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(NASA-CR-174060) LABORATORY EVALUATION OF MICROWAVE ABSORPTION PROPERTIES UNDER SIMULATED CONDITIONS FOR PLANETARY ATMOSPHERES Annual Status Report, 1 Feb. 1984 - 31 Jan. 1985 (Georgia Inst. of Tech.) G3/91 N85-11960 Unclas 24426

REPORT

TO THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ANNUAL STATUS REPORT

for

GRANT NAGW-533

LABORATORY EVALUATION OF MICROWAVE ABSORPTION PROPERTIES UNDER SIMULATED CONDITIONS FOR PLANETARY ATMOSPHERES

Paul G. Steffes, Principal Investigator

February 1, 1984 through January 31, 1985

Submitted by

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I. INTRODUCTION AND SUMMARY

Radio absorptivity data for planetary atmospheres obtained from spacecraft radio occultation experiments and earth-based radio astronomical observations can be used to infer abundances of microwave absorbing atmospheric constituents in those atmospheres, as long as reliable information regarding the microwave absorbing properties of potential constituents is available. The use of theoretically-derived microwave absorption properties for such atmospheric constituents, or laboratory measurements of such properties under environmental conditions which are significantly different than those of the planetary atmosphere being studied, often lead to significant misinterpretation of available opacity data. Steffes and Eshleman (1981) showed that under environmental conditions corresponding to the middle atmosphere of Venus, the microwave absorption due to atmospheric SO_2 was 50 percent greater than that calculated from Van Vleck-Weiskopff theory. Similarly, the opacity from gaseous H_2SO_4 was found to be a factor of 7 greater than theoretically predicted for conditions of the Venus middle atmosphere (Steffes and Eshleman, 1982). The recognition of the need to make such measurements over a range of temperatures and pressures which correspond to the periapsis altitudes of radio occultation experiments, and over a range of frequencies which correspond to both radio occultation experiments and radio astronomical observations, has led to the development of a facility at Georgia Tech which is capable of making such measurements.

In the initial year of Grant NAGW-533, this facility has been developed, and then operated, in order to evaluate the microwave absorbing properties of gaseous sulfuric acid (H_2SO_4) under Venus atmospheric conditions. The results have then been applied to measurements from Mariner 5, Mariner 10, and Pioneer-Venus Radio Occultation experiments, to determine abundancies of gaseous sulfuric acid in the Venus atmosphere, with accuracies exceeding those achieved with in-situ instruments. (Steffes et al, 1984). Measurements of the microwave properties of the vapors accompanying liquid H_2SO_4 have also resulted in more accurate estimates of the vapor pressure behavior of sulfuric acid, which are critical for modeling the behavior and structure of the Venus atmosphere (Ibid).

The initial results of this work were presented at the 16th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society (Steffes et al, 1984). Response from colleagues has been extremely positive, with suggestions for joint research and/or publications coming from Jet Propulsion Laboratory, Stanford University, and the University of Massachusetts. Currently, four journal publications are being prepared to document this work.

Plans for future work include, first, completing the shorter wavelength (approximately 1 cm) absorptivity measurements for H_2SO_4 and application of these measurements to radio astronomical measurements of Venus, including measurements made with the NRAO Very Large Array (VLA). The measurement facility would then be reconfigured, so as to allow measurement of the microwave absorption of ammonia (NH_3), methane (CH_4), and other potential microwave absorbers under simulated conditions for the outer plantes (Jupiter, Saturn, Uranus, and Neptune). These results would then be applied to Voyager radio occultation data, as well as a wide range of radio astronomical data for these planets, in order to establish accurate atmospheric abundance profiles for these gases on the outer planets.

II. THE GEORGIA TECH RADIO ASTRONOMY AND PROPAGATION (R.A.P.) FACILITY

As part of the Electromagnetics Group of the School of Electrical Engineering, the Radio Astronomy and Propagation (R.A.P.) Laboratory has been developed to facilitate research related to radio propagation in telecommunications and remote sensing of planetary atmospheres. The overall configuration for our planetary atmosphere simulator is similar to those used previously by Steffes and Eshleman (1981 and 1982). As shown in Figure 1, a resonator is used to detect losses at microwave frequencies from an introduced gas mixture. The major differences between the Georgia Tech atmospheric simulator and those used previously are as follows:

(1) The pressure containment vessel is large enough (0.33 m diameter, 0.38 m height) so that it will allow the use of resonators which operate at frequencies as low as 1.5 GHz (20 cm wavelength), and yet still be heated to temperatures over 500 K while maintaining pressures up to 10 atmospheres.

(2) The resonator used to measure absorption in the 1.5 to 8 GHz range (20 to 3.7 cm wavelengths) exhibits a higher "quality factor," or Q, due to special construction techniques. These techniques include the use of stainless steel to construct the resonator, and then plating with nickel, copper, and silver. This not only maximizes "Q," but insures that the Q will remain high in spite of drastic thermal shifts. As a result, the system sensitivity is greater, resulting in lower measurement uncertainties.

(3) The use of a digitally-refreshed spectrum analyzer further serves to increase the sensitivity of the system. As a consequence, when measurements are to be made of the microwave absorption from gases

which are obtained from liquid-derived vapors, a smaller amount of source liquid can be used, allowing operation at lower temperatures without condensation.

(4) Uncertainties of mixing ratios of gases obtained from liquid-derived vapors have been greatly reduced for two reasons. First, the amounts of liquid used to generate these gases can be determined with a volume accuracy of ± 0.005 ml. Thus when an amount of liquid becomes vapor, it becomes possible to compute the partial pressure due to that vapor from the ideal gas equation and the measured change in liquid volume. The second method for accurately measuring amounts of liquid-derived vapors is by measuring the refractivity of those vapors. Since the index of refraction is proportional to the vapor abundance, our ability to accurately measure the refractivity of such vapors can also be used to determine the resulting vapor abundance/pressure. This has been especially useful for gases such as H_2SO_4, where little accurate vapor pressure data has been available.

(5) Signal source and spectrum analzyer frequency ranges have been extended to allow measurement up to 40 GHz. A resonator operating in the 8 to 26 GHz range is also being constructed.

(6) A refridgerant capability can be added which will allow operation as low as -140 C (133 K), so as to allow measurements under simulated conditions for the outer planets.

The initial development of the microwave/millimeter-wave atmospheric absorption simulator has now reached completion. Much of the capital support required to construct this facility has been provided by the Georgia Tech Research Corporation (GTRC), with additional equipment available from existing laboratories within the Georgia Tech School of Electrical Engineering. This facility has now provided absorption measurements which are being used to accurately calibrate the radioscientific data from Mariner 5, Mariner 10, Pioneer-Venus, and, in the future, the Venus Radar Mapper spacecraft. In addition, absorption measurements in the 1.1 to 10 cm wavelength range are providing a basis for interpretation of a wide range of Venus radio astronomica observations.

In the second year of this program, we hope to be able to complete measurements of the vapor pressure behavior of gaseous H_2SO_4, as well as its microwave absorption behavior in the 26 to 40 GHz (7.5 mm to 1.1 cm) frequency range, under simulated Venus conditions. This will require the integration of a 26 to 40 GHz Fabry-Perot type resonator into our system. Subsequently we will begin system reconfiguration for simulation of the atmospheres of the outer planets. This will require moving the simulator from a heated environment (simulating Venus) to a refrigerated environment (simulating outer planets). It will also require changes in the simulator components so as to be compatible to the extremely flammable constituents (predominantly hydrogen) of the outer planets. Measurements in the 1.5 to 40 GHz range will then be made.

III. LABORATORY MEASUREMENTS

A wide range of laboratory measurements of the microwave absorbing properties of gaseous H_2SO_4 in a predominantly CO_2 atmosphere have been made under temperature and pressure conditions (temperatures to 575 K and pressures to 6 atm.) simulating the middle atmosphere (30-50 km altitude) of Venus. The initial measurements were made at frequencies of 2.24 and 8.44 GHz (13.4 cm and 3.6 cm wavelengths) in order to allow direct application to absorptivity data from Pioneer-Venus, Mariner 5, and Mariner 10 radio occulatation experiments.

Since absorptivity at radio frequencies is generally directly proportional to the abundance (either by number or by volume) of the absorbing constituent, the results of our measurements, shown in Figures 2 and 3, are plotted as absorptivities normalized by H_2SO_4 mixing ratio. Figure 2 shows the normalized absorptivity of gaseous H_2SO_4 in a CO_2 atmosphere (taken around 570 K temperature and at 2.24 GHz frequency) as a function of pressure. Similarly, Figure 3 shows similar measurements taken around 525 K and at a frequency of 8.42 GHz. The H_2SO_4 mixing ratios used to normalize the plots were obtained using vapor pressure data from Figure 4, which were obtained by the measurement techniques described in Section II. Several significant discoveries have been made as a result of these measurements:

(1) While generally confirming the initial laboratory measurements made by Steffes and Eshleman (1982) of H_2SO_4 vapor absorption at a single temperature and pressure, it has been found that the microwave absorption of H_2SO_4 in a CO_2 atmosphere has a significant pressure dependence at both the 13 cm and 3.6 cm wavelengths. This is in sharp contrast to the theoretical calculation presented in Cimino (1982) (actually performed by Janssen and Poynter).

(2) A new relation for H_2SO_4 vapor pressure has been developed which generally confirms the work of Roedel (1979) and Ayers *et al* (1980). ($\ln p(atm) = 9.42 - 7330/T$.) However, our findings are different enough that they significantly affect the condensation temperatures and altitudes predicted for Venus. This will be of great help to investigators trying to model convection and cloud condensation in the Venus atmosphere, especially given the current uncertainties in

the vapor pressure behavior of H_2SO_4. (For further discussion, see Esposito et al, 1983.)

(3) Frequency dependences which vary significantly with pressure have been found for the absorption from gaseous H_2SO_4, ranging from $f^{1.23}$ at 1 atm pressure to $f^{1.7}$ at 6 atm pressure. This will significantly effect comparisons of radio occultation data with radio astronomical data from Venus.

(4) Simple multiplicative expressions for the absorption from gaseous H_2SO_4 in a CO_2 atmosphere at 13 cm and 3.6 cm wavelengths have been developed. ($\alpha_{13} = 6.1 \times 10^9 (P)^{1/2} T^{-3}$ and $\alpha_{3.6} = 3.13 \times 10^{10} (P)^{0.85} T^{-3}$ where α is in dB km^{-1}, P is atmospheres and T is in Kelvins.) These will be highly useful in converting microwave absorptivity profiles to H_2SO_4 abundance profiles.

In addition to the measurements at 13 cm and 3.6 cm wavelengths, measurements in the 1.1 to 3.6 cm wavelength range are currently being conducted and should yield similar valuable data for interpretation of a wide range of radio astronomical data.

IV. APPLICATION OF LABORATORY RESULTS

We are now beginning a wide range of analytical studies based on the laboratory data. These studies cover an area which is so wide that complete documentation would be difficult at this point in time. Examples of application of the data can be seen in Figures 5 and 6. Figure 5 shows the 13 cm wavelength microwave absorption which would arise from a 20 ppm abundance of gaseous H_2SO_4 in the Venus atmosphere which condenses to form clouds at 48 km altitude. It can be seen from this figure that gaseous H_2SO_4 is the predominant microwave absorber in the 35 to 48 km altitude range as compared to other absorbing constituents. It can also be seen that abundances on the order of 20 to 30 ppm could account for most of the absorption measured in a number of radio occultation measurements.

Figure 6 shows abundances of gaseous sulfuric acid, at several altitudes, obtained by attributing all of the 13 cm opacity measured in the 3 radio occultation experiments shown, to gaseous sulfuric acid. Also shown are curves showing saturation vapor abundance as a function of altitude. Note that the vapor will not condense at a given altitude unless its abundance equals or exceeds the saturation abundance. The saturation vapor abundance from Gmitro and Vermeulen (1964) would imply that no significant cloud formation could occur except at altitudes well above 50 km. This, of course, conflicts with in-situ atmospheric probe findings. (See, for example, Knollenberg and Hunten, 1980.) The saturation vapor abundance from Ayers et al. (1980) would require cloud formation below the 45 km altitude, which likewise conflicts with in-situ findings. The saturation abundances inferred from our measurements are consistent with cloud formation in the 46 to 48 km range, for the given abundances of gaseous H_2SO_4, except for a single peak measurement from the Mariner 10 experiment. However, it should be noted that the average Mariner 10 absorptivity measurements were well below that figure (Lipa and Tyler, 1979).

Thus, abundances of gaseous sulfuric acid below the main Venus cloud layer on the order of 20-35 ppm are indicated from radio occultation 13 cm absorptivity measurements. However, positional and temporal variations in the measured opacity at 13 cm (from radio occultation experiments) and at 3.6 cm (from radio astronomical and radio occultation experiments) indicate as much as factor of 2 variations in the gaseous H_2SO_4 abundance in the 30-50 km altitude range. The variations are suggestive of significant atmospheric changes, such as would be induced by volcanic activity. Further study into this issue is being conducted.

V. PUBLICATIONS AND INTERACTION WITH OTHER INVESTIGATORS

Three presentations of the initial results of this work have been made. The major presentation was given at the 16th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society (Steffes et al., 1984--Abstract attached, see Appendix 1). Presentations have also been made to the Georgia Tech Community and to the Atlanta IEEE. Response from colleagues has been extremely positive, with suggestions for joint research and/or publications coming from the Jet Propulsion Laboratory, Stanford University, and the University of Massachusetts.

Four publications are currently being prepared:

(1) A paper presenting our laboratory results for the microwave absorption and vapor pressure behavior of gaseous sulfuric acid under simulated conditions for the Venus atmosphere.

(2) An accompanying paper which applies our laboratory results to a wide range of microwave absorption data and to atmospheric structure data from Venus, and results in abundance profiles for H_2SO_4 in the Venus atmosphere.

(3) A paper written jointly with Drs. Michael J. Klein and Michael A. Janssen of JPL, discussing variations of the microwave emission from Venus at 3.6 cm over the past 20 years, and the implications, in light of our laboratory results, for volcanism related atmospheric changes.

(4) A paper which will discuss the vapor pressure behavior of H_2SO_4.

In addition to the analysis/research being conducted jointly with

Drs. Klein and Janssen, joint measurements with the Stanford University Center for Radar Astronomy (V. R. Eshleman, Director) of the microwave properties of gaseous sulfuric acid have been made, using the Georgia Tech facility. Also, in the general are of planetary atmospheres, we have had interaction with a number of workers both within the Georgia Tech Schools of Physics, Geophysical Sciences, and Chemistry, and with workers at other institutions. Topics of these discussions have ranged from simulator hardware construction to the abundance and structure of sulfuric acid dimers and hydrates.

VI. CONCLUSION

The work conducted during the first year of NASA Grant NAGW-533 has resulted in laboratory measurements, which when applied to data from the Venus atmosphere, give new insight into the abundance and structure of sulfuric acid vapor in the Venus atmosphere. Because of instrumental limitations of in-situ probes, this has become the major technique for determining the H_2SO_4 abundance profiles. Application of the laboratory results to a wider range of radio astronomical data may even provide evidence for active volcanism on Venus.

Future work under this grant will include absorptivity measurements under simulated Venus conditions for a wider range of wavelengths. This will allow for analysis and interpretation of an even wider range of radio astronomical data. Upon completion of these measurements, the system will be reconfigured so as to allow for the beginning of microwave absorptivity measurements of several gaseous constituents under simulated conditions for the outer planets. Such measurements will be used to interpret data from Voyager radio occultation experiments, radio astronomical observations of the outer planets, and, in the future, radio absorption measurements from the Galileo spacecraft and probe.

VII. REFERENCES

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Cimino, J. B. (1982). The composition and vertical structure of the lower cloud deck on Venus. Icarus 51, 334-357.

Esposito, L. W., Knollenberg, R. G., Marov, M. Y., Toon, O. B., and Turco, R. P. (1983). The clouds and hazes of Venus, in Venus by Hunten, et al., pp. 484-564.

Fjeldbo, G., Kliore, A. J., and Eshleman, V. R. (1971). The neutral atmosphere of Venus as studied with the Mariner V radio occultation experiments. Astron. J. 76, 123-140.

Roedel, W. (1979). Measurements of sulfuric acid saturation vapor pressure; implications for aerosol formation by heteromoleculor nucleation. J. Aerosol Sci. 10, 375-386.

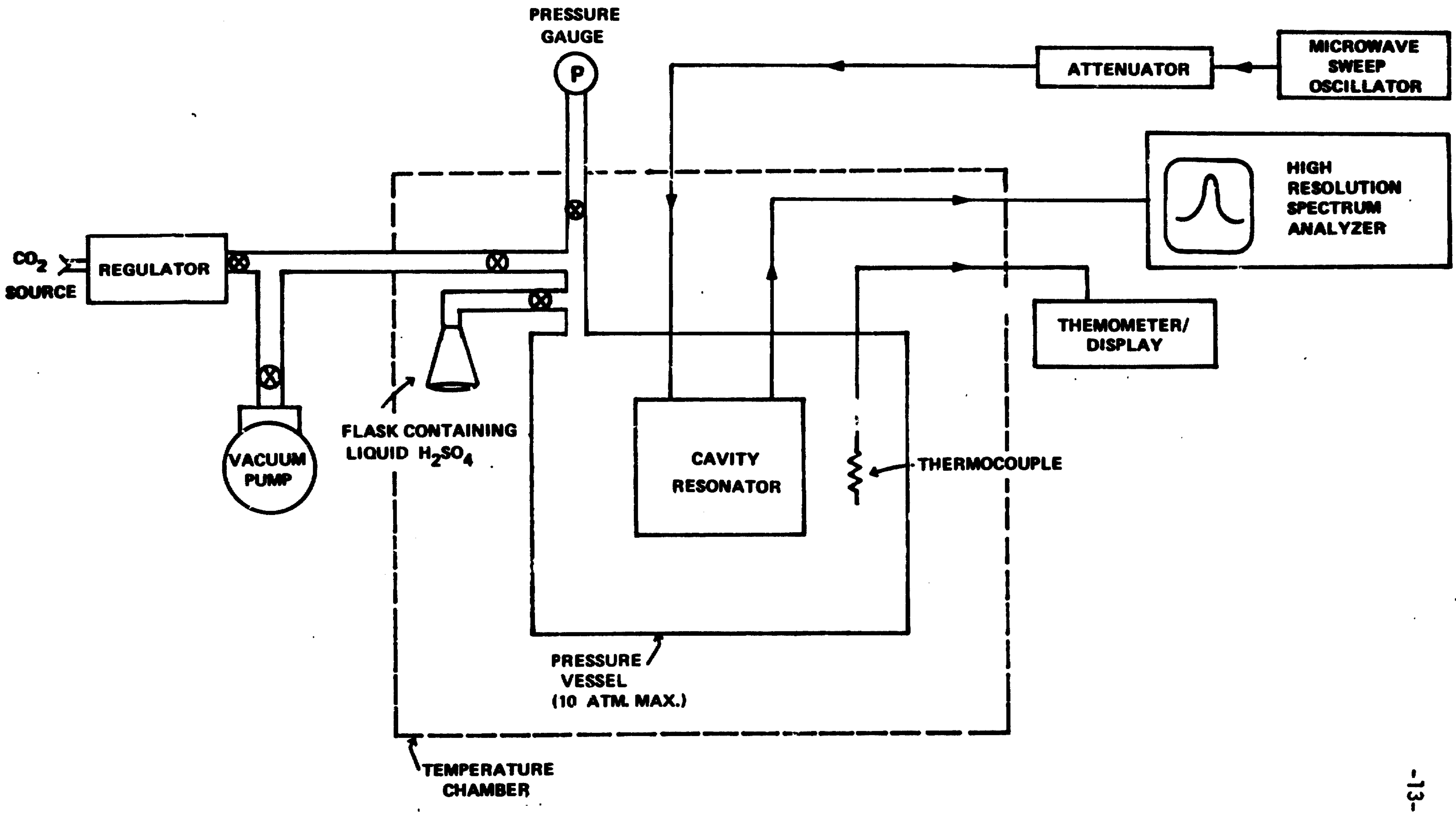
Steffes, P. G. and Eshleman, V. R. (1981). Laboratory measurements of the microwave opacity of sulfur dioxide and other cloud-related gases under simulated conditions for the middle atmosphere of Venus. Icarus 48, 180-187.

Steffes, P. G. and Eshleman, V. R. (1982). Sulfuric acid vapor and other cloud-related gases in the Venus atmosphere: abundances referred from observed radio opacity. Icarus 51, 322-333.

Steffes, P. G., Stellitano, P. S., and Lott, R. C. (1984). Measurements of the microwave opacity and vapor pressure of gaseous sulfuric acid under simulated Venus conditions. Bull. Amer. Astron. Soc. 16, 694. (Attached in Appendix 1.)

VIII. KEY FIGURES

Figure 1: Gerogia Tech Planetary Atmospheres Simulator, as configured for measurements of microwave absorption of gaseous H_2SO_4 under Venus atmospheric conditions.



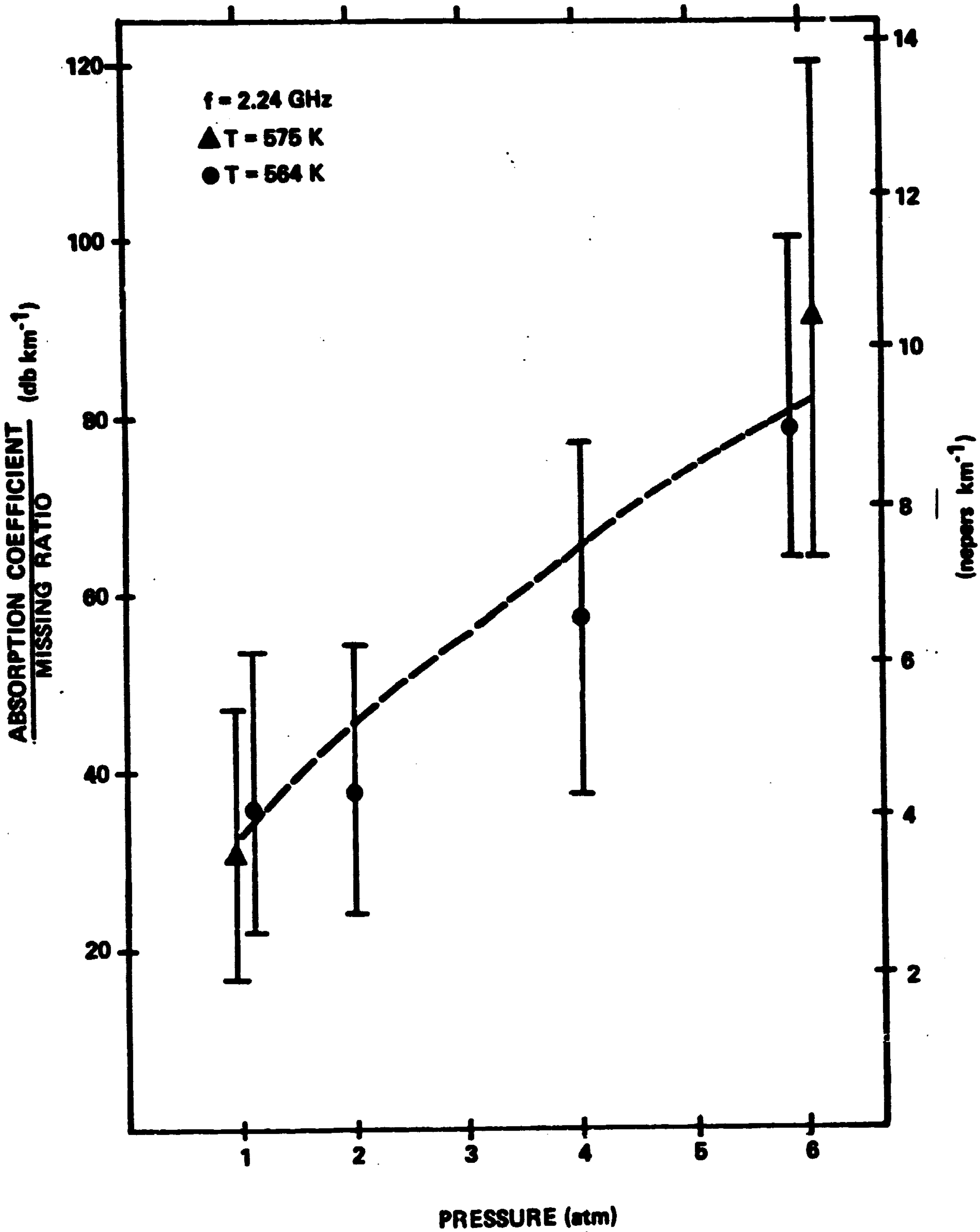


Figure 2: Measured microwave absorption (normalized by number mixing ratio) for gaseous H_2SO_4 in a CO_2 atmosphere at 2.24 GHz. Mixing ratio was obtained from data in figure 4. Dashed line represents a best fit multiplicative expression for absorption.

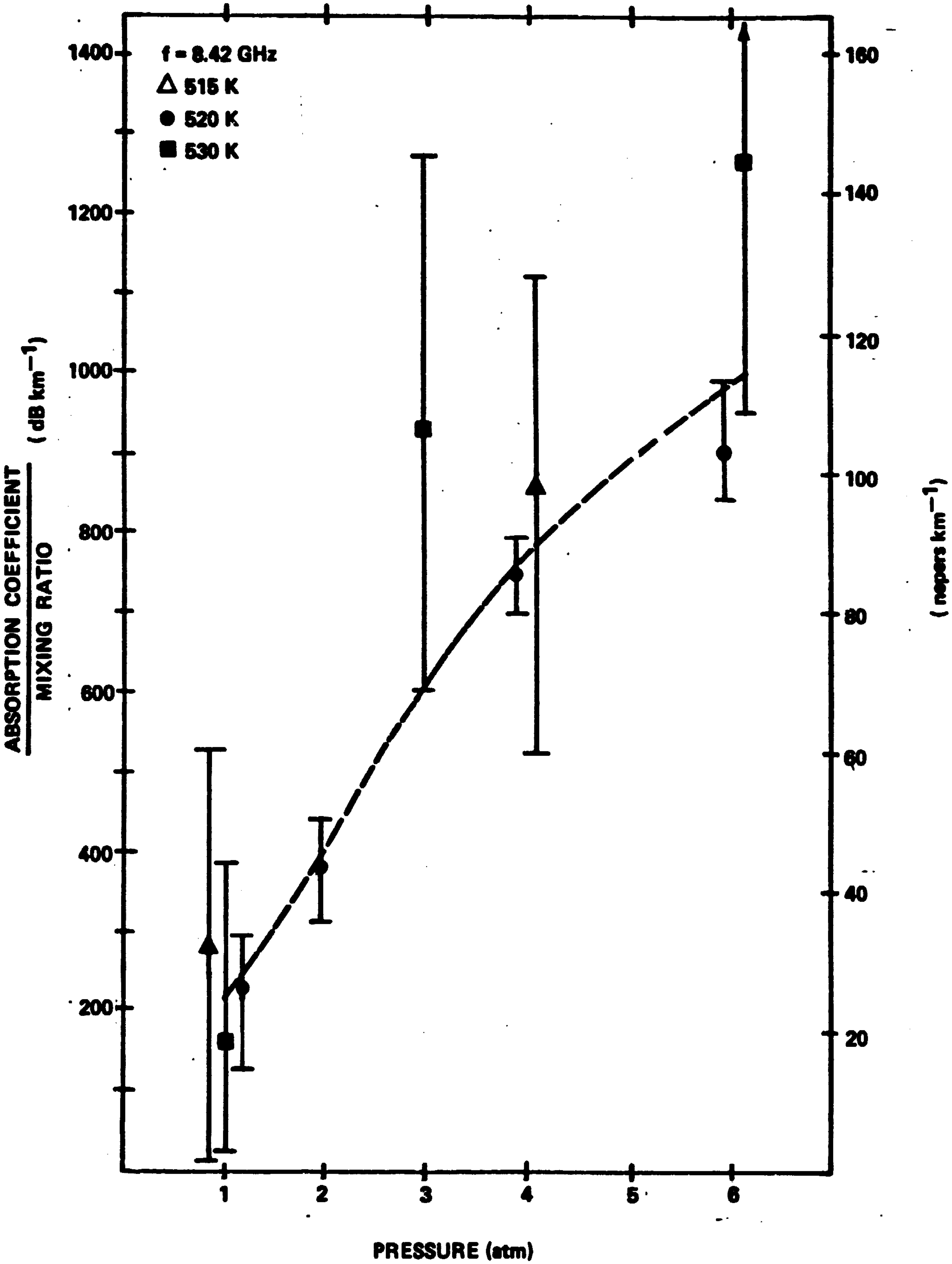


Figure 3: Measured microwave absorption (normalized by number mixing ratio) for gaseous H_2SO_4 in a CO_2 atmosphere at 8.42 GHz. Mixing ratio was obtained from data in figure 4.Dashed line represents best-fit multiplicative expression.

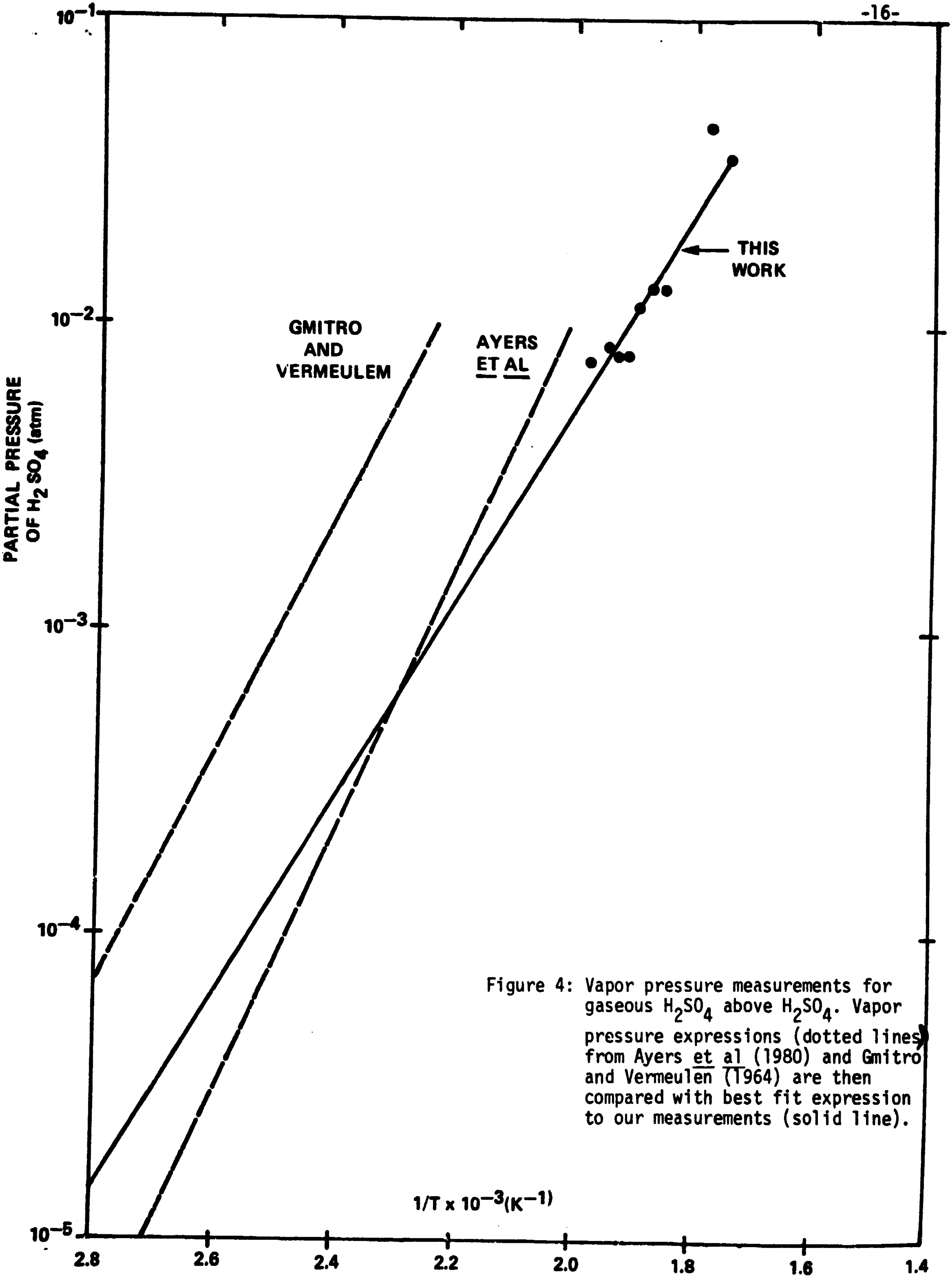


Figure 4: Vapor pressure measurements for gaseous H_2SO_4 above H_2SO_4. Vapor pressure expressions (dotted lines) from Ayers et al (1980) and Gmitro and Vermeulen (1964) are then compared with best fit expression to our measurements (solid line).

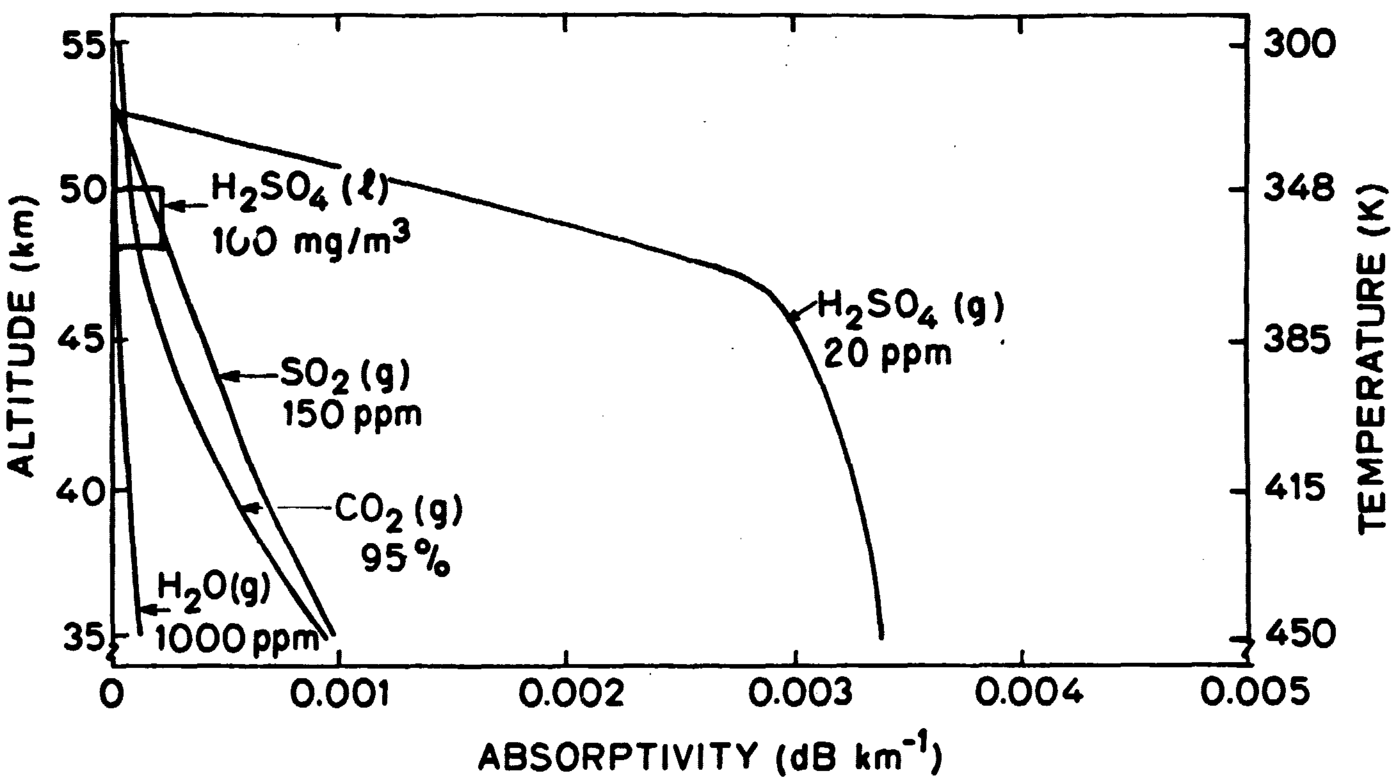


Figure 5: Comparative 13 cm opacity of several constituents in the middle atmosphere of Venus, assuming the pressence of gaseous(g) H_2SO_4 (20ppm), gaseous SO_2(150ppm), gaseous H_2O (1000 ppm), CO_2(95%) and liquid (l) H_2SO_4 (100 mg per cubic meter in the 48 to 50 km altitude range). We assume the cloud-related gases to be depleted above the cloud layer (50 km and above).

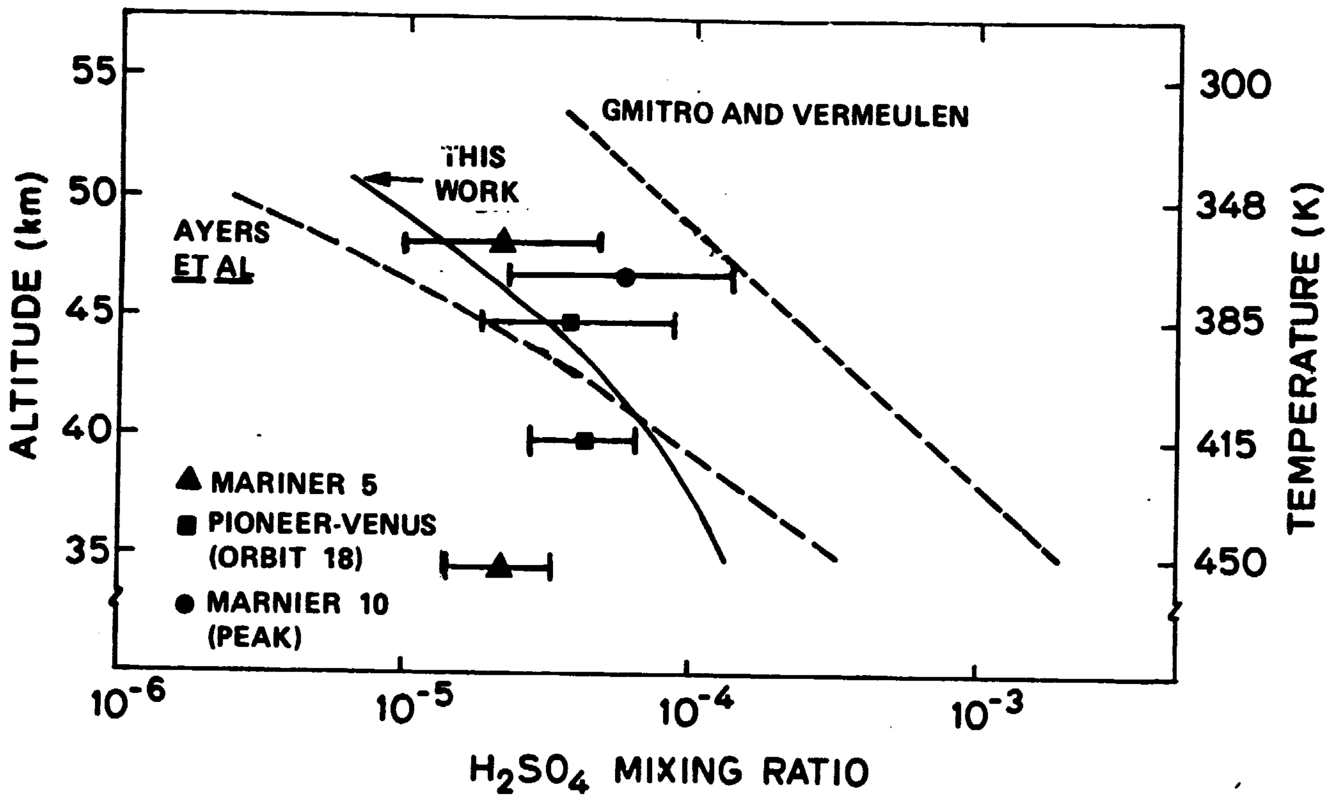


Figure 6: Saturation densities for gaseous sulfuric acid (H_2SO_4) under conditions for the Venus middle atmosphere. Dashed lines represent data from Ayers et al. (1980) and Gmitro and Vermeulen (1964). Solid line represents data from this work. The illustrated points represent the abundances of gaseous H_2SO_4 required to explain the radio occultation results at 13 cm, using the laboratory measurements described.

IX. APPENDICES

AMERICAN ASTRONOMICAL SOCIETY ABSTRACT FORM

APPENDIX 1:

Measurements of the Microwave Opacity and Vapor Pressure of Gaseous Sulfuric Acid Under Simulated Venus Conditions

P. G. Steffes, P. S. Stellitano, R. C. Lott (Georgia Institute of Technology)

Based on initial laboratory studies, it has been suggested by Steffes and Eshleman (1982, Icarus 51, 322-333) that sulfuric acid vapor contributes significantly to the microwave opacity observed in the 30 to 50 km altitude range of the Venus atmosphere. The development of a facility at Georgia Tech capable of making highly accurate measurements of the microwave opacity of gas mixtures in the 1 to 15 cm wavelength range, under pressure and temperature conditions simulating this altitude range of the Venus atmosphere (pressures ranging to 8 atm, temperatures to 550K), has resulted in absorptivity measurements of gaseous H_2SO_4 in a CO_2 atmosphere which are used for interpretation of both radio occultation and radio astronomical microwave absorptivity data. Besides providing abundance profiles for gaseous H_2SO_4 in the middle Venus atmosphere, these measurements have also been used to infer the partial pressure of gaseous H_2SO_4 above liquid H_2SO_4, based on the microwave absorptivity of the vapors. Both results are used in modelling the sulfur compound chemistry of the Venus middle atmosphere.

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Abstract submitted for the DPS Meeting

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APPENDIX 2: Communications with Reprentatives regarding the planetary exploration program.

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

TELEPHONE: (404) 8943128

March 7, 1984

Congressman Wyche Fowler
1210 Longworth House Office Building
Washington, DC 20515

Dear Congressman Fowler:

As a supporter of the Space Sciences and Solar System Exploration, I thought I would take this opportunity to extend our congratulations and heartfelt thanks for your support to these programs, and to alert you to potential problems with the FY 1985 budget for the solar system exploration program within NASA as released by OMB. We were encouraged to see inclusion of start-up funding for the MGCO (Mars Geoscience and Climatology Orbiter) mission, but were deeply concerned by the significant reduction in funding for the Research and Analysis program. A large portion of these funds is provided to university scientists to support research at the highest levels of excellence. It has been pointed out by William L. Quaide, Chief Scientist of NASA's Solar System Exploration Division, that an augmentation of $15 million will be needed to maintain the supporting level included in the FY 84 appropriation. An augmentation for the research and analysis program is included in the president's budget, but only for $6 million, which would fall far short of the 1984 level.

The future of U.S. leadership in this field, which you have characterized as "prestigious and technology-expanding," lies not simply in the development by industry of spacecraft hardware, but in the elements of basic research and analysis, which involve students and faculty at American universities. Your support of such research in the past has been greatly appreciated. We hope to see it continue in the current and future sessions of Congress.

Sincerely,

Paul G. Steffes

Paul G. Steffes
Assistant Professor

PGS/jd

cc: D.T. Paris, Director
School of Electrical Engineering

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WYCHE FOWLER, JR.
5TH DISTRICT, GEORGIA

COMMITTEE ON
WAYS AND MEANS

SELECT COMMITTEE ON
INTELLIGENCE

Congress of the United States
House of Representatives
Washington, D.C. 20515

March 22, 1984

Mr. Paul Steffes
Assistant Professor
Georgia Institute of Technology
School of Electrical Engineering
Atlanta, Georgia 30332

Dear Mr. Steffes:

Thank you for your letter concerning appropriations for the solar system exploration program, specifically funding for the Research and Analysis program.

The House Committee on Science and Technology recently completed consideration for the NASA Authorization Bill. $59.5 million had been allocated in the Fiscal Year 1984 budget for Research and Analysis under planetary exploration. The Reagan Administration had requested $54.5 million for FY'85. However, the Committee decided to recommend $64.5 million. Of the extra $10 million, $2 million is slated to go towards lab equipment, and $8 million for basic planetary research at universities. The bill goes to the Rules Committee next week, and should reach the full House within the next two weeks.

As you know, I strongly support the role of the United States as the world leader in the space sciences. In pursuit of this goal, I contacted the members of the Committee of Science and Technology, urging them to strengthen Congressional commitment to our space science programs. I was pleased by their response in the NASA Authorization mark-up. I have enclosed a copy of this letter for your interest.

I appreciate your interest in this important issue, and hope you will continue to inform me of other matters in which you have an interest.

Sincerely,

Wyche

WYCHE FOWLER, JR.
Member of Congress

Enclosure