Women and mission leadership

Susan M. Niebur*

Niebur Consulting, 418 Hillsboro Drive, Silver Spring, MD 20902, USA

Abstract

Only one of NASA’s planetary science flight missions in the past 30 years has been led by a women scientist as Principal Investigator. The number of senior women in the field is small, but women are still underutilized, as seen by a cohort age analysis correlating with median ages for various key science roles. Worse, the more junior women are not joining missions as Co-Investigators and Participating Scientists at rates approaching their representation in the field of planetary science. In fact, they are underutilized in these roles not by a few percent, but by greater than a factor of two. The pipeline of women gaining mission experience today is increasing, but it is not keeping pace with the rate that women are now choosing to stay in the field for postdoctoral studies and beyond. The numbers definitively show for the first time that, for whatever reason, women are still underrepresented in mission leadership at NASA.

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1. Introduction

The National Aeronautics and Space Administration (NASA) selects two major kinds of planetary science missions for flight: institutional (also known as flagship) and Principal Investigator-led (PI-led) missions. While the traditional institution-directed missions dominated the nation’s planetary science missions in NASA’s first 35 years, PI-led missions have played a large role over the most recent decade and a half. NASA increasingly solicits mission proposals for small, PI-led missions, directed by a single PI with the support of a small consortium of universities, research laboratories, and/or NASA Centers. Small missions, such as those in the Discovery and Mars Scout programs, and medium missions, such as those in the New Frontiers mission line, are able to accomplish focused science investigations for limited cost. Costs vary by mission line: Discovery missions, for example, are allotted up to $425 million [1]; New Frontiers missions can cost up to $650 million [2]. Both are significantly more focused than the traditional institutional missions, which cost in excess of $1 billion each. With these smaller cost caps comes recognition that the investigations must be tightly focused, teams small, and changes during development resisted. Fifteen years after the first of these PI-led missions was competitively selected, with dozens of missions successfully launched and operated, the concept has been validated. Today there is a fleet of small, focused scientific investigations throughout the inner Solar System, and a set of Principal Investigators (PIs) proven capable of leading these missions to success.

The set of experienced PIs includes few women. Worse, the proportion of women in the pipeline to become PIs, such as those in other leadership positions and on the science teams, is not sufficient to dramatically increase the proportion of women leading future missions. In this sense, current selections, particularly those of Co-Investigator (Co-I) and science mission support positions, have an impact on future selections. Earlier in 2009, NASA confirmed that selection of new missions will be performed using a standard Announcement of Opportunity (AO) solicitation and thorough proposal review that would continue to assess, among many other technical, scientific, and cost related factors, “the commitment, spaceflight experience, and past performance of the PI and of the implementing institutions” [2]. Spaceflight experience does matter, and an aspiring PI would be well-served to work on others’ missions before proposing to lead one. As planetary

* Tel./fax: +1 301 754 0939.
E-mail address: susanniebur@nieburconsulting.com

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science progresses in large part thanks to data returned from new space missions, participation on flight missions has become an essential aspect of the work of the planetary science community.

A recent policy that required proposing PIs to show prior experience as a PI on a flight mission [3] had the effect, if not necessarily the intent, of barring younger investigators and almost all women from submitting proposals, because of their lack of previous experience in these specific science leadership positions, despite mission experience as members of the science team in numbers more proportionate to their representation in the field as a whole. A recent paper in this journal discussed the question of age [4]. This paper will examine the question of women’s leadership on NASA planetary science missions and discuss the pipeline of women poised to propose in the future.

2. Mission management

As budgets permit, NASA periodically releases AOs calling for planetary science mission proposals. In response, PIs propose complete mission packages including instrument design and development; spacecraft bus specifications; integration, test, and launch parameters; mission operations; and a team of scientists essential for successful conclusion of the core scientific investigation. The PI has primary responsibility for implementing and executing the selected investigation, and “is accountable to NASA for the success of the investigation, with full responsibility for its scientific integrity and for its execution within committed cost and schedule” [2]. PIs rely on project managers and project system engineers for much of the daily engineering leadership, but the PI maintains final approval over all trades that may affect the acquisition of the science or the integration of the instruments, as well as any that would significantly change the budget or require greater reserves. Clearly, a mission PI must not only be an outstanding scientist, but must have sufficient project and mission experience to plan and execute a new mission, from design and development to operations. Each mission is selected as a complete package; all members of the science team necessary for design, development, implementation, mission operations, and preliminary data analysis are named at proposal.

2.1. Key science roles

One way to augment the PI’s effectiveness is to appoint key players to assist in the planning and implementation of the mission. Key scientists on the mission team can be charged with roles such as managing the science team, interacting with the engineering leads, overseeing instrument development, and planning for operations. Popular options include a Deputy Principal Investigator (DPI), whose role is defined by the PI, and a Project Scientist (PS). The PS is typically appointed by and located at the managing institution, typically a NASA Center or the Applied Physics Laboratory (APL) at Johns Hopkins University. PSs provide day-to-day support and communication between the scientists who have defined the requirements and the engineers building the hardware. In addition, a Deputy Project Scientist (DPS) may be located at the managing institution or elsewhere, such as on location with an industry partner. These four roles, following the nomenclature used in the previous PI experience policy announcements [3], will be collectively referred to as the “key science roles” in this paper.

2.2. Co-Investigators

Additional science team members, or Co-Is, each play a vital role on a mission team, and each is generally responsible for implementation of a part of the mission’s science plan. The range of responsibilities varies greatly, but may include delivery and/or operation of an instrument, completion of a scientific investigation, and/or performance of supporting observations from ground-based telescopes or other space assets.

2.3. Participating Scientists

Occasionally NASA, the mission team, or both wish to add more investigators to the science team. These new investigators are called Participating Scientists; they are integrated into the mission to varying degrees. The Participating Scientists are selected by NASA Headquarters, as were those in the originally selected key science roles. For Participating Scientists, NASA, in cooperation with the PI, releases a NASA Research Announcement requesting proposals of complete science investigations that may be performed using one or more instruments on a particular operating mission. These proposals undergo a rigorous peer review that considers the proposed investigation, how the proposed investigation would complement those already planned by the science team, potential contribution to mission operations and planning, possible improvement in the planned data products for team use and delivery to the Planetary Data System, and the need of the proposer to be on the team to ensure the acquisition of the appropriate data during the mission’s operation [5]. Through Participating Scientist Programs, teams can boost their membership as needed, a technique that is particularly appropriate when used to bring new scientists into teams that have been working on the mission for many years, and the spacecraft is finally approaching its target.

3. Methodology

Leading a planetary science mission is incredibly difficult; it is not something that is easily attempted without prior experience with a flight mission or project. Qualified PI candidates, therefore, are most likely to be drawn from the pool of scientists who have previously worked on a mission in one of the key science roles or as a member of the science team, such as Co-Is or Participating Scientists. To take a closer look at the demographics of the scientists in these roles, the paper will first examine closely the representation of women in these roles in the oldest PI-led mission line, the Discovery
Program, and then look across the broader field of planetary science.

Demographic data are not collected or used by NASA. To perform this study, the author used data collected from publicly available sources, such as press releases and mission web sites. Collated lists of names for Discovery missions were then confirmed with NASA representatives and/or mission Principal Investigators for accuracy. Additional statistical data were received from NASA Headquarters and the American Astronomical Society upon request. All analysis was done specifically for this study and is outside of the selection process at NASA. The results reported in this paper and the preceding paper [4] are the first known demographic study of scientists selected to lead NASA missions.


A case study was performed of the demographics of scientists filling the key science roles and Co-Is selected by NASA to implement a mission in the Discovery Program of small PI-led planetary science missions from the program’s start in 1992 to mid-2009, and of Participating Scientists selected to participate at later stages of the missions. The Discovery missions are NASA’s least complex planetary science missions and can be characterized as relatively low in cost (less than $425 million in Fiscal Year 2006), straightforward in development (less than 35 months from the beginning of implementation to launch), and without constraint of a particular management structure imposed by NASA [1]. The missions are Mars Pathfinder, NEAR, Lunar Prospector, Stardust, Genesis, CONTOUR, MESSENGER, Deep Impact, Dawn, Kepler, and GRAIL. All missions after Mars Pathfinder and NEAR were competitively selected and PI-led.

Where possible, the author has chosen to avoid “single point” data bins that would identify a unique individual. In some cases, however, the statistics are so small that there was no other meaningful way to aggregate the results.

3.2. All planetary science missions, 1979–2009

While the Discovery missions are recent and varied, the past 30 years in planetary science have also included many Mars missions, several institution-class missions, and several smaller missions that fall outside the Discovery mission line, including two in the New Frontiers line of larger missions. After the presentation of the case study results, the paper will repeat the analysis for the set of all 27 planetary science missions launched since 1979 or currently in development in order to determine the number of women with experience on planetary science missions in the past 30 years.

Besides Discovery, 14 other planetary science missions have been launched in the past three decades; eight of these have been sent to Mars. Mars missions are Mars Observer, Mars Global Surveyor, Mars Climate Orbiter, Mars Polar Lander and Deep Space 2 probes, Mars Odyssey, Mars Exploration Rovers, Mars Reconnaissance Orbiter, and Mars Phoenix. Other planetary missions are Magellan, Galileo, Clementine, Cassini, Deep Space 1, and New Horizons. All these missions have been institution-led except for Mars Phoenix and New Horizons. Two additional PI-led missions, Juno and MAVEN, have been selected but not yet launched, for a total of 11 Discovery and 16 non-Discovery missions.

4. Results from the Discovery Program

4.1. Key science roles

The number of planetary scientists selected by NASA to serve in a key science role on a Discovery mission is shown in Fig. 1, by gender. In each category, only once has a woman been selected in that role. None of the missions have had more than one woman in the key science roles combined. There are therefore only three women who served in a key science role on a Discovery mission, in sharp contrast to the 20 men (see Fig. 1).

4.2. Co-Investigators

Expanding the field to include Co-Is improves the numbers of women, but not the percentage of the population. In addition to the key science roles above, women have been selected to participate on missions as Co-Is 19 times in the history of the Discovery Program; 159 men were selected in the same time period. The percentage of female Co-Is (11%), is therefore consistent with the percentage of women in key roles (13%) but both numbers are small.

Individual missions show more variation, but even the most diverse do not show equity in proportion to the number of women in the population at large (51%). Each of the 11 Discovery mission teams, analyzed separately, has had a relatively small fraction of women on the science team, in key science roles or as Co-Is (0–23% female).

4.3. Participating Scientists

The argument has been made that the gender diversity of the missions can be supplemented by the Participating Scientist selections made by NASA Headquarters. The
numbers do not indicate that this has happened, however. Only nine of the 74 Participating Scientists (12%) selected for Discovery missions have been female. This percentage is roughly equal to both the percentage of women in key science roles and the percentage of female Co-Is.

Interestingly, four of the nine women selected as Participating Scientists were selected as part of a single NRA call, making up 21% of the Participating Scientists on MESSENGER. That leaves just five women on the remaining four missions, leading to the conclusion that, in general, Participating Scientist Programs, while helpful in adding early career scientists to missions [4], have not been an effective mechanism for recruiting additional women for NASA missions. These programs are a tool that can be used to increase diversity on mission teams in many ways, from scientifically to operationally, but these selections have not been shown to add significant gender diversity to previously selected teams.

5. Results over all planetary science missions, 1979–2008

The case study of the Discovery Program has shown some clear trends in age [4] and gender for the various science leadership roles on small planetary science missions. Because of the small numbers of both missions and women in planetary science, however, it is also instructive to look at these trends over the entire suite of planetary science missions over the past 30 years. Expanding the investigation also allows a more complete description of the field of experienced scientists who may propose missions in the future.

5.1. Key science roles

The 16 other missions have been led by 72 PIs, DPIs, and (in the cases where there is no single PI) Instrument PIs (IPIs). There have been 21 PSs and 11 DPSs. Some, like the technology demonstration mission Deep Space 1, have had relatively young teams, while larger, once-a-decade flagship missions have tended to have teams of more experienced PIs and Co-Is. There has been some movement from Co-I to PI across this set of larger missions, but not significant repetition in the lead PI roles.

The data are striking in the analysis of gender. None of the 16 other missions has been led by a female planetary scientist in the role of PI, making the Discovery mission GRAIL the only one of the 27 planetary science missions in the past 30 years to be led by a woman. Only Galileo has had a female IPI. If one were to add the two launched Discovery missions of opportunity to the data set, only the Moon Mineralogy Mapper has had a female IPI on a stand-alone instrument. Only Dawn has had a female mission DPI. In all, women have made up just 12% of the scientists in key science roles. The combined data set for all 27 planetary missions, 1979–2008, shows a clear underutilization of women in mission leadership in all key science roles except the most junior (see Fig. 2).

5.2. Co-Investigators

It is in the examination of the gender balance of Co-Is, however, that we can most closely approximate the pool of potential PIs. The Co-Is from PI-led missions are among the most recent, but a census of all missions over the past 30 years provides a more comprehensive look at the total community of experienced Co-Is who may be ready to lead a mission. This census, like all the other data summations in this paper, is a count of the selections made by NASA, not the number of actual scientists. For instance, while the number of times that a woman has been selected as a Co-I is 64 (of 888) the actual number of women with Co-I experience is only 41, because experienced scientists often serve on multiple missions. Of Co-Is selected to participate on planetary science missions over the past 30 years, 7% of the selections were women.

5.3. Participating Scientists

Twelve of the planetary science missions have had Participating Scientist Programs: NEAR, Mars Pathfinder,
Mars Observer, Mars Global Surveyor, Mars Odyssey, Mars Exploration Rovers, Mars Reconnaissance Orbiter, Magellan, Cassini, MESSENGER, Stardust, and Kepler. In all these proposal opportunities, women have been selected as Participating Scientists 18 times; men have been selected 217 times. Women have therefore participated at a rate of less than 8% of the total.

6. Cohort analysis

A common argument when faced with the question of the underutilization of women in key roles begins with the assertion that there is simply not a significant number of women entering and staying in the relevant fields from which these leaders are drawn, and therefore the number of women at the top of the field is expected to be small [6]. The American Institute of Physics has knocked down this issue in a related area by utilizing cohort analysis: the importance in tracking the collective success of women scientists over time in relation to their numbers in the field. In fact, a recent study shows that women in astronomy are currently significantly more successful in obtaining tenured professorships mid-career than their male peers, relative to their numbers in the field [7].

In the same way any consideration of women’s success in proposing and participating in PI-led missions must discuss their representation on missions relative to their representation in the field as a whole. We can combine the data in the previous section with the age data released earlier this year [4] and cross-reference it with membership statistics obtained from the American Astronomical Society (AAS) [8] to determine how, for example, women planetary scientists have fared. The AAS maintains historical records for the membership as a whole, including planetary, astrophysics, and heliophysics researchers, and kindly provided a snapshot of the AAS Division of Planetary Science (AAS DPS) membership data from the current membership rolls for use in this study.

6.1. Median ages at selection

First, let us look at the case study again, the Discovery Program. In the previous paper, median times since PhD for the key science roles were calculated for the various roles: 28 years for PIs, 32 for DPIs, 18 for the set of PSs and DPSs, 22 for other Co-Is, and 13 for the Participating Scientists. Using a nominal time-to-degree of 28 years, we can calculate that the median ages are therefore 56 for PIs, 60 for DPIs, 46 for PSs and DPSs, 50 for Co-Is, and 41 for Participating Scientists. It must be emphasized here that, for privacy reasons, these ages were not calculated based on birth dates; a given scientist may have taken more or less time to complete his Ph.D.

6.2. Gender balance, varying with age

While these median ages are spread by no more than 20 years, from Participating Scientist to DPI, the proportion of women in the field does vary significantly over these 20 years [9]. Where women make up only 10% of the community, for example, it is not reasonable to expect them to make up more than 10% of the science leadership. So to quantify the underutilization of women in planetary science missions, we must look at the relative numbers of women by age and relate that to the median ages of the key science roles discussed above. For simplicity, we will postulate that the median ages calculated for the Discovery Program correlate adequately to the median ages expected for planetary science as a whole.

Table 1 combines 2009 data from the AAS on the percentage of AAS DPS members that are women in various age groups with data from the current demographic study to show the representation of women on flight missions, relative to their representation in the AAS DPS population at large. AAS DPS May 2009 membership data included 1237 members; 912 gave both gender and birth date. Of the 912, 165 were women, 746 men [10]. AAS DPS membership data from earlier years were not available.

6.3. Women’s participation relative to population

In the Discovery Program the PI role was determined to be filled by scientists with a median age of 56. At 56, 15% of DPS members are women. Across all NASA’s planetary science missions in the past 30 years, only two of the 80 PIs or IPIs are female, giving a percentage of less than three. Comparing 3% to 15%, we conclude that women are underutilized as PIs and IPIs in planetary science by more than a factor of five (see Table 1).

Women are, however, filling the role of PS or DPS about twice as often as their representation in the field would suggest. This may indicate a discrepancy between the role of

<table>
<thead>
<tr>
<th>Role</th>
<th>Median Age [4]</th>
<th>% DPS members in 5 y age bracket who are women</th>
<th>%Planetary Scientists in role who are women</th>
<th>Relative representation of women on planetary science missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI, IPI</td>
<td>56</td>
<td>15</td>
<td>2.6</td>
<td>Underrepresented ~5</td>
</tr>
<tr>
<td>DPI</td>
<td>60</td>
<td>12</td>
<td>10</td>
<td>About the same</td>
</tr>
<tr>
<td>PS, DPS</td>
<td>46</td>
<td>14</td>
<td>26</td>
<td>Overrepresented ~2</td>
</tr>
<tr>
<td>Co-I</td>
<td>50</td>
<td>18</td>
<td>7.2</td>
<td>Underrepresented ~2.5</td>
</tr>
<tr>
<td>Participating Scientist</td>
<td>41</td>
<td>24</td>
<td>8.6</td>
<td>Underrepresented ~3</td>
</tr>
</tbody>
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Co-I, filled by the PI of each mission, and the roles of PS and DPS, filled by the implementing institution with the approval of the PI. The trend is not strong enough to make any conclusions on this issue, however, as women are serving as DPI, a critical and PI-appointed position, at about the same rate as their participation in the field.

Co-Is in Discovery are, on average, about 50 years old. Eighteen percent of DPS members aged 48–52 are female. Only 7% of Co-Is on planetary science missions over the past 30 years have been female. Women are therefore underutilized as Co-Is by a factor of 2.5.

The median age for Participating Scientists is about a decade younger than the median for Co-Is [4]. Over this decade, the proportion of women drops from 24% of all DPS members to 18% of all DPS members. The ratio of women to men in Participating Scientist Programs is 8.6%, less than the expected 24% by nearly a factor of three.

Although women are being tapped for DPI, PS, and DPS positions, women are still underutilized in the roles of PI, Co-I, and Participating Scientist in proportion to their representation in the community at the typical ages that fill those roles. This is an issue for the future of the planetary science community, as today’s Co-Is are tomorrow’s leading PI candidates.

7. Women’s participation over time

Over time the percentage of women selected as Co-I has increased unevenly. The percentage of women selected as Participating Scientists has increased at a more regular rate (see Fig. 3). The two data points shown in the figure for selection of female PIs and IPIs reflect the selection of a woman as a Galileo IPI in 1991, one of the 18 PIs or IPIs selected that year, and the GRAIL PI in 2006, selected during the same time period as Juno and MAVEN. Although the overall statistics are small, it is also interesting to note that five of the six female DPSs have been on missions launched since 1999.

The only comparable data available to illustrate changing demographics in the field of planetary science over this time period, the decadal AAS DPS surveys, indicated that the overall AAS DPS membership was 14% female in 1995 and 23% female in 2005 [10]. More women are joining AAS DPS over time, and, presumably, staying in the field, but they are not yet selected as Co-Is, Participating Scientists, or many of the other leadership positions in similar numbers.

It has previously been shown that the representation of women in broader fields of physical sciences is growing [6,7,9–11]. One way to illustrate the increase of women in planetary science and closely related fields over a longer time period is to review the number of women obtaining doctoral degrees and proceeding to postdoctoral appointments in those fields.

The National Science Foundation’s Survey of Earned Doctorates annually tabulates the demographics of recent PhD graduates and their career path. Planetary science is not a standard field in this survey, but the numbers may be approximated by an examination of the three main fields in which planetary scientists are trained: earth science, astronomy, and physics. In 1999, the first year for which such information is available, 23% of earth science postdoctoral fellows were women, 16% of astronomy postdoctoral fellows were women, and 11% of physics postdoctoral fellows were women. By 2006, the most recent year available, the numbers had increased to 28% for earth science, 23% for astronomy, and 15% for physics [11]

Comparison with historical trends over a larger time scale is limited to discussion of doctoral recipients, which introduces even greater lag time between data collection and selection as Co-I. In 1966, the earliest year available, 3% of earth science doctoral degrees, 5% of astronomy degrees, and less than 2% of physics degrees went to women. Since the first missions in this study were selected in 1979, this cohort of doctoral degree recipients would have been 13 years post-Ph.D., just younger than the average Co-I selected for Discovery missions (and probably not far from the correct age range for the Magellan mission). By 2006, 35% of earth science degrees, 28% of astronomy degrees, and 17% of physics degrees were earned by women [11].

Clearly, the field is changing. The typically lengthy career path to selection as PI means that women are unlikely to be selected in numbers this high for years, but it is probable that numbers of women in mission leadership will continue to grow with the numbers of women in the field.

8. Conclusions

This paper grew out of an attempt to determine the accuracy of the perception that few women are leading NASA planetary science — and, in fact, space science — missions. Although it is popularly held that the number of senior women in the field is too small to support many women PIs, this analysis has shown that the number of women PIs is actually even smaller than it should be, based on the typical age of PI selection and the percentage of women in planetary science at that age. This statement is no less true for Co-Is and Participating Scientists, although women are being selected as DPI and PS at rates comparable to their participation in the field.
The underutilization of women scientists on missions today has consequences for the future. The absolute numbers are quite small — possibly too small to support an equitable number of women likely to propose and serve on missions in the coming years. The pipeline of women gaining mission experience today is not keeping pace with the rate that women are now choosing to stay in the field for postdoctoral studies and beyond. It is not clear why the numbers are so low, particularly at the Co-I and Participating Scientist levels, but this study shows that the representation of women is depressed, and brings the discussion beyond the anecdotal. For a significant number of women to be prepared to lead missions as PI in the next 20 years, they must be selected for Co-I and science roles in greater numbers than the statistics show are true today.

The analysis in this paper is limited by the statistics of small numbers — but the women in planetary science are not. There is no preconception on the part of NASA Headquarters or the author that women should be selected in proportion to their representation in the population as a whole, their participation in the field of planetary science, or their subdiscipline. In fact, it is quite possible that women will lead missions in proportions in excess of their representation in the field, simply because their representation in the field as a whole is currently depressed with respect to their representation in the general population.

The figures presented in this paper definitively show for the first time that, for whatever reason, women are still under-represented in mission leadership at NASA. It would serve the community well to understand the reasons for this, to be sure that needed leadership and talent are not being overlooked when selecting teams to plan and execute the challenging space science missions proposed in years to come. Exploration of the Solar System is a task that requires the very best scientists, engineers, and managers, regardless of gender.

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