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Gender Bias in Academic Authorship: A 24-Year Analysis of Physics Literature

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ABSTRACT

Women tend to comprise a waning proportion of prestigious positions in physics academia, a phenomenon known as *leaky pipeline*. In this paper, a possible contribution to *leaky pipeline* is examined through physics publications from 1998 to 2022.The proportion of female physicists employed at a research institution (provided by the American Institute of Physics) was compared to the sample proportion of female authors in six prominent physics journals. 100 articles were randomly selected in six sample cohorts in four-year intervals from which authors' genders were inferred. In each sample cohort, a significantly fewer proportion of female authors than employed female physicists was observed. The discrepancy between these values tended to increase over time. In addition, the proportions of female first authors and female authors in low- and high- cited quartiles of sampled literature were established. Using statistical significance testing, no difference was found for the proportions of sampled female first authors when compared to overall sampled female authors. In citation quartiles, no definitive trend in the over- or underrepresentation of female authors in highly-cited or less frequently cited literature was established. However, women were significantly overrepresented in the top citation quartile in 2010, and conversely, overrepresented in the bottom citation quartile in 2014. These findings strongly suggest that the representation of women in prestigious physics journals is much less than expected if gender played no role in publication frequency. Therefore, *leaky pipeline* is hypothesized to contribute to, and be impacted by, the underrepresentation of women in physics publications.

Introduction

The proportion of women in science, technology, engineering, and mathematics (STEM) fields has increased significantly in recent years, but disparities persist in physics. In 2017, 46% of all STEM PhDs were earned by women–the highest proportion in history—while only 18% of all physics PhDs were earned by women that same year (Porter, 2020). Moreover, further gender imbalance is apparent in high-level academic physics positions. As of 2022, only 13% of all Full Professors employed at research institutions in America identified as female (American Institute of Physics, 2022). These figures place physics as the STEM field with the least female representation even among mathematics, engineering, computer science, chemistry, and astronomy (Porter, 2020).

The underrepresentation of women in physics can be accredited to many factors, including publication performance. Scientometrics, the study and application of citation data, is now standard practice in evaluating the impact of authors' papers and institutions in scientific fields (Bornmann & Daniel, 2008). Data of an author's publication metrics, which is closely tied to career success, can be found via public internet search. The lack of female physicists employed in the field thus raises the question as to whether female physicists are systematically disadvantaged in academic literature.

Literature Review

The *Leaky Pipeline* Phenomenon

The underrepresentation of women in the field of physics is often attributed to the *leaky pipeline* phenomenon, defined by Ross et al. (2020) as the tendency for women to comprise fewer positions as prestigious career prospects are reached. With the track of full tenure professorship analogous to a literal leaky pipe, women tend to drop off or *leak* out in all levels of physics academia before arriving at the end of the pipe. According to authors in *Communication Physics*, *leaky pipeline* phenomenon stems from a combination of "unequal division of childcare, parental leave policies, career breaks, limited access to role models and resources" available to women (Kong et al., 2022). These barriers are hypothesized to affect female physicists throughout their educational years and post-doctoral careers. Social connectivity and therefore scientific collaboration are subsequently penalized.

Several phenomenological studies have attempted to investigate this phenomenon, which suggests that social isolation is perpetrated by educational sexism. A study conducted by Barthelemy et al. (2016) analyzing women's experiences in astronomy and physics found that the strong majority, or 17 of 21, female participants encountered hostile sexism, gendered microaggressions, or both by the time they entered their doctoral physics program. Further, a closer 2018 case study of two female astrophysics students expanded on the influence of these commonly experienced gender-based aggressions. Both women reported that their gender marked them as *outsiders* throughout their higher education, which significantly stunted their career advancement and collaboration networks (Gonsalves, 2018). Collaboration within the scientific community is vital to the careers of researchers, as it enhances the visibility of published literature and expands research opportunities. The covert sexism expressed in qualitative studies necessitates investigation of the role of gender in collaboration networks, work environments, research trajectories, and, consequently, publication metrics.

Gender Disparities in Physics Publications

As the study of scientometrics—the measurement of the impact of academic authors, journals, and/or articles—has advanced over time, the accessibility of scholarly literature index metrics has also proliferated. Nearly any simple Google search of an author yields scientometric data on his or her publications, which is closely tied to the identity of the author. In fact, bibliometric researchers Aksnes, Langfeldt, and Wouters (2019) assert that there is a direct relationship between career and publication performance: Scientometric index scores are used to evaluate research proposals, funding, and hiring of university faculty. These indices are calculated using various weightings of citation count, authorship order, and authorship frequency. Because publication performance impacts the position of scientific researchers, it can be hypothesized that the *leaky pipeline* is observable in physics literature.

Citation Count

A primary factor in publication success is citation count, or the number of citations received on a single scholarly article. In physics, as in most fields of science, studies suggest that gender disparities exist in scholarly citation count: Female-authored papers tend to receive fewer citations than male-authored papers. For instance, in a sample of nearly 150,000 astrophysics publications in *National Astronomy,* female astrophysicists received 10.4 +/- 0.9% fewer citations over their careers assuming gender played no role in citation frequency (Caplar et al., 2017). Not only do female-authored papers receive fewer citations altogether, but a 2022 study of 40,000 *Nature* publications concluded that female-authored papers were also less likely to be in the top-cited cohort (Ross et al., 2022). Citation count is analogous to the impact of a single article in the scientific community.

Thus, as women tend to comprise a small percentage of high-level university positions, they also tend to receive less recognition than those of higher status.

The overall lower status of women in physics research positions also impacts their collaboration networks. Numerous studies have established a connection between citation count and research collaboration. A study in *Scientometrics* found that more contributing authors in a publication–particularly international authors–led to greater citation counts (Puuska et al., 2014). Within the *Journal of Geophysical Research: Space Physics,* highly cited articles tended to have more than five contributing authors and more articles in their reference sections (Moldwin & Liemohn, 2018). While the number of authors alone does not determine the success of a publication, it indicates the presence of a beneficial citation network and audience for the published work. This network, however, is less accessible to female researchers: A 2014 study of over 25,000 research scientists' citation habits found that women were significantly less likely than men to be included in international collaboration (Kwiek & Roszka, 2021). Structural barriers, such as workplace toxicity and male-favoring culture, have greater detriments than social isolation–they may damage the careers of female physicists.

Productivity

According to a study published in *Physical Review E*, another major metric that quantifies the success of a physicist is his/her productivity, or cumulative contribution of scholarly research (Petersen et al., 2010). Several studies suggest, however, that gender accounts for differences in research productivity in STEM authorship. A bibliometric analysis of 74,000 World of Science publications found that female researchers tended to be 70% as productive as male researchers (Van Den Besselaar & Sandström, 2017). The existence of a gender productivity gap can be explained through the lens of male-centric workplace cultures. Insufficient parental leave policies and unequal division of child care may contribute to premature departure of female physicists in academia, consistent with that of *leaky pipeline*. Additionally, the systematic exclusion of female researchers' contributions may contribute to the group's overall productivity gap. In support of this explanation was a 2022 study across all scientific domains that found that women were significantly less likely than men to be accredited authorship at all career stages when they contributed to multi-authored research (Ross et al., 2022). In addition to systemic barriers, women's research may be undervalued and therefore less published.

Several studies have attempted to quantify whether these factors result in fewer female-authored physics publications than expected, but discrepancies exist in scholarly conversation. A complete bibliometric analysis of the American STEM database, arXiv, found that the proportion of female physics authorship across the database was approximately ten percent in 2020 and rising significantly slower than that of any other field (Mihaljević & Santamaría, 2020). The tendency of women to receive fewer authorship credentials than men, coupled with low female representation in arXiv, suggests that women may incur implicit bias in physics publications. However, a bibliometric analysis of publications in a peer-reviewed physics journal contrasts the results of Milhaljevic and Santamaria. A 2018 study of all publications in the *Journal of Geophysical Research: Space Physics* found that women tended to publish at the same frequency as their representation in the field (Moldwin & Liemohn, 2018). Differing publication review and editorial processes and acceptance rates likely impact the findings of these studies.

Authorship Order

Generally, in physics literature, the author whose name appears first, also referred to as the *first author*, is the author who is accredited with the greatest influence in a publication. First authorship is becoming so valuable to scientists' careers that many institutions are relying on first authorship frequency to determine productivity (Pritychenko, 2016). However, numerous studies suggest that women tend to sign as first author significantly less than expected given their representation in their respective fields. A three-year study following the bibliometric trends of 583 physics and astronomy faculty members, found that women were accredited first authorship significantly less than men, which furthers this idea (Dabas & Kumar, 2018). Given that the leading author is

often the most senior author, it is possible that men tend to receive first authorship because of their historic dominance in the fields. Assuming so, female first authorship should collectively increase over time. Across all scientific fields, however, gender disparities in authorship order do not appear to be closing over time. According to West et al., (2013), the gender gap in coveted scientific authorship positions remains. At least 5% fewer female first authors than female authors were published in the Web of Science database from 1990 to 2012. Again, the *leaky pipeline* is evoked: fewer female scientists tend to receive high-level university positions, such as tenured professor, and therefore are less likely to be named the lead author.

Research Inquiry

Bibliometric studies of STEM literature strongly suggest that women incur barriers to publishing successful, scholarly research in several domains—arguably the one of the most critical influences in academic position. However, few studies have specifically attempted to measure the proportion of female physicists in physics journals over time, especially across more than one journal. Moreover, no studies have measured a combination of scientometric metrics over time, including overall female authorship, female first authorship, and citation count of female-authored papers, nor compared these measured values to hypothesized values to evaluate statistical significance.

The absence of investigation of the *leaky pipeline* theory through female physicists' publication frequency thus raises the inquiry: To what extent are female physicists under-published in American physics journals when compared to their overall proportion in the field? Secondarily, to address the specific bibliometric trends of citation count, productivity, and first authorship, a second question is posed: What are the trends in female authorship, female first authorship, and citation count in American Physics Journals from 1998 to 2022?

Methodology

Overview

The purpose of this study is to determine whether female physicists publish significantly less than their overall proportion in the field, identify whether further discrepancies exist between the overall proportion of female authors and first authors, and identify whether females tend to author a significantly different proportion of high- or low-cited literature than expected. The study will calculate these metrics from 1998 to 2022 in four-year intervals to determine whether the hypothesized gap between female physicists and female authors is changing over time.

Throughout this study, the *overall proportion of female physicists*, *expected proportion of female authors*, and *hypothesized proportion of female authors* will refer to the proportion of female physicists employed at a research institution in the United States, as reported by the American Institute of Physics (AIP). The AIP Statistical Research Center has published values for the proportion of female physicists between 1998 and 2022, as shown in Table 1, such that they can be compared to the sample proportion of female authors for each corresponding data collection year.

Table 1. Expected Values for Proportion of Female Authors in Physics Journals (p_0).

Year	Proportion of Female Physics Faculty (p_0)
1998	10.75%
2002	12.60%
2006	13.6%

2010	16.80%
2014	18.80%
2018	20.80%
2022	21.60%

Note. Adapted from American Institute of Physics Statistical Research Center (2023).

The values were averaged across all research positions, including Full Professor, Associate Professor, Instructor/Adjunct, and Other Ranks, because position title does not definitively determine research output. All physicists who are employed at a research institution are required to publish or contribute to published research, and all physicists in this study were employed at a research institution. Thus, the proportion of female authors in physics journals is hypothesized to be equal to the proportion of employed female physicists assuming that females publish at the same frequency as their overall representation in the field.

Data Collection

To estimate the proportion of female physicists in American physics journals, a secondary data analysis of six prominent American physics journals was conducted. The journals selected included *The Journal of High Energy Physics, Physical Review Letters, Physical Review A, Physical Review B, Physical Review C*, and *Physical Review D.*

These journals comprised the top-six US-based physics journals as of 2023, as reported by Google Scholar via journal impact factor and h5-index. Journals that were strictly astrophysics were not included, as the AIP categorizes astrophysics as its own field with a significantly different gender distribution than physics. Thus, if astrophysics journals were included, the validity of subsequent statistical tests would be compromised. However, nearly every field of physics was represented in the selected six journals, including high energy, atomic, molecular, optical, quantum, condensed matter, material, nuclear, particle, field, gravitation, and cosmology physics. As such, the sample of authors in this study closely represents the field of physics as a whole.

Sampling

Seven stratified random samples were taken from the listed six physics journals, with the number of articles selected per journal per year proportional to the number of articles published per journal per year. The number of articles sampled per journal per year was calculated by the following equation:

$$\frac{N\ of\ articles\ published\ in\ Journal\ A}{Total\ N\ of\ articles\ published\ in\ all\ journals} \times 100$$

The sample years comprised seven cohorts, beginning in 1998 and separated by 4-year intervals ending in 2022. For each cohort, 100 articles were randomly selected, distributed by journal by the equation above. Every article in each journal was numbered and selected via a random number generator. Errata, publisher's notes, comments, and replies were not included in the sample as they did not qualify as original research.

The number of authors, number of female authors, gender of first listed author, and citation count were recorded and stored in Microsoft Excel sheets for selected articles.

Disambiguating Gender

Determining the probabilistic gender(s) of the author(s) in a selected article began with a simple inspection of first and middle names. Individuals listed under a definitively masculine or feminine name, such as *John* or *Grace*, were automatically assigned a gender. If a first name was listed but not identifiable, then the name was

entered into Gender API, a gender disambiguation software, and assigned a gender with at least 95% confidence. If 95% confidence was not achieved, the process followed that of authors with only initials and last names.

Most authors in this study were listed with first and/or middle initial(s), which prompted further investigation. Determining these authors' genders began with a simple Google search of the listed name with keywords such as *physics* or *physicist*. Then, websites such as Google Scholar, InspireHEP, ResearchGate, and Scopus Preview and other author identification websites were used to generate an image and/or first name of the author that corresponded with a gender. If the simple search did not yield an identifiable first name and/or photo, then a second Google search of the author's listed name followed by their institution name and key word was performed. The same websites were again used in addition to websites of author's institutions to generate a photo and/or first name. Authors' identities were cross-referenced with their corresponding institutions and period of publication to ensure accurate identification. Figure 1 displays the process used to identify authors' probabilistic genders.

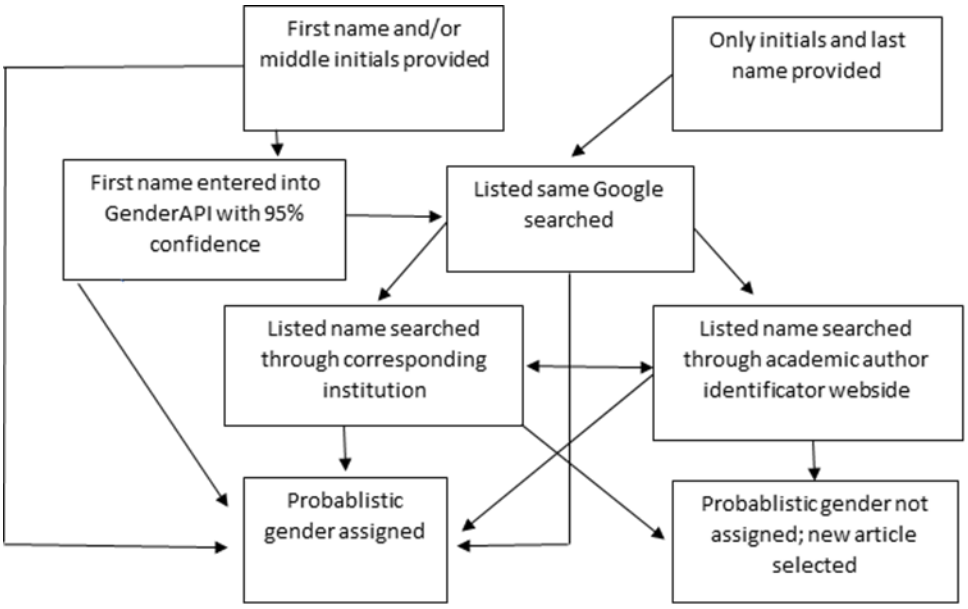

Figure 1. Gender Disambiguation Process.

If several Google searches did not yield an identifiable photo or first name of one or more authors in an article, then the article was excluded from the study and replaced by another article using a random number generator. Articles were not selected more than once per sample cohort per journal. It is important to note that the purpose of this study was to determine the probabilistic proportion of female authorship in physics journals; thus, if an individual author appeared more than once in various articles, journals, or time intervals, it was acceptable to the study.

Statistical Analysis

Overall Authorship

One Sample Z-Test: To determine whether the proportion of female physicists in physics journals was significantly less than the proportion of female physicists, a one-sided, one-sample z-test was performed. The one-sample z-test assumes that the population standard deviation is unknown and must be estimated from sample

data, which is appropriate as the AIP does not report standard deviation. Further, utilizing one-sided tests provided p-values only to the left of the hypothesized distribution, which improved the power of the significance test. The equation governing the z-statistic of the statistical test is as follows:

$$z = \frac{p - p_0}{\sqrt{\frac{p_0(1 - p_0)}{n}}}$$

Where p is the sample proportion of female authors, p_0 is the hypothesized proportion of female authors, and n is the total number of authors in the given sample.

Linear Regression Test: To determine whether the increase in female physics authors over time was significantly different than the increase in female physicists over time, two linear regression tests were performed. The linear regression tests determined the slope of the best-fit lines of proportion of females (y-axis) over time (x-axis) assuming a linear relationship between the two variables. The slopes were calculated within 95% confidence intervals. If the slopes within the 95% confidence intervals did not overlap, they were considered statistically different at the α=0.05 level.

Additionally, the coefficient of determination, r^2, was calculated for both distributions to describe the extent of the influence of time on the increase of female physicists and increase of female physics authors, respectively.

First Authorship

To determine whether the proportion of female first authors was significantly different than the overall proportion of female authors, a two-sided, one-sample z-test was used. The two-sided test allowed for a comparison of the two values on both sides of the hypothesized distribution, which was useful in this case as the proportion of female first authors was not always less than the proportion of female authors. The same z-statistic formula given in the overall authorship z-test was used, but with p equal to the sample proportion of female first authors, p_0 equal to the sample proportion of female authors, and n equal to the total number of first authors in a given sample.

Citation Count

To determine whether females tended to be over- or underrepresented in highly cited and less frequently cited literature, the 100 articles sampled per year were organized into quartiles based on citation count. Papers that received at or above the top twenty-five percent of citations per yearly sample were considered in the third quartile sample, Q3, and papers that received at or less than the bottom twenty-five percent of citations per yearly sample were considered in the first quartile sample, Q1. To determine whether female-authored papers were significantly over- or underrepresented in both the top (Q3) and bottom (Q1) citation quartiles, both one-sided and two-sided one-sample z-tests were performed, with p equal to the sample proportion of female authors in a given quartile, p_0 equal to the sample proportion of female authors, and n equal to the total number of authors in a given quartile.

Results

Overall Authorship

Over the course of the 24-year journal analysis, 2,472 authors were identified as male or female. The average sample size was 353 authors per yearly cohort, with the least sampled authors being 311 in 2002 and the greatest

being 387 in 2014 and 2022. For every cohort, the sample proportion of female physicists was extremely significantly less than ($p << 0.01$) the hypothesized proportion given by the overall proportion of employed female physicists. Table 2 presents the sample proportions and p-values when tested against the null hypothesis.

Table 2. Sample and Hypothesized Proportions, 1998 to 2022.

Year	Sample Size (n)	Sample Proportion (p)	Hypothesized Proportion (p_0)	P-Value
1998	324	0.0623	0.1075	0.00431
2002	311	0.0611	0.126	0.00028
2006	344	0.0785	0.136	0.00121
2010	347	0.0922	0.168	0.00008
2014	387	0.0827	0.188	0.00000
2018	372	0.0941	0.208	0.00000
2022	387	0.0775	0.216	0.00000

Further, as the years after 1998 increased, the z-statistics and p-values also decreased. The only exception to this pattern appeared in 2006, where the p-value increased from 0.00028 in 2002 to 0.00121. Both values, however, were still highly significant. Generally, the sample proportion of authors deviated further from the expected proportion each year. Figures 2 and 3 display the p-values and z-scores, respectively, over the 24-year interval.

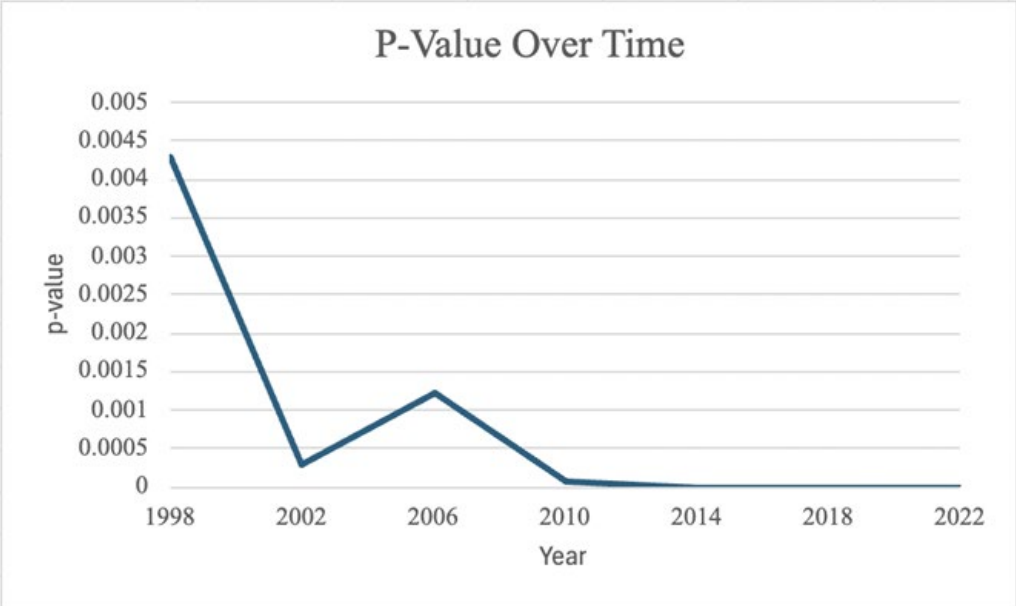

Figure 2. P-value by Year.

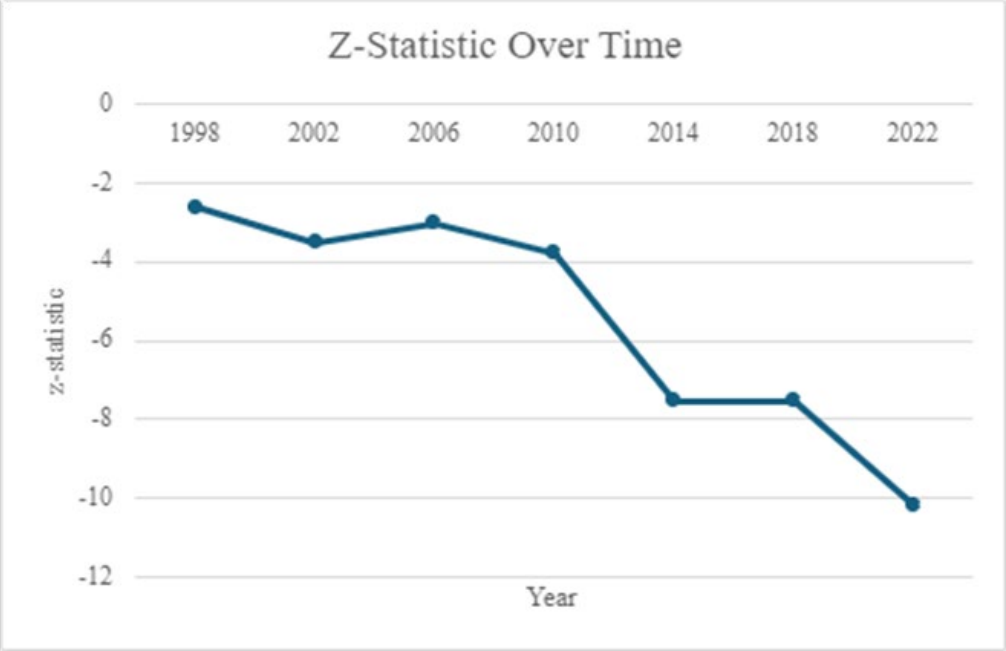

Figure 3. Z-statistic by Year.

Because the p-value and z-statistic tended to deviate further from the mean each year, a gap between the observed and expected proportions of female authors emerged and widened. Figures 4 and 5 illustrate the difference between the two groups.

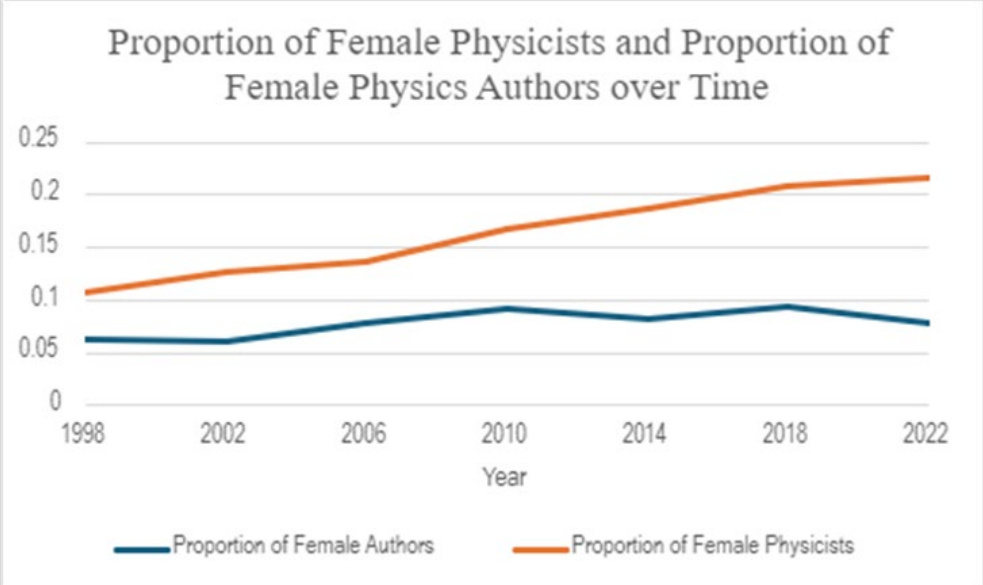

Figure 4. Proportions of Female Physicists and Female Physics Authors over Time.

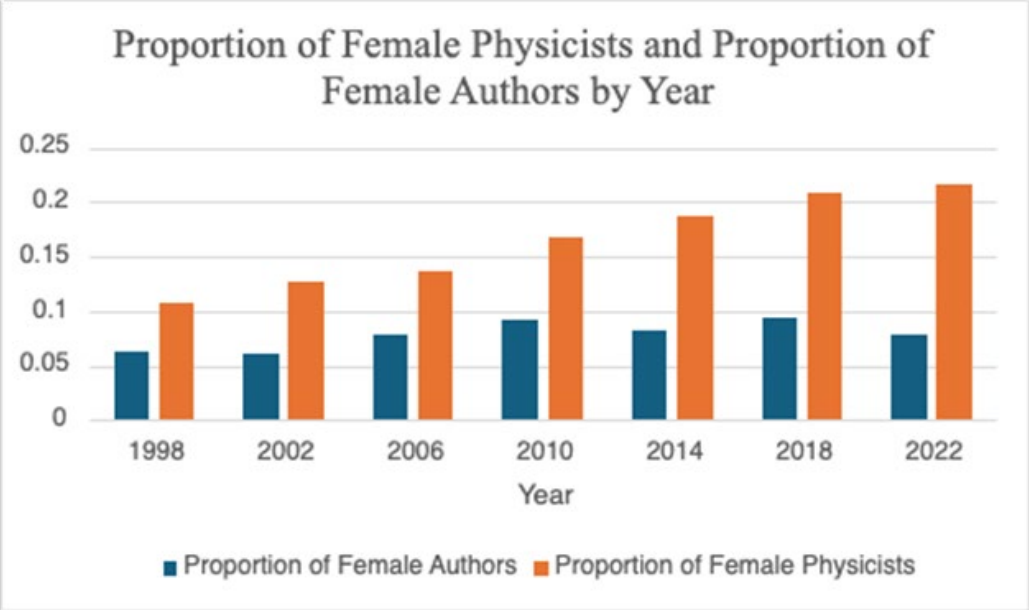

Figure 5. Difference in Proportions of Female Physicists and Female Physics Authors by Year.

To determine the statistical significance of the increase in proportions over time, two linear regression tests were performed, summarized in Table 3. While the graph of the proportion of female physicists in the US from 1998 to 2022 increased significantly over time ($p < 0.0001$), the graph of the proportion of female authors in US physics journals from 1998 did not increase significantly over time ($p=0.0882 > \alpha=0.05$). Additionally, within 95% confidence ($p << 0.05$), the average proportion increase of female authors per year was significantly different than that of female physicists; the observed slope p was much less than the expected value p_0. Comparing the coefficients of determination, time was a much greater explanation of the increase in female physicists than that of female physics authors. The coefficient of determination of the graph of female physicists was 0.983, more than twice as great as that of female physics authors, with a coefficient of 0.472.

Table 3. Linear Regression of Observed and Hypothesized Proportions of Female Physics Authors Over Time.

	Slope (%/yr.)	r^2	F	p-value
p	0.001034 ± 0.0004891	0.472	4.496	0.0882
p_0	0.004835 ± 0.0002832	0.9831	291.4	<0.0001

First Authorship

To determine whether female first authors were significantly over- or underrepresented in each yearly sample, one-proportion, two-sided z tests were performed. Utilizing the sample proportions of female physics authors as a baseline (p_0), females did not tend to be listed as first author significantly more or less frequently than their overall publication frequency. Table 4 displays the sample proportions p of female first authors and corresponding p-values when tested against the sample proportion of overall female authors. Notably, single-authored papers were not included in this sample, as authorship order was irrelevant in these instances.

Table 4. First Authorship by Gender, 1998 to 2022.

Year	Fem. First	Male First	Tot. First	Fem. First /Tot. First (p)	All Fem./All Tot. (p_0)	P-Value
1998	3	85	88	0.0341	0.0623	0.2737
2002	6	84	90	0.0667	0.0611	0.8245
2006	7	82	89	0.0787	0.0785	0.9944
2010	6	91	97	0.0619	0.0922	0.3023
2014	11	86	97	0.1130	0.0827	0.2786
2018	9	80	89	0.1010	0.0941	0.8236
2022	8	87	95	0.0842	0.0775	0.8071

Citation Count

As displayed in Tables 5 and 6 and Figure 6, citation count did not exhibit a clear trend between 1998 and 2022, but rather oscillated between proportional female over- and underrepresentation in the first and third citation quartiles. There was no statistical difference between the hypothesized and observed proportions of females in Q1 or Q3 except for in 2010 and 2014. In 2010, a significantly greater proportion of Q3 authors than expected were women ($p=0.0454 < \alpha=0.05$), and in 2014, a significantly greater proportion of Q1 authors than expected were women ($p=0.0077 < \alpha=0.01$).

Table 5. Proportion of Female Authors in Top-Cited (At/Above Third Quartile) Physics Articles, 1998 to 2022.

Year	Prop. Fem. Q3 (p)	Prop Fem. Tot. (p_0)	n	P-Value (one-sided)	P-Value (two-sided)
1998	0.1132	0.0623	53	0.0626	0.1252
2002	0.0896	0.0611	67	0.1655	0.3309
2006	0.1150	0.0785	113	0.0746	0.1491
2010	0.0375	0.0922	80	0.0454	0.0908
2014	0.0496	0.0827	121	0.0930	0.1861
2018	0.1111	0.0941	126	0.2566	0.5131
2022	0.1026	0.0775	117	0.1554	0.3107

Table 6. Proportion of Female Authors in Least Cited (At/Below First Quartile) Physics Articles, 1998 to 2022.

Year	Prop. Fem. Q1 (p)	Prop. Fem. Tot. (p0)	n	P-Value (one-sided)	P-Value (two-sided)
1998	0.0536	0.0623	56	0.3935	0.7869
2002	0.0694	0.0611	72	0.3838	0.7676
2006	0.0405	0.0785	74	0.1121	0.2242
2010	0.1196	0.0922	92	0.1818	0.3637
2014	0.1642	0.0827	67	0.0077	0.0154
2018	0.0928	0.0941	97	0.4822	0.9645
2022	0.0877	0.0775	114	0.3416	0.6832

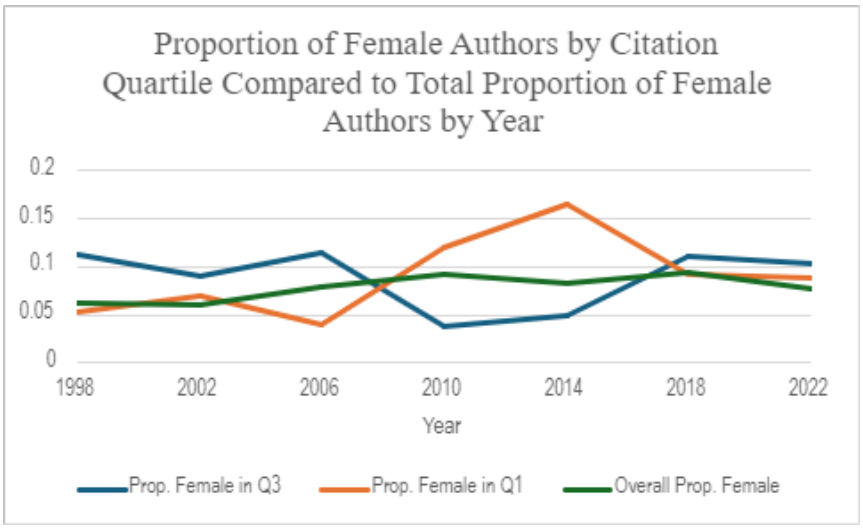

Figure 6. Proportion of Female Authors per Citation Quartile per Year.

Discussion

Overall Authorship

The statistically significant discrepancy ($p<<0.01$) between the proportion of female physicists and the observed proportion of female physics authors between 1998 and 2022 strongly suggests that female physicists do not publish literature at the same proportion as their representation in the field. This finding directly contrasts that of Moldwin and Liemohn (2018) in the *Journal of Geophysical Research: Space Physics*, which found that women tended to publish at the same frequency as their representation in the field. Thus, it can be suggested that the trends in female authorship established by Moldwin and Liemohn are applicable to that of the *Journal of Geophysical Research: Space Physics*, but not generalizable to that of physics journals as a whole. Moreover, the low proportion of female physics authors established in this study supports that of Mihaljević and Santamaría (2020), which found a low proportion of female physics authorship in the arXiv database. Statistical tests between the proportion of female physicists and female physics authors, however, demonstrate that the low proportion of female physics authors in this study cannot be attributed to the pre-existing, low proportion of women in the field.

Leaky Pipeline Phenomenon

While the state of gender equality in physics faculty membership appears to be improving linearly, significantly fewer women than expected are recognized in the scholarly paradigm. As expressed by Asknes et al. (2019), there is reason to hypothesize a strong connection between female physicists' publication frequency and the *leaky pipeline* phenomenon. Publication metrics are used to determine salary, hiring, and grants of physics researchers, which penalizes under-published female researchers. Women then tend to be placed in positions of lower status and thus lower research output, which perpetuates a vicious cycle. Building on the conclusions of Asknes et al., Van Den Besselaar and Sandström (2017) found that a large proportion of productivity differences in male and female scientific researchers could be attributed to the fact that males tended to hold higher univer-

sity positions. The widening gap between the proportion of female physicists and female physics authors established in this study thus suggests that the *leaky pipeline* phenomenon is both an antecedent to, and consequence of, disparities in physics literature.

First Authorship

No significant difference between the proportion of female physics authors and female first authors in physics journals was observed. This finding diverges from that of Dabas and Kumar (2018), which concluded that female astrophysicists and physicists tended to sign as corresponding author more frequently than first author. However, considering the differences in the values tested against in this study, there is strong evidence for the concurrence of *leaky pipeline* in this finding. In the Dabas and Kumar study, the astrophysicists and physicists sampled from were done so from research institutions, which were not disambiguated by prestige. Conversely, this study sampled from six physics journals of relatively high prestige. The female physicists published in these journals therefore comprised a cohort of top-performing female physicists. These physicists represent the small proportion that have nearly surpassed, or completely surpassed, the *leaky pipeline.* Testing this proportion of female authors against the proportion of female first authors subsequently yielded no significant difference between the two values.

Citation Count

No definitive trend in the over- or underrepresentation of female authors in highly cited articles or low-cited articles was established, although females were significantly overrepresented in the top citation quartile in 2010 and, contrarily, overrepresented in the bottom citation quartile in 2014.

The overrepresentation of women in highly cited literature in 2010 is supported by the findings of Chan and Torgler (2020), which found that top-cited authors in several fields tended to be disproportionately female when compared to overall female authorship rates. This finding implies that top female scholars in physics perform higher than their male counterparts. However, most female physics authors remain over-represented in mid- to lower citation quartiles.

Conversely, the overrepresentation of female authors in least-cited articles may be attributed to the lack of female physicists' access to citation networks. Kwiek and Roszka (2021) concluded that female STEM authors were less likely to be included in international collaboration networks, subsequently penalizing this group's citation metrics. Moreover, the general lack of female representation in physics journals and *leaky pipeline* phenomenon is likely to contribute to an over-representation of women in least-cited physics literature.

Limitations

The parameters of this study present several limitations. Primarily, the six physics journals sampled were not discerned by prestige. Although the journals were relatively close in h-index and impact factor, female authorship in physics journals varies based on the journal's peer review process and acceptance rate. Three journals sampled from in this study, *Physical Review A*, *Physical Review C*, and *Physical Review Letters,* were found to have differing proportions of female authorship, with the most prestigious journals corresponding to the lowest female authorship (Ross et al., 2020). Stratified random sampling may have skewed the influence of one journal's female authorship rate. *Physical Review B* tended to publish the most articles per year and was thus sampled from the most in this study. However, no studies have quantified the proportion of female authorship in this journal and therefore the consequences of stratified random sampling remain relatively disambiguated.

Further, the six physics journals sampled were categorized by high h-index and journal impact factor scores and thus represent journals of high prestige. Considering the findings of Ross et al., (2020) which found lower rates of female authorship in high-prestige physics journals, the female authorship rates in these journals are likely lower than less prestigious journals.

Additionally, averaging the proportions of female physics faculty members across all positions potentially creates a confounding variable. As the *leaky pipeline* phenomenon describes, the proportion of female faculty tends to dwindle as prestigious positions are reached. Therefore, in this average proportion of faculty, there is an over-representation of women in positions such as Assistant Professor as opposed to Full Professor. This lack of differentiation in scholarly positions assumes that authorship frequency is not impacted by faculty position. As previously discussed, Van Den Besselaar and Sandström (2017) found this not to be the case, as a large proportion of publication frequency differences in male and female researchers is due to the higher status of men in academia. Therefore, statistical significance between authorship and faculty membership values is likely heightened. The measured proportion of female physics authors in this study is most likely representative of that of the proportion of female Full Professors considering these individuals' prestigious scholarly status.

Conclusion

This study found that the proportion of female authors in American physics journals was significantly less than, and increasing significantly less than, the proportion of female physicists employed at American research institutions between 1998 and 2022. The existence and increase in discrepancy between these two values implies that a vicious cycle may be present in physics academia. Poor publication metrics penalize female physicists' career mobilities. Women then tend to be placed in positions of lower status and research status, which again perpetuates the observably low proportion of women in physics journals. This hypothesized vicious cycle corresponds with *leaky pipeline* phenomenon, as it prevents women from reaching highly coveted positions in physics academia.

Future Directions

Because of the limited sample size in this study, a more extensive study of female physics researchers' first authorship and citation count tendencies is suggested. Considering the Caplar et al. (2017) study of Indian female astrophysicists' citation counts over their careers, it is possible that citation count discrepancies in physics literature span over decades and are thus not observable unless directly compared between individuals. To address this limitation, a similar study of individual female physicists' publication trends, calculated through their lifetime publications, would be sufficient to close the gap in understanding.

Additionally, as a new understanding of gender discrepancy in physics literature has been established, it gains relevance for a study connecting the relationship between faculty position and publication success. This study's lack of disambiguation between career position and authorship frequency, order, and citation count limits the scope of explanation as to why female physicists tend to author significantly less than their overall proportion in the field. While existing studies strongly suggest that this phenomenon contributes to, and is a consequence of, the low proportion of female physicists in prestigious university positions, further investigation is necessary to determine the rationale behind the findings of this study.

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