Sarah Rugheimer

Contact Information

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Research Interests

I study the climate and atmospheres of habitable exoplanets. My research particularly focuses on the star-planet interaction, studying the effect of UV activity on the atmospheric chemistry and the detectability of biosignatures in a planet's atmosphere with future missions such as JWST, E-ELT and LUVOIR.

Appointments

Simons Research Fellow, University of St. Andrews **Oct 2015 - present**

Simons Origins of Life Postdoctoral Research Fellow

Research Associate, Cornell University, Carl Sagan Inst. **Feb 2015 - Aug 2015**

Education

Harvard University, Cambridge, MA **September 2008 - January 2015***

M.A. in Astronomy *June 2010*

Ph.D. in Astronomy & Astrophysics *June 2010 - January 2015*

- Thesis Title: Hues of Habitability: Characterizing Pale Blue Dots Around Other Stars
- Advisors: Lisa Kaltenegger and Dimitar Sasselov
- Chosen as one of 8 PhD students at Harvard in Arts and Sciences as a 2014 Harvard Horizons Scholar: www.gsas.harvard.edu/harvardhorizons

* Harvard recognized a 1.5 years delay in time caring for terminally ill father.

University of Calgary, Calgary, Alberta Canada

B.Sc. (First Class Honors), **September 2003 - June 2007**

- Graduated top of class in Department of Physics and Astronomy
- Senior Thesis Topic: Uses of Attractive Bose-Einstein in Atom Interferometers
- Undergrad summer research projects: placing quantum dots in phospholipid vesicles as a precursor to tracking active neuron cells with Dr. X.L. Wu (2003); modeling MEG data on brain surfaces generated from MRI data with Dr. Mingui Sun (2005); and numerically modeled Earth-like planets in the habitable zone of the nearby star system of HD 69830 with Dr. Haghighipour (2006).

Flathead Valley Community College **September 2002 - May 2003**

Awards

- Glasstone Oxford Fellowship
- Simons Postdoctoral Origins of Life Fellowship
- 2014 Harvard Horizons Scholar
- D.A.A.D Fellowship for International Research Collaboration in Germany
- Derek Bok Center Distinction in Teaching Award for *The Energetic Universe*, Spring 2012, Harvard University
- Venkatesan Silver Medallion, for being the top graduate in my physics class at the University of Calgary in 2007

Observing Proposals

Co-I on HST Cycle 22 - The MUSCLES Treasury Survey: Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems (PI - Kevin France, ID 13650)

Co-I on HST Cycle 25 The Mega-MUSCLES Treasury Survey: Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems (PI - Cynthia Froning, ID 15071)

Co-I on HST Cycle 25 The M Dwarf UV Spectra Irradiating Nearby Transiting Terrestrial Planets (PI - Zach Berta-Thompson, ID 15264)

Publications

Referred Publications (4 first author, 15 total)

Rugheimer, S. and Kaltenegger, L. (2018) Spectra of Earth-like Planets Orbiting FGKM Stars Through Geological Evolution, *ApJ*, 854:19. doi:10.3847/1538-4357/aaa47a

Schwieterman, E.W., Kiang, N.Y., Parenteau, M.N., Harman, C.E., DasSarma, S., Fisher, T.M., Arney, G.N., Hartnett, H.E., Reinhard, C.T., Olson, S.L., Meadows, V.S., Cockell, C.S., Walker, S.I., Grenfell, J.L., Hegde, S., **Rugheimer, S.**, Hu, R., Lyons, T.W. (2017) Exoplanet Biosignatures: A Review of Remotely Detectable Signs of Life, *Submitted to Astrobiology* arXiv:1705.05791

Blumenthal, S.D., Mandell, A.M., Hébrard, E., Batalha, N.E., Cubillos, P.E., **Rugheimer, S.**, Wakeford, H.R. (2018) A Comparison of JWST Spectra From Equilibrium and Disequilibrium Chemistry Models in Gaseous Planets. *ApJ* 853, 138. doi:10.3847/1538-4357/aa9e51

Loyd, R.O.P., France, K., Youngblood, A., Schneider, C., Brown, A., Hu, R., Segura, A., Linsky, J., Redfield, S., Tian, F., **Rugheimer, S.**, Miguel, Y., Froning, C. (2018) The Muscles Treasury Survey V: FUV Flares on Active and Inactive M Dwarfs. *submitted ApJ*

Youngblood, A., France, K., Loyd, R.O.P., Brown, A., Mason, J.P., Schneider, P.C., Tilley, M.A., Berta-Thompson, Z.K., Buccino, A., Froning, C.S., Hawley, S.L., Linsky, J., Mauas, P.J.D., Redfield, S., Kowalski, A., Miguel, Y., Newton, E.R., **Rugheimer, S.**, Segura, A., Roberge, A., and Vieytes, M. (2017) The Muscles Treasury Survey IV: Scaling Relations for Ultraviolet, Ca II K, and Energetic Particle Fluxes from M Dwarfs. *ApJ.* 843: 31. doi:10.3847/1538-4357/aa76dd

Domagal-Goldman Shawn D., Wright Katherine E., & 47 co-authors including **Rugheimer, S.**, (2016) Astrobiology Primer 2.0, *Astrobiology* 16: 8, 561-653. doi:10.1089/ast.2015.1460

France, K., Loyd, R.O.P., Youngblood, A., Brown, A., Schneider, P.C., Hawley, S.L., Froning, C.S., Linsky, J.L., Roberge, A., Buccino, A.P., Davenport, J., Fontenla, J.M., Kaltenegger, L., Kowalski, A.K., Mauas, P., Miguel, Y., Redfield, S., **Rugheimer, S.**, Tian, F., Vieytes, M.C., Walkowicz, L.M., and Weisenburger, K.L. (2016) The MUSCLES Treasury Survey I: Motivation and Overview, *ApJ*, 820: 2, 89. doi:10.3847/0004-637X/820/2/89

Youngblood, A., France, K., Loyd, R.O.P., Linsky, J.L., Redfield, S., Schneider, P.C., Wood, B.E., Brown, A., Froning, C., Miguel, Y., **Rugheimer, S.**, and Walkowicz, L. (2016) The MUSCLES Treasury Survey II: Intrinsic Lyman Alpha and Extreme Ultraviolet Spectra of K and M Dwarfs with Exoplanets, *ApJ.* 824: 2, 101. doi:10.3847/0004-637X/824/2/101

Loyd, R.O.P., France, K., Youngblood, A., Schneider, C., Brown, A., Hu, R., Linsky, J., Froning, C.S., Redfield, S., **Rugheimer, S.**, and Tian, F. (2016) The MUSCLES

Treasury Survey III: XRay to Infrared Spectra of 11 M and K Stars Hosting Planets, *ApJ.* 824: 2, 102. doi:10.3847/0004-637X/824/2/102

Rugheimer, S., Kaltenegger, L., Segura, A., Linsky, J. and Mohanty, S. (2015) Influence of UV activity on the Spectral Fingerprints of Earth-like Planets around M dwarfs. *ApJ.* 809:57. doi:10.1088/0004-637X/809/1/57

Rugheimer, S., Segura, A., Kaltenegger, L., Sasselov, D. (2015) Surface UV fluxes for Earth-like planets around FGKM stars. *ApJ.* 806:137. doi:10.1088/0004-637X/806/1/137

Miguel, Y., Kaltenegger, L., Linksy, J. and **Rugheimer, S.** (2015) The Effect of Lyman alpha Radiation on Mini-Neptune Atmospheres Around M Stars: Application to GJ 436b. *MNRAS.* 446: 345-353. doi:10.1093/mnras/stu2107

Kaltenegger, L., Sasselov, D. and **Rugheimer, S.** (2013) Water Planets in the Habitable Zone: Atmospheric Chemistry, Observable Features, and the case of Kepler-62e and -62f. *ApJL.* 775: L47. doi:10.1088/2041-8205/775/2/L47

Rugheimer, S., Kaltenegger, L., Zsom, A., Segura, A., Sasselov, D., (2013) Spectral Fingerprints of Earth-like Planets around FGK Stars. *Astrobiology.* March 2013, 13(3): 251-269. doi:10.1089/ast.2012.0888

Kaltenegger, L, Miguel, Y. and **Rugheimer, S.**, (2012) Rocky exoplanet characterization and atmospheres. *International Journal of Astrobiology* 11(04): 297-307. doi:10.1017S1473550412000134

Conference proceedings

Rugheimer, S., Qiang Liu, Robert J. Sclabassi, and Mingui Sun. Displaying Raw MEG Measurements with FreeSurfer. 32nd NE Bioengineering Conference. April 2006.

White papers

Parry, I. and 22 co-authors including **Rugheimer, S.** (2018) SUPERSHARP - Segmented Unfolding Primary for Exoplanet Research via Spectroscopic High Angular Resolution Photography. *arXiv:1801.06111*

Domagal-Goldman, S. and 40 co-authors including **Rugheimer, S.** (2018) Life Beyond the Solar System: Remotely Detectable Biosignatures. This is a white paper that was submitted to the National Academies of Sciences Study: Astrobiology Science Strategy for the Search for Life in the Universe. *arXiv:1801.06714*

Airapetian, V. S. , Danchi, W. C.1, Dong, C. F.3, Rugheimer, S. and 32 co-authors (2018) Life Beyond the Solar System: Space Weather and Its Impact on Habitable Worlds. Submitted to the National Academy of Sciences in support of the Astrobiology Science Strategy for the Search for Life in the Universe. *arXiv:1801.07333*

In prep

The following papers have drafts and will be submitted this spring:

Rugheimer, S. & Robinson, T. (2017) Detecting Life in the Universe: A concise review of biosignatures *Invited review to Astrobiology.*

Rugheimer, S. & Rimmer, P. (2017) Detecting Prebiotic Molecules in Early Earth Atmospheres around G and M dwarfs. *planned submission to ApJ*

*Kawashima, Y. & **Rugheimer, S.** (2017) Theoretical Reflectance Spectra of Earth-Twins Through Their Evolutions: Impact of Clouds and Detectability of O2, H2O, and CH4 with LUVIOR Telescope. *planned submission to ApJ*

*Student Advised

Advising Experience

University of St. Andrews, St Andrews, UK

- **Co-advising PhD student Bethan Gregory** **Sept 2016 - present**
  Project title: "Numerical modelling of oxygen isotopes over Earth's history"

Kavli Exoplanet Atmospheres Summer Program, Santa Cruz, CA

- **Advised graduate student Yui Kawashima** **Summer 2016**
  Project title: "Impact of clouds on detecting oxygen," paper in prep
- **Advised postdoc Dr. Liu Hui-Gen** **Summer 2016**
  Project title: "TRAPPIST-1 and Assessing the Habitability of Ultra-cool Dwarfs"

Cornell University, Ithaca, NY

- **Co-advised PhD student Thea Kozakis** **Jan 2015 - July 2016**
  Project title: "Habitability of White Dwarfs"

Teaching Experience

University of St. Andrews, St. Andrews, Scotland, UK

- **Astrobiology: The Search for Life in the Universe, ID1006** **Spring 2017**
  I designed and led a new first year interdisciplinary module with 105 students..
- **Environmental Geochemistry, ES 5010** **Spring 2016**
  Taught module "Mineral evolution through geological history" for this senior level geology course

Tufts University, Medford, MA USA

- **Life on Earth and Beyond** **Fall 2013**
  - Visiting Lecturer Fall 2013 to teach a course of my own design at Tufts ExCollege and offered for full credit at Tufts University as a natural science credit.
  - Course filled to maximum capacity within 1 hour of registration opening
  - One of 4 courses requested back by Tufts ExCollege for following semester
  - Nominated by graduating seniors in 2016 for this course as having been one of the "most impactful to your intellectual and personal development while at Tufts"
  - Complete course evals: www.cfa.harvard.edu/~srugheimer/EXP022_Eval.pdf

Harvard University, Cambridge, MA USA

Teaching Fellow for following courses:

- **The Energetic Universe** **Spring 2012**
  - An introductory Astronomy course for non-majors taught by Robert Kirshner.
  - Received Distinction in Teaching Award
- **Stellar and Planetary Astrophysics** **Fall 2010**
  - A graduate level Astronomy course taught by Dimitar Sasselov.
- **Life as a Planetary Phenomenon** **Spring 2010**

- An introductory Astrobiology course for non-majors taught by Dimitar Sasselov.

Teacher Training

- Completed Harvard's Bok Center Teaching Certificate
- Harvard University's "Scientists Teaching Science" hands-on course on active learning and effective science education with Professor Philip Sadler
- Harvard University's Bok Center Course "Problems with the Blackboard: Tools for Teaching Science & Math" with John Girash.
- Harvard University's Finding Your Voice workshop on giving effective presentations with Nancy Houfek.

Selected Press

Planetary.org - Creating a guidebook for Earth's hypothetical twin
BBC Radio 4 Inside Science - Understanding Biosignatures
Cornell - Astronomers create array of Earth planet models
Daily Mail UK - Computer models reveal how Earth-like Planets Evolve in Time
Harvard Gazette - Doctoral student focuses on atmosphere in search for extrasolar life
Flathead Beacon - Looking for life beyond our own

Presentations

Invited Oral

- *UV, Biosignatures, and Life* NYU - Abu Dhabi, colloquium, 8 Oct 2017
- *UV, Biosignatures, and Life* Climate Science, Atmospheres and Life: From the Earth and Beyond, University of Cambridge, 17 May 2017
- *Impact of UV on Characterizing Pale Blue Dots Around FGKM Stars*, Exoplanetary Space Weather, Climate and Habitability Workshop, NASA NExSS, 1 Dec 2016
- *How to Detect Life on Another Planet*, Next in Science, Radcliffe Institute for Advanced Study, Harvard, 14 Oct 2016
- *Terrestrial Exoplanets under M dwarf Irradiation*, Opportunity M, Harvard, 31 August 2016
- *A Review of Biosignatures*, NExSS, 27 June 2016
- *Characterizing Pale Blue Dots Around FGKM Stars*, AGU, San Francisco, 18 Dec 2015
- *Characterizing Pale Blue Dots Around Other Stars*, Villanova University Physics & Astronomy Colloquium, Villanova, PA, 23 October 2015
- *Hues of Habitability - Characterizing Pale Blue Dots Around Other Stars*, University of Houston Physics Colloquium, Houston, TX, 23 April 2015
- *Hues of Habitability - Characterizing Pale Blue Dots Around Other Stars*, University of Montana Colloquium, Missoula, MT, 20 March 2015
- *Applying to Harvard*, Flathead Valley Community College, Kalispell MT, 17 March 2015
- *Hues of Habitability - Characterizing Pale Blue Dots Around Other Stars*, University of Calgary Astroseminar, Calgary, AB Canada, 16 March 2015
- *Spectral Fingerprints of Another Earth*, Harvard Horizons, Harvard University, Cambridge, MA, 22 April 2014
- *Exoplanet Overview Lecture*, AbGradCon, Caltech, August 2012

Contributed Oral

- *Remote Detectability of Oxygen Through Geological Time Around FGKM Stars*, AbSciCon, Phoenix, 24 April 2017
- *Using the PandExo JWST Simulator*, UK EXOM, St. Andrews, UK, March 2017
- *Characterizing Pale Blue Dots around Other Stars* FRESH Planetary Symposium, University of St. Andrews, 28, April 2016.
- *Hues of Habitability*, UK EXOM, Exeter, UK, March 2016
- *Importance of UV in Characterizing Pale Blue Dots Around FGKM Stars*, Extreme Solar Systems - Kona, Hawaii, Dec 2015

- *Modeling Atmospheres - Warming Archean Earth to Detecting Biosignatures*, Simons Origins of Life Meeting - New York City, NY, October 2015
- *UV Surface Environments of Earth-like Planets Orbiting FGKM Stars Through Geological Evolution*, AbSciCon - Chicago, IL, June 2015
- *Characterizing Pale Blue Dots Around Other Stars*, AAS Dissertation Talk - Seattle, WA, January 2015
- *Astrobiology Education: Lessons from Designing and Teaching a Course at Tufts*, AbGradCon - RPI - Troy, NY, July 2014
- *Influence of UV activity on the Spectral Fingerprints of Earth-like Planets around M dwarfs*, AbGradCon - RPI - Troy, NY, July 2014
- *Influence of UV activity on the Spectral Fingerprints of Earth-like Planets around M dwarfs*, AAS - Boston, MA, June 2014
- *Influence of UV activity on the Spectral Fingerprints of Earth-like Planets around M dwarfs*, EBI - Search for Life Beyond the Solar System - Tuscon, AZ, March 2014
- *Influence of UV activity on the Spectral Fingerprints of Earth-like Planets around M dwarfs*, Max Planck Institute for Astronomy - Heidelberg, Germany, 5 March 2014
- *Comparison of Transit Spectra of the First Small Exoplanets in the HZ Kepler 62* e *&* f, Division for Planetary Sciences - DPS - Denver, Oct 2013
- *Spectral Fingerprints of Earth-like Planets*, ELSI, Tokyo, Japan, 27 March 2013
- *Spectral Fingerprints of Earth-like Planets around FGK Stars*, AbGradCon, Caltech, August 2012
- *Spectral Fingerprints of Earth-like Planets around FGK Stars*, Characterizing & Modeling Extrasolar Planetary Atmospheres Theory & Observation - Heidelberg, Germany, July 2012
- *Cosmic Habitability*, AbGradCon, Sweden, June 2010
- *Habitable Planets in the Planetary System of HD 69830*, Canadian Undergraduate Physics Conference, Oct 2006
- *Habitable Planets in the Planetary System of HD 69830*, NASA Astrobiology Undergraduate Summer Research Seminars, July 2006
- *Displaying Raw MEG Measurements with FreeSurfer*, 32nd Northeast Bioengineering Conference, April 2006

Mentoring & Service

At UC Santa Cruz and the University of St. Andrews, I developed two workshops for PhD students on the impostor syndrome and public speaking which have run in my department and are now being run University wide through Student Services. I also volunteer for a geoscience outreach to local Scottish secondary schools called GeoBus and am on the Equality and Diversity Committee at St. Andrews.

I was a mentor through Harvard Graduate Woman in Science and Engineering (HGWISE) for a female undergraduate student at Harvard. I served as a departmental representative on the HGWISE board in 2011 to 2013. I also was a mentor for an internal graduate mentoring program.

For four years (2009-2013), I served as one of two graduate representatives on the Committee for Academic Studies which monitored the progress of all graduate students in our department and advocated for student concerns.

Public Outreach

I co-host a podcast with Dr. Sarah Ballard called "Self-care with Drs. Sarah" where we discuss techniques for productivity, mental health, and successfully managing the pressures of academia to bring your full engagement to science in a sustainable way.

On BBC Radio 4's *Inside Science* with Adam Rutherford I gave an interview on the prospect of detecting biosignatures in the next few decades and the steps required to be prepare for observations with JWST and large ground-based observatories.

Through GeoBus, I've led workshops on Mars exploration and scientific literacy, and created a youtube video on biosignatures in a minute. This video was chosen as for

the Goldschmidt 2017 Wild Orbit Film Festival.

I am interested in science and education policy and how scientists can better communicate our findings to the public. With two other graduate students I launched PolicyLab in 2013 as an outlet for Harvard science graduate students where I served as senior editor the communications director.

I have written for Science in the News (STIN), a public outreach organization dedicated to presenting scientific concepts to the public. Scientific literacy and reforming the way we teach science are fundamental to our future economic, social, and world growth and sustainability. The articles I have written include "Can Humans Play Red Rover?"; "A Tale of Two Worlds"; and "Are We Alone? - How astronomers hope to find life in the Universe."

I have spoken on live radio at Boston's National Public Radio (NPR) about finding Earth-like planets and biosignatures, and was on a panel at MIT to discuss the science behind the movie *Interstellar*.

Interests

I love high altitude and glacier mountaineering and have climbed e.g. Cayambe (18,996' / 5790m), Chimborazo - Veintimilla (20,440' / 6230m), Mt. Rainier (14,410' / 4392 m), Mt. Baker (10,781' / 3286 m), Mt. Kilimanjaro (19,341' / 5895 m), and Aconcagua (22,841' / 6962 m). I also competed internationally in Irish Dance for 11 years.

Academic References

Prof. Dimitar Sasselov dsasselov@cfa.harvard.edu
Phillips Professor of Astronomy, Harvard University
Director of Origins of Life Initiative

Prof. Lisa Kaltenegger lkaltenegger@astro.cornell.edu
Associate Professor at Cornell University
Director of Carl Sagan Institute

Prof. Tony Prave ap13@st-andrews.ac.uk
Head of School Earth & Environmental Sciences, University of St. Andrews

Prof. Avi Loeb aloeb@cfa.harvard.edu
Frank B. Baird Jr. Professor of Science at Harvard
Chair of the Harvard Astronomy Department
Founding Director of Harvard's Black Hole Initiative
Chair of the Advisory Committee for the Breakthrough Starshot Initiative
Director of the Institute for Theory & Computation at the Harvard-Smithsonian Center for Astrophysics

Prof. Robert Kirshner rkirshner@cfa.harvard.edu
Clowes Professor of Science, Harvard University
Chief Program Officer for Science at the Gordon & Betty Moore Foundation

Dr. Shawn Domagal-Goldman shawn.goldman@nasa.gov
NASA Goddard