Phosphine in Venus' Clouds - local biosignature experiences

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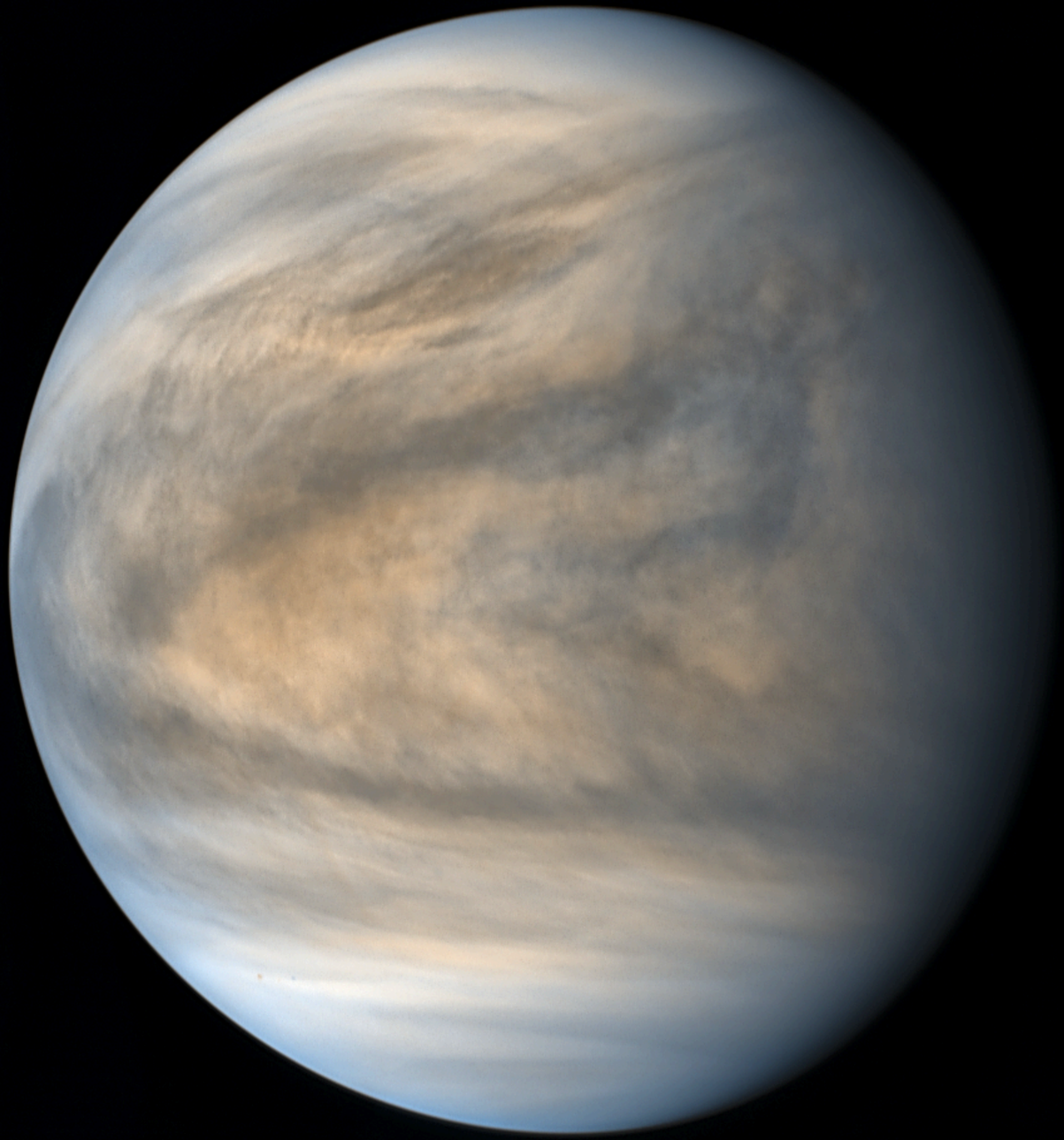
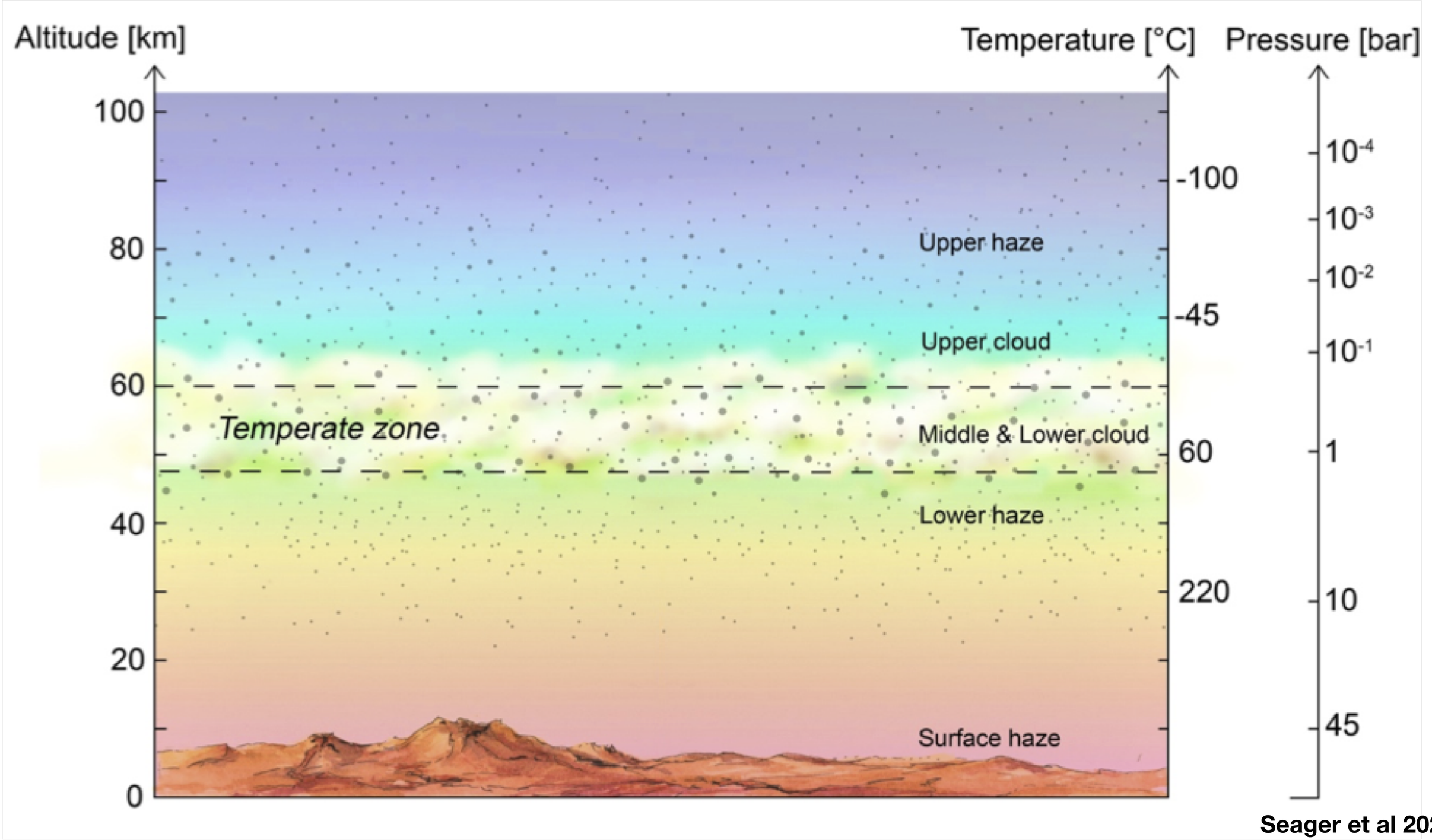
A balmy day on Venus from Venera 9

Outline

- JCMT-Venus project: observations and motivation
- Data challenges & how to overcome them
- Current results on phosphine and future prospects
- Lessons for future bio- and techno-signature searches

Venus in UV from AKATSUKI





Seager et al 2021

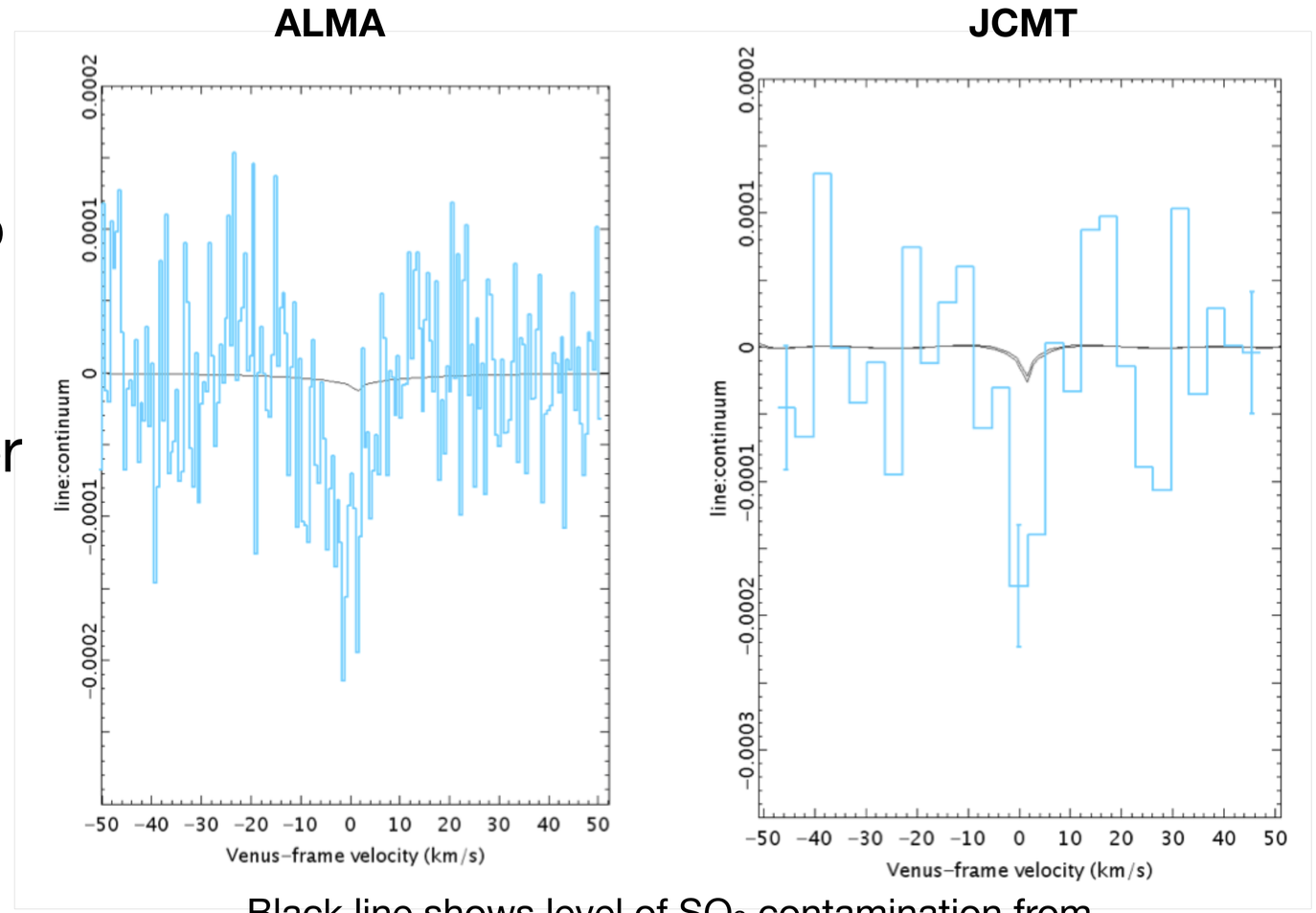
Anomalies in Venus' Atmosphere

- Various unexplained aspects of Venus' atmosphere include:
  - Unknown UV absorber (see AKATSUKI images)
  - Presence of O_2 at ~10 ppm in clouds
  - Large (~7μm), possibly aspheric, particles of unknown composition in cloud layers
  - Vertical abundances of SO_2 and H_2O unexplained

Bains et al., 2021

Phosphine - a new anomaly

- Observations proposed to set an upper limit on biological activity - no detection expected
- Proposed as an exoplanet biomarker (Sousa-Silva et al., 2020)
- Discovery of PH_3 J=1-0 line in data from JCMT with ALMA confirmation adds another anomaly to atmospheric data for Venus

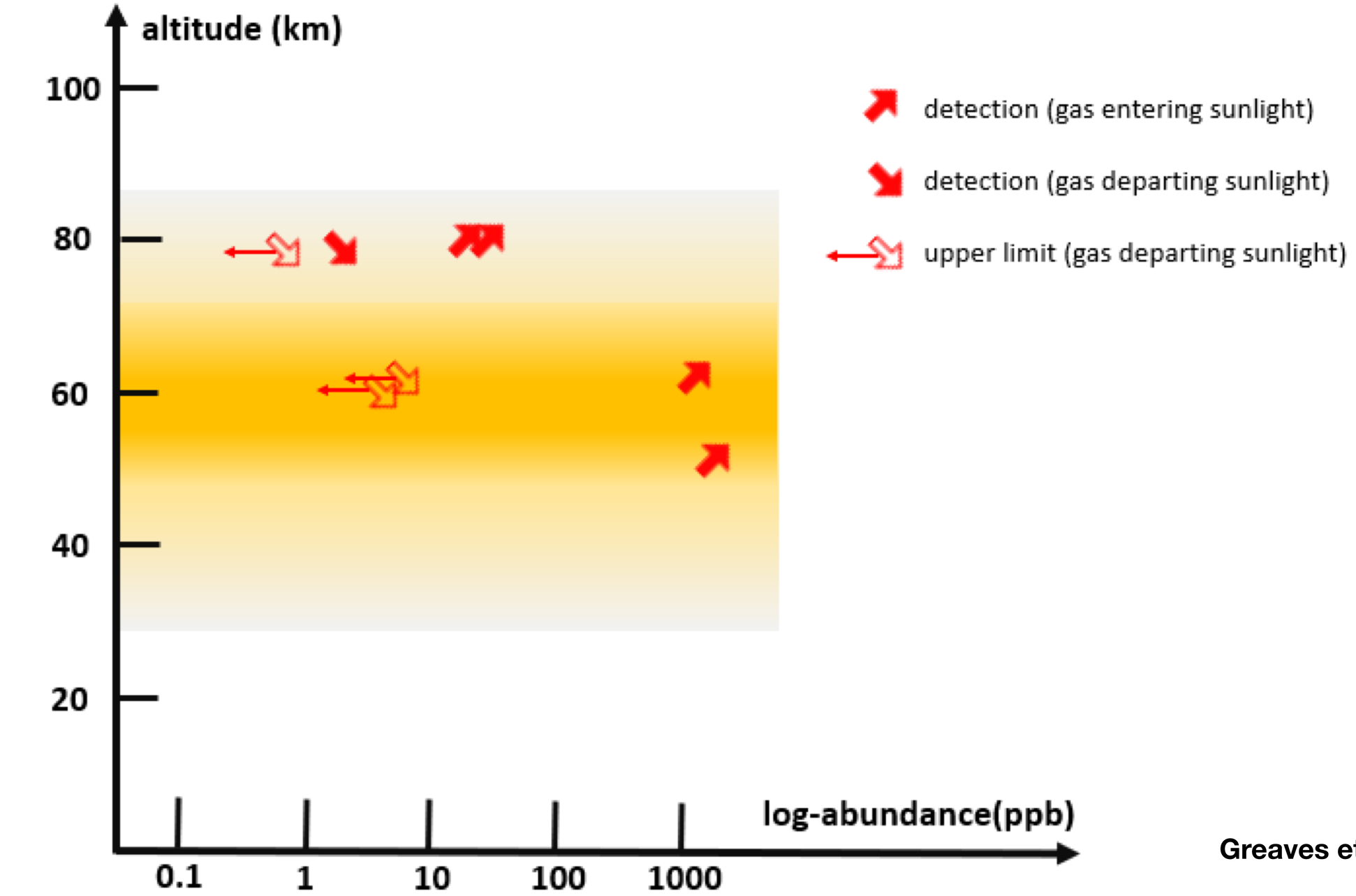


Black line shows level of SO_2 contamination from simultaneous (ALMA) & near-simultaneous (JCMT) measurements of a different transition

Greaves et al., 2022

Phosphine Detection Challenged

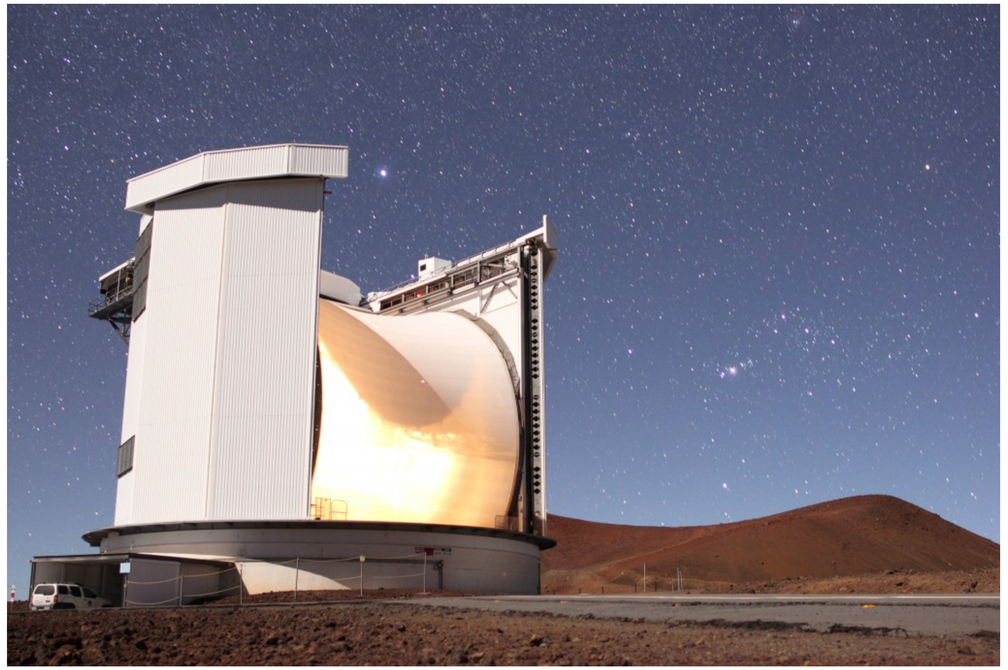
- False detection?
  - $< 1.5\%$ chance at PH_3 frequency; coincident in JCMT & ALMA
- Misidentified SO_2 line?
  - Wrong central frequencies (1.3 km/s); parallel observations show SO_2 too weak
- No near- or mid-IR detections of PH_3
- Detection in situ by PVP Mass-spec (Mogul et al. 21) & possibly by SOFIA (Greaves et al. 24)
- Is PH_3 variable (like HDO & SO_2)? And if so what drives variability?

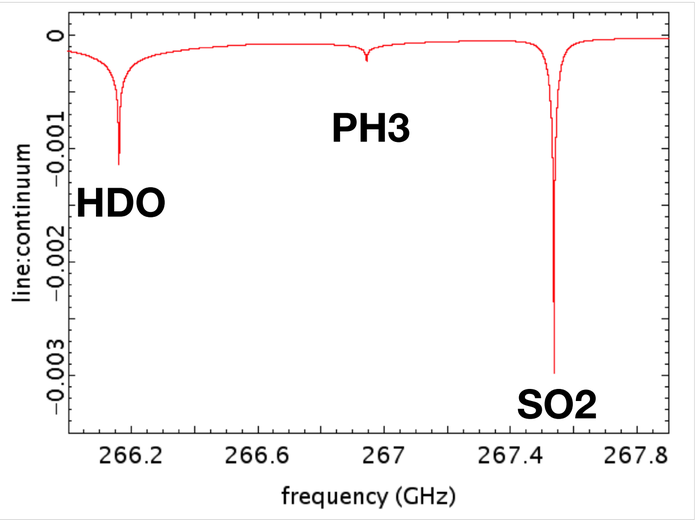


Greaves et al., 2024

JCMT-Venus

- Need for more data and monitoring to see how PH_3 varies, and if it varies in relation to other species
- Use new wider band more sensitive receiver Ū’ū
- Levels of SO_2, H_2O (via HDO), other species, albedo etc. vary with time
- A long term monitoring programme may provide indications of the chemistry that produces PH_3





When can we observe?

- Venus is a moving target
  - Size changes with relative positions of Earth and Venus
- Want to have JCMT beam filled by Venus
- Awarded 200 hours of time
- Three observing campaigns when Venus was accessible

From one run: about 140x as much information as in previous runs

Period 1	20 days	1-20 Feb 2022
Period 2	29 days	6 Jul - 3 Aug 2023
Period 3	30 days	24 Aug - 22 Sep 2023

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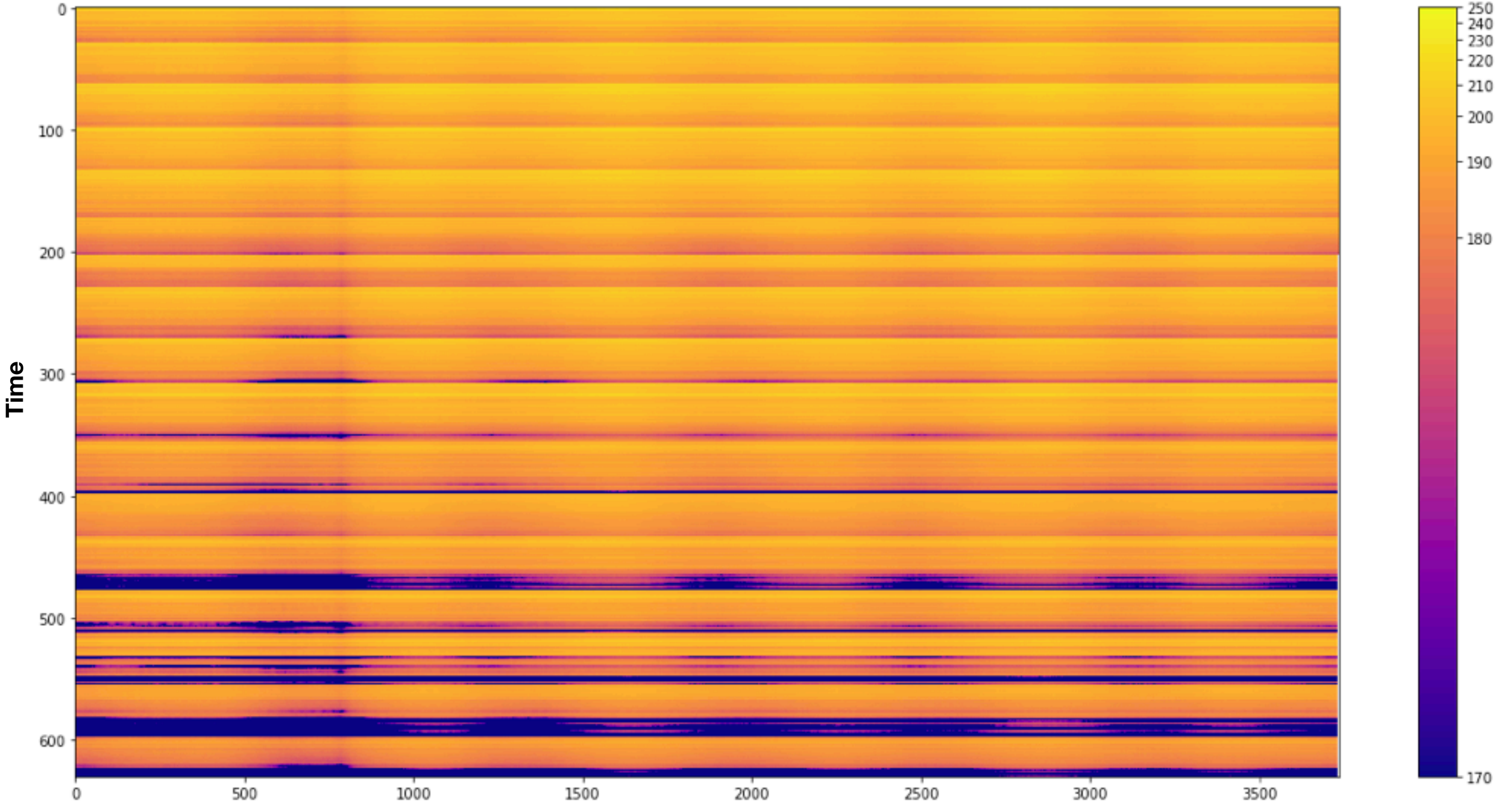
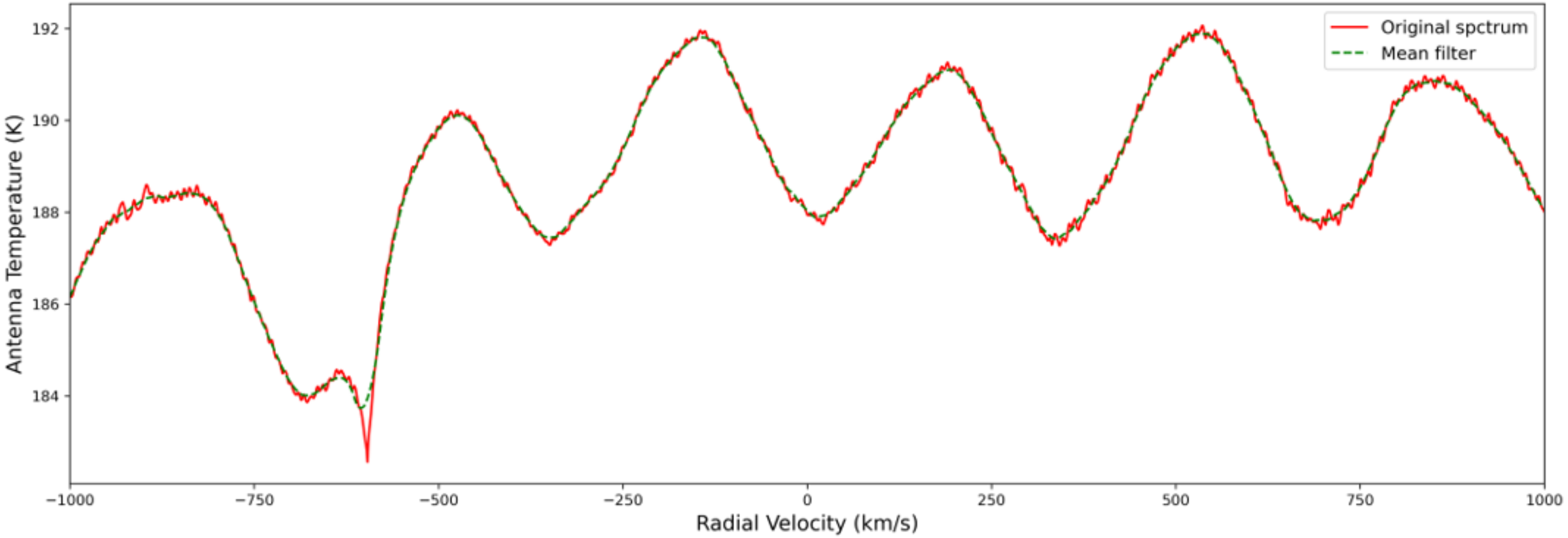
Period 4	10 days	21 April - 1 May 2025

Coincident with radio observations at SRT Effelsburg & elsewhere

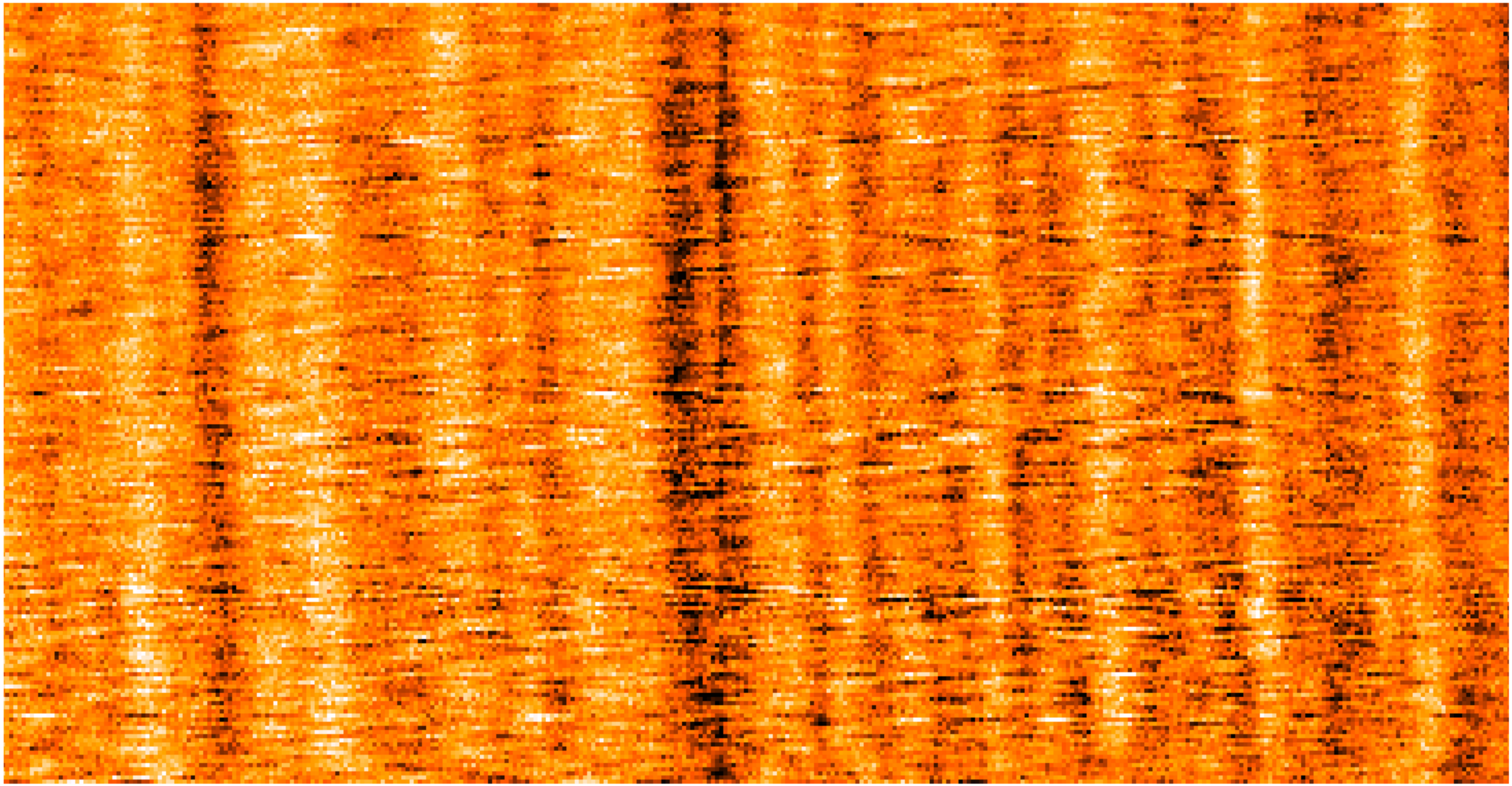
Data are not nice - Venus is so bright that reflections and straylight lead to baseline drifts & spurious signals




Original spctrum
Mean filter
Antenna Temperature (K)
192
190
188
186
184
−1000
−750
−500
−250
0
250
500
750
1000
Radial Velocity (km/s)

Remove baseline drift & can see HDO absorption in Venus frame

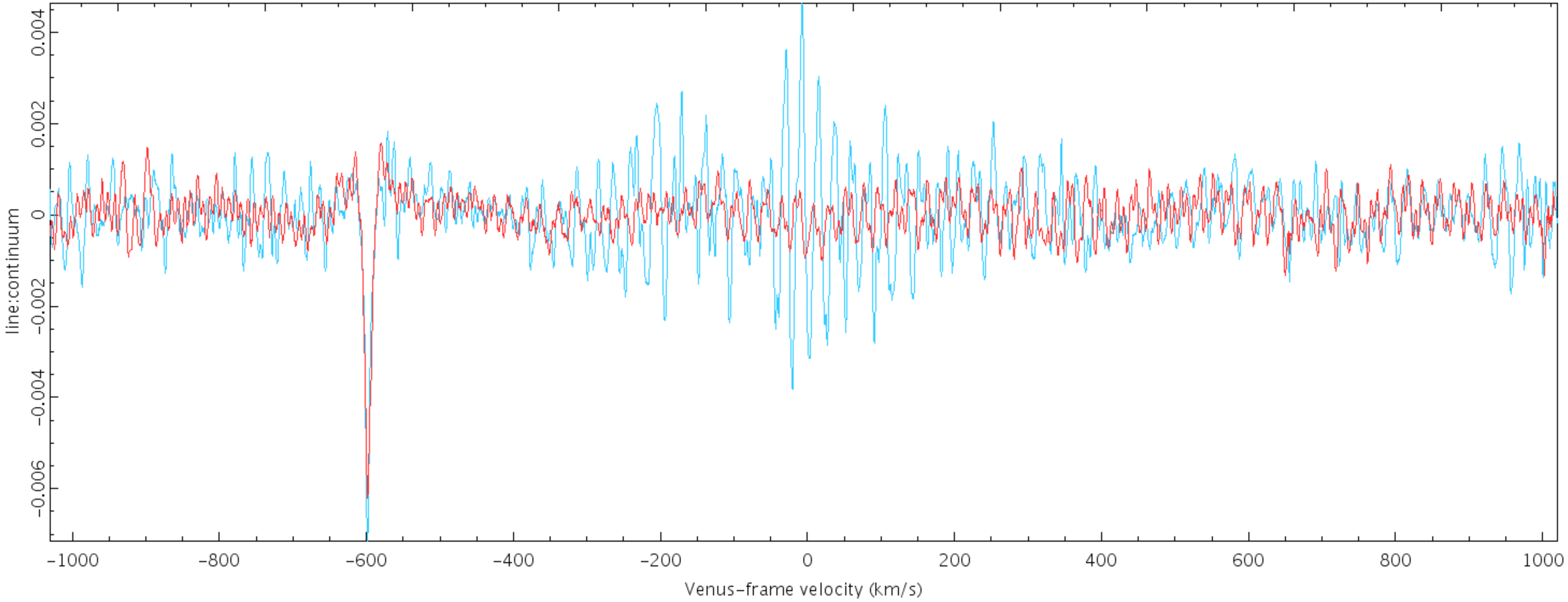
v *instrumental*



^ *HDO line*

v *terrestrial O_3*

v *HDO line*

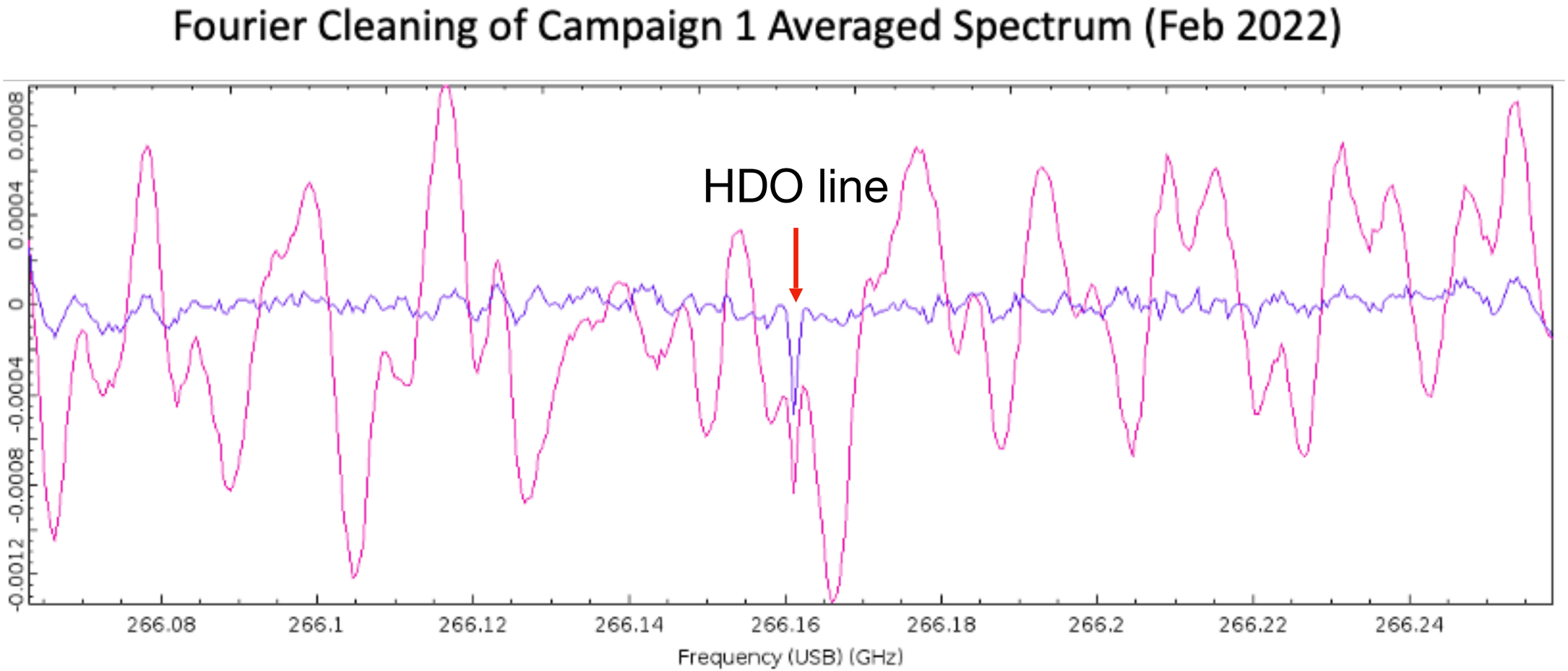


Net line/continuum spectrum after mean-filtering; detector (polarization) 2, in blue, is more ripply

Removing the Ripples

- Running median removes the baseline drifts, but suppresses large scale features
- Could then apply standard polynomial method, but this is inappropriate with large number of ripples - need very high order
- Instead apply Fourier cleaning after removing baseline drift with running median
- Take FT of scan, remove low S/N fourier components to get ripple spectrum, then remove
- For weak features may need to mask out frequencies around expected line

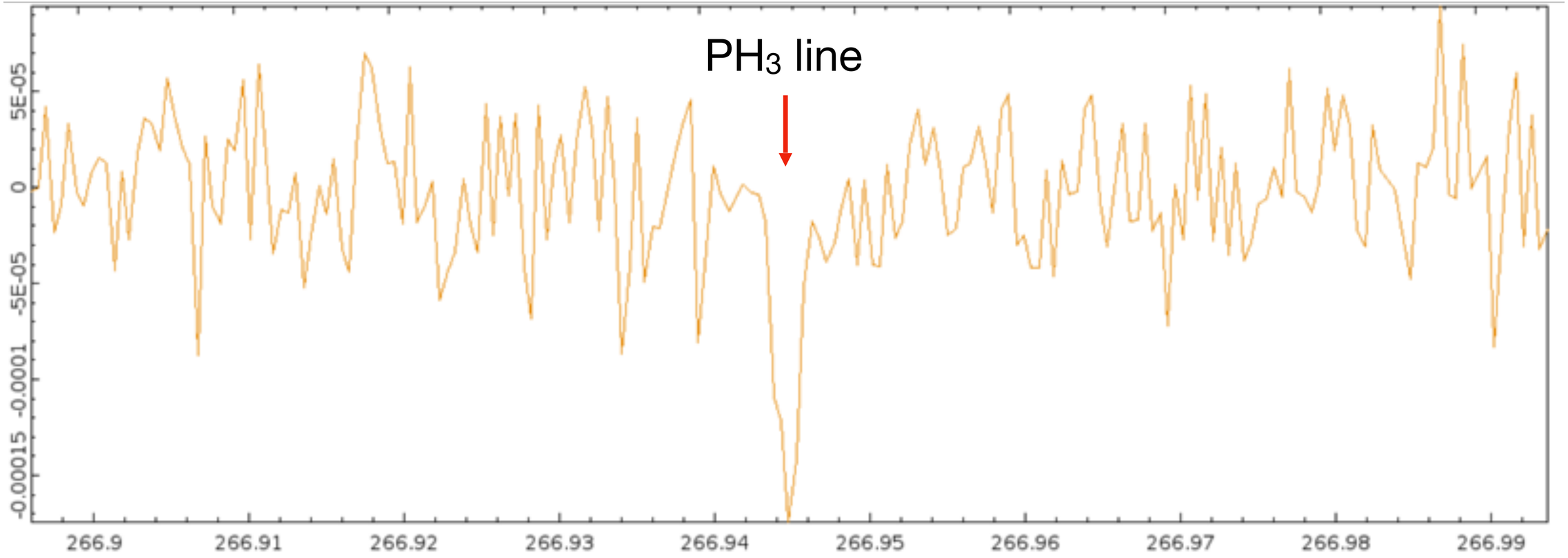
Campaign Averaged Examples



For day-to-day and cross campaign variability see talk by Wei Tang on Thursday afternoon

Phosphine Recovery

PH_3 Line Detection in Campaign 2 Averaged Spectrum (July 2023, Post-Fourier Cleaning)

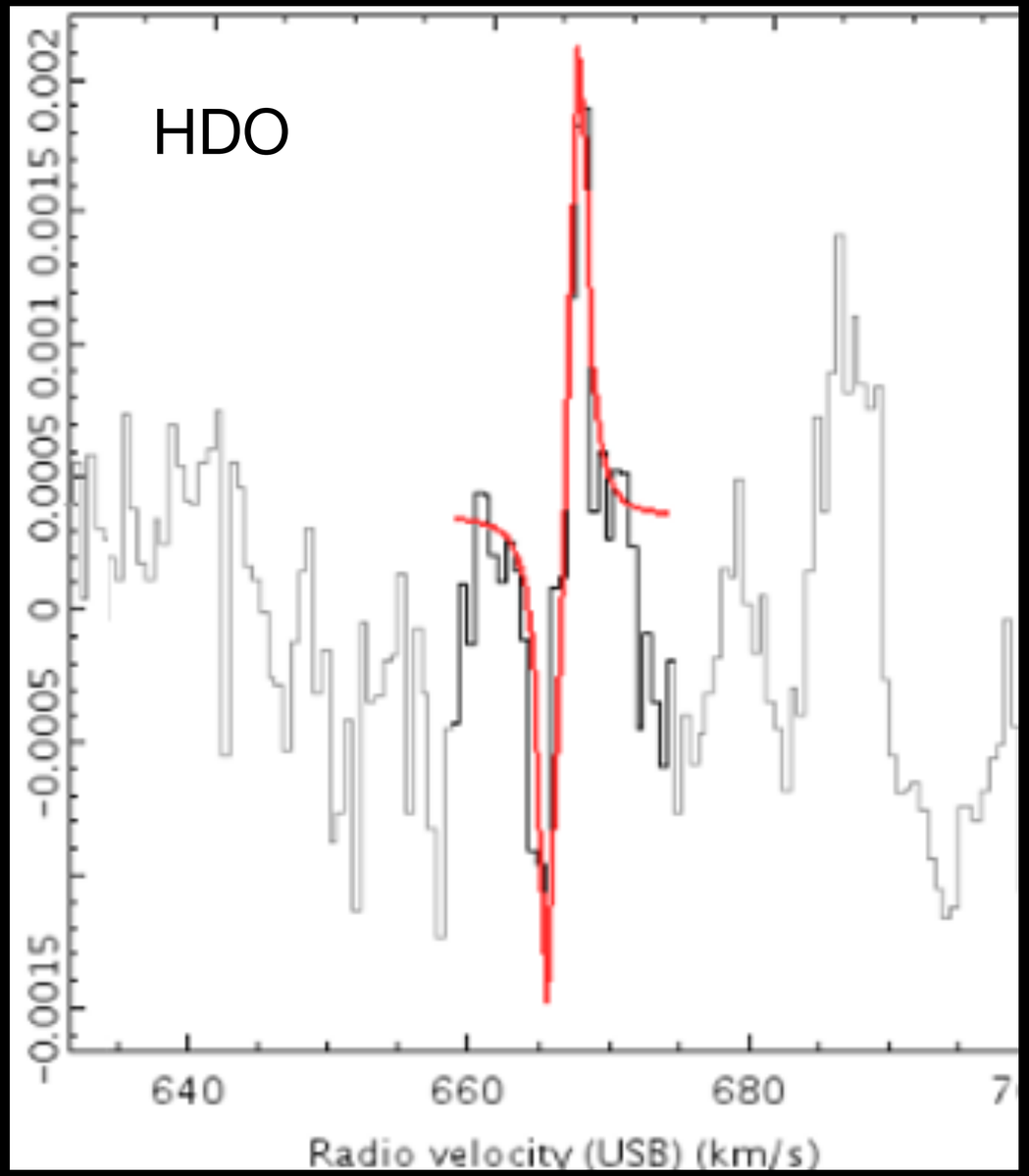


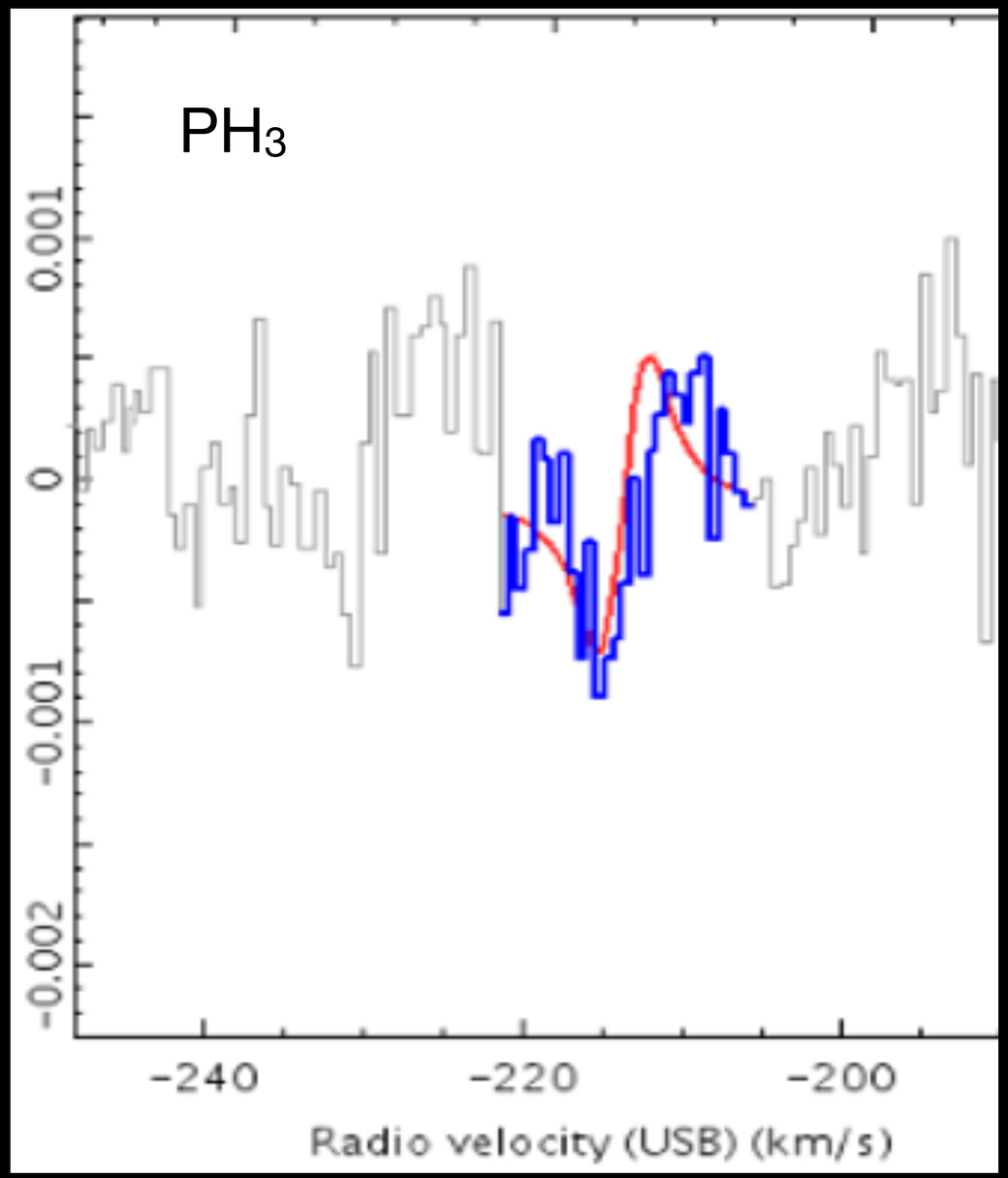
SO_2 very weak during this campaign so not mis-ID

Alternatie Approaches

- Ripples stay fixed in Earth-centric coordinates, but velocity of a line at Venus shifts relative to this
- If ripples are ~constant over a significant time can subtract them by subtracting scans in Earth-centric coordinates
- This will leave a p-Cygni-like profile for any real line at Venus velocities, with the peak-to-trough-width given by the change in the velocity of Venus relative to the Earth between observations
- No other processing needed!

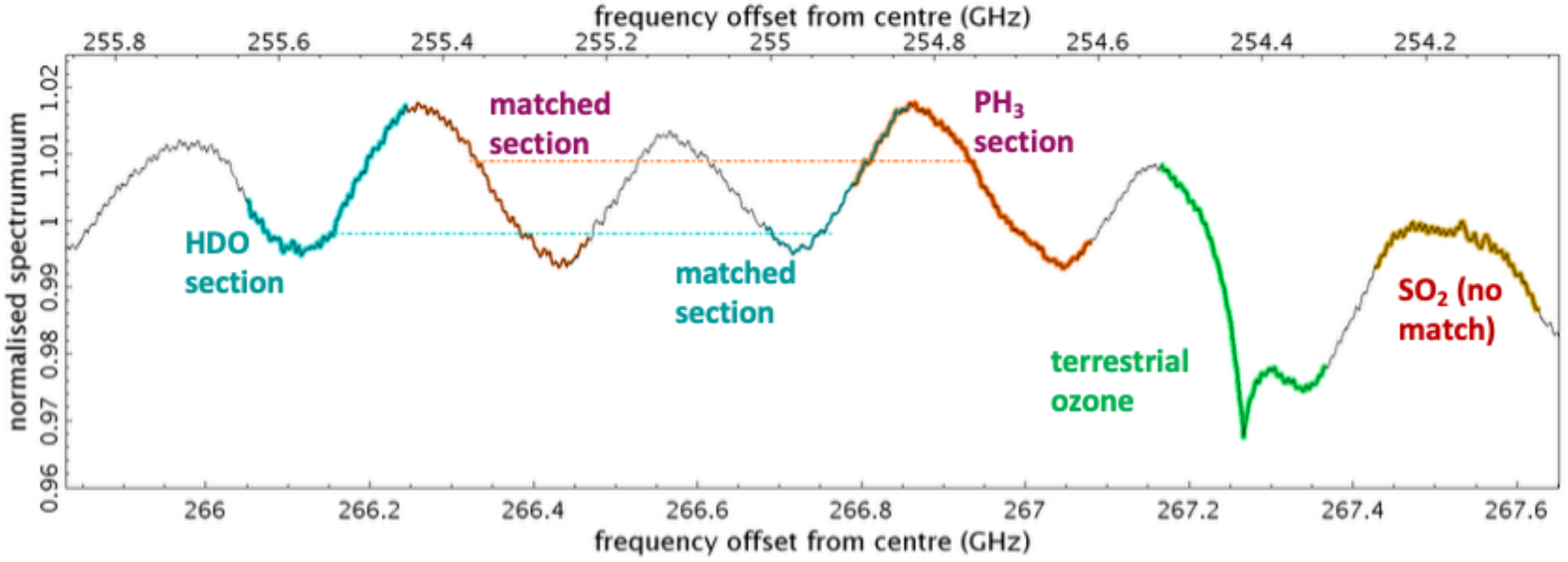
Campaign 2 start subtracted from end



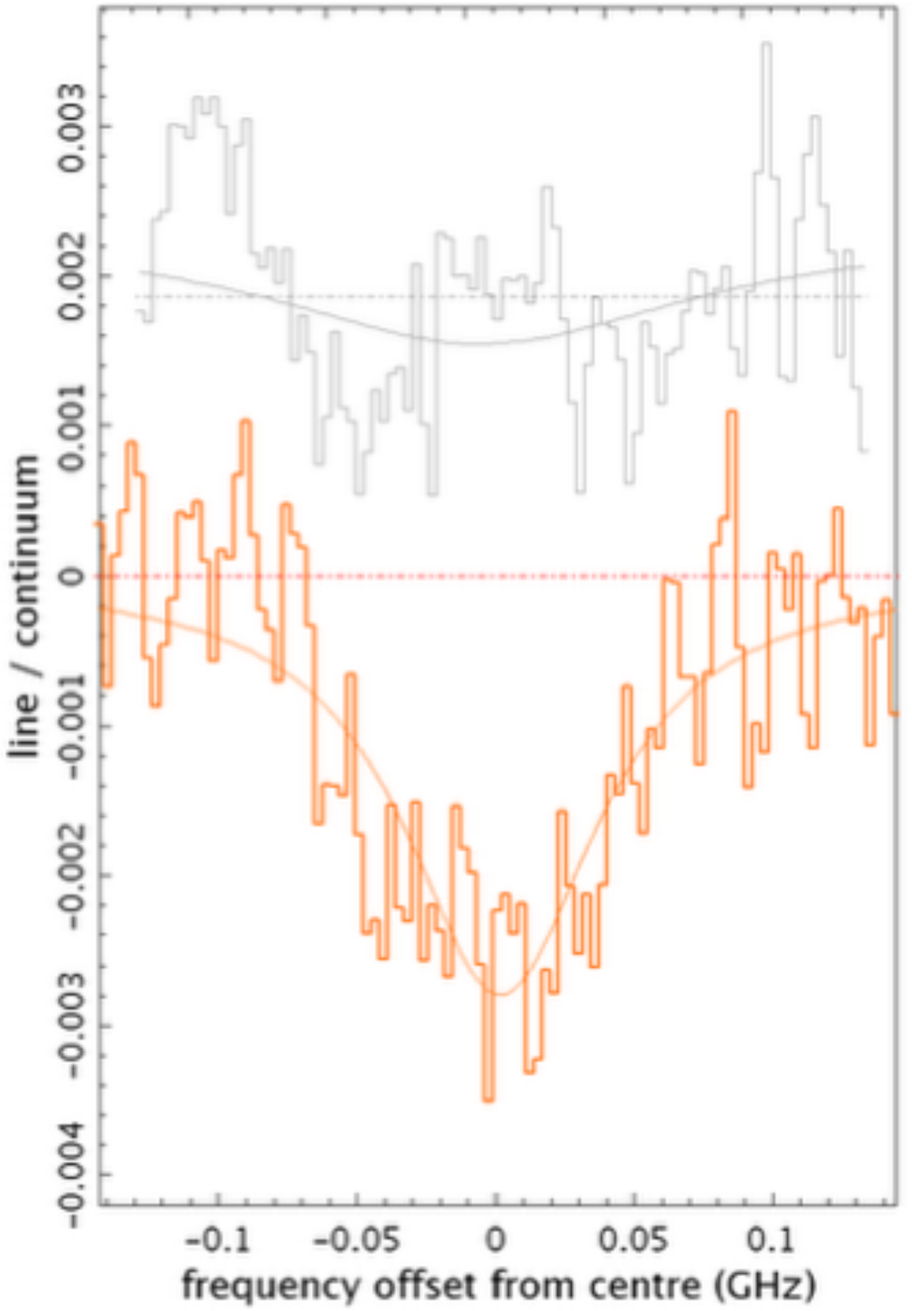


Broad Line Recovery

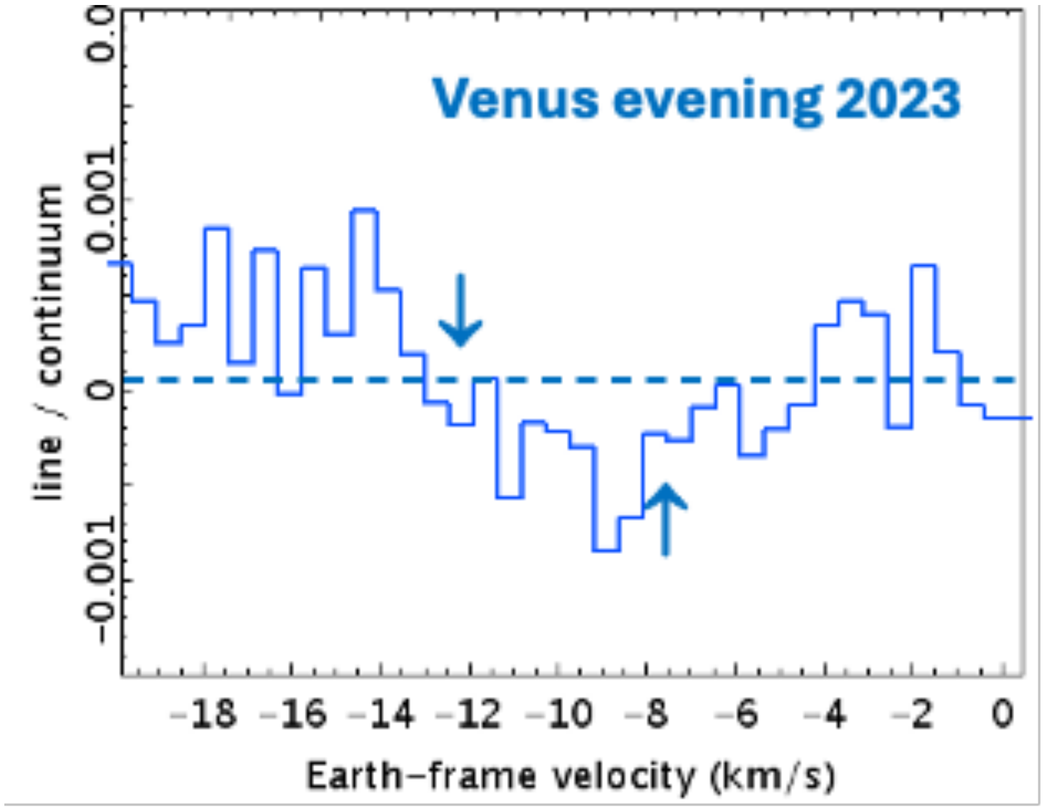
- Narrow lines come from high in atmosphere (~80 km)
- Lines closer to clouds will be broader because of pressure broadening
- Broader features suppressed by baseline removal with running median
- Is there a way around this?

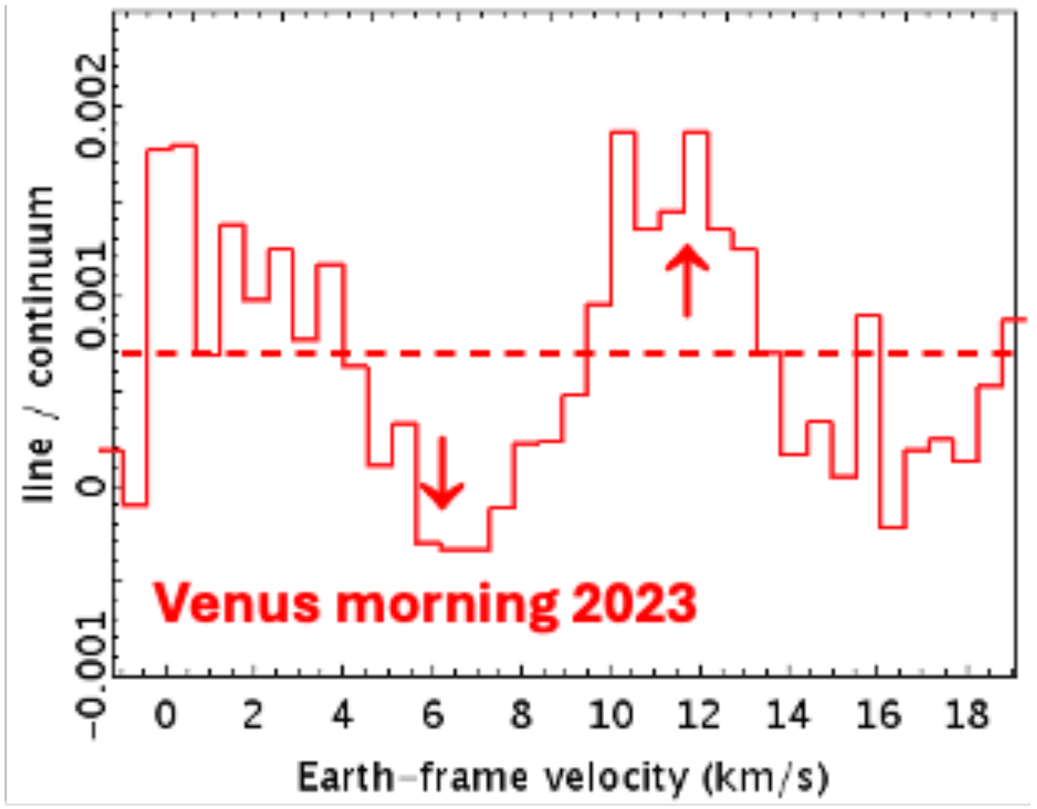

frequency offset from centre (GHz)
255.8
255.6
255.4
255.2
255
254.8
254.6
254.4
254.2
normalised spectrumuum
1.02
1.01
1
0.99
0.98
0.97
0.96
matched section
PH3 section
HDO section
matched section
terrestrial ozone
SO2 (no match)
266
266.2
266.4
266.6
266.8
267
267.2
267.4
267.6
frequency offset from centre (GHz)

- Recovery of much wider PH_3 J=1-0 line in 2022 data
- Fake line null result
- HDO also recovered at expected depth & width
- Tension with other limits?
  - Very sparse monitoring
  - A Venus day-night effect?



Day-night effect in preliminary p-Cygni extraction





Venus Conclusions

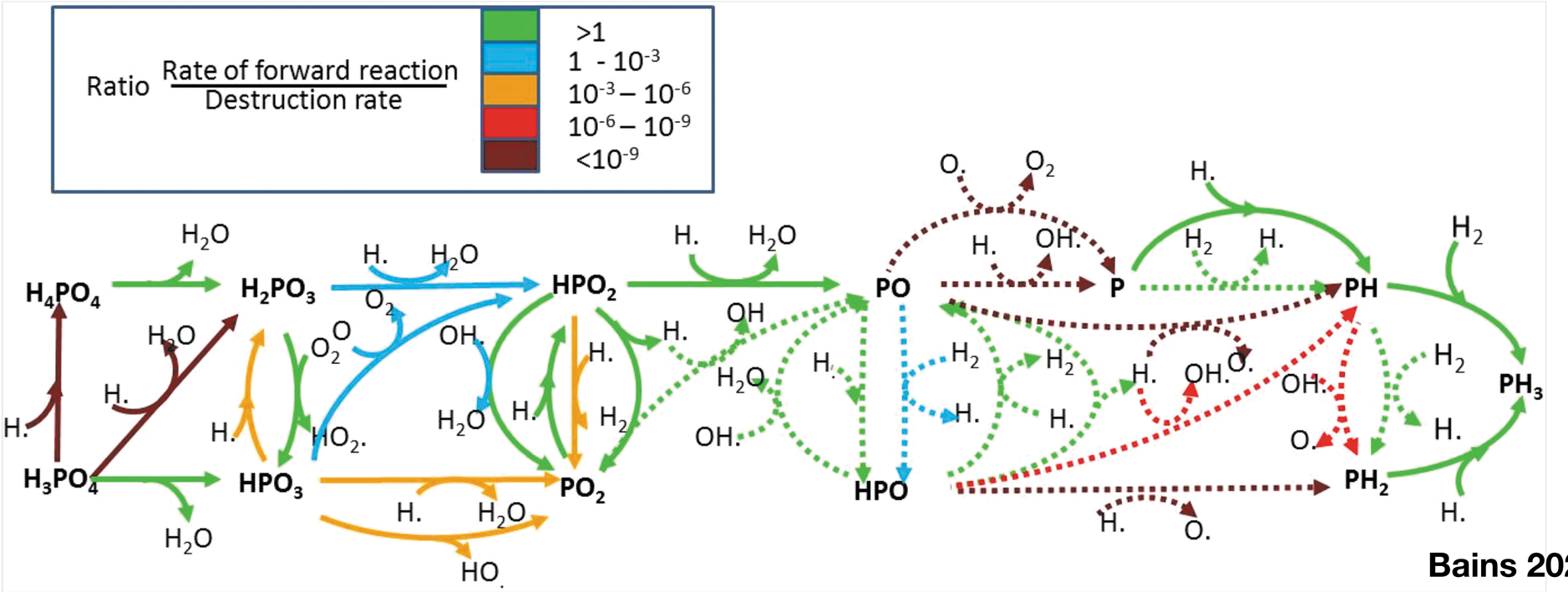
- Lots of data in hand
- Complex processing problem in looking for small absorption features against a very bright background and systematics
- PH_3 still found, but possibly variable in both time and across face of Venus
- JCMT-Venus data also useful for monitoring other species - see talk by Wei Tang Thursday afternoon

Lessons For SETI

- Complex data analysis problems lead to plenty of room for disagreement
- Especially true for data with major implications: potential signs of life or intelligence
- To convince people need multiple analysis approaches and ideally corroborating independent data - difficult if something is time variable
- You will never convince some people
- The universe can come up with more ideas than astronomers to produce life-like signals
    - Took over 40 years to explain Wow! signal (Mendez+ 24)

Spare Slides

Hard to make phosphine on Venus



- No route to making phosphine in Venus' oxidising atmosphere
- Lightning, impactors, volcanoes cannot account for it (definitely not volcanoes*, Bains et al., 2022, 2024)

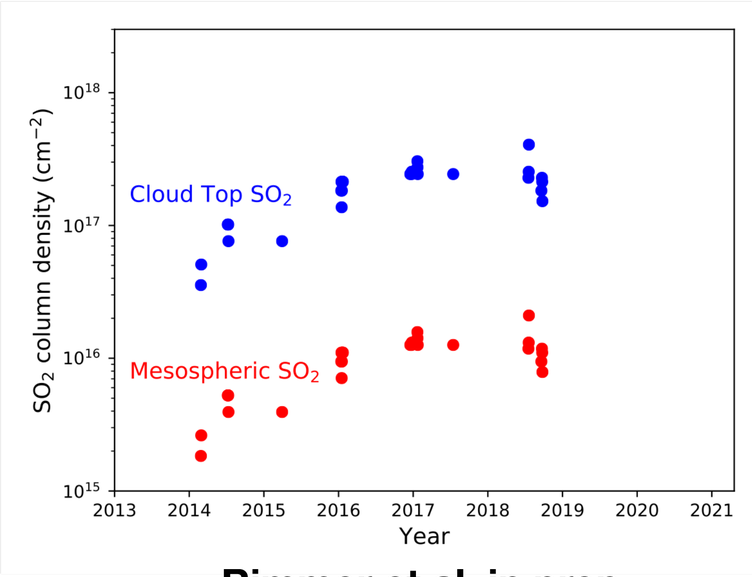
*** Needs one Olympus Mons every 138 years (Bains et al., 2022)**

What makes Phosphine on Earth?

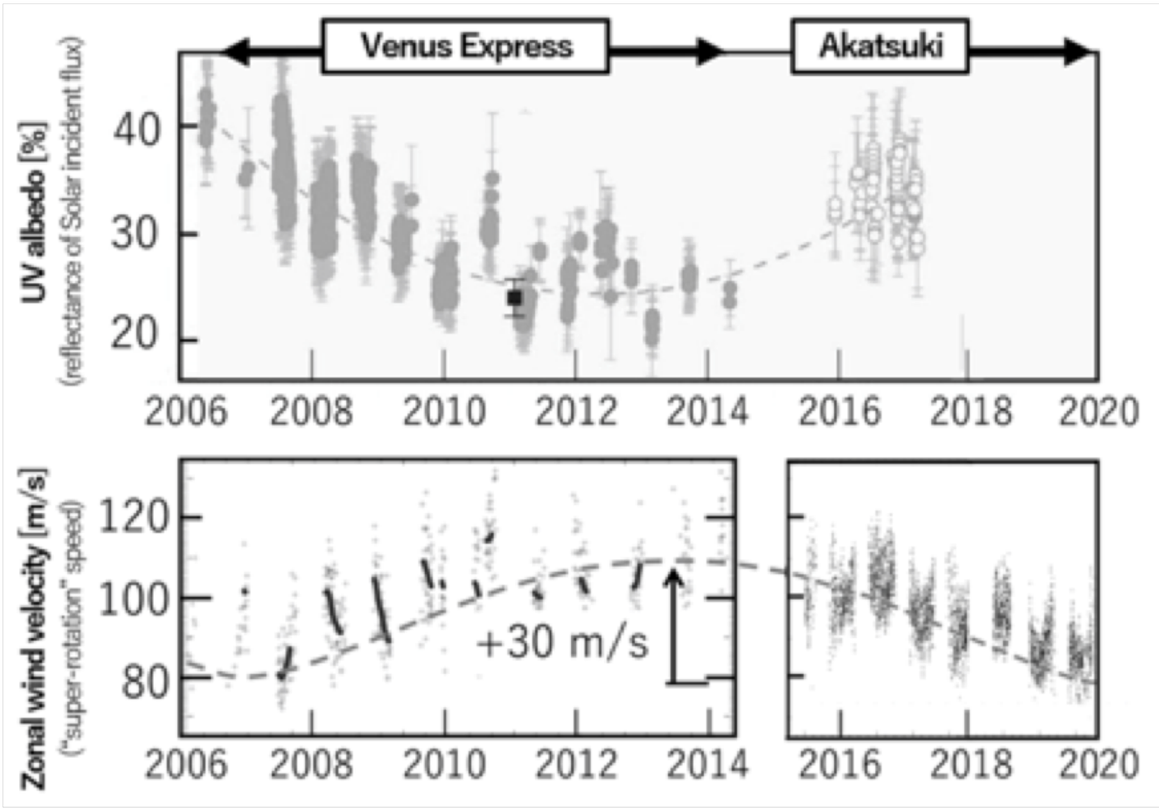
- Sources of phosphine in Earth's oxidising atmosphere are entirely biological
  - Human industrial processes
  - Anaerobic microbial processes in eg. badger guts and penguin guano
- Phosphine proposed as an exoplanet biomarker (Sousa-Silver et al., 2020)

JCMT-Venus

- Need more information on PH_3 and its relationship to other chemical species in the atmosphere of Venus
- Levels of SO_2, H_2O (via HDO), other species, albedo etc. vary with time
- A long term monitoring programme may provide indications of the chemistry that produces PH_3



Rimmer et al. in prep



Imai et al.