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Application of Bradford's law of scattering on research publication in Astronomy & Astrophysics of India

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Abstract: *The present study is focused on examining the application of Bradford's law of scattering on research articles published in the field of Astronomy & Astrophysics by Indian scientist during 1988-2017. The bibliographic data was retrieved from Web of Science (WoS) bibliographic data base for different period of time. Total 18,877 journal's article have been published by Indian scientist in the field of Astronomy & Astrophysics during 1988-2017 which was further retrieved and analyzed separately for different blocks of 10 years as well as for 30 years consolidated too. The core journal of the field was identified. The Bradford law of scattering and Leimkuhler model was also tested to verify the data set and failed to establish the consistency in scattering of literature due to high level concentration of articles in very few journals.*

Key words: Bradford's Law of Scattering, Leimkuhler model, Citation Analysis, Bibliomatrics, Scientomatrics, Astronomy & Astrophysics, India.

1. Introduction:

Assessing the productivity of sources of literature in a subject concern is much important than publishing. The growth of literatures is very fast. It is not possible for any institution, Library or individual to subscribe or have access of all the literature. Any individual may not have time to consult all the sources of recent advancement in their subject interest. The Bradford's law of scattering is the tool to identify the core or important sources of recent information in a subject to get recent knowledge in the concern domain with investment of minimum time, effort and money. It is an aid to policy making too.

A researcher uses various resources for conducting research work in his field of interest. They look at periodical and non- periodical literature to fulfill the thirst of knowledge but the journals are the main focus as source of information to get the new knowledge of its domain. In many subject, it is mostly observed that some of the journals which are often cited by the scholars due to very close connection between the subject domain of the journals consulted and the field of their research interest. These very much referred journals are acknowledged as 'nucleus or core journals' of the particular subject. These most cited journals are identified as 'core of the publishing journals' that are mainly reflecting the theoretical spirit of the research which are published in the related subject of research interest.

The recognition of core publications as 'significant journals' in a subject field is needed to guide and provide the selective information resources to the users so that the researcher may concentrate on his work rather than literature searching which is complex task in various disciplines. For this idea, Aficionado's repeatedly endeavor to define the limits of the specific disciplines by screening and presenting that which journals are best, most productive, read and /or most cited by the users. Library & Information Science professionals and educators have described different methods and purposes for developing such lists. Some of them have corresponded to the necessity to define a subject field's boundaries and some corresponded to acquisition and retention needs. The core journals always hold focused and most relevant articles of a particular discipline that attracts further more citations.

There are quite a lot of approaches for deciding the core journals, some of them are subjective findings, citation data, uses statistics, indexing coverage, overlapping of library's collections, citation network analysis, co-citation analysis, Law of scattering, faculty publication data etc.

The cited reference's analysis is one of the most accepted and widely used analysis tool in use from last many years for identification of core documents in a particular subject; to shows the multifarious association between citing and cited documents of a specific field of research.

The quantity of scholarly published documents over a period of time is generally measured to be a pointer of the number of research publications during the specific length of time in a particular subject. The quantity of scholarly literature continues to be double very fast and now, it is called the age of information explosion. To judge and select rightly scholar information sources, various studies have been carried out earlier measuring the different subject's publication sources using the Bradford's Law of Scattering. The idea of 'core journals' was derived from Bradford's Law of Scattering, which was given by S. C. Bradford[1] in the year 1934. Bradford's Law of Scattering describes how the literature is scattered or spread in the different journals of a particular subject field. In the midst of the several numerical interpretations, Bradford's Law of Scattering is possibly the much accepted and admired bibliometric law to quantify the literature for selection.

2. Review of Literature:

There is various type of literature available for Bradford's law of scattering on different aspects. The law has been analyzed, re-verified, re-stated and contributed with various mathematical models due to discrepancies in its verbal and graphical presentation given by S.C. Bradford since its assertion. Two approaches are in use: verbal and graphical, in analyzing the law of scattering. The first remarkable article on Bradford's law of scattering was published by Vickery[2] who discovered that the law as stated by Bradford is not in total accordance with his algebraic interpretation. Few of the outstanding interpretation of verbal formulation of the Bradford's law were given by Leimkuhler[3], Goffman and Warren[4] where as graphical demonstration of the law was demonstrated by Kendall[5], Cole[6], and Brooks[7-8]. Kendall[5] analyzed the 370 journals of 170 references in operation research and found that there is obvious resemblance between these types

of distribution. Cole[6] found that a comparison of reference scattering co-efficient derived from data obtained for study. Brooks[7-8] gave a mathematical expression.

A good number of literatures have been published over the period of time on the law of scattering. Remarkable studies was done by Sengupta[9] who stated that during phases of rapid and vibrant expansion of knowledge in a subject, article of significance to that subject published in journals outlying from that field. Maheswarappa and Prakash[10] verified Bradford's law of scattering on botanical lierature and examined the cited references in PhD theses to check out the literature uses practices by the researchers, and analyzed the bibliography, the information sources utilized, obsolescence, the scattering of literature with publishing nation and language, referencing pattern, and found that Bradford's Law of scattering is applied to the literature of Botany. Eto[11] carried out the application of the Bradford's law to firms expending on the Research & Development and fruitfully recognized the core firms, peripheral firms, and minor firms. Gupta[12] studied the application of Bradford's law of scattering on cited reference in Ethiopian medical journal. Everett and Pecotich[13] studied the citation pattern of 'The Journals of Psychology' published by the American Psychological Association (APA) for ranking their productivity and showing the interrelatedness with different aspects. Arjun Lal and Panda[14] carried out the application of various approaches of Bradford's law on collected from thesis submitted for award of doctorate degree to the RAU, Pusa, Bihar on plant pathology literature for the period 1980 - 1993. Sudhir[15] reviewed the scholarly contribution on the various aspects of Bradford's Law and studied pattern of uses by researchers, examining 79 doctoral theses cited by the physicists at the IISc, Bangalore to verify the application of Bradford's law of scattering. The journal scattering pattern did not match the Bradford's law but Leimkuhler model was found valid for the data set. Dhanamjaya et. al.[16] analyzed the 17,151 cited references from 137 doctoral theses of engineering awarded by Karnataka University during 1961-2008. Jena, Swain and Sahu[17] studied the applicability of Bradford's Law of Scattering on the journal titled 'The Electronic Library' for the years 2003-09 found in shape for distribution of the articles. Zafrunnisha[18] applied the law of scattering on the cited references of doctoral theses of psychology, and identified the Bradford's group of distribution, cited core journals and instituted that distribution of journal titles in psychology doesn't suit the Law of Scattering. Banateppanvar and Biradar[19] suggested that the citation analysis study is role model for information professional's to develop and offer modern services to universities academic users as well as to administrative authorities in decision making. Further, his study states that journals are the favorite sources of consulted documents by the scholars in the subject of Biotechnology with counting of 79.72% cited reference documents although citations was used from other sources like thesis, conference proceeding, books, patent and different types of reports were also identified, but majority of citations was used from periodicals. Ram and Paliwal[20] applied the Bradford's law on literature produced in 49 years (1960-2009) on Psoriasis disease and found that theoretical aspect of Bradford law didn't suit the data set, but the Leimkuhler model support dispersion of Psoriasis literature. Joshi, Mamdapur and Rajgoli[21] studied the application of Bradford's Law for the literature of 'stellar physics' for the period 1988–2013 from WoS

database, A total of 2738 articles were found in 188 journals, hypothetical aspects of Bradford's Law of Scattering were examined and found that the studied data doesn't match the advocated distribution pattern but Leimkuhler model was found valid to for the data set.

The above studies have verified the selection or rejection of the application of Bradford's law of scattering in various subject fields for a specific data set. Till now, no one researcher has tested the applicability of law of scattering on literature of Astronomy & Astrophysics. The present study aimed to test the applicability of Bradford's law of scattering for the literature of Astronomy & Astrophysics produced by Indian Scientist.

3. Objectives:

The objectives of the study:

(i) To know the core journals of Astronomy & Astrophysics in order of their productivity.
(ii) To verify the application of Bradford's law of scattering and Leimkuhler Model.
(iii) To draw the Bradford Bibliograph to examine the graphical distribution of the articles.

4. Scope and Limitations

The scope of the present study is to examine the application of Bradford's Law of scattering and Leimkuhler Model in research publications of Astronomy & Astrophysics of India as journal articles. The present study is focused on the published literatures scattered in journals and limited for the specific time period of 30 years from 1988 to 2017.

5. Methodology

Web of Science[22] (WoS) bibliographic database were used to collect the bibliographical data of referred research publications of India in the field of Astronomy & Astrophysics. 'Advance search' option was used as (SU=Astronomy & Astrophysics) AND (CU=India). The Time period was used for thirty years from 1988-2017. Total 21,332 research papers have been published in different document format and it was further re-scrutinized and found that 18,877 articles have been published in 210 journals during 1988-2017. The same syntax (as above) was applied for the different blocks of ten years and found that 3,877 articles in 80 journals; 5,110 articles in 148 journals and 9,890 articles in 62 journals have been published during 1988-1997, 1998-2007 & 2008-2017 respectively which was further used for the present study to examine the application of Bradford's law of scattering and Leimkuhler Model in different span of time.

6. Theoretical facet of Bradford's Law of Scattering

Bradford's Law deals with efficiency of the journals in term of quantitative publications and examines the assemblage of articles in a specific subject inside a definite set or zone of scholarly

publishing journals. Bradford's Law of scattering states that huge number of publications are scattered in very less number of journals and a big amount of journals have proportionally less number of articles. Articles scattering in different journals can be separated in a quantity of estimated proportion. The Bradford's law of scattering proclaims that papers on a particular subject are spread in accordance with nearly a defined arithmetic ratio. Samuel Clement Bradford (British mathematician and Librarian at Science Museum in London) analyzed the list of two geophysics bibliographies namely, the 'Current Bibliography of Applied Geophysics' (for the period 1928-1931) and 'Quarterly Bibliography of Lubrication' (for the period 1931-1933), and organized them in diminishing order of productivity. He recognized three zones of journals arranged by their publication output. The first zone had the smallest number of journals but very much prolific journals called the 'core or nucleolus group of journals' and the second zone had a moderately very high number of journals with same number of articles. The succeeding third group had even very large number of journals with same number of articles. Observing his experiment, S. C. Bradford[23] stated that if scientific journals are organized in the way of diminishing the yield of publications on a specific subjects field, and further separated into nucleus of periodicals predominantly dedicated to the subject and numerous other groups hold the similar number of publication as the nucleus and succeeding zones will be as 1: n: n^2 and so on, where 'n' is a multiplier called the 'Bradford multiplier'.

Vikery[24] observed that application of Bradford's law of scattering can be seen in any number of zones of equal output value. In 1969, Brookes[7] gave the linear equation to describe the Bradford's law of scattering as shown below:

$$F(x) = a + b \log x$$

Where, F(x) is the cumulative no. of cited reference available in the first *x* highest prolific journals. 'a' and 'b' are the variables. Later, Leimkuhler[26] gave another mathematical model for Bradford's law of distribution as below:

$$R(r) = a \log (1+b*r)$$

Where, R(r) is the no. of cumulative research articles produced by periodicals rated 1^{st} through r, and 'a' and 'b' are the constants.

In the same way, Brookes linear equation can be shown as:

$$R (r) = a \log (b / r)$$

Where, r = Natural numbers i.e. 1, 2, 3, 4, 5……..

There are a number of mathematical formulations and models have been given on Bradford's law of scattering by different bibliometricians / mathematicians but Brookes and Leimkuhler model got widely recognition among scholars.

7. Leimkuhler Model

Based on verbal distribution of Bradford's law, Leimkuhler[25] mathematical model can be shown as below:

$$R(r) = a \log (1+b*r) \quad \text{---------- (i)}$$

Where, R(r) is the cumulative number of research paper published by journals with positioned 1st through r, and 'a' and 'b' are the variables.

Later, in 1990, Egghe[26] calculated the value of 'a' and 'b' which is given in Brookes and Leimkuhler mathematical model and can be shown as follows:

$$a = y_o / \text{Log } k \quad \text{---------- (ii)}$$

$$b = k - 1 / r_o \quad \text{---------- (iii)}$$

where, y_o = Number of items in each Bradford zone (Items of each zone being of equal sizes), r_o = Number of source periodicals in the core zone i.e. nucleus zone and k = Bradford multiplier.

If the source journals are ranked in diminishing order of yielding, then 'Y^m' is the number of papers in the most yielding periodical (i.e. the first ranked journal) and R(r) is the accumulative number of articles published by the sources journals of rank 1,2, 3, 4 ,5 ……r, and 'a' and 'b' are parameters shown in the Leimkuhler model.

In establishing the Bradford zone, let 'P' be a parameter that is chosen without any restraint.

When 'P' is decided then the value of k would be calculated as:

$$k = (e^{\gamma} * Y^m)^{1/P} \quad \text{---------- (iv)}$$

where, $e^{\gamma} = 1.781$

Then, 'y_o' and 'r_o' value will be calculated by the formula given as under:

$$y_o = (Y^m)^2 * \text{Log } k \quad \text{---------- (v)}$$

$$r_o = (k-1) * Y^m \quad \text{---------- (vi)}$$

In addition, $y_o = A / P$

Where, 'A' represents gross number of publication in the defined data of the study which has 'P' number of zones with 'yo' publications in each zone.
If 'T' is the gross number of periodicals in the defined data of study, then the total sources would be $r_o * k^{i-1}$ (where, i = 1, 2, 3, 4, 5,…..P).

Hence, $T = r_o + r_o * k + r_o * k^2 + r_o * k^3 \ldots\ldots + r_o * k^{P-1}$

So, the value of r_o would be $T / (1 + k + k^2 + k^3 + k^4 + \ldots\ldots + k^{P-1}) = T (k-1) / k^P-1$ ------- (vii)

When the value of 'A' and 'T' is identified from the available data set for the study then 'r_o'& 'y_o' can be calculated very simply, if the value of 'k' is find out by the equation given above at equation number (iv).

8. Data Analysis and Interpretation

8.1 Type of Published Documents

Document Type	**Number of Publications**	**Percentage**	**Cumulative**	
			Number of Publication	**Percentage**
Journal Articles	18,877	88.49 %	18,877	88.49 %
Conference Proceeding papers	2,387	11.19 %	21,264	99.68 %
Others	68	0.32 %	21,332	100 %
Total	**21,332**	**100 %**	**21,332**	**100 %**

Table-01

Astronomy & Astrophysics literature of India has been published in different document formats but the majority of the publication's are as journal articles. Total 18,877 (88.49%) research papers have been published in 210 source journals during 1988-2017. The present study is focused on analysis and examination of the articles published in journals.

8.2 Year wise Publication of research articles in journals

Year	**No. of articles**	**Percentage**	**Cumulative**	
			No. of articles	**Percentage**
1988	324	1.72	324	1.72
1989	332	1.76	656	3.48
1990	393	2.08	1049	5.56
1991	423	2.24	1472	7.80
1992	388	2.06	1860	9.86
1993	433	2.29	2293	12.15
1994	394	2.09	2687	14.24
1995	340	1.80	3027	16.04
1996	393	2.08	3420	18.12
1997	457	2.42	3877	20.54
1998	435	2.30	4312	22.84
1999	429	2.27	4741	25.11
2000	456	2.42	5197	27.53
2001	529	2.81	5726	30.34
2002	535	2.83	**6261**	**33.17 (1st zone)**

2003	480	2.54	6741	35.71
2004	487	2.58	7228	38.29
2005	500	2.65	7728	40.94
2006	633	3.35	8361	44.29
2007	626	3.32	8987	47.61
2008	686	3.63	9673	51.24
2009	733	3.88	10406	55.12
2010	778	4.12	11184	59.24
2011	908	4.81	**12092**	**64.05 (2nd zone)**
2012	994	5.27	13086	69.32
2013	1026	5.44	14112	74.76
2014	1124	5.95	15236	80.71
2015	1198	6.35	16434	87.06
2016	1187	6.29	17621	93.35
2017	1256	6.65	**18877**	**100 (3rd zone)**
Total	**18,877**	**100 %**	**18,877**	**100 %**

Table-02

The first one–third of the total article has been published in fifteen years (during 1988-2002), the next one-third of the article was produced in nine years (during 2003-2011) and the second next one third of the articles was published in last six years (2012-2017) only. The above table no.02 indicates a rapid increase in research articles publication over period of time for the same number of articles.

8.3 Verbal formulation of Bradford's Law

8.3.1 Scattering of literature during 1988-1997

Zone	Number of Articles (%)	Number of Journals (%)	Bradford Multiplier
1	1,413 (36.44 %)	3 (3.75 %)	-
2	1,386 (35.75 %)	5 (6.25 %)	1.67
3	1,078 (27.81 %)	72 (90 %)	14.4
Total	**3,877 (100 %)**	**80 (100 %)**	

Table-03

The Bradford multiplier was calculated dividing the number of journals in a zone by preceding zone's number of journals. The three zones were decided on putting almost one-third of articles in each zone at most possible way so that the percentage of error be minimum in distribution of articles. Total 3,877 articles have been published by 80 journals during 1988-1997 in the A & A subject by Indian scientist. The articles were divided in three zones. 1,413 articles were produced by 3 journals; 1,386 articles by 5 journals and 1,078 articles by 72 journals. As per Bradford's law, the number of periodicals in three group should be in the geometrical form of 1: n: n^2. In the present data set the relation is 3: 5: 72:: 3: 3*1.67: 3*$(1.67)^2$*8.6 which is not appropriate sequence of distribution of journals as per Bradford's law of scattering. Here, 3 denotes number

of nucleus zone's journals and n=8.04 which is the mean value of multipliers [(1.67+14.4)/2=8.04].

So, 1: n: n^2 :: 3: 3*8.04: 3*$(8.04)^2$ :: 3: 24.12: 193.9 >> 221.02

Hence, the percentage of error = [(221.02-80)/80]*100 = **176.28 %.** The percentage of error is abnormally higher and the distribution of literature doesn't follow the Bradford's law.

8.3.2 Scattering of literature during 1998-2007

Zone	Number of Articles (%)	Number of Journals (%)	Bradford Multiplier
1	1,679 (32.86 %)	2 (1.35 %)	-
2	1,810 (35.42 %)	5 (3.38 %)	2.5
3	1,621 (31.72 %)	141 (95.27 %)	28.2
Total	**5,110 (100 %)**	**148 (100 %)**	

Table-04

The second block of ten years was observed and found that total 5,110 articles have been published in 148 journals during 1998-2007. The Bradford zone was determined splitting the articles in almost one-third in each zone. Only 2 journals produced first 1/3rd i.e. 1,679 articles (32.86 %) in nucleus zone; 1,810 (35.42 %) articles in 5 journals as second zone and 5,110 (31.72 %) articles in 141 journals as third zone. The present values of journals in the zones are 2: 5: 141:: 2: 2*2.5: 2*$(2.5)^2$*2.26. The scattering of literature in this data set is not as per Bradford's law. Now, The mean value of Bradford's multiplier n=15.35 [(2.5+28.2)/2].

So, 1: n: n^2:: 2: 2*15.35: 2*$(15.35)^2$:: 2: 30.7: 471.2 >> 503.9

Hence, the percentage of error = [(503.9-148)/148] *100 = **240.47 %.** The percentage of error is abnormally too towering and the distribution doesn't follow the Bradford's law.

8.3.3 Scattering of literature during 2008-2017

Zone	Number of Articles (%)	Number of Journals (%)	Bradford Multiplier
1	3,422 (34.60 %)	2 (3.22 %)	-
2	3,400 (34.38 %)	5 (8.06 %)	2.5
3	3,068 (31.02 %)	55 (88.72 %)	11
Total	**9,890 (100 %)**	**62 (100 %)**	

Table-05

The third block of the study period (2008-2017) has produced total 9,890 articles in 62 journals. The nucleus group has only 2 journals with 3,422 (34.60 %) articles; second and third zone has 3,400 articles in 5 journals and 3,068 articles in 55 journals respectively. So, the actual distribution over zone is 2: 5: 55:: 2: 2*2.5: 2*$(2.5)^2$*4.4. This division doesn't follow the Bradford's law. Now, the mean value of Bradford multiplier n=6.75 [(2.5+11)/2].

Therefore, 1: n: n^2:: 2: 2*6.75: 2*$(6.75)^2$ :: 2: 13.5: 91.1 >> 106.6

The percentage of error = [(106.6-62)/62] *100 = **71.93 %.** The percentage of error is less than previous two blocks of study but it is very high and the distribution doesn't follow the Bradford's law.

8.3.4 Scattering of literature over period of 30 years (1988-2017)

Zone	Number of Articles (%)	Number of Journals (%)	Bradford Multiplier
1	5,706 (30.23 %)	2 (0.95 %)	-
2	6,958 (36.86 %)	5 (2.38 %)	2.5
3	6,213 (32.91 %)	203 (96.67 %)	40.6
Total	**18,877 (100 %)**	**210 (100 %)**	

Table-06

The table-06 shown above is zone wise distribution of published articles in different journals. Only 2 journals have published 5,706 (30.23 %) articles; next 5 journals have published 6,958 (36.86 %) articles and third zone's 203 journals have published 6,213 (32.91 %) articles. So, the Bradford distribution of this data set of journal is 2: 5: 203:: 2: 2*2.5: 2*$(2.5)^2$*16.24. This is inappropriate and doesn't support the law of scattering what advocates. The mean value of multiplier n = 21.55 [(2.5+40.6)/2].

Hence, 1: n: n^2:: 2: 2*21.55: 2*$(21.55)^2$:: 2: 43.1: 928.8 >> 973.9

The percentage of error = [(973.9-210)/210] *100 = **363.76 %.** The percentage of error is exceptionally high and the data of present study doesn't follow the distribution of literature as per Bradford's law of scattering. No one data set in the above four set of data has been testified fit as Bradford's law of scattering advocates.

8.4 Rank list of journals (1988-2017)

S. No.	Journal	Country	Articles Published (%)	Cumulative no. of articles (%)	Rank
1.	Physical Review D	USA	3,600(19.07)	3,600(19.07)	1
2.	Physics Letters B	Netherlands	2,106(11.16)	5,706(30.23)	2
3.	MNRAS	UK	1,768(9.37)	7,474(39.59)	3
4.	Astrophysics and Space Sc.	Switzerland	1,599(8.47)	9,073(48.06)	4
5.	Astrophysical Journal	USA	1,475(7.81)	10,548(55.88)	5
6.	Astronomy & Astrophysics	European countries(ESO)	1,134(6.01)	11,682(61.88)	6
7.	Modern Physics Letters A	Singapore	982(5.20)	12,664(67.08)	7
8.	Advances in Space Res.	France	542(2.87)	13,206(69.96)	8

9.	JGR-Space Physics	USA	492(2.61)	13,698(72.56)	9
10.	Jr. of Astrophysics & Astronomy	India	456(2.42)	14,156(74.99)	10
11.	Solar Physics	Netherlands	433(2.29)	14,587(77.27)	11
12.	Classical and Quantum Gravity	UK	419(2.22)	15,006(79.49)	12
13.	Indian Jr. of Radio & Space Physics	India	414(2.19)	15,420(81.68)	13
14.	International Jr. of modern Physics D	Singapore	375(1.99)	15,795(83.67)	14
15.	General Relativity and Gravitation	Switzerland	311(1.65)	16,106(85.32)	15
16.	Annales Geophysicae	Germany	283(1.50)	16,389(86.82)	16
17.	Jr. of Cosmology & Astroparticle Physics	UK	253(1.34)	16,642(88.16)	17
18.	Planetary and Space Science	Netherlands	176(0.93)	16,818(89.09)	18
19.	Astrophysical Journal Letters	UK	173(0.92)	16,991(90.01)	19
20.	IAU Symposia	France	164(0.87)	17,155(90.87)	20
21.	Astronomical Journal	USA	152(0.81)	17,307(91.68)	21
22.	New Astronomy	Netherlands	151(0.80)	17,458(92.48)	22
23.	Earth Moon and Planets	Switzerland	129(0.68)	17,587(93.16)	23
24.	Research in Astronomy & Astrophysics	UK	113(0.60)	17,700(93.76)	24
25.	BASI	India	109(0.58)	17,809(94.34)	25
26.	Radio Science	USA	100(0.53)	17,909(94.87)	26
27.	Astroparticle Physics	Netherlands	98(0.52)	18,007(95.39)	27
28.	Astrophysical Jr. Supplement series	USA	83(0.44)	18,090(95.83)	28
29.	Annales Geophysicae Atmospheres Hydrospheres and Space Sciences	USA	82(0.43)	18,172(96.26)	29
30.	Astronomy & Astrophysics Supplement Series	France	70(0.37)	18,242(96.64)	30
31.	Experimental Astronomy	Netherlands	60(0.32)	18,302((96.95)	31
32.	ICARUS	USA	54(0.29)	18,356(97.24)	32
33.	Gravitation Cosmology	Switzerland	50(0.26)	18,406(97.50)	33
34.	Astronomische Nachrichten	UK	48(0.25)	18,454(97.76)	34
35.	PASP	USA	48(0.25)	18,502(98.01)	34

36.	Advances in Space Research Series	USA	41(0.22)	18,543(98.23)	35
37.	PASJ	Japan	36(0.19)	18,579(98.42)	36
38.	PASA	Australia	34(0.18)	18,613(98.60)	37
39.	Celestial Mechanics Dynamical Astronomy	Switzerland	22(0.12)	18,635(98.72)	38
40.	Others (171 journals)	-	242(4.46)	18,877(100)	-
Total			18,877(100 %)		

Table-07

Only 3 Indian journals in the field of Astronomy & Astrophysics have been found below 30 in the rank list of journals. These journals are under third zone of Bradford distribution of articles in the present study. Journal of Astrophysics & Astronomy 456 (2.42 %) holds 10th rank; Indian Journal of Radio & Space Physics ranked 13th with 414 (2.19 %) articles and Bulletin of Astronomical society of India (BASI) has published 109 (0.58 %) articles with 25th rank. None of the Indian journal has been identified as core or nucleus journal in the field of Astronomy & Astrophysics. All core journals are published from western countries.

8.5 Distribution of articles during 1988-2017

Rank	**No. of Journal**	**Cumulative no. of Journal**	**No. of article**	**Total no. of article**	**Cumulative no. of article**	**Log N**	**% of cumulative no. of articles**	**% of cumulative no. of Jr.**
1	1	1	3,600	3,600	3,600	0.0000	19.07	0.48
2	1	2	2,106	2,106	5,706	0.6931	30.23	0.95
3	1	3	1,768	1,768	7,474	1.0986	39.59	1.43
4	1	4	1,599	1,599	9,073	1.3862	48.06	1.90
5	1	5	1,475	1,475	10,548	1.6094	55.88	2.38
6	1	6	1,134	1,134	11,682	1.7917	61.88	2.86
7	1	7	982	982	12,664	1.9459	67.08	3.33
8	1	8	542	542	13,206	2.0794	69.96	3.81
9	1	9	492	492	13,698	2.1972	72.56	4.28
10	1	10	456	456	14,154	2.3025	74.99	4.76
11	1	11	433	433	14,587	2.3978	77.27	5.24
12	1	12	419	419	15,006	2.4849	79.49	5.71
13	1	13	414	414	15,420	2.5649	81.68	6.19
14	1	14	375	375	15,795	2.6390	83.67	6.67
15	1	15	311	311	16,106	2.7080	85.32	7.14
16	1	16	283	283	16,389	2.7726	86.82	7.62
17	1	17	253	253	16,642	2.8332	88.16	8.09

18	1	18	176	176	16,818	2.8903	89.09	8.57
19	1	19	173	173	16,991	2.9444	90.01	9.05
20	1	20	164	164	17,155	2.9957	90.87	9.52
21	1	21	152	152	17,307	3.0445	91.68	10
22	1	22	151	151	17,458	3.0910	92.48	10.47
23	1	23	129	129	17,587	3.1355	93.16	10.95
24	1	24	113	113	17,700	3.1781	93.76	11.43
25	1	25	109	109	17,809	3.2189	94.34	11.90
26	1	26	100	100	17,909	3.2581	94.87	12.38
27	1	27	98	98	18,007	3.2958	95.39	12.86
28	1	28	83	83	18,090	3.3322	95.83	13.33
29	1	29	82	82	18,172	3.3672	96.26	13.81
30	1	30	70	70	18,242	3.4012	96.64	14.28
31	1	31	60	60	18,302	3.4339	96.95	14.76
32	1	32	54	54	18,356	3.4657	97.24	15.24
33	1	33	50	50	18,406	3.4965	97.50	15.71
34	2	35	48	96	18,502	3.5553	98.01	16.67
35	1	36	41	41	18,543	3.5835	98.23	17.14
36	1	37	36	36	18,579	3.6109	98.42	17.62
37	1	38	34	34	18,613	3.6376	98.60	18.09
38	1	39	22	22	18,635	3.6636	98.72	18.57
39	1	40	15	15	18,667	3.6889	98.89	19.05
40	1	41	8	8	18,675	3.7136	98.93	19.52
41	2	43	4	8	18,683	3.7612	98.97	20.48
42	10	53	3	30	18,713	3.9703	99.13	25.24
43	7	60	2	14	18,727	4.0943	99.20	28.57
44	150	210	1	150	18,877	5.3471	100	100

Table-08

8.6 Ranking of Journals and distribution of articles in different blocks of ten years

8.6.1 During 1988-1997

Jr. Rank	Journal	Cum. no. of Jr.	Log N	Articles Published (%)	Cum. no. of articles (%)
1	Astrophysics and Space Science	1	0.0000	500(12.89)	500(12.89)
2	Physics Letters B	2	0.6931	490(12.64)	990(25.53)
3	Physical Review D	3	1.0986	423(10.91)	1413(36.44)
4	Indian Journal of Radio Space	4	1.3862	414(10.68)	1827(47.12)

	Physics				
5	Modern Physics Letters A	5	1.6094	320(8.25)	2147(55.38)
6	Astrophysical Journal	6	1.7917	280(7.22)	2427(62.59)
7	Monthly Notices of The Royal Astronomical Society	7	1.9459	199(5.13)	2626(67.73)
8	Astronomy & Astrophysics	8	2.0794	173(4.46)	2799(72.19)
9	Journal of Astrophysics and Astronomy	9	2.1972	156(4.02)	2955(76.22)
10	Solar Physics	10	2.3025	107(2.76)	3062(78.99)
11	IAU Symposia	11	2.3978	104(2.68)	3166(81.66)
12	Earth Moon and Planets	12	2.4849	85(2.19)	3251(83.85)
13	Journal of Geophysical Research Space Physics	13	2.5649	82(2.12)	3333(85.97)
14	General Relativity and Gravitation	14	2.6390	81(2.09)	3414(88.06)
15	Annales Geophysicae atmospheres Hydrospheres and Space Sciences	15	2.7080	66(1.70)	3480(89.76)
16	Classical and Quantum Gravity	16	2.7726	64(1.65)	3544(91.41)
17	Advances in Space Research	17	2.8332	52(1.34)	3596(92.75)
18	Planetary and Space Science	18	2.8903	47(1.21)	3643(93.96)
19	Astronomy & Astrophysics Supplement Series	19	2.9444	39(1.05)	3682(94.97)
20	Astronomical Journal	20	2.9957	31(0.80)	3713(95.77)
	Others (60 journals)			164(4.23)	3877(100)
Total				3,877(100 %)	

Table-09

8.6.2 During 1998-2007

Jr. Rank	Journal	Cum. no. of Jr.	Log N	Articles Published (%)	Cum. no. of articles (%)
1	Physical Review D	1	0.0000	950(18.59)	950(18.59)
2	Physics Letters B	2	0.6931	729(14.26)	1679(32.86)
3	Astronomy & Astrophysics	3	1.0986	446(8.73)	2125(41.58)
4	Astrophysical Journal	4	1.3862	388(7.59)	2513(49.18)
5	Monthly Notices of the Royal Astronomical Society	5	1.6094	374(7.32)	2887(56.49)
6	Modern Physics Letters A	6	1.7917	353(6.91)	3240(63.40)
7	Astrophysics and Space Science	7	1.9459	249(4.87)	3489(68.27)
8	Journal of Astrophysics and Astronomy	8	2.0794	170(3.33)	3659(71.60)

9	International Jr. of Modern Physics D	9	2.1972	168(3.31)	3827(74.29)
10	Classical and Quantum Gravity	10	2.3025	153(2.99)	3980(77.88)
11	Advances in Space Research	11	2.3978	149(2.92)	4129(80.80)
12	Solar Physics	12	2.4849	142(2.78)	4271(83.58)
13	Annales Geophysicae	13	2.5649	114(2.23)	4385(85.81)
14	JGR- Space Physics	14	2.6390	84(1.64)	4469(87.45)
15	General Relativity and Gravitation	15	2.7080	83(1.62)	4552(89.08)
16	IAU Symposia	16	2.7726	60(1.17)	4612(90.25)
17	Bulletin of the Astronomical Society of India	17	2.8332	55(1.08)	4667(91.33)
18	Planetary and Space Science	18	2.8903	39(0.76)	4706(92.09)
19	Astronomical Journal	19	2.9444	37(0.72)	4713(92.23)
20	Astroparticle Physics	20	2.9957	36(0.71)	4779(93.52)
	Others (128 journals)			331(6.48)	5110(100)
Total				5,110(100 %)	

Table-10

8.6.3 During 2008-2017

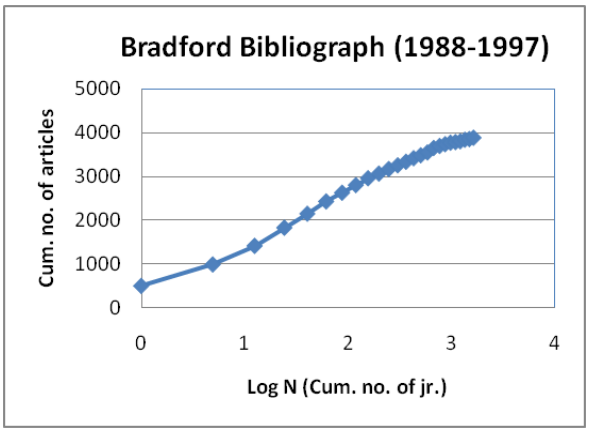
Jr. Rank	Journal	Cum. no. of Jr.	Log N	Articles Published (%)	Cum. no. of articles (%)
1	Physical Review D	1	0.0000	2227(22.52)	2227(22.52)
2	Monthly Notices of the Royal Astronomical Society	2	0.6931	1195(12.08)	3422(36.60)
3	Physics Letters B	3	1.0986	887(8.97)	4309(43.57)
4	Astrophysics and Space Science	4	1.3862	850(8.59)	5159(52.16)
5	Astrophysical Journal	5	1.6094	807(8.16)	5966(60.32)
6	Astronomy & Astrophysics	6	1.7917	515(5.21)	6481(65.53)
7	Advances in Space Research	7	1.9459	341(3.45)	6822(68.98)
8	Journal of Geophysical Research Space Physics	8	2.0794	326(3.29)	7148(72.27)
9	Modern Physics Letters A	9	2.1972	309(3.12)	7457(75.40)
10	Journal of Cosmology and Astroparticle Physics	10	2.3025	227(2.29)	7684(77.69)
11	Classical and Quantum Gravity	11	2.3978	202(2.04)	7886(79.73)
12	International Journal of Modern Physics D	12	2.4849	189(1.91)	8075(81.64)
13	Solar Physics	13	2.5649	184(1.86)	8259(83.50)
14	Astrophysical Journal Letters	14	2.6390	173(1.75)	8432(85.26)
15	Annales Geophysicae	15	2.7080	169(1.71)	8601(86.97)

16	General Relativity and Gravitation	16	2.7726	147(1.49)	8748(88.45)
17	New Astronomy	17	2.8332	133(1.34)	8881(89.79)
18	Journal Of Astrophysics and Astronomy	18	2.8903	130(1.31)	9011(91.11)
19	Research In Astronomy and Astrophysics	19	2.9444	113(1.14)	9124(92.25)
20	Planetary and Space Science	20	2.9957	90(0.91)	9214(93.16)
	Others (128 journals)			676(6.83)	9890(100)
Total				9890(100%)	

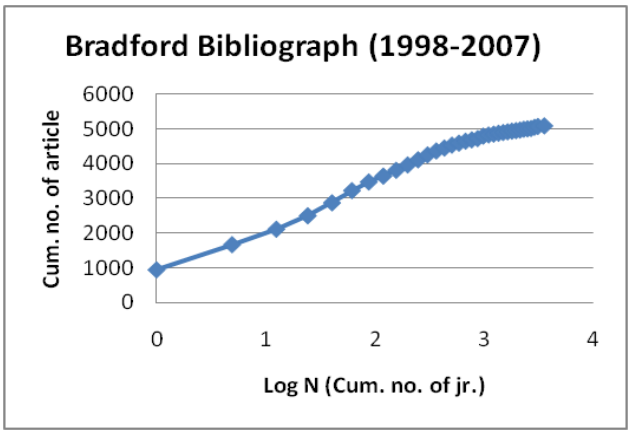
Table-11

8.7 Graphical Formulation

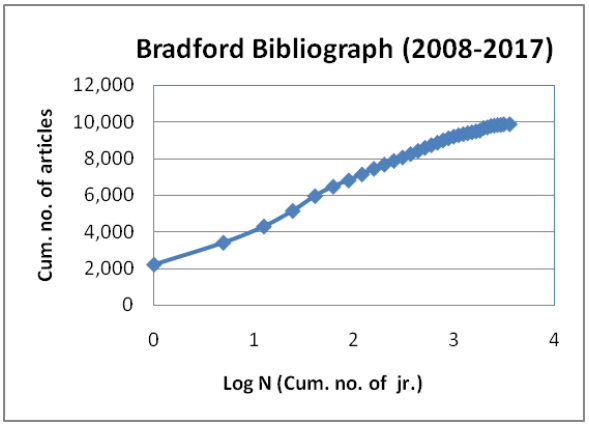
Graphical formulation of the Bradford's law of scattering was given by Boorkes[28] which testifies the verbal formulation of the law of scattering. Brookes gave three conditions for the graphical formulation: (i) the graph may have sharp rise at beginning which shows the core journals; (ii) a linear growth in the middle indicating strong relation between the variables and (iii) a droop at the end point that denotes incompleteness of the bibliography verified.



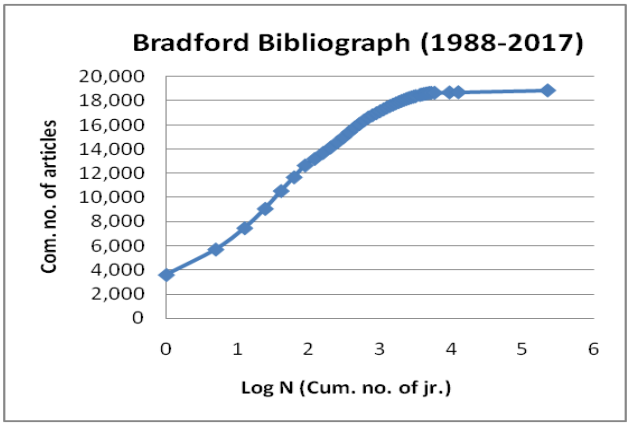
Graph-01



Graph-02



Graph-03



Graph-04

Bradford graphs of article distribution in journals

The rank list of journals and distribution of articles as per their productivity has been shown for different durations in table number 08 to 11. The above graph no. 1, 2, 3 and 4 represents the data set for the period 1988-1997, 1998-2007, 2008-2017 and 1988-2017 respectively. All these graph shows different characteristic of the data examined. It can be observed from the graph that less no. of journals has very high level of concentration in productivity.

8.8 Applicability of Leimkuhler Model

Leimkuhler Model can be testified with the present data set for the Bradford law of scattering. The Bradford multiplier 'k' can be calculated as $k = (e^{\gamma} * Y^{m})^{1/P}$

Here, the data set has been divided in 3 zones. So, P=3

e^{γ} =1.781 (constant) and Y^{m} = 3600 (Y^{m} = no. of papers in highest prolific source journal)

Now, **k** = $(1.781*3600)^{1/3} = (6411.6)^{1/3}$ = **18.5775**

Using the value of multiplier 'k' different Bradford's group can be found as below:

Nucleus zone or First Zone r_0 = T (k-1) / (k^P – 1), where T= whole number of source journals in the data set of study.

= 210 (18.5775-1) / [$(18.5775)^3$ – 1]

= 3691.275 / (6411.53-1)

So, **r_0= 0.5758**

y_0 = A / P

=18877 / 3 = **6292.3333**

a = y_0 / Log k = 6292.3333 / Log 18.5775

= 6292.3333 / 2.9219 = **2153.5074**

b = k-1 / r_0

= (18.5775 – 1) / 0.5758 = **30.5271**

Different Bradford's group / zone can be identified using the quantified value of 'r_0' and 'k'.

Nucleus zone or First zone = r_0*1 = 0.5758 * 1= **0.5758** >>1

Second zone = r_0 * k = 0.5758 * 18.5775 = **10.4969** >> 10

Third zone = r_0 * k^2 = 0.5758 * $(18.5775)^2$ = **198.7221** >>199

So, after normalizing the no. of journals in different group/ zone, the Bradford zone would be as shown below as per Leimkuhler Model:

Bradford Zone	Number of journals	Number of articles	k
1 (r_0*1)	1	3600	-
2(r_0 * k)	10	10987	3.05
3(r_0 * k^2)	199	4290	0.39
Total	**210**	**18,877**	**1.72**

Table-09

As per table-09, the zone distribution of the journals is 1:10:199:: 1: 1*10:: $1*10^2$ * 1.99 i.e. 1: n : n^2 * 1.99 which doesn't support the Bradford's law. According to Brookes[27], the value of multiplier 'k' should be greater than one (k >1) and the size of the articles/citation in each group (y_0) should be almost equal in size. Here, the size of the 'y_0' is not same in all groups; have very high level of fluctuation.

The group distribution as per actual calculation through Leimkuhler model is **0.5758**: **10.4969**: **198.7721**

The core group / nucleus group's number of journal calculated is **0.5758** which cannot be a feasible number for journal. Hence, the Leimkuhler model is also failed to prove the Bradford law of scattering in the present data set.

9. Finding and Conclusion

Assessing the resources of information is very much important for collection development in a Library. The Bradford's law of scattering is an aid to access the subject concern and identify the core journals for the knowledge seekers so that they may get maximum useful resources with minimum effort, time and money. It gives glimpse of productivity of the sources. The productive journals were identified by the present study in Astronomy & Astrophysics. The present data set was evaluated through the law of Bibliometrics namely Bradford's law of scattering and further re-examined by Leimkuhler model. It was failed to prove the law of scattering as well as Leimkuhler model. The percentage of error was exceptionally high and the value of multiplier 'k' is also varying from different zone to zone. The reason identified that the concentration of literature in core journals is so high it could not further followed the law of scattering of literature in succeeding zones. The graphical formulation also shows the non-consistency in scattering of literature. But, the law was useful in identifying the productive journals in the field of Astronomy & Astrophysics that may help the librarians, researchers and policy makers as well in their objects of interest.

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