

# **Richard J. Cartwright**

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## **Research Objectives**

I am keenly interested in understanding the geologic and compositional links between the surfaces and interiors of icy bodies. I am also interested in determining the spectral signature of volatile ices and organics that were incorporated into icy bodies as they formed in the early Solar System. To investigate these topics, I measure and model absorption features detected in reflectance spectra collected by ground and space-based telescopes and spacecraft, and I analyze geologic features and terrains observed in imaging datasets. I am currently analyzing data collected by the James Webb Space Telescope to investigate chemical tracers of interior-surface exchange on Europa, as well as the exogenic processes that have shaped the surface composition of Callisto. In the near future, I will utilize JWST data to study possible compositional links between the interiors and surfaces of the Uranian moons. For a related project, I am studying charged particle bombardment of Uranus' large moons using data collected by the Hubble Space Telescope. I am also interested in developing the science case and instrument requirements for a flagship spacecraft mission to explore the Uranian system.

## **Recent Employment History**

2017 – present: Research Scientist, The Carl Sagan Center for Research at the SETI Institute.  
2014 – 2017: Research Assistant, University of Tennessee, *NASA Earth & Space Science Fellow*.  
2010 – 2017: Teaching Assistant, University of Tennessee.

## **Education**

Ph.D. Geology, 2017, University of Tennessee, Knoxville, TN.  
Dissertation: *Surface modification of icy moons: Space weathering of the large moons of Uranus and alluvial fan formation on Saturn's moon Titan*. (Co-advisors J.P. Emery, D.M. Burr).  
M.A. Geosciences, 2009, Georgia State University, Atlanta, GA.  
Thesis: *Analysis of channel networks and the potential for sediment transport in the vicinity of the north polar seas of Titan*.  
B.A. English, 2002, Oglethorpe University, Atlanta, GA.

## **Funding**

**2023-2026 (TBS):** Space Telescope Science Institute (JWST Cycle 1, program 1786). *The moons of Uranus: A NIRSpec investigation of their origins, organic constituents, and possible ocean world activity*. (PI, TBD: 0.19 FTE/year).  
**2023-2026:** Solar System Observations. *Unraveling the origin and nature of non-ice species on the icy Galilean moons*. (PI, 0.26 FTE/year, 80NSSC23K0031).  
**2022-2025:** Space Telescope Science Institute (JWST Cycle 1, program 2060). *Unraveling the primordial constituents and exogenic processes that shaped Callisto's surface*. (PI, 0.17 FTE/year, STScI-JWST-GO-0206.001-A).

- 2022-2024:** Space Telescope Science Institute (HST Cycle 29, program 16704). *Are the surfaces of the large moons of Uranus modified by charged particle bombardment?* (PI, 0.22 FTE/year, STScI-HST-GO-16704.001-A).
- 2021-2024:** Discovery Data Analysis Program. *Do Polygonal Impact Craters Form on Mercury's Lobate Scarps? Implications for Contractual Tectonism throughout the Solar System.* (Co-I, 0.24 FTE/year, 80NSSC21K1016).
- 2021-2023:** Cassini Data Analysis Program. *Unraveling Iapetus' Tectonic and Orbital History Using Polygonal Impact Craters.* (Co-I, 0.23 FTE/year, 80NSSC21K0537).
- 2020-2023:** JPL Strategic Initiative for the Research and Technology Development Fund. *The Uranian moons as possible active worlds.* (Telescope observing lead, 0.12 FTE/year).
- 2020-2022:** New Frontiers Data Analysis Program. *The icy Galilean satellites as seen from New Horizons.* (Co-I, 0.06 FTE/year, 80NM0018F0612).
- 2020-2022:** Solar System Workings. *Ammonia hydrates on Saturnian and Uranian moons? Implications for heat fluxes and ocean worlds.* (Co-I, 0.11 FTE/year, 80NSSC20K0143).
- 2021-2022:** Solar System Observations (COVID funding extension). *Spectral mapping of the moons of Uranus: Why are these surfaces dark, red, and rich in CO<sub>2</sub>?* (Science PI, 0.5 FTE, 80NSSC20K0292).
- 2017-2021:** Solar System Observations. *Spectral mapping of the moons of Uranus: Why are these surfaces dark, red, and rich in CO<sub>2</sub>?* (Science PI, 1.0 FTE/year, NNX17AG15G).
- 2014-2017:** NASA Earth and Space Sciences Fellowship. *Dark material on the large moons of Uranus: What is it and where did it come from?* (Student recipient, NNX10AP16H).

### **Publications**

- Beddingfield, C.B., **Cartwright, R.J.** et al., 2023. *Tethys' heat fluxes bounding Ithaca Chasma near Telemus Crater.* Planetary Science Journal [In Press].
- Cartwright, R.J.** et al., 2023. *Evidence for nitrogen-bearing species on Umbriel: Sourced from a subsurface ocean, undifferentiated crust, or impactors?* Planetary Science Journal 4, 42. <https://doi.org/10.3847/PSJ/acbc1f>
- Castillo-Rogez, J.C., ... **Cartwright, R.J.** et al., 2023. *Compositions and Interior Structures of the Large Moons of Uranus and Implications for Future Spacecraft Observations.* Journal of Geophysical Research: Planets. 128, 1. <https://doi.org/10.1029/2022JE007432>
- Beddingfield, C.B. and **Cartwright, R.J.**, 2022. *Regolith mantled craters on Uranus' moon Miranda: Sourced by rings, plumes, or a large impact event.* Planetary Science Journal 3, 11. <https://doi.org/10.3847/PSJ/ac9a4e>
- Beddingfield, C.B., **Cartwright, R.J.** et al., 2022. *High heat flux near Inverness Corona on Uranus' moon Miranda.* Planetary Science Journal 3, 7. <https://doi.org/10.3847/PSJ/ac7be5>
- Rivkin A.S., ... **Cartwright, R.J.** et al., 2022. *The nature of low-albedo small bodies from 3- $\mu$ m spectroscopy: One group that formed within the ammonia snow line and one that formed beyond it.* Planetary Science Journal 3, 7. <https://doi.org/10.3847/PSJ/ac7217>
- DeColibus D.R., Chanover, N.J., and **Cartwright, R.J.**, 2022. *Longitudinal variations of H<sub>2</sub>O ice absorption on Miranda.* Planetary Science Journal 3, 5. <https://doi.org/10.3847/PSJ/ac694e>

- Beddingfield, C.B., **Cartwright, R.J.** et al., 2022. *Ariel's elastic thicknesses and heat fluxes*. Planetary Science Journal 3, 5. <https://doi.org/10.3847/PSJ/ac63d1>
- Cartwright, R.J.** et al., 2022. *A CO<sub>2</sub> cycle on Ariel? Radiolytic production and migration to low latitude cold traps*. Planetary Science Journal 3, 8. <https://doi.org/10.3847/PSJ/ac3d30>
- Roser, J.E., Ricca, A., **Cartwright R.J.** et al., 2021. *Infrared Optical Constants of Amorphous Ammonia Ice and an Ammonia/Water Ice Mixture at the Pluto/Charon Surface Temperature (7000–440 cm<sup>-1</sup>)*. Planetary Science Journal 2, 6. <https://doi.org/10.3847/PSJ/ac3336>
- Beddingfield, C.B. and **Cartwright, R.J.** 2021. *A lobate feature adjacent to a double ridge on Ariel: Formed by cryovolcanism or mass wasting?* Icarus 367, 114583. <https://doi.org/10.1016/j.icarus.2021.114583>
- Leonard, E.J., ... **Cartwright, R.J.** et al., 2021. *UMaMI: A New Frontiers-style Mission Concept to Explore the Uranian System*. Planetary Science Journal 2, 5. <https://doi.org/10.3847/PSJ/ac0e3b>
- Cartwright, R.J.** et al. 2021. *The science case for spacecraft exploration of the Uranian satellites: Candidate ocean worlds in an ice giant system*. Planetary Science Journal 2, 3. <https://doi.org/10.3847/PSJ/abfe12>
- Cartwright, R.J.** et al. 2020c. *Evidence for sulfur-bearing species on Callisto's leading hemisphere: Sourced from Jupiter's irregular satellites or Io?* Astrophysical Journal Letters 902 (2), L38. <https://doi.org/10.3847/2041-8213/abbdae>
- Cartwright, R.J.**, et al., 2020b. *Evidence for NH<sub>3</sub>-bearing species on the Uranian satellite Ariel supports recent geologic activity*. Astrophysical Journal Letters 898 (1), L22. <https://doi.org/10.3847/2041-8213/aba27f>
- Kollmann P., ... **Cartwright, R.J.** et al., 2020. *Magnetospheric Studies: A requirement for addressing interdisciplinary mysteries in the Ice Giant systems*. Space Sci. Rev. 216, 5, 1-26. <https://doi.org/10.1007/s11214-020-00696-5>
- Beddingfield, C.B. and **Cartwright, R.J.**, 2020. *Hidden Tectonism on Miranda's Elsinore Corona revealed by polygonal impact craters*. Icarus 343, 113687. <https://doi.org/10.1016/j.icarus.2020.113687>
- Cartwright, R.J.**, et al., 2020a. *Probing the regoliths of the classical Uranian satellites: Are their surfaces mantled by tiny H<sub>2</sub>O ice grains?* Icarus 338, 113513. <https://doi.org/10.1016/j.icarus.2019.113513>
- Cruikshank D.P., ... **Cartwright, R.J.** et al., 2019. *Recent Cryovolcanism in Virgil Fossae on Pluto*. Icarus 330, 155-168. <https://doi.org/10.1016/j.icarus.2019.04.023>
- Lucas, M.P., ... **Cartwright, R.J.** et al., 2019. *(HARTSS) II: Spectral Homogeneity Among Hungaria Family Asteroids*. Icarus 322, 227-250. <https://doi.org/10.1016/j.icarus.2018.12.010>
- Cook, J.C., ... **Cartwright, R.J.** et al., 2018. *Composition of Pluto's Small Satellites: Analysis of New Horizons Spectral Images*. Icarus 315, 30-45. <https://doi.org/10.1016/j.icarus.2018.05.024>
- Cartwright, R.J.**, et al., 2018. *Red material on the large moons of Uranus: Dust from the irregular satellites?* Icarus 314, 210-231. <https://doi.org/10.1016/j.icarus.2018.06.004>

**Cartwright, R.J.** and Burr, D.M., 2017. *Using Synthetic Aperture Radar data of terrestrial analogs to test alluvial fan formation mechanisms on Titan*. Icarus 284, 183-205.

<https://doi.org/10.1016/j.icarus.2016.11.013>

**Cartwright, R.J.** et al., 2015. *Distribution of CO<sub>2</sub> ice on the large moons of Uranus and evidence for compositional stratification of their near-surfaces*. Icarus 257, 428-456.

<https://doi.org/10.1016/j.icarus.2015.05.020>

Burr, D.M., Drummond, S.A., **Cartwright, R.J.**, Perron, T., Black, B., 2013. *Morphology of fluvial networks on Titan: Evidence for structural control*. Icarus 226, 742-759.

<https://doi.org/10.1016/j.icarus.2013.06.016>

**Cartwright, R.J.**, Clayton, J., Kirk, R., 2011. *Channel Morphometry, sediment transport, and implications for tectonic activity and surficial ages of Titan basins*. Icarus 214, 561-570.

<https://doi.org/10.1016/j.icarus.2011.03.011>

### **Under Review and In Prep Manuscripts**

Villanueva, G.L. ... **Cartwright, R.J.** et al. [Under Review]. *Discovery of a complex CO<sub>2</sub> ice matrix and a sensitive search for plumes on Europa with JWST*.

Villanueva, G.L. ... **Cartwright, R.J.** et al. [Under Review]. *JWST observations show Enceladus' water vapor plume extends far from its cryovolcanic source*.

**Cartwright, R.J.** et al. [In Prep]. *JWST/NIRSpec observations of Callisto's carbon-rich surface and atmosphere*.

**Cartwright, R.J.** et al. [In Prep]. *Investigating charged particle bombardment and radiolytic production cycles on the large Uranian moons using HST/STIS*.

**Cartwright, R.J.** et al. [In Prep]. *Measuring the spectral signature of hydrated salts on Europa*.

### **Leadership**

Actively working on spacecraft mission concepts to explore Uranus and its rings and moons:

- First author of a Planetary Science & Astrobiology Decadal Survey white paper advocating for a Flagship-class Uranus orbiter to study the moons of Uranus. This work was published in: *The Science case for spacecraft exploration of the Uranian satellites: Candidate ocean worlds in an ice giant system*. <https://iopscience.iop.org/article/10.3847/PSJ/abfe12/meta>
- Composition team lead on a New Frontiers mission concept to the Uranian system: *Uranus Magnetosphere and Moon Investigator (UMaMI)*. <https://doi.org/10.3847/PSJ/ac0e3b>
- Co-author on another spacecraft mission concept to explore the Uranian system: *New Frontiers-class Uranus Orbiter: Exploring the feasibility of achieving multidisciplinary science with a mid-scale mission*. <https://baas.aas.org/pub/2021n4i323/release/1>

Actively working to define the Solar System science goals for the next generation space telescope HWO (formerly LUVOIR) and the ground-based Extremely Large Telescopes (ELTs):

- First author of an Astro2020 white paper describing key science goals for icy bodies that could be achieved with LUVOIR: *Exploring the Composition of Icy bodies Beyond Saturn with Next Generation Space Telescopes*. <https://arxiv.org/abs/1903.07691>
- Co-author on the Astro2020 white paper: *Investigating the Solar System's Ocean Worlds with Next Generation Space Telescopes*. <http://adsabs.harvard.edu/abs/2019BAAS...51c..65N>

- Co-author on three Astro2020 white papers and one Planetary Science & Astrobiology Decadal Survey paper describing investigation of the Solar System using Extremely Large Telescopes (ELTs). <https://arxiv.org/abs/1903.06321>, <https://arxiv.org/abs/2009.08029>, <https://baas.aas.org/pub/2020n3i340/release/1>, <https://baas.aas.org/pub/2020n3i519/release/1>

Co-author on other white papers advocating for exploration of icy bodies in the Solar System:

- Investigation of icy bodies in the Kuiper Belt with an interstellar probe mission. <https://baas.aas.org/pub/2021n4i007/release/1>
- Solar System dedicated space telescope: <https://arxiv.org/abs/2008.08069>
- The need for laboratory-derived optical constants for species on icy bodies: <https://baas.aas.org/pub/2021n4i195/release/1>
- Exploration of candidate ocean worlds: <https://baas.aas.org/pub/2021n4i212/release/1>
- Exploration of small icy and rocky bodies: <https://elib.dlr.de/147035/>

### **Mentoring, Service, and Memberships**

Working with a Ph.D. student to investigate the spectral properties of the Uranian moon Miranda using TripleSpec on the 3.5m at Apache Point Observatory, GNIRS on Gemini North, and SpeX on NASA's Infrared Telescope Facility. Mentoring tasks include providing feedback on all conference abstracts, observing proposals, and publications.

Served in person and remotely on nine NASA & NSF funding review panels. Conducted numerous external reviews for a wide range of review panels.

Conducted peer review on seven planetary astronomy/science journal articles and refereed the *Surface Composition of Charon* chapter in *The Pluto System After New Horizons* book.

Member of the US Extremely Large Telescope Program Solar System Science Group.

- Participated in workshops that led the writing of four ELT white papers submitted to the Astronomy and Astrophysics and the Planetary Science and Astrobiology Decadal Surveys.

Member of the Division for Planetary Sciences of the American Astronomical Society.

- Co-chaired the DPS 2021 session *A Plethora of Icy Satellites*.

Member of the American Geophysical Union.

- Co-chaired the AGU 2020 session *The Uranus and Neptune Systems and Their Relation to Other Planets*.

### **Research Experience and Skills**

- Eleven years of observing experience and data reduction and analysis of telescope datasets, spanning the ultraviolet, visible, and near infrared with the James Webb Space Telescope, Hubble Space Telescope, Spitzer Space Telescope, Infrared Telescope Facility, Gemini North, Lowell Discovery Telescope, and the Vatican Advanced Technology Telescope (**PI of 35 selected observing proposals**).
- Twelve years of spatial analysis and image processing experience using data collected by spacecraft and Earth-orbiting satellites, including: the Cassini spacecraft (Radar, VIMS, and ISS instruments), the Voyager 2 spacecraft (ISS camera), Landsat 7 and 8, ALOS-PALSAR, CSA RADARSAT-1, SIR-C/X-SAR, and Sentinel-1.

- Data analysis experience in: Python, IDL, ESRI ArcGIS, bash, R, ENVI, JMARS, processing of Cassini Radar and VIMS (USGS ISIS) and terrestrial radar datasets (ASF MapReady).
- Extensive experience with the reduction and analysis of spectroscopic and imaging datasets collected with telescope facilities and spacecraft.
- Extensive experience using Hapke and Mie based radiative transfer modeling programs.

### **Recent First Author Research Talks**

- Space Telescope Science Institute Symposium, May 2023. *JWST/NIRSpec observations of the Galilean moon Callisto*. (Invited talk)
- Clipper Composition Working Group Monthly Townhall, April 2023. *Investigating the icy Galilean moons with ground-based telescopes and JWST*. (Invited talk)
- Europa Clipper Lecture Series, April 2023. *Investigating hydrated salts on Europa*. (Invited talk)
- Lunar and Planetary Science Conference, March 2023. *Are nitrogen-bearing species present on Uranus' moon Umbriel?* Abstract 1268.
- University of Central Florida, Florida Space Institute seminar, February 2023. *Exploring Ocean Worlds: Salts, Ices, and Organics in the Jovian and Uranian Systems*. (Invited talk)
- Division for Planetary Sciences, October 2022. *A future mission to Uranus: Exploration of five possible ocean worlds and a bevy of small icy moons*. Abstract 407.03. (Invited plenary talk)
- Division for Planetary Sciences, October 2022. *HST observations of the large moons of Uranus and implications for radiolytic processing and radiation darkening*. Abstract 106.07.
- International Space Science Institute, Ring-Planet Interactions Team, July 2022. *Surface modification of Uranus' large moons*. (Invited talk)
- Jet Propulsion Laboratory ICE seminar, October 2021. *Are the large moons of Uranus active worlds? Volatile cycling and possible tracers of ocean world activity*. (Invited talk)
- Europlanet Science Conference, September 2021. *The moons of Uranus: Five candidate ocean worlds and a bevy of small satellites in an ice giant system*.
- American Geophysical Union, December 2020. *Evidence for ammonia-bearing species on the classical Uranian satellite Ariel supports recent geologic activity*.
- Outer planet moon – magnetosphere interaction workshop, November 2020. *Investigating the origin of sulfur-bearing species on the Galilean moon Callisto*.
- Division for Planetary Sciences, October 2020. *The Science case for spacecraft exploration of the Uranian satellites*.
- Division for Planetary Sciences, October 2020. *What is the origin and composition of Callisto's 4- $\mu$ m band?*

### **Recent News Articles and Public Talks**

- Spacepod Podcast, February 2023. *The science case for spacecraft exploration of the Uranian satellites*. <https://www.listentospacepod.com/>
- The Planetary Society, September 2022. *Patience for Uranus*. <https://www.planetary.org/articles/patience-for-uranus>

SFGATE, July 2022. *Bay Area researchers granted use of NASA's James Webb Space Telescope.* <https://www.sfgate.com/news/article/california-researchers-use-webb-telescope-17307779.php>

SETI Institute, July 2022. *JWST and our cosmic backyard: Infrared observations of the icy moons of the outer Solar System.* [https://www.youtube.com/watch?v=tniZP3eu\\_Ms](https://www.youtube.com/watch?v=tniZP3eu_Ms)

Forbes Science, April 2022. *We're Going To Uranus! NASA Will Spend \$4.2 Billion And \$4.9 Billion On New Flagship Missions To The 'Ice Giant' And Saturn's 'Wet Moon' Enceladus.* <https://www.forbes.com/sites/jamiecartereurope/2022/04/19/were-going-to-uranus-nasa-will-spend-2-billion-on-jaw-dropping-missions-to-the-ice-giant-and-saturns-wet-moon/?sh=5821652d23e3>

Space.com, April 2022. *Uranus by 2049: Here's why scientists want NASA to send a flagship mission to the strange planet.* <https://www.space.com/nasa-uranus-orbiter-probe-mission-science>

Fernbank Science Center, September 2021. *Shakespeare's Moons: The Case for Uranus.* <https://www.facebook.com/fernbankcenter/videos/158320219716532>

Forbes Science, August 2021. *Why We Need To Explore The 'Shakespearean' Ocean Moons Of Uranus—And There's No Time To Waste.* <https://www.forbes.com/sites/jamiecartereurope/2021/08/12/why-we-need-to-explore-the-shakespearean-ocean-moons-of-uranus-and-theres-no-time-to-waste/?sh=2050e7ea77dc>

AAS Journal Author Series, August 2021. *The Science case for spacecraft exploration of the Uranian satellites: Candidate ocean worlds in an ice giant system.* <https://www.youtube.com/watch?v=fX5MIoIJDB4>

SETI Institute, August 2020. *A new mission to Uranus?* [https://www.youtube.com/watch?v=j\\_vDcAtCcgs&t=296s](https://www.youtube.com/watch?v=j_vDcAtCcgs&t=296s)

### **Teaching Assistant Appointments**

- Data Analysis for Geoscientists (graduate), Fall 2016.
- Planetary Geoscience (upper-level undergraduate), Spring 2011 – 2016.
- Mineralogy (upper-level undergraduate), Fall 2012.
- Dynamic Earth (Introductory Geology), Fall 2010, 2014, 2015, Spring 2017.
- Solar System Astronomy (Introductory Astronomy), Fall 2009, Spring 2010.
- Introduction to Landforms (Introductory Geography), Fall 2007 – Summer 2009.
- Introduction to Weather and Climate (Introductory Geography), Fall 2007 – Summer 2009.