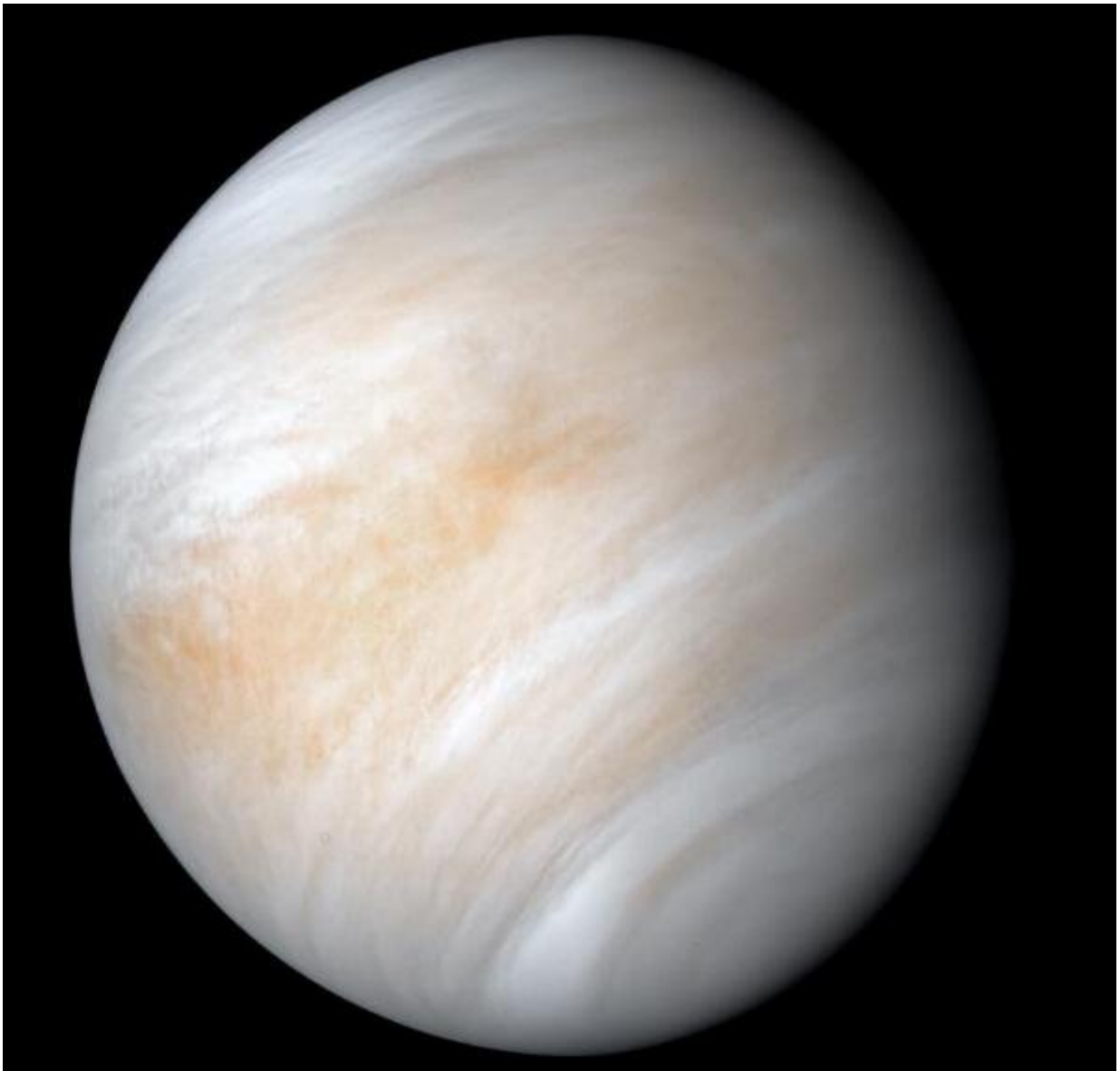


# New analysis shows how sulfur clouds can form in Venus' atmosphere

August 9 2022

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A reprocessed image of archived Mariner 10 data collected in 1974. This is a

false color image created using orange and ultraviolet filters for the red and blue channels, respectively. The clouds are at about 60 kilometers altitude, and the image illustrates the presence of an unknown ultraviolet absorber in the atmosphere, a long unsolved mystery of Venus. Credit: NASA/JPL-Caltech

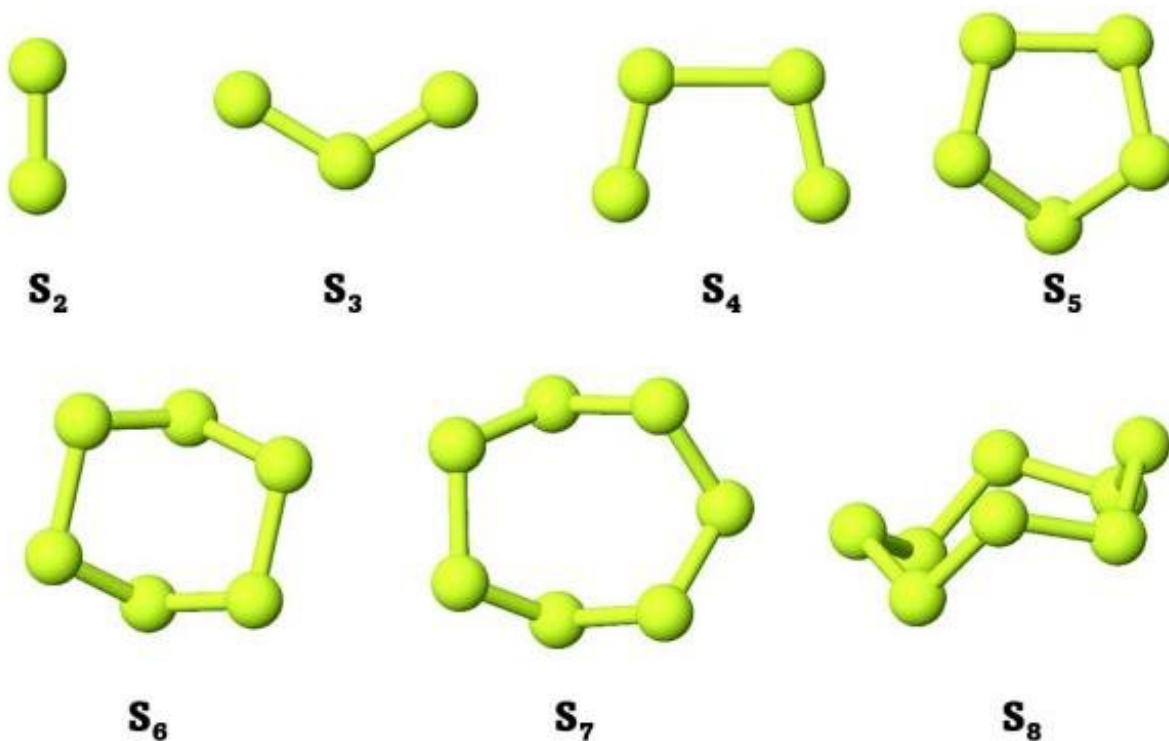
Scientists using sophisticated computational chemistry techniques have identified a new pathway for how sulfur particles can form in the atmosphere of Venus. These results may help to understand the long sought-after identity of the mysterious ultraviolet absorber on Venus.

"We know that the [atmosphere](#) of Venus has abundant  $\text{SO}_2$  and sulfuric acid particles. We expect that ultraviolet destruction of  $\text{SO}_2$  produces [sulfur](#) particles. They are built up from atomic S (sulfur) to  $\text{S}_2$ , then  $\text{S}_4$  and finally  $\text{S}_8$ . But how is this process initiated, that is, how does  $\text{S}_2$  form?" said Planetary Science Institute Senior Scientist James Lyons, an author on the *Nature Communications* paper "Photochemical and thermochemical pathways to  $\text{S}_2$  and polysulfur formation in the atmosphere of Venus."

One possibility is to form  $\text{S}_2$  from two [sulfur atoms](#), that is, reaction of S and S. Molecules of  $\text{S}_2$  and  $\text{S}_2$  can then combine to form  $\text{S}_4$ , and so on. Sulfur particles can form either by condensation of  $\text{S}_8$  or by condensation of  $\text{S}_2$ ,  $\text{S}_4$  and other allotropes—different physical forms in which an element can exist—which then rearrange to form condensed  $\text{S}_8$ .

"Sulfur particles, and the yellow sulfur we more commonly encounter, are made up of mostly  $\text{S}_8$ , which has a ring structure. The [ring structure](#) makes  $\text{S}_8$  more stable against destruction by UV light than the other allotropes. To form  $\text{S}_8$ , we can either start with two S atoms and make  $\text{S}_2$ , or we can produce  $\text{S}_2$  by another pathway, which is what we've done

in the paper," said Lyons.



Sulfur molecules come in many forms called allotropes, from  $S_2$  up to  $S_8$ . The subscript indicates the number of S atoms in the allotrope. We are proposing here a new pathway to  $S_2$  formation. With  $S_2$  available in the atmosphere,  $S_4$  and  $S_8$  are produced.  $S_8$  is the common form of yellow sulfur that can be seen near volcanic vents or that comes in a bottle. The sulfur allotropes  $S_3$  and  $S_4$  have been proposed to be the mysterious UV absorber in the Venus atmosphere. Although there is no consensus yet on the identity of the absorber, it's very likely that sulfur chemistry is involved. Credit: Figure adapted from Jackson et al., Chem. Sci., 2016, published by the Royal Society of Chemistry.

"We found a new pathway for  $S_2$  formation, the reaction of sulfur monoxide (SO) and disulfur monoxide ( $S_2O$ ), which is much faster than

combining two S atoms to make S<sub>2</sub>," Lyons said.

"For the first time, we are using computational chemistry techniques to determine which reactions are most important, rather than waiting for laboratory measurements to be done or using highly inaccurate estimates of the rate of unstudied reactions. This is a new and very much needed approach for studying the atmosphere of Venus," Lyons said. "People are reluctant to go in the lab to measure rate constants for molecules made up of S, chlorine (Cl), and oxygen (O)—these are difficult and sometimes dangerous compounds to work with. Computational methods are the best—and really only—alternative.

Computational methods were used to compute the rate constants and to determine the expected reaction products. These are state-of-the-art computational models (what we call ab initio models). These ab initio calculations were done by the authors from Spain and from the University of Pennsylvania.

"This research illustrates another [pathway](#) to S<sub>2</sub> and sulfur particle formation. Sulfur chemistry is dominant in Venus' atmosphere, and very likely plays a key role in the formation of the enigmatic UV absorber. More generally, this work opens the doors to using molecular ab initio techniques to disentangle the complex chemistry of Venus," Lyons said.

**More information:** Antonio Francés-Monerris et al, Photochemical and thermochemical pathways to S<sub>2</sub> and polysulfur formation in the atmosphere of Venus, *Nature Communications* (2022). [DOI: 10.1038/s41467-022-32170-x](https://doi.org/10.1038/s41467-022-32170-x)

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