A Multi-Spacecraft Mission to Saturn Enabled by Ares-V: *Atmospheric Probes, Ring Observer and "Beyond Cassini" Orbiters*

By

T. R. Spilker*[1], S. K. Atreya[2], L. J. Spilker, T. Balint[1]
E. Venkatapathy[3] and J.O. Arnold[4]
*Presenter
[1]JPL, [2]Univ. of Michigan, [3]NASA ARC, [4]UARC/UC Santa Cruz

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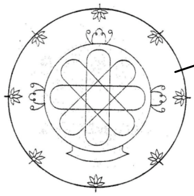


Symbol for Saturn known as "Shani" in Sanskrit

Disclaimers

Pre-decisional Information for Workshop Discussion Only

• In the spirit of the August 2008 Ares-V workshop, the authors have assembled a small set of charts describing the scientific merit of sending, simultaneously, a suite of spacecraft to Saturn which could greatly advance our understanding of the origins of the outer planets in the Solar System.

• While the authors articulate here the considerable scientific value of sending a fleet of spacecraft to Saturn enabled by the Ares-V, they also realize that the considerable cost of such a mission, beyond that of the Ares-V launch, would require international collaboration and cost sharing.

• This presentation is not intended to compromise ongoing or future New Frontiers discussions involving shallow probes to Saturn.

Outline

- **Saturn Science - Mission Pull**
  - Composition of well-mixed atmosphere including H_2O, H_2S, NH_3, CH_4, Ne, Ar, Xe, He, noble gas isotopes, D/H, $^{14}N/^{15}N$, $^{3}He/^{4}He$ and disequilibrium species CO, PH_3, GeH_4, AsH and SiH_4
  - Deep (100 bar) water abundances
  - Atmospheric dynamics and metrology
  - Saturn ring dynamics from Saturn Ring Observer (SRO) platform
  - "Beyond Cassini" observations from orbit: for SRO context and inner satellite exploration
- **Mission Scenario**
  - Two high-speed (36.6 km/s) direct probe entries
  - Microwave Radiometery (MWR) for deep atmosphere sounding
  - Aerocapture of SRO
  - "Beyond Cassini" orbiter
- **Key Technology Challenges**
  - Thermal Protection Systems (TPS) for probes and aerocapture
  - Communication from deep probes
  - Payload performance at high temperatures and pressures
- **Mass of Saturn Spacecraft (WAGS)**

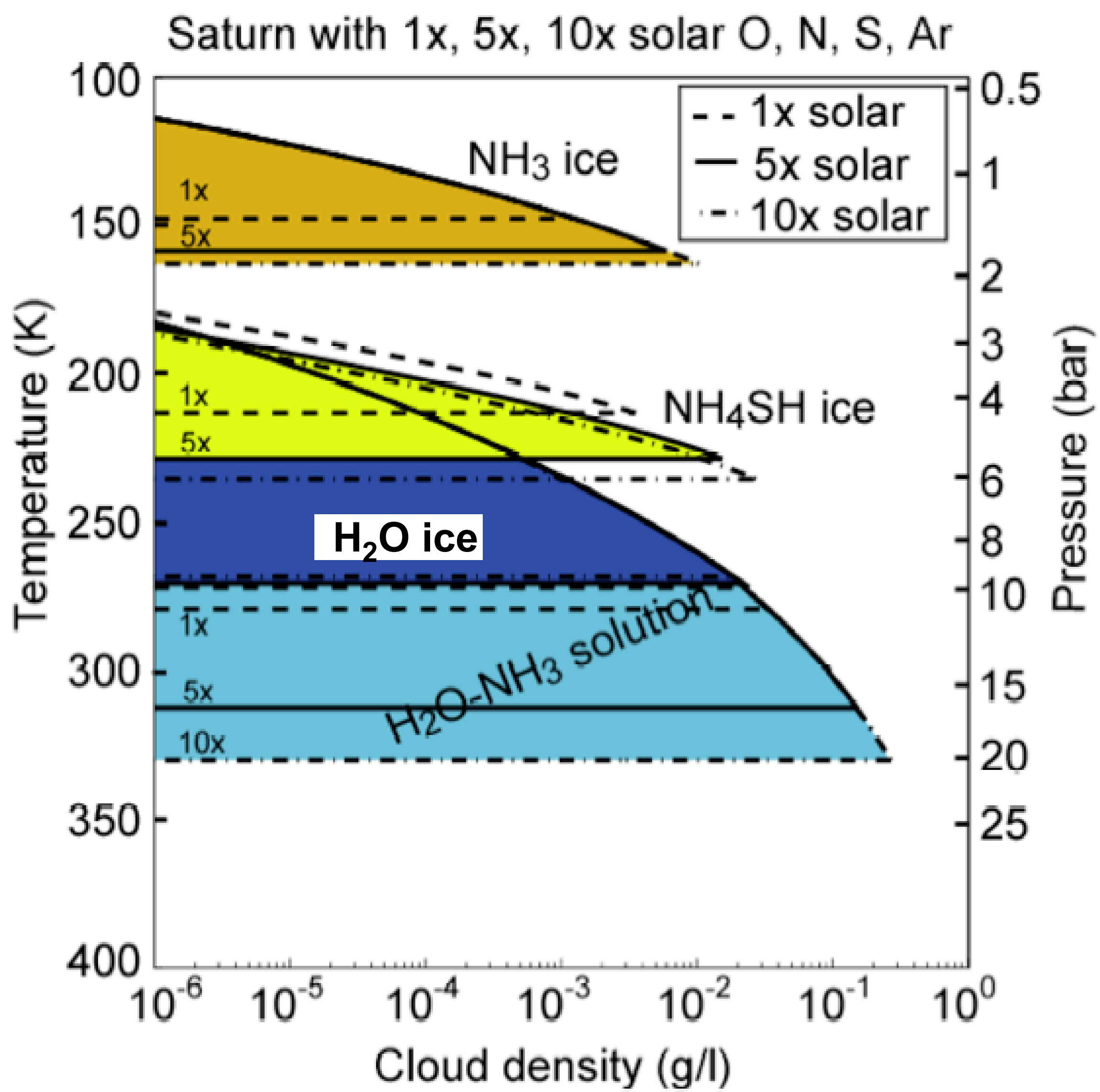
- **Not considered: Advantage of shorter transit time possible by Ares-V**

Outer Planet Atmospheric Science

- **Comparative planetology** of the Outer Planets is key to understanding the **origins and evolution** of our Solar System, validating the planetesimal accretion model [1] and, by extension, that for Exo-Solar Systems.
  - **Heavy element abundances, including isotopes** in well-mixed Giant Planet atmospheres must be characterized.
  - **Water abundance**, as the primary carrier of heavy elements to Outer Planets, must be determined.
  - **Planetary processes** (dynamics, global circulation, interior processes – e.g., disequilibrium species) to be measured in situ.
- **NASA's 2006 SSE Roadmap** replaced the proposed **New Frontiers** class Jupiter Flyby with Probes mission with a **proposed Saturn Flyby with Probes mission*.**

**NASA's 2006 SSE Roadmap,JPLD-35618, September 15, 2006*

Estimated [1] Cloud Distributions for Saturn



Atmosphere should be well-mixed at 100 bars.

Temperatures continue to increase with depth.

Previous Approaches for Saturn Atmospheric Science Options Possibly Afforded by Ares-V

Primary Science Objectives[1,2]

- Measure Heavy Elements & Water abundances to 100 bars

Multiple probes to avoid Galileo's Problem.
Probe Entry Latitude Locations:
- Dissimilar regions (zones/belts);
- e.g., 2 sides of the ±13° Equatorial zone

Microwave Radiometry (MWR).
- MWR on carrier (Flyby or Orbiter)
- Remote sensing of H_2O, NH_3 (water & ammonia are hard to separate / interpret). Non-Uniqueness issue.

Science Driven Requirements

Primary objectives can be met in an alternate way

- **Shallow** Probes
- Down to **~10 bars**

- **Deep** Probes
- Down to **~100 bars**
- *Without MWR*

- **Microwave radiometry (MWR)**
- Down to **~100 bars**

Challenges: In-atmosphere comm., and high temp.operations.

Ares-V Offers a Better Option

- ***Simultaneous*** Deep Probes and MWR. Provides probe "ground truth" validation of MWR Saturn deep water measurement ***and,*** indirectly, those on Jupiter by the Juno Mission (no probes)

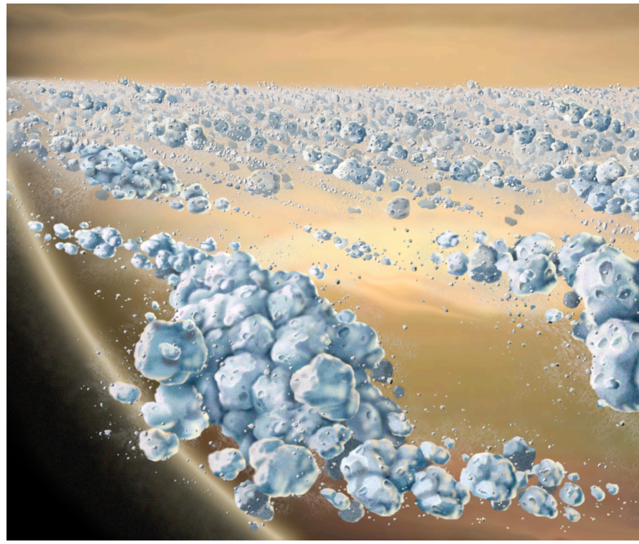
Ref: S. Atreya; T. Balint & FY06 Study Team members; ESA CV-KRONOS Proposal
Ref: SSE Roadmap Team, "Solar System Exploration; This is the Solar System Exploration Roadmap for NASA's Science Mission Directorate", NASA SMD PSD, Report #: JPL D-35618, September 15, 2006; Website: solarsystem.nasa.gov

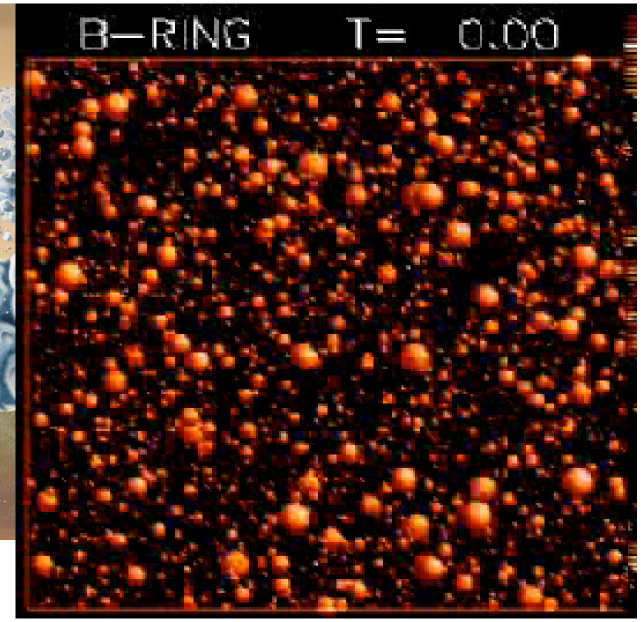
Saturn Ring Science

Desired Observations Enabled by Aerocapture

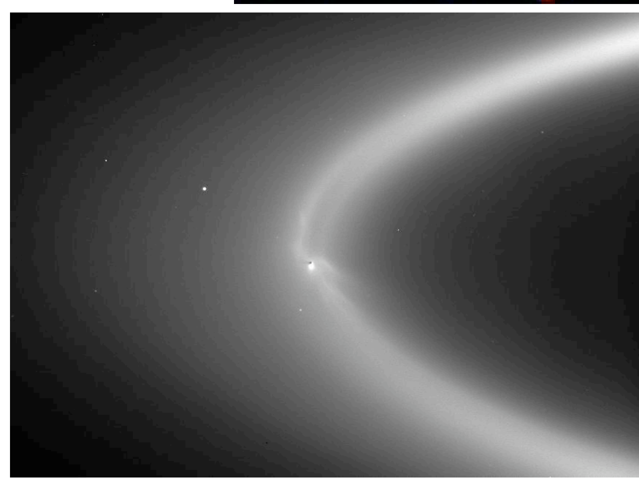
Saturn's Rings: ***Natural test bed for the planetesimal accretion model***

Observation in the A & B rings of time varying "clumping" of matter (typical dimensions are tens of meters).



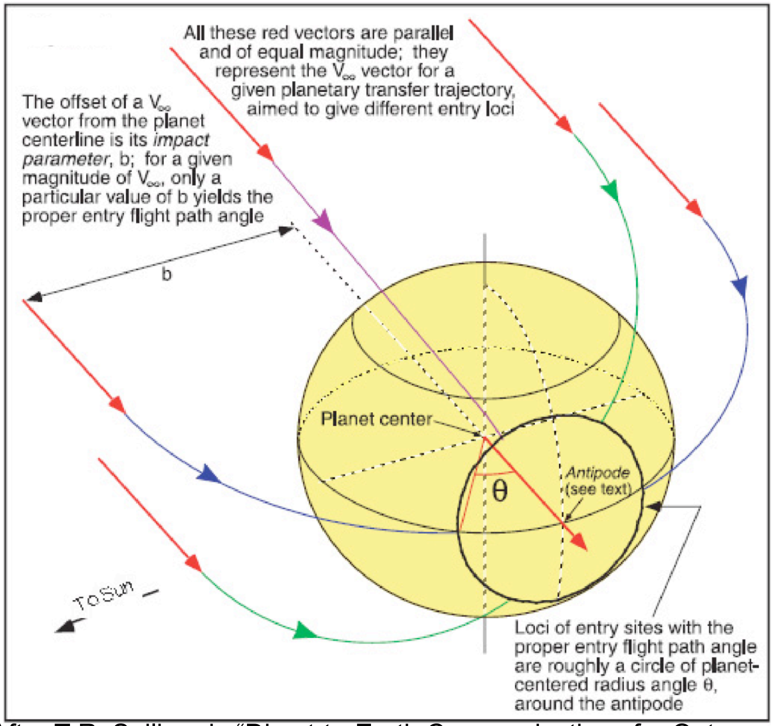


Understanding how matter from Enceladus' South pole contributes to the E ring and ring evolution.



Mission Scenarios

Two entry probes, <u>each</u> of which deploy <u>two</u> descent modules

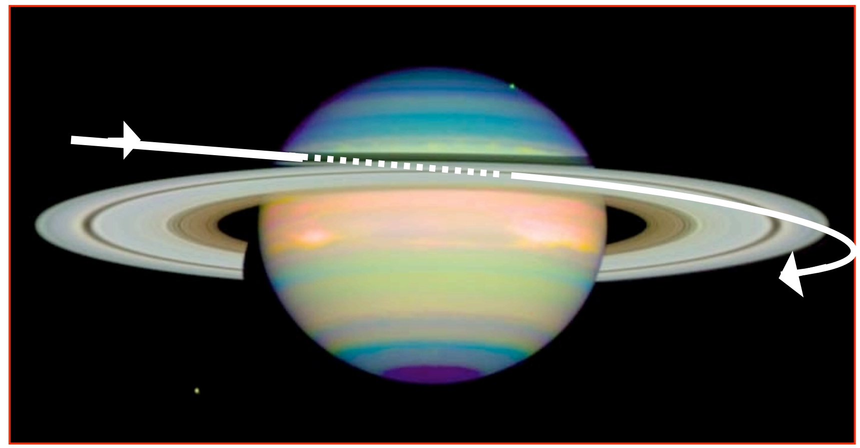


After T.R. Spilker, in "Direct-to-Earth Communications for Outer Planet Entry Probe Missions", International Planetary Probes Workshop 4, Pasadena CA, June 2006.

A deep, fast-moving module is dropped from a shallow, slower-descending module. A flyby provides comm. to Earth

Aerocapture

Insertion into Saturn Ring observation orbit via passage through Saturn's atmosphere from interplanetary trajectory [3]



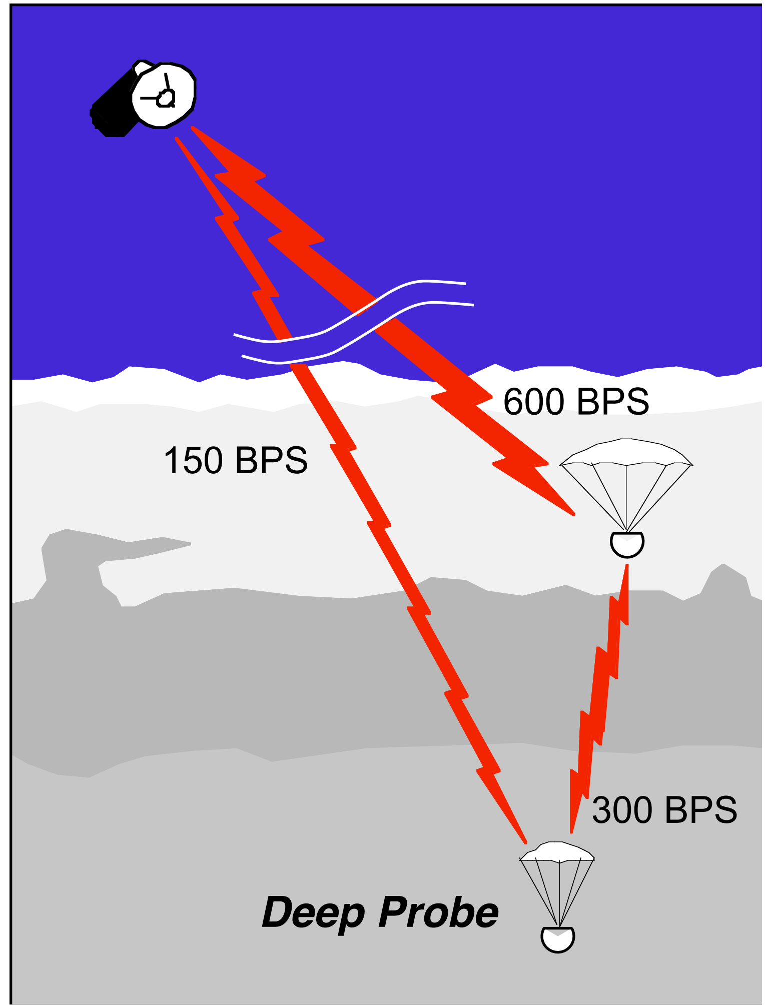
Never Performed - Mixed Opinions regarding TRL

Large mass leveraging possible for Saturn
(infinite % increase for 120,000 km circular orbit)
Ref: M. Munk and T. Kremic, OPAG March 2008

[3] Saturn Ring Observer , T. Spilker IAA-L-0604-2000
SRO flies at 2 km or less below the ring plane !

Communications Relay Between Deep Probes and Orbiter or Flyby Spacecraft

Atmospheric attenuation requires that signals from deep probes must be relayed to assets higher in the atmosphere (other probes or comm relays to flyby spacecraft).



T.R. Spilker, "Planetary Entry Probes in the Foreseeable Future: Destinations, Opportunities, and Techniques", International Planetary Probe Workshop, Lisbon, Portugal, Oct. 8, 2003

Applicability of Some Candidate TPS Materials at Stagnation Point Conditions For Candidate Saturn Missions [4]

Material	Hyperbolic 4540 W/cm^2, 2.97 atm.	Aerocapture 2985 W/cm^2, 1.0 atm.	Flight Heritage
Carbon Phenolic	Robust	Robust	Galileo, P-V
PICA			Stardust, (MSL), (CEV)
Avcoat			Apollo, (CEV)
ACC/Insulator	Robust? Lighter		Genesis
Densified PICA			(CEV)
PhenCarb			None
H/C multi layer*			None

Legend (cell colours):

- Teal (Carbon Phenolic, both columns): Applicable, may be heavy
- Orange (ACC/Insulator, Hyperbolic): Likely Applicable
- Yellow (H/C multi layer*, both columns): Conceptual, *disclosure filed
- Red (all other coloured cells): Not applicable

Proposed Developmental Arcjet Facility (DAF) can provide necessary Hydrogen/Helium Testing and USAF Laser facility (LHEML) can identify failure modes needed for TPS Qualification [4].

Other Technology Challenges

- Spacecraft Power: See [2] for discussion.
- High-Temperature Instrumentation: See IPPW references by Kolawa (JPL), et. al.
- Pressure Vessel capable of going to 100 bars: possibly Pioneer-Venus technology, with slight advancement.
- Communications from Saturn to Earth -- many options possible, depending upon Ares-V launch date.

WAG for Ares-V payload to Saturn

Spacecraft	Mass, kg (WAG)	Basis for WAG
Two probes: Each deploys shallow & deep modules and in-atmosphere comm.	1,700	2.5X Galileo
Flyby for probe-to-Earth communication	1,200	Neptune flyby study
Flyby with MWR for deep atmospheric sounding	1,100	Juno, Neptune flyby
Saturn Ring Observer (SRO)	3,000	90's Team X study
SRO Aerocapture vehicle	3,000	= SRO
"Beyond Cassini" orbiter	5,000	90% of wet Cassini
Total, kg	15,000	

Summary

Given Ares V launch capability and adequate funding, the multi-spacecraft mission to Saturn would provide a huge advancement in our understanding of outer planet formation and validation of the Planetesimal Accretion Model.

- Composition of Saturn's well-mixed atmosphere to 100 bars bars via deep probes by mass spectroscopy. This provides nearly simultaneously (time/location) determined "ground truth" for MWR of Saturn's deep water abundance and, indirectly, validation of Juno's MWR experimental approach.
- Saturn ring observations as a natural, time-dependant laboratory for the study of accretion physics.
- Observations of Saturn's inner moons "beyond Cassini".

Key Technology Challenges are tough, but do-able.

- Thermal Protection Systems (TPS) for Probes and Aerocapture.
- In-atmosphere communications from deep probes.
- Power.
- Pressure vessel.
- Science Instruments that can operate at high temperatures.

Provided WAGs for the mass of spacecraft "fleet" to be launched to Saturn on a single Ares-V vehicle.

Key References

[1] “Saturn Probes Why, Where, How?”, S. Atreya, IPPW4, Pasadena CA, June 2006

[2] “Mission Trades to Explore Saturn with Probes”, T. Balint, J. Cutts, and E. Kolawa, 37th COSPAR Scientific Assembly, Montreal Canada, July 2008

[3] “Saturn Ring Observer”, T. Spilker, Proceedings of the 4 th International Conference on Low-Cost Planetary Missions, IAA-L-0604, May 2000

[4] “Thermal Protection System (TPS) Development, Testing and Qualification for Planetary and Aerocapture Mission Examples: Saturn, Titan and Sample Return”,E. Venkatapathy, B. Laub, G. J. Hartman, J. O. Arnold, M. J. Wright and G. A. Allen, Jr. 37 th COSPAR Scientific Assembly, Montreal Canada, July 2008