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Solving the gravitational N-body problem with machine learning

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PUBLICATIONS

Refereed publications

1. *Structure-preserving neural networks for the n-body problem*
P. Horn, **V. Saz Ulibarrena**, B. Koren, S. Portegies Zwart
8th European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS 2022
2. *A hybrid approach for solving the gravitational N-body problem with Artificial Neural Networks*
V. Saz Ulibarrena, P. Horn, S. Portegies Zwart, E. Sellentin, B. Koren, M.X. Cai
Journal of Computational Physics, Volume 496, 1 January 2024, 112596
3. *Individual chaotic behaviour of the S-stars in the Galactic centre*
S.J. Beckers, C.M. Poppelaars, **V. Saz Ulibarrena**, T.C.N. Boekholt, S. Portegies Zwart
Astronomy and Astrophysics, 685, A12, 2024
4. *A Generalized Framework of Neural Networks for Hamiltonian Systems*
P. Horn, **V. Saz Ulibarrena**, B. Koren, S. Portegies Zwart
Journal of Computational Physics, Volume 521, Part 1, January 2025, 113536.
5. *Reinforcement Learning for Adaptive Time-Stepping in the Chaotic Gravitational Three-Body Problem*
V. Saz Ulibarrena, S. Portegies Zwart
Communications in Nonlinear Science and Numerical Simulation, Volume 145, June 2025, 108723

Submitted publications

1. *Reinforcement Learning for the Determination of the Bridge Time Step in Cluster Dynamics Simulations*
V. Saz Ulibarrena, S. Portegies Zwart
Submitted to *Communications in Nonlinear Science and Numerical Simulation*

CURRICULUM VITAE

I was born on the 13th of August of 1996 in León, Spain. Before starting high school, I was selected for the participation in the first *Estalmat* program in Castilla y León for the stimulation of mathematical talent. That, together with the amazing work of the teachers of my high school *Agustinos de León*, made me grow fascinated by science, technology, and specially, mathematics. Although I toyed with the idea of studying architecture, physics, and mathematics, I finally chose the bachelor in Aerospace Engineering at the University of León which allowed me to learn in more depth about all the topics that I was passionate about. In the three years that I spent at the University of León, I became a member of *AEPSA*, a student association for the promotion of autonomous systems, where I learned about the assembly of drones, regulations, and I taught courses to adults and children.

Having decided that 21 years was enough time in the same city, in August 2017 I moved to the United States of America to spend a year at the University of Vermont finishing my bachelor and thesis. While being there, I enrolled in all courses related to space, astrophysics, and most importantly, astrodynamics. The passion shown by Prof. Darren Hitt in the topic and my own realization that this was what I wanted to do in the future, were the detonating forces for me to pursue a master in Orbital Mechanics at the University of Delft. During my studies, I focused on the topics of optimization and interplanetary mission design. Realizing that it would be interesting to integrate Artificial Intelligence into my studies, I decided to focus my master thesis topic on the use of Neural Networks for the optimization of an interplanetary trajectory to Mars.

In 2019, I moved to Darmstadt, Germany, for my internship at the Mission Analysis department of the European Space Agency. In the four months that I worked in the optimization of the trajectory of JUICE mission, I had the opportunity to get in touch with the internal workings of the European Space Agency and learn from some of the leading experts in the field. After the end of my internship, I returned to the Netherlands to finish my Master's degree. During my master, I worked for two months as a `Python` modeller for the company *Delft Offshore Turbine* in Delft.

The end of my Master's thesis came with a fundamental decision for me. Although I remained passionate about the topic of Orbital Mechanics, I felt discouraged from pursuing this career path. That, together with the feeling that I still wanted to learn more about physics, and specially astrophysics, led me to look for other Master's programs and related jobs. By a stroke of luck, I found an opening for a Ph.D. position that combined my current expertise with a more scientific focus. I did not hesitate to apply. I started my Ph.D. in May 2021 to explore the use of machine learning for the gravitational N -body problem.

In the past four years I have had the opportunity to learn about astronomy and machine

learning from professors, master students, and specially, my fellow Ph.D. students. I have presented my work at international conferences in the fields of Machine Learning, Astronomy, and Mathematics. I have carried out discussions with experts in a diversity of fields and I have had the opportunity to learn about the scientific world and the good and bad of academia.

After having both enjoyed and struggled working on the interface of astronomy, computer science, and mathematics, I have made the decision to move on to my next challenge outside of the academic world to hopefully find a place where I can continue pursuing my passion for science and challenging problems, while making the world a better place.

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“Sometimes the smallest things take up the most room in your heart.”

– Winnie the Pooh

I cannot finish this journey without looking back to thank all the people that have helped throughout. First of all, I want to thank my supervisor, Simon, for teaching me to be a researcher and for prioritizing making my Ph.D. fun and exciting. I would also like to thank Barry Koren, Philipp Horn, Elena Sellentin, Lourens Veen, and the other members of the UNRAVEL project for their fresh perspective in our discussions. A big thank you also goes to the IT department, Secretariat, and other support members of the observatory for their unconditional help.

If I take something with me from this Ph.D. is how much I enjoyed my days at the office surrounded by my office mates. Thank you Maite for being such a good listening ear with my daily struggles, Erwan and Martje for the crazy office moments and penguin pictures, and Josh and Jeger for your warm company in the otherwise always-cold office during my last months at the observatory. Even if we did not share an office, thank you to all the people at the observatory that have made me laugh consistently every day: Alessia, Beth, Bianca, Christian, Christiaan, Elia, Nicco, Nicole, Osmar, Paola, Roland, Thijs, Thomas, Will, and Willeke. To Pranjal and Jelle, thank you for the support (photography and life-wise) and to my dutch pal Ciarán for the much needed motivation in this *lange tocht* that is learning dutch.

In some of the hardest moments, I found amazing people that were there for me. Sill, Josh, Naadiyah, and Silvia, thank you for being a listening ear when it mattered. Roi, thank you for becoming the person I could always go to when I needed it. You have helped me grow, be a bit less harsh on myself, and specially, you have never let me feel lonely. Corné, in the past months I have asked for so much and you have always chosen to give more. I am so thankful for your patience, your effort to understand my world, and your unconditional support.

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You have been for years a rock in a turbulent river. Alex, Michael, Kuldeep, Iñigo, thank you for the support and bad jokes from the distance.

I would not have remained sane in the long gray winter days without the people at Kishido. Thank you for helping me rediscover my passion for karate and making me completely disconnect for some hours every week.

I also want to thank those teachers that paved the path that I follow after all these years. Starting with the school Agustinos de León: Marta, Elena, Belén, Benito, Ana Cristina, Bermejo, thank you for your hard work and for believing in 17-year-old me. I would also like to thank Prof. Darren L. Hitt who, even though is no longer with us, made sure his passion for space was passed on to all his students.

I would like to finish by thanking my parents, for teaching me to not give up, for showing me with their example what hard work is, and most importantly, for showing me that no matter what, what really matters is caring for those we care about. Finally, thank you to my brother Dani, for understanding what others do not, for our discussions about the meaning of life, and for sharing your journey with me and allowing me to share mine.