Women's and men's career choices in astronomy and astrophysics

Rachel Ivie,* Susan White, and Raymond Y. Chu
American Institute of Physics, One Physics Ellipse, College Park, Maryland 20740, USA
(Received 30 January 2015; published 1 August 2016)

[This paper is part of the Focused Collection on Gender in Physics.] The Longitudinal Study of Astronomy Graduate Students (LSAGS) arose from the 2003 Women in Astronomy Conference, where it was noted that a majority of young members of the American Astronomical Society were women. The astronomy community wishes to make every effort to retain young women in astronomy, so they commissioned a longitudinal study to be conducted that would pinpoint the factors that contribute to retention in general, with a focus on differences between women and men. The LSAGS follows a cohort of people who were graduate students in astronomy or astrophysics during 2006–07. The first survey was conducted during 2007–08 and the second during 2012–13. The analysis presented in this paper used a subset of the respondents, all of whom had Ph.D.s in astronomy, astrophysics, or a related field at the time of the second survey. We tested the effects of four major concepts on two measures of attrition from physics and astronomy. These concepts included the imposter syndrome, mentoring and advising during graduate school, the "two-body problem" that occurs when a couple needs to find two jobs in the same geographic area, and the sex of the respondent. While the imposter syndrome and mentoring affected the likelihood of respondents' thinking about leaving the field, they did not directly contribute to actually working in a field that was not physics or astronomy. Relationship with graduate advisors and the two-body problem both had significant effects on working in physics or astronomy, as did completing a postdoc. The sex of the respondent had no direct effect on our measures of attrition, but indirectly affected attrition because women were less likely to report positive relationships with graduate advisors and more likely to report two-body problems. This research identifies specific areas of concern that can be addressed by the scientific community to increase the retention of all people, but especially women, in astronomy and astrophysics.

DOI: 10.1103/PhysRevPhysEducRes.12.020109

I. INTRODUCTION

There is evidence that women, once they have completed doctoral degrees in physical sciences, advance up the academic ladder at about the same rates as men [1–3]. However, it is still true that many women are lost to physical sciences at some point before the doctorate. In physics, for example, about 50% of high school students are female [4], but the proportion of bachelor's degrees earned by women is only 20% [5]. Attrition is similar in astronomy and astrophysics, although women earn a higher percentage (just over one-third) of the bachelor's degrees in these fields [5].

At the Women in Astronomy II conference held in Pasadena, CA in 2003, concern about possible differential attrition for women arose from the relatively high percentage of young women among American Astronomical Society (AAS) members compared to the lower representation of women among astronomy faculty members [6]. At that time, about 60% of AAS members ages 18 to 23 were female. In 2010, about 35% of Ph.D.s in astronomy were earned by women [7], and in 2010, 19% of astronomy faculty members were women [8]. Each of these data points represents one moment in time. Taken together, they may suggest different attrition rates for men and women in astronomy.

To address these concerns, the Committee for the Status of Women in Astronomy (CSWA) and the AAS Council concluded that a longitudinal study was needed to collect data about variables that affect career choices in astronomy and to determine whether any of these variables exert a disproportionate force on either sex. The resulting study, the Longitudinal Study of Astronomy Graduate Students (LSAGS), is a joint project of the American Astronomical Society (AAS) and the American Institute of Physics (AIP).

This paper addresses the issue of attrition from astronomy and astrophysics for men and women who have completed some graduate training in these fields. Using a cohort of people who had been graduate students in astronomy or astrophysics during 2006–2007, we obtained data at two points in time: (i) during 2007–2008 and (ii) during 2012–2013. Out of 2056 graduate students contacted in 2007–2008, we had 1143 usable responses to the first survey. 877 responded to the second survey, and 666 responded to both surveys.

*rivie@aip.org

We present an analysis that examines whether respondents were still working in the field at the time of the second survey and which variables are likely to influence that outcome. Our original hypothesis was that women would be more likely to leave the field, but we recognize that other factors may also influence working in or out of field. These factors include (i) completing a postdoc, (ii) time since degree, (iii) the imposter syndrome, (iv) mentoring and advising during graduate school, and (v) the two-body problem, which occurs when spouses or partners have difficulty finding jobs in the same geographic area. Using regression analysis, we examined the direct effects of being female on attrition while controlling for these other factors. We found that several factors directly affected the likelihood of leaving the field, but the sex of the respondent was not one of them.

In addition, some of the factors that had direct effects on attrition were related to the sex of the respondent. This indicates that there are indirect effects of being female on working out of field. Because there are no direct effects of being female on working out of field, we know that women are *not* more likely to leave astronomy just because they are women. However, women were more likely than men to encounter two-body problems, were more likely to show characteristics of the imposter syndrome, and were more likely to be dissatisfied with their graduate school advisors. Since women were more likely to experience these problems, women were ultimately more likely to work out of field.

II. BACKGROUND

A. Careers in and out of science

In 2007, the National Academies conducted a review of the literature concerning issues for women in science and engineering. This report concluded that while women have the ability and motivation to succeed, they are lost to science and engineering careers at every educational transition. The report cited several reasons for this, including documented discrimination, implicit bias, evaluation criteria that disadvantage women, and the structure of academic organizations [9]. These factors are characteristics of the institutions and hierarchies in which people work and cannot be easily measured in studies of individual scientists' careers.

Some studies used national data sets to examine the entry into and exit out of science careers over time. For example, Xie and Shauman [10] looked at sex differences in the careers of scientists. They found that women with master's degrees in science and engineering were less likely than men to work in a science and engineering job. Women's family status was a major determinant of their pursuit of science and engineering occupations after graduate training in these fields [10]. Because of the nature of their data, Xie and Shauman were not able to show results for specific fields such as astronomy and physics.

An analysis of data from the NSF's *Survey of Doctoral Recipients* (SDR) showed that men were more likely than women to leave academe for nonacademic jobs, but did not provide data on the propensity of people to leave their specific fields altogether for another field [9]. In addition, results from the SDR are almost always reported by broad field, such as "physical science," which means that trends in smaller fields such as physics are astronomy are buried among trends for larger fields that have much different economic prospects.

The fact that national data rely on samples such as the SDR means that generally not enough information is available to draw conclusions about astronomy, which has even fewer people than physics. However, working environments and job prospects differ greatly by specific field within physical sciences (consider, for example, the differences between chemistry and astronomy). Therefore, to understand factors causing attrition, it is essential to study specific fields so that we can determine factors contributing to individual career decisions.

One study that focused specifically on physicists' careers is Joseph Hermanowicz's examination of the careers of 55 physicists at various types of universities [11]. This study may be the only longitudinal study of physicists' careers. Hermanowicz interviewed 55 physics faculty members once, and then followed up 10 years later as several in his study were beginning to retire. Hermanowicz found that the characteristics of the college or university in which the physicists worked strongly influence career outcomes.

B. Attrition from astronomy

According to The National Research Council's Decadal Survey of Astronomy and Astrophysics, graduate training in astronomy often emphasizes academic careers for students. However, the survey committee recognized the broad applicability of astronomy training to other fields and recommended that professional training should correspond to the actual range of career paths taken by those who have received graduate training in astronomy and astrophysics. The committee estimated that at least 20% of Ph.D. astronomers leave the field at some point after earning their doctorates [12]. In the Decadal Survey's report, the percentage of astronomers who leave the field before receiving a Ph.D. was not addressed because that number is unknown.

C. Factors that may influence attrition

Many causes of attrition from science careers have been hypothesized in the literature [1,9]. It is beyond the scope of this study to account for or test them all. But we hope to shed light on the role of four major areas of concern: the imposter syndrome, the role of mentoring, family and relationship situations (specifically, the two-body problem), and gender differences in general.

1. Imposter syndrome

The first questionnaire used on the LSAGS measured characteristics of the imposter syndrome because we hypothesized that students with the imposter syndrome would be more likely to leave the field. The imposter syndrome was first used by psychologists Clance and Imes in 1978 [13] to describe highly successful women who nevertheless had difficulty internally recognizing their own achievements and continued to feel as though they were imposters in their careers. Since that time, additional research demonstrated that men can also exhibit characteristics of the imposter syndrome. In further describing the imposter syndrome, Langford and Clance [14] wrote that the syndrome is defined by "believing that one's accomplishments came about not through genuine ability, but as a result of having been lucky, having worked harder than others, and having manipulated other people's impressions." One key aspect of the imposter syndrome is the attribution of success to factors beyond individual control, such as luck, while attributing the success of others to skill or knowledge. But it is not just external factors to which those with the imposter syndrome attribute their successes. People with the imposter syndrome can also discount their successes by attributing them to hard work, while believing that others sail through based on natural talent. The imposter syndrome also can cause individuals to believe that people will soon realize that they are not really capable after all [14]. In the first survey in the LSAGS, women showed characteristics consistent with the imposter syndrome [15], so in this analysis, we will examine whether the relationship between sex and the imposter syndrome is a predictor of attrition from the field.

2. Mentoring

Mentoring is often cited as a mechanism for improving retention of students, especially women, in science, but mentoring has not often been linked in research to outcomes such as graduation rates and employment [16]. The results of the first round in the LSAGS [15] showed that mentoring reduces the imposter syndrome among these students, but it is currently unknown whether mentoring and relationships with advisors will decrease attrition out of astronomy or whether the imposter syndrome itself will predict the likelihood of leaving astronomy.

3. Two-body problem

Increasingly, universities are hiring dual-career couples [17]. In physics, these dual-career couples are often said to have "the two-body problem." In 1998, physicists McNeil and Sher defined the two-body problem as "the difficulty of finding two professional jobs (possibly two physics jobs) in the same geographic location." Because women are more likely to be married to other academics than men, women may be more likely to experience the two-body problem [18]. A more recent study shows that the number one reason women turned down offers of employment at academic institutions is because their partners did not find appropriate employment at the new location [17]. McNeil and Sher hypothesized that the frustration of finding jobs may ultimately lead one of the partners in a dual-career couple to leave the field altogether [18]. So far, studies of dual-career couples have collected data from people still employed in academe, so the effects of the two-body problem on leaving science are unknown.

4. Being female

Generally, the studies of women's career pathways in science have not been able to include data on women in specific fields such as astronomy. Nevertheless, there have been studies of the representation of women in astronomy, several of which attempted to look for drop-out points for women by using cross-sectional data rather than individual longitudinal data. These cross-sectional studies have not necessarily presented a consistent picture. For example, Hoffman and Urry [19] concluded in their 2004 analysis of three Space Telescope Science Institute surveys in 1992, 1999, and 2003 that while women were progressing at about the same rate as men during the 1990s, differential attrition may have been occurring between 1996 and 2003. An AIP report published in 2005 by Ivie and Ray [3] concluded that there appeared to be no leak in the pipeline at the faculty level for either physics or astronomy, although there may have been a small leak in astronomy between bachelor's degrees and Ph.D.s. Yet this study revealed a dramatic leak from high school to college physics. In a reanalysis of AIP's data, Bagenal [20] concluded a significant differential leak remains for women in astronomy from undergraduate to graduate school, but that the percentage of women within the three main professorial ranks was approximately what was expected considering the number of Ph.D.s awarded to women. Marvel [6] reported that snapshot surveys of AAS membership revealed dramatic changes in the demographics of the AAS, with women making up 60% of the youngest AAS members in 2004. The question raised by this is whether these younger women will stay in the field.

III. ABOUT THE DATA

The Longitudinal Study of Astronomy Graduate Students arose from the recommendations discussed at the *Women in Astronomy II* conference held in Pasadena, CA in 2003. One of the key recommendations was that the AAS commission a "longitudinal study of young women in astronomy," in order to "measure whether there is differential attrition of women from the pipeline and if so, to learn the reasons for it… " [21]. The Committee for the Status of Women in Astronomy and the AAS Office of Education organized the LSAGS in 2006 and established a

project team to conduct the study. To date, there have been two questionnaires sent to respondents who were graduate students in astronomy or astrophysics in 2006–2007.

A. First survey

In 2007, we identified 2056 possible astronomy and astrophysics graduate students from the AAS junior membership and American Institute of Physics survey data. The first LSAGS survey was carried out in 2007–2008; 1143 individuals (447 women, 696 men) responded to the first survey. The questionnaire instrument was available both on the web and on paper; the first questionnaire can be seen at Ref. [22]. We contacted respondents via both Email and postal mail to increase the likelihood that everyone received a survey invitation. We used four Email contacts and three paper contacts. This study is a cohort study. We have collected data from the same individuals at more than one point in time, and every respondent to both surveys was a graduate student in astronomy or astrophysics during the 2006–2007 academic year.

B. Second survey

Data collection for the second round spanned 2012–2013. Where possible, we updated the contact information for the cohort using (i) contact information provided by the respondents to the first survey, (ii) AAS membership lists, and (iii) a postal address updater service. At this time, 1555 individuals remained in the cohort (we discovered during the first survey that not all of the 2056 people in the cohort were astronomy graduate students during 2006–2007, and we discovered we did not have current contact information for others). We sent three Email requests and a final request via postal mail. This survey, which had multiple skip patterns so that questions were tailored to the specific situations of respondents, was available only on the web [23]. The postal mail request gave respondents a url directing them to the survey. We received 837 responses and of these, 666 also responded to the first survey. Unfortunately, time constraints meant that we could not collect as many respondents to the second survey as we did to the first.

IV. MEASUREMENT

A. Attrition

We had two measures of attrition. One was based on the respondents' perceptions of whether or not they had left or had considered leaving the field of astronomy. The second was based on their fields of employment at the time of the second survey.

1. Respondents' thoughts about leaving astronomy

We asked respondents whether they were considering or had ever considered leaving the field of astronomy. This question had three possible answers: had considered leaving, had never considered leaving, or had already left. We can think of this measure as a self-report of attrition or consideration of it. For the model we tested, we had responses for all of the questions in the model from 300 participants. Over one-half of the 300 responded that they had considered leaving, about one-fourth had not considered leaving the field, and about one in five said they had already left the field. For this model, we included all respondents with Ph.D.s in astronomy, astrophysics, or related fields. We classified them into three groups: current postdocs, previous postdocs, and those who had never been postdocs.

2. Employment in or out of the field

In addition to asking respondents for their own assessment of leaving, we used the respondents' fields of employment to determine whether or not they had left the fields of astronomy, astrophysics, and physics. We decided to include respondents who reported being employed in physics as employed in field. Our determination about what is in or out of field does not necessarily match the respondents' perceptions in measure (1). For example, it was not uncommon for respondents employed in planetary science to report that they were working out of field, although we considered them in field.

In the model of this second measure of attrition, our analysis was limited to those who were not currently postdocs because almost all current postdocs were working in physics or astronomy. We had over 150 respondents who had data on the questions included in the model; about 25% were working outside the fields of astronomy or physics. Because this model did not include postdocs, who almost all were working in astronomy or physics, the percentage of respondents outside the field appears higher on this measure than on measure (1).

B. Factors that may influence attrition

1. Imposter syndrome

Respondents to the first survey answered a set of 7 questions designed to measure characteristics of the imposter syndrome based on the scale developed by Clance [13,14]. Answers to these questions were combined into a score ranging from 7 to 35, with a higher score indicating respondents who feel more like imposters in their field. The imposter syndrome questions were on the first questionnaire. The inclusion of this variable accounts for a reduction in the number of respondents included in the analysis because we could include only respondents who responded to both rounds of the survey.

2. Mentoring and relationship with advisor

On the second survey, we asked respondents a yes/no question about whether they had a mentor other than their

advisor during graduate school. We asked a yes/no question about whether they had changed advisors during graduate school, which could indicate a level of dissatisfaction at least with their first advisor.

We also asked several questions about respondents' relationships with their advisors. These four questions asked respondents to indicate on a four-point scale whether their advisors were encouraging about respondents' career goals, encouraging about research, easy to discuss ideas with, and gave adequate input. For parsimony and ease of interpretation, we summed the responses into a score ranging from 4 to 16, with a higher score indicating a higher level of satisfaction with the respondents' advisors.

3. Two-body problem

We asked respondents three yes/no questions designed to measure whether they had experienced a situation related to the need to find two jobs in the same geographic area:

(1) Have they relocated because of a spouse or partner?
(2) Do they maintain a residence in a different location from their family in order to work or study?
(3) Have they limited their career options because of someone else?

Each of these was included separately in the models tested. We did not create a score because the questions measure very different aspects of the two-body problem. The first two questions were asked only of respondents who are married or partnered, and this fact accounts for some of the reduction in respondents that could be included in the analysis.

4. Other variables

Because they may influence attrition, we also included measures of sex (male or female), postdoc status at the time of the second survey (currently a post doc, completed a postdoc, and a Ph.D. who had never been a postdoc), and the number of years that have elapsed since the respondents earned their Ph.D.s. We hypothesized that people who have had postdocs may be less likely to leave astronomy, and we wanted to control for differences in the amount of time that respondents had been out of graduate school.

In addition, including the respondents' sex in our analysis allowed us to test both for whether attrition was different for men and women (the direct effect of sex), and also for whether or not sex affected attrition because of its effects on the other variables in our model (an indirect effect). For example, consider the two-body problem. If the two-body problem is found to be a significant predictor of attrition and if women are more likely than men to have a two-body problem, then women would be more likely to work outside the field. This would be an indirect effect of sex on attrition.

Among the respondents to the second survey, 83% had completed Ph.D.s in astronomy, astrophysics, or a related field. Of these, about 50% were current postdocs, 20% had completed one or more postdocs, and 30% had never been postdocs. All of the respondents included in this analysis had Ph.D.s at the time of the second survey.

V. ANALYSIS AND RESULTS

A. Bivariate sex differences

Since we wanted to examine indirect effects of respondents' sex on attrition, we first looked for sex differences in each factor that could influence attrition. Overall, 39% of the respondents included in the analysis were women. For five measures, we found highly significant differences (p value <0.01) by sex.

- Women were much more likely to have relocated for a spouse or partner than men.
- Women were much more likely to maintain a separate residence for work or study than men.
- Women had a lower opinion of their advisors than men.
- Women were much more likely than men to have had a mentor other than their advisor during graduate school.
- Women were more likely to feel like imposters than men.

Table I provides a summary of the variables included in the analysis with more details on differences between men and women on these variables. Although sex of the respondent may be related to these variables, this relationship may not hold in multivariate models, which we examine in the next section.

B. Multivariate path analysis

We hypothesized that several factors would have effects on working in or out of physics and astronomy. Path analysis allows us to examine the direct and indirect effects of these factors on attrition [24,25]. In our path models, direct effects are factors which are found to be significant in multivariate regression models with attrition as the dependent variable. Indirect effects are factors which are found to be significant in multivariate models with one of the factors (such as imposter syndrome, advising, and the two-body problem) as dependent variables. A factor may be found to have

- a direct effect on attrition,
- an indirect effect on attrition, or
- both a direct and an indirect effect on attrition.

In addition, testing multivariate regression models that included all the factors as independent variables allowed us to consider the simultaneous effects of all the factors that could affect attrition. With these models, we could determine which factors directly affected attrition given that all of them were included in the model. For example, we could determine whether the sex of the respondent was

TABLE I. Characteristics of variables in the study that might affect attrition.

Variable	Overall	Differences by sex?	Level of significance[a]
Relocated for spouse or partner	24%	Women (33%) were much more likely to have relocated for a spouse or partner than men (18%).	Highly significant
Maintained residence in different location from family in order to work or study	13%	Women (21%) were much more likely to maintain a separate residence than men (9%).	Highly significant
Advisor rating (scale is 4 to 16 with a lower score implying a worse opinion of the advisor)	13.6	Women's scores (13.2) were lower than men's (13.9) meaning women had a lower opinion of their advisor.	Highly significant
Had a mentor other than one's advisor	54%	Women (62%) were much more likely than men to have had a mentor other than their advisor (48%).	Highly significant
Imposter syndrome (scale is 7 to 35) with a higher score meaning respondent feels more like an imposter	19.2	Women's scores (19.9) were higher than men's (18.8) meaning women felt more like imposters than men.	Highly significant
Changed advisors while in graduate school	28%	No	...
Respondent limited career options because of someone else	44%	No	...
Respondent was currently a postdoc	53%	No	...
Respondent had completed a postdoc	21%	No	...
Time since degree	2.6 years	No	...

[a]Highly significant with p value <0.01.

statistically significant in the regression model, in essence, examining whether sex directly affected attrition, while controlling for all the other measures that could affect attrition. Any factor that is statistically significant in the multivariate regression model is found to have a direct effect on attrition.

Using additional multivariate regression models, we then used each factor as a dependent variable to see how the other factors, including sex of the respondent, affected it. Factors which are significant in these models are said to have indirect effects on attrition. For example, sex had significant effects on some of the factors that could influence attrition. If any of these factors have direct effects on attrition, then we would be able to document the indirect effects of sex on attrition.

In this survey, we had two measures of attrition: (1) respondents' thoughts about leaving astronomy and (2) employment in or out of field. For each of the two attrition measures (dependent variables), we tested regression models using path analysis.

1. Respondents' thoughts about leaving astronomy

Since this dependent variable had three outcome categories (considered leaving, already left, never considered leaving), we used multinomial logistic regression. The reference group in our regression was the respondents who had never considered leaving astronomy. The results of this model allowed us to compare the relative likelihood of the same outcome for respondents who were alike in all respects except on one of the independent variables, for example, being mentored versus not being mentored. Of the twelve factors tested, seven were statistically significant: respondents' scores on the imposter syndrome scale, three measures of mentoring or advising (whether or not respondents had a mentor other than their advisor in graduate school, whether or not respondents had changed advisors, and respondents' ratings of their advisor), two measures of the two-body problem (whether or not respondents had relocated because of a spouse or partner and whether or not respondents had limited career options because of someone else), and whether or not respondents were currently postdocs (Table II). The sex of the respondent was not a significant predictor of the respondents' thoughts about leaving astronomy.

2. Employed in or out of the field

To model this measure of attrition, we included the same variables we had used in the previous model with the exception of whether or not the respondent was currently a postdoc. We intentionally excluded current postdocs from the models of this measure since almost all postdocs were working in astronomy or physics.

Because this dependent variable was binary (in or out of field), we used logistic regression. Of the eleven factors considered, four were statistically significant and therefore had direct effects on this measure of attrition: one measure of mentoring or advising (whether or not respondents had changed advisors during their graduate education), two measures of the two-body problem (whether or not respondents had relocated because of a spouse or partner and whether or not respondents had limited their career options because of someone else), and whether or not respondents

TABLE II. Factors directly affecting respondents' thoughts about or decision to leave astronomy.

Considered leaving astronomy compared to never considered leaving astronomy		
For each 1 point increase in a respondent's overall average imposter rating, the respondent was[b]	1.74 times	more likely to have considered leaving astronomy than a respondent with an average rating that was 1 point lower; a respondent who felt the most like an imposter was 9.13 times more likely to have considered leaving astronomy than a respondent who felt the least like an imposter.
A respondent who had a mentor other than his or her advisor while in graduate school was[b]	1.77 times	more likely not to have considered leaving astronomy than a respondent who did not have a mentor other than his or her advisor.
A respondent who changed advisors while in graduate school was[b]	2.14 times	more likely to have considered leaving astronomy than a respondent who had not changed advisors.
For each 1 point decrease in a respondent's overall average advisor rating, the respondent was[a]	2.17 times	more likely to have considered leaving astronomy than a respondent with an average rating that was 1 point higher; a respondent who gave their advisor the worst rating was 10.17 times more likely to have considered leaving astronomy than a respondent who gave their advisor the best rating.
A respondent who had relocated because of spouse or partner was[a]	4.18 times	more likely to have considered leaving astronomy than a respondent who had not relocated.
A respondent who had limited career options because of someone else was[b]	1.95 times	more likely to have considered leaving astronomy than a respondent who had not limited career options.
A respondent who was currently a postdoc was[a]	6.60 times	more likely to have considered leaving astronomy than a respondent who was not currently a postdoc.
Already left astronomy compared to never considered leaving astronomy		
A respondent who changed advisors while in graduate school was[c]	2.14 times	more likely to have already left astronomy than a respondent who had not changed advisors.
For each 1 point decrease in a respondent's overall average advisor rating, the respondent was[c]	1.52 times	more likely to have already left astronomy than a respondent with an average rating that was 1 point higher; a respondent who gave their advisor the worst rating was 3.50 times more likely to have already left astronomy than a respondent who gave their advisor the best rating.
A respondent who had relocated because of spouse or partner was[b]	3.44 times	more likely to have already left astronomy than a respondent who had not relocated.
A respondent who was currently a postdoc was[b]	5.09 times	more likely not to have already left astronomy than a respondent who was not currently a postdoc.

[a]highly significant (1% level)
[b]significant (5% level)
[c]marginally significant (10% level)
(All tests are one-tail tests.)

had completed a postdoc (Table III). Neither the imposter syndrome rating nor the respondents' sex contributed significantly to this model.

3. The indirect effects of the respondents' sex on working outside the field

Path diagrams are useful to help understand direct and indirect effects. In Fig. 1, we show that

- changing advisors,
- limiting career options because of someone else,
- relocating for one's spouse or partner, and
- not taking a postdoc

directly affected working outside the field of astronomy (our second measure of attrition); the sex of the respondent had no direct effect. As the path diagram illustrates, being female *indirectly* affected attrition from astronomy because sex significantly predicted whether or not the respondent had relocated for a spouse or partner, which directly affected working out of the field. In addition, sex also indirectly affected working out of the field through the imposter score and the advisor rating. Relocating for a spouse or partner had both direct and indirect effects on working outside the field. The indirect effects of sex on working outside the field are shown in red on the path diagram in Fig. 1; the direct effects are shown in blue.

TABLE III. Factors directly affecting respondents' employment in or out of physics and astronomy.

A respondent who had changed advisors was[b]	2.33 times	more likely not to be working in physics and astronomy than respondents who had not changed advisors.
A respondent who had relocated because of spouse or partner was[a]	2.72 times	more likely not to be working in physics and astronomy than a respondent who had not relocated.
A respondent who had limited career options because of someone else was[c]	1.80 times	more likely not to be working in physics and astronomy than a respondent who had not limited career options.
A respondent who had completed a postdoc was[b]	2.49 times	more likely to be working in physics and astronomy than a respondent who had not completed a postdoc.

[a]highly significant (1% level)
[b]significant (5% level)
[c]marginally significant (10% level)
(All tests are one-tail tests.)

A path model of sex on respondents' thoughts about leaving astronomy (our first measure of attrition) is not shown graphically to save space, but can be derived from Table II.

VI. DISCUSSION

We hypothesized that being female, experiencing the imposter syndrome, the nature of the relationship with a graduate school advisor or mentor, and having a two-body problem would all affect respondents' decisions to work in the fields of astronomy and physics. Our hypotheses were confirmed for both measures of attrition in our study.

A. Imposter syndrome

Respondents who scored higher on the imposter syndrome were more likely to have thought about leaving the field. Since the imposter syndrome is characterized by feelings of not belonging in the field, it is perhaps not surprising that those with higher scores had at some point considered leaving. However, it is worth noting that higher scores on the imposter syndrome scale were not directly related to actually leaving the field. There is an indirect effect because a high imposter score increased the likelihood of changing advisors, which in turn increased the odds of working outside the field.

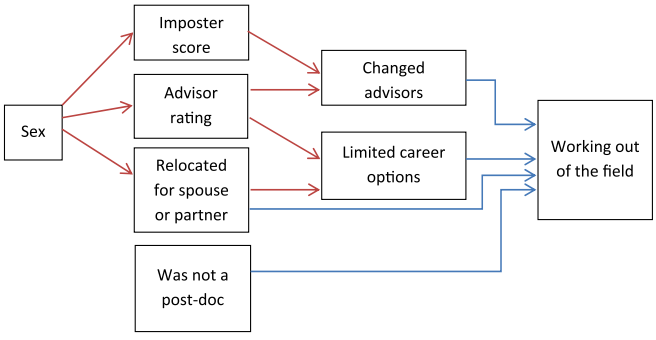

FIG. 1. The indirect effects of sex on whether or not respondent worked out of the field.

B. Mentoring and relationship with advisor

Our measures of mentoring and advising during graduate school included (1) a rating of the relationship with the advisor, (2) having a mentor other than the advisor during graduate school, and (3) changing advisors during graduate school. All three of these were directly related to considering leaving the field. Respondents who changed advisors and who gave their advisors worse ratings were more likely to have thought about leaving astronomy and astrophysics. Respondents who had mentors other than their advisors during graduate school were less likely to have considered leaving the field. In the first model, respondents who had changed advisors and who gave their advisors less desirable ratings were more likely to have self-reported already leaving the field. In our second model of the employment field of respondents, we found that respondents who had changed advisors during graduate school were twice as likely to be working in a field that was not physics or astronomy as respondents who did not change advisors.

These results about the relationships of graduate students with their advisors and the role of mentors echo literature which advocates that mentoring and a good working relationship with graduate advisors to be generally good for students. In our study, positive relationships with graduate advisors indirectly predicted the propensity to work in the fields for which the respondents had been trained. It is worth noting, however, that mentoring did not predict working in or out of field. Our study showed only that mentored students were less likely to consider leaving, but being mentored was not necessarily a safeguard against leaving the field.

C. Two-body problem

We had three measures of experiences with the two-body problem, which is defined as the need of an academic couple to find employment in the same geographic area. One of these measures, maintaining a separate residence in order to work or study, was not related to either of our measures of attrition. The other two measures of the two-body problem were directly related to both measures of

attrition. In the first model, respondents who had relocated because of a spouse or partner were 4 times more likely to have considered leaving than respondents who had not relocated for this reason. Relocated respondents were also more than 3 times more likely to self-report already having left astronomy than respondents who had not relocated. On the second measure of attrition, respondents who had relocated were also almost 3 times more likely to work in a field that is not physics or astronomy.

In addition to the effects of relocation, we tested the effects of respondents' reporting that they had limited their career options for someone else. We found that these respondents were almost twice as likely to (i) have considered leaving astronomy (part of the first measure of attrition) and (ii) work in a field that is not physics or astronomy (the second measure of attrition). Our results showed that the two-body problem is indeed a significant contributor to attrition in astronomy.

D. The importance of postdocs

We controlled for several variables that may affect attrition or considering leaving astronomy. These included sex of the respondent (covered below), number of years since earning a Ph.D. (not significant in either model), and postdoc status. Recall that all of the respondents in this analysis had Ph.D.s in astronomy, astrophysics, or a related field at the time of the second survey. Half of these were current postdocs, 20% had completed postdocs, and 30% had never been postdocs. Our analysis of the first measure of attrition compared the current and completed postdocs to those who had never been postdocs. We found that current postdocs were more likely than those who had never been postdocs to have considered leaving astronomy, but they were also less likely to self-report that they had left astronomy. This latter finding is perhaps expected because almost all postdocs in our study worked in physics or astronomy. While current postdocs were more likely to have considered leaving astronomy, we found that ultimately completing a postdoc increased the likelihood of respondents' working in physics or astronomy (Table II) compared to respondents who had never been postdocs. In other words, respondents who did not take a postdoc were more likely to be working in a field that is not astronomy or physics.

E. The indirect effects of respondents' sex

The respondents' sex had no direct effects on either measure of attrition. However, being female indirectly increased the likelihood of working outside the field because of its relationship to the imposter syndrome, to the advising relationship, and to the two-body problem (Fig. 1).

1. Women and the imposter syndrome

Women were more likely to feel like imposters in the field. Those with higher imposter scores were more likely to have changed advisors, and changing advisors increased the likelihood of working in a field that is not physics or astronomy.

2. Women and the advising relationship

Women tended to be less satisfied with their advisors, which increased the likelihood of changing advisors, which in turn increased the odds of working outside physics and astronomy. There was also an unexpected effect of advisor rating on limiting career options, in which we found that respondents who gave their advisors a lower score were more likely to have limited their career options for someone else. We suggest that this finding reflects the interactive relationship between students and their advisors. Advisors who encourage their students may be likely to be more highly rated, and students who receive more encouragement from their advisors may be less likely to limit their career options for someone else.

3. Women and the two-body problem

Women were more likely to report that they had relocated for a spouse or partner. This type of relocation affected the likelihood of working outside physics or astronomy in two ways: (1) by directly increasing the likelihood of working outside the field and (2) by indirectly increasing the likelihood of limiting career options for someone else, which itself had direct effects on working outside the field.

There were similar pathways from the respondents' sex through the other independent variables to the first measure of attrition that are not shown in Fig. 1.

VII. CONCLUSION

Our results showed that the process of understanding attrition from astronomy and astrophysics must include multiple factors and cannot be reduced to a simple model in which respondents' sex alone is the causal factor. The respondents' sex had no direct effect on working outside the field. There were pathways from being female to considering leaving and even to actually working outside the field, but these involved multiple steps. Women who receive less than satisfactory advising may ultimately leave. And women who experience two-body problems may ultimately leave as well.

As many practitioners and observers of the situation of women in science, technology, engineering and math fields have asserted, the advising relationship is crucially important for retention in our study. Respondents who rated their advisors more positively were more likely to work in the fields in which they have been trained. Our results suggested that efforts to increase the retention of women in astronomy and physics would do well to focus on various aspects of the advising relationship, perhaps extending to training for graduate advisors in best practices.

Furthermore, our results suggest that mentoring may make students less likely to question their career choices. However, mentoring beyond the relationship with the advisor had no effect on retention after respondents started working.

This study also documented the effects of needing to find two jobs in the same geographic location for a dual-career couple. Respondents who had been in this situation were in fact less likely to work in the fields in which they have been trained. The prevalence of these two-body problems was notable, with one-fourth of respondents reporting relocation and 44% reporting limiting careers. As we have noted, women were more likely to report two-body problems, and through these problems, were more likely to have left the field. Although not all the astronomers in this study were employed in academe, universities have become more aware of these two-body constraints and should continue their efforts to retain trained scientists by helping to solve the two-body problem.

Finally, we hope that this study will contribute to a growing body of knowledge about the areas in which the community should focus its efforts to retain scientists of both sexes. In the past, some efforts to do this have been well intentioned but may not have been supported by research on best practices for retention. This study showed that we should focus on improving the advising relationship and solving the two-body problem. Since this is a longitudinal study, we may be able to learn more about which aspects of the advising relationship and the two-body problem are most influential. We look forward to other research that documents specific remedies that will attract and retain a scientifically trained workforce.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. AST 1347723.

[1] S. J. Ceci, D. K. Ginther, S. Kahn, and W. M. Williams, Women in Academic Science: A Changing Landscape, Psychol. Sci. Publ. Interest **15**, 75 (2014).

[2] National Research Council, *Gender Differences at Critical Transitions in the Careers of Science, Engineering, and Mathematics Faculty* (National Academies Press, Washington, DC, 2010).

[3] R. Ivie and K. N. Ray, Women in physics and astronomy, 2005, http://www.aip.org/statistics/reports/women-physics-and-astronomy-2005.

[4] S. White and C. L. Tesfaye, Female students in high school physics, http://www.aip.org/statistics/reports/female-students-high-school-physics.

[5] P. Mulvey, AIP (private communication).

[6] K. Marvel, AAS membership demographics, http://www.aas.org/~cswa/MEETING/marvel.pdf.

[7] S. Nicholson and P. Mulvey, Focus on astronomy enrollments and degrees, http://aip.org/statistics/reports/astronomy-enrollments-and-degrees accessed 1/28/15.

[8] R. Ivie, S. White, A. Ephraim, and G. Anderson, Women among physics and astronomy faculty, http://aip.org/sites/default/files/statistics/faculty/womenfac-pa-10.pdf accessed 1/28/15.

[9] National Academy of Sciences (US), National Academy of Engineering (US), and Institute of Medicine (US) Committee on Maximizing the Potential of Women in Academic Science and Engineering, *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering* (National Academies Press, Washington, DC, 2007), http://www.ncbi.nlm.nih.gov/books/NBK9813/ accessed 1/28/15.

[10] Y. Xie and K. Shauman, *Women in Science: Career Processes and Outcomes* (Harvard University Press, Cambridge, MA, 2003).

[11] J. C. Hermanowicz, *Lives in Science: How Institutions Affect Academic Careers* (University of Chicago Press, Chicago, IL, 2009).

[12] National Research Council (U.S.). Committee for a Decadal Survey of Astronomy and Astrophysics, *New Worlds, New Horizons in Astronomy and Astrophysics* (National Academies Press, Washington, DC, 2010).

[13] P. R. Clance and S. A. Imes, The imposter phenomenon in high-achieving women: Dynamics and therapeutic intervention, Psychother. Theor. Res. Pract. **15** 241 (1978).

[14] J. Langford and P. R. Clance, The imposter phenomenon: Recent research findings regarding dynamics, personality and family patterns and their implications for treatment, Psychother. Theor. Res. Pract. Train. **30** 495 (1993).

[15] R. Ivie and A. Ephraim, Women and the imposter syndrome in astronomy, http://www.aas.org/cswa/status/STATUS_jan11_FINAL.pdf accessed 1/28/15.

[16] Y. George and D. Neale, Report from Study Group Meetings to Develop a Research and Action Agenda on STEM Career and Workforce Mentoring *American Association for the Advancement of Science* (National Academic Press, Washington, D.C., 2006.

[17] L. Shiebinger, A. Davies Henderson, and S. K. Gilmartin, Dual Career Couples: What Universities Need to Know, http://gender.stanford.edu/sites/default/files/DualCareerFinal_0.pdf accessed 1/28/15.

[18] L. McNeil and M. Sher, Dual Science Career Couples: Survey Results, http://www.physics.wm.edu/~sher/survey.pdf, accessed 1/28/15.

[19] J. L. Hoffman and M. Urry, Portrait of a Decade: Results from the 2003 CSWA Survey of Women in Astronomy, CSWA Status 1 & 8–12 (2004), http://www.aas.org/~cswa/status/STATUS_Jun04sm.pdf accessed 1/28/15.

[20] F. Bagenal, The Leaky Pipeline for Women in Physics and Astronomy, CSWA Status 13–19 (2004), http://www.aas.org/~cswa/status/STATUS_Jun04sm.pdf accessed 1/28/15.
[21] Equity Now: The Pasadena Recommendations for Gender Equality in Astronomy, http://www.aas.org/~cswa/pasadenarecs.html accessed 1/28/15.
[22] http://aipsurveys.aip.org/cgi-bin/astrograd2006.pl.
[23] http://aipsurveys.aip.org/cgi-bin/astrograd2012.pl.
[24] K. A. Bollen, *Structural Equations with Latent Variables* (John Wiley & Sons, New York, 1989).
[25] E. Babbie, *The Practice of Social Research* (Wadsworth Publishing Company, Belmont, CA, 1998).