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A study on the contributions of Stephen William Hawking during his journey in the Universe

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Abstract: Prof. Stephen William Hawking is recognized as one of the great scientists in the field of physics of the 20th and 21st century. He has 159 research articles which appeared during 1966 to 2017 in the domains like Cosmology, Black hole, Quantum Mechanics and so on. The focus of the paper is to gauge the impact of his contribution.

Keywords: Stephen William Hawking, Black hole, Citation study, Altmetrics, AAS

Introduction: Late Prof. Stephen William Hawking was born on 8th January 1942 and left us on 14th March 2018 at the age of 76. He was a physicist, cosmologist and director of Centre for Theoretical Cosmology. His major research areas were 'Cosmology' (study of dynamics of the universe), 'Black hole', 'Gravitational singularity theorems' and 'Quantum Mechanics'. Due to his extra ordinary research work concerning the universe, some of the research works are named after him, such as 'Hawking radiation', 'Penrose–Hawking theorems', 'Bekenstein–Hawking formula', 'Hawking energy'. He has been awarded 18 times for his contribution. There are 15 books and 159 research articles written by Prof. Hawking. In this article the main focus is to measure the scientific output of Prof. Hawking's publications and their impact.

Review of Literature: The journey of using metrics to measure scholarly impact started with the onset of Bibliometrics. Slowly, with the emergence of new application domains and metrics Scientometrics and later on Webometrics came. The use of indices similar to those used in biobliometrics was noticed in Webometric studies from 1997 onwards. Ingwersen P. (1998) and Alastair, S. (1999) have shown the process of measuring impact from web links and citations. The definition of Webometrics by Bjornborn and Ingwersen (2004) describes it as "The study of the quantitative aspects of the constructions and use of information resources, structures and technologies on web drawing on bibliometric and informetric approaches". Thelwell (2009) has

called webometrics as “The study of web-based content with primarily quantitative methods for social science research goals using techniques that are not specific to one field of the study”.

Recently, metric studies focused on using social media to measure scholarly impact are surfacing. This new branch of study is called ‘Altmetrics’. Priem, J, et. al. (2012) have shown the use of social media to estimate scholarly impact. Though Altmetrics is used to measure scholarly impact, there is lack of scientific evidence advocating the practice. The studies by Costas, R. (2015), Thelwall, M (2013), Eysenbach G.(2011) and C. Syamili, R.V. Rekha (2017) and Didegah, F. et.al (2018) show a comparison between altmetric indicators and citations. Also they have tried to find out whether any correlation exists. Bakker, CJ, et.al (2018) have provided an assessment of tools used in altmetrics studies. Robinson-Garcia, N, et.al (2018) have demonstrated the use of altmetric data for mapping societal impact. Enkhbayar, A., & Alperin, J. P. (2018) have listed the challenges of capturing engagement data on Facebook for Altmetric studies. Bornmann, L. (2014) has pointed out the advantages and disadvantages of altmetrics. Zahedi, Z. (2014) has analysed the possibilites for Altmetrics using the web based tool Impact Story. Papakostidis, C & Giannoudis, PV (2018) have tried to gauge the future of studies using impact factor and altmetrics.

Objectives of the study:

1. To measure the year wise distribution of publication. This will help in finding out the years in which he was the most and least productive.
2. To find out authorship pattern. This is to shed light on his collaboration pattern.
3. To analyze the citation. This is to find out the articles receiving the most number of citations. Also the type of citation is to be found out.
4. To count the Altmetric Attention Score (AAS). This score sheds light on an individual's research output, and points out the attention an item has received.

Methodology: The present study is limited to 159 papers by Prof. Stephen William Hawking (1966-2017) and only the journal papers were taken excluding the conference papers. The list of Prof. Hawking’s publications is available on his personal website i.e. http://www.hawking.org.uk. The number of citations was collected from Google Scholar and Altmetric Attention Score (AAS) was calculated by using bookmarklet tool (freely available from www.altmetric.com).

Analysis: In this analysis part the main focus is to analyze the results obtained while carrying out the objectives of the study.

i. **Year wise distribution of publication:** Prof. Hawking started his scientific intellectual output through research journal from 1965 and the last article was published in 2017. During these 52 years, he has published 159 articles in various renowned journals. In this part the main focus is to draw the year wise distribution of publication. The whole time spans are grouped into 11 groups and each group has 5 years. The bar diagram (Fig-1) shows that he has published 27 articles in between 1995-1999 and in between 1975-1979, 24 articles were published. 2000-2004, 2005-2009 and 2010-2014 are the less productive years.

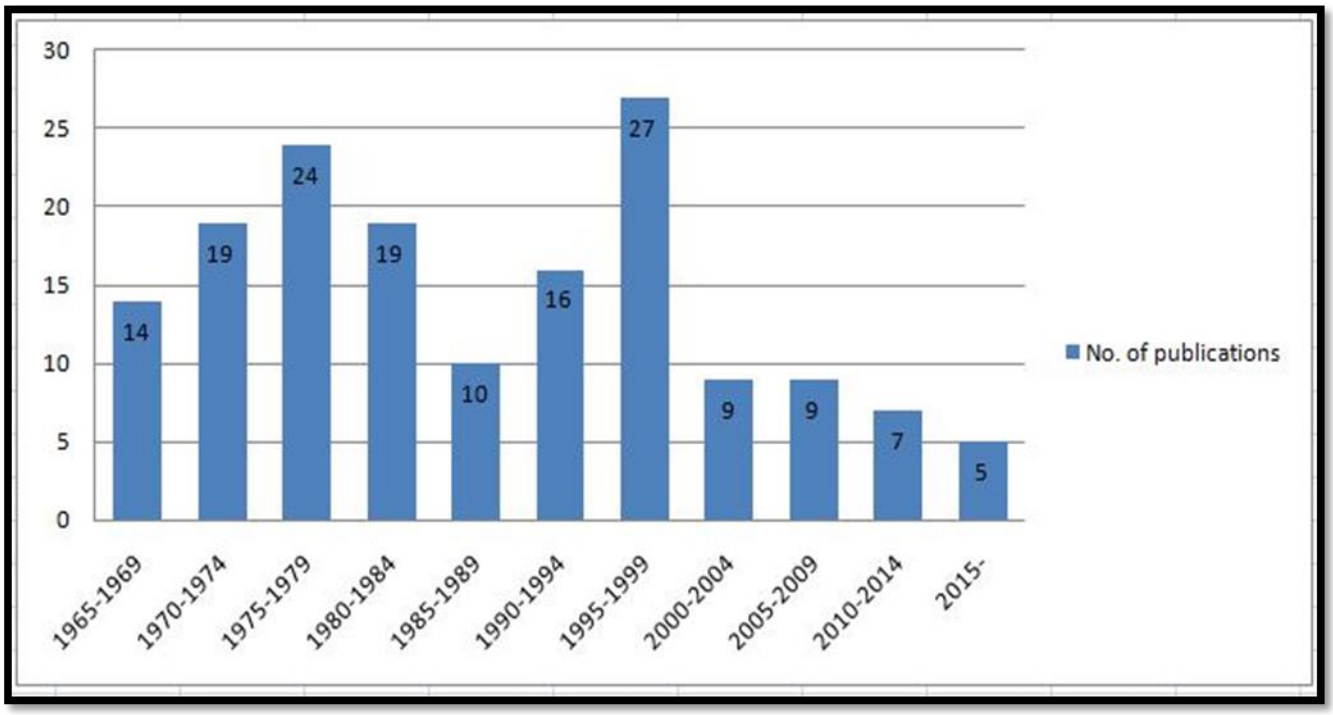

Fig-1: Year wise distribution of publication

ii. **Citation analysis:** Fig-2 shows the citation analysis of Prof. Hawking during his publication period, where it has been clearly stated that he got the highest citations (i.e. 25598) during 1975-1979. In this time period he published 24 articles. But, he has the highest publication (i.e. 27) during 1995-1999 when he got 3965 citations, which is his fourth highest citation received per time span of 4 years starting from 1965. He got 13884 citations during 1970-1974 and 11651 citations during 1980-1984.

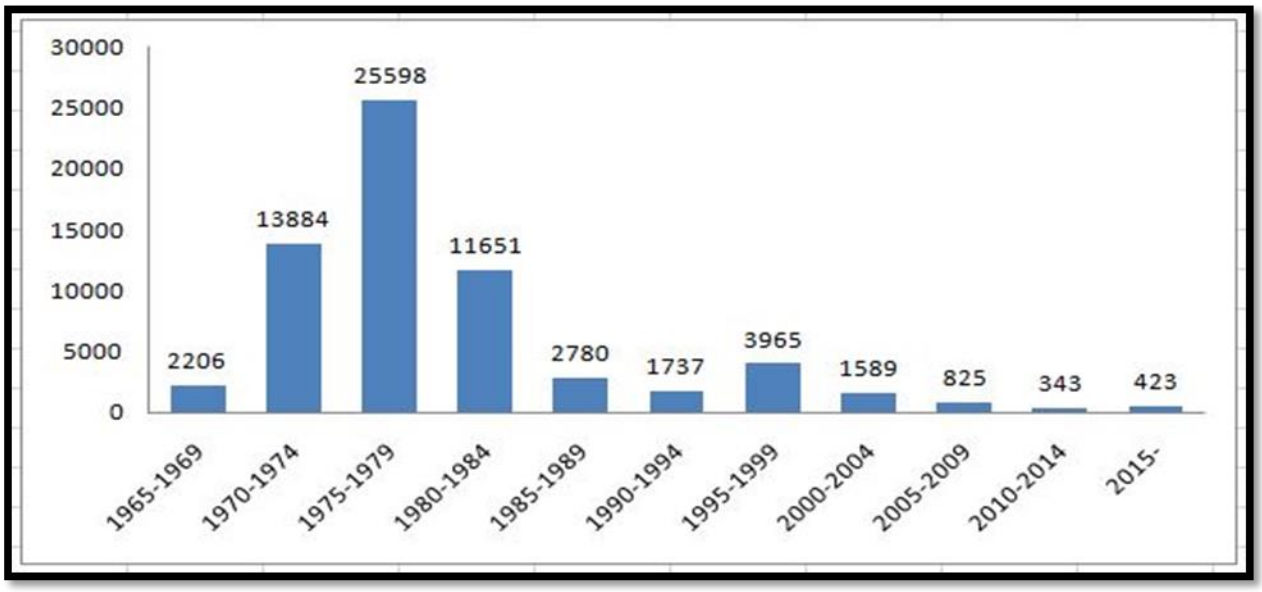

Fig-2: Citation analysis

iii. Altmetric Attention Score (AAS) analysis: Though Altmetrics came into the picture in 2010 but Prof. Hawking's publications before 2010 have remarkable AAS. After analyzing the score, it was surprising that he got the highest AAS at the very beginning of his publication life.

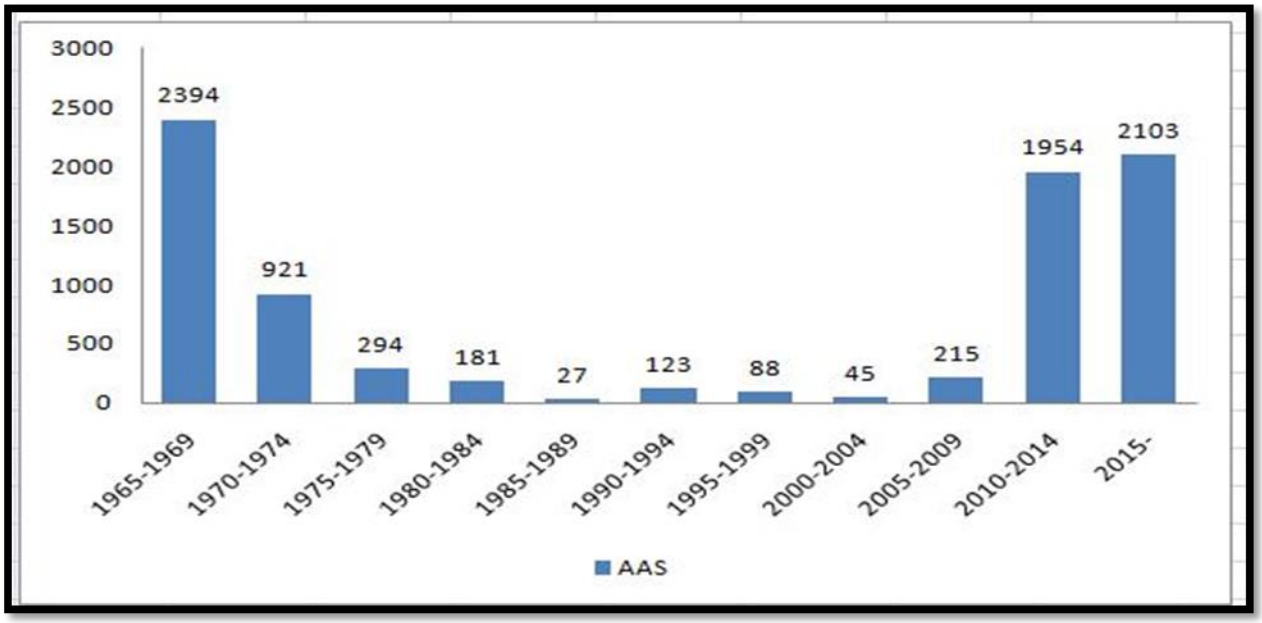

Fig-3: Altmetric Attention Score

iv. **Authorship pattern:** Fig-4 shows that Prof. Hawking shared his work with various famous scientists. 71 (44.65%) of his total publications were written by him as a single author, without any co-author. The remaining 88 papers are collaborative papers of which 48 (30.18%) are as first authored, 39 (24.52%) are as second authored and 1 (0.62%) is third authored.

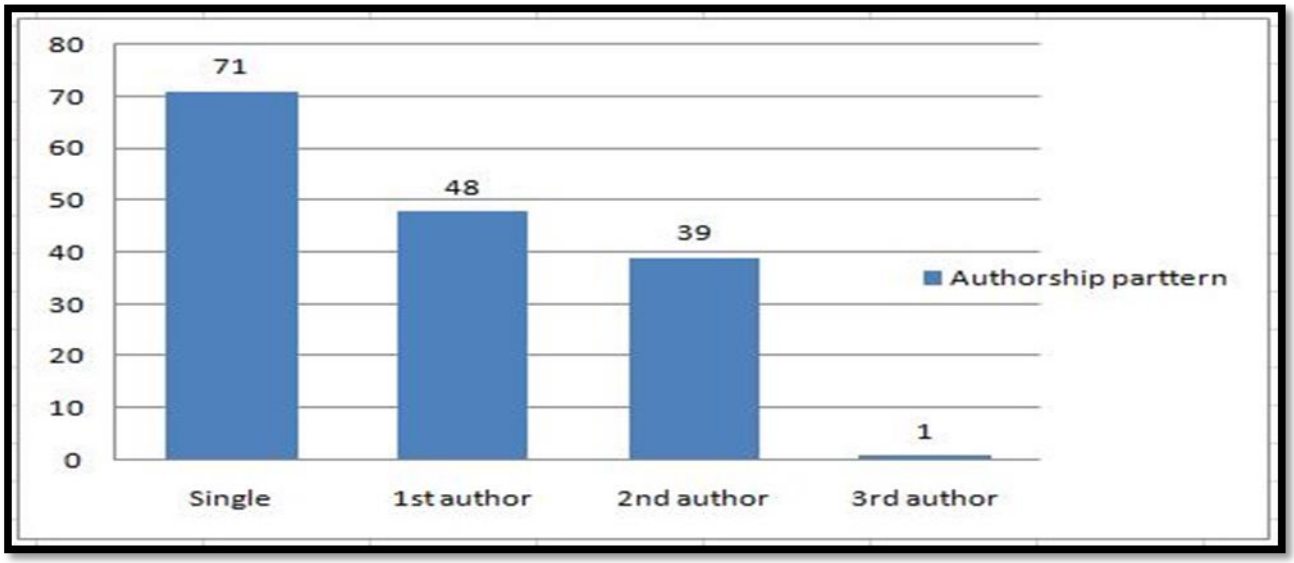

Fig-4: Authorship Pattern

Conclusion: This study is a quantitative evaluation of Prof. Stephen Hawking's publication productivity. During the 53 years of his academic life he had published 159 articles (excluding conference articles) i.e. 3 articles per year. 71 articles were written by him as a single author and remaining were co-authored. Till the time of conducting this study he had got 65001 citations that means 1226.43 citation per year and 8345 AAS that means 157.45 AAS per year.

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Appendix : List of Articles

Sl No.	Article	Year of publication	Citation	AAS
1	Singularities in homogeneous world models	1965	62	0
2	On the Hoyle-Narlikar theory of gravitation	1965	28	13
3	Occurrence of Singularities in Open Universes	1965	122	13
4	Perturbations of an Expanding Universe	1966	481	0
5	Singularities in the Universe	1966	91	1
6	Helium Production in an Anisotropic Big-Bang Cosmology	1966	44	63
7	The occurrence of singularities in cosmology	1966	167	8
8	Properties of expanding universes	1966	2	2288
9	The occurrence of singularities in cosmology. III. Causality and singularities	1967	326	1
10	Gravitational Radiation in an Expanding Universe	1968	336	4
11	The Cosmic Black-Body Radiation and the Existence of Singularities in Our Universe	1968	164	3
12	Singularities in Collapsing Stars and Expanding Universes	1969	0	0
13	On the rotation of the Universe	1969	259	0
14	The existence of cosmic time functions	1969	124	0
15	The singularities of gravitational collapse and cosmology	1970	1538	155
16	The conservation of matter in general relativity	1970	54	14
17	Theory of the Detection of Short Bursts of Gravitational Radiation	1971	106	13
18	Gravitational Radiation from Colliding Black Holes	1971	911	41
19	Evidence for Black Holes in Binary Star Systems	1971	15	63
20	The definition and occurrence of singularities in general relativity	1971	0	0
21	Stable and generic properties in general relativity	1971	64	0
22	Gravitationally Collapsed Objects of Very Low Mass	1971	662	17
23	Solutions of the Einstein-Maxwell equations with many black holes	1972	282	3
24	Energy and angular momentum flow into a black hole	1972	162	0
25	Black holes in the Brans-Dicke	1972	255	0

26	Black holes in general relativity	1972	1089	33
27	A variational principle for black holes	1973	27	0
28	The four laws of black hole mechanics	1973	2636	5
29	The Rotation and Distortion of the Universe	1973	290	0
30	Why is the Universe Isotropic?	1973	598	8
31	Black hole explosions?	1974	4408	566
32	Black Holes in the Early Universe	1974	683	3
33	Causally continuous spacetimes	1974	104	0
34	Particle creation by black holes	1975	10187	121
35	Gamma rays from primordial black holes	1976	393	0
36	Breakdown of predictability in gravitational collapse	1976	1872	102
37	Path-integral derivation of black-hole radiance	1976	1105	1
38	Black holes and thermodynamics	1976	1179	11
39	A new topology for curved space–time which incorporates the causal, differential, and conformal structures	1976	233	0
40	Cosmological event horizons, thermodynamics, and particle creation	1977	2642	19
41	The Quantum Mechanics of Black Holes	1977	105	9
42	Gravitational instantons	1977	556	0
43	Zeta function regularization of path integrals in curved spacetime	1977	1475	8
44	Action integrals and partition functions in quantum gravity	1977	2862	9
45	The Density Matrix of the Universe	1978	7	0
46	Who's Afraid Of (higher Derivative) Ghosts?	1978	22	0
47	Spacetime foam	1978	492	3
48	Gravitational multi-instantons	1978	711	3
49	Symmetry breaking by instantons in supergravity	1978	128	0
50	Path integrals and the indefiniteness of the gravitational action	1978	548	3
51	Quantum gravity and path integrals	1978	184	2
52	Generalized spin structures in quantum gravity	1978	179	0
53	Black Holes and Unpredictability	1978	1	0

54	Yang-Mills instantons and the S-matrix	1979	4	0
55	The propagation of particles in spacetime foam	1979	114	0
56	Classification of Gravitational Instanton symmetries	1979	508	3
57	Euclidean Quantum Gravity	1979	91	0
58	Quantum gravitational bubbles	1980	158	0
59	Is the End in Sight for Theoretical Physics?	1981	156	1
60	Interacting quantum fields around a black hole	1981	48	0
61	The development of irregularities in a single bubble inflationary universe	1982	2044	70
62	The unpredictability of quantum gravity	1982	665	0
63	Bubble collisions in the very early universe	1982	434	7
64	Supercooled phase transitions in the very early universe	1982	807	12
65	Wave function of the Universe	1983	3359	80
66	The boundary conditions for gauged supergravity	1983	109	0
67	Fluctuations in the inflationary universe	1983	190	6
68	Thermodynamics of black holes in anti-de Sitter space	1983	1669	0
69	Positive mass theorems for black holes	1983	273	0
70	The Quantum Mechanics of the Universe	1984	0	0
71	Higher derivatives in quantum cosmology: (I). The isotropic case	1984	182	0
72	Non-trivial topologies in quantum gravity	1984	84	0
73	The isotropy of the universe	1984	129	2
74	The cosmological constant is probably zero	1984	555	3
75	The quantum state of the universe	1984	787	0
76	The Loss of Quantum Coherence due to Virtual Black Holes	1984	2	0
77	Arrow of time in cosmology	1985	243	4
78	Origin of structure in the Universe	1985	698	1
79	Limits on inflationary models of the universe	1985	91	0
80	Numerical calculations of minisuperspace cosmological models	1985	80	0
81	Operator ordering and the flatness of the universe	1986	329	0

82	Quantum coherence down the wormhole	1987	310	0
83	A natural measure on the set of all universes	1987	155	9
84	Wormholes in spacetime	1988	584	10
85	How probable is inflation?	1988	147	3
86	Black holes from cosmic strings	1989	143	0
87	Spectrum of wormholes	1990	222	46
88	Gravitational radiation from collapsing cosmic string loops	1990	29	1
89	Baby Universes II	1990	57	1
90	Do wormholes fix the constants of nature?	1990	1	0
91	Wormholes in string theory	1991	20	1
92	The alpha parameters of wormholes	1991	6	1
93	The effective action for wormholes	1991	21	1
94	Evaporation of two-dimensional black holes	1992	159	3
95	Kinks and topology change	1992	57	2
96	Selection rules for topology change	1992	71	1
97	Chronology protection conjecture	1992	818	61
98	Supersymmetric Bianchi models and the square root of the Wheeler-DeWitt equation	1993	101	1
99	Origin of time asymmetry	1993	99	1
100	Naked and thunderbolt singularities in black hole evaporation	1993	56	1
101	Superscattering matrix for two-dimensional black holes	1994	6	1
102	Quantum coherence in two dimensions	1994	14	1
103	Probability for primordial black holes	1995	109	1
104	Pair Production of Black Holes on Cosmic Strings	1995	84	1
105	Duality between electric and magnetic black holes	1995	195	1
106	Quantum coherence and closed timelike curves	1995	53	2
107	Entropy, area, and black hole pairs	1995	464	25
108	Pair creation of black holes during inflation	1996	194	9
109	Primordial Black Holes: Tunnelling vs. No Boundary Proposal	1996	7	1

110	The gravitational Hamiltonian in the presence of non-orthogonal boundaries	1996	105	6
111	The gravitational Hamiltonian, action, entropy and surface terms	1996	595	1
112	Trace anomaly of dilaton-coupled scalars in two dimensions	1997	101	1
113	Loss of quantum coherence through scattering off virtual black holes	1997	24	1
114	Evolution of near-extremal black holes	1997	35	1
115	Black holes in inflation	1997	3	1
116	Inflation, singular instantons, and eleven dimensional cosmology	1998	25	1
117	Open inflation, the four form and the cosmological constant	1998	116	2
118	Open inflation without false vacua	1998	255	2
119	Comment on `Quantum Creation of an Open Universe', by Andrei Linde	1998	66	1
120	Bulk charges in eleven dimensions	1998	32	1
121	(Anti-)evaporation of Schwarzschild–de Sitter black holes	1998	146	1
122	Virtual black holes	1998	128	16
123	Baby universes and the non-renormalizability of gravity	1998	91	1
124	Charged and rotating AdS black holes and their CFT duals	1999	203	6
125	Primordial Black Holes: Pair Creation, Lorentzian Condition, and Evaporation	1999	17	1
126	Rotation and the AdS-CFT correspondence	1999	505	1
127	NUT charge, anti–de Sitter space, and entropy	1999	224	2
128	Gravitational entropy and global structure	1999	150	1
129	Lorentzian condition in quantum gravity	1999	38	1
130	Brane new world	2000	321	25
131	Gravitational waves in open de Sitter space	2000	77	2
132	Stability of AdS and phase transitions	2000	9	1
133	Brane-world black holes	2000	524	1
134	Trace anomaly driven inflation	2001	187	1
135	DeSitter entropy, quantum entanglement and ADS/CFT	2001	191	9
136	Why does inflation start at the top of the hill?	2002	49	1
137	Chronology protection: Making the world safe for historians	2002	9	0

138	Living with ghosts	2002	222	5
139	Information Loss in Black Holes	2005	445	121
140	A non singular universe	2005	10	0
141	Black holes and the information paradox	2005	4	0
142	Populating the landscape: A top-down approach	2006	101	15
143	Volume Weighting in the No Boundary Proposal	2007	29	28
144	The measure of the universe	2007	3	1
145	The Classical Universes of the No-Boundary Quantum State	2008	122	23
146	No-Boundary Measure of the Universe	2008	111	26
147	Why did the Universe Inflate?	2009	0	1
148	The No-Boundary Measure in the Regime of Eternal Inflation	2010	38	1
149	Local Observation in Eternal inflation	2011	28	1
150	Quantum Probabilities for Inflation from Holography	2012	23	12
151	Accelerated Expansion from Negative Λ	2012	36	28
152	Vector Fields in Holographic Cosmology	2013	5	1
153	Information Preservation and Weather Forecasting for Black Holes	2014	173	1869
154	Singularities and the geometry of spacetime	2014	40	42
155	The Information Paradox for Black Holes	2015	78	165
156	Soft Hair on Black Holes	2016	262	1072
157	A Smooth Exit from Eternal Inflation?	2017	5	791
158	The Conformal BMS Group	2017	9	0
159	Superrotation Charge and Supertranslation Hair on Black Holes	2017	69	75