

# Sam Hadden

ASTROPHYSICIST

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## Professional Experience

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### Canadian Institute for Theoretical Astrophysics

Postdoctoral Fellow

Toronto, ON

Sept 2021 - Present

### Center for Astrophysics | Harvard & Smithsonian

CfA Fellow

Postdoctoral Researcher

Cambridge, MA

July 2018 - August 2021

July 2017 - July 2018

## Education

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### Northwestern University

PhD in Physics & Astronomy

Evanston, IL

September 2011 - Sept 2017

- **Thesis:** “Characterizing Kepler’s Multiplanet Systems with Transit Timing Variations”
- **Advisor:** Yoram Lithwick

### Purdue University

BSc in Physics & Mathematics

West Lafayette, IN

September 2007 - May 2011

## Awards & Fellowships

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2021 **CITA Postdoctoral Fellowship**, Canadian Institute for Theoretical Astrophysics

2018 **CfA Postdoctoral Fellowship**, Center for Astrophysics | Harvard & Smithsonian

2015 **Earth & Space Science Graduate Fellowship**, NASA

## Research Interests

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- Exoplanet and solar system dynamics
- Exoplanet characterization & demographics
- Nonlinear and chaotic dynamics of Hamiltonian systems
- Numerical methods for  $N$ -body dynamics
- Bayesian inference methods

## Publications

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27 papers, 23 as first to third author

### LEAD AUTHOR

1. **Hadden, S.** & Tremaine, S. “Scattered Disk Dynamics: The Mapping Approach”, 2023, submitted
2. **Hadden, S.** & Tamayo, D. “`celmech`: A Python Package for Celestial Mechanics”, 2022, AJ, 164, 179
3. **Hadden, S.** & Payne, M. J. “Modeling Radial Velocity Data of Resonant Planets to Infer Migration Histories”, 2020, AJ, 160, 106
4. **Hadden, S.** “An Integrable Model for the Dynamics of Planetary Mean-motion Resonances”, 2019, AJ, 158, 238
5. **Hadden, S.**, Barclay, T., Payne, M. J., Holman, M. J., “Prospects for TTV Detection and Dynamical Constraints with TESS” 2019, AJ, 158, 146
6. **Hadden, S.** & Lithwick, Y., “A Criterion for the Onset of Chaos in Systems of Two Eccentric Planets”, 2018, AJ, 156, 95
7. **Hadden, S.**, Li, G., Payne, M. J., Holman, M. J., “Chaotic Dynamics of Trans-Neptunian Objects Perturbed by Planet Nine”, 2018, AJ, 155, 249

8. **Hadden, S.** & Lithwick, Y., “Kepler Planet Masses and Eccentricities from TTV Analysis”, AJ, 154, 5
9. **Hadden, S.** & Lithwick, Y., “Numerical and Analytical Modeling of Transit Timing Variations”, ApJ, 828, 44
10. **Hadden, S.** & Lithwick, Y. “Densities and Eccentricities of 139 Kepler Planets from Transit Time Variations”, 2014, ApJ, 787, 80

#### STUDENT LEAD AUTHOR

1. Lammers, C., **Hadden, S.**, Murray, N., “Intra-system Uniformity: A Natural Outcome of Dynamical Sculpting”, 2023, MNRAS, 525, 66
2. Rath, J., **Hadden, S.**, Lithwick, Y., “The Criterion for Chaos in Three-planet Systems”, 2022, ApJ, 932, 61
3. Murray, Z., **Hadden, S.**, Holman, M. J., “The Effects of Disk-induced Apsidal Precession on Planets Captured into Mean Motion Resonance”, 2022, ApJ, 932, 61
4. Goldberg, M., **Hadden, S.**, Payne, M. J., Holman, M. J., “Prospects for Refining Kepler TTV Masses using TESS Observations”, 2019, AJ, 157, 4

#### CONTRIBUTING AUTHOR

1. Abbot, D. S., Webber, R. J., et. al. including **Hadden, S.**, “Mercury’s chaotic secular evolution as a subdiffusive process”, 2023, submitted.
2. Lu, T., Rein, H., et. al. including **Hadden, S.**, “Self-consistent Spin, Tidal, and Dynamical Equations of Motion in the REBOUNDx Framework”, 2023, AJ, 948, 41
3. Abbot, D. S., Hernandez, David M., **Hadden, S.**, et. al., “Simple physics and integrators accurately reproduce Mercury instability statistics”, 2023, AJ, 944, 190
4. Hernandez, D. M., Zeebe, R. E., **Hadden, S.**, “Stepsize Errors in the N-body Problem: Discerning Mercury’s True Possible Long-term Orbits”, 2022, MNRAS, 510, 4302
5. Abbot, D. S., Webber, R. J., **Hadden, S.**, et al., “Rare Event Sampling Improves Mercury Instability Statistics”, 2021, ApJ, 923, 236
6. Yee, S. W., Tamayo, D., **Hadden, S.**, Winn, J. N., “How Close are Compact Multi-Planet Systems to the Stability Limit?” , 2021, AJ, 162, 55
7. Cranmer, M., Tamayo, D., Rein, Hanno., et al. including **Hadden, S.**, “A Bayesian Neural Network Predicts the Dissolution of Compact Planetary Systems” 2021, PNAS, 118, 40
8. Bhaskar, H., Li, G., **Hadden, S.**, et al., “Mildly Hierarchical Triple Dynamics and Applications to the Outer Solar System”, 2021, AJ, 161, 48
9. Tamayo, D., Cranmer, M., **Hadden, S.**, et al., “Predicting the Long-Term Stability of Compact Multiplanet Systems” 2020, PNAS, 117, 18194
10. Hernandez D. M., **Hadden, S.**, Makino, J., “Are Long-term  $N$ -body Simulations Reliable?” 2020, MNRAS, 493, 191
11. Kostov, V. B., Schlieder, J. E., Barclay, T., et al. including **Hadden, S.** “The L 98-59 System: Three Transiting, Terrestrial-size Planets Orbiting a Nearby M Dwarf” 2019, AJ, 158, 32
12. Quinn, S. N., Becker, J. C., Rodriguez, J. E., **Hadden, S.**, et al., “Near-resonance in a System of sub-Neptunes from TESS” 2019, AJ, 158, 177
13. Li, G., **Hadden, S.**, Payne, M. J., Holman, M. J., “The Secular Dynamics of TNOs and Planet Nine Interactions”, 2018, AJ, 156, 263
14. Rodriguez, J. E., Becker, J. C., Eastman, J., **Hadden, S.**, “A Compact Multi-Planet System With A Significantly Misaligned Ultra Short Period Planet”, 2018, AJ, 156, 245
15. Mann, A., Dupuy, T., Muirhead, P., et al. including **Hadden, S.**, “The Gold Standard: Accurate Stellar and Planetary Parameters for Eight Kepler M Dwarf Systems Enabled by Parallaxes”, 2017, AJ, 153, 267
16. Lyutikov, M. & **Hadden, S.**, “Relativistic Magnetohydrodynamics in One Dimension”, 2012, Phys. Rev. E, 85, 026401

## Open-source Software

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### CELMECH

Open-source Python code for celestial mechanics.  
Extensively documented at [celmech.readthedocs.io](https://celmech.readthedocs.io)  
Designed to interface with the `rebound`  $N$ -body code.

### TTV2FAST2FURIOUS

Open-source Python code for fitting transit timing variation  
Available at [github.com/shadden/TTV2Fast2Furious](https://github.com/shadden/TTV2Fast2Furious)

## Selected Presentations

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### INVITED TALKS

<b>Astronomy Seminar</b> , Iowa State University (virtual)	September 2023
<b>Astronomy Department Colloquium</b> , University of British Columbia	February 2023
<b>Department of the Geophysical Sciences Seminar</b> , University of Chicago	October 2022
<b>Special Seminar</b> , Northwestern University	October 2022
<b>TAC Seminar</b> , University of California Berkeley	October 2022
<b>Grupo de Dinâmica Orbital e Planetologia Seminar</b> , São Paulo State University (virtual)	August 2022
<b>Exoplanets and Stars Seminar</b> , Yale University (virtual)	March 2022
<b>CITA Seminar</b> , Canadian Institute for Theoretical Astrophysics	October 2021
<b>Center for Exoplanets and Habitable Worlds Seminar</b> , Penn State University	February 2019
<b>Center for Relativistic Astrophysics Seminar</b> , Georgia Institute of Technology	April 2018
<b>SSP Seminar</b> , Center for Astrophysics   Harvard & Smithsonian	April 2018
<b>Yale Center for Astronomy and Astrophysics Seminar</b> , Yale University	March 2018
<b>Extrasolar Planets Seminar</b> , NASA Goddard	February 2018
<b>CITA Seminar</b> , Canadian Institute for Theoretical Astrophysics	June 2017

### CONTRIBUTED TALKS & POSTERS

<b>Comlex Planetary Systems II</b> , Namur, Belgium	July 2023
<b>Division of Dynamical Astronomy (DDA)</b> , 54th DDA Annual Meeting	May 2023
<b>EMAC Virtual Workshop on Open-Access Exoplanet Modeling &amp; Analysis Tools</b> , (virtual)	February 2023
<b>Division of Dynamical Astronomy (DDA)</b> , 53rd DDA Annual Meeting	April 2022
<b>Division of Dynamical Astronomy (DDA)</b> , 52nd DDA Annual Meeting (virtual)	May 2021
<b>ExoDyn2021</b> , Virtual conference	January 2021
<b>Extreme Solar Systems IV</b> (poster), Reykjavik, Iceland	August 2019
<b>MPIA Heidelberg</b> , Planetary Dynamics Conference	June 2019
<b>Division of Dynamical Astronomy (DDA)</b> , 49th DDA Annual Meeting	April 2018
<b>Division of Planetary Sciences (DPS)</b> , 49th DPS Annual Meeting	October 2017
<b>Univ. of Toronto</b> , Numerical Integration Methods in Planetary Science	August 2017
<b>Aspen Winter Conference</b> , Formation and Dynamical Evolution of Exoplanets	April 2017
<b>AAS Winter Meeting</b> , Formation and Dynamical Evolution of Exoplanets	April 2017
<b>Extreme Solar Systems III</b> , Waikola Beach, HI	November 2015
<b>Kepler Science Conference II</b> (poster), Mountain View, CA	November 2013

## Student Advising & Mentoring

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**Summary:** 9 student projects, 4 student-led papers

### Ethan Short

Supervisor, AST 425 research project

- Dynamical modeling of planetary system instabilities leading to free-floating planets

*Univ. of Toronto*

*2023-Present*

### Audrey Burggraf

Supervisor, CITA SURF summer undergraduate research project

- Modeling astrometric signals of multi-planet systems

*Univ. of Toronto*

*2023-Present*

## Caleb Lammers

Co-supervisor with Prof. Norm Murray, undergraduate research

- Using the `celmech` code to conduct numerical experiments on the causes of dynamical instability in multi-planet systems
- Explored the role of giant impacts in producing intra-system uniformity
- Published paper “**Intra-system uniformity: a natural outcome of dynamical sculpting**”

Univ. of Toronto

2022 - Present

## Michael Poon

Co-supervisor with Prof. Hanno Rein, graduate research

- Implementing time-transformed symplectic integration method for in the `rebound`  $N$ -body code

Univ. of Toronto

2021 - 2022

## Ian Chow

Lead supervisor, AST 425 undergraduate research project/CITA SURF summer research

- Fitting radial velocity data of planets in mean motion resonance using  $N$ -body simulations
- AST 425 project awarded department's 2022 Smith Solis Research Scholarship

Univ. of Toronto

2021 - 2022

## Zach Murray

Lead supervisor, graduate student research project

- Analytical and  $N$ -body dynamical modeling of planet migration and resonance capture.
- Published paper “**The Effects of Disk-induced Apical Precession on Planets Captured into Mean Motion Resonance**”

CfA

2020 - 2021

## Daniel Yahalomi

Joint supervisor with Dr. Sam Quinn, post-baccalaureate research project

- Joint analysis of radial velocity and transit timing data for a planetary system
- Presented at **AAS 235 Meeting**

CfA

2019

## Max Goldberg

Lead supervisor, undergraduate summer research project

- Analysis of prospects for TESS observations to improve mass and orbit constrains for Kepler planets exhibiting transit timing variations.
- Resulted in publication “**Prospects for Refining Kepler TTV Masses using TESS Observations**”

CfA

2019

## Jeremy Rath

Co-supervisor with Prof. Yoram Lithwick, graduate student project

- Developed analytic theory of chaos in three-planet systems.
- Published paper “**The Criterion for Chaos in Three-planet Systems**”

Northwestern

2019-2022

## DDA Mentoring Program

Division of Dynamical Astronomy program

- Virtual and in-person meetings with participating graduate students working in dynamics on approximately quarterly basis.
- Discussions focused on career guidance.

DDA

2021-Present

# Teaching

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## COURSES

### GK-12 Reach for the Stars Fellow

High school introductory physics/ middle school general science

- Designed and taught lessons in collaboration with participating teachers
- Developed formal lesson plans and receive instruction in science pedagogy

Chicago, IL

2013 - 2015

### General Physics/College Physics (Physics 130-1,2/Physics 135-3)

Graduate Teaching Assistant

- Introductory algebra-based and calculus-based physics courses
- Designed and graded quizzes
- Led weekly recitation section

Northwestern University

2012-2013

## LECTURES & READING GROUPS

### Differential Geometry Reading Group

Lead organizer

- Reading group covering “The Geometry of Physics” by T. Frankel
- Responsibilities include organizing group discussions & informal lectures

CITA

Fall 2022

### Dynamics Discussion Group

Lead organizer

- Discussion group comprised of CfA members focused on papers on dynamics
- Responsibilities include organizing group discussions and assigning presenters
- Website at [shadden.github.io/dynamics\\_group](https://shadden.github.io/dynamics_group)

CfA

Spring 2019

Lecturer

- “Resonance Capture in Planetary Systems and Beyond”, Winter 2022
- “A Mapping Approach to the Dynamics of Closely-spaced Planets”, Fall 2021

## Service

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**Lead Local Organizer**, AAS Division for Dynamical Astronomy 2024 Annual Meeting

*Present*

**Lead Conference Organizer**, CITA Planet Day

*Aug. 17-18, 2023*

**Conference SOC Member**, NASA EMAC Virtual Workshop

*February 2023*

**Conference Co-organizer**, CITA Planet Day

*Aug. 9-10, 2022*

**Panel Reviewer**, NASA Exoplanets Research Program

**Panel Reviewer**, NASA Emerging Worlds Program

**Panel Reviewer**, C2W Postdoctoral Program

**Referee**, A& A, AJ, ApJ, ApJL, MNRAS, Phys. Rev. X

## References

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### **Scott Tremaine**

Emeritus Professor, Institute for Advanced Study

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Email: [tremaine@ias.edu](mailto:tremaine@ias.edu)

### **Norman Murray**

Professor, Canadian Institute for Theoretical Astrophysics, Univ. of Toronto

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Phone: (416) 978-1778

Email: [murray@cita.utoronto.ca](mailto:murray@cita.utoronto.ca)

### **Yanqin Wu**

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### **Matthew Holman**

Senior Astrophysicist, Center for Astrophysics | Harvard & Smithsonian

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