MONT
Montana Nanotechnology Facility

An NSF NNCI Node in the Northern Rocky Mountain Region

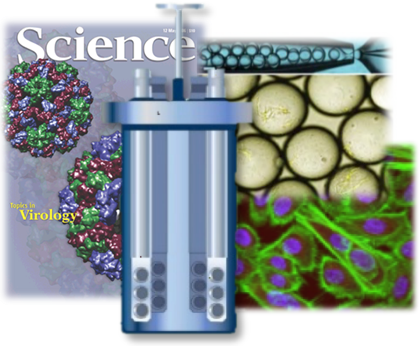
Year 4 Snapshot

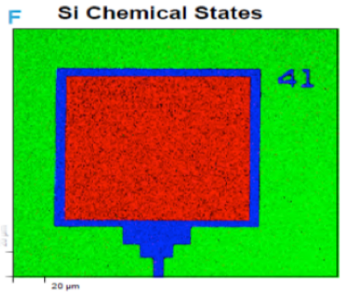
David Dickensheets

NNCI Y4 Annual Conference, Oct.23-25, 2019

nano.montana.edu

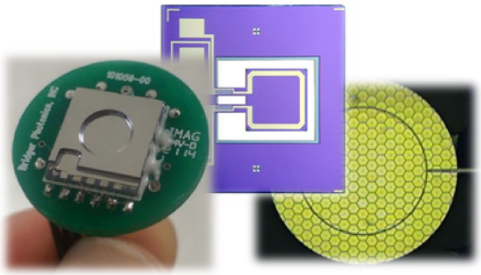
MONT Focus Areas

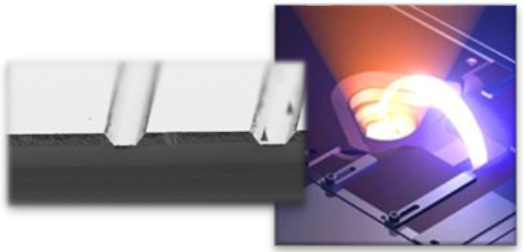




Program Emphases

- **Optical MEMS and Nanosystems** – with local industrial collaborations
- **Biology and Nanotechnology** – Biofilms and Microfluidics, bio-corrosion
- **Novel optical and high temperature materials**
- **2D Quantum Materials**
- **Nanoscale characterization** – SEM, nanoAuger, XPS, XRD, ToF-SIMS, TEM
- **Education and Outreach** emphasizing undergraduate research, K-12 students/teachers, web-based educational materials with **SERC at Carlton College**





National Nanotechnology Coordinated Infrastructure

NSF MONT

Our Team: Some Changes!

David Dickensheets

Recep Avci

ICAL

Phil Stewart

CBE

Mark Young

CBIN / VPR

Sean Fox

Education Specialist

Carleton College Science Education Resource Center

Dave Mogk

Geology / E&O

Carolyn Plumb

Assessment

Phil Himmer

MMF Manager

Manjula Nandasiri

ICAL Manager

Heather Rauser

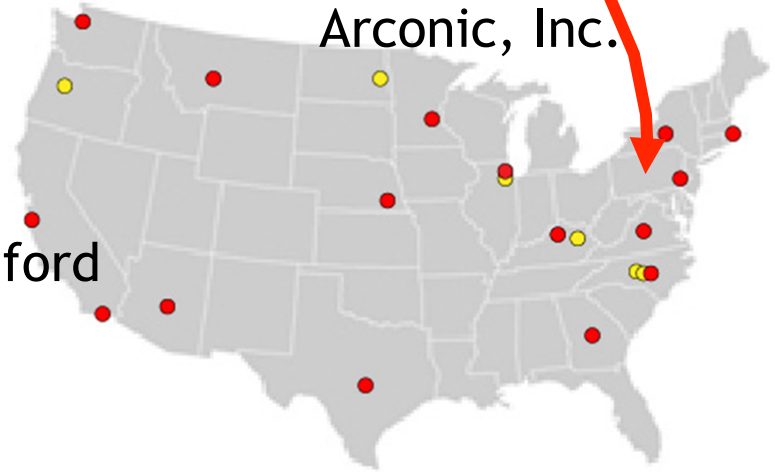
Administrator

MONTANA STATE UNIVERSITY

Mountains and Minds

nano@Stanford

Arconic, Inc.



National Nanotechnology Coordinated Infrastructure

NSF

MC

Our Team: Montana State + Carleton College

David Dickensheets

Recep Avci
ICAL

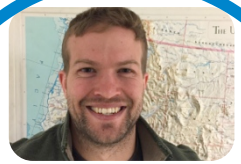
Phil Stewart
CBE

Mark Young
TEM

Sean Fox
Education Specialist
Carleton College
Science Education
Resource Center

Dave Mogk
Geology / E&O

Carolyn Plumb
Assessment



Andrew Lingley
MMF Manager

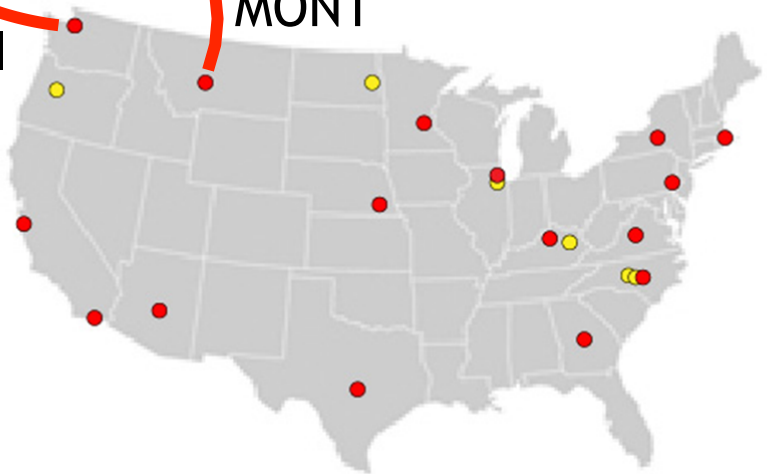
Elif Roehm
ICAL Manager

Heather Rauser
Administrator

MONTANA STATE UNIVERSITY
Mountains and Minds

NNI

MONT



National Nanotechnology Coordinated Infrastructure

NSF

MC

Facility Enhancements in Y4

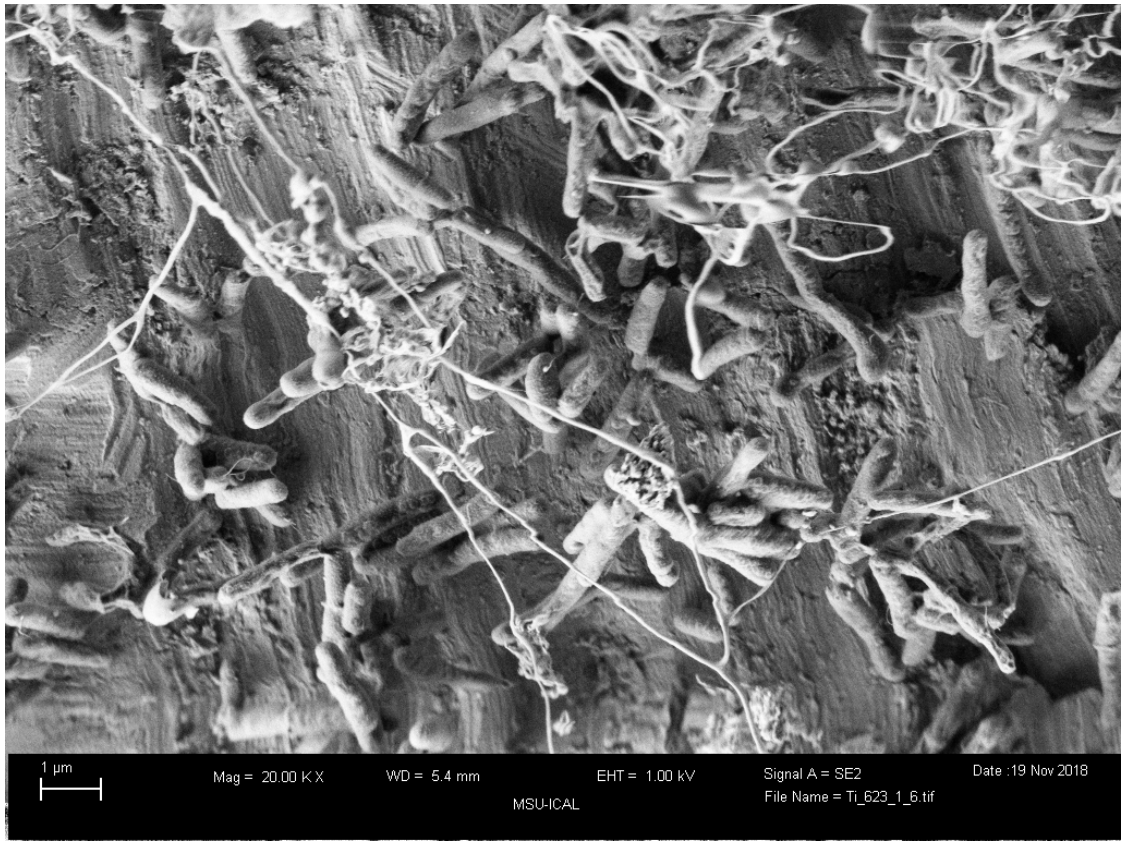
Cryo-FE-SEM (Field Emission Scanning Electron Microscope) image showing the attachment of biofilm formed by a non-tuberculous mycobacterium, *M. chimaera*on on a titanium surface.

We are partnering with **Archana Siddam of the US Food and Drug Administration.**

This image provides information about the morphological structure of this biofilm, including these fine "nanowires" that are important in our understanding of the underlying mechanisms through which these biofilms cause pathogenicity. The samples must be cooled to see image these fine features.

The new cryo-stage has catalyzed our partnership with the FDA on this project.

New cryo-stage on Zeiss FE-SEM



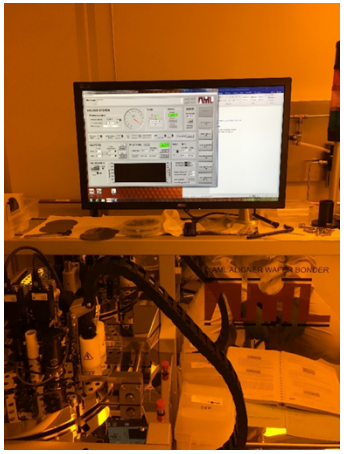
National Nanotechnology Coordinated Infrastructure

NSF

MONT

Facility Enhancements in Y4

- Two confocal Raman microscopes
- AML Wafer Bonder in service
- Expansion of Cobleigh Cleanroom underway – making space for enhanced microfluidics capabilities
- On the horizon: • Co-PI Young received an NSF MRI award for a **200 keV cryo-TEM** (NSF #1828765)



We continue to leverage our NNCI award as match to secure State and Private investment in our facility.

Total investment in new instruments since project inception is

4.8x

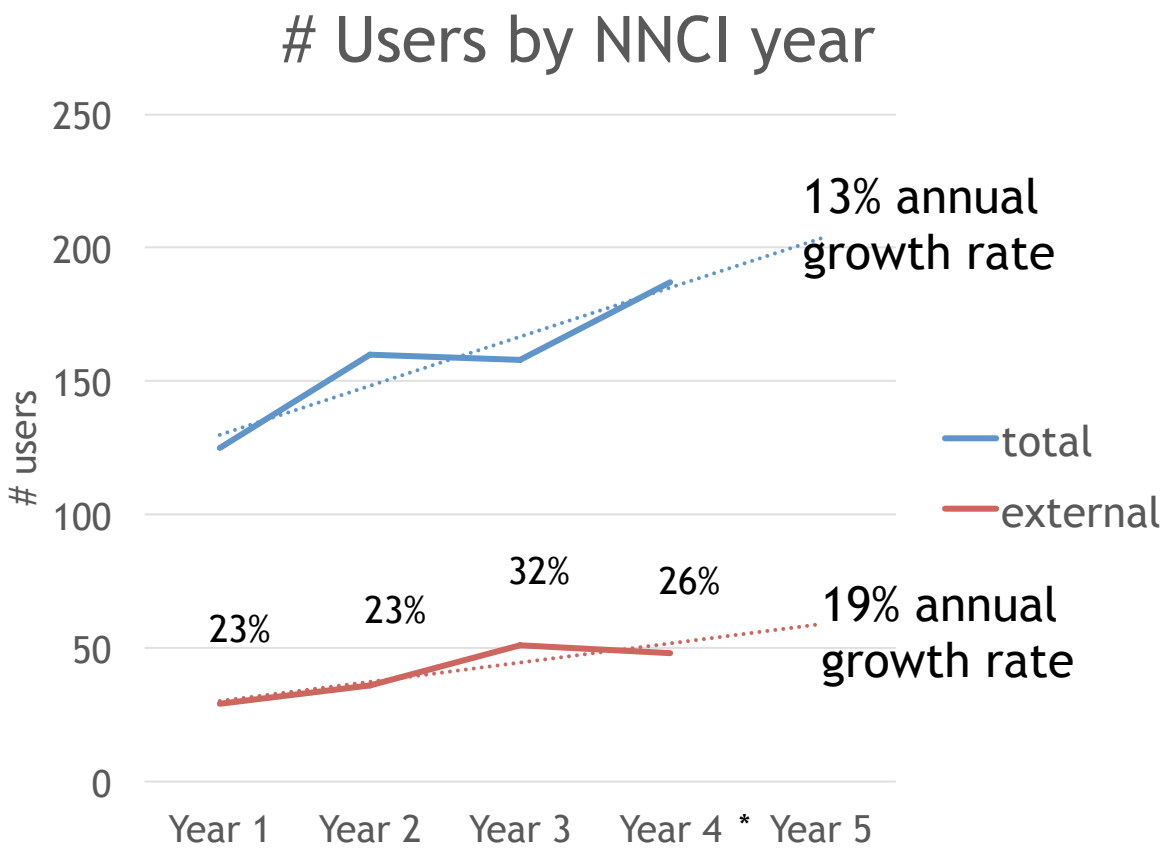
our NNCI capital expenditures.

National Nanotechnology Coordinated Infrastructure

NSF

MONT

User Data: Annual Growth Rates



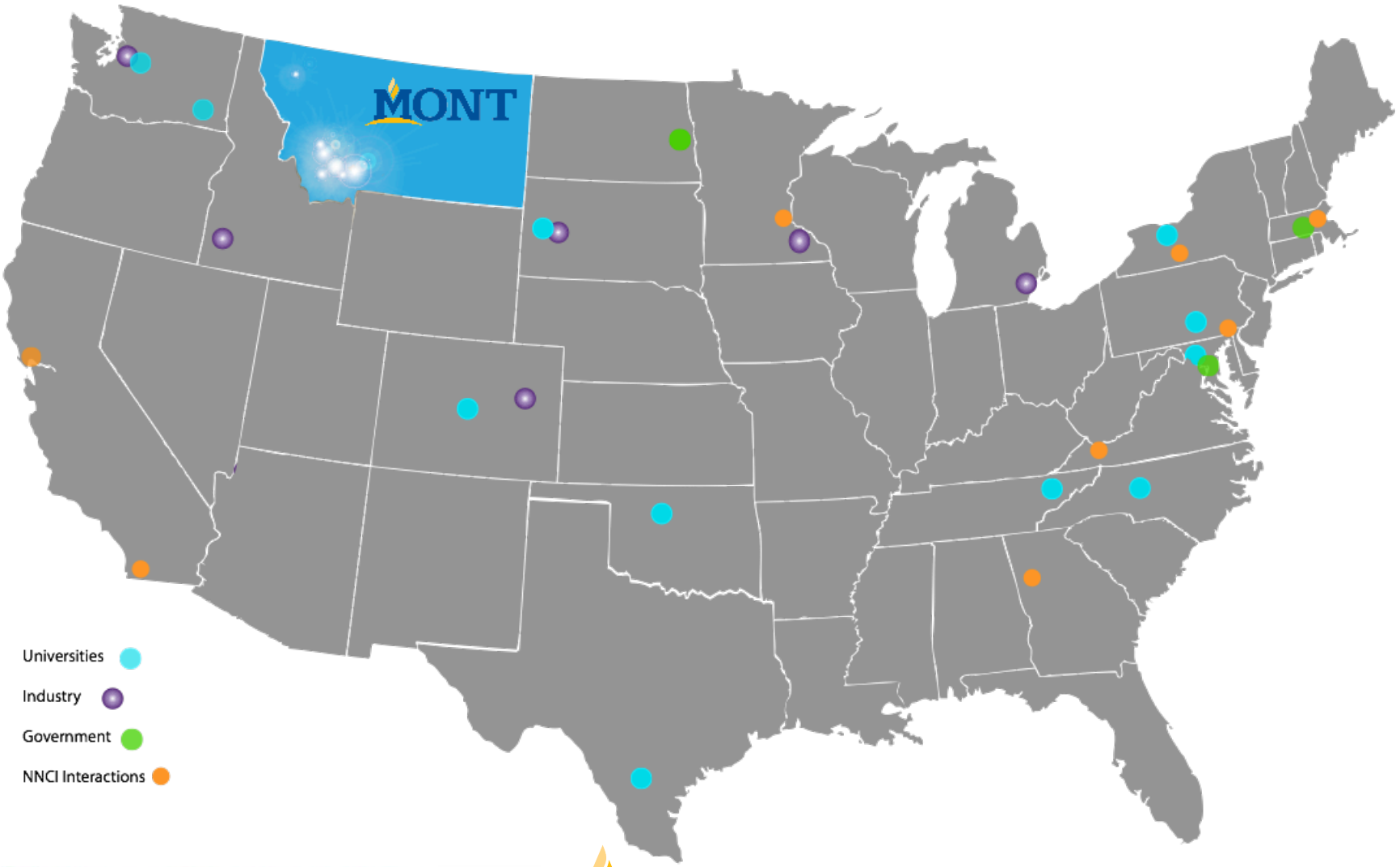
*year 4 data is preliminary

National Nanotechnology Coordinated Infrastructure

NSF

MONT

External Users: Geographic Representation



National Nanotechnology Coordinated Infrastructure

NSF

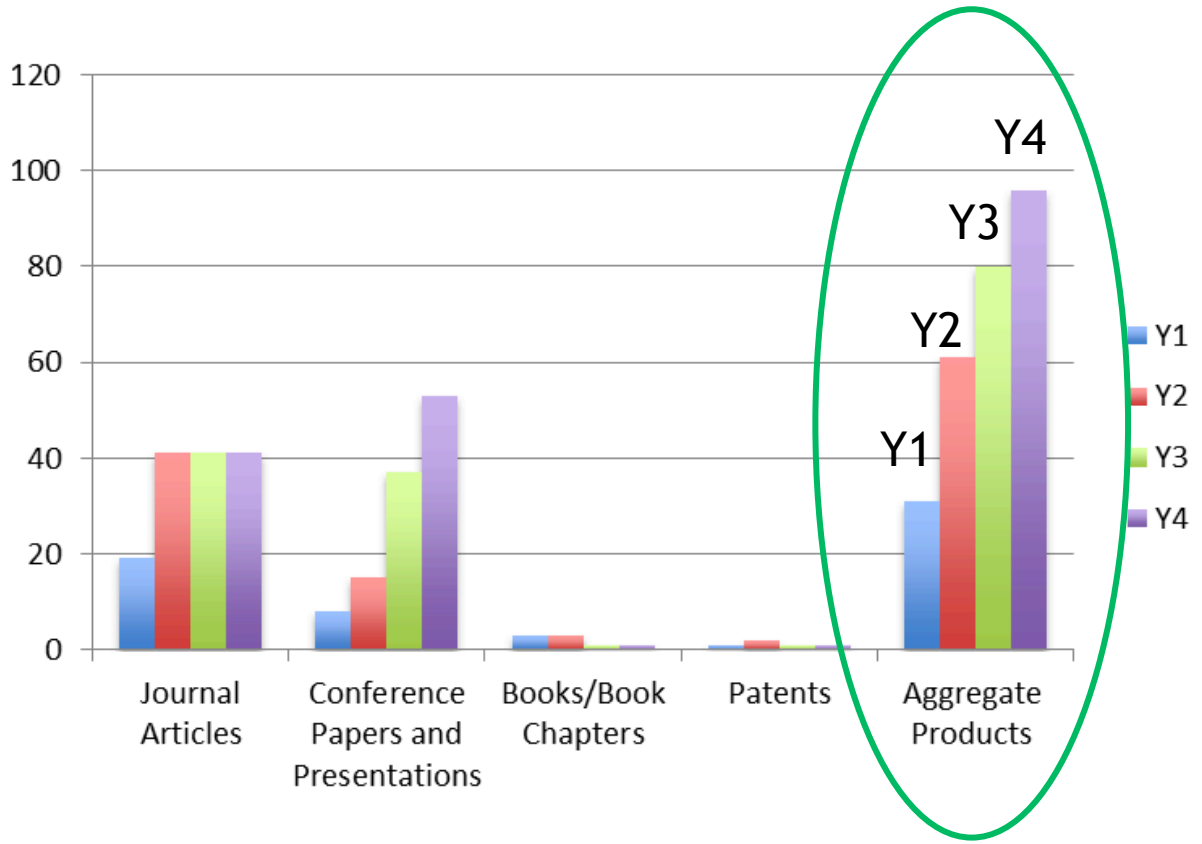
MONT

Publications in 2018

96 Publications total

- 41 Journal Articles
- 53 Conference papers
- 1 book chapters
- 1 patent

Up 20% over 2017



National Nanotechnology Coordinated Infrastructure

NSF

MONT

Publications in 2018

- Hochstein, R., et. Al. *Structural studies of Acidianus tailed spindle virus reveal a structural paradigm used in the assembly of spindle- shaped viruses.* **PNAS** 115:2120-2125, 2018.
- Tianbo Liu et. al., *MEMS 3-D Scan Mirror With SU-8 Membrane and Flexures for High NA Microscopy,* **Journal of Microelectromechanical Systems** Volume: 27 , Issue: 4 , Aug. 2018.
- Hunt KA, et. al. *Multiscale analysis of autotroph-heterotroph interactions in a high-temperature microbial community,* **PLoS Comput Biol**. 2018 Sep 27;14(9)
- Jay ZJ, Beam JP, Dlakić M, Rusch DB, Kozubal MA, Inskeep WP. Marsarchaeota are an aerobic archaeal lineage abundant in geothermal iron oxide microbial mats. **Nature Microbiol**. 2018 3(6): 732-740
- MH Schweitzer, et. al., *Preservation potential of keratin in deep time* **PloS one** 13 (11), e0206569

MONT PI David Mogk co-authored the ***Science*** review article "***Natural, incidental, and engineered nanomaterials and their impacts on the Earth system.***" This invited review grew out of an NSF-sponsored workshop Mogk and lead-author Michael Hochella from NanoEarth hosted in 2018. Dr. Hochella serves on the MONT External Advisory Board.

Modern Earth, from a nanoperspective.

Michael F. Hochella Jr. et al. Science 2019;363:eaau8299

National Nanotechnology Coordinated Infrastructure

NSF

MONT

Soft-gel microchannels to better understand neural disorders

Abnormalities in the folding landscape of the cerebral cortex have been linked to epilepsy, autism, and schizophrenia. Here we grow dissociated primary neurons under confined curvature patterns within soft-gel microchannels to study the impact of curvature on calcium communication. We use the MMF to fabricate a **poly(dimethyl-siloxane) mold to** create hydrogel barriers within a cell culture assay. This project tests growth and transport behavior of degenerative signals in primary cortical neurons.

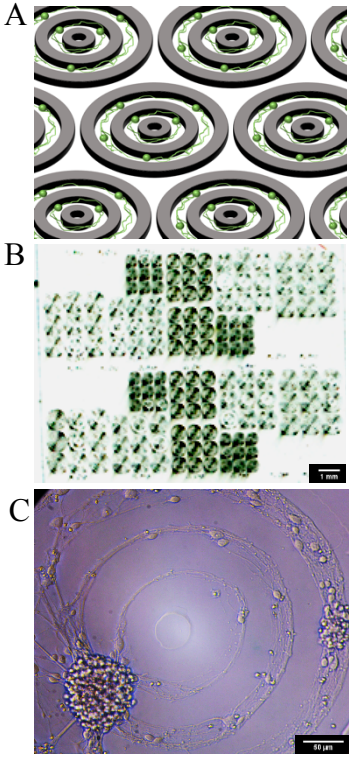


Figure 1. Neuronal cell growth and signaling multi-curvature based soft-gel micro channels. A) Schematic shows the 3D design of the multi-curvature-based cell assay. B) PDMS pattern shows high-throughput array of the cell assay. Scale bar = 1 mm. D) DIC image of neurons grown in multi-curvature channels. Scale bar = 50 µm. E) Calcium signaling in curved neuronal networks, 9 days in vitro. Scale bar = 50 µm.

Hammad Khan, Connor Beck, Anja Kunze, Montana State University
NSF CAREER Award #1846271 (ENG)
Work performed at Montana State University, MONT facility: MMF

National Nanotechnology Coordinated Infrastructure

MONT Impact – CAREER Awards

MSU professor wins prestigious award from National Science Foundation

Marshall Swearingen, MSU News Service
MARCH 15, 2019

Anja Kunze, right, is shown working with undergraduate students in her lab, where small networks of brain cells are gently stretched using precise magnetic force. MSU Photo by Adrian Sanchez-Gonzalez

BOZEMAN — Some electrical engineers design the giant dynamos and transmission lines that power society. Others apply their prowess to electronics in cars and televisions, or — still smaller — the microprocessors in phones and watches.

Montana State University's Anja Kunze, assistant professor in the Department of Electrical and Computer Engineering, studies the tiny electrochemical signals that occur between individual brain cells to produce thought and awareness.

"We are actually very versatile," Kunze said of electrical engineers.

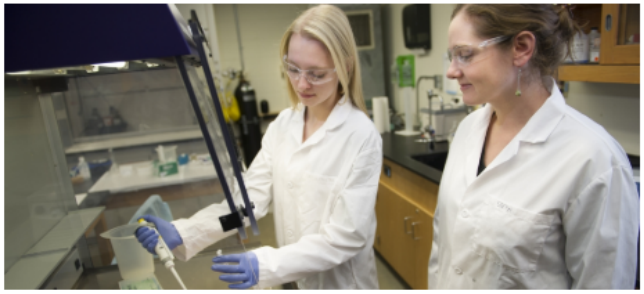
Prof. Kunze received an NSF CAREER award!

Prof. McCalla received an NSF CAREER award!

Congratulations!

MSU professor wins prestigious National Science Foundation award

Marshall Swearingen, MSU News Service
MARCH 21, 2019



Stephanie McCalla, right, in her lab with an MSU student on October 30, 2017. MSU photo by Kelly Gorham

BOZEMAN — One day, a technician in a small, rural hospital may be able to reliably diagnose breast cancer, Alzheimer's disease or traumatic brain injury using a tab of paper that would change color like a pH strip dipped in vinegar.

A small sample of blood or other fluid is all that would be needed to trigger the tool's engineered biochemicals, which would be sensitive enough to detect tiny amounts of protein or DNA associated with illness.

Just as computing was revolutionized with more efficient digital on-off transistors, switch-like biosensors have the potential to transform medical diagnosis and research, according to Montana State University's Stephanie McCalla.

Designing the biosensors remains a complex challenge, but the end goal "is something that's cheap and simple, that could be used in any clinic," said McCalla, assistant professor in the Department of Chemical and Biological Engineering in the Norm Asbjornson College of Engineering.

National Nanotechnology Coordinated Infrastructure

NSF

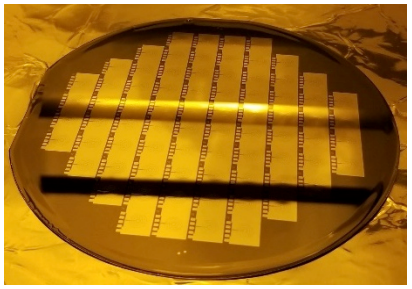
MONT

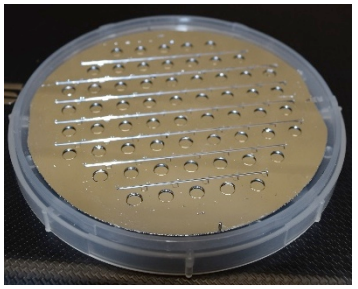
Deformable Membrane Mirror Development

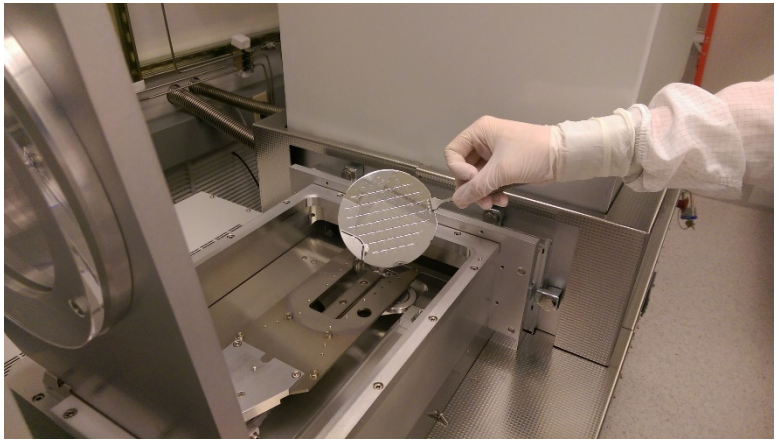
During the past year Revibro Optics has utilized the MMF to develop tunable mirror technology. These efforts have been funded through two grants: a Phase II SBIR from NSF and an MBRCT grant. Our work in the MMF is producing active mirrors with an industry-leading combination of high-speed and long focusing range.

"The MMF has been an invaluable resource for commercializing this technology."

REVIBRO OPTICS







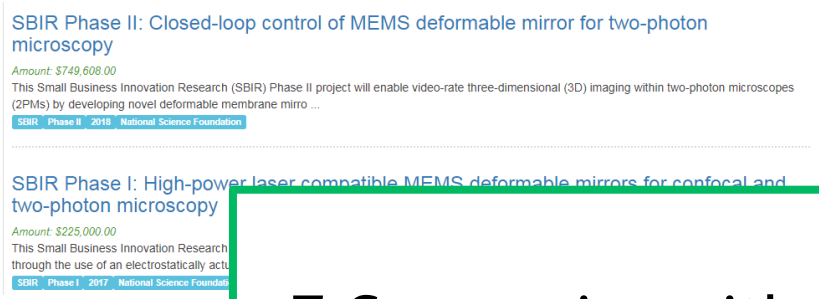
Chris Arrasmith & Scott Gneiting, Revibro Optics LLC
NSF SBIR Phase II #1831287, MBRCT Grant #19-51-037(A)
Work performed at Montana State University, MONT facility **Montana Microfabrication Facility**

National Nanotechnology Coordinated Infrastructure

NSF

MONT

MONT Impact – 10 SBIR Awards, private investment

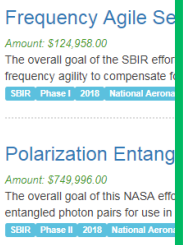


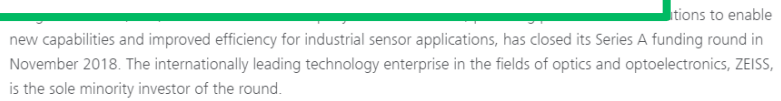
Revibro Optics,
Congratulations on NSF SBIRs!

7 Companies with 10 Active SBIR Awards worth $4.5M

+ private investment
+ corporate revenue…

Economic Impact = ?





Bridger Technologies, Congratulations on your acquisition by Bio-Rad!

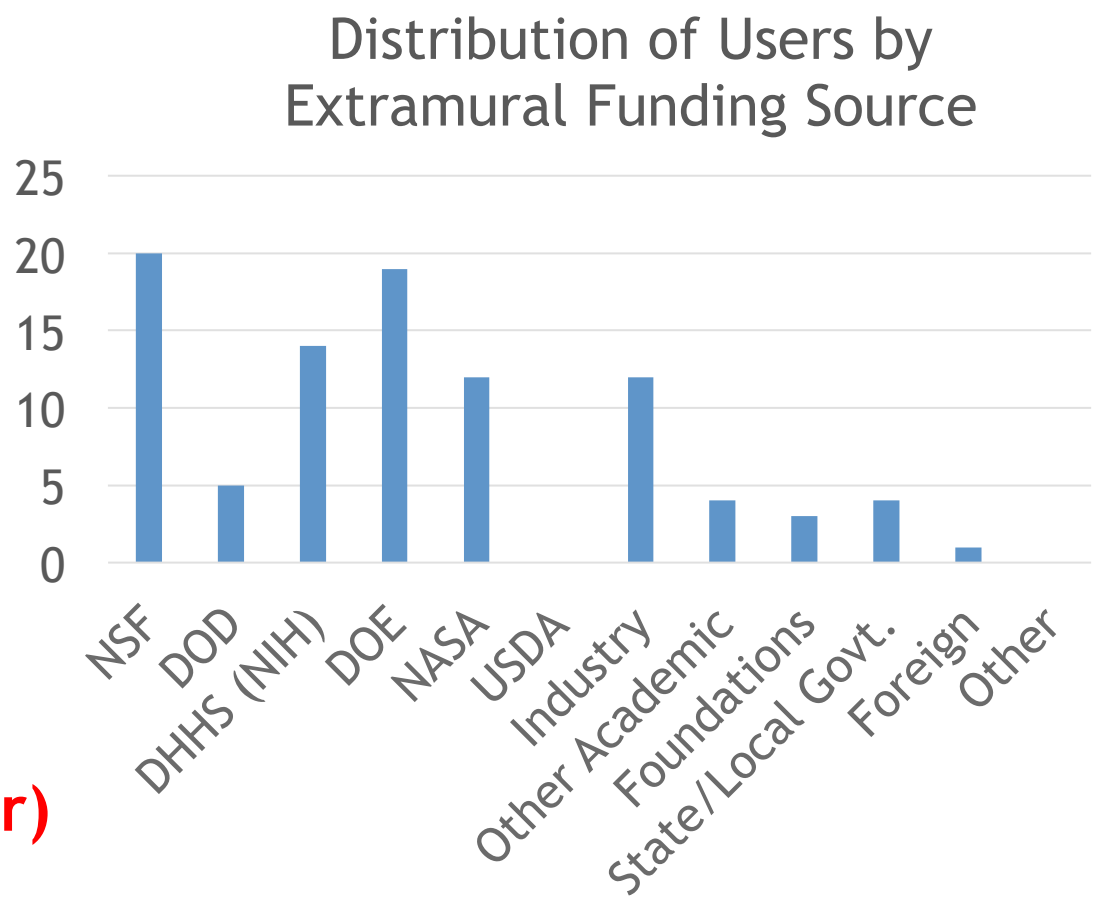
National Nanotechnology Coordinated Infrastructure

NSF MONT

MONT Impact – Montana State Grant Data

94 of 107
on-campus users
supported by
56 "grants"
totaling
>$23M

($23M/107 = $215k / user)



National Nanotechnology Coordinated Infrastructure

NSF

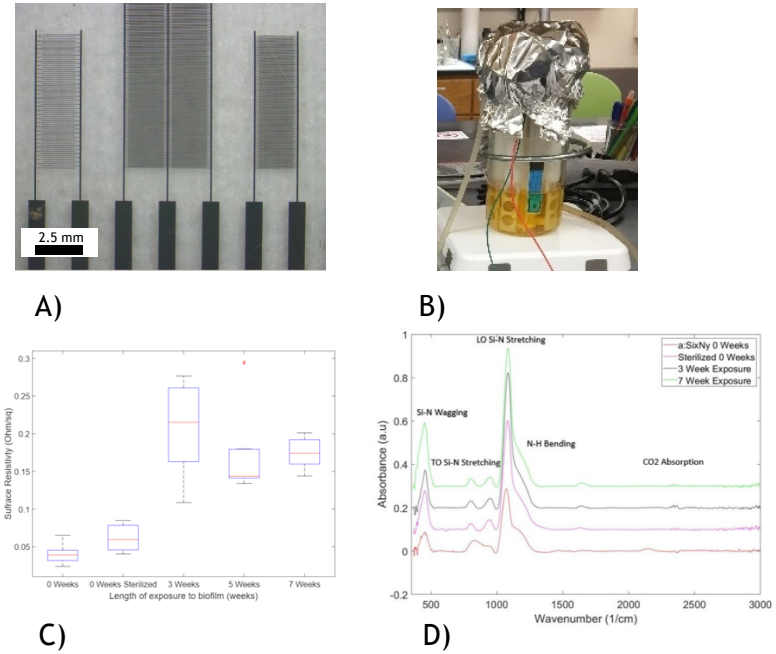
MONT

MONT Impact: 9 Research Initiation Grants in Y4

Effects of Biofilm Growth on Thin Films

Biofilms can inhibit the performance of micro-fabricated water monitoring sensor platforms. A bacterial strain (*Escherichia coli K12*) that forms corrosive biofilms may alter surface and material properties and consequently sensor performance.

An inert interface between the active sensor surface and the aqueous media is required for reliable operation. This study investigates common thin films (Al, poly-Si, Au and a:Si_xN_y-H) regarding material degradation and studies how biofilm growth influences sensor performance such as impedance spectroscopy sensors to study microbial loads in groundwater.



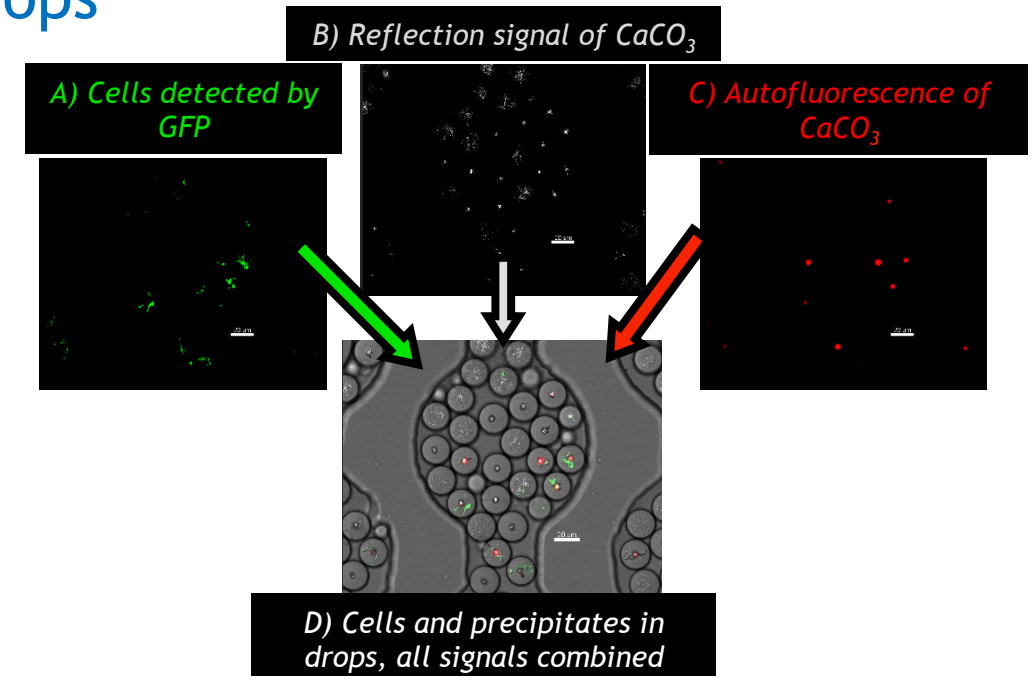
A) **Micro-fabricated Impedance Spectroscopy sensor** used to monitor biofilm growth (feature size: 30 µm). B) Biofilm reactor to control biofilm growth. C) Surface resistivity increase of Al due to prolonged biofilm exposure. D) FTIR of potential inert a:Si_xN_y-H encapsulation layer (no changes in vibration modes after biofilm exposure).

M. McGlennen, S. Warnat. Mechanical & Industrial Engineering. C. Foreman. Chemical & Biological Engineering Montana State University Startup (S. Warnat). Thornton Excellence in Engineering Research (Warnat, Foreman).
Work performed at Montana State University, MONT facility **Montana Microfabrication Facility**

MONT Bringing PIs Together

Mineral precipitation in drops

The inverted confocal scanning laser microscope was used to image droplets containing ureolytic bacterial cells (detected by GFP, figure panel A). The drops also contain dissolved urea and calcium. The ureolytic bacteria hydrolyze the urea, leading to an increase in surrounding alkalinity and pH. This causes the dissolved calcium to precipitate out of solution as calcium carbonate ($CaCO_3$), a process called **Microbially Induced Calcium carbonate Precipitation (MICP).** The precipitates were detected by their strong reflection signal (figure panel B). The $CaCO_3$ crystals that formed in the drops also exhibited autofluorescence (figure panel C). This work allows the visualization of MICP at the single-cell level in real time and *in-situ*.



Multi-channel imaging using the confocal scanning laser microscope allowed for the detection of bacterial cells and microbially induced calcium carbonate precipitation in drops.

Neerja Zambare, Robin Gerlach, and Connie Chang Montana State University
NSF CAREER #1775332 (DMR), and DOE STTR DE-SC0010099
Work performed at Montana State University, MONT facility **Center for Biofilm Engineering**

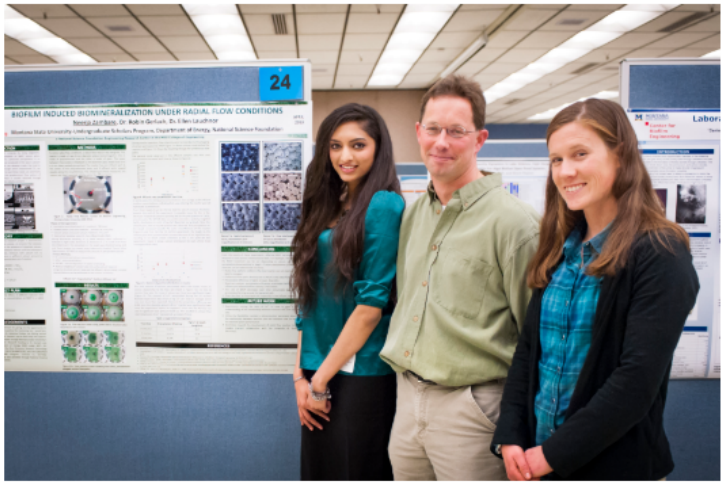
National Nanotechnology Coordinated Infrastructure

MONT: Developing the Workforce

- Neerja Zambare began working in MONT as an undergraduate
- Continued studies on biomineralization with MONT PI Prof. Gerlach
- Will complete Ph.D. in 2019
- Neerja was a featured speaker at the MONT Users' Meeting in May, 2019.

MSU student's research on bio-cement selected as one of the top posters in U.S.

By Carol Schmidt, MSU News Service
APRIL 25, 2013



The innovative research of a Montana State University student who traveled half way around the globe to study engineering at MSU has taken her just a bit farther.

Neerja Zambare, a senior from Pune, India, majoring in both chemical engineering and biological engineering, was selected as one of the country's undergraduate researchers for her poster about a bio-cement that effectively plugs cracks near wells and drilling sites.

Zambare exhibited her research poster, "Biofilm induced biomineralization in a radial flow reactor," at the Council on Undergraduate Research's Posters on the Hill Exhibition April 23-24 in Washington, one of the country's most prestigious undergraduate research fairs. Zambare was accompanied by Robin Gerlach, MSU professor of chemical and biological engineering and Zambare's research mentor.

National Nanotechnology Coordinated Infrastructure

NSF

MONT

Impacts summary

MONT sees its impact through:

- **User's research accomplishments**: increasing publications, prestigious grant awards (CAREER, SBIR, etc.)
- **Economic impact**: new businesses who now rely on MONT, successful commercialization of technology
- Increased **cross-disciplinary research** – nano is going places, like food science!
- **Catalysis of new research thrusts**: New Ph.D. in Materials Science (NSF supported), Q-AMASE-I 2D Quantum Materials Foundry (NSF proposal), New ARL research facility
- **Education and workforce development**: 70-100 users are students; coursework brings 80-100 students into the facilities each year

NNCI amplifies MONT's impact through:

- Lets us **focus on external users** while improving service for all users
- Network of services and expertise – **our users have access to all of NNCI**!
- **Improvement of local capabilities**: >$2M in new instrumentation so far

National Nanotechnology Coordinated Infrastructure

NSF

MONT

Education & Outreach Activities

MSU Family Science Day is MONT's largest outreach event. The event features research in nanotechnology and other small-scale science and engineering projects from MSU faculty and students.

MONT also hosts:

- a photovoltaics summer course for K-12 teachers,
- technical webinars, workshops and seminars.

Our collection of on-line tutorials with partner SERC (at Carleton College), reached 1249 unique visitors.

Green boxes show activities which were evaluated.

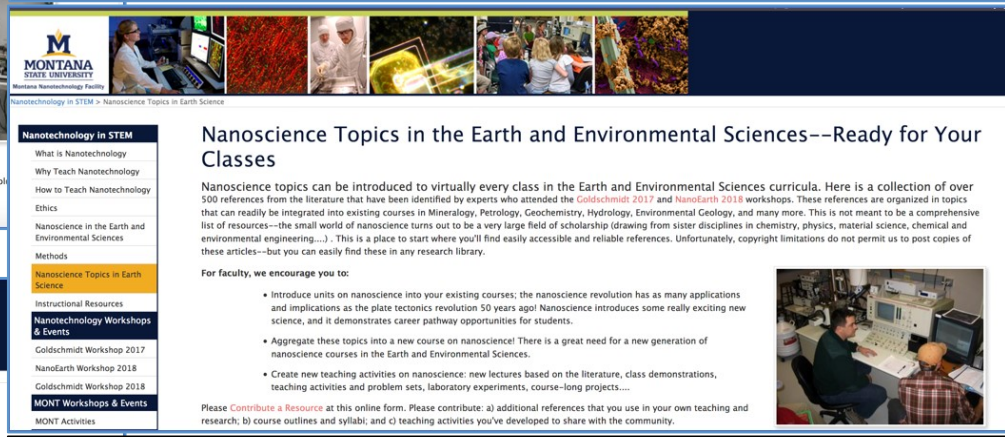
MONT 2018 Education & Outreach Events		
MSU-Location of MONT	# Participants	Percentage
Family Science Day	601	30%
REU and Convocation	3	<1%
Teacher Courses (MSSE)	9	<1%
Technical Events	205	8%
Online tutorials (with Carleton College)	1249* *unique visitors	59%
Students in courses	80	4%
Total MONT	2147	

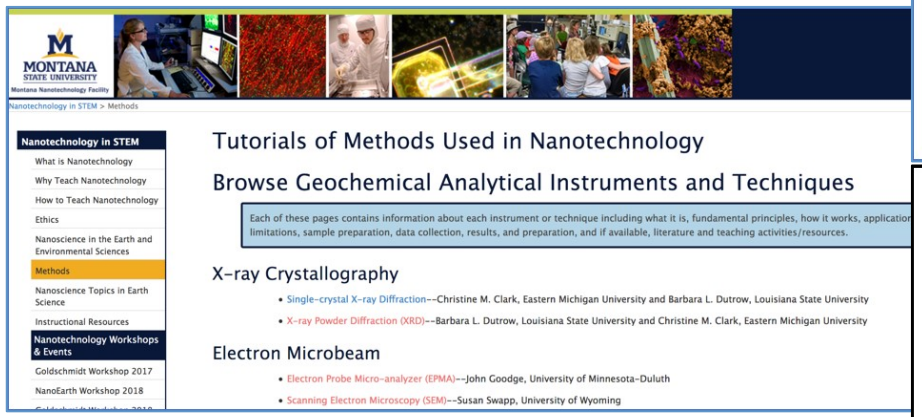
National Nanotechnology Coordinated Infrastructure

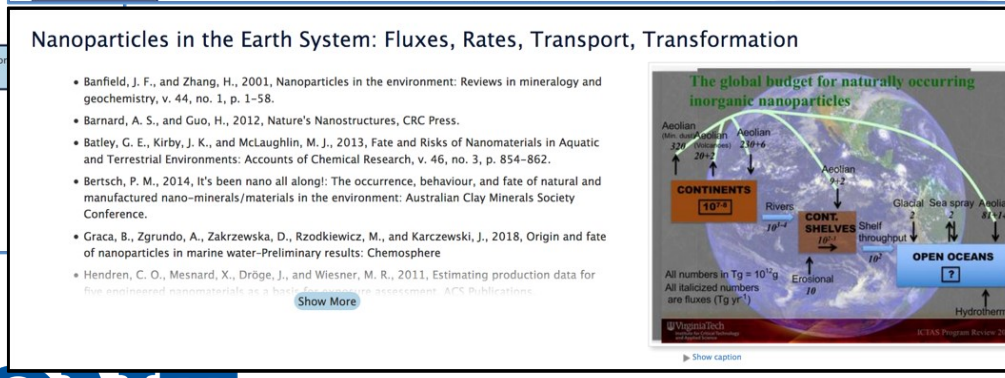
NSF

MONT

Screen shots of Web Modules at SERC







National Nanotechnology Coordinated Infrastructure

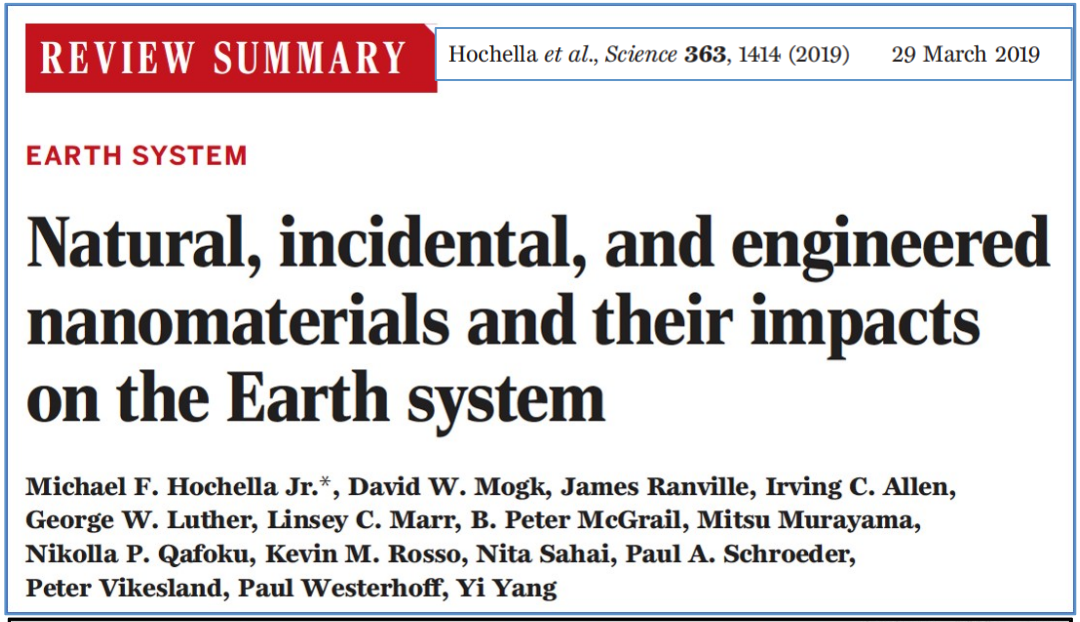
NSF

MONT

A Teaching "Primer" on Nanoscience for Earth Scientists

Hosted at Carleton College Science Education Resource Center (SERC)

- Review article in Science to reintroduce nanoscience to Earth scientists
- Companion website developed to demonstrate "what", "why" and "how" to teach nanoscience, includes
  - Analytical methods, Ethics
  - >500 vetted references on Nanoscience topics in E. Sci., ready to introduce into existing courses
- Webinar to National Association of Geoscience Teachers (NAGT)
- Participant survey and focus group usability study of website use in progress with SERC Assessment Team



REVIEW SUMMARY | Hochella *et al.*, *Science* **363**, 1414 (2019) | 29 March 2019

EARTH SYSTEM

Natural, incidental, and engineered nanomaterials and their impacts on the Earth system

Michael F. Hochella Jr.*, David W. Mogk, James Ranville, Irving C. Allen, George W. Luther, Linsey C. Marr, B. Peter McGrail, Mitsu Murayama, Nikolla P. Qafoku, Kevin M. Rosso, Nita Sahai, Paul A. Schroeder, Peter Vikesland, Paul Westerhoff, Yi Yang

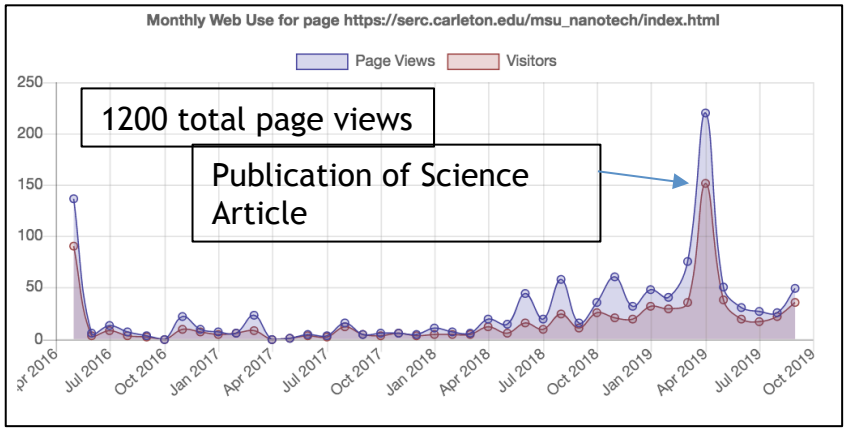
National Nanotechnology Coordinated Infrastructure

NSF

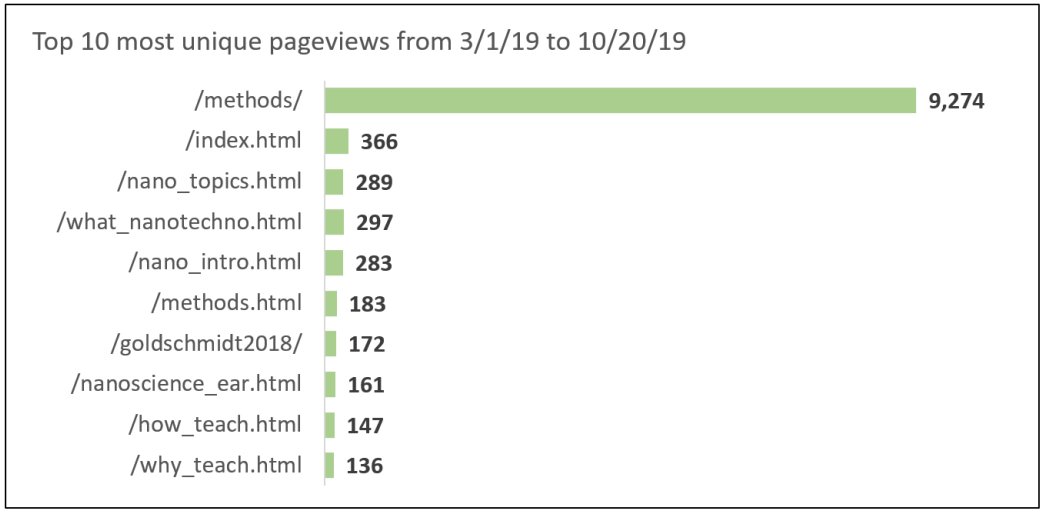
MONT

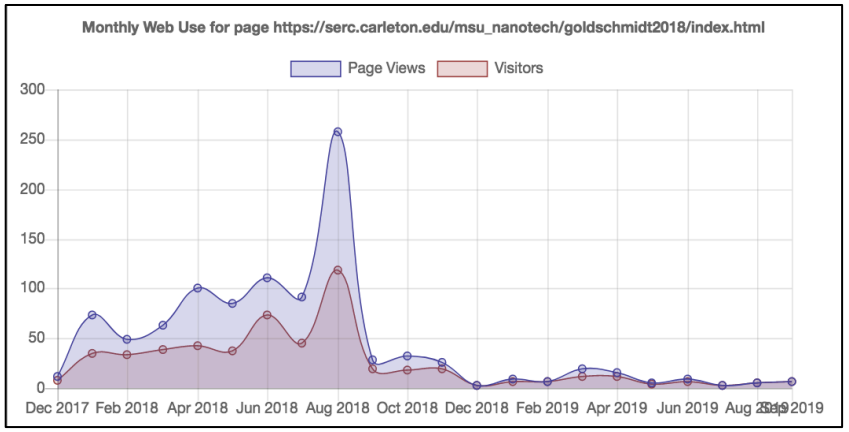
Google Analytics for Teaching Nanoscience Webpages

- Website in development, 2016-present
- Formally launched with publication of Science review article, April 2019
- Advertised on numerous Earth and Environmental Science listservs (Mineralogical Society of America
- Presentation at 2019 Earth Educators' Rendezvous (National Association of Geoscience Teachers)
- User Pop-Up Survey is in progress
- Usability study with focus user groups is in progress



Metrics for Index page of the Teaching Nanoscience web module





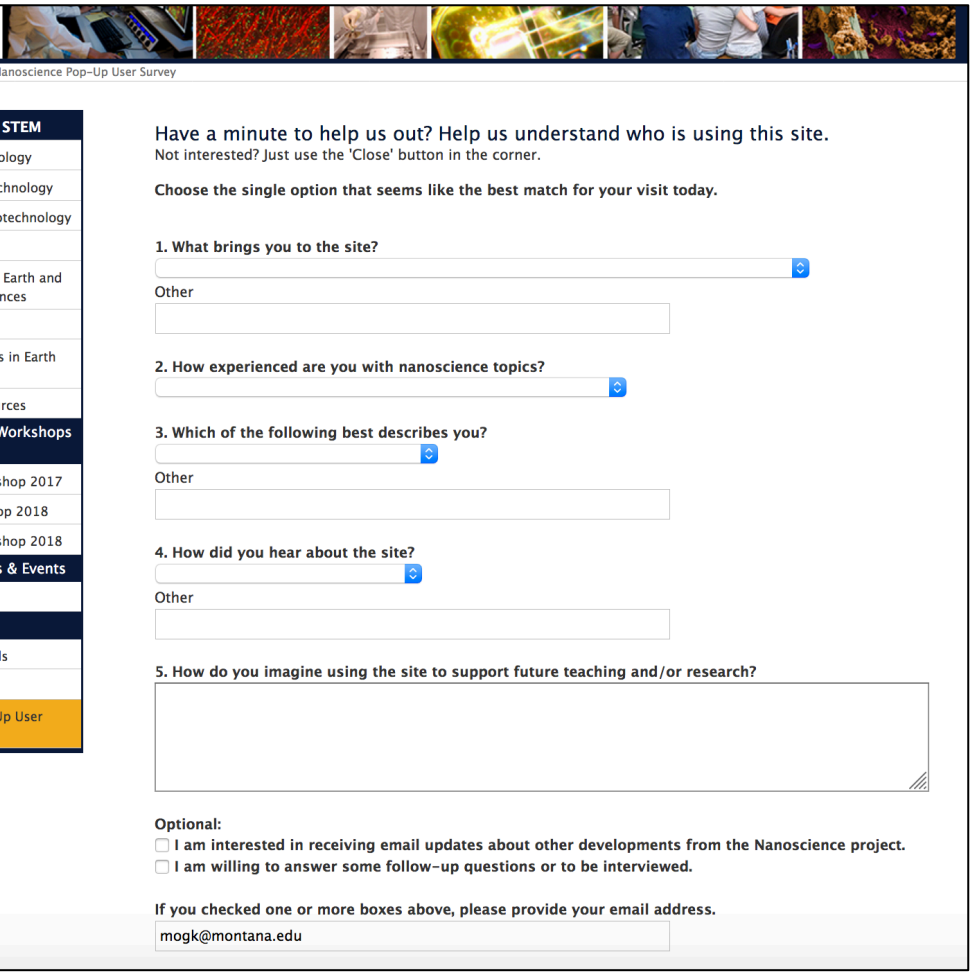
Metrics for webpages supporting 2018 Goldschmidt Workshop

National Nanotechnology Coordinated Infrastructure

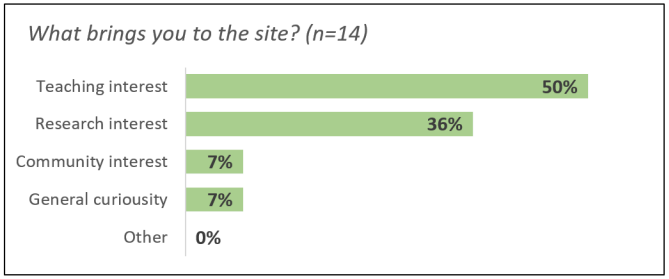
NSF

MONT

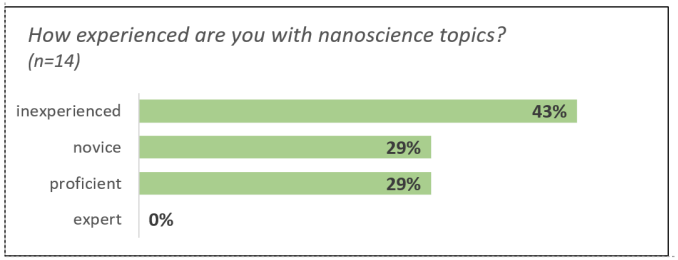
Pop-up Assessment for Teaching Nanoscience Webpages



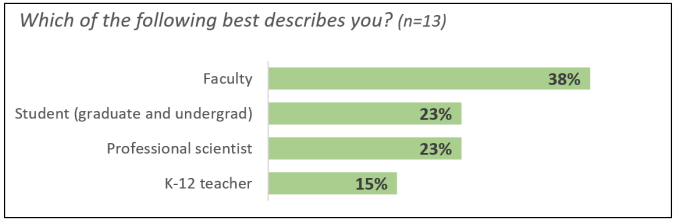
Audience



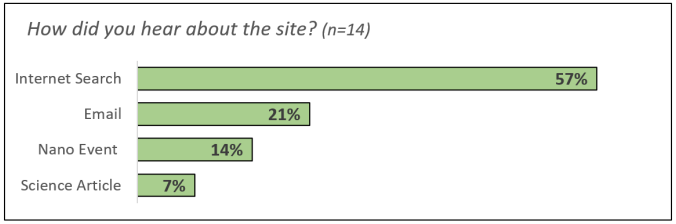
Nanoscience Experience



Professional Status



Connections



National Nanotechnology Coordinated Infrastructure

NSF

MONT

NNCI Cooperative Network Activities

Network-Wide

- Participation in subcommittees (New Equipment and Research, Entrepreneurship, Assessment and Evaluation) and working groups (Microscopy, SEI and Education), resulting in shared reports and best practices
- Attendance at REU convocation and NNCI annual conference
- Participation in Nano Day activities

Multi-Site

- Staffing across the network:
  - Dr. Phil Himmer joined **nano@Stanford**
  - Dr. Andrew Lingley joined **MONT** from **NNI**
- User project support and staff technical interactions with **SDNI**, **MINIC**, **nano@Stanford** and **CNS**
- Working with **SENIC**, leveraging their expertise and investment in facility management software

Georgia Tech Shared User Management System

- Workshop organization and co-authored Science paper with **NanoEarth**
- Hosted Karl F. Böhringer of **NNI** / UW for seminar

On Behalf of the Network

- Planning for visit to DC to meet with congressional staff – Summer or Fall 2019

National Nanotechnology Coordinated Infrastructure

NSF

MONT

Highlights from MONT/NNCI in first 4 years

- Continue to show significant facility enhancement; excellent leveraging of NSF funds to grow State/Private investment in facility
- Continue to see growth in number of users; good gender and academic diversity
- Strong Regional Workforce Development, with ~100 students using facilities, another ~100 taking courses that rely on access to MONT
- Strong Education & Outreach portfolio, locally and on the web in partnership with Carleton College's SERC; Partnership with NanoEarth is elevating "nano" awareness in Geosciences
- Growing impact relative to on-campus research: new directions, increased productivity, high-impact funding (multiple CAREER awards)
- Growing impact for external researchers and the economy in the northern Rocky Mountain Region: new companies and jobs, new Federal funding (10 active SBIR Phase I and Phase II awards), new private funding; MONT companies are finding success

National Nanotechnology Coordinated Infrastructure

NSF

MONT