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AIRBORNE PLATFORM MEASUREMENTS

by

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INTRODUCTION

The purpose of this presentation is to outline the capabilities of aircraft for scientific research. Because of time limitations, the discussion will be restricted to jet aircraft which operate at altitudes of 10 km (33,000 ft) or higher. It is recognized that a large number of other aircraft have been instrumented for scientific research, most of them for meteorology up to 6 or 7 km (22,000 ft).

Because of my personal knowledge, I will use as primary examples the aircraft operated by the Ames Research Center of the NASA (this Center is located about 60 km south of San Francisco). This is not in any way intended to minimize the importance of other similar aircraft, and I will try to indicate also what these other aircraft are doing. I should mention, however, that the NASA aircraft are operated specifically for guest investigators, so that they are the most accessible and responsive to requirements from scientists from universities and other non-NASA organizations, both from the United States and from foreign countries.

Finally, because of the nature of this Symposium, I will put primary emphasis on the uses of aircraft for astronomy. I will mention more briefly the other principal research areas, which are: auroras, cosmic rays, geomagnetic fields, airglow, meteorology, earth resources.

FIGURE 1

The first three aircraft listed are small, short range jets which can accommodate some 200 to 500 kg of payload plus one to five people, including the flight crew. The first two are modified military aircraft used primarily for meteorology research. The Lear Jet is a small business executive aircraft used by NASA primarily for aeronautical research, but it is also available and used for astronomy, where its altitude capability is particularly valuable.

The Convair 990 is a medium range, four-engine jet transport which, in airline operations, carries about 100 passengers. In research usage, it has typically carried about 6500 kg of scientific instruments plus 40 people. The electrical power available to experimenters is about 40 KVA at 400 Hz and 12 KVA at 60 Hz.

The NC-135 and KC-135 are military versions of the Boeing 707 aircraft used by many airlines. They are slightly larger than the CV-990, but otherwise very similar in their research capabilities. The three NC-135 aircraft are limited in performance by their heavy semi-permanent payload, much of which is designed to monitor and study nuclear explosions; these aircraft have also been used to study solar eclipses, cosmic rays, and auroras. The KC-135 is used for studies of earth infrared radiation, geodesy, and electromagnetic phenomena (including cosmic rays, auroras).

The U-2 and B-57-F are very small payload, high altitude aircraft used primarily for meteorological (cloud physics) research. They accommodate one or two people and about 100 kg of research equipment.

FIGURE 2

This is a picture of the NASA CV-990, parked in front of the VARIG maintenance hangars in Porto Alegre. The black squares near the top are special cut-outs which accept optical glass for astronomical and similar measurements. The other large aircraft (KC-135 and NC-135) are generally similar, but have different sizes and arrangements of windows.

FIGURE 3

This is a close-up of the special windows in the CV-990. These are at 65° elevation, on the port (left) side of the aircraft. We also have some zenith and nadir windows and have modified some of the passenger windows (14° elevation) to accept optical glass. The second and fourth (from the left) 65° windows shown on this picture have mechanical shutters, actuated from the inside, to protect the glass from weather and dirt when not in use (shutters shown closed in this picture). The first, without shutter, is shown with optical glass; the third is closed by a plate of a type which we often use for mounting external instrumentation, such as temperature probes, air samples, etc.

FIGURE 4

This list is an actual record of CV-990 programs, and it is also a good representation of typical uses of jet aircraft for scientific research. The astronomical items are self-explanatory. Telescopes and detector systems are installed aboard the aircraft which is then flown at the appropriate times and locations to view the objects of interest. The sky background measurements have yielded valuable data on telluric atmospheric transmission, to be discussed further later.

Under the meteorology heading are included cloud physics, energy exchange between the earth and the atmosphere, and terrain and resources mapping by infrared and microwave techniques. The various mapping devices (infrared, microwave, radar) are to be used aboard spacecraft for remote determinations of planetary organic and mineral constituents.

The CV-990 is presently in the midst of its first aurora expedition. The other large aircraft (KC-135 and NC-135), however, have made extensive studies of auroral phenomena, geomagnetic fields, and cosmic rays in various parts of the earth. In particular, the simultaneous occurrence of symmetrical auroras at magnetically conjugate points was demonstrated by coordinated flights by two aircraft at these points; it was interesting to see that the expected distortion by the solar wind did not occur.

FIGURE 5

Since I will concentrate on astronomical applications, a few additional important aircraft characteristics need to be mentioned. This figure shows a typical stability record for the CV-990 (applicable also to other large jet aircraft) with a well-adjusted autopilot. The principal motions are under ±15 arcmin in amplitude, except for a slow (period of about 100 sec) roll motion of ±45 arcmin. The faster motions have a period of about 5 sec.

These motions can be compensated down to ±3 arcmin by hand guiding and to ± a few arcsec by automated techniques.

FIGURE 6

Two means of image stabilization are illustrated on this picture. The one in the foreground is a gyrostabilized mirror which moves so as to counter aircraft motions and keep the light from the window (overhead) reflected steadily down along the axis of the optical and recording instrumentation, which is fixed in the aircraft (in this figure, the first optical element is in the black ring to the left of the mirror). This system gives a line-of-sight stability of ±10 arcsec, even in light turbulence.

The white tube at the left of the figure is a telescope mounted in a gyro-controlled set of gimbals and pointed directly at the overhead window. In this case, the detectors must be mounted on the stabilized platform, and they move with the optics. This system has yielded about ±30 arcsec image stability with a moving weight of about 40 kg.

Both of these stabilization systems could be refined to yield ±2 to 5 arcsec stability, but we have not had the need to do so.

The equipment shown is fairly typical of astronomical instrumentation carried aboard large aircraft, in addition to racks of electronic support equipment. Some ten to twelve such installations plus about 40 people can be carried aboard the large jet aircraft (CV-990, KC-135, etc.).

FIGURE 7

Precise navigation is essential to nearly all research programs. In general, one can expect to be at best within a radius of five nautical miles (five minutes of arc) of planned position after a flight of several hours without ground support. The timing may be wrong by several minutes, depending on how well the winds are known.

The 1966 eclipse flights may serve as an example of some navigation problems. No ground support, such as LORAN, was available; weather (particularly winds) reports were sparse and unreliable. The south polar jet stream was in the eclipse intercept area and severe wind shears were encountered, so that the winds ranged from 50 to 200 knots and varied by 90° in direction along the flight path. The problems were further complicated by the fact that five aircraft intercepted the eclipse in the same area, and over 20 rockets were being fired near that area. Both collisions and contrail interference had to be avoided.

It was agreed that the NASA CV-990 would take-off early for a weather reconnaissance and radio the information to the other aircraft. The primary desired intercept area was chosen slightly east of the point of maximum totality in order that the aircraft be out of the rocket danger areas before impact. The weather in the primary area was found to be clear, so that there was no need to continue the reconnaissance eastward, and the CV-990 returned to get a position fix on the ship "Oceanographer" and on land and compute back what the winds were along the flight path (the CV-990 was not equipped with Doppler radar at that time).

The three AEC aircraft (LASL, LRL, Sandia) came up from Buenos Aires and flew below and behind us on the final leg. The AFCRL aircraft flew in from Rio de Janeiro, went much further east, and intercepted the eclipse flying westward exactly below the CV-990; they were supposed to be 14 nautical miles north of us, but, computing back from the observed eclipse contact times, we found that they were five miles south of their planned course, while we were nine miles north of ours. A late shift to higher altitude by the CV-990 to avoid collision was partly responsible for the northward error because of the great wind variability as a function of altitude (we reconnoitered between 11.3 and 11.9 km and flew the final leg at 12.5 km).

FIGURE 8

This figure shows the significance of altitude for astronomical observations, particularly in the infrared. The measurements were obtained by three techniques which gave results in good agreement: sky temperature measurements at 1 mm, sky temperature at 10 μ, and examination of moon spectra from 1 to 3 μ.

The sky temperature formulas permit extrapolation above 12.5 km (CV-990 ceiling altitude); these estimates were confirmed up to 15.2 km by actual measurements from the Lear Jet.

It would appear from these data that an altitude of 1 to 1.5 km (3 to 5 k ft) above the nominal tropopause is sufficient to reach a level beyond which little further improvement is obtainable by small increments in altitude.

FIGURE 9

Referring back to Figures 1 and 8, one sees from Figure 9 that the type of aircraft we have considered can get above most of the telluric water vapor in temperate zones and higher latitudes. The same general numbers hold also for southern latitudes.

FIGURE 10

This figure shows very strikingly the advantage of airborne measurements in the near infrared. Only four of the dips seen on the 12.5 km curve are telluric absorptions; all other features have been identified as solar lines.

FIGURE 11

In the submillimeter region, the only transmission window from the ground is the one around 300 μ with about two percent transmission. The data in this figure are not completely calibrated, but we estimate the peak transmissions to be above sixty percent.

FIGURE 12

This example of a recent result obtained from the NASA CV-990 has told us that the water vapor content of Venus' atmosphere is 1 μ; previous estimates had ranged from 20 to 400 μ. (Data are available with about three times better resolution than could be shown on this figure.)

FIGURE 13

Aircraft altitude gives a considerable advantage even in the region where the atmosphere is considered transparent, mostly because of reduced scattering. The original solar spectra from which this figure was derived have a resolution of 1 to 2 Å, and the intensities were absolutely photometrically calibrated.

FIGURE 14

This is another way to show reduced sky brightness in the visible region of the spectrum, with particular application to solar eclipse work. One can expect to see at most to 1.3 solar radii from the center with a coronagraph on the ground; to 3.5 radii during eclipse; and to 9 radii during eclipse at 12.2 km (40 k ft). By using the near infrared, around 7,000 Å, the corona has been photographed (from the CV-990 aircraft) to 14 radii.

FIGURE 15

This figure summarizes the points which have been discussed and is generally self-explanatory. The only point not previously mentioned is the extended observation time, which is due to the aircraft speed. The usefulness of this for eclipse observations is obvious. For other astronomical work, we note that the speeds of the aircraft considered are such that they can keep up with the earth's rotation at about 60° latitude, and they almost keep up at other latitudes; this permits extended near-transit observations.

CONCLUDING REMARKS

Aircraft have demonstrated their usefulness in many fields of scientific research: astronomy, meteorology, geophysics, and their many subdivisions and related areas. A number of high performance jet aircraft are presently engaged in this type of research in the United States, and many significant contributions are being made to modern science. Aircraft are well suited for many projects which are impractical (technically and/or financially) either from the ground or from space vehicles.

I personally think that the future will see an expansion in airborne scientific research activities. At NASA, for example, we are planning to install a 36-inch (90-cm) aperture telescope aboard the CV-990 for infrared and submillimeter astronomy. Perhaps some day the supersonic transport aircraft can provide large scientific payload capability in the 20 km (70 k ft) altitude range.

SOME JET AIRCRAFT REGULARLY USED FOR SCIENTIFIC RESEARCH IN THE UNITED STATES

AIRCRAFT	ORGANIZATION	TYPICAL SPEED (a) knots (b) km/hr	TYPICAL RANGE (a) n.mi. (b) km	CEILING ALTITUDE km	CEILING ALTITUDE k ft
B 57-A	U.S. WEATHER BUREAU	(a) 430 (b) 800	1200 2200	13.7	45
CF 100	UNIVERSITY OF MICHIGAN	(a) 400 (b) 740	870 1600	12.2	40
LEAR JET	NASA	(a) 480 (b) 890	1200 2200	15.2	50
CV 990	NASA	(a) 490 (b) 910	3300 6100	12.5	41
NC 135	LASL, LRL, SANDIA	(a) 450 (b) 830	3500 6500	11.3	37
KC 135	USAF-CRL	(a) 480 (b) 890	7000 13,000	13.7	45
U2, B 57-F	USAF-CRL			~21	~70

M. BADER -- FIGURE 1

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M. BADER -- FIGURE 2

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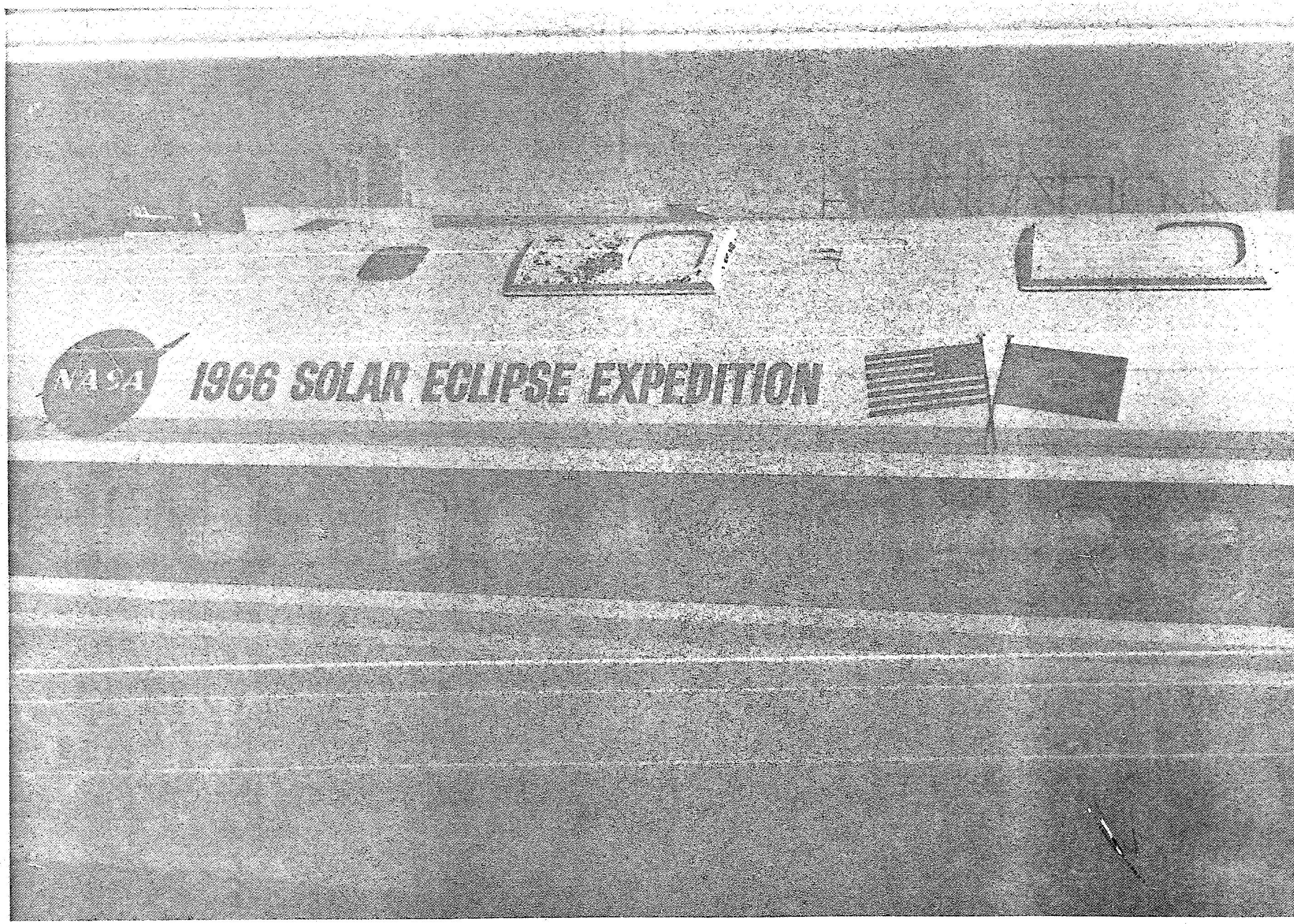

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CV-990 SPACE SCIENCES PROGRAMS

APRIL 1965 - APRIL 1968

- 1965 AND 1966 SOLAR ECLIPSES
- IKEYA-SEKI COMET
- LUNAR LIBRATION CENTERS
- METEOROLOGY (1966, 1967)
- RADAR AND MICROWAVE TERRAIN MAPPING
- SKY BACKGROUND IR MEASUREMENTS
- MOL CREW VISUAL TRAINING
- APOLLO HAND SEXTANT DEVELOPMENT
- SOLAR SPECTRUM 0.3μ TO 2mm
- PLANETARY IR (MARS, VENUS, JUPITER, SATURN)
- STELLAR IR (ORION NEBULA, α-ORIONIS, SIRIUS)
- AURORA BOREALIS

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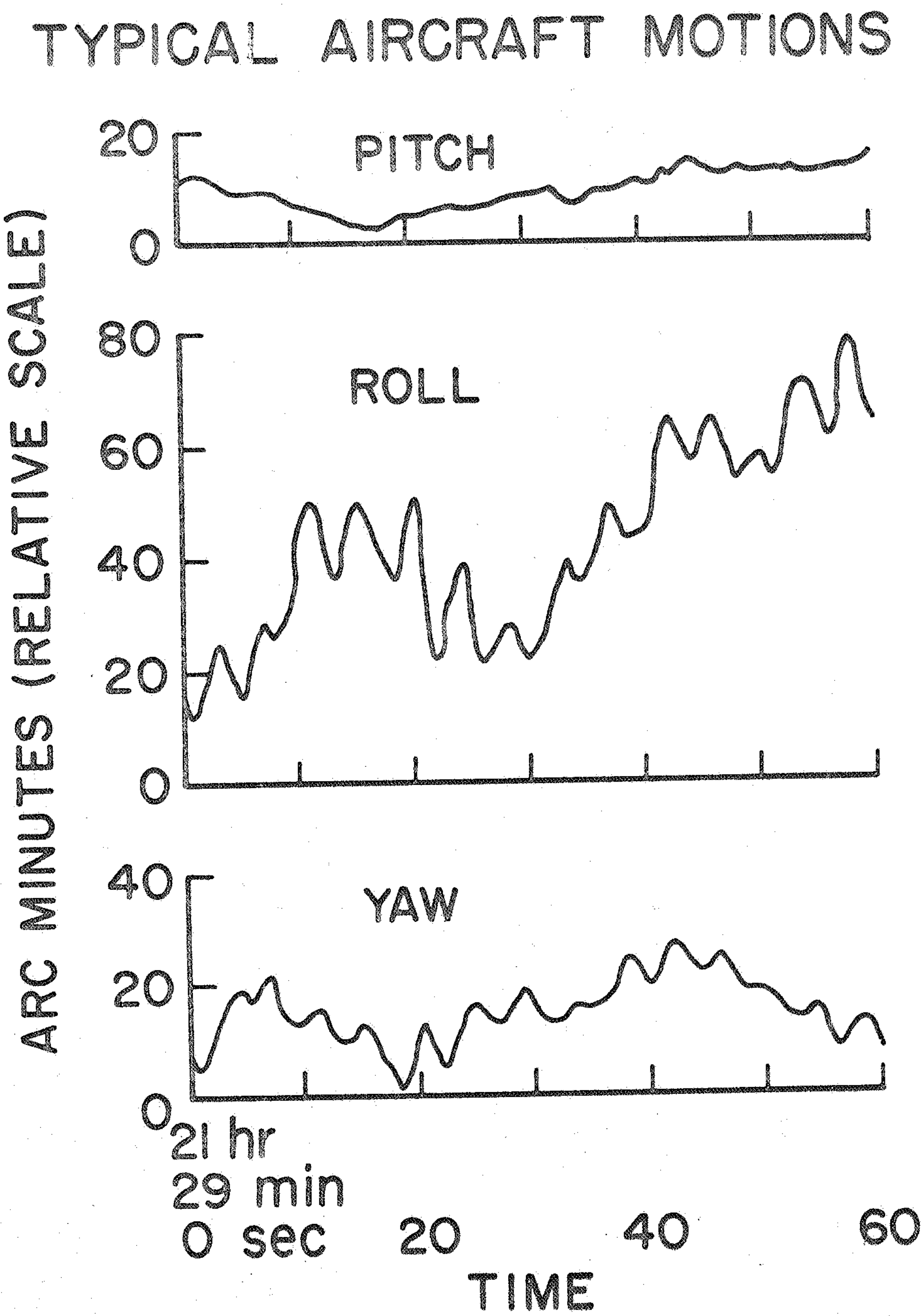

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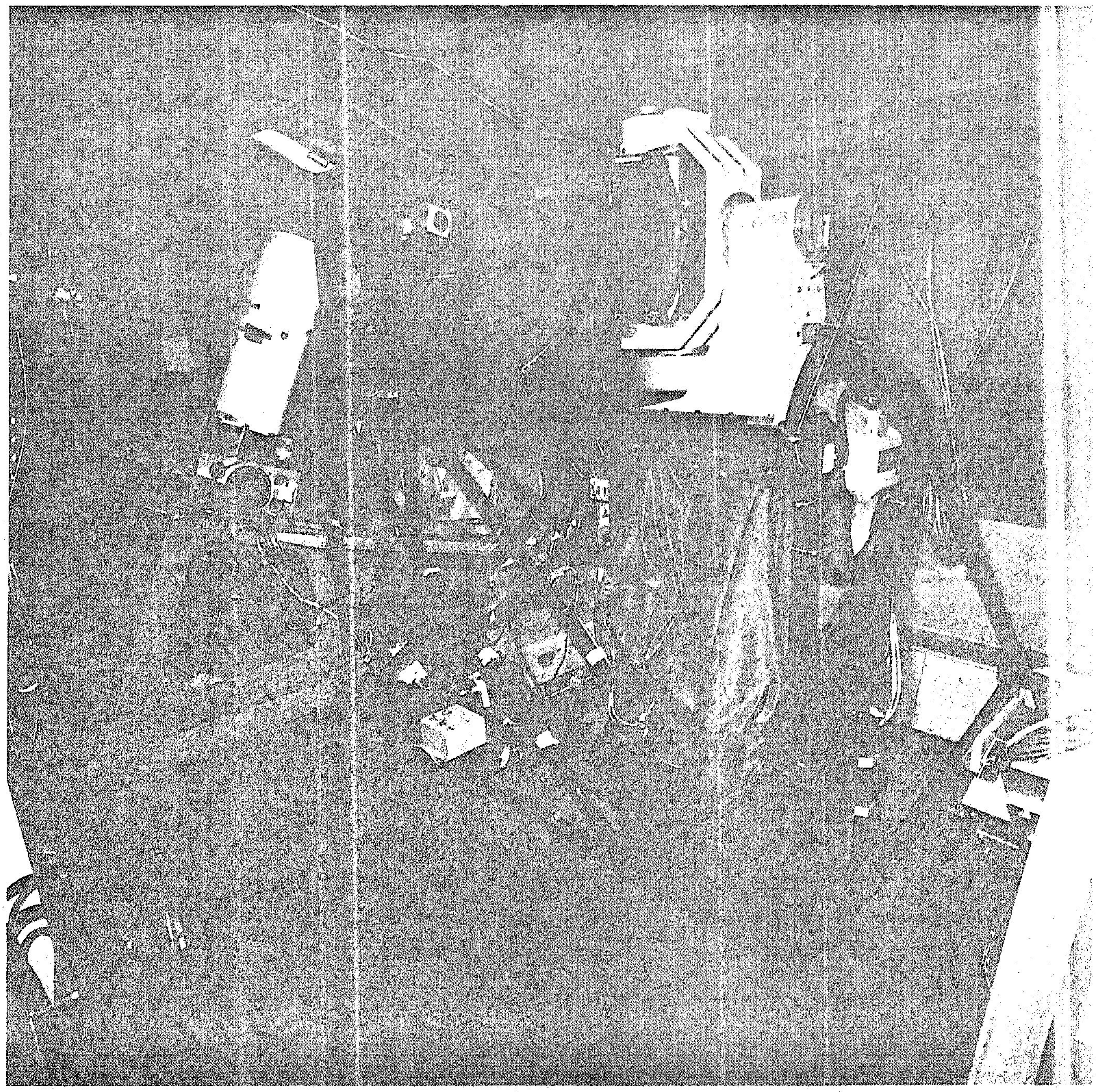
M. BADER -- FIGURE 5



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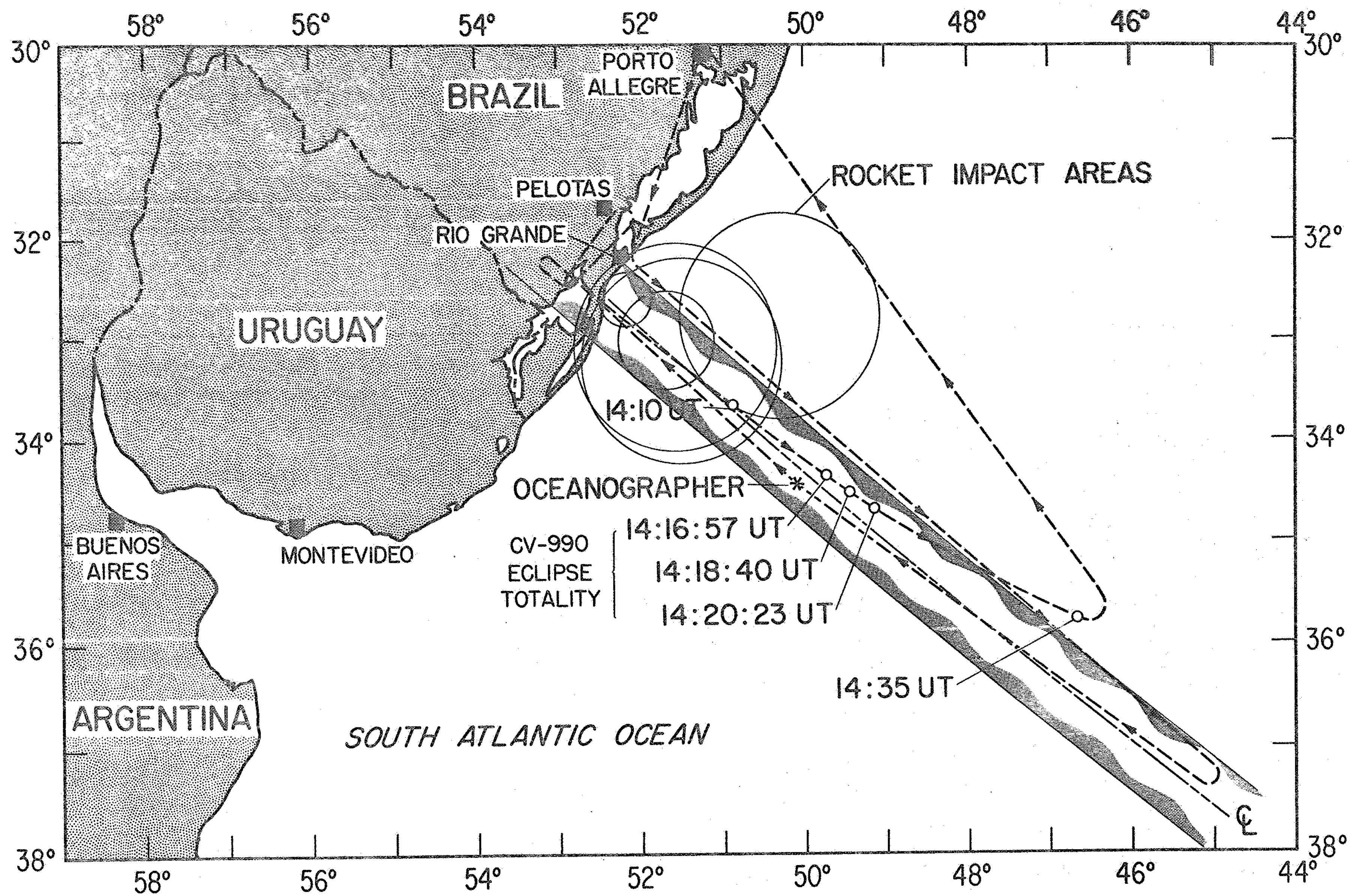
M. BADER -- FIGURE 6



M. BADER -- FIGURE 7

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OVERHEAD WATER VAPOR

TROPOPAUSE: 36 - 38 k ft (11.0 - 11.6 km)

LATITUDE: NEAR 38° N (SAN FRANCISCO)

TIME: SPRING, SUMMER, FALL - 1967

MOUNT WILSON OBSERVATORY			7000μ (WINTER)
CATALINA OBSERVATORY			750μ (WINTER)
CV-990:	k ft	km	
	30	9.1	80μ
	40	12.2	8μ
	45	13.7	$2-3\mu$
	50	15.2	$1.5-2.5\mu$

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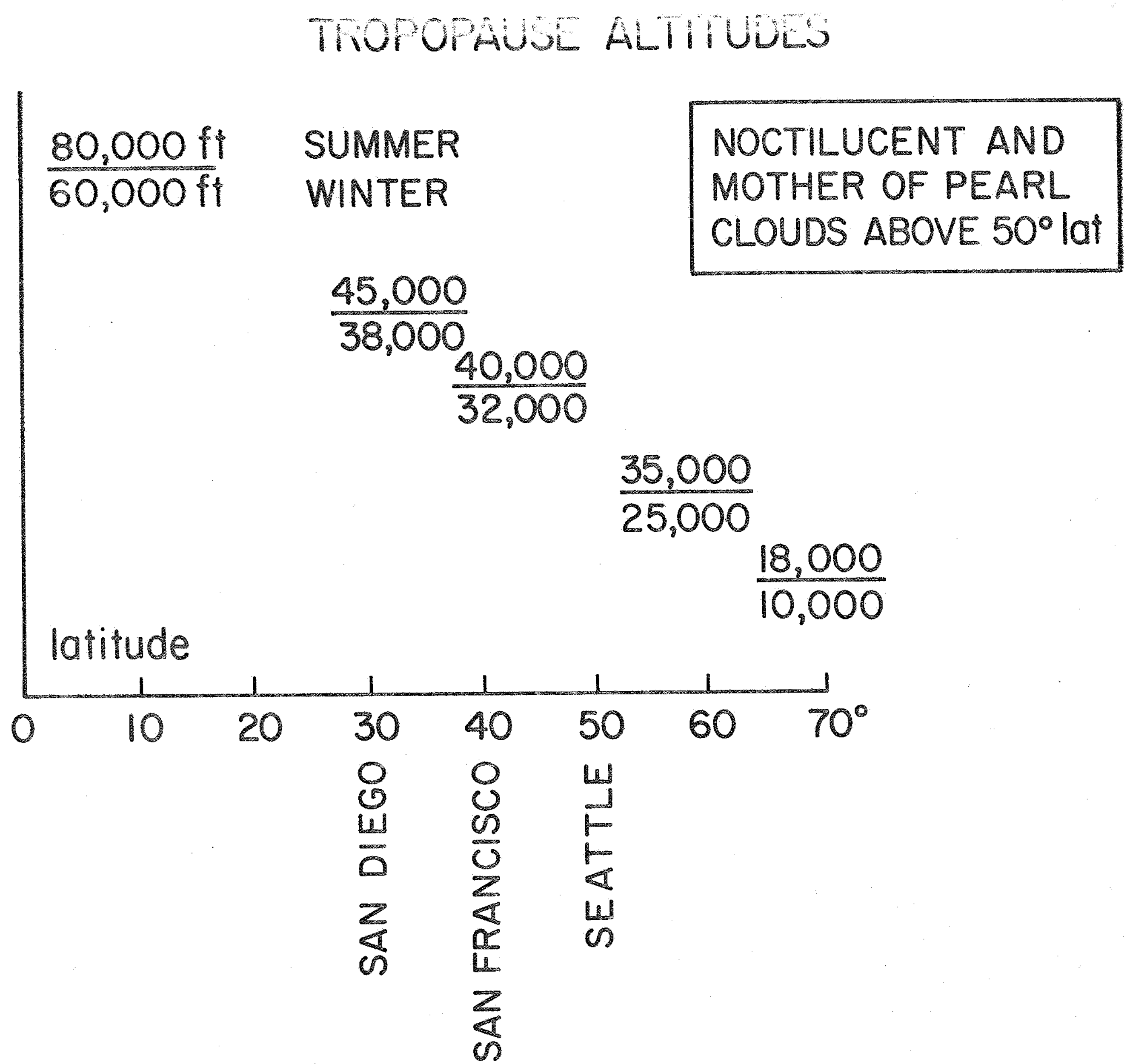

M. BADER -- FIGURE 9

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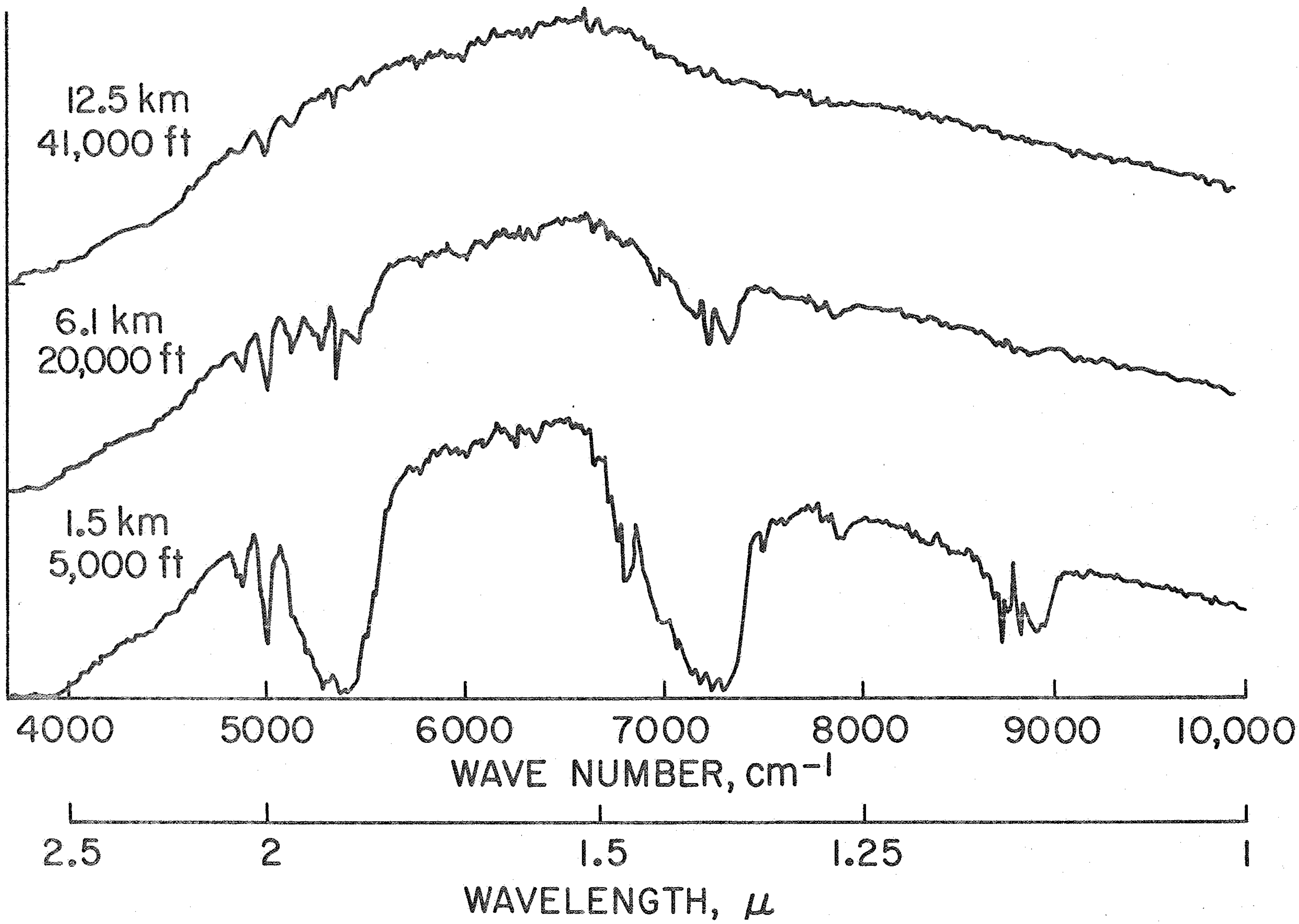
SOLAR SPECTRA



M. BADER -- FIGURE 10

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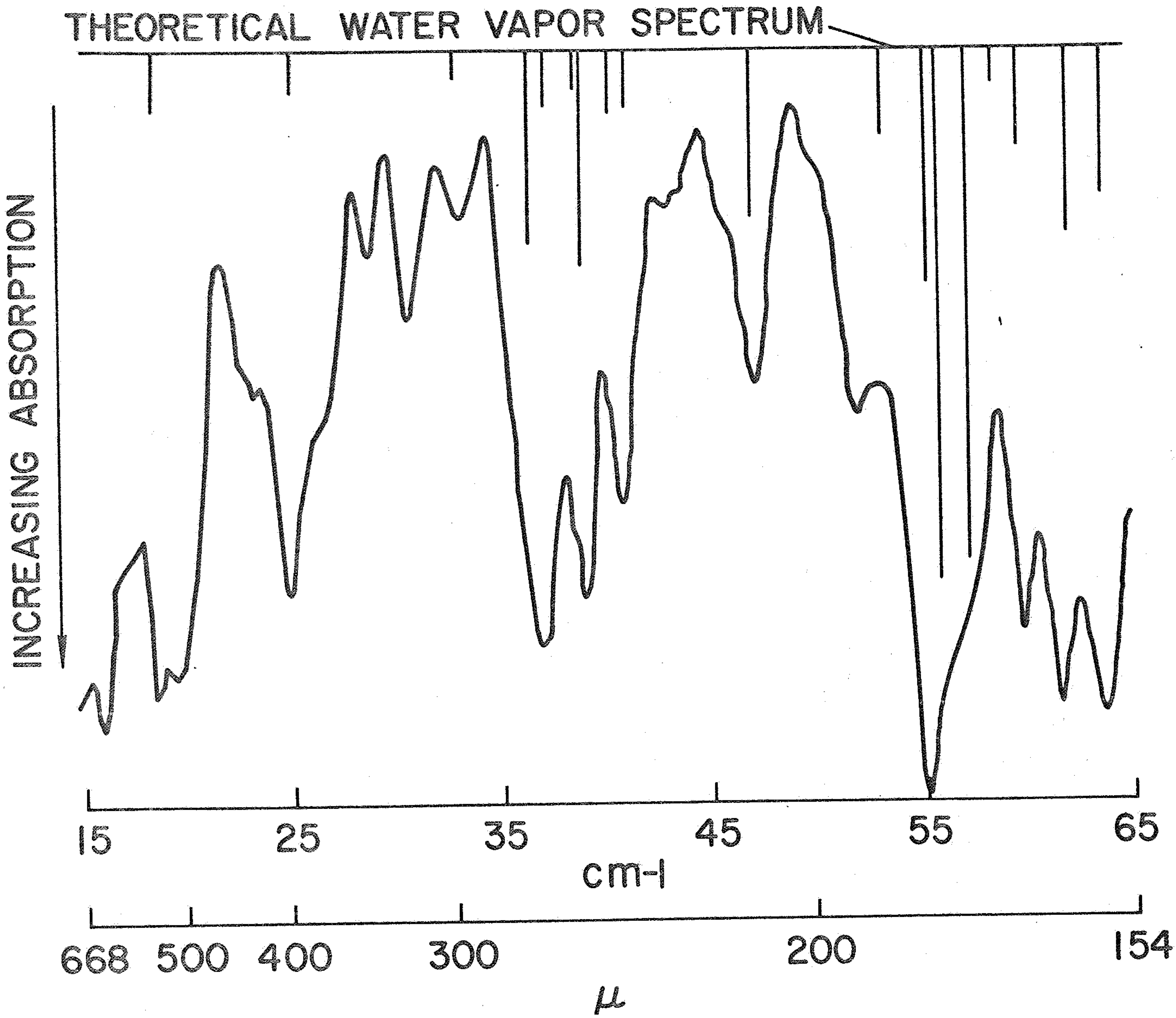
SKY SPECTRUM AT 12km ALTITUDE



M. BADER -- FIGURE 11

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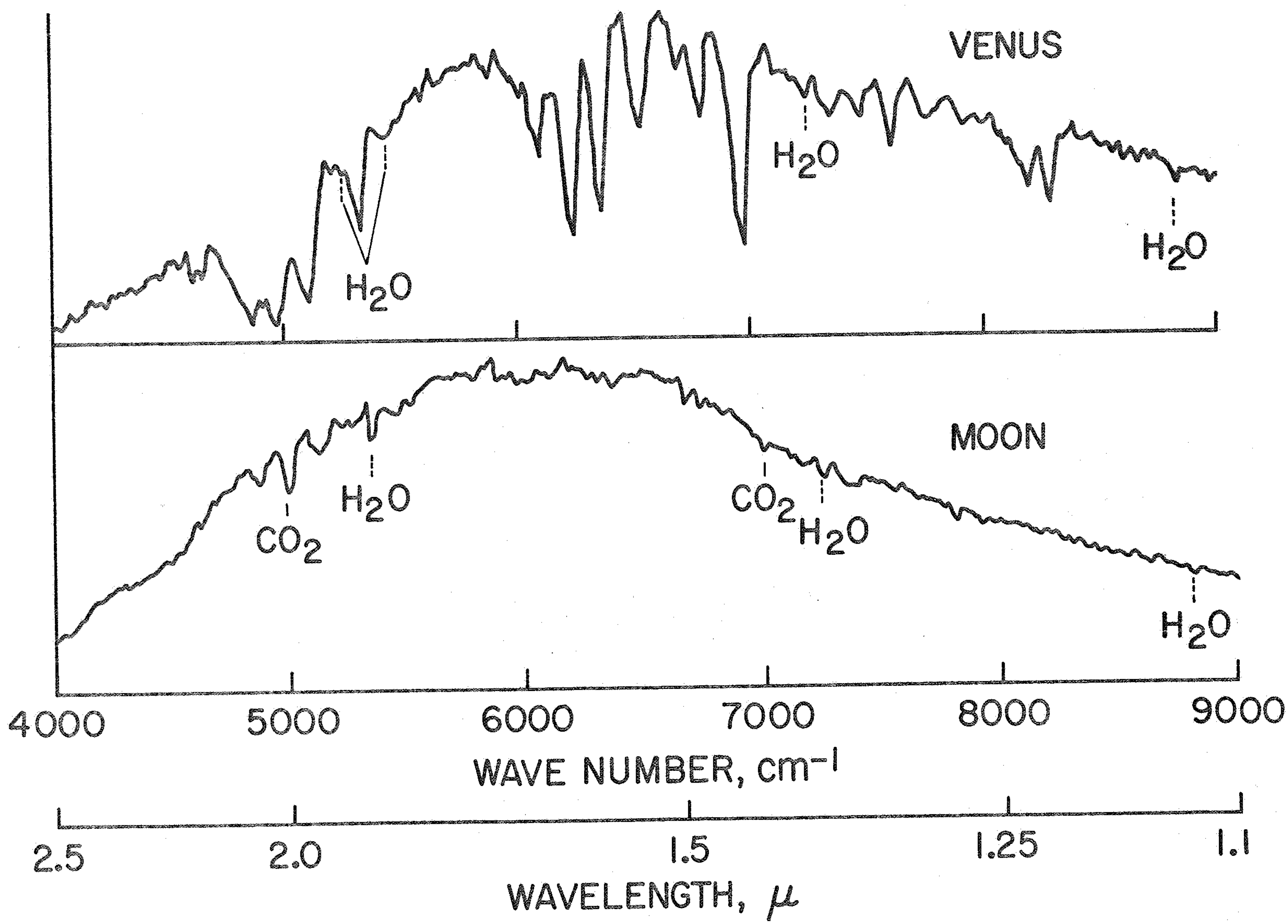
AAA615-1

VENUS AND MOON SPECTRA

λ 1.1–2.5 μ, ALTITUDE 11.3 km, TEMPERATURE = -52°C



M. BADER -- FIGURE 12

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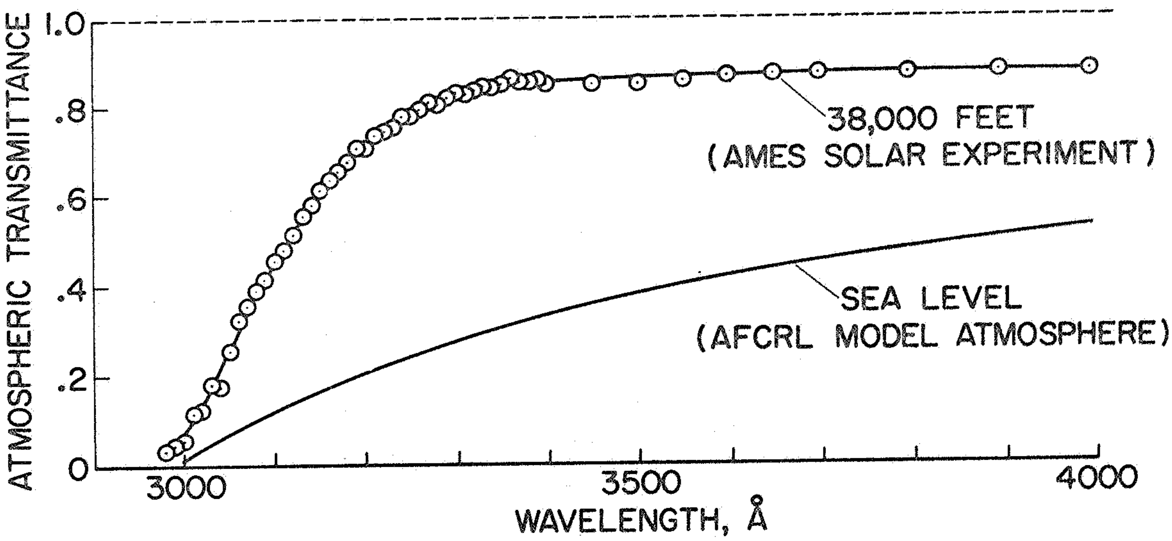
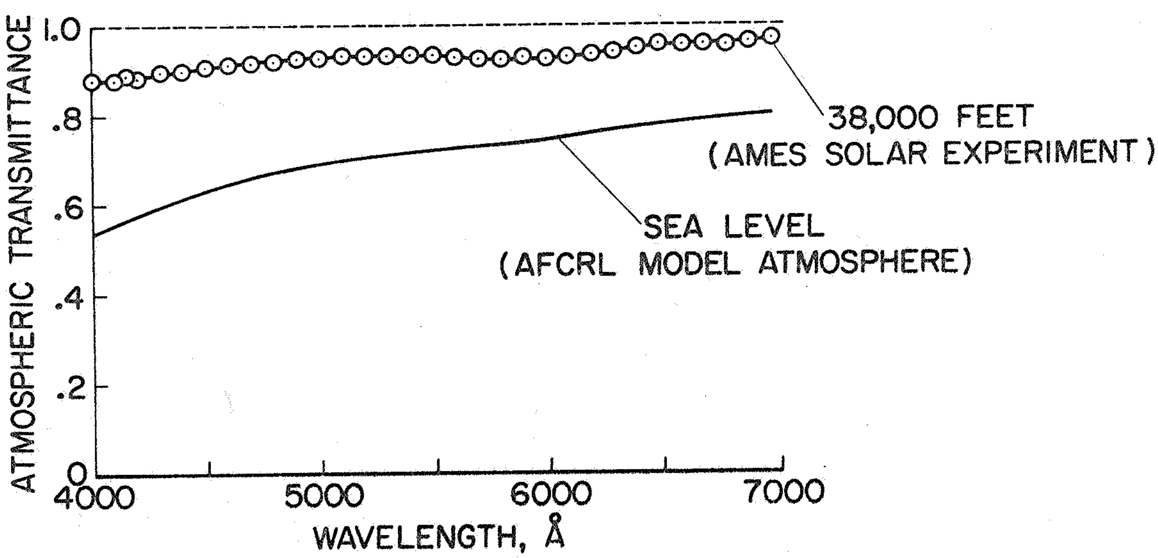
ATMOSPHERIC TRANSMITTANCE FROM SPACE TO 38,000 FEET
ULTRAVIOLET REGION

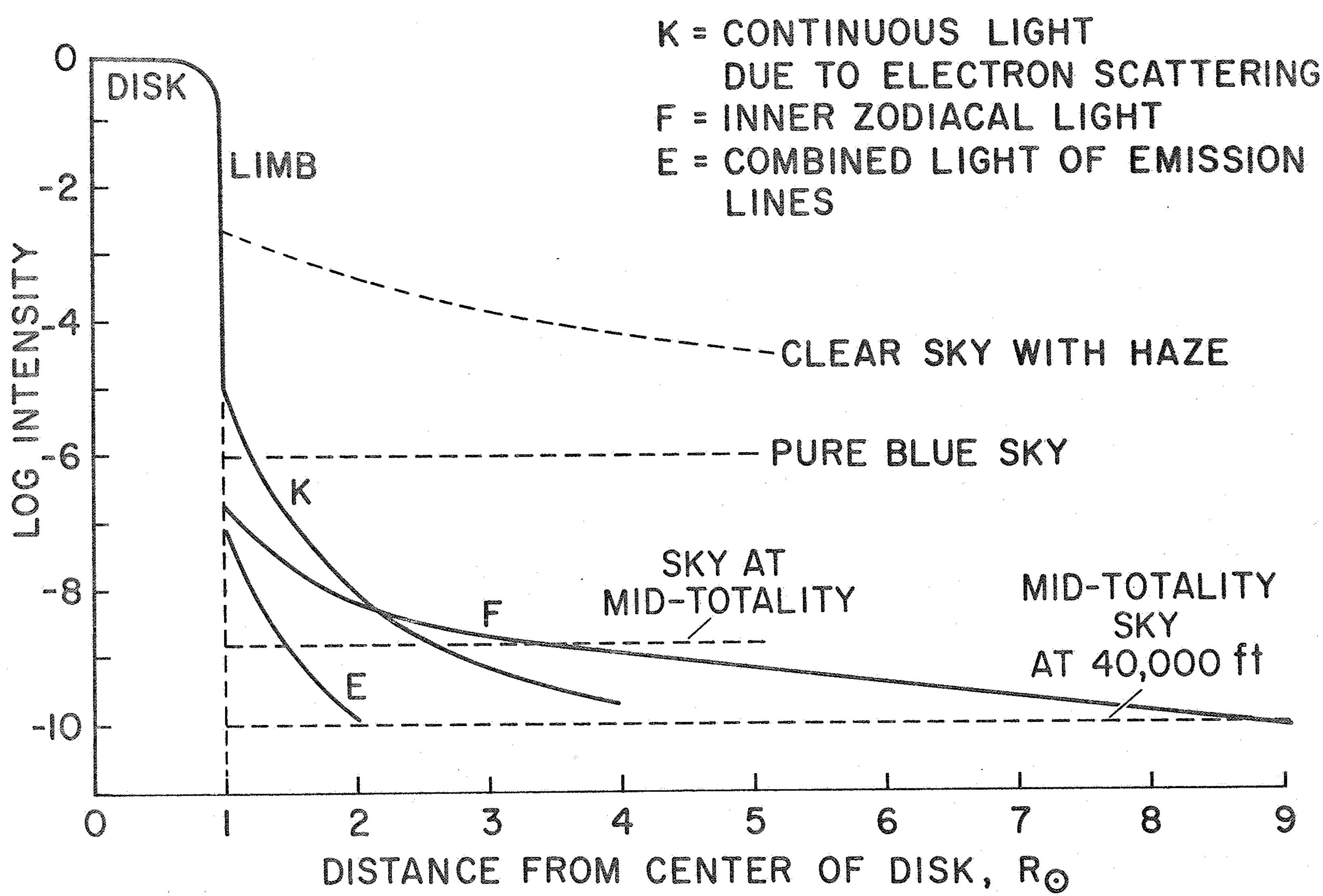


ATMOSPHERIC TRANSMITTANCE FROM SPACE TO 38,000 FEET
VISIBLE REGION



M. BADER -- FIGURE 13

RELATIVE CORONAL AND SKY INTENSITIES



M. BADER -- FIGURE 14

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ADVANTAGES OF AIRBORNE ASTRONOMY

A. COMPARED TO BALLOONS, ROCKETS, SATELLITES

- RELATIVELY SHORT-NOTICE, INEXPENSIVE OPERATION–DAILY IF NEEDED
- LARGE PAYLOAD AND PLENTY OF POWER AVAILABLE
- PERSONNEL ABOARD FOR DECISIONS, REPAIRS, ADJUSTMENTS
- COMPLETELY RECOVERABLE SYSTEM
- DISADVANTAGE: SOME REMAINING TELLURIC ATMOSPHERE

B. COMPARED TO GROUND

- FREEDOM FROM CLOUD COVER
- EXTENDED OBSERVATION TIME
- CHOICE OF LATITUDE AND LONGITUDE
- REDUCED SKY BRIGHTNESS (OR TEMPERATURE) AND SCATTERING
- IMPROVED ATMOSPHERIC TRANSMISSION
- REDUCED LINE BROADENING AND BLENDING

M. BADER -- FIGURE 15

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