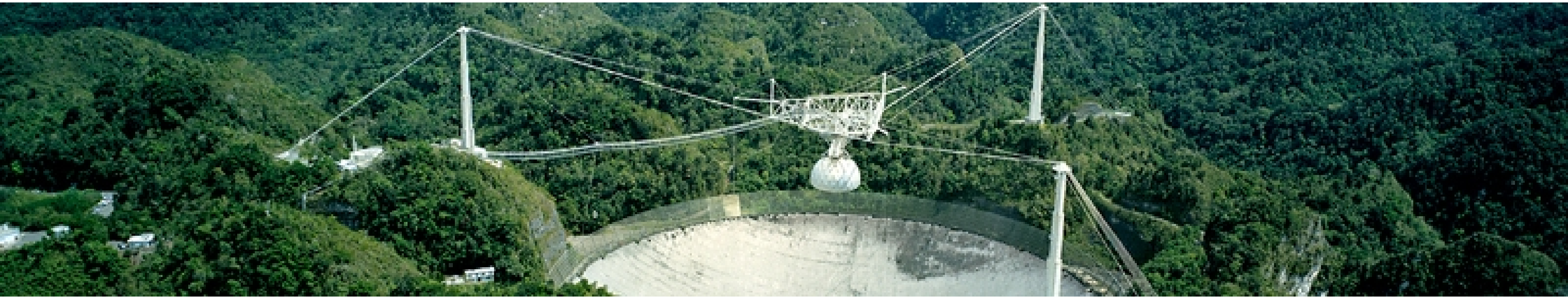
Arecibo Observatory and its 305-m Telescope

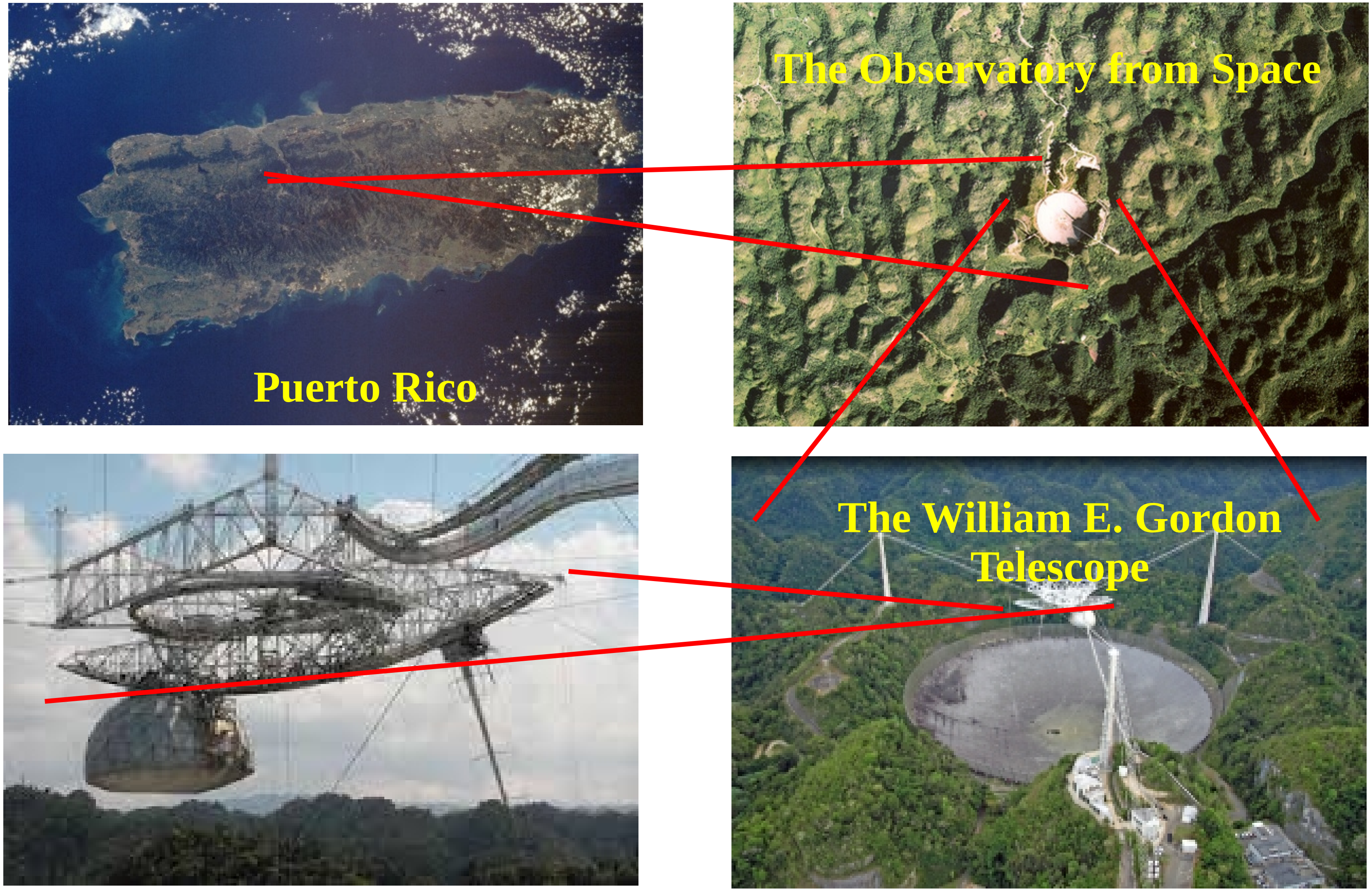


Chris Salter

Green Bank and Arecibo Observatories

Single-Dish Summer School, Green Bank: Aug., 2019

Geographical Context



Incoherent Scattering of Radio Waves by Free Electrons with Applications to Space Exploration by Radar*

W. E. GORDON†, MEMBER, IRE

Summary—Free electrons in an ionized medium scatter radio waves weakly. Under certain conditions only incoherent scattering exists. A powerful radar can detect the incoherent backscatter from the free electrons in and above the earth's ionosphere. The received signal is spread in frequency by the Doppler shifts associated with the thermal motion of the electrons.

On the basis of incoherent backscatter by free electrons a powerful radar, but one whose components are presently within the state of the art, is capable of:

1) measuring electron density and electron temperature as a function of height and time at all levels in the earth's ionosphere and to heights of one or more earth's radii;
2) measuring auroral ionization;
3) detecting transient streams of charged particles coming from outer space; and
4) exploring the existence of a ring current.

The instrument is capable of

1) obtaining radar echoes from the sun, Venus, and Mars and possibly from Jupiter and Mercury; and
2) receiving from certain parts of remote space hitherto-undetected sources of radiation at meter wavelengths.

* Original manuscript received by the IRE, June 11, 1958; revised manuscript received, August 25, 1958. The research reported in this paper was sponsored by Wright Air Dev. Ctr., Wright-Patterson Air Force Base, O., under Contract No. AF 33(616)-5547 with Cornell Univ.

† School of Elec. Eng., Cornell Univ., Ithaca, N. Y.

Proceedings of IRE
Nov 1958

1960 - 1963 – (AIO)
CONSTRUCTION

Inauguration in Nov 1963
William Gordon – Director

Proc IRE 58

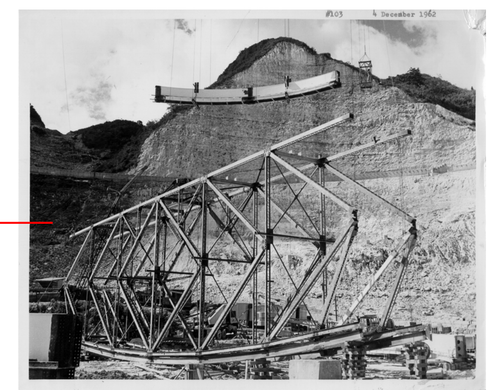
The Arecibo bowl, as it looked in June 1960, when it was still a tobacco farm

The Arecibo Ionospheric Observatory (AIO) takes Shape

27 April 1961

Late 1961

June 1962



Late 1962

28 February 1963

1 November 1963

Arecibo Ionospheric Observatory: 1963

The Early Years (1963 - 1972)

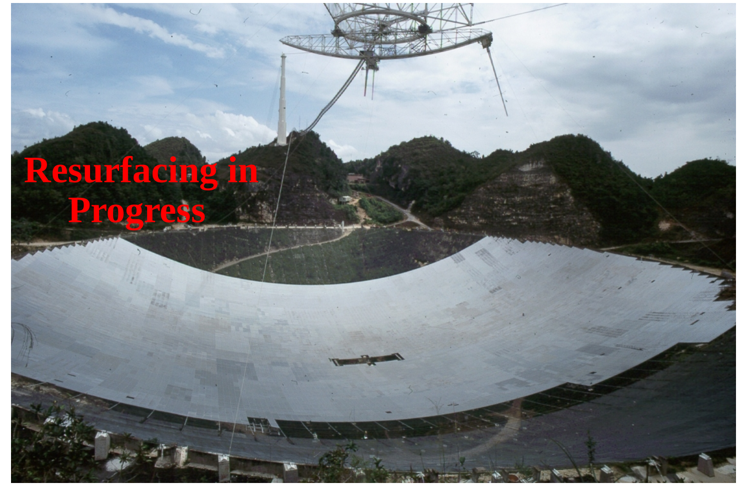
1963 Arecibo Ionospheric Observatory Commissioned for service, 1 November, 1963. [$9.7M]

1965 One of its first accomplishments: Establishing the rotation rate of Mercury, which turned out to be 59 days rather than the previously estimated 88 days.

1968 Sporadic radio pulses from the direction of the Crab Nebula supernova remnant found at Green Bank were shown by Arecibo to come from a 33-ms period pulsar situated at the center of the nebula.

1969 The National Science Foundation assumes operations from DoD on 1 October, 1969. AIO becomes the National Astronomy and Ionosphere Center (NAIC) in 1971.

The First Upgrade 1972-74



1972-1974: FIRST ARECIBO UPGRADE

NEW SURFACE (RMS < 3mm)

HIGHER FREQUENCY OPERATION (SPECTRAL LINE OF NEUTRAL HYDROGEN AT 1420.405 MHz)

AND A NEW 2380 MHz RADAR (S-BAND).

JULY 1974 - PSR 1913+16 FIRST DETECTED
(Joe TAYLOR & Russ HULSE)

Nature: 1979

Measurements of general relativistic effects in the binary pulsar PSR1913+16

J. H. Taylor, L. A. Fowler & P. M. McCulloch*

Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

Measurements of second- and third-order relativistic effects in the orbit of binary pulsar PSR1913+16 have yielded self-consistent estimates of the masses of the pulsar and its companion, quantitative confirmation of the existence of gravitational radiation at the level predicted by general relativity, and detection of geodetic precession of the pulsar spin axis.

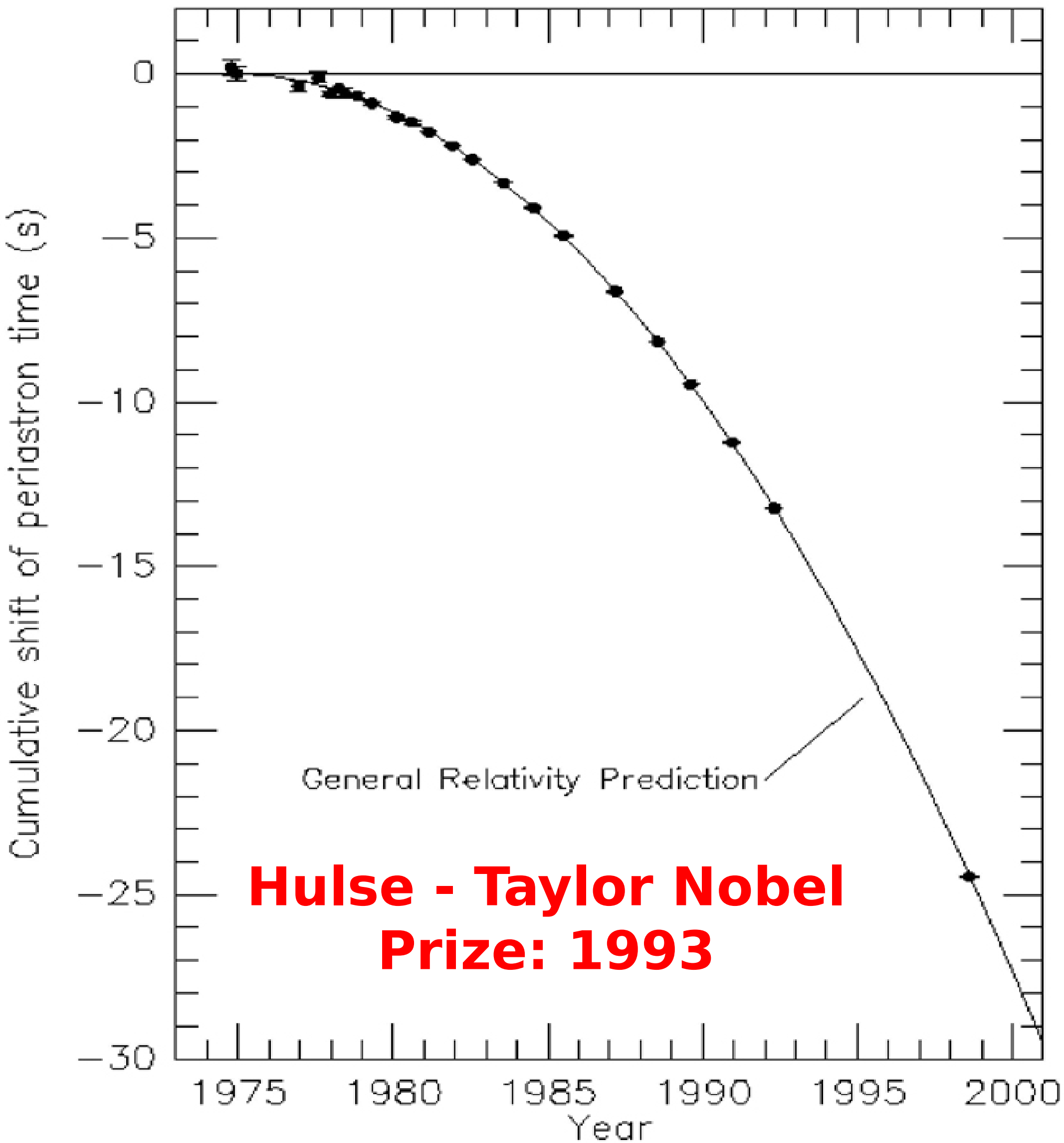
THE earliest observations of binary pulsar PSR1913+16 showed that, because its orbit involved large velocities ($v/c \approx 10^{-3}$), a high eccentricity ($e \approx 0.617$), and relatively strong gravitational fields ($GM/c^2r \approx 10^{-6}$), several special and general relativistic effects should eventually be observable[1]. The advance of periastron (at the rate $\dot{\omega} \approx 4.2$ deg yr^{-1}) was the first of these effects to be measured[2], and the rate of advance has now been determined to better than 0.1% accuracy[3,4]. We report here the detection of four more effects of relativistic origin, including quantitative measurements of three of them. Together with the much larger effects already measured, the new parameters over-determine the system and provide: (1) the first determination of the mass of a radio frequency pulsar; (2) constraints on the nature of the companion star, and a measurement of its mass; (3) determination of the angle of inclination between the plane of the orbit and the plane of the sky; (4) quantitative confirmation of the existence of gravitational radiation at the level predicted by general relativity; and (5) qualitative observation of geodetic precession of the pulsar spin axis. The data are consistent with the general theory of relativity and provide some strong constraints on any alternative theory of gravitation.

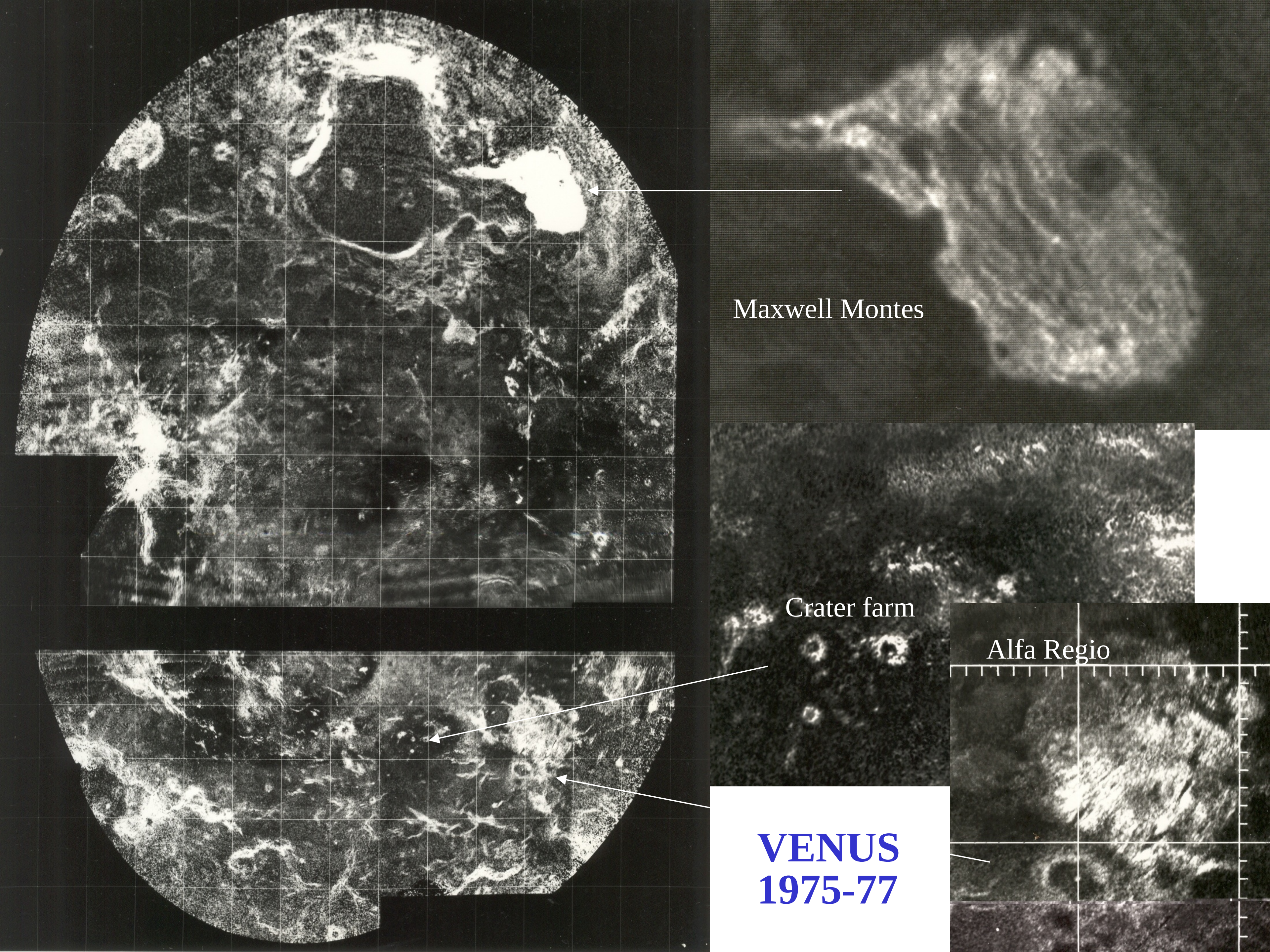
~1 ms to ~50 μs. Data have been acquired at intervals not exceeding 7 months, and in spite of the short period of the pulsar ($P = 0.059$ s), there has been no problem in keeping track of the number of elapsed pulse periods.

Our analysis of the timing data follows the formulation of Epstein[6], and proceeds by the following steps. First, the pulse arrival times are corrected from the location of the observatory to the barycentre of the Solar System, including a relativistic clock correction to account for annual changes in gravitational potential at the Earth. A correction is then made for the dispersive delay in the interstellar medium, using the frequency of observation as Doppler-shifted by the Earth's motion. Finally, the proper time t_p in the pulsar's reference frame is obtained by correcting for (1) the projection onto the line of

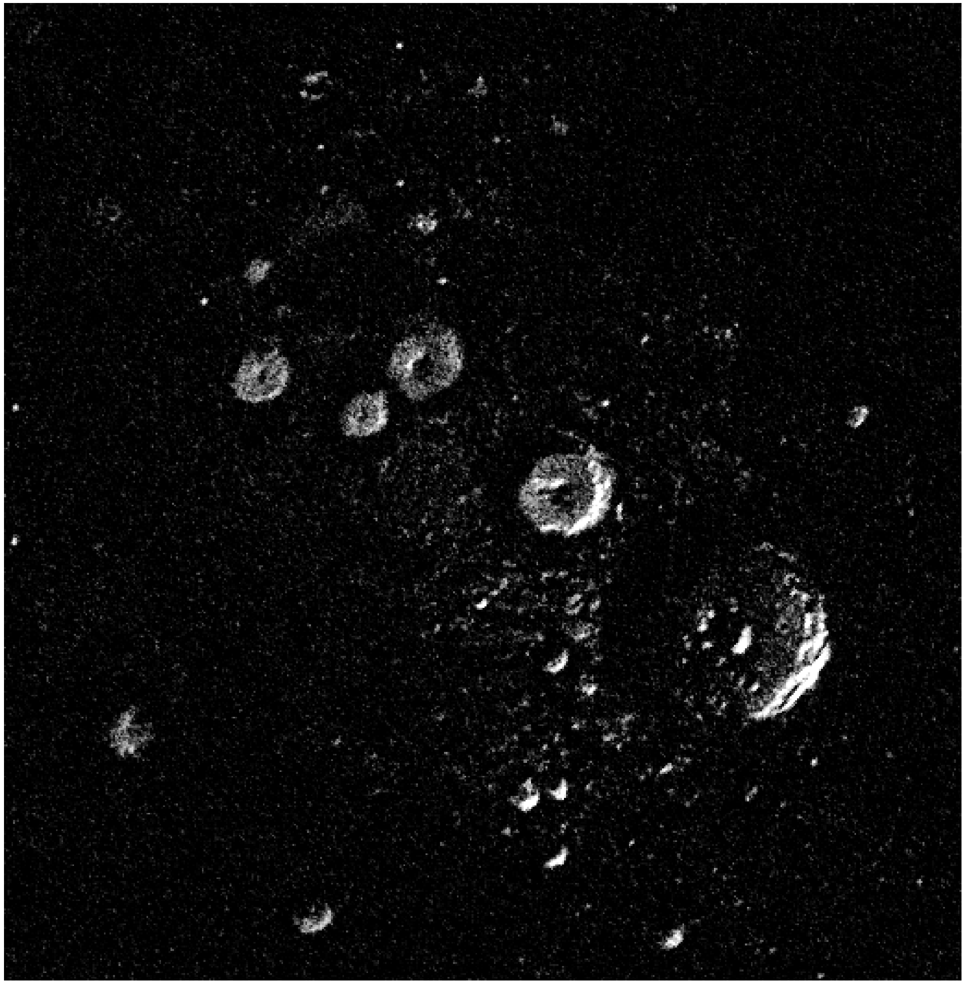
Table 1 Parameters derived from timing data

Right ascension (1950.0)	$\alpha = 19$ h 13 min 12.474 s $\pm$ 0.004 s
Declination (1950.0)	$\delta = 16° 01' 08''.02 \pm 0''.06$
Period	$P = 0.059029995269 \pm 2$ s
Derivative of period	$\dot{P} = (8.64 \pm 0.02) \times 10^{-18}$ s s^{-1}
Projected semimajor axis	$a_1 \sin i = 2.3424 \pm 0.0007$ light s
Orbital eccentricity	$e = 0.617155 \pm 0.000007$
Binary orbit period	$P_b = 27906.98172 \pm 0.00005$ s
Longitude of periastron	$\omega_0 = 178.864 \pm 0.002°$
Time of periastron passage	$T_0 =$ JD 2442321.433206 $\pm$ 0.000001
Rate of advance of periastron	$\dot{\omega} = 4.226 \pm 0.002$ deg yr^{-1}
Transverse Doppler and gravitational redshift	$\gamma = 0.0047 \pm 0.0007$ s
Sine of inclination angle	$\sin i = 0.81 \pm 0.16$
Derivative of orbit period	$\dot{P}_b = (-3.2 \pm 0.6) \times 10^{-12}$ s s^{-1}


0
−5
−10
−15
−20
−25
−30
Cumulative shift of periastron time (s)
1975
1980
1985
1990
1995
2000
Year
General Relativity Prediction
Hulse - Taylor Nobel Prize: 1993


Maxwell Montes
Crater farm
Alfa Regio
VENUS
1975-77

Ice at the Poles of Mercury



Gregorian Upgrade 1993 –1997

(Second Upgrade)

1 – Ground Screen to reduce spillover noise

2 – New drive systems including active platfordm tie-downs

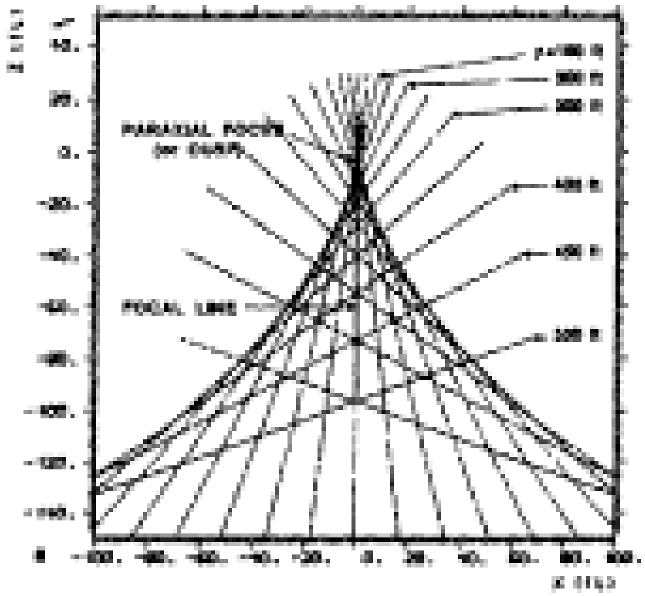
3 – Replace most line feeds with a reflector feed system

4 – New receivers (up to 10 GHz)

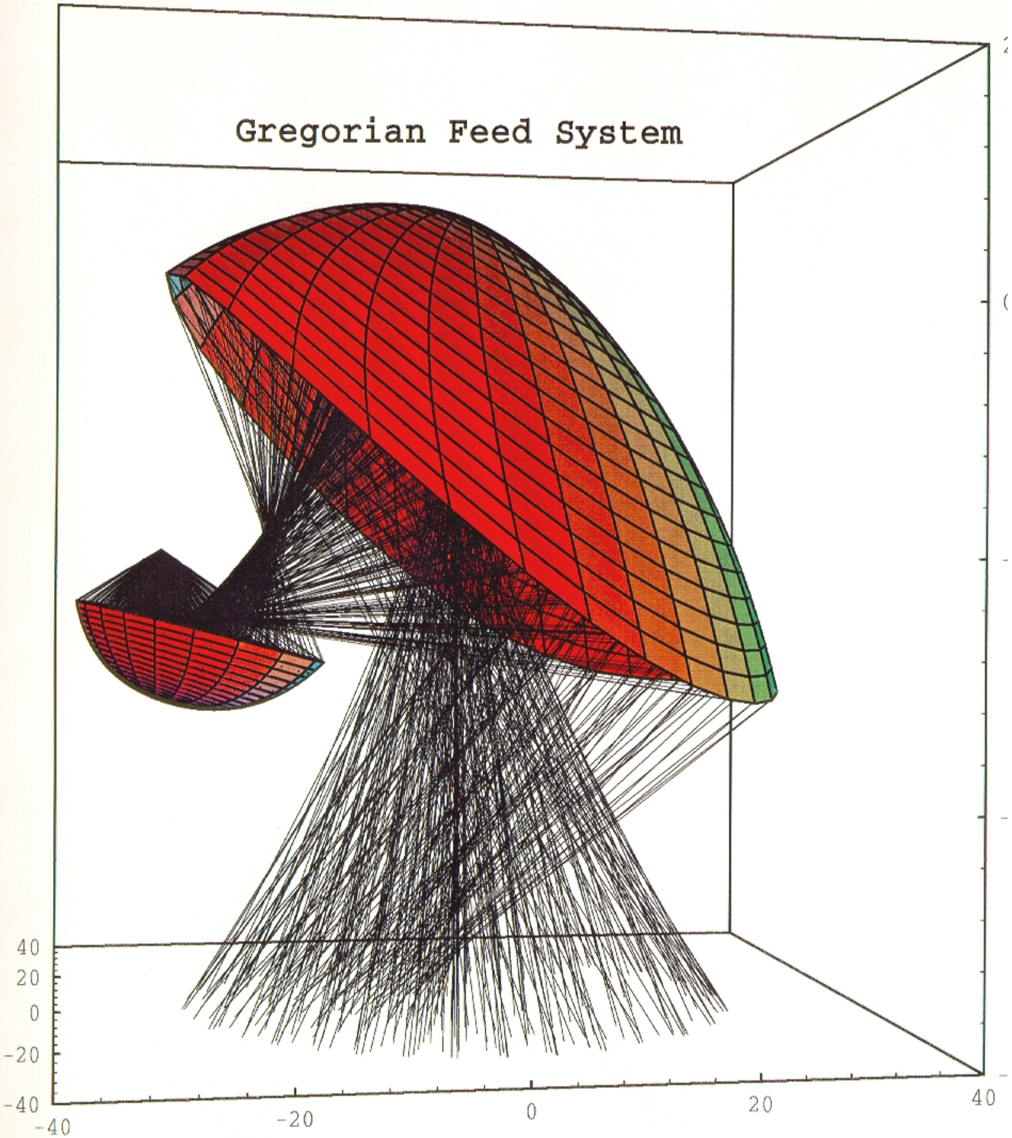
5 – New S-band transmitter with twice the power

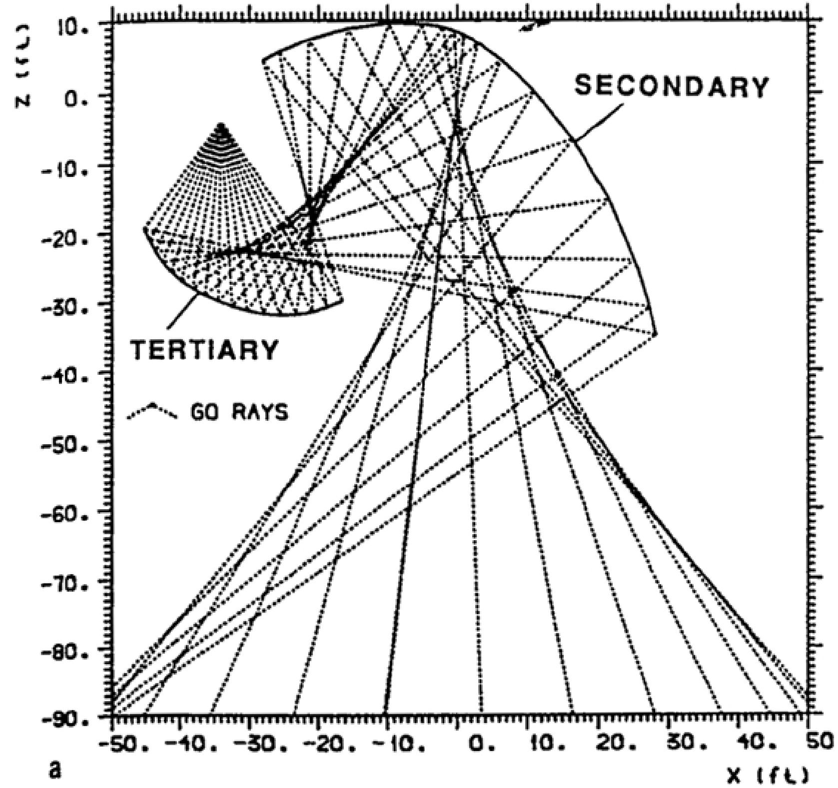
6 – Improve surface accuracy of reflector to reach 10 GHz

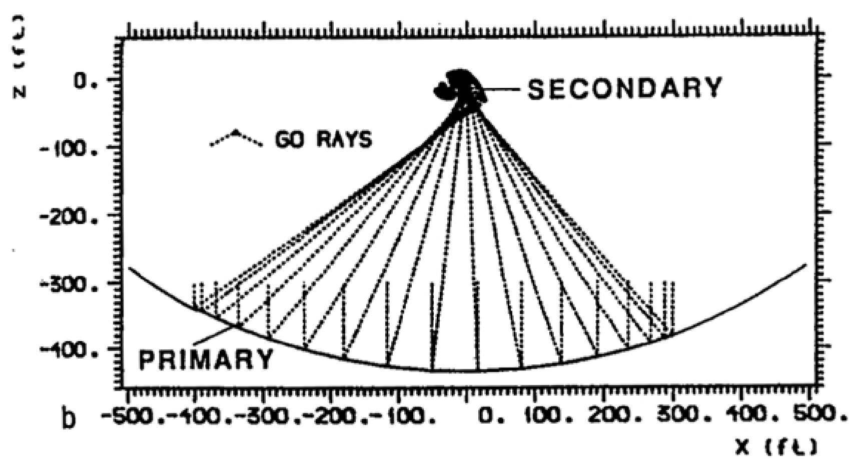
“Parabolizing” the Sphere!



The 430-MHz line feed. Line feeds are intrinsically narrow band.





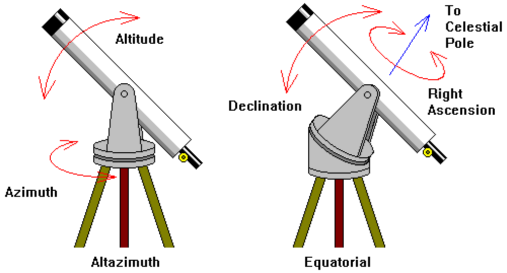


Totally Achromatic

Pointing the Arecibo Telescope

Arecibo is an Alt-Az mounted telescope.

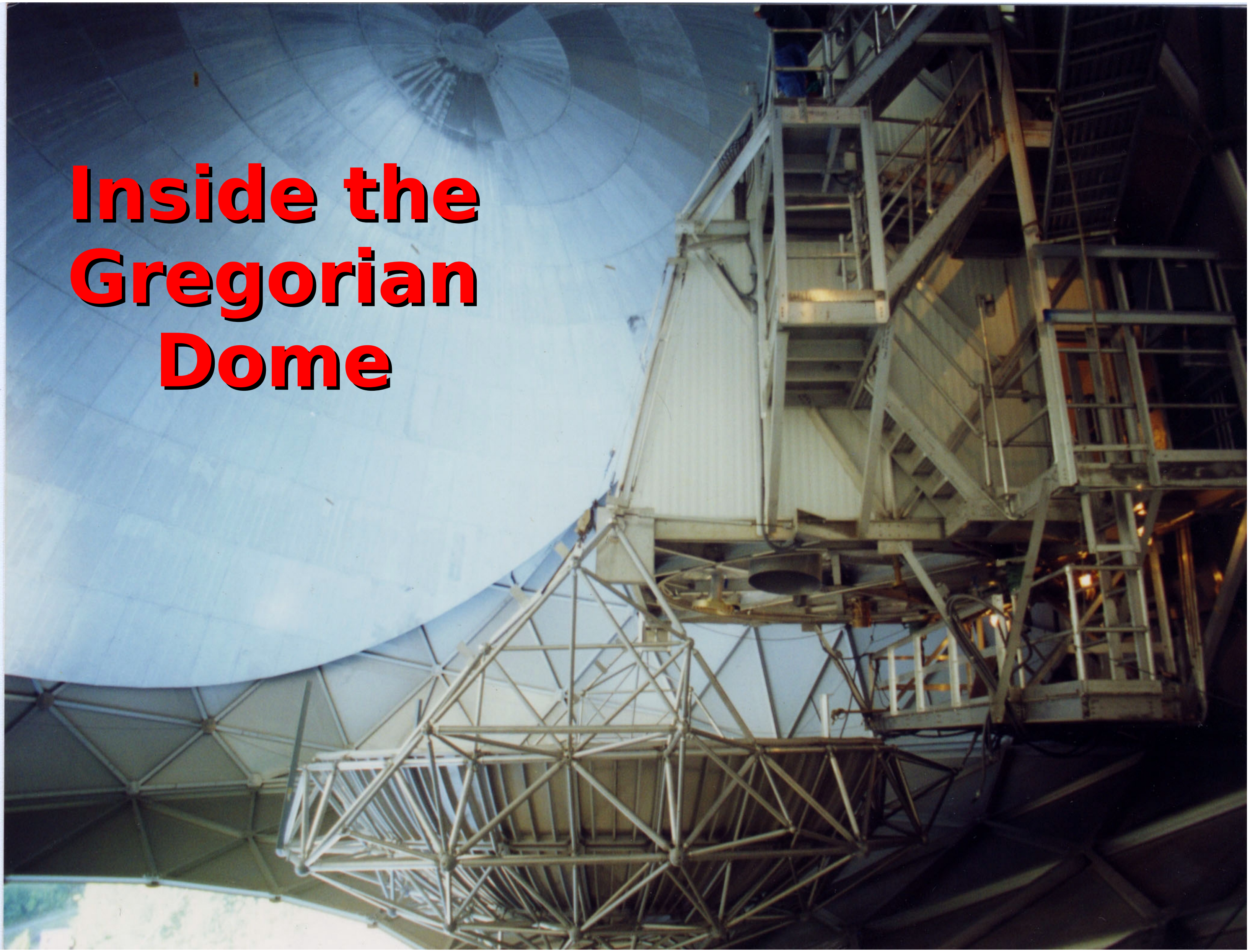
Its surface is a spherical end cap.

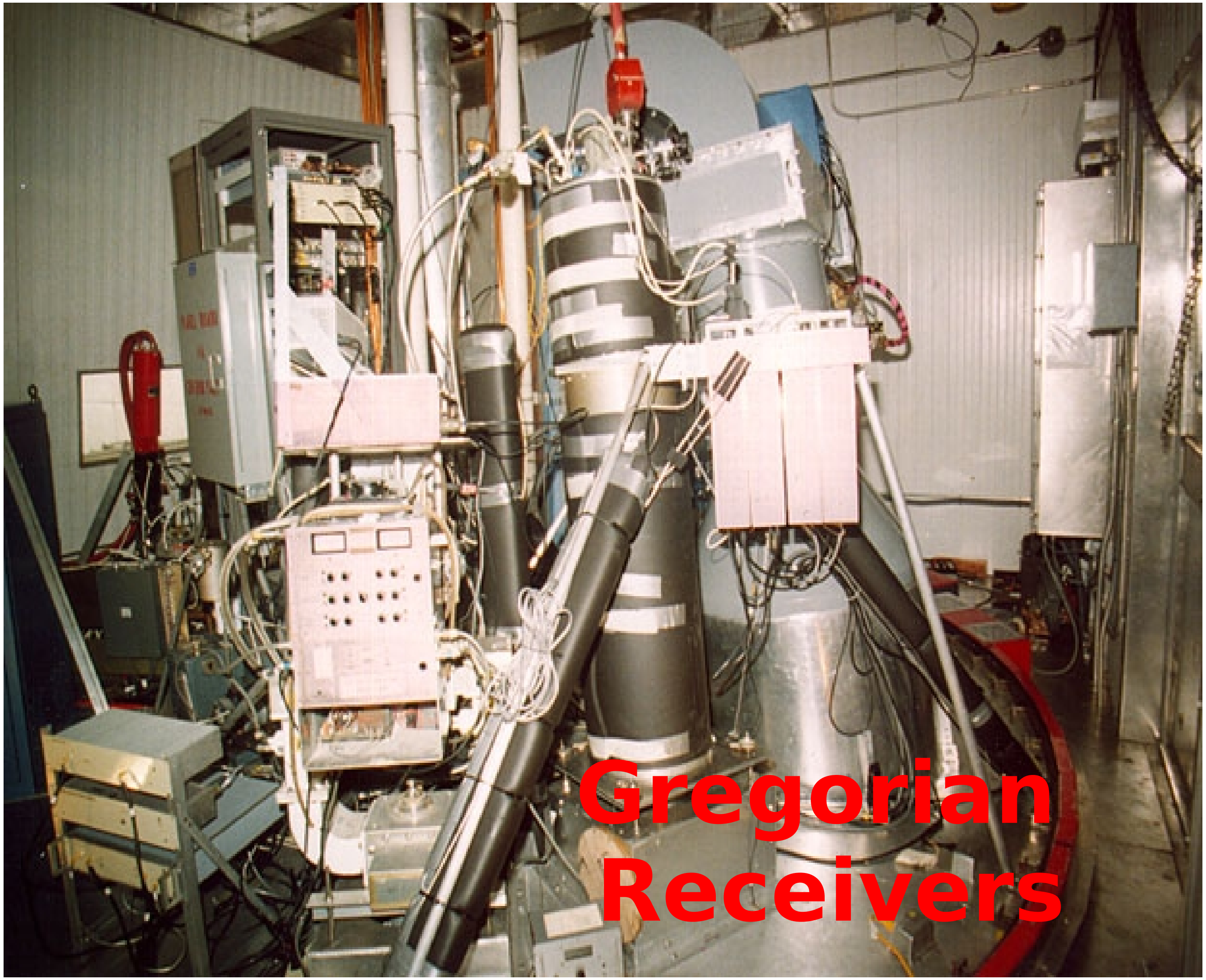


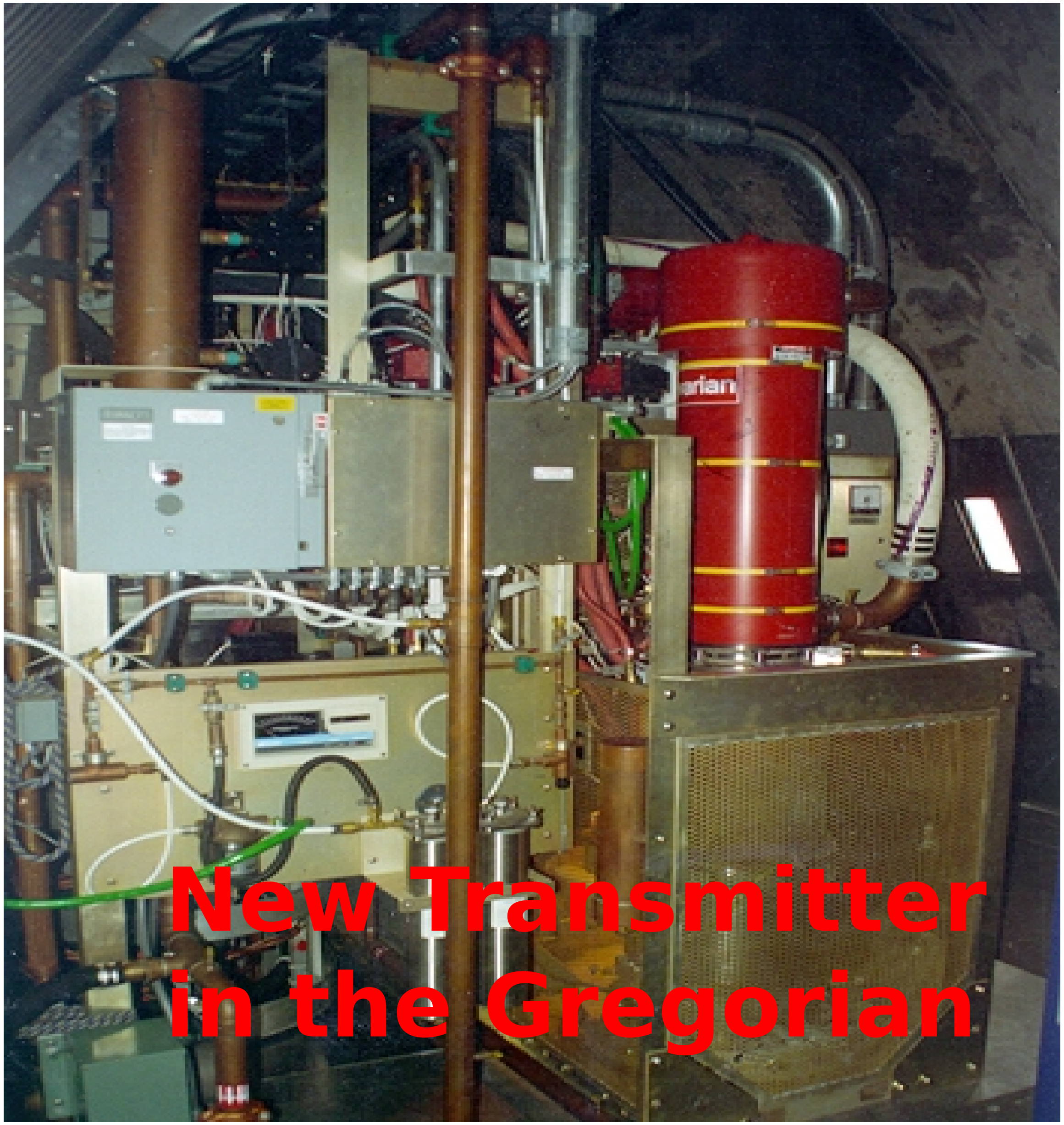
The Platform and Az Arm

May 16, 1996

Inside the Gregorian Dome




Gregorian
Receivers


New Transmitter
in the Gregorian


AO 1998

Receivers

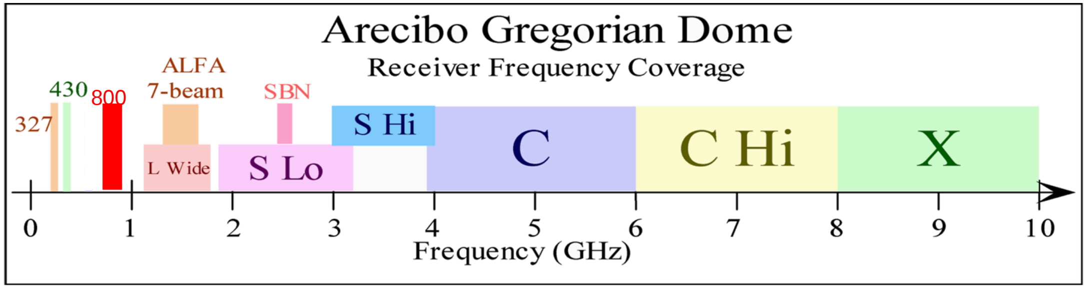
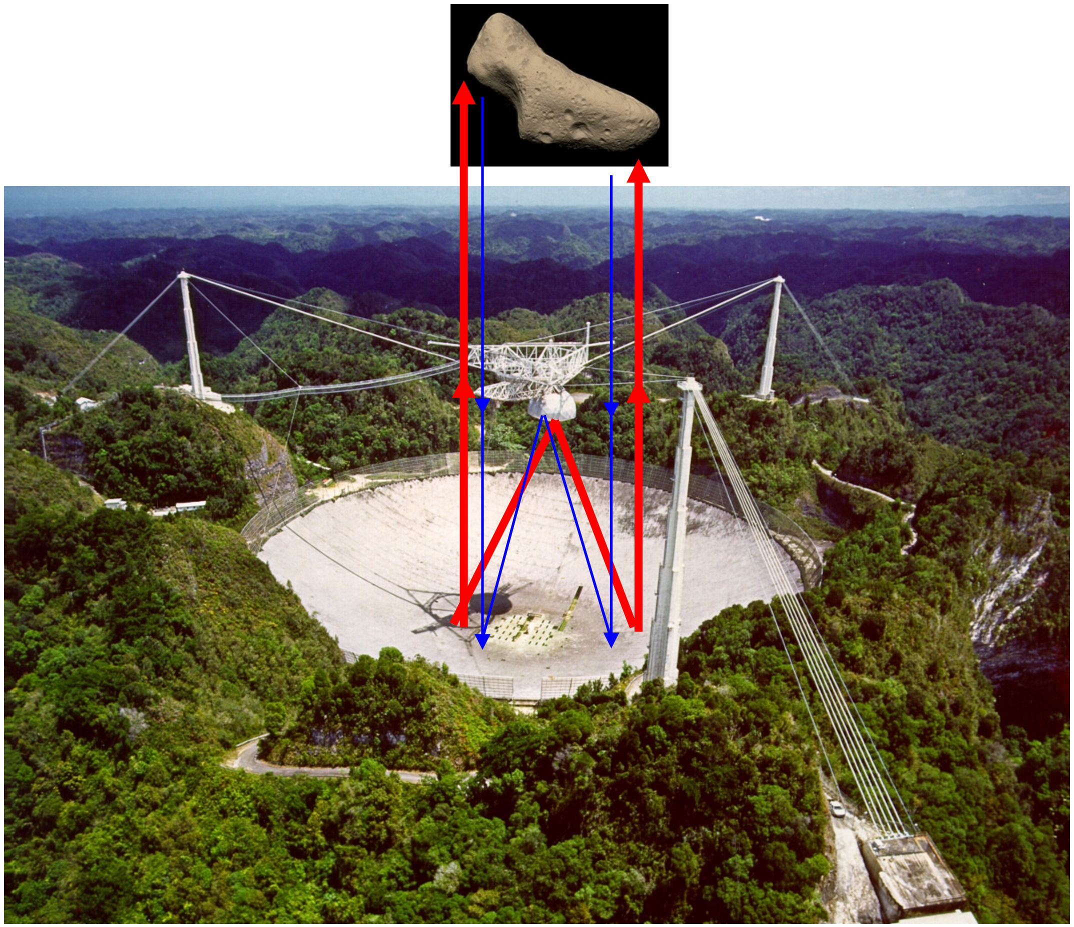


Table: Available Receivers

Receiver Designation	Freq Range (GHz)	System Temp[a] (K)	Gain[a] K/Jy	SEFD[a,b] Jy (at zenith)	HPBW[a,f] Az × ZA (Arcmin)
Carriage House					
430ch[g]	0.425 - 0.435	70 - 120	10 - 20	3.5 - 10	10 × 12
Gregorian Dome: Single-Pixel Receivers					
327	0.312 - 0.342	90 + T_{sky}	10.5	11	14 × 15
430	0.425 - 0.435	35 + T_{sky}	11	5	10 × 12
lbw	1.120 - 1.730	25	10.5	2.4	3.1 × 3.5
sbw	1.800 - 3.100	32	9.5	3.4	1.8 × 2.0
sbn	2.240 - 2.340	25	10	2.5	1.8 × 2.0
	2.330 - 2.430	25	10	2.5	1.8 × 2.0
sbh	3.000 - 4.000	29	8.8	3.3	1.35 × 1.5
cb	3.850 - 6.050	31	8	3.9[c]	0.9 × 1.0
cbw[d]	4.000 - 8.000	-	-	-	-
xb	8.0 - 10.0	33	4.5	7.5[e]	0.5 × 0.6
Gregorian Dome: Feed Array					
ALFA					
Center Pix	1.225 - 1.525	30	11	2.8	3.3 × 3.7
Outer Pixs	1.225 - 1.525	30	8.5	3.5	3.3 × 3.7

Radar Astronomy



The basics:

A radar transmitter transmits radio waves at a known frequency for a certain time interval.

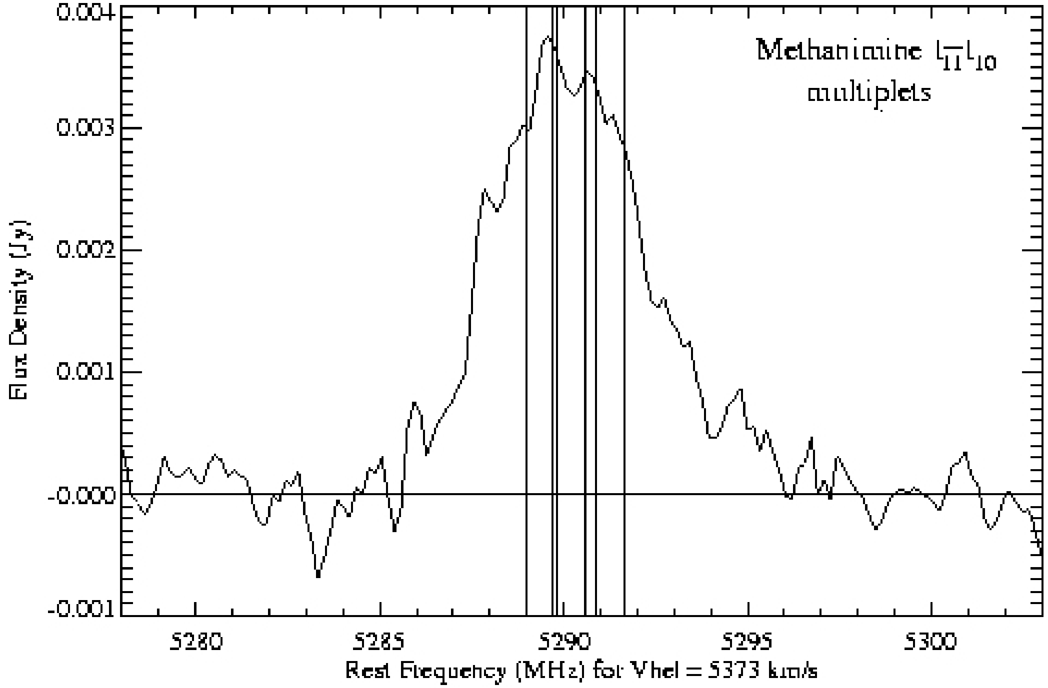
The waves hit the object, bounce off of it, and return to the telescope. The receiver, now moved into the focus of the telescope, detects the weak echo.

Transmitted wave

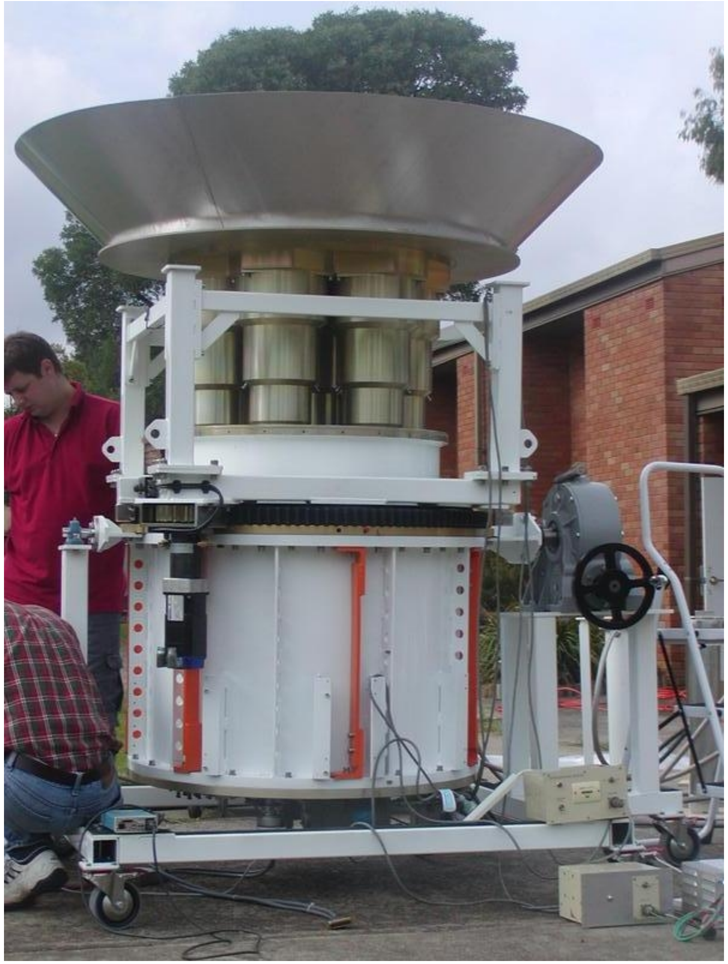
Echo from distant object

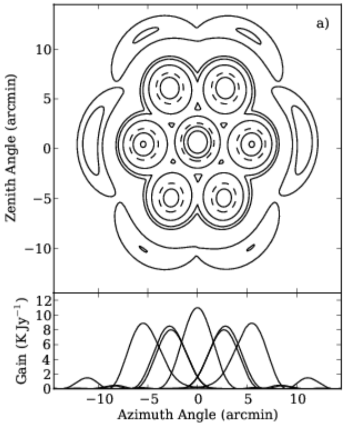
Molecular Lines in Galaxies

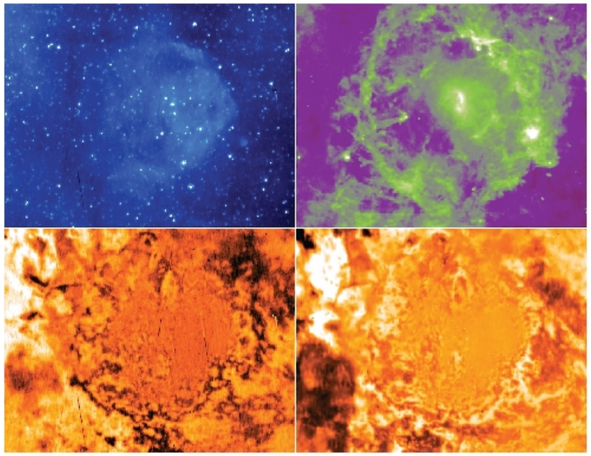
Using a then-unprecedented 800-MHz bandwidth, a dozen molecular lines were found in the starburst galaxy ARP 220 – including the 1st extragalactic detection of the organic molecule methanimine. CH_2NH combines with HCN (also detected) in the presence of water to produce the simple amino acid, glycine.



The ALFA 7-beam Focal-Plane Array







λ-Orionis

Arecibo 305-m Telescope Parameters – I

Table: Basic Information on the AO Site and the 305-m Telescope

Site	
Longitude (Geodetic)	$66^\circ 45' 11.1''$ W
Latitude	$18^\circ 20' 36.6''$ N
Elevation of reflector center of curvature	497 m (1630 ft) above MSL
Telescope	
Primary Reflector	
Diameter of Spherical cap	305 m (1000 ft)
Radius of Curvature	265 m (870 ft)
Illuminated Area (at zenith):	
Gregorian Feeds	213×237 m (700×776 ft)
430-MHz Line Feed	305 m (1000 ft)
Surface Accuracy	2 mm (rms)
Frequency range	300 MHz $< \nu <$ 10 GHz (Gregorian)
Wavelength range	1 m $> \lambda >$ 3 cm (Gregorian)

Arecibo 305-m Telescope Parameters – II

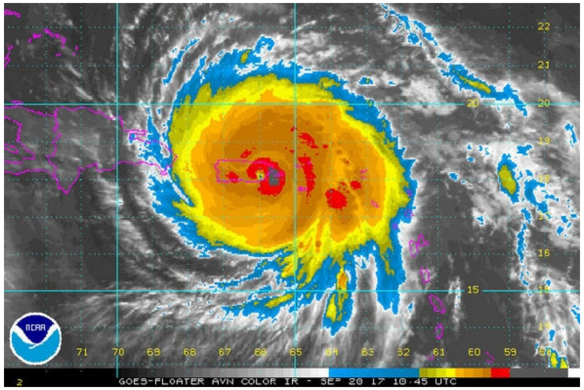
Slew Rates:	
Azimuth	24°/min
Zenith Angle	$2^\circ.4$/min
Pointing Limits:	
Azimuth	0°-720°
Zenith Angle	0°-$19^\circ.7$
	($1^\circ.06$ -$19^\circ.7$ in tracking mode)
Declination range	$-1^\circ 20' < \mathrm{Dec} < +38^\circ 02'$
Pointing Accuracy	$\simeq 5''$ (rms)

Backend Processors Currently Available at Arecibo

- **Spectrometers:**
  "The Interim Correlator"
  The WAPP spectrometer
  The Mock Spectrometer
- **Continuum Backends:**
  The Above Spectrometers
  The Radar Interface
- **Pulsar Backends:**
  PUPPI (the Puerto-rican Pulsar Processing Instrument)
  The WAPP spectrometer
  The Mock Spectrometer
- **VLBI:**
  The Mk5A recorder and RDBE backend
  The Mk5C recorder and RDBE
  The Mk6 recorder and RDBE backend, (being implemented)
  Real-time e-VLBI operations

Spectral-Line Observing:
(a) Frequency Switching is NOT available at Arecibo.
(b) For wider total bandwidths, use ON-OFF position switching.
(c) For narrower total bandwidths, simple ON-only observations can be used.

The Arecibo Telescope and Hurricane Maria



- Hurricane Maria struck Puerto Rico on September 20th, 2017, as a Cat. 4/5 storm.
- Winds were up to 150 mph. Arecibo Observatory received 34 inches of rain in 24 hr.
- Major damage was destruction of the 430-MHz line feed and the flooding of the bowl.
- Ground saturation and settling has resulted in a drop of sensitivity by about a factor of ~1.35 at 1.4 GHz, 1.6 at 3.3 GHz, 2.0 at 5 GHz, and 4-5 at 9 GHz.
- Plans have been made, and finance received, for replacing the line feed, and resetting the primary surface.

Single-Dish Summer School, Green Bank: Aug., 2019