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Productivity and impact of astronomical facilities: A recent sample

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The papers published in 11 key astronomical journals in 2008, and a year of citations to those from the first half of the year, have been associated with the telescopes, satellites, and so forth where the data were gathered using a form of fractional counting. Some numbers are also given by journal, by subfield, and by wavelength band. The largest numbers of papers, and generally also quite highly cited ones, in their respective wavelength bands come from the Very Large Array, the Hubble Space Telescope, the Sloan Digital Sky Survey, the Spitzer Space Telescope, and the Chandra X-ray Telescope. Optical astronomy is still the largest sector; and papers about cosmology and exoplanets are cited more often than papers about binary stars and planetary nebulae. The authors conclude that it is of equal importance to recognize (a) that a very large number of papers also come from less famous facilities, (b) that a very large fraction of papers (and their authors) are concerned with the less highly-cited topics, (c) that many facilities are quite slow in achieving their eventual level of influence, and (d) that one really needs at least three years of citation data, not just one or two, to provide a fair picture of what is going on.

1 Introduction

It has been almost 30 years since Helmut Abt (1981, 1985) used numbers of published papers and citations to them to address whether the large, publicly-supported American telescopes (the 4-meters at Kitt Peak and Cerro Tololo) were producing as much science as the privately supported ones (especially the 3-m Lick and 5-m Palomar mirrors). The answer was (and probably still is) yes, though the user communities were different and the methods of time assignment different for the two types. The line between publicly and privately supported is no longer quite so sharp, but the two 8-m Gemini telescopes and the two 10-m Kecks can serve as prototypes. Because it takes a number of years for large telescopes to make their maximum impact, it is still not quite certain that they will be of comparable importance to the astronomical community.

Our most recent foray into this territory (Trimble & Ceja 2008) considered about 300 optical telescopes and roughly 100 each radio and space facilities as represented in more than 11 000 papers, published in 2001–2003, with average citation rate of 4.55 citations per paper per year in the three years after publication. In this, we divided credits among all telescopes used equally within three classes. Others have, of course, contributed to the subject, including several authors who focused on one or a few telescopes (generally giving full credits for papers and citations to the ones they were interested in, even if others were also used). Madrid & Machetto (2006, 2009) apportioned credit, but look at only the 200 most-cited papers in each of two years, and only about 18 months of citations to them. Inevitably, these narrower foci yield a somewhat different picture of what is going on in astronomy from what is found by looking at everything. They are also considerably less labor-intensive.

The present study was initially motivated by the first author's wondering to what extent some of the new, very large mirrors (Gemini, the Large Binocular Telescope, the Hobby Eberly Telescope, the South African Large Telescope, Magellan, and so forth) were beginning to show up in the literature, and was encouraged by a request from a UK colleague for the most recent possible information to help a committee there to think about which countries and which facilities might be most valuable for the UK to collaborate with. The corresponding US group (the decadal survey) wasn't quite sure it wanted data of this sort, but reluctantly accepted an early draft of this paper informally. The purpose of the present publication is to make sure that the numbers are available to anyone who wants them and remain so for comparisons with future studies.

2 Methods

This is mostly a matter of making decisions: (1) which journals to include, (2) what time frame, (3) which source of citation data to use, (4) how to divide credit for papers (now the majority, though this was not so in 1960s) using data from 2 to 22 or more telescopes (etc.), (5) how long a period of citation accumulation to allow, and (6) what other information, if any, to keep track of.

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Table 1: Number of papers by journal.

Astrophysical Journal	1262
Astrophysical Journal, Letters	381
Astrophysical Journal, Supplment	101
Astronomy & Astrophysics	1095
Monthly Notices of the Royal Astronomical Society	841
Astronomical Journal	415
Nature	51
Science	46
Icarus	178
Publications of the Astronomical Society of Japan	136
Revista Mexicana de Astronomia y Astrofisica	16
Total	4524

The initial motivation determined that the time frame should be papers published in 2008. The journals used were those in Table 1. The first six were obvious; Science and Nature have very high rates of citations per paper (impact factor, though not as high as for their biology papers); Icarus is a major repository for solar system papers; and Publications of the Astronomical Society of Japan and Revista Mexicana de Astronomia y Astrofisica were included in hopes of fleshing out our statistics for the Subaru 8-m and the smaller telescopes on the very good site at San Pedro Martir. This was not entirely successful, but we did catch large groups of papers using data from Suzaku, Akari, Nobeyama, and the Japanese VLBI network.

A number of journals used in our earlier studies are not included here. These are Astronomy Reports and Astronomy Letters (Russia), Acta Astronomica (Poland), Astronomicsche Nachrichten (Germany), Astrophysics & Space Science (international), Publications of the Astronomical Society of the Pacific (US), Observatory (UK), Journal of Astrophysics and Astronomy (India), and Journal of the Royal Astronomical Society of Canada. None of these is a primary outlet for data from the relatively new, large, expensive telescopes that we were most wondering about, but their exclusion has discriminated against facilities located in Russia, Eastern Europe, and Asia and small ones in Western Europe and the US.

Citation numbers come from the Web of Science Citation Index rather than the Astrophysics Data Service at Harvard. Spot checks show that numbers are comparable, but the latter includes some citations from conference proceedings, papers posted on astro-ph but not yet published, and a few duplications of papers that appeared first on line and later in archival journals.

Division of credit ought, perhaps, in principle be proportional to the importance of the data from each telescope, dish, satellite, or other facility, Most papers do not include this information explicitly. Indeed figuring out which facilities were actually used is probably the hardest part of this sort of project, since it requires looking not just at titles, abstracts, footnotes, and acknowledgements, but also at figure captions, and the full text, even for primarily theoretical papers that also compare results with observations. The choice made (following Trimble & Ceja 2008 and earlier papers cited therein) was to divide up facilities in three classes: (1) Optical – ground-based optical and IR plus HST, (2) Radio – ground-based and space-based radio, millimeter, and submillimeter, and (3) Space – everything else in space (balloons, rockets, satellites, solar system missions, and all) at all other wavelengths plus very high energy installations on the ground like MAGIC and AUGER. Then equal credit for papers and their citations was given to each telescope within each class, resulting in the three tables that conclude this paper. For example, a paper that used five optical telescopes, three radio ones, and two space missions and was cited 15 times would appear in all three tables, contributing 0.2 papers and 3 citations to each optical telescope, 0.33 papers and 5 citations to each radio telescope, and 0.5 papers and 8 or 7 citations to each space facility. Where some data in at least one band could be attributed to a specific telescope (etc.) but data in other bands could not, this was also recorded. We even included (for January to June only) papers that used lots of observational data taken entirely from archives and catalogues and not attributable to any particular telescopes.

The period during which citations would be allowed to accumulate was also driven by the 'as current as possible' goal. Thus we have 12 months of citations in a sliding window for all the January to June papers and no citations for July to December papers.

As for what else to keep track of, the choices were subfields (from solar system to cosmology) and the nationalities of every author, as determined from his or her first-listed affiliation. The nationality data do not appear here, nor do papers in solar astronomy, which will be reported separately since they use an almost completely disjoint set of telescopes both on the ground and in space.

3 Results: non-inflammatory

Experience with earlier papers of this type indicates that reporting numbers of publications by wavelength band and papers and citations by subfield does not disturb any large fraction of our colleagues, while some other formats do. We avoid, therefore, citations per paper by journal title and put the numbers by facility in the next section. A few papers obviously used observational data, but it was not entirely obvious what the paper was about or what wavelengths were concerned. Thus, the total number of papers in Tables 2 and 3 is smaller than in Table 1, and because we have included papers using archival and catalog data the numbers in Tables 4-6 are still smaller.

Table 2 is number of papers for all of 2008 counted as optical, radio, and space. Multiwavelength papers appear in two or all three columns, so do not add up the three numbers on the last line! Optical astronomy is still the largest division, and also, we will see, uses the largest number of telescopes (etc.).

Table 2: Number of papers by wavelength band.

Optical(O)	1788	Radio(R)	301	Space(S)	796
O+R	283	R+O	283	S+O	783
O+S	783	R+S	164	S+R	164
O+R+S	301	O+R+S	301	O+R+S	301
All Optical	3155	All Radio	1049	All Space	2044

Table 3: Papers and citations by topic.

Topic	Papers[1]	C/P[2,3]
Cosmology	181	5.15
Clusters of Galaxies	239	3.72
Gamma Ray Bursts	99	3.38
Galaxies	576	4.54
Active Galaxies	459	3.32
Milky Way	132	4.23
Supernovae / Remnants	201	4.48
Neutron Stars / Black Holes / XRB's	315	2.76
Cosmic Rays	15	3.00
Interstellar Medium	261	2.72
Star Formation	308	3.05
Star Clusters	228	3.27
Stars	339	2.57
Binary Stars	162	1.45
Cataclysmic Variables	110	1.37
Planetary Nebulae	76	1.64
White Dwarfs	46	2.71
Brown Dwarfs	55	4.48
Exoplanets	160	6.26
Solar System	358	2.07
Service	155	5.87
Total	4479	3.51

[1] Includes *all* papers published in 2008.
[2] Includes *only* papers published January–June 2008.
[3] Citations are tallied for the 12 months after publication.

Table 3 shows the numbers of papers by subdiscipline, ordered from large, distant things to smaller, nearby ones for all the 2008 papers, but the citations per paper (C/P) numbers pertain only to publications in January-June 2008, cited in the 12 months after publication.

The subject divisions are those in use since 2001, and one might well make different choices if starting now from scratch (dividing galaxies into high and low redshift or into formation, evolution, and current properties, for instance, or merging CV's with other binaries) but would thereby lose some of the ease of tracking rises and falls of various topics in popularity, whether defined by number of papers or by citations per paper per year. In terms of number of papers, the top subdisciplines include galaxies (576), active galaxies (459), solar system (358), stars (339), neutron stars/black holes/XRB's (315), and star formation (308). In terms of citations per paper, clearly exoplanets (6.26), cosmology (5.15), galaxies (4.54), brown dwarfs (4.48), and supernovea (4.48) are 'in', while PNe (1.64), binary stars (1.45), and CV's (1.37) are 'out', even more than in earlier years. We suspect, however, that in these more traditional fields, citations may be slower to accumulate, so that three years of citation data might make a good deal of difference. 'Service' means catalogues with several types of objects; calibrations of detectors, color bands, etc., and astrometry.

The clearest indication that one year of citations is not enough lies in the numbers for citations per paper per year, averaged over all fields. This is 3.51 for the 2297 papers from the first half of 2008, but was 4.55 for papers published in 2001–03 and cited during the three years after publication (that is 2002–04 for 2001 papers, and so forth). The difference is really larger than this for two reasons. First, the nine journals used in our 2008 study but omitted here are characterized by relatively low impact factors (though, to repeat our previous refutations of common catch phrases, it is not true either that 'most papers aren't read/cited by anyone,' or that 'our journals have more authors than readers'). Second, not only do the numbers of astronomy papers published per year continue to increase monotonically, but so do the lengths of their reference lists, so that citations per paper cannot help but rise monotonically if measured in a self-consistent fashion.

4 Results: potentially inflammatory

Tables 4, 5, 6 are, in that order, papers, citations, and C/P for the first half of 2008 plus total papers for the full year, from radio, space, and optical facilities. There is a somewhat arbitrary cut-off at 4–5 papers per facility to appear in the tables, which often meant use in 10–15 papers given that we have adopted fractional counting. Facilities that cross over that line in the second half of the year, but have little or no citation data are mentioned in our comments on the bottom of each table. Please keep in mind that, even for the listed telescopes and all, where the number of papers is small, C/P whether small, medium, or large, will have very large error bars.

5 Conclusions and sermons

1. The 91 papers from January to June with only archival observations, drawn from catalogs, virtual observatories, and such were cited 373 times for a C/P ratio of 4.04, slightly larger than that for papers from identified telescopes. We are not advising you to give up observing on this basis.
2. HST and SDSS really are all they are cracked up to be, if you crack a bit carefully, while the importance of the VLA in world radio astronomy is perhaps not fully recognized.
3. In space, it was undoubtedly the year of SST and, to a lesser extent, of SWIFT and GALEX. If you would like to start a trans-Atlantic fight, you could probably ask why the XMM paper total is smaller than the Chan-

dra total. On the ground, a similar quarrel could start by asking why the 4 VLT mirrors yield more than twice as many papers as the 2 Keck mirrors. Gemini, LBT, and Magellan were pretty obviously still not up to full productivity. Telescopes need to be debugged; many programs require data from several years; and the papers still have to be written, refereed, and published.

4. Optical astronomy is still more than half the total. The impression given by the tables that its papers are more often cited than radio and space ones is an artifact of leaving out more than 100 small telescopes. Numbers exist for these, they just don't all fit on one page!
5. That more than half of all papers have fewer than average C/P numbers cannot be helped. That some large subdisciplines of astronomy (Table 3) collectively fall below that average means they, and the facilities they use, will not appear in studies like those of Madrid and Machetto (2006,2009). We think they are still important. Given that many journals have impact factors (citations in 18 months after publication, roughly) of 1–2, even our less spectacular subfields are doing very well.
6. A single year of citations is NOT enough. Not only do rates peak in years 2 and 3, but considerable smoothing of the difference between 0 and 2 per year occurs, and it is easier to divide the citations fairly among all the contributing facilities. A proper study of 2008 papers will be possible only in the early months of 2012, when the IAU will be tooling up to meet in Beijing, the Olympics will be heading for London, and the US will be enduring the prelude to another presidential election.
7. Other interesting results can be obtained only by authors with access to in-house data. For instance, more HST papers per orbit and more citations per paper come from projects carried out with director's discretionary time than from projects awarded time in the standard peer-review process (Apai & Williams 2009). It would be very interesting to know whether this is also a characteristic of other observing facilities.

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Table 4: Radio papers and citations by facility.

Facility	Papers[1]	Citat.[1]	C/P[1]	Papers[2]
VLA	129.1	396	3.07	262.9
WMAP	24.7	101	4.09	54.9
IRAM	36.3	172	4.74	65.0
JCMT	26.65	123	4.62	52.8
SMA	15.1	35	2.32	37.1
BIMA	8.0	15	1.88	11.7
CSO	8.7	28	3.22	17.8
OVRO	4.45	7	1.57	8.2
FCRAO	9.0	39	4.33	14.0
APEX/ASTE	8.5	11	1.29	19.0
ATCA	23.2	47	2.03	48.0
Parkes	16.2	47	2.90	31.0
VLBA	17.2	52	3.02	39.0
Eur VLBI Network	7.1	19	2.68	19.6
GMRT	15.0	31	2.07	24.4
Arecibo	19.1	47	2.46	33.7
GBT	13.9	32	2.30	29.9
Nobeyama	11.5	19	1.65	15.2
WSRT	11.3	27	2.39	22.2
Effelsberg	9.45	12	1.27	19.0
SEST	6.0	11	1.83	9.5
ARO	5.0	6	1.20	12.1
Merlin	4.45	19	4.27	9.2
NANTEN	4.3	12	2.79	11.6
Ryle	4.25	6	1.41	5.35
TOTAL RADIO	479.3	1369	2.86	1010.6

[1] Papers published January–June 2008, cited in the 12 months after publication.
[2] Papers pubished during *all* of 2008.

The total at the bottom includes a number of facilities not mentioned in the table. The European VLBI Network includes a number of dishes, like Dwingloo, Metsahove, Nancay, Noto, Medicino, and Torun, that are sometimes also used separately, but which individually were not responsible for more than four papers. The full year of papers brought some old facilities (COBE, U. Michigan, and 3–7 C surveys) and some new ones (e.g., CARMA) above the 4–5 paper line, but with little or no citation data. WMAP and supporting facilities like BOOMERANG yield many more papers and very high C/P in years when there is a major data release. That 1010.6 is not an integral is round-off error; that it is smaller than 1049 (Table 2) means that some papers used only radio data that could not be associated with a particular observatory or telescope.

Table 5: Space papers and citations by facility.

Facility	Papers[1]	Citat.[1]	C/P[1]	Papers[2]
IR:				
SST	199.2	1053	5.29	401.0
IRAS	51.5	119	2.31	82.1
ISO	33.8	67	1.98	55.1
MSX	14.8	27	1.82	27.1
Other IR	2.9	2	0.69	8.5
IR Total	302.2	1268	4.20	589.9
X-Ray:				
Chandra	127.2	437	3.44	265.1
XMM/Newton	96.5	274	2.84	202.6
RXTE	43.9	128	2.92	79.1
ROSAT	39.6	147	3.72	76.9
Suzaku	34.7	100	2.88	38.7
BeppoSAX	7.5	19	2.53	15.5
HETE	5.8	9	1.55	8.7
Ohter X-Ray	10.3	18	1.75	16.9
X-Ray Total	365.5	1132	3.10	703.2
Gamma Ray:				
SWIFT	43.6	200	4.59	95.5
INTEGRAL	18.7	67	3.58	42.9
CGRO	22.6	72	3.19	33.8
Other Gamma Ray	7.9	29	3.67	14.6
Gamma Ray Total	92.8	368	3.97	186.8
UV:				
GALEX	18.1	82	4.53	47.8
IUE	14.8	48	3.24	24.3
FUSE	14.2	39	2.75	33.8
Other UV	2.3	2	0.87	5.0
UV Total	49.4	171	3.46	110.9
Optical:				
HIPPARCOS	43.7	156	3.57	80.2
MOST	10.9	48	4.40	14.9
CoRoT	4.0	34	8.50	10.0
Optical Total	58.6	238	4.06	105.5
Solar System:				
Cassini	45.8	115	2.51	63.8
All Mars	22.9	80	3.49	63.5
Other Solar System	19.0	59	3.11	57.4
Solar System Total	87.7	254	2.90	184.7
UHE:				
HESS	12.4	53	4.27	22.3
MAGIC	6.1	39	6.39	13.4
Other UHE	18.6	85	4.57	31.9
UHE Total	37.1	177	4.77	67.7

Continued on next page.

Table 5: Continued.

Facility	Papers[1]	Citat.[1]	C/P[1]	Papers[2]
TOTAL SPACE	988.3	3608	3.65	1955.2

[1] Papers published January–June 2008, cited in the 12 months after publication.
[2] Papers pubished during *all* of 2008.

The total number of space papers is not an integer because of round-off errors, and it is smaller than the number in Table 2 (2044) because of papers using space-based data not trackable to particular facilities – commonest are synoptic X-ray studies using a dozen or more mission archives, including some very old ones like Ginga and Einstein. Other UHE is a particularly heterogeneous collection, including HEGRA, AUGER, etc., but also AMANDA, Pamela, LIGO, MILAGRO, and some cosmic ray balloons. New satellites Akari and Agile yielded 5.3 and 15.2 papers in the second half of the year and the newly-renamed Fermi 2.2 papers, but no citation data. About 8 Mars missions were represented, with the largest numbers of papers coming from MGS in the first half of the year and Mars Messenger in the second. Space missions typically have short active lives, and their teams try hard to catch the most important photons first. There is, nevertheless, some ramp-up time, and it is perhaps worth thinking about those satellite that are in steady state (about the same numbers of papers in two halves of year, like SST, Chandra, and XMM), those apparently still growing (more papers in the second half like GALEX, Swift, and Integral), and also the archival-only ROSAT, IRAS, and HIPPARCOS (which did things that have not yet been done better, though future missions will presumably outclass them).

Table 6: Optical papers and citations by telescope/observatory.

Telescope	Papers[1]	Citat.[1]	C/P[1]	Papers[2]
HST	206.6	765	3.70	391.5
VLT	139.1	452	3.25	290.6
Keck	59.6	333	5.59	121.5
CFHT	38.0	152	4.00	69.6
Gemini	34.3	108	3.15	63.7
Subaru	33.0	138	4.18	70.0
AAT	23.0	83	3.61	42.4
WHT	19.5	55	2.82	34.7
IRTF	16.9	46	2.72	31.2
UKIRT	15.8	54	3.42	34.3
Okayama 1.88m	9.9	30	3.03	17.0
U.Hi. 2.2m	5.1	17	3.33	10.4
HET	5.0	35	7.00	8.9
LBT	4.8	18	3.75	8.2
MDM 2.4m	4.6	17	3.70	7.0
APO 3.5m	4.5	16	3.56	9.5
Lyot (PduM)	3.0	5	1.67	8.9
ESO NTT	19.0	54	2.84	38.6
ESO 3.6m	11.4	40	3.51	23.1
ESO/La Silla, Other	28.9	120	4.15	67.6
CTIO 4m	12.8	53	4.14	26.4
CTIO other	15.2	37	2.43	29.8
KPNO 4m	11.6	47	4.04	21.4
KPNO other	10.7	19	1.78	21.1
Magellan	16.4	68	4.15	33.4
MMT	14.7	63	4.29	20.8
WIYN	11.6	42	3.62	19.6
TNG	9.3	15	1.61	16.4
INT	8.2	43	5.24	15.3

Continued on next page.

Table 6: Continued.

Telescope	Papers[1]	Citat.[1]	C/P[1]	Papers[2]
NOT	6.6	21	3.18	20.7
Other Canarias	8.3	23	2.77	25.2
Calar Alto	17.2	40	2.33	28.3
OHP	14.2	67	4.72	28.5
Palomar	12.9	42	3.25	18.4
McDonald	9.2	25	2.72	18.3
SAAO	9.2	24	2.61	19.9
Lick	7.6	29	3.82	17.4
San Pedro Martir	7.25	3	0.41	14.5
Steward	7.2	28	3.89	10.1
Las Campanas	5.1	24	4.71	15.7
SDSS	133.0	863	6.49	336.1
2MASS	136.2	479	3.52	275.8
48" Schmidts	45.8	95	2.07	100.7
MACHO, ASAS, etc.	29.1	123	4.23	47.1
TOTAL OPTICAL	1233.8	4764	3.86	2530.4

[1] Papers published January–June 2008, cited in the 12 months after publication.
[2] Papers pubished during *all* of 2008.

No attempt has been made to distinguish among the multiple mirrors of VLT, Keck, Gemini, Magellan, or LBT; many published papers (some with data obtained from service modes and queue scheduling) do not. If you would like to select Subaru as your standard, then a set of two 8-m mirrors 'should' have yielded about 140 papers and a set of four 8-m telescopes about 280. The set of names running from Calar Alto to Las Campanas means all the telescopes on those sites. As usual, 2530.4 is not an integer because of round-off errors. It is very much smaller than 3155 (Table 2) partly because of the use of 'virtual observatory' data, but mostly because (a) about 80 papers are attributable to a large number of small automated, astronometric, interferometric, and networked amateur telescopes, (b) another 500+ come from other small telescopes on other sites used less systematically, and (c) even some mirrors with diameters of 2 meters or more did not produce as many as 4.5 papers in the first half of 2008. This group includes SALT, the Xinglong 2.06-m, the Russian (SAO) 6-m, the Crimean 2.6-m, six 2-m class telescopes in Eastern Europe and the former USSR, the Hanle 2-m, the Liverpool 2-m, the Foulkes telescopes north and south, and Casleo. That the average C/P for optical data (3.86) is larger than the average for radio or space data is an artifact of leaving out this sizable group of undercited papers.