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HIGH SPATIAL RESOLUTION MULTI-COLOR OBSERVATIONS OF NEPTUNE DURING OCCULTATIONS BY THE MOON

September 30, 1975 - March 31, 1976

Principal Investigator: Professor Joseph Veverka

Cornell University

Laboratory for Planetary Studies
NASA Grant NSG 7126

Period September 30, 1975 - March 31, 1976

Semi-Annual Report

HIGH SPATIAL RESOLUTION MULTI-COLOR OBSERVATIONS OF NEPTUNE DURING OCCULTATIONS BY THE MOON

Prepared: March 25, 1976

J. Veverka
Principal Investigator

Our preparations to observe the August and September 1975 occultations of Neptune by the Moon, and the observations themselves, were described in two previous progress reports (September 30 and November 28, 1975).

In the November 28, 1975 Progress Report we stated our belief that due to the poor weather conditions which obtained at the time of the events, our data were not of sufficient quality to warrant detailed analysis. A sample occultation "light curve," marred by clouds, was included with the November 28, 1975 report.

In a letter which accompanied the November progress report we asked permission to expend the remaining funds on preparations for the April 8, 1976 occultation of ϵ Gem by Mars, and on the reduction of data obtained during previous occultations.

We are happy to report that we will be observing the Mars occultation using the 36" telescope on NASA's C-141 Airborne Observatory. The importance of this occultation is described in Appendix 3. Since this will be an airborne observation we will <u>not</u> get clouded out this time and expect to obtain unique and excellent results.

It should be noted that our ability to carry out this airborne experiment depends fundamentally on equipment purchased and constructed with funds from this grant (Appendix 1). Similarly, getting ready for this occultation has involved a lot of manpower, and again this grant has provided very essential support in this area. In other words, if it weren't for this grant we would not be flying on April 8, 1976!

We have also used support from this grant to reduce and prepare for publication data obtained during a previous occultation event (Appendix 2).

APPENDIX 1

Development of Occultation Instrumentation Supported by This Grant

Several improvements in our instrumentation and capability to observe occultations resulted directly from the support of this grant and from our preparations to observe the Neptune events. These permanent improvements played a key role in our ability to be able to observe the coming Mars occultation from the C-141.

In essence these improvements amounted to:

a) refurbishing our 3-channel occultation photometer

b) developing a real-time computer driven data acquisition/ data reduction system.

The data system developed is shown in Figure 1. At the core of the system is a CRT graphics terminal hooked up to a NOVA mini-computer. The system allows the rapid evaluation of data in real-time and has proven essential in the numerous laboratory calibrations (linearity, aperture response, stability) that must be performed on our photometer before an occultation. Attached to the CRT display is a hard-copy unit so that it is possible to obtain final graphs in real time.

Two other technical improvements that might be singled out are:

1) <u>Construction of a New-type of Voltage/Frequency Converter</u>

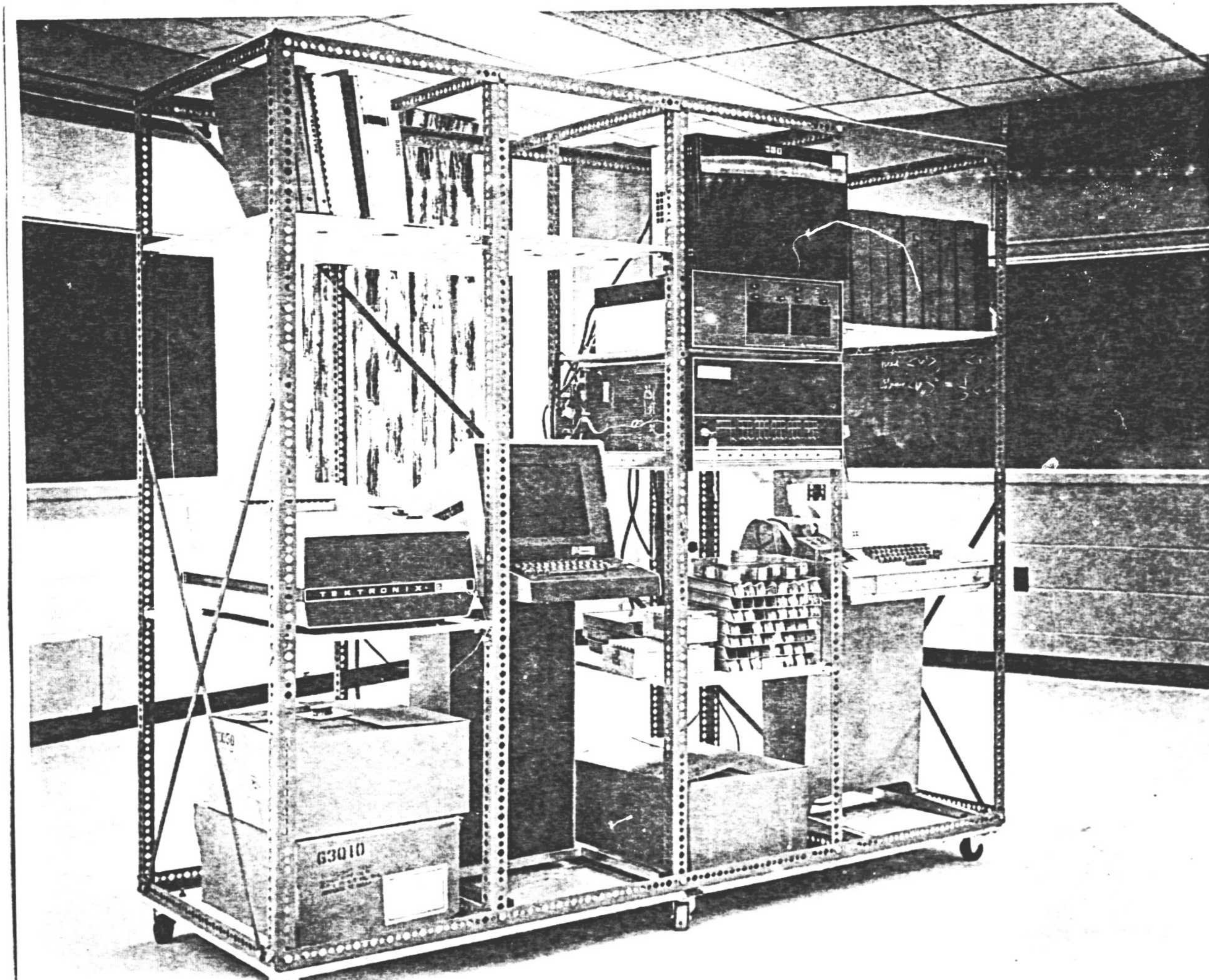
The output circuit of these converters produces pulses that are identical to those produced by our pulse counters. Hence we can easily switch to any of our channels from a pulse counter to a voltage to frequency converter if the signal is too great for reliable use of pulse counting techniques. In occultation work this occurs most frequently because of scattered moonlight in lunar occultations, but a similar situation arises when bright objects are involved in stellar occultations -- such as the occultation of ϵ Gem by Mars.

2) <u>The Acquisition of a Digital Tape-recorder</u>

The acquisition of a digital tape recorder eliminated the necessity of borrowing one for every occultation.

FIGURE 1. Data acquisition/reduction system developed.

Left to right on the racks are: a Tektronix hard copy unit; a Tektronix CRT terminal; a CIPHER digital tape recorder, a DATA GENERAL cassette tape reader/recorder, and a NOVA minicomputer.



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APPENDIX 2

Abstracts of Publications in Preparation Partially or Totally Supported by This Grant

ATMOSPHERIC COMPOSITION FROM REFRACTIVITY MEASUREMENTS MADE DURING OCCULTATIONS

J. Elliot

A critical literature search has been made to find the best refractivity data for gases which are, or could be, present in planetary atmospheres. These include H_2, He, CO_2, CH_4, NH_3, O_2, N_2, Ar and Ne. Refractivity measurements provide a sensitive method of determining the relative abundances in helium/hydrogen atmospheres (outer planets) and carbon dioxide/argon atmospheres (Mars). The method can also be used to measure accurately the amount of nitrogen that may be present in the CH_4/H_2 atmosphere of Titan.

[Presented at the 1976 DPS Meeting, Austin, Texas]

HOW BIG IS IAPETUS?

J. Veverka, J. Burt and J. Elliot

By considering both the photometric lightcurve of Iapetus and data obtained during the March 30, 1974 occultation of the satellite by the Moon, we have derived information about the brightness distribution on the bright face of Iapetus, and obtained an accurate determination of the satellite's radius.

Acceptable models have the bright face of Iapetus consisting of a single albedo material, with little or no limb-darkening. Acceptable limb-darkening parameters (Minnaert k's) range from k = 0.5-0.8; corresponding radii range from 698 ± 58 to 762 ± 65 km. The specific model proposed by Morrison et al. (1974 Icarus 22, 157) yields a radius of 723 ± 60 km, which is smaller than the radiometric radius of 835 (+50, -75) km.

[Presented at the 1976 DPS Meeting, Austin Texas]

THE DIAMETER OF TITAN

J. Veverka, J. Burt and J. Elliot

We have extended our analysis of the lightcurves obtained during the March 30, 1974 occultation of Titan by the Moon to include realistic model atmospheres. Our earlier conclusion (Elliot et al., Icarus 26, 307, 1975) that the diameter of Titan is at least 5800 km is confirmed. Models corresponding to diameters of around 5200 km give unacceptably high residuals. However, at this stage, we cannot exclude models which give diameters in excess of 6000 km. Such large diameters would have interesting cosmogenic implications about the chemical composition of Titan since they lead to mean density of less than 1.3 g/cm^3. Models such as those proposed by Danielson et al. (Icarus, 20, 437, 1973) do lead to diameters in excess of 6000 km.

DESIGN AND OPERATING CHARACTERISTICS OF VOLTAGE TO FREQUENCY CONVERTERS SUITED FOR OCCULTATION WORK

J. Elliot and T. Dunham

Lunar occultation observations are made in the presence of a large amount of scattered moonlight. For the telescope apertures, photometer apertures and filter passbands required, the level of scattered light is sometimes too great for the successful use of pulse counting techniques for detection of the photomultiplier signals (due to the large coincidence corrections that would be necessary), and voltage to frequency conversion methods must be used.

We have designed, constructed and tested a voltage to frequency converter particularly suited for occultation work, in that it has the following features: (i) compact and lightweight, (ii) highly linear, (iii) low temperature drift and (iv) a frequency response to $\sim$ 10 kHz.

APPENDIX 3

Planned Observations of the April 8, 1976 Occultation of ε Gem from NASA C-141 Airborne Observatory

SUMMARY

Multichannel visible and near-ultraviolet C-141 observations are proposed for the occultation of the star ε Gem by Mars on 8 April, 1976 from the vicinity of Washington, D.C. Aircraft observations are required both to assure that data will be obtained at a time of inclement weather conditions, and to substantially improve the accuracy of the results. The temperature profiles and argon composition obtained from the occultation light curves can be directly compared with the measurements of these quantities to be made by Viking, providing a test of the validity of the occultation method for making the measurements and the capability of the C-141 Airborne Observatory for optical occultation observations.

The optical characteristics of our three-channel occultation photometer are summarized in the following table:

CHARACTERISTICS OF THE THREE CHANNEL PHOTOMETER

Channel No.	Center Wavelength (Å)	Passband (Å)	Detector
1	3700	200	Photomultiplier
2	4500	100	Photomultiplier
3	8000	100	Photomultiplier

I. TECHNICAL DESCRIPTION

A. BACKGROUND AND JUSTIFICATION

Observations of stellar occultations by planets and satellites can yield valuable information about the temperature and composition of the atmosphere (if any) of the occulting body. The information about planetary atmospheres that has been learned from stellar occultations has been reviewed by Hunten and Veverka (1976) and Elliot and Veverka (1976). Exactly what can be learned from a given occultation depends on the circumstances of the occultation and its signal-to-noise ratio. Observations of scientifically valuable stellar occultations have been few, primarily because (i) these events are rare, (ii) cloudy weather/poor photometric conditions, and (iii) inadequate telescope facilities within the zone of occultation visibility.

It is likely that within the next five years either Titan, Neptune, Saturn, Uranus or Pluto, objects about which we know relatively little, will be involved in a stellar occultation of potential scientific value. Because most of the earth's atmosphere would be below, airborne observations of high-quality stellar occultations would offer several definite advantages over ground-based techniques. These are:

1. assurance of clear weather;
2. adequate telescope facilities within the zone of occultation visibility;
3. greatly reduced scintillation noise for bright objects;
4. better stability of atmospheric transmission on timescales of minutes;
5. less extinction of ultraviolet light.

Before we can take advantage of the scientific opportunities offered by airborne observations of a future stellar occultation we must know the capabilities of the C-141 for optical occultation observations. Then we can be reasonably certain of what new information will be gained about the occulting body's atmosphere, given the signal-to-noise ratio of the occultation.

Although we ourselves are confident of the great advantages to be gained from airborne occultation observations, the most convincing evidence of all would be to actually observe a good quality stellar occultation and let the results speak for themselves. Fortunately, an ideal occultation will occur soon: on April 9, 1976 UT Mars will occult ϵ Geminorum. As discussed later in this proposal, the signal-to-noise ratio of this event is high enough to test the accuracy of the temperature profiles and atmospheric composition obtained from the occultation observations against the measurements soon to be made by Viking. Observation of this occultation would serve as a backup, in case any of the relevant Viking instrumentation should fail.

Another purpose for observing the ε Gem occultation by Mars is an effort to determine what atmospheric structures are responsible for the "spikes," so prevalent in the light curves of the β Scorpii occultation by Jupiter and the occultation of BD-17°4388 by Neptune. If turbulent structures cause the spikes (Young, 1976), then the light curves obtained from observing stations only a few km apart on Earth should not show the same spikes, since the starlight would have sampled different turbulent elements in the Martian atmosphere. However, if density waves of the type predicted by Zurek (1974) are present, then the light curve spikes caused by these structures should appear similar on occultation curves obtained from observing stations separated by hundreds of km.

It is highly unlikely that any occultation of a bright star by a planet or satellite will occur so close in time to a spacecraft entry into the atmosphere of that planet or satellite during the rest of the twentieth century. The present opportunity is unique.

B. THE OCCULTATION OF ε GEMINORUM BY MARS

1. Circumstances for Observation

Mars (m_V = + 1.2) will occult ε Gem (m_V = + 3.0, Sp G8Ib) at approximately 0100 hours on 9 April 1976 UT (8 April 1976 local date for the eastern U.S.). The occultation occurs after sunset only for sites east of the Mississippi River and is favorable for observation, since the altitude of Mars is about 60° above the horizon.

2. Sampled Portion of the Martian Atmosphere

The region of the Martian atmosphere probed by this occultation will encompass the number density range between 2×10^{13} and 10^{15} cm^{-3}. According to present models (NASA SP-8010, 1974), these number densities correspond to altitudes between ∿50 and ∿90 km above the mean surface of Mars. Since the eddy and molecular diffusion coefficients are expected to be equal at an altitude of ∿120 km (McElroy and McConnell, 1971), the atmosphere at the level of the occultation is well-mixed and the relative amounts of CO_2 and Ar should be representative of the Martian lower atmosphere.

3. Advantages of Airborne Observations

The general advantages expected from airborne observations over ground-based ones for stellar occultations have been discussed previously, but below we list the advantages that would specifically apply to the ε Gem occultation:

(1) ASSURANCE OF CLEAR SKIES!!
The weather in the eastern U.S., the only land area for which this occultation occurs after sunset, is notoriously bad in the Spring.

(2) The atmospheric transmission (on time scales of minutes) should be much steadier to an airborne telescope than to a ground-based site.

(3) Scintillation noise from Mars should be 4-5 times lower (see the signal-to-noise discussion below).

(4) The extinction of ultraviolet light will be much less.

4. Instrumentation and Observations

To observe the occultation we plan to attach our three channel occultation photometer to the bent Cassegrain focus of the telescope. The occultation photometer and data recording system have been described in detail by Elliot et al. (1975). Basically, the photometer is of conventional design, except for a dichroic reflector system that allows light curves from three different photometric passbands to be recorded simultaneously. The photometric passbands to be used are given in the accompanying table and were chosen to give good signal-to-noise ratios and balanced wavelength coverage.

Since Mars will have an angular diameter about 6 arc sec, we plan to use a large focal plane diaphragm that will include the entire planet. Continuous recording of the light curves as a series of 0.01 second integration will commence about $\sim$10 minutes before immersion and continue until $\sim$10 minutes after emersion.

5. Signal to Noise Ratio

a. Light Curve

The quality of the results that can be obtained will depend on how accurately the occultation curve of ϵ Gem can be determined in the presence of shot noise and scintillation noise, primarily from Mars. In the accompanying table we have listed the center wavelengths and passbands for the three photometric channels for which we plan to obtain simultaneous light curves. For each channel we have computed the fraction q of photons initially incident on the Earth's atmosphere that would be ultimately detected by the photomultiplier; this computation included losses in the atmosphere, mirror reflections (3), losses in the photometer optics and the quantum efficiency of the photomultiplier.

TABLE

SHOT NOISE AND SCINTILLATION NOISE
(Expected Levels for Airborne Observations)

Channel No.	Center wavelength, λ_c (Å)	Passband, $\Delta\lambda$ (Å)	Photon detection efficiency q	Flux from ϵ Gem, f_E †	Flux from Mars, f_M †	Shot noise fractional error,* ϵ_p	Scintillation, fractional error,* ϵ_s
1	3700	200	0.032	1.4	16	0.15	0.06
2	4500	100	0.029	19	100	0.04	0.03
3	8000	100	0.0015	200	1200	0.06	0.03

† photons $cm^{-2} sec^{-1} Å^{-1}$ outside the atmosphere.

* for each 0.01 sec integration.

Also in the table we have given the approximate photon fluxes from ε Gem (f_E) and Mars (f_M), which were computed from the UBVRI magnitudes of these objects. We define the fractional error ϵ_p produced by shot noise as the ratio of the rms error in the photon count (from Mars and ε Gem) divided by the photon count from ε Gem. Using the quantities given in the table, we can find ϵ_p for an integration of τ seconds:

$$\epsilon_p = \frac{(f_E + f_M)^{1/2}}{f_E(q\Delta\lambda A\tau)^{1/2}} , \qquad (1)$$

where A is the area of the telescope. For a 36-inch telescope and an integration time τ = 0.01 seconds we have tabulated values for ϵ_p in the table. The values for the shot noise errors are comparable to the truncation error in 0.01 seconds for our β Scorpii occultation data (Liller et al., 1974).

Since ε Gem and Mars are bright, we must also consider the effects of scintillation noise. The fractional error ϵ_s produced by scintillation for an integration of τ seconds is given by Young (1974, p. 101):

$$\epsilon_s = \frac{.05\ D^{-2/3}\ M^{p} e^{-h/h_o}}{(4\tau)^{1/2}} \qquad (2)$$

where D is the telescope aperture in inches, h_o is the scale height of the atmosphere, h is the altitude of the telescope, M is the airmass and p is a constant. For values of these constants appropriate to airborne observations of the ε Gem occultation, the expected scintillation errors are given in the table. Note that they are comparable to, but less than, the shot noise errors.

The scintillation noise expected for ground-based observations would be about 5 times greater because of the exponential factor in eqn. (2). Clearly, airborne observations are substantially less affected by scintillation noise. Although turbulence near the airplane causes poor <u>seeing</u> this should not affect our proposed observations. The turbulence causing <u>scintillation</u> is at a much greater altitude and eqn. (2) should give correct estimates of the noise levels to be expected from scintillation.

b. <u>Argon-CO_2 Mixing Ratio</u>

From the occultation data we can determine a refractivity ratio (ν_1/ν_2) for the Martian atmosphere where ν_1 and ν_2 are the atmospheric refractivities at wavelengths λ_1 and λ_2. To maximize this ratio we shall obtain light curves at two well-separated wavelengths, 3700 Å and 8000 Å, for example. From refractivity measurements for argon (Peck and Fisher, 1964) and carbon dioxide (Old et al., 1971), we have computed the refractivity ratio $\nu(8000\ \text{Å})/\nu(3700\ \text{Å})$

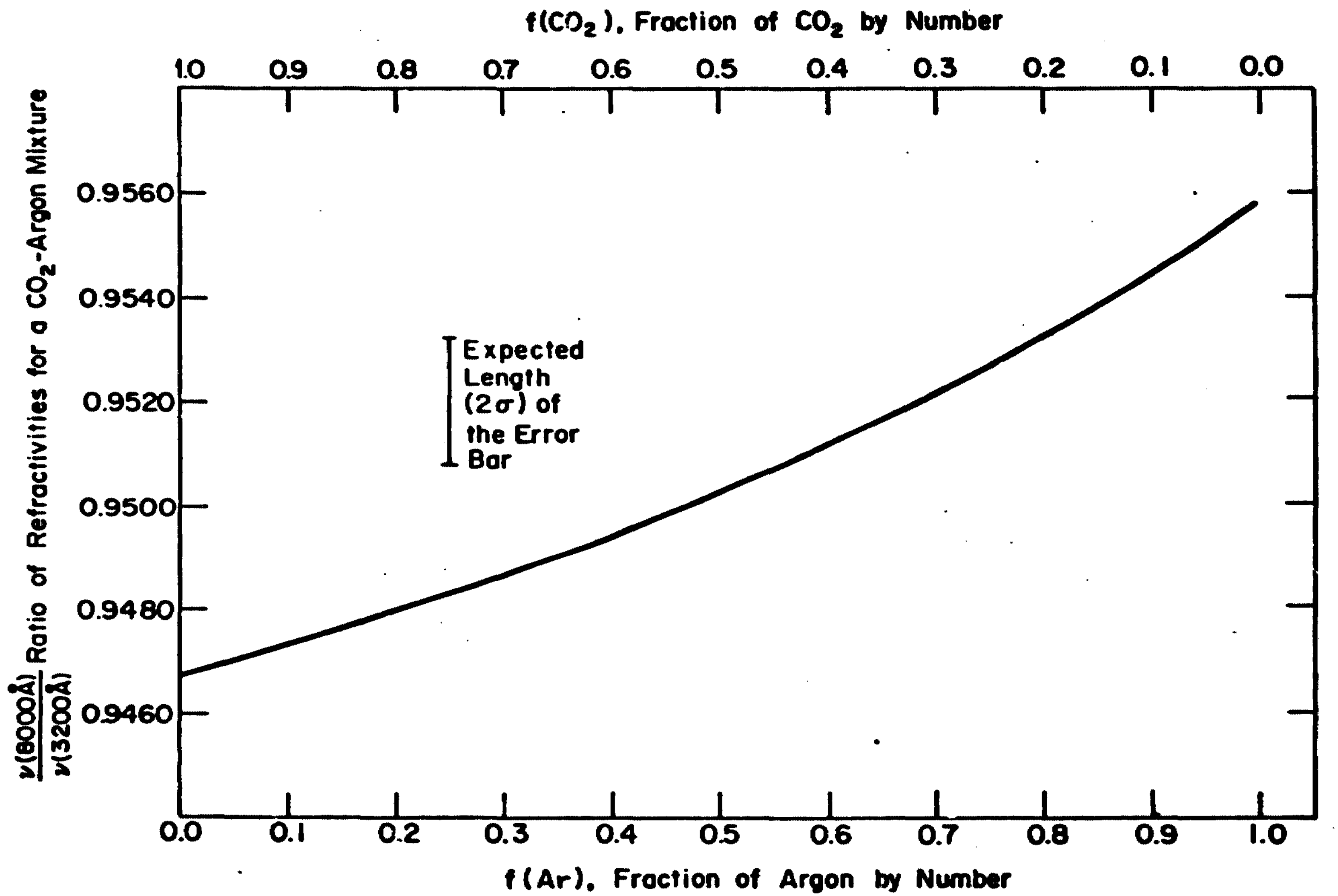

Figure -- The refractivity ratio at 3200 Å and 8000 Å for a mixture of argon and carbon dioxide. From the occultation observations of ε Gem by Mars we can expect to determine the ratio ν(8000 Å)/ν(3200 Å) with an error of ± 0.0013, as shown by the error bar in the figure. This leads to an error of ± 0.15 in number fraction of argon f(Ar). This error estimate was based on data from the β Scorpii occultation as described in the text, and is valid for airborne observations. If observations are made only from the ground, the error will be several times larger due to decreased ultraviolet transmission and increased scintillation noise from Mars.

as a function of the argon fraction f(Ar) of a CO_2-Ar gas mixture. From this function and the signal-to-noise ratios given in the table of the previous section it appears that this occultation should yield a value of f(Ar) accurate to $\pm$ 0.15, based on our experience from the β Scorpii occultation (Elliot et al., 1974).

6. Ground-based Observations

We have been in contact with several of our colleagues and expect that observations of the ε Gem occultation will be attempted from the following sites: Mees Observatory, Rochester, N.Y.; Agassiz Station, Harvard, Mass.; Atlanta, Ga.; and Greenbelt, Md. If quality light curves are obtained from any one of these sites, then they can be compared with the light curves obtained from the C-141 to learn about the lateral density structure of the Martian atmosphere.

C. EXPECTED RESULTS

From successful airborne observations of the occultation of ε Gem by Mars we expect to obtain the following results:

(1) Two temperature profiles of the Martian atmosphere.

(2) Characteristics of temperature variation in the Martian upper atmosphere.

(3) The argon number fraction (f(Ar)) in the Martian atmosphere with an accuracy of ± 0.15.

(4) If any ground-based observations of the occultation are also successful, we can determine some characteristics of the lateral temperature structure of the Martian atmosphere.

All these results can be compared with the temperature profiles and atmospheric composition measurements of the Viking entry probe, providing a critical test of stellar occultations as a method for obtaining atmospheric temperature profiles and composition.