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A generation of astronomical telescopes, their users, and publications

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Abstract Research astronomers and the telescopes they use each have typical life spans of about 40 years. Most of their journals live a good deal longer, though the second most important one today is only 40 years old. This paper looks at numbers for productivity and impact of specific astronomical facilities, changes in equality of opportunities and achievements in observational astronomy, and some aspects of national contributions. The focus is on optical astronomy, though something is also said about radio telescopes and astronomy from space. In summary, nothing stays “best of class” for very long; the fraction of the community with access to the most valuable facilities has increased with time (more equality of opportunity); but the fraction of citations earned by the few super-star papers has also increased (less equality of achievement); and the USA remains the host of the most-cited journals and the most productive telescopes, though Europe (meaning in this context the member nations of the European Southern Observatory, the European Space Agency, and the supporters of the journal *Astronomy & Astrophysics*) are fast closing the gap, with the UK retaining its own journal and some observing facilities not shared with either the USA or other European countries. Detailed examination of specific facilities indicates that size (of telescope, community, and budget) are all of great importance, but that the most significant “focal plane instrument” is still the astronomer at the virtual eyepiece. The changes have happened against a background of enormous increases in numbers of astronomers, sizes of available facilities (but not total number), numbers of papers (but not of journals), and numbers of citations per paper. A significant subset of the conclusions on turnover of people and facilities accompanying major growth: opportunity versus achievement; Europe versus the USA; and the trade-off between community size and the influence of individual scientists undoubtedly apply in many other fields.

Keywords Telescope · Observational astronomy · Publication productivity · Citation impact

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Introduction

Counting of papers and citations provides one way of assessing the importance of scientists, their pursuits, and their facilities on a time scale intermediate between the verdict of history and the report of the peer review panel on your most recent research proposal. The degree of objectivity is perhaps also intermediate. With this in mind, I have attempted to assess the productivity and impact of astronomical facilities in two time periods, separated by about 40 years, which comes fairly close to the turn-over time (roughly, that is, a generation) for both astronomers and ground-based telescopes.

The raw data consist of nearly all the papers in observational astronomy (11,831 of them) published in 2001–2003 and the citations to these (161, 556) during the 3 years after publication of each (Trimble and Ceja 2008) and corresponding numbers for 2,164 papers published in 1960–1964 and cited 15,240 times in 1965–1969 (Trimble 2009). Credit for each paper and the citations to it has been equally divided among all the telescopes contributing in the optical or radio or space wavebands (“fractional counting”). The time frame for the historical study was driven by availability of journals and of the Science Citation Index, but the two periods turn out to bracket a number of significant changes (and some eternal verities) which are examined here.

An obvious change is a large increase in average rate of citations per paper per year, from 1.41 for the 1960s to 4.55 in the present century. Part of the increase stems from larger numbers of references per paper, some from the ever-increasing numbers of papers always looking back to when there were fewer, and some from a gradual increase in the set of journals counted in SCI/Web of Science. In both time frames, the most highly cited papers turn out to be a mix of single important results (the discovery of quasars: the Hubble Space Telescope value for the Hubble constant) and collections that will be used by many people (catalogues and explanations of important methods, for instance).

The inventory of major journals has, with the exception of one major merger, been steady, but with changes of relative paper numbers and citedness, reflecting, at least broadly, changes in world demographics and economics, to the detriment of the former Communist countries.

The total numbers of astronomical facilities have changed rather little, something in excess of 300 optical telescopes, 100 radio ones, and about 80 lifted above the surface of the earth appear in each set of papers; and a large number of 40+ year-old telescopes are still in use. But there have been two almost complete turnovers in which contributed the most papers and the most cited papers, from 1960–1964, to 1990–1993 (Trimble 1996, Trimble et al. 2005) to 2001–2006. Three factors are important:

- New is good, because technology advances, but not too new, because it takes a typical facility 4–6 years to come up to full productivity.
- Well-supported is good, as you probably don’t need to be told, meaning good roads (or helipads), computing facilities, lots of knowledgeable people besides the researchers to keep things running, and many other expensive entities.
- But one or a few people with first-class innovative ideas and the persistence to carry through with them are also enormously important, though hard to quantify, as can be seen over the years in the triumphs of the Palomar Observatory Sky Survey, several systematic searches for exoplanets, pulsars, etc., and most recently, the Sloan Digital Sky Survey, whose achievements in finding very distant galaxies and quasars and large scale structure in the universe, but also some of the coolest and closest stars and small

galaxies orbiting our own, have exceeded even the substantial imaginations of the survey designers.

What about people? Well, they too come and go over decades, and are the subject of the next section.

The half-life of an astronomer

The total number of astronomers has grown, like the populations in other sciences, almost exponentially from 1960 to 2000+. The membership of the International Astronomical Union, for instance, increased from about 1,200 in 1961 to 9000 in 2003. The actual increase is probably somewhat larger, since astronomers (particularly those working with space-based facilities) are not as likely to be members now as then, when nearly everybody joined and half or more came to the triennial General Assemblies (Moscow 1958, Berkeley 1961, Hamburg 1964, Prague 1967). Incidentally none of the other international scientific unions has this sort of individual-member structure (a part of the answer to a question asked by Abt (2005) a few years ago).

A subset of astronomers remain part of the publishing community for very many years. Willem Luyten (Netherlands and USA) and Alan Cousins (South Africa) are classic examples, reaching beyond the 60-year mark. They started young, with papers before they turned 20, and lived to advanced ages. Abt (1986) has shown that astronomers can write highly-cited papers at any age from 30 to 80 (but peaking rather later than supposed by people who would like to end tenure somewhere around age 50). The current membership of the American Academy of Arts and Sciences includes about 10 astronomers and astrophysicists elected in 1969 or earlier, meaning that they have been distinguished for 40 or more years. Probably the same thing can be said about members of other academies and honorary societies. This just happens to be the one whose membership directory was available. The field has also seen meteoric rises and falls, including Beatrice Muriel Hill Tinsley, whose first, 1967, paper reported a fundamental discovery, that galaxies change their colors and luminosities significantly over a few billion years and that this evolution can be meaningfully calculated. Her last paper appeared shortly after her 1981 death.

What about averages? A half-life close to 40 years seems to be implied by the papers published in 1960–1964. The most-cited 1% of the papers (22 by number) had 20 unique first authors, of whom 13 are still part of the community, in the sense of maintaining society memberships, coming to meetings, winning prizes, and answering their email (not all of these for all of them). It is obviously not a coincidence that the authors of highly cited 1960–1964 papers include two living Nobel Prize winners (Anthony Hewish and Riccardo Giacconi) and winners of many other significant prizes. Co-authors can, of course, be either more or less likely to survive another 40 years than first authors, but for very highly cited papers in both time frames, the first author is quite generally the leader if a team is involved.

More generally, I checked the first authors of the 440 papers published in 1962, in the journals listed in Table 1. Of them 206 were still members of the astronomy community (in the same senses) in 2003 though several have since died. Of the 234 who were not still members, the single largest set are dead. A few dropped out after five or more years of publishing. More, especially those associated with shorter papers reporting data from relatively small telescopes, were students at the time and went on to careers in completely different fields. Finally, a handful were or are distinguished scientists, but not astronomers,

Table 1 Papers and citations by journal

Journal (region, subject)	Papers 1960–1964	Citations 1965–1969	C/P Normalized	Papers 2003	Citations 2004–2006	C/P Normalized
Astrophysical J (US)	500	4964	1.00	1326	17,422	1.00
Astrophys. J. Suppl (US)	21	377	1.81	78	7,407	5.55 (1)
Astronomical J. (US)	272	1341	0.61	429	7,225	0.98
P. Astr. Soc. Pacific (US)	234 (2)	545	0.24	81	931	0.67
Mon. Not. Roy. Ast. Soc. (UK)	147	1426	0.98	598	8,740	0.85
Observatory (UK)	94 (2)	176	0.19	14	15	0.06
Icarus (solar system)	19	203	1.08	112	858	0.45
Bull. Astron. Inst. NL (3)	47	338	0.73			
Ann. d' Astrophys. (FR, 3)	75	378	0.51			
Zs. f. Astrophys. (West Germany, 3)	67	197	0.30			
Bull. Astro. Inst. CZ (3)	50	45	0.09			
Sum of previous four	239	959	0.41			
Astron. & Astrophys. (Europe, 4)				1228	12,898	0.62
Nature (broad, UK)	192	1603	0.84	44	2,452	3.26
Science (broad, US)	72	462	0.65	26	780	1.75
P. Astron. Soc. Japan	67	270	0.41	75	564	0.44
Sov. Astron. + Lett. (Rus)	173	622	0.36	87	185	0.13
Acta Astron. (Poland)	45	92	0.11	18	225	0.73
Astron. Nach. (E. Germany)	58	43	0.07	13	31	0.14
Phys. Rev. Lett. (US, 5)	66	958	1.47			
Astr. J. Phys. (Australia, 5)	15	241	1.52			

(1) Heavily affected by a dozen papers reporting data on cosmic microwave background from Wilkinson Microwave Anisotropy Probe; normalized C/P = 1.24 without them. The anomaly has also been remarked upon by Abt (2008)

(2) Included many 1–2 page papers of a type no longer published

(3) These and three other smaller journals merged to form Astronomy and Astrophysics

(4) The merger product

(5) These no longer publish significant amounts of observational astronomy

who were first authors on papers about cosmic rays, radio or space observations of the heliosphere, and so forth.

Coming at it from the other direction, many 2001–2003 first authors were already active astronomers in 1960–1964. But this was true of only one of the 110 first authors of the most-cited 1% of recent papers, (and he was a physicist then, not an astronomer). It will be interesting for someone (not I!) to find out how many of these high-profile authors are still astronomers in 2040. For what it is worth, my own first astronomy paper appeared in 1967 and several are currently in press for 2009, so in this respect, at least, I am at least average.

Shifting subfields

Astronomers have always claimed to own the entire universe outside the earth's atmosphere, from the time when this meant not much more than a shell of "fixed stars" surrounding the "wanderers" right down to the present with its infinite and perhaps multiple universes. But emphasis on the various parts has shifted a good deal. A simplified, basic division of topics might include (a) solar system, (b) normal stars including binaries and clusters, (c) stars experiencing extreme events like novae and supernovae, (d) the Milky Way galaxy as a whole, and (e) extragalactic topics, including quasars and cosmology. Some currently hot topics, with highly cited papers, for instance exoplanets, pulsars, and gamma ray bursters were not part of the 1960–1964 inventory.

It is important to be clear that large communities working on a topic (for which number of papers is a fair proxy) do not guarantee large citation rates. The 2001–2006 subfields include all possible combinations of large community/high citation rate (cosmology), large community/low citation rate (stars), small community/high citation rate (exoplanets and brown dwarfs), and small communities/low citation rates (planetary nebulae). And if you follow science columns of newspapers and magazines, you will be aware that extragalactic topics now dominate popular astronomy.

In 1960–1964, the solar system, Milky Way, and extragalactic things each made up a little more than one-fifth of the papers, with citation rates a bit below average, about average, and somewhat above average, respectively, while the remaining one-third was stars, with slightly below average citation rates. For 2001–2006, the solar system has shrunk to 5% of the papers, very much undercited; the Milky Way has held its own in fraction of papers and citedness; stars are still about 1/3 of the papers, but with citation rates per paper now only about half the average; and extragalactic topics are up to 35% of the papers, with generally much higher than average citation rates (see Trimble and Ceja 2008; Trimble 2009 for more numbers). The individually most-cited papers are also more heavily concentrated in extragalactic topics, especially cosmology, than they were 40+ years ago. The gradual shift from photographic plates to image tubes and then CCD detectors has allowed extragalactic work to be done with smaller telescopes than was formerly possible, but it remains concentrated toward large mirrors.

A sample of the most-cited 1% of papers in each time frame allows us to consider one aspect of rising inequality in observational astronomy. The fraction of all citations received by the top 1% of papers has risen from 12% of the citations in the earlier sample to 15% for papers published in 2003.

One might also reasonably ask about the range of observing facilities used in the most-cited papers. I am not quite sure how to do this fairly, but the top dozen for 1960–1964 (13–28 citations per year in the following quinquennium) reported data from four radio observatories, five optical telescopes, and two (single-use) Aerobee rockets. The top dozen for 2001–2003 (103–927 citations per year in the following triennia) included data from three radio observatories (one in space and all focused on the cosmic microwave background), 14 optical telescopes (counting the four mirrors of the VLT and the two of Keck as one each, and including the Hubble Space Telescope), and two X-ray satellites. Additional optical and X-ray data were not credited to specific facilities, so that the total number used was actually somewhat larger. The total number of possible facilities in each waveband has not actually increased over the intervening 40 years.

It is not, of course, possible to provide three years of citation data for papers published in 2006–2008, but a preliminary examination of about 10% at the 2008 inventory indicates that the newer optical facilities (Gemini, the Large Binocular Telescope, Magellan)

continue to come on line rather slowly. In space, the appearance of new satellites in the data base (Spitzer Space Telescope in the infrared; Swift and Integral in X- and gamma-rays) is roughly balanced by the fading of old ones. The same has happened to radio facilities; the Atacama Pathfinder Experiment is there, but some of the more traditional European dishes and arrays have nearly disappeared.

Astronomical periodicals

Astronomers, like other natural philosophers, once promulgated their findings through books, pamphlets, science academy proceedings, and letters to their distant colleagues. Then, unique to astronomy, came observatory publications, with more than 200 series of them between 1800 and 1970, generally with lifetimes much less than the full 170 years. These were published by government, town, and university observatories and by wealthy amateurs with their own telescopes. Many included results only from the sponsoring observatories; others were broader-based. And they were generally exchanged quid-pro-quo among the observatories, rather than being sold by subscription.

The familiar sorts of scientific journals, supported by professional societies and/or publishers, appear gradually through the nineteenth century, and are now unquestionably the dominant form of exchange of research results within the astronomical community. But up until about 1940, about one-sixth of all astronomical papers appeared in observatory publications, including some that we still recognize as being of great importance. Examples include the first redshifts of galaxies (from Vesto Melvin Slipher at Lowell), the discovery of interstellar absorption (Robert J. Trumpler at Lick), and the first mass estimate for binary galaxies (Eric Holmberg at Lund). It is, I think, a coincidence that these all begin with L, since the total population ranged from Aarhus and Abastumani to Zo-se and Zurich. Nearly all these series have now vanished, though the one from Dominion Astrophysical Observatory, in Victoria, Canada, included valuable catalogues well into the 1970s, and I still receive a quarterly publication from the Skalnaté Pleso Observatory in the Slovak Republic (and read it, too). In the largest journals, only 1.2% of citations in recent years have been to observatory publications (Abt 2009).

To collect anything like a complete sample of astronomical papers from this period of observatory publications and tie them to the telescopes used would not be impossible, but it would require many hours in the stacks of one of the few libraries that collected nearly all of them and has kept them (Paris, perhaps; the US Naval Observatory, Mt. Wilson, and Lick, at least until recently; but sadly no longer the Royal Greenwich Observatory nor Cambridge Observatories, where I once spent a happy afternoon reading the proceedings of Dushanbe Observatory, which struggled right on through World War II, at about 38° north latitude, 68° east longitude, if you would like to visit). Some of these are or will be available electronically, but only someone who has looked at every page of a paper (a) to recognize telescopes not mentioned in the title or abstract and not called by their standard names and (b) to ignore telescopes mentioned for some reason other than use of data obtained with them can appreciate how difficult this counting is without being able to flip pages rapidly back and forth.

By 1960, a very large fraction of the literature of observational astronomy was concentrated into about 20 weekly to quarterly journals, listed in Table 1. A few small ones of the period (e.g. Irish Astronomical Journal and Quarterly Journal of the Royal Astronomical Society) have completely disappeared; and a few are new since 1960 (two published in

India; *Revista Mexicana de Astronomia y Astrofisica*; *Astrofisica* from Armenia and *Astrophysics & Space Science*), none with very many papers or highly cited ones.

The most significant change in the journal landscape between 1960 and 2001 was the 1969 merger of three major journals (*Annales d'Astrophysique*, France; *Bulletin of the Astronomical Institutes of the Netherlands*; *Zeitschrift für Astrophysik*, West Germany) and three smaller ones, from Sweden and France, later joined by the *Bulletin of the Astronomical Institutes of Czechoslovakia*, to form a European journal, *Astronomy and Astrophysics*. *Monthly Notices of the Royal Astronomical Society* (London) declined the opportunity, and the UK still maintains a separate journal and is not a partner in the European Southern Observatory. *Acta Astronomica* (Poland) and *Astronomische Nachrichten* (East Germany) were on the wrong side of the Oder-Neisse line in 1969 and did not have the opportunity to join in, though presumably they could now.

Table 1 represents 2164 papers published in 1960–64, which received 15,240 citations in 1965–1969 and 4,148 papers published in 2003, which received 64,996 citations in 2004–2006. The average number of citations per paper per year has, therefore, increased from 1.4 to 5.2. As tabulated, the citation rates have been normalized to those for the *Astrophysical Journal* (including *Letters*) which had the largest number of papers in each data set, and for which *C/P* was 9.90 and 17.11 for the two periods (or *C/P* per year about 2 and 5.7).

American dominance exists in both periods. Leaving out the essentially international *Science*, *Nature*, and *Physical Review Letters*, we find that the American journals (*ApJ*, *ApJS*, *AJ*, *PASP*) were responsible for 45% of the papers and 51% of the citations for 1960–1969 and in 46% of the papers and 58% of the citations in 2003–2006.

Western Europe is, however, very close to overtaking the USA in recent years. The European journals (*MNRAS*, *Observatory*, *A&A* or the four publications folded into it) contained 23% of the papers and received 18% of the citations for the 1960–1969 but 45% of the papers and 33% of the citations for 2003–2006. Clearly the merger to form *A&A* has been an enormous success, arguably both benefiting from and contributing to the rise of European astronomy relative to American. The numbers in Table 1 won't quite reproduce these percentages, because the original data base included a few of the smaller journals just mentioned.

This is another place where we can easily look for changes in equality of some aspect of astronomical research and publications. For the 1960–1964 period, the two largest journals were both American (*ApJ* and *AJ*) and contained 36% of the papers, while in 2003, *ApJ* and *A&A* contained 62% of the papers. The major sufferers clearly have been the Soviet Union (Russia) and Eastern Europe, with 13% of the papers in the earlier time frame and only 3% in the latter. Citedness has also declined sharply, with the exception of the Polish *Acta Astronomica* which in 2001–2003 included a number of papers reporting results from searches for gravitational lensing by dark matter candidates and for exoplanets passing in front of their host stars. The searches used dedicated small telescopes, maintained in Chile by the Polish astronomical community, and, in comparison with other aspects of the table indicate that very creative groups of scientists can go far towards balancing the great advantages generally enjoyed by large, well-supported communities. You will meet another example in a later section concerning moderate-sized, aging telescopes.

On average, astronomers still tend to publish in their “home” journals, though far less so now than in the past, partly because the fraction of papers involving international collaborations has increased enormously (Abt 2005). Journal selection by authors is also a good deal influenced by the imposition of page charges in excess of \$100 per page by *ApJ*,

ApJS, AJ, and PASP. A&A assesses member institutions rather than their individual researchers, and most of the others have no page charges at all.

Evaluation of researchers by the impact factors of the journals in which they publish has been much criticized in these pages and elsewhere, but notice that *Science* and *Nature*, which cover many fields, some with much higher average citation rates than astronomy nevertheless include astronomical papers that are more highly cited than average at present, though this was not true 40+ years ago, when astronomers first began to submit to these journals (and to *Physical Review Letters*).

Non-optical astronomy

The astronomers of 1960–1964 focused largely on optical observations from the ground. Radio astronomy was developing rapidly, but within a community almost entirely separate from the optical one. And space astronomers really were rocket scientists, typically with little or no astronomical background. Only about 1.5% of papers reported results from more than one of these bands (and many of those pertained to solar phenomena), while multi-wavelength papers are now about 16% of the total, and many people work in two or all three of the regimes.

Space astronomy

Astronomical observations from space (the only sort possible in the ultraviolet, X-ray, and gamma-ray bands, but also important for visible and infrared radiation) have changed beyond recognition. The 1960–1964 period included results from rockets, balloons, and detectors on probes and earth orbiters intended primarily for other purposes, and the general rule was one result (and one paper) per rocket. All the highly cited 2001–2003 papers report measurements from satellites launched specifically to do astronomy.

For both time frames, about 80 different facilities contributed, but very different sorts. The largest numbers of papers, and the highly cited ones, in 2001–2006 come from earth-orbiting satellites collecting X-rays (especially *Chandra* and *XMM*, roughly American and European respectively) and to a lesser extent gamma rays and infrared radiation, for which the earth's atmosphere is a major noise source. The discoveries of the first two non-solar X-ray sources, *Sco X-1* and the Crab Nebula, belong to 1960–1964 and came from two different rocket flights. Discovery of the gamma-ray background and of the solar wind came from probes intended primarily for lunar and planetary studies.

Among the non-solar papers cited at least four times in 1965–69, space-based results appeared in 5%, with citation rates about 50% larger than for the optical papers. In recent years, space-based papers still get cited rather more often than ground-based ones, but by only about 20%. And they made up 35% of all papers in observational astronomy.

Radio astronomy

That astronomical objects emits radio waves was an accidental discovery made as part of an effort to determine backgrounds for radio ship-to-shore and other communications. World War II radar experience and left-over equipment contributed to very rapid growth beginning in the UK, Australia, and the Netherlands, with the US arriving late but with heavy ammunition. The groups responsible for the largest numbers of papers in 1960–64 were at Cambridge University, Jodrell Bank (Manchester, UK), in Australia (several sites),

Owens Valley (California, belonging to the California Institute of Technology), and Greenbank (West Virginia, the National Radio Astronomy Observatory). All five groups still exist, though only a very few of the same telescopes are still in use (the 250' and 60-m in Jodrell and Australia, both fully steerable parabolas, and a couple of the Owens Valley interferometer antennas). Each time frame has something like 100 facilities on 80 sites, but with these exceptions, not the same ones!

Papers reporting radio data were common in both time frames, about 15% in 1960–1964 (at least of the more highly cited papers) and 22% in 2001–2003. Early radio papers and recent ones both have citation rates not very different from the optical. Table 2 has some numbers for papers and citation rates for the five early leaders, but the leap up for NRAO is due largely to the post-1960 development of the Very Large Array in Socorro, New Mexico, now the most productive radio facility (and among the most highly cited) in the world. There are more traditional facilities responsible for 50–100 papers each in the later data set at Westerbork (NL), Effelsberg (DE), Arecibo (Puerto Rico), and several places in Russia.

The extension of radio astronomy into the millimeter and submillimeter regimes for study of individual sources and discovery of the cosmic microwave background in 1965 also enormously changed the radio landscape. Large numbers of papers (e.g. 178 from the James Clark Maxwell submillimeter telescope, a UK facility in Hawaii) and exceedingly highly cited ones (hundreds of citations per year per paper for results from the Wilkinson Microwave Anisotropy Probe in 2003) are characteristic of these newer wavebands.

The most rapid changes of physical landscape associated with radio astronomy undoubtedly belong to the facilities associated with Mullard Radio Astronomy Observatory, in the Cavendish Laboratory, at Cambridge University. Their 1960–1964 papers had results from 4 or 5 generations of antennas, and the most important 2001–2003 facility, the Ryle Telescope, has already been taken apart and reassembled as part of the AMI facility for study of anisotropies in the cosmic microwave background radiation. It is a little hard to think of a radio astronomer at an eyepiece, but the general principle of the right sorts of people being able to compensate for the wrong sorts of environment clearly applies.

Table 2 Papers and citations from major radio astronomy groups

Place/organization	1960–1964 Papers	C(1965–1969)/P	2001–2003 Papers	C(3 years)/P
(1) Jodrell Bank	42.0	10.6	19.6	11.1
(2) Australia	41.9	14.9	238.0	14.2
(3) Owens Valley	35.8	24.0	57.2	11.6
(4) Cambridge	35.3	16.8	69.4	11.0
(5) NRAO	33.4	8.2	621.0	14.5

(1) Everything on site, but 250' dish dominates in both time frames

(2) Everything on multiple sites for 1960–1964 including Parkes. The Australia Telescope greatly dominates 2001–2003 numbers

(3) Two antennas operating as an interferometer in 1960–1964; larger number and at shorter wavelengths in 2001–2003

(4) No facilities in common between the two time frames. Primarily the Ryle Telescope and Merlin for 2001–2003

(5) Everything on the Greenbank site 1960–1964, including first results from the 300' dish; Greenbank (GBT), and the Very Large Array (VLA, Socorro NM) for 2001–2003

The right people in the right environment can be even more effective. The three most impressive modern radio observatories (Parkes, the VLA, and the Australia Telescope) were successively directed by the same person, Ron Ekers, who later became president of the International Astronomical Union.

The rise and fall of optical telescopes

In 1960, the largest astronomical mirrors in use were the 5 m Hale Telescope at Palomar Mountain, the 3 m Lick at Mt. Hamilton, the 2.5 m Hooker at Mt. Wilson, and the 2.1 m McDonald in Texas, followed by five with diameters of about 72" (6 ft., 1.8 m), two in Canada, and one each in Australia, South Africa, Japan, and the USA (next section).

By 1990, the largest were a 6-m in the Zelenchukskij region of Russia, the Palomar 5 m (still), the 4.5 m Multi-Mirror Telescope in Arizona, the 4.2 m William Herschel Telescope in the Canary Islands, followed by 7 mirrors of 3.5–4 m diameter in Arizona, Chile (3, two European, one US), Hawaii, Spain, and Australia. Ownership was already more diverse than it had been, with the German-Hispanic telescope in Calar Alto, and the Hawaiian site occupied by a joint Canada–France–Hawaii facility. To this period also belong two infrared facilities, one US and one UK, both in Hawaii, and the only telescopes prominent in that period now producing more papers than they did then.

The telescopes yielding the largest numbers of papers and the most cited from this intermediate time frame (Trimble 1996) were characterized by relatively large mirror diameters, relatively high, dry sites (compared to earlier times, but not to later times), and intermediate-sized user communities, somewhere between a dozen astronomers at one institution and hundreds across a whole country. They were all also relatively difficult to get to, selecting for observers who really wanted data.

The twenty-first century population is still more numerous, larger, and more diverse, with eleven 8-m class mirrors (two each for the American Gemini and Magellan projects, two for Keck in Hawaii, the Japanese Subaru also in Hawaii, and the four that make up the European Very Large Telescope in Chile). Still more were in the process of coming up to speed, including still larger collecting areas (roughly 11 m equivalent diameter) in Texas and South Africa. Incidentally, the 8-m class actually extends from 6.5 to 10 m, and there are some very new ones of those as well, that did not contribute to papers published in 2001–2003, like the Large Binocular Telescope in the USA and the Gran Telescopio Canarias in the Canary Islands.

Table 3 attempts to track the leaders from the three periods. Clearly no one telescope remains dominant in even two, though the Palomar 5-m comes closest to holding its own through all three periods (and, yes, it still appears in 2008 papers). But neither it nor any of the other twelve most important telescopes in the 1990–1993 time frame produced as many papers per year in 2001–2003 except for the two infrared facilities (IRTF, UKIRT). The infrared is a relatively new, very important spectral range, for which larger telescopes were only just being developed shortly after 2000. It is, perhaps, a prediction of this study that by about 2010 the IRTF and UKIRT will also be producing fewer papers per year than previously, because the most enthusiastic IR astronomers will have moved their work to larger mirrors.

The largest numbers of papers now come from the Hubble Space Telescope. The mirror is no larger than the old Mt. Wilson 100", but the location above the earth's atmosphere allows it access to the ultraviolet wavelength regime and provides much sharper images than those seen through the changing screen of air. It is also enormously well supported,

Table 3 Papers and citations for the most significant optical telescopes in three periods

Telescope location/size	1960–1969		1990–1993		2001–2006	
	Papers/ year	Citations/ paper/year	Papers/ year	Citations/ paper/year	Papers/ year	Citations/ paper/year
Palomar 5 m	17.4	2.82	43.7	3.61	19.3	4.18
Pal. 48'' Schmidt	16.0	1.15	In use, not tracked		41.3	4.61
Mt. Wilson 100''	33.0	2.15	Little/no research		Little/no research	
Mt. Wilson 60''	7.4	1.78	Little/no research		Little/no research	
Lick 120''	9.9	1.05	31.8	4.30	15.6	5.6
Lick 36'' Crossley	8.5	1.06	In use, not tracked		Lost in noise	
McDonald 2.1 m	15.9	1.04	7.1	3.77	6.6	3.86
McDonald 2.7 m			17.5	4.41	17.1	4.08
Canada–France–Hawaii			58.1	3.00	41.3	5.02
Anglo-Australian			62.8	4.96	56.7	8.99
Kitt Peak 4 m			38.1	4.71	26.4	5.24
Cerro Tololo 4 m			52.5	4.61	32.0	4.16
UK Infrared Tel.			38.9	3.10	43.4	3.83
InfraRed Tel. Facility			21.4	4.2	27.5	4.04
Multi-mirror Tel.			22.0	4.97	12.3	5.67
U. Hawaii 2.2 m			12.8	5.50	17.8	4.17
Euro. So. Obs. 3.6 m			50.1	2.62	39.0	3.63
Hubble Space Tel.					354.4	4.83
Keck (2 × 10 m)					121.9	7.78
Very Large Tel. (ESO, 4 × 8 m)					115.2	5.50
Sloan Digital Sky Survey (US)					53.7	15.00

with observers receiving funding in proportion to their observing time to process and publish their data (that is, fund their students and postdoctoral fellows). This does not happen for any ground-based facility. The result is that its current 350 papers per year exceeds the entire optical output (about 290 papers/year) of the early 1960s.

While big is generally thought of as better, small telescopes (more than 150 of them, some privately owned) are still a significant part of astronomy. Apart from HST, no one facility contributed in 2001–2003 as many papers as the 533.7 that came from telescopes smaller than 1.5 m. The corresponding category for 1960–1964 was smaller than 20'' (0.5 m) and again a very large number of these contributed as much to the literature as any one large telescope. In both cases, the papers from the smaller facilities were cited only about one-third as often as those from major observatories.

The Palomar 48'' Schmidt is something of a special case. It was used for the original Palomar Observatory Sky Survey of the northern 2/3 of the sky around 1950 (later matched by southern Schmidt surveys). The 48'' has been in almost continuous use for 60 years, but many of the recent publications make use of the earlier surveys and catalogues derived from them to search, for instance, for variable objects and for visible counterparts of sources discovered at other wavelengths. Credit for “the astronomer at the eye piece” here has to be shared among Bernhard Schmidt, inventor of the design, Walter Baade, Fritz Zwicky and a few other people insightful enough to recognize that a suitable Schmidt

could survey the entire sky in reasonable time, and the current users of the archival data, a form of observational astronomy rapidly becoming more common.

HST also illustrates a “person at the eyepiece” effect. Former director Robert Williams devoted 100% of his director’s discretionary observing time to multiple, very long exposures of a single part of the sky, the so-called Hubble Deep Field. It told us more about the objects in the very distant universe (particularly half-formed galaxies) than could have been learned any other way at the time, and a very large number of published papers used and use HDF data.

What happens to formerly-outstanding telescopes when they get really old? Some of the important ones of the early years of the twentieth century are now used for observing by school groups and the public. This includes large refractors (telescopes with lenses rather than mirrors) in the USA and Europe and the Mt. Wilson reflectors, which contributed almost no papers in our latter two time bands (though some work on variable stars continues), but can be hired for individual projects from the private owners. Has any large telescope ever been completely destroyed? Not deliberately yet (although the 74'' in Eastern Canada is apparently at risk; observations ceased in 2008), but a couple were burnt to the ground at the Mt. Stromlo and Siding Spring Observatories in Australia in 2005 when brush fires swept many dry square miles. Exactly what to rebuild is still under discussion. These were 2-m class mirrors, not the spectacularly productive Anglo-Australia Telescope. But the victims did include what had once been the Great Melbourne Telescope (1878) with a 48'' speculum mirror, later replaced with silvered glass, and still more recently refitted for a gravitational lens search that resulted in a number of highly-cited paper in the 1990s.

The numbers from Table 3 also imply a very large increase in equality of opportunity in observational astronomy. The four observatories responsible for the largest numbers of papers in 1960–1964 (Palomar, Mt. Wilson, Lick, and McDonald) each belonged to a single institution or pair, and astronomers not at those institutions had access to the telescopes only very occasionally and by special arrangements. These four contributed 42% of the papers and 59% of the citations in the 1960–1964 and 1965–1969 periods. All were also in the USA, three in California.

In the intermediate time frame (details from Trimble 1996), the five largest observatories contributed 47% of the papers and 49% of the citations, but they were then located in Arizona, Chile, Hawaii, and Australia, with the Arizona and one Chilean observatory available to all American astronomers, the other Chilean one to most European astronomers, and the Canada–France–Hawaii and Anglo-Australian telescopes at least with national ownerships rather than single institutions.

And moving into the twenty-first century, it becomes somewhat difficult to decide which are actually the dominant observatories, because good sites (like Mauna Kea, Hawaii, and the Canary Islands) have many telescopes with different ownership; the American facilities are spread across multiple sites; and even the European Southern Observatory now supports both Paranal and La Silla in Chile. But the four obvious major entities—Mauna Kea, Canary Islands, European Southern Observatory, and, of course, the Hubble Space Telescope produced 48% of the papers and 49% of the citations. Plus ça change, plus c’est le meme chose, if you wish. But those four are still more international, with HST, at least, in principle available to any astronomer in the world. It must be said, however, that only 28 of the 958 proposals in the most recent cycle (Reid 2008) came from outside the core sponsors of the US and European Space Agency and only 6 of the 228 approved programs were from outsiders in this sense.

Observatory sites as well as their telescopes age, with all of the four leaders of the 1960s (and Kitt Peak in Arizona as well) now suffering badly from the incursion of artificial lighting. There is no guarantee that Mauna Kea, the Chilean Andes, and the Canary Islands won't eventually be similarly affected, and some aspects of human development (contrails from jets, for instance) and climate changes could eventually render all ground-based sites unsatisfactory.

A very small, but complete, sample

At the time astronomical data were being gathered that would be published in 1960 to 1964, there existed six rather similar telescopes, with mirror diameters between 69" and 74" and rather similar capabilities for (mostly) spectroscopy and some imaging. Table 4 lists these in the order in which they came into operation ("first light"). Two more similar ones were built by the same firm that erected the Japanese 1.88 m (Grubb-Parsons) after 1960, one in Egypt and one in France. The former is invisible in the 2001–2006 data, the latter contributed 42 papers with respectable citation rates. It is the largest mirror on its (relatively good, quite high) site.

Of the telescopes in Table 4, the Stromlo and Radcliffe are in reasonably dry, high, dark places. The two Canadian telescopes are fairly close to sea level in places with more water overhead than an astronomer normally wants. The Japanese site falls in between (and the 1.88 m is the largest mirror there; the Japanese Subaru having been built on Mauna Kea, Hawaii), while the Perkins telescope was moved from Ohio (low, wet, cloudy) to Flagstaff Arizona (much better) in the mid 1960s, but in recent years has produced too few papers to be visible in the literature compared to other small telescopes in Arizona. In the past year, the Perkins has been equipped with new, modern focal plane instrumentation and the David Dunlap facility has been closed. And the Stromlo 72" was burned along with other buildings on the site, though it was still contributing to a moderate number of papers with citation rates not much below the optical average (13.46 in 3 years) for the 2001–2006 period.

The stand-out, clearly, is the 74" Radcliffe telescope in South Africa (also moved to a better site after it was built and in use.) It seems to have been 3–4 times as productive as the apparent competition, despite years of political turmoil in its host country. It is the largest telescope on its site, but my own impression is that the most important factor has been, and remains, a stable (small) group of serious observers focused on kinds of astronomy (binary and variable stars) for which the telescope and its instrumentation are suited. They now have access to the much larger SALT (South Africa Large Telescope),

Table 4 The 69"–74" mirrors of 1960

Name/location	First light	1960–1964 papers	1965–1969 Cit/P	2001–2003 papers	2003–2006 Cit/P
Dominion Astrophysical Observatory, Canada	1917	12.0	4.5	14.0	4.9
Perkins 69" Ohio/Arizona	1932	7.6	3.7	Lost in noise	
David Dunlap Observatory, Canada	1945	11.2	4.5	12.0	6.9
Radcliffe 74" South Africa	1948	49.9	4.5	43.4	6.5
Mt. Stromlo Australia	1955	36.3	4.0	26.1	10.5
Okayama, Japan	1960	5.0	4.6	11.1	3.1

with an effective mirror diameter near 11 m, and gradual decline of the productivity and impact of the Radcliffe telescope is a reasonable, if perhaps sad, prediction as a result.

Conclusions

Any attempt at synoptic studies over decades to centuries of scientists, their publications, their journals, and the facilities they use inevitably first sees “more, more, more.” Most of our communities have continued to grow exponentially into the twenty-first century, though this obviously cannot continue forever. Suitable counting and normalization can reveal both things that have changed and things that have not on top of this background of growth. Within astronomy since 1960, at least two things have remained stable, the number of journals (about 20) in which we publish (but with one major merger) and the number of telescopes (optical, radio, and lifted above the earth’s surface) that we have used—a total of something like 500, both in the 1960s and recently, perhaps larger than most would have guessed.

There have been major changes in (1) which were the most productive and most influential observatories (etc.), (2) equality of access to them (greatly increased), (3) identities of the scientists using them (suggesting a half life of about 40 years for us as well as for our telescopes), and (4) dominance of the USA and especially California over optical astronomy (both greatly decreased). The fraction of all citations that go to the high-profile papers has increased, but not enormously, from about 12% to 15% for the top 1% of papers. And the influence of individual astronomers and small groups can still be seen.

I, at least, would like to know about similar constants and changes in other sciences—that Europe is catching up to or passing the USA has been noted many places, and a curious inequality of achievement at least once recently (Jones et al. 2008).

Such investigations are probably most easily done by people who know the particular sciences fairly well.

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