Program Review Self Study for The Nicholas and Lee Begovich Center for Gravitational-Wave Physics and Astronomy, 2016-2023

Name – The Nicholas and Lee Begovich Center for Gravitational-Wave Physics and Astronomy

Names and academic titles of the persons who head the CCI – Director: Dr. Joshua Smith, Professor of Physics, Dan Black Director of The Nicholas and Lee Begovich Center for Gravitational-Wave Physics and Astronomy

Associate Director: Dr. Jocelyn Read, Associate Professor of Physics

College within which the CCI conducts its functions – The College of Natural Sciences and Mathematics

Contact information – x3716, josmith@fullerton.edu, MH-601

Year established – 2012

Year of last review– 2016

Date the review is being submitted – March 15, 2023

Authors – Dr. Joshua Smith, Dr. Jocelyn Read, Dr. Alphonso Agnew, Dr. Geoffrey Lovelace

Mission and Goals –

The mission of The Nicholas and Lee Begovich Center for Gravitational-Wave Physics and Astronomy (GWPAC) 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.

Our mission and goals closely align with the CSUF Mission:

California State University, Fullerton enriches the lives of students and inspires them to thrive in a global environment. We cultivate lifelong habits of scholarly inquiry, critical and creative thinking, dynamic inclusivity, and social responsibility. Rooted in the strength of our diversity and immersive experiences, we embolden Titans to become intellectual, community, and economic leaders who shape the future.

Especially around enrichment of student lives and emboldening them to become leaders, dynamic inclusivity, and scholarly inquiry and critical and creative thinking.

The CNSM vision states:

Through creating knowledge and learning by discovery, NSM changes the lives of students while preparing them for advanced degrees and successful careers in science and mathematics.

Our goals are closely aligned with this vision as we focus on learning by discovery and preparing students for advanced degrees and successful careers in STEM.

Activities – The Nicholas and Lee Begovich Center for Gravitational-Wave Physics and Astronomy (GWPAC) was founded at California State University Fullerton (CSUF) in 2012. Center members have contributed to gravitational-wave discoveries from merging black holes and neutron stars and developed techniques and technologies to further the field. More than 50 students have graduated from CSUF as members of the center with roughly half entering Ph.D. programs, and half entering STEM industry or teaching. The center has been able to provide outstanding opportunities through significant federal and philanthropic support.

With support from Dan Black and family, the National Science Foundation, Nancy Goodhue-McWilliams, and Nicholas and Lee Begovich, GWPAC operates a research center (MH601), research laboratories (DBH168), and a supercomputer (Ocean) on the Cal State Fullerton campus and employs 25 group members. These students, faculty, and staff work together to broaden our understanding of the universe through gravitational waves. The current research focuses are to, 1) make and interpret gravitational-wave discoveries from black holes and neutron stars with LIGO; 2) model and interpret the waveforms and spacetime around black holes and neutron stars to help interpret and extend LIGO's discoveries; 3) improve the state-of-the-art in gravitational-wave optics; and 4) design the next generation US gravitational-wave detector, Cosmic Explorer, that will operate in the 2030s and observe stars to the farthest reaches of the universe.

Training the next generation of leaders in gravitational-wave science and STEM – CSUF is internationally known for training undergraduate students in gravitational-wave physics. Since 2012, 25 of the graduates of our Center have entered physics/optics PhD programs at Caltech (1), MIT (1), Northwestern (2), Zaragoza (1), Brandeis/Michigan (1), LSU (3), Syracuse (6), Arizona (1), Chapman (1), Washington State (1), Illinois (1), Michigan State (2), Mississippi (1), Ohio (1) and UCLA (1). Of the 25 students who have entered PhD programs, 11 have been women, 44%, double the national average tracked by the American Physical Society. Half our graduates who have entered PhD programs are members of underrepresented groups in physics, whereas the national averages are only 15% of bachelors and 7% for PhDs. This impact is underscored by the NSF's $1.2M renewal of the CSUF-led partnership for doctoral programs in gravitational-wave astronomy and its expansion to include new partners Northwestern University and Washington State University. A similar number of students have entered industry and teaching positions at the Aerospace Corporation, the US Air Force, Newport MKS, Hedgefog Inc., and Intellisense Inc. Many of our students also participate in summer research experiences, such as at Cornell, UNH, and internationally. To commemorate a decade of student success, we hosted both a scientific meeting and an alumni barbeque.

Expanding our knowledge of the universe through gravitational-wave observations – GWPAC faculty, staff, and students have played key roles in the discovery and interpretation of gravitational waves. Highlights include the observations of gravitational waves from a binary neutron star for the first time (CSUF News, a watershed moment in science in which Dr. Jocelyn Read played a leading role, especially in observing the presence of tides on the neutron star), a neutron star swallowed by a black hole (CSUF News), a black hole merger with 20 times the mass of the sun and the other 30 times the mass of the sun, from 3 billion light years away (CSUF News), a merger with a "mystery object" (CSUF News).

Organizational Structure and Governance – The center is led by a director, currently Smith, and an Associate Director, currently Read. Faculty members Lovelace and Agnew are closely involved in the center's decision making and reporting processes (although we note that Agnew is currently less available for GWPAC activities due to his high level of service as chair of Mathematics). This group meets to discuss plans and goals informally throughout the year and all have access to center documents. This group 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. Center events such as scientific meetings and barbeques also serve as venues to get input on center planning from the wider center and from visitors.

In the NSF-funded PAARE project, "Catching a new wave: the CSUF-Syracuse partnership for inclusion of underrepresented groups in gravitational-wave astronomy," and its renewal, "The CSUF-led 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. These teams were carefully selected to include leaders in science and education. They include(d) Gabriela Gonzalez (LSU, Physics), Lynn Cominsky (Sonoma State, Physics), John Tillotson (Syracuse University, Education), and Sissi Li (CSUF, Chemistry). Their oversight on these major grant activities also provides a high degree of external review for the operation of GWPAC, since the center and grant are closely intertwined.

Resources and Sustainability –

Private Support ($6.61M new support received in last 3 years) –

- 2021 $6.35M donation by Nicholas and Lee Begovich to benefit CSUF gravitational-wave faculty and student research. CSUF News
- 2021 $225,000 Dan Black Family Trust donation to support gravitational-wave research through the named directorship, the Dan Black Director of GWPAC
- 2020 $30,00 donation by Nancy Goodhue-McWilliams to support the Nancy Goodhue-McWilliams Graduate Fellowship

External Support ($2.13M new funding received in last 3 years) –

- 2022 (Read PI) National Science Foundation (NSF) PHY-1806962, "RUI: Dense Matter and Gravitational Waves: The Coalescence of Neutron Star Binaries", $204,874 awarded 2022-2025.
- 2022 (Lovelace PI), NSF PHY-2208014, "RUI: Next-Generation Numerical Relativity for Future Gravitational-Wave Observatories, $225,832 awarded 2022-2025.
- 2022 (Smith PI) NSF PHY-2207998, "RUI: Advancing gravitational-wave optics to further explore the cosmos," $355,683 awarded 2022-2025.
- 2022 (Smith Subcontractor, CSUF PI), Department of Defense SBIR topic AF221-0005, Contract Number: FA9451-22-P-A007, "Computer Vision Enhanced Reflectance Analyzer (CoVERA)," $4,482 awarded 2022-2023.
- 2022 (Lovelace PI, Smith, Read Co-PI) NSF AST-2219109, "The CSUF-led partnership for inclusion of underrepresented groups in gravitational-wave astronomy," $1,180,214 awarded 2022-2027.
- 2021 (Smith Senior Personnel) NSF PHY-2110594, "Data Handling and Analysis Infrastructure for Gravitational-wave Astronomy," $753,324 awarded 2021-2025.
- 2020 (Smith PI) NSF PHY-2019184 "MRI: Acquisition of a Cryogenic Testbed for Advancing Gravitational-Wave Observation Technology," $159,934 awarded 2020-2023.

CSUF Support (6 WTU/year) –

- Release time for center director Smith, 6 WTU per year

Faculty and staff associated with center and their approximate time base –

- Al Agnew - faculty member, 0.02 FTE (full FTE as chair of mathematics department)
- Joseph Areeda – scientific computing specialist, 1.0 FTE
- Gabriel Bonilla - postdoctoral research associate, 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 (1 visit / year)
- Phillipe Landry – visiting member, Canadian Institute of Theoretical Astrophysics, 0 FTE (1 visit/ year and remote student mentoring)
- 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 named directorship, 100% of research in GWPAC, 0.75 FTE
- Lynn Washatka – administrative assistant, 0.63 FTE

Assigned space and administrative unit that assigns it – GWPAC is 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. The GWPAC laboratory, for conducting physics experiments, is in Dan Black Hall room 168. This 1280 square-foot lab has been newly

renovated and upgraded (with philanthropic and external support) to feature technology for next-generation gravitational-wave observatories. GWPAC manages a small, heterogeneous computing cluster, Ocean, housed in the CSUF Data Center (a secure facility providing redundant power and cooling). Ocean contains the following groups of compute nodes: 35 Intel Sandy Bridge nodes, 420 total cores, 2.66 GB of RAM/core, Gigabit Ethernet networking; 12 Intel Xeon Broadwell nodes, 240 total cores, 3.2GB RAM/core, FDR InfiniBand networking; 8 Intel Xeon Cascade Lake nodes, 192 total cores, 4GB RAM/core, FDR InfiniBand networking; Ocean also contains a head node (20 Xeon Broadwell cores, 64GB RAM, FDR InfiniBand networking, 33 terabytes of storage). The GWPAC center and laboratory are assigned by CNSM. The Data Center location of Ocean 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-168 (GWPAC Lab). The furniture, supplies, computers, etc. in these spaces are funded by philanthropic and external support. 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 – Several highlights were covered above in activities. It is worth reiterating the leading role that Dr. Jocelyn Read and her students played in the discovery of GW170817, the first binary neutron star system seen with gravitational waves (CSUF News). Additionally, Lovelace, Read, and Smith are among the leaders planning the United States' next-generation gravitational-wave observatory, Cosmic Explorer (Titan Magazine, Cosmic Explorer Horizon Study). These activities, both deeply involving faculty and student research, have positioned GWPAC very well along research avenues for the coming six years. Additional accomplishments, including student-faculty publications are listed on the GWPAC website.

Planning and Strategic Outlook – Based on the GWPAC mission and goals and its organizational structure and governance above, and context in the field of gravitational-wave science and at CSUF, our center has outlined the following plans for the coming 6 years.

Plan 1: Student success. To provide exceptional opportunities to CSUF students that will advance their knowledge and their careers and help them to become future leaders in STEM. Sub-Plan 1: To have a national impact on the number of students from backgrounds traditionally underrepresented in STEM that achieve PhDs in gravitational-wave science and related fields.

Plan 2: Gravitational-wave discoveries. To contribute prominently, through student, faculty, and postdoctoral research, to the experimental measurement and interpretation of gravitational-wave discoveries.

Plan 3: Making the vision for future gravitational-wave observatories a reality. To chart and execute a vision for gravitational-wave research at CSUF in the new era of discovery. To play leading roles in the design of the United States' next-generation gravitational-wave observatory that will allow humanity to observe gravitational waves across almost the entire universe.