Seasonal Change in the Deep Atmosphere of Uranus: 1981-2022

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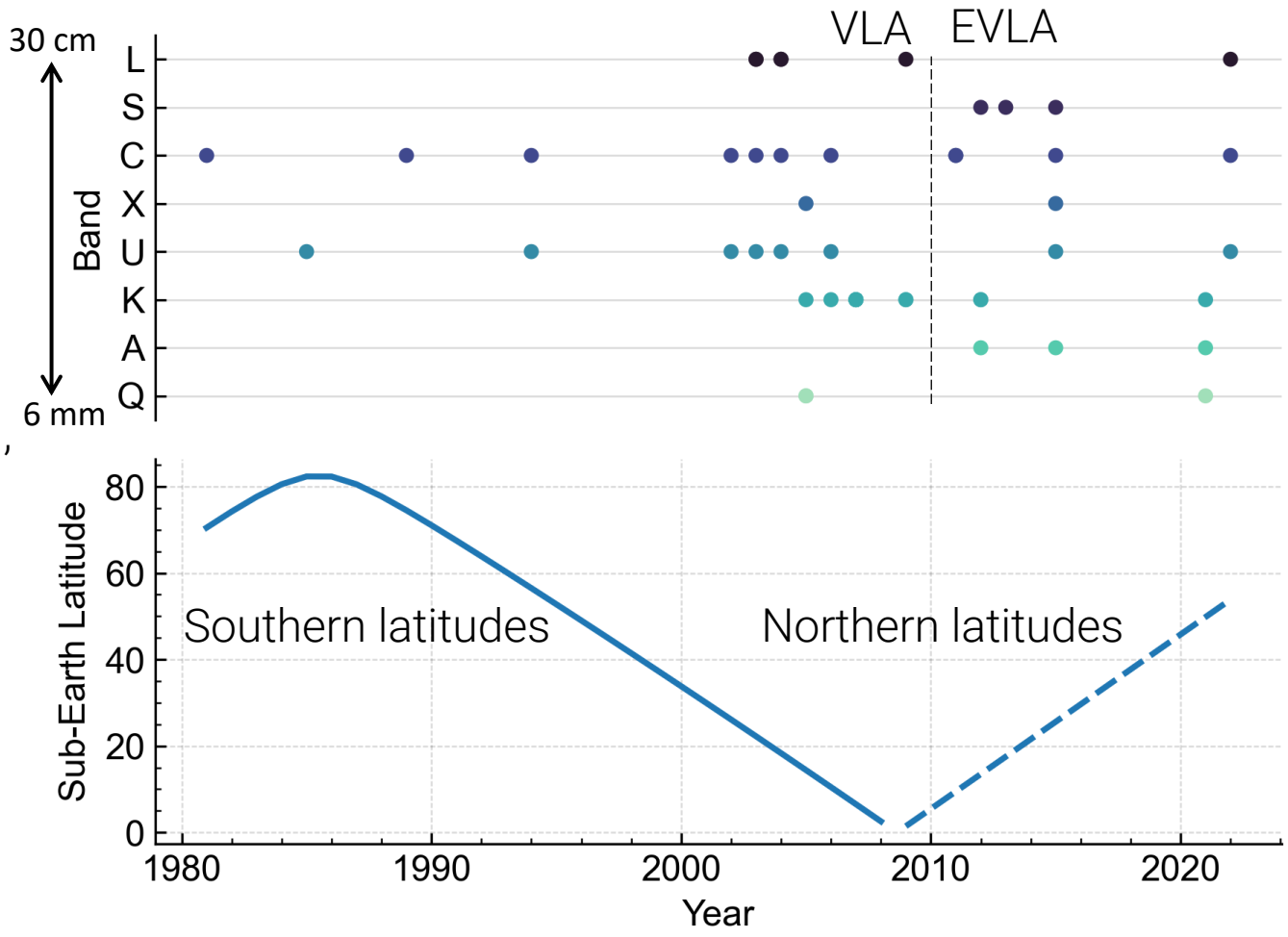
Overview

- Our group is analyzing a record of ground-based VLA observations of Uranus spanning over 40 years (1/2 Uranus year).
  - 1981(Nearer South Polar Solstice) – 2022 (Nearer North Polar Solstice)
  - Continuation of work discussed by Hofstadter et al. 2021 at EGU
- Uranus' brightness temperature as a function of latitude has remained generally consistent over the duration of this record.
  - Evidence for changes in polar contrast near solstice
- Equilibrium models are consistent with $H_2S > NH_3$.

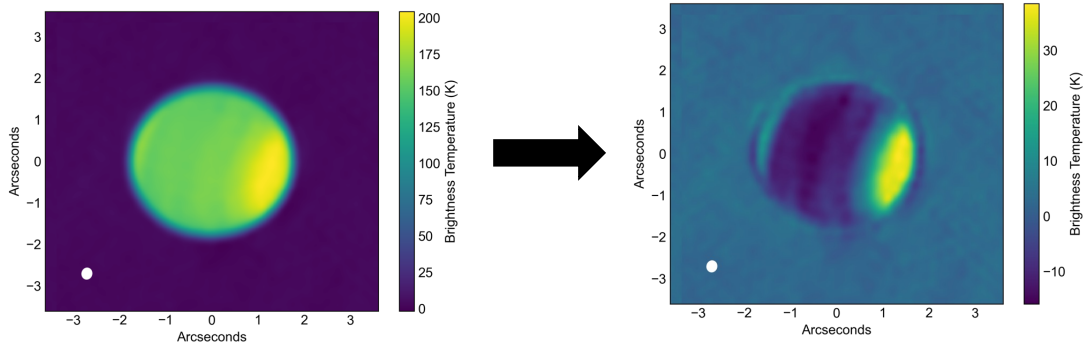
The VLA observing record

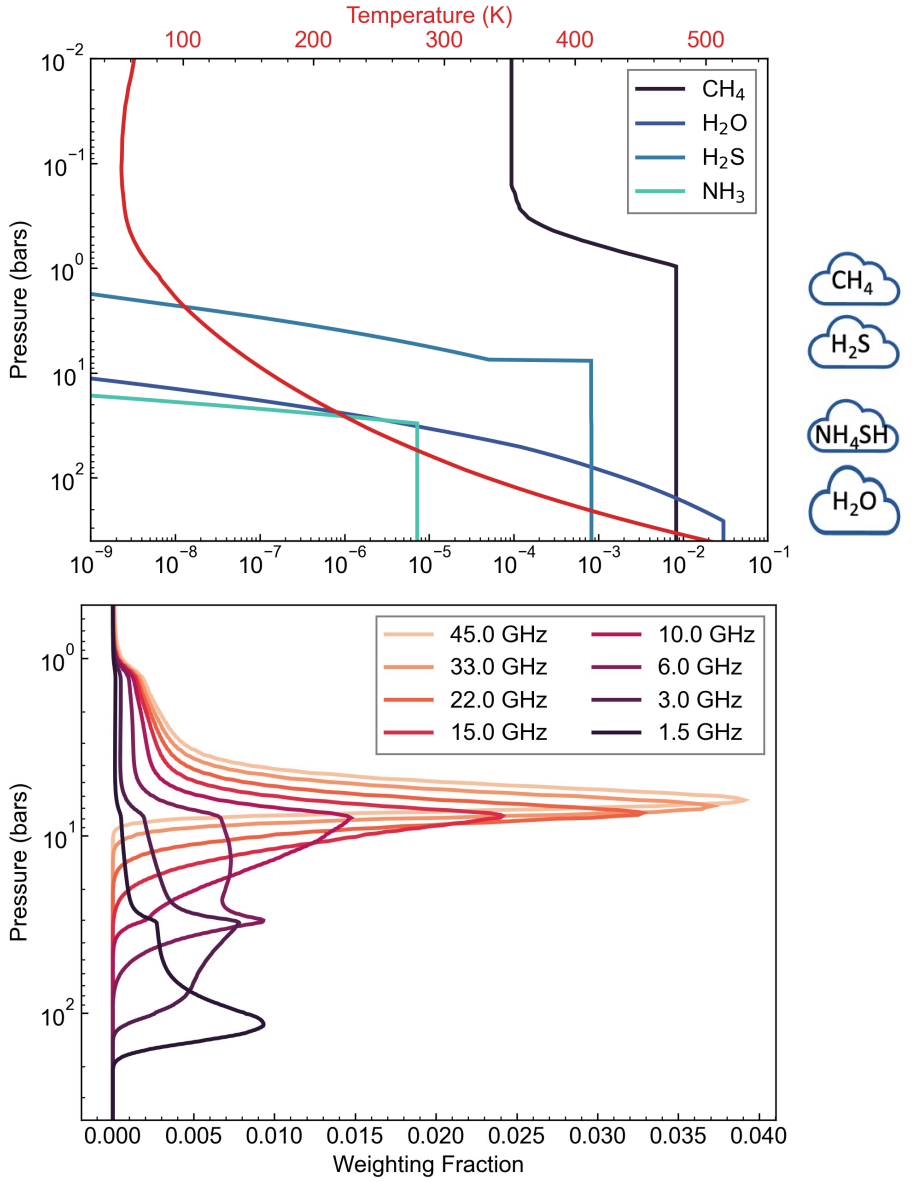
- VLA spectral coverage: 30 cm (1 GHz, L band) to 6 mm (50 GHz, Q band)
  - Pre-2010 VLA bandwidth = 100 MHz
  - Post-2010 EVLA bandwidth > 2 GHz
- L-Q band observations spanning 1981-2012
  - Hofstadter and Muhleman (1989, Icarus), Hofstadter and Butler (2003, Icarus), Hofstadter et al. (2011, EPSC)
- S-Ka band observations in 2015
  - Molter et al. (2021, PSJ)
- L-Q band observations in 2021/2022
  - Discussed here for the first time



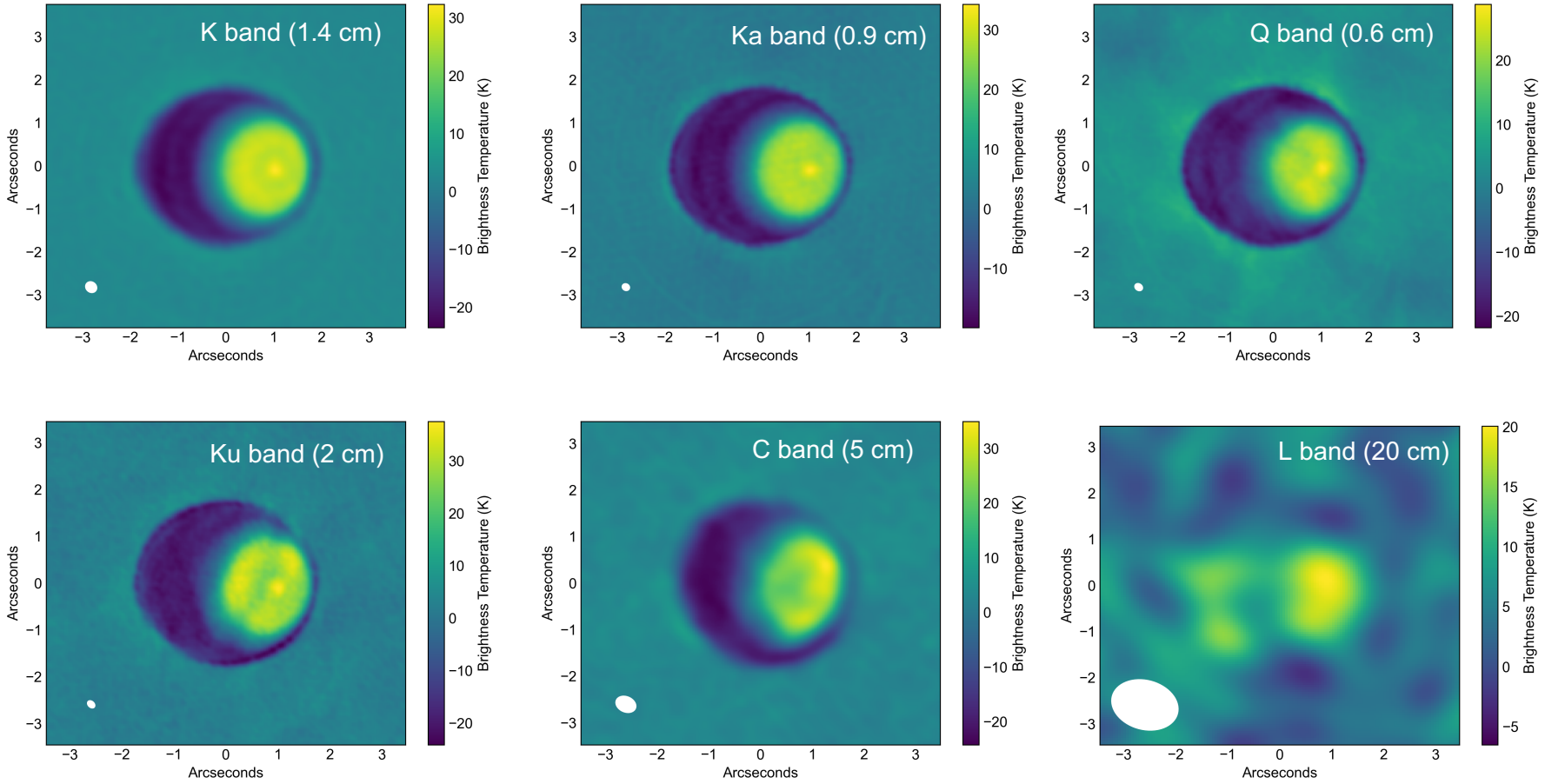
Reference atmosphere

- We use an equilibrium model with deep abundances fit by Molter et al. 2021 at 25° as a reference across all datasets.
- Subtraction of the reference model from the observations compensates for limb-darkening and highlights contrasts in brightness structure.

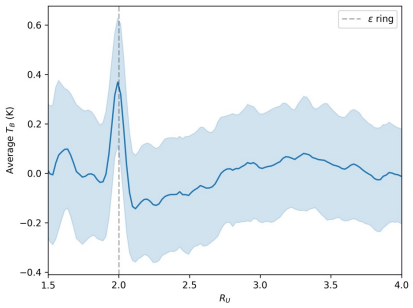




2021-2022 Observations

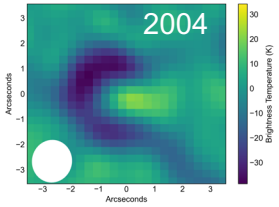


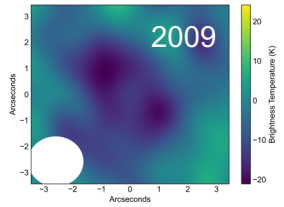
- Confirmation of polar contrast at longest wavelength yet
- Bright spot at the pole (> 85 latitude) is present in several bands, suggests Uranus' polar vortex extends down to the NH_4SH condensation level (and perhaps deeper)
- Bonus: ε ring detection



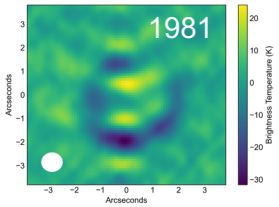
1981-2009 (Pre-EVLA) Observations

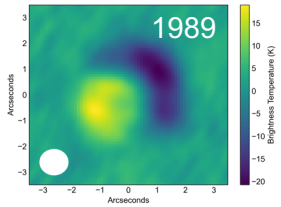
L band (20 cm)

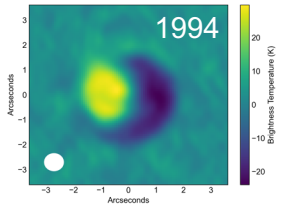


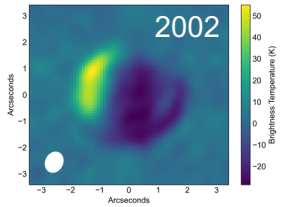


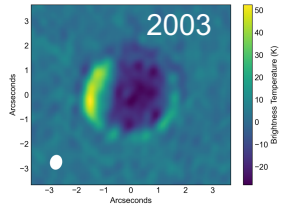
C band (5 cm)

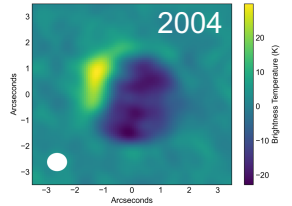


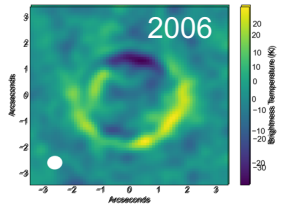




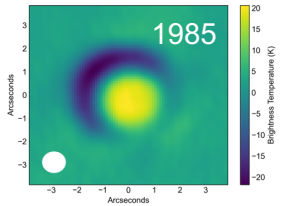


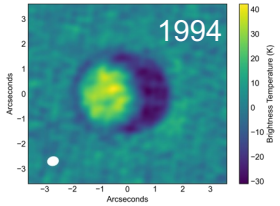


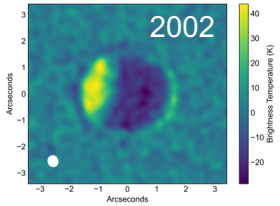


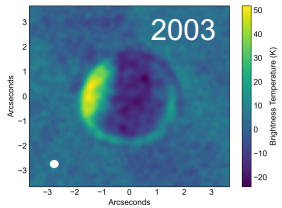


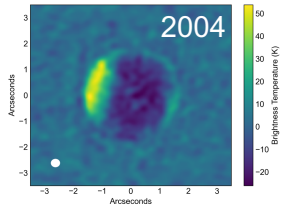
Ku band (2 cm)

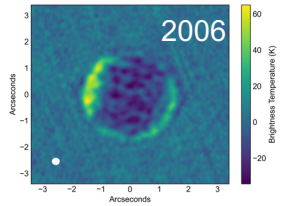




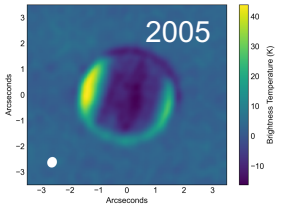


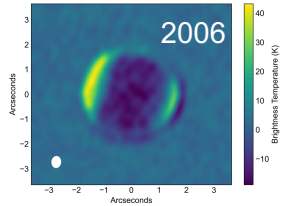


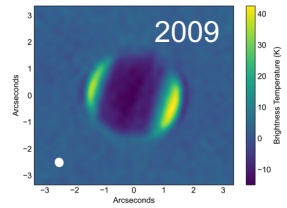




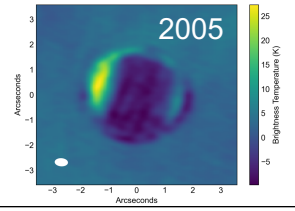
K band (1.4 cm)







Q band (0.6 cm)



2011-2022 (EVLA) Observations

L band (20 cm)

S band (10 cm)

C band (5 cm)

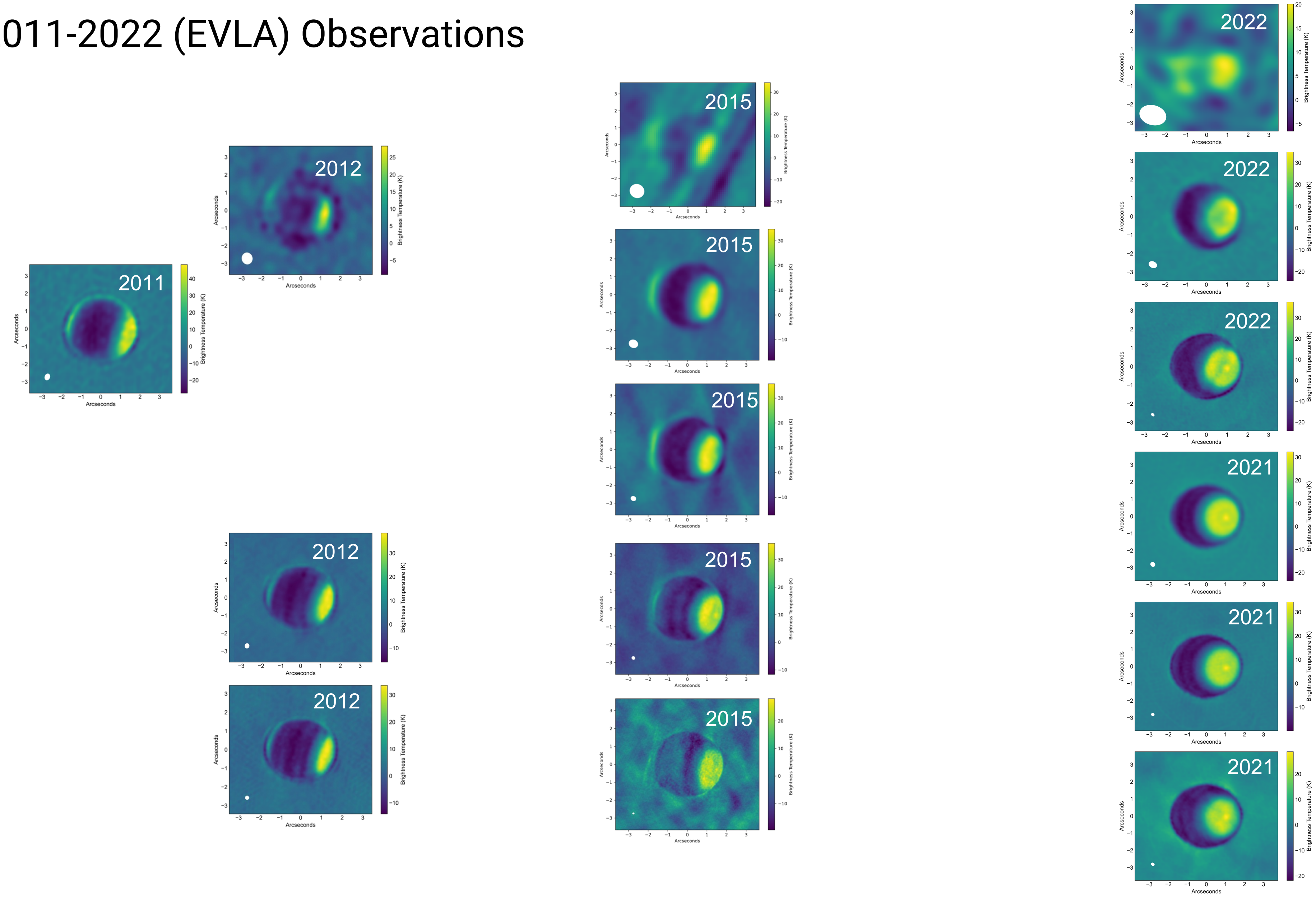
X band (3 cm)

Ku band (2 cm)

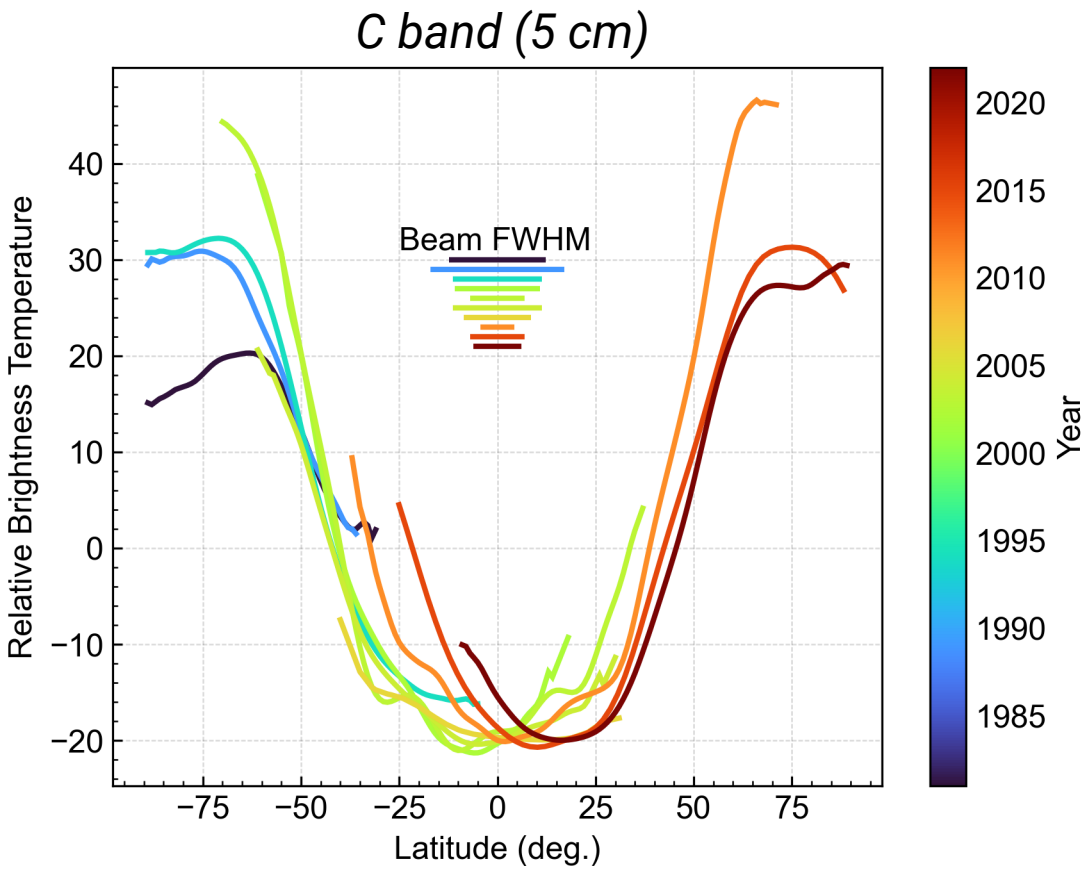
K band (1.4 cm)

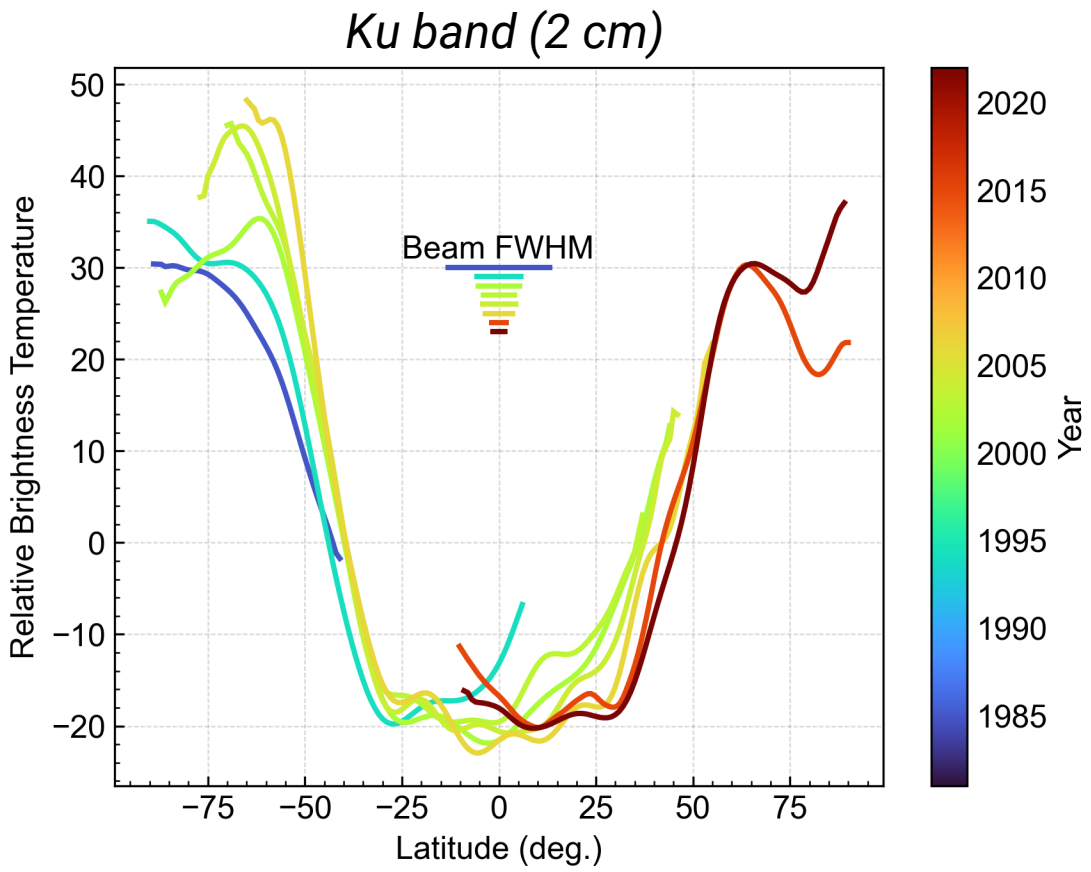
Ka band (0.9 cm)

Q band (0.6 cm)

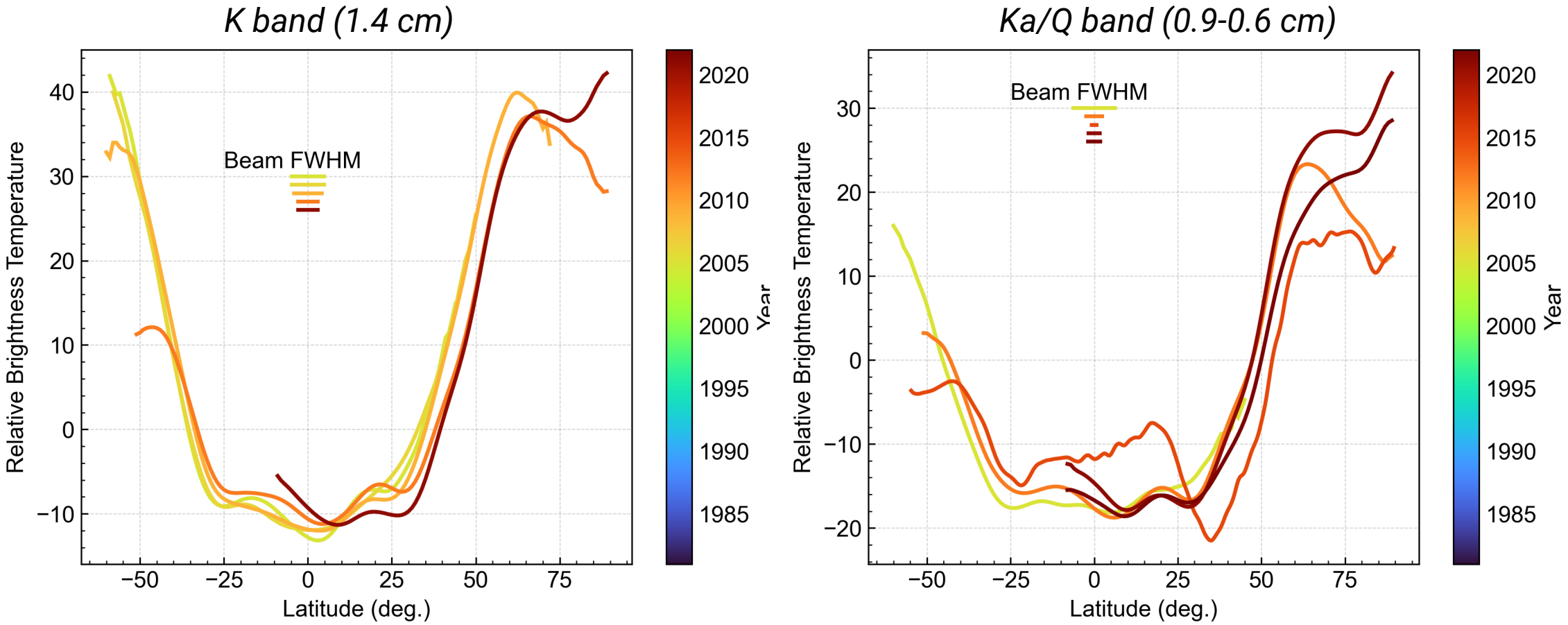


C and Ku band latitude profiles





K, Ka, and Q band latitude profiles



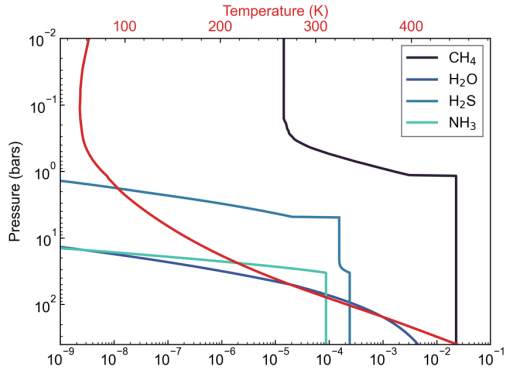
Brightness structure

- Change in polar brightness contrast near solstice in the early record is consistent with changes in atmospheric composition.
  - Apparent limb-darkening is greater at the pole, hence the equator-pole brightness contrast should increase with sub-Earth latitude if composition is invariant; the opposite is observed.
- Marked increase in polar spot brightness (> 85^{o}) suggests it is even more depleted of volatiles than the rest of the polar cap.
  - Polar vortex likely inhibits horizontal transport.
- Zonal banding is generally consistent across datasets.
  - Bands at 20^{0} are ~2 K brighter than other latitudes.

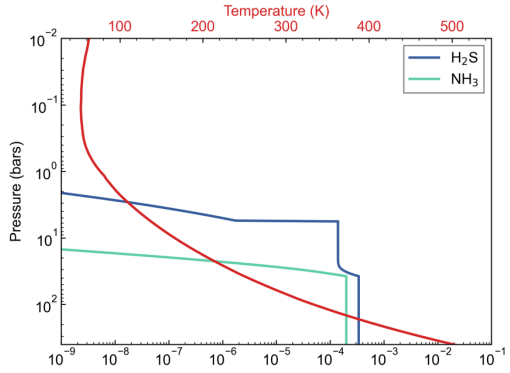
Model for the 2006 Epoch

- Current best fit equilibrium model with (solid line) and without (dashed line) varying composition with latitude

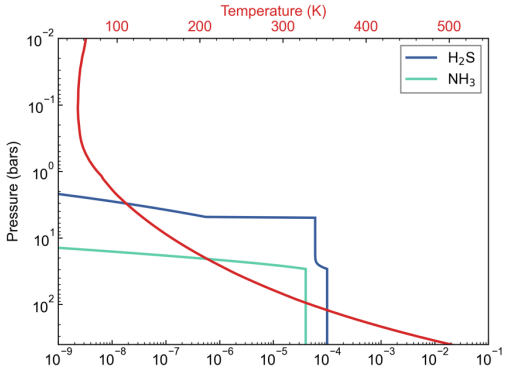
Disk-average model



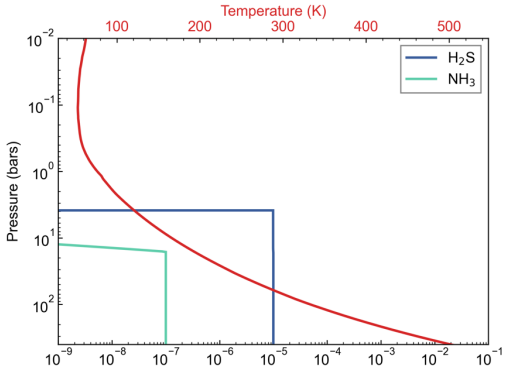
Lower latitudes
0-30°

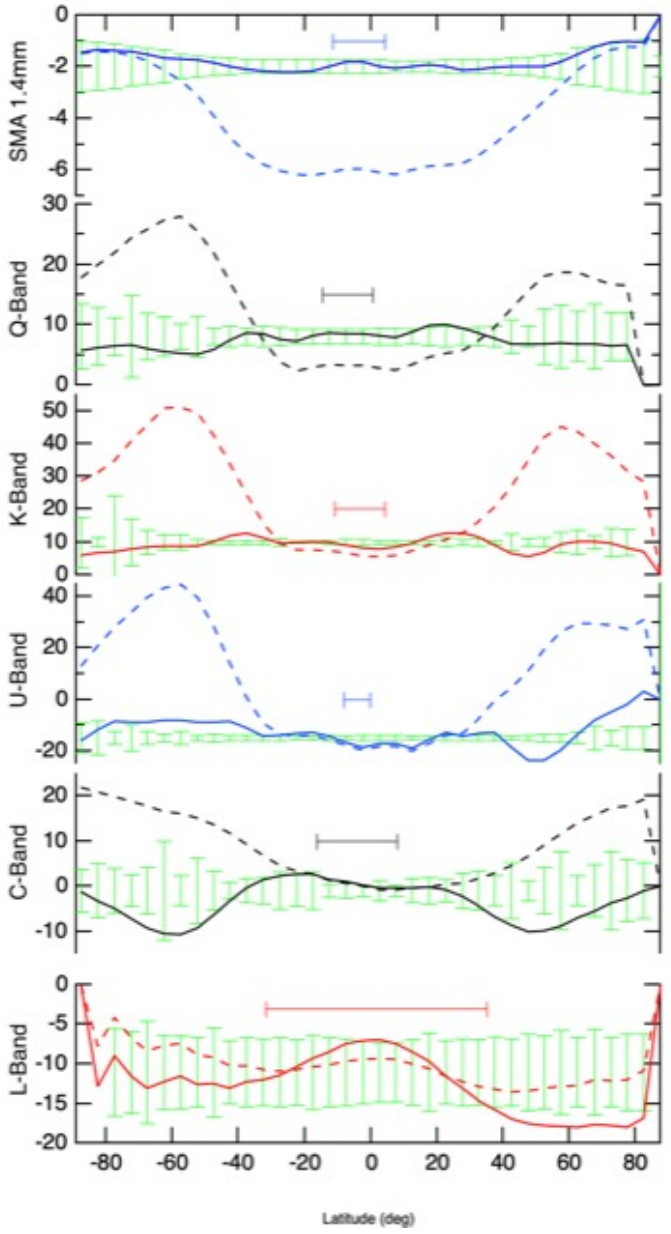


Mid-latitudes
30-50°

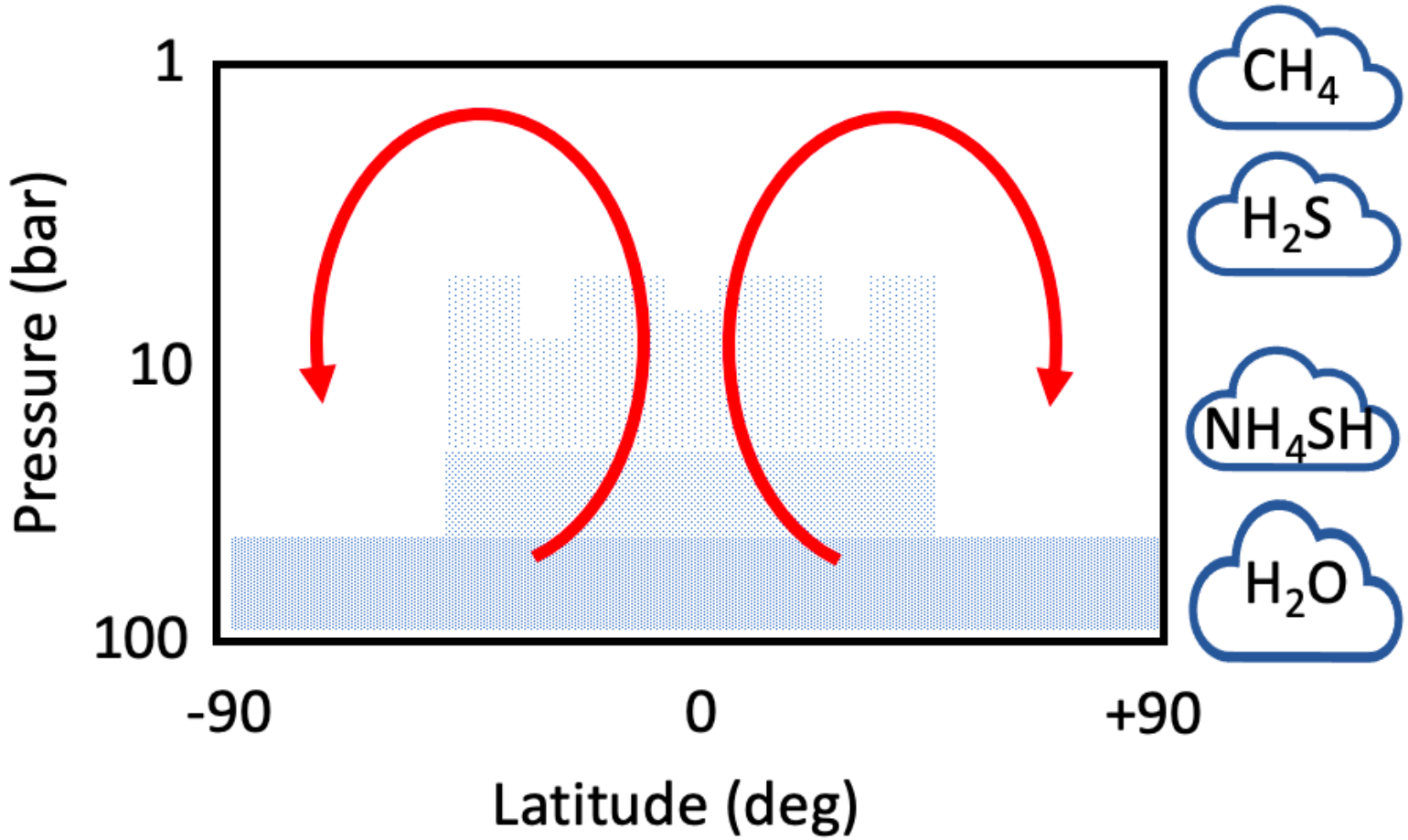


Upper latitudes
50-90°





Distribution of absorbers



Atmospheric composition

- Regions poleward of 50˚ are depleted in condensables relative to lower latitudes by a factor of 50, down to a depth of 20 to 50 bars.
- Regions between the equator and 30˚ are richer in condensables. Equilibrium models require more H_2S in these regions than NH_3.
- Regions between 30˚ and 50˚ are intermediate in their abundance of condensables.
- In the 1-5 bar region, relative humidities at low latitudes are 1.5% and they are 0% over the poles, and/or the meridional temperature variations of ~ 2 K observed near 800 mbar extend to these depths.
- The abundance of condensables over a large altitude range varies by ~30% near latitudes of 0˚, 20˚ and 75˚.

Review

- Our group is analyzing a record of ground-based VLA observations of Uranus spanning over 40 years (1/2 Uranus year).
  - Recent wide-band observations (2015, 2021) have resulted in exceptionally detailed images.
- Uranus' brightness temperature as a function of latitude has remained generally consistent over the duration of this record.
  - Evidence for changes in polar contrast near solstice.
- Equilibrium models are consistent with $H_2S > NH_3$.
  - Models with three distinct latitude regions are necessary to fit data.
- Future work will include fitting to non-equilibrium atmosphere models.

Appendix

Regional Spectra