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PRODUCTIVITY AND IMPACT OF LARGE OPTICAL TELESCOPES

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An attempt is made to provide quantitative measures of the amount of data gathered at large optical telescopes throughout the world and the impact these data have on astronomical research. The data base comprises 1163 papers reporting data from 39 telescopes, published between January 1990 and June 1991, and 4052 citations to them in 1993. Productivity measured in papers per square meter of telescope mirror varies by a factor of six, and impact measured in citations per paper varies by a factor of more than 10. Predictably, high productivity and high impact are associated with telescopes located at good sites and fully supported for many years by organizations with large budgets. Low productivity and low impact are associated with less favorable locations, short periods of operation, and financial stringency. In addition, the most productive telescopes seem to be ones whose users include astronomers from a wide range of geographical locations.

Introduction

This project had its origins in two earlier ones,[1,2] whose primary purpose was to determine whether the large American optical telescopes that are publicly owned and available to astronomers from throughout the country (the Kitt Peak and Cerro Tololo 4-meters) are more or less productive than the ones that are privately owned and available only to astronomers from selected institutions (the Palomar 5-meter and Lick 3-meter). The answer, based on papers published in three major American journals, was that they are very nearly the same.

The present investigation expands the inquiry to include all telescopes with primary mirror diameters of two meters or larger that contributed data to papers published in any of eleven major archival research journals in 1990–91. At least one very productive telescope, the 1.9-meter in South Africa, just missed the cut. But a line had to be drawn somewhere!

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* January to June.

** July to December

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Table 1

Names and primary mirror diameters of large optical telescopes owned and primarily used by various astronomical communities

<u>USA</u>

Palomar (200", Hale), 5^m (in California)
Multi-Mirror Telescope, 4.5^m (in Arizona)
Cerro Tololo Interamerican Observatory (Blanco), 4^m (in Chile)
Kitt Peak National Observatory (Mayall), 4^m (in Arizona)
Kitt Peak National Observatory, 2.1^m (in Arizona)
Kitt Peak National Observatory Coudé Auxiliary, 2.1^m (in Arizona)
Lick (120", Shane, Mt. Hamilton), 3^m (in California)
McDonald Observatory (Fort Davis), 2.7^m (in Texas)
McDonald Observatory (Fort Davis), 2.1^m (in Texas)
Mt. Wilson (100", Hooker), 2.5^m (in California)
Las Campañas (100", DuPont), 2.5^m (in Chile)
McGraw-Hill Observatory, 2.5^m (in Arizona)
Michigan-Dartmouth-MIT, 2.4^m (in Chile)
Steward Observatory, 2.3^m (in Arizona)
University of Hawaii, 2.1^m (in Hawaii)
InfraRed Telescope Facility, 3.0^m (in Hawaii)
Canada-France-Hawaii Telescope (1/3 share), 3.6^m (in Hawaii)
Sum of squares of diameters = 154.3 m^2

<u>Western Europe</u>

William Herschel Telescope, 4.2^m (in Canary Islands)
Canada-France-Hawaii Telescope (1/3 share), 3.6^m (in Hawaii)
European Southern Observatory, 3.6^m (in Chile)
European Southern Observatory, 2.2^m (in Chile)
ESO New Technology Telescope, 3.5^m (in Chile)
ESO Coudé Auxiliary Telescope, 2^m (in Chile)
ESO-Nordic Optical Telescope, 2.5^m (Canary Islands)
Calar Alto (German-Spanish), 3.5^m (in Spain)
Calar Alto (German-Spanish), 2.1^m (in Spain)
Isaac Newton Telescope, 2.4^m (in Canary Islands)
Pic du Midi, 2^m (in France)
United Kingdom InfraRed Telescope (UKIRT), 3.8^m (in Hawaii)
Anglo-Australian Telescope (1/2 share), 3.9^m (in Australia)
Sum of squares of diameters = 109.0 m^2

<u>Eastern Europe</u>

Special Astrophysical Observatory, 6^m (in Zelenchukskij region, Russia)
Crimean Astrophysical Observatory, 2.6^m (in Crimea, Russia)
Byurakan Astrophysical Observatory, 2.6^m (in Armenia)
Shemakha Astrophysical Observatory, 2^m (in Azerbaijan)
Bulgarian, 2^m
Sum of squares of diameters = 57.5 m^2

Table 1 (cont)

Other
Mt. Stromlo & Siding Spring, 3.9^m (Australia)
Mt. Stromlo & Siding Spring, 2.1^m (Australia)
Vainu Bappu, 2.3^m (India)
El Leoncito (CASLEO), 2.15^m (Argentina)
San Pedro Martir, 2.1^m (Mexico)
Anglo-Australian Telescope (1/2 share), 3.9^m (in Australia)
Canada-France-Hawaii Telescope (1/3 share), 3.6^m (Canada, in Hawaii)
Sum of squares of diameters = 46.7 m^2

The telescopes, their ownership and/or location, and mirror diameters are listed in Table 1. The light collecting power of a telescope is proportional to the area of its primary mirror, and the table therefore also indicates the sums of the squares of the mirror diameters available to each of three main astronomical communities (USA, Western Europe, Eastern Europe, and Other). Two of the telescope (UKIRT, IRTF) are used primarily at near infrared wavelengths, which are emitted and absorbed by the same processes that emit and absorb visible light, but reach us better from dusty regions of space. Several (including the CFHT and WHT) are sometimes used in the infrared, and others (like the Lick 120") could be if they were provided with suitable focal plane instrumentation.

The data base

The most difficult decision was which journals to include in the survey. A well-read astronomer would have to scan something like sixty separate publications. Some, however, cover a restricted topic range that does not depend much on data from large optical telescopes (Icarus, Solar Physics). Other focus on reviews, meeting abstracts, or conference proceedings (Space Science Reviews, Bulletin of the American Astronomical Society, Memoires of the Italian Astronomical Society). A few, while of considerable importance to astronomy as a whole, come from countries that did not have ready access to large telescopes in 1990–91 (Publications of the Astronomical Society of Japan, Journal of Astrophysics and Astronomy, published in India). Finally, some observatories, particularly in Eastern Europe, still produce their own publication series. These are virtually unavailable outside the home countries, so that the papers are never cited. Finally, Science Citation Index includes none of these observatory publications or any other astronomical/astrophysical publications that are not available in English.

Table 2 lists the journals actually used by location of publication. Most of the ones mentioned in the previous paragraph (and several others) were scanned to verify my expectation that they would contribute very little to the present data base. The Journal of Astrophysics and Astronomy had one paper from the 2.3-meter Vainu Bappu telescope in India, which was just then being commissioned and is not otherwise represented in any of the journals. PASJ included a couple of articles partly based on data from American telescopes. Issues of Astrophysics and Space Science that contained conference proceedings were excluded from the survey, and, although the journal is published in The Netherlands, most of its papers come from authors in developing countries, and the papers were therefore apportioned between Western and Eastern Europe in accordance with the nationalities of the authors.

Table 2
Archival journals of astronomy and astrophysics included in the data base

Published in USA (total of 663 papers)	
	Astrophysical Journal, Letters, and Supplements
	Astronomical Journal
	Publications of the Astronomical Society of the Pacific
Published in Western Europe	
	Astronomy and Astrophysics, Letters, and Supplements (221 papers)
	Monthly Notices of the Royal Astronomical Society (116 papers)
	Nature (18 papers)
	Astrophysics and Space Science (11 papers)
Published in Eastern Europe	
	Soviet Astronomy (9 papers)
	Soviet Astronomy Letters (25 papers)
	Astrofizica (Armenian, 18 papers)
	Acta Astronomica (Polish, 2 papers)
Examined but not included	
	Journal of Astrophysics and Astronomy (Indian, 2 papers)
	Publications of the Astronomical Society of Japan (Japanese, 1 paper)
	Science (American, fewer than 10 papers; nearly impossible to search)

All issues of these journals with publication dates between January 1990 and June 1991 were then examined, except for Astrofizica, published in Armenia, whose distribution was so badly delayed by earthquake and political events that the nominal publication dates of issues that appeared in 1990–91 were January 1989 to June 1990. Each paper was examined carefully enough to determine (a) whether it reported or analyzed any data gathered at an optical telescope with primary mirror diameter of 2 meters or more and (b) which telescopes had contributed. There were 1163 such papers (much less than 10% of all papers published in these journals).

For each paper, I recorded the name of the senior author, the number of co-authors, the bibliographic reference and number of pages, the approximate subject matter, and the name(s) of the telescopes used. Numbers of authors ranged from 1 to 17, numbers of pages from 2 to nearly 100, and numbers of large telescopes in any one paper from 1 to 7. Whenever a paper reported data from more than one large telescope, the paper, pages, and citations were shared equally among them all. Papers reporting data from both large and small telescopes or at both optical and other wavelengths were fully credited to the large optical telescope(s) concerned. These are, of course, arbitrary decisions (and the simplest possible). Some other method of sharing credit would lead to slightly different numbers. Naturally, not all journal pages are the same length. The number of words per page is, however, close to 1000 for all three American journals and the Western European ones apart from Astrophysics and Space Science (which contributed very few papers). The smaller capacity of the pages in Eastern European journals is at least partly compensated by greater terseness of the authors.

Each of the 1164 papers was then sought in the 1993 edition of *Science Citation Index* and the number of citations to it recorded. Self citations (citing author same as cited author) were included. This is another arbitrary decision. Omitting self-citations would have increased the range in numbers found for citations per paper among different telescopes, journals, and countries. By using the paper edition of SCI, I found it possible to locate most of the possible variant spellings and misspellings of authors' names and to identify papers even if volume number, page number, or year was wrong. Citations that got the senior author's name or the journal name wrong will generally have been missed. Such errors are fairly rare, but not unknown: The Bohm-Aharonov effect was actually published by Aharonov and Bohm.

Table 3 shows the numbers of papers, pages, and citations that resulted from these operations. Sixteen of the 30 lines in the "USA" columns have previously appeared in Ref. 2. The other numbers are new. The line labelled "other" includes papers reporting data collected at all the telescopes listed in Table 1 that do not have separate lines in Table 3. There are 10 of these. Only one, the San Pedro Martir telescope in Baja California, was responsible for more than 8 papers. Finally, Table 4 shows the numbers of 1993 citations per paper for papers published in the three regional groups of journals grouped by telescope and by the region that owns and operates the telescopes. These provide some measure of the impact of the data gathered at the various telescopes. Telescopes owned and operated by institutions in more than one region have been grouped with the region where the largest number of authors publish their papers (the CFHT with USA, the AAT with Western Europe). Explicit zeros under "citations per paper" mean that there were papers from those telescopes in those journals, but they were not cited in 1993. Dashes mean that there were no papers to be cited.

Table 3

Papers and pages reporting data from large optical telescopes, and citations thereto

Telescope	American journals			W. European journals			E. European journals			Total		
	Papers	Pages	Citations	Papers	Pages	Citations	Papers	Pages	Citations	Papers	Pages	Citations
USA												
Palomar	62.6	550	222	3.0	13	15	-	-	-	65.6	663	237
MMT	31.2	432	162	1.8	12	2	-	-	-	33.0	444	164
CTIO 4^m	72.8	843	338	5.9	42	25	-	-	-	78.7	885	363
KPNO 4^m	52.0	564	238	4.1	44	31	1.0	7	0	57.1	615	269
KPNO 2.1^m	52.2	588	178	2.0	20	1	1.0	2	0	55.2	610	179
KPNO CAT	9.3	113	4	4.0	25	10	-	-	-	13.3	138	14
Lick	45.4	506	179	2.3	21	5	-	-	-	47.7	527	203
McDonald 2.7^m	20.0	205	104	5.3	70	12	1.0	9	0	26.3	284	116
McDonald 2.1^m	9.6	142	40	1.0	6	0	-	-	-	10.6	148	40
Las Campanas	35.0	443	120	1.7	10	2	1.0	10	0	37.7	463	122
Steward	21.2	214	85	0.5	2	1	-	-	-	21.7	216	82
U. Hawaii	17.2	193	94	2.0	9	3	-	-	-	19.2	202	97
IRTF	26.0	191	120	6.0	37	15	-	-	-	32.0	228	135
CFHT	58.6	559	213	26.0	222	47	0.5	12	0	87.1	793	261
USA Total	513.1	5643	2115	65.6	533	168	4.5	40	1	583.2	6216	2284
W. Europe												
WHT	6.0	66	25	33.5	247	114	-	-	-	39.5	313	139
ESO 3.6^m	19.1	184	56	56.1	505	141	-	-	-	75.2	689	197
ESO 2.2^m	12.0	138	48	43.3	319	89	-	-	-	55.3	557	137
ESO NTT	4.0	42	22	10.8	49	29	-	-	-	14.8	91	51
ESO CAT	6.0	58	17	14.3	170	34	-	-	-	20.3	228	51
Calar Alto 3.5^m	5.5	60	19	21.7	203	80	-	-	-	27.2	263	99
Calar Alto 2.2^m	5.5	57	18	20.0	207	49	-	-	-	25.5	264	67
INT	6.5	58	27	44.9	452	194	-	-	-	51.4	510	221

Table 3 (cont.)

Telescope	American journals			W. European journals			E. European journals			Total		
	Papers	Pages	Citations	Papers	Pages	Citations	Papers	Pages	Citations	Papers	Pages	Citations
W. Europe, continued												
UKIRT	23.4	157	78	34.9	291	103	-	-	-	58.3	448	181
AAT	37.1	502	184	57.1	597	283	-	-	-	94.2	1099	467
W. Eur. Total	125.1	1322	494	336.9	3140	1116	-	-	-	462.0	4462	1610
E. Europe												
6-meter	1.5	12	2	8.0	55	15	31.5	172	5	41.0	239	22
Crimean	-	-	-	1.0	6	1	8.0	49	5	9.0	50	6
Byurakan	-	-	-	-	-	-	7.0	52	3	7.0	52	3
Shemakha	-	-	-	-	-	-	4.0	33	2	4.0	33	2
Bulgarian	0.5	4	0	2.0	9	3	5.0	43	5	7.5	56	8
E. Eur. Total	2.0	16	2	11.0	70	19	55.0	340	20	68.5	430	41
Other												
Sum, 10 teles.	23.4	309	94	25.5	191	23	1.0	16	0	49.9	516	117
World Total	663.0	7209	2705	439.0	3934	1326	61.0	396	21	1163.0	11620	4052

Table 4
Citations per paper (impact) for large optical telescopes

Telescope	American journals	W. European journals	E. European journals	Total
USA				
Palomar	3.55	3.00	–	3.61
MMT	5.19	1.11	–	4.97
CTIO	4.64	4.24	–	4.61
KPNO 4^m	4.58	7.56	0.0	4.71
KPNO 2.1^m	3.41	0.50	0.0	3.24
KPNO CAT	0.43	2.50	–	1.05
Lick	4.34	2.17	–	4.26
McDonald 2.7^m	5.20	2.26	0.0	4.41
McDonald 2.1^m	4.17	0.0	–	3.77
Las Campanas	3.45	1.18	0.0	3.24
Steward	4.01	2.00	–	3.96
U. Hawaii	5.46	1.50	–	5.50
IRTF	4.61	2.50	–	4.22
CFHT	3.64	1.81	2.00	3.00
USA Total	4.12	2.56	0.22	3.92
W. Europe				
WHT	4.17	3.40	–	3.52
ESO 3.6^m	2.91	2.51	–	2.62
ESO 2.2^m	4.00	2.06	–	2.48
ESO NTT	5.50	2.69	–	2.45
ESO CAT	2.83	2.38	–	4.47
Calar Alto 3.5^m	3.45	3.69	–	3.64
Calar Alto 2.2^m	3.27	2.45	–	2.63
INT	4.15	4.32	–	4.30
UKIRT	3.93	2.95	–	3.10
AAT	4.96	4.96	–	4.96
W. Eur. Total	3.95	3.31	–	3.48
E. Europe				
6-meter	1.33	1.88	0.16	0.54
Crimean	–	1.00	0.62	0.67
Byurakan	–	–	0.43	0.43
Shemakha	–	–	0.50	0.50
Bulgarian	0.0	1.50	1.00	1.07
E. Eur. Total	1.00	1.73	0.36	0.60
Other	4.02	0.90	0.0	2.34
WORLD TOTAL	4.08	3.02	0.34	3.48

Results for the various telescopes

The most conspicuous feature of Tables 3 and 4 is the wide range of numbers found. There is more than an order of magnitude difference in papers per telescope between the most and least productive and in numbers of citations per paper between the most and least influential. It is reasonable to ask what, if anything, these numbers should be corrected for. The obvious item is the area of the primary mirror, which determines how much light from astronomical objects can be collected by the telescope in a given length of time. Dividing the tabulated numbers of papers, pages, or citations by mirror area actually increases the spread between highest and lowest productivity and impact, because the largest numbers of papers, pages, and citations belong to telescopes (the Anglo-Australian, the Canada-France-Hawaii, and the Cerro Tololo Interamerican Observatory) that are not the very biggest. With such normalisation, Lick becomes the most productive of the large American telescopes, and the KPNO 2.1 meter looks truly extraordinary.

Other plausible corrections might be made for the number of cloud-free nights and the darkness of the sky at the various sites or other conditions over with the user community has little control. These corrections would tend to narrow the range of productivity and impact, since most astronomers would agree that Chile (CTIO) and Hawaii (CFHT) are at present clearer, darker sites than Mt. Hamilton (Lick) or Nizhny Arkhyz (6 meter). Data to make such corrections do not currently exist, nor is there even any single, agreed-upon way to quantify the merits of particular locations.

The largest variations are not, however, correlated with mirror size or with site quality, but with economic and political factors. Papers based on data collected with Eastern European telescopes and/or published in Eastern European journals are both few and rarely cited. At the other extreme, papers based on data collected with American telescopes and/or published in American journals are numerous and frequently cited. Western Europe comes in between. Particularly noteworthy are the high productivity of CFHT and AAT, each less than 4 meters in diameter and each co-owned and operated by institutions on more than one continent.

The rates of citation per paper in 1993 range from zero to 45. The top 5%, cited 13 or more times in the year, includes at least one paper from most of the telescopes 3.5 meters or more in diameter. The outstanding players are AAT (6.2 such papers), CTIO (5.3), Lick (4.1), KPNO 4-meter (3.5), and CFHT (3.0).

Other results

The complete data set reveals other trends. The average astronomical paper is just over 10 pages long, with the infrared ones from IRTF and UKIRT a bit shorter than average, but frequently cited. The ones from the Eastern European literature are considerably shorter than average.

Citation rate are, on average, higher for long papers than for short one (with the exception of Letters sections and Nature) and for papers with large numbers of authors. There are also significant variations among subdisciplines. All but two of the papers cited more than 20 times come from the areas of galaxies (including quasars) and cosmology. These trends have been seen before.[1-3]

The statement is frequently made that "most papers aren't read by anybody." This is not precisely true. In fact, 246 of the 1163 papers were not cited at all in 1993, 21% of the total.

*

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