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A selective review of bibliometric studies on Indian physics and astronomy research output

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This paper presents a review of 159 bibliometric studies on Indian physics and astronomy research output. The distribution of the 159 papers from1964 to 2020, contributing authors and specific subject domains are analysed. It is found that current research topics of physics and astronomy are hardly selected for the bibliometric study. A few papers incorporate currently relevant aspects of bibliometric analysis to carry out the studies. Both facets, i.e., bibliometrics and physics & astronomy as tool and subject respectively, need to be focussed upon as per the requirement and relevance of time.

Keywords: Bibliometrics; Scientometrics; Physics; Astronomy; Scientometrics of physics; Scientometrics of astronomy

Introduction

Of major science disciplines, physics is the field where Indian contributions during both pre-and post-independence era have been outstanding. It is borne out by the fact that one physicist from pre-independent India received the Nobel Prize, and scientists like J.C. Bose, M.N. Saha, S.N. Bose and K.S. Krishnan missed it narrowly. Several physicists were elected as FRS from colonial India, to mention a few, J.C Bose (FRS- 1920), C.V Raman (FRS- 1924), M.N. Saha (FRS- 1927), K.S. Krishnan (FRS- 1940) and others.

The inception of the first Indian research institute dates to the year 1876, which marks the foundation of the Indian Association for the Cultivation of Science in Kolkata. Physics and astronomy research during the post-independence era distinguished India in global academic and research map with prestigious recognitions. The research output in terms of scholarly publications and patents has been growing, as is evident from bibliographic and citation databases like Indian Science Abstracts, Web of Science, Scopus etc.

The quantitative analysis of the research output is a bibliographic control mechanism that manages documentary chaos owing to the explosion of research information. This quantitative study in relation to bibliography is known as bibliometrics, the term coined by Pritchard[1]. In India, the term librametry, coined by Ranganathan[2] precedes bibliometrics. The scope of librametry includes the application of statistical tools and techniques in the evaluation of library systems and services. There are other synonymous terms like scientometrics, informetrics etc., having the concept of bibliometrics. The bibliometric, scientometric or informetric studies of various subjects in the context of Indian research output showed an upward trend since the 1970s. This can be seen from the growth in the number of Indian bibliometric publications.

This paper presents a review of bibliometric and scientometric studies on Indian physics and astronomy research output. The first article devoted to bibliometrics on Indian physics and astronomy research appeared in 1964[3]. Although this paper was not a bibliometric study in a strict sense, it was a quantitative analysis of the coverage of Indian physics literature by *Physics Abstracts*. It showed the path towards quantitative analysis of Indian physics and astronomy research, which was shaped in domain-specific bibliometric and scientometric studies later.

Review of literature

The first bibliometric publication appeared from India in 1958[4], six years earlier than the publication of the first paper about bibliometrics on Indian physics. It seems that physics attracted the attention of the bibliometricians or scientometricians since the dawn of Indian bibliometric research.

In 1963, the first seminar on bibliometrics was organized in India at DRTC[5]. Sen and Kumar[6]contributed the review article on Indian bibliometric papers published from1958 to 1984. This was the first review work on bibliometrics from India. Garg and Tripathy[7]carried out a review on Indian bibliometric research and compiled a comprehensive bibliography of 902 papers on the same covering the period 1995-2014[8]. Sen[5] compiled another bibliography on bibliometrics of 301 papers for the period1958 to 1994. These two bibliographies, combined figuring 1203 articles on Indian bibliometric research, portrays a complete picture of bibliometric research output in India covering all possible subjects, including disciplines of science, social science, and arts & humanities.

Basu and Garg[9]carried out another review on Indian bibliometrics and scientometrics research over the period 1970-1994. Patra and Muchie[10]mapped the scientific publications and different types of collaboration pattern in pre-independent India by using scientometrics and social network analysis tools. Their result shows that the maximum number of scientific literatures was published in the year 1936.

The literature survey shows that no review on bibliometric studies devoted to any specific subject domain in the context of Indian research output has yet been observed, which creates a gap during studies on Indian bibliometric review. This paper intends to bridge the said research gap. Since the subject-specific bibliometric and scientometric studies enable to spot the active research domains, potential authors, core sources and prolific institutions, it is necessary to carry out a review of subject-specific bibliometric and scientometric papers.

Research questions

1. What are the specific facets of bibliometrics covered by the corpus of papers on bibliometric analysis of Indian physics and astronomy research output?
2. What are the domains of physics bibliometrically analysed so far therein?
3. What are the specific objects like Indian physics journals, Indian institutions, distinguished physicists etc. and how they are bibliometrically analysed therein?

Objectives of the study

- To investigate the growth pattern of Indian output of bibliometric studies on Indian physics and astronomy research;
- To prepare a comprehensive bibliography of bibliometric and scientometric studies in this area;
- To carry out a review of the bibliometric and scientometric studies on Indian physics and astronomy research output;
- To execute the quantitative analysis of all facets of bibliometric studies accomplished by the said corpus of papers;
- To identify prolific contributing authors and core publishing journalson bibliometric analysis of physics.

Methodology and limitation

The data for the present study were extracted from the following citation-cum-bibliographic and indexing/abstracting databases, viz., Web of Science; Scopus; Library, Information Science and Technology Abstracts; Indian Science Abstracts and Indian Library Science Abstracts. The Boolean search strategy followed was *(Bibliometric OR Scientometric OR Informetric) AND (Physics OR {Astronomy OR Astrophysics}) AND INDIA*. The publication span of the retrieved results ranged from 1964 to 2020. The data for Indian output was also searched by using the names of the potential authors of bibliometrics in Google Scholar for further verification over the said period. The open-access repository in library and information science, e-LiS, and two bibliographies by Sen[5] and Garg & Tripathy[8] were also searched to find out relevant data. The retrieved articles were systematically arranged in a spreadsheet. The retrieval from different sources resulted in several duplicate records, which were removed.

The content analysis was executed by a careful and investigative reading of the titles, keywords, and abstracts of the 159 sample documents. The papers were also fully or partially read out at times to get an in-depth idea about the bibliographic aspects as and when required. If any research paper or article has not yet been indexed either by the above-mentioned databases or by the indexing and abstracting

periodical, or e-LiS, bibliography or even Google Scholar, that item has not been included in this study. The inability to include items not indexed in the above sources is the limitation of this study.

Results and analysis

In all, 159 bibliometric and scientometric studies on Indian physics and astronomy research output were obtained. The list of 159 papers along with the details about the facets of bibliometric studies covered by each paper, along with times cited, time-normalized citation and age, are furnished in Annexure 1. Of these, 145 articles were published in 44 journals, four articles were published in two edited books, and two articles were published in two conference proceedings. There were eight articles, which were presented in different seminars, conferences and workshops and retrieved from the repository e-LiS. There was one thesis also found in this subject area. The content analysis of these 159 documents has been carried out at first to get an idea about the focal subject domain and the aspects of bibliometric studies covered therein. There were no papers on the historical or genesis study. The period for the study of majority papers varies from a five-year span to fifteen years span.

Year-wise distribution of papers

The changing pattern of literature on bibliometric studies of Indian physics and astronomy research output is given in Table 1. The per-year productivity is maximum in 2007 and 2013, with 12 papers each. The pattern fora cumulative growth of the number of papers follows a parabolic graph with an equation: $y = 0.092x^2 - 0.334x + 4.61$ with R^2=0.996.

Facets of bibliometric studies: An overall scrutiny

Based on the content analysis, the 159 papers were grouped into 19 facets of bibliometrics and scientometrics (Table 2). It is observed that 159 papers carried out 19 facets of bibliometric and scientometric studies 532 times, which indicates, on average, each paper covers more than three facets (3.32) of studies. As each paper carried out each facet once only, therefore the figures in the fourth column

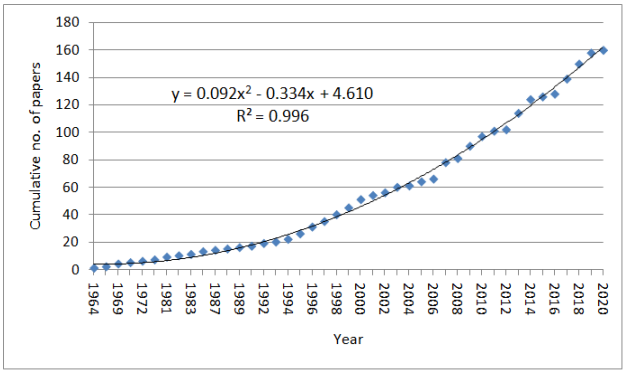

Fig. 1 — Year-wise distribution (Cumulative). Facets of bibliometric studies: An overall scrutiny

Table 1 — Year-wise distribution of bibliometric papers (1964-2020)

Year	Frequency	%	Cumulative frequency	Year	Frequency	%	Cumulative frequency
1964	1	0.63	1	1999	5	3.13	45
1965	1	0.63	2	2000	6	3.75	51
1969	2	1.25	4	2001	3	1.88	54
1971	1	0.63	5	2002	2	1.25	56
1972	1	0.63	6	2003	4	2.50	60
1979	1	0.63	7	2004	1	0.63	61
1981	2	1.25	9	2005	3	1.88	64
1982	1	0.63	10	2006	2	1.25	66
1983	1	0.63	11	2007	12	7.50	78
1986	2	1.25	13	2008	3	1.88	81
1987	1	0.63	14	2009	9	5.63	90
1988	1	0.63	15	2010	6	4.38	96
1989	1	0.63	16	2011	4	2.50	100
1990	1	0.63	17	2012	1	0.63	101
1992	2	1.25	19	2013	12	7.50	113
1993	1	0.63	20	2014	10	6.25	123
1994	2	1.25	22	2015	2	1.25	125
1995	4	2.50	26	2016	2	1.25	127
1996	5	3.13	31	2017	11	6.88	138
1997	4	2.50	35	2018	11	6.88	149
1998	5	3.13	40	2019	8	5.00	157
				2020*	2	1.25	159

(*Data shown published up to 31st July 2020)

Table 2 — Facets of bibliometric studies (Paper-wise details are furnished in Annexure 1)

S. no.	Facets of bibliometric, scientometric or informetric studies	Specific topics covered under each facet	Frequency of coverage of each facet by 160 articles	% of articles (out of 160)	% of coverage of facets (out of 532)
1	Age Analysis	Age of a source, subject, article, citation etc.	2	1.3	0.4
2	Altmetric Analysis	Analysis of different altmetric indicators and impact of social/ research networks	3	1.9	0.6
3	Article Length Analysis	The length of an article in terms of the number of pages covered	4	2.5	0.8
4	Authorship Analysis	Authorship pattern of research papers and distribution of authors over contributed papers	80	50.0	15.0
5	Bibliometric Model & Indicator Analysis	Analysis of bibliometric indicators like Impact Factor, h-index etc. and development of any biblio/scientometric model	28	17.5	5.3
6	Bio-bibliometrics	Bibliometric profile of an individual scientist	8	5.0	1.5
7	Citation Analysis	Citation count, citation pattern and citation distribution over different types of documents	41	25.6	7.7
8	Collaboration Analysis	Pattern of inter-institutional collaboration on regional/ national/ international level	43	26.9	8.1
9	Country & Place Analysis	Country, state, city etc. (different types of geographical locations) and cross-national assessment	29	18.1	5.5
10	Empirical Law Analysis	Investigation and interpretation of fundamental bibliometric laws (Bradford's, Lotka's, Zipf's, Sengupta's, Pareto's and other similar laws) and to test their applicability	25	15.6	4.7
11	Growth &/or Obsolescence of Literature	Genesis, growth, scattering and obsolescence of published literature or research output, analysis of publication trend etc.	72	45.0	13.5
12	Institutional Analysis	Affiliating institutions and organizations	31	19.4	5.8
13	Keyword & Subject Analysis	Analysis of keywords, subject descriptors, index terms etc. and to find out the subject domains	31	19.4	5.8
14	Open Access Analysis	Analysis of open access journals and articles	3	1.9	0.6
15	Patent Analysis	Analysis of filed patents	2	1.3	0.4
16	Single Institutional Analysis	Bibliometric profile of an individual institution	33	20.6	6.2
17	Single Source Analysis	Bibliometric profile of an individual journal or book etc.	15	9.4	2.8
18	Source Analysis	Analysis of journal, proceedings, books etc. (different types of documents)	70	43.8	13.2
19	Theses Analysis	Analysis of thesis/ dissertation submitted	12	7.5	2.3
	Total		532		

of the table indicates both the number of articles and the frequency of facet coverage as well. The specific topics covered under each facet are indicated in the table, along with the abbreviations used.

There are two percentage columns in the Table 2, the percentage of articles and the percentage of facet coverage that implies the percentage of facets covered, out of the total number of coverage (532), by

the percentage of papers out of total 159papers. Therefore, it is evident from the Table 2 that 50% of papers (80) carried out 'Authorship Analysis' 80 times, which figures 15% of the total number of coverage, i.e. 532.It is found that 'Authorship Analysis' is the most frequent study (15%), followed by 'Growth and Obsolescence Study' (13.5%), 'Source Analysis' (13.2%), 'Collaboration Analysis' (8.1%), 'Citation Analysis' (7.7%) and 'Single Institutional Analysis' (6.2%), which figure 64%together. Apart from the top six facets, the other 13 facets covered 36% of total facet coverage. It signals the high popularity of authorship study, growth and obsolescence study, collaboration and journal or source analysis among the Indian bibliometricians.

There are other important aspects which need detailed discussions. For instance, 33 papers carried out 'Single Institutional Analysis' and 31 papers executed analysis of multiple institutions along with comparative studies. The cross-national comparative analysis of scientometric aspects was carried out by 29 papers. The institutions of national importance, which are covered in the study are, National Physical Laboratory; Bhabha Atomic Research Centre; Indian Institute of Science; Physical Research Laboratory; Institute for Plasma Research; Indian Institute of Technology-Delhi; Tata Institute of Fundamental Research; Indian Institute of Science, Education and Research- Thiruvananthapuram and Saha Institute of Nuclear Physics.

Besides, several universities were also covered by the papers, which includes Annamalai University; Karnataka University; University of Burdwan; Babasaheb Ambedkar Marathwada University; University of Kerala; Banaras Hindu University; Jawaharlal Nehru University, Guru Nanak Dev University, S. P. Pune University, Bangalore University and Aligarh Muslim University.

The individual journals were analysed by 15 papers, termed as ‘Single Source Analysis'. The journals analysed include *Indian Journal of Physics* (published by The Indian Association for the Cultivation of Science, Kolkata); *Indian Journal of Pure and Applied Physics* (published by CSIR-NISCAIR, New Delhi); *Pramana-Journal of Physics* (published by Indian Academy of Science, Bengaluru) and *Indian Journal of Radio and Space Physics* (published by CSIR-NISCAIR, New Delhi).

The bio-bibliometric profiles of the eminent scientists are depicted in 8 papers. The names of the said distinguished figures are, P. K. Iyengar (nuclear physics); C. V. Raman (spectroscopy and optics, Physics Nobel Laureate in 1930); S. Chandrasekhar (astrophysics (stellar dynamics) and cosmology, Physics Nobel Laureate in 1983); K. S. Krishnan (optics, crystallography etc. FRS in 1940); R. Chidambaram (nuclear physics); Vikram A. Sarabhai (space physics); Ramgopal Rastogi (plasma physics) and G. N. Ramachandran (biophysics and crystallography).

The bibliometric indicators were discussed and analysed in 28 papers. These papers also developed different statistical models. The empirical bibliometric laws were analytically studied and interpreted in 25 papers, which included mainly Lotka's and Bradford's laws. Few papers analytically interpreted Sengupta's correction to Bradford's law, Pareto's Principle and Zipf's Law. The citation patterns and other related aspects of submitted theses on physics and astronomy to different universities are studied by 12 papers. The quantitative analysis of keywords of papers is a vital component of bibliometric studies. The statistics of the keywords probes into the idea of specific subject domains within a broad discipline. Here, 31 papers are on quantitative analysis of keywords and subject descriptors.

Some important aspects in the present day's context, i.e., ‘Open Access Analysis', 'Altmetric Analysis' and 'Patent Analysis’ are covered by very few papers. The open access analytics, altmetric analytics and impact analysis of social networking are active research facets of bibliometrics and scientometrics, which need to be covered extensively to upgrade the discipline today.

Out of 160 papers collected as the sample for the study, only 15 papers covered one facet, 37 papers covered two facets, 41 papers covered three facets, and 33 papers covered four facets. Hence, 111 papers covered either two, three or four facets. Out of the remaining 34 papers, five facets are covered by 18 papers, six facets are covered by 14 papers, and seven facets are covered only by two papers. Few papers covered more than four facets of bibliometric studies. The detailed coverage of facets of bibliometric studies by the sample of 159 papers is presented in Table 2.

Citation pattern analysis

The citation is a measure of the reputation and quality of a scholarly article. An article belonging to a particular subject domain may receive citations both from the items belonging within and beyond the boundary of the subject domain. The study indicating

how the bibliometric analysis of physics papers are cited within the bibliometrics and scientometrics and outside the discipline is examined here.

Of the 159 sample papers, 125 papers received 2205 citations, indicating nearly 18 citations on average per paper. The remaining 34 papers received no citations. The bibliographic details of 159 papers along with the bibliometric facets covered therein (FBSC) and the number of citations received (TC) are listed in Annexure 1. The Age (A) and Time-Normalized Citation (TNC) of respective papers are also furnished. Only one paper received more than one hundred citations (126, S. No. 132, Annexure 1), and two papers received more than 75 citations (81 and 89, S. No. 65 and 22, Annexure 1). The ranges of citations received by all papers with a frequency of each range are listed in Table 3. It is noticed that 11 papers received citations ranging from 11 to 100, 22 papers received citations ranging from 6 to 10 and 51 papers were cited one to five times. Nine papers are cited once, and 17 papers are cited twice.

The ranked list of top-cited ten papers is presented in descending order in Table 4. Also, the ranked list of the top ten papers arranged in accordance with Time-Normalized Citation (TNC) is presented in descending order in Table 5.

The TNC is obtained by dividing the number of citations received or Times Cited (TC) by the Age (A) of the paper, i.e., TNC = TC/Age. The subtraction of the year of publication of a paper from 2020, i.e., the current year, yields the age of that paper. The age of the first ranked paper of Table 5 is calculated as 0.5 or (1/2) year, as it was published in April 2020. The TC gives accumulation of citation over the entire life span of the paper, while TNC gives accumulation of citation per unit time or rate of citation accumulation. It indicates how fast a paper can gather citations. The time is measured in terms of age in years. The TNC thus predicts the speed of citation accumulation.

Table 3 — Distribution of papers in different citation ranges

Sl. no.	Citation range	No. of papers	S. No.	No. of citations	No. of papers
1	>100	1	11	10	5
2	>90-100	0	12	9	3
3	>80-90	2	13	8	6
4	>70-80	1	14	7	3
5	>60-70	8	15	6	5
6	>50-60	5	16	5	8
7	>40-50	2	17	4	6
8	>30-40	5	18	3	11
9	>20-30	8	19	2	17
10	>10-20	20	20	1	9

Table 4 — Citation share of top ten ranked papers within and outside the domains of bibliometrics/ scientometrics (Ranked by Times Cited (TC))

Rank	S. No. as in Annexure 1	Year of Publication	Times Cited (TC)	Age	TNC = TC/Age	Specific bibliometric facets focussed on the papers	No. of citations from bibliometrics/ scientometrics		No. of citations from other disciplines outside bibliometrics
							Citations from the said focussed facets	Citations from other allied facets	
1	132	2017	126	3	42	Single Source Analysis	50	76	0
2	22	1994	89	26	3.4	Biobibliometrics	61	27	1
3	65	2006	81	14	5.8	Subject-Specific Bibliometric Analysis	51	30	0
4	67	2007	73	13	5.6	Collaboration Studies	14	37	22
5	51	2000	67	20	3.4	Biobibliometrics	50	15	2
6	41	1999	66	21	3.1	Subject-Specific Bibliometric Analysis	34	27	5
7	56	2002	65	18	3.6	Subject-Specific Bibliometric Analysis	10	35	20
7	57	2003	65	17	3.8	Biobibliometrics	46	14	5
8	31	1996	64	24	2.7	Biobibliometrics	48	10	6
9	29	1996	63	24	2.6	Biobibliometrics	48	10	5
10	7	1981	62	39	1.6	Multiple Source Analysis	7	27	28
						Total Citation	419 (51%)	308 (37.5%)	94 (11.5%)

Table 5 — Citation share of top ten ranked papers within and outside the domains of bibliometrics/ scientometrics (Ranked by Time Normalised Citation (TNC))

Rank	Sl. no. as in Annexure 1	Year of Publication	Times Cited (TC)	Age	TNC = TC/Age	Specific bibliometric facets focussed on the papers	No. of citations from bibliometrics/ scientometrics		No. of citations from other disciplines outside bibliometrics
							Citations from the said focussed facets	Citations from other allied facets	
1	159	2020	51	0.5	102	Empirical Law Analysis	24	23	4
2	132	2017	126	3	42	Single Source Analysis	50	76	0
3	129	2017	31	3	10.3	Bibliometrics/ Scientometrics in General	2	25	4
4	65	2006	81	14	5.8	Subject-Specific Scientometrics/Bibliometrics	51	30	0
5	67	2007	73	13	5.6	Collaboration Studies	14	37	22
6	156	2019	5	1	5	Subject-Specific Bibliometrics	1	3	1
7	143	2018	9	2	4.5	Single Institution Analysis	5	2	2
8	88	2009	48	11	4.4	Single Source Analysis	33	14	1
9	66	2006	60	14	4.3	Subject-Specific Scientometrics/Bibliometrics	40	18	2
10	133	2017	12	3	4	Single Institution Analysis	8	2	2
						Total Citation	228 (46%)	230 (46.4%)	38 (7.6%)

The simultaneous analysis of Table 4 and Table 5 instantly reveals that the ranking of papers by TC and TNC does not coincide. The Rank Correlation Coefficient between them is found as 0.25, which indicates a weak positive correlation. It may thus be inferred that the speed of citation may not be concurrent with a total number of citations overage.

The highest values of TC and TNC are 126 and 102, respectively. The paper entitled *Bibliometric studies on single journals: a review* is a unique one sample possessing the highest TC (126) and second highest TNC (42) simultaneously. This paper received 126 citations within just three years, as it was published in 2017. The paper entitled *Application of Bradford's law of scattering to the physics literature: a study of doctoral theses citations at the Indian Institute of Science* possesses the highest TNC (102), but its TC is 51 only (Rank 15). This paper was published just six months back but received 51 citations within such a short span of time. The fall of TNC is high compared to TC, as the ratio of highest to second highest values is (102/42 =) 2.4, which is (126/89 =) 1.4 for TC The top two values of TNC are 102 and 42, followed by 10.3, 5.8, 5.6 and so on. The TNC varies from 4 to 5 for only four papers and from 2 to 3 only for 21 papers. The number of papers lying from 1 to 1.9 TNC values is 29. Finally, 64 papers are found out with TNC less than one.

The specific bibliometric facets focussed on the top ten ranked papers (Table 4 and Table 5) are estimated by analysing the title, keyword and abstract of the respective papers. The number of citations gathered from citing papers belonging to both the said focussed facets and other allied facets are found out. The number of citations gathered from outside the boundary of the bibliometrics discipline is also calculated. It is observed that out of 821 citations received by top-cited papers, 727 (88.5%) citations came from citing sources on bibliometrics and scientometrics, while only 94 (11.5%) citations came from other disciplines except for bibliometrics and scientometrics (Table 4).

Out of 727 bibliometrics citing sources, 419 (51%) citations came from papers belonging to focussed facets, while 308 (37.5%) citations came from papers on peripheral allied facets. The focussed bibliometric facets are listed in Table 4 and Table 5. Other peripheral or allied bibliometric facets include authorship analysis, country, and place analysis etc. Also, the disciplines other than bibliometrics and scientometrics included here are—science & technology in general, library and information science with bibliography, physics, chemistry, social science, medicine, computer science, biological science, and environmental science. It is further observed that out of 496 citations received by ten ranked top-TNC

papers, 458 (92.3%) citations came from citing sources on bibliometrics and scientometrics, while only 38 (7.7%) citations came from other disciplines except for bibliometrics and scientometrics (Table 5). Out of 458 bibliometrics citing sources, 308 (62.1%) citations came from papers belonging to focussed facets, while 150 (30.2%) citations came from papers on peripheral allied facets. It is thus evident that the citations from the subject bibliometrics and scientometrics outshine citations from the disciplines outside bibliometrics.

Authorship pattern, author productivity analysis and Lotka's Law

Analysis of authorship pattern reveals that out of 159 papers, there are 52 (33%) single-author and 107 (67%) multi-author contributions. The multi-author papers are dominated by 61 (38%) 2-authored papers, 26 (16.3%) 3-authored papers, 15 (9.4%) 4-authored papers, 3 (1.9%) .5-authored papers and 2 (1.3%) 6-authored papers.

It is found that 159 papers have been contributed by 191 authors, which means, on average, 1.2 authors are associated with each paper. Out of 191authors, top-ranked 14 authors are associated with 75% of total papers, while the remaining 177 authors are associated with the rest 25% papers. The list of the top 14 authors ranked 1 to 9 are given in Table 6.

The variations of the number of papers with several authors (both individual and cumulative figures) are presented in Table 7. The graphical variation of the cumulative number of authors with the cumulative number of papers is presented in Figure 2, which shows power model graph with equation $y = 188.8 * x^{-1.72}$, that is in accordance withLotka's equation $x^n y = c$, where x and y indicate the number of papers and ranked authors respectively, n and c are constants. Here, c=188.8 and n=1.72, the value of 'n' normally varies within the range 1.8 to 2.2, whichimplies the proximity of n (1.72) to the lower boundary of the range (1.8).

Source analysis and Bradford's Law

It is observed that 159 papers are scattered over 55 documents, of which 44 are journals, followed by 11 other types of documents such as proceedings (6), conference papers (3) and books (2). The scattering of papers over source documents follows Bradford's pattern with the number of core, allied and alien documents 3, 11 and 41, respectively. The ratio (3:11:41) =3*(1: 3.67: 13.67) is in consonance with Bradford's k (1: n: n^2) pattern, where k is Bradford's multiplier. Usually, Bradford's Law is not obeyed for feeble sample size.

The top 14 journals ranked 1 to 7 are listed in Table 8, where the top journals are *Annals of Library*

Table 6 — Top fourteen authors ranked from one to nine

Sl. no.	Rank	Name of the top 14 authors	No. and (%) of papers associated with
1	1	B. S. Kademani	16 (10)
2	2	B. M. Gupta	13 (8.1)
3	3	S. Kumar	11 (6.9)
4	4	K. G. Sudhier Pillai	10 (6.3)
5	5	K. C. Garg	9 (5.6)
6	5	V. L. Kalyane	9 (5.6)
7	6	S. M. Dhawan	8 (5)
8	6	V. Kumar	8 (5)
9	7	S. Bhattacharya	7 (4.4)
10	8	A. K. Bandyopadhyay	6 (3.8)
11	8	B. Dutta	6 (3.8)
12	8	B. K. Sen	6 (3.8)
13	8	G. Surwase	6 (3.8)
14	9	E. R. Prakasan	5 (3.1)

Table 7 — Variation of the number of papers vs number of authors

No. of papers	No. of papers (cumulative) (x)	No. of authors	No. of authors (cumulative) (y)
1	1	148	191
2	3	22	43
3	6	4	21
4	10	3	17
5	15	1	14
6	21	4	13
7	28	1	9
8	36	2	8
9	45	2	6
10	55	1	4
11	66	1	3
13	79	1	2
16	95	1	1

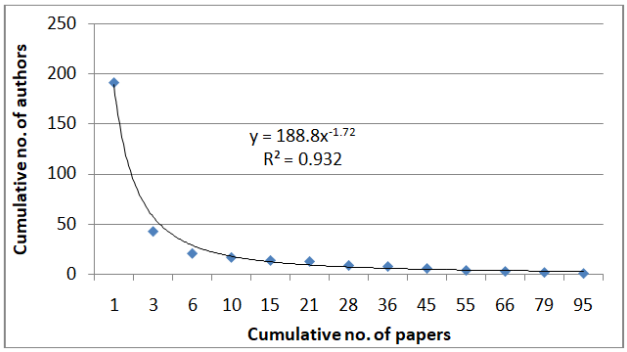

Fig. 2 — Variation of the cumulative number of papers vs cumulative number of authors. Source analysis and Bradford's Law

and Information Studies and *Scientometrics*, followed by *DESIDOC Journal of Library and Information Technology* (Rank 2). These three journals, indexed by both Web of Science and Scopus, form the core nuclear zone of journals of the subject domain concerned. There are 11 allied journals (Ranks 3 to 7), of which only two journals are from abroad, i.e., *Library Philosophy and Practice* and *Malaysian Journal of Library and Information Science*, which are indexed by Scopus. The remaining nine journals from the allied zone are published from India, where only two journals, *COLLNET Journal of Scientometrics and Information Management* and *JISSI: The International Journal of Scientometrics and Informetrics* belong to the discipline of scientometrics.

Besides, another Indian journal is found in the alien zone, which belongs to bibliometrics and scientometrics discipline solely, i.e. *Journal of Scientometric Research*. The first Indian journal in the discipline was *JISSI: The International Journal of Scientometrics and Informetrics*, which ceased publication after 1996. At present, only the *Journal of Scientometric Research* is indexed by Web of Science and Scopus. The ranked list of core and allied journals containing papers on bibliometric analysis of physics are presented in Table 8.

Subject domain analysis

The coverage of specific domains in the discipline of physics by 159 papers is listed (Table 9). It is found that 77 papers (48%) covered physics exclusively, while 24 papers (15%) covered physics in relation to other facets of the general science discipline. For instance, some papers discussed quite a

Table 8 — Core and allied journals for bibliometrics on Indian physics and astronomy

Sl. no.	Rank	Core and allied journals	No. of papers published therein
1	1	*Annals of Library and Information studies*	21
2	1	*Scientometrics*	21
3	2	*DESIDOC Journal of Library & Information Technology*	14
4	3	*Library Philosophy & Practice*	9
5	3	*SRELS Journal of Information Management*	9
6	4	*International Journal of Information Dissemination and Technology*	6
7	5	*Malaysian Journal of Library & Information Science*	5
8	6	*IASLIC Bulletin*	4
9	6	*Journal of Indian Library Association*	4
10	6	*Library Herald*	4
11	7	*COLLNET Journal of Scientometrics and Information Management*	3
12	7	*Information Studies*	3
13	7	*JISSI: The International Journal of Scientometrics and Informetrics*	3
14	7	*Journal of Advances in Library and Information Science*	3

Subject domain analysis

Table 9 — Coverage of specific subject domains

Sl. no.	Rank	Subject domains	Frequency & percentage
1	1	Physics (Comprehensive)	77 (48.1)
2	2	Physics & General Science	24 (15.0)
3	3	Nuclear Physics (Accelerator, Bhabha Scattering, Neutron Scattering, Thorium)	15 (9.4)
4	4	Astrophysics & Cosmology	11 (6.9)
5	5	Optics (LASER)	6 (3.8)
6	6	Condensed Matter Physics (Superconductivity, Thin Film, Hall Effect, Molecular Dynamics, Crystallography)	5 (3.1)
7	6	Geophysics	5 (3.1)
8	7	Physics & Engineering Science (Rubber Technology, Metallurgy)	4 (2.5)
9	7	Biophysics	4 (2.5)
10	8	Plasma Physics	2 (1.3)
11	8	Spectroscopy (Mossbauer Effect)	2 (1.3)
12	8	Solar Physics	2 (1.3)
13	8	Nanoscience & Nanotechnology (Carbon Nanotube)	2 (1.3)
14	9	Statistical Physics	1 (0.6)

few facets of chemistry, mathematics, material science, medicine etc., with physics. Fifteen papers (9.4%) covered nuclear physics, followed by 11 papers (6.9%) covered astrophysics and cosmology, six papers covered optics, and five papers covered condensed matter physics and geophysics each. The specific topics are mentioned in the adjacent parenthesis to each subject.

The emerging multi-disciplinary subjects like nanoscience, nanotechnology, plasma physics, biophysics, solar physics etc., are also covered. Although a wide range of facets are covered, yet current dynamic research topics like quantum gravity, beyond standard model physics, the amplituhedron, the conformal bootstrap, black hole thermodynamics, black hole information problems, holographic entanglement entropy etc., are not yet bibliometrically or scientometrically analysed. It is high time to widen the scope of bibliometric studies to include these new facets of physics.

Conclusion

The findings of this study reveal that physics is a focal subject to Indian bibliometricians for long. The first paper in this area was published in 1964, which is continuing. Indian bibliometricians focus mainly on authorship analysis, growth and obsolescence study, single-source analysis, single-institution analysis, and citation analysis. But there is almost no scientometric analysis regarding open access or open science. Researchers, so far, have not looked altmetric analysis of Indian physics research output especially when open-source repository like Arxiv is highly active in the social networking platform. The currently active research areas have not been chosen by the Indian bibliometricians. There is considerable scope for bibliometric research using recent topics on the modern and emerging areas of physics.

Acknowledgement

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ANNEXURE

List of papers with the citation metrics

The metrics in parenthesis after each reference gives the facets of bibliometric studies, times cited (TC); age of the article (A) and Time-Normalized Citation (TNC)

1) Rajagopalan TS and Sen BK, Reporting of Indian physics literature in the *Physics Abstracts*, *Annals of Library Science and Documentation,* 11(4)(1964) 87-95.**(**Growth &/or Obsolescence of Literature | Source Analysis | TC-3; A-56; TNC-0.05)
2) Guha B, Gupta AK, Joseph A and Kachroo ML, Scattering of articles by Indian authors in foreign periodicals, *Annals of Library Science and Documentation*, 12(2)(1965) 76-86.(Authorship Analysis | Source Analysis | TC-0; A-55; TNC-0)
3) Gupta AK, Characteristics of documents cited by Indian physicists: a case study, *In Proceedings of the paper presented at the* DRTC Seminar 7,1969, Paper JB.(Authorship Analysis | Citation Analysis | TC-0; A-51; TNC-0)
4) Sen BK, Indian contribution in Nobel lectures, *Annals of Library Science and Documentation*, 16(1)(1969) 35-36.(Authorship Analysis | Citation Analysis | TC-0; A-51; TNC-0)
5) Nagarathna RA, Use of documents by nuclear physicists and metallurgists: a case study, *In Proceedings of the paper*

presented at the DRTC Seminar 9, 1971, Paper BD. (Authorship Analysis | Citation Analysis | Source Analysis | TC-1; A-49; TNC-0.02)

6) Dhawan SM and Yadav RS, A Study on most frequently cited journals by Indian Scientists in Physics, *Annals of Library Science and Documentation*, 19(4)1972 185-192.(Growth &/or Obsolescence of Literature | Citation Analysis | Source Analysis | TC-6; A-48; TNC-0.13)
7) Arunachalam S and Markanday S, Science in the middle-level countries: a bibliometric analysis of scientific journals of Australia, Canada, India and Israel, *Journal of Information Science*, 3(1)(1981) 13-26.(Citation Analysis | Country & Place Analysis | Source Analysis | TC-62; A-39; TNC-1.59)
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13) Sengupta IN and Deshpande KS, International channel of communication of biophysics literature, *Annals of Library Science and Documentation*, 33(4)(1986) 143-149.(Growth &/or Obsolescence of Literature | Citation Analysis | Empirical Law Analysis | Source Analysis | TC-0; A-34; TNC-0)
14) Shalini R and Khan MA, Communication behaviour of Indian geophysics: a citation analysis, *International Library Review*, 19(4)(1987) 401-411.(Citation Analysis | Source Analysis | TC-2; A-33; TNC-0.06)
15) Garg KC and Rao MKD, Bibliometric analysis of scientific productivity: a case study of an Indian physics laboratory, *Scientometrics*, 13(5-6)(1988) 261-269.(Growth &/or Obsolescence of Literature | Authorship Analysis | Source Analysis | Single Institutional Analysis | TC-33; A-32; TNC-1.03)
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