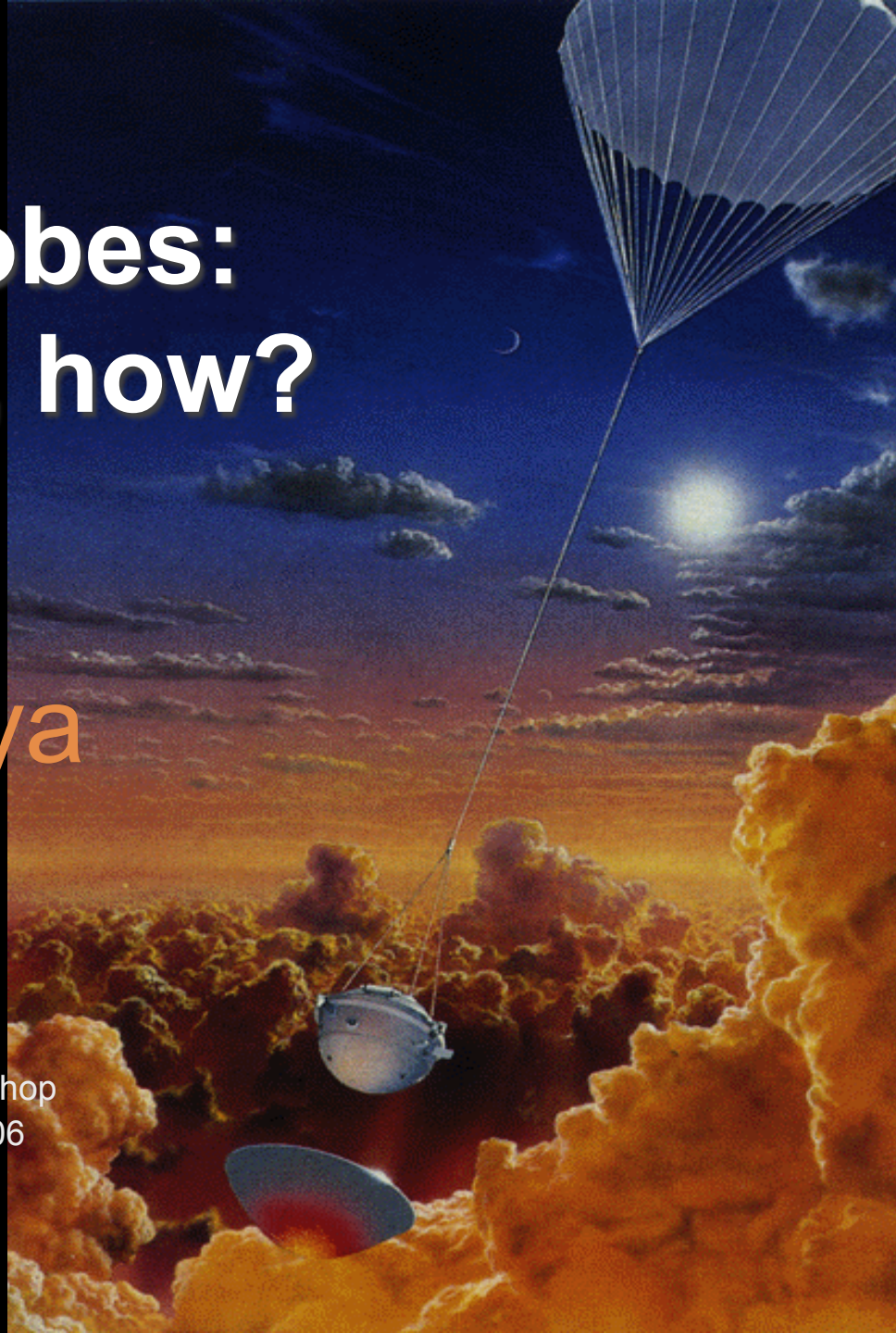
Saturn Probes: why, where, how?

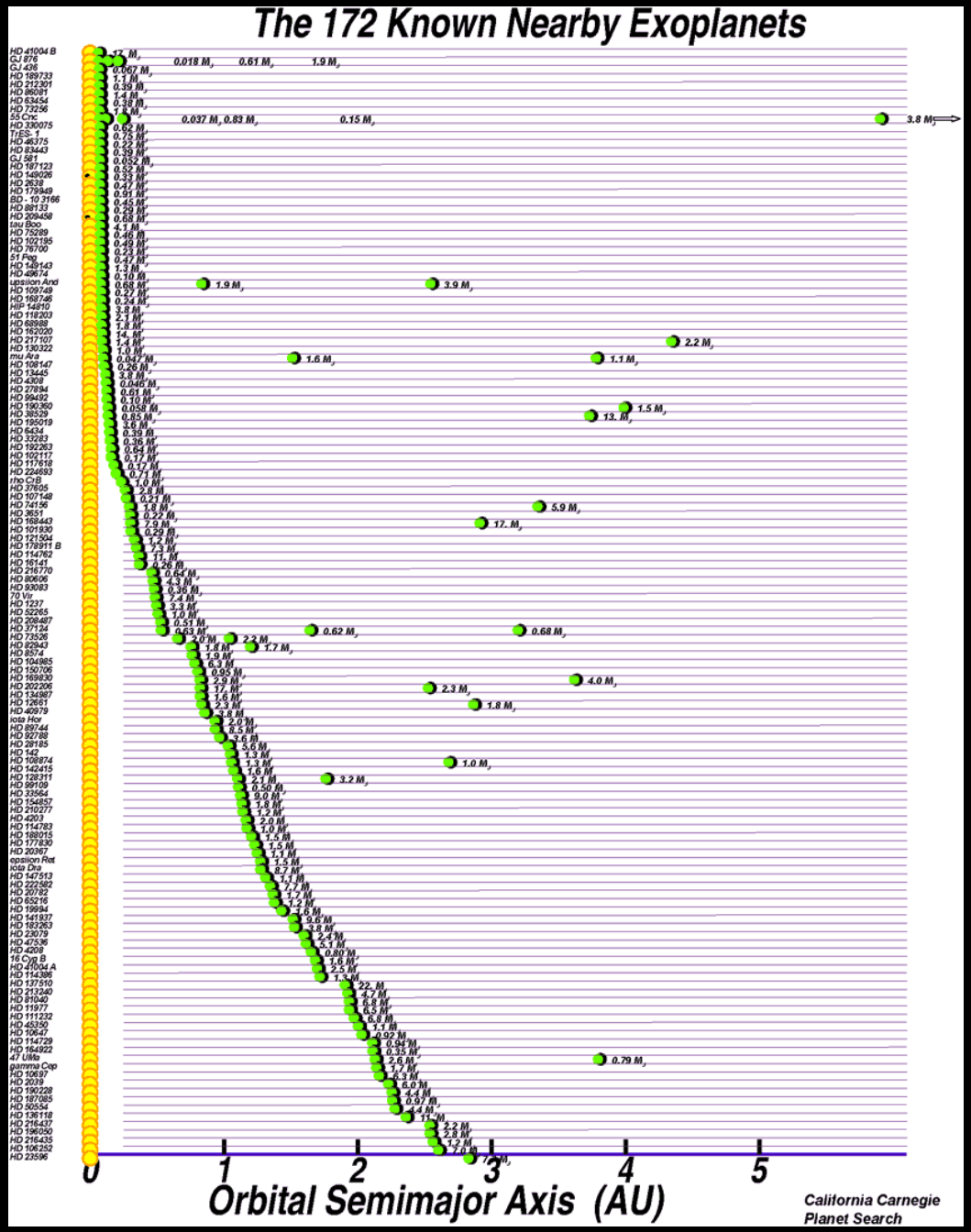
Sushil Atreya

International Planetary Probe Workshop
Pasadena, California, 28 June 2006

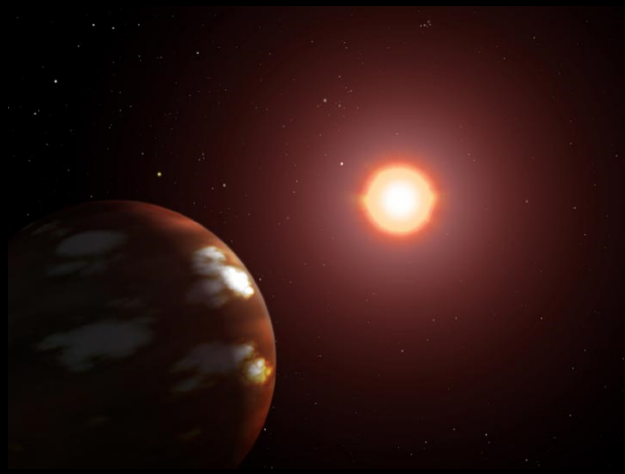


map

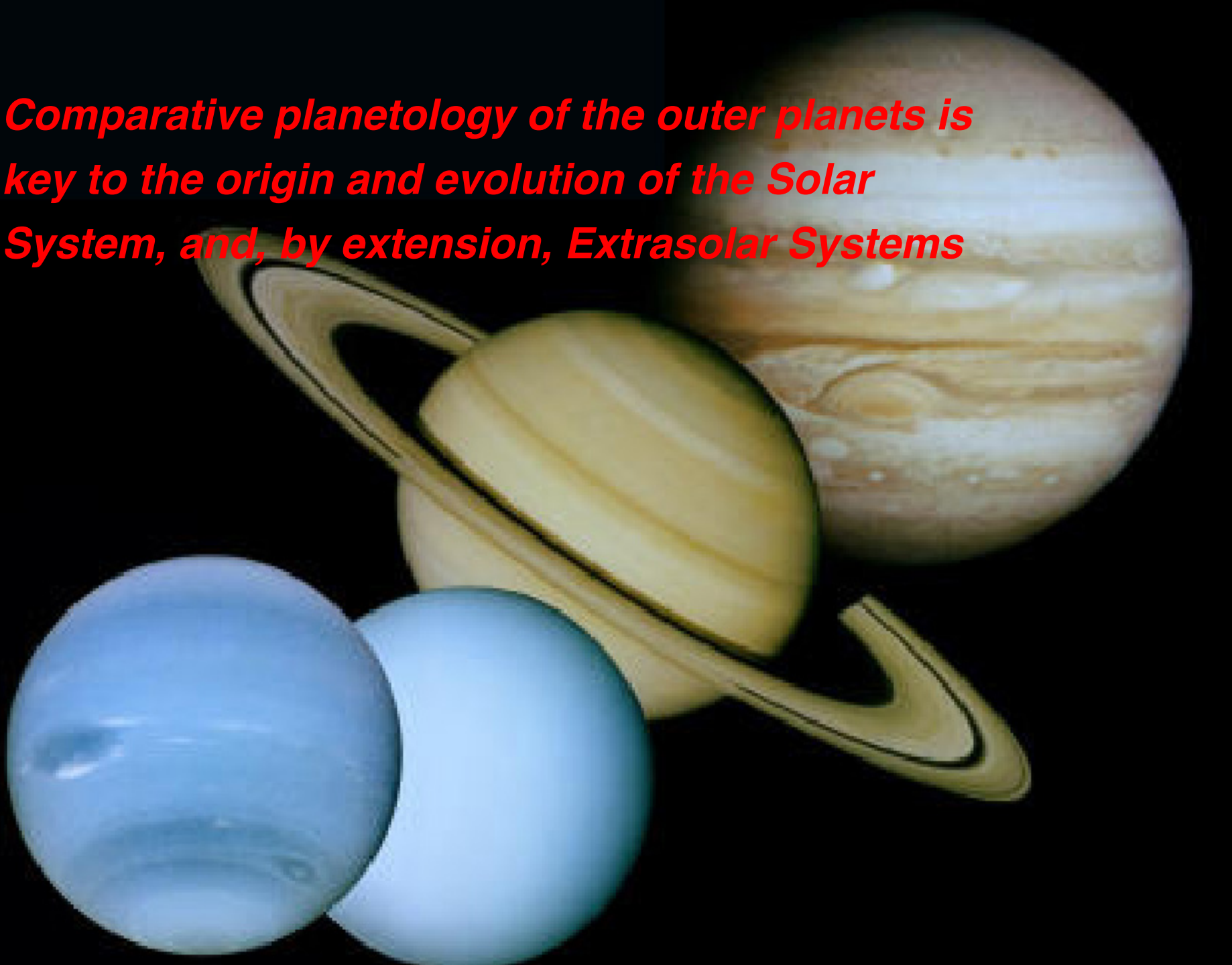
- why even bother with the giant planets?
- why Saturn now?
- what about Cassini?
- what to expect - jovi-centric view?
- where to go?
- what to measure, and how?



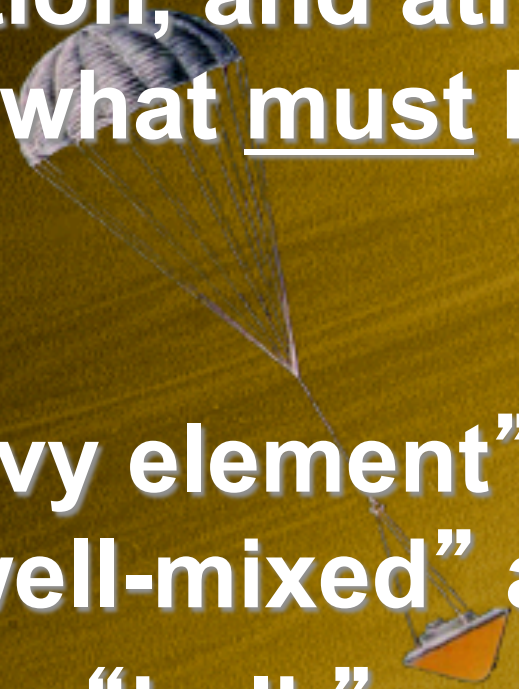
Extrasolar Giant Planets (EGP)



Comparative planetology of the outer planets is key to the origin and evolution of the Solar System, and, by extension, Extrasolar Systems



formation, and atmospheric origin: what <u>must</u> be known?



“heavy element”* abundances in “well-mixed” atmosphere, i.e. <u>“bulk” composition</u>

* m/z > ^{4}He

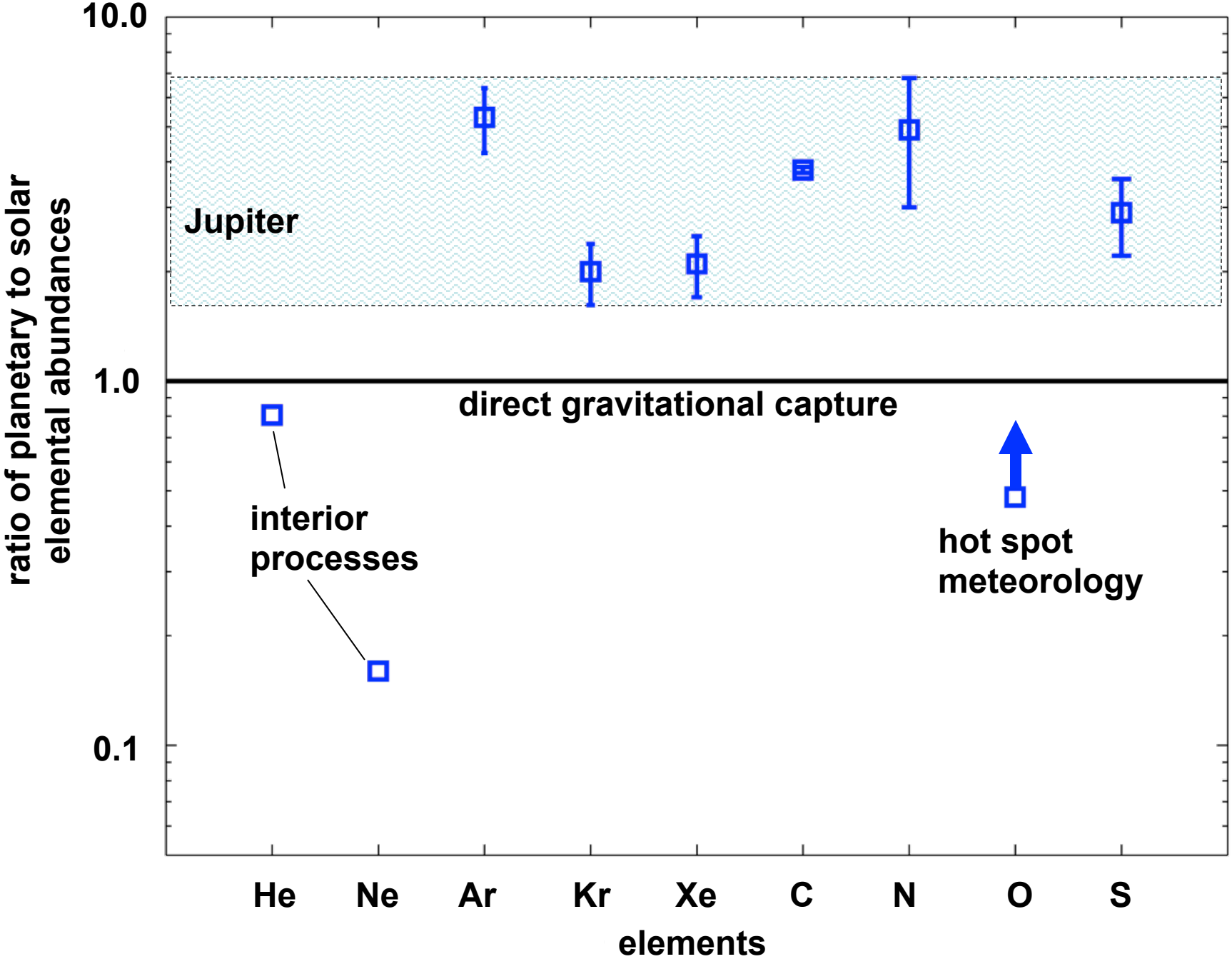
jovi-centric view of giant planet formation…

formation of Jupiter and origin of atmosphere

***gravitational instability: protoplanetary clumps**

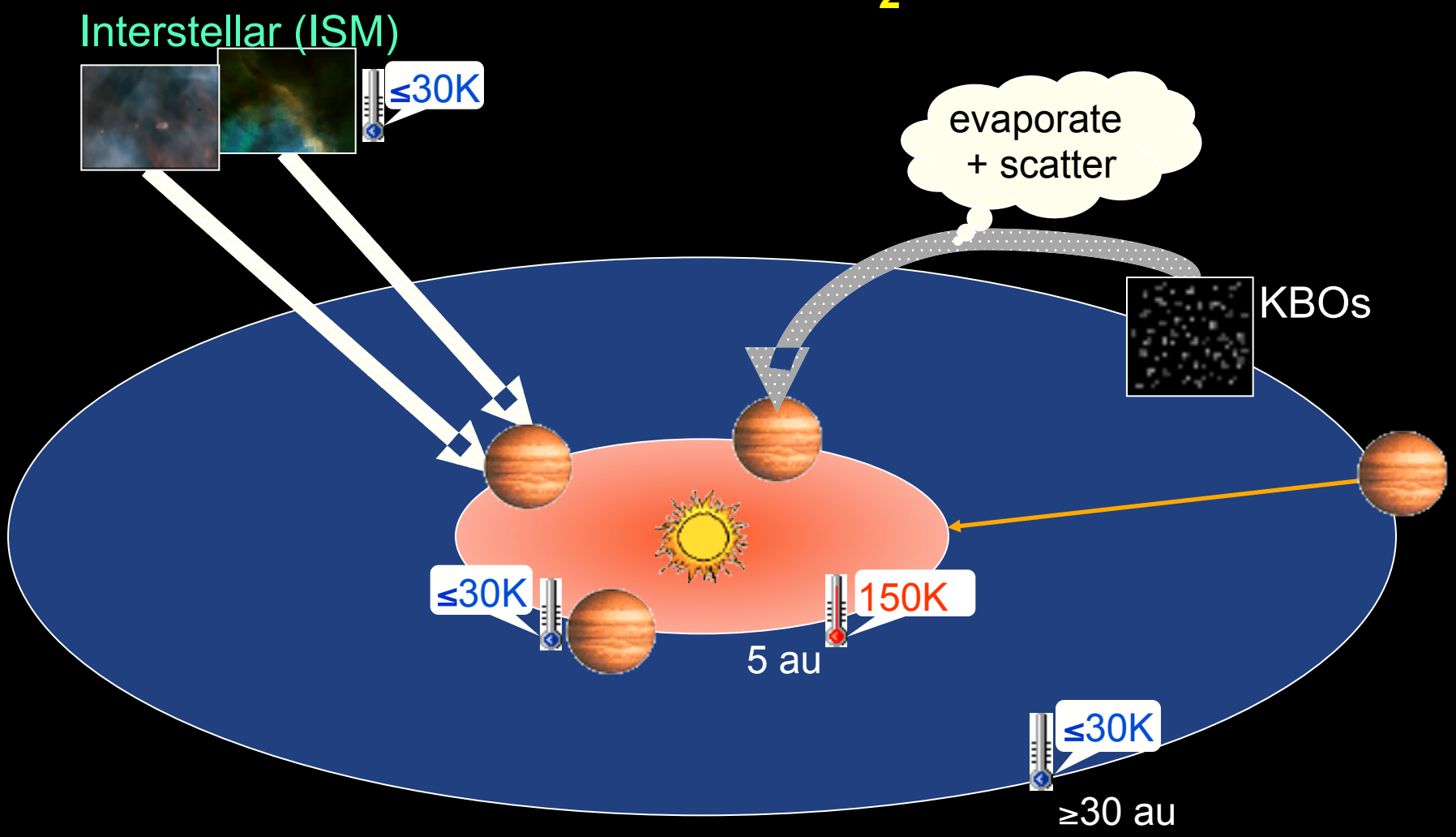
*core accretion model

- core from grains of ice, rock, metal
- core grows to critical mass (~10 M_E)
- gravitational collapse: H_2, He, Ne (most volatile gases) captured
- atmosphere forms from H_2, He, Ne, & volatiles released from core
- planetesimals added throughout the formation (and afterward) to explain heavy element enrichment
  - cold icy planetesimals
  - clathrate hydrates, “cold”, nevertheless


10.0
1.0
0.1
ratio of planetary to solar elemental abundances
Jupiter
direct gravitational capture
interior processes
hot spot meteorology
He
Ne
Ar
Kr
Xe
C
N
O
S
elements

cold planetesimals and heavy element enrichment requires T≤ 30 K to trap N_2 and Ar

4±2 × solar H_2O



Origin: clathrate-hydrates

cold planetesimals from interstellar cloud may not have survived the formation of solar nebula (high T)

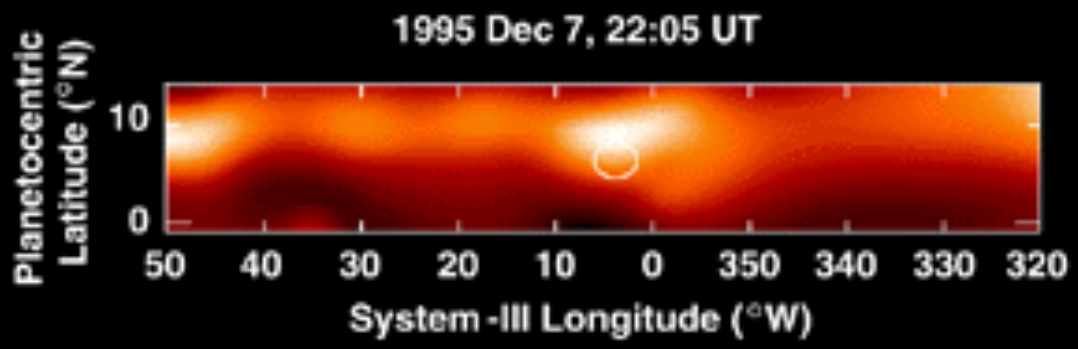
- clathrate hydrates trap volatiles containing heavy elements in the cooling, feeding zone of Jupiter

- predicts 15 × solar H_2O, with 100% efficiency of trapping in clathrates (Gautier *et al*., 2001), but

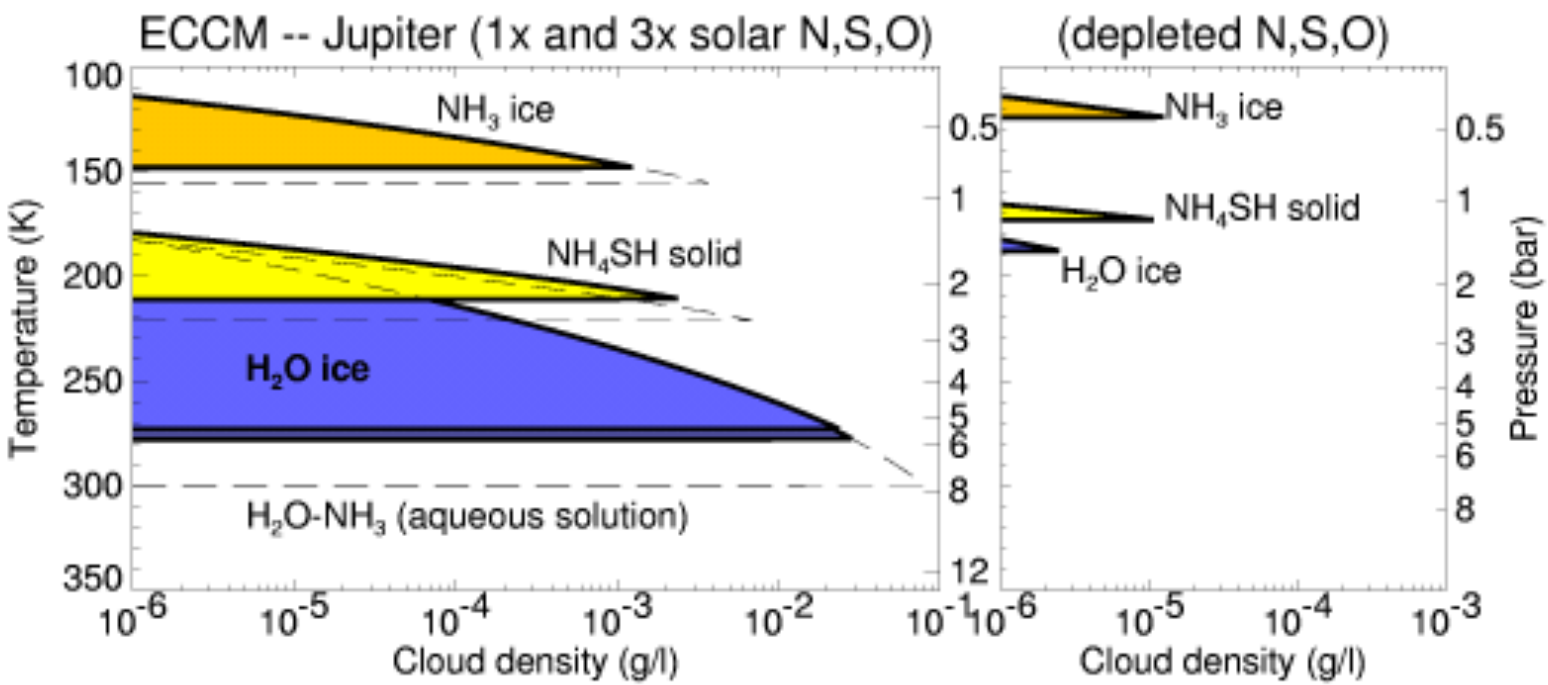
  clathrates must be cold (< 38K) to trap argon

Cylindrical Maps of Jupiter: 1° S – 14° N

NASA Infrared Telescope Facility
Middle Infrared Array Camera: 4.8μm



Jupiter clouds



Equilibrium

Hot Spot

Jupiter: what is missing?

water

abundance in “well-mixed” atmosphere

H_2O is presumably the original carrier of heavy elements to Jupiter.

Help is on the way!

Juno 2011

Cassini at Saturn

- atmos <1 bar; magnetosphere → formidable!

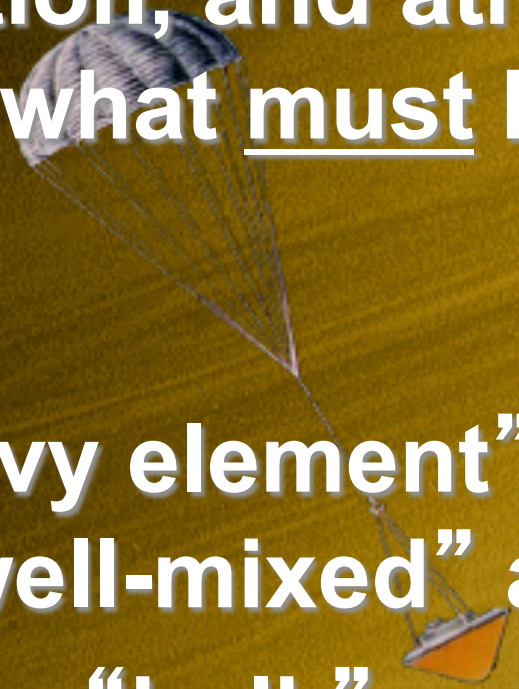
- heavy elements:

  measures C/H = 9 x solar (from CH_4)

  P/H = 5 - 10 x solar → *disequilibrium*

  other heavy elements and isotopes? *no*

formation, and atmospheric origin: what <u>must</u> be known?

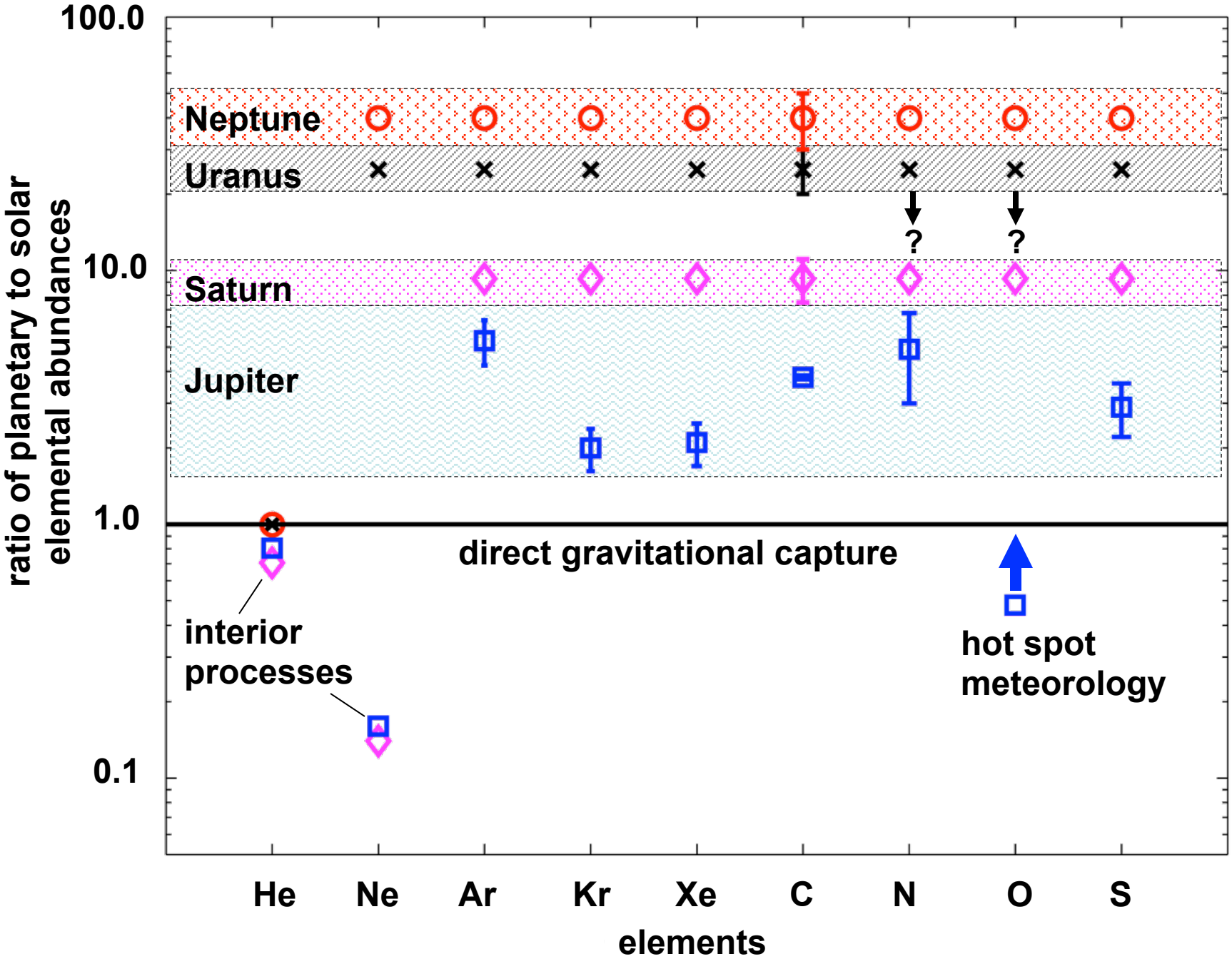


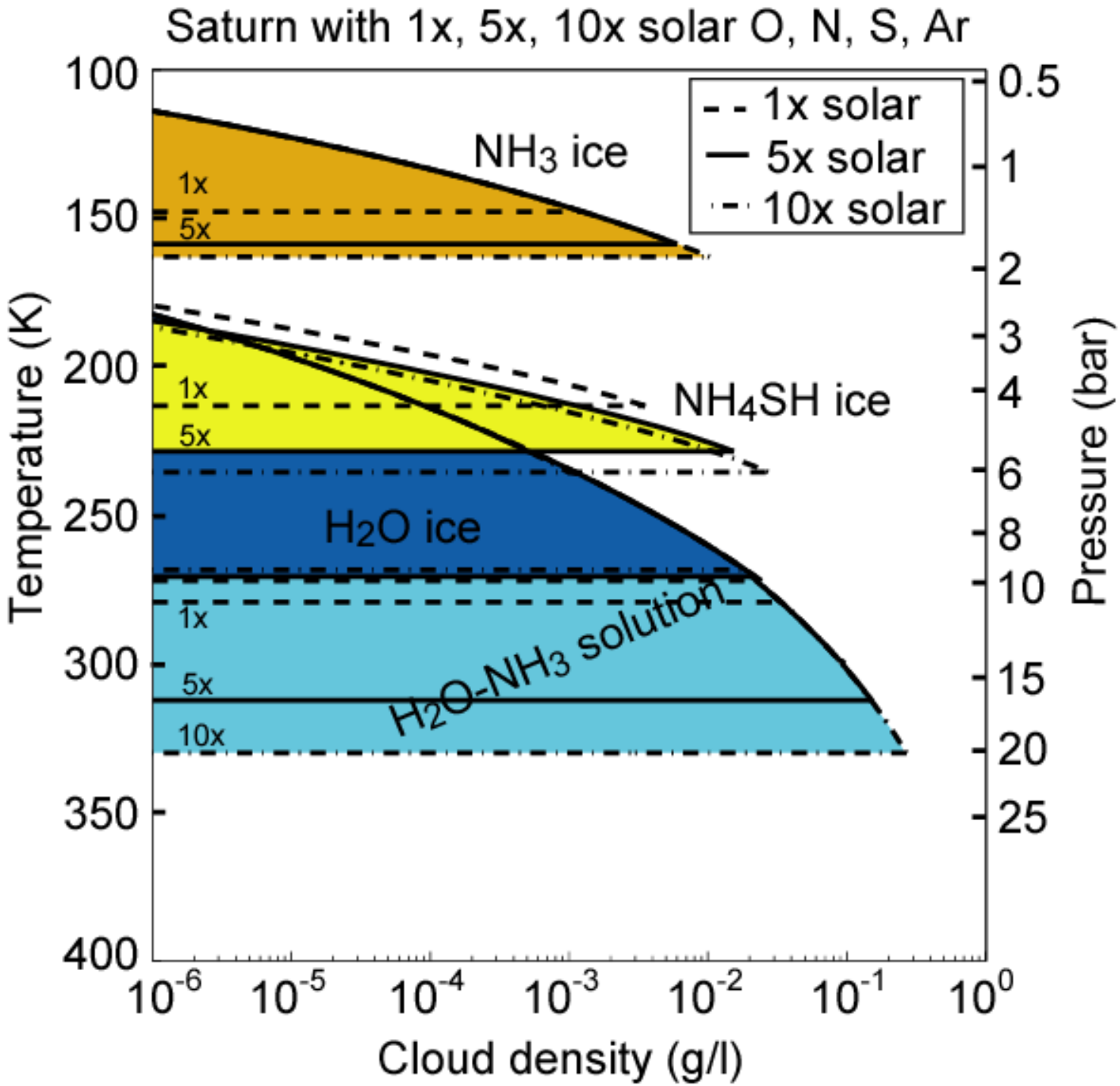
“heavy element”* abundances in “well-mixed” atmosphere, i.e. <u>“bulk” composition</u>

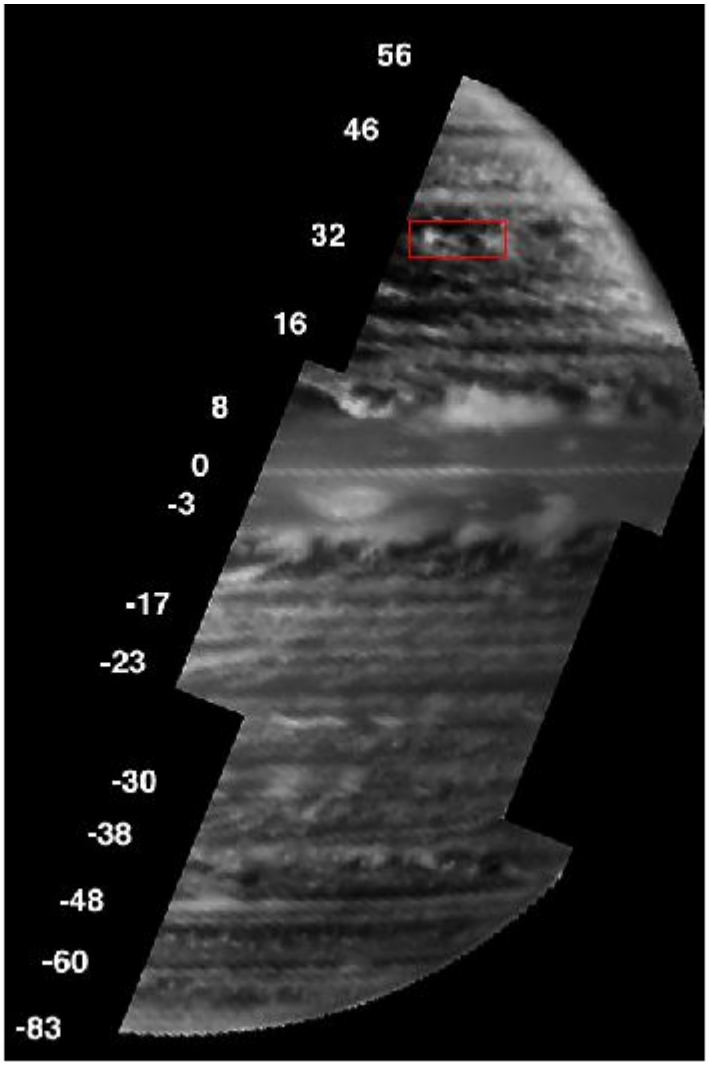
* m/z > ^{4}He

Saturn

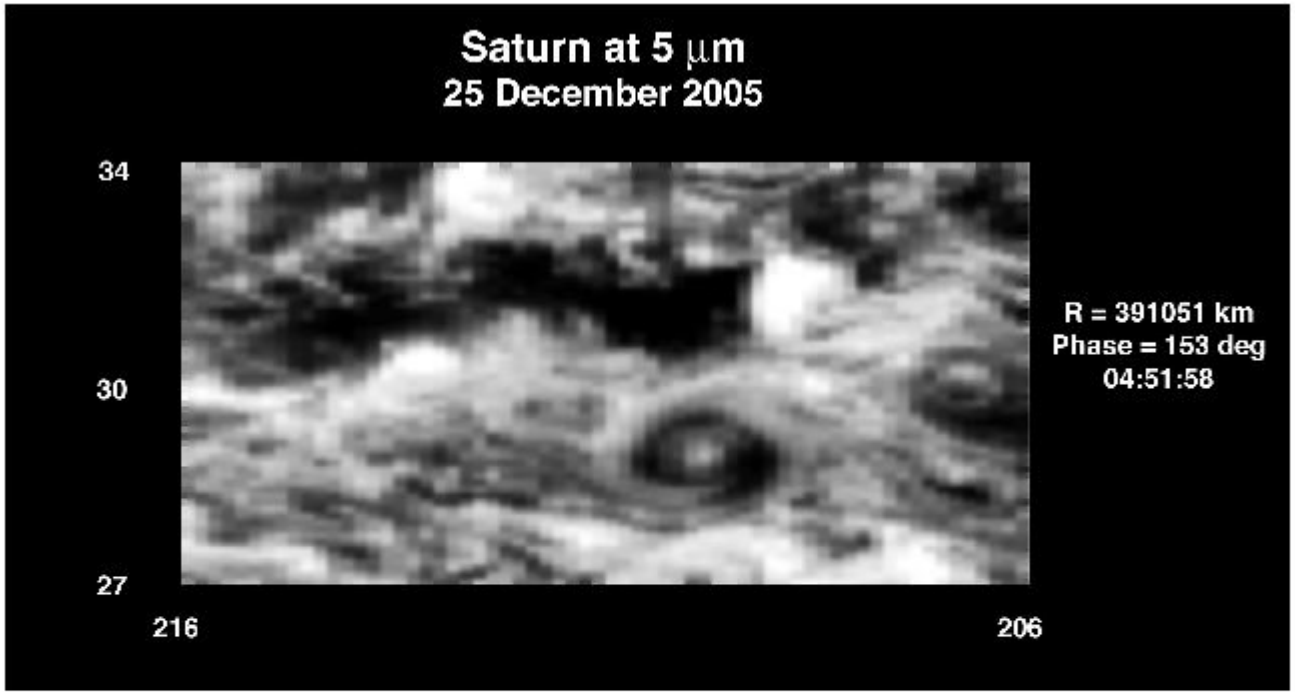
- what to expect for bulk composition?
- where to find it?
- how to access it?


100.0
10.0
1.0
0.1
ratio of planetary to solar elemental abundances
Neptune
Uranus
Saturn
Jupiter
?
?
direct gravitational capture
interior processes
hot spot meteorology
He
Ne
Ar
Kr
Xe
C
N
O
S
elements


Saturn with 1x, 5x, 10x solar O, N, S, Ar
1x solar
5x solar
10x solar
NH3 ice
NH4SH ice
H2O ice
H2O-NH3 solution
1x
5x
10x
Temperature (K)
Pressure (bar)
Cloud density (g/l)
100
150
200
250
300
350
400
0.5
1
2
3
4
6
8
10
15
20
25
10-6
10-5
10-4
10-3
10-2
10-1
100



VIMS/Baines


Saturn at 5 μm
25 December 2005
34
30
27
216
206
R = 391051 km
Phase = 153 deg
04:51:58

Saturn Probes

how deep → shallow or deep?

- probes only: deep (50 - 100 bar), or
- probes + microwave radiometry: shallow (~10 bar)

how many?

- 2 - 3, for diversity and risk mitigation

where?

- equatorial, mid- and/or high latitudes

Saturn Probes

critical measurements:

- composition of <u>well-mixed</u> atmosphere
  C, O, N, S, noble gases and their isotopes
  D/H, $^{3}He/^{4}He$, $^{14}N/^{15}N$ isotopes
  GeH_4, SiH_4, AsH_3, PH_3, CO: internal process
- deep winds, dynamics
- core determination?

Saturn Probes

technology challenges

- tps (heat shield):
  left over from Galileo probe?
- communication:
  direct-to-earth, or relay?
- power:
  solar cells (battery assisted?), or rps/rtg?
- microwave radiometry: from flyby s/c or probe/s?

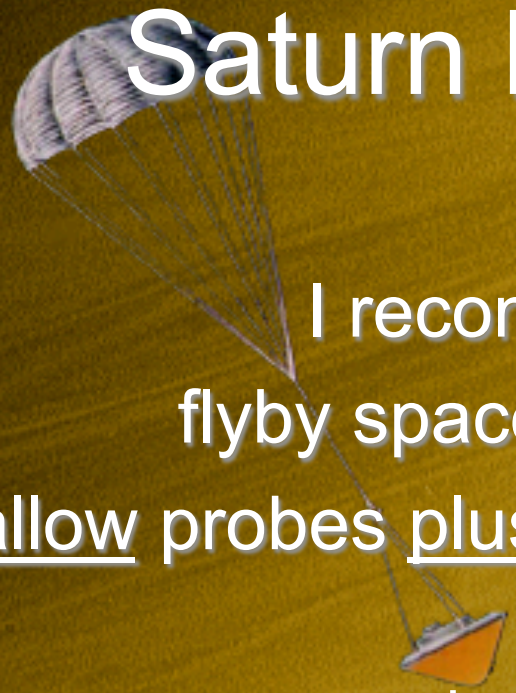
modelling: H_2O retrievals from microwave radiometry

Saturn Probes

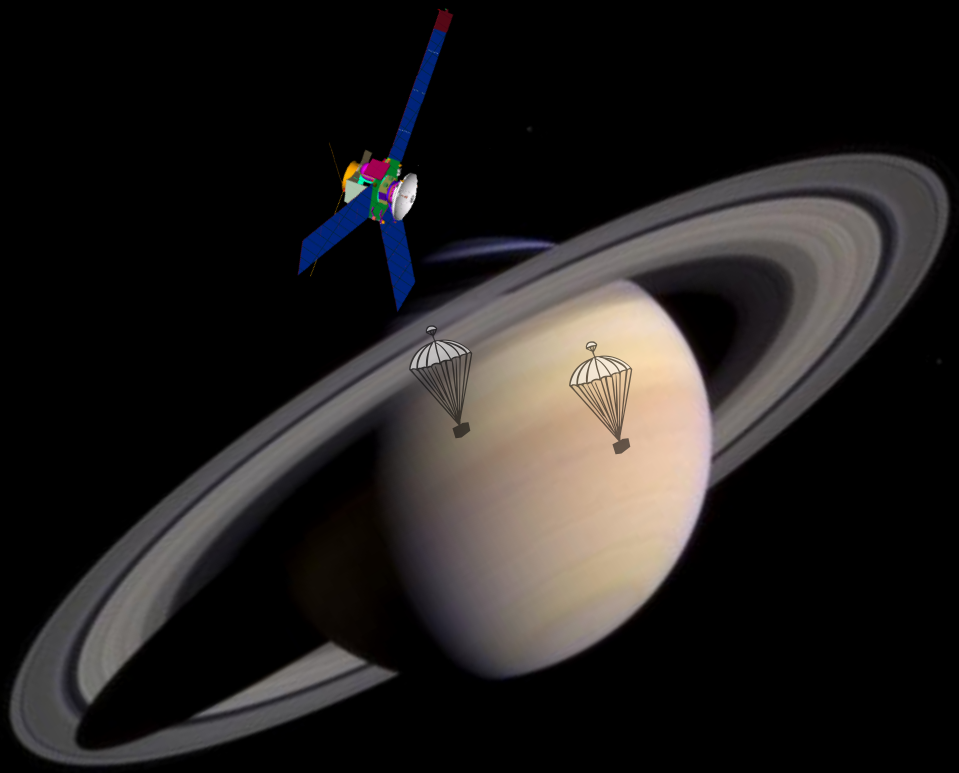
some related papers:

- Tom Spilker: mission design (IV)
- Tibor Balint: feasibility study (IV)
- Dave Atkinson: direct-to-earth comm. (VII)
- Alessandro Atzei: JEP (IV)

Saturn Probes



I recommend
flyby spacecraft, with
two <u>shallow</u> probes <u>plus</u> microwave radiometry
in the
New Frontiers program



Saturn Probes

?

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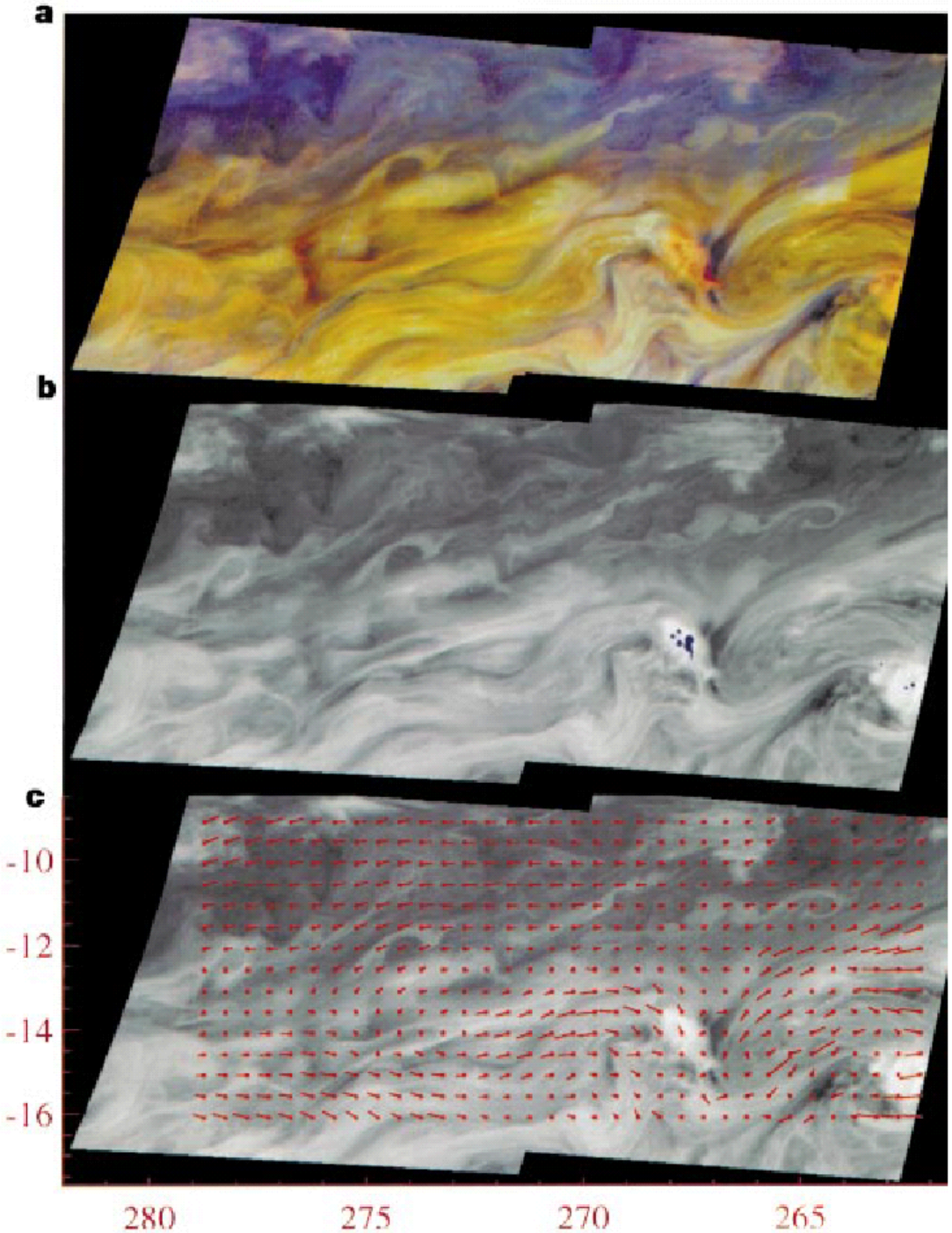
http://www-personal.engin.umich.edu/~atreya/

(or simply google sushil atreya to download papers)



889 nm (0.5 bar)
727 nm (3 bar)
756 nm (>3 bar)

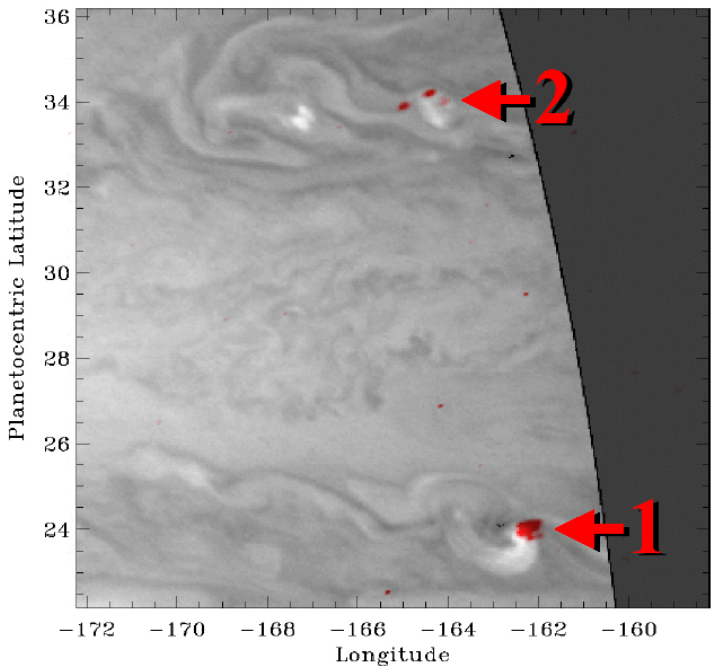
winds

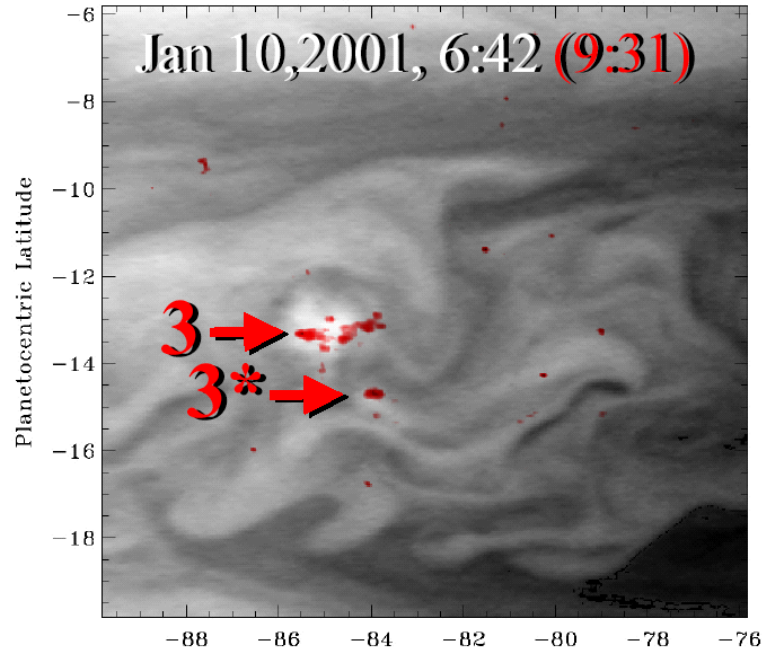
Galileo Imaging

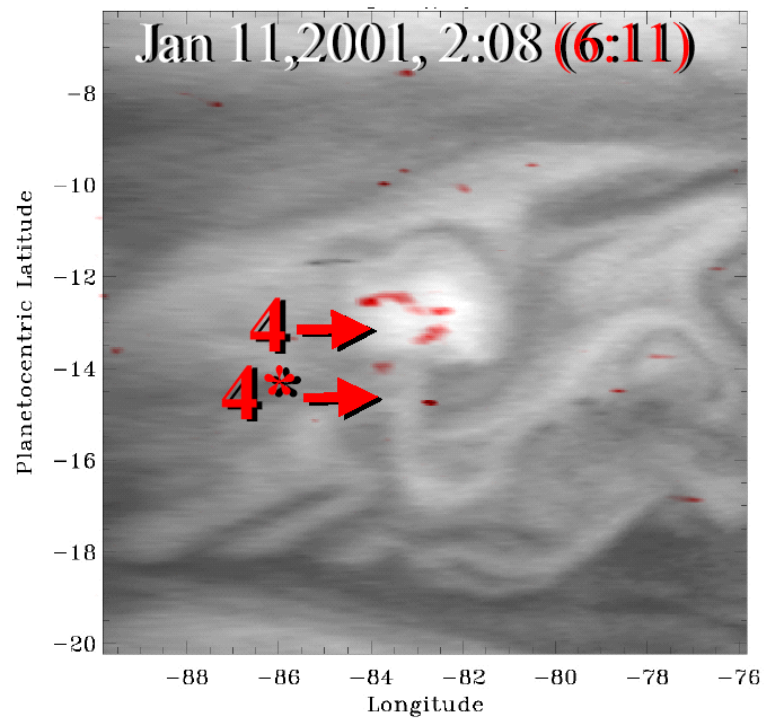
Gierasch, et al; Ingersoll, et al (2000)

Day side clouds and night side lightning

Jan 1,2001, 6:37 (8:21)



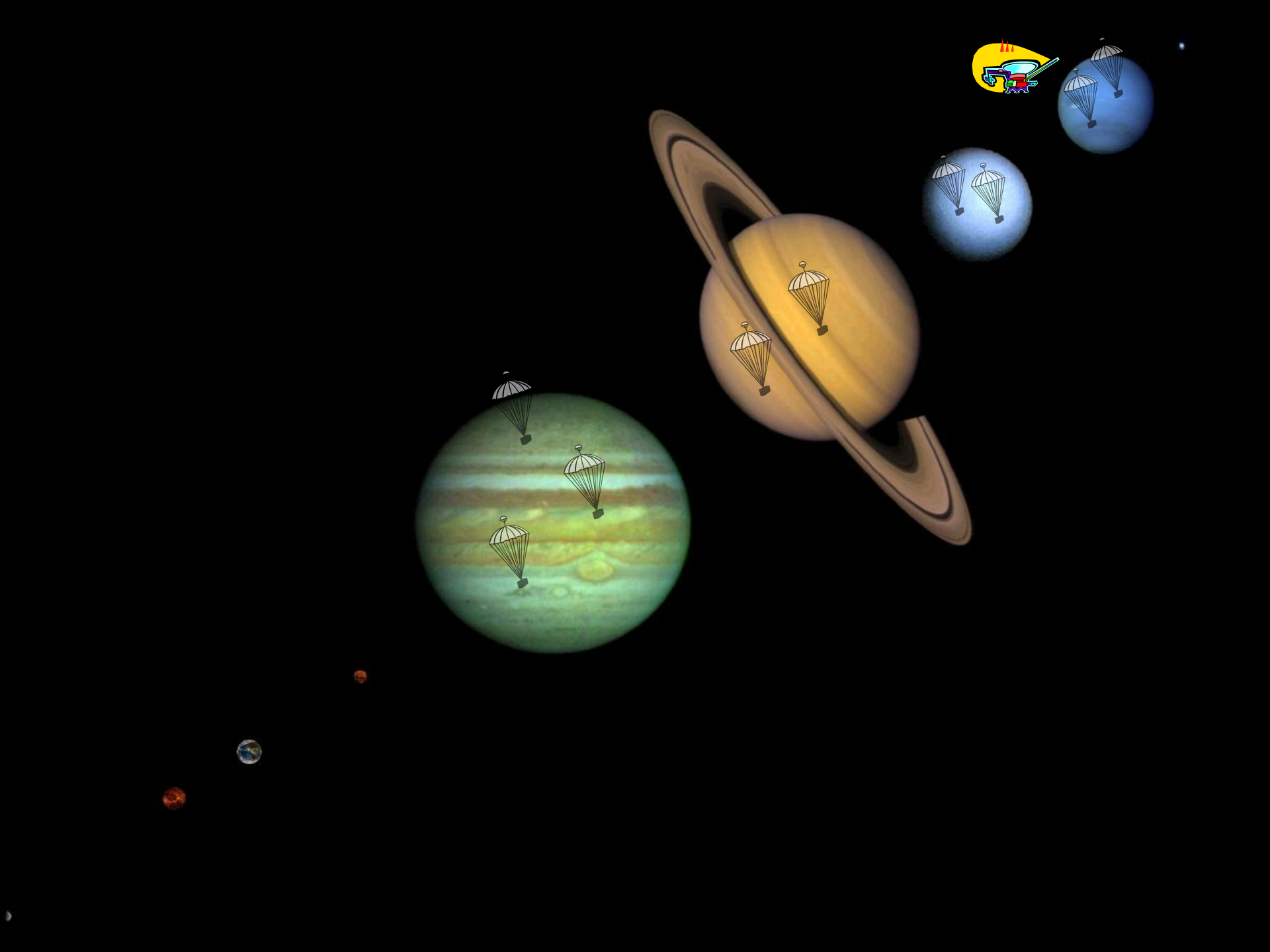




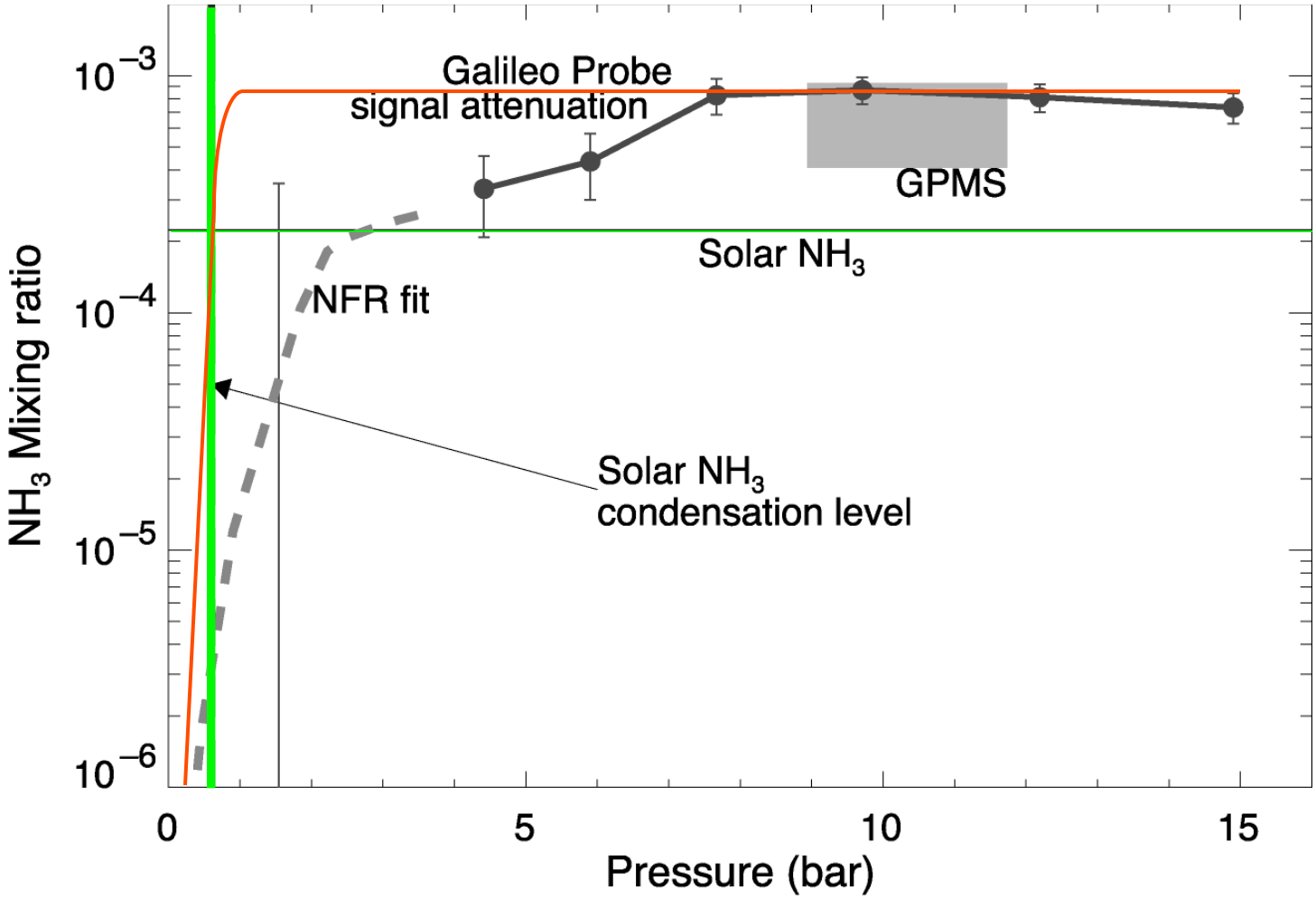
Cassini Imaging

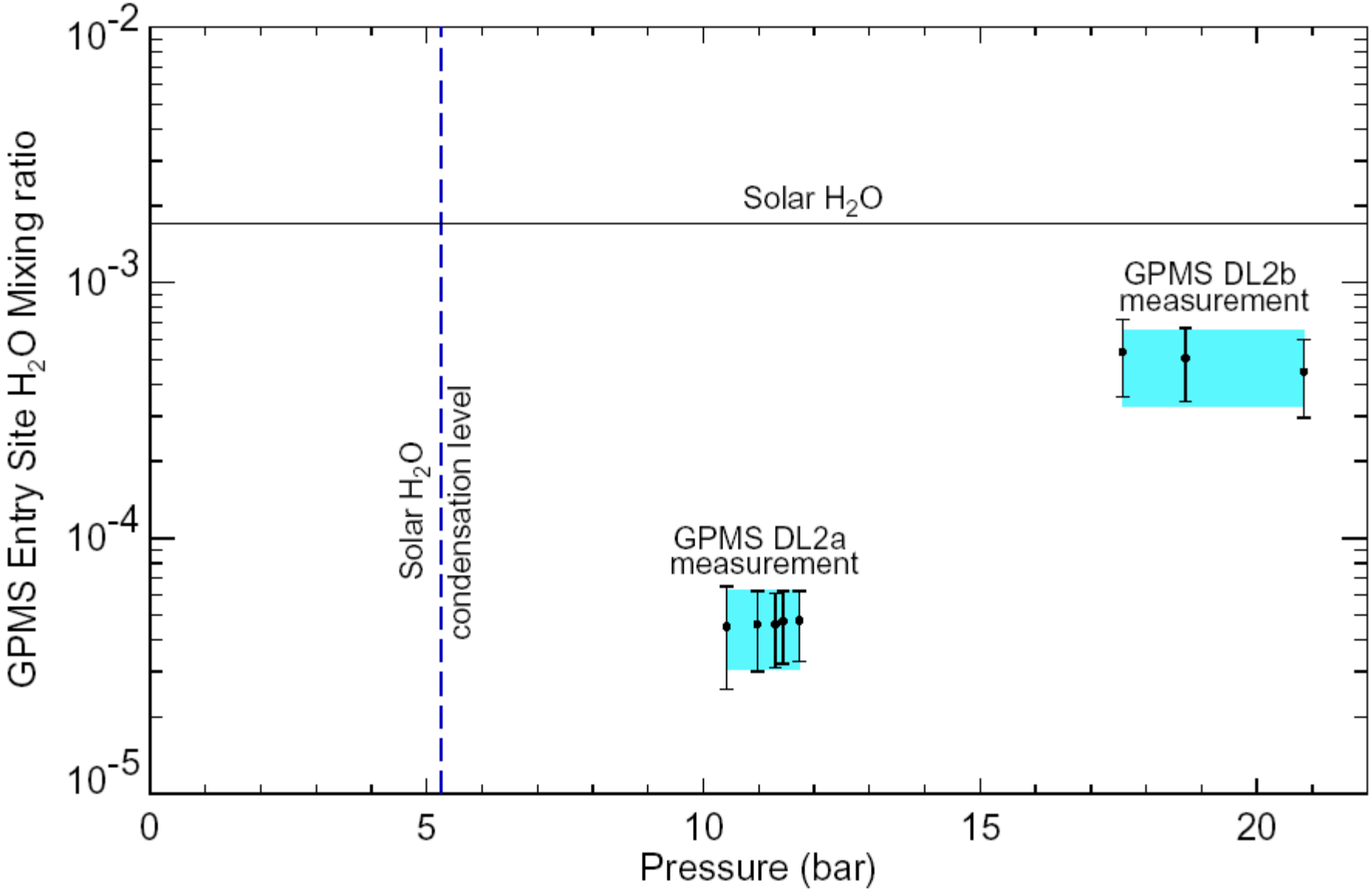
(140 R_J=10 Mkm)

(Dyudina, etal., 2004)

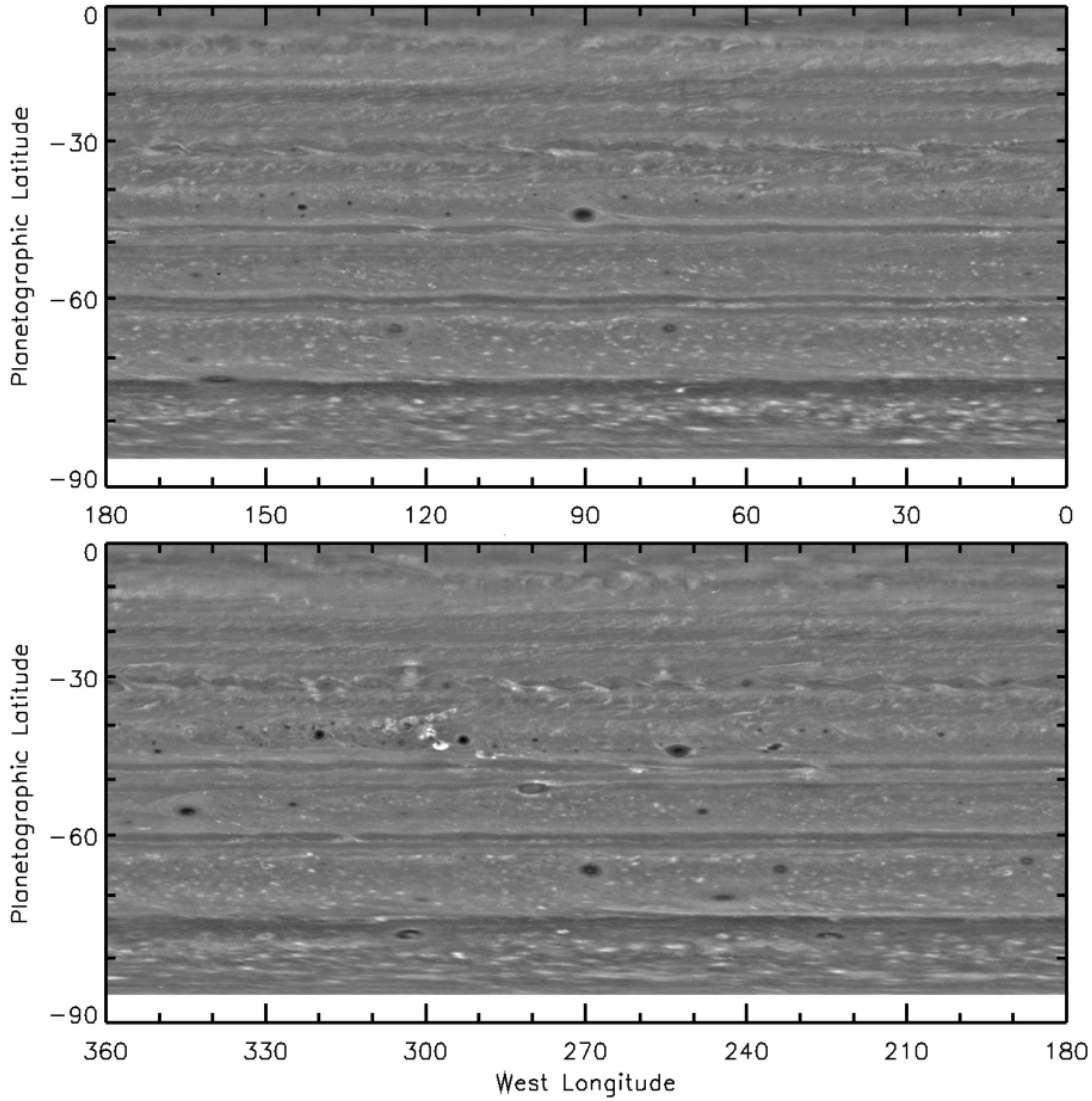


NH_3 Mixing Ratio vs. Pressure

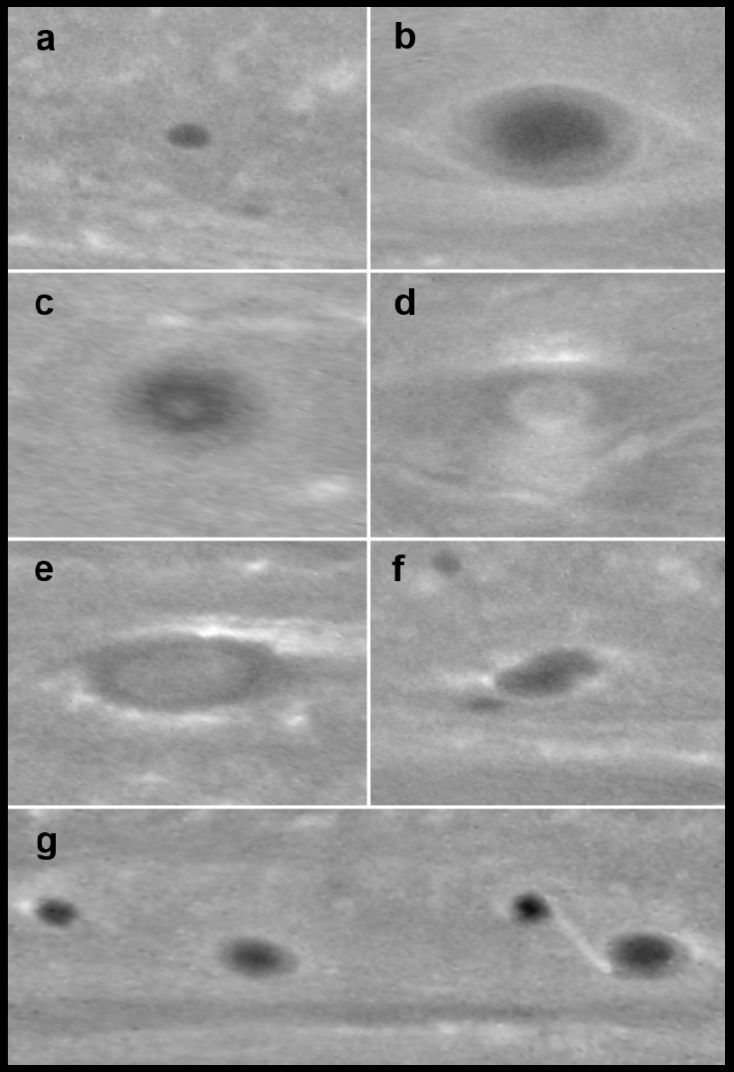



GPMS Entry Site H_2O Mixing ratio
10^{-2}
10^{-3}
10^{-4}
10^{-5}
Solar H_2O
GPMS DL2b measurement
GPMS DL2a measurement
Solar H_2O condensation level
0
5
10
15
20
Pressure (bar)

Saturn cloud morphologies



Saturn vortices



Vasavada et al. 2006