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CITATION ANALYSIS OF ASTRONOMICAL LITERATURE: COMMENTS ON CITATION HALF-LIVES

CHARLES J. PETERSON
Department of Physics and Astronomy, University of Missouri-Columbia, Columbia, Missouri 65202
and
Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics
5071 West Saanich Road, Victoria BC V8X 4M6, Canada

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ABSTRACT

We point out that half-life periods for the citation decay pattern given in scientometric studies of astronomical (and other) literature are more meaningful if citation counts are corrected for changes in the annual publication rate of the respective journals; such normalization is not a standard practice in citation analysis studies. We use available 1984 *Science Citation Index* data to study the citation probability as a function of age of the cited papers and to compute citation half-lives for papers published in a selection of astronomical journals. The current half-lives are compared to normalized values from the study of Abt (1981*a*) from which we conclude that citation behavior practices by astronomers have not changed appreciably over the last two decades. The citation half-life for astronomical papers is five years, similar to the standard for scientific papers in general.

Key words: astronomers–journals–citation statistics

I. Introduction

Citation indexing has been used to study several aspects of the sociology of the astronomical profession. Abt has looked at the usage of astronomical literature over time (Abt 1981*a*), studied the age at which astronomers tend to publish their most influential research (Abt 1983), compared federally-funded and unfunded research (Abt 1984*a*), evaluated the influence of paper length and coauthorship (Abt 1984*b*), and considered the research accomplished with the largest telescopes of the major American observatories (Abt 1985). Trimble (1985, 1986*a*) also has studied citation patterns in papers by American astronomers and deduced the extent to which personal influence may affect citation rates. Although all of these studies provide insight into the workings of science (see also Garfield 1977), it should be clearly noted that citation indices provide a quantitative measurement for only part of the complicated process by which scientific communication takes place. (Edge (1979) and Cronin (1984) give critical discussions concerning this topic.)

In this article, we wish first (Section II) to address a specific aspect of citation indexing, namely their use in determining the half-life of the citation rate decay pattern for astronomical publications. Our interest was aroused originally by the apparent conflict in half-life values that have appeared in the literature. We suggest that the conflict reflects not changes in citation practices over the years, but stems from failure to take into account changes in the annual number of publications appearing during the periods over which citations have been considered; in other words, a half-life is more meaningful when it comes not from a simple count of the annual number of citations over a period of time, but rather when it derives from a probability of citation of papers published each year. The probability of citation is proportional to the total number of citations for the year divided by the number of papers published that year. Unfortunately, noncorrection for publication growth appears to be a standard practice in sociometric studies of science and introduces an unnecessary complication and a confusing factor into intercomparison of results obtained in different studies.

In the third section of this paper, we use published data from the *Science Citation Index* (hereafter, SCI) to make an assessment of current citations for a selected group of astronomical journals. We compute citation probabilities and citation decay patterns for several American, European, and other journals, look at the total citation pattern versus the self-citation pattern, and further compare our data with the prior results of Abt (1981*a*).

II. Citation Half-Life Studies

In Abt's (1981*a*) first paper in these *Publications*, the long-term citation history of papers published in the 1961 *Astrophysical Journal* and its *Supplement* (hereafter the two are referenced as ApJ and ApJS, respectively) and the *Astronomical Journal* (AJ) was studied by counting all citations to these papers in the annual or five-year cumulative *Science Citation Index* (SCI) over the following 18-year period (i.e., 1962 to 1979 inclusive). Abt found that, on the average, a paper received 1.06 citations per year during this period. The maximum in the annual citation counts was found to occur five years after publication, followed by a linear decrease of 3.7% of the maximum per year until at least 20 years after publication when the citation rate was about half of the maximum rate. Abt, however, did point out that part of the "half-life" of 20 years was due to the expansion of the astronomical field, but no correction was attempted for this effect. In actuality, the number of published papers in these two journals increased by 4.6 times during this 18-year period (Fig. 1), indicative of the overall growth in all publications during this time. Such a large increase in the publication rate suggests that the long half-life might be more a matter of the increase in the numbers of citing authors overbalancing a natural decline of interest in the older literature.

In contrast to Abt's results, Meadows (1967) determined a rather different pattern of citation decay. Meadows studied the citation practice of the British astronomical community by surveying the references in the papers published in the *Monthly Notices of the Royal Astronomical Society* (MNRAS) for the years 1963 to 1965. Although his approach of "looking back" is different than Abt's method of "looking forward," the final results should, in principal, be equivalent. Meadows, however, found that as a function of age of the cited paper, the citation rate showed an initial and fairly rapid exponential decay (half-life 5.4 ± 0.4 years for the first 15 years) followed by a less rapid exponential decay (half-life 9.7 ± 0.7 years). At face value, we would conclude either that the British practice of citing past literature differs from that of American astronomers or that another factor must be present to explain the difference between the Meadows and Abt results. We suggest again that the highly relevant factor of journal growth rate is present. During the pre-1965 period serving as a publication base for the citations in Meadows' study, the MNRAS was relatively stable in its annual number of published papers (the MNRAS accounted for approximately 30% of the total number of citations) whereas the three major American journals (AJ, ApJ, and the *Publications of the Astronomical Society of the Pacific* (PASP) accounted for about 25% of the MNRAS citation sample) doubled their rate of publication in the 20 years after the end of the Second World War (Abt 1981*b*). Lack of correction for these rather different patterns of growth may explain the major part of the differences in the two studies. Meadows' data, however, were not presented in such a form to allow a quantitative test of this assertion.

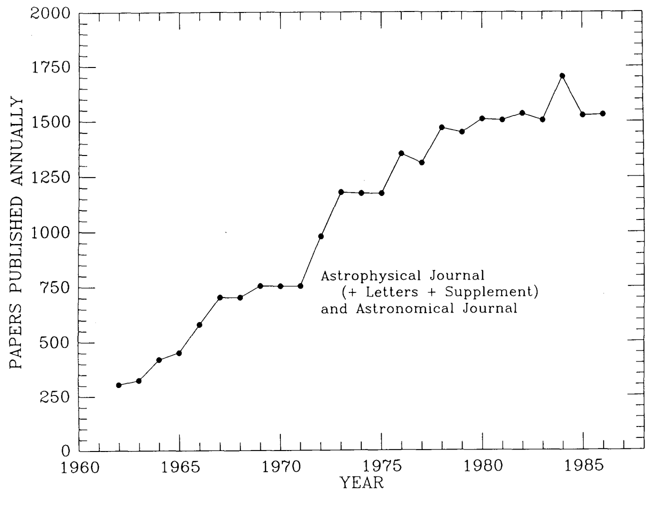

FIG. 1–The annual number of published papers in the *Astrophysical Journal* (including the *Letters* and the *Supplement*) and the *Astronomical Journal*. These data are illustrative of the overall pattern of growth shown by all astronomical journals. Data come from the annual "Journal Citation Reports" section of the *Science Citation Index*, the editors' reports which appear in the American Astronomical Society "Annual Report," and, where numbers are otherwise not available, the author's paper counts.

Lack of explicit consideration of the growth pattern in the number of papers appearing in journals seems to be the standard practice in citation analysis (see, for example, the "Journal Citation Reports" section of the annual SCI). A recent study by Garfield (1985) yields a second example where this practice makes intercomparison of results difficult. Garfield's Table 5 gives half-life periods (defined by Garfield as the *median* age of articles in a given journal which were cited by all other publications) for the major astronomical journals: these half-lives cluster significantly in the range of four to seven years, rather different from Abt's 20-year half-life for an average astronomical publication in his sample. Once again we claim that this is not due to a significant change in citing practices between today and the period covered in Abt's study (actually, his survey period overlaps with the time period for publication of the papers cited in Garfield's sample of citations), but reflects differences in the relative growth rates of publication in the relevant time periods. Figure 1 shows that the annual number of published astronomical papers has been reasonably stable for the last few years as compared to the explosive growth during the decades of the 1960s and 1970s.

That the number of publications per year definitely affects the citation rate for an average paper may be seen in one final sense. Abt (1981*a*) noted that on the average, papers received one citation per year in the early 1960s. By the late 1970s, the rate had increased to three citations per paper per year (Abt 1984*b*) which only in part could be explained by an increase in average paper length. At the present time, the average astronomical publication receives approximately four citations per year in the years immediately after publication (Section 8 of the "Journal

Citation Reports" of the SCI for 1985).

III. Current Citation Half-Lives of Astronomical Publications

In Tables Ia and Ib, we illustrate the type of data on citations that can be derived from data in the "Journal Citation Reports" section of the SCI. For 13 selected journals, Table Ia shows where papers published in these journals *receive* their citations. Table Ib shows to which publications papers in the journals *give* citations. The journals include the leading American and European astronomical journals, one (*Icarus*) selected as a leading journal in a major subdiscipline of astronomy and astrophysics, and two journals from non-Western countries. The tables are incomplete as the SCI does not give detailed breakdowns for citations from *Astronomy and Astrophysics Supplement* (AASu) and *Astrophysical Letters* (ApL), nor does the SCI survey all the minor journals in astronomy.

We briefly note a few of the details that may be found through inspection of these two tables. First, there is the (not unexpected) dominance of the ApJ. It is a major contributor of citations to other journals (Table Ia) and is a major recipient of citations from other journals (Table Ib). It is the only journal which receives as many citations as it gives during a year, a factor due both to its large number of papers and to its overall high probability of citation by other journals.

From Table Ia, the reader may note that ApJ authors are as cosmopolitan (compared to the authors who publish in other journals) in where their citations imply they have obtained literature influence upon their research: papers published in ApJ contribute essentially similar percentages to the citation totals of the *Annual Review of Astronomy and Astrophysics* (ARAA), AJ, AA, MNRAS, *Publications of the Astronomical Society of Japan* (PASJ), and PASP. Among the general journals, only *Soviet Astronomy* and *Soviet Astronomy Letters* (the two combined as SA; counts include citations both to the translation journals and to the original Russian *Astronomicheskii Zhurnal* and *Pisma V Astronomicheskii Zhurnal*) and *Astrophysics and Space Science* (ApSS) are under-represented in ApJ citations. The rather different patterns of citation to and from the specialty journal *Icarus* is not surprising. The

Table Ia

Distribution of Citations in Astronomical Journals: Percentage of Citations Received by Cited Journals[1]

Citing Journal[2,3]	Cited Journal[2] ARAA	AJ	AA	AASu	ApJ	ApJS	ApL	ApSS	Icarus	MNRAS	PASJ	PASP	SA
Total citations in 1984	2110	4425	10156	2769	44427	3264	1939	1831	2173	9965	612	2022	1029
Received/given	0.68	0.79	0.58	-	1.02	0.85	-	0.35	0.47	0.74	0.54	0.55	0.26
ARAA	*2.6*	2.0	2.3	0.9	2.3	0.8	2.5	0.9	1.2	2.5	2.8	1.6	1.3
AJ	4.4	*17.7*	3.0	5.5	3.8	6.2	7.0	1.4	2.3	3.3	1.5	9.1	2.0
AA	11.4	11.0	*26.7*	20.4	10.6	13.4	17.9	10.5	3.8	12.0	11.4	10.0	8.6
ApJ	35.3	26.6	24.2	33.9	*41.1*	37.2	21.4	16.9	5.2	26.6	26.0	31.4	12.6
ApJS	2.2	3.4	1.8	5.9	2.6	*5.4*	1.3	1.5	0.9	1.9	2.8	5.5	2.1
ApSS	3.3	2.5	2.9	2.1	2.3	2.1	1.1	*21.1*	*	2.9	4.6	4.0	7.1
Icarus	*	3.9	1.0	0.8	*	*	*	0.6	*42.9*	*	*	0.8	1.0
MNRAS	8.6	11.7	9.9	9.5	9.3	10.8	6.3	6.9	2.3	*21.2*	6.9	10.5	5.4
PASJ	0.9	0.9	*	1.1	*	0.7	2.4	1.1	*	0.9	*15.2*	*	*
PASP	2.8	3.7	1.5	3.6	3.1	4.7	*	0.7	*	2.0	1.5	*11.5*	*
SA	1.3	1.6	1.6	1.3	1.2	1.1	*	3.0	*	1.5	1.8	1.3	*33.9*
All others[4]	28.1	17.2	25.0	16.1	23.8	18.2	42.4	36.5	41.4	26.2	25.5	14.3	25.9

Notes to the table:

1 Citation statistics adpated from the 1984 *Science Citation Index*. Columns may not add to 100% due to round off error. Self-citation percentages are italicized.

2 Journal codes:

ARAA = *Annual Review of Astronomy and Astrophysics*
AA = *Astronomy and Astrophysics*
ApJ = *Astrophysical Journal* and *Astrophysical Journal Letters*
ApL = *Astrophysical Letters*
MNRAS = *Monthly Notices of the Royal Astronomical Society*
PASP = *Publications of the Astronomical Society of the Pacific*
AJ = *Astronomical Journal*
AASu = *Astronomy and Astrophysics Supplement*
ApJS = *Astrophysical Journal Supplement*
ApSS = *Astrophysics and Space Science*
PASJ = *Publications of the Astronomical Society of Japan*
SA = *Soviet Astronomy* and *Soviet Astronomy Letters*

3 Data not available for *Astrophysical Letters* and *Astronomy and Astrophysics Supplement.*

4 Includes all starred items.

reader will, no doubt, find other patterns of interest from study of the data presented in the tables.

We have argued above that a more meaningful determination of citation half-lives must take into account yearly changes in the size of the sample of cited or citing publications. With such a correction, studies are directly intercomparable and thus can be used to assess sociological questions related to real changes in citation practices over time as the profession and its membership evolves (see, for example, Thronson and Lindstedt (1986) for changes in the American astronomical community) or which concern real differences in the citing practices by members of subgroups within the scientific community.

Given $N_{p'}(t)$ citing papers in the year t with a total of $N_c(t,t-t_0)$ citations to the $N_p(t_0)$ papers published previously in year t_0, the probability $P(t,t-t_0)$ that a paper of age $t-t_0$ will be cited in a new publication may be written as

$$P(t,t-t_0)=\frac{N_c(t,t-t_0)}{N_p(t_0)N_{p'}(t)}\ . \tag{1}$$

This relationship is valid whether a fixed sample of published papers $N_p(t_0)$ is considered (as by Abt 1981*b*) or a fixed sample of citing papers $N_{p'}(t)$ is used (Meadows 1967).

Presented in Table II is the probability that a paper in a journal will cite any given paper published during the prior four years in a cited journal (a four-year period was selected to reduce the influence of annual variation in citation numbers). Expressed in this manner, citation patterns are clearer than is shown in Tables Ia and Ib. Again we see that authors tend to cite more from papers published in the same journal, but this tendency has a large range in numerical probability. The single exception to the tendency of self-citation is the high probability of citation to the review papers of ARAA; only authors of the PASJ are more likely to cite a paper in the same journal than a review paper from ARAA. (N.B. Our use of the term "self-citation" is not to be confused with self-citation in the sense of an author citing his or her own papers, a matter which has been discussed elsewhere by Trimble (1986*b*).)

The accuracy of the figures in Tables Ia, Ib, and II is not easy to estimate as it depends on the recording accuracy of the compilers of the SCI. The one obvious potential source of systematic error that was noticed in the SCI is due to the inconsistent use by several journals of abbreviations to the *Astronomical Journal*. In Table II, an error has been indicated by considering the number of citations

Table Ib

Distribution of Citations in Astronomical Journals: Percentage of Citations Made in Citing Journals[2,3]

Cited Journal[2]	Citing Journal[2,3] ARAA	AJ	AA	ApJ	ApJS	ApSS	Icarus	MNRAS	PASJ	PASP	SA
Papers in 1984	19	215	603	1354	75	267	165	484	61	155	229
Total citations made	3110	5630	17642	43779	3844	5255	4582	13466	1131	3709	3900
(Citations per paper)	164	26	29	32	51	20	28	28	22	24	17
ARAA	*1.7*	1.7	1.4	1.7	1.2	1.3	0.3	1.4	1.6	1.6	0.7
AJ	3.2	*13.9*	3.1	3.8	6.0	2.1	3.8	4.2	3.6	6.2	2.2
AA	7.4	5.5	*15.4*	5.6	4.8	5.7	2.3	7.5	6.6	4.1	5.6
AASu	0.8	2.7	3.2	2.1	4.2	1.1	0.5	2.0	2.7	2.7	1.4
ApJ	32.3	29.7	26.7	*41.7*	30.3	19.8	5.7	30.8	26.6	36.6	16.9
ApJS	0.9	3.6	2.5	2.8	*4.6*	1.3	0.3	2.6	2.0	4.1	1.3
ApL	1.6	2.4	2.0	0.9	0.7	0.0	0.1	0.9	4.2	0.4	0.6
ApSS	0.5	0.4	1.1	0.7	0.7	*7.3*	0.2	0.9	1.8	0.3	1.9
Icarus	0.9	0.9	0.5	0.3	0.5	0.2	*20.4*	0.4	0.8	*	0.3
MNRAS	7.9	5.8	6.8	6.0	4.9	5.6	0.8	*15.7*	7.8	5.5	4.6
PASJ	0.5	0.2	0.4	0.4	0.4	*	*	0.3	*8.2*	0.2	0.3
PASP	1.2	3.6	1.2	1.6	3.1	1.7	0.4	1.7	1.2	*6.8*	1.0
SA	0.8	0.4	0.6	0.3	0.6	1.9	0.2	0.6	0.5	*	*14.2*
All others[4]	40.4	29.3	35.2	32.0	38.0	51.6	65.0	31.0	32.3	31.4	49.1

Notes to the table:

1 Citation statistics adpated from the 1984 *Science Citation Index*. Columns may not add to 100% due to round off error. Self-citation percentages are italicized.

2 Journal codes are the same as for Table 1a.

3 Data for *Astronomy and Astrophysics Supplement* are not tabulated in the *Science Citation Index* for 1984. The SCI lists only 128 citations in 8 papers for *Astrophysical Letters*, a sample too small for adequate statistical study.

4 Includes all starred items.

Table II

Probability of Citation[1]

Cited Journal[2]	Citing Journal[2] ARAA	AJ	AA	ApJ	ApJS	ApSS	Icarus	MNRAS	PASJ	PASP	SA
ARAA	*15.8 ± 3.7*	7.1 ± 1.3	7.9 ± 0.8	11.6 ± 0.7	10.5 ± 2.7	3.8 ± 0.9	–	7.4 ± 0.9	4.2 ± 2.1	6.5 ± 1.5	2.5 ± 0.8
AJ	3.2 ± 0.4	*1.8 ± 0.1*	0.32 ± 0.03	0.47 ± 0.02	1.01 ± 0.13	0.12 ± 0.02	0.41 ± 0.05	0.48 ± 0.03	0.46 ± 0.11	0.54 ± 0.06	0.12 ± 0.02
AA	2.3 ± 0.2	0.24 ± 0.02	*0.90 ± 0.02*	0.32 ± 0.01	0.47 ± 0.05	0.36 ± 0.03	0.13 ± 0.02	0.36 ± 0.02	–	0.20 ± 0.02	0.11 ± 0.01
AASu	0.85 ± 0.25	0.40 ± 0.05	0.59 ± 0.04	0.40 ± 0.02	1.00 ± 0.11	0.14 ± 0.03	0.04 ± 0.02	0.31 ± 0.03	0.27 ± 0.09	0.32 ± 0.06	0.08 ± 0.02
ApJ	10.0 ± 0.4	0.68 ± 0.03	0.69 ± 0.02	*1.32 ± 0.01*	1.46 ± 0.06	0.28 ± 0.01	–	0.74 ± 0.02	–	0.74 ± 0.03	0.16 ± 0.01
ApJS	2.2 ± 0.6	1.33 ± 0.15	–	1.08 ± 0.06	*3.1 ± 0.4*	0.33 ± 0.07	–	0.72 ± 0.08	–	1.35 ± 0.18	0.13 ± 0.05
ApL	19.4 ± 3.5	3.0 ± 0.4	2.5 ± 0.2	1.37 ± 0.11	1.43 ± 0.48	0.45 ± 0.05	–	1.30 ± 0.18	3.1 ± 0.9	–	–
ApSS	0.37 ± 0.13	0.04 ± 0.01	0.11 ± 0.01	0.07 ± 0.01	0.11 ± 0.04	*0.73 ± 0.05*	–	0.08 ± 0.01	0.14 ± 0.05	–	0.13 ± 0.02
Icarus	1.25 ± 0.32	0.15 ± 0.03	0.12 ± 0.02	0.07 ± 0.01	0.15 ± 0.06	–	*2.8 ± 0.1*	0.08 ± 0.02	–	–	–
MNRAS	3.9 ± 0.4	0.39 ± 0.03	0.43 ± 0.02	0.48 ± 0.01	0.65 ± 0.07	0.26 ± 0.02	–	*1.34 ± 0.04*	0.33 ± 0.06	0.28 ± 0.03	0.14 ± 0.02
PASJ	2.2 ± 0.8	0.07 ± 0.04	0.21 ± 0.04	0.18 ± 0.06	0.42 ± 0.17	0.18 ± 0.06	–	0.17 ± 0.04	*5.3 ± 0.7*	0.03 ± 0.03	0.02 ± 0.02
PASP	1.30 ± 0.32	0.58 ± 0.06	0.19 ± 0.02	0.37 ± 0.02	1.03 ± 0.15	0.12 ± 0.03	0.08 ± 0.03	0.31 ± 0.03	–	*1.15 ± 0.11*	0.05 ± 0.02
SA	0.46 ± 0.14	0.02 ± 0.01	0.05 ± 0.01	0.03 ± 0.01	0.14 ± 0.04	0.14 ± 0.02	–	0.04 ± 0.01	–	–	*1.13 ± 0.06*

Notes to the table:

1 Probability in units of 10^{-3} that a given paper in the citing journal references a particular paper published in the cited journal in the prior 4 years. Self-citation probabilities are italicized. Data from the *Science Citation Index* for 1984.

2 Journal codes are the same as for Table 1a.

as a random variable with assumed Poisson statistics.

Two questions may be considered concerning the time dependency of the citing probability P. First, what is the form of the citation pattern as a function of the time $(t-t_0)$ elapsed since publication; and second, is this dependency also variable with the time period over which citations are considered?

In the "Journal Citation Reports" volume of the SCI, citation data are broken down by year of publication of the cited papers (papers older than ten years are lumped together). For all journals we give in Table III the number of 1984 citations to papers in prior years, the number of papers in those years, and a ratio which we have termed the annual impact $I\,(t,t-t_0)$, the number of citations in year t received by papers published in year t_0 divided by the number $N_p(t_0)$ of papers published in that previous year t_0. By reference to equation (1), our annual impact is equivalent to

$$I\,(t,t-t_0) = \frac{N_c(t-t_0)}{N_p(t_0)} = P\,(t,t-t_0)N_{p'}(t) \ . \tag{2}$$

Ideally, to answer the two questions posed above, we wish to deal directly with the probability $P(t,t-t_0)$, but calculation of this quantity requires knowledge of the size of the sample of citing papers $N_{p'}(t)$. $N_{p'}(t)$ is the sum of papers not only in our selected 13 journals, but also all other astronomical publications included in the SCI as well as all papers, astronomical or otherwise, which cite the papers which appeared in our selected journals. Only two of these three contributors are recoverable from the extensive tabulations of the SCI. Inasmuch as the impact parameter $I\,(t,t-t_0)$ and the probability $P\,(t,t-t_0)$ are proportional, it serves our purpose to use the annual impact which can be numerically computed from SCI data.

Figures 2 through 5 show a comparison of the citation decay patterns for our 13 journals through use of the impact parameter. Since we are interested in the *shape* of the decay pattern and not its absolute value, and because the 1984 annual impacts vary from a maximum range of 2–21 (for the review papers of ARAA) to a minimum of 0.2–0.6 (for SA), we must introduce a further normalization for purposes of graphical intercomparison. We choose to normalize the set of annual data for each journal to the mean annual impact for that journal in the period 1983–80 (i.e., we normalize to the four-year period of maximum citation). The run of normalized annual impact is equivalent to a normalized citation probability. The citation pattern for seven journals is shown in Figure 2. The maximum citation impact or citation probability occurs for papers published two or three years earlier; older papers are cited with decreasing likelihood. This pattern is quite similar to the pattern found by Abt (1981*a*) except that Abt's analysis showed the maximum in citations to occur five years after publication. Within the range of year-to-year variations, the citation probability pattern of each of these journals appears alike, with the minor exception that older papers in *Icarus* may be less likely to be cited than those published in the other journals. We will refer to the mean normalized run of impact parameter of these seven journals as a "standard" for further comparison.

Data for four journals appear to deviate from the standard pattern; their individual normalized annual impacts are shown in Figure 3. The year-to-year variation in impact of ARAA papers is modest except for a sharp decline after five years. That older review papers are less well cited than older papers in general is perhaps attributable to the appearance of more recent reviews on the same subjects. ApL papers appear to have uniform citation probability if less than six years old (in 1984), but

Table III

Citations (in 1984) Distributed by Year of Publication

Journal	Year / t-t$_o$	1984 / 0	1983 / 1	1982 / 2	1981 / 3	1980 / 4	1979 / 5	1978 / 6	1977 / 7	1976 / 8	1975 / 9
ARAA	all citations	36	156	184	226	257	337	95	125	89	90
	papers	19	13	20	13	14	16	20	18	17	17
	annual impact	1.89	12.0	9.20	17.4	18.4	21.1	4.75	6.94	5.24	5.29
AJ	all citations	101	386	479	550	327	482	356	193	215	162
	papers	215	193	199	224	213	235	208	160	150	182
	annual impact	0.47	2.00	2.41	2.46	1.54	2.05	1.71	1.21	1.43	0.89
AA	all citations	229	1093	1488	1463	1208	790	810	778	432	485
	papers	603	654	683	737	728	565	596	609	479	497
	annual impact	0.38	1.67	2.18	1.99	1.66	1.40	1.36	1.28	0.90	0.98
AASu	all citations	103	218	235	290	321	209	280	202	136	164
	papers	157	179	149	177	174	164	158	145	103	81
	annual impact	0.66	1.22	1.58	1.64	1.84	1.27	1.77	1.39	1.32	2.02
ApJ	all citations	1452	4844	5566	5129	4268	3528	3465	2530	2210	1739
	papers	1354	1214	1243	1197	1221	1135	1194	1079	1145	1018
	annual impact	1.07	3.99	4.48	4.28	3.50	3.11	2.90	2.34	1.93	1.71
ApJS	all citations	117	251	269	109	357	412	248	192	355	85
	papers	75	75	67	55	66	80	69	73	59	22
	annual impact	1.56	3.35	4.01	1.98	5.41	5.15	3.59	2.63	6.02	3.86
ApL	all citations	71	201	195	218	135	158	73	100	134	77
	papers	8	22	26	19	17	18	14	31	47	38
	annual impact	8.88	9.14	7.50	11.5	7.94	8.78	5.21	3.23	2.85	2.03
ApSS	all citations	72	206	218	233	118	137	120	83	105	107
	papers	267	322	287	257	257	251	234	248	249	194
	annual impact	0.27	0.64	0.76	0.91	0.46	0.55	0.51	0.33	0.42	0.55
Icarus	all citations	99	303	245	271	223	193	190	121	82	76
	papers	165	163	141	145	183	172	177	148	166	150
	annual impact	0.60	1.86	1.74	1.87	1.22	1.12	1.07	0.82	0.49	0.51
MNRAS	all citations	343	1074	1143	1129	829	736	767	513	477	402
	papers	484	465	401	400	388	379	365	352	310	249
	annual impact	0.71	2.31	2.85	2.82	2.14	1.94	2.10	1.46	1.54	1.61
PASJ	all citations	12	60	57	55	47	70	45	47	32	31
	papers	50	47	41	52	49	64	50	56	56	52
	annual impact	0.24	1.28	1.39	1.06	0.96	1.09	0.90	0.84	0.57	0.60
PASP	all citations	42	183	309	226	211	184	115	121	157	85
	papers	155	162	188	151	148	169	154	169	132	161
	annual impact	0.27	1.13	1.64	1.50	1.43	1.09	0.75	0.72	1.19	0.53
SA	all citations	36	171	169	174	123	108	89	70	54	58
	papers	229	305	300	318	325	310	297	287	312	281
	annual impact	0.16	0.56	0.56	0.55	0.38	0.35	0.30	0.24	0.17	0.21
AA	self citations	118	385	453	405	276	198	202	187	100	109
	papers	0.20	0.59	0.66	0.55	0.38	0.35	0.34	0.31	0.21	0.22
ApJ	self citations	828	2237	2436	2215	1799	1505	1405	1117	886	734
	annual impact	0.61	1.84	1.96	1.85	1.47	1.33	1.18	1.04	0.77	0.72
MNRAS	self citations	153	299	296	277	197	128	143	92	90	76
	annual impact	0.32	0.64	0.74	0.69	0.51	0.34	0.39	0.26	0.29	0.31

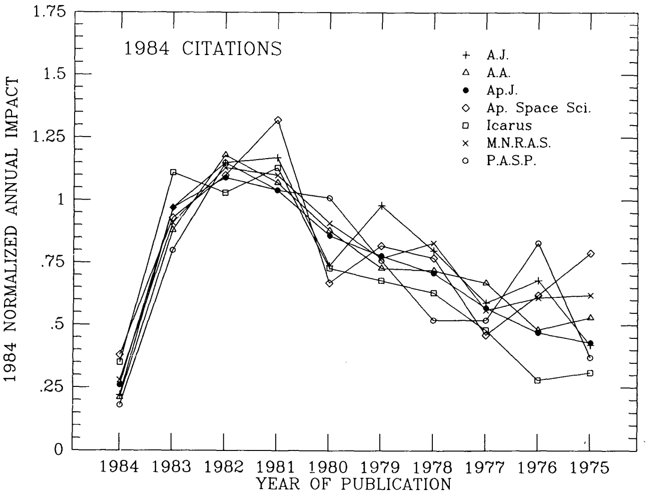

FIG. 2–The normalized annual impact (equivalent to a normalized citation annual probability) for seven astronomical journals. Citation data have been taken from the 1984 *Science Citation Index*.

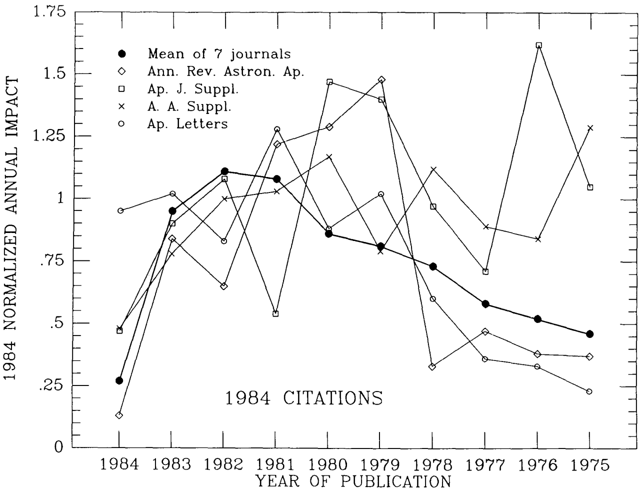

FIG. 3–The normalized annual impact for citations to papers in the *Annual Review of Astronomy and Astrophysics*, the *Astrophysical Journal Supplement, Astrophysical Letters*, and *Astronomy and Astrophysics Supplement*. For comparison, the mean normalized annual impact curve for the seven journals of Figure 2 is also shown.

older ApL papers are proportionately less well cited than papers in the standard journals.

On the other hand, the longer and more detailed papers appearing in *Astrophysical Journal Supplement* (ApJS) and AASu show significantly greater longevity than papers of the standard journals. The year-to-year variation in impact is larger, which we suggest may be a product of the relatively small number of papers published each year and subsequent differences in levels of research activity in the different specializations.

To determine whether nationalistic influences affect citation patterns, in Figure 4 we show the normalized run of annual impact for the two non-Western journals SA and PASJ. The pattern for PASJ agrees well with that of the standard journals, whereas older papers in SA tend to be cited perhaps slightly less frequently.

Another aspect of journal preference is addressed in Figure 5 where we show the citation pattern based only on self-citation, i.e., on citations to papers which previously appeared in the same journal. The ApJ self-citation curve is similar to the curve for all citations to ApJ (Fig. 2) and both are similar to the standard citation curve. In particular, Garfield (1985) has commented on this, stating that "a citation analysis of the obvious and central journal in the field can often provide a remarkably accurate picture of that field." There is some indication that MNRAS

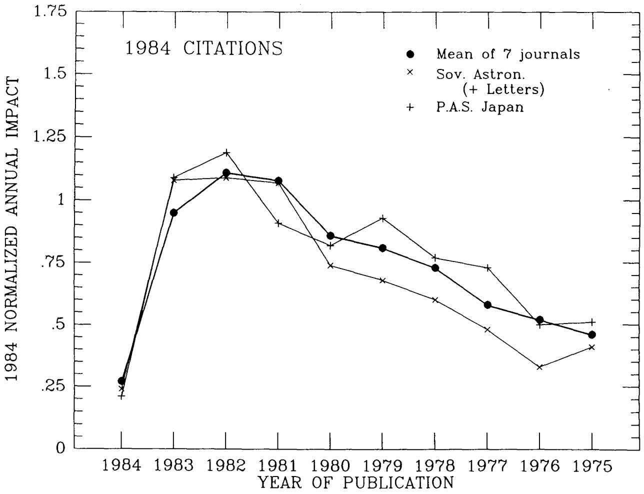

FIG. 4–The normalized annual impact for citations to *Soviet Astronomy* plus *Soviet Astronomy Letters* and to *Publications of the Astronomical Society of Japan*. For comparison, the mean normalized annual impact curve for the seven journals of Figure 2 is also shown.

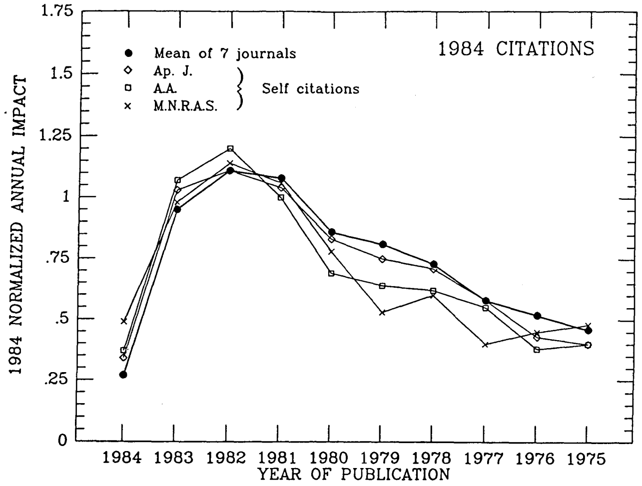

FIG. 5–The normalized annual impact for self-citations in the *Astrophysical Journal, Astronomy and Astrophysics*, and *Monthly Notices of the Royal Astronomical Society*. For comparison, the mean normalized annual impact curve for the seven journals of Figure 2 is also shown.

and AA authors may tend to cite older papers in these journals somewhat less frequently, although this is not true for all authors using these journals (Fig. 2).

All in all, our brief comparison suggests that the citation behavior of authors is relatively universal in astronomy. Major differences in citing prior literature appear to be primarily a function of the type of the source literature with papers in the two supplement series journals having greater longevity than do typical papers and review articles having their greatest citation influence in the years immediately after publication.

The data presented in Figures 2 through 5 strongly suggest that subsequent to the peak of the citation frequency two or three years after publication, the citation probability declines in a linear manner with time (though subsequent decline cannot continue linearly as this would lead to negative citations per year after another 10–20 years). We have thus made linear least-squares fits to the post-maximum period ($t - t_0$ = 3 to 9 years) normalized annual impact to determine the yearly rate of decrease in the citation activity. These values are given in Table IV. The decline may also be expressed as the number of years to decrease to one-half the maximum citation probability. The computed half-lives are typically five to seven years with the shortest periods belonging to ARAA and ApL. A five-year half-life is representative of all scientific literature(Umstätter, Rehm, and Dorogi 1982). For comparison, we also list the median ages of cited papers from the study of Garfield (1985).

We now consider Abt's (1981*a*) analysis in which all citations to 1961 ApJ, ApJS, and AJ papers were counted in subsequent years. Assuming that the increase of ApJ and AJ papers shown in Figure 1 parallels the increase of papers in all citing journals, we can compute from Abt's citation counts an annual impact function. Normalized to unity in the four-year period 1962–65, the result can be compared directly with our data from the 1984 SCI statistics. In Figure 6 we see that the citation decay pattern for all papers in Abt's study closely follows our current results: we conclude that on the average, citation practices have not changed appreciably in the last 20 years. Papers obtain their highest probability of citation two to three years after their publication appearance followed by a roughly linear decline in the likelihood of citation. There is some indication in our reconstruction of Abt's data for a change to a slower rate of decline after a decade, comparable to the change found by Meadows (1967).

Abt also identified a small group of frequently cited papers (19 to 326 papers in his whole sample) which show a slower decline in citations (that a small fraction of papers do have greater longevity has also been pointed out by Margolis 1967). Their normalized annual impact also is shown in Figure 6 where a very different behavior is indicated. Not only do the highly cited papers have a greater absolute probability of citation, but their influence is substantially longer lived. Highly cited papers reach their maximal citation probability after four to five years followed by a decay with a half-life twice as long as that of the average paper.

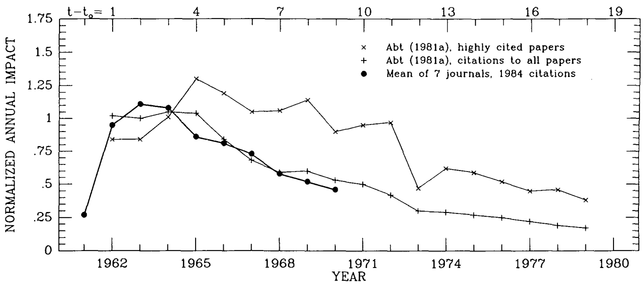

FIG. 6–The data of Abt (1981*a*), normalized by the number of papers appearing each year in the two major American astronomical journals. For comparison, the mean normalized annual impact curve for the seven journals of Figure 2 is also shown.

IV. Discussion and Summary

Analyses of citations usually deal with *counts* of citations on a yearly basis. The total number of citations, however, depends both on the number of papers which are available to be cited and on the number of citing papers. Citation half-lives based solely on citation counts thus will show a strong dependence on the growth rate of the number of publications. A probability of citation (eq. (1)) or a parameter like the impact (eq. (2)) will not be so influenced and provides a significantly better indicator of the actual citation practices of members of a professional discipline.

Our study of only a small part of the information that is now available in the data base provided by 30 years of the *Science Citation Index* suggests the following:

1. The major main-stream astronomical and astrophysical journals and a major journal in one subdiscipline (planetary science) all show a characteristic pattern in the normalized probability of citation as a function of the age of the cited papers. This pattern holds for all citations in the journals we have considered and also for self-citations only. This pattern with maximal citation two to three years after publication does not fit the exponential decay pattern that is often assumed for sociological models of citation behavior (for example, Dieks and Chang 1976; MacRae 1969), though we cannot rule out that citations to the older literature ($t - t_0 > 10$ years) may fit an exponential decay curve.

2. Papers in a major review journal (ARAA) are less likely to be cited with increasing age as papers in the main-stream journals.

3. Papers in the two major supplement series show a citation pattern that is independent of age (at least for ten years after publication).

4. A comparison with the data of Abt (1981*a*) suggests that the citation behavior practice of the astronomical

Table IV

Time Dependence of Citation Rates for Papers in Astronomical Journals

Journal	Annual change in citation rate[1] (% of the maximum)	Years to half-maximum citation rate[1]	Median age of cited papers (Garfield 1985)[2]
Average of 7 journals	-8.9 ± 2.2	5.6 ± 1.4	-
Annual Review of Astronomy and Astrophysics	-17.3 ± 33.1	2.9 ± 5.5	5.4
Astronomical Journal	-8.8 ± 4.5	5.6 ± 2.9	5.3
Astronomy and Astrophysics (all citations)	-8.0 ± 2.4	6.3 ± 1.9	4.4
(self citations)	-8.0 ± 3.2	6.3 ± 2.5	-
Astronomy and Astrophysics Supplement	+0.5 ± 6.8	-	-
Astrophysical Journal (all citations)	-9.1 ± 1.5	5.5 ± 0.9	4.9[3]
Astrophysical Journal Supplement	+3.7 ± 33.0	-	-
Astrophysical Journal (self citations)	-9.3 ± 1.8	5.4 ± 1.0	-
Astrophysical Letters	-15.2 ± 9.9	3.3 ± 2.1	9.9
Astrophysics and Space Science	-5.6 ± 9.2	8.9 ± 14.6	5.1
Icarus	-11.2 ± 5.2	4.5 ± 2.1	4.4
Monthly Notices of the Royal Astronomical Society			
(all citations)	-6.7 ± 3.4	7.5 ± 3.8	5.3
(self citations)	-8.1 ± 6.1	6.2 ± 4.6	-
Publications of the Astronomical Society of Japan	-6.7 ± 2.8	7.5 ± 3.1	5.4
Publications of the Astronomical Society of the Pacific	-8.5 ± 8.5	5.9 ± 5.9	6.5
Soviet Astronomy	-9.8 ± 4.5	5.1 ± 2.3	6.5
Abt (1981a), all citations[4], 1964-1970	-8.8 ± 2.7	5.7 ± 1.8	-
1971-1979	-3.7 ± 1.2	13.5 ± 4.4	-
Abt (1981a), highly cited papers [3], 1964-1970	-5.0 ± 1.8	11.0 ± 3.5	-
1971-1979	-4.6 ± 4.1	10.8 ± 9.5	-

Notes to the table:

1 Citations in papers published in 1984. Baseline for decline of citation rate is 1981 - 1975.
2 Citations in papers published in 1982.
3 Includes citations to the *Astrophysical Journal Supplement.*
4 Citations to papers published in the 1961 *Astrophysical Journal* and *Astronomical Journal.*

community has not significantly changed in the nearly quarter of century between 1961 and 1984.

A substantially greater amount of citation data is available to study the citation practices of astronomers over the last 30 years as well as citation behavior in many other related and nonrelated disciplines. The cumulative citation data from 1955 to the present is available in a computer accessible form (cf. Garfield 1986) and thus there is the potential to analyze citation practices in far greater detail than we have attempted in this study. Of particular interest would be confirmation that a characteristic citation behavior does exist as we have suggested for the main-stream journals, determination of its standard deviation by consideration of year-to-year variations, an assessment of secular changes which may occur as the population of astronomers evolves, and whether or not this citation pattern is universal among all scientific disciplines.

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