SCiMMA

Scalable Cyberinfrastructure to support Multi-Messenger Astrophysics

Education, Training and Workforce Development

SCiMMA Project
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January 2021

Abstract

Besides developing a scalable cyberinfrastructure to support multi-messenger astrophysics (MMA) observations, SCiMMA's goals include the formulation of education and training curricula that will enable building and leveraging the human capacity needed for supporting MMA-science-related software and data services. In recent years, multi-messenger astrophysics has grown from a pioneering field into a distinct discipline with strong public interest, including the younger generation who will drive its science for decades. Educating, including, and enabling the next generation to participate in our new field is a key deliverable for a future SCiMMA institute.
THIS DOCUMENT IS CURRENTLY AVAILABLE FOR COMMUNITY COMMENTING.

1 Introduction

This white paper describes the state of education, training, and workforce development in the MMA community, and identifies gaps and needs in this area. SCiMMA's training and EPO activities will target its staff at its institutions and also catalyze changes in the broader community. The overall goal is to build up and maintain the human capacity needed for MMA science. Specifically,

1. bringing people into the field, including people from underrepresented groups (§2),
2. training them in needed aspects of science and information/computer technology (ICT) (§3), and
3. advancing their careers through mentoring and inclusion (§4).

In addition to training, education and public outreach generate broader interest and excitement in the field, contribute to long term capacity and diversity goals in STEM, and also educate current and future government decision makers (§5).

In this community white paper, we describe a set of challenges in education, training, and workforce development that need to be addressed by an MMA-focused cyberinfrastructure institute in order to support its scientific goals and activities inside an inclusive atmosphere that also targets the broader community and the general public. Here we build on existing activities from overlapping fields and fields with similar requirements that address some of the foreseen challenges in part, while we also discuss plans how these challenges can be more fully addressed by existing and new activities.

2 Diversity and Accessibility

Fundamentally, everyone deserves equal access and opportunity in science, and focused efforts promoting diversity and equity are necessary to reach this objective. Statistically speaking, the current system does not meet this standard. In this section we outline the status of gender and racial diversity in STEM, as well as accessibility and disability inclusion. This is by no means an exhaustive overview but rather a brief description of the current state of representation. We also discuss our strategies for improvement.

2.1 Lack of representation and challenges in hiring

A 2019 report led by Anne Marie Porter provides an overview of the representation of women in physics and astronomy. The authors found that while the percentage of women earning physics and astronomy bachelor degrees has remained constant in recent years, the percentage of women enrolling in physics graduate programs has risen. Additionally, while women only held 10% of full professor positions in 2014, this work found this number in accordance with the number of women who had earned doctorates in the past. Notably, this positive trend in gender diversity at the undergraduate and graduate levels does not extend to certain racial demographics, particularly Black women. The authors remark, "the number of Hispanic women earning physics and astronomy degrees is growing rapidly over time, while the number of African-American women has not shown similar growth." [1]

The number and proportions of Black, Hispanic, and Native American women earning bachelor's degrees was also explored in a 2017 report by Laura Merner using data from the National Center for Education Statistics. The authors found there was an increase in the number of bachelor's degrees earned by Black, Hispanic, and Native American women between 2003 and 2013. The number of degrees awarded to these demographics grew by a combined 65%, compared to 36% growth among all US bachelor recipients. However, in the physical sciences and engineering disciplines there has been significantly less growth. Specifically in physics, degrees earned by Black, Hispanic, and Native American women grew by 40%, whereas the increase in physics for all US bachelors was 59%. In engineering, the growth rate for Black, Hispanic, and Native American women was just 15%, significantly lower than the overall growth rate. As Merner remarks, "at these rates, African American, Hispanic, and Native American women will continue to be significantly underrepresented in the physical sciences and become even more underrepresented in engineering." [2]

Examining the STEM workforce at large, minoritized scientists (i.e., Black, Hispanic or Latino/Latina, American Indian, and Alaska Natives) comprise only 7.3% of STEM Doctorates in faculty positions in the United States of America despite accounting for 29.3% of the US population and 14.7% of STEM Bachelor's degrees, indicating a "leaky pipeline" where institutional barriers prevent minoritized scientists from advancing in their careers [3]. Black and Hispanic women account for an even smaller percentage of the STEM workforce, less than 2% for each demographic [4]. While gender and racial representation constitute two independent problems that should not be conflated, it is important to recognize and address intersecting categories of race and gender that are systematically associated with wide disparities. The lack of advancement in STEM careers at the post-doctoral level for women and minoritized scientists was explored in a 2019 study led by Asia Eaton. This work found that physics faculty exhibited hiring bias favoring men and Asian or White candidates. Black women and Latinx people were ranked the lowest in hireability, illustrating the compounding effect of gender and racial stereotypes [5].

In addition to racial and gender barriers, accessibility and disability inclusion is another major issue in STEM. Nearly 20% of the US population has a disability [6] and yet people with disabilities account for only 8.4% of employed scientists and engineers in the US [7]. At the undergraduate level, those with disabilities account for 11% of students enrolling in institutions, yet they persist to graduation at much lower rates than their non-disabled counterparts [8, 9, 10, 11].

2.2 SCiMMA's Diversity Goal

All SCiMMA participants have agreed to conduct themselves in a manner that ensures an inclusive and harassment-free experience for everyone. The SCiMMA code of conduct includes the following explicit statement on diversity:

> "In the interest of fostering an open and welcoming environment, we as contributors and participants, pledge to making participation in our project and our community a harassment-free and bullying-free experience for everyone, regardless of age, body size, disability, ethnicity, sex characteristics, gender identity and expression, veteran status, level of experience, education, socio-economic status, nationality, personal appearance, race, religion, family structure or sexual identity and orientation."

All individuals should be given equal opportunity simply because everyone fundamentally deserves to have a space in STEM, but increased diversity can also have a positive impact on organizations and communities [12, 13]. Diverse teams tend to be more innovative, and studies have shown that diversity in groups leads to better problem solving and decision making [14, 15]. Additionally, research at McKinsey & Company and Credit Suisse have shown that companies with diversity at the executive level tend to financially outperform those without [16, 17].

2.3 Strategies for addressing gaps

As a nexus of multiple institutions, disciplines, and facilities, SCiMMA can facilitate positive cultural shifts across its entire user community. The institute can foster an open and welcoming environment and increase diversity, and promote healthy and creative interactions. The longevity of a successful institute provides the opportunity to effect a generational shift in our communities' approach to diversity, equity, and inclusion, leading to increased creativity, better problem solving, and improved decision making. Our vision for change will be integrated into the institute's policies, procedures, and activities as follows.

SCiMMA's Diversity and Inclusion Policy Development Plan includes the formation of a Community Standards Committee (CSC). The CSC will be tasked with developing a comprehensive diversity and inclusion policy for the Institute. We will document this *Diversity and Inclusion Policy* following to the maximal extent best practices adopted by projects similar in nature and scale, such as the Multimessenger Diversity Network (MDN) [18], and incorporate lessons learned from the conceptualization phase.

In order to ensure that new members and fellows experience a supportive working environment across all cohorts, SCiMMA could create a Fellowship Selection Committee. This committee would recruit members of underrepresented groups and prepare fellows, students, and postdocs for employment opportunities within academia and at technology firms. Additionally, SCiMMA can prepare them to further enact progressive transformation in future stages of their career.

An MMA institute could include a Diversity Officer who organizes regular DEI training for SCiMMA members and program participants. They will ensure that our education, training, and workforce development activities promote a sense of inclusiveness that will encourage underrepresented participants to progress within the field. The Diversity Officer could also coordinate a DEI group for those interested in focused discussion and action on increasing diversity and fostering a welcoming collaborative environment. The DEI group would provide a forum in which to share knowledge, experiences, and resources among institute members.

SCiMMA scientists can continue to support current minoritized colleagues by inviting them to co-author grants and reviews, citing their research, or inviting them for institute colloquia. Colloquia or seminar series can be further diversified by including people from outside academia. At the institutional level, SCiMMA can commit to using paying for conference travel or other expenses in advance, rather than requiring a later pay-then-be-reimbursed process because such expenses can be a high financial burden to pay up front, one that many scientists may not be able to afford. Mentoring is a critical component to SCiMMA's workforce development efforts, as explained in §4, and as SCiMMA develops its mentoring program, the CSC can ensure the inclusion of explicit support systems and opportunities for minoritized scientists. The CSC can also commit to enforcing more inclusive hiring practices and addressing hiring biases with SCiMMA leadership. Additionally, the CSC could create a board for representation tasked with ensuring groups are equally represented and supported within the collaboration. Another possible initiative is creating an avenue for anonymous feedback on potentially racist or oppressive behaviors and a regular town hall to discuss and reflect on the input [19, 20, 21, 22].

A number of studies have suggested that one's experience at the late high school or early undergraduate stage has the most effect on the "leaky pipeline" referenced in §2.1 [23]. As detailed in §5, SCiMMA's EPO initiatives will strive to explicitly include and target underrepresented communities so as to combat this trend. SCiMMA will promote these ideas during events, presentations, and discussions with members of the public. Personal discussions with scientists at public lectures and professional meetings, especially scientists from underrepresented groups, are especially vital for the minority population and young women, including, inspiring and enabling them to stay engaged and becoming part of new discoveries.

3 Building capacity

Education and workforce development are essential components of the future SCiMMA Institute. Investment in training and education will lead to transformative impacts on a scale beyond that of any immediate scientific discoveries in astrophysics.

To establish the foundation of a future institute, we must significantly expand cross-fertilization among computer and data scientists, engineers, astronomers, and astrophysicists. This will let students acquire skills that have broad applicability; data science and engineering are experiencing rapid growth across all sectors and require personnel who are versed in mathematics, statistics, and software engineering (including coding skills, development best practices, etc.), and who have the ability to identify and deploy the software and methodologies best suited to process large and/or complex data sets.

Overall, we want to create a convergent yet extensible training model, enabling both cross-experimental and cross-disciplinary product development while also remaining accessible to students at different levels.

For the future SCiMMA institute, we consider a training model with a pyramidal structure structure, with broadly applicable software development and engineering skills at the bottom, the use of general domain (astrophysics/astronomy) software in the middle, and application-specific development driven by a clear MMA science goal at the top, as shown in Figure 1.

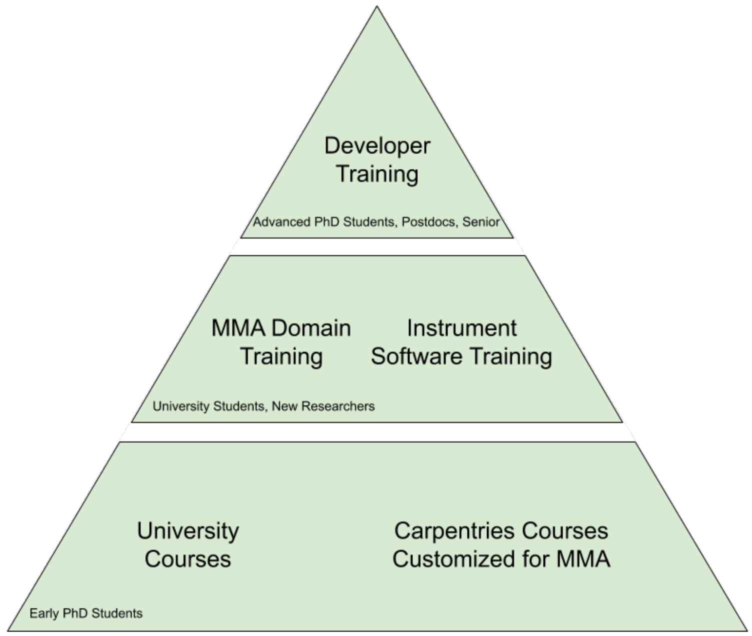

Figure 1: Diagram showing the pyramid structure of SCiMMA's training model. Training begins at the bottom level with broadly applicable software skills. The middle layer shows the next level of training where the skills to use domain specific software are acquired, and the top layer includes developer training on how to contribute to widely used packages.

For example, the bottom layer will target undergraduates and early PhD students and include work with the Carpentries [24] (both Software Carpentry and Data Carpentry) to develop curriculum modules with astrophysics examples and use cases that will be contributed back to the Carpentries. The middle layer will include training on the use of packages that enable MMA science, on example being `gwpy`, a Python package for gravitational wave analysis [25]. The top developer training layer will include guidance on how to contribute to packages such as AstroPy [26].

The style of training will vary with each layer. While online materials will be made available in all cases (e.g., using MyBinder [27]), the bottom layer will typically be taught via in-person summer schools and short courses, with the middle and top layers taught in person or remotely in short sessions, perhaps up to a half-day. The top layer may also involved personalized mentoring, e.g., via the fellows program (§3.3).

Overall, the role of an institute would be to provide information about existing education and training activities, to create a community of educators and trainers who create and run such activities, to find gaps in the existing activities, and to either develop new activities to fill those gaps as part of the institute or to publicize those gaps and encourage members of the community to fill them outside of the institute.

3.1 General and specialized formal education

While designing the institute's training approach, we will collect, adopt, and in many cases transform general (e.g., from the Carpentries [24]) and specific training solutions (e.g., from LIGO [28], VRO, IceCube) that can be the basis of an introductory MMA data analysis curriculum at the undergraduate and graduate levels. The goal of these program will be to introduce MMA science and a variety of specific techniques to students through hands-on tools. SCiMMA can leverage common and approachable formats such as Jupyter notebooks to develop training examples that can expose students to MMA tools. Additionally, given that MMA is a fast pace real-time science, these training materials can include examples that require communication with SCiMMA's alert system.

In addition to hands-on training materials, multiple review works became available on the topic of MMA science in the past few years, and such texts can be used as supplementary course readings [29, 30, 31].

3.2 Specialized training

SCiMMA's work will contribute to the establishment of common standards for MMA, an easily accessible "language" for astronomers, physicists, and computer/data scientists alike. Standardized data formats and analysis tool sets will be shared with and tested by end users. To this end, SCiMMA will produce a handbook of best practices for cyberinfrastructure and data services development and operations. The handbook will cover software licenses, version control, continuous integration and testing, documentation, development and operations processes and will be used to guide the institute's internal development and operations. Moreover, it will be a key element of the institute's training and broader engagement programs. Beyond formal in person course work, SCiMMA's specialize training will contain online self-teaching elements, and the material will also be adoptable to virtual training sessions.

3.3 Fellowships

A well-organized and broad fellows program can facilitate the long-term sustainability in the SCiMMA institute. Engaging junior researchers, from undergraduates through postdocs and beyond, through internships and fellowships will help them build new skills, to enable members of SCiMMA to gain domain-specific knowledge in new speciality areas, and to diffuse best practices into the community. SCiMMA will recruit members of underrepresented groups and ensure that fellows experience a supportive working environment even across distributed projects. Fellows will be given opportunities to present their work at appropriate conferences (AAS, Astronomical Data Analysis Software & Systems, etc), and publish in Astronomy & Computing, the Astrophysics Source Code Library, and other venues. We organize the fellowships as follows:

3.3.1 Undergraduate Summer Internships

Undergraduate internship programs are a way to bring in undergraduate students interested in both MMA and computing. Research Experience for Undergraduate (REU) program are a specific type of undergraduate internship funded by the NSF. There are two types of REU activities, sites and supplements, and some universities also have REU-site-like programs that are not formally REUs, e.g. NCSA [32]. Both REU sites and supplements are elements of an NSF program [33]. REU sites are programs that bring in cohorts of students (typically about 10) for an about 10-week program where the students participate in research projects and get a sense of how research works, with the goal of potentially encouraging them to continue to graduate school. REU supplements lead to similar undergraduate experiences, but they are typically done one or two students at a time associated with an already-funded NSF project.

Undergraduate summer internships can be coordinated under a distributed SCiMMA institute through these mechanisms. One or more institutions could run REU sites, perhaps cooperatively; multiple projects could have RUE supplements; and some universities and lab could have REU-site-like activities. Summer research students associated with SCiMMA would at least have remote interaction with each other and with the full MMA community, and in some cases, in-person interaction as well. These internships would be open to students at any US institution, regardless of prior participation in MMA, in SCiMMA, or subject area. SCiMMA fellowships organizers and summer research project mentors will ensure that the students work as a cohort distributed across multiple institutions and areas, and use this as an opportunity to expand our reach demographically. The internships will develop skills, given students exposure to a broader range of both scientific and technical areas, and prepare them for new job opportunities.

3.3.2 Graduate Internships

The SCiMMA institute should also engage graduate student research fellows, where a graduate student is paired with institute product development during the summer, for a semester, or possibly longer to provide training and education in software deployment and integration. SCiMMA graduate fellowships would be advertised broadly in the Astronomy, Physics, and CS/DS communities for interested students to apply. The institute would use an internal selection committee to match the top students with research teams who express interest in participating for 10-week programs. At the beginning of the research program, the institute would convene all of the selected interns with mentors for an "MMA Bootcamp," to establish a common vocabulary among the different communities and introduce participants to the institute's cyberinfrastructure environment, codebase and coding standards, and software engineering practices. This would also serve to identify overall goals, elaborate on project structure, and start building a cohort among the students. If needed the institute could also gather material for the bootcamp from existing educational efforts such as the GROWTH summer school [34] or GW Open Science Center workshop materials [35]. The students would work primarily on their project tasks, and would meet once a week online for joint progress updates (as well as informal "Slack" discussions, etc.) Their results would then be presented at one of the Institute workshops during the following year, as well as (if suitable) a national research conference.

3.3.3 Open Source Fellowships

The MMA community depends on a number of open source codes that are critical to analysis of observations and simulation, but are maintained by volunteers. The deep knowledge resides in just a few major developers, whose absence would be deeply felt not just with the software projects that they run, but within the larger community as well. At the same time, educating students in best practices in software engineering is a crucial aspect of sustainable cyberinfrastructure. In an effort to make the MMA open source ecosystem and cyberinfrastructure more robust and sustainable, SCiMMA would offer Open Source Fellowships. During a 4-8 weeks long term, fellows would contribute to and expand ongoing projects, and may spark new initiatives that could be pursued through the longer-term fellowships below.

3.3.4 Seed / Investment Fellowships

The successful experience of the Molecular Sciences Software Institute (MolSSI) [36] in developing these seed / investment fellowships is an excellent example to follow. Initially, graduate students and postdocs will likely come from institutions affiliated with SCiMMA, transitioning to a cohort drawn from a wider range of subject areas over time. The goal is to identify challenging projects that will deliver new capabilities/tools, and have an external Fellow work with mentors within SCiMMA. Within these types of fellowships seeking engagement in subject areas outside MMA or other areas of expertise of SCiMMA, but complementary in the need for solving real-time data synthesis and distribution challenges, would provide a unique engagement with external communities. Seed fellowships could last typically 6 month and some could be extended to 18 months long investment fellowships to cover a full development cycle. Successful applicants would have basic programming knowledge; mentors will guide the m through the conceptualization, development, testing, and release cycle.

3.4 Summer schools

Summer schools are a common way to bring together a cohort of students (who could actually be students, postdocs, or staff) for focused learning about a specific topic or closely related set of topics. These summer schools could be developed and run by an institution/research group, an instrument, or a project. Some examples are the GROWTH summer school [34], Summer School for Statistics for Astronomers XV [37], and Penn State Summer School on Multi-Messenger Astronomy [38].

SCiMMA would contribute back to the community while not reinventing existing venues or opportunities. Instead, SCiMMA members would participate in existing summer schools like the Summer School in Statistics for Astronomers, the The LSSTC Data Science Fellowship Program (which has 3 schools per year), and others by engaging in their planning processes to provide suitable lecturers and modules drawn from SCiMMA personnel. This way SCiMMA can help disseminate knowledge and expertise, without adding a competing summer school.

3.5 Future paths for trained personnel

There is now a strong demand for data scientists in the US workforce, and this is expected to continue to grow, while the supply of skilled applicants is growing more slowly [39]. In addition, 30 to 40% of the highest-level scientists at national laboratories are nearing retirement age [40]. Given these trends, students with data and software skills in MMA areas will not only be prime candidates for MMA positions in universities and national labs, but also will be strong candidates for more general data and software positions in national labs and industry. The institute's approach to long term sustainability includes responding to interest articulated by the stakeholders and the wider community, as well as keeping an an open eye on emerging techniques that may become of interest in the future. SCiMMA expects that through the fellowship program and via participation in summer schools, conferences, and workshops its personnel will have the opportunity to get involved and even support development of innovative techniques (e.g. in machine learning) and thus gain a wide repertoire of frontier tools used in the industry.

4 Mentoring and integration

The aim of both mentoring and integration is to enable people in the field to remain in the field, if that is their favored future goal. We want to ensure that each person has sufficient information to understand their options and to make the choices that are best for them. We also want to remove systematic obstacles that may lead to sacrificing careers, and to ensure all those who want to participate can fully do so. While this is sometimes called inclusion, here we use integration to move away from language that places overrepresented scholars as the default or as arbiters of who should be allowed to participate [41].

4.1 Mentoring

The goal of mentoring is to provide the skills, knowledge, and experiences necessary to help researchers excel in their chosen career path. Mentoring is generally one-to-one (mentor/mentee), but can also include group activities. Mentoring can take place in both informal and formal settings. The process of mentoring does not depend on the person being mentored, though the topics discussed do. Here, we discuss mentoring for postdocs, staff, and faculty (student advising is discussed in the previous section).

Though all topics are not appropriate for all mentees, typical topics of mentoring include training, career counseling and advising. Mentors may advise mentees on which proposal and funding opportunities exist, and how to write successful applications. Additionally, mentors may give feedback on papers and presentations, teaching strategies, sabbaticals and visits, and professional reputation and branding. The mentor may also advise on interpersonal communication and professional practice, as well as teach the mentee how they can become an effective mentor.

The processes of matching mentors and mentees is important to consider, and some institutions may have specific procedures for this task. In other cases, the potential mentee might have to find mentors themselves, including asked them to enter into a mentoring relationship. An MMA institute can help by gathering names of potential mentees and mentors, and suggesting pairings based on mutual interests or career goals. These pairings could be both within and across disciplines, for example, between astrophysics and computer science. An MMA institute could also suggest or provide structure on activities, allowing these mentoring relationships to more easily solidify.

4.2 Integration

While integration refers to the behaviors and social norms that ensure people feel welcome, here we use the term more broadly to consider the systematic problems (e.g., social, cultural, and organizational) we need to overcome that cause people to not feel that they truly part of the field, which in turn can cause them to leave the field. As we mentioned previously, this is sometimes also called inclusion.

A 2004 survey of 330 HR executives [42] found a set of common factors related to inclusion, including: collaborative and participatory work environments and processes; a flat organizational structure; a leadership commitment to diversity, including diversity education and training, and tolerance of and respect for differences; continuous learning; a focus on innovation and creativity; employee support groups, networks or affinity groups; equitable systems for recognition, acknowledgment and reward; representation of different demographic groups in and fair treatment for all internal and external stakeholders; a demonstrated commitment to community relationships; and equal access to opportunity for all employees.

While some of these may be difficult to obtain in a university with a hierarchical structure and culture that has solidified over hundreds of years, others are possible, and many can be addressed at a different level, such as the MMA community, a department, an institute, or a project. Many of these items can be adopted by an MMA institute, and additionally SCiMMA members can espouse these ideals in the community.

A simpler definition is of a collaborative, supportive, and respectful environment that increases the participation and contribution of all by removing all barriers, discrimination, and intolerance [43].

An MMA institute can publicize problems and success stories in the community, and leverage the MMA community to attempt to make systematic changes, alongside other organizations that seek to make similar changes. For example, the Particles for Justice [44] and Vanguard STEM [45] groups seek to challenge racism, misogyny/sexism, ableism, transphobia, queerphobia, xenophobia, anti-Indigeneity and other dehumanizing biases in the broader STEM community. The Maintainers is a global research network interested in the concepts of maintenance, infrastructure, repair, and the myriad forms of labor and expertise that sustain our human-built world [46]. The international software engineering community has formed to support Research Software Engineers (RSEs), a group who combine professional software expertise with an understanding of research, and have typically had little recognition and few career paths in universities [47]. An MMA institute can be uniquely valuable for promoting the work of these organizations given its position at the crossroads of different disciplines and institutions.

5 Education and Public Outreach (EPO)

Beyond training activities that directly serve the institute, additional investment into education and public outreach can allow the institute's data-intensive research to become transformative on a wider scale beyond the immediate key scientific discoveries.

SCiMMA is expected to be led by a cohesive team where cross-fertilization among astronomers/astrophysicists, data scientists, and cyberinfrastructure experts has already achieved a significant level, and will also involve a wider community with expertise in all these areas. The wide range of expertise will enable a unique educational and public outreach program that combines a frontier science topic of MMA - opening a "new window to the Universe" - with directly transferable knowledge in cyberinfrastructure, data science. Public and often time real-time availability of the associated astrophysics observational data also provide opportunity for EPO tool development.

Additionally, SCiMMA's EPO efforts can be carried out in tandem with other EPO programs and existing infrastructures at stakeholder organizations, allowing for the most effective use of resources. For example these include EPO efforts within LIGO, IceCube and VRO. The gravitational-wave community recently established the International Gravitational Waves Outreach Group (IGrav), with a dedicated MMA working group.

This section is organized in subsections addressing specific sectors of SCiMMA's Education and Public Outreach efforts with explicit goals stated at the top. Section 5.1 addresses outreach to the professional community, section 5.2 focuses on higher education, section 5.3 similarly addresses formal education at the K-12 level, and finally section 5.4 explains SCiMMA's informal education and public outreach plan.

5.1 Outreach to the professional community

Goal: Advertise SCiMMA tools widely in order to gain traction in the broader scientific and academic community for MMA science.

SCiMMA will enable a variety of scientific projects in the following areas: data management; communication and collaboration; analysis and inference, including machine learning and modeling. Critically, these goals can only be achieved through widespread community adoption of SCiMMA tools and involvement in SCiMMA projects, and thus outreach to the professional community is paramount. Ideally, scientists will begin to use out tools for their own projects, and build scientific projects on our platform. Additionally, some people may become involved more deeply in SCiMMA by working to develop new SCiMMA tools.

SCiMMA can also serve as an advocate for funding for the instrumental side of MMA science by supporting the different observatories that collect the data to make MMA science possible. This general funding advocacy for astrophysics will extend to projects such as future generation gravitational wave detectors such as LISA or Cosmic Explorer, improvements to neutrino detectors such as IceCube Gen2, or future electromagnetic telescopes such as the Vera Rubin Observatory (VRO) or Nancy Grace Roman Space Telescope.

5.2 Higher education

Goal: Teach MMA science in a way that showcases both how it is intrinsically linked to big data science and how this science is enabled by tools that SCiMMA provides.

Higher education is conducted in community colleges and universities by faculty and via online settings. SCiMMA can provide well-tested classroom materials, as well as train the faculty who will deliver these materials. Web materials such as standard lecture slides or think-pair-share activities can be developed for use in introductory courses. Video recordings of SCiMMA presentations or demonstrations can also be distributed. Many of the materials developed for senior high school students may also apply to lower division undergraduate students. SCiMMA scientists can work directly with college students in classroom settings and through research opportunities, and SCiMMA tools can be used in an educational setting in lab-based courses. MMA courses are already being offered at some universities where students can complete smaller scale research projects. Additionally, as mentioned in Section 3, undergraduate summer programs and graduate internships are effective ways to include and train students. Participating in University's Colloquium or Seminar series is another potential path for SCiMMA to reach students at the higher education level.

5.3 Formal education, teachers' professional development (K-12)

Goal: Engage students from a young age by increasing the accessibility of MMA research through physical science and computer science education.

Formal education targets direct work with students in a classroom setting. Creation of easily accessible and well-tested classroom materials on MMA is preferentially done jointly with the teachers who will eventually deliver these materials. For general science classrooms in middle schools and high schools, demonstrating that discoveries happen in a fast pace in near real-time will generate excitement and interest in our frontier field.

SCiMMA can broaden its impact through collaborating with and training teachers to bring MMA science to a classroom setting on a large scale, both in physical science and computer science courses. Well-tested material that aligns with curriculum standards is critical, and can be developed with the Next Generation Science Standards (NGSS) [48]. The NGSS outlines K-12 science content standards and emphasizes three equally important dimensions in science education: Disciplinary Core Ideas (DCIs), Science and Engineering Practices, and Cross-Cutting Concepts. The High-School level DCIs relevant to SCiMMA include PS2: Motion and Stability: Forces and Interactions; PS3: Energy; PS4: Waves and Their Applications in Technologies for Information Transfer; and ETS1: Engineering Design. PS4 also includes information technologies, and SCiMMA's cyberinfrastrucre framework can be used as an example of how information technology can be applied to scientific research.

By leveraging existing networks to engage teachers, the SCiMMA team will be able to further their reach. Organizations such as Girls who Code [49], Black Girls Code [50], or the Computer Science Teachers Association (CSTA) [51] already have systems in place to disperse cutting edge computer science materials to students. Additionally, SCiMMA scientists can directly reach K-12 classrooms through programs such as Skype a Scientist [52], a non-profit organization that matches scientists with teachers around the world for guest lectures in classes.

SCiMMA can also contribute to increasing the accessibility of science by developing classroom materials with disability inclusion in mind. These materials could include tactile objects, such as 3D printed models of astronomical objects [53], or audio tracks generated through the sonification of real data [54].

5.4 Informal education, public outreach

Goal: Introduce multi-messenger science to the general public and amplify the connection between astrophysics and big data science methods.

Informal activities can effectively strengthen the broader impact of SCiMMA on the public. These initiatives will allow SCiMMA science to reach a larger audience in a more accessible and sustainable way. Social networks are a valuable tool for making current science news accessible to members of the public. Common social networking sites such as Facebook and Twitter are frequently used for science communication and outreach, and SCiMMA can create pages through these sites to amplify news and events. Social media sites also provide another avenue of professional outreach to the science community in addition to the public. SCiMMA can also reach the public through web-based outreach on the `scimma.org` website. This site includes a "News" page which highlights items such as updates on awarded NSF grants, recordings of public telecons, and information on SCiMMA presence at meetings or conferences.

Another way for SCiMMA to participate in public outreach initiatives is through utilizing existing groups to expand our network. Many universities and observatories already host regular public outreach events such as stargazing nights or planetarium shows. SCiMMA can generate standard presentation slides or planetarium shows which can be distributed through these networks, and additionally SCiMMA scientists can participate or host some of these events at their local institutions. Additionally, an MMA institute could coordinate participation with stakeholder partners in broader events such as the USA Science & Engineering Festival or the World Science Festival in order to further extend its reach.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant Nos. 1841370, 1841544, 1841586, 1841588, 1841590, 1841591, 1841594, 1841598, 1841612, 1841617, 1841625, 1841636.

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