OVERVIEW OF KEY SATURN PROBE MISSION TRADES

by

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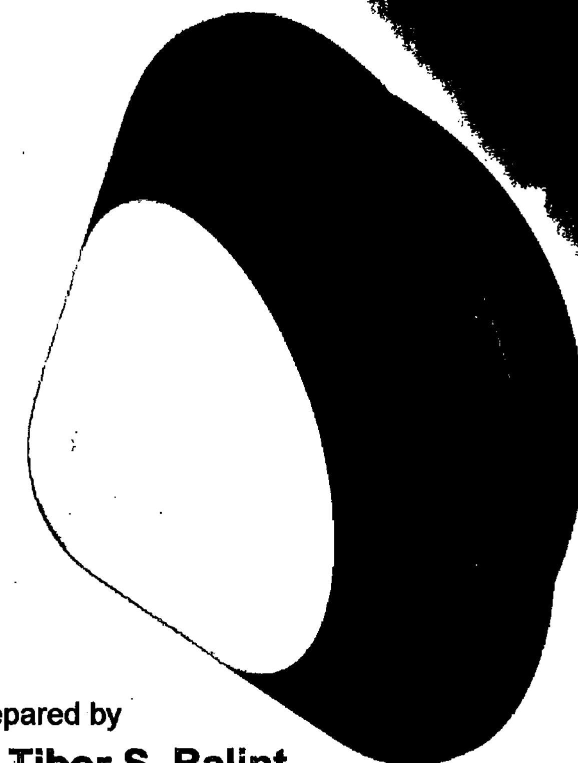
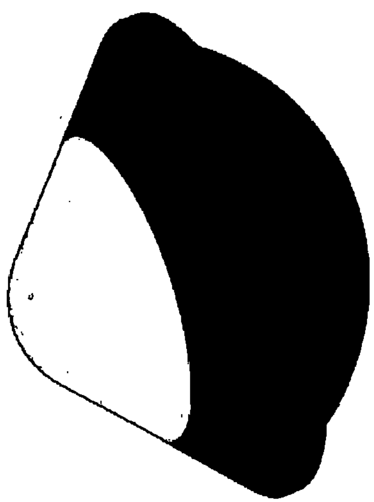
JPL/Caltech





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TB

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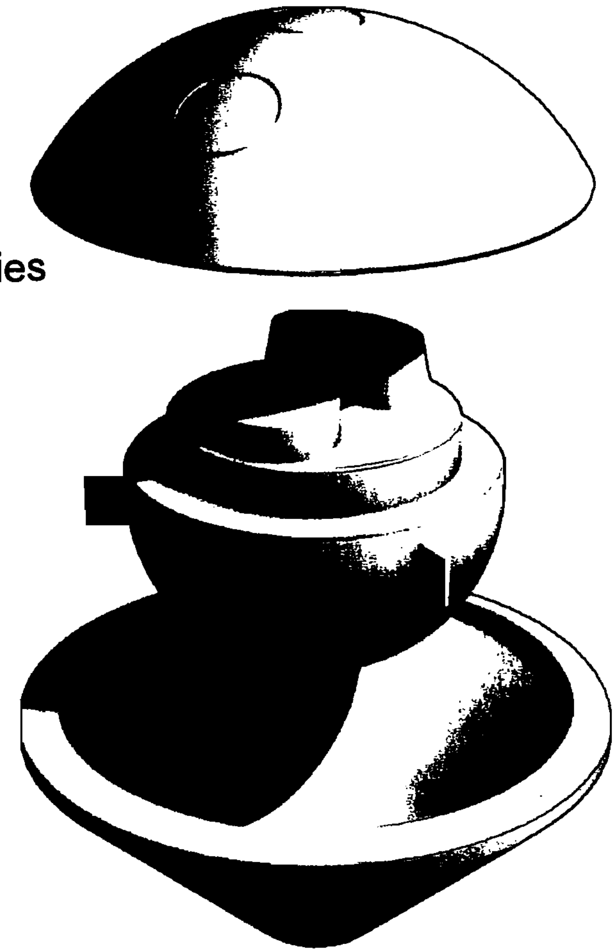
Overview

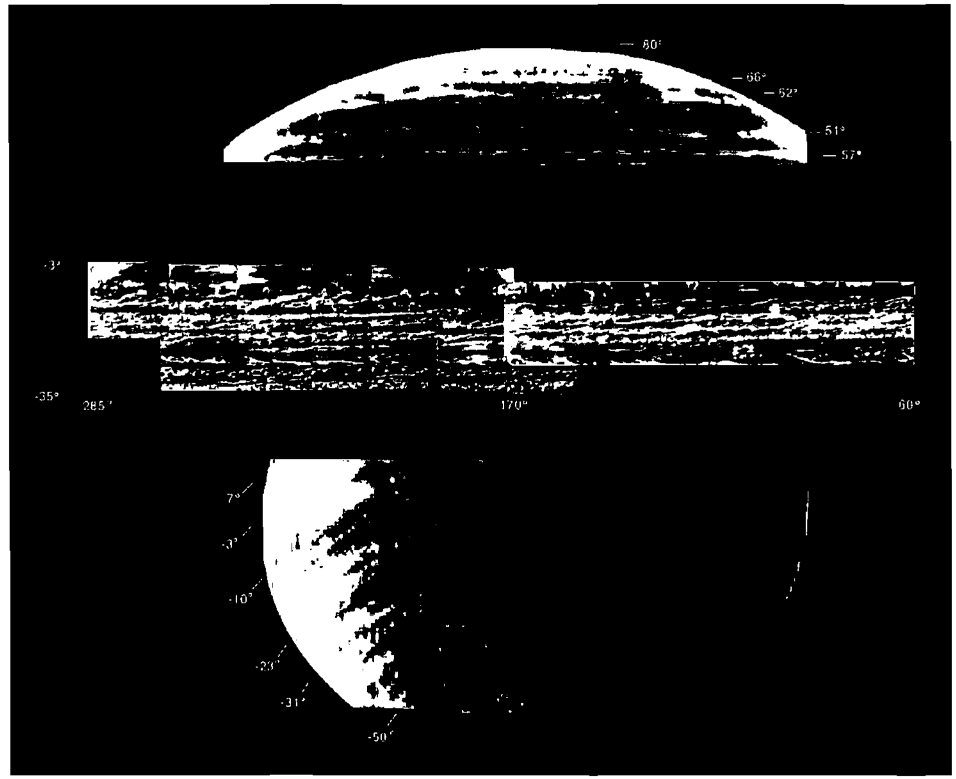
- Science measurement objectives
- Initial assumptions for Saturn multi-probes studies
- Probe and carrier notional science instruments
- Key mission architecture stages & elements
  - Trajectory options
  - Key mission drivers for the carrier s/c
  - Key mission drivers for the probes
- International collaboration
- Conclusions & recommendations



Science Measurement 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)

- **Origin and Evolution**
  - Saturn atmospheric elemental ratios relative to hydrogen (C, S, N, O, He, Ne, Ar, Kr, Xe)
  - Key isotopic ratios (e.g., D/H, 15N/14N, 3He/4He and other noble gas isotopes)
  - Helium abundance relative to solar & Jupiter
  - Gravity and magnetic fields
- **Planetary Processes**
  - Global circulation
  - Dynamics
  - Meteorology
  - Winds (Doppler and cloud track)
  - Interior processes (by measuring disequilibrium species, such as PH_3, CO, AsH_3, GeH_4, SiH_4)



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

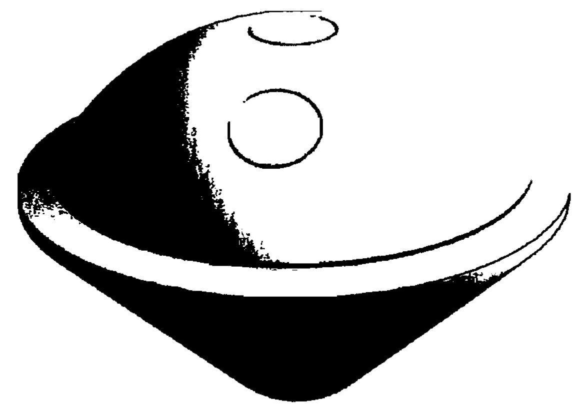
Ref: Atreya, S. K. et al., "Multiprobe exploration of the giant planets – Shallow probes", Proc. International Planetary Probes Workshop, Anavyssos, 2006.

Initial Assumptions for Saturn Multi-Probes Studies

Required → driven by Science Objectives:

- **Two (2) shallow probes to 10 bars**
  - Latitude location: dissimilar regions (zones/belts)
  - E.g., two sides or the ±13° Equatorial zone
  - Relay OR Direct-to-Earth communication
- **Microwave radiometry (MWR) to ~100 bars**
  - MWR on carrier
  - Carrier options: Flyby or Orbiter
- **Fields and particles**
  - Saturn's gravity field
  - Saturn's magnetic field

Ref: S. Atreya; T. Balint & FY06 Study Team members; ESA CV-KRONOS Proposal



Programmatics:

- **New Frontiers** class mission
  - Cost cap assumptions: today's $750M
  - Next NF Opportunity: ~ 2015
- **Potential International Collaboration**
  - Cosmic Vision KRONOS proposal (2017 launch?) descent modules provided by ESA (w/o aeroshell)

Ref: SSE Roadmap Team, "Solar System Exploration; This is the Solar System Exploration Roadmap for NASA's Science Mission Directorate", NASA SMD PSD, Report #: JPL D-35618, September 15, 2006; Website: solarsystem.nasa.gov

Probe & Carrier Notional Science Instruments

Assumed for Saturn Probes & Flyby S/C in Previous Studies – Galileo Probe Heritage

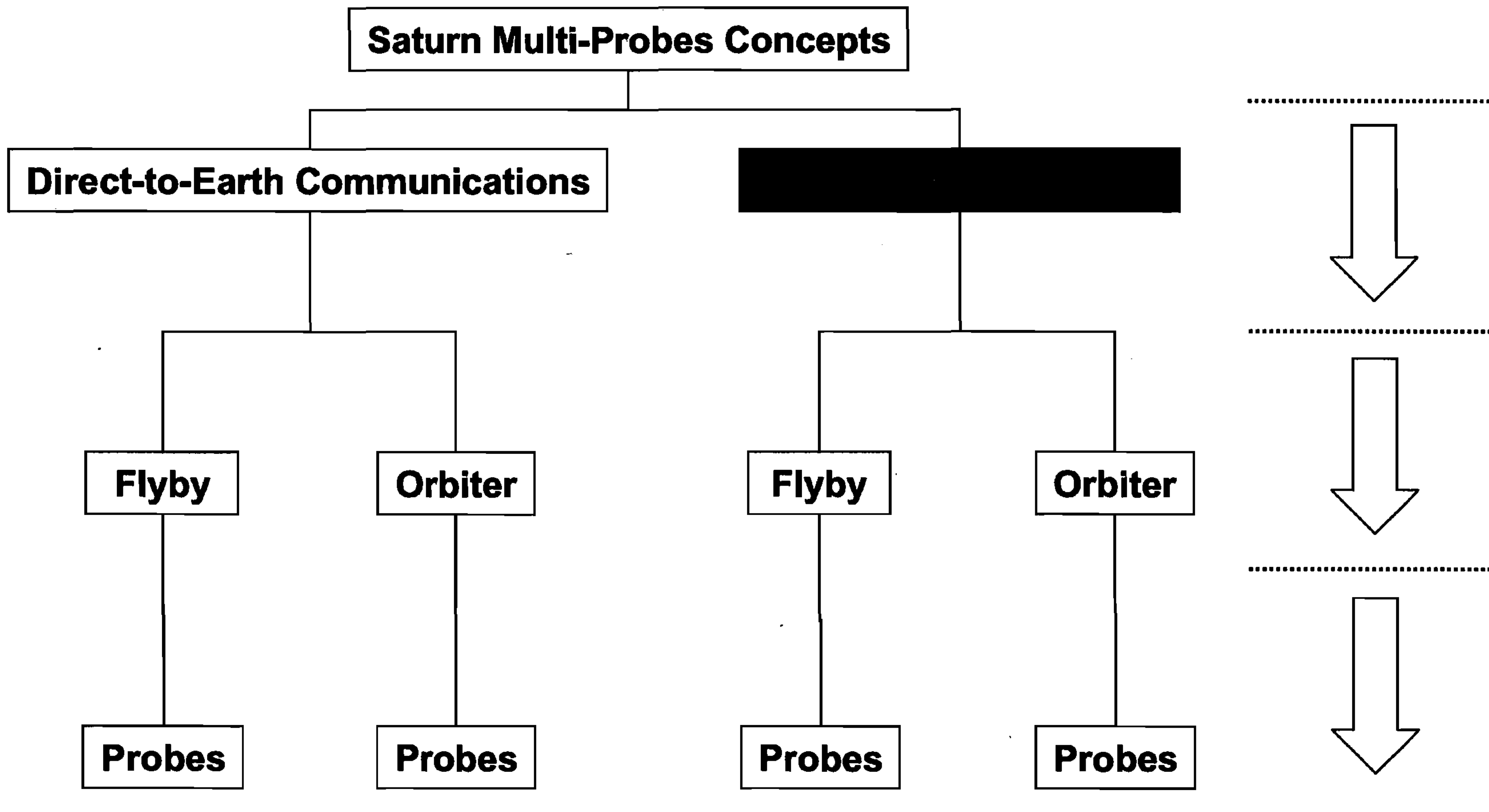
Shallow Probe to 10 bars	
ASI	– Atmospheric Structure
NEP	– Nephelometer
HAD	– Helium abundance
NFR	– Net flux radiometer
NMS	**– Neutral mass spectrometer**
LRD /EPI	– Lightning / Energetic particles
ARAD	– Ablation monitor – on TPS
DWE	– Doppler wind experiment
OPH	– Ortho-Para Hydrogen
TLS	– Tunable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

Carrier: Flyby or Orbiter	
MWR	**– Microwave radiometer**
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 design and mission cost allocation for New Frontiers missions
- In previous studies we assumed the same instrument **sampling rate per distance traveled as used on the Galileo probe** (this will be reassessed based on the telecom option)

Ref: FY06 studies: Dave Atkinson, Bill Smythe (with comments from Sushil Atreya)

Key Mission Architecture Trades

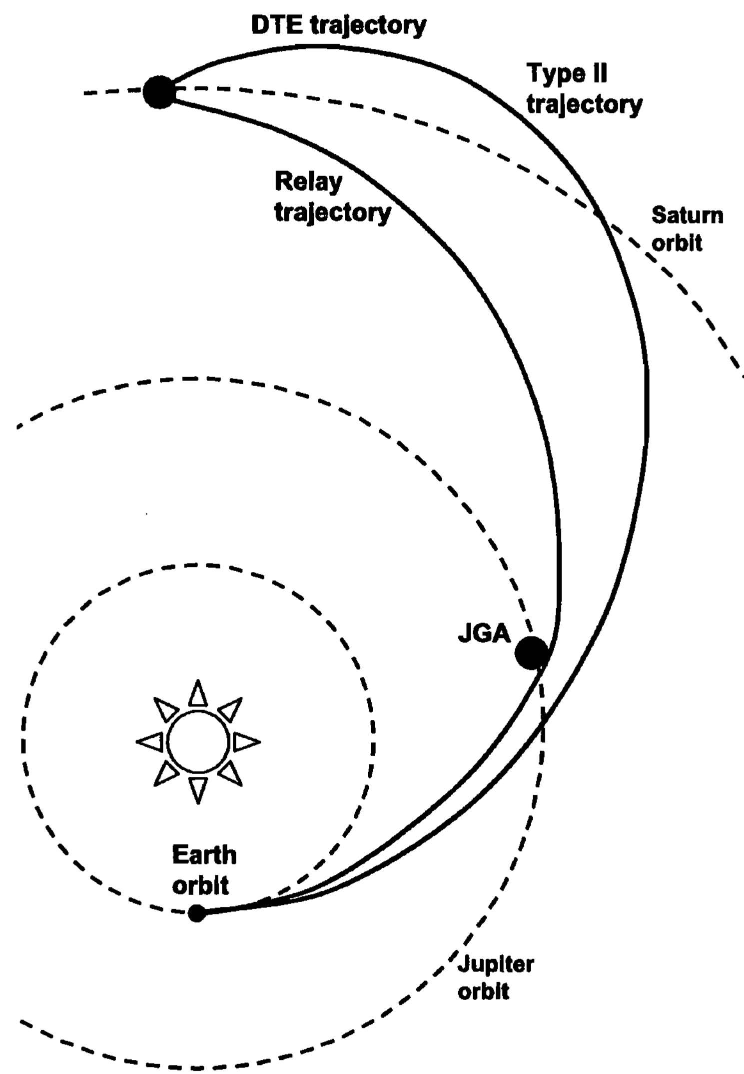


Each of these mission architecture trade option has significant impacts on the mission, with distinct advantages and limitations. There isn't a single best solution yet.

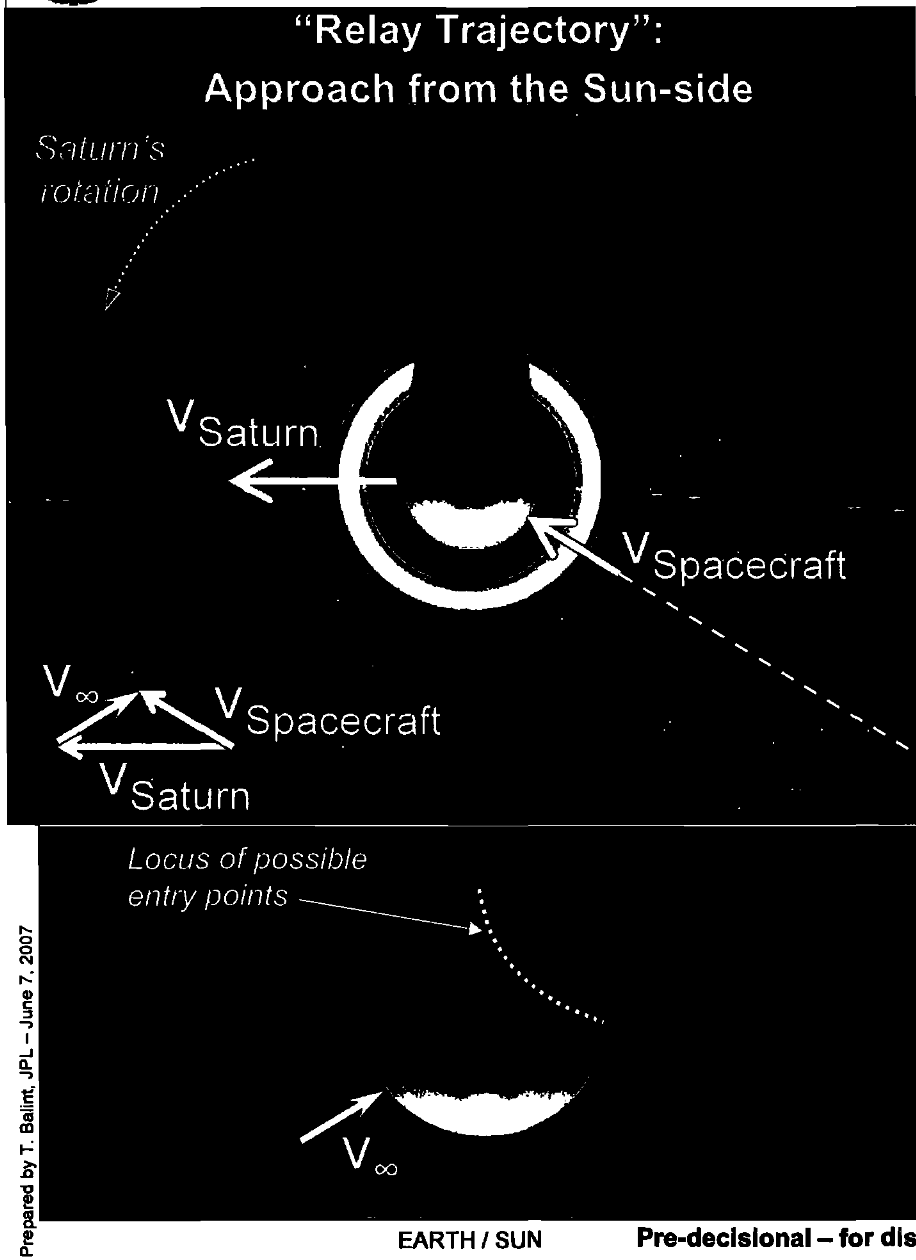
Prepared by T. Balint, JPL – June 7, 2007

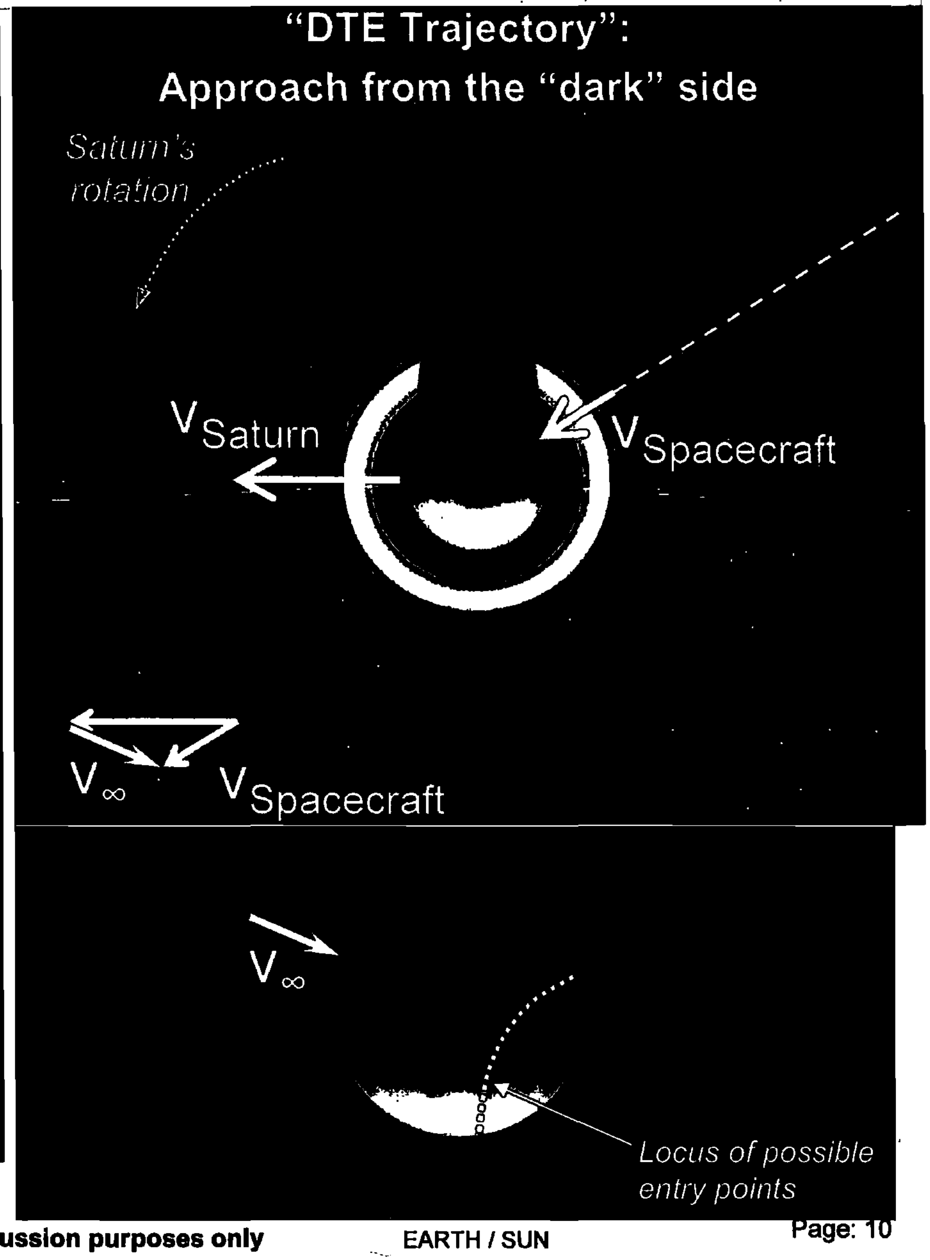
Getting there: Trajectory options

- **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: probe → carrier → Earth
    - **No visibility between probe and Earth!**
  - For **DTE** telecom from probes:
    - **Can't use Jupiter GA;**
    - **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



Trajectory options for Relay and DTE telecom





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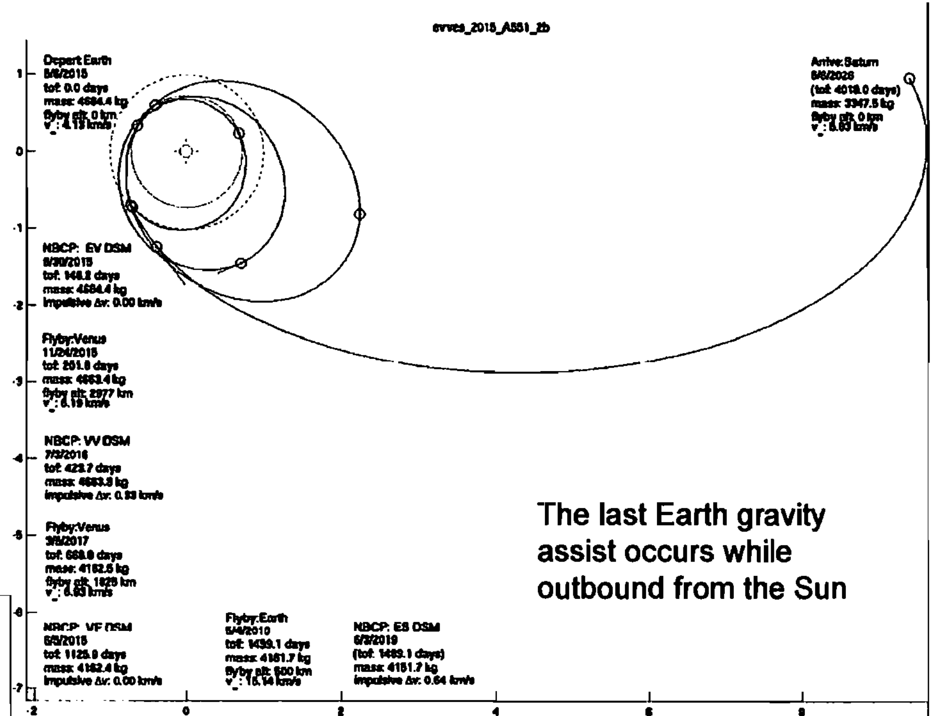
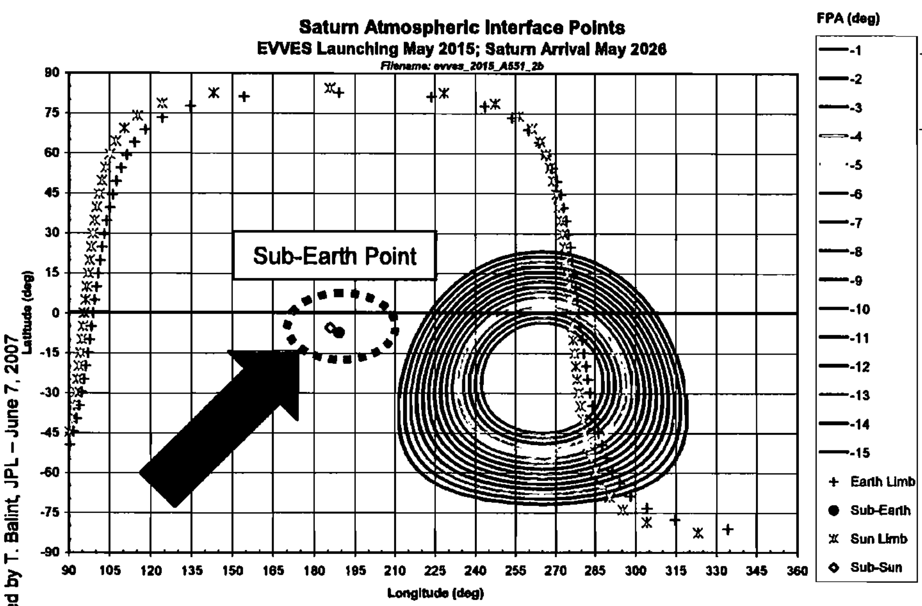
Representative DTE Trajectory: EVVES 11-years

- Flight time to Saturn: **~11 years**
- C3=~17 km^2/s^2
- Launch mass (on Atlas 551): **~4665 kg**
- Mass at Saturn arrival: **~3345 kg**
- Mass post-SOI: **~2720 kg**
- **Entry ~30° from sub-Earth point**
- *Note: use -13 deg FPA curve*





- During probe descent, location changes from ~30° to ~70° with respect to sub-Earth point
- Impact on telecom

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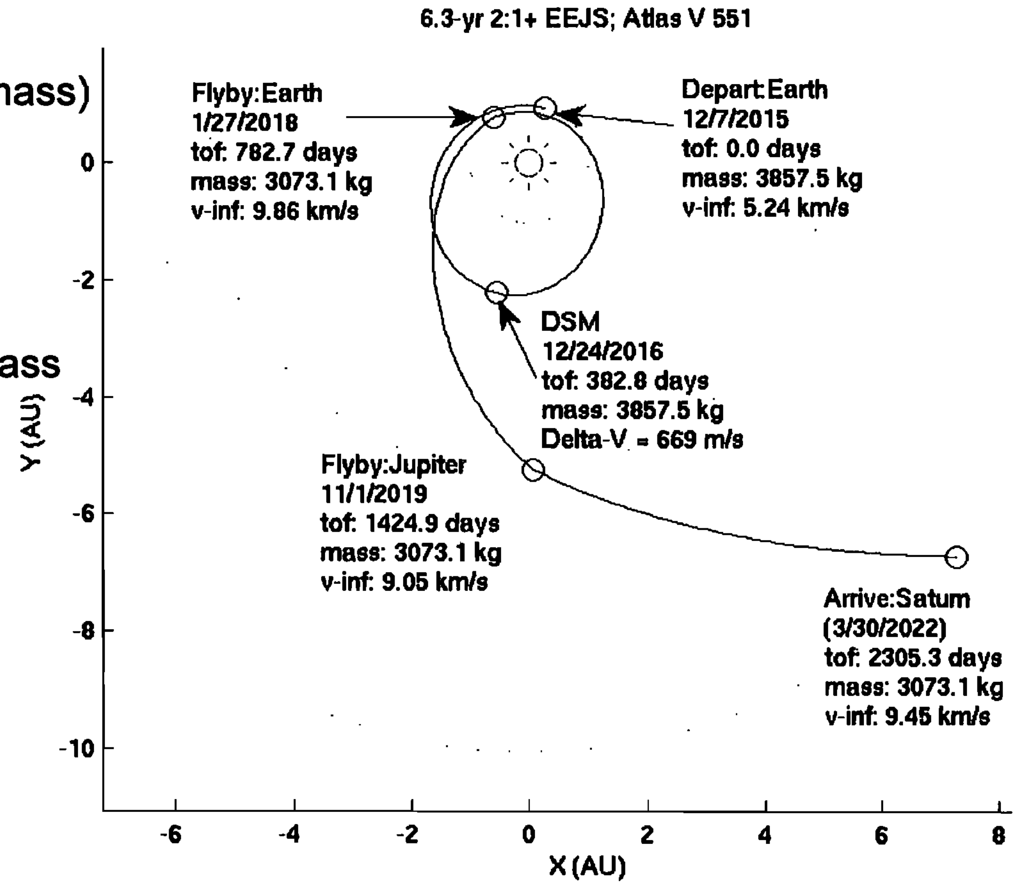
Ref: Theresa Kowalkowski, JPL, January-March, 2007

Representative Relay Trajectory: EEJS 6.3-years

- Representative baseline trajectory
  - EEJS; ~685 m/s DSM
  - December 2015 Launch
  - ~6.3-yr flight time (2017 launch ~6.5-7 years & ~10% less delivered mass)
  - Probes enter on the dark side
  - Supports Relay telecom option
  - SEP option → delivers ~30% more mass

Launch Vehicle	Delivered Mass*
Delta IV - 4050H	4411 kg
Atlas V - 551	3073 kg
Atlas V - 521	2124 kg
Atlas V - 401	1566 kg
Delta IV - 4040-12	956 kg

*Deterministic and optimal performance values; does not include statistical estimates or a 21-day launch period analysis

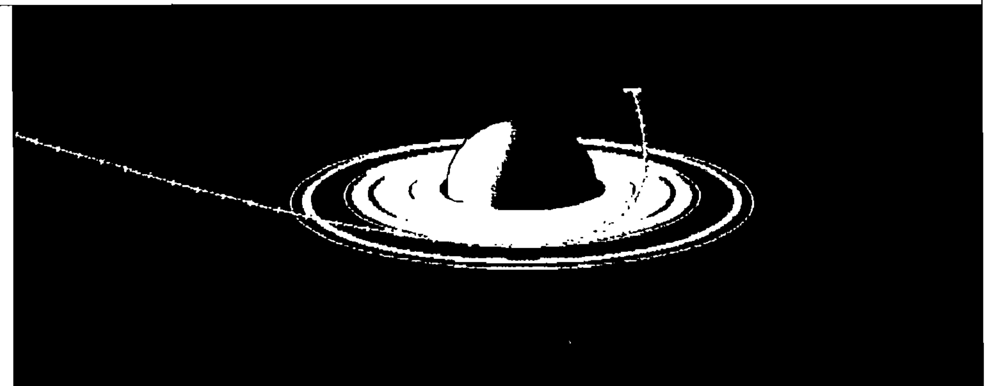


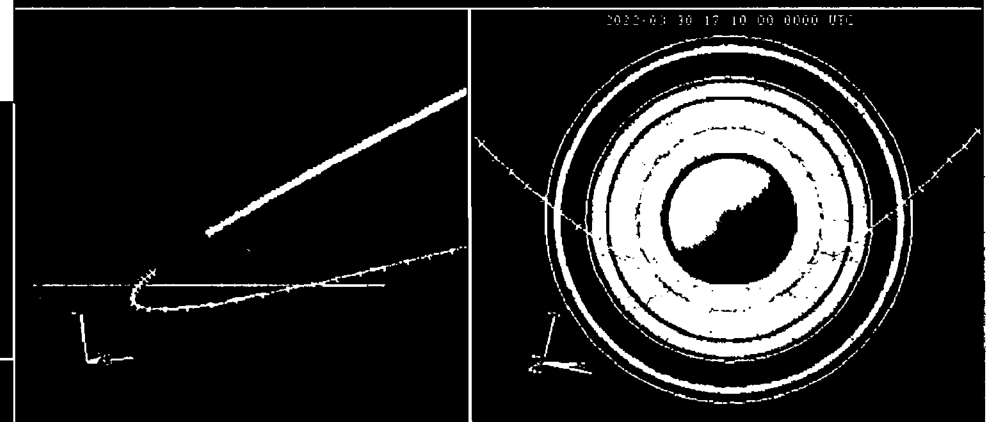
Point design could result in a smaller Launch Vehicle, thus reducing cost

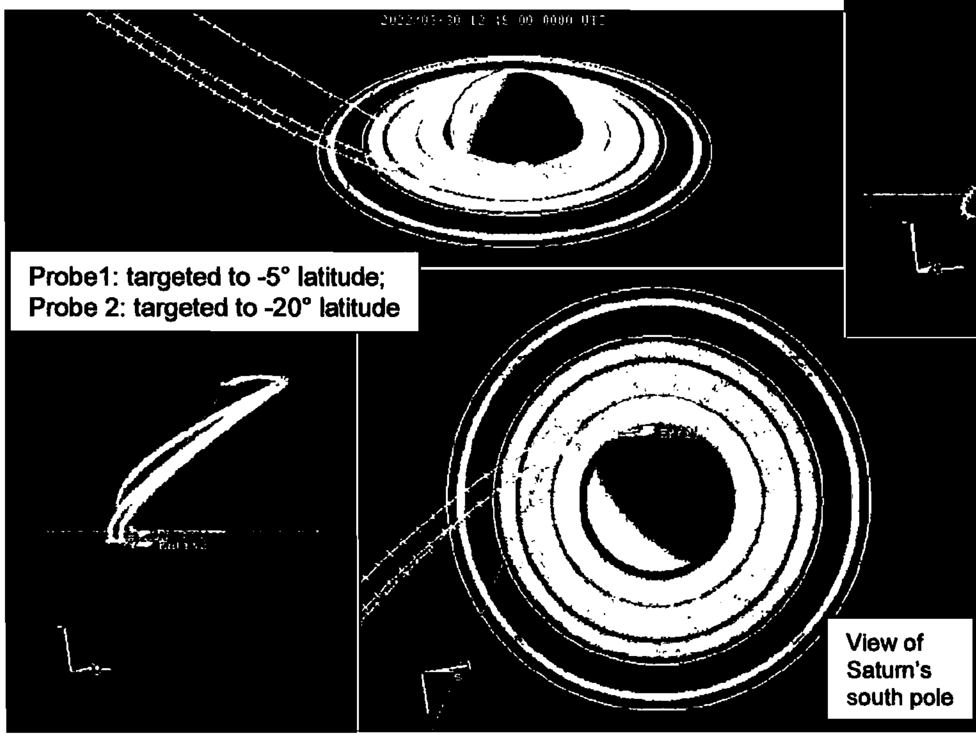
Ref: Theresa Kowalkowski, Try Lam

Representative Baseline Relay Trajectory: Flyby /w Probes

- **Pass through the ring plane twice**, both times through the gap **between the F- and G-rings**
  - Time **"beneath" the rings**: **~3 hrs**
  - **Closest approach** to Saturn: **~11,700 km** (good for MWR)
  - Most southern latitude: **-19 deg**







Note that the minimum altitude and maximum latitude achieved are a function of arrival DLA, which is a function of a arrival date (among other things)

Impact of an Orbiter (instead of Flyby)

- Assumptions for **Saturn orbit insertion (SOI)** delta-V & mass calculations:
  - **Impulsive maneuver** (no gravity-losses) performed at 64,000 km radius (~3,700 km altitude)
    - **Inside the D-ring**, which "begins" at a radius of ~67,000 km
    - **Periapsis set between the D-ring and the Saturn** cloud-tops (at ~60,000 km)
  - Insert into **120-day orbit**
    - This is roughly the size of **Cassini's initial orbit**
    - Inserting into smaller orbits with shorter periods will be more costly
  - **I_{sp} = 300 sec**

Saturn Orbit Insertion (SOI) to a 120-day orbit further **reduces the mass by ~25% to 30%**

Additional mass penalty applies for pumping down to Juno like **short period orbit** (~11 days)

Other Issues: Ring Crossing / Particle Collision Risk

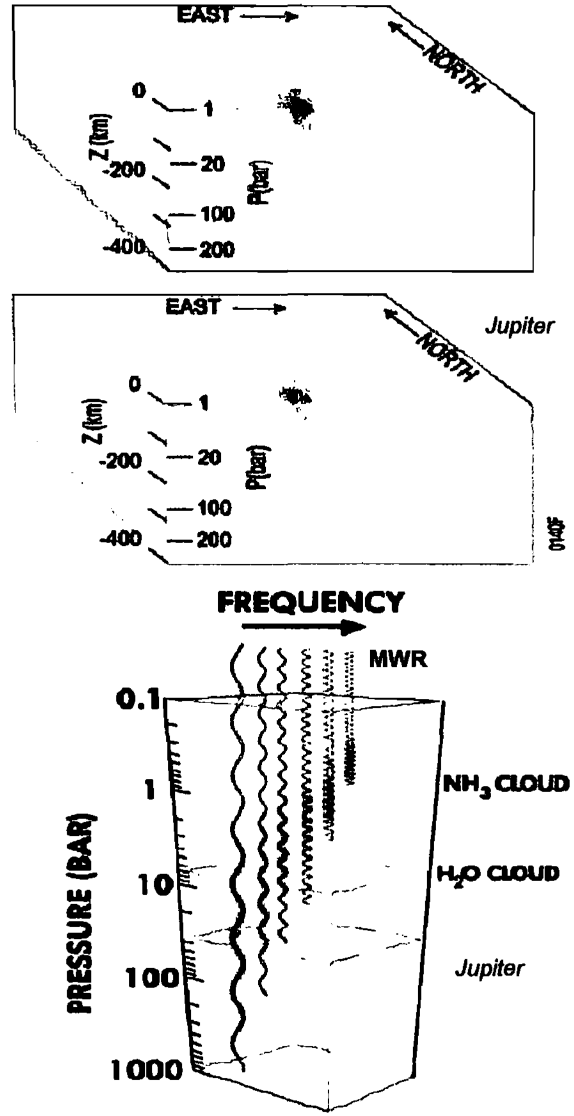
Architecture	Flyby	Orbiter
DTE + Probes	- Low/medium risk - Single ring crossing - Inside D ring (particle density?)	- Potentially high risk - Multiple ring crossing - Inside D ring (particle density?)
Relay + Probes	- Low risk - Two ring crossing - Between F and G rings (similar to Cassini)	- Low/medium risk - Multiple ring crossing - Between F and G rings (similar to Cassini)

- **Flyby missions:**
  - Lower risk: require one or two ring crossings
- **Orbiter missions:**
  - Higher risk: require multiple orbits / ring crossings
- **Ring Crossing:**
  - At Clear gaps, e.g., between rings F & G; or inside the D-ring are considered lower risk
- **Ring Collision :**
  - Juno-like elliptic orbit: would precess faster due to Saturn's obliqueness

Key Mission Drivers for the Carrier Spacecraft

Microwave Radiometry: MWR Requirements

- **Close proximity to Saturn** is **required** for effective MWR measurements:
  - E.g., Juno performs MWR measurements from 60,000 km to 4,000 km
- **Perpendicular spin to flight direction** is **required**
  - For scanning sky, limb & atmosphere
  - For scanning same cloud location from various angles
- **Polar flyover** is **desirable** (but not necessary)
  - This could be **achieved with an orbiter** or **flyby after decoupling the probes from the carrier**, (both option would **require a "DTE trajectory"**)
  - Polar flyover or flyby allows for magnetometer measurements (**desirable**)
- **Multiple MWR measurements** are **desirable** (but not necessary)
  - This would **require an orbiter**



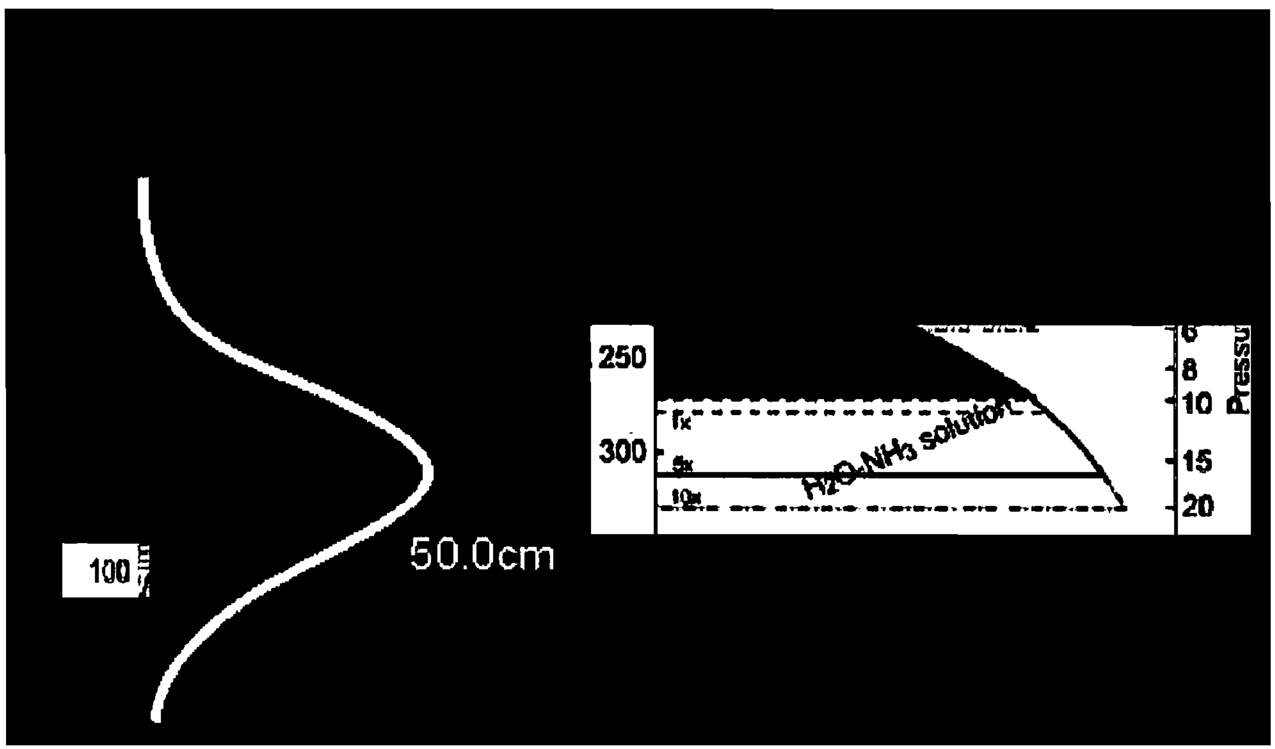
Ref: Scott .J. Bolton, Tristan Guillot, Michel Blanc, & the JUNO team, Juno Presentation Juno Presentation to the SSWG to the SSWG, April 20th, 2006, ESA HQ, Paris

Microwave Radiometry: Antenna Selection

- Primary science goal: → measure water abundance to 100 bars
- Microwave radiometry: → remote sensing of H_2O, NH_3 (hard to separate)

- **MWR antenna size**: NOT KNOWN; must be resized for Saturn
- **Weighting functions**: NOT KNOWN; must be recalculated for Saturn

- **Heritage**: Similar instrument will fly on **Juno**, but here a new design is required

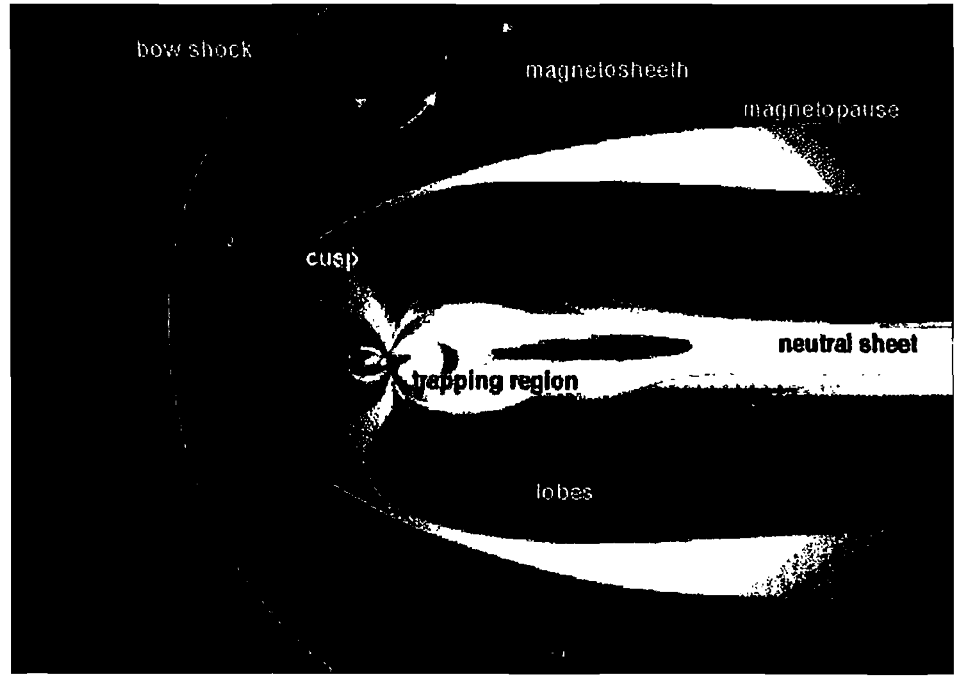


Ref: Gulkis, S., and Janssen, M. (2005) *Ref: Atreya, S. (2006)*

Ref: PSSS-2 (2006)

Gravity & Magnetic Field Measurement Requirements

- Magnetic field and magnetospheric measurements:
  - Science priority drives the inclusion of these measurements
- Magnetic and gravity field lines:
  - Polar trajectory is required
  - Orbiter → multiple pass → desirable, but mission impacts (e.g., complexity, cost)
  - Flyby → single pass only → limited science benefit
- Inner radiation belt:
  - Near equatorial trajectory, with less than 30° inclination



Passing through **field lines**:
- **DTE** architecture **suitable**: decouples probes and carrier
- **Relay** architecture: does not support polar flyby, but **sub-satellite** could provide **single flyby**

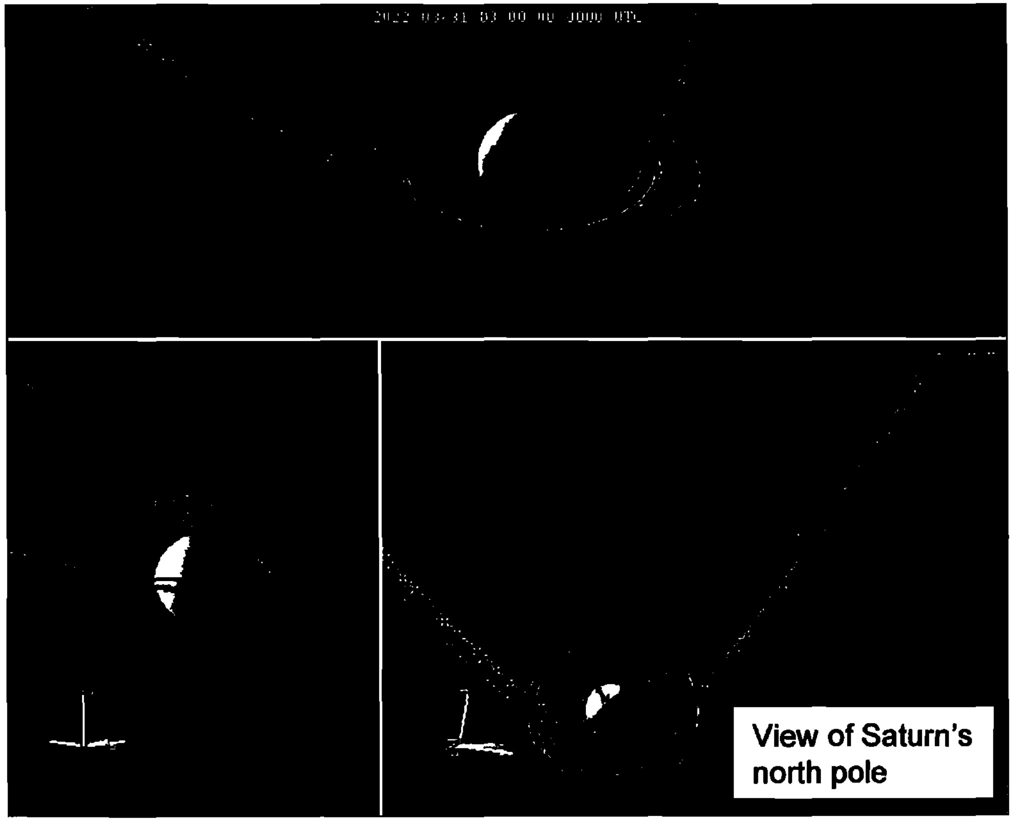
Inner radiation belt:
- **Relay** architecture: **suitable**, simple, short cruise
- **DTE** architecture: **not suitable** if targets polar flyby/orbiter trajectory

Prepared by T. Balint, JPL – June 7, 2007

Field Measurements with Sub-Satellite

- SS to Earth visibility (but 1 hour occultation)
  - Occultation from ~20 min before to ~40 min after ring-plane crossing;
- SS to Flyby visibility: always
  - EXCEPT potential ring occultation
- **Periapsis at ~3000 km** above Saturn
- **Ring plane crossing** at **~4000 km** above Saturn
- North Pole crossing:
  - ~60 min. *before* periapsis
  - Range to Saturn: 106,337 km (1.76 R_S)
  - Altitude: ~50,000 km above Saturn
- South Pole crossing:
  - ~130 min. *after* periapsis
  - Range to Saturn: 186,912 km (3.10 R_S)
  - Altitude: ~130,000 km
- SS transits:
  - 225° of latitude ±3 hrs from periapsis
  - From +54° (at -3 hrs), across the North pole, through the equator, down to the South pole, to -81° (at +3 hrs)
  - Range at -3 hrs: 244,183 km (4.05 R_S)
  - Range at +3 hrs: 243,602 km (4.04 R_S)

Snapshot shows 3 hours post-periapsis



Sub-satellite with a polar flyby can augments science for a **Relay architecture**.

Flyby is less desirable than an orbiter, but simpler, with lower mission impact

- **Solar Panels on a flyby s/c with relay telecom**
  - **Before Saturn:**
    - Solar panels would generate power during cruise
      - Operation: checks in every 3 weeks, when operating from solar power and secondary batteries
  - **At Saturn:**
    - Flyby s/c science operations would be ~6 hours near Saturn (telecom and MWR on carrier)
      - Preliminary studies indicate that this could be done with primary batteries; i.e., solar panels are not required for this operational phase
  - **After Saturn:**
    - If collected data is not down-linked during a single pass using batteries, the solar panels could trickle charge the batteries and send the data back in subsequent passes

Flyby + Relay telecom based architecture can be supported with **batteries**, with **LILT solar panels for backup** during non-mission critical modes

Power systems for an orbiter architecture can be **significantly more challenging** and the feasibility should be assessed accordingly

Power Systems: for a Saturn Orbiter

- **Solar Panel size for a Saturn orbiter based on Juno analogy:**
  - At Jupiter, solar flux is ~4% of that at Earth
    - Juno potential solar panels: 45 m^2 from 3 panels (2 m x 7.5 m each);
    - ~300 We
  - At Saturn, solar flux is ~1% of that at Earth
    - Assuming the same power requirement for a "Juno-2" orbiter (~300 We)
    - Potential solar panel size: ~4 x 45 m^2 = 180 m^2 (this might be too large)
      - Additional issue: ring crossing inside the D-ring for an orbiter
    - Potential solar Panels will be sized during the point design exercise
    - NOTE: this only accounts for panel sizing, but does not account for other issues, such as shadowing, ring avoidance, solar pointing etc.
  - Alternative power source
    - Equivalent RPS: 3 x MMRTG → ~330 We (likely beyond the scope of a NF mission)

Power systems for an orbiter architecture can be **significantly more challenging** and the feasibility should be assessed accordingly

Note: Solar power is feasible for the Juno for several reasons: LILT solar cell designs; Relatively modest power needs (460 W) at beginning of orbital operations at Jupiter to 414 W at EOM Science Instruments requiring full power for only about six hours out of the s/c's 11-day orbit; Eclipse avoidance through polar orbit; All science measurements are designed to be taken with the solar panels pointing within 35 degrees of the Sun to maximize amount of sunlight that reaches the panels >1 year operation at Jupiter

Key Mission Drivers for the Probes

Probe Entry / Aeroshell / TPS

Entry direct.	Latitude deg	Rel. entry V, km/s	Max diameter, m	Entry mass, kg	Max. heat rate*, kW/cm²	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

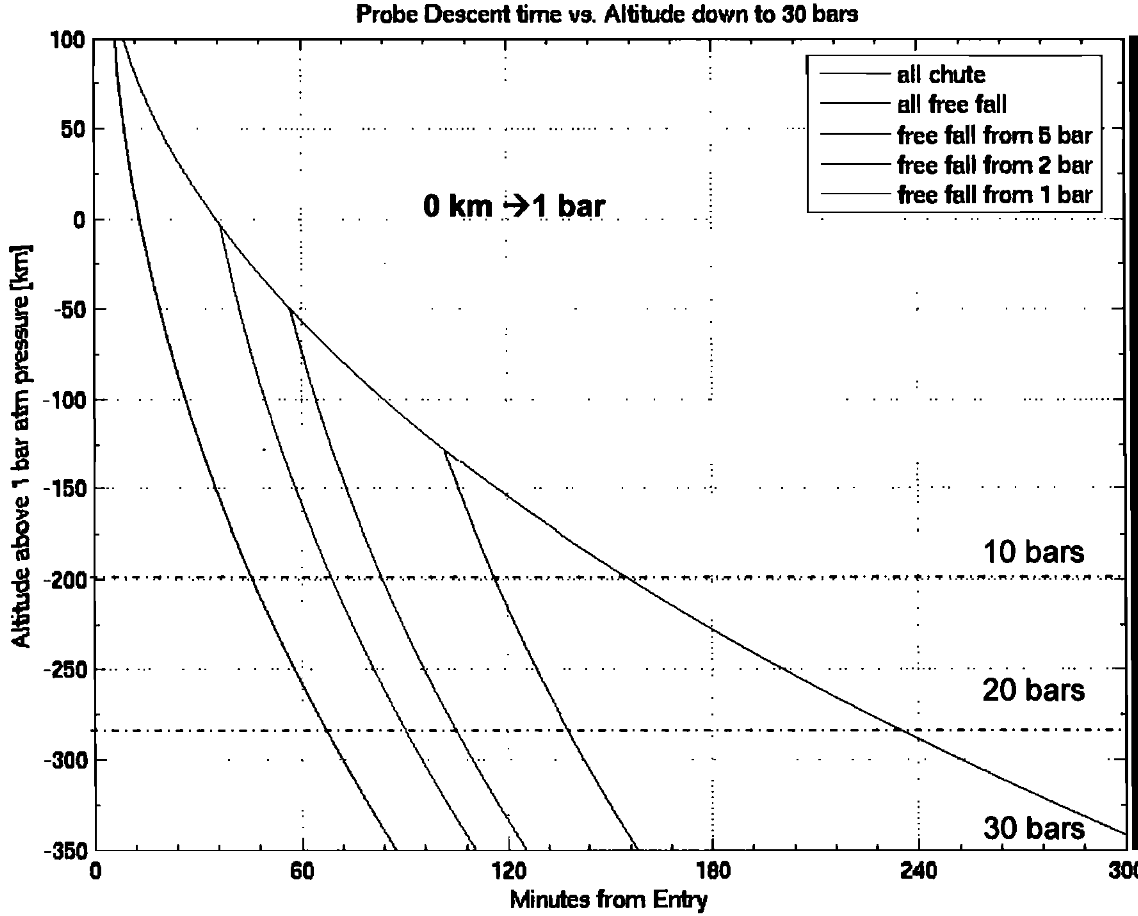
- **TPS availability for Galileo size probes H/S were confirmed by NASA ARC**
  – C-P for **prograde entry can be supported** (heating rate about 10% of Galileo's)
  – **Retrograde heat flux** might be **too high to support** with current testing facilities

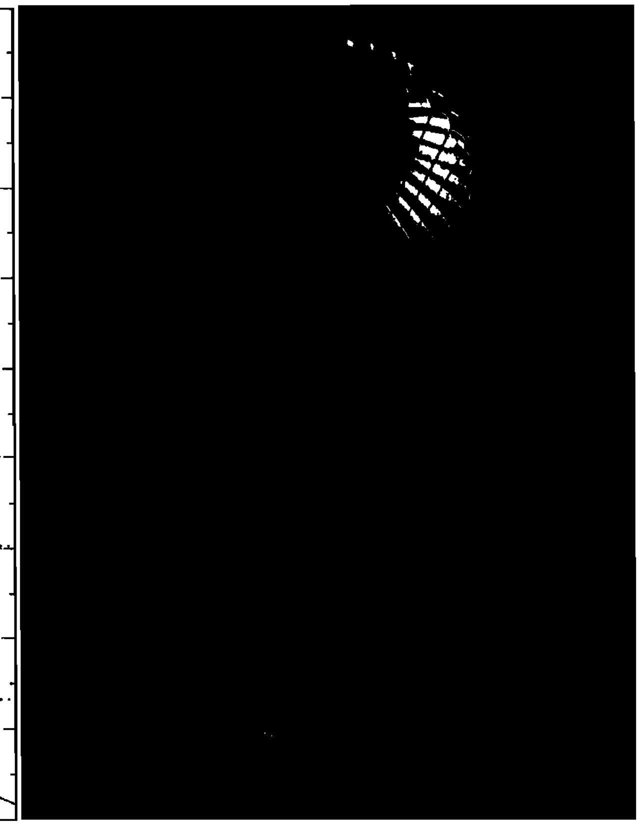
- **TPS** requirement **at Saturn** is **less demanding** than at Jupiter

- **TPS mass-fractions** 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**

Probe Descent time vs. Altitude Down to 30 bars (10 bars required)

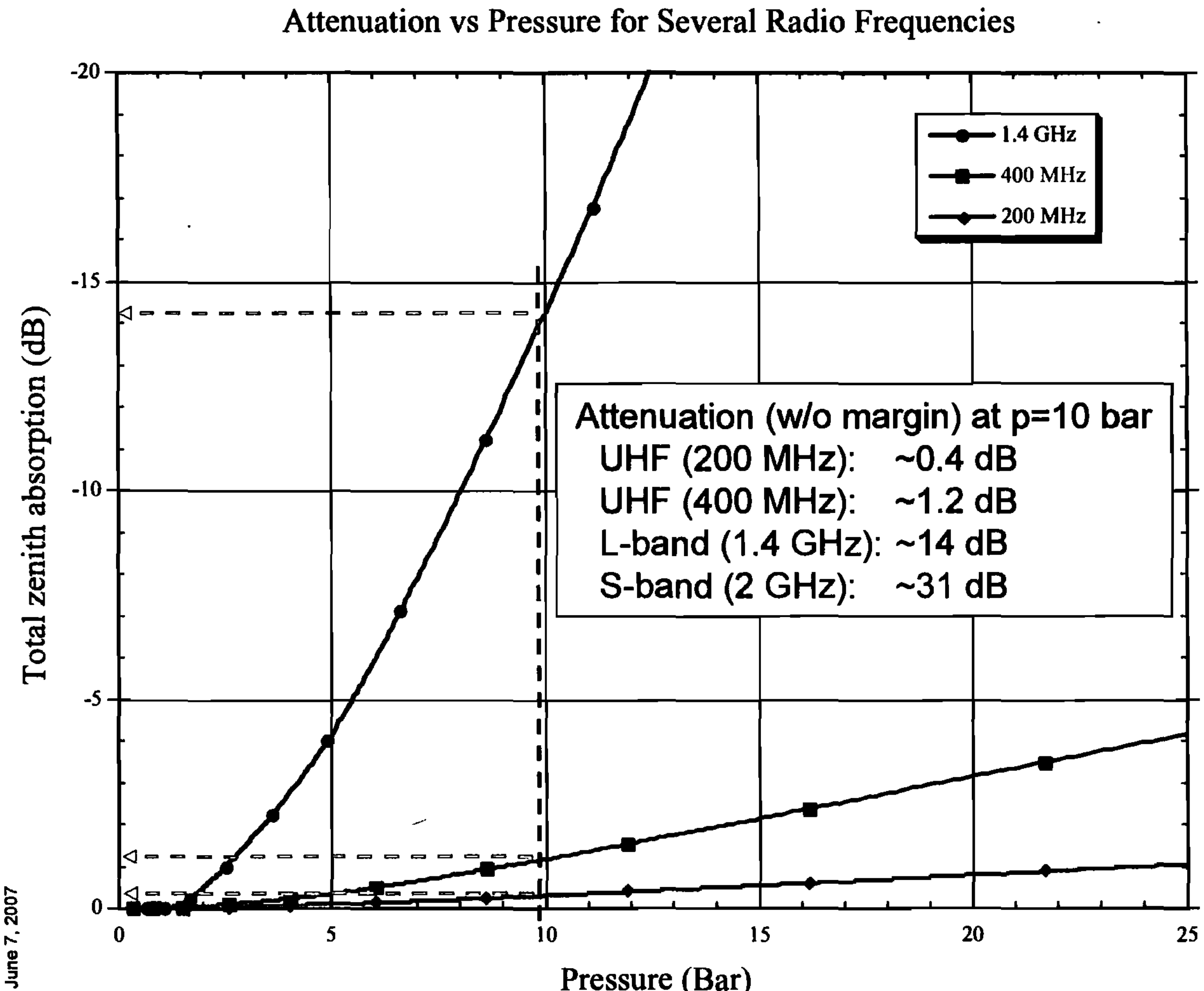




- **If free fall begins at pressure of 1 bar**, it will take **~70 minutes** from entry to reach **10 bars**
- *For better probe stability, the freefall phase could be replaced with descent with a drogue parachute (This requires further analysis)*
- If the descent is **entirely on the parachute**, it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

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

Zenith Attenuation Based on Ammonia at 10x Solar Abundances



- **Saturn's scale height is ~2x that of Jupiter's**
  ~45 km at the pressures of interest
- Saturn has
  - **no radiation** environment
  - **no synchrotron** radiation, thus we can use low (UHF) frequencies
- Independent calculations by Tom Spilker and Bill Folkner yielded close results

Zenith attenuation of radio signal as a **function of probe depth** (measured by atmospheric pressure), based on concentrations at 10 times solar abundances, in atmosphere model by Atreya. (Here only NH_3 has been calculated)

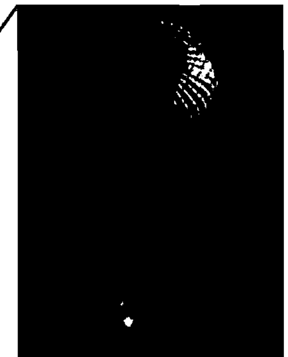
Ref: Bill Folkner, JPL; Tom Spilkner, JPL

Direct-To-Earth Telecom

Probes Telecom for DTE:
Frequency:
  UHF 200 MHz

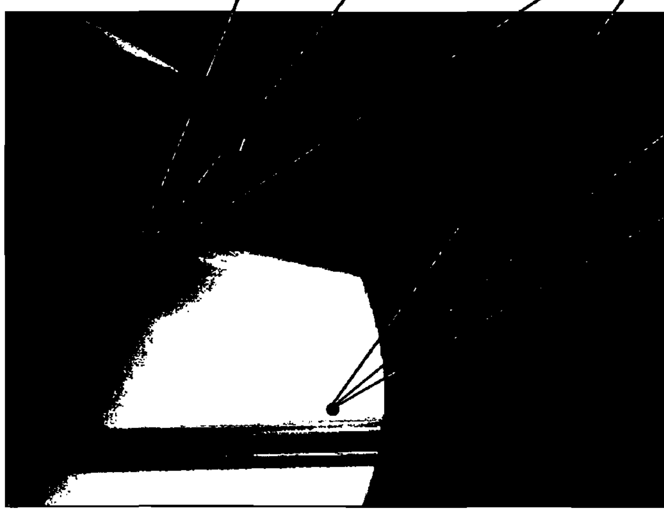
Antenna:
  UHF **Patch**
  (requires new design)

Probe hardware:
  TBD (100W) (new)

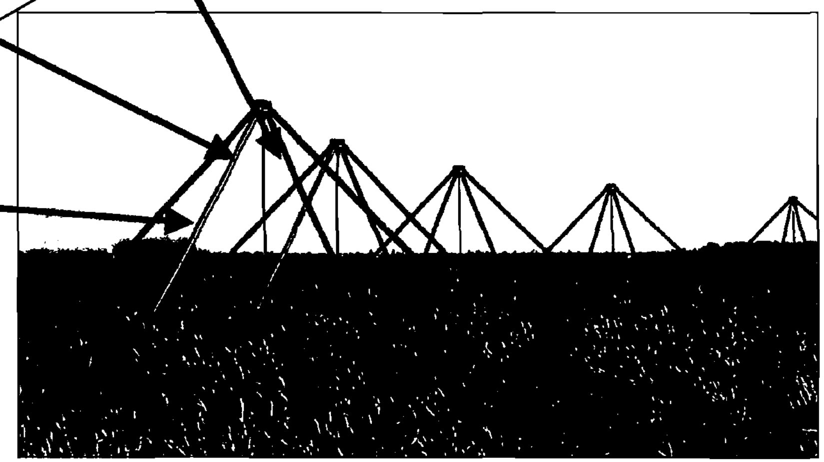


__Data rates from a probe__
  Probe: **60 bps (~0.22 Mb)**

__Data volume from 2 probes__
  Total from 2 probes: **~0.44Mb**
  (~14 x less than with relay)



Carrier: TBD
Not an issue



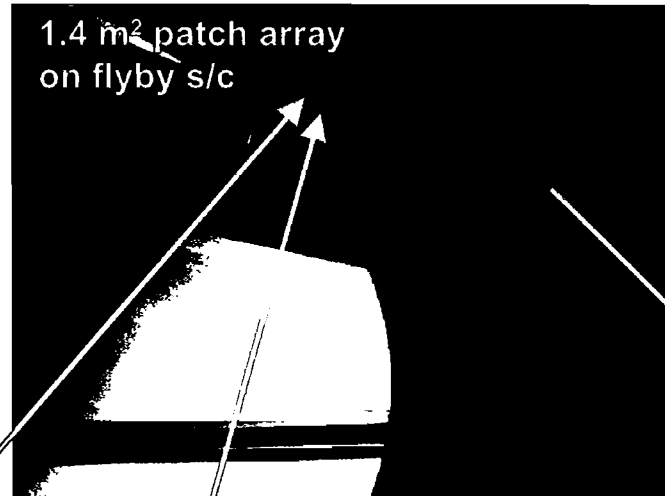
LOFAR (operates below 250 MHz)
Strategy:
- Record all data at given frequency
- Analyze later

NOTE: DTE calculations still need V&V

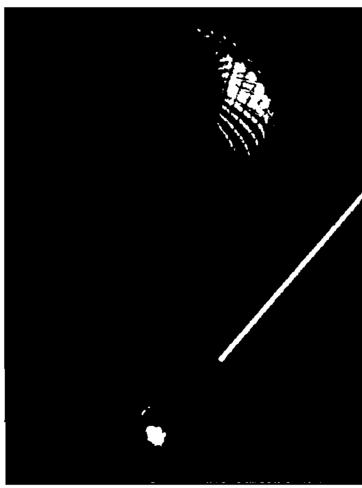
Relay Telecom

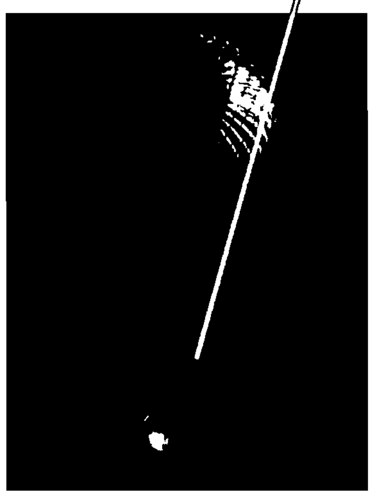
Data rates
Probe 1: 1024 bps (~3.7Mb)
Probe 2: 512 bps (~1.9Mb)

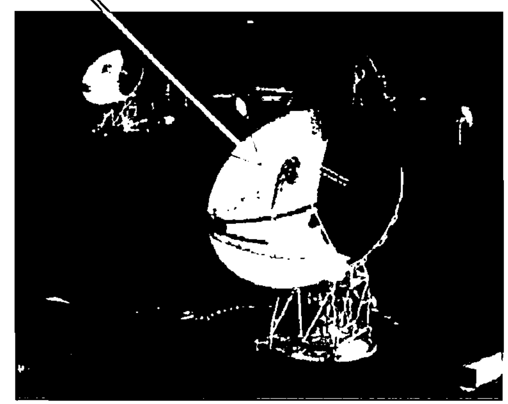
Data volume
Total from 2 probes: ~6.3Mb



35W X-ban DTE for science and telemetry
3 m HGA for downlink
(MGA & LGA emergency links)







34 meter DSN

Frequency:
UHF 401 MHz
Antenna:
UHF **LGA**
Probe hardware:
Electra-lite (20W)

- "**Store and dump**" operation
- **Probes** has **NO line of sight with Earth**
- All data downloadable within the **first two hours of a single tracking pass**

Ref: David Morabito, Anil Kantak and Arv Vaisnys, FY06

Potential International Collaboration

- **ESA Cosmic Vision** Announcement of Opportunity:
  - Proposals due by June 29, 2007
  - Down-selection for further studies
    - 3 Class M & ~3 Class L concepts; October, 2007
    - Class M: 300M Euros; Class L: 650M Euros

- KRONOS: Saturn multi-probe mission proposal
  - ~200-250M Euros cost cap targeted
  - ESA contribution on NASA lead mission
    - ESA: probes w/o TPS (maybe LILT panels)
    - NASA would provide carrier and TPS for the probes

- Steps to make International collaboration a reality:
  - If KRONOS is selected for further studies: October 2007
  - Discussions could be initiated on high level collaboration
    - NASA's PSD Director, Dr. Jim Green, and
    - ESA's Director of Science, Prof. David Southwood

- Impact of NASA New Frontiers & ESA Cosmic Vision Program/Proposal Cycles:
  - New Frontiers AO is expected by the end of 2008
  - NF launch date is expected for 2015, but as early as 2014
  - Cosmic Vision Class M mission launch window: 2016 to 2018
  - **Potential launch date for international collaboration mission: 2016-17**

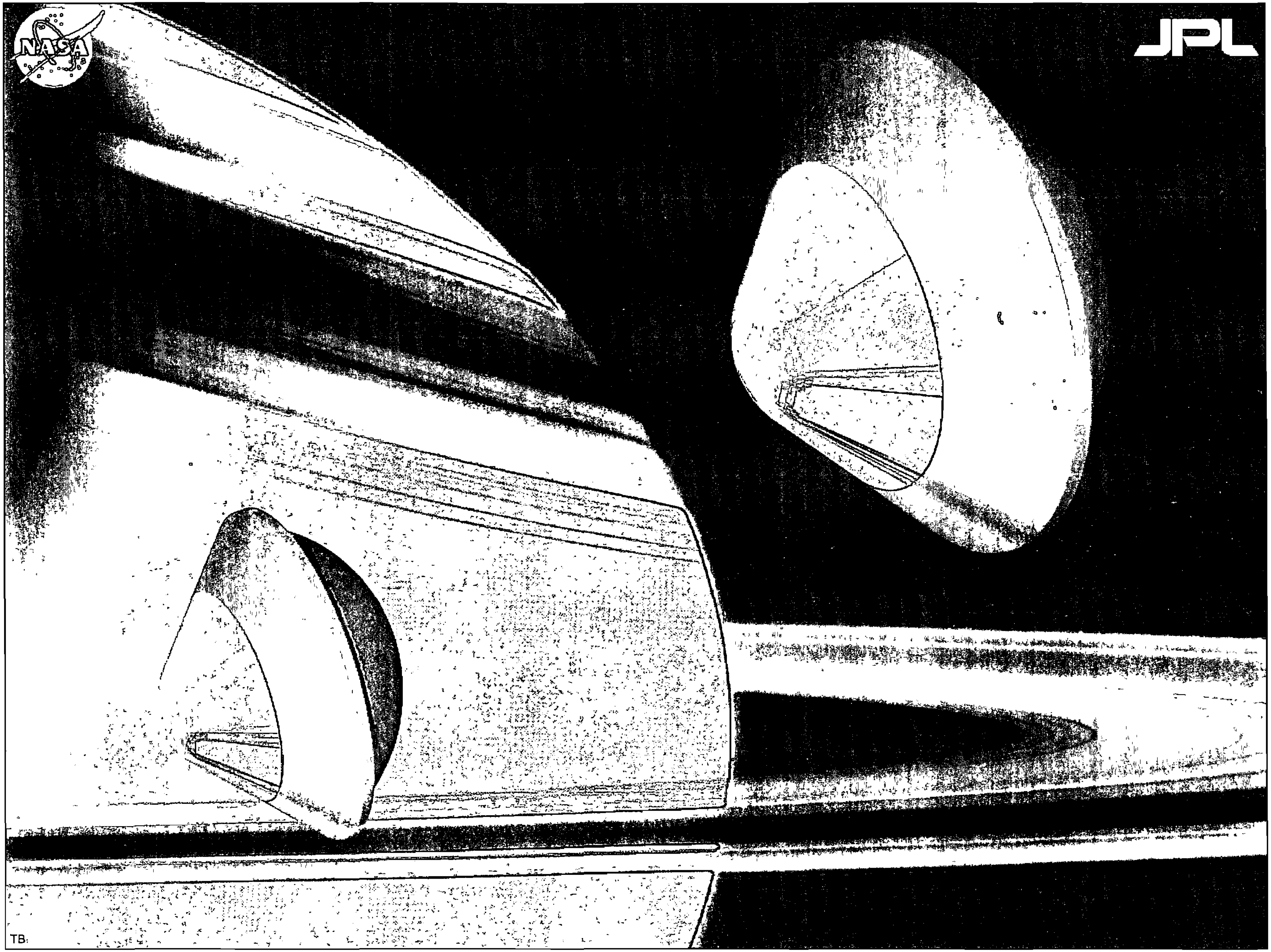
Conclusions & Recommendations

- Ongoing **studies**, performed **at NASA/JPL** over the past two years in support of NASA's SSE Roadmap activities, **proved the feasibility of a NF class Saturn probe mission**

- This proposed mission could also provides a good opportunity for **international collaboration** with the proposed Cosmic Vision KRONOS mission
  - With **ESA contributed probes (descent modules) on a NASA lead mission**
  - Early 2017 launch could be a good programmatic option for ESA-CV/NASA-NF

- A **number of mission architectures** could be suitable for this mission, e.g.,
  - **Probe Relay** based architecture with short flight time (~6.3-7 years)
  - **DTE probe telecom based** architecture with long flight time (~11 years), and low probe data rate, but with the probes decoupled from the carrier, allowing for polar trajectories / orbiter. This option may need technology development for telecom.
  - **Orbiter** would likely impact mission cost over **flyby**, but would provide significantly higher science return

- The Saturn probes mission is **expected** to be identified **in NASA's New Frontiers AO**
- Thus, **further studies are recommended** to refine the most suitable architecture
- **International collaboration** is started through the KRONOS proposal work; further collaborated studies will follow **once KRONOS is selected in October** under ESA's Cosmic Vision Program


NASA
JPL
TB:

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