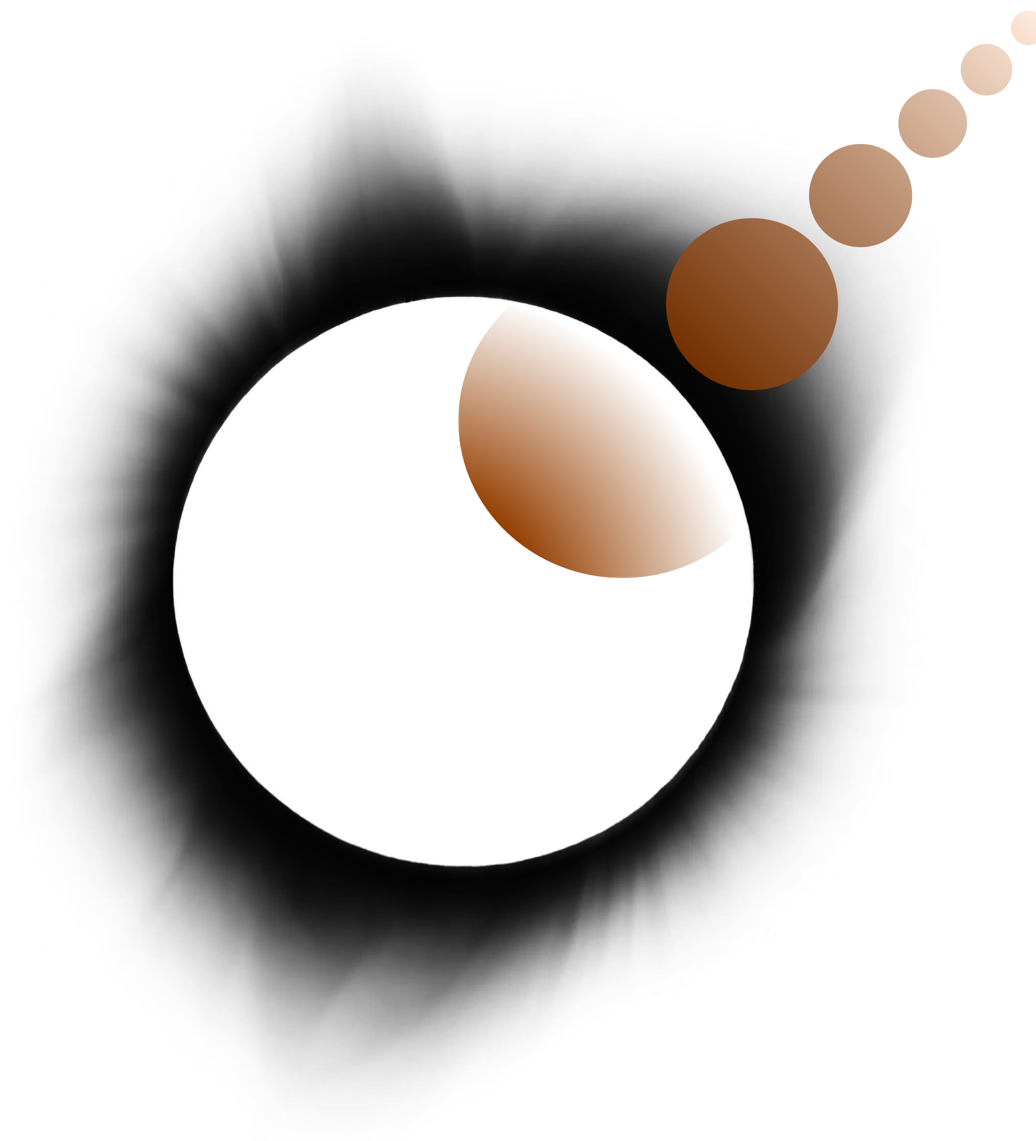
IMPACT WORKSHOP



Booklet

April 8-12, 2024

Rochester, NY, USA

Committee members

Scientific Oversight Committee (SOC)

Doris Breuer (Institut für Planetenforschung)
Gregor Golabek (University of Bayreuth)
Miki Nakajima (University of Rochester)
Kai Wünnemann (Museum für Naturkunde)

Local Organization Committee (LOC)

Laetitia Allibert (Museum für Naturkunde)
Alice Chau (University of Rochester)
Kim Cone (University of Rochester)
Jérémy Couturier (University of Rochester)
Scott Hull (University of Rochester)
Alex Jasko (University of Rochester)
Victor Lherm (University of Rochester)
Nic Litza (University of Rochester)

Funding Agencies

The National Aeronautics and Space Administration (NASA) Grant No: 80NSSC24K0141
The Meteoritical Society (MetSoc) for travel fund for early career scientists

Host Institution

University of Rochester

List of Participants

Last Name	First name	Institution
Alexander	Amanda	Southwest Research Institute
Allibert	Laetitia	Natural History Museum, Berlin
Anghel	Simon	Astronomical Institute of the Romanian Academy
Bill	Carys	Imperial College London
Bolin	Bryce	NASA Goddard Space Flight Center
Braun	Alexander	Queen's University
Brunner	Kaela	University of Rochester
Cambioni	Saverio	Massachusetts Institute of Technology
Caracas	Razvan	Institut de Physique du Globe de Paris
CHARNOZ	Sebastien	Institut de Physique du Globe
Chau	Alice	University of Rochester
Cone	Kim A.	University of Rochester
Couturier	Jérémy	University of Rochester
Dale	Katherine	Observatoire de la Cote d'Azur
Dasgupta	Archishman	University of Rochester
Denton	C. Adeene	University of Arizona
Dres	Yoseph Muhabaw	University of Rochester
Gallinger	Cailin	University of Western Ontario
Genda	Hidenori	Tokyo Institute of Technology
Glade	Rachel	University of Rochester
Glisovic	Petar	Queen's University
Golabek	Gregor	Bayerisches Geoinstitut
Helhoski	Soren	Brown University
Hull	Scott	University of Rochester
Ida	Shigeru	Tokyo Institute of Technology
Jasko	Alex	University of Rochester
Kegerreis	Jacob	NASA Ames
Lherm	Victor	University of Rochester
Licata	Sydney	University of Rochester
Litza	Nicolas	University of Rochester
Maller	Augustin	Institut de Physique du Globe de Paris
Marchi	Simone	Southwest Research Institute
Melikyan	Robert	University of Arizona Lunar and Planetary Laboratory
Miljkovic	Katarina	Curtin University
Morbidelli	Alessandro	Collège de France & Observatoire de la Côte d'Azur
Morra	Gabriele	University of Louisiana at Lafayette
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Sandnes	Tom	Durham University
Schwartz	Stephen	Planetary Science Institute / U. Alicante
Sokolowska	Aleksandra	Brown University
Stewart	Sarah T.	U. California Davis
Tarduno	John A.	University of Rochester
Thaker	Ashka	The University of Western Ontario
Trail	Dustin	Univ. Rochester
Vidaurri	Monica	Stanford University
Weinberger	Alycia	Carnegie Institution for Science, Earth and Planets Laboratory
Wright	Esteban	University of Maryland, College Park
Wünnemann	Kai	Museum für Naturkunde Berlin
Zhou	Tinghong	University of Rochester

Impact Workshop April 2024

Workshop Locations

Hilton Garden Inn Rochester/University & Medical Center

Rush Rhees Library - Main Workshop Location

Quick Food Options

Mount Hope Cemetery

Genesse River Trail

Eclipse Viewing

Day Parking - Library Lot

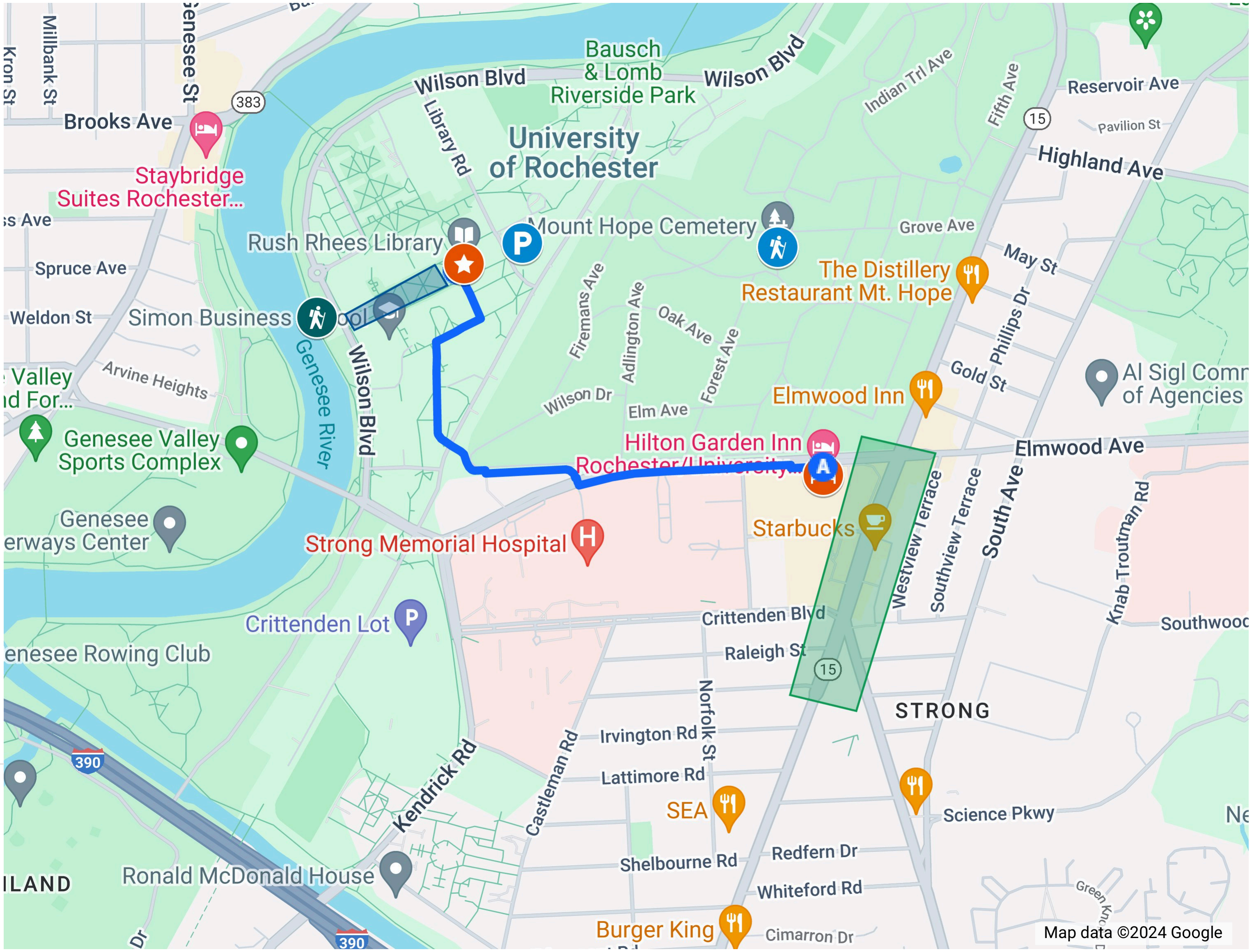
Walk from hotel to workshop

A

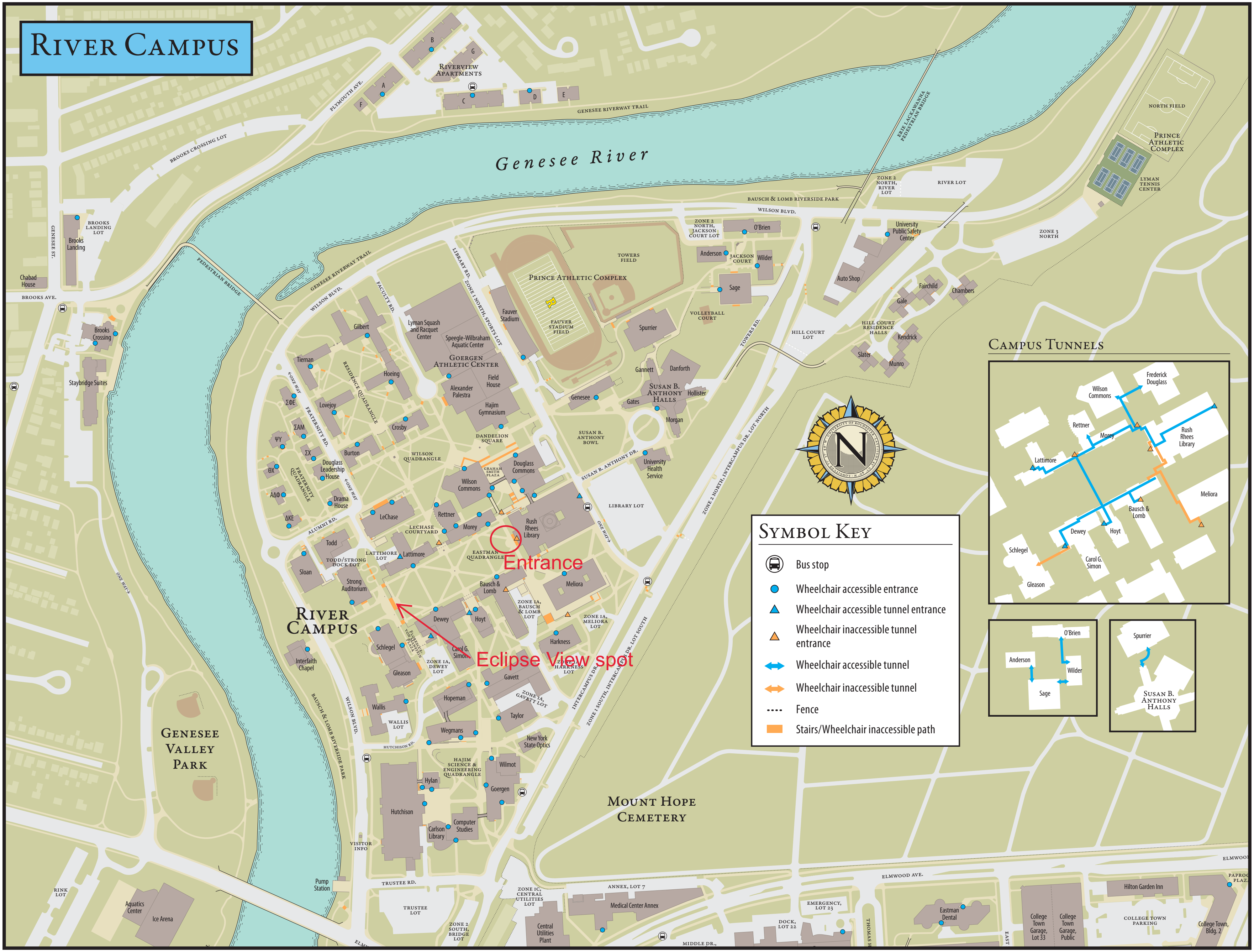
Hilton Garden Inn Rochester/University & Medical Center

B

Rush Rhees Library - Main Workshop Location



Impact Workshop 2024

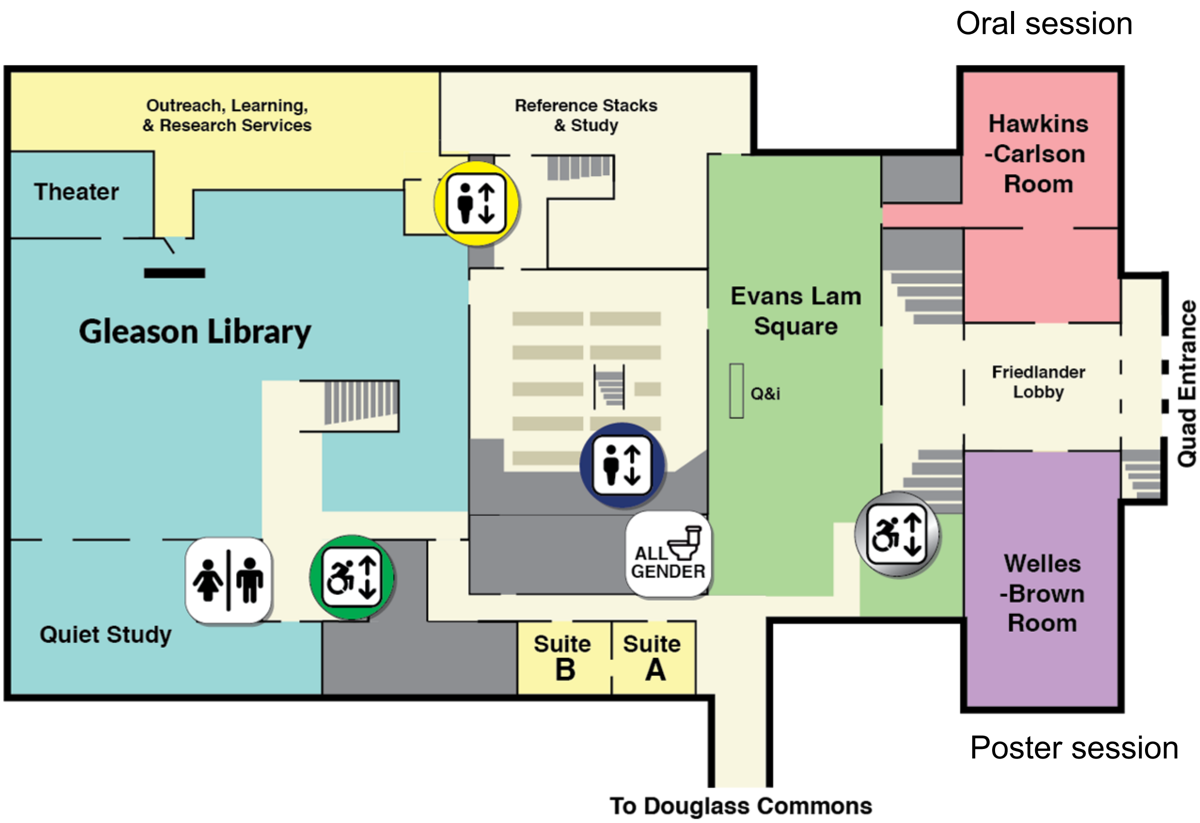


INFORMATION CURRENT AS OF 8/3/2021

UNIVERSITY COMMUNICATIONS

1st Floor

Rush Rhees Library, University of Rochester



Mentor	Mentee
Alice Quillen	Amanda Alexander
Alessandro Morbidelli	Alice Chau
Sean Raymond	Monica Vidaurri
Gregor Golabek	Sydney Licata
Adeene Denton	Carys Bill
Katarina Miljkovic	Ashka Thaker
Razvan Caracas	Saverio Cambioni
Alycia Weinberger	Bryce Bolin
Jacob Kegerreis	Adriana N. Postema
Kai Wünnemann	Simon Anghel
Sebastien CHARNOZ	Arnaud Salvador
Simone Marchi	Nicolas Litza
Sarah T. Stewart	Robert Melikyan
Ana-Catalina Plesa	Tinghong Zhou
Gabriele Morra	Augustin Maller
Miki Nakajima	Katherine Dale
Stephen Schwartz	Aleksandra Sokolowska

MetSoc Travel fund recipients

Simon Anghel (Astronomical Institute of the Romanian Academy)
Carys Bill (Imperial College London)
Bryce Bolin (NASA Goddard Space Flight Center)
Augustin Maller (Institut de Physique du Globe de Paris)
Arnaud Salvador (LPL/University of Arizona)
Aleksandra Sokolowska (Brown University)

The Meteoritical Society

sas.rochester.edu/ees/impact-workshop/

Impact Workshop Proceedings

1 Schedule

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
6:30pm-8pm Dinner at GRAPPA	**9am-9:15am** Introduction **9:15am-9:45am** A. Morbidelli **9:45am-10:15am** J. Kegerreis **10:15am-10:45am** S. Stewart **10:45am-11:15am** Coffee break **11:15am-11:45am** S. Charnoz **11:45am-12pm** A. Denton **12pm-12:30pm** S. Raymond **12:30pm-1:30pm** Lunch **1:30pm-6pm** Eclipse session **2:07pm** First contact **3:20:05-3:23:45pm** Totality **4:33pm** Last contact **6pm-7:30pm** Dinner	**9am-9:30am** S. Cambioni **9:30am-9:45am** A. Alexander **9:45am-10am** S. Marchi **10am-10:30am** A-C. Plesa **10:30am-10:40am** Photo Shoot **10:40am-11am** Coffee break **11am-11:30am** C. Bill **11:30am-12pm** A. Salvador **12pm-1:30pm** Mentorship lunch **1:30pm-2pm** K. Miljkovic **2pm-2:30pm** A. Sokołowska **2:30pm-3pm** Poster flash talk **3pm-3:30pm** Coffee break **3:30pm-5:15pm** Poster session **5:15pm-5:30pm** B. Bolin **5:30pm-6pm** A. Quillen **6pm-6:30pm** S. Schwartz **6:30pm-8pm** Dinner	**9am-9:30am** V. Lherm **9:30am-10am** K. Dale **10am-10:30am** G. Morra **10:30am-11am** Coffee break **11am-11:30am** L. Allibert **11:30am-11:45am** R. Röhlen **11:45am-12pm** A. N. Postema **12pm-12:15pm** A. Maller **12:15pm-1:45pm** Lunch **1:45pm-2:15pm** R. Caracas **2:15pm-2:45pm** H. Genda **2:45pm-3:15pm** Coffee break **3:15pm-5pm** Open discussion **5pm-6:30pm** Poster session **6:30pm-8pm** Dinner	**9am-9:15am** A. Chau **9:15am-9:45am** J. Tarduno **9:45am-10:15am** T. Zhou **10:15am-10:45am** Coffee break **10:45am-11:15am** P. B. Rimmer **11:15am-11:45am** S. Ida **11:45am-12pm** M. Vidaurri **12pm-1:30pm** Lunch **1:30pm-2pm** S. Anghel **2pm-2:30pm** A. Weinberger **2:30pm-3:45pm** Open discussion **3:45pm-4:15pm** Coffee break **4:15pm-5:30pm** Open discussion **5:30pm-5:45pm** Closing statement **5:45pm-6pm** Survey **6pm-7:30pm** Dinner	**8:45am-5:30pm** Niagara Falls

2 Presenters

Click on the name of a presenter to be sent to their abstract.

Talks (Monday & Tuesday)
- Alessandro Morbidelli
- Jacob Kegerreis
- Sarah Stewart
- Sébastien Charnoz
- Adeene Denton
- Sean Raymond
- Saverio Cambioni
- Amanda Alexander
- Simone Marchi
- Ana-Catalina Plesa
- Carys Bill
- Arnaud Salvador
- Katarina Miljkovic
- Aleksandra Sokołowska
- Bryce Bolin
- Alice Quillen
- Stephen Schwartz

Talks (Wednesday & Thursday)
- Victor Lherm
- Katherine Dale
- Gabriele Morra
- Letitia Allibert
- Randolph Röhlen
- Adriana N. Postema
- Augustin Maller
- Razvan Caracas
- Hidenori Genda
- Alice Chau
- John Tarduno
- Tinghong Zhou
- Paul B. Rimmer
- Shigeru Ida
- Monica Vidaurri
- Simon Anghel
- Alycia Weinberger

Posters (Tuesday & Wednesday afternoon)
- Jérémy Couturier
- Nicolas Litza
- Cailin Gallinger
- Petar Glisovic
- Taishi Nakamoto
- Soren Helhoski
- Scott Hull
- Alex Jasko
- Alexander Braun
- Robert Melikyan
- Miki Nakajima
- Gregor Golabek
- Ashka Thaker
- Thomas Sandnes
- Kai Wünnemann
- Erik Asphaug

3 Talks abstracts

The oral talks will take place at *Hawkins - Carlson Room, Rush Rhees Library*, whereas the posters will be presented in *Welles-Brown Room*. The talks have been organized into five main topics, described hereafter.

3.1 Accretion dynamics for planetary and satellite formation. Focus on fragmentation, SPH and N-body simulations and giant impacts

Giant impacts during terrestrial planet formation from a ring

9:15am – 9:45am, Monday

Alessandro Morbidelli[1]

[1] Collège de France & Observatoire de la Côte d'Azur

In the framework of the ERC-funded HolyEarth project, we have conducted a series of numerical simulations of the formation of terrestrial planets from a ring of planetesimals centered at 1 au. Differently from previous simulations, we do not start from a pre-imposed population of planetesimals and planetary embryos in the ring, at the end of the gas-disk phase, but we simulate self-consistently the accretion of the embryos from a population of 100km planetesimals embedded in the disk of gas. Our simulations, performed with the GPU-code GENGA, account for all interactions among the planetesimals, as well as migration and eccentricity/inclination damping exerted by the disk. After the removal of the disk, at 10My with an e-folding time of 1My, we continue the simulations for 150My, featuring a giant planet instability at various epochs (at 15, 60 or 100My). We will report statistics on the giant impacts observed in this more realistic model, particularly on the characteristics of the last giant impact that should correspond to the Moon-forming event.

Contact: `morby@oca.eu`

Making and breaking planets and moons: SWIFT open-source simulations and giant impacts

9:45am – 10:15am, Monday

Jacob Kegerreis[1], *Thomas Sandnes, Vincent Eke, Jack Lissauer, Paul Estrada, Luís Teodoro & Rick Elphic*

[1] NASA Ames

Alongside some recent results from models of the diverse formation of Earth's, Mars's, and Saturn's moons, I will discuss our open-source SPH code SWIFT and how it has enabled a jump of two orders of magnitude in simulation resolution. SWIFT is now officially released as a free resource for the community, with extensive documentation and examples. I will talk briefly about the surprisingly simple ways that SWIFT takes advantage of modern supercomputing architectures, while we keep the physics modules separate to facilitate the development of extensions, such as material strength and improvements to mixing issues in standard SPH. I will then present some of the new satellite-forming science that SWIFT has helped us to study, and how cinematic visualizations can help communicate those results to both each other and the general public.

Contact: `jacob.kegerreis@gmail.com`

The Formation of Chondritic Mixtures by Vaporizing Collisions Between Planetesimals

10:15am – 10:45am, Monday

Sarah T. Stewart[1]*, Philip J. Carter, Simon J. Lock, Erik J. Davies, Michael I. Petaev & Stein B. Jacobsen*

[1] U. California Davis

We present the collapsing impact vapor plume model for the formation of chondrules and chondritic mixtures of materials. Dynamical excitation by the growth and migration of giant planets instigates periods of disruptive and vaporizing collisions between planetesimals in the solar nebula. The vapor plume produced by a vaporizing impact interacts with the surrounding nebula by generating a shock front in the nebular gas. The nebula shock runs ahead of the material interface between the vapor plume and the nebula. Initially, the interface is defined by a denser (bulk) vapor plume front driving the nebular gas and dust, and the outward flow has a distinct material boundary. Eventually, the outward flow stalls and reverses direction due to pressure gradient forces between the plume and surrounding nebula. Then, the plume and a portion of the nebula flow into the low-pressure 'bubble' generated by the plume outward expansion. In the reverse flow, the low-density nebular gas drives the higher-density plume mixture, leading to Rayleigh-Taylor instabilities and mixing across the plume-nebula boundary. We have calculated the size of particles that are coupled to the nebular shock and plume environment, which are distinct redox environments in the outward flow. We find that the collapsed plume contains a size-sorted mixture of planetesimal and nebular-derived materials with varying thermal and redox histories that are consistent with observations of chondritic meteorites.

Contact: `ststewart@ucdavis.edu`

Escape of volatiles during moon formation

11:15am – 11:45am, Monday

Sébastien Charnoz[1]*, Gustavo Madeira & Frédéric Moynier*

[1] Institut de Physique du Globe de Paris

How the moon lost its volatiles remains a mostly unanswered questions. Many isotopic evidence show that evaporation should have been a key process but evaporation from a disk is difficult due to the lack of light species; while condensation in a protolunar disk is difficult because of intense gas drag. Here we explore the loss from a molten proton-moon in a 2D disk using the FARGO hydrocode coupled to thermochemical models of evaporation from magma oceans. We show that Na and K are efficiently lost and does not come back to Earth. We also find that lunar Water should be depleted very rapidly. We quantify also how much Moon volatiles was accreted by the Earth and lost to space. We conclude that moon's volatiles could have been lost efficiently after the protolunar disk phase and before the moon tidally migrated outward.

Contact: `charnoz@ipgp.fr`

A New Giant Impact Origin for Pluto and Charon

11:45am – 12pm, Monday

Adeene Denton[1]*, Erik Asphaug, Robert Melikyan & Alexandre Emsenhuber*

[1] University of Arizona

Pluto's massive satellite Charon is generally believed to have formed following a giant impact, similar to that which formed the Earth's moon, which also imparted the system with its large angular momentum. Here we show that the addition of material strength during the initial impact strongly alters the pathways of satellite formation between two similarly-sized Kuiper Belt Objects (KBOs), which is a regime where velocities are slow and sizes are relatively small. Our giant impact simulations illustrate a new "kiss-and-capture" framework for the formation of an intact satellite:

momentary merging of Pluto and Charon produces a stable satellite on a tight, low-eccentricity orbit, from which it may subsequently evolve outwards. We find that inclusion of material strength maintains the structural integrity of both bodies, though Charon deposits significant mantle and core material onto Pluto during the collision. These changes to Charon's formation likely alter the thermal and orbital evolution of both bodies, including the lifetime and stability of early oceans. Because many of the largest Kuiper Belt Objects possess similarly large satellites, similar giant impacts may have exerted a primary control on the thermal-orbital evolution of many bodies in the outer Solar System.

Contact: `adeened@arizona.edu`

Crash Chronicles: relative contribution from comets and carbonaceous asteroids to Earth's volatile budget

12pm – 12:30pm, Monday

Sean Raymond[1], *Sarah Joiret, Guillaume Avice & Matthew Clement*

[1] Laboratoire d'Astrophysique de Bordeaux

Recent models of solar system formation suggest that a dynamical instability among the giant planets happened within the first 100 Myr after disk dispersal, perhaps before the Moon-forming impact. As a direct consequence, a bombardment of volatile-rich impactors may have taken place on Earth before internal and atmospheric reservoirs were decoupled. However, such a timing has been interpreted to potentially be at odds with the disparate inventories of Xe isotopes in Earth's mantle compared to its atmosphere. This study aims to assess the dynamical effects of an Early Instability on the delivery of carbonaceous asteroids and comets to Earth, and address the implications for the Earth's volatile budget. We perform 20 high-resolution dynamical simulations of solar system formation from the time of gas disk dispersal, each starting with 1600 carbonaceous asteroids and 10000 comets, taking into account the dynamical perturbations from an early giant planet instability. Before the Moon-forming impact, the cumulative collision rate of comets with Earth is about 4 orders of magnitude lower than that of carbonaceous asteroids. After the Moon-forming impact, this ratio either decreases or increases, often by orders of magnitude, depending on the dynamics of individual simulations. An increase in the relative contribution of comets happens in 30% of our simulations. In these cases, the delivery of noble gases from each source is comparable, given that the abundance of 132Xe is 3 orders of magnitude greater in comets than in carbonaceous chondrites. The increase in cometary flux relative to carbonaceous asteroids at late times may thus offer an explanation for the Xe signature dichotomy between the Earth's mantle and atmosphere. In order to match both a 4 - 10% carbonaceous contribution to Earth and a late accretion dominated by non-carbonaceous material, we propose that carbonaceous material was partly accreted before gas disk dispersal.

Contact: `rayray.sean@gmail.com`

Giant impacts between rocky bodies

1:45pm – 2:15pm, Wednesday

Razvan Caracas[1]

[1] Institut de Physique du Globe de Paris

Giant and large-scale impacts are ubiquitous features of early solar systems that dominate the end of the accretion stage. The last major accretion event in Earth's history was the Moon-forming giant impact. Depending on the impact parameters, the outcome of this impact was the formation of such a protolunar disk. During cooling, liquids and gases separate according to the liquid-vapor stability dome. The liquid droplets rain toward the center, forming the planet as a magma ocean (MO). The leftover gas forms the hot, dense disk atmosphere.

We study the formation and condensation of the disk and the evolution of the MO using molecular dynamics simulations based on ab initio calculations. We work on a multi-component silicate fluid with bulk silicate Earth composition. From the pressure-density variation and the Maxwell construction, we determine the limits of stability of the molten silicate and the position of the critical point. We find that the Earth's protolunar disk reached the supercritical state of the silicate mantle. Then we follow the chemical evolution of the disk during its cooling.

Contact: `caracas@ipgp.fr`

Impact Origin of Martian Moons

2-15pm – 2:45pm, Wednesday

Hidenori Genda[1]

[1] Tokyo Institute of Technology

I will review the current understanding about the origin of Martian moons (Phobos and Deimos) and future sample return mission from Phobos named MMX. I will deeply explore the possibility that they were formed via a giant impact on Mars.

Contact: genda@elsi.jp

3.2 Evolution of planetary bodies due to impacts

Do metal-rich worlds form by giant impacts?

9am – 9:30am, Tuesday

Saverio Cambioni[1]

[1] Massachusetts Institute of Technology

High-density planetary bodies like asteroid (16) Psyche, planet Mercury and high-density exoplanets ("super-Mercuries") are a recently recognized compositional class of objects that are widespread throughout the galaxy, but whose formation mechanism remains unknown. A commonly adopted theory is that these planets were born with a metal-to-silicate ratio similar to that of Earth and later evolved into metal-rich worlds by losing their rocky mantles in giant impacts. In my talk, I will test this giant-impact hypothesis for several observed exoplanetary systems by combining orbital dynamics, impact physics and machine learning. Our results indicate that erosive giant impacts preferentially form metal-rich worlds that are smaller than the observed super-Mercuries. This suggests that while Psyche and Mercury may have lost their mantles in giant impacts, most of the observed super-Mercuries are unlikely to be metal-rich giant impact remnants.

Contact: cambioni@mit.edu

Impact-generated fragmentation, porosity and permeability within the Chicxulub impact structure

9:30am – 9:45am, Tuesday

Amanda Alexander[1]

[1] Southwest Research Institute

Frequent impacts would have shaped the evolution of the early Earth. With the goal of exploring impact-generated hydrothermal systems for the Hadean earth, we first model the well-studied Chicxulub impact event. Using a version of the iSALE shock physics code which includes tensile fragmentation and porosity, impact-generated porosity, fragmentation and permeability is quantified and compared with drill core data.

Contact: amanda.alexander@swri.org

Impact-generated evolution of the early Earth's crust

9:45am – 10am, Tuesday

Simone Marchi[1]

[1] Southwest Research Institute

In this talk I will present a suite of iSALE simulations mimicking conditions on the early Earth. In particular, I will describe impact-generated porosity, fracturing and permeability and discuss implications for the physical and chemical evolution of the early Earth crust, including computations of crustal fluid mobility.

Results of the impact and hydrothermal simulations will be coupled with a stochastic impact flux model to assess the overall importance of impact-related process for the Hadean/Archean Earth.

Contact: marchi@boulder.swri.edu

Consequences of impacts for the geodynamics of Europa's ice shell

10am – 10:30am, Tuesday

Ana-Catalina Plesa[1], *Tina Rückriemen-Bez & Kai Wünnemann*

[1] German Aerospace Center

The exchange of material between the surface and the subsurface ocean of Jupiter's moon Europa is a key aspect in assessing the ocean habitability. Material from the subsurface ocean that may be exposed at the surface can provide valuable information about the ocean chemistry and its organic content. Downward transfer of surface material may provide oxidants to the underlying ocean, which are thought to be crucial for the development of habitable environments

The interaction between the surface and the subsurface ocean on Europa may have been largely facilitated by impacts whose basins' shape provide important information about the ice shell structure, thickness, and dynamics. We will show the effects of series of impacts on the geodynamics in the ice shell of Jupiter's moon Europa. Our models will track how impact-induced thermal and chemical anomalies redistribute within the ice shell. As weak zones may develop at the location of the impacts, we will test whether surface mobilization can take place and for how long it lasts after the impact event. This may provide an efficient way to bring surface material into the ocean as well as to expose fresh icy material at the surface.

The efficiency of material exchange between the surface and the ocean on Europa both at the time of the impact and during the subsequent evolution will provide important implications for the ocean composition and the ice shell structure that can be tested with future measurements of the JUICE and Europa Clipper missions.

Contact: `ana.plesa@dlr.de`

Constraining Impact Parameters for the Formation of the South-Pole Aitken Basin

11am – 11:30am, Tuesday

Carys Bill[1], *Gareth Collins, Tom Davison, Doyeon Kim & Namya Baijal*

[1] Imperial College London

The 2500 km diameter South-Pole Aitken (SPA) Basin is the largest and oldest-known impact crater in our Solar System. Its formation dramatically influenced the Moon's interior and surface evolution. To better understand the role this impact event played in shaping the Moon we see today, numerical models of SPA's formation are required. We conduct numerical simulations of the SPA basin formation using iSALE-3D. The Moon was modelled with three distinct layers: a 350 km radius iron core, a dunite mantle and a 50km-thick granitic crust. The impactor was modelled as a spherical body with a dunite mantle and iron core. Simulations were performed using impactor velocities between 10 - 15 km/s, impactor radii of 93-200 km, thermal gradients of 10 K/km (cold profile) to 50 K/km (hot profile) and impact angles between 20 - 45°. We process simulation outputs to construct a post-impact ejecta distribution, crustal thickness distribution and crater morphology. To help constrain impact parameters we compare these results to a variety of observational constraints from lunar spacecraft data. Our simulations generate SPA-scale craters which show good agreement with observational constraints. The crust is completely excavated in all simulation scenarios supporting the idea that the mantle is exposed during the SPA impact event. Ballistic ejecta projections produce a downrange near-symmetrical pattern with the thickest distribution around the downrange rim of the basin. Our findings help further constrain impact parameters for SPA's formation.

Contact: `c.bill23@imperial.ac.uk`

Implications of Impacts in Volatile Speciation and Distribution Between the Planetary Reservoirs

11:30am – 12pm, Tuesday

Arnaud Salvador[1]

[1] Lunar and Planetary Laboratory – University of Arizona

Impacts can dramatically affect the surface conditions of rocky planets and define the initial thermo-chemical state of their evolution. Coupled interior-atmosphere models simulating the early evolution of rocky planets generally assume simplistic scenarios, where the thermal evolution starts following a single giant impact event, responsible for melting the entire planetary mantle. Yet, both the accretion sequence, determining the timing and occurence rate, and the nature of each collision (e.g., the size, composition, trajectory of each impactor) may significantly affect the thermo-chemical evolution of the forming planet. Here, in light of recent studies, I will discuss how impacts may affect the oxidation state of the molten mantle, the speciation of outgassed volatile species and their distribution between the planetary reservoirs. In particular, I will emphasize their possible implications in atmospheric formation, early evolution of rocky planets, and habitability requirements.

Contact: salvadorarnaud@hotmail.fr

A new asteroid family as a potential source of L-chondrites

5:15pm – 5:30pm, Tuesday

Bryce Bolin[1]

[1] NASA Goddard Space Flight Center

We have identified a potential new collisional asteroid family in the Main Belt. Preliminary analysis with visible data from the Sloan Digital Sky Survey and Gaia suggests that it may be an S-type family. Due to its location in the Main Belt, it may also be a source of meteorites. We investigate the possible connection between the members of this asteroid family and some of the common meteorites such as L-chondrite. We use NIR spectroscopy to confirm the spectra of the family members and provide a basis for analysis of their spectral features as a test of their mineralogy and comparison with meteorites.

Contact: bolin.astro@gmail.com

3.3 Cratering, surface and atmosphere: Perspectives from observations, models and granular experiments

Impact basins on the Moon and Mars

1:30pm – 2pm, Tuesday

Katarina Miljkovic[1]*, Hely C. Branco, Ana-Catalina Plesa & Abigail C. Allwood*

[1] Curtin University

The largest and oldest impact craters provide evidence of the earliest crustal structure and evolution in the inner solar system. Significant progress has been made in understanding lunar impact basins in the last decade. Some of the latest works will be reviewed. Thanks to the NASA InSight mission seismic survey, the interior mapping, and crustal and thermal evolution modelling made in the last few years, we have started to better understand the structure and evolution of Mars' ancient crust via preserved impact basins. The most recent advancements include updated impact scaling relationships for Mars basins, with implications for the largest and oldest impact rates in the inner solar system. We also show the investigation of the diverse structural morphology observed in impact basins on Mars. We discuss the formation and structure of the Isidis basin in detail, with applications to understanding the Mars 2020 landing site on a broad scale.

Contact: katarina.miljkovic@curtin.edu.au

The link between subsurface rheology and ejecta mobility (EM): the case of small new impacts on Mars

2pm – 2:30pm, Tuesday

Aleksandra Sokołowska[1]*, Gareth Collins, Ingrid Daubar & Martin Jutzi*

[1] Brown University

Much like crater size and morphology, the dynamics of ejecta can be sensitive to the target properties. Most craters on Mars have the so-called ejecta mobility (EM) - the maximum radial extent of ejecta scaled by the crater radius - varying across the planet, and some studies show that this number changes with latitude and types of plains. These differences have often been associated with the sliding of material on the planetary surface. In this study we isolate the effect of target properties on ejecta dynamics and quantify the expected variations in spatial distributions of ejecta blankets and EM caused by different shallow subsurface composition and layering. We compile geologically-motivated subsurface structures based on extensive literature review of data gathered by orbiters and landers, and we scrutinize the effects of varying properties of materials in single layers of various rheology; study the impact of the presence and thickness of regolith on these results; and evaluate the sensitivity of ejecta dynamics to complex layering. We realize 2D simulations with the iSALE shock physics code. We pick new craters on Mars discovered in the period of spacecraft observation as our case study because they are in the strength regime and can provide an upper limit on these effects. The results from first iSALE simulations show promise for using numerical modeling in concert with observations to study the shallow subsurface of Mars in the future, to depths greatly exceeding the excavation depths of these craters.

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Laboratory studies of impacts in granular systems and Erosion and transport on forming planetesimals

5:30am – 6pm, Tuesday

Alice Quillen[1] *& Stephen Luniewski*

[1] University of Rochester

Studies of impacts often focus on impacts at speeds of km/s into solid materials. However low velocity impacts take place during planetesimal formation, from secondary ejecta, during spinout and reacculumation events, and many astronomical objects host granular materials. I will discuss laboratory experiments at low and intermediate velocity in granular systems and how we can extend our interpretation of impact processes to cover these different regimes. Low velocity impacts are particularly important during planetesimal formation where impacts from particles in a disk can cause erosion, particle transport and mixing.

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How collisions affect the shapes and spins of NEOs

6pm – 6:30pm, Tuesday

Stephen Schwartz[1]

[1] Planetary Science Institute / U. Alicante

NEOs of roughly 1 km in size are likely to have experienced multiple reshaping collisions during its prior orbit in the Main Belt. Shapes and spins of the NEO population are thus bound to have been affected by their collisional history post-formation. We are performing numerical simulations of subcatastrophic impacts in this context to better understand the process and how it effects the present population of NEOs. Results will be presented.

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Hit Me Baby Many Times: The Role of Impacts on the Growth of Oxygen Pre-GOE

11:45am – 12pm, Thursday

Monica Vidaurri[1] *& Laura Schaefer*

[1] Stanford University

Earth is the only known celestial body that supports life, and therefore, we look for other Earths and Earth-like conditions, specifically abundant atmospheric oxygen. However, the history of life on our pale blue dot is quite turbulent: though we look for oxygen, the early Earth was anoxic until the Great Oxidation Event (GOE) at 2.5 Gya. It has also seen many impacts - some of which are large enough to vaporize oceans. These impacts likely come from planetesimals forming in the inner solar system, which may play a role in suppressing O2 due to the reducing material of such impacts. In addition, regional oxygen buildup, oxidative processes, and an oxidizing mantle likely existed prior to the GOE, but global oxygen remained negligible. To investigate which oxygen sinks were able to keep oxygen low, we look to impact events, whose reducing material was delivered to the surface then oxidized over time, which may have contributed to both keeping oxygen low and oxygen buildup necessary for the GOE. Studying the ways oxygen can suppressed is as important as studying oxygen itself; a young planet that may be undergoing late accretion but show no signs of oxygen in the atmosphere may not mean that the planet is void of life. Here we present preliminary results of modeling that investigates the reducing power of the impacts of the late heavy bombardment period, and whether the smaller, less frequent impacts of the Archean acted as both the oxygen sink necessary to maintain reducing conditions, but whose oxidation over time may have also contributed to the GOE.

Contact: mvidaurri@stanford.edu

How to estimate the size of large meteoroid impacts

1:30pm – 2pm, Thursday

Simon Anghel[1]

[1] Astronomical Institute of the Romanian Academy

Cosmic objects are impacting the Earth's atmosphere on a daily basis. Due to their small size, these meteoroids cannot be seen before interacting with the air particles. Thus, to better constrain the size of an impactor, we need calibrated multi-detector observations, combined with state-of-the-art theoretical models. In this study we explore several published techniques of measuring the pre-entry mass of meteoroids with well-known trajectory (also a subject of meteorite recoveries), at the source of ton TNT-scale atmospheric impacts. On this scale, the fireball is less likely to cause an airwave signal detectable on multiple specialized stations, or the estimation methods carry high uncertainty. Thus, in this analysis we focused on the optical energy signature of the objects and we derived a relation between the radiated light and the object's kinetic energy. This, in turn will help to cross-calibrate other methods of estimating the source energy, allowing to further constrain the size-frequency distribution of atmospheric impacts.

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Observations of Giant Impacts Around Not-so-young Stars

2pm – 2:30pm, Thursday

Alycia Weinberger[1]

[1] Carnegie Institution for Science, Earth and Planets Laboratory

Debris disks around mature stars signal the presence of bodies at least the size of planetesimals. Collisions of these bodies provide the population of small dust grains observed. Disk structures on the spatial scale of our Kuiper Belt, including warps and eccentric orbits, also suggest the presence of larger planets. However, only about 15 stars older than 80 Myr are known to have copious warm (> 300 K) dust. These are the only systems we know of that must have experienced a recent major collision, one that includes a planetary body larger than 100 km in diameter. I will review what is known about the dust composition in these disks, which provides a window into the interior composition of planets. I will also discuss what the number of such dusty stars tells us about the likelihood of late giant impacts.

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3.4 Impact-induced metal-silicate equilibration

Crater Dynamics and Metal-Silicate Mixing in Planetary Impacts: Insights from Drop Impact Experiments

9am – 9:30am, Wednesday

Victor Lherm[1]*, Renaud Deguen, Thierry Alboussière, Ludovic Hughet & Maylis Landeau*

[1] University of Rochester

During planetary formation, thermal and chemical partitioning between the core and the mantle is influenced by the physical mechanisms of segregation between the metal of the impactors' core and the silicates of the growing planet, with major implications on the chemical, thermal and magnetic evolution of the planet. In particular, the cratering process is responsible for the initial dispersion and mixing of the impactors' core. Interpreting the consequences of these planetary impacts requires an accurate description of the flow and mixing processes associated with the cratering process. In this context, we use analogous drop impact experiments, which are dynamically similar to planetary impacts, to investigate the dynamics of the cavity and impact-induced mixing produced during the formation of the crater.

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Using giant impact simulations to improve a model of metal/silicate differentiation during Earth's accretion

9:30am – 10am, Wednesday

Katherine Dale[1]*, Dave C. Rubie, Miki Nakajima, Seth Jacobson, Gabriel Nathan, Gregor J. Golabek, Saverio Cambioni & Alessandro Morbidelli*

[1] Observatoire de la Côte d'Azur

In the process of hierarchical growth of the terrestrial planets, giant impacts between large bodies known as embryos play a key role in defining the chemical structure of the planet formed. The speed, angle and mass of these impactors relative to their target determine the amount of melting the target experiences. This, in turn, defines three things: the mass of material the impactor mantle can equilibrate with and the pressure and temperature at which this equilibration occurs. We make improvements to the model of Rubie et al. (2015) which couples the accretion of the Earth to its geochemical evolution. These improvements use the work of Nakajima et al. (2021) to determine the degree of melting produced by an impact on an embryo. This enables us to determine the depth, and thus pressure, at which chemical equilibration occurs as well as the amount of material available for this equilibration. The pressure is thus eliminated as a free parameter and can be determined using the properties of a given collision. Furthermore, planetesimal impacts are now regarded as being too small to cause melting upon impact. They are accumulated within the crust of the target embryo until a giant impact occurs. A giant impact creates a hydrostatically relaxed magma ocean that then allows these planetesimals to equilibrate with the target's mantle. These changes allow us to use the properties of the sequences of growth that form terrestrial planets to assess whether or not a given model can produce a planetary mantle with a similar chemical composition to that of the bulk silicate Earth.

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Numerical Models of Planetary Formation and Core Differentiation

10am – 10:30am, Wednesday

Gabriele Morra[1]*, Hunter L. Bouillion, Leila Honarbakhsh & Peter Mora*

[1] University of Louisiana at Lafayette

The emergence of a magma ocean (MO) is a critical phase in the accretionary process of a planet. The depth and composition of the MO can affect elemental and isotopic partitioning, core differentiation, atmosphere formation, cooling time, and more. Here we present two types of models, referring to two stages of planetary formation. The first referring to the duration of a magma ocean and the second to the iron-silicate differentiation. In the first the melt history from 20 planetary accretion are modelled over the span of 100 million years. Impact conditions on a proto-Earth were obtained using Mercury 6.2 simulations comprising a proto-Earth, 40 large embryos, and 100 smaller non-interacting planetesimals. These models give insight to the pressure and temperature condition of the planet interior over time and provide evidence for multiple melting events instead of a single long-lasting MO. The second type of models refer to large impactors, more common in the late accretionary stages, contain iron cores that can emulsify into extremely small drops, which then rain down into the rocky planetary core. Using a newly developed fluid-dynamic numerical approach, based on the Lattice Boltzmann Method for fluid-dynamics, and Rothman-Keller approach for multiphase flow, we model the fate of the metal-silicate fluid dynamics in response to a wide range of realistic magma ocean scenario, considering impactors falling a different angles, iron content and speed.

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Giant impacts into magma ocean: metal-silicate mixing constrained by coupling analog laboratory experiments and numerical modelling

11am – 11:30am, Wednesday

Laetitia Allibert[1]*, Maylis Landeau, Miki Nakajima, Randolph Röhlen, Augustin Maller & Kai Wünnemann*

[1] Natural History Museum, Berlin

Planetary formation models suggest that Earth experienced multiple high-energy impacts. They can produce substantial melt in the proto-Earth's silicate mantle, possibly forming a global magma ocean. Mixing of the impactor's metallic core into the molten Earth's silicate mantle controls the chemical equilibration between metal and silicates, which defines the respective compositions of Earth's core and mantle. Previous studies explore mixing upon large impacts either with numerical modelling or with analog laboratory experiments. Numerical simulations are efficient in reproducing the shock physics of hypervelocity impacts. However, their spatial resolution is limited and does not allow for reproducing the turbulent features that are responsible for metal-silicate mixing in a magma ocean. On the other hand, liquid impact experiments that do produce small-scale mixing and turbulence are subsonic: they neglect compressibility effects. Recent simulations and experiments disagree on the degree of mixing between the impactor and target materials. The origin of these differences is still unclear. We present a scaling-law that extends laboratory impact experiment results to hypervelocity cases. The implications of the hypervelocity effect of the impact dynamics is discussed with respect to core material mixing in a silicate magma ocean. In particular, we find that the Mach number (impact velocity to sound speed ratio) decreases the estimates of metal-silicate mixing upon impacts derived from laboratory experiments. The extent of its effect however depends on the other impact parameters such as the impactor size.

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Asteroid Core Breakup During Magma Ocean Impacts

11:30am – 11:45am, Wednesday

Randolph Röhlen[1], *Kai Wünnemann & Laetitia Allibert*

[1] Museum für Naturkunde, Berlin

Impacts into magma oceans, for example during Earth's late accretion phase, could have had a significant effect on the later mantle composition of planets. On Earth, they could explain the relatively high concentration of highly siderophile elements (HSE) that we observe in the mantle today. For the HSE concentration, the fate of iron cores of larger differentiated bodies is especially important. More fragmented cores would convect longer in the target magma ocean and have a higher surface to volume ratio. This would drastically increase the material exchange with the surrounding magma ocean.

We study such impacts with numerical simulations, using an improved fragmentation method, which we implemented in the grid-based Eulerian shock physics code iSALE. Our new method reduces the effect of simulation artifacts by identifying when the resolution of pieces of impactor core material approaches the grid resolution and treating it with separate petrophysical criteria instead. If fragmentation occurs due to this method, the material is removed from the simulation grid and instead represented by a particle. We study the effect of different parameters like impact velocity, impactor size, magma ocean depth or impact angle.

We focus on the size-frequency distribution of impactor core fragments for the different simulation setups. Our results show a significant breakup of the impactor core for most setups. A shallower magma ocean as well as lower impact velocities reduce the fragmentation and can still allow larger pieces of the core to reach the magma ocean bottom.

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Thermal effects of collisions during rocky planet accretion

11:45am – 12pm, Wednesday

Adriana N. Postema[1] *& Sarah T. Stewart*

[1] University of California, Davis

Almost all planetary bodies experience major collisions during planet formation, ranging from small collisions of sub-moon-sized bodies to giant impacts between protoplanets. These impacts cause a large amount of thermal and chemical processing, creating magma ponds and causing iron and silicates to become miscible. We explore the thermal outcomes of an impact simulation suite representative of early solar system conditions and the consequences for metal-silicate partitioning near the core-mantle-boundary. We used updated ANEOS equation of state models with the SWIFT hydrocode package to more accurately describe the temperatures, pressures, and heat budgets of post-impact planets. We find that our modeled post-impact pressure profiles are generally lower than previous assumptions of metal-silicate equilibration conditions, due to both thermal effects and rotational contributions from added angular momentum. Accretionary collisions contain both effects while hit-and-run collisions are more rotation-driven. In all collision outcomes, post-impact mantles contain the majority of the heat budget with bulk heating partitioned into the mantle in excess of mantle/core mass ratios. We present scaling laws for post-impact pressures and temperatures near the CMB and the contributions of rotation to CMB pressures. We present additional scaling laws for the efficiency of impact heating and mantle/core heat partitioning as a function of specific impact energy and other initial impact conditions. We also characterize the amount of material heated past the Fe-Mg solvus. We aim for our scaling relations to be applied to studies of core formation in order to more accurately describe metal-silicate equilibration conditions after giant impacts.

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Condition for metal fragmentation during Earth-Forming collisions

12pm – 12:15pm, Wednesday

Augustin Maller[1], *Maylis Landeau, Sébastien Charnoz & Laetitia Allibert*

[1] Institut de Physique du Globe de Paris

The long-term evolution of the deep Earth depends on its initial temperature and composition, which were set by the large planetary collisions that formed the Earth. After each collision, the metallic core of the impactor fell into a molten silicate magma ocean. As it sank, the core fragmented into drops. The overall fragmentation controlled the efficiency of chemical transfers between the impactor metal and the magma ocean, thus controlling the composition of the Earth's core and mantle. However, it remains unknown whether the impactor core fragmented on impact.

To answer this question, we conduct laboratory experiments on the impact of a centimetric liquid volume, representing the impactor core, onto a lighter immiscible liquid representing the magma ocean.

We find that the impactor fragments into drops when the Froude number (Fr), which measures the relative importance of inertia to gravity, is larger than 40. In contrast, when Fr¡10, the impactor remains coherent.

Our results suggest that the core of an impactor less than 250 km in radius, impacting at escape velocity onto an Earth-sized planet, fully fragments into drops during the impact process, whereas the core of a giant Moon-forming impactor fragments only partially. We derive a model for the fragmentation depth in the magma ocean as a function of the impactor size and velocity. This model predicts that impactors with a radius less than 800 km in radius fully fragment before reaching the bottom of the magma ocean.

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3.5 Early dynamo and magnetic fields

The role of collisions on Uranus and Neptune

9am – 9:15am, Thursday

Alice Chau[1]*, Ravit Helled, André Izidoro, Christian Reinhardt & Joachim Stadel*

[1] University of Rochester

Giant impacts are thought to be ubiquitous in the solar system, thus being potentially responsible for the diverse physical properties of the planets. In the case of Uranus and Neptune, sometimes referenced as ice giant "twins" due to their similar properties, giant impacts could be the mechanism that explains their final dichotomy in internal structure (e.g., in heat flux, moment of inertia, tilt) and satellite system. In parallel, the formation history of the ice giants is also debated. A possible scenario involves a chain of collisions of planetary embryos beyond Saturn's orbit. We revisited those formation pathways using SPH simulations. While the dichotomy can be explained by violent impacts at the end of their history, forming Uranus and Neptune in a purely collisional scenario remains challenging. For example, the inferred obliquities on Uranus and Neptune can only be matched in a few cases. We also find that the planets rotate too fast, close to break-up speed and have massive disks. We suggest that future planet formation models should aim to reproduce the various physical properties of the planets such as their masses, compositions, obliquities, rotation rates and satellite systems.

Contact: `achau2@ur.rochester.edu`

Evidence for impact magnetization of young lunar glass

9:15am – 9:45am, Thursday

John A. Tarduno[1]*, Rory D. Cottrell & Tinghong Zhou*

[1] University of Rochester

If impact plasmas can induce magnetizations in planetary surface samples, it might be possible to hindcast the characteristics of past impacts from measurements of remanent magnetization. The Moon is arguably the best environment to test this charge-separation magnetization process because lunar impact samples can be free from post-impact alteration. Here we study Apollo 17 70019, a ca. 2-million-year-old impact glass, coating regolith. We apply Thellier paleointensity analyses, with rapid CO2 laser heating and partial thermoremanent magnetization checks for alteration, to pristine specimens of 70019. We use the University of Rochester ultrasensitive 3-component DC SQUID magnetometer and find a paleointensity of approximately 2 microteslas from experiments that pass alteration checks. This value is some 10 times greater than average local fields measured on the Moon, and nearly identical to that found by Sugiura et al. (1979) who used a variant of Thellier analysis but without alteration checks. The consistency of our data and those of Sugiura et al. (1979), using different magnetometers spanning four decades, together with recent confirmation of magnetizations from Apollo 16 impact glass sample 64455 (Tarduno et al., AGU, 2023), provides strong evidence supporting the impact magnetization hypothesis.

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Atmospheric transfer from Earth to the Moon since the Hadean, and the impact origin of some lunar magnetic signals

9:45am – 10:15am, Thursday

Tinghong Zhou[1], *John A. Tarduno & Rory D. Cottrell*

[1] University of Rochester

Understanding lunar magnetism is important because it sets the boundary conditions for the transfer of Earth's atmosphere to the Moon via the geomagnetotail. Modern thermal single crystal paleointensity (SCP) results indicate null lunar field strengths between 3.9 and 3.2 Ga and the absence of a long-lived dynamo and paleomagnetosphere for the Moon (Tarduno et al., 2021). New SCP analyses indicate a null lunar field after 4.36 Ga (Zhou et al., 2024), suggesting that Earth-Moon atmosphere transfer could have occurred as early as the Hadean. The SCP data supersede older data, but the cause of some high nominal magnetization values from nonthermal whole rock paleointensity (WRP) analyses remains unclear. To examine this, we compared SCP and WRP data from the same Apollo samples. We find WRP yield extraordinarily high and inconsistent nominal field values, whereas the SCP data consistently yield zero field strengths. The anomalous WRP values may be recording shock magnetizations from past impacts. Impact fields have been defined in young 2 Ma Apollo glass samples from small craters/impacts (Tarduno et al., 2024). For larger impacts, impact field strengths can reach many thousands of microTesla and can provide the seed fields for shock magnetizations in lunar bulk rocks.

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What can Impacts Deliver?

10:45am – 11:15am, Thursday

Paul B Rimmer[1]

[1] University of Cambridge

Several experiments and theoretical studies have been undertaken investigating the stability of molecules in comets and meteorites, to predict whether they could be delivered intact onto the surface of early Earth. Few of these investigations have considered the thermal degradation products of these molecules. I will present new theoretical investigations into the delivery of hydrogen cyanide and glycolaldehyde, two prebiotically relevant compounds. Our results provide predictions about the probability that these molecules will survive delivery, and the molecules that emerge from their thermal degradation, some of which are themselves prebiotically relevant. I will conclude by talking about planned experimental work to measure the thermal stability of hydrogen cyanide and glycolaldehyde in the presence of water.

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Monte Carlo simulation of amino acids synthesis at a celestial body impact

11:15am – 11:45am, Thursday

Shigeru Ida[1]

[1] Tokyo Institute of Technology

Synthesis of complex organic molecules (COMs) including biomolecules such as amino acids, sugars, and nucleobase is one of the most attractive problems in astrobiology. For chemical reactions to proceed to COMs synthesis, the molecules need to be chemically activated by such as UV, gamma rays, cosmic rays, electric discharge, or hot water in high pressure.

We have developed Monte Carlo scheme to follow chemical reactions sequences to sugars and amino acids on icy grain surface irradiated by UV in the upper layer of a protoplanetary disk, using Arrhenius-type weighing with activation energy to select reactions from all the possible reactions including radial reactions (Ochiai et al., in prep; Takahara et al. 2022). Because this scheme does not require to set up reaction networks in advance and does not use computationally expensive quantum chemical calculations, we can perform broad parameter surveys of COMs synthesis.

Here we theoretically discuss synthesis of amino acids and sugars during celestial body impacts in asteroid belts or early Earth, which are another chemical activation events that should happen during planet formation, using the Monte Carlo scheme that we have developed.

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4 Posters abstracts

The Poster board size is 36 x 48 inches maximum. Poster presentors can have a one-minute flash talk on Tuesday to advertise their poster. If you would like to present, please send a one page PDF by April 5th to the organizers (we will annouce the person in charge soon). If you want to print out your poster on site, print it out at Fedex (1906 Monroe Ave, Rochester, NY 14618) and make sure it is ready to be picked up by 8am on April 5^{th}. We will give you the poster on Monday morning. If you are late for this pick up time, you will need to pick it up by yourself. The abstracts of the posters are as follow.

Ncorpi$\mathcal{O}$N, a $\mathcal{O}(N)$ N-body software

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Jérémy Couturier[1]*, Alice Quillen & Miki Nakajima*

[1] University of Rochester

Ncorpi$\mathcal{O}$N is a N-body software designed for the integration of collisional and fragmenting systems. We applied our software to the formation of the Moon from a protolunar disk of liquid-silicate moonlets, originated from a giant impact between the young Earth and Theia. We used the built-in fragmentation model of Ncorpi$\mathcal{O}$N to properly manage cases where a high-velocity encounter between moonlets leads to their fragmentation rather than to an accretion.

We show that in most cases, the fragmenting and collisional evolution of the protolunar disk yields several submoons on non-resonant orbits which fail to collide to complete the formation of the Moon. Our software takes into account perturbations from Earth's equatorial bulge, tides and perturbations from the Sun. As such, it is able to simulate capture into the evection resonance (*e.g.* Touma & Wisdom, 1998). The formation of the Moon completes when the inner submoon is destabilized by the evection resonance and is sent on a colliding trajectory with the outer submoon.

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Evolution of Spatial Heterogeneities including the Giant Impact in Mantle Convection Models

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Alexander Braun[1]*, Fadhli Atarita & Petar Glisovic*

[1] Queen's University

Present-day multi-scale spatial heterogeneities in the Earth's interior are evident from seismic tomography models. Assuming that heterogeneities existed in the early Earth and to understand the relevance of spatial scales the long-term evolution of the planet, we present insights into the spatial scale dependency of mantle convection models, focusing on thermal structures. Mantle-convection models include initial conditions of radial viscosity variations, boundary conditions at surface and the core-mantle boundary and prescribed thermal heterogeneities. Models were computed at multiple spatial resolutions (32, 64, and 128 spherical harmonic degrees) with 129 radial nodes and a 4.5 Gyr timespan. Results from over 100 model runs show that differences in model resolution change the scale evolution of the Earth, regardless of initial model scales. Higher resolutions allow smaller scales to evolve and stabilize between degrees 32 and 64, while larger scales are shown to be more persistent in the long term. Furthermore, higher resolutions proved to be effective in reducing a numerical artefact during the first 100-200 Myr, in which vigorous convection and initial conditions are not in balance. All simulations show that mantle convection reaches a quasi-steady state (with respect to spatial scales) within 1 Gyr. The scales of the initial model are also found to be of little relevance for the evolution of thermal heterogeneities in mantle convection models. This study is focused on thermal structures as an indicator for evaluating multi-scale heterogeneity as we assume temperature to have a significant effect on the long-term evolution of the Earth. However, the heterogeneity inside the mantle is controlled by complex thermo-chemical processes, which are necessary to evaluate the influence of spatial scale in which advection processes may become more important. These models will be expanded by using giant impact models as the input for the initial conditions and test the impact on short-term and long-term evolution of the Earth.

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Surface and subsurface rock populations in the ejecta of Tycho crater determined with reprocessed Surveyor 7 television camera images and LRO Diviner/Mini-RF data

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Cailin Gallinger[1]

[1] University of Western Ontario

The Surveyor 7 mission, launched in 1968, is to date the only spacecraft (crewed or robotic) to have visited the continuous ejecta blanket of a large, young (<200 Ma) lunar crater. We will use recent digitally-scanned Surveyor 7 television images and Lunar Reconnaissance Orbiter Camera (LROC) Narrow-Angle Camera (NAC) stereo DEMs to locate and determine the diameters of rocks between 5 cm and 10 m across within 500 m of the Surveyor 7 landing site, and compare these to rock abundances inferred using thermal infrared observations from LRO's Diviner thermal radiometer instrument as well as data from LRO's Miniature Radio Frequency (Mini-RF) synthetic aperture radar instrument. This will provide the first ground-truth validation of rock abundances derived using remote sensing techniques on a region of the Moon with a significantly elevated surface rock population. Additionally, increased understanding the rock population in this region will enable development of improved models of the surface and subsurface physical properties of this morphologically-pristine impact crater's ejecta, which could improve our understanding of impact melt deposition and rock fragmentation processes during hypervelocity impact events on all terrestrial bodies.

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Shock Compression of (Mg,Fe)O: Dynamo Generation within Basal Magma Layers

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Alex Jasko[1]*, Miki Nakajima, Danae Polsin, Kim Cone, & Dustin Trail*

[1] University of Rochester

A basal magma layer (BML) may have existed on Earth before the solidification of the inner core, which we now know plays a significant role in the modern geomagnetic dynamo. Therefore, it is possible that a BML on the early Earth may have been responsible for Earth's magnetic field in the distant past. BMLs likely also exist within both Earth-like and Super-Earth exoplanets, so understanding their potential for dynamo generation is incredibly important for understanding magnetic field generation in rocky planets as a whole. Through shock compression experiments held at the Laboratory for Laser Energetics, my project aims to constrain the conductivity of (Mg,Fe)O at the extremely high temperatures and pressures to provide some insight into BML dynamo generation. A certain conductivity must be achieved within the (Mg,Fe)O melt for a dynamo to be generated. It has been theorized that the conductivity of (Mg,Fe)O increases with Fe content, so as part of my project, we have synthesized (Mg,Fe)O targets from pure MgO to 25% FeO to test the conductivity dependence on Fe.

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Numerical Modelling of Thermally Coupled Core-Mantle Evolution over 4.5 billion years: Implications for Initial Core-Mantle Temperatures, Mantle Rheology, and Surface Boundary Conditions

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Petar Glisovic[1]*, Alexander Braun & Fadhli Atarita*

[1] Queen's University

The thermal evolution of our planet, spanning over 4.5 billion years, presents a complex puzzle with many missing pieces. Utilizing state-of-the-art numerical simulations of mantle convection, we investigate the critical roles of initial temperature conditions, mantle rheology, and surface boundary conditions in governing Earth's thermal history. We employ a pseudo-spectral approach to solve the conservation equations for mass, momentum, and energy in a compressible, self-gravitating mantle over 4.5 billion years. This methodology also incorporates time-dependent treatments for dislocation and diffusion creep mechanisms of primary mantle minerals, along with a thermally coupled core-mantle evolution. To constrain the range of allowable parameters and conditions, we compare our model predictions to present-day observables, such as heat flux, inner-core radius, and core-mantle temperatures. Our results reveal significant insights into Earth's past and present. Firstly, we find that the initial melting temperature at the inner-core boundary and initial temperature at the core-mantle boundary have to be either equal or within a 300 K range to predict the observed seismic inference of the inner-core radius. This demonstrates that the inner-core's growth onset is sensitive to the initial temperatures, providing constraints on its age. Our simulations suggest that the initiation of inner-core growth occurred between approximately 1.6 and 0.9 billion years ago. We also delve into the profound influence of mantle rheology on Earth's intricate thermal evolution. Our investigation unveils the crucial role played by upper mantle viscosity, exerting a significant impact on the rates at which the mantle cools over time. Additionally, our present-day predictions of depth-dependent viscosity profiles align with those obtained from joint inversions of seismic, mineral physics, and geodynamic data, emphasizing the role of surface boundary conditions in shaping mantle dynamics. Namely, we demonstrate that the choice of surface boundary conditions, specifically no-slip and free-slip, can dramatically influence Earth's temperature evolution over geological time scales. Both boundary conditions, especially the free-slip, prove to be exceedingly efficient in cooling the planet, resulting in an Earth that is considerably colder than anticipated at present. This results suggests that the present-day internal heating may be higher than 27 TW. While our findings closely align with those from independent studies that emphasize the significance of mantle rheology and surface boundary conditions in shaping Earth's thermal history, they also contribute to the refinement of parameters and conditions governing our planet's evolution. We also emphasize the need for further research to understand how collision events, such as the one between the proto-Earth and a Mars-sized object, may have influenced Earth's thermal evolution and geological history.

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Post-impact thermal evolution of iron-rich planetesimals

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Gregor Golabek[1]

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Iron-rich bodies have been proposed to be the result of high-energy collisions removing most of the silicate mantle from differentiated bodies [1]. Here we use the results of high velocity sub-catastrophic collisions at 10 km/s into differentiated planetesimals with initially 30-40 km thick mantles and 100 km radius iron cores performed using the iSALE-2D shock physics code [2]. In order to study the long-term thermal evolution of these iron-rich remnant bodies, we employ a 1D finite-difference code considering material-dependent heat diffusion, latent heat of crystallization and time-dependent radiogenic heating by 26Al and 60Fe in the leftover mantle and the iron core, respectively. For the thermal evolution calculations, we use an initial composition and temperature structure based on radial profiles through the center of the post-impact bodies. The start time after CAI formation of the long-term models is based on the Pd-Ag dating for various iron meteorites [3]. Finally, we compare the results with the cooling rate constraints for various iron meteorite types based on Widmanstätten pattern formation [4] and Pd-Ag data [3] with both methods covering different temperature intervals during the body's cooling.

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[3] Hunt, A. C., K. J. Theis, M. Rehkämper, G. K. Benedix, R. Andreasen & M. Schönbächler (2022). Nat. Astron. 6, 812-818.
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Pressure and Mass Constraints on the Origin of Lunar Impact Ejecta

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Soren Helhoski[1]*, Miki Nakajima, Jonathan Gagné & Dustin Trail*

[1] Brown University

Terrestrial planets and moons in our solar system bear heavily cratered surfaces, hinting at significant early bombardment. The Late Heavy Bombardment (LHB) theory posits an intense impact period around 4.1 to 3.7 billion years ago, potentially initiated by planetary migration. Recent studies challenge this hypothesis due to uncertainties in shock age dating and concerns over contamination from major impacts like the Imbrium basin, complicating the interpretation of the solar system's early chronology, particularly lunar cratering records.

This study aims to quantify contamination effects on Apollo sample ages from nearby crater ejecta. Using the iSALE code, we simulate impacts to assess ejecta distribution and pressure-temperature conditions. We analyze ejecta landing locations and through a combination of kernel density estimation and interpolation, we estimate the likely sources of contamination at the Apollo Landing sites.

Through these simulations, we seek to refine understanding of contamination's impact on lunar sample ages, critical for reconstructing the solar system's early history.

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The influence of thermal evolution and interior structure on impact-induced melt generation on terrestrial planets

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Kai Wünnemann[1]*, Lukas Manske, Thomas Ruedas, Ana-Catalina Plesa, Natalia Artemieva, Philipp Baumeister & Nicola Tosi*

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We investigate the melting efficiency of planetary impacts as a function of planet size, impactor size, and core size ratio using numerical simulations. We find that melt production is more efficient for large planets when struck by smaller impactors, while for small planets, melt production is more efficient when impacted by larger impactors. This diverging behavior can be explained by the planets' thickness of the thermal boundary layer and the shape of its thermal and lithostatic pressure profile. We also find that melting is usually most efficient on Earth-size planets for impactors of about 50 km in diameter. We show that the melting efficiency is not strongly affected by the core size ratio except for very large cores and older planets, where melt production is decreased significantly compared to smaller core size ratios. Projecting the lunar impactor flux on the generic planets, we find that on a Mars-size planet, most melt is produced relative to its planet volume. Furthermore, we compare our findings with scaling laws, which only consider shock melting. We find, that those fail to predict melt at large scales, where target inhomogeneity's regarding temperature and lithostatic pressure meters.

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Hydrodynamic Volatile Escape and Moderately Volatile Isotope Fractionation in Giant Impact Ejecta

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Scott Hull[1]*, Miki Nakajima, Robin M. Canup, Channon Visscher & Paolo A. Sossi*

[1] University of Rochester

The Moon is depleted in volatile elements and enriched in heavy moderately volatile element (MVE) isotopes relative to the BSE, a feature it likely attained during its formation. In the context of a giant impact origin of the Moon, we assess whether impact vaporization and subsequent hydrodynamic escape of an impact-generated vapor jet can explain the depletion of volatiles and MVE isotope fractionation in the protolunar ejecta. We combine smoothed particle hydrodynamics (SPH) models of two giant impacts with hydrodynamic vapor escape and fractional thermodynamic codes to model the mass loss fraction of the impact vapor and the composition of the remaining protolunar material. We find that the observed lunar volatile depletion can be reproduced from a canonical impact vapor jet with a modest amount of vapor mass recovery, although the vapor jet's expansion into a vacuum results in lunar δ^{41}K abundances that are significantly heavier than observed. We also use mass balance to assess the bulk composition and origin of Theia, and find that Theia must have had a considerable amount of Si in its core if it was compositionally like enstatite chondrites. Otherwise, Theia was more reflective of ordinary or carbonaceous chondrites.

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Modeling the Impact Process and Crystallization Sequence of the Sudbury Igneous Complex: Implications for Hadean Crust Formation

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Nicolas Litza[1]*, Miki Nakajima*[1]*, J. Brian Balta*[2,3]*, Steven B. Shirey*[4]*, Dustin Trail*[1]*, Ian Szumila*[1]*, Scott Hull*[1]*, Rasmus Haugaard*[5]*, Taus R. C. Jørgensen*[5] *& Michael Ackerson*[6]

[1] University of Rochester

[2] Cornell University

[3] Lunar and Planetary Institute

[4] Carnegie Institution for Science

[5] Laurentian University

[6] Smithsonian Institution

The Sudbury Basin is a massive, 1.85 Ga, impact structure containing the Sudbury Igneous Complex (SIC), Earth's largest preserved impact-induced melt sheet. This site is crucial for studying processes that might have shaped Earth's early crust. The SIC consists of geological units like mafic and felsic norite, quartz gabbro, and granophyre, believed to result from fractional crystallization of impact-induced melt. Two types of simulations were performed: iSALE to replicate crater features and rhyolite-MELTS to model SIC differentiation. iSALE suggested a rocky bolide with

specific energy levels created the crater size, while MELTS results indicated that later-formed units deviated from observations due to assimilation of country rock. This research aims to explore the role of impact melt crystallization in Hadean crust formation.

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Giant Impact Debris and Where to Find Them

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Robert Melikyan[1]*, Erik Asphaug, Saverio Cambioni, Alexandre Emsenhuber & Stephen Schwartz*

[1] University of Arizona Lunar and Planetary Laboratory

Evidence for giant impacts exist across the explored solar system, at various scales, and while modeling efforts have focused on specific problems like the origin of the Moon and Mercury, less attention has been paid to their broader consequences. It is increasingly recognized that even the most common giant impact conditions do not result in perfect merging —the most common assumption— but rather in the formation of one or two major bodies plus remnants. Remnants being, for the purpose of this analysis, the accumulation 'clumps' and 'debris', where clumps are self-gravitating assemblages and debris are unbound discrete masses below model resolution. Our database of 1250 3D SPH simulations of terrestrial planet forming collisions includes material strength and explores a wide range of impact parameters throughout the three main collisional regimes; hit-and-run, single remnant, and graze-and-merge. We find that most impacts have significant remnant mass (up to a percent or more) with much of the mass in clumps depending on the scale of the collision. We analyze the properties of clumps, their mass fraction, and report their size frequency distributions as a function of impact regime. Overall we find that erosive or disruptive collisions result in steep distributions dominated by small clumps, while graze-and-merge collisions are dominated by larger clumps, with clump SFDs tending to correlate to the giant impact regime.

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Shock experiments on (Mg,Fe)O: Implications for dynamo in magma oceans

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Miki Nakajima[1]*, Alex Jakso, Danae Polsin, Victor Lherm, Eric Blackman, Kim Cone, & Dustin Trail*

[1] University of Rochester

During the planetary accretion stage, growing planets experience a number of giant impacts, which create magma oceans (MO) on these protoplanets. During the magma ocean crystallization, the melt can move downwards if it is denser than the ambient solid mantle and forms a basal magma ocean (BMO). The BMO is predicted to be enriched in iron, because iron is incompatible. Such iron-enriched BMO or magma oceans (MO) may have been hosted by early Earth and super-Earths. These magma oceans may generate a dynamo, if their electrical conductivities are high enough. However, electrical conductivity of analogue materials of BMO and MO are not well known, especially under high pressures. To address this issue, we conducted shock experiments of (Mg,Fe)O, as an analogue material of BMO and MO, at 450-1400 GPa at the OMEGA EP laser facility at the University of Rochester. We measure the reflectivity of (Mg,Fe)O during the shock experiments and estimate their electrical conductivity using the Drude model. We use the velocity interferometer system for any reflector (VISAR) to measure the shock velocity as well as the reflectivity and use the nanosecond streaked optical pyrometry (SOP) to estimate the temperature. Our analyses show a slight increase of the reflectivity of (Mg,Fe)O compared to MgO (by several 10%) with the electrical conductivity ranges of 4×104-105 S/m. Combining these measurements and theoretical investigations, we find that dynamo generation in BMO and MO in super-Earths is possible, whereas it is not straightforward to apply this model to Earth's BMO condition (∼130GPa). Our work suggests that the presence of a BMO has a significant impact on the thermal and magnetic history of the planet.

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Collision of Dust Particles, Generation of Lightning, and Formation of Chondrules

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Taishi Nakamoto[1]

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In the solar nebula, electrical charge-up of dust particles happens due to collisions between dust particles. As the density of dust particles increases, the ionization degree of the gas decreases. Then, the separation of positively/negatively charged particles occurs, the electric fields is increased, and finally lightning is generated. Lightning can melt dust particles and form chondrules. We studied a series of these processes using theoretical models. We found that charge-up occurs properly around forming planetesimals caused by gravitational instability of the dust layer in the solar nebula, and that lightning is generated in the vicinity of forming planetesimals. We also found that dust particles heated by lightning cool at an appropriate rate of temperature decrease when the lightning is surrounded by dense dust particles. Then, those particles can be chondrules that are found in lots of chondritic meteorites today.

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Analysis of the radar-dark halo craters on the Moon

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Ashka Thaker[1]

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Impact cratering is a ubiquitous geological process in our Solar System and plays an important role in shaping the landscape of many planetary bodies, including the Moon. Our study focuses on the unique radar-dark halo craters (RDHCs) on the Moon. These craters are surrounded by distinctive, ring-shaped structures (i.e., haloes) that have unusually low radar backscatter. Our aim is to improve our characterization of the scatterer distribution in the RDHs and shed light on the mechanism responsible for their radar-dark appearance. Additionally, we aim to understand the interaction between the RDHCs and the lunar regolith by assessing the local depths of the regolith surrounding RDHCs. We used S- and P-band radar, TIR and microwave data to characterize the scatterer distribution at the haloes. We used high-resolution optical data to compute regolith depths using the small crater morphology method. RDHs exhibit decreased circular polarization ratio (CPR) in radar data, lower rock abundance values in TIR data, and warmer brightness temperatures in microwave images compared to the craters' continuous ejecta blankets. These results indicate decreased surface roughness at the wavelength scale (∼decimeters) and escape of microwave emissions from a greater depth at the haloes. This means that the local lunar regolith at these haloes is unusually fine-grained. Our assessment of regolith depths at these craters shows that younger craters have thicker regolith in the dark halo regions, while older craters have thicker regolith in their continuous ejecta blankets. Overall, our results indicate that the haloes are a much deeper phenomenon than S-band and microwave wavelengths and that crater's age plays an important role in their associated regolith depth estimates.

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Improving material mixing in impact simulations with REMIX SPH

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Thomas Sandnes[1]*, Jacob A. Kegerreis, Vincent R. Eke, Richard J. Massey, Sergio Ruiz-Bonilla, Matthieu Schaller & Luis F. A. Teodoro*

[1] Durham University

Smoothed particle hydrodynamics (SPH) simulations underpin much of our understanding of impacts, especially giant ones. However, artificial suppression of mixing is a well-established shortcoming of traditional SPH schemes. These effects are particularly strong for the stiff equations of state used in simulations of planetary impacts. I will discuss different approaches to resolving these issues, and present the REMIX SPH scheme (freely available as part of the open-source SWIFT code): a new construction of SPH, developed to address these issues by directly targeting sources of errors within the equations of standard SPH formalisms. I will present results that demonstrate the improved treatment of mixing both in standard hydrodynamical test cases, and in giant impacts onto Jupiter to investigate whether this is a feasible formation mechanism for the planet's dilute core.

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A New Systematic Giant Impact Database with Strength

3:30pm – 5:15pm, Tuesday & 5pm – 6:30pm, Wednesday

Erik Asphaug[1]*, Alexandre Emsenhuber*[2]*, Saverio Cambioni*[3]*, Travis Gabriel*[4]*, Stephen Schwartz*[5]*, Robert Melikyan*[1]*, Adeene Denton*[1]*, Namya Baijal*[1] *& Aleksandar Antonic*[1]

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[5] University of Alicante, Spain & Planetary Science Institute, Tucson

We present a significant new database of terrestrial planet-forming giant impacts derived from 3D SPH simulations with strength, that meets the following requirements: It is applicable to a wide range of sizes, properties and impact parameters for collisions between differentiated rocky bodies, from major asteroids and rocky satellites, to terrestrial planets up to several Earth-masses. It samples the transitions between collision regimes, such as between graze-and-merge and hit-and-run. It provides outcomes of collisions for bodies with various core mass fractions to predict final core mass fractions. It provides sufficient machine-learning training and validation data to develop advanced surrogate models. We present initial findings including final body properties, velocity of debris, and formation of satellites.

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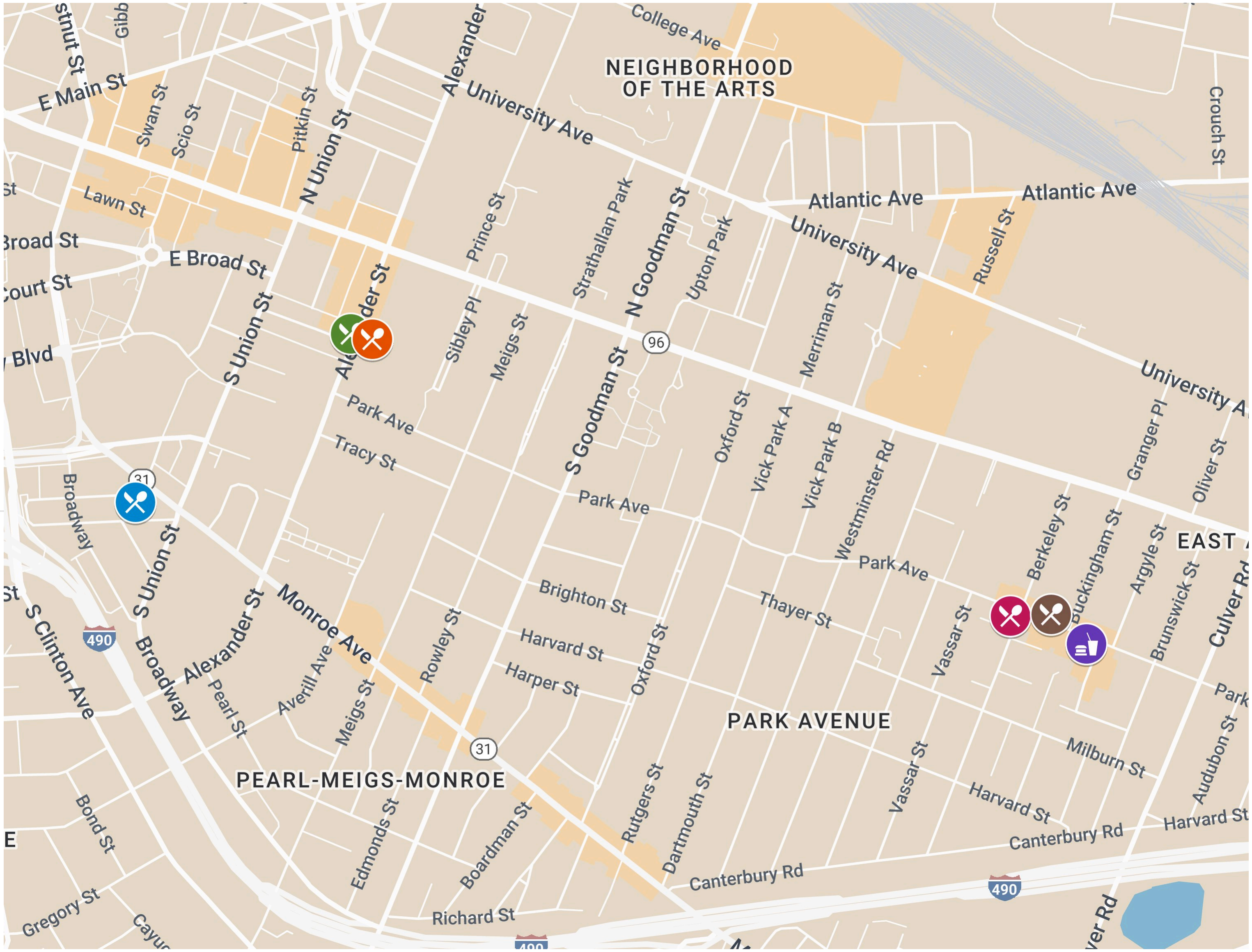
Impact Workshop 2024 - Food Suggestions

Sit-down restaurants

- The Owl House
- Ox and Stone
- Vern's
- Shema Sushi
- Blu Wolf Bistro

Quick Food

- Moe's Southwest Grill
- Taichi Bubble Tea & Ramen
- Chipotle Mexican Grill
- Crave
- Pittsford Dairy - Ice Cream



Our recommendations for nearby food options.

Impact Workshop 2024 - Food Suggestions

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Quick Food

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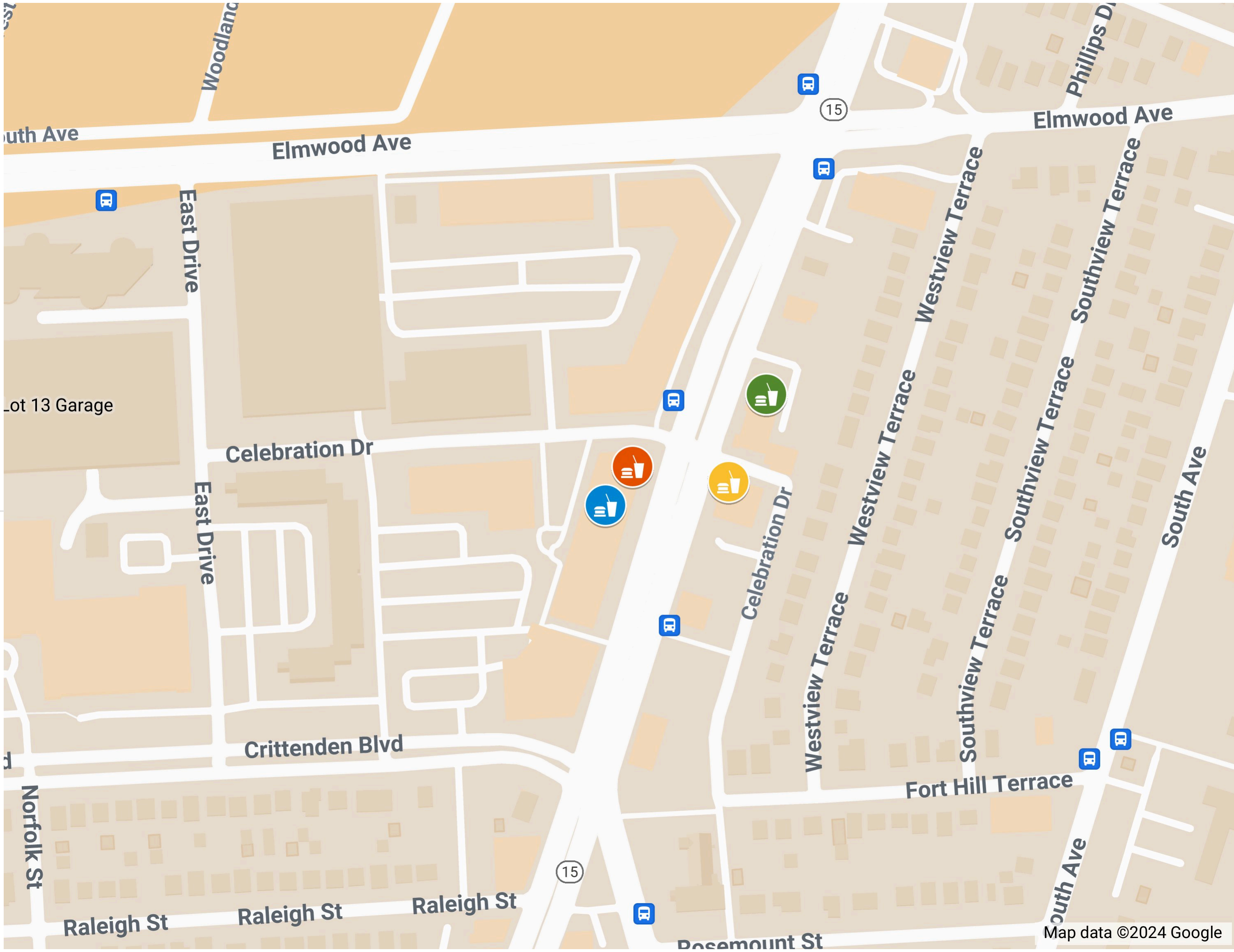

Our recommendations for nearby food options.