Mathematically Significant: A Review of Awards in Mathematics with Emphasis on the Fields Medal

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There are several major international awards in the field of mathematics. Arguably the most prestigious of these is the Fields Medal, which has been awarded to fifty-one mathematicians since 1936. This article will examine aspects of the Fields Medal winners such as age, nationality, affiliated institution upon award, area of work, and the impact of their publications in the mathematics literature. MathSciNet author profiles were examined to collect both publication and citation data for this study. Several other awards in mathematics including the Wolf Prize, Abel Prize, and Kyoto Prize are also discussed.

KEYWORDS mathematics, Fields Medal, awards, citation studies, mathematicians, nationality

Running title: A Review of Awards in Mathematics

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Introduction

There exist a large number of awards for achievement in the sciences to recognize impact, promise, or other excellence. Since before the twentieth century associations and institutions have bestowed awards upon scientists in many fields, but until the establishment of the Nobel Prize in 1901 there were few permanent awards and none had a true international scope (Monastryrsky 1997). The subject of mathematics was excluded from the fields of the Nobel Prize, most likely due a conflict between Alfred Nobel and the Swedish mathematician Gosta Mittag-Leffler (Garding and Hormander 1985). Thus the first truly international award for mathematics did not arrive until the Fields Medal was awarded in 1936. This paper will focus on the Fields Medal, but will also discuss other major awards in mathematics.

Fields Medal

The eponymous John Charles Fields was a mathematician born in 1863 in Canada. He spent most of his career at the University of Toronto but worked and studied in both Europe and the United States of America (USA). Throughout his career he was a tireless advocate for international cooperation in mathematics. He worked until the time of his death in 1932 to promote unity in International Congress of Mathematicians (ICM) and to establish an award in the field mathematics. The ICM, hosted by the International Mathematical Union (IMU), is still the largest mathematical conference in the world(International Mathematical Union 2011a). His original proposal and much of his estate funds generated what was to become the Fields Medal. Ironically, Fields was

of the opinion that the award should not be affiliated with any nation, institution, or individual (Fields Institute 2011).

The Fields Medal was inaugurated at the 1936 ICM in Oslo, Norway. The medal itself, featuring an image of Archimedes, and a modest cash prize were awarded to two mathematicians, Lars Ahlfors of the University of Helsinki and Jesse Douglas of the Massachusetts Institute of Technology (MIT). Douglas did not even attend the conference since the recipients identities were kept secret before the meeting. World War II interrupted the Congresses and the awarding of the Fields Medal until it resumed in 1950 at Cambridge, UK (Albers, Alexanderson, and Reid 1987).

The ICM met every four years after that time with the maximum number of awards increasing from two to four in 1966 due to an increase in funds available from the sponsoring trust (Tropp 1976). Most often the maximum number of awards was distributed. The graph in Figure 1 shows the number of medals awarded by year from the first award until the most recent ICM. **[insert figure 1 here]**

The Soviet Union (USSR) for a number of years would not allow their mathematicians to attend the Congresses (Monastryrsky 1997), so Sergei Novikov and Grigory Margulis could not accept their awards in person. The only person to decline the Fields Medal is Grigori Perelman, who famously proved the Poincare conjecture. Not only did he publish his proof on the web rather than in a scholarly journal, but he also worked at home rather than in any institutional setting. He had distanced himself from the mathematical profession and did not attend the ICM. His rationale for this has been explored in a number of books (Gessen 2009), articles, and interviews (Nasar and Gruber 2006) and is a matter open to question.

It was important to John Charles Fields that future professional potential should be encouraged. By tradition the Fields Medal has been awarded only to mathematicians under 40, though this is not a requirement of the funding endowment (Albers, Alexanderson, and Reid 1987). It is generally assumed that mathematicians do their most significant work when they are young, but studies on the topic have not been comprehensive (Camina and Wright 2000). The youngest to win the prize was Jean-Pierre Serre at age 28, though the median age of recipients is 36. The distribution in Figure 2 shows most ages are close to the maximum age allowed. **[insert figure 2 here]**

The next IMU meeting will take place in 2014 in Seoul, Korea and up to four Fields Medals, each accompanied by a C$15,000 (about the same in $ US), could be awarded (International Mathematical Union 2011a). The IMU will also award the Rolf Nevanlinna Prize for Mathematical Aspects of Information Science that includes scholars in computer science and related fields. There have been eight Rolf Nevanlinna Prizes awarded also only to mathematicians under the age of 40. For applied mathematics the IMU has awarded two Carl Friedrich Gauss Prizes, one to Kiyoshi Ito in 2006 and the second to Yves Meyer in 2010. There is no age limit on the Gauss Prize in order to recognize a broad applied impact of the mathematician's work. In 2010 the IMU also awarded the first Chern Medal for lifelong achievement to the Canadian mathematician Louis Nirenberg for his work in partial differential equations (PDE).

Since 1978 the Wolf Foundation in Israel has awarded one of its six Wolf Prizes in the field of mathematics (Wolf Foundation 2010). The Wolf Prize in Mathematics is

awarded annually to up to three mathematicians, though in some years it is not awarded at all (1991, 1998, 2004, 2009). The cash award of $100,000 is divided among the winners if there is more than one. There are no age limits placed upon the award and a selection committee of "renowned experts" is appointed by the Foundation. There have been fifty mathematicians honored by the Wolf Prize, which is a close second to the number of Fields Medalists in just the past thirty-three years, due to the increased frequency of the award. Thirteen of those fifty were previously recipients of the Fields Medal. In 2000, a two volume *Wolf Prize in Mathematics* was published containing a great deal of information on the winners to that point (Chern and Hirzebruch 2000).

Scandinavia finally entered the mathematical awards scene in 2003 with Norway establishing the Abel Prize (The Norwegian Academy of Science and Letters 2011). With an accompanying cash award on par with the Nobel Prize, approximately $1 million US, the Abel Prize is awarded annually. The award committee is made up of members nominated by the IMU as well as the European Mathematical Society (EMS). Four of the eleven recipients have also been Fields Medalists, though two have shared the Abel with another mathematician. A book containing the work of the Abel Prize winners from 2003-2007 was recently published by Springer (Holden and Piene 2010).

Another prestigious award that recognizes mathematicians is the Kyoto Prize (Inamori Foundation 2011). While it is awarded annually the "mathematical sciences" are honored every four years in the "basic sciences" category. The medal and 50 million yen, over half a million US dollars, are awarded by the Inamori Foundation. The prize honors the "scientific, cultural, and spiritual betterment of mankind" rather than simply mathematical discoveries and has no restrictions on age. Since 1985 there have

been seven awards in the mathematical sciences including laureates of other awards such as the Abel Prize and the Gauss Prize.

Methodology

An analysis of data on recipients of the Fields Medal was conducted because it presented the largest data set of all awards and has existed for the longest period of time. Other studies that have examined international awards over a short time span have been unable to show correlation between country and award (Rodriguez-Navarro 2011). Monastyrsky's book (Monastryrsky 1997) actually set a goal of using the work of the Fields Medalists to map progress in mathematics in the twentieth century. As journal literature remains the primary means of communicating research among mathematicians (Crowley, Rankin, and Vaughn 2011), it was hypothesized that an analysis of journal articles published by these winners would reflect the most significant research topics in modern mathematics. As discussed previously in this article, age of recipients was analyzed. In addition other demographic information of the winners was examined to see if certain countries were more frequently represented.

Data gathering for the project utilized a combination of web and print resources. From the books available listing Fields Medal recipients (Albers, Alexanderson, and Reid 1987; Monastryrsky 1997) and journal articles (Tropp 1976) there were also the official (International Mathematical Union 2011b) and aggregator websites (Wikimedia Foundation 2011). The name, nationality, birth year, institution that awarded the Ph.D. and current institutional affiliation were recorded for each winner. Gender was not recorded; all Fields Medalists to date have been male. Institutional affiliation was the

most difficult to determine as some of the Medalists changed jobs throughout their careers. The institutions where they spent the most time prior to receipt of the Fields Medal were chosen as the best representation. This primary data was then used to generate the age of the winner upon receipt of the Medal.

In order to determine their most cited publication and their fields of publication and reputation, the mathematical review index MathSciNet (American Mathematical Society 2011) was accessed in November, 2011. MathSciNet is the current online version of Mathematical Reviews which began indexing the mathematics literature in 1940. Since its inception mathematicians have been frequent users of MathSciNet (Brown 1999). Articles covered date back to the early nineteenth century and forthcoming publications are added at a rate of over 100,000 per year. One recent feature of MathSciNet that made this data gathering possible was an author identification system that included “Author Profiles” on mathematicians. Citation information is also available within the index of MathSciNet showing the impact of a particular article or journal within the mathematical literature.

Each author was queried using the “Author Name” search (American Mathematical Society 2011) and the corresponding author profile was retrieved. Due to very accurate author identification (Richert 2011), even of non-English names, author profiles for all Fields Medalists were located. The most cited publication within the field of mathematics, again only those indexed in MathSciNet, was obtained by selecting the “Citations” link. It provided the top 10 most cited articles or books by that author. The MR number, a unique identifier tied to the record, and the number of citations of the most cited publication were recorded.

On each author profile were two word clouds, which provided a pictorial representation of the number of publications by an author and the number of citations of the author's articles. The size of each word in these clouds represented the comparative share of citations or publications, hence larger words indicated a greater number of publications or citations. Also visible was the actual number of publications or citations so it was simple to record the Mathematics Subject Classification (MSC) of the "largest" subject for each Medalist.

Unlike Diodato and Stankus (Stankus and Diodato 1983) the actual MSC was used in place of ten specialty categories. Indeed Monastyrsky (Monastryrsky 1997) used only seven specialty categories to group the work of Fields medalists including the category "Miscellany". Science Citation Index (SCI) has five subject categories that involve mathematics (Bensman, Smolinsky, and Pudovkin 2010) and Gregg Sapp (Sapp 1989) mapped portions of the MSC to only six subject categories. Despite a historic variation between author supplied indexing of mathematics articles and editor classification (Diodato 1981), the MSC is at least an accepted standard for the field of mathematics. In the case of "Number Theory" the current and expired MSC codes 10 and 11 were combined.

Analysis

[insert figure 3 here]

Nationalities are listed in Figure 3 with the USSR changed to the current name of the former Soviet republic where the winner was born, in essence Vladimir Drinfel'd is Ukrainian and all others are Russian. The USA is the lead country with France, Russia,

and the United Kingdom among the other frequently occurring nationalities. These countries are those with a large financial investment in education and research institutions. Almost every continent is represented among the nationality of winners with the exceptions of Africa and South America. This pattern also applies when the country where the Fields Medalist attained their PhD. Rodriguez-Navarro (Rodriguez-Navarro 2011) postulated there are “Nobel class countries” with sufficient academic research resources necessary to attain the award whose scientists have not won due to the scarcity and infrequency of awards.

[insert figure 4 here]

Figure 4 is an expansion of the affiliation and workplace of the winner by listing the universities or institutions with multiple laureates. A few institutions in Europe and the USA clearly dominate in these totals. Even more significant is that the Institute for Advanced Study is in Princeton, NJ -- therefore the city has been home to eleven Medalists.

[insert figure 5 here]

Only 15 of the 51 winners eventually spent most of their career at their graduating institution as listed in Figure 5. Perhaps this could be labeled “loyalty”, though the similarity to results for institutions with more than one Fields Medalist is enough to suggest simply an attraction of mathematicians to greater research support. Some academic disciplines emphasize pursuit of graduate degrees at a different university than undergraduate studies, though this was not examined in this study.

[insert figure 6 here]

The most difficult analysis to complete was that of subject matter among the work of the Fields Medalists. The prize is awarded work in a specified area of mathematics, which is referenced in the citations accompanying the award, but not a particular article or proof. The MSC for both the most published subject area by the Fields Medalist and the subject area in which they were most cited are listed in Figure 6. For the six most frequently occurring subjects, there is a strong similarity between fields published in and citations. However for the less frequently occurring subjects, the pattern begins to break down. "Dynamical Systems and Ergodic Theory" (MSC 37), which has three Fields Medalists highly published, has no Medalists highly cited in that area. The reverse is true for "Nonassociative Rings and Algebras" (MSC 17), where three Medalists are highly cited but none publish most of their papers in this area. It should be noted that Edward Witten, the only physicist to win the Fields Medal, was not the only Medalist published or cited in the field of "Quantum Theory" (MSC 81).

MathSciNet data was also used for citations to determine the highest cited paper, although other sources such as Science Citation Index also provide citation data. Garfield (Garfield 1982) in his review of highly cited mathematics journals identified "citation classics" as papers cited more than 50 times (See Appendix I). By this metric only four of the fifty-one Fields Medalists have not written a classic paper, though one of those is a recent award recipient. It should be noted that Garfield showed that mathematicians both cite fewer papers per article and cite older material more frequently than other disciplines. For example, for his analysis of a portion of Nobel Prize winners (Garfield 1986) 83 percent were found to have written a "citation classic" of 300 citations or more.

The impact of any one paper or journal in mathematics has proven difficult to measure with traditional metrics both in the past (Garfield 1982) and present (Bensman, Smolinsky, and Pudovkin 2010). Though there are evidently highly cited authors among the fields medalists, there is a wide range in total citations of their most cited work, see Figure 7. Indeed the analysis by Bensman of citation rates in mathematical journals seems to support that data measures vary in the way of "random error". **[insert figure 7 here]**

Conclusions and Further Study

It seems evident from Figure 3 that as a Medalist moves through his career, he literally moves to countries already leading in excellence as measured by number of Fields Medalists. Career path in this instance begins in the nation of birth before moving to the PhD issuing university and finally ending at the institution where they spent the majority of their career. Russia in particular seems unable to retain Fields Medalists although many winners are Russian by birth and education. This follows patterns of the Nobel Prize of "wealthy" nations receiving the majority of awards (Rodriguez-Navarro 2011).

Due to the dominance of a few subjects among the publication patterns of the Fields Medalists as shown in Figure 6, it was concluded that there could be little inferred about the subject focus of modern mathematics. Perhaps it could be said that algebraic geometry was important to the past century, though the comparison MSC categorizes was not normalized for the number of papers that are published in each area. Even Monastryrsky did not find equal numbers of Fields Medalists to represent "modern mathematics," and his chapter on Topology is by far the longest. (Monastryrsky 1997)

It is notable that almost all Fields Medalists have written a classic paper in mathematics, according to Garfields operational definition (Garfield 1982). Using citation analysis to predict future Fields Medalists is likely extremely difficult; however, it may be possible to distinguish a small population of Fields Medal class mathematicians from which the winners will likely arise (Garfield and Malin 1968). As age is a limiting factor, all candidate over forty years old can be eliminated. Choosing the highly cited is not guaranteed to indicate the winners since other factors have been required to guess even a few Nobel Prize winners (Brynko 2010). Analysis of recent trends in the mathematical literature or in previous year's awards could also determine the areas of mathematics where the winners may work in the future.

There is always speculation about favoritism or prejudices that may exist in the awarding of prizes. Though the IMU committee that awards the Fields Medal is diverse, there may be opportunity to study relationships between the winners and the award committee, perhaps by use of nationality, affiliation, or even advisor-student relationships, such as those tracked by the Mathematics Genealogy Project (North Dakota State University Department of Mathematics 2011). The IMU stipulates that "If a former student (Ph.D. thesis only) of a Committee member is seriously considered, such a member shall not continue to serve on the Committee for its final decision, " (International Mathematical Union 2011a) which should help mitigate potential conflicts of interest.

In recent years, the significant mathematical work of the award recipients has been reviewed by other authors in select journals or books. Further studies could examine the articles cited by these reviews to determine the seminal paper from each

Fields Medalist. Another potential study would be an analysis of the recipients of the Wolf Prize in Mathematics. There are almost as many winners of that prize; it has the potential to outpace the Fields Medal over the next few years if it is awarded regularly.

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Figure 1

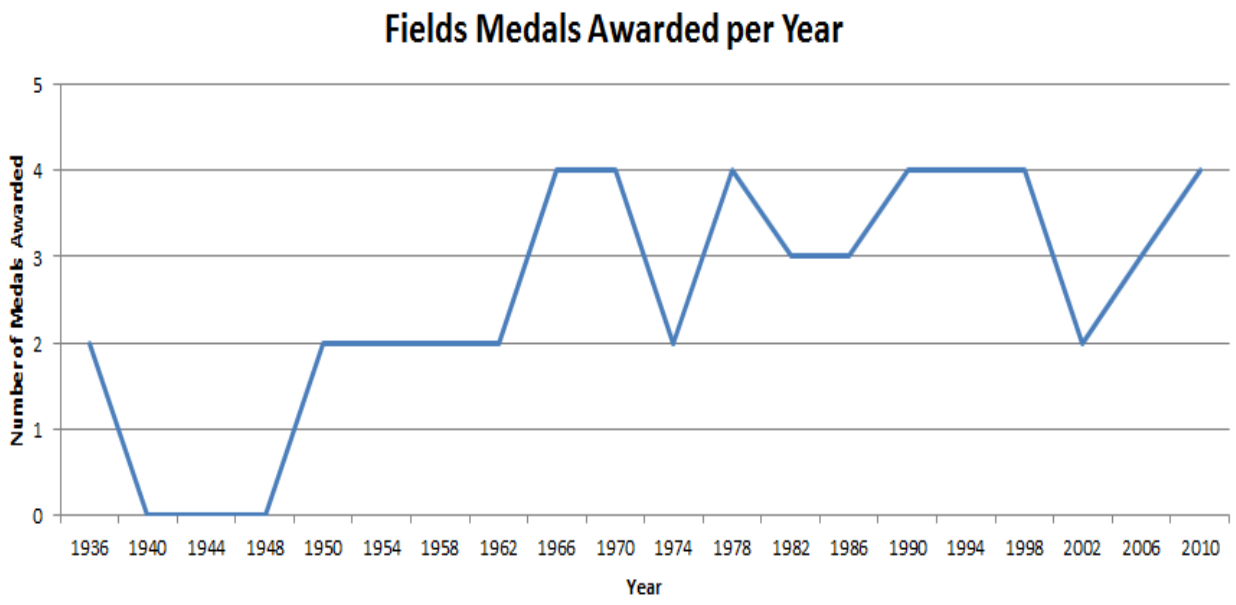
Fields Medals Awarded per Year
Number of Medals Awarded
0
1
2
3
4
5
1936
1940
1944
1948
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006
2010
Year

Figure 2

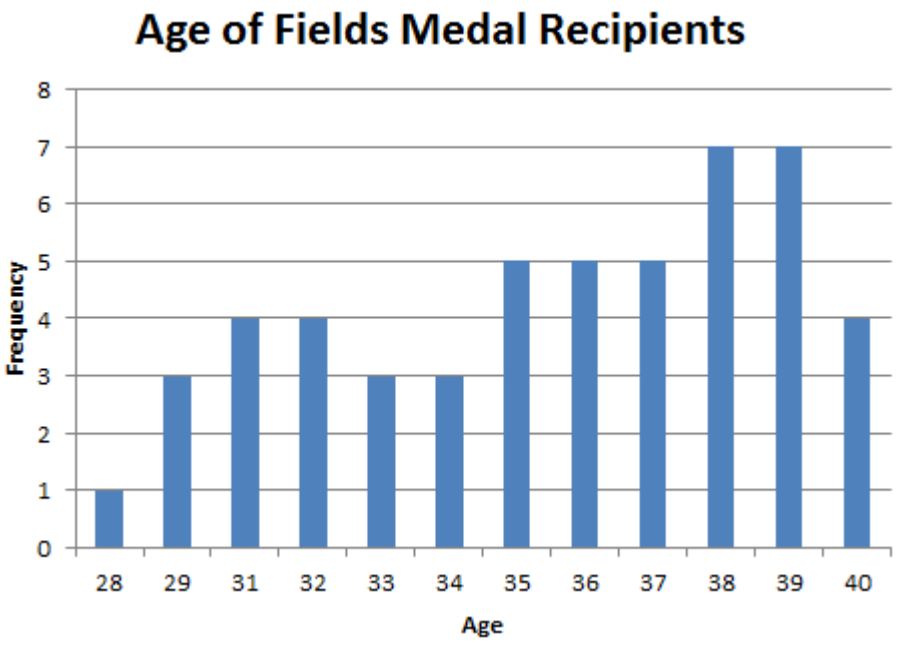
Age of Fields Medal Recipients
Frequency
0
1
2
3
4
5
6
7
8
28
29
31
32
33
34
35
36
37
38
39
40
Age

Figure 3

Number of Fields Medalists from each country			
Country	**Nationality**	**Alma Mater**	**Affiliation**
United States	13	16	23
France	9	11	13
Russia	7	6	2
United Kingdom	6	6	6
Japan	3	2	1
Belgium	2	2	0
Germany	2	2	0
Finland	1	1	1
Italy	1	1	1
Sweden	1	1	1
Israel	1	1	1
Norway	1	1	0
Ukraine	1	0	1
Vietnam	1	0	0
Australia	1	0	0
New Zealand	1	0	0
Switzerland	0	1	1

Figure 4

Institutions with more than one Fields Medalist	
Issued PhD	**Affiliated**
University of Cambridge (5) Princeton University (5) École Normale Supérieure (5) Moscow State University (5) Harvard University (4) University of California, Berkeley (2) Université de Paris-Sud (2) University of Chicago (2)	Institute for Advanced Study (6) Princeton University (5) Institut des Hautes Etudes Scientifiques (5) University of Cambridge (3) Harvard University (3) University of California, Berkeley (3) Université de Paris-Sud (3) Moscow State University (2) University of Oxford (2) Massachusetts Institute of Technology (2)

Figure 5

Fields Medalists who spent their career at their PhD issuing institution
Harvard University – Heisuke Hironaka, David Mumford, Curtis T. McMullen
University of Cambridge – Alan Baker, Richard Borcherds, Timothy Gowers
Princeton University – John Milnor, Charles Fefferman
Moscow State University – Sergei Novikov, Grigory Margulis
University of Helsinki – Lars Ahlfors
University of Oxford – Simon Donaldson
University of Kyoto – Shigefumi Mori
Hebrew University of Jerusalem – Elon Lindenstrauss
Université de Paris-Sud - Ngô Bảo Châu

Figure 6

Subjects in which more than one Fields Medalist published the most articles or had their research cited most		
Area of Mathematics (MSC)	**Published**	**Cited in**
Algebraic Geometry (14)	13	9
Manifolds and Cell Complexes (57)	6	7
Number Theory (10 and 11)	5	5
Functional Analysis (46)	4	4
Partial Differential Equations (35)	3	4
Global Analysis, Analysis on Manifolds (58)	3	3
Dynamical Systems and Ergodic Theory (37)	3	0
Nonassociative Rings and Algebras (17)	0	3
	2	0
	2	0
	0	2

Figure 7

Highest cited papers among Fields Medalists	
Number of Medalists	**Citations of most cited work**
4	500+ *
8	400-499
10	300-399
9	200-299
6	100-199
9	50-99
4	1-49

* Vladimir Drinfel'd (529), Lars Hörmander (709), Alain Connes (862), Pierre-Louis Lions (871)

Appendix I

The Mathematical Reviews (MathSciNet) code for the highest cited work is recorded under “MR of most cited work” next to the number of times it was cited. The Mathematical Subject Classification (MSC) code where the Fields Medalists were most published “MSC pub” and most cited (MSC cited) were also recorded.

	Fields Medalist	MR of most cited work	# of citations	MSC pub	MSC cited
1936	Lars Ahlfors	MR0510197	355	30	30
1936	Jesse Douglas	MR0004740	37	20	49
1950	Laurent Schwartz	MR0209834	498	46	46
1950	Atle Selberg	MR0088511	154	10	10
1954	Kunihiko Kodaira	MR0187255	84	32	32
1954	Jean-Pierre Serre	MR0607504	406	14	12
1958	Klaus Roth	MR0072182	87	10	10
1958	René Thom	MR0061823	111	58	57
1962	Lars Hörmander	MR0705278	709	35	35
1962	John Milnor	MR0440554	444	57	57
1966	Michael Atiyah	MR0242802	438	57	57
1966	Paul Joseph Cohen	MR0232676	36	2	2
1966	Alexander Grothendieck	MR0075539	240	14	14
1966	Stephen Smale	MR0228014	369	57	57
1970	Alan Baker	MR0422171	113	10	10
1970	Heisuke Hironaka	MR0199184	391	14	14
1970	Sergei Novikov	MR0779467	224	1	58
1970	John G. Thompson	MR0166261	104	20	20

1974	Enrico Bombieri	MR0318163	81	11	11
1974	David Mumford	MR0282985	466	14	14
1978	Pierre Deligne	MR0751966	435	14	14
1978	Charles Fefferman	MR0447953	441	81	42
1978	Grigory Margulis	MR1090825	344	22	22
1978	Daniel Quillen	MR0338129	471	19	18
1982	Alain Connes	MR1303779	862	58	46
1982	William Thurston	MR1161694	351	57	57
1982	Shing-Tung Yau	MR0480350	344	53	53
1986	Simon Donaldson	MR1079726	324	57	57
1986	Gerd Faltings	MR0718935	212	14	14
1986	Michael Freedman	MR0679066	207	57	57
1990	Vladimir Drinfel'd	MR0934283	529	14	17
1990	Vaughan F. R. Jones	MR0696688	287	46	46
1990	Shigefumi Mori	MR1658959	310	14	14
1990	Edward Witten	MR0990772	311	81	81
1994	Jean Bourgain	MR1215780	295	46	35
1994	Pierre-Louis Lions	MR1118699	871	35	35
1994	Jean-Christophe Yoccoz	MR1367353	94	37	58
1994	Efim Zelmanov	MR1044047	66	17	17
1998	Richard Borcherds	MR0843307	259	11	17
1998	Timothy Gowers	MR1201238	162	46	46
1998	Maxim Kontsevich	MR2062626	278	14	14
1998	Curtis T. McMullen	MR1312365	200	58	58
2002	Laurent Lafforgue	MR1875184	44	14	11
2002	Vladimir Voevodsky	MR1813224	125	14	14

2006	Andrei Okounkov	MR1758751	98	14	5
2006	Terence Tao	MR1646048	377	35	35
2006	Wendelin Werner	MR1879850	82	60	60
2010	Elon Lindenstrauss	MR2195133	58	37	37
2010	Ngô Bảo Châu	MR1923579	21	14	14
2010	Stanislav Smirnov	MR1851632	96	37	60
2010	Cédric Villani	MR1964483	390	82	82