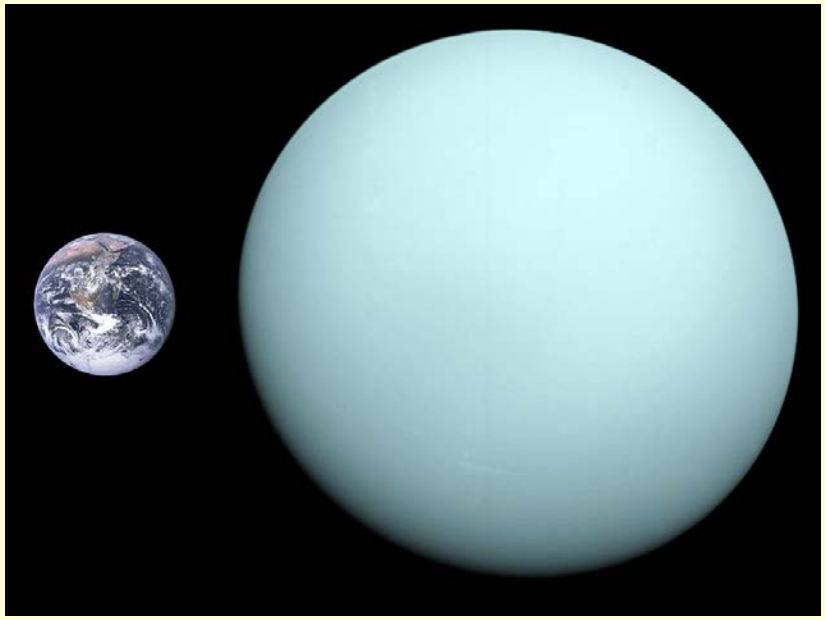
Uranus and Neptune



Dave Stevenson, Caltech

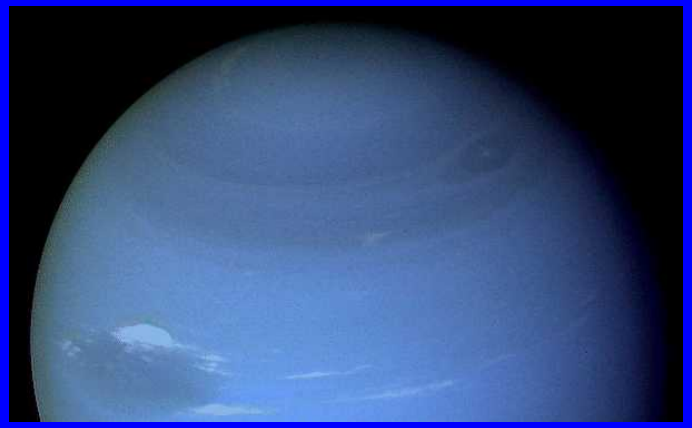
Ice Giants Workshop

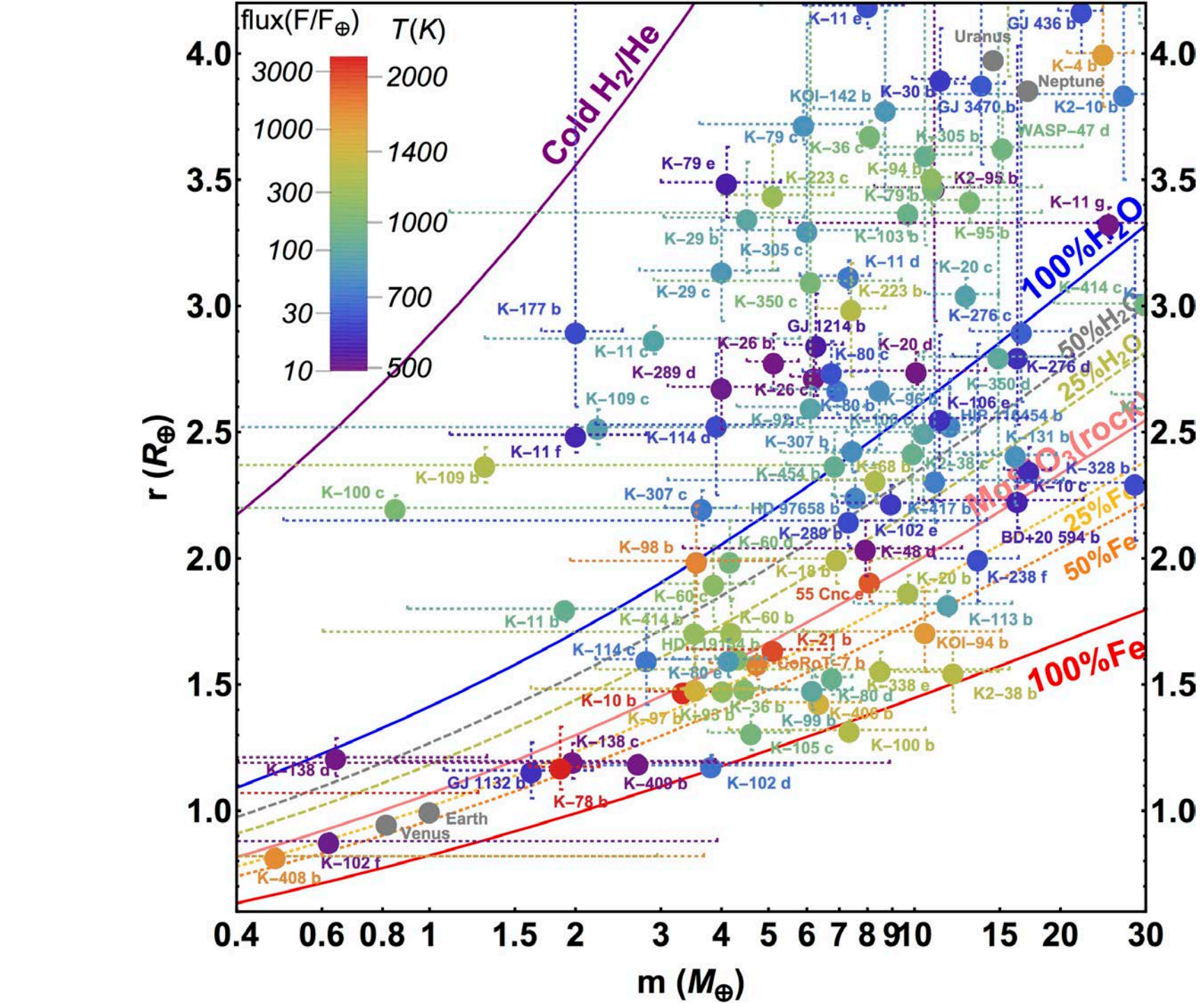
October 16, 2017

Fluid Planets

- *Gas Giants (primarily hydrogen and helium)*-
  Jupiter and Saturn

- *Ice Giants (everything, but presumably including large amounts of H_2O at high P,T)*
  Uranus and Neptune



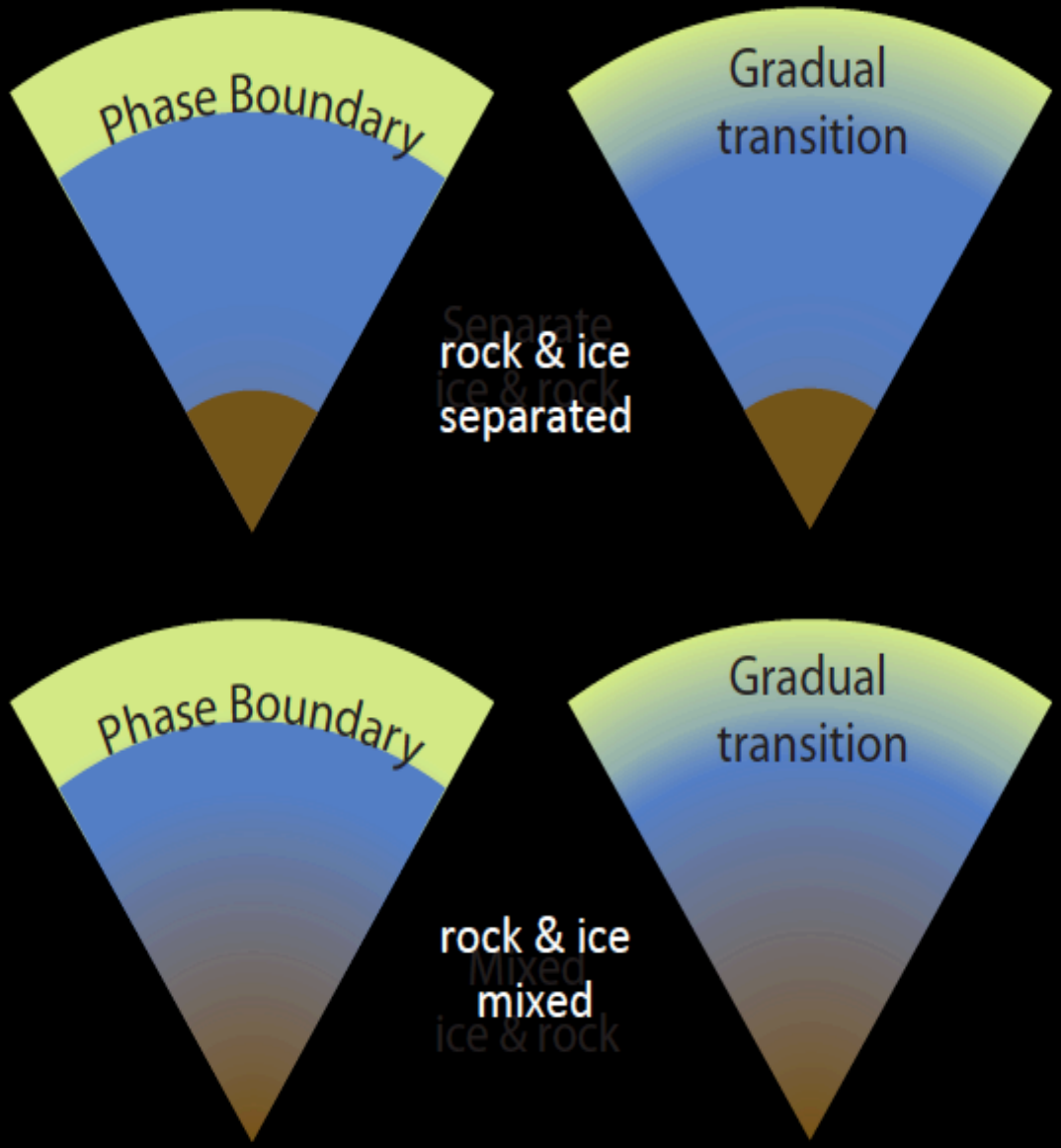

flux(F/F⊕)
T(K)
3000
1000
300
100
30
10
2000
1400
1000
700
500
Cold H2/He
100%H2O
50%H2O
25%H2O
Mg2SiO3(rock)
25%Fe
50%Fe
100%Fe
Uranus
Neptune
Earth
Venus
r (R⊕)
m (M⊕)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.4
0.6
0.8
1
1.5
2
3
4
5
6
7
8
9
10
15
20
30

(Li Zeng)

Why U&N Matter

- Essential part of understanding planetary origin and evolution.
  - “Naked” Jupiter and Saturn cores?
  - Formed in presence of nebula (since contain some gas)
  - Exist in other planetary systems

- Distinctively different (from other planets)!
  - Magnetic fields are dominated by $l+m=2$ [$(l,m)=(2,0)$ and $(1,1)$]
  - Low heat flow. Not isentropic? Some stable stratification



What are the interior structures of Uranus and Neptune?

Interior model Challenge

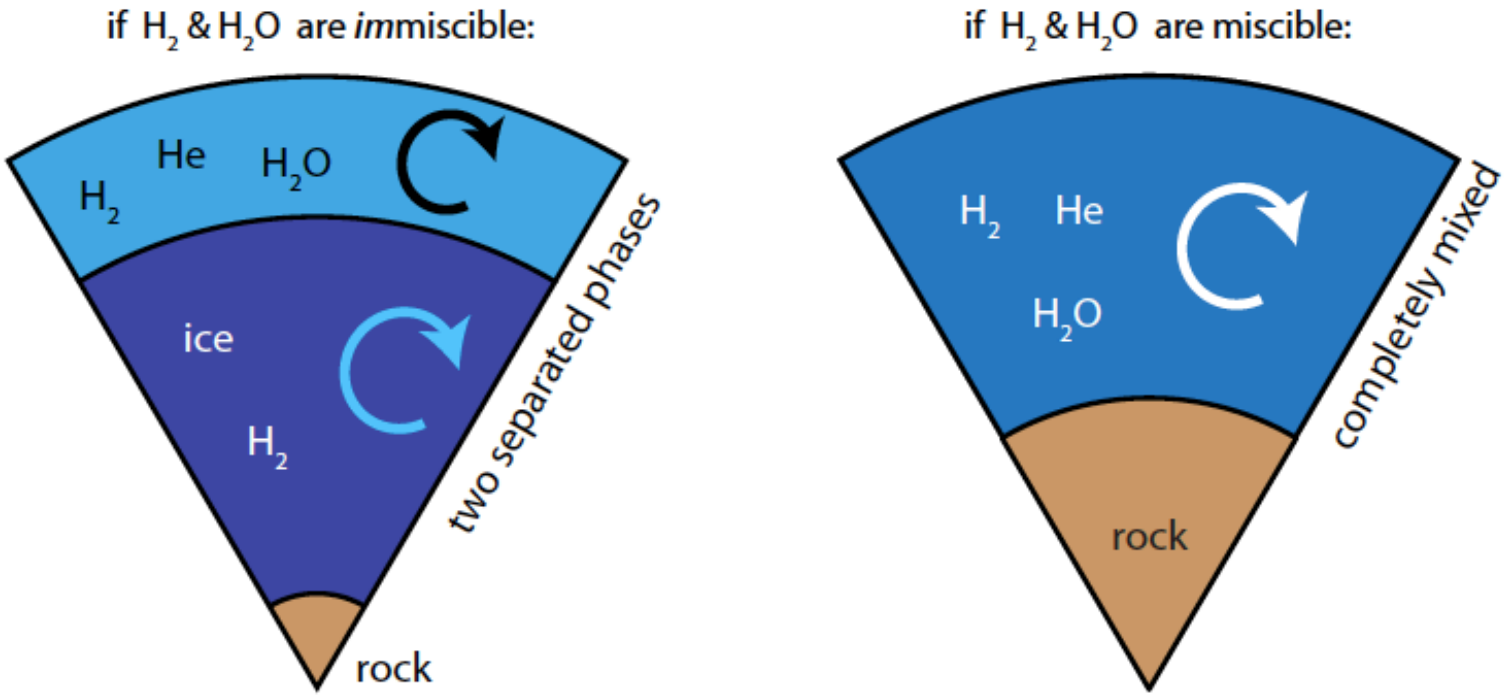
Any acceptable model for Uranus or Neptune must satisfy two requirements (in addition to being compatible with the observed atmosphere, mass, radius, rotation and gravity field):

1. It must be compatible with the phase diagram for the assumed constituents and their mixtures.

2. It must be compatible with the observed magnetic field. This means that the outer region
(the outermost 20% at least) cannot have a substantial compositional gradient or any compositional jumps other than those mandated by the phase diagram. A dynamo requires large scale vertical motions and this is incompatible with a stable compositional gradient).

Most published models violate these requirements or are in danger of violating these requirements (because they introduce unphysical layering).

Thermodynamic rationale



Bailey & Stevenson [in prep]

Interior Unknowns

- A “deep” water ocean (that begins where H_2 and H_2O become insoluble, perhaps a few GPa)
- An even deeper ocean or solid where water becomes superionic
- Diamonds?
- A mess
  - but accretion is a mess

How Can we learn about the Interior?

- Gravity will help with the deep interior
- But the biggest benefit of gravity may be to determine the differential rotation
  - This is the lesson of Juno and Cassini
  - Truncation of differential rotation at depth is diagnostic of interior conditions, possible layering.
- Magnetic Field is also diagnostic of the outer regions (since we know the field is generated far out).. And might be diagnostic deep down (Cassini experience).
- Atmosphere may be determined in part by the interior

Seismology?

- Seismology is great… if it works and we don’t know if it will work
  - Ground based evidence for normal mode excitation in Jupiter
  - Saturn’s rings are the best seismometer in the solar system… But for a very limited set of modes and it will not work at Uranus
  - The issue is not instrument capability so much as unknown source characteristics
  - Excitation by storms? Deep seated storms where rock clouds form? (Markham & Stevenson 303.04, Wednesday)
  - Not ready for prime time?

Atmosphere Challenge

- Enriched in heavy elements
  - Is this because of upward convection of heavy material below (the “core” and “mantle”)
  - Or this material added along with the gas (as we think was the case for J & S)
- Noble gases are key (and that’s why we need a probe (does not have to be deep)
  - Tell us both about what was delivered and (perhaps) about interior processes
- How is the atmosphere bounded below (if there is a lot of water then the “wet adiabatic” effect can be huge)?

Don’t forget the Satellites! And the Rings!

- Uranian satellite system is compact, diagnostic of the formation of Uranus
- Small satellites can have internal processes when they form at very low T.
- Rings diagnostic of evolution

Conclusion

- Important, distinctive, diagnostic
- We must go there
  - Both Uranus and Neptune (eventually) because they are different