Basic Questions about the Solar System: The Need for Probes

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Relevance to NASA/OSS Objectives: SSE Roadmap

- Origin and evolution of our SS
- What our SS tells about extrasolar systems
- Distribution of volatile compounds in SS
- Differences among terrestrial planets
- SS characteristics that led to origin of life
- Sources of prebiotic compounds
- Habitable zones in the SS

Scope of this Talk, History

- Venus - Venera probes (Soviet Union) and Pioneer Venus Probes (US)
- Titan - Huygens probe (ESA) and Cassini spacecraft (US)
- Giant Planets - Galileo probe (US)

Documents and Sources

- Decadal Survey (DS) - *New Frontiers in the Solar System,* Michael J. S. Belton, chair (National Academy of Sciences, 2003)
- Community White Papers (CWP) - *The Future of Solar System Exploration, 2003-2013,* Mark V. Sykes, editor (Astronomical Society of the Pacific, 2002)

What Probes Measure (1 of 3)

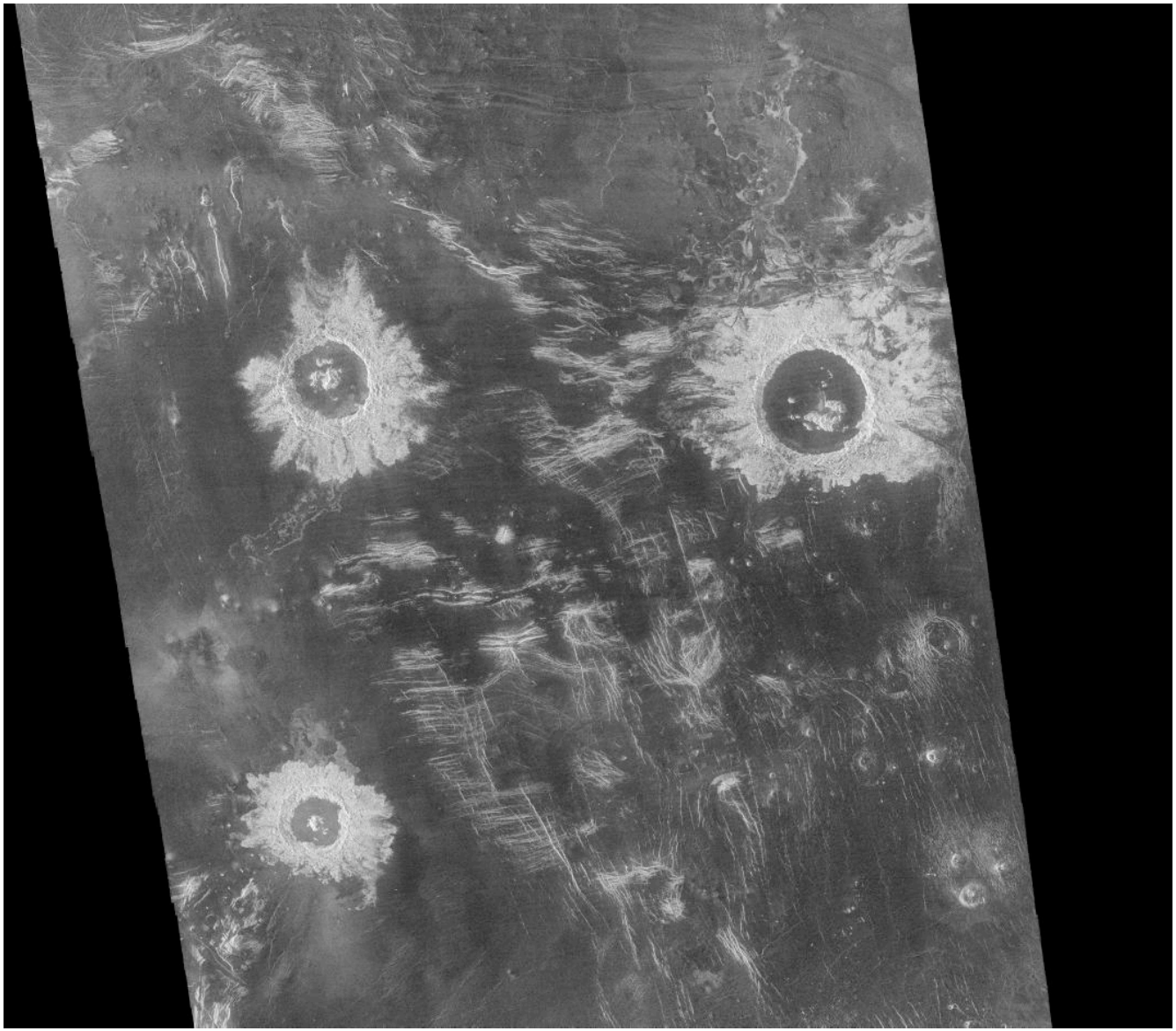
- Atmospheric chemical composition - major and minor constituents including noble gases and isotopes (gas chromatographs, mass spectrometers, optical spectrometers, chemical sensors)
- Atmospheric physical structure - T, P, ρ, turbulence, waves - all as functions of depth
- Clouds - particle properties (composition, size, shape, optical constants) and vertical distribution

What Probes Measure (2 of 3)

- Large-scale winds from Doppler tracking and VLBI, turbulence and waves from accelerometers and on-board wind sensors
- Radiative heating from optical and IR sensors (net flux radiometer)
- Miscellaneous - lightning, He/H_2, radio opacity (NH_3), exosphere composition

What Probes Measure (3 of 3)

- Probes deliver landers to the surface of Venus and Titan, and with difficulty, Mars
- Observe surface morphology, mineralogy, elemental composition, subsurface structure, seismology, surface-atmosphere interaction
- Probes deliver aerobots (balloons, airplanes, helicopters) that survey the surface remotely at altitudes 1/100 of orbital altitude

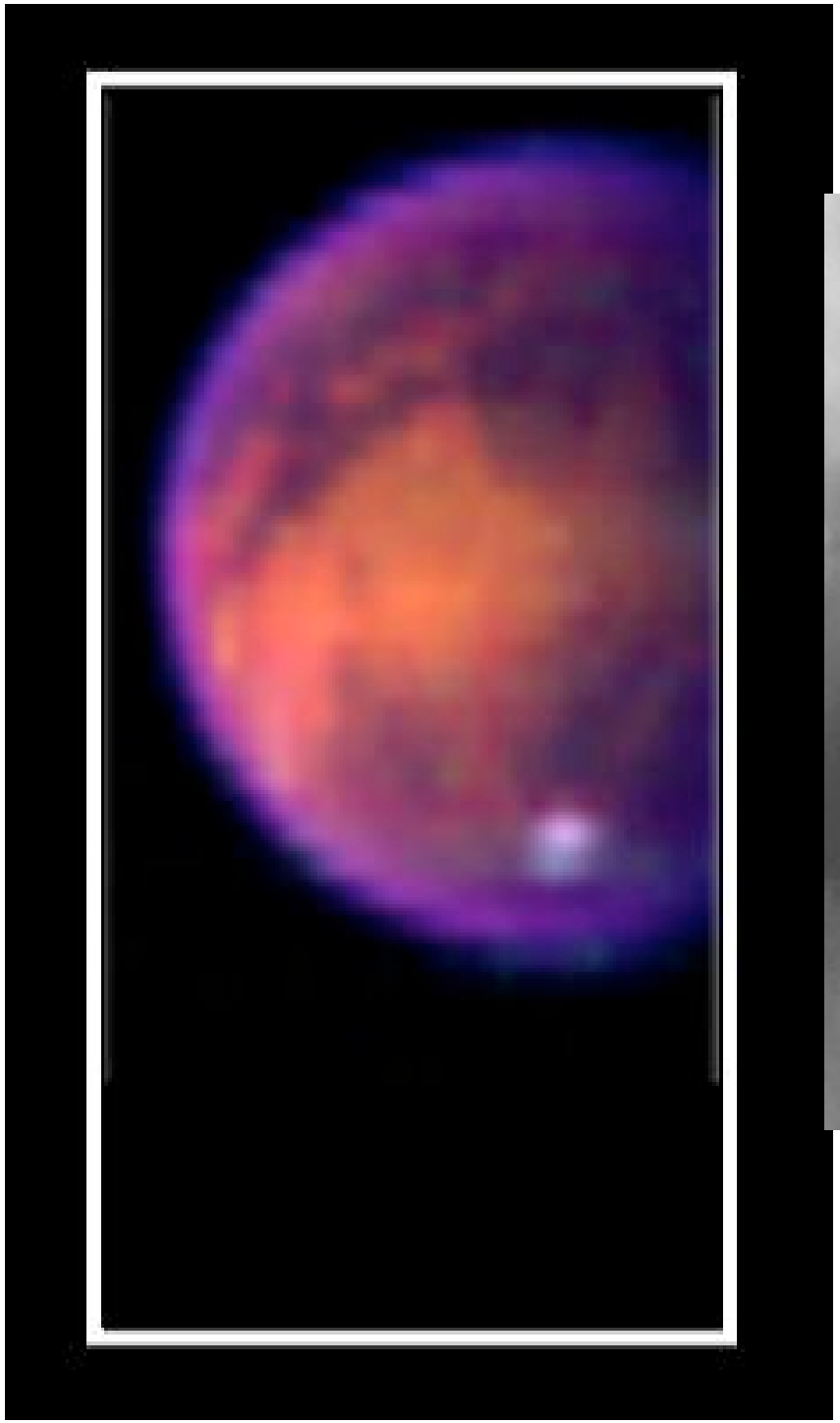


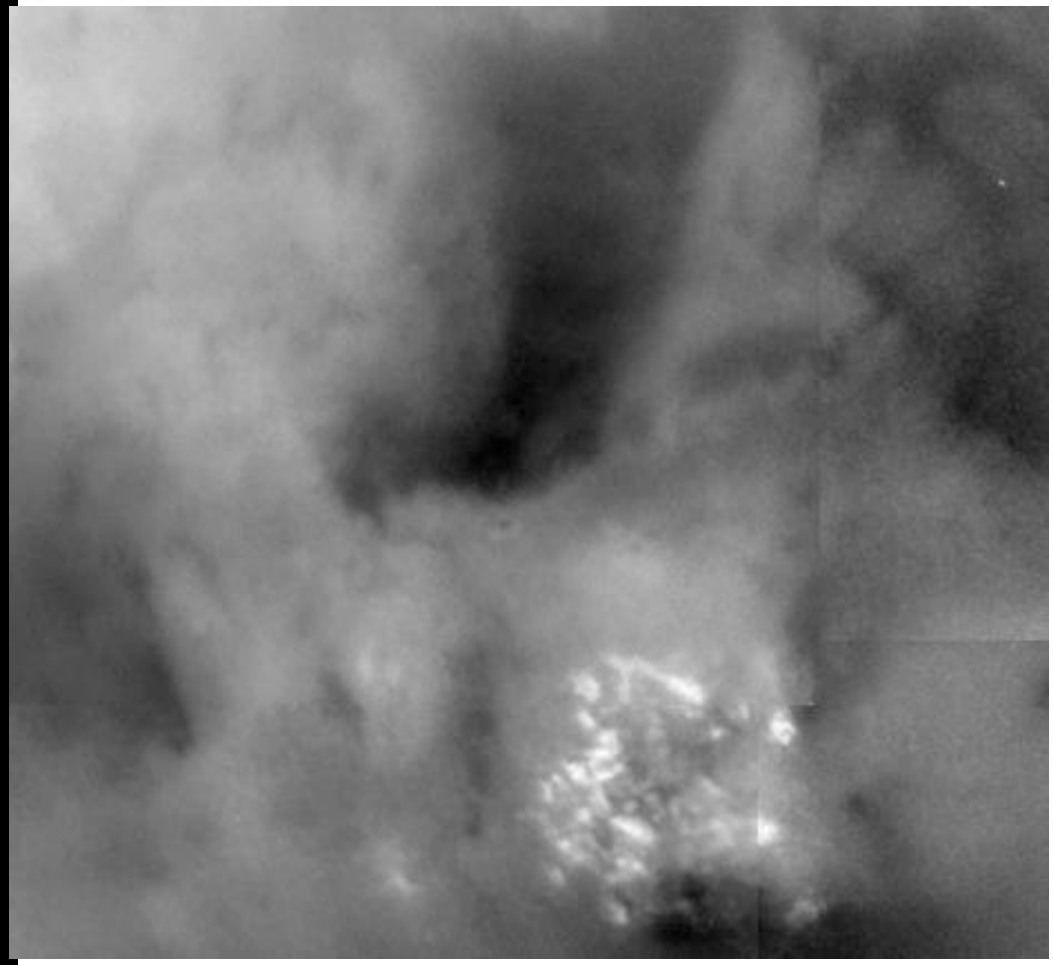
Venus Science Questions

- Surface history - impacts, tectonics, volcanism, erosion; global resurfacing “event” 500 Myr BP?
- History of water (loss of an ocean) and evolution of the atmosphere - noble gas composition, isotopes of O & H, outgassing, reactions with surface (C, S, O, H, Cl)
- Greenhouse effect and climate - trace gases, clouds, penetration of sunlight, IR opacity
- Super-rotation of the atmosphere

Recommended Venus Missions

- VISE (DS) - Compositional and isotopic analysis of atmosphere, core sample of the surface lofted to balloon altitude and analyzed there, winds and radiometry during descent and at balloon station
- Noble gas and trace gas explorer (CWP) - single probe to the surface
- Dynamics explorer (CWP) - Four to eight probes
- Landers (months to year), sample return (CWP)



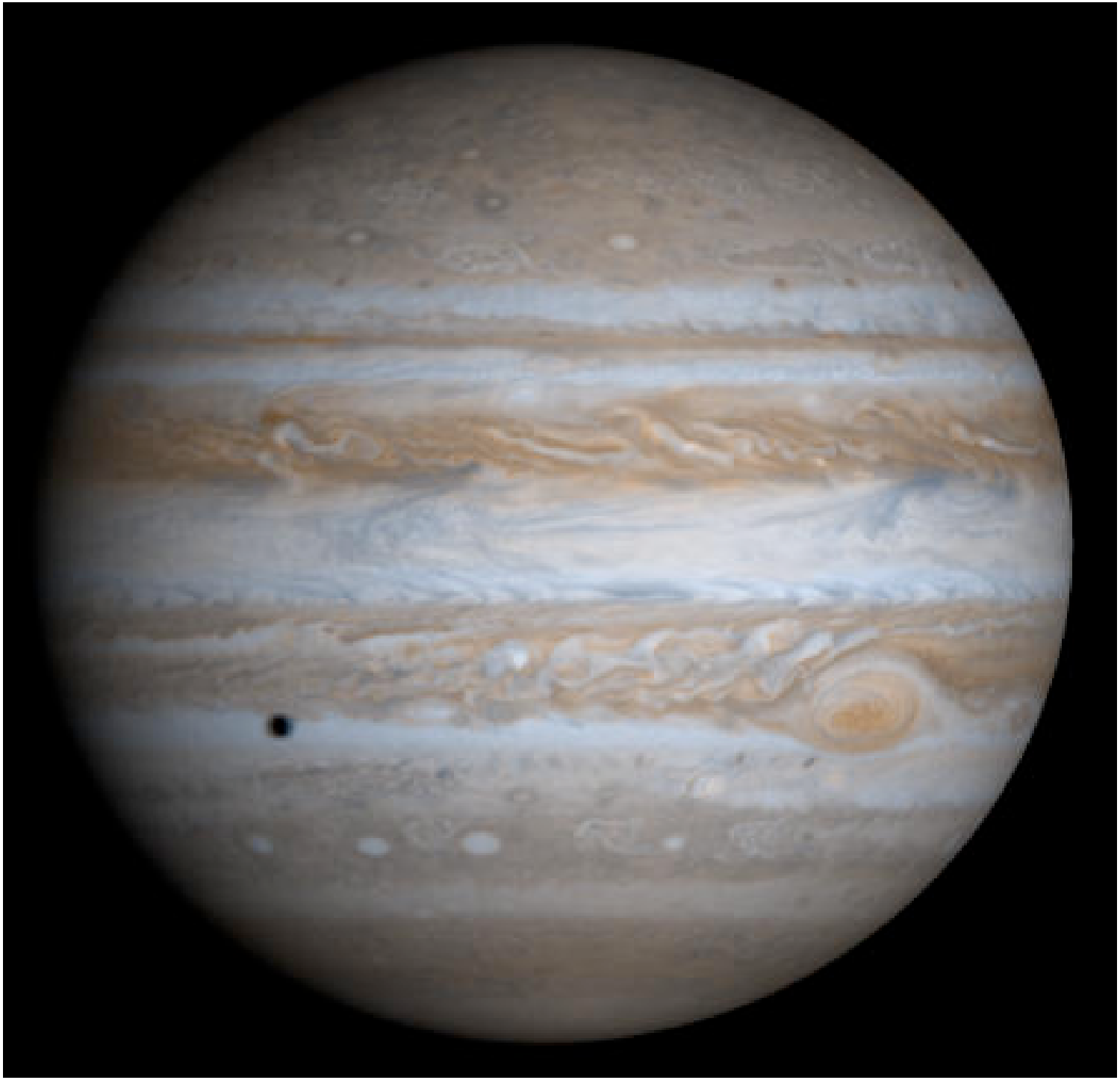


Titan Science Questions

- Composition and extent of surface organics
- Subsurface ocean - composition, depth
- Evidence of episodic heating and exposure of organics to aqueous solutions
- Atmospheric dynamics - winds, clouds, precipitation, radiative heating, atmosphere-surface interaction

Recommended Titan Missions

- Titan Explorer (DS) - orbiter (for relay) and probe (aerobot); use atmosphere for mobility; descend repeatedly to the surface; make high-resolution remote observations and repeated atmospheric measurements
- Airship and mobile lander (CWP) - balloons, airplane, or helicopter.
- Radioisotope power source is critical



Giant Planet Science Questions

- Composition of their atmospheres and interiors - water is key (O/H ratio); major elements, noble gases, isotopes; cloud base may exist only for Jupiter and Saturn
- Liquid oceans on Uranus and Neptune?
- Deep winds, temperature structure, clouds, radiation, convection, lightning - relation to meteorology at cloud top level

Recommended Giant Planet Missions

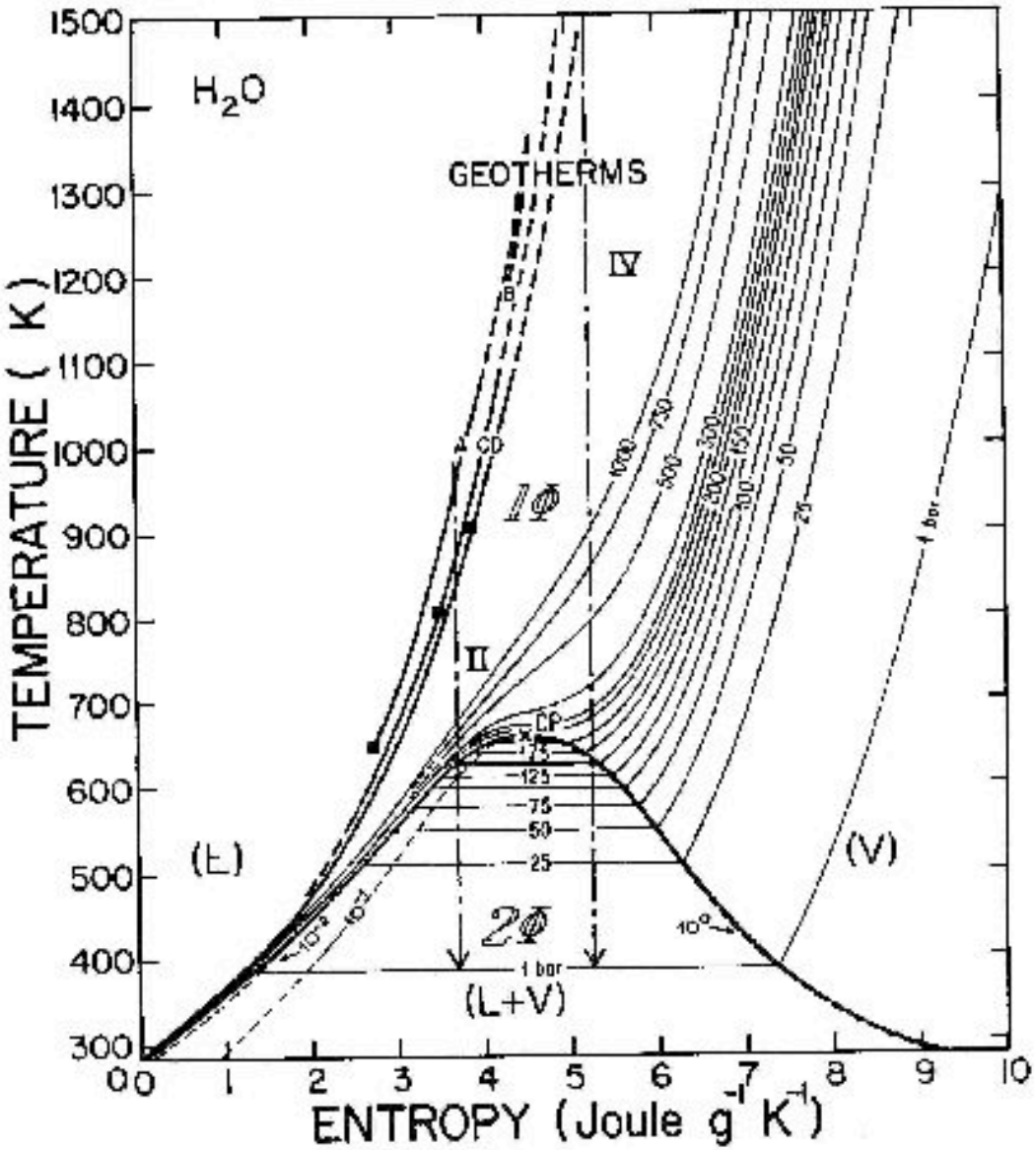
- JPOP (DS) - Polar orbiter with probes at 3 different latitudes (≤ 30°) down to 100 bars
- Neptune Orbiter with Probes (DS) - measure planet's C, S, noble gases, isotopes
- Jupiter Microwave Sounder (CWP) - Either orbiter or flyby; water & ammonia to 100 bars and below, no noble gases or isotopes
- Deep probes to all giant planets (CWP); can we detect probe signals directly at Earth?

Generic Recommendations (DS)

- Thermal protection system for probes and aerocapture - Jupiter is the driver
- Radioisotope power sources
- Nuclear-powered electric propulsion
- Advanced telecommunications
- Balanced program - factors of 2 in cost - Discovery, New Frontiers, Flagship
- 2xFlagship, Prometheus, humans on Moon/Mars

Oceans on Uranus and Neptune

- Bulk density and cosmic O abundance imply planet is 15% H_2 , 85% H_2O by mole
- Internal heat implies convection, which implies moist adiabatic structure
- Must pass through T = 63 K, P = 1 bar
- Need a liquid water interface at T ~ 560 K, $P(H_2)$ ~1.5 kbar, $P(H_2O)$ ~ 75 bar


H2O
GEOTHERMS
TEMPERATURE (K)
ENTROPY (Joule g-1 K-1)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
0
1
2
3
4
5
6
7
8
9
10
I
II
IV
CD
CP
1Φ
2Φ
(L)
(V)
(L+V)
1 bar
1000
750
500
300
150
100
50
25
10
-125
-75
-50
-25