nature astronomy

ARTICLES

https://doi.org/10.1038/s41550-021-01341-z

Check for updates

Closing the gender gap in the Australian astronomy workforce

Lisa J. Kewley [1,2] ✉

Australian data show that women's participation at the senior levels in astronomy remains at historically low levels, and that women depart astronomy at two to three times the rate of men. We present data-driven workforce models that predict the future trajectories of the gender fraction in academia, given different hiring and retention initiatives. If the status quo is maintained, the fraction of women at all levels will be below 30% for at least 60 years. If gender parity in hiring and retention targets are adopted, the fraction of 33% women at all levels can be achieved in 20 years. If affirmative action is introduced, the fraction of 33% and 50% women at all levels can be achieved in 10 and 25 years, respectively. Academic institutions need to (1) undertake exit surveys to understand why women depart, (2) adopt retention targets and initiatives to retain women, (3) develop equal hiring at all levels, and (4) support the advancement of women into senior positions.

In astronomy, the fraction of women at the senior levels in academia remains critically low worldwide; the fraction of senior women in astronomy in the US, Germany, Canada, Australia, China and the UK has remained at or less than 20% for several decades, despite 30–40% of PhDs in astronomy being completed by women internationally over the same timeframe[1–8]. Astronomy labour market models suggest that women depart astronomy at a rate 3–4 times higher than men, but international statistics on the fraction of women and men leaving astronomy are still lacking[9].

Women in physics and astronomy report that their careers progress more slowly and that they received fewer career resources and opportunities than men[7]. Widespread implicit bias towards men exists in hiring[10], writing referee reports of papers[11], citing papers[12], inviting speakers for colloquia[13] and conferences[14], student assessments of teaching[15], allocation of grants[16], awards[17,18] and telescope time[19–21]. These implicit biases have been shown to play a role in the gender gap in science by impacting recruitment rates and promotion rates[10,22].

The Astronomical Society of Australia Pleiades Awards, introduced in 2014, triggered widespread change across Australian astronomy institutions. Based on the UK Athena SWAN model, Pleiades awards are given to organizations for taking concrete actions to advance the careers of women and close the gender gap. Initiatives introduced include longer-term (five-year) postdoctoral positions with part-time options, support for return to astronomy research after career breaks, increasing the fraction of permanent positions relative to fixed-term contracts, offering women-only permanent positions, recruitment of women directly to the professorial levels, and mentoring of women for promotion to the highest levels[23]. If these initiatives are making an impact, we should now see a rise in the number of women at the middle and senior levels in Australian institutions.

Australian universities recruit into a standardized set of academic levels similar to the UK and US systems. Postdoctoral researchers who have between 0–5 years experience post-PhD are hired into level A. Level B is equivalent to the US assistant professor level, and is for researchers with more than 5 years experience post-PhD. Level A and B positions are usually fixed-term positions. Level C is equivalent to the US associate professor level and may be either fixed-term or permanent (tenured). Level D is equivalent to the US professor level and is usually permanent. Level E is a distinguished professor level and is permanent. Astronomers usually retire from levels D or E.

We analyse the current fraction of women at all levels using 2019 demographics data from the Mid-Term Review of the Australian Astronomy Decadal Plan[8]. In this Article, we use the term 'women' to represent all people who identify as women and the term 'men' to represent all people who identify as men. The fraction of women PhD students and postdocs is currently 30–37%, while the fraction of women at more senior levels is below 20% (Fig. 1). These fractions are not caused by the larger fraction of women on fixed-term contracts compared to men because at level B and above, the proportion of individuals whose positions are permanent is higher for women than for men, even though there are relatively fewer women (Fig. 2). The higher proportion of women on contract positions is caused by the larger fraction of women at the lower levels, where fixed-term positions dominate the astronomy labour market. We also find no statistically significant difference in the promotion rates for Australian universities with astronomer departments (see Table 1 and the analysis in the Methods).

To gauge how well men's and women's careers are progressing from the junior to senior levels through the pipeline, we define a 'pipeline stress' statistic as the percentage change (ΔS_i) of the number of women and men at each level transition, relative to their cohorts:

$$\Delta S_i = \frac{< n_i > - < n_{i+1} >}{< n_i >}, \quad (1)$$

where $<n_i>$ is the average number of women or men per year at level i, and $<n_i> = n_i/t_i$ where n_i is the total number of women or men at level i, and t_i is the average amount of time spent at level i. If $<n_{i+1}>$ is greater than $<n_i>$, there are sufficient positions at level $i+1$ to accommodate all promotions from level i, and we set ΔS_i to zero to reflect zero pipeline stress. The pipeline stress statistic, shown in Fig. 3, gives the proportion of people leaving the academic pipeline

[1]Research School for Astronomy & Astrophysics, Australian National University, Canberra, Australian Capital Territory, Australia. [2]ARC Centre of Excellence for All-Sky Astrophysics in 3 Dimensions (ASTRO 3D), Canberra, Australian Capital Territory, Australia. ✉e-mail: Lisa.Kewley@anu.edu.au

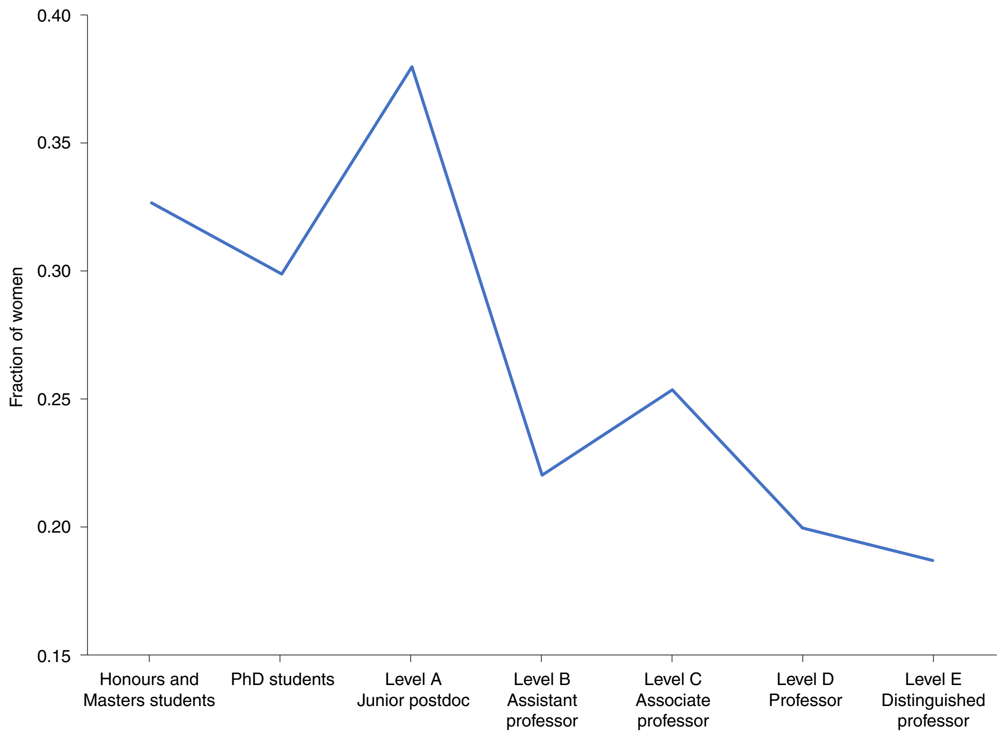

Fig. 1 | Fraction of women at university levels in Australian astronomy. The fractions encompass all contract and permanent staff in Australian astronomy in December 2019. Levels A–E correspond to postdoc, assistant professor, associate professor, professor and distinguished professor in the US system.

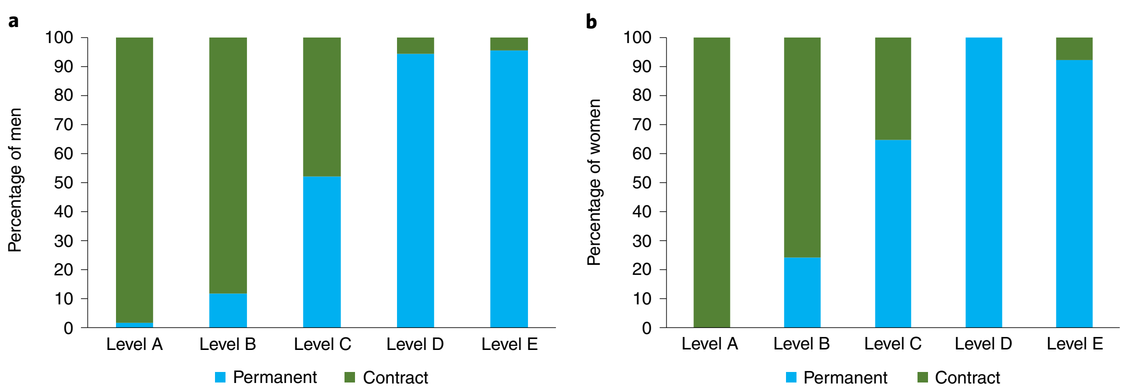

Fig. 2 | Women and men on fixed-term contracts and permanent positions in Australian astronomy. a,**b**, More men (**a**) than women (**b**) are on fixed-term positions at levels B, C and D, indicating that a gendered difference in fixed-term versus permanent positions is not responsible for the gender gap in Australian astronomy.

at each career transition. A total of 62% of women and 17% of men at the postdoc level A are no longer in the pipeline at the assistant professor level B. A similar trend occurs just before the professor level, with 47% of women and 28% of men departing the pipeline at the associate professor level C. Women are leaving Australian astronomy at least three times the rate as men at the postdoc level, and almost double the rate of men at the associate professor level.

To determine whether the gender gap will close with time and to quantify the impact of the high rate of departures of women on the future astronomy workforce, we have created nationwide gender workforce models. The models are data-driven, calculating the number of men and women at each level per year using the current astronomer level populations, with given promotion rates, hire rates, retirement rates, and departure rates for men and women at each level.

We first consider the impact of maintaining the status quo. Figure 4a shows the predicted gender fractions at each level compared to the Australian Astronomy Decadal Plan target of 33% women at all levels and a more ambitious target of 50% women at all levels. If the current promotion rates, hire rates, retirement rates and departure rates are maintained, the Decadal Plan target for women cannot be achieved at any level within 60 years, and likely indefinitely.

Ambitious new initiatives are required even to reach the fraction of 33% women at all levels. To equalize the flow of women and men away from Australian astronomy, we introduce a retention balance target of 50:50 departures relative to cohorts, that is, the number of women departing per year relative to the total number of women equals the number of men departing per year relative to the total number of men in the workforce. Figure 4b shows that while the

Table 1 | Mean promotion rates in STEMM at Australian astronomer institutions

Level	Promotion rate		Mean age	
	Female (%)	Male (%)	Female	Male
A	4.0 ± 0.2	3.8 ± 0.3	38.2 ± 0.1	36.5 ± 0.1
B	6.5 ± 0.4	6.6 ± 0.4	44.1 ± 0.1	43.1 ± 0.1
C	6.7 ± 0.5	6.1 ± 0.4	48.7 ± 0.1	48.2 ± 0.1
D	7.3 ± 0.7	6.3 ± 0.4	54.1 ± 0.1	54.7 ± 0.1

In Australia, astronomers are usually employed within physics departments or physics and astronomy departments. We refer to institutions that employ astronomers as 'astronomer institutions' and departments that contain astronomers as 'astronomer departments'.

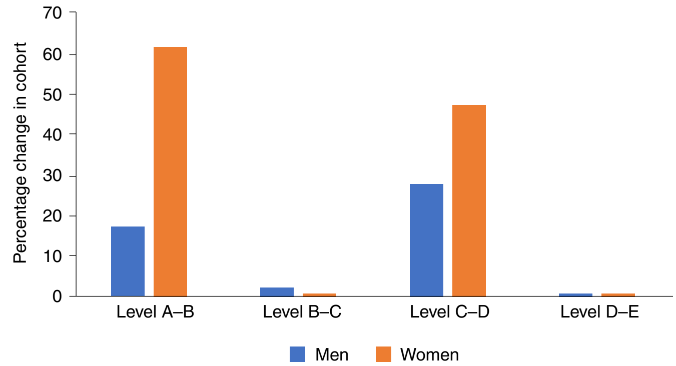

Fig. 3 | The pipeline stress statistic is defined as the percentage change in the number of men and women positions across each level transition, relative to cohorts. Significantly more women than men exit astronomy at the transitions between levels A to B (postdoc to assistant professor) and C to D (associate professor to professor). Pipeline stress is zero for women for the level B to C transition, and for both men and women for the level D to E transition because there are sufficient positions to allow promotion across these levels without departures from the field.

fraction of women at all levels increases with time, the 33% target is not achieved at levels B through E within 60 years. The low promotion rates and low recruitment rates of women maintain the small fractions of women at these levels.

Some Australian astronomer institutions and organizations have introduced hiring targets for women. The ARC Centre of Excellence in All-Sky Astrophysics in 3 Dimensions (ASTRO 3D, https://astro3d.org.au) has a target of 50:50 women at all levels in the centre by 2021, and has maintained 50% women hires into levels A and B since 2017. The ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav, https://ozgrav.org) aims to attain 50% women postdocs into levels A and B by 2021.

If 50:50 hiring is introduced across all Australian astronomer institutions at all levels, our models predict that the Decadal Plan target of 33% women at all levels will be achieved in 25 years, by 2045 (Fig. 4c). The slow rise in the fraction of women, even with 50:50 hiring, is caused by the large departure rates of women, which directly impact the fraction of women at each level as well as the pipeline for promotions. If both 50:50 hiring and balanced retention are achieved, the Decadal Plan target of 33% can be achieved within a shorter timeframe of 20 years, and the target of 50% can be achieved at most, but not all, levels in approximately 45 years, by 2065 (Fig. 4d).

Affirmative action produces faster rises in the fraction of women. The Australian Commonwealth Equal Opportunity for Women in the Workplace Act 1999 states that all employers with 100 or more employees and all higher education institutions must implement an 'affirmative action program' to promote equal opportunity for women. State-level Equal Opportunity Acts allow many universities to advertise women-only positions to correct their historic gender gap. The Workplace Gender Equality Act 2012 further requires universities to lodge reports each year containing information relating to various gender equality indicators. In line with these requirements, several astronomer institutions have introduced women-only hires into level C, D and E positions. The University of Sydney has adopted university-wide targets of 45% women at level D, 40% women at level E and at least 40% women appointments to permanent academic positions, with all targets to be achieved by 2025. The University of Sydney School of Physics includes astronomy and has exceeded these targets with 7/9 women appointments to permanent positions over the past three years.

To model the impact of such affirmative action policies, we consider an 'affirmative action and retention' model where we include 50:50 retention. We adopt the Centres of Excellence policy of 50:50 hires into levels A and B, and the University of Sydney School of Physics rate of 78% women appointments to permanent level C–E positions. With this combination of initiatives, the fraction of 33% women can be achieved in just 11 years, and the fraction of 50% women can be achieved in 25 years (Fig. 4e).

The fraction of women at higher levels in Australian astronomy has remained low for over two decades, despite a large pipeline at the lower levels, and major diversity and culture initiatives introduced across Australia as part of the Pleiades Awards programme. We have shown that current targets of 33% or 50% women at all levels is unattainable at current hiring, promotion and departure rates. The ongoing low fraction of women is caused by three factors: (1) significantly more women than men departing astronomy between levels A to B, and C to D; (2) low promotion rates at Australian universities; and (3) continued inequitable hiring into all levels.

Discussion

We recommend that Australian astronomer departments and organizations introduce retention and hiring targets as well as develop strategies to reach those targets. Because promotion rates are controlled by broader university procedures, and these rates are equal for men and women in science, technology, engineering, mathematics and medicine (STEMM) at Australian universities, the two main ways that astronomer institutions can improve their binary gender diversity are (1) to increase the rate at which women are hired and (2) to retain more women in astronomy.

Standard merit-based appointments have failed to increase the fraction of women at the highest levels. This failure may be caused by direct implicit bias in hiring committee decisions and/or a type of 'legacy implicit bias'. Even if recruitment committees have extensive recent implicit bias training and are unbiased in their assessments, implicit bias towards men has already played a hidden 'legacy' role in the metrics that are used to judge and rank candidates. Bias has been proven in the referee reports of papers[11], paper citations[12], speaker invitations[13,14], grant and award decisions[16–18], and allocation of telescope time[19–21]. It is unclear how to fully correct merit-based rankings for these biases. Consideration of track record relative to opportunity improves women's grant outcomes, and should be made an integral part of recruitment and promotion processes. Committees could require candidates to nominate their top 3 or 5 publications that the committee reads, and/or require candidates to submit a pre-recorded webinar on their research and skills that the committee watches. Both initiatives could help shift the focus away from metrics and towards the expertise and skills required for the position.

Hiring rates at the lower levels are strongly impacted by the two Australian Research Council (ARC) Centres of Excellence,

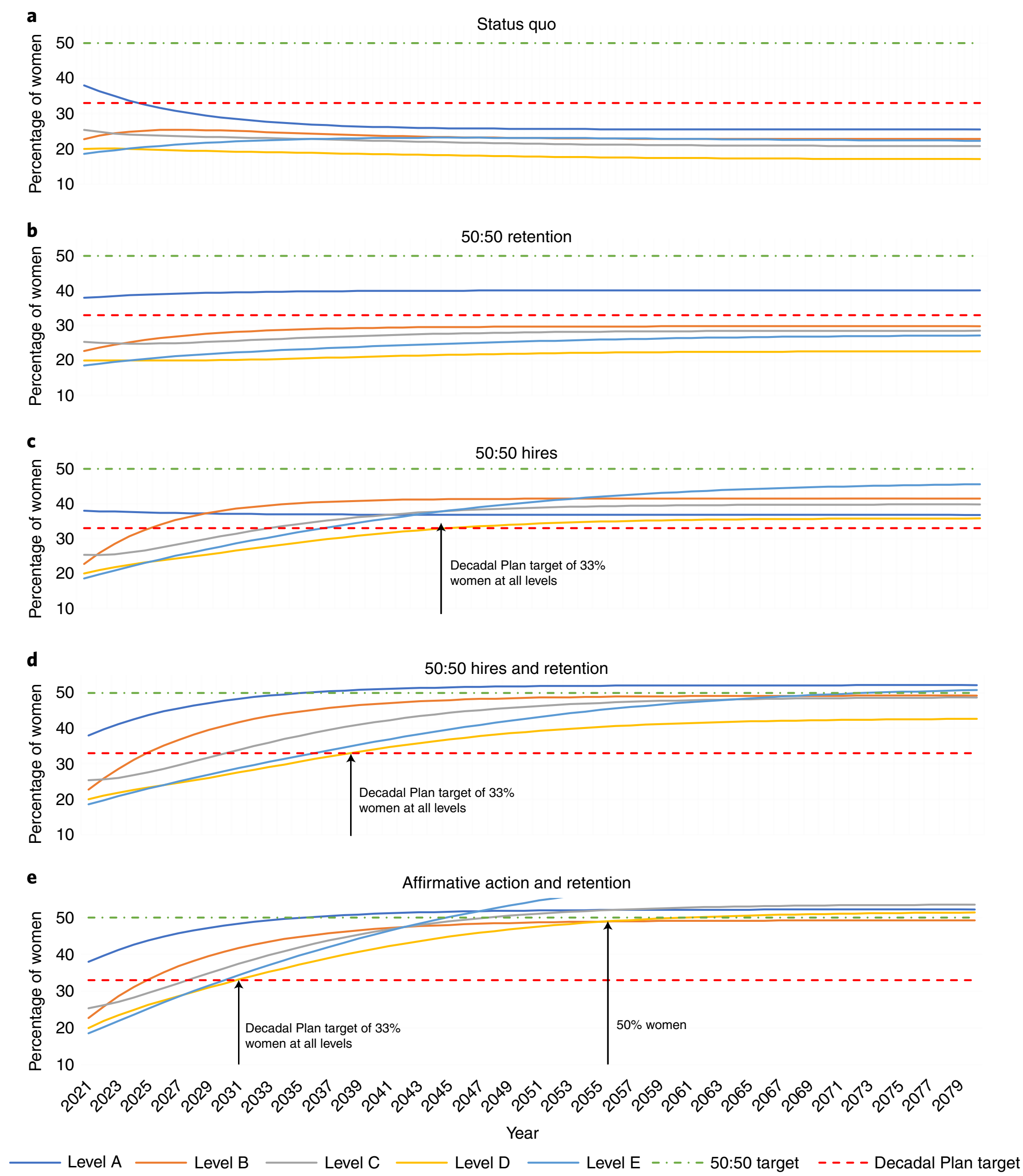

Fig. 4 | Predictions of our astronomy workforce models for the percentage of women at each level over 60 years. a–e, Predictions are shown for the percentage of women at each level for the status quo (**a**), 50:50 retention (**b**), 50:50 hiring (**c**), both 50:50 hiring and retention (**d**) and affirmative action (**e**).

which between them account for more than half of the postdocs hired in Australia. The 50:50 hiring rates of these centres should be maintained. We recommend that astronomer organizations take this further by introducing balanced 50:50 hiring at all levels, which can be accomplished in multiple ways. Some departments, such as the Research School for Astronomy & Astrophysics at the Australian National University, fill two positions simultaneously by hiring from separate shortlists for men and women. Other organizations have adopted policies that stipulate that if a man is hired during one recruitment round, a woman must be hired during the next round through a female-only-position advertisement. Both methods avoid the implicit bias towards male applicants that is notoriously difficult to remove from hiring committees and the metrics they use to evaluate merit. However, these 50:50 methods are slow to increase the fraction of women over time in large departments.

Faster change in the number of women is being achieved in some departments through merit-based female-only hires. Open and transparent female-only hires avoid implicit bias towards male applicants. At the same time, female-only hires avoid effort spent by men applying for positions that are advertised as open hires but are actually aimed towards hiring women to correct historic gender imbalances.

One of the main concerns regarding female-only positions is that the recruited female hired may be labelled as a 'token' woman. This concern can be mitigated by making female-only positions highly prestigious to encourage outstanding women in the field to submit applications. These women may not apply if the position is an average (non-prestigious) open hire. A position can be made prestigious by extending the length of the term, adding a fellowship to a tenure-track or permanent position, and/or increasing the salary or benefits package above the standard level. Another proven method to overcome the token woman label is to advertise for multiple female positions simultaneously. This method sends a signal that the advertising department is female-friendly, and therefore may increase the number of high-quality applicants that meet the selection criteria. Female-only hires have typically been at levels C or D, which impact the level E gender balance only through promotion and retention.

Retention targets and policies will require exit surveys to understand the reasons why women are leaving individual Australian astronomy departments and organizations in larger numbers than men (relative to their cohorts), as well as corrective action to ensure that women are retained in astronomy at equal rates as men, relative to their cohorts. The pipeline stress statistic can help inform institutions on which academic level(s) to target retention initiatives. Attrition at the transition between levels A and B (equivalent to US postdoc and junior faculty levels) is a persistent problem worldwide. Uncertainty in obtaining long-term employment and dual-career issues are the most common reasons cited by both men and women who have departed astronomy[24]. Women astronomers in dual-career couples are more likely to leave astronomy than men astronomers to ensure a job for a spouse or partner in the same geographical area[25]. Longitudinal studies tracking the progress of physics PhD students indicate that women depart more frequently than men due to a lack of women role models who are seen to have a good balance between their family life and academic career, a dislike of the culture or atmosphere, and doubts that they will attain a senior position[26]. These concerns may also be relevant to astronomers, who have few women role models at senior positions. Women in astronomy also experience sexism and microaggression at a higher rate than men[27,28]. Both sexism and microaggression must be addressed at the departmental level to ensure an inclusive and welcoming culture for all astronomers.

Intersectionality plays an important role in the experience of women in astronomy. Women of colour experience more sexism and microaggression than white women[29]. A 2019 report on the workplace for LGBT+ physical scientists prepared by the UK Institute of Physics, Royal Astronomical Society and Royal Society of Chemistry concluded that nearly one-third of UK physical scientists from sexual and gender minorities have considered leaving their jobs because of their workplace climate[30].

Successful retention policies will need to include, but are not limited to: (1) increasing the number of women in senior positions through promotion support and recruitment; (2) improving and celebrating work life balance for all department members; (3) clear action against sexism, insults, microaggression, exclusionary behaviour and other factors that produce a poor work culture and atmosphere for women and other minorities; (4) help for partners of astronomers to obtain positions in the same geographical location through internal or external recruitment agencies; and (5) more permanent and less fixed-term positions. Only when these issues are addressed, will we be able to stem the high departure rate of women.

Here, we have applied forward modelling to the Australian astronomy workforce. We have shown that workforce forward modelling is highly effective in assessing the future impact of various diversity policies and initiatives. Forward modelling should be applied by universities, organizations and departments to assess the feasibility of stated gender targets within specific timescales and to inform new policies and practices to achieve true binary gender diversity.

Methods

We estimated the Australian astronomy gender gap using data reported by the 15 Australian institutions and organizations that contain astronomers for the 2019 Mid-Term Review of the Australian Astronomy Decadal Plan[8]. Universities included in these statistics are the Australian National University, CSIRO Astronomy & Space Science, Curtin Institute of Radio Astronomy, Macquarie University, Monash University, Swinburne University of Technology, University of Adelaide, University of Melbourne, University of New South Wales, University of Queensland, University of Southern Queensland, University of Sydney, University of Tasmania, University of Western Australia and the University of Western Sydney. The data from these 15 organizations provide a complete census of the Australian astronomy community.

Our models require an estimate of the number of external hires from outside Australian universities. For the models, we estimated external recruitment rates by searching the American Astronomical Society Jobs Register for advertisements based in Australia for April 2019–March 2020, before the beginning of the Australian COVID-19 shutdowns. Over this period, 18 positions in Australia were advertised. Where the academic level was given in the advertisement, we assumed that the position was filled at the advertised level. Where the advertised academic level was given as a range, we assumed that the advertisement was filled at the lower end of the range 70% of the time. For the status quo models, we assumed that the fraction of women hired into these positions was consistent with the current gender fractions at each level (Fig. 1). Australians are strongly encouraged to move overseas after their PhD to gain experience and expand their collaborations. Therefore, the majority of advertised positions are filled by astronomers from outside Australia. We assumed that these positions were filled with people residing outside Australia. If 30% of these positions are filled by Australians (who are already included in the Australian population statistics), the gender fraction models change by 4% on average towards lower final female fractions.

In Australia, universities require jobs to be advertised unless there are extenuating circumstances. Extenuating circumstances are typically continuations of existing appointments, and are already accounted for in our model population statistics. Sometimes astronomers are hired into Australian astronomy through non-astronomy avenues such as university-wide fellowships, or through dual-career hiring programmes. We have verified that if 20% of Australian astronomy jobs are not advertised on the American Astronomical Society Jobs Register, the change in gender fractions over time is minimal, with an average 1% change towards larger female fractions.

The ARC adds to astronomy recruitments and promotions through Discovery Early Career Awards (DECRAs) and Future Fellowships. We used the 2009–2019 ARC Selection Outcome Reports to calculate the average number of men and women offered astronomy fellowships per year per level. Astronomy receives an average of 4 DECRAs per year with 39% awarded to women, with the ARC reported distribution of 91% awards at level A, and the remaining awards at level B. An average of 7 Future Fellowships per year are allocated to astronomers, with 28% awarded to women. Future Fellowships are taken at levels C, D and E with average published distributions of 34%, 36% and 31%, respectively.

We used the ARC reported fraction of international to domestic successful fellowship applicants to determine the fraction of DECRAs and Future Fellowships awarded to astronomers who are already in the Australian workforce (counted as promotions) compared with the fraction of DECRAs (36%) and Future Fellowships (17%) awarded to astronomers from outside the Australian workforce (counted as new hires).

Promotions in Australian universities are conducted at the university-wide or college level, which usually include applications across the sciences, or across all areas. The astronomy promotion rate is assumed to be the average promotion rate for STEMM, given in the Science in Australia Gender Equity (SAGE) applications from the Australian Academy of Science using applications from organizations that contain astronomers (the Australian National University, Curtin University, University of Melbourne, Monash University, Swinburne University, University of Sydney, University of Tasmania, University of Western Sydney, University of New South Wales, University of Queensland and University of Western Australia). Table 1 gives promotion rates in terms of percentage of cohort at the level being promoted from (that is, a level A–B women promotion rate of 4% means that 4% of level A women are promoted per year to level B). Error ranges shown are the standard error of the mean. The promotion rates are equal for men and women at all levels, within the errors. We checked the time spent at each level using the Higher Education Research Data Collection (HERDC) age data for people doing teaching and research in the physical and natural sciences (Table 1). In the HERDC, level E data have been added to level D data. On average, women in science academia are 2 years older than men at level A, 1 year older at level B, 0.5 years older at level C, and are 0.5 years younger than men at level D–E. It is unclear whether women complete their PhDs and enter the workforce later than men, or whether women spend longer at level A than men. The difference in mean ages provides a rough estimate of the time spent at each level. On average, women spend 5.9, 4.6 and 5.4 years achieving levels B, C and D–E compared with 6.6, 5.1 and 6.5 years for men. We found no evidence that men experience preferential treatment for promotions than women, and we found no evidence that men spend less time at academic levels (above level A) than women.

The number of retirements per year ($R(t)$) is constrained by the age distribution of academics from the HERDC. We assumed that the retirement rate is 5% per year, consistent with the current national average for research and teaching staff in STEMM. We further assumed that the fraction of women and men retiring relative to their cohorts was equal, and that retirements occured from level E.

We assumed that the total astronomer population (currently 100, 66, 67, 45, 70 people at levels A through E) will remain constant with time, while the proportion of men and women varies with time through recruitments, promotions and retirements. The total departure rate $D_i(t)$ from each level i is then:

$$D_i(t) = H_i(t) - P_{i+1}(t) + P_i(t) \quad (2)$$

where $i = 1, \ldots, 5$, corresponding to levels A, B, C, D and E, $H_i(t)$ is the number of hires into level i per year, $P_i(t)$ is the number of promotions into level i per year, and $P_{i+1}(t)$ is the number of promotions into the next level $i+1$ per year. At level A ($i = 1$), $P_i(t) = 0$, and at level E ($i = 5$), $P_{i+1}(t) = R(t)$. The total departure rate includes astronomers who depart Australian astronomy to begin positions overseas as well as astronomers who leave the field of astronomy. Our models are not sensitive to, and cannot discriminate between, these two scenarios. We do not have sufficient data to estimate the relative ratio of astronomers who begin positions overseas and those who leave astronomy.

The relative fraction of women and men departing astronomy per year at each level relative to their cohort is given by S_i (equation (1)). To calculate S_i, we used the natural and physical sciences age data from the HERDC to calculate the total amount of time spent at each level, based on the mean age at each level. According to these data, the time spent at each level is approximately equal (6 ± 0.5 years), with no statistically significant difference between men and women. Therefore, $t_{i+1} = t_i$ and equation (1) becomes simply $\Delta S_i = \frac{n_i - n_{i+1}}{n_i}$.

Data availability

The data that support the plots within this paper and other findings of this study are available from the Mid-Term Review of the Australian Astronomy Decadal Plan 2016–2025 supplementary data (https://www.science.org.au/supporting-science/science-policy-and-analysis/decadal-plans-science/), the Australian Research Council DECRA and Future Fellowships Outcome Reports (https://www.arc.gov.au/grants/grant-outcomes/selection-outcome-reports), the Australian Academy of Science SAGE proposal database (https://www.sciencegenderequity.org.au/cohort-applications/), the Astronomy Jobs Register (https://jobregister.aas.org) and the Higher Education Research Data Collection (https://www.education.gov.au/higher-education-research-data-collection). These data are also available from the author upon reasonable request. Source data are provided with this paper.

Code availability

The Australian astronomy workforce code calculations and input data are fully described in the Methods. The code, written in the data language IDL, is available upon request from the author.

Received: 8 October 2020; Accepted: 4 March 2021;
Published online: 19 April 2021

References

1. Shuhua, Y. et al. Status of women astronomers in China. In *Highlights of Astronomy, XXIInd General Assembly of the IAU 1994* Vol. 10, 105–106 (Cambridge Univ. Press, 1995).
2. Reid, M. A. & Matthews, B. C. Women in Canadian astronomy: fifteen years of hard data. *STATUS* https://aas.org/sites/default/files/2019-09/StatusJune07.pdf (AAS, 2017).
3. Cesarsky, C. & Walker, H. Head count: statistics about women in astronomy. *Astron. Geophys.* **51**, 2.33–2.36 (2010).
4. Fohlmeister, J. & Helling, C. Careers in astronomy in Germany and the UK. *Astron. Geophys.* **55**, 2.31–2.37 (2014).
5. Wyithe, S., Asplund, M., Bok, D., Kewley, L. & Staveley-Smith, L. *Decadal Plan for Australian Astronomy 2016–2025* (Australian Academy of Science National Committee for Astronomy, 2016); https://go.nature.com/3sIg7o6
6. Primas, F. Promoting gender equality in the European astronomical community. *Nat. Astron.* **3**, 1075–1079 (2019).
7. Porter, A. M. & Ivie, R. *Women in Physics and Astronomy, 2019* (American Institute of Physics, 2019); https://www.aip.org/statistics/reports/women-physics-and-astronomy-2019
8. Staveley-Smith, L., Davis, T. A. M., Karakas, A., Tinney, C. & Trott, C. *Decadal Plan for Australian Astronomy 2016–2025: Mid-Term Review* (Australian Academy of Science National Committee for Astronomy, 2019); https://go.nature.com/3ues3hS
9. Flaherty, K. The leaky pipeline for postdocs: a study of the time between receiving a PhD and securing a faculty job for male and female astronomers. Preprint at https://arxiv.org/abs/1810.01511 (2018).
10. Moss-Racusin, C. A., Dovidio, J. F., Brescoll, V. L., Graham, M. J. & Handelsman, J. Science faculty's subtle gender biases favor male students. *Proc. Natl Acad. Sci. USA* **109**, 16474–16479 (2012).
11. Helmer, M., Schottdorf, M., Neef, A. & Battaglia, A. Gender bias in scholarly peer review. *eLife* **6**, e21718 (2017).
12. Caplar, N., Tacchella, S. & Birrer, S. Quantitative evaluation of gender bias in astronomical publications from citation counts. *Nat. Astron.* **1**, 0141 (2017).
13. Nittrouera, C. L. et al. Gender disparities in colloquium speakers at top universities. *Proc. Natl Acad. Sci. USA* **115**, 104–108 (2018).
14. Martin, J. L. Ten simple rules to achieve conference speaker gender balance. *PLoS Comput. Biol.* **10**, e1003903 (2014).
15. Fan, Y. et al. Gender and cultural bias in student evaluations: why representation matters. *PLoS ONE* **14**, e0209749 (2019).
16. Viner, N., Powell, P. & Green, R. Institutionalized biases in the award of research grants: a preliminary analysis revisiting the principle of accumulative advantage. *Res. Policy* **33**, 443–454 (2004).
17. Yifang, M., Oliveira, D. F. M., Woodruff, T. K. & Uzzi, B. Women who win prizes get less money and prestige. *Nature* **565**, 287–288 (2019).
18. Lunnemann, P., Jensen, M. H. & Jauffred, L. Gender bias in Nobel Prizes. *Palgrave Commun.* **5**, 46 (2019).
19. Reid, N. I. Gender-correlated systematics in HST proposal selection. *Publ. Astron. Soc. Pac.* **126**, 923–934 (2014).
20. Patat, F. Gender systematics in telescope time allocation at ESO. *The Messenger* **165**, 2–9 (2016).
21. Spekkens, K., Cofie, N. & Crabtree, D. Sex-disaggregated systematics in Canadian time allocation committee telescope proposal reviews. *Proc. SPIE* **10704**, 107040L (2018).
22. Régner, I., Thinus-Blanc, C., Netter, A., Schmader, T. & Huguet, P. Committees with implicit biases promote fewer women when they do not believe gender bias exists. *Nat. Hum. Behav.* **3**, 1171–1179 (2019).
23. Kewley, L. J. Diversity in Australian astronomy. *Nature* **3**, 1067–1074 (2019).
24. Arka, I. The psychological aspects of a well-known issue. *Nat. Astron.* **2**, 16–19 (2018).
25. Ivie, R., White, S. & Chu, R. Y. Women's and men's career choices in astronomy and astrophysics. *Phys. Rev. Phys. Educ. Res.* **12**, 020109 (2016).
26. Whitelegg, E., Hodgson, B. K., Scanlon, E. & Donovan, C. Young women's perceptions and experiences of becoming a research physicist. In *Proc.12th Int. Conf. of Women Engineers and Scientists* Paper no. 167 (Open Univ., 2002).
27. Barthelemy, R. R., McCormick, M. & Henderson, C. Barriers beyond equity: an exploratory study of women graduate students' career pathways in astronomy. *Int. J. Gender Sci. Technol.* **7**, 57–73 (2015).
28. Barthelemy, R. S., McCormick, M. & Henderson, C. Understanding women's gendered experiences in physics and astronomy through microaggressions. In *Phys. Educ. Res. Conf. Proc.* **12**, 020119.1-14 (APS, 2016).
29. Clancy, K. B. H., Lee, K. M. N., Rodgers, E. M. & Richey, C. Double jeopardy in astronomy and planetary science: women of color face greater risks of gendered and racial harassment. *J. Geo. Res. Planets* **122**, 1610–1623 (2017).
30. *Exploring the Workplace Climate for LGBT+ Physical Scientists: Report by the Institute of Physics, Royal Astronomical Society and Royal Society of Chemistry* (IOP, 2019); https://ras.ac.uk/education-and-careers/exploring-workplace-lgbt-physical-scientists

Acknowledgements

L.J.K. is supported by the Australian Research Council Centre of Excellence for All-Sky Astrophysics in 3 Dimensions (ASTRO 3D), through project number CE170100013. I acknowledge the Australian Academy of Science SAGE program, the Australian Research Council reports, the Higher Education Research Data Collection, and the American Astronomical Society Jobs Register.

Competing interests

The author declares no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41550-021-01341-z.

Correspondence and requests for materials should be addressed to L.J.K.

Peer review information *Nature Astronomy* thanks Anne Green, Pauline Leonard and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.