Atmospheric Chemistry

Week 7 (2nd June 2025), Lecture 6

Why is atmospheric chemistry interesting?

Teaches you *how* to be surprised

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DETECTION OF CARBON MONOXIDE IN JUPITER*

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ABSTRACT

New, ground-based, 5-μ spectra of Jupiter have revealed the presence of a trace quantity of carbon monoxide in the lower atmosphere of the planet. A preliminary analysis suggests a number mixing ratio in the neighborhood of 10^{-9} and a column abundance of roughly 5×10^{17} molecules cm^{-2} to a depth of at least 2 atmospheres. It is suggested that the observation might be confirmed by microwave techniques.

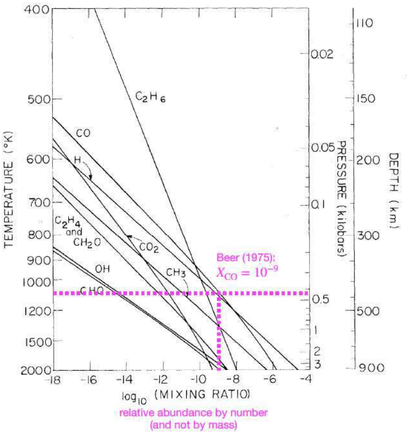
Subject headings: atmospheres, planetary — Jupiter — molecules

Example: why is the detection of CO in Jupiter's atmosphere surprising?

The amount of CO detected in Jupiter's H_2-dominated atmosphere is surprising because this is **much higher than predicted by equilibrium chemistry**.

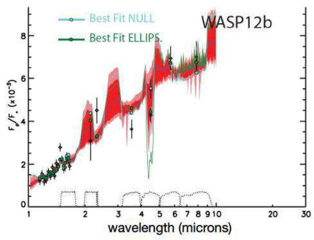
The photospheric temperature of Jupiter is about 88 K. At this temperature, the predicted abundance of CO is many orders of magnitude below the measured value by Beer (1975).

Therefore, the CO must be out of chemical equilibrium and mixed up from a deeper, hotter part of Jupiter's atmosphere to the photosphere.



Prinn & Barshay (1977, Science, 198, 1031)

Exoplanet example: hot Jupiter WASP-12b



By using an inversion technique known as atmospheric retrieval, Line et al. (2014) inferred the volume mixing ratios (chemical abundances relative to H_2) of simple molecules.

However, CO_2 is inferred to be at least an order of magnitude more abundant than CO (in a hydrogen-dominated atmosphere).

Is this surprising? Why?

Summary of the Abundance Retrieval Results for each Planet Compared with the Literature[a]

Planet	Source	H_2O[b]	CH_4[b]	CO[b]	CO_2[b]	C/O[c]
WASP-12b	Best-fit Null (χ^2_{best}/N =1.74)	0.0082×10^{-6}	0.024×10^{-7}	2210×10^{-6}	56400×10^{-6}	0.51
	68% Interval-Null	$[0.0016–5430] \times 10^{-6}$	$[0.00017–8270] \times 10^{-7}$	$[0.00018–10400] \times 10^{-6}$	$[0.0074–48400] \times 10^{-6}$	0.30–1.00
	Best-fit Ellipsoidal (χ^2_{best}/N =1.71)	512×10^{-6}	0.002×10^{-7}	2170×10^{-6}	107000×10^{-6}	0.50
	68% Interval-Ellipsoidal	$[0.00011–863] \times 10^{-6}$	$[0.00028–75.3] \times 10^{-7}$	$[0.000051–1460] \times 10^{-6}$	$[51100–146000] \times 10^{-6}$	0.11–0.22
	Madhusudhan et al. 2011a	$[0.00005–6.00] \times 10^{-6}$	$[40–8000] \times 10^{-7}$	$[30–3000] \times 10^{-6}$	$[0.2–7] \times 10^{-6}$	>1.0
	Swain et al. 2013	$[0.000000047–28000] \times 10^{-6}$	$[0.9–60.12] \times 10^{-7}$	$[0.0000011–567000] \times 10^{-6}$	$[0.007–2400] \times 10^{-6}$	0.3

Line et al. (2014, ApJ, 783, 70)

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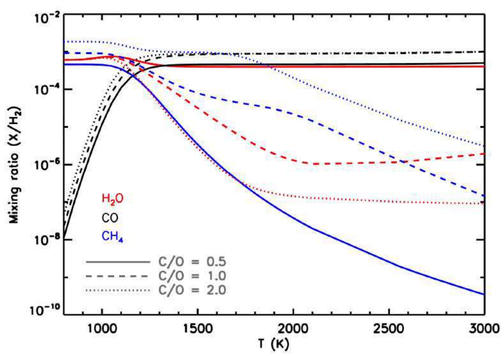
Teaches you *how* to be surprised

- Do we expect methane to be abundant in a cold atmosphere?
- What does "cold" exactly mean?
- Are carbon-rich atmospheres also water-poor?
- Generally, what are the dominant carriers of carbon, nitrogen, oxygen, etc?

Generally, given a set of elemental abundances (C/H, O/H, N/H, etc), how may we predict the molecular abundances (CH_4, CO, CO_2, H_2O, etc)?

What are the chemical trends with temperature?



Madhusudhan (2012, ApJ, 758, 36)