RFP 15190 - Appendix 1

Following the success of building sustainable research infrastructure in bionanotechnology for public security and environmental safety, WVEPSCoR is seeking to build with this RII, world-class programs in two research areas of local and national importance by capitalizing on existing strengths. The research foci address fundamental science questions that align with state and NSF priorities in water resources science and gravitational wave astrophysics. Across both research foci, education, workforce development, and faculty mentoring programs engage students, the public, and faculty in research activities. Research efforts are led by WV Univ., Marshall Univ., and WV State Univ. Predominantly Undergraduate Institutions are also actively engaged in related research and workforce development activities. The proposed effort builds on recent investments by all three institutions, the state, and federal agencies in new faculty hires, shared experimental facilities, high-speed networks, and comprehensive workforce development programs. This proposal is aligned with *Vision 2015*, the state's science and technology plan.

Intellectual Merit: The combined science activities span the range of applied science to basic research. The common theme of both research areas is the development of tools needed to acquire and analyze large quantities of measurements and numerical simulations. Critically needed infrastructure will be built for two key, state-relevant research areas. The biologists, ecologists, environmental engineers and scientists, chemists, and geologists that will collaborate with each other through the Appalachian Freshwater Initiative (AFI) will develop analytical facilities and expertise to form a world-class research team focused on understanding and detecting ecological and biological impacts of complex mixtures of contaminants in water under varying climate change scenarios. To understand and manage the risks of environmental contamination and to ensure a future clean water supply, the AFI will develop population, physiological, and toxicological metrics and evaluate responses of aquatic, wetland, and riparian organisms to watershed-scale and localized disturbances, model fate and transport and develop means of remediating contaminants under a range of likely future climate scenarios. This research will contribute to regional and world-wide water quality enhancement and protection. The gravitational wave (GW) astrophysics component builds physical and personnel infrastructure necessary for researchers across WV to enhance their role in the worldwide effort to directly detect and characterize GWs. Detection of GWs and the characterization of GW sources will allow studies ranging from early universe cosmology to formation and evolution of galaxies to populations of compact objects in the local universe to tests of general relativity and alternative theories of gravity. Through an interdisciplinary and multi-institutional effort involving faculty from physics and astronomy, mathematics, electrical engineering, and computer science, we will enhance the sensitivity of pulsar timing arrays to nanoHertz frequency gravitational waves emitted by supermassive black-hole binaries. This will be accomplished through addition of more millisecond pulsars to the array, development of improved algorithms for characterization of pulsars, better understanding of the source populations we wish to detect, and improvements in the sensitivity and efficiency of algorithms for detecting gravitational wave signatures. We will also develop a new capacity in WV to contribute to searches for hertz to kilohertz GWs using ground-based laser interferometers. Both research foci will hire important expertise and add needed equipment to build the infrastructure needed to reach competitive goals.

Broader Impacts: With both research areas working collaboratively in areas of overlapping activity, this proposal will provide new opportunities for scientists, engineers, and students in academic institutions and federal research centers to collaborate. The AFI research will have significant impacts on federal and state land management policies; end users of water from the WV watershed; will engage WV students in water quality research and watershed management; it will be shared with resource managers throughout the world facing similar challenges, e.g., mining regions and urban areas and municipalities withdrawing water downstream of wastewater discharges or agricultural runoff. The GW components of this project will increase the likelihood of low-frequency GW detection while also establishing models for electromagnetic counterparts to GW events that will be of interest to the wider astrophysical community. Students trained in data mining, signal processing, and electronics design techniques required for GW detection will provide a workforce for growth of new industries in WV, e.g., high-bandwidth communications, and big data analysis. This proposal will build and strengthen international linkages and partnerships through collaborative research projects in these research areas. Both will also disseminate information arising from their research via traditional scientific means and to the public via museum/outdoor displays. A unique feature of this project is the use of hands-on science activities for K-12 students and the public to develop a pipeline of future scientists in WV and enhance participation of individuals from under-represented groups. The research discoveries, education, and workforce development programs will enhance the prosperity of the State and the nation while also developing and retaining STEM teachers.

4.1 STATUS AND OVERVIEW

Ongoing investments in human and physical infrastructure are enabling West Virginia (WV) to transform its once largely extractive economy to a more knowledge-driven economy. Central to this goal is a strategy to broaden participation, particularly of underrepresented groups, minorities and females, in STEM professions. While substantial work remains, strategic decisions have led to development of research parks in key areas of the state, allocation of a portion of lottery proceeds for research investment, and a wide range of state-industrial partnerships focused on technology development and commercialization. Prior RII investments provided modern shared facilities and built a research culture at partner institutions.

The proposed RII plan for FY 2014-2018 leverages existing science and technology capabilities in two strategic and WV-specific research areas that are at critical junctures and where a significant investment will likely lead to scientific breakthroughs: freshwater science and gravitational wave (GW) astrophysics. Freshwater research includes components of both fundamental research and applied science, is ripe for integration across all three primary institutions, and takes advantage of WV's status as a major headwaters state. Gravitational wave research, a prototypical fundamental science activity, takes advantage of a unique WV resource, the Green Bank Telescope (GBT), is ideal for building a pipeline of new scientists and for engaging astronomy faculty at primarily undergraduate institutions (PUIs) across WV, and has the potential for significant, near-term, scientific impact. WV's vision is to build nationally recognized in sustainable freshwater science and gravitational wave astrophysics that integrate research, education, workforce development, and active participant science activities.

This interdisciplinary, multi-institutional effort is led by WV Univ. (WVU), Marshall Univ. (MU), and WV State Univ. (WVSU). The overarching goals of the proposed project are to: 1) Build sustainable research infrastructure in faculty hires and needed equipment, 2) Advance the fundamental science and inform the application of that science in both research areas 3) Develop a healthy STEM pipeline in WV to provide a STEM capable workforce for the future 4) Improve the diversity of the STEM workforce in WV, with specific emphasis on first generation college students and those from low socio-economic backgrounds (the two accessible underrepresented populations in STEM in WV) and 5) Build the foundation for technology transfer from the three academic institutions to industry while also developing partnerships with existing industries and national laboratories in WV.

State Science and Technology Plan: In FY2005, WVEPSCoR led academic and business leaders to produce the state's S&T strategic plan, *Vision 2015.* In FY2008, then-Governor Manchin and the Legislature embraced *Vision 2015* and created "Bucks for Jobs," which provided $140M for research and economic development. *Bucks for Jobs* has four components: two are the Research Trust Fund (RTF, $50M with matching totals $100M) and the Eminent Scholars Recruitment and Enhancement Program (ESRE, $10M matching to $20M). Under the third component, the Governor created two Advanced Technology Centers (ATC, $30M) to strengthen the technical workforce. The fourth includes a consolidated Workforce Development Council and Jobs Investment Trust to assess and invest in workforce and job creation. The plan was updated in 2012 and continues to guide the research strategy of WV. In addition to the four original research areas emphasized during the creation of the Research Trust Fund, the *Vision 2015* plan calls for the identification "of two or more emerging clusters by identifying research areas within the state's research universities that have the greatest potential for allowing researchers to obtain competitive funding and enhance economic development." In 2013, the emerging research areas of freshwater resources and gravitational wave astrophysics were selected by the WV Science and Research Council (SRC), which serves as the EPSCoR Steering Committee, as having the greatest likelihood of having a transformative impact on the national scientific and economic enterprise; building on existing core strengths and near-competitive research activity; likely to serve as a bridge for collaboration between academic institutions, national facilities, and the private sector; and timely in terms of capitalizing on recent institutional, state, and federal investments.

Academic and R&D Enterprise: WV's public universities and colleges serve more than 69,000 students, including 12,900 graduate students, with more than 3,500 graduate and professional degrees awarded in 2012. The WV Higher Education Policy Commission (HEPC) is the state agency charged with oversight of academic programs, state budgets, student financial aid, policy, and governance of state institutions of higher education. Each of our university partners has unique strengths and missions. WVU is a land-grant institution with a medical and pharmacy school, an engineering college, a law school, and has a Carnegie Research Universities (high research activity) ranking. MU has three doctoral programs, while WVSU, an HBCU and 1890 Land Grant institution, has 3 M.S. programs including one in biotechnology. WV ranks 43rd of 54 states and territories in academic R&D; in FY2012, WV academic R&D expenditures were \$189.1M. WVU has the most R&D activity on campus with expenditures of \$163.5M (NSF, 2012).

Strengths: S&T policies and programs serve as cornerstones of the state's economic development plan. Effective use of prior RII support has strengthened WVU, MU and WVSU research and STEM education capabilities with people and tools and has increased competitiveness for federal and private sector research grants. The SRC oversees all state investments in R&D and focuses investments on research opportunities that lead to innovation and economic development. Core *strengths* in new faculty, shared facilities, and education and outreach projects have developed as a result of *sustained investment* by the State, institutions, federal investment, and WVEPSCoR. Significant investments by WV in the specific areas of freshwater and radio astronomy research have positioned the state to leverage this RII investment. For example, ~\$8M of the \$126M appropriated for the WV Statewide Broadband Infrastructure Project was recently expended to build a dedicated high-speed connection between the National Radio Astronomy Observatory (NRAO) in Green Bank, WV and the Internet-2 access point in Morgantown, WV. In 2012, WVU identified five core research areas, or "Mountains of Excellence", in which to focus investments of faculty positions, research support funds, and large-scale program development. Three of those Mountains of Excellence - radio astronomy, water research, and STEM Education - are featured in this proposal. WVU has already filled six new faculty positions in these research areas and is committed to at least six more. The state's Division of Environmental Protection and other state and federal agencies have made significant investments in analytical laboratories, personnel, and monitoring technologies specifically for freshwater research. WVU has also become a major purchaser of time, at a cost of \$500,000 per year, on the Green Bank Telescope (GBT) for astrophysics faculty research. These investments have positioned WV to develop world-class research programs with integrated STEM education.

Barriers and Opportunities: To sustain freshwater resources, WV must balance the needs of energy industries that use processes such as widespread hydraulic fracturing for gas extraction, mountaintop removal mining, energy production, and chemical production with the needs of local and downstream populations for clean and safe water. WV sits at the headwaters of the Chesapeake Bay and also contributes to major Midwest river systems. The 100-m GBT - the most advanced and largest fully steerable telescope in the world - sits in the only radio emission protected (or "quiet") zone in the U.S.. For GW research, the GBT is a unique WV resource that is playing a critical role in the worldwide race to directly detect gravitational waves. These unique state resources are integral to development of high-quality research programs that address nationally important scientific and economic issues. However, barriers to creating such research programs within WV exist and include a lack of a critical mass of researchers and research infrastructure and outdated structural, organizational and incentive-related policies and possible divestment of the GBT by NSF. Resource allocation is also an issue. WV, like other states, has had its higher education budgets cut, making recruitment of senior faculty, diversity hires, and top quality post docs and graduate students a challenge. However, WV has maintained due to advances in state, institutional, and EPSCoR efforts. Specifically, state support and research investments from the WVU and MU Foundations support endowed professorships and chairs, doctoral fellowships, and graduate student fellowships targeted for support of this research.

Goal: One goal of this proposal is to provide the personnel and equipment infrastructure required for a world-class freshwater research program that includes development of novel detection methods for contaminants; models capable of predicting the effects of combined contaminants across an entire watershed; and understanding and the ability to predict the amplification effects that might arise due to climate change-related water quantity shifts. Another goal is to add key personnel at the faculty and scientist level who will develop new analysis methods for detection and characterization of GW signatures across the electromagnetic spectrum and over a wide range of frequencies while continuing to expand the pulsar timing array needed to achieve direct GW detection in the coming decades. RII financial support and mentoring programs will facilitate recruitment of high-quality graduate students and post docs, a critical element in establishment of world-class programs in these research areas. Linking the research consortia are statewide education and workforce training programs that focus on pre-service science teacher training and early career support with an emphasis on preparation for adoption of next generation science standards for K-12 and expansion of citizen science programs.

4.2 RESULTS FROM RELEVANT PRIOR NSF SUPPORT

Taylor: "**2010 RII grant"** OIA-1003907, 2010–2015, $20M. Intellectual Merit: The current RII is the strategic framework for an integrated effort that is positioning West Virginia (WV) to achieve measurable growth in bionanotechnology, an area of importance in diversifying and transforming WV from an extractive industrial base to a more high-tech knowledge-driven economy. The specific goal was to provide necessary infrastructure to stimulate innovative research while integrating education, workforce development and diversity programs focused on ***bionanotechnology for enhanced public security and environmental safety.*** Scientific and engineering research focuses on development of fundamental knowledge needed for field-deployable sensors that can monitor, in real-time, presence of specific heavy metals, pathogens, and other environmental threats. Research is focused on creating tools with real-time readouts and validating those against existing standards to ensure utility. Three IRTs - IRT 1 Portable and Rapid Identification Platforms, IRT 2 Field-deployable Microfluidic Electrochemical Sensors for Multiplexed Detection of Heavy Metals and Small Molecule Toxins and IRT 3 *Ex Vivo* and *In Vitro* Biomimetics for Cellular Response Monitoring include faculty with complementary expertise to create new platforms for integrated devices. This RII led to award of WV's first IGERT (NSF DGE-1144676). Investments in faculty and equipment have resulted in 109 peer-reviewed publications, 3 patents, and $21M in new awards. Broader Impacts: Outreach and Education activities have reached 84 teachers, more than 1400 students directly, and approximately 22,000 students via the WV edition of Nanooze. Working with WV Public Broadcasting and the WV statewide radio network, more than 150,000 citizens of the state were introduced to bionanotechnology through the words and videos of our scientists. The Governor has convened a STEM Task Force which includes industry as well as K-12 and higher education representatives to work on strategies to increase the STEM workforce in WV. The Chancellor's Diversity Council continues its work on increasing retention of underrepresented students through college and through the STEM pipeline. In this proposal, 6 faculty from the Emerging Area of the current RII will be involved in the Appalachian Freshwater Initiative. No faculty will be involved in the Gravitational Wave Initiative.

Table 1. Summary of Research Infrastructure Improvements During WV RII 2010-2013	
Scientific	
Publications	- Published 109 manuscripts in peer-reviewed journals in Years 1-4
Funding Success	- Submitted 204 proposals, 74 have been funded for $21M
Tech Transfer	- Received 3 patents, 3 patents pending, 1 license - Held 2 NanoSafe Bioelectronics and Biosensing International Symposia with Industry Panels - WVU Linking Innovation Industry & Commercialization (LIINC) project: events to link WVU faculty researchers and graduate students with industry representatives from private sector and government with similar interests in a particular research area
Awards and Honors	- Awarded 2 NSF CAREER awards - Awarded an NSF IGERT award - Awarded 2 REUs, 3 MRIs, 3 EHR grants, 1 GOALI, 2 BRIGEs, 1 NSF Fellow
Infrastructure	
Cyber-infrastructure	- Expanded Shared Computing Facility at WVU – Mountaineer 384 cores, 82TB shared disk; Spruce Knob ~1400 cores, 9 GPU Accelerators ~22,464 "Cuda" cores. High performance parallel storage system 257TB -95 active users; % capacity Mountaineer 58.4; Spruce Knob 55.6 - New hybrid condo model; 48+ condo nodes and growing - Conducted Summer Institutes for HPC – 20 participants from 6 different WV institutions each year
Facilities	-Built new shared facility: BioNano Research Facility (BNRF) at WVU which provides engineering and microfluidic device tools in conjunction with molecular biology applications at a single site.

Core Instrumentation Acquisitions	-Acquired and installed in BNRF: cell culture facilities, sample preparation infrastructure, spectrofluorometer, digital inverted fluorescent microscope, synchronized video fluorescent microscope, inverted fluorescent microscope, mass spectrometer - Acquired and installed next generation genomic sequencer at MU; microarray scanner and dryer, hybridization system, Nanodrop spectrophotomer; GC/Mass spectrometer, real-time PCR sytem at WVSU
Human Resources	
Faculty	- Filled 4 tenure-track faculty positions - Established collaborations with 5 private companies and NIOSH
Students	- Involved 17 postdocs in RII research - Supported 49 graduate students (40% female) - Supported the participation of 44 undergraduates (>50% women) in RII research - Funded 7253 new "Dakota Corps" and "SD Opportunity" undergraduate scholarships through SD Legislature.
Policy	
HEPC/State of WV	- New statewide Office of Minority Affairs in the Governor's Office - Chancellor's Diversity Council - Offices of Undergraduate Research at all 3 partner institutions
Outreach and workforce development	
Outreach Activities	- Graduate Fellowship – 11 students, 7 female, 2 minorities, 6 underserved rural - Learning Assistants – Learning gains in Physics 111/112 from .22 to .41 using the Force Motion Conceptual Evaluation instrument - TREK summer research experience for teachers – 84 teachers - NanoDays with Children's Discovery Museum of WV ~150 children - WV regional edition of Nanooze - ~22,000 8th grade science students -RII radio campaign – reached listenership of more than 150,000

4.3 RESEARCH and EDUCATION PROGRAM

Freshwater and gravitational wave astrophysics research in WV have a number of strategic features in common. Over the past decade, both have benefited from significant federal and state investment in research infrastructure. Both are primed for significant scientific advances; provide fertile ground for training postdocs, graduate students, and undergraduates; have significant current and potential future economic impact in WV (through direct employment in these specific research areas, through providing a trained workforce, and through technology commercialization); are transformational in nature, i.e., they have the potential to dramatically alter scientific fields outside of their research area; and the targeted research infrastructure investments from this RII are sufficient to fill critical "skills" gaps, enabling both research collaborations to pursue a wider range of research projects in the future. Another compelling reason to invest in these two research areas with this RII is that the WVU has targeted these areas, plus STEM education, for significant and sustained investment. Moving forward on these research areas leverages ongoing investments in the Mountains of Excellence, thereby enhancing the impact of the RII in WV.

The proposed Science and Engineering (S&E) research activities will be organized into two statewide Research Consortia (RC) centered on research competitiveness, infrastructure investment (human capital and equipment), and STEM education. RC will include investigators from science, engineering, math, and educational research across multiple institutions: WVU, MU, Shepherd Univ., WV Wesleyan College, WVSU, and federal researchers from the National Radio Astronomy Observatory. These investments will establish new areas of competitive research, enhance the capacity of existing research efforts, foster true collaborations, and train a new generation of STEM educators. Proposed education activities will improve science teacher retention and competency through a preparation and early career support program. The proposed citizen science component integrates research activities with outreach and education programs through meaningful engagement of citizens in research activities. Collectively, these initiatives will strengthen the State's human resource base and develop core science competencies that focus on areas of critical national and local significance. Computational modeling aspects have been enabled by previous federal and state investments in WV cyberinfrastructure and the new high-speed link between the GBT and WVU that greatly facilitates analyses of large quantities of astronomical data.

4.3.A . RC 1: Appalachian Freshwater Initiative: RC Leader- Anderson (WVU)

Appalachian watersheds are a valuable asset for economic development within Appalachia and are a critical source of freshwater for downstream population centers and ecosystems along the Ohio River and eastern seaboard. Despite broad-scale improvements to water quality since enactment of the Clean Water Act in 1972, stresses on the nation's water supply continue to escalate. The Appalachian region faces a unique combination of water-related stressors that include coal and gas extraction, energy production, and insufficient wastewater facilities resulting from poverty and severe topography (Merovich *et al*., 2013, Petty *et al*., 2013; Strager *et al*., 2009, 2011). Of particular concern is the broad scale occurrence of untreated wastewater effluent that constrains economic development within the Appalachian region and limits access to clean freshwater downstream. Given that regional demands for freshwater are expected to grow and that certainty in water availability is expected to decrease as a result of climate change (Pitchford *et al*., 2012), the degraded state of Appalachian freshwater requires immediate attention.

Securing Appalachian freshwater resources for the future is constrained by our 1- inability to rapidly

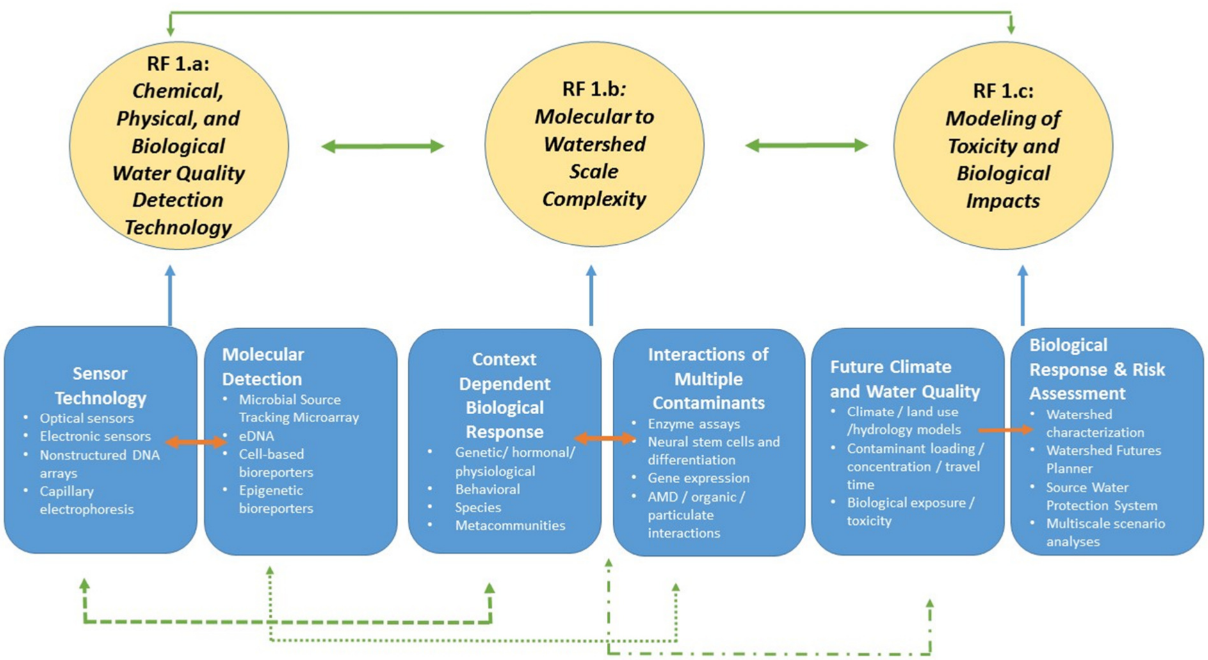

Fig.2. Conceptual diagram of the synergistic nature of the water research focal areas (yellow ovals) and research clusters (blue boxes).

detect novel or dilute contaminants and pathogens; 2- failure to understand complex chemical interactions and pathogen characteristics (survival, transport, and infectivity), an inability to predict contaminant transport, toxicity, and degradation pathways, and a lack of understanding of the impacts to biological communities from new chemicals of concern within multi-source contaminant mixtures characteristic of Appalachian rivers; and 3- failure to understand how climate-related changes in precipitation regimes (total amounts and timing) may affect contaminant sources, concentrations, and biological communities. These issues are particularly important in our topography where water transports contaminants quickly to downstream users and limits the potential for microbial degradation of contaminants.

These knowledge gaps motivate three core research needs that will be addressed by the Appalachian Freshwater Initiative (Fig. 2). Links between the field and bench science groups (1a and 1b) will be coordinated through the theoretical group (1c) via a two way flow of information. Biological and chemical data will be databased and used to feed the predictive tools, and potential areas of concern, identified by data mining and the theoretical models, will drive experimental work. Our goal is to use a broad array of approaches in order to develop the strongest predictive and analytical tools possible, and to improve our understanding of interactive, ecosystem level impacts

Collaborating researchers will use a watershed research framework, across multiple disciplines, to address clean water challenges currently affecting WV and to respond to future potential threats. A watershed approach is critical in the Appalachian terrain as the unidirectional flow arising from the mountainous topography makes upstream conditions critical to downstream users. Core research themes include:

1) Improving detection of chemical, physical, and biological threats to water quality;
2) Developing a fundamental understanding of the complex interactive chemical, physical, and biological impacts of environmental perturbations and anthropogenic substances from the molecular to the watershed scale; and
3) Development of models capable of predicting the toxicological impacts of complex chemical processes on biological communities in Appalachian watersheds and potential water quality issues resulting from climate change-related water quantity shifts.

The teams that will investigate these topics are from multiple institutions and include chemists, ecologists, molecular, cellular, and physiological biologists, microbiologists, engineers, geologists, spatial modelers, and stream and watershed specialists. All three research foci: 1.a (*Chemical, physical, and biological water quality detection technology*), 1.b (*Molecular to watershed scale complexity*), and 1.c (*Modeling of toxicity and biological impacts*) will be co-led by WVU, WVSU, and MU. Institutional Coordinators (Anderson WVU, Toledo WVSU, Somerville MU) will coordinate and oversee the overall effort of faculty and staff. Anderson and Somerville are senior faculty with extensive federal funding experience in water and related research areas. Research Focus Leaders will administer overall activities within a research focus area and have specific research duties.

Strategic investments from this RII will positively impact the infrastructure of each collaborating institution while also building research capacity of integrated research consortia through acquisition of new equipment, augmentation of scientific expertise via new faculty hires, and improvement of shared research facilities. New faculty hires at WVU include (1) groundwater hydrologist who can construct three-dimensional models for predicting groundwater flow, solute transport, and multiphase flow; (2) organic analytical chemist who can model interactions of different organic compounds in water, their rate of decay over time, and effects of dilution; and (3) regional-scale watershed modeler to integrate the layers of spatial complexity in water quality dynamics. Proposed hires at WVSU include: (1) environmental engineer specializing in water quality, and (2) environmental toxicologist. Proposed hires at MU include an organic chemist to work in detection technology (Focus 1.a.), an environmental toxicologist (Focus 2.b.), and an ecologist with expertise in environmental modeling (Focus 1.c.)

Research Focus 1.a: Chemical, Physical, and Biological Water Quality Detection Technology
Research Focus Leaders: Norton (MU-CHEM), Weidhaas (WVU-CEE), Fultz (WVSU-CHEM)

Background. Rapid, sensitive, low cost remote detection of chemical, physical, and biological perturbations is essential for water security and must be integrated into future dynamic databases. USGS conducted the first nationwide survey for the presence of pharmaceutical compounds, hormones, and other wastewater-related chemicals in US surface waters from 1999–2000 (Kolpin *et al*., 2002). This study revealed numerous contaminants that are recalcitrant to standard wastewater treatment practices. Treated wastewater also contains bacterial pathogens, helminths, protozoa, and viruses. This research area will develop sensitive detection technologies for organic and inorganic contaminants, pathogens, and biological assemblages that have potential for transforming how we assess the condition of aquatic ecosystems and the water supply as they change with time. These technologies include: 1) Ultrasensitive, real-time sensor technology for detecting organic and inorganic contaminants and 2) Molecular detection: microarray technology for detecting pathogens, eDNA technology for detecting response of biological assemblages, and bioreporters for detecting cellular responses to low level environmental contaminants.

Approach: *Ultrasensitive sensor technology.* Norton and Wang will develop optical and electronic sensors based on use of nanostructured DNA (Rahman *et al*., 2014) to produce arrays of carbon nanotubes (Anshuman *et al*., 2013), graphene (Rahman and Norton, 2013), RNA aptamers (Wang *et al*., 2008), and employing organic binding moieties developed by the team of Fultz and Sklute (Kolodney *et *al*., 2007). All binding species will be designed to enable *in situ* analysis of specific organic and inorganic contaminants and metabolites. In cases of charged ligands, such as the aptamer/small molecule, e.g., 17β-estradiol (Yildirim, 2012) interaction, a capillary electrophoresis system will be used to characterize the kinetics and thermodynamics of ligand/target interactions (de Jong, 2011). Nanostructured DNA arrays with single molecule analyte detection, once realized, should rival the fM (Howorka, 2014) and even aM (Chang, 2012) analyses which have been demonstrated for single molecule sensor systems lacking such high spatial organization. Such micro- and nano-scale devices, capable of capturing target molecules from complex mixtures of chemicals in solution, will be designed for integration into distributable microfluidic sensing platforms. WVU's electrical engineering department has an active research program in low power, distributed sensor networks (Graham, et al., 2011) and technologies developed by those faculty for data accumulation will be employed for deployment of these sensors for real-time reporting from the field.

New strategies for improving and expanding the cohort of detectable compounds, and for validating the bioreporter and nanosensor technologies, will be developed by a team led by Schloss. The approach to be employed involves use of standard mixtures of emerging organic contaminants or toxic metals to challenge chemical-physical (Hussam and Munir, 2007) or biological (Xu *et al*., 2010; Phillips *et al*., 1995) methods for water treatment, followed by analysis of resulting effluents by LC-MS/MS or ICP-MS. Recent advances in mass spectrometry have the potential to increase the specificity and range of this detection method [U.S. Patents 8,664,000 (2014); 8,487,247 (2013); and 8,373,118 (2013)]. Uncharged molecules, which are difficult to detect by conventional LC-MS/MS instruments employing electrospray ionization techniques or related technology (e.g., APCI, APPI, MALDI, DART, DESI, LAESI, DAPCI, or ELDI), can be detected with high-sensitivity by use of this new source methodology. We will develop these new advances in source technology to increase the range of existing instrumentation and to develop instruments that have the potential for analysis of contaminants in the field by application of 'sniffer' technology.

Molecular detection – Advanced molecular methods such as microarrays in combination with qPCR, offer improved detection and quantification for pathogens in water and soils compared to fecal indicator bacteria (FIB) detection. A microbial source tracking (MST) microarray developed at WVU contains 15,000 DNA oligonucleotides that targets most known FIB, human and animal fecal (MST) markers, waterborne pathogens, and viruses. Preliminary work indicates this microarray can detect pathogens and discriminate between fecal sources in sewage impacted streams. Weidhaas will use the microarray in combination with quantitative polymerase chain reaction (qPCR) to determine persistence/decay and transport of pathogens in sewage and AMD impacted streams in laboratory and field-scale mesocosms and in environmental sampling campaigns.

Collection and analysis of environmental DNA (eDNA; DNA that has detached from individuals) from the water column is an emerging technique that offers advantages over traditional tools for monitoring species and communities (Thomsen *et al*., 2012, Taberlet *et al*., 2012), including potential for improved cost efficiency, a broader range of taxa assessed, and improved detection of rare or cryptic species (Thomsen *et al*., 2012; Pilliod *et al*., 2013, 2014). Petty and Anderson will determine the presence of target DNA in environmental samples via targeting specific species/communities. Quantitative PCR will be performed using the ABI Prism 7900 Sequence Detection System using DNA extract. For community assessments, next-generation DNA sequencing platforms (Roche 454 or Illumina miSEQ) will be used.

We will develop a novel approach based on monitoring biological responses at the cellular level, providing detection of known and/or emerging biological stressors. These cell-based bioreporter responses can in turn motivate deeper investigation of specific waterbodies. In this effort to employ intracellular changes for detection, Georgel (MU) and Iwanowicz (USGS) will work in collaboration with Hager (Head, Hormone and Oncogeneisis Section, NIH/NCI), who has developed a set of unique human cell lines for use in the investigation of highly specific epigenetic effects of endocrine disrupting chemicals and their often ignored metabolites present in water at levels virtually undetectable using standard methods (Stavereva *et al*., 2012). This approach enables monitoring biological and epigenetic cellular responses (Georgel *et al*., 2003) to exposure to products which cannot be readily detected otherwise, and at sub-toxic concentrations. A similar approach to detect epigenetic markers will be taken by Blough's group, using specifically designed cell lines to evaluate the effects of low level exposure to toxins on well-characterized signal transduction pathways (Rice and Blough, 2013, Nalabotu et al, 2014). These systems will be developed into assays for the presence of endocrine disrupting chemicals.

Research Focus 1.b: Molecular to Watershed Scale Complexity

Research Focus Leaders: Petty (WVU-WFR), Armstead (MU), and Hankins (WVSU)

Background: Interactions of low levels of emerging and historic contaminants with effects at the molecular scale can have significant implications for organism and community health. Research will focus on sub-lethal, chronic, and cumulative effects of the often complex chemical, biological and physical contaminants in Appalachian streams. For example, natural coagulants existing in mine drainage such as iron and aluminum may serve as a sink in river sediments for phosphorus (Simmons, 2010) and affect nutrient export from watersheds. Fine coal particulates can affect partition and environmental fate of a wide range of organic chemicals. Relatively high total dissolved solids and metal content in some Appalachian waters may cause significant effects on chemical degradation and partitioning among environmental media and may affect microbial degradation of leaf material. Interactions between untreated sewage and mine drainage may affect breakdown of pharmaceutical and personal care products and pathogen degradation kinetics in ways unique to Appalachia. Currently, interactive effects of the suite of contaminants outlined are unknown at molecular scales as are subsequent impacts on aquatic and wetland ecosystems.

This research focus will continue and expand our existing experimental research to investigate the interactive effects of multiple contaminants at various spatial and temporal scales which cause impacts at cellular, organismal, and community levels. In particular, it will focus on water quality issues pertinent to WV. Socioeconomic and terrain conditions limit wastewater treatment in smaller drainages which substantially affect chemical and pathogen concentrations, degradation and transport. Specific areas of interest include: 1) Interactions of multiple contaminants; and 2) Evaluating context dependent biological responses to organic and inorganic contaminants.

Approach: Interactions of multiple contaminants – Research will focus on evaluating sub-lethal and chronic effects of low-levels of regulated and unregulated contaminants and the cumulative effects of multiple contaminants. Sub-lethal and chronic effects of low-levels of regulated and unregulated contaminants will be investigated using non-traditional endpoints which are more sensitive than growth, reproduction and mortality generally evaluated. These assessments may include in-vitro and organism responses such as enzyme assays, changes in stem cell differentiation and gene expression, cellular response, and structural and functional changes in microbial, algal, macroinvertebrate, fish, and amphibian communities. Examples of the types of evaluations included for which the research team has experience include behavioral responses of crayfish exposed to atrazine, alterations in microbial community evaluated by DNA sequencing, in vitro fish cell assays, behavioral and growth response of amphibians in wetland mesocosms, and benthic macroinvertebrate community analysis in stream mesocosms. The research team will collaborate on experimental studies to elucidate the fundamental reaction pathways among multiple contaminants and between contaminants and environmental conditions. Specifically, 1.Antonsen will investigate sub-lethal effects of single and multiple contaminants using a DanioVision tracking system which evaluates zebrafish larval responses to contaminant exposures. Behavioral responses of other aquatic species, such as crayfish, will also be investigated. 2.The effects of environmental contamination on neural stem cell differentiation and changes in gene expression during differentiation will be investigated using a number of primary and cultured cell methods (Spitzer). 3. Kolling will investigate the effects of contaminants of concern on photosystems and electron transfer in photosynthesis, the driving process in primary productivity in stream ecosystems. 4. Lin, McDonald, and Skousen will conduct laboratory and in-situ work to investigate how AMD-containing coagulants in drainage/river sediments affect chemical fate and nutrient export from the region. 5. McDonald will determine the role of coal-fines in governing organic chemicals, industrial chemicals (miscible and partially miscible solvents), and known toxic metals common in Appalachia. 6. Sekabunga will investigate ligand of metal contaminants from AMD and hydraulic fracking. 7. Vesper will study how mine drainage affects pathogen degradation in elevated TDS environments. 8. Lin and Sklute will examine the predominant environmental processes that govern chemical fate during chemical spill events into source waters for select chemicals of concern in the region. 9. Using bench-top batch and flow-through experiments Hass will evaluate the efficacy of selected soil additives (e.g. biochar) as sorbents for in/organic contaminants (e.g. heavy metals, excess nutrients, DOC). This will follow development and evaluation of different soil mixes and selected plant material as soil-based runoff mitigation practice (e.g. bioretention system) in detached lysimeter studies.

Context dependent biological response – Both the nature of contaminants and environmental conditions change in a downstream direction in WV. To validate the research described above, naturally occurring populations or individuals of microbes, fish, invertebrates, amphibians, and reptiles associated with aquatic and wetland systems will be studied in situ and ex situ with awareness of the specific chemical and physical conditions on the stream continuum. In mesocosm testing, levels of multiple contaminants can be manipulated and directly linked to the effects evaluated above. Field studies in areas with specific contaminant combinations will also inform the effects database. Eya, Anderson, and Hankins will evaluate reproduction, condition, and physiological stress of multiple stressors and additive vs. synergistic vs. antagonistic effects of multiple contaminants based on endocrine profiles, epigenetic alterations, enzyme immunoassays, hormone levels, and newly evolving population-level nuclear markers via comparative transciptomics, an area that is ripe for new discoveries (Narayan, 2013, Schultheis et al., 2014). Source-sink metacommunity responses will be investigated using recently developed and novel molecular, cellular, and whole-organism methods in addition to standard techniques (Anderson and Davis 2013). Microbes respond quickly to changes in environment, evident from changes in their community structure (Tiguia 2010, Sangwan et al. 2012) and functional genes (Xia et al. 2014); this will be investigated by Huber, Haas and Malkaram. The primary source for biogeochemical and bioremediation processes in riverine environments resides with the sediment microbial communities. Recent studies have shown that river sediments represent the highest microbial diversity for any environment yet sampled by the Earth Microbiome Project (Gibbons et al. 2014). However, microbial diversity of rivers is greatly under-sampled and the role of the rare biosphere in maintaining riverine ecosystem services is practically unknown, although some work has shown that sediment microbial diversity can reflect ecological degradation (Feris et al. 2009). Meta-omics studies including meta-(genomic, transcriptomic) and metabolomic analyses, on microbial samples from spatially and temporally defined points, will be used to correlate microbial community characteristics with environmental parameters and identify functional gene/metabolite signatures. Using field collected and mesocosm exposed communities, microbial community dynamics and the influence of environmental and toxicological factors will be investigated using modern genomic approaches (Schultz and Mosher). Kovatch and Armstead will investigate aquatic invertebrate behavioral responses to contaminant exposures in mesocosms, as well as, microbial, algal and community responses ex situ. These studies will extend the range of biological assays used to assess potential impacts of contaminants to accomplish two major goals: first, to improve our understanding of sub-lethal biological impacts at the organismal level and, second, to construct predictive and testable in silico models of impacts from the level of genes to communities.

Research Focus 1.c: Modeling of Toxicity and Biological Impacts

Research Focus Leaders: Strager (WVU) and Szwilski (MU-ITE)

Background: Watershed and water quality models will be used to predict the impact of watershed management, climate change and contaminants in water bodies and on biological communities. Quantitative scenario analysis is a method of using data and models to predict the effects of alternative management actions (Kepner *et al*., 2012). The objectives of our proposed scenario analysis are to predict cumulative impacts of multi-contaminant mixtures on ecological communities, model effects of climate change as an additional stressor, identify priority areas within watersheds for restoration and conservation, highlight the potential value of development techniques that reduce impacts to aquatic resources, and improve data flow and communication between groups working on water toxicology in WV and surrounding areas. Specifically we will evaluate: 1) Contaminant loading and transport under a range of likely *future climate scenarios*; and 2) Expected *biological response and contaminant toxicity under current and potential future conditions.* To accomplish this, we will enhance our capabilities in three main areas: 1) Current predictive modeling tools in development at WVU will be enhanced to address questions of interest to this working group. 2) Biochemical and ecological models will be developed at all three participating institutions, in concert with hard data collection. 3) Computational tools to facilitate development of sensor technologies and analysis of reporter system pathways. 4) A database focusing on local concerns will be developed, in order to facilitate data sharing and identification of threats or possible areas of insufficient research.

Approach: *Future Climate Scenarios* will be based on the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) made available on the NASA Earth Exchange scientific platform [Nemani *et al*., 2011]. This archive includes historical (1950–2005) and future (2006–2099) monthly average precipitation, and minimum and monthly air temperature projections and ensemble statistics for four relative concentration pathways (Thrasher *et al*., 2013). Zegre will use gridded monthly climate projections for the Appalachian region, downscaled to daily data and made available online (WVU Environmental Research Center). These data complement an on-going effort characterizing overland flow, hydrologic regimes, and travel time estimation (Strager, 2012) and will be used to simulate future hydrologic and ecological conditions and assess the role of multiple environmental stressors on ecosystem and human health. This research task will develop an adaptive, time-sensitive GIS-based modeling system to protect natural water resources and public water infrastructure from chronic and acute contamination and effectively respond to accidental and/or intentional events under current and predicted climate scenarios.

This task will be accomplished by an integrative and enhanced Surface Water Protection System (SWPS) which will bring spatial data and surface water modeling to the desktop of the West Virginia Bureau of Public Health (WVBPH), Office of Environmental Health Services, and Environmental Engineering Division. The SWPS will integrate spatial data and associated information with the overall goal of helping to protect public drinking water supply systems. The SWPS will be comprised of a specialized GIS project interface, incorporating relevant data layers with customized GIS functions. The previously mentioned data layers and model outputs assembled for the entire state of WV will be combined with the ability to map display and query, zone of critical concern delineation, stream flow modeling, water quality modeling, and susceptibility ranking. These functions are designed to meet the goals of the Surface Water Assessment and Protection (SWAP) Program which are to assess, preserve, and protect WV's source waters that supply water for the state's public drinking water supply systems. This effort will help to assure and provide for long term availability of abundant, safe water in sufficient quality for present and future citizens of West Virginia. Our approach will help meet this goal by addressing the three major components of the SWAP program: delineating the source water protection area for surface and groundwater intakes, cataloging all potential contamination sources, and determining the public drinking water supply system's susceptibility to contamination.

Biological Response/Risk Assessment – Bench and theoretical science will be integrated to drive targeted research in areas of potential risk and to develop predictive tools validated by supporting research in appropriate biological systems. Areas of potential risk will be identified by the Future Scenarios group and through analysis of existing data to identify chemical stressors to be examined for their impacts on biological systems. Data provided by labs working in a variety of systems (Spitzer, Kolling, Schultz, Antonsen, Georgel, Armstead) will be fed back into the models by Szwilski, Smith, Toledo, and the new MU hire. These models will build upon WVU's Watershed Characterization and Modeling System, the Source Water Protection System (Strager *et al*., 2010), and Watershed Futures Planner (WFP), which is a comprehensive modeling system developed over the past ten years as a tool for conducting multi-scale scenario analyses in highly impacted or rapidly developing watersheds (Fig. 1) (Strager *et al*., 2009, Merovich *et al*., 2013, Merriam *et al*., 2013, Petty *et al*., 2013). These systems aid in watershed and stream-level characterization by allowing scenario analysis of spatially explicit changes to local conditions and will be improved by incorporation of novel preventive processes, and enhancement or creation of new technologies linked to improving or sustaining water quality resources. Strager, Petty, Toledo, and the new WVSU hire will assess frequencies, magnitudes, and potential routes of a range of short- and long-term pollution conditions under the climate change scenarios and under a variety of remediation technologies.

4.3.B RC 2: Gravitational Wave Astrophysics: <u>RC Leader - McLaughlin (WVU)</u>

In 2006, WVU established a research program in radio astronomy, capitalizing on the proximity of WVU to the National Radio Astronomy Observatory in Green Bank, WV. The radio astronomy program has since expanded to encompass a variety of astrophysical research areas and significant investments by WVU are underway, and are focused on gravitational wave (GW) research through complementary techniques that span the entire GW spectrum.

Gravitational waves are ripples in space-time produced by accelerating massive objects. Their existence, a key prediction of Einstein's theory of General Relativity, has been demonstrated through measurements of the orbital decay of binary pulsars (Taylor & Weisberg 1982), which was recognized with the 1993 Nobel Prize, and, possibly, as a signature of early-universe inflation in the BICEP2 measurements of the polarization of the cosmic microwave background radiation (Ade et al. 2014). A major worldwide effort (Fig. 3) is currently aimed at the large-scale GW experiments that will allow more stringent tests of gravitational theories and usher in a new era of astrophysics in which we are able to study exotic objects such as relativistic black-hole (BH) binaries that are not detectable through electromagnetic observations alone. We will use two complementary methods – pulsar timing and ground-based interferometry – to achieve this goal.

WVU astronomers are founding members of NANOGrav (North American NanoHertz Observatory for Gravitational Waves) and WVU has also become a member of the LIGO (Laser Interferometer Gravitational Observatory) Scientific Collaboration. Through investments proposed here, WV will advance three forefront gravitational wave (GW) astrophysics research foci by developing tools and building infrastructure in: **1) Gravitational Wave Detection and Algorithm Development**, **2) Gravitational Wave Signals and Populations**, and **3) Pulsar Timing Array Development**. All three of these efforts will enable a new era of GW research and are essential to build a network of researchers and students in WV that are trained to take advantage of opportunities in this emerging field. Specific infrastructure improvements targeted for this RC are new faculty hires in the Departments of Physics and Astronomy and Computer Science and Electrical Engineering, a dedicated server for GBT pulsar data storage and analysis at WVU that will enable collaborations with scientists through the U.S. and the world, the establishment of WVU as a member center of the LIGO Data Grid, and integration of faculty across WV into a powerful regional research collaboration. Here we describe the three research subtopics, highlighting the tools and infrastructure that will be developed through each. A detailed timeline for these deliverables is presented in section 4.8.4.

Research Focus 2.a: Gravitational Wave Detection and Algorithm Development
Research Focus Leader: McLaughlin (WVU-P&A)

Background: With this research focus, we will develop GW detection algorithms for both pulsar timing arrays (PTAs) and ground-based laser interferometers like LIGO (referred to as “LIGO” for simplicity). Pulsars are rotating neutron stars that emit extremely regular pulses. This allows them to be used as accurate celestial clocks. accurate celestial clocks. A PTA is a network of pulsars with millisecond spin periods, known as millisecond pulsars (MSPs), that are regularly observed with radio telescopes to search for correlations in pulse arrival times due to GWs in the nHz to μHz band (e.g. Demorest 2013). At WVU, Lorimer, McLaughlin, and McWilliams (with WVU undergraduate and graduate students and postdocs) are members of NANOGrav, a collaboration of researchers in the US and Canada who are undertaking this experiment using the GBT and the Arecibo Observatory in Puerto Rico (McLaughlin 2013). Lorimer is chair of the Searching working group; McLaughlin is a member of the Searching, Timing, Interstellar Medium Mitigation, Noise Budget, and Outreach working groups; and McWilliams is a member of the GW Detection and Astrophysics working groups. In addition, McLaughlin is PI on an NSF PIRE award which supports collaboration with researchers in Europe and Australia through the International Pulsar Timing Array (IPTA). New collaborations with China, India, and South Africa are also being formed with development of research and education collaborations the subject of a planned NSF PIRE proposal.

LIGO is NSF's most costly development project and consists of two interferometers (Livingston, LA and Hanford, WA) which pass lasers through beam-splitters to measure small variations in light travel times due to passing GWs. Such GWs will tend to elongate one detector arm while simultaneously compressing the orthogonal arm, thereby changing the relative path length of the light along each arm, and the resulting phase of the light beams when they are allowed to interfere. LIGO is currently undergoing an upgrade to its Advanced LIGO detector configuration, with the goal of commencing science operations in 2015.

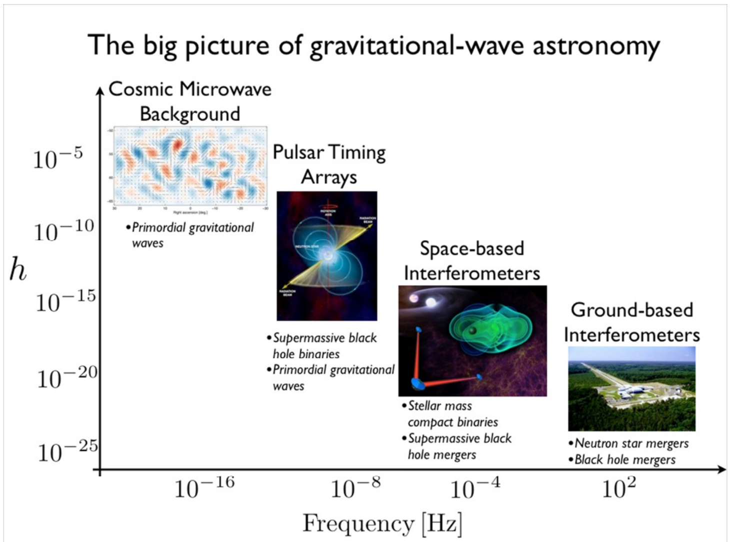

Fig.3. Gravitational waves (GWs) span many orders of magnitude in amplitude (measured by the gravitational wave strain *h*) and frequency generated by bulk motion of a variety of different astrophysical sources. These range from the primordial waves the size of the Universe that leave their imprint on the cosmic microwave background (CMB), to the gravitational waves with periods of years detectable by pulsar timing arrays (PTAs) like NANOGrav, the hour-long period waves detectable by space-based instruments such as eLISA, and the millisecond period waves detectable by ground-based interferometers like LIGO and Virgo. Each of these experiments probes different time-scales and hence a wide range of objects and phenomena.

WVU is currently a member institution of the LIGO Scientific Collaboration (PI: McWilliams). McWilliams is principal coordinator for the development and implementation of a search for signals from eccentric neutron star (NS) or black hole (BH) binaries in Advanced LIGO detector data, and he is also a principal contributor to the search for signals from intermediate mass-ratio inspirals. The activities proposed here will place WV researchers at the forefront of both PTA- and laser interferometer-based GW astrophysics.

Approach: The principal signals to which both PTAs and LIGO are sensitive are generated by NS or BH binaries. Binary systems emit "continuous" GWs at twice their oribital frequency (Fig 4). Because thesesystems are continually losing energy to GWs, their orbital frequencies increase (and separations decrease) until the compact objects merge, produce a "burst" of GW emission (Fig 4). GWs at the very low frequencies to which PTAs are sensitive is generated by pairs of gravitationally bound, supermassive (perhaps billions of solar masses) BHs. While PTAs could detect individual BH binary systems, they are most sensitive to the stochastic signal from the extraordinary number of very massive BH binaries throughout the Universe. Detection of the GW signal within PTA data relies upon searching for a specific angular dependence (Hellings & Downs 1983) in the correlated timing signatures of many MSPs distributed over the sky. Detection algorithms rely on accurate models for noise in the PTA detector (Demorest et al. 2013, Arzoumanian et al. 2014). McLaughlin and a postdoctoral researcher will develop techniques to characterize and mitigate sources of noise in the times of arrival, with a particular focus on the effects interstellar scattering and dispersion and pulse jitter. Along with McWilliams, who has expertise in predicting, detecting, and characterizing diverse classes of GW signals, and a graduate student they will then work to enhance current NANOGrav detection pipelines and apply them to NANOGrav data. For instance, published NANOGrav upper limits to date have employed limits on signal strength that do not allow for noise variations or for nontrivial power spectra from the GW stochastic background. McLaughlin and McWilliams will incorporate physically motivated noise variations in the calculation of constraints and introduce a varying power spectrum that allows dynamical effects other than gravitational-wave emission to drive the evolution of some sources (e.g. Merritt and Milosavljevic 2005). It has been shown (McWilliams, Ostriker, and Pretorius 2014) that fully understanding the impact of non-GW dynamics is critical to both predicting future performance and to interpreting the spectrum that we ultimately observe with PTAs. In addition, the intrinsic pulsar parameters are measured through linear least-squares fitting.

While the fitting procedure is accounted for in the analysis, it is done as a separate process from detection analysis. The group will work on development and application of Bayesian methods that include all possible sources of variability in the pulsar timing residuals within a single coherent framework, including parameters that describe the pulsars, measurement noise, and possible source parameters. This will be done in collaboration with NANOGrav members at other institutions, particular the University of Wisconsin-Milwaukee. As part of the RII investment, funds are requested for a 5 Petabyte storage system that can store and serve NANOGrav data taken with the GBT, as well as pulsar searching data (see 2c). This will make the data accessible for the proposed work, and will also, along with a mirror site at the Cornell Center for Advanced Computing, serve data to other NANOGrav members and the public. Transfer from the GBT to WVU will be facilitated by the recently completed high-speed link supported by the WV Statewide Broadband Infrastructure Project.

The proposed work will provide critical capabilities for nHz GW detection. Some noise characterization work is underway, but the methods have not been implemented in a publishable search of actual PTA data. Furthermore, the majority of existing effort is provided by a small group of postdoctoral fellows at NASA's Jet Propulsion Laboratory, and there is currently no existing effort to incorporate non-GW dynamics in PTA searches. Therefore, the contributions from McLaughlin and McWilliams will introduce critical institutional knowledge of the novel methods under development.

This research theme will also build infrastructure for WV researchers to play a leading role in GW detection using LIGO. McWilliams is the lead developer of search techniques for two classes of LIGO sources: binaries in eccentric orbits and binaries with significantly different mass components known as intermediate mass-ratio inspirals (IMRI). All current LIGO detection algorithms rely on searching many templates. This is computationally infeasible, particularly for the more sophisticated binary systems McWilliams is studying. Therefore, McWilliams will develop non-template-based search algorithms. He will collaborate with Etienne, a new faculty hire in Math at WVU, arriving in the fall of 2014, and part of the investment in this research area. Such searches will then be run on Advanced LIGO detector data using the LIGO Data Grid, part of which will be supported locally at WVU through this proposal. McWilliams is the lead author of the Advanced LIGO search proposal for eccentric binaries, and is a central contributor to the IMRI search proposal. Students and post docs will also become experts in manipulating and mining large datasets – essential skills which are immediately transferable to other scientific and industrial applications.

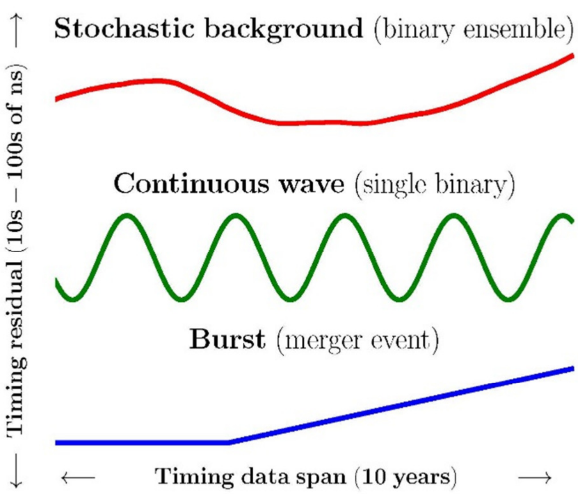

Fig. 4 Pulsar timing signatures expected for different types of GW signals. The vertical axis is the difference between measured and expected pulsar arrival times, and the horizontal axis is time. There are three expected manifestations of supermassive black hole binaries in pulsar timing data. The first is as a *stochastic background*, or superposition of many binaries. This will appear as excess low-frequency power. Detection will enable us to constrain the population of these binaries and, at the same time, test general relativity. We also expect *continuous wave sources*, or gravitational wave signatures from individual binary systems. These would induce quasi-sinusoidal signatures in timing residuals. The last are bursting sources from binary mergers or close approaches. For reasonable SMBBH parameters, the residual amplitudes expected for all three signal types range from tens to hundreds of nanoseconds. (Credit: Cordes)

Development efforts for eccentric binaries and IMRIs constitute a revolutionary advance in LIGO data analysis. In particular, eccentric binaries have been argued to be critical Advanced LIGO sources (e.g. O'Leary, Kocsis, and Loeb 2012), and may possibly be the dominant detectable source. While their event rates are highly uncertain, there is currently no sensitivity to this possibly important class of objects, and they could not have been detected with existing methods (East *et al.* 2013). The first template-based search algorithm for these sources has very recently been implemented within the LIGO Algorithm Library

(Huerta *et al.* 2014). Furthermore, a non-template-based method was recently developed (Tai, McWilliams, and Pretorius 2014) that mitigates the sensitivity to systematic template errors which are intrinsically larger for eccentric sources. For this proposal, we will take development one step farther to create an optimized template-free search and parameter estimation algorithm which we have included in the official LIGO search proposal.

This novel search algorithm will repurpose the existing BayesWave algorithm (Littenberg and Cornish 2013) which coherently models transient events in LIGO data as a linear combination of wavelet basis functions. The number of functions required is a model parameter and is determined through Bayesian model selection. In our operating mode, BayesWave will produce relative probabilities that excess power is due to a a sequence of GW bursts from an eccentrics source instead of an instrument artifact and also provide source parameter estimates in case of a detection. Numerical simulations and analytical models of eccentric waveforms described in RF 2.b will provide predictions for time-frequency locations of GW bursts emitted during binary closest approaches and can be used as Bayesian priors for signal recovery. . In this way, BayesWave will be able to coherently add up the contributions of each individual burst from an eccentric signal, without requiring that any individual burst be loud enough to be detectable on its own.

Tools: New algorithms for noise characterization in PTA data and GW detection for both PTAs and LIGO.
Infrastructure: High-capacity storage system for NANOGrav data.

Research Focus 2.b: Gravitational wave signals and populations
Research Focus Leader: McWilliams (WVU-P&A)

Background: Understanding the expected characteristics of GW signals is essential to directly detect GWs and use them to measure source properties. For PTAs, this involves understanding how massive BH binaries evolve and merge, and how parameters describing these systems influence the signal. In the case of LIGO, the challenge is instead to predict the signal from an individual source. Since the signal in this case is generated during very late stages of the binary inspiral and the final merger, it can be very complex. With this research focus, we will establish WV as a leading center for signal characterization, source signal and population modeling, and numerical simulations.

In addition to these theoretical approaches, electromagnetic (EM) observations can inform our understanding of source properties, and may even provide triggers for targeted searches. Massive BH binaries may generate EM signals, either through generation of orbit-modulated jets near the BHs or emission from the inner boundary of a circumbinary disk (Burke-Spolaor 2014). These counterpart signals would provide candidates for targeted searches within pulsar timing data. Likewise, high-energy emission generated by neutron stars during the final stages of merger as well as radio afterglow emission following the merger may provide additional information about properties of a LIGO source. We will therefore carry out an ambitious EM campaign aimed at identifying compact binary candidates, facilitated by a faculty hire with expertise in observation of EM signatures of BH binaries relevant for PTA GW detection.

Approach: At nHz frequencies relevant to PTAs, our efforts will focus on prediction of source populations, and simulation of potential EM counterparts. McWilliams will concentrate on improving estimates for the expected level of the GW stochastic background signal and, after the proposing team makes its first detection, he and Etienne will use the GW properties to characterize source populations and make predictions about expected EM counterparts..

At much higher kHz frequencies, LIGO will be sensitive to much less massive binaries, containing either neutron star (NS) or BH components ranging from slightly more than the mass of the Sun to hundreds of times the Sun's mass. With the first direct detection of GWs by LIGO expected within the next several years, there is an urgent need for accurate theoretical GW templates. Babiuc-Hamilton (and MU graduate student), Etienne (and WVU graduate student), and McWilliams will work to develop such templates using new numerical relativity techniques based on previous work (Babiuc 2009; Babiuc *et al*., 2011a, b). In addition, codes used to simulate promising GW sources for LIGO (Etienne *et al*., 2008, 2010) will be enhanced to generate theoretical predictions for EM counterparts to these sources. Eitenne will work with McWilliams and Babiuc-Hamilton to build needed next-generation tools that will both enhance the physical realism of these simulations and provide unprecedented accuracy in theoretical predictions. McWilliams pioneered early LIGO source modeling and data analysis efforts (McWilliams *et al*., 2010), and is an expert in predicting and modeling potential EM counterparts.

EM observations at multiple wavelengths will identify counterparts to GW sources through signatures from sources such as double-peaked emission lines (optical), jets and morphology changes (radio), and circumbinary disk emission (X-ray) and from kHz sources such as gamma-ray bursts and radio afterglows from r-process reactions of neutron-rich material. These will involve Delaney at WV Wesleyan College, Saken at MU and a faculty hire at WVU who will initiate a new research area, and a WVU postdoctoral researcher. The new hire will be mentored by faculty members at WVU and within the broader NANOGrav collaboration who have been successful at receiving telescope time on radio interferometers, optical telescopes, and X-ray satellites. The computational resources provided by this and the prior RII will be used for this effort.

Tools: Codes which constrain properties of EM counterparts to both PTA and LIGO sources. **Infrastructure**: New hire in EM observations of BH binaries

Research Focus 2.c: Pulsar Timing Array Development

Research Focus Leader: Lorimer (WVU-P&A)

Background: The sensitivity of PTAs to GW sources depends on four key parameters, including number of MSPs in the array, their timing precisions, cadence of observations, and total timespan of the experiment. For the stochastic background, GW sensitivity increases linearly with the number of MSPs, making this the dominant contribution (Siemens et al. 2013). For individual sources, the sensitivity is dominated by the MSPs with the highest timing precisions, but additional MSPs will allow more accurate localization. For these reasons, pulsar searches are critical to the GW detection effort. They are also crucial for determining fundamental properties of the neutron star population, such as minimum spin period (e.g., Hessels *et al.,* 2006) and maximum mass (e.g., Demorest et al. 2010), and for developing models for pulsar demography (for a review, Lorimer & McLaughlin 2010). Searching involves using a radio telescope to scan the sky for faint periodic signals buried in noise and radio frequency interference. Due to the tremendous time and frequency resolution required, pulsar search datasets are enormous, with current GBT surveys producing roughly 10 Gbytes of data in a 5-minute pointing. Also, analyzing these data is computationally challenging with this same sample taking 1-2 CPU days to process.

Currently, NANOGrav's timing program includes 42 MSPs, an increase of roughly 20 MSPs over the past five years. WVU is involved in several MSP surveys with the GBT and Arecibo that should result in more than 100 MSPs, roughly 20% of which may ultimately be added to the NANOGrav array. We are currently able to process search data at a reasonable rate, but the searches produce a large number (up to hundreds for each 5-minute pointing) of candidate detections, each accompanied by a diagnostic plot that must be analyzed to determine whether it is associated with an astrophysical source. Inspection of these plots has traditionally been done by students, including high-school students in the NRAO/WVU Pulsar Search Collaboratory program. In the future, however, new telescopes such as LOFAR in the Netherlands, which has recently begun pulsar surveys, the HI Mapping Experiment (CHIME) in Canada, and the MeerKAT array in South Africa will synthesize *thousands* of beams at once, necessitating new methods for candidate sifting.

Approach: WVU is a natural data center for GBT surveys, as copious amounts of data can be transferred over the new high-speed link. This project will involve students at all levels across WV in inspection of plots from the GBT and Arecibo to discover pulsars and provide them with an authentic research experience that will increase interest in STEM careers. This effort will be grounded in the Pulsar Search Collaboratory (PSC) program (Rosen *et al*., 2010, 2013) and will have hubs at WVU, MU, WV Wesleyan, and Shepherd University.

With astronomers Lorimer and McLaughlin and a graduate student, a new hire in the WVU Dept. of Computer Science and Electrical Engineering (CSEE) will help develop highly parallelized search hardware and software implementations for processing large amounts of search data with the ultimate goal of quasi-real time (likely GPU-based) implementations. Data will be processed on the existing computing cluster in the Dept. of Physics and Astronomy as well as shared Mountaineer and Spruce Knob clusters developed through the previous RII grant. This team with another graduate student will also develop methods for automated inspection of diagnostic plots (Fig. 5). Various parametric and non-parametric models and algorithms used in radar imaging (Van Trees, 2001), machine learning (Murphy 2012), pattern recognition, and data mining (Witten *et al.*, 2011) will be considered. Lorimer and McLaughlin have already participated in development of automated candidate inspection (Lee *et al.*, 2013, Zhu *et al.*, 2014), but these have relied on a set of relatively simple metrics. Our work will be focused on identification and extraction of new metrics that have better predictive power, and on development of algorithms that can handle two important challenges in automatic identification of pulsars: highly imbalanced datasets (with many more examples of noise and RFI than of pulsars) and efficient analysis of large amounts of data. Goseva-Popstojanova and Schmid will combine their expertise in machine learning algorithms, big data, and stochastic modeling, and algorithms with the expertise in astrophysics of Lorimer and McLaughlin. A set of fully automated optimized algorithms for detecting candidate pulsars implemented in software is an expected outcome. Cyberinfrastructure for this research area is a 5 petabyte data server that will provide storage of up to 1 year of GBT survey data. The data server and existing computational nodes will enable the GW team to participate in the LIGO data grid and will host the analysis software and data repository for GW and water research educational programs

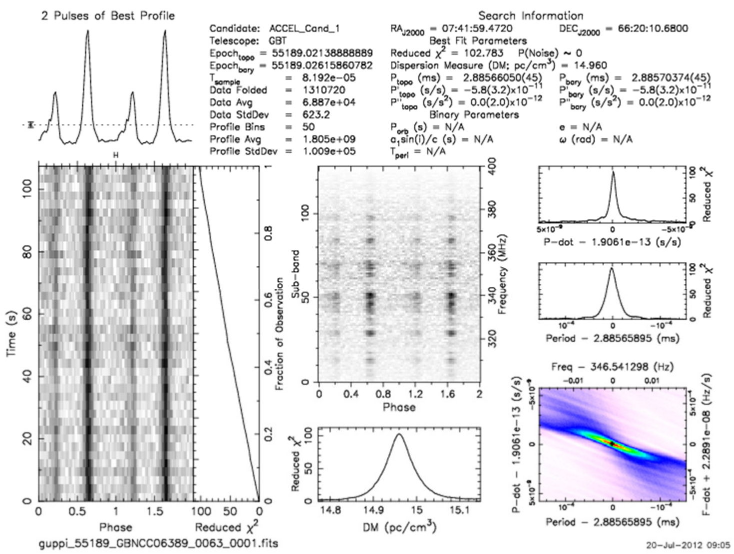

Fig 5. Example periodicity search output plot showing data folded in time (lower left) and radio frequency (upper center) as well as the integrated pulse profile (upper left) and optimal DM search (lower center). The statistical significance of the signal in each of these diagrams is measured in terms of the reduced chi-squared value computed from the integrated pulse profiles.

Identifying a pulsar candidate is only the first step in the pulsar search process. The vast majority of the scientific potential of a pulsar can only be extracted via a dedicated campaign of radio observations to determine its properties. Since pulsars emit over a broad range of the electromagnetic spectrum, observations with X-ray, gamma-ray, or optical telescopes may provide unique information about a pulsar and/or its companion (Kaplan et al. 2014). This effort will involve students at all levels in these experiments with collaborators across the country to provide them with a broad research experience. This will also provide graduate students and postdocs with a wide range of research expertise and mentoring opportunities. Lorimer, McLaughlin, and Delaney have extensive experience in multi-wavelength observations and will lead this effort.

A large number of middle school, high school, and undergraduate students will participate in the pulsar detection effort through RII-supported growth of the established PSC program. Students across the state will gain expertise in signal processing, pattern recognition, and manipulation of large datasets. We will develop PSC hubs at WVU, MU, Wesleyan, and Shepherd at which undergraduate students will mentor local high-school students in these activities. High school students will be able to participate remotely. Graduate students will also receive research-based interdisciplinary cross-training in astrophysics, signal processing, pattern recognition, and big data analytics. These skills are transferable to a variety of STEM fields and technological applications. The WVU storage system will serve pulsar search data to a broad collaboration of researchers, ranging from International Pulsar Timing Array partners throughout the world to middle-school students.

Tools: New algorithms for pulsar searching and pulsar candidate classification.
Infrastructure: Hardware and software configurations that can handle data intensive computations, new hire in CSEE, and statewide outreach program based on analysis of GBT data.

4.3.1 WORKFORCE DEVELOPMENT PLAN

Through this RII, WV is complementing the Governor's investments in workforce development by focusing on building a diverse workforce in STEM fields, specifically in environmental sciences, large dataset analysis, astrophysics, and signal processing. Workers with these skills are needed to support and minimize the impact of existing extraction and chemical industries, new extractive industries (e.g., shale gas extraction and cracking), and high-tech industries in software testing, biometrics, and manufacturing. WV's objective is to grow the number of technically competent graduates from the state's colleges, universities, and secondary schools through strategies that intentionally span many levels of the STEM "pipeline," from engaging youth in STEM experiences in middle school to encouraging growth of industries that provide employment for graduates with STEM skills at every degree level.

Technology and Economic Development Program: This program will provide regional competitive advantages by providing support and expertise to the technology business sector. The WVU and MU Technology Transfer Offices, led by Harbaugh at WVU, will create a webinar series which will guide faculty from WV institutions through a framework for moving AFI and GW innovation from concept to market. Participants will be trained in subjects like technology commercialization, intellectual property, strategic alliances, and SBIR/STTR proposal development submission. The program will specifically focus bridging the technology commercialization "valley of death" - a gap recognized as a primary reason that economic value has not been derived from scientific research and federally-funded technology development (Barr *et al.*, 1999). This "valley of death" exists between the point at which a technology concept is developed using research resources within a university, but before the point at which the resulting technology is mature enough to satisfy commercial requirements. To bridge this gap, researchers, universities, regions, and entrepreneurs must create a system that proactively seeks technologies with the highest commercial potential, and utilizes funding from sources such as SBIR and STTR awards, as well as strategic partnerships, coaching, and hands-on support from mentors, industry partners and service providers.

Early Career Faculty and Junior Researcher Mentoring Program: The three lead institutions provide a wide range of mentoring and career development programs for early career faculty, junior researchers, and graduate students. These include programs such as the "Faculty Success Program", available through the National Center for Faculty Diversity and Development, an intensive 12 week on-line program aimed to enhance research productivity and scholarship, while maintaining positive work-life integration and strengthening networks. Participants receive coaching and peer mentoring via conference calls and access to an extensive online set of resources. Other programs include one-on-one workshops with professional grant writers, external pre-submission reviews of proposals by junior faculty, interviewing and resume writing workshops for graduate students, and pedagogical training courses for postdoctoral researchers and research staff interested in careers that involve teaching. NSF ADVANCE programs at WVU and MU provide mentorship and collaborative resources for early career women faculty. Early career faculty engaged in this RII at WVU, MU, and WVSU will be mentored in accessing these programs.

Mountain State Graduate Fellowship Program: These Fellowships will address recruitment of a diverse population of highly qualified graduate students to research programs. Each year, cohorts of six students from historically underrepresented groups will receive two-year graduate fellowship stipends for research in the two research areas of this RII proposal. As WV is an unusually ethnically homogenous state (~ 5% minority), its underrepresented minority (UREP) population includes racial and ethnic minorities, women, persons with disabilities, and rural, first-generation and/or economically disadvantaged students. Fellows will receive training in ethics, interdisciplinary research, technical communication, professional conduct, and cross-cultural team building, leading to a Ph.D. in a STEM discipline. Students will be mentored by RII faculty and will enroll in a graduate course in proposal writing and scientific presentation strategies. They will visit national centers and learn to network beyond WV including participating in international research internships. As part of their fellowship responsibilities, the graduate fellows will mentor participants in the pre-service and early career teacher research experience program (Section 4.7.1).

PROMISE and HEG Scholarships: Recognizing that cost and access are two significant barriers to STEM-centered educational achievement, the State will continue to fund the PROMISE scholarship and WV Higher Education Grants (HEG) programs for undergraduates to attend college to demonstrate its commitment to an educated workforce. Both programs and their impact are described in detail in Section 4.4 of this proposal. By dovetailing new workforce initiatives with ongoing support of PROMISE and HEG programs, WV will enhance production of STEM trained students.

WV Undergraduate Research Communications Program: We will expand upon the SPOT (Space Public Outreach Team) program, recently established in WV and supported by NRAO, WVU Physics and Astronomy, NASA IV&V, and WV Space Grant. This program, coordinated by Kathryn Williamson at NRAO, trains undergraduate students throughout the state to deliver presentations at middle and high schools. Students receive coaching and must pass a practice talk before they are able to travel to schools. This provides students with valuable communication skills for their future STEM careers and ensures that middle- and high-school students receive quality presentations. Currently SPOT presenters give one of two presentations, “The Invisible Universe” (about the GBT and radio astronomy, with a focus on pulsars) and “Mission to Mars” (about Mars exploration). We will expand these presentations to include two on water research, and train new undergraduate presenters within the same framework. One presentation, “Water in WV,” will describe the challenges of water quality in WV; the second, “Watery Worlds,” will describe the importance of water for life, evidence for water on other planets and moons, and how features on these planets and moons compare to those on Earth. This RII will provide funds to support travel of the undergraduates to the NRAO facility in Green Bank, WV to receive training during summers.

Citizen Science – Engagement of Students and the Public in Research**:** One of the strengths of the two research areas supported through this RII is the opportunity to actively involve a broad range of participants, particularly high-school and middle-school teachers, students, and the public, in actual performance of the research. This RII will expand implementation of standards-based, self-contained, classroom science modules using the existing GLOBE curriculum to develop an outreach effort that targets Appalachian water quality issues. This program, called Water in Appalachia: Testing, Extraction, and Remediation (WATER), will incorporate a variety of strategies for sustained engagement with K-12 students, such as professional training for teachers, and hands-on experiments led by university students and faculty. The program will target vocational schools throughout WV, especially those with training programs for students pursuing careers in the mining, drilling and forestry industries. Each year will focus on a different facet of water science and results from student-led measurements will be incorporated into statewide models of existing watershed water quality. The advantage of using GLOBE is that an already established network of citizen scientists exists around the world using GLOBE curriculum which will allow for expanding state, national and international data and interactions with WV citizens.

The NSF-ITEST-funded Pulsar Search Collaboratory (PSC) program has involved over 2000 high-school students over the past seven years in analysis of pulsar search data taken with the GBT (Rosen *et al.*, 2010, 2013). Students are trained in a summer workshop, analyze data throughout the academic year, facilitated through email contact and videoconferences with Lorimer and McLaughlin at WVU, and attend a Capstone event at WVU where they present their research, tour labs, and learn about STEM majors and careers. The program has been both a scientific and workforce development success with six new pulsars discovered and a large majority of students reporting increased interest in STEM majors - an astonishing 47% of high-school student participants stating that they plan to pursue a PhD in a STEM field. We will expand this program to involve middle-school students and their teachers, so that we reach them at the critical period at which many begin to shy away from STEM. We will also encourage pre-service teachers to serve as PSC mentors at high-schools local to their institutions. As these teachers move into their first teaching positions, many will start PSC clubs at their high schools, ensuring sustainability of the program and expanding its reach throughout WV and beyond. Finally, WVU Physics and Astronomy researchers will work with STEM researchers to develop standards-based, self-contained activity kits to be used by teachers to enable GW astrophysics to be used as a vehicle for teaching basic scientific concepts (e.g., conservation of energy and momentum).

4.3.2 SEED FUNDING and EMERGING AREAS: Emerging areas, or rapidly developing research opportunities, are likely to arise during the period of this project. Examples of such opportunities include the recent chemical spill in the Elk River in Charleston, WV or the discovery of compact objects that warrant further astronomical observation, such as the recent detection of a triple star system by WVU pulsar astronomers. Seed funding will be provided for: 1) initial data acquisition for potentially transformative projects; 2) competitive researchers changing directions into more cross-cutting or fundable fields; 3) junior faculty pursuing an NSF CAREER award; and 4) innovative educational/research alliances with industry. The themes of the proposed projects must be consistent with scientific aims of the RII; proposals will be accepted annually and evaluated by external referees. NSF merit review criteria will be used with an emphasis on novelty and contribution to RII core investigations. Selection of projects for funding will be made by research consortium leaders and the PI. Seed project annual reports will be evaluated externally to determine if the project should receive second year renewal. Metrics include: number of papers published or submitted for publication, proposals submitted to external agencies, impact on workforce development, patents filed, and intellectual property licensed. These faculty will be mentored in grantsmanship, and CAREER award−eligible faculty will be mentored by CAREER awardees from WVU.

4.4 DIVERSITY PLAN

This RII dedicates nearly $3M in new funding to WVSU, a historically black university, to enable WVSU faculty to participate in fundamental scientific research. The breadth of the science in this RII also provides opportunities for PUI faculty and students in physics, astronomy, statistics, mathematics, engineering, chemistry, biology, geology, geography, environmental sciences, ecology, economics, and the social sciences to collaborate in research with the lead institutions. PUIs educate a significant fraction of first-generation college students and those that are geographically bound to their current locations in WV. WV also has a significant veteran population and undergraduate research participants will be actively recruited through the veterans' programs established at the institutions.

Increase Access: The State will continue to fund the PROMISE scholarship program. In 2011-12 the HEPC provided more than 34,000 state financial aid awards totaling almost $93M dollars to West Virginia postsecondary students. Through administration and stewardship of the PROMISE Scholarship, Higher Education Grant, Higher Education Adult Part-Time Student Grant, Engineering, Science and Technology Scholarship, and Underwood-Smith Teacher Scholarship programs, HEPC has incentivized both recent high-school graduates and non-traditional adult students to enroll, helping to eliminate cost as one of the greatest enrollment barriers. The HEG currently supports more underrepresented minority student STEM majors than the overall percent of those minorities in the State. Approximately 63% of all scholarships are awarded to first generation college students. PROMISE and HEG scholarship recipients represent 52% of the 56,000 WV undergraduate students in four-year institutions. Although PROMISE and HEG programs are not specifically focused on STEM, WVEPSCoR will use outreach activities to increase college awareness and enlarge the pool of college-bound UREP and STEM students. These scholarships have moved WV from 49^{th} to 5^{th} in the nation in need-based scholarships, making increased access a driver of future STEM enrollments. Furthermore, the number of students majoring in STEM fields in WV increased by 11% between 2007 and 2011. Considerable efforts will be focused on targeting student retention so that WV can capitalize on its significant commitment to enhance college access.

Leverage Innovation for Retention Initiatives: WV will capitalize on current programs that broaden UREP participation in STEM. They include: Undergraduate Bridge (WVU, WVSU); the Summer Undergraduate Research Experience (WVU, MU, WLSU, WVUIT, and WVSU); ADVANCE (WVU); Summer LAUNCH (WVU); NSF LSAMP: KY-WV Mid-Level Alliance (WVU, MU, WVSU), and SREB Minority Doctoral Scholars (WVU), among others. These programs provide everything from early outreach activities to minority recruitment for doctoral programs, and from summer bridge programs and academic support services to research experiences. These programs – which reach more than 1000 UREP STEM students each year – will be continued with state and institutional funding.

In the 2013-2018 Master Plan, HEPC set specific retention goals for state institutions. These include: increase the first-year retention rate of full-time, first-time degree-seeking freshmen to 80%; increase the first-year retention rate of part-time, first-time degree-seeking freshmen to 50%; increase the first-year retention rate of low-income, first-time degree-seeking freshmen to 75%; increase the first-year retention rate of first-time degree-seeking freshmen from underrepresented racial/ethnic minority groups to 75%; increase the one-year retention rate of returning adult degree-seeking students to 65%; and increase the one-year retention rate of degree-seeking transfer students to 76%. Data from 2004-2012 show retention rates of the entire student population at MU have a 5-yr average of 67.3%, at WVSU, 56.8%, and at WVU, it is 79.6%. (WV HEPC Data Notebook, rev. Jan. 2014). De-aggregated retention rates will be acquired from the statewide HEPC database for tracking from 2014 through the course of the grant.

In addition to statewide initiatives and goals, we are engaged on a national scale in recruitment of UREP students to our STEM programs. WVU is a member of the National Astronomy Consortium, a group composed of NRAO and universities and colleges, which aims to increase the number of UREPs in STEM. We will actively recruit undergraduates for summer research opportunities and, ultimately, graduate studies from HBCUs in the consortium. Through other NANOGrav member institutions, we also have close ties with institutions with diverse demographics, including the Hispanic-serving Univ. of Texas at Brownsville. We will target undergraduates at these institutions for graduate study in water and astrophysics.

WVEPSCoR's diversity plan is designed to address student retention issues of underrepresented populations in the STEM enterprise. Through previous RII projects, WVEPSCoR has established working relationships with state leaders and key diversity recruitment and retention programs on partner campuses. Through the Chancellor's Diversity Council, best practices were identified from partner programs and will be initiated system-wide, supported and evaluated throughout the project to ensure that benchmarks and milestones are met. Critical to success is support for improvement in UREP student retention at the highest administrative levels, inclusion of retention goals in strategic plans and annual work plans, and accountability mechanisms for achieving goals. UREP student retention will serve as the keystone of diversity initiatives. Anchoring this plan is implementation of the campus compacts that established retention milestones listed above. Other milestones and metrics are provided in Section 4.8.

4.5 PARTNERSHIPS and COLLABORATION

Multiple partnerships and collaborations build upon the unique contributions and connections the three partner institutions have with their communities. While the initial group includes WVU, MU and WVSU, there are a smaller, undergraduate institutions that are active participants in this proposal, e.g., Best (Shepherd) and Delaney (Wesleyan). As a result of these active collaborations, the PUI faculty can also leverage research support funds from the NASA WV EPSCoR program specifically directed towards PUI faculty engaged in space-relevant research. Engagement of additional PUIs will enhance entry of minorities and first-generation college students into STEM graduate study at WVU and MU.

National laboratory facilities within WV are also partners in research and education activities of this RII. The National Energy Technology Laboratory in Morgantown, WV has a large research program that focuses on fossil energy extraction and usage industries and their impact on water quality. They will provide key information on emerging issues regarding fracking water compounds. The US Geological Survey (USGS) National Water Quality Laboratory, USGS Water Science Center in WV, and the Leetown Science Center all provide existing important partnerships regarding water research. The US Department of Agriculture--Forest Service (USFS; Monongahela National Forest and the Timber and Watershed Laboratory) provide collaborative expertise and ample reference study conditions for watershed studies. The water group works extensively with the USFS on critical watershed-scale research and demonstration projects. These partnerships are critical to leveraging the investments of this RII in ways that will have statewide and regional impacts.At the international level, existing partnerships with the University of Puerto Rico, Institution of Hydrobiology of the Chinese Academy of Sciences, and Gujarat Ecological Education and Research (GEER) Foundation (India) provide opportunities for collaborative research and education opportunities

The NRAO facility will play a key role in the GW astrophysics program as well as in educational programs. The Educator Research Center at the NASA IV&V facility in Fairmont, WV will play a collaborative role in the proposed SPOT and traveling planetarium programs.The GW astrophysics program will leverage existing partnerships with the International Pulsar Timing Array (IPTA) and LIGO collaborations and will partner closely with IPTA institutions, in particular University of Manchester (UK), Max Planck Institute for Radio Astronomy (Germany), ASTRON (Netherlands), the Australia Telescope National Facility (Australia), and the National Center for Radio Astrophysics (India). The group is actively building new collaborations with South Africa and China, as their sensitive radio telescopes (MeerKAT and FAST, respectively) come online. Through this RII, a broader community of scientists, engineers, and students will have access to the intellectual resources provided by these collaborations. Membership in these collaborations will increase the funding potential of faculty and number of international research collaborations with faculty and students throughout the state.

4.6 COMMUNICATION AND DISSEMINATION

The goal of WVEPSCoR's Communication and Dissemination Plan is to communicate results and the benefits and processes of science to WV's citizens at all education levels. These efforts will help build scientific literacy in the state and strengthen education and research capacity. Proposed activities include: 1) Communicating the importance and benefits of STEM research by continuing publication of *The Neuron* and our partnership with WV Public Broadcasting, which highlight WV STEM research and related economic development; 2) Publishing the *Neurite* which targets 7th grade science students and will introduce them to WV scientists; 3) Developing a planetarium outreach program aimed at grade-school through high-school students. This program will include our NSF- and NASA-funded documentary about the PSC program and will be given at the ten regularly-operated planetaria within WV as well as at the NRAO Education Center in Green Bank, WV (visited by over 50,000 people each year). Schools can also request the program to accompany the portable Starlab planetarium available through the NASA Educator Resource Center in Fairmont. This program will describe the births of pulsars in supernova remnants, their properties, general relativity, and GWs. We will accompany it with lectures from students participating in the SPOT program. 4) The development of an interactive watershed display for the West Virginia University Natural History Museum. 5) Using the Summit Bechtel Reserve, Boy Scout Camp (on the Upper New River— with a whitewater rafting section that is impaired due to fecal coliforms) as a site to demonstrate water quality impacts. The Bechtel site is home to the new National Jamboree site for all Boy Scouts in the USA and will thus have a national impact. 6) Engaging the public by hosting workshops and disseminating information related to crowd sourcing water quality and quantity sampling based on a low-cost distributed sensor network. 7) Engaging the public by measuring West Virginia residents' perceptions of the water quality, their quality of life, and their perception of the impacts of global climate change in West Virginia. 7) Focusing on educating industry, legislators, the public, and other stakeholders about the value of new practices (e.g. preventative measures) which can result in sustainable ecological services. We will also disseminate science and education results through publication in peer-reviewed papers and through contributed and invited talks at national meetings. Software developed for GW detection will be shared online as will the software for sharing PSC data with students. Watershed model predictions will be shared publically through a website and will be available for community planning and resource management by the public, industries, and public officials.

4.7 SUSTAINABILITY PLAN

The investments of past RIIs, faculty hires and Shared Facilities, through improvement of research policies at the institutions and through combined funding of the Shared Facilities – user fees, university and state funding – have been sustained and upgraded. We expect that investments in this proposal will be similarly sustained. The various elements of the proposed project target the eight key organizational and contextual domains that will build capacity for maintaining these research programs over the long term: 1) Environmental support – addressed through adherence to the *Vision 2015* plan, the communications plan, and the engagement of state and institutional leadership in the management structure; 2) Funding stability – addressed by increasing number and competitiveness of individual, group and large-scale, multidisciplinary proposals from all faculty, research clusters and partners and the new incentive program for "Centers" project development; 3) Partnerships – addressed through new research collaborations with internal (to WV) and external academic, federal, and industrial partners; 4) Organizational Capacity – addressed by the increased human and equipment infrastructure provided by this RII that leverages recent and ongoing institutional investments; 5) Program Evaluation – addressed by the built-in program evaluation process described below; 6) Program Adaptation – addressed by seed funding and emerging areas programs and feedback provided by the program evaluation process; 7) Communications – addressed by the communication, outreach, and education programs supported through this project; and 8) Strategic Planning – addressed by the focus on the objectives of the state's *Vision 2015* and its successor as well as the research and broader impact objectives outlined in this proposal. Additional sustainability elements of this project include our continuing emphasis on postdoc and junior faculty mentoring, improvement of institutional research policies, and financial and infrastructure support for workforce and research enterprise. After attracting and nurturing a diverse, competitive research faculty, the research equipment and supporting infrastructure will be sustained by the state and institutions.

One critical aspect of the sustainability plan is to identify and mitigate risks. For astrophysics, the greatest risk is loss of access to the GBT, which was recommended for divestment in the recent NSF Portfolio Review. While the long-term funding model is still emerging, and includes a contribution to the operating costs from WVU, we are confident that a solution will be found and that the GBT will remain operational through the lifetime of this proposal. However, we consider the impact of the loss of the GBT and possible mitigation strategies. Activities in 2a would be unaffected, as algorithms developed would continue to be applied to data acquired with the Arecibo Observatory. Time to detection would be pushed back by several years, but our sensitivity to GWs would continue to increase with time. Activities in 2b, aimed at understanding GW source populations, would continue unaffected. Algorithmic developments for pulsar searching described in 2c would also continue unaffected, as they are critical for pulsar searches with many telescopes, and in particular future surveys with widefield interferometers. The PSC effort would be significantly affected by loss of the GBT, but this could be partly compensated by including students in our search efforts with the Arecibo Observatory and in the application of new algorithms to archival GBT data. We would continue to reach the same number of students and conduct the same program, despite the important loss of onsite GBT workshops and the relevance of working with data acquired in the state.

4.7.1 Education and Human Resources Development: WV consistently ranks at or near the bottom nationally in academic performance and economic vitality. Ladner and Myslinski (2013) rank WV 51st out of 50 states and the District of Columbia on overall educational achievement. The US Census Bureau reports that WV is 49th out of 50 states in bachelor's degrees held by citizens over the age of 25 and in personal income. One key to improving WV's performance on these important metrics and the lives of its citizens is improving STEM education in the state. There are currently 600 teachers in WV who are teaching on probationary certificates without certification or in many cases even appropriate content course work for the subject classroom in which they are teaching. In 2004, only 24.3% of all public high school physical science teachers nationally hold a major in the discipline of their main assignment (U.S. Department of Education, 2004). While specific data for physical science in WV was not available, WV closely follows the national trends on teacher qualifications. Furthermore, only 40% of students tested in the 2011-2012 administration of the WESTTEST2 achievement test achieved at the mastery level or higher in science (WVDE, 2014). If teachers are not prepared in content, pedagogy, and pedagogical content knowledge, students have little chance of being judged as successful on standardized tests or being highly qualified to enter the STEM workforce. WV does not produce enough graduates to fill its needs for K−12 STEM teachers. These already dismal statistics are dramatically impacted by problems in teacher retention; 40% to 50% of all early career teachers leave the field within their first five years of teaching (Ingersoll 2003). Furthermore, Ingersoll (2011) reports that this teacher turnover, rather than increasing retirements or student populations, accounts for the difficulty in staffing math and science positions.

WVEPSCoR will leverage the experience gained from the prior summer research experiences for veteran high school science teachers and high school students, and will focus on engaging pre-service (PS), early career (EC) science teachers and in-service teachers (IST) in authentic research experiences and early career support, which will occur at all three partner institutions. To partially address the critical needs of EC teachers, we propose a support system for PS and EC science teacher engagement in the further development of their content knowledge, pedagogical skill, and pedagogical content knowledge. The goals of ***The Preparation and Early Career Support of Science Teachers (PECS)*** program are threefold 1) to enhance the training of high quality science teachers entering the teaching field in WV, 2) to support EC teachers in order to increase retention during a period in the teacher's career that is most difficult and most susceptible to attrition, and 3) to engage PS, EC teachers in unique and authentic research experiences that are both transformative to their teaching methods as well as preparing them for success as teachers in an ever-changing world of scientific innovation and discovery.

PECS will provide PS teachers with early research experiences in watershed research and GW detection and connect those research experiences to pedagogical practice through classroom inquiry. This activity will be synergistic with other work being done throughout WV related to restructuring science teacher preparation. PS teachers will engage in authentic research experiences during the academic year. With the release of the 2012 NSTA standards for science teacher preparation, research experiences for PS science teachers are required. PS and EC teachers will interact with IS teachers via face to face and online programming at each institution. The scientific research proposed is particularly well suited to transfer to the K-12 classroom because of increased public awareness of watershed issues caused by a catastrophic, nationally publicized chemical spill into the Elk River and the extremely technically important and broadly used image and data processing techniques required by GW research. As PS teachers enter the profession, they will be eligible to participate in the EC part of the program. The EC program will work directly with IS teachers upon entering the profession through their third year of teaching. Through this multi-year model, four levels of support will be developed for teachers just entering the classroom: 1) a cohort of PS teachers will develop that go through the job search and first year teaching experience together, 2) this cohort will be joined by a cohort of EC teachers and bond over the summer experiences, 3) the PS teachers will engage over multiple semesters to renew research and professional connections, 4) through the entire experience both EC and PS teachers will develop career long connections with both educational and scientific researchers including long-term mentoring relations.

Teachers will spend two weeks at the beginning of the summer learning background information about the research they will be conducting and familiarizing themselves with the research program. They will return to campus for two weeks at the end of the summer to engage in authentic research activities in labs on campus. The final piece of the PECS program involves bringing middle/high school science students to the research locations participating in the RII. PS, EC, and IS teacher participants will have the opportunity to mentor these young and emerging scientists during a week of exploration of science and research activities. This student engagement can only occur by leveraging existing connections available at all three institutions to reach out into the community of learners.

The PECS program (led by Carver, Stewart at WVU, Cartwright at MU, and McDilda at WVSU) will measure program success by implementation and institutionalization of the revised science education program at all 3 institutions using pre-existing and newly generated data collection instruments. PS and EC teacher researchers in both GW and AFI research will be tasked with identifying parts of their research, with the help of scientific staff, that can form new citizen science research activities, similar to the PSC. These new activities will be aligned with the Next Generation Science Standards (NGSS). Incoming WVU faculty hire G. Stewart served as a critical reviewer of the NGSS for the American Association of Physics Teachers. She will vet developed activities to make sure that they meet both the letter and spirit of the NGSS.

For the AFI consortium, each fall there will be an orientation workshop where new and continuing students and post-docs meet each other and faculty to learn about the program. A series of 1-hour lectures by faculty in their specialty will be intermingled as part of the orientation. In addition, a 2-week summer trainee academy will be held on the WVU campus and focus on laboratory and field analytical training methods. Graduate students will enroll in a 1-credit Water Research course focused on water, professional development, and research development during the spring semester. To stimulate interactions, each member of the Appalachian Freshwater Initiative will record a 2 minute video about themselves and their research during their first year. The videos will be shared with the all the research teams. These activities will serve to increase camaraderie and technical expertise of participants. Similarly, all student researchers in GW Astrophysics will meet yearly at the Green Bank Telescope for a training session which involves instruction in gravitational waves and data analysis and also in observing with the Green Bank Telescope. This yearly meeting, held each fall, will include talks by researchers in their specialties. In the spring, a symposium at WVU will be held where all students, from the undergraduate to postdoctoral level, will present the results of their research. This will coincide with the Capstone event for the PSC program as high-school students will benefit from hearing about the research of more advanced students, and more advanced students can serve as judges of high school student posters.

4.7.2 Post RII Extramural Funding: The decision to invest in these two research consortia was based entirely on the expectation that these two research areas have tremendous potential for significant future non-EPSCoR funding from NSF, other federal agencies, and regional industries and/or national laboratories. Both research consortia have established realistic and detailed milestones for scientific, programmatic, and workforce development progress (Section 4.8). These milestones include expectations for participating faculty as well as for each consortium team. All three universities have developed comprehensive support infrastructure for research active faculty, including project management staff, grant writing mentoring and external pre-submission proposal review for all faculty and WVU has embarked on a new effort to incentivize the creation of large research Centers by allocating a fixed fraction of facilities and administrative costs for investment in Center development. These consortia are specifically expected to develop large, center-level proposals during the period of this project. The seed funding/emerging areas program will play a critical role in developing and growing new research programs aligned with these two core research areas and supporting junior faculty as they pursue new, non-EPSCOR funding.

4.8 MANAGEMENT, EVALUATION, AND ASSESSMENT PLAN

4.8.1 PROJECT MANAGEMENT TEAM: The Science and Research Council (SRC) provides strategic portfolio investments that assure fidelity to *Vision 2015*. The SRC a) authorizes proposals and program implementation, b) serves as liaison to institutions, industries, and businesses, c) oversees WVEPSCoR and IDeA programs, and d) directs state research programs in concert with WV strategic objectives. The WVEPSCoR program office directly guides NSF and DOE EPSCoR programs. Similar programs funded by USDA, NASA, EPA, and NIH are managed by committees that report to the SRC and the Director/PI. SRC members are appointed by the Governor, hold three-year terms, and represent government, academia, and the private sector. The SRC is chaired by Dr. Paul Hill, HEPC Chancellor and has 12 additional members including three women and one African-American male.

RII Executive Leadership Team (ELT). The ELT is the senior management team for the RII. They will meet quarterly to insure that project milestones are met and will utilize evaluation feedback to modify project activities. The ELT is the primary management interface with the PI and NSF. The ELT is led by RII PI and WVEPSCoR Project Director, Dr. Jan Taylor. Dr. Maura McLaughlin and Dr. James Anderson are responsible for the day-to-day management of the research at WVU. Dr. Jeffrey Carver leads the Education and Outreach group on the three campuses. Dr. Charles Somerville represents the scientific staff at MU. Also serving on the ELT are the campus EPSCoR Coordinators and co-PIs, Drs. Fred King, WVU VPR, John Maher, MU VPR, and Ulises Toledo, Assoc. Dean, Land-Grant Institute, WVSU. ELT membership includes 2 women and one Hispanic male.

There are two research consortia and a unifying set of cross-cutting programs. Each research consortium and the education program for teachers has a technical director. Technical directors will hold quarterly meetings with the technical coordinators to assure progress with research goals and will report to the ELT. The research consortia have three research focus areas, each with a technical coordinator (in bold in the management chart). The focus area technical coordinators are responsible for organizing monthly focus area meetings where progress will be shared and graduate students will give presentations on their work. The technical directors are responsible for allocating budgets, student and postdoctoral positions, and reporting to the external advisory board. ELT members with responsibilities for assuring that the milestones of each overarching project goal are met are: 1) Advancing the fundamental science – McLaughlin and Anderson; 2) Developing a STEM pipeline-Carver; and 3) Improving diversity – Maher, King and Toledo; and one non-ELT member 4) Building technology transfer foundation – Harbaugh.

Succession. Succession for project leadership is assured by the WV SRC and institutional leaders. The WV SRC will provide NSF with qualified names of replacements for current leadership should they no longer be available for service. Policies established by the SRC authorize RII proposals and ensure responsive leadership succession. WVEPSCoR will hire a Deputy Director/Education and Diversity Coordinator to assist in project management and oversee education and diversity programs. Through the experience gained in this position, the Deputy Director would be a possible replacement for the Project Director if needed. At the universities, technical leads would be replaced by Co-PIs on each campus. Should Co-PIs require replacement, other administrative leaders would be recruited to fill those spots.

Fiscal Accountability. Financial management of the RII is assured by the financial structure of the Finance and Facilities Division of the HEPC, fiscal agent for WVEPSCoR. *Annette Echols* is EPSCoR Program Administrator and provides financial reporting for WVEPSCoR.

Integration across Institutions. Cross-cutting activities are shared across both research areas which will be managed by technical and educational coordinators on each campus. These include the pre-service and in-service teacher education programs, the Seed and Emerging Research Areas Program, the Graduate Fellowship Program, the SPOT Program, and the Technology and Economic Development Program. These activities also cross institutional boundaries and in conjunction with the collaborative research programs provide pathways for integration among the institutions. The three technical coordinators will meet with their research focus leaders via videoconference or in person monthly to assure that research, education, workforce development and cross-cutting programs are proceeding as intended. The entire ELT will also meet quarterly with the PI via videoconference or in person to review and evaluate progress. Within each research consortium, communication and partnerships are maintained through frequent meetings and monthly progress reporting. Research focus team leaders will meet weekly with their respective technical coordinators to discuss project needs, progress reports and to apprise other research focus teams of new advances. Biannually, all the scientific staff, post-docs and students of each research consortium, will meet for a research retreat to share latest results and further encourage cross-institutional collaborations. Dr. Taylor, the RII PI, will also visit all three campuses each semester and summer to evaluate progress and fidelity to the proposal work plan.

Technical Assistance The project will have an External Advisory Board (EAB) composed of up of two national experts in the research areas from non-EPSCoR research institutions and one EPSCoR State Director from another state. The Board will: (a) review annual progress reports, provide advice and make recommendations for strengthening the RII Program to the PI and to Research Consortia Directors and; (b) make two on-campus review visits during the grant period and advise the PI, institutional officials and SRC on strengths, weaknesses and progress.