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RESEARCH TRENDS ON ASTROMETRY AND CELESTIAL MECHANICS IN INDIA: A SCIENTOMETRIC STUDY

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ABSTRACT:

The present study explores the characteristics of the literature and growth of Astrometry and Celestial Mechanics research in India during 1960-2014, based on Web of Science (WoS) database and make quantitative and qualitative assessment by way of analysing various features of research output by using the scientometric techniques. A total of 3013 literature were published on Astrometry and Celestial Mechanics, which received total 42275 citations. The average number of publications per year is 70.06 and Compound Annual Growth Rate (CAGR) is 12.53% and the average number of citations per publication was 14.03. The publications peaked in the year 2014 with 285 publications and the highest number of citations (4096) was in 2009. This study analyzes the research studies based on year of publication, journal, international collaboration, spatial distribution and keyword

occurrence frequency. The results of this work reveal that the publication on the Astrometry and Celestial Mechanics have grown high at a slow rate over the past 54 years and the curve fits the polynomial curve with $R^2 = 0.972$. Publications on Astrometry and Celestial Mechanics appeared in 101 journals of which most active journal was “Physical Review D” published by American Physical Society originating from USA and 415(13.774%) of the total 3013 publications. A total of 17475 authors contributed on Astrometry and Celestial Mechanics research. The most active author was Sagar, R produced maximum no. of publications 51(1.693%) of total publications. 2188 institutions contributed of which Tata Institute of Fundamental Research; Mumbai, India is the most productive institution. For globalization of Astrometry and Celestial Mechanics Research in India, the results show there were 91 Countries/territories which participated in Astrometry and Celestial Mechanics research. USA produced maximum publications 665 that is 22.071% of total publication with higher citations (19054). A Keyword analysis reveals that ‘‘Model’’, ‘‘stars’’, ‘‘time’’, “Universe” and “region” are the most used keywords.

KEYWORDS: Astrometry and Celestial Mechanics, Scientometric, Bibliometrics, Citation Indicator, Bibliometric Indicator, INDIA

1. INTRODUCTION:

Astrometry is the branch of astronomy that involves precise measurements of the positions and movements of stars and other celestial bodies. The information obtained by astrometric measurements provides information on the kinematics and physical origin of our Solar System and our galaxy, the Milky Way. Apart from the fundamental function of providing astronomers with a reference frame to report their observations in, astrometry is also fundamental for fields like celestial mechanics, stellar dynamics and galactic astronomy. In observational astronomy, astrometric techniques help identify stellar objects by their unique motions. It is instrumental for keeping time, in that UTC is basically the atomic time synchronized to Earth's rotation by means of exact observations. Astrometry is an important step in the cosmic distance ladder because it establishes parallax distance estimates for stars in the Milky Way.

Astrometric measurements are used by astrophysicists to constrain certain models in celestial mechanics. By measuring the velocities of pulsars, it is possible to put a limit on the asymmetry of supernova explosions. Also, astrometric results are used to determine the distribution of dark matter in the galaxy ("What are cosmologists,astrometrists,pla..,"n.d.)

Astronomers use astrometric techniques for the tracking of near-Earth objects. Astrometry is responsible for the detection of many record-breaking Solar System objects. To find such objects astrometrically, astronomers use telescopes to survey the sky and large-area cameras to take pictures at various determined intervals. By studying these images, they can detect Solar System objects by their movements relative to the background stars, which remain fixed. Once a movement per unit time is observed, astronomers compensate for the parallax caused by Earth’s motion during this time and the heliocentric distance to this object is calculated. Using this distance and other photographs, more information about the object, including its orbital elements, can be obtained ("Astrometry ," n.d.)

There has been increasing importance of the research on the Astrometry and Celestial Mechanics as well as the Scientometric research; however there has not been any published study of scientometric study on the Astrometry and Celestial Mechanics research as of November 2014. Therefore, this study aims at carrying out a Scientometric evaluation of the research on the Stars published during the last fifty four years and to identify the main trends and issues in this field.

2. Methods and Materials:

To assess the trend of research publication on Astrometry and Celestial Mechanics research and locate and collect the literature, Web of Science (WoS) was used. The Search Strategy used to conduct Web of Science (WoS) search is as mentioned below:

TS= "Astrometry and Celestial Mechanics" OR "structure" = (Search Term) ; Where TS is a topic search that retrieves occurrences of the search term in the article title, abstract, keywords within a time span of 1960-2014, were used to locate publications that contained these words in publications' titles, abstracts, and keyword lists. This process was followed for another series of search terms given by (Kennicutt et. al., 2001). These were used to locate publications that contained the words in publications' titles, abstracts, and keyword lists.

3. Results and Analysis

There were 3013 publications that met the selection criteria which appeared in the WoS database during 1960-2014 and these were analyzed. The specific characteristics of the publications such as the number of publications, the number of authors involved in the production of these publications, institutions, journals etc were taken into consideration.

3.1. Publication characteristics of Astrometry and Celestial Mechanics Research in India during 1960-2014.

From Table 1, the output of 3013 paper received a total of 42275 citations during the said period with an average of about 14.03 citations per paper (Table 2).

Table 1: Bibliographic Record of Astrometry and Celestial Mechanics research in India during study period

Bibliometric indicators	No.
Total Article found:	3013
Total No. of Countries contribution	91
Total No. of Author's contribution	17475
Total No. of Institution's contribution	2188
Total No. of Journal appeared	101
Total No. of Keywords (raw) appeared	9506

Source: WoS

Table 2: Citation Metrics of Astrometry and Celestial Mechanics research in India during study period

Citation-based indicators	No.
Total Article found:	3013
Sum of the Times Cited	42275
Sum of Times Cited without self-citations	38947
Citing Articles	30217
Citing Articles without self-citations	28762
Average Citations per Item	14.03
h-index	71

Source: WoS

3.2. Publication Pattern

Publication Pattern of Astrometry and Celestial Mechanics research from 1960 to 2014 is presented in figure-1. It is important to mention here that initial publication in the field of Astrometry and Celestial Mechanics research is observed in the year 1972. A near about one hundred fourty time's increase was observed over the study period, (from 2 in 1972 to 285 in 2014). The highest number of papers was published in the year 2014, with 285 and the lowest in 1976 with 0.The average number of publications per year is 70.06 and Compound Annual Growth Rate (CAGR) is 12.53%

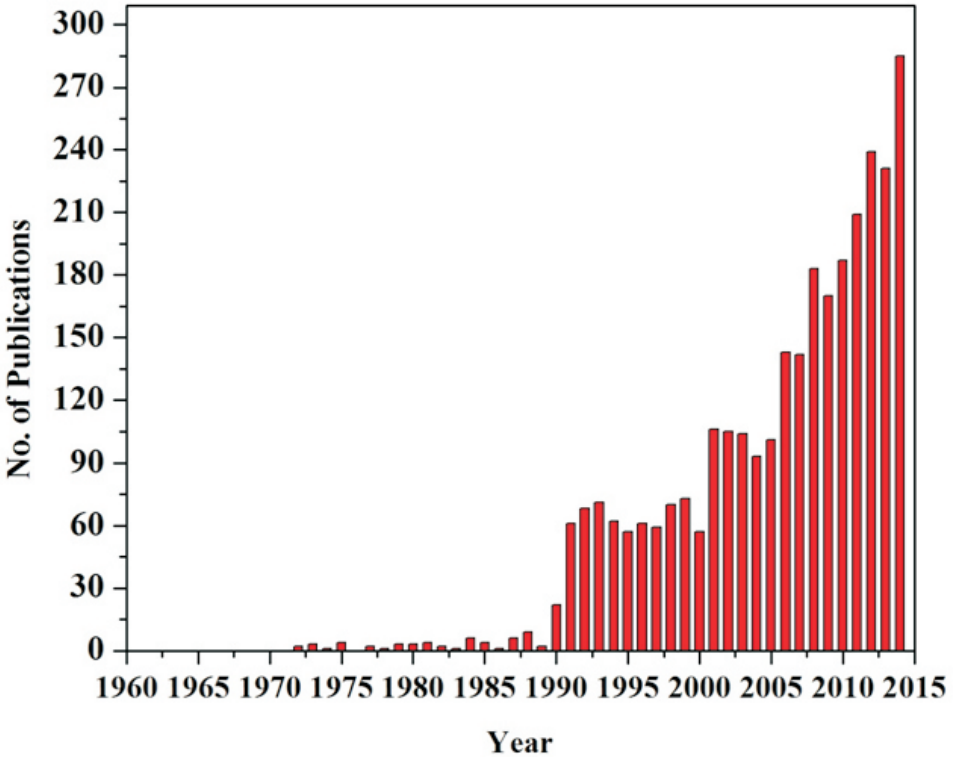

Fig 1: Publication pattern of Astrometry and Celestial Mechanics research in India during 1960-2014

3.3. Growth Pattern

The cumulative progression was represented by a 4th degree power law distribution during 1960-2014 giving an idea of the polynomial growth rate (Fig. 2). The fit produced a high regression coefficient (Table 3) of determination to the collected data (R^2 = 0.972). The polynomial best fit as shown in table 3 for Astrometry and Celestial Mechanics research was found to be: $y = 0.0004x^4 - 2.9858x^3 + 8914.3x^2 - 1E+07x + 6E+09$, where y is the cumulative number of publications and x is the number of years since 1960.

Table 3: Different Regression Type with Regression coefficient

Regression Type	Equation	Regression (R^2)
Linear	$y = 5.6494x - 11189$	$R^2 = 0.8254$
Logarithmic	$y = 11246\ln(x) - 85371$	$R^2 = 0.8235$
Polynomial	$y = 0.0004x^4 - 2.9858x^3 + 8914.3x^2 - 1E+07x + 6E+09$	$R^2 = 0.972$

The growth of literature shown in figure 2 can be divided into 2 parts, in 1st part (1960-1971)

there is no literature published by Indian scientist as (India) is an affiliation country found in Web of Science (WoS). In 2nd part (1972-2014), follows polynomial growth rate which indicate that the number of papers concerning Astrometry and Celestial Mechanics were growing at a high but slow growth rate.

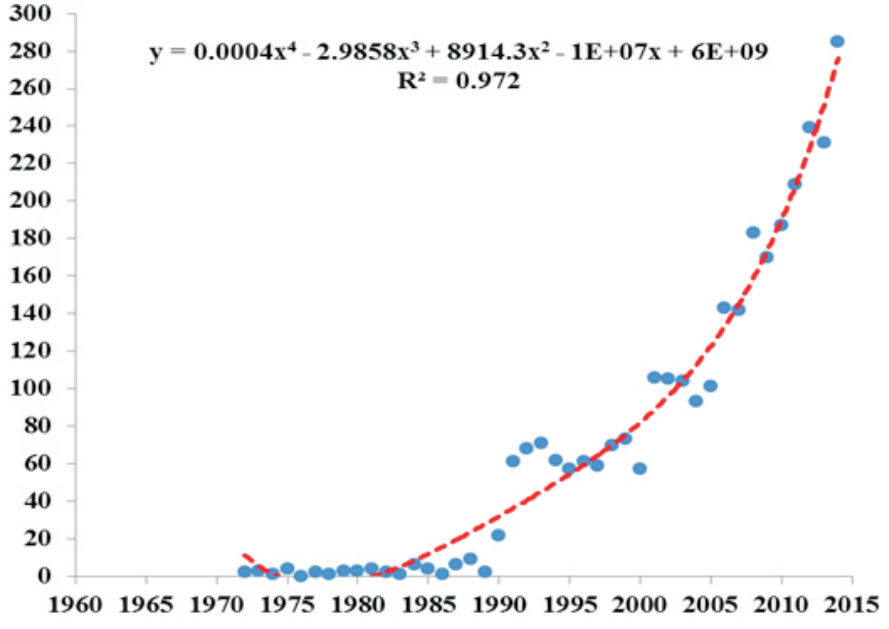

Fig 2: Growth pattern of Astrometry and Celestial Mechanics research in India during 1960-2014. Blue dot describe the distribution of publication (observed value) and Red dashed line describe the correlation of distribution of publication where regression coefficient $R^2 = 0.972$

3.4. Citation pattern

Fig 3 and 4 represent the year wise total no. of citation and no. of citations vs. no. of publications per year. 3013 research papers received a total of 42275 citations. The pattern of citation is very fluctuating. In the year 1972, the total number of citations received was 31 with an average citation of 15.5. The minimum citation received in the year 1986 and 1989 was zero (0) and the maximum citation received in the year 2009 is 4096 with an avg. citation 24.09. It is important to note here that after the year 2011 publication increases but citation decreases (Fig4).

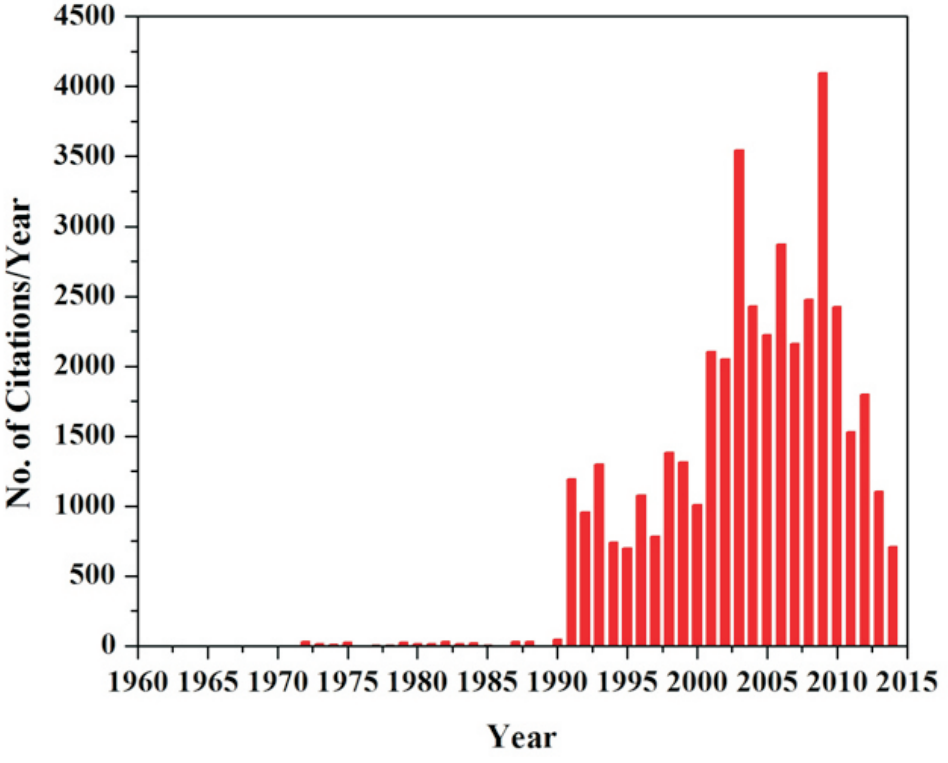

Figure 3: Citation pattern of Astrometry and Celestial Mechanics research in India during 1960-2014

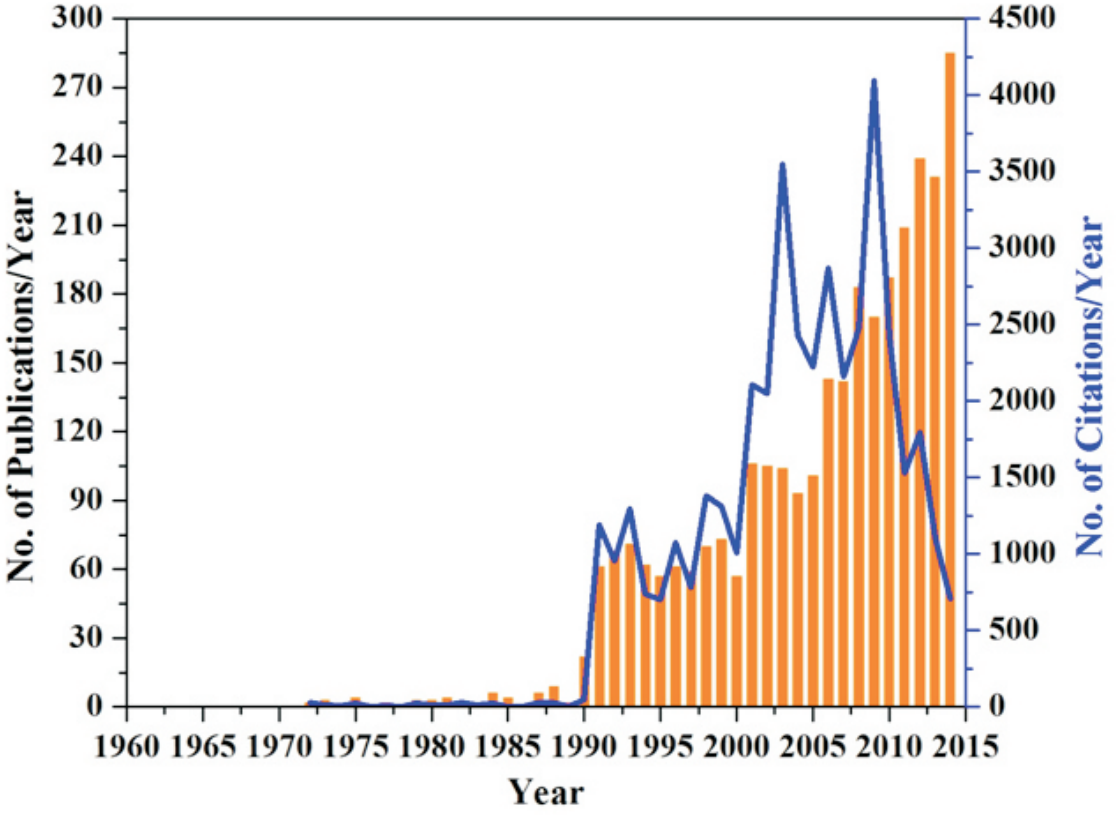

Fig4: Citation pattern of Astrometry and Celestial Mechanics research in Astronomy in India during 1960-2014: no. of publications Vs no. citations. Blue line (right Y axis) indicate the citation pattern

against orange bar describe the publication pattern.

3.5. Top 20 Institutions and their research impact

The contribution of different institutions was estimated by taking into account the affiliated institution of at least one author. 3013 publications on Astrometry and Celestial Mechanics appeared from 2188 institutions. Out of 2188 institution, 950 institutions appeared one time and contributed 31.53% of total articles, while 268 institutions appeared two times and contributed 8.89% of total article.

Table 4 shows out of the top 20 institutions only 10 institutions are Indian institutions. Tata Institute of Fundamental Research, Mumbai (Department of Atomic Energy) and Physical Research Laboratory (PRL), Ahmadabad and Vikram Sarabhai Space Center (Department of Space) had published 442 and 206 ,94 papers respectively. Indian Institute of Astrophysics (IIA), Raman Research Institute, Bangalore, and Aryabhatta Research Institute of Observational Sciences, Nainital and Indian Institute of Geomagnetism, Mumbai, come under the Department of Science and Technology and have published papers 345, 132,110 and 92 respectively. Inter University Centre for Astronomy Astrophysics and Jadavpur University have published papers 330 and 106 respectively. They come under UGC, a autonomous body under ministry of HRD. Indian Institute of Science (IISc) Banglore had published 82 papers.

Out of top 20, 10 are foreign institutions, among these 5 belong to the USA namely National Aeronautics Space Administration (NASA), California Institute of Technology, USA; University of California System, United States Department of Energy,Goddard Space Flight Center; 2 are belong to France namely Centre National De La Recherche Scientifique CNRS, France; Observatoire De Paris, France; 1 Max Planck Society, Germany;1 Russian Academy of Sciences, Russia and 1 Chinese Academy of Sciences, China.

Table 4: Top 20 Institutions and their research impact

Institution	Region	TP (%)	TC	AgCPA	h-index
Tata Institute of Fundamental Research	India	442(14.670)	11711	26.50	45
Indian Institute of Astrophysics	India	345(11.450)	4760	13.80	34
Inter University Centre for Astronomy Astrophysics	India	330(10.953)	7160	21.70	45
Physical Research Laboratory	India	206(6.837)	1991	9.67	22
Max Planck Society	Germany	186(6.173)	6145	33.04	38
Centre National De La Recherche Scientifique	France	182(6.040)	5054	27.77	39
National Aeronautics Space Administration	USA	164(5.443)	7080	43.17	40
Russian Academy of Sciences	Russia	136(4.514)	3312	24.35	33
Raman Research Institute	India	132(4.381)	2036	15.42	24
California Institute of Technology	USA	116(3.850)	4889	42.15	33
Aryabhatta Research Institute of Observational Sciences	India	110(3.651)	976	8.87	16
University of California System	USA	107(3.551)	4606	43.05	31
Jadavpur University	India	106(3.518)	736	6.94	16
Chinese Academy of Sciences	China	98(3.253)	1936	19.76	25
Vikram Sarabhai Space Center	India	94(3.120)	738	7.85	16
United States Department of Energy	USA	94(3.120)	5788	61.57	30
Indian Institute of Geomagnetism	India	92(3.053)	900	9.78	16
Goddard Space Flight Center	USA	89(2.954)	3049	34.26	33
Observatoire De Paris	France	85(2.821)	3056	35.95	33
Indian Institute of Science	India	82(2.722)	1503	18.33	25

TP= Total no. of Astrometry and Celestial Mechanics related articles published by an institution; **TC =** Total no. of citation received; **AgCPA=** Average no. of citations per article; **h-index=**defined by the no. of h papers among an institution's no. of publications that have at least h citations each. Source: WoS

Table 4 reveals the impact of research in terms of quality of papers. The AgCPA and the h- index are used to identify which institution has the largest no. of high quality publications in the field of Astrometry and Celestial Mechanics research. It is seen from the above table that Astrometry and Celestial Mechanics related articles authored in foreign institution (United States Department of Energy) have the highest average impact (AgCPA=61.57) followed by National Aeronautics Space Administration have average impact (AgCPA=43.17). Among Indian institutions, Tata Institute of Fundamental Research has impact (26.50) in AgCPA index.

3.6. Top 20 Journals and their research impact

Astrometry and Celestial Mechanics papers appeared in 101 journals. Papers have appeared in highest no. in the journal "Physical Review D" published by American Physical Society originating from USA. Table 3 shows the top 20 productive journals. These 20 out of the 101 journals had published 1724 (73.20 %) of the total 2656 articles. The "Physical Review D" ranked first with 415 (13.774%) ; "Astrophysics and Space Science 383 (12.712%); "Monthly Notices of the Royal Astronomical Society 365 (12.114)" "Astrophysical Journal 292(9.691%) ", "Astronomy Astrophysics" 254(8.430%); ranked at 2nd, 3rd, 4th, and 5th, respectively.

Table 5: Top 20 Journals and their research impact

Journal	TP(%)	TC	AgCPA	Journal Metrics (2013) SJR	IPP	SNIP	Country
Physical Review D	415(13.774)	9796	23.60	1.899	3.192	1.136	USA
Astrophysics and Space Science	383(12.712)	2246	5.86	1.081	1.748	1.056	Netherland
Monthly Notices of the Royal Astronomical Society	365(12.114)	5426	14.87	3.196	4.911	1.494	USA
Astrophysical Journal	292(9.691)	6712	22.99	3.159	4.348	1.145	UK
Astronomy Astrophysics	254(8.430)	4583	18.04	1.471	1.932	0.612	France
Journal of Geophysical Research Space Physics	130(4.315)	1328	10.22	2.376	3.286	1.412	USA
Solar Physics	127(4.215)	1737	13.68	2.256	3.184	1.769	Netherland
Advances in Space Research	111(3.684)	454	4.09	0.751	1.416	1.291	Netherland
Annales Geophysicae	101(3.352)	903	8.94	1.176	1.533	1.533	Germany
International Journal of Modern Physics D	96(3.186)	795	8.28	0.733	1.021	0.540	Singapore
General Relativity and Gravitation	87(2.887)	774	8.90	1.109	1.628	1.015	UK
Journal of Astrophysics and Astronomy	77(2.556)	276	3.58	0.477	0.541	0.224	India
Classical and Quantum Gravity	71(2.356)	1196	16.85	1.476	2.192	0.966	UK
Indian Journal of Radio Space Physics	49(1.626)	86	1.76	0.347	0.514	0.621	India
Journal of Cosmology and Astroparticle Physics	36(1.195)	482	13.39	0.615	2.374	0.465	UK
Astrophysical Journal Letters	35(1.162)	503	14.37	3.914	4.852	1.487	UK
Radio Science	33(1.095)	282	8.55	0.994	1.265	1.078	USA
Planetary and Space Science	31(1.029)	384	12.39	0.925	1.560	0.800	Netherlands
Astronomical Journal	30(0.996)	304	10.13	2.795	3.282	1.092	UK
Annales Geophysicae Atmospheres Hydrospheres And Space Sciences	30(0.996)	390	13.00	-	-	-	Germany

TP= Total no. of Astrometry and Celestial Mechanics related articles published by a Journal (followed by the percentage of Astrometry and Celestial Mechanics related articles in the journal of a total Stars

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

Table 5 shows the citation impact on top 20 journals. The AvgCPA and h-index are used to identify which journals have the largest no. of high quality articles in the Astrometry and Celestial Mechanics research. It is seen from the above table that the journal "Physical Review D" published by IOP Publishing for the American Physical Society in USA highest no. of publication as well as highest average impact (AvgCPA=23.60) followed by the journal "Astrophysical Journal" has the average impact (AvgCPA=22.99).

3.7. Top 20 most Prolific Authors and impact of their research output

A total of 3013 articles included the author addresses. Articles on Astrometry and Celestial Mechanics have been contributed by 17475 authors. Top 20 productive authors were ranked based on the no. of total articles. Sagar, R produced maximum no. of publications 51 i.e. 1.693 % of total publications with ranked first followed by Chakraborty, S ; Chakrabarti,SK; Padmanabhan,T; Choi,Y ; ranked at 2nd , 3rd , 4th , 5th and 6th respectively. Table 6 showed the top 20 productive authors during the last 54 years, 1960-2014.

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

Author	TP(%)	TC	TC woSC	CI	CIwoSC	AgCPA	h-index
Sagar, R	51(1.693)	940	904	773	751	18.43	19
Chakraborty, S	50(1.659)	241	216	197	183	4.82	9
Chakrabarti, SK	48(1.593)	766	694	447	417	15.96	16
Padmanabhan, T	45(1.494)	1199	1144	899	876	26.64	18
Choi, Y	45(1.494)	1079	1022	830	803	23.98	16
Sakai, Y	44(1.460)	1072	1015	821	794	24.36	16
Schneider, O	43(1.427)	1061	1004	812	785	24.67	16
Piilonen, Le	43(1.427)	1061	1004	812	785	24.67	16
Nishida, S	43(1.427)	1061	1004	812	785	24.67	16
Li, J	43(1.427)	1151	1113	948	927	26.77	20
Eidelman, S	43(1.427)	1061	1004	812	785	24.67	16
Cheon, BG	43(1.427)	1061	1004	812	785	24.67	16
Zhang, ZP	42(1.394)	983	942	785	761	23.40	16
Yamashita, Y	42(1.394)	1061	1004	812	785	25.26	16
Wang, Ch	42(1.394)	1060	1005	812	786	25.24	16
Uno, S	42(1.394)	1058	1001	810	783	25.19	16
Unno, Y	42(1.394)	853	825	695	676	20.31	14
Uehara, S	42(1.394)	1060	1005	812	786	25.24	16
Teramoto, Y	42(1.394)	1058	1004	811	785	25.19	16
Miyata, H	42(1.394)	845	796	667	641	20.12	16

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

Table 6 reveals the impact of research in terms of quality of papers. The AgCPA and the h-index used to identify which author has the largest no. of high quality articles in the Astrometry and Celestial Mechanics research. It is seen from the above table 6 that Astrometry and Celestial Mechanics related articles authored Padmanabhan,T have the highest average impact (AgCPA=26.64) followed by Yamashita,Y (AgCPA=25.26) although Sagar, R ranked 18th in the AgCPA index.

3.8. Top 10 Cited Publication in Astrometry and Celestial Mechanics research in India during 1960-2014

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

S.N	Bibliography	TC	Ag.C
1	Abazajian, K. N., Adelman-McCarthy, J. K., Agueros, M. A., Allam, S. S., Prieto, C. A., An, D., … Zucker, D. B. (2009). THE SEVENTH DATA RELEASE OF THE SLOAN DIGITAL SKY SURVEY. Astrophysical Journal Supplement Series, 182(2), 543–558. http://doi.org/10.1088/0067-0049/182/2/543	1979	282.71
2	Winget, D., Nather, R., Clemens, J., Provencal, J., Kleinman, S., Bradley, P., … Kawaler, S. (1991). Asteroseismology of the Dov Star Pg-1159-035 With The Whole Earth Telescope. *Astrophysical Journal*, *378*(1), 326–&. http://doi.org/10.1086/170434	226	9.04
3	Chand, H., Srianand, R., Petitjean, P., & Aracil, B. (2004). Probing the cosmological variation of the fine-structure constant: Results based on VLT-UVES sample. *Astronomy & Astrophysics*, *417*(3), 853–871. http://doi.org/10.1051/0004-6361:20035701	178	14.83
4	Goldstein, K., Iizuka, N., Jena, R. P., & Trivedi, S. P. (2005). Nonsupersymmetric attractors. *Physical Review D*, *72*(12), 124021. http://doi.org/10.1103/PhysRevD.72.124021	176	16.00
5	Mccarthy, P., Vanbreugel, W., & Kapahi, V. (1991). Correlated Radio And Optical Asymmetries In Powerful Radio-Sources. *Astrophysical Journal*, *371*(2), 478–490. http://doi.org/10.1086/169911	156	6.24
6	Sahni, V. (2002). The cosmological constant problem and quintessence. *Classical and Quantum Gravity*, *19*(13), 3435–3448. http://doi.org/10.1088/0264-9381/19/13/304	153	10.93
7	Paranjape, A., Sarkar, S., & Padmanabhan, T. (2006). Thermodynamic route to field equations in Lanczos-Lovelock gravity. *Physical Review D*, *74*(10), 104015. http://doi.org/10.1103/PhysRevD.74.104015	139	13.90
8	Ledoux, C., Petitjean, P., Fynbo, J. P. U., Moller, P., & Srianand, R. (2006). Velocity-metallicity correlation for high-z DLA galaxies: evidence of a mass-metallicity relation? *Astronomy & Astrophysics*, *457*(1), 71–78. http://doi.org/10.1051/0004-6361:20054242	125	12.50
9	JOG, C., & SOLOMON, P. (1992). A Triggering Mechanism For Enhanced Star Formation In Colliding Galaxies. *Astrophysical Journal*, *387*(1), 152–161. http://doi.org/10.1086/171067	122	5.08
10	Bedding, T. R., Huber, D., Stello, D., Elsworth, Y. P., Hekker, S., Kallinger, T., … Weiss, A. (2010). Solar-Like Oscillations in Low-Luminosity Red Giants: First Results From Kepler. *Astrophysical Journal Letters*, *713*(2), L176–L181. http://doi.org/10.1088/2041-8205/713/2/L176	121	20.17

Citation Style: APA (6th edition); **TC:** Total Citations; **AgC:** Average Citations

3.9. Spatial Distribution of Astrometry and Celestial Mechanics of Publications

Based on the author attributions, we can map the world-wide geographic distribution of Astrometry and Celestial Mechanics research publication. The major spatial clusters of research institutes located in Europe, followed by Asia and Africa. Several minor clusters distributed in other parts of the world like South America, North America and Australia.

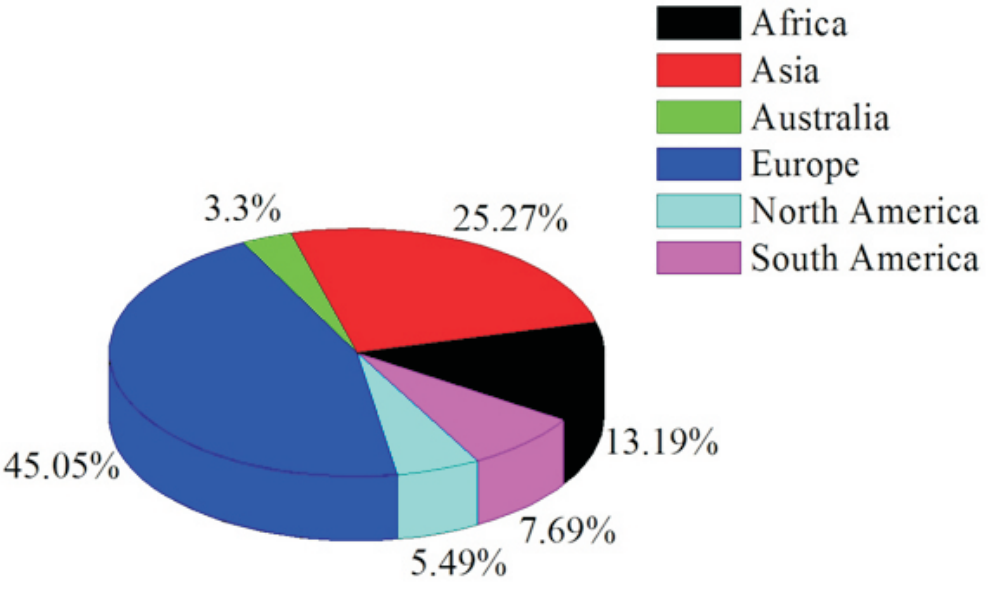

Figure 4: Spatial distribution of publications on Astrometry and Celestial Mechanics research in India

3013 articles which included author address, source country and research institute. There were 91 collaborating Countries/territories except India which participated in Indian institution in Astrometry and Celestial Mechanics research. Out of 91 Countries/territories there are four countries with which the collaboration is high, over 200 publications: United States (665) Germany (323) France (223) Japan (212) and ten countries with medium-high collaboration, over 100 publications: England (200) Italy (193) Russia (179) Australia (163) Spain (145) Peoples R China (129) South Korea (125) Poland (119) Taiwan (110) Canada (102) and there are 10 countries with little collaboration over 25 publications and rest of 22 Counting just 1–2 collaborations, 21 with just 3–10 and 24 with just 11-50.

3.10. Top 20 Countries International Collaborations and impact of their research output

Top 20 countries / territories were ranked based on the no. of total articles, along with the citations, percentage of internationally collaboration publications (Table-8). Out of these 20 countries / territories, The USA produced maximum publication 665 that is 22.071% of total publication with higher citations (19054).The AvgCPA (the average no. of citation per article) indicates the average impact of articles published by a country and the h-index (define as the no. of h papers among a country's no. of publications that have at least h citation each) are used to identify which country has the largest no. of high quality articles in the Astrometry and Celestial Mechanics research. It is seen from the below table 8 that Astrometry and Celestial Mechanics related articles authored in South Africa (Africa) have the highest average impact (AvgCPA=53.34) followed by Chile (South America)

AvgCPA=53.09 although USA ranked 13th in the AgvCPA index. Data regarding international research collaboration shows that it become more prevalent during study period and fruits of cooperation contributed to the overall scientific output in various countries and in the broad field of Astrometry and Celestial Mechanics research.

Table 8: Countries working collaboratively with Indian institutions on Astrometry and Celestial Mechanics during period 1960-2014.

Countries	Continent	TP(%)	TC	AvgCPA	h-index
USA	North America	665(22.071)	19054	28.65	61
Germany	Europe	323(10.720)	9941	30.78	48
France	Europe	223(7.401)	6377	28.60	42
Japan	Asia	212(7.036)	6417	30.27	40
England	Europe	200(6.638)	7431	37.15	41
Italy	Europe	193(6.406)	5258	27.24	41
Russia	Europe	179(5.941)	4548	25.41	39
Australia	Australia	163(5.410)	6614	40.58	40
Spain	Europe	145(4.812)	5444	37.54	37
Peoples R China	Asia	129(4.281)	2596	20.12	30
South Korea	Asia	125(4.149)	4132	33.06	26
Poland	Europe	119(3.950)	4550	38.24	31
Taiwan	Asia	110(3.651)	1946	17.69	26
Canada	North America	102(3.385)	4608	45.18	32
Switzerland	Europe	87(2.887)	3933	45.21	27
Netherlands	Europe	85(2.821)	3802	44.73	29
Brazil	South America	84(2.788)	1609	19.15	24
Austria	Europe	79(2.622)	1745	22.09	22
Chile	South America	68(2.257)	3610	53.09	24
South Africa	Africa	65(2.157)	3467	53.34	23

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

3.11 Analysis of keywords

Keyword analysis in research paper is very interesting in order to follow and identify the trends in the science and engineering branch (Montoya et. al, 2014). As a result of our work a total of 9506 different keywords, from 1960 to 2014 in the Astrometry and Celestial Mechanics research have been identified. The no. of analysed publications during the study period was 2656. Of them only 2483 provides key words. While the rest (173) do not provide the mentioned information. To obtain accurate results, we pre-processed the keywords by merging the singular and plural forms of the same terminology, and those keywords with the same meaning while using different expressions. A total 8746 unique Keywords are obtained. Among these unique keywords 2886 (32.99 %) appear once or twice at the most, we can deduce that this can be a sign of lack of research continuity or of a wide range of research focus. Table 9 shows the most used keywords during the considered period.

3.10.1 Hot topic and directions

Keywords ranking changes in the five 10-year and one 4-years (2010-2014) intervals are indicative of changes in the hot fields. In first three 10-years period (since 1960), there is no keyword appear. The Keywords appears from 1990 onwards that is 4th 10-years period. The top 20 most frequently used keywords for the study period are listed in Table 9. The five most frequently used keywords were ''Model'', ''stars'', ''time'', "Universe" and "region"

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

			1990-1999		2000-2009		2010-2014	
Keywords	Total	%	NO	R	NO	R	NO	R
Model	495	5.65	52	2	222	1	221	1
stars	463	5.29	93	1	193	3	177	3
time	443	5.06	42	5	212	2	189	2
Universe	300	3.43	32	9	121	4	147	4
region	292	3.33	37	6	114	6	141	6
dynamics	274	3.13	35	7	96	11	143	5
Emission	270	3.08	48	3	108	9	114	8
Evolution	267	3.05	43	4	118	5	106	9
Sun	262	2.99	31	10	109	8	122	7
Radiation	246	2.81	34	8	111	7	101	11
Cosmology	203	2.32	34	8	100	10	69	16
gravity	190	2.17	16	14	72	13	102	10
oscillations	168	1.92	19	13	75	12	74	14
Ionosphere	166	1.89	26	11	71	14	69	16
variability	158	1.80	21	12	67	15	70	15
supernovae	155	1.77	3	17	67	15	85	13
Dark energy	126	1.44	0	18	31	19	95	12
space-time	118	1.34	8	15	63	16	47	18
general-relativity	95	1.08	6	16	40	17	48	17
cosmological constant	81	0.92	0	18	36	18	45	19

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

3.10.2 Quick rising themes

The Compound Annual Growth Rate (CAGR) was used to identify the top most frequently used keywords and to select quick rising themes of Astrometry and Celestial Mechanics research, which could be indicators of future research directions. The Compound Annual Growth Rate (CAGR) of top 20 keywords were separately calculated based on the following formula:

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

$V(t_0)$: Initial observed value, $V(t_n)$: last observed value, $t_n - t_0$: number of years ("Compound annual growth rate", n.d.).

The CAGR provides smoothed growth rates free from the annual fluctuations of keywords occurrences during the study period. Table 5 lists the top 20 keywords according to the CAGR and sorted them by their rank. The ranks in Table 5 show that ''Dark energy'' and ''Stars'' and "Sun" are three leading hot issues that continue to attract broad attention. ''stars'' (CAGR, 15.97%) kept its dominance in terms of total quantity and annual growth rate.

Table 10: Top 20 Quick rising themes for the study period

Keywords	V(t0)	V(tn)	t0	tn	CAGR(%)	R
Model	4	55	1991	2014	12.07	11
Stars	1	35	1990	2014	15.97	2
Time	3	53	1991	2014	13.30	7
Universe	4	33	1991	2014	9.61	15
Region	1	31	1990	2014	15.38	5
Dynamics	4	32	1992	2014	9.91	14
Emission	7	29	1991	2014	6.37	19
Evolution	5	25	1991	2014	7.25	17
Sun	1	33	1990	2014	15.68	3
Radiation	3	34	1991	2014	11.13	12
Cosmology	3	19	1991	2014	8.36	16
Gravity	1	21	1991	2014	14.15	6
Oscillations	1	14	1991	2014	12.16	10
Ionosphere	3	19	1991	2014	8.36	16
Variability	4	18	1991	2014	6.76	18
Supernovae	1	21	1993	2014	15.60	4
Dark energy	1	25	2003	2014	33.99	1
space-time	1	13	1992	2014	12.37	8
general-relativity	1	10	1992	2014	11.03	13
cosmological constant	2	10	2000	2014	12.18	9

t0: the Initial (first) year (The Year in which no. of keywords occurrence first time) ; **tn:** the last year (No. of keywords occurrence); **V(t0):** Initial observed value (no. of keywords occurrence); **V(tn):** last observed value (no. of keywords occurrence); **CAGR(%):** Compound Annual Growth Rate (CAGR); **R:** Rank. **Source: WoS**

4. CONCLUSION:

Results of this study relating to the scientometric analysis of the research on the Astrometry and Celestial Mechanics during 1960-2014 provided helpful insights into the research on the Astrometry and Celestial Mechanics in many fronts including the patterns of publication outputs, journals, geographic and institutional contributions, and the keyword frequencies. In total 2656 article published during the investigation period. The following conclusions have been drawn from this study:

(1) Astrometry and Celestial Mechanics related research has significantly increased in the last 54 years. The amount of Astrometry and Celestial Mechanics related publication outputs rose at an average annual growth rate of % over the past five decades. The growth curve fit 4th degree polynomial with the $R^2 = 0.972$. This growth has been slow rate and significantly high though not exponential in nature. It is concluded that the growth is on a rise and will surely increase further.

The results also provided valuable information on the citations made to the Astrometry and Celestial Mechanics research papers. Total Number of Citations, Average Citations per Item, and H-index. There were 42275 total citations with 14.03 average citations to 3013 papers on the Astrometry and Celestial Mechanics research from this study. The research field has had a significant impact on the general literature with H-index of 71, a rough measure of its impact.

(2) A total of 101 journals had published 3013 articles on Astrometry and Celestial Mechanics. The most

active journal was “Physical Review D” published by American Physical Society originating from USA which published 415 (13.774%) of the total 3013 article, followed by “Astrophysics and Space Science 383 (12.712%); “Monthly Notices of the Royal Astronomical Society 365 (12.114)”

The results also provided valuable information on the citations received by journal. The journal “Physical Review D” highest no. of publication as well as highest average impact (AvgCPA=23.60) followed by the journal “Astrophysical Journal” has the average impact (AvgCPA=22.99).

(3) A total of 3013 articles on Astrometry and Celestial Mechanics appeared from 2188 institutions. Tata Institute of Fundamental Research, Mumbai,India contributed maximum no (442), followed by Indian Institute of Astrophysics (IIA), India 345 and Inter University Centre for Astronomy Astrophysics, Bangalore, India (330). It has been found that Astrometry and Celestial Mechanics related articles authored in foreign institution (United States Department of Energy) have the highest average impact (AgCPA=61.57) followed by National Aeronautics Space Administration have average impact (AgCPA=43.17). Among Indian institutions, Tata Institute of Fundamental Research has impact (26.50) in AgCPA index.

(4) A total of 17475 authors contributed on Astrometry and Celestial Mechanics research. The most active author was Sagar, R produced maximum no. of publications 51 of total publications 3013 with ranked first followed by Chakraborty, S ; Chakrabarti,SK; Padmanabhan,T. It is important to note that Astrometry and Celestial Mechanics related articles authored by Padmanabhan,T have the highest average impact (AvgCPA=26.64) followed by Yamashita,Y (AvgCPA=25.26) although Sagar, R ranked 18th in the AgvCPA index.

(5) For globalization of Astrometry and Celestial Mechanics Research in India, there were 91 collaborating Countries/territories except India which participated in Indian institution in Astrometry and Celestial Mechanics research. USA produced maximum publications 665 followed by Germany (323) and France (223) both comes under European continent. South Africa (Africa) have the highest average impact (AvgCPA=53.34) followed by Chile (South America) AvgCPA=53.09 although USA ranked 12th in the AgvCPA index.

(6) The keyword analysis of the studied publications revealed the hot direction and quick rising themes of Astrometry and Celestial Mechanics research. Models, Stars, Time, Universe were the hottest issues of Astrometry and Celestial Mechanics research. There are 20 top quick rising themes which calculated by CAGR. Dark Energy, Stars, Sunand Supernovae are the some of them.

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