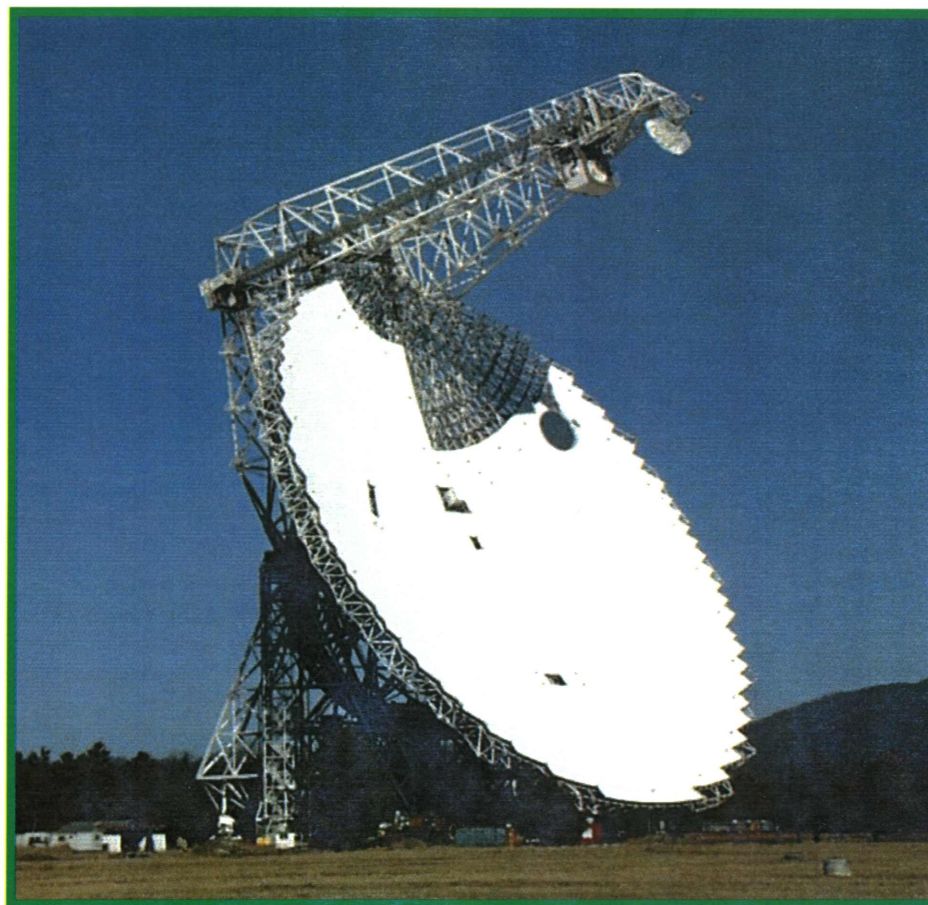


OBSERVING

NATIONAL RADIO



SUMMARY

ASTRONOMY OBSERVATORY



1999 STATISTICS

NATIONAL RADIO ASTRONOMY OBSERVATORY

Observing Summary — 1999 Statistics



March 2000

SCIENTIFIC HIGHLIGHTS

- **The VLBA has been used to make the most precise, absolute extragalactic distance measurement to date—a measurement that will be important in calibrating the size and age of the Universe:** The VLBA measured proper motions of water maser spots in the circumnuclear disk of the galaxy NGC 4258. The measures, in a disk previously shown to be in Keplerian rotation around a supermassive object at the galaxy's center, allowed a direct geometric determination of the distance to the galaxy. This distance, 7.2 +/- 0.3 Mpc, is independent of all other measurement techniques that make up the cosmic distance ladder. Because this measurement is inconsistent with the distance 8.1 ± 0.4 Mpc derived from Cepheid variable stars observed by the HST, the Cepheid observers propose to use the VLBA distance to derive the absolute magnitudes of the Cepheids in NGC 4258 and thus recalibrate the Cepheid period-luminosity relation. This recalibration could then result in a revised value for the Hubble Constant and for the expansion age of the Universe.
- **The VLBA has detected the Earth's motion around the Milky Way's center:** Observing subtle shifts in the apparent position of Sagittarius A* at the center of the Milky Way, compared to background quasars, the VLBA can detect Earth's motion around the Galactic Center in ten days' time. The observations constrain peculiar motions of Sgr A* and thus also strengthen the case for a black hole at the Galactic Center. The new data indicate a minimum mass for Sgr A* of 1000 solar masses, which rules out a multiple star system and strengthens the case for a black hole.
- **Observations with the VLA have revealed a spectacular and complex structure, more than 200,000 light-years across, in M87, the largest galaxy in the Virgo Cluster:** The new image of large, bubble-like, radio-emitting lobes requires revision of theories about the origin of X-ray emission arising from gas surrounding the galaxy. Previously, the X-ray emission has been attributed to Virgo Cluster gas cooling and falling inward toward M87. However the newly-revealed radio lobes are within the X-ray emitting region of the galaxy, and analysis of the new VLA image indicates that the central engine provides more energy to this region than is lost in the X-rays, thus calling into question the "cooling flow" model. It appears that the new results force a revision of the physics of such X-ray emitting regions in galaxy clusters.
- **In the last year of its life, the 140 Foot Telescope was used to make a new survey of Galactic H I covering 10 degrees of the Galactic Plane between longitudes of 65 and 185 degrees, and a velocity range of -300 to +200 km/s, a substantial improvement over previous ones in angular resolution, completeness, and sensitivity.** It will be corrected for stray radiation and is fully sampled at the Nyquist spatial frequency. The survey will be valuable for studies of H I shells and supershells, the association of H I with molecular clouds and star-forming regions, and supernova remnants. A major goal of the survey is to provide the zero spacing flux for the Canadian Galactic Plane Survey, an aperture synthesis H I survey. Moreover, the 140 Foot Survey will extend beyond the CGPS to provide additional information on extended objects.

- **The VLBA has been used to make the first-ever time-lapse “movie” of gas motions around a star other than the Sun:** The “movie” of the pulsating red supergiant TX Cam is the result of the largest observational project yet undertaken using Very Long Baseline Interferometry. The proper motions of SiO maser spots in the star's outer envelope contradict expectations, showing that expansion of the envelope continues past the point in the pulsation cycle where models predict contraction to begin. In addition, the gas motions are not uniform around the star, leading to speculation that the rate of mass loss may not be the same from all parts of the star's surface. Such a long-term observational project, covering the star's entire 557-day pulsation period, has only become possible with the advent of the VLBA.
- **The VLA has revealed for the first time important aspects of gas flow in a barred galaxy:** Sensitive polarization observations with the VLA have shown that shocked gas in the barred galaxy NGC 1097 is diverted by nearly 90 degrees to flow directly down the bar toward the galaxy's nucleus. The polarization shows the magnetic field orientation, which is a tracer of the gas velocity. The results are in general agreement with computer simulations, but show that the shock front where the diversion occurs is closer to the bar's center, not at its edge, as the simulations suggested. In addition, the magnetic field near the center of the galaxy indicates that magnetic stress may serve as the mechanism for feeding the central black hole with the amount of material required to account for the observed activity.
- **The 12 Meter Telescope has discovered the first rhomboidal-shaped molecule in space:** It is the molecular ring SiC₃, the most stable structure with the elemental formula SiC₃ having a transannular bond. The successful search with the 12 Meter Telescope involved previous laboratory determination of the molecular spectroscopic constants. Seven transitions are detected in the rich molecular circumstellar shell of the evolved carbon star IRC+10216. This follows earlier detections of the diatomic radical SiC, the closed-shell ionic ring SiCC, and the closed-shell linear chain SiC₄. Rhomboidal SiC₃ is the fifth and largest cyclic molecule so far identified in space. The excitation of SiC₃ is similar to that of SiCC, with a low rotational temperature within the K-stacks of 10-20 K, and a high rotational temperature of ~ 50 K across the K-stacks, probably close to the kinetic temperature of the shell.
- **Global VLBI observations at 7 mm wavelength have imaged the inner region of M87 at unprecedented resolution, and have revealed the collimation region of the M87 jet:** The new image shows a remarkably broad jet with an “opening angle” of about 60 degrees near the center, with strong collimation of the jet occurring at 30-100 Schwarzschild radii from the black hole. This work supports the hypothesis that jets are formed by an accretion disk around the black hole and collimated by magnetic fields. These observations are the first to show that AGN jets do not reach their final, collimated configuration until many tens of Schwarzschild radii from the black hole. The VLBA, along with telescopes in Europe, was used for this work.

OBSERVING HOURS

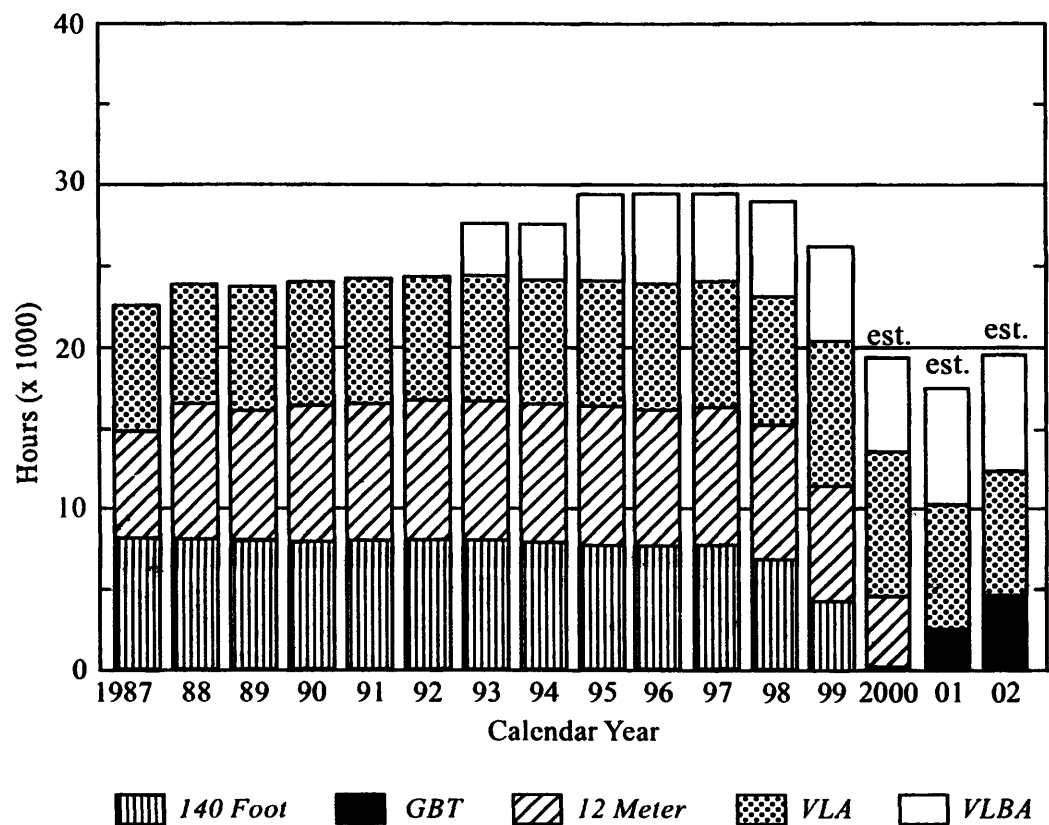


Figure 1. This figure shows the hours for observing on each telescope during the last decade. It includes astronomical observing, testing, and calibration. The 140 Foot Telescope closed in July of 1999, the 12 Meter Telescope will close in July of 2000, and the GBT is expected to begin operations in the summer of 2000.

DISTRIBUTION OF SCHEDULED OBSERVING TIME

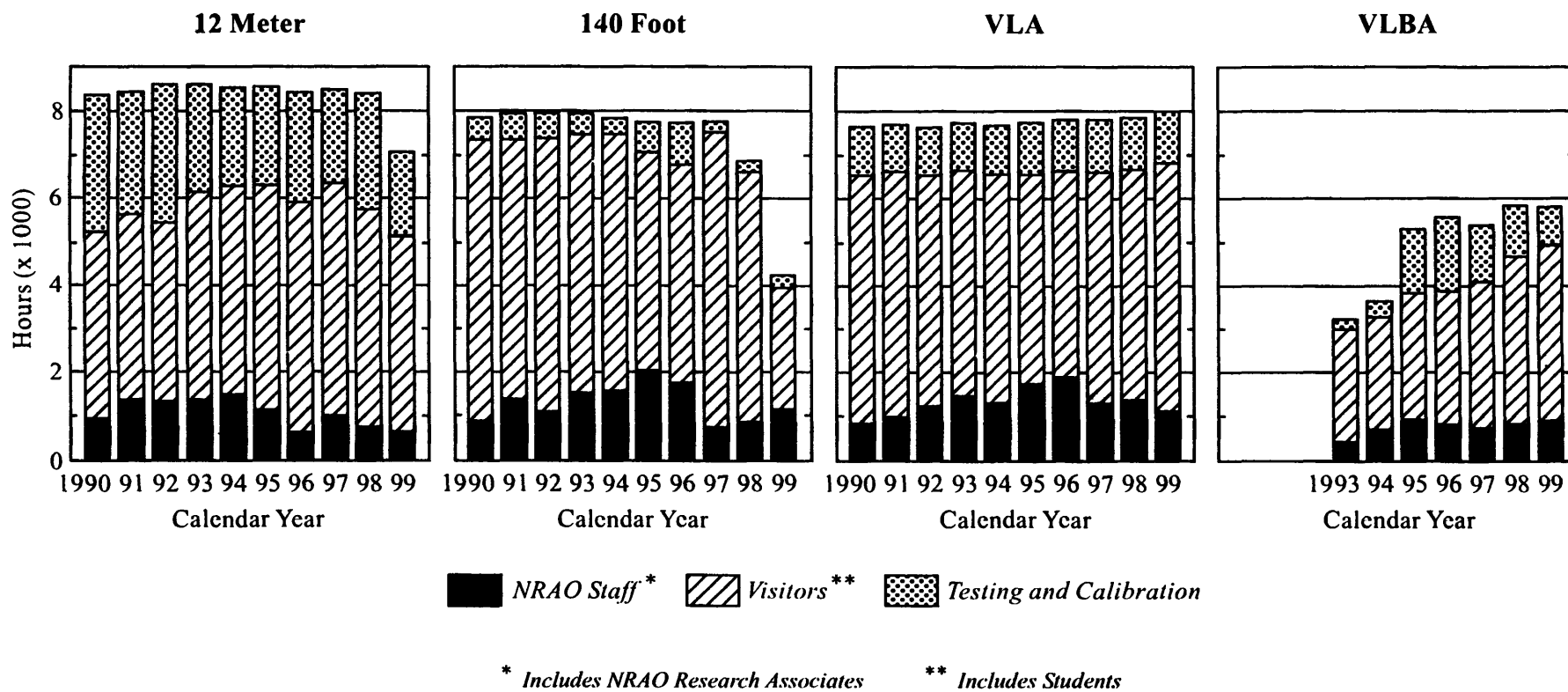


Figure 2. These graphs show the number of hours scheduled for testing and calibration, and for observing by the NRAO staff and by visitors on each telescope system.

12 METER RADIO TELESCOPE SUMMARY

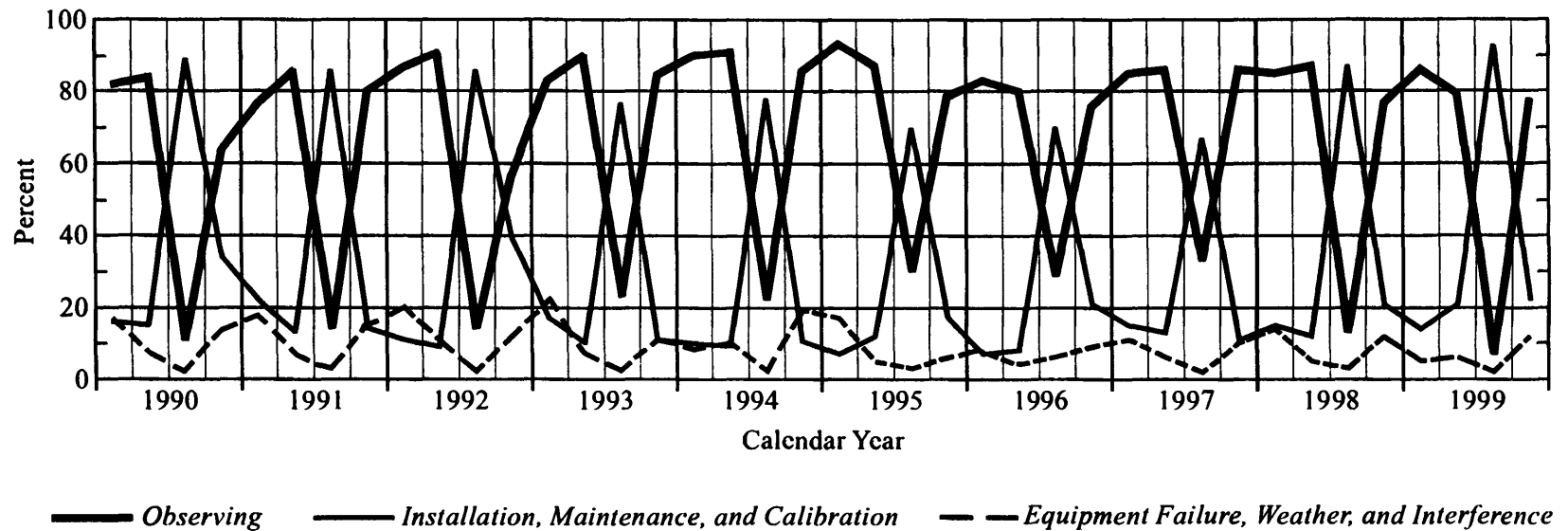


Figure 3. This summary for each quarter of the calendar year shows the percentage of the total time in the year (8760 hours) that the telescope was scheduled for observing; for routine calibration, maintenance, and installation of new experiments; and the percentage of time lost due to equipment failure, bad weather, and radio interference. The telescope is removed from service for a period of four to six weeks each summer during the wet season. This period is used for maintenance and upgrading of the instrument, which in 1999 included installation of a new dome covering.

140 FOOT RADIO TELESCOPE SUMMARY

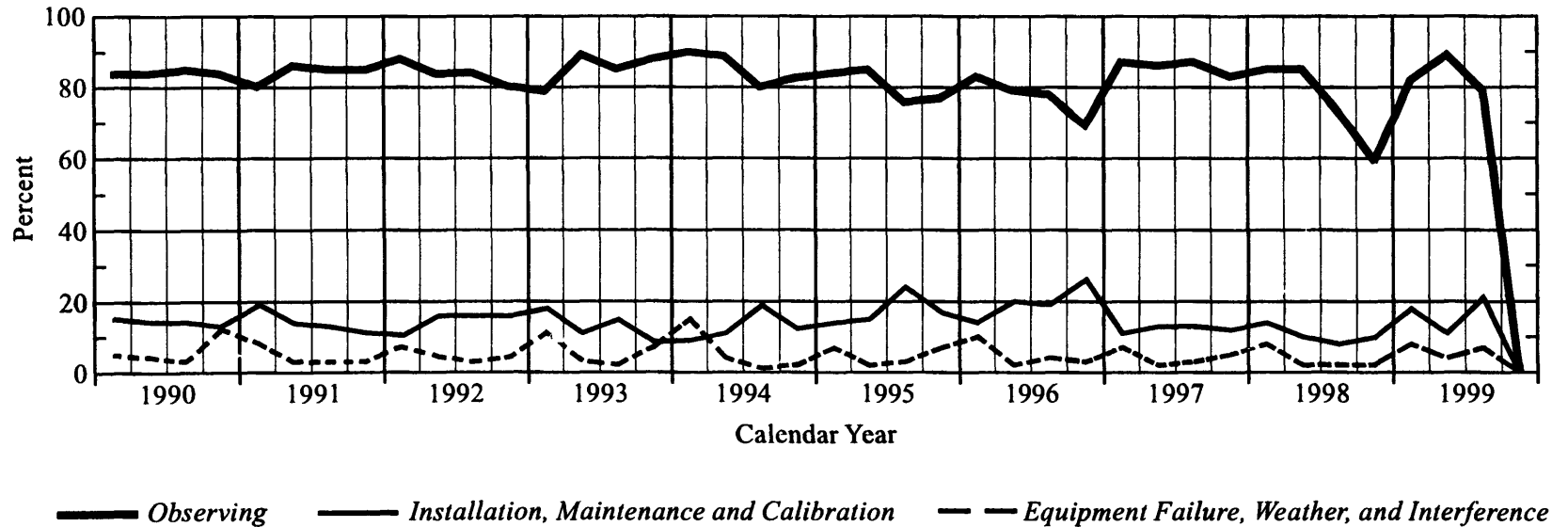


Figure 4. This summary for each quarter of the calendar year shows the percentage of the total time in the year (8760 hours) that the telescope was scheduled for observing; for routine calibration, maintenance, and installation of new experiments; and the percentage of time lost due to equipment failure, bad weather, and radio interference. The 140 Foot Telescope ceased operations in July of 1999.

VERY LARGE ARRAY TELESCOPE SUMMARY

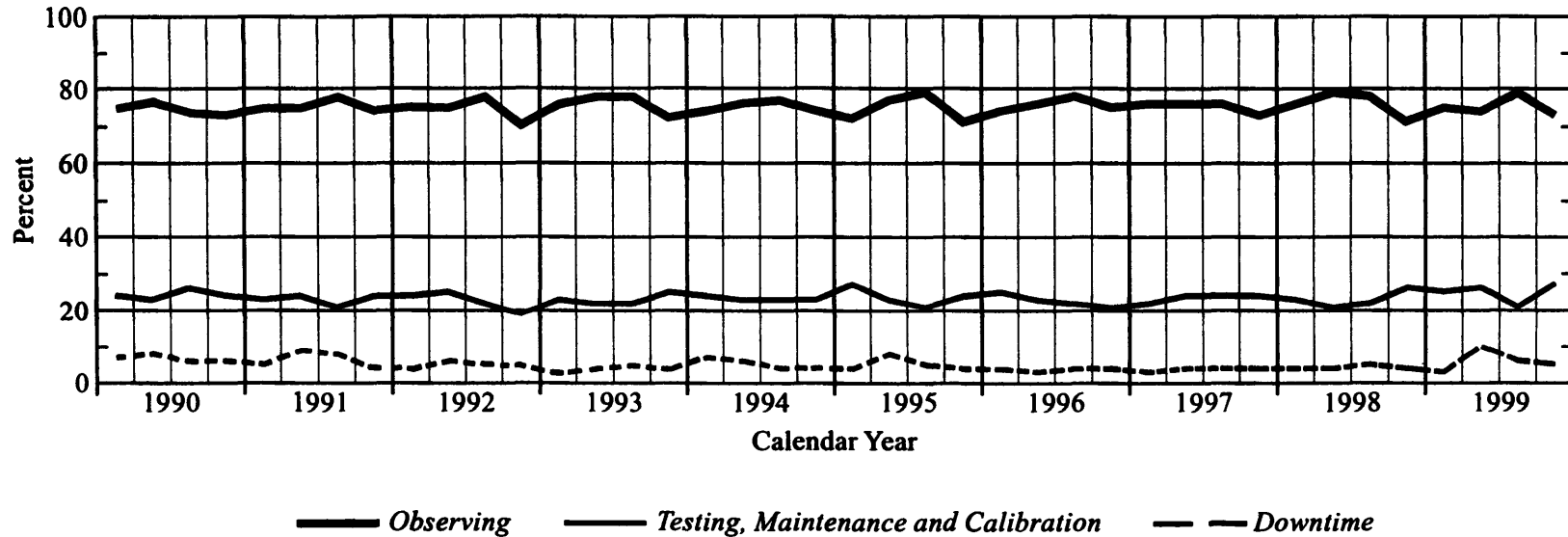


Figure 5. This summary for each quarter of the calendar year shows the percentage of the total time in the year (8760 hours) that the telescope was scheduled for observing; for routine system testing, maintenance, and calibration; and the percentage of time lost due to hardware or software failure, power failure, or bad weather.

VERY LONG BASELINE ARRAY TELESCOPE SUMMARY

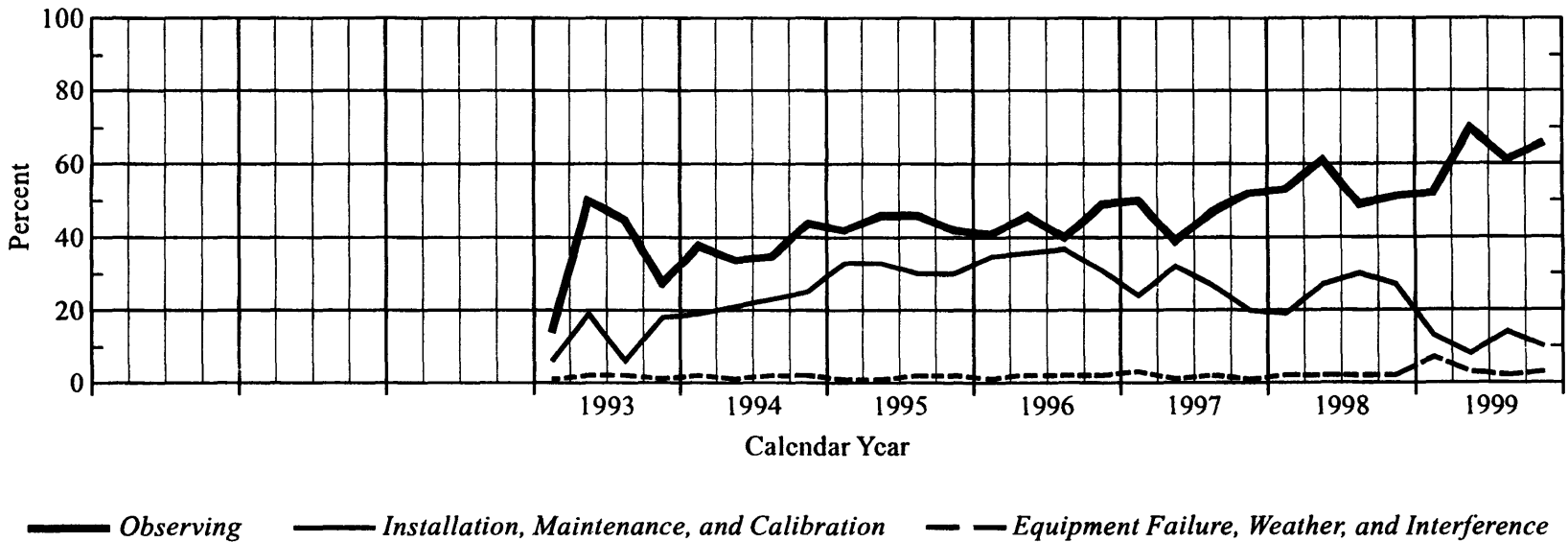


Figure 6. This summary for each quarter of the calendar year shows the percentage of the total time in the year (8760 hours) that the telescope was scheduled for observing; for routine calibration, maintenance, and installation of new experiments; and the percentage of time lost due to equipment failure, bad weather, and radio interference. It should be noted that about 15 percent of the time cannot be scheduled as it results from the time difference across the array; this is reflected as a difference in the time between the end of one program and the start of the next.

FULL-TIME EMPLOYEES

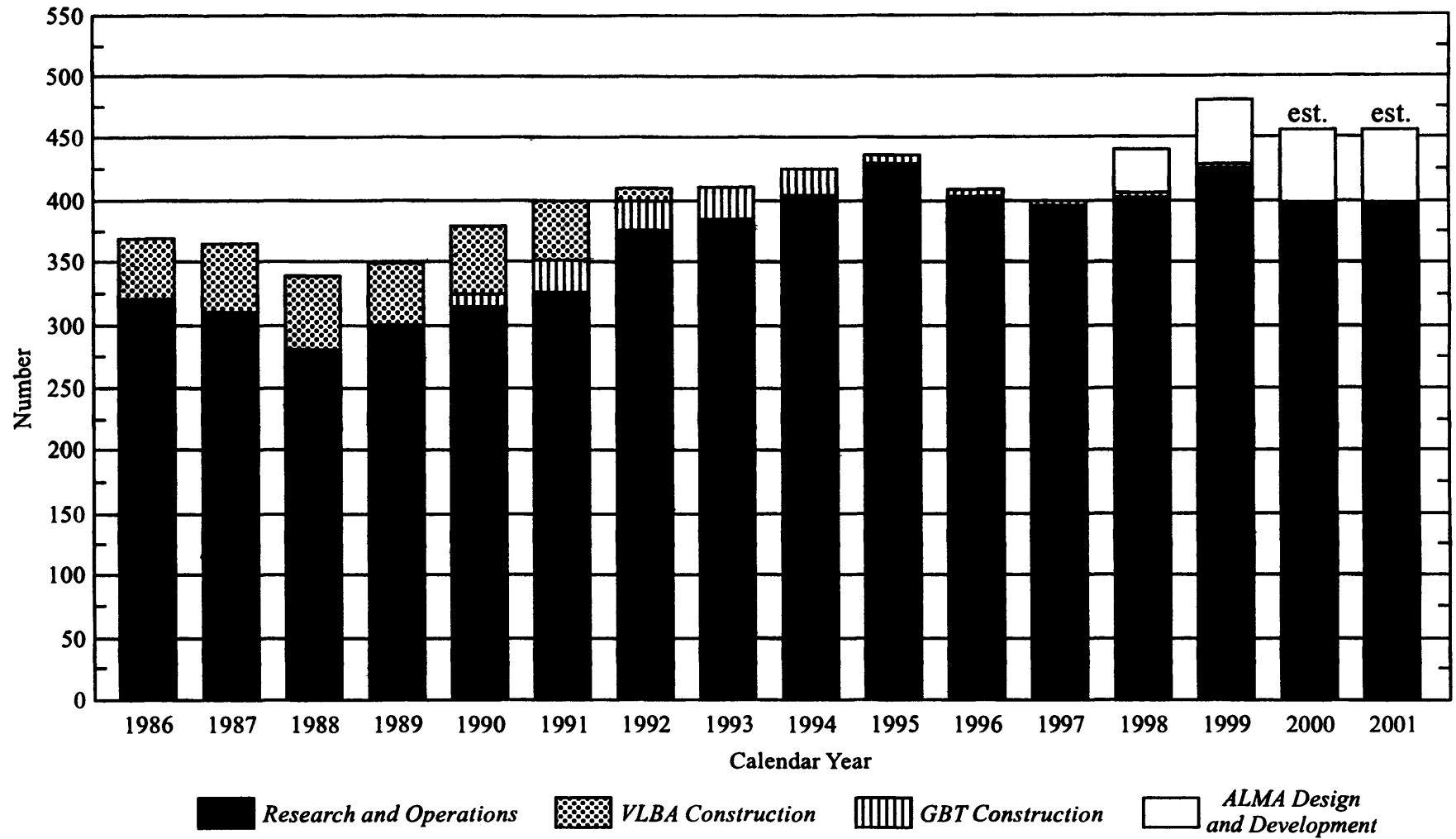


Figure 7. This figure shows the total number of NRAO full-time employees at the end of each year, projected into the future.

NUMBER OF PEOPLE OBSERVING WITH NRAO TELESCOPES

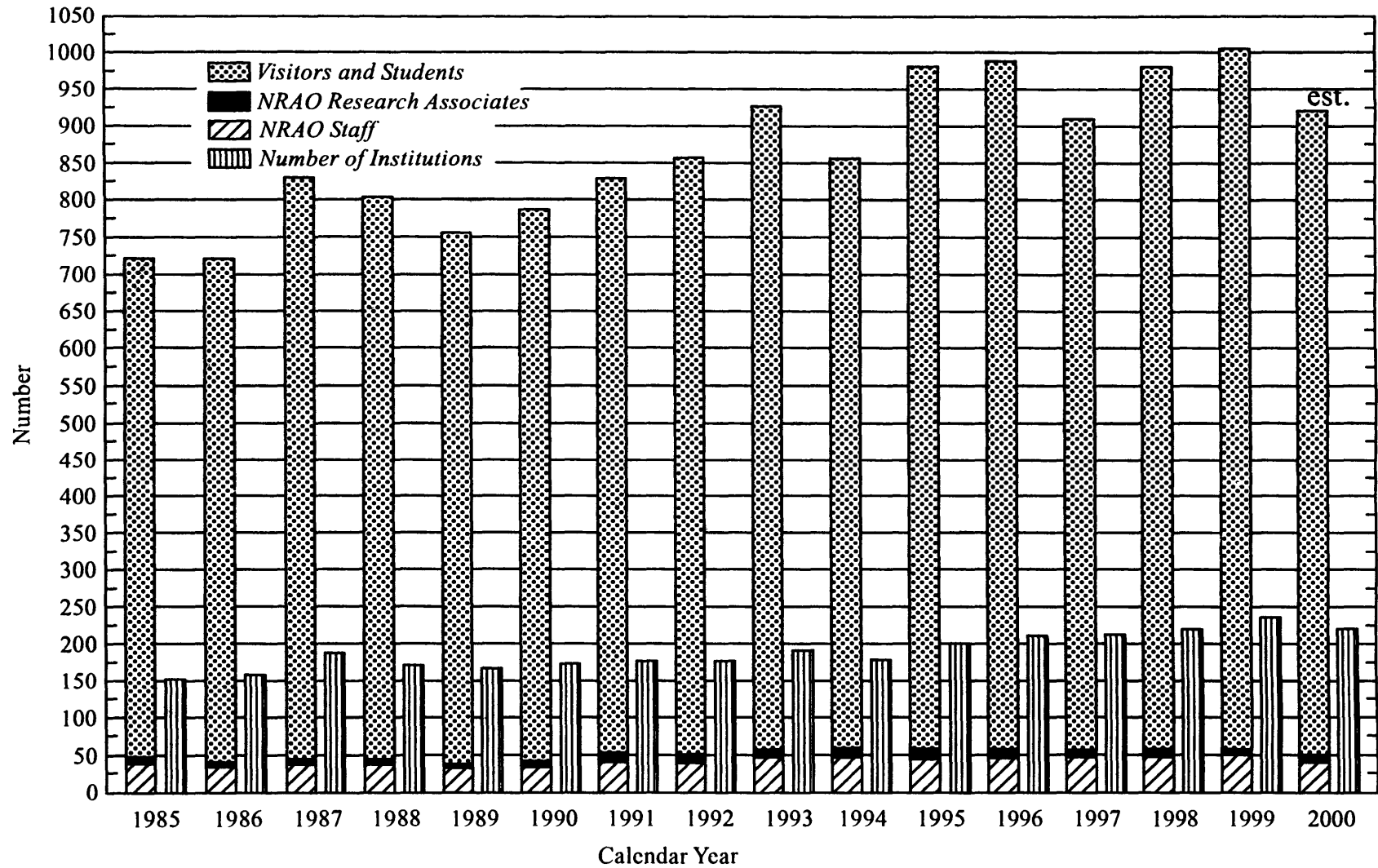


Figure 8. The bar chart shows for each calendar year the number of NRAO research staff and the number of NRAO research associates who used the telescopes. In addition, it shows the total number of visitor-users of NRAO telescopes and the number of institutions from which the NRAO visitors came.

**DISTRIBUTION OF SCHEDULED OBSERVING PROGRAMS
IN VARIOUS RESEARCH AREAS, BY PERCENT**

	12 Meter	140 Foot	VLA	VLBA	Overall
I. SOLAR SYSTEM —					
Sun, Planet, Satellites, and Comets	8%	1%	6%	7%	6%
II. STELLAR —					
Pulsars, X-ray Sources, Planetary Nebulae, Circumstellar Shells, Supernova Remnants, Masers, Novae, Supernovae, and Stars	13%	19%	17%	12%	15%
III. GALACTIC —					
Galactic Structure, Center, Molecular Clouds, H II Regions, Star Formation, Molecules, and Interstellar Medium	51%	71%	18%	10%	34%
IV. EXTRAGALACTIC —					
Normal and Active Galaxies, Radio Galaxies, Clusters, Quasars, VLBA Studies, Extragalactic Molecules, and Cosmology	28%	9%	59%	71%	45%

DISTRIBUTION OF TELESCOPE TIME BY PERCENT

	12 Meter	140 Foot	VLA	VLBA	1999 Summary
Visitors	51%	28%	55%	42%	44%
Students	11%	4%	8%	4%	7%
NRAO Staff	7%	13%	11%	8%	10%
Jansky Research Associates	2%	0%	1%	2%	1%
Test and Calibration	16%	3%	14%	11%	11%
Maintenance and Installation	12%	4%	10%	10%	9%
Holidays and Unscheduled	1%	48%	1%	23%	18%

INSTITUTIONS FROM WHICH VISITORS CAME TO USE NRAO TELESCOPES DURING 1999

	140 FOOT	12 METER	VLA	VLBA
1. Academia Sinica, IAA (Taiwan)		X	X	X
2. Adelaide University (Australia)				X
3. Alabama, University of (AL)	X			
4. American Institute of Physics (NY)		X	X	
5. Amsterdam, University of - Astronomy Institute (Netherlands)			X	X
6. Anglo Australian Observatory - UKSTU (Australia)			X	X
7. Applied Physics Institute (Russia)		X		
8. Arcetri Astrophysical Observatory (Italy)		X		
9. Arizona State University (AZ)		X	X	
10. Arizona, University of - Steward, LPL, SMTO (AZ)		X	X	
11. Astro Space Center (Russia)		X		
12. Astrophysical Institute, Potsdam (Germany)			X	
13. Astrophysical Observatory - University Firenze (Italy)			X	
14. Barcelona, University of (Spain)			X	X
15. Beijing Astronomical Observatory (China)		X	X	
16. Bochum, University of (Germany)			X	
17. Bologna, University of (Italy)			X	X
18. Bonn University (Germany)			X	
19. Bordeaux Observatory (France)		X		X
20. Boston College (MA)		X		

140 FOOT 12 METER VLA VLBA

21 .	Boston University (MA)	X		X	X
22 .	Brandeis University (MA)		X	X	X
23 .	Brera Osservatorio (Italy)			X	
24 .	Bristol - Cantock Close (UK)			X	
25 .	British Columbia, University of (Canada)			X	X
26 .	Calgary, University of (Canada)			X	X
27 .	California, University of, Berkeley - Hat Creek (CA)	X	X	X	X
28 .	California, University of, Davis (CA)			X	
29 .	California, University of, Los Angeles (CA)		X	X	X
30 .	California, University of, San Diego (CA)			X	X
31 .	California, University of, Santa Barbara (CA)			X	X
32 .	California, University of, Santa Cruz - Lick Observatory (CA)		X	X	
33 .	Caltech - OVRO, Palomar, Big Bear Solar (CA)		X	X	X
34 .	Cambridge University - Cavendish, MRAO, IoA (UK)		X	X	X
35 .	Canadia Military College (Canada)			X	
36 .	Catania University (Italy)			X	
37 .	Catholic University of America (DC)			X	
38 .	CEA/DSM/DAPNIA (France)		X		
39 .	Center for Astrophysics - Harvard, SAO (MA)	X	X	X	X
40 .	Chalmers-Onsala Space Observatory (Sweden)		X	X	X

140 FOOT 12 METER VLA VLBA

41 .	Chicago, University of - Yerkes Observatory (IL)		X	X	
42 .	Chile, University of (Chile)			X	
43 .	CNRS - CEN, Saclay (France)			X	X
44 .	Cologne, University of (Germany)			X	
45 .	Colorado, University of - JILA, CASA, LASP (CO)		X	X	X

46 .	Columbia University (NY)			X	
47 .	Connecticut, University of (CT)		X	X	X
48 .	Copenhagen University Observatory (Denmark)			X	
49 .	Cornell University (NY)	X	X	X	X
50 .	CSIRO - ATNF, Parkes Observatory (Australia)		X	X	X

51 .	Danish Space Research Inst. (Denmark)			X	
52 .	Dartmouth College (NH)			X	
53 .	Delaware, University of (DE)			X	
54 .	Dominion Astrophysical Observatory (Canada)			X	
55 .	Dominion Radio Astroph Observatory (Canada)			X	X

56 .	Drake University (IO)		X		
57 .	Durham, University of (UK)			X	
58 .	East Tennessee State (TN)		X		
59 .	Edinburgh, University of (Scotland)			X	
60 .	European Southern Observatory (Chile, Germany)			X	

140 FOOT 12 METER VLA VLBA

61 .	European Space Agency - ESTEC, EXOSAT (Netherlands)		X	X	
62 .	Fermi National Accelerator Lab (IL)				X
63 .	Florida International University (FL)			X	
64 .	Florida, University of (FL)		X	X	
65 .	George Mason University (VA)			X	X
66 .	Georgia, University of (GA)	X	X		
67 .	Göttingen University (Germany)				X
68 .	Granada, Universidad de (Spain)			X	
69 .	Grenoble, Univ/Observatory (France)			X	
70 .	Groningen, University of - Kapteyn Inst. (Netherlands)			X	X
71 .	Halmstad University (Sweden)		X		
72 .	Hamburg University (Germany)			X	X
73 .	Hanscom Air Force Base - AFGL (MA)		X		
74 .	Hartebeesthoek Radio Astronomy Observatory (South Africa)			X	X
75 .	Haverford College (PA)			X	
76 .	Hawaii, University of - Institute for Astronomy (HI)			X	
77 .	Haystack Observatory - NEROC (MA)		X	X	X
78 .	Heidelberg Observatory (Germany)				X
79 .	Helsinki, University - HUT, Metsähovi (Finland)		X	X	X
80 .	Herfordshire, University of (UK)			X	X

140 FOOT 12 METER VLA VLBA

81 .	High Altitude Observatory - NCAR (CO)	X		
82 .	Hofstra University (NY)	X		
83 .	IAFE - Buenos Aires (Argentina)	X		
84 .	IAS-Frascati (Italy)		X	
85 .	Ibaraki University (Japan)			X

86 .	IEM-CSIC (Spain)	X		
87 .	Illinois, University of - Vermillion River Observatory (IL)	X	X	X
88 .	Imperial College (London)		X	
89 .	Indiana, University of (IN)	X		
90 .	Infrared Processing/Analysis Center (CA)	X	X	

91 .	Inst Space & Aeronautical Sciences (Japan)	X	X	X
92 .	Institute for A&A, Andalusia (Spain)		X	X
93 .	Institute for Molecular Science (Japan)	X		
94 .	Institute Radio Astronomie Millimetrique (France)	X	X	
95 .	Iowa State University (IA)	X	X	

96 .	Iowa, University of (IA)		X	X
97 .	IRA/CNR (Italy)	X		
98 .	Jaen University (Spain)		X	X
99 .	Jagellonian University (Poland)		X	X
100 .	Jet Propulsion Laboratory - Goldstone (CA)	X	X	X

140 FOOT 12 METER VLA VLBA

101 .	Johns Hopkins University (MD)	X		X	
102 .	Joint Astronomy Center (HI)		X		
103 .	Kagoshima University (Japan)				X
104 .	Keele, University of (UK)			X	
105 .	Kennesaw State College (GA)		X	X	

106 .	Kentucky, University of (KY)			X	
107 .	Kyoto University (Japan)			X	
108 .	Lafayette College (PA)			X	
109 .	Lancashire, University of Central (UK)			X	X
110 .	Lawrence Livermore National Laboratory (CA)			X	

111 .	Lebedev Physics Institute - ASC (Russia)			X	X
112 .	Leeds, University of (UK)			X	
113 .	Leicester, University of (UK)			X	
114 .	Leiden Univ/Obs - Huygens Labs (Netherlands)			X	X
115 .	Lisbon, University of (Portugal)			X	

116 .	Liverpool John Moores University (UK)		X	X	
117 .	Lockheed Research Laboratory (CA)			X	
118 .	Lowell Observatory (AZ)		X		
119 .	Madeira University (Portugal)			X	X
120 .	Madrid Observatory (Spain)		X		

140 FOOT 12 METER VLA VLBA

121 .	Manchester, University of - Jodrell Bank, NRAL (UK)		X	X	X
122 .	Maria Mitchell Observatory (MA)		X		
123 .	Marseille Observatory (France)			X	
124 .	Maryland, University of - Clark Lake Observatory (MD)	X	X	X	X
125 .	Massachusetts Institute of Technology - Lincoln Labs (MA)			X	X

126 .	Massachusetts, University of (MA)		X	X	
127 .	Mexico, University of - UNAM (Mexico)			X	X
128 .	Michigan, University of (MI)			X	X
129 .	Milano Observatory (Italy)			X	
130 .	Minnesota, University of (MN)	X	X	X	

131 .	Missouri, University of (MO)	X		X	X
132 .	Montreal, University of (Canada)			X	
133 .	Morehead State University (KY)			X	
134 .	Moscow State University - Sternberg State AI (Russia)			X	X
135 .	Mount Wilson Observatories (CA)			X	

136 .	MPIA Heidelberg (Germany)			X	
137 .	MPIAP Munich (Germany)			X	
138 .	MPIfEP Garching (Germany)		X	X	X
139 .	MPIR Bonn (Germany)	X	X	X	X
140 .	Mt. Stromlo Observatory - ANU (Australia)		X	X	

140 FOOT 12 METER VLA VLBA

141 .	Munchen University (Germany)			X	
142 .	NASA/Ames Research Center (MD)		X		
143 .	NASA/Goddard Space Flight Center (MD)			X	X
144 .	National Astron & Ionophere Center - Arecibo Observatory (NY)	X		X	X
145 .	National Research Council (Canada)			X	

146 .	National Astronomical Observatory (Japan)			X	X
147 .	National Center for Radio Astrophysics (India)			X	
148 .	National Central University (Tiawan)			X	
149 .	National Institute of Standards & Technology (MD)		X		
150 .	National Optical Astronomy Observatory (AZ)			X	X

151 .	National Radio Astronomy Observatory (VA,NM,AZ,HI)	X	X	X	X
152 .	National Science Foundation (DC)		X		
153 .	Naval Research Laboratory (DC)	X		X	X
154 .	New Hampshire, University of (NH)			X	X
155 .	New Jersey Inst. of Technology (NJ)			X	

156 .	New Mexico Inst. of Mining Technology (NM)			X	X
157 .	New Mexico State University (NM)	X		X	
158 .	New Mexico, University of (NM)		X	X	X
159 .	Newcastle, University of (UK)			X	
160 .	NFRA - JIVE, Dwingeloo, Zwiggelte, Westerbork (Netherlands)			X	X

140 FOOT 12 METER VLA VLBA

161 . Nobeyama Observatory (Japan)		X	X	X
162 . Northwestern University (IL)			X	
163 . Observatory Carnegie Institute of Washington - Santa Barbara Street (CA)			X	
164 . Observatoire de Paris (France)		X	X	X
165 . Observatorio Astronomico Nacional (Spain)		X		

166 . Ohio State University (OH)		X		
167 . Oklahoma, University of (OK)			X	X
168 . Osaka Prefecture University (Japan)		X		
169 . Oxford University (UK)			X	X
170 . Padova, University of (Italy)			X	

171 . Pennsylvania State University (PA)			X	
172 . Pennsylvania, University of (PA)			X	X
173 . Potchefstroom, University of (South Africa)			X	
174 . Princeton University (NJ)	X		X	X
175 . Puerto Rico University (Puerto Rico)			X	

176 . Puget Sound University (WA)			X	
177 . Purple Mountain Observatory (China)	X			
178 . Queens University (Canada)			X	
179 . Queens University of Belfast (N. Ireland)			X	
180 . Raman Research Institute (India)			X	

140 FOOT 12 METER VLA VLBA

181 .	Rome Astronomical Observatory (Italy)			X	
182 .	Royal Observatory - UKIRT, JCMT (Scotland)			X	X
183 .	Royal Observatory of Belgium (Belgium)			X	
184 .	Sao Paulo, University - IAG (Brazil)				X
185 .	Science Applications International Corp.			X	

186 .	Seoul National University (Korea)		X		
187 .	Shanghai Observatory (China)			X	
188 .	Sheffield, University of (UK)			X	
189 .	Southampton, University of (UK)			X	
190 .	Southwest Research Institute (TX)		X	X	

191 .	Space Science Institute (Boulder) (CO)		X		
192 .	Space Telescope Science Institute (MD)		X	X	X
193 .	St. Cloud State University (MN)		X		
194 .	St. Mary's College (CA)			X	
195 .	St. Mary's University (Canada)		X		

196 .	St. Petersburg State University (Russia)				X
197 .	State University of New York (all campi) (NY)		X		
198 .	Stockholm Observatory (Sweden)		X		X
199 .	Swinburne University (Australia)				X
200 .	Swiss Federal Institute of Tech - ETH, SFIT (Switzerland)			X	X

140 FOOT 12 METER VLA VLBA

201 .	Sydney, University of (Australia)			X	X
202 .	Tasmania, University of (Australia)			X	X
203 .	Tata Inst Fundamen Res - GMRT, RAC (India)			X	
204 .	Tel-Aviv University - Wise Observatory (Israel)			X	
205 .	Texas, University of - McDonald Observatory, MM-wave Observatory (TX)		X		

206 .	Tohoku University (Japan)			X	
207 .	Tokyo, University of - Tokyo Astron. Observatory (Japan)		X	X	
208 .	Torino Univ/Obs (Italy)				X
209 .	Toronto, University of - David Dunlap Observatory (Canada)		X	X	
210 .	Trinity College (TX)				X

211 .	Tufts University (MA)			X	
212 .	Turku, University of - Tuorla Observatory (Finland)		X	X	X
213 .	United States Naval Academy (MD)			X	
214 .	United States Naval Observatory (DC)			X	X
215 .	Universidad de Guanajuato (Mexico)			X	

216 .	Universidad Federal de Santa Maria (Brazil)			X	
217 .	University College Dublin (Ireland)			X	
218 .	University College London - MLSS (UK)	X		X	
219 .	Uppsala Astronomical Observatory (Sweden)		X		
220 .	Utsunomiya University (Japan)			X	X

140 FOOT 12 METER VLA VLBA

221 .	Valencia, University of (Spain)			X	X
222 .	Vassar College (NY)		X		
223 .	Victoria, University of (Canada)			X	
224 .	Vienna University (Austria)				X
225 .	Villanova University (PA)			X	

226 .	Virginia, University of (VA)	X	X		X
227 .	Wales, University of, Cardiff (Wales)			X	X
228 .	Wellesley College (MA)		X	X	X
229 .	Wesleyan University (CT)		X	X	
230 .	Western Ontario, Univ of (Canada)		X		

231 .	Wisconsin, University of - Washburn Observatory (WI)		X	X	X
232 .	Yale University (CT)				X
233 .	Yebes Observatory - CAY, OAN (Spain)		X	X	X
234 .	Yekatarinburg, University of (Russia)		X		
235 .	Yonsei University - Center for Space Astrophysics (Korea)		X		

236 .	York University (Canada)			X	X
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140 FOOT 12 METER VLA VLBA

NUMBER OF INSTITUTIONS	19	92	179	96
<hr/>				
NUMBER OF VISITORS	54	152	525	267
NUMBER OF STUDENTS	7	18	96	50
NUMBER OF NRAO JANSKY RESEARCH ASSOCIATES	0	2	10	6
NUMBER OF PERMANENT STAFF	15	9	31	29
<hr/> <hr/>				
TOTAL OBSERVERS	76	181	662	352

All told, 1,005 visitors, including 143 students, from 236 institutions.

NRAO STUDENT PROGRAM

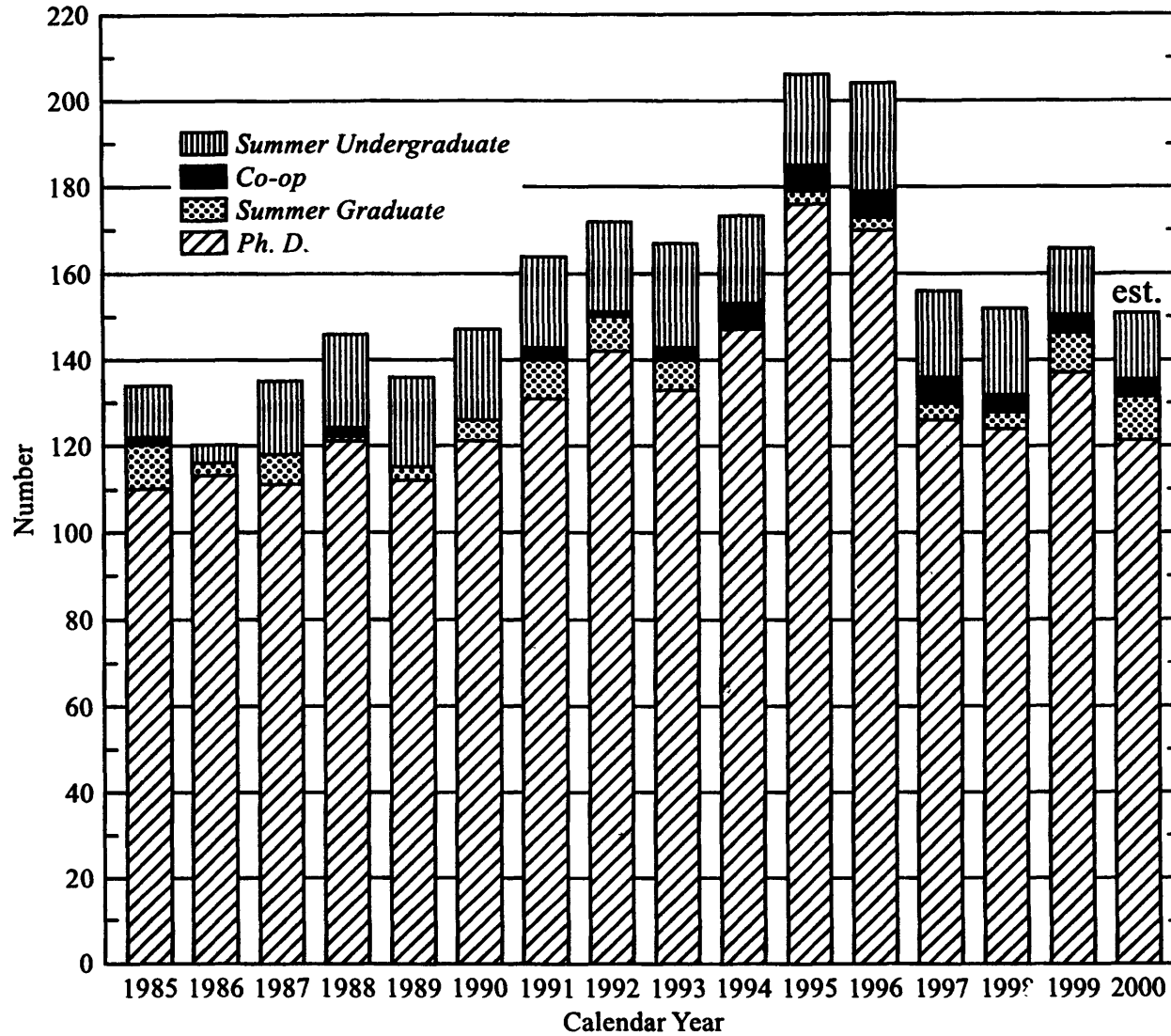


Figure 9. This figure shows for each calendar year the number of PhD students (salaried at NRAO and non-salaried), co-op students, and summer undergraduate and graduate students who observed or worked at the NRAO during that year. Beginning in 1987 the majority of the undergraduate summer students were funded by a separate NSF Grant for Research Experience for Undergraduates. The decline in the number of PhD students from 1999 to 2000 reflects the anticipated loss due to the shutdown of the 12 Meter Telescope (16 students).

NRAO FRONT-END STATUS 140 FOOT TELESCOPE

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RECEIVER NAME	FREQUENCY (GHz)	AMPLIFIER TYPE	SYSTEM TEMPERATURE (KELVIN)	3 dB BANDWIDTH (MHz)	FEED TYPE	POLARIZATION	CALIBRATION VALUE	SWITCHING SYSTEM	REMARKS	PERSON(S) IN CHARGE
50-500 MHz Rx	50-88 MHz	HIGH DYNAMIC RANGE TRANSISTOR DUAL CHANNEL	300 + Tsky	38	OPEN SLEEVE CROSSED DIPOLE	ORTHOGONAL LINEAR OR REMOVABLE QUAD HYBRID AT FEED FOR RCP AND LCP	ADJUSTABLE 2 TO 2500K	DICKE SWITCH: REFERENCE TEMPERATURE ADJUSTABLE FROM 100 TO 100,000K OR FREQUENCY SWITCH	FEED CHANGES FROM 50-88 MHz TO 110-240 MHz OR TO 450-500 MHz REQUIRE TWO HOURS.	NORROD (SHANK)
	110-240 MHz			130	BROADBAND CROSSED DIPOLE			FREQUENCY SWITCH		
	450-500 MHz	FET AMP	50-80	50	CAVITY BACKED CROSSED DIPOLE	RCP AND LCP		FREQUENCY SWITCH	450-500 MHz AMP IN 50-250 MHz Rx	
300-1000 MHz Rx	300-350 MHz	COOLED GASFET AMP DUAL CHANNEL	60-100	70	280-350 350-410 CAVITY BACKED CROSSED DIPOLES	DUAL ORTHOGONAL LINEAR RF HYBRID FOR RCP AND LCP	5K	FREQUENCY SWITCHING	ONE OF THE FIVE FEEDS 280-350 MHz 350-410 MHz 500-750 MHz 750-850 MHz OR 750-1000 MHz CAN BE USED. TO CHANGE FEEDS REQUIRES TWO HOURS. CHANGE BETWEEN 750-950 HFETS AND 750-1000 FETS REQUIRES 5 DAYS	NORROD (SHANK)
	350-410 MHz			60						
	500-750 MHz	COOLED GASFET AMP DUAL CHANNEL	50-70	80	500-750 SCALAR WITH CROSSED DIPOLES					
	750-950 MHz	COOLED HFET DUAL CHANNEL	45-50	80	750-850 CAVITY OR 750-1000 SCALAR					
	750-1000 MHz	COOLED GASFET AMP DUAL CHANNEL	50-70	80	750-1000 SCALAR WITH CROSSED DIPOLES					
6/25 CM Rx	1.00-1.45 (25 CM)	COOLED GASFET DUAL CHANNEL	35-40	450	SINGLE BEAM SCALAR	ORTHOGONAL LINEAR	4K TO 6K	FREQUENCY SWITCHING NOISE ADDING	FEED CHANGE REQUIRED TO SWITCH BANDS TAKES TWO HOURS.	NORROD (SHANK)
	4.47-5.05 (8 CM)	COOLED GASFET DUAL CHANNEL	50-80	580	SINGLE BEAM DUAL BEAM OFFSET 3 HPBW	ORTH CIRCULAR OR ORTH LINEAR IDENTICAL OR ORTH CIRCULAR OR IDENTICAL LINEAR	1.4K OR 12.8K	OTHER POLARIZATION BEAM SWITCHING		

NRAO FRONT-END STATUS 140 FOOT TELESCOPE

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RECEIVER NAME	FREQUENCY (GHz)	AMPLIFIER TYPE	SYSTEM TEMPERATURE (KELVIN)	3 dB BANDWIDTH (MHz)	FEED TYPE	POLARIZATION	CALIBRATION VALUE	SWITCHING SYSTEM	REMARKS	PERSON(S) IN CHARGE
1.3-1.8 GHz Rx	1.30-1.80	DUAL CHANNEL COOLED HFET	19-25	UP TO 120 FEED LIMITED	THREE 2HE SINGLE BEAM 1.30-1.36 1.36-1.43 1.60-1.72 ZEEMAN 1.36-1.43 ZEEMAN 1.6-1.72	ORTHOGONAL LINEAR OR CIRCULAR	2K AND 200K	FREQUENCY OR POLARIZATION SWITCHING OR NOISE ADDING	EITHER CIRCULAR OR LINEAR POLARIZATIONS ARE SELECTABLE. CIRCULAR POLARIZATION REQUIRES ADJUSTMENTS FROM THE CONTROL ROOM. BAND CHANGE REQUIRES 2 TO 3 HOURS. OBSERVATIONS OUTSIDE STATED FEED BANDS POSSIBLE AT REDUCED EFFICIENCIES.	NORROD (SIMMONS)
2-5 GHz Rx	2.9-3.4	DUAL CHANNEL COOLED FET	38±4	UP TO 250 FEED LIMITED	TWO 2HE SINGLE BEAM 2.90-3.1 3.20-3.4	ORTHOGONAL LINEAR	APPROX 1.6K AND 150K	FREQUENCY SWITCHING NOISE ADDING	BAND CHANGE REQUIRES FEED CHANGE. THIS TAKES 2-3 HOURS. FREQUENCY SWITCHING REQUIRES 50 MS BLANKING TIME.	ANDERSON (SIMMONS)
	4.6-5.0	DUAL CHANNEL COOLED HFET	28±5	UP TO 200 FEED LIMITED	ONE 2HE SINGLE BEAM 4.6-4.8	CIRCULAR	3K AND 150K		RECEIVER BAND LIMITED BY 4.6-4.8 GHz FEED. FREQUENCY SWITCHING REQUIRES 50 MS BLANKING TIME.	
6 CM, 7-FEED Rx	4.6-5.1	COOLED HFET FOURTEEN CHANNEL	35-45	500	7 CORRUGATED HORNS 3 HPBW APART	DUAL CIRCULAR	4K	NONE	CONTINUUM USE ONLY. TOTAL POWER RF DETECTION.	ANDERSON (SIMMONS)
CASSEGRAIN RECEIVERS	3.95-5.85	COOLED HFET	25K	300	CASSEGRAIN	DUAL LINEAR DUAL CIRCULAR	2-2.5K	FREQUENCY OR NUTATOR BEAM	FIXED 7 GHz LO FREQ. FEED LIMITS LOWER FREQ. OPERATION TO 4.7 GHz	NORROD (SIMON)
	8-10	COOLED HFET	30-35	300	CASSEGRAIN	DUAL CIRCULAR	2-4K	FREQUENCY OR NUTATOR BEAM		STENNES (DUNBRACK)
	18.0-26.5	COOLED HFET	30-60	300	CASSEGRAIN	DUAL CIRCULAR	3-7K	FREQUENCY OR NUTATOR BEAM	TWO BANDS: 18.0-22.5, 22.0-26.5 4 HOURS TO SWITCH BANDS	STENNES (DUNBRACK)
									BEAM SHIFT = 0-8 ARC MIN.	NUTATOR RATE 5 Hz MAXIMUM

NRAO FRONT-END STATUS 12 METER TELESCOPE

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FREQUENCY (GHz)	AMPLIFIER TYPE	RECEIVER TEMPERATURE (KELVIN)	CONTINUUM SENSITIVITY (JANSKY $\sqrt{\text{SEC}}$)	3 dB BANDWIDTH (MHz)	FEED TYPE	POLARIZATION	CALIBRATION VALUE	SWITCHING SYSTEM	REMARKS	PERSON(S) IN CHARGE
85-118	SIS MIXER	60-100 SSB	1.0	600	COOLED HORN-LENS + OFFSET PARABOLA	DUAL LINEAR	6 K	NUTATING SUBREFLECTOR	SINGLE-SIDEBAND MIXERS	PERFETTO
70-115	SIS MIXER	30 DSB	NOT MEASURED	600	8 CHANNEL	DUAL POLARIZATION 4 BEAMS	6 K	NUTATING SUBREFLECTOR	UNDER CONSTRUCTION COMPLETED DECEMBER 97	SHILLUE
130-170	SIS MIXER	100-180 SSB	NOT MEASURED	600	COOLED HORN-LENS + OFFSET PARABOLA	DUAL LINEAR	-	NUTATING SUBREFLECTOR	SINGLE-SIDEBAND MIXERS	PERFETTO
200-300	SIS MIXER	150-400 SSB	NOT MEASURED	600	COOLED HORN-LENS	DUAL LINEAR	-	NUTATING SUBREFLECTOR	SINGLE-SIDEBAND FILTER IMAGE TERMINATED IN COLD LOAD	PERFETTO
220-250	SIS MIXER	100 DSB	NOT MEASURED	600	8 FEEDS	LINEAR	-	NUTATING SUBREFLECTOR	8 BEAM RECEIVER	SHILLUE

NRAO FRONT-END STATUS VERY LARGE ARRAY

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FREQUENCY (MHz)	AMPLIFIER TYPE	SYSTEM TEMPERATURE (KELVIN)	3 dB BANDWIDTH (MHz)	FEED TYPE	POLARIZATION	CALIBRATION VALUE	SWITCHING SYSTEM	REMARKS	PERSON(S) IN CHARGE
74	UNCOOLED FET	~ 1200	0.8	PRIME	DUAL ORTHOGONAL CIRCULAR	120	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.	INSTALLED BETWEEN 000114 - 000619	MERTELY
306-343	UNCOOLED FET	150	3 MHz (LIMITED BY INTERFERENCE)	PRIME FOCUS	DUAL ORTHOGONAL CIRCULAR	10	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.		MERTELY
1340-1730	COOLED HFET	35	55	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	4	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.		MERTELY
4500-5000	COOLED HFET	60	55	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	4	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.		MERTELY
8000-8800	COOLED HFET	35	55	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	4	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.		MERTELY
14400-15400	COOLED FET	110	55	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	7	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.		MERTELY
22000-24000	COOLED HFET	130/35	55	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	10/4	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.	35K Toys ON ANT 5, 9, 10, 17, 18, 19, 20, 21, 23, 24, 26, 28	MERTELY
40000-50000	COOLED HFET	60	55	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	7	NOISE INJECTION, 9.6 Hz, 50 PERCENT CYCLE.	19 ANTENNAS: 3, 4, 6, 8, 10, 11, 12, 13, 14, 16, 18, 19, 20, 21, 22, 24, 25, 27, 28 EFFICIENCY LOW, DEPENDS ON FREQUENCY	MERTELY

NRAO FRONT-END STATUS VERY LONG BASELINE ARRAY

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FREQUENCY (MHz)	AMPLIFIER TYPE	SYSTEM TEMPERATURE (KELVIN)	3 dB BANDWIDTH (MHz)	FEED TYPE	POLARIZATION	CALIBRATION VALUE	SWITCHING SYSTEM	REMARKS	PERSON(S) IN CHARGE
312-342	UNCOOLED FET	200	30	PRIME FOCUS	DUAL ORTHOGONAL CIRCULAR	10	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
596-822	UNCOOLED FET	200	30 OR 4	PRIME FOCUS	DUAL ORTHOGONAL CIRCULAR	5	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
1350-1750	COOLED HFET	30	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	2	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
2150-2350	COOLED HFET	35	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	2	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
4800-5100	COOLED HFET	40	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	2	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
8000-8800	COOLED HFET	37	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	3	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
12000-15400	COOLED HFET	60	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	4	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
21700-24100	COOLED HFET	100	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	5	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
41000-45000	COOLED HFET	120	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	8	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.		MERTELY
82000-89000	COOLED HFET	140	128	CASSEGRAIN	DUAL ORTHOGONAL CIRCULAR	50	NOISE INJECTION, 80 Hz, 50 PERCENT CYCLE.	PT, LA, MK, FD	MERTELY

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