Saturn Multi-Probe Architectures

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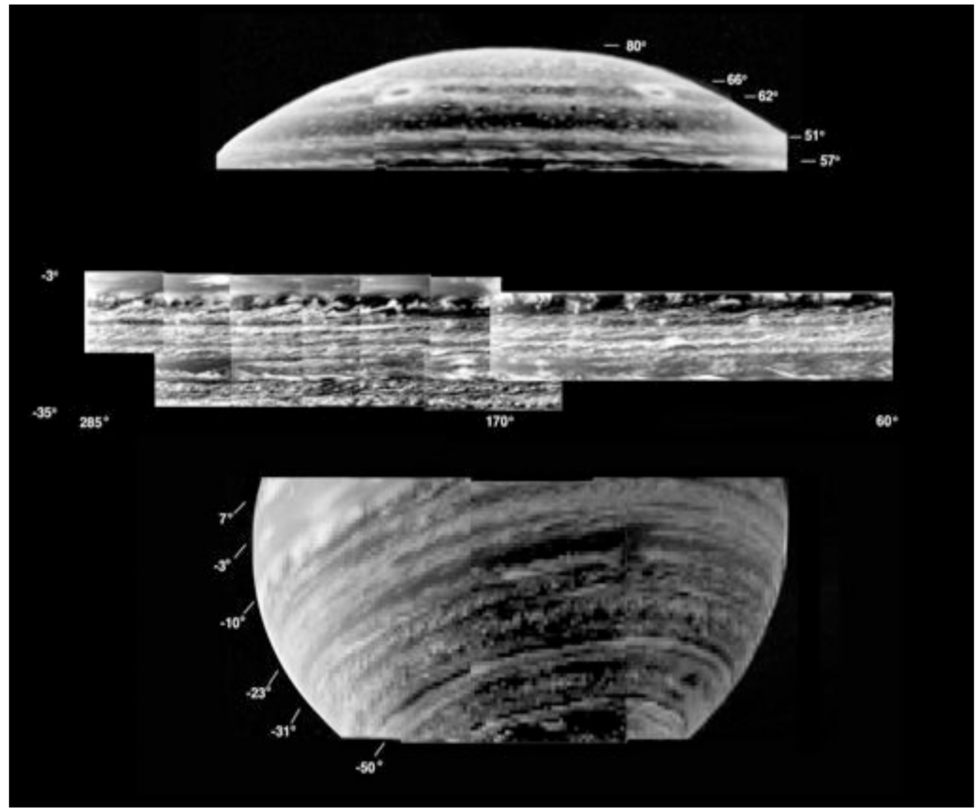
Presented to the Decadal Survey Giant Planets Panel
October, 26 2009

High Priority Science

The key science objectives that would be addressed by a Saturn Probe mission include:

- **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), He relative to solar, Jupiter.
- **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: David Atkinson

Focused Science

Key Measurements to Constrain Composition

Element	Sun	Jupiter/Sun	Saturn/Sun	Uranus/Sun	Neptune/Sun
He	0.09705	.807+/- .02	0.56-.85	0.92-1.0	0.92-1.0
Ne	2.1×10^{-4}	.059+/- .004	?	20-30 (?)	30-50 (?)
Ar	1.7×10^{-6}	5.34±1.07	?	20-30 (?)	30-50 (?)
Kr	2.14×10^{-9}	2.03±.38	?	20-30 (?)	30-50 (?)
Xe	2.10×10^{-10}	2.11 +/- .40	?	20-30 (?)	30-50 (?)
C	2.75×10^{-4}	3.82±.66	9.3 +/- 1.8	20-30	30-50
N	6.76×10^{-5}	4.90±1.87	2.6-5	20-30 (?)	30-50 (?)
O	5.13×10^{-4}	.48±.17 (a)	?	20-30 (?)	30-50 (?)
S	1.55×10^{-5}	2.88±.69	?	20-30 (?)	30-50 (?)
P	2.57×10^{-7}	4.8 (b)	5-10	20-30 (?)	30-50 (?)
Isotope	**Sun**	**Jupiter**	**Saturn**	**Uranus**	**Neptune**
D/H	2.1±.5E-5	2.6±.7E-5	2.25±.35E-5	5.5(+3.5,-1.5)E-5	6.5(+2.5,-1.5)E-5
$^3He/^4He$	1.5±.3 E-5	1.66±.05 E-5			
$^{15}N/^{14}N$	$\leq 2.8 \times 10^{-3}$	$2.3 \pm .3 \times 10^{-3}$			

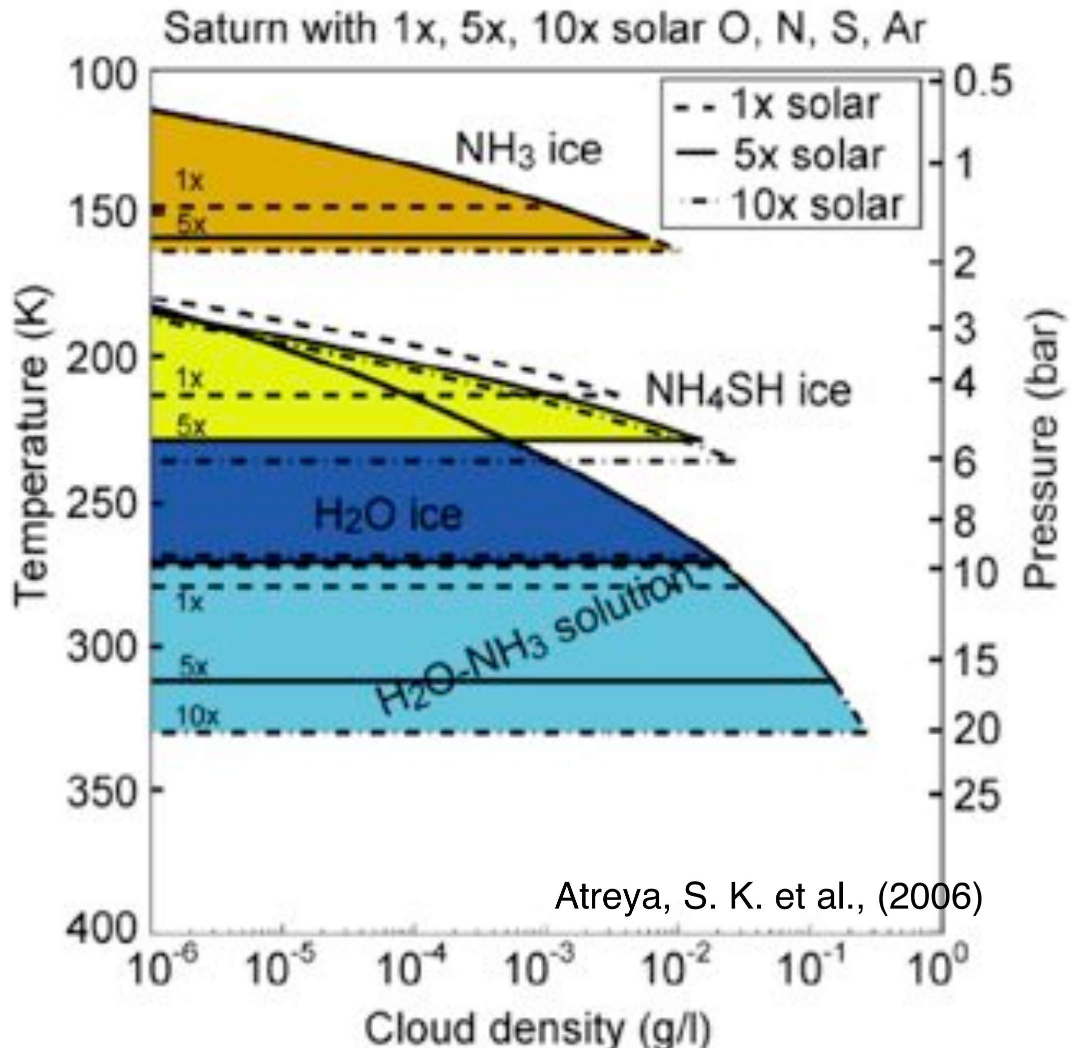
(a) Jupiter hotspot meteorology

(b) Fletcher, L.N., et al., Icarus, 202, 543–564, (2009). Relative to solar composition of Grevesse et al (2007)

Focused Science

The "Tall Pole" is still just how deep does one need to go:

- The water depth could be as shallow as 20 bars or deeper than 50 bars
- Any measurement below 30 bars could provide a strong constraint on models
- The problem has been always how to get deep

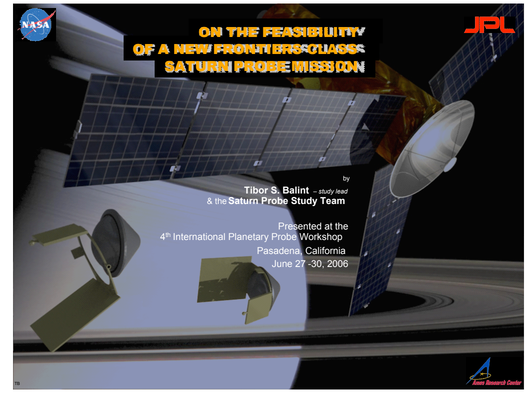


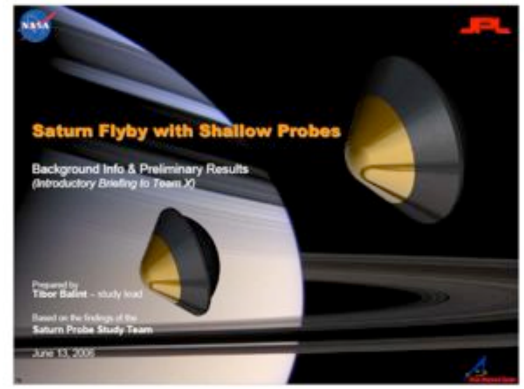
Atreya, S. K. et al., (2006)

A Well Studied Problem…

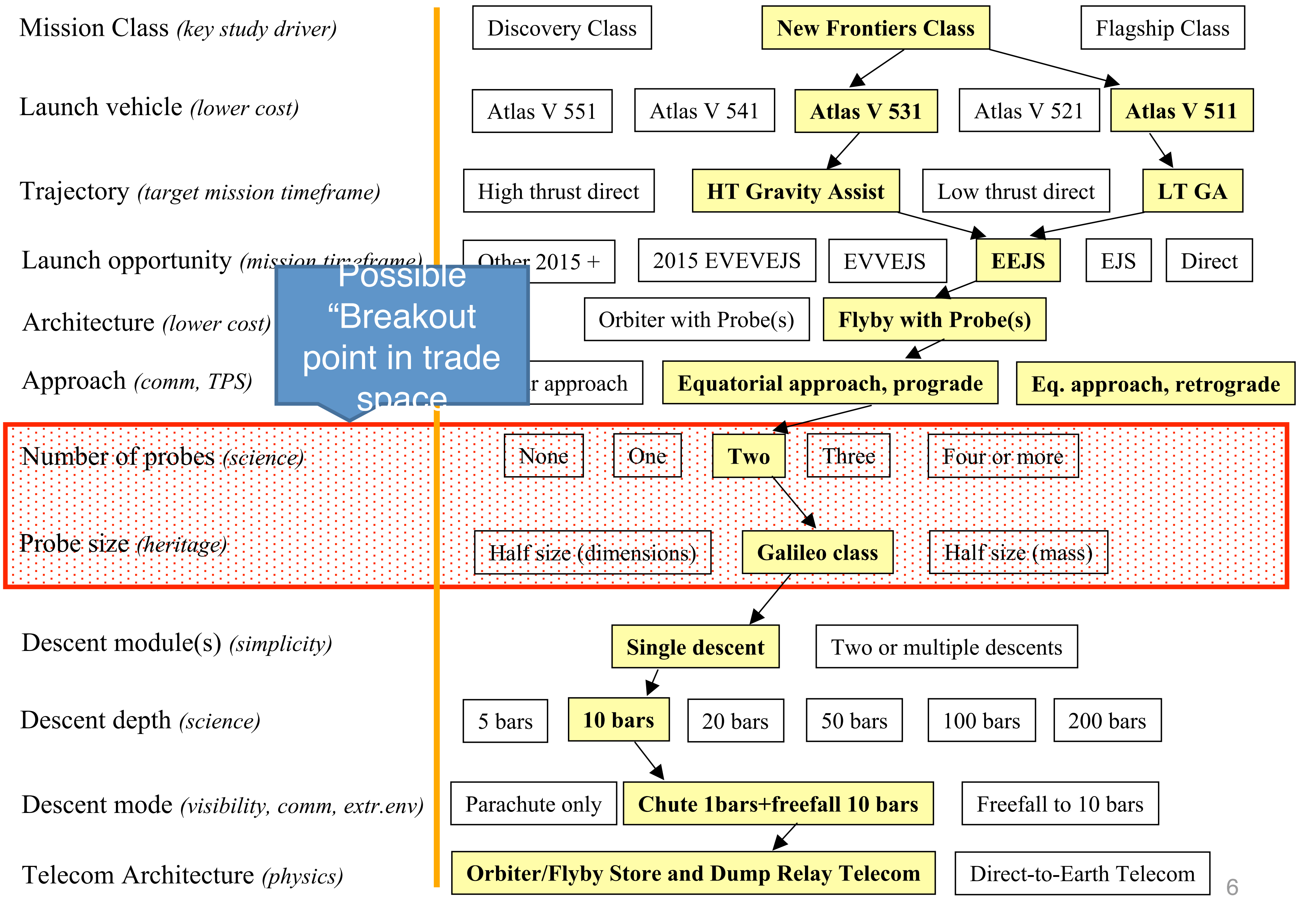
But No Obvious Solution Yet Within NF Budget

- The science is compelling, thus several mission studies have been conducted
- Most recent focus on multi–probes (two) of Galileo stock (e.g., similar size, measurement types, and complexity)
- Typically had to limit themselves to only shallow probes (<10 bars) due to technical issues primarily surrounding telecom (in particular telecom window vs descent time)
- Has been difficult to close the mission within previous New Frontiers cost cap (more recent studies show it would be close)
- Several other novel approaches may result in a “breakout solution”





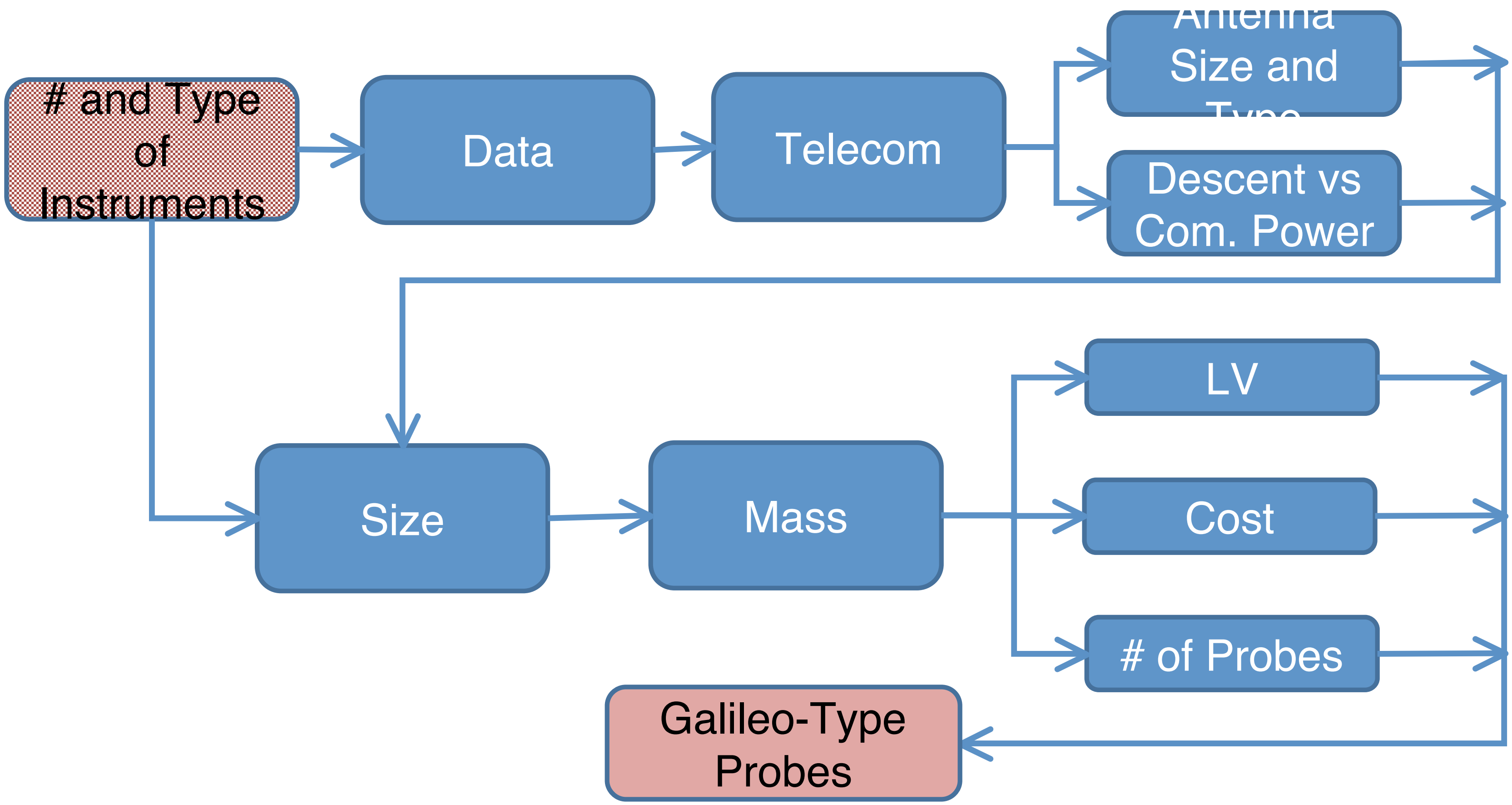
Previous Trade Elements & Decision Drivers



(from Balint et al., 2006

Probe Size and Data Rate Drive Architecture

A high-level view to illustrate how two key parameters drive design to the same conclus



Traditional trade loop usually ends with Galileo heritage probes; Not a bad thing if one wants to stay shallow (~10 bars), as to go deeper would drive to a larger, more massive and costly combination Galileo/Pioneer-Venus-type probe to account for the increasingly harsh environment (p/T).

The Galileo Instrument Suite

Instrument	Mass	Power	Bit rate	Volume	Special Acc. Requirements
Atmosphere structure instrument (ASI)	4.0 kg	6.3 W	18 bps	3100 cm^3	Pressure inlet port; temperature sensor outside boundary layer; 12,408 bits storage
Nephelometer (NEP)	4.8 kg	13.5 W	10 bps	3000 cm^3	Free-stream flow through sample volume; 800 bits data storage; pyro for sensor deployment
Helium abundance detector (HAD)	1.4 kg	1.1 W	4 bps	2400 cm^3	Sample inlet port
Net flux radiometer	3.0 kg	10.0 W	16 bps	3500 cm^3	Unobstructed view 60° cone +/-45° with respect to horizontal
Neutral mass spectrometer (NMS)	12.3 kg	29.3 W	32 bps	9400 cm^3	Sample inlet port at stagnation point
Lighting and radio emission detector/ energetic particle detector (LRD/EPI)	2.5 kg	2.3 W	8 bps	3000 cm^3	Unobstructed 4P Sr FOV; RF transparent section of aft cover, 78° full cone view at 41° to spin axis
Total	**28 kg**	**62.5 W**	**128 bps$^+$**	**24,400 cm^3**	

An example of a "focused" Instrument suite that addresses a subset of critical science measurements would only include those underlined in red.

Alternate Architectures

An alternate Architecture would start with the most focused payload possible

For example, to address the critical questions regarding composition, the most important instruments are:

- Neutral Mass Spectrometer (NMS) or Gas Chromatograph Mass Spectrometer (GCMS)
- Atmosphere Structure Instrument (ASI)

Accepting just these two measurement/instrument types would approximately halve the data, mass, and power requirements of the payload

- This assumes no improvements over Galileo instrumentation, which is an incorrect assumption
- Significant savings can be realized in reduced mass instrumentation, in particular in the area of the NMS/GCMS

The lower mass, power and data rate can result in a smaller probe

- Assuming a payload mass fraction of approximately 10% the probe mass, a 100-150 kg probe is a reasonable goal

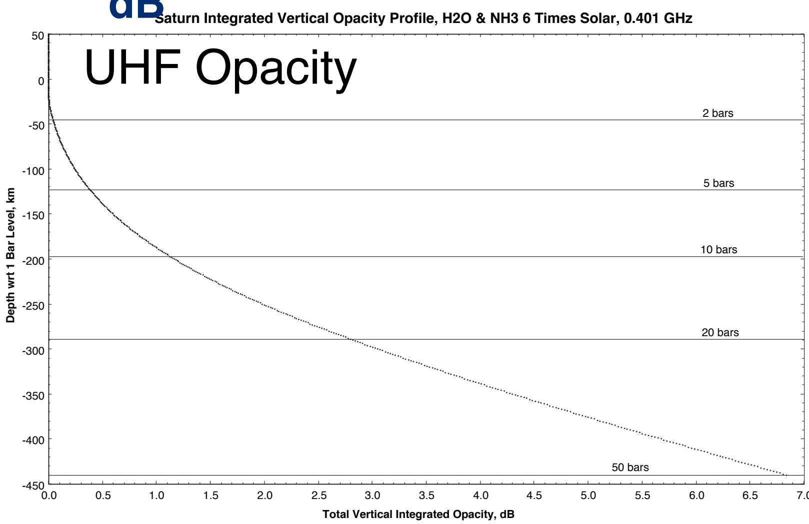
Additional instrumentation may include:

- Tunable Diode Laser (for compact water and D/H measurements)
- Microwave radiometer (MR) (from carrier for remote sensing of deep water)
  - Optimum MR measurements from carrier may be inconsistent with optimum carrier-to-probe requirements

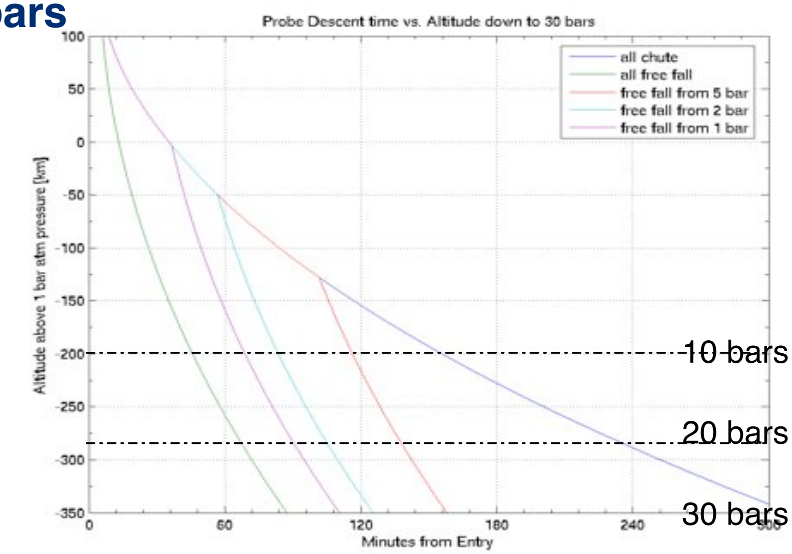
Alternate Architectures

With a focused payload, one still must overcome the atmosphere attenuation and descent time if one wants to go deep (>40 bars).

At 50 bar UHF opacity loss is ~7 dB



Free fall descent time ~2 hours to reach 40 bars



The atmospheric opacity and descent conspire to severely limit the total data rate from a probe:

- Opacity increases approximately as f^2; lower frequency reduces attenuation.
- As the probe falls, both the atmospheric attenuation and range to the carrier/relay spacecraft *may* increase
- At ~2 hours from entry UHF data rates are down to about 100 bps
- A focused payload again helps by limiting the data rate, but to get deep, the range may still need to be mitigated

Alternate Architectures

So how to get deep?

Maybe one doesn’t: Microwave radiometry (e.g., Juno) on Carrier

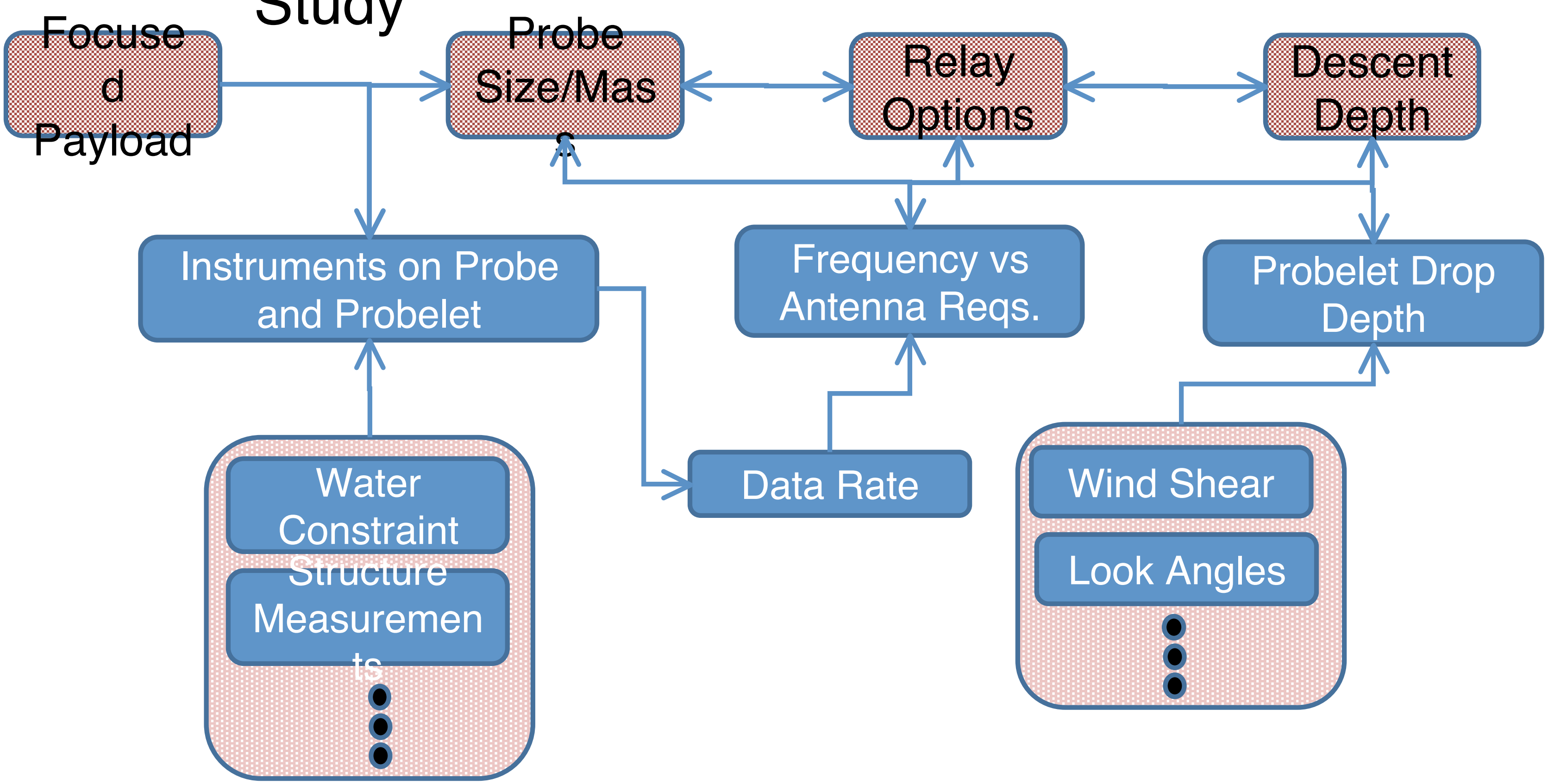
- or –

Extend the relay concept that is nominally between the Probe-Carrier-Earth to an additional “deep” probe: The “Chain of Probes”

- “Mother Probe” stays shallow (1-10 bars)
  - Deploys chute to slow descent
  - Relays between “Probelet” (dropsonde) and Carrier
  - Contains full payload compliment (composition and structure).
- “Problet” dropped for free descent
  - Freefall descent to get deep quick
  - Further reduced instrument suite to limit data rate (e.g., only TDL or NMS)

Alternate Architectures

Example of New Trade Space Needing Study



A fresh look, beginning with a focused measurement set, greatly opens otherwise closed trade space

Conclusions / Recommendations

- Critical, high-priority science at Saturn can be accomplished with a **very focused** set of measurements

- Maintaining a disciplined approach to minimizing the payload will ripple through the system, reducing required mass, power, data rates, and data volume.

- These savings can result in a overall **reduction in probe size (by ~50% or more)**, which in turn enables consideration of multiple-probe concepts

- A new multi-probe concept, the Chain-of-Probes, has the potential to enable deep (>40 bar) in-situ measurements
  - If limiting agent is descent time and depth, a chain-of-probes and/or carriers (flying in secession) may double probe-to-carrier visibility

- Moving to a small, multi-probe architecture re-opens previously closed trade space

- It is recommended that a Rapid Mission Architecture (RMA) study be supported to evaluate the variety of mission architectures and trade space opened with a focused payload, including multi-probe systems that utilizes probes in a relay chain is recommended