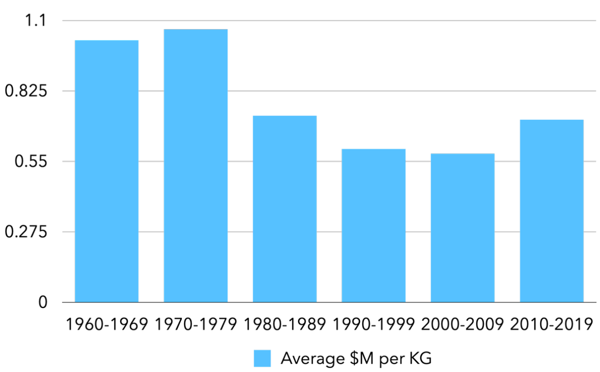
THE PEOPLE EQUATION IN PLANETARY SCIENCE MISSIONS. D. M. Reinecke[1] and J. A. Vertesi[2], [1] Princeton University, Department of Sociology, 327 Wallace Hall, Princeton, NJ 08540, reinecke@princeton.edu, [2] Princeton University, Department of Sociology, jvertesi@princeton.edu.

Introduction: Robotically exploring the solar system ranks amongst the biggest of big science experiments with budgets into the billions of dollars. Large price tags for space missions, especially in recent years, automatically invite political controversy, raise the lobbying costs for new starts, and are popular targets for cuts when money becomes tight. Such costs have remained high despite repeated efforts to lower the costs of space exploration. Figure 1 averages the development costs per kg for planetary missions by decades, showing that after a considerable decline in the first two decades of space exploration, development costs have remained relatively flat since the 1980s[1].

Figure 1: Average Development Costs per Kg for Planetary Missions by Decade (in FY 2019 $M/Kg)



Why are space science experiments so expensive? Conventional answers generally highlight a combination of the rocket equation (e.g., accessing outer space is difficult and expensive using conventional chemical propulsion) and the first-mover disadvantage associated with discovery science (e.g., many missions have never been tried before, requiring considerable upfront R&D and often the minimal reuse of existing designs and parts) [2,3]. Such explanations tend to cast big science costs as outside the control of scientists and therefore naturalizes these expenditures as the unavoidable "costs of doing business."

These explanations miss that mission funding serves a variety of purposes beyond just advancing next-generation science. Building upon our historical and ethnographic observations of space science teams, we make several empirical observations of mission costs. The majority of the funds in planetary science missions go to paying for people and supporting their organizations rather than material or machine costs. This labor-centered or people-centered view of space science costs surfaces many problems often ignored by funding authorities or our conventional views on big science costs.

The People Equation: "The primary cost in any NASA project is wages and salaries. It is not taxes, basic commodities, not profits," once observed a leading NASA project manager [4]. Then and now, anywhere from 2/3 to 3/4th of a total mission lifecycle cost is devoted to direct labor and organizational overhead costs [5]. This relative ratio has stayed fixed since the 1960s as far as we can observe in budgetary microdata for individual missions. Such observations accord with the "standing army" metaphor often ascribed to mission personnel and recent surveys of planetary scientists, which show that 43% of surveyed scientists earn a portion of their salaries from NASA missions [6]. Many within the planetary science community look to highly competitive mission funds to advance technology, support researchers, contribute to institutional overhead, *and* do good science. NASA has generally resisted efforts to separate and adequately fund these different functions despite repeated calls going back to the 1960s from the space science community [7].

With this people-centered view in line, mission planners have discovered that the most reliable way for missions to keep costs low is not to cut back on science or technology or reuse existing designs but to keep the team and associated overhead small from the outset [8]. As leading NASA cost estimators recognize, critiquing parametric cost models that use spacecraft mass or other technical measures, "almost all the cost of aerospace systems is labor at some point in the supply chain. Weight does not cause cost just because more mass is more expensive than less mass. It can only cause cost insofar as more mass requires more labor" [9]. Such lessons are often not lost on project managers of cost-capped missions. With the advent of faster, better, cheaper missions in the 1990s, nearly all successful missions principally managed their constrained budgets by dramatically reducing team sizes and organizational lines of authority [10]. Indeed, many enterprising institutions in the planetary space that emerged in the 1990s, such as Arizona's Lunar & Planetary Laboratory, the Southwest Research Institute, or JHU's Applied Physics Laboratory, have offered a competitive advantage over long-time rivals like Caltech's JPL through reduced overhead charges [11].

Like many other labor-intensive industries, planetary science missions have also tried to manage cost through new regimes of precarious labor [12] that disproportionately shift the risks of the profession onto the workers themselves. Rare is the scientist we interviewed who works full time for any single institution, project, or mission. Instead, many scientists and technical workers must piece together full-time equivalents from multiple sources, many of which are funded on short time scales or are highly uncertain. Moreover, the practice of cost-capping mission budgets or the common threat of cancellation or sequestration frequently leads to pressures to "donate labor" or underreport work hours. As a 2006 SSB study of small-PI led missions observed, "interviewees estimated the understatement for just the amount of unrecorded-uncompensated labor and recorded-uncompensated labor to be at least 20-30 percent" [13]. Many scientists we interviewed expressed "guilt" or "fear of judgment" in recording their labor hours, especially under financial pressure or in early pre-phase A concept studies that are frequently self-funded.

Conclusion: The evidence here suggests that the majority of costs in space science experiments go to people rather than machines. This suggests that dramatic cost savings on future experiments can likely only come through concomitant reductions in the scientific workforce or growing precarity—an outcome that will likely undermine future space science capabilities. Unlike many other labor-intensive industries in the wider economy, there are no easy ways to automate the complex labor of building and operating new missions. Furthermore, there is a noticeable disconnect in how the scientific community prioritizes future observations in terms of science return while often minimizing problems of institutional support. Recent calls in the Astro2020 recognizing that the "scarcity of funding threatens" not only "capacities…essential to bold scientific advancement" but also "the culture of workplaces and the training of the next generation" are an essential first step to realigning funding realities with the increasingly diversified needs of the space science workforce [14].

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