BHANU KUMAR

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Mission Design and Navigation
Jet Propulsion Laboratory,
California Institute of Technology
Pasadena, CA 91109, USA

RESEARCH INTERESTS

Development and adaptation of theoretical and computational tools from dynamical systems, including hyperbolic, resonant, & chaotic dynamics; differential algebra; and invariant manifold parameterization methods, for spacecraft astrodynamics and natural celestial mechanics. Applications of these methods to dynamical analysis of real celestial systems of interest for current/future space missions and astronomy.

PROFESSIONAL EXPERIENCE

Mission Design and Navigation Systems Engineering Group (392K)
NASA Jet Propulsion Laboratory, California Institute of Technology

NSF Mathematical Sciences Postdoctoral Research Fellow   10/2022 - present

- Funded by National Science Foundation individual researcher grant DMS-2202994, project "New dynamical systems-based mathematical and computational tools for applications to astrodynamics"

Student Visiting Technologist   6/2018 - 7/2022

- Developed improved methods for computing periodic and quasi-periodic orbits, stable and unstable manifolds, and heteroclinic connections. Researched applications to tour design for Jupiter's moons.

Radio Science Systems Group (332K)
NASA Jet Propulsion Laboratory, California Institute of Technology

Engineering Co-op Student   6/2014 - 8/2017

- Worked on various technical and research tasks, including conceptual development of a novel method for interplanetary lander trajectory reconstruction using only Doppler tracking data.

EDUCATION

Ph.D. Mathematics, Georgia Institute of Technology   2015 - 2022
   Dissertation title: *New Numerical and Computational Methods Leveraging Dynamical Systems Theory for Multi-Body Astrodynamics*
   Research Advisor: Prof. Rafael de la Llave

M.S. Aerospace Engineering, Georgia Institute of Technology   2015 - 2021

B.S. Applied Mathematics, Georgia Institute of Technology   2010 - 2015

B.S. Aerospace Engineering, Georgia Institute of Technology   2010 - 2015

GRANTS, HONORS, AND AWARDS

- Top Graduate Student Award of the Georgia Tech School of Mathematics   2022
- US National Science Foundation Mathematical Sciences Postdoctoral Research   2022 - 2026
   Fellowship (accepted). Grant DMS-2202994. Total Award: $150,000.

- EU Marie Sklodowska-Curie H2020-MSCA-COFUND MathInGreaterParis   2022
  postdoctoral fellowship (declined). Total Award: €111,600.

- NASA Space Technology Research Fellowship (NSTRF18). Grant 80NSSC18K1143.   2018 - 2022
  Grant title: Leveraging Dynamical Instabilities to Design Efficient Mission Trajectories

- Georgia Tech President's Fellowship for Doctoral Studies   2015 - 2019

- Selected by NASA for sponsorship to present at the 70th International Astronautical Congress   2019
  and as a NASA student delegate for International Space Education Board activities

- Outstanding Undergraduate Math Major Award of the Georgia Tech School of Mathematics   2015

PUBLICATIONS

SUBMITTED JOURNAL ARTICLES

1. B. Kumar, R.L. Anderson, and R. de la Llave (2023). "Rapid GPU-Assisted Search & Parameterization-Based Refinement and Continuation of Connections between Tori in Periodically Perturbed Planar Circular Restricted 3-Body Problems," submitted to *SIAM Journal on Applied Dynamical Systems*. arXiv:2109.14814v2.

JOURNAL ARTICLES

1. B. Kumar, R.L. Anderson, and R. de la Llave (2023). "Transfers between Jupiter-Ganymede and Jupiter-Europa Resonant Tori In a Concentric Circular Restricted 4-Body Model," *Acta Astronautica* 211(2023): 76–87. https://doi.org/10.1016/j.actaastro.2023.05.040.

2. B. Kumar, R.L. Anderson, and R. de la Llave (2022). "Rapid and Accurate Methods for Computing Whiskered Tori and Their Manifolds in Periodically Perturbed Planar Circular Restricted 3-Body Problems," *Celest Mech Dyn Astron* 134:3. https://doi.org/10.1007/s10569-021-10057-1.

3. B. Kumar, R.L. Anderson, and R. de la Llave (2021). "High-Order Resonant Orbit Manifold Expansions For Mission Design In the Planar Circular Restricted 3-Body Problem," *Commun Nonlinear Sci Numer Simulat* 97(2021): 105691. https://doi.org/10.1016/j.cnsns.2021.105691.

CONFERENCE PROCEEDINGS

1. B. Kumar, R.L. Anderson, and R. de la Llave (2023). "4th Body-Induced Secondary Resonance Overlapping Inside Unstable Resonant Orbit Families: a Jupiter-Ganymede 4:3 + Europa Case Study," paper presented at the 2023 AAS/AIAA Astrodynamics Specialist Conference, Big Sky, MT, USA, August 2023. Paper AAS 23-397. arXiv:2309.06073.

2. B. Kumar, R.L. Anderson, and R. de la Llave (2022). "Transfers between Jupiter-Ganymede and Jupiter-Europa Resonant Tori In a Concentric Circular Restricted 4-Body Model," paper presented at the 73rd International Astronautical Congress, Paris, France, September 2022. Paper IAC–22–C1,8,4,x73382. https://dl.iafastro.directory/event/IAC-2022/paper/73382/.

3. B. Kumar, R.L. Anderson, R. de la Llave, and B. Gunter (2021). "Computation and Analysis of Jupiter-Europa and Jupiter-Ganymede Resonant Orbits in the Planar Concentric Circular Restricted 4-Body Problem," paper presented at the 2021 AAS/AIAA Astrodynamics Specialist Conference, Virtual, August 2021. Paper AAS 21-651. arXiv:2109.14815.

4. B. Kumar, R.L. Anderson, and R. de la Llave (2021). "Using GPUs and the Parameterization Method for Rapid Search and Refinement of Connections between Tori in Periodically Perturbed

Planar Circular Restricted 3-Body Problems," paper presented at the 2021 AAS/AIAA Space Flight Mechanics Meeting, Virtual, February 2021. Paper AAS 21-349. arXiv:2109.14814v1.

5. B. Kumar, R.L. Anderson, and R. de la Llave (2020). "Rapid and Accurate Computation of Invariant Tori, Manifolds, and Connections Near Mean Motion Resonances in Periodically Perturbed Planar Circular Restricted 3-Body Problem Models," paper presented at the 2020 AAS/AIAA Astrodynamics Specialist Conference, Virtual, August 2020. Paper AAS 20-694.

6. B. Kumar, R.L. Anderson, and R. de la Llave (2019). "High-Order Resonant Orbit Manifold Expansions For Mission Design In the Planar Circular Restricted 3-Body Problem," paper presented at the 70th International Astronautical Congress, Washington, D.C., USA, October 2019. Paper IAC–19–C1.4.9x51517. https://dl.iafastro.directory/event/IAC-2019/paper/51517/.

PRESENTATIONS

CONFERENCE TALKS AND ABSTRACTS

1. B. Kumar, R.L. Anderson, and R. de la Llave. "Europa-induced Overlapping of Secondary Resonances in the 4:3 Jupiter-Ganymede Unstable Resonant Orbit Family," talk presented at the Complex Planetary Systems II – Kavli-IAU Symposium 382, University of Namur, Namur, Belgium, July 2023.

2. B. Kumar, R.L. Anderson, and R. de la Llave. "Europa-induced Overlapping of Secondary Resonances in the 4:3 Jupiter-Ganymede Unstable Resonant Orbit Family," talk presented at 13th International Conference on Nonlinear Mathematics and Physics "NoLineal", Centre de Recerca Matematica, Barcelona, Spain, June 2023.

3. B. Kumar, R.L. Anderson, and R. de la Llave. "Europa-induced Overlapping of Secondary Resonances in the 4:3 Jupiter-Ganymede Unstable Resonant Orbit Family," talk presented at the 13th AIMS Conference on Dynamical Systems, Differential Equations and Applications, Wilmington, NC, June 2023.

4. B. Kumar, R.L. Anderson, and R. de la Llave. "Jupiter-Ganymede and Jupiter-Europa Unstable Resonant Tori In a Restricted 4-Body Model: Analysis and a Search for Transfers," talk presented at the SIAM Conference on Applications of Dynamical Systems (DS23), Portland, OR, May 2023.

5. B. Kumar, R.L. Anderson, and R. de la Llave. "GPU-assisted search for low-cost transfers between whiskered tori, with applications to resonance transfers in a restricted 4-body model," talk presented at 5th International Workshop on Key Topics in Orbit Propagation Applied to Space Situational Awareness (KePASSA), University of la Rioja, Logroño, Spain, June 2022.

6. B. Kumar, R.L. Anderson, and R. de la Llave. "GPU-assisted search for Jupiter-Ganymede to Jupiter-Europa resonance transfers in a restricted 4-body model," talk presented at Theory, Models and Simulations in Celestial Mechanics Workshop, University of Pisa, Pisa, Italy, June 2022.

7. B. Kumar, R.L. Anderson, and R. de la Llave. "Dynamical systems-based methods for multi-body space mission design," talk presented at Midwest Dynamical Systems Early Career Conference, University of Notre Dame, South Bend, IN, May 2022.

8. B. Kumar, R.L. Anderson, R. de la Llave, and B. Gunter. "Tori and Manifolds of Jupiter-Europa and Jupiter-Ganymede Resonances in the Planar Concentric Circular Restricted 4-Body Problem," talk presented at IAU Symposium 364 on Multi-scale (time and mass) Dynamics of Space Objects, October 2021.

9. B. Kumar, R.L. Anderson, and R. de la Llave. "Rapid and Accurate Computation of Invariant Tori, Manifolds, and Connections Near Mean Motion Resonances in Periodically Perturbed PCRTBP Models," talk presented at the SIAM Conference on Applications of Dynamical Systems, May 2021.

10. B. Kumar, R.L. Anderson, and R. de la Llave. "Using GPUs and the Parameterization Method for Rapid Search and Refinement of Connections between Tori in Periodically Perturbed Planar Circular Restricted 3-Body Problems," abstract presented at the AMS Spring Southeastern Sectional Meeting, March 2021.

11. B. Kumar, R.L. Anderson, and R. de la Llave. "Rapid and Accurate Computation of Invariant Tori and Manifolds Near Mean Motion Resonances in Periodically Perturbed PCRTBP Models," abstract presented at the AMS Spring Southeastern Sectional Meeting, March 2021.

12. B. Kumar, R.L. Anderson, and R. de la Llave. "Using GPUs and the Parameterization Method for Rapid Search and Refinement of Connections between Tori in Periodically Perturbed Planar Circular Restricted 3-Body Problems," talk presented at the Georgia Tech Exploration and Origins Colloquium, Atlanta, GA, February 2021.

INVITED SEMINARS AND TALKS

1. "Jupiter-Ganymede and Jupiter-Europa Unstable Resonant Tori In a Restricted 4-Body Model: Analysis and a Search for Transfers," invited talk in Astronomy and Dynamical Systems Seminar, Institute of Celestial Mechanics and Computation of Ephemerides (IMCCE), Paris Observatory, September 2022.

2. "New Numerical and Computational Methods Leveraging Dynamical Systems Theory for Multi-Body Astrodynamics," invited talk in Aerospace Robotics and Control Group Special Seminar, California Institute of Technology, December 2021.

3. "Rapid and Accurate Computation of Invariant Tori, Manifolds, and Connections Near Mean Motion Resonances in Periodically Perturbed Planar Circular RTBP Models," invited talk in I-CELMECH Seminar Series, University of Milan, November 2020.

4. "Rapid and Accurate Computation of Invariant Tori, Manifolds, and Connections Near Mean Motion Resonances in Periodically Perturbed Planar Circular RTBP Models," invited talk given in CDSNS Colloquium Series, Georgia Tech, July 2020.

5. "Computation and Usage of High-Order Resonant Orbit Manifold Expansions For Mission Design In the Planar Circular Restricted 3-Body Problem," seminar at MSRI, Berkeley, CA, Dec. 2018.

POSTERS

1. B. Kumar, R.L. Anderson, and R. de la Llave. "GPU-assisted search for Jupiter-Ganymede to Jupiter-Europa resonance transfers in a restricted 4-body model," poster presented at the 2022 Global and Local Aspects in Dynamical Systems Conference, Barcelona, Spain, July 2022.

2. B. Kumar, R.L. Anderson, and R. de la Llave. "Computation and Analysis of Invariant Tori Near Resonances in the Planar Elliptic Restricted 3-body Problem," poster presented at the 2020 Georgia Tech Exploration and Origins Colloquium, Atlanta, GA, January 2020.

3. B. Kumar, R.L. Anderson, R. de la Llave, and M. Gidea. "Exploiting Geometric Structures at Resonances and Diffusion to Enable Rapid Tour Design," poster presented at the 2019 Georgia Tech Exploration and Origins Colloquium, Atlanta, GA, March 2019.

4. R.L. Anderson, R. de la Llave, M. Gidea, B. Kumar, M. Musser, and W.T. Lam. "Accelerating Diffusion to Enable Rapid Tour Design," poster presented at the 2018 JPL Research Poster Conference, Pasadena, CA, November 2018.

TEACHING EXPERIENCE AND AWARDS

- **Thank-A-Teacher Certificate**, School of Mathematics, Georgia Tech   Spring 2019
  - MATH 3770 Statistics and Applications, for unofficial volunteer tutoring of a former student
- **Graduate Teaching Assistant**, School of Mathematics, Georgia Tech
  - MATH 2552 Differential Equations   Spring 2018
  - MATH 1554 Linear Algebra   Fall 2017
  - MATH 2552 Differential Equations   Spring 2017
  - MATH 2552 Differential Equations   Fall 2016
  - MATH 2552 Differential Equations   Spring 2016
  - MATH 2552 Differential Equations   Fall 2015

SERVICE AND PROFESSIONAL ACTIVITIES

- Referee work for the journals *Celestial Mechanics and Dynamical Astronomy; SIAM Journal on Applied Dynamical Systems (2 times); Journal of Guidance, Control, and Dynamics; Physica D: Nonlinear Phenomena*
- Session Chair for the Contributed Papers Session CP9 on Many Body Problems at the   5/2023
  May 2023 SIAM Conference on Applications of Dynamical Systems (DS23)
- Lead organizer of the Special Session on Celestial Mechanics and Applied Astrodynamics   3/2021
  at the March 2021 AMS Spring Southeastern Sectional Meeting (12 invited speakers)
- Program Associate in the semester *Hamiltonian systems, from topology to applications*   Fall 2018
  through analysis held at the Mathematical Sciences Research Institute, Berkeley, CA
- Summer volunteer coach for the Georgia ARML state high school math team   5/2012-5/2017

TECHNICAL AND LANGUAGE SKILLS

Programming: Julia (including CUDA.jl and OpenCL.jl for GPUs), MATLAB, C, Java, Bash scripting
Software: LaTeX, AGI Systems Tool Kit, Autodesk Inventor, AutoCAD, Microsoft Office
Languages spoken: English (native speaker), French (proficient), Hindi (native speaker)