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Report No. 5

on

Contract AF 19(604)-41

J. Allen Hynek
February 24, 1953

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION

Report No. 5

RF Project 480

REPORT

By

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION

COLUMBUS 10, OHIO

Cooperator AF CAMBRIDGE RESEARCH LABORATORIES
230 Albany Street, Cambridge 39, Mass.
Contract AF 19(604)-41

Investigation of FLUCTUATIONS OF STARLIGHT AND SKYLIGHT

Subject of Report Progress for the period October 1, 1952 to December 31, 1952

Submitted by J. Allen Hynek

Date February 24, 1953

STATEMENT OF THE PROBLEM AND METHOD OF ATTACK

The chief problem under investigation is, of course, the manner of the scintillation of stars in the daytime, both as a basic astronomical phenomenon and as a possible probe of upper atmospheric conditions.

Equipment has been devised and assembled to record such scintillations and to study their frequency distribution.

The methods used by the two principal observational investigators, Mr. Hosfeld and Mr. Protheroe, in obtaining and reducing the observations have been described in previous reports, particularly Report No. 4. It will suffice here to summarize very briefly. Mr. Hosfeld records the sub-audio frequency scintillations (0-10 cps), obtains the "per cent scintillation" of a daytime star, and separates the primary variables contributing to the over-all scintillation. (Scintillation here is strictly defined as the variation in intensity of the starlight arriving at the telescope objective and is considered apart from "steadiness" or "sharpness" of image and other items which are often covered by the loose term "astronomical seeing.") Mr. Protheroe, on the other hand, is concerned with the harmonic analysis of daytime stellar scintillation and employs appropriate electronic equipment.

Dr. Keller, of the Perkins Observatory, is the chief theoretical investigator on the project and has concerned himself with the basic theory of astronomical seeing. His first paper is now in press (The Astronomical Journal) and is being issued as a separate technical report on this project. He is currently at work on an extension of the theory to cover the problem of scintillation specifically.

SUMMARY OF SIGNIFICANT RESULTS OBTAINED DURING REPORT PERIOD

THEORETICAL

Dr. Keller has treated the passage of starlight through the atmosphere of the earth from the standpoint of physical optics. If there exists a horizontal layer in the atmosphere composed of successive density inequalities, it is shown that this layer can be treated as a coarse diffraction grating. Since the atmospheric inequalities are slight, the angular spread of an incoming stellar beam will be small--of the order of the observed angular diameter of the tremor disc of a star. Keller predicts that, under good "seeing" conditions, the zero order should be visible as an extremely sharp nucleus. This appears to be borne out by observations, recently come to our attention, by astronomers using very large reflecting telescopes.

Dr. Keller treats the case of unequal variations within one atmospheric layer as well as that of several superposed similar layers. The distribution of light in the final star image is predicted for various turbulent layers aloft.

The Keller theory, extended, suggests that the use of properly oriented rectangular apertures, rather than the usual circular ones represented by the typical telescope objective, should in the ideal case result in the vanishing of certain frequency components in the observed flicker of starlight.

It may be that the rise or "hump" in the scintillation-frequency curve found by Mr. Protheroe, described below, constitutes experimental evidence of the ideal prediction of the theory. Mr. Protheroe plans to use rectangular apertures which, theory predicts, should result in much more pronounced "humps" in the scintillation-frequency curve.

OBSERVATIONAL

During the report period Mr. Hosfeld continued his observation and reduction of sub-audio frequency scintillation measures. To illustrate the approach used by Mr. Hosfeld, consider Figure 1 which is a trace of Capella observed in the daytime (1 P.M., August 24, 1952). The zero level is at 10 units and the sky is the steady trace at 60 units. The star increases the deflection by about 4 units and the scintillation is represented by the band (purposely adjusted to be one unit wide) at the top of the star trace. The per cent scintillation is taken as the width of the band divided by the mean deflection of the star -- in this case about 25 per cent.

Figure 2 shows a plot of several days of observations of Arcturus, per cent scintillation plotted against time of day.

Obviously the observed curve also contains the effects on scintillation of the changing zenith distance of Arcturus. Observations of several stars throughout the day allow this variable to be isolated. Figure 3 shows the relative scintillation at constant zenith distances throughout the day. The data were obtained from observations of Sirius, Capella, Rigel, Arcturus and Vega.

Finally, in Figure 4, the relative effects of zenith distance and time of day are presented. The average effect of increasing zenith distance is an increase in scintillation by the factor $(\sec Z)^{1.4}$. The values in Figure 4 are relative; the minimum value of scintillation at the zenith at twilight is taken as unity. When $Z > 45°$ the zenith distance factor is more effective in increasing scintillation than is the time of day. For a given day, with a given air mass over the place of observation, it is therefore possible to predict the relative changes in scintillation of a given star throughout the day.

Mr. Protheroe has continued his measures of the harmonic content of stellar scintillations, using the instrumentation and reduction technique described in Report No. 4. One primary objective in this phase of the work has been to compare daytime with nighttime scintillation in view of the bearing this has on the question of whether scintillation is a low level or high level phenomenon in the atmosphere.

One detailed comparison between the two was made on November 11, 1952 (Figure 5). Curve A represents the average noise spectrum of Vega during the day and curves B and C those of γ Trianguli that night, at two different zenith distances, B greater than and C less than for A, respectively.

No striking differences between night and day scintillation appear to be present in this one instance (except perhaps at very low frequencies). This is in essential agreement with previously described changes, which were relatively small, in per cent scintillation during the course of the day. Auxiliary visual observations showed that image movement, or "dancing," was considerably greater than at night. No quantitative measures have been obtained as yet, however. If these qualitative estimates are borne out, it will be strong evidence that scintillation and image steadiness are independent. It appears probable that image unsteadiness is caused by local heating effects of insolation whil scintillation may be less dependent on solar heating.

Daytime scintillation measures were made on every clear day from October 21 to November 13, a period of favorable weather.

Figure 6 shows four representative scintillation curves for Vega taken at approximately the same zenith distance. The smooth fall of the curve with higher frequencies is broken by a "hump" in the region of 10-20 cps. This may indicate a hidden periodicity at these frequencies. Similar "humps" have been found by Dr. Mikesell of the U.S. Naval Observatory for night observations (private communication).

Owing to the manner in which the observed frequencies have been chosen, the detailed structure of the "humps" is lost; likewise it is not possible, in general, to detect similar features if present at higher frequencies. It is anticipated that the required higher resolution can be obtained after recordings are made on a magnetic tape recorder which will allow, say, a five-minute scintillation signal to be "played back" at will and measures made under constant conditions at as many points on the curve as desired.

Figure 7 illustrates the effect of zenith distance upon the position and character of the "hump". It appears to be a characteristic effect.

It is tempting to speculate that the "hump" of the scintillation-frequency curve is a function of the turbulence spectrum of the disturbing medium, the apparent velocity of such turbulence structure across the line of sight, and the telescope aperture. Clearly, further observational and theoretical work is indicated.

During the present report period it has been determined that for a 17.5 circular-second section of blue sky, the scintillation is less than 0.01 per cent in the frequency range 2.5 to 640 cps, for all days on which stellar measures were made. Furthermore, there is a positive and negative scatter (negative indicates an apparent excess of noise from the standard dc lamp over the sky noise); when this scatter is taken into account, the upper limit of sky noise above shot noise can be set at less than 0.005 per cent sine wave modulation per unit bandwidth. The scatter is experimental and results primarily from the difficulty in matching the dc level of the standard noise source with that of the open sky.

FUTURE WORK

It is anticipated that weather conditions during the winter in Columbus will permit relatively few operations. Extensive calibration runs with the magnetic tape recorder will be made in preparation for spring skies and reduction of previous observations will be completed. Mr. Hosfeld will give some attention to the problem of the independence of scintillation and image steadiness and also to the problem of sky background intensities. In addition, Mr. Protheroe will conduct experiments with rectangular apertures.

Investigator W M Protheroe Date 3/19/53

R Hosfeld 3/19/53

Supervisor J. Allen Hynek Date 3/19/53

For The Ohio State University Research Foundation

Executive Director Oram C. Woolpert Date 3/23/53

FIGURE 1

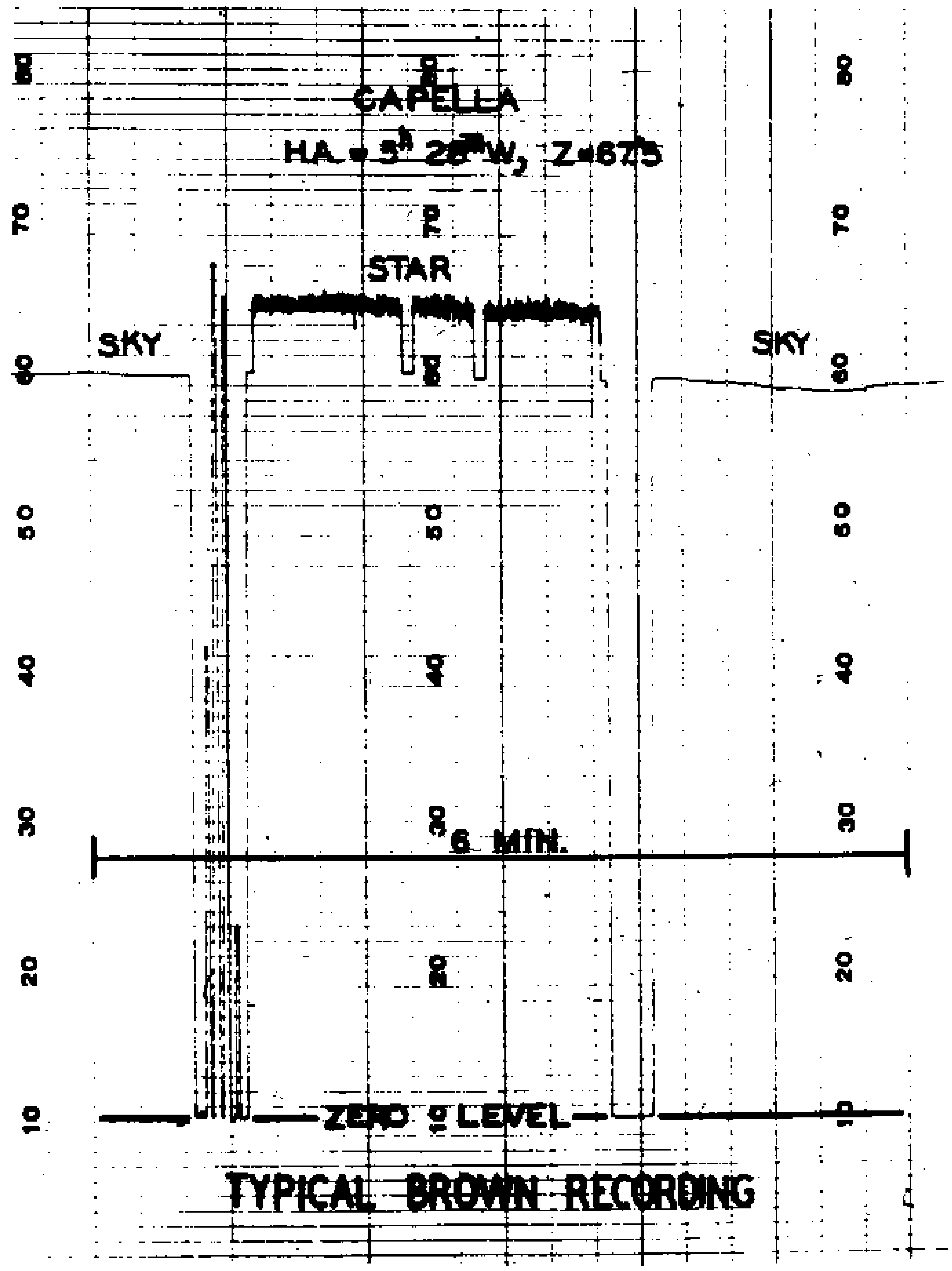

CAPELLA
SKY
STAR
SKY
6 MIN.
ZERO LEVEL
TYPICAL BROWN RECORDING

FIGURE 2

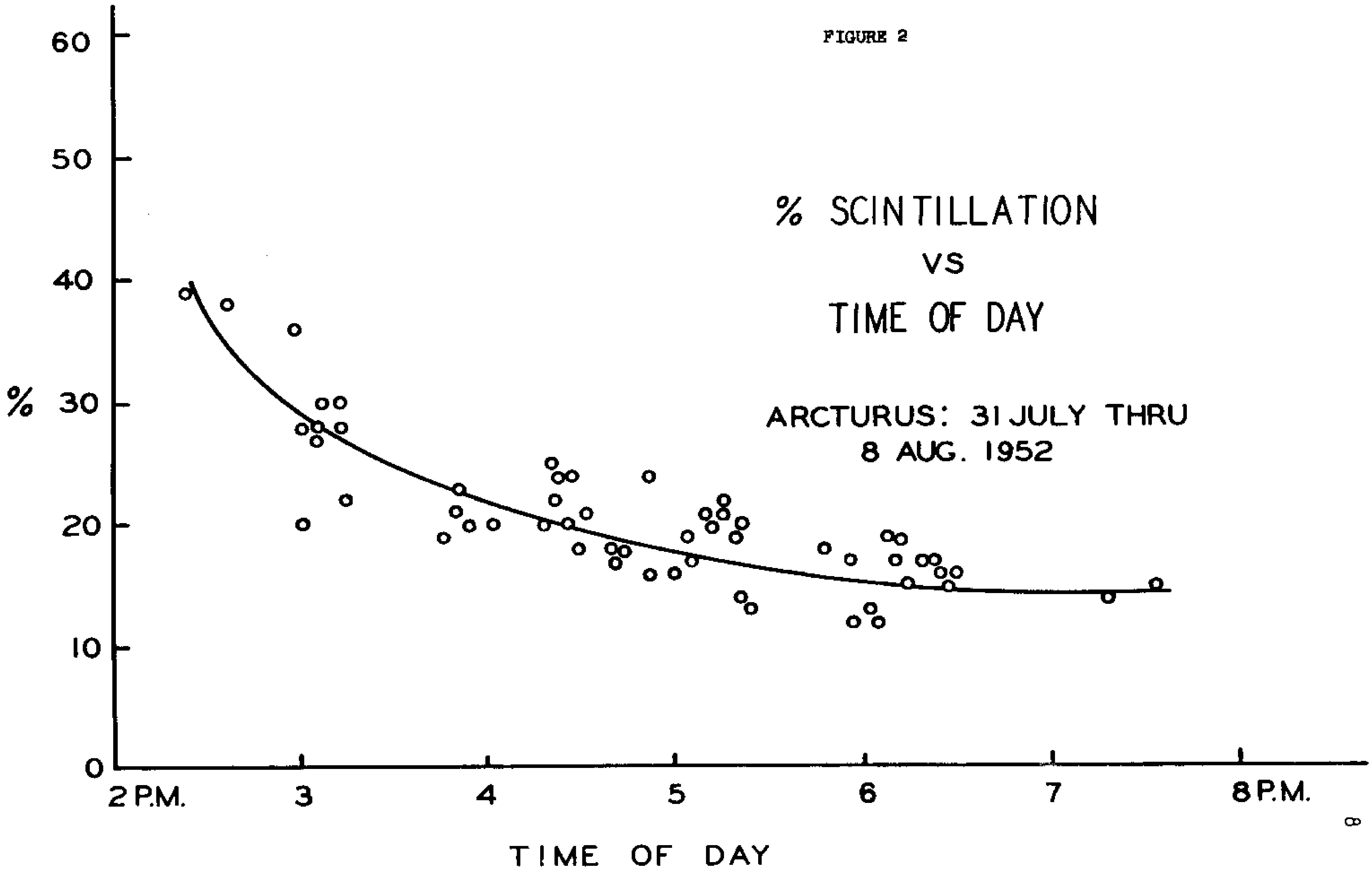
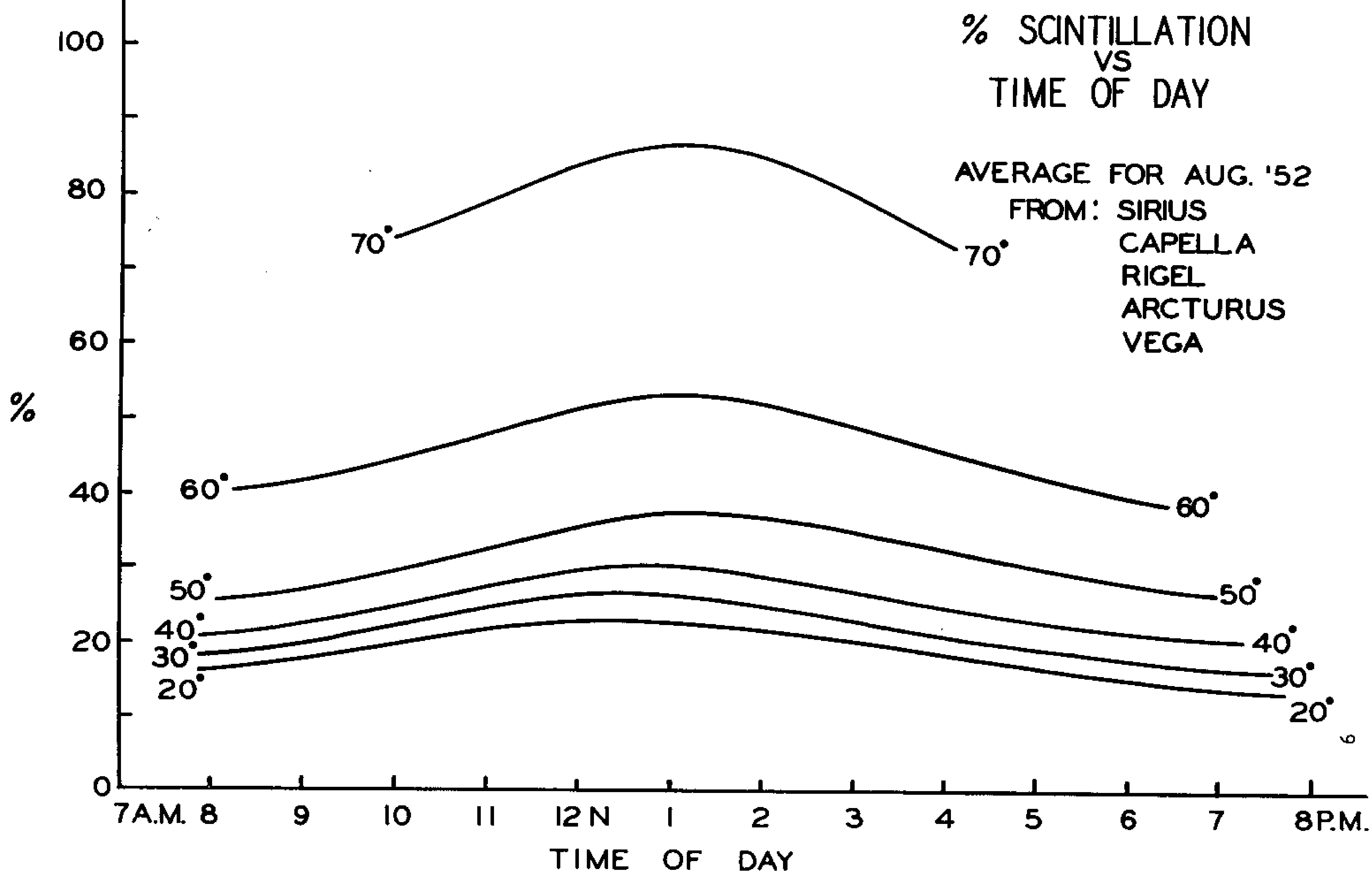

% SCINTILLATION
VS
TIME OF DAY
ARCTURUS: 31 JULY THRU
8 AUG. 1952
%
0
10
20
30
40
50
60
2 P.M.
3
4
5
6
7
8 P.M.
TIME OF DAY

FIGURE 3


% SCINTILLATION
VS
TIME OF DAY
AVERAGE FOR AUG. '52
FROM: SIRIUS
CAPELLA
RIGEL
ARCTURUS
VEGA
%
100
80
60
40
20
0
70°
60°
50°
40°
30°
20°
7A.M. 8
9
10
11
12 N
1
2
3
4
5
6
7
8P.M.
TIME OF DAY

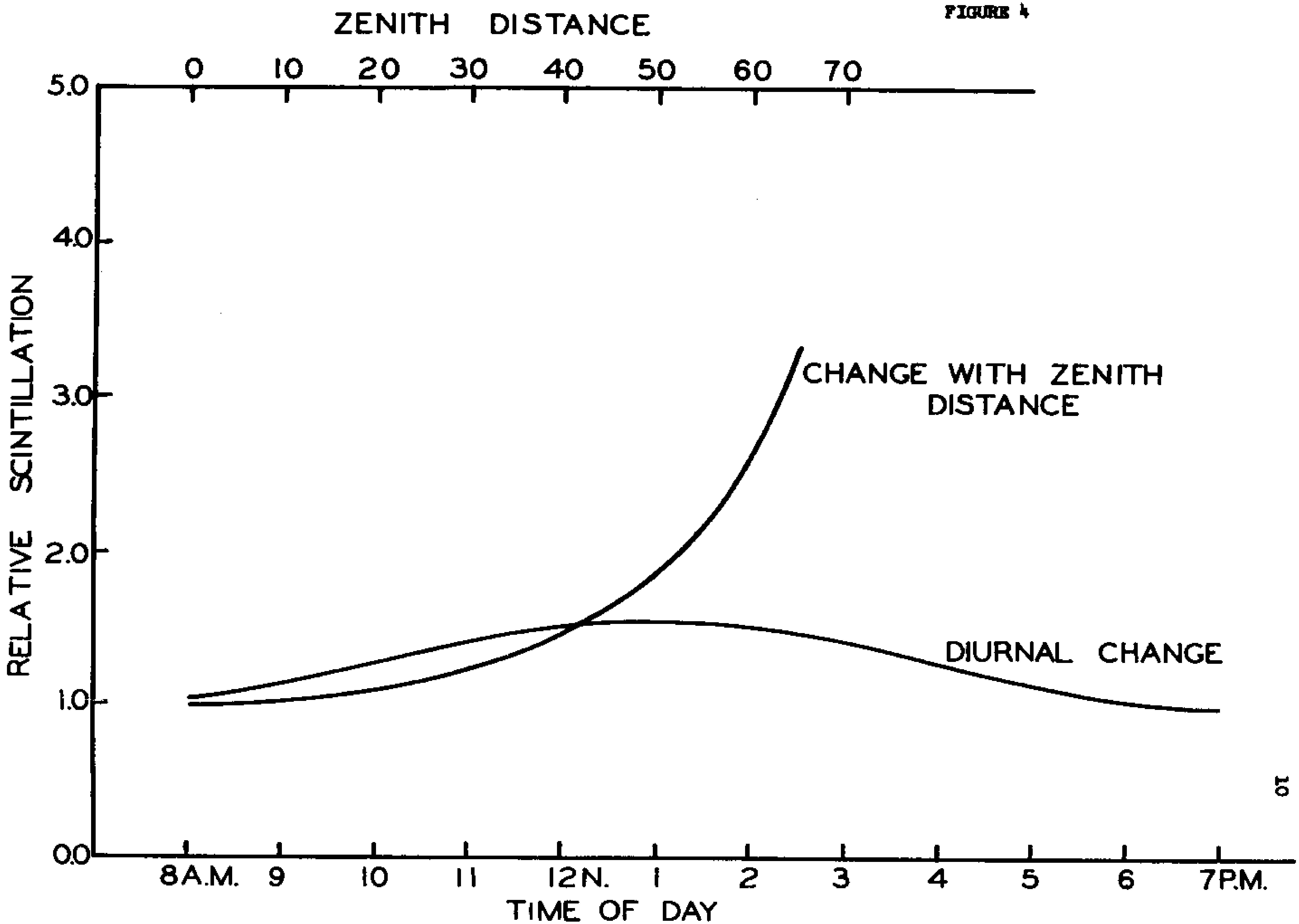
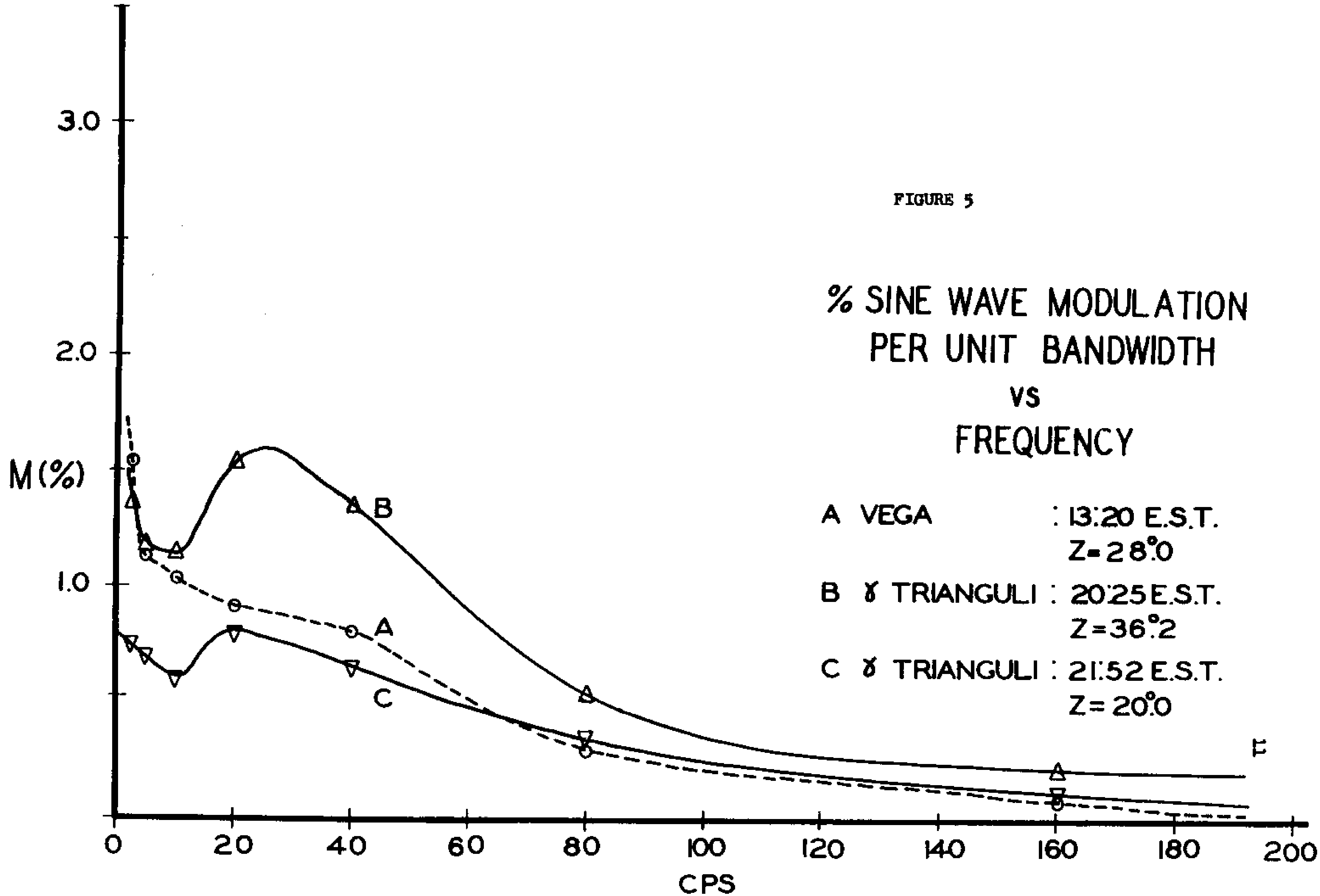

ZENITH DISTANCE
0
10
20
30
40
50
60
70
RELATIVE SCINTILLATION
5.0
4.0
3.0
2.0
1.0
0.0
CHANGE WITH ZENITH DISTANCE
DIURNAL CHANGE
8A.M.
9
10
11
12N.
1
2
3
4
5
6
7P.M.
TIME OF DAY

FIGURE 5


% SINE WAVE MODULATION
PER UNIT BANDWIDTH
VS
FREQUENCY
A VEGA : 13:20 E.S.T.
Z=28°0
B γ TRIANGULI : 20:25 E.S.T.
Z=36°2
C γ TRIANGULI : 21:52 E.S.T.
Z=20°0
M(%)
3.0
2.0
1.0
0
20
40
60
80
100
120
140
160
180
200
CPS
A
B
C

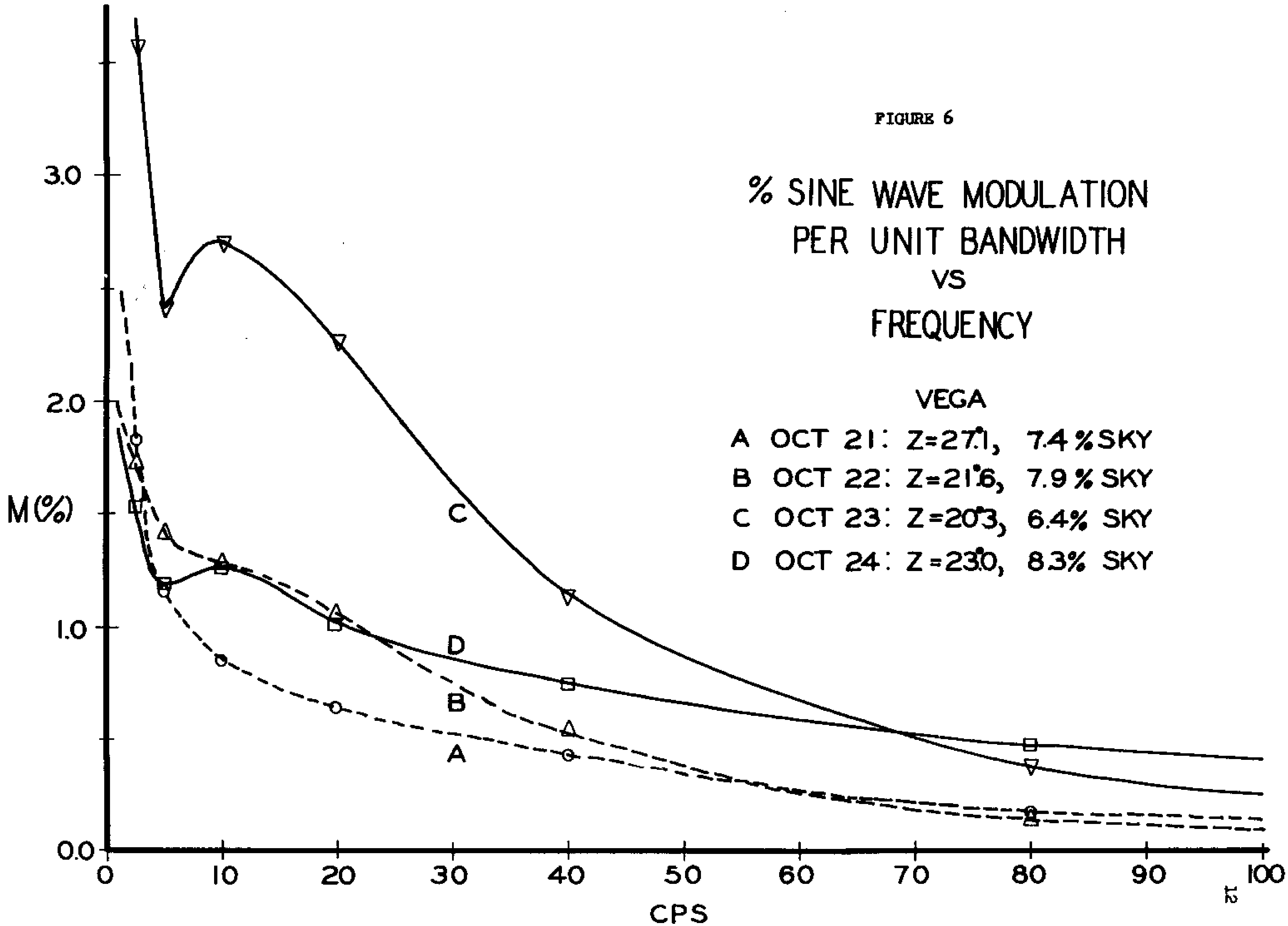


FIGURE 6

% SINE WAVE MODULATION PER UNIT BANDWIDTH VS FREQUENCY

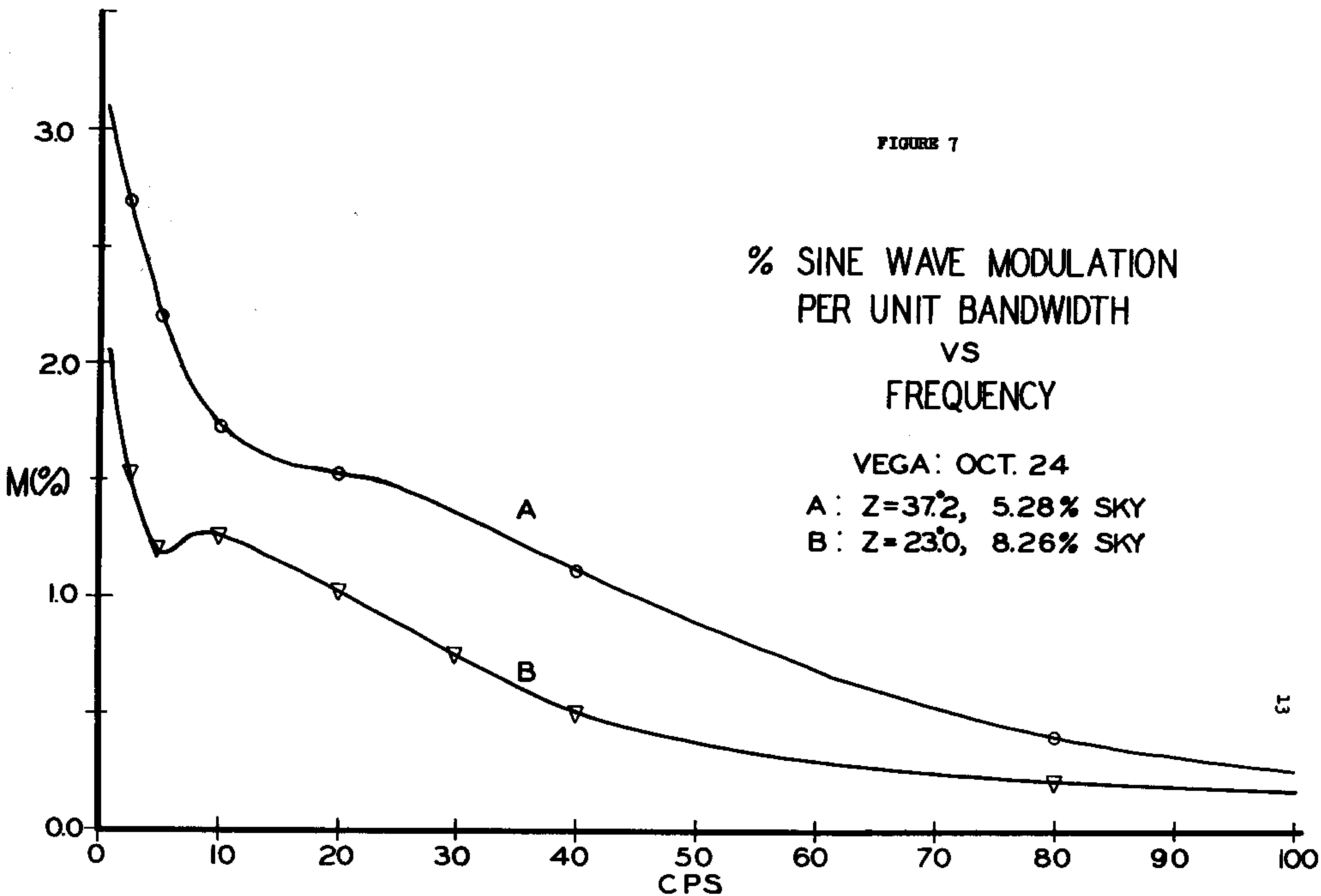

% SINE WAVE MODULATION
PER UNIT BANDWIDTH
VS
FREQUENCY
VEGA: OCT. 24
A: Z=37.2°, 5.28% SKY
B: Z=23.0°, 8.26% SKY
A
B
M(%)
3.0
2.0
1.0
0.0
0
10
20
30
40
50
60
70
80
90
100
CPS

FIGURE 7