



2015-2016 Center Self-Study/Program Review

Official name of center: Gravitational-Wave Physics and Astronomy Center

Name(s) and academic title(s) of the person(s) who head(s) the center/institute:

Joshua Smith

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Year established: 2012

Year of last review: N/A

Date the review is being submitted: April 15, 2016

Name of primary authors:

Dr. Joshua Smith (Director)

Dr. Al Agnew

Dr. Geoffrey Lovelace

Dr. Jocelyn Read



Mission and goals: The mission of the Gravitational-Wave Physics and Astronomy Center is to conduct research, education and outreach in gravitational-wave astronomy, physics and astrophysics. The goals of GWPAC are to train the next generation of leaders in gravitational-wave science and other STEM disciplines, to promote a diverse gravitational-wave science community, to communicate exciting new developments to the broader community, and to expand our knowledge of the universe through gravitational-wave observations.

Activities: [Gravitational wave discovery press conference](#) - GWPAC worked with CSUF Strategic Communications and Advancement to hold a campus press conference highlighting GWPAC contributions to the first direct detection of gravitational waves. "One of the most dramatic predictions of Einstein's century-old theory of general relativity has been substantiated—there are observable ripples in the fabric of spacetime."

[Hosted Chancellor White, Vice Chancellor Blanchard, and President García](#) - GWPAC welcomed Chancellor White, Executive Vice Chancellor Loren Blanchard, and President García among other guests to discuss the recent discovery and the operations of the center. Smith gave an overview of GWPAC and its participation in the historic gravitational-wave observation. In a follow-on poster session, the guests met with students to discuss their research.

[Gravitational wave discovery philanthropic event](#) –On April 7 2016 GWPAC faculty and students worked with CNSM and development to hold the "Gravitational Waves: Examining the Universe in a Whole New Way" event at the Center Club in Costa Mesa. It was attended by donors, faculty, administrators, students and other supporters. Black's major support was announced.

[2016 TACIB Program Event](#) – Transforming Academic and Cultural Identidad through Biliteracy (TACIB) members Read and Agnew and three GWPAC students participated in an outreach event with 3 45 minute interactive sessions of the gravitational-wave discovery with hands on demos for 120 Anaheim middle school students.

[Pacific Coast Gravity Meeting](#) - The 32nd Pacific Coast Gravity Meeting (PCGM) was held at CSUF April 1- 2, 2016. As with past PCGM meetings, this was a relaxed and informal conference open to researchers and students interested in all areas of gravitational physics. Lovelace organized the meeting and three Fullerton students were among the presenters.

[Established the Orange county Relativity Cluster for Astronomy \(ORCA\)](#) - With funding from the Research Corporation for Science Advancement, a Major Research Instrumentation award from the National Science Foundation, and startup funds from CSUF, GWPAC completed a major upgrade and expansion of its on-campus computing cluster. This more than doubles the number of student projects that ORCA can support, including simulations of merging black holes and neutron stars, gravitational-waveform modeling, and LIGO detector characterization algorithms.

[Posters on the Hill event in Washington DC](#) – Undergraduate Haroon Khan was selected as one of 60 students from the entire US out of an applicant pool of more than 500. Haroon and Lovelace also met with U.S. Representative Ed Royce (CA-39) and his staff, and with staff from the offices of U.S. Representative Loretta Sanchez (CA-46) and U.S. Senator Dianne Feinstein.

[Hosted NARDA 2014 conference](#) – Lovelace and Read organized the Numerical and Analytical Relativity and Data Analysis (NARDA) meeting held at CSUF. The purpose of the meeting was to bring together numerical relativists, analytic relativists, and gravitational-wave astronomers to discuss progress and challenges in gravitational-wave source modeling and searches.

[Hosted TASC meeting 2015](#) – Lovelace organized the Theoretical Astrophysics in Southern California (TASC) meeting to bring together the theoretical astrophysics community in Southern California, including students, postdocs, researchers, and faculty members.

[Hosted Syracuse University Gravitational Wave Group as part of Bridge Program](#) - Syracuse University Gravitational-Wave Group members Samantha Usman (undergraduate), Fabian Magaña-Sandoval (grad student), and Duncan Brown (faculty) visited GWPAC from May 19 to



23 2014. Their visit was part of the bridge program between the BS/MS program at Fullerton and the Ph.D. program in Syracuse. Throughout the week discussions focused on graduate school opportunities at Syracuse, collaborative research projects, and career mentoring.

[Read and Smith invited to workshop in Pune, India](#) - Read and Smith were invited participants at the Gravitational Wave Physics and Astronomy Workshop (GWPAW) held December 17- 20, 2013 at the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in Pune, India. Read presented on "Measuring the Neutron Star Equation of State," and Josh on "Detector characterization to prepare for the first gravitational-wave detections."

[Center opening](#) - GWPAC opened with an event attended by scientists, center members, alumni, and other friends of the center. Keynotes were given by Gabriela Gonzalez and Kip Thorne, after an introduction by Interim CNSM Dean Bob Koch, and followed by a reception and a student research poster session. Leaders from gravitational-wave science in attendance also included Dave Reitze, Director of LIGO, Albert Lazzarini, Deputy Director of LIGO, Alan Weinstein, Caltech, and Duncan Brown, Syracuse. Gonzalez also met with the Physics Club to describe summer-research and graduate-study opportunities in the LIGO community.

Organizational structure and governance: The center is directed by Smith, and Associate Director Read. Faculty members Lovelace and Agnew are closely involved in the center's decision making. This group of faculty members meets to discuss plans and goals informally throughout the year and all have access to the GWPAC dropbox with all center documents. We are also considering having a GWPAC faculty retreat focused on the future plans of the center. This group of faculty could be called the Governing Board, but we prefer a more informal structure. Additionally, we hold weekly (in summer) or bi-weekly (in the academic year) meetings of GWPAC with all faculty, staff, and students present, and we invite members of the public and visiting members of GWPAC to join these meetings and our mailing list. Both are forums for all members of the center to discuss not only science but also organization.

Finally, in the PAARE proposal, "Catching a new wave: the CSUF-Syracuse partnership for inclusion of underrepresented groups in gravitational-wave astronomy," we formed an advisory board whose role is to provide annual review of the program based on outcomes and site visits. This team is a carefully selected team of leaders in science and education, including Gabriela Gonzalez (LSC Spokesperson, LSU), Lynn Cominsky (Sonoma State, Physics), John Tillotson (Syracuse University, Education), and Sissi Li (CSUF, Chemistry), and we believe that their oversight on this major grant will also provide a high degree of external review for the operation of our center, since the center and grant are closely intertwined.

Resources and sustainability: *List of revenue received by the center/institute –*

Private Support (\$233,000)

- Establishment of Dan Black Director of Gravitational Wave Physics and Astronomy, **\$225,000**
- Smart Board from Dan Black, **\$5,000**
- 2016 GWPAC Scholarship, donation by Nancy Goodhue-McWilliams and match by Dan Black, **\$3,000**



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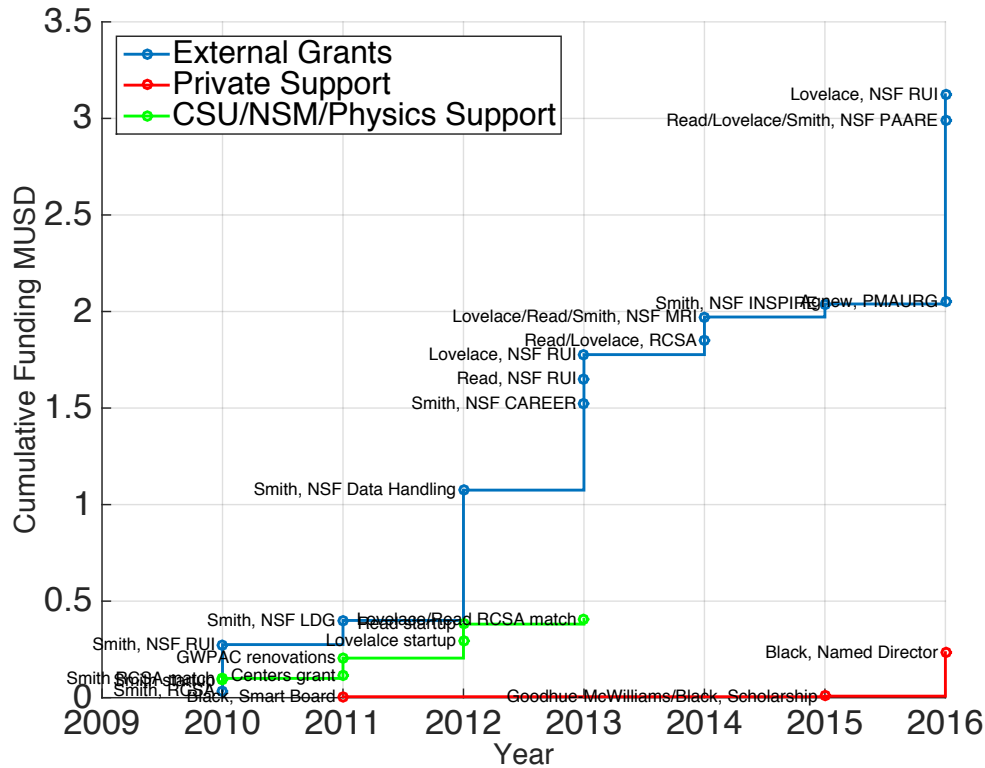


Figure 1: Grants and support for GWPAC broken down by external (federal and private) grants, private philanthropic support, and CSU/CNSM/Department grants and support.

External Funding (\$3,122,382)

- Smith, Research Corporation for Science Advancement (RCSA), Cottrell College Science Award # 19838, “Extending the astronomical reach of gravitational-wave detectors with all- reflective interferometry,” **\$35,000, awarded 2010-2012**
- Smith, National Science Foundation (NSF) PHY-0970147, “RUI: LIGO detector characterization and optical scatter research,” **\$240,000, awarded 2010-2013**
- Smith (Senior Personnel), NSF PHY-0600953, “Enabling Gravitational- Wave Astronomy on the LIGO Data Grid,” **\$125,000 subcontract to CSUF, awarded 2011-2012**
- Smith (Senior Personnel), NSF PHY-1104371, “Data Handling and Analysis Infrastructure for Advanced LIGO and Beyond,” \$9,000,000 all institutions, **\$675,000 CSUF sub- contract, awarded 2012-2017**
- Smith, NSF PHY-1255650, “CAREER: Gravitational-Wave Detector Characterization and Science Education in the Advanced LIGO Era,” **\$450,000, awarded 2013-2018**
- Read, NSF PHY-1307545, "RUI: Dense Matter and Gravitational Waves: The Coalescence of Neutron Star Binaries," **\$126,000, funded 2013–2016**
- Lovelace, NSF PHY - Gravitational Theory, “RUI: 2012 Numerical Simulations of Merging Black Holes and Neutron Stars,” **\$125,723, awarded 2013–2016**
- Read/Lovelace, RCSA, Multi Investigator Cottrell College Science Award, “Developing a numerical injection analysis pipeline for gravitational waves from merging black holes and neutron stars,” **\$75,000, awarded 2014–2016**



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- Lovelace/Read/Smith, NSF PHY-1429873, “MRI: Acquisition of a high-performance computer cluster for gravitational-wave astronomy with Advanced LIGO,” **\$119,791, awarded 2014-2017**
- Smith (Col), NSF 1547880, “INSPIRE: Glitch Zoo: Teaming citizen science with machine learning to deepen LIGOs view of the cosmos,” **\$67,500, awarded 2015-2018**
- Agnew, Pacific Math Alliance Undergraduate Research Groups grant (PMAURG, part of a broader NSF grant), “On an Extension of the Manifold Concept,” **\$11,000, awarded**
- Read/Lovelace/Smith: NSF AST-, “Catching a new wave: the CSUF-Syracuse partnership for inclusion of underrepresented groups in gravitational-wave astronomy,” **\$937,368 for five years, recommended**
- Lovelace, NSF PHY-, “RUI: Computational gravitational-wave research for the era of first observations” **\$135,000 for three years, recommended**

CSU Funding (\$15,000)

- (PI) CSUF Office of the Associate Vice President for Graduate Programs and Research, Center and Institute Planning and Expansion Program, “Three-year plan for funding and expansion of the Gravitational-Wave Physics and Astronomy Center (GWPAC),” **\$15,000, funded 2011-2012**

Department/NSM Support (\$391,000+39WTUs)

- MH601 room renovations for the GWPAC center, **\$90,000**
- Release time for center director Smith since 2014, **6 WTU per year**
- Smith startup package: **\$90,000 and 6 WTU release time for two years 2010-2012**
- Lovelace startup package: **\$88,000 and 3 WTU release time for two years 2012-2014**
- Read startup package: **\$88,000 and 3 WTU release time for two years 2012-2014**
- NSM match of NSF teaching release for Lovelace, **3 WTU**
- NSM institutional match for Smith Research Corporation award **\$10,000**
- NSM institutional match for Lovelace/Read Research Corporation award **\$25,000**

Additional resources – Facilities: GWPAC has a 590 square-foot main room with video-conferencing capability and student work areas that are available to the faculty, staff, students, and collaborators for interaction, group meetings, and collaboration teleconferences. Lovelace, Read, and Smith each have a roughly 140-square-foot individual office in the Center. Smith’s group has dedicated lab space with four rooms totaling 730 square-feet of floor space. Students have work areas available to them in the GWPAC student work area and in Smith’s lab.

Equipment: GWPAC manages a 576-compute-core computing cluster, ORCA (576 Intel Sandy Bridge compute cores, 2.66 GB of RAM per core, QDR Infiniband networking, 33 TB storage) located in the CSUF Data Center. Additionally, GWPAC has five desktop computers for student researchers. Smith’s lab houses two optical benches, two soft-wall cleanrooms, four workstations, and a custom-built scatterometer. These computing resources and equipment are available for student research as part of the center activities.

Other resources: Many center members have access to LIGO data and computing resources on the LIGO Data Grid as part of their LIGO Scientific Collaboration membership, and the usage of these resources is coordinated within the LSC’s working groups. Similarly, SXS resources including the active Extreme Science and Engineering Discovery Environment (XSEDE) allocation are available to students working on related projects with Lovelace.



Faculty and staff associated with center and their approximate time base – Smith is the only faculty member that has had support, in the form of 3 WTU per semester for the past two years, for directly participating in GWPAC leadership and activities. Below are Full-Time-Equivalent estimates of time that faculty and staff devote to GWPAC-related activities such as gravitational-wave research, education, and outreach, regardless of funding source.

- Al Agnew - faculty member, 100% of research time in GWPAC, 0.25 FTE
- Joseph Areeda – scientific computing specialist, 1.0 FTE
- Duncan Brown – visiting member, Syracuse University 0 FTE (1 visit / year)
- Matthew Duez - visiting member, Washington State University 0 FTE (1 visit / two years)
- Prashanth Jaikumar – visiting member, CSU Long Beach 0 FTE (3 visits / year)
- Geoffrey Lovelace – faculty member, 100% of research time in GWPAC, 0.5 FTE
- Jocelyn Read - faculty member, 100% of research time in GWPAC, 0.5 FTE
- Joshua Smith – faculty member and director, 6 WTU per year and 12-month director, 100% of research in GWPAC, 0.75 FTE

Assigned space and administrative unit that assigns it – GWPAC is located in McCarthy Hall room 601, which includes a 590 square-foot main room that is used for interaction, center meetings, and collaboration video conferences. Additionally, Lovelace, Read, and Smith each have a roughly 140-square-foot office in the Center. Smith's group has four lab rooms totaling 730 square-feet. GWPAC manages a 576-compute-core computing cluster, ORCA (576 Intel Sandy Bridge compute cores, 2.66 GB of RAM per core, QDR Infiniband networking, 33 TB storage) located in the CSUF Data Center. The GWPAC center and Smith's lab are assigned by CNSM. The Data Center location of ORCA is assigned jointly by CNSM and IT.

Costs associated with the space – We are not aware of additional costs associated with MH-601 (GWPAC), or DBH-167/168 (Smith Lab). The costs of the power and cooling for ORCA housed in the university data center are covered via an agreement between CNSM and IT.

Degree of sustainability – Based on the level of funding and accomplishments of the center, compared with the costs, we believe that the center is highly sustainable.

Highlights and accomplishments: *Student training* - Since its inception, GWPAC has trained 39 students in research. Nine of those students are now in PhD programs: Abbott (LSU), Avila-Alvarez (Florida), Giesler (Caltech), Katebi (Ohio), Kuper (Arizona) Magaña-Sandoval (Syracuse), Muniz (Syracuse), Vander-Hyde (Syracuse), Serna (Syracuse). Nine are in industry: Foley (DNB Engineering), Islas (Liminit), Padilla (Northrop Grumman), Francis (Air Force), Griffio (Celestron), Kuper (Cytec), Lee (Northrop Grumman), Chen, and Harris. Other students are pursuing different degrees: Wood and Vong (transferred to UC Berkeley), and Rodriguez (Stanford MBA program). Lockett, Hankins, and Ozaeta are teaching as adjunct faculty.

Diversity – Of the 39 students that have participated in GWPAC activities, 11 are women and 14 more are members of minority groups traditionally underrepresented in physics, mathematics, and astronomy. Further information about GWPAC students is given in Figure 1.

Scientific output - GWPAC members have authored more than 30 publications since the center formed, many with student co-authors, as listed on the [GWPAC publications page](#). Additionally, members have given dozens of presentations at national and international meetings.



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Letters from government - Smith received a letter from Senator Dianne Feinstein (CA) congratulating him on the recent observation of gravitational waves. In 2013, Smith received a CA Assembly Resolution by Diane Harkey (CA-73) and Mimi Walters (CA-37) congratulating him on receipt of the NSF CAREER award and on leadership as the director of GWPAC.

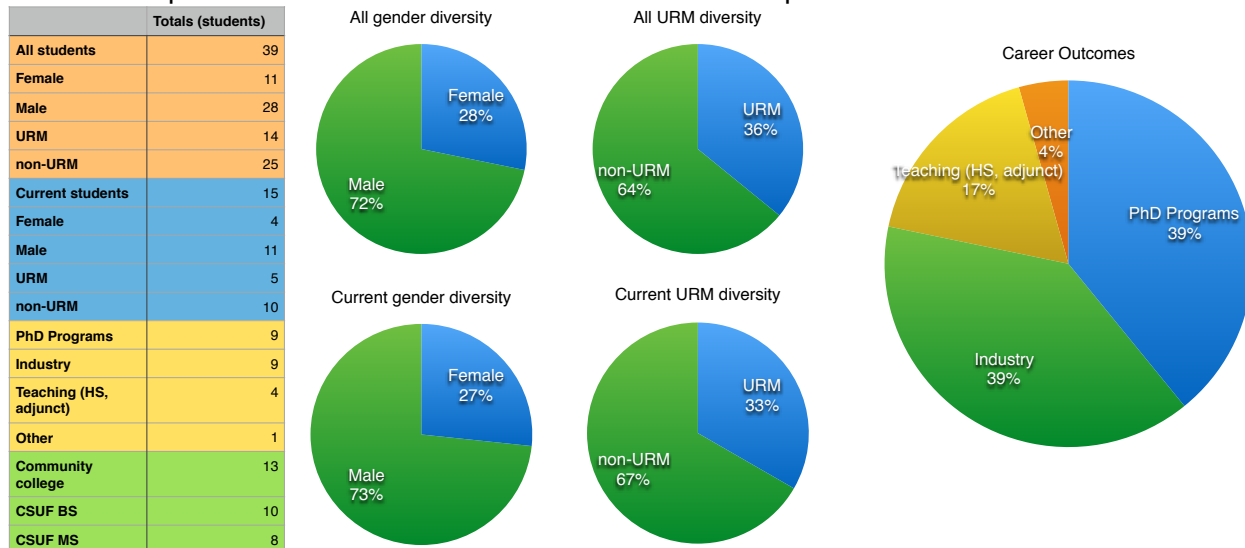


Figure 2: GWPAC student diversity and career outcomes, at a glance. All refers to all students that have done significant projects in GWPAC and current is the subset of those currently in GWPAC.

Role in discovery - The members of GWPAC played important roles in the discovery of gravitational waves from merging black holes. Smith was one of six primary editors of the [scientific paper announcing the discovery](#). Lovelace and students led computation of the waveform models used to compare with the signal in the paper and Lovelace wrote software to filter the data and make the figures shown in the paper. Read helped make choices about the parameters of the search used to find the gravitational waves. She was also the editor of the [science summary of the paper](#) and a social media coordinator for LIGO. Lovelace, Smith, Read, and [six CSUF alumni](#) (Abbott, Hacker, Islas, Magaña-Sandoval, Serna, Vander-Hyde) are co-authors on the paper, one of the most significant publications of the 21st century.

Selected media coverage related to the gravitational-wave discovery - The [CSUF News](#), "Gravitational Waves: A Cosmic Discovery," [Ars Technica](#), "How gravitational wave detectors survived the Contract With America" (Lovelace quoted on taxpayer funding of basic research), [Nature News](#), "Young scientists poised to ride the gravitational wave," (Read quoted), [89.3 KPCC](#) (Read interviewed), [CNET Tomorrow Daily](#), "LIGO team member Joshua Smith explains gravitational waves discovery with Tomorrow Daily," [OC Register](#), "José Luis Cruz: The 'ripple effect' of the university's centers and institutes," [LIGO Magazine Issue 8](#) (Cartoons include Smith and Abbott), [CBS2 LA](#) "Cal State Fullerton Researchers Help Confirm Presence Of Gravitational Waves Predicted By Einstein," The [Daily Titan](#), "Fullerton faculty and students involved in the discovery of Gravitational Waves," The [Daily Titan](#), "The brains behind the wave discovery," [Microcap magazine](#), [UDN](#), and Adirondack Life.

These achievements have greatly contributed to the goal of promoting faculty and student research and engagement; GWPAC Students, faculty, and staff work together to accomplish research, education, and outreach. Having experts that span complimentary aspects of gravitational-wave science, and members at different stages of their careers, and strong



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collaborations provides diverse opportunities, allowing our members to accomplish more together than they could separately.

Planning and strategic outlook: Our goals for the coming three-year period are to: Grow research, teaching, and outreach capacity in the center by hiring staff members or postdoctoral associates; Continue and expand our contributions to gravitational-wave discoveries, their interpretation, and communicating them to other scientists and the public; Increase our student career training and placement capabilities through stronger ties with industry and better graduate school preparation, particularly for the subject GRE exams; Carry out the newly recommended NSF PAARE program, which we expect to have a national impact on diversity in physics PhDs.