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NASw-1762

MEMORANDUM
RM-6261-NASA
MARCH 1970

VENUS CUSP OBSERVATIONS DURING 1969: SYNOPSIS OF RESULTS

G. F. Schilling, G. E. Kocher, R. C. Moore and M. Turner

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The RAND Corporation
SANTA MONICA • CALIFORNIA

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This research is sponsored by the National Aeronautics and Space Administration under Contract No. NASw-1762. This report does not necessarily represent the views of Rand or of the National Aeronautics and Space Administration.

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PREFACE

This Memorandum summarizes the scientific work performed for the Office of Space Science and Applications of the National Aeronautics and Space Administration under Contract NASw-1762, "Telescopic Observations of Venus Cusp Phenomena". It represents the final report on this contract. The studies centered on a program of astronomical observations of the inferior conjunction and of the greatest western elongation of Venus in 1969, conducted simultaneously at Table Mountain Observatory, California and at New Mexico State University Observatory, New Mexico. The principal results and conclusions are summarized here. The unique, heretofore nonexistent data base, including photometric measurements as well as the reduced photographic data, is presented in a companion Memorandum: Observations of the 1969 Inferior Conjunction and Greatest Western Elongation of Venus: Data Catalog and Preliminary Analysis, RM-6262-NASA. It is believed that these data will be of general interest to planetary astronomers, and to certain investigators of upper atmospheric phenomena.

Progress of the contractual work has been reported quarterly to NASA. A description and theoretical analysis of the roles played by the atmospheres of Earth and Venus in causing the observational phenomena, investigated by the present studies, was published earlier as The Twilight Atmosphere of Venus, RM-5386-PR.

SUMMARY

The motivation for the investigation described in this Memorandum was the lack of available observational data of sufficient information content for a test of the theory developed in the Twilight Atmosphere of Venus (RM-5386-PR). The unorthodox method required to meet the theoretical demands is described, and the resulting observational data base presented, in a companion Memorandum (RM-6262-NASA).

The principal results of the investigation are three-fold. The planetocentric extension of the Venus twilight zone was found to average 5°, implying that the effectively scattering atmosphere extends to an average height of 20 to 25 km above the opaque cloud deck. The discrepancy in the occurrence of dichotomy was verified, although the curtailment of the observing period prevented an exact determination.

The apparent cusp extension angle had been theoretically determined to be a function of sky brightness. This was verified observationally, and was found to be related to exposure time as well. The occurrence of a maximum in this angle depends on a combination of the two parameters. Although further theoretical analysis of this phenomenon is necessary before a complete explanation can be given, a relationship now exists that may yield a terrestrial technique for deriving the brightnesses of portions of a planet's atmosphere as if seen from space.

Values of surface brightness for selected areas of the sky corroborate those of Koomen, et al. some twenty years ago, suggesting little change in the atmospheric aerosol content.

Finally, recommendations are made concerning daylight photography, sky photometry, space-flight projects, and photographic threshold phenomena that could greatly assist astronomers.

ACKNOWLEDGEMENTS

The success of the observational part of the work was in large measure due to the outstanding cooperation of the staff members of the Jet Propulsion Laboratory associated with Table Mountain Observatory, and the director and staff of New Mexico State University Observatory. We thank especially Messrs. C. F. Capen, T. Kirby, L. A. Kocher, R. J. Mackin, R. H. Norton, B. A. Smith, J. W. Young for their help and assistance.

CONTENTS

I. OBJECTIVES

THEORETICAL BASIS

It has been known since about 1790 that, when Venus is near inferior conjunction, the cusps of her crescent extend far beyond a half-circle. It is further known that the visible portion of Venus, at greatest elongation, does not present the expected half-moon shape but, rather, appears concavo-convex. In a recent theoretical study,[(1)] these observational phenomena were explained quantitatively, revealing the causative roles played by the atmospheres of Earth and Venus. This new theory augmented and partially replaced one proposed by Russell[(2)] in 1899 but yielded greatly different numerical results.

Application to the scanty available observational data contradicted the heretofore prevalent opinion[(3)] that the scattering atmosphere of Venus extends only one to three kilometers above the opaque cloud deck.[(4)] But the inadequacies inherent in the available data[(5)] prevented conclusive testing of the theory, although strong indications were obtained that the minimum height of the scattering atmosphere was 15 to 23 km.[(6)]

The theoretical study[(1)] made a number of specific predictions for observational verification. Among others, the theory stated that the measured value of the cusp extension angle of Venus is related to the brightness of the terrestrial sky and would be expected to increase markedly from daylight through twilight and night. In addition, it indicated that this angle may also be a function of telescope properties and that the date of occurrence of apparent dichotomy depends on observing conditions. If quantitative observational data of these predicted effects could be obtained, new information about the physical properties of the atmosphere of Venus could be provided.

CONTRACT OBJECTIVES

The principal objectives of the work performed under this contract were the acquisition of observational data that would test the validity of the theory, the use of such data for gaining additional knowledge about the atmosphere of Venus, and an estimate of the feasibility and value of conducting similar observations from spacecraft.

The original contract proposal included a planned work schedule for a two-year period, determined by the dates of occurrence of specific celestial phenomena from 1967 through 1969. Upon execution of the contract in November 1968 at a CPFF of $29,660, the planned work schedule was adjusted to conform to the available celestial events during the resulting contract period of sixteen months. Reductions in the NASA budget made it impossible to pursue the originally proposed plan of one year of observational work, followed by a one-year period of data analysis and research. Hence, only a portion of the originally planned data reduction and analysis could be performed. It is hoped that further scientific analysis will be supported.

However, the observational information gathered constitutes a unique, heretofore nonexistent data base for scientific studies of the Venus cusp phenomena. Beyond the use made of it in our own preliminary analyses, the data will be of interest to other investigators and are therefore made available in a readily usable form.(7) In addition to the analyses performed to date and reported here, it is planned that selected portions of the results be prepared for publication in the scientific literature.

METHOD OF APPROACH

The program objectives, translated into observational requirements, called for simultaneous observing programs at two astronomical observatories, with measurements of the Venus cusp extensions under varying terrestrial observing conditions of elongation angle and solar zenith distance. The difficulties lay primarily in the nature of the observational data to be obtained: specifically, photographs of Venus at small angular distances from the sun during daytime, at low altitudes near the horizon during twilight, and with the luminance of the terrestrial foreground sky ranging over several orders of magnitude. Note that these circumstances are essentially the opposite conditions to those normally considered desirable for astronomical work. In fact, the physical configurations of many telescopes make it impossible even to attempt such a program.

As will be discussed in subsequent sections, our results not only prove that this type of program can be successfully conducted but also manifest the potential future value of similar programs to planetary astronomy in general.

II. OBSERVING PROGRAMS*

REQUIREMENTS

The scientific program objectives placed severe requirements on the nature of the observational data to be obtained. Preliminary tests conducted in 1967 served as the basis for designing detailed observing schedules and techniques that promised to acquire the desired information.

These tests had established that usable photographic images of Venus could indeed be obtained at very low altitudes in the twilight sky as well as close to the Sun in the bright daylight sky, provided that a number of conditions could be met:

a. Care had to be taken to select telescopes of suitable characteristics (i.e., telescopes of limited aperture and well separated in longitude), and to match them with photographic plates and films of appropriate sensitivity and contrast;

b. Appropriate measures were taken to prevent access of direct and indirect solar illumination to the telescope optics; and

c. Durations of exposure were carefully selected, depending on the relative positions of Venus and Sun and on the brightness of the terrestrial sky near Venus.

COMPUTER PROGRAMS

A major contribution to the success of the observational program was the development of a number of on-line JOSS** computer programs. These permitted the precise preplanning of observational details as a function of the expected celestial configurations and terrestrial sky conditions for each of the two sites. Table 1 is a descriptive listing

---

*Detailed descriptions of the instrumentation used and the methods and techniques developed are given in Ref. 7; in this section, we summarize only the principal aspects of the observing program.

**JOSS is the trademark and service mark of the Rand Corporation for its computer program and for services using that program.

Table 1

DESCRIPTIONS OF JOSS COMPUTER PROGRAMS

Input	Output	Location
	Ephemeris	
Tabulated distances Earth-Venus, Sun-Venus, and Sun-Earth from the American Ephemeris and Nautical Almanac	Elongation and phase angle every day (or every 1/10 of a day)	Program on p. 9 Output examples on pp. 10 and 11
	Look Angles	
Tabulated hourly values of GHA and declination of Venus and the Sun	Altitudes and azimuths of Venus & Sun; and bearing (Sun azimuth minus Venus azimuth): Intervals, 10 minutes or smaller, GMT, LST, or both	Program on pp. 12 and 13 Output examples on pp. 6, 7, and 8
	Plate Analysis	
Image measurements on plate; Ephemeris data	Values of apparent radius, cusp extension angles, angular extent of twilight zones	Program in Ref. 7

GMT	PDT	Venus alt.	Az.	SUN alt.	Az.	Bearing
14: 0	7: 0	47.11'	110.01'	14.32'	71.19'	38.42'
14:10	7:10	49.06'	112.16'	16.30'	72.33'	39.43'
14:20	7:20	51.00'	114.39'	18.28'	73.46'	40.53'
14:30	7:30	52.51'	117.13'	20.27'	74.59'	42.14'
14:40	7:40	54.40'	119.58'	22.27'	76.12'	43.47'
14:50	7:50	56.26'	122.57'	24.28'	77.24'	45.33'
15: 0	8: 0	58.08'	126.11'	26.29'	78.36'	47.34'
15:10	8:10	59.46'	129.42'	28.31'	79.49'	49.53'
15:20	8:20	61.18'	133.32'	30.33'	81.02'	52.30'
15:30	8:30	62.45'	137.44'	32.35'	82.16'	55.28'
15:40	8:40	64.05'	142.18'	34.38'	83.30'	58.48'
15:50	8:50	65.16'	147.16'	36.41'	84.46'	62.31'
16: 0	9: 0	66.18'	152.39'	38.44'	86.02'	66.37'
16:10	9:10	67.10'	158.26'	40.48'	87.21'	71.05'
16:20	9:20	67.49'	164.34'	42.52'	88.42'	75.52'
16:30	9:30	68.15'	170.59'	44.56'	90.06'	80.54'
16:40	9:40	68.28'	177.35'	46.59'	91.32'	86.02'
16:50	9:50	68.26'	184.13'	49.03'	93.02'	91.11'

TMO, 19 June 1969

GMT	MDT	Venus alt.	Az.	SUN alt.	Az.	Bearing
14: 0	8: 0	56.24'	118.28'	22.45'	75.49'	42.39'
14:10	8:10	58.14'	121.27'	24.48'	76.56'	44.31'
14:20	8:20	60.00'	124.42'	26.52'	78.02'	46.40'
14:30	8:30	61.42'	128.18'	28.57'	79.09'	49.08'
14:40	8:40	63.19'	132.15'	31.01'	80.16'	51.59'
14:50	8:50	64.50'	136.38'	33.06'	81.24'	55.14'
15: 0	9: 0	66.13'	141.29'	35.12'	82.32'	58.56'
15:10	9:10	67.27'	146.49'	37.18'	83.41'	63.08'
15:20	9:20	68.31'	152.40'	39.24'	84.51'	67.49'
15:30	9:30	69.23'	159.01'	41.30'	86.03'	72.58'
15:40	9:40	70.02'	165.49'	43.37'	87.16'	78.32'
15:50	9:50	70.25'	172.56'	45.44'	88.31'	84.24'
16: 0	10: 0	70.33'	180.13'	47.50'	89.50'	90.24'
16:10	10:10	70.25'	187.31'	49.57'	91.11'	96.20'
16:20	10:20	70.00'	194.37'	52.04'	92.36'	102.00'
16:30	10:30	69.21'	201.23'	54.10'	94.06'	107.17'
16:40	10:40	68.29'	207.43'	56.17'	95.42'	112.00'
16:50	10:50	67.24'	213.32'	58.23'	97.25'	116.07'

NMSU, 19 June 1969

GMT	PDT	Venus alt.	Az.	SUN alt.	Az.	Bearing
1: 0	18: 0	22.50'	273.42'	14.14'	266.59'	6.43'
1:10	18:10	20.46'	275.03'	12.11'	268.25'	6.38'
1:20	18:20	18.42'	276.24'	10.07'	269.50'	6.34'
1:30	18:30	16.38'	277.44'	8.03'	271.15'	6.29'
1:40	18:40	14.35'	279.04'	5.60'	272.39'	6.25'
1:50	18:50	12.33'	280.24'	3.56'	274.03'	6.20'
2: 0	19: 0	10.31'	281.44'	1.53'	275.28'	6.16'
2:10	19:10	8.29'	283.04'	-.10'	276.52'	6.12'
2:20	19:20	6.28'	284.25'	-2.12'	278.17'	6.08'
2:30	19:30	4.28'	285.47'	-4.14'	279.43'	6.04'
2:40	19:40	2.29'	287.10'	-6.16'	281.10'	5.60'
2:50	19:50	.31'	288.34'	-8.17'	282.38'	5.55'
3: 0	20: 0	-1.26'	289.59'	-10.18'	284.08'	5.51'
3:10	20:10	-3.23'	291.26'	-12.17'	285.39'	5.47'
3:20	20:20	-5.18'	292.55'	-14.16'	287.12'	5.42'
3:30	20:30	-7.12'	294.25'	-16.14'	288.47'	5.37'
3:40	20:40	-9.04'	295.57'	-18.10'	290.25'	5.32'
3:50	20:50	-10.55'	297.32'	-20.06'	292.05'	5.27'

TMO, 4 April 1969

```
1.05 * Ephemeris (every 1/10 of a day and SUMMARY).
1.2 Set e=[S(j)*2+v(j)*2-l(j)*2]/[2•S(j)•v(j)].
1.3 Set E=d(arg[e,sqrt(1-e*2)]).
1.4 Set i=[v(j)*2+l(j)*2-S(j)*2]/[2•v(j)•l(j)].
1.5 Set I=d(arg[i,sqrt(1-i*2)]).
1.8 Set A=d[r(180)-r(I)].
1.89 Line if fp(j/10)=0.
1.9 Type j/10,E,A,I in form 1.

2.1 Set a=a.
2.2 Do part 3 for b=0(1)9.

3.1 Set j=(10•a)+b.
3.2 Set S(j)=b•([S(a+1)-S(a)]/10)+S(a).
3.3 Set l(j)=b•([l(a+1)-l(a)]/10)+l(a).
3.4 Set v(j)=b•([v(a+1)-v(a)]/10)+v(a).
3.5 Do part 1.

5.5 Set l(m+1)=l(m)-[[l(m)-l(m+2)]/2].

9.1 Demand S(j).
9.2 Demand l(j).
9.3 Demand v(j).

10.1 Delete S(n).
10.2 Delete l(n).
10.3 Delete v(n).

Form 1:
Jun __.__: Elongation: ___.___" Alpha: ___.___" i: ___.___"

      D(r,c):  ip(r•c)+.01•ip[60•fp(r•c)]+.006•fp(60•r•c)
      R(d,c):  [ip(d)+ip(100•fp[d])/60+fp(100•d)/36]/c
        d(x):  D(x,45/arg(1,1))
        h(x):  R(x,3/arg(1,1))
        r(x):  R(x,45/arg(1,1))
      s(x,y):  d(r(x)+r(y))
        t(x):  D(x,3/arg(1,1))
```

Apr 4.0:	Elongation:	10.4407"*	Alpha:	14.5842"	i:	165.0118"**
Apr 5.0:	Elongation:	9.3929"	Alpha:	13.2746"	i:	166.3214"
Apr 6.0:	Elongation:	8.4302"	Alpha:	12.0832"	i:	167.5128"
Apr 7.0:	Elongation:	7.5807"	Alpha:	11.0539"	i:	168.5421"
Apr 8.0:	Elongation:	7.2847"	Alpha:	10.2440"	i:	169.3520"
Apr 9.0:	Elongation:	7.1821"	Alpha:	10.1008"	i:	169.4952"
Apr 10.0:	Elongation:	7.2823"	Alpha:	10.2415"	i:	169.3545"
Apr 11.0:	Elongation:	7.5713"	Alpha:	11.0442"	i:	168.5518"
Apr 12.0:	Elongation:	8.4141"	Alpha:	12.0709"	i:	167.5251"
Apr 13.0:	Elongation:	9.3733"	Alpha:	13.2547"	i:	166.3413"
Apr 14.0:	Elongation:	10.4128"	Alpha:	14.5600"	i:	165.0360"
Apr 15.0:	Elongation:	11.5042"	Alpha:	16.3406"	i:	163.2554"
Apr 16.0:	Elongation:	13.0315"	Alpha:	18.1723"	i:	161.4237"
Apr 17.0:	Elongation:	14.1742"	Alpha:	20.0354"	i:	159.5606"
Apr 18.0:	Elongation:	15.3300"	Alpha:	21.5218"	i:	158.0742"
Apr 19.0:	Elongation:	16.4823"	Alpha:	23.4133"	i:	156.1827"
Apr 20.0:	Elongation:	18.0318"	Alpha:	25.3056"	i:	154.2904"
Apr 21.0:	Elongation:	19.1718"	Alpha:	27.1953"	i:	152.4007"
Apr 22.0:	Elongation:	20.3003"	Alpha:	29.0757"	i:	150.5203"
Apr 23.0:	Elongation:	21.4118"	Alpha:	30.5450"	i:	149.0510"

* The first elongation should be read as $10^{\circ}44'07''$.

**The symbol "i" stands for phase angle.

Jun	15.0:	Elongation:	45.4527"	Alpha:	87.5403"	i:	92.0557"
Jun	16.0:	Elongation:	45.4626"	Alpha:	88.3240"	i:	91.2720"
Jun	17.0:	Elongation:	45.4657"	Alpha:	89.1050"	i:	90.4910"
Jun	18.0:	Elongation:	45.4703"	Alpha:	89.4836"	i:	90.1124"
Jun	19.0:	Elongation:	45.4642"	Alpha:	90.2555"	i:	89.3405"
Jun	20.0:	Elongation:	45.4558"	Alpha:	91.0252"	i:	88.5708"
Jun	21.0:	Elongation:	45.4449"	Alpha:	91.3925"	i:	88.2035"
Jun	22.0:	Elongation:	45.4318"	Alpha:	92.1537"	i:	87.4423"
Jun	23.0:	Elongation:	45.4124"	Alpha:	92.5126"	i:	87.0834"
Jun	24.0:	Elongation:	45.3910"	Alpha:	93.2656"	i:	86.3304"
Jun	25.0:	Elongation:	45.3632"	Alpha:	94.0204"	i:	85.5756"
Jun	26.0:	Elongation:	45.3336"	Alpha:	94.3654"	i:	85.2306"
Jun	27.0:	Elongation:	45.3019"	Alpha:	95.1124"	i:	84.4836"
Jun	28.0:	Elongation:	45.2643"	Alpha:	95.4536"	i:	84.1424"
Jun	29.0:	Elongation:	45.2248"	Alpha:	96.1930"	i:	83.4030"

```
1.0 Set X=57.295779.
1.05 * Table Mt. Venus Angles (every 10 minutes).
1.1 Type form 15 if $≤4.
1.2 Do part 3 for b=0(1)5.

2.2 Set m=sin(E)•sin[r(34.22)]+cos(E)•cos(U)•cos[r(34.22)].
2.25 Set M=sin(e)•sin(r[34.22])+cos(e)•cos(u)•cos(r[34.22]).
2.3 Set a=d(arg[sqrt(1-m*2),m]).
2.35 Set k=d(arg[sqrt(1-M*2),M]).
2.4 Set n=-cos(E)•sin(U)/cos[r(a)].
2.45 Set N=-cos(e)•sin(u)/cos[r(k)].
2.5 Set A=d(arg[sqrt(1-n*2),n]).
2.55 Set K=d(arg[sqrt(1-N*2),N]).
2.6 Set p=(sin(E)•cos[r(34.22)]-cos(E)•cos(U)•sin[r(34.22)])/cos[r(a)].
2.65 Set P=d(arg[p,sqrt(1-p*2)]).
2.66 Set q=(sin(e)•cos[r(34.22)]-cos(e)•cos(u)•sin[r(34.22)])/cos[r(k)].
2.665 Set q=-1 if q<-1.
2.67 Set Q=d(arg[q,sqrt(1-q*2)]).
2.8 Line if b=0.
2.91 Set P=d(r[360]-r[P]) if n≤0.
2.93 Set Q=d(r[360]-r[Q]) if N≤0.
2.95 Set Z=d(r[P]-r[Q]) if Q≥P.
2.96 Set Z=d(r[P]-r[Q]-r[360]) if Q<P.
2.965 Set Z=d(r[360]+r[Z]) if r[Z]<r[-180].
2.97 Do part 11 if i≥7.
2.98 Do part 12 if i<7.

3.2 Set U=b•([V(i+1)-V(i)]/6)+V(i) if V(i+1)≥V(i).
3.24 Set U=b•([V(i+1)+r[360]-V(i)]/6)+V(i) if V(i+1)<V(i).
3.3 Set E=b•([F(i+1)-F(i)]/6)+F(i).
3.41 Set u=b•([W(i+1)-W(i)]/6)+W(i) if W(i+1)≥W(i).
3.43 Set u=b•([W(i+1)+r[360]-W(i)]/6)+W(i) if W(i+1)<W(i).
3.51 Set e=b•([f(i+1)-f(i)]/6)+f(i).
3.9 Do part 2.

9.0 Type i in form 2.
9.1 Demand v(t,i) as "GHA-Venus".
9.2 Demand G(t,i) as "DEC-Venus".
9.3 Demand w(t,i) as "GHA-SUN".
9.4 Demand g(t,i) as "DEC-SUN".
9.5 Line.

11.05 Do part 15 if $>47.
11.1 Type i,10•b,i-7,10•b,a,P,k,Q,Z in form 1.

12.1 Type i,10•b,i+17,10•b,a,P,k,Q,Z in form 1.
```

15.1 Page.
15.2 Type form 15.
15.3 Line.

Form 1:

__:__ __:__ ___.__' ___.__' ___.__' ___.__' ___.__'

Form 2:

GMT __:00

Form 15:

GMT PDT Venus alt. Az. SUN alt. Az. Bearing

```
D(r,c):  ip(r•c)+.01•ip[60•fp(r•c)]+.006•fp(60•r•c)
  F(i):  [ip[G(t,i)]+fp[G(t,i)]/.6]/X
R(d,c):  [ip(d)+ip(100•fp[d])/60+fp(100•d)/36]/c
  V(i):  [ip[v(t,i)]+fp[v(t,i)]/.6]/X-r[117.41]
  W(i):  [ip[w(t,i)]+fp[w(t,i)]/.6]/X-r[117.41]
  d(x):  D(x,45/arg(1,1))
  f(i):  [ip[g(t,i)]+fp[g(t,i)]/.6]/X
  r(x):  R(x,45/arg(1,1))
```

Recall item 17.
Done.
Type t.

t = 19

Do part 1 for i=15.

15: 0	8: 0	58.08'	126.11'	26.29'	78.36'	47.34'
15:10	8:10	59.46'	129.42'	28.31'	79.49'	49.53'
15:20	8:20	61.18'	133.32'	30.33'	81.02'	52.30'
15:30	8:30	62.45'	137.44'	32.35'	82.16'	55.28'
15:40	8:40	64.05'	142.18'	34.38'	83.30'	58.48'
15:50	8:50	65.16'	147.16'	36.41'	84.46'	62.31'

Type form 15.

GMT PDT Venus alt. Az. SUN alt. Az. Bearing

Delete all.

of the programs developed and used. The three major programs and examples of the output are reproduced in this Memorandum and in Ref. 7, although a full explanation of the program would demand a separate report.

The time intervals between computer outputs could be varied according to needs. Thus, ephemeris data could be printed out every hour, if needed. Look angles could be obtained for time intervals as short as one minute, for example.

Of special usefulness was the ability of the JOSS system to provide desired information nearly instantaneously at remote typewriter consoles. During processing and analysis of the observational material, such data as the precise altitude of Venus and the Sun at the instant a planetary photograph was taken, were readily available.

OBSERVING SCHEDULES

The observational program was conducted at Table Mountain Observatory near Wrightwood, California and at New Mexico State University Observatory near Las Cruces, New Mexico. Station particulars are summarized below.

	Table Mountain	NMSU
Latitude	34°22'54".02 N	32°17'17".12 N
Longitude	117°41'51".22 W	106°41'.8 W
Altitude	2287 meters	1453 meters
Cassegrain Reflectors	16 inches	24 inches
Focal ratio	50	74

The observations scheduled for the greatest eastern elongation of Venus (26 January 1969) had to be cancelled; Southern California experienced its worst storm of the twentieth century during that time.

Observations of the inferior conjunction of Venus (15:00 UT 8 April 1969) were conducted at Table Mountain Observatory from 3 April to 22 April 1969. Successful photographic, visual, and photometric data were obtained.

Observations of the greatest western elongation of Venus (17:00 UT 17 June 1969) and of geometric dichotomy (07:00 UT 18 June 1969) were conducted both at Table Mountain Observatory and at NMSU Observatory between 14 June and 21 June 1969. At both locations, successful photographic, visual, and photometric data were obtained. All observing programs are described in detail in Ref. 7.

The celestial observing conditions during both periods, as characterized by the variations of elongation and phase angle, are summarized on pages 10 and 11 in the form of ephemeris computer output. An example of the resulting local observing conditions in terms of altitude and azimuth is shown on pages 6, 7, and 8.

III. DATA BASE

The reduced data tabulated in the catalog[7] are here briefly summarized in Tables 2 and 3. The values are those resulting from the astronomical observations and from the brightness measurements. In addition, selected positional information is depicted in graphical form.

Figure 1 is an example of the celestial observing conditions at Table Mountain Observatory on 8 April 1969, the day of the inferior conjunction. The lower portion of the figure shows the celestial altitudes of Venus and Sun as a function of time. Above, the figure shows corresponding values of the absolute brightness of the terrestrial sky at the zenith, at the horizon, and around Venus.

Figure 2 is a corresponding example of the celestial observing conditions at both Table Mountain Observatory and NMSU Observatory on 19 June 1969 near greatest western elongation.

Pages 6 and 7 are brief examples of computer print-out of the celestial positions for the two observatory locations on 19 June 1969. Reproduction of complete positional information in the catalog would have been bulky; this information can always be easily recalculated. Selected positional information for the times when photographs were obtained is given in the appropriate catalog tables.

Measureable photographic images of the angular extent of the crescent of Venus were obtained at celestial altitudes as low as 36 minutes of arc below the true horizon (i.e., at a true zenith distance of 90°36'). Brightness values of the terrestrial sky around Venus ranged from 2.8 candles per square centimeter, when daylight exposures were made near the time of inferior conjunction, to 10^{-5} candles per square centimeter in the dark twilight sky near greatest elongation.

Page 8 is a computer print-out of look angles for Table Mountain on 4 April 1969. Taking this day as an example, the Sun was setting about 40 minutes before Venus. At the time of apparent sunset as seen from the observatory, Venus was still some eight degrees above the horizon and its azimuth was six degrees greater than that of the Sun. In equatorial coordinates, of course, Venus was still some five days from inferior conjunction, being three degrees east of the Sun, at an elongation of ten degrees.

Table 2

CONTENTS OF DATA CATALOG TABLES FOR 1969, INFERIOR CONJUNCTION (REF. 7)

Tab. No.	Title	Period Covered	Data Content
4	Angular Extent of Venus Image Obtained from III-F Plate Measurements	4 April to 15 April	Image number UT Photometer reading Exposure time Angular extent of crescent Altitude of Venus
5	Angular Extent of Venus Image Obtained from Film Measurements	16 April to 22 April	Image number UT Photometer reading Exposure time Angular extent of crescent Altitude of Venus
6	Visual Estimates of the Angular Extent of the Venus Crescent	16 April to 22 April	UT Photometer reading Observer Angular extent Altitude of Venus
7	Sky Brightness at Table Mountain Observatory	3 April to 22 April	UT Sky brightness (in cd cm^{-2}) in the vicinity of Venus, in the zenith, and at the horizon

Table 3

CONTENTS OF DATA CATALOG TABLES FOR 1969,

GREATEST WESTERN ELONGATION (REF. 7)

Tab. No.	Title	Covered Period	Data Content
8	Sky Brightness at Table Mountain Observatory	17 June to 21 June	UT Sky brightness (in cd cm^{-2}) in the vicinity of Venus and in the zenith
9	Sky Brightness at NMSU Observatory	14 June to 20 June	UT Sky brightness (in cd cm^{-2}) in the vicinity of Venus and in the zenith

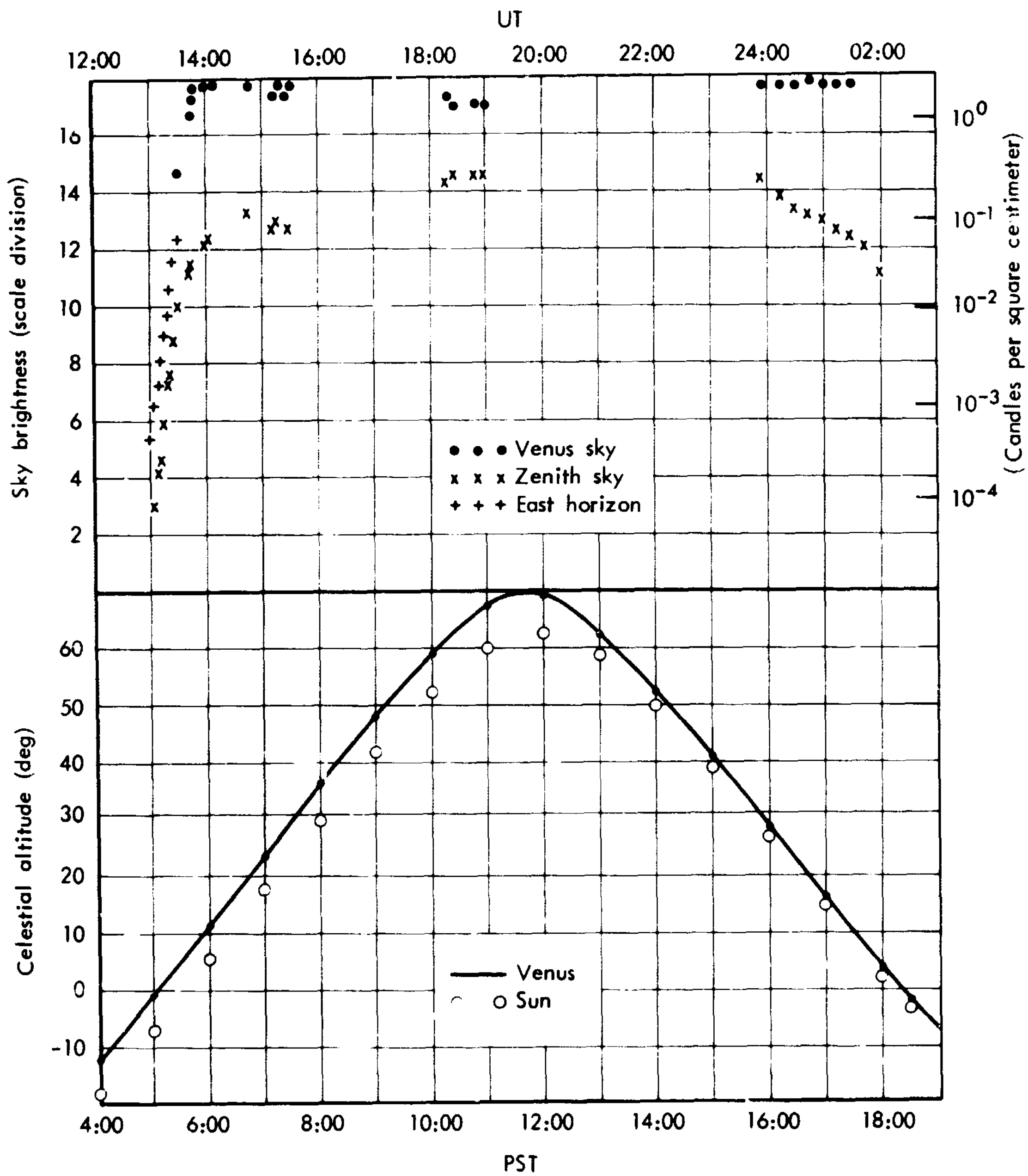

Fig. 1 -- Sky brightness and celestial altitudes of Venus and the Sun at TMO, 8 April 1969, the day of inferior conjunction.

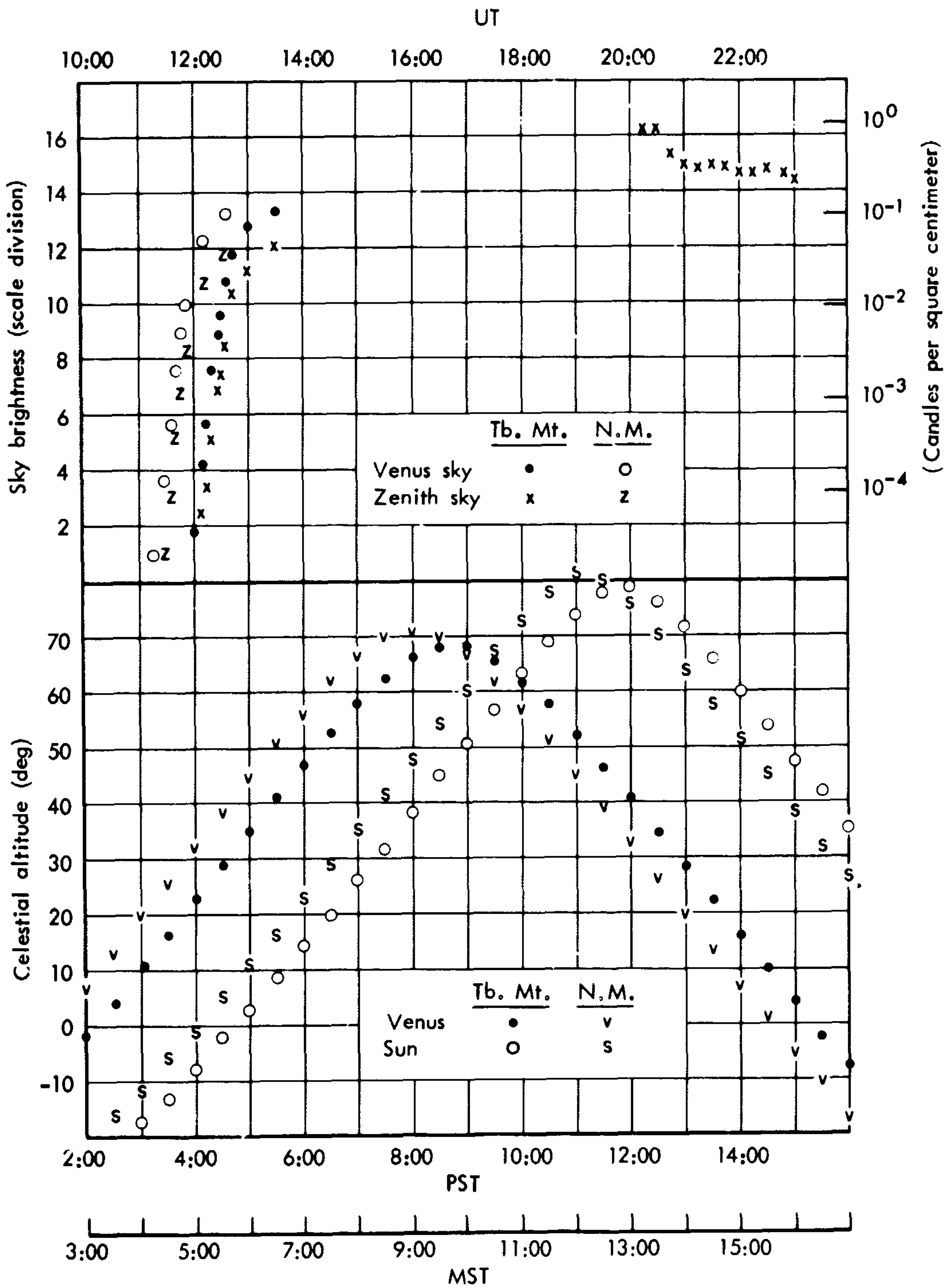

Fig. 2 -- Sky brightness and celestial altitudes of Venus and the Sun at TMO and NMSU Observatory on 19 June 1969.

IV. ANALYSIS AND CONCLUSIONS

THEORETICAL RELATIONS

Venus, as seen -- or photographed -- from the Earth near and at inferior conjunction, is sketched in Fig. 3. Astronomical observations provide measurements of the angular extent γ of the visible crescent. The cusp extension angles π represent the amount by which the two cusps extend beyond the geometric half-circle HH. For the case where the north and the south cusps are equal,

$$2\pi = \gamma - 180°$$

Russell,[2] using a simplified geometry, determined that the observed cusp extension angle π can be related to the twilight zone angle σ by the approximate relation

$$\sin(\sigma + \frac{d}{2}) \approx \sin(\pi)\ \sin(\frac{\alpha}{2})$$

where α is the exterior orbit angle (180° minus the phase angle), d is the Sun's apparent semi-diameter as seen from Venus (about 22 minutes of arc), and the angular extent σ of the twilight zone, measured at the center of the planet, is determined by the height h of the effectively scattering atmosphere above the opaque cloud deck.

Once π is obtained from observations, this height h is easily derived from

$$h = R(\sec \sigma - 1)$$

where R is the optical semi-diameter of Venus, to the top of the cloud deck.

But our earlier study[1] showed that Russell's geometry assumed that the cusp extension was visible tc its maximum extent at all times. We concluded that the observed values of π should be a function of the

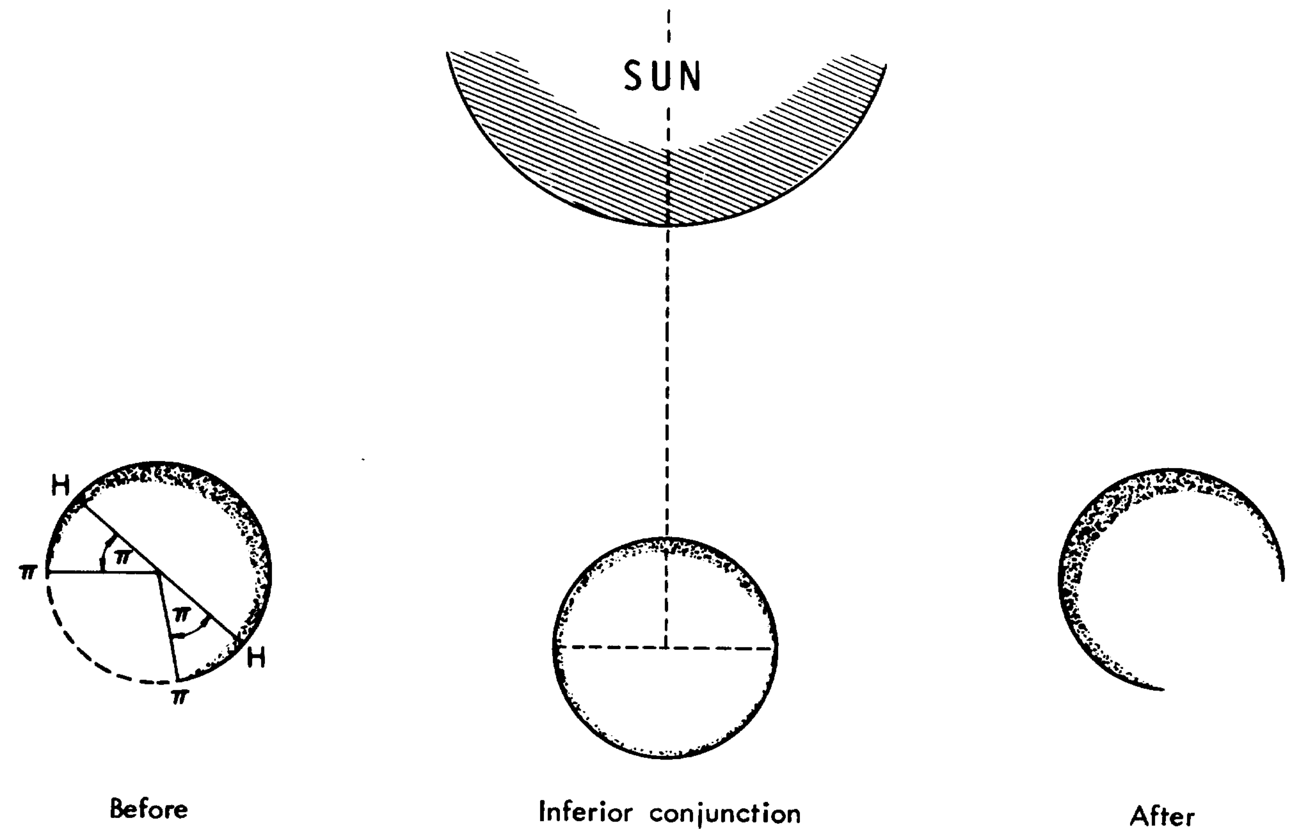

Fig. 3 -- Schematic appearance of Venus in the terrestrial sky near and at inferior conjunction (not to scale).

luminance of the terrestrial sky at the time of observation. The replacement of Russell's simplified approach by a rigorous, though more complex geometry, resulted in a theory (a) that gave the minimum height of the scattering atmosphere above the cloud deck as about 15 km rather than of the order of a few hundred meters as derived from Russell's theory; (b) that provided a quantitative explanation for the heretofore unexplained discrepancy between the dates of expected and actually observed dichotomy; and (c) that made a number of specific predictions subject to observational tests.

Our theory, as well as its application to whatever observational data were available, is fully detailed in Refs. 1 and 6. The significance of its deductions about the physical nature of the atmosphere of Venus has been discussed, for example, by Abhyankar(8) and Kuiper.(9)

In the following, we provide a synopsis of the results obtained during the 1969 observation of the inferior conjunction and greatest western elongation of Venus. The reduced data which form the basis of our determinations, are collected in Ref. 7.

OBSERVATIONAL ROUTINE

As is discussed in Refs. 1 and 7, the observational program employed methods and techniques that can be considered rather unorthodox compared to routine astronomical practice. A conventional approach would have employed a technique that, in effect, attempted to obtain as many celestial exposures as possible with the hope that a few would evidence just the right combination of seeing, exposure, etc. to result in good-quality images. While such a technique may indeed lead to excellent images, it suffers from major deficiencies: (a) it does not really ensure that the "excellent" images are really the best obtainable for the given circumstances; (b) it often does not concern itself with the physical reasons that create the differences between good and bad images; and, most important, (c) it does not contribute to a quantitative understanding of the physical effects that influence the image's quality and its information content.

Our methods were designed to provide quantitative information on the influence of the terrestrial sky on the apparent image of Venus. This meant that we had to deal with contrast threshold problems in regard to limiting sensitivities of appropriate combinations of telescope optics, emulsions, exposure times, development timing, and the relative brightness of Venus and the surrounding sky. The observational techniques concentrated on obtaining as many images as practicable on a single plate or film strip to avoid well-known photometric sensitivity differences from plate to plate. On each plate or film, a series of exposures was taken over a range of exposure times as rapidly as feasible, while concurrent photometric measurements were made. Intervals between different exposure series on one plate depended on various circumstances, and ranged from a few minutes to as much as several hours.

During April 1969, a total of 26 III-F plates with an average of 16 images on each, and 12 strips of 35-mm films (II-F, III-F, and Tri-X) with an average of 25 images on each, were obtained. In addition to Venus exposures, the plates and films contained star trails for precise angular reduction, and images of Jupiter or the Moon for photometric comparisons. The complementary and precisely timed photometric measurements consisted of values of the brightness of the terrestrial sky (a) around Venus, (b) at the zenith, and (c) at the horizon. Supplementary visual observations were conducted with the 6-in. guide refractor at various magnifications.

During June 1969, a total of 25 strips of 35-mm film (III-F) with an average of 19 images on each were obtained at Table Mountain Observatory. At New Mexico State University Observatory, 22 plates (III-F) were obtained with an average of 25 images on each. Photometric comparison images were taken of Mercury, Jupiter, Saturn, and the Moon.

In addition to these images obtained without filters, series of Venus and sky exposures with various filters were made. This material has not yet been reduced. Preliminary analysis shows the known phenomenon of the dependence of the apparent diameter of Venus on the filter used. The problems of cusp extension analysis are rather complex, even if limited to visual light. While reduction and analysis of the filter data would be highly desirable, it would involve considerable additional effort.

SKY PHOTOMETRY

Two spot photometers were used to measure the surface brightness of the terrestrial sky with fields of view of 1° and 2°, respectively. The instrument response followed the relations:

$$B[cd/ft^2] = 10 \times 2^{(SD-10)}$$

$$SD = (\log B[cd\ cm^{-2}] - \log 1.0511631 \times 10^{-5})/\log 2$$

where B is the surface brightness, and SD is the instrument response in linear scale divisions. A summary of the calibration values is given in Table 4.

Table 4: PHOTOMETER CALIBRATION IN ABSOLUTE UNITS

Instrument Scale Divisions	Surface Brightness in cd cm^{-2}
0	1.05×10^{-5}
2	4.20×10^{-5}
4	1.68×10^{-4}
6	6.72×10^{-4}
8	2.69×10^{-3}
10	1.08×10^{-2}
12	4.31×10^{-2}
14	1.72×10^{-1}
16	6.89×10^{-1}
18	2.76

Figures 4 and 5 are examples of the variation of terrestrial sky brightness during the morning hours of 17 and 18 June 1969. The brightness values of the sky around Venus and in the zenith have been plotted against time for both stations. The upper scale refers to New Mexico State University Observatory, and the lower scale to Table Mountain

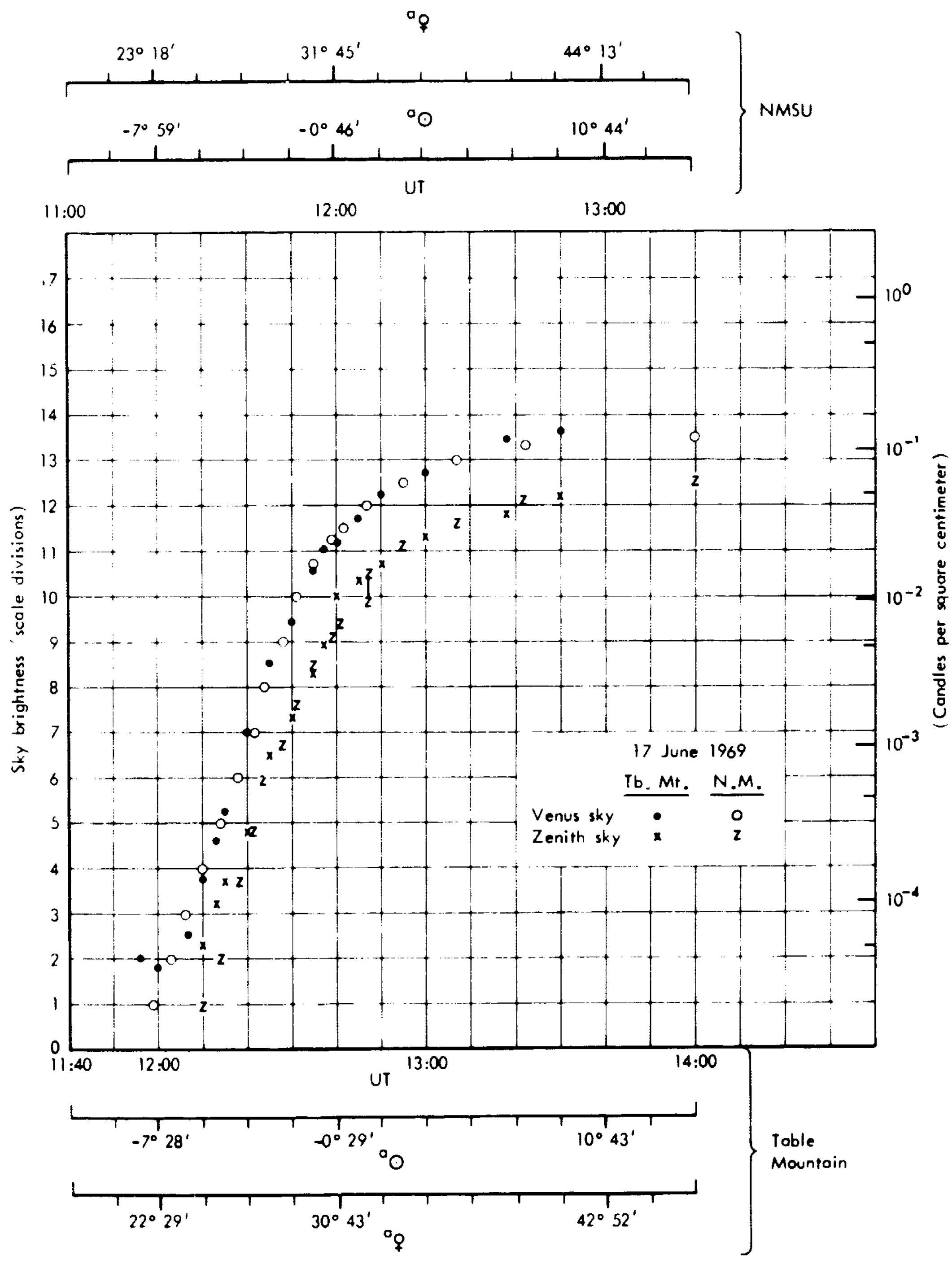

Fig. 4 -- Sky brightness at TMO and NMSU Observatory on 17 June 1969. ($a_{\odot}$ and $a_{♀}$ are the celestial altitudes of the Sun and Venus above the horizon.)

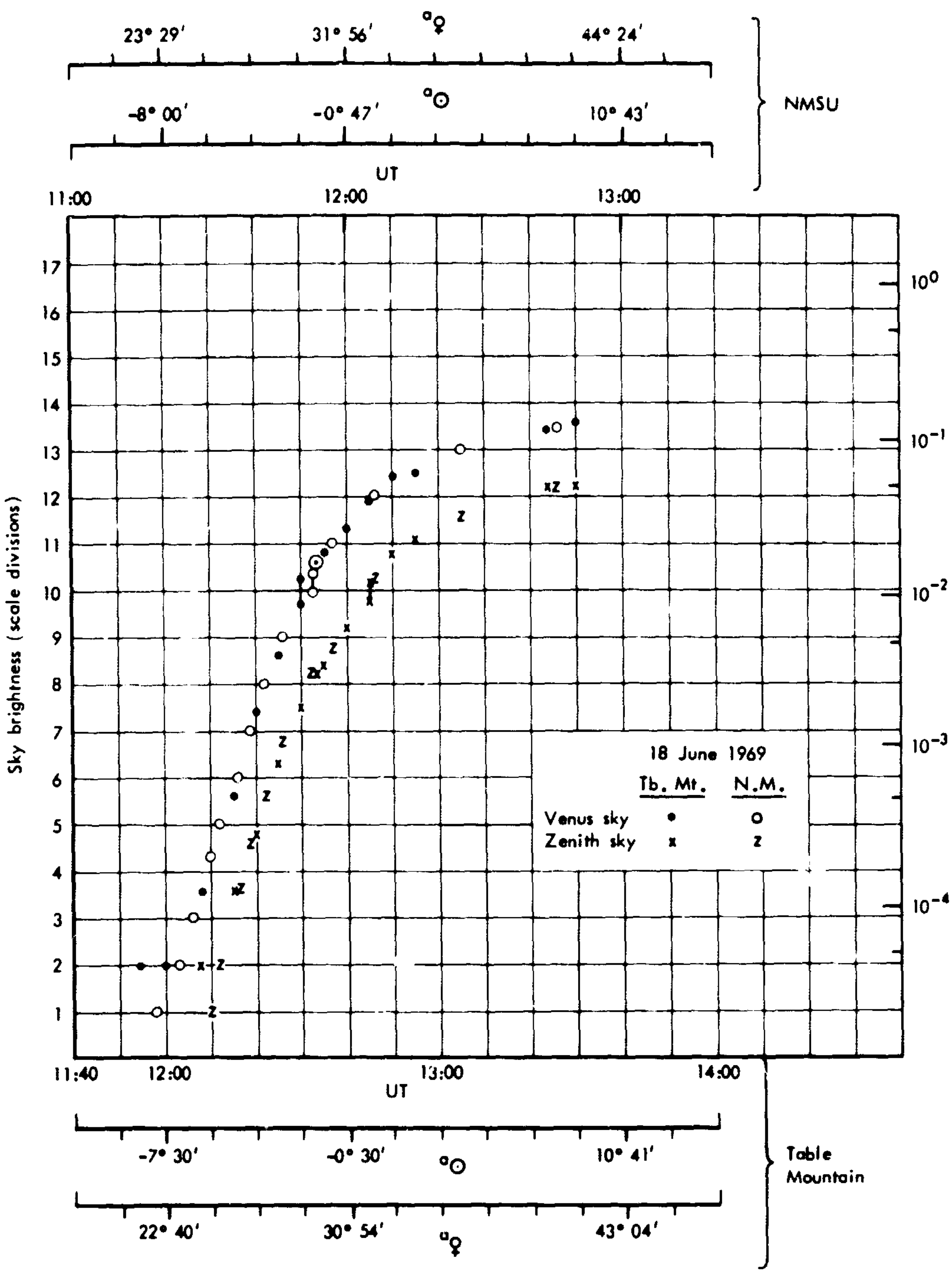

Fig. 5 -- Sky brightness at TMO and NMSU Observatory on 18 June 1969. ($a_{\odot}$ and $a_{♀}$ are the celestial altitudes of the Sun and Venus above the horizon.)

Observatory. The scales give information also about the celestial altitudes of Venus and the Sun from the respective locations.

If one time scale is displaced 40 minutes relative to the other -- the observatories are separated approximately 11° in longitude -- the resulting correspondence is close.

As the brightness of the sky changed by four orders of magnitude during the two hours of observations, such correspondence is rather satisfactory in evidencing the equivalence of local observing conditions at the two locations. In addition, comparisons among Figs. 1, 2, 4, and 5 reveal the consistency of good observing conditions from day to day.

SKY BRIGHTNESS

Horizon Conditions

Without impurities due to aerosol contamination, clouds, or haze, the surface brightness of a specific area of the terrestrial sky was generally a consistent function of the celestial altitude of the Sun and, hence, of local time. Over a range of a few days, while the elongation of Venus (the angular distance between Venus and Sun) changed little, a plot of B_ν, the sky brightness around Venus, against local time was therefore nearly equivalent to its plot against solar altitude. This is shown in Fig. 6.

An example of the daily consistency of the brightness of the sky around Venus at sunrise during clear conditions is given in Tables 5, 6, and 7.

When aerosol contaminants were present near the horizon, the sky brightness differed from average conditions as characterized in Table 8.

The general behavior of sky brightness illustrated in the table is due to the scattering effects of aerosols. Atmospheric extinction due to aerosols in the light path from the Sun to a specific area in the sky will decrease its surface brightness, but increased scattering due to aerosols in a specific area in the sky can cause an increase in surface brightness. The luminance of Venus, on the other hand, was directly dependent on the air mass and aerosol contaminants present

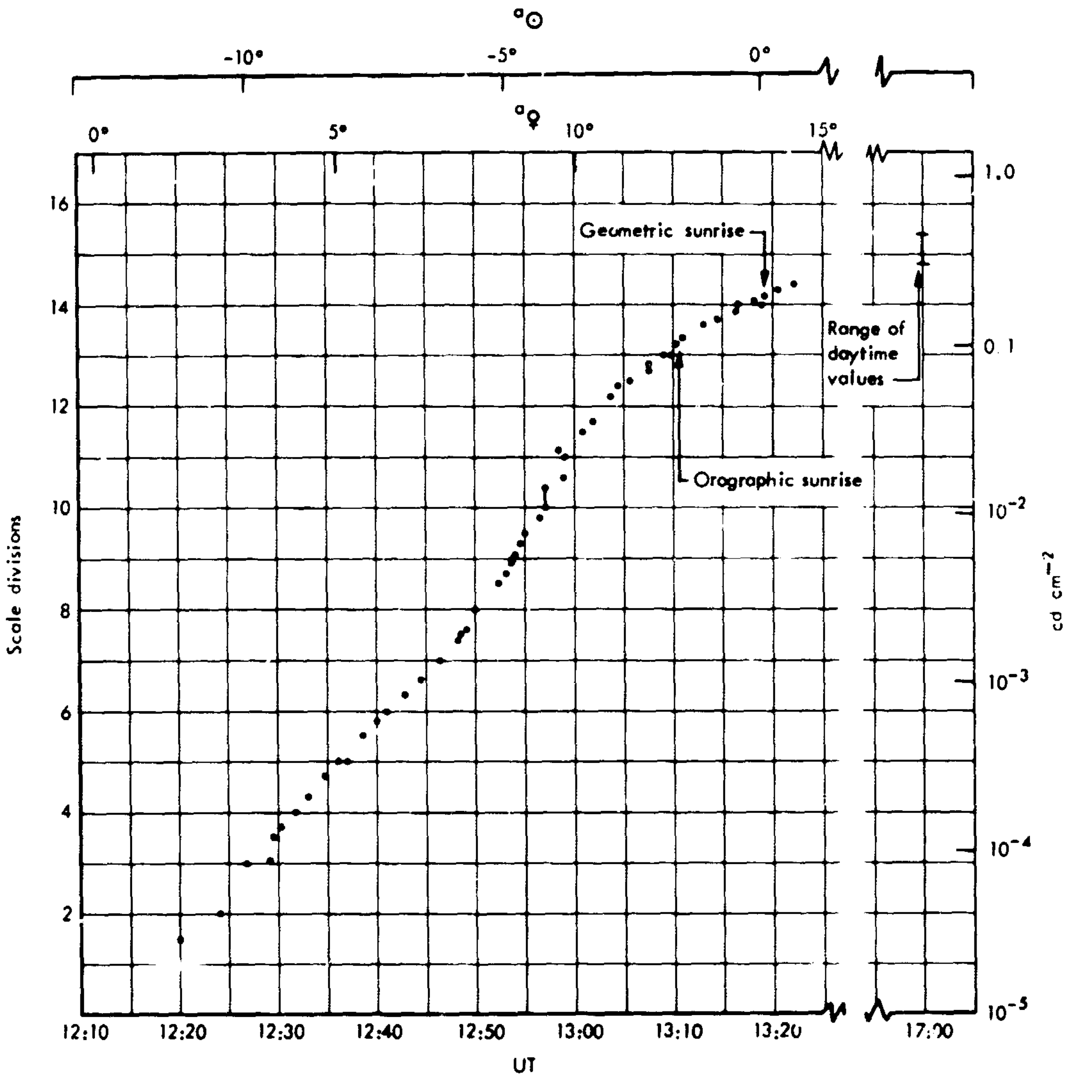

Fig. 6 -- Typical variation of sky brightness around Venus before and during sunrise; TMO; 19 April 1969.

Table 5

SKY BRIGHTNESS AROUND VENUS AT INSTANT OF GEOMETRIC SUNRISE AT TABLE MOUNTAIN OBSERVATORY (TRUE SOLAR ZENITH DISTANCE OF 90°)

Date (1969)	Venus Altitude	Brightness (cd cm^{-2})
16 April	$11^\circ45'$	1.5×10^{-1}
17 April	$12^\circ26'$	1.2×10^{-1}
19 April	$13^\circ46'$	2.0×10^{-1}
20 April	$14^\circ18'$	2.0×10^{-1}
21 April	$14^\circ49'$	1.5×10^{-1}
22 April	$15^\circ22'$	1.4×10^{-1}

Table 6

SKY BRIGHTNESS AT INSTANT OF OROGRAPHIC SUNRISE (REFRACTED UPPER LIMB) AT TABLE MOUNTAIN OBSERVATORY

		Celestial Altitude		Surface Brightness	
Date (1969)	Time (UT)	Sun	Venus	Venus Sky	Zenith Sky
17 June	1237:15	$-0^\circ58'$	$30^\circ09'$	2.2×10^{-2}	5.0×10^{-3}
18 June	1233:40	$-1^\circ38'$	$29^\circ36'$	1.6×10^{-2}	3.1×10^{-3}
19 June	1233:12	$-1^\circ45'$	$29^\circ41'$	1.5×10^{-2}	3.1×10^{-3}
20 June	1234:30	$-1^\circ33'$	$30^\circ07'$	1.5×10^{-2}	3.2×10^{-3}
21 June	1235:53	$-1^\circ42'$	$30^\circ10'$	1.5×10^{-2}	3.1×10^{-3}

Table 7

SKY BRIGHTNESS NEAR SUNRISE AT SPECIFIC UT AT NMSU OBSERVATORY

		Celestial Altitude		Surface Brightness	
Date (1969)	Time	Sun	Venus	Venus Sky	Zenith Sky
16 June	12:00	$-0^\circ44'$	$31^\circ34'$	2.7×10^{-2}	7.1×10^{-3}
17 June	12:00	$-0^\circ46'$	$31^\circ45'$	2.8×10^{-2}	6.2×10^{-3}
18 June	12:00	$-0^\circ47'$	$31^\circ56'$	2.8×10^{-2}	6.6×10^{-3}
19 June	12:00	$-0^\circ49'$	$32^\circ06'$	2.7×10^{-2}	6.2×10^{-3}
20 June	12:00	$-0^\circ51'$	$32^\circ15'$	2.7×10^{-2}	6.2×10^{-3}

Table 8

ILLUSTRATIVE DEVIATION OF HORIZON SKY BRIGHTNESS FROM NORMAL CONDITIONS DUE TO THE PRESENCE OF AEROSOL CONTAMINANTS

Aerosols in Horizon Sky	Before Sunrise	After Sunrise
More than average	sky dimmer	sky brighter
Less than average	sky brighter	sky dimmer

in the sky, of course. The combination of these effects could be responsible for certain apparent anomalies in the data.

General Consistency

Photometric measurements of sky brightness were obtained over a considerable range of solar altitudes above and below the horizon, Venus altitudes, and bearings, i.e., the difference in azimuth between the Sun and Venus. Similar data were obtained by Koomen et al.[10] some twenty years ago at Sacramento Peak, New Mexico.

Tables 9 and 10 provide comparisons between Koomen's data and some of our data for a few selected sky positions. (Koomen's data shown are averages over seven days. Our data are averaged over three days in April and over five days in June.) The good agreement confirms the earlier conclusions about the relative stability of atmospheric conditions.

VENUS CRESCENT

Observational Information

Examples of visual observations for the dates 16 April to 22 April 1969, near inferior conjunction, are summarized graphically in Fig. 7. During this period, the elongation varied from 13° to 21°, and the exterior orbit angle, α, varied from 19° to 30°. The apparent cusp extension angle remained approximately constant near a value of 20° from planet rise until shortly before sunrise. The surface brightness of the terrestrial sky increased from 10^{-5} to 10^{-2} cd cm^{-2} during this time. Subsequent to sunrise, the values of π dropped rapidly and reached negative values (i.e., the apparent crescent of Venus was less than 180°) when the sky brightness exceeded 10^{-1} cd cm^{-2}.

Examples of photographic observations near inferior conjunction are summarized graphically for 17 April to 21 April 1969 in Fig. 8. Like the visual data, the photographic observations at 1 second and at 1/8 second show the rapid decrease in the apparent angular extent of the Venus crescent as sunrise approaches. Also, it can be noted, the apparent angular extent is a function of the exposure times, and the

Table 9

SURFACE BRIGHTNESS OF THE ZENITH SKY IN CANDLES PER SQUARE CENTIMETER

Solar Altitude (degrees above horizon)	Sacramento Peak (Ref. 10) March-June 1951	Table Mountain April 1969	Table Mountain June 1969	NMSU June 1969
+5°	3.1×10^{-2}	3.8×10^{-2}	3.3×10^{-2}	3.8×10^{-2}
+3°	2.1×10^{-2}	2.8×10^{-2}	2.7×10^{-2}	2.6×10^{-2}
0°	8.0×10^{-3}	8.2×10^{-3}	8.2×10^{-3}	6.6×10^{-3}
-3°	1.0×10^{-3}	1.3×10^{-3}	1.1×10^{-3}	2.0×10^{-3}
-6°	2.2×10^{-5}	4.2×10^{-5}	5.2×10^{-5}	2.3×10^{-5}

Table 10

SURFACE BRIGHTNESS OF SELECTED SKY AREAS IN CANDLES PER SQUARE CENTIMETER

Solar Altitude	Altitude of Area Measured	Bearing	Sacramento Peak (Ref. 10) March-June 1951	Table Mountain April; June 1969	NMSU June 1969
0°	15°	11°	9.7×10^{-2}	1.6×10^{-1}	. . .
-3°	11°	11°	1.4×10^{-2}	3.3×10^{-2}	. . .
-6°	9°	11°	7.0×10^{-3}	7.4×10^{-3}	. . .
+5°	38°	34°	9.4×10^{-2}	8.6×10^{-2}	9.9×10^{-2}
+3°	36°	34°	5.7×10^{-2}	7.0×10^{-2}	7.5×10^{-2}
0°	32°	34°	2.7×10^{-2}	2.5×10^{-2}	2.8×10^{-2}
-3°	30°	34°	4.1×10^{-3}	4.7×10^{-3}	7.6×10^{-3}
-6°	25°	34°	2.3×10^{-4}	1.5×10^{-4}	1.8×10^{-4}

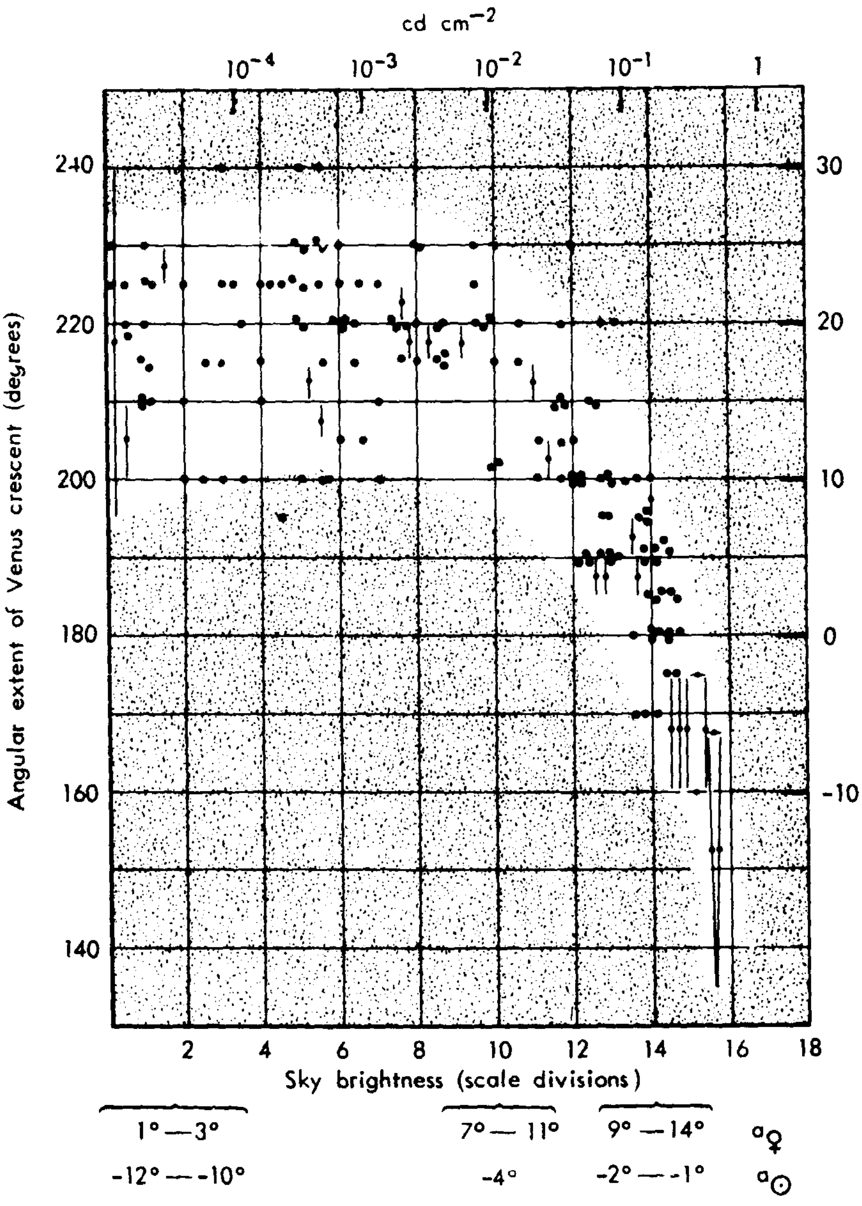

Fig. 7 -- Variation of the apparent angular extent of the Venus crescent with the surface brightness of the sky surrounding the planet (TMO, 16 to 22 April 19'9). ($a_{\odot}$ and $a_{♀}$ are representative ranges of celestial altitudes of the Sun and Venus.)

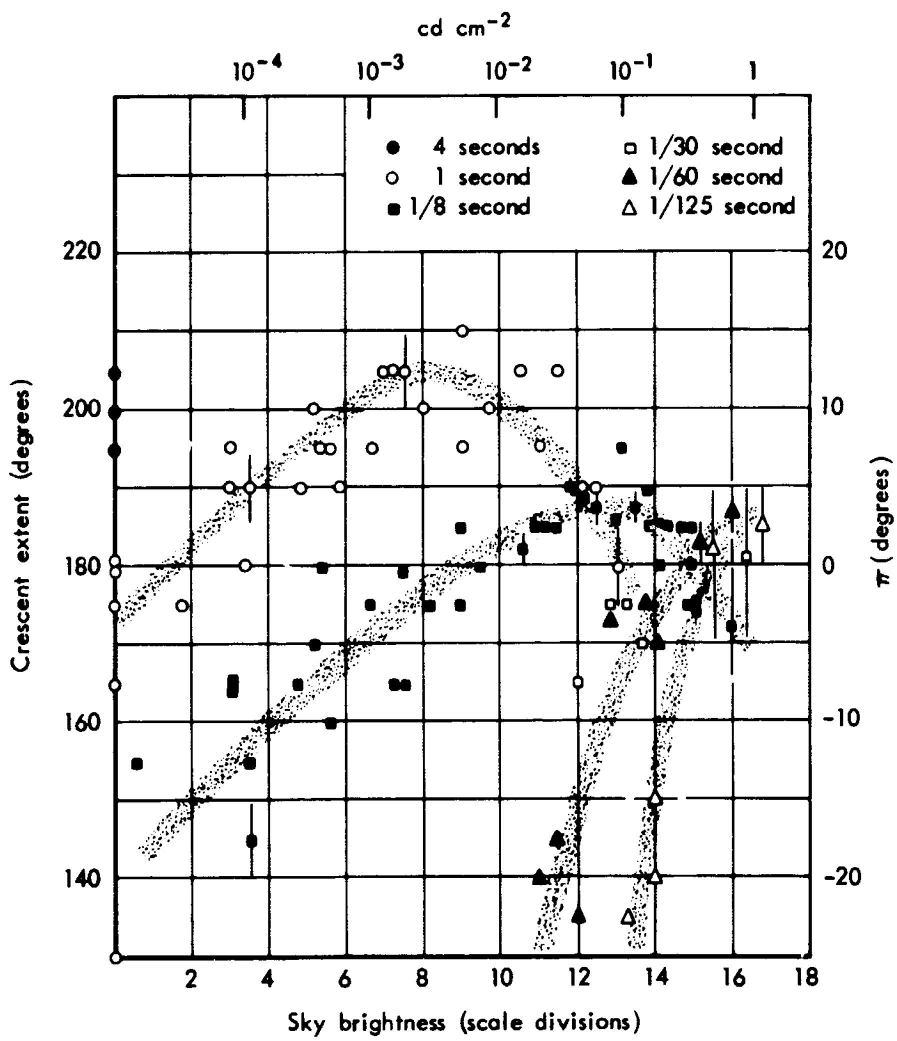

Fig. 8 -- Variation of the apparent angular extent of the Venus crescent as a function of both sky brightness and exposure time (TMO, 17 to 21 April 1969).

apparent maxima are reached at different values of sky brightness. This phenomenon is related to atmospheric extinction when Venus is at low altitudes near the horizon, and to the emulsion sensitivity and threshold characteristics of photographic material.

Interpretation

The observational data show clearly the dominant influence of the terrestrial sky on the apparent image of the planet. Essentially, three major effects are superimposed.

1. At low celestial altitudes, the apparent surface brightness $A_♀$ of any part of the image is less because of the air mass. It can be characterized by the relation

$$A_♀ = I_♀/m \approx I_♀ \times \sin a_♀$$

where $I_♀$ is the surface brightness outside the earth's atmosphere, m is the relative intervening air mass, and $a_♀$ is the celestial altitude of Venus above the horizon.

2. The combination of telescopic optics and emulsion sensitivity results in limits for usable exposure times at a given object brightness; i.e.,

$$E_{min} \geq t \times B \geq E_{max}$$

where t is the exposure time in seconds, B is the object brightness in candles per square centimeter, and E are the limiting exposure values in sec-cd/cm^2.

At New Mexico State University, E_{min} was about 10^{-3}. At Table Mountain, E_{min} was about 10^{-3} during the April observations, but was 10^{-4} during the June observations. E_{max} was about 10^{-1}.

3. As is discussed in Ref. 1, the apparent angular extent of the crescent is a contrast threshold problem, where image detection depends on the luminance of the foreground field. For visual observations, it is characterized by the relations

$$A_\pi - B_\nu = f(B_\nu)$$

and

$$A_\pi = (I_\pi/m) + B_\nu$$

where A_π is the apparent surface brightness of that small-area element of the Venus cusp that can just be detected as the observed cusp extension angle, π, and B_ν is the surface brightness of the terrestrial sky around Venus.

The combined relative action of these effects can be noticed in Figs. 7 and 8. In the visual data, the eye's ability to adjust to different contrast levels results in a rather smooth decrease of the apparent angular extent of the crescent as the sky brightens. The photographic data show that maxima of the angle π occur as functions of both exposure time and sky brightness, approximately expressed by:

$$\pi_{max} \text{ if } B_\nu \times t \approx 10^{-2} \text{ sec-cd/cm}^2.$$

Further theoretical analysis of this phenomenon is necessary before a complete quantitative explanation can be given. We expect that it will yield a technique that would permit a routine terrestrial derivation of the brightnesses of portions of a planet's atmosphere as if seen from space.

RESUME OF RESULTS

1. It was shown and documented that the apparent cusp extension angle π of Venus is a reproducible function of the surface brightness of the terrestrial sky surrounding the planet at the time of observation. The data confirm the theoretical prediction[1] that the extension angle observed in the evening should markedly increase during twilight and night conditions. Applying the theory of Ref. 1 to the reduced data obtained near inferior conjunction, we obtain an average value of 5° (dark-sky visual and photographic data) for the planetocentric extension of the twilight zone on Venus, and an average height of

20 to 25 km for the effectively scattering atmosphere above the opaque cloud deck.

2. Greatest western elongation occurred at 17:00 UT on 17 June 1969 with an elongation value of 45°47'. Geometric dichotomy, the celestial position of exact half-phase, from which Venus should give the appearance of a half-moon to a terrestrial observer, was computed to occur at 07:00 UT on 18 June 1969. By the end of our observing period on 21 June, the telescopic images of Venus at both observing sites still showed the illuminated side not as a semicircle, but as a crescent. The degree of concavity on any specific day depended on the local sky condition, with pronounced cusp extensions visible in the dark morning sky, and diminishing as the terrestrial sky brightness increased.

From the theory of Ref. 1, it was estimated that apparent dichotomy probably did not occur until about 27 June.

3. Separate analysis of the sky-brightness measurements showed that both observatories evidenced the general characteristics of a mountain location with relatively small aerosol contamination.[10] It was found that the variations of horizon and zenith sky brightness were reproducible functions of solar altitude. Deviations were minor, unless clouds were present.

V. RECOMMENDATIONS

Our major conclusions about the work on this contract can be expressed as recommendations with regard to the importance of absolute sky photometry in planetary investigations.

1. Daylight Planetary Photography

Astronomical observations of planets are seldom conducted during daylight and twilight. Our results show that such observations are observationally feasible, and permit the acquisition of scientific data not obtainable otherwise.

WE RECOMMEND that NASA give special attention in its program planning to daylight, moonlight, and twilight planetary astronomy as a cost-effective means for the maximum utilization of existing astronomical ground facilities in support of its planetary exploration programs, especially in studies of Mercury, Venus, and Jupiter.

2. Sky Photometry

The interpretation and analysis of planetary images obtained by astronomical photography would be greatly assisted by the availability of concurrent data on the absolute brightness of the terrestrial sky in the vicinity of the planetary object. The art of photometric instrumentation is well advanced, and simple instruments are available that can acquire reliable data over a range of orders of magnitude. There is evidence that if the brightness values of the terrestrial sky are unknown, planetary photographs -- while often representing interesting pictorial material -- are more often a product of the properties of the terrestrial sky than of the physical properties of the planet's surface or atmosphere. This situation includes night as well as day observations, because even during an apparently dark night, the actual brightness of the sky may vary considerably.

WE RECOMMEND that NASA consider the potential scientific value of adding sky photometry to such programs as planetary patrol observations, whether conducted by day or by night. This information will increase the value of the astronomical material; it will benefit various geophysical studies in basic atmospheric science; and it will be of use in research related to national security interests and environmental pollution.

3. Space Flight Projects

The placing of simple photometric instrumentation, capable of providing absolute values of luminance, aboard manned as well as unmanned spacecraft, can represent a low-weight means of acquiring valuable scientific data. Such instrumentation is practically a mandatory supplement to any spacecraft experiment designed to provide pictures or images of celestial objects. Such simple photometers are to be distinguished from spectro-photometric equipment and the like. As a specific example, we adapt below a suggestion to add such an experiment to the Viking missions:*

> Suggested Investigation: Measurements of the spatial and temporal variations of the absolute brightness of the planetary surface and the sky of Mars, with special emphasis on the analysis of complementary and interrelated investigations from the Lander and the Orbiter.
>
> Instrument Locations: Aboard Orbiter with identical instrument aboard Lander.
>
> Instrument Characteristics: Type: surface brightness spot photometer to measure absolute luminance. Sensitivity range: 1×10^{-5} candles per square centimeter. Field of view: 1 square degree. Weight, off-shelf: about 2 lbs. Sensor: rugged CdS. Availability: extensive commercial use in motion-picture and television industry.
>
> Scientific Objectives: From Orbiter - determination of absolute brightness and variations in brightness of different areas of the surface of Mars, as well as of the sky near the limb of the planet. Albedo information will be correlated with data from earth-based astronomical observations, enhancing also the value of astronomical studies of other planets. Absolute luminance values will provide information on local surface characteristics, and their spatial and temporal variations over planetary surface. For nominal orbit characteristics, approximate radius of area observed will range from 8 km near periapsis to 280 km near apoapsis. Results will supplement and integrate with scientific information obtained from other orbiter and lander experiments.

---

*Letter to Dr. Milton A. Mitz, NASA Headquarters, from G. F. Schilling, 6 August 1969.

From Lander - determination of absolute brightness and temporal variations in brightness of a surface area in the vicinity of the landing point, and if feasible, of the variations of the brightness of the Martian sky. Scientific data would also supplement and enhance information obtained from other experiments. In addition, instruments would provide reliable information on variations in the amount of solar radiation reaching the Lander location.

Advantages: Proposed investigation should provide a relatively simple, reliable, straight-forward, rugged means of obtaining scientific information about surface and atmospheric characteristics of Mars.

WE RECOMMEND that NASA consider the scientific merit of supplementing all pertinent spacecraft instrumentation intended to obtain pictorial images of celestial bodies, with photometric devices capable of recording absolute values of surface brightness within the applicable field of view. The scientific value of such an approach applies regardless of the experimental objective; e.g., planetary spaceprobes, orbiting geophysical and astronomical observatories, or manned exploration of the Moon.

4. Further Studies

There are many worthwhile further investigations that could be suggested as appropriate follow-on to our own contractual study. In the light of stringent budget limitations, however, our recommendation below concentrates on those possibilities that promise maximum scientific returns from the more efficient utilization of available resources with minimum additional expenditures.

WE RECOMMEND that NASA request its advisory panels to assess the potential scientific merits of the three recommendations made above, as well as the future support of such studies as:

a. Laboratory and field investigations of photographic threshold phenomena in astronomy, and the development of better photographic plates and films for low light-level uses in astronomy.

b. Conduct ground-based observation of the Venus cusp phenomenon during future inferior conjunctions, combined with reference observations of Mercury, to assess the presence of temporal changes in the physical state of the atmosphere of Venus. Of special value would be a program involving the participation of a number of observatories with telescopes of various properties.

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