BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- The Polar Temperature of Venus

TM-69-10[illegible]-3

DATE- January 15, 1969

FILING CASE NO(S)- 103

AUTHOR(S)- W.A. Gale
A.C.E. Sinclair

FILING SUBJECT(S)- Venus Temperature
(ASSIGNED BY AUTHOR(S)-

ABSTRACT

Published results of interferometric and polarization measurements of the microwave radiation from Venus have been examined. The 25% polar cooling derived from the interferometric measurement at 10.6 cm is rejected because of the presence of a large systematic error. The polarization measurement at this wavelength does indicate some polar cooling, but the uncertainty in the amount of cooling is large. Neither interferometer nor polarization measurements have detected polar cooling at shorter wavelengths.

SEE REVERSE SIDE FOR DISTRIBUTION LIST

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: The Polar Temperature on Venus
Case 103

DATE: January 15, 1969

FROM: W. A. Gale
A. C. E. Sinclair

TM-69-1014-3

TECHNICAL MEMORANDUM

INTRODUCTION

We present here a critical review of earth-based microwave measurements of the polar temperature of Venus.

Measurements at 10.6 cm[(1)] have been thought to show the presence of substantial polar cooling on Venus, with the poles approximately 25% cooler than the equator. Such cooling would be very significant in considerations of the planet's meteorology[(2)] and biogenic capability.

Reexamination of the interferometric data at 10.6 cm, from which the cooling was primarily deduced, indicates that a systematic error was present. No confidence can therefore be placed in the derived cooling. Polarization measurements at the same frequency show some evidence for polar cooling, with magnitude 23%*, but the measurement has large uncertainty.

A recent interferometric study at 3.12 cm[(3)] has shown no significant departure from a circularly symmetrical distribution for the observed disk brightness. The high atmospheric opacity at this wavelength implies, however, that the surface temperature was not directly measured.

TEMPERATURE DISTRIBUTION

Since earth-based measurements cannot, at present, make a point-by-point survey of the spatial distribution of temperature on Venus, interpretation of present data requires some assumptions with regard to the functional form of the distribution. Expanding the surface temperature in spherical harmonics Y_{lm}, and retaining only the lowest order terms which represent a uniform temperature, Y_{00}, and polar cooling symmetric about the equator, Y_{20}, one obtains

---

* Percent of polar cooling is defined as 100 (T equator - T pole)/T average, with T in degrees Kelvin.

$$T = T_o - T_p \cos^2\Psi$$

where T_o is the equatorial temperature

T_p is the polar cooling amplitude

and Ψ is the colatitude

It is also necessary to assume values for the physical parameters describing the surface and atmosphere. We shall use values derived from a model[4] which extrapolates the upper atmosphere found by Mariner V and Venera 4 to the surface, with constraints imposed by earth-based microwave measurements. The model is given in the appendix. The results calculated on the basis of this model are not strongly dependent on the model for wavelengths greater than about 6 cm.

INTERFEROMETRY MEASUREMENTS

The 10.6 cm interferometric study of Venus' polar cooling was made during the period of the inferior conjunction of 1964. The technique has been fully described[5,6], and we need note here only that the measurements determine the fringe visibility $F(\beta, \chi)$. We have

$$F(\beta, \chi) = \frac{\int T(x,y)\, e^{2\pi i\beta(x \sin \chi + y \cos \chi)}\, dxdy}{\int T(x,y)\, dxdy}$$

where x,y are Cartesian coordinates on the disc of the planet, and the integrals extend over the disc. $F(\beta, \chi)$ is the Fourier transform of the planetary brightness distribution. β and χ are the length and position angle of the interferometer baseline, as projected onto the plane of the sky at Venus. F is normalized to be unity at $\beta = 0$. The projected baseline varies with the physical spacing of the interferometer and with time during a day. For east-west and north-south baselines of unit length on earth, the projected baseline varies with Venus' hour angle H in the manner shown in Figures 1a and 1b. The hour angle is measured from meridian transit, the time when Venus crosses the observer's meridian. The latitude of the interferometer (37°) and declination of Venus (20°) were chosen as the values which obtained during the 10.6 cm observations.

The polar cooling of the planet is readily determined by comparing the visibilities F at two baselines with particular β but different χ. The difference ΔF in these visibilities is given by[1]

$$\Delta F \approx \tfrac{1}{2}h(\beta)\,[\cos 2(\gamma-\chi_2) - \cos 2(\gamma-\chi_1)]$$

where $h(\beta)$ is the difference of fringe visibilities for baselines parallel and perpendicular to Venus' pole.

Figure 2 shows the results obtained by Clark and Kuz'min, together with the curve predicted by the model with no polar cooling. Polar cooling results in deviations from this line, with the amount of deviation dependent on χ and γ as well as β. It is important to note that during the period June 4-10, the position angle of the Venus pole, γ, was less than 1°, as is now known from recent radar measurements of the pole position[7]. The projected east-west baseline was then equally inclined to the equator of Venus for the two times at equal hours before and after meridian transit. This can be seen by reference to Figure 1a which shows the baselines for $+4^h$ and -4^h. Hence, the same distribution of temperature should have been found above and below each of these projected baselines, regardless of the form or magnitude of polar cooling. Since the values of β were equal for these two times, the visibilities measured -- $F_<(\beta)$, for the time before meridian transit, $F_>(\beta)$ for the time after meridian transit -- should have been the same.

It can be seen from Figure 2 that during June 4-10, the measured $F_<$ (filled circles) was consistently smaller than $F_>$ (open circles). For $\beta = 0.438$ this difference was five times the random error from noise. This difference was used to determine Venus' polar direction and polar cooling. From the radar determination of Venus' polar direction, it can now be seen that the difference $F_> - F_<$ was due to a large systematic error, rather than to polar cooling. The error may possibly be explained as arising from an error in telescope pointing for $H<0$, greatest when the source had just appeared above the horizon[8].

From the differences $F_> - F_<$ the data of June 27-30 and July 10-13 indicate some polar cooling, but a similar systematic error cannot be excluded. We therefore conclude that the 10.6 cm measurements give no reliable interferometric evidence for polar cooling on Venus.

Observations at 3.12 cm have recently been made by Berge and Greisen[3]. Their measurements were made at baselines such that the projected length β was constant (~ 0.68), while their inclinations from Venus' north pole were either 20° or 70°. The difference in fringe visibilities ΔF under these conditions was measured to be $(-3.6 \pm 5.0) \times 10^{-3}$. From computations using the model described in the appendix, this visibility difference implies a small polar <u>heating</u> with magnitude $2.0 \pm 2.8\%$ of the average surface temperature. In view of the experimental error the apparent heating is not statistically significant.

The total optical depth of the Venus atmosphere is large at 3.12 cm, being 1.8 for the model of the appendix. The atmosphere thus both strongly emits radiation itself and attenuates the radiation from the surface. It is primarily the distribution of atmospheric absorptivity and temperature which is measured, and the surface temperature distribution is only important as it affects the atmospheric distribution. Thus we would place a limit of 3% on the polar cooling of the atmosphere seen at 3.12 cm. In view of the sensitive temperature and pressure dependence of the absorptivities of the known constituents of Venus' atmosphere[(9)], the question of polar cooling of the surface must remain open.

POLARIZATION MEASUREMENTS

The electromagnetic radiation from a given surface element of a planet will be partially linearly polarized[(10)]. For a given polarization, maximum emission occurs at two points near the edge of the planet's disk, on the diameter defined by the polarization direction. If the planet is at a uniform temperature, these "Brewster angle" highlights will have a constant intensity for all choices of polarization direction, so that the integrated emission from the planet has no net polarization. With polar cooling, however, the highlights for polarization in the direction of the axis will be cooler than those for polarization in the direction of the equator. Thus, there will be a net polarization in the direction of the equator.

At 10.6 cm wavelength and for short interferometric baselines, so that the measurement was effectively that for a single telescope, Clark and Kuz'min[(1)] found the net polarization p = 0.8 ± 0.5% at an angle 20° ± 20° from the equator. For the atmospheric model considered in the appendix this implies a polar cooling of 23 ± 14%.

At 6 cm wavelength, Dickel[(11)] found p = 0.5 ± 0.9% in the direction of the poles. The equatorially directed polarization expected on the basis of the model with 23% polar cooling is 0.3%, one third of the stated error. It is apparent that the net polarization at 6 cm has not been detected.

In summary, while it appears that there is some experimental evidence for polar cooling on Venus, present knowledge of the cooling is quite limited. However, it can be expected that further interferometric measurements, with the considerably improved accuracy now available, will determine the cooling within narrow limits.

We warmly thank Dr. B. E. Clark and Dr. G. L. Berge for interesting discussions on their measurements and on Venus' temperature distribution.

1015-WAG
1014-ACES-blm

W. A. Gale

A. C. E. Sinclair

Attachments
  Figures 1 and 2

REFERENCES

1. B. E. Clark & A. D. Kuz'min, Astrophys. J. 142, 23 (1965).
2. I. O. Bohachevsky & T. T. J. Yeh (in preparation).
3. G. L. Berge & E. W. Greisen, Preprint.
4. W. Gale, M. Liwshitz & A. C. E. Sinclair (in preparation).
5. J. D. Kraus, Radio Astronomy (McGraw-Hill, 1966) Ch. 6.
6. A. T. Moffet, Astrophys. J. Suppl. 7, No. 67, 93 (1962).
7. I. I. Shapiro, Science 157, 423 (1967).
8. B. E. Clark, private communication.
9. W. Ho, I. A. Kaufman & P. Thaddeus, J. Geophys. Res. 71, 5091 (1966).
10. C. E. Heiles & F. D. Drake, Icarus 2, 281 (1963).
11. J. R. Dickel, Icarus 6, 417 (1967).

APPENDIX

Parameters of the Venus surface and atmosphere

We shall use the parameters derived by Gale et al.[4], who used earth-based radar and microwave data to extrapolate the upper atmosphere found by the Venus probes, Mariner V and Venera 4. The model was derived with the assumption that the atmosphere contained 90% CO_2, 0.4% H_2O and other unspecified but inactive constituents. The derived temperature profile was isothermal from the surface to an altitude of 9.9 km, and thereafter adiabatic to the tropopause at 240°K. Other characteristics were as follows:

Total microwave optical depth = $17.4/\lambda^2$ where λ is the wavelength in cm

Surface dielectric constant = 4.4 (assumed independent of wavelength)

Surface temperature (uniform) = 645°K

Surface pressure = 90 atmos.

To establish a model with polar cooling, the desired ratio T_p/T_o was used in equation (2), the average temperature was held at 645°K, and the surface pressure was assumed uniform at 90 atmos.

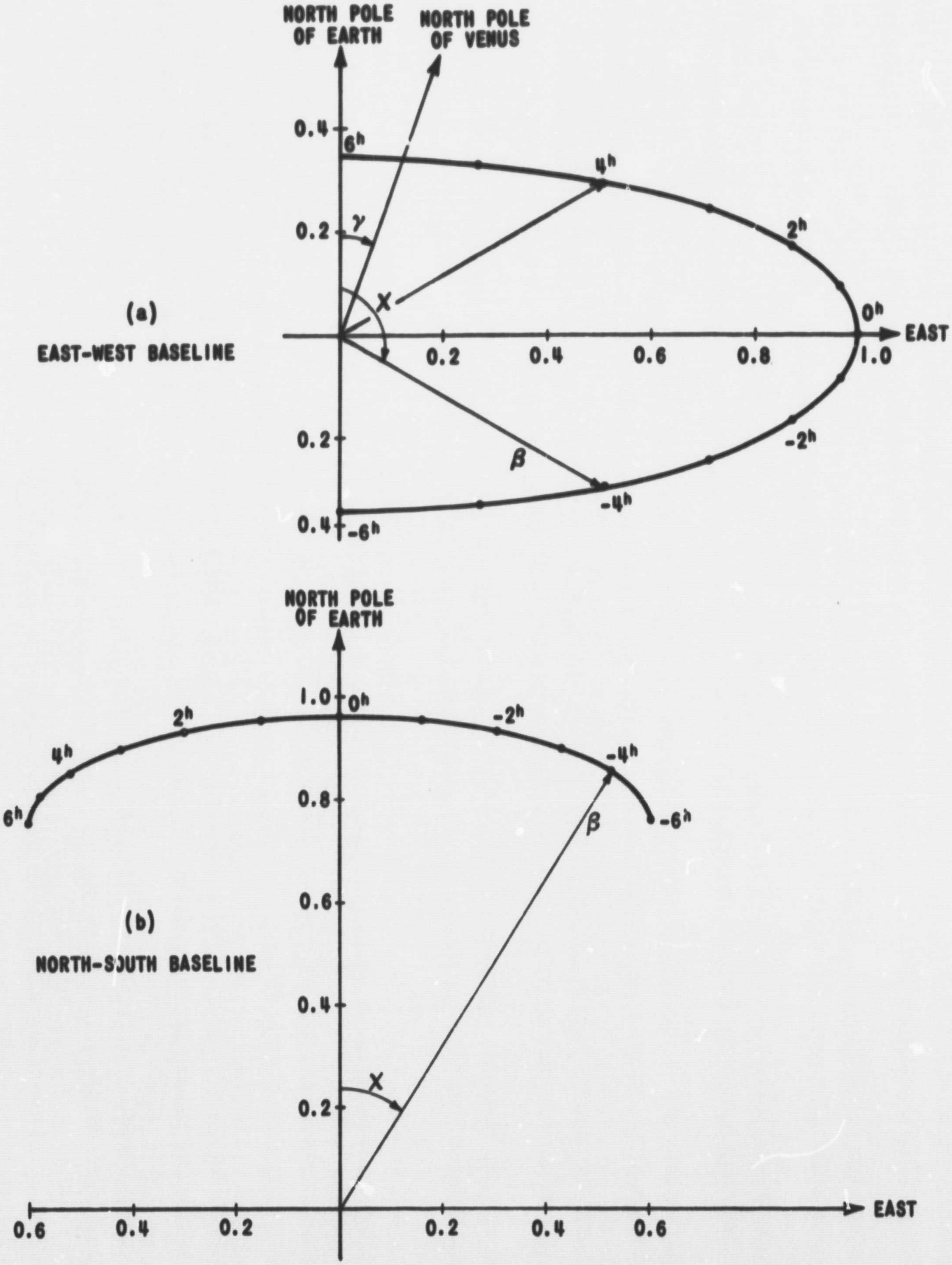

FIGURE 1. - LENGTH β AND POSITION ANGLE χ OF INTERFEROMETER BASELINE, AS PROJECTED ON PLANE OF SKY AT VENUS

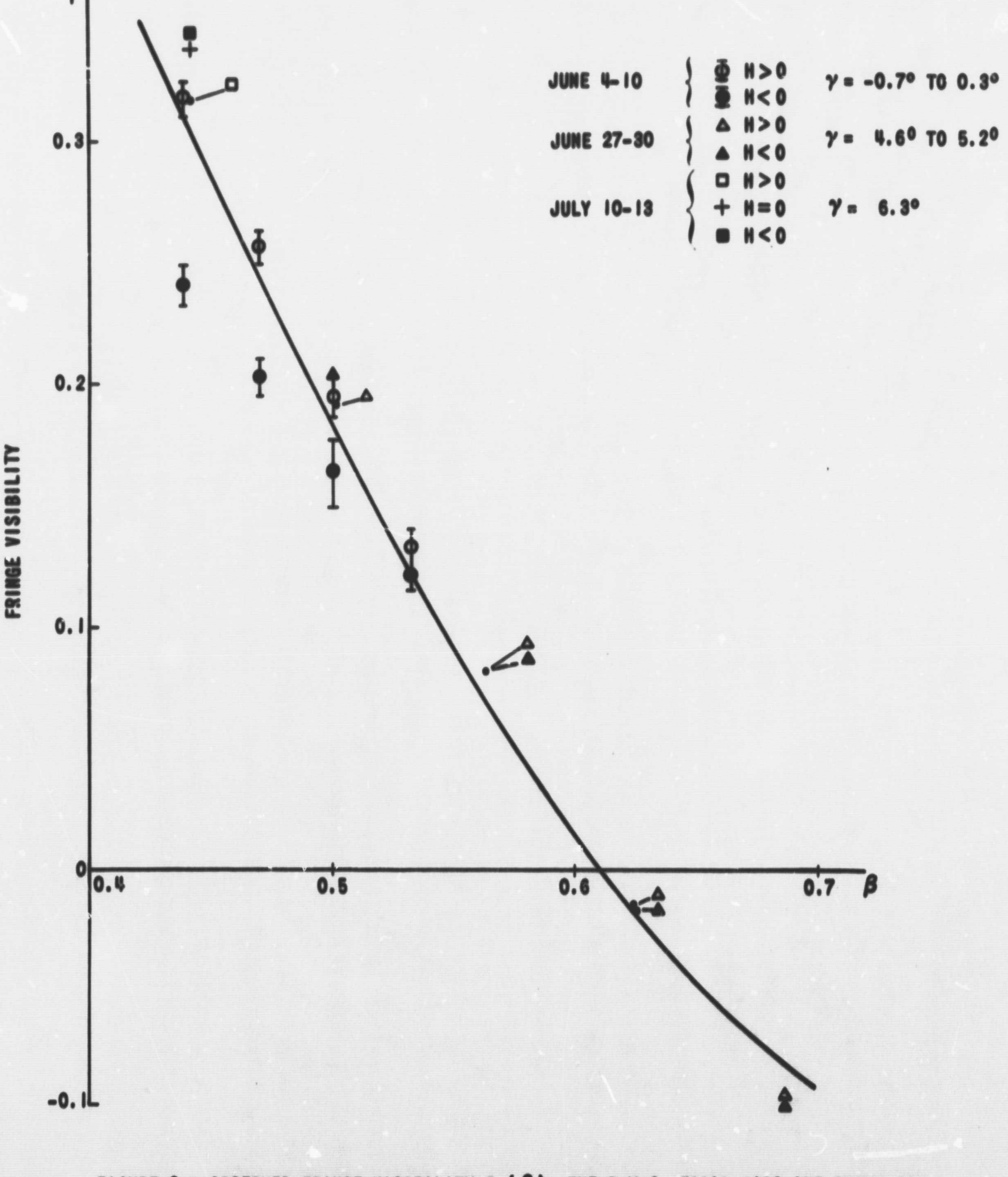

FIGURE 2 - OBSERVED FRINGE VISIBILITY F (β). THE R.M.S. ERROR BARS ARE SHOWN FOR THE DATA OF JUNE 6-10. THE SOLID CURVE SHOWS THE CALCULATED F (β) FOR NO POLAR COOLING.