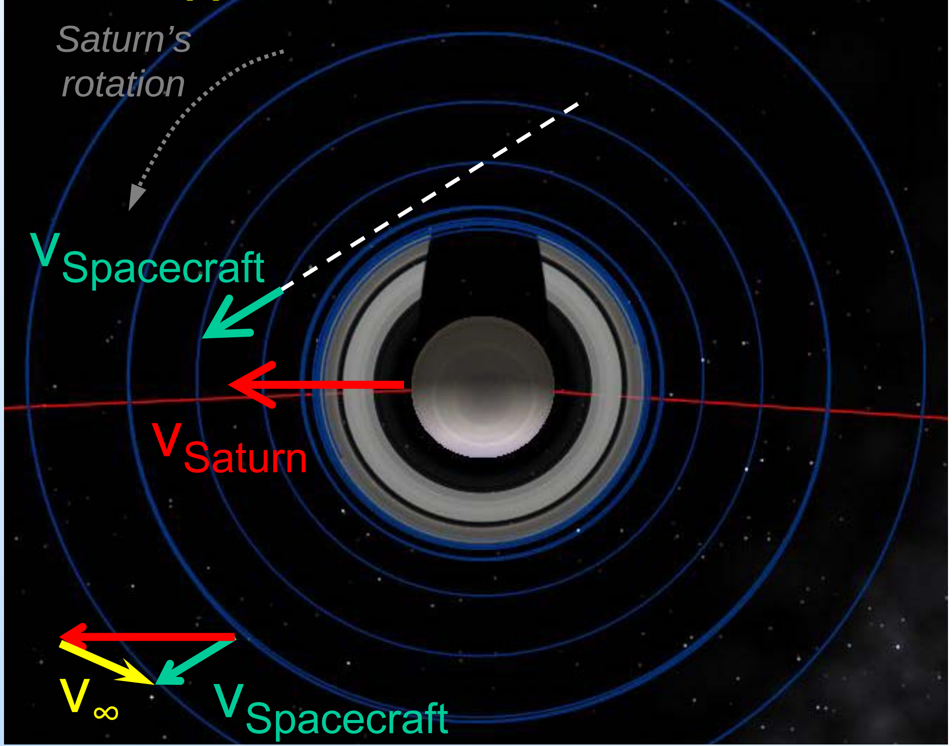
Trajectories for Relay and DTE telecom

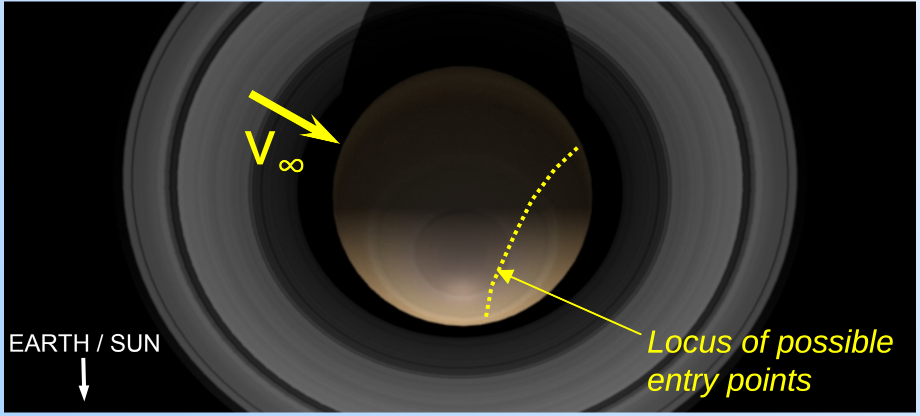
"Relay Trajectory": Approach from the sun-side





"DTE Trajectory": Approach from the "dark" side

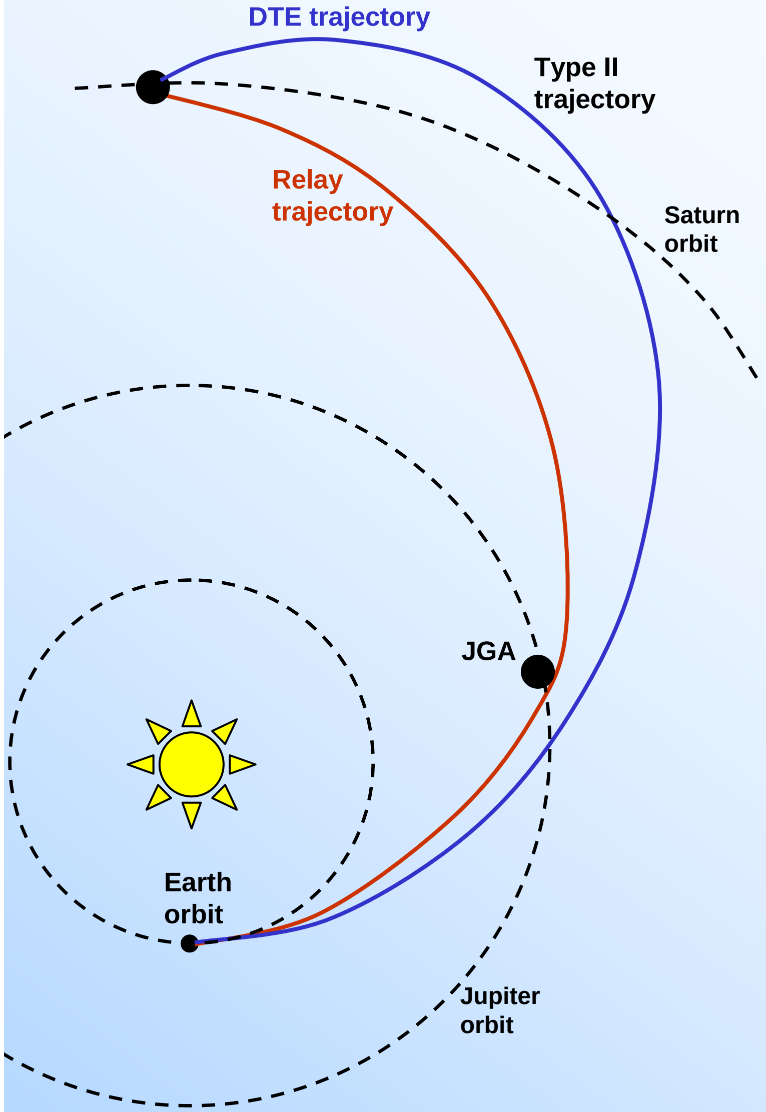




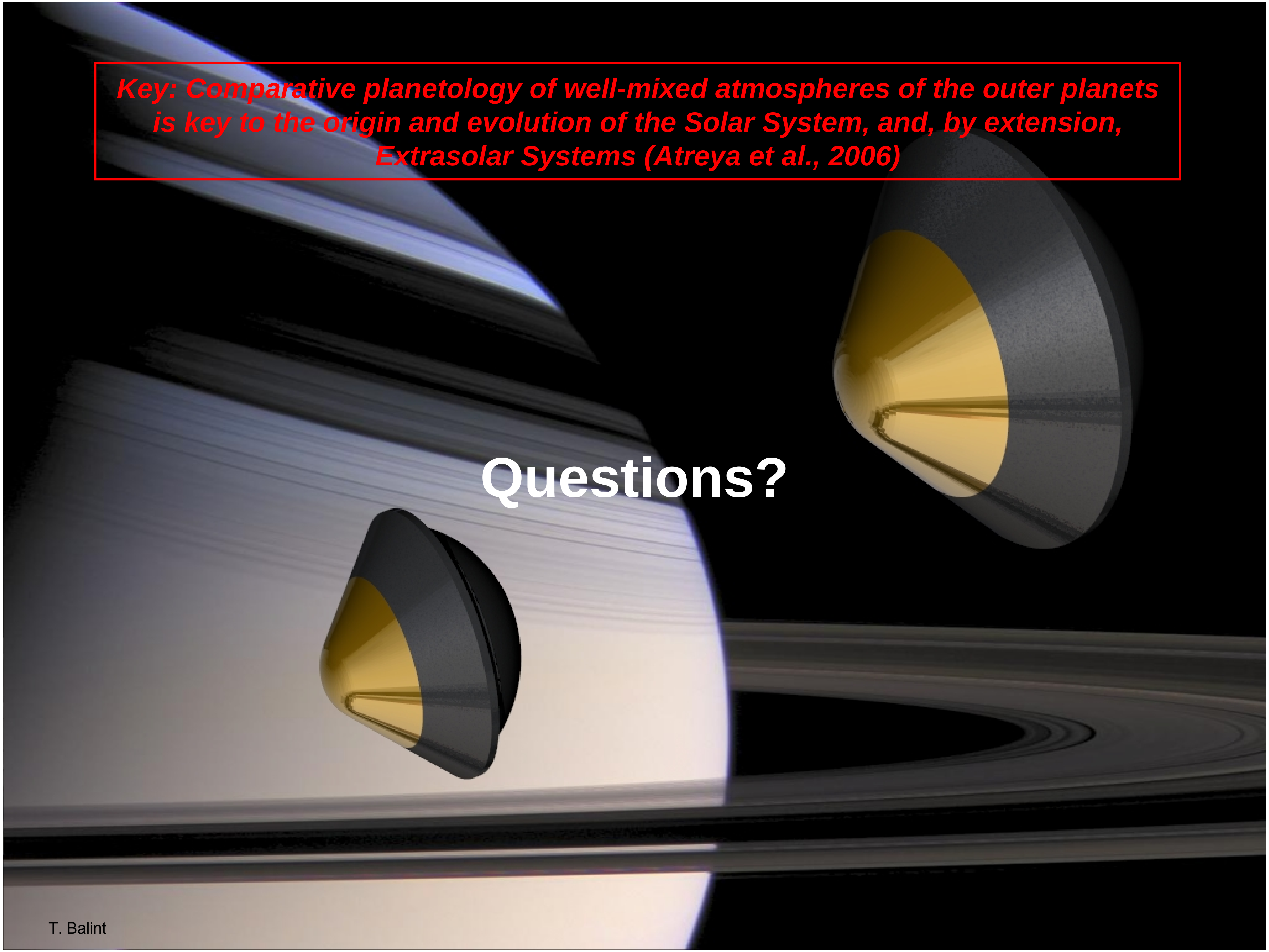
Ref: T.S, T.B., T.K

Direct-to-Earth vs. Relay Trajectory Trades

- Different trajectory strategies are required for Direct-to-Earth (DTE) and Relay telecom:
  - For Relay telecom from probes:
    - Benefit from Jupiter GA
    - Reduced eccentricity
    - Shorter trip time, higher delivered mass
    - Telecom: from probe to CRSC to Earth
    - No visibility between probe and Earth!
  - For DTE telecom from probes:
    - Type II trajectory for DTE probe access
    - Longer trip time to achieve suitable probe trajectory for DTE telecom
    - Telecom: Visibility to Earth for DTE link



Ref: T. Spilker, T. Balint, T. Kowalkowski, T. Lam – FY06



Key: Comparative planetology of well-mixed atmospheres of the outer planets is key to the origin and evolution of the Solar System, and, by extension, Extrasolar Systems (Atreya et al., 2006)

Questions?

T. Balint