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Science Librarians Analysis of the 2011 Nobel Prize in Physics: The Work of Saul Perlmutter, Brian P. Schmidt, and Adam G. Riess

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The Nobel Prize in Physics 2011 was awarded to scientists from two different research collaborations that independently and contemporaneously discovered from observations of distant supernovae that the universe's expansion is accelerating. One half of the prize was awarded to Saul Perlmutter and the other half jointly to Brian P. Schmidt and Adam G. Riess. The findings, first reported in 1998, shocked the cosmology community, as the prevailing theory at the time favored a 'closed' or 'steady state' universe, rather than one wherein the universe expands faster and faster, ultimately ending as a cold, dark, (largely) empty space. It was, perhaps, fortuitous that two independent groups came up with the same result using different methods, as it offered an immediate initial verification of the, at the time, very controversial results.

KEYWORDS Nobel Prize Physics 2011, astronomy, astrophysics, expanding universe, cosmology, Saul Perlmutter, Brian P. Schmidt, Adam G. Riess

INTRODUCTION

One of the long-standing, fundamental questions in cosmology is how the universe will end. To borrow from T. S. Eliot, will it be ‘with a bang or a whimper?’ It is hard to believe that it was only in the 1920’s, with the help of a new telescope at Mt. Wilson, that Edwin Hubble showed that the universe even extended beyond our own galaxy. He was able to resolve individual stars in other galaxies, and, using a ‘standard candle’ of Cepheid variable stars (they have a relationship between their brightness and period of rotation that allows one to determine their relative distances), determined a proportionality between a galaxy’s distance and its redshift (that is, how fast it is moving away from us). Hubble not only found that other galaxies exist, but that, contrary to prevailing wisdom, that the universe is expanding, and not in a ‘steady-state.’ Albert Einstein had applied his theory of general relativity to the universe in 1917 and found that a steady-state universe was unstable, so he introduced his infamous cosmological constant background energy term that could make the universe stable. Once the universe was found to be expanding, Einstein called his cosmological constant his worst blunder. However, it was to make a reappearance as a result of the work of Perlmutter, Schmidt, and Riess and their project teams, the Supernova Cosmology Project (SCP) and the High-z Supernova Search Team (High-z), respectively.

The measurement of astronomical distances by using Cepheid variable stars only works up to a certain distance, after which those stars become too dim to be resolved by our telescopes. This allows scientists to measure distances in the local part of our universe. However, in an effort to ‘see’ farther and farther away (and consequently, farther into the past, since light travels at a fixed speed, so light we see now may have left a galaxy a billion or more years ago), scientists sought a brighter ‘standard candle.’ One of the brightest objects in the universe is a supernova. This occurs, basically, when a star explodes (or sometimes, implodes), and a supernova can shine, for a few short weeks, brighter than an entire galaxy. A particular type of supernova, the Ia, is thought to occur when a white dwarf in a binary system accumulates enough material from its companion star to raise its temperature enough to ignite carbon fusion. This leads to a runaway nuclear fusion reaction.

Crucially, for this research, the type Ia supernovae are remarkably consistent in the characteristics of their explosion process, and they can be identified quite unambiguously. Adam Riess’ model that ‘standardized’ the type Ia light curves, enabling them to be used as standard candles was one of his important contributions to the Nobel Prize discovery. Since supernovae are so bright, this vastly increases the farthest distance scientists can see into the universe. The major drawback of this measuring stick is that explosions are pretty rare and impossible to predict. You might want to know the distance to a particular galaxy, but unless a highly cooperative star happens to go supernova (and the right type of supernova) while you are looking at it, you are out of luck. Even if you do happen to see the supernova occur, you have to catch it early in its ‘death cycle’ in order to get enough data to characterize it accurately. If only you could predict when a supernova was going to occur, or have enough ‘eyes’ on the universe to detect the beginnings of a supernova and train more telescopes on that part of the sky, you could start gathering data in time to take useful measurements.

Fundamentally, developing schemes for doing just that, identifying supernovae quickly, coordinating multiple astronomical instruments to take more detailed data, and analyzing that data, made the Nobel Prize winning discoveries possible. Early on in the project, the SCP would locate a candidate supernova and then have to call up and try to convince astronomers at one of the large observatories to give up their time and point the telescope at the point in space they needed to resolve. This was hardly an efficient, or reliable, way to collect data, but at the time, there was no way to predict the required months in advance that schedules were drawn up, when and where a supernova was going to occur. By vastly improving the processing power and harnessing new CCD camera technologies, Perlmutter was able to finally guarantee, statistically, that when his scheduled time on one of the major telescopes came up, he would have supernovae to image.

This is perhaps the first intrinsically e-science Nobel Prize, that is, a discovery that depends crucially on computing power, connectivity of that data, and real-time collaboration and coordination from scientists from around the globe. The two competing groups both developed the infrastructure and expertise to carry out the search for supernovae in far-off galaxies. In an interesting twist, in order to image the farthest off supernovae that would enable a definitive measurement of the history of the universe, the rival projects were simultaneously granted time on the Hubble Space Telescope (on alternate days). Since the HST is located in orbit, images can be collected without the blurring and complications of light having to traverse the atmosphere...fainter stars can be imaged with vastly more resolution than anything available from an Earth-based telescope.

The results of the HST observations were announced at the January 1998 American Astronomical Society meeting at a joint news conference for both collaborations. That was when the bombshell was dropped, not only is the universe not closed, or even static, but points are receding faster and faster from each other. Cosmologists have for many years tried to calculate the age of the universe. Prior calculations of the Hubble constant (the expansion rate of the universe) have resulted in predictions that the universe was younger than the earth itself (4 billion years), or, after some more fine tuning, that the universe was merely younger than some of the oldest stars (12 billion years).   Now, however, with an accelerating universe measured by these groups, an age of the universe greater than the age of the stuff in it could actually be verified. This resolved one of the more embarrassing predictions of cosmology, but at a high price.

Another fundamental question of cosmology has been how to 'weigh' the universe to determine whether it is open or closed. All the matter that cosmologists can find only yields about 30% of the critical mass needed to create the 'flat' universe we seem to be living in, and only about a sixth of that matter is what we can 'see,' the rest being 'dark matter' that we have not been able to detect, except through indirect means. We don't know what the properties of dark matter are, but we know from observations of galaxies that not only does it exist, but there is much more of it than there is of 'regular matter.' The result of this project, however, provided evidence that made this funny stuff called dark matter seem downright normal. Adam Riess' calculations of the matter content of the universe based on the data from this project within a standard cosmological model indicated not that there is very little matter in the universe, but that in fact, according to that standard model, there is a negative matter density...that is, the cosmological model only works if there is less than zero matter in the universe.

Obviously, the standard cosmological model could not be correct, and indeed, there was one parameter that could still be added, but which the scientific community had almost always set to zero shortly after Einstein called it his biggest blunder. Yes, the cosmological constant, which was thrown out of mainstream cosmology after it was found that the universe isn't static, reared its head again. According to the more inclusive theory, the critical density of the universe was still 1, and the matter density was still around 0.3, meaning the rest of the density comes from this 'cosmological constant' term, dubbed 'dark energy.' If scientists don't know what dark matter is (there are some theories, and, indeed, experiments to try and detect some of the proposed dark matter particles), they are completely stumped by dark energy...dark energy that makes up 70% of our known universe! Dark energy might be a property of the 'vacuum,' that is, empty space itself, or 'quantum fluctuations' in that vacuum, but theorists haven't been able to find any model that naturally provides a value close to a 70% critical density.

Not only have the discoveries of the SCP and High-z projects given us an idea of the history and likely future of the universe, they have made us question anew what the universe is fundamentally made of and how it works. Few Nobel Prizes have had such a transformative effect on our understanding of the universe and how it works. It has answered a fundamental question, and in the process opened up many more for scientists to investigate in the coming decades.

The seminal papers for the Nobel Prize are

Perlmutter, S. et al. (1999). Measurements of the cosmological parameters f and Λ from 42 high-redshift supernovae. (The Supernova Cosmology Project). *Astrophysical Journal* 517: 565 (1999).

Reiss, A. et al. (1998). Observational evidence from supernovae for an accelerating universe and a cosmological constant. *Astronomical Journal* 116: 1009-1038.

THE SCIENTISTS

Saul Perlmutter

Biography

Saul Perlmutter was born in 1959 in Urbana-Champaign, Illinois, and grew up in Philadelphia. His mother was a professor of social work at Temple, and his father a professor in chemical engineering at the University of Pennsylvania (Penn Engineering 2011). In an autobiographical interview for the Shaw Prize, Permutter describes that his grandparents immigrated to the United States from Eastern Europe, “part of a generation of poor but optimistic intellectuals, who expected that education and rationalism would build a better world.” (Perlmutter 2006). Growing up listening to their friends and socializing, he developed the desire “to know about all the universal ‘languages’ --music, literature, math, science, architecture, psychology.” (Perlmutter 2006). Perlmutter graduated from Harvard in 1981 and went to the University of California, Berkeley for graduate school, working under Richard Muller.

His interest in high-impact science was evidenced by his dissertation topic, searching for an 'invisible' companion star, Nemesis, which had been hypothesized as a potential cause for periodic (every 26 million years) asteroid storms in the inner planets. While at Lawrence Berkeley National Laboratory (LBNL), he began collaborating with Carl Pennypacker, developing software and hardware to locate and measure the properties of supernovae. In 1987 they began the project that would lead to the Nobel Prize, constructing a wide-field CCD camera and software that could search through 10,000 galaxies each night for prospective supernovae. The project was funded through LBNL's newly created Center for Particle Astrophysics. The project was not without its setbacks, as the first few years were plagued by software glitches and bad weather. By 1992, amid funding challenges due to a lack of results, Perlmutter was named the group leader and given a few more years to show the effectiveness of the approach. About that time, the group identified what was then the highest ever red-shift supernova (the farthest way). This was the turning point for the project, and the supernovae started rolling in, enough that Perlmutter was able to convince the Hubble Space Telescope Users Committee to give them observing time. With the assistance of the Hubble Space Telescope, Perlmutter's group was able to collect and analyze 42 supernovae to determine that the universe is accelerating in its expansion (Panek, 2011).

Perlmutter has remained at LBNL as a Senior Scientist and Group Leader, and Professor of Physics at University of California Berkeley. He continues to work on the Supernova Cosmology Project, as well as the Nearby Supernova Factory, which attempts to fine-tune the calibration of supernova properties by analyzing supernova at moderate distances, SNAP (the SuperNova/Acceleration Probe) a proposed next-generation space telescope, and BOSS (Baryon Oscillation Spectroscopic Survey), which will attempt to measure the effects of baryon acoustic oscillations in the primordial universe to try and characterize some of the properties of dark matter (Perlmutter 2011).

Other Awards

2011 Albert Einstein Medal

2007 Gruber Cosmology Prize

2006 Antonio Feltrinelli International Prize in Physical and Mathematical Sciences

2006 Shaw Prize in Astronomy

2005 Padova Citta Delle Stelle (Padua Prize)

2002 E.O. Lawrence Award in Physics (Department of Energy)

1996 Henri Chretien Award (American Astronomical Society)

Perlmutter is a member of the National Academy of Sciences and a fellow of the American Physical Society and the American Association for the Advancement of Science.

Publications

According to Web of Science results from a search conducted on November 11, 2011, Perlmutter has authored 120 documents, and has been cited 14,341 times since 1996. He has self-cited 484 times. With an average citation rate of 463.28 per year, he is the most highly cited author of this year's physics prize.

[Insert Figure 1]

His *h index* from Web of Science is 40, meaning of all the documents considered for the *h index,* 40 have been cited at least 40 times.

A graph of his publications over time, from Web of Science, shows the highest output during 2006 with 11 documents published. The next highest publication years are 1995, and 2009, with 9 documents each year.

[Insert Figure 2]

Scopus identifies 131 documents by Perlmutter, with the largest number of those documents being articles (90). He has a high number of conference papers (25), and review articles (14). He has most frequently published in *Astrophysical Journal Letters*, with 33 of his articles appearing there, and also in the *Proceedings of SPIE, the International Society for Optical Engineering,* with 17 articles each.

As mentioned above articles by Permutter are well cited. Also of special note are the large number of authors on most of his articles, a standard in cosmology fields. According to Scopus, Perlmutter's most frequent co-authors are Greg Aldering, and Peter E. Nugent, both located at Berkeley.

[Insert Figure 3]

The seminal paper for this award, Measurements of the cosmological parameters *f* and Λ from 42 high-redshift supernovae. S. Perlmutter et al. (The Supernova Cosmology Project), Astrophysical Journal, **517,** 565 (1999), is his most highly cited article, as one would expect, and has been cited 4,916 times with an average yearly citation rate of 378.15.

Brian P Schmidt

Biography

Brian Schmidt was born in Missoula, Montana, in 1967, the son of teen-age parents, who 'grew up together,' moving around frequently early in his childhood. His early life was spent in Montana and his later childhood was spent in Alaska. He enjoyed helping his father do his research, camping, and exploring nature, including the Northern Lights in Alaska. He attended college at the University of Arizona, where he came to the realization that astronomy is the one career he'd 'do for free.' He attended Harvard University for graduate school, receiving a PhD in 1993 for his work on Type II supernovae, under Robert Kirschner (Heard, 2001).

Having gotten married in 1992 to a doctoral student from Australia, and looking for positions in the same city for both he and his wife, he spent another two years at Harvard as a post-doctoral fellow before finding a permanent position at Mt. Stromlo in Canberra in 1994 (Panek, 2011).Once Mario Hamuy showed that Type Ia supernovae could be used as more accurate measuring sticks and Saul Perlmutter reported a process for finding far-off supernovae, Schmidt and Nick Suntzeff formed the High-Z Supernova search team, direct competition to Perlmutter's Supernova Cosmology Project (Schmidt, 2006).

At this time, the high-Z supernova search team was formed, a team that, contrary to the predominant model, attempted to run as a collaborative and not a top-down hierarchical project. Within a year, the team had found its first high-red shift supernova, beating the SCP's record (Panek, 2011). At that point the race was on to measure the acceleration of the universe. Having acquired their own time on the Hubble Space Telescope, the high-Z project collected and reported on 15 supernovae of their own at the famous 1998 AAS press conference (Panek 2011).

Beginning as a post-doctoral fellow at Mount Stromlo in 1995, Schmidt was named a research fellow in 1997 and a fellow in the Research School of Astronomy and Astrophysics of the Australian National University in 1999. In 2010, he was named a distinguished professor at the Australian National University and Fellow of the Australian Research Council. Currently, he continues to work on supernova physics as well as using Mount Stromlo's automatic telescope to study gamma ray bursts. He is also spearheading the SkyMapper project to build a telescope to comprehensively map the Southern Sky (Schmidt, 2011).

Additional Awards

2007 Gruber Prize for Cosmology

2006 Shaw Prize in Astronomy

2001 The Australian Academy of Science Pawsey Medal

2000 The Australian Government's Malcolm McIntosh Prize (Inaugural)

2000 Bok Prize for outstanding Astronomical Thesis, Harvard University

Brian Schmidt is a fellow of the (U.S.) National Academy of Science and the Australian Academy of Sciences.

Publications

According to Web of Science results, Schmidt has authored 173 documents, and has been cited 15,609 times since 1996. His *h index* from Web of Science is 53, meaning of all the documents considered for the *h index,* 53 have been cited at least 53 times.

[Insert Figure 4]

A graph of his publications over time, from Web of Science, shows the highest output during 2006 and 2007 with 17 articles each year.

[Insert Figure 5]

[Insert Figure 6]

Scopus identifies 126 documents by Schmidt , with the largest number of those being articles. He has a relatively low number of conference papers at 10. He has most frequently published in *Astrophysical Journal Letters*, with 45 articles, and *Astrophysical Journal*, with 20 articles.

According to Scopus, Schmidt's most frequent co-authors are Peter Challis, of Harvard, and Bruno Leibundgut, Technische Universitat Munchen.

As expected, the seminal paper for this award, Observational evidence from supernovae for an accelerating universe and a cosmological constant. Adam Riess et al. *Astronomical Journal,* **116**, 1009-1038 (1998), is his most highly cited article.

Adam G Riess

Biography

Adam Riess was born in 1969 in Washington, DC to a psychologist mother and engineer father. He grew up in Warren, New Jersey, displaying the inquisitiveness and talent that led to a Nobel Prize. "At 8, he and a sister built a tree-house and outfitted it with a basement and a working telegraph line...at 11, he was giving orders to his Radio Shack computer and, at 13, teaching an adult class in programming." (Anft, 2008). Despite his precociousness, his parents kept him and his sisters humble, making them work in his father's deli. The lesson being that, in order to do what you want in life, you have to work hard to have that opportunity.

Riess graduated from MIT in 1992 with a degree in physics and a minor in history. He gravitated toward cosmology because of the potential to answer fundamental questions, like the fate of the universe. Since technologies were starting to allow scientists to actually gather data relevant to those bigger questions, he saw it as a field where progress could be made, moving it from a speculative field to a data-driven one (Anft 2008).

As a result, Riess attended Harvard for graduate school, working for Robert Kirschner in collaboration with William Press. The topic of his research was measuring the distances to type Ia supernovae, exactly the measurement needed for answering cosmological questions. Riess' thesis on the Multicolor Light Curve Shape Method 'distinguished the effects of distance, dust, and dimness,' enabling type Ia supernovae to be used as standard candles. (Riess 2006) Indeed, his dissertation won the Trumpler Award from the Astronomical Society of the Pacific and Harvard University's Bart J. Bok Prize.

Upon graduation, Riess was recruited by Saul Perlmutter, but ended up working 'down the hill' in Berkeley on a Miller Fellowship, joining Brian Schmidt's high-Z supernova search team (Schmidt had also been a graduate student in Kirschner's research group). Riess led the data analysis of the supernovae identified by the high-Z group, and it was he that first discovered that according to the prevailing cosmological model, the universe had to have a negative mass density, and that a cosmological constant could explain the discrepancy between theory and data (Riess 2006)

In a widely reported anecdote, he had been writing up the results for the Nobel Prize winning paper in the weeks before the January 1998 American Astronomical Society Meeting. Coincidentally, he had also just gotten married, and before leaving on his honeymoon, he stopped to check email and found himself in the middle of a discussion by the work group of whether to include an announcement of a non-zero cosmological constant in their paper. "I cannot believe you are working on an e-mail," his new wife said. "Well, this is a really important one." "Oh, I think I'm going to be hearing this all the time." "No, no. This...you're not. This really is...this is the one." (Panek 2011, p. 160).

After finishing his fellowship at University of California Berkeley, in 1999, he joined the Space Telescope Science Institute (which manages the Hubble Telescope) as an Assistant Astronomer. There he said he was "still a junior guy, a largely unknown quantity. People might have been thinking: 'is he a one-hit wonder?'"Anft, 2008) But, Riess was far from done making important discoveries. The basis of the discovery of accelerating universe was the fact that distant supernovae were dimmer than what one would expect. However, there was still a possibility that some exotic effect was causing the dimming.

Riess decided to troll through old Hubble Space Telescope images, especially those of the Deep Field image. This was an experiment where the Hubble was pointed to a point in the universe and left there to collect light from the farthest distances, up to 10 billion light years away. But, the Deep Field only took one image, and several images were needed to plot the light curve of the explosion. However, looking through test image files (taken when doing diagnostic checks of the telescope), he was able to locate images of the supernova over several days. As a result he could determine the brightness and red-shift of this very old (10.2 billion years ago) explosion, and was able to show that it was actually brighter than expected, a deceleration of the universe before the current acceleration.

This finding was important for two reasons. First, a brighter supernova meant that the previous dimming effect was very unlikely due to exotic dust or some other material. If everything was dimmed by some interstellar/intergalactic dust, then the farthest off supernovae should be dimmed as well. Secondly, it fulfilled the expectation that when the universe was very young and the matter was all, relatively, close together, gravity actually dominated this 'dark energy' or cosmological constant and we had a decelerating rate of expansion (it was still expanding, but just not as fast as it is now). Riess was one of the first people to discover an accelerating universe, and was also the first to discover a decelerating universe as well. (Panek 2011, p 180).

Riess was named a Full Astronomer at the Space Telescope Science Institute in 2004, as well as a Professor of Physics and Astronomy at Johns Hopkins University. Currently, he is working on the SHOES project, which uses the Hubble Space Telescope to not only image far-off Cepheid variable stars (to calibrate distance scales more accurately) but also to search for the farthest off supernovae to help learn more about the properties of dark energy. He is also working on Pan-STARRS, a telescope to detect and identify Earth-approaching objects such as asteroids and comets, as well as transient phenomena such as supernovae (Riess 2011).

Additional Awards

Einstein Medal, 2011

Gruber Prize in Cosmology, 2007

Shaw Prize, Hong Kong, 2006

Raymond and Beverly Sackler Prize, Tel-Aviv University, 2004

Helen B. Warner Prize, American Astronomical Society, 2003

Bok Prize, Harvard University, 2001

Trumpler Award, Astronomical Society of the Pacific, 1999

Adam Riess was named a Fellow of the National Academy of Science in 2009, a member of the American Academy of Arts and Sciences in 2008, and was given a MacArthur Foundation ‘genius’ grant in 2008.

Publications

According to Scopus results, Riess has authored 110 documents, 50.9 % of those, 56 documents, have been published in *Astrophysical Journal Letters. Astronomical Journal* comes in second, with only 15 articles. He tends to mostly write articles, with only 11 conference papers listed in Scopus, and 10 review documents.

A graph of his publications over time, from Web of Science, (Figure 7) shows the highest output during 2008, with 10 documents published.

[Insert Figure 7 here]

Scopus reports that he has had 150 co-authors on papers, his most frequent co-author is Peter Garnavich, at the Harvard-Smithsonian Center for Astrophysics, with 40 co-authored documents. Riess has co-authored 28 documents with Schmidt.

Starting in 1995, Reiss had 22 citations to his work, to an astronomical 2,315 in 2010. However, that has declined so far in 2011, to 1,842. His articles receive an average 1040.47 citations per year, with an average per article of 184.25.

[Insert Figure 8]

Riess has been cited 9,726 times since 1996, with 110 documents in Scopus. His *h index* is equal to 47, meaning of the 108 documents considered for the *h index,* 47 have been cited at least 47 times. The seminal paper for this award, Observational evidence from supernovae for an accelerating universe and a cosmological constant. Adam Riess et al. *Astronomical Journal,* **116**, 1009-1038 (1998), has a total of 5,254 citations, with a yearly average of 375.29.

[Insert Figure 9]

He followed the above work with a number of studies to test the susceptibility of this measurement to contamination by unexpected types of dust or evolution. To this aim, Dr. Riess led the Hubble Higher-z Team beginning in 2002 to find 25 of the most distant supernovae known with the Hubble Space Telescope, all at redshift greater than 1. This work culminated in the first highly significant detection of the preceding, decelerating epoch of the universe and helped to confirm the reality of acceleration by disfavoring alternative, astrophysically-motivated explanations for the faintness of supernovae (Riess et al. 2004, ApJ, 607, 655). (http://www.stsci.edu/~ariess/)

Note: Every journal, proceedings, and magazine article that AIP (American Institute of Physics) has published by these Nobel Laureates is currently accessible free of charge at journals.aip.org/Nobel2011.html

Conclusion

Something short, 3-4 sentences, just to bring the paper to a close and reiterate the contributions they have made or how profound their discovery was.

ADDITIONAL READING

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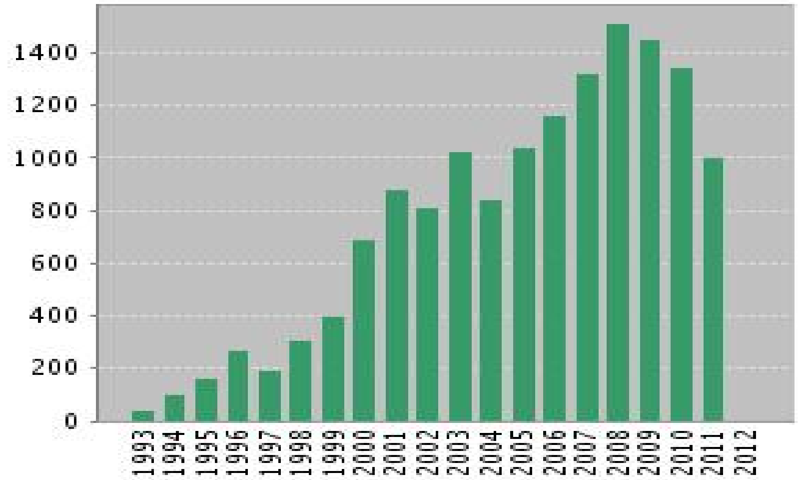
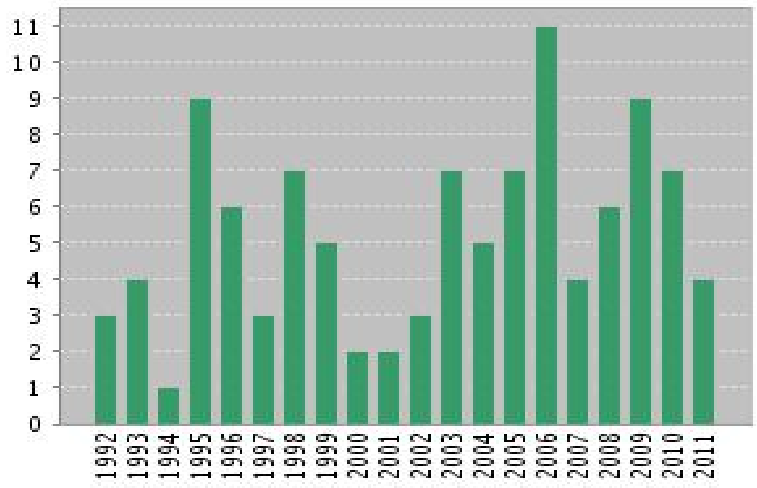
Schmidt, B. 2011. Brian P Schmidt. http://msowww.anu.edu.au/~brian. Accessed November 15, 2011.

Figure 1. Citations to Saul Perlmutter's papers over time



(Source: Web of Knowledge databases)

Figure 2. Number of Papers published per year by Saul Perlmutter



(Source: Web of Knowledge databases)

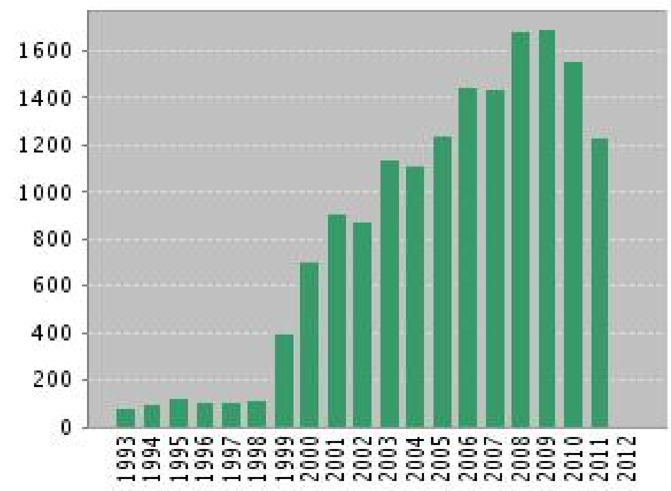
Figure 3. Perlmutter's Top Ten Articles by Total Citations

Article	Times Cited	Author Keywords
Perlmutter, S., Aldering, G., Goldhaber, G., Knop, R.A., Nugent, P., Castro, P.G., Deustua, S., Fabbro, S., Goobar, A., Groom, D.E., Hook, I.M., Kim, A.G., Kim, M.Y., Lee, J.C., Nunes, N.J., Pain, R., Pennypacker, C.R., Quimby, R., Lidman, C., Ellis, R.S., Irwin, M., McMahon, R.G., Ruiz-Lapuente, P., Walton, N., Schaefer, B., Boyle, B.J., Filippenko, A.V., Matheson, T., Fruchter, A.S., Panagia, N., Newberg, H.J.M., Couch, W.J. 1999. Measurements of Ω and Λ from 42 high-redshift Supernovae. ***Astrophysical Journal Letters*** 517 (2 Part 1): 565-586.	4852	Cosmology: observations; Distance scale; Supernovae:general
Perlmutter, S., Aldering, G., Della Valle, M., Deustua, S., Ellis, R.S., Fabbro, S., Fruchter, A., Goldhaber, G., Groom, D.E., Hook, I.M., Kim, A.G., Kim, M.Y., Knop, R.A., Lidman, C., McMahon, R.G., Nugent, P., Pain, R., Panagia, N., Pennypacker, C.R., Ruiz-Lapuente, P., Schaefer, B., Walton, N. 1998. Discovery of a supernova explosiona at half the age of the Universe. ***Nature*** *391* (6662): 51-54.	885	
Knop, R.A., Aldering, G., Amanullah, R., Astier, P., Blanc, G., Burns, M.S., Conley, A., Deustua, S.E., Doi, M., Ellis, R., Fabbro, S., Folatelli, G., Fruchter, A.S., Garavini, G., Garmond, S., Garton, K., Gibbons, R., Goldhaber, G., Goobar, A., Groom, D.E., Hardin, D., Hook, I., Howell, D.A., Kim, A.G., Lee, B.C., Lidman, C., Mendez, J., Nobili, S., Nugent, P.E., Pain, R., Panagia, N., Pennypacker, C.R., Perlmutter, S., Quimby, R., Raux, J., Regnault, N., Ruiz-Lapuente, P., Sainton, G., Schaefer, B., Schahmaneche, K., Smith, E., Spadafora, A.L., Stanishev, V., Sullivan, M., Walton, N.A., Wang, L., Wood-Vasey, W.M., Yasuda, N. 2003. New constraints on ΩM, ΩΛ and w from an independent set of 11 high-redshift supernovae observed with the Hubble Space Telescope. ***Astrophysical Journal Letters*** 598 (1 I):102-137.	737	Cosmological parameters; Cosmology: observations; Supernovae: general

Perlmutter, S., Gabi, S., Goldhaber, G., Goobar, A., Groom, D.E., Hook, I.M., Kim, A.G., Kim, M.Y., Lee, J.C., Pain, R., Pennypacker, C.R., Small, I.A., Ellis, R.S., McMahon, R.G., Boyle, B.J., Bunclark, P.S., Carter, D., Irwin, M.J., Glazebrook, K., Newberg, H.J.M., Filippenko, A.V., Matheson, T., Dopita, M., Couch, W. J. 1997. Measurements1 of the cosmological parameters Ω and Λ from the first seven supernovae at z ≥ 0.35. ***Astrophysical Journal Letters*** 483 (2 PART I):565-581.	692	Cosmology:observations; Distance scale; Supernovae:general
Bahcall, N.A., Ostriker, J.P., Perlmutter, S., Steinhardt, P.J. 1999. The cosmic triangle: Revealing the state of the universe. ***Science*** 284 (5419):1481-1488.	626	
Kowalski, M., Rubin, D., Aldering, G., Agostinho, R.J., Amadon, A., Amanullah, R., Balland, C., Barbary, K., Blanc, G., Challis, P.J., Conley, A., Connolly, N.V., Covarrubias, R., Dawson, K.S., Deustua, S.E., Ellis, R., Fabbro, S., Fadeyev, V., Fan, X., Farris, B., Folatelli, G., Frye, B.L., Garavini, G., Gates, E.L., Germany, L., Goldhaber, G., Goldman, B., Goobar, A., Groom, D.E., Haissinski, J., Hardin, D., Hook, I., Kent, S., Kim, A.G., Knop, R.A., Lidman, C., Linder, E.V., Mendez, J., Meyers, J., Miller, G.J., Moniez, M., Mourão, A.M., Newberg, H., Nobili, S., Nugent, P.E., Pain, R., Perdereau, O., Perlmutter, S., Phillips, M.M., Prasad, V., Quimby, R., Regnault, N., Rich, J., Rubenstein, E.P., Ruiz-Lapuente, P., Santos, F.D., Schaefer, B.E., Schommer, R.A., Smith, R.C., Soderberg, A.M., Spadafora, A.L., Strolger, L.-G., Strovink, M., Suntzeff, N.B., Suzuki, N., Thomas, R.C., Walton, N.A., Wang, L., Wood-Vasey, W.M., Yun, J.L. 2008. Improved cosmological constraints from new, old, and combined supernova data sets. ***Astrophysical Journal Letters*** 686 (2):749-778.	447	Cosmological parameters; Cosmology: observations; Supernovae: general
Alcock, C., Akerlof, C.W., Allsman, R.A., Axelrod, T.S., Bennett, D.P., Chan, S., Cook, K.H., Freeman, K.C., Griest, K., Marshall, S.L., Park, H.-S., Perlmutter, S., Peterson, B.A., Pratt, M.R., Quinn, P.J., Rodgers, A.W., Stubbs, C.W., Sutherland, W.1993. Possible gravitational microlensing of a star in the	357	

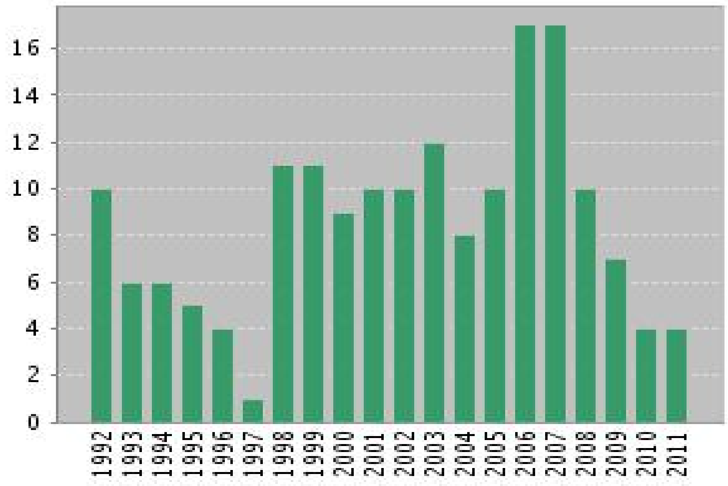
Large Magellanic Cloud ***Nature*** 365 (6447): 621-623.		
Bloom, J.S., Kulkarni, S.R., Djorgovski, S.G., Elchelberger, A.C., Côté, P., Blakeslee, J.P., Odewahn, S.C., Harrison, F.A., Frall, D.A., Filippenko, A.V., Leonard, D.C., Riess, A.G., Spinrad, H., Stern, D., Bunker, A., Dey, A., Grossan, B., Perlmutter, S., Knop, R.A., Hook, I.M., Feroci, M.1999. The unusual afterglow of the γ-ray burst of 26 March 1998 as evidence for a supernova connection. ***Nature*** 401 (6752): 453-456.	284	
Perlmutter, S., Turner, M.S., White, M. 1999. Constraining dark energy with type Ia supernovae and large-scale structure. ***Physical Review Letters*** 83 (4): 670-673.	257	
Sullivan, M., Borgne, D.L.E., Pritchet, C.J., Hodsman, A., Neill, J.D., Howell, D.A., Carlberg, R.G., Astier, P., Aubourg, E., Balam, D., Basa, S., Conley, A., Fabbro, S., Fouchez, D., Guy, J., Hook, I., Pain, R., Palanque-Delabrouille, N., Perrett, K., Regnault, N., Rich, J., Taillet, R., Baumont, S., Bronder, J., Ellis, R.S., Filiol, M., Lusset, V., Perlmutter, S., Ripoche, P., Tao, C. 2006 Rates and properties of type Ia supernovae as a function of mass and star formation in their host galaxies. ***Astrophysical Journal*** 648 (2 part I):868-883.	162	Distance scale; Galaxies: evolution; Supernovae: general; Surveys

Figure 4. Citations to Brian P. Schmidt's papers over time



(Source: Web of Knowledge databases)

Figure 5. Number of Papers published per year by Brian P. Schmidt



(Source: Web of Knowledge databases)

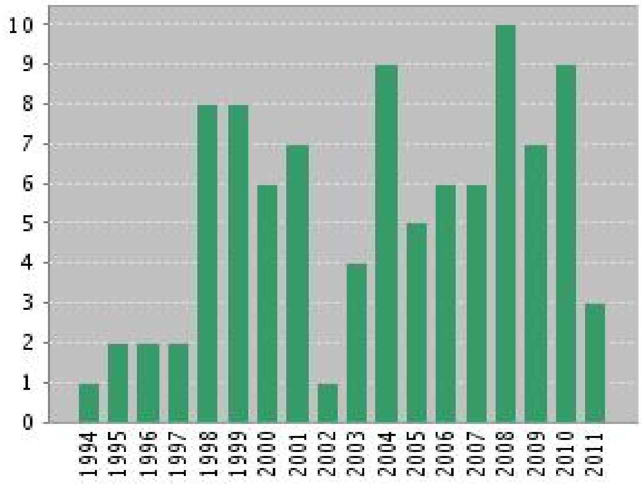
Figure 6. Schmidt's Top 10 articles by Total Citations

Article Title	Times Cited	Author Keywords
Riess, A.G., Filippenko, A.V., Challis, P., Clocchiatti, A., Diercks, A., Garnavich, P.M., Gilliland, R.L., Hogan, C.J., Jha, S., Kirshner, R.P., Leibundgut, B., Phillips, M.M., Reiss, D., Schmidt, B.P., Schommer, R.A., Smith, R.C., Spyromilio, J., Stubbs, C., Suntzeff, N.B., Tonry, J. 1998. Observational evidence from supernovae for an accelerating universe and a cosmological constant. ***Astronomical Journal*** 116 (3):1009-1038.	4803	Cosmology; General; Observations -supernovae
Tonry, J.L., Schmidt, B.P., Barris, B., Candia, P., Challis, P., Clocchiatti, A., Coil, A.L., Filippenko, A.V., Garnavich, P., Hogan, C., Holland, S.T., Jha, S., Kirshner, R.P., Krisciunas, K., Leibundgut, B., Li, W., Matheson, T., Phillips, M.M., Riess, A.G., Schommer, R., Smith, R.C., Sollerman, J., Spyromilio, J., Stubbs, C.W., Suntzeff, N.B. 2003. Cosmological results from high-z supernovae. ***Astrophysical Journal Letters*** 594 (1 I): 1-24.	884	Cosmological parameters; Cosmology: observations; Distance scale; Galaxies: distances and redshifts; Supernovae: general
Schmidt, B.P., Suntzeff, N.B., Phillips, M.M., Schommer, R.A., Clocchiatti, A., Kirshner, R.P., Garnavich, P., Challis, P., Leibundgut, B., Spyromilio, J., Riess, A.G., Filippenko, A.V., Hamuy, M., Chris Smith, R., Hogan, C., Stubbs, C., Diercks, A., Reiss, D., Gilliland, R., Tonry, J., Maza, J., Dressler, A., Walsh, J., Ciardullo, R. 1998. The high-Z supernova search: Measuring cosmic deceleration and global curvature of the universe using type Ia supernovae. ***Astrophysical Journal Letters*** 507 (1 PART I): 46-63.	592	Cosmology: Observations; Galaxies: Distances and redshifts; Supernovae: General; Supernovae: Individual (SN 1995K)
Garnavich, P.M., Jha, S., Challis, P., Clocchiatti, A., Diercks, A., Filippenko, A.V., Gilliland, R.L., Hogan, C.J., Kirshner, R.P., Leibundgut, B., Phillips, M.M., Reiss, D., Riess, A.G., Schmidt, B.P., Schummer, R.A., Chris Smith, R., Spyromilio, J., Stubbs, C., Suntzeff, N.B., Tonry, J., Carroll, S.M. 1998. Supernova limits on the cosmic equation of state. ***Astrophysical Journal Letters*** 509 (1 PART I): 74-79.	448	Cosmology: observations; Cosmology: theory; Supernovae: general

Garnavich, P.M., Kirshner, R.P., Challis, P., Tonry, J., Gilliland, R.L., Smith, R.C., Clocchiatti, A., Dlercks, A., Fllippenko, A.V., Hamuy, M., Hogan, C.J., Leibundgut, B., Phillips, M.M., Reiss, D., Riess, A.G., Schmidt, B.P., Schommer, R.A., Spyromilio, J., Stubbs, C., Suntzeff, N.B., Wells, L. 1998. Constraints on cosmological models from Hubble Space Telescope observations of high-z supernovae. ***Astrophysical Journal Letters*** 493 (2 PART II): L53-L57.	405	Cosmology: observations; Galaxies: distances and redshifts; Supernovae: general; Supernovae: individual (SN 1995K, SN 1997ce, SN 1997cj, SN 1997ck)
Wood-Vasey, W.M., Miknaitis, G., Stubbs, C.W., Jha, S., Riess, A.G., Garnavich, P.M., Kirshner, R.P., Aguilera, C., Becker, A.C., Blackman, J.W., Blondin, S., Challis, P., Clocchiatti, A., Conley, A., Covarrubias, R., Davis, T.M., Filippenko, A.V., Foley, R.J., Garg, A., Hicken, M., Krisciunas, K., Leibundgut, B., Li, W., Matheson, T., Miceli, A., Narayan, G., Pignata, G., Prieto, J.L., Rest, A., Salvo, M.E., Schmidt, B.P., Smith, R.C., Sollerman, J., Spyromilio, J., Tonry, J.L., Suntzeff, N.B., Zenteno, A. 2007. Observational constraints on the nature of dark energy: First cosmological results from the essence supernova survey. ***Astrophysical Journal*** 666 (2 I): 694-715.	375	
Riess, A.G., Nugent, P.E., Gilliland, R.L., Schmidt, B.P., Tonry, J., Dickinson, M., Thompson, R.I., Budavári, T., Casertano, S., Evans, A.S., Filippenko, A.V., Livio, M., Sanders, D.B., Shapley, A.E., Spinrad, H., Steidel, C.C., Stern, D., Surace, J., Veilleux, S. 2001. The farthest know supernova: Support for an accelerating universe and a glimpse of the epoch of deceleration. ***Astrophysical Journal Letters*** 560 (1 Part I):49-71.	344	
Barris, B.J., Tonry, J.L. Blondin, S. et al. Twenty-three high-redshift supernovae from the institute for astronomy deep survey: Doubling the supernova sample at Z >0.71,2. 2004. ***Astrophysical Journal Letters*** 602 (2 PART I): 571-594.	283	
Riess, A.G., Kirshner, R.P. Schmidt, B.P. and et all. 1999. BV RI light curves for 22 type la supernovae. ***Astronomical Journal*** 1117 (2): 707-724.	247	

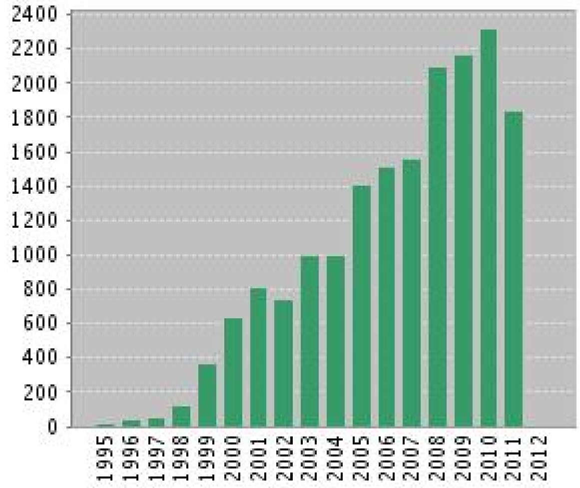
Fox, D.B., Frail, D.A., Price, P.A., Kulkarni, S.R., Berger, E., Piran, T., Soderberg, A.M., Cenko, S.B., Cameron, P.B., Gal-Yam, A., Kasliwal, M.M., Moon, D.-S., Harrison, F.A., Nakar, E., Schmidt, B.P., Penprase, B., Chevalier, R.A., Kumar, P., Roth, K., Watson, D., Lee, B.L., Shectman, S., Phillips, M.M., Roth, M., McCarthy, P.J., Rauch, M., Cowie, L., Peterson, B.A., Rich, J., Kawai, N., Aoki, K., Kosugi, G., Totani, T., Park, H.-S., MacFadyen, A., Hurley, K.C. The afterglow of GRB 050709 and the nature of the short-hard γ-ray bursts. (2005) ***Nature*** 437 (7060), pp. 845-850. Cited 240 times.	240	

Figure 7. Number of Papers published per year by Adam G. Riess



(Source: Web of Knowledge Databases)

Figure 8. Citations to Adam G. Riess's papers over time



(Source: Web of Knowledge databases)

Figure 9. Reiss Top 10 articles by Total Citations

Article Title	**Total Citations**
Riess AG; Filippenko AV; Challis P; et al. 1998. Observational evidence from supernovae for an accelerating universe and a cosmological constant ***Astronomical Journal*** 116 (3):1009-1038.	5254
Riess, A.G., Strolger, L.G. Tonry J; et al.Type Ia supernova discoveries at z > 1 from the Hubble Space Telescope: Evidence for past deceleration and constraints on dark energy evolution. 2004. ***Astrophysical Journal*** 607(2): 665-687.	1828
Tonry JL; Schmidt BP; Barris B; et al. Cosmological results from high-z supernovae. 2003. ***Astrophysical Journal*** 594(1):1-24.	910
Schmidt BP; Suntzeff NB; Phillips MM; et al. 1998. The High-Z Supernova Search: Measuring cosmic deceleration and global curvature of the universe using Type IA supernovae ***Astrophysical Journal*** 507 (1): p.46-63.	666
Adelman-McCarthy Jennifer K.; Agueros Marcel A.; Allam Sahar S.; et al. 2008. The Sixth Data Release of the Sloan Digital Sky Survey. ***Astrophysical Journal Supplement Series*** 175(2); 297-313.	580
Abazajian Kevork N.; Adelman-McCarthy Jennifer K.; Agueros Marcel A.; et al. 2009. The Seventh Data Release of the Sloan Digital Sky Survey.***Astrophysical Journal Supplement Series*** 182 (2): 543-558.	580
Riess Adam G.; Strolger Louis-Gregory; Casertano Stefano; et al.New hubble space telescope discoveries of type Ia supernovae at z >= 1: Narrowing constraints on the early behavior of dark energy. 2007. ***Astrophysical Journal***. 659(1):98-1212.	567
Garnavich PM; Jha S; Challis P; et al.Supernova limits on the cosmic equation of state. 1998. ***Astrophysical Journal*** 509(1):74-79.	495
Riess AG; Nugent PE; Gilliland RL; et al.The farthest known supernova: Support for an accelerating universe and a glimpse of the epoch of deceleration. 2001. ***Astrophysical Journal*** 560(1):49-71.	432

Wood-Vasey W. M.; Miknaitis G.; Stubbs C. W.; et al.Observational constraints on the nature of dark energy: First cosmological results from the ESSENCE supernova survey. 2007. ***Astrophysical Journal*** 666(2):695-715.	387