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THE TRANSITION FROM AN INDIVIDUAL SCIENCE TO A COLLECTIVE ONE: THE CASE OF ASTRONOMY

J. A. FERNÁNDEZ

Departamento de Astronomía, Facultad de Ciencias, Tristan Narvaja 1674,
11200 Montevideo (Uruguay)
e-mail: julio@fisica.edu.uy

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The trend toward collectivization in Astronomy during this century (1901-1996), as measured by the increase in the number of authors per paper, is analyzed. For this purpose, two leading astronomical journals: *The Astrophysical Journal* and *Monthly Notices of the Royal Astronomical Society* are surveyed. It is found that the average number of authors per paper has jumped from a little more than one in the first half of this century to about three at present. Most of this dramatic increase has taken place during the last 20–25 years. At the same time, the ratio of *collective* papers (three or more authors) to single-authored ones has passed from nearly zero to 3–4 at present. The latter means that collective papers were almost nonexistent until the fifties or sixties to become nowadays 3-4 times more frequent than single-authored ones. The reasons underlying the collectivization of Astronomy (and perhaps of all natural sciences) are analyzed. The growing professionalization of science accompanied by a massive influx of graduate students into University research institutes, the revolution in communication, the pressure to publish in order to progress in a scientific career, and the growing complexity of knowledge are invoked as causes for the abandonment of the traditional individualism in science to a collective regime.

Introduction

Since ancient times Astronomy, as well as all science, has occupied an important place in the development of humanity. The reason behind that was the need to solve some practical problems, such as a reliable measure of time or the knowledge of position and motion of heavenly bodies to guide caravans through the desert or ships at sea, as well as the mere curiosity for the unknown and the vain attempt, deeply rooted in man, to learn about the future through the occurrence of certain celestial phenomena.

The scientific revolution that shaped modern science took place in Europe during the seventeenth century. The authority of Aristotle and other classical greeks was challenged. Furthermore, science started to get rid of all the superstitious elements that

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were part of it and became more rigorous and quantitative with the incorporation of new mathematical tools. The advance of technology made possible the incorporation of new instruments into scientific research (for instance, telescope, microscope, vacuum pump) that led to new experiments and observations, essential to advance in our knowledge of nature. At the same time scientists started to organize the first national academies of sciences in the most advanced European countries. During the last century scientific research started to have an increasing importance in Universities of Europe and the U.S. that ended up with programs of graduate studies in different fields of science. Once students completed their graduate studies they expected to be employed by Universities or research laboratories, so they could make a living by fully devoting their time to research. The career scientist came into being; science became a fully professional activity.

Until not long ago the development of Astronomy, as well as the rest of the scientific enterprise, rested on the shoulders of a few privileged, talented people from wealthy societies whose work was finantially supported by mecenas or by themselves. Like artists and writers, those scientists (if we can apply this modern term to them) used to work individually. Terms like "research group", "team leader" or "critical mass" were entirely unknown until recently. There have been dramatic changes during the last few decades; the scientific enterprise has been *collectivized* adopting in the process a bureaucratic and businesslike structure. Expressions like "project manager", "research priorities", "overheads", "accountancy on research funding", "international agreements of scientific cooperation", are now usually heard in the labs. *Ziman*[1] adds: "the great majority of those involved (in a big project) have surrended their personal scientific autonomy to the collective authority of the team – usually directed by a very powerful leader". One of the features of modern science is thus a sort of *taylorization* of the scientific work in which the scientist becomes a link in a production line (the research group),[2] where his or her level of productivity is measured by certain parameters (number of scientific publications, involvement in research projects, invited talks, citations, etc.).

The scope of this paper is to analyze the phenomenon of collectivization within the field of Astronomy by assuming it to be closely correlated to the trend toward multiple authorship in scientific papers. This is no doubt a very interesting feature of the practice of modern science that has however been paid only little attention. Among the few scattered studies on this topic we can quote *Price*,[3] *Clarke*[4] and *Abt*[5] who analyzed trends toward multiple authorship in the fields of Chemistry, Biology and Astronomy, respectively, some time ago. Considering the fast changes in the practice of science that have taken place during the last few decades, we feel that these previous studies are by now somewhat out of date, so we deem interesting to re-analyze such trends as well as to delve into their causes.

Measure of the growing collectivization: The method

At least for the last one century or so, it has become usual that researchers submit the results of their experiments or theoretical work to *scientific journals* as *papers* whose editors, in many cases after receiving reports from peer reviewers, decide on their acceptance for publication. Most of the modern progress in scientific knowledge is thus contained in these collections of papers. Furthermore, they provide an accurate idea about authors, institutions, nationalities. In this sense scientific journals are a valuable source of information to get clues about the modern scientific endeavour in its more epistemological aspects. This is a task that has been addressed by some researchers, in particular by *Price*[3] who made an excellent analysis of several trends in science until the sixties or early seventies. In the field of Astronomy we can quote Abt's analysis of several trends as, for instance, the growth rate in the number of papers, the average paper lenght and multiple authorship,[5] the internationalization of astronomical papers,[6] and a discussion on how astronomical papers are remembered as time passes, by checking the number of citations in the years following their appearance.[7].

In our field of interest – Astronomy – we have to define first which journals should be selected as representative of the development of the subject during the studied period (in our case 1901–1996). Such selection was done on the basis of the two following criteria:

- The selected journals must have existed throughout the considered period without significant changes in their scope. Furthermore, they must cover a wide range of fields within astronomy and astrophysics.
- They must have an international reputation and be the recipient of a large fraction of the scientific output of a broad and very active astronomical community.

According to the above criteria we have chosen: *The Astrophysical Journal* (ApJ) and *Monthly Notices of the Royal Astronomical Society* (MNRAS) for our study. Among 35 international journals of astronomy and astrophysics, MNRAS and ApJ are ranked in the third and fourth place, respectively, according to the ISI Impact Factors for 1995. The ApJ was founded by George E. Hale and James E. Keeler in 1895 to become a leading journal in the field in the U.S. A brief account of the birth and early development of the ApJ is given by *Osterbrock*.[8] MNRAS, a British journal, was founded in 1827 and is therefore one of the oldest scientific journals still in circulation. Even though both journals represent national astronomical communities (American and British), they receive many contributions from elsewhere. Thus, it is frequent to find there authors from Europe, Japan, Australia, India, South Africa and Latin America. Furthermore, both journals have had the honor of publishing many of the most important pieces of research in Astronomy carried out during this century. Most of the famous astronomers of this century, James Jeans, Henry Norris Russell, Arthur S. Eddington, Edwin Hubble, Harlow Shapley and Subrahmanyan Chandrasekhar among others, can be counted as assiduous contributors to one or both of these journals and in some cases were active members of their editorial boards.

There are other first-rate journals in Astronomy. For instance, *The Astronomical Journal*, founded in 1849, is also a leading journal in the U.S. Yet, it has suffered more changes throughout its history, evolving from letters and observatory reports with a strong emphasis on astrometry and celestial mechanics a few decades ago to a fully-developed journal with a broad interest in all areas of astronomy at present. *Astronomy and Astrophysics* is the leading European journal but it did not appear until 1969, so it does not fulfill one of our requirements. The *Astronomische Nachrichten* was the leading German journal, and a very prestigious one, but it followed the fate of the Third Reich and almost disappeared in 1945 (it was continued in East Germany afterwards but without much success).

We thus considered samples of a variable number of 2 to 6 issues per year from both ApJ and MNRAS (we increased the number of sampled issues in recent decades following the explosive increase in the number of published issues). We chose the sampled issues arbitrarily, for instance those corresponding to January and July of each year. We then proceeded to count the number of authors in every paper appearing in the sampled issues. To keep the sample as homogeneous as possible, Letters to the Editor, Invited Lectures and Reports from Observatories were not included. Therefore, only original contributions appearing as main papers were included in our study (in the case of ApJ, when it split into the Main Journal, Letters and Supplement, only the first one was followed). In the end we surveyed 6186 papers of ApJ and 3983 papers of MNRAS (about 19% and 25% of the total number of papers published in ApJ and MNRAS during 1901-1996, respectively).

Results

The average numbers of authors per paper (within intervals of 4 years) are plotted in Fig. 1 as a function of time. For both ApJ and MNRAS the average number of authors per paper, N_A, stayed more or less constant, at a value slightly above unity, until the fifties. This result clearly shows the predominance of single authorship during the first

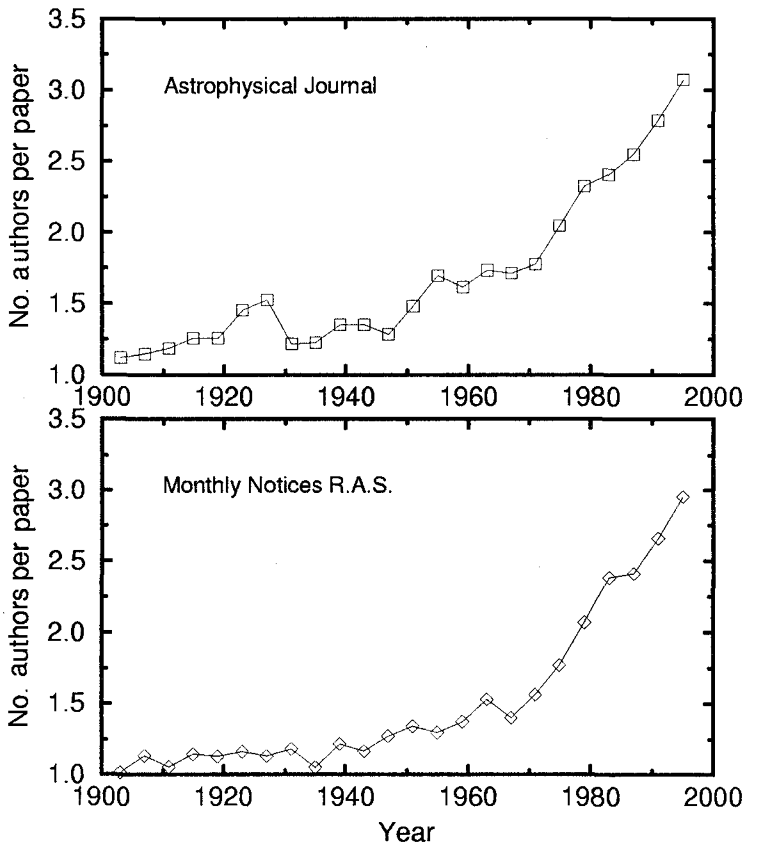

Fig. 1. Average number of authors per paper (taken over 4-year intervals) as a function of time

half of the century. N_A started to grow significantly in the sixties, acquiring a very steep increase in the last 20-25 years. At present, N_A has reached a value around 3. These results are in good agreement with those presented by *Abt*[5] for three American astronomical journals: *The Astrophysical Journal*, *The Astronomical Journal*, and *Publications of the Astronomical Society of the Pacific.* Abt found that single-authored papers were the most common early in the century, while the average rose to nearly two authors for theoretical papers and three for observational ones in his last studied year (1980).

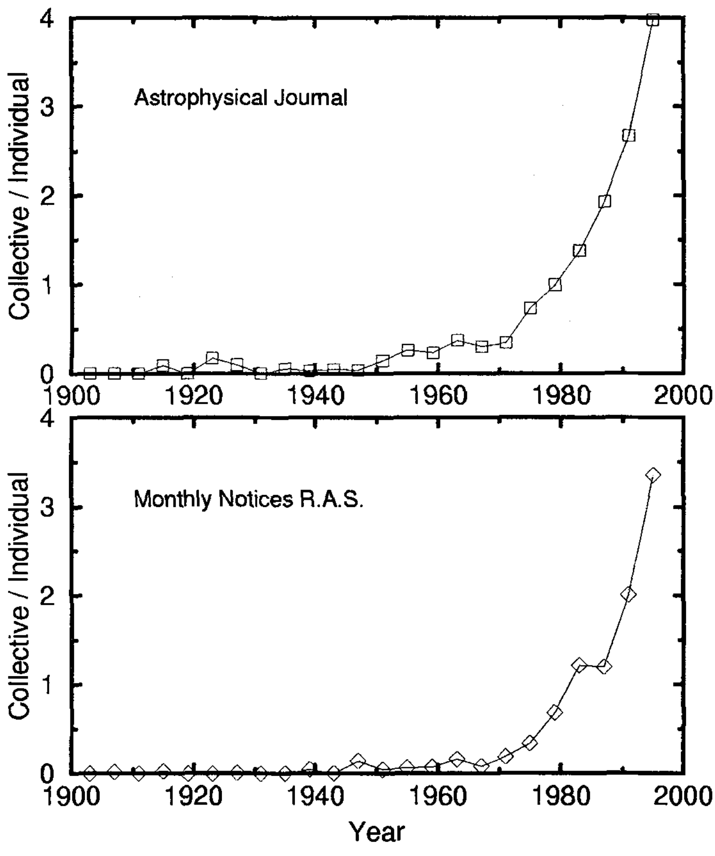

Fig. 2. Average ratio of collective (three or more authors) to individual papers (taken over 4-year intervals) as a function of time.

Taking into consideration that the percentage of theoretical papers was according to Abt 32%, the average N_A for all papers turns out to be about 2.7 authors per paper. Our derived values for 1980 are about 2.4 authors per paper for ApJ and 2.3 for MNRAS. Our estimated errors in N_A for the last two decades are about 12% for ApJ (they are somewhat larger, about 20-25%, for the first few decades), while they are about 15-20% for MNRAS (they remain more or less constant throughout the studied period). It is to be noted that our average values of N_A do not include multiauthor papers with more than 10 authors. These are becoming increasingly common as a result of international observing campaigns or research projects sharing big facilities. Given that their inclusion would somewhat distort our average numbers (we found a paper signed by 124 authors!), we have decided to discard them from the computed N_A. Of course, their inclusion would make it appear that the growth of N_A in recent decades was even more explosive than shown here.

Figure 2 shows the evolution of the ratio of *collective* to individual papers. As *collective* we considered those papers co-authored by three or more people. A number such as three people starts to give an idea of changes of behaviour in the practice of science. A project with three people already requires a certain coordination with somebody among them taking a leading role. Thus the concept of research team or group emerges, as opposed to the individual research or even that shared by two people. It is clear that the incidence of collective papers is negligible until the fifties. A slow increase started afterwards to become very steep since the seventies. At present, collective papers outnumber single-authored ones by a factor of 3-4 in both ApJ and MNRAS. The estimated errors in these results are around 12%-18%.

Figure 3 shows the estimated number of authors and papers that contribute to ApJ and MNRAS each year. The fast increase in their numbers during the last few decades is noticeable and closely parallels the other trends discussed before. The increase in the number of authors is much steeper than that of papers in agreement with what was previously discussed. *Glass*[9] stated that the number of scientific papers has been doubling almost every 10 years. We have checked how our results fit this empirical rule. From Figure 3 we can see that neither ApJ nor MNRAS grew at this rate during the first decades of this century. On the contrary, the numbers of scientific papers per year stayed more or less constant. But the growth rate of papers in ApJ for the last 60 years, and that of MNRAS for the last 30 years, fit reasonably well the "doubling-every-ten-years" empirical law (dashed curves of Fig. 3). The later takeoff of MNRAS might be a consequence of the ravages of the World War II in Great Britain. Our results are in fairly good agreement with the doubling time of 7.8 years found by *Abt*[5] for the three American astronomical journals mentioned above with a slower rate in more recent times. Finally, Figure 4 shows the histogram-distribution of the number of authors per paper in the last five years (1992-1996) for the ApJ and MNRAS. The maximum of the distribution is found for papers written by two authors with a smooth decay towards larger numbers. Long tails of multiauthor papers stretch well beyond 10 authors.

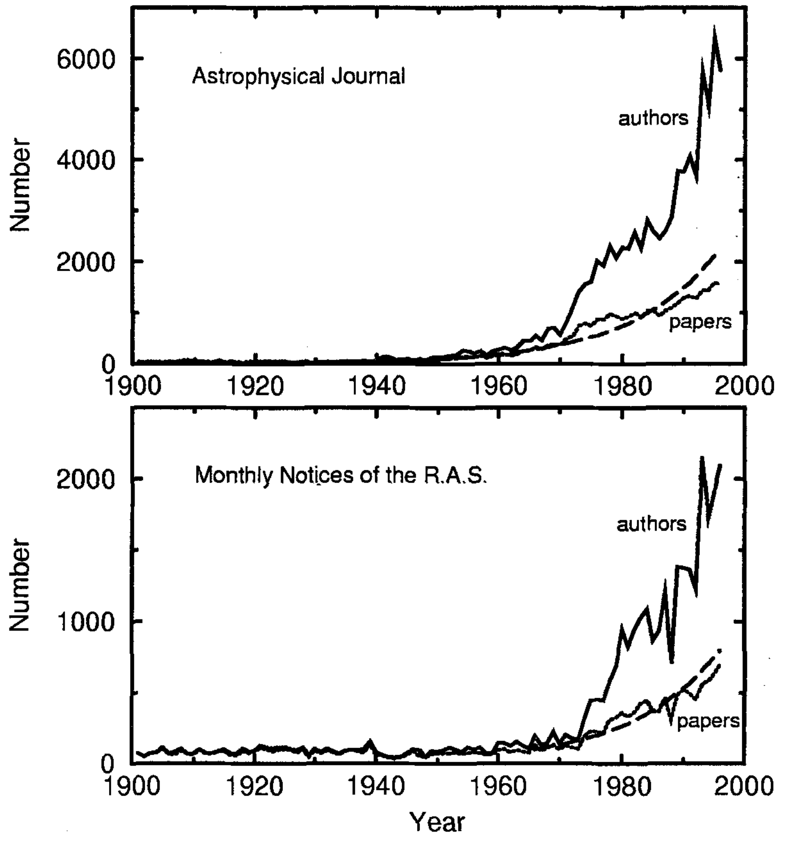

Fig. 3. Estimated number of authors and papers per year contributing to ApJ and MNRAS. The dashed curves are fits to the "doubling-every-ten-years" empirical law (see text)

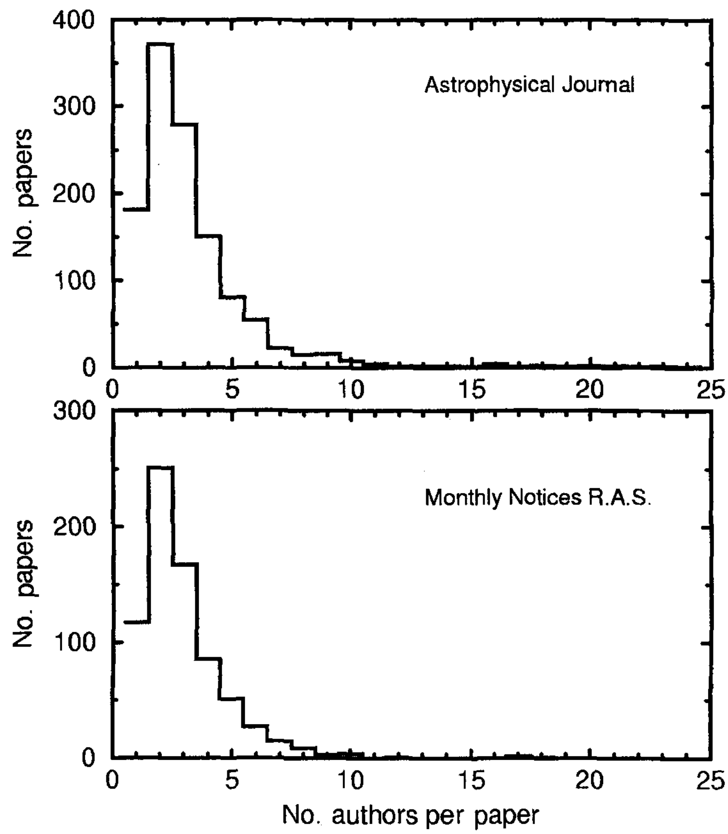

Fig. 4. Histogram-distributions of the number of authors per paper

Changing face of science: Discussion

Beyond the mere quantitative aspects, the above results express, to our understanding, deep changes in the way research in Astronomy (and, perhaps, in all natural sciences) is carried out. Is the trend toward multiple authorship a specific phenomenon of Astronomy or does it also involve other sciences? A few scattered studies tend to show that it is indeed a quite widespread phenomenon in modern science. Almost forty years ago *Price*[3] already found the same trend in chemistry by analyzing the Chemical Abstracts for the period 1910-1960. A result in seeming conflict with the previous ones was presented by *Clarke*[4] who found no marked trend toward multiple authorship among the biomedical writers during the period 1946-1963. Yet, a close scrutiny of his data also shows a steep increase in the fraction of multiauthor papers (≥4 authors) during the previous period 1934-1946. It would be very interesting, no doubt, to know what happened in the biomedical sciences from 1963 to the present, when most of the growth of multiauthor papers in Astronomy has taken place. As mentioned, the trend toward multiple authorship was later corroborated by *Abt*[5] in the field of Astronomy.

Why has science abandoned its traditional individual characteristics of former times and gone collective? Some reasons for this change of behavior may seem rather obvious and others may be more subtle and, perhaps, more startling. Let us analyze these possible causes:

1. The *professionalization* of science, a trend that goes back to the last century when some European universities started to offer graduate courses. The first degree in science was awarded by the University of London in 1860.[10] But it was not until the end of the Second World War that Universities in the developed world started to receive a massive influx of students willing to follow scientific careers. At a slower pace, this phenomenon is also seen in several Third World nations, such as India, South Africa and some Latin American countries. National research councils and other scientific bodies were set up and started to support scientific research at an unprecedented scale in Universities and other research institutes. Small Departments and Observatories suddenly found themselves in a position to appreciably enlarge their staffs as a result of the new wealth. Consequently, the probability of having colleagues willing to carry out projects of common interest increased and, what is more important, University departments and observatories could have the money to support graduate students and post-docs, so researchers started to find plenty of brainpower available to cooperate in their research projects.
2. As never before, the rule that scientists have to produce papers, as a measure of their competence, is strongly imposed. As such, young scientists are very hard pressed, since their first steps as graduate students, to produce publishable results. Generally this leads to multiauthor papers where one or more graduate students appear together with their advisor and, maybe, other researchers in the authors' list.

3. It is our impression, though this may require further substantiation, that many scientists nowadays are prepared to work within research teams and not quite to undertake independent creative thinking. The widespread use of computers and other very sophisticated equipment has all but deepened this trend. This class of researcher is what *Price*[3] called the *fractional author*, i.e. the scientist that produces the n^{th} part of a scientific paper. Furthermore, funding agencies put strong constraints on personal choices of research by favoring certain well-defined problems deemed of high priority. These sociological aspects of modern science led *Ziman*[11] to raise the question: "Should scientists be regarded as members of a trasnational community devoted to the 'search for truth', or are they simply typical employees of governmental and commercial organizations with very worldly aims?". Such scientists, either fractional authors or employees, may greatly contribute to multiauthor papers.
4. The revolution in communication has made contact among scientists from different places very easy. Traveling is now not only cheaper and faster, but e-mail allows scientists to keep in touch daily without having to actually displace. Therefore, planning common projects among scientists located in different places is now a much easier task. The revolution in communication has fostered international cooperation at an unprecedented scale. In this regard *Abt*[6] has found a strong change toward multinational authorship in the major astronomical journals worldwide since around 1970, in such a way that about one-quarter of all the papers published there are nowadays the result of multinational collaboration. In a sense, this has also contributed to the increase in the number of collective papers in which the authors come from different institutes and countries.
5. Last but not least, there is a disturbing question that transcends the boundaries of purely institutional or technological changes, as an explanation of collectivization, to become a major epistemological issue. The question is: Is the growing collectivization in part a response to the need to solve increasingly complex problems? Are we reaching the point in which a single individual is no longer capable to strike upon a major scientific discovery? This question applies not only to Astronomy, but also to the other natural sciences. The individual scientist is giving way to a pool of brains, working in parallel, to try to solve a certain very complex problem.

Major scientific discoveries used to be closely associated to great scientists and philosophers: the heliocentric system to Copernicus, the telescope and classical mechanics to Galileo, gravitation to Newton, the origin of the species to Darwin, relativity to Einstein, to give just a few examples. We might be entering a stage of faceless science where a major discovery will not result from the perseverant work of an outstanding scientist working in his or her personal laboratory, but will be to the credit of a research team, probably with ramifications in several institutes at a national and international level, and with access to a major international facility. For instance, Karl Jansky, the father of radioastronomy, could work alone in his backyard with a radiotelescope that costed US$ 1000. Nowadays, a major radioastronomical facility like Arecibo will cost about US$ 150 million. It is very likely that the observing time in such a large facility and later publication of results will be shared by a team of several people.

Collectivism can manifest itself in other aspects of scientific life beyond multiple authorship: at the beginning of the century most Nobel prizes in scientific disciplines (physics, chemistry, and physiology or medicine) were awarded to a single person (an average of 1.2 awardees per discipline for the period 1900-1930), whereas the average has risen to about two at present. While one may argue that the interpretation of this phenomenon is ambiguous (one can invoke, e.g., changes of criteria of the Nobel committees), one can also argue that it responds to the fact that most major scientific discoveries are now the cooperative effort of several people (working together or separately), so the award must be shared by more than one person (bear also in mind that rules do not allow the Nobel prize to be awarded to more than three people in a given discipline, imposing in practice a ceiling to the increasing average number of awardees per discipline).

If collectivism is a new step to gain access to increasingly complex problems, one may wonder if our capability to learn new things can go on forever; in other words, if the realm of natural phenomena accessible to man's comprehension is limited and therefore exhaustible. "Are there finite limits to scientific understanding, or are there endless horizons?" asked Bentley Glass, retiring president of the American Association for the Advancement of Science, in his presidential address more than 25 years ago.[9] He seemed to answer himself when he stated: "There are still innumerable details to fill in, but the endless horizons no longer exist." Later *Harwit*[12] discussed our progress in the discovery of new cosmic phenomena and speculated about how much can still be left for discovery. More recently, in a provocative book *Horgan*[13] has addressed the same issue arguing that sooner or later (perhaps sooner in some fields of the natural sciences) mankind will meet insurmountable barriers beyond which only those unfathomed ultimate questions will be left. Surely, it would be very daring to claim that a given field of knowledge is closed. This probably belongs to the category of ultimate questions that we will never be able to answer with certainty. There will always be the latent possibility of dramatic breakthroughs, previously totally unforeseen. Nevertheless, it is quite possible that every new revolutionary discovery will require the input of an increasing number of people and resources. "The further we have advanced on the accelerating curve (of growth), the closer we inevitably come to the time when limiting factors will curb the growth and bring it into some degree of stasis, or equilibrium, or possibly decline", added *Glass* in the above mentioned presidential address. Under this perspective, collectivism in science (and, therefore, in the scientific papers that bring its results) can be understood as a new (and perhaps the last) attempt of humanity to go even deeper in our understanding of the microcosmos and macrocosmos.

The reasons explaining why science has gone collective are then quite different in nature. Some of them may be circumstantial as, for instance, the availability of a large pool of graduate students for research. This plentifulness may disappear if budgets for research become very tight. Yet, the growing complexity of science is a permanent feature (unless civilization were obliterated and the clock of scientific discoveries had to be reset) suggesting that collective science really represents a turning point in the development of the scientific enterprise, as important as the scientific revolution of the seventeenth century.

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