

Postgraduate Application Form

UNIVERSITY OF CAMBRIDGE
Postgraduate Admissions Office

Shao, Ms Helen

Course

MASt in Astrophysics (MASAS)

Department

Institute of Astronomy

Course start date

01 Oct 2024 (MT 2024)

Date submitted

11 Oct 2023

Mode of study

Full Time

PUF

No

Academic History

B.A in Astrophysics (Astrophysical Sciences) - All or mostly full-time

3.7

Princeton University (United States)

Immigration

Nationality

United States (1st), China (2nd)

Country of birth

United States

Currently ordinarily resident

United States

Country of birth is ordinary residence since birth

Yes

Estimated fee status

Overseas

Visa

Required

Visa type

I do not currently have a UK visa

Language

Not required

Adverse Effects of COVID

1264/2000 chars

The financial strain my family experienced, triggered by my father's job loss during the COVID pandemic, impacted my academic performance during my freshman year. Juggling the stress of this instability alongside my coursework posed a considerable hardship, leading to a temporary setback in my grades. Moreover, during my freshman year, I faced the challenges of online learning, which affected my academic performance due to reduced peer communication, difficulties in reaching professors across different time zones, and the struggle to adapt to college-level rigor while feeling isolated. However, I have since made substantial strides in my academics. Transitioning to in-person lectures, attending office hours, and participating in study sessions have been pivotal in my academic success. These opportunities allowed me to engage more with both my peers and professors, fostering a productive learning environment. As a result, my subsequent academic years reflect notable improvement, which is evident in my transcript. Overcoming the initial hurdles of the pandemic and virtual learning, I have embraced active participation in both my classes and extracurricular activities, enabling me to excel and contribute meaningfully to my research and coursework.

Scholarships

Apply for funding

Yes

Apply for Cambridge Trust

Yes

Apply for Gates Cambridge

Yes

* Document not uploaded at the point of submission
** Other university

Curriculum Vitae

Uploaded

Career Goals

997/1000 chars

We are at the forefront of a new era in cosmology marked by two seminal catalysts: the unprecedented size of upcoming cosmic surveys that will yield vast data and the transformative power of machine learning (ML) able to harness that data. I aim to unify these domains, drawing from both theoretical and observational analyses, to constrain fundamental properties of the Universe. Specifically, I seek to build physics-driven statistics and ML models to optimally extract information from this data, such as of the large-scale structure and CMB. Within this framework, I can explore novel cross-correlations between various probes to elucidate non-standard physics, such as massive neutrinos and dark energy. At Cambridge, I will hone these skills and solidify my knowledge of the theory underpinning robust models. This is pivotal for my goals to earn an astrophysics PhD, subsequently conduct impactful postdoctoral research, and become a professor - dedicating my career to advancing cosmology.

Additional Information to Support Application

995/1000 chars

By partaking in all aspects of astrophysics research - from discussing latest works over coffee with Princeton scientists, to giving talks at various universities and meeting professors across the country, to collaborating internationally - I have witnessed the beauty of the science community. Yet, I am also keenly aware of the structural disparities that bar certain groups from accessing it. Hence, I am passionate about advancing academic inclusivity and equal representation in STEM. Currently, as the undergraduate representative of Princeton's Astrophysics Climate Committee, I strive to maintain a healthy and transparent environment for research by organizing crosstalk between students and professors of the physics, astrophysics, and math departments. My efforts also extend to outside my university where I am mentoring a high school student on her independent research project. In the future, I will continue to engage in active public outreach and mentorship of future scientists.

Course Specific Questions

Core - statement of interest	My extensive research experiences have illuminated my passion for synthesizing knowledge across various disciplines - from hydrodynamic modeling to machine learning - to tackle fundamental problems in cosmology. My recent projects combined these tools to constrain cosmological models. At Cambridge, I would expand my knowledge on cosmic microwave background (CMB) analysis, such as with Professors Anthony Challinor and Blake Sherwin. Specifically, I aim to develop statistical methods that are accelerated with machine learning to extract maximal information from the CMB and other probes. I am also eager to explore other domains, such as employing astrophysical simulations to resolve parameter tensions with Professor Debora Sijacki. After contacting Professor Sherwin and discussing his projects, I am confident that this course will equip me with the breadth of expertise needed to develop integrative solutions for cosmological questions. Moreover, given that I am interested in working at the intersection of cosmology, statistical methods, and computational astrophysics, I am attracted to the dynamic cross-disciplinary atmosphere fostered between the Institute of Astronomy, Kavli Institute for Cosmology, and DAMTP, where I can collaborate with theorists while also interacting with computational experts. Thus, Cambridge represents an optimal juncture in my journey towards an astrophysics PhD, offering the ideal environment for me to realize both my academic and research ambitions.
Core - reasons for applying	The diverse classes offered by the Tripos Part III course will fortify my foundation in theoretical cosmology and astrophysics, equipping me with essential tools to excel in my future research. I am particularly excited to take "Field theory in cosmology" and "Formation of Structure in the Universe" to expand my knowledge of these topics and explore their mathematical

intricacies in greater depth. The course project will also be a fluid and productive extension of my research experiences where I can cultivate new skills that will be integral for my pursuit of an astrophysics PhD. To further enhance my learning, I will also take full advantage of opportunities to broaden my research horizons and build potential collaborations by attending the Colloquia talks and Cavendish Astrophysics Seminars. With Cambridge's resources and training, I will strengthen my grasp of cosmology theory which I can subsequently inquire through the lens of statistics and numerical simulations in my research.

Astronomy - Extra Materials WP Uploaded

Application Information

Academic Awards			
President's Fund (Undergraduate Fund for Academic Conferences)	Award for excellence in research and published paper. Used to present my work at Harvard University.	30 Jun 2023	£708.00
CUWIP First prize	Awarded for best poster at the regional conference for undergraduate women in physics	31 Jan 2023	
Sigma Xi	Elected to Sigma Xi honor society for excellence in science and physics research	28 Feb 2023	
Class of 1956 Memorial Scholarship	Awarded for academic excellence, top 1% of class	30 Jun 2020	£1,887.00
National regeneron scholar	Among 300 recipients in country for nationwide research competition	31 Mar 2020	£1,887.00

Employment History		
Jun 2022 - Aug 2022	Research Assistant / Summer Intern	Simons Foundation (New York City, United States)
Aug 2019 - Feb 2022	Volunteer Research Assistant	Center for Computational Astrophysics (New York City, United States)
Jun 2023 - Aug 2023	Summer Intern	Princeton University (Princeton, United States)

Other Applications Made

No other applications entered

Personal Information

Identifying Information

Full name

Shao, Ms Helen

Date of birth

04 Sep 2002

Previous name

Legal gender

Prefer to self-describe

Contact

Email

hshao@princeton.edu

Phone

6464687845 (1st)

Skype address

99-32 66th Road, APT 7V

Home address

Same as contact address

Contact address

99-32 66th Road, APT 7V, rego park,
New York, 11374, United States

Valid until

Dependants

Partner

WILL NOT bring partner

Child

WILL NOT bring children

Disability

Disability

No

Further information

Adjustment for Interview

Adjustment required

No

Details

College Preferences

College

Trinity College (1st)
Girton College (2nd)

Current Membership

College

Not College member

Visa Requirement

Visa type

I do not currently have a UK visa

Study Visas

Applicant previously HAS NOT STUDIED in the UK

Visa not entered

Funding Application

Cambridge Trust

Here is a list of CT awards that you would like to be considered

Cambridge Masters Studentship

I am well-prepared by my extensive undergraduate coursework in various branches of astrophysics for the rigor I will encounter as a MASt astrophysics student. Also, my ample past research experience will enable me to excel in the course project.

Gates Cambridge Scholarships (Overseas)

Apply for Gates Cambridge

Yes

US citizen

Yes

Research proposal

Personal Statement

2999/3000 chars

As I stand before a sea of excited faces, the auditorium hums with the curiosity of hundreds of young scientists. Their eager hands shoot up with questions like "What's the Big Bang?", "Why is space growing?". Pushing aside my stage jitters, I join in their wonders of astronomy with my answers and we embark together on a 13-billion-year voyage. That was a snapshot of Champ Gear Up, a summer initiative where I spoke to over 200 students from the Camden public schools on how my research, analyzing some of the largest surveys of our Universe, can answer the questions they asked. With 99% minority enrollment and a math proficiency rate five times below national average, this district faces a stark educational disparity. Yet, the unwavering excitement of these young minds is a testament to the boundless potential that resides in all students, regardless of their backgrounds. Thus, as a scientist, I will take meticulous approaches to not only investigate cosmological data but also break barriers for minorities in STEM. To this end, I mentored a student on her first research project. Harnessing what my own advisors have taught me, I aimed to empower her with two pillars I embrace in my research: being bold in asking scientific questions and persistent in pursuing them. I thoroughly reviewed her proposal, challenged her with critical questions, and honed her communication skills at presentations. In turn, working with her has enriched my view on the importance of fostering symbiotic relationships between scientists of all roles. An equally vital relationship to sustain is that between scientists and the general public. The pandemic made this difficult as communication ties between the scientific community and public were cut. Undeterred, I actively seized opportunities to maintain that connection. In 2021, I joined the online platform CosmologyTalks where I discussed my artificial intelligence (AI) project to predict galaxy masses. I aimed to bridge the gap between the public's view of astrophysics and our research frontiers. I also answered questions from live listeners on the impact and future of AI – a crucial topic to demystify for the general public in this age. As a MaSt student, I will harness the Gates-Cambridge community and dynamic institutes at Cambridge to sustain such dialogues. This naturally arises from my interdisciplinary research in cosmology, AI, and computational astrophysics. Specifically, I aim to develop statistics to unveil fundamental physics in cosmic surveys, aligning with the works of Dr. Anthony Challinor and Dr. Blake Sherwin. I also wish to work with Dr. Debora Sijacki to enhance cosmological analyses with AI and hydrodynamic models. Thus, the rigorous Tripos Part III curriculum will fortify my grasp of cosmology theory, which I can then inquire with data in my project. Alongside my work, I will engage in efforts such as AstroEast to connect schools beyond the Cambridge area, like in Norfolk, with the marvels of astronomy.

Harding Scholarship

Mastercard Foundation

UKRI

Department Funding

College Funding

Based on the information you have provided, you are eligible to apply for these awards.

Girton Joyce Biddle Scholarship

You have applied for Girton Joyce Biddle Scholarship

Sheepshanks Studentship in Astronomy

You have applied for Sheepshanks Studentship in Astronomy

Your Funding

Funding Sources

Details	Date of decision	Tenure years	Amount per year
		Total available	£0.00

Declaration

The information you have provided forms the legal basis of your application to the University of Cambridge. We reserve the right to refuse admission in the event of any misrepresentation by you. Submission of an application does not imply an offer of admission.

- The University of Cambridge, the Cambridge Colleges, the Gates Cambridge Trust and the Cambridge Commonwealth, European and International Trust (and their collaborators) will use your personal information for the purpose of processing your applications for admission and funding and deciding whether to offer you a place for the course you have applied for. For further information on the use of your personal information during the application process, please see [How we use your personal information \(for applicants\)](#).
- I certify that all the information given in this application is complete and accurate. I also understand that if I have given false or misleading information, the University of Cambridge will not admit me as a Postgraduate student and may take legal action against me.
- I certify that I am the original and sole author of all work submitted as part of this application, except where clearly indicated otherwise.
- I understand that if my application is unsuccessful, the papers relating to it will be destroyed and cannot be returned.

I confirm that I have read, understand and agree to the above declarations.

PRINCETON UNIVERSITY

HELEN SHAO entered Princeton as a First-Year Student on 08/31/20.
Current Department is Astrophysical Sciences. This transcript prepared on 09/09/23.

Fall Term 2020-2021 (First Year)					Spring Term 2020-2021 (First Year)				
			Grade	Courses				Grade	Courses
MAT	215	Single Variable Analysis with an Intro	B	1.0	AST	204	Topics in Modern Astronomy	A-	1.0
PHY	105	Advanced Physics (Mechanics)	B-	1.0	COS	126	Computer Science: An Interdisciplinary A	A-	1.0
SPA	103	Intensive Beginner's & Intermed Spanish	A-	1.0	MAT	202	Linear Algebra with Applications	B	1.0
WRI	153	Writing Seminar	A	1.0	PHY	106	Advanced Physics (Electromagnetism)	B	1.0
					SPA	107	Intermediate/Advanced Spanish	A	1.0

The Covid-19 pandemic required all instruction to be conducted remotely during the fall 2020 semester. Students were permitted to elect the Pass/D/Fail option in all undergraduate courses.


Fall Term 2021-2022 (Sophomore)					Spring Term 2021-2022 (Sophomore)				
			Grade	Courses				Grade	Courses
HIS	396	History of Biology	A-	1.0	AST	401	Cosmology	A+	1.0
MAE	305	Mathematics in Engineering I	A-	1.0	MAT	330	Complex Analysis with Applications	A	1.0
ORF	245	Fundamentals of Statistics	A	1.0	PHY	208	Principles of Quantum Mechanics	A-	1.0
PHI	202	Introduction to Moral Philosophy	A	1.0	REL	252	Jesus: How Christianity Began	A	1.0
PHY	205	Classical Mechanics	A-	1.0	VIS	230	Video Installation	A	1.0

Fall Term 2022-2023 (Junior)					Spring Term 2022-2023 (Junior)				
			Grade	Courses				Grade	Courses
ANT	201	Introduction to Anthropology	A	1.0	AST	403	Stars and Star Formation	A	1.0
AST	303	Deciphering the Universe: Research Metho	A	1.0	GER	323	Fairy Tales: The Brothers Grimm	A	1.0
PHY	301	Thermal Physics	A-	1.0	ORF	309	Probability and Stochastic Systems	A-	1.0
PHY	305	Introduction to Quantum Theory	B	1.0	PHY	304	Advanced Electromagnetism	B+	1.0
AST		Junior Independent Work	A+	1.0	AST		Junior Independent Work	A+	1.0

Fall Term 2023-2024 (Senior)				
			Grade	Courses
MAT	345	Algebra I		1.0
ORF	418	Optimal Learning		1.0
PHY	523	Introduction to Relativity		1.0
REL	100	Religion and the Public Conversation		1.0

REMARKS:

Summer Undergraduate Internship Milestone Credit - 2022 Summer
Granted 2 Units of Advanced Placement in Chemistry
Granted 1 Unit of Advanced Placement in English
Granted 1 Unit of Advanced Placement in History
Granted 2 Units of Advanced Placement in Mathematics


 Emily Shandley, Registrar

PRINCETON UNIVERSITY

GRADING SYMBOLS

In undergraduate courses (numbered below 500) and independent work

A+	Exceptional; significantly exceeds the highest expectations
A	Outstanding; meets the highest standards for the assignment or course
A-	Excellent; meets very high standards for the assignment or course
B+	Very good; meets high standards for the assignment or course
B	Good; meets most of the standards for the assignment or course
B-	More than adequate; shows some reasonable command of the material
C+	Acceptable; meets basic standards for the assignment or course
C	Acceptable; meets some of the basic standards for the assignment or course
C-	Acceptable, while falling short of meeting basic standards in several ways
D	Minimally acceptable; lowest passing grade
F	Failing; very poor performance
P	Grades of A+ through C- in courses taken on pass/D/fail basis (prior to 1988-89, earned grades of A+ through D were converted to P) Satisfactory
AUD	Completion of required work in a course taken on an audit basis
INC	Course not completed at end of term (late completion authorized)
T	Course successfully completed at another institution for Princeton credit
UNR	Course grades not reported by instructor
W	Student withdrew from the University after the term's ninth week of class

In graduate courses (numbered 500 and above)

With the exception of T and W, all of the foregoing grading symbols are used in graduate courses. The following symbols may also appear:

HP	High Pass (used in some graduate courses in the School of Architecture)
LP	Low Pass (used in some graduate courses in the School of Architecture)
N or *	No grade given in the course. Between 1948-49 and 1973-74, represented by N; from 1974-75, represented by *

GRADING POLICY 2004-2014

From fall term 2004-05 through spring term 2013-14, the faculty had a common grading expectation for every department and program: A's (A+, A, A-) were to account for less than 35 percent of the grades given in undergraduate courses and less than 55 percent of the grades given in junior and senior independent work. Each department or program determined how best to meet these expectations. In the fall term 2014-15, the faculty reaffirmed rigorous and transparent assessment measures and removed a numeric target for the percent of A grades.

COURSE OF STUDY

Undergraduate students at Princeton enroll in a four-year course of study as candidates for the degree of Bachelor of Arts (A.B.) or the degree of Bachelor of Science in Engineering (B.S.E.). Undergraduate course credit is awarded in the form of course units. Each undergraduate course is one course unit; one course unit may be considered the equivalent of 4.0 semester hours. The A.B. program consists of eight terms of fulltime study to satisfy the requirement of 31 courses (30 courses for students matriculating before 2001). Beginning in the junior year a candidate for the A.B. degree undertakes a program of departmental concentration including course work, independent study in the junior year, a two-term senior thesis, and a departmental examination at the end of the senior year. The B.S.E program consists of eight terms of full-time study to satisfy the requirement of 36 courses, which usually include one or two terms of independent work. B.S.E. students pursue departmental concentrations beginning in the sophomore year. Prior to fall term 1974-75, an undergraduate's departmental courses were indicated by a (D) preceding the course title. In addition to the departmental concentration, many students elect to pursue certificates in one or more programs, nearly all of which are interdisciplinary.

Graduate students pursue full-time study toward the Ph.D. degree in the arts and sciences, engineering, architecture, and public affairs; and final professional master's degrees in architecture, engineering, finance, Near Eastern studies, public affairs, and public policy. To qualify for the Ph.D., a candidate spends at least one academic year in residence, passes the general examination, presents an acceptable dissertation, and passes the final public oral examination. Additional requirements for the Ph.D. vary by program. Ph.D. candidates may earn a Master of Arts (M.A.) degree incidentally as part of the Ph.D. program and is awarded once a student successfully passes all parts of the general examination. Requirements for a final professional master's degree, in programs that offer that option, vary by program. Graduate students who are enrolled full time and in residence hold regular student status as they pursue work toward the degree. Students registered *in absentia* are also enrolled full time but are absent from campus in order to make use of materials, facilities, and expertise not available in residence. In their last years of enrollment, the majority of post-graduates Ph.D. students take no courses, but pursue full-time research toward completion of the dissertation. Ph.D. students who come to the end of the defined program length without having completed all requirements for the degree may hold dissertation completion enrollment (DCE) status for up to two years and enrollment terminated/degree candidacy continues (ET/DCC) status thereafter. DCE students are enrolled students. ET/DCC students are not enrolled, but they are entitled to submit a dissertation.

TO TEST FOR AUTHENTICITY: Translucent globe icons *MUST* be visible from both sides when held to a light source. The face of the transcript is printed on light brown SCRIP-SAFE® paper bordered in orange on four sides with the name of the institution appearing in white type over the face of the entire document.

ADDITIONAL TESTS: The repeated words UNOFFICIAL COPY appear as a latent image. A black and white or color copy of the document is not an original and should not be accepted as an official institutional document. In accordance with the Family Educational Rights and Privacy Act of 1974, this document cannot be released to a third party without the written consent of the student. If you have any questions about this document, please contact our office at registrar@princeton.edu or (609) 258-3361.

Academic reference for Ms Helen Shao

MASt in Astrophysics

Referee Details

Name	Professor Neta Bahcall	Job title	Professor
Email	neta@astro.princeton.edu	Department	Astrophysics
Phone		Institution	Princeton University
Relationship	Research Adviser	City	Princeton
Known for	2 years	Country	United States

Reference

Academic ranking	Among the top 5% in year (i.e., in the top 2 if the group size was 40) 50
Student potential	Outstandingly original/creative/independent of thought
Course suitability	Exceptionally Suitable

Reference provided as uploaded file. Please see the next page.

Department of Astrophysical Sciences
Princeton University
Professor Neta A. Bahcall
Eugene Higgins Professor of Astrophysics
Director, Undergraduate Program in Astrophysics
<https://web.astro.princeton.edu/people/neta-bahcall>
<http://web.astro.princeton.edu/bahcall-cv>
Email: neta@astro.princeton.edu Phone: 609-258-6065

October 8, 2023

Recommendation Letter for Helen Shao
For the MAST in Astrophysics (Michaelmas Term 2024)
at the University of Cambridge

I write in strong support of the application of Helen Shao for the MAST in Astrophysics at the University of Cambridge. Helen is an outstanding candidate for this program. She is currently a Senior majoring in Astrophysical Sciences at Princeton University, expected to graduate in June 2024 with a Major in Astrophysical Sciences and Certificates in Statistics & Machine Learning and in Applied & Computational Mathematics. Helen is an exceptionally strong student – at the top-tier of our class this year and among our very top students in the last decade or more. She is an ‘A’ student in a demanding academic program, with A+ on her independent research projects. She has extensive research experience -- and has 9 publications! This is an impressive achievement for an undergraduate. Her interests focus on theoretical cosmology, large-scale structure, the early universe, and the use of statistical and computational methods to understand the physics and cosmology of our universe, neutrino masses, dark-matter and dark-energy. Her outstanding academic achievements have been recognized with the Princeton President’s Award from the Office of Undergraduate Research (2023), as well as other honors listed below. Helen is not only a bright, able and accomplished student who sets the highest standards for herself -- she is also very mature, thoughtful, innovative, dedicated, hard-working, and friendly. She is a highly promising student who will be an outstanding graduate student and an outstanding researcher. She is an excellent candidate for the Cambridge MAST program in Astrophysics.

I have known Helen for the last couple of years in my capacity as Director of the Undergraduate Program in Astrophysics, as a teacher in her Cosmology class (AST401) for which she received the top grade of A+, and as her research adviser on her Junior Independent Research project. We frequently discuss her research, her academic plans, and her future career goals. Helen is highly focused on her research and her academic studies; she has a deep desire to learn and explore higher-level courses and expand her scientific skills in fields such as math, computation, physics and cosmology. Her goal is to become a cutting-edge academic researcher working on important topics in theoretical cosmology, the early Universe, and understanding the nature of dark-matter and dark-energy. She is extremely thoughtful, thorough, and well prepared. She digs in deeply to understanding her research topics and she selects important topics to work on. She is innovative and brings original ideas to her research.

Helen has extensive research experience investigating important topics. She has 9 papers (and the 10th, with me, is in-preparation) ; this is impressive for an undergraduate! Her research focuses on theoretical cosmology, large-scale structure, the cosmic microwave background, and the use of sophisticated tools in statistics, computation and machine-learning to help shed light on

physics of our universe. She investigated the mapping of dark-matter to neutral hydrogen using convolutional neural network, and determined universal relations in sub-halo properties with artificial intelligence. She helped derive a universal equation to predict the mass-density parameter of the universe from halo and galaxy catalogs. These results have been published in several papers in the astrophysical journals. With me she has worked on resolving the missing baryon problem when accounting for the Circumgalactic Medium. Helen did an excellent job on our research -- she dove deeply to explore the broad issues, showed great initiative in analyzing the available data and interpreting it, and in reaching conclusions. She obtained more extensive and significant results than I have expected. A paper of the results is currently in preparation. For her recent summer project and her current Senior Thesis Helen is investigating the Cosmic Microwave Background Radiation results from Planck and other large-scale surveys to help determine neutrino masses and their impact on the standard Lambda-CDM cosmology. As clear from the topics above, Helen's main interest is in theoretical cosmology and using her outstanding knowledge of physics, math, and computational methods.

Helen's goal for the MAST program is to use the extensive and diverse courses offered in the program and the independent project to expand and strengthen her knowledge in theoretical cosmology and astrophysics, and further improve her skills in computational and mathematical tools so as to further advance her research career. The broad and cross-disciplinary work offered by the program will be an excellent asset to Helen's interest and skills. I know that she will greatly grow and benefit from this outstanding program, and I am sure she will be one of your best and most dedicated students.

In addition to her outstanding academic and research experience, Helen is also a leader in outreach and teaching activities, serving as a Physics Peer Tutor, STEM Tutor for High-School students, CHAMP Gear-Up for undergraduates in STEM, Adviser for Minorities in Physics and Astronomy at Princeton & Rutgers, volunteer leader in Princeton's public observing nights at the telescope, Designer and Lead outreach efforts connecting Princeton designers with non-profit organizations, and more.

In recognition of her achievements, Helen has been awarded Princeton's President Award in 2023; a 1st-place award from Princeton Undergraduate Research Journal (2023); Best Poster presentation at the American Physics Society conference for undergraduates (2022); and a Memorial Scholarship for Academic Excellence (Top 1%) in 2020. Helen was also invited to present talks on her research results at Harvard and at Penn (2023) – impressive invitations for an undergraduate student. I am sure more honors will follow in the future.

Based on the above, I most highly recommend Helen for the MAST program in Astrophysics at Cambridge. She is a rising star and she will be one of your best students.

With best wishes,

Neta Bahcall *Neta Bahcall*
Neta Bahcall

Neta A. Bahcall
Eugene Higgins Professor of Astrophysics
Director, Undergraduate Program, Astrophysics
Princeton University
609-258-6065
neta@astro.princeton.edu
<http://web.astro.princeton.edu/bahcall-cv>

Academic reference for Ms Helen Shao

MASt in Astrophysics

Referee Details

Name	Dr Francisco Villaescusa-Navarro	Job title	Research Scientist
Email	villaescusa.francisco@gmail.com	Department	Center for computational astrophysics
Phone		Institution	Flatirion Institute/Simons Foundation
Relationship	Supervisor	City	New York City
Known for	Since 2018	Country	United States

Reference

Academic ranking	The best performance you have known in the last 5 years I have worked with over 40 students (from high-school to graduate). Helen is the best undergraduate I have worked with so far
Student potential	Outstandingly original/creative/independent of thought
Course suitability	Exceptionally Suitable

Reference provided as uploaded file. Please see the next page.

Recommendation letter for Helen Shao

Dear members of the search committee,

My name is Francisco Villaescusa-Navarro, and I'm a research scientist at the Flatiron Institute in New York City. I'm writing this letter to strongly support the application of Helen Shao to your position. Over my career, I have mentored over 40 students, from high school to graduate, and Helen is the best undergraduate student I have worked with so far.

I first met Helen in 2018, when she was a high-school student. She contacted me to do a research project. The project I gave her was to use convolutional neural networks to learn the mapping from the matter field in N-body simulations to the neutral hydrogen field in hydrodynamic simulations. I was really impressed by how fast she learned, and she managed to train a model that performed really well. She applied to the Regeneron national competition with that project, and she managed to be within the top 300 for the entire country. After that, she presented her work at the Junior Science and Humanities Symposium, and she won the regional award. Let me emphasize that back in 2018, when the usage of machine learning in astrophysics was not as spread as it is today, it was really shocking to see a high-school student performing such tasks with such good results. It was during this first project that I realized the immense potential Helen had.

Helen applied to Princeton University for her undergraduate and she was selected. After that project, already as an undergraduate, Helen focused her attention on using neural networks to find relationships between subhalo properties. The idea was to study if subhalo properties reside in a lower dimensional manifold that could be characterized by fewer numbers than the input ones. For this, she trained a neural network that used subhalo properties such as velocity dispersion, radius, or star-formation rate, to predict the total mass of the subhalo. While interesting, it is known that machine learning is very good at finding relationships between quantities in large datasets. What made this project unique was the fact that the model, trained on some particular simulations, was able to extrapolate really well: it worked when tested on subhalos from thousands of hydrodynamic simulations run with different cosmologies, different astrophysics, different codes, different redshifts, and different

resolutions. Helen not only stopped there, but she used symbolic regression to derive analytic formulae that led us to think that what the network was learning was likely a version of the virial theorem. Helen carried out all the calculations for this project and wrote most of the paper herself. After working on it for just 3 months, the paper was on the arXiv and was later published on ApJ. The paper got some attention and Helen was invited to present the paper on a YouTube channel. In my opinion, this is a spectacular result that demonstrates the power of combining machine learning with numerical simulations.

After this project, Helen continued working with me. I gave her a more challenging project that consisted of using graph neural networks to infer the value of the cosmological parameters using likelihood-free inference. Also, in this case, I was really surprised by how fast she learned these new concepts to her. In just a couple of weeks, she was training graph neural networks to infer the value of the cosmological parameters from dark matter halos of state-of-the-art hydrodynamic simulations. The main goal of the project was to assess, for the first time, whether different N-body codes give convergent results at the field-level. For that, Helen trained her GNN on halo catalogs from Gadget N-body simulations and applied them to halo catalogs created from different N-body codes such as Abacus, Enzo, Ramses, PKDGrav3, and CUBEP3M. She showed which halo features were robust and which were not. On top of that, for the models that were robust, she showed that the models also worked when tested on halo catalogs from hydrodynamic simulations run with different codes, employing different cosmologies, and astrophysics. Helen did all this project over the summer, and she wrote the entire paper by herself.

Helen presented the above work in the CCA summer school in machine learning. During that event, she got the idea of trying to combine her graph neural network with symbolic regression to derive analytic equations that approximate the behavior of the model and can shed light on the underlying physics. Helen decided to carry out this project during her junior thesis. Let me emphasize that at this point, Helen had the idea of the project and needed some basic supervision to carry out the work. Both Romain Teyssier and I met with her weekly and in just a few months, she was able to derive a set of equations that were able to predict the value of Ω_m directly from halo catalogs. The equation works not only on halo catalogs from N-body simulations run with 6 different codes but also on thousands of halo catalogs obtained by running hydrodynamic simulations with 4 different codes. She wrote the entire paper herself and finished the project in just 4 months. The junior thesis

committee at Princeton was really impressed by this. This is another spectacular result showing the power of machine learning to discover analytic equations that should reflect some fundamental underlying symmetry or law in the Universe.

Helen also helped in many other projects. For instance, during the summer of 2022 I asked her if she could train GNNs on halo catalogs with primordial non-Gaussianities to see how well we can infer the fNL parameter. She did that very quickly and she also found that a deep set performed almost as well as the GNN. Because of that, we concluded that the halo mass function was likely the estimator being used by the model. With some collaborators, we then wrote an entire paper on it (<https://arxiv.org/abs/2305.10597>) and of course Helen was one of the co-authors. She also helped in many other projects, which is why she is part of many other papers; she as co-authored 7 papers.

After this project, I encouraged Helen to work with other researchers on different areas so that she could survey which area she would like to focus her research during graduate school. Helen then did her senior thesis with Jo Dunkley using ACT data to infer cosmological parameters. She showed me some preliminary results and I was really impressed with how fast she was able to achieve such constraints in such a short time without previous experience in CMB. This clearly demonstrates that Helen is already a very mature researcher who requires very little supervision to achieve major results.

Helen has lots of strong technical skills. For instance, she writes very clearly and concisely. While I tend to spend a significant amount of time going through the drafts written by undergraduate (and also graduate) students, with Helen it was very different, and I only had to make relatively minor modifications. Her technical skills are also remarkable. She has done all the training on the different architectures we have used for several projects, from CNNs to GNNs. This is not normal for an undergraduate student. Besides, every time I asked her to perform any calculation beyond the main three projects I discussed above, she did that very fast. One of the reasons why her papers tend to have lots of appendices is because she is very fast doing all kinds of calculations, so I ask her to check all possible angles of complex calculations. On top of that, Helen learns and understands things really fast. I have explained to her in the past complex concepts (e.g. how graph neural network work) and she got things really quickly.

During our second project, I realized that perhaps I was not giving Helen challenging enough problems. One day, I went to her desk and found her watching some videos on YouTube. I then asked her what she was watching, and she told me that it was lectures on Quantum physics by Leonard Susskind. She told me that she was waiting for the graph neural networks to train before analyzing the results. I then realized that perhaps I was not giving Helen complex enough projects to work on, even if I don't think it is normal for an undergraduate student to learn to train graph neural networks to perform likelihood-free inference in 2 weeks. Helen is also a very hard worker. I have received results from her in the middle of the night or over the weekends.

Finally, Helen is also a very nice person. All my interactions with her have been pleasant, and she has helped other undergraduate and graduate students with their projects.

In summary, Helen is the best undergraduate student I have worked with so far. She has 10 papers, 3 of them as first author. I consider two of the papers she wrote as a first author some of my best papers. She is really smart and a really hard worker. If she would apply for a postdoc position at Flatiron right now, we will likely include her in our shortlist. She is a rising star, and I look forward to seeing what she will accomplish in the coming years.

Please reach out to me if you need further information.

Best,

Francisco Villaescusa-Navarro

New York, October 2nd, 2023



We thank you for your time spent taking this survey.
Your response has been recorded.

Below is a summary of your responses

[Download PDF](#)

Institute of Astronomy

Important: please read before continuing

In this form, you will be asked a series of questions to help us gather information about your **previous** university study. The questions relate to your previous study, not the course that you are currently applying to. Depending on department procedures, relevant contextual data may have a small impact on some funding opportunities, so if your application is eligible for University funding, we encourage you to fill in this form.

You will be given the opportunity to tell us about any events or circumstances that have had an impact on your education, and limited your ability to perform in your studies. **You do not need to provide personal or detailed information about these circumstances**, we only ask you give details of the **impact** that they have had on your studies.

Please only provide the information that you are asked for in the form, and leave the text box blank if you cannot/ do not wish to respond. You should only provide information in the form if you feel comfortable to do so. Your application will not be disadvantaged if you choose not to respond to the questions, and your academic merit will be assessed based on the information you provide in other parts of the application. Once you have completed this form, you will need to download a PDF copy of your answers to upload to the [applicant portal](#). You will be given the option to download the PDF at end of the form, and you will also receive a copy by email. This

the PDF at end of the form, and you will also receive a copy by email. This will be sent to you as soon as the form is submitted.

Your first name:

Helen

Your surname:

Shao

Your email address:

hshao@princeton.edu

Confirm your email address:

hshao@princeton.edu

The following questions relate to your experience of studying at undergraduate/ bachelor's level.

Your undergraduate/ bachelor's institution:

Princeton University

Did you undertake your degree full-time or part-time?

☒ **Full-time**

☐ Part-time (for any part of the degree)

When choosing your university, were there any factors other than grades that you felt limited your choice of institution?

e.g. not being able to live away from home, financial considerations, concerns about fitting in

Living close to home, financial aid, research opportunities and advisor availability

Characters remaining: 916

Did you have any essential regular commitments that impacted the extent to which you could dedicate yourself to your studies? If so, please explain the impact of this on your studies.

e.g. caring responsibilities, being a single parent or guardian, employment during studies

My family financial burdens caused by my dad losing his job during the COVID pandemic affected my grades in my freshmen year. Moreover, I attended freshmen year online where courses were all taught through virtual platforms, which negatively affected by learning and ability to perform well in classes. However, since then, I have made significant improvements to my academic performance.

Characters remaining: 612

Did you experience any serious disruption to your studies that prevented you from studying for at least 3 months over the course of a year? If so, please explain the impact of this on your studies. It is not necessary to provide details about the nature of the disruption.

e.g. illness, bereavement

No

Characters remaining: 998

The following questions relate to your previous experience of university study at all levels (undergraduate and/or postgraduate).

Some students get off to a slower start than others in their studies, and later show an upward progression in their marks.

Were there any circumstances that you feel initially inhibited your academic performance? If so, please provide details of the impact on your studies, and the change in circumstances that allowed you to improve your performance.

Building off of a previous question, I attended freshmen year online where courses were all taught through virtual platforms, which negatively affected by learning and ability to perform well in classes. A number of factors contributed to this, including the reduced communication between peers, difficulty reaching professors remotely from various timezones, and adapting to college-level academic rigor amidst isolation. However, since then, I have made significant improvements to my academic performance. Attending in-person classes, office hours, and study sessions in person have been integral in my coursework success as I have been able to engage more deeply with my peers and professors.

Characters remaining: 303

Please use the space below to let us know about anything else that has had an impact on your studies or educational pathway. You might like to explain any incomplete qualifications or course changes.

none

Characters remaining: 996

Helen Shao

Department of Astrophysics, Princeton University | hshao@princeton.edu | (646) 468 7845 | github.com/HelenShao

RESEARCH INTERESTS

Large scale structure; cosmic microwave background; statistical and computational cosmology; machine-learning; field-level inference; massive neutrinos; numerical simulations; graph neural networks; primordial non-gaussianity

EDUCATION

PRINCETON UNIVERSITY

Princeton, NJ

B.A. Astrophysics, Cumulative GPA: 3.7/4.0

Expected May 2024

Minors: Statistics and Machine Learning, Applied & Computational Mathematics

Relevant Coursework: Advanced Classical Mechanics, Advanced Electromagnetism, Differential Equations, Quantum Theory, Linear Algebra, Cosmology, Statistics and Probability, Stochastic Systems, Optimization, Algebra

BRONX HIGH SCHOOL OF SCIENCE

New York, NY

Cumulative GPA: 4.0/4.0

Sep 2016 - Jun 2020

RESEARCH EXPERIENCE

Astrophysics REU (USRP, Princeton University)

Summer, 2023

Topic: “Beyond Λ CDM: Massive neutrinos, dark energy, and more”

Advisors: Prof. Jo Dunkley, Dr. Jahmour Givans,

I investigated parameter degeneracies with neutrino mass in various extensions of the standard cosmology using combinations of the latest data on the cosmic microwave background (CMB), CMB lensing, baryonic acoustic oscillations, and supernova measurements. Using my implementation of the supernova likelihood code, I achieved significantly tighter constraints on neutrino mass within different dark energy models.

Junior Research Paper (Princeton University)

Spring, 2023

Topic: “Resolving the Missing Baryon Problem with the Circumgalactic Medium”

Advisors: Prof. Neta Bahcall

I analyzed gas distribution in the circumgalactic medium (CGM) to resolve the observed baryon deficit in the Universe. By comparing observations to simulations, I revealed physical insights underlying relations between various astrophysical processes and CGM gas composition, such as galaxy merging and AGN feedback.

Junior Research Paper (Princeton University)

Fall, 2022

“A Universal Equation to Predict Ω_m from Halo and Galaxy Catalogs”

Advisors: Prof. Romain Teyssier, Dr. Francisco Villaescusa-Navarro

I examined the galaxy-halo bias within the context of cosmological inference. Building off of the previous summer project with graph neural networks and expanding my knowledge on cosmic velocity fields, I obtained an effective analytic equation that can map from the properties of dark matter halos to galaxy fields in order to constrain Ω_m .

Center for Computational Astrophysics, Flatiron Institute

Simons Foundation, NY

Research Assistant

Jun 2019 – Aug 2022

Topics: “Mapping Dark Matter to Neutral Hydrogen with Convolutional Neural Networks” (2020),

“Universal Relations in Subhalo Properties with Artificial Intelligence” (2021),

“Robust Field-Level Inference with Dark Matter Halos” (2022)

Advisors: Dr. David Spergel, Dr. Francisco Villaescusa-Navarro,

I undertook multiple projects emphasizing machine learning and statistical methods in cosmology, such as generating neutral hydrogen maps from N-body simulations, discovering robust models of galaxy mass as a function of internal galactic properties, modeling halo distributions using graph neural networks, constraining primordial non-gaussianity, and performing field-level inference of cosmological parameters.

PUBLICATIONS

9 publications, 3 of which first-author, 1 second-author

1. **Shao, H.**, Givans, J., Dunkley, J., et al. (2023) “Updated neutrino mass constraints with latest ACT lensing and Pantheon+ data”, In prep.
2. **Shao, H.**, de Santi, N. S. M., Villaescusa-Navarro, F., Teyssier, R., Ni, Y., Angles-Alcazar, D., Genel, S., Hernquist, L., Steinwandel, U. P., Castro, T., Hernandez-Martinez, E., Dolag, K., Lovell, C. C., Visbal, E., Garrison, L. H., & Kulkarni, M. (2023). “A universal equation to predict Ω_m from halo and galaxy catalogs.” *The Astrophysical Journal*. (accepted)
3. Ni, Y., Genel, S., et al. (2023) “The CAMELS project: Expanding the galaxy formation model space with new ASTRID and 28-parameter TNG and SIMBA suites”, arXiv:2304.02096
4. **Shao, H.**, Bahcall, N. “Resolving the Missing Baryon Problem with the Circumgalactic Medium”, In prep.
5. de Santi, N. S. M., **Shao, H.**, Villaescusa-Navarro, F., Abramo, L. R., Teyssier, R., Villanueva-Domingo, P., Ni, Y., Anglés-Alcázar, D., Genel, S., Hernandez-Martinez, E., Steinwandel, U. P., Lovell, C. C., Dolag, K., Castro, T., & Vogelsberger, M. (2023). “Robust field-level likelihood-free inference with galaxies”. *The Astrophysical Journal*. 952(1); 69
6. Villaescusa-Navarro, F., Genel, S., Anglés-Alcázar, D., Perez, L., Villanueva-Domingo, P., Wadekar, D., **Shao, H.**, Mohammad, F., Hassan, S., Moser, E., Erwin, T., +34 authors. (2023). “The CAMELS Project: Public Data Release” *The Astrophysical Journal*, 265(2), 54.
7. Jung, G., Ravenni, A., Baldi, M., Coulton, W. R., Jamieson, D., Karagiannis, D., Liguori, M., **Shao, H.**, Verde, L., Villaescusa-Navarro, F., & Wandelt, B. D. (2023). Quijote-PNG: The Information Content of the Halo Mass Function. *The Astrophysical Journal*. *The Astrophysical Journal*, 943(2), 178.
8. **Shao, H.**, Villaescusa-Navarro, F., Villanueva-Domingo, P., Teyssier, R., Garrison, L. H., Gatti, M., Inman, D., Ni, Y., Steinwandel, U. P., Kulkarni, M., Visbal, E., Bryan, G. L., Angles-Alcazar, D., Castro, T., Hernandez-Martinez, E., & Dolag, K. (2022). Robust field-level inference with dark matter halos. *The Astrophysical Journal*, 944(1), 27.
9. **Shao, H.**, Villaescusa-Navarro, F., Genel, S., Spergel, D. N., Angles-Alcazar, D., Hernquist, L., Dave, R., Narayanan, D., Contardo, G., & Vogelsberger, M. (2022). “Finding universal relations in subhalo properties with artificial intelligence”. *The Astrophysical Journal*, 927(1), 85.
10. Villaescusa-Navarro, F., et al. (2022) “The CAMELS Multifield Dataset: Learning the Universe's Fundamental Parameters with Artificial Intelligence”, *The Astrophysical Journal*, 259(2), 61.
11. Villaescusa-Navarro, F., Genel, S., Angles-Alcazar, D., Spergel, D. N., Li, Y., Wandelt, B., Thiele, L., Nicola, A., Matilla, J. M. Z., **Shao, H.**, Hassan, S., Narayanan, D., Dave, R., & Vogelsberger, M. (2021). “Robust marginalization of baryonic effects for cosmological inference at the field level”. *The Physical Review*

AWARDS & HONORS

President’s Award , Princeton Office of Undergraduate Research (OUR)	2023
1st Place , Princeton Undergraduate Research Journal (PURJ)	2023
“A universal equation to predict Ω_m from halo and galaxy catalogs”	
Elected to Sigma Xi Science Honor Society	2023
Best Poster , APS Conference for Undergraduates in Physics	2022
“Robust Field-Level Cosmological Inference with Dark Matter Halos”	
Class of 1956 Memorial Scholarship for Academic Excellence (Top 1%)	2020
Junior Science and Humanities Regional Scholar	2020
National Regeneron Scholar	2020
Selected for one of the nation’s top 300 research projects for my paper	
“Predicting Intensity Maps of Cosmic Neutral Hydrogen from Dark Matter using Convolutional Neural Networks”	

TALKS & PRESENTATIONS

Invited Talks

- Unlocking the Universe: the Power of Machine Learning in Cosmology*
Prof. Daisuke Nagai's Interpretable Machine Learning Group | Yale University Oct 2023
- Beyond Λ CDM: Massive neutrinos, dark energy, and more*
Princeton Undergraduate Summer Research Program (USRP) Final Presentation Jul 2023
- A universal equation to predict Ω_m from halo and galaxy catalogs*
Prof. Jain Bhuvnesh's Group Meeting | University of Pennsylvania Jun 2023
Prof. Lars Hernquist's Group Meeting, The Center for Astrophysics | Harvard University Jun 2023
AstroAI Meeting, The Center for Astrophysics | Harvard University Jun 2023
- Robust field-level likelihood-free inference with halos*
EUCLID X Machine Learning for CosmoSims Conference Jan 2023
AstroCoffee Meeting | Princeton University Feb 2023
- Finding Universal Relations in Subhalo Properties*
AI in Astronomy | University of Sao Paulo, Brazil Apr 2022
Open-panel Discussion, "Cosmology From Home" Podcast Feb 2021
CosmologyTalks Web Series Sep 2021
Prof. Lars Hernquist's Group Meeting, The Center for Astrophysics | Harvard University Oct 2021
- Multiple paper presentations*
CAMELS Meetings and Workshops, CCA | Flatiron Institute, NY 2021-2023
- Posters**
- APS East Coast Conference for Undergraduate Women in Physics Jan 2022
A universal equation to predict Ω_m from halo and galaxy catalogs
AstroCom Summer Poster Presentation, CCA | Flatiron Institute, NY Jul 2022
Robust Field-Level Inference with Graph Neural Networks and Dark Matter Halos

TEACHING EXPERIENCE

- Physics Peer Tutor** 2022-Present
- Guided peers through assignments and materials for: thermodynamics, statistical physics, classical mechanics, electromagnetism, quantum mechanics
- STEM Tutor for High School students** Feb 2023
- Helped prepare students for AP exams and assignments

SERVICE & OUTREACH

- Princeton High School Research Program 2023-Present
Mentor for high school sophomores in building research skills and carrying out independent projects
- CHAMP Gear Up, Rowan University Summer 2023
Panelist in discussions of research frontiers in astrophysics and empowering minorities in STEM
- Minorities in Physics and Astronomy: Princeton X Rutgers 2023-Present
Facilitated discussions on improving research environments for underrepresented groups in science
- Junior Member, American Astronomical Society 2023-Present
- Interview with *New Scientist*, article: "Will artificial intelligence ever discover new laws of physics?" Jan 2022
Spoke about my paper and implications of employing machine learning to build physical models
- CAMELS blog 2021-2022
Author/editor and designer of blog posts explaining papers published using CAMELS simulations

Peyton Observatory Public Observing Nights	2021–2022
Volunteer for leading stargazing events and guiding public attendants	
“Cosmology From Home” Web Series	Feb 2021
Invited to speak on research frontiers in cosmology in an online series targeted at general public	
Princeton Entrepreneurship Club	2020-Present
Designer, lead outreach efforts in connecting Princeton designers with non-profit organizations	

TECHNICAL SKILLS

Advanced: Python, Java, Linux Bash shell, Mathematica
Machine Learning: PyTorch, Scikit-Learn, PYSR, TensorFlow
Experience parallelizing applications with MPI and OpenMP

REFERENCES

Dr. Francisco Villaescusa-Navarro

CCA, Princeton University
fvillaescusa@flatironinstitute.org

Dr. David Spergel

Simons Foundation, Princeton University
dspergel@flatironinstitute.org

Prof. Neta Bahcall

Princeton University
neta@astro.princeton.edu

Prof. Jo Dunkley

Princeton University
jdunkley@princeton.edu

Prof. Romain Teyssier

Princeton University
teyssier@princeton.edu

Gates Cambridge reference for Ms Helen Shao

MASt in Astrophysics

Referee Details

Name	Professor Jo Dunkley	Job title	Professor
Email	jdunkley@princeton.edu	Department	Physics
Phone		Institution	Princeton University
Relationship	Project advisor	City	Princeton
Known for	1 year	Country	United States

Reference

Gates ranking	Top 1% - Exceptional	Gates group	Students in the year group
Gates group size	100		

Reference provided as uploaded file. Please see the next page.

Jo Dunkley
Direct line: +1 6093564833
Email: jdunkley@princeton.edu

October 2023

Dear Committee,

I am writing in the strongest support of Helen Shao's Gates Cambridge Scholarship application for the MAST in Astrophysics. She is exactly who you should be recruiting for this program! She is a stellar prize-winning Princeton student with an impressive publication record, having worked with multiple senior collaborators already. She has astonishingly been first author on three publications, is co-author on six more, and with me is preparing yet another first-author paper. She is outstandingly productive and has achieved this through her own strong independence and drive.

Helen enjoys working at the intersection of cosmology, statistics, and computational astrophysics. She is currently doing her senior thesis with me at Princeton, and I have known her for the past year. She started her thesis work early over the summer, working with postdoctoral fellow Jahmour Givans and myself. As one of our very top Princeton students I was thrilled that she was interested in doing research with us.

The project that Jahmour and I have been advising her on is focused on constraining the mass of neutrino particles from cosmology, and exploring how this measurement can depend on our assumption about the cosmological model. We do not measure the neutrino mass directly, but rather through their effects on cosmic structures: the more massive neutrino particles are, the more they 'wash out' large cosmic structures over the history of the universe. Using a new measurement of cosmic growth from the gravitational distortion of relic light from the early universe (which was reported in a recent paper using the Atacama Cosmology Telescope, led by members of Blake Sherwin's Cambridge group), Helen has been exploring how our current upper limit on the sum of neutrino masses depends on our assumptions about the cosmological model itself. She has shown how it depends only weakly on assumptions about spatial curvature, about the dark energy equation of state, the number of neutrino species, and the form of primordial perturbations.

To do this, Helen quickly learnt how to use a numerical package 'Cobaya' that is widely used in the cosmological community for estimating cosmological parameters, and became familiar with it at the speed of an advanced graduate student! She learnt how to combine datasets together, test different models, and analyse her results. After carefully reproducing the ACT collaboration's results, she then found new results of her own by exploring more complex models, as well as taking the latest Type IA supernova data and building a new likelihood code for Cobaya by adapting one from a different sampler. In her skills and independence, Helen is already operating like an advanced graduate student. We now hope to write up her work on neutrino mass limits as a short paper, and then explore further avenues of this topic for the remainder of her senior thesis project. I expect her to get top marks in her senior thesis.

Looking ahead, I am already actively encouraging colleagues to offer Helen PhD positions, as she is so productive and technically skilled, and such a pleasure to work with. I think it would be an excellent career step for her to first do the MAST at Cambridge, and to make connections in Cambridge as a Gates scholar that will benefit her future career. I know that Helen wants to take *Field theory in cosmology* and *Gravitational waves and numerical relativity*, and perhaps to work further on cosmic microwave background analysis with Anthony Challinor and/or Blake Sherwin, or to study large scale structure via simulations with Debora Sijacki. These areas would be a great fit for her skills and would be a natural path into further PhD research.

Before moving to Princeton I taught at Oxford for eight years as a tutorial fellow, and advised a number of Masters projects in Astrophysics. In comparison to the cohort of Oxford students that I taught or advised, Helen would rank in the top handful, and she would be the very top in terms of research output as an undergraduate. As a reflection of her great success at Princeton, she has already won the Class of 1959 Memorial Prize for academic excellence, which indicates she is in the top 1% of students, and received the President's Award from the Princeton Office of Undergraduate Research for her junior paper. She also received the first prize award from the Princeton Undergraduate Research Journal for her work on graph neural networks. Her presentation this past summer at the end of the summer research program was extremely polished and accessible to students who had been working in quite different areas of astrophysics.

I can also speak to Helen's broader achievements beyond research. She has mentored a Princeton High School student and worked with an organization that helps low-income students at Camden public schools learn essential tools to be successful in STEM. She is a wonderful role model as a first generation college student. She is also a peer tutor for students in the lower years in physics at Princeton. Most recently she has taken on responsibility as one of the undergraduate members of the Princeton Astrophysics Climate Committee, seeking to improve the academic environment for all cohorts in our department. She clearly has a passion for helping others follow her successful path.

In summary, I would assess that Helen is an ideal Gates Scholarship candidate, and I am sure she would thrive at Cambridge with the unique intellectual experience it can offer her.

Sincerely,



Jo Dunkley

Professor, Departments of Physics and Astrophysics, Princeton University