Research with Joel Primack
UCSC Distinguished Professor of Physics Emeritus

I will be happy to supervise grad student research projects. I am currently supervising two UCSC Physics grad students, and two of my former students recently finished their PhDs and are now working as data scientists. Here's a brief summary of sample research projects that I would be glad to supervise in three areas: (1) cosmology, (2) galaxy formation, and (3) planet habitability. I will be available to Zoom with prospective students all day after 9 am on Friday March 19 — students can email me at <joel@ucsc.edu> to arrange this or ask other questions.

(1) Cosmology. The cosmic microwave background and other early-universe measurements plus the standard modern ΛCDM cosmology imply that the expansion rate of the universe that is inconsistent with local measurements, a challenge known as the "Hubble tension". In a paper just accepted for publication in MNRAS (https://arxiv.org/pdf/2006.14910.pdf), we showed that if the Hubble tension is resolved by a brief (~5,000 year) period about 50,000 years after the Big Bang during which "early dark energy" (EDE) contributed about 10% of cosmic density, this EDE theory predicts earlier formation of galaxies and galaxy clusters than standard ΛCDM. We are now running high-resolution paired simulations of ΛCDM and EDE in order to make more detailed predictions. Sample student projects:
-- Analyzing these new cosmological simulations,
-- Filling them with galaxies and clusters by methods including Semi-Empirical and Semi-Analytic Models
-- Comparing the results with observations.

(2) Galaxy formation. My research group has been running and analyzing very high resolution simulations of forming galaxies and comparing them with observations using machine learning methods (see for example https://news.ucsc.edu/2018/04/deep-learning-galaxies.html%20galaxies.html and https://www.americanscientist.org/article/why-do-galaxies-start-out-as-cosmic-pickles). Here are some sample student projects:
-- Run and analyze more high-resolution galaxy simulations, now including the effects of supermassive black holes, and convert them into realistic images, including galaxy substructures
-- Use improved Semi-Analytic Models to predict galaxy populations
-- Compare with observations as they become available from space telescopes (HST, JWST, Roman Space Telescope) and ground-based telescopes (including DESI, Subaru HSC, and Rubin/LSST).

(3) Planet habitability. Heat from decay of the longest-lived radioactive elements Th and U provides about half the subsurface heat of Earth. The abundance of Th and U varies by more than a factor of 4 in rocky planets, and we recently showed that this can have big effects on habitability — as I summarized in the article on the next page. Here are some sample student projects:
-- Predict radioactive heating habitability of rocky exoplanets using their star's Europium abundance
-- Run 2D and 3D simulations of rocky planets, to verify and improve on our 1D modeling
-- Examine other long-term constraints on habitability of rocky planets: changes in orbits, obliquity, effects of nearby supernovas ...

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Chair, American Physical Society Forum on Physics and Society 2019
President, Sigma Xi (Scientific Research Honor Society, publisher of *American Scientist*) 2018-19

Here's the article about radioactive heading of rocky planets that I wrote for the Winter 2021 UCSC Physics Department Newsletter:

FEATURED

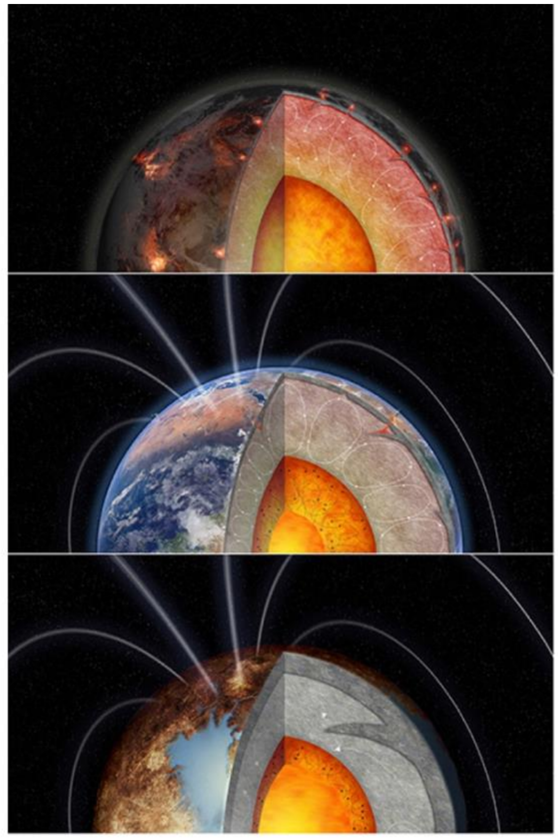
Radioactively, Earth is a Goldilocks Planet

by Joel Primack

Most of the gold in your jewelry, the rare earth elements in your cell phone, and the thorium and uranium whose radioactive decay provides much of the heat of the deep earth, all originated in mergers of neutron stars with other neutron stars or with black holes. We learned the source of these heavy elements when gravitational waves detected in April 2017 allowed astronomers to point powerful telescopes at a neutron-star merger for the first time. The resulting heavy elements detected added up to about 1/20th of the mass of the sun—including about ten times the mass of Earth just in gold!

At a recent meeting of UCSC scientists, gathering to organize a new Astrobiology institute, I pointed out that the neutron star merger discovery implied that the amount of the longest-lived radioactive elements thorium (Th) and uranium (U) was likely to vary quite a lot between different stars and their planets. Many astronomers had thought that the origin of such heavy elements, as with many of the lighter ones like oxygen and magnesium, was core-collapse supernovae—the giant explosions that end the lives of massive stars and leave behind neutron stars or black holes. But while core-collapse supernovae are relatively common, about one per hundred years in a big galaxy like our Milky Way, mergers of neutron stars and black holes are much rarer, only a few per million years. This rareness implies that stars that formed close to where such mergers had recently occurred would contain larger amounts of these heavy elements.

At the same meeting, UCSC Earth and Planetary Sciences Professor Francis Nimmo responded that he could calculate the effects of such variations using an Earth model he had created nearly twenty years ago. What he found was a delicate balance; if Earth had twice as much Th and U, for hundreds of millions of years it would have lacked a magnetic field, which protects the atmosphere and surface from destructive effects of cosmic radiation. Earth would also have had widespread volcanism that could have caused frequent mass extinctions. On the other hand, if Earth had half as much of these radioactive elements, this could have led to less or even no plate tectonics, the essential process that recycles the planet's carbon. Plate tectonics and a magnetic field may both be necessary for the evolution of complex life. Thus, as our recently published paper shows, Earth may be a Goldilocks planet in this sense, with neither too little nor too much Th and U.



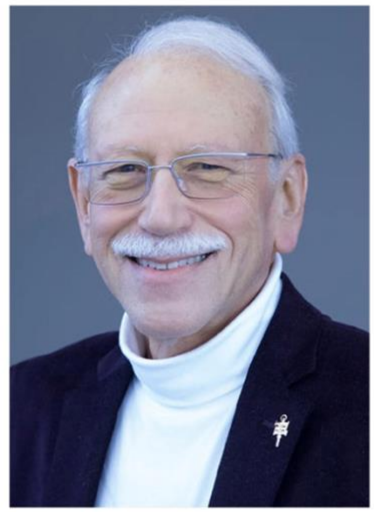
Shown here are three versions of a rocky planet with different amounts of internal heating from radioactive elements. The middle planet is Earth-like, with plate tectonics and an internal dynamo generating a magnetic field. The top planet, with more radiogenic heating, has extreme volcanism but no dynamo or magnetic field. The bottom planet, with less radiogenic heating, is geologically "dead," with no volcanism. (Illustrations by Melissa Weiss).

In searching for life in the Universe, astronomers look for planets in the "habitable zone" around their stars, that is, at distances where liquid water could exist. The rare earth element europium forms with Th and U, but unlike them, it is relatively easy to measure in the spectra of stars. Therefore, europium can tell us how much of these radioactive elements are in rocky planets orbiting these stars, and thus whether such planets are also likely to have tectonics and magnetic fields. This could help narrow the search for planets with advanced forms of life.

This article has been adapted and edited with permission from the UCSC Newscenter and edited by Tim Stephens:
https://news.ucsc.edu/2020/11/planet-dynamos.html.
Please see the piece on Joel Primack's recently won prize (page 24) for more content on his research.

Here's some background about me from the Winter 2021 UCSC Physics Department Newsletter:

The 2020 Julius Edgar Lilienfeld Prize



Early last year, Distinguished Professor Emeritus Joel Primack was awarded The American Physical Society's 2020 Julius Edgar Lilienfeld Prize.

The prize recognizes Primack "for seminal contributions to our understanding of the formation of structure in the Universe, and for communicating to the public the extraordinary progress in our understanding of cosmology." One of the APS's highest honors, the Lilienfeld Prize recognizes outstanding contributions to physics by a single individual who also has exceptional skills in lecturing to diverse audiences.

He is one of the leading creators and developers of the modern theoretical model of the universe structured around cold dark matter with a cosmological constant, which explains why galaxies exist, how they form, and how they are distributed in space. For example, although our own Milky Way galaxy and many other nearby galaxies are disk-shaped, by comparing Hubble Space Telescope images with their supercomputer simulations, Primack and his colleagues recently discovered that most galaxies start out pickle-shaped due to the filamentary distribution of dark matter in the early Universe.

"Joel Primack is an inspired choice for this year's Lilienfeld Prize," said APS President-Elect Philip H. Bucksbaum, chair of the 2020 prize selection committee. "He has contributed greatly to our current understanding of the fundamental makeup of the Universe and has helped to establish the paradigm of cold dark matter cosmology." Equally important is his work as an effective voice for science in the public and in public policy, not only through lectures and books to general audiences, but also through active participation in policy initiatives.

See also http://scipp.ucsc.edu/personnel/profiles/primack.html

Joel Primack RECENT PhD STUDENTS

Rachel Somerville (PhD 1997) Jerusalem (postdoc) – Cambridge (postdoc) – Michigan (Asst. Prof.) – MPI Astronomy Heidelberg (Professor) – STScI/Johns Hopkins – Rutgers (Professor)
Michael Gross (PhD 1997) Goddard (postdoc) – UCSC (staff) – NASA Ames (staff)
James Bullock (PhD 1999) Ohio State – Harvard (Hubble Fellow) – UC Irvine (Professor, Dean)
Ari Maller (PhD 1999) Jerusalem – U Mass Amherst (postdoc) – CityTech CUNY (Assoc. Prof.)
Risa Wechsler (PhD 2001) Michigan – Chicago (Hubble Fellow) – Stanford U (Prof., KIPAC Dir.)
T. J. Cox (PhD 2004) – Harvard (postdoc, Keck Fellow) – Carnegie Observatories (postdoc) – Data Scientist at Voxer, San Francisco – Data Scientist at Apple, Cupertino
Patrik Jonsson (PhD 2004) UCSC (postdoc) – Harvard CfA (staff) – SpaceX Senior Programmer
Brandon Allgood (PhD 2005) – Numerate, Inc. (co-founder)
Matt Covington (PhD 2008) – analytic understanding of galaxy mergers, semi-analytic models of galaxy formation – U Minn (postdoc) – U Arkansas (Assoc. Prof. of Geology)
Greg Novak (PhD 2008) – running and comparing galaxy merger simulations with observations – Princeton (postdoc) – Inst Astrophysique de Paris (postdoc) – Data Scientist at Stitch Fix
Christy Pierce (PhD 2009) – AGN in galaxy mergers – Georgia Tech (postdoc) – teaching
Rudy Gilmore (PhD 2009) – WIMP properties and annihilation; extragalactic background light and gamma ray absorption – SISSA, Trieste, Italy (postdoc) – Data Scientist at TrueCar, L.A.
Alberto Dominguez (PhD 2011) – UCR (postdoc), Clemson (postdoc), Madrid (postdoc)
Lauren Porter (PhD 2013) – semi-analytic predictions vs. observations – Data Sci at Facebook
Chris Moody – analysis of high-resolution galaxy simulations: galaxy morphology transformations (PhD 2014) – Data Scientist at Square – Chief Data Scientist at Stitch Fix, San Francisco
Christoph Lee (PhD 2019) – galaxy simulations vs. observations with AI – Data Sci at Outschool
David Reiman (PhD 2020) – astrophysics deep learning applications – AI Scientist at DeepMind

Joel Primack CURRENT PhD STUDENTS

Viraj Pandya — semi-analytic models compared with observations (with Rachel Somerville)
Clayton Strawn — circumgalacticlactic medium: simulations vs. observations
James Kakos — combining spectroscopic & photometric redshifts with SORT