LETTER TO THE EDITOR

Re-analysis of the 267 GHz ALMA observations of Venus
No statistically significant detection of phosphine

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Received 19 October 2020 / Accepted 13 November 2020

ABSTRACT

Context. ALMA observations of Venus at 267 GHz that show the apparent presence of phosphine (PH₃) in its atmosphere have been presented in the literature. Phosphine currently has no evident production routes on the planet’s surface or in its atmosphere.

Aims. The aim of this work is to assess the statistical reliability of the line detection via independent re-analysis of the ALMA data.

Methods. The ALMA data were reduced the same way as in the published study, following the provided scripts. First, the spectral analysis presented in the study was reproduced and assessed. Subsequently, the spectrum, including its dependence on selected ALMA baselines, was statistically evaluated.

Results. We find that the 12th-order polynomial fit to the spectral passband utilised in the published study leads to spurious results. Following their recipe, five other >10σ lines can be produced in absorption or emission within 60 km s⁻¹ from the PH₃ 1−0 transition frequency by suppressing the surrounding noise. Our independent analysis shows a feature near the PH₃ frequency at a ∼2σ level, below the common threshold for statistical significance. Since the spectral data have a non-Gaussian distribution, we consider a feature at such level as statistically unreliable, which cannot be linked to a false positive probability.

Conclusions. We find that the published 267 GHz ALMA data provide no statistical evidence for phosphine in the atmosphere of Venus.

Key words. planets and satellites: individual: Venus

1. Introduction

Atacama Large Millimeter Array (ALMA) observations of Venus at 267 GHz that show the apparent presence of phosphine (PH₃) in its atmosphere at ∼20 parts-per-billion (Greaves et al. 2020; hereafter GRB20) have recently been presented. Since phosphorus is expected to be in oxidised forms, phosphine has no easily explained production routes on the planet’s surface or in its atmosphere at this level (Bains et al. 2020). At the same time, PH₃ is identified as a potential biomarker gas (Sousa-Silva et al. 2020), and an aerial biosphere of Venusian microbes (Seager et al. 2020) has been proposed as the possible source. The required biomass is potentially just a fraction of that of the Earth’s aerial biosphere (Lingam & Loeb 2020). Furthermore, the Venusian life may have an Earth origin (Siraj & Loeb 2020). A balloon mission is proposed to search in situ for these life forms (Hein et al. 2020), which could be launched as soon as 2022–2023. In the meantime, Encrenaz et al. (2020) have provided a stringent upper limit on the PH₃ abundance of <5 ppb from observations in the thermal infrared, which, in the absence of variability, is in conflict with the results presented by GRB20.

The aim of this work is to assess the statistical reliability of the PH₃ J = 1−0 line detection by independently re-analysing the ALMA data. In Sect. 2, the processing and calibration of the ALMA data are described, which was performed in a similar way as by GRB20. In Sect. 3, the procedure that led to the ∼15σ detection of PH₃ by GRB20 is reproduced and is shown to give spurious results. In Sect. 4, an independent analysis of the ALMA spectrum is presented and discussed. Short conclusions follow in Sect. 5.

2. Processing and calibration of ALMA data

The ALMA data processing and calibration are briefly discussed here, but the reader should consult GRB20 for more details. The aim was to perform the processing and calibration in the same way as in the original study, making use of the (updated) scripts provided by GRB20. This study only concentrates on the high-resolution narrow-band data centred on PH₃.
The raw data from ALMA project 2018.A.00023.S were retrieved from the ALMA Science Archive. The python script Supplementary Software 2 and 3 from GRB20 was used for the initial calibration to produce the ALMA data cubes. The script selects data from baselines >33 m; this is the range chosen by GRB20 to maximise the signal-to-noise (S/N) of the proposed PH$_3$ 1–0 signal, and it also forms the main focus of the analysis presented here. The 33 m cutoff is near the second minimum of the visibility amplitudes of the Venus disk at this frequency. These procedures were subsequently altered to process the data for different baseline selections, including all baselines as well as baselines >20 m and >50 m, which correspond to the first and third minimum of the visibility amplitudes, respectively. Verify that your intended meaning has not been changed. Supplementary Software 4 was used to image the data cubes$^1$. Following GRB20, the Venus rest-frame frequency of the PH$_3$ 1–0 transition was adopted to be 266.9445 GHz (Müller 2013). The spectral data were binned to velocity steps of 1.10 km s$^{-1}$.

### 3. Reproduction of the phosphine results

At the time of observations, the angular diameter of Venus was 15.36” (GRB20). Since for the >33 m baseline selection the spectral line data from the limb of the planet still show strong ripples, data from within one major axis of the synthesised beam (<1.16”) of the planet limb were excluded from analysis. The continuum-subtracted line data were summed over the planet disk and divided by the summed continuum data to make the continuum-normalised line-spectrum (1/c).

To further mitigate the effects of the instrumental ripples and obtain the flattest spectral baseline, GRB20 fitted a 12th-order polynomial over a restricted passband of ±40 km s$^{-1}$ around the PH$_3$ transition, interpolating across |v| < 5 km s$^{-1}$. The central region needs to be masked out, otherwise any line will also be removed. This procedure was reproduced here. The disk-integrated spectrum obtained by GRB20 is shown in the left-hand panel of Fig. 1 and our reproduction is shown in the right-hand panel. Since in this study the continuum level of Venus is found at 12.8 Jy beam$^{-1}$ but is reported as 16.1 Jy beam$^{-1}$ in GRB20, the reproduced spectrum is artificially scaled down by a factor of 12.8/16.1. The two spectra appear similar, although the line feature is slightly off-centre in the reproduction. In addition, the reproduced signal is stronger, but the spectrum is also noisier. The S/N is estimated to be ~18 by measuring the peak and standard deviation of the spectrum after applying a boxcar smoothing over seven velocity steps. This is very similar (15σ) to that presented by GRB20.

In general, removal of a 12th-order polynomial over a small spectral range in this way has the effect of removing noise structures and instrumental effects. This can lead to severe overestimations of the significance of spectral features as well as artificial results. To demonstrate this, a search by eye for other features over the observed spectral range of |v| < 60 km s$^{-1}$ was performed and they were subsequently treated with the same procedure. The result is shown in Fig. 2. It leads to at least five other lines with an S/N > 10, three in absorption and two in emission. The S/N is estimated in the same way as for the feature near the phosphine transition. No plausible assignments to the rest frequencies of these features were found. It shows that the procedure followed by GRB20 is incorrect and results in spurious, high S/N lines.

### 4. Independent analysis

To independently assess the possible significance of a PH$_3$ 1–0 line in the ALMA data, the disk-averaged l:c spectrum, as shown in the left-hand panel of Fig. 3, was fitted with a third-order polynomial to remove the low-frequency curvature of the spectral baseline. This polynomial is removed from the spectrum, as shown in the right-hand panel of Fig. 3, resulting in a standard deviation of 3.5 × 10$^{-5}$. The central dip, identified by GRB20 as the PH$_3$ 1–0 line, has an S/N of ~2. Without the polynomial fitting, the S/N is ~1. In astronomy, features at such a low S/N are generally not deemed statistically significant. Furthermore, as is

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1 Imaging was performed as in GRB20, with mask “circle[121 pix, 96 pix, 50 pix]” and the multiscale clean method (niter 1000000; cycleniter 200000).
shown in Fig. 4, the noise distribution in these data is highly non-Gaussian, as expected for data dominated by systematic ripples. In the absence of other noise factors, systematic effects like sinusoidal and sawtooth ripples can result in extremities at 1.5–2 times the standard deviation in the data. This implies that any features at such levels have no statistical meaning because they cannot be reliably linked to a false positive probability.

As described in Sect. 2, the ALMA data were also calibrated, processed, and reduced using different selections on baseline length. The final disk-integrated 1σ spectra are shown in Fig. 5 for, from top to bottom, all data and for baselines >20 m, >33 m (as used for the main analysis), and >50 m. These baseline limits correspond to the first, second, and third minima in the visibility amplitudes. Only the spectrum based on the >33 m limit exhibits a central dip at an S/N of ~2, implying that this chosen limit has maximised any potential PH$_3$ signal.

5. Conclusions
We find that the 267 GHz ALMA observations presented by GRB20 provide no statistical evidence for phosphine in the atmosphere of Venus. The reported 15σ detection of PH$_3$ 1–0 is caused by a high-order polynomial fit that suppresses the noise features in the surrounding spectrum. The same procedure creates a handful of other >10σ lines without plausible spectroscopic assignments, both in emission and absorption, in the direct vicinity of the phosphine 1–0 transition. Low-order spectral baseline fitting shows a feature near the expected wavelength at a signal-to-noise of only ~2. While this already in itself is not enough to claim a statistical detection, the noise on the ALMA spectrum is highly non-Gaussian, making any link to a false positive probability unreliable.

GRB20 provide several arguments to support the validity of their identification of the PH$_3$ feature, including comparison to the JCMT data and a test at offset frequencies. Our analysis, however, shows that at least a handful of spurious features can be obtained using their method, and we therefore conclude that the presented analysis does not provide a solid basis to infer the presence of PH$_3$ in the atmosphere of Venus.

Acknowledgements. We thank the authors of GRB20 for publicly sharing their calibration and imaging scripts. Venus was observed under ALMA Director’s Discretionary Time program 2018.A.0023.S. ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada), MOST and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ. Data processing was performed at Allegro, the European ALMA Regional Center in the Netherlands. Allegro is funded by NWO, the Netherlands Organisation for Scientific Research.

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