The Research Productivity of Small Telescopes and Space Telescopes

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We present statistics on the research productivity of astronomical telescopes. These were compiled by finding papers in which new data were presented, noting which telescopes were used, and then counting the number of papers, number of pages, and other statistics. The journals used were the *Astronomical Journal*, the *Astrophysical Journal* (including the Letters and Supplements), and the *Publications of the Astronomical Society of the Pacific*. We also compiled citations from the *Science Citation Index*. This work was designed to be similar to that of Trimble (1995), except that more recent journals (from 1995) and citations (from 1998) were used. We also did not restrict our sample to large telescopes only: we included all telescopes from which new data were presented, the smallest of which was a 0.1-m. The data were gathered by first-year work-study undergraduates, who were instructed to include data for all telescopes for which they found new data were included in the journals. A by-product of this research was therefore the relative productivity of ground-based versus space telescopes, and the relative productivity of radio and other telescopes across the spectrum, versus optical telescopes.

Keywords: Sociology of astronomy—space vehicles: instruments—telescopes

INTRODUCTION

Many small telescopes, with apertures of less than 3 m, are being closed at U.S. national and other observatories (e.g. ESO, NOAO). (See Table 1.) This is disturbing, since small telescopes are still capable of first-class science, often at far less cost than for large telescopes. For example, the MACHO, EROS, and OGLE gravitational microlensing projects all use 1.3-m or smaller telescopes (Alcock et al. 1995; Beaulieu et al. 1995; Paczynski et al. 1994). Mayor and Queloz (1995) used the 1.9-m telescope at Haute Provence for the first extrasolar planet detection, for a normal star; Marcy and Butler (1996) used the Lick 3-m and the 0.6-m coudé feed at Lick. Multi-longitude stellar seismology campaigns (Nather et al. 1990) mainly use telescopes in ‘‘the lowly 1-m class’’ (as in the words of R. E. Nather). The Center for Backyard Astrophysics is a worldwide network mainly composed of 10-inch amateur telescopes dedicated to photometry of cataclysmic variables, and has produced many results on accretion disk physics (e.g. Patterson 2001). A single automated 0.4-m telescope called ‘‘RoboScope,’’ in Indiana, a state not usually noted as an astronomical site, has been used to discover several unexpected accretion disk phenomena (Robertson, Honeycutt, & Turner 1995; Honeycutt, Robertson, & Turner 1998). Other examples of competitive small-telescope science include echo mapping of active galactic nuclei (Welsh & Horne 1991) and finding stellar-mass black holes (Shahbaz et al. 1994).

Small telescopes can hold their own with larger instruments since more time is available on them. This makes possible monitoring campaigns, areal surveys, and time-resolved campaigns, particularly if the telescopes are networked or automated—all difficult to carry out with larger telescopes, for which even small amounts of telescope time are in great demand.

DATA ON TELESCOPE PRODUCTIVITY

How productive are small telescopes? Three first-year undergraduates (RLL, SAK, YVT) spent a school year looking at papers in the *Astronomical Journal*, the *Astrophysical Journal* (including the main journal and the Letters), and the *Publications of the Astronomical Society of the Pacific*. A fourth, more advanced student (JMC) spent half a semester compiling similar data for the *ApJ Supplements*. These were the same journals used by Trimble (1995) in her study of the productivity of large, American optical telescopes.

TABLE 1. U.S. National Optical Astronomy Observatories (NOAO) Telescopes, in 1995 and in 2002

NOAO in 1995	NOAO in 2002
N (Kitt Peak, Arizona)	N (Kitt Peak and elsewhere)
4-m Mayall	8-m Gemini N (50%)
3.5-m WIYN (40%)	4-m Mayall
2.1-m	3.5-m WIYN (40%)
0.9-m coude feed	9.2-m Hobby-Eberly Telescope (7%)
0.9-m	6.5-m MMT (7%)
0.6-m Burrell Schmidt	2.1-m
1.3-m	0.9-m (25%)
S (Cerro Tololo, Chile)	S (Cerro Tololo & Cerro Pachon)
4-m Blanco	8-m Gemini S (50%)
1.5-m	4-m Blanco
0.9-m	4-m SOAR (30%) (not yet online)
1-m (50%)	1.5-m (25% planned)
0.6-m Curtis Schmidt	1.3-m 2MASS (25% planned)
0.6-m Lowell	1-m YALO (25% planned)
(0.4-m USNO)	0.9-m (25% planned)
(0.4-m MPI)	

TABLE 2. Top Telescopes, Sorted by Number of Papers (Weighted)

	Total Papers	f	Papers (Weighted)	Pages	Citations	Pages/ Paper	Citations/ Page	Citations/ Paper	Papers/ Area	Pages/ Area	Citations/ Area	
HST all instruments (2.4)	163	0.79	129.1	1306	484.4	10.11	0.37	3.75	28.5	288.7	107.1	space
VLA	129	0.73	94.7	952	250.0	10.05	0.26	2.64				radio
ROSAT (all instruments)	110	0.75	82.1	747	290.3	9.10	0.39	3.54				space
CTIO Blanco (4)	61	0.55	33.4	373	108.9	11.17	0.29	3.26	2.7	29.7	8.7	
KPNO Mayall (4)	56	0.57	32.1	415	142.4	12.93	0.34	4.44	2.6	33.0	11.3	
CGRO (all instruments)	35	0.83	29.1	251	148.0	8.63	0.59	5.09				space
ASTRO (all instruments)	34	0.84	28.6	194	56.5	6.79	0.29	1.98				space
CFHT (3.6)	44	0.63	27.8	294	101.9	10.57	0.35	3.66	2.7	28.9	10.0	
Palomar Hale (5)	42	0.61	25.5	386	95.3	15.11	0.25	3.73	1.3	19.6	4.9	
KPNO (2.1)	52	0.49	25.5	281	70.4	11.03	0.25	2.77	7.3	81.1	20.3	
MMT (4.5)	48	0.52	25.0	285	97.7	11.41	0.34	3.92	1.6	17.9	6.1	
NRAO (12) mm-wave	32	0.71	22.9	222	34.7	9.70	0.16	1.52	0.2	2.0	0.3	mm
Keck I & II (10)	27	0.81	22.0	125	106.3	5.71	0.85	4.84	0.3	1.6	1.4	
Steward (2.3)	37	0.51	18.9	190	55.2	10.07	0.29	2.92	4.5	45.8	13.3	
IUE (0.45)	33	0.57	18.9	227	62.7	12.01	0.28	3.32	118.7	1426.1	394.2	space
Lick Shane (3)	33	0.56	18.4	213	57.1	11.58	0.27	3.11	2.6	30.1	8.1	
Palomar (1.52)	27	0.60	16.1	211	44.3	13.11	0.21	2.75	8.9	116.2	24.4	
IRTF (3)	22	0.70	15.5	123	43.0	7.95	0.35	2.77	2.2	17.4	6.1	
AAT (3.9)	27	0.56	15.0	142	51.6	9.47	0.36	3.44	1.3	11.9	4.3	
Arecibo (305)	17	0.87	14.8	154	35.3	10.39	0.23	2.38	0.0	0.0	0.0	radio
JCMT (15) sub-mm	21	0.68	14.3	190	28.2	13.32	0.15	1.98	0.1	1.1	0.2	sub-mm
CTIO (1.5)	27	0.48	12.9	151	38.1	11.72	0.25	2.96	7.3	85.4	21.5	
CTIO (0.9)	25	0.51	12.8	152	25.4	11.94	0.17	1.99	19.6	234.2	39.0	
WHT (4.2)	21	0.60	12.6	101	31.0	8.01	0.31	2.46	0.9	7.3	2.2	
Caltech Sub-mm Obs (10) sub-mm	19	0.65	12.3	139	27.5	11.23	0.20	2.23	0.2	1.8	0.4	sub-mm
BIMA	16	0.77	12.3	86	26.3	7.02	0.31	2.14				mm
Yohkoh solar	15	0.78	11.8	109	32.0	9.26	0.29	2.72				solar
UKIRT (3.8)	20	0.57	11.5	104	57.0	9.05	0.55	4.96	1.0	9.2	5.0	
INT (2.5)	19	0.60	11.5	123	32.5	10.76	0.26	2.84	2.3	25.1	6.6	
KPNO (0.9)	25	0.43	10.8	112	36.0	10.33	0.32	3.33	16.6	171.9	55.4	
IRAM (30) mm-wave	18	0.59	10.7	84	46.9	7.81	0.56	4.38	0.0	0.1	0.1	mm
VLBA	19	0.56	10.6	110	38.1	10.37	0.35	3.61				radio
NRAO (43) radio	18	0.59	10.5	151	29.6	14.33	0.20	2.80	0.0	0.1	0.0	radio
KPNO (1.3)	21	0.49	10.3	116	26.0	11.32	0.22	2.53	7.7	87.5	19.6	
IRAS	16	0.64	10.3	91	30.4	8.89	0.33	2.97				space
Las Campanas Dupont (2.5)	19	0.53	10.0	169	39.1	16.86	0.23	3.91	2.0	34.3	8.0	
MDMO Hiltner (2.4)	21	0.45	9.6	100	21.4	10.46	0.21	2.24	2.1	22.1	4.7	
CTIO Yale (1.02)	20	0.46	9.3	107	16.2	11.53	0.15	1.75	11.3	130.7	19.9	
Kuiper Airborne (KAO) (0.91)	10	0.90	9.0	85	25.5	9.39	0.30	2.83	13.8	129.9	39.2	aircraft
McDonald (2.7)	15	0.57	8.5	124	37.6	14.50	0.30	4.40	1.5	21.6	6.6	
Other	797	0.48	405	4141	1107	10.22	0.27	2.73				
Total (or average)	2211	0.50	1322	13632	4088	10.31	0.30	3.09				

Following Trimble (1995), who studied telescope productivity in 1990–91, and Abt (1985), who did so for 1980–81, the students read every paper that appeared in 1995 well enough to answer the following questions: Were new data presented? Which telescopes were used? How many pages did each paper have? How many citations did each paper have? They also counted citations from the *Science Citation Index* for 1998, the most recent complete year available when the project was begun in 1999 Fall.

Identifying individual telescopes was quickly found to be a problem, because these were first-year students, who had not yet heard of many telescopes. The PI (FAR) therefore advised them to collect data for all telescopes. This included several types of instruments not considered by Trimble (1995): (1) Large and small telescopes (Trimble included only large [>2 m] telescopes); (2) Space telescopes (Trimble included only ground-based); (3) Instruments operating at radio and other wavelengths (Trimble included only optical/near-infrared). Therefore, as a by-product of examining small telescopes, we compiled productivity statistics for space-based and other telescopes.

American journals were chosen, to reflect American telescopes. These statistics are not necessarily reliable for other telescopes: for example, papers from British and Australian telescopes are often published in the *Monthly Notices of the Royal Astronomical Society*, and papers from European telescopes are often published in *Astronomy & Astrophysics*. Solar telescopes were included, but are probably underrepresented, as the journals *Solar Physics*, *Journal of Geophysical Research*, and *Icarus* were not used. Solar telescopes have an advantage, however, when correlations with collecting area are considered: the Sun is so bright, apertures often need not be large. Radio telescopes and interferometers were included, but have a disadvantage for any statistic in-

TABLE 3. Top Ground-based, Optical/IR Telescopes, Sorted by Number of Papers (Weighted)

	Total Papers	f	Papers (Weighted)	Pages	Citations	Pages/ Paper	Citations/ Page	Citations/ Paper	Papers/ Area	Pages/ Area	Citations/ Area
CTIO Blanco (4)	61	0.55	33.4	373	108.9	11.17	0.29	3.26	2.7	29.7	8.7
KPNO Mayall (4)	56	0.57	32.1	415	142.4	12.93	0.34	4.44	2.6	33.0	11.3
CFHT (3.6)	44	0.63	27.8	294	101.9	10.57	0.35	3.66	2.7	28.9	10.0
Palomar Hale (5)	42	0.61	25.5	386	95.3	15.11	0.25	3.73	1.3	19.6	4.9
KPNO (2.1)	52	0.49	25.5	281	70.4	11.03	0.25	2.77	7.3	81.1	20.3
MMT (4.5)	48	0.52	25.0	285	97.7	11.41	0.34	3.92	1.6	17.9	6.1
Keck I & II (10)	27	0.81	22.0	125	106.3	5.71	0.85	4.84	0.3	1.6	1.4
Steward (2.3)	37	0.51	18.9	190	55.2	10.07	0.29	2.92	4.5	45.8	13.3
Lick Shane (3)	33	0.56	18.4	213	57.1	11.58	0.27	3.11	2.6	30.1	8.1
Palomar (1.52)	27	0.60	16.1	211	44.3	13.11	0.21	2.75	8.9	116.2	24.4
IRTF (3)	22	0.70	15.5	123	43.0	7.95	0.35	2.77	2.2	17.4	6.1
AAT (3.9)	27	0.56	15.0	142	51.6	9.47	0.36	3.44	1.3	11.9	4.3
CTIO (1.5)	27	0.48	12.9	151	38.1	11.72	0.25	2.96	7.3	85.4	21.5
CTIO (0.9)	25	0.51	12.8	152	25.4	11.94	0.17	1.99	19.6	234.2	39.0
WHT (4.2)	21	0.60	12.6	101	31.0	8.01	0.31	2.46	0.9	7.3	2.2
UKIRT (3.8)	20	0.57	11.5	104	57.0	9.05	0.55	4.96	1.0	9.2	5.0
INT (2.5)	19	0.60	11.5	123	32.5	10.76	0.26	2.84	2.3	25.1	6.6
KPNO (0.9)	25	0.43	10.8	112	36.0	10.33	0.32	3.33	16.6	171.9	55.4
KPNO (1.3)	21	0.49	10.3	116	26.0	11.32	0.22	2.53	7.7	87.5	19.6
Las Campanas Dupont (2.5)	19	0.53	10.0	169	39.1	16.86	0.23	3.91	2.0	34.3	8.0
MDMO Hiltner (2.4)	21	0.45	9.6	100	21.4	10.46	0.21	2.24	2.1	22.1	4.7
CTIO Yale (1.02)	20	0.46	9.3	107	16.2	11.53	0.15	1.75	11.3	130.7	19.9
McDonald (2.7)	15	0.57	8.5	124	37.6	14.50	0.30	4.40	1.5	21.6	6.6
ESO NTT (3.5)	14	0.60	8.5	64	18.0	7.55	0.28	2.13	0.9	6.6	1.9
Las Campanas Swope (1.02)	13	0.65	8.4	95	25.8	11.33	0.27	3.06	10.3	116.8	31.5
Lowell Perkins (1.8)	15	0.52	7.8	97	19.7	12.49	0.20	2.54	3.1	38.1	7.7
KPNO coude feed (0.9)	12	0.64	7.7	130	18.0	16.93	0.14	2.34	11.8	200.5	27.7
Mt. Laguna (1.0)	10	0.76	7.6	54	9.9	7.16	0.18	1.31	9.7	69.2	12.6
UHawaii (2.2)	12	0.62	7.4	95	58.2	12.80	0.61	7.84	2.0	25.0	15.3
McDonald (2.1)	12	0.59	7.0	89	12.8	12.70	0.14	1.82	2.0	25.8	3.7
McGraw-Hill (1.3)	13	0.53	6.9	54	11.3	7.90	0.21	1.64	5.2	40.8	8.5
Burrell Schmidt (0.6)	10	0.63	6.3	55	9.3	8.67	0.17	1.47	22.4	194.2	33.0
ESO (2.2)	10	0.57	5.7	53	13.2	9.24	0.25	2.32	1.5	13.9	3.5
Whipple (1.2)	12	0.47	5.6	52	12.0	9.28	0.23	2.15	4.9	45.8	10.6
Siding Spring (2.3)	10	0.55	5.5	63	29.0	11.46	0.46	5.24	1.3	15.3	7.0
Kiso Schmidt (1.05)	7	0.70	4.9	54	10.0	10.94	0.19	2.04	5.7	61.9	11.5
McMath-Pierce (2.1)	7	0.65	4.6	60	17.0	13.16	0.28	3.71	1.3	17.4	4.9
DAO (1.8)	9	0.49	4.4	55	7.3	12.36	0.13	1.66	1.7	21.4	2.9
Whipple (1.5)	10	0.44	4.4	50	19.0	11.35	0.38	4.34	2.5	28.1	10.8
Other	390	0.44	175	1619	391	9.25	0.24	2.24			
Total (or average)	1275	0.46	672	7135	2017	10.61	0.28	3.00			

volving telescope collecting area, since they are so large. They were not included in comparisons involving area anyway, because it is often unclear how to make fair comparisons involving interferometers.

For each telescope, the total number of papers was counted, listed in Table 2 as ''total papers.'' Table 3 lists similar data, but only for ground-based, optical/near-IR telescopes. Since many papers include new data taken from many telescopes, following Trimble (1995), we computed the weighted number of papers, listed in Tables 2 and 3 as ''papers (weighted),'' by assigning equal weight to each telescope (large and small) used in each project. This weighted number of papers means that if three telescopes were used in one paper, each telescope is credited with 1/3 of a paper, for that paper. Whether this is a fair comparison between telescopes is an open question. Giving equal weights may over-count or under-count the relative importance of small telescopes. Some research would not be possible without large telescopes, e.g. high-resolution spectroscopy of faint objects. Other research would never be carried out without small telescopes, e.g. surveys or time-resolved campaigns. Since we wanted our results to be comparable to those of Trimble (1995) and Abt (1985), we retained this convention.

The statistic f, included in Tables 2 and 3, is papers (weighted) divided by the total number of papers. It shows how often a given telescope is used in collaborative projects, involving other telescopes. If $f = 1$, the telescope is always used only by itself. If $f \ll 1$, it is often used in large projects involving many telescopes. Figure 1 shows f plotted against aperture for all ground-based, optical/near-infrared telescopes. Figure 2 shows the same, for small telescopes only. There is one outlying point from the 10-m Keck telescope, which has the highest value of this statistic for any instrument, $f = 0.81$. This might have been expected, for a uniquely large and (in 1995) relatively new instrument: much commissioning science, involving only the unique ca-

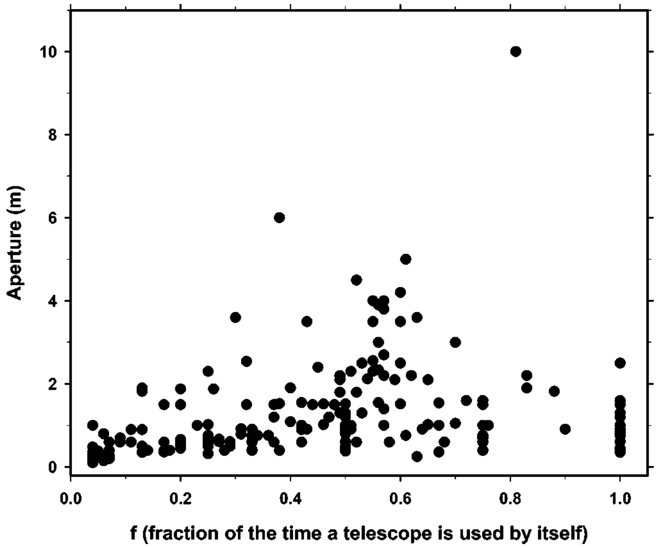

FIG. 1. Ground-based, optical/near-IR telescopes.

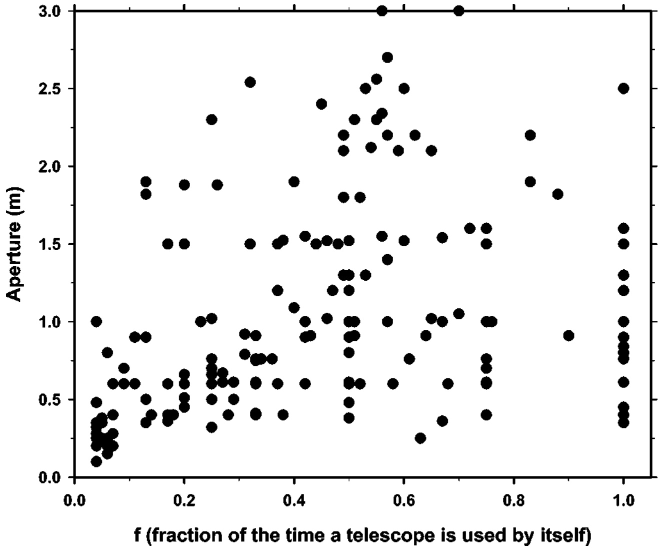

FIG. 2. Same as Figure 1, but for small telescopes only.

TABLE 4. Space Instruments, Sorted by Number of Papers (Weighted)

	Total Papers	*f*	Papers (Weighted)	Pages	Citations	Pages/ Paper	Citations/ Page	Citations/ Paper
HST all instruments (2.4)	163	0.79	129.1	1306	484.4	10.11	0.37	3.75
ROSAT (all instruments)	110	0.75	82.1	747	290.3	9.10	0.39	3.54
CGRO (all instruments)	35	0.83	29.1	251	148.0	8.63	0.59	5.09
ASTRO (all instruments)	34	0.84	28.6	194	56.5	6.79	0.29	1.98
IUE (0.45)	33	0.57	18.9	227	62.7	12.01	0.28	3.32
Yohkoh solar	15	0.78	11.8	109	32.0	9.26	0.29	2.72
IRAS	16	0.64	10.3	91	30.4	8.89	0.33	2.97
ASCA	8	0.81	6.5	44	36.5	6.77	0.83	5.62
EUVE (all instruments)	8	0.67	5.4	51	17.1	9.37	0.34	3.18
EXOSAT (all instruments)	11	0.36	4.0	37	9.2	9.35	0.25	2.32
SIGMA/GRANAT	5	0.73	3.7	26	7.7	7.09	0.29	2.09
SAMPEX	4	0.78	3.1	20	5.0	6.28	0.25	1.60
Ginga	3	0.83	2.5	20	2.5	7.80	0.13	1.00
Atlas-1 (FAUST)	3	0.83	2.5	22	6.0	8.80	0.27	2.40
ORFEUS (1)	4	0.58	2.3	22	4.8	9.50	0.22	2.07
HEAO A-1	4	0.46	1.8	24	4.7	12.82	0.20	2.55
Einstein (all instruments)	5	0.26	1.3	4	0.9	3.32	0.22	0.73
Spacelab 2 solar	1	1.00	1.0	9	1.0	9.00	0.11	1.00
NASA Sounding rocket	1	1.00	1.0	7	0.0	7.00	0.00	0.00
ONR-604	1	1.00	1.0	11	0.0	11.00	0.00	0.00
Voyager 1	1	1.00	1.0	3	0.0	3.00	0.00	0.00
COBE (all instruments)	1	1.00	1.0	12	17.0	12.00	1.42	17.00
Solar Max (all instruments)	1	1.00	1.0	11	0.0	11.00	0.00	0.00
UARS all instruments	1	1.00	1.0	4	5.0	4.00	1.25	5.00
STS-39 Far-UV Cameras	1	1.00	1.0	21	1.0	21.00	0.05	1.00
GOES	1	0.50	0.5	8	0.5	16.00	0.06	1.00
Spartan 201 (solar)	1	0.50	0.5	2	6.0	4.00	3.00	12.00
Voyager 2	1	0.25	0.3	1	0.0	5.00	0.00	0.00
Uhuru	1	0.17	0.2	2	0.3	9.00	0.22	2.00
Ariel V	1	0.17	0.2	2	0.3	9.00	0.22	2.00
Salyut 6	1	0.13	0.1	1	0.0	5.00	0.00	0.00
S81-1	1	0.13	0.1	1	0.0	5.00	0.00	0.00
Spacelab 1	1	0.13	0.1	1	0.0	5.00	0.00	0.00
Spacelab 3	1	0.13	0.1	1	0.0	5.00	0.00	0.00
Cosmos 2022	1	0.13	0.1	1	0.0	5.00	0.00	0.00
Total (or average)	479	0.62	353	3288	1230	9.31	0.37	3.48

TABLE 5. Top Radio Telescopes, Sorted by Number of Papers (Weighted)

	Total Papers	f	Papers (Weighted)	Pages	Citations	Pages/ Paper	Citations/ Page	Citations/ Paper	
VLA	129	0.73	94.7	952	250.0	10.05	0.26	2.64	radio
NRAO (12) mm-wave	32	0.71	22.9	222	34.7	9.70	0.16	1.52	mm
Arecibo (305)	17	0.87	14.8	154	35.3	10.39	0.23	2.38	radio
JCMT (15) sub-mm	21	0.68	14.3	190	28.2	13.32	0.15	1.98	sub-mm
Caltech Submillimeter Obs (10)	19	0.65	12.3	139	27.5	11.23	0.20	2.23	sub-mm
BIMA	16	0.77	12.3	86	26.3	7.02	0.31	2.14	mm
IRAM (30) mm-wave	18	0.59	10.7	84	46.9	7.81	0.56	4.38	mm
VLBA	19	0.56	10.6	110	38.1	10.37	0.35	3.61	radio
NRAO (43) radio	18	0.59	10.5	151	29.6	14.33	0.20	2.80	radio
Nobeyama (45) radio	8	0.85	6.8	61	7.5	8.98	0.12	1.10	radio
Five College (FCRAO) (14) radio	11	0.57	6.3	133	27.7	21.11	0.21	4.38	radio
Lovell (76) radio	11	0.57	6.3	133	27.7	21.11	0.21	4.38	radio
Parkes (64) radio	11	0.57	6.3	133	27.7	21.11	0.21	4.38	radio
Owens Valley mm array	10	0.63	6.3	36	33.8	5.77	0.93	5.37	mm
Nobeyama mm array (NMA)	7	0.76	5.3	41	16.0	7.66	0.39	3.00	mm
Haystack (37) radio	10	0.49	4.9	30	13.1	6.05	0.44	2.67	radio
ATCA	6	0.78	4.7	38	14.0	8.21	0.37	3.00	radio
Effelsberg (100) radio	12	0.36	4.3	47	15.6	10.86	0.34	3.65	radio
Australia Telescope (ATNF)	6	0.48	2.9	25	7.5	8.60	0.30	2.60	radio
Westerbork radio array	8	0.27	2.1	27	9.7	12.79	0.36	4.55	radio
Owens Valley (10.4) radio	4	0.49	2.0	16	2.7	7.95	0.17	1.36	radio
DRAO radio array	3	0.48	1.5	13	3.3	8.97	0.25	2.28	radio
Merlin array	6	0.24	1.4	17	5.9	11.92	0.35	4.13	radio
Molongo Obs Synth Telescope (MOST)	2	0.67	1.3	14	2.0	10.50	0.14	1.50	radio
Green Bank Interferometer radio	2	0.67	1.3	12	5.3	8.75	0.46	4.00	radio
ESO Swedish (15) sub-mm	2	0.67	1.3	11	4.0	8.25	0.36	3.00	sub-mm
RATAN RT-22 radio	1	1.00	1.0	9	2.0	9.00	0.22	2.00	radio
Nagoya (4) mm-wave	1	1.00	1.0	5	0.0	5.00	0.00	0.00	mm
JPL Goldstone radar	1	1.00	1.0	4	1.0	4.00	0.25	1.00	radar
Python (0.75) sub-mm	1	1.00	1.0	4	3.0	4.00	0.75	3.00	sub-mm
Hartbeesthoek (26) radio	1	1.00	1.0	8	3.0	8.00	0.38	3.00	radio
Tokyo-Nobeyama (0.6) sub-mm	1	1.00	1.0	10	3.0	10.00	0.30	3.00	sub-mm
Owens Valley (40) radio	5	0.17	0.9	13	6.1	14.71	0.47	6.93	radio
Deep Space Network (DSN) radio (70)	2	0.35	0.7	5	5.6	7.14	1.12	8.00	radio
Hat Creek (26) radio	1	0.50	0.5	5	5.0	9.00	1.11	10.00	radio
Inst Argentino de Radioastr (30)	1	0.50	0.5	3	0.5	6.00	0.17	1.00	radio
U Michigan radio (20)	2	0.25	0.5	8	2.7	15.67	0.34	5.33	radio
AT&T Bell Labs (7) radio	2	0.20	0.4	6	3.2	15.50	0.52	8.00	radio
Cambridge One-Mile radio	1	0.33	0.3	9	1.3	27.00	0.15	4.00	radio
Cambridge 5 km radio	1	0.33	0.3	9	1.3	27.00	0.15	4.00	radio
Algonquin radio	1	0.33	0.3	7	0.7	21.00	0.10	2.00	radio
Medicina radio (32)	2	0.15	0.3	6	1.4	21.75	0.22	4.81	radio
Noto radio (32)	2	0.15	0.3	6	1.4	21.75	0.22	4.81	radio
Nancay radio	1	0.25	0.3	2	0.3	7.00	0.14	1.00	radio
Robledo radio (34)	1	0.20	0.2	2	0.4	8.00	0.25	2.00	radio
DSN (34) radio	1	0.20	0.2	3	2.6	15.00	0.87	13.00	radio
Total (or average)	437	0.56	280	2996	784	10.71	0.26	2.80	

pabilities of that instrument, was being done at the time. If one excludes the point from Keck, both Figures 1 and 2 show only a slight correlation ($R < 0.1$ for a linear regression) between f and aperture (or area) for ground-based telescopes, so perhaps it is fair to give equal weights to the contributions of different telescopes. Large (4-m) and medium-size (2–3-m) telescopes were most often used with other telescopes, with $0.5 < f < 0.6$, giving the distribution a triangular shape. Small (0.3–1-m) telescopes have a nearly uniform distribution in f, with the largest spread in f of any kind of instruments, showing their versatility: they are used both by themselves ($f = 0.76$ for the Mt. Laguna 1.0-m) and in combination with other telescopes ($f = 0.43$ for the KPNO 0.9-m). The clustering of points in the bottom-right corner of Figure 2 shows that the very smallest telescopes (0.1–0.4-m) are usually, but not always, used in large campaigns. There were only six campaigns involving ten or more telescopes: one was a VLBI radio campaign (Xu et al. 1995), two were multiwavelength campaigns on AGNs (Courvoisier et al. 1995; McDowell et al. 1995), one was a Whole Earth Telescope, multi-longitude seismological campaign (Kawaler et al. 1995), and two were done primarily with small university and amateur telescopes, organized by professionals (Hall et al. 1995; Kaye et al. 1995).

Statistics involving areas of the telescopes were also compiled (see Tables 2, 3, 12, and 13). This is of interest since

TABLE 6. Summary of Data from the 1995 *AJ*, *ApJ* (Including Letters and Supplements), and *PASP*

	All 292 Telescopes of all Kinds (Table 2)	Telescopes with > 9.0 Citations (Table 2) (1)	From Trimble (1995) (2)	Space Instruments (Table 5) (3)	Radio Telescopes (Table 6) (4)
Total papers:	2211	1399		479	437
Papers (weighted):	1322	908	663	353	280
Pages:	13632	9367	7290	3288	2996
Citations:	4088	2943	2705	1230	784
Mean pages per paper:	10.31	10.30	11.00	9.31	10.71
Mean citations per page:	0.30	0.31	0.27	0.37	0.26
Mean citations per paper:	3.09	3.24	4.08	3.48	2.80

(1) These 39 telescopes include:
11 large ground-based optical/IR telescopes (10-m to 3-m),
11 small ground-based optical/IR telescopes (2.5-m to 0.9-m),
9 ground-based radio (4), mm-wave (3), or sub-mm (2) telescopes,
6 space instruments (*HST, ROSAT, CGRO, ASTRO, IUE, IRAS*),
One solar instrument (the *Yohkoh* spacecraft),
One other instrument (Kuiper Airborne Observatory).
(2) Trimble (1995) included results only from 16 large (> 2 m), optical/near-IR telescopes, all with > 9 citations in 1990-91.
(3) All cases are between 20–30% of the total for each.
(4) Including mm, sub-mm, and longer wavelengths.

Abt (1980) noted that telescope costs often correlate with collecting area.

RESULTS

The journals under review and published in 1995 contained new data from 292 telescopes of all kinds. The smallest was a 0.1-m (4-inch) at Dublin Observatory in Delaware (Hall et al. 1995). There were 2211 total papers, 1322 weighted papers, and 4088 total citations, for all telescopes.

In 1995, space instruments produced 354 weighted papers, 480 total papers, 3294 pages, and 1233 citations. We summarize the data from space instruments in Table 4. Since three of four Nobel Prizes given for observational astronomy were for radio observations (1974 to Hewish and Ryle; 1978

TABLE 7. Top Telescopes, Sorted by Number of Pages

	Pages		Pages
HST all instruments (2.4)	1306 space	AAT (3.9)	142
VLA	952 radio	Caltech Submillimeter Obs (10) sub-mm	139 sub-mm
ROSAT (all instruments)	747 space	Lovell (76) radio	133 radio
KPNO Mayall (4)	415	Parkes (64) radio	133 radio
Palomar Hale (5)	386	KPNO coude feed (0.9)	130
CTIO Blanco (4)	373	Keck I & II (10)	125
CFHT (3.6)	294	McDonald (2.7)	124
MMT (4.5)	285	INT (2.5)	123
KPNO (2.1)	281	IRTF (3)	123
CGRO (all instruments)	251 space	KPNO (1.3)	116
IUE (0.45)	227 space	KPNO (0.9)	112
NRAO (12) mm-wave	222 mm	VLBA	110 radio
Lick Shane (3)	213	Yohkoh solar	109 solar
Palomar (1.52)	211	CTIO Yale (1.02)	107
ASTRO (all instruments)	194 space	UKIRT (3.8)	104
Steward (2.3)	190	WHT (4.2)	101
JCMT (15) sub-mm	190 sub-mm	MDMO Hiltner (2.4)	100
Las Campanas Dupont (2.5)	169	Other	3956
Arecibo (305)	154 radio		
CTIO (0.9)	152		
NRAO (43) radio	151 radio		
CTIO (1.5)	151		
		Total	13632

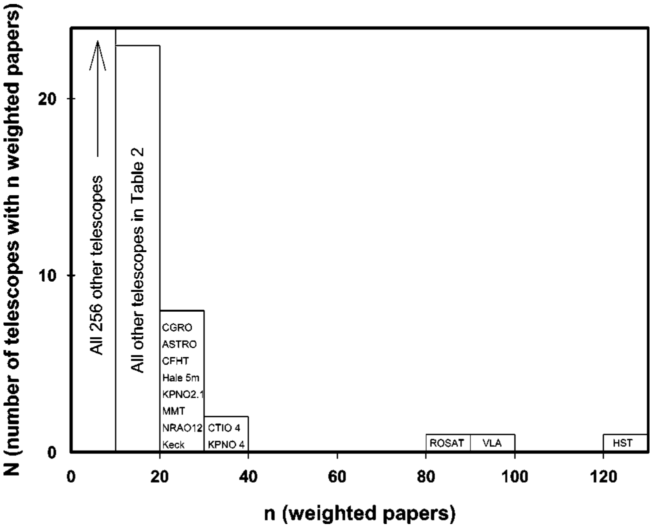

FIG. 3. The research productivity of telescopes.

to Penzias and Wilson; 1993 to Hulse and Taylor; the 2002 prize went to Giacconi for X-ray astronomy, and to Davis and Koshiba for neutrino astronomy), we also summarize results from radio telescopes, including millimeter- and submillimeter wave, in Table 5. We did not subdivide wavebands further, however, because where they begin and end is often a matter of opinion, driven by detector technology, e.g., 7800–10,000 Ångströms was called near-infrared in the days of photography (Keenan & Hynek 1950), but now is often called visible light since CCDs can detect it, even though human eyes cannot.

Table 3 lists telescopes with > 9.0 citations, following Trimble (1995), sorted by number of papers. The data from these 39 instruments are summarized in Table 6, along with those of Trimble (1995). Most of these data are similar, so that between 1990–91 (Trimble's sample) and 1995 (ours), use patterns between telescopes changed relatively little. The main difference was that the total number of papers published for our sample was 1.3 times larger. This is not difficult to understand: although Trimble's sample covered a time span 1.5 times longer than ours, it included data from only 16 telescopes.

Table 2 shows that *Hubble Space Telescope* is significantly more productive than any other instrument, with regard to numbers of papers, pages, and citations. It also does well with statistics normalized by telescope area (Table 12). Table 2 also shows that other expensive facilities, such as the VLA, *ROSAT*, and *CGRO* are also among the most productive facilities.

Tables 7 (number of pages) and 8 (number of citations) correlate with Table 2 (total and weighted number of papers), since these tables include many of the same instruments (34/38, or 90%, for Table 7, and 33/38, or 87%, for Table 8). That the numbers of papers, pages, and citations would all correlate with each other is not surprising: Abt (1984) found this too. So did science historian Derek de Solla Price, who showed that quantity and quality often go together in scientific publication of all kinds (Price 1972, 1986). In particular, Price showed that on average, scientists in all fields who are doing the most important work are most often the scientists doing the most work, and that the most productive scientists are also the scientists that most often produce the most important science. This has also been confirmed by Abt (2000) and by Burstein (2000).

A useful model for this, elaborated on by Price, is Alfred J. Lotka's Law of Scientific Productivity, which states that the number of scientists with just *n* publications is proportional to $1/n^2$ (Lotka 1926; Price 1972; Price 1986, p. 38). Our data, plotted in Figure 3, show that this roughly applies

TABLE 8. Top Telescopes, Sorted by Number of Citations

	Citations		Citations
HST all instruments (2.4)	484.4 space	VLBA	38.1 radio
ROSAT (all instruments)	290.3 space	CTIO (1.5)	38.1
VLA	250.0 radio	McDonald (2.7)	37.6
CGRO (all instruments)	148.0 space	ASCA	36.5 space
KPNO Mayall (4)	142.4	KPNO (0.9)	36.0
CTIO Blanco (4)	108.9	Arecibo (305)	35.3 radio
Keck I & II (10)	106.3	NRAO (12) mm-wave	34.7 mm
CFHT (3.6)	101.9	INT (2.5)	32.5
MMT (4.5)	97.7	Yohkoh solar	32.0 solar
Palomar Hale (5)	95.3	WHT (4.2)	31.0
KPNO (2.1)	70.4	IRAS	30.4 space
IUE (0.45)	62.7 space	NRAO (43) radio	29.6 radio
UHawaii (2.2)	58.2	Siding Spring (2.3)	29.0
Lick Shane (3)	57.1	JCMT (15) sub-mm	28.2 sub-mm
UKIRT (3.8)	57.0	Five College (FCRAO) (14) radio	27.7 radio
ASTRO (all instruments)	56.5 space	Lovell (76) radio	27.7 radio
Steward (2.3)	55.2	Parkes (64) radio	27.7 radio
AAT (3.9)	51.6	Other	1035
IRAM (30) mm-wave	46.9 mm		
Palomar (1.52)	44.3		
IRTF (3)	43.0		
Las Campanas Dupont (2.5)	39.1		
		Total (or average)	4088

TABLE 9. Top Telescopes, Sorted by Mean Pages/Paper

	Pages/ Paper		Pages/ Paper
Onsala (26)	52.0	Torun (0.9)	18.0
VU-TSU (0.4)	37.8	Lick CAT (0.6)	17.6
NRAO (91) radio	36.2 radio	CASLEO (2.2)	17.2
Cambridge One-Mile radio	27.0 radio	Yale-Columbia (0.66)	17.0
Cambridge 5 km radio	27.0 radio	Yale Southern (0.51)	17.0
Palomar (0.45) Schmidt	24.0	KPNO coude feed (0.9)	16.9
UNM Capilla Peak (0.61)	24.0	Las Campanas Dupont (2.5)	16.9
MSU (0.6)	24.0	Mt. Wilson (2.54)	16.4
Okayama (1.88)	23.0	GOES	16.0 space
Medicina radio (32)	21.8 radio	Beijing A O (0.6)	16.0
Noto radio (32)	21.8 radio	Ege Univ. Obs. (0.48)	16.0
Five College (FCRAO) (14) radio	21.1 radio	U Michigan radio (20)	15.7 radio
Lovell (76) radio	21.1 radio	AT&T Bell Labs (7) radio	15.5 radio
Parkes (64) radio	21.1 radio	UK Schmidt (1.2)	15.2
STS-39 Far-UV Cameras	21.0 space	Pine Bluff (0.91)	15.2
James Gregory (0.9)	21.0	Palomar Hale (5)	15.1
Algonquin radio	21.0 radio	DSN (34) radio	15.0 radio
Mt. Wilson (1.524)	18.7	Owens Valley (40) radio	14.7 radio
MIRA (0.9)	18.0	McDonald (2.7)	14.5
Table Mt (0.5)	18.0	Other	8.4
Cima Ekar (1.82)	18.0		
		Total	10.1

TABLE 10. Top Telescopes, Sorted by Citations/Page. This May or May Not Be a Useful Benchmark: Note the Small Number of Papers Often Involved

	Citations/ Page	Papers (Weighted)	Pages	Citations	
Spartan 201 (solar)	3.00	0.5	2	6.0	solar
CANGAROO (3.8) gamma ray	2.75	0.5	2	5.5	gamma-ray
COBE (all instruments)	1.42	1.0	12	17.0	space
UARS all instruments	1.25	1.0	4	5.0	space
Mt. Stromlo (1.3)	1.19	2.0	16	19.0	
Deep Space Network (DSN) radio (70)	1.12	0.7	5	5.6	radio
Hat Creek (26) radio	1.11	0.5	5	5.0	radio
Mees Solar coronagraph (0.25)	1.06	0.8	6	6.3	solar
Balloon-borne IR Carbon Explorer (BICE)	1.00	1.0	4	4	balloon
Teide (0.8)	1.00	0.5	2	2.0	
Owens Valley mm array	0.93	6.3	36	33.8	mm
DSN (34) radio	0.87	0.2	3	2.6	radio
Keck I & II (10)	0.85	22.0	125	106.3	
ASCA	0.83	6.5	44	36.5	space
Swedish solar VT (0.48)	0.81	2.0	16	13.0	
ESO Dutch (0.9)	0.79	0.8	6	4.5	
Python (0.75) sub-mm	0.75	1.0	4	3.0	sub-mm
Mt. Wilson (1.524)	0.73	0.8	14	10.3	
Mt. Wilson (2.54)	0.70	1.0	16	10.9	
FL Whipple (10) gamma ray	0.66	2.5	22	14.3	gamma-ray
UHawaii (2.2)	0.61	7.4	95	58.2	
CGRO (all instruments)	0.59	29.1	251	148.0	space
CBA East (0.66)	0.59	0.5	6	3.3	
Brigham Young Obs (BYO) (0.6)	0.58	0.8	4	2.5	
Stony Brook (0.36)	0.57	0.2	1	0.7	
IRAM (30) mm-wave	0.56	10.7	84	46.9	mm
ARGO balloon (1.2)	0.56	1.0	9	5.0	balloon
UKIRT (3.8)	0.55	11.5	104	57.0	
AT&T Bell Labs (7) radio	0.52	0.4	6	3.2	radio
NSO VTT solar	0.50	4.0	24	12.0	solar
Byurakan (1.0) Schmidt	0.50	1.0	14	7.0	
Kitt Peak NSO VT solar	0.50	1.0	6	3.0	solar
U. Missouri (0.35)	0.50	1.0	4	2.0	
Suhora (0.6)	0.50	0.3	2	0.8	
Kavalur (2.3)	0.50	0.3	2	0.8	
Foggy Bottom (0.4)	0.50	0.2	1	0.7	
Loiano (1.5)	0.50	0.2	1	0.7	
Kagoshima Space Center (0.6)	0.50	0.2	1	0.7	
Asiago Schmidt (0.40)	0.50	0.3	1	0.3	
Catania Schmidt (0.4)	0.50	0.3	1	0.3	
Other	0.27	1200	12673	3424	
Total (or average)	0.30	1322	13632	4088	

TABLE 11. Top Telescopes, Sorted by Citations/Paper. Again, Small Numbers of Papers Are Often Involved: But Note Also the Highly Cited Papers

	Citations/ Paper	Papers (Weighted)	Pages	Citations	
COBE (all instruments)	17.00	1.0	12	17.0	space
Mt. Wilson (1.524)	13.67	0.8	14	10.3	
DSN (34) radio	13.00	0.2	3	2.6	radio
Spartan 201 (solar)	12.00	0.5	2	6.0	solar
Mt. Wilson (2.54)	11.42	1.0	16	10.9	
CANGAROO (3.8) gamma ray	11.00	0.5	2	5.5	gamma-ray
Onsala (26)	11.00	0.1	5	1.0	
Hat Creek (26) radio	10.00	0.5	5	5.0	radio
Mt. Stromlo (1.3)	9.50	2.0	16	19.0	
Deep Space Network (DSN) radio (70)	8.00	0.7	5	5.6	radio
AT&T Bell Labs (7) radio	8.00	0.4	6	3.2	radio
UHawaii (2.2)	7.84	7.4	95	58.2	
Mees Solar coronagraph (0.25)	7.60	0.8	6	6.3	solar
UK Schmidt (1.2)	7.47	3.0	45	22.1	
Byurakan (1.0) Schmidt	7.00	1.0	14	7.0	
Owens Valley (40) radio	6.93	0.9	13	6.1	radio
CBA East (0.66)	6.67	0.5	6	3.3	
VU-TSU (0.4)	6.60	0.6	21	3.7	
Swedish solar VT (0.48)	6.50	2.0	16	13.0	
MSU (0.6)	6.00	0.5	12	3.0	
Cima Ekar (1.82)	6.00	0.1	2	0.8	
Torun (0.9)	6.00	0.1	2	0.8	
FL Whipple (10) gamma ray	5.73	2.5	22	14.3	gamma-ray
ASCA	5.62	6.5	44	36.5	space
ESO Dutch (0.9)	5.40	0.8	6	4.5	
Owens Valley mm array	5.37	6.3	36	33.8	mm
U Michigan radio (20)	5.33	0.5	8	2.7	radio
Siding Spring (2.3)	5.24	5.5	63	29.0	
CGRO (all instruments)	5.09	29.1	251	148.0	space
ARGO balloon (1.2)	5.00	1.0	9	5.0	balloon
UARS all instruments	5.00	1.0	4	5.0	space
ISAS (1.3)	5.00	0.5	6	2.5	
James Gregory (0.9)	5.00	0.5	11	2.5	
Yale-Columbia (0.66)	5.00	0.2	3	1.0	
Yale Southern (0.51)	5.00	0.2	3	1.0	
UKIRT (3.8)	4.96	11.5	104	57.0	
Keck I & II (10)	4.84	22.0	125	106.3	
Medicina radio (32)	4.81	0.3	6	1.4	radio
Noto radio (32)	4.81	0.3	6	1.4	radio
Westerbork radio array	4.55	2.1	27	9.7	radio
Other	2.83	1207	12580	3416	
Total (or average)	3.09	1322	13632	4088	

to telescopes, too, although the curve is steeper, fitting a $1/n^{3.4+0.1}$ law. But then, as Price (1986) points out, the high scorers will be exceptions anyway, so that excluding the *HST*, VLA, and *ROSAT* data, our data fit a $1/n^{1.5+0.1}$ law.

Table 9 (pages/paper), Table 10 (citations/page) and Table 11 (citations/paper) all show a mix of instruments significantly different from Tables 2 and 7-8. This is probably due to these statistics being capable of being strongly affected by single, highly cited papers, from instruments with relatively few total papers. Still, Table 10 (citations/page) features well-known, highly cited work, e.g., the MACHO project with the 1.3-m at Mount Stromlo (Alcock et al. 1995), and the discovery of Trans-Neptunian Objects, with the U. Hawaii 2.2-m (Jewitt & Luu 1995).

Table 12 lists papers, pages, and citations, all divided by telescope collecting area. A small space telescope, the 0.45-m *International Ultraviolet Explorer*, leads this list. *Hubble Space Telescope* also places high on this list, reassuring because it is such an expensive facility. Still, Table 12 is dominated by smaller instruments, as is Table 13, which lists similar data for ground-based optical/near-infrared telescopes only. These smaller instruments are often automated (e.g., the 0.25-m APT on Mt. Hopkins, or Indiana University's 0.4-m RoboScope) or networked or both (e.g., telescopes participating in Center for Backyard Astrophysics [CBA] campaigns). Nationally run Schmidt telescopes, such as the Burrell Schmidt on Kitt Peak and the CTIO Curtis Schmidt, place well in Tables 12 and 13. So do small, nationally run telescopes, such as the CTIO 0.9-m and the KPNO 0.9-m. The KPNO 2.1-m, CTIO 1.5-m, Palomar 1.52-m, and Steward 2.3-m (which, although productive, is always behind the public KPNO 2.1-m on the same mountain) are among the few others common to Table 12 and Tables 2 and 7-8.

TABLE 12. Top Telescopes, Sorted by Papers/Collecting Area. Radio Telescopes and Interferometers of All Kinds Have Been Excluded

	Papers/ Area	Pages/ Area	Citations/ Area	Total Papers	
IUE (0.45)	118.7	1426.1	394.2	33	space
Mt. Hopkins APT (0.25)	50.9	336.1	40.7	4	
HST all instruments (2.4)	28.5	288.7	107.1	163	space
Burrell Schmidt (0.6)	22.4	194.2	33.0	10	
CTIO (0.9)	19.6	234.2	39.0	25	
Mees Solar coronagraph (0.25)	17.0	122.2	129.0	2	solar
KPNO (0.9)	16.6	171.9	55.4	25	
Kuiper Airborne (KAO) (0.91)	13.8	129.9	39.2	10	aircraft
CTIO Lowell (0.6)	13.5	134.0	27.4	9	
CBA West (0.36)	13.1	49.1	13.1	2	
CBA (0.32)	12.4	126.4	49.7	4	
Goethe-Link Roboscope (0.4)	11.9	63.7	19.9	2	
KPNO coude feed (0.9)	11.8	200.5	27.7	12	
CTIO Yale (1.02)	11.3	130.7	19.9	20	
Swedish solar VT (0.48)	11.1	88.4	71.8	2	
U. Missouri (0.35)	10.4	41.6	20.8	1	
Las Campanas Swope (1.02)	10.3	116.8	31.5	13	
Mt. Laguna (1.0)	9.7	69.2	12.6	10	
CTIO Curtis Schmidt (0.6)	9.5	56.6	10.6	4	
UHawaii (0.6)	9.2	96.3	11.1	5	
Palomar (1.52)	8.9	116.2	24.4	27	
Mentor (0.4)	8.0	39.8	0.0	1	
KPNO (1.3)	7.7	87.5	19.6	21	
KPNO (2.1)	7.3	81.1	20.3	52	
CTIO (1.5)	7.3	85.4	21.5	27	
Landis (0.2)	7.0	49.3	10.5	3	
Palomar (0.45) Schmidt	6.3	150.9	12.6	1	
SAAO (0.5)	6.0	60.7	9.0	4	
Rothney (0.4)	6.0	63.7	2.0	2	
Mt. Hopkins (0.4)	5.7	36.2	2.6	4	
Kiso Schmidt (1.05)	5.7	61.9	11.5	7	
Braeside (0.4)	5.5	68.4	9.8	5	
Mt. Laguna (0.6)	5.3	37.1	3.5	2	
Lick CAT (0.6)	5.2	91.8	16.4	4	
McGraw-Hill (1.3)	5.2	40.8	8.5	13	
Sproul (0.61)	5.1	35.9	3.4	2	
Toronto (0.61)	5.1	24.0	5.1	2	
Whipple (1.2)	4.9	45.8	10.6	12	
Dublin Obs (0.1)	4.9	53.9	4.9	1	
Steward (2.3)	4.5	45.8	13.3	37	
Other				1628	
Total (or average)				2211	

The original question that motivated Abt (1985) and Trimble (1995) to carry out their studies was whether public (CTIO 4-m, KPNO 4-m) or private (Palomar 5-m, Lick 3-m) large telescopes are more productive. Both Abt and Trimble found they were about even. Tables 2 and 7-8 show the public telescopes to be ahead, at least in the optical/near-infrared. In Figure 3, the CTIO 4-m (the Blanco telescope) and the KPNO 4-m (the Mayall telescope) are the most productive ground-based optical/near-infrared telescopes of any kind, with 33.4 and 32.1 weighted papers in 1995, versus 25.5 for the Hale 5-m, and 18.4 for the Lick Shane 3-m (and 27.8 for the Canada-France-Hawaii 3.6-m, remarkable since it is primarily a foreign telescope: one might have expected the Canadian observers to have published in the *MNRAS*, and the French observers to have published in *A&A*). Normalizing by telescope aperture still favors the public telescopes, with Table 2 showing the CTIO 4-m to have produced 2.7 papers/area, versus the KPNO 4-m at 2.6, the Hale 5-m at 1.3, and the Lick 3-m at 2.6, and CFHT at 3.6.

However, none of these five telescopes even place in Tables 12 or 13, which is dominated by much smaller instruments. Among the telescopes common to Tables 2 and 12 are the CTIO 0.9-m, the KPNO 0.9-m, the KPNO 2.1-m, and the Palomar 1.52-m. Cursory examination of Figure 3 might lead one to conclude that, because most results come from only a few telescopes, one might therefore get away with supporting only those few telescopes. That small, inexpensive telescopes can and do place near the top contradicts this. Furthermore, when normalized by area, which to a large degree reflects costs, small telescopes come out distinctly ahead: not one of the telescopes in Tables 12 or 13 has a 3-m or larger aperture.

We therefore conclude that it is a tragedy for science that many observatories are closing their small telescopes, and

TABLE 13. Top Ground-based, Optical/IR Telescopes, Sorted by Papers/Collecting Area

	Total Papers	*f*	Papers (Weighted)	Pages	Citations	Pages/ Paper	Citations/ Page	Citations/ Paper	Papers/ Area	Pages/ Area	Citations/ Area
Mt. Hopkins APT (0.25)	4	0.63	2.5	17	2.0	6.60	0.12	0.80	50.9	336.1	40.7
Burrell Schmidt (0.6)	10	0.63	6.3	55	9.3	8.67	0.17	1.47	22.4	194.2	33.0
CTIO (0.9)	25	0.51	12.8	152	25.4	11.94	0.17	1.99	19.6	234.2	39.0
Mees Solar coronagraph (0.25)	2	0.42	0.8	6	6.3	7.20	1.06	7.60	17.0	122.2	129.0 solar
KPNO (0.9)	25	0.43	10.8	112	36.0	10.33	0.32	3.33	16.6	171.9	55.4
CTIO Lowell (0.6)	9	0.42	3.8	38	7.7	9.94	0.20	2.03	13.5	134.0	27.4
CBA West (0.36)	2	0.67	1.3	5	1.3	3.75	0.27	1.00	13.1	49.1	13.1
CBA (0.32)	4	0.25	1.0	10	4.0	10.17	0.39	4.00	12.4	126.4	49.7
Goethe-Link Roboscope (0.4)	2	0.75	1.5	8	2.5	5.33	0.31	1.67	11.9	63.7	19.9
KPNO coude feed (0.9)	12	0.64	7.7	130	18.0	16.93	0.14	2.34	11.8	200.5	27.7
CTIO Yale (1.02)	20	0.46	9.3	107	16.2	11.53	0.15	1.75	11.3	130.7	19.9
Swedish solar VT (0.48)	2	1.00	2.0	16	13.0	8.00	0.81	6.50	11.1	88.4	71.8 solar
U. Missouri (0.35)	1	1.00	1.0	4	2.0	4.00	0.50	2.00	10.4	41.6	20.8
Las Campanas Swope (1.02)	13	0.65	8.4	95	25.8	11.33	0.27	3.06	10.3	116.8	31.5
Mt. Laguna (1.0)	10	0.76	7.6	54	9.9	7.16	0.18	1.31	9.7	69.2	12.6
CTIO Curtis Schmidt (0.6)	4	0.68	2.7	16	3.0	5.93	0.19	1.11	9.5	56.6	10.6
UHawaii (0.6)	5	0.52	2.6	27	3.2	10.50	0.12	1.21	9.2	96.3	11.1
Palomar (1.52)	27	0.60	16.1	211	44.3	13.11	0.21	2.75	8.9	116.2	24.4
Mentor (0.4)	1	1.00	1.0	5	0.0	5.00	0.00	0.00	8.0	39.8	0.0
KPNO (1.3)	21	0.49	10.3	116	26.0	11.32	0.22	2.53	7.7	87.5	19.6
KPNO (2.1)	52	0.49	25.5	281	70.4	11.03	0.25	2.77	7.3	81.1	20.3
CTIO (1.5)	27	0.48	12.9	151	38.1	11.72	0.25	2.96	7.3	85.4	21.5
Landis (0.2)	3	0.07	0.2	2	0.3	7.07	0.21	1.51	7.0	49.3	10.5
Palomar (0.45) Schmidt	1	1.00	1.0	24	2.0	24.00	0.08	2.00	6.3	150.9	12.6
SAAO (0.5)	4	0.29	1.2	12	1.8	10.15	0.15	1.51	6.0	60.7	9.0
Rothney (0.4)	2	0.38	0.8	8	0.3	10.67	0.03	0.33	6.0	63.7	2.0
Mt. Hopkins (0.4)	4	0.18	0.7	5	0.3	6.33	0.07	0.46	5.7	36.2	2.6
Kiso Schmidt (1.05)	7	0.70	4.9	54	10.0	10.94	0.19	2.04	5.7	61.9	11.5
Braeside (0.4)	5	0.14	0.7	9	1.2	12.36	0.14	1.78	5.5	68.4	9.8
Mt. Laguna (0.6)	2	0.75	1.5	11	1.0	7.00	0.10	0.67	5.3	37.1	3.5
Lick CAT (0.6)	4	0.37	1.5	26	4.6	17.58	0.18	3.15	5.2	91.8	16.4
McGraw-Hill (1.3)	13	0.53	6.9	54	11.3	7.90	0.21	1.64	5.2	40.8	8.5
Sproul (0.61)	2	0.75	1.5	11	1.0	7.00	0.10	0.67	5.1	35.9	3.4
Toronto (0.61)	2	0.75	1.5	7	1.5	4.67	0.21	1.00	5.1	24.0	5.1
Whipple (1.2)	12	0.47	5.6	52	12.0	9.28	0.23	2.15	4.9	45.8	10.6
Dublin Obs (0.1)	1	0.04	0.0	0	0.0	11.00	0.09	1.00	4.9	53.9	4.9
Steward (2.3)	37	0.51	18.9	190	55.2	10.07	0.29	2.92	4.5	45.8	13.3
McDonald (0.76)	6	0.34	2.0	25	5.2	12.48	0.21	2.58	4.4	55.4	11.5
Other	892	0.44	476	5031	1544	10.57	0.31	3.25			
Total (or average)	1275	0.46	672	7135	2017	10.61	0.28	3.00			

not replacing them. Even if they are often handed over to private institutions, these telescopes do not become as productive as they are when they are open to proposals selected primarily by scientific merit. This is especially so for instruments with replacements that are not immediately forthcoming.

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