(NASA-CR-164997) RADAR INVESTIGATION OF ASTEROIDS Semiannual Status Report, 1 May - 31 Oct. 1981 (Cornell Univ., Ithaca, N. Y.) 14 p HC A02/MF A01 CSCL 03B
N82-13036
Unclas
G3/91 08371

CORNELL UNIVERSITY
Center for Radiophysics and Space Research
ITHACA, N.Y.

SEMI-ANNUAL STATUS REPORT
to the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
under
NASA Grant NAGW-116

RADAR INVESTIGATION OF ASTEROIDS

May 1, 1981--October 31, 1981

Principal Investigator: Professor Steven J. Ostro

CENTER FOR RADIOPHYSICS AND SPACE RESEARCH
CORNELL UNIVERSITY
ITHACA, NEW YORK 14853

SEMI-ANNUAL STATUS REPORT

NASA Grant NAGW-116

May 1, 1981--October 31, 1981

RADAR INVESTIGATION OF ASTEROIDS

Prepared November 1981

Steven J. Ostro
Principal Investigator

TABLE OF CONTENTS

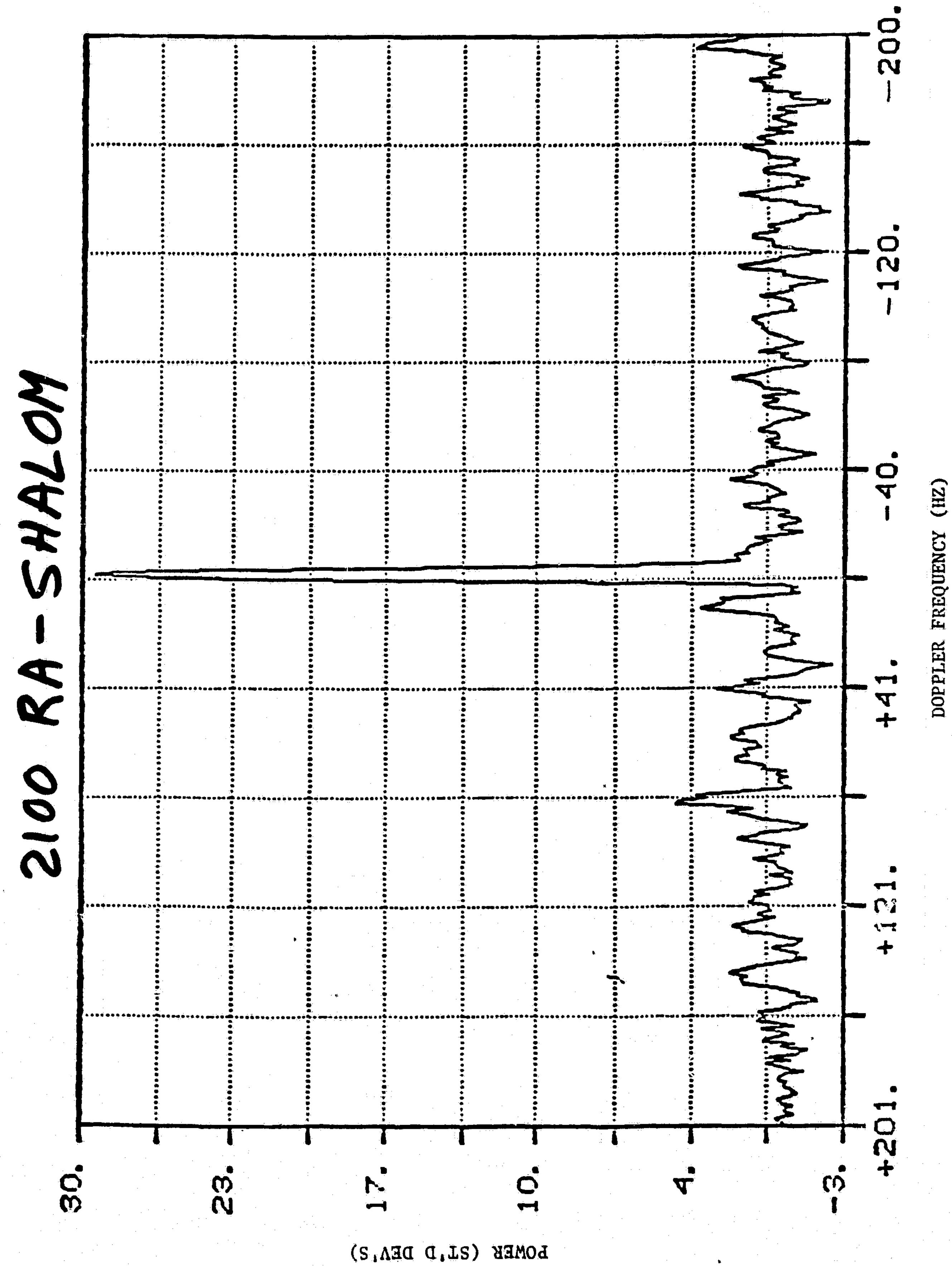
I. SUMMARY OF PROGRESS

Research supported under NASA Grant NAGW-116 proceeded as planned during the current report period. Efforts were devoted to (i) development of software to support all stages of asteroid radar observation and data analysis, and (ii) completion of first-order analysis of all data in hand. This work produced reportable estimates of radar cross sections, circular polarization ratios, and limb-to-limb echo spectral bandwidths for asteroids 7 Iris, 16 Psyche, 97 Klotho, 1862 Apollo, and 1915 Quetzalcoatl. These results were recently presented at the Pittsburgh meeting of the Division for Planetary Sciences (see abstract on final page of this report).

Radar observations of two previously unobserved asteroids were conducted in August 1981 at the Arecibo Observatory. A strong detection (Fig. 1) was obtained for 2100 Ra-Shalom, an Aten asteroid with the smallest known semimajor axis (0.83). Preliminary data reduction indicates a circular polarization ratio comparable to those of Apollo, Quetzalcoatl, and Toro. A modest attempt to detect echoes from 219 Thusnelda was not successful, but did provide a useful upper limit on this object's radar cross section. Since Thusnelda's diameter is known, the upper limit can be expressed as a radar reflectivity. Thusnelda (possibly a type M object) is certainly less reflective than Psyche (the canonical type M asteroid).

The research performed under NAGW-116 during 1980-1981 has amassed an asteroid-radar data set which permits the

FIGURE 1.


2100 RA-SHALOM
-200.
-120.
-40.
+41.
+121.
+201.
DOPPLER FREQUENCY (HZ)
30.
23.
17.
10.
4.
-3.
POWER (ST'D DEV'S)

following generalizations about asteroid radar properties:

(i) Unlike the Moon and inner planets, asteroids as a rule are non-specular radar scatterers.

(ii) Very large asteroids (Iris, Psyche, Vesta) have very low circular polarization ratios*, $\mu_C \lesssim 0.1$. Thus their echoes result primarily from single reflections and their surfaces are smooth at scales $\sim \lambda 12.6$ cm. However, (i) requires that their surfaces be rough at some scale(s) $>> \lambda 12.6$ cm.

(iii) Small asteroids (Toro, Apollo, Quetzalcoatl, Ra-Shalom) have circular polarization ratios ranging from ~ 0.2 to ~ 0.5, indicative of greater wavelength-scale roughness than their larger, mainbelt counterparts.

(iv) Psyche and Iris are the most radar-reflective asteroids, presumably due to free metal on their surfaces. The reflectivities of other radar-detected asteroids are comparable to those of the Moon and inner planets.

It is clearly necessary to enlarge and broaden the radar sample of observed asteroids. The principal investigator intends to observe four to eight minor planets during the next four months.

---

* The circular polarization-ratio, μ_C, of echo power received in the same sense of circular polarization as transmitted (i.e., the "SC" sense) to that received in the opposite ("OC"), would be zero for single scattering from a smooth surface and could reach unity if the surface were extremely rough at wavelength scales and/or if there were lots of multiple reflections.

II. FUNDING STATUS

The current report period has seen spending at the anticipated rate.

Two persons, Karl Vogel and Brenda MacFarlane, were employed during the 1981 summer to assist the principal investigator with computer programming and data analysis.

III. SOFTWARE DEVELOPMENT

An interactive computer program which predicts echo signal-to-noise ratios has been written to assess the Arecibo radar detectability of minor planets through 1990. This program incorporates recent calibrations of antenna gain and system temperature as functions of zenith angle and azimuth, as well as up-to-date estimates of target diameter and rotation period. It combines predictions of target distance and declination to generate an optimum observing itinerary within the available hour-angle window, and acknowledges the inability of the Arecibo telescope to track within one degree of zenith. Using this program, a list of favorable asteroid apparitions has been constructed. An average of five asteroids per year are detectable (at or above the five-standard-deviation level) in a single night ($<$ 3 hours) at Arecibo.

An interactive program has been placed on the Arecibo Harris/6 computer to compute optimum radar setups for frequency-switched CW observations. Such setups must accommodate various combinations of analyzing bandwidths, echo bandwidths, frequency resolutions, and roundtrip times. They must also satisfy certain algebraic and hardware constraints on transmitted frequency sequence, real-time Fourier analysis, and post-real-time background removal.

A program has been developed to generate model delay and/or Doppler distributions of echo power from a rotating triaxial ellipsoid with arbitrary axis ratio, orientation with respect to the radar, and scattering law. (This program was used to generate the model spectra in Fig. 3, discussed below.)

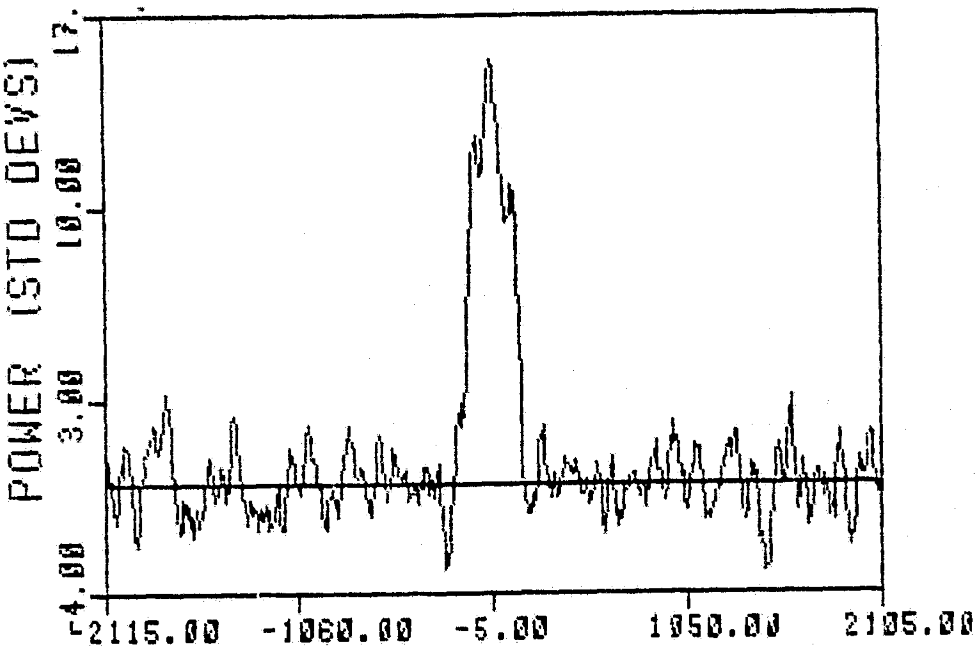
IV. HIGHLIGHTS OF DATA ANALYSIS

Figure 2 shows the strong OC echo, but lack of an SC echo, for Iris. The circular polarization ratio (SC/OC) is very small, requiring that the echo be due to single reflections from smooth surfaces. Figure 3 compares a close-up of the OC spectrum to model spectra derived from a quasi-specular scattering law (heavy solid curve) and from a cosine law corresponding to a uniformly bright disc (dashed curve). If Iris' surface were like the lunar surface, the solid curve would be a good match to the spectrum. In fact, Iris backscatters radar waves in a manner resembling the way the Moon backscatters visible waves.

The mainbelt object 97 Klotho was observed on several nights earlier this year. Recent summation of all the data reveals a modest, but convincing, detection precisely at the predicted Doppler frequency (Fig. 4). This type M asteroid

FIGURE 2.

7 IRIS



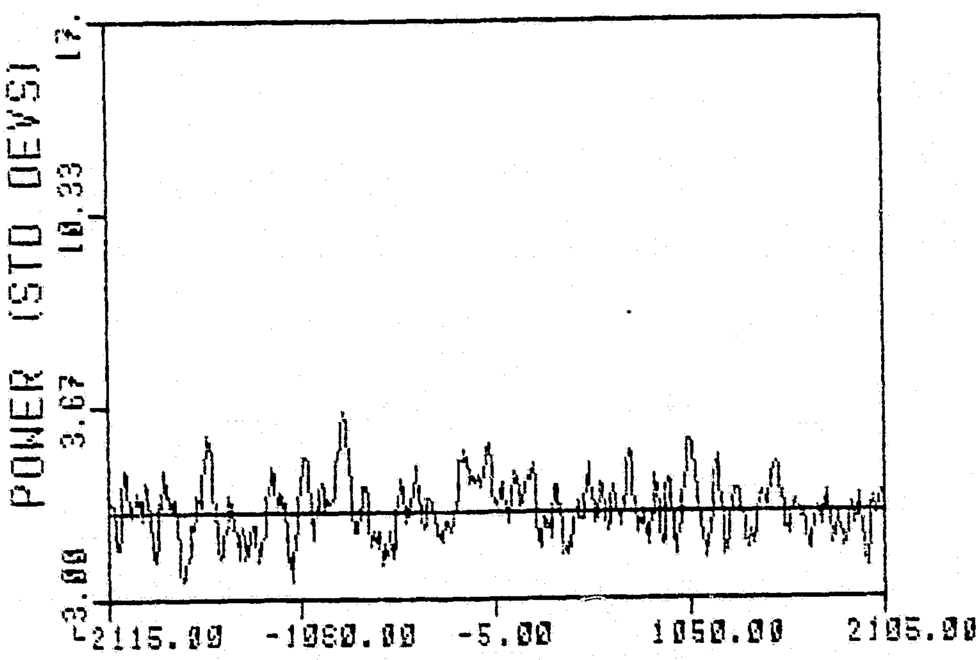


FIGURE 3.

7 IRIS

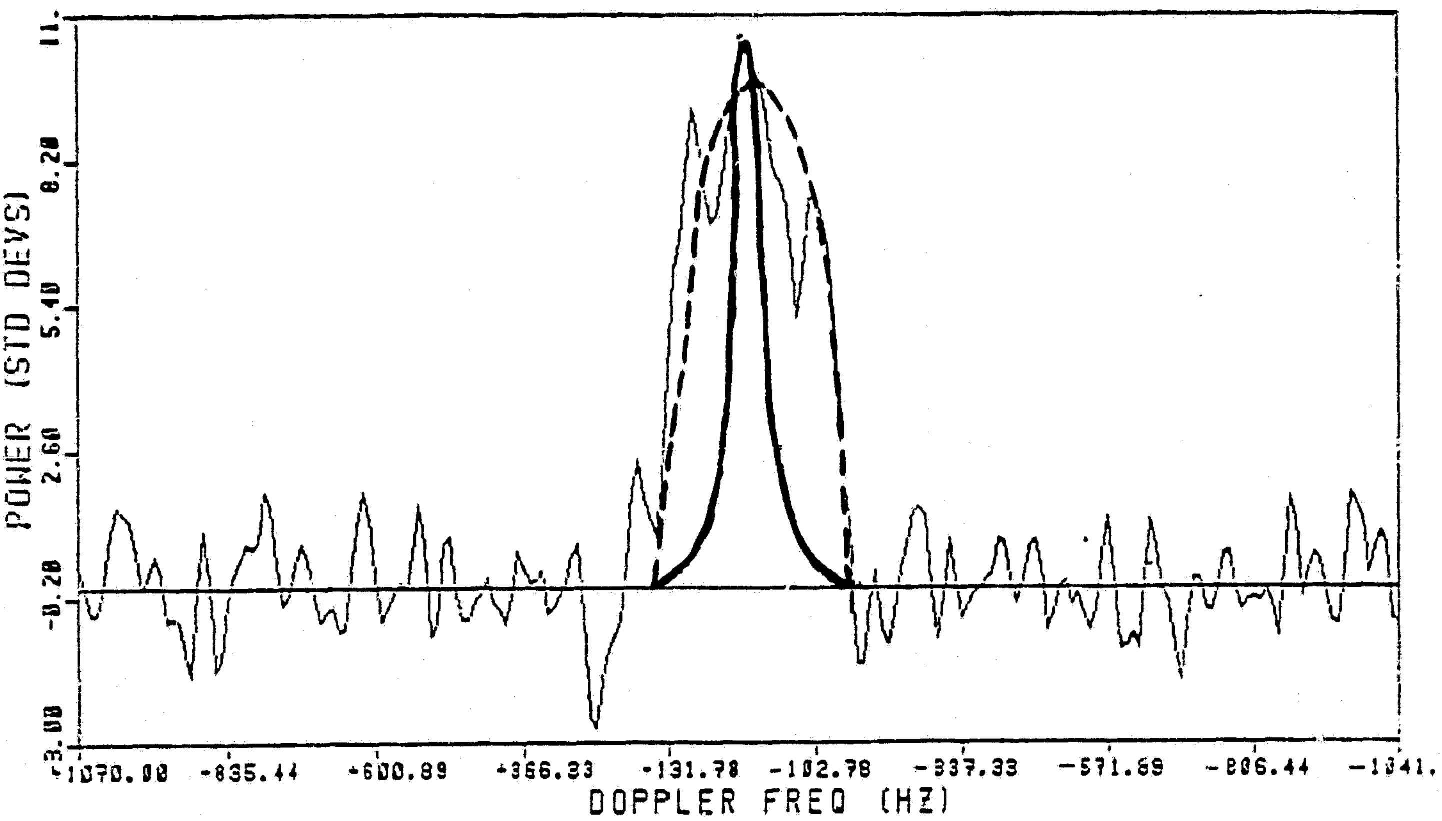
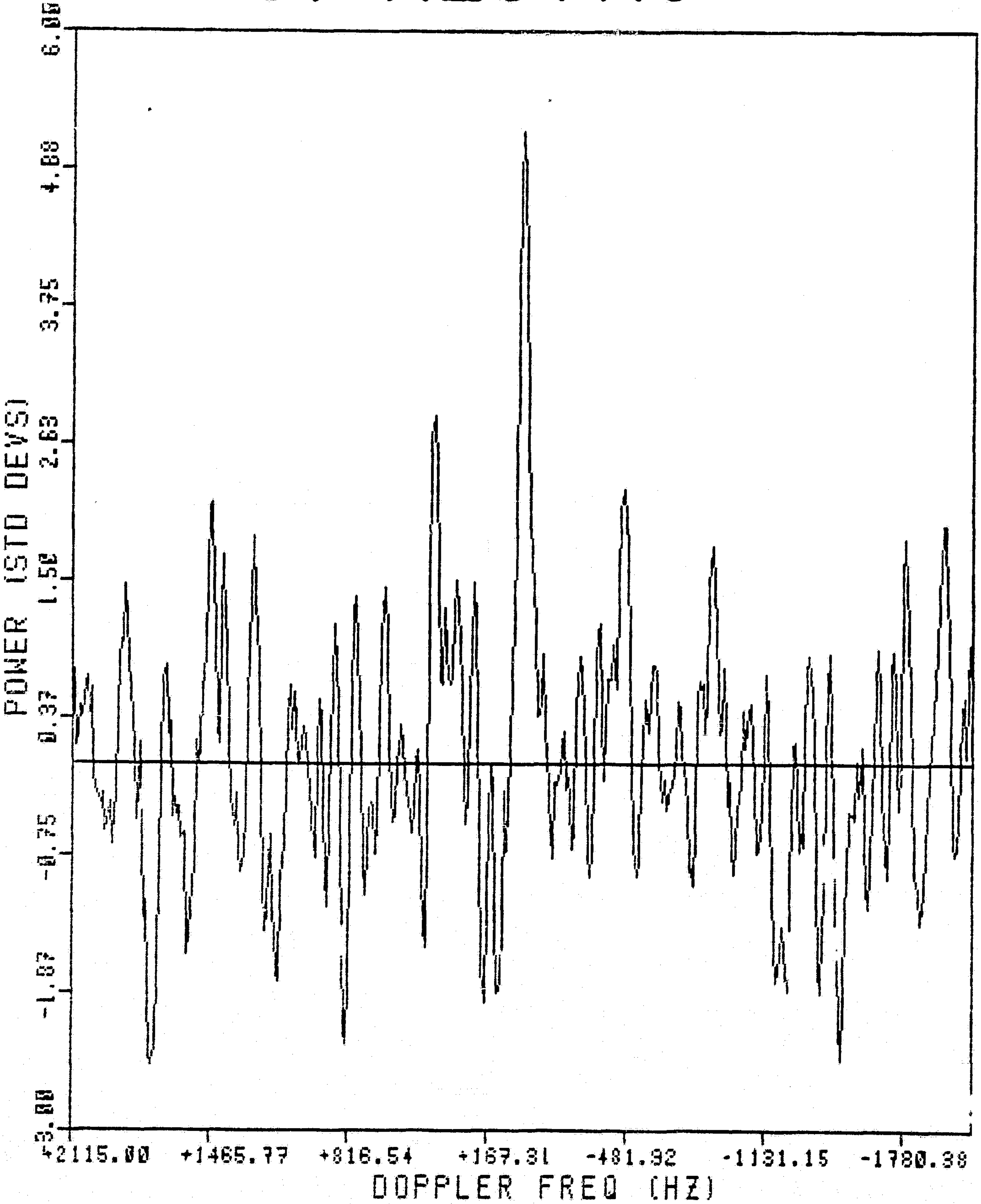


FIGURE 4.

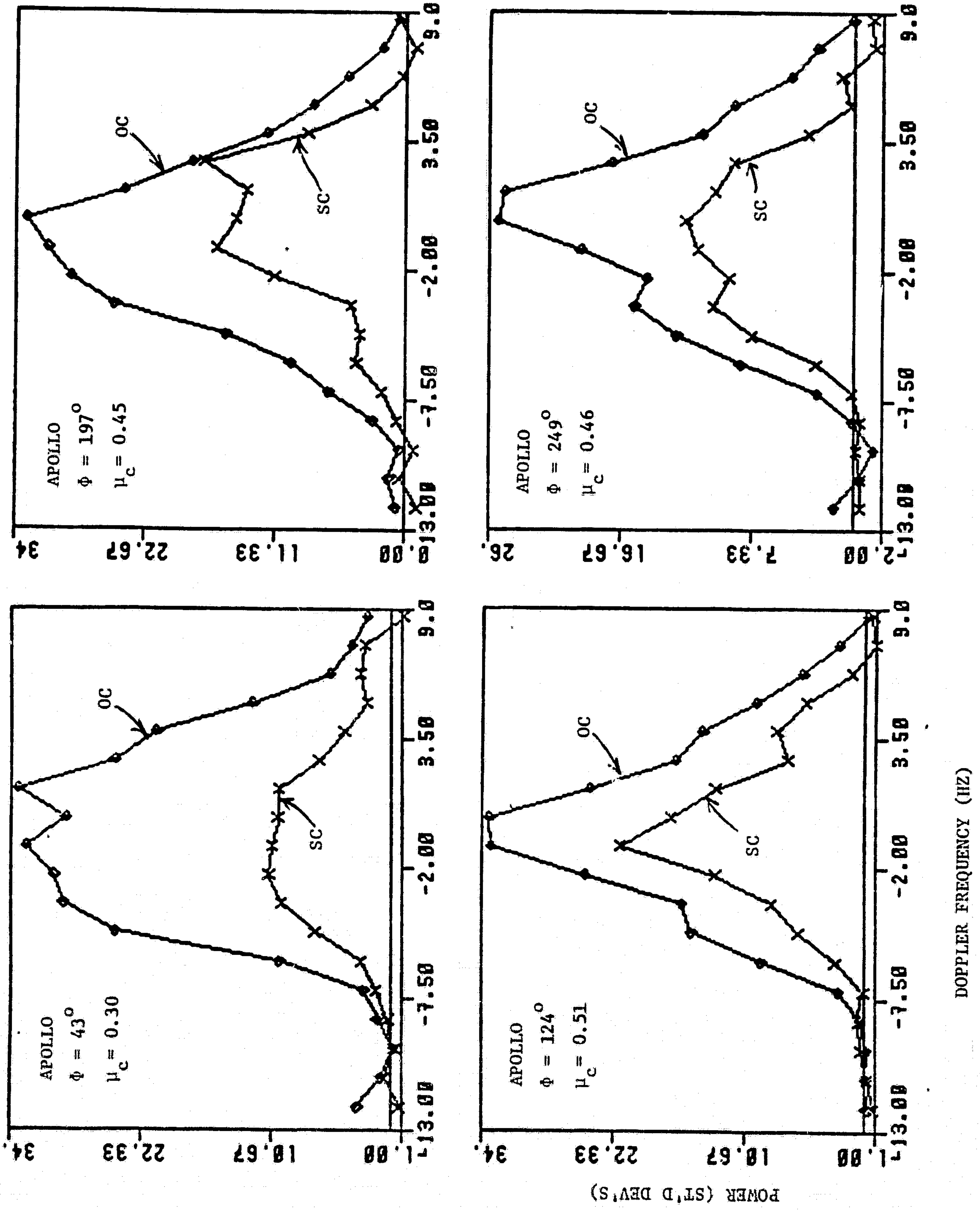
97 KLOTHO



has a radar reflectivity only slightly greater than that of Venus.

Figure 5 shows four sets of dual polarization (SC and OC) spectra obtained for Apollo at widely separated rotational phases, Φ. The variation in spectral bandwidth corresponds to variation in Apollo's equatorial radius by a factor near 1.3. The disc-integrated value of the circular polarization ratio, μ_C, varies by nearly a factor of two as Apollo rotates. Variation in μ_C across individual echo spectral pairs is considerable at some rotational phases. These results suggest that Apollo's surface is quite heterogeneous at decimeter scales.

FIGURE 5.


APOLLO
Φ = 197°
μc = 0.45
APOLLO
Φ = 249°
μc = 0.46
APOLLO
Φ = 43°
μc = 0.30
APOLLO
Φ = 124°
μc = 0.51
OC
SC
DOPPLER FREQUENCY (HZ)
POWER (ST'D DEV'S)

APPENDIX

Abstract of paper presented at the 13th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society in Pittsburgh, October 1981 (Abstract reproduced in B.A.A.S. 13, 716).

Radar Detection of Iris, Psyche, Klotho, Apollo, and Quetzalcoatl, S. J. OSTRO, Cornell/NAIC, D. B. CAMPBELL, NAIC, and I. I. SHAPIRO, MIT -- These asteroids were observed with the Arecibo Observatory's 2380 MHz (λ12.6 cm) radar during apparitions between 1980 Sep and 1981 Mar. The echo power spectra are broad and show no evidence for quasispecular scattering. The table lists our preliminary estimates of (i) the circular polarization ratio, μ_C, of power received in the same sense of circular polarization as transmitted (i.e., the SC sense) to power received in the opposite (OC) sense; (ii) the mean OC radar cross section, σ_{OC}; and (iii) the limb-to-limb spectral bandwidth, B.

Target	μ_C	σ_{OC}, km^2	B, Hz
7 Iris	< 0.2	5.8×10^3	300
16 Psyche	< 0.3	1.4×10^4	830
97 Klotho	no data	1.0×10^3	$\gtrsim 30$
1862 Apollo	0.33 ± 0.05	0.21	12.5 to 16.0
1915 Quetz'l	0.27 ± 0.10	0.017	6.5

The fractional uncertainty associated with estimates of σ_{OC} is $\sim$ 30%, due largely to systematic sources of error. The estimates of B are based on visual inspection of the spectra; their fractional error is probably no more than 10%. The quantity B can be equated to 55.41 $a(\sin\delta)/P$, where P is the synodic rotation period in hours, δ is the colatitude of the subradar point, and a is the "effective" equatorial radius in kilometers. Our observations provide constraints on these targets' sizes, shapes, spin vectors, and surface properties.
The Arecibo Observatory is part of NAIC, which is operated by Cornell under contract with NSF and with support from NASA. This research was supported in part by NASA Grant NAGW-116 (Ostro) and NSF Grant PHY 78-07760 (Shapiro).