Multiple Probe Measurements at Uranus Motivated by Spatial Variability

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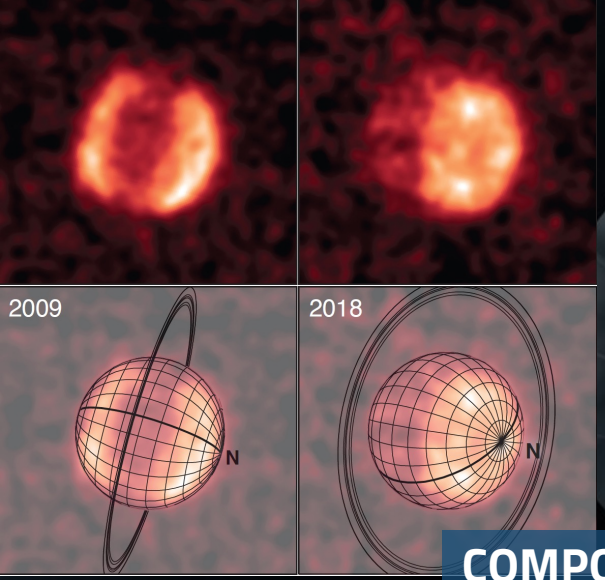
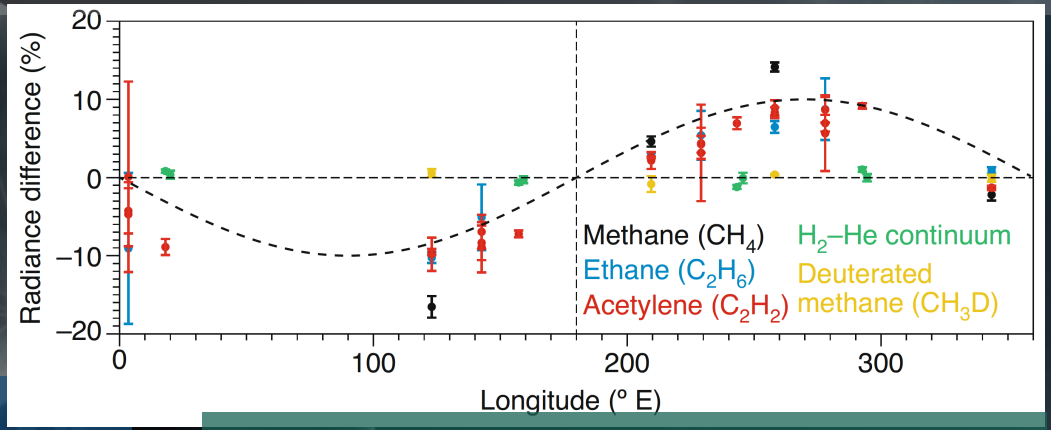
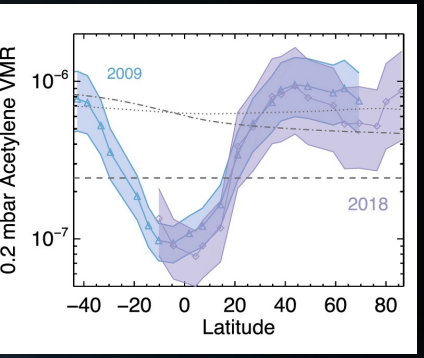
Abstract #8196

Stratospheric spatial variation







COMPOSITION

- Meridional variation and a hemispheric asymmetry in C_2H_2
- Dynamical link between troposphere and stratosphere

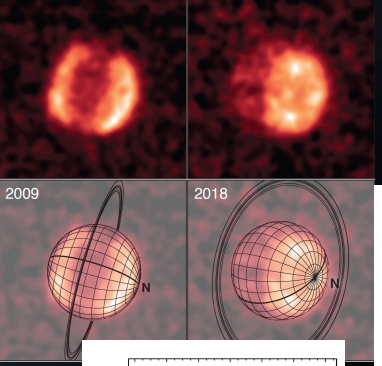
Roman++2020, 2023

TEMPERATURE

- Longitudinal variation over one rotation
- Large variation measured on global scale
- Possible link to upwelling from small scale tropospheric systems

Rowe-Gurney++2021

Stratosphere-troposphere link



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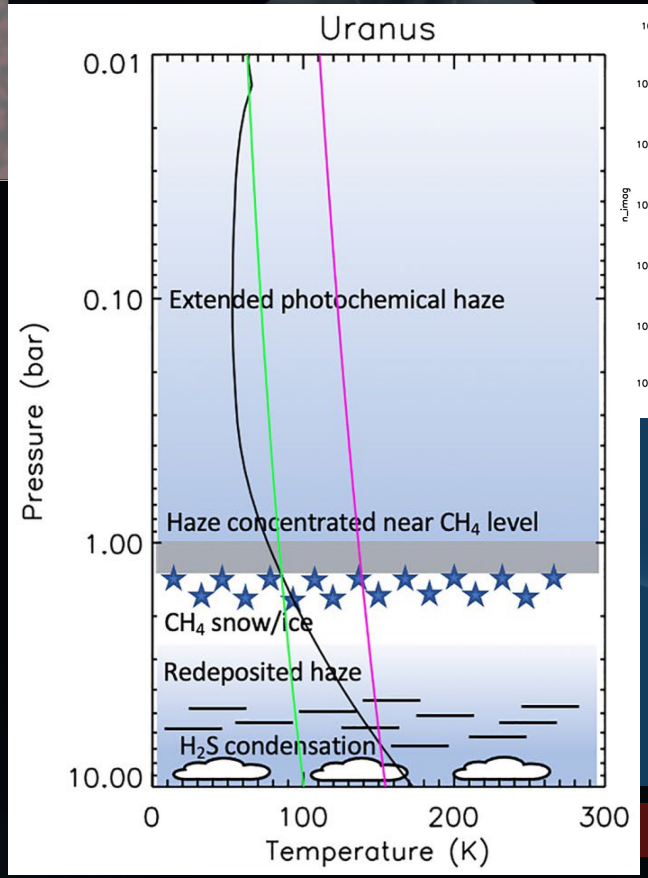
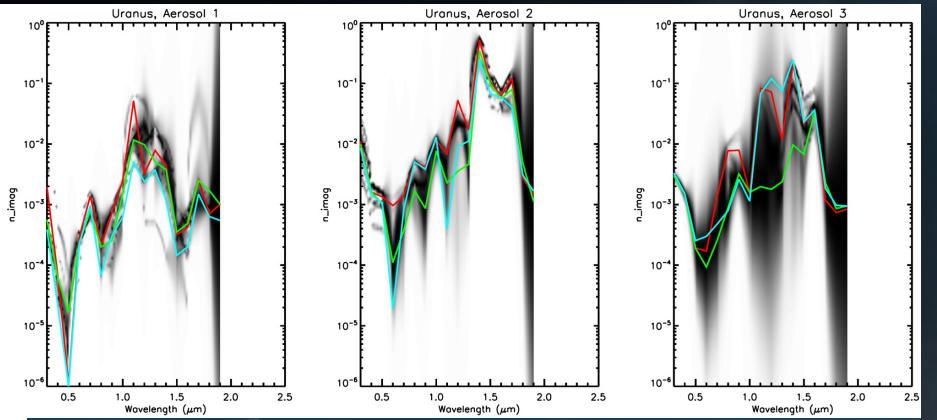




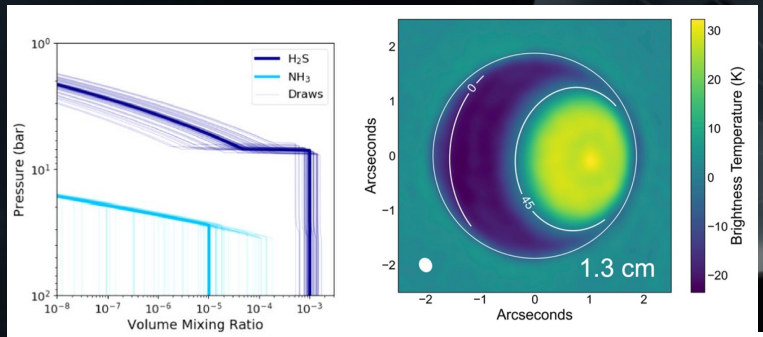
TROPOSPHERIC AEROSOL DIVERSITY

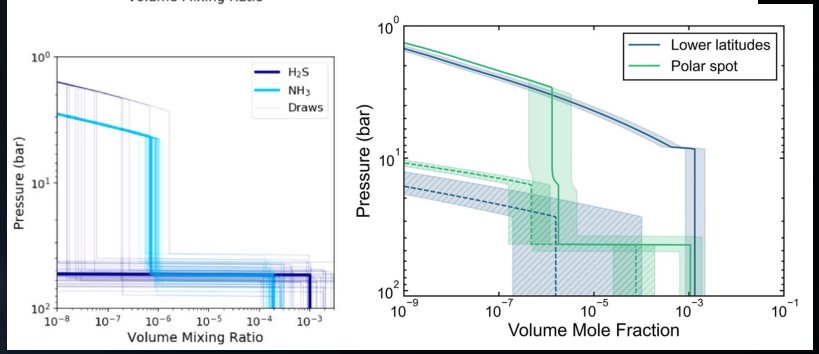
- $n_i < 10^{-4}$ is typical of ices
- Spectral retrievals with $n_i > 10^{-4}$ at many wavelengths: aerosols of color
- Widespread presence of haze particles within tropospheric cloud levels

Irwin++2022

Tropospheric spatial variation

H_2S vs NH_3
Very different polar and low-latitude profiles



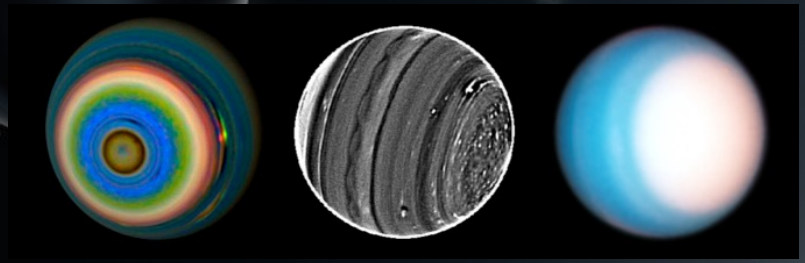


Molter++2021

Akins++2023

Spatial scales observed

- Current: 160 km (vis, Voyager),
  600 km (NIR AO),
  2000 km (mm/cm with ALMA/VLA)
- Future: 150 km (ELTs), 150 km (mm/cm)



Karkoschka2015, Sromovsky++2015, Simon++2022

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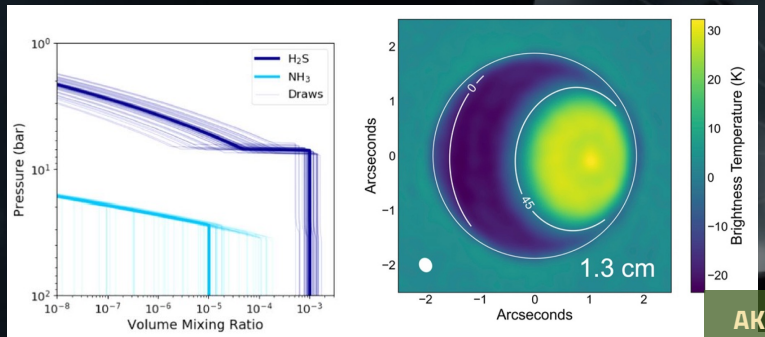
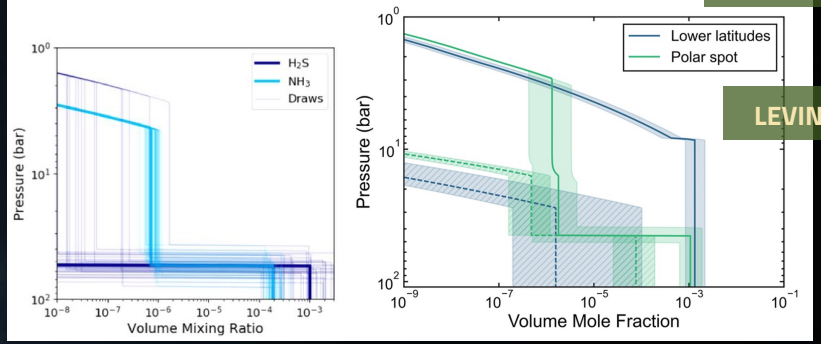


AKINS #8066



LEVIN #8129

Molter++2021

Akins++2023

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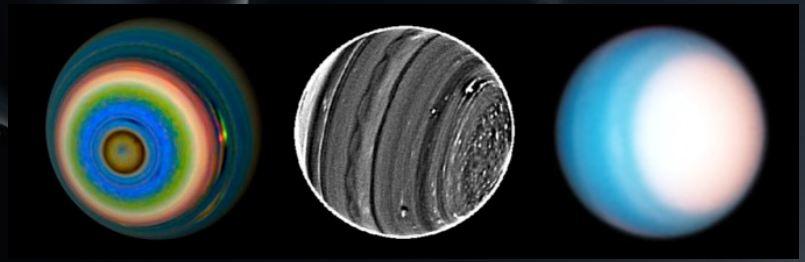
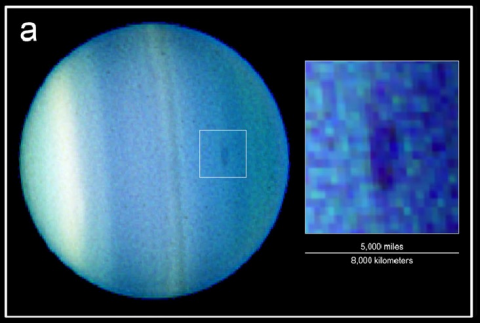
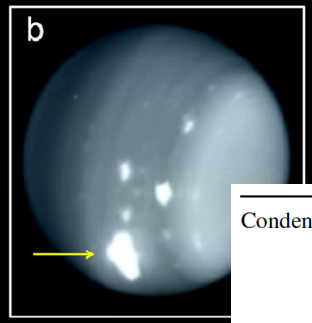
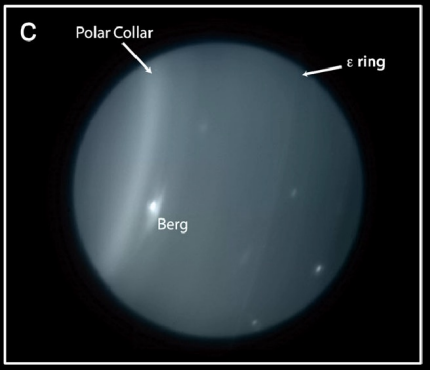


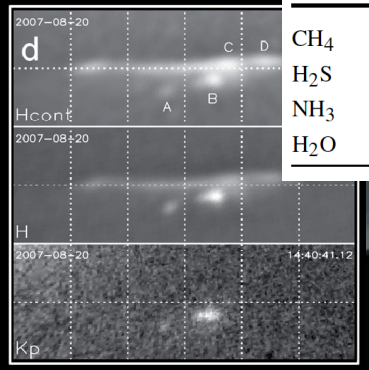
Karkoschka2015, Sromovsky++2015, Simon++2022

Moist convection



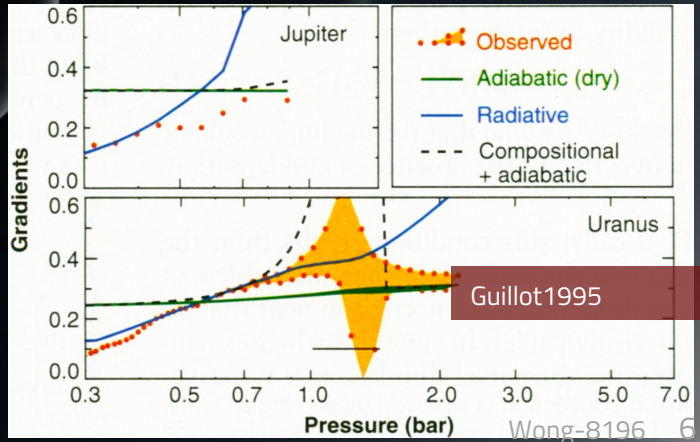






Condensable	Latent heat ($KJ\,Kg^{-1}$)	ϵ (1)	X_{solar} (2)	$30X_{solar}$ (3)	Energy capacity (Joules mol^{-1}) (4)	ΔT_L (K) (5)	$-(\epsilon-1)X$ (6)	ΔT_v (cond) (K) (7)
CH_4	553	7.0	5.9×10^{-4}	1.8×10^{-2}	160	5.2	−0.106	−9.2
H_2S	549	14.8	2.9×10^{-5}	8.7×10^{-4}	16	0.5	−0.012	−3.1
NH_3	1369	7.4	1.5×10^{-4}	4.5×10^{-3}	200	7.0	−0.028	−4.8
H_2O	2260	7.8	1.1×10^{-3}	3.2×10^{-2}	1300	44	−0.219	−140

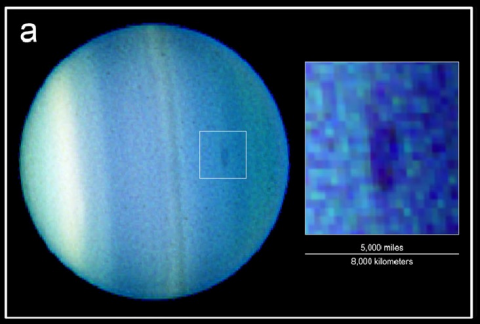
Hueso+Sanchez-Lavega2019

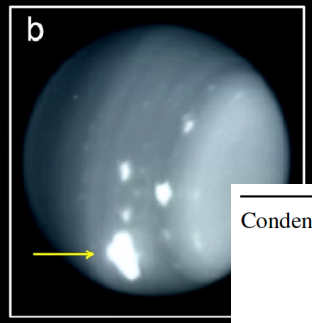


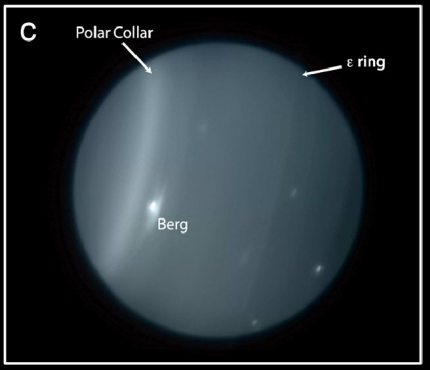
Guillot1995

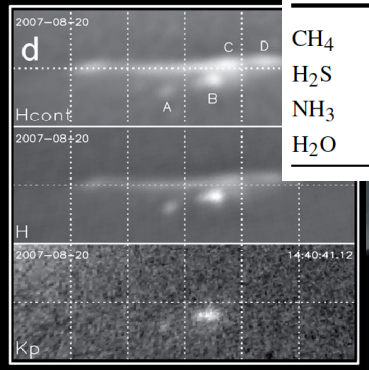
- No cloud features conclusively identified as convective storms
- Thermal and compositional gradients give clues to convective history/potential/inhibition
- CH_4 cloud layer: an accessible model for other layers

Moist convection









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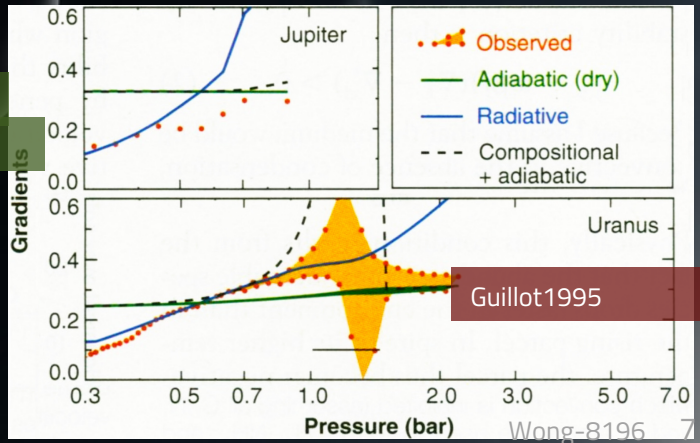
Hueso+Sanchez-Lavega2019

MARKHAM #8116

GE #8108

LI #8116



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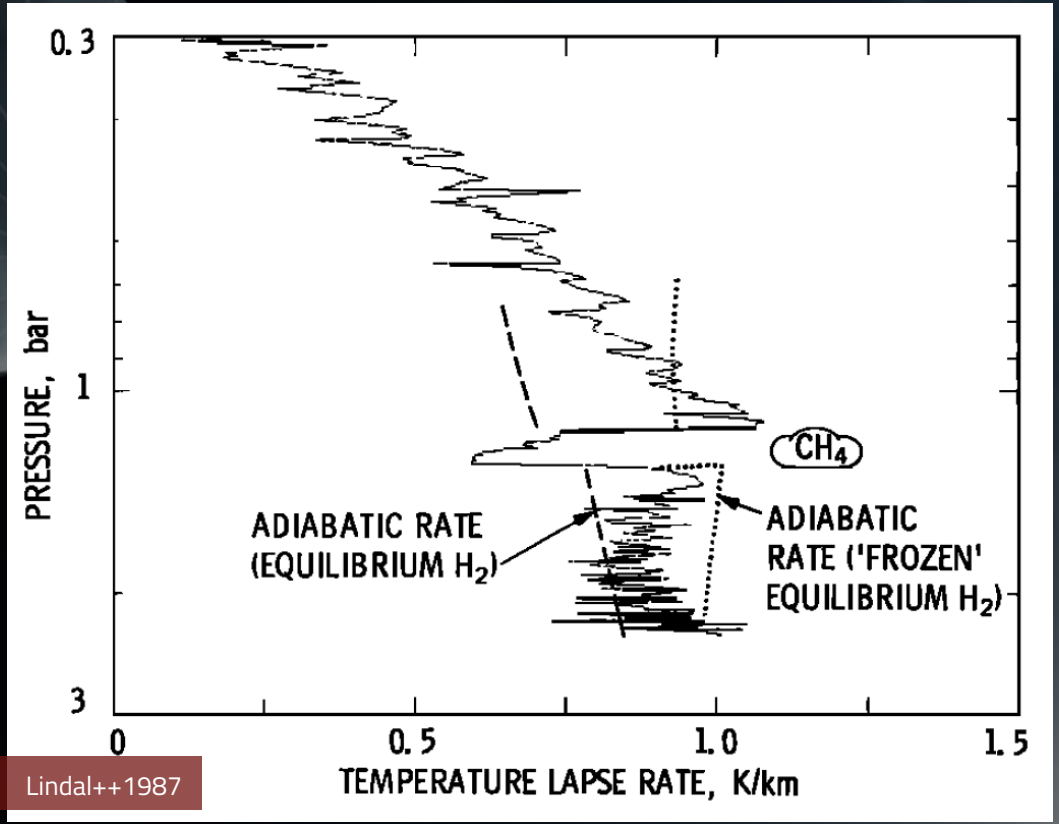
Uranus secondary probes: key measurements

MEASUREMENTS
- Temperature profile
- Volatile composition
- Vertical wind shear

REQUIREMENTS
- Vertical resolution (H_P/10 for "Lindal blip")
- Composition dynamic range (0.1 ppm H_2S/NH_3 to 5% CH_4)
- Composition specificity (distinguish different trace gases)



Lindal++1987

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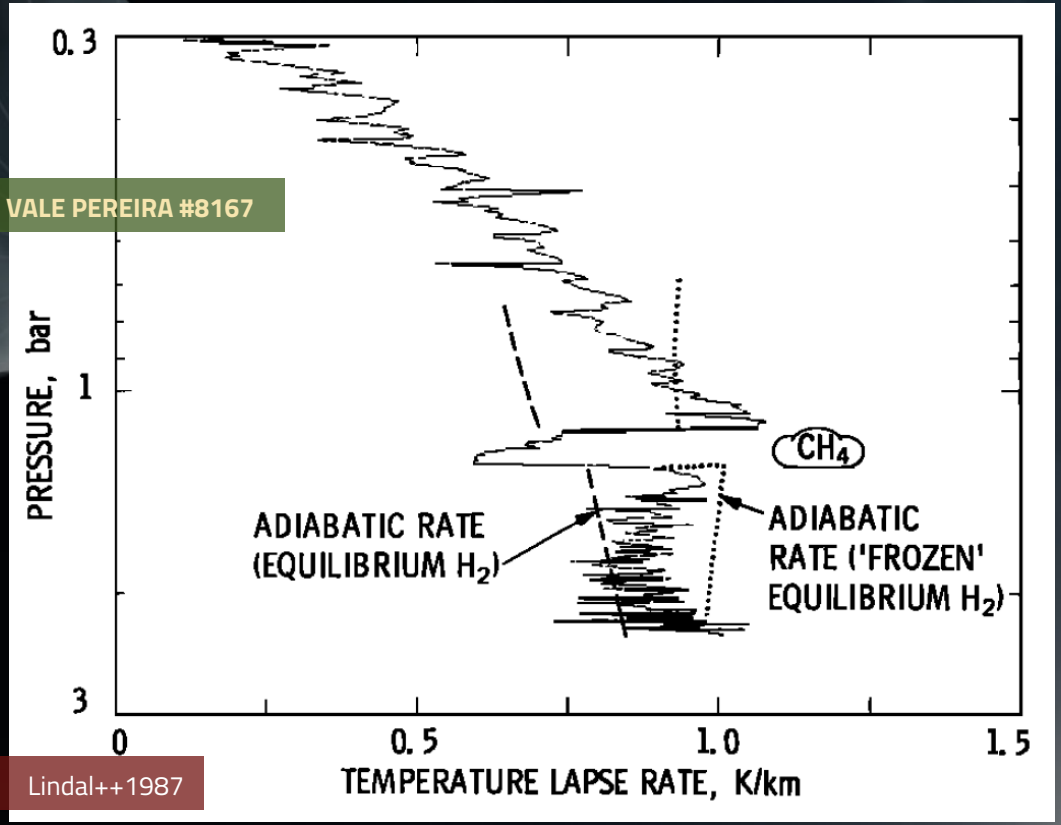
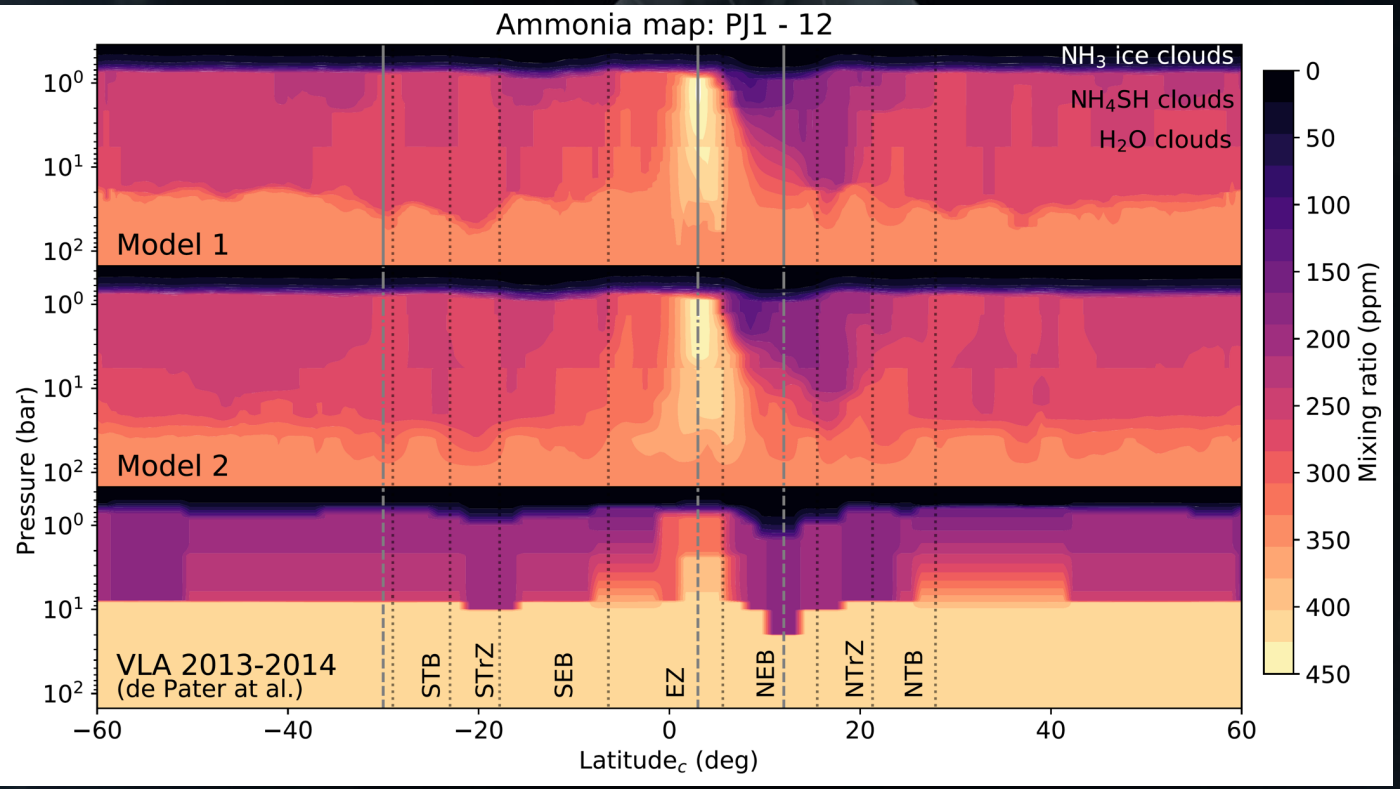
DO VALE PEREIRA #8167



Lindal++1987

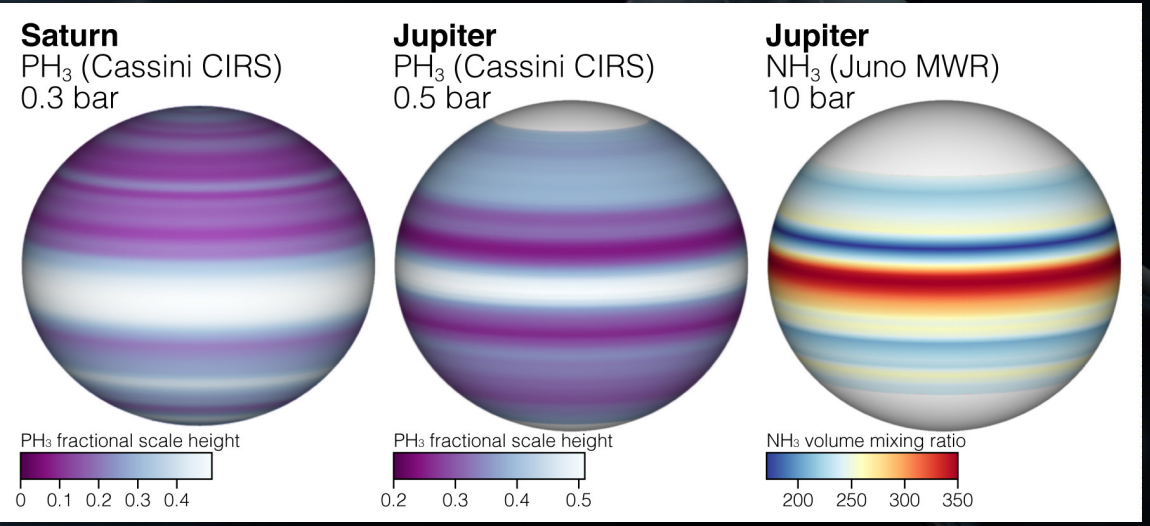
Lessons learned from Jupiter



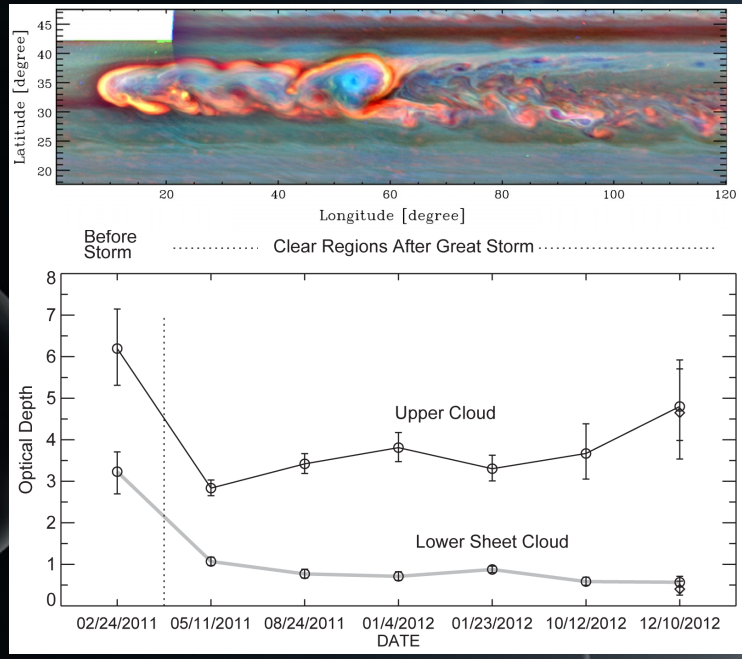
- Deep NH_3 depletion: mushballs? CIN?
- Probe entered 5-μm hot spot, near edge of equatorial high-NH_3 anomaly
- H_2S, H_2O vertical profiles: how are they related to NH_3?

Li++2017, Bolton++2017, de Pater++2019, Moeckel++2023

Lessons learned from Saturn



Fletcher++2009, Li++2017



Sayanagi++2013, Sromovsky++2016

- Latitudinal composition varies (e.g., PH_3)... how does this extend to deeper levels?
- Long-term atmospheric changes after convective outburst

Multiprobe challenges

CHALLENGES: Cost, integration

- SMD Rideshare type opportunities not an option because secondary probes depend on primary spacecraft for cruise power, separation, communication, etc.
- Secondary probes must be included early in mission design process

SOLUTION:

- Mini-probe within scope of competed instrument AO

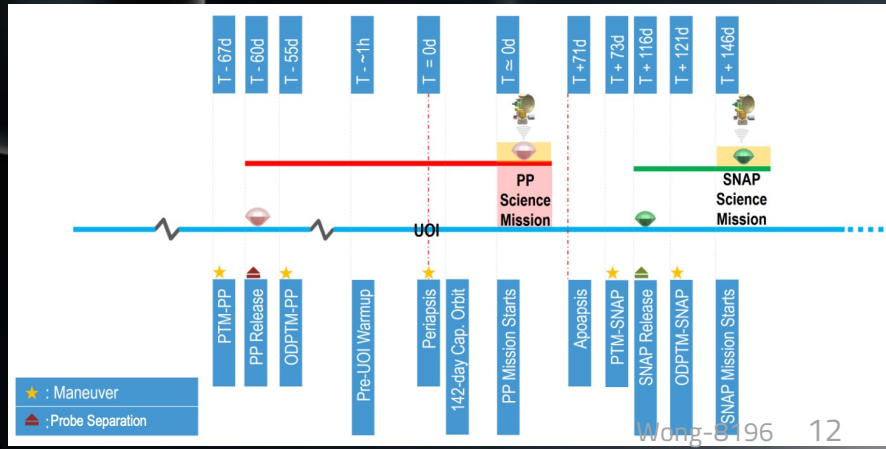
CHALLENGE:
Trajectory / targeting multiple latitudes

- Low vs. high latitudes
- Spring vs. autumn hemisphere

SOLUTION:
Planning

- Science/resource /risk trades
- Separate probe releases

Sayanagi++2020



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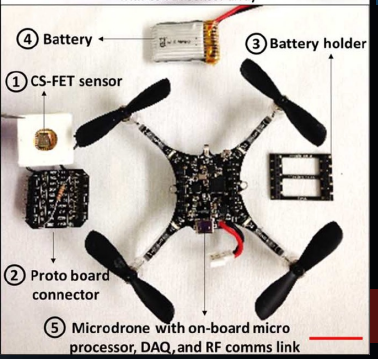


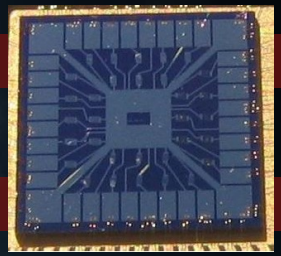
Fahad++2017

CHALLENGE: Composition sensor maturity

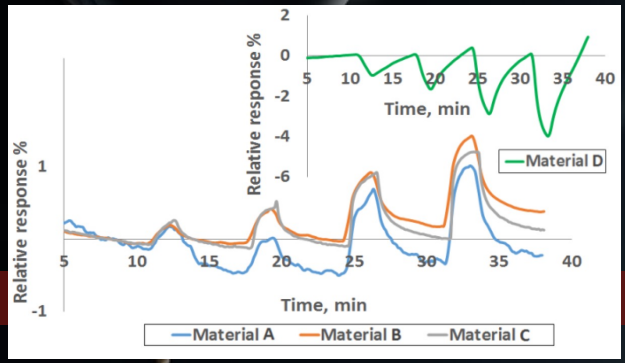
- Mass spectrometers are heavy/large
- Chemiresistive chip-based sensors available for commercial applications (not qualified for Uranus probe)

SOLUTION:

- Maturation of chip-based composition sensor instruments
- Mini-probes without composition sensors (with only T-P, density) as ground truth for orbiter retrievals



Li++2003



Hannon++2016

Summary

Spatial variability and atmospheric processes, origins

- Exchange between troposphere and stratosphere
- Moist convective process in hydrogen atmospheres
- Cloud chemistry and physics, global circulation
- Atmospheric abundances as constraints on formation/evolution

Multi (mini) probes

- Complementary to orbiter remote sensing, particularly microwave
- Need for mature, miniature composition sensors
- Include from earliest stages of mission design
- Mini-probe within scope of competed instrument AO