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Global Trends in Astrobiology Research: Bibliometric and Visualization Studies

R. Santhakumar

Arulmigu Kapaleeswarar Arts and Science College, Kolathur, Chennai - 600 099, Tamil Nadu

***Corresponding Author**
R.Santhakumar, Arulmigu Kapaleeswarar Arts and Science College, Kolathur, Chennai - 600 099, Tamil Nadu.

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Abstract
Astrobiology is an interdisciplinary scientific field composed of a range of subjects that have developed dramatically over the last few decades. However, there is little research on astrobiology from the perspectives of bibliometrics and visualization. The scientific research on the basic aspects of astrobiology itself is also rare. This study aims to comprehensively examine the astrobiology research field by conducting a bibliometric analysis if 1,848 publications between 2012 and 2021 from the Web of Science database. The findings showed that the USA, Germany, England and France are the most productive countries on astrobiology. Cockell, C S is the most influential author, and astrobiology researchers host universities are mainly from the USA, France and Germany. Articles appeared in 285 journals and were cited nearly 34300 times. Astronomy and astrophysics are the most preferred categories to publish based on Web of Science subject categories. The findings shows that field specialized journals were having publish high research as compared to multidisciplinary journals. Since the number of studies involved in this field has been found to be less, efforts should be undertaken to strengthen the research on astrobiology to explore the wide range of its applications. This article calls for greater engagements among researchers to more explicitly consider how their work might contribute to the understanding challenges in this field.

Keywords: Astrobiology, scientific productivity, collaboration, bibliometric analysis, vosviewer

Introduction

The development of new technologies in recent years has highlighted interdisciplinary as a tool to solve complex problems faced by scientists in research work. Worldwide, the area of space science and specifically astrobiology has high technological development. Astrobiology research has the potential to reconfigure many of our assumptions about the origins of life and the fundamental nature of reality. Science alone cannot answer the questions raised by astrobiology research; the humanities and social sciences also will play a key role. Astrobiology is an interdisciplinary scientific field concerned with the origins, early evolution, distribution, and future of life in the universe. The field of astrobiology has a wide range of possibilities and questions and is changing constantly. Astrobiology broken down is the study of life on earth and surrounding space. As the field of astrobiology has grown, there has been an increased need to train the next generation of astrobiology researchers and educators. Astrobiology concerns itself with interpretation of existing scientific data, and although speculation is entertained to give context, astrobiology concerns itself primarily with hypotheses that fit firmly into existing scientific theories.

Bibliometrics is a quantitative analysis of published academic literature on a particular topic. Based on citation counts that indicate the impact of a paper on the scientific community, it can conduct an in-depth evaluation of the literature and its references. This analysis is effective and convenient for assessing the productivity of authors, countries, and institutions; identifying geographic distributions and cooperative relations and development trends. Bibliometric analysis methods and tools have been developed to help researchers in different research fields. Bibliometrics is the cross-disciplinary science of quantitative analysis of all knowledge carriers by statistical methods. The most obvious advantage of the bibliometrics is that it allows researchers to study specific research area by analyzing citations and ggeographical distribution. Moreover, the visualization also can excavate valuable information by astrobiology and display it intuitively. With the continuous deepening of research on Astrobiology, especially in recent years, its research objects have also changed. More and more researches have begun to focus on the study of Astrobiology research.

Review of Literature

Explored the growth and degrees of collaboration and interdisciplinary in Origins of Life research using statistical analysis of science publications [1]. The study identified the most prolific authors, most cited articles, popular journals, and research trends. They also tracked the rise in OoL research in relation to factors such as the funding of astrobiology research by the NASA Astrobiology Institute, and mapped the increase in citations and connections between authors, institutions, countries, and keywords and concepts over time. Analysed a bibliometric investigation of the NASA astrobiology institute funded research was published between 2008 and 2012 [2]. The study creates an inventory of publications coauthored through NAI funding and investigates journal preferences, international and institutional collaboration and citation behaviors of researchers to reach a better understanding of interdisciplinary and collaborative astrobiology research funded by the NAI.

Attempt to analyse the pattern and trends of patent-based literature in Astronomy and Astrophysics retrieved from the SCOPUS database from a bibliometric stand point [3]. There are 293 patent-based published documents in the fields of astronomy and astrophysics. The examination of productivity by country/region, institution, and funding source revealed that the research landscapes in the United States, Germany, and Spain, in particular, are focused on the confluence of patent-based literature in astronomy and astrophysics. Investigated the intellectual structure of HSE research with a focus on human related factors [4]. A bibliometric approach with quantitative analytical techniques is applied to study the development and growth of the research. This study retrieves 1921 papers on HSE related to human factors from the year 1990 to the year 2016 from Web of Science and constructs a critical citation network composed of 336 papers.

Objectives for the Study

The main objective of this study is to analyze the global research output in patent-based research and literature in the field of astrobiology.

- To study the year wise growth of publications
- To study the most prolific authors
- To study the highly productive countries
- To study the highly productive institutes
- To study the most preferred source titles
- To study the high productive subject areas

Data and Methods

The core database of the Web of Science (WoS) is adopted as the retrieval platform, and the research data of astrobiology included in the WoS core collection database represents the relevant research status in the world. In the study choose Astrobiology topic terms to search related papers published in 2012-2021. A total of 1848 papers were obtained after screening and elimination. The contents of the records were selected as full records and the last update date of the literature data searched above was November 21, 2022.

Results and Discussion

Growth of publications: A total of 1848 astrobiology publications were published during 2012-2021. The highest number of publications was 231 (12.50%) published in 2021. The least no. of publication is found to be of 2012 and 2013, because it was the first and second period of the study. The average number of publications published per year was 184.8. It reveals that research productivity does not remain constant each year. It increases or decreases year after year. The research productivity of astrobiology fluctuates year after year.

Table 1: Growth rate of publications

Year	No. of Publications	Percentage	Citations	ACPP	AGR
2012	153	8.28	4524	29.57	-
2013	153	8.28	5839	38.16	0
2014	177	9.58	4926	27.83	15.69
2015	181	9.79	4212	23.27	2.26
2016	161	8.71	3813	23.68	-12.42
2017	183	9.90	3427	18.73	13.66
2018	211	11.42	3564	16.89	15.30
2019	206	11.15	1825	8.86	-2.37
2020	231	12.50	1438	6.22	12.13
2021	192	10.39	695	3.62	-16.88
Total	1848		34263	18.54	

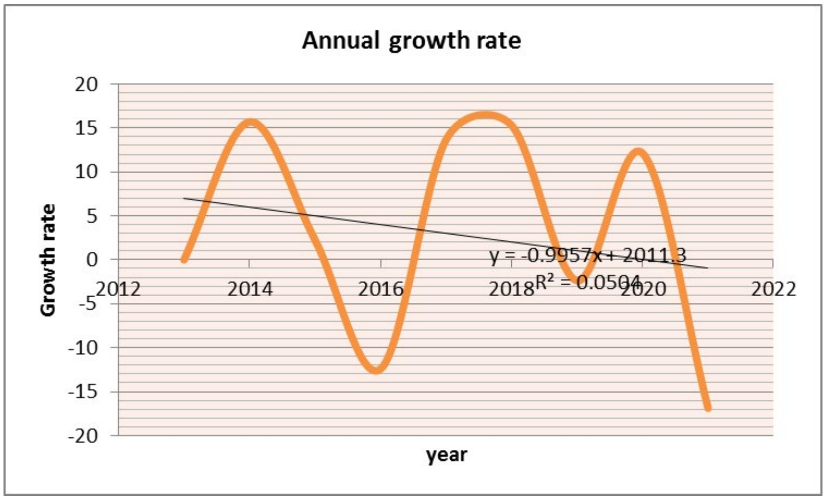

Figure 1: Relative growth rate for research output

Annual Growth Rate (AGR)

There was variation in Annual Growth during the study period and suddenly increased from 0 in 2013 to 15.69 in 2014. Where as in suddenly decreased to 2.26 in the year 2015, it was decreased to -12.42 in 2016 and it was increased to 13.66 in the year 2017. There was slightly increased to 15.30 in 2018 and decreased to -2.37 in the year 2019. There was a variation after year as indicated in figure 1 in the AGR for the publications. The significant reason for variations is that there is no constant growth of publications every year in the area of study.

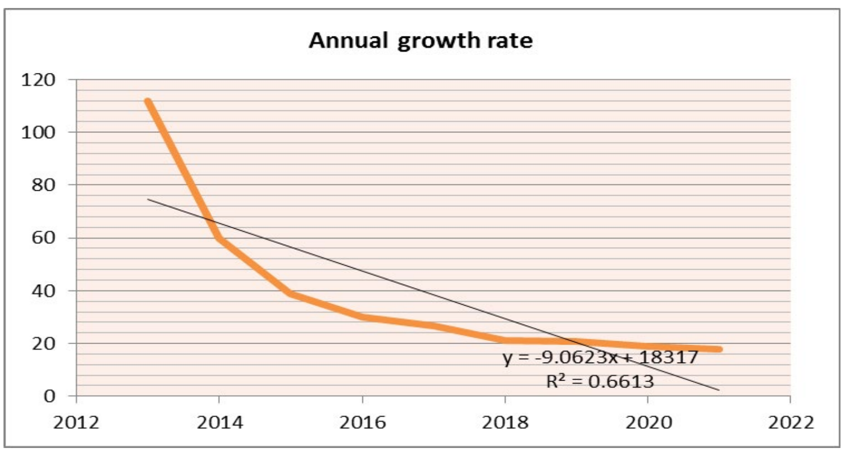

Figure 2: Annual growth rate of research output

Trend Analysis –Method of Least Squares

This is the best method for obtaining the trend values. It provides a convenient basis for obtaining the line of best fit in a series.

The straight line trend has an equation of the type: Y = a + bX,

Where,

Y represents the estimated values of the trend, X represents the deviations in time period; ‘a’ and ‘b’ are constants.

The values of two constants ‘a’ and ‘b’ are estimated by solving the following two normal equations.

$\Sigma Y = Na + b\Sigma X$

$\Sigma XY = a \Sigma X + b\Sigma X2$

Where N represents number of years for which data is given.

Table 2: Computation of straight line trend by the least squares method

Year	Actual value (Y)	Deviation	Multiply (X)	XY	X^2	Trend value
2012	153	-4.5	-9	-1377	81	114
2013	153	-3.5	-7	-1071	49	130
2014	177	-2.5	-5	-885	25	146

2015	181	-1.5	-3	-543	9	161
2016	161	1	1	161	1	193
2017	183	1.5	3	549	9	208
2018	211	2.5	5	1055	25	224
2019	206	3.5	7	1442	49	240
2020	231	4.5	9	2079	81	255
2021	192	5.5	11	2112	121	271
2022			13			287
2023			15			302
2024			17			318
2025			19			334
2026			21			349
2027			23			365
2028			25			381
2029			27			396
2030			29			412
2031			31			428
Total	1848			3522	450	

Since ∑ X=0, therefore

∑ X 1848
a = ------ = ------ = 184.8
N 10

∑ XY 3522
b = -------- = ------ = 7.83
∑ X^2 450

Thus, substituting the value of 'a' and 'b' in the straight line of the trend, we get

Y= a + bX
Estimate of 2031 will be calculated on the basis of X= 31
Y_{2031} = 184.8 + (7.83) x 31 = 2060

With the use of the trend analysis, the trend values are calculated up to 2031. The trend line and actual line are presented in the figure 2. And, it is seen from the table 2, that the actual trend was standard in the year 2012 and 2013 since then there is a fluctuated trend up to the year of 2021. The trend value has been increased from 114 in 2012 to 428 in 2031. From this it can be interpreted that the upward trend in the actual line reflects in the trend line also

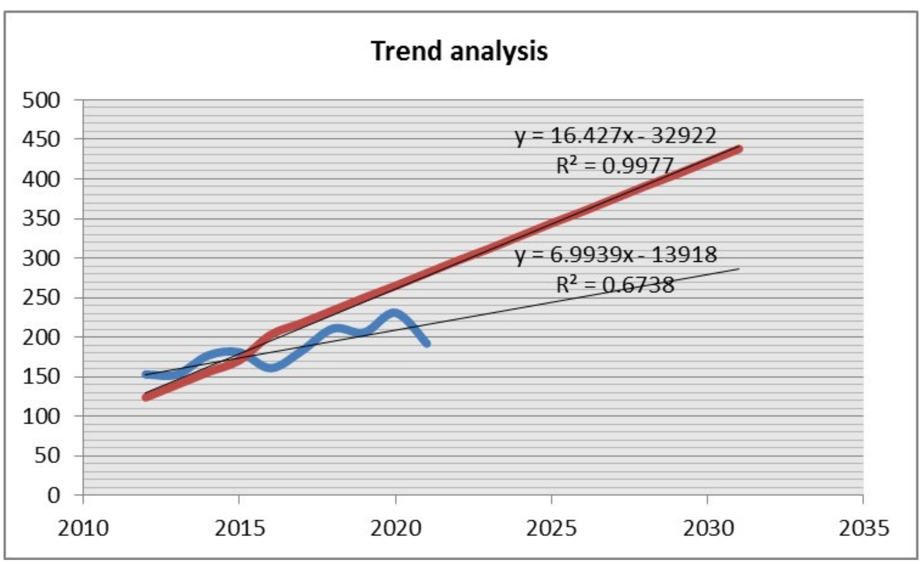

Figure 3: Trend analysis of research output

Document type of publications

Table 3: Document type of publications

S. No.	Title	Documents	Percentage	Citations	CPP
1	Articles	1568	84.85	28237	18.01
2	Review articles	159	8.60	5287	33.25
3	Editorial materials	52	2.81	87	1.67
4	Proceeding paper	29	1.57	309	10.65
5	Meeting Abstract	12	0.65	1	0.08
6	Book review	8	0.43	1	0.12
7	News Item	7	0.38	156	22.28
8	Book Chapters	6	0.32	182	30.33
9	Letter	5	0.27	2	0.40
10	Biographical-Items	2	0.11	1	0.50
Total	1848	100.00	34263	18.86	

CPP- Citation per Publications

Table 3 lists the numbers and proportions of various document types. Ten document types were found in these 1848 publications. The most frequent document type is article (1,568), accounting for 84.85% of total publications. At the second position is review (159), with a proportion of 8.60%. Other document types including editorial material (52), proceedings paper (29), meeting abstract (12), book review (8), news item (7), book chapter (6), letter (5) and Biographical-Items (2).

Citation data for different document types were presented in Table 3. This shows that higher publication output of a particular document type led to higher visibility of citation within that document type. It was not surprising that reviews had higher citations per paper (CPP) than articles because review papers cover a wider perspective of a research topic. However, unusual that book chapters and conference proceedings in the current analyses had higher CPP than the articles. This indicates that astrobiology research in global is still developing as researchers in mature research fields. However, only the 1568 original research articles found in the current work were further examined as articles represented the majority of the peer-reviewed documents in this field.

Most productive authors

Table 4: Most productive authors

S. No.	Author	Publications	Citations	CPP	H-index
1	Cockell C S	43	1083	25.18	16
2	Lingam M	36	702	19.5	16
3	Kane S R	29	699	24.1	14
4	Loeb A	27	446	16.52	15
5	Kaltenegger L	25	695	27.8	12
6	Rettberg P	21	594	28.29	14
7	Abbot D S	20	961	48.05	15
8	Edwards H G M	20	529	26.45	11
9	De Vera J P	19	541	28.47	12
10	Rabbow E	19	623	32.79	12

The list of most productive and influential authors is shown in Table 4. The most productive authors are ordered by the maximum number of total publication while the most influential authors are accounted by total citation. The table also describes authors with total citations, citations per paper and h-index.

Cockell C S is the most relevant author with 43 publications and 1083 citations, followed by Lingam M, with 36 publications and 702 citations. This reflects that the relevance of the publications is related to the quality of the journals and the impact of the article on the research community. Author Cockell C S from UK authored a total of 43 documents and received the highest citation count of

1083, according to the results. He also has the highest H- index, indicating that Cockell, C S is still the most influential author in the field of astrobiology literature.

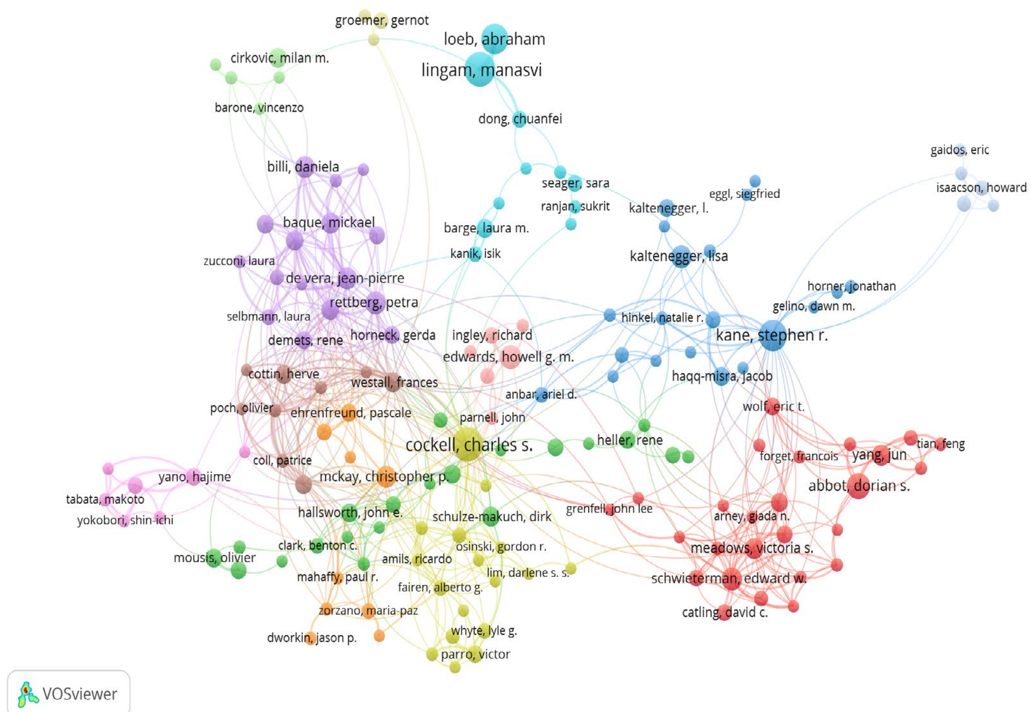

Figure 4: Most productive authors

Authorship pattern

Degree of Collaboration: The degree of collaboration is defined as the ratio of the number of collaborative research papers to the total number of research papers in the discipline during a certain period of time. The formula suggested by Subramanyam (1983) is used. It is expressed as

$$C = \frac{N_m}{N_m + N_s}$$

Where, C is the degree of collaboration in a discipline. N_m is the number of multiauthored research papers in the discipline published during a year. N_s is the number of single authored papers in the discipline published during the same year.

Table 5: Degree of Collaboration

Year	Single Author		Multi Authors		Total Publications	Total Authors	Degree of Collaboration (DC)	Collaboration Index (CI)
	No. of Output	%	No. of Output	%				
2012	17	7.90	136	8.33	153	434	0.89	2.84
2013	19	8.84	134	8.20	153	407	0.87	2.66
2014	23	10.70	154	9.43	177	509	0.87	2.87
2015	21	9.77	160	9.80	181	742	0.88	4.10
2016	16	7.44	145	8.88	161	613	0.90	3.81
2017	22	10.23	161	9.86	183	745	0.88	4.07
2018	18	8.37	193	11.82	211	592	0.91	2.80

2019	23	10.70	183	11.21	206	659	0.89	3.20
2020	31	14.42	200	12.25	231	813	0.86	3.52
2021	25	11.63	167	10.22	192	538	0.87	2.80
Total	**215**	**100.00**	**1633**	**100.00**	**1848**	**6052**	**0.88 (Average)**	**3.27 (Average)**

The authorship pattern was analysed to determine the percentage of single and multiple authors. Table 5 presents the single and multiple author's productivity pattern on yearly basis. There were 1633 (88.37%) multi authored and only 215 (11.63%) single authored publications. The productivity patterns on the astrobiology publications are much contributed by the multiple authors than the single author since 2012 to 2021.

The degree of collaboration is determined by using this formula based on this study, the result of degree of collaboration C = 0.88. i.e, 88 percents of collaborative author's articles is published in this study. The degree of collaboration in producing research output on astrobiology research has shown a fluctuating trend during the study period.

Collaboration Index means number of authors per joint papers. Analysis in the table 5 shows the variation in the Collaboration Index. It varies from 2.66 in 2013 and highest collaboration notices in 2015 i.e. 4.10. The average collaboration index is 3.27. It implies the research team falls between 3 and 4 authorship patterns in field of astrobiology.

Highly productive countries

Table 6: Highly productive countries

S. No.	Country	Publications	Citations	CPP	H Index
1	USA	1059 (57.30%)	24070	22.73	70
2	Germany	231 (12.50%)	5420	23.46	38
3	England	229 (12.39%)	5329	23.27	42
4	France	216 (11.69%)	5044	23.35	41
5	Italy	165 (8.93%)	2868	17.38	29
6	Spain	148 (8.01%)	3041	20.55	30
7	Canada	123 (6.66%)	2606	21.19	30
8	Japan	109 (5.90%)	2354	21.60	26
9	Scotland	105 (5.68%)	2407	22.92	28
10	Netherlands	81 (4.38%)	2132	26.32	26

According to the web of science database, researchers on astrobiology are mainly distributed in more than 70 countries in the world. The top 10 countries in the total number of published papers are shown in table 6. Apart from total papers, the table also mentions other indicators such as: total citations, citations per paper, and h-index. It can also be seen from Fig.3, the United States has the largest number of papers published in this field, with a total of 1059 papers, accounting for 57.30% of the total number of papers, ranking second is Germany, with a total of 231 papers, accounting for 12.50%, and the third place in England, with 229 papers in total, accounting for 12.39%, followed by Italy, Spain and Canada. The top four countries' contributions were all above 10%, which indicated that they contributed major shares in research achievements.

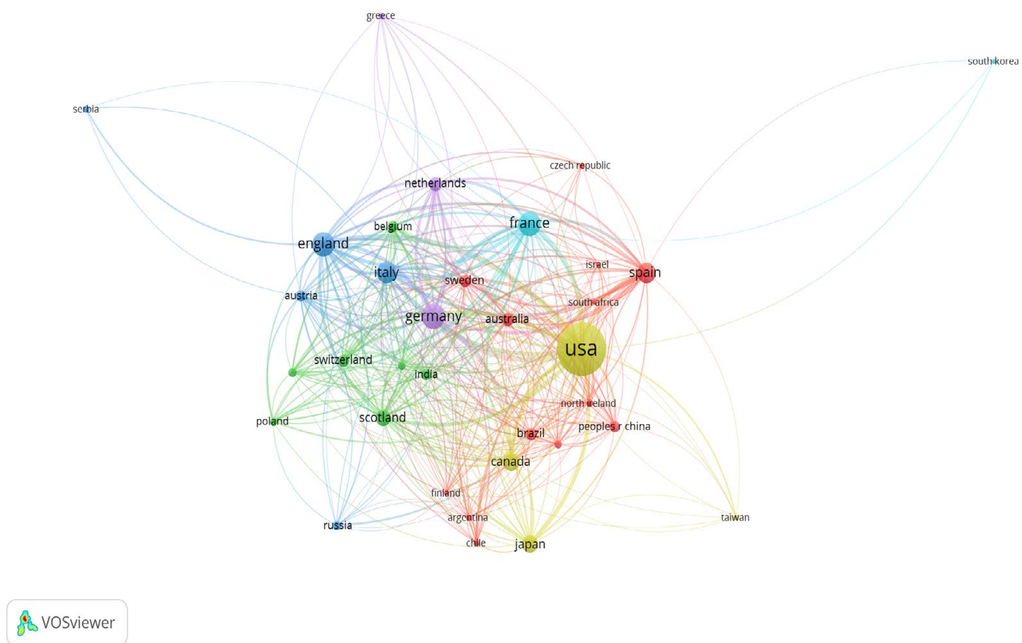

Figure 5: Highly productive countries

Citation and H-Index Analysis

The number of citations is the main factor to reflect the quality of a paper. The ranking of most influential countries remains the same with respect to the most productive countries for USA (TC = 24,070) and the Germany (TC = 5,420). Interestingly, then comes England with 5329 citations in only 229 publications. The citation per paper shows a different image of the influence of the countries. Netherlands tops the list with citation per publications and top 9 countries whose CPP is more than 20.

H-index stands for high citations. With respect to the h-index, USA tops the list with a value of 70 followed by England (42), France (41) and Germany (38). Then Spain and Canada share the same h-index value of 30. The dominance of USA can also be seen in the Figure 4 which describes the co-citation analysis of countries. The inference from this visualization shows that, a paper originating from USA is cited along with papers originating from other countries.

Most productive institutes

Table 7: Most productive institutes

S. No.	Institutions	Country	Publications	Citations	CPP	H Index
1	National Aeronautics Space Administration (NASA)	USA	389	9521	24.48	52
2	Udice French Research Universities	France	169	4661	27.58	37
3	Centre National De La Recherche Scientifique (CNRS)	France	165	4673	28.32	37
4	California Institute of Technology	USA	142	4120	29.01	36
5	NASA Jet Propulsion Laboratory JPL	USA	127	3411	26.86	32
6	NASA Ames Research Center	USA	126	2731	21.67	31
7	NASA Goddard Space Flight Center	USA	120	3313	27.61	33
8	University of California System	USA	119	3780	31.76	33
9	Helmholtz Association	Germany	111	2547	22.95	28
10	Harvard University	USA	99	3455	34.90	34

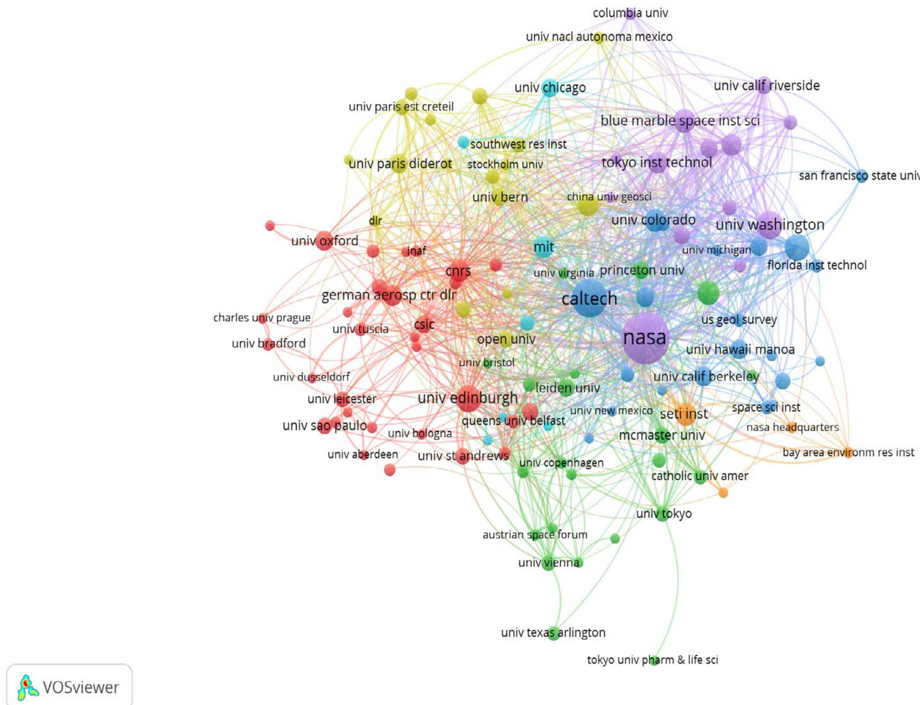

Figure 6: Highly productive institutes

The 10 most productive institutions are displayed in table 7. The 1848 articles were published by 1618 different authoring organizations. National Aeronautics Space Administration (NASA) has the greatest number of publications with a total of 389 papers, accounting for 21.05% of all publications in this field. At the second position is the Udice French Research Universities with 169 publications followed by the Centre National De La Recherche Scientifique (CNRS), California Institute of Technology, and NASA Jet Propulsion Laboratory JPL. Additionally, seven out of the ten institutions with higher number of publications were from US, followed by France, which was the fourth country with higher number of publications. The total papers from the institute with total citations and citations per paper (CPP) are also given in the table, along with the h-index of each institution.

However in terms of Total Citations, National Aeronautics Space Administration (NASA), USA stands at the top with 9521 citations followed by Centre National De La Recherche Scientifique (CNRS), France (4673) and Udice French Research Universities, France (4661). The institutes with the highest average citation per paper (CPP) were Harvard University, USA (34.90), University of California System (31.76), and California Institute of Technology (29.01).

National Aeronautics Space Administration (NASA) is in the first position of h-index of 52. Two institutes have an h-index of 37, Udice French Research Universities and Centre National De La Recherche Scientifique (CNRS), both are from France. They are followed by the California Institute of Technology, USA (36) and Harvard University, USA (34). However, among the institutions, as shown by the institution co-citation network in Figure 6, the dominance of the National Aeronautics Space Administration (NASA) can be concluded, which overlaps with almost all the other institutions. This determines that almost every time the publications from National Aeronautics Space Administration (NASA) are cited along with all other institutions.

Most preferred source titles

Table 8: Source Title of Publications

S. No.	Source Title	Publications	Citations	H Index	Impact Factor
1	Astrobiology	364	7697	73	4.091
2	Astrophysical Journal	206	6012	45	5.521
3	International Journal of Astrobiology	120	879	16	2.026
4	Monthly Notices of the Royal Astronomical Society	91	1224	19	5.235
5	Astronomy Astrophysics	89	2104	25	6.240
6	Astrophysical Journal Letters	86	2591	27	8.811
7	Icarus	82	1901	25	3.508
8	Planetary and Space Science	50	811	17	2.03
9	Astronomical Journal	47	839	18	6.263
10	Life Basel	36	246	10	3.251

A total of 285 journals published publications related to deep learning in astrobiology research. The top 10 journals are presented in table 8. The highest count belonged to the Astrobiology (n=3643), followed by Astrobiology (n=206). Among these journals, Astrophysical Journal Letters had the highest impact factor (8.811). The h-index gives to highly cited publications. Astrobiology, Astrophysical Journal and Astrophysical Journal Letters have received maximum number of citations i.e 7697, 6012, 2591 and their h-index are 73, 45, and 27 respectively.

High productivity subject areas

Table 9: High productivity subject areas

S. No.	Subject	Articles	Percentage
1	Astronomy Astrophysics	1247	67.48
2	Life Sciences Biomedicine	578	31.28
3	Geology	537	29.06
4	Microbiology	104	5.63
5	Science Technology	81	4.38
6	Geochemistry Geophysics	72	3.90
7	Chemistry	70	3.79
8	Engineering	51	2.76
9	Biochemistry Molecular Biology	33	1.79
10	Physics	33	1.79

The scientific literature on astrobiology research is spread over 65 different subjects. The top 10 subjects with their frequencies are shown in Table 9. It is found that Astronomy Astrophysics has highest number of articles with 1247 (67.48%) followed by Life Sciences Biomedicine contributing 578 (31.28%) articles. Geology occupies the third position with 537 (29.06%) articles. The fourth highest articles belonged to the subject Microbiology with 104 (5.63%), Science Technology with 81 (8.38%) and Geochemistry Geophysics with 72 (3.90%) articles respectively.

Discussions and Conclusions

This study made a bibliometric analysis and visualization on astrobiology publications. We explored some interesting results concerning the astrobiology publications, which can be summarized as follows:

First, the astrobiology related publications fluctuated at low level during the study period. In total, 1848 documents were included in this study from 2012 to 2021, with 1568 articles and 159 reviews.

In terms of institutes, National Aeronautics Space Administration (a US pioneer in this research when it began) remains the leader, having authored the most astrobiology documents.
The USA has 7 institutes ranked the top 10 regarding to the number of astrobiology related publications. The USA has the most publications, highest number of citation frequency and H-index.

It implies that the USA is the bellwether in this field. The journal, Astrobiology, ranks first among the source titles.

The United States, Germany, England, France and other countries have done more research in the field of astrobiology and also have a good scientific research foundation.

Multi-authored documents contained an average of 4.5 authors, with only 6% of the documents being single-authored. The collaboration index (CI) averaged 3.27 and was highest in the year 2015 (CI=4.10)

From the understanding of the importance of astrobiology research production of the quantitative analysis through specific technical methods, the research on astrobiology gradually becomes mature. The development of this field depends on the improvement of general technical methods and the application of new technology, the research direction is also gradually from highly generalized conditions to challenge for the complex natural conditions in the past few years. With the global trend of extensive cooperation, the countries should strengthen international communication with scientists of other countries to promote the development of Astrobiology. This analysis will be helpful to find out the obstacles of research productivity, which would help to develop research capacity and lead to more number of publications in future.

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