Recovering Venusian Phosphine with SOFIA/GREAT

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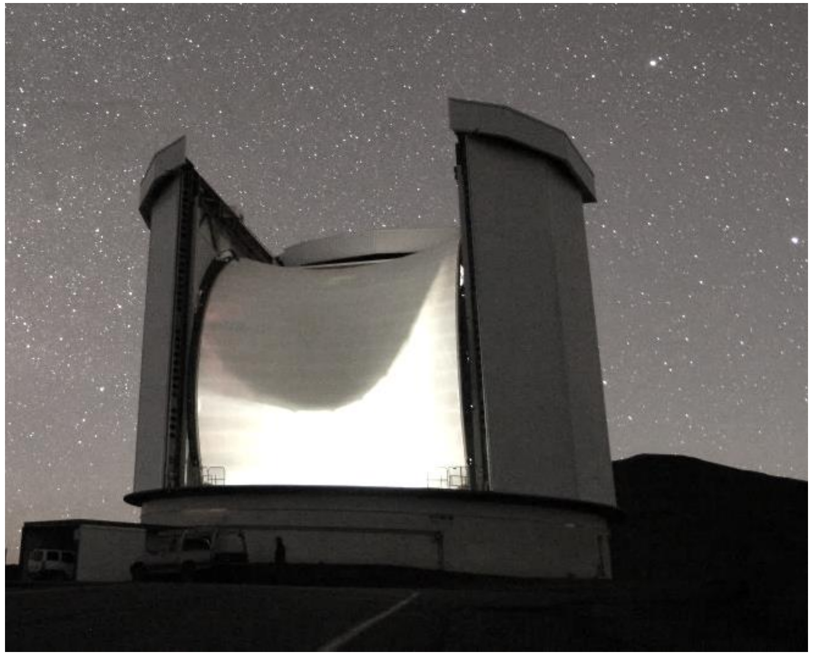
& the Team

background

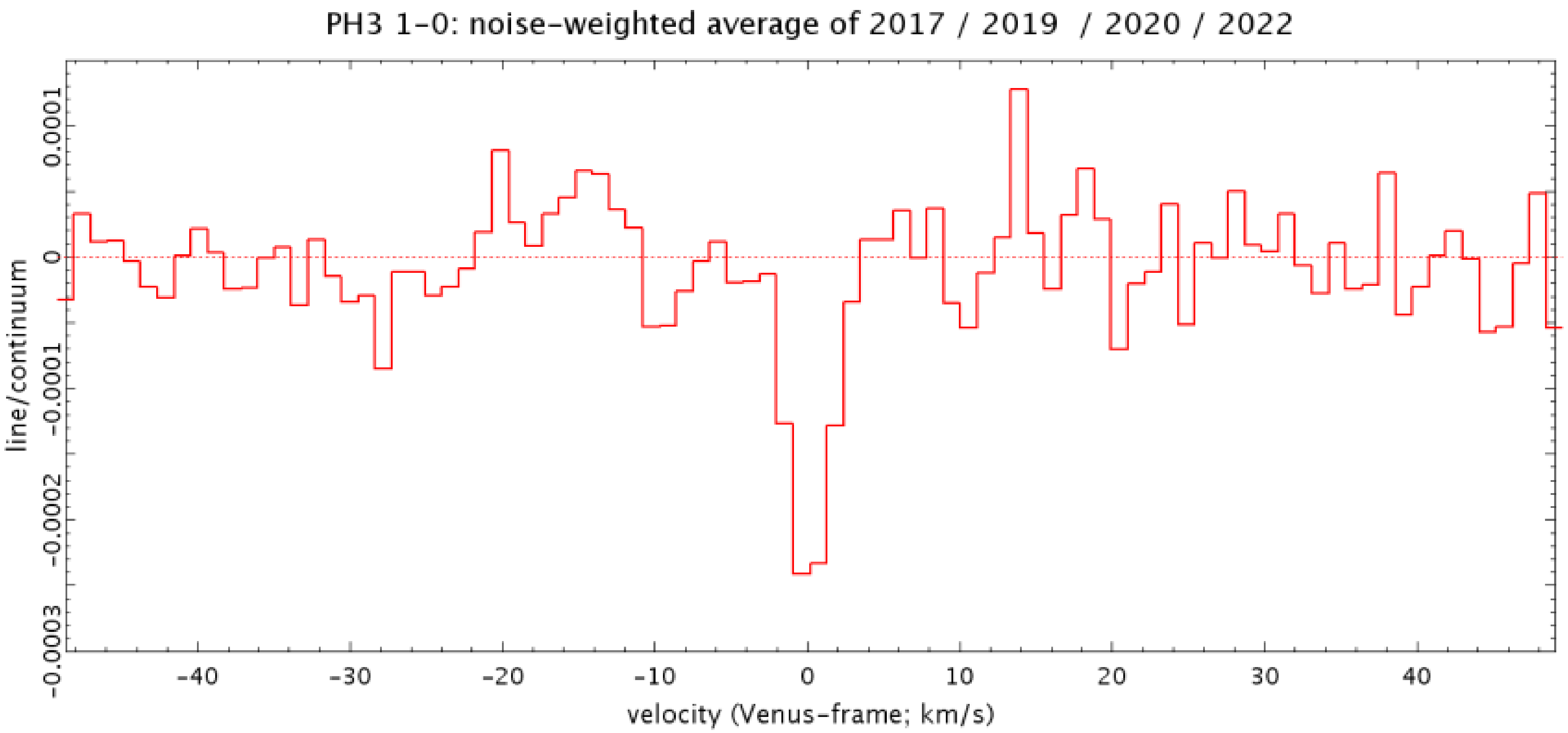
- starting in 2017, we made a targeted biomarker search of Venus: PH_3 has a ground-accessible rotational transition: **J=1-0 at 267 GHz**

- the idea was that Venus' clouds could be an anaerobic habitat, and PH_3 is found where there are anaerobic micro-organisms on Earth
  - it's not easily produced by other routes



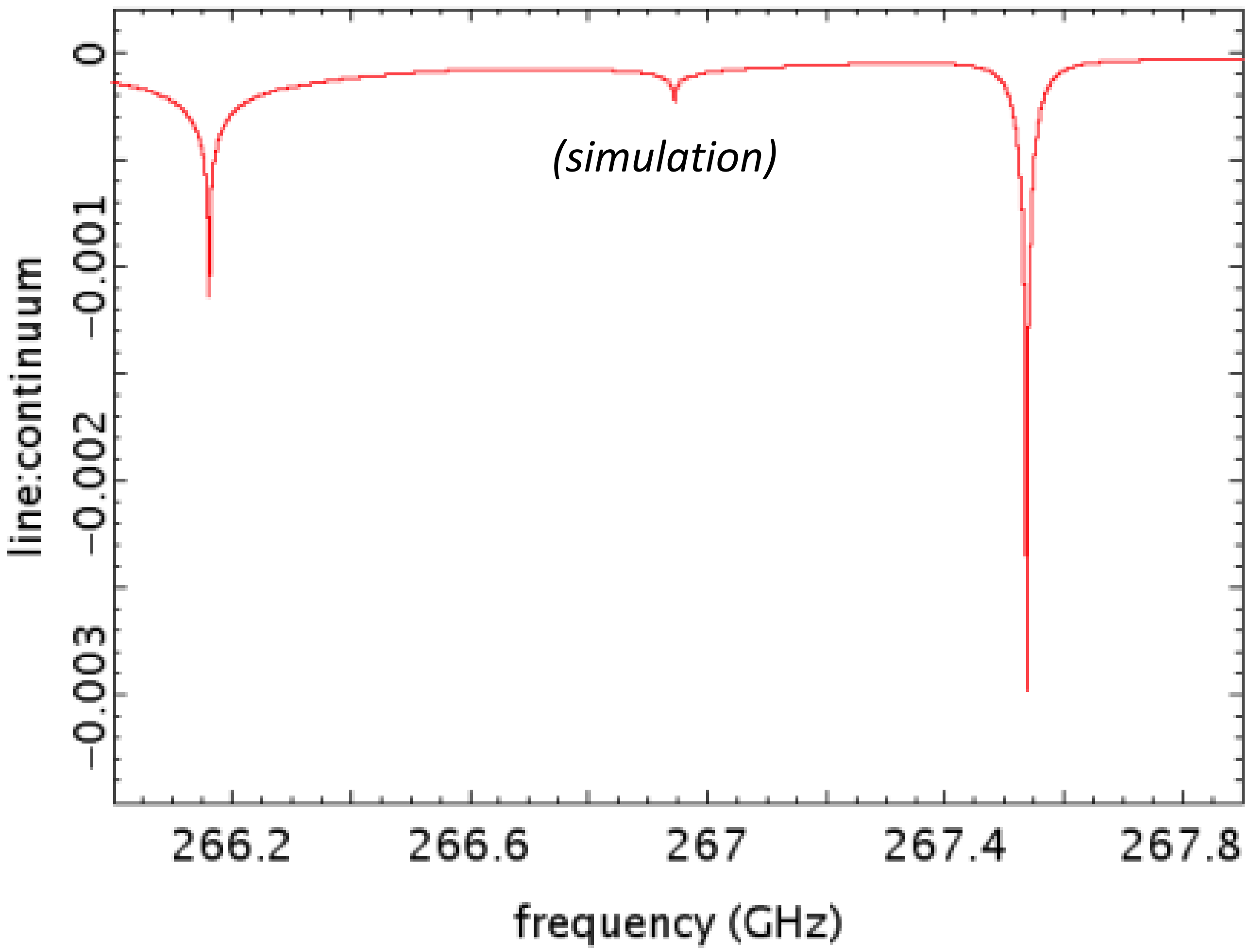
current status

- the 1-0 transition has been seen at 4 epochs…



current status

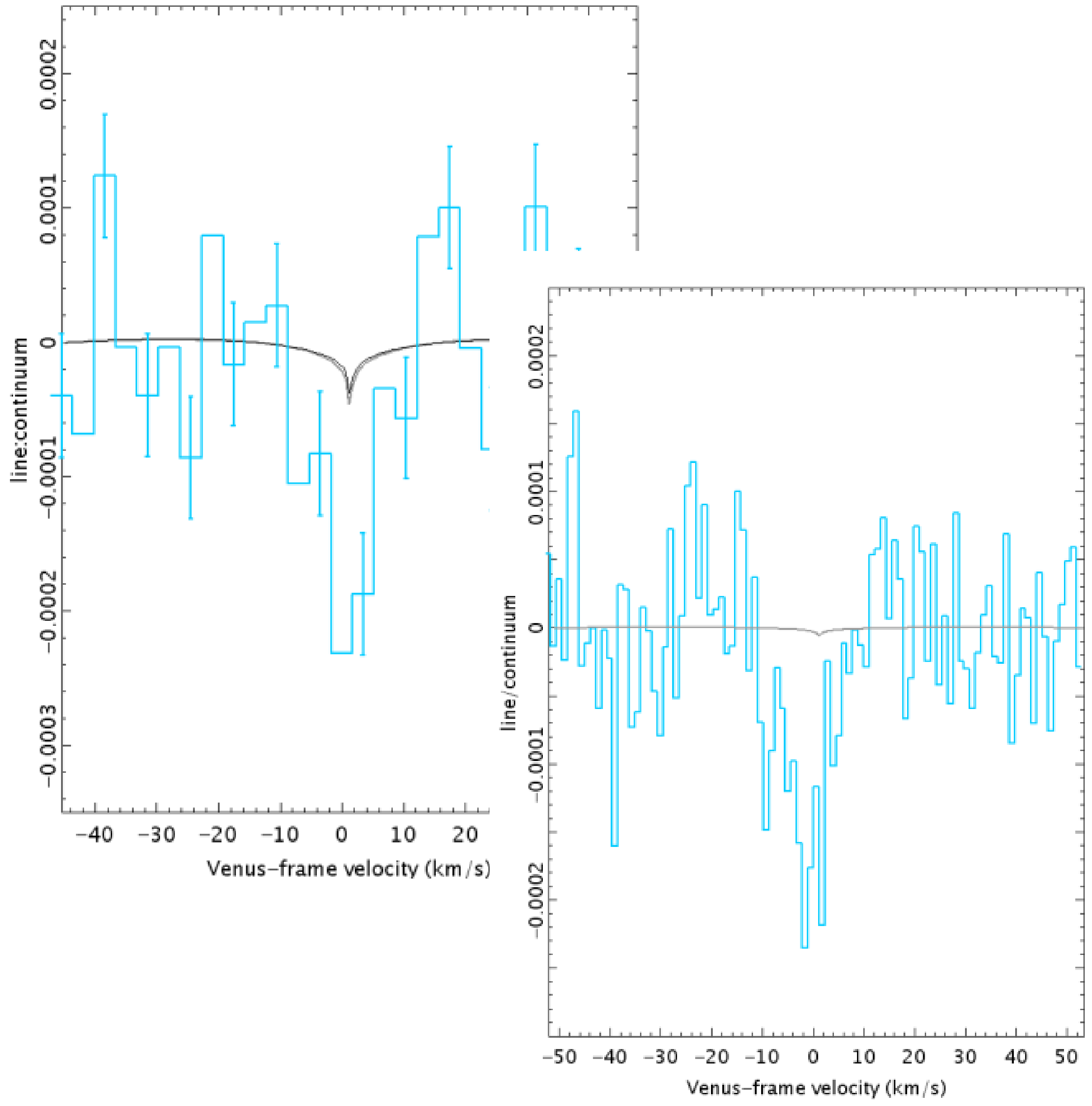
- … and the 2022 data appears to show a broad-line component from PH_3 in the clouds (the "habitable" region)



https://www.eaobservatory.org/jcmt/science/large-programs/jcmt-venus-monitoring-phosphine-and-other-molecules-in-venuss-atmosphere/

data issues

- solved to the limits of what is possible (e.g. we don't know ALMA's PSF to 10^{-5}!)
- different processing methods give PH_3 detections (and low probability of "fake lines")
- it's not a mis-identification with SO_2
  - via (near-)simultaneous data



mis-identification?

- requires a strong absorber that is *uncatalogued*, and has a suitable transition *extremely* close to 266.9445 GHz

- but to be sure! … observe another rotational* line of PH_3

- problem: no other ground-accessible lines
    - e.g. 10 days of excellent stable weather at ALMA could possibly get J=3-2 – but this is unlikely to happen, let alone be scheduled!

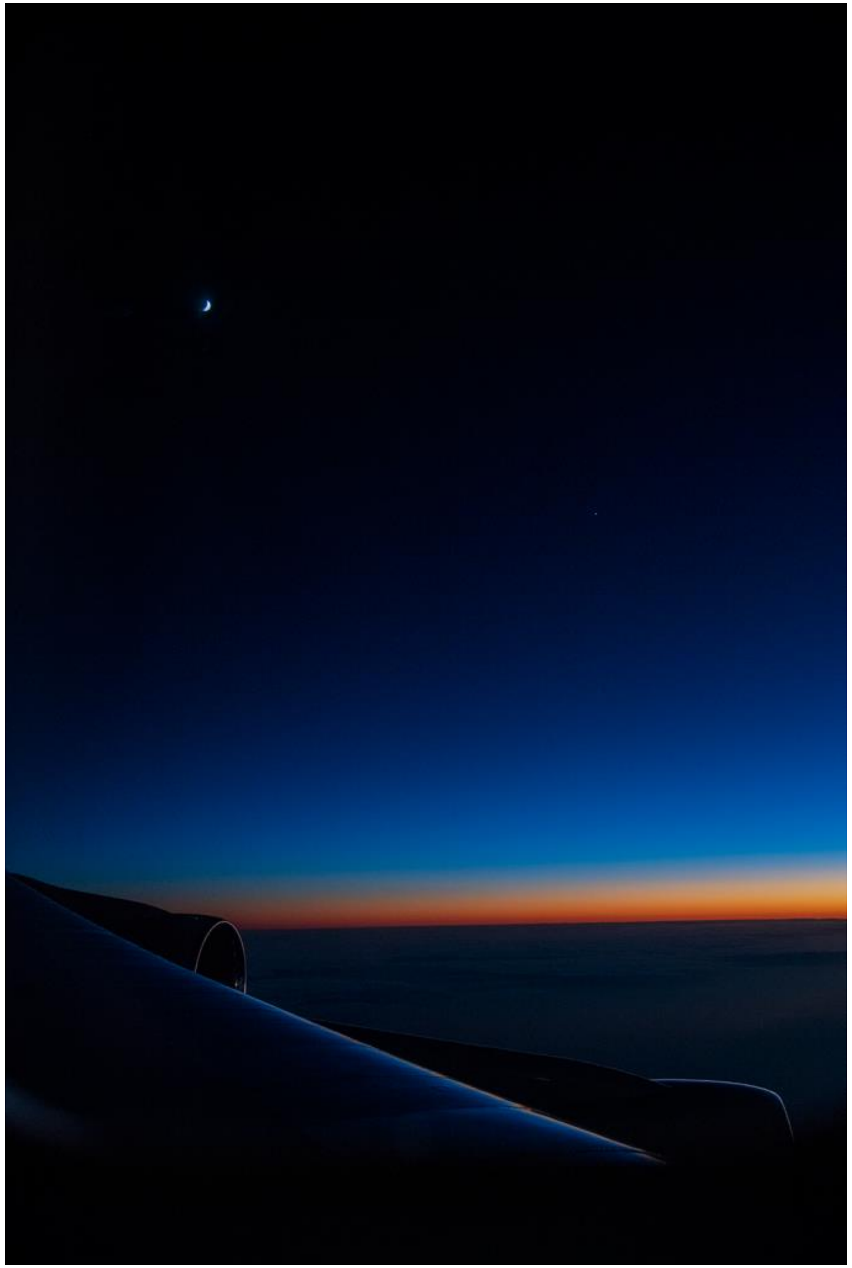
*noting there are excellent upper limits from *vibrational* (IR) transitions, from serendipitous datasets

SOFIA & GREAT

- unique opportunity to search for J=2-1 and J=4-3 lines
  - Cordiner et al., November 2021

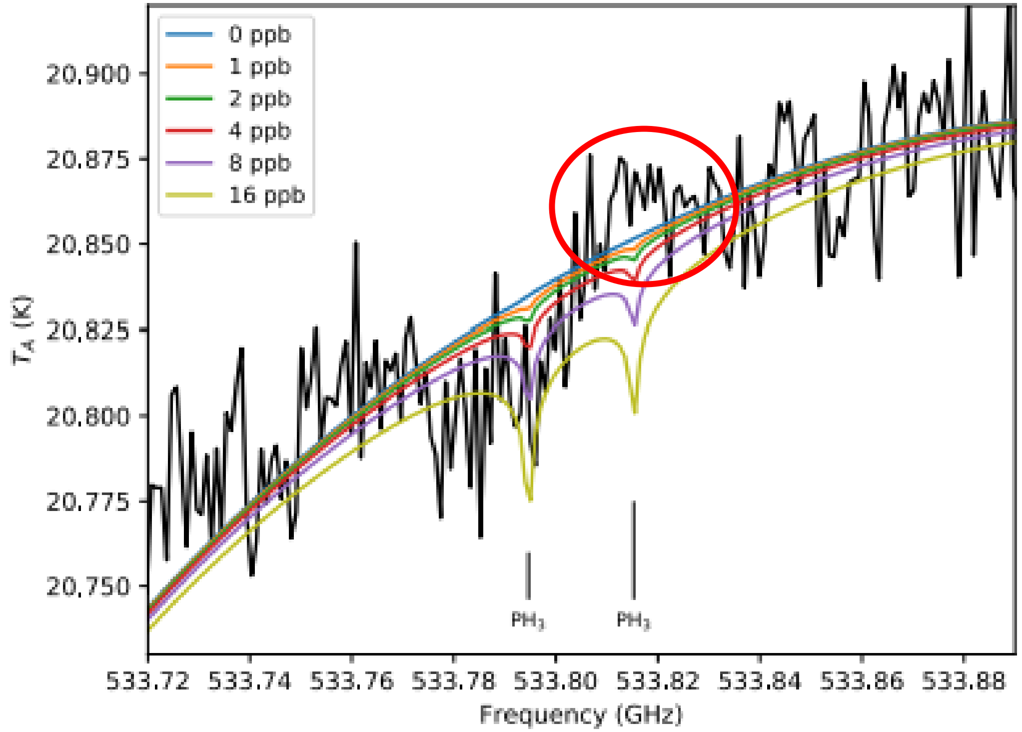
- extraordinarily difficult observations!

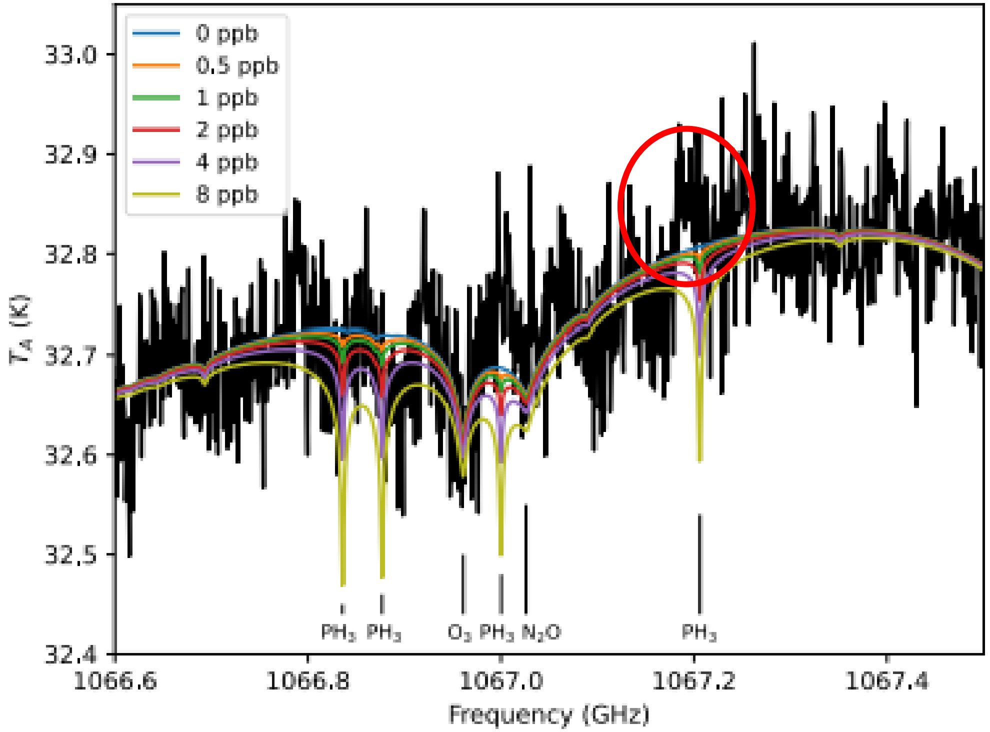
https://blogs.nasa.gov/sofia/2022/01/20/sofia-observes-venus-a-delicate-dance-to-understand-our-hot-and-cloudy-twins-atmosphere/



processing

- Cordiner et al. (2022) clean the data to extremely good depth, but still limited by “bumps” in the spectral baseline – residual “fringing” that comes from reflections

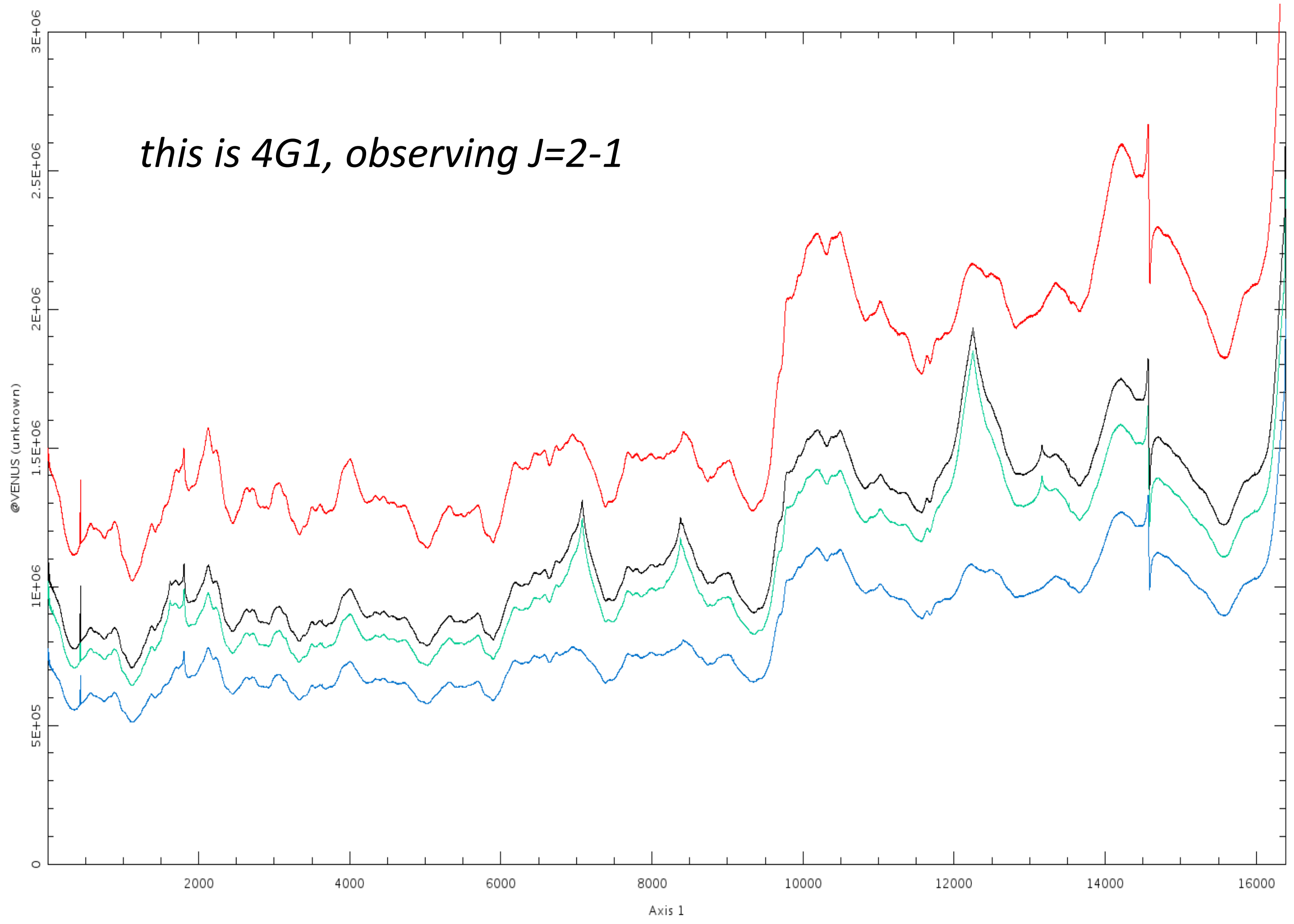




re-processing

- In the Level 1 data, noticeable that **ON** and **OFF** spectra are similar, but **HOT** and **COLD** differ
- so fringing made *worse* in operation

$$T_A = \frac{ON - OFF}{HOT - COLD} * (T_{hot} - T_{cold})$$



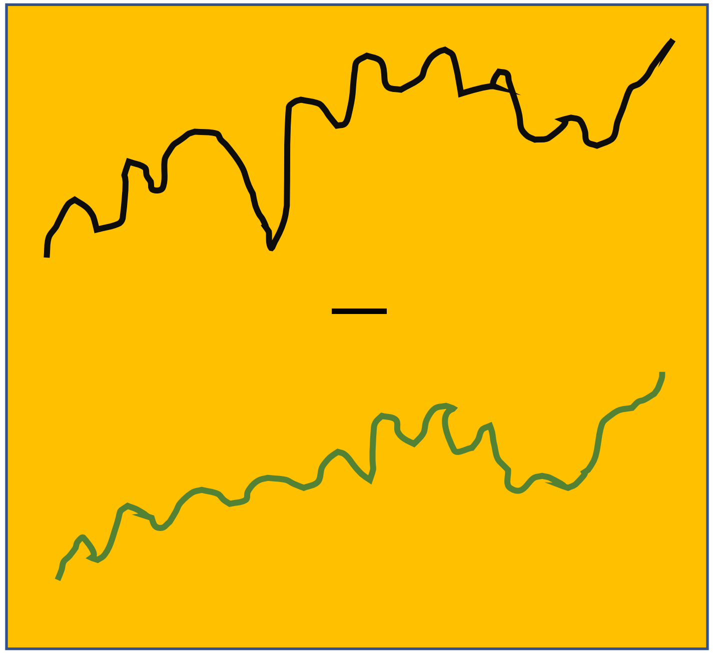
fringe suppression

! the information we need is the *fractional* line-depth… HOT and COLD not essential

➢ for 4G2 (J=4-3), a modification works well:

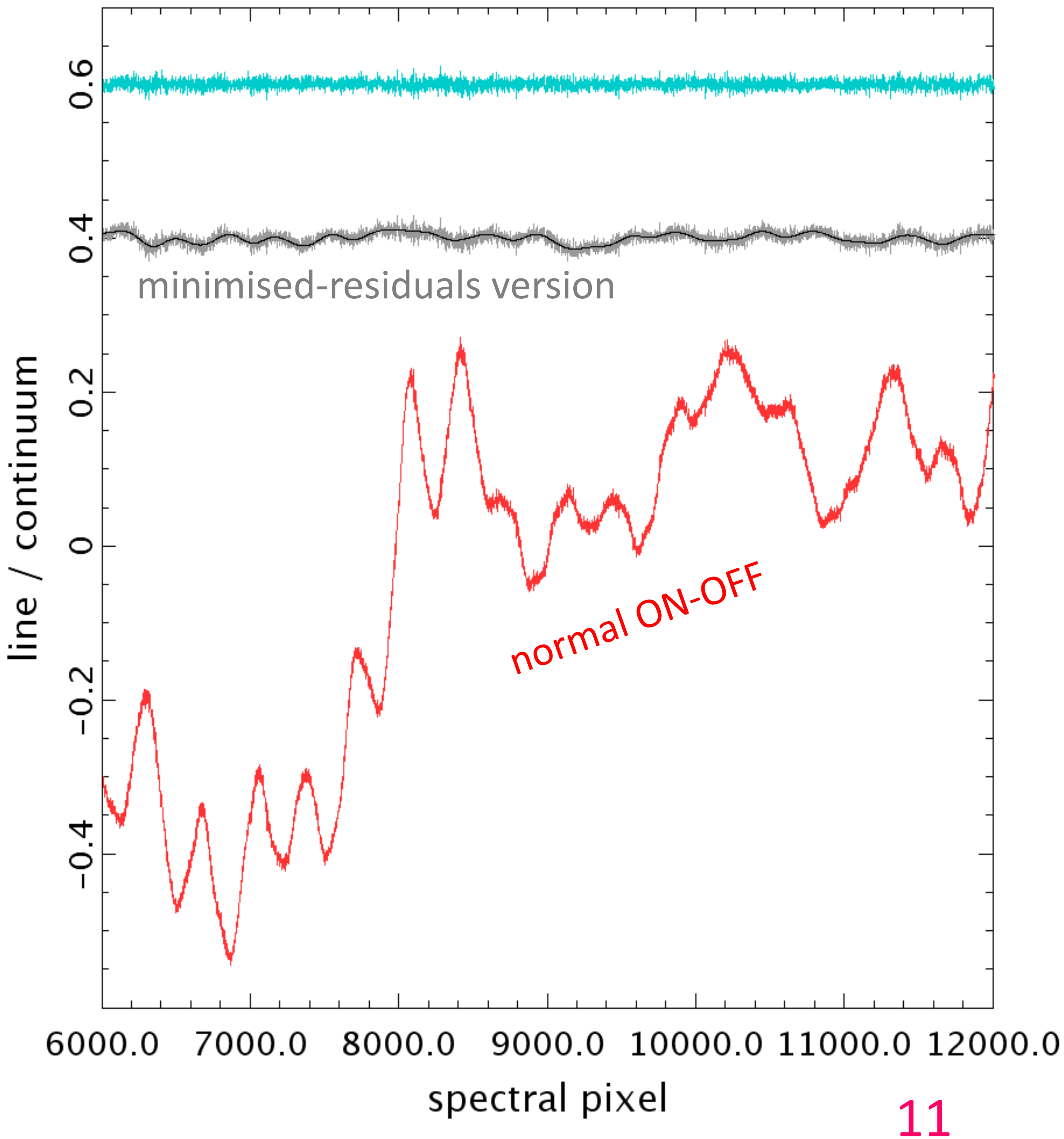
$$line/continuum = (On_{line} - Off^{*}_{line})/(On - Off)$$

- numerator uses a scaled version of the OFF spectrum as a template: a bandpass free of real lines but with instrumental ripples
- then numerator = estimate of line signal, and denominator = continuum signal



fringe suppression

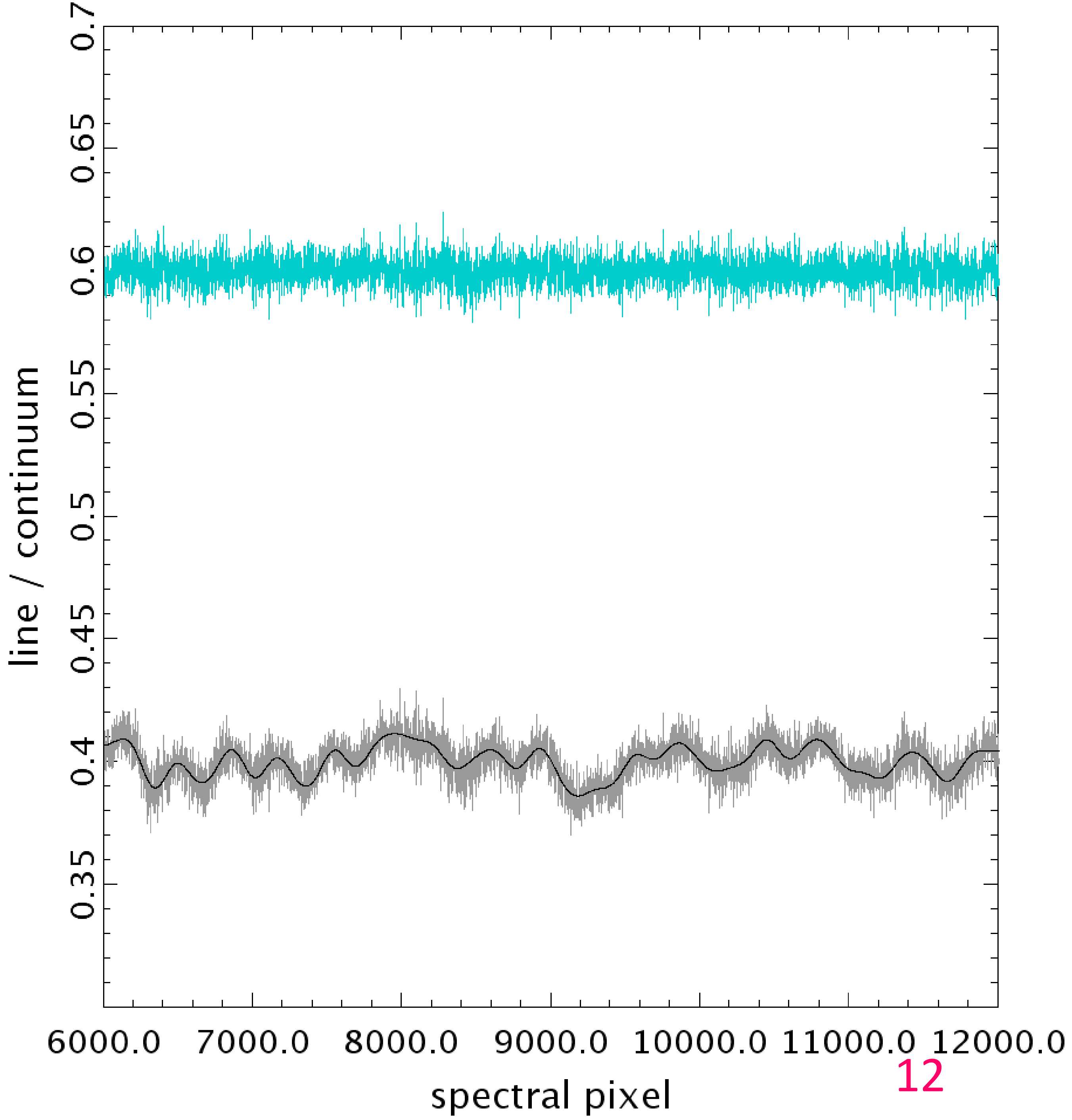
- minimising the residuals in the numerator (i.e under the null hypothesis) gives a much flatter spectrum
- the remaining ripples are more tractable, e.g. model with a Fourier transform



fringe suppression

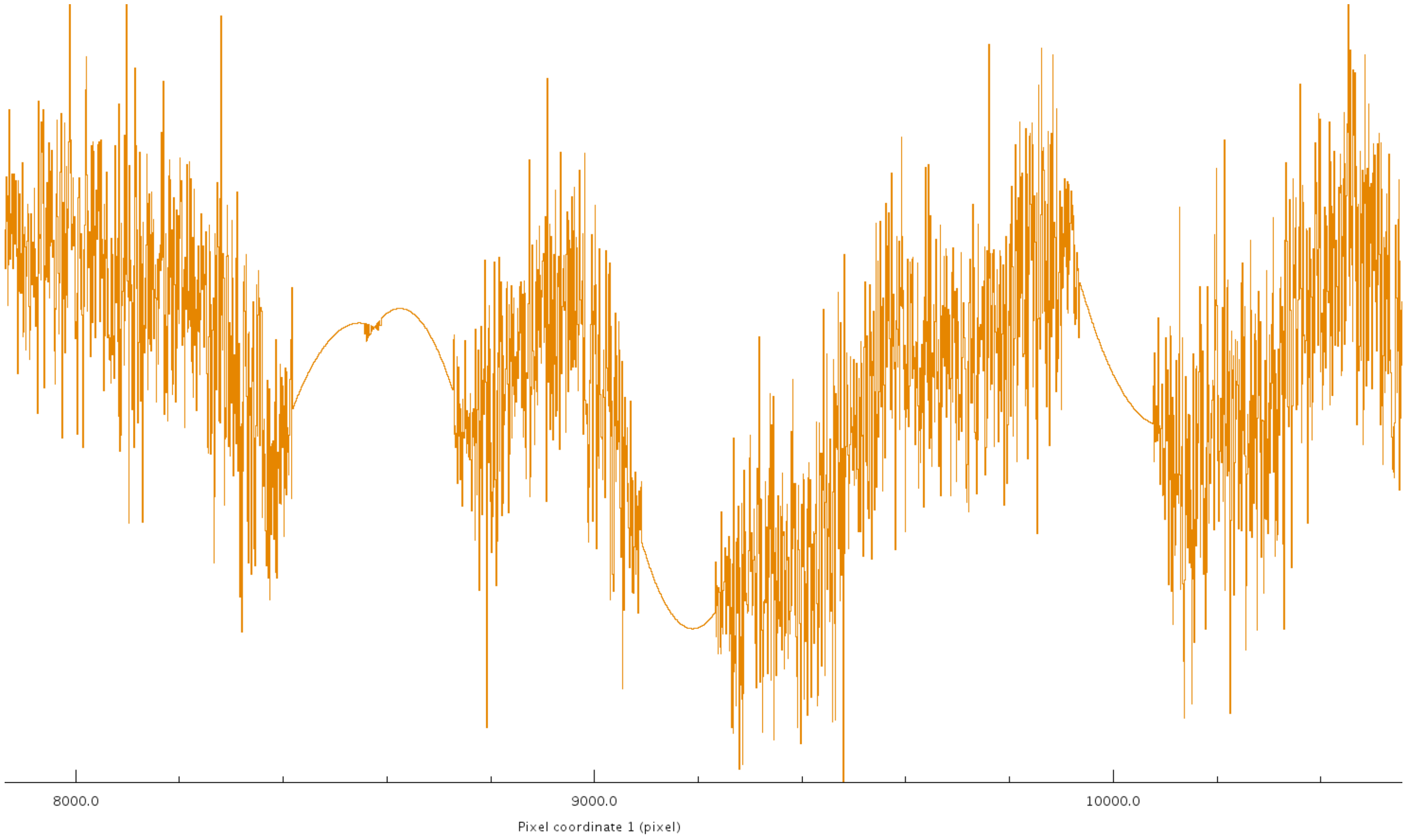
- sinusoids become delta-functions in Fourier space
  - here, made a 3σ cut & inverse-transformed these components

- this model baseline is subtracted to give the final de-fringed spectrum

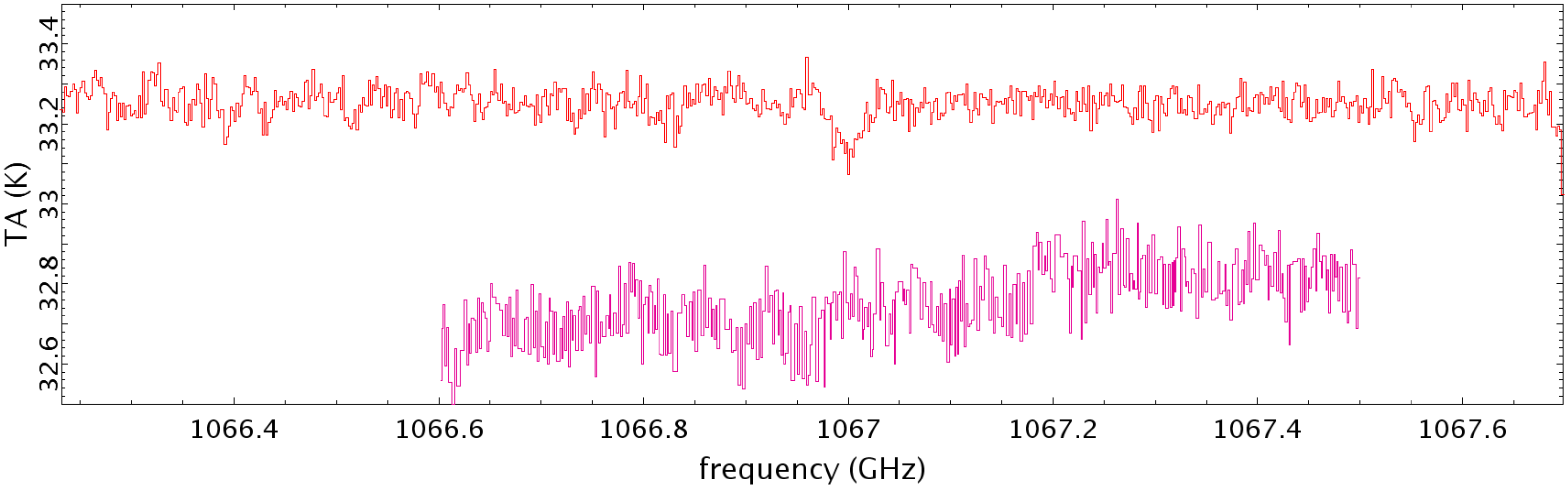


masking

- a critical step (as in Cordiner+ 2022) is to mask the line regions, to avoid real lines being removed
  - here a quadratic function was used to interpolate over the masked regions

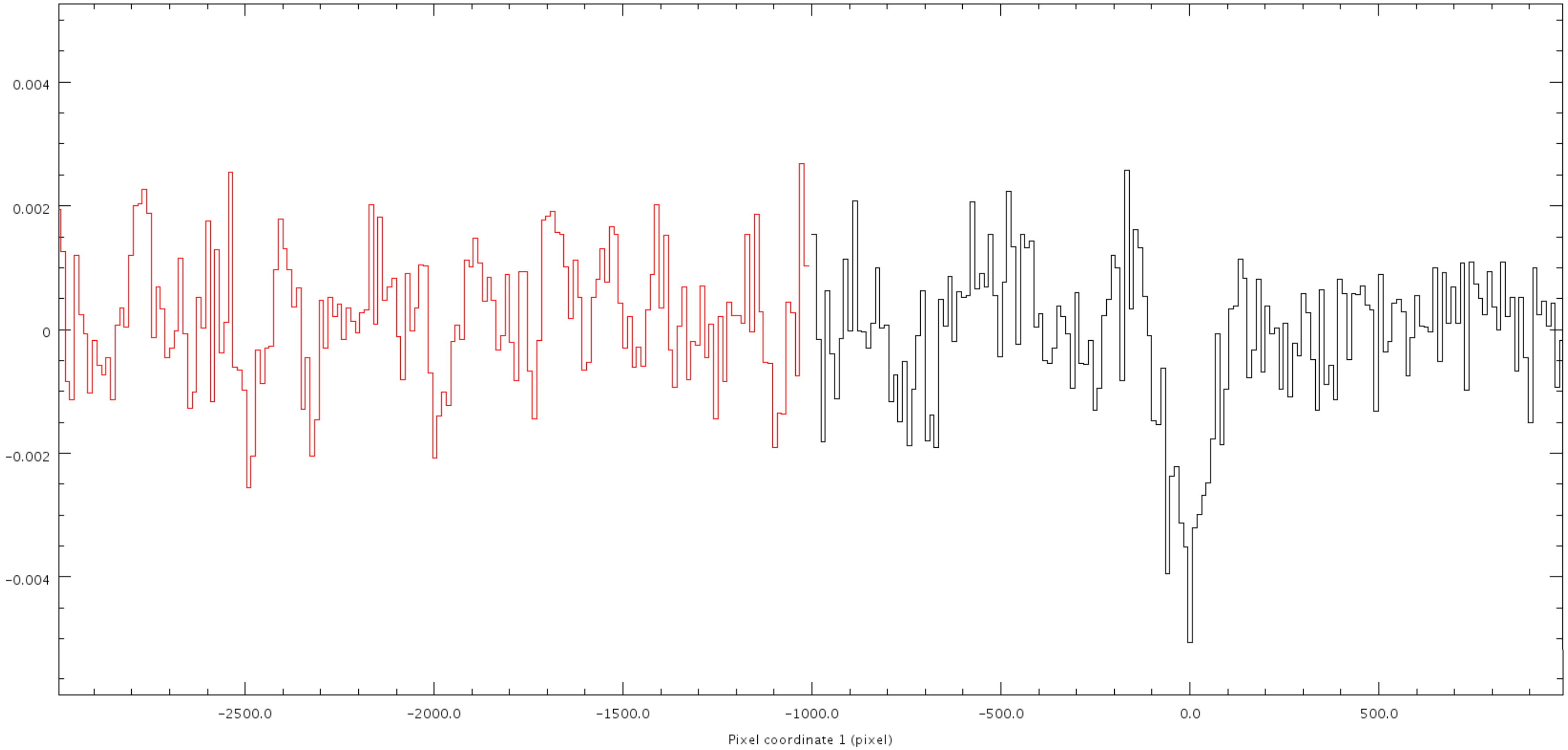


- net result has lower noise than in Cordiner+ 2022
  - likely because by-passing the cal-loads reduced the fringing – all other steps in the processing had similar rationales

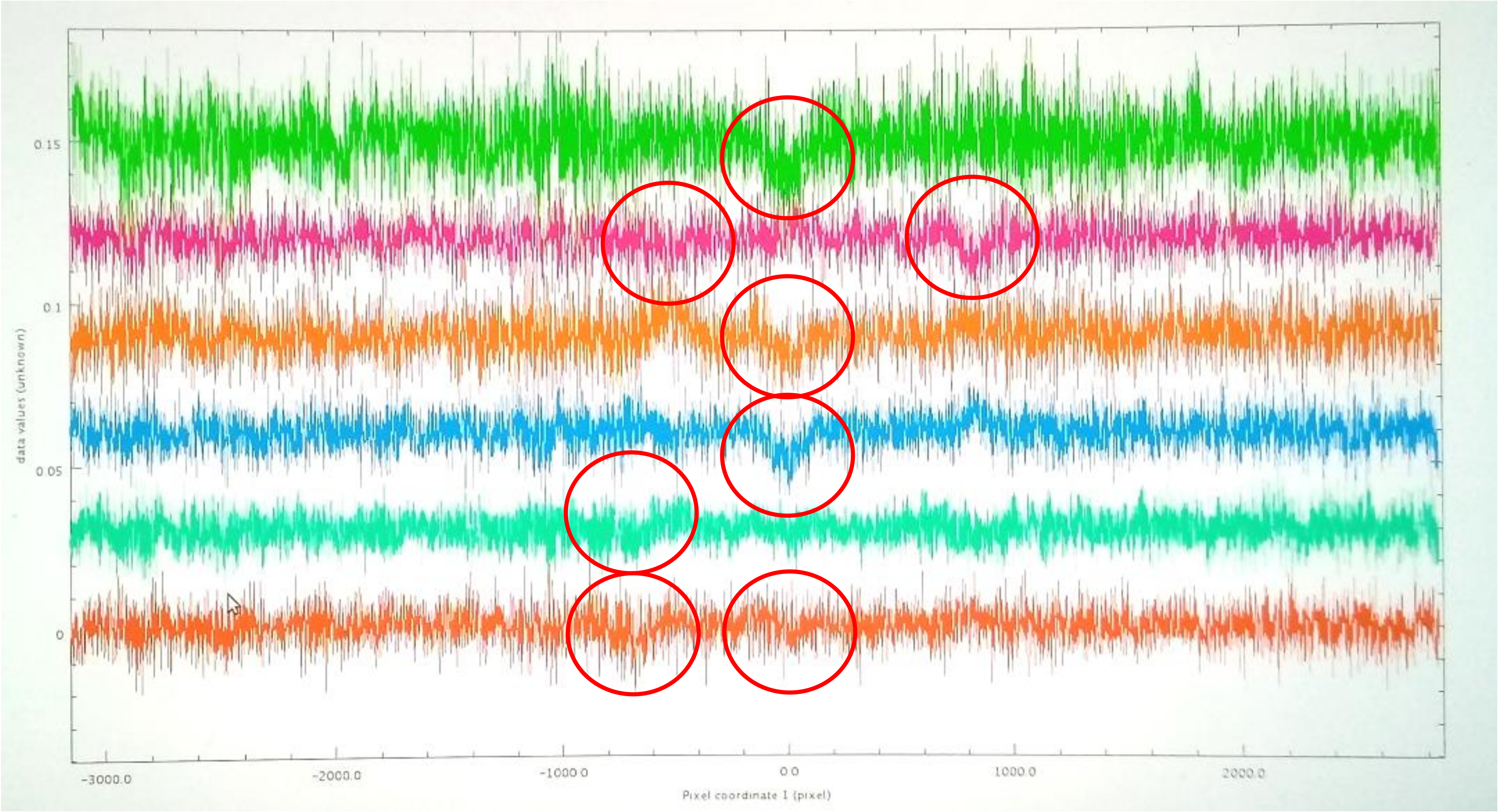


is this robust?

- running it over a different section of the band *doesn't make fake lines* – but recovery of real PH_3 J=4-3 features is uneven

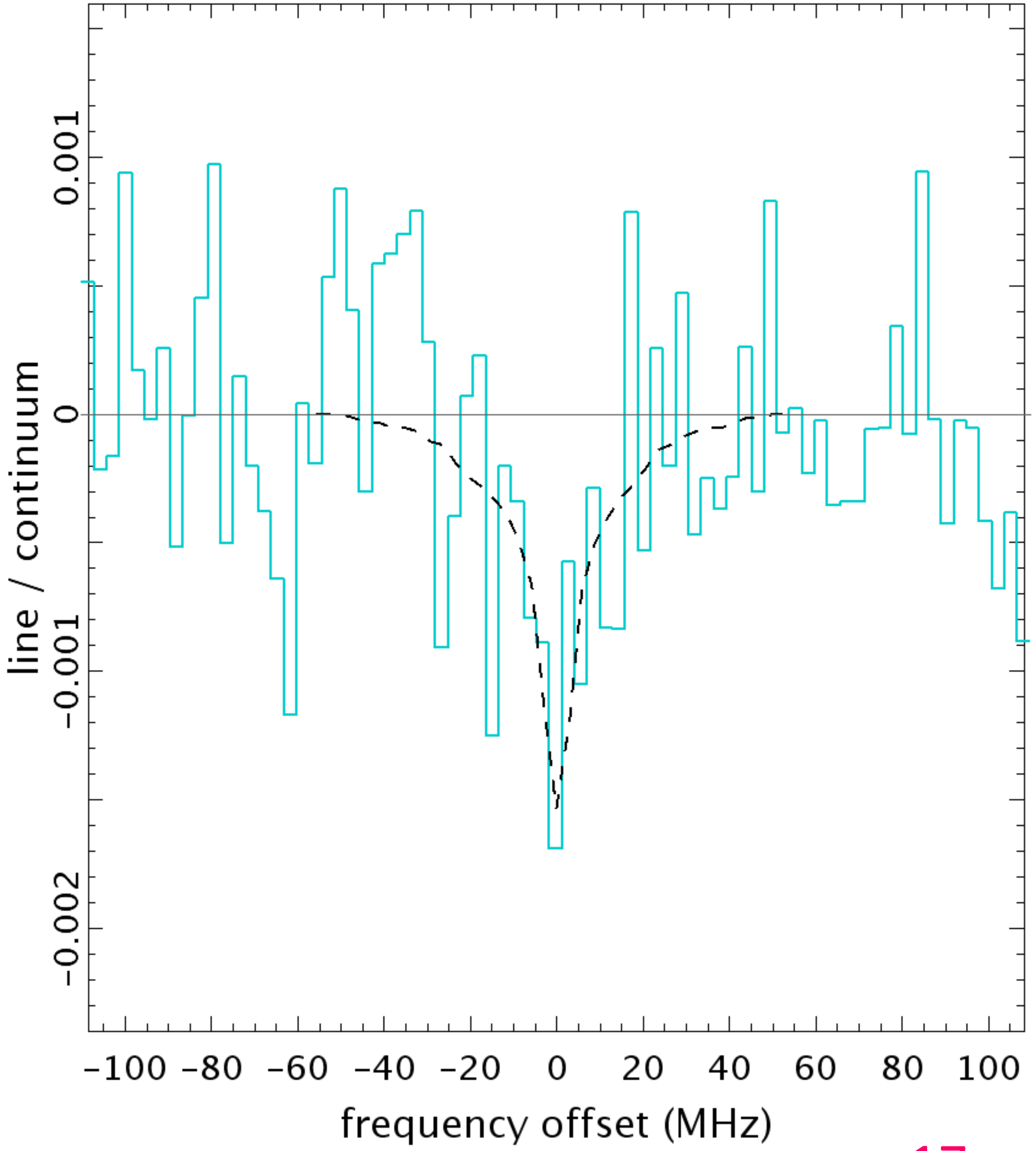


- there should be 4 similar line-components, in the 6 observations

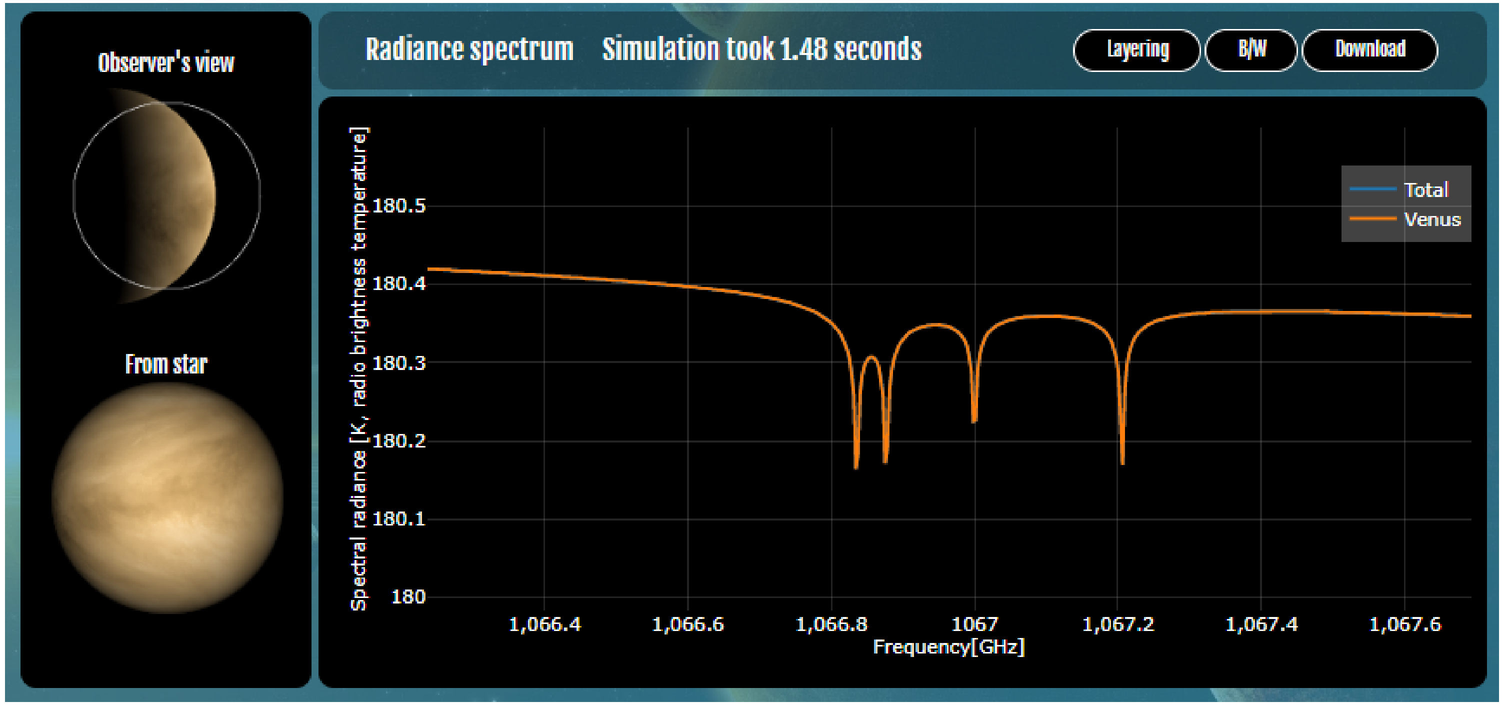


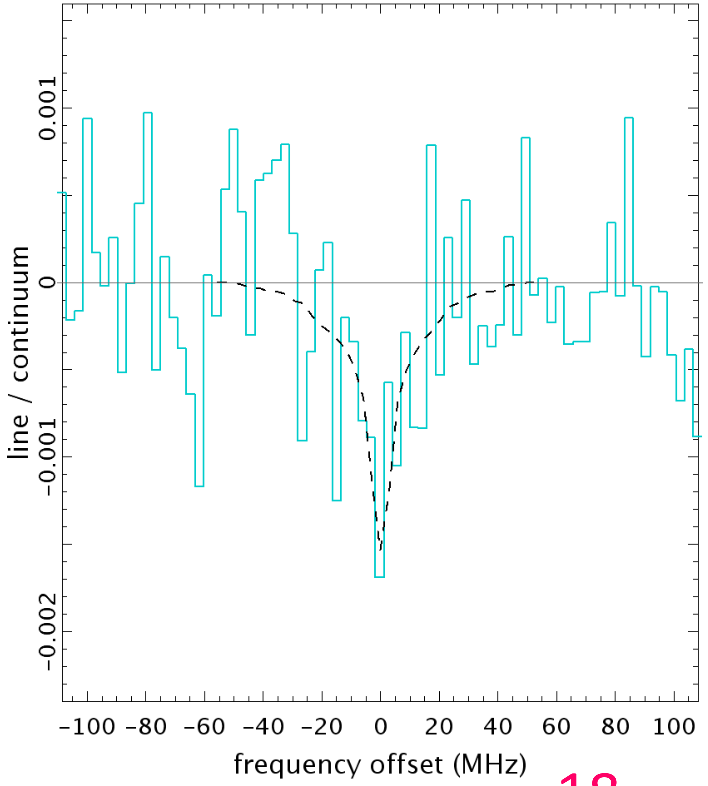
recovery

- least biased: average all 6*4 “versions” of the absorption
  - generate uncertainties from the internal dispersion
- result: 5.7σ detection
  - integrated over masked regions
- line centre in Venus frame: at +0.1 ± 0.6 km/s
  - very unlikely if from artefacts



- model PH_3 line is from https://psg.gsfc.nasa.gov/ (plus masking + stacking like the data) –> best fit is 1.75 (±0.2) parts-per-billion
- not much different from Cordiner+ 2022: <0.8 ppb from J=4-3 or ~2.3 ppb? from J=2-1 (1.5σ)





why not more?

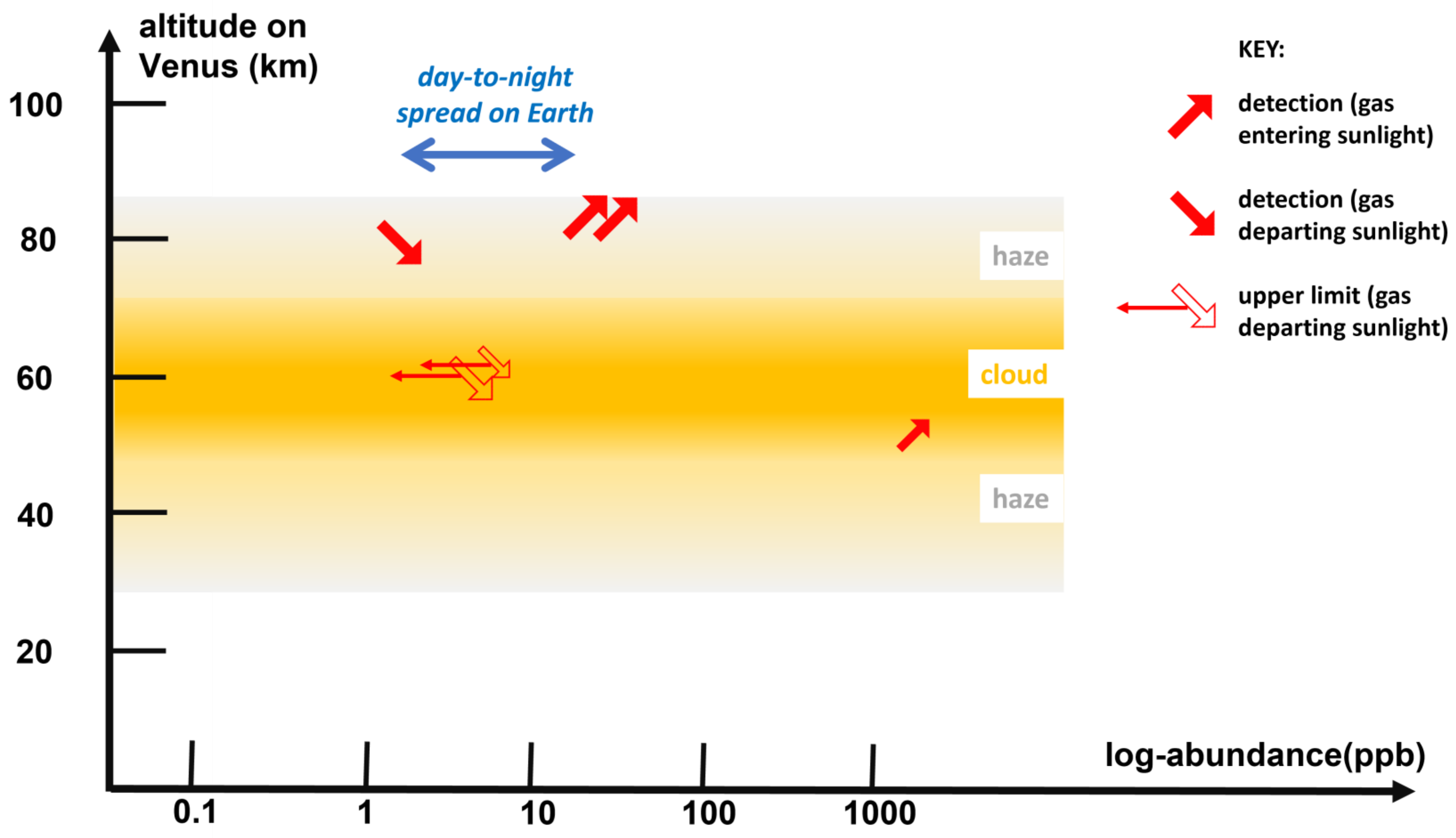
- original J=1-0 data suggested ~20 ppb of phosphine
- and the Pioneer-Venus descent-probe data: ~ 2ppm of PH_3
  - Mogul et al. re-analysis

- limits deeper than the candidate detections have led to understandable scepticism regarding phosphine's presence

- but! we noticed differences in *which part* of Venus' rapidly rotating atmosphere had been observed
  - different operational reasons for SOFIA vs. JCMT and ALMA, e.g.

reconciliation

- plausible solution: photo-destruction of PH_3 molecules
- the spread of abundances is *notably similar to the night/day spread in Earth's atmosphere*



conclusions

- please let’s talk to each other… no need to “take a side”, when there is wealth of new data we can all enjoy ☺
- if phosphine is present, it’s a weird biosignature for an H-poor environment (but it’s weird on Earth too…)
  - so many info gaps for Venus -> hard to meaningfully discuss phosphates in volcanic plumes, for example
- lots more we will learn from new missions!