

Sam Hadden

ASTROPHYSICIST

Canadian Institute for Theoretical Astrophysics, University of Toronto, 60 St. George Street, 14th floor, Toronto, ON M5S 3H8

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Professional Experience

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

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

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

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

Open-source Software

CELMECH

Open-source Python code for celestial mechanics.

Extensively documented at 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

Publications

33 papers, 25 as first to third author, 5 student led

LEAD AUTHOR

1. **Hadden, S.**, “Action-Angle Variables for Axisymmetric Potentials via Birkhoff Normalization”, 2024, ApJ, 972, 64
2. **Hadden, S.** & Tremaine, S., “Scattered Disc Dynamics: The Mapping Approach”, 2024, MNRAS, 527, 2

3. **Hadden, S.** & Tamayo, D., “celmech: A Python Package for Celestial Mechanics”, 2022, AJ, 164, 179
4. **Hadden, S.** & Payne, M. J., “Modeling Radial Velocity Data of Resonant Planets to Infer Migration Histories”, 2020, AJ, 160, 106
5. **Hadden, S.**, “An Integrable Model for the Dynamics of Planetary Mean-motion Resonances”, 2019, AJ, 158, 238
6. **Hadden, S.**, Barclay, T., Payne, M. J., Holman, M. J., “Prospects for TTV Detection and Dynamical Constraints with TESS”, 2019, AJ, 158, 146
7. **Hadden, S.** & Lithwick, Y., “A Criterion for the Onset of Chaos in Systems of Two Eccentric Planets”, 2018, AJ, 156, 95
8. **Hadden, S.**, Li, G., Payne, M. J., Holman, M. J., “Chaotic Dynamics of Trans-Neptunian Objects Perturbed by Planet Nine”, 2018, AJ, 155, 249
9. **Hadden, S.** & Lithwick, Y., “Kepler Planet Masses and Eccentricities from TTV Analysis”, 2017, AJ, 154, 5
10. **Hadden, S.** & Lithwick, Y., “Numerical and Analytical Modeling of Transit Timing Variations”, 2016, ApJ, 828, 44
11. **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., “The instability mechanism of compact multiplanet systems”, 2024, ApJ, 972, 53
2. Lammers, C., **Hadden, S.**, Murray, N., “Intra-system Uniformity: A Natural Outcome of Dynamical Sculpting”, 2023, MNRAS, 525, 66
3. Rath, J., **Hadden, S.**, Lithwick, Y., “The Criterion for Chaos in Three-planet Systems”, 2022, ApJ, 932, 61
4. 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
5. Goldberg, M., **Hadden, S.**, Payne, M. J., Holman, M. J., “Prospects for Refining Kepler TTV Masses using TESS Observations”, 2019, AJ, 157, 4

2ND & 3RD AUTHOR

1. Abbot, D. S., Hernandez, David M., **Hadden, S.**, et al., “Simple physics and integrators accurately reproduce Mercury instability statistics”, 2023, AJ, 944, 190
2. 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
3. Abbot, D. S., Webber, R. J., **Hadden, S.**, et al., “Rare Event Sampling Improves Mercury Instability Statistics”, 2021, ApJ, 923, 236
4. Bhaskar, H., Li, G., **Hadden, S.**, et al., “Mildly Hierarchical Triple Dynamics and Applications to the Outer Solar System”, 2021, AJ, 161, 48
5. 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
6. Tamayo, D., Cranmer, M., **Hadden, S.**, et al., “Predicting the Long-Term Stability of Compact Multiplanet Systems”, 2020, PNAS, 117, 18194
7. Hernandez D. M., **Hadden, S.**, Makino, J., “Are Long-term N -body Simulations Reliable?”, 2020, MNRAS, 493, 191
8. Li, G., **Hadden, S.**, Payne, M. J., Holman, M. J., “The Secular Dynamics of TNOs and Planet Nine Interactions”, 2018, AJ, 156, 263
9. Lyutikov, M. & **Hadden, S.**, “Relativistic Magnetohydrodynamics in One Dimension”, 2012, Phys. Rev. E, 85, 026401

CONTRIBUTING AUTHOR

1. Abbot, D. S., Webber, R. J., et al. including **Hadden, S.**, “Mercury’s chaotic secular evolution as a subdiffusive process”, 2024, ApJ, 967, 2
2. Cloutier, R., Greklek-McKeon, M., et al. including **Hadden, S.**, “Masses, Revised Radii, and a Third Planet Candidate in the “Inverted” Planetary System Around TOI-1266”, 2024, MNRAS, 527, 3
3. 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
4. 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
5. 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
6. 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
7. 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
8. 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

Student Advising & Mentoring

Summary: 9 student projects, 4 student-led papers

Ethan Shore

Supervisor, AST 425 research project

- Dynamical modeling of planetary system instabilities leading to free-floating planets
- Currently a Univ. of Toronto undergraduate student

Univ. of Toronto

2023-2024

Audrey Burggraf

Supervisor, CITA SURF summer undergraduate research project

- Modeling astrometric signals of multi-planet systems
- Currently a McMaster University undergraduate student

Univ. of Toronto

2023

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**”
- Currently a Princeton University graduate student

Univ. of Toronto

2022-2023

Michael Poon

Co-supervisor with Prof. Hanno Rein, graduate research

- Implementing time-transformed symplectic integration method for in the **rebound** N -body code
- Currently a Univ. of Toronto graduate student

Univ. of Toronto

2021 - 2022

Ian Chow

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
- Currently a Western University graduate student

Univ. of Toronto

2021 - 2022

Zach Murray

Supervisor, graduate student research project

- Analytical and N -body dynamical modeling of planet migration and resonance capture.
- Published paper “**The Effects of Disk-induced Apsidal Precession on Planets Captured into Mean Motion Resonance**”
- Currently a Harvard University graduate student

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**
- Currently a Columbia University graduate student

CfA

2019

Max Goldberg

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”**
- Currently a Caltech graduate student

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”**
- Formerly a Northwestern University graduate student

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

Selected Presentations

INVITED TALKS

| | |
|--|----------------|
| Invited talk , Rebound Conference 2024 (virtual) | July 2024 |
| Astronomy Seminar , Iowa State University (virtual) | September 2023 |
| Astronomy Department Colloquium , University of British Columbia | February 2023 |
| Department of the Geophysical Sciences Seminar , University of Chicago | October 2022 |
| Special Seminar , Northwestern University | October 2022 |
| TAC Seminar , University of California Berkeley | October 2022 |
| Grupo de Dinâmica Orbital e Planetologia Seminar , São Paulo State University (virtual) | August 2022 |
| Exoplanets and Stars Seminar , Yale University (virtual) | March 2022 |
| CITA Seminar , Canadian Institute for Theoretical Astrophysics | October 2021 |
| Center for Exoplanets and Habitable Worlds Seminar , Penn State University | February 2019 |
| Center for Relativistic Astrophysics Seminar , Georgia Institute of Technology | April 2018 |
| SSP Seminar , Center for Astrophysics Harvard & Smithsonian | April 2018 |
| Yale Center for Astronomy and Astrophysics Seminar , Yale University | March 2018 |
| Extrasolar Planets Seminar , NASA Goddard | February 2018 |
| CITA Seminar , Canadian Institute for Theoretical Astrophysics | June 2017 |

CONTRIBUTED TALKS & POSTERS

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| Challenging Theory with Roman , IPAC/Caltech | July 2024 |
| Division of Dynamical Astronomy (DDA) , 54th DDA Annual Meeting | May 2024 |
| Complex Planetary Systems II , Namur, Belgium | July 2023 |
| Division of Dynamical Astronomy (DDA) , 54th DDA Annual Meeting | May 2023 |
| EMAC Virtual Workshop on Open-Access Exoplanet Modeling & Analysis Tools , (virtual) | February 2023 |
| Division of Dynamical Astronomy (DDA) , 53rd DDA Annual Meeting | April 2022 |
| Division of Dynamical Astronomy (DDA) , 52nd DDA Annual Meeting (virtual) | May 2021 |
| ExoDyn2021 , Virtual conference | January 2021 |
| Extreme Solar Systems IV (poster), Reykjavik, Iceland | August 2019 |
| MPIA Heidelberg , Planetary Dynamics Conference | June 2019 |
| Division of Dynamical Astronomy (DDA) , 49th DDA Annual Meeting | April 2018 |
| Division of Planetary Sciences (DPS) , 49th DPS Annual Meeting | October 2017 |
| Univ. of Toronto , Numerical Integration Methods in Planetary Science | August 2017 |
| Aspen Winter Conference , Formation and Dynamical Evolution of Exoplanets | April 2017 |
| AAS Winter Meeting , Formation and Dynamical Evolution of Exoplanets | April 2017 |
| Extreme Solar Systems III , Waikola Beach, HI | November 2015 |
| Kepler Science Conference II (poster), Mountain View, CA | November 2013 |

Teaching

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

CfA

Spring 2019

CITA Blackboard Lectures

Lecturer

- “The Mapping Approach to Trans-Neptunian Dynamics”, Fall 2023
- “Resonance Capture in Planetary Systems and Beyond”, Winter 2022
- “A Mapping Approach to the Dynamics of Closely-spaced Planets”, Fall 2021

CITA

COURSES

Research Computing (CTA200H)

Guest Instructor

- Introduction to `sympy`

CITA

Summer 2023 & 2024

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

Outreach

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

Astronomy On Tap

Public lecturer

- Delivered public outreach lectures based on my research

Chicago, IL

2015

Professional Service

LOC Chair, AAS Division for Dynamical Astronomy 2024 Annual Meeting

May 2024

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

Scott Tremaine

Emeritus Professor, Institute for Advanced Study

Address: Institute for Advanced Study, School of Natural Sciences, Einstein Drive, Princeton, NJ 08540

Phone: (609) 734-8191

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Norman Murray

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

Address: McLennan Physical Laboratories, Room 1404D, 60 St. George Street, Toronto Ontario, Canada M5S 3H8

Phone: (416) 978-1778

Email: murray@cita.utoronto.ca

Yanqin Wu

Professor, Department of Astronomy & Astrophysics, Univ. of Toronto

Address: 50 St. George Street, Toronto, Ontario, Canada M5S 3H4

Phone: (416) 946-5633

Email: yanqin.wu@utoronto.ca

Matthew Holman

Senior Astrophysicist, Center for Astrophysics | Harvard & Smithsonian

Address: 60 Garden Street, MS #51, Cambridge, MA 02138

Phone: (617) 496-7775

Email: mholman@cfa.harvard.edu

Yoram Lithwick

Associate Professor, Dept. of Physics and Astronomy, Northwestern University

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Phone: (847) 491-8646

Email: y-lithwick@northwestern.edu