update on phosphine in Venus' atmosphere

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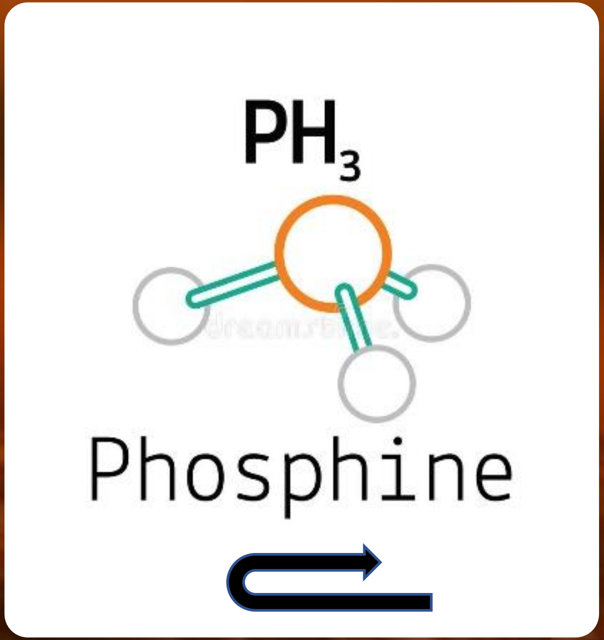
the 19 members of our discovery team

ESA

project: 2015-2021

- this was a dedicated biosignature search
    - phosphine produced by anaerobic micro-organisms on Earth (+ not, or very sparsely, by abiotic routes)
    - Venus' clouds are a possible habitat for anaerobic acidophile micro-organisms
- *an idea inexpensive in telescope time*:
    - a search for the ground-state rotational transition, PH_3 1-0, in absorption in Venus' high atmosphere, against the quasi-continuum generated at ~55 km altitude



rotation of the PH3 molecule

we were privileged to use the James Clerk Maxwell Telescope (2017, 2020) and the Atacama Large Millimeter/submillimeter Array (2019), through Directors' Time

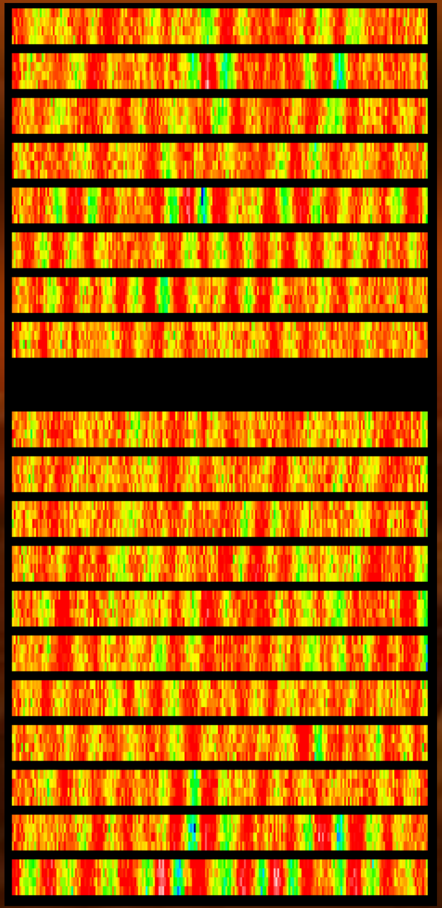
why is this challenging in practice?

- instrumental "wiggles" in the spectra when looking at very high continuum-to-line dynamic range

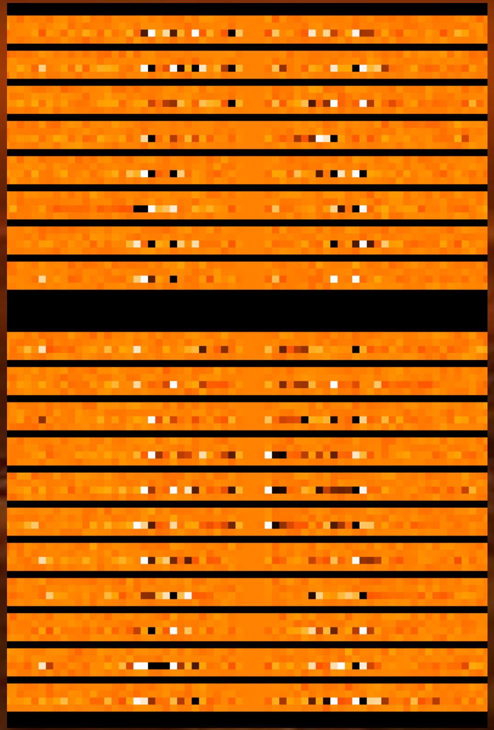
a stack of the 2020 JCMT spectra:

↑ time

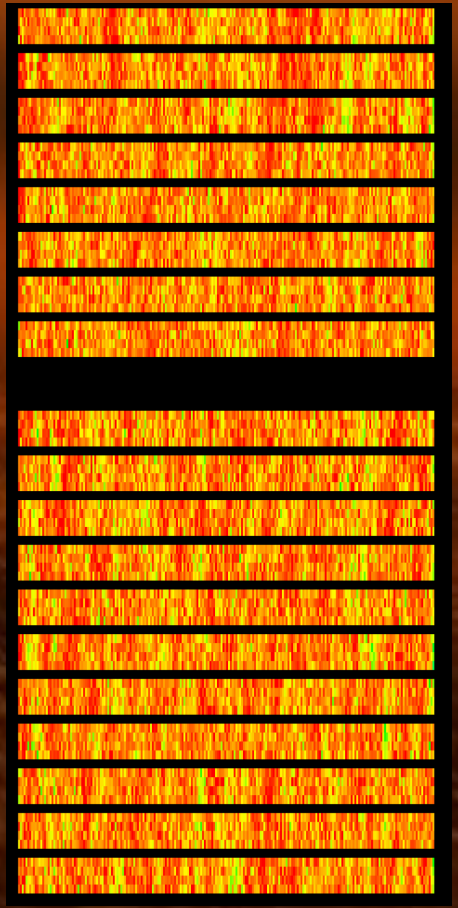
wavelength →



a Fourier Transform (Hermitian) showing the principal components of the wiggles



the spectra after cleaning



some misconceptions about the results

1) the "detections" are by-chance slightly-bigger wiggles ☹

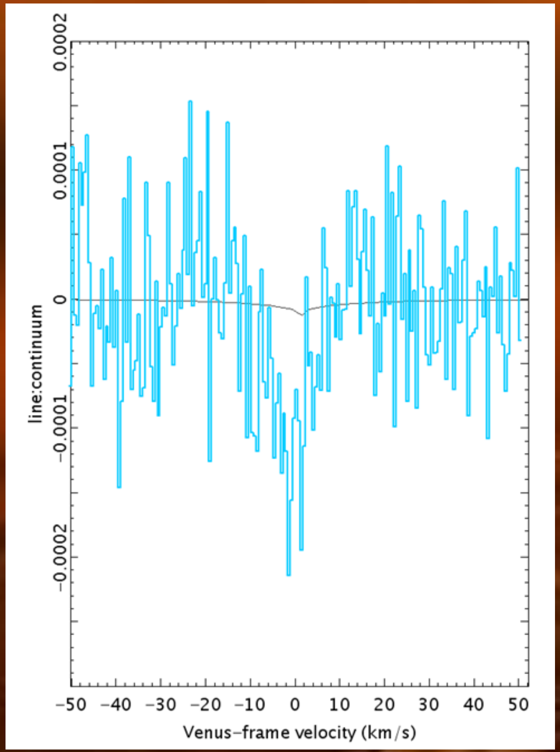
- NO: the statistical test used is not amplitude, but: the very precise (to $\approx 10^{-6}$) coincidence of observed and expected wavelength

- there are now 3 independent datasets for PH_3 1-0 (different instrumentation) $\rightarrow$ ALL pass this test

- data processing (as we learned more) has moved towards <u>no subjective user intervention</u> $\rightarrow$ we are NOT "making lines we want to see"
  - e.g. the 2020 data-processing uses only a 5σ cut in the FT-components

2) *the "detections" are much more likely to be a (high rotational state) transition of sulphur dioxide* ☹

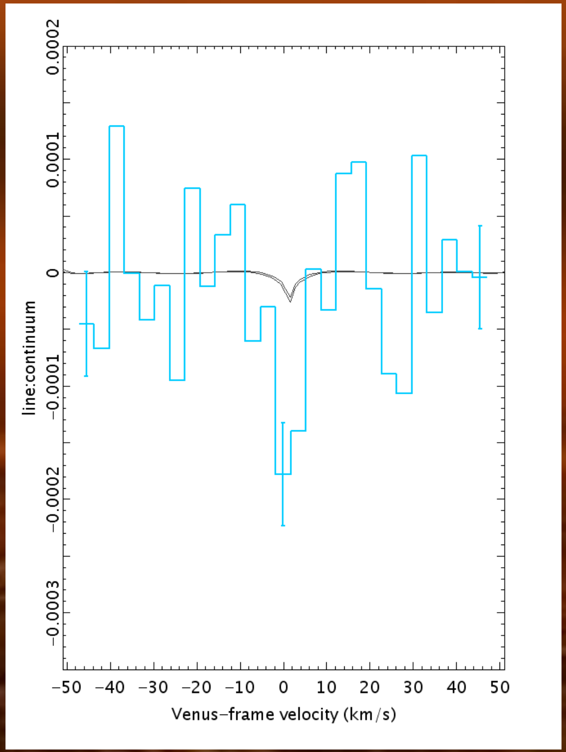
- NO: not only does this violate the wavelength coincidence test, but for the 2017 and 2019 epochs, we observed other SO_2 transitions



inferred maximum contamination *by SO_2 $30_{9,21}$–$31_{8,24}$ (black curves) of the observed spectra identified as mainly PH_3 1-0 absorption (blue histograms)*

Left: 50%-planetary-disc, lower-latitudes from ALMA/2019

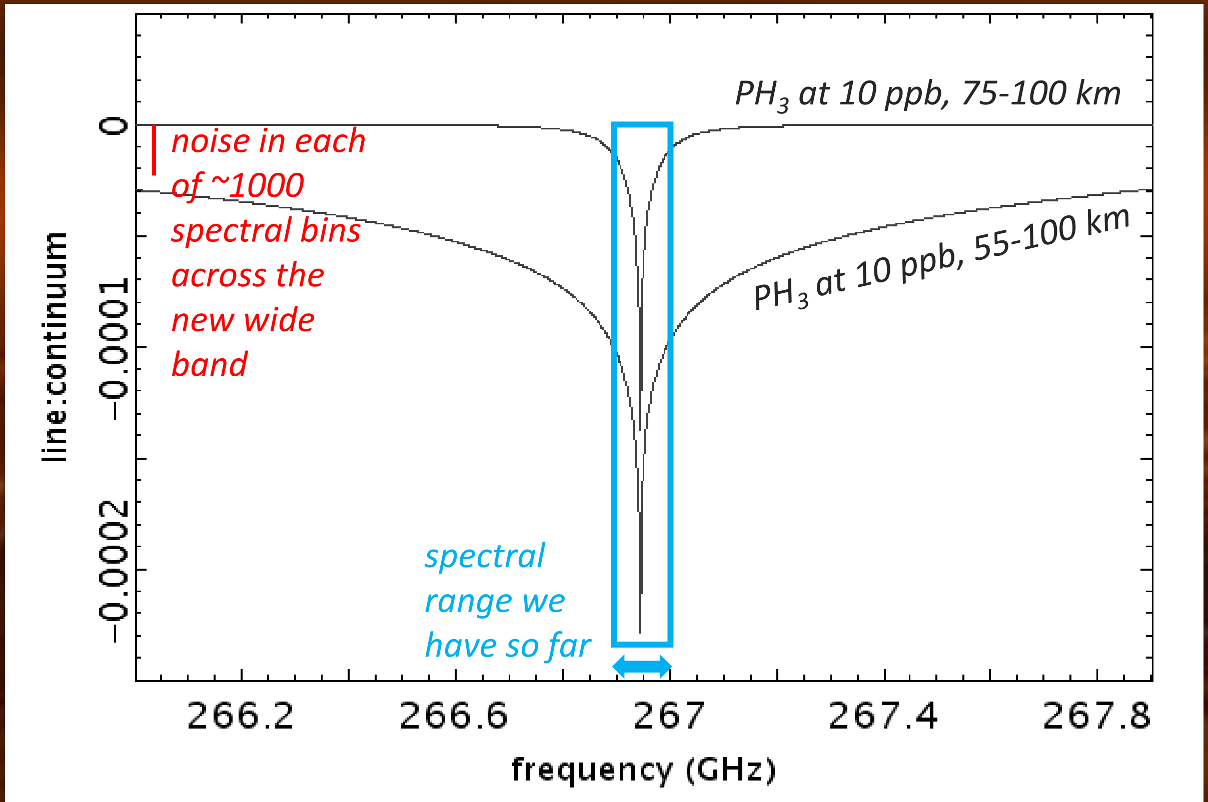
Right: whole planet from JCMT/2017 (additional spectral binning for clarity)



(NB all published radiative-transfer models give very similar predictions for relative strength of the "SO_2 contaminant line": https://arxiv.org/abs/2108.08393)

3) *the narrow lines indicate the absorption is all coming from the cold mesosphere, with none from the warmer clouds – NOT necessarily!*

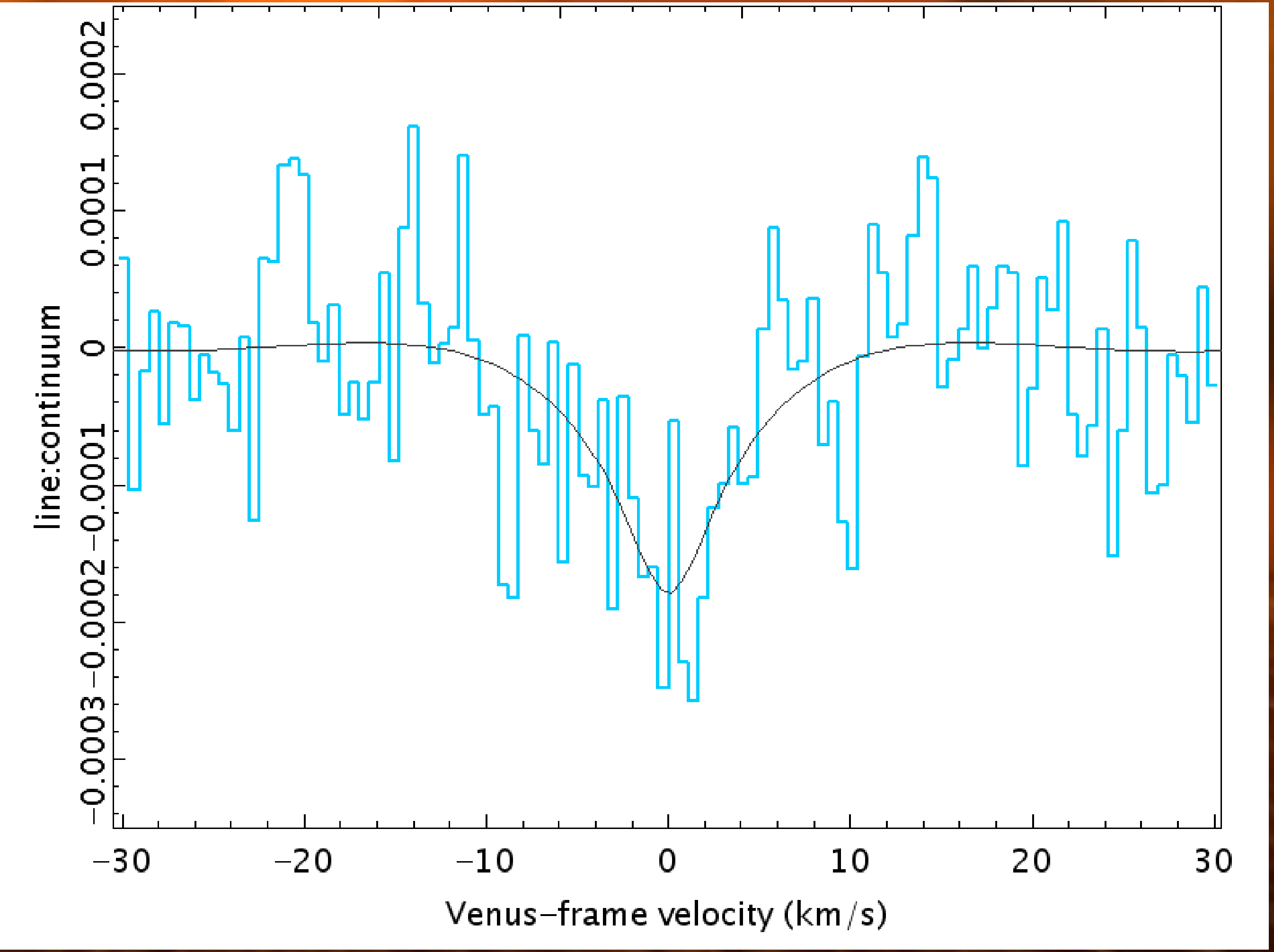
- "clouds+mesosphere" presently hard to distinguish from "mesosphere-only", because of the loss of line wings when cleaning out the wiggles → our JCMT Large Programme (proposed for 2022/23, ~90 hours) requests a wider band



proposed new JCMT observations

robustness of PH_3 detection

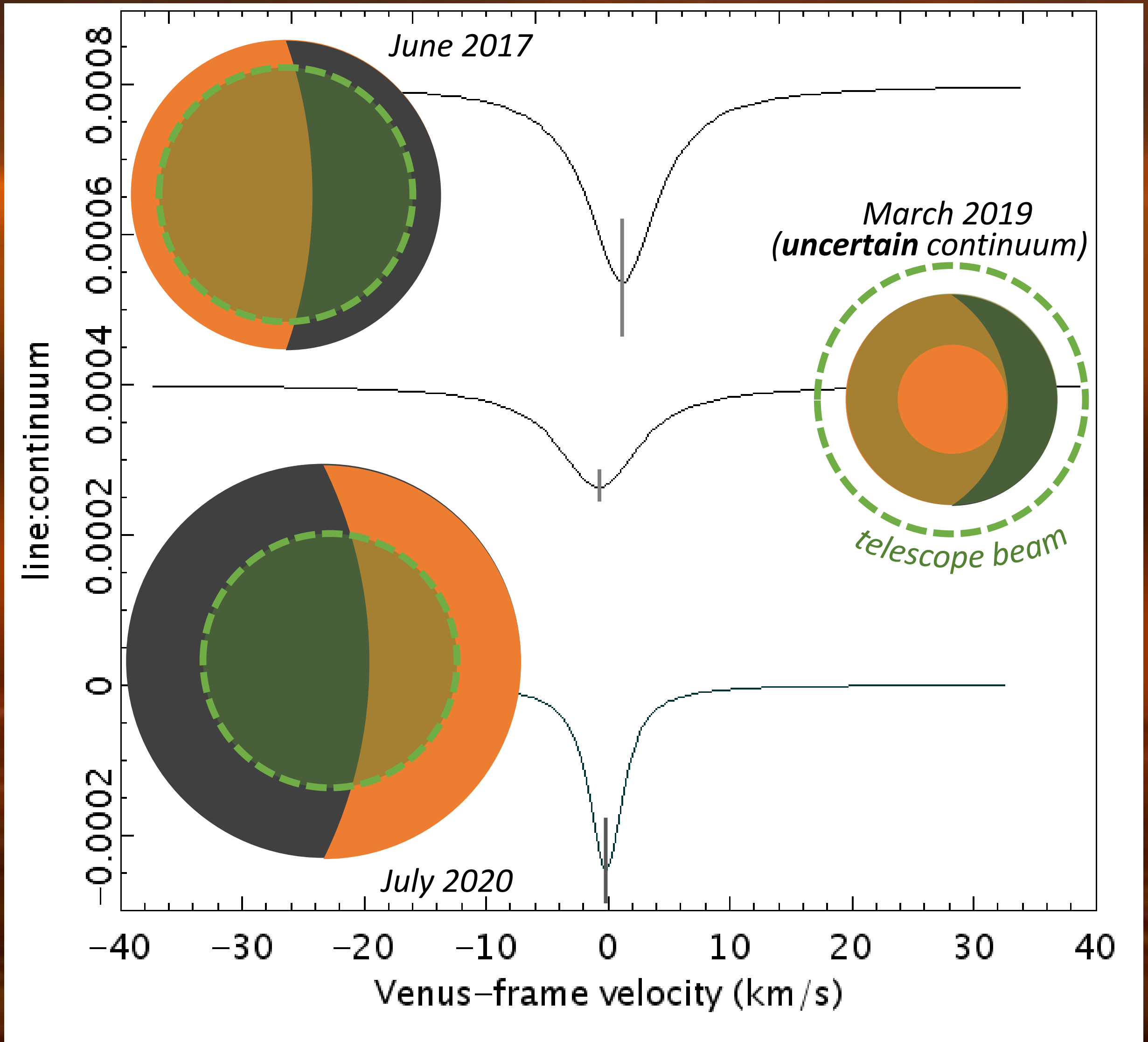
- get a strongly detected feature from a simple average of the spectra from all 3 epochs
  - superposed is a simple radiative transfer model for 20 ppb of PH_3 at all altitudes 55-90 km, which was post-processed to mimic the handling of the real data
  - *true fit uncertain* (no usable info on line wings, no lab-based info on PH_3-CO_2 line-broadening coefficient, …)



co-added PH_3 1-0 spectrum, and a corresponding 20 ppb model

variation of PH_3

- different areas and illuminations were seen in each observation (*green shaded regions* were the best sampled)
    - differences in fitted Lorentzian line profiles are likely just due to modest signal-to-noise (5-8σ per spectrum)
- <u>no</u> clear temporal or spatial variations



fits for the 3 epochs and corresponding planetary views

where from here?

- acquire new spectra (e.g. PH_3 2-1?)
- model phosphine with various drift patterns, lifetimes, etc.

- reconcile all data (infrared + millimetre spectra + in-situ mass-spec) with a chemically-plausible altitude profile

(NB this has taken a long time e.g. for sulphur compounds – where more inter-related species are observable! – need more P-species)

→ answer: does PH_3 have a clouds origin?

- exciting future for in-situ missions and telescopic monitoring!