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Economic Power, Population, and Size of Astronomical Community

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Abstract: It is known that the number of astronomers of a country registered to the International Astronomical Union (IAU) is correlated with that country's gross domestic product (GDP). However, the robustness of this relationship could be doubted, as the fraction of astronomers joining the IAU differs from country to country. Here we revisit this correlation by using more recent data, updated as of 2017. We find a similar correlation by using the total number of astronomers and astrophysicists with PhD degrees that are working in each country, instead of adopting the number of IAU members. We confirm the existence of the correlation. We also confirm the existence of two subgroups within this correlation. One group consists of advanced European countries having a long history of modern astronomy, while the other group consists of countries having experienced recent rapid economic development. In order to determine the cause for the correlation, we obtained the long-term variations of the number of astronomers, population, and the GDP for a number of countries. We find that the number of astronomers per capita for recently developing countries has increased more rapidly as GDP per capita increased, than that for fully developed countries. We collected demographic data of the Korean astronomical community and find that it has experienced recent rapid growth. From these findings we estimate the proper size of the Korean astronomical community by considering Korea economic power and population. The current number of PhD astronomers working in Korea is approximately 310, but it should be 550 in order for it to be comparable and competitive to the sizes of the Spanish, Canadian, and Japanese astronomical communities. If current trends continue, this number will be reached by 2030. In order to be comparable to the German, French, and Italian communities, there should be 800 PhD astronomers in Korea. We discuss ways to overcome the vulnerability of the Korean astronomical community, based on the statistics of national R&D expenditure structure in comparison with that of other major advanced countries.

Key words: sociology of astronomy — methods: data analysis — methods: statistical

1. Introduction

The scientific curiosity of human beings has long been due to the wonders of the universe, which has motivated intelligent people to develop modern astronomy into being one of the most fascinating subjects in the world today. Being a pure science, the size of the astronomical community of a country can be used as a measure of the scientific development of the country. It is of great interest to governments, as well as scientific communities, to gauge a nation's position among the international science communities. Thus, by analyzing other astronomical communities, some insight can be gained.

There have been a large number of previous studies on the relationship between economic capability and scientific research output, in either quantitative or qualitative aspects. For example, May (1997) analyzed the scientific output of several countries, based on the Science Citation Index established by the Institute for Scientific Information. They found large differences in the performance of nations. This was ascribed to differences in the nature of the institutional settings between Germany/France and the UK/USA/Scandinavian countries. They stressed that the latter performed better because of their heritage of non-hierarchical work cultures and continuous stimulation from young researchers. A similar approach on this topic was taken by King (2004), Moed (2005), and Hohmann, Glatt, & Tetsworth (2017), who performed bibliometric analyses of publication and citation rates.

The NASA Astrophysics Data System (ADS) abstract service was first demonstrated in 1992 and was made available for general use in 1993. This system is widely used in the international astronomical communities, and so provides the best data for bibliometric research. Kurtz et al. (2005) analyzed NASA ADS query data in detail. They made several observations. First, when we consider the research intensity rather than total volume, the largest per capita users of the ADS are not the USA or other large communities, but France and the Netherlands. Second, they found that while the difference in per capita income between the richest and poorest countries is a factor of ten to fifteen, the difference in per capita ADS use reaches roughly a factor of three hundred. Lastly, eastern European

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Table 1

GDP per capita, populations, and number of astronomers registered with the IAU.

No.	Country	GDP/cap. USD	Population million	IAU members	No.	Country	GDP/cap. USD	Population million	IAU members
1	USA	59,495	326.6	2,824	31	China	8,583	1,379.3	663
2	Japan	38,550	126.5	728	32	Taiwan	24,227	23.5	75
3	France	39,673	67.1	856	33	Argentina	14,061	44.3	148
4	Germany	44,184	80.6	654	34	Australia	56,135	23.2	328
5	India	1,852	1,281.9	281	35	Austria	46,436	8.8	64
6	Indonesia	3,859	260.6	17	36	Belgium	43,243	11.5	145
7	Iran	5,252	82.0	40	37	Brazil	10,020	207.4	204
8	Israel	39,974	8.3	97	38	Canada	44,773	35.6	307
9	Italy	31,619	62.1	670	39	Chile	14,315	17.8	115
10	Kazakhstan	8,585	18.6	10	40	Czech Rep.	19,818	10.7	125
11	Korea, DPR	1,360	25.2	18	41	Denmark	56,335	5.6	90
12	Korea Rep.	29,730	51.2	158	42	Egypt	3,685	97.0	67
13	Mexico	9,249	124.6	147	43	Finland	45,693	5.5	80
14	Mongolia	3,553	3.1	6	44	Norway	73,615	5.3	41
15	Netherlands	48,272	17.1	228	45	Romania	10,372	21.5	33
16	New Zealand	41,629	4.5	35	46	Serbia	5,600	7.1	51
17	Poland	13,429	38.5	162	47	Slovak Rep.	17,491	5.4	46
18	Portugal	20,575	10.8	69	48	Venezuela	6,850	31.3	22
19	Russian Fed.	10,248	142.3	436	49	Uruguay	17,252	3.4	5
20	Greece	18,945	10.8	121	50	Algeria	4,225	41.0	2
21	Hungary	13,460	9.9	72	51	Armenia	3,690	3.0	28
22	South Africa	6,089	54.8	122	52	Azerbaijan	4,098	10.0	10
23	Spain	28,212	49.0	378	53	Bulgaria	7,924	7.1	67
24	Sweden	53,248	10.0	145	54	Colombia	6,238	47.7	27
25	Switzerland	80,837	8.2	138	55	Estonia	19,618	1.3	33
26	Thailand	6,336	68.4	33	56	Ireland	68,604	5.0	50
27	Turkey	10,434	80.8	80	57	Malaysia	9,660	31.4	10
28	Ukraine	2,459	44.0	152	58	Nigeria	2,092	190.6	10
29	UK	38,847	64.8	724	59	Philippines	3,022	104.3	5
30	Vietnam	2,306	96.2	13	60	Singapore	53,880	5.9	2

Exceptionally, the GDP per capita of the Democratic Peoples Republic of Korea (North Korea) is not provided by the IMF or the World Bank. Thus we choose the figure of 1,360 USD estimated by Statistics Korea of the government of the Republic of Korea. The GDP per capita for Egypt is also not provided for the year 2017, and so we used the value from the year 2016.

countries perform efficient astronomical research by using the ADS system, which means that GDP is not a proper measure of the wealth of nations when they are undergoing substantial economic and political changes. Henneken & Kurtz (2019) introduced reading activity or query frequency to the ADS in order to attempt to quantify research efficiency, in addition to traditional bibliometric indicators, like publications and citations.

We concur with the idea that astronomy can be regarded as a proxy for all basic sciences because there is no applied astronomy, as was pointed out by Kurtz et al. (2005). Testing this approach is beyond the scope of this paper. However, if we make this assumption, we will only focus on the astronomical community rather than consider the entire scientific community. Additionally, we will not consider bibliometric data, which usually indicate the output or performance of research activities. Instead, in this paper, we will concentrate on traditional indicators such as the number of astronomers and GDP, in either volumes or intensities. We note that this work is meaningful because we use the most recent available data and include time series data that trace the developments of the last 30 years.

2. DATA

One potential indicator for characterizing astronomical communities is the number of astronomers registered to the International Astronomical Union (IAU). It is known that this number is correlated with the gross domestic product (GDP), which is often regarded as an indicator of economic power (Hearnshaw 2001, 2006; Ribeiro et al. 2013). However, the percentage of astronomers joining the IAU varies from country to country. Thus, we need to consider the full volume of the astronomers in this paper.

We adopt the GDP per capita, the GDP purchasing power parity (PPP) in current United States Dollars (USD), and populations as of the year 2017 provided in the World Bank database.[1] The number of IAU members for each country is obtained from the statistics published by the IAU.[2] Table 1 shows the number of IAU members, the GDP per capita, and population for each country.

[1] The World Bank national account data, and OECD National Accounts data files (data.worldbank.org)

[2] International Astronomical Union, Geographical and Gender Distribution of Individual Members (iau.org)

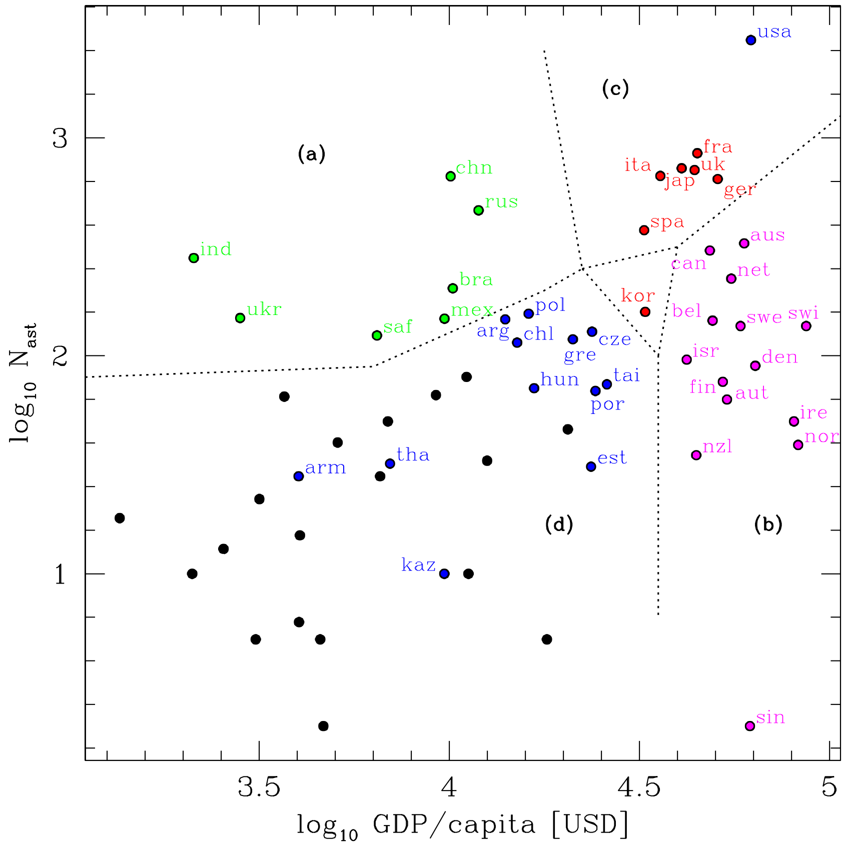

Figure 1. GDP per capita versus number of IAU members. The dotted lines distinguish the BRICS countries denoted by green points in partition (a), the rich but relatively less populous countries denoted by magenta dots in partition (b), the developed and populous countries in Europe denoted by red dots in partition (c), and developing countries denoted by black dots in partition (d). The three-letter-codes represent the country names. Exceptionally, "nkr" represents the Democratic Peoples Republic of Korea (North Korea), while "kor" represents the Republic of Korea (South Korea). "Chn" represents the Peoples Republic of China, while "chl" represents Chile. "Nzl" stands for New Zealand.

3. Results

3.1. GDP vs. IAU members

First, we plot the number of IAU members versus the GDP per capita in Figure 1 to see that there are several groups of countries: BRICS countries,[3] rich but less populous countries, developing countries, and rich and populous countries. It is noteworthy that the Republic of Korea, denoted by "kor", is positioned at a crossroads in between the groups.

In order to observe the correlation between economic power and size of astronomical community by country as a whole, the GDP and the number of IAU members are plotted in Figure 2. We confirm that the number of IAU astronomers in developed countries correlates with the national GDP. Interestingly, the correlation in Figure 2 is branched into two groups, which are represented by the two dashed trend lines. We find that Kurtz et al. (2005) performed a similar analysis for the data as of the year 2000 and also found the two branches, which are separated by a factor of three along the GDP axis. We reach the same result, but our results are obtained by using approximately-twenty-year-more-recent data. Note that the axes of our Figure 2 is inverted comparing with their Figure 5. From least-square fits to two data branches, we find best-fit lines $y = 0.91x - 8.59$ for the upper and $y = 0.82x - 7.78$ for the lower group of data. Here $x \equiv \log_{10} GDP$ and $y \equiv \log_{10} N_{ast}$, where N_{ast} is the number of astronomers. These correspond to a separation of the two branches by a factor of 2.2 to 2.6 times along the GDP axis. We believe that this factor is in rough agreement with the factor of three given by Kurtz et al. (2005). However, it is not clear if there have been any changes in the trends within the two branches over the last twenty years.

Kurtz et al. (2005) also found that 31 European countries were located on the upper branch while only three on the lower branch, and that seventeen Asian countries were located on the lower branch. However, they did not take into account Latin American countries such as Mexico and Brazil, which can be seen in Figure 2 of this paper and in their Figure 5. Kurtz et al. (2005) interpreted the polarization as being due to cultural differences between western and eastern nations, in terms of support for basic science. Partially we agree with that opinion. However, we think that it would be proper to ascribe the polarization at least partially to the different economic development stages of those countries.

The GDP per capita represents the average economic living standard of an individual citizen, and the number of IAU members per inhabitant indicates how much an individual citizen enjoys astronomy or is influenced by astronomical knowledge. We plot the GDP per capita and the number of IAU members per inhabitant in Figure 3. We can see that developed countries usu-

[3]BRICS: Brazil, Russia, India, China, and South Africa.

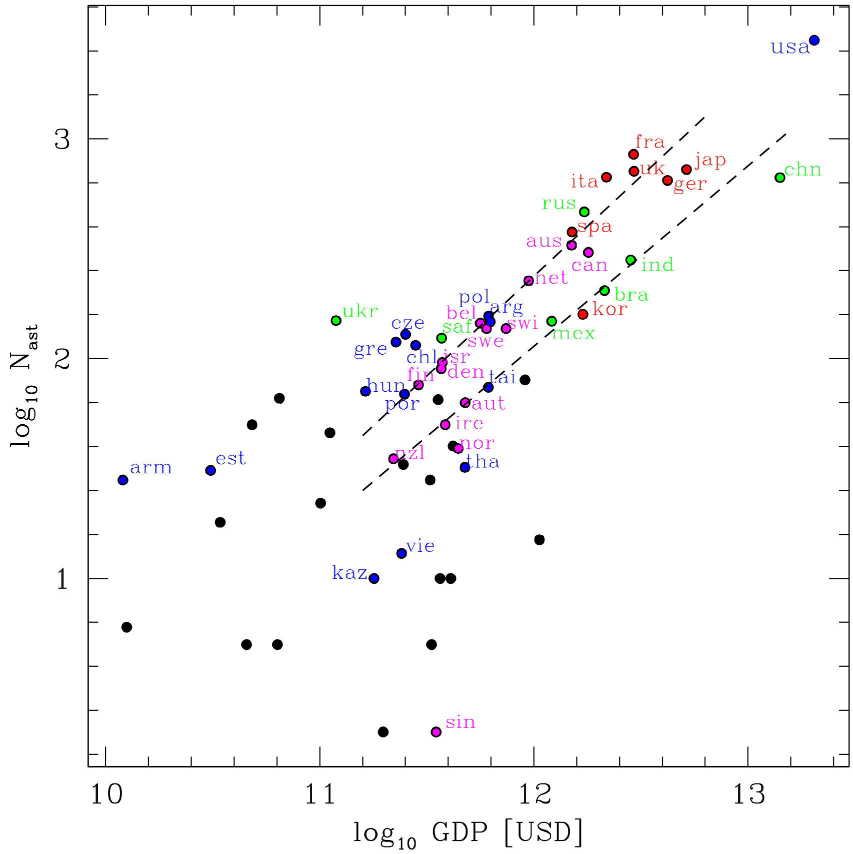

Figure 2. GDP and number of IAU members, showing a correlation between economic strength and size of astronomical community. The colors have the same meaning as in Figure 1. Two branches of correlations exist. The countries belonging to the upper branch have relatively long histories of modern astronomy and are developed economies, while those belonging to the lower branch have relatively short histories of modern astronomy and are relatively less-developed economies.

ally have approximately one astronomer per 100,000 inhabitants, while the so-called BRICS countries, marked with green dots, have approximately one astronomers per million inhabitants. We confirm that there is a rough correlation between GDP per capita and number of IAU members per citizen. As was also noted in previous studies (Hearnshaw 2001, 2006), there are a number of outliers. For example, Estonia is located far from the correlation in Figure 3, meaning that the country has a relatively large number of astronomers compared to their GDP per capita. Other outliers such as Korea, Taiwan, Japan, Austria, and Norway have a relatively small number of astronomers compared to their GDP per capita values. In Figure 3 we can roughly see the existence of two branches within this correlation. However, the constituent countries for the two branches do not coincide with those seen in Figure 2.

3.2. Enumeration of Astronomers by Country

As is mentioned above, the percentage of astronomers that have joined the IAU varies from country to country. Hence, in order to overcome this limitation, we need to count the total numbers of doctoral astronomers working in each country instead of just adopting the IAU members. We try to include astronomers, astrophysicists, and even physicists who study cosmology, high energy astrophysics, or astroparticle physics. However, engineers and technicians engaged in the development of instruments are not included in this paper, despite their important contribution to astronomical research.

Some countries like the United States[4] (Pold & Ivie 2017), the United Kingdom (Massey et al. 2017; McWhinnie 2017; Murdin 2012), Germany,[5] Spain (Barcons 2007; Gorgas 2016), and Canada[6] provide useful results of demographic surveys in either their long-term plans or annual reports, which can be used for

[4] We also collect data from the Astronomy and Astrophysics Survey Committee, *Status of Profession, in Working Papers: Astronomy and Astrophysics Panel Reports*, 321–325, National Academy Press, 1991 (nap.edu); the National Research Council, *Federal Funding of Astronomical Research – chapter 4: Demographics*, 16–20, National Academy Press, 2000; and the American Astronomical Society (aas.org).

[5] Deutsche Forschungsgemeinschaft 2003, *Status und Perspektiven der Astronomie in Deutschland 2003–2016*, ed. Burkert, A., Genzel, R., Hasinger, G., Morfill, G., Schneider, P. Koester, D., 229–230, WILEY-VCH Verlag (dfg.de); Redaktionskomitee des Rats deutscher Sternwarten 2017, *Denkschrift 2017, Perspektiven der Astrophysik in Deutschland 2017–2030: Von den Anfängen des Kosmos bis zu Lebensspuren auf extrasolaren Planeten*, ed. Steinmetz, M., Brueggen, M., Burkert, A., Schinnerer, E., Stutzki, J., Tacconi, L. Wambsganss, J. & Wilms, J., 25–31, Astronomische Gesellschaft (denkschrift2017.de).

[6] Canadian Astronomical Society 2011, *Unveiling the Cosmos: a Vision for Canadian Astronomy – Report of the Long Range Plan 2010 Panel*, 13 & 83 (casca.ca); Canadian Astronomical Society 2015, *Unveiling the Cosmos: Canadian Astronomy 2016–2020, Report of the Mid-Term Review 2015 Panel*, 104–106, (casca.ca); Racine, R. *The evolution of astronomical and astrophysical populations in Canadian Universities*, which provides statistical data for the results of the five astronomical and astrophysical censuses for the years of 1999, 2004, 2007–08, 2009-10, and 2013–14 (kcvs.ca).

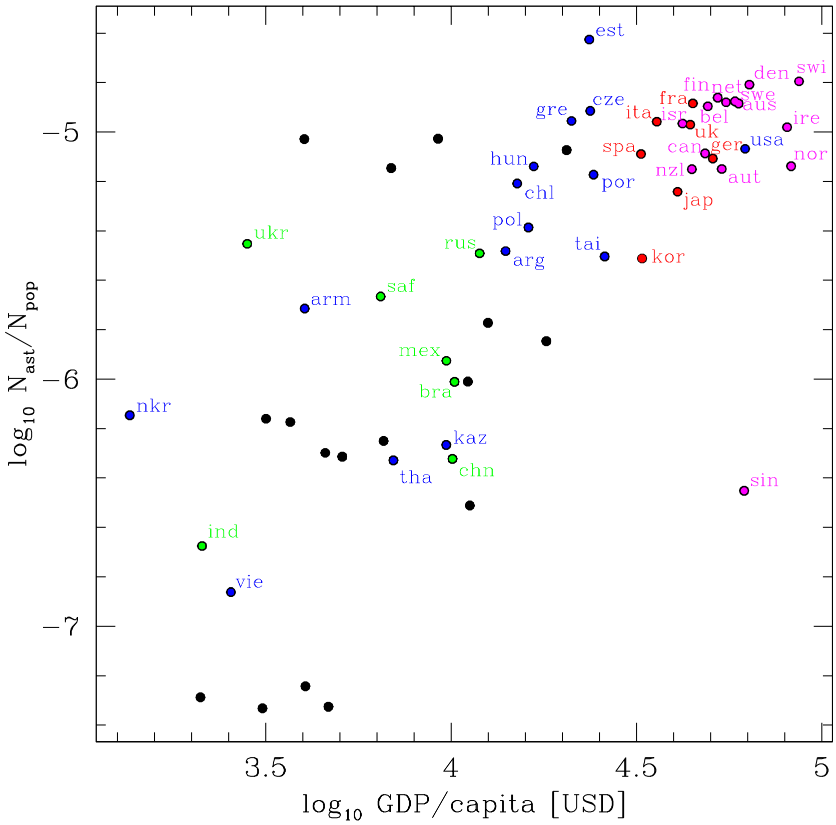

Figure 3. GDP per capita and the number of IAU members per inhabitant. Colors and country codes are the same as in Figure 1. There is indication of two correlation branches for the countries with relatively large GDP per capita.

making estimates.

We obtained the statistics for Germany from Denkschrift 2003 and 2017, especially Table 2.2 of Denkschrift 2017, published by the German Astronomical Society. However, the German academic ranking system is complex and therefore its equivalence is confirmed by M. Steimetz (priv. comm.). The Japanese astronomical community provided the results of demographic surveys in the long-term plan[7] (Sawa 2000), and we also take into account the member statistics in the Bulletins of the Japanese Astronomical Society.[8] The number of astronomical scientists working in France as of 2003 was given by Mamon (2003), and the numbers as of 2018 are estimated by G. A. Mamon (priv. comm.).

The number of professors working in Korean universities is given in the long-term plan produced by the Korean Astronomical Society (Lee et al. 2017). The number of astronomers in the Korea Astronomy and Space Science Institute is obtained from their internal data,[9] and similar data for the universities are obtained by inspecting the Bulletin of the Korean Astronomical Society.[10]

The astronomical community of the Netherlands is composed of mainly four organizations (Boland & Habing 2013): NOVA,[11] ASTRON,[12] SRON,[13] and JIVE.[14] We counted only doctoral scientists directly from their web sites. In particular, the number of scientists in ASTRON at the end of 2017 was checked via private communication[15] which gives a result consistent with our estimate.

The Italian astronomical community has a structure similar to the Korean one. The astronomers are working in either the Instituto Nazionale di Astrofisica (INAF in abbreviation) or within 25 universities, and the number of PhD scientists in 2012 was reported by Sciortino (2013). It is reasonable to assume that the number of astronomers in universities has not changed much. We can find detailed demographic information in the Astro-Dip database[16] from which we can count the numbers of doctoral astronomers and astrophysicists working in INAF.

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[7]Science Council of Japan, Physics Committee, Astronomy and Space Physics Subcommittee 2010, *Prospects and Long-term Planning of Astronomy and Astrophysics*, 14 (`scj.go.jp`)

[8]Astronomical Society of Japan 2016, Annual Reports (`asj.or.jp`).

[9]Human Resources Team of Korea Astronomy and Space Science Institute, 2018, private communication.

[10]The relevant annual reports have been published in the Bulletin of the Korean Astronomical Society 1990–2018. For example, see Korean Astronomical Society (2018).

[11]Nederlandse Onderzoekschool Voor Astronomie (`nova-astronomy.nl`)

[12]Netherlands Institute for Radio Astronomy (`astron.nl`)

[13]Member list of each group (`sron.nl`)

[14]Joint Institute for VLBI ERIC (`jive.eu`)

[15]Steenbergen, A. 2018, private communication: "At the end of 2017, ASTRON employed 20 scientists (excluding R&D engineers) on a permanent basis, and 28 scientists on fixed-term contracts. At the end of 2016, these figures were 14 and 31, respectively."

[16]Astro-Dip Anagrafica dipendent, Database H1-HRMS (`ced.inaf.it`)

Table 2
Total numbers of astronomers and astrophysicists, populations, GDP per capita, and GDP(PPP) per capita.

Country	Astronomers (A)	Population (B)	GDP/capita USD	GDP/capita (PPP) USD	PhDs/million (A)/(B)	IAU members (C)	Ratio (C)/(A)
USA	7,000	326.6	59,532	59,532	21	2,824	40%
Germany	1,400	80.6	44,470	50,639	18	654	47%
Japan	1,500	126.5	43,279	43,279	12	728	49%
UK	1,400	64.8	40,412	42,656	22	724	52%
France	950	67.1	38,477	42,850	14	856	90%
Italy	1,000	62.1	31,953	39,427	16	670	67%
Spain	555	49.0	26,617	36,305	11	378	68%
Rep. of Korea	310	51.2	29,743	38,335	6	158	51%
Taiwan	130	23.5	24,318	49,827	6	75	58%
Netherlands	390	17.1	45,638	52,503	23	228	58%
Canada	400	35.6	45,032	46,705	11	305	76%
Australia	530	23.2	62,328	46,743	23	328	62%

The populations and the GDP per capita are the same as in Table 1, while the numbers of astronomers and astrophysicist are counted or estimated for the entire astronomical community.

Similarly, the Taiwanese astronomical community provides a report of demographic investigation (Ip 2017), from which we make a list of institutions and universities and count the number of PhD scientists from their web sites. The number of doctoral astronomers in Australia was published by Sadler (2017), and the relevant information can also be found in a decadal survey report published by the Australian Academy of Science in 2015.[17] All these numbers are faithfully cross-checked with the relevant literature, but all procedures and more detailed descriptions are given in the Appendix section, and here we only show the data in Table 2.

In Table 2, we confirm our hypothesis that the percentage of IAU membership varies from country to country. With the data in Table 2, we draw Figure 4 and Figure 5 in a similar manner to Figure 2 and Figure 3. We find correlations similar to those in Figure 2 and Figure 3. Interestingly, we can roughly confirm the existence of two groups in the correlations. Those countries including Australia, the USA, Japan, Canada, Korea, and Taiwan can be grouped as countries experienced recent rapid economic growth, while the others have longer histories and have experienced recent more gradual growth of the economy.

In the previous studies that used IAU membership information, it was pointed out that Republic of Korea, Taiwan, Japan, Austria and Norway have a relatively small number of astronomers compared to their economic power (Hearnshaw 2006). This fact cannot be ascribed to the low fraction of astronomers who had joined the IAU, because the fractions for those countries were not so much different from the other countries. We note that countries such as Republic of Korea, Japan, Canada, Australia, and the USA have experienced relatively recent and rapid economic development in spite of their short history of modern astronomy, while the European countries have had a relatively long history.

We also investigate temporal variations of the number of astronomers for several countries. We see, in the upper panel of Figure 4, a general trend that the number of astronomers has increased with the same rate as their GDP growths, which is conspicuous for countries such as the UK, Germany, France, Spain, the Netherlands, and the USA. What is more interesting is that the number of astronomers per inhabitant for the advanced countries, such as Australia, the USA, and the UK, has been nearly constant for the last 30 years, as can be seen in the lower panel of Figure 4. Their GDP values and populations have nevertheless been increased for that period. Hence, the total number of astronomers has also increased as much. On the other hand, France, Spain, Italy, and Germany show the relatively rapid growth of astronomers in recent times. In particular, Germany shows quite a large increase in the number of astronomers per capita, which might be caused by the government-driven development of science after German reunification.

Until now we have adopted the GDP per capita in US dollars, which is just a nominal value. In order to compare living standards in a more realistic manner, we adopt the gross domestic product based on purchasing power parity or GDP(PPP). In Figure 5 we show the results obtained by adopting the GDP(PPP). Korea and Taiwan have relatively low living costs and so the GDP(PPP) values are larger than the nominal GDP values. Since the GDP(PPP) per capita values for these countries are larger, their living standards are nearly at a similar level to those of advanced countries. However, the numbers of astronomers, having PhD degrees and working in those countries, are relatively small as compared with those of advanced countries. This means that those countries need more investment on astronomy.

Based on the current number of astronomers per citizen of other advanced countries, we can estimate the proper number of astronomers that should be working

[17] Australian Academy of Science 2015, *Australia in the Era of Global Astronomy: the Decadal Plan for Australian Astronomy 20162025* (science.org.au)

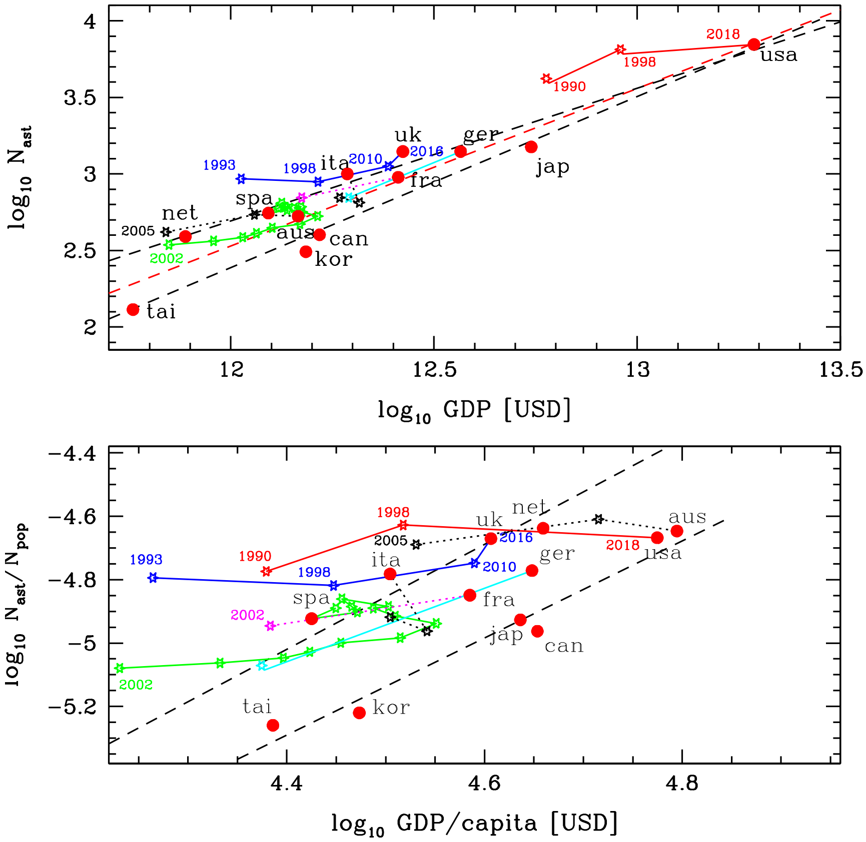

Figure 4. GDP and number of PhD astronomers. The *upper panel* shows the strong correlation of total number of astronomers with PhD degrees with GDP for a number of countries. Note that the countries having a relatively young history of modern astronomy show a correlation (lower black dashed line with a Pearson correlation coefficient $R^2 = 0.98$) that is slightly different from the correlation seen in the European countries that have a relatively long history of modern astronomy (upper black dashed line with a Pearson correlation coefficient $R^2 = 0.93$). The red dashed-line represents the linear regression for the entire dataset with a Pearson correlation coefficient $R^2 = 0.89$. Stars linked by lines represent the temporal variations of the relevant quantities, which follow these correlations. The *lower panel* shows the relationship between the GDP per capita and the number of astronomers per citizen. The existence of two groups is also apparent here. We see that most advanced countries show rather constant numbers of astronomers, while the numbers of Spanish, French, and the German astronomers increased with the national GDPs.

in Korea. In order for the Korean astronomical community to have comparable and competitive size to those of Spain, Canada, and Japan, the total number of astronomers working in Korea should be 550 as of 2018. If approximately 800 PhDs were working in Korea as of 2018, the Korean astronomical community would be comparable to those of Germany, France, and Italy. In order for the Korean astronomical community to be comparable to those of the USA, the UK, the Netherlands, and Australia, the total number of astronomers with PhD degrees and working in Korea should be approximately 1,000. However, since the current number of astronomers, with PhD degrees and working in Korea, is at most 310, the Korean astronomical community should be able to create a large number of additional jobs in the near future as soon as possible in order to carry out fundamental and cutting-edge research projects and lead creative and meaningful discoveries.

3.3. Korean Astronomical Community

It is now clear that the current size of the Korean astronomical community is by far smaller than those of advanced countries. Then, we need to investigate the history of the Korean astronomical community and its current status in order to define a problem and to look for solutions by estimating the adequate number of astronomers working in the country.

We collected demographic data mainly from previous issues of the Bulletin of the Korean Astronomical Society and complemented by the Bulletin of the Korean Space Sciences Society. Each member institution has reported their annual members and activities, and therefore we can trace the demographics back to the early 1990s. We grouped PhD into those with permanent positions, either in Universities or in research institutes, and those with non-permanent positions, either in contract positions or postdocs.

We display the data in Table 3, and see that temporal variations in the number of PhDs in Figure 6. We can see a rapid increase in the number of PhD astronomers in Korea over the last 30 years, which can be fitted with the function $N(t) = 2.35(t - 1990)^{1.46} + 35$. For permanent positions in research institutes, a government-supported national institute called KASI has dominated the increase, and its workforce outnumbered professors in the Universities after the year 2006 and has become three times larger as of 2018. We can see that the number of PhDs working in Korea can be extrapolated to be approximately 550 by the year 2030 if this increasing trend continues. The number density is comparable to the current number densities of astronomical communities such as Spain, Canada, and Japan.

4. CONCLUSIONS

In summary, we have found that the astronomical communities of countries around the world can be grouped into a several categories in the domain of the GDP per capita and the number of astronomers per citizen: i.e. large, populous, but less developed countries (or BRICS

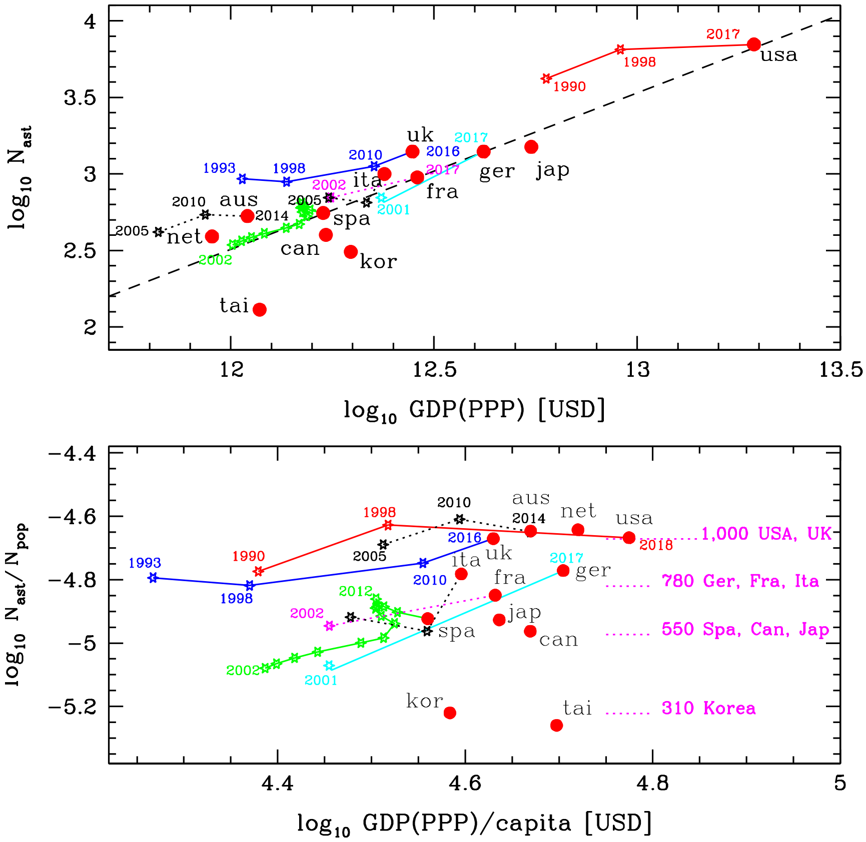

Figure 5. Purchasing power corrected GDP per capita and number of PhD astronomers. Same analysis as in Figure 4, but using the GDP based on purchasing power parity per capita (GDP(PPP)/capita) in order to account for differences in living standards between nations. The GDP(PPP) and the number of astronomers show a moderate – with a Pearson correlation coefficient $R^2 = 0.75$ – correlation. The correlation becomes stronger after excluding the Republic of Korea (South Korea), Taiwan, and Canada, with a Pearson correlation coefficient $R^2 = 0.93$. It appears that several countries, including the Republic of Korea, Taiwan, Canada, and Japan, have less astronomers and astrophysicists than expected considering their living standards.

countries); highly matured, populous, and highly advanced countries; less populous but highly developed countries; developing countries. The Korean astronomical community lies between them, which means that the Korean community is now at a crossroads of science development.

We have confirmed the correlation between the size of astronomical community and a country's economic power. Additionally, we confirm that the correlation for the countries having a long tradition of modern astronomy is slightly different from countries that have emerged later. This can be ascribed to the fact that some countries have experienced a recent economic development so rapidly that their pure science sectors could not yet have been supported and developed.

However, in general, a correlation may not imply causation. Hence, in order to investigate if any causation holds in this case, we assume that the larger economic capacity a country or their people have, the more supportive to astronomy they would be: that is, the number of astronomers working in that country must have been smaller in the past when the GDP of that country was lower. We obtained the temporal variation of the number of astronomers and the GDP values for a number of countries such as the United States of America, the United Kingdom, Germany, Australia, Spain, Italy, and France. From these statistics, we have found that the number of astronomers is generally an increasing function of GDP or time. We also found that the number of astronomers for countries that have experienced recent rapid economic growth, such as Germany, also show rapid increases, while the countries having a sufficiently developed economy, such as the United States, show a relatively slow increase or nearly constant number of astronomers per citizen. Thus, we conclude that the number of astronomers per citizen is a more important measure than other indicators in order to measure and estimate an adequate size of astronomical community.

Base on these observations, we have estimated that the proper number of astronomers working in Korea, considering GDP and population. We conclude that the Korean astronomical community could be competitive and comparable to those of Spain, Japan, and Canada if it had approximately 550 astronomers with PhDs; it could be comparable to the German, French, and Italian astronomical communities if it had approximately 800 astronomers with PhD degrees; and it could be comparable to the astronomical communities of the USA and the UK, if it had approximately 1,000 astronomers with PhD degree.

Subsequently, we have investigated the temporal variation of the size of the Korean astronomical community for the last 30 years. Although the community has experienced a rapid growth for the last three decades, the number of astronomers working in Korea is by far smaller than those of astronomers working in advanced countries when considering population and economic capability. The Korean astronomical community will be able to reach the capability of communities such

Table 3
Temporal evolution of the number of astronomers and astrophysicists working in the Republic of Korea.

Year	Universities		Institutes (mostly KASI)			Sum		
	perm.	temp.	perm.	contract	PDF	perm.	temp.	total
1990	24	7	8	0	0	32	7	39
1992	25	0	10	0	0	35	0	35
1994	42	3	16	0	0	58	3	61
1996	43	4	20	1	0	63	5	68
1999	50	14	25	4	0	75	18	93
2000	46	20	27	5	0	73	25	98
2001	51	21	33	7	1	84	29	113
2002	49	17	38	6	0	87	23	110
2003	59	23	44	17	4	103	44	147
2004	59	39	52	13	2	111	54	165
2005	60	33	59	9	7	119	49	168
2006	64	28	64	10	5	128	43	171
2007	65	20	77	9	14	142	43	185
2008	67	30	78	7	11	145	48	193
2009	70	22	81	17	19	151	58	209
2010	78	19	85	29	22	163	70	233
2011	77	29	91	39	26	168	94	262
2012	79	37	97	35	14	176	86	262
2013	77	46	105	56	20	182	122	304
2014	75	57	117	55	14	192	126	318
2015	77	51	127	56	8	204	115	319
2016	77	44	129	56	10	206	110	316
2017	82	42	138	38	6	220	86	306
2018	86	50	147	20	7	233	77	310

Data are from the Bulletin of the Korean Astronomical Society. Positions are categorized as permanent or temporary; for non-university institutes, temporary positions are subdivided into contract positions and postdoctoral fellowships (PDF).

as Spain, Canada, and Japan, if it grows at a similar rate for the next decade.

There are some problems related with our results, which must be solved in order to achieve a high level of astronomical science in Korea. One problem is that more astronomers of the baby-boomer generation will retire during the next decade than the last decade. However, there are only a few institutions that can produce PhDs. The current rate of PhD production in Korea is at most 10 PhDs per year (Lee et al. 2017), including both domestic and abroad. However, we need to at least double-to-triple rates in the next decade, when considering the retirement rate. In spite of the circumstances, there are only 7 Universities having departments of astronomy and each of them is small in size. Another problem is the Korean education system. The number of professors that deliver astronomical knowledge to teachers has not grown as much as those teaching professional astronomers, which is also shown in Figure 5.4 of page 68 of Lee et al. (2017). In other words, the number of professors in Universities of education has not increased to the necessary level. In fact, the number is nearly flat in recent years. Thus, astronomical knowledge cannot be delivered to young students in elementary to high schools. Moreover, astronomy classes are not widely taught in a majority of universities except for the few Universities having astronomy-related departments. Thus, public understanding of astronomical knowledge is not so high in Korea. Surely, this situation will eventually affect the procedures to decide the science policy, because the Republic of Korea is a democratic country.

Another problem is that there are few opportunities for middle and high school students to do experiments in person during their school days. The students spend too much time preparing for entrance examinations for university. The same is true among the undergraduates, to say nothing of the decreasing number of undergraduate studying science and engineering these days. Research institutes are not immune from these trends. The experimental parts of the institutes are relatively weak, also. Although in this study we have only considered the numbers of astronomers and astrophysicists with PhD degrees, it is noteworthy that there should be engineers and technicians as much as scientists that are carrying out astronomical studies in order to form a healthy ecosystem of scientific research.

We will now consider the R&D policy of the Korean government. It is well known that the Republic of Korea (South Korea) spends large amounts from its budget for supporting the science and technology sector. According to a KISTEP[18] statistics brief and the press release by the Ministry of Science, Technology, and ICT in July 2018 (Lee & Kim 2018), the total amount of Koreas R&D investment reached 78.8 trillion won (69.73 billion USD) in 2017, up more than 13.5% from that in 2016. The South Korean R&D ex-

[18]Korea Institute of S&T Evaluation and Planning

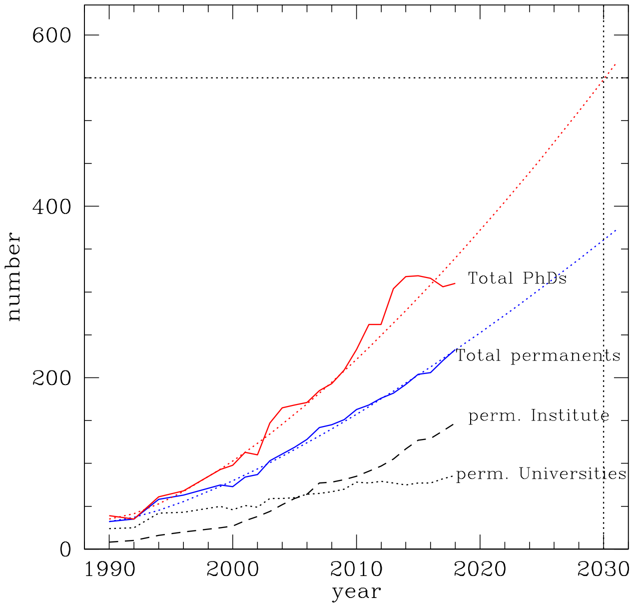

Figure 6. Temporal evolution of the number of astronomers in Korea over the last 30 years. The number of astronomers working on permanent positions in research institutes has increased faster than that of professors in universities; the sum of these two categories is the total number of permanent positions. Adding postdoctoral and contract positions gives the total number of PhD astronomers. If this trend continues, the number of PhD astronomers working in Korea will reach 550, which corresponds to the current size of astronomical communities of Spain, Canada, and Japan, by the year 2030.

penditure ranks fifth among OECD member countries after the United States, China, Japan and Germany. What is more interesting is that South Koreas ratio of expenditure on R&D to the GDP was 4.55% in 2017, higher than that of Israel at 4.25%. A similar statistics as of 2015 can also be found in the Tables 4–5 in the Science and Engineering Indicators 2018 published by NSB (2018), which suggests there has been continuous support for the Korean science and technology sector by both the government and private companies in recent years.

Then, what makes the pure-science sector represented by astronomy so vulnerable in Korea? We see, in the survey presented by the Korean government mentioned above, that the R&D sources, either from the government or from the private companies, are not so different from other countries like the USA, Japan, Germany, France, the UK, and China. In many ways, it seems that the Korean science policy has been benchmarked to that of Japan, as well as the USA.

One may ask if Korean astronomers spend less money than astronomers in other advanced countries. However, this is not the case. The R&D expenditure per FTE (Full-time equivalent) in Korea is 182 thousand USD per year (see Figure 3 on page 4 of Lee & Kim 2018). As of 2018, the Korean astronomical community has approximately 240 astronomers with permanent positions, as we have shown in Table 3, and they spend roughly 45 million USD per year. Hence, the R&D expenditure per FTE per year is approximately 190 thousand USD per year. If we count all 310 PhDs, the R&D expenditure per FTE per year is approximately 150 thousand USD per year, which is slightly smaller but nearly as large as that of the UK.

There are two major differences in the Korean gross domestic R&D expenditure structures from those of advanced countries. First, the relative share of the pure/basic science sector has been decreasing, especially in the last 5 to 10 years (see Figure 11 on page 8 of Lee & Kim 2018). It is lower than the values of advanced countries such as France, the USA, and the UK (see Figure 12 on page 9 of Lee & Kim 2018.) Second, the expenditure for R&D personnel is less than that of other advanced countries such as Germany and France, but larger than that of Japan and China (see the Figure on page 10 of Lee & Kim (2018)). Maybe this is because labor costs are different from country to country. In other words, the labor cost in Korea is cheaper than those in advanced countries. This also means that the Korean government did not hire as many astronomers as they can hire with the same amount of budget in comparison with advanced countries. We have shown that the number of astronomers per citizen in Korea is too small to carry out outstanding research. The most urgent issue is to increase the number of scientists in the astronomy sector in order to match the size of advanced countries. We need a vision to make the country strong in basic science.

Perhaps one of the most persuasive justifications for investment in astronomy lies in the important role that astronomy has in making a society innovate in cutting-edge sectors of science and technology by stimulating the deep desire of human beings to understand the origin, existence, and fate of the cosmos and human beings. Historically, there are many examples that a societys support for purely curiosity-driven scientific research has led to technology advances that provided a long-term benefit to society. National investment in science is commonly viewed as an essential element of economic strength and competitiveness. These concerns and interests lead to popular support for maintaining the appropriately number of astronomers in their countries, and in order to realize such a consensus, a sufficient financial capacity is needed. Thus, we can see the correlation between the GDP and the number of astronomers, which can be a guideline for emerging and developing countries.

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Appendix A. Detailed description of Census by Country

USA. The 2016 demographic survey of the American Astronomical Society (AAS) showed that the entire AAS membership consisted of 61% full members, 21% junior members, 9% associate members, 9% emeritus, and 1% educational affiliates (Pold & Ivie 2017). According to the same survey of members with addresses in the United States, the percentage of respondents with doctoral degrees was approximately 80% (Pold & Ivie 2017). As of 2018, the number of AAS members is about 7,000.[19] Therefore, it is estimated that approximately 5,600 members of the AAS have PhD degrees. Moreover, there are about 1,000 astrophysicists who have exclusively joined the astrophysics division of the American Physical Society (APS), and there are also several hundred people who have not joined both societies. Thus, we estimate that there are approximately 7,000 doctoral astronomers or astrophysicists in the United States as of May 2018.

According to a survey by the National Research Council of the United States in 1998,[20] the AAS had 6,700 members as of 1998. When applying the ratio of doctoral members, 80%, in the year 2017 to the number of members in 1998, the number of doctoral members in the AAS as of 1998 is estimated to be around 5,400. The same investigation shows that the APS had around 1,600 members in astrophysics in 1998. One third of them joined both societies, and so there were about 1,070 additional researchers exclusively in the APS. Therefore, by combining both societies, it can be estimated that in 1998 there were about 6,500 astronomers and astrophysicists working in the United States. The Field Committee report in 1991 notes that the United States had a pool of nearly 4,200 astronomers in 1990, up by 42 percent since 1980 as seen in the caption of Figure 1 in the report.[21] Hence, there were about 3,000 astronomers around 1980.

Japan. In order to estimate the number of astronomers in Japan, we look up the membership of the Astronomical Society of Japan[22] (ASJ). The members of the ASJ are divided into full members, associate members, group members, and supporting members. Among the full members, there are student or graduate members who study astronomy or related disciplines. According to the 2016 Annual Report of the ASJ[23] as of March 31, 2017, there were 2,059 full members including 506 student members, and 1,105 associate members. A full member is defined as an individual who is engaged in astronomy and related fields and is responsible for the operation of the society.[24] In official documents that describe the long-term plan of the Japanese astronomical community, the number of full members is regarded as a proxy for the number of Japanese astronomers.[25] Therefore, the number of full members of the ASJ, excluding student members, is regarded as the number of PhD astronomers in Japan. The number for the year 2017 is approximately 1,500 persons.

We can obtain this number in another way. According to a survey of members of the ASJ published in January 2000 (Sawa 2000), 607 persons among 1,316 respondents were doctoral researchers. Assuming that this ratio did not change much afterwards, we find the current number of doctoral astronomers in Japan to be 1,500, estimated from the fact that there were 3,243 members in the ASJ as of March 31, 2017.[26]

United Kingdom. The Royal Astronomical Society (RAS) published the demographic characteristics of RAS members as of autumn 2016 (McWhinnie 2017). Table 2 of that report provides us with the number of staff members in astronomy and solar system sciences in 1993, 1998, 2010, and 2016. Thus, we can count the number of staff members in universities and research establishments with interests in astronomy, solar system sciences, and cross disciplinary, excluding technical/support staffs and visitors. From Table 1 of the report, we estimate the fraction of scientists working in cross disciplinary fields to be 10%. Thus, we find 1,000 scientists in 1993, 1,000 scientists in 1998, 1,200 scientists in 2010, and 1,400 scientists in 2016.

France. According to Mamon (2003), there were approximately 750 French scientists in the fields of astronomy and astrophysics as of 2002. Of those, 44% were working in the Centre National de la Recherche Scientifique (CNRS), 30% were in the Observatories, 19% were working in the Universities, and 7% were hired by other institutions. G. A. Mamon (priv. comm.) estimates approximately 800 full-time astronomers and astrophysicists in France, by extrapolating the net growth rate of tenure-track scientists and faculty: 15 posts per year from 1980 to 1987, 25 posts per year from 1988 to 2010, and 15 per year since 2011. In addition, by extrapolating the postdoc ratio of the Institut Astrophysique de Paris (IAP) to other institutions in France, the number of postdocs working in France is estimate to be 135. Hence, the number of doctoral scientists excluding engineers with PhDs is approximately 935. Including retired staff and others, we estimate that there are approximately 1,000 astronomers or astrophysicists working in France as of 2018.

Germany. A national member of the IAU on behalf of the German scientific community is the Rat

[19] American Astronomical Society (aas.org)

[20] National Research Council, Committee on Astronomy and Astrophysics, Board on Physics and Astronomy, Space Studies Board 2000, *Federal Funding of Astronomical Research*, 16–20, Washington D.C.: National Academy Press (nap.edu).

[21] Astronomy and Astrophysics Survey Committee 1991, *Status of Profession, in Working Papers: Astronomy and Astrophysics Panel Reports*, 321–325, Washington D.C.: National Academy Press (nap.edu).

[22] Astronomical Society of Japan (asj.or.jp)

[23] Astronomical Society of Japan, Annual Report 2016 (asj.or.jp)

[24] Astronomical Society of Japan, Regulations (asj.or.jp)

[25] Science Council of Japan, Physics Committee, Astronomy and Space Physics Subcommittee 2010, *Prospects and Long-term Planning of Astronomy and Astrophysics*, 14 (scj.go.jp).

[26] Astronomical Society of Japan, Annual Report 2016 (asj.or.jp)

Deutscher Sternwarten (RDS). According to Table 2.2 of Denkschrift 2017 or the 2017–2030 German Physics Development Plan published by the RDS,[27] there are approximately 2,674 persons working in astronomy in Germany including 556 technical staff and 706 graduates ("Promotion"). Considering the German academic ranking system,[28] we estimate that 1,412 doctoral astronomers and astrophysicists were working in the German scientific community as of August 2017. A demographic survey was also published in 2003.[29] Its Table 6.2 provides a numbers of 674 scientific staff members in German institutes as of 2001. Its Table 6.3 also gives numbers for 1962, 1987, and 1999. However, Germany was reunified on October 3, 1990, and so it is not certain whether the numbers include the east Germans or not. Hence, we adopt only the number 577 for the year of 1999, which is the sum of 375 scientists in *Planstellen* and 202 scientists in *Drittmittel*. It is remarkable that the number of astronomers and astrophysicists in Germany has increased rapidly during the 21st century.

Spain. According to a recent demographic survey for 50 research institutes in Spain, as of 2016, there were 391 professional astronomers, 210 postdocs, and 186 graduates in Spain (Gorgas 2016). In a presentation for *Segundo informe de los recursos humanos en Astronomia y Astrofisica en Espana*,[30] the number statistics of human resources from 2002 to 2016 are given, summarized in Table 4. We count the number of scientists classified as *Plantilla* (posts or staff members) and Postdocs and exclude the number of predoctors to obtain the number of PhDs. We find the number of doctoral astronomers or astrophysicists working in Spain to be 555 as of 2016.

Table 4
Evolution of the Spanish astronomy community.

	Plantilla	Postdocs	Predocs	Total
2002	233	112	130	475
2003	242	123	141	506
2004	251	134	159	544
2005	261	148	173	582
2006	279	166	190	635
2007	291	179	185	655
2008	306	224	209	739
2009	317	247	216	780
2010	320	280	216	816
2011	334	276	218	828
2012	348	297	229	874
2013	343	265	218	826
2014	341	241	214	796
2016	347	208	185	740

Data have been obtained from a presentation for *Segundo informe de los recursos humanos en Astronomia y Astrofisica en Espana*.

Italy. According to Sciortino (2013), scientists carrying out astronomical research in Italy were working either within the Instituto Nazionale di Astrofisica (INAF) or within research groups in about 25 universities, plus a small number of Italian Institute for Nuclear Physics (INFN) scientists working on astroparticle physics or related topics. He also said that these scientists were either permanent or temporary staff members, or junior, or senior postdocs. Thus, we can regard the number of these scientists as that of astronomers and astrophysicists with a PhD degree working in Italy. Sciortino (2013) reported that, as of June 2012, there were 450 staff scientists, 70 temporary staff members, and 270 postdoctoral researchers in INAF, and 95 professors, 73 researchers, 30 postdoctoral researchers, and approximately 90 graduates working in the universities (Sciortino 2013). Adding them all up, we estimated that there were 980 doctoral scientists working in the astronomical community of Italy as of June 2012. Sciortino (2013) also mentioned that there were 1,037 permanent staff employees in INAF as of 2005, and 540 among them were scientists or technicians, which is a slightly larger number than that of 2012. Assuming the numbers of both postdocs in INAF and doctoral scientists in universities have not changes substantially, we estimate the number of astronomers and astrophysicists working in Italy to be about 1,000 as of 2005.

According to the INAF database,[31] as of November 2018, the INAF has a total of 1,153 employees, with 745 persons being research personnel and 408 persons being technical or administrative personnel. There are 466 permanent staff researchers, 61 temporary staff researchers, and 271 postdocs or fellows. If we can assume the human resources in the universities did not change much, we can estimate the number of their researchers to be about 190. Hence we estimate that about 1,000 doctoral astronomers are working in Italy, as of 2018.

Republic of Korea. In the Republic of Korea (South Korea), approximately two thirds of doctoral astronomers are working in the Korea Astronomy and Space Science Research Institute (KASI), and the other one third is working in a few universities. As of November 2018, KASI has 147 full-time employees and 27 fixed-term researchers and postdocs with doctoral degree, including approximately 10 administrative staff

[27] Redaktionskomitee des Rats deutscher Sternwarten 2017, *Denkschrift 2017, Perspektiven der Astrophysik in Deutschland 2017–2030: Von den Anfängen des Kosmos bis zu Lebensspuren auf extrasolaren Planeten*, ed. Steinmetz, M., Brueggen, M., Burkert, A., Schinnerer, E., Stutzki, J., Tacconi, L. Wambsganss, J. & Wilms, J., 25–31 (denkschrift2017).

[28] Steinmetz, M. 2018, private communication: "The categories are roughly: W3/C4 represents full professors and directors, W2/C3 represents associate professors, AT/W1 represents assistant professors, E15 leaders of independent research groups, E13/E14/A13/A14 are scientists usually with a PhD degree, and *Promotion* are graduate students."

[29] Deutsche Forschungsgemeinschaft 2003, *Status und Perspektiven der Astronomie in Deutschland 2003–2016*, ed. Burkert, A., Genzel, R., Hasinger, G., Morfill, G., Schneider, P. Koester, D., 229–230, Bonn: WILEY-VCH Verlag (dfg.de)

[30] Sociedad Espanola de Astronomia, Evolucion del personal, in presentation: Segundo informe de los recurso humanos en Astronomia y Astrofisica en Espana (sea-astronomia.es).

[31] Astro-Dip Anagrafica dipendent, Database H1-HRMS (ced.inaf.it)

members with doctoral degrees, and 4 research fellows.[32] Thus, KASI has approximately 168 doctoral researchers. According to Bulletins of Korean Astronomical Society, as of April 2018, 76 full-time professors, 15 research professors, and 35 postdoctoral researchers are studying in the universities (Korean Astronomical Society 2018). About ten additional PhDs are counted in other research institutes, science high-schools, science museums, and private companies. Hence, we see that there are approximately 310 doctorate astronomers working in the Republic of Korea.

The Netherlands. According to a survey on the status of astronomy in the Netherlands (Boland & Habing 2013), as of 2012, the Dutch astronomers belonged to the Nederlandse Onderzoekschool Voor Astronomie (NOVA), the Netherlands instituut voor radioastronomie (ASTRON) dedicated to radio astronomy, Stichting Ruimte Onderzoek Nederland (SRON), and the Joint Institute for VLBI ERIC (JIVE). Since these four organizations provide member lists in their websites, we count the number of doctoral scientists there. We also visited some of the personal websites to check whether a specific person has a PhD degree.

As of 2018, four universities participate in NOVA: Amsterdam, Groningen, Nijmegen, and Leiden.[33] Amsterdam has 54 PhDs among 161 employees, 49 doctoral students and 45 master students. Groningen has 40 doctors among 93 employees and 11 PhD students. Nijmegen has 31 doctors among 68 employees, 21 doctoral students, and 8 master students. Leiden observatory has 116 PhDs among 450 employees, 89 doctoral students, and 90 master students. Thus, there are 241 doctors in NOVA as of 2018.

According to NOVA's 2015 annual report,[34] the NOVA members consisted of approximately 56 full-time equivalent (FTE) senior staff members in permanent and tenure-track positions, approximately 10 FTE senior postdocs, 83 FTE postdoctoral fellows, approximately 40 instrumentalists, 171 PhD students, and 5 FTE co-workers from ASTRON and SRON. Thus, the number of astronomers with PhD degrees involved with the NOVA program was approximately 150 as of 2015.

ASTRON has four groups: an astronomy group, radio observatory, R&D labs, and NOVA IR/Optical.[35] Excluding technical and administrative staff, ASTRON has 52 PhDs among 146 employees. According to a private communication with Anneke Steenbergen,[36] there were 48 scientists employed excluding R&D engineers, 20 having permanent positions and 28 having fixed-term contracts as of 2018, which is not significantly different from the direct counting from the web site. SRON has six subgroups: Earth, exoplanet, astrophysics, technology, instruments, and engineering groups.[37] It has 89 PhDs among 204 employees. JIVE has 10 doctors among 26 employees.[38] Hence, the total number of PhDs working in these three organisations is estimated to be 151 as of 2018.

If all being combined, it is estimated that there are approximately 390 doctoral researchers investigating astronomy and astrophysics in the Netherlands. There are also highly educated engineers working in the Dutch astronomical community as much as this number. It is also remarkable that the Netherlands host a couple of huge centers for astronomical researches and space exploration in Europe.

Canada. According to a survey by the Association of Canadian Universities for Research in Astronomy (ACURA), as of the year 2010, the Canadian astronomical community consists of 200 professor-level researchers, 100 postdocs, and 300 graduate students.[39] According to an updated survey of ACURA, as of 2013, the number of astronomers had increased by 17 professors, 37 postdocs, and 71 graduate students.[40] Thus, there were approximately 350 PhDs as of 2013, and the growth rate was only 3%. Adopting this growth rate, the number of doctoral astronomers is extrapolated to be approximately 400 as of 2018.

According to additional research,[41] the combined number of tenure stream faculty members, adjuncts and postdocs was 164 in 1999, 247 in 2004, 285 in 2008, 305 in 2010, and 341 2014. If we again apply the manpower growth rate of 3% and extrapolate, then we can estimate the number of PhD astronomers and astrophysicists working in Canada to be 410 as of 2018, which is close to the number estimated by the ACURA demographic survey. In conclusion, we estimate that the number of PhD astronomers and astrophysicists working in Canada is approximately 400.

Australia. The number of doctoral astronomers in Australia is given in Sadler (2017). According to them, the number of astronomy positions in Australia was 417 in 2005, 542 in 2010, and 527 in 2014. In 2014, the percentage of full-time astronomers was 64%, so the number of doctoral researchers is approximately 530, among which 340 are full-time astronomers.

Taiwan. In order to estimate the number of doctoral astronomers in Taiwan as of 2018, the professors, researchers, and postdoctoral researchers working in Taiwan's major astronomical institutes and universities, as mentioned in a paper on the history of Taiwanese astronomy (Ip 2017), were surveyed using the institutions' websites. The Institute of Astronomy of the National

[32] KASI human resources database
[33] http://nova-astronomy.nl/people/
[34] NOVA Annual Report 2013–2015 (nova-astronomy.nl).
[35] ASTRON astronomy group (astron.nl).
[36] Steenbergen, A., private communication: "At the end of 2017, ASTRON employed 20 scientists (excluding R&D engineers) on a permanent basis, and 28 scientists on fixed-term contracts. At the end of 2016, these figures were 14 and 31, respectively."
[37] SRON group member lists (sron.nl).
[38] JIVE staff list (jive.eu).
[39] Canadian Astronomical Society 2011, *Unveiling the Cosmos: a Vision for Canadian Astronomy – Report of the Long Range Plan 2010 Panel*, 13 & 83 (casca.ca).
[40] Canadian Astronomical Society 2015, *Unveiling the Cosmos: Canadian Astronomy 2016-2020, Report of the mid-Term Review 2015 Panel*, 104–106 (casca.ca).
[41] Racine, R., *The evolution of astronomical and astrophysical populations in Canadian Universities* (kcvs.ca).

Ting Hua University has 11 doctoral researchers, the National Taiwan University has 4 doctoral researchers, the National Taiwan Normal University has 8 doctoral researchers, the National Central University has 17 doctoral researchers, the Academia Sinica Institute of Astronomy and Astrophysics has 83 doctoral researchers, and the Academia Sinica Institute of Physics has 4 doctoral researchers working in Taiwan. Thus, the number of doctoral researchers working in astronomy and astrophysics in Taiwan is estimated to be approximately 130.

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