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Cosmology research in India: a scientometric study

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Abstract: The scientometric study of 1198 articles on Cosmology research in India spanning over the years 1999 to 2012 downloaded from *Web of Science* has been executed in this paper. The study analyses literature growth trends, which reveals a uniform growth of literature over the said time span with a little droop in the year 2010. It also examines collaborations with different countries worldwide. The authorship pattern, document types involved and active Indian institutions co-coordinating research in this subject area have also been studied. Bradford law of scattering was employed to identify the core journals and Lotka's law was employed to study the authors' productivity pattern.

Keywords: Scientometrics, informetrics, bibliometrics, cosmology, astrophysics research, Bradford's law, Lotka's law, research trend in India, Scientometric study of cosmology

1. Introduction

The main purpose of cosmology is to depict a unified scientific description of the entire universe. In ancient era, at the beginning of human civilization, the sky and the earth were considered as the only two fundamental components of the universe, and they were given the status of father and mother respectively. With the advancement of knowledge, the sky was found to be occupied by increasingly larger entities, demoting the earth to the position of a minuscule fleck in the vast universe. The earth, which has dimension of the order of 10^4 km, is a part of the solar system having an extent of about 10^{10} km, which is million times larger than the earth. Also, our solar system itself occupies a little corner of the great system of stars known as the Milky Way galaxy, which has a diameter of 10^{18} km and which is 100 million times larger than the size of the solar system. Finally, the Milky Way itself is only one among the billions of galaxies which build up the entire universe, where the distances are of the order of 10^{24} km that are larger by another factor of one million[1]. Modern cosmology deals with this universe of galaxies. As Narlikar[2] pointed out that "No branch of science can claim to have a bigger area of interest than cosmology, for cosmology is the study of the universe, and the universe by definition contains everything….Astronomy started as a study of the properties of planets and stars, and gradually reached out to include the limits of the Milky Way system, which is our galaxy. Modern astronomical techniques have taken the subject beyond the Galaxy to distant objects from which light may take billions of years to reach us. Cosmology is thus concerned mainly with this extragalactic world. It is a study of the large-scale structure of the universe extending to distances of billions of light-years". The domain of cosmology belongs to the broad subject area of astronomy and astrophysics.

In India, there is a long tradition of astronomical studies and observations since dates back to several B.Cs. *Yajurveda* mentions of *Nakshatradarsha* (astronomer) and *Nakshatra Vidya* (astronomy) has been mentioned in *Chandyogyaponishad* at several places. In ancient India astronomy was considered as one of the six *Vedangas*, which are *Siksha*, *Kalpa*, *Vyakarana*, *Nirukta*, *Jyotisha* (astronomy) and *Chhanda*[3]. Indian astronomy may thus be reckoned as old as the Vedas. Astronomical calculations like calculations of eclipses, time of full moon and new moon etc. had a vital role in any important public or personal activity that can be evidenced at a number of places in Ramayana and Mahabharata. The Rig Veda contains number of *sloakas* about the universe (*Bramhbhanda*) that may be surmised as themed on astronomy, astrophysics and cosmology. The ancient Indian *Rishis* had deep insight in the concept of infinity and the universe. In the line of great mathematician-astronomers since the classical age of Indian mathematics and astronomy, Aryabhatta may be regarded as the foremost stalwart. He is the author of several treatises on mathematics and astronomy, some of which are lost. His major work, *Aryabhatiya*, a compendium of mathematics and astronomy, was extensively referred to in the Indian mathematical literature and has survived to modern times. The mathematical part of the *Aryabhatiya* covers arithmetic, algebra, plane trigonometry, and spherical trigonometry. It also contains continued fractions, quadratic equations, sums-of-power series, and a table of sines. The *Arya-siddhanta*, a lot work on astronomical computations, is known through the writings of Aryabhata's contemporary, Varahamihira, and later mathematicians and commentators, including Brahmagupta and Bhaskara I. This work appears to be based on the older Surya Siddhanta. It also contained a description of several astronomical instruments[4].

The seed of modern cosmological and astrophysical research in India was sown in 1786 at the then Madras when the East India Company resolved to establish an observatory there for promoting the knowledge of Astronomy, Geography and Navigation in India. The Madras series of astronomical observations had commenced in 1787 through the efforts of a member of the Madras Government, William Petrie, who had in his possession two three-inch achromatic telescopes, two astronomical clocks with compound pendulums and an excellent transit instrument. This equipment formed the nucleus of instrumentation of the new observatory, which soon embarked on a series of observations of the stars, the moon and eclipses of Jupiter's satellites, with the accurate determination of longitude, as its first concern. The Helium lines were discovered during the total solar eclipse in 1868 by Pogson and Janssen. This initial effort led to the establishment of the Kodaikanal Observatory in 1899. In 1955, an ionosonde and geomagnetic facilities were installed at the Kodaikanal Observatory. In 1977, many of the astronomers from Kodaikanal shifted to Bangalore and established the Indian Institute of Astrophysics (IIA)[5].

Besides IIA, today so many other institutions are engaged with study and research in astronomy and astrophysics. To mention a few, Aryabhatta Research Institute of Observational Sciences, Nainital; Harish Chandra Research Institute, Allahabad; Raman Research Institute, Bengaluru; National Centre for Radio Astrophysics, TIFR, Pune; Inter-University Centre for Astronomy and Astrophysics, Pune; Indian Institute of Science, Bengaluru; IITs; University of Delhi; Jadavpur University, Kolkata et al. Some Indian stalwarts in this area are Subramanian Chandrasekhar, Meghnad Saha, Venkataraman Radhakrishnan, J.V. Narlikar et al. Chandrasekhar's most notable work was the astrophysical Chandrasekhar limit. The limit describes the maximum mass of a white dwarf star, which is approximately equal to 1.44 times solar mass. It is thus minimum mass of a star that must be exceeded to ultimately collapse into a neutron star or black hole. The limit was first calculated by Chandrasekhar in 1930 during his voyage from India to Cambridge for graduate studies. In 1999, NASA named the third of its four "Great Observatories" after Chandrasekhar[6]. Meghnad Saha's best-known work concerned the thermal ionization of elements, and it led him to formulate what is known as the Saha equation. This equation is one of the basic tools for interpretation of the spectra of stars in astrophysics. By studying the spectra of various stars, one can find their temperature and from that, using Saha's equation, the ionization state of the various elements making up the star can be determined[7]. Venkataraman Radhakrishnan was associated with the field of radio astronomy since 1950s. He was one of the persons who founded the science of observational astronomy in India. His observations and theoretical insights helped the community in unraveling many mysteries surrounding pulsars, interstellar clouds, galaxy structures and various other celestial bodies[8]. Narlikar is a proponent of steady state cosmology. He developed with Sir Fred Hoyle the conformal gravity theory, commonly known as Hoyle–Narlikar theory. It synthesizes Albert Einstein’s Theory of Relativity and Mach's Principle. It proposes that the inertial mass of a particle is a function of the masses of all other particles, multiplied by a coupling constant, which is a function of cosmic epoch. In cosmologies based on this theory, the gravitational constant G decreases strongly with time[9]. According to Simon Mitton[10], the biggest mystery in modern cosmology is to understand why the expansion rate of the universe is accelerating. The 2011 Nobel Prize in Physics was awarded for the discovery of the acceleration, which commenced in a cosmic jerk five billion years ago. In the context of R & D in today’s Indian S & T, cosmology is one of the most dynamic areas conducting active research.

2. Scientometric study

Scientometric study is a statistical method of counting to evaluate and quantify the growth of a subject. The research trend during the said time span would be clearly understood from this study and a predictive projection may be made for anticipatable future. There are several areas in science, social science and arts for which scientometric studies were carried out. A number of studies have been accomplished to evaluate research output and productivity in different areas of physics. In 2009, Kumara[11] et al carried out scientometric studies in major areas of physics and engineering sciences. Some other scientometric studies in different subject domains include Jain[12] (Laser research), Kademani[13] (Thorium research), Stanhill[14] (climatology), Garg[15] (Laser patent literature), Upadhye[16] (physics Noble lectures), Lee[17] (molecular and cell biology), Schummer[18] (chemistry), Braun[19] and Gupta[20] (Fullerene research) et al. A number of scientometric studies in the areas of astronomy and astrophysics have also been executed. Basu[21] evaluated research output of global astronomy and astrophysics by an analysis of papers in the Science Citation Index identified with a special filter and found out leading Indian institutions and authors. Jamali[22] attempted scientometric analysis from a new angle. The results presented by him revealed intradisciplinary differences within physics and astronomy in terms of reading behaviour. Leta[23] executed a comparative analysis of Brazilian research trend in astronomy, immunology and oceanography. Davoust[24] studied publishing activities of the astronomers since 1969. Fernández[25] studied transitional steps from individual science to collectivization in astronomy during twentieth century. Uzun[26] studied publication pattern of Turkish astronomers. Marx[27] showed the transition from the static view of the universe to the big bang theory in cosmology through citation analysis. The general definition and scope of scientometrics for all major science subjects in the context of web resources (cybermetrics) was discussed by Sen[28].

3. Objectives

The principal objective of the study is to find:

- Pattern of growth of literature since 1999 to 2012
- Authorship pattern of the articles and to find out core authors
- Core journals of this subject domain
- Applicability of Bradford's law and Lotka's law in this domain
- Collaborating countries
- Document types in which cosmology literature was published
- Core Indian institutions carrying out research in this subject domain
- Subject areas embracing the cosmology facet

4. Scope and methodology

The data for this study was downloaded at Central Library, Indian Association for the Cultivation of Sciences, Kolkata, from the *Web of Science* database. For downloading the data, the search term applied was “Cosmology” AND Author address= “India”. This may be considered as central keyword of the topic discussed. As indicated by Lancaster[29], main heading takes care of synonyms, nearly synonyms and homonyms. Therefore, the maximum retrieval may be expected by using this term. A total of 1198 records spanning over the years 1999 to 2012 were downloaded on 29th May, 2013. Each record contains English language abstract with detail bibliographic information, e.g. author, name of journal, author address, affiliation, keywords, cited items etc. The downloaded data was analysed for source items to find out the research trend. It has been found that observed data are in approximate conformity with Bradford’s[30] and Lotka’s[31] distributions.

5. Data analysis

5.1. Growth of literature: Figure 1 shows yearwise variation in no. of cosmology research articles published from India since 1999 to 2012. In all, 1198 articles came out over this time span. The no. of articles in the year 1999 was 61, while that in 2012 was 122, i.e. just doubled in fourteen years, which means 7.7% growth on average. The lowest no. of article was published in the year 2000, i.e. 56 (4.7%) and the highest no. of article was published in 2011, i.e. 133 (11.1%). The no. of articles published along with corresponding fluctuations, percentages and cumulative numbers are presented in Table 1. As growth is assisted at times by decay in no. of literature during the said time span, therefore fluctuation was negative for five years (2000, 2004, 2007, 2010 and 2012) and positive for other years. The average fluctuation rate over the entire time span is 7.2%. The mean straight line in Figure 1 is drawn by the method of least squares. The yearwise variation of percentage of articles is presented in Figure 2, which shows several fluctuations, in particular the fluctuations between 2009 and 2011 is noteworthy. A steep drop in no. of articles in the year 2010 is an aberration in such more or less uniform growing trend. The yearwise variation of cumulative no. of articles is presented in Figure 3, which shows a uniform growth represented by the straight line. The growth pattern of published literature thus is in good consonance with straight line. It is thus evident that, in India cosmology research has been continued since long and at present it is also growing with momentum.

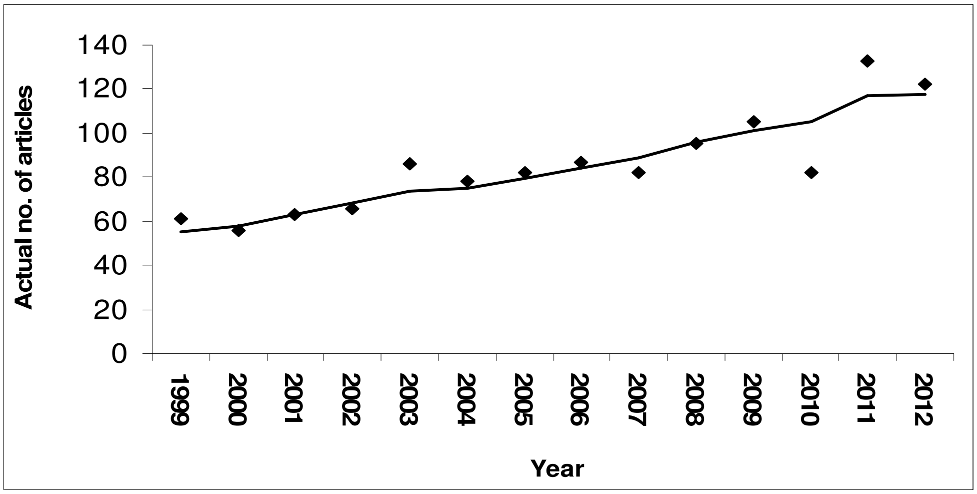

Figure 1: Yearwise variation of no. of articles

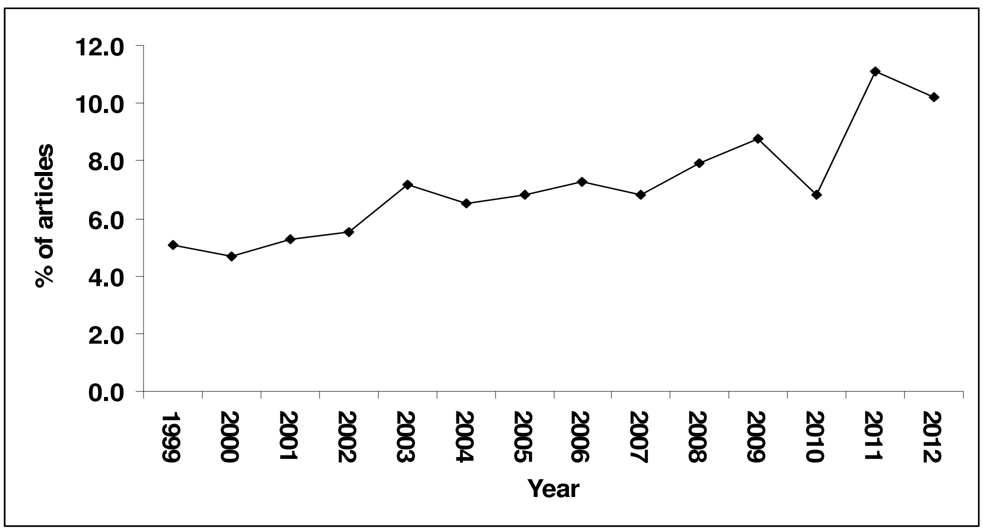

Figure 2: Yearwise variation of percentage of articles

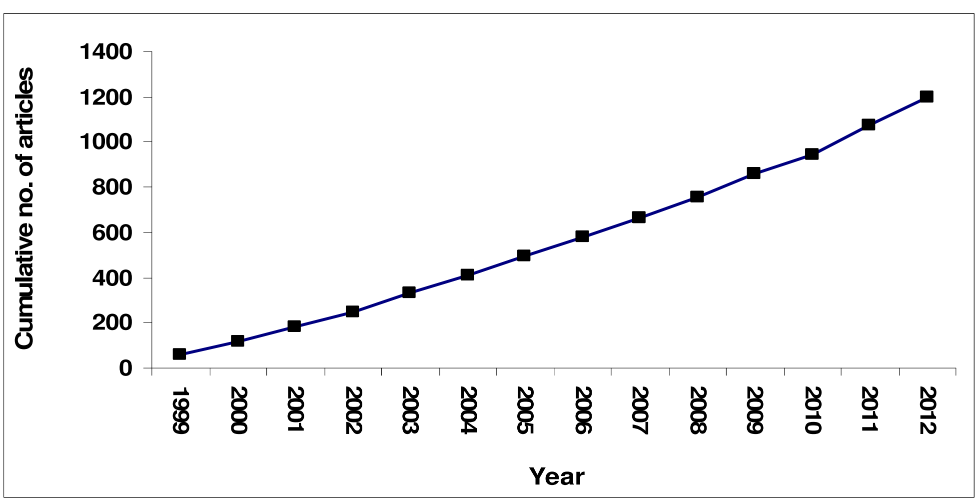

Figure 3: Yearwise variation of cumulative no. of articles

Table 1: Yearwise distribution of no. of articles

S. No.	Year	No. of articles	% of articles	% of fluctuation	Cumulative no. of articles
1	1999	61	5.1		61
2	2000	56	4.7	-8.2	117
3	2001	63	5.3	12.5	180
4	2002	66	5.5	4.8	246
5	2003	86	7.2	30.3	332
6	2004	78	6.5	-9.3	410
7	2005	82	6.8	5.1	492
8	2006	87	7.3	6.1	579
9	2007	82	6.8	-5.7	661
10	2008	95	7.9	15.9	756
11	2009	105	8.8	10.5	861
12	2010	82	6.8	-21.9	943
13	2011	133	11.1	62.2	1076
14	2012	122	10.2	-8.3	1198
	Total	1198			

5.2. Authorship pattern: The authorship pattern for all publications is presented in Table 2. The research team sizes have been categorized according to no. of authors involved are presented in Table 3. The relative distribution of articles over different team sizes are graphically presented in Figure 5. The single-author involvement is indicated as solo and two-author involvement is indicated as duet. The solo and duet researches have not been recognized as team research as it is customary that at least three members are required to form a team. The three-author and four-author teams have been recognized as very small. The teams with number of members ranging from five to ten are categorized as small. The medium-sized teams consist of number of members ranging from eleven to thirty. The number of authors in the large teams ranges from thirty one to fifty and lastly, if the number of authors exceeds fifty then the team has been recognized as very large one. In this study, eighteen such teams have been found. The number of authors in very large team varies over a wide range, i.e. 51 to 715. The numbers of authors found in all very large teams are 51, 53, 57, 63, 64, 107, 124, 156, 168, 170, 225, 244, 391, 405, 411, 449, 655 and 715. Such a gargantuan authorship figure is quiet unusual in any discipline but observed in the area of cosmology. It is thus a special characteristic feature of this subject domain unlike others. It has also been observed that for more than 300 authored publications the authors involved belong to almost all major nations throughout the Globe. Such huge authored publications thus may be reckoned as global publications literally in true sense. Cosmology deals with the universe containing entities ranging from infinitesimally minute particles to infinitely large galaxies, or Yocto (10^{-24}) to Yotta (10^{24}) in scale. Perhaps it may be metaphorically analogized that just like cosmology its authorship pattern also ranges from one to infinity. The very large team researches are generally experimental in nature and involved with observational astronomy in most cases. These works are controlled from different observatories by different groups of scientists that cause deluge in team size.

The actual numbers of publications corresponding to each and every kind of authorship are given along with percentage values shown in adjacent parenthesis (Table 2). The authorship pattern is graphically presented in Figure 4. It is observed that two-authored and three–authored publications together (59%) outshined the other modes of authorship. The two-authored publications account highest share, i.e. almost 33% (390 in number). Single-authored publication is also fairly large, i.e. 22.4% and more than three authored publication also holds a potential strength, i.e. 18.2%. Theoretical researches in general are published by single or two authors, while an experimental set up requires large group involvement for its smooth functioning and easy progress. Hence it is clear that team research is dominant here with very small size though large-sized teams are also there. Both the solo and duet researches (single and two authors) together account for 55%. In case of team research the numbers of team members are mostly 3, 4, 5 and 6 that accounts 39.7% of total strength. The percentage of team research with more than ten members is only 3.3% and the same with more than fifty members is 1.5%. Thus large teams are hardly involved here compared to small teams.

Table 2: Distribution of authorship pattern over all articles

S. No.	No. of authors	No. and % of publications
1	1	268 (22.4%)
2	2	390 (32.6%)
3	3	322 (26.9%)
4	4	110 (9.2%)
5	5	29 (2.4%)
6	6	15 (1.3%)
7	7	11 (0.9%)
8	8	9 (0.8%)
9	9	4 (0.3%)
10	11	1 (0.1%)
11	12	1 (0.1%)
12	13	2 (0.2%)
13	14	1 (0.1%)
14	15	3 (0.3%)
15	17	1 (0.1%)
16	19	2 (0.2%)
17	22	2 (0.2%)
18	26	1 (0.1%)
19	27	1 (0.1%)
20	31	1 (0.1%)
21	33	2 (0.2%)

22	36	1 (0.1%)
23	40	1 (0.1%)
24	42	1 (0.1%)
25	49	1 (0.1%)
26	>50	18 (1.5%)

Table 3: Categorization of research team size according to no. of authors involved

Team size	No. of authors involved	No. and % of publications
Solo	1	268 (22.4%)
Duet	2	390 (32.6%)
Very small	3 -- 4	432 (36.1%)
Small	5 -- 10	68 (5.7%)
Medium	11 -- 30	15 (1.3%)
Large	31 -- 50	7 (0.6%)
Very large	>50	18 (1.5%)

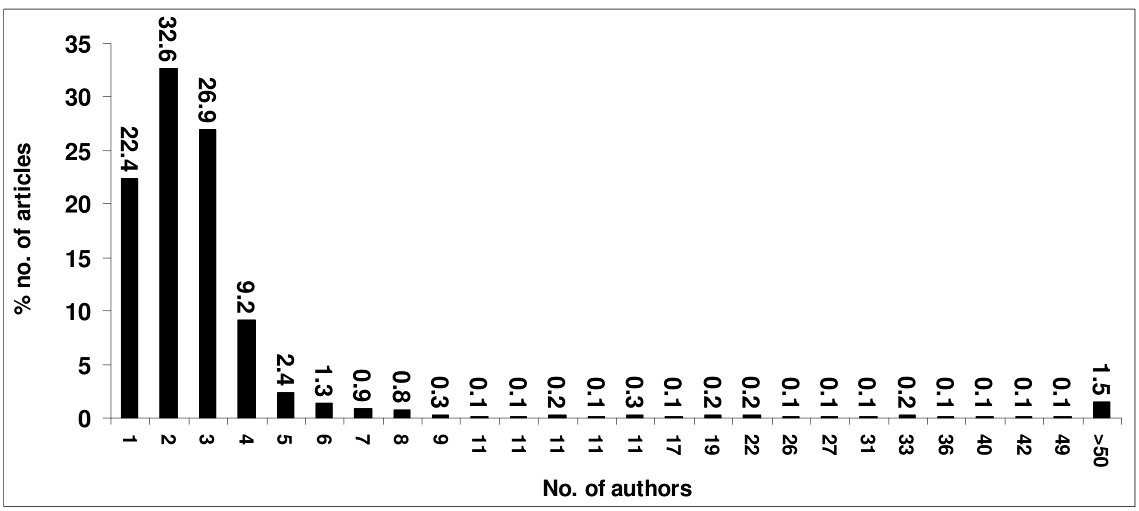

Figure 4: Distribution of authorship pattern

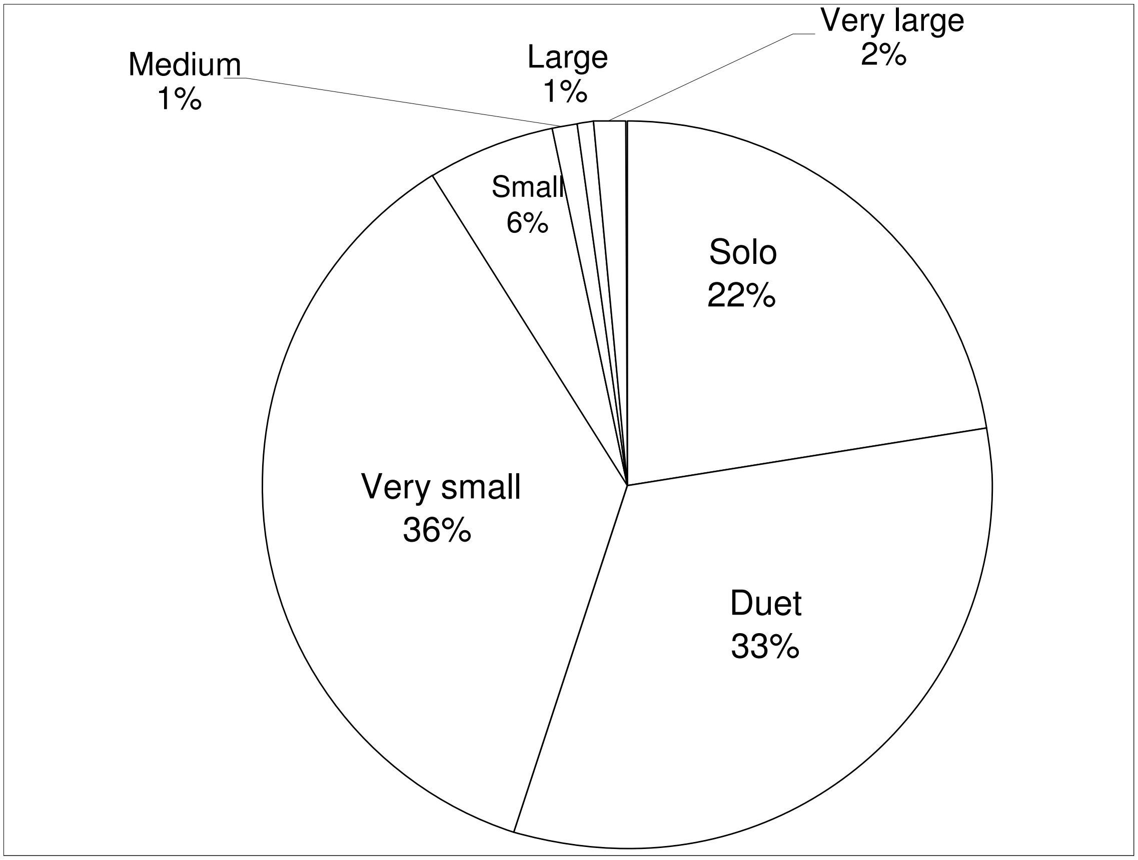

Figure 5: Relative distribution of articles over different team size

5.3. Author productivity and Lotka's law: Lotka's law describes the frequency of publication by different authors in a given subject field. It states that the number of authors making contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that make a single contribution, is about 60 percent. This means that out of all the authors in a given field, 60 percent will have just one publication, and 15 percent will have two publications ($1/2^2$ times of 60). Seven percent authors will have three publications ($1/3^2$ times of 60), and so on. According to Lotka's law of scientific productivity, only six percent of the authors in a field will produce more than 10 articles. Lotka's law, when applied to large bodies of literature over a fairly long period of time, can be accurate in general, but not statistically exact. The general form of Lotka's law can be expressed as $y=c/x^n$ where y=percentage of authors, x=number of articles published by an author, c=constant and –n=slope of the log-log plot. In this study, 3441 authors contributed 1198 articles; on an average 2.9 (~3) authors per articles. The number of authors per article is fairly large here. It may thus be anticipated that team research is very frequent here. Among 3441 authors, 1914 authors (55.6%) contributed only one article; 698 authors (20.3%) contributed two articles; 340 (9.9%) authors contributed three articles and 240 (7%) authors contributed four articles. Hence the author productivity in case of Indian cosmology research approximately confirms Lotka's law. Actually two-authored article is comparatively larger than single-authored article in this case. In general, single-authored article amounts nearly 60% and two-authored article is 15%. But here single-authored article amounts nearly 56%, i.e. 4% less than usual value, which was appended to two-authored article to make it nearly 20%, i.e. 5% more than usual value of 15%. Usually 7% authors will have three publications, but here 9.9% (~10%) authors have been found having three publications while 7% authors are found having four publications. Figure 6 shows the graph in which the Ln(no. of author) is plotted against Ln(no. of publications). The log-log plot of cumulative number of authors and their cumulative number of contributions is presented in Figure 7 that gives an approximate straight line which is not in exact confirmation with Lotka's law, but approximately so.

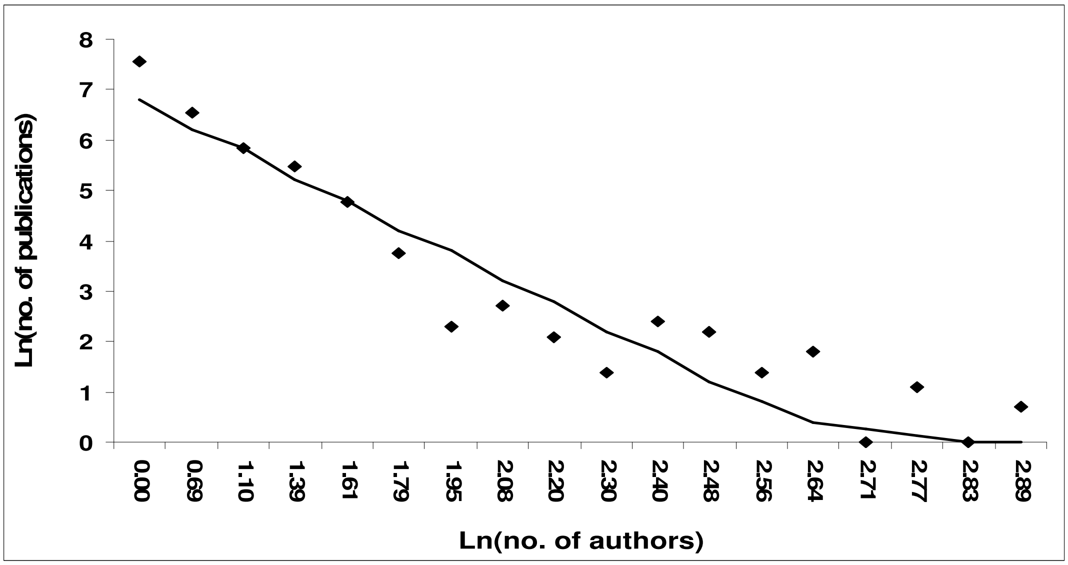

Figure 6: Ln (no. of authors) vs. Ln (no. of publications) plot

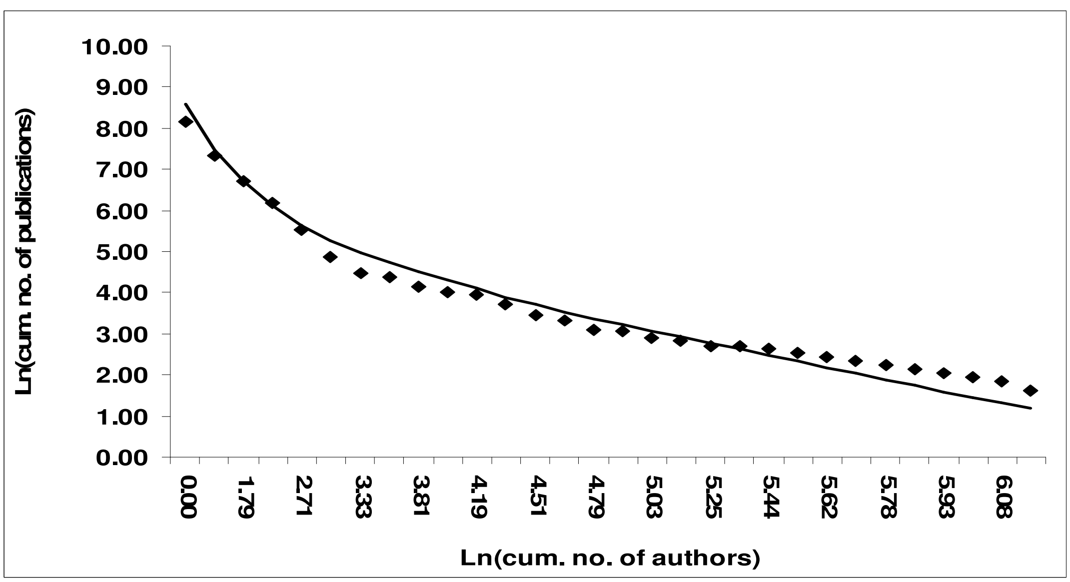

Figure 7: Ln (cum. no. of authors) vs. Ln (cum. no. of publications) plot

The ranking of contributing authors along with list of top fifty two authors who contributed more than ten articles are presented in Table 4. It is observed that A. Pradhan is the most productive author with 57 publications followed by S. Chakraborty (46 publications), R. Srianand (34 publications), S. Bharadwaj (33 publications) and P. Petitjean (31 publications). The celebrated cosmologist and astrophysicist J. V. Narlikar has been ranked as 7th as shown in Table 4. The number of articles contributed vs. percent contribution by each author is plotted in Figure 8, which shows an initial straight line and curvature for more than twenty articles.

Table 4: Ranking of authors

S. No.	Rank	Authors' name (surname first)	Number and % of articles contributed by each author
1	1	Pradhan, A	57 (0.77%)
2	2	Chakraborty, S	46 (0.62%)
3	3	Srianand, R	34 (0.46%)
4	4	Bharadwaj, S	33 (0.45%)
5	5	Petitjean, P	31 (0.42%)
6	6	Debnath, U	29 (0.39%)
7	6	Sami, M	29 (0.39%)
8	6	Singh, CP	29 (0.39%)
9	6	Souradeep, T	29 (0.39%)
10	7	Narlikar, JV	28 (0.38%)
11	7	Padmanabhan, T	28 (0.38%)
12	8	Ledoux, C	27 (0.37%)
13	9	Adhav, KS	26 (0.35%)
14	9	Sahni, V	26 (0.35%)
15	10	Choudhury, TR	20 (0.27%)
16	11	Chengalur, JN	18 (0.24%)
17	11	Ray, S	18 (0.24%)
18	12	Paul, BC	17 (0.23%)
19	13	Date, G	16 (0.22%)
20	13	Khadekar, GS	16 (0.22%)
21	13	Sen, AA	16 (0.22%)
22	14	Kanekar, N	15 (0.20%)
23	15	Bagla, JS	14 (0.19%)
24	15	Bali, R	14 (0.19%)
25	15	Chatterjee, S	14 (0.19%)
26	15	Das, S	14 (0.19%)
27	15	Nath, BB	14 (0.19%)
28	15	Tsujikawa, S	14 (0.19%)
29	16	Panda, S	13 (0.18%)
30	16	Seshadri, TR	13 (0.18%)
31	16	Sethi, SK	13 (0.18%)
32	16	Singh, P	13 (0.18%)
33	17	Jain, D	12 (0.16%)
34	17	Jain, P	12 (0.16%)

35	17	Kumar, S	12 (0.16%)
36	17	Mitra, S	12 (0.16%)
37	17	Modak, B	12 (0.16%)
38	17	Noterdaeme, P	12 (0.16%)
39	17	Rahaman, F	12 (0.16%)
40	17	Rama, SK	12 (0.16%)
41	17	Sanyal, AK	12 (0.16%)
42	18	Bansod, AS	11 (0.15%)
43	18	Biswas, S	11 (0.15%)
44	18	Dev, A	11 (0.15%)
45	18	Katore, SD	11 (0.15%)
46	18	Maharana, J	11 (0.15%)
47	18	Majumdar, S	11 (0.15%)
48	18	Pal, S	11 (0.15%)
49	18	Pandey, B	11 (0.15%)
50	18	Roukema, BF	11 (0.15%)
51	18	Sidharth, BG	11 (0.15%)
52	18	Subramanian, K	11 (0.15%)
53	19	4 authors	Contributed 10 articles each 0.54% (total) 0.14% (per unit author)
54	20	8 authors	Contributed 9 articles each 0.97% (total) 0.12% (per unit author)
55	21	15 authors	Contributed 8 articles each 1.62% (total) 0.11% (per unit author)
56	22	10 authors	Contributed 7 articles each 0.95% (total) 0.10% (per unit author)
57	23	43 authors	Contributed 6 articles each 3.49% (total) 0.08% (per unit author)
58	24	117 authors	Contributed 5 articles each 7.92% (total) 0.07% (per unit author)
59	25	240 authors	Contributed 4 articles each 12.99% (total) 0.05% (per unit author)
60	26	340 authors	Contributed 3 articles each 13.81% (total) 0.04% (per unit author)
61	27	698 authors	Contributed 2 articles each 18.9% (total) 0.03% (per unit author)
62	28	1914 authors	Contributed 1 articles each 25.91% (total) 0.01% (per unit author)

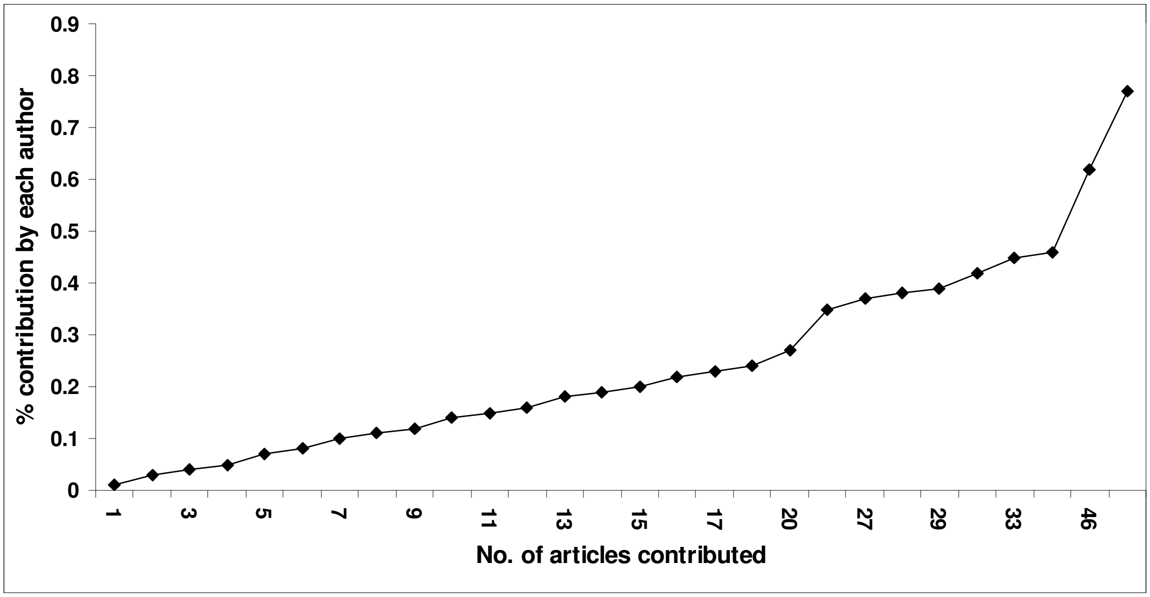

Figure 8: No. of articles contributed vs. % contribution by each author plot

5.4. Collaboration pattern: Of the 1198 contributions in total, 937 (78%) papers were contributed due to collaborative research work of India with other countries and remaining 261 (22%) papers came out without any collaborative effort. The topmost collaborating country is USA (12.1% contribution) followed by France (6.6%) in the second position, Germany (6.2%) in the third position, England (6.1%) in the fourth position and Italy (4.4%) in the fifth position. These are top five collaborating nations. The next five countries in decreasing order of contributions are Russia, Japan, Spain, Chile and Australia respectively. The list of collaborating countries is presented in Table 5 and the relative percentage contribution is presented in Figure 10. The overall relative share of collaborative and non-collaborative research is shown in Figure 9. It is evident that non-collaborative effort in research is far behind the collaborative venture for this subject area.

Table 5: List of collaborating countries

Collaborating countries	No. and % of contributions
USA	147 (12.13%)
France	80 (6.6%)
Germany	75 (6.19%)
England	74 (6.11%)
Italy	53 (4.37%)
Russia	48 (3.96%)
Japan	44 (3.63%)
Spain	34 (2.81%)
Chile	30 (2.48%)
Australia	28 (2.31%)

Netherlands	24 (1.98%)
Peoples R China	22 (1.82%)
Canada	20 (1.65%)
Iran	14 (1.16%)
Scotland	14 (1.16%)
South Korea	14 (1.16%)
South Africa	12 (0.99%)
Poland	11 (0.91%)
Sweden	11 (0.91%)
Ukraine	11 (0.91%)
Wales	11 (0.91%)
Brazil	10 (0.83%)
Mexico	10 (0.83%)
Switzerland	10 (0.83%)
Denmark	9 (0.74%)
Pakistan	9 (0.74%)
Israel	8 (0.66%)
Turkey	7 (0.58%)
Belgium	6 (0.5%)
Finland	5 (0.41%)
Norway	5 (0.41%)
Portugal	5 (0.41%)
Taiwan	5 (0.41%)
Ireland	4 (0.33%)
Kazakhstan	4 (0.33%)
New Zealand	4 (0.33%)
Thailand	4 (0.33%)
Czech Republic	3 (0.25%)
Hungary	3 (0.25%)
Malaysia	3 (0.25%)
Argentina	2 (0.17%)
Austria	2 (0.17%)
Bulgaria	2 (0.17%)
Egypt	2 (0.17%)
Greece	2 (0.17%)

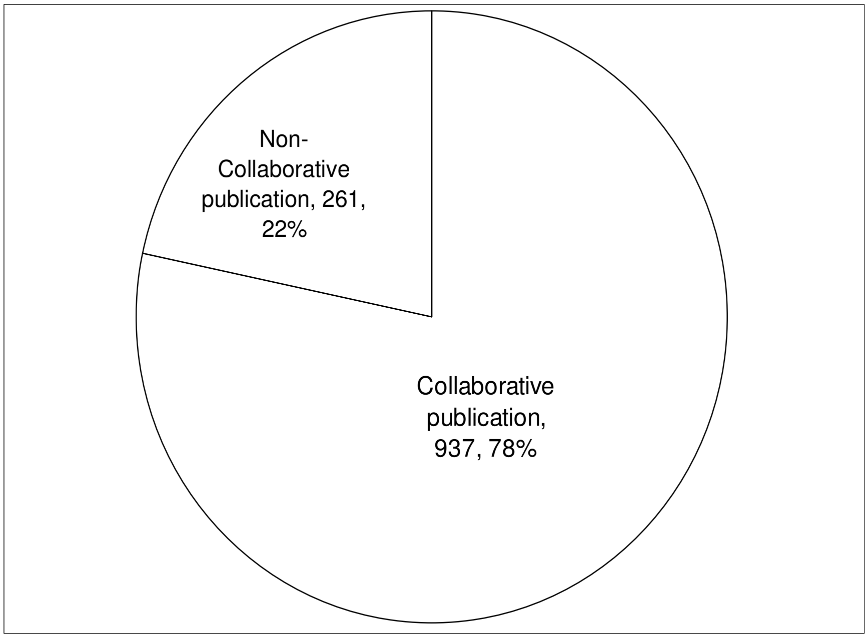

Figure 9: Relative share of collaborative and non-collaborative research

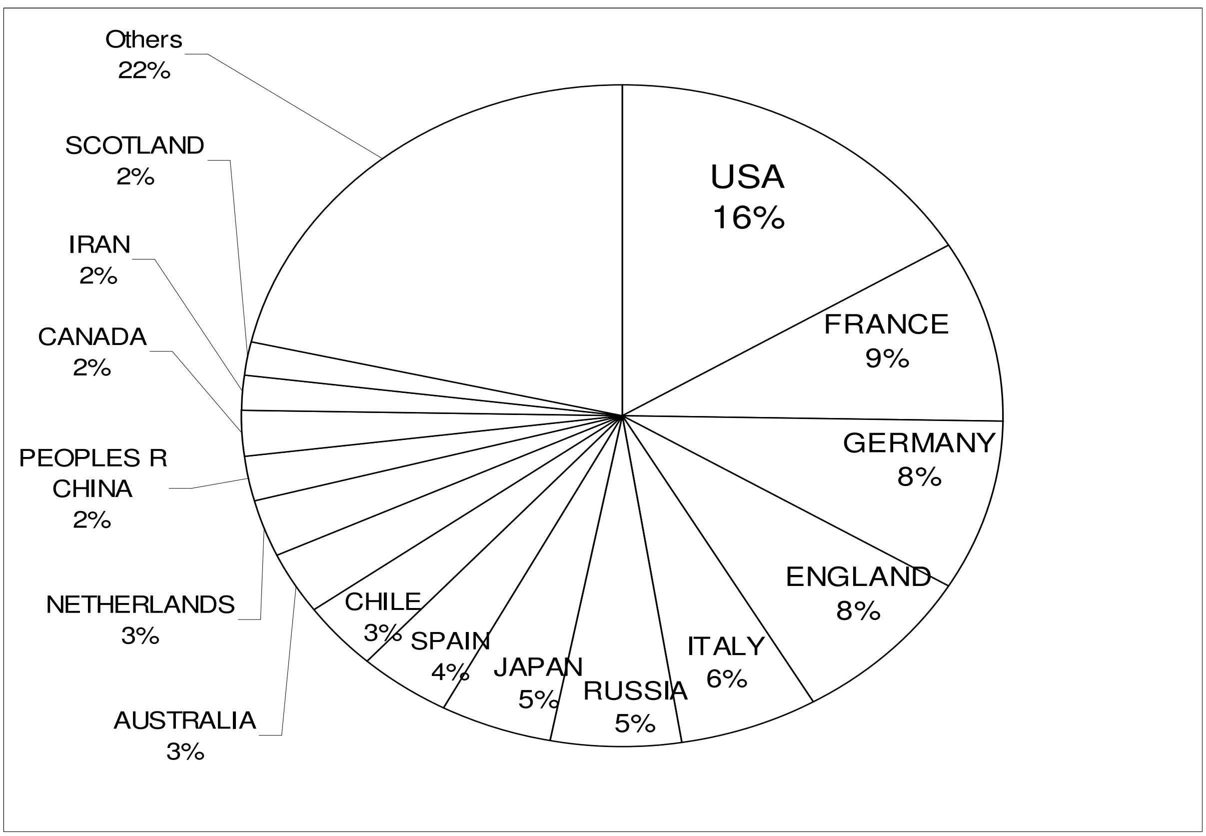

Figure 10: Percentage distribution of literature over collaborating countries

5.5. Document type: Out of 1198 publications, journal articles amount 1039 that accounts for 87%; conference and seminar papers amount 100 that accounts for 8.3%; review amounts 38 (3.2%); editorial material amounts 10 (0.8%); the no. of letters is 8 (0.7%) and the no. of reprints is 3 (0.3%). It is thus evident that journal articles are most usual form of outcome of research publication in this subject area. The strength of seminar and conference papers as probable research outcome is far behind the journal articles. Other forms of research outcomes are negligibly trifle here.

Table 6: Different document types

Document Types	No. and % of records
Article	1039 (86.7%)
Proceedings paper	100 (8.3%)
Review	38 (3.2%)
Editorial material	10 (0.8%)
Letter	8 (0.7%)
Reprint	3 (0.3%)

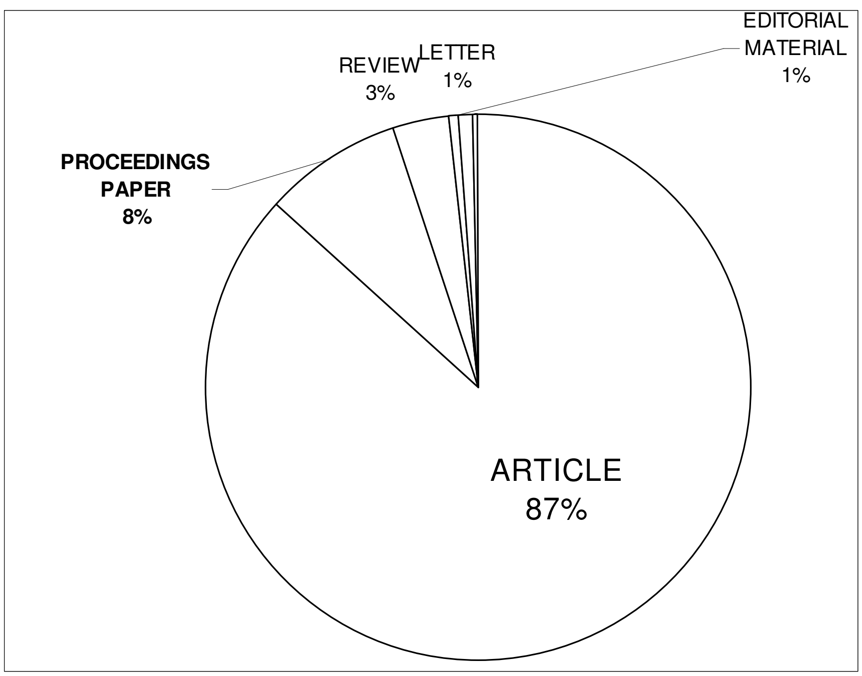

Figure 11: Relative share of different document types

5.6. Core journals and Bradford's law: In all, there are 127 journals, which published 1198 articles. The scattering of articles over journals may be studied by using Bradford's law of bibliographic scattering. The Bradford's distribution is generally used for identifying the 'core' journals. Core journals are central to a subject because they mainly produce a subject's maximum probable content. Bradford's law gives information about the core journals in a specific subject field. Figure 12 shows Bradford plot, where cumulative number of articles is plotted against the journal's rank.

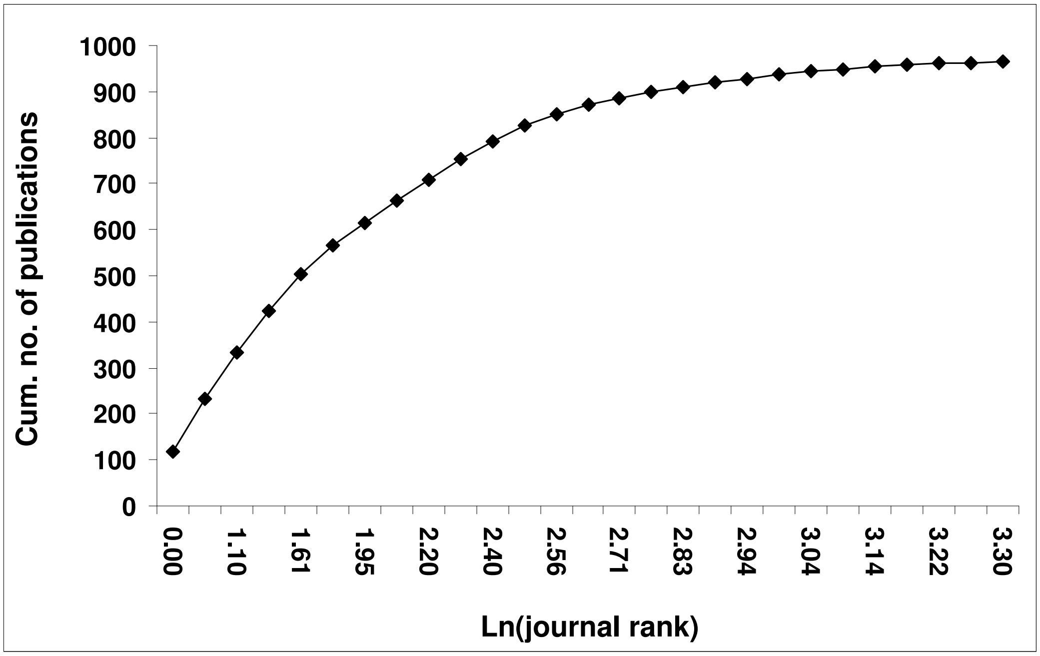

Figure 12: Journal-rank vs. cumulative no. of publications plot

In all, 1198 articles were published in 127 journals. The division of all articles in three equal zones retaining 400 articles in each zone instantly reveals the corresponding Bradford's ratio of number of journals involved as follows:

$$4 : 8 : 115$$

This ratio can be rewritten as:

$$4*(1 : 2 : 28)$$

This ratio may be approximated with the following values, $4*(1: 2: 7*(2)^2)$. The number of journals in core and allied regions is in consonance with the well-known Bradford's pattern, i.e. $k*(1 : n : n^2)$, where k is the Bradford's multiplier. But the number of alien journals is not at per Bradford's pattern. An additional multiplier '7' comes here with '2' for alien journals. In this study, k = 4 and n = 2. The numbers of core, allied and alien journals in Indian cosmology research are thus 4, 8 and 115 respectively. The notable feature is that the articles are highly concentrated within few core journals. The numbers of core and allied journals are thus very low compared to alien journals. The list of core and allied journals, i.e. top nineteen journals is given in Table 7. A look through Table 7 instantly reveals that of the nineteen journals in all, only three are Indian, and remaining sixteen journals are published from USA, UK, Netherlands, Singapore, Europe and Romania. Here four journals are published by Springer; three journals are published by IOP pub. and two journals are published by World Scientific. Other journals are published by various publishers like Oxford University Press, EDP Sciences, American Physical Society, Elsevier and Romanian Academy. All these nineteen journals are closed-access. There is thus no open-access major journal found in Indian cosmology research. The Indian scientists of this subject area publish their articles mostly in international journals. Indian journals are rare in this subject, only three out of nineteen here, i.e. just 16%. Of these journals, the *Astrophysical Journal* possesses highest 2011 Impact Factor, i.e. 6.733, followed by *Journal of Cosmology and Astroparticle Physics* (IF = 6.036) and *Journal of High Energy Physics* (IF = 5.618). The lowest 2011 Impact Factor is possessed by *Indian Journal of Pure and Applied Mathematics* (0.274). In accordance with 5-year Impact Factor the topper journal is also *Astrophysical Journal* (IF = 5.945) followed by *Journal of Cosmology and Astroparticle Physics* (IF = 5.295) and *Monthly Notices of the Royal Astronomical Society* (IF = 5.009). Also, the ranking by immediacy index reveals the top three journals as *Physics Letters B* (3.708), *Journal of High Energy Physics* (2.658) and *Journal of Cosmology and Astroparticle Physics* (2.387). Out of nineteen, ten journals possess impact factor below two. It is found that the cited half life is greater than ten for two journals, viz. *Physics Letters B* and *Indian Journal of Pure & Applied Mathematics*. It may thus be inferred that the Indian scientists doing research in this field prefer publication in high impact journals.

Table 7: List of top nineteen journals of cosmology

Rank	Journal Title	ISSN	Publisher and place	No. and % of articles published therein	2011 Impact Factor	5-Year Impact Factor	Immediacy Index	Cited Half-life
1	Monthly Notices of the Royal Astronomical Society	0035-8711	Oxford Univ. Press; UK	118 (9.8%)	5.521	5.009	1.794	5.5
2	Physical Review D	1550-7998	American Physical society; USA	114 (9.5%)	4.691	4.170	1.834	6.5
3	Astrophysics and Space Science	0004-640X	Springer Science + Business Media; Netherlands	101 (8.4%)	2.064	1.594	0.715	7.1
4	International Journal of Theoretical Physics	0020-7748	Springer Science + Business Media; Netherlands	92 (7.7%)	1.086	0.824	0.258	8.5
5	Pramana-Journal of Physics	0304-4289	Indian Academy of Science; India	78 (6.5%)	0.562	0.494	0.100	7.9
6	Astronomy & Astrophysics	0004-6361	EDP Sciences, Europe	63 (5.3%)	5.084	4.422	1.451	7.0
7	General Relativity and Gravitation	0001-7701	Springer Science + Business Media; Netherlands	50 (4.2%)	1.902	2.023	0.593	8.4

7	International Journal of Modern Physics D	0218-2718	World Scientific; Singapore	50 (4.2%)	1.030	0.949	0.453	6.6
8	Journal of Cosmology and Astro-particle Physics	1475-7516	IOP Pub; UK, Italy	47 (3.9%)	6.036	5.295	2.387	3.2
9	Classical and Quantum Gravity	0264-9381	IOP Pub; UK, Italy	46 (3.8%)	3.562	2.895	1.048	6.2
10	Astrophysical Journal	0004-637X	IOP Pub; UK, Italy	43 (3.6%)	6.733	5.945	2.047	7.4
11	Physics Letters B	0370-2693	Elsevier; USA	38 (3.2%)	4.569	3.677	3.708	>10.0
12	Modern Physics Letters A	0217-7323	World Scientific; Singapore	37 (3.1%)	1.110	0.863	0.360	7.8
13	Journal of High Energy Physics	1126-6708	Springer Science + Business Media; Netherlands	25 (2.1%)	5.618	4.712	2.658	3.7
14	International Journal of Modern Physics A	0217-751X	World Scientific; Singapore	19 (1.6%)	1.127	0.902	0.510	7.9
15	Romanian Journal of Physics	1221-146X	Roman Academy Pub. Romania	14 (1.2%)	0.526	0.403	0.250	3.7
16	Journal of Astrophysics and Astronomy	0250-6335	Indian Academy of Science; India	13 (1.1%)	0.336	0.495	0.118	8.3
17	Indian Journal of Pure & Applied Mathematics	0019-5588	Indian National Science Academy; India	11 (0.9%)	0.274	0.234	0.000	>10.0
18	Chaos Solitons & Fractals	0960-0779	Elsevier; USA	10 (0.8%)	1.246	1.550	0.310	6.1

5.7. Subject domains covered: The bibliographic records as obtained from *Web of Science* incorporate subject categories at per their own scheme. The subject categories described by different descriptors indicate both specific domains and broad disciplines as well. Any particular record contains several descriptors as actual subject coverage mostly claims fairly large number of descriptors for accurate encompassing of the right content imbibed therein. The list of descriptors indicating both broad and specific domains of this study is presented in Table 8. Here some broad descriptors are found, e.g. biology, biophysics and environmental sciences. This subject is closely related with some basic subjects like astronomy, mathematics, physics, chemistry etc. The central facet of the subject cosmology around which granules of concepts from several other subjects are amassed is the universe. The mode of formation of the same may thus be categorized under *cluster* at per Ranganathan's scheme of subject formation mechanism that was further modified by Gopinath and Seetharama[32].

Table 8: List of broad subjects and specific domains at per *Web of Science* categories

Descriptors indicating different subject areas	No. and % of articles contributed
Astronomy and astrophysics	720 (60.1%)
Physics of particles and fields	376 (31.4%)
Nuclear physics	69 (5.8%)
Mathematical physics	61 (5.1%)
Multidisciplinary sciences	21 (1.8%)
Mathematics	14 (1.2%)
Mathematics with interdisciplinary applications	11 (0.9%)
Applied physics	8 (0.7%)
Applied mathematics	6 (0.5%)
Optics	5 (0.4%)
Instruments and instrumentation	4 (0.3%)
Electrical and electronic engineering	2 (0.2%)
Condensed matter physics	2 (0.2%)

The most relevant or core facet of cosmology research is thus astronomy and astrophysics, followed by particle physics, nuclear physics and mathematical physics. Other subject domains involved are also related with both physics, mathematics and engineering sciences.

5.8. Institutional distribution: In this study, 1198 articles have been contributed by 3441 authors affiliated to 962 institutions in all, i.e. 3.6 (~4) authors per institution on average. Of these, 486 institutions affiliated only one author once only. All these one-off institutions have not been considered as a sample for study. The remaining 476 affiliating institutions are categorized in fifteen types as listed in Table 9. The number and percentage of affiliated authors by each institution is presented in Table 10 and Figure 13. The list of top thirty five affiliating institutions that account for 40% of entire authors is furnished in Table 11. Highest percentage of authors have come from foreign institutions (57.1%) followed by universities (14.7%) and inter-university centre (6.9%). Then comes colleges (6%) followed by DAE (5.2%). The authors affiliated by foreign institutions work in collaboration with Indian institutions. It is thus a notable feature that foreign collaborative research in this subject highly dominates. The IUCAA is the topper institute in terms of author's affiliation followed by IITs and Jadavpur University. Of the universities, Jadavpur University, Institute of Mathematical Sciences and Jamia Millia Islamia are fore-runner in this subject as appeared within first ten. The other important top-ranked Indian institutions are Tata Institute of Fundamental Research, Harish Chandra Research Institute, Hindu Post-Graduate College and Raman Research Institute. It is an important finding that although collectively foreign institutions are the topmost affiliating institution, but individually IUCAA, IITs and Jadavpur University are foremost institutions.

Table 9: Different categories of affiliating institutions

Institutions and some broad categories	Abbreviation used	No. and % of affiliating institutes
Council of Scientific and Industrial Research	CSIR	1 (0.2%)
Dept. of Atomic Energy	DAE	6 (1.0%)
Dept. of Science and Technology	DST	6 (1.3%)
Foreign institutions	FI	367 (77.1%)
Indian colleges	College	36 (7.7%)
Indian engineering colleges	E-COL	3 (0.6%)
Indian Institute of Astrophysics	IIA	2 (0.4%)
Indian Institute of Science	IISC	1 (0.2%)
Indian Institute of Science, Education & Research	IISER	3 (0.6%)
Indian Institute of Technology	IIT	4 (0.8%)
Indian Space Research Organization	ISRO	1 (0.2%)
Indian Statistical Institute	ISI	1 (0.2%)
Indian Universities	Univ.	43 (9.0%)
Inter-University Centre	IUC	1 (0.2%)
Raman Research Institute	RRI	1 (0.2%)

Table 10: Affiliated authors by different categories of institutions

Institution category	No. and % of affiliated authors
Council of Scientific and Industrial Research	3 (0.08%)
Dept. of Atomic Energy	182 (5.15%)
Dept. of Science and Technology	50 (1.41%)
Foreign institutions	2019 (57.13%)
Indian colleges	213 (6.03%)
Indian engineering colleges	16 (0.45%)
Indian Institute of Astrophysics	27 (0.76%)
Indian Institute of Science	4 (0.11%)
Indian Institute of Science, Education & Research	12 (0.34%)
Indian Institute of Technology	178 (5.04%)
Indian Space Research Organization	3 (0.08%)
Indian Statistical Institute	12 (0.34%)
Indian Universities	520 (14.71%)
Inter-University Centre	244 (6.90%)
Raman Research Institute	51 (1.44%)

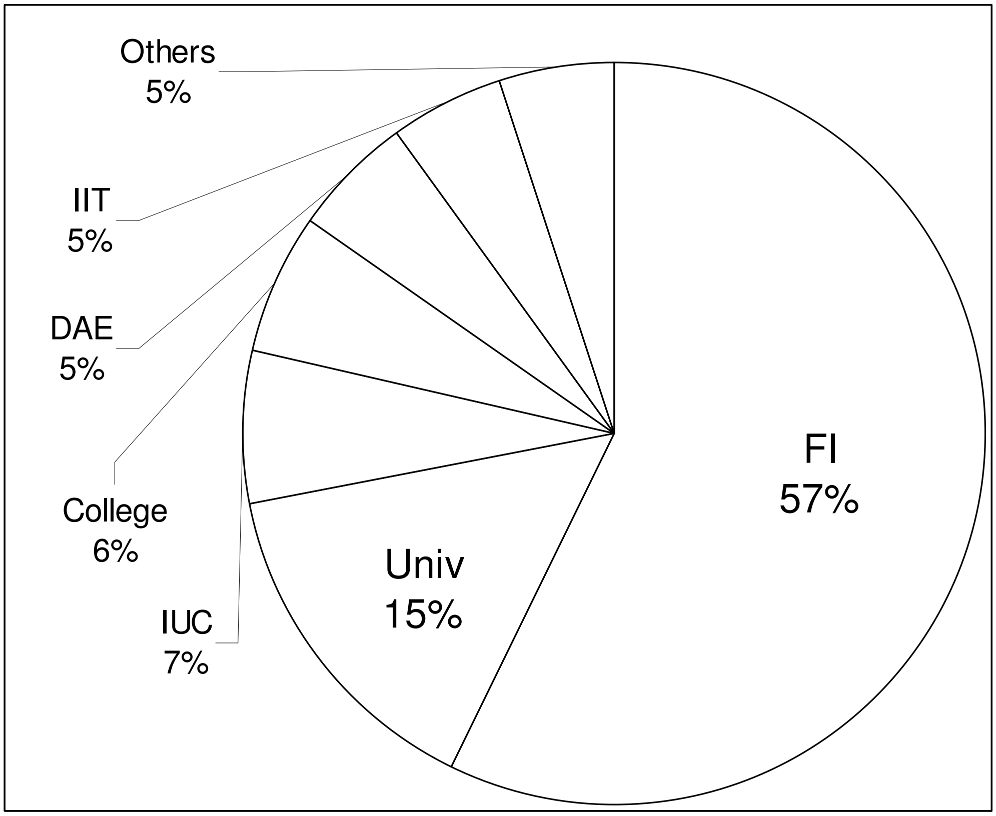

Figure 13: Affiliated authors by different categories of institutions

Table 11: Top thirty-five affiliating institutions

S. No.	Rank	Institution	Category	No. and % of contributions	
1	1	Inter-university Centre for Astronomy and Astrophysics (IUCAA)	IUC	244	6.90
2	2	Indian Institute of Technology	IIT	178	5.04
3	3	Jadavpur University	Univ.	92	2.60
4	4	Tata Institute of Fundamental Research	DAE	72	2.04
5	5	Harish Chandra Research Institute	DAE	64	1.81
6	6	Hindu Post Grad College	College	57	1.61
7	7	Raman Research Institute	RRI	51	1.44
8	8	Max Planck Society	FI	46	1.30
9	9	Institute of Mathematical Sciences	Univ.	37	1.05
10	10	Jamia Millia Islamia	Univ.	35	0.99
11	11	University of Delhi	Univ.	34	0.96
12	12	Bengal Engineering and Science University	Univ.	28	0.79
13	12	European Southern Observatory	FI	28	0.79
14	12	University of California System	FI	28	0.79
15	13	California Institute of Technology	FI	26	0.74
16	13	National Aeronautics Space	FI	26	0.74

		Administration (NASA)			
17	14	Indian Institute of Astrophysics	IIA	23	0.65
18	14	Institute of Physics, India	DAE	23	0.65
19	14	University of Cambridge	FI	23	0.65
20	15	Observatoire de Paris	FI	22	0.62
21	15	Physical Research Laboratory, India	DAE	22	0.62
22	15	Pierre Marie Curie University, France	FI	22	0.62
23	16	Centre national de la recherche scientifique, France	FI	21	0.59
24	16	Delhi College of Engineering	College	21	0.59
25	16	Pennsylvania State University	FI	21	0.59
26	17	Indian Association for the Cultivation of Science	DST	20	0.57
27	17	University of Kalyani	Univ.	20	0.57
28	18	University of Paris	FI	19	0.54
29	19	Saha Institute of Nuclear Physics	DAE	18	0.51
30	20	Banaras Hindu University	Univ.	17	0.48
31	20	Consejo Superior De Investigaciones Cientificas Csic, Spain	FI	17	0.48
32	20	Nagpur University	Univ.	17	0.48
33	20	S. N. Bose National Centre for Basic Sciences	DST	17	0.48
34	20	Sant Gadge Baba Amravati University	Univ.	17	0.48
35	21	Institute of Astrophysics, France	FI	16	0.45

6. Conclusion: This study deals with the scientometric analysis of Indian cosmology research as reported in *Web of Science*. The study shows that cosmology research in India is on boost. The research has shown a steady growth since 1999 and maximum hike occurred in 2011. The cosmology research in India is mainly a collaborative effort with USA and other European countries. The study of authorship pattern shows dominance of two-authored and three-authored articles. As this research field has a strong theoretical base, a considerable number of solo researches have been found. Team research is prominent with tiny team size while large teams are also there. In this subject some exorbitantly large teams have been found with team members more than one hundred and ranging upto 715. The author productivity pattern is not in close proximity with Lotka's law, but approximately confirms the same. The number of core journals of this subject area is comparatively less as obtainable by employing Bradford's law of scattering. Almost all core journals are published from USA and European countries and possess fairly high impact factor. The subject domain analysis shows that it is a more or less pure disciplinary subject area with few subjects overlapped thereon. The analysis of institutional pattern shows that the top three sectors, viz. foreign institutions, university and IUCAA affiliate nearly 79% of total number of authors. Also, individually IUCAA, IITs and Jadavpur University are top three affiliating institutions. The potential universities in cosmology research include TIFR, Harish Chandra

Research Institute and Raman Research Institute. It can thus be inferred that cosmology research in India is in steady growth and it is chiefly a collaborating effort with so many other countries.

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