



## Evaluating Cosmology Research in India using Bibliometric and Citation Indicators Science 1960s

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### Abstract

*The present study explores the characteristics of the literature and growth of Cosmology research in India during 1960-2014, based on Web of Science (WoS) database and make quantitative and qualitative assessment by way of analysing various features of research output by using the scientometric techniques. A total of 2423 literature were published on Cosmology, which received total 40944 citations. The average number of publications per year was 59.09; Compound Annual Growth Rate (CAGR) is 14.62% and the average number of citations per publication was 16.90. The publications peaked in the year 2014 with 235 publications and the highest number of citations (3053) was in 2004. This study analyzes the research studies based on year of publication, journal, international collaboration, spatial distribution and keyword occurrence frequency. The results of this work reveal that the publication on the Cosmology have grown high at a slow rate over the past 54 years and the curve fits the polynomial curve with  $R^2 = 0.9837$ . Publications on Cosmology appeared in 54 journals of which most active journal was "Astrophysics and Space Science" published by Springer from Netherlands and 434(17.912%) of the total 2423 publications. A total of 12599 authors contributed on Cosmology research. The most active author was Srianand, R produced maximum no. of publications 101 i.e. 4.168 % of total publications. 1605 institutions contributed of which Inter University Centre for Astronomy Astrophysics; Pune, India is the most productive institution. For globalization of Cosmology Research in India, the results show there were 70 Countries/territories which participated in Cosmology research. USA produced maximum publications 464 that is 19.150% of total publication with higher citations (8234). A Keyword analysis reveals that "Theory", "Redshift", "Observations", "Dark Energy" and "Cosmological constant" are the most used keywords.*

**Keywords:** Cosmology, Scientometric, Bibliometrics, Citation Indicator, Bibliometric Indicator, India.

### Introduction

After the demise of the Aristotelian world picture, it took hundreds years of astronomical observations and physical theories to reach a level at which a satisfactory modern scientific picture of the physical universe could be formed. The decisive steps in the development were the clarification of the nature of the galaxies in the 1920's and the general theory of relativity developed by Einstein in the 1910's. Research in cosmology tries to answer questions such as : How large and how old is the universe? How is matter distributed? How were the elements formed? What will be the future of the Universe? The central tenet of modern cosmology is the model of the expanding universe<sup>1</sup>. Cosmology is the study of the structure, origin and the evolution of the universe as a whole. Observationally, luminous matter in the universe is distributed in a clumpy fashion, being aggregated together into individual galaxies, group of galaxies, clusters and superclusters. On the very large scale, however, the universe appears to be homogeneous (i.e. is the same everywhere) and isotropic (i.e. look the same in every direction). This implies that all observers will see the same large-scale view of the universe regardless of

where they are located. No individual galaxy or observer occupies a privileged position, and the universe has no definable center or edge<sup>2</sup>.

Cosmology research has experienced a considerable increase over the last few decades. A Scientometric studies in this topic was performed by Dutta and Rath<sup>3</sup> covering the period of 1999-2012 examines collaborations with different countries, authorship pattern, document types and Bradford law of scattering and Lotka's law been studied. However, there have been no attempts to provide a qualitative assessment of the current status and trends of this research so far. Therefore, the aim of this study is to assess the publications of Cosmology research in Science Citation Index (SCI) over the past 54 years (1960–2014) by applying bibliometric and citation indicators, to identify patterns and growth trends as well as the most prolific authors, journals etc.

### Database and Scope

To assess the trend of research publication on Cosmology research and locate and collect the literature i.e. journal articles

only, Web of Science (WoS) was used. The Search Strategy used to conduct Web of Science (WoS) search is as mentioned below:

TS= "Cosmology" OR "structure" = (Search Term) ; Where TS is a topic search that retrieves occurrences of the search term in the article title, abstract, keywords within a time span of 1960-2014, This was used to identify the papers which included these terms in their titles, abstracts, and keywords. This process was followed for another series of search terms given by Kennicutt et al.<sup>4</sup>

## Results and Analysis

There were 2423 articles that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed. The specific characteristics of the publications such as no. of publications, the no. authors involved in the production of these publication, institutions, journals etc were taken into consideration.

**Publication characteristics of Indian Cosmology Research during 1960-2014:** The total 2423 articles of Indian scientists during 1960-2014 were abstracted from WoS related to Cosmology publication. From Table-1, the output of 2423 paper received a total of 40944 citations during the said period with an average of about 16.90 citations per paper. The average number of publications per year is 59.09 and Compound Annual Growth Rate (CAGR) is 14.62%.

**Table-1**  
**Bibliographic Record of Cosmology research in India during study period**

Bibliometric indicators	No.
Total Article found:	2423
Total No. of Countries contribution	70
Total No. of Author's contribution	12599
Total No. of Institution's contribution	1605
Total No. of Journal appeared	54
Total No. of Keywords (raw) appeared	6172

Source: WoS

**Publication Pattern:** Publication Pattern of Cosmology research from 1960 to 2014 is presented in Figure-1. The lowest (1) and highest (235) numbers of publications were in 1974 and 2014. It is important to mention here that initial publication observed in the year 1974. A two hundred thirty five time's increase was observed over the study period, (from 1 in 1974 to 235 in 2014).

**Table-2**  
**Citation Metrics of Cosmology research in India**

Citation-based indicators	No.
Total Article found:	2423
Sum of the Times Cited	40944
Sum of Times Cited without self-citations	34945
Citing Articles	22473
Citing Articles without self-citations	20912
Average Citations per Item	16.9
h-index	74

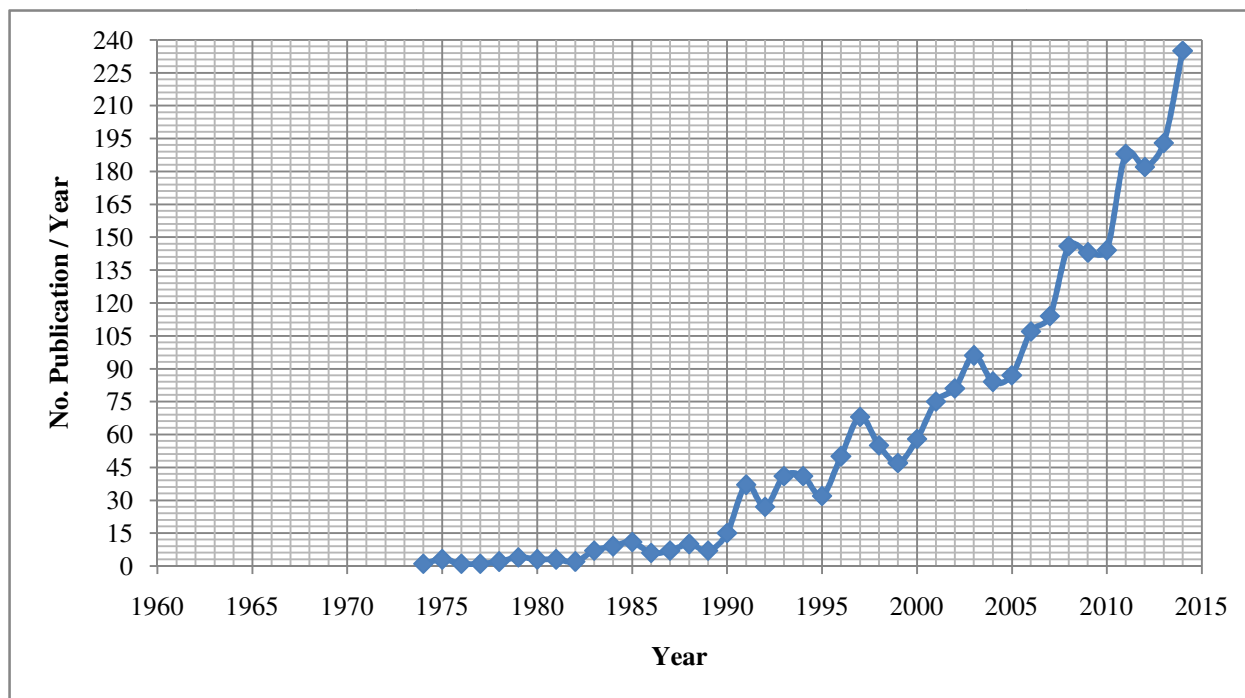
Source: WoS

**Growth Pattern:** The cumulative progression was represented by a second degree power law distribution during 1960-2014 giving an idea of the polynomial growth rate (Figure-2). The fit produced a high regression coefficient (Table-1) of determination to the collected data ( $R^2 = 0.959$ ). The polynomial best fit as shown in Table-3 for Cosmology research was found to be:  $y = 0.0002x^4 - 1.9259x^3 + 5748.3x^2 - 8E+06x + 4E+09$ , where y is the cumulative number of publications and x is the number of years since 1960.

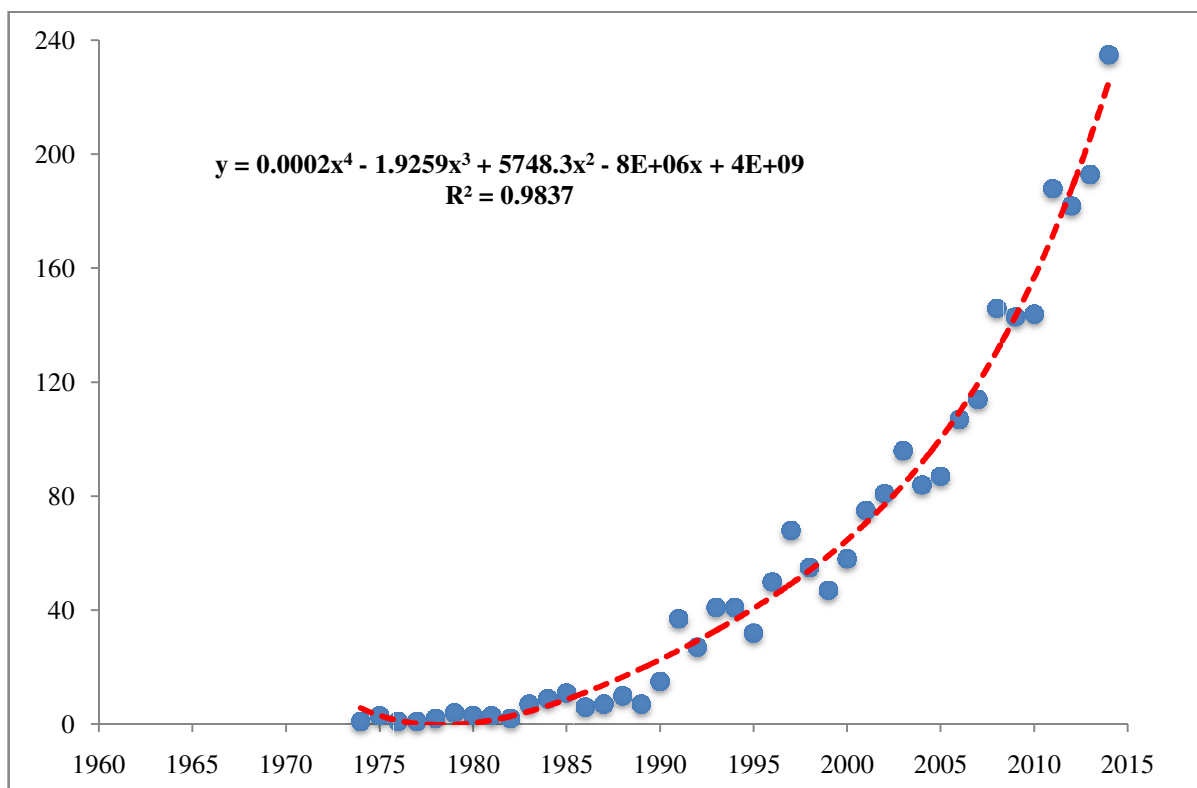
**Table-3**  
**Different Regression Type with Regression coefficient**

Regression Type	Equation	Regression ( $R^2$ )
Exponential	$y = 1E-116e^{0.1355x}$	$R^2 = 0.9375$
Linear	$y = 4.8847x - 9680.9$	$R^2 = 0.8367$
Logarithmic	$y = 9729.3\ln(x) - 73863$	$R^2 = 0.8349$
Polynomial	$y = 0.0002x^4 - 1.9259x^3 + 5748.3x^2 - 8E+06x + 4E+09$	$R^2 = 0.9837$
Power	$y = 0x^{270.21}$	$R^2 = 0.9383$

The growth of literature shown in Figure-2 can be divided into 2 parts, in 1<sup>st</sup> part (1960-1973) there is no literature published by Indian scientist as (India) is an affiliation country found in Web of Science (WoS). In 2<sup>nd</sup> part (1974-2014), follows polynomial growth rate which indicate that the number of papers concerning Cosmology research were growing at a high but slow growth rate.



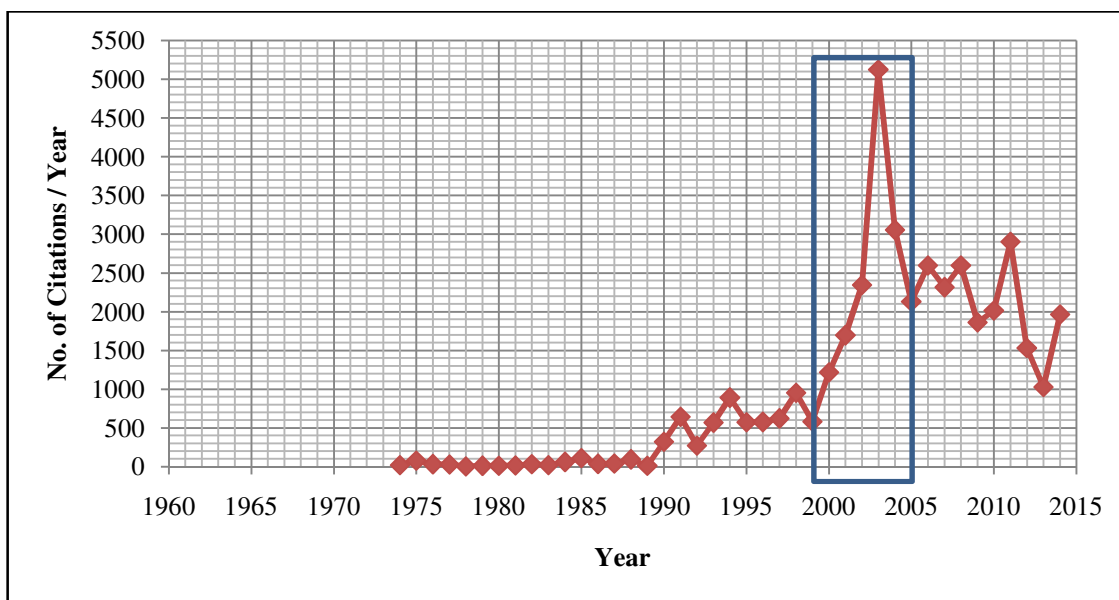
**Figure-1**  
**Year wise Publication pattern of Cosmology research in India during 1960-2014**



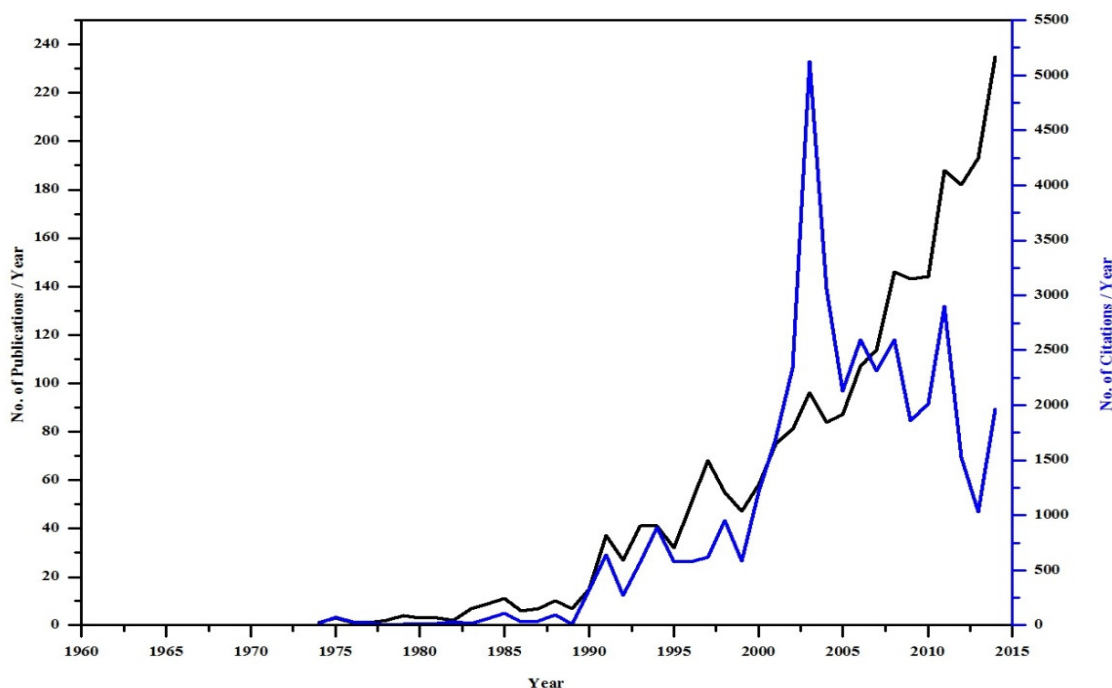
**Figure-2**  
**Growth pattern of Cosmology research in India during 1960-2014. Blue dot describe the distribution of publication (observed value) and red dashed line describe the correlation of distribution of publication where regression coefficient  $R^2 = 0.983$**

**Citation pattern:** Figure-3 and 4 represents the year wise growth of citations received by Indian author and total no. of publications per year and no. of citations per year during 1960-2014 on Cosmology research. The total 2423 articles of Indian scientists during 1960-2014 were abstracted from WoS related to Cosmology research publication which received a total of 40944 citations.

The pattern of citation received during the said year is very fluctuating. in the starting year 1974, the total number of citation received 18 with an average citation 18. The minimum citation received in the year 1978 is three (3) with age rage citation 1.5 and the maximum citation received in the year 2004 is 3053 with Ag. citation 36.35. From Figure-4, it is important to note here that after the year 2006 publication increases but citation decreases and again increases that is very fluctuating.



**Figure-3**  
Year wise Citation Pattern of Cosmology research in India during 1960-2014



**Figure-4**

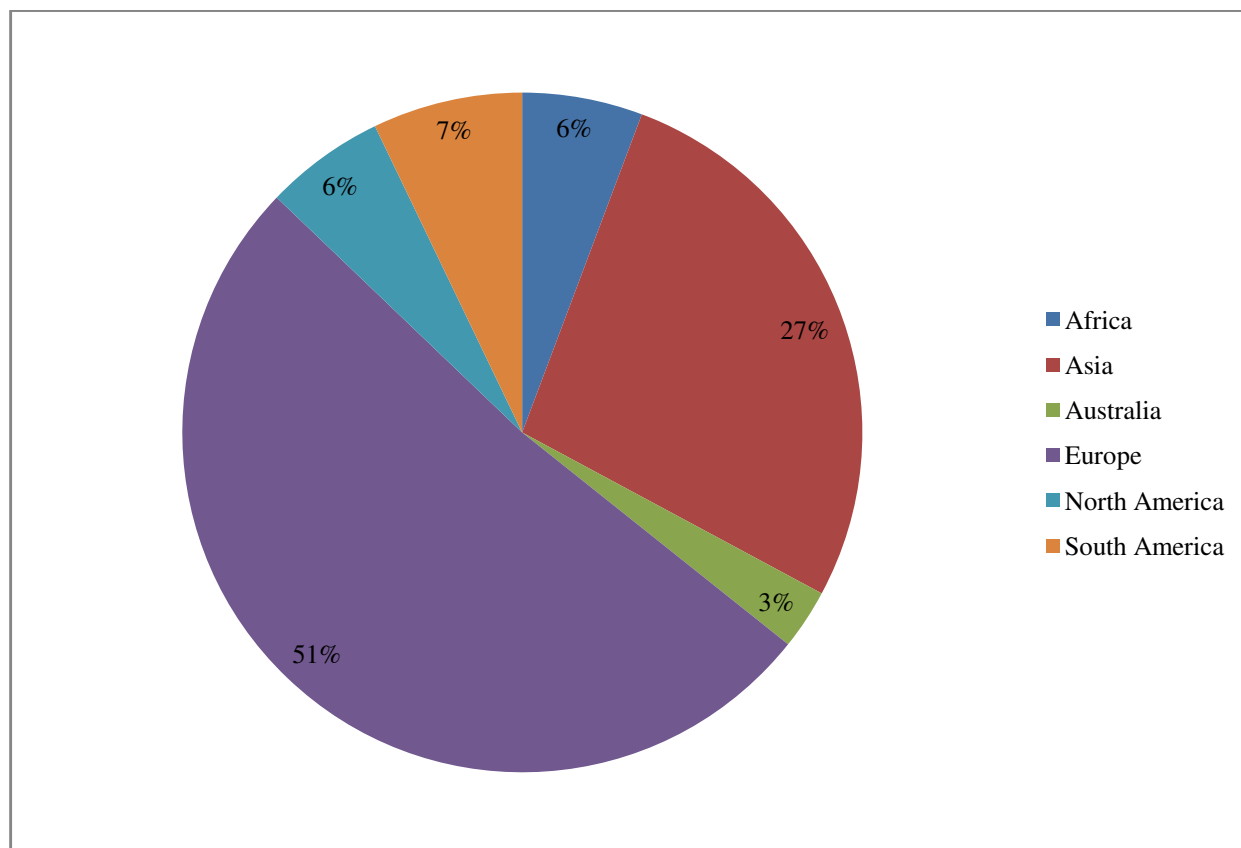
Citation pattern of Cosmology research in India during 1960-2014: no. of publications/year Vs no. of citation/year. Blue line (right Y axis) indicates the citations pattern against black line (left Y axis)

**Top Institutions and their research impact:** The contribution of different institutions was estimated by affiliated institution of at least one author. A total of 2423 Articles on Cosmology research appeared from 1605 institutions. Out of 1605 institution, 624 institutions appeared one time contributed 38.87 % of total article and 219 institutions appeared two time contributed 13.64 % of total article. Out of these top 20 institutions only 7 institutions are Indian institution. Inter University Centre for Astronomy Astrophysics contributed highest no. of publications (531), followed by Tata Institute of Fundamental Research, Mumbai , Indian Institute of Astrophysics had published 279 and 196 papers respectively.

While the other 13 are foreign institutions. Among these 5 are belong to USA namely National Aeronautics Space Administration (NASA), University of California System, California Institute of Technology, United State Department of Energy ; University of Cambridge; 4 are belong to France namely Centre National De La Recherche Scientifique, Pierre Marie Curie University Paris Paris Diderot University and Paris-Sorbonne University; 2 are belong to Germany namely Max Planck Society and European Southern Observatory ; 1 Russian Academy of Sciences , Russia and 1, Centre for Extragalactic Astronomy , South Africa.

Table-4 reveals the impact of research in terms of quality of papers. The AvgCPA (the average no. of citation per article) indicates the average impact of articles published by a institution and the h-index (defined as the no. of h papers among a institution's no. of publications that have at least h citation each) are used to identify which institution has the largest no. of high quality articles in the Cosmology research. It is seen from the above table that Cosmology related articles authored in foreign institution (United States Department of Energy) have the highest average impact (AvgCPA=64.11).Among Indian institution, Inter University Centre for Astronomy Astrophysics ranked 15<sup>th</sup> in the AvgCPA (30.38) index.

**Top Journals and their research impact:** Cosmology papers appeared in 54 journals. Papers have appeared in highest no. in the journal "Astrophysics and Space Science" published by Springer from Netherlands. Table 3 shows the top 20 productive journals. These 20 out of the 54 journals had published 2363 (97.52 %) of the total 2656 articles. The "Astrophysics and Space Science" ranked first with 434(17.912%); "Physical Review D 420(17.334%)", "Monthly Notices of the Royal Astronomical Society 356(14.693%)", "Astrophysical Journal 231(9.534%)", "Astronomy Astrophysics 226(9.327%)"; ranked at 2nd, 3rd, 4th, and 5th, respectively.



**Figure-5**  
Geographic distribution of Cosmology research publications

**Table-4**  
**Top 20 Institutions and their research impact**

Institution	Region	TP (%)	TC	AvgCPA	h-index
Inter University Centre for Astronomy Astrophysics	India	531(21.915)	16132	30.38	60
Tata Institute of Fundamental Research	India	279(11.515)	6563	23.52	36
Centre National De La Recherche Scientifique	France	246(10.153)	7779	31.63	45
Indian Institute of Astrophysics	India	196(8.089)	2433	12.41	23
Jadavpur University	India	147(6.067)	1349	9.18	18
Max Planck Society	Germany	145(5.984)	5269	36.34	39
Observatoire De Paris	India	130(5.365)	4963	38.18	40
Raman Research Institute	India	127(5.241)	1930	15.2	25
National Aeronautics Space Administration	USA	123(5.076)	5036	40.94	38
University of California System	USA	119(4.911)	4719	39.66	36
Pierre Marie Curie University Paris	France	113(4.664)	3895	34.47	35
California Institute of Technology	USA	110(4.540)	3946	35.87	36
European Southern Observatory	Germany	107(4.416)	4648	43.44	38
United States Department of Energy	USA	91(3.756)	5834	64.11	35
Paris Diderot University	France	84(3.467)	3726	44.36	35
Paris-Sorbonne University	France	84(3.467)	3726	44.36	35
Centre for Extragalactic Astronomy	South Africa	83(3.426)	4070	49.04	35
University of Cambridge	USA	81(3.343)	3703	45.72	34
Russian Academy of Sciences	Russia	81(3.343)	2900	35.8	34
Physical Research Laboratory	India	81(3.343)	846	35.8	34

TP= Total no. of Cosmology related articles per institution; TC = Total no. of citation received; AvgCPA= Average no. of citations received by each article; h-index= defined by the number of h papers in an institution's number of papers that have at least h citations each. Source: WoS

Table-5 shows the citation impact on top 20 journals. The AvgCPA (Average no. of citations that Cosmology articles in a journal received and the h-index (defined by the no. of h papers among a journal's no. of publications that have at least h citations each) are used to identify which journals have the largest no. of high quality articles in the Cosmology research.

It is seen from the above table that the journal "Astrophysical Journal Supplement Series" published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA=90.20) although the journal "Astrophysics

and Space Science" has the highest no. of publication but ranked 15<sup>th</sup> in the AvgCPA index.

**Top most Prolific Authors and impact of their research output:** A total of 2423 articles included the author addresses. Articles on Cosmology have been contributed by 12599 authors. Top 20 productive authors were ranked based on the no. of total articles. Srianand, R produced maximum no. of publications 101 i.e. 4.168 % of total publications with ranked first followed by Chakraborty, S; Petitjean, P; Padmanabhan, T; Mitra, S; ranked at 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> respectively. Table 4 showed the top 20 productive authors during the last 54 years, 1960-2014.

**Table-5**  
**Top 20 Journals and their research impact**

Journal Metrics (2013)							
Journal	TP (%)	TC	AvgCPA	SJR	IPP	SNIP	Country
Astrophysics and Space Science	434(17.912)	2771	6.38	1.08 1	1.74 8	1.056	Netherlan ds
Physical Review D	420(17.334)	10554	25.13	1.89 9	3.19 2	1.136	USA
Monthly Notices of the Royal Astronomical Society	356(14.693)	6823	19.17	3.19 6	4.91 1	1.494	USA
Astrophysical Journal	231(9.534)	4141	17.93	3.15 9	4.34 8	1.145	UK
Astronomy Astrophysics	226(9.327)	6113	27.07	1.47 1	1.93 2	0.612	France
International Journal of Modern Physics D	138(5.695)	1257	9.11	0.73 3	1.02 1	0.54	Singapor e
General Relativity and Gravitation	123(5.076)	1293	10.51	1.10 9	1.62 8	1.015	UK
Classical and Quantum Gravity	112(4.622)	2428	21.68	1.47 6	2.19 2	0.966	UK
Journal of Cosmology and Astroparticle Physics	103(4.251)	1651	16.03	0.61 5	2.37 4	0.465	UK
Journal of Astrophysics and Astronomy	64(2.641)	343	5.36	0.47 7	0.54 1	0.224	India
Astrophysical Journal Letters	33(1.362)	650	19.7	3.91 4	4.85 2	1.487	UK
Astronomical Journal	23(0.949)	763	33.17	3.15 9	4.34 8	1.145	UK
Research in Astronomy and Astrophysics	20(0.825)	84	4.2	0.95 3	1.33 1	0.768	UK
Gravitation Cosmology	17(0.702)	49	2.88	0.39 5	0.48 6	0.478	Russia
New Astronomy	13(0.537)	126	9.69	0.73 4	1.05 3	0.523	Netherlan ds
Astroparticle Physics	13(0.537)	173	13.31	3.01 2	3.82 8	2.776	Netherlan ds
Advances in Space Research	12(0.495)	34	2.83	0.75 1	1.41 6	1.291	Netherlan d
Astrophysical Journal Supplement Series	10(0.413)	902	90.2	6.85 7	9.68 7	3.125	USA
IAU Symposia	8(0.330)	5	0.62	-	-	-	Puerto Rico
Publications of the Astronomical Society of Japan	7(0.289)	88	12.57	1.52 1	1.62 6	0.75	Japan

TP= Total no. of Cosmology related articles published by a Journal (followed by the percentage of Cosmology related articles in the journal of a total Cosmology related articles); TC = Total no. of citation received ; AgCPA= Average no. of citations that Cosmology related articles in a journal received ; h-index= no. of h papers among a journal's no. of publications that have at least h citations each. SJR = SCImago Journal Rank is weighted by the prestige of a journal. Subject field, quality and reputation of the journal have a direct effect on the value of a citation. SJR also normalizes for differences in citation behavior between subject fields; IPP = Impact per Publication (IPP) measures the ratio of citations per article published in the journal; SNIP = Source Normalized Impact per Paper measures contextual citation impact by weighting citations based on the total number of citations in a subject field. Source: WoS and SCOPUS.

**Table-6**  
**Top 20 most Prolific Authors and impact of their research output**

Author	TP (%)	TC	TC woSC	CI	CIwoSC	AvgCPA	h-index
Srianand, R.	101(4.168)	2800	2276	1281	1193	27.72	30
Chakraborty, S.	79(3.260)	505	458	412	381	6.39	10
Petitjean, P.	73(3.013)	2907	2486	1459	1395	39.82	30
Padmanabhan, T.	61(2.518)	2399	2298	1678	1640	39.33	22
Mitra, S.	58(2.394)	2025	1265	873	831	34.91	30
Sahni, V.	51(2.105)	2875	2740	2026	1984	56.37	28
Souradeep, T.	46(1.898)	1088	971	687	654	23.65	19
Bharadwaj, S.	46(1.898)	740	562	387	349	16.09	16
Pradhan, A.	45(1.857)	882	773	404	367	19.6	20
Munshi, D.	44(1.816)	1903	1102	775	740	43.25	31
Nagendra, K.N.	43(1.775)	339	199	146	111	7.88	11
Ledoux, C.	43(1.775)	1800	1535	705	666	41.86	26
Debnath, U.	43(1.775)	482	445	382	360	11.21	10
Ensslin, T.A.	42(1.733)	1849	1050	715	682	44.02	31
Banday, A.J.	42(1.733)	1826	1020	695	661	43.48	30
Narlikar, J.V.	41(1.692)	619	526	409	382	15.1	15
De Zotti, G.	41(1.692)	1840	1042	697	663	44.88	32
Bouchet FR	41(1.692)	1782	984	660	628	43.46	29
Hildebrandt, S.R	40(1.651)	1758	959	635	603	43.95	29
Gorski, K.M.	40(1.651)	1805	1004	680	648	45.12	30

TP (%): Total no. of Cosmology related articles published by a author (followed by percentage of Cosmology related articles by a author of the total Cosmology related article) TC: Total no. of citation; TC woSc: Sum of Times Cited without self-citations; CI: Citing Articles ; CIwoSC: Citing Articles without self-citations; AgC: Average Citations per Article; h-index : no. of h papers among a author's no. of publications that have at least h citations each. Source: WoS



**Table-7**  
**Top 10 most Prolific papers and impact of their research output**

S.N	Bibliography	TC	Ag.C
1	Kachru, S., Kallosh, R., Linde, A., & Trivedi, S. P. (2003). de Sitter vacua in string theory. <i>Physical Review D</i> , 68(4), 046005. <a href="http://doi.org/10.1103/PhysRevD.68.046005">http://doi.org/10.1103/PhysRevD.68.046005</a>	1666	128.15
2	Padmanabhan, T. (2002). Accelerated expansion of the universe driven by tachyonic matter. <i>Physical Review D</i> , 66(2), 021301. <a href="http://doi.org/10.1103/PhysRevD.66.021301">http://doi.org/10.1103/PhysRevD.66.021301</a>	626	44.71
3	Kachru, S., Kallosh, R., Linde, A., Maldacena, J., McAllister, L., & Trivedi, S. P. (2003). Towards inflation in string theory. <i>Journal of Cosmology and Astroparticle Physics</i> , (10), 013. <a href="http://doi.org/10.1088/1475-7516/2003/10/013">http://doi.org/10.1088/1475-7516/2003/10/013</a>	496	38.15
4	Nojiri, S., Odintsov, S. D., & Sami, M. (2006). Dark energy cosmology from higher-order, string-inspired gravity, and its reconstruction. <i>Physical Review D</i> , 74(4), 046004. <a href="http://doi.org/10.1103/PhysRevD.74.046004">http://doi.org/10.1103/PhysRevD.74.046004</a>	445	44.50
5	Ade, P. A. R., Aghanim, N., Armitage-Caplan, C., Arnaud, M., Ashdown, M., Atrio-Barandela, F., ... Zonca, A. (2014). Planck 2013 results. XVI. Cosmological parameters. <i>Astronomy &amp; Astrophysics</i> , 571, A16. <a href="http://doi.org/10.1051/0004-6361/201321591">http://doi.org/10.1051/0004-6361/201321591</a>	402	201.00
6	Eisenstein, D. J., Weinberg, D. H., Agol, E., Aihara, H., Allende Prieto, C., Anderson, S. F., ... Zhao, B. (2011). SDSS-III: Massive Spectroscopic Surveys of the Distant Universe, The Milky Way, and Extra-Solar Planetary Systems. <i>Astronomical Journal</i> , 142(3), 72. <a href="http://doi.org/10.1088/0004-6256/142/3/72">http://doi.org/10.1088/0004-6256/142/3/72</a>	396	79.20
7	Grogin, N. A., Kocevski, D. D., Faber, S. M., Ferguson, H. C., Koekemoer, A. M., Riess, A. G., ... Yun, M. S. (2011). CANDELS: THE COSMIC ASSEMBLY NEAR-INFRARED DEEP EXTRAGALACTIC LEGACY SURVEY. <i>Astrophysical Journal Supplement Series</i> , 197(2), 35. <a href="http://doi.org/10.1088/0067-0049/197/2/35">http://doi.org/10.1088/0067-0049/197/2/35</a>	338	67.60
8	Koekemoer, A. M., Faber, S. M., Ferguson, H. C., Grogin, N. A., Kocevski, D. D., Koo, D. C., ... Yun, M. S. (2011). CandelS: The Cosmic Assembly Near-Infrared Deep Extragalactic Legacy Survey-The Hubble Space Telescope Observations, Imaging Data Products, and Mosaics. <i>Astrophysical Journal Supplement Series</i> , 197(2), 36. <a href="http://doi.org/10.1088/0067-0049/197/2/36">http://doi.org/10.1088/0067-0049/197/2/36</a>	337	67.40
9	Alam, U., Sahni, V., Saini, T. D., & Starobinsky, A. A. (2003). Exploring the expanding Universe and dark energy using the statefinder diagnostic. <i>Monthly Notices of the Royal Astronomical Society</i> , 344(4), 1057-1074. <a href="http://doi.org/10.1046/j.1365-8711.2003.06871.x">http://doi.org/10.1046/j.1365-8711.2003.06871.x</a>	325	25.00
10	Alam, U., Sahni, V., Saini, T. D., & Starobinsky, A. A. (2004). Is there supernova evidence for dark energy metamorphosis? <i>Monthly Notices of the Royal Astronomical Society</i> , 354(1), 275-291. <a href="http://doi.org/10.1111/j.1365-2966.2004.08189.x">http://doi.org/10.1111/j.1365-2966.2004.08189.x</a>	320	26.67

Citation Style: APA 6<sup>th</sup> edition

**Globalization of Cosmology Research in India: Spatial Distribution of Publications:** Based on the author attributions, we can map the world-wide geographic distribution of Cosmology research publication. The major spatial clusters of research institutes located in Europe, followed by Asia and Africa. Several minor clusters distributed in other parts of the world. North America and South America did equal contribution. 2423 articles which included author address, source country and research institute. There were 72 collaborating Countries/ territories except India which participated in Indian institution in Cosmology research. Out of 70 Countries /territories there are four countries with which the collaboration is high, over 200 publications: United States (464), France (276), Germany (239) United Kingdom (205) and six countries with medium-high collaboration, over 100 publications: Italy (183), Russia (124), Spain (113), Netherlands (111), Canada (109) and Chile (108) and there are 20 countries with little collaboration over 25 publications and rest of 10

Counting just 1-2 collaborations, 21 with just 3-10 and 9 with just 11-24.

**Top Countries International Collaborations and impact of their research output:** Top 20 countries / territories were ranked based on the no. of total articles, along with the citations, percentage of internationally collaboration publications (Table-8). Out of these 20 countries / territories, the USA produced maximum publication 464 that is 19.150% of total publication with higher citations (14425). The AvgCPA (the average no. of citation per article) indicates the average impact of articles published by a country and the h-index (define as the no. of h papers among a country's no. of publications that have at least h citation each) are used to identify which country has the largest no. of high quality articles in the Cosmology research. It is seen from the below Table-8 that Cosmology related articles authored in Spain (Europe) have the highest average impact (AvgCPA=44.05) followed by Taiwan (Asia) AvgCPA=42.18 although USA ranked 14<sup>th</sup> in the AvgCPA index.

**Table-8**  
**Countries working collaboratively with Indian institutions on Cosmology during period 1960-2014**

Country	Continent	TP(%)	TC	AvgCPA	h-index
USA	North America	464(19.150)	14425	31.09	53
France	Europe	276(11.391)	8854	32.08	46
Germany	Europe	239(9.864)	7247	30.32	45
England	Europe	205(8.461)	7316	35.69	42
Italy	Europe	183(7.553)	6014	32.86	40
Russia	Europe	124(5.118)	5127	41.35	37
Spain	Europe	113(4.664)	4978	44.05	36
Netherlands	Europe	111(4.581)	3214	28.95	35
Canada	North America	109(4.499)	4305	39.5	35
Chile	South America	108(4.457)	3999	37.03	35
Australia	Australia	96(3.962)	2651	27.61	27
Japan	Asia	92(3.797)	3031	32.95	28
Switzerland	Europe	76(3.137)	2239	29.46	33
South Africa	Africa	75(3.095)	2413	32.17	33
Denmark	Europe	74(3.054)	2666	36.03	34
Poland	Europe	71(2.930)	2444	34.42	33
Wales	Europe	62(2.559)	2535	40.89	34
Taiwan	Asia	56(2.311)	2362	42.18	31
Norway	Europe	53(2.187)	2083	39.3	33
Peoples R China	Asia	51(2.105)	1538	30.16	20

TP= Total no. of Cosmology related articles published by a country (followed by the percentage of Cosmology related articles in the country of a total Cosmology related articles); TC = Total no. of citation received; AgCPA= Average no. of citations; h-index= no. of h papers among a country's no. of publications that have at least h citations each. Source: WoS

**Analysis of keywords:** Keyword analysis in research paper is very interesting in order to follow and identify the trends in the science and engineering branch<sup>5</sup>. As a result of our work a total of 6172 different keywords, from 1960 to 2014 in the Cosmology have been identified.

same meanings and in singular and plural forms were merged. A total 5617 unique Keywords are obtained. Among these unique keywords 2078 (36.99 %) appear once or twice at the most, we can deduce that this can be a sign of lack of research continuity or of a wide range of research focus.

The no. of analysed publications during the study period was 2423. In order to acquire correct results, the keywords with

Table-9 shows the most used keywords during the considered period.

**Hot topic and directions:** The order of Keywords changes in 5 decades and the later four year intervals. This change actually signifies the alterations in the hot fields of the research. The first three decades do not have any keywords, while the rest of the period under study sees appearance of various keywords. It is

observed that “Theory”, “Redshift”, “Observations”, “Dark Energy” and “Cosmological constant” are the five most frequently used keywords. Here is a table of the top 20 keywords.

**Table-9**  
**Top 20 most frequently used keywords for the study period**

Keywords	Total	%	1990-1999		2000-2010		2011-2014	
			NO	R	NO	R	NO	R
Cosmic Background Radiation	44	0.78	0	12	0	17	44	9
Cosmic strings	49	0.87	6	8	24	12	19	14
Cosmological constant	218	3.88	10	7	108	4	100	5
Cosmological models	101	1.79	10	7	53	7	38	10
Cosmological Parameters	79	1.4	0	12	28	10	51	7
Dark Ages	16	0.28	0	12	0	17	16	15
Dark Energy	305	5.42	0	12	90	6	215	1
Dark Matter	59	1.05	14	6	32	9	13	17
Diffuse Radiation	33	0.58	3	9	10	13	20	13
Distance Scale	15	0.26	2	10	9	14	4	19
Early Universe	102	1.81	17	5	38	8	47	8
First Stars	13	0.23	0	12	0	17	12	18
Inflation	214	3.8	24	3	91	5	99	6
Large-Scale Structure of Universe	79	1.4	17	5	38	8	24	12
Observations	370	6.58	23	4	166	3	181	2
Quantum cosmology	32	0.56	2	10	8	15	14	16
Redshift	397	7.06	60	2	180	2	157	4
Reionization	60	1.06	3	9	25	11	32	11
Supersymmetry	21	0.37	1	11	6	16	14	16
Theory	447	7.95	63	1	204	1	180	3

NO: Number of time occurrences; R : rank Source: WoS

**Table-10**  
**Top 20 Quick rising themes for the study period**

Keywords	V(t <sub>0</sub> )	V(t <sub>n</sub> )	t <sub>0</sub>	t <sub>n</sub>	CAGR (%)	R
Cosmic Background Radiation	1	28	2010	2014	130.03	1
Cosmic strings	1	2	1992	2014	3.2	17
Cosmological constant	2	22	1991	2014	10.99	11
Cosmological models	1	11	1991	2014	10.99	11
Cosmological Parameters	1	13	2000	2014	20.11	4
Dark Ages	4	5	2011	2014	7.72	12
Dark Energy	6	57	2003	2014	22.71	3
Dark Matter	1	4	1991	2014	6.21	15
Diffuse Radiation	1	4	1993	2014	6.82	14
Distance Scale	1	1	1992	2014	0	0
Early Universe	1	13	1991	2014	11.8	10
Inflation	2	24	1992	2014	11.96	9
Large-Scale Structure of Universe	5	11	1993	2014	3.83	16
Observations	2	64	1991	2014	16.26	6
Quantum cosmology	1	5	1991	2014	7.25	13
Redshift	2	39	1991	2014	13.79	8
Reionization	1	5	1997	2014	25.85	2
Supersymmetry	1	2	1999	2014	14.87	7
Theory	1	47	1991	2014	18.22	5

t<sub>0</sub>:the Initial (first) year (The Year in which no. of keywords occurrence first time) ; t<sub>n</sub>: the last year (No. of keywords occurrence); V(t<sub>0</sub>): Initial observed value (no. of keywords occurrence) ; V(t<sub>n</sub>): last observed value (no. of keywords occurrence) ; CAGR(%): Compound Annual Growth Rate (CAGR); R: Rank. Source: WoS

**Quick rising themes:** To identify the top most frequently occurring keywords and quick rising themes, the Compound Annual Growth Rate (CAGR) was put to use. The quick rising theme can symbolise the future research trends. The Compound Annual Growth Rate (CAGR) of top 20 keywords was calculated using the below mentioned formula:

$$CAGR(t_0, t_n) = (V(t_n)/V(t_0))^{\frac{1}{t_n-t_0}} - 1$$

V (t<sub>0</sub>): Initial observed value, V (t<sub>n</sub>): last observed value, t<sub>n</sub> - t<sub>0</sub>: number of years<sup>6</sup>.

Table-10 lists the top 20 keywords according to the CAGR and sorted them by their rank. The ranks in the said table show that “Cosmic Background Radiation” and “Reionization” and “Dark Energy” are three leading fields which attract more attention. “Dark Energy” (CAGR, 22.71%) is dominant quantity and anyal growth rate wise respectively.

## Conclusion

Results of this study relating to the scientometric analysis of the research on the Cosmology during 1960-2014 provided helpful

insights into the research on the Cosmology on many fronts in terms of paper quantity, top journals, keyword frequencies, collaborations and Institutions' outputs. In total 2423 articles were published during the investigation period. The following conclusions have been drawn from this study: i Cosmology related research has significantly increased in the last 54 years. The growth curve fit 4<sup>th</sup> degree polynomial with the  $R^2 = 0.983$ . This growth has been slow rate and significantly high though not exponential in nature. It is concluded that the growth is on a rise and will surely increase further. The results also provided valuable information on the citations made to the Cosmology research papers. Total Number of Citations, Average Citations per Item, and H-index. There were 40944 total citations with 16.90 average citations to 2423 papers on the cosmology research from this study. The research field has had a significant impact on the general literature with H-index of 74, a rough measure of its impact. ii A total of 54 journals had published 2423 articles on Cosmology. The most active journal was "Astrophysics and Space Science" published by Springer from Netherlands which published 434 (17.912%) of the total 2423 article, followed by "Physical Review D 420 (17.334%) " and "Monthly Notices of the Royal Astronomical Society 356(14.693%)". The results also provided valuable information on the citations received by journal. the journal "Astrophysical Journal Supplement Series" published by IOP Publishing for the American Astronomical Society in USA has the highest average impact (AvgCPA=90.20) although the journal "Astrophysics and Space Science" has the highest no. of publication but ranked 15<sup>th</sup> in the AgvCPA index. iii A total of 2423 articles on Cosmology appeared from 1605 institutions. Indian institution. Inter University Centre for Astronomy Astrophysics contributed highest no. of publications (531), followed by Tata Institute of Fundamental Research, Mumbai, Indian Institute of Astrophysics had published 279 and 196 papers respectively. It has been found that Cosmology related articles authored in foreign institution (United States Department of Energy) have the highest average impact (AvgCPA=64.11). Among Indian institution, Inter University Centre for Astronomy Astrophysics ranked 15<sup>th</sup> in the AgvCPA (30.38) index. (iv) A total of 12599 authors contributed on Cosmology research. The most active author was Srikanand, R produced maximum no. of publications 101 i.e. 4.168 % of total publications 2423 with ranked first followed by Chakraborty, S and Petitjean, P.

It is important to note that the highest average impact factor is that of the articles authored by Mukherjee, S (AvgCPA=43.60) followed by Yoshida, S (AvgCPA=43.34) although Sagar, R ranked 12<sup>th</sup> in the AgvCPA index. (v) For globalization of Cosmology Research in India, 70 Countries/territories participated in Cosmology research. USA produced maximum publications (464) followed by France (276) and Germany (239) both comes under European continent. Spain (Europe) have the highest average impact (AvgCPA=44.05) followed by Taiwan (Asia) AvgCPA=42.18 although USA ranked 14th in the AgvCPA index. (vi) The keyword analysis of the studied publications revealed the hot direction and quick rising themes of Cosmology research. There are 20 top most frequently used keywords, "Theory", "Redshift", "Observations", "Dark Energy" and "Cosmological constant" were the some of them hottest issues of Cosmology research. There are 20 top quick rising themes which calculated CAGR. "Cosmic Background Radiation" and "Reionization" and "Dark Energy" are the some of them.

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