ADELPHI UNIVERSITY

FINAL REPORT

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"PHOTOGRAPHIC SEARCH FOR COMETS DURING 12 NOVEMBER 1966 SOLAR ECLIPSE"

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INTRODUCTION

Under a NASA grant to Adelphi Unviersity a four-man team set up and operated a ground-based photographic station near Bagé in southern Brazil at the centerline of the eclipse path on 12 November 1966. The principal goal for the effort was a search for small, bright comets in the vicinity of the Sun.

Our best information indicates that ours was the only ground-based search for comets during the 1966 total solar eclipse. Wesleyan University (Van Vleck Observatory) supported an airborne observer under a NASA grant, but due to technical difficulties at the time of totality, his data is inconclusive. The lack of confirmation data for our findings will of necessity control the depth of our conclusions. Some hope is held that upon circulation of the Adelphi results other observers, who may have unknowingly acquired data of interest to us, will come forth, perhaps from among the South American astronomical community, perhaps from other airborne observers.

Statistically, one might anticipate the presence of several cometary objects within a few degrees of the Sun at any given time. The majority of the predicted objects are not expected to be very bright, or more exactly, could not have been very bright as they approached the Sun otherwise previous detection would have been probable. Of course, an exception would be a comet which had an approach trajectory lying very near to superior conjunction with the Sun. One might conclude that any objects discovered during the search either belong in the latter classification or are intrinsically faint and will be detectable only because of immediate proximity to the Sun.

SUMMARY

Support of the remote observation effort in a relatively remote corner of southern Brazil was accomplished in an efficient and relatively inexpensive manner. The majority of the equipment was shipped from the United States, relying on local procurement only for batteries and fuel. In general the equipment proved adequate for the task, only minor difficulties being experienced with a single, slightly defocused camera.

Reduction and analysis of the photographic plates was completed by early June 1967. Subsequently, the raw plates were rescanned with a view toward confirming the earlier conclusions.

Ten extremely faint images have been found on various combinations of photographic plates and have so far defied identification with known stellar sources. The only positive statement one can make is that there were no bright cometary bodies in the vicinity of the Sun at the time of eclipse, i.e. brighter than sixth magnitude.

Selective filtering was employed in combination with a wide spectrum of exposure times. If one were to interpret the ten non-stellar images in terms of the filters which were chosen specifically to emphasize the classical cometary emission bands, one might state that there is some evidence for suspecting the presence of a number of small, faint

cometary bodies. Positive claims at this time, based on the very tenuous evidence, must be avoided. To date, confirmation data, separated in terms of time and distance, has not been uncovered. Unless such data is forthcoming from other eclipse observers who may have inknowingly made such recordings, we are left with observations from only a single station.

The observational experiment did meet with some degree of success. There is sufficient evidence to support the original prediction for the existence of solar-proximate comets to warrant further experimentation during the next total solar eclipse.

EQUIPMENT

Six photographic systems were employed by the Adelphi team to record the 1966 total solar eclipse:

(a) three (3) modified K37 aerial cameras, 300 mm fl, f 2.5, sidereally driven mount

(b) one (1) modified K40 aerial camera, 1200 mm fl, operating at f 7.1, sidereally driven mount

(c) one (1) five inch refracting telescope, attached to the K40 system, and recorded on 35 mm film.

(d) one 35 mm Leica with 400 mm telephoto lens, stationary mount. (see Plate 1)

The K37 and K40 systems were selected for the comet search for several reasons. Primary among these is the wide field of view, approximately 50 and 11 degrees, respectively, and their ready adaptability to 8 x 10 inch glass photographic plates. Secondly, and of great financial attractiveness, was the immediate availability of a complete set of cameras and mounts from the Grumman Aircraft Engineering Corporation on loan at no cost to Adelphi or the National Aeronautics and Space Administration. Further, a good deal of experience had been acquired with these particular types of cameras in photographing star fields, and the total solar eclipse of 1963. (Plate 2 shows the crated equipment upon arrival at Bagé in Brazil.)

At a later point in this report the particular disadvantages of employing the Aero Ektar lenses, with their poor spectral transmission in the shorter wavelengths, will be discussed. Positive recommendations for updating and improving the selection of equipment for future experiments of this type will be set forth in some detail.

Redundancy has been mentioned previously as one of the basic concepts employed in planning the field expedition. To assure high reliability, standby modes for driving the camera shutters and tracking mounts were designed into the system. The primary power system consisted of two 12 volt lead-acid, automobile-type batteries wired in parallel with quick disconnects. Both batteries were at full charge on the morning of the event. Either battery was able to carry the entire load independently, with just a few seconds required to cut a questionable unit off the line. The 12 volt d.c. battery power supplied current through hand-held pickle switches to directly drive the rotary solenoids which operated the camera shutters. The bank of three K37 cameras were controlled by a single operator, although an additional man was required to service one camera with fresh cassettes. The shutter controller serviced two cameras. The K40 camera was serviced and controlled by a single operator.

During the photographic operation the sidereal drives were powered indirectly from the lead-acid batteries through a solid state converter which produced a 60 hertz signal at 120 volts for the synchronous motors in the drives. On immediate standby was a 1000 watt gasoline generator which had, besides lts 120 VAC capability, a 12 VDC tap. Had the battery system malfunctioned quick disconnect clips would have transferred both sidereal drives and shutter operations to the standby generator.

As mentioned previously the change of film cassettes was entirely a manual operation. Switching of filters was handled in a like manner.

DESCRIPTION OF THE EVENT

The total solar eclipse of 12 November 1966 began at $12^h\ 45^m$ U.T. or 10:45 A.M. local time. The sun was approximately 68 degrees above the northern horizon and the sky quite clear except for a few percent coverage with high thin cirrus clouds.

Using Kodak 2475 recording film on .060,8 x 10 inch glass plates, three exposures were made at 5, 10, and 15 seconds, respectively with the K37 cameras designated "A" and "B". Two were made on camera "C", which jammed part way through the second exposure. Camera "D", the 48 inch K40, recorded five exposures during the phase of totality with individual exposure times of 2, 5, 10, 15, and about 16 seconds, respectively. (A K40 photograph is reproduced on Plate 3.)

During the totality exposures Corning optical filters 4-72, 3-71 and 3-66 were interchanged among cameras A, B, and C. Camera D operated unfiltered. Effectiveness of the filtering techniques will be discussed under "Data Interpretation".

At third contact, 118 seconds after totality began, it became apparent that the sky clarity had deteriorated noticeably. This was not at all apparent visually during the total phase. One suggestion is that the moisture laden upper atmosphere (it had been heavily overcast for a week prior to the eclipse) condensed out its moisture in the form of ice crystals at very high altitude upon rapidly cooling during solar obscuration. A hand-held 35 mm camera recorded the 25 degree wide ring around the just-covered sun a few seconds after third contact. (see Plate 4)

(Plate 5 was taken with the 400 mm fl Leica camera.)

DATA REDUCTION

Initial inspection of the developed plates was very disappointing, indeed. After a few minutes it was easy to conclude that there were no very bright comets.

Star-like images down to approximately sixth magnitude were discernible upon careful scrutiny. Closer examination with a strongmagnifier over a very bright light box began to reveal extremely faint star-like images, especially near the center of the plates where sharpest focus had been achieved.

A first attempt was made to identify the images by over-laying the negatives on transparancies of the Skalnate-Pleso maps which we had especially reproduced to match both the 12 and 48 inch camera scales. With the exception of a few of the brighter stars most of the images on the negatives were too faint to discern through the overlay transparency. In fact, the majority of the star-like images seem too faint for employment of standard astronomical blink techniques.

Several methods were investigated for locating the images in some sort of coordinate system for the intraplate comparison. Each proved inadequate or extremely time consuming. The images of objects down to approximately +9 visual magnitude are, without much question, on the plates but could only be observed with a 10 power magnifier in perfect focus with the emulsion and then only when strongly backlighted. The intensity of the backlighting source necessitated masking all but a small circle to reduce the total illumination falling on the eye of the viewer. In spite of this precaution the plates could only be inspected for short periods of time each day without severe eye fatigue.

Working through the restricted aperture permitted inspection of small areas of the plates, but precluded all but the crudest spatial reference for the images. Consequently, a rather unorthodox procedure was developed. The plates, mounted emulsion side away from the observer, were suspended from the edges to avoid scratching from contact with the light box. Upon locating an interesting image through the magnifier a small circle was made directly on the non-emulsion side of the glass plate with a fine-pointed, felt-tipped marking pen. Each plate gradually became covered with twenty five to thirty circles.

Next, clear acetate sheets were overlaid on the negatives and the circles transcribed, each negative having its own acetate. We now had reasonable facsimiles of the eclipse plates for comparison, an accomplishment which could not have been achieved with photographic reproductions because of the extremely faint images.

The marked up acetate from each individual plate was then superimposed on each of the nine other plates. Where circles had been recorded on the acetate and no matching circle appeared on the original negative a careful search of the immediate area on the negative was initiated. Often a faint image was discovered which had been overlooked during the first examination. The acetate for the negative with the newly discovered image was then updated. Through a number of iterations we achieved a high probability for discovering most of the images on each plate. However, this procedure is somewhat suspect, as marginal images are very subjective.

The process of intercomparing images plate to plate was accomplished by making still another acetate overlay, this time coding the "images" transcribed from the individual acetates. For example, one might find an "image" appearing at the same general coordinates on several plates (actually the acetate facsimiles in this case). Coding the master acetate soon revealed that we were dealing with a number of entities which had been photographed on several plates and, as shall be discussed later on, through various filters. (See Plate 6) As a first cut through the mass of images, a number were eliminated because they either appeared on fewer than three plates (some judgment regarding white light vs. filtered plates was exercised) or were readily identifiable as star images from the Skalnate Pleso or the Bonner Durchmusterung star charts. Several additional images were discarded by roughly measuring their celestial coordinates and then crosschecking with the recently published Smithsonian tables.

Lacking confidence in the completeness of the available star references, and because a significant number of images still remained unidentified a photographic comparison was made during the month of June 1967. A series of additional sky photographs were made of the same area occupied by the sun in November 1966, i.e. centered in the constellation Libra. Not only was the same K40 camera used, but also glass plate film from the same batch secured for the eclipse event. The film had been kept under refrigeration and exhibited no noticeable degradation.

A spread of exposure times was made, with both trailed and tracked images. Those plates which most nearly approximated the depth of the event plates were most carefully scrutinized.

Only one additional image was identified as probably stellar by this method. Should future comet searches be planned it would seem expedient to make the necessary comparison plates before, rather than after, the event.

We were left with ten images, appearing on a minimum of three plates each, which we have not been able to identify as stellar. Known asteroids of similar brightness have pretty well been ruled out by checking their published ephemerides.

The rough coordinates of the ten unidentified objects are shown in Plate 7.

Close scheduling between funding date and departure for South America precluded procurement of specially tailored filters for our cameras, leaving us a choice among commercially-available filters. Three transmission filters by Corning (3-66, 3-71, and 4-72) were selected to give us some differentiation in the brighter cometary spectral bands. The relative bandpasses of the three filters are shown in Plate 8 superimposed over the brightest cometary bands and the spectral transmission window of the optical systems.

During the eclipse event the filters on the three 12 inch cameras were interchanged between exposures. Some of this interchange is shown in Plate 9. Additional changes were made among cameras A, B, and C, but are not reflected in the figure since a number of plates, overexposed at the onset of third contact, were not used in the data analysis.

The film used during the solar eclipse, Kodak 2475 Recording Film, has an essentially flat spectral response over the entire area of interest (out to 0.7 micron), therefore it is not depicted separately on Plate 8.

A simple go, no-go table (Plate 9) has been compiled to show the comparative frequency of appearance of the ten unidentified images on the ten usable photographic plates, crossreferencing at the same time the filters used with the individual exposures. Note that Object No. 7 appears on the least number of plates, i.e. a total of three. Other plate "images" which appeared on less than three negatives were discarded previously. It may be significant that Object No. 7, seen on the least acceptable number of plates, is also the most difficult to interpret in terms of the filter comparison data to be discussed later on. Of the remaining nine objects two appear on at least four plates, three on five plates, one on six plates, one on seven plates, and two on eight plates.

Possibly significant data was lost when camera "C" jammed, although this camera was poorly focused from the outset.

Exposure time was varied during the operation. Of the data plates used from the three 12 inch cameras the first exposure was of five seconds duration, the next lasted ten seconds. The white light camera (48 inch) operated at 2, 5, 10, 15 and approximately sixteen seconds, respectively, and in that order.

When interpreting the data, steps were taken to normalize all the exposure times. This permits a rather easily interpretable display as shown in Plate 10, where the various curves define, in relative exposure time and filter transmission, the probability of having recorded particular portions of the anticipated bright spectral outputs of cometary bodies. For example, the curve designated "Al", referring to the first exposure made on camera "A", is used to determine the possibility of certain cometary bands contributing to the images, namely CN and the three C_2 bands. The sodium band obviously does not lie under the Al curve, therefore, any interpretation of images on this single plate would necessarily preclude this band. One could only state that the possibility for CN and three C_2 bands exists for the objects designated 1,2,4,6,7,8 and 9 (Plate 9).

The experiment, however, was not carried out using a single camera or a single filter. Let us now consider curve Bl, which used a different filter (3-71), and in this instance an identical exposure time. From Plate 10 one sees that C_2 (0,0), C_2(0,1), and Na will be readily transmitted, with a very reduced possibility for C_2(1,0), and no possibility for CN. Photograph Bl has images for object 1, 2, 3, 5, and 9. The same type of interpretation scheme can be applied to plates A2,B2,and Cl. Camera D was operated in white light with the exposures stated previously and can be considered as somewhat of an experimental control. Although the 48 inch system operated at a focal ratio of 7.1, this is an approximate speed equivalency to the 12 inch of 2.5 systems because of the relatively low transmission of the filters. While it is impossible to reconstruct the actual sky conditions one might deduce something relevant from the absence of certain images on the "D" plates. Perhaps the indications are that the atmospheric transmission was lowered locally by high, thin cirrus clouds, thereby attenuating some images and not others. On the other hand we may have an indication for a general, fluctuating attenuation, giving somewhat the effect of a neutral density filter being applied. In superimposing this "neutral density" filter to the relative transmission curves shown in Figure 10 we find that there will be some deviation from the predicted probable presence of specific cometary bands as interpreted solely from the data supplied by the filtered cameras.

Table I shows an approximate time cross reference between the plates exposed in cameras A, B, and C and those exposed in the white light camera (D).

TABLE I

Camera	A, B, C	D
Plate No.	1	1,2
	2	3

The next bit of information is derived from checking the appearance or non-appearance of each of the ten object images on the plates of camera D. The object images which are absent on specific D plates are shown in Table II.

TABLE II

Plate No.	D1	D2	D3
Missing Objects	3	1	3
	7	5	4
		8	7
			10

By making some assumptions regarding exposure duration and cloud obscuration for the white light camera plates and applying these in conjunction with the data from plates A, B and C and the curves shown in Plate 10 we have arrived at the distribution of cometary bands vs. photographed objects shown on Plate 11, i.e. if we assume that we are looking at real objects, and their luminous output is due chiefly to the standard cometary bands rather than a continuum, then we are able to set up the relationships shown in Plate 11.

We might group these objects further in accordance with this interpretation by the following table:

TABLE III

Object No.	Content
1,2,9	all bands
4,6,8,10	CN and $C_2(1,0)$
3,5	$C_2(0,0)$, $C_2(0,1)$ and Na(5 only)
7	$C_2(0,0)$

One might also note that seven of the objects lie within about seven solar radii, the other three within ten. Three are essentially coincident with the ecliptic plane, an additional two lie within 3 solar radii of that plane.

The limiting magnitude of the plates extends between +7 and +9 magnitudes over the areas of interest, with an +8.8V star visible just outside the inner corona, and well within the outer corona.

CONCLUSIONS

From the photographic evidence it is obvious that there were no very bright comets within forty solar radii. The ten images of interest on our plates have not been identified with either stars or asteroids. While the catalog search might have been pursued further, we feel that the comparison plates of the sky made seven months after the eclipse offer rather strong evidence that for the most part the images cannot be stellar.

We are left with a number of interesting possibilities. They are listed in the order of decreasing probability:

(a) small bright comets whose presence could not have been detected as they approached because of low intrinsic luminosity

(b) ordinary cometary bodies which approached the Sun from a superior conjunction position, perhaps fragmenting into a number of smaller bodies

(c) asteroids missed in our search of the standard ephemerides

(d) systematic plate or emulsion defects

(e) subjective effects when viewing very faint images

(f) intramercurial planetary bodies

(g) a combination of the above

An understandable first approach is to attribute the unidentified images to optical defects; however, four separate cameras were used. Almost four years of satellite tracking activities with these particular cameras failed to uncover such defects even when the plates were scrutinized for very faint images. Only one denominator is common to the four optical systems, the film itself, Kodak 2475 Recording Film on 0.060 inch thick microfinished glass plates. Conceivably, a manufacturing defect could identically mar a number of plates in a production run. It would be even more of a coincidence if only the plates used in the field were similarly marked, while those used for comparison at home escaped the defects. We know that all the plates came from the same production run.

With only one observation site operating it would be unscientific to claim absolute identification of new objects. Original plans called for direct cooperation with an airborne observer, also supported under NASA. Unfortunately, that observer's cameras did not acquire good images. It has recently come to our attention that there were other American investigators who, while performing their own experiments, may have acquired confirmation data. These investigators are being solicited for their support. Further, during the presentation of our invited paper to be given at the Eclipse Symposium in Sao Paulo, 5-11 February 1968, an appeal will be made to other investigators and lay observers along the eclipse path to make their broadfield photographs available to us for a detailed search.

RECOMMENDATIONS

The spectral transmission of the Aero-Ektar lenses leave much to be desired at the shorter wavelengths. It will be noted from Plate 8 that while this lens passes well in the red, transmission is down to 50 percent by 4300 Angstroms. Speed, ruggedness, availability - all these were in abundance, but the moderate degree of success in this experiment warrants an extended effort to obtain more suitable instrumentation for future observations.

We were satisfied with the mounts, drives, and other support gear with two exceptions: the glass plates and individual filters. Recharging cameras with fresh plates, and manually switching glass filters in front of objectives was time consuming and somewhat risky. Although no human errors occurred their possibility was always present. For future operations it is recommended that film magazines be utilized and that each camera be adapted with a filter wheel. Magazines are presently available with vacuum platens and only lack the pumps to become operational. Since the comet search does not require the extreme dimensional stability of glass plates roll film is considered adequate. The high degree of success with our redundant approach to electrical operation convinces us that we can readily operate automated film magazines without much difficulty. Rotation of filter wheels might still be left for manual operation.

Future efforts in ground-based photography or photometry should include a system for real time monitoring of the sky background with direct feedback to exposure duration on individual plates.

Although a high degree of certitude is lacking, the positive indication shown in this report for the existence of the predicted family of comets is a strong recommendation for repeating the experiment, using more suitable equipment designed for this purpose.

ACKNOWLEDGEMENT

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The University expresses its thanks to the Grumman Aircraft Engineering Corporation which made available much of the optical equipment required to conduct our experiment.

A great deal of assistance in planning the expedition to Brazil, along with welcome logistic support in that country, was made available to us through the combined efforts of Dr. Robert Fleischer of the National Science Foundation and Dr. Fernando de Mendonca of the Comissao National de Atividades Espaciais (CNAE).

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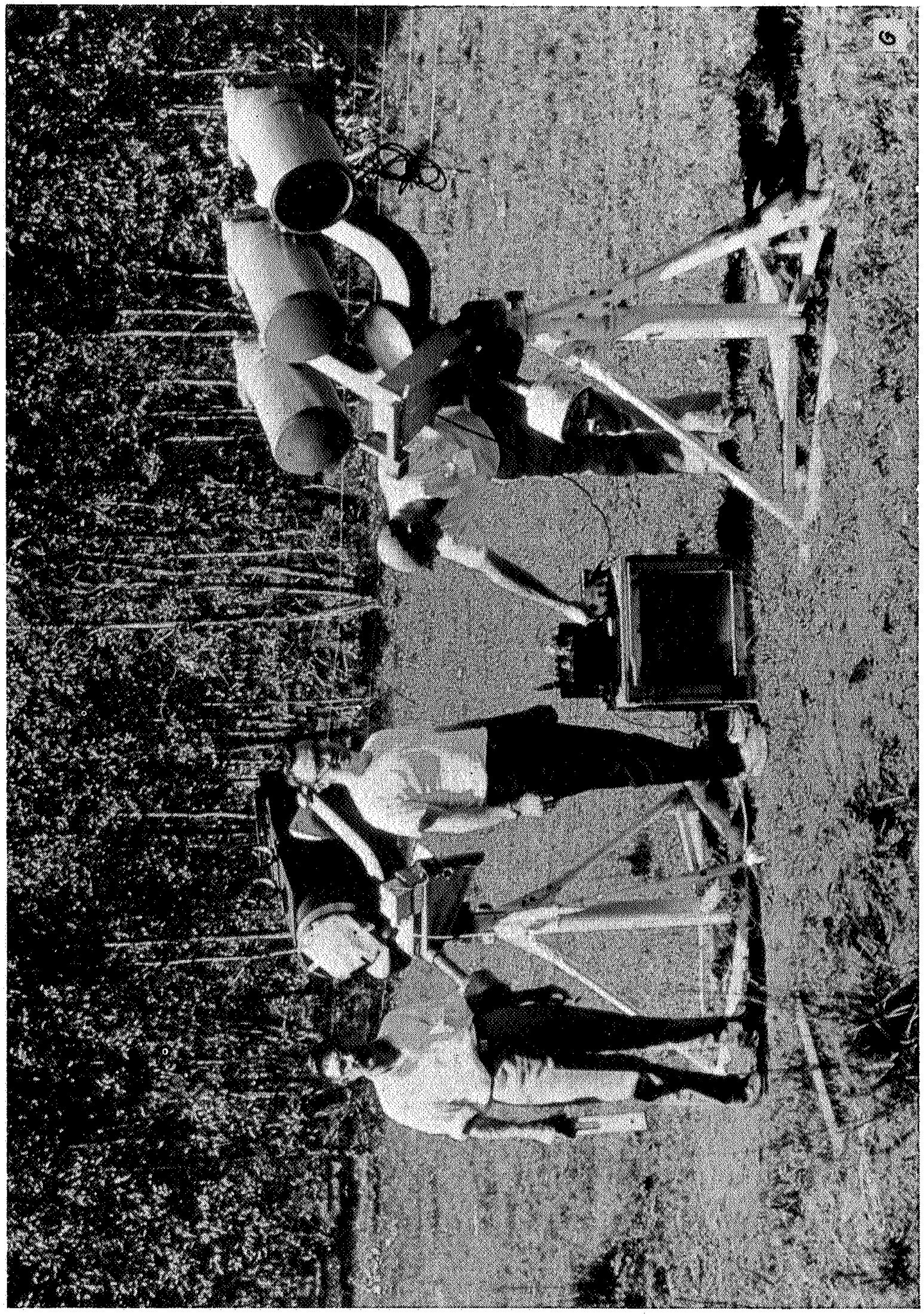
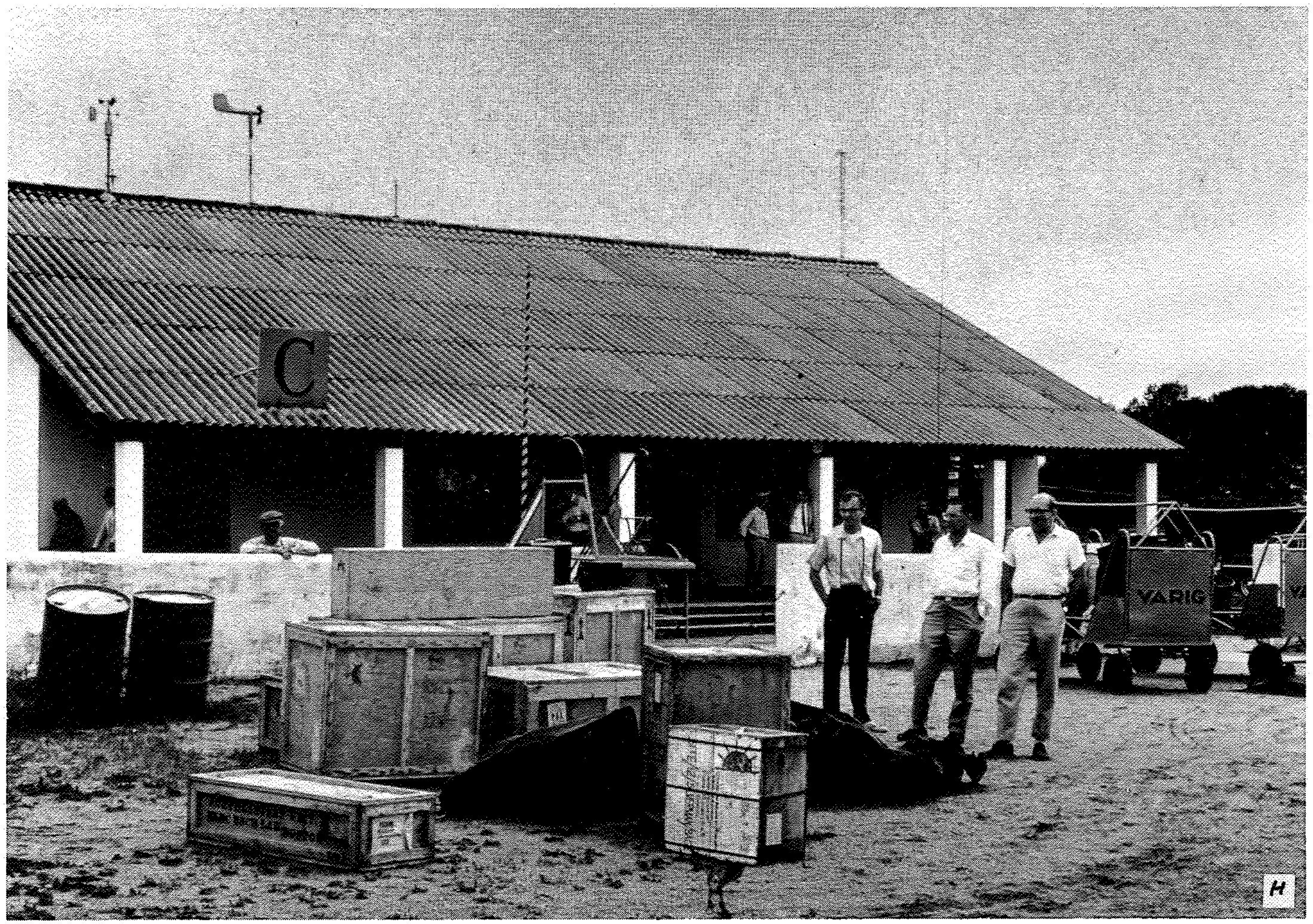
d) Dr. Herbert S. Ogden - Physician, Private Practice

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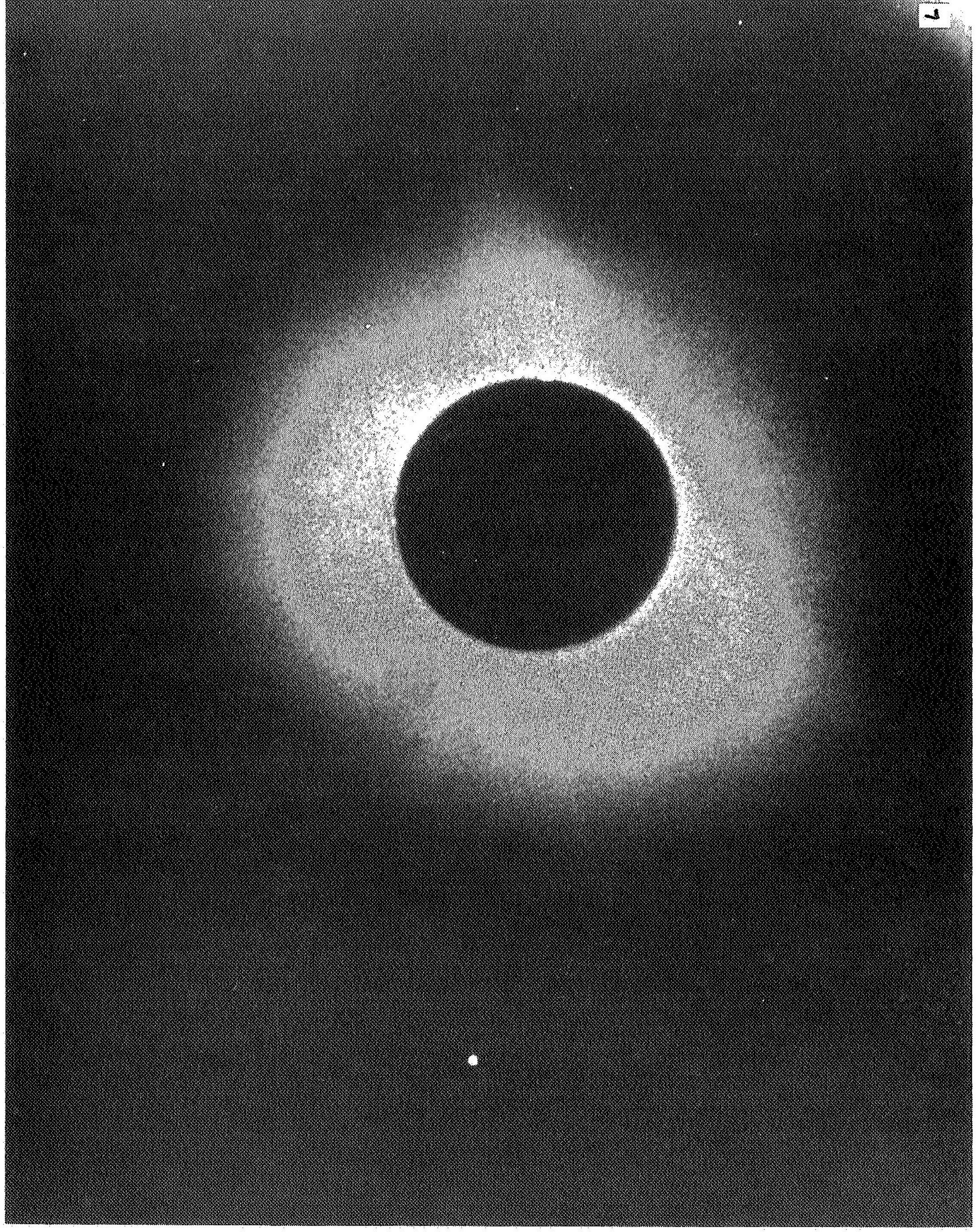
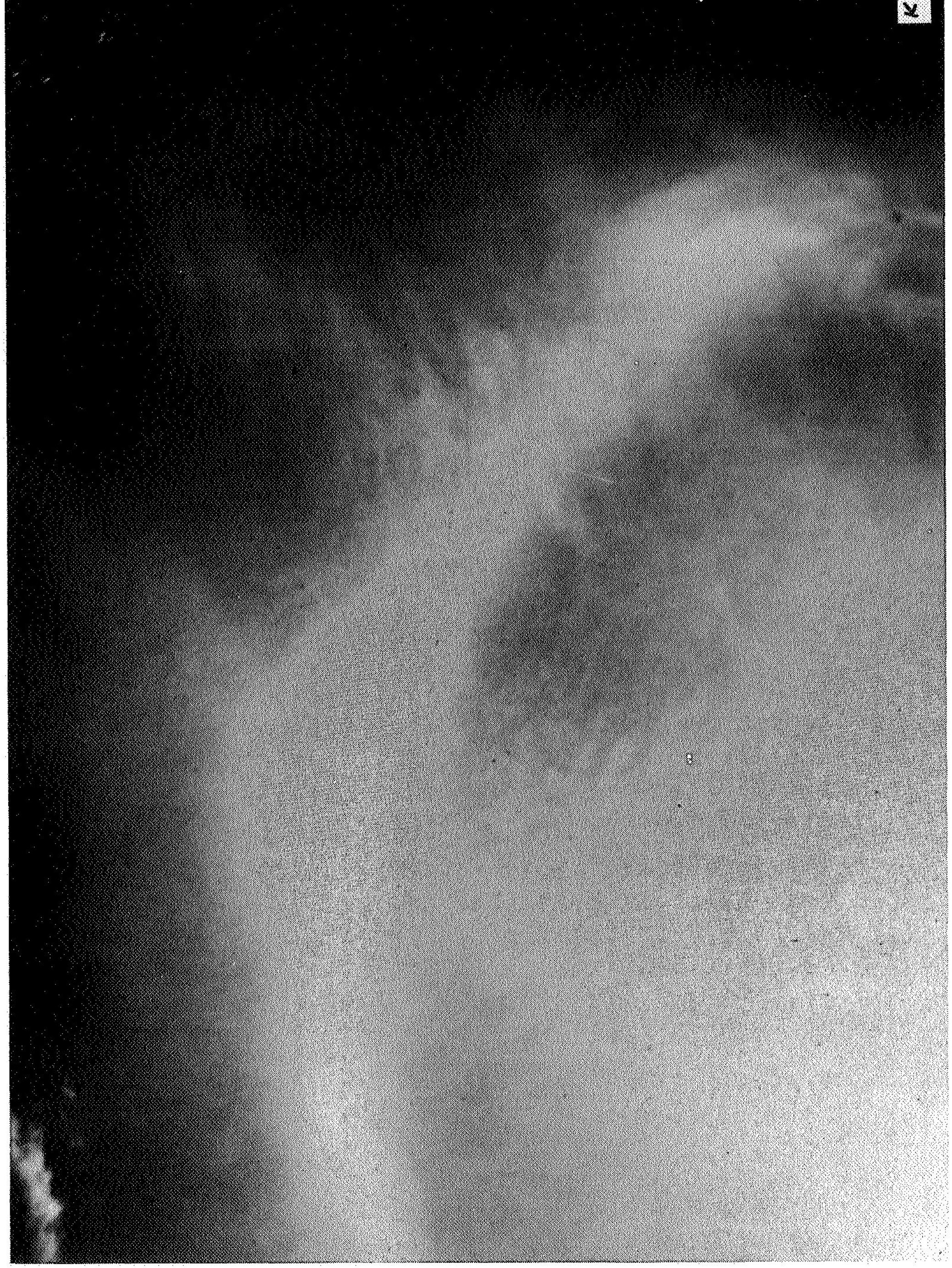
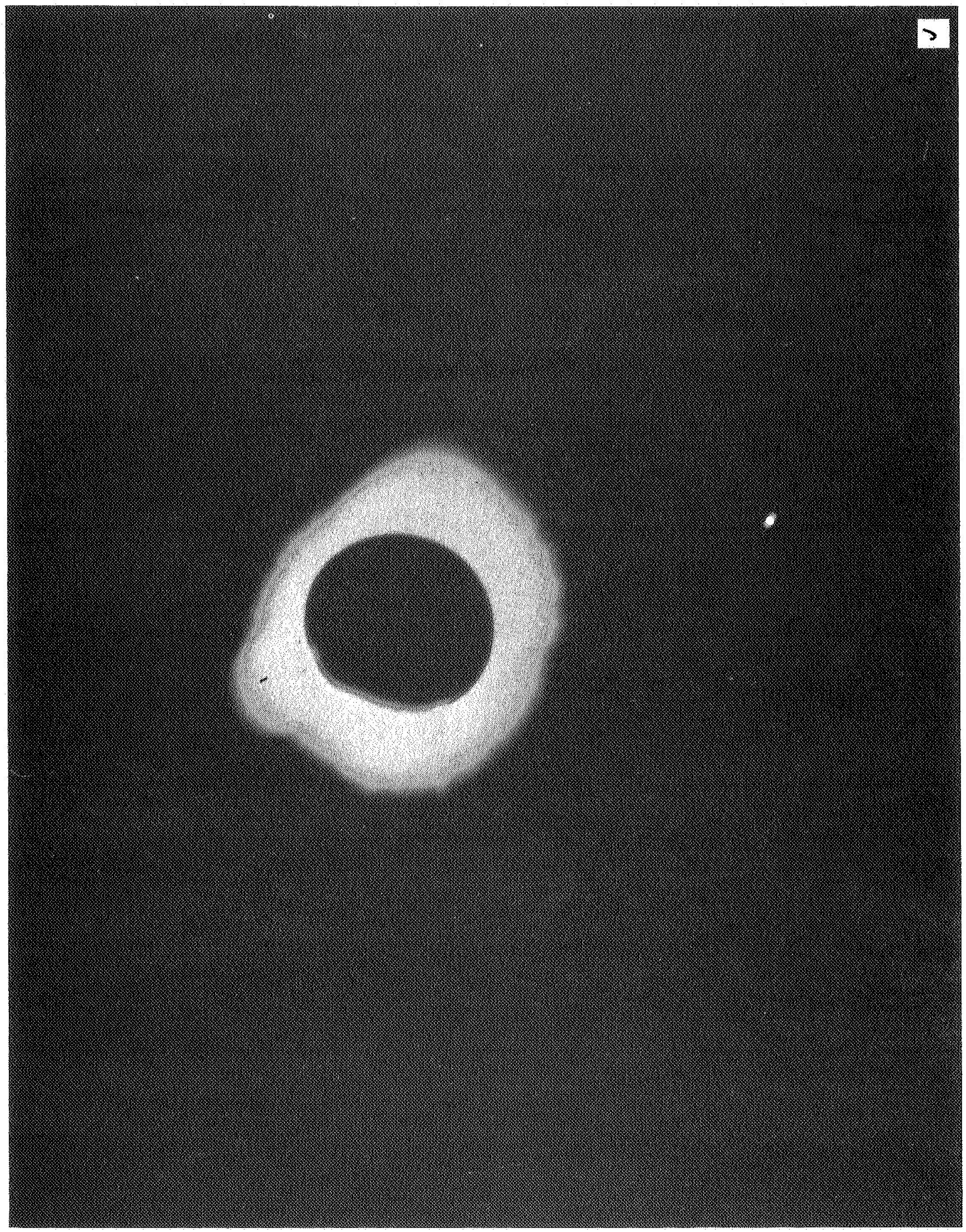
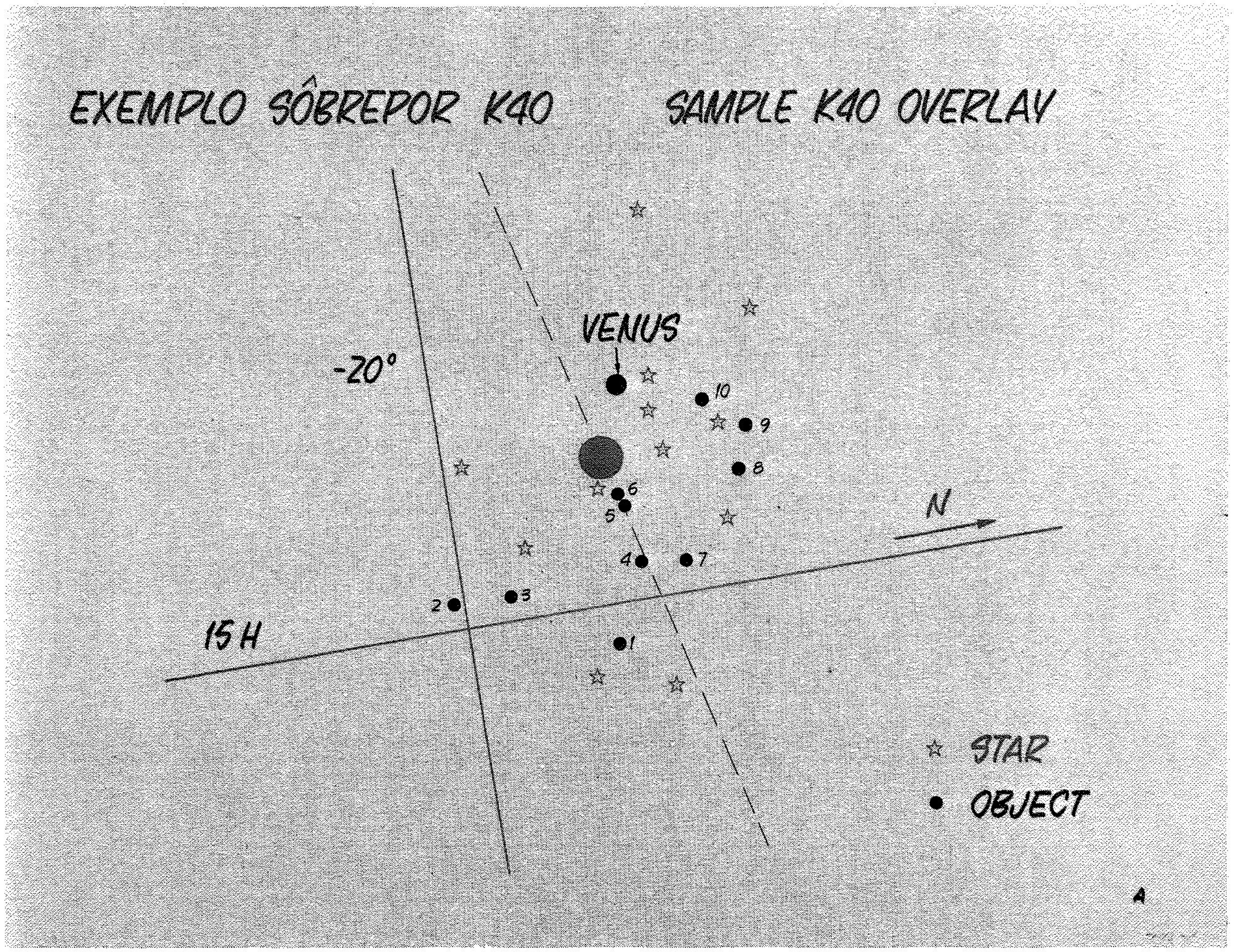






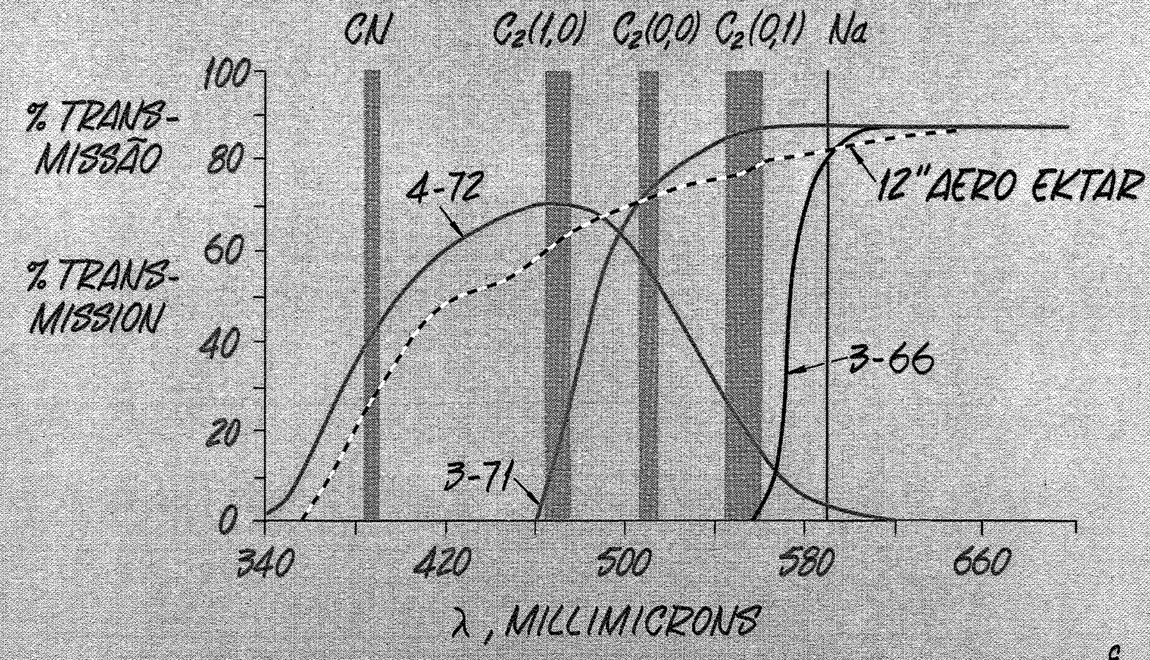

EXEMPLO SÔBREPOR K40
SAMPLE K40 OVERLAY
VENUS
-20°
15 H
N
1
2
3
4
5
6
7
8
9
10
STAR
OBJECT
A

COORDINADAS DE IMÁGENS

COORDINATES OF IMAGES

OBJ NO.	RIGHT (H)	ASCENSION (M)	DECLIN. (DEG)
1	14	57.5	-17.97
2	15	01.5	-20.15
3	15	01.2	-19.31
4	15	03.8	-17.56
5	15	05.6	-17.56
6	15	05.9	-17.61
7	15	01.5	-16.74
8	15	05.9	-15.78
9	15	08.6	-15.60
10	15	11.1	-16.11

CARACTERÍSTICAS DE LENTILHAS E FILTROS ÓPTICOS
LENS & FILTER CHARACTERISTICS

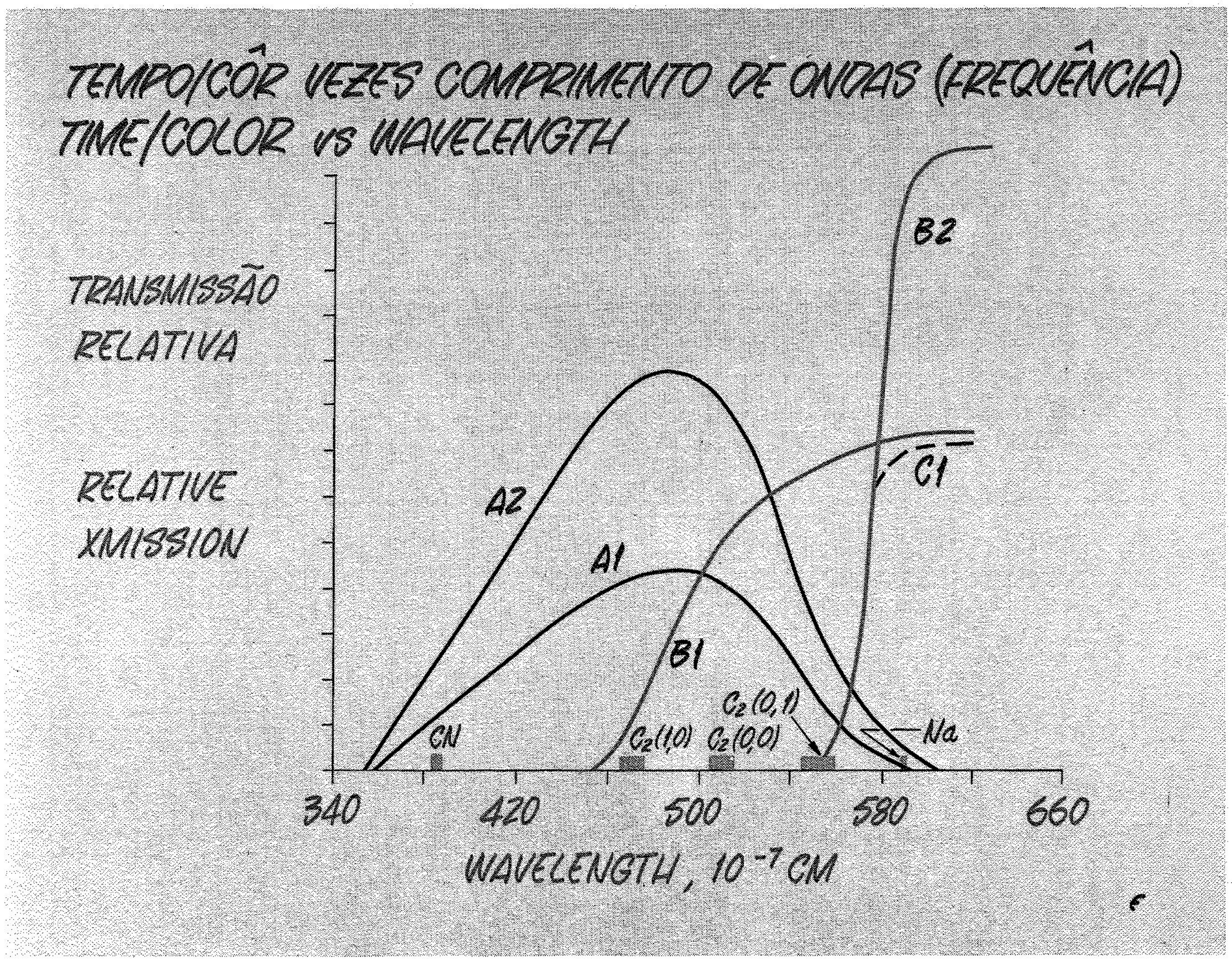


IMÁGENS REGISTADAS VEZES MÁQUINAS FOTO-GRÁFICAS/FILTROS

RECORDED IMAGES vs CAMERAS/FILTERS

NUM. DO OBJ. / OBJECT NO.	CAMERA	A	A	B	B	C	D	D	D	D	D
	PLATE	1	2	1	2	1	1	2	3	4	5
	FILTER	4-72	4-72	3-71	3-66	3-66	LUZ BRANCA WHITE LIGHT				
1		●	●	●	●	●	●	■	●	●	■
2		●	●	●	●	*	●	●	●	■	■
3		■	●	●	■		■	●	■	●	■
4		●	●	■	■		●	●	■	●	■
5		■	●	●	●	●	●	■	■	■	●
6		●	●	■	■		●	●	●	■	■
7		●	■	■	■		■	●	■	●	■
8		●	●	■	■		●	■	●	●	■
9		●	●	●	●		●	●	■	●	●
10		■	●	■	■		●	●	■	●	■

* MÁQUINA-FOTOGRÁFICA "C" DESFOCADA
POOR FOCUS ON CAMERA C


TEMPO/CÔR VEZES COMPRIMENTO DE ONDAS (FREQUÊNCIA)
TIME/COLOR vs WAVELENGTH
TRANSMISSÃO RELATIVA
RELATIVE XMISSION
A2
A1
B1
B2
C1
CN
$C_2(1,0)$
$C_2(0,0)$
$C_2(0,1)$
Na
340
420
500
580
660
WAVELENGTH, 10^{-7} CM

BANDAS COMETÁRIAS VEZES IMÁGENS

COMETARY BANDS vs IMAGES

OBJ	COMETARY BANDS				
NO.	CN	$C_2(1,0)$	$C_2(0,0)$	$C_2(0,1)$	Na
1	•	•	•	•	•
2	•	•	•	•	•
3			•	•	
4	•	•			
5			•	•	•
6	•				
7			•		
8	•	•			
9	•	•	•	•	•
10	•	•			