ON THE FEASIBILITY OF A NEW FRONTIERS CLASS SATURN PROBE MISSION

by

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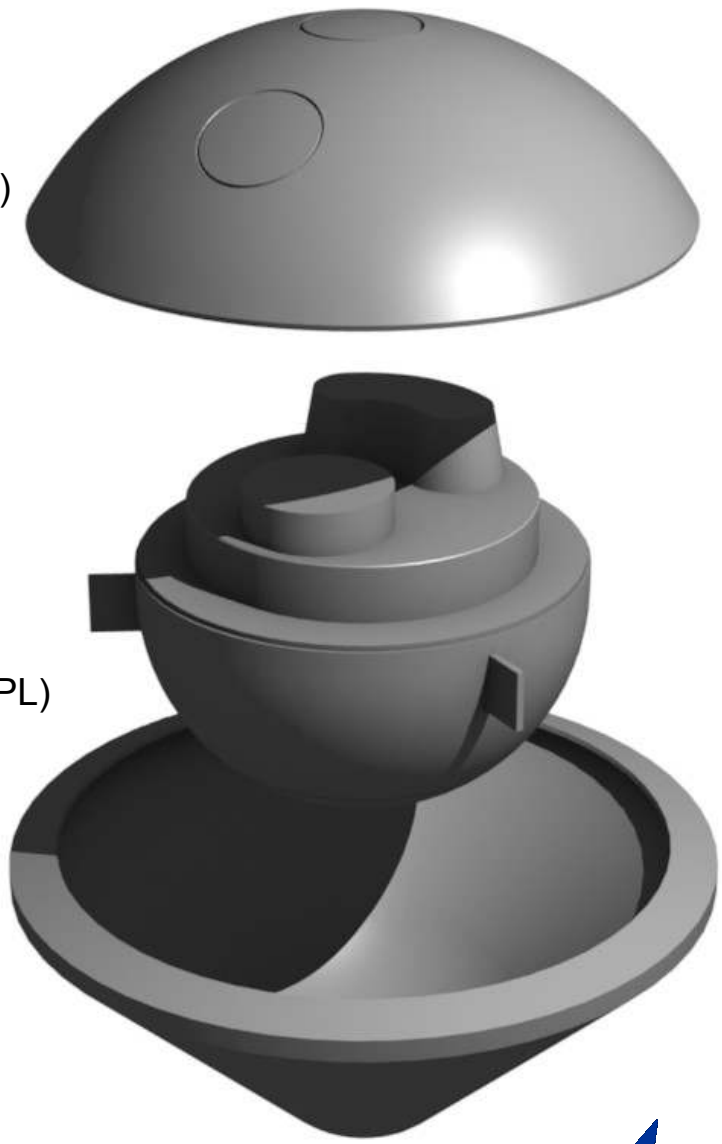


Caveat

- This presentation focuses strictly on
  - Science goals and strawman payload
  - Trajectories
  - Telecom / attenuation
  - Atmospheric entry, descent and TPS issues
  - Communications

- **The presentation does NOT provide a full systems engineering description**

- It is assumed that the operation for the Saturn flyby mission concept described here would last only for about 5 hours, therefore, the power requirements on the flyby spacecraft would be satisfied by the combination of solar power generation and batteries. Longer missions at this distance from the Sun would likely require internal power sources, such as RPSs.

In this study:

- For Power:
  - We could assume a Juno class solar panel configuration
- For Thermal Management:
  - On the probes we would likely require RHUs for component heating

The views and opinions expressed here are those of the author and does not necessarily represent official NASA policy.

Overview

- **Introduction:**
  How does the Saturn Flyby with Shallow Probes mission fit into the SSE Roadmap?

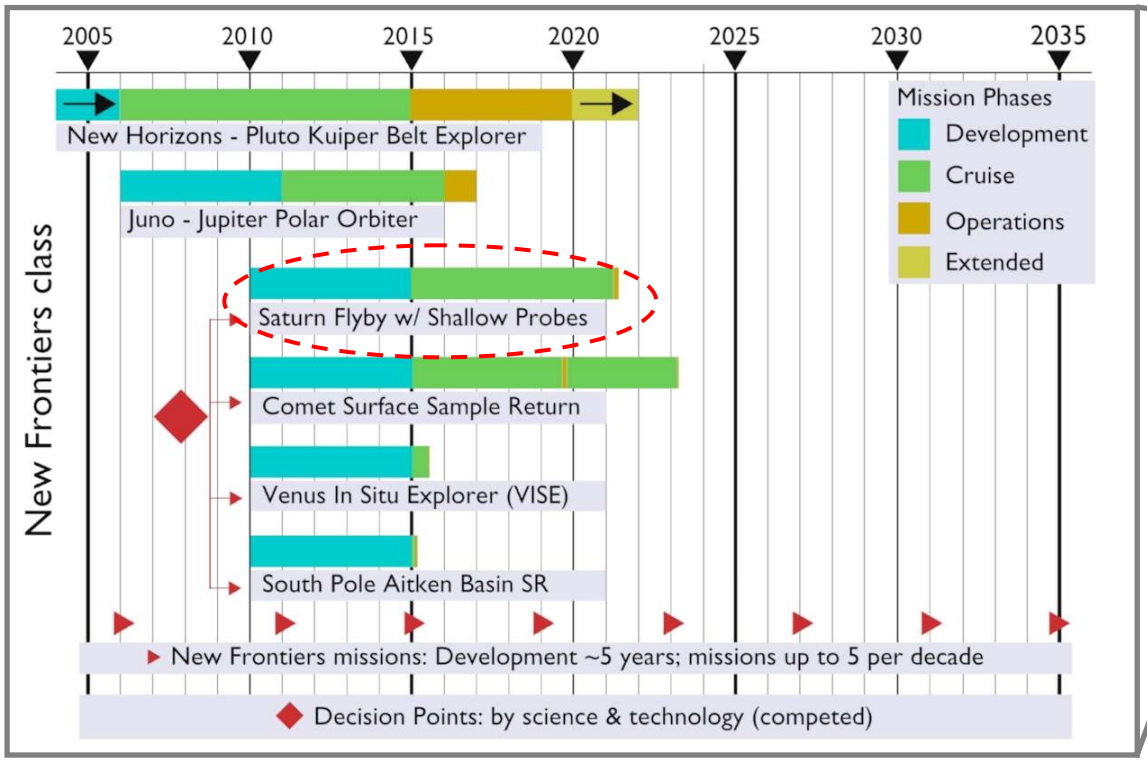
- **Questions to be answered in this presentation:**
  1: What are the Science Objectives & Instruments?
  2: What is the mission "wish list" & a representative mission architecture?

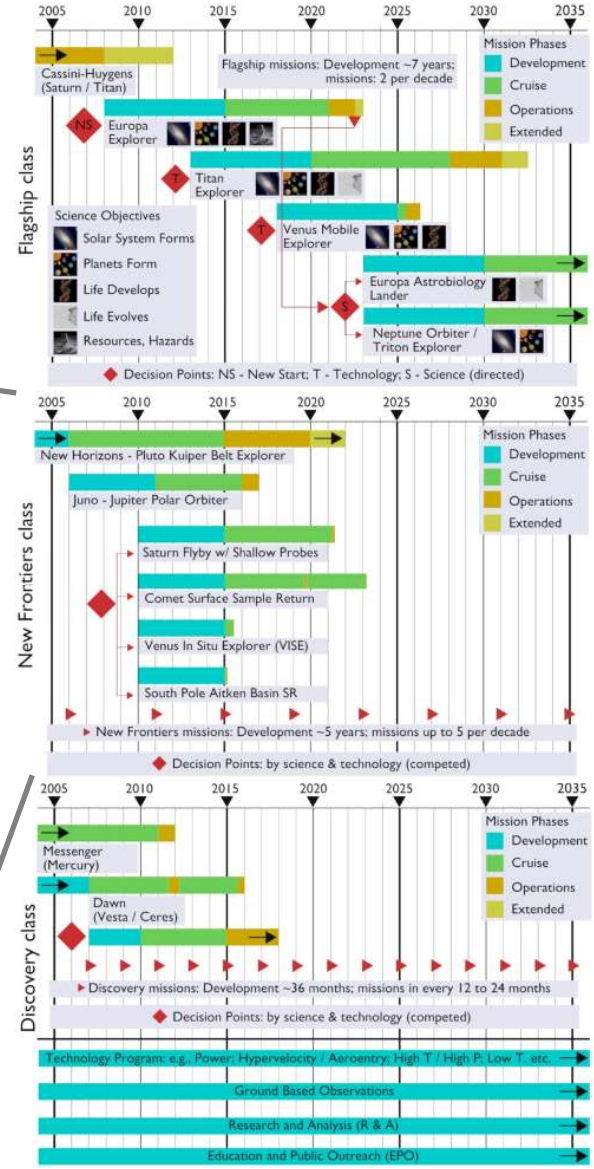
  3: How to get from Earth to Saturn?
  4: What is an "ideal flyby" at Saturn?
  5: Can we / How to do microwave radiometry?
  6: Any issues with atmospheric entry and descent?
  7: Can we communicate back the probe data?
  8: Can we do Direct to Earth communication from the probe?

- **Conclusions**

Saturn Probes & the 2006 SSE Roadmap

- The **2006 SSE Roadmap** is currently under way
- It identifies a **New Frontiers Class Saturn Flyby with Probes Mission** as one of the options for the next New Frontiers opportunity
- **The goal is to demonstrate that we can do this**



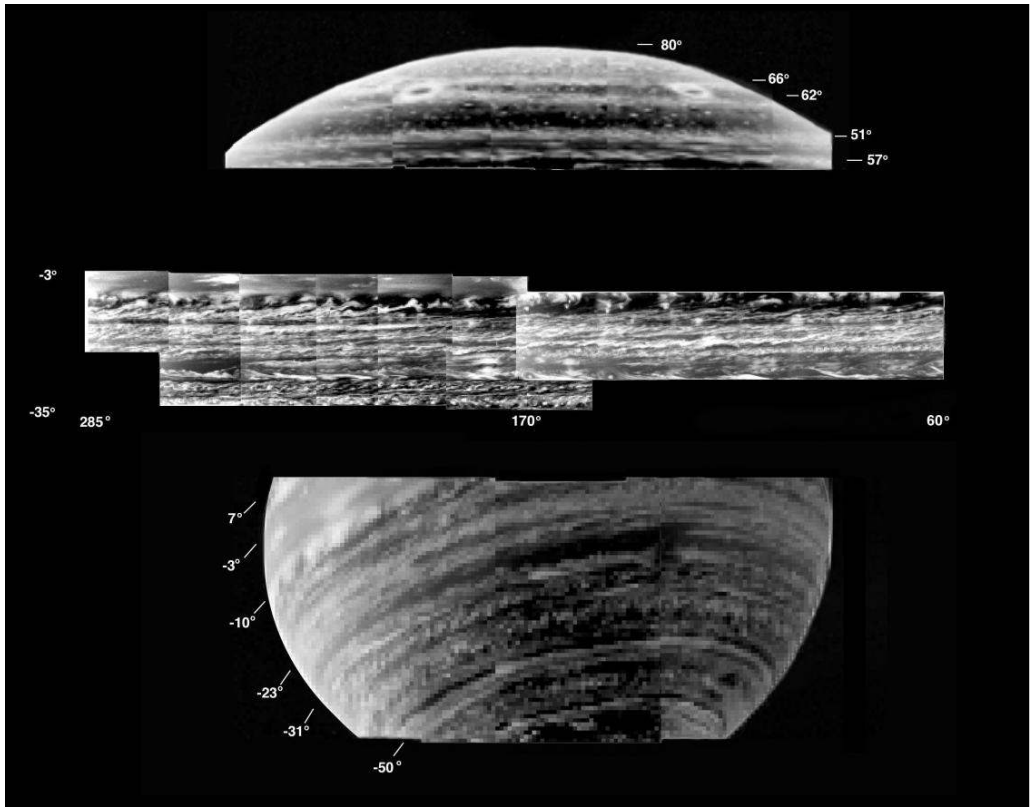


Ref: Solar System Roadmap 2006

What are the Science Objectives?

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)

- The key science objectives that would be addressed by the Saturn Probe mission are:
  - **Origin and Evolution** – Saturn atmospheric elemental ratios relative to hydrogen (C, S, N, O, He, Ne, Ar, Kr, Xe) and key isotopic ratios (e.g., D/H, 15N/14N, 3He/4He and other noble gas isotopes), gravity and magnetic fields; He relative to solar, Jupiter. [P, C]
  - **Planetary Processes** – Global circulation, dynamics, meteorology. Winds (Doppler and cloud track), interior processes (by measuring disequilibrium species, such as PH3, CO, AsH3, GeH4, SiH4). [P, C]



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

Ref: Atreya, S. K. et al., (2006) Multiprobe exploration of the giant planets – Shallow probes, Proc. International Planetary Probes Workshop, Anavyssos, 2006.
Ref: Dave Atkinson

Typical Science Instruments Expected for a Saturn Probes & Flyby S/C

Shallow Probe to 10 bars	
ASI	– Atmospheric Structure
NEP	– Nephelometer
HAD	– Helium abundance
NFR	– Net flux radiometer
NMS	– Neutral mass spectrometer
LRD /EPI	– Lightning / Energetic particles
ARAD	– Ablation monitor – on TPS
DWE	– Doppler wind experiment
OPH	– Ortho-Para Hydrogen
TLS	– Tunable laser spectrometer
IMG	– Imaging
MWR	– Microwave radiometer

Flyby	
GRV	– Gravity mapping
MAG	– Magnetometer
SSI	– Imaging
DWE	– Doppler Wind Experiment

- This **might be** an **oversubscribed** strawman payload set
- The actual number of instruments would be dictated by the final mission cost, fixed at $750M FY05 for a NF mission *(Juno)*
- **We assumed the same instrument sampling rate per distance traveled as used on the <u>Galileo probe</u>**

Ref: Dave Atkinson, Bill Smythe (with comments from Sushil Atreya)

What is the mission "wish list" & a typical mission architecture?

Science community "wish list" for mission success:

- Saturn Flyby with two (2) shallow probes to 10 bars
- Microwave radiometry to ~100 bars
- Probe 1: equatorial probe (0°), and
- Probe 2: mid-latitude probe (-45°)

Representative mission architecture assumptions:

- Identical Galileo class probes; Spin stabilized
- (a) Chemical propulsion or (b) SEP (to get there)
- Multiple Gravity Assist (to increase delivered mass)
- Probes Released 6 months before Saturn flyby (the same way as Galileo did it)
- Go between F and G rings ~2.34-2.82 R_s (2.634 R_s – where Cassini passed, to avoid ring particles)

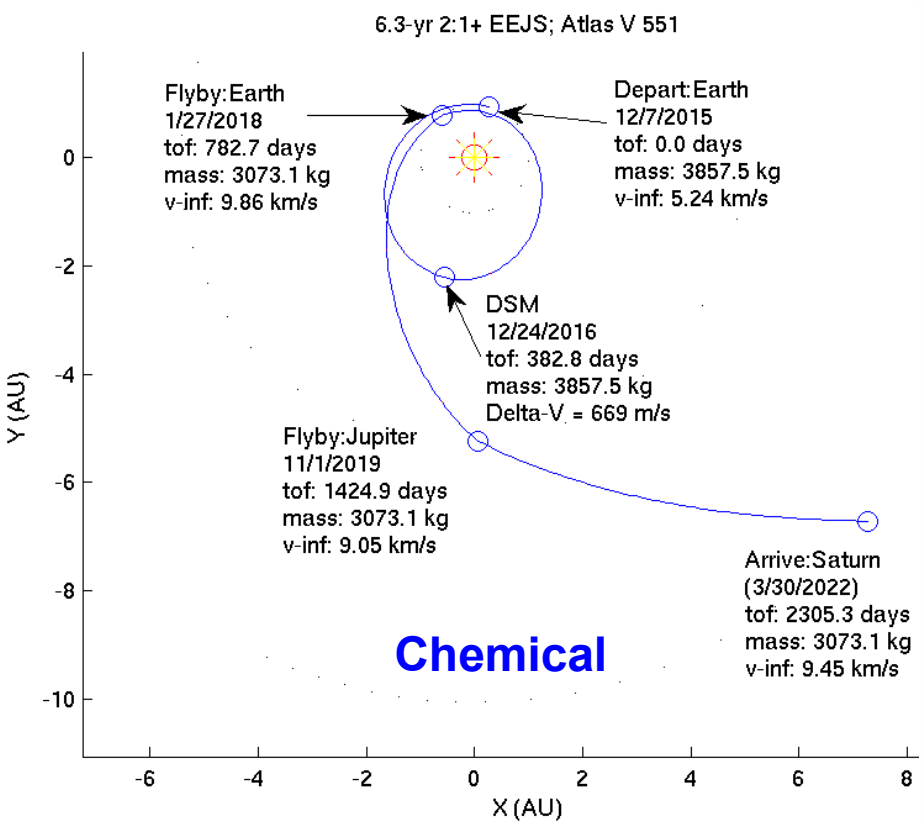
- UHF communication between probes and flyby S/C
- X-band from Flyby S/C to Earth

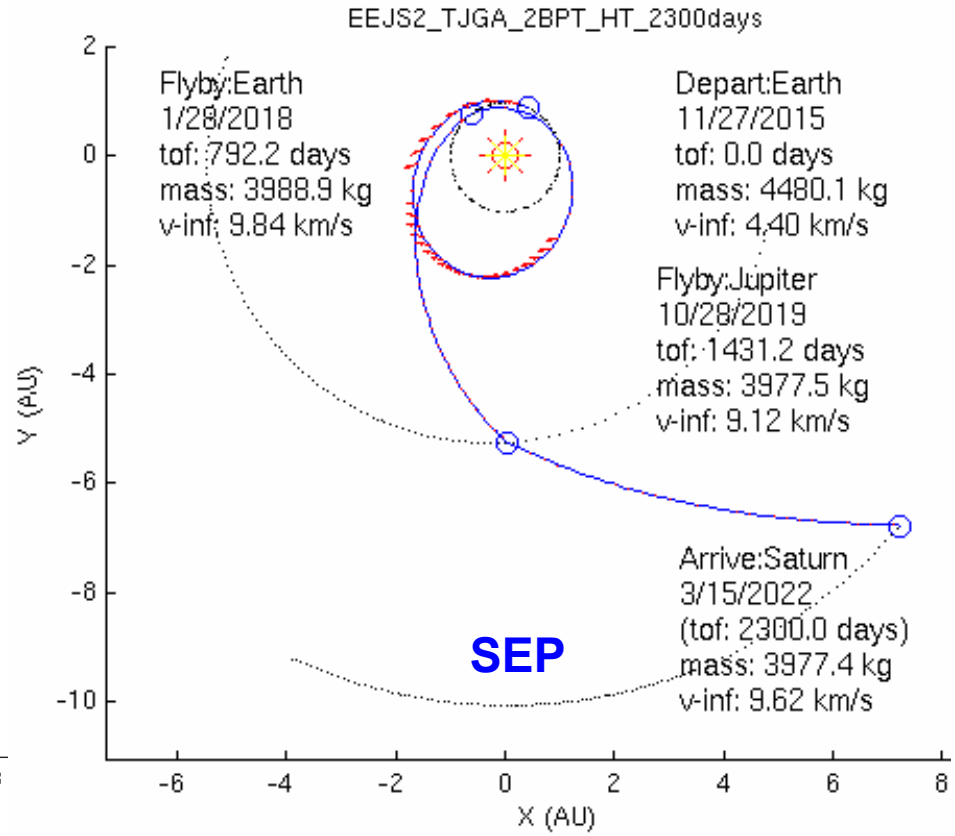
- Power sources considered in this study:
  - On flyby S/C: LILT-solar / batteries
  - On probes: primary batteries

Ref: T. Spilker, T. Balint, N. Strange, W. Folkner, & the Saturn Probe Study Team, with input from S. Atreya and D. Atkinson on science rationale

Chemical & SEP Options for the Same Representative Trajectory

- **2015 Launch – 6.3 years flight time – EEJS Gravity Assist Trajectory**
- For the **same flight time** the **SEP** system delivers approximately **30% more** mass to Saturn for our case; or the same mass at a smaller L/V

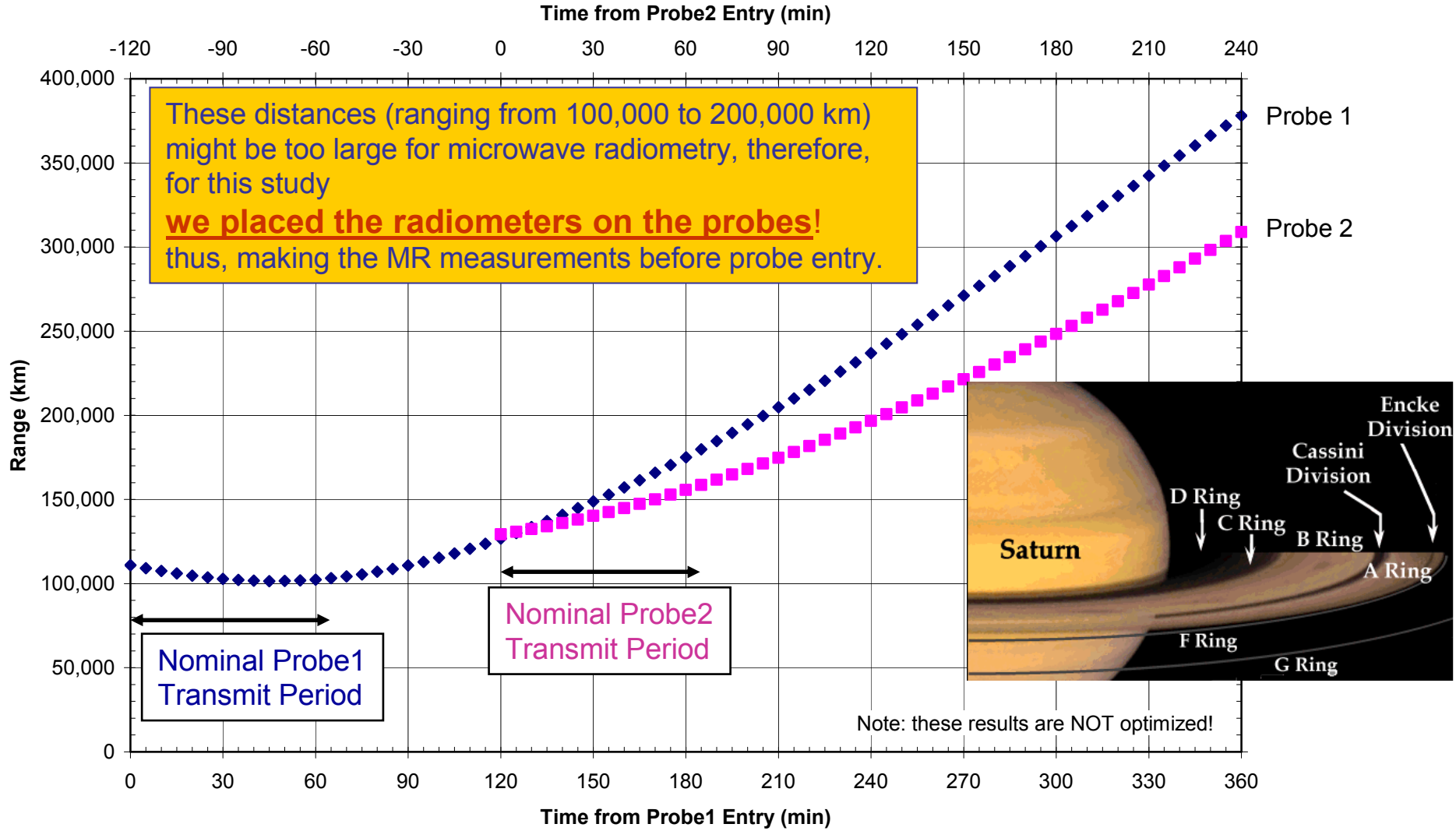




Ref: Theresa Kowalkowski, Try Lam

Saturn Arrival Geometry – Passing Through the F & G Ring Gap

Flying inside the rings:	good distance / short visibility, telecom window
Flying outside the rings:	too far / but long telecom window



These distances (ranging from 100,000 to 200,000 km) might be too large for microwave radiometry, therefore, for this study **we placed the radiometers on the probes**! thus, making the MR measurements before probe entry.

NOTE: Range & elevation calculations are made with respect to a fixed point rotating with Saturn

Ref: Theresa Kowalkowski, Try Lam

Any issues with atmospheric entry and descent?

Probe Entry / Aeroshell

Entry direct.	Latitude deg	Rel. entry V, km/s	Max diam.,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	0.235	0.258	43.6
Pro.	6.5	26.8	0.8	130	3.27	0.243	0.267	43.3
Pro.	-45	29.6	0.8	130	4.44	0.256	0.282	47.7
Pro.	-45	29.6	1.265	335	3.67	0.248	0.273	47.9
Retro.	6.5	46.4	1.265	335	21.5	0.352	0.387	76.4
Retro.	6.5	46.4	0.8	130	22.3	0.348	0.383	75.3

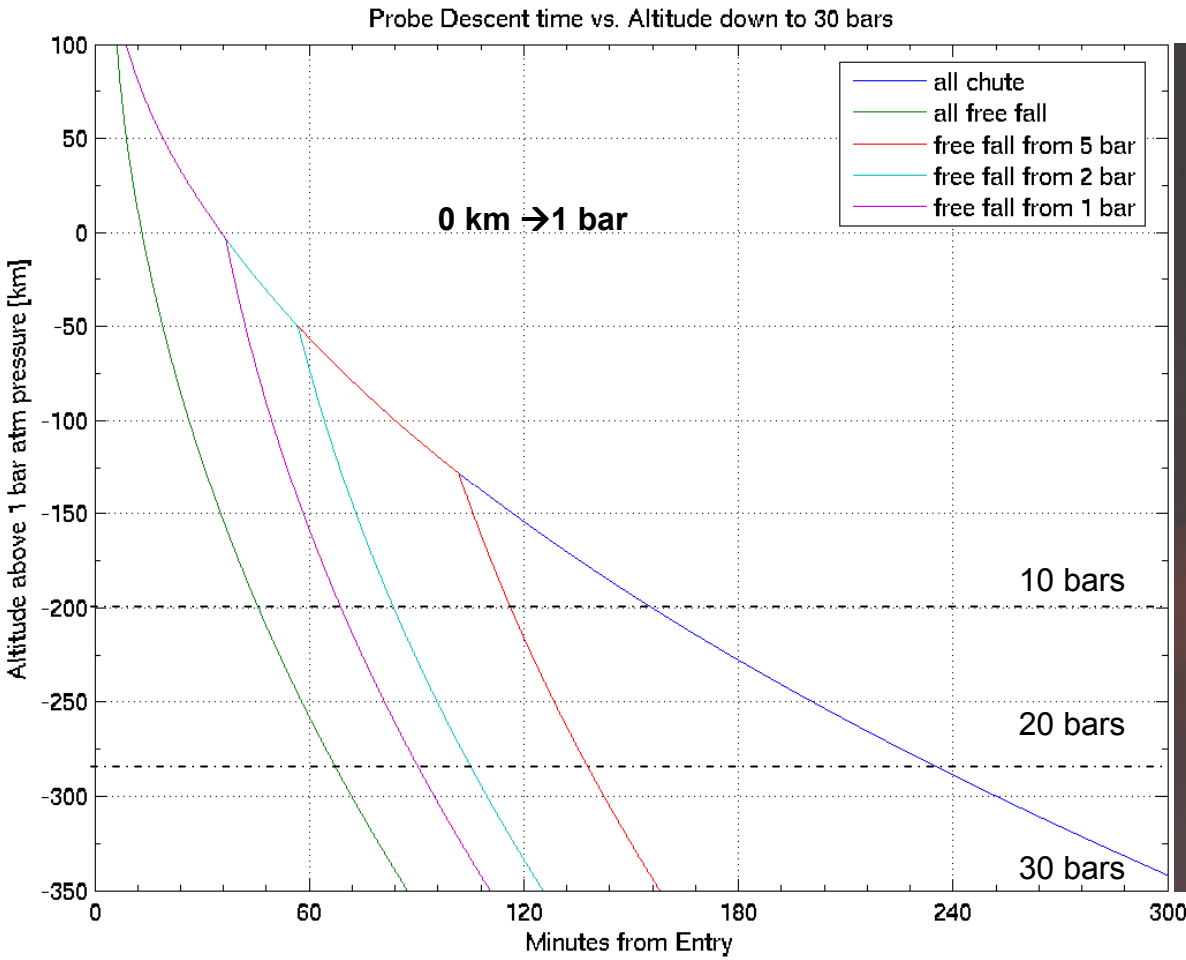
Note: these table values are given for a flight path angle of -10°, whereas the trajectory calculations on Page 16 are given for -8°. At -8° the equatorial retrograde entry results in a TPS mass fraction that exceeds that of the Galieo probe.

- **TPS mass-fractions**
  - For low-latitude retrograde entries, about same as Galileo probe (~50% including margins, etc.)
  - **For prograde entries, about 30% less than Galileo**
  - Nearly same for big and small probes if m/C_DA same
- **Max. heating rates** and **max. g** about **35% of Galileo**
- **Heating pulse about 2.5 times longer** (atm. density scale height about 2.5 larger at Saturn than Jupiter)
- Saturn probes have **less ablation**, but need more insulation
- **Time to parachute deployment** is about **5 minutes**
- Time to **descend to 10 bar** altitude is about **2 hr. 26 min**. (using Galileo parachute size)
- *(note: very similar to the independent calculations by Bill Strauss)*

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

Any issues with atmospheric entry and descent?

Probe Descent time vs. Altitude Down to 30 bars

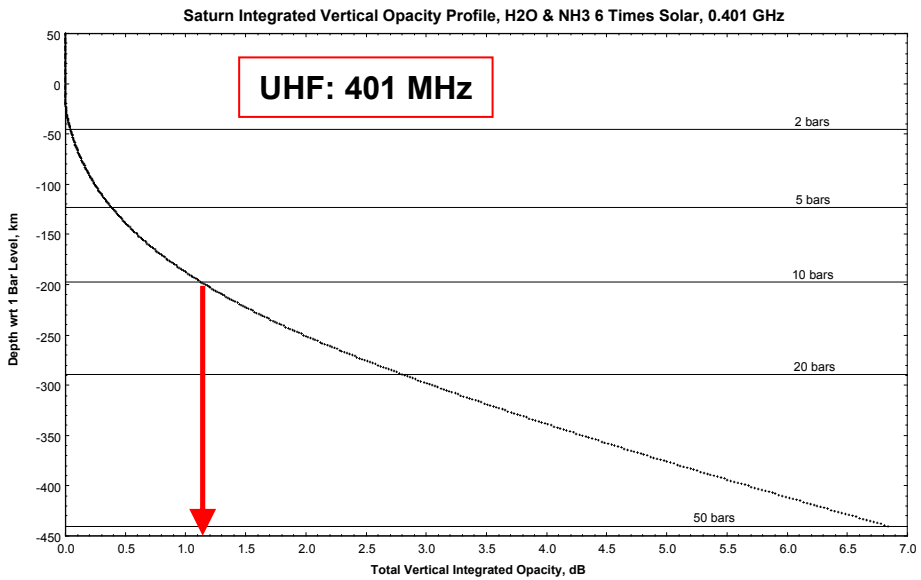


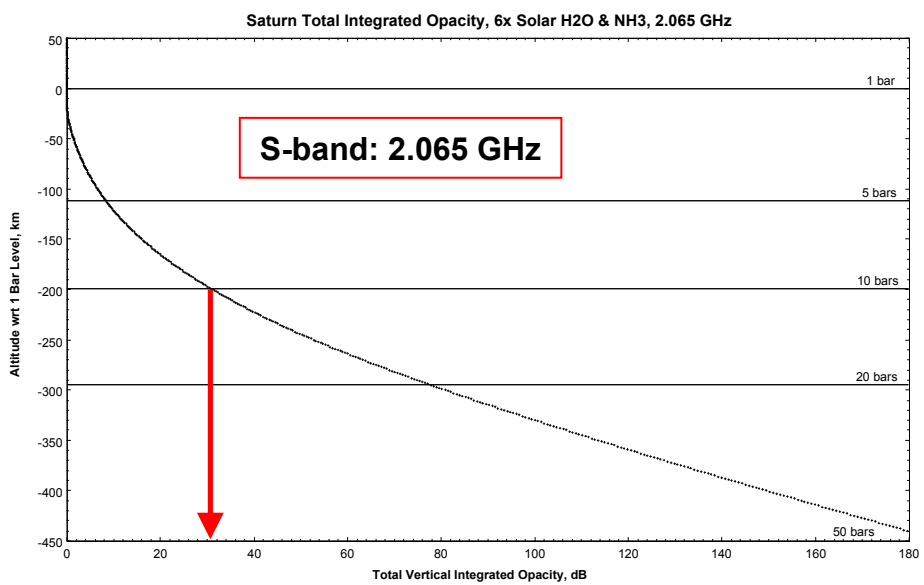
- If **free fall begins at pressure of 1 bar**, it will take **~70 minutes** from entry **to** reach **10 bars**
- *For better probe stability, the freefall phase could be replaced with descent with a smaller second parachute*
- If the descent is **entirely on the parachute**, it will take **~2.5 hours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

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

Can we communicate back the probe data?

Attenuation in Saturn's Atmosphere





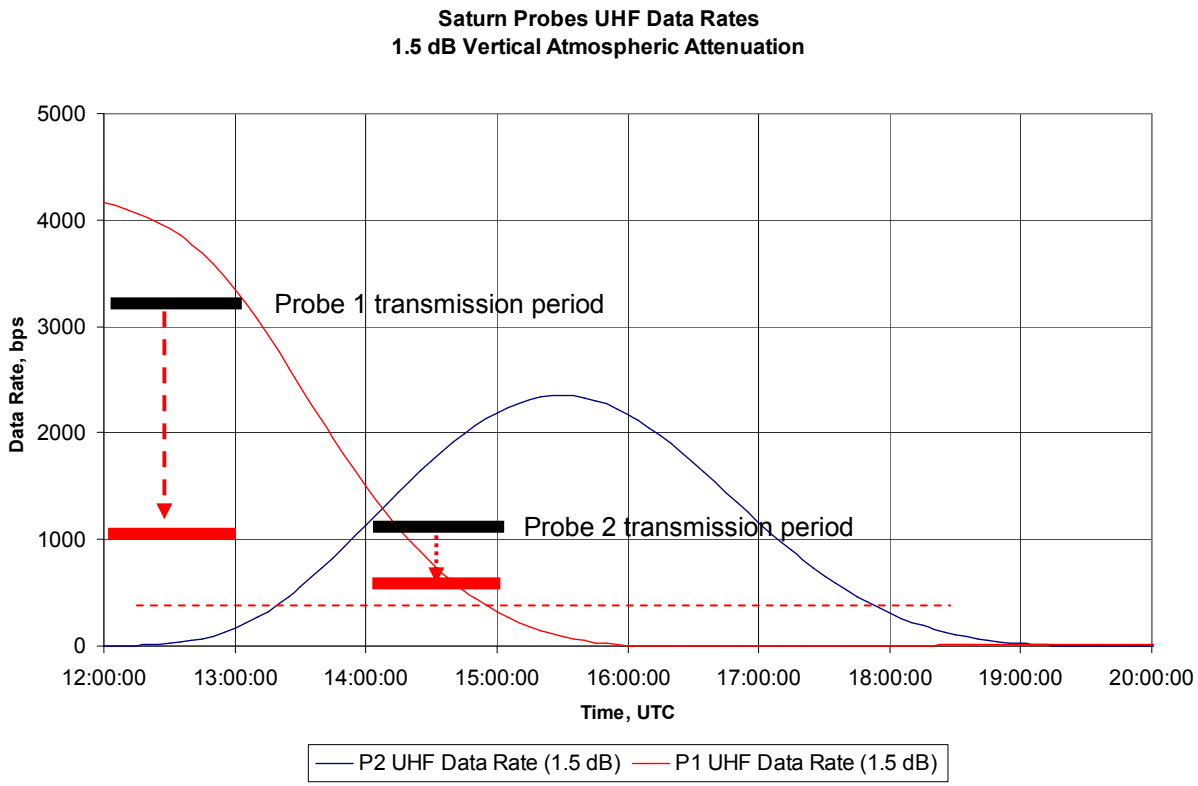
Ref: Tom Spilker

- **NOTE: This is discussed in detail by Tom Spilker in his presentation**
- **One of a kind computer code** was developed **by Tom Spilker** specifically for this study to calculate attenuation for Saturn's atmosphere
- Findings:
  Attenuation at 10 bar
  - **UHF: ~1.5 dB** (~1.2 dB + margin)
  - **S-band**: ~31 dB (**No link!**)
- These results feed directly into the telecom link budget calculations, and also impact Direct-to-Earth feasibility
- Saturn atmospheric model for Tom's calculations was provided by Glenn Orton
  - **Scale height is ~2x that of Jupiter's** ~45 km at the pressures of interest
  - However, **no radiation** environment

Pre-decisional – for discussion purposes only

Can we communicate back the probe data?

Saturn Probes Proximity Data Rates at UHF



From Probe to Flyby S/C

Point design resulted in a lower data rate, than preliminary calc.:

Probe	data rate	(volume)
Probe 1:	1024 bps	(~3.7 Mb)
Probe 2:	512 bps	(~1.9 Mb)

Still sufficient to upload the data to the flyby S/C, including the additional ~1.5Mbits stored from the Microwave Radiometry and piggybacked with the normal probe data.

With the current trajectories, studied here, **neither probe has line-of-sight to Earth** during atmospheric descent

Flyby would be occulted ± 20 minutes around Probe 2's prime transmit time

Consequently, we assumed **store and dump** operation

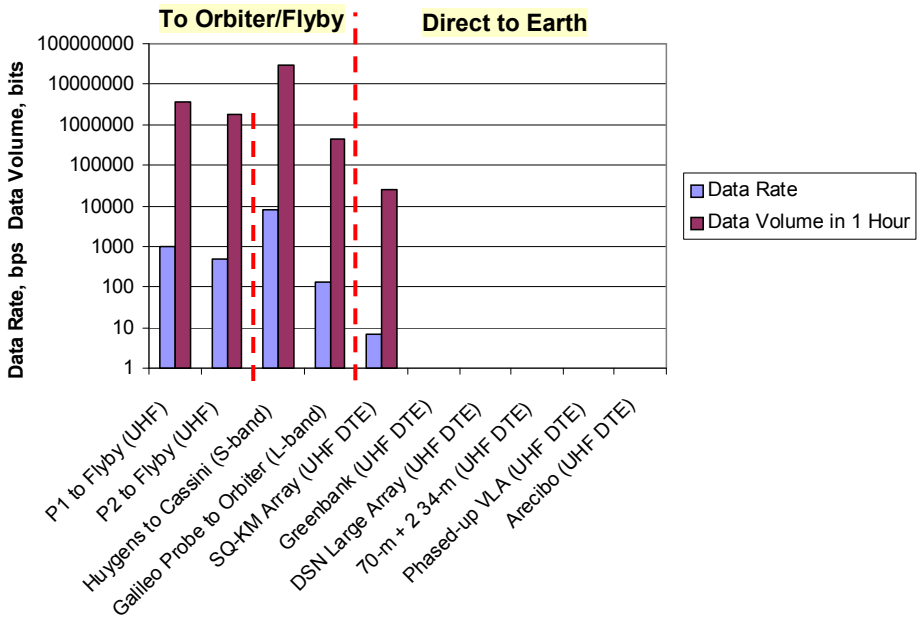
From Flyby S/C to Earth

The data from the two probes would be relayed back to Earth at X-band using a 35-W TWTA and 3-m diameter antenna to a 34-m antenna within the first two hours of a single tracking pass

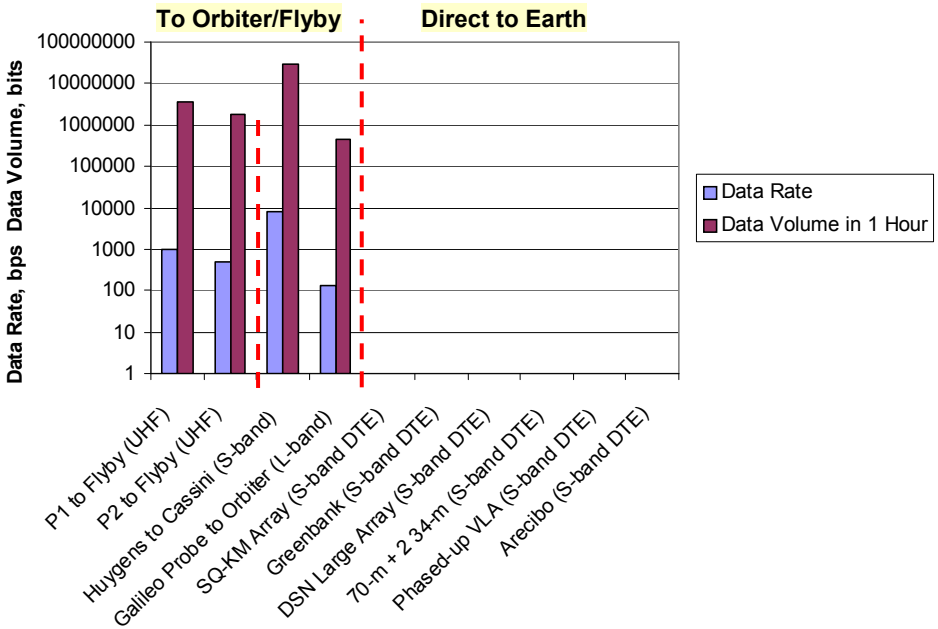
Ref: David Morabito, Anil Kantak and Arv Vaisnys

Telecom: DTE Communications:
Direct-to-Earth from Saturn using UHF and S-band

UHF Case



S-band Case



Case	UHF Data Rate (bps)	UHF Data Volume (bits)
P1 to Flyby (UHF)	1024	3686400
P2 to Flyby (UHF)	512	1843200
Huygens to Cassini (S-band)	8192	29491200
Galileo Probe to Orbiter (L-band)	128	460800
SQ-KM Array (UHF DTE)	7	25200
Greenbank (UHF DTE)	0	0
DSN Large Array (UHF DTE)	0	0
70-m + 2 34-m (UHF DTE)	0	0
Phased-up VLA (UHF DTE)	0	0
Arecibo (UHF DTE)	0	0

To Orbiter/Flyby

Direct to Earth

Case	Data Rate (bps)	Data Volume (bits)
P1 to Flyby (UHF)	1024	3686400
P2 to Flyby (UHF)	512	1843200
Huygens to Cassini (S-band)	8192	29491200
Galileo Probe to Orbiter (L-band)	128	460800
SQ-KM Array (S-band DTE)	0	0
Greenbank (S-band DTE)	0	0
DSN Large Array (S-band DTE)	0	0
70-m + 2 34-m (S-band DTE)	0	0
Phased-up VLA (S-band DTE)	0	0
Arecibo (S-band DTE)	0	0

Antenna and Telecom power on probe would be limited, and not sufficient to provide Direct to Earth communication; Probe size would limit scaling up antenna & power.

Notes – additional atmospheric attenuation makes S-band prohibitive;
For Arecibo, Saturn is outside of the declination range

Conclusions

- A proposed Saturn Flyby with Shallow Probes mission is in line with New Frontiers requirements
  - The actual cost would be based on the given point design with a suitable instrument suite

- This type of mission would not require technology development and could leverage from flight heritage, e.g.:
  - Galileo probe design/instruments; Juno solar panels and microwave radiometry; Electra UHF transceiver from the Mars program

- SEP trajectory option is comparable in cost to Chemical option
  - For the same delivered mass SEP uses a smaller L/V, offsetting SEP cost

- Thermal Protection System:
  - TPS mass fraction: For retrograde entry: Galileo-like; For prograde: ~30% less
  - For prograde entry the heating rate is at least an order of magnitude less than at Jupiter, but the heat pulse is longer
  - entry latitude is not limited by TPS

- UHF communication
  - From probes to flyby is feasible (including probe + radiometry data)
  - Direct-to-Earth communication is not NOT feasible for the expected data rate
    - Only the (not yet available) SQ KM array would be capable of any DTE data return, and only while conditions are favorable at UHF (link along vertical)
    - S-band links would be prohibitive for DTE, for this mission concept, due to significant atmospheric attenuation.

The End