CMEDE
CENTER FOR
MATERIALS IN EXTREME
DYNAMIC ENVIRONMENTS

MEDE
CRA
CAPSTONE
2022

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INTRODUCTION

On behalf of the Materials in Extreme Dynamic Environments Collaborative Research Alliance (MEDE CRA), we would like to welcome you to the capstone event.

Awarded in April of 2012, the MEDE CRA is a ten-year, basic research program which has developed a materials by design process which has improved protection materials for armor applications. Commensurate with the recommendations of two National Research Council boards, only a program of this scale could integrate experimental, computational, testing, characterization, and processing research activities into a single program. Research activities were performed jointly amongst academia, the DEVCOM Army Research Laboratory (ARL), and industry.

The impact of the MEDE CRA has been significant. This booklet includes the major technical, workforce development, and collaborative highlights. We are proud of the over 600 individuals who have been involved in the MEDE CRA. This program has developed the next generation of materials-by-design workforce who are already making a difference. Despite the challenges presented by COVID-19, everyone found a way to accomplish the research. We are truly amazed at the resiliency of MEDE CRA.

The information presented during today's event is the result of ten years of dedicated faculty, postdoctoral fellows, students, and staff working in close collaboration with DEVCOM ARL researchers. We are proud to say that the accomplishments made by the MEDE program will save soldiers' lives.

Sincerely,

Prof. Lori Graham-Brady
Recipient Program Manager
MEDE CRA

Dr. Sikhanda Satapathy
Collaborative Alliance Manager
MEDE CRA

A BRIEF HISTORY

In 2010, two National Research Council boards established a committee to examine opportunities in protection materials science and technology for future Army applications. This committee recommended that the Department of Defense establish an initiative for protection materials by design. This initiative would include a combination of computational, experimental, and materials testing, characterization, and processing research to be conducted by academia, government, and industry.

In response to the committee's recommendation, in April 2012 the U.S. Army Combat Capabilities Development Command Army Research Laboratory (DEVCOM ARL) established a framework to integrate the Army's multiscale basic research in materials into one coordinated enterprise. Called the Enterprise for Multiscale Research of Materials (EMRM), the focus of the program is to develop a materials-by-design capability for the U.S. Army using validated multiscale and multidisciplinary modeling capabilities to predict material structure, properties, and performance.

The EMRM enables DEVCOM ARL to coordinate its in-house activities with extramural research efforts. The EMRM is organized into four major areas: protection materials, energetic materials, electronic materials, and cross-cutting computational science.

"THIS IS SOME INCREDIBLE WORK THAT WAS DONE. IT'S CUTTING-EDGE TECHNOLOGY AS FAR WHAT IT'S DONE FOR BODY ARMOR."

—GENERAL JAMES C. MCCONVILLE

40th Chief of Staff of the U.S. Army

To launch the protection materials research component of EMRM, DEVCOM ARL competitively awarded and then signed the Materials in Extreme Dynamic Environments cooperative research agreement with Johns Hopkins University (JHU), the California Institute of Technology (Caltech), the University of Delaware (Delaware) and Rutgers University. The agreement allowed JHU, which is the lead research organization within the consortium of university and research partners, to establish the Center for Materials in Extreme Dynamic Environments, or CMEDE. CMEDE is a center within the Hopkins Extreme Materials Institute, and focuses on advancing the fundamental understanding of materials in high-stress and high-strain-rate regimes, with the goal of developing a materials-by-design capability for these extreme environments. This 10-year agreement represents a significant investment and demonstrates the importance of the design of protection materials to the U.S. Army.

The MEDE program also supports the Presidential Materials Genome Initiative (MGI) for Global Competitiveness. Established in June 2011, MGI aims to double the speed at which materials are discovered, developed, and deployed. The MEDE program represents one of the largest investments in extramural basic research in support of the MGI.

KEY PERSONNEL

CONSORTIUM MANAGEMENT COMMITTEE

LORI GRAHAM-BRADY

Professor, Civil and Systems Engineering, Johns Hopkins University

Director, CMEDE

Associate Director, Hopkins Extreme Materials Institute (HEMI)

KAUSHIK BHATTACHARYA

Howell N. Tyson, Sr., Professor of Mechanics and Materials Science

Professor, Materials Science, California Institute of Technology

JOHN W. GILLESPIE, JR.

Donald C. Phillips Professor of Civil and Environmental Engineering

Professor, Mechanical Engineering, Materials Science and Engineering, University of Delaware

RICHARD HABER

Professor, Materials Science and Engineering, Rutgers University

ASSOCIATE DIRECTOR

K.T. RAMESH

Alonzo G. Decker Jr. Professor of Science and Engineering

Professor, Departments of Mechanical Engineering, Earth and Planetary Sciences, Materials Science and Engineering, Johns Hopkins University

Director, Hopkins Extreme Materials Institute

Former Director, CMEDE (2012–2020)

COLLABORATIVE ALLIANCE MANAGERS

SCOTT SCHOENFELD

Technical Lead, EMRM, Senior Research Scientist (ST) for Terminal Ballistics, DEVCOM ARL

SIKHANDA SATAPATHY

Collaborative Alliance Manager, MEDE CRA, DEVCOM ARL

2021 COLLABORATIVE MATERIALS RESEARCH GROUP CO-LEADS

TODD HUFNAGEL

Consortium Lead, Metals CMRG

RICHARD HABER

Consortium Lead, Ceramics CMRG

JOHN W. GILLESPIE, JR.

Consortium Lead, Composites CMRG

JEFFREY LLOYD

DEVCOM ARL Lead, Metals CMRG

JERRY LASALVIA

DEVCOM ARL Lead, Ceramics CMRG

DANIEL J. O'BRIEN

DEVCOM ARL Lead, Composites CMRG

MEDE SCIENCE ADVISORY BOARD MEMBERS

DR. DOUGLAS TEMPLETON
Chair

DR. CHARLES E. ANDERSON, JR.*

PROF. IRENE BEYERLEIN

PROF. RODNEY CLIFTON

PROF. HORACIO ESPINOSA*

PROF. DAVID MCDOWELL*

PROF. STEVE MCKNIGHT*

PROF. MARC MEYERS*

PROF. ANTHONY ROLLETT*

PROF. THOMAS RUSSELL*

DR. DONALD SHOCKEY

PROF SUSAN SINNOTT*

PROF NANCY SOTTOS*

* *Current Member*

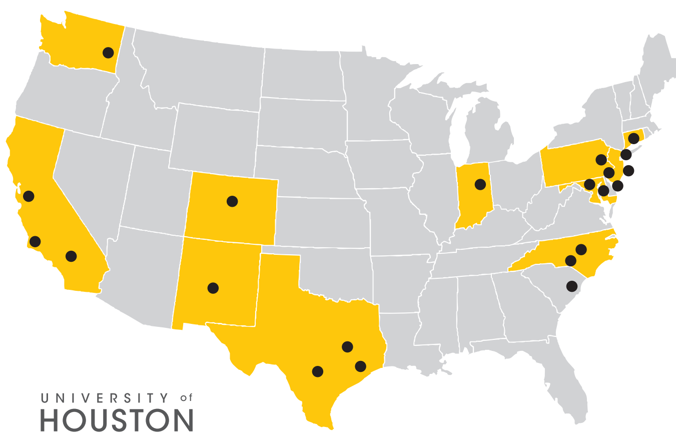
STRUCTURE & RESEARCH STRATEGY

ORGANIZATION

The MEDE Collaborative Research Alliance is composed of a consortium of university and research partners and the DEVCOM Army Research Laboratory. The MEDE consortium members include:

- Johns Hopkins University (Lead)
- California Institute of Technology
- CoorsTek
- Defence Science and Technology Laboratory (United Kingdom)
- Drexel University
- Ernst Mach Institut (Germany)
- ETH Zürich (Switzerland)
- Lawrence Livermore National Laboratory
- Lehigh University
- Morgan State University
- New Mexico Institute for Mining and Technology
- North Carolina Agricultural and Technical State University
- Northwestern University
- Purdue University
- Rutgers University
- Southwest Research Institute
- Texas A&M University
- University of California Berkeley
- University of California Santa Barbara
- University of Delaware
- University of Houston
- University of North Carolina at Charlotte
- University of Texas at San Antonio
- Washington State University

The MEDE CRA is composed of a consortium of university and research partners and the DEVCOM Army Research Laboratory.



United Kingdom

Germany

Switzerland

ORGANIZATIONAL STRUCTURE

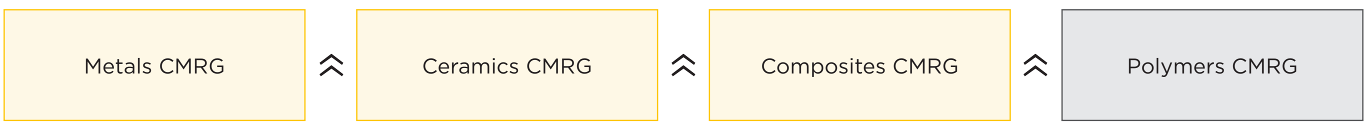
The CMEDE Director is located within CMEDE at Johns Hopkins University, the lead research organization for the MEDE CRA.

The MEDE Science Advisory Board complements DEVCOM ARL's Technical Advisory Board. It provides important scientific insight, oversight, and expertise to the CMEDE consortium. The Board reports to the CMEDE Director.

The Consortium Management Committee (CMC) is composed of a senior representative from the four major consortium partners and the DEVCOM ARL Collaborative Alliance Manager. The CMC is the final decision authority for the MEDE CRA.

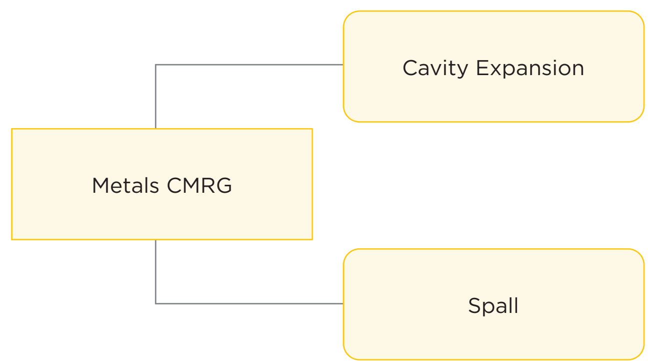
A Collaborative Materials Research Group (CMRG) coordinates all research activities for each material type. Each CMRG is co-led by a consortium principal investigator and a DEVCOM ARL researcher.

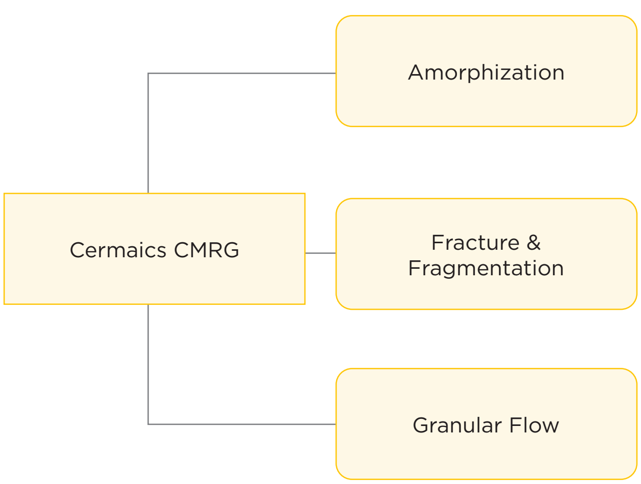
Within each CMRG, there are multiple technical areas, separated by scale or mechanism. The CMRGs are highly integrated with a consortium PI and a DEVCOM ARL researcher co-leading each major effort.

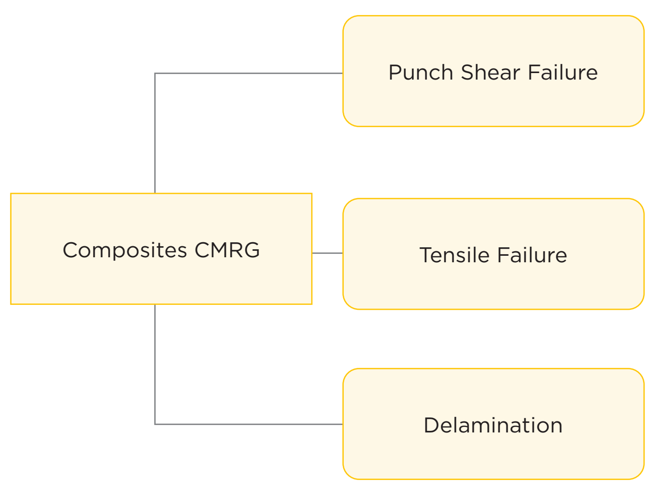


(closed out from program in 2017)

- Research in each material system is managed by a Collaborative Materials Research Group (CMRG).
- CMRGs consist of faculty, ARL scientists, students and postdocs.
- Each CMRG has a Consortium lead and an ARL co-lead.
- Research strategy within each CMRG incorporates both intramural and extramural research, organized around key mechanisms
- Capabilities, tools and expertise flow into each CMRG from across the enterprise.
- Each CMRG studies a model material (ceramics—BC, composites—glass/epoxy, metals—Mg alloys)



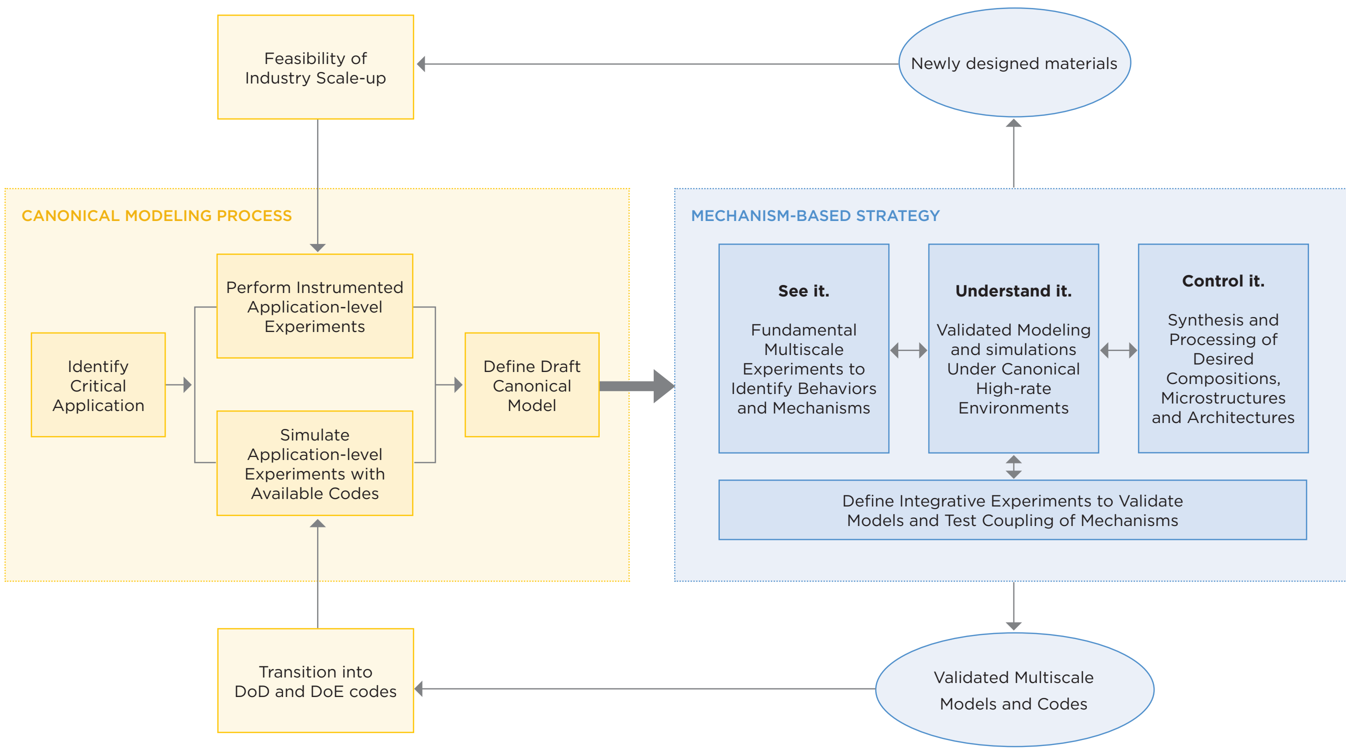




RESEARCH STRATEGY

To achieve the MEDE program objectives, research activities are focused on a materials-by-design process involving a canonical model and a mechanism-based strategy as shown in the below figure. We have established a canonical model for each model material under investigation. A canonical model is defined as: "A simplified description of the system or process, accepted as being accurate and authoritative, and developed to assist calculations and predictions." Typically such a canonical model defines key variables and their ranges, defines critical mechanisms, and then prioritizes the variables and mechanisms. Beginning with a canonical model allows a large group of researchers to ensure that efforts are relevant in terms of both science and application.

Once the canonical description is established, researchers can then proceed with the mechanism-based strategy. Researchers seek to see the mechanisms during the extreme dynamic event, to understand them through multiscale models, and to control them through synthesis and processing. Understanding the mechanisms through multiscale models provides the capability to define integrative experiments and to test the coupling of mechanisms. This information leads to validated models and codes, which feed back into the canonical model, by transitioning into Department of Defense (DoD) and Department of Energy (DoE) codes. Similarly, controlling the mechanism through synthesis and processing leads to newly designed materials for the canonical environment. Industry helps to determine the scale-up feasibility of these newly designed materials, which are then fed back to the experiments in the canonical modeling effort.



RESTRICTED/SENSITIVE DOMAIN:

- Able to see full application, but fundamentals may be unknown
- Gaps in fundamental understanding hinder improvements
- Translate into a "canonical model" (e.g., set of important variables and their ranges)

OPEN DOMAIN:

- Able to see fundamentals, but not full application
- Develop fundamental science solutions for the representative conditions specified by the canonical model to ensure relevance

MEDE MATERIALS BY DESIGN PROCESS

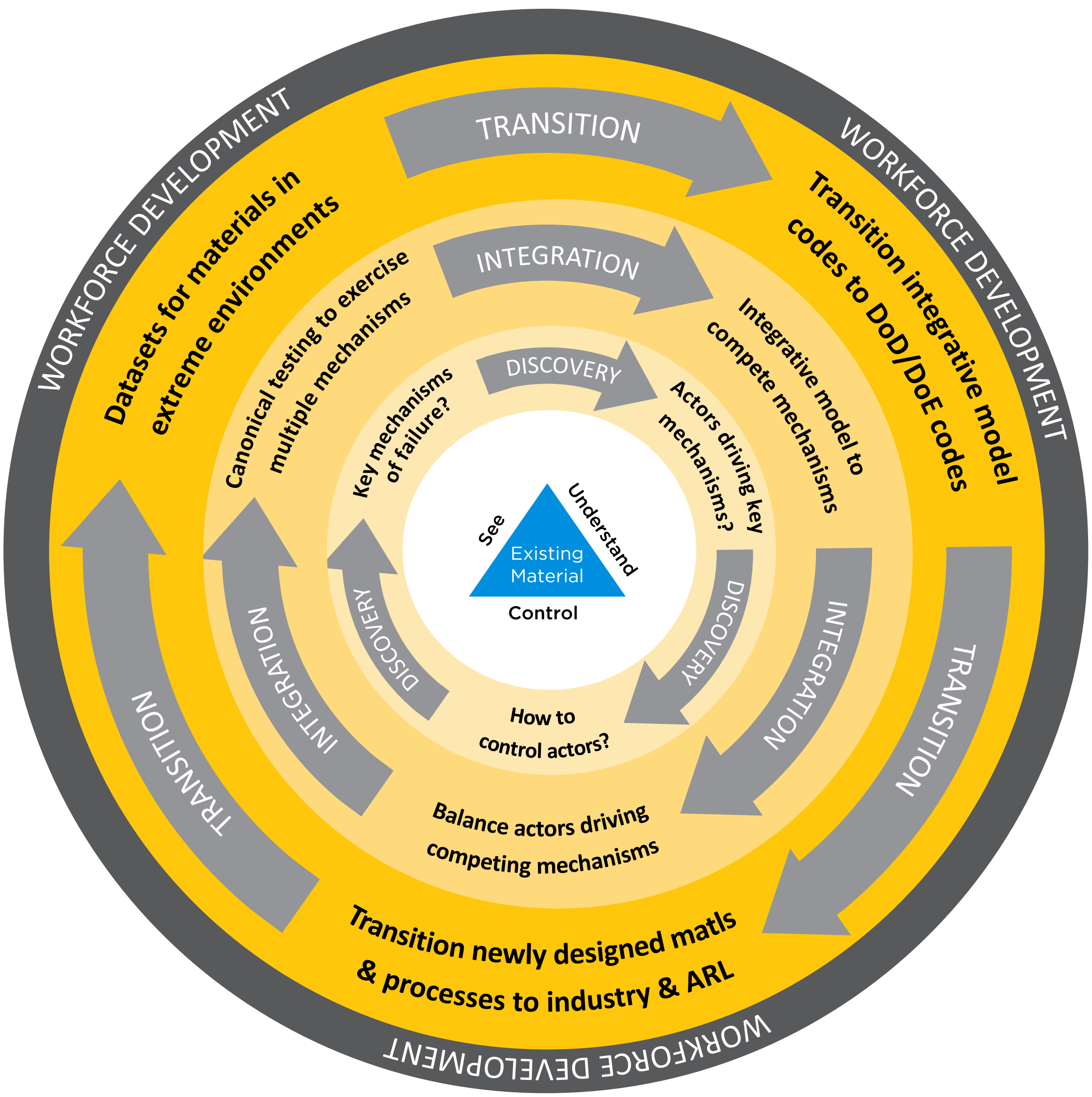
Throughout the program, each CMRG has progressed through discovery, integration and transition for multiple candidate materials. The See/Understand/Control mechanism-based framework has been a constant throughout the program. The final and critically important piece of the program is workforce development, which encompasses all aspects of MEDE.

Mechanism-based, See It-Understand It-Control It Paradigm:

- See It: Observe mechanisms through testing in extreme environments
- Understand It: Computational models to understand mechanisms
- Control It: Synthesis & processing to control mechanisms

- Discovery Phase: evaluation and control of key mechanisms
- Integrative Phase: consider competition between key mechanisms in canonical model
- Transition Phase: codes, datasets, scaled-up material specimens transitioned to DEVCOM ARL

- Workforce Development: throughout and across the entire program



RESEARCH ACTIVITIES & ACCOMPLISHMENTS

RESEARCH ACTIVITIES

The MEDE program examines one model material in each of the following four material classes: ceramics, composites, and metals. The discoveries and insights developed can be used for other materials in the same class.

Ceramics: Boron Carbide

Boron carbide is the model material for the Ceramics CMRG because it has the unrealized potential of dramatic improvements in ballistic performance for soldier and vehicular protection at very low weight. The Ceramics CMRG seeks to understand and control the dynamic failure processes in this protective ceramic material and to improve its dynamic performance by controlling mechanisms at the atomic and microstructural levels through multiscale modeling, advanced powder synthesis, control of polytypes, and microstructural improvements.

Application: Boron carbide is one of the component materials used to protect soldiers and military vehicles from blast and ballistic threats.

Composites: S-2 Glass/Epoxy

Composite materials subjected to dynamic loads are essential examples of high performance systems in the conventional sense. In order to focus on the complexities raised by the interfaces and architectures, S-2 Glass/Epoxy is the model system for the Composites CMRG. The Composites CMRG develops the fundamental understanding of the role of interfaces, component interactions, and composite architecture over the full range of length scales and time scales that are manifested in the system during the dynamic event.

Application: S-2 Glass/Epoxy provides a strong, structural backing system to support protective plates for military vehicles.

Metals: Magnesium

The magnesium alloy system is the model material for the Metals CMRG because it is the lightest-weight structural metal that offers the potential of approaching steel-like ballistic performance while using conventional low-cost and time-tested processing techniques. We are enhancing the dynamic performance of this hexagonally-close-packed metal using experimentally validated modeling and alloy design to control dynamic strengthening and failure mechanisms, including deformation twinning.

Application: In comparison to steel, magnesium offers the potential for a lightweight metal system that could enhance the deployability and protection of military vehicles.

CMEDE RESEARCH ACTIVITIES ADDRESS THE FOLLOWING FIVE CORE ELEMENTS:

- **Advanced Experimental Techniques**: developing experimental methodologies to interrogate and characterize the in-situ materials response to extreme dynamic environments at critical length and time scales.
- **Modeling and Simulation**: developing computational approaches to predict the materials response to extreme dynamic environments at critical length and time scales.
- **Bridging the Scales**: developing physical and mathematical constructs necessary to bridge critical length and time scales.
- **Material Characteristics and Properties at Multiple Scales**: utilize existing and novel experimental methodologies to identify the comprehensive set of material characteristics, microstructural features, and dynamic properties that govern high rate deformation and failure phenomena, and to validate computational approaches in order to bridge the characteristic length and time scales.
- **Synthesis and Processing**: incorporate research discoveries to enable the synthesis of novel materials and the processing of final products with critical material characteristics and resulting properties.

TRANSITIONS FROM THE MEDE PROGRAM

People

- STEM workforce skilled in materials design for extreme environments
- Balance of academic, industry, DoD career paths

Codes and models

- Understanding material response in extreme dynamic environments
- Controlling synthesis and processing of new materials
- Designing materials for extreme dynamic environments

Materials

- New materials developed through materials-by-design loops
- New processes for making designed materials
- Collaboration/partnership with industry

Legacy publications

- Legacy articles from each CMRG in journal special issues

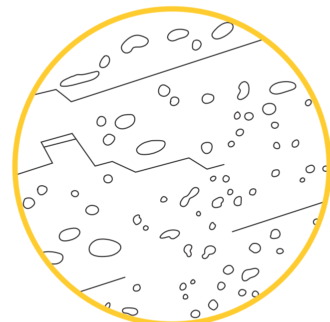
Datasets

- Valuable data from novel experimentation, models and synthesis/processing

CMRG ACCOMPLISHMENTS

Each CMRG has designed a number of candidate materials, and they all have ended up with 2 of the most promising candidates emerging as their success stories. All of these material designs stem from rigorous mechanism-driven materials by design loops. An added note is that collaborations with industry have been central to the scale-up of new ceramics and composites.

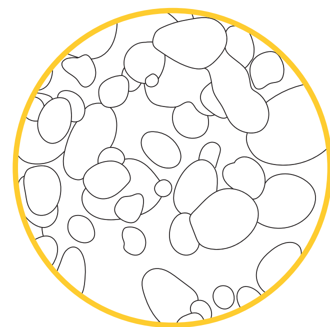
METALS



Magnesium alloys (2 processing routes):

- Pretwinning improves V50 by 13% (weight reduction of 16% for the same protection relative to baseline AZ31B). Alloy design for pre-twinning not optimized yet.
- Precipitate control improves V50 by 16% (weight reduction of 20% compared with AZ31B).

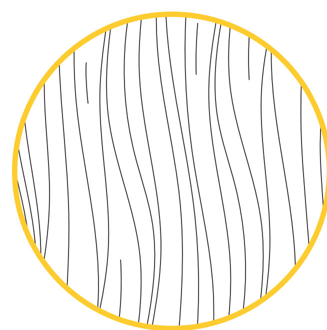
CERAMICS



Boron Carbide (2 processing routes):

- Eliminating free carbon increases modulus (~12%), hardness (~3%), dynamic strength (~11%) relative to baseline PAD B4C. Depth of penetration in aluminum backing at high velocity reduced by 11-18%, suggesting potential for weight reduction of 16%.
- Si-doped BC with TiB_2 additives shows increased hardness (~6%), comparable strength, toughness (~54%) and amorphization resistance (~39%), with only a 6% increase in density. Crater volume at high velocity was reduced 67% relative to baseline.

COMPOSITES



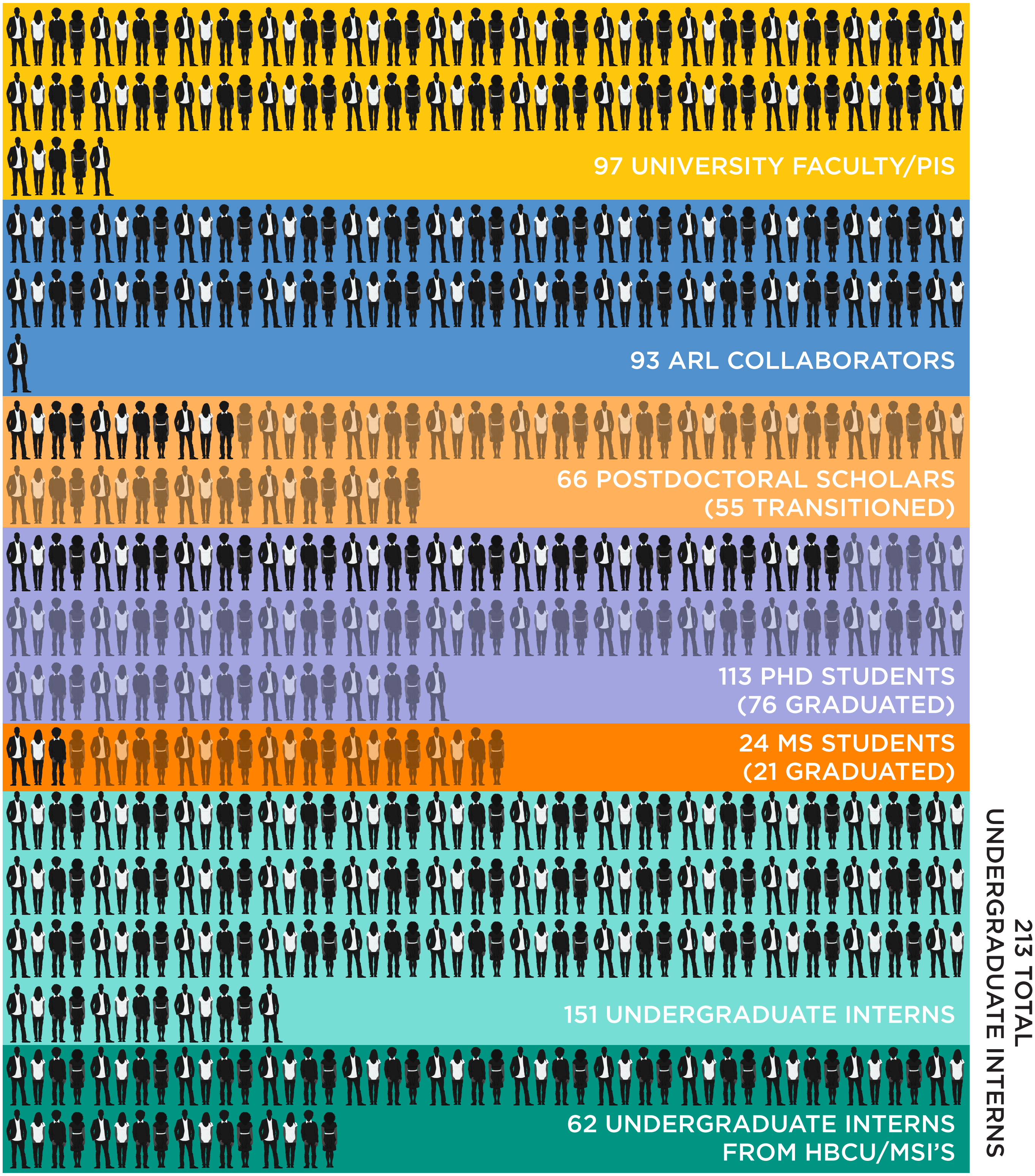
Glass-epoxy Composites (2 configurations):

- Leveraged newly designed resins/interfaces in a functionally graded plate to achieve a 16% increase in V50 and 34% higher energy absorption (or 23% thickness reduction and 14% weight reduction at equivalent protection levels).
- Interlayer toughening in 44-layer plain-weave thick section using Polyurethane interleaves reduces delamination and improves stiffness retention from 44% to 91% relative to baseline.

IMPACT

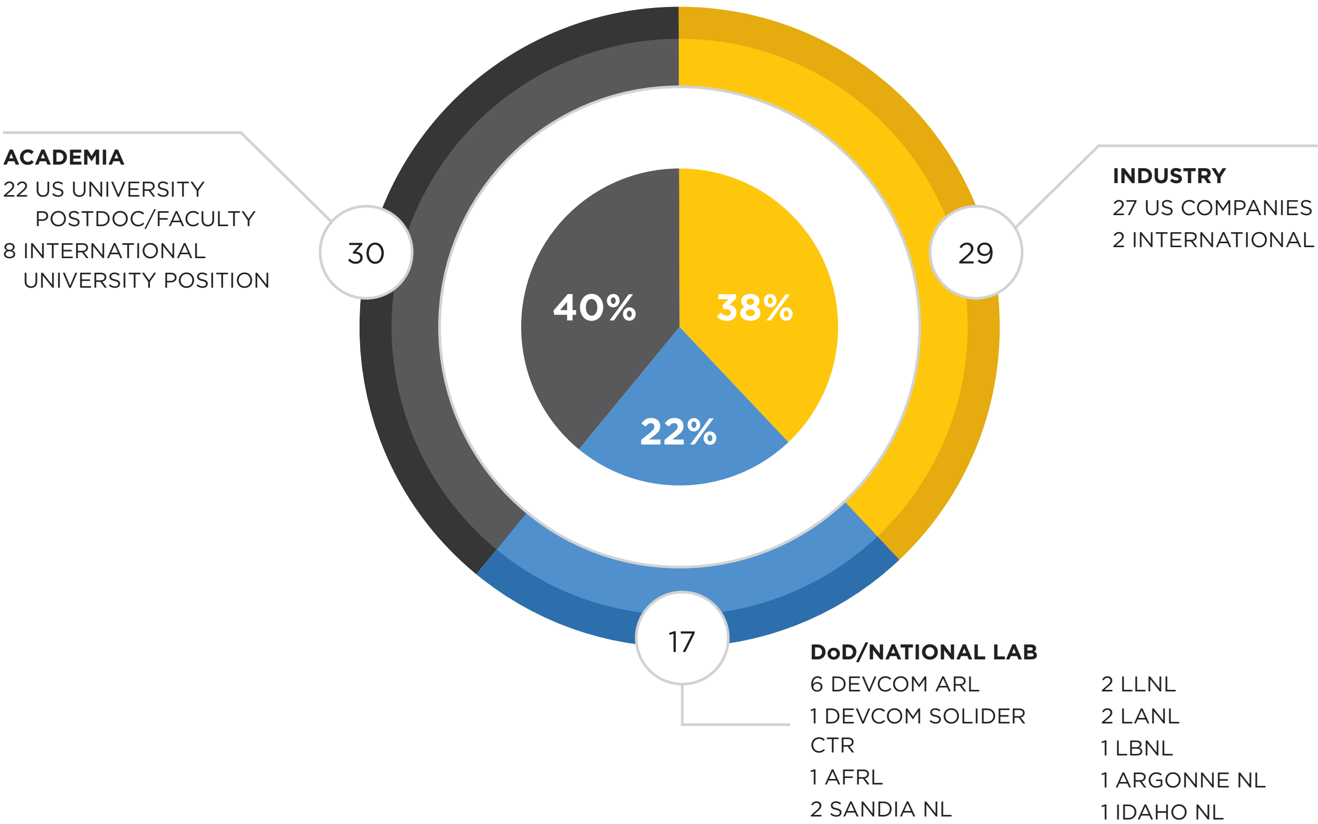
PEOPLE

Below is a graphic showcasing the people involved by the MEDE program. For a full listing of personnel, see Appendix A.

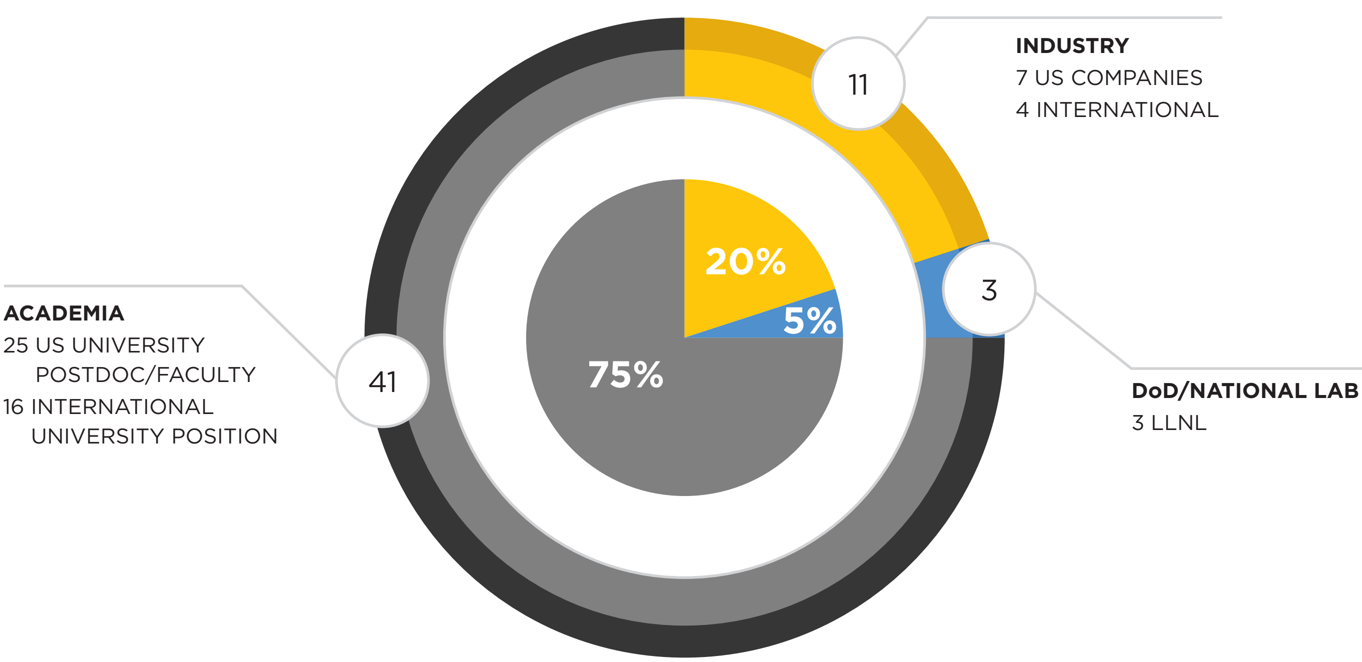


OUR GRADUATES: WHERE DID THEY GO?

PhD GRADUATES



POSTDOCTORAL SCHOLARS



HIGHLIGHTED PROGRAMS

ARMY EDUCATIONAL OUTREACH PROGRAM (AEOP) APPRENTICESHIPS

Army Educational Outreach Program (AEOP) apprenticeship programs, sponsored by the US Army DEVCOM, provide the following summer research opportunities:

- **High School Apprenticeships**: underserved and under-represented high school minorities in STEM (JHU Host Site)
- Total number of students hosted: 25
- Very competitive—185 applicants for 4 slots in 2021

- **Undergraduate apprenticeships**: hosted at MEDE universities: JHU, Delaware, Rutgers, NCAT, Houston, and TAMU
- Total number of students: 39
- MEDE CRA consistently received the most applications for this AEOP apprenticeship program

aeop
ARMY EDUCATIONAL OUTREACH PROGRAM

EXTREME SCIENCE INTERNSHIP (ESI) PROGRAM

The ESI program is a year-round, paid internship program with Morgan State University. ESI provides internal internships at Morgan State to allow students to develop their research skills before participating in an external internship at a MEDE CRA location. ESI has been a highly successful program and serves as a model collaboration for student development.

- External internships during the summer at MEDE consortium institutions (JHU, Caltech, Lehigh, Drexel, NCAT, Purdue, EMI) and DEVCOM ARL

- Total number of internships completed 2014–2021:
  - Internal: 112; External: 32
  - **Number of students: 38**

SELECT ESI ALUMNI: FIRST EMPLOYER OR GRADUATE STUDIES

MICHAEL STRAKER
PhD candidate,
Biomedical Engineering
University of Maryland

JOSHUA SAMBA
PhD candidate, Physics
Rice University

ORELUWA ADESINA
MS Systems Engineering
Johns Hopkins University

YANNICK WILLIAMS
MS Education
Johns Hopkins University

ALEXANDER NEWMAN
Systems Missile Engineer
JH-Applied Physics Laboratory

DENNIS ARYEE
Systems Engineer
Northrop Grumman

PUBLICATIONS

Below is a chart showcasing MEDE-related publications & conference proceeding from 2012–2021. For a full listing, please see Appendix B (publications).

CMRG	Journal Articles*	Journal Article Citations	Conference Proceedings**
Ceramics	133	1885	11
Composites	107	1217	68
Integrative	27	425	1
Metals	137	2,808	12
Polymers	74	1,760	24
TOTAL	**478**	**8,095**	**116**

**journal articles which have been submitted, accepted or published.*

***very conservative estimate of proceedings (not presentations)—not tracked as carefully as journal articles*

EVENTS

There have been a number of high-profile MEDE-related events that have engaged the broader community, including workshops, the Research Management Boards, highly successful short courses, CMEDE seminars at JHU and at DEVCOM ARL, and DEVCOM ARL news articles. In the last year, there were a few workshops of note—one related to the impact of the pandemic on research, and two related to AI for materials, which is a critical direction for DEVCOM ARL in the coming years.

MEDE-RELATED EXTERNAL EVENTS FOR THE BROADER COMMUNITY

Type	Quantity
Workshops (chaired or invited speaker)	2—National Academies 1—NSF 1—DEVCOM ARL 3—JHU/HEMI
Research Management Boards hosted at JHU	3
Short Courses	12
Seminars (hosted by JHU/CMEDE)	52
ARL news articles	6

MACH CONFERENCE

The Mach Conference is an annual, open event that showcases the state of the art of multiscale research in materials, with an emphasis on advancing the fundamental science and engineering of materials and structures in extreme environments. MEDE CRA members are significant participants in this event, which shares research discoveries to the broader community.

	2013	2014	2015	2016	2017	2018	2019	2020	2021*	Totals
# Attendees	113	176	225	227	236	235	236	**	194	1,642
# Plenary speakers	3	6	5	5	5	5	5		3	37
# Presentations	93	98	112	118	116	108	110		83	838
# Posters	16	17	45	35	47	49	45		23	277

**Virtual*

***Cancelled due to Covid-19*

APPENDICES

Appendix A

Personnel 2012-2021

Principal Investigators and Research Faculty

1. Cameron Abrams, Drexel Univ.
2. Suresh Advani, Univ. of Delaware
3. Nick Alvarez, Drexel Univ.
4. Qi An, Caltech
5. Charlie Anderson, SwRI
6. Petros Arakelian, Caltech
7. Tom Arsenlis, LLNL
8. Kadir Aslan, Morgan State Univ.
9. Sylvie Aubry, LLNL
10. Kaushik Bhattacharya, Caltech
11. Peter Brown, DSTL
12. Tamas Budavari, JHU
13. Bob Cammarata, JHU †
14. MVS Chandrashekhar, Morgan State Univ./Univ. of South Carolina
15. Wayne Chen, Purdue
16. Sidney Chocron, SwRI
17. Sanjib Chowdhury, Univ. of Delaware
18. Rodney Clifton, Caltech/Brown Univ.
19. Paul Curtis, DSTL
20. Kathryn Dannemann, SwRI
21. Nitin Daphalapurkar, JHU
22. Joe Dietzel, Univ. of Delaware
23. Vlad Domnich, Rutgers Univ.
24. Jaafar El-Awady, JHU
25. Dave Elbert, JHU
26. Schoenberger Erica, JHU
27. Horacio Espinosa, Northwestern Univ.
28. Michael Falk, JHU
29. John Foster, UTSA
30. Joelle Frechette, JHU
31. Somnath Ghosh, JHU
32. Jack Gillespie, Univ. of Delaware
33. Bill Goddard, Caltech
34. Ashutosh Goel, Rutgers Univ.
35. Lori Graham-Brady, JHU
36. Julie Greer, Caltech
37. Yogi Gupta, WSU
38. Rich Haber, Rutgers Univ.
39. Bazle Haque, Univ. of Delaware
40. Martin Harmer, Lehigh Univ.
41. Chris Hawkins, DSTL
42. Mo-Rigen He, JHU
43. Kevin Hemker, JHU
44. Tim Holmquist, SwRI
45. Todd Hufnagel, JHU
46. Ryan Hurley, JHU
47. Chawon Hwang, Rutgers Univ.
48. Ilyas Ilyas, Morgan State Univ.
49. Andres Jaramillo-Botero, Caltech
50. Shailendra Joshi, Univ. of Houston
51. Laszlo Kecskes, JHU
52. Michael Keefe, Univ. of Delaware
53. Alvin Kennedy, Morgan State Univ.
54. Michael Kessler, WSU
55. Jamie Kimberley, NMT
56. Dennis Kochmann, Caltech/ETH Zurich
57. Munetaka Kubota, Univ. of Delaware
58. Yucheng Lan, Morgan State Univ.
59. Chris Marvel, Lehigh Univ.

Principal Investigators and Research Faculty (cont.)

60. James McCauley, JHU
61. Bob McMeeking, UCSB
62. Peke Milas, Morgan State Univ.
63. Nilanjan Mitra, JHU
64. Victor Nakano, JHU
65. Vicky Nguyen, JHU
66. Gaurav Nilakantan, Univ. of Delaware
67. Michael Normandia, Rutgers Univ.
68. Michael Ortiz, Caltech
69. Birol Ozturk, Morgan State Univ.
70. Devdas Pai, NCAT
71. Giuseppe Palmese, Drexel Univ.
72. William Rafaniello, Rutgers Univ.
73. KT Ramesh, JHU
74. Guruswami Ravichandran, Caltech
75. Mark Robbins, JHU †
76. Alexandr Samokhvalov, Morgan State Univ.
77. Jag Sankar, NCAT
78. Steve Sauerbrunn, Univ. of Delaware
79. Nathan Scott, JHU
80. Michael Shields, JHU
81. Adam Sierawkowski, JHU
82. Michael Spencer, Morgan State Univ.
83. Elmar Strassburger, EMI
84. Andrew Stuart, Caltech
85. PK Swaminathan, JH-APL
86. Jamil Tahir-Kheli, Caltech
87. Eric Walker, JHU
88. Qiuming Wei, UNCC
89. Tim Weihs, JHU
90. Justin Wilkerson, UTSA/TAMU
91. Michael Winey, WSU
92. Kelvin Xie, JHU
93. Zhigang Xu, NCAT
94. Shridhar Yarlagadda, Univ. of Delaware
95. Sergey Yarmolenko, NCAT
96. Peng Yi, JHU
97. Hongtao Yu, Morgan State Univ.

Key, Abbreviations, and Acronyms

† = deceased

Caltech - California Institute of Technology

EMI - Ernst Mach Insitut

JHU - Johns Hopkins University

JH-APL - Johns Hopkins Applied Physics Laboratory

LLNL - Lawrence Livermore National Laboratory

NCAT - North Carolina Agricultural & Technical State University

NMT - New Mexico Tech

SwRI - Southwest Research Institute

TAMU - Texas A&M University

UCSB - University of California Santa Barbara

UNCC - University of North Carolina at Charlotte

UTSA - University of Texas at San Antonio

WSU - Washington State University

ARL Collaborators

1. Jan Andzelm
2. Brady Aydelotte
3. Iskander Batyrev
4. John Beatty
5. Richard Becker
6. Cynthia Bedell
7. Kristopher Behler
8. Stephan Bilyk
9. Todd Bjerke
10. Travis Bogetti
11. T. Gordon Brown
12. Brady Butler
13. Jim Campbell
14. Dan Casem
15. Tanya Chantawansri
16. Kyu Cho
17. Peter Chung
18. John Clayton
19. Shawn Coleman
20. Joshua Crone
21. Dattatraya Dandekar
22. Robert Elder
23. Dan Everson
24. Micah Gallagher
25. George Gazonas
26. Michael Grinfeld
27. Matthew Guziewski
28. Vince Hammond
29. Efrain Hernandez
30. Sergiy Izvyekov
31. Phillip Jannotti
32. Tyrone Jones
33. Ryan Karkkainen
34. Shashi Karna
35. Laszlo Kecskes
36. Jarek Knap
37. Dan Knorr
38. Nicholas Ku
39. Jerry LaSalvia
40. John LaScala
41. Brian Leavy
42. Joe Lenhart
43. Jonathan Ligda
44. Krista Limmer
45. Jeff Lloyd
46. Bryan Love
47. Daniel Magagnosc
48. Debjoy Mallick
49. Kevin Masser
50. Suveen Mathaudhu
51. William Mattson
52. Heidi Maupin
53. James McCauley
54. Jason McDonald
55. Christopher Meredith
56. Chris Meyer
57. Paul Moy
58. Danny O'Brien
59. Parimal Patel
60. Brendan Patterson
61. John Pittari
62. Peter Plostins
63. Adam Rawlett
64. Betsy Rice
65. Brett Sanborn
66. James Sands
67. Tomoko Sano
68. Sikhanda Satapathy
69. Scott Schoenfeld
70. Brian Schuster
71. Taylor Shoulders
72. JP Singh
73. Timothy Sirk
74. James Snyder
75. Kenneth Strawhecker
76. Jeffrey Swab
77. Jennifer Synowczynski-Dunn
78. DeCarlos Taylor
79. Andrew Tonge
80. Niru Trivedi
81. Mark Tschopp
82. Mark VanLandingham
83. Lionel Vargas-Gonzalez
84. Scott Walck
85. Tusit Weerasooriya
86. N. Scott Weingarten
87. Eric Wetzel
88. Raymond Wildman
89. Cyril Williams
90. Chi-Chin Wu
91. Chian Fong Yen
92. Nicole Zander
93. Wayne Ziegler

Postdoctoral Fellows

1. Sara Adibi, UTSA/TAMU
2. Zafir Alam, JHU
3. Fredy Aquino Quispe, JHU
4. Zeynep Ayguzer-Yasar, Rutgers Univ.
5. Ravi Sastri Ayyagari Venkata, JHU
6. Aurelie Azoug, JHU
7. Berra Beyoglu Siglam, Rutgers Univ.
8. Stella Brach, Caltech
9. Ankur Chauhan, JHU
10. Kerri-Lee Chintersingh-Dinnall, JHU
11. Mehmet Burak Cil, JHU
12. Nitin Daphalapurkar, JHU
13. Chris DiMarco, JHU*
14. Hai Dong, JHU
15. Jun Du, Rutgers Univ.
16. Haidong Fan, JHU
17. Lukasz Farbaniec, JHU
18. Dipankar Ghosh, Caltech
19. Dimitrios Giovanis, JHU
20. Kavan Hazeli, JHU
21. James Hogan, JHU
22. M. Zubaer Hossain, Caltech
23. Bamdad Hosseini, Caltech
24. Guangli Hu, JHU
25. Vikram Jadhao, JHU
26. Minju Kang, JHU
27. Atta Khan, Rutgers Univ.
28. YunHo Kim, JHU
29. Owen Kingstedt, Caltech
30. Trenton Thomas Kirchdoerfer, Caltech
31. Eswar Korimilli, JHU
32. Jessica Krogstad, JHU
33. Soonho Kwon, Caltech
34. Leslie Lamberson, JHU
35. Andrew Fwu Tay Leong, JHU
36. Weixin Li, JHU
37. Burigede Liu, Caltech
38. Xiaolong Ma, JHU
39. Pinkesh Malhotra, JHU*
40. Chris Marvel, Lehigh Univ.
41. Juan Pedro Mendez Granado, Caltech
42. Chengyun Miao, JHU
43. MH Motamedi, JHU
44. Suraj Muthiramalil Ravindran, Caltech
45. Susmita Naskar, JHU
46. Audrey Olivier, JHU
47. Avinash Parashar, JHU
48. Mauricio Rene Ponga De La Torre, Caltech
49. Rezwanur Rahman, UTSA
50. Amuthan Arunkumar Ramabathiran, Caltech
51. Amol Ravaji, Univ. of Houston
52. Hyeyoung Shin, Caltech
53. Gidong Sim, JHU
54. George Soimoiris, JHU
55. Kinshuk Srivastava, JHU
56. Angela Stickle, JHU
57. Xingsheng Sun, Caltech
58. Christian van Engers, JHU
59. Thomas Voisin, JHU
60. Babak Vuppuluri, Univ. of Houston
61. Guanyuan (Kevin) Wang, Caltech
62. Yu Xuan (Kelvin) Xie, JHU
63. Moon Young Yang, Caltech
64. Jejoon Yeon, Univ. of Delaware
65. Peng Yi, JHU
66. Arezoo Zare, JHU
67. Salman Zarrini, Drexel Univ.
68. Qinglei Zeng, JHU

Abbreviations and Acronyms

* = not included in original reported number of postdoctoral fellows (p.18)

Caltech - California Institute of Technology

JHU - Johns Hopkins University

TAMU - Texas A&M University

UTSA - University of Texas at San Antonio

PhD Students

1. Zach Aitken, Caltech
2. Andrew James (Andy) Akerson, Caltech
3. Mustafa Alazzawi, Rutgers Univ.
4. Qi An, Caltech
5. Shinu Baby, JHU
6. Aakash Bangalore Satish, JHU
7. Shahmeer Baweja, Univ. of Houston
8. Anindya Bhaduri, JHU
9. Amartya Bhattacharjee, JHU
10. Christopher Bond, NMT
11. Enock Bonyi, Morgan State Univ.
12. Sakshi Braroo, JHU
13. Cindy Byer, JHU
14. Nicholas Carey, JHU
15. Tom Cender, Univ. of Delaware
16. Yingrui (Ray) Chang, Caltech
17. Kent Christian, Rutgers Univ.
18. Jou-mei Chu, Purdue Univ.
19. Joel Clemmer, JHU
20. Vaclav Cvicek, Caltech
21. Amy Dagro, JHU
22. Armin Daneshwar, Univ. of Houston
23. Showren Datta, Univ. of Houston
24. Vincent DeLucca, Rutgers Univ.
25. Neha Dixit, JHU
26. Steven Dubelman, Purdue Univ.
27. Charles El Mir, JHU
28. Suhas Eswarappa Prameela, JHU
29. Anthony Etzold, Rutgers Univ.
30. Caleb (Stephen) Foster, TAMU
31. Marco Aurelio Galvani Cunha, JHU
32. Raja Ganesh, Univ. of Delaware
33. Jinling Gao, Purdue Univ.
34. Jian Gao, Drexel Univ.
35. Jesse Grant, JHU
36. Michael Grapes, JHU
37. Zherui Guo, Purdue Univ.
38. Adyota Gupta, JHU
39. Ashwini Gupta, JHU
40. Janelle Guy, Morgan State Univ.
41. Christopher Hale, NCAT
42. Christopher Henry, Drexel Univ.
43. Chance Holland, UCSB
44. Yannick Hollenweger, ETH Zurich
45. Mathew Hudspeth, Purdue Univ.
46. Farah Huq, JHU
47. Ahmed Hussein, JHU
48. Akshay Joshi, Caltech
49. Vignesh Kannan, JHU
50. Cynthia Katcoff, JHU
51. Christian Kettenbeil, Caltech
52. Alex Kinsey, JHU
53. Nikola Kovachki, Caltech
54. Pavitra Krishnan, UNCC
55. Jenna Krynicki, JHU
56. Nicholas Krywopusk, JHU
57. Taka Kubota, Univ. of Delaware
58. Kanak Kuwelkar, Rutgers Univ.
59. Zachary Lamberty, JHU
60. Zachary Larimore, Univ. of Delaware
61. Steven Lavenstein, JHU
62. Zhiye Li, JHU
63. Junwei Liu, JHU
64. Luoning Ma, JHU
65. Debjoy Mallick, JHU
66. Quinn McAllister, Univ. of Delaware
67. Preston McDaniel, Univ. of Delaware
68. Paul McGhee, NCAT
69. Chris Meyer, Univ. of Delaware
70. Sarah Louise Mitchell, Caltech
71. Tyler Munhollon, Rutgers Univ.
72. Vicente Munizaga, JHU
73. Thao Nguyen, UTSA/TAMU
74. Thomas O'Connor, JHU
75. Eric Ocegueda, Caltech
76. Tomoyuki Oniyama, Caltech
77. Metin Ornek, Rutgers Univ.
78. Niranjan Parab, Purdue Univ.
79. Jason Parker, JHU
80. Paul Plucinsky, Caltech
81. Jin Qian, Caltech
82. Jiao Quan, JHU
83. Pritha Renganathan, WSU
84. Paul Roberts, JHU
85. Paul Samuel, Univ. of Delaware
86. Mark Schaefer, Rutgers Univ.
87. Srinivas Selvarajou, Univ. of Houston
88. Majid Sharifi, Drexel Univ.
89. Hao Sheng, JHU
90. Gary Simpson, JHU
91. Joshua Smeltzer, Lehigh Univ.
92. Subramani Sockalingam, Univ. of Delaware
93. Dingyi Sun, Caltech
94. Xiangyu Sun, JHU
95. Sandeep Tamrakar, Univ. of Delaware

PhD Students (cont.)

96. Ying Shi Teh, Caltech
97. Fatih Toksoy, Rutgers Univ.
98. Andrew Tonge, JHU
99. Abbas Tutcuoglu, Caltech
100. Vidyasagar Vidyasagar, Caltech
101. Zheliang Wang, JHU
102. Xin (Cindy) Wang, Caltech
103. John Weeks, Caltech
104. Justin Wilkerson, JHU
105. Hai Xiao, Caltech
106. Yanrong Xiao, JHU
107. Qi Rong (Bruce) Yang, Rutgers Univ.
108. Michael Yeager, Univ. of Delaware
109. Minyoung Yun, Univ. of Delaware
110. Alex Zelhofer, Caltech
111. Xiaofan Zhang, JHU
112. Honglin Zhang, NCAT
113. Meng Zhao, JHU

Abbreviations and Acronyms

Caltech - California Institute of Technology

JHU - Johns Hopkins University

NCAT - North Carolina Agricultural & Technical State University

NMT - New Mexico Tech

TAMU - Texas A&M University

UCSB - University of California Santa Barbara

UNCC - University of North Carolina at Charlotte

UTSA - University of Texas at San Antonio

WSU - Washington State University

Master's Students

1. Kimberly Andes, JHU
2. Michael Brothers, UTSA
3. Alexander Caffee, JHU
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6. Jiajie Huang, JHU
7. Caleb Hustedt, JHU
8. Matthew Koelle, Rutgers Univ.
9. Stephen Levine, Purdue Univ.
10. Wen-Ju Liu, JHU
11. Andrew Matejunas, NMT
12. Alexander Newman, Morgan State Univ.
13. Angela Olinger, TAMU
14. Jastin Paul, NMT
15. Nathaniel Pfeifer, NMT
16. Andrew Robinson, JHU
17. Brandon Rowell, NMT
18. Joshua Samba, Morgan State Univ.
19. Jianzhuo Sun, Purdue Univ.
20. Jun Sunghyun, NCAT
21. Audrey Swanenberg, JHU
22. Victoria Tsarkova, Rutgers Univ.
23. Haley Wolf, Lehigh Univ.
24. Mantong Zhao, JHU

Abbreviations and Acronyms

JHU - Johns Hopkins University

NCAT - North Carolina Agricultural & Technical State University

NMT - New Mexico Tech

TAMU - Texas A&M University

UTSA - University of Texas at San Antonio

Staff

1. Jessica Ader, JHU
2. Petros Arakelian, Caltech
3. Bess Bieluczyk, JHU
4. Andre Bothelo, JHU
5. Ryan Bradley, JHU
6. Denise Brown, JHU
7. Tia Brownlee, JHU
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9. Angela Coleman, JHU
10. Lisa Eklund, JHU
11. Amanda Fabrizio, JHU
12. Dale Fleetwood, Univ. of Delaware
13. Heather Gordon, Univ. of Delaware
14. Megan Hancock, Univ. of Delaware
15. Amanda He, Caltech
16. Levi Johnson, JHU
17. Scott McGhee, JHU
18. Justin Moreno, JHU
19. Jack Pollock, Univ. of Delaware
20. Andrew Proulx, JHU
21. Steven Ransom, JHU
22. Leslie Rico, Caltech
23. Melissa Rosenberger, JHU
24. Clarissa Roth, Univ. of Delaware
25. Phyllis Sevik, JHU
26. Lynn Seymour, Caltech
27. Matt Shaeffer, JHU
28. Michelle Sole, Rutgers Univ.
29. Therese Stratton, Univ. of Delaware
30. Katie Vaught, JHU
31. Mehwish Zuberi, JHU

Abbreviations and Acronyms

Caltech - California Institute of Technology

JHU - Johns Hopkins University

CMEDE | CENTER FOR MATERIALS IN EXTREME DYNAMIC ENVIRONMENTS

Appendix B

Journal articles 2012 — 2021

Submitted, Accepted, Published

Total number: 478

[N] Number of times this journal article has been cited

Ceramics

2021

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Summary

Number of journal articles

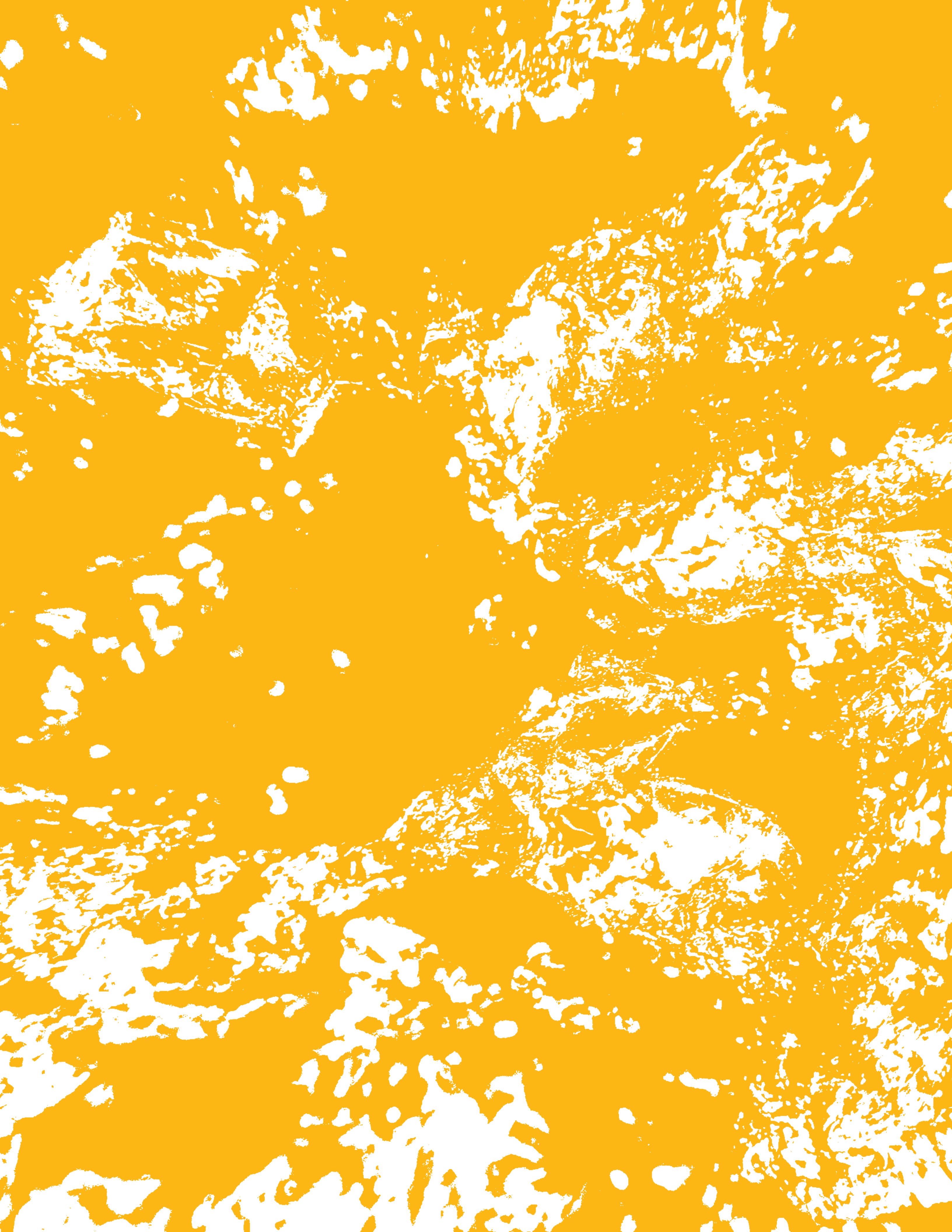
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Ceramics	7	5	6	21	23	20	7	19	10	15
Composites	7	2	5	13	16	8	14	11	9	22
Integrative	2	4	6	4	3	4	0	4	0	0
Metals	6	11	20	12	20	18	7	12	19	12
Polymers	10	8	10	7	9	17	7	4	1	1
Total	32	30	47	57	71	67	35	50	39	50

	Total
Ceramics	133
Composites	107
Integrative	27
Metals	137
Polymers	74
Total	478

Number of times journal articles were cited

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Ceramics	107	142	175	529	483	193	67	144	40	5
Composites	51	38	212	231	354	83	139	63	45	1
Integrative	24	42	107	129	75	16	0	32	0	0
Metals	212	327	550	523	458	400	83	148	97	10
Polymers	394	276	173	310	239	251	71	45	1	0
Total	788	825	1217	1722	1609	943	360	432	183	16

	Total
Ceramics	1885
Composites	1217
Integrative	425
Metals	2808
Polymers	1760
Total	8095



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