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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

November 1, 1981--April 30, 1982

Principal Investigator: Professor Steven J. Ostro

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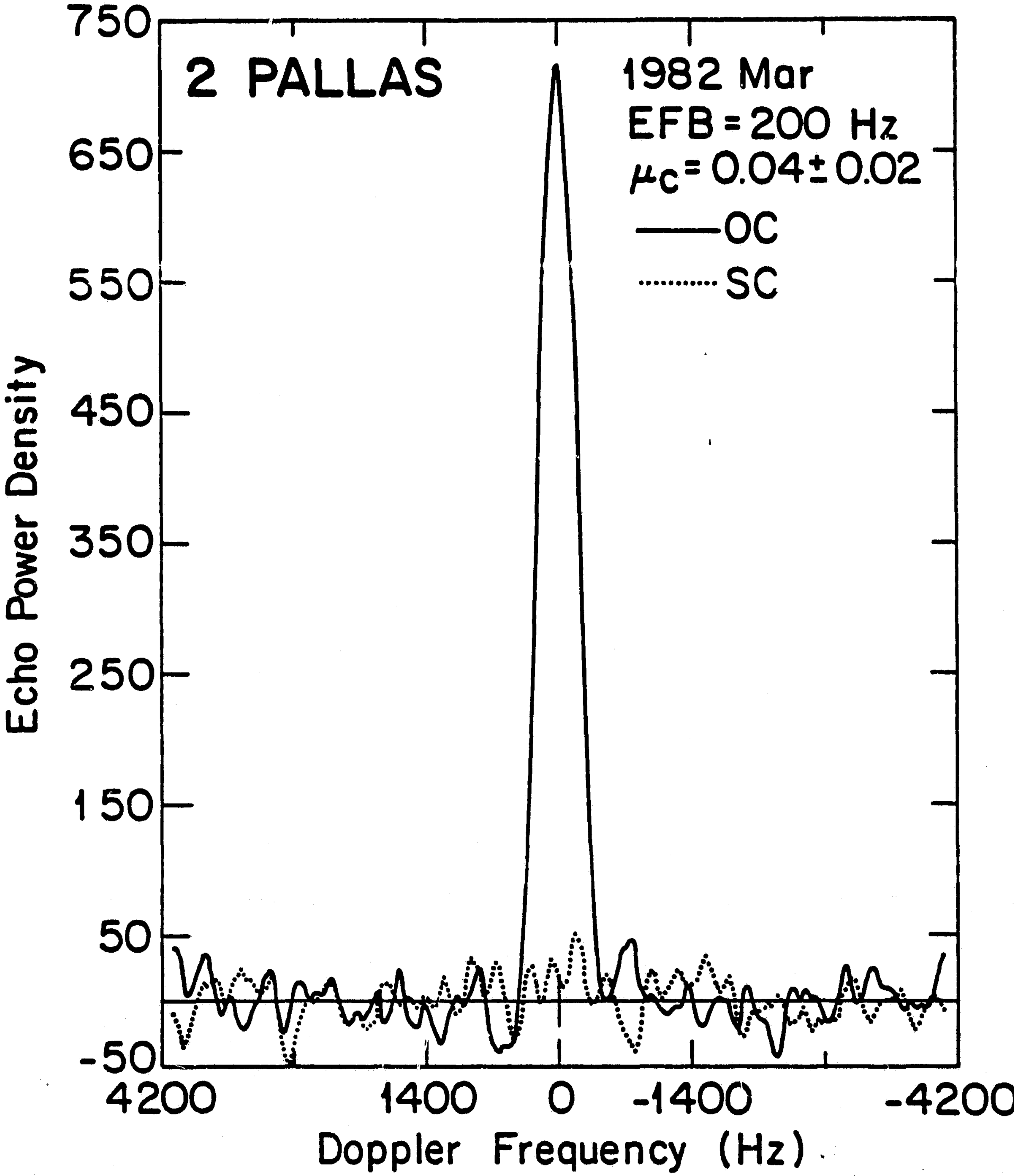
I. SUMMARY OF PROGRESS

During the current report period, research supported under NASA Grant NAGW-116 proceeded in several important directions:

1. With completion of data-reduction software, the Arecibo Observatory's dual-polarization CW radar system became fully operational. This system, which permits simultaneous reception in the same rotational sense of circular polarization as transmitted (i.e., the "SC" sense) and in the opposite ("OC") sense, was used to observe five previously unobserved asteroids: 2 Pallas, 8 Flora, 22 Kalliope, 132 Aethra, and 471 Papagena. Echoes from Pallas and Flora were easily detected in the OC sense on each of several nights. Weighted mean echo power spectra (Figs. 1 and 2) also show marginally significant responses in the SC sense. An approximately 4.5-standard deviation signal was obtained for Aethra (Fig. 3), a poorly studied object and the first Mars-crosser discovered. The Doppler shift of the peak is about 100 Hz higher than that predicted from the a priori trial ephemeris. Calculations are being performed to determine whether this frequency offset can be reconciled dynamically with optical positions reported for Aethra. If the response in Fig. 3 represents a radar

FIGURE 1*



*In each figure in this report, the vertical bar at the origin represents plus and minus one standard deviation of the background noise.

FIGURE 2

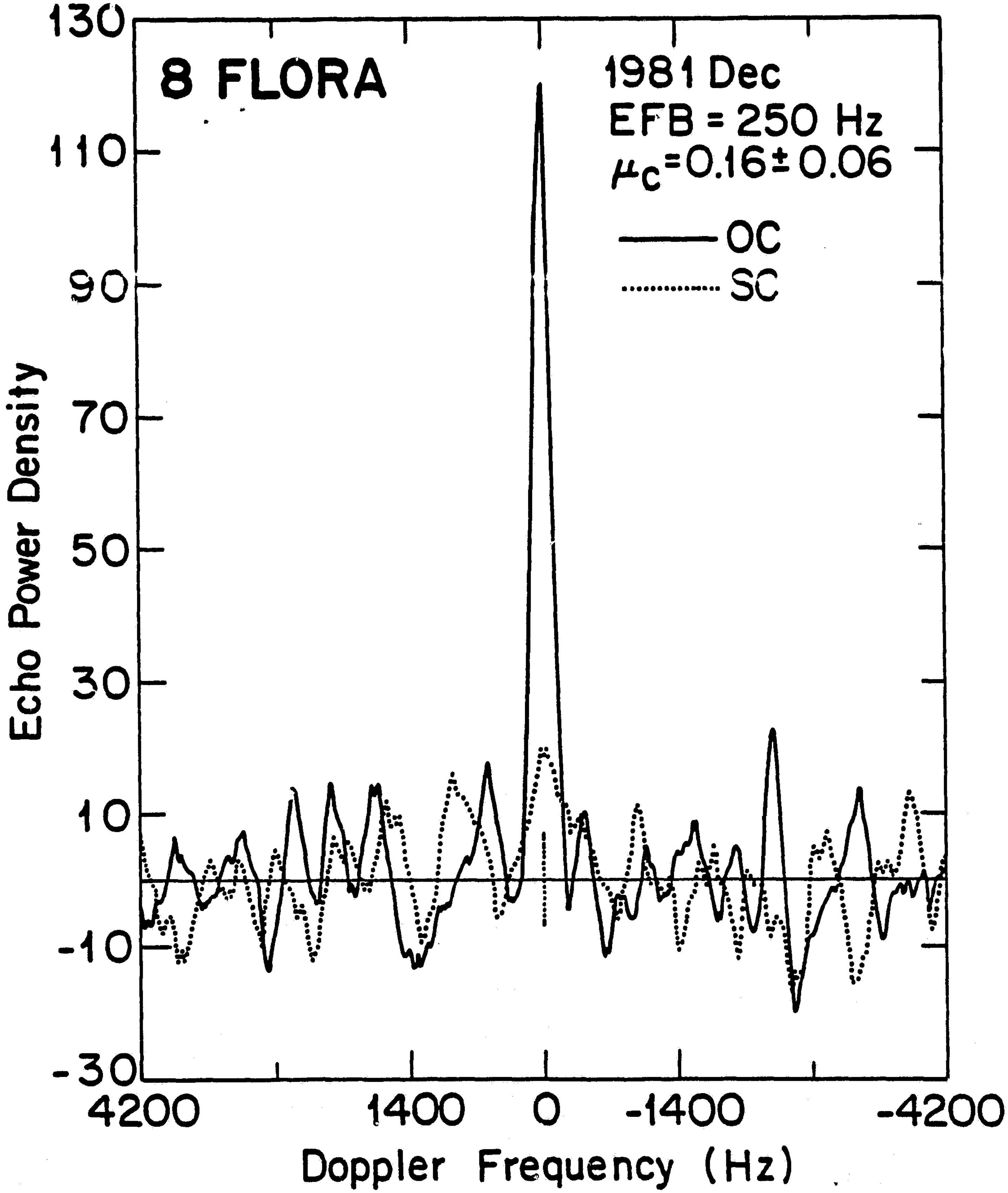
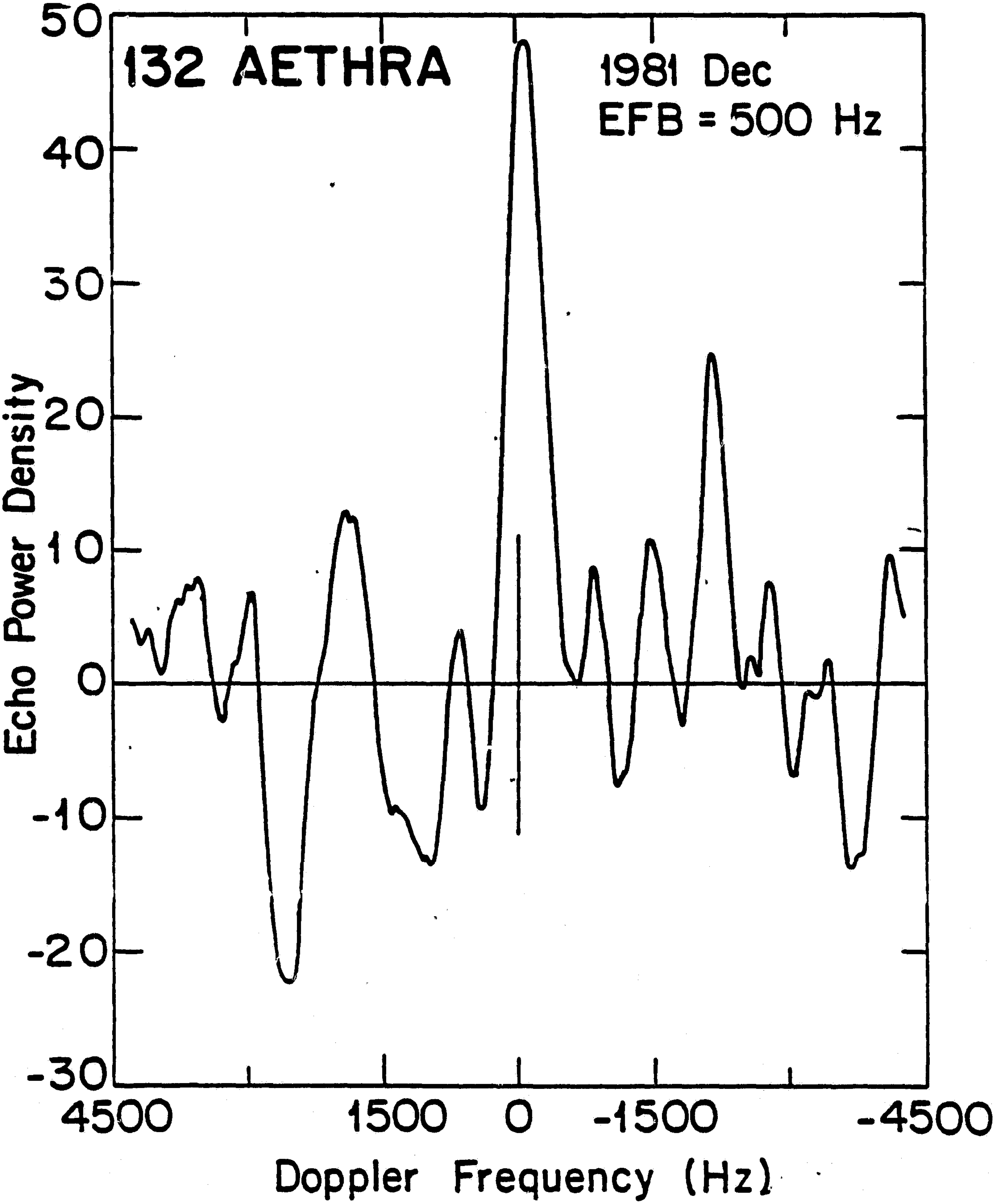

8 FLORA
1981 Dec
EFB = 250 Hz
μ_C=0.16±0.06
OC
SC
130
110
90
70
50
30
10
-10
-30
Echo Power Density
4200
1400
0
-1400
-4200
Doppler Frequency (Hz)

FIGURE 3


132 AETHRA
1981 Dec
EFB = 500 Hz
Echo Power Density
50
40
30
20
10
0
-10
-20
-30
4500
1500
0
-1500
-4500
Doppler Frequency (Hz)

detection and if Aethra's radar reflectivity is close to the asteroidal average, then this object's diameter is somewhat larger than 100 km, and its rotation period is less than 10 hours. Neither Kalliope nor Papagena were detected.

2. Software has been written to search through the Pallas data for evidence of a satellite. (The possible existence of a companion about one-third the size of Pallas has been claimed on the basis of speckle-interferometric observations.) The Pallas radar data in hand provide about 300° of rotational phase coverage, but show none of the "Doppler wobble" expected if Pallas had a massive satellite. By reconstructing an a posteriori ephemeris for any hypothesized satellite orbit, the search program would find an object 25% as large as Pallas. However, searches of the most likely circular orbits do not reveal the presence of a satellite.

3. Analysis of radar data obtained for 1685 Toro approached completion. Software and analytic techniques developed for Toro (e.g., weighted-least-squares fitting routines employing ellipsoidal and cylindrical models) will be applied to Apollo, Ra-Shalom, and Quetzalcoatl.

4. An ephemeris-generating program has been modified to identify radar detectability windows for newly discovered minor planets. Of the several previously unknown

opportunities that have been revealed, the most striking is in September 1988, when the object 1980PA will be detectable from Arecibo at the 100- to 300-standard-deviation level on each of several nights.

II. FUNDING STATUS

During the current report period, spending was kept slightly below the anticipated rate, because (i) a klystron failure in February forced cancellation of observations planned for Eros, and (ii) each of two graduate students participating in the asteroid investigations obtained limited funding from academic fellowships, permitting deferral of NAGW-116 graduate student support until 1983.

A computer terminal, purchased in April and currently being installed, will permit the transfer of much of the radar data analysis to a Harris computer on the Cornell campus, reducing net computing costs and expediting several stages of data processing.

A Cornell senior, Denise Gineris, was employed part-time to assist the principal investigator with computing.

III. HIGHLIGHTS OF DATA ANALYSIS

The circular polarization ratio μ_c, of SC to OC echo power, is a critical indicator of asteroidal surface structure at scales within about an order of magnitude of the observing wavelength (12.6 cm). This ratio could take on extreme values of zero for single-reflection backscattering from a perfectly smooth surface, or unity for complete depolarization of the incident wave either by single-reflection backscattering from an extremely rough interface or by multiple scattering. Planetary surfaces generally yield intermediate values. For example, $\mu_c \approx 0.1$ for the Moon, with much of the depolarization (i.e., SC contribution) due to small rocks in the ejecta blankets of fresh craters. For asteroid investigations, μ_c is especially valuable because its estimation does not require knowledge of target size, shape, or orientation. The dominant source of error in estimates of the single-polarization radar cross sections σ_{OC} and σ_{SC} arises from uncertainty in the radar system sensitivity. However, calculation of $\mu_c = \sigma_{SC}/\sigma_{OC}$ largely eliminates systematic errors, leaving only the statistical error associated with fluctuations in the noise background.

In the dual-polarization experiments supported by this grant, OC and SC reception was either simultaneous or interleaved. Thus, whenever an OC echo was detected, the spectral band containing any SC echo was delineated, whether or not a significant SC response was detected. Integration over this band in each polarization yields estimates of σ_{OC} and σ_{SC} along with their associated errors. In this manner, values of μ_C for the main-belt asteroids (none of which have yielded SC detections at convincing statistical levels) can be estimated.

Results of all existing λ12.6-cm estimates of μ_C for asteroids are tabulated below. Although the small-body average is about three times the large-body average,

ASTEROID λ12.6-cm CIRCULAR POLARIZATION RATIOS, μ_C

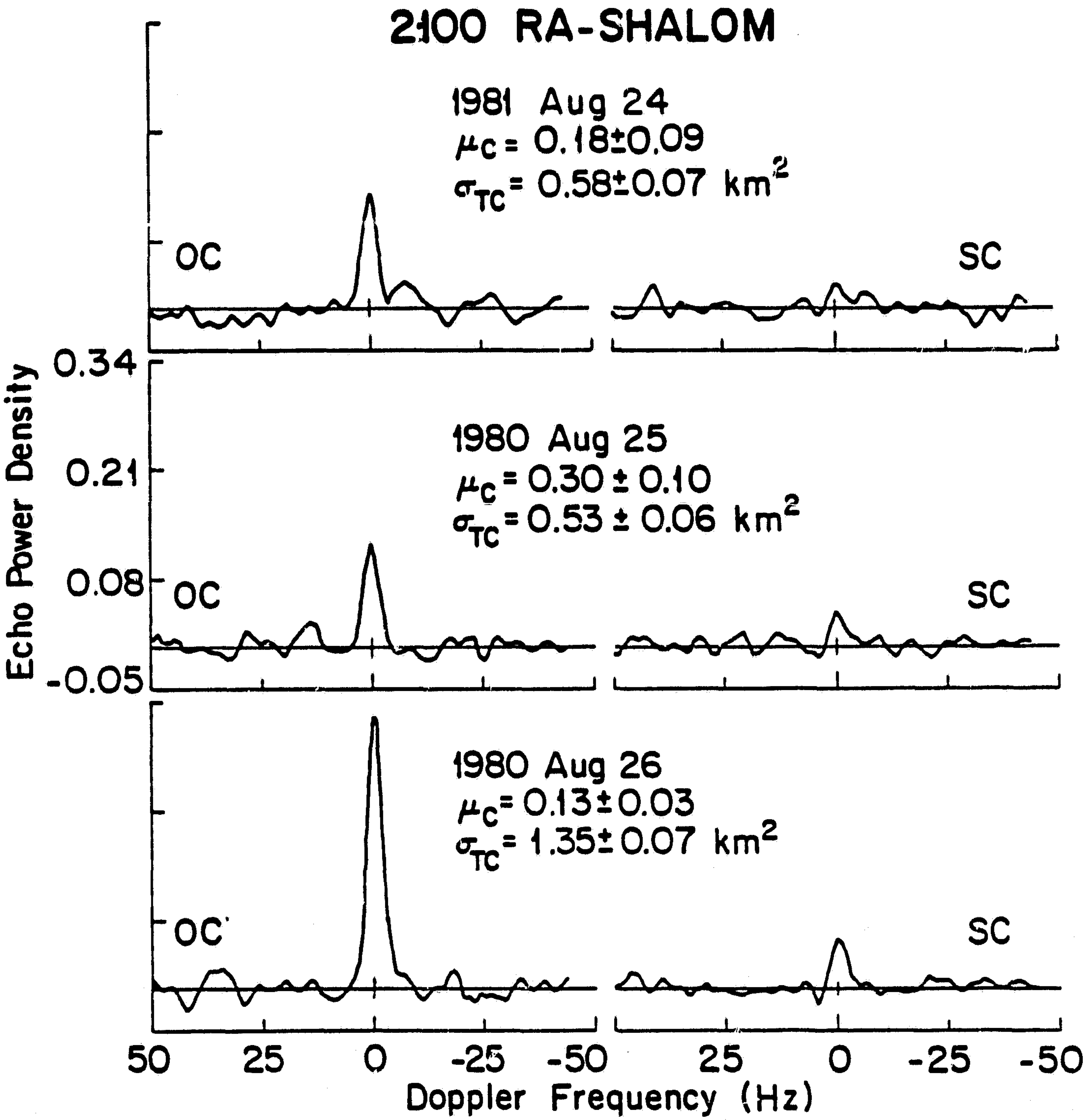
2 PALLAS	0.04 ± 0.02
7 IRIS	0.08 ± 0.03
8 FLORA	0.16 ± 0.06
16 PSYCHE	0.00 ± 0.13
(Average for large, main-belt objects: 0.07 ± 0.07)	
1685 TORO	0.18 ± 0.04
1862 APOLLO	0.33 ± 0.05
1915 QUETZALCOATL	0.27 ± 0.10
2100 RA-SHALOM	0.15 ± 0.03
(Average for small, planet-crossing objects: 0.23 ± 0.08)	

individual values of μ_C vary by a factor of 2 for small objects and may be similarly dispersed for large objects. Thus, the apparently valid generalization that "small objects tend to be rougher than large objects at centimeter-to-meter scales" must be tempered by evidence that similar-sizes objects can have structurally different surfaces (cf. Apollo and Ra-Shalom), and that the surfaces of certain large objects (Flora?) may be structurally similar to those of smaller objects.

Figure 4 demonstrates considerable night-to-night variation in Ra-Shalom's circular polarization ratio (μ_C) and total radar cross section (σ_{TC}). Similar (but less extreme) results for Toro, Apollo, Quetzalcoatl, and Pallas suggest that asteroidal surfaces are structurally inhomogeneous at centimeter-to-meter scales.

The value of μ_C for Pallas (0.04 ± 0.02) is the same as that for Venus but lower than that for any other radar-detected planetary object. Since Pallas is not a quasi-specular scatterer, its surface is much rougher than Venus' at some scale(s) $\gtrsim$ 10 m. Nevertheless, it is interesting that at centimeter-to-meter scales Pallas and Venus are similarly smooth.

FIGURE 4


2100 RA-SHALOM
1981 Aug 24
μ_C = 0.18±0.09
σ_{TC} = 0.58±0.07 km^2
OC
SC
0.34
0.21
0.08
-0.05
Echo Power Density
1980 Aug 25
μ_C = 0.30 ± 0.10
σ_{TC} = 0.53 ± 0.06 km^2
OC
SC
1980 Aug 26
μ_C = 0.13±0.03
σ_{TC} = 1.35±0.07 km^2
OC
SC
50 25 0 -25 -50 25 0 -25 -50
Doppler Frequency (Hz)