# JCMT-Venus
# A JCMT Large Programme

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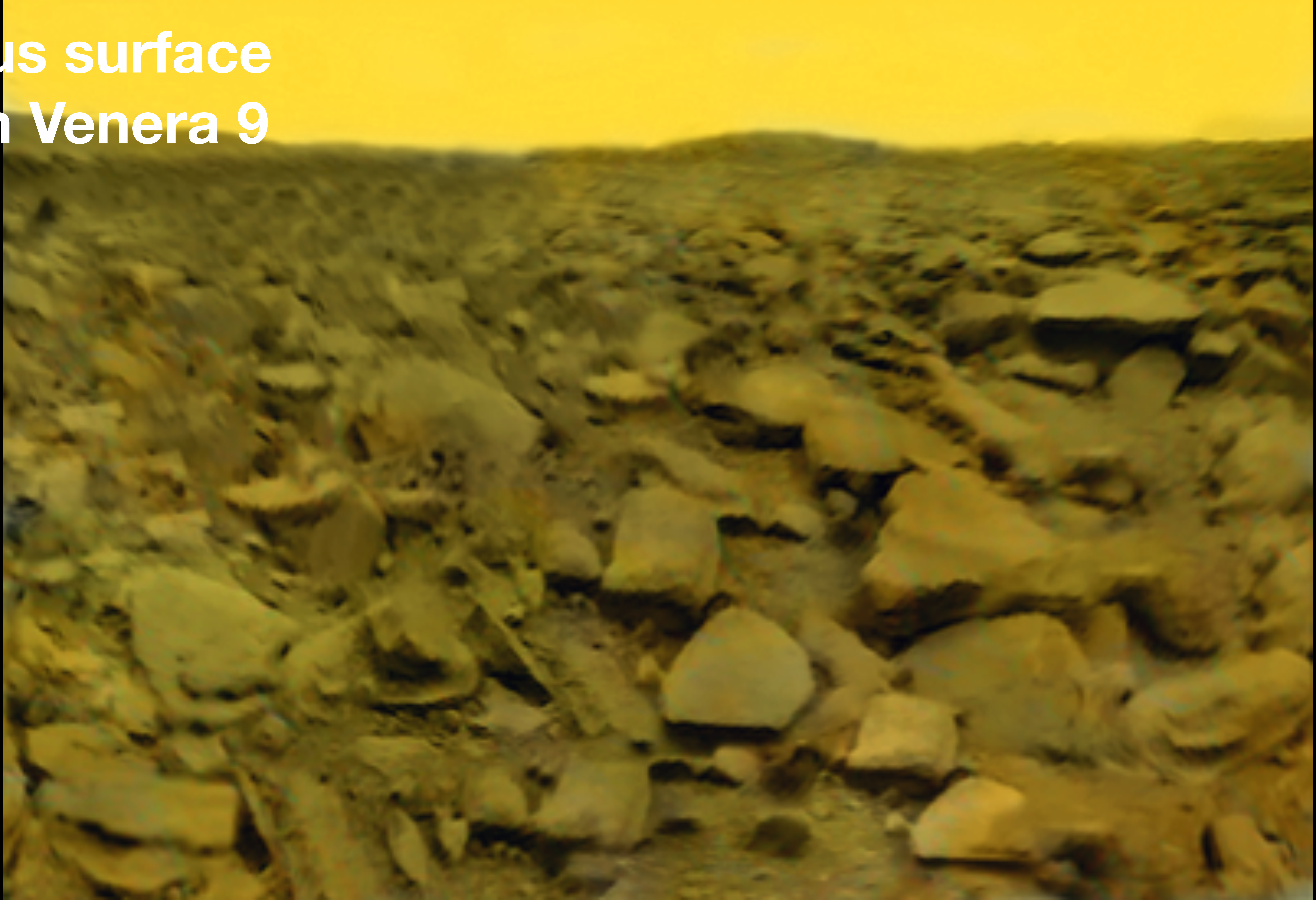
on behalf of
The JCMT-Venus Team

# Overview

- Motivation - why do a large scale programme observing Venus?
- The Project - what data is being taken, what needs to be done
- The Team - current team members and organisation
- Data already being taken - first glimpses

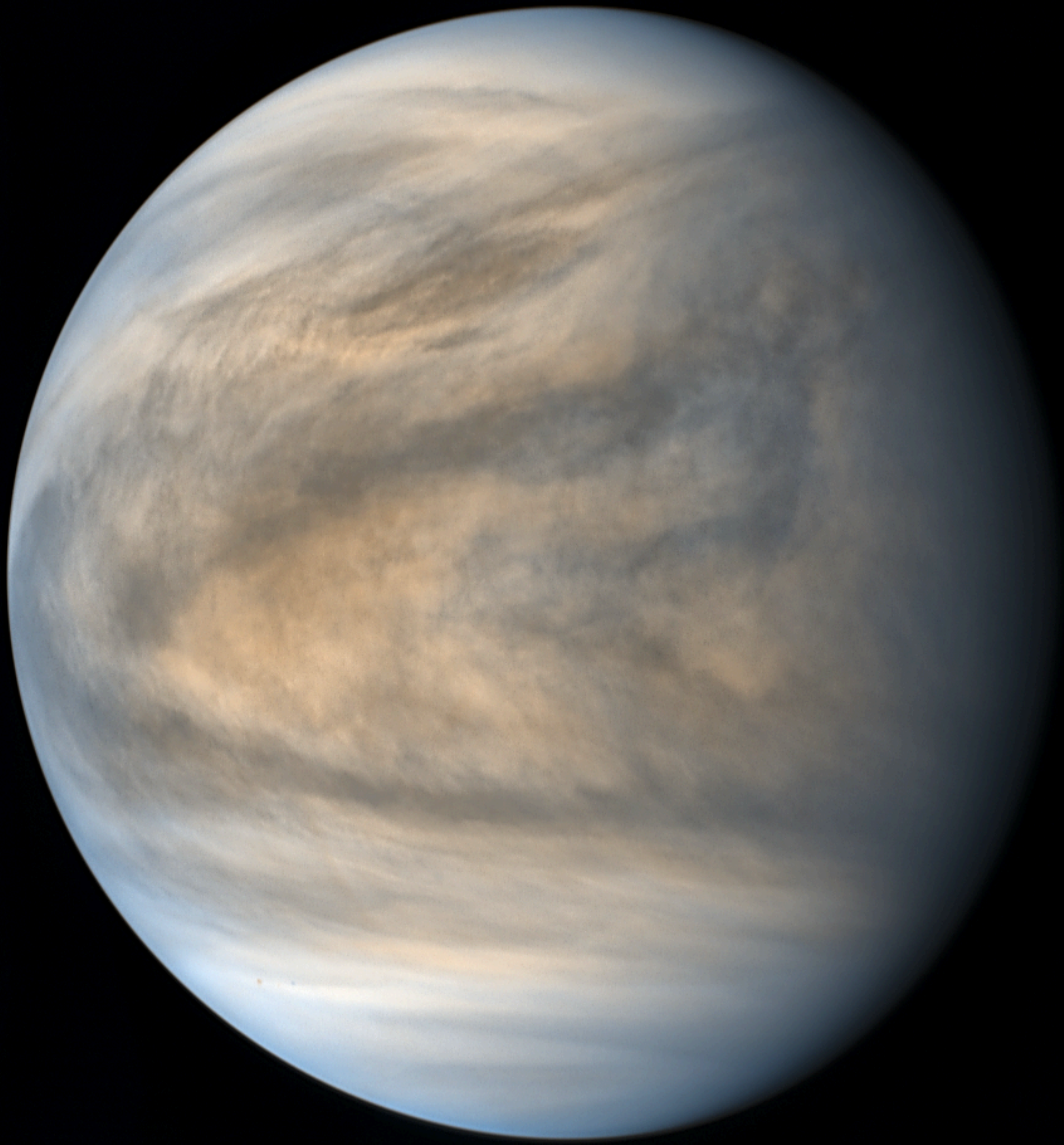
# Venus surface from Venera 9



# Venus - Earth's Evil Twin

- Similar size and mass to Earth but very different characteristics
- Surface of Venus very hot ~730K, very high pressure, ~ 90 bar
- Very thick atmosphere dominated by $CO_2$
- Runaway greenhouse effect leads to high temperatures
- But thick atmosphere leads to complex structure and chemistry

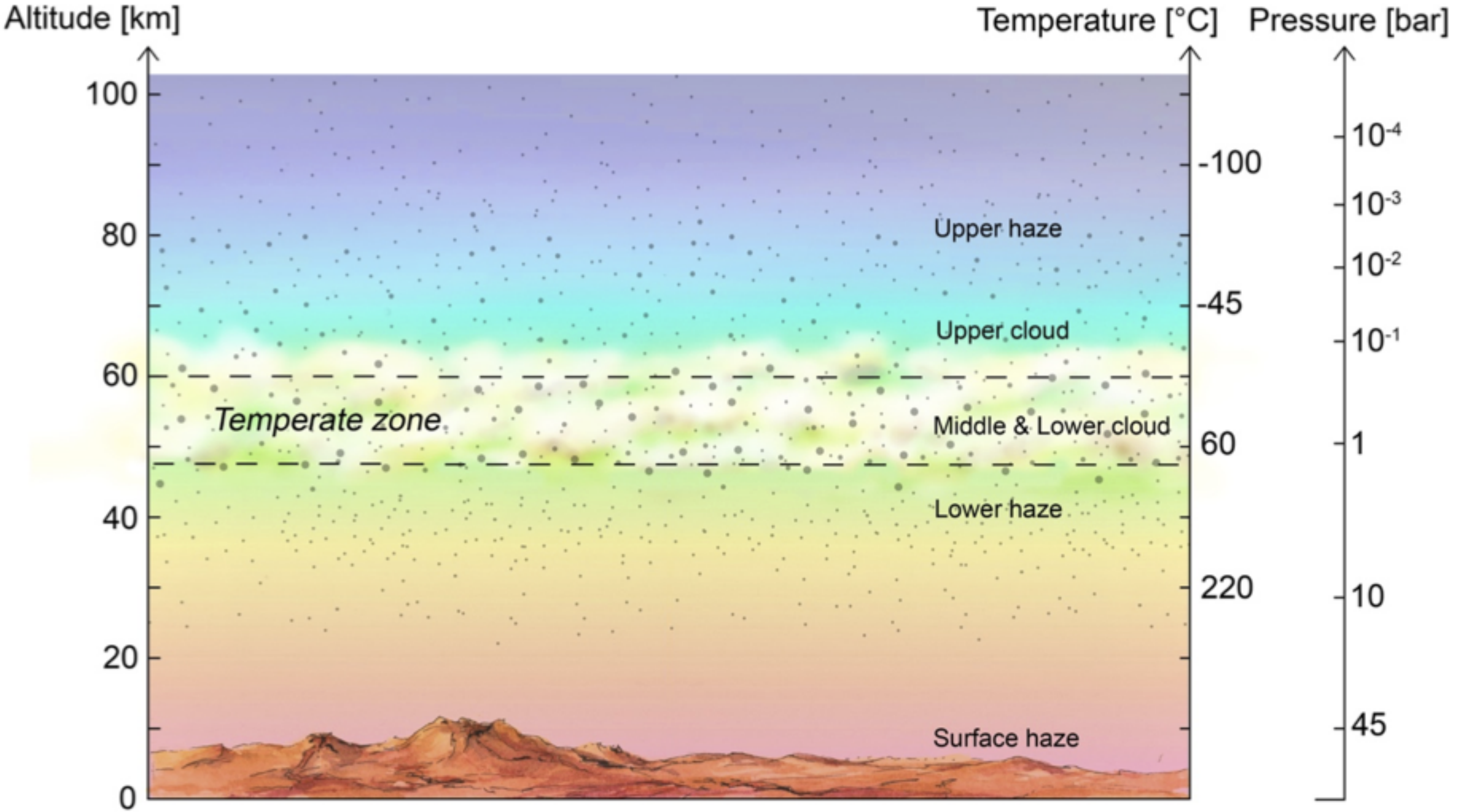
# Venus in UV from AKATSUKI



# 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 particles of unknown composition in cloud layers
  - Vertical abundances of $SO_2$ and $H_2O$ unexplained

**Bains et al., 2021**




**Seager et al 2021**

# Phosphine - a new anomaly

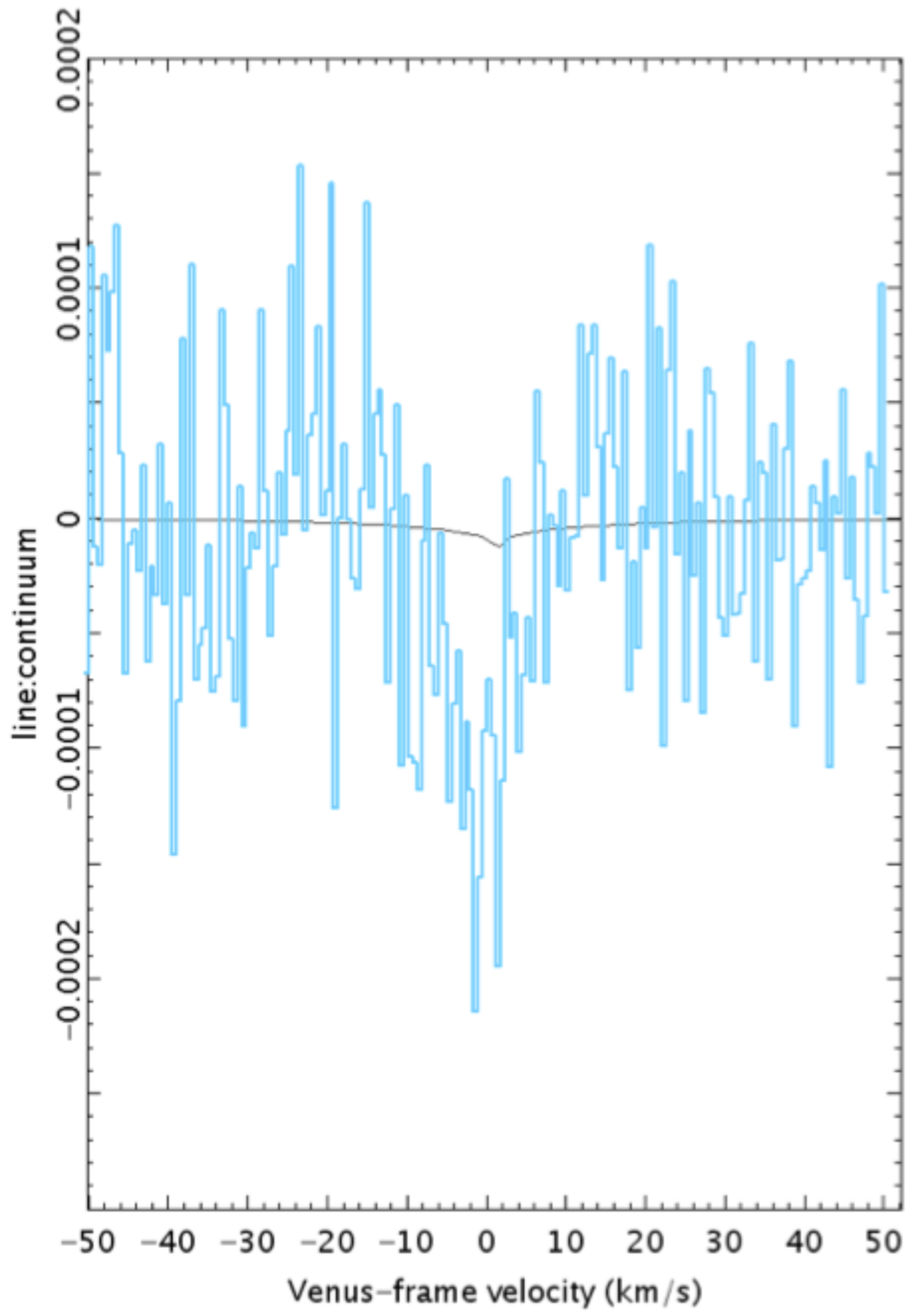
- Discovery of PH3 J=1-0 line in data from JCMT with ALMA confirmation added another anomaly to atmospheric data for Venus

- Confirmed by archival PVO mass spec

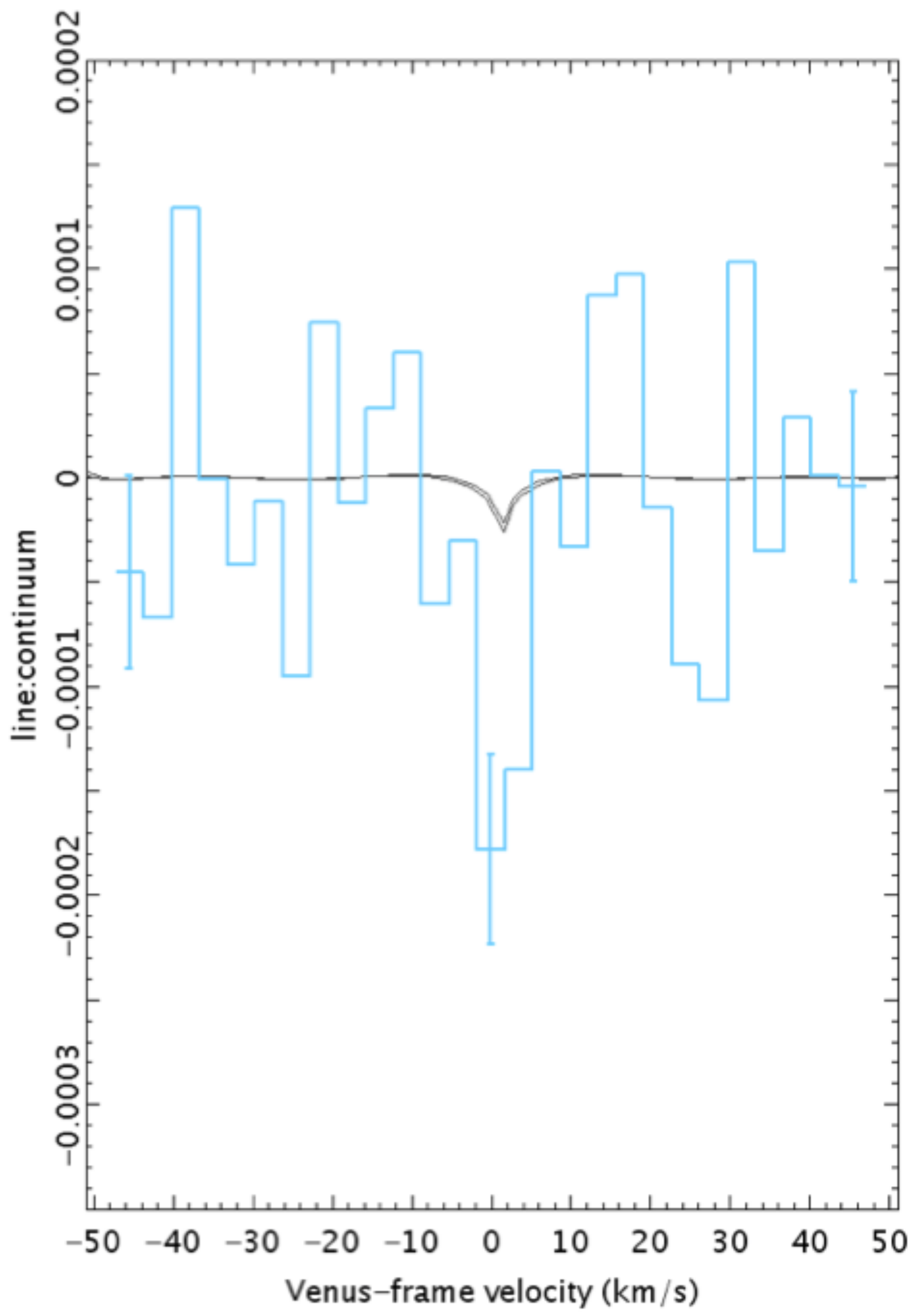
- Origin of PH3 is unclear, but it cannot come from conventional chemical processes (Bains et al., 2020), including volcanoes (Bains et al., 2021)

- Where does it come from?

**ALMA**



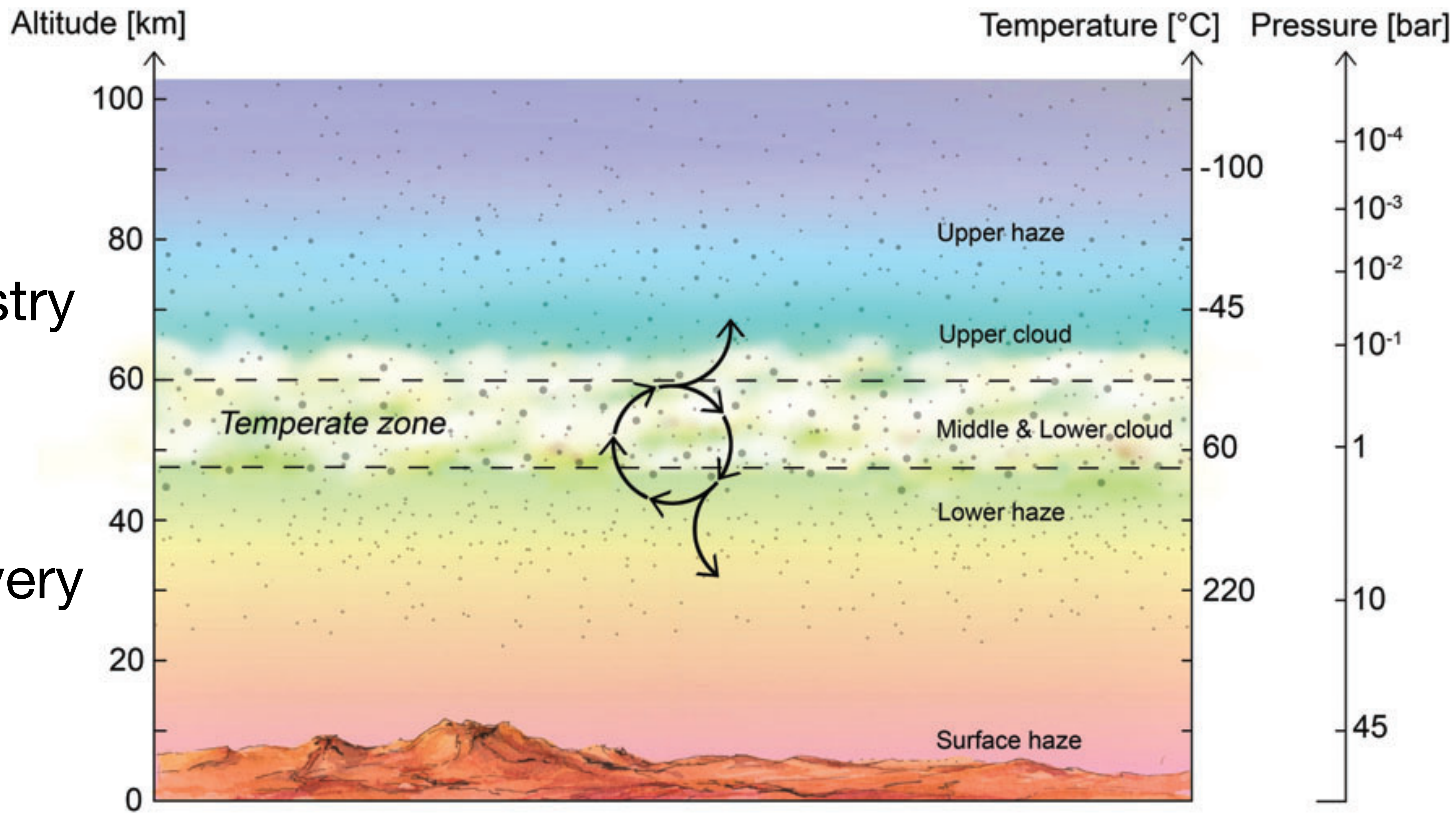

**JCMT**




**Greaves et al., 2022**

# We Don't Know

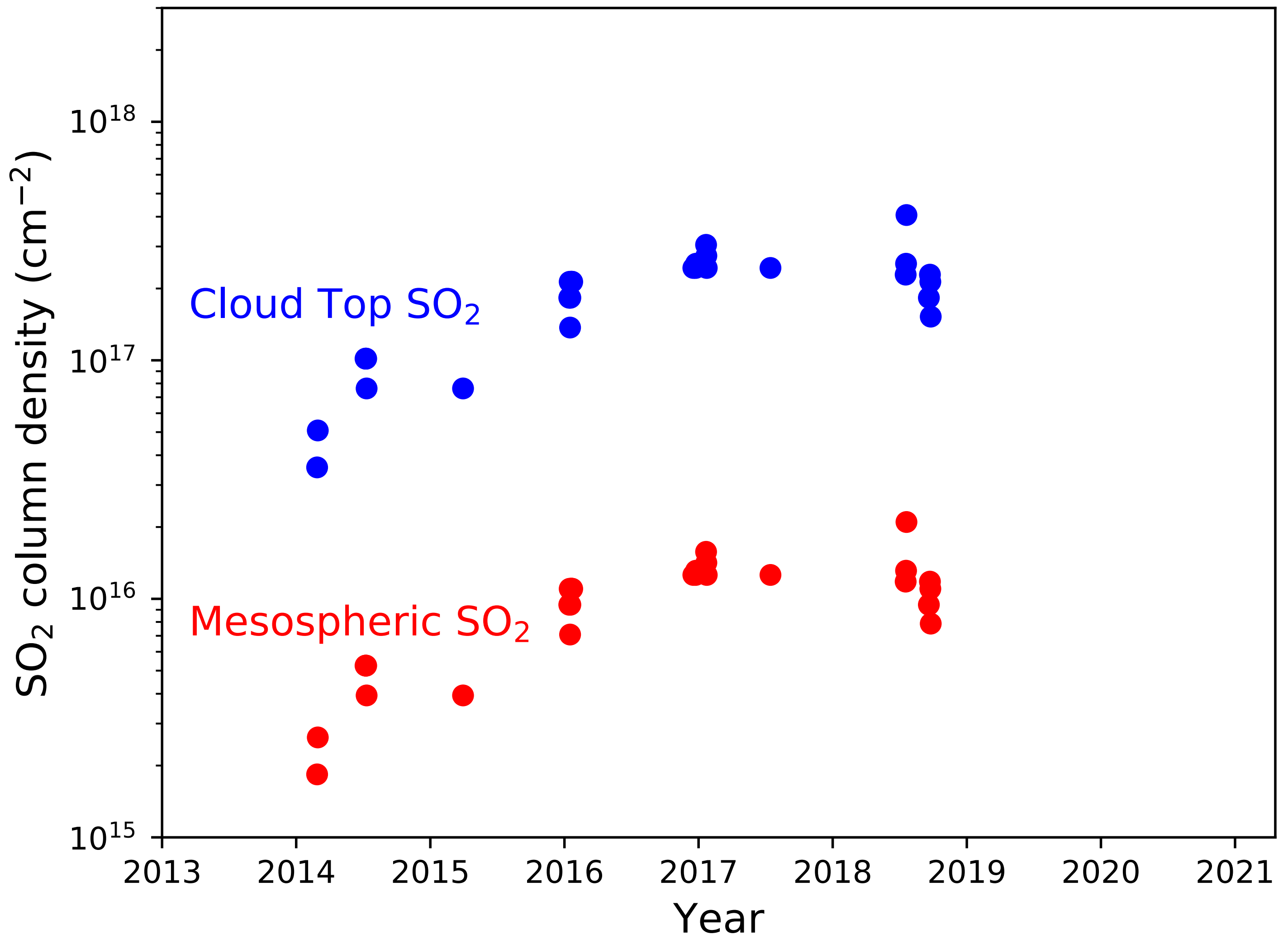
- Origin of PH3 is unclear
- Requires unknown chemistry
- Or possibly life!
- But the life hypothesis is very far from proven



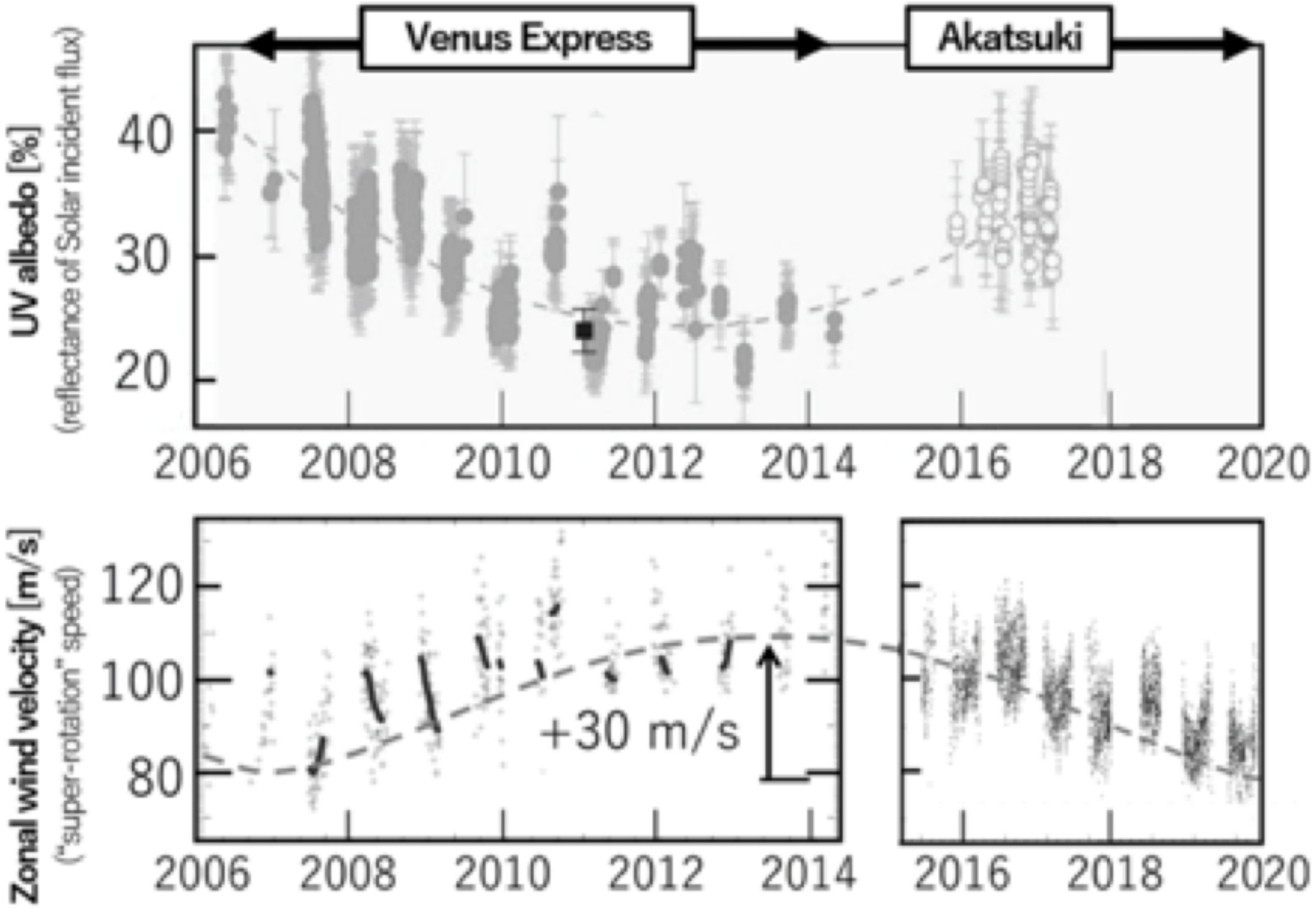

**Seager et al 2021**

# JCMT-Venus

- What is needed is more information on PH3 and its relationship to other chemical species in the atmosphere of Venus
- Levels of SO2, H2O (via HDO), other species, albedo etc. vary with time
- Indicates that a long term monitoring programme may provide indications of the chemistry that produces PH3




**Rimmer et al. in prep**



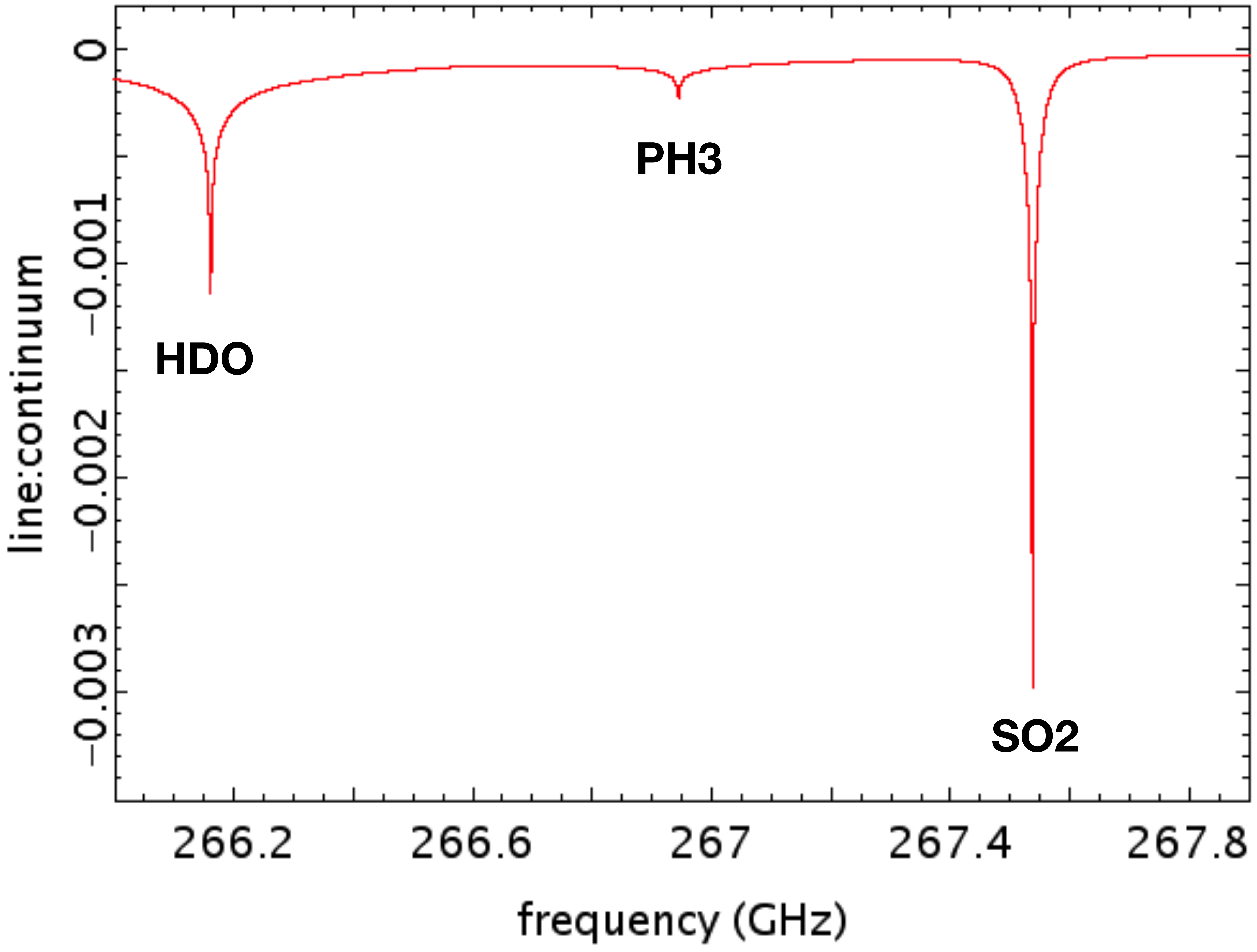

**Imai et al.**

# Ū’ū - the new receiver

- The new Ū’ū receiver with ACSIS allows observations over a wide band, covering PH3, SO2, HDO and other lines of interest

- Sensitivity and stability better than RxA - especially important when observing weak absorption against a very bright source

- With enough S/N hope to recover PH3 line wings & thus altitude distribution



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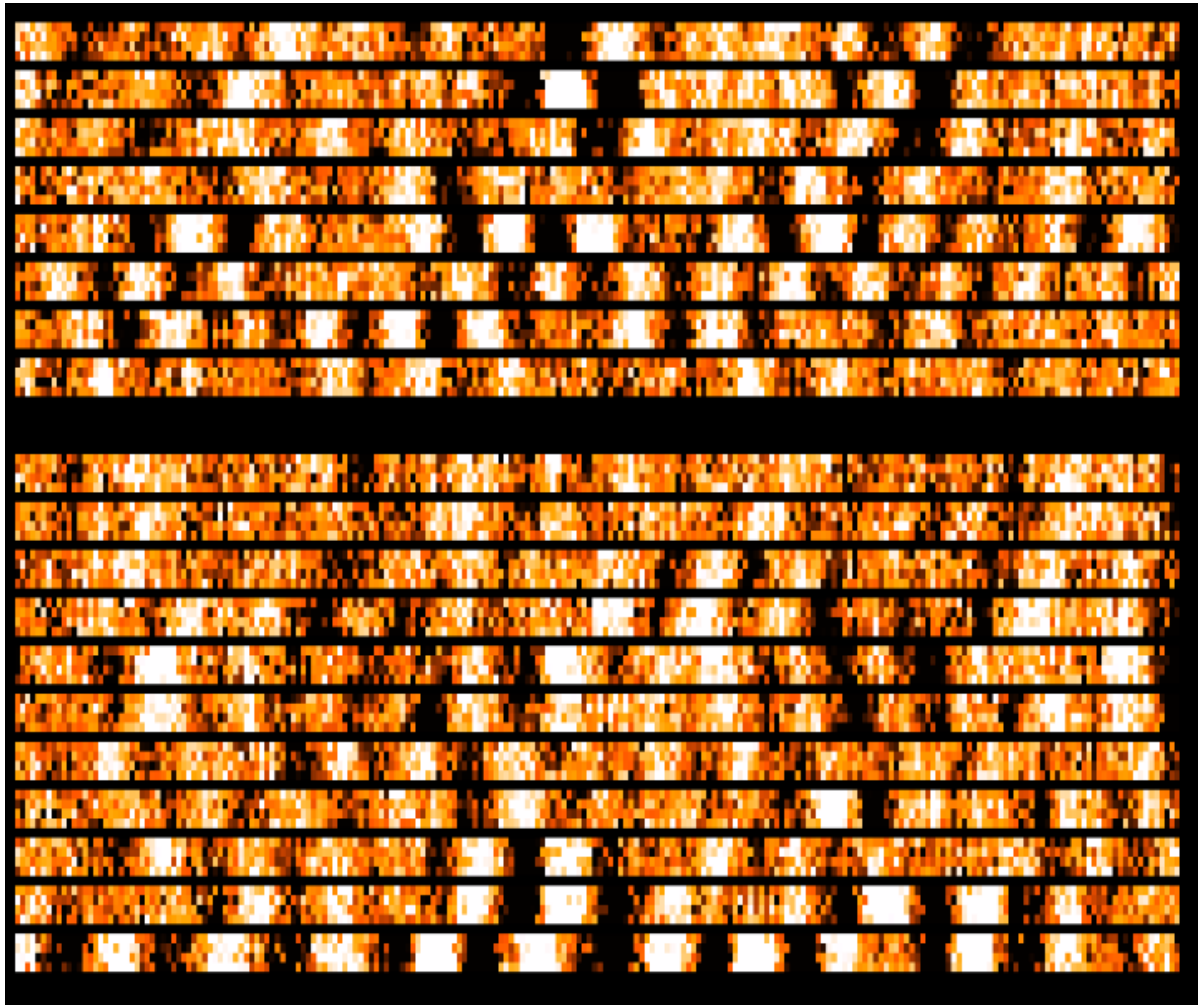
**RxA baseline ripples and drifts**



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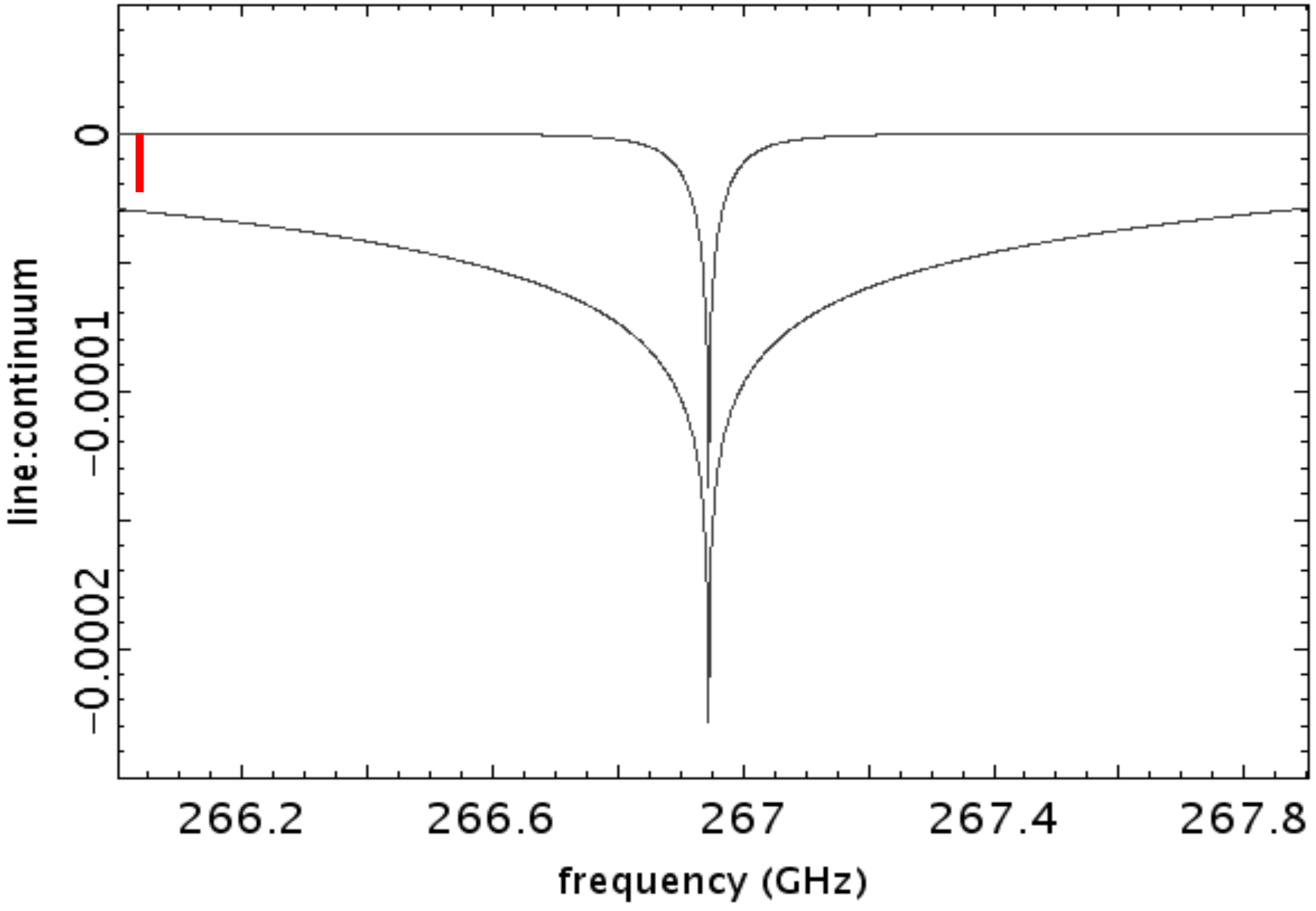



**Red bar indicates S/N after 30 days of morning observations**

# Other Lines of Interest

- Lines from other species also appear in the Ū'ū broad band
- We will look for detections and monitor their variation
- Possibility of discovering other, unexpected species

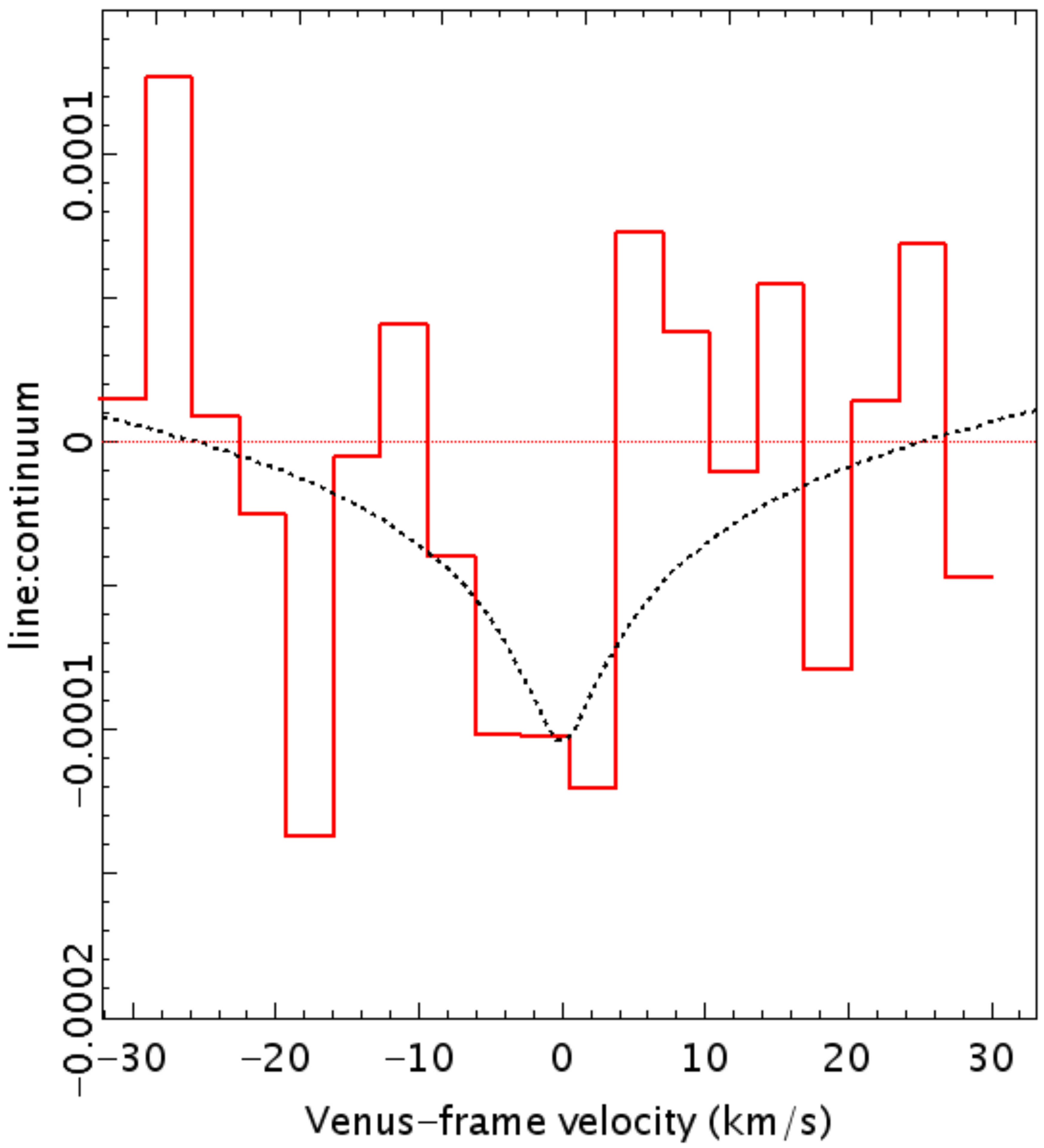
| | |
|---|---|
| $PO_2$ 13(12)-12(11) | 266.0556 GHz |
| $PO_2$ 13(13)-12(11) | 266.1131 GHz |
| *HDO 2(2,0)-3(1,3) | 266.1611 GHz |
| *$PH_3$ 1-0 | 266.9445 GHz |
| SO 4(3) - 3(4) | 267.1979 GHz |
| $H_2SO_4$ 26(24,3)-25(23,3) | 267.2498 GHz |
| OCS 2(2)-1(1) | 267.5302 GHz |
| *$SO_2$ 13(3,11)-13(2,12) | 267.5374 GHz |
| $HCO^+$ 4-3 | 267.5575 GHz |
| $H_2SO_4$ 26(25,2)-25(24,2) | 267.6304 GHz |

# Ū’ū can do it

- 30 minute test integration in Band 1/2 conditions in July 2020 successfully recover PH3

- Sensitivity comparable to 1 hour of integration in band 4/5

- Black curve: 15 ppb PH3 from radiative transfer model



# 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
- 3 periods in next 3 years
- Awarded 200 hours of time
- Morning twilight observing using extended observing time

| | | |
|---|---|---|
| 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 |

# What needs to be done?

- Rapid data validation - was each observing block successful?
- Data reduction and analysis
  - Ideally have several independent methods for baseline removal and line detection/extraction
- Atmospheric modelling incorporating PH3 generation mechanisms and allowing for time variation of the other species being observed
- Interaction with other Venus projects eg. AKATSUKI, JUICE, future missions from eg. NASA, ESA and RocketLabs
- Outreach and engagement

# The Current Team pt. 1

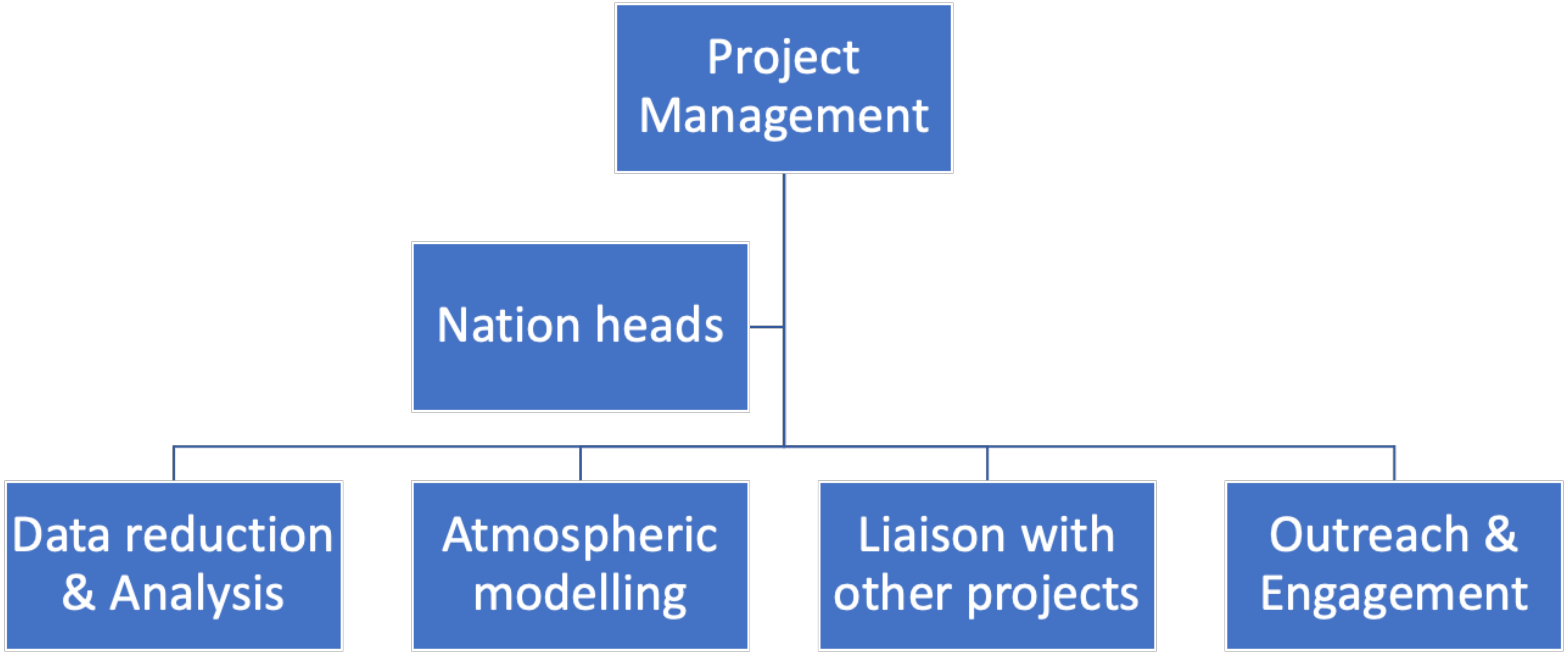
- Dr David L. Clements, Imperial College London (UK) - project manager, data reduction and analysis, JUICE liaison, UK PI
- Prof Jane Greaves, Cardiff University (UK) - project scientist, data reduction and analysis, line modelling
- Dr Masataka Imai, Kyoto Sangyo University (Japan) - Venus atmosphere modelling, AKATSUKI liaison, Japanese PI
- Dr Kitiyanee Asanok, NARIT (Thailand) - molecular line astronomy, Thai PI
- Prof Gerald Schieven, Herzberg Institute (Canada) - data analysis, planetary atmosphere modelling, Canadian PI
- Dr Supachai Awiphan, NARIT (Thailand) - planetary atmospheres
- Dr William Bains, Cardiff University (UK) - chemical modelling
- Dr Malcolm Currie EAO (EAO) - data reduction and analysis
- Dr Emily Drabek-Maunder, Royal Observatory Greenwich and Imperial College London (UK) - data reduction and analysis, outreach and public engagement

# The Current Team pt. 2

- Prof Helen Fraser, Open University (UK) - chemical modelling, lab astrophysics
- Dr Steve Mairs, EAO (EAO) - data reduction and analysis
- Dr Ingo Mueller-Wodarg, Imperial College London (UK) - Venus upper atmosphere modelling
- Prof David Naylor, Lethbridge University (Canada) - data reduction and analysis
- Dr Anita Richards, Manchester University (UK) - data analysis, ALMA liaison
- Dr Paul Rimmer, Cambridge University (UK) - atmospheric chemistry modelling
- Dr Sirinrat Sithajan, NARIT (Thailand) - data analysis
- Dr Nahathai Tanakul, NARIT (Thailand) - data analysis

**Your name here!**

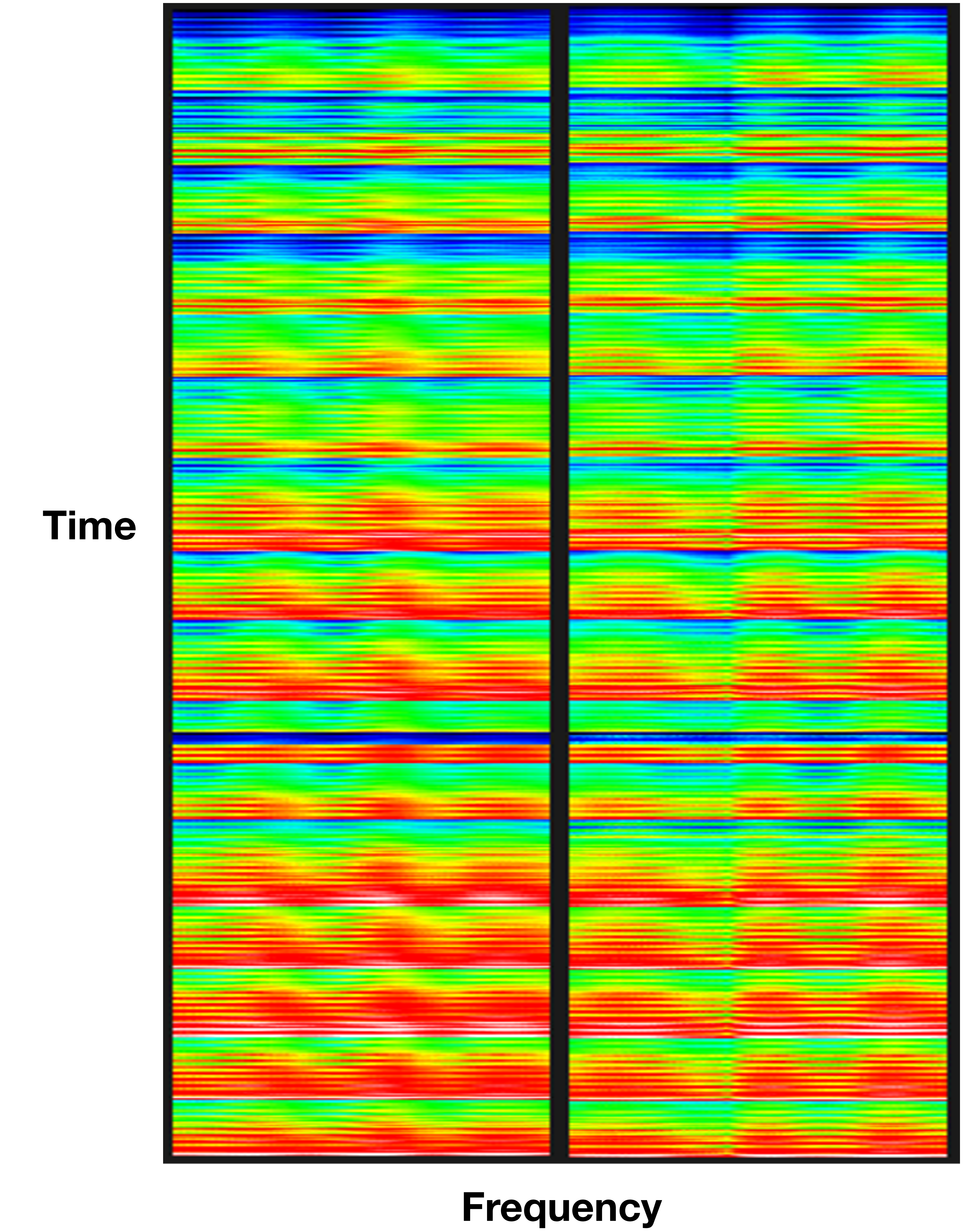
# Organisation



# Current Status

- The first Venus observing period is already upon us
- Data has been taken most mornings throughout February
- Have concentrated so far on rapid quality checks, optimisation of observing setup, and initial development & testing of reduction methods

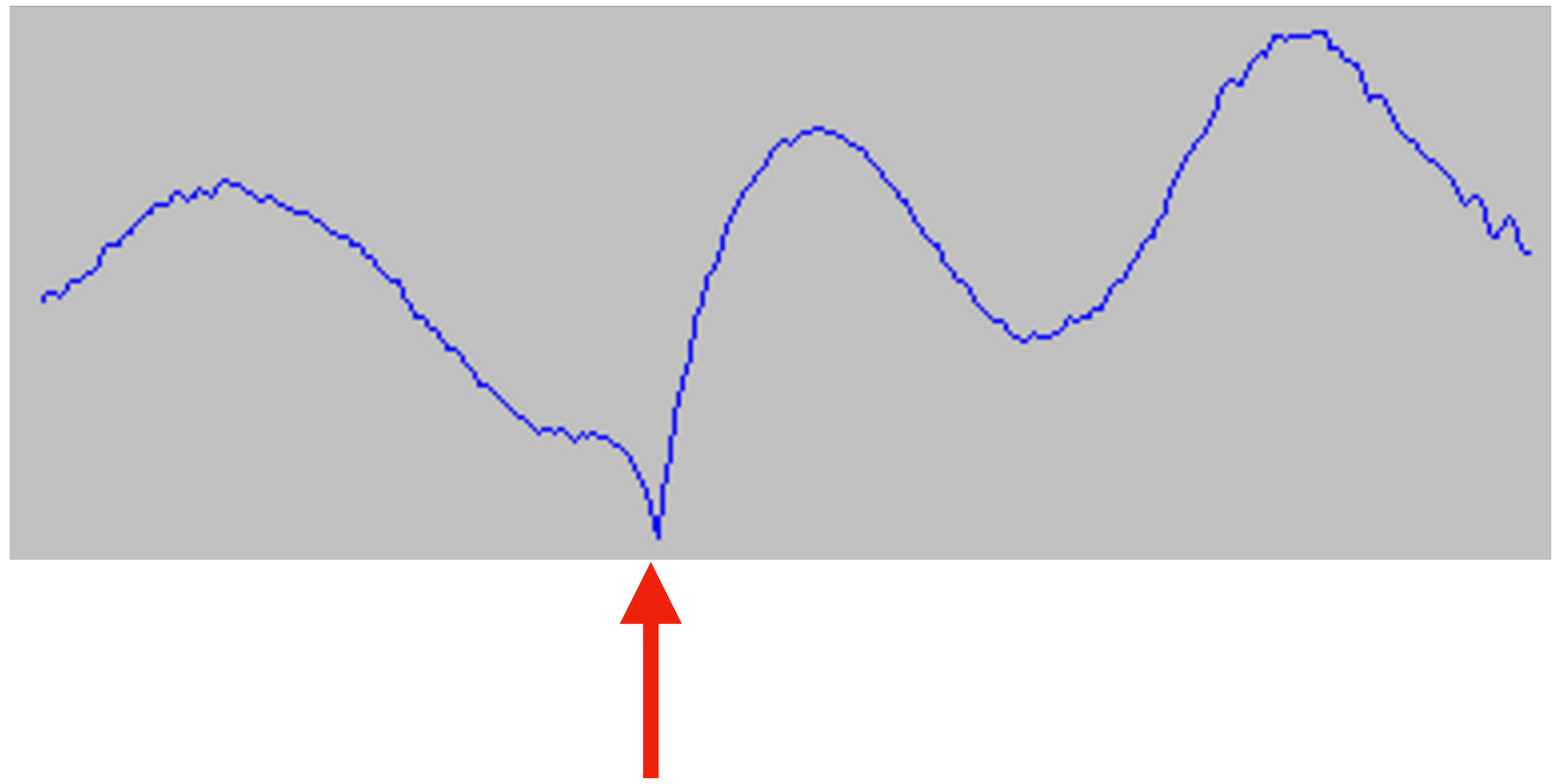
# First Observing Cycle




18 mornings of data, with two spectral windows -> 1800 MHz band
Y-axis shows time (detectors 0 & 1 are on alternate rows)
X-axis is spectral channel

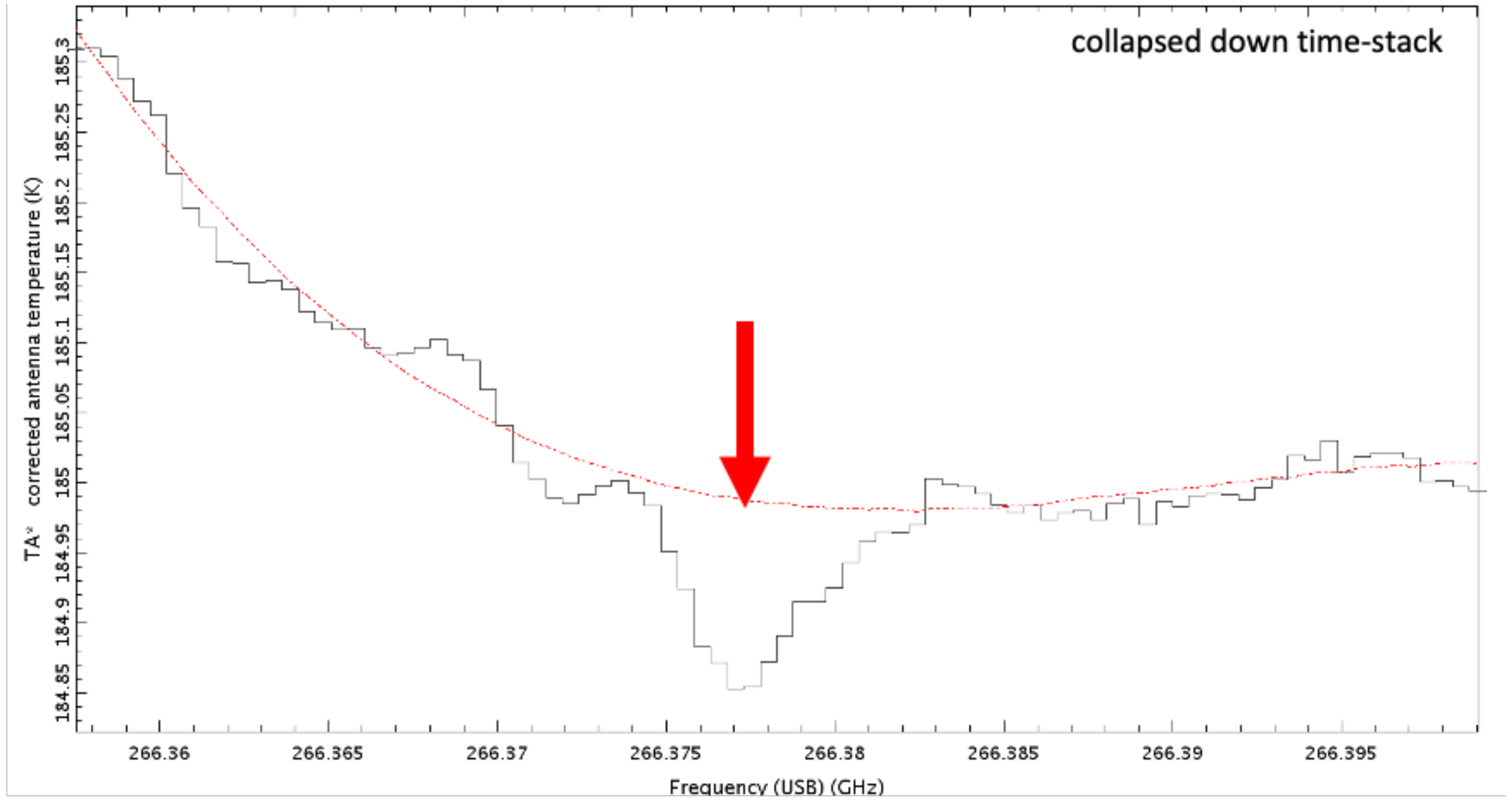
This is already ***~150x more information*** than we previously obtained with RxA on Venus, as we have both more time and a wider passband

If we collapse down the time-axis, we see mainly big stable ripples, due to reflected signals entering ACSIS

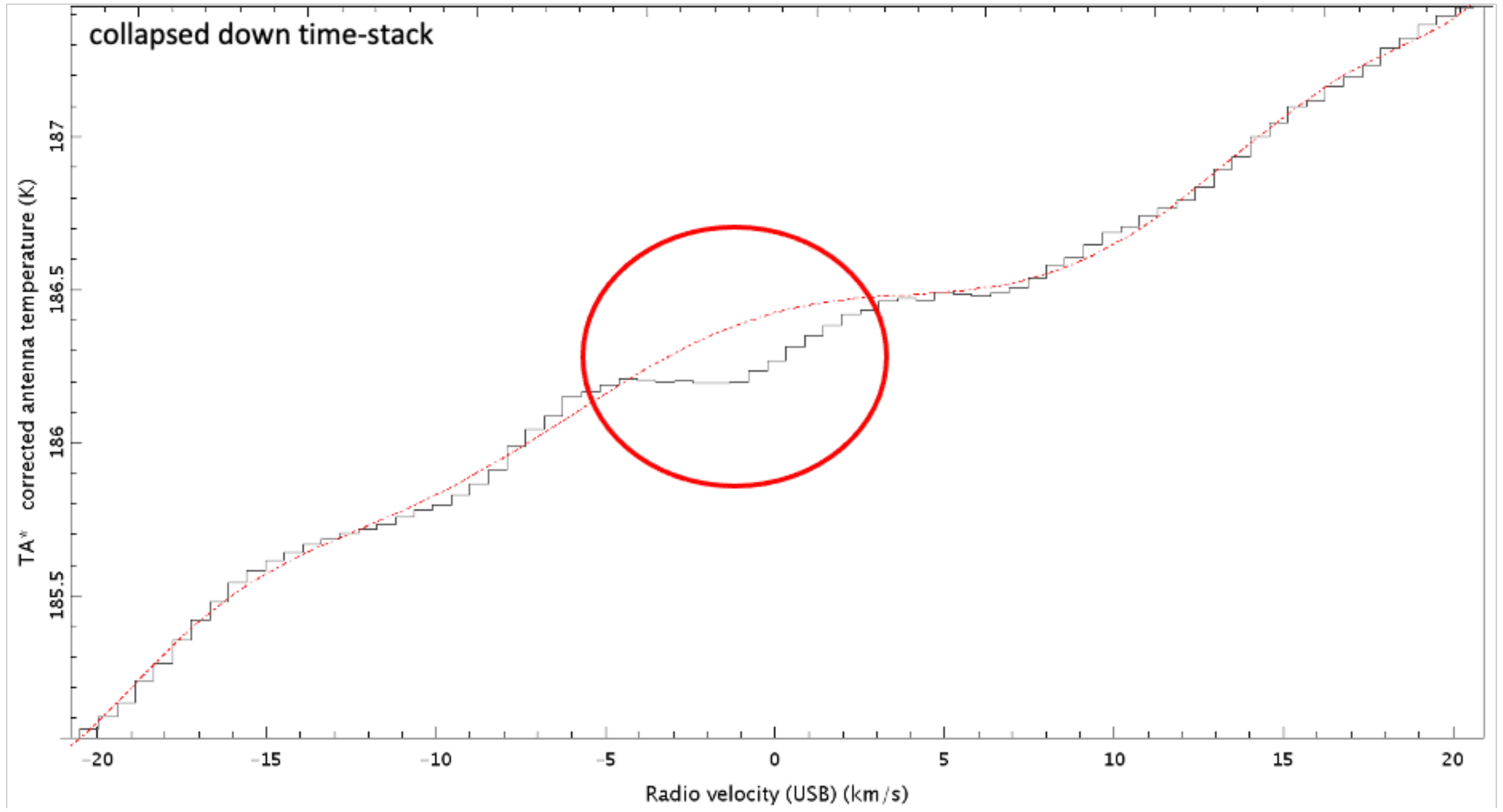


This spiky feature is terrestrial ozone
(more absorption is seen against Venus than blank sky)

A major strength of the survey is the depth of the data (45/200 hours taken so far) – we can see lines *before* any complex processing



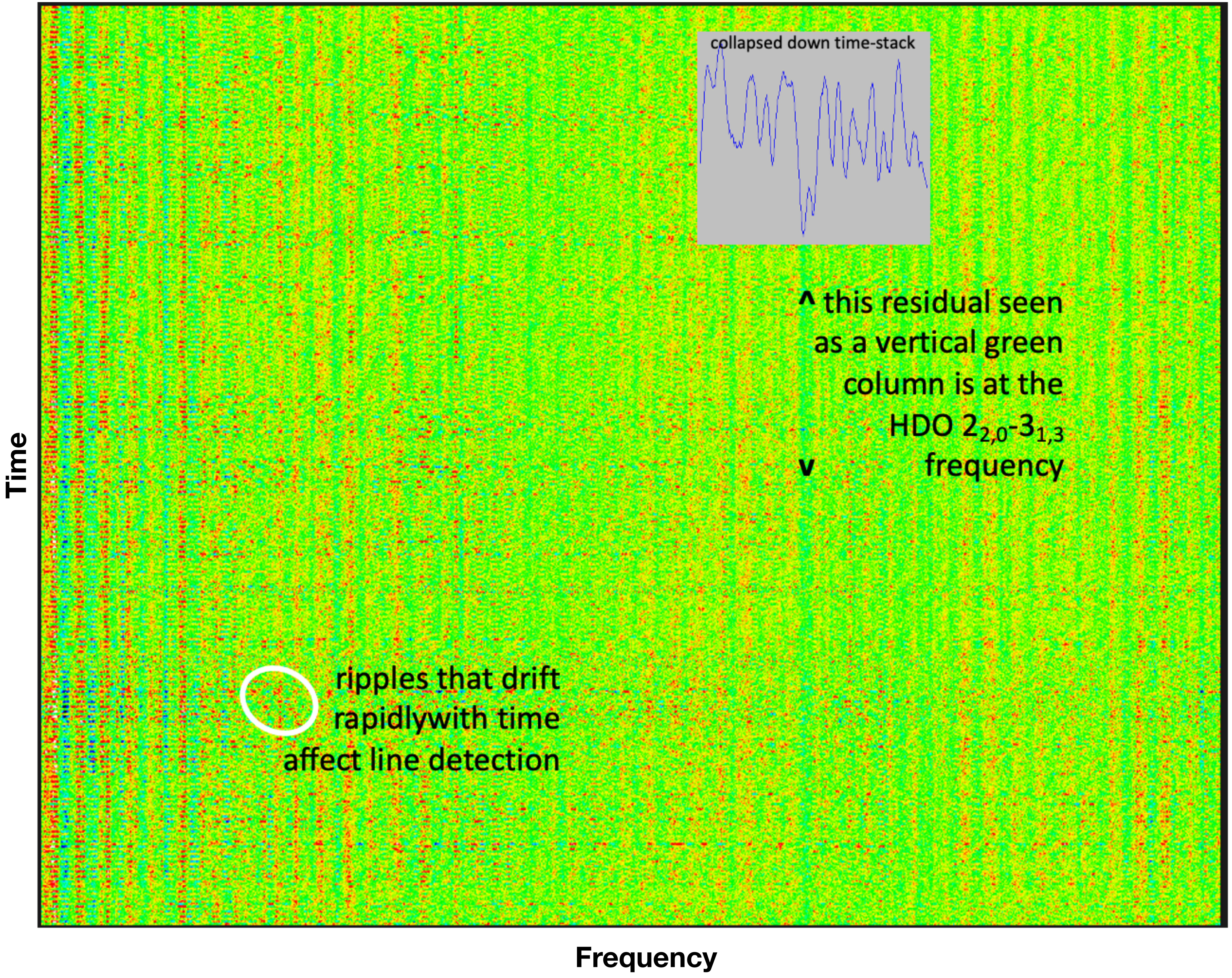

… so there may be unexpected discoveries: this line looks real, and is so far <u>unidentified</u>




There is a hint that the phosphine ($PH_3$ 1-0) line from Venus is seen ***without any additional processing!*** (not possible in any earlier dataset)

Here we are looking at the smaller ripples (a median filter of the original data has been subtracted)

These narrow ripples are fairly stable, but comparable in brightness to lines we are looking for - not helpful



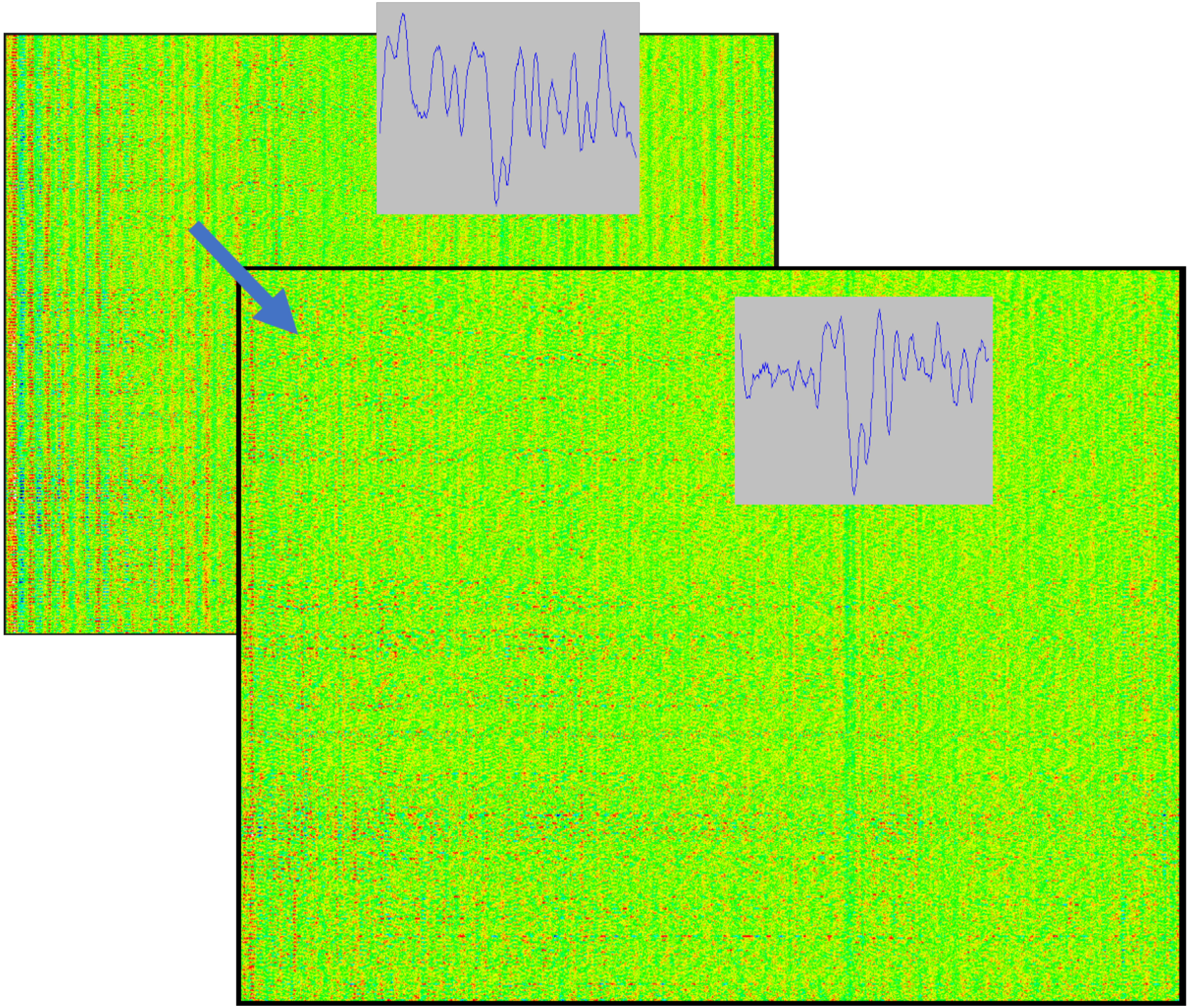
A method in development is to Fourier Transform the entire data frame - then identify peaks (repeating patterns in frequency, or day-to-day).

An Inverse-Fourier-Transform then generates a model to subtract from the original “ripply” data.

This example shows some reduced ripple around the HDO feature … *it worked*!

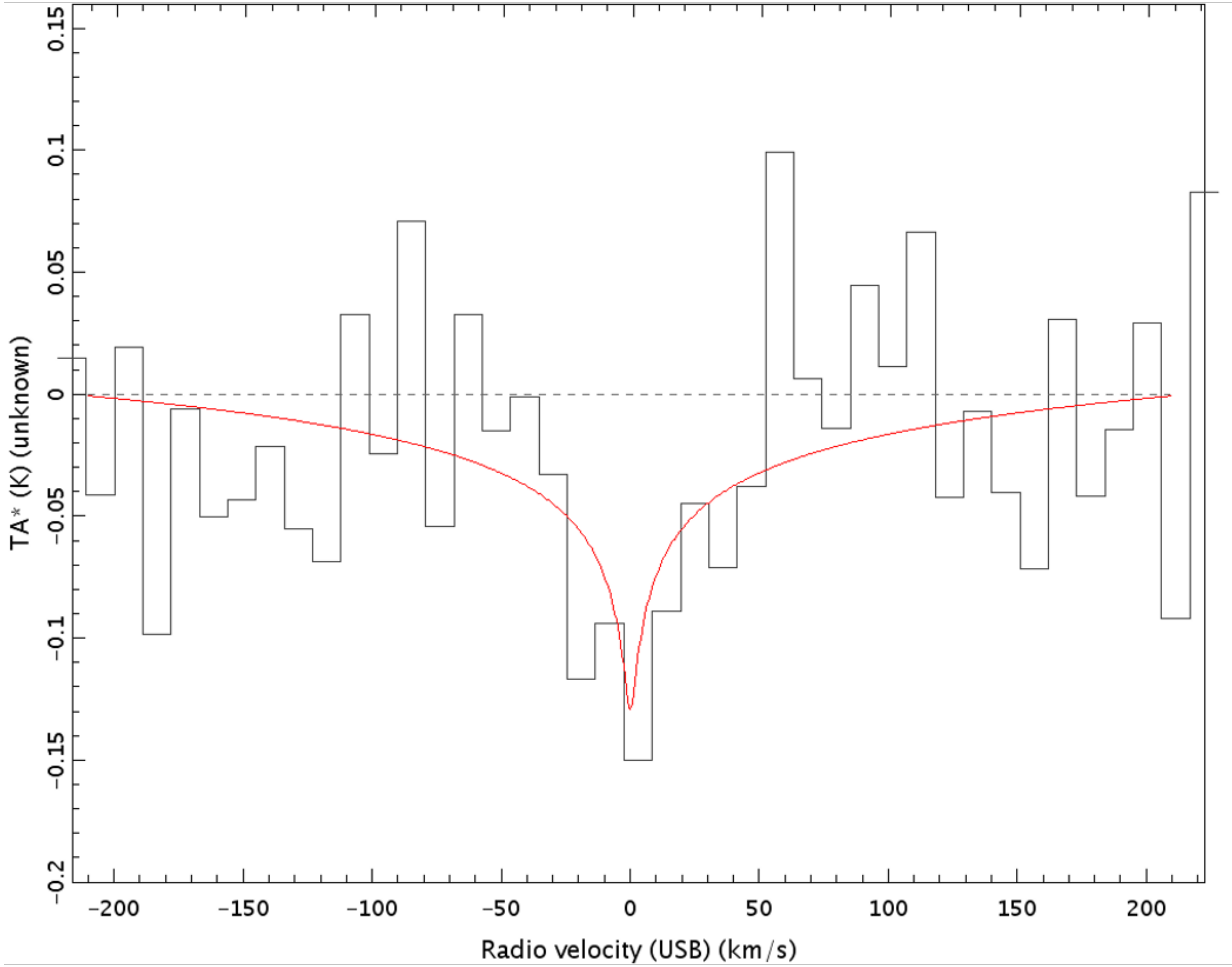
(But we need more testing, to optimise choices in the FT-model – the method is new just in the last few weeks.)

Unexpected lines might also be missed by this method
(here data-columns near the HDO line were “blanked” before running the FT).



This is a <u>very preliminary</u> result for **phosphine**, using the same method, and overlaid with a preliminary model – looks like a solid detection!

NB, the frequency-range shown here is ***~5x as wide*** as previously possible, so we can start to test for phosphine at warm higher-pressure layers of the atmosphere



# What’s Next

- First cycle observations completed
- Need to apply multiple methods to clean the spectra and identify lines
- Need to prepare for the next data collection cycles in 2023
    - Better data quality analysis
    - Possible observation optimisation
- Need to analyse and publish results from the completed campaign
- Need to work on improved atmospheric, chemical & radiative transfer models
- Compare our results with those from other missions and facilities

# JCMT-Venus

- By the end of this project we should have a much better idea of the chemistry and chemical variability in the clouds of Venus
- This includes a better understanding of PH3 and why it is there
- New insights into our nearest neighbour planet
- A clearer idea of whether chemistry or biochemistry is behind PH3 in Venus