

Jay W. McMahon

CONTACT INFORMATION Smead Aerospace Engineering Sciences
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CITIZENSHIP United States of America

CURRENT POSITION University of Colorado Boulder **August 2016 to present**
Assistant Professor, H.J. and Ann Smead Aerospace Engineering Sciences

EDUCATION **University of Colorado Boulder August 2008 to August 2011**
Ph.D., Aerospace Engineering Sciences (August 2011 conferral)

- Dissertation: An Analytical Theory for the Perturbative Effect of Solar Radiation Pressure on Natural and Artificial Satellites
- Advisor: Daniel J. Scheeres

University of Southern California January 2005 to May 2006
M.S.E., Astronautical Engineering, May 2006
University of Michigan August 2000 to May 2004
B.S.E., *Cum Laude*, Aerospace Engineering, May 2004

RESEARCH INTERESTS Astrodynamics; celestial mechanics; asteroid dynamics and evolution; spacecraft guidance, navigation and control; autonomy; flash/scanning LIDAR; space resources; orbit determination; gravity estimation

POSITIONS HELD **University of Colorado Boulder**
H.J. and Ann Smead Aerospace Engineering Sciences
Assistant Professor **August 2016 to present**
Assistant Research Professor **March 2013 to August 2016**

- Deputy PI, NASA Janus Mission
- Science Team Co-I, Deputy Radio Science Lead, NASA OSIRIS-REx Mission
- Science Team Co-I, Astrodynamics Team, JAXA Hayabusa 2 Mission
- Binary asteroid dynamical evolution
- Binary-YORP and YORP effect modeling
- Asteroid proximity navigation
- Autonomous rendezvous and docking
- Flash/scanning LIDAR uses for navigation
- High-fidelity solar radiation pressure modeling
- Space robotics
- Asteroid mining / In-situ Resource Utilization (ISRU)
- Stochastic Guidance

University of Colorado Boulder

H.J. and Ann Smead Aerospace Engineering Sciences

Research Associate

September 2011 to March 2013

- Radio Science team member, OSIRIS-REx mission under Co-I Dr. Daniel Scheeres.
 - Responsible for estimating properties of the target asteroid, Bennu, including its mass, mass distribution, and gravity field.
 - Collaborated with the Flight Dynamics and Navigation teams concerning orbit design near the asteroid and implications of the asteroid properties for the sampling maneuver.

University of Colorado Boulder

Graduate Research Assistant

August 2008 to August 2011

- PhD research focused on the orbital effects of solar radiation pressure (SRP).
- Developed an analytical SRP model based on a Fourier series representation.
- Analyzed the orbital perturbations and determined the secular effects of SRP through the use of averaging theory.
- Applied this theory to binary asteroids systems and to Earth orbiting spacecraft.

The Aerospace Corporation

Member of the Technical Staff

June 2004 to June 2008

- Guidance Performance Section, Guidance Analysis Department
- Analyzed launch vehicle guidance in support of Air Force satellite launches.
- Supported the entire mission from open-loop trajectory analysis to day-of-launch support to post-launch performance analysis.
- Used high-fidelity 6 degree-of-freedom simulations to verify guidance performance.
- Used 3 degree-of-freedom simulations that were used for Monte Carlo analysis to make statistical predictions of injection accuracy and fuel reserve levels in the presence of unknown vehicle parameters.
- Supported 4 Delta II, 5 Delta IV, and 4 Atlas V missions pre-flight through day-of-launch.
- Developed an independent tool to build Delta IV guidance and control mission constants from open-loop nominal trajectories.
- Conducted various research studies on guidance systems for Titan IV, Inertial Upper Stage, and ARES I-X.
- Internal funded research on unmanned vehicle guidance and control.

TEACHING &
SERVICE

University of Colorado Boulder

Instructor/Professor

January 2011 to present

- Dynamics and Systems, ASEN 2003 (Springs 2018, 2020)
- Statistical Orbit Determination 2, ASEN 6080 (Springs 2012, 2014, 2016, 2017, 2018)
- Space Vehicle Guidance, ASEN 6015/6519 (Springs 2011, 2013, 2015, Falls 2018, 2020)
- Senior Projects, ASEN 4018/4028 (Fall 2016, Spring 2017)
- Planetary Sciences Seminar, ASTR/ATOC/GEOL 5835 (Spring 2020)
- Statistical Estimation of Dynamical Systems, ASEN 5044 (Fall 2019)

AES Department Committees

- Undergraduate Committee - 2017-20
- Strategic Vision Committee - 2017-18
- Graduate Committee - ASN focus area lead - 2016-17
- Outreach Committee - 2016-18

- Teaching Assistant **January to May 2009, January to May 2010**
- Intro. to Dynamical Systems, ASEN 2003 (Spring 2010 with Dr. Daniel Scheeres and Dr. Penina Axelrad)
 - Intro. to Orbital Dynamics, ASEN 3200 (Spring 2009 with Dr. George Born)

- ASN Seminar Coordinator **August to December 2010**
- Recruited speakers for, advertised for, and hosted weekly seminar on topics in astrodynamics and satellite navigation.

- Aerospace Graduate Student Organization (AGSO) **2008 to 2010**
- Founding member of graduate student organization that serves the Aerospace engineering graduate student population by facilitating communication between the department and the students and organizing social events. Served as a Focus Area and Faculty Interaction chair.

External

Editorial Positions

- Associate Editor, AIAA Journal of Guidance, Control and Dynamics **2020 to Present**
- Associate Editor, AIAA Journal of Spacecraft and Rockets **2018 to Present**
- Guest Editor, Acta Astronautica, IWSCFF Special Issue **2017-2018**
- Edited conference proceedings, AAS Spaceflight Mechanics 2017, Advances in the Astronautical Sciences, Vol. 160, American Astronautical Society

- AAS Space Flight Mechanics Committee **2014 to 2018**
- Elected to serve 4-year term
 - Technical Chair for Winter 2017 meeting in San Antonio.

- AAS RMS Board of Directors **2019 to 2020**
- Elected to serve 2-year term

- AIAA Astrodynamics Technical Committee **2020 to 2023**
- Elected to serve 4-year term

Conferences/Workshops Organized

- AAS Spaceflight Mechanics Conference, San Antonio, TX, Technical Chair 2017
- IAF IWSCFF, Boulder, CO, Co-Chair 2017
- Bridging the Gap in Space Robotics Workshop, RSS, Boston, MA, Organizer 2017
- Autonomous Space Robotics Workshop, RSS, Pittsburgh, PA, Organizer 2018
- Advanced Navigation Applications and Technologies Session, AAS GNC, Breckenridge, CO, National Chair 2019
- AAS Division of Dynamical Astronomy Meeting, Boulder, CO, Chair 2019
- IAF IWSCFF, Glasgow, Scotland, UK, SOC 2019
- Binaries in the Solar System 5, Fort Collins, CO, SOC 2019
- Asteroid and Small Body Exploration and Sample Return Session, AAS GNC, Breckenridge, CO, National Chair 2020

Referee for Peer-Reviewed Journals

- *Icarus*
- *Celestial Mechanics and Dynamical Astronomy*
- *AIAA Journal of Guidance, Control, and Dynamics* (Excellent Reviewer 2018)
- *AIAA Journal of Spacecraft and Rockets*
- *Advances in Space Research*
- *AAS Journal of the Astronautical Sciences*

- *Journal of Nonlinear Mechanics*
- *Journal of Computational and Nonlinear Dynamics*
- *Journal of Aerospace Engineering*
- *Acta Astronautica*
- *Earth, Moon, and Planets*
- *International Journal of Dynamics and Control*
- *Planetary and Space Science*
- *AIAA Journal of Aerospace Information Sciences*
- *IEEE Transactions on Aerospace and Electronic Systems*
- *IEEE Geoscience and Remote Sensing Letters*
- *Nature: Scientific Reports*
- *Aerospace Science and Technology*

Review Panel Member

- NASA Science Mission Directorate
- NASA Planetary Data System (PDS)
- NASA Physical Sciences Informatics (PSI)

MENTORING

University of Colorado Boulder

- PhDs Awarded:
 - Dr. Ann Dietrich (defended Summer 2017)
 - Dr. Jeroen Geeraert (defended Fall 2017)
 - Dr. Benjamin Bercovici (defended Spring 2019)
 - Dr. Daniel Brack (defended Fall 2019)
 - Dr. Andrew French (defended Summer 2020)
- Postdoctoral Scholars:
 - Prof. Davide Amato, Imperial College London (May 2019 - Dec 2020)
- PhD Students:
 - Kenshiro Oguri (exp. graduation 2021)
 - Don Kuettel (exp. graduation 2021)
 - Sean Napier (exp. graduation 2021)
 - Luke Bury [**NSTRF18**] (exp. graduation 2021)
 - Mark Moretto [**NSTRF18**] (exp. graduation 2022)
 - Evan Roelke [**Draper Fellowship 18**] (exp. graduation 2021)
 - Hermann Kaptui Sipowa [**GEM20**] (exp. graduation 2022)
 - Taralicin Deka (exp. graduation 2022)
 - Shayna Hume [**NSF18**] (exp. graduation 2023)
 - Dahlia Baker [**NSF18**] (exp. graduation 2023)
 - Benjamin Grace (exp. graduation 2023)
 - Ryan Bull (exp. graduation 2023)
 - Chloe Long (exp. graduation 2024)
 - Anivid Pedros Faura [**La Caixa20**] (exp. graduation 2024)
 - Matt Givens (exp. graduation 2022)
 - Spencer Boone (exp. graduation 2022)
 - Jacopo Villa (exp. graduation 2023)
 - Ken Kuppa [**Draper Fellowship 20**] (exp. graduation 2023)
 - Jana Cuberovic (exp. graduation 2025)
 - Jens Rataczak (exp. graduation 2025)
- MS Students:
 - Jonathan Nikkel (graduated Fall 2018)
 - Lubna Zubair (graduated Spring 2019)
 - Hunter Mellema (graduated Spring 2020)
 - Jonathan Manni [**Draper Fellowship 18**] (graduated Summer 2020)
 - Jesse Tambornini (graduated Summer 2020)

- Rachel Mamich (graduated Fall 2020)
- Michael Caudill (exp. graduation Spring 2021)
- Visiting Scholars:
 - Paolo Panicucci, ISAE-Supaero, Spring-Summer 2019
 - Anivid Pedros Faura, Universitat Politècnica De Catalunya, Spring-Summer 2019
 - Marc Trullas, TU Delft, Spring 2017 (MS Defended Spring 2018)
 - Alessandro Vanzella, TU Delft, Spring 2016
 - Michael Van den Broeck, TU Delft, Fall 2015
- Advised 2 Discovery Learning Apprentices, 2014–2015
- Advised SPUR student, summer 2018
- Advised UROP student, AY19–20
- PhD Thesis Committee Membership, 26 students
- MS Thesis Committee Membership, 11 students

AWARDS

AIAA

- Elected AIAA Associate Fellow 2017
- AIAA-Rocky Mountain Section Young Engineer of the Year 2017

NASA

- NASA STMD Early Career Faculty fellow 2018-2021
- NIAC Fellow 2017-2020
- Group Achievement Award - OSIRIS-REx Mission Team 2017
- Group Achievement Award - ARRM Team 2015
- Center Group Award - ARRM “Option B” Team 2015
- Director’s Group Award - ARRM Alternate Concept Study Team 2014
- Earth and Space Sciences Graduate Fellowship 2010–2011

DARPA

- DARPA YFA Fellow 2020–2021

Student Awards

- Breakwell Student Travel Award, AAS (Spencer Boone) SFM 2020
- 2nd Place, Student Paper Competition, AAS (Kenshiro Oguri) GNC 2020
- 1st Place, Student Paper Competition, 2nd Space Imaging Workshop (Jonathan Manni) RPI 2019
- 3rd Place, Student Paper Competition, 2nd Space Imaging Workshop (Dahlia Baker) RPI 2019
- Aviation Week 20 Twenties (Mark Moretto) 2019
- Bahls Student Travel Award, CCAR (Kenshiro Oguri) SFM 2019
- Aviation Week 20 Twenties (Luke Bury) 2018
- Breakwell Student Travel Award, AAS (Daniel Brack) ASC 2018
- Breakwell Student Travel Award, AAS (Kenshiro Oguri) ASC 2018
- 2nd Place, Student Paper Competition, AAS (Ben Bercovici) GNC 2018
- 2nd Place, Student Paper Competition, AAS (Ann Dietrich) GNC 2016
- Breakwell Student Travel Award, AAS (Ann Dietrich) ASC 2015

University of Colorado Boulder

- Smead Aerospace Engineering Sciences Outstanding Junior Faculty Award 2020
- Smead Aerospace Engineering Sciences Outstanding Junior Faculty Award 2017
- Aerospace Engineering Sciences Departmental Fellowship 2008

The Aerospace Corporation

- Independent Research and Development Award 2008
- Graduate Studies Fellowship 2005–2006

ORGANIZATIONS

- American Astronomical Society
 - Division for Planetary Sciences
 - Division on Dynamical Astronomy
- American Astronautical Society
- American Institute of Aeronautics and Astronautics

INVITED TALKS	MIT Space Systems Laboratory Seminar <i>Autonomy for Small Body Exploration</i>	February 26, 2020
	NASA NIAC Symposium <i>Dismantling Rubble Pile Asteroids with Area-of-Effect Soft-bots</i>	September 25, 2019
	Stanford University <i>Autonomy for Small Body Exploration</i>	May 22, 2019
	NASA NIAC Symposium <i>Dismantling Rubble Pile Asteroids with Area-of-Effect Soft-bots</i>	September 26, 2018
	International Space Development Conference <i>Dismantling Rubble Pile Asteroids with Area-of-Effect Soft-bots</i>	May 27, 2018
	Museum of Science and Industry Chicago <i>Robotic Asteroid Exploration & Mining with AoES</i>	April 7, 2018
	University of Arizona <i>A New Approach to Mining Near-Earth Asteroids</i>	March 27, 2018
	Georgia Institute of Technology <i>A New Approach to Mining Near-Earth Asteroids</i>	November 6, 2017
	NASA NIAC Symposium <i>Dismantling Rubble Pile Asteroids with Area-of-Effect Soft-bots</i>	September 25, 2017
	University of Illinois at Urbana-Champaign <i>A New Approach to Mining Near-Earth Asteroids</i>	September 18, 2017
	JPL Planetary Science Colloquium <i>Is YORP “Stochastic”?</i>	August 7, 2017
	University of Colorado Boulder <i>Enabling a Sustainable Space Economy</i>	April 20, 2016
	The University of Texas at Austin <i>Enabling a Sustainable Space Economy</i>	March 31, 2016
	Purdue University <i>Fusing Planetary Science and Aerospace Engineering to Expedite the Exploration and Exploitation of Space</i>	April 18, 2013

53. E.B. Bierhaus, J.T. Songer, B.C. Clark, R.D. Dubisher, S.L. Deden, K.S. Payne, D. Wurts, **J. W. McMahon**, B. Rozitis, D.S. Lauretta, “Bennu regolith mobilized by TAGSAM: Expectations for the OSIRIS-REx sample collection event and application to understanding naturally ejected particles,” *Icarus*, Vol. 355, Feb. 2021, <https://doi.org/10.1016/j.icarus.2020.114142>
52. P. Scheirich, P. Pravec, P. Kusnirak, K. Hornoch, **J. W. McMahon**, et al., “A satellite orbit drift in binary near-Earth asteroids (66391) 1999 KW4 and (88710) 2001 SL9 – Indication of the BYORP effect,” *Icarus*, Accepted January 2021
51. K. Oguri* and **J. W. McMahon**, “Robust Spacecraft Guidance around Small Bodies under Uncertainty: Stochastic Optimal Control Approach,” *Journal of Guidance, Control, and Dynamics*, Accepted December 2020
50. S. Boone* and **J. W. McMahon**, “Orbital Guidance Using Higher-Order State Transition Tensors,” *Journal of Guidance, Control, and Dynamics*, published online December 2020. <https://doi.org/10.2514/1.G005493>
49. D. J. Scheeres, A. S. French*, P. Tricarico, S.R. Chesley, Y. Takahashi, D. Farnocchia, **J. W. McMahon**, D. N. Brack*, et al., “Heterogenous mass distribution of the rubble-pile asteroid (101955) Bennu”, *Science Advances*, Vol. 6, No. 41, 2020. <https://doi.org/10.1126/sciadv.abc3350>
48. K. Oguri*, G. Lantoine, W. Hart, **J. W. McMahon**, “Science orbit design with a quasi-frozen beta angle: Effects of body obliquity on J2-perturbed dynamics,” *Celestial Mechanics and Dynamical Astronomy*, Vol. 132, No. 48, August 2020. <https://doi.org/10.1007/s10569-020-09987-z>
47. L. Bury* and **J. W. McMahon**, “The Effect of Zonal Harmonics on Dynamical Structures in the Circular Restricted Three Body Problem Near the Secondary Body,” *Celestial Mechanics and Dynamical Astronomy*, Vol. 132, No. 45, August 2020. <https://doi.org/10.1007/s10569-020-09983-3>
46. D. Brack* and **J. W. McMahon**, “Effects of Momentum Transfer Deflection Efforts on Small Body Rotational State,” *Journal of Guidance, Control, and Dynamics*, Vol. 43, No. 11, Nov. 2020. <https://doi.org/10.2514/1.G004963>
45. Y. Oki, K. Yoshikawa, H. Takeuchi, S. Kikuchi, H. Ikeda, D. J. Scheeres, **J. W. McMahon**, J. Kawaguchi, Y. Takei, Y. Mimasu, N. Ogawa, G. Ono, F. Terui, M. Yamada, T. Kouyama, S. Kameda, K. Yoshida, K. Nagaoka, T. Yoshimitsu, T. Saiki, Y. Tsuda, “Orbit Insertion Strategy of Hayabusa2’s Rover with Large Release Uncertainty around the Asteroid Ryugu,” *Astrodynamic*, Vol. 4, 2020, pp. 309 - 329. <https://doi.org/10.1007/s42064-020-0080-y>
44. S. Napier*, **J. W. McMahon**, J. Englander, “A Multi-Objective, Multi-Agent Transcription for the Global Optimization of Interplanetary Trajectories,” *Journal of the Astronautical Sciences*, Vol. 67, 2020. pp 1271 - 1299. <https://doi.org/10.1007/s40295-020-00215-2>
43. M. Moretto* and **J. W. McMahon**, “Evolution of Orbits about Comets with Arbitrary Comae,” *Celestial Mechanics and Dynamical Astronomy*, Vol. 132, July 2020, <https://doi.org/10.1007/s10569-020-09973-5>

42. S. R. Chesley, A. S. French^{*}, A. B. Davis, R. A. Jacobson, M. Brozović, D. Farnocchia, S. Selznick, A. J. Liounis, C. W. Hergenrother, M. C. Moreau, J. Pelgrift, E. LessacChenen, J. L. Molaro, R. S. Park, B. Rozitis, D. J. Scheeres, Y. Takahashi, D. Vokrouhlický, C. W. V. Wolner, C. Adam, B. J. Bos, E. J. Christensen, J. P. Emery, J. M. Leonard, **J. W. McMahan**, M. C. Nolan, F. C. Shelly, D. S. Lauretta, "Trajectory estimation for particles observed in the vicinity of (101955) Bennu," *Journal of Geophysical Research: Planets*, published online July 2020, <https://doi.org/10.1029/2019JE006363>
41. B. Bercovici^{*}, P. Panicucci, and **J. W. McMahan**, "Analytical shape uncertainties in the polyhedron gravity model," *Celestial Mechanics and Dynamical Astronomy*, Vol. 132, June 2020, <https://doi.org/10.1007/s10569-020-09967-3>
40. D. N. Brack^{*} and **J. W. McMahan**, "Active Mass Ejection for Asteroid Manipulation and Deflection," *Journal of Spacecraft and Rockets*, Vol. 57, No. 3, May 2020, <https://doi.org/10.2514/1.A34631> -
39. **J. W. McMahan**, D. J. Scheeres, S. R. Chesley, A. French^{*}, D. N. Brack^{*} et al, "Dynamical Evolution of Simulated Particles Ejected From Asteroid Bennu," *Journal of Geophysical Research: Planets*, published online May 2020, <https://doi.org/10.1029/2019JE006229>
38. P. Panicucci, B. Bercovici^{*}, E. Zenou, **J. W. McMahan**, M. Delpéch, J. Lebretton, and K. Kanani, "Uncertainties in the gravity spherical harmonics coefficients arising from a stochastic polyhedral shape," *Celestial Mechanics and Dynamical Astronomy*, Vol. 132, April 2020, <https://doi.org/10.1007/s10569-020-09962-8>
37. D. Scheeres, **J. W. McMahan**, D. N. Brack^{*}, A. S. French^{*}, S. R. Chesley, D. Farnocchia, D. Vokrouhlický, R.L. Ballouz, J. P. Emery, B. Rozitis, M. C. Nolan, C. W. Hergenrother, D. S. Lauretta, "Particle Ejection Contributions to the Rotational Acceleration and Orbit Evolution of Asteroid (101955) Bennu," *Journal of Geophysical Research: Planets*, Vol. 125, No. 3, March 2020, <https://doi.org/10.1029/2019JE006284>
36. A. S. French^{*} and **J. W. McMahan**, "Independent estimate of asteroid 433 Eros' spin state using surface Doppler from the NEAR-Shoemaker mission," *Icarus*, Vol. 338, March 2020, <https://doi.org/10.1016/j.icarus.2019.113537>
35. A. Dietrich^{*} and **J. W. McMahan**, "Filter Initialization with Three-Dimensional Lidar Images in Proximity to Small Bodies," *Journal of Guidance, Control, and Dynamics*, *Journal of Guidance, Control, and Dynamics*, Vol. 43, No. 2, February 2020, <https://doi.org/10.2514/1.G004468>
34. K. Oguri^{*} and **J. W. McMahan**, "Solar Radiation Pressure-Based Orbit Control with Application to Small-Body Landing," *Journal of Guidance, Control, and Dynamics*, Vol. 43, No. 2, February 2020, <https://doi.org/10.2514/1.G004489>
33. D. S. Lauretta, C. W. Hergenrother, S. R. Chesley, J. M. Leonard, J. Y. Pelgrift, C. D. Adam, M. Al Asad, P. G. Antreasian, R.-L. Ballouz, K. J. Becker, C. A. Bennett, B. J. Bos, W. F. Bottke, M. Brozović, H. Campins, H. C. Connolly Jr., M. G. Daly, A. B. Davis, J. de León, D. N. DellaGiustina, C. Y. Drouet dAubigny, J. P. Dworkin, J. P. Emery, D. Farnocchia, D. P. Glavin, D. R. Golish, C. M. Hartzell, R. A. Jacobson, E. R. Jawin, P. Jenniskens, J. N. Kidd Jr., E. J. LessacChenen, J.-Y. Li, G. Libourel, J. Licandro, A. J. Liounis, C. K. Maleszewski, C. Manzoni, B. May, L. K. McCarthy, **J. W. McMahan**, P. Michel, J. L. Molaro, M. C. Moreau, D. S. Nelson, W. M. Owen Jr., B. Rizk, H. L. Roper, B. Rozitis, E. M. Sahr, D. J. Scheeres, J. A. Seabrook, S. H. Selznick, Y. Takahashi, F. Thuillet,

- P. Tricarico, D. Vokrouhlický, C. W. V. Wolner, “Episodes of particle ejection from the surface of the active asteroid (101955) Bennu,” *Science*, Vol. 366, No. 6470, 06 Dec 2019, DOI: 10.1126/science.aay3544
32. D. N. Brack* and **J. W. McMahon**, “Modeling the coupled dynamics of an asteroid with surface boulder motion,” *Icarus*, Vol. 333, November 2019, pp 96 - 112, <https://doi.org/10.1016/j.icarus.2019.05.038>
 31. J. Geeraert* and **J. W. McMahon**, “Dual-Satellite Geolocation with Ephemeris Correction and Uncertainty Mapping,” *IEEE Transactions on Aerospace and Electronic Systems*, published online 30 May 2019, <https://doi.org/10.1109/TAES.2019.2920045>
 30. B. Bercovici* and **J. W. McMahon**, “Robust Autonomous Small Body Shape Reconstruction and Relative Navigation using Range Images,” *Journal of Guidance, Control, and Dynamics*, Vol. 42, No. 7, July 2019, pp 1473-1488, <http://arc.aiaa.org/doi/abs/10.2514/1.G003898>
 29. B. Bercovici* and **J. W. McMahon**, “Inertia parameter statistics of an uncertain small body shape,” *Icarus*, Vol. 328, August 2019. pp 32 - 44. <https://doi.org/10.1016/j.icarus.2019.02.016>
 28. D. Scheeres, **J. W. McMahon**, A. French*, D. N. Brack*, S. R. Chesley, D. Farnocchia, Y. Takahashi, J. M. Leonard, J. Geeraert, B. Page, P. Antreasian, K. Getzandanner, D. Rowlands, E. M. Mazarico, J. Small, D. E. Highsmith, M. Moreau, J. P. Emery, B. Rozitis, M. Hirabayashi, P. Sanchez, S. Van wal, P. Tricarico, R.-L. Ballouz, C. L. Johnson, M. M. Al Asad, H. C. M. Susorney, O. S. Barnouin, M. G. Daly, J. A. Seabrook, R. W. Gaskell, E. E. Palmer, J. R. Weirich, K. J. Walsh, E. R. Jawin, E. B. Bierhaus, P. Michel, W. F. Bottke, M. C. Nolan, H. C. Connolly Jr, D. S. Lauretta, The OSIRIS-REx Team, “The dynamic geophysical environment of (101955) Bennu based on OSIRIS-REx measurements,” *Nature Astronomy*, 19 Mar 2019, <https://doi.org/10.1038/s41550-019-0721-3>
 27. O. S. Barnouin, M. G. Daly, E. E. Palmer, R. W. Gaskell, J. R. Weirich, C. L. Johnson, M. M. Al Asad, J. H. Roberts, M. E. Perry, H. C. M. Susorney, R. T. Daly, E. B. Bierhaus, J. A. Seabrook, R. C. Espiritu, A. H. Nair, L. Nguyen, G. A. Neumann, C. M. Ernst, W. V. Boynton, M. C. Nolan, C. D. Adam, M. C. Moreau, B. Rizk, C. Y. Drouet DAubigny, E. R. Jawin, K. J. Walsh, P. Michel, S. R. Schwartz, R.-L. Ballouz, E. M. Mazarico, D. J. Scheeres, **J. W. McMahon**, W. F. Bottke, S. Sugita, N. Hirata, N. Hirata, S.-i. Watanabe, K. N. Burke, D. N. DellaGiustina, C. A. Bennett, D. S. Lauretta, The OSIRIS-REx Team, “Shape of (101955) Bennu indicative of a rubble pile with internal stiffness,” *Nature Geosciences*, 19 Mar 2019, <https://doi.org/10.1038/s41561-019-0330-x>
 26. S. Watanabe, M. Hirabayashi, N. Hirata, Na. Hirata, R. Noguchi, Y. Shimaki, H. Ikeda, E. Tatsumi, M. Yoshikawa, S. Kikuchi, H. Yabuta, T. Nakamura, S. Tachibana, Y. Ishihara, T. Morota, K. Kitazato, N. Sakatani, K. Matsumoto, K. Wada, H. Senshu, C. Honda, T. Michikami, H. Takeuchi, T. Kouyama, R. Hondaz S. Kameda, T. Fuse, H. Miyamoto, G. Komatsu, S. Sugita, T. Okada, N. Namiki, M. Arakawa, M. Ishiguro, M. Abe, R. Gaskell, E. Palmer, O. S. Barnouin, P. Michel, A. S. French*, **J. W. McMahon**, D. J. Scheeres, P. A. Abell, Y. Yamamoto, S. Tanaka, K. Shirai, M. Matsuoka, M. Yamada, Y. Yokota,, H. Suzuki, K. Yoshioka, Y. Cho, S. Tanaka, N. Nishikawa, T. Sugiyama, H. Kikuchi, R. Hemmi, T. Yamaguchi, N. Ogawa, G. Ono, Y. Mimasu, K. Yoshikawa, T. Takahashi, Y. Takei, A. Fujii, C. Hirose, T. Iwata, M. Hayakawa, S. Hosoda, O. Mori, H. Sawada, T. Shimada, S. Soldini, H. Yano, R. Tsukizaki, M. Ozaki, Y. Iijima, K. Ogawa, M. Fujimoto, T.-M. Ho, A. Moussi, R. Jaumann, J.-P. Bibring, C. Krause,

- F. Terui, T. Saiki, S. Nakazawa, Y. Tsuda, "Hayabusa2 arrives at the carbonaceous asteroid 162173 Ryugu - A spinning top-shaped rubble pile," *Science*, 19 Mar 2019, <https://doi.org/10.1126/science.aav8032>
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