

# Paul O. Hayne

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**Summary** I am an assistant professor of astrophysical and planetary sciences at the University of Colorado, Boulder. My research focuses on the surfaces and atmospheres of icy planets and moons. I develop computational models and use the latest observational data to better understand these planetary bodies. Teaching, mentoring, and public engagement are also fundamental to my work.

**Positions Held** **University of Colorado, Boulder**  
*Assistant Professor*, January 2018 – present  
Astrophysical & Planetary Sciences Department, and  
Laboratory for Atmospheric & Space Physics

**NASA – Jet Propulsion Laboratory**, California Institute of Technology  
*Research Scientist*, 2012 – 2017

**California Institute of Technology**  
*Postdoctoral Scholar*, 2011 – 2012  
Division of Geological & Planetary Sciences (with Oded Aharonson)

**Education** **University of California, Los Angeles**  
*Ph.D.*, Geophysics & Space Physics, 2010 (Advisor: David A. Paige)

**Stanford University**  
*M.S.*, Geophysics, 2005 (Advisors: Norman H. Sleep & Jack J. Lissauer)  
*B.S.*, Geophysics, 2003

**Mission Involvement** **NASA Europa Clipper**  
*Co-Investigator* (2017–present) and *Investigation Scientist* (2015–2018)  
Europa Thermal Emission Imaging System (E-THEMIS)

**NASA Mars Reconnaissance Orbiter**  
*Co-Investigator* (2017–present) and *Affiliate* (2007–2016)  
Mars Climate Sounder

**NASA Lunar Flashlight**  
*Co-Investigator* (2012–present)

**NASA Lunar Reconnaissance Orbiter**  
*Co-Investigator* (2011–present)  
Diviner Lunar Radiometer Experiment

*Science Team Affiliate: NASA Dawn at Ceres* (2016–present) and  
**NASA/ESA Cassini-Huygens Mission to Saturn** (2006–2014)

Visiting  
Appointments

**Lawrence Livermore National Laboratory**  
*Visiting Scientist* (2017)  
Planetary Defense Program / Weapons and Complex Integration (WCI)

**Weizmann Institute of Science**, Israel  
*Visiting Scientist* (2015, 2016)  
The Helen Kimmel Center for Planetary Science

Leadership  
& Service

**Keck Institute for Space Studies**, California Institute of Technology  
*Study Co-Lead*  
2017–2018: [Unlocking the Climate Record Stored within Mars' Polar Layered Deposits](#)  
2013–2014: [New Approaches to Lunar Ice Detection and Mapping](#)

**American Astronomical Society**, Division for Planetary Sciences  
*Member* of the Federal Relations Subcommittee (2017–present)  
*Local Organizing Committee*, Annual Meeting (2016)  
*Panelist*, Annual Meeting (2015)

**American Geophysical Union**  
*Session Organizer* (Mars Atmosphere), Annual Meeting (2014–2017)

**Young Scientists for Planetary Exploration**  
*Co-founder* (2012) and *Co-leader* (2012–present)  
World-wide advocacy organization for early-career planetary scientists

**Ad Astra Academy**  
*Co-founder and Co-leader*, Ad Astra - Brazil (2015–2016)  
Science and exploration program for school-aged students in developing countries

**NASA Science Mission Directorate**  
*Review Panel Member* (2012–present)

**National Research Council – Space Studies Board**  
*Raconteur*, Planetary Science Decadal Survey (2009–2010)

**Earth & Space Sciences Student Organization**, UCLA  
*President* (2007–2008)

**Stanford Astronomical Society**  
*President* (2002–2004)

**Referee** for major scientific journals:  
*Journal of Geophysical Research*  
*Geophysical Research Letters*  
*Icarus*  
*Astrophysical Journal*  
*Planetary & Space Science*  
*Advances in Space Research*  
*Space Science Reviews*  
*Geology*  
*Science Advances*

Honors & Awards	2013	<i>NASA Group Achievement Award</i> , Diviner Lunar Radiometer science team
	2011	<i>NASA Group Achievement Award</i> , Mars Climate Sounder science team
	2010	<i>Best Student Paper Award</i> , NASA Lunar Science Forum
	2010	<i>NASA Group Achievement Award</i> , Diviner Lunar Radiometer operations team
	2010	<i>NASA Group Achievement Award</i> , Diviner Lunar Radiometer science team
	2008	<i>Simon Latimer Award for Service</i> , UCLA
	2006	<i>Graduate Fellowship</i> , Institute of Geophysics and Planetary Physics
	2006	<i>Chancellor's Prize</i> , UCLA
	2003	<i>Graduate Fellowship</i> , Dept. of Geophysics, Stanford University
	2001	<i>Summer Research Fellowship</i> , Dept. of Physics, Stanford University

## Teaching

### **University of Colorado, Boulder**

*ASTR 1030: Accel. Introductory Astronomy* (Fall, 2018)

Professor for undergraduate majors course (115 students)

*ASTR 3720: Planets and their Atmospheres* (Spring, 2018)

Professor for upper-division undergraduate course (84 students)

### **California Institute of Technology**

*Ge 151: Planetary Surfaces* (2011)

Guest Lecturer for graduate course (~6 students)

### **University of California, Los Angeles**

*ESS 10: Exploring Mars* (2008)

Teaching Assistant and Guest Lecturer for undergraduate course (60 students)

### **Stanford University**

*Geophysics 150: Physics of the Earth* (2004, 2005)

Teaching Assistant for graduate course (~6 students)

*Physics 50: Observational Astronomy* (2002, 2003)

Teaching Assistant for undergraduate course (~20 students)

## Mentoring

### **Laboratory for Atmospheric and Space Physics**

*Mentor*

2018–present: Carlos Eytan Gary Bicas (APS Dept., U. Colorado)

2018–present: Tyler Horvath (APS Dept., U. Colorado)

2018–present: Tara Tomlinson (APS Dept., U. Colorado)

### **Caltech Summer Undergraduate Research Fellows (SURF)**

*Mentor*

2017: James Haber (Cornell University)

2015: Léa Bonnefoy (Cornell University)

2014: Clifford Watkins (Carleton College)

2011: Michael Lauria (Caltech)

### **Maximizing Student Potential (MSP)**

*Mentor*

2015–2018: Jose Martínez Camacho (Citrus College → Cal-Poly University)

### **Caltech Postdoctoral Fellows at JPL**

*Mentor*

2017–2018: Dr. Quentin Vinckier (*co-mentor* with Dr. R. Glenn Sellar)

2016–2018: Dr. Catherine M. Elder

External Grants	2018–2021	<i>Boulders on Bennu: Modeling Thermal Emission from Boulders for Yarkovsky Effect and Thermal Inertia Investigations</i> PI: P. Hayne (Science PI: C. Elder) NASA OSIRIS-REx Participating Scientist Program / \$346,000
	2013–2019	<i>Lunar Flashlight Science Investigation</i> PI: B. Cohen (Co-I: P. Hayne) NASA Advanced Exploration Systems / ~\$400,000 for P. Hayne
	2017–2018	<i>Unlocking the Climate Record Stored within Mars' Polar Layered Deposits</i> PI: P. Hayne W. M. Keck Institute for Space Studies / \$50,000
	2016–2018	<i>Lunar Reconnaissance Orbiter Extended Mission 3</i> PI: D. Paige (Co-I: P. Hayne) NASA Discovery Program / ~\$600,000 allocation for P. Hayne
	2016–2018	<i>Mars Reconnaissance Orbiter Extended Mission 4</i> PI: J. T. Schofield (Co-I: P. Hayne) NASA Mars Program / ~\$300,000 allocation for P. Hayne
	2015–2018	<i>Inter-seasonal and Inter-annual Surface Dust Fluxes on Mars</i> PI: P. Hayne (Science PI: S. Piqueux) NASA Mars Data Analysis Program / \$330,690
	2015–2018	<i>Europa Thermal Emission Imaging System</i> PI: P. Christensen (Co-I: P. Hayne) NASA Europa Clipper Mission / ~\$30,000 allocation for P. Hayne
	2013–2017	<i>Volatile Regolith Thermal Investigation Consortium for Exploration and Science (VORTICES)</i> PI: A. Rivkin (Co-I: P. Hayne) NASA Solar System Exploration Research Virtual Institute / ~\$120,000
	2014–2016	<i>Thermal Infrared Observations of the Moon during Lunar Eclipse</i> PI: P. Lucey (Co-I: P. Hayne) NASA Planetary Astronomy / \$142,810 allocation for P. Hayne
	2013–2014	<i>Development of Large Format Rad-Hard Focal Plane Arrays and Readouts for Thermal Radiometer for Europa Clipper Mission</i> PI: M. Kenyon (Co-I: P. Hayne) Instrument Concepts for Europa Exploration / \$16,460 allocation for P. Hayne
2013–2014	<i>New Approaches to Lunar Ice Detection and Mapping</i> PI: P. Hayne W. M. Keck Institute for Space Studies / \$50,000	

Invited Lectures	2018	Applied Physics Laboratory, Johns Hopkins University
	2017	Lawrence Livermore National Laboratory
	2017	University of Colorado, Boulder
	2016	Lunar & Planetary Institute
	2016	Weizmann Institute of Science (Israel)
	2015	International Space Exploration Coordination Group,
	2015	NASA Exploration Science Forum
	2015	University of California - Santa Cruz
	2014	SETI Institute
	2013	Lunar & Planetary Institute
	2012	California Institute of Technology
	2012	NASA – Jet Propulsion Laboratory
	Professional Affiliations	American Astronomical Society - Division for Planetary Sciences
American Geophysical Union		
European Geosciences Union		
Asia Oceania Geosciences Society		
Geochemical Society		
Sigma Xi		
Skills & Training	<b>Remote sensing &amp; spacecraft instrumentation</b>	
	Spectroscopy (ultraviolet through submillimeter)	
	Thermal imaging and radiometry	
	<b>Modeling and Numerical Simulation</b>	
	Heat transfer (thermal modeling)	
	Radiative transfer for planetary atmospheres and surfaces	
	Geophysical inversion	
	Transient and stochastic phenomena	
	<b>Computer programming languages</b>	
	Proficient/expert: C/C++, Python, MATLAB, IDL, bash, c-shell	
	Familiar: Fortran 90/95, awk, javascript, etc.	
	<b>Mission formulation experience</b>	
	<i>Team-X</i> , NASA Jet Propulsion Laboratory	
	<i>Team-A</i> , NASA Jet Propulsion Laboratory	
	<i>Capture Lead Training</i> , NASA Jet Propulsion Laboratory	
	Co-I on proposals to NASA's <i>Discovery</i> and <i>New Frontiers</i> programs	
	PI on instrument proposals to NASA mission programs	
<b>Additional training</b>		
<i>Astrobiology Winter School and Field Course</i> (2011)		
NASA Astrobiology Institute and Hawaii Institute for Astronomy		
<i>International Astrobiology Summer School</i> (2008)		
NASA Astrobiology Institute and Universidad Internacional Menéndez Pelayo, Spain		
<i>PADI Open Water Diver</i> scuba certification (50+ dives)		
<i>Eagle Scout</i> (1998), BSA Troop 676, Issaquah, WA		

## Publications: Refereed Journal Articles

Number of peer-reviewed papers: 32 (as of August, 2018)

*h-index*: 15 (Web of Science), 18 (Google Scholar)

Total citations: 717 (Web of Science), 1,140 (Google Scholar)

2018

1. Heavens, N. G., Kleinböhl, A., Chaffin, M. S., Halekas, J. S., Kass, D. M., **Hayne, P. O.**, McCleese, D. J., Piqueux, S., Shirley, J. H., & Schofield, J. T. (2018), Hydrogen escape from Mars enhanced by deep convection in dust storms, *Nature Astronomy*, *2*, 126–132. doi: [10.1038/s41550-017-0353-4](https://doi.org/10.1038/s41550-017-0353-4).
2. Li, S., Lucey, P. G., Milliken, R. E., **Hayne, P. O.**, Fisher, E., Williams, J-P., Hurley, D. M., Elphic, R. C. (2018), Direct evidence of surface exposed water ice in the lunar polar regions, *Proceedings of the National Academy of Sciences*, *2* 2018.

2017

3. **Hayne, P. O.**, Bandfield, J. L., Siegler, M. A., Vasavada, A. R., Ghent, R. R., et al. (2017), Global regolith thermophysical properties of the Moon from the Diviner Lunar Radiometer Experiment, *J. Geophys. Res.*, *122*, 2371–2400. doi: [10.1002/2017JE005387](https://doi.org/10.1002/2017JE005387)
4. Elder, C. M., **Hayne, P. O.**, Bandfield, J. L., Ghent, R. R., Williams, J-P., Donaldson Hanna, K. L., & Paige, D. A. (2017), Young lunar volcanic Features: Thermophysical properties and formation, *Icarus*, *290*, 224–237. doi: [10.1016/j.icarus.2017.03.004](https://doi.org/10.1016/j.icarus.2017.03.004)
5. Mitri, G., Postberg, F., Soderblom, J. M., ..., **Hayne, P. O.**, et al. (2017), Explorer of Enceladus and Titan (E<sup>2</sup>T): Investigating ocean worlds' evolution and habitability in the solar system, *Planetary and Space Science*, doi: [10.1016/j.pss.2017.11.001](https://doi.org/10.1016/j.pss.2017.11.001)
6. Landis, M. E., Byrne, S., Schörghofer, N., Schmidt, B. E., **Hayne, P. O.**, Castillo-Rogez, J., ... Russell, C. T. (2017), Conditions for sublimating water ice to supply Ceres' exosphere, *J. Geophys. Res.*, *122*, 1984–1995. doi: [10.1002/2017JE005335](https://doi.org/10.1002/2017JE005335)
7. Davies, A. G., Gunapala, S., Soibel, A., Ting, D., Rafol, S., Blackwell, M., **Hayne, P. O.**, & Kelly, M. (2017), A novel technology for measuring the eruption temperature of silicate lavas with remote sensing: Application to Io and other planets, *J. Volcanology & Geothermal Res.*, *343*, 1–16. doi: [10.1016/j.jvolgeores.2017.04.016](https://doi.org/10.1016/j.jvolgeores.2017.04.016)
8. Fisher, E. A., Lucey, P. G., Lemelin, M., Greenhagen, B. T., Siegler, M. A., Mazarico, E., Aharonson, O., Williams, J-P., **Hayne, P. O.**, Neumann, G. A., Paige, D. A., Smith, D. E., & Zuber, M. T. (2017), Evidence for surface water ice in the lunar polar regions using reflectance measurements from the Lunar Orbiter Laser Altimeter and temperature measurements from the Diviner Lunar Radiometer Experiment, *Icarus*, *292*, 74–85. doi: [10.1016/j.icarus.2017.03.023](https://doi.org/10.1016/j.icarus.2017.03.023)

2016

8. Piqueux, S., Kleinböhl, A., **Hayne, P. O.**, Heavens, N. G., Kass, D. M., McCleese, D. J., ... & Shirley, J. H. (2016), Discovery of a widespread low-latitude diurnal CO<sub>2</sub> frost cycle on Mars, *J. Geophys. Res.*, *121*, 1174-118. doi: [10.1002/2016JE005034](https://doi.org/10.1002/2016JE005034)
9. Greenhagen, B. T., Neish, C. D., Williams, J. P., Cahill, J. T., Ghent, R. R., **Hayne, P. O.**, ... & Bandfield, J. L. (2016), Origin of the anomalously rocky appearance of Tsiolkovskiy crater, *Icarus*, *273*, 237-247. doi: [10.1016/j.icarus.2016.02.041](https://doi.org/10.1016/j.icarus.2016.02.041)
10. Bennett, K. A., Horgan, B. H., Gaddis, L. R., Greenhagen, B. T., Allen, C. C., **Hayne, P. O.**, ... & Paige, D. A. (2016), Complex explosive volcanic activity on the Moon within Oppenheimer crater, *Icarus*, *273*, 296-314. doi: [10.1016/j.icarus.2016.02.007](https://doi.org/10.1016/j.icarus.2016.02.007)
11. Bonnefoy, L. E., A. G. Hayes, **P. O. Hayne**, et al. (2015), Compositional and spatial variations in Titan dune and interdune regions from Cassini VIMS and RADAR, *Icarus*, *270*, 222-237, doi:[10.1016/j.icarus.2015.09.014](https://doi.org/10.1016/j.icarus.2015.09.014)

2015

12. **Hayne, P. O.**, and Oded Aharonson (2015), Thermal stability of ice on Ceres with rough topography, *J. Geophys. Res.*, *120*, 1567-1584, doi: [10.1002/2015JE004887](https://doi.org/10.1002/2015JE004887)
13. Heavens, N. G., Cantor, B. A., **Hayne, P. O.**, et al. (2015), Extreme detached dust layers near Martian volcanoes: Evidence for dust transport by mesoscale circulations forced by high topography, *Geophys. Res. Lett.*, *42*, 10, 3730-3738. doi: [10.1002/2015GL064004](https://doi.org/10.1002/2015GL064004)
14. **Hayne, P. O.**, A. R. Hendrix, E. Sefton-Nash, P. G. Lucey, K. D. Retherford, J-P. Williams, et al. (2015), Evidence for exposed water ice in the Moon's south polar regions from Lunar Reconnaissance Orbiter ultraviolet albedo and temperature measurements, *Icarus*, *255*, 58-69, doi:[10.1016/j.icarus.2015.03.032](https://doi.org/10.1016/j.icarus.2015.03.032)
15. Glotch, T. D., Bandfield, J. L., Lucey, P. G., **Hayne, P. O.**, et al. (2015), Formation of lunar swirls by magnetic field standoff of the solar wind, *Nature Communications*, *6*. doi: [10.1038/ncomms7189](https://doi.org/10.1038/ncomms7189)
16. Piqueux, S., Kleinböhl, A., **Hayne, P. O.**, Kass, D. M., Schofield, J. T., & McCleese, D. J. (2015), Variability of the Martian seasonal CO<sub>2</sub> cap extent over eight Mars Years, *Icarus*, doi:[10.1016/j.icarus.2014.10.045](https://doi.org/10.1016/j.icarus.2014.10.045)
17. Bandfield, J. L., **Hayne, P. O.**, Williams, J. P., Greenhagen, B. T., & Paige, D. A. (2015), Lunar surface roughness derived from LRO Diviner Radiometer observations, *Icarus*, *248*, 357-372. doi: [10.1016/j.icarus.2014.11.009](https://doi.org/10.1016/j.icarus.2014.11.009)

2014

18. **Hayne, P. O.**, McCord, T. B., & Sotin, C. (2014), Titan's surface composition and atmospheric transmission with solar occultation measurements by Cassini VIMS, *Icarus*, *243*, 158–172. doi: [10.1016/j.icarus.2014.08.045](https://doi.org/10.1016/j.icarus.2014.08.045)
19. **Hayne, P. O.**, D. A. Paige, N. G. Heavens (2014), The role of snowfall in forming the seasonal ice caps of Mars: Models and constraints from the Mars Climate Sounder, *Icarus* *231*, 122–130. doi: [10.1016/j.icarus.2013.10.020](https://doi.org/10.1016/j.icarus.2013.10.020)
20. Ghent, R. R., **Hayne, P. O.**, Bandfield, J. L., Campbell, B. A., Allen, C. C., Carter, L. M., & Paige, D. A. (2014), Constraints on the recent rate of lunar ejecta breakdown and implications for crater ages, *Geology*, *42*(12), 1059–1062. doi: [10.1130/G35926.1](https://doi.org/10.1130/G35926.1)
21. Bandfield, J. L., E. Song, **P. O. Hayne**, B. D. Brand, R. R. Ghent, A. R. Vasavada, D. A. Paige (2014), Lunar cold spots: Granular flow features and extensive insulating materials surrounding young craters, *Icarus* *231*, 221–231. doi: [10.1016/j.icarus.2013.12.017](https://doi.org/10.1016/j.icarus.2013.12.017)
22. Ingersoll, R. V., Pratt, M. J., Davis, P. M., Caracciolo, L., Day, P. P., **Hayne, P. O.**, ... & Hendrix, E. D. (2014), Paleotectonics of a complex Miocene half graben formed above a detachment fault: The Diligencia basin, Orocochia Mountains, southern California, *Lithosphere*, *6*(3), 157–176. doi: [10.1130/L334.1](https://doi.org/10.1130/L334.1)

2013

23. Barnes, J. W., B. J. Buratti, E. P. Turtle, J. Bow, P. A. Dalba, J. Perry, R. H. Brown, S. Rodriguez, S. Le Mouelic, K. H. Baines, C. Sotin, R. D. Lorenz, M. J. Malaska, T. B. McCord, R. N. Clark, R. Jaumann, **P. O. Hayne**, et al. (2013), Precipitation-Induced Surface Brightenings Seen on Titan by Cassini VIMS and ISS, *Planetary Science*, *2*, p. 1. doi: [10.1186/2191-2521-2-1](https://doi.org/10.1186/2191-2521-2-1)

2012

24. **Hayne, P. O.**, D. A. Paige, J. T. Schofield, D. M. Kass, A. Kleinböhl, N. G. Heavens, and D. J. McCleese (2012), Carbon dioxide snow clouds on Mars: South polar winter observations by the Mars Climate Sounder, *J. Geophys. Res.*, *117*, E08014, doi: [10.1029/2011JE004040](https://doi.org/10.1029/2011JE004040)
25. Vasavada, A. R., J. L. Bandfield, B. T. Greenhagen, **P. O. Hayne**, et al. (2012), Lunar Equatorial Surface Temperatures and Regolith Properties from the Diviner Lunar Radiometer Experiment, *J. Geophys. Res.* *117*, E00H18. doi: [10.1029/2011JE003987](https://doi.org/10.1029/2011JE003987)

2010

26. **Hayne, P. O.**, B. T. Greenhagen, M. C. Foote, M. A. Siegler, A. R. Vasavada, and D. A. Paige (2010), Diviner Lunar Radiometer Observations of the LCROSS Impact, *Science*, *330*, 477. doi: [10.1126/science.1197135](https://doi.org/10.1126/science.1197135)
27. Paige, D. A., M. A. Siegler, J. A. Zhang, **P. O. Hayne**, et al. (2010), Diviner Observations of Cold Traps in the Lunar South Polar Region: Spatial Distribution and Temperature, *Science* *330*, 479. doi: [10.1126/science.1187726](https://doi.org/10.1126/science.1187726)
28. Greenhagen, B. T., P. G. Lucey, M. B. Wyatt, T. D. Glotch, C. C. Allen, J. A. Arnold, J. L. Bandfield, N. E. Bowles, K. L. Hanna, **P. O. Hayne**, E. Song, I. R. Thomas, and D. A. Paige (2010), Global Silicate Mineralogy of the Moon from the Diviner Lunar Radiometer, *Science* *329*, 1507. doi: [10.1126/science.1192196](https://doi.org/10.1126/science.1192196)
29. McCord, T. B., Hansen, G. B., Combe, J-P., & **P. O. Hayne** (2010), Hydrated minerals on Europa's surface: An improved look from the Galileo NIMS investigation, *Icarus* *209*, 639–650. doi: [10.1016/j.icarus.2010.05.026](https://doi.org/10.1016/j.icarus.2010.05.026)



2009

30. Barnes, J. W., ..., **P. O. Hayne**, et al. (2009), VIMS Spectral Mapping Observations of Titan during the Cassini Prime Mission, *Planet. and Space Sci.*, *57*, 1950–1962. doi: [10.1016/j.pss.2009.04.013](https://doi.org/10.1016/j.pss.2009.04.013)

2008

31. McCord, T. B., **P. Hayne**, et al. (2008), Titan’s surface: Search for spectral diversity and composition using the Cassini VIMS investigation, *Icarus*, *194*, 212–242. doi: [10.1016/j.icarus.2007.08.039](https://doi.org/10.1016/j.icarus.2007.08.039)

### Publications: Book Chapters & Reports

1. Aharonson, O., A. Hayes, **P. O. Hayne**, R. Lopes, A. Lucas, J. T. Perron, (2012), Titan’s Surface Geology, in: C. G. Mueller-Wodarg, T. Cravens and E. Lellouch (Ed.), *Titan: Surface, Atmosphere and Magnetosphere*, Cambridge University Press, Cambridge, UK.
2. **Hayne, P. O.**, A. P. Ingersoll, D. A. Paige, & 32 co-authors (2014), “New approaches to lunar ice detection and mapping,” *Keck Institute for Space Studies Report*. [\[PDF\]](#)

### Publications: Commentaries

1. **Hayne, P. O.** (2013), Abandoned frontier, *Nature Geosci.*, *6(3)*, 155-156. doi: [10.1038/ngeo1753](https://doi.org/10.1038/ngeo1753)