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Dark energy: A scientometric mapping of publications

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ABSTRACT

This paper attempts to highlight the growth and development of dark energy literature and make the quantitative and qualitative assessment by way of analyzing various features of research output based on Web of Science database. A total of 5858 publications were published on dark energy, which received 157,581 citations during 1999-2011. The average number of publications per year was 450.62, and the average number of citations per publication was 26.90. The publications peaked in 2011 with 934 publications, and the highest number of citations (26,404) were received in 2003. There were 3857 (65.84%) single country publications from 74 countries and 2001 (34.16%) multi-country collaborative publications. The highest number of publications were from Europe with 3723 (41.15%) publications and 126,747 (39.88%) citations followed by Asia with 2614 (28.89%) publications and 63,267 (19.90%) citations, and North America with 1980 (21.89%) publications and 105,132 (33.08%) citations. European scientists have been playing an important role on dark energy-related research followed by Asian Scientists. The exponential growth of publications was observed during the period. USA had the highest share (26.84%) of publications followed Peoples Republic of China with 13.74% publications, England with 11.71% publications, Italy with 10.84% publications, Spain with 7.90% publications, Germany with 7.27% publications, and India with 7.07% publications. Astronomy and Astrophysics accounts for the largest share 3920 (66.92%) of publications in the total worldwide output on dark energy which received 117,919 (74.83%) citations followed by Multidisciplinary Physics with 1242 (21.20%) publications, 29,775 (18.90%) citations and 23.97 average citations per publication. More than 80% of the publications appeared only in 15 key-journals.

Keywords: Activity index, citations, co-authorship index, dark energy, nobel laureates, publications, publication efficiency index, scientometric mapping

INTRODUCTION

Dark energy is the name given to the unknown cause of the universe's accelerating expansion, one of the most significant discoveries in recent cosmology. Understanding the enigmatic ingredient of the universe and its gravitational effects is a very active, and growing, field of research. We commonly denote as dark energy the physics yet to be determined that causes the present acceleration of the universe. Dark energy is a very wide subject residing in unknowns of very different kinds, since the origin of the cosmic acceleration can be of very diverse nature. It can be linked to the presence of a new component of the universe in the form of a field with similarities to the field that causes inflation. It can be a departure of gravity from general relativity, or it can be related to vacuum energy.[1] The simplest model for dark energy is the cosmological constant introduced by Einstein into the equations of General Relativity in order to produce a static and finite Universe. Alternatively, dark energy might be due to a fluid of unknown particles, similar to the axion but much smaller in mass-quantum theory predicts that such particles could supply the requisite negative pressure to accelerate the cosmic expansion.[2] The discovery that the expansion of the Universe is accelerating put in place the present cosmological model, in which the Universe is composed of 4% baryons, 20% dark matter, and 76% dark energy.[3]

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However, in 1998, it appeared that instead of slowing down, the expansion of the universe was accelerating. This was explained by postulating the presence of an anti-gravity component in the universe, for which gravitational interaction is repulsive rather than attractive. It is believed that such as repulsive invisible fluid is permeating the universe and this is called 'dark energy.'

Scientometric evaluations have its own characteristics. Scientometric researchers are exploring features of information processes in scientific research but are far from finding the solution to all problems.[4] Scientometric studies covering all quantitative and qualitative aspects of the science of science also include quantitative and qualitative analysis of scientific literature (bibliometrics) as a reflection of science development and state-of-the-art[5] compared science to an edifice building upon the past, and indicated the potential for examining science through its literature, since published papers being the end product of much science research and its "building blocks" show the structure of this "edifice." Many scientometric studies have appeared in the literature to focus on the performance of nuclear science and technology.[6-27]

OBJECTIVES

The objective of the study was to perform a scientometric analysis of all dark energy publications in the world. The parameters studied include:

- to find out growth of publications and citations
- to find out continent-wise distribution of publications and citations
- to find out country-wise distribution of publications
- to verify publication efficiency index
- to verify activity index
- to verify co-authorship index
- to find out publications share of highly productive countries
- to find out publication and citations according to number of collaborating countries
- to find out country-wise distribution of publication according to impact factor range
- to document, publications of Nobel Laureates in physics (2011) on dark energy
- to document domain-wise distribution of publication and citations
- to find out highly cited publication
- to find out highly preferred journals and
- to document quality of research output.

MATERIALS AND METHODS

Web of Science database was used for retrieving data on dark energy for all years using the search term 'dark energy' in 'topic' field. Records pertaining to dark energy were retrieved only from 1999 onwards. A total of 5858 publications and 157,581 citations received to these publications were transferred to spread sheet application and analyzed the data as per objectives of the study.

ANALYSIS

Year-Wise Growth of Publications and Citations

A total of 5858 publications were published during 1999-2011, which received 157,581 citations during the period. There were only 5 publications in 1999 on dark energy. The highest numbers of publications (934) were in 2011, and these publications have received the 4000 citations. The highest number of citations (26,404) were received in 2003. The average number of publications published per year was 450.62, and the number of citations per publication during the period was 26.90. Figure 1 gives the year-wise growth of publications and citations. The highest number of average citations per publication (233.40) was in 1999. An exponential growth of publications on dark energy was observed. The highest growth rate (220.00%) was observed in 1999. Table 1 provides year-wise growth rate of publications and citations on dark energy. The highest average citations per publication was 233.40 in 1999 and 111.41 in 2003 [Figure 2].

Continent-wise Distribution of Publications and Citations

Publications and citations by world countries were grouped

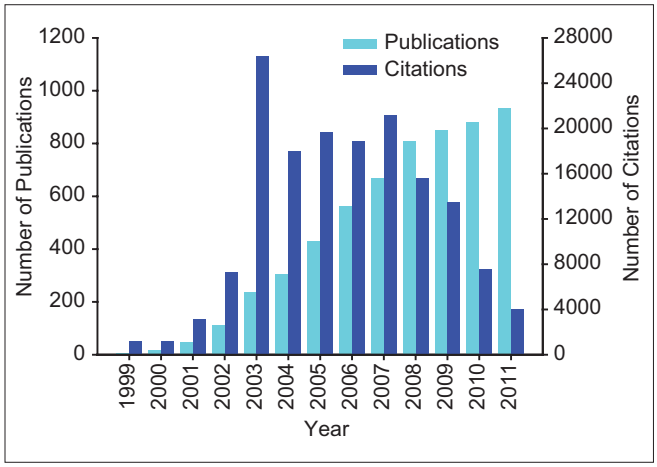

Figure 1: Year-wise distribution of publications on dark energy

into six continents: Africa, Asia, Australia/Oceania, Europe, North America, and South America. Europe is the most productive continent with 3723 (41.15%) publications and 126,747 (39.88%) citations followed by Asia with 2614 (28.89%) publications and 63,267 (19.90%) citations, North America with 1980 (21.89%) publications and 105,132 (33.08%) citations, South America with 483 (5.34%) publications and 14,782 (4.65%) citations, Australia/Oceania with 131 (1.45%) publications and 5094 (1.60%) citations, and Africa with 111 (1.23%) publications and 2826 (0.89%) citations. Publications from North America received the highest average number of citations (53.10) per publication followed by Australia/Oceania with 38.89 average citations per publication, Europe with 34.04 average citations per publication, South America with 30.60 average citations per publication, Africa 25.46 average citations per publication, and Asia with 24.20 average citations per publication.

Chronological distribution of dark energy publications and citations of six continents is given in Figure 3. It is observed from the figure that Europe had the highest number of publications in 2010, and a declining trend was noticed for Europe and North America in 2011. There is no significant change in publication productivity of other continents.

England is the highly productive country in Europe with 686 (11.71%) publications, 30,736 (19.50%) citations and 44.80 average citations per publication. Peoples Republic of China is the highly productive country in Asia with 805 (13.74%) publications, 15,823 (10.04%) citations and 19.66 average citations per publication. USA is the highly productive country in North America with 1572 (26.84%) publications, 77,278 (49.04%) citations and 49.16 average citations per publication. Brazil is the highly productive country in South America with 320 (5.46%) publication,

Table 1: Year-wise growth rate (in %) of publications and citations

Year	Total publications	% of total publications	Growth rate of publications	Total citations	% of total citations	Growth rate of citations	Average citations/pub.
1999	5	0.09	-	1167	0.74	-	233.40
2000	16	0.27	220.00	1218	0.77	4.37	76.13
2001	48	0.82	200.00	3180	2.02	161.08	66.25
2002	112	1.91	133.33	7312	4.64	129.94	65.29
2003	237	4.05	111.61	26404	16.76	261.11	111.41
2004	305	5.21	28.69	17954	11.39	−32.00	58.87
2005	430	7.34	40.98	19662	12.48	9.51	45.73
2006	563	9.61	30.93	18904	12.00	−3.86	33.58
2007	669	11.42	18.83	21153	13.42	11.90	31.62
2008	807	13.78	20.63	15617	9.91	−26.17	19.35
2009	852	14.54	5.58	13448	8.53	−13.89	15.78
2010	880	15.02	3.29	7562	4.80	−43.77	8.59
2011	934	15.94	6.14	4000	2.54	−47.10	4.28
Total	5858	100	-	157581	100.00	-	26.90

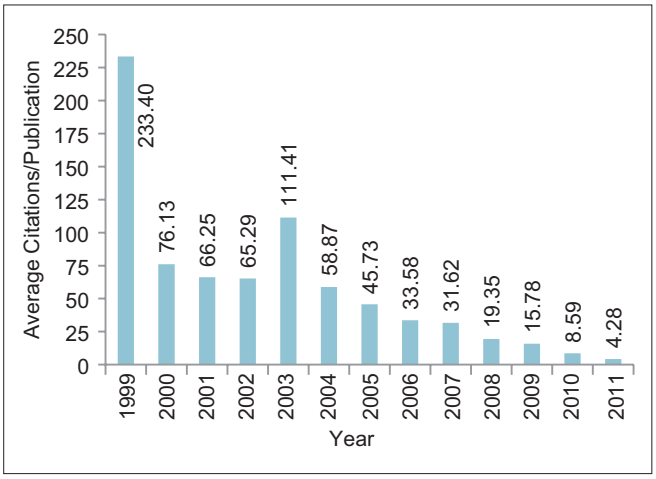

Figure 2: Year-wise distribution of average citations per publication

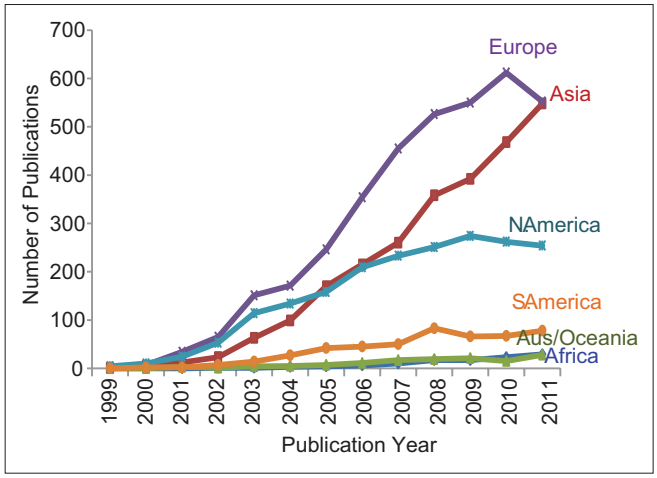

Figure 3: Year-wise distribution of publications of six continents

5228 (3.32%) citations and 16.34 average citations per publication. Australia is the highly productive country in Australia/Oceania with 102 (1.74%) publications, 4391 (2.79%) citations and 43.05 average citations per publication, and South Africa is the highly productive country in Africa with 93 (1.59%) publication, 2757 (1.75%) citations and 29.65 average citations per publication. Table 2 provides the highly productive countries in each continent.

Share of Publications of Highly Productive Countries

In all, there were 74 countries involved in research in dark energy, which published at least one publication. The publication share of highly productive countries (≥50 publications) on dark energy is given in Figure 4. USA had the highest share (26.84%) of publications followed by Peoples Republic of China with 13.74% publications, England with 11.71% publications, Italy with 10.84% publications, Spain with 7.90% publications, Germany with 7.27% publications, India with 7.07% publications, Japan with 6.59% publications, France with 5.79% publications, and Brazil with 5.46% publications.

Publication Efficiency Index

Publication Efficiency Index (PEI) was used by Guan & Ma (2007)[8] in their studies as a measure of research quality. It indicates whether the impact of publications in a country in a research field is compatible with the research efforts. The value of PEI > 100 for a country indicates that the impact of publications is more than the research effort devoted to it for that particular country and vice versa.

$$PEI = \frac{TNC_i / TNC_t}{TNP_i / TNP_t}$$

Where:
TNC_i denotes the total number of citations of country i
TNC_t denotes the total number of citations of all countries
TNP_i denotes the total number of papers of country i
TNP_t denotes the total number of papers of all countries

Table 2: Highly productive countries on dark energy research

Continent	Rank	Country	TP	% of TP	TC	% of TC	ACP
Europe	1	England	686	11.71	30736	19.50	44.80
	2	Italy	635	10.84	16810	10.67	26.47
	3	Spain	463	7.90	17175	10.90	37.10
	4	Germany	426	7.27	15515	9.85	36.42
	5	France	339	5.79	9319	5.91	27.49
Asia	1	Peoples R China	805	13.74	15823	10.04	19.66
	2	India	414	7.07	10251	6.51	24.76
	3	Japan	386	6.59	20619	13.08	53.42
	4	Iran	285	4.87	3460	2.20	12.14
	5	Russia	278	4.75	7807	4.95	28.08
North America	1	USA	1572	26.84	77278	49.04	49.16
	2	Canada	285	4.87	26565	16.86	93.21
	3	Mexico	101	1.72	1042	0.66	10.32
	4	Cuba	19	0.32	213	0.14	11.21
	5	Trinidad and Tobago	2	0.03	34	0.02	17.00
South America	1	Brazil	320	5.46	5228	3.32	16.34
	2	Chile	100	1.71	8488	5.39	84.88
	3	Argentina	43	0.73	893	0.57	20.77
	4	Colombia	20	0.34	173	0.11	8.65
Australia/Oceania	1	Australia	102	1.74	4391	2.79	43.05
	2	New Zealand	29	0.50	703	0.45	24.24
Africa	1	South Africa	93	1.59	2757	1.75	29.65
	2	Sudan	5	0.09	26	0.02	5.20
	3	Algeria	4	0.07	1	0.00	0.25
	3	Morocco	4	0.07	5	0.00	1.25
	4	Benin	3	0.05	35	0.02	11.67

ACP=Average citations per publication, TP=Total publications, TC=Total citations

Canada had the highest PEI (346.51%) followed by Chile with 315.54%, Sweden with 254.34%, Scotland with 220.76%, Japan with 198.58%, USA with 182.75%, England with 166.56%, Australia with 160.03%, Portugal with 141.07%, Denmark with 139.02%, Spain with 137.90%, Germany with 135.39%, South Africa with 110.2%, Norway with 109.52%, Russia with 104.40%, and France with 102.19% [Figure 5].

Activity Index

The first research activity on dark energy was started in USA and People Republic of China in 1999. The countries like England, Italy, Spain, Germany, Japan, and Brazil had publications in 2000, and India and France in 2001. Table 3 presents the year-wise Activity Index of top ten countries. The Activity Index (AI) characterizes the relative research efforts of a country in a given subject (2007).[28] USA (460.15) and Peoples Republic of China (224.65) had highest activity Index in 1999, Germany (265.32) and Brazil (235.47) in 2000, Japan (218.63) and France (142.25) in 2001, England (158.17) and Italy (151.89) in 2002, Spain (139.49) in 2006, and India (148.15) in 2011.

Publication and citation counting techniques have been used in the assessment of scientific activity for at least 50 years. During this activity, the main thrust of interest seems to flow along two connected but parallel paths: The bibliometric path of publication and citation counts as tools and an evaluative path using the same tools to illuminate the mosaic of scientific activity.[29]

Co-authorship Index

Co-authorship Index (CAI) has been firstly elaborated by Schubert and Braun (1986),[30] and is obtained by

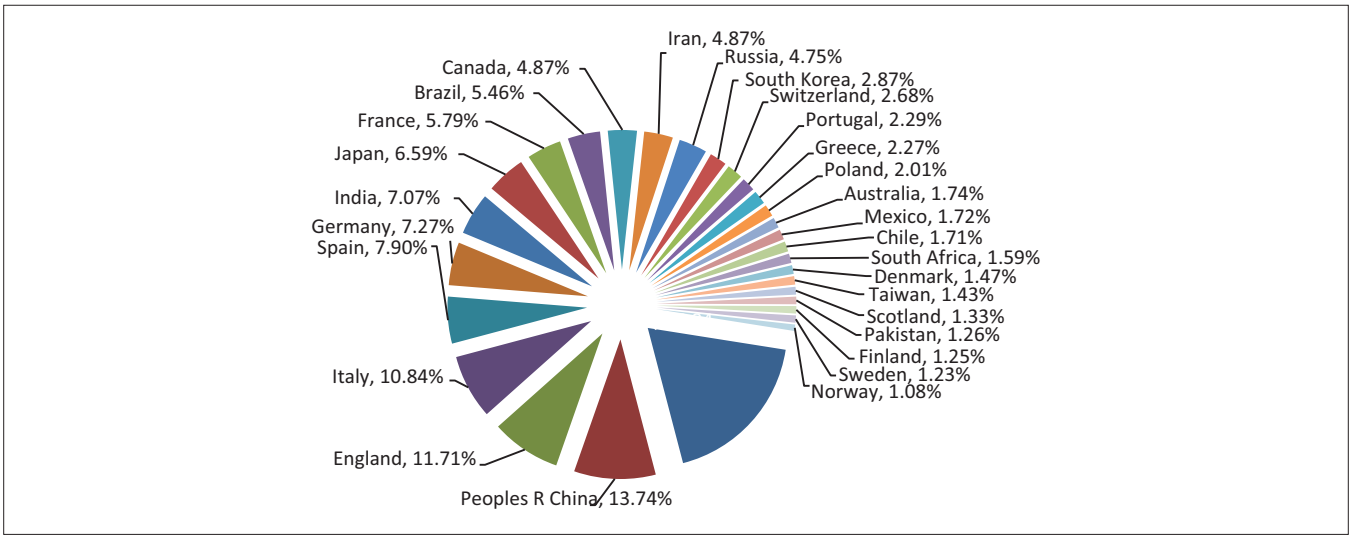

Figure 4: Countries-wise share of publications on dark energy (≥1.00% publications)

Table 3: Activity index of top ten countries

Year	USA	People's R China	England	Italy	Spain	Germany	India	Japan	France	Brazil
1999	460.15	224.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	215.70	140.40	54.92	118.66	81.37	265.32	0.00	97.60	0.00	235.47
2001	161.05	14.98	105.45	132.90	26.04	198.10	29.12	218.63	142.25	75.35
2002	187.90	7.49	158.17	151.89	13.02	99.05	145.60	78.08	124.47	113.03
2003	165.76	51.79	136.75	143.62	84.42	110.10	107.00	74.26	107.61	73.29
2004	146.75	81.88	120.10	116.77	102.32	67.69	64.68	144.07	85.06	141.60
2005	118.34	121.82	94.60	106.74	96.56	94.79	90.57	130.76	63.81	139.70
2006	116.41	105.64	103.56	100.01	139.49	63.17	83.20	128.28	92.08	107.64
2007	99.89	112.87	110.59	109.75	85.74	115.96	74.58	82.27	98.88	93.73
2008	92.20	106.59	108.26	106.74	99.67	99.86	92.31	106.48	127.62	114.92
2009	89.33	113.17	100.85	91.69	90.25	110.95	99.28	67.44	103.05	92.05
2010	80.69	87.72	86.54	88.57	110.67	114.41	99.62	114.94	108.75	80.06
2011	73.78	102.59	78.78	81.29	103.61	88.38	148.15	81.81	85.98	89.19

calculating proportionally the publications by single, two, multi- and mega-authored papers for different nations or for different sub-disciplines. This methodology is similar to the Activity Index.[31] CAI = 100 indicates that the number of publications corresponds to the average within a co-authorship pattern. CAI >100 reflects higher than the average, and CAI <100 indicates lower than the average. Here, the papers have been divided into four categories according to the number of authors, namely single-authored, two-authored, multi-authored papers with three to four authors, and mega-authored papers with five or more authors. It is clearly evident from the Figure 6, which shows that the CAI for mega-authored publications for continents Africa, Australia/Oceania, Europe, and North America is more than the average. The relatively higher CAI of mega-authored papers indicates that scientists in these continents prefer to work in larger groups when compared to scientists in Asia and South America. The CAI which is lower than other continents indicates that the scientists in these two continents prefer to work in smaller groups.

Figure 7 shows that the CAI for mega-authored publications for the countries England, Germany, Italy, Japan, and USA is more than the average. The relatively higher CAI of mega-authored papers for these countries indicates that their scientists prefer to work in larger groups when compared to scientists in India, Republic of China, and Spain. The CAI which is lower than other countries indicates that the scientists in these three countries prefer to work in smaller groups.

Top Countries According to Average Citations per Publication

The Average citations per publication (ACP) is one of the important indicators to know the quality of publications. Distribution of the highly productive countries (≥50 publications) according to average citations per publication is given in Figure 8. Canada had the highest average citations (93.21) per publication followed by Chile with 84.88 citations, Sweden with 68.42 citations, Scotland with 59.38 citations, Japan with 53.42 citations, USA with 49.16 citations, England with 44.80 citations, Australia with 43.05 citations, Portugal with 37.95 citations, Denmark with 37.40 citations, Spain with 37.10 citations, Germany with 36.42 citations, South Africa with 29.65 citations, Norway with 29.46 citations, Russia with 28.08 citations, France with 27.49 citations, Italy with 26.47 citations, India with 24.76 citations, and Switzerland with 23.57 citations.

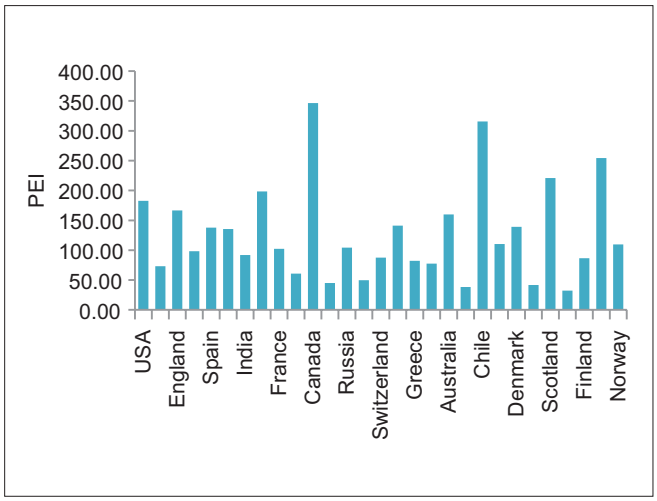

Figure 5: Publication efficiency index of highly productive countries on dark energy

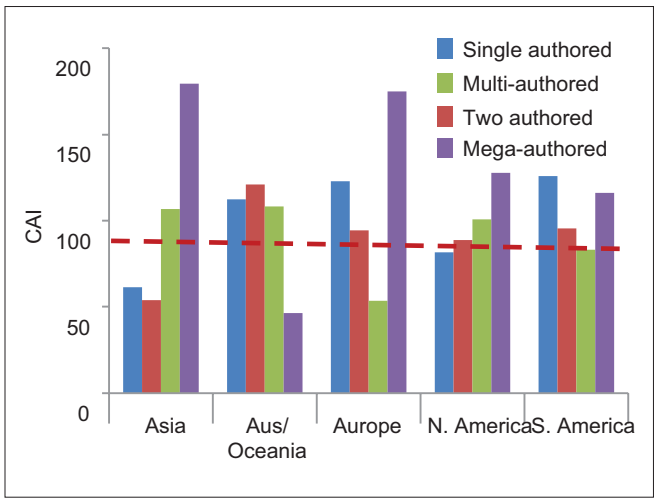

Figure 6: Continent-wise co-authorship index on dark energy publications

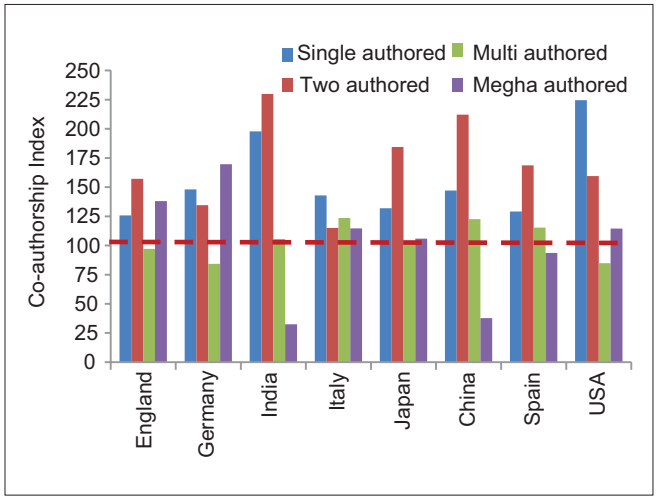

Figure 7: Country-wise co-authorship index on dark energy publications

Distribution of Publications and Citations According to Number of Countries Collaborating

Table 4 gives distribution of publications and citations according to number of countries collaborating. The highest share of publications 3857 (65.84%) and 77,595 (49.24%) citations with 20.12 average citations per publications account for single country affiliation followed by two countries with 1345 (22.96%) publications and 42,588 (27.03%) citations with 31.66 average citations per publication and three countries with 407 (6.95%) publications and 22,997 (14.59%) citations with 56.50 average citations per publication.

Country-Wise Distribution of Publications According to Impact Factor Range

In all, there were 74 countries involved in research on dark energy. The publications were classified into four categories as publications without IF (000-000), Low IF (≥0.01-2.00), Medium IF (≥2.01-4.00), and High IF (≥4.01-52.00). Table 5 gives country-wise distribution of publications according to impact factor range.

Domain-Wise Distribution of Publications and Citations on Dark Energy

Based on the classification of subject-categories in web of Science, the publication output data of dark energy research was classified into six sub-domains [Figure 9]. Astronomy and Astrophysics accounts for the largest share of 3920 (66.92%) publications from the total worldwide output on dark energy, which received 117,919 (74.83%) citations with 30.08 average citations per publication followed by Multidisciplinary Physics with 1242 (21.20%) publications and 29,775 (18.90%) citations with 23.97 average citations per publication, Mathematics with 290 (4.95%) publications and 2725 (1.73%) citations with 9.40 average citations per publication, Particles and Fields Physics with 244 (4.17%) publications and 3276 (2.08%) citations with 13.43 average citations per publication, Nuclear Physics with 107 (1.83%) publications and 656 (0.42%) citations with 6.13 average citations per publication and Multidisciplinary Sciences with 55 (0.94%) publications and 3230 (2.05%) citations

Table 4: Distribution of publications and citations according to number of countries collaborating

Number of countries collaborating	TP	% of TP	TC	% of TC	ACP
One country	3857	65.84	77595	49.24	20.12
Two countries	1345	22.96	42588	27.03	31.66
Three countries	407	6.95	22997	14.59	56.50
Four countries	131	2.24	4023	2.55	30.71
Five countries	49	0.84	2224	1.41	45.39
Six countries	25	0.43	3771	2.39	150.84
Seven countries	19	0.32	1593	1.01	83.84
Eight countries	12	0.20	1502	0.95	125.17
Nine countries	6	0.10	512	0.32	85.33
Ten countries	2	0.03	126	0.08	63.00
Eleven countries	3	0.05	587	0.37	195.67
Twelve countries	2	0.03	63	0.04	31.50
	5858	100.00	157581.00	100.00	26.90

TP=Total publications, TC=Total citations, ACP=Average citations per publications

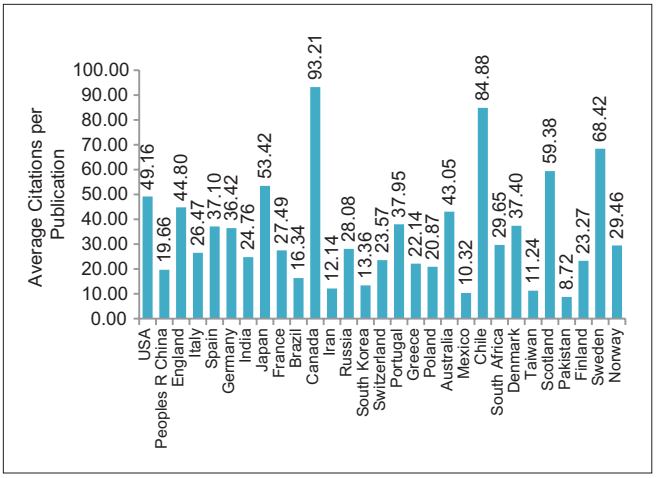

Figure 8: Average citations per publication of top countries (≥60 publications) on dark energy

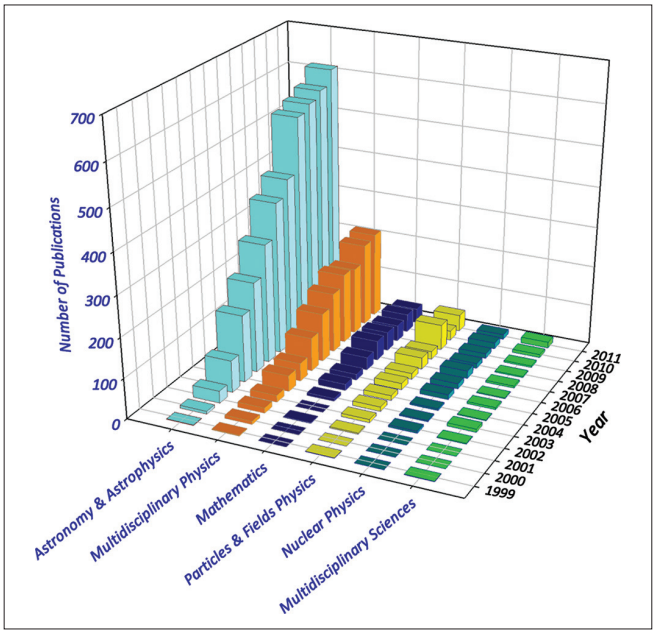

Figure 9: Year-wise distribution of publications on dark energy domains

Table 5: Country-wise distribution of publications according to impact factor range

Country	Total number of publications				% of high IF publications	Total publications
	Without IF (000-000)	Low IF (≥0.01-2.00)	Medium IF (≥2.01-4.00)	High IF (≥4.01-52.00)		
USA	198	218	125	1031	65.59	1572
Peoples R China	45	266	71	423	52.55	805
England	147	54	55	430	62.68	686
Italy	93	110	50	382	60.16	635
Spain	30	69	51	313	67.60	463
Germany	85	34	33	274	64.32	426
India	28	203	46	137	33.09	414
Japan	21	46	42	277	71.76	386
France	45	34	28	232	68.44	339
Brazil	18	64	52	186	58.13	320
Canada	34	30	21	200	70.18	285
Iran	14	113	33	125	43.86	285
Russia	23	104	28	123	44.24	278
South Korea	7	59	15	87	51.79	168
Switzerland	29	13	12	103	65.61	157
Portugal	5	11	15	103	76.87	134
Greece	10	11	9	103	77.44	133
Poland	15	20	13	70	59.32	118
Australia	38	16	7	41	40.20	102
Mexico	10	17	18	56	55.45	101
South Africa	12	4	15	62	66.67	93
Denmark	14	4	2	66	76.74	86
Taiwan	2	21	7	54	64.29	84
Scotland	37	7	6	28	35.90	78
Pakistan	4	40	19	11	14.86	74
Finland	4	8	12	49	67.12	73
Sweden	4	4	4	60	83.33	72
Norway	7	7	10	39	61.90	63
Netherlands	10	8	3	26	55.32	47
Argentina	2	10	6	25	58.14	43
Israel	8	8	6	19	46.34	41
Croatia	-	6	3	29	76.32	38
New Zealand	2	6	7	14	48.28	29
Belgium	5	4	1	18	64.29	28
Wales	3	7	5	13	46.43	28
Ukraine	-	9	1	15	60.00	25
Colombia	1	8	5	6	30.00	20
Turkey	-	12	2	6	30.00	20
Cuba	-	1	7	11	57.89	19
Rep of Georgia	3	3	1	10	58.82	17
Armenia	2	10	-	3	20.00	15
Hungary	-	1	2	12	80.00	15
Thailand	-	-	3	12	80.00	15
Kazakhstan	-	7	4	2	15.38	13
Estonia	2	2	-	6	60.00	10
Czech Republic	1	2	1	5	55.56	9
Singapore	-	1	-	8	88.89	9
Austria	-	2	2	4	50.00	8
Byelarus	1	1	1	2	40.00	5
Kyrgyzstan	-	1	-	4	80.00	5

Contd...

Table 5: Contd...

Country	Total number of publications				% of high IF publications	Total publications
	Without IF (000-000)	Low IF (≥0.01-2.00)	Medium IF (≥2.01-4.00)	High IF (≥4.01-52.00)		
Sudan	-	3	-	2	40.00	5
Algeria	-	3	1	-	0.00	4
Morocco	-	1	1	2	50.00	4
Nepal	-	1	1	2	50.00	4
Benin	-	1	-	2	66.67	3
Malaysia	-	3	-	-	0.00	3
Saudi Arabia	-	2	-	1	33.33	3
Egypt	1	-	-	1	50.00	2
Iceland	-	-	-	2	100.00	2
Slovenia	-	-	1	1	50.00	2
Trinidad and Tobago	-	-	-	2	100.00	2
Uzbekistan	-	1	-	1	50.00	2
Bangladesh	-	1	-	-	0.00	1
Bulgaria	-	-	-	1	100.00	1
Costa Rica	-	1	-	-	0.00	1
Indonesia	-	-	1	-	0.00	1
Ireland	-	-	-	1	100.00	1
North Ireland	-	-	-	1	100.00	1
Philippines	-	1	-	-	0.00	1
Slovakia	-	-	1	-	0.00	1
Sri Lanka	-	-	1	-	0.00	1
Vietnam	-	1	-	-	0.00	1

IF=Impact factor

with 58.73 average citations per publication. Figures 10 a-f provide year-wise distribution of publications on dark energy domains.

Variation of Mean Impact Factor in Dark Energy Domains

Figure 11 gives the distribution of various dark energy domains according to mean impact factor during the period under study. It is revealed from the analysis that there is a significant variation in mean impact factor in various dark energy domains. There are many reasons for variation in impact factor in various domains.[32] The highest mean impact factor (12.89) was for Multidisciplinary Sciences followed by Astronomy and Astrophysics (4.67) and Multidisciplinary Physics (3.44).

Publications of Nobel Laureates in Physics (2011) on Dark Energy

The Nobel Prize in physics (2011) was divided, one half was awarded to S. Perlmutter, and the other half was awarded jointly to B. P. Schmidt and A. G. Riess for the discovery of the "Accelerating Expansion of the Universe through Observations of Distant Supernovae." Table 6 provides the publications and citations received by the Nobel laureates in physics on dark energy. Figure 12 provides year-wise distribution of publications of Nobel laureates in physics (2011) on dark energy. It may be noted that the publications of Nobel laureates on 'dark energy' only were considered for this analysis.

Highly Productive Universities/Institutions

Among universities, the highly productive universities were: Univ Calif Berkeley-USA with 218 (3.72%) publications and 15,188 (9.64%) citations with 69.67 average citations per publication, Univ Cambridge-England with 145 (2.48%) publications and 6597 (4.19%) citations with 45.5 average citations per publication, Univ Chicago-USA with 200 (3.41%) publications and 29,453 (18.69%) citations with 147.27 average citations per publication, Univ Oxford-England with 126 (2.15%) publications and 10,011 (6.35%) citations with 79.45 average citations per publication, Univ Portsmouth-England with 145 (2.48%) publications and 7460 (4.73%) citations with 51.45 average citations per publication, and Univ Tokyo-Japan with 106 (1.81%) publications and 5697 (3.62%) citations with 53.75 average citations per publication.

Among research institutions, the highly productive universities were: Chinese Acad Sci-Peoples Republic of

highly cited publications, 14 are journal articles and 13 are review articles.

Journals Preferred for Publication by the Scientists

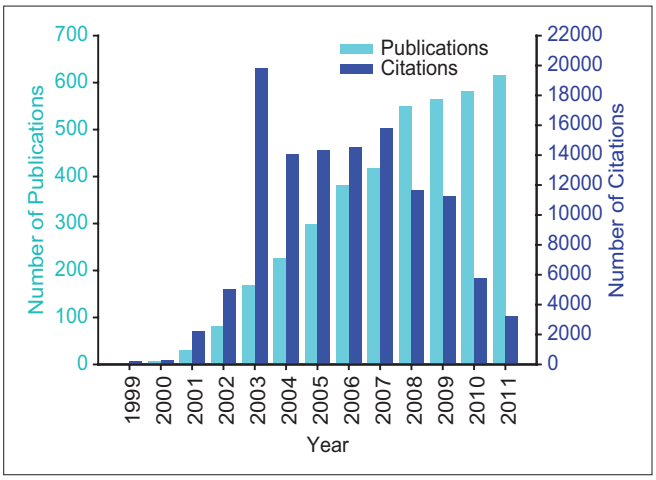

Figure 10a: Year-wise distribution of publications on astronomy and astrophysics

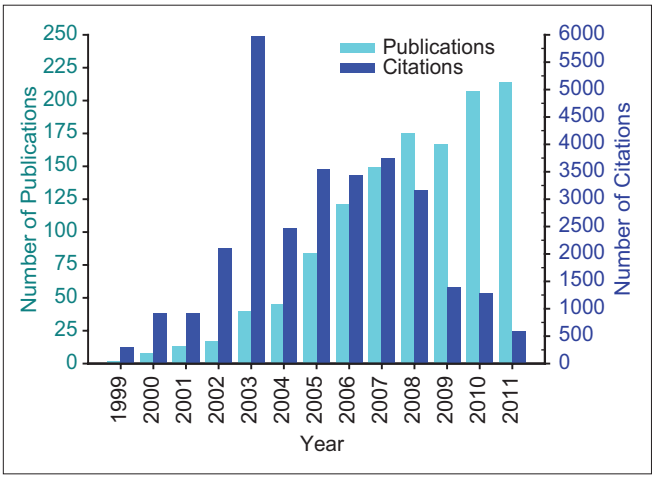

Figure 10b: Year-wise distribution of publications on multidisciplinary physics

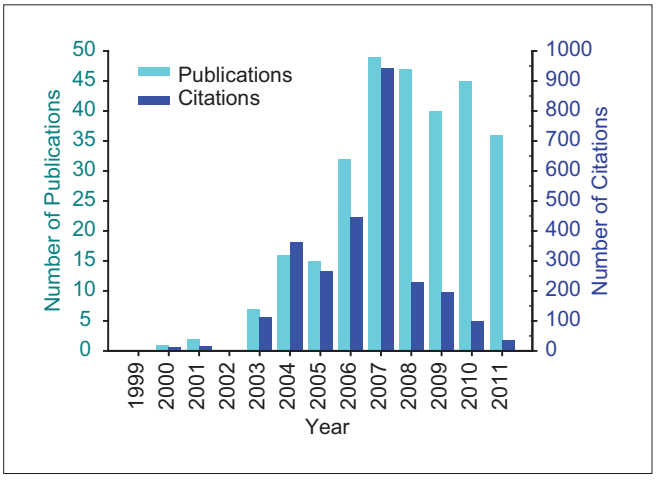

Figure 10c: Year-wise distribution of publications on mathematics

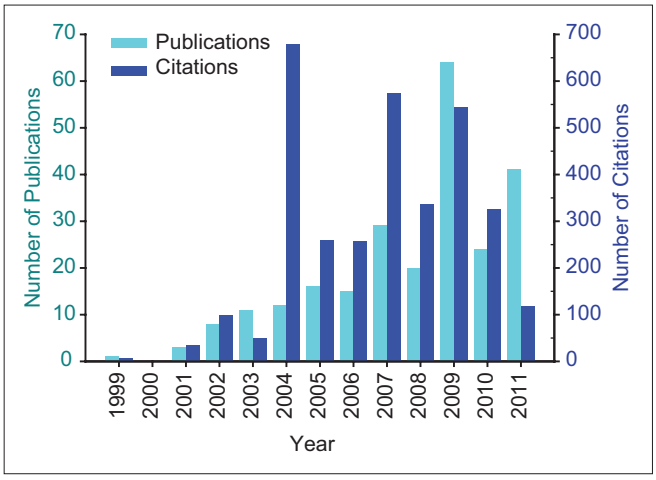

Figure 10d: Year-wise distribution of publications on particles and fields physics

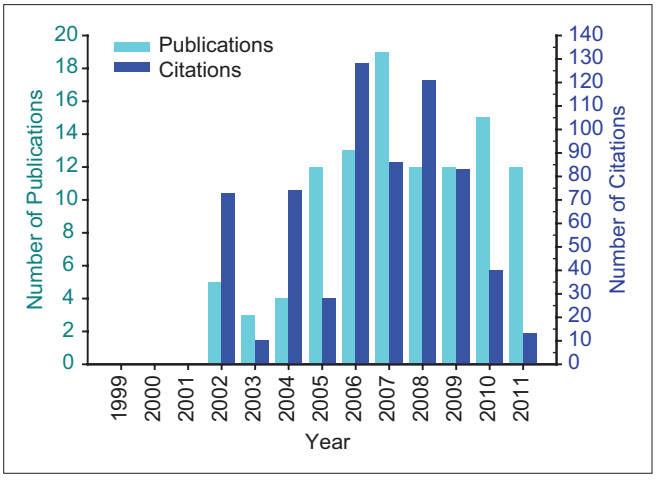

Figure 10e: Year-wise distribution of publications on nuclear physics

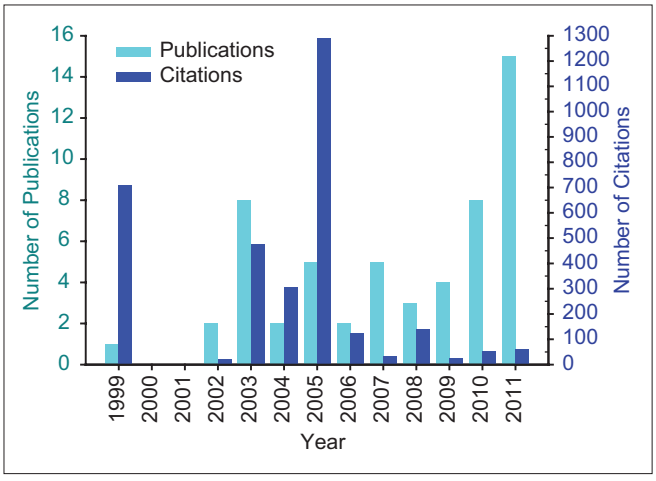

Figure 10f: Year-wise distribution of publications on multidisciplinary sciences

China with 374 (6.38%) publications and 11,383 (7.22%) citations with 30.44 average citations per publication, Ist Nazl Fis Nucl-Italy with 316 (5.39%) publications and 6921 (4.39%) citations with 21.90 average citations per publication, CSIC-Spain with 181 (3.09%) publications and 8959 (5.69%) citations with 49.50 average citations per publication, CALTECH-USA with 179 (3.06%) publications and 13,380 (8.49%) citations with 74.75 average citations per publication, CNRS-France with 130 (2.22%) publications and 2663 (1.69%) citations with 20.48 average citations per publication, and Fermi Natl Accelerator Lab, NASA-USA with 114 (1.95%) publications and 18,143 (11.51%) citations with 159.15 average citations per publication.

Highly Cited Publications

The highly cited 27 dark energy publications (which have got at least 500 citations) during the period of study are listed in Table 7. The most frequently cited one was "Spergel *et al.* First-year Wilkinson microwave anisotropy probe (WMAP) observations: Determination of cosmological parameters. Astrophysical Journal Supplement Series. (2003). Vol. 148 (1): p. 175-194" with 5864 citations. Out of 27

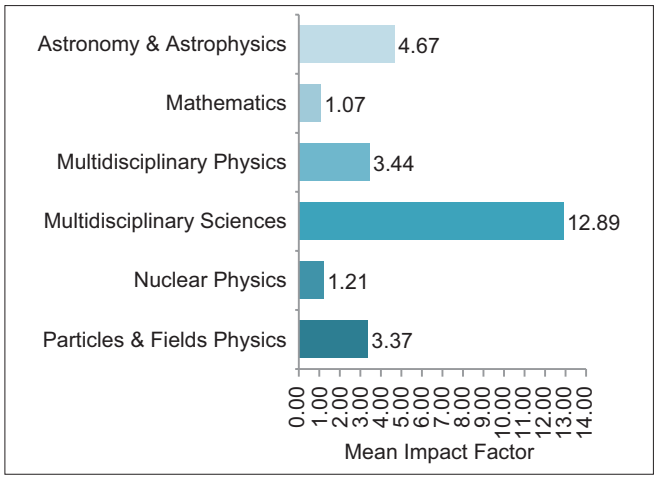

Figure 11: Variation of mean impact factor on dark energy domains

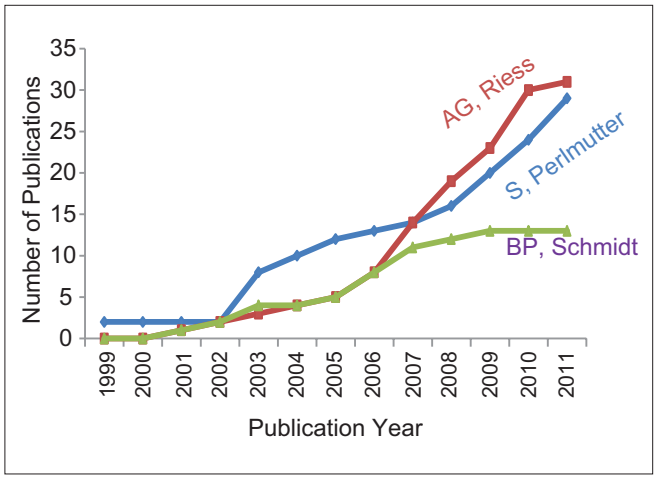

Figure 12: Year-wise distribution of publications of Nobel laureates in physics (2011) on dark energy

Table 6: Publications and citations by the Nobel laureates in physics (2011) on dark energy

Novel laureate in physics (2011)	Total publications	Total citations	Average citations /publications
Riess, AG	31	2386	76.97
Perlmutter, S	29	3203	110.45
Schmidt, BP	13	6192	476.31
Total	73	11781	161.38

Table 7: Highly cited publications in dark energy (≥500 citations)

Bibliographic details	Times cited	Document type	Country collaboration	Author (s) in by-line
Spergel *et al.* First-year Wilkinson Microwave Anisotropy Probe (WMAP) observations: Determination of cosmological parameters. Astrophysical Journal Supplement Series. (2003). Vol. 148 (1): p. 175-194	5864	Review	USA-Canada	17
Spergel *et al.* Three-year Wilkinson Microwave Anisotropy Probe (WMAP) observations: Implications for cosmology. Astrophysical Journal Supplement Series. (2007). Vol. 170 (2): p. 377-408	3150	Review	USA-Canada-Chile	22
Bennett *et al.* First-year Wilkinson Microwave Anisotropy Probe (WMAP) observations: Preliminary maps and basic results. Astrophysical Journal Supplement Series. (2003). Vol. 148 (1): p. 1-27	2655	Article	USA-Canada	21
Komatsu *et al.* Five-Year Wilkinson Microwave Anisotropy Probe Observations: Cosmological Interpretation. Astrophysical Journal Supplement Series. (2009). Vol. 180 (2): p. 330-376	2173	Review	USA-England-Canada	19
Riess *et al.* Type Ia supernova discoveries at z>1 from the Hubble Space Telescope: Evidence for past deceleration and constraints on dark energy evolution. Astrophysical Journal. (2004). Vol. 607 (2): p. 665-687	1946	Article	USA-Germany	19
Peebles *et al.* The cosmological constant and dark energy. Reviews of Modern Physics. (2003). Vol. 75 (2): p. 559-606	1458	Review	USA	2

Contd...

Table 7: Contd...

Bibliographic details	Times cited	Document type	Country collaboration	Author (s) in by-line
Eisenstein *et al.* Detection of the baryon acoustic peak in the large-scale correlation function of SDSS luminous red galaxies. Astrophysical Journal. (2005). Vol. 633 (2): p. 560-574	1290	Review	USA-England-Spain-Japan-Scotland-Hungary	48
Copeland *et al.* Dynamics of dark energy. International Journal of Modern Physics-D. (2006). Vol. 15 (11): p. 1753-1935	1250	Review	England-Japan-India	3
Caldwell, RR. A phantom menace? Cosmological consequences of a dark energy component with super-negative equation of state. Physics Letters-B. (2002). Vol. 545: p. 23-29	1209	Article	USA	1
Springel *et al.* Simulations of the formation, evolution and clustering of galaxies and quasars. Nature. (2005). Vol. 435 (7042): p. 629-636	1169	Article	USA-England-Germany-Japan-Canada-Scotland	17
Padmanabhan, T. Cosmological constant-the weight of the vacuum. Physics Reports-Review-Of Physics Letters. (2003). Vol. 380: p. 235-320	1169	Review	India	1
Komatsu *et al.* Seven-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Cosmological Interpretation. Astrophysical Journal Supplement Series. (2011). Vol. 192 (2): Article No. 18	1086	Article	USA-England-Canada	21
Tonry *et al.* Cosmological results from high-z supernovae. Astrophysical Journal. (2003). Vol. 594 (1): p. 1-24	954	Review	USA-Germany-Chile-Australia-Sweden	25
Dunkley *et al.* Five-Year Wilkinson Microwave Anisotropy Probe Observations: Likelihoods and Parameters from the WMAP data. Astrophysical Journal Supplement Series. (2009). Vol. 180 (2): p. 306-329	856	Review	USA-England-Canada	19
Knop *et al.* New constraints on Omega (M), Omega (Lambda), and w from an independent set of 11 high-redshift supernovae observed with the Hubble Space Telescope. Astrophysical Journal. (2003). Vol. 598 (1): p. 102-137	799	Review	USA-England-Spain-Japan-France-Portugal-Chile-Sweden	48
Caldwell *et al.* Phantom energy: Dark energy with w <−1 causes a cosmic doomsday. Physical Review Letters. (2003). Vol. 91 (7): Article No. 71301	773	Article	USA	3
Carroll *et al.* Is cosmic speed-up due to new gravitational physics?. Physical Review-D. (2004). Vol. 70 (4): Article No. 43528	761	Article	USA	4
Bahcall *et al.* Cosmology-The cosmic triangle: Revealing the state of the universe. Science. (1999). Vol. 284 (5419): p. 1481-1488	709	Review	USA	4
Tegmark *et al.* Cosmological constraints from the SDSS luminous red galaxies. Physical Review-D. (2006). Vol. 74 (12): Article No. 123507	678	Review	USA-England-Italy-Spain-Japan-South Korea-South Africa	67
Riess *et al.* New hubble space telescope discoveries of type Ia supernovae at z≥1: Narrowing constraints on the early behavior of dark energy. Astrophysical Journal. (2007). Vol. 659 (1): p. 98-121	630	Review	USA	21
Bento *et al.* Generalized Chaplygin gas, accelerated expansion, and dark-energy-matter unification. Physical Review-D. (2002). Vol. 66 (4): Article No. 43507	616	Article	Portugal	3
Hinshaw *et al.* Five-Year Wilkinson Microwave Anisotropy Probe Observations: Data Processing, Sky Maps, and Basic Results. Astrophysical Journal Supplement Series. (2009). Vol. 180 (2): p. 225-245	607	Article	USA-England-Canada	21
Armendariz-Picon *et al.* Dynamical solution to the problem of a small cosmological constant and late-time cosmic acceleration. Physical Review Letters. (2000). Vol. 85 (21): p. 4438-4441	605	Article	USA-Germany	3
Nojiri *et al.* Introduction to modified gravity and gravitational alternative for dark energy. International Journal of Geometric Methods in Modern Physics. (2007). Vol. 4 (1): p. 115-145	566	Article	Spain-Japan	2
Nojiri *et al.* Modified gravity with negative and positive powers of curvature: Unification of inflation and cosmic acceleration. Physical Review-D. (2003). Vol. 68 (12): Article No. 123512	559	Article	Spain-Japan-Russia	2
Feng *et al.* Dark energy constraints from the cosmic age and supernova. Physics Letters-B. (2005). Vol. 607: p. 35-41	542	Article	Peoples R China	3
Kowalski *et al.* Improved Cosmological Constraints From New, Old, and Combined Supernova Data Sets. Astrophysical Journal. (2008). Vol. 686 (2): p. 749-778	504	Article	USA-England-Spain-Germany-France-Canada-Portugal-Chile-Australia-Sweden-Ireland	70

collaborative publications had more average citations per publication when compared to single country publications. The highest number of publications came from Europe with 3723 (41.15%) publications and 126,747 (39.88%) citations followed by Asia with 2614 (28.89%) publications and 63,267 (19.90%) citations, and North America with 1980 (21.89%) publications and 105,132 (33.08%) citations.

Table 8: Preference of journals for publication on dark energy (≥26 publications)

Journal	IF 2010	TP	% of TP	TC	% of TC	ACP
Physical Review-D	4.96	1350	23.05	44820	28.44	33.20
Journal of Cosmology and Astroparticle Physics	6.50	647	11.04	9925	6.30	15.34
Physics Letters-B	5.26	517	8.83	15462	9.81	29.91
Monthly Notices of the Royal Astronomical Society	4.89	384	6.56	9713	6.16	25.29
Astrophysical Journal	6.06	329	5.62	19938	12.65	60.60
International Journal of Modern Physics-D	1.11	245	4.18	3360	2.13	13.71
Classical and Quantum Gravity	3.10	208	3.55	3976	2.52	19.12
Modern Physics Letters-A	0.99	198	3.38	1458	0.93	7.36
Astronomy and Astrophysics	4.42	161	2.75	3262	2.07	20.26
General Relativity and Gravitation	2.54	161	2.75	2373	1.51	14.74
International Journal of Theoretical Physics	0.67	120	2.05	384	0.24	3.20
Astrophysics and Space Science	1.44	119	2.03	337	0.21	2.83
Physical Review Letters	7.62	96	1.64	6906	4.38	71.94
European Physical Journal-C	3.25	89	1.52	1028	0.65	11.55
International Journal of Modern Physics-A	1.00	64	1.09	385	0.24	6.02
Journal of High Energy Physics	6.05	56	0.96	1043	0.66	18.63
Nuclear Physics-B-Proceedings Supplements	0.00	55	0.94	149	0.09	2.71
Chinese Physics Letters	1.08	49	0.84	210	0.13	4.29
Astroparticle Physics	3.81	37	0.63	648	0.41	17.51
Nuclear Physics-B	4.64	37	0.63	897	0.57	24.24
Communications in Theoretical Physics	0.49	34	0.58	335	0.21	9.85
Journal of Physics-A	1.64	33	0.56	403	0.26	12.21
New Astronomy Reviews	1.92	33	0.56	291	0.18	8.82
Astrophysical Journal Letters	5.16	30	0.51	395	0.25	13.17
Brazilian Journal of Physics	0.66	29	0.50	164	0.10	5.66
Astronomical Journal	4.55	26	0.44	798	0.51	30.69
EPL	2.75	26	0.44	91	0.06	3.50
Gravitation and Cosmology	0.56	26	0.44	62	0.04	2.38

IF=Impact factor, TP=Total publications, TC=Total citations, ACP=Average citations per publications

Table 9: Distribution of publications and citations as per impact factor range

IF range (JCR-2010)	Total number of journals	TP	% of TP	TC	% of TC	ACP
0.01 to <1.00	54	697	11.90	3994	2.53	5.73
1.00 to <2.00	36	677	11.56	6035	3.83	8.91
2.00 to <3.00	15	252	4.30	3143	1.99	12.47
3.00 to <4.00	8	377	6.44	6588	4.18	17.47
4.00 to <5.00	8	1970	33.63	59606	37.83	30.26
5.00 to <30.31	15	1733	29.58	75960	48.20	43.83
Without IF	24	152	2.59	2255	1.43	14.84
Total	160	5858	100.00	157581	100.00	26.90

IF=Impact factor, TP=Total publications, TC=Total citations, ACP=Average citations per publications

USA had the highest share (26.84%) of publications followed Peoples Republic of China with 13.74% publications, England with 11.71% publications, Italy with 10.84% publications, Spain with 7.90% publications, Germany with 7.27% publications and India with 7.07% publications.

Astronomy and Astrophysics accounts for the largest share 3920 (66.92%) of publications in the total worldwide output on dark energy, which received 117,919 (74.83%) citations followed by Multidisciplinary Physics with 1242 (21.20%) publications, 29,775 (18.90%) citations and 23.97 average citations per publication, and Mathematics with 290 (4.95%) publications, 2725 (1.73%) citations and 9.40 average citations per publication.

The highest publication efficiency index (PEI) retained by Canada with 346.51% PEI, followed by Chile with 315.54% PEI, Sweden with 254.34% PEI, Scotland with 220.76% PEI, Japan with 198.58% PEI, USA with 182.75% PEI, England with 166.56% PEI, and Australia with 160.03% PEI.

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The scientific literature on dark energy is spread over 160 different source journals. More than 80% of the publications are published in only 15 key-journals. Table 8 gives the leading journals each with impact factor, number of publications, number of citations, and average citations per publication. The highly productive journals are: Physical Review D with 1350 (23.05%) publications, Journal of Cosmology and Astroparticle Physics with 647 (11.04%) publications, Physics Letters-B with 517 (8.83%) publications, Monthly Notices of the Royal Astronomical Society with 384 (6.56%) publications, and Astrophysical Journal with 329 (5.62%) publications.

Quality of Research Output

Around 97.41% (5706) of the total publications were published in the journals with impact factors (IF) ranging from 0.001 to 51.70 and received 98.57% (155,326) citations, and 1.43% (2255) publications published in journals having zero impact factor. Table 9 gives distribution of publications and citations according to impact factor range of journal publications. It is revealed from the Table 9 that the highest number of publications (1970, 33.63%) appeared in 8 journals having impact factor range 4.00 to < 5.00 have received 59,606 (37.83%) citations with 30.26 average citation per publication and 1733 (29.58%) publications appeared in 15 journals having impact factor range 5.00 to < 30.31 have received 75,960 (48.20%) citations with 43.83 average citation per publication. This indicates that more than 63% of publications were published in 23 key journals having impact factor 4.00 to <30.31.

DISCUSSION AND CONCLUSION

The phenomenon of dark energy which was reported in 1998 caught up the imagination of the scientists all over the world, and more than 400 publications were reported in various scientific journals within 4 to 5 years. As per the Web of Science database, a total of 5858 publications were published on dark energy, which received 157,581 citations during 1999-2011. The average number of publications per year was 450.62, and the average number of citations per publication was 26.90. The research was peaked in 2011 with 934 publications, and the highest number of citations (26,404) were received in 2003. The exponential growth of publications was observed. This may be attributed to a new field for research to demystify the phenomena of dark energy. There were 3857 (65.84%) single country publications by the scientists from 74 countries and 2001 (34.16%) multi-country collaborative publications. Multi-country

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