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Productivity and Impact of Space-based Astronomical Facilities

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ABSTRACT. In 2001, 18 journals published about 1270 astronomical papers that reported and/or analyzed data gathered by space-based observatories and missions. These papers were cited 24,460 times in papers published in 2002–2004, an average of 19.26 citations per paper or 6.42 citations per paper per year (sometimes called impact or impact factor). About 60 satellites, rockets, balloons, and planetary missions were represented, including six ground-based Cerenkov detectors for ultra-high energy gamma rays, because we didn't know where else to put them. Of these facilities, 21 provided the data for at least five papers, when credit was divided equally among all contributing facilities. We analyze here distributions of papers, citations, and impact factors among the facilities and among subject areas and compare the results with studies of optical and radio telescopes (Trimble et al. and Trimble & Zaich). Some similarities include the rarity of completely uncited papers (only 41 of 1274, or 3.2%) and the concentrations of the most highly cited papers toward popular topics, high-profile journals, and the most successful telescopes of the year. Some important differences arise because many space-based observatories have lifetimes shorter than the typical time required to think of an interesting astronomical observation, propose for it, get the data, write the paper and publish it (including the fight with the referee), and have citations accumulate. The result is superstar status in citation numbers for *XMM-Newton* (whose first-light package appeared in 2001) and in paper numbers for *Chandra* (launched 5 months earlier), while aging satellites (*RXTE*, *BeppoSAX*, *ASCA*) and the archival-only *ROSAT*, *ISO*, *IRAS*, etc., were still important contributors, but with fewer papers and less highly cited papers. The impact factor of 6.42 for the totality of these gamma-ray, X-ray, ultraviolet, space infrared and optical, and planetary mission papers (6.42) was larger than the corresponding radio (4.52) and optical (5.47) numbers. Notice that *HST* is included with “optical” but *Hipparcos* with “space.” A contemplated fourth paper will divide credit for papers and citations among every observatory of any sort that contributed to each published paper.

1. INTRODUCTION

Bean counting of papers and citations in optical astronomy began in 1981 (Abt 1981). Paper I of this series (Trimble et al. 2005) provided a synoptic view of the papers resulting from optical telescopes and the citations to them by comparing data from 2001 to 2003 with data from 1990 to 1993 (Trimble 1996). An extension to the literature of radio astronomy was fairly straightforward (Trimble & Zaich 2006, Paper II), because radio telescopes, like optical ones, generally stay put for a number of years after their commissioning. The situation for X-ray, ultraviolet, gamma-ray, and other space-based astronomy is by no means analogous, because most missions have lifetimes that are shorter than the “cycle time” for proposals to be written, data acquired, papers written and published, and citations to accumulate.

We nevertheless attempt here a compilation of paper num-

bers and citation rates for everything that is not ground-based optical and infrared astronomy, plus *HST* (Paper I) and not ground-based or satellite radio, millimeter, and submillimeter astronomy (Paper II). This turns out to include the obvious wave bands, but also one optical space-based mission (*Hipparcos*) and ground-based observations of very high energy gamma rays, because they had not appeared anywhere else. After some cogitation, the decision was made to also include data from solar system missions (*Apollo* to *Galileo*) that had contributed to the astronomical literature of 2001, most often through studies of the objects they were aimed at, but sometimes through use of ultraviolet or particle monitors aimed at non-solar-system objects.

No previous analogous studies seem to exist for either radio or space astronomy to provide either guidance or a basis for examining changes. We have made the analyses of Paper II and the present work as nearly identical as possible to that of the optical telescope study in Paper I.

2. METHODS

Keeping in mind the goal of including all observational astronomy not represented in Papers I and II, V. T. went page by page through all the issues of 19 journals published in 2001

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and identified all the papers that reported or analyzed data from any space-based astronomical facility (including balloon, rocket, and shuttle-borne detectors, and *Hipparcos*, but excluding *HST* from Paper I and the satellite radio and millimeter missions—*HALCA*, *COBE*, etc.—from Paper II). There were 1274 such papers, 217 of which also included optical data and 55 of which also included radio (but no optical) data. Get out your abacus to verify that the total of non-optical papers is therefore 2055, compared to about 2100 with optical data. Half of all observational astronomy, in other words, remained in the wave band of its birth, at least until 2001.

The journals and paper yields were *A&A* (including *Letters*, 355), *ApJ* (354), *ApJ Letters* (200), *MNRAS* (156), *AJ* (53), *Icarus* (48), *PASJ* (23), *ApJS* (19), *Astronomy Letters* (13), *Science* (13), *Nature* (12), *PASP* (9), *Astronomy Reports* (5), *Astron. Nachr.* (4), *J. Astrophys. Astron.* (4), *Observatory* (3), *Acta Astronomica* (2), *Ap&SS* (1), and *JRASC* (0).

For each paper, the following information was recorded: name of first author, number of additional authors, volume and page number, total number of pages, subject matter (using the same categories as in Paper I), and the identity of all the satellites, missions, detectors, and so forth contributing data to the paper in the order they were mentioned by the authors. For a few papers, it was not possible to determine which facilities were used, and for a few others the subject was unclear. These do not appear in Tables 2 and 3. Assignment of subject was based on what the authors said they had in mind. For instance, a measurement of the D/H ratio might have been aimed at constraining big bang nucleosynthesis (“cosmology”) or chemical evolution in our Galaxy (“Milky Way”) or fractionation in the interstellar medium (“ISM”).

P. Z. then went to the online version (Web of Science) of the Science Citation Index (SCI) and recorded the number of citations to each paper from 2002 to 2004. That we find fewer completely uncited papers than have been recorded in other studies (e.g., Meylan et al. 2004) suggests that the SCI database is somewhat more complete than the Astrophysics Data System (ADS) version. T. B. did some of the citation counting for Paper I and collected the information on birth and death dates that were important to Table 3 and some of the results in § 3.

The most difficult decisions were how to apportion papers and citations among the facilities used for a single paper and which facilities to report individually. The decisions made were those of Papers I and II. That is, equal credit was given to all satellites (etc.) used for a paper, according to the authors. The maximum number was seven (fewer than in the optical and radio cases) for several studies of long-term variability of X-ray sources, with memories stretching back to *Tenma* (1983–1985) and *Ariel V* (1974–1980) in the X-ray and *ANS* (1974–1976) in the ultraviolet, but not to *Uhuru* (1970–1975) or *OSO 7* (1971–1973). Citations were similarly divided equally, except that even the chief bean counter drew the line at assigning one-seventh of a citation to an ultraviolet balloon. Division was as equal as integers could make it, with one extra given to each of the

telescopes mentioned first in the paper to make up the total. Thus, 14 references to three facilities were divided as 5, 5, 4, and so forth.

About 80 facilities contributed at least a fraction of a paper to the 2001 literature. Of these, 21 were credited with at least five papers (often made up of assorted fractions) and appear individually in Table 3.

3. RESULTS

These are divided into small subsections, titled to suggest either what you might have expected or the opposite. They are somewhat different from the subsections of Papers I and II, reflecting a rather different set of phenomena.

3.1. Friends Don’t Let Friends Go Uncited

For the optical sample, only 133 of the 2100 papers (6.3%) went completely uncited in the 2 years after publication (Paper I), and this drops to 63 of 2100 (3.0%) with 3 years of citations. The radio rate was not very different, 28 zeros out of 836 papers (3.3%) after 3 years (Paper II). And in the space sample, 41 of 1274 papers (3.2%) gathered no morsel of citations. The uncited space papers came from both unpopular subdisciplines (e.g., cataclysmic variables) and popular ones (e.g., active galactic nuclei) and from both high and low profile journals. But there were no uncited papers reporting data from *XMM*, *Chandra*, *FUSE*, *EUVE*, or *CGRO*.

Proportional uncitedness is even lower for multiwavelength papers: 5 of 220 (2.3%) for space+optical; and none of the space+radio or optical+radio papers scored an impact factor of zero. The percentages of uncited papers represent upper limits to reality, because they include a few substantial ones by well-known authors, on hot topics pursued with major instruments, and published in high-profile journals, indicating that somehow the papers were not being retrieved correctly or were not properly entered in the SCI database.

Table 1 represents the other end of the citation spectrum, listing the most-cited papers, ordered by numbers of citations and indicating the journal of publication, the topic, and the facilities used. We list 20 papers (extending down to 100 citations in 3 years) rather than the 10 of Papers I and II, because the top of the list is so heavily weighted by the reports of the instrument package on *XMM-Newton*. As in the optical and radio cases, these highly cited papers represent a relatively small subset of topics, journals, and facilities. It is worth noting that all the *XMM* ones come from the “first light” package, which filled an entire issue of *Astronomy and Astrophysics* with *Letters*.

3.2. One Wavelength’s Mite Is Another Wavelength’s Poisson?

Table 2 is a slightly cluttered one, dividing up the “space” papers and citations by subdiscipline, with columns for numbers of papers, numbers of citations, citations per paper, and

TABLE 1
THE MOST-CITED SPACE-BASED PAPERS

| Number of Citations | Telescope(s) | Journal | Subject |
|---------------------|--|----------------|----------------------|
| 380 | <i>XMM</i> | <i>A&A</i> | Mission description |
| 370 | <i>XMM</i> | <i>A&A</i> | Mission description |
| 306 | <i>XMM</i> | <i>A&A</i> | Mission description |
| 186 | <i>Chandra</i> +optical | <i>ApJ</i> | AGNs |
| 179 | <i>XMM</i> | <i>A&A</i> | Mission description |
| 162 | <i>XMM</i> | <i>A&A</i> | Clusters of galaxies |
| 152 | <i>Chandra</i> | <i>AJ</i> | Catalog |
| 134 | <i>Chandra</i> +optical+radio | <i>AJ</i> | Galaxies |
| 133 | <i>XMM</i> | <i>A&A</i> | Clusters of galaxies |
| 130 | <i>XMM</i> | <i>MNRAS</i> | AGNs |
| 121 | <i>Chandra</i> | <i>ApJ</i> | Clusters of galaxies |
| 114 | <i>ROSAT</i> + <i>ASCA</i> | <i>A&A</i> | Stars |
| 111 | <i>ROSAT</i> +radio | <i>ApJ</i> | AGNs |
| 110 | <i>ASCA</i> + <i>HEAO-1</i> + <i>ROSAT</i> | <i>A&A</i> | AGNs |
| 108 | <i>Chandra</i> | <i>Nature</i> | Milky Way |
| 105 | <i>IRTS</i> + <i>COBE</i> | <i>ApJ</i> | ISM |
| 103 | <i>Chandra</i> | <i>ApJ</i> | Survey |
| 101 | <i>ROSAT</i> | <i>ApJ</i> | Cosmology |
| 101 | <i>Chandra</i> | <i>ApJ</i> | Galaxies |
| 100 | <i>Chandra</i> | <i>ApJ</i> | Clusters of galaxies |

fraction of all papers in that subdiscipline. In addition, it shows citations per paper and fraction of all papers for the optical sample (updated from Paper I) and the radio one (Paper II). Some subjects are loved and much written about across the full electromagnetic spectrum (active galaxies for instance). On the other hand, white dwarfs and exoplanets belong largely to the

optical astronomers, while radio folk are more interested in the interstellar medium, and users of space-based facilities in neutron stars and black holes.

Some subjects also have much higher than average citation rates in all three samples. These include cosmology (with many papers), but also gamma-ray bursts, brown dwarfs, and exoplanets (with rather few papers each). Galaxies (normal and active) beat out stars at all wavelengths, although “optical observations of stars” is still the largest single category of paper when the three samples are summed. And binary stars of all sorts (except those with neutron star or black hole components) always do badly in citations per paper. So, curiously, do solar system topics, although less so for the papers reporting data acquired by actually going to the objects of study.

3.3. Are We Holding Our Own?

In the case of optical telescopes, bean counting goes back at least to Abt (1981), and Paper I was partly a decade-on update of a 1990–1993 study (Trimble 1996). We are not aware of any previous comparative study of papers and citations in space-based astronomy. Given the “aging gorilla” phenomenon (§ 3.4), it might not even be very wise to try. It would, however, be possible to go back to the literature of some years when missions other than *XMM* and *Chandra* should have been at peak productivity, and parcel out credit for papers and later citations among all the missions (etc.) that contributed to papers in each year. You could do this if we don’t get around to it.

TABLE 2
CITATION RATES BY TOPIC AND COMPARISON WITH OPTICAL AND RADIO NUMBERS

| TOPIC | CITATIONS | SPACE PAPERS | C/P | % OF PAPERS | OPTICAL | | RADIO | |
|---|-----------|--------------|--------------------|-------------|---------|-------------|-----------------|-------------|
| | | | | | C/P | % of Papers | C/P | % of Papers |
| Cosmology | 668 | 27 | 2522.48 | 2.1 | 39.97 | 5.1 | 28.02 | 4.4 |
| Clusters of galaxies | 2992 | 95 | 31.49 | 7.5 | 15.64 | 4.0 | 16.69 | 3.8 |
| GRBs | 801 | 34 | 23.56 | 2.7 | 28.04 | 1.2 | 51.54 | 1.1 |
| AGNs | 3773 | 191 | 19.75 | 15.1 | 17.46 | 9.6 | 13.36 | 17.1 |
| Galaxies | 2799 | 113 | 24.77 | 8.9 | 23.44 | 14.7 | 14.03 | 17.2 |
| Milky Way | 529 | 25 | 21.26 | 2.0 | 29.30 | 0.8 | 12.95 | 2.6 |
| ISM | 1155 | 78 | 14.81 | 6.2 | 10.37 | 6.6 | 10.90 | 20.8 |
| SNe/SNR | 909 | 67 | 13.17 | 5.3 | 13.98 | 2.1 | 8.50 | 4.3 |
| NS/BH/XRB/psr | 3607 | 241 | 14.97 | 19.1 | 14.76 | 2.1 | 15.19 | 8.7 |
| YSO/star formations | 940 | 42 | 22.38 | 3.3 | 17.65 | 4.1 | 14.62 | 6.3 |
| Star clusters | 585 | 29 | 20.17 | 2.3 | 14.23 | 8.5 | (with stars) | |
| Stars | 1452 | 104 | 13.96 | 8.2 | 9.99 | 15.3 | 9.05 | 5.1 |
| Brown dwarfs | 129 | 4 | 32.25 | 0.3 | 29.71 | 1.1 | (with stars) | |
| Binary stars | 315 | 33 | 6.52 | 2.6 | 6.89 | 2.7 | 6.17 | 0.7 |
| Cataclysmic variables | 306 | 38 | 8.05 | 3.0 | 7.15 | 2.5 | (with binaries) | |
| Planetary nebulae | 281 | 18 | 15.61 | 1.4 | 9.07 | 2.7 | (with WDs) | |
| White dwarfs | 22 | 5 | 4.40 | 0.4 | 17.70 | 1.6 | 12.43 | 3.5 |
| Exoplanets/SETI | 186 | 7 | 26.57 | 0.6 | 27.63 | 1.5 | 16.25 | 0.5 |
| Solar system | 1092 | 76 | 14.37 | 6.0 | 11.61 | 5.1 | 8.91 | 2.8 |
| Service (surveys, catalogs, calibrations, astrometry, mission, and instrument descriptions) | 1807 | 38 | 47.55 ^a | 3.0 | 27.29 | 0.6 | 7.12 | 3.0 |
| Total | 24,368 | 1265 | 19.26 | 100 | 16.42 | 100 | 16.18 | 100 |

^a 14.17 excluding the three very highly cited descriptions of *XMM* and its instruments.

TABLE 3
PAPERS AND CITATIONS BY SATELLITE (ETC.)

| Facility | Period of Operation | Citations | Papers | C/P |
|--|---------------------|-----------|--------|-------------------|
| X-Ray | | | | |
| <i>XMM-Newton</i> | 1999 Dec–present | 3622 | 83.5 | 43.4 ^a |
| <i>Chandra</i> | 1999 Jul–present | 6092 | 175.8 | 34.6 |
| <i>ROSAT</i> | 1990 Jun–1999 Feb | 2212 | 130.3 | 17.0 |
| <i>BeppoSAX</i> | 1996 Apr–2003 Apr | 1196 | 81.2 | 14.7 |
| <i>ASCA</i> | 1993 Feb–2000 Jul | 1553 | 111.5 | 13.9 |
| <i>RXTE</i> | 1995 Dec–present | 1749 | 125.2 | 14.0 |
| <i>Einstein</i> | 1978 Nov–1981 Apr | 84 | 5.6 | 15.0 |
| <i>Ginga</i> | 1987 Feb–1991 Oct | 28 | 5.2 | 5.0 |
| Other X-ray missions | | 125 | 16.4 | 7.6 |
| X-ray total | | 16,661 | 734.7 | 22.7 |
| UV | | | | |
| <i>FUSE</i> | 1999 Jun–present | 629 | 35.3 | 17.8 |
| <i>EUVE</i> | 1992 Jun–2001 Jan | 182 | 19.8 | 9.2 |
| <i>IUE</i> | 1978 Jan–1996 Sep | 438 | 58.9 | 7.4 |
| <i>UIT</i> | Two weeks in 1995 | 116 | 8.3 | 13.9 |
| Other UV missions | | 117 | 17.0 | 6.9 |
| UV total | | 1482 | 139.6 | 10.6 |
| IR/optical | | | | |
| <i>Hipparcos</i> | 1989 Aug–1993 Aug | 1005 | 80.2 | 12.5 |
| <i>ISO</i> | 1995 Nov–May 1998 | 2511 | 131.4 | 19.1 |
| <i>IRAS</i> | 1983 Jan–1983 Nov | 786 | 48.4 | 16.2 |
| Other IR missions | | 290 | 13.6 | 21.3 |
| IR/optical total | | 4592 | 273.7 | 16.8 |
| Gamma Ray | | | | |
| <i>CGRO</i> | 1991 Apr–2000 Jun | 563 | 38.8 | 14.5 |
| <i>Mir-Kvant</i> , etc. | 1987 Mar–2001 Mar | 74 | 10.0 | 7.4 |
| Other space gamma-ray missions | | 102 | 4.0 | 25.5 |
| <i>HEGRA</i> | | 123 | 6.5 | 18.9 |
| Other ultra-high energy missions | | 69 | 6.3 | 10.9 |
| Gamma-ray total | | 931 | 65.9 | 15.2 |
| Solar System | | | | |
| <i>Galileo</i> | 1989 Oct–2003 Sep | 254 | 16.5 | 15.4 |
| <i>Mars Global Surveyor</i> | 1996 Nov–present | 235 | 16.0 | 14.7 |
| <i>Voyager</i> | 1979–present | 44 | 8.7 | 5.0 |
| Other solar system missions | | 251 | 14.0 | 17.9 |
| Solar system missions total | | 784 | 55.2 | 14.2 |
| Space total | | 24,365 | 1268 | 19.2 |

^a 31.88 without the three heavily cited mission description papers.

Any trends that might be found would need to be compared with the monotonic rise in all citation rates, from 3.48 to 4.81 per paper per year for the set of telescopes considered both in 1990–1993 and in Paper I.

We are not at all sure whether *XMM* and *Chandra* are in any sense more or less important than *Einstein* and *HEAO-1* (both of which contributed a few papers to the present sample), let alone *ROSAT* (which contributed many) and *Uhuru* (not represented at all in 2001 papers, except via source names like 4U 1234+56). Any careful attempt to find out should probably calibrate the secular trend for space-based papers separately from optical ones.

3.4. The Aging Gorilla

In the optical sample, *HST* was responsible for the largest number of papers (16%) and citations (19%), and in the radio, the Very Large Array (VLA) is an even more dominant primate (22% of papers and 27% of citations; Paper II). The most productive and influential (in our limited, quantitative sense) in 2001–2004 were *XMM* (6.6% of papers, 14.9% of citations) and *Chandra* (13.9% of papers, 25.0% of citations). The situation would surely have been at least somewhat different for a data sample taken in a year when *CGRO* or *ISO* was in its prime. And it is worth mentioning more than once that the aging *ASCA*

(1993–2000), *RXTE* (1995–present), and *BeppoSAX* (1996–2003) and the deceased *ROSAT* (1990–1999) were each responsible for the data in roughly 100 papers (prorated as usual, since they often appear in combination with each other and with current facilities). The papers have impact factors of 4.3 to 5.2 citations per paper per year, not much smaller than the averages in any of the wave bands.

The three most-cited papers (Table 1) are all descriptions of the *XMM* mission and its instrument package. Each has more than 300 citations, while the most-cited “science” paper reports *Chandra* and optical data for AGNs and garnered only 186 citations, a mere 10 times the average. In contrast, the radio star (Frail et al. 2001), with 298 citations in 3 years (about 10 times the average), reported data on gamma-ray bursts from the VLA and optical telescopes. And our optical gorilla remains the *HST* Key Project team determination of the Hubble constant (Freedman et al. 2001), with 632 citations in the 3 following years, about 38 times the optical average.

4. SUMMARY AND PREDICTIONS

The patterns of paper and citation numbers for astronomical data gathered from space-based missions (planetary, X-ray and gamma-ray, ultraviolet, infrared, and all) are similar in many ways to optical and radio patterns, particularly in which sub-

disciplines yield many papers and many citations per paper. Important differences in numbers of papers and citations per observing facility surely arise from the relatively short lifetimes of many orbiting telescopes.

It would, we think, be exceedingly interesting to prorate among all facilities used the papers and citations from years when other missions were probably at peak productivity. Suitable years might be 1994–1995 for *ASCA*, 1996–1997 for *RXTE*, and 1997–1998 for *BeppoSAX* and *ISO*. The proper years for *Hipparcos*, *IRAS*, and *ROSAT* should probably be the ones just after their catalogs were made public (1987–1988 for *IRAS*, for instance). We predict, not very imaginatively, that during these peak years, the various missions will be responsible for a larger fraction of the papers than they were in 2001, although not necessarily a much larger number, given historic trends in astronomical publishing, and that their papers will be cited more often than average within disciplines.

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