Einstein's landmark paper – 100 years on

100 years after publication, why is Einstein's "The Electrodynamic moving body" still so influential?

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In September 1905, Albert Einstein published a landmark paper, "Zur Elektrodynamik bewegter Körper" *("The Electrodynamic moving body") [1], concerning a revolutionary modification to the definitions of space and time and a relativistic approach to mechanics and electrodynamics. This was the first and most basic introduction of Einstein's Special Theory of Relativity. Although this paper was published over 100 years ago, it is still influential.*

Searching for citations

The influence of an article can be measured by the citations to it, so an analysis of the citations to Einstein's work was conducted to reveal why there is still so much interest in it. The Thomson Scientific resource *Web of Science*® was used as the source, since it provides over 100 years of consistently indexed, high quality citation data.

Searching for citations to Einstein's "*The Electrodynamic moving body"* (EMB) has proven complex. The original paper has been republished and translated many times, sometimes as part of collections. These factors cause variations and errors in the cited page, volume, and even author, such as instances where the editor of a collection is cited instead of Einstein. Another variation occurs when an author uses one of Einstein's equations and cites the page where the equation is located, instead of the first page of the article.

When cited references were found that were so vague or incomplete that it was impossible to definitely determine what was intended as the cited source, the citations were not included as part of this analysis.

Where can the citations be found?

As of September 2006, a total of 958 papers cited Einstein's "*The Electrodynamic moving body* ". Within *Web of Science*, these articles can be found — with some overlap of coverage — in three multidisciplinary citation indexes: *Science Citation Index Expanded*™, *Social Sciences Citation Index*®, and *Arts & Humanities Citation Index*®.

- 860 citations were found in *Science Citation Index Expanded*
- 149 citations are in *Social Sciences Citation Index*
- 99 citations are in *Arts & Humanities Citation Index*
- 798 of the papers are original articles, 69 are review articles and the remaining 91 are editorial material or letters

What do the citations tell us?

- **Einstein's article has been influential beyond his field of study:** Considering that Einstein's field of research is theoretical physics, it is surprising to see so many citations from the social sciences, arts and humanities. This shows that Einstein's work has been influential beyond his field of study, but it also indicates that a significant proportion of citations to Einstein's work are as a result of its sociological or historic significance.

- **Einstein's article is following an unexpected, exceptional citation trend:** An inspection of the yearly distribution of the citations as shown in *Figure 1* clearly shows that the recent citation rate is high and increasing at an exceptional rate. This is in stark contrast to the citation activity for this Journal, as shown in *Figure 2*. What is perhaps surprising is the relatively low citation rate after the initial publication of the article, with only 38 citing articles between 1905 and 1915.

Six of these articles were written by Einstein, and are the only articles where Einstein cited the EMB paper. This suggests that 10 years after the publication of the paper, Einstein's own research had progressed beyond the 1905 article.

Figure 1: *Citations to Einstein's "The Electrodynamic moving body"*

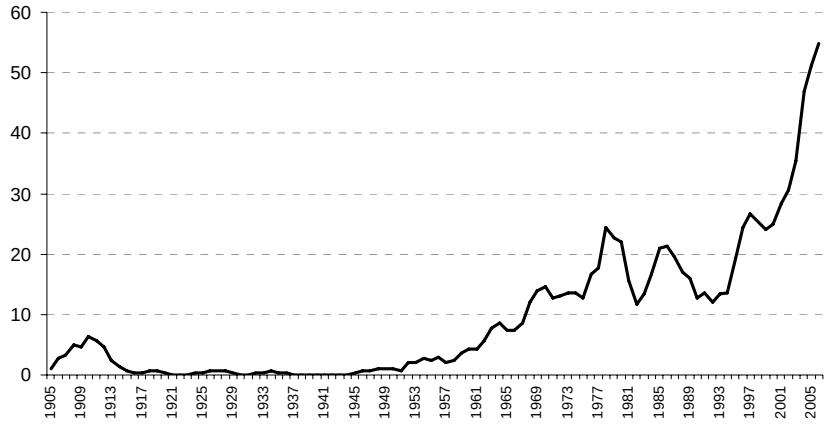
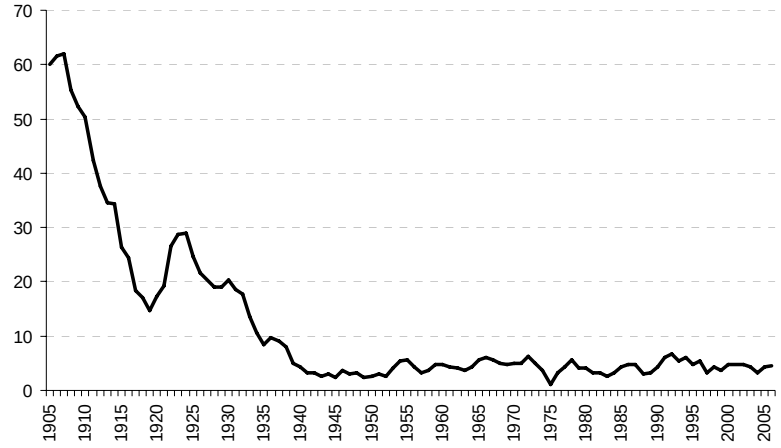


Figure 2: *Citations to all articles published in "Annalen Der Physik" in 1905, except those published by Einstein*



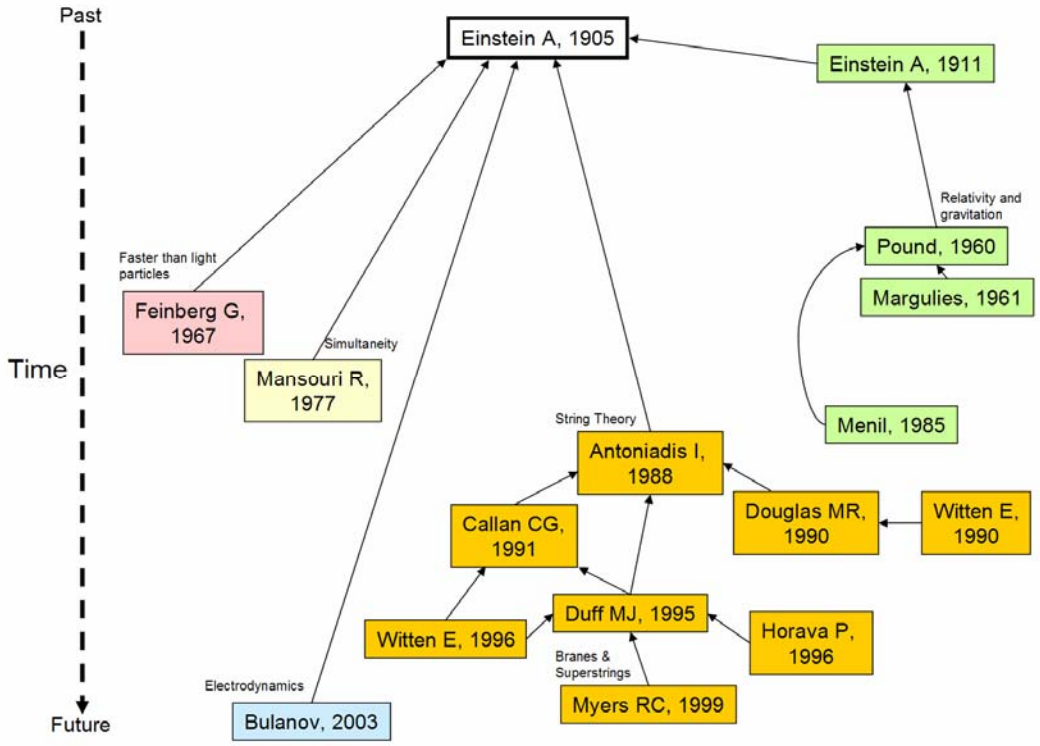
This is not the only Einstein paper to follow this unusual citation trend. Einstein published three more papers in *Annalen der Physik* in 1905. Two of these [3,4] discuss unrelated research, and the third [5] is an extension of the EMB article. All 3 papers follow roughly the same citation trend as the EMB paper, with increasing citation rates in recent years. Other papers by Einstein also follow this trend, but not all of them. For example, for the paper *"Quantum theory of radiation"* [6] the citation rate peaked in the mid-1990s and now has a decreasing citation rate.

An increasing citation rate has also been observed for other researchers publishing in the early part of the 20th century [7]. This suggests that although Einstein's papers are exceptional, they are not exclusively so.

Generations of influence

Figure 3 shows selected articles that cite Einstein's work, and which have in turn been highly cited. These articles represent highly influential original research that is based on Einstein's work. This process has been continued to show second and third generation citing papers.

Figure 3:
Selected highly cited articles that are citing Einstein's "T*he Electrodynamic moving body*"



It can be seen that the 1988 article by Antoniadis [8], which is concerned with String Theory, has also been highly influential and has in turn led to many new developments in String Theory and brane research (see Duff [9], Horava[10], Witten[11, 12] and Myers[13]). Many of these second generation papers do not directly cite Einstein. Yet they are indirectly influenced by his pioneering work.

How is Einstein influencing today's latest research?

Keyword and subject analyses

In order to discover more about how Einstein's work is influencing current research, the body of work citing Einstein has been limited to only those papers published since January, 2000.

Garfield's 1981 analysis [14] of Einstein's work showed that keyword occurrence can provide a valuable insight into the nature of the citing works. In this case the occurrences of author keywords have been used and the results are recorded in Table 1.

Table 1: Commonly occurring author keywords from papers that cite Einstein's *"The Electrodynamic moving body"* limited to papers published since January 2000

Author Keyword	Occurrence
Special Relativity	28
General Relativity	14
Inertia/Mass	9
Lorentz Transformation	7
Gravitation	6
Hyperbolic Geometry	6
Synchronization	5
Time dilation	5

An additional common keyword is that of Einstein's own name (6 occurrences). Although keywords associated with the current cutting edge in theoretical physics and cosmology [15], such as *String-theory*, *Solitons* and *Branes* are not present in this list, they are commonly found in the 2nd and 3rd generation of citing articles shown in Figure 3.

Table 2: Journal Subject categories of papers that cite Einstein's *"The Electrodynamic moving body"* limited to papers published since the year 2000

Journal Subject Category	Record Count
Physics, Multidisciplinary	117
Education, Scientific Disciplines	27
Physics, Mathematical	24
History & Philosophy Of Science	18
Optics	12
Engineering, Electrical & Electronic	11
Mathematics, Applied	10
Physics, Applied	10
Physics, Atomic, Molecular & Chemical	10
Multidisciplinary Sciences	8

Table 2 shows the journal categories for the same set of papers. It is clear that although the core discipline is the physical sciences, Einstein's work is also influential to the applied sciences and social sciences.

Why Einstein's citation rates are increasing

There are several reasons why the citation rate of Einstein's work continues to increase.

- **A rapidly growing field**

  During the 100 years since Einstein published his work, there has been a huge increase in the amount of research in this field, as well as a corresponding increase in the number of articles published each year. Even if the amount of interest in a particular work were to remain constant, the citation rate would be expected to increase, because the number of articles that could potentially cite the work has increased over time.

  One reason the amount of research in this field continues to grow is the research community's continuing and as yet incomplete search for a Unified Theory that will unify electromagnetic and gravitational theories. This is something that Einstein himself unsuccessfully worked on from 1925 until his death in 1955. Until a satisfactory Unified Theory is discovered to supersede Einstein's theories, it is likely that Einstein's early work will continue to be influential.

- **Changes in the way citations are written**

  There have also been many changes in the way that citations are written over time. On occasion a cited work would be simply mentioned in the body of an article without any formatted footnote or bibliography. However, today's stricter journal editorial policies have led to the inclusion of more material in formatted bibliographies. This has a positive effect on the citation rate.

- **Delayed impact**

  Marx [16] suggests that the amount of time before citations to an article reach their peak can be exceptionally long because the theories and predictions are so revolutionary that they cannot be fully tested until decades after publication. This would appear to be the case with Einstein's work and would also explain the reason for the relatively low citation rate in the 10 years directly after the initial publication.

- **Enhanced access to older information**

  Finally, Boyack & Backer [17] suggest that improvements to the ease of access to information has led to increased citation rates for older publications. The last few years have seen the

introduction of extended historical coverage of electronic resources, such as bibliographic databases and full text archives. The addition of over 100 years of backfiles to *Web of Science* is an example of this trend. Essentially, if researchers have easy access to a historical archive, they will use it.

My previous investigation (with R. Stembridge) [7] into an unrelated but highly cited article published in 1938 found that the majority of authors who cited the work used the print copy of the journal, as opposed to electronic archives or Web searching. However, most initially found this article via a reference in a more recent work. This suggests that the increased availability of citation databases and enhanced accessibility to citing material has improved the awareness of historic material as well as the ability to cite it.

- **The 100th anniversary of publication**
  Articles celebrating the centennial of Einstein's *Annus Mirabilis* probably helped increase the citation rate around the year 2005. However, the impact appears to account for only a small part of the increase in citation rate.

Conclusion:

It is without doubt that Einstein's article, "*The Electrodynamic moving body"* has been a highly influential work over the 100 years since it was published and continues to be influential today.

The celebration of the centennial of publication of Einstein's work has positively influenced the citation rates to the EMB paper. Additionally, improved visibility and improved accessibility to Einstein's works and the works that cite Einstein have also positively impacted the citation rates. However, these effects alone do not account for the very high citation rate experienced today.

It is clear that Einstein's work is still relevant and important to current researchers, and the basic principles outlined in the EMB paper are still of interest. Einstein's theories have yet to be superseded and his works have been influential beyond the core physical sciences.

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