# Sarah C. Millholland

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## Research Interests

Extrasolar planet detection and characterization, planetary dynamics, architectures of planetary systems, orbital resonances

## Current Position

**NASA Sagan Fellow** 2020 - present
Department of Astrophysical Sciences
Princeton University, Princeton, NJ

## Education

**Yale University, New Haven, CT** July 2016 – May 2020
**Ph.D.** in Astronomy, May 2020
*Thesis: Data-Driven Dynamics of Planetary Systems*
*Advisor: Prof. Greg Laughlin*
**M.S., M.Phil.** in Astronomy, May 2018

**UC Santa Cruz, Santa Cruz, CA** Sept. 2015 – June 2016
Pursuit of Ph.D. in Astronomy & Astrophysics
(transferred after completing first year)

**University of Saint Thomas, Saint Paul, MN** Sept. 2011 – May 2015
**B.S.** in Physics; **B.A.** in Mathematics, May 2015
*Summa Cum Laude*, GPA: 4.00

## Awards

- Lyman Spitzer Jr. Postdoctoral Fellowship, Princeton University 2023-2025
- NASA Hubble Fellowship Program (NHFP) Sagan Fellowship 2020-2023
- Tinsley Award for the Best Paper by a Yale Astronomy Graduate Student (for Millholland & Laughlin 2017b) 2018
- DDA/AAS Raynor L. Duncombe Prize for Student Research 2018
- Yale Conference Travel Fellowship 2017
- NSF Graduate Research Fellowship 2017 – 2020
- Summer Sagan Workshop Travel Award 2016
- UCSC Regents Fellowship 2015
- NSF Graduate Research Fellowship Honorable Mention 2015
- Barry M. Goldwater Scholarship (national science scholarship) 2014 – 2015
- Smith Academic Scholarship 2014 – 2015
- Danger Mathematics Scholarship 2013 – 2014, 2014 – 2015
- UST Collaborative Inquiry Research Scholarship 2014
- Walczak Mathematics Scholarship 2013 – 2014
- B. John Barry Academic Scholarship 2012 – 2013
- UST Endowed Scholarship 2011 – 2015

## Teaching Experience

- Teaching Fellow, Planets and Stars, Yale University Spring 2017
- Teaching Fellow, Physics of Planetary Systems, UCSC Spring 2016
- Teaching Fellow, Overview of the Universe, UCSC Fall 2016
- Teaching Assistant, Modern Physics, UST Springs 2014, 2015
- Observatory Lab Instructor, Introduction to Astronomy, UST and the UST Observatory Fall 2012 – Spring 2015

## Mentoring Experience

- Samantha Berek, Yale University undergraduate student (mentored through the "Astro Sib" program), 2018 – 2020

- Adrian Kulesza, Yale University undergraduate student (research project in "Astrophysics Research Methods"), Spring 2019
- Rachel Cohen, Yale University undergraduate student (research project in "Astrophysics Research Methods"), Spring 2019
- Marguerite Epstein-Martin, Yale University undergraduate student (co-advised with Greg Laughlin), 2017 – 2018

## 1st Author Papers

10. **Millholland, S.**, Petigura, E., & Batygin, K. "Tidal Inflation Reconciles Low-Density Sub-Saturns with Core Accretion." 2020, ApJ, 897, 7
9. **Millholland, S.** "Tidally Induced Radius Inflation of Sub-Neptunes." 2019, ApJ, 886, 72
8. **Millholland, S.** & Batygin, K. "Excitation of Planetary Obliquities Through Planet-Disk Interactions." 2019, ApJ, 876, 119
7. **Millholland, S.** & Laughlin, G. "Obliquity-Driven Sculpting of Exoplanetary Systems." 2019, Nature Astronomy, 3, 424, arXiv: 1903.01386
6. **Millholland, S.** & Laughlin, G. "Obliquity Tides May Drive WASP-12b's Rapid Orbital Decay." 2018, ApJL, 869, L15
5. **Millholland, S.**, Laughlin, G., Teske, J., et al. "New Constraints on Gliese 876 – Exemplar of Mean-Motion Resonance." 2018, AJ, 155, 106
4. **Millholland, S.**, Wang, S., & Laughlin, G. "*Kepler* Multi-Planet Systems Exhibit Unexpected Intra-system Uniformity in Mass and Radius." 2017, ApJL, 849, L33
3. **Millholland, S.** & Laughlin, G. "Supervised Learning Detection of Sixty Non-Transiting Hot Jupiter Candidates." 2017, AJ, 154, 83
2. **Millholland, S.** & Laughlin, G. "Constraints on Planet Nine's Orbit and Sky Position within a Framework of Mean-motion Resonances." 2017, AJ, 153, 91
1. **Millholland, S.**, Wang, S., & Laughlin, G. "On the Detection of Non-Transiting Hot Jupiters in Multiple Planet Systems." 2016, ApJL, 823, L7

## 2nd Author Papers

2. Spalding, C. & **Millholland, S.** "Stellar Oblateness versus Distant Giants in Exciting *Kepler* Planet Mutual Inclinations." 2020, AJ, in press
1. Adams, A. D., **Millholland, S.**, & Laughlin, G. "Signatures of Obliquity in Thermal Phase Curves of Hot Jupiters." 2019, AJ, 158, 3

## Other Co-Author Papers

5. Davis, A., Wang, S., Jones, M., Eastman, J., Günther, M., Stassun, K., et al. including **Millholland, S.** [51 total] "TOI 564 b and TOI 905 b: Grazing and Fully Transiting Hot Jupiters Discovered by TESS." 2020, AJ, in press
4. Bryan, M., Chiang, E., Bowler, B. P., Morley, C. V, **Millholland, S.**, Blunt, S., Ashok, K. B., Nielsen, E., Ngo, H., Mawet, D., Knutson, H. A. "Obliquity Constraints on an Extrasolar Planetary-Mass Companion." 2020, AJ, 159, 181
3. Wang, S., Jones, M., Shporer, A., Fulton, B. J., Paredes, L. A., Trifonov, T., Kossakowski, D., Eastman, J., Redfield, S., Günther, M. N., Kreidberg, L., Huang, C. X., **Millholland, S.**, et al. [60 total] "HD 202772Ab: A Transiting Hot Jupiter Around a Bright, Mildly Evolved Star in a Visual Binary Discovered by TESS." 2019, AJ, 157, 51

2. Becker, J. C., Khain, T., Hamilton, S. J., Adams, F. C., Gerdes, D. W., Zullo, L., Franson, K., **Millholland, S.**, et al. [66 total] "Discovery and Dynamical Analysis of an Extreme Trans-Neptunian Object with a High Orbital Inclination." 2018, AJ, 156, 81

1. Janvier, M., Savcheva, A., Pariat, E., Tassev, S., **Millholland, S.**, Bommier, V., McCauley, P., McKillop, S., Dougan, F. "Evolution of Flare Ribbons, Electric Currents and Quasi-separatrix Layers During an X-class Flare." 2016, A&A, 591, A141

## Observing Programs

1. Keck I, HIRESr, "Non-Transiting Hot Jupiters: Hidden Companions to Known Exoplanets", (motivated by Millholland & Laughlin 2017b), 2020B, 2 nights, Co-I (PI: Malena Rice)
2. Keck I, HIRESr, "Non-Transiting Hot Jupiters: Hidden Companions to Known Exoplanets", (motivated by Millholland & Laughlin 2017b), 2020A, 2 nights, Co-I (PI: Songhu Wang)
3. Keck I, HIRESr, "Are Hot Jupiters Dynamically Hot?", 2020A, 2 nights, Co-I (PI: Songhu Wang)
4. Keck I, HIRESr, "Non-Transiting Hot Jupiters: Hidden Companions to Known Exoplanets" (motivated by Millholland & Laughlin 2017b), 2019B, 4 nights, Co-I (PI: Songhu Wang)
5. Keck I, HIRESr, "Do Multi-planet Systems Share Alignment with Their Parent Stars?", 2018A, 1 night, Co-I (PI: Songhu Wang)

## Conference Talks

1. "The Role of Tidal Inflation in Explaining Sub-Saturn Structures." Boston Area Exoplanet Science Meeting #7, virtual conference, April 2020
2. "Tidally-Induced Radius Inflation of Sub-Neptunes." Extreme Solar Systems IV, Reykjavik, Iceland, August 2019
3. "Tidally-Induced Radius Inflation of Sub-Neptunes." Emerging Researchers in Exoplanet Science (ERES) V, Cornell University, Ithaca, NY, June 2019
4. "Excitation of Planetary Obliquities Through Planet-Disk Interactions." Division of Dynamical Astronomy Meeting, Boulder, CO, June 2019
5. "Obliquity Tides and their Role in Understanding the Kepler Planet Period Ratio Distribution." Kepler & K2 Science Conference V, Glendale, CA, March 2019
6. "The Surprising Role of Obliquity Tides in Short-Period Exoplanets." Boston Area Exoplanet Science Meeting #5, Boston University, Boston, MA, January 2019
7. "Consequences of Large Planetary Obliquities in Extrasolar Systems." 2018 Connecticut Exoplanets Meeting, Wesleyan University, Middletown, CT, July 2018
8. "Obliquity-Driven Sculpting of Exoplanetary Systems." Emerging Researchers in Exoplanet Science (ERES) IV, Pennsylvania State University, State College, PA, June 2018
9. "On $f$ for 9." Planet Nine Workshop, California Institute of Technology, Pasadena, CA, May 2018

10. "On the Obliquities of Planets in Close-in, Coplanar Systems." Division of Dynamical Astronomy Meeting, San Jose, CA, April 2018
11. "New Constraints on the Multi-Resonant Planetary System, Gliese 876." Numerical Integration Methods in Planetary Science, University of Toronto at Scarborough, Toronto, Ontario, August 2017
12. "Constraints on Planet Nine in a Mean-Motion Resonant Framework." Numerical Integration Methods in Planetary Science, University of Toronto at Scarborough, Toronto, Ontario, August 2017
13. "Supervised Learning Detection of Sixty Non-Transiting Hot Jupiter Candidates." Kepler & K2 Science Conference IV, NASA Ames Research Center, Moffett Field, CA, June 2017
14. "Supervised Learning Detection of Sixty Non-Transiting Hot Jupiter Candidates." Emerging Researchers in Exoplanet Science (ERES) III, Yale University, New Haven, CT, June 2017
15. "Supervised Learning Detection of Sixty Non-Transiting Hot Jupiter Candidates." 2017 Connecticut Exoplanets Meeting, Wesleyan University, Middletown, CT, May 2017
16. "Constraints on Planet Nine in a Mean-Motion Resonant Framework." 2017 Aspen Winter Conference, Formation and Dynamical Evolution of Exoplanets, Aspen, CO, March 2017

## Seminars & Colloquia (*=invited)

1. * Special Seminar, Climate and Space Sciences and Engineering, University of Michigan, February 2020
2. * Cosmos Seminar, The University of Texas at Austin, October 2019
3. * Institute for Theory and Computation Seminar, Harvard University, October 2019
4. Friday Lunch Time Astrophysics Seminar, University of California Santa Cruz, October 2019
5. Tuesday Lunch Talk, University of California Los Angeles, October 2019
6. Astronomy Tea Talk, California Institute of Technology, October 2019
7. Exoplanet Tea Talk, Massachusetts Institute of Technology, September 2019
8. * Planetary Lunch Seminar, Cornell University, September 2019
9. Astronomy Seminar, Columbia University, September 2019
10. Star and Planet Formation Seminar, University of Michigan, March 2019
11. Princeton Extrasolar Planet Discussion Group, Princeton University, February 2019
12. * Penn State Center for Exoplanets & Habitable Worlds Seminar, Penn State University, February 2019
13. * Extrasolar Planets Seminar, NASA Goddard Space Flight Center, April 2018
14. * Planetary Science Seminar, California Institute of Technology, December 2017
15. * Stars & Planets Seminar, Harvard-Smithsonian Center for Astrophysics, November 2017
16. Exoplanet Pizza Lunch, Harvard-Smithsonian Center for Astrophysics, March 2017

## Poster Presentations

1. Adams, A., **Millholland, S.** & Laughlin, G. "Detecting Planet Obliquity in Thermal Phase Curves." Summer Sagan Workshop, Pasadena, CA, July 2018
2. **Millholland, S.** & Laughlin, G. "Obliquity-Driven Sculpting of Exoplanetary Systems." Exoplanets II Conference, Cambridge, UK, July 2018
3. **Millholland, S.**, Laughlin, G., Butler, P., et al. "New Dynamical Constraints on the Multi-Resonant System, GJ 876." Summer Sagan Workshop, Pasadena, CA, July 2016
4. **Millholland, S.**, Laughlin, G., Burt, J., et al. "A Search for Non-Transiting Hot Jupiters with Transiting Super-Earth Companions." Exoplanets I Conference, Davos, Switzerland, July 2016
5. **Millholland, S.** & Ruch, G. "An Analysis of the Fixed Star Approximation in Transit Light Curve Models." IAU General Assembly, Meeting #29, id.2255909, Honolulu, HI, August 2015
6. **Millholland, S.**, Savcheva, A. & DeLuca, E., "Magnetic Field Modeling of Complex, Flare Producing Active Regions." American Geophysical Union Fall Meeting, abstract #SH13A-4079, San Francisco, CA, December 2014
7. **Millholland, S.**, Maruyama, N., Maute, A., et al. "Modeling Sudden Stratospheric Warming Events Using the Ionosphere-Plasmasphere Electrodynamics Model." American Geophysical Union Fall Meeting, abstract #SA23A-2034, San Francisco, CA, December 2013
8. **Millholland, S.** & Ruch, G., "Modeling and Fitting Exoplanet Transit Light Curves." AAS Meeting #221, id.343.10, Long Beach, CA, January 2013

## Invited Blog Posts

- "Tilting Planets and Sculpting Orbits", guest post by S. Millholland at *Nature Research Behind the Paper*, March 2019. (Click here to follow link.)

## Outreach Talks and Publications

1. "Keys to Alien Worlds: How Astronomers Find Extrasolar Planets", Yale Young Global Scholars Research Showcase (`http://globalscholars.yale.edu`), Yale University, New Haven, CT, July 2019
2. Talk at the Institute for Learning in Retirement, Albertus Magnus College, New Haven, CT, October 2018
3. "Chaos in Outer Space", Yale Young Global Scholars Research Showcase (`http://globalscholars.yale.edu`), Yale University, New Haven, CT, June & July 2018
4. "The Hunt for Planet Nine", Public Talks on Current Astronomy Research at Yale, Leitner Family Observatory & Planetarium, New Haven, CT, February 2018
5. "The Search for Planet Nine", Pathways Summer Scholars Program Science Café (`http://pathwayssummerscholars.yale.edu`), Yale University, New Haven, CT, July 2017
6. "What and Where is Planet Nine?", Yale Young Global Scholars Research Showcase (`http://globalscholars.yale.edu`), Yale University, New Haven, CT, July 2017
7. "Keys to Alien Worlds: How Astronomers Find Extrasolar Planets", Pathways Summer Scholars Enrichment Workshop (`http://pathwayssummerscholars.yale.edu`). One-hour interactive introduction to exoplanet detection and characterization. Yale University, New Haven, CT, July 2017

8. "The Hunt for Planet Nine", Yale Open Labs Science Café (http://theopenlabs.org), Yale University, New Haven, CT, April 2017

9. Invited panelist, 9th Annual Women in Leadership Conference, Yale University, New Haven, CT, February 2017

10. "The Search for Planet Nine", a publication for the Hartford Courant News in Education series, *Science Matters!*, Hartford, CT, January 2017

11. "Exoplanet Exploration: How Astronomers are Uncovering the Mysteries of Alien Worlds", LAMAT REU Program, UCSC, Santa Cruz, CA, July 2016

12. "Reading Scientific Literature", LAMAT REU Program, UCSC, Santa Cruz, CA, June 2016

13. "Exoplanets: The Search for Another Earth", Public Observing Night, University of St. Thomas Observatory, St. Paul, MN, March 2013

14. "Exoplanets: Methods of Detection and Characterization", Minnesota Optical Society Meeting, St. Paul, MN, March 2013

## Tutoring Experience

- Head Tutor (i.e. tutor and supervisor of other student tutors), Mathematics Resource Center, UST — 2015
- Tutor of Mathematics and Physics, Mathematics Resource Center, UST — 2012 – 2015
- Private Tutor of Mathematics and Physics — 2013 – 2015

## Professional Activities & Service

- Referee for AJ, ApJ, MNRAS, Nature Astronomy — 2017 – present
- Scientific Organizing Committee Member, Emerging Researchers in Exoplanet Science (ERES) Conference III (Yale) and V (Cornell) — 2017, 2019
- External reviewer for the OPTICON trans-national telescope access program — 2019
- Featured subject for a University of St. Thomas television commercial and advertising campaign — 2018
- Organizing committee of the UCSC astronomy prospective student visit — 2015

## Selected Outreach & Leadership

- Organizer of ERES V Panel: "Diversity & Inclusion in Astronomy" — 2019
- Yale Open Labs (http://theopenlabs.org) — 2016 – 2018
  - Committee chair for Science Café Talk Series — 2017 – 2018
  - Executive board member — 2016 – 2017
- Organizer of Yale Young Global Scholars Program visits to the Astro. Department (http://globalscholars.yale.edu) — 2017, 2018
- Public Night Volunteer, Lick Observatory — Summer 2016
- Astronomy Public Night Leader, UST Observatory — 2012 – 2015
- UST Math Club Vice President — 2014 – 2015
- UST Math Club Communications Administrator — 2013 – 2014
- UST Physics Club President — 2012 – 2013
- UST Student Alumni Council Member — 2012 – 2013
- UST Women's Choir Board Member — 2012 – 2013
- UST Volunteers in Action weekly volunteer — 2011 – 2013

## Selected Media Coverage

- **Tilted planets** (Millholland & Laughlin 2019) featured in Scientific American, Sky & Telescope, Popular Science, Science Daily, Live Science, Space.com, Yale News.
- **Intra-system uniformity** (Millholland et al. 2017) featured in AAS Nova, Nature Research Highlights.
- **Machine learning detection of hot Jupiters** (Millholland & Laughlin 2017b) featured in National Geographic, Sky & Telescope, FOX 61 Connecticut News (television), University of St. Thomas News, Yale News.