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Patterns in Citations of Papers by American Astronomers

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SUMMARY

Numbers for annual citation rates to papers by American Astronomical Society prizewinners, officers, and randomly selected members are brought up to date. The range is more than three orders of magnitude (from $\lesssim 0{\cdot}5$ to 908 citations per year). Many of the correlations found in 1982 persist, including those with authors' ages, subdisciplines and places of employment. It still pays to be a mature, prizewinning theorist, working on cosmology or high-energy astrophysics at a prestigious institution. It also still pays to be male, by the same narrow margin as before. Some changes suggest that the astronomical community is more polarized into 'haves' and 'have nots' than it was 8 years ago. For instance, mature astronomers at prestigious places are further ahead of average than they were in 1982, while the younger cohorts at teaching- and mission-oriented institutions have slipped further behind.

A table presents citation rates as a function of career length, subdiscipline, gender and type of employment for the prizewinners, officers and randomly selected members separately, and for most possible totals. A number of demographic attributes of the sample, and changes therein, are noted. For instance, stellar astronomers still outnumber those studying other kinds of object, but not by as much as they used to. Other points concern very highly cited and completely uncited astronomers, the Associate Members of AAS, women, and the age distribution of astronomers employed at the most prestigious places.

Readers can use these numbers to decide whether particular people, departments, etc. are above or below average, but applications to individuals should be made cautiously, because citations are associated only with senior or sole authors of the cited papers. The author remains resolutely average.

1 INTRODUCTION

'Some notes on patterns in citations of papers by American astronomers' (Trimble 1985) made use of data from the 1983 edition of the American Astronomical Society membership directory and the 1982 *Science Citation Index*. That investigation re-established the truth of a theorem due to Landau, that scientists should be evaluated on a logarithmic scale. It also identified a number of correlations between average citation rates and characteristics of astronomers, including the subfield they work in, when they joined the astronomical community, and the kinds of institutions at which they are employed.

Since 1982 a new generation of researchers has joined the community, and the numbers of people publishing and papers published per year have

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increased by 46 and 31 per cent respectively (Davoust & Schmadel 1987; Burkhardt *et al.* 1991). In addition, many of us feel that we have at least anecdotal evidence that the new younger generation is having a harder time finding secure jobs, research support, and even time to think than earlier cohorts did.

The purpose of the present paper is to look at current numbers for how often papers by (mostly) American astronomers are cited, as a function of the author's subdiscipline, age, institution of employment and gender, and to compare these numbers with those from 1982. The current database comes from the 1991–92 membership directory of the American Astronomical Society and the *Science Citation Index* for 1990, the most recent complete year available in spring 1992.

The previous investigation had a twofold motivation—first, pure curiosity on the part of the author about whether, for example, X-ray papers are cited more often than radio papers, and second, the desire to provide average values that could be used to answer questions (from university administrators, sponsoring agencies, etc.) about whether particular people's work was 'recognized as influential'. Both, I think, remain valid. But, readers who decide to figure out whether they and their colleagues rank above or below average in citation rates are warned to be careful with whom they share the results. The author's recent experience is that numbers of this sort are not universally welcome.

2 SAMPLE SELECTION AND DATABASE

2·1 The study population

The three groups of astronomers studied are very similar to the previous sample, but come from the 1991–92 AAS membership directory, rather than 1983. The first group includes all living and recently deceased winners of AAS awards (pp. 19–21 of the directory). These 143 astronomers are hereafter called the Prize-winners (P in the tables and figures). The second group is all incumbents of AAS and divisional offices and members of standing committees (inside front cover and pp. 15–18 of the directory). They number 132 (including 21 overlaps with the Prize-winners) and will be called the Officers (O in the tables and figures). The final group includes all Full and Associate Members on every tenth directory page from 41 to 141. The goal was to end up with about 10 per cent of the total membership, while avoiding whatever advantages in citation rate Althea Aardvark of Akron Tech may have over Zachary Zebra of Zürich Observatory. This third group of 493 astronomers (27 overlaps with groups P and O) will be called the Random sample (R in the tables). It includes two Honorary Members, 72 Associate and 419 Full Members (including division associates). The 76 Junior Members on these pages and a handful of Corporate Members are not part of the sample analysed.

Examination of the 1990 *Science Citation Index* (vs. 1982 last time around) then yielded the numbers of citations (excluding self-citations) to papers of which each sample astronomer was the sole or senior author. The range is 0–908 citations in the year (vs. 0–787 in 1982). Four Officers and 18 of the Random group disappear at this point because I found it impossible to disentangle their citations from those to works of other scientists of the same name in closely related disciplines.

In addition, five Os and 94 Rs were not cited at all in 1990. This is a smaller uncited fraction of Random members than in 1982; 94/493 or 19 per cent, vs. 82/312 or 26 per cent. It is, nevertheless, nearly one-fifth of the R group, and I made somewhat more effort than before to find out something about them. Four of the uncited Officers and 12 of the Random members were cited at least once in 1989. They are included in the subsequent analysis with citation rates equal to half the 1989 number (0·5 to 1·5 citations/year). As a result, 143 Prize-winners, 127 Officers and 393 Random members (614 people, eliminating overlaps) constitute the sample discussed in the following sections. Section 2.4 says a bit more about the remaining 83 uncited astronomers.

2.2 The subsamples

The 614 cited astronomers were assigned to subsamples by gender, institution of employment, chronological cohort and subdiscipline. Gender was determined from given names, and I have probably missed a few women with unusual names who are not personally known to me. One – but only one – error of this type has since come to light in the 1982 sample. If all eight of the Random members who give only initials in the directory and on their papers or who have gender-neutral given names are women, the sample total would rise from 75 to 83. Statistically, probably one or two of them have been misclassified.

The institution is that listed in the AAS directory. Where only a home address is given, institutions have been found from the *AIP Directory of Physics and Astronomy Staff Members* or the most recent cited paper. Emeritus members and others known to be retired are associated with the institutions from which they retired (found from older directories publications, etc.). No institutional affiliation could be found for 13 people (all in the R sample). Most are Associate Members who have not published since parting company with the place where they were Junior Members.

The classification scheme for employers has been slightly revised. Remaining unchanged are categories U (universities with PhD programs in astronomy and/or physics), C (colleges and other teaching-oriented organizations), and M (mission-oriented laboratories, industrial organizations and other non-research-oriented employers). Examples of M institutions include Sandia, JPL, Motorola, NASA headquarters, and the 'Beltway bandit' computing firms that ring Washington D.C. The 13 cited astronomers for whom no institutional affiliation could be determined are grouped in the tables with C and M.

The groups previously collected as observatories, research institutes and laboratories (O/L) have, however, been split. An important change in astronomical demographics since 1982 is the foundation and growth of Space Telescope Science Institute. Well over 100 AAS members are now affiliated with it full or part time, and their responsibilities are a complex mix of research, research support and mission support. Thus STScI does not fit comfortably into either the mission-oriented (M) or research institute (O/L) category. Neither, upon reflection, do the NASA centres (Goddard, Marshall, Ames), Los Alamos or several other places. Thus the category O/I now contains observatories (Carnegie, Lick, ESO, NOAO, NRAO...) and research institutes (IAS Princeton, DTM, GISS, the various branches of MPI...); while the category L (for laboratory) includes STScI, the NASA centres, LANL, LLNL, NRL, USNO, etc. The groups O/I and L appear to be somewhat distinct in average citation rates.

Finally, the 'prestigious institutions' sample deliberately comprises astronomers at the same 13 universities and four observatories as before (Arizona, Berkeley, Caltech, Chicago, Columbia, Harvard, Illinois, MIT, Princeton, Texas, Yale, Cambridge and Oxford; NRAO, KPNO, Lick and Carnegie [formerly Mt Wilson/Palomar]). This is a fairly broad definition of 'prestigious' and results in 26 per cent of the total sample (33 per cent in 1982) having prestigious affiliations.

The chronological cohorts are defined, as before, by the publication date of the earliest cited paper (quite typically the PhD dissertation) and are meant to reflect the time at which each individual became an active member of the astronomical community. The advancing years have added a sixth cohort to the five from 1982. They are 1928–45, 1946–56, 1957–67, 1968–74, 1975–81 and 1982–91. The largest number of Prize-winners fall in 1957–67, Officers in 1968–74 and Random members in 1975–81. All three peaks are in the same cohorts as they were in 1982 (an aspect of the phenomenon dubbed 'the greying of astronomy' by Thronson & Lindstedt, 1986).

The oldest cohort is not well represented, except among the Prize-winners. This undoubtedly contributes to the strong correlation of citation rate with age discussed in Section 3.2 (Fig. 2). Short of examining all the astronomers on many more directory pages, I cannot think of any unbiased way of increasing this sample. People whom one knows, *a priori*, to belong to this cohort are systematically the most active (and so over-cited), while those who have chosen emeritus status are systematically the least active (and so under-cited).

Subdiscipline assignments were also done, as nearly as possible, in the same way as before. Each astronomer received a two- to seven-word 'job description', based on the contents of his most-cited papers and my own knowledge. A major change from the author's point of view was the larger fraction of people (especially the R members in the two younger cohorts) whose papers I had to look up to be sure of exactly what they do. The subclasses, as before, are

Theory	Sun	Optical
Observation	Solar system	Radio
Instruments, experiments, lab data, etc.	Stars	X- and gamma-ray
	Milky Way and ISM	Infra-red and ultraviolet
	Dynamics	
	Galaxies/Extragalactic	
	High-energy astrophysics	
	Cosmology	

Each individual was placed in every subclass where he belonged on the basis of the job description. AAS division members were automatically also placed in the corresponding subclasses, Sun, Dynamics, etc. The history division is an exception. Its members include both real historians (whose papers are generally not cited in physical sciences journals) and astronomers interested in our history (many of them quite senior and highly cited, but for work in fields other than history). The average did not seem to be very meaningful.

Most individuals ended up in three boxes ('instrument development for solar gamma rays,' 'optical observations of stars' – still the commonest category, though not by so much as it was 8 years ago – 'extragalactic radio theorist', etc.) A few rolling stones ended up in six or seven. The previous arbitrariness of the lines between some subclasses remains. Some people working on Seyfert galaxies went into 'extragalactic', others into 'high-energy astrophysics'. A few topics have moved; superclustering of galaxies now seems to belong to 'cosmology' rather than to 'galaxies'. But optical observations done from space still count as optical observations.

Once the subsamples had been established using the above criteria for institutions, chronological cohorts and subdisciplines, mean citation rates were calculated for the P, O and R classes and Totals thereof. Section 3 presents and discusses the results.

2.3 Normalization procedure

Some sort of normalization is necessary if various subdisciplines, types of institutions and such are to be compared. For instance, the older cohorts, whose members have many more papers to be cited, are concentrated in more traditional fields and institutions; some areas have far more than their fair share of Prize-winners, and so forth. On the other hand, if corrections are made for everything, all subsamples will end up looking exactly alike; if the solar astronomers consisted of exactly the same mix – of old and young, observers and theorists, Prize-winners and Officers, optical and radio, university and college, male and female – as the cosmologists, their citation rate would probably be the same too.

The compromise adopted is the same as in 1982. Table 1 shows the data uncorrected for anything and with a normalization for the effect of the one variable over which we have no control – chronological cohort. It is easy to think of two ways to do this. Only one works. It is not possible to take the citation rates for a particular subsample (e.g. X- and gamma-ray astronomers) and say what their citation rate would be if that subsample had the average distribution of career lengths, because some of the chronological cohorts are completely unrepresented in some subsamples – there are no X- and gamma-ray astronomers with PhDs before 1945 in the database. It is, however, possible to go the other way, and ask what the citation rate would be for the total population if it had the age-mix of the subsample. Then the ratio of the actual citation rate to the 'predicted' one is a measure of whether that particular subsample is doing better or worse than average. Ratios greater than one indicate above-average citation rates. These ratios were calculated for the R group and the Total = P+O+R for each subsample (employer, subdiscipline, gender) and for the whole P, O and R classes.

TABLE I

Mean 1990 citation rates of American astronomers classified by chronological cohort, employer, gender and scientific subdiscipline. Numbers of astronomers per subsample in parentheses

Cohort	Class	University	O/I	L	C+M	Prestigious	Women	Total
1928–45	P	228·4 (7)	83·0 (6)	—	651·0 (1)	193·4 (10)	651·0 (1)	196·3 (14)
	O	—	—	—	—	—	—	—
	R	113·5 (2)	32·7 (3)	—	4·0 (1)	89·5 (2)	—	56·5 (6)
	T	216·6 (8)	68·5 (8)	—	327·5 (2)	193·4 (10)	651·0 (1)	182·4 (18)
1946–56	P	144·3 (14)	180·8 (9)	8·0 (1)	30·0 (1)	237·0 (11)	51·3 (3)	147·4 (25)
	O	127·3 (4)	113·8 (5)	—	11·0 (1)	128·7 (7)	162·0 (1)	108·9 (10)
	R	111·6 (11)	49·5 (2)	0·5 (1)	7·8 (5)	207·2 (5)	74·0 (1)	66·1 (19)
	T	116·0 (22)	130·6 (15)	4·3 (2)	11·4 (7)	187·6 (17)	79·0 (4)	100·0 (46)
1957–67	P	130·8 (25)	100·1 (11)	59·2 (5)	19·0 (1)	134·2 (24)	—	114·9 (42)
	O	59·6 (15)	87·5 (10)	50·0 (1)	24·0 (1)	68·6 (11)	32·8 (4)	68·3 (27)
	R	42·5 (21)	28·0 (12)	32·2 (5)	6·9 (2)	54·6 (11)	19·0 (1)	34·4 (41)
	T	80·6 (54)	54·3 (29)	43·8 (10)	11·1 (4)	102·2 (37)	32·8 (4)	66·1 (97)
1968–74	P	114·6 (20)	49·0 (6)	—	—	152·8 (13)	63·7 (7)	99·4 (26)
	O	100·4 (23)	168·0 (4)	16·0 (2)	10·5 (11)	133·5 (15)	34·8 (8)	81·7 (40)
	R	36·3 (37)	31·3 (19)	32·9 (14)	8·7 (28)	53·2 (14)	30·0 (8)	27·1 (98)
	T	64·3 (64)	52·8 (28)	30·8 (16)	9·2 (38)	98·5 (33)	39·2 (18)	44·1 (146)
1975–81	P	98·6 (18)	80·7 (7)	—	4·0 (1)	107·3 (12)	68·3 (4)	90·1 (26)
	O	63·7 (18)	50·8 (5)	43·4 (7)	23·3 (8)	49·8 (9)	37·3 (12)	49·7 (38)
	R	40·9 (52)	42·3 (16)	32·5 (24)	10·5 (26)	46·3 (18)	23·7 (12)	32·7 (118)
	T	56·5 (84)	49·8 (26)	35·0 (31)	13·2 (35)	63·3 (37)	33·3 (27)	43·1 (176)
1982–91	P	42·8 (8)	117·0 (1)	26·0 (1)	—	58·0 (4)	27·7 (4)	48·5 (10)
	O	13·5 (2)	7·0 (1)	12·5 (4)	5·8 (3)	13·5 (2)	9·3 (3)	10·1 (10)
	R	15·2 (39)	13·6 (23)	9·8 (22)	6·3 (27)	14·1 (20)	12·1 (14)	11·6 (111)
	T	19·6 (49)	17·5 (25)	10·8 (27)	6·2 (30)	20·8 (26)	14·7 (21)	14·3 (131)
Total	P	122·8 (92)	102·6 (40)	47·1 (7)	176·0 (4)	152·3 (74)	86·1 (19)	114·9 (143)
	O	78·7 (62)	95·1 (25)	31·1 (14)	14·7 (24)	78·5 (44)	37·5 (28)	63·4 (127)
	R	39·5 (162)	28·2 (75)	24·5 (66)	8·3 (90)	52·2 (70)	21·8 (36)	27·6 (393)
	T	65·7 (281)	51·9 (131)	26·9 (86)	15·3 (116)	94·0 (160)	40·1 (75)	48·7 (614)

Expected citation rate	P							71·6
	O							52·1
	R	29·0	26·9	25·1	26·8	28·8	24·2	42·5
	T	51·1	57·9	38·2	42·6	58·7	41·4	48·7
Ratio: total to expected	P							1·60
	O							1·22
	R	1·36	1·05	0·98	0·31	1·81	0·90	0·65
	T	1·28	0·90	0·70	0·36	1·60	0·97	1·00

Cohort	Class	Obs.	Theory	Inst./Exp.	Optical	Radio	X + Gamma	UV + IR
1928–45	P	78·0 (8)	285·0 (5)	274·3 (3)	89·7 (6)	43·0 (2)	—	—
	O	—	—	—	—	—	—	—
	R	76·0 (3)	53·5 (2)	4·0 (1)	76·0 (3)	—	—	—
	T	78·6 (10)	239·2 (6)	206·7 (4)	87·5 (8)	43·0 (2)	—	—
1946–56	P	185·3 (13)	160·5 (12)	99·0 (5)	173·6 (8)	81·5 (2)	8·0 (1)	63·0 (1)
	O	96·7 (6)	145·0 (4)	165·0 (1)	109·0 (5)	35·0 (1)	—	—
	R	104·0 (9)	44·2 (8)	78·0 (5)	94·3 (8)	137·0 (1)	75·0 (1)	—
	T	121·5 (24)	118·3 (19)	77·3 (9)	100·7 (18)	66·0 (3)	41·5 (2)	63·0 (1)
1957–67	P	80·4 (20)	156·2 (21)	29·4 (5)	113·6 (11)	48·8 (5)	30·0 (3)	54·7 (4)
	O	45·2 (20)	112·2 (9)	9·0 (1)	66·3 (10)	23·3 (7)	—	28·0 (3)
	R	44·9 (26)	23·5 (12)	21·0 (5)	42·6 (14)	38·2 (10)	60·5 (2)	52·0 (4)
	T	52·4 (59)	101·9 (38)	39·9 (10)	68·0 (32)	31·9 (19)	35·3 (4)	55·7 (9)
1968–74	P	58·1 (15)	160·5 (11)	29·0 (3)	63·6 (5)	68·0 (3)	50·0 (4)	49·2 (5)
	O	45·3 (23)	137·9 (15)	26·5 (2)	47·1 (11)	48·2 (5)	29·5 (2)	31·5 (4)
	R	25·4 (56)	32·3 (34)	20·1 (9)	21·5 (23)	27·7 (18)	11·5 (4)	27·8 (13)
	T	33·9 (85)	64·6 (54)	23·7 (13)	31·9 (37)	33·5 (23)	30·3 (9)	33·3 (19)
1975–81	P	85·4 (16)	120·0 (7)	4·0 (1)	91·7 (11)	111·0 (3)	35·0 (2)	45·5 (2)
	O	52·7 (31)	29·2 (5)	138·0 (1)	64·6 (15)	35·5 (4)	40·0 (2)	53·0 (11)
	R	36·4 (68)	33·6 (45)	12·7 (10)	25·4 (32)	42·9 (16)	37·3 (8)	33·7 (10)
	T	46·9 (110)	41·3 (56)	22·4 (12)	48·4 (57)	44·9 (22)	37·3 (23)	45·0 (20)

TABLE 1 (*cont.*)

Cohort	Class	Obs.	Theory	Inst./Exp.	Optical	Radio	X+Gamma	UV+IR
1982–91	P	53·0 (6)	57·0 (5)	—	43·8 (4)	—	26·0 (1)	—
	O	16·4 (5)	5·0 (3)	—	13·3 (4)	11·0 (1)	31·0 (1)	—
	R	10·4 (64)	14·8 (39)	5·7 (18)	9·6 (29)	11·8 (16)	13·8 (5)	8·9 (16)
	T	14·2 (75)	18·6 (47)	5·7 (18)	13·7 (36)	11·7 (17)	18·0 (7)	8·9 (16)
Total	P	92·3 (78)	156·1 (61)	91·5 (17)	104·0 (45)	68·7 (15)	35·8 (11)	51·6 (12)
	O	49·9 (85)	106·1 (36)	72·6 (5)	62·2 (44)	32·9 (18)	34·0 (5)	43·5 (18)
	R	30·5 (226)	28·0 (140)	18·9 (48)	29·0 (109)	31·0 (61)	30·4 (20)	24·4 (43)
	T	43·7 (363)	64·6 (220)	39·4 (66)	48·5 (188)	33·1 (86)	31·5 (86)	34·5 (65)
Expected citation rate	R	27·2	27·9	27·9	29·2	26·3	28·1	23·3
	T	48·7	49·9	55·1	53·1	48·0	43·5	40·4
Ratio: total to expected	R	1·12	1·01	0·68	0·99	1·18	1·08	1·05
	T	0·90	1·30	0·71	0·91	0·69	0·72	0·85

Cohort	Class	Stars	Sun	Solar system	MW & ISM	Dynamics	Galaxies	HEAP	Cosmology
1928–45	P	163·5 (8)	514·0 (2)	—	124·0 (5)	114·0 (1)	66·0 (1)	339·7 (4)	92·5 (2)
	O	—	—	—	—	—	—	—	—
	R	113·5 (2)	—	—	—	—	47·0 (2)	53·5 (2)	93·0 (1)
	T	160·2 (9)	514·0 (2)	—	124·0 (5)	114·0 (1)	47·0 (2)	274·6 (5)	92·5 (2)
1946–56	P	117·5 (8)	190·8 (5)	113·0 (5)	316·5 (2)	78·7 (3)	310·0 (6)	171·0 (10)	70·0 (3)
	O	61·0 (2)	—	126·5 (2)	164·0 (3)	126·5 (2)	144·3 (3)	114·0 (3)	158·0 (1)
	R	14·6 (6)	72·3 (3)	109·0 (3)	26·5 (2)	104·0 (1)	420·0 (2)	39·7 (3)	88·5 (2)
	T	102·5 (16)	147·7 (7)	104·1 (7)	156·7 (6)	97·8 (5)	257·1 (8)	140·1 (13)	92·0 (4)
1957–67	P	206·6 (7)	21·5 (4)	73·7 (14)	153·8 (6)	84·7 (9)	131·4 (7)	182·8 (15)	196·2 (10)
	O	82·2 (12)	48·0 (3)	44·0 (5)	92·6 (7)	—	62·7 (3)	189·3 (4)	126·7 (3)
	R	40·0 (11)	17·1 (8)	30·8 (4)	37·6 (10)	37·0 (4)	85·5 (2)	63·8 (4)	103·5 (2)
	T	85·2 (27)	24·4 (15)	58·9 (21)	72·1 (21)	79·0 (11)	108·8 (9)	151·8 (19)	164·8 (13)

1968–74	P	61·2 (9)	17·5 (2)	76·0 (2)	90·0 (2)	149·0 (1)	90·3 (6)	118·0 (14)	66·4 (5)
	O	71·1 (16)	13·0 (4)	18·2 (4)	68·0 (6)	82·0 (4)	106·2 (5)	116·0 (16)	78·3 (3)
	R	23·0 (38)	28·0 (15)	27·8 (9)	47·3 (8)	10·5 (2)	45·6 (13)	33·7 (18)	71·8 (4)
	T	59·6 (33)	24·5 (19)	31·7 (15)	51·4 (11)	58·2 (6)	66·0 (23)	70·0 (40)	82·1 (9)
1975–81	P	82·3 (4)	53·0 (2)	48·8 (5)	66·8 (4)	60·5 (2)	121·3 (9)	63·8 (5)	161·3 (4)
	O	43·6 (12)	40·0 (1)	40·0 (3)	22·8 (5)	46·5 (2)	60·1 (10)	43·4 (7)	151·5 (2)
	R	23·9 (32)	26·3 (11)	27·6 (18)	34·3 (18)	14·9 (4)	46·7 (16)	47·9 (26)	103·2 (6)
	T	33·7 (48)	31·1 (14)	29·6 (26)	31·0 (23)	34·2 (8)	67·2 (33)	50·8 (36)	125·5 (11)
1982–91	P	—	—	31·0 (5)	62·0 (3)	—	26·0 (1)	64·0 (2)	63·0 (3)
	O	—	5·5 (2)	11·0 (4)	—	4·0 (1)	4·0 (1)	21·0 (2)	—
	R	6·7 (26)	3·0 (2)	6·9 (18)	11·3 (19)	16·2 (4)	16·9 (20)	13·4 (19)	25·7 (6)
	T	6·7 (26)	4·2 (4)	13·3 (27)	18·2 (22)	13·8 (5)	16·7 (22)	18·4 (23)	38·1 (9)
Total	P	140·4 (36)	147·3 (15)	69·3 (31)	127·7 (22)	86·4 (16)	150·2 (30)	158·2 (50)	130·5 (27)
	O	66·1 (42)	24·7 (10)	39·4 (18)	79·1 (21)	75·3 (9)	79·9 (22)	115·7 (32)	119·6 (9)
	R	22·3 (115)	27·4 (39)	24·4 (52)	28·7 (57)	26·4 (15)	50·6 (55)	35·9 (72)	73·2 (21)
	T	58·2 (159)	54·9 (61)	37·2 (96)	54·0 (88)	60·1 (36)	74·5 (7)	81·8 (136)	107·4 (48)
Expected citation rate	R	28·4	32·4	26·5	25·9	29·0	25·8	27·8	30·1
	T	56·1	58·3	44·3	53·3	58·1	46·5	52·3	54·7
Ratio: total to expected	R	0·79	0·85	0·92	1·02	0·91	1·96	1·29	2·43
	T	1·04	0·94	0·84	1·01	1·04	1·60	1·56	1·96

2.4 The uncited astronomers

All Prize-winners were cited in 1990, and all but one of the Officers in 1990 or 1989, the one exception coming from the history division. But one in six of the randomly chosen members (82 of them) had no citation in either year.

These uncited astronomers are statistically different from the other randomly selected members. Fifteen (18 per cent) are emeritus members, compared to 10 (2·5 per cent) of the 393 cited Random group. Twenty (24 per cent) are women, vs. 36 (9·2 per cent) of the cited group. Not surprisingly, Associate Members are also over-represented (32/82 or 39 per cent, vs. 40/393 or 10 per cent in the cited group), as are affiliations with teaching- and mission-oriented institutions (40/82 or 49 per cent vs. 90/393 or 23 per cent of the cited R astronomers). And only four (5 per cent) are associated with prestigious institutions, compared to 70 (18 per cent) of the cited Rs. Similar trends were presented in the 1982 data, though in general not so strongly. The 'have' and 'have not' portions of the astronomical community are diverging, as seems to be true of society as a whole.

For 16 (19 per cent) of the uncited astronomers, no institutional affiliation could be determined (vs. 13 or 3 per cent of cited Rs). This means that (*a*) the AAS directory lists only a home address and (*b*) there have been no abstracted publications in recent years, or (*c*) the person has clearly moved from the last listed institution.

2.5 Sources of error

Something like 12 per cent of all current citations are wrong (Abt 1992). Common errors include wrong volume numbers, page numbers, authors' initials and years of publication. Many of these mistakes are caught by the compilers of *Science Citation Index*, but they do not, in any case, matter for our purposes. The one kind of error that matters, a completely incorrect name for the first author, occurs so rarely (less than 1 per cent of citations, Abt 1992) as to be negligible for the present investigation. Such errors do, however, happen. The author is (not surprisingly) aware of a short 1973 paper by Trimble and Reines that is nearly always cited as Reines and Trimble.

Owing to the format of *SCI*, citations can be associated only with the first-named (senior) author of multi-authored papers. Where authors are ordered alphabetically, this makes no difference to averages over cohort, subdiscipline, institution, etc.: 'A' stars are not studied preferentially by people whose names begin with A.

There may, however, be systematic differences among subdisciplines, institutions and generations about who comes first on papers co-authored by students or postdocs and advisers. Always putting the student first would tend to flatten the gradient of numbers of citations vs. age of the first author. Always putting the adviser first would steepen it. The present data show no obvious internal evidence for such differences. But both the alphabetical issue and the question of who comes first need to be kept in mind when comparing individuals with averages.

Individual citation rates appear here only for the most-cited astronomers at the end of Section 3.1. Within this elite group, there is no strong evidence for alphabetical discrimination. The median surname in the AAS directory is Lee. The middles of the highly cited groups come between Moore and Parker for the 'top ten', at Maeder for the second group, and at Moore for the entire 23. Anomalies deriving from first authorship of multi-generation works are harder to assess. The distribution among cohorts (4, 6, 8, 4, 1, 0 in the six groups, from old to young) is more peaked toward the older groups than are the Prize-winners in general, but I cannot see any way to decide whether this reflects 'fair' or 'unfair' senior authorship. One member of the group has, at any rate, expressed a strong opinion that he (all living members are male) and perhaps one other astronomer would rank much higher if they came earlier in the alphabet relative to their colleagues and had been less generous with their students and postdocs about first authorship. At some level, this is undoubtedly so. The amount of the effect can be checked only by someone with access to complete lists of publications by all the people in the sample.

3 RESULTS AND DISCUSSION

3.1 Basic data

Table 1 shows the mean citation rates for all the assorted subsamples, separated into Prize-winners, Officers and Random members and into chronological cohorts, plus most of the possible summations. The last few lines of each column are means for the entire subsample, the age-adjusted expected citation rate for the subsample, and the ratio of the actual rate to the expected one. Subsamples with ratios, r, greater than one are doing better than average. Individuals who happen to be both Prize-winners and Officers, or one of these and also in the Random group, appear in each data set where they belong, but only once in each relevant total. Not all the duplications were correctly removed in 1982. They have been this time.

Average rates for the larger categories have changed surprisingly little since 1982 (114·9 vs. 108·7; 63·4 vs. 62·0; and 27·5 vs. 28·6 for P, O and R respectively). The drop in overall average from 53·0 to 48·7 reflects primarily the larger fraction of randomly chosen members in the total this time.

As before, it pays to be a mature, prizewinning theorist, working on high-energy astrophysics or cosmology at a prestigious institution. It also still pays to be male, though only slightly.

Most of the trends seen in the 1982 data persist, though the differences among astronomers studying different kinds of objects are not as large. Observers (with $r = 0·90$ now vs. 0·85 in 1982) are still cited less often than theorists ($r = 1·30$ vs. 1·35), but more often than instrument builders, etc. ($r = 0·71$ vs. 0·76). Optical ($r = 0·91$ vs. 0·86) and UV/IR ($r = 0·85$ vs. 1·03) observers still do better than radio ($r = 0·69$ vs. 0·73) and X/γ ($r = 0·72$ vs. 0·79) observers. Workers on the sun and solar system are still under-cited ($r = 0·94$ and 0·84) though not by so much as before ($r = 0·72$ and 0·56). Stars, the Milky Way and dynamics remain very close to average. But galaxies, high-energy astrophysics and cosmology are, if anything, even more over-cited than in 1982 ($r = 1·60$, 1·56 and 1·96, vs. 1·36, 1·77 and 1·83).

Differences among astronomers at different kinds of institution have grown. The ratios for the total sample in 1982 were: universities = 1·13, observatories and laboratories = 0·94, college and mission-oriented = 0·38

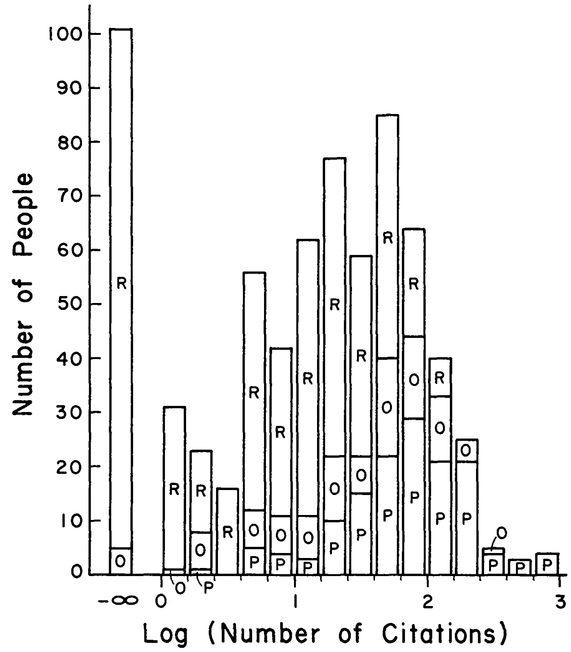

FIG. 1. Histogram of numbers of Prize-winner, Officer and Random astronomers cited N times during 1990, binned logarithmically.

and Prestigious = 1·51. The 1990 values are U = 1·28, O/I = 0·90, L = 0·70, C+M = 0·36 and Prestigious = 1·60.

Prize-winners continue to be cited more often than Officers and Officers more often than Random members for the total sample and most possible subsamples. The differences have increased somewhat since 1982: P has r = 1·60 vs. 1·31; O has r = 1·22 vs. 1·14; R has r = 0·65 vs. 0·69; and, of course, the total sample has r = 1·00 by definition at both times. Because a larger fraction of the prizes are given to young astronomers now than in the past, the P–O–R differential is smaller without age normalization.

The averages for the two oldest cohorts have continued to increase almost linearly with time, from 153·5 to 182·4 for the 1928–43 group, and from 89·9 to 100·0 for the 1946–57 group. The youngest cohort in the present sample (1982–91) is now about the same 'scientific age' as the 1975–81 cohort was in 1982. Their Prize-winners are doing a bit better (48·5 vs. 38·4 citations/year) and their Random members a bit less well (11·6 vs. 14·1 citations/year) than the previous group at the same stage. The change in the Random group is associated with a larger fraction of the youngest cohort being affiliated with institutions in the L, C, and M categories (but the data do not tell us the direction of the causation).

Figure 1 is a histogram of numbers of citations for the Prize-winner, Officer and Random groups. The bins are logarithmic. People in more than one group appear only once in the histogram (as P if P and O; as P or O if also in R). As in 1982, the shape is not much like a Gaussian or other simple function because of the large number of people with only one or two citations in the year, even if you ignore the group at zero.

The most-cited astronomers and numbers of citations in 1990 are: William Press (908), S. Chandrasekhar (797), Allan Sandage (679), Charlotte

Moore-Sitterly (651), Gerard de Vaucouleurs (566), Icko Iben (415), John Bahcall (413), Eugene Parker (397), Lyman Spitzer (377) and James Peebles (325). All are Prize-winners. Others with more than 200 citations in 1990 include Aaronson, Anders, van den Bergh, Blandford, Eggen, Herbig, Lynden-Bell, Maeder, Ostriker, Osterbrock, Paczyński, Rees and Woosley (Maeder and Woosley from the Officer sample; others from P). Five of these people (but none of the 'top ten') are also among the twenty-one astronomers who appear most often in the acknowledgements of papers written by others (Verner 1992). The 1982 'top ten' were Chandrasekhar, Moore-Sitterly, Hans Bethe (who was in the R sample and is not in the 1990 database), Sandage, Spitzer, Parker, Harold Johnson, Sidney van den Bergh, Bahcall and Peter Goldreich, with citation rates ranging from 787 to 259, and six members in common with the 1990 most-cited. All six have more citations in 1990 than in 1982.

3.2 Demographics and other sidelights

In addition to the average citation rates presented in Section 3.1, the data sample revealed an assortment of statistical facts about the survey population and its changes since 1982.

(1) The Prize-winner and Officer classes have both grown. But where Os used to outnumbers Ps (99 to 83), Ps now outnumber Os (143 to 132). The Ps and Os are not drawn independently from the total AAS membership. The overlap of 21 people in samples of 143 and 132 means that the parent population is about 900 (out of 6000 or so AAS members). It was 600 in 1982 and so has grown at about the same rate as the Society as a whole.

(2) The strong correlation of citation rate with career length persists (Fig. 2). The six cohorts have median starting dates of 1938, 1953, 1964, 1972, 1978, and 1986. If their mean citation rates are divided by career length up to 1990, the average numbers of citations per year of career are 3·5, 2·7, 2·5, 2·5, 3·6 and 3·6 for the six cohorts in order. This is the motivation for the normalization procedure discussed in Section 2.3. The corresponding numbers for average citation rate per year of career in 1982 were 3·4, 3·1, 3·6, 4·4 and 4·0. Only the oldest cohort is entirely holding its own!

(3) The Prize-winner, Officer and Random samples differ noticeably in their distributions by chronological cohort (Ps are oldest; Rs youngest) and by institutional affiliation. For instance, the college and mission-oriented group includes 3 per cent of the Ps, 19 per cent of Os and 23 per cent of Rs. The 1982 fractions were 0, 11 and 19 per cent.

There are some differences in subdiscipline as well. Compared to the Random and total samples, Prize-winners include an excess of theorists (43 vs. 36 per cent), while the Officers include more observers (67 vs. 58 per cent) and fewer instrument builders (4 vs. 12 per cent) than average. There are relatively few large anomalies among wave-lengths and objects of study, although the Prize-winners include more than half of the cosmologists and only 17 per cent of the radio astronomers. Any reader with a slide rule (or more modern computational aid) can look for other trends or correlations.

(4) The subdiscipline distributions of the total sample have changed since 1982 in directions you might have guessed. Observers still outnumber

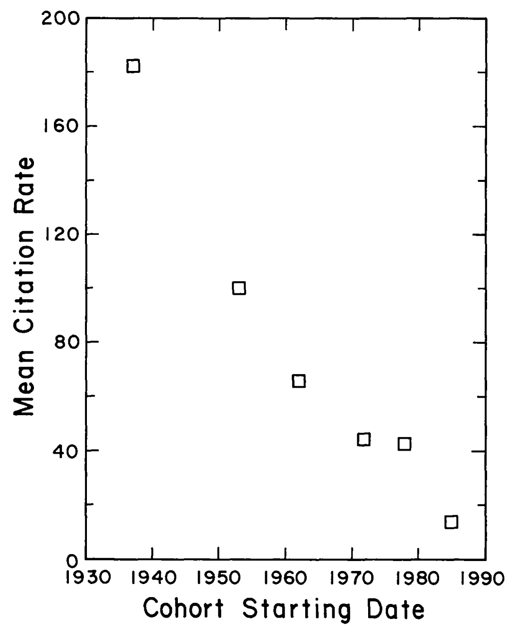

FIG. 2. Mean citation rate in 1990 for all astronomers in the sample, as a function of the average date at which members of each cohort published their first cited papers.

theorists about 1·6 to 1. Optical astronomers make up a smaller fraction of the total (31 per cent) than they used to (36 per cent), though they still slightly outnumber (188 people) the sum of all the other wavebands (185 people). Stellar astronomers still out-number those in any other single field of study, but they have fallen from 35 to 26 per cent of the total. The solar system group has grown from 12 to 16 per cent, partly because space-based data (like the Voyager encounters with Uranus and Neptune) encouraged related theoretical work. Halley helped too.

(5) Women make up 12 per cent of the complete sample, including 13 per cent of the Prize-winners, 21 per cent of the Officers and 9 per cent of the (cited) Random members (but 12 per cent of the total, cited+uncited, Random group). Rates for women in the cited group are, however, only very slightly smaller than the average for the complete sample, as was true in 1982. Women also make up 11 per cent of the astronomers at prestigious institutions (vs. 6 per cent in 1982), and so are no longer under-represented there. Many of them are, however, in temporary positions and will probably spend most of their careers elsewhere, as is true for the youngest cohort in general at the prestigious places.

In comparison with 1982, the fraction of total Prize-winners who are women has stayed about the same (13 vs. 12 per cent), while the fraction of non-Cannon winners who are women has gone up considerably (1 to 6 per cent). You might be tempted to draw the conclusion that the fraction of Cannon winners who are women has gone down. You would be wrong, it is still 100 per cent. However, there are more other prizes than there used to be.

(6) Prestigious institutions currently employ about half the Prize-winners, a third of the Officers, but only 19 per cent of the Random members. The 1982 fractions were one-half, one-third and one-quarter. The astronomers at these institutions are cited more often than average (by 10–120 per cent) in every

cohort and most other possible subgroups, though the 18 women there, with an average citation rate of 43·1, are nearly indistinguishable from the women as a whole at 40·1.

In 1982 the population at the prestigious institutions was slightly older than average. This disparity has grown with time. The fractions of the six cohorts so employed are, from old to young, 62, 37, 38, 23, 21 and 20 per cent. The disparity can only grow with time, at least for the 614 individuals in the present sample. Most of the members of the 1982–91 group and some from 1975–81 are in postdoctoral and other short-term positions. More of them will move to less-exalted jobs in the long term than will move into tenure at prestige places from postdocs elsewhere, unless there is a major change in current practice. Thus, 10 years downstream, quite a lot less than 20 per cent of the 1982–91 cohort are likely to be at prestigious institutions.

(7) The 72 Associate Members are a distinct group, though a handful are highly cited astronomers who apparently just don't like to fill out forms. They include 13 (18 per cent) women and 32 (44 per cent) uncited astronomers. Most of the cited ones are young (none in the first three cohorts; 5, 9 and 26 in cohorts 4, 5 and 6). The average citation rates for the three youngest cohorts are 8·5, 14·7 and 7·1, all well below the cohort averages. Institutional affiliations include 13 people at universities, eight at observatories and research institutes, 15 at laboratories and 35 with a college, mission-oriented or home address.

(8) The author remains resolutely average, contributing 90 citations to cohort 4, the subsamples officer, women, university and so forth.

(9) For an average astronomer, with neither a very high nor a very low citation rate, the published version of the PhD dissertation is very often still the most-cited paper a decade or two later.

(10) These American astronomers are different from European ones. The European data (Jaschek 1992) consist of 1988 citations to papers of which all 1072 IAU members resident in France, GFR, Spain, Sweden and Switzerland that year were senior or sole authors (apparently including self-citations). Almost a quarter (24 per cent) were not cited at all in the reference year, compared with 14 per cent of the American group. Of the 83 uncited American astronomers, only nine are IAU members (three who have never worked in the US, one historian, and five administrators at sponsoring agencies, etc.). For those European astronomers who were cited in 1988, the range in number of citations is 1–229 (1–908 in the US sample) and the mean is 15·9, compared to 48·9 citations per year for the 1990 American astronomers and 53·0 in 1982.

You might feel that it is not fair to include the American Prize-winners and Officers (though nearly all European national society Officers and Prize-winners are IAU members); but then cohort six, most of whom are not yet senior enough to have been elected to the IAU, must also be excluded. The mean citation rate for the 282 Random astronomers in the five oldest cohorts is 32·5 (38·7 for the four oldest cohorts in 1982), still more than twice the European average. Jaschek (1992) did not make this comparison, although he was aware of the 1982 data.

(11) UK astronomers have not (yet) been subjected to this sort of scrutiny, although citation rate analysis has been used among other tools to assess

particular cases like the Isaac Newton telescope (Irvine & Martin 1983). There is one indicator of a pattern of relative stability like the American one from the fact that the fraction of the world's astronomy/astrophysics papers and citations contributed by UK scientists has risen along with the number of practitioners, in contrast to the situation in physics as a whole and some other disciplines (Martin *et al.* 1987). The author intends to compile a set of numbers like those of Table 1 for RAS Prize-winners, Officers and Random members. The editor has promised at least to consider it for the next issue.

4 ACKNOWLEDGEMENTS

I am grateful to Robert Becker, who asked the question that partially motivated the 1982 citation rate analysis, and to the staff of the UC Irvine Physical Sciences Library for the decision to keep getting *Science Citation Index* in a form that permits extraction of numbers like these (as the disk version does not). Much of this analysis was done while the author was a visiting professor at the University of Texas, Austin. I am most grateful to the Curtis T. Vaughan and Beatrice M. Tinsley funds for support and to the department and its chairman, Gregory Shields, for their hospitality.

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