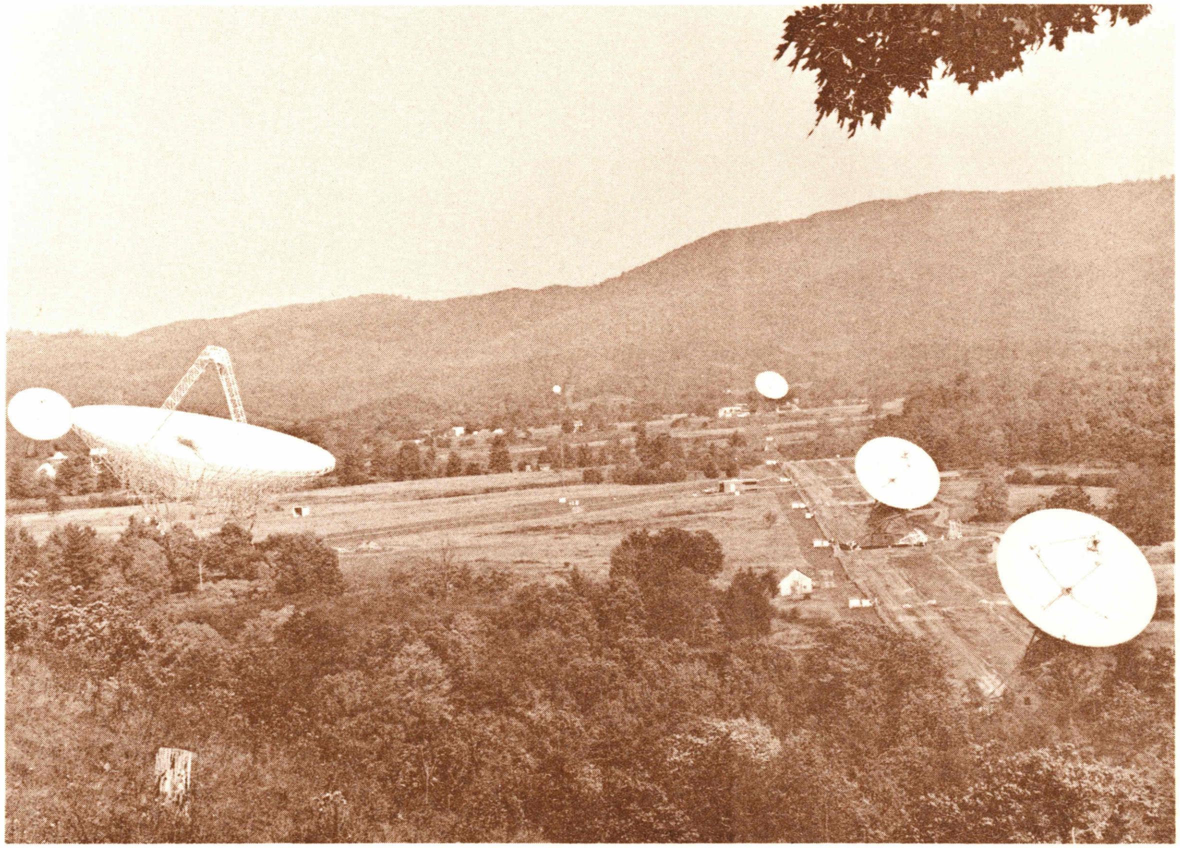
NATIONAL RADIO ASTRONOMY OBSERVATORY



1972

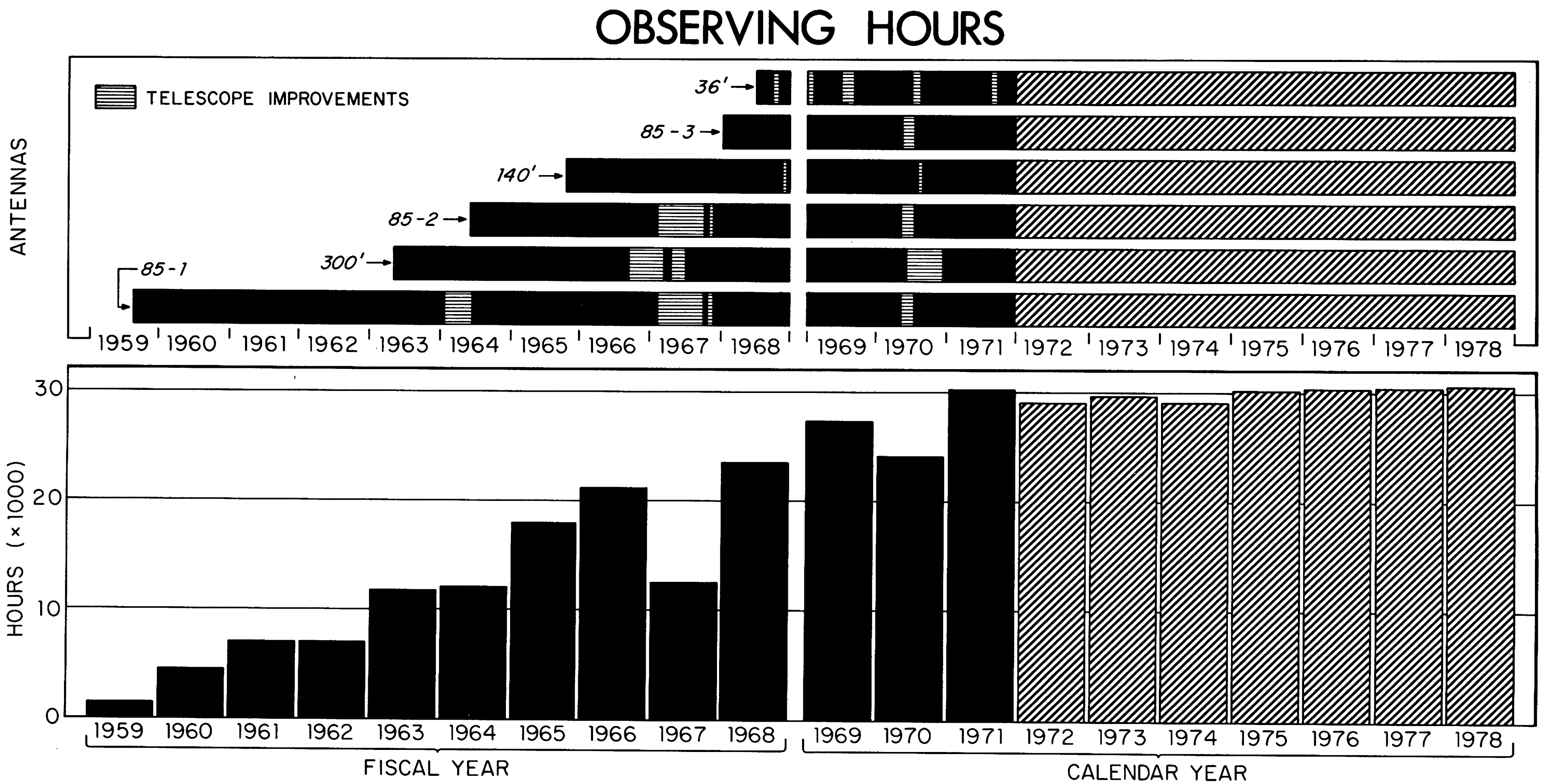


Fig. 1. The upper figure shows the year in which existing (black) or planned (shaded) telescope systems are incorporated into the NRAO observing program. The lower figure shows the total number of hours of observing time during each year.

OBSERVING TIME DISTRIBUTION

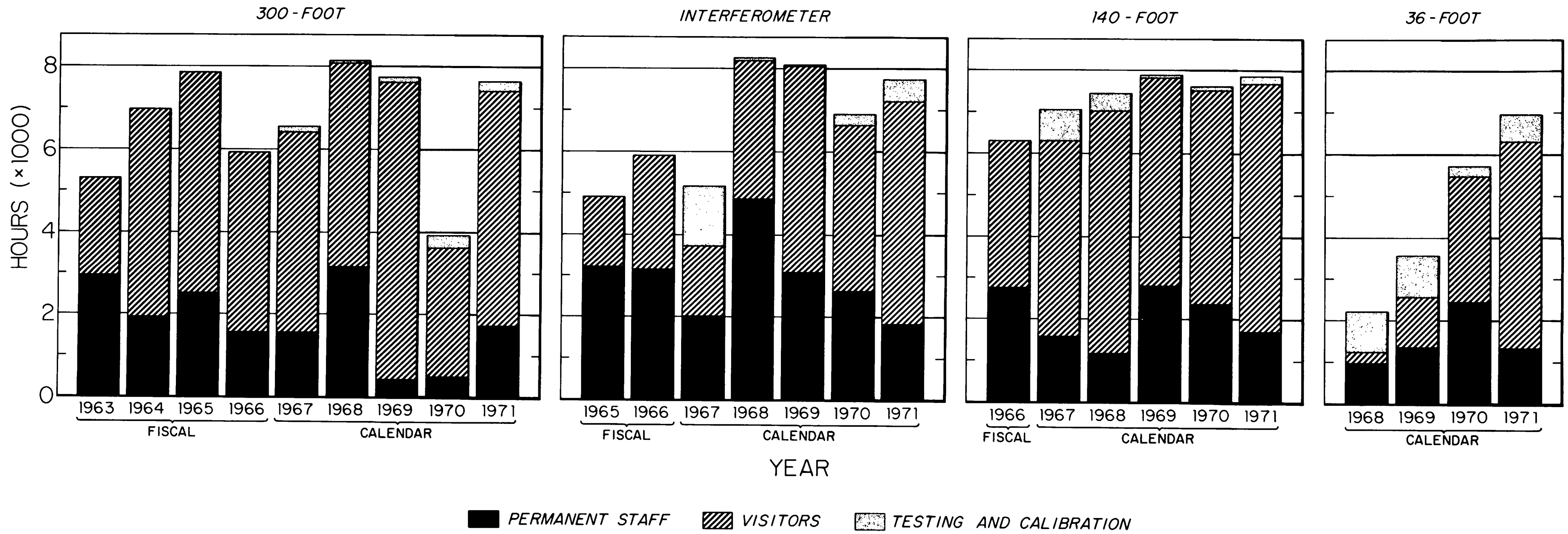


Fig. 2. These graphs show the number of hours devoted to calibration and testing and to observing by NRAO permanent staff members and by visitors on each telescope system during each year the telescope has been operative.

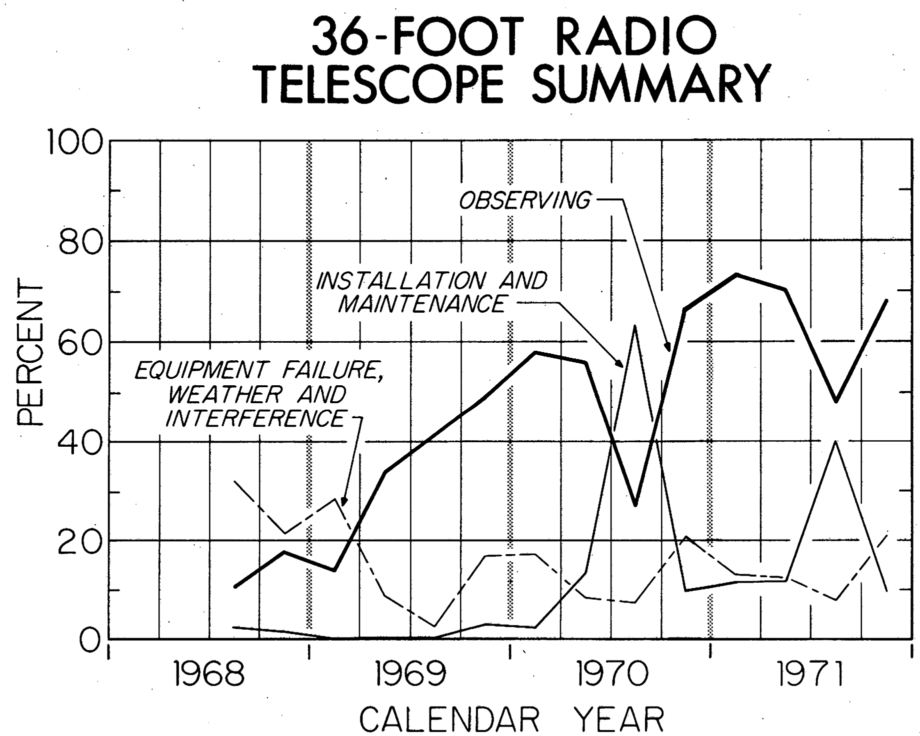


Fig. 3. This summary for each quarter of the calendar year shows the percentage of time the telescope was scheduled for observing, for routine maintenance and installation of new experiments, and the percentage of time lost due to equipment failure, bad weather, and radio interference.

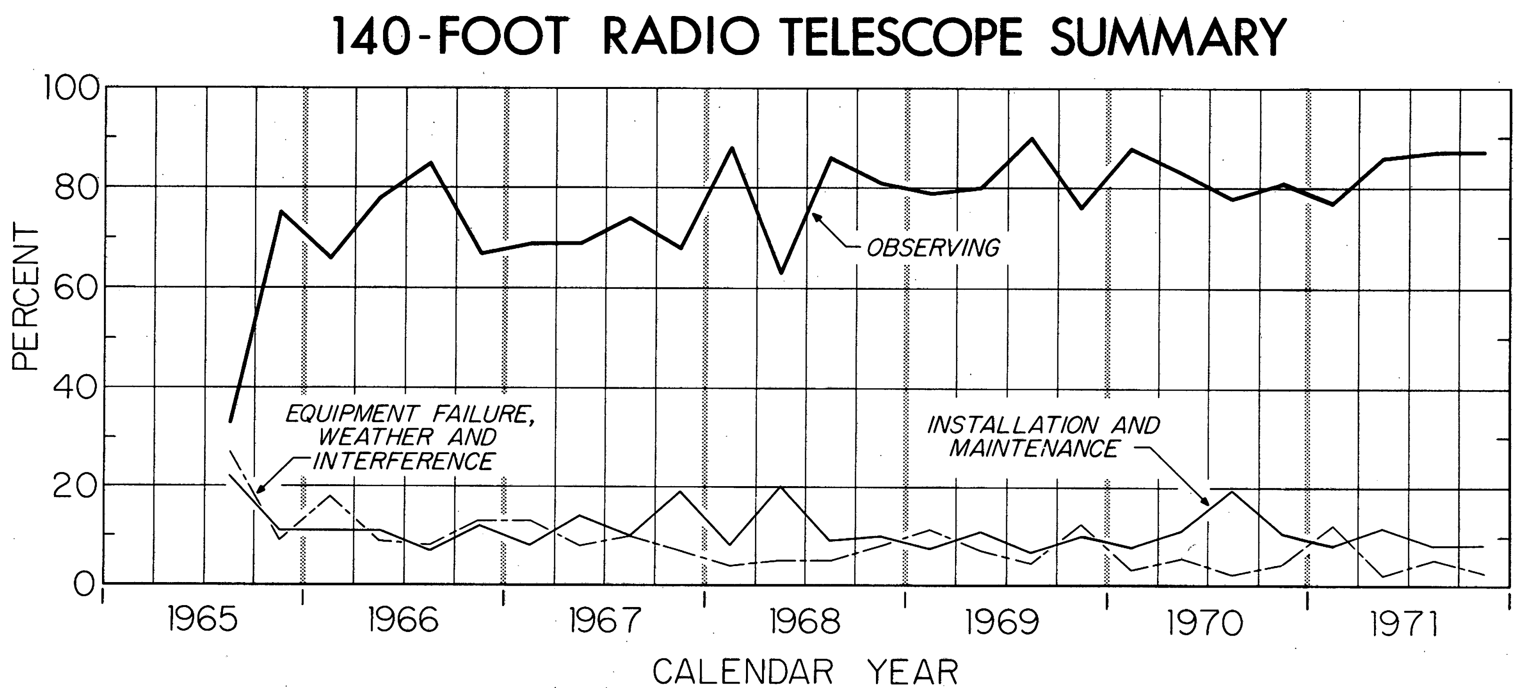


Fig. 4. This summary for each quarter of the calendar year shows the percentage of time the telescope was scheduled for observing, for routine maintenance and installation of new experiments, and the percentage of time lost due to equipment failure, bad weather, and radio interference.

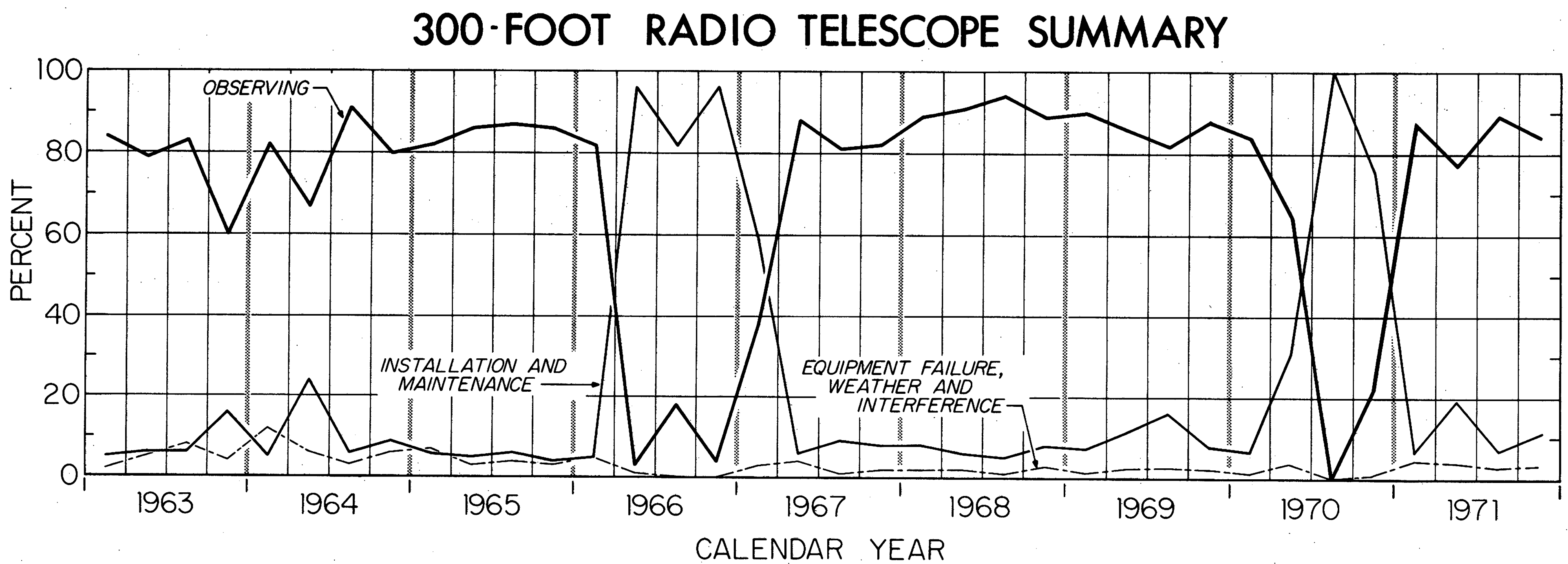


Fig. 5. This summary for each quarter of the calendar year shows the percentage of time the telescope was scheduled for observing, for routine maintenance and installation of new experiments, and the percentage of time lost due to equipment failure, bad weather, and radio interference.

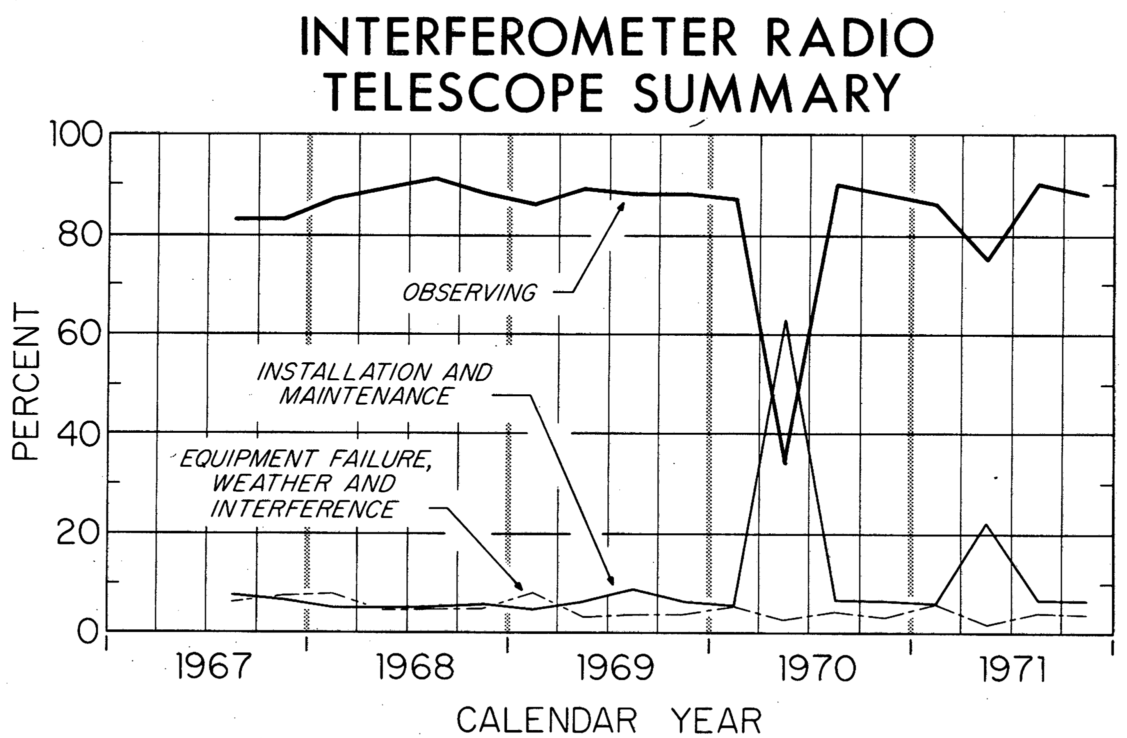


Fig. 6. This summary for each quarter of the calendar year shows the percentage of time the telescope was scheduled for observing, for routine maintenance and installation of new experiments, and the percentage of time lost due to equipment failure, bad weather, and radio interference.

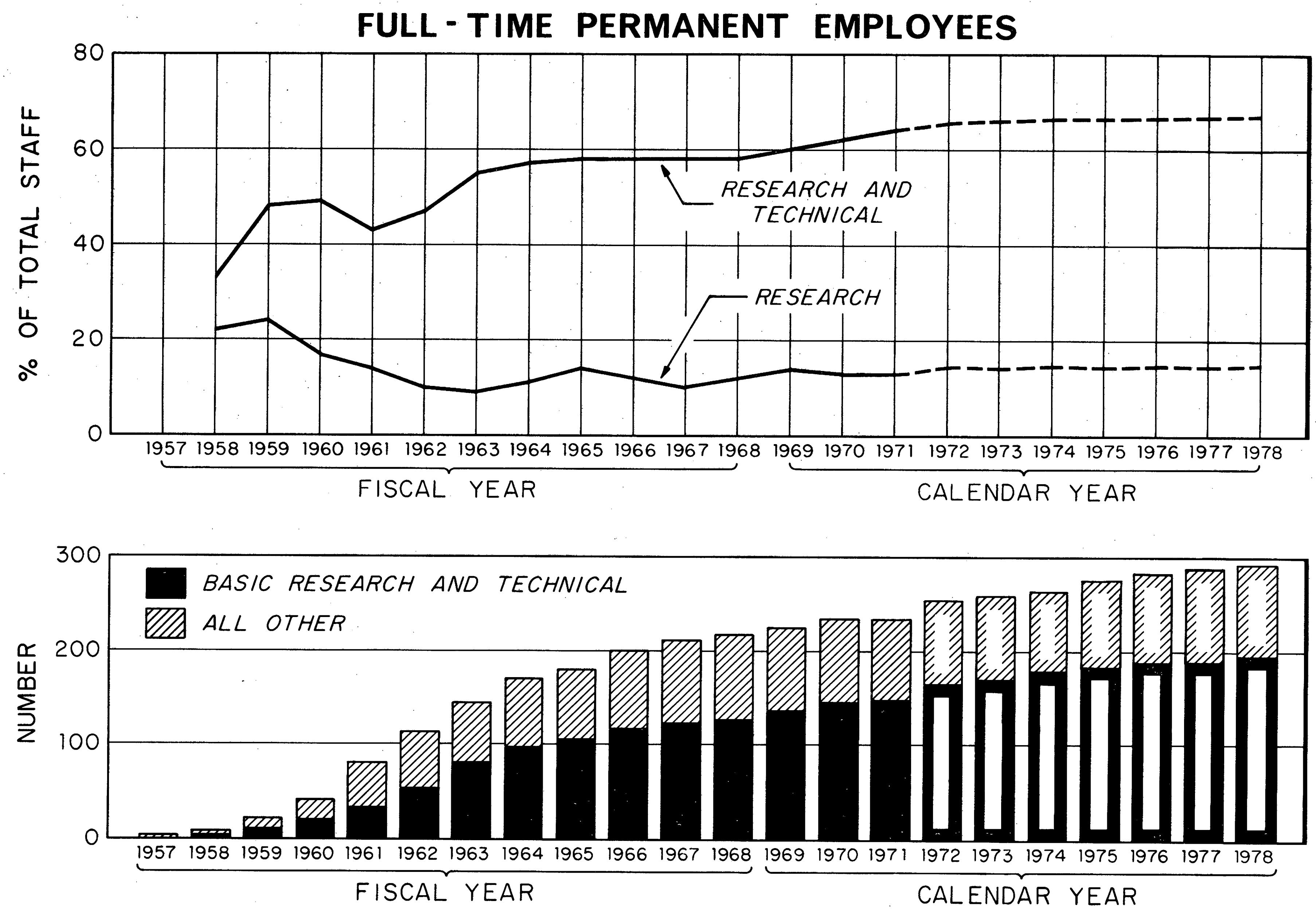


Fig. 7. The lower figure shows the total number of NRAO full-time, permanent employees at the end of each year, projected into the future. The upper figure shows the percentage of these employees each year that are in the basic research staff (lower curve) or who are either research or technical (upper curve).

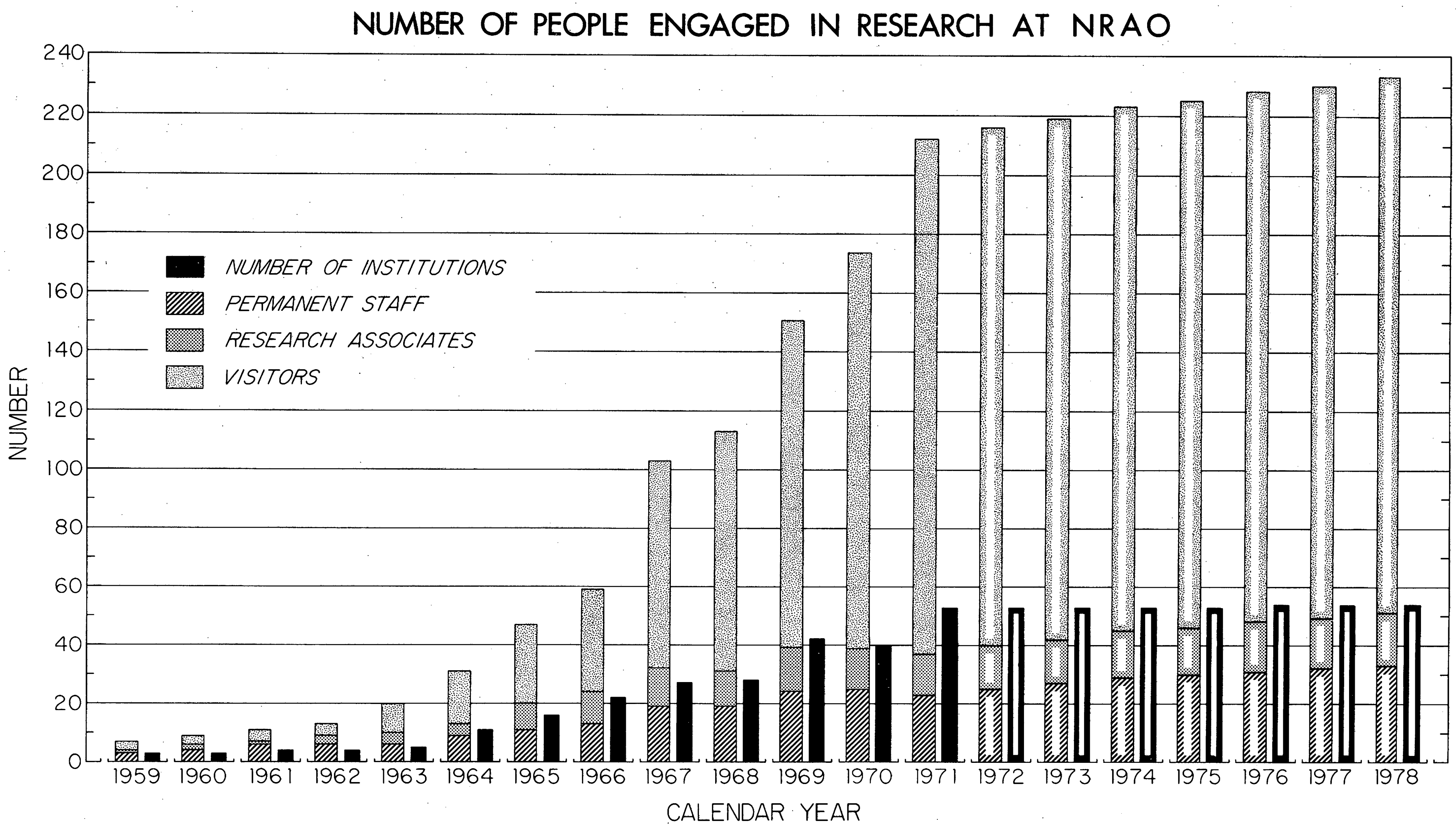


Fig. 8. This bar chart shows for each calendar year the size of the NRAO permanent research staff and the number of research associates on one or two year appointments. In addition it shows the total number of visitor-users of NRAO telescopes and the number of institutions from which the NRAO visitors come.

TELESCOPE TIME DISTRIBUTION BY PER CENT

	140-ft	300-ft	36-ft	Interferometer
Visitors	58%	47%	59%	34%
Students	16	13	12	13
Permanent Staff	22	22	16	23
Research Associates	1	15	3	23
Test Time	3	3	10	6

INSTITUTIONS FROM WHICH VISITORS CAME TO USE NRAO TELESCOPES DURING 1971

	Telescope			
Institution	36-foot	Interferometer	140-foot	300-foot
Advanced Kinetics Corp.	X			
Aerospace Corp.	X		X	
Alabama			X	
Arizona	X	X		
Bell Telephone Laboratories	X			
Berkeley		X	X	X
Bochum, Germany	X			
Calif. Inst. of Technology		X	X	X
Chalmers Inst. Tech., Sweden			X	
Chicago	X	X	X	
Columbia	X		X	
Cosmic Space Inst., USSR	X		X	
Crimean Astrophys. Obs., USSR	X		X	
Dept. Terrestr. Magnetism, Carnegie			X	
Dominion Obs., Canada			X	
Hale Obs.				X
Harvard	X		X	
Hawaii	X			
Haystack Facility			X	
Illinois	X	X	X	X
Jagellonian Univ., Poland				X
Leiden Obs., Netherlands		X		
Lockheed Corp.	X			
Louisville		X		
Maryland	X	X	X	X
Massachusetts	X	X	X	X
Mass. Inst. of Technology		X	X	X
Max Planck Inst., Germany	X	X	X	X
Meudon, France	X	X	X	
Minnesota	X			

Fig. 9

Institution	36-foot	Interferometer	140-foot	300-foot
	Telescope			
Monmouth		X		
NASA-Ames	X			
NASA-Goddard (Greenbelt)	X	X	X	X
NASA-Goddard (NYC)	X		X	
National Astronomy and Ionosphere Ctr.	X	X	X	X
National Research Council, Canada			X	
Naval Research Laboratory	X		X	X
Penn State			X	
Princeton	X			
Puerto Rico			X	
Queens, Canada			X	
Rensselaer Poly. Inst.			X	
Smithsonian Astrophys. Obs.	X		X	
Sperry Management Systems		X		
SUNY-Albany			X	
SUNY-Stony Brook	X			
Sydney, Australia				X
Tata Institute, India				X
Toronto, Canada		X	X	
UCLA		X		
Virginia	X	X	X	X
Wisconsin			X	
York, Canada				X
No. Institutions :	27	19	33	16
No. Visitors :	42	28	70	25
No. Students :	9	13	30	12
No. Research Associates :	4	8	4	5
No. Permanent Staff :	10	8	10	5
Total Observers	65	57	114	47

Fig. 9, cont.

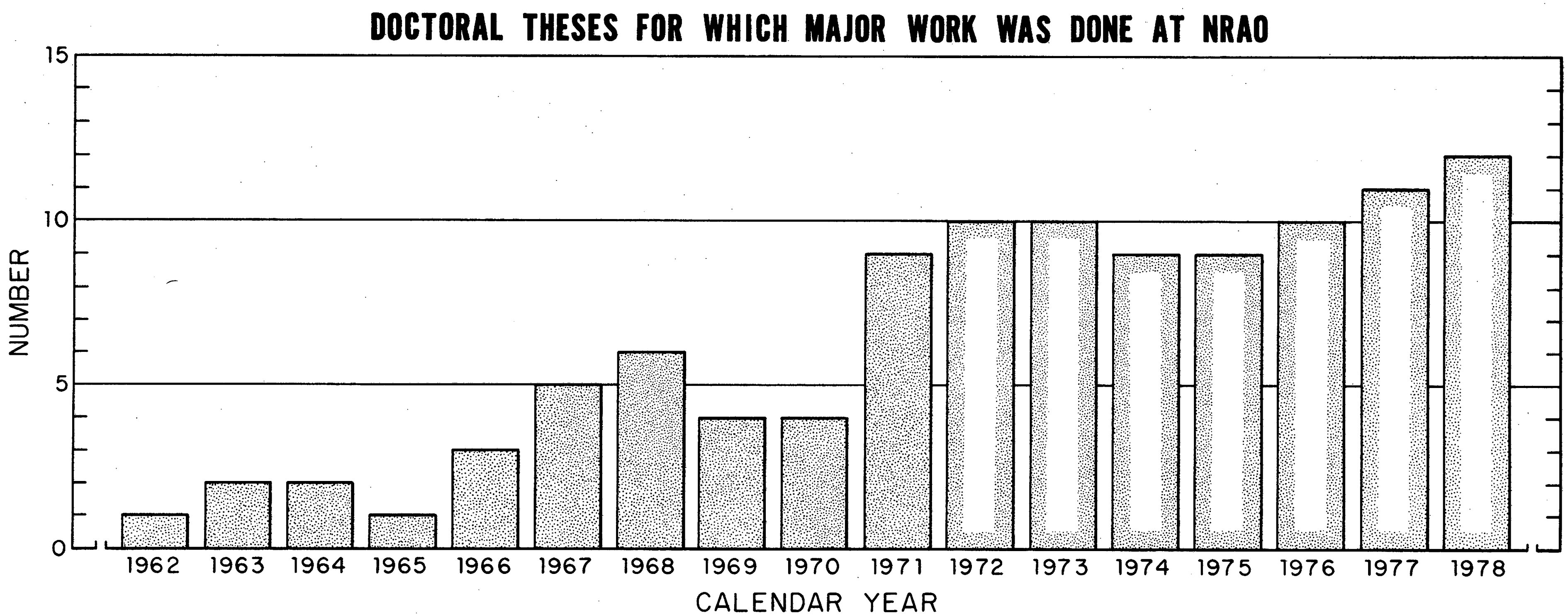


Fig. 10. This bar chart shows the number of doctoral dissertations produced each calendar year by Ph.D. students where the major work on the theses was done at the NRAO.

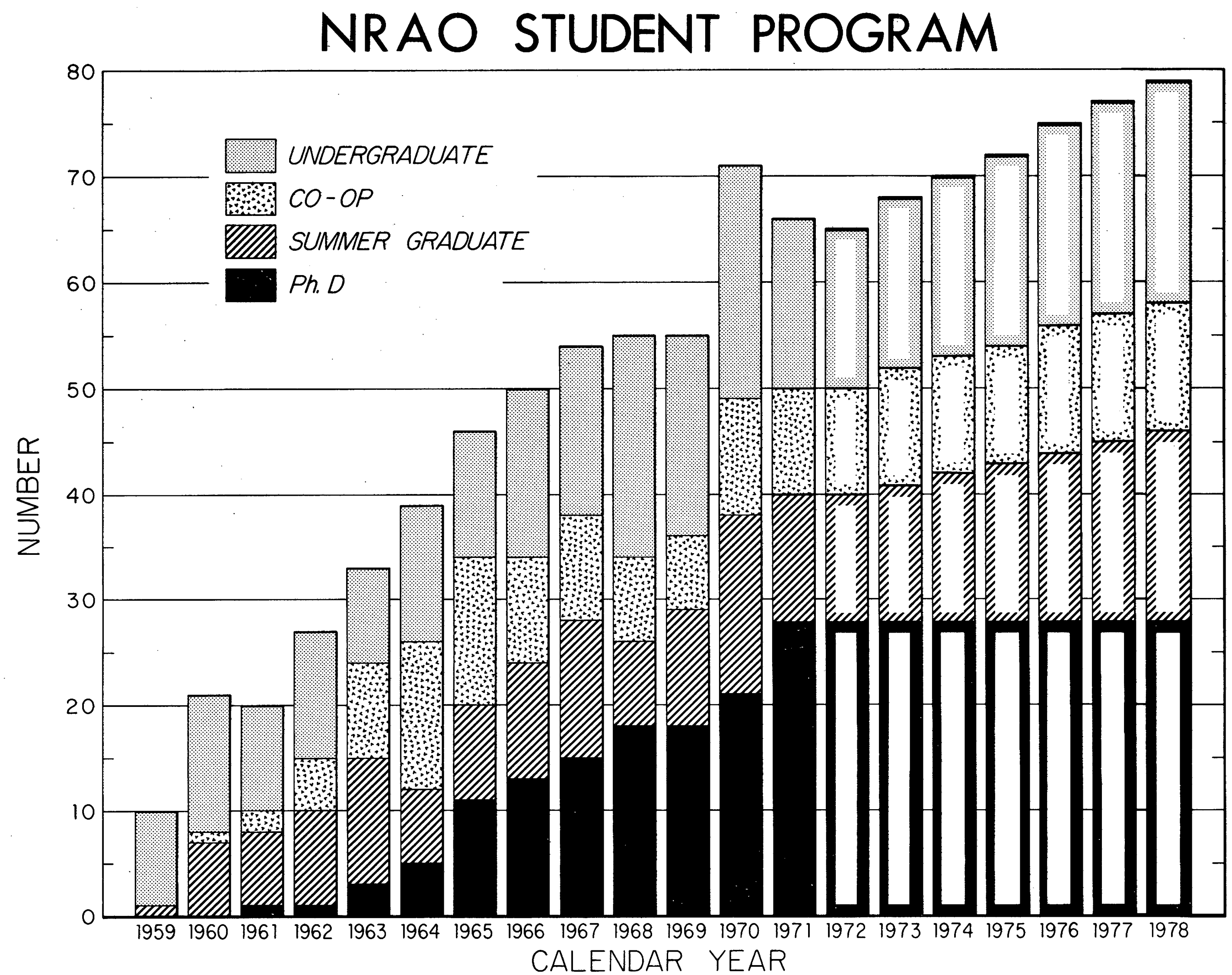
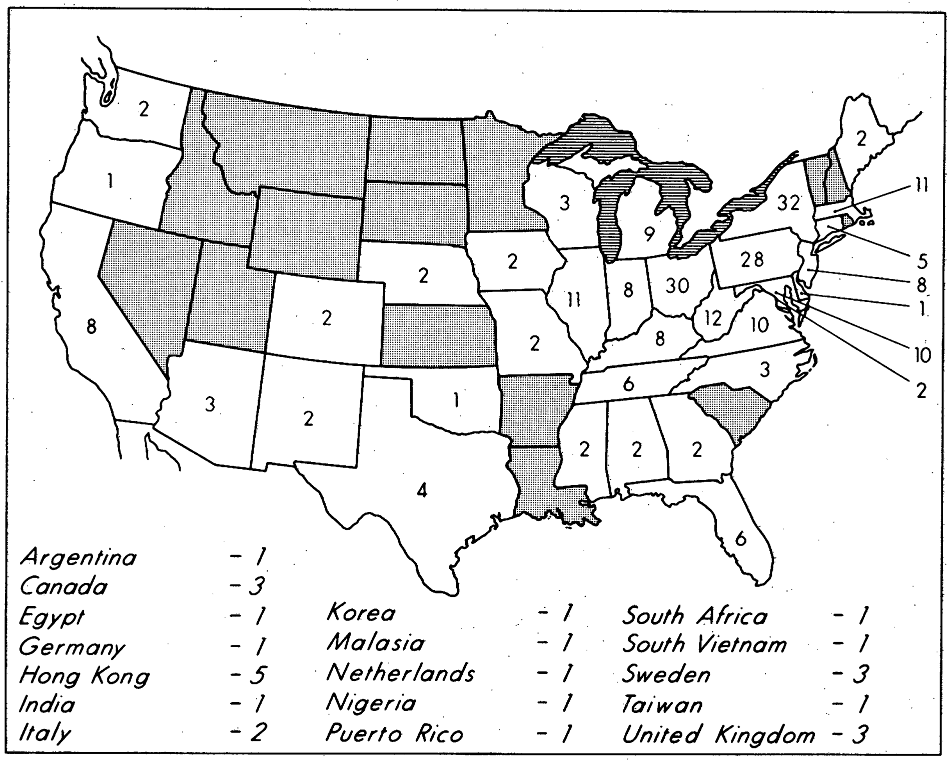
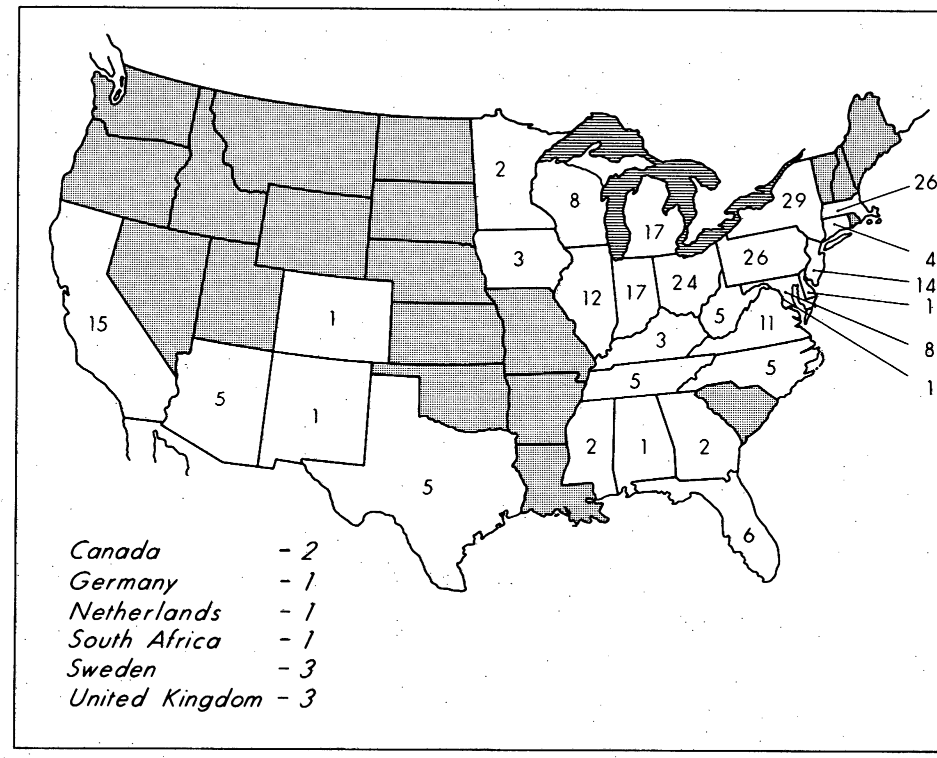


Fig. 11. This figure shows for each calendar year the number of Ph.D. students (salaried and non-salaried), co-op students, and summer undergraduate and graduate students who observed or worked at the NRAO during that year.

NRAO SUMMER STUDENT PROGRAM



Home States



College-University Affiliation

Fig. 12. This figure shows the total number of graduate and undergraduate students by home state or country and by college location who did summer work at the NRAO since the beginning of the summer student program in 1959.

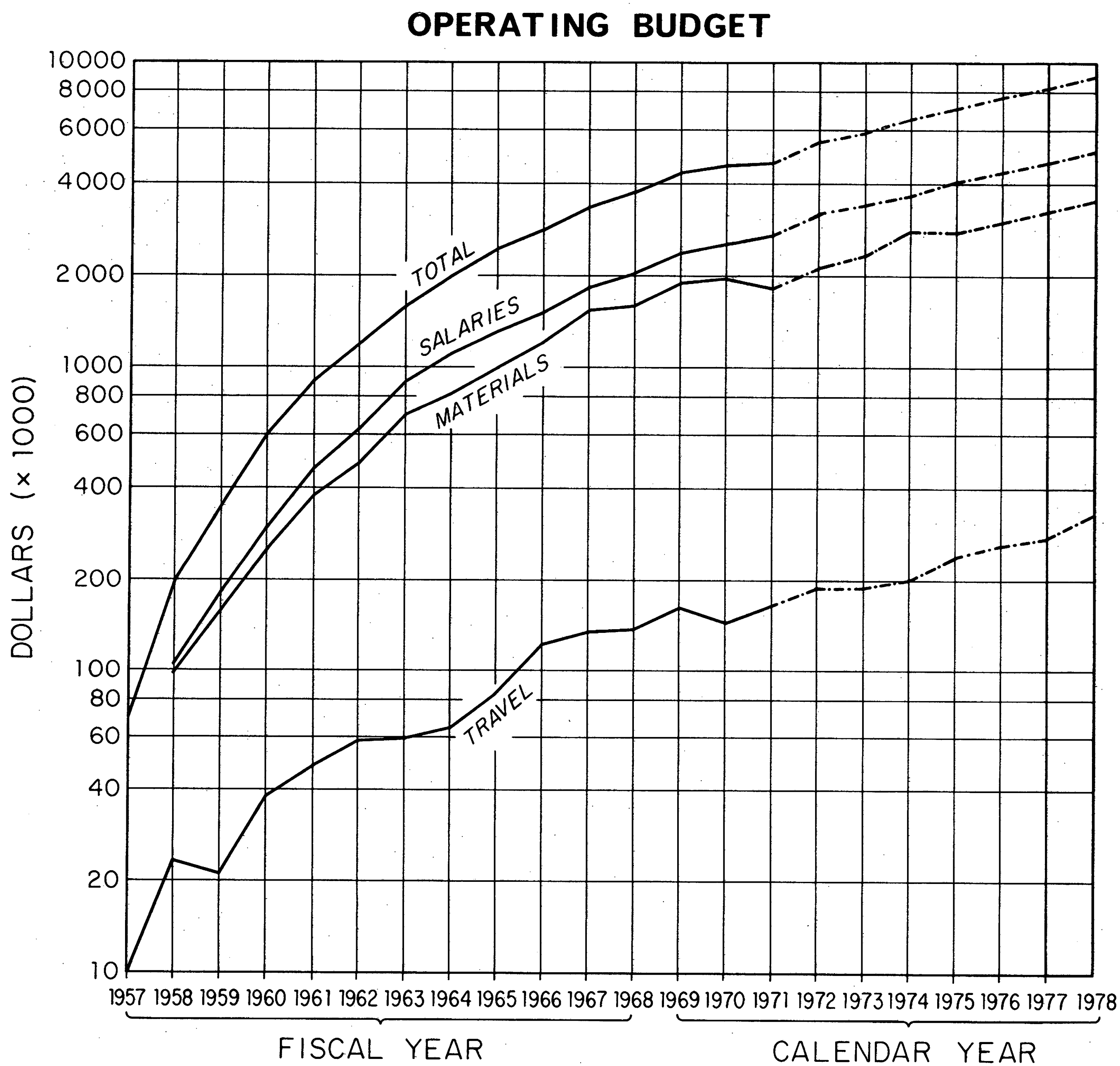


Fig. 13. The NRAO total operating budget is shown on the upper curve with actual expenditures to the left and projected expenditures (shaded) to the right. Below is shown a breakdown of this total by salaries, materials and supplies, and travel.

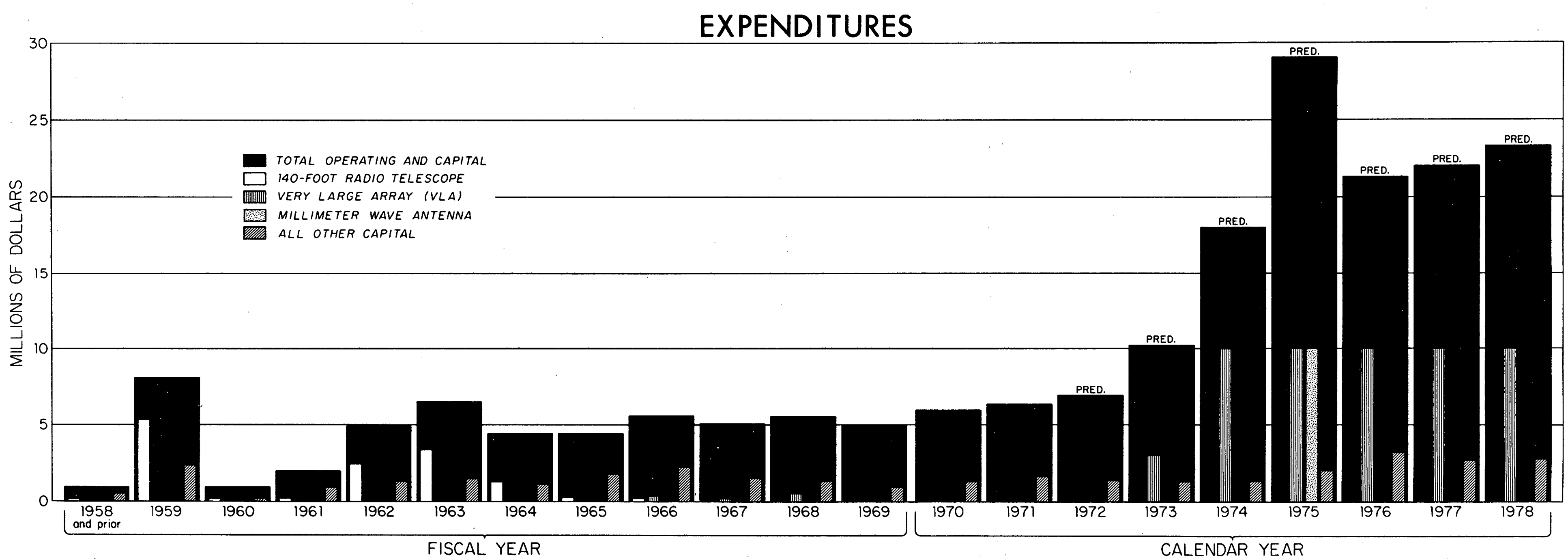


Fig. 14. Actual and projected NRAO expenditures are shown for each year in this chart.

Telescopes and Receiver Systems

λ cm	T_{system} (°K)	Bandwidth	36-ft	140-ft	300-ft	Interf.
0.25 - 0.30	4,000	100 MHz	(X)			
0.3	4,000	1 GHz	X			
0.3 - 0.45(line)	4,000	100 MHz	X			
0.60 - 0.90	1,500	100 MHz	(X)			
0.95	1,000	400 MHz	X	[X]		
0.95	700	300 MHz	X	[X]		
1.35 (line)	600	50 MHz	X	X		
1.7 - 2.5 (line)	1,500	200 MHz		X		
1.95	1,200	2 GHz	X	X		
2.05	100	500 MHz		(X)		
3-6 (line)	400	50 MHz		X		
3	75	300 MHz		X		
3 and 11	100	30 MHz				X
6	90	200 MHz		X		
6	70	300 MHz		X		
11 (3 beam)	120	50 MHz			X	
7.5 - 30 (line)	100 - 300	45 MHz		X	X	
18 (line)	150	20 MHz		X	X	
18	70	50 MHz		X	X	
21 (line)	120	60 MHz		X	X	X
21 (4 beam)	150	60 MHz			X	
21	70	50 MHz		(X)	(X)	
30 - 60	150	20 MHz		(X)	(X)	
40	500	90 MHz		[X]	X	
50	170	4 MHz		X	X	
75	400	8 MHz		[X]	X	
60 - 150	400	300 MHz			X	
120	400	3 MHz		X	X	
200	400	100 MHz			X	
300 - 30	300 - 600	Octave		X		

Key: X Available
(X) On order or planned
[X] Available, not optimum

December 1971

NRAO FRONT-END BOX STATUS

Applicable Telescope	Frequency (MHz)	Amplifier Type	System Temperature (°K)	Bandwidth (MHz)	Feed Type	Polarization	Calibration Value	Switching System	Remarks	Person in Charge
140/300'	750	Transistor	600°	20	Dipole	Linear	10 °K or 100 °K	300° load	Simultaneous operation with 1400 MHz box with on-axis feed at both frequencies.	Brundage-Balister
300' Fixed on Traveling Feed	50-80	Transistor	> 350°	30	Tuned Crossed-Dipole	Simultaneous 0°, 45°, 90°, 135° Linear, RCP and LCP.	Adjustable 50° to 2000°.	No Dicke switch. Total power or frequency switching.	Designed for pulsar and line work. 110-500 MHz feeds can be rotated 90° for polarization work. Usable with 4-channel multi-bandwidth receiver and all NRAO line receivers.	Brundage
	110-250		≥ 200°	140	Broadband Crossed-Dipole					
	250-500		≥ 200°	250	Broadband Crossed-Dipole					
140/300'	500-740	Paramps	100°	20	Broadband Crossed-Dipole	Single Linear—all frequencies. Dual Linear—610.	10 °K	Frequency switching.	Traveling feed box for 300' can be used on 140' as clip on. Available June 1972.	Brundage
140/300'	740-1000	Paramps	100°	20	Broadband Crossed-Dipole	Single Linear—all frequencies. Dual Linear—835.	10 °K	Frequency switching.	Traveling feed box for 300' can be used on 140' as clip on. Available June 1972.	Brundage
140'	100 to 1000	Transistor	300° to 500°	Limited by feed to 5%	Tunable Dipole	Dual Linear	50 °K	Frequency.	Line work and VLB.	Balister
300/140'	1400 x 4	Paramp	150°	60	4 Horns Scalar	Linear Dual Linear	4 °K and 15 °K	300° load or frequency switching.	Line or continuum from control room.	Fleming
140/300'	1420	Paramp	120°	60	1420	Linear	10 °K	Frequency switching.		Balister
140/300'	1410 Dual Channel	Cooled Paramp	60°	40	Scalar	Dual Linear	≈ 5°	Frequency switching.	Under construction. Available January 1972.	Thacker
140/300'	1610-1720 Dual Channel	Cooled Paramp	70°	30	Scalar	Dual Linear	5 °K	Normally frequency switched. Can be polarization switched.	Can be remotely tuned anywhere in frequency range 1610-1720 MHz. Two channels can be used simultaneously at different frequencies. Six polarizations are available simultaneously with IF polarimeter. Will tune 1540-1780 with higher noise temperature outside range 1610-1720 MHz.	Moore
140/300'	1000 to 2000	Paramp	270°	30	1-2 GHz Scalar	Linear	10 °K	300° load or frequency switching.	Tuning over a 200-400 MHz range is from control room. Larger frequency changes require paramp module change approximately 2 hours. Box, including feed, changed at 2000 MHz. Control room equipment will drive either. Change time approximately 4 hours.	Payne
140/300'	2000 to 4000	Paramp	270° to 350°	30	2-4 GHz Scalar	Linear	10 °K	300° load or frequency switching.		Payne
Any	2295	Paramp	100°	50	Horn	Circular	10 °K	None.	Packaged in small temperature-stabilized box. Can be installed on other telescopes with little effort.	Payne
140/300'	2695 x 4	Degenerate Paramp	120°	100 DSB	3 Horns	Dual Circular or Dual Linear	4 °K	300° load or polarization.	Continuum receiver. On-axis horn has paramps on both polarizations.	Fleming
140/300'	2695	Paramp	200°	40	TRG Scalar	Dual Linear	3 °K	300° load sky horn, other polarization.	Choice of switching system from control room.	Behrens

NRAO FRONT-END BOX STATUS

Technical Data Sheet
November 1971

No. 12

Applicable Telescope	Frequency (MHz)	Amplifier Type	System Temperature (°K)	Bandwidth (MHz)	Feed Type	Polarization	Calibration Value	Switching System	Remarks	Person in Charge
140'	4750-5100	AIL Cooled Paramp	80° line 135° cont.	225	TRG Scalar or 2 Horns	Dual Linear Orth. Linear	4 °K	Any two of: 60 °K load, sky horn, other beam.	Feed change requires 3 hours. Dual horns are used for beam switching. A horn can be mounted off-axis to scalar feed, but beam spacing is high, approximately 30'.	Behrens
140'	4500-5200	TRG Cooled Paramp	70° Scalar Feed 100° Horns	400	2 Horns or Scalar	Orth. Linear	≈ 5 °K	Other beam or 25 °K load	Two feed arrangements are available: (1) Scalar and (2) dual horns for beam switching	Behrens
Any	4600-5100	Paramp	150°	20	Horn	Linear	≈ 10 °K	None.	Packaged in small temperature-controlled box. Can be installed on other telescopes with little effort.	Payne
140'	5.2-10.4 GHz	Paramps	300° to 400°	40	Horn	Linear	≈ 10 °K	Frequency switching.	Set of 7 tunable paramps in 2 bands about 7 GHz. Paramp change 1 1/2 hour. Band change 3 hours.	Moore
Any	10,695	Paramp	250°	20	Horn	Linear	≈ 10 °K	None.	Packaged in small temperature-controlled box. Can be installed on other telescopes with little effort.	Payne
140'	10,300-11,000	TRG Cooled Paramp	100°	300	2 Horns or Scalar	Orth. Linear	≈ 5 °K	Other beam or 25 °K load.	Two feed arrangements available: (1) Scalar and (2) dual horns for beam switching.	Behrens
140'	14.4-14.9 Dual Ch.	Paramp	60°	500	2 Horns or Scalar	Orth. Linear Dual Circular	5 °K	Correlation, dual beam or polarization.	Under development. Available June 1972.	Moore
140'	15,400-5000	TDA TDA	1100° 1100°	3 GHz 400	Horns Horns	Linear Linear	17 °K 8 °K	Beam or load switching.	Can be installed on 140' telescope in front of existing box in 2 hours. Box may be removed in a similar time, allowing lower frequency programs to continue when weather is too bad for 15 GHz observations.	Dolan
36'	15,375	TDA	1600°	2 GHz	2 Horns	Parallel Linear	5 °K	Other beam or sky horn.	Original 2 cm receiver repackaged in 36' box.	Dolan
140'	12.4-18 GHz	TDA's	1000°	50 (1 GHz continuum)	Horn	Orth. Linear	≈ 10 °K	Frequency switching.	Contains LO system tunable 12.4 - 18 GHz. Tunnel diode amplified continuum receiver on orthogonal polarization (used for pointing).	Balister
	14.4-14.9 GHz	Paramp	500°	70				Load switching continuum.		
36/140'	22-24 GHz	Degenerate Paramp	300° DSB	100 DSB	Horn	Linear	≈ 20 °K	Load, beam, or frequency.	Stabilized LO system.	Edrich
36'	31.2 GHz	Degenerate Paramp	800° DSB	400	2 Horns	Parallel Linear	15 °K	Other beam or load.	Has stabilized LO system for line work.	Albaugh
36'	31.4 GHz	Mixer	1100° DSB	400	2 Horns	Variable	28 °K	Other beam or load.		Albaugh
36'	45.6 GHz	Degenerate Paramp	150° DSB	1000 DSB	Horn	Linear	10 °K	Beam, load.	Under development. Estimate completion June 1972.	Edrich
36'	85 GHz	Mixer	4000° DSB	1 GHz	2 Horns	Variable	28 °K	Other beam or load.	Single horn mechanically position-modulated or ferrite switch.	Albaugh
36'	85 GHz	Mixer	4000° SSB	100	Beam Switch	Linear	30 °K	Beam or frequency.	Stabilized LO for line work. Can be used with some difficulty over the 67-101 GHz range.	Albaugh

March 23, 1972

The NRAO Seven-Year Plan for Budget and Manpower

I. PERSONNEL LEVELS

The personnel levels are projections from CY 1972 through CY 1978. The figures for CY 1972 and 1973 are based on budget requests already submitted to the National Science Foundation.

Table I. Seven-Year Plan Personnel Projections by Category of Employees CY 1972-1978

Category	(Actual) Dec. 31, 1971	1972	1973	1974	1975	1976	1977	1978
1. Scientific & Engineering	50	58	60	64	65	65	66	69
2. Technical	73	83	86	88	92	96	98	99
3. Administrative & Clerical	56	58	58	58	60	62	63	63
4. Operations & Maintenance	55	56	56	56	60	61	61	62
Total	234	255	260	266	277	284	288	293
Total Visitor-Users:	175	176	177	178	179	180	181	182

II. SCIENTIFIC RESEARCH: OPERATIONS

The operating budget projection is based on the manpower levels shown in Table I.

Table II. Operating Budget Projections by Calendar Year

(Figures in thousands of dollars)

Item	Actual 1971	1972	1973	1974	1975	1976	1977	1978
Salaries (1)	2730	3200	3400	3680	4050	4400	4750	5100
Benefits (2)	424	484	540	570	640	700	760	830
Travel (3)	168	190	190	200	240	260	280	330
Other (4)	1402	1651	1790	2250	2150	2300	2500	2700
Subtotal, Operations:	4724	5525	5920	6700	7080	7660	8290	8960

Notes and Assumptions for CY 1975 and beyond:

(1) Salaries at $13.84K per man in CY 1974, then increasing at 6% per year, compounded.

(2) Benefits at 15.5% of salaries in CY 1974, then increasing at 0.2% per year.

(3) Travel at 6.0% of salaries.

(4) Computer rent, communications, utilities, building and maintenance, management fee and all other materials, supplies and services and miscellaneous receipts are included here. Assume, according to past experience, 53% of salaries.

From the personnel projections (Table I) and the operating budget summary (Table II), we can derive the operating cost per man in Table IIA.

Table IIA. Operating Cost Per Man CY 1971-1978

Calendar Year	Operating Cost Per Man
1971 Actual	$20,200
1972 Estimated	21,700
1973 "	22,800
1974 "	25,200
1975 "	25,600
1976 "	27,000
1977 "	28,800
1978 "	30,600

III. SCIENTIFIC RESEARCH: RESEARCH AND OPERATING EQUIPMENT

Table III gives the budget projections for the NRAO research and operating equipment budgets through CY 1978. (Figures in thousands of dollars)

Table III. Research and Operating Equipment Budget Projections CY 1972-1978

Item	Calendar Year 1972	1973	1974	1975	1976	1977	1978
A. RESEARCH EQUIPMENT							
Other Observing Equipment	845	900	900	1100	1300	1370	1450
Electronic Research Equipment	250	250	250	300	310	330	350
Electronic Test Equipment	50	50	50	74	80	85	90
Subtotal	1145	1200	1200	1474	1690	1785	1890
B. OPERATING EQUIPMENT							
Maintenance, Shop & Repair Equipment	80	40	60	65	65	70	75
Office & Library Equipment	18	10	15	16	17	18	19
Living Quarters, Furniture & Equipment	2	2	3	5	6	6	6
Building Equipment	26	18	12	15	16	17	18
Scientific Services & Engineering Equipment	24	10	10	11	11	12	13
Subtotal	150	80	100	112	115	123	131
Subtotal, Equipment	1295	1280	1300	1586	1805	1908	2021
Subtotal, Sci. Research	6820	7200	8000	8666	9465	10198	10981

IV. CONSTRUCTION

Table IV gives the budget projections for NRAO construction items through CY 1978. Beyond CY 1974 price increases of approximately 6% per year, compounded, have been applied to estimates of standard items in order to allow for anticipated increased cost of construction and materials.

Table IV. Construction Budget Projections CY 1972-1978
(in thousands of dollars)

Item	Calendar Year	1972	1973	1974	1975	1976	1977	1978
A.	SITE DEVELOPMENT							
1.	Roads, Green Bank	0	0	0	20	10	10	10
2.	Water and Sewer	0	0	0	40	40	20	20
3.	Electric Power & Communications	0	0	0	15	16	16	17
4.	General Site Improvements	0	0	0	6	10	7	11
	Subtotal	0	0	0	81	76	53	58
B.	PLANNING, DESIGN AND CONSTRUCTION OF BUILDINGS							
1.	Green Bank Tourist Center	0	0	0	20	300	0	0
2.	Green Bank Activities Center	0	0	0	0	20	300	0
3.	Misc. Alterations & Additions	0	0	0	11	12	12	13
4.	GB Lab & Residence Hall Extension	0	0	0	70	700	0	0
5.	GB, Additional Houses	0	0	0	0	0	60	0
6.	GB Indoor-Outdoor Electronics Test Facility	30	0	0	0	0	0	0
7.	GB New Works Area Bldg.	0	0	0	0	0	30	400
8.	CV Building Extension, Design	50	0	0	0	0	0	0
	Subtotal	80	0	0	101	1032	402	413

Table IV - continued

Item	Calendar Year 1972	1973	1974	1975	1976	1977	1978
C. CONSTRUCTION OF RESEARCH FACILITIES							
1. Homology Telescope	0	0	0	10000	0	0	0
2. VLA	0	3000	10000	10000	10000	10000	10000
3. Major Alterations to Existing Telescopes	0	0	0	225†	310	320	340
Subtotal	0	3000	10000	20225	10310	10320	10340
Subtotal, Construction	80	3000	10000	20407	11418	10775	10811
TOTAL BUDGET	6900	10200	18000	29073	20883	20973	21792

†New Surface, 36-foot

After completion of the homology telescope and the VLA, the estimated number of operating personnel and the operating costs are shown in Table V.

Table V

Telescope System	Total Time to Construct	Total Personnel to Operate	Operating Budget
1. Homology Antenna	4 years	26	0.72 million (1978 dollars)
2. VLA	10 years	83[1]	5.00 million[2] (1981 dollars)

Details for the VLA will be found in the VLA Reports.

[1] 62 on-site and 21 off-site personnel

[2]

Site Operations:	3200K
Off-Site Operations:	800K
Total Operations:	4000K
New Equipment:	1000K
Total Operating: (1981 dollars)	5000K

NOTE: Price escalation of 6% per year has been used in projecting the final 1981 operating budget.

March 15, 1972

ASSOCIATED UNIVERSITIES, INC.
NATIONAL RADIO ASTRONOMY OBSERVATORY

BUDGET REQUEST
CY 1974

	Financial Plan 1972	Requested to NSF 1973	New Funds Proposed 1974
I. SCIENTIFIC RESEARCH			
Operations			
Personnel Services	$3,200,000	$ 3,400,000	$ 3,680,000
Personnel Benefits	484,000	540,000	570,000
Travel	190,000	190,000	200,000
Computer Rental	400,000	550,000	700,000
Communications & Utilities	165,000	170,000	180,000
Building Rental & Maintenance	53,000	60,000	260,000
All Other Materials, Supplies & Services	1,013,000	965,000	1,075,000
Management Fee	100,000	125,000	125,000
Miscellaneous Income	(80,000)	(80,000)	(90,000)
Subtotal	$5,525,000	$ 5,920,000	$ 6,700,000
Research Equipment			
Other Observing Equipment	$ 847,000	$ 900,000	$ 900,000
Electronic Research Equipment	250,000	250,000	250,000
Electronic Test Equipment	50,000	50,000	50,000
Subtotal	$1,147,000	$ 1,200,000	$ 1,200,000
Operating Equipment			
Maintenance, Shop & Repair	$ 65,000	$ 40,000	$ 60,000
Office & Library	15,000	10,000	15,000
Living Quarters	2,000	2,000	3,000
Building	25,000	18,000	12,000
Scientific Services & Engineering	16,000	10,000	10,000
Subtotal	$ 123,000	$ 80,000	$ 100,000
Subtotal - Scientific Research	$6,795,000	$ 7,200,000	$ 8,000,000
II. CONSTRUCTION			
A. Indoor/Outdoor Test Facility	$ 30,000	$ -0-	$ -0-
B. VLA	-0-	3,000,000	10,000,000
C. Design of Charlottesville Bldg.	50,000	-0-	-0-
Subtotal Construction	$ 80,000	$ 3,000,000	$10,000,000
TOTAL REQUEST	$6,875,000	$10,200,000	$18,000,000

NATIONAL RADIO ASTRONOMY OBSERVATORY .... CY 1974, $18,000,000

Funds in the total amount of $18,000,000 are requested for CY 1974. An amount estimated at $8,000,000 is required for the direct support of scientific research and for the costs of Observatory operations, administration, and maintenance. This amount will provide for the salaries, wages, and fringe benefits of a full-time staff of 266 scientists, engineers, technicians, and other personnel; essential travel; continued development and acquisition of auxiliary instrumentation and equipment for telescope, procurement of research equipment and general equipment needed to support Observatory research programs, facilities and activities; and other costs of operations, administration, and maintenance.

The remainder of the funds, $10,000,000, is requested to continue construction of the Very Large Array (VLA).

The summary of funds provided and planned, by calendar year, is shown in the following table:

Obligations

	Actual CY 1972	Estimate CY 1973	Estimate CY 1974
Scientific Research	$6,795,000	$ 7,200,000	$ 8,000,000
Construction of Buildings and Research Facilities	80,000	3,000,000	10,000,000
Total	$6,875,000	$10,200,000	$18,000,000

Funding requested for CY 1974 is $7,800,000 more than the amount provided in CY 1973. $800,000 is the net increase in the costs of personnel, equipment, materials, services and general supplies -- and the remaining $7,000,000 of the increase is attributable to continuance of the Very Large Array (VLA) construction program.

Scientific Research .... ($8,000,000)

The NRAO major telescope systems include a 300-foot meridian transit telescope with a surface capable of operation to 6-cm wavelength, a 140-foot fully steerable telescope, a 3-element 3.8 and 11-cm interferometer consisting of 85-foot telescopes with a portable 42-foot telescope for remote operation and a 36-foot millimeter wave telescope that will operate down to 1-mm wavelength. These telescopes are used by scientists from both the U.S. and abroad on a wide variety of radio-astronomical investigations. In 1971, for example, 175 visiting scientists and students from 53 institutions used the NRAO telescopes. In keeping with Observatory policy, these visitors were allocated more than 60% of the available observing time.

These visitors, together with the resident Observatory staff, conduct the scientific programs carried out at the NRAO.

During 1971-72 a new computer processor was installed on the 36-foot telescope that provides on-line display, hard copy and editing of spectra. New 21-cm front ends operating at 21 cm were installed on the 85-foot telescopes for programs involving hydrogen-line interferometry. A tunable, low-noise parametric amplifier covering the 22-24 GHz range was developed and used on the 36 and 140-foot telescopes. A new 384-channel autocorrelation receiver operated on a shared time basis at the 300-foot and the interferometer.

During the period 1972-1974 a more complete computer control system will be installed at the 140-foot telescope and a new cooled 21-cm receiver will become available for the 140 and 300-foot telescopes. Increased emphasis will be given to the design of cooled diodes that promise lower noise temperatures for receivers operating at millimeter wavelengths. Major scientific programs will include investigation of the positions, polarization and pulse shapes of pulsars, the time variations, spectra, positions, polarization and radio brightness distribution of quasars as well as increased use of Very Long Baseline (VLB) interferometry techniques involving networks of radio telescopes located, and observing simultaneously, in the U.S. and overseas. More than two dozen molecules are now known to exist in interstellar space and attempts to detect new, more complicated constituents of the interstellar medium will be made in the hope of achieving a better understanding of the role played by molecules in the formation of stellar systems as well as life itself. Further work will be done on radio emission from X-ray sources, novae, infrared stars, red supergiants, B-star binaries and supernova remnants. Continued observations of these objects should yield valuable data that will give us a clearer understanding of the evolutionary relationships that exist among them. This area is one in which cooperative efforts among radio and optical, IR and X-ray astronomers should prove particularly worthwhile. Finally, many studies involving the 21-cm line and recombination lines of neutral hydrogen, the OH lines, H_2CO and CO lines will be made that will increase our understanding not only of the broad scale distribution, temperature, and density and motions of the gas in the Milky Way, but also the same set of physical characteristics in young clusters of stars and dust clouds out of which stars are formed.

The distribution of funds provided and requested for scientific research operations, administration, maintenance, and equipment is shown in the following table:

Obligations

	Actual CY 1972	Estimate CY 1973	Estimate CY 1974
Research Operations, Administration, and Maintenance:			
Personnel Compensation	$3,200,000	$3,400,000	$3,680,000
Personnel Benefits	484,000	540,000	570,000
Travel & Transportation of Persons..	190,000	190,000	200,000
Computer Rental	400,000	550,000	700,000
Communications & Utilities	165,000	170,000	180,000
Building Rental	53,000	60,000	260,000
All Other Services, Supplies, and Materials	1,013,000	965,000	1,075,000
Management Fee	100,000	125,000	125,000
Miscellaneous Revenue	(80,000)	(80,000)	(90,000)
Subtotal	$5,525,000	$5,920,000	$6,700,000
Equipment	1,270,000	1,280,000	1,300,000
Total	6,795,000	$7,200,000	$8,000,000

Research Operations, Administration and Maintenance .... ($6,700,000)

Personnel Compensation ($3,680,000) - Funding in the amount of $3,680,000 is requested for salaries and wages of personnel, including approximately $3,470,000 for regular full-time personnel and an estimated $210,000 for non-regular personnel (visiting scientists, part-time and student employees, etc.). The requested amount is $280,000 more than was provided in CY 1973. Approximately $170,000 of the increase will result from promotional, merit, and cost of living adjustments averaging about 6%. An estimated $100,000 of the increase will be required to annualize salaries of full-time positions filled in 1973. The remainder of the increase will be required to cover added costs of the non-regular personnel.

The following table summarizes the distribution of the regular staff:

Staffing

	Estimate Full-time 12/31/72	Estimate Full-time 12/31/73	Estimate Full-time 12/31/74	Difference CY 1974-73
Scientific & Engineering	58	60	64	+4
Technical	83	86	88	+2
Administrative & Clerical	58	58	58	0
Operations & Maintenance	56	56	56	0
Total	255	260	266	+6
Estimated Man-Years:				
Full-time Regular Staff	246	257	263	+6
Non-Regular Staff	36	38	39	+1

Personnel Benefits ($570,000) - Funds requested for Personnel Benefits represent the Observatory's share of the costs of employees' retirement and group insurance programs, Federal social security, unemployment compensation, etc. In CY 1974, requirements are expected to be approximately 15.5% of Personnel Compensation.

Travel and Transportation of Persons ($200,000) - Requirements for travel and transportation of persons are expected to increase by about $10,000 in CY 1974, mainly due to increased observing and activities at Green Bank and Tucson.

Computer Rental ($700,000) - Computer rental charges will amount to approximately $700,000 in CY 1974, or about $150,000 more than in CY 1973. The increased lease cost will result from annualizing the rental cost of the new computing system added in mid-1973.

Communications and Utilities ($180,000) - Requirements for communications and utilities are estimated to be $70,000 and $110,000, respectively.

Building Rental ($260,000) - Lease of the Laboratory in Charlottesville for CY 1974 is estimated to cost $260,000. Of this, $185,000 is estimated for payment towards the cost of the new addition to the Charlottesville building under an anticipated pay-back agreement with the University of Virginia. $75,000 is estimated for maintenance and building services.

All Other Services, Supplies and Materials ($1,075,000) - Requirements for facilities maintenance, supplies and materials, and other services are estimated to total $1,075,000.

Facilities maintenance funding requirements are estimated to total $425,000. The major portion of these funds ($335,000) will be needed for replacement components, spare parts, and tools and services for use in maintaining the telescopes and complex electronic equipment of the Observatory. The remainder of these funds will be required for maintenance of buildings, grounds, roads, airstrip, and utility systems; and maintenance equipment. Maintenance of real property facilities at Green Bank is performed almost entirely by in-house capability, and requirements for this function will consist mainly of expendable items, such as building repair and road patching materials, snow removal salt, paint, plumbing and electrical supplies, small tools, and similar items. Maintenance of automotive equipment is accomplished mainly by in-house capabilities, but requirements also include gasoline, oil, tires, batteries, and replacement parts for vehicles.

Supplies and materials requirements will amount to about $390,000 for magnetic computer tapes, office and library supplies, shop supplies, research and laboratory supplies, and general supplies.

Other services, totaling approximately $260,000, will include freight and express charges; auditing services; food, lodging and housing services; costs of employee medical services, laundry and dry cleaning services; GSA vehicle rentals, and miscellaneous services, including office equipment maintenance and service. Also included is an estimated $80,000 for antenna improvement studies which are a continuing part of NRAO operations.

Management Fee ($125,000) - The contract between the Foundation and Associated Universities, Inc., the non-profit corporation that manages and operates the NRAO for the Foundation, provides that the NSF will pay a fee of $125,000 covering corporate expenses related to administration and operation of the Observatory.

Equipment .... ($1,270,000)

The requested funding will provide auxiliary instrumentation and equipment required to maintain and improve the capabilities of the research telescopes, including new systems development, major modifications and upgrading of existing systems, etc. The principal requirements for CY 1974 are expected to include improvements to existing receivers and completion of a new 1.2-cm cooled receiver for the 140-foot telescope ($100,000), development of an 18-cm cooled receiving system and a pulsar processor for the 300-foot telescope ($130,000), development of a wideband back-end system for the NRAO interferometer ($150,000), development and improvement of mm receivers and completion of a 9-mm cooled paramp for the 36-foot telescope ($220,000), additional equipment for the Very Long Baseline (VLB) system and other general systems ($200,000), and additional improvements to the NRAO-owned computing systems ($100,000).

Research and test equipment requirements in the estimated amount of $300,000 will consist of the latest equipment for testing and maintaining the extremely complex electronic systems of the Observatory, general upgrading of systems, and small systems modifications.

Principal requirements for equipment other than research equipment are expected to include replacement of trucks and tractors that have reached the end of their useful life, a number of items of maintenance and machine shop and building equipment; furniture and equipment for the offices, and living quarters.

Construction of Buildings and Research Facilities .... ($10,000,000)

The distribution of funds provided and requested for the planning, design, and construction of buildings and research facilities is shown in the following table:

Obligations

	Actual CY 1972	Estimate CY 1973	Estimate CY 1974
Construction of Buildings & Research Facilities	$30,000	$3,000,000	$10,000,000
Subtotal	$30,000	$3,000,000	$10,000,000
Planning & Design of Buildings & Facilities	$50,000	$ -0-	$ -0-
Total	$80,000	$3,000,000	$10,000,000

Construction of Buildings and Research Facilities ....(-0-)

	Actual CY 1972	Estimate CY 1973	Estimate CY 1974
Construction of Buildings:			
Indoor/Outdoor Electronic Test Fac..	$30,000	$ -0-	$ -0-
Subtotal	$30,000	$ -0-	$ -0-

Construction of Facilities .... ($10,000,000)

	Actual CY 1972	Estimate CY 1973	Estimate CY 1974
Very Large Array (VLA)	$ -0-	$3,000,000	$10,000,000
Subtotal	$ -0-	$3,000,000	$10,000,000

Very Large Array (VLA) ($10,000,000) - $10,000,000 is requested to continue construction of the VLA. In 1973 site acquisition and engineering will be undertaken, together with detailed engineering and construction of the first antenna unit and transporter. This work will continue in 1974 and, in addition, the engineering and procurement of site facilities and track system (Wye) will commence. Detailed design, engineering and prototyping of various elements of the electronics and computer systems will also begin in 1973 and continue through 1974.

Full details of the proposed instrument, including scientific considerations, designs, cost estimates and time schedules are contained in the various documents previously submitted.

VLA PERFORMANCE DATA

The VLA performance given in the two tables below is based on an array consisting of 27 antenna elements, each 25 m diameter, distributed along three arms of a wye. Each arm of the wye is 21 km long. The distribution of antenna elements is not symmetric, nor is the distance between elements equal. The positions of the antenna elements have been optimized for best performance (low sidelobes) over the sky above -15° declination.

The basic VLA operates at one frequency only, but both circular polarizations are available on a time-shared basis (only one IF channel).

The addition of continuum equipment will extend this capability to a second frequency related to the first by a factor of 3 (or 2). Then one polarization at each frequency or both polarizations at one of the frequencies will be available simultaneously (two IF channels).

Table I shows the basic performance specifications for the VLA. The resolution and the fields of view given in the table correspond to the maximum resolution available with 21 km arms. There will be a total of 100 stations available which will permit operation at a total of 4 different resolutions as shown in Table II.

TABLE I

f (MHz)	λ (cm)	Max. Resolution (arc sec)	Field of View at Max. Resolution (arc sec)	Max. Side-lobe within Field of View (dB) [1]	Mean Distant Sidelobe (dB)	System Temperature (°K)	Sensitivity 12-hour Track [2] ($W\ m^{-2}\ Hz^{-1}$)	IF Bandwidth (MHz)
2695	11.1	1	94	-15	-30	80	$\sim 10^{-30}$	35
8085	3.7	0.3	40	-15	-30	100	$\sim 10^{-30}$	35

[1] At declinations above -15°.

[2] About 5 times the rms noise level.

TABLE II

Frequency		2695 MHz (11.1 cm)				8085 MHz (3.7 cm)			
Configuration		#1	#2	#3	#4	#1	#2	#3	#4
Arm Length		21 km	7 km	2.3 km	0.8 km	21 km	7 km	2.3 km	0.8 km
Resolution		1"	3"	9"	27"	0.3"	1"	3"	9"
Field of View	Combined	94" 1.6'	286" 4.8'	846" 14.1'	1080" 18.0'	40" 0.7'	120" 2'	360" 6'	360" 6'

ALTERNATE FUNDING SCHEDULES FOR THE VLA

The original funding schedule for the VLA is based on a minimum cost construction plan (63,033 k$ assuming start of the project in 1973). There are several possible ways to change the construction plan to accommodate a stretched out funding schedule, all of which will increase the total cost of the project because of (a) inefficiencies caused by interrupted or artificially delayed construction, (b) escalation, and (c) prolonged indirect costs such as project management. One construction plan, which assumes a maximum funding level of $10 million in any single year, is shown in Table I.

Table I

Very Large Array (VLA) Construction Program

<u>CY 1973 (First Year)</u>

Detail Design and Procure Prototype Antenna System

Acquire VLA Site

<u>CY 1974 (Second Year)</u>

Build and Evaluate Prototype

Design and Procure Site Facilities

Design Track System

<u>CY 1975 (Third Year)</u>

Procure 4 Antenna Systems

Complete Site Facilities

Construct 5 Miles of Track

<u>CY 1976 (Fourth Year)</u>

Add 4 Antenna Systems (8 Total)

Add 8 Miles of Track (13 Total)

Start Partial Operation

<u>CY 1977 (Fifth Year)</u>

Add 5 Antenna Systems (13 Total)

Add 6 Miles of Track (19 Total)

<u>CY 1978 (Sixth Year)</u>

Add 5 Antenna Systems (18 Total)

Add 5 Miles of Track (24 Total)

<u>CY 1979 (Seventh Year)</u>

Add 5 Antenna Systems (23 Total)

Add 2 Miles of Track (26 Total)

<u>CY 1980 (Eighth Year)</u>

Add 4 Antenna Systems (27 Total)

Add 7 Miles of Track (33 Total)

<u>CY 1981 (Ninth Year)</u>

Add 6 Miles of Track (39 Total)

Phase Into Full Operation

<u>CY 1982 (Tenth Year)</u>

Full Operation

The corresponding funding schedule is shown in Table II.

Table II

Alternate Funding for the VLA
k$

Year		Optimum	Alternate
1973		3,700	3,000
1974		10,345	10,000
1975		48,028	10,000
1976		480	10,000
1977		480	10,000
1978		-	10,000
1979		-	10,000
1980		-	10,000
1981		-	3,000
	Total	63,033	76,000

The alternate schedule provides 4 antennas on 8 km of track in 1975, 4 antennas and 13 km of track in 1976, for a total of 8 antennas on one arm of the Wye (21 km).

The cost increases caused by non-optimum, stretched-out construction are detailed in Table III. These increases apply to the antennas, the railroad track system and the electronics. It is estimated that the artificially delayed construction of these items will increase the cost by about 6%.

Table III

Additional Costs Caused by "Inefficiency"
1975 dollars

	Original Cost k$	Added Cost k$	New Cost k$
Antennas	16,741	1,005	17,746
Wye	9,971	598	10,569
Electronics	16,111	967	17,078
Total	42,823	2,570	45,393
Contingency 10%		257	
Total Additional Cost		2,827	

For all three categories, it is estimated that the stretched out funding will cause 6% extra cost.

An escalation factor corresponding to 6% per year is applied to all deferred funding, and time dependent costs such as project management are added for the years 1978 through 1981. Table IV shows the detailed calculations.

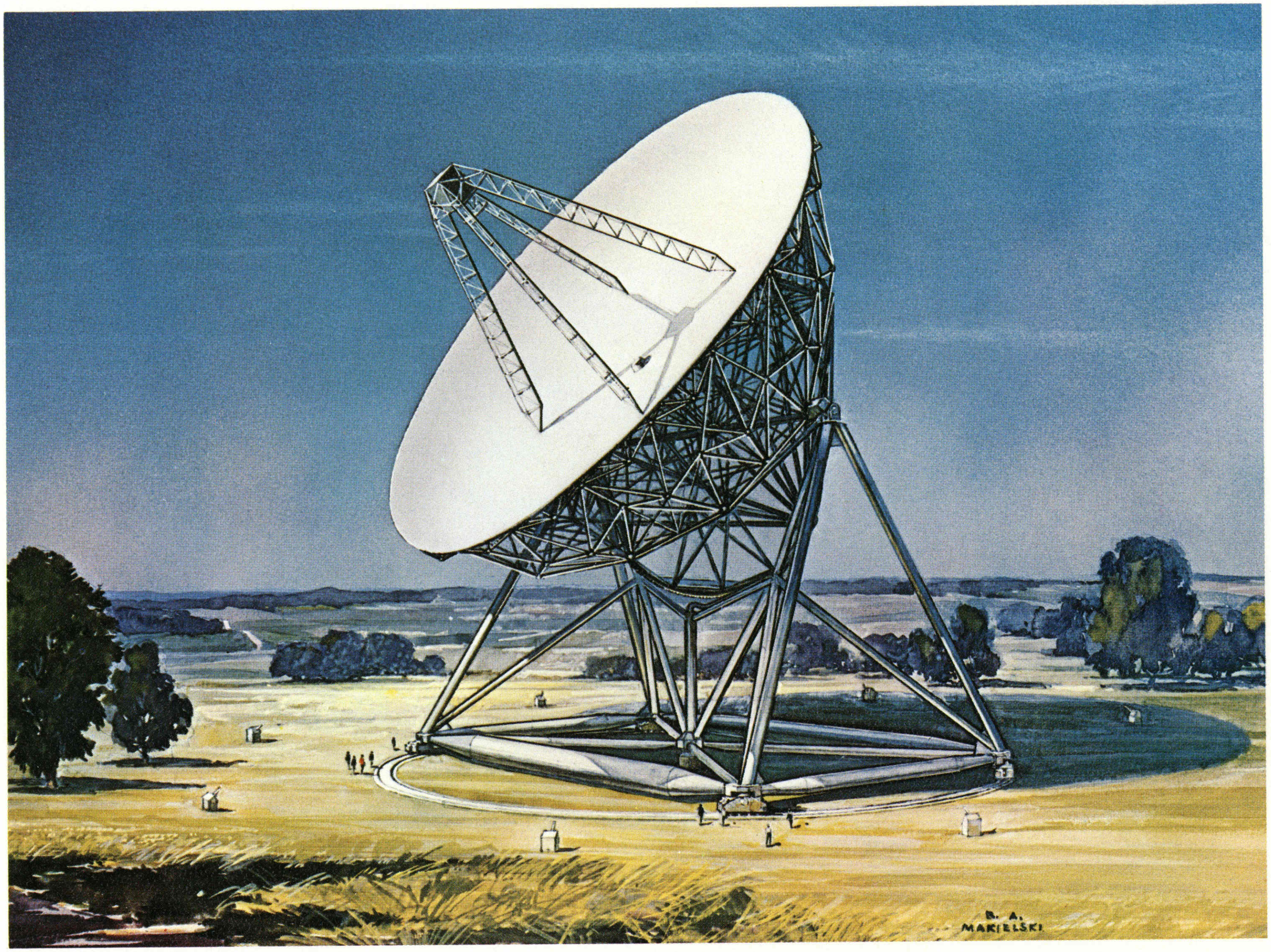
Table IV

Year	(1) Carry (5)-(6)	(2) Escalated Carry 1.06x(1)	(3) Original Estimate	(4) Other Costs	(5) Adjusted Estimate (2)+(3)+(4)	(6) New Budget[3]	Operating Original	Operating New[3]
1973		-	3,700		3,700	3,000		
1974	700	742	10,345	-	11,087	10,000		
1975	1,087	1,152	48,028	2,827[1]	52,007	10,000		
1976	42,007	44,498	480	-	44,978	10,000	975	500
1977	34,978	37,076	480	-	37,556	10,000	1,900	1,200
1978	27,556	29,210	-	500[2]	29,710	10,000	4,260	1,800
1979	19,710	20,893	-	500[2]	21,393	10,000	4,500	2,500
1980	11,393	12,076	-	500[2]	12,576	10,000	4,750	3,100
1981	2,576	2,731	-	269[2]	3,000	3,000	5,000	5,000
Total Project Cost			63,033			76,000		

[1] Costs from Table III

[2] Project Management Cost

[3] Assumes $10 million per year maximum funding



THE 65-METER TELESCOPE FOR MILLIMETER WAVELENGTHS

65-meter Telescope Design Specification

Dish diameter	:	65 meters (213 feet)
Mounting	:	Altitude-Azimuth
Sky cover	:	Complete--but no tracking inside a small zone near zenith
*RMS surface accuracy	:	0.22 mm (0.009 inches)
*Short wavelength limit	:	3.5 mm (86 GHz)
*Tracking accuracy	:	3 arc seconds RMS
Slew rates (both axes)	:	20° per minute
Optics	:	Prime focus f/D = 0.42 Cassegrain--subreflector diameter 3.7 m (12 feet)
Instrument cabins	:	Behind prime focus; behind Cassegrain focus
Equipment room	:	Rotates in azimuth

* This performance is only possible under benign environmental conditions.

<u>65-meter Telescope Cost Estimate (1972 dollars)</u>

	Thousands of $
Fabrication of reflector and tower structure, including counterweight	1,475
Fabrication of intermediate structure	441
Erection of complete telescope	1,080
Surface plates, installation and adjustment	1,540
Azimuth trucks, gear boxes and motors	340
Pintle bearing	50
Elevation bearings	95
Elevation gear, gear boxes, drive motors	190
Foundation and track	146
Feed and subreflector supports, subreflector instrument cabins	250
Optical position reference system	460
Servo control system	500
Telescope control computer, including software	200
Ladders, walkways, hoists, cable trays	42
Telescope cabling	100
Painting, start-up and test	200
Site preparation	634
Project management and engineering	450
	8,193
Add 15% contingency	
TOTAL	9,422

65-meter Telescope -- Operating Cost Estimate

	Totals	$
On-Site Personnel		
Site manager, administrative assistant, clerk, secretary	4	49k
Electronic engineer (3) and electrical/mechanical	4	60k
Technicians, electronic (3) and computer (1)	4	40k
Telescope operators	6	60k
Telescope mechanics	2	20k
Programmer	1	15k
Laborers/handymen/driver	2	12k
Guards (night only)	2	12k
Housekeeper/cook	1	5k
Part-time, temporary, overtime -- 10%		27k
TOTALS	26	300k

Salaries of on-site personnel	300k
Benefits, 15%	45k
Travel	15k
Utilities--telephone 5k; power 15k	20k
Materials, services and supplies	100k
One-third cost of painting telescope (paint every three years)	32k
TOTAL ANNUAL OPERATING	512k

National Radio Astronomy Observatory, *Charlottesville, Virginia, Green Bank, West Virginia, and Tucson, Arizona*

I. FACILITIES

The National Radio Astronomy Observatory is a national research center for radio astronomy, funded by the National Science Foundation under a management contract with Associated Universities, Inc. The NRAO facilities are available to any qualified scientist or graduate student and visitors are assigned at least 60% of the observing time on the telescopes for research programs, which they may conduct independently or cooperatively with staff members.

The major Observatory telescopes include a 300-ft meridian transit telescope, a 140-ft fully steerable telescope, a three-element interferometer consisting of 85-ft telescopes that can operate in conjunction with a remote portable, 42-ft antenna, and a 36-ft millimeter-wave antenna located on Kitt Peak in Arizona. Receivers are available for observing programs that cover the wavelength range from 1 mm to 3 m. Autocorrelation and multichannel receivers are available for studies that require frequency discrimination. Each telescope is equipped with on-line computers that provide telescope control and real-time data analysis. Data are recorded on magnetic tape for further processing by general purpose computers, an IBM 360/50 located in Charlottesville and a CDC 6400 located in Tucson.

Visitors from other institutions may apply for observing time by writing to the **Director, National Radio Astronomy Observatory, Edgemont Road, Charlottesville, Virginia 22901.** The NRAO will send to any potential observer, on request, information sheets that give brief descriptions of each major telescope, receiver, feed, and computer system, that provide a general familiarization with Observatory procedures, and that advise how to prepare an observing proposal.

II. NEW INSTRUMENTATION

The spectral-line equipment of the Observatory has been enhanced by the addition of a 100-channel filter processor for the 36-ft telescope and a 384-channel auto- or cross-correlator for use on the 300-ft telescope or interferometer. The processor for the 36-ft telescope can accommodate any two of the NRAO 50-channel filter banks and provides on-line display, hard copy, and editing of spectra. The correlator can be partitioned in four 96-channel or two 192-channel segments and can analyze total bands of 39 kHz to 10 MHz in steps of two. Front-ends operating in the 1370-1430-MHz range have been installed on the three-element interferometer and are utilized for spectral-line measurements with the new correlator. A tunable degenerate-paramp receiver covering the 22-24-GHz range has been completed and used on the 36- and 140-ft telescopes. The paramp was developed by NRAO and has a single-sideband noise temperature of 700°

The NRAO is assisting other observatories in the construction of a dozen terminals for observations involving very long baseline interferometry (VLB) of radio sources. Four of these Mark II VLB terminals were completed during fiscal year 1971 as well as a special VLB processor that will provide the first stage of data reduction. The new system provides 4 Mb/sec recordings for a one hour period on a single video tape.

III. VISITORS, STUDENTS, AND STAFF

From 1 January through 31 December 1970, 135 visitors, including 36 students, observed on NRAO telescopes. They came from 40 different institutions. The following table summarizes, by telescope, the numbers of visitors, students, and NRAO permanent staff who observed on each instrument, as well as the number of different institutions from which they came:

Telescope	Visitors	Students	NRAO Staff	Total	Number of institutions
36-ft	34	8	7	49	20
Interferometer	19	3	12	34	8
140-ft	70	26	11	107	32
300-ft*	18	4	4	26	9

*The installation of a new surface reduced observing time to 50% of normal operation.

Eleven co-op students and 39 summer undergraduate and graduate students worked at NRAO for three months or more during the summer of 1970. On 31 December 1970, there were 236 permanent employees of whom 14 were on the permanent scientific staff in the basic research group, 10 held research associate appointments, and 23 were structural, mechanical, or electronics engineers.

Visiting colloquia were delivered by R. H. T. Bates, G. Carruthers, R. H. Dicke, B. Donn, B. J. Eastlund, R. Ebert, D. Goldsmith, W. M. Goss, J. M. Greenberg, D. Jauncey, H. van der Laan, I. Lerch, P. O. Lindblad, H. Murdoch, I. D. Novikov, D. Osterbrock, G. Pimentel, W. Quirk, V. Radhakrishnan, J. Romig, W. K. Rose, V. Rubin, J. S. Shklovsky, A. Toomre, R. Wagoner, L. Weliachew, and R. Wielebinski.

IV. JANSKY LECTURESHIP; COMMITTEES

The fifth annual Karl G. Jansky Lectureship was awarded to Professor Robert H. Dicke, chairman of the Department of Physics at Princeton University. Dicke, noted for his research in gravitation, relativity, and cosmology, delivered the lecture entitled "Gravitation and the Universe" in October 1970. The Jansky Lectureship, established by the AUI Trustees in 1966, is awarded annually to an outstanding scientist, usually chosen for his contribution to astronomy. It is named in the honor of Karl G. Jansky, who pioneered the field of radio astronomy.

The six-man NRAO Visiting Committee, appointed by the AUI Board of Trustees to review the management and research programs of the Observatory, consisted of the following individuals between October 1970 and October 1971: F. D. Drake (Chairman), A. G. Smith, C. H. Mayer, A. T. Moffet, L. Woltjer, and H. van der Laan. A. G. Hill was an AUI Trustee Member of the Committee.

The NRAO Users Committee, which meets twice each year to advise the NRAO Director and staff on the future needs for instrumentation and facilities, consisted of the following members on 30 June 1971: A. H. Barrett, B. F. Burke, W. A. Dent, J. R. Dickel, J. Douglas, F. D. Drake, W. C. Erickson, S. J. Goldstein, Jr., C. E. Heiles, D. Jauncey, F. J. Kerr, H. C. Ko, M. R. Kundu, A. E. Lilley, C. H. Mayer, P. Palmer, K. Riegel, A. G. Smith, L. E. Snyder, G. W. Swenson, Jr., J. Taylor, A. R. Thompson, J. Warwick, G. Westerhout, D. R. W. Williams, R. W. Wilson, and B. Zuckerman.

V. PERSONNEL

Additions to the NRAO scientific staff included W. B. Burton, J. D. G. Rather, E. H. Tademaru, and M. C. H. Wright as Research Associates, and E. B. Fomalont as Assistant Scientist. Visiting Appointments were held by F. Biraud (Meudon, France), C. E. Heiles (Berkeley), T. K. Menon (Hawaii and Tata Institute, India), H. S. Murdoch (Sydney, Australia), S. D. Shawhan (Iowa), and R. N. Whitehurst (Alabama). Leaving NRAO during this period to take positions elsewhere included E. B. Churchwell, P. G. Mezger, G. K. Miley, and W. J. Webster, Jr., while J. Maslowski (Kracow, Poland), W. B. McAdam (Sydney, Australia), S. D. Shawhan (Iowa), and R. N Whitehurst (Alabama) returned to their respective institutions. D. E. Hogg succeeded M. S. Roberts as Assistant Director for Green Bank Operations. G. L. Verschuur returned in July from a six-month leave of absence at Berkeley and UCLA, and D. S. De Young spent a one-month leave of absence at Los Alamos Scientific Laboratory in July 1970.

VI. RESEARCH PROGRAMS

The following section is a brief summary of resident staff, student, and visitor scientific activity. Visitor activities will usually be found in more detail in the *Reports* of their own institutions.

A. Solar System

Solar Studies: G. Feix (Bochum, W. Germany) observed the quiet Sun and active solar regions using circular polarization at 85 GHz. The Maryland observers M. Kundu and R. Sinha carried out a similar program at 31 and 85 GHz. Nonthermal processes in solar flares were investigated at 31 and 85 GHz by E. Mayfield and F. Shimabukuro (both Aerospace Corporation) and S. Edelson (NASA-Ames). M. Simon and P. Berger (both SUNY-Stony Brook) made observations of the solar oscillatory component at 260 GHz and attempted to detect solar recombination lines at 85-91 GHz on the 36-ft telescope.

Planets: The Illinois observers J. Dickel and W. Warnock used the 140-ft telescope to measure the flux density of Venus at frequencies between 2 and 4 GHz. D. Morrison (Hawaii) and E. Epstein (Aerospace) investigated the flux density of Mars with the 36-ft telescope in the millimeter-wave continuum. W. Webster (NASA-Goddard), G. Webster (Sperry Management Systems), and A. Webster (Monmouth College) observed Uranus and Neptune with the interferometer and attempted to detect Pluto.

B. Galactic Studies

1. Hydrogen-Line Studies and the Interstellar Medium

H I Distribution: W. B. Burton interpreted 21-cm observations of hydrogen near the galactic plane in terms of two sorts of kinematic models of the galactic velocity field. The existence of large-scale streaming motions makes interpretation in terms of circular galactic rotation unsatisfactory. Application of a velocity field of the type predicted by the density-wave theory leads to a more satisfactory interpretation. Burton finds that 21-cm profiles are more sensitive to small variations in the streaming motions than to small variations in the hydrogen density. W. B. Burton and G. Verschuur used the 300-ft telescope to map an extension of hydrogen, associated with a spiral arm, to a high z distance of 3.5 kpc. A study of the transition region between the galactic plane and the halo is continuing. G. Knapp (Maryland) made high-resolution, 21-cm line observations on the 140-ft telescope of absorption spectra in the directions of continuum sources near the galactic center. Using the interferometer, K. Riegel (UCLA) conducted optical depth measurements of cold, neutral hydrogen in front of galactic continuum sources in the longitude range 30° to 352°. Observations of 21-cm neutral hydrogen were made by the Maryland observers G. Westerhout, S. Simonson, R. Harten, and G. Mader to calibrate the Green Bank–Maryland 21-cm line survey.

Special Studies: Neutral-hydrogen observations by S. Gottesman of the Cygnus X region employing the 300-ft telescope and the 10-kHz filter-bank system have been completed. The region examined covers R.A. 20^h to 21^h and Dec. +38° to +45° and should yield information about the dynamics and structure of the local spiral arm and about the distribution of thermal sources in the Cygnus X complex. S. Gottesman and M. Gordon detected the weak recombination lines H 157α and H 197β from regions along the galactic plane chosen to be free of discrete radio sources. The large velocity extent of the lines suggests that the line radiation is generated over long path lengths. These observations are consistent with a diffuse medium having a mean electron temperature $T_e \sim 1000$°K and a mean emission measure $E \sim 280$ pc cm^{-6}. No emission is observed at radial velocities corresponding to or greater than the distance of the Sun from the galactic center. At a galactic radius of 8 to 10 kpc, it is clear that the ionized conditions of this medium change markedly. These lines constitute a new tool for exploring galactic structure because the line brightness temperature determines $\langle n_e n_{HII} t_e^{-1.5} \rangle$ as a function of radial velocity. (Non-LTE effects can only amount to a factor of 2.) In a similar study, F. Kerr and P. Jackson (both Maryland) made 6-cm observations on the 140-ft telescope of distributed H II in the galactic spiral arms to study correlations between the structure, distribution, and kinematics of these H I and H II regions. R. Harten and G. Mader (both Maryland) made observations of galactic H I with the 300-ft telescope to compare and to aid in combining data taken in the northern and southern hemispheres. G. Verschuur followed up earlier 21-cm Zeeman effect work and set a limit of 3.6 μG to the line-of-sight field in the Taurus dust cloud. Together with G. Knapp, G. Verschuur measured spin temperatures of 12 and 20°K in two nearby H I clouds by analyzing the emission-line shapes in detail.

Continuum Structure and the Interstellar Medium: G. Westerhout (Maryland) began a program of observations at 20 cm on the 300-ft telescope to study the polarization of the galactic background. G. Verschuur undertook a statistical analysis of the optical polarization properties of stars in 50 to 60 clusters and associations to investigate the scale length of the interstellar magnetic field. R. L. Brown investigated the role that atomic processes, such as charge transfer and photoionization with accompanying Auger transitions, may plan in determining the relative abundance of atomic species in the interstellar medium.

2. OH Studies

a. Survey Work

The total number of sources now found by B. Turner in his OH survey on the 140-ft telescope is 180, out of 264 regions searched to a sensitivity of 0.7 f.u. in the range $337° \leq \ell \leq 75°$. These 180 OH sources include 424 separate OH clouds. The satellite lines of the 180 OH sources in the Turner survey are being observed in collaboration with D. Dickinson (Harvard), using the 85-ft Agassiz Station telescope. The goal is to see whether the combined properties of all four lines in the 180 new OH sources continue to be consistent with the classification scheme of anomalous OH excitation proposed by Turner. The OH sources have been compared with the 60 presently known H_2CO sources, and with the recombination-line material of the NRAO–MIT survey. OH is found not to be physically closely associated with continuum sources, as evidenced by both spatial and velocity relationships. OH opacities appear not to be correlated either with any continuum source parameters, or with H_2CO opacities. The Maryland observers F. Kerr and G. Knapp observed with the 140-ft telescope to catalog the OH distribution toward Kapteyn Selected Areas. B. Zuckerman (Maryland), C. Gottlieb (Harvard), H. Radford (Smithsonian), and J. Ball (Harvard) conducted absorption measurements in the ^{18}OH line and searched for the ^{17}OH line. A 6-cm OH survey of known 18-cm OH sources was carried out by A. Barrett (MIT), W. Wilson (Aerospace), and D. Thacker on the 140-ft telescope.

b. Special Studies

Clouds: Of a total of 18 positions in 10 clouds, B. Turner and C. Heiles (Berkeley) find all but one continue to show enhanced 1720-MHz emission, apparently due to infrared pumping, of the near-infrared variety (at 2.8μ). The one exception, showing enhanced 1612-MHz emission, can also be explained by near-infrared pumping, but requires higher densities (more IR trapping). In addition, one case appears to show an enhancement of the 1667/1665 ratio over the LTE ($\tau = 0$) value of 1.8. G. Knapp (Maryland) observed the 1667-MHz OH line with the 140-ft telescope in dust clouds where neutral-hydrogen self-absorption measurements have shown the existence of large amounts of cold neutral hydrogen. G. Verschuur searched for, and found, OH emission in a number of high-latitude H I clouds which are relatively dust free and searched for, but did not find, formaldehyde in these clouds. R. Manchester and M. Gordon observed apparently normal 1667-MHz emission from the OH cloud seen in absorption against Orion B. This observation showed that the excitation temperatures of the four ground-state transitions were close to the radiative background temperature and that the OH is probably imbedded in a dense H I cloud with very low kinetic temperature. Manchester and Gordon have also detected OH emission at 18 cm on either side of Orion B which appears to be caused by an extensive OH cloud covering Orion B as well. Using the emission and the Orion B absorption, they calculate the excitation temperature of the OH to be nearly 2.8°K. In this region at least, collisions are an unimportant mechanism for populating the 18-cm OH levels.

Infrared Stars and Stellar Objects: G. Grasdalen, C. Heiles (both Berkeley), and B. Turner have conducted a survey for OH in approximately 200 stellar-type objects thought to be very young and to have conditions (e.g., circumstellar envelopes, IR excesses) favorable for the existence of molecules. All four ground-state lines were searched to a limit of 0.5 f.u. with the 300-ft transit telescope and traveling feed. No detections of OH were made which can definitely be associated with these objects. Using the 140-ft telescope, W. Wilson (Aerospace) and A. Barrett (MIT) observed 18-cm OH emission associated with infrared stars to investigate time variations and other physical properties of the radiation and to search for new OH/IR sources.

6-cm OH: In addition to their work at 18 cm, Barrett, Wilson, and D. Thacker expanded their OH/IR star survey at 6 cm and studied the sources Sgr B2 and NGC 6334 to obtain high-resolution spectra, angular extent, and polarization data. The 6.031- and 6.035-GHz lines of the $^2\pi_{3/2}$, $J = 5/2$ state of OH were used by D. Dickinson (Harvard) to investigate Sgr A and the supernova remnants W28, W44, and W81, and by P. Palmer (Chicago), B. Zuckerman (Maryland), C. Gottlieb (Harvard), and J. Yen (Toronto, Canada) to investigate a number of sources, particularly NGC 6334N. Both studies were conducted on the 140-ft telescope.

Other Work: The Berkeley observers C. Townes, N. Evans, and R. Hills, in collaboration with O. Rydbeck (Chalmers University, Sweden), observed the 1667-MHz line in strong OH sources to determine whether the line emission has the characteristics of random or nonrandom noise. At the same frequency, J. M. Greenberg (Albany) searched for the presence of magnetic fields in OH emission sources by investigating Faraday rotation through the accurate measurement of polarization at very high-frequency resolution. F. Kerr and W. Sullivan (both Maryland) measured the Stokes parameters in all four 18-cm OH lines in a number of sources, placing special emphasis on time variations and correlations between the intensities of OH and the H_2O line. Several new types of OH sources have been found by B. Turner which display type I anomalous emission. One is the planetary nebula NGC 2438. Others are compact optical nebulae ($\lesssim$ 10 arc min in size) that have no radio counterparts (S247, S269, IC 2162, etc.). These sources are the first to have the potential of combining detailed optical data with type I OH emission to see if the OH emission is related to any detectable optical properties.

3. Supernova Remnants, Stellar Radio Astronomy

Supernova Remnants: Polarization measurements of supernova remnants at 11 cm were conducted by the Illinois observers J. Dickel and W. Warnock using the 140-ft telescope for an investigation of CTB 1, and, with A. Willis (Illinois), on the 300-ft telescope where a number of supernova remnants were mapped. M. Kundu and T. Velusamy (both Maryland) have used the 140- and 300-ft telescopes at 3, 6, and 11 cm to map brightness and polarization structure of a number of supernova remnants, including the Cygnus Loop.

Novae and Stars: M. Simon and P. Berger (both SUNY-Stony Brook) searched for evidence of mass loss from giant stars at 31 GHz, using the 36-ft telescope. R. Hjellming, C. Wade, and V. Herrero detected emission from Nova Scuti 1970, and continued observing radio emission from Nova Delphini 1967 and Nova Serpentis 1970, with the three-element interferometer and the 36-ft telescope at wavelengths of 11.1, 3.7, 0.95, and 0.35 cm. Variations in the emission have been observed, with time scales of the order of months for Nova Serpentis, and weeks for Nova Scuti. R. Hjellming and C. Wade, using the three-element interferometer, found the x-ray source Sco X-1 to be an unusual triple radio source in which the components lie on a straight line. The central source, coincident with the x-ray star, varies in intensity by two orders of magnitude on time scales of a few hours. The spectral index is variable, but always nonthermal. One of the comparison sources seems to have changed position. The first detections of variable radio sources associated with Cyg X-1 and GX 17+2 were also made. A radio source near Antares was found to be variable both in flux and spectral index and associated with the B3 V component of the red supergiant.

Infrared Stars – Continuum: Three observers from the Aerospace Corporation, W. Wilson, E. Epstein, and W. Fogerty, searched for millimeter-wave emission from infrared sources at 85 GHz, using the 36-ft telescope.

4. H II Regions and Star Formation

Continuum Studies: On the 36-ft telescope, observations of symmetric galactic nebulae were made by H. Johnson (Lockheed) at 31 and 85 GHz, and compact H II regions were observed by K. Johnston (NRL) and R. Hobbs (NASA-Goddard) at 85 and 260 GHz. W. Altenhoff and T. Wilson (both Bonn, W. Germany) observed the Rosetta Nebula in the 6-cm continuum with the 140-ft telescope. Using the interferometer at 4 and 11 cm, W. Webster (NASA-Goddard) and the Bonn observers, W. Altenhoff, J. Wink, and P. Mezger, investigated condensations in H II regions. Purdue student T. Williams and M. Gordon restored a high-precision map of M17 made at 2 cm with the Haystack telescope. They found the source to be a complex of small H II regions. Gordon, J. Ball (Harvard) and E. Chaisson (Harvard) continued their large-scale mapping of H II regions with the Haystack telescope at 2 and 4 cm. The sources H2-3 and H2-6, previously catalogued as planetary nebulae, were studied in the continuum at 3 and 6 cm and in the H85α, H107β, H109α, and H137β recombination lines by B. Turner and R. Rubin (Illinois). These observations show that, like K3-50, these sources are not planetary nebulae, but compact H II regions in an early stage of development. Optical data were obtained for all three objects at Kitt Peak and for two objects (H2-3, H2-6) at Cerro Tololo.

Recombination-Line Studies: The Harvard observers D. Cesarsky, J. Ball, A. Dupree, L. Goldberg, and A. E. Lilley observed recombination lines of hydrogen, helium, and carbon in a number of H II regions at a frequency near 880 MHz. J. Ball (Harvard) and B. Zuckerman (Maryland) investigated hydrogen and carbon recombination lines in Orion A and other sources at frequencies near 695 MHz and 1 GHz, using the 140-ft telescope. E. Churchwell, P. Mezger (both Bonn, W. Germany) and J. Maslowski (Kracow, Poland) studied the Stark broadening of 11-cm higher-order recombination lines of hydrogen, searched for radio-recombination lines in dark clouds having molecular-line emission and in a dark cloud containing T Tauri stars, and searched for carbon-line emission in the dark bay of the Orion Nebula. M. Gordon and Cornell student D. Wallace analyzed H109α and H137β maps of the thermal component of W49. They found that this giant H II region has the same kind of structure in electron density as Orion A, namely characteristic clump sizes $\sim$0.01 pc and electron densities as large as 10^5 cm^{-3}. The greatest clumping occurs along lines of sight through the OH and H_2O source regions, which are coincident with the dense thermal sources detected by interferometers. M. Gordon investigated α and β helium and carbon-recombination lines at 3 cm to explore the behaviour of these lines as a function of quantum number. T. Wilson, (Bonn, W. Germany) measured 6-cm recombination lines in the source G45.5+0.1 and, in collaboration with W. Altenhoff (Bonn, W. Germany), engaged in a study of 6-cm recombination lines in the Rosette Nebula. M. Gordon and E. Churchwell (Bonn, W. Germany) analyzed high-precision observations of hydrogen and helium lines at 3 cm in order to separate thermal and turbulent broadening. Electron temperatures determined in this way are independent of departures from LTE. Temperatures determined for M42 and W3 agree well with those obtained from non-LTE analyses. But M17 and W3 were seen to contain additional spectral lines which have since been identified as weak recombination lines of unidentified origin. P. Mezger and E. Churchwell (both Bonn, W. Germany) observed the 3-cm recombination lines of hydrogen, helium, and carbon 85α in H II regions. D. Cesarsky (Harvard) used the 140-ft telescope to make 3-cm high-precision recombination-line observations to determine the physical conditions in H II regions. A study of the line-to-continuum intensity ratios of the alpha-recombination lines of H, He, and C and the beta-recombination lines of H at 12.5 GHz were conducted on the 140-ft telescope by the Harvard observers J. Ball, D. Cesarsky, A. Dupree, A. E. Lilley, and L. Goldberg. M. Andrews, R. Hjellming, and E. Churchwell obtained non-LTE solutions for electron temperature, electron concentration, and emission measure from radio recombination-line data for M8, W3, W43, W49, and W51.

Star Formation: T. Nakano (Kyoto, Japan) investigated the condensation of solid hydrogen on grains in contracting interstellar clouds. Nakano and E. Tademaru investigated the decoupling of magnetic fields in dense clouds with angular momentum.

5. Planetary Nebulae

Y. Terzian and B. Balick (both Cornell) searched for the H85α, 3-cm recombination line in NGC 7027 and other planetary nebulae.

6. Pulsars

Observations of pulsar polarization at the 300-ft telescope have continued by R. Manchester. The range of observing frequencies has been extended and a number of weaker pulsars have also been studied. Polarization measurements have also been made at 1665 MHz using the 140-ft telescope. Absolute pulse arrival times have been determined, allowing calculation of accurate periods, period derivatives, positions, and dispersion measures. Rotation measures have also been calculated giving information on the galactic magnetic field and intrinsic angle of the pulsar emission. The Massachusetts observers G. R. Huguenin and J. Taylor used the 300-ft telescope at frequencies of 112, 74, and 52 MHz to investigate pulse-broadening phenomena in pulsars. At the interferometer, they were joined by R. Hjellming and C. Wade in a search for variations in pulsar intensity during the pulsar "off" time. The x-ray source Cygnus X-1 was observed by M. Ewing, D. Feith, J. Krolick, and D. Staelin (all MIT) at 110 to 235 MHz on the 300-ft telescope in a search for evidence for periodic or single dispersed radio pulses from the source having pulse periodicities of 10 ms and longer. In a theoretical study, E. Tademaru investigated a model for the coherent radio emission for pulsars. He also calculated the cyclotron emission from relativistic particles with very small pitch angles.

7. Other Line Studies

Water Vapor (H_2O) and Ammonia (NH_3): A survey of the 180 OH sources in Turner's OH survey has been made in the 1.35-cm H_2O line. Collaborators with B. Turner on the 36-ft Kitt Peak telescope are J. Matthews

(Illinois) and R. Rubin (Illinois). Preliminary data analysis shows 7 new H_2O sources have been found associated with continuum sources (i.e., not IR stars) and type I OH emission. The new H_2O sources of this type, along with the 11 previously known, are always found where there is type I OH emission, never where OH is seen only in absorption. This is consistent with the Gwinn, Turner, Goss theory of type I OH emission, in which the OH is formed in appropriately excited states via the collisional breakup of H_2O. There is always sufficient energy to pump the water in such regions. H_2O emission is not always seen with type I OH emission, but type I OH emission is always seen with H_2O emission in these nonstellar sources. This is explainable if we assume that the H_2O masers are unsaturated while the OH masers are saturated, and that the H_2O/OH abundance ratio does not vary too widely from source to source. S. Gottesman has attempted to detect water-vapor emission from the direction of prominent H II regions in nearby extragalactic systems. Observations have been made at several positions in the galaxies NGC 224, NGC 598, NGC 3034 (M82), NGC 6822, IC 1613, IC 10, and Sextans A. Both the NRAO 36-ft telescope at Kitt Peak and the 120-ft telescope at the Haystack Observatory were used for these observations. Velocity resolutions of 1.5 and 3.4 km/sec were used in these experiments to cover a velocity bandwidth respectively of 68 and 169 km/sec. No emission comparable to a W49 source has been observed at these positions and velocities. In other observations made at the 36-ft telescope, L. Snyder (Virginia), D. Buhl, and J. Edrich searched for molecular-line emission from H_2O and NH_3 in a number of sources, and P. Palmer (Chicago), B. Zuckerman (Maryland), and B. Turner conducted a more extensive study of NH_3 emission.

Formaldehyde (H_2CO): Four galactic clouds were mapped at the 6-cm H_2CO line by A. Barrett and P. Myers (both MIT). Y. K. Minn (Rensselaer) and J. M. Greenberg (Albany) observed the formaldehyde line for the purpose of studying dust clouds and galactic structure. The interface between late-type stars and dust clouds was investigated by the Virginia observers L. Snyder and F. Clark. T. Wilson (Bonn, W. Germany) observed the 4830-MHz line to search for formaldehyde in Bok globules, to measure the characteristic size of structure in W40 and W48, and to measure formaldehyde absorption near several strong, isolated radio sources. M. Gordon and M. Roberts used the 140-ft telescope to search 31 locations along the galactic equator in hopes of detecting H_2CO absorption against the isotropic microwave background. With the exception of one region close to the galactic center, no absorption was found to a limit of 0.1°K in brightness temperature. The analysis of observations on and around Cas A suggests that the H_2CO is indeed widespread but that its excitation temperature is close to 2.8°K and that the $F(1-e^{-\tau}) \gtrsim 0.02$, where F is the filling factor and τ the optical depth of H_2CO. To further investigate H_2CO in the interstellar medium, M. Gordon and B. Höglund (Chalmers, Sweden) have used the Onsala telescope at 6 cm to make a deep survey of three regions, each 1° square, located on the galactic equator and free from discrete radio sources. E. Fomalont and L. Weliachew (Caltech) have mapped the distribution of formaldehyde in front of several strong galactic sources. The main absorption features show variation of optical depth over the sources but there is no significant clumping. The isotopic ratio $^{12}C/^{13}C$ of 10 for Sgr A and Sgr B2 should be increased to about 25 because of the high optical depths at the center of the absorbing clouds of H_2CO. The +40 km/sec cloud associated with Sgr A appears to be rotating as a solid body with a calculated mass of $3\times10^5\ M_\odot$. Most of the mass is probably in the form of molecular hydrogen. P. Solomon (Columbia), P. Thaddeus (NASA-Goddard), and N. Scoville (Columbia) expanded their galactic center map in H_2CO and searched for formaldehyde in several galactic dark clouds. B. Turner and C. Heiles (Berkeley) made a survey of H_2CO with the Hat Creek 85-ft telescope. The 180 OH sources of Turner are being surveyed to continue study of the relative distributions of OH and H_2CO. The ^{13}C isotope is being mapped in a few selected sources. Combining these data with the ^{12}C isotope maps allows separation of the excitation temperature and abundances, assuming $H_2{}^{12}CO/H_2{}^{13}CO = 89$, the terrestrial value. It is hoped to discover whether the disappearance of H_2CO lines away from the continuum sources (and apart from dust clouds) is due to a decrease in the abundance, or to an equilibrium of the excitation temperature with the 3°K background. Determination of T_s in this fashion will also indicate whether the anomalous refrigeration of the 6-cm transition is universal, or only restricted to dust clouds. B. Turner finds the OH and H_2CO velocities are correlated, in the sense that the distribution of the number of clouds versus velocity difference peaks at zero difference, but is strongly skewed. Many more H_2CO clouds have positive velocities with respect to the OH clouds. In the northern hemisphere, this corresponds to larger distances on the average for the H_2CO. It is possible that the excitation temperature of H_2CO is < 3°K, accounting for the ability to see it in absorption at relatively larger distances. A search by M. Roberts for 6-cm formaldehyde absorption against the 3°K background in nearby, normal galaxies was unsuccessful. This result is consistent with the conclusion derived from galactic studies that, except for very dark clouds, the extensive formaldehyde distribution is at or near temperature equilibrium with the background radiation. B. Zuckerman (Maryland), P. Palmer (Chicago), L. Snyder (Virginia), and D. Buhl searched for $H_2{}^{12}C^{17}O$ at 4953 MHz. At the 36-ft telescope, P. Thaddeus (NASA-Goddard), M. Kutner (NASA-Goddard), A. Penzias (Bell Labs), R. Wilson (Bell Labs), and K. Jefferts (Bell Labs) investigated the distribution of ortho- and para-formaldehyde at 140, 145, and 150 GHz in dense clouds.

Carbon Monoxide (CO) and Cyanogen (CN): Further observations of CO and CN molecules at 115 GHz were made on the 36-ft telescope by the Bell Labs observers A. Penzias, R. Wilson, and K. Jefferts.

Hydrogen Cyanide (HCN) and "X-ogen": D. Buhl and L. Snyder (Virginia) used the 36-ft telescope to continue their study of the HCN and "X-ogen" emission lines. The molecular cloud in Orion appears to be extended, covering several minutes of arc centered on the infrared nebulae and OH source. No splitting of the "X-ogen" line has been detected. HCN was found in the bright infrared object IRC +10216.

Other Line Searches: Several new molecular lines were detected using the 36-ft telescope. D. Buhl and L. Snyder (Virginia) detected the 5_0-4_0 transition of methyl acetylene (CH_3C_2H) at a frequency of 85 GHz as well as the $4_{04}-3_{03}$ transition of isocyanic acid (HNCO) at 88 GHz. Both molecules were found in the galactic center source Sgr B2. In addition, a new line was found at a frequency near 91 GHz which has been tentatively identified as hydrogen isocyanide (HNC). This is a peculiar isomer of HCN which has never been identified on the Earth. The line was found in W51 and DR 21OH. Together with J. Edrich, Buhl and Snyder detected a weak line in Sgr B2 due to the ground state $1_{01}-0_{00}$ transition of HNCO. This line is at a frequency of 22 GHz. The Bell Labs observers A. Penzias, R. Wilson, and K. Jefferts detected the interstellar molecules methyl cyanide (CH_3CN) and carbonyl sulphide (OCS). Together with P. Solomon (Columbia) they detected carbon monosulphide (CS) and, together with P. Thaddeus and M. Kutner (both NASA-Goddard), they detected silicon oxide (SiO) in the interstellar medium. B. Turner, P. Palmer (Chicago), and B. Zuckerman (Maryland) detected propynal (HCCCHO), the 5_1-4_0 (E_2 symmetry) line of methanol (CH_3OH) and two unidentified lines in the galactic center region in the frequency band 85 to 95 GHz.

Cyanoacetylene (HC_3N) was discovered in Sgr B2 by B. Turner at a wavelength of 3.4 cm. The signal is in emission, and the observed relative strengths of the three high-frequency components of the $J = 0-1$ transition suggests the molecules have excitation close to LTE. The Harvard–Smithsonian team of C. Gottlieb, J. Ball, A. E. Lilley, H. Penfield, and H. Radford discovered the methyl alcohol (CH_3OH) line at 834 MHz in Sgr A and Sgr B2. R. Rubin, G. Swenson, R. Benson, H. Tigelaar, and W. Flygare (all Illinois) discovered the 4620-MHz line of formamide (HN_2COH) on the 140-ft telescope.

Approximately 37 observers from 15 different institutions attempted to detect at least 50 other molecular lines without success.

C. Discrete Sources

1. Occultations

R. Sramek used the NRAO interferometer to measure the gravitational deflection of 3C 279 as it was occulted by the Sun in October 1970. Simultaneous observations at 4- and 11-cm wavelengths gave a measurement of the refraction in the solar corona that was independent of the gravitational deflection. With this refraction removed, the gravitational deflection was 0.90 ± 0.05 of the deflection predicted by Einstein's General Relativity. This result is in good agreement with the scalar–tensor theory of Brans and Dicke. The lunar occultation of the galactic center was observed on the 140-ft telescope in the main lines of OH by F. Kerr and A. Sandqvist (both Maryland).

2. Polarization

R. Hobbs (NASA-Goddard) and G. Marandino (Maryland) conducted a 3-cm survey of polarization of quasistellar objects down to levels about 0.01 f.u. of polarized flux on the 140-ft telescope. On the interferometer, P. Kronberg and C. Faubert (both Toronto, Canada) conducted dual-frequency observations to study the polarization structure of extragalactic radio sources. D. Hogg and D. DeYoung began the observations necessary to make maps of the distribution of polarization at 11 and 4 cm across eight radio galaxies, in an attempt to determine the magnetic field structure within the extended components. E. Fomalont has used the 42-ft radio-linked interferometer to determine the fine-scale linear-polarization distribution of several strong radio sources, Cyg A, 3C295, Virgo A, 3C380. This initial experiment was used mainly to determine the polarization characteristics of the system. E. Fomalont has continued to analyze the 11-cm polarization data from the interferometer. Many sources show regions of polarization greater than 25% and a few sources show evidence of a toroidal-shaped magnetic field in one radio component. Intrinsic polarization angles are usually aligned perpendicular or parallel to the source major axis. E. Fomalont, M. Wright, and J. Högbom (Leiden, Netherlands) have recently completed observations at 4 and 11 cm to determine the rotation measure distribution and intrinsic angle of the electric field across some extragalactic sources. The polarization calibrations suggest accuracies of about 0.3% at 11 cm and 1.0% at 4 cm. J. Wardle has used the three-element interferometer to make fanbeam observations of the distribution of linear polarization in 80 sources at 4 cm. He has also measured linear polarization in six strong sources at 9.5 mm using the 36-ft telescope at Kitt Peak. J. Wardle and R. Sramek are observing the polarization of normal E galaxies using the interferometer. The possibility that circular polarization observed in some compact sources may originate from an anisotropic distribution of synchrotron electrons is being investigated by F. Biraud (Meudon, France).

3. Spectral Studies and Time Variations

K. Johnson (Arizona) is monitoring 3C120 for variability at 31 and 85 GHz on the 36-ft telescope. He and K. Kellermann are observing flux densities of variable sources with the dual-frequency system on the interferometer. In addition, periodic measurements of the flux densities of variable sources at 31 and 85 GHz are being made on the 36-ft telescope by W. Dent (Massachusetts) and R. Hobbs (NASA-Goddard) while D. Morrison (Hawaii) and E. Epstein (Aerospace) are engaged in a similar survey of flux densities of extragalactic variable sources at 85 GHz. K. Kellermann and I. Pauliny-Toth (Bonn, W. Germany) have continued their study of radio source spectra by completing flux density measurements on approximately 500 sources at 2.8 cm. D. DeYoung and D. Hogg have detected secular variations in Cas A, Cygnus A, and Virgo A with the NRAO interferometer. Preliminary results indicate variation of Virgo A at both 4 and 11 cm. H. Murdoch is obtaining spectra for sources from sections of the 3-arc-min pencil-beam survey being carried out with the one-mile Mills Cross at Molonglo, Australia. He has carried out observations to a limit of 0.5 f.u. at 408 MHz on the 300-ft telescope at NRAO at 21 cm and on the Arecibo telescope at 606 MHz. The stronger sources have also been observed at 318 MHz at Arecibo. F. Biraud identified two radio sources with objects previously known to be variable stars, ON231 (W Com) and PKS 1514–24 (AP Lib). In view of its very fast optical variations, the latter source strongly resembles the very peculiar radio source BL Lac.

4. Source Surveys

Interferometer: W. Webster (NASA-Goddard) and the Bonn observers W. Altenhoff, J. Wink, and P. Mezger used the interferometer to observe the size, flux density, position, and polarization characteristics of a number of small-diameter, high-flux-density sources in Altenhoff's 11-cm survey. G. Miley and J. Wardle have used the three-element interferometer at 4 and 11 cm to synthesize maps of 119 quasars in order to investigate the frequency dependence of their structure and to improve the statistics on the "largest-angular-size-redshift" correlation. E. Fomalont and K. Kellermann have synthesized one beam area near Dec. = +70° and R.A. = 6^h, using all spacings between 100 and 900 m at 11 cm. One strong source of about 25 milliflux units was found, but no other sources greater than about 3 milliflux units. Observations of 30 min duration at 11 cm were also made of 40 blank regions of sky to determine the net confusion flux density in the main beam of the 85-ft telescope. They find an average value of 18 milliflux units at the 100-m spacing and a substantially lower value at the 1800- and 1900-m spacings. S. Gottesman, J. Broderick, R. Brown, and P. Palmer (Chicago) have begun an interferometric investigation of recent extragalactic supernovae. It is hoped that these observations will yield information about the intensity, spectra, and variability of these objects. The position of recent supernova 1970g which occurred in the galaxy M101 has been monitored since August 1970. The supernova probably has not been detected. However, an extended source has been observed at both 4 and 11 cm with an intensity of about 5×10^{-29} W m^{-2} Hz^{-1}. The source appears to be coincident with the H II region NGC 5455 with which the supernova is probably associated. M. Wright and C. Moore have developed a software system for calibrating and displaying data from the NRAO line interferometer.

36-ft Telescope: Eighty-three percent of selected sources from the Ohio State Catalogue were detected with intensities ≥ 0.5 f.u. by E. Conklin at 31 and 85 GHz. Of these, about 80% are probably variable. The millimeter spectral indices range from −0.2 to +0.4, with many sources showing peaks. The source OJ+287 has especially large, rapid ($\sim$ days) fluctuations which are correlated with optical variations.

140-ft Telescope: A 3-cm survey of objects in the General Catalog of Planetary Nebulae and in Wray's Catalogue was made by R. Rubin and J. Cahn (both Illinois). M. Davis, K. Kellermann, and I. Pauliny-Toth (Bonn, W. Germany) have continued their 6-cm source survey which is now complete in an area of 2.1 steradians to a flux density limit of 0.6 f.u. Analysis of the differential number counts shows a deviation from a −1.5 slope only at the highest flux density levels, where a 50% deficit of five sources per ster was found.

300-ft Telescope: M. Davis has detected 171 sources at 6 cm in a 190-deg^2 survey at Dec. = +33° with the newly resurfaced 300-ft telescope. The survey is complete to 0.067 f.u. Using 408-MHz flux densities from the Bologna survey, he finds that 42% of the sources have spectral indices > -0.5. This large sample of faint sources confirms the lack of systematic change of spectral index distribution with flux density, contrary to what is expected if the weak sources have systematically greater redshifts than the strong sources. Flux densities at 21 cm have also been obtained for many of the sources. Eleven-centimeter data that will determine source positions and flux densities in a strip of sky between Dec. = +46° to +52° and between R.A. $7^h 15^m$ to $16^h 25^m$ have been gathered by J. Maslowski (Kracow, Poland) and a large sample of weak radio sources in the Vermilion River Observatory Catalog have been observed with the same receiver by J. Dickel and J. Webber (both Illinois). The Maryland observers M. Kundu and T. Velusamy searched at 20 cm for weak extended sources in the direction of pulsars having long periods. T. K. Menon (Hawaii and Tata Institute, India) measured the 20-cm fluxes of 350 sources for which occultation positions are available from the Ooty telescope in India. Further observations at 20 cm were made of the spectra of weak sources by H. Murdoch (Sydney, Australia) and of the confusion background level of radio sources by D. Jauncey (Cornell). A. Bridle (Queen's University, Canada), M. Davis, E. Fomalont, and J. Lequeux (Meudon, France) have compiled a catalogue containing accurate position, flux density, structure, and polarization data for sources brighter than 1.7 f.u. at 20 cm. The surroundings of each source have been mapped at that wavelength with the 300-ft telescope, and positions have been determined for most sources with the Caltech interferometer. In related programs, C. Purton and J.E.D. Kennedy (York University, Canada) conducted 20-cm observations of structures of approximately 50 faint, extended galactic sources and of pairs of interacting galaxies which might display unusual radio properties.

Other Telescopes: E. Fomalont has analyzed interferometric data from Caltech to determine the structure of 76 extragalactic radio sources with a resolution of 45 sec of arc. Most sources show a well-defined major axis with the usual double symmetry. Fomalont and A. T. Moffet (Caltech) have determined accurate flux densities and positions of 352 small-diameter radio sources using data obtained from the Caltech interferometer.

5. Very Long Baseline (VLB) Surveys

Three NRAO staff members (J. Broderick, B. Clark, and K. Kellermann) and 27 visitors participated in one or more VLB experiments that employed different pairs of 11 telescopes located throughout the world. Three spectral-line (1.35 cm H_2O, 5-cm OH, and 18-cm OH) and seven continuum (2.8, 3.56, 3.7, 6, 13, 50, and 75 cm) wavelengths were used. The following telescopes were involved in VLB experiments: 73-ft (Crimea, USSR), 84-ft (Chalmers, Sweden), 85-ft (Goldstone), 120-ft (Illinois), 120-ft (Haystack), 130-ft (Caltech), 140-ft (NRAO), 150-ft (Algonquin Park, Canada), 150-ft (Sugar Grove), 210-ft (Goldstone), and the 1000-ft (Arecibo). Visitor participants included J. Ball (Harvard), N. Broten (NRC, Canada), B. Burke (MIT), T. Clark (NASA-Goddard), M. Cohen (Caltech), V. Efanov (Crimean Astrophysical Obs., USSR), S. Goldstein (NRC, Canada), C. Gottlieb (Harvard), D. Jauncey (Cornell), K. Johnston (NRL), S. Knowles (NRL), L. Matveyenko (Cosmic Space Institute, USSR), M. L. Meeks (Lincoln Lab), I. Moiseev (Crimean Astrophysical Obs., USSR), J. Moran (Lincoln Lab), P. Palmer (Chicago), D. C. Papa (MIT), G. Papadopoulos (MIT), G. Purcell (Caltech), B. Ronnang (Chalmers, Sweden), O. Rydbeck (Chalmers, Sweden), D. Shaffer (Caltech), I. Shapiro (MIT), P. Schwartz (MIT), L. Shatrovsky (Cosmic Space Institute, USSR), J. Yen (Toronto, Canada), and B. Zuckerman (Maryland).

B. Clark has spent the past year designing and building a new tape recorder interferometer receiver. It is hoped that this receiver will provide a standard system uesful for several years. This system has recently been used for observations between the East and West Coasts of the U.S. and between the U.S. and the U.S.S.R.

6. Theory

A series of calculations which simulate the dynamics of extended extragalactic radio sources has been completed by D. DeYoung. The method follows the evolution of an energetic radio source after it has been injected into an intergalactic medium by numerically integrating the full hydrodynamic equations. With an initial ejection velocity of 0.1 c and for sources of energy 10^{57} to 10^{59} ergs, it is found that an intergalactic medium can confine the sources to a degree which agrees with observations only if the density of the intergalactic medium is equal to or greater than the "critical" value of 10^{-29} g cm^{-3}. Two other theoretical efforts have been completed by DeYoung which deal with active compact radio sources, in particular, galactic nuclei and quasi-stellar objects. The first of these shows, by examining the spectra of all compact sources with two or more self-absorption peaks, that the magnetic field associated with variable sources is uncorrelated from variation to variation. He then shows that it is difficult for a single object to regenerate a magnetic field between successive outbursts and hence that models of variable radio sources which employ a single nuclear object to produce successive outbursts are perhaps less likely than those that do not. His second calculation has been done in collaboration with W. Saslaw (Virginia and Cambridge, England) and considers whether self-gravitating stellar systems can be in energy equipartition if many species of different mass are present. It is found that for a wide class of distributions this equipartition is impossible, and hence for such systems the development of a dense nuclear core and its accompanying outbursts will proceed more rapidly than is concluded from the usual equipartition arguments. Recent observations of 3C279 have prompted an interest in the appearance of relativistically expanding radio sources, as well as the variation of their total flux. A calculation is under way by D. DeYoung to obtain the distribution of intensity across such a source for arbitrary optical depth and for various geometries such as a sphere and a jet.

R. Brown has considered the implications of the recent discovery of x-ray emission from several extragalactic radio sources by assuming that the x-rays are produced through Compton scattering of the synchrotron photons in the very compact regions indicated by VLB measurements. W. R. Burns has studied the effect of confusion noise on the flux estimate of a point source. Analytical expressions for the resulting uncertainty were derived. Particular interest was given to the case where the observing instrument has a complex-shaped beam. Such a case occurs in interferometric synthesis when the coverage of the $u-v$ plane is not complete.

D. Galaxies

1. Continuum Studies

Observations of giant elliptical galaxies were made by E. Conklin and D. Heeschen at 31 and 85 GHz on the 36-ft telescope. Many have relatively flat spectra and at least two are variable sources, with time scales on the order of one year; thus they resemble QSO's. B. Burke and J. Spencer (both MIT) observed with the dual-frequency interferometer in an attempt to detect continuum emission from the H II regions in the galaxies M31 and M33. W. B. Burton used the three-element interferometer at 4 and 11 cm to determine the Faraday rotation of the radiation from a number of discrete sources near the spiral galaxies M33, M51, and M101. The observations were made to allow the intrinsic polarization angle to be found on the 21-cm full-synthesis polarization maps made at Westerbork by D. Mathewson and J. Oort. W. Saslaw (Virginia and Cambridge, England) attempted to detect radio radiation from selected Haro galaxies at 11 and 20 cm. Normal E and S0 galaxies detected by J. Pfleiderer at 21 cm with the 300-ft telescope are being observed at 4 and 11 cm with the interferometer by R. Sramek. Also, normal E galaxies known to have radio cores were observed by him with the 11.3-km radio-link interferometer.

2. Line Studies

M. Roberts has mapped the neutral hydrogen in the direction of M81. He finds that the hydrogen distribution extends to and envelopes the two Ir *II* companions M82 and NGC 3077. The beam-averaged velocity map is fairly well ordered over this region, showing irregularities only in the region of the companion galaxies. S. Gottesman and L. Weliachew (Caltech) have started a line interferometry project at the Owens Valley Radio Observatory. The neutral-hydrogen structure of several nearby late-type galaxies will be synthesized. Full coverage of the $u-v$ plane will be available for the galaxies M51, M81, and M82. A partial synthesis will be available of several other systems including NGC 6822, NGC 253, and the interacting pair NGC 672+IC 1727. The angular resolution achieved will be $\sim$2 min of arc, with a velocity resolution of 20 km/sec for the spiral galaxies and 10 km/sec for the irregular galaxies. Preliminary results show that both neutral-hydrogen emission and absorption have been detected from the Seyfert galaxy NGC 1068. Also, the neutral-hydrogen diameter of the compact galaxy II ZW 40 has been found to be $\sim$3 min of arc. S. Gottesman and M. Wright have commenced a series of observations looking for OH absorption in galaxies. The traveling focal mount on the resurfaced 300-ft telescope is being used in conjunction with the new MK III 384-channel autocorrelation receiver. The galaxies observed include NGC 3034, NGC 4651, and NGC 5194. It is hoped that optical depths of $\tau \simeq 0.1$ can be achieved for the weaker sources. In the case of M82, an optical depth of 1% will be detectable. Wright and Gottesman have also started a program looking for emission and absorption of neutral H I associated with extragalactic radio sources near spiral galaxies. The objects being observed are 3C13/M31, 4C29.3/M33, 3C232/NGC 3067, and 3C275.1/NGC 4651. Observations for emission using the 300-ft telescope and the new autocorrelation receiver have begun. The absorption experiment will be performed with the NRAO line interferometer in the summer of 1971. M. Wright has continued analysis of data from the Cambridge M33 hydrogen-line survey.

W. B. Burton simulated interferometer observations of the 21-cm line in a study of the optimum observing procedures for detecting expanding motions in the nuclei of external galaxies. The simulated observations incorporated a model galaxy similar in size, mass, and rotation to the Milky Way, but located at a distance of 10 Mpc. They show under what observing conditions it would be possible to detect a structure analogous to the 3-kpc arm with the Green Bank interferometer.

J. Broderick, R. Whitehurst (Alabama), and M. Roberts attempted to detect 600-MHz recombination lines and redshifted H I lines from extragalactic nebulae on the 140-ft telescope. R. Rubin (Illinois) conducted a series of observations at 3 cm to search for recombination lines in the Seyfert galaxies 3C120 and 3C84.

E. Miscellaneous

Observations were made on the 140-ft telescope by E. Chaisson (Harvard) to confirm the presence of an anomalous line near 10.525 GHz. R. Hjellming developed speculations concerning the possible causal relationship between black holes and white holes and possible coupled universes.

VII. CONTINUING PROJECTS

A. Telescope Design Projects

The Observatory is continuing its design of a 65-meter-diameter radio telescope, useful for observations at wavelengths down to 3.5 mm and has developed plans for expanding the Green Bank interferometer. Further work on the VLA, a very large array of radio telescopes, awaits authorization for the project.

B. Interferometer Line Work

In June 1971, instrumentation was added to enable the interferometer to undertake spectral-line observations. The system noise temperature is 120°K. The cross-correlator can analyze one, two, or three pairs of antennas, with total bandwidths ranging between 10 MHz and 39 kHz. The highest resolution is approximately 0.8 kHz in the three-baseline mode, and 0.2 kHz in the one-baseline mode. The transform of the cross-correlation function is done with the on-line computer, and the resultant visibility spectrum is displayed at the control building.

C. 300-ft Telescope Improvements

A traveling front-end box mount has been installed on the 300-ft telescope. The mount accommodates any NRAO front-end box and allows tracking of ± 30 min of arc in azimuth, full rotation for polarization work, and remote control of focus. The box mount is not to be confused with the traveling feed carriage which provides ± 10° of scanning (useful only for low-frequency receivers because of coma distortion) but no polarization or axial focus movement. A three-feed, four-channel (center-fed dual-polarized) 11-cm wavelength parametric amplifier receiver has been completed and is often used with the traveling box mount.

A new reflecting surface, using 1308 individually adjustable panels, has been installed on the NRAO 300-ft telescope. The manufacturing tolerance of each panel was 2.3 mm rms and the allowable adjustment tolerance was 1.5 mm rms, giving a total surface error of 2.7 mm rms in the zenith position. The deflection of the surface support structure as a function of telescope zenith angle has been calculated and measured. Subsequent radio measurements at 1400 MHz (21 cm), 2695 MHz (11.1 cm), and 4995 MHz (6 cm) confirm the mechanical tolerances and deflections. For the three wavelengths, the aperture efficiencies are 54%, 52%, and 40% in the zenith, and 51%, 44%, and 22% at a 30° zenith angle. The half-power beamwidths are 9.7, 5.2, and 2.7 arc min, respectively.

A new, computer-controlled, variable-speed drive has been installed. It will drive the telescope in declination at speeds up to 2.25 deg/min. Moreover, a new 2000-ft^2 addition to the 300-ft control building has been designed and built during the fall of 1971.

D. 36-ft Telescope Improvements

J. Rather is developing a 1-mm capability for the 36-ft telescope. Experiments to date have established the limiting factors in the existing cryogenic system and germanium bolometer. Efforts are being directed toward improved optics and filtering. Experiments with other types of detectors are also being conducted. The control room space was doubled, and the telescope was placed in full, 24-hour operation during the year. A new receiver for spectral-line work became operational in the frequency range 67 to 101 GHz. Improvements in the 36-ft servo system permitting operation in winds to about 30 miles per hour have been made. Typical pointing errors are of ∿6 sec of arc rms. Capability to do circular polarization at 3.5- and 9.5-mm wavelengths was added during the year. Studies of the pointing, focusing, and astigmatism have shown that they are predictable functions of temperature distribution on the telescope surface. As a result, modifications of the focal support structure are being made to reduce temperature problems and increase telescope observing efficiency, especially at frequencies in excess of 85 GHz.

D. S. HEESCHEN,
Director

NRAO - STAFF AND VISITOR PUBLICATIONS 1971

Andrew, B.H., Van den Bergh, S., Conklin, E., and Kraus, J.D. "Radio and Optical Observations of the Source OZ-252." Pub. Astron. Soc. Pacific, 83, 87-88, 1971. (A193)

Andrews, M.H., Hjellming, R.M., and Churchwell, E. "Non-LTE Analysis of Radio Recombination Line Data for Five HII Regions." Astrophys. J., 167, 245-248, 1971. (B249)

Biraud, F. "Rapid Optical Variability of the Source PKS 1514-24." Nature, 232, 178-179, 1971. (B279)

Bridle, A.H. and Kesteven, M.J.L. "The Nature of 3C 391." Astron. J., 76, 958-964, 1971.

Brown, R.L. "The 1/4 keV X-ray Background: A Reply." Nature-Phys. Sci., 229, 85, 1971. (B244)

Brown, R.L. "On the Photoionization of Hydrogen and Helium." Astrophys. J., 164, 387-388, 1971. (B223)

Burns, W.R. and Roberts, M.S. "The Neutral-Hydrogen Distribution and Rotation Parameters of the Spiral Galaxy NGC 2403." Astrophys. J., 166, 265-274, 1971. (B238)

Buhl, D. "The Chemical Constituents of Interstellar Clouds." Nature, 234, 332-334, 1971.

Buhl, D. "Lunar Rocks and Thermal Anomalies." J. Geophys. Res., 76, 3384-3390, 1971. (B240)

Buhl, D. and Snyder, L.E. "From Radio Astronomy Towards Astrochemistry." Technol. Rev., 73, 54-62, 1971. (A207)

Buhl, D. and Snyder, L.E. "Microwave Receivers for Molecular Line Radio Astronomy." Nature-Phys. Sci., 232, 161-163, 1971. (A230)

Cohen, M.H., Cannon, W., Purcell, G.H., Shaffer, D.B., Broderick, J.J., Kellermann, K.I., and Jauncey, D.L. "The Small-Scale Structure of Radio Galaxies and Quasi-Stellar Sources at 3.8 centimeters." Astrophys. J., 170, 207-217, 1971. (B281)

Davies, R.D. "Observations of Radio Recombination Lines with $\Delta n = 1$ to 5." Astrophys. J., 163, 479-493, 1971. (B220)

Davis, M.M. "The NRAO 5-GHz Radio Source Survey. I. A Survey of Faint Sources." Astron. J., 76, 980-992, 1971.

Dent, W.A. "A Search for the Redshifted Line of Neutral Hydrogen in Selected Quasi-Stellar Sources." Astrophys. J., 165, 451-456, 1971.

DeYoung, D.S. "The Dynamics of Extended Extragalactic Radio Sources." Astrophys. J., 167, 541-551, 1971. (B248).

DeYoung, D.S. "The Structure of Compact Extragalactic Radio Sources." Astrophys. Letters, 9, 43-46, 1971. (A221)

DeYoung, D.S. and Hundhausen, A.J. "Two-Dimensional Simulation of Flare-Associated Disturbances in the Solar Wind." J. Geophys. Res., 76, 2245-2253, 1971. (B230)

DeZafra, R.L., Thaddeus, P., Kutner, M., Scoville, N., Solomon, P.M., Weaver, H., and Williams, D.R.W. "Search for Interstellar Furan and Imidazole." Astrophys. Letters, 10, 1-3, 1971.

Dickinson, D.F. and Gottlieb, C.A. "Comments on the Excitation and Abundance of Interstellar SiO, Based on a Search at 87 GHz." Astrophys. J., 7, 205-207, 1971. (A203)

Edelson, S., Mayfield, E.B., and Shimabukuro, F.I. "Polarized Solar Radio Emission at MM-Wavelengths Associated with Sunspot Magnetic Fields." Nature-Phys. Sci., 232, 82-84, 1971.

Edrich, J. "A Parametric Amplifier for 46 GHz." IEEE Proc., 59, 1125-1126, 1971. (A214)

Findlay, J.W. "Filled Aperture Antennas for Radio Astronomy." Ann. Rev. Astron. Astrophys., 9, 271-292, 1971. (B256)

Fomalont, E.B. "Two-Dimensional Structures of 76 Extragalactic Radio Sources at 1425 MHz." Astron. J., 76, 513-524, 1971.

Ford, Jr., W.K., Rubin, V.C., and Roberts, M.S. "A Comparison of 21-cm Radial Velocities and Optical Radial Velocities of Galaxies." Astron. J., 76, 22-24, (Plate 1) 87, 1971. (A192)

Gordon, K.J. "A 21-centimeter Study of the Spiral Galaxy Messier 33." Astrophys. J., 169, 235-270, 1971. (B275)

Gordon, M.A. "Radiation Transfer of Radio Recombination Lines in the Diffuse Interstellar Medium." Astrophys. J., 167, 21-25, 1971. (B243)

Gordon, M.A. and Gottesman, S.T. "Electron Density and Temperature in the Diffuse Interstellar Medium Determined From Recombination Lines." Astrophys. J., 168, 361-371, 1971. (B258)

Gordon, M.A. and Roberts, M.S. "The Absence of Formaldehyde Radiation Towards Cold Regions of the Galactic Plane." Astrophys. J., 170, 277-279, 1971. (B284)

Gordon, M.A. and Wallace, D.C. "Physical Characteristics of W49A as Determined From Radio Recombination Lines." Astrophys. J., 167, 235-243, 1971. (B247)

Gordon, M.A. and Williams, T.B. A Continuum Map of M17 at λ 1.94 cm and its Restored Brightness Distribution." Astron. & Astrophys., 12, 120-125, 1971. (A204)

Heeschen, D.S. "National Radio Astronomy Observatory ⌊Annual Report⌋" Bull. Amer. Astron. Soc., 3, 156-166, 1971. (A200)

Heeschen, D.S., Morgan, W.W., and Walborn, N.R. "The Distribution of Light in the Central Regions of Some Giant Elliptical Galaxies." Astrophys. J., 165, L65-166, 1971. (B229)

Heiles, C.E. and Turner, B.E. "Search for Interstellar SH at Radio Frequencies." Astrophys. Letters, 8, 89-91, 1971. (A224)

Herrero, V. "Design of Optical Telescope Arrays for Intensity Interferometry." Astron. J., 76, 198-202, 1971.

Herrero, V., Hjellming, R.M., and Wade, C.M. "Radio Observations of Nova Scuti 1970." Astrophys. J., 166, L19-L20, 1971. (B237)

Hjellming, R.M. "Black and White Holes." Nature-Phys. Sci., 231, 20, 1971. (B255)

Hjellming, R.M. and Gordon, M.A. "Radio Recombination Lines and Non-LTE Theory; A Re-analysis." Astrophys. J., 164, 47-60, 1971. (B219)

Hjellming, R.M. and Wade, C.M. "Radio Emission from Antares B." Astrophys. J., 168, L87-L89, 1971. (B263)

Hjellming, R.M. and Wade, C.M. "Radio Emission from X-ray Sources." Astrophys. J., 168, L21-L24, 1971. (B254)

Hjellming, R.M. and Wade, C.M. "The Radio Sources Associated with Scorpius X-1." Astrophys. J., 164, L1-L7, 1971. (B222)

Hjellming, R.M. and Wade, C.M. "Radio Stars." Science, 173, 1087-1092, 1971. (A227)

Hjellming, R.M., Wade, C.M., Hughes, V.A., and Woodsworth, A. "The Radio Spectrum of Cygnus X-1." Nature, 234, 138, 1971.

Hobbs, R.W. and Marionni, P. "Search for 3.5 millimeter Continuum Radiation from Infrared Stars and Related Objects." Astrophys. J., 167, 85-87, 1971.

Hobbs, R.W., Modali, S.B., and Maran, S.P. "Evidence for an Optically Thick Component in the Galactic Radio Source Sagitarius B^2." Astrophys. J., 165, L87-L93, 1971.

Huguenin, G.R., Manchester, R.N., and Taylor, J.H. "Properties of Pulsars." Astrophys. J., 169, 97-104, 1971. (B274)

Huguenin, G.R., Taylor, J.H., Hjellming, R.M., and Wade, C.M. "Interferometric Observations of Pulsars at 2.7 and 8.1 GHz." Nature-Phys. Sci., 234, 50-51, 1971. (B296)

Jackson, P.D. and Kerr, F.J. "Detection of Radio Recombination-Line Emission Associated with Distributed Ionized Hydrogen." Astrophys. J., 168, 29-35, 1971. (B251)

Jefferts, K.B., Penzias, A.A., Wilson, R.W., Kutner, M., and Thaddeus, P. "An Initial Search for the Interstellar Formyl Radical, HCO, and for $HC^{13}O^{+}$." Astrophys. Letters, 8, 43-44, 1971. (A209)

Jefferts, K.B., Penzias, A.A., Wilson, R.W., and Solomon, P.M. "Detection of Interstellar Carbonyl Sulphide." Astrophys. J., 168, L111-L113, 1971. (B262)

Johnson, H.M. "Radiofrequency Observations of Symmetric Nebulae Around Wolf-Rayet Stars and an O7f Star." Astrophys. J., 167, 491-498, 1971. (B268)

Johnson, H.M. "The Sky Near the Brightest X-Ray Source in Scorpius. III." Astrophys. J., 164, 67-76, 1971. (B216)

Johnson, H.M. and Rubin, R.H. "Observation and Classification of the Nebula YM 29." Astrophys. J., 163, 151-153, 1971. (B202)

Johnston, K.J., Knowles, S.H., Sullivan, W.T., III, Moran, J.M., Burke, B.F., Lo, K.Y., Papa, D.C., Papadopoulos, G.D., Schwartz, P.R., Knight, C.A., Shapiro, I.I., and Welch, W.J. "An Interferometer Map of the Water Vapor Sources in W49." Astrophys. J., 166, L21-L26, 1971. (B235)

Kellermann, K.I. "Compact Radio Sources in the Nuclei of Galaxies." Pontificiae Acad. Scien. Scripta Varia, 35, 217-244, 1971. (B270)

Kellermann, K.I. "Joint Soviet-American Radio Interferometry." Sky and Telescope, 42, 132-133, 1971. (A218)

Kellermann, K.I., Davis, M.M., and Pauliny-Toth, I.I.K. "Counts of Radio Sources at 6-centimeter Wavelength." Astrophys. J., 170, L1-L5, 1971. (B283)

Kellermann, K.I., Jauncey, D.L., Cohen, M.H., Shaffer, D.B., Clark, B.G., Broderick, J., Rönnäng, B., Rydbeck, O.E.H., Matveyenko, L., Moiseyev, I., Vitkevitch, V.V., Cooper, B.F.C., and Batchelor, R. "High-Resolution Observations of Compact Radio Sources at 6 and 18 cm." Astrophys. J., 169, 1-24, 1971. (B266)

Kellermann, K.I. and Pauliny-Toth, I.I.K. "The Millimeter-Wavelength Spectra of Extragalactic Radio Sources." Astrophys. Letters, 8, 153-160, 1971. (A211)

Kellermann, K.I. and Pauliny-Toth, I.I.K. "Radio Observations of the Infrared Object IRC 10216." Astrophys. J., 166, L17-L18, 1971. (B234)

Kerr, F.J. and Knapp, G.R. "A Search for OH in Nine High Latitude Selected Areas." Astron. J., 76, 993-994, 1971.

Kinman, T.K. and Conklin, E.K. "Observations of OJ 287 at Optical and Millimeter Wavelengths." Astrophys. Letters, 9, 147-149, 1971. (A231)

Kundu, M.R. "Polarization of the Supernova Remnant HB 21 at a Wavelength of 6 Centimeters." Astrophys. J., 165, L55-L60, 1971. (B226)

Kundu, M.R. "Solar Radio Emission at 1.2 Millimeter Wavelength." Solar Phys., 21, 130-136, 1971. (B298)

Kundu, M.R. and Velusamy, T. "Polarization of Tycho's Supernova Remnant at a Wavelength of 2.8 Centimeters." Astrophys. J., 163, 231-234, 1971. (B209)

Kundu, M.R. and Velusamy, T. "Structure of the Nonthermal Radio Source G55.7+3.4 in the Direction of Pulsar CP 1919." Nature-Phys. Sci., 234, 54, 1971.

Kutner, M. and Thaddeus, P. "Six-centimeter Formaldehyde Absorption and Emission in the Orion Nebula." Astrophys. J., 168, L67-L71, 1971. (B264)

Kutner, M., Thaddeus, P., Jefferts, K.B., Penzias, A.A., and Wilson, R.W. "Observation of 140 GHz Formaldehyde Line Emission from the Trapezium Region of the Orion Nebula." Astrophys. J., 164, L49-L54, 1971. (B228)

Macdonald, G.H. and Miley, G.K. "The Radio Structures of Seventy-Nine Quasi-Stellar Objects." Astrophys. J., 164, 237-247, 1971. (B224)

Manchester, R.N. "Crab Pulsar Radiation Characteristics." IAU Symposium, 46, 209-210, 1971. (B260)

Manchester, R.N. "Faraday Rotation of the Crab Pulsar Radiation." IAU Symposium, 46, 118, 1971. (B259)

Manchester, R.N. "Observations of Pulsar Polarization at 410 and 1665 MHz." Astrophys. J., Suppl Ser., 23, 283-322, 1971. (B267)

Manchester, R.N. "Observations of the Crab Pulsar at 410 MHz and 1664 MHz." Astrophys. J., 163, L61-L63, 1971. (B208)

Manchester, R.N. "Properties of PSR 0525+21." Astrophys. J., 167, L101-L105, 1971. (B253)

Manchester, R.N. "Rotation Measure and Intrinsic Angle of the Crab Pulsar Radio Emission." Nature-Phys. Sci., 231, 189-191, 1971. (A233)

Manchester, R.N. and Gordon, M.A. "Excitation Temperatures of the 18-centimeter OH Transitions in an Absorbing Cloud." Astrophys. J., 169, 507-514, 1971. (B276)

Manchester, R.N. and Tademaru, E. "Crab Pulsar Radiation Mechanism." Nature-Phys. Sci., 232, 164-165, 1971. (B294)

Maslowski, J. "A Green Bank Sky Survey in Search of Radio Sources at 1400 MHz. I. A Spectral Analysis of the 5C1 Sources." Astron. & Astrophys., 14, 215-222, 1971. (A228)

Miley, G.K. "The Radio Structure of Quasars--A Statistical Investigation." Mon. Not. R. Astr. Soc., 152, 477-490, 1971. (B265)

Miley, G.K. and Wade, C.M. "The Fine Structure of Cygnus A." Astrophys. Letters, 8, 11-15, 1971. (A205)

Morris, M., Zuckerman, B., Palmer, P., and Turner, B. "HCN in IRC+10216." Astrophys. J., 170, L109-L112, 1971. (B286).

Nakano, T. "Condensation of Solid Hydrogen in Contracting Interstellar Clouds." Progress of Theor. Phys., 45, 1737-1746, 1971. (A216)

Penzias, A.A., Jefferts, K.B., and Wilson, R.W. "Interstellar $^{12}C^{16}O$ and $^{12}C^{18}O$." Astrophys. J., 165, 229-240, 1971. (B231)

Penzias, A.A., Solomon, P.M., Wilson, R.W., and Jefferts, K.B. "Interstellar Carbon Monosulphide." Astrophys. J., 168, L53-L58, 1971. (B257)

Pfleiderer, J. "Short-Term Stability of the Crab Pulsar." Astron. & Astrophys., 13, 496-497, 1971. (A215)

Predmore, C.R., Goldwire, H.C., and Walters, G.K. "Limiting ^3He Abundances in Four H II Regions." Astrophys. J., 168, L125-L129, 1971.

Riegel, K.W. "H I Spectral-Line Observations in the Direction of W31." Astrophys. J., 164, 29-45, 1971.

Rubin, R.H. and Palmer, P. "Radio Recombination Line in NGC 7027." Astrophys. Letters, 8, 79-82, 1971. (A226)

Rubin, R.H., Swenson, G.W., Jr., Benson, R.C., Tigelaar, H.L. and Flygare, W.H. "Microwave Detection of Interstellar Formamide." Astrophys. J., 169, L39-L44, 1971. (B273)

Rubin, R.H. and Turner, B.E. "Observations of Compact H II Regions With Optical Counterparts." Astrophys. J., 165, 471-478, 1971. (B242)

Saslaw, W.C. and DeYoung, D.S. "On Equipartition in Galactic Nuclei and Gravitating Systems." Astrophys. J., 170, 423-429, 1971. (B292)

Silk, J. and Brown, R.L. "On the Ultraviolet Absorption-Line Spectra Produced by HI Regions." Astrophys. J., 163, 495-502, 1971. (B221)

Simon, M. and Shimabukuro, F.I. "Observations of the Solar Oscillatory Component at a Wavelength of 3 millimeters." Astrophys. J., 168, 525-529, 1971.

Simon, M. and Wickström, B.A. "Radio Observations of Filaments During the Eclipses of September 11, 1969 and March 7, 1970." Solar Phys., 20, 122-129, 1971.

Snyder, L.E. and Buhl, D. "Observations of Radio Emission From Interstellar Hydrogen Cyanide." Astrophys. J., 163, L47-L52, 1971. (B206)

Snyder, L.E. and Buhl, D. "Radio Emission from Interstellar Hydrogen Cyanide and X-ogen." IAU Highlights in Astronomy, 2, 407-412, 1971. (B278)

Solomon, P.M., Jefferts, K.B., Penzias, A.A., and Wilson, R.W. "Detection of Millimeter Emission Lines from Interstellar Methyl Cyanide." Astrophys. J., 168, L107-L110, 1971. (B261)

Solomon, P., Jefferts, K.B., Penzias, A.A., and Wilson, R.W. "Observation of CO Emission at 2.6 Millimeters from IRC+10216." Astrophys, J., 163, L53-L56, 1971. (B225)

Sramek, R.A. "A Measurement of the Gravitational Deflection of Microwave Radiation Near the Sun--October 1970." Astrophys. J., 167, L55-L60, 1971. (B250)

Sullivan, W.T., III. "Variations in Frequency and Intensity of 1.35 Centimeter H_2O Emission Profiles in Galactic HII Regions." Astrophys. J., 166, 321-332, 1971.

Sutton, J.M., Staelin, D.H., and Price, R.M. "Individual Radio Pulses from NP 0531." IAU Symposium, 46, 97-102, 1971. (B269)

Tademaru, E. "Pulsar Radio Emission from Expanding Charge Sheets." Astrophys. & Space Sci., 12, 193-203, 1971. (B289)

Tademaru, E., Newman, C.E., and Jones, F.C. "Comments on 'On the Formation of Energy Spectra in Synchrotron Sources' by Donald B. Melrose." Astrophys. & Space Sci., 10, 453-457, 1971.

Taylor, J.H. and Huguenin, G.R. "Observations of Rapid Intensity and Phase Fluctuations in Pulsar Emissions." Astrophys. J., 167, 273-291, 1971. (B246)

Taylor, J.H., Huguenin, G.R., Hirsch, R.M., and Manchester, R.N. "Polarization of the Drifting Subpulses of Pulsar 0809+74." Astrophys. Letters, 9, 204-208, 1971. (A232)

Thaddeus, P., Wilson, R.W., Kutner, M., Penzias, A.A., and Jefferts, K.B. "Discovery of Para-Formaldehyde and the 2-Millimeter Formaldehyde Distribution in the Orion Infrared Nebula." Astrophys. J., 168, L59-L65, 1971. (B271)

Turner, B.E. "Anomalous OH Emission from New Types of Galactic Objects." Astrophys. Letters, 8, 73-77, 1971. (A208)

Turner, B.E. "Detection of Interstellar Cyanoacetylene." Astrophys. J., 163, L35-L39, 1971. (B200)

Turner, B.E. "OH as a Constituent of the Interstellar Medium." IAU Highlights in Astronomy, 2, 378-390, 1971. (B277)

Turner, B.E. and Heiles, C. "Nonthermal OH Emission in Interstellar Dust Clouds." Astrophys. J., 170, 453-462, 1971. (B288)

Turner, B.E. and Rubin, R.H. "New Galactic H_2O Sources Associated with HII Regions." Astrophys. J., 170, L113-L118, 1971. (B285)

Verschuur, G.L. and Knapp, G.R. "H I Clouds with Spin Temperatures Less than $25^{\circ}K$." Astron. J., 76, 403-408, 1971. (A210)

Verschuur, G.L. "OH Emission from Interstellar H I Clouds." Astrophys. Letters, 7, 217-220, 1971. (A202)

Verschuur, G.L. "Observations of a Rotating Neutral Hydrogen Cloud." Astron. J., 76, 105-109, 1971. (A201)

Verschuur, G.L. "Observations of Intermediate Velocity Clouds and a Model for Their Existence." Astron. J., 76, 317-321, 1971. (A206)

Verschuur, G.L. "Recent Measurements of the Zeeman Effect at 21 centimeter Wavelength." Astrophys. J., 165, 651-653, 1971. (B232)

Wade, C.M. and Hjellming, R.M. "Detection of Radio Emission from Antares." Astrophys. J., 163, L105-L106, 1971. (B214)

Wade, C.M. and Hjellming, R.M. "Further Radio Observations of Novae." Astrophys. J., 163, L65-L67, 1971. (B207)

Wade, C.M. and Hjellming, R.M. "Further Radio Observations of Scorpius X-1." Astrophys. J., 170, 523-528, 1971. (B287)

Wade, C.M., Hjellming, R.M., Kellermann, K.I., and Wardle, J.F.C. "Radio Emission from the Nucleus of NGC 5128." Astrophys. J., 170, L11-L13, 1971. (B282)

Wade, C.M. and Miley, G.K. "Positions of Unidentified Radio Sources." Astron. J., 76, 101-102, 1971. (A199)

Wardle, J.F.C. "The Polarization of Strong Radio Sources at 9.5 mm Wavelength." Astrophys. Letters, 8, 183-186, 1971. (A213)

Wardle, J.F.C. "The Structure and Polarization of 3C 459 at 610 MHz." Astrophys. Letters, 8, 53-55, 1971. (A225)

Wardle, J.F.C. "The Structure of Double Radio Sources." Astrophys. Letters, 8, 221-225, 1971. (A219)

Wardle, J.F.C. and Miley, G.K. "Radio Emission from Quasi-Stellar Objects." Astrophys. J., 164, L119-L123, 1971. (B227)

Webber, J.C. and Willis, A.G. "Radio Continuum Observations of Maffei 2." Nature, 231, 36, 1971.

Webster, W.J., Altenhoff, W.J., and Wink, J.E. "Aperture-Synthesis Observations of M17 and W49A at 2.695 GHz." Astron. J., 76, 677-682, 1971. (A222)

Wendker, H.J. "Radio Observations of Selected H II Regions." Astron. & Astrophys., 13, 65-70, 1971. (A212)

Willis, A.G. and Dickel, J.R. "The Radio Source CTB 1." Astrophys. Letters, 8, 203-207, 1971. (A220)

Wilson, R.W., Penzias, A.A., Jefferts, K.B., Kutner, M., and Thaddeus, P. "Discovery of Interstellar Silicon Monoxide." Astrophys. J., 167, L97-L100, 1971. (B252)

Wilson, R.W., Solomon, P.M., Penzias, A.A., and Jefferts, K.B. "Millimeter Observations of CO, CN, and CS Emission from IRC+10216." Astrophys. J., 169, L35-L37, 1971. (B272)

Wilson, W.J. "Infrared Stars: Search for 3.5-Millimeter Radiation and Tentative Detection of VY Canis Majoris." Astrophys. J., 166, L13-L16, 1971. (B236)

Wilson, W.J. and Barrett, A.H. "Properties of OH Emission Associated with Infrared Stars." In: Lockwood, G.W. and Dyck, H.M., editors. Conf. on Late-Type Stars. Tucson, Kitt Peak National Observatory, 77-94, 1971. (A217)

Wright, M.C.H. "On the Interpretation of Observations of Neutral Hydrogen in External Galaxies." Astrophys. J., 166, 455-464, 1971. (B239)

Zuckerman, B., Ball, J.A., and Gottlieb, C.A. "Microwave Detection of Interstellar Formic Acid." Astrophys. J., 163, L41-L45, 1971. (B210)

Zuckerman, B., Morris, M., Turner, B.E., and Palmer, P. "New Ammonia Lines and Sources in the Galaxy." Astrophys. J., 169, L105-L108, 1971. (B280)

A and B numbers in parentheses indicate number in NRAO Reprint Series, A or B.

64