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THE H- AND A-INDEXES IN ASTRONOMY

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Abstract. Astronomers can compute h-indexes using either the Science Citation Index (World of Science) or the Astrophysical Data System (ADS). These two data systems sample different sets of publications. We compare the different results from these and the advantages and disadvantages of each. Because the Hirsch h-index is a steep function of time, their values for young and old astronomers cannot be compared. We define an a-index that is constant with time. Whether the h-index or a-index is more indicative of important research depends upon how one accredits the citation counts of authors in multi-author papers. We list current mean h- and a-indexes for astronomers in four countries. We conclude that on the average, individual astronomers in France, Germany, the UK, and USA are doing equally well in research importance but those in the first three countries are still not producing as much research as those in the USA, relative to total populations.

1. Introduction

How does one evaluate the accomplishments of an individual scientist? One can count his or her papers, but not all papers are equally important; some scientists publish many trivial papers while others may write just a few that are frequently quoted. Or one can note his or her papers that receive the largest numbers of citations, but if those papers were written by many authors, the individual's share of the credit may be small. Or one can count the total citations to all of a person's papers but it may not be fair to compare a person who published many major papers in his/her career with a person who published a few very outstanding papers.

Jorge Hirsch (2005), a physicist at the University of California, San Diego, proposed a rapid method of evaluation that allows for the productivity of many important papers. His h-index is defined as the number of papers that have received that number or more citations to each. For example, if a person has published 40 papers that each received 40 or more citations to date, then his or her h-index is 40. The h-index is generally easy to compute because the on-line version ("Web of Science") of the Science Citation Index (SCI) or the Astrophysics Data System (ADS) allows a person's papers to be arranged in the order of decreasing citations to date. Hirsch discussed the various ways in which a person's publications can be evaluated (total number of papers, total citations, number of outstanding papers, etc.); he commented on the disadvantages of each. He set up the equations relating these parameters and applied his h-index to physicists, primarily.

This method, although generally easy to compute, has three disadvantages, namely:

1. It is biased against young people whose papers have not yet been published long enough to accumulate many citations. However, Hirsch found that, to a first approximation, an h-index will increase linearly with time since the beginning of a publication career, so junior and senior scientists can be compared by the differing rates of growth of their h-indexes.
2. It is biased for scientists who work in large teams unless one divides the number of citations for a paper by the number of authors. For instance, the first Sloan Digital Sky Survey paper (York 2000) has received 2877 citations to date, but it has 144 authors. Should each author be given credit for 2877 citations or for $2877 \div 144 = 20$ citations? Hirsch acknowledges this problem. The ADS allows one to sort papers either by "citation count" (e.g. 2877 for the above paper) or by "normalized citation count" (e.g. 20 citations per author in that example). This allocation may not be fair to the author(s) who do most of the work in a multi-author paper. Unfortunately there is no consensus regarding the ordering of authors' names and their relative contributions to the research.
3. It is biased for people working in popular fields (currently galaxies and cosmology in astronomy). For instance, Hirsch reports that h-indexes up to 190 are possible in biology, but in physics the record is 110. Thus h-indexes for individuals generally should be compared only with those of other people in the same field.

Hirsch found that in physics an $h = 12$ should be considered enough to secure university tenure, 20 is a sign of success after 20 years of research, 40 indicates an outstanding scientist likely to be found only at major research centers, and 45 is typical for a person elected to the National Academy of Sciences. What numbers are typical for astronomers?

2. Comparison of SCI and ADS Counts

Astronomers have two sources of data about the published papers, namely the SCI and ADS. Unfortunately these two sources give results that are significantly different and each has advantages and disadvantages.

For the SCI the advantages are:

1. SCI includes many journals in other sciences (chemistry, mathematics, general science) not sampled by ADS.
2. SCI is limited to about 8000 reliable journals that are available to most scientists.
3. SCI is limited to published papers.
4. Results from SCI can be compared with Hirschs results and other studies.

The disadvantages are:

1. The subscription rate for SCI is expensive.
2. Because it includes scientists in many different fields, there is often a confusion of names and initials. That means that for astronomers with family names and initials similar to those of other scientists (called homographs), the lists of their papers includes those of others and must be separated. This can usually be done by using the "Analyze" option wherein papers are separated by fields of research. Hirsch mentions that his statistics do not include some authors complicated with homographs.

The ADS has the following advantages:

1. It is free to all users.
2. It is limited to astronomers and, largely, to astronomical journals so there is less confusion of names.
3. It gives immediately the total number of citations to all of a person's papers. One can click on "Astronomy and Astrophysics" or "Physics and Geophysics"; the default position for the latter includes the former.
4. It allows one to sort papers by "normalized citation count" in which the citation count is divided by the number of authors.

The ADS has these disadvantages:

1. It includes material that is often not wanted, such as unpublished papers (e.g. astro-ph), abstracts (only) of papers given at meetings, papers given at conferences whose publications may be difficult to find, errata, editorials, etc. That material can be either in the articles listed by author and in the citations to those articles. I recommend that

users select the option "All refereed articles" when compiling lists of substantial papers.

2. A spot check indicates that it will have a confusion of names (homographs) in 5-10% of the time, but because one does not know which 5-10%, one needs to scan visually each list of papers to see if they come from more than one author. Homographs are likely with names like Davis, Smith, and Jones, but can occur for less common names.

Both sources have problems with the forms of the names that will give the full data for substantial papers. For SCI one must give the full initials to reduce the confusion with other scientists (with no comma after the family name) or use an asterisk (e.g. G* Smith) to recover papers written using both one or two initials. For ADS giving the full initials may fail to include papers published with the first name only. For instance, for the fictitious name (but based on a real person) "Roger D. Smith", searching under "R. Smith", "Roger Smith", or "Roger D. Smith" will yield all of his papers, but "R.D. Smith" will not. One must be careful in using these sources because one can easily obtain partial or excessive information without realizing it.

I compared the SCI and ADS results obtained for 81 astronomers who are members of the National Academy of Sciences (NAS). I used the "All refereed papers" option in ADS. I did not include five names for which the homographs made separation with others difficult to disentangle. It turned out that the difference in h-indexes was h(SCI)– h(ADS) = -1.0 $\pm$0.8 (mean error in the mean), i.e. no significant difference in mean h-index. However, some individual h-indexes differed by as much as 32 (80 in SCI, 48 in ADS) due, in this case, to an astronomer who wrote and had citations to many papers in physics and chemistry. The mean error in h-index per individual was $\pm$7.0 or $\pm$15%. Therefore it seems safe to compare the average h-indexes in SCI and ADS for a large number of astronomers, but definitely not for individuals. Therefore stay with one database.

To continue this comparison of results from SCI and ADS for 81 astronomers in the NAS, their highest number of citations per paper agreed in the mean at C_{max}(SCI) – C_{max}(ADS) = -13$\pm$28 (error in the mean), but the mean scatter for individual astronomers is $\pm$247 citations or $\pm$34.4%, i.e. not good. The mean number of papers differed by n(SCI) – n(ADS) = -28$\pm$11 but the error for individuals is $\pm$100 papers or $\pm$59.0%, i.e. not good. Therefore do not use interchangeably data from the two data sources.

3. The a-Index

A major problem with using the h-index is that the counts from young and old researchers cannot be compared. The h-index increases rapidly with time, but it is laborious to determine h-indexes for times other than the present. The changes with time are shown in Fig. 1. The values of the h-indexes at decadal intervals increase linearly, within their statistical errors, as Hirsh noted.

Abt (2012) found that if the h-index is divided by the number of decades, or fractional decades, the result is statistically constant with time. Those are shown in Fig. 1 for the same four astronomers. He called the result the "a-index" for "age-independent". For the 12 astronomers discussed by Abt (2012), Fig. 2 shows that the a-index is correlated with the slope of the h-index with a cross-correlation coefficient (cc) of 0.932. Like the h-index, it is not well correlated with the total number of papers (cc = 0.868) or with the total citations (cc = 0.876).

In Fig. 2 we see that the astronomers with high, medium, and low h-index slopes have high, medium, and low a-indexes, respectively. However, the scatter is disturbing. It turns out the scatter is mostly due to an uncertainty in how to allocate the citation credit for multi-author papers. Therefore we cannot tell whether the slopes of the h-indexes or the a-indexes are better measurements of productivity.

4. Comparison of Four Countries

Whereas the USA dominated over most other countries in the development of astrophysics during much of the 20^{th} century, other countries have been catching up. I collected data for 2011 for the first 106-119 individual 2009 IAU members in France, Germany, UK and the USA. I tried to eliminate homographs (identical family names and initials). The results are shown in Table 1.

The first noticeable result is that that USA is an older population with a mean year for the first published papers of 1973.1 compared with 1978.9 for the other three countries. This is partly because the USA has no IAU members whose first papers were published in the 21^{st} century, compared with an average of 6 (5.0%) for each of the other three countries. Because values of the h-index increases each year, the longer publication times of the American astronomers easily explains the marginally larger mean value of the h-index for the Americans.

However, the larger mean value of the a-index for the first three countries suggests that the (younger) European astronomers are catching up to the Americans. An alternate explanation is that younger astronomers strongly tend to work in teams (the average number of authors per paper has been steadily increasing), so the younger European astronomers have the advantage of getting credit for team research. For the 16 European IAU astronomers whose first papers were published in the 21^{st} century, the average number of authors per paper was 9.3 ± 1.7. Compared with 4.4 ± 0.6

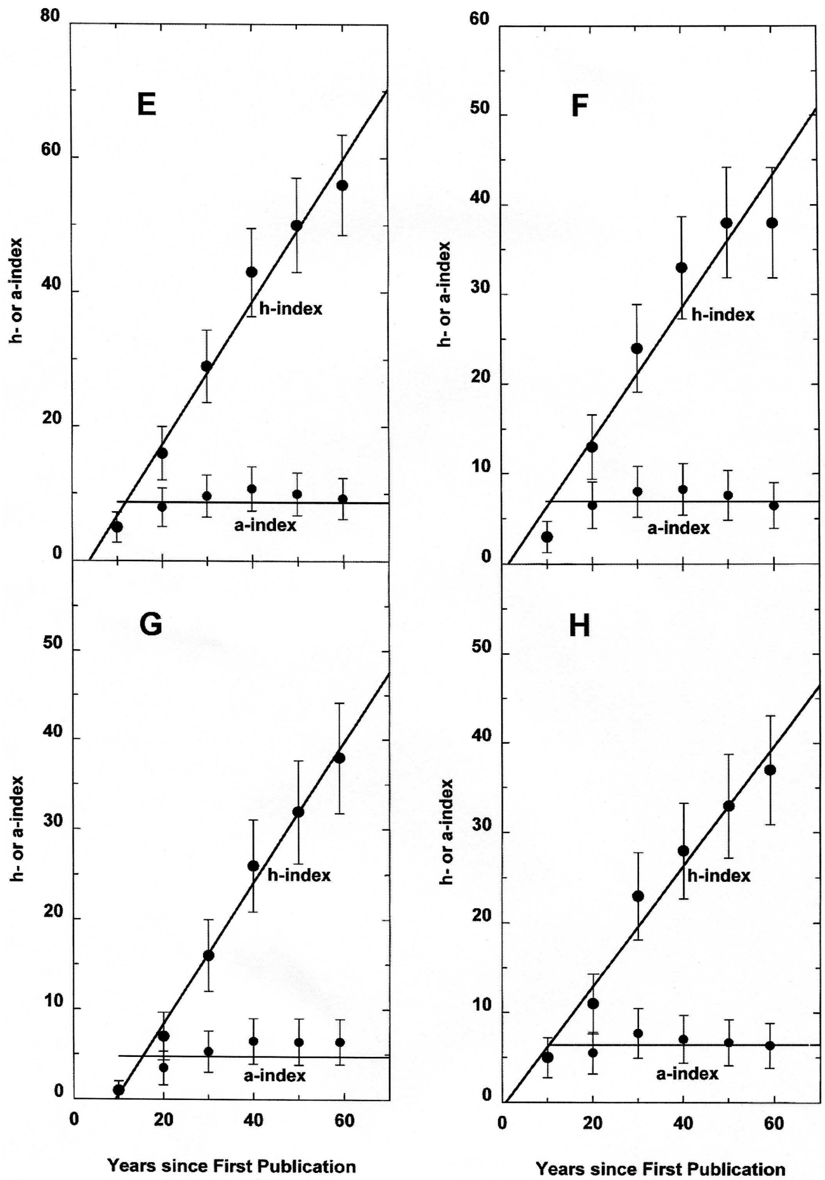

Figure 1. The h- and a-indexes are plotted with time, namely the number of years since the authors published their first papers. The four panels are for four astronomers whose maximum h-indexes are 56 (for astronomer E) to 37 (for astronomer H). (Reprinted with permission from Scientometrics)

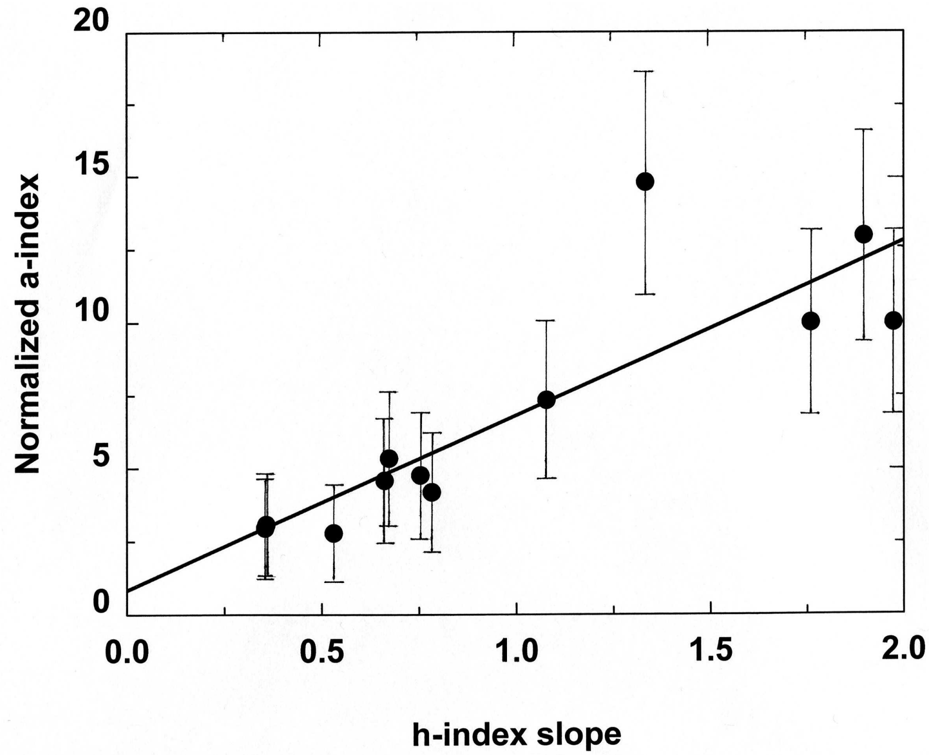

Figure 2. For 12 American and European astronomers near the ends of their careers, their a-indexes are plotted against the slopes of their h-indexes. The cross-correlation coefficient is 0.932. The lack of a better correlation is attributed to uncertainties of how much credit to give individual authors of multi-author papers. (Reprinted with permission from Scientometrics)

authors per paper during 1990-1995 for those three European countries, we see that the recent astronomers shifted strongly toward team research. Therefore the higher values of the mean a-indexes for the three European countries compared with the older USA astronomers is due to the former engaging more heavily in team research.

A recent study of the publication output of European and American astronomers (Abt 2010) showed that the amount of astronomical publication in Europe and the UK lagged behind that of the USA by 12 years, relative to their populations. How can we reconcile this lag with the evidence above that the quality of the former is now comparable to that of the USA? The answer is that the American papers are longer. Currently the *Astronomical Journal* and *Astrophysical Journal* papers average 13.7 and 12.1 pages per paper, respectively, compared with 7.5 pages per paper for *Astronomy and Astrophysics*. In addition, the American papers in 2009 contain far more

TABLE 1. Mean h- and a-indexes for IAU members in four countries

Country	Year of first paper	Mean h-index	Mean a-index
France	1979.2±1.1	21.1±1.1	8.0±0.6
Germany	1978.6±1.3	24.2±1.3	8.7±0.6
UK	1978.9±1.4	23.5±1.5	9.0±1.1
USA	1973.1±1.1	24.5±1.5	7.1±0.5

on-line material than the others.

We conclude that the individual astronomers in the major European countries and the United Kingdom are doing as well qualitatively as the average American but collectively they are not producing as much astronomical research as the Americans relative to their total populations.

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