4.1. STATUS AND OVERVIEW

Investments in human and physical infrastructure are enabling West Virginia (WV) to transform its once largely extractive economy to a more knowledge-driven one. Central to this goal is a strategy to broaden participation, particularly of underrepresented groups, minorities and females, in STEM professions. Leading the way is WV's Experimental Program to Stimulate Competitive Research (EPSCoR). The proposed RII plan leverages existing science and technology capabilities in strategic and WV-specific research areas that are at critical junctures and where significant investments will likely lead to scientific breakthroughs. 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 (GW) 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 potential for significant, near-term, scientific impact. WV's vision is to build nationally-recognized and sustainable freshwater science and GW wave astrophysics integrating 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). 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 to provide a STEM-capable workforce for the future; 4) Improve the diversity of the STEM workforce, with specific emphasis on underrepresented minorities, first generation college students and those from low socio-economic backgrounds; and 5) Build the foundation for technology transfer from the 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 ($50M with matching totals $100M) and the Eminent Scholars Recruitment and Enhancement Program ($10M matching to $20M). Third, the Governor created two Advanced Technology Centers ($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, *Vision 2015* 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 higher education serves 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 charged with oversight of academic programs, state budgets, financial aid, policy, and governance of state higher education institutions. WVU is a land-grant institution with medical and pharmacy school, engineering college, a law school, and has a Carnegie Research Universities (high research activity) ranking. MU has 3 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. 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) (Green Bank) and the Internet-2 access point (Morgantown). 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 6 new faculty positions in these research areas and is committed to at least 6 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 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. While these state resources are integral to developing high-quality research programs, barriers exist. They 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. WV has, however, been able to maintain key assets due to advances in state, institutional, and EPSCoR efforts. Specifically, state support and the WVU and MU Foundations support endowed professorships and chairs, doctoral fellowships, and graduate student fellowships targeted for support of this research.

Building Capacity: This proposal will provide personnel and equipment 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 amplification effects that might arise due to climate change-related water quantity shifts. It will also add key personnel at the faculty 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. Statewide education and workforce training programs focus on pre-service science teacher training and early career support and will emphasize preparation for adoption of next generation K-12 science standards and expansion of citizen science programs.

4.2 RESULTS FROM RELEVANT PRIOR NSF SUPPORT

WV has successfully used its recent EPSCoR awards to develop competitive programs in biometrics (9871948. $3.0M and 0132740, $3.0M) and bionanotechnology (1003907, $20M). The most recent award period (OIA-1003907, 2010–2015, J. Taylor, $20M) positioned the state to achieve measurable growth in an important sector of WV's economy: bionanotechnology. (See *Table 1*.) Intellectual Merit: This work provided the necessary infrastructure to stimulate innovative research while integrating education, workforce development and diversity programs focused on ***bionanotechnology for enhanced public security and environmental safety.*** Fundamental knowledge needed for field-deployable sensors that can monitor, in real-time, the presence of specific heavy metals, pathogens, and other environmental threats has been realized. Interdisciplinary Research Teams (IRTs) created tools with real-time readouts and validated those against existing standards to ensure utility. IRT focal areas included: (1) Portable and Rapid Identification Platforms, (2) Field-deployable Microfluidic Electrochemical Sensors for Multiplexed Detection of Heavy Metals and Small Molecule Toxins and (3) *Ex Vivo* and *In Vitro* Biomimetics for Cellular Response Monitoring. 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. The prior EPSCoR awards allowed 10 faculty hires, 9 of whom are still employed at our partner institutions and showing success. Two have received CAREER awards, and all have been successful in acquiring grant support from NSF, NIH and other federal and private sources. 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. Moreover, the Governor called for the creation and assembled a STEM Task Force which includes industry, K-12 leaders, and higher education representatives. This Task Force has been charged with developing a plan to increase the STEM workforce in WV. Finally, 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 from the current RII will be involved in the Gravitational Wave work.

Table 1. Summary of Research Infrastructure Improvements, 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 w/Industry - Hosted WVU Linking Innovation Industry & Commercialization (LIINC) Events: Links WVU faculty researchers and graduate students with industry, 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 - Established new hybrid condo model; 48+ condo nodes and growing - Conducted Summer Institutes for HPC – 20 participants from 6 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 system 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
Policy	
HEPC /State of WV	- Established: (1) New statewide Office of Minority Affairs in the Governor's Office; (2) Chancellor's Diversity Council; and (3) 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 students - 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

Introduction: The proposed Science and Engineering (S&E) research activities are organized into two statewide Research Consortia (RC): RC-1, *Appalachian Freshwater Initiative* and RC2, *Gravitational Wave Astrophysics*. Each is a multi-disciplinary, multi-institutional effort involving researchers from WVU, MU, Shepherd Univ., WV Wesleyan College, WVSU, and federal researchers from NRAO (specific to GW). These investments will establish new areas of competitive research, enhance the capacity of existing research efforts, foster collaborations, and train a new generation of STEM educators. Proposed education activities will improve science teacher retention and competency through preparation and early career support program. The 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 facilitates analyses of large quantities of astronomical data. The AFI research will have significant impacts on federal and state land management policies and end users of water from the WV watershed. The GW components of this project will lead to cutting edge discoveries in astrophysics such as low-frequency GW detection and establishing models for electromagnetic counterparts to GW events that will be of interest to the international astrophysical community.

4.3.A . Appalachian Freshwater Initiative (AFI)
Leader- James Anderson (WVU)
Post Docs: 3 | Graduate Students: 20 | Undergraduate Students: 9

Appalachian watersheds 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 1972 Clean Water Act, 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 (Merovich *et al*., 2013, Petty *et al*., 2013; Strager *et al*., 2009, 2011). Of particular concern is broad-scale occurrence of untreated wastewater effluent that constrains economic development within Appalachia 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 freshwater resources for the future, however, is constrained by: (1) an inability to rapidly detect novel or dilute contaminants and pathogens; (2) failure to understand complex chemical interactions and pathogen characteristics (survival, transport, and infectivity), (3) inability to predict contaminant transport, toxicity, and degradation pathways coupled with 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 (4) 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 to be addressed by the AFI. Links between 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 predictive tools. Potential areas of concern, identified by data mining and theoretical models, will drive experimental work. Our goal is to use an array of approaches to develop the strongest predictive and analytical tools possible, and improve our understanding of interactive, ecosystem level impacts.

- AFI researchers will use a watershed research framework to address clean water challenges affecting WV and to respond to future potential threats. Core **research themes** include: *Chemical, physical, and biological water quality detection technology:* improving detection of chemical, physical, and biological threats to water quality;
- *Molecular to watershed scale complexity:* 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;

- *Modeling of toxicity and biological impacts:* innovating 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*.*

Each focal area *w*ill be co-led by WVU, WVSU, and MU. Institutional Coordinators (Anderson WVU, Toledo WVSU, Somerville MU) will manage the overall effort. Anderson and Somerville are senior faculty with extensive funding experience in water and related research areas. Research Focus Leaders will administer overall activities within a research focus area. Research teams include chemists, ecologists, molecular, cellular and physiological biologists, microbiologists, engineers, geologists, spatial modelers, and stream and watershed specialists.

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 faculty hires, and improvement of shared research facilities. Faculty hires at WVU include a groundwater hydrologist; an organic analytical chemist; and a regional-scale watershed modeler. Proposed hires at WVSU include: an environmental engineer and an aquatic toxicologist. Proposed hires at MU include an organic chemist, an environmental toxicologist, and an ecologist with expertise in environmental modeling.

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: Development of 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 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 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 the 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). 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 aptamer/small molecule, e.g., 17β-estradiol (Yildirim, 2012) interaction, a capillary electrophoresis system will be used to characterize 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 nanoscale 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 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 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 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, 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 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 – Our goal is to establish genetic, epigenetic, and biological signatures that will allow us to detect otherwise undetectable or rare species and traits. We will employ the techniques below to the same system so a comprehensive view of the various signatures can be obtained allowing new insights into previously unknown relations. Advanced molecular methods such as microarrays in combination with quantitative polymerase chain reaction (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 target 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 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) 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's team will determine 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.

New approaches providing detection of known and/or emerging biological stressors.will be developed based on monitoring biological responses at the cellular level. These cell-based, bioreporter responses will likely motivate deeper investigation of specific waterbodies. Georgel (MU) and Iwanowicz (USGS) will work in collaboration with Hager (Head, Hormone and Oncogeneisis Section, NIH/NCI), who has developed unique human cell lines to investigate 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 the monitoring of biological and epigenetic cellular responses (Georgel *et al*., 2003) to exposure to products not 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). Epigenetics profiles have been demonstrated to be reliable biomarkers to monitor cellular health (Seligson et al., 2005; Seligson et al., 2009; Bianco-Miotto et al., 2010). We propose to use biochemical (signal transduction), genetic (gene expression profiling), and epigenetic (specific histone post-translational modifications) methods to establish specific biological signatures triggered by otherwise unknown or undetectable perturbations. Systems will be developed into assays for presence of endocrine disrupting chemicals.

Tools: Nanostructured DNA optical & electronic water sensors. Development of cell-based bioreporters.
Infrastructure: New environmental DNA sampling capacity. Expanded cohort of detectable compounds

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. The goal of this research is to focus on sub-lethal, chronic, and cumulative effects of the often complex chemical, biological and physical contaminants in Appalachian streams and rivers and to explore upstream remediation alternatives.

Significantly, investigators will work across the entire stream order continuum: WVU researchers have extensive experience in lower order streams while those from MU and WVSU bring knowledge of mid to high order rivers. This focal area will expand our existing experimental research to investigate interactive effects of multiple contaminants at various spatial and temporal scales. The goals are to: (1) elucidate fundamental interactions between complex contaminant mixtures and environmental conditions (with special emphasis on Appalachian water systems impacted by AMD); and (2) characterize and quantify biological effects and responses of these contaminants on diverse biological systems. Expected outcomes include increased research capabilities to predict contaminant fate, transport, and degradation in multi-contaminant mixtures; and their effect on biological responses in multi-contaminant landscapes typical of Appalachia. In particular, the team will provide a fundamental understanding of primary reaction pathways among and between contaminants and environmental conditions in Appalachian streams.

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. Working with the modeling group, we will evaluate and predict how these contaminants move through the system, and what their biological response is. This study will employ non-traditional endpoints more sensitive than growth, reproduction and mortality measurements generally evaluated. Assessments will include *in-vitro* and organism responses (i.e., enzyme assays, changes in cell differentiation and gene expression, cellular response, and structural and functional changes in microbial, algal, macroinvertebrate, and fish communities) [redacted] 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. In collaboration with Vesper, they will also examine how mine drainage affects pathogen degradation in elevated TDS environments. Sekabunga will investigate ligands for metal contaminant removal from AMD water as a possible remediation tool.

Context dependent biological response – Both the nature of contaminants and environmental conditions change in a downstream direction in WV. To validate the research above, naturally occurring populations or individuals of microbes, fish, and invertebrates associated with aquatic systems will be studied *in situ* and *ex situ* with awareness of specific chemical and physical conditions associated with different positions on the stream continuum. Antonsen will investigate sub-lethal effects of single and multiple contaminants under a wide range of environmental conditions, using a DanioVision tracking system which simultaneously evaluates larval fish responses to multiple exposure mixtures and conditions. Using other fish models, Eya will complement Antonsen's approach by evaluating 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). This team's studies will focus on creek chub and fathead minnow since these species are widely present in WV and full genetic information is available to allow the use of powerful genomic tools.

Kovatch, Schultz, and Mosher will use large-scale mesocosm testing to control the levels of multiple contaminants under conditions that more closely mimic field conditions. Field studies in areas with known specific contaminant combinations will also be studied to inform the effects database. 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). 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 and Hass. The primary source for biogeochemical and bioremediation processes in riverine environments resides with the sediment microbial communities. Microbial diversity of rivers is under-sampled and the role of the rare biosphere in maintaining riverine ecosystem services is nearly unknown, although some work has shown that sediment microbial diversity can reflect ecological degradation (Feris et al. 2009). Huber will perform metagenomic and meta-transcriptomic analyses on microbial samples from spatially and temporally defined points in the Kanawha River system which will be used to correlate microbial community characteristics with environmental parameters and identify functional gene/metabolite signatures. Kovatch, Armstead and one MU hire will investigate aquatic invertebrate 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 and (1) improve our understanding of sub-lethal biological impacts at the organismal level and , (2) construct predictive and testable *in silico* models of impacts from the level of genes to communities.

Tools: New AMD and other chemical transport models, pathogen degradation models, and phytoremediation techniques. **Infrastructure:** New hire in contaminant exposure and new capacity in nutrient export sampling and transcriptomics.

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 effects of alternative management actions (Kepner *et al*., 2012). The objectives of our proposed scenario analysis are to: (a) predict cumulative impacts of multi-contaminant mixtures on ecological communities, (b) model effects of climate change as an additional stressor, (c) identify priority areas within watersheds for restoration and conservation, (d) highlight potential value of development techniques that reduce impacts to aquatic resources, and (e) improve data flow and communication between groups working on water toxicology in WV and surrounding areas. We will evaluate contaminant loading and transport under a range of likely *future climate scenarios* and expected *biological response and contaminant toxicity under current and potential future conditions.* Capabilities will be enhanced in 3 main areas: 1) current predictive modeling tools (WVU); 2) improved biochemical and ecological models (WVU, MU and WVSU) in concert with hard data collection. 3) better computational tools to facilitate development of sensor technologies and analysis of reporter system pathways. A database focusing on local concerns will be developed to facilitate data sharing and identification of threats or possible areas of insufficient research.

Approach: *Future Climate Scenarios* or climate models will be based on the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) made available on the NASA Earth Exchange (NEX) 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 4 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 our 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 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 or intentional events under current and predicted climate scenarios.

Strager with Petty, Zegre and the WVU modeling hire will develop an integrative and enhanced Surface Water Protection System (SWPS) that will bring spatial data and surface water modeling to the desktop of the WV Bureau of Public Health, Office of Environmental Health Services, and Environmental Engineering Division. The SWPS will integrate spatial data and associated information to help protect public drinking water supply systems. The SWPS will be a specialized GIS project interface, incorporating relevant data layers with customized GIS functions. 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 public drinking water supply systems. This effort will help assure and provide for long term availability of abundant, safe water for present and future WV citizens. Our approach will help meet this goal by addressing the three major components of the SWAP program: delineating 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 develop predictive tools validated by supporting research. 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 impacts on biological systems. Data provided by labs working in a variety of systems (1a and 1b) will be fed back into the models developed by Szwilski, J. Smith, Malkaram, and the MU hire. These models will build upon WVU's Watershed Characterization and Modeling System, the SWPS (Strager *et al*., 2010), and Watershed Futures Planner (WFP), which is a comprehensive modeling system developed over the past 10 years as a tool for conducting multi-scale scenario analyses in highly impacted or rapidly developing watersheds (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. They will be improved by incorporating novel preventive processes, and enhancement or creation of new technologies linked to improving or sustaining water quality resources. Strager, Petty, Toledo, and the 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 various remediation technologies.

Tools: Development of an adaptive, time-sensitive GIS modeling system to protect water resources.
Infrastructure: New hire in large-scale water modeling.

4.3.B Gravitational Wave Astrophysics

RC Leader - McLaughlin (WVU)
Post Docs: 2 | Graduate Students: 6 | Undergraduate students: 8

In 2006, WVU established a research program in radio astronomy, capitalizing on the proximity of WVU to the National Radio Astronomy Observatory (NRAO) in Green Bank, WV. The radio astronomy program has since expanded to encompass a variety of astrophysical research areas, and prior significant investments by the state Research Challenge Fund and currently WVU 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 polarization of the cosmic microwave background radiation (Ade et al. 2014). A major worldwide effort (Fig. 1) is aimed at 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 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**. These efforts will enable a new era of GW research

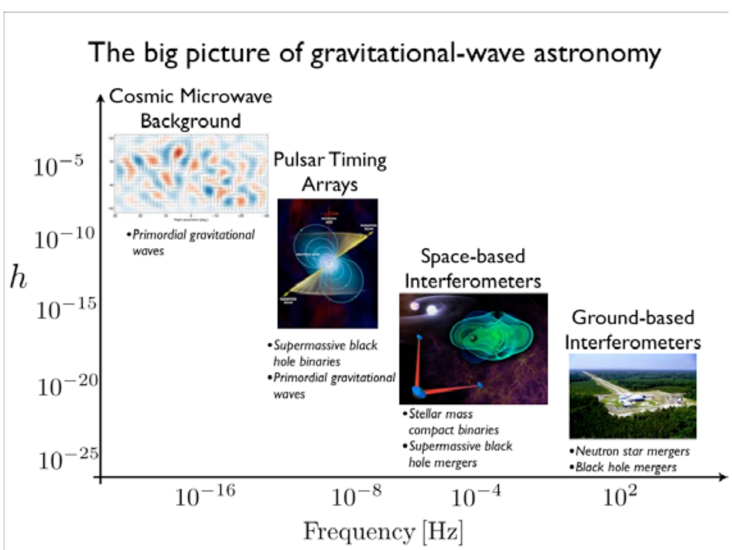

Fig.1. Gravitational waves (GWs) span many orders of magnitude in amplitude (measured by the gravitational wave strain h) and frequency generated by bulk motion of a variety of different astrophysical sources. These range from the primordial waves the size of the Universe that leave their imprint on 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.

and are essential to building a network of researchers and students in WV who are trained to take advantage of opportunities in this emerging field. Specific infrastructure improvements targeted for this RC are faculty hires in the Departments of Physics and Astronomy and Computer Science and Electrical Engineering, a dedicated server for GBT pulsar and LIGO GW data storage and analysis at WVU that will enable collaborations with scientists throughout the U.S. and world and integration of faculty across WV into a powerful regional research collaboration. The three research subtopics, highlighting tools and infrastructure that will be developed are described. (See 4.84 for a detailed timeline of deliverables.)

Research Focus 2.a: Gravitational Wave Detection and Algorithm Development

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

Background: We will develop GW detection algorithms for both pulsar timing arrays (PTAs) and ground-based laser interferometers like LIGO ("LIGO" for simplicity). Pulsars are rotating neutron stars that emit extremely regular pulses. This allows them to be used as accurate celestial clocks. 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 undergrads.graduate students and post docs) 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. Also, McLaughlin is PI on an NSF PIRE award that supports collaboration with researchers in Europe and Australia through the International Pulsar Timing Array. Additional new collaborations (China, India) are being formed.

LIGO is of 2 interferometers (Livingston, LA and Hanford, WA), which pass lasers through beam-splitters to measure small variations in light travel times due to passing GWs. GWs will tend to elongate one detector arm while simultaneously compressing the orthogonal arm, thereby changing relative path length of the light along each arm, and the resulting phase of the light beams when they are allowed to interfere.

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

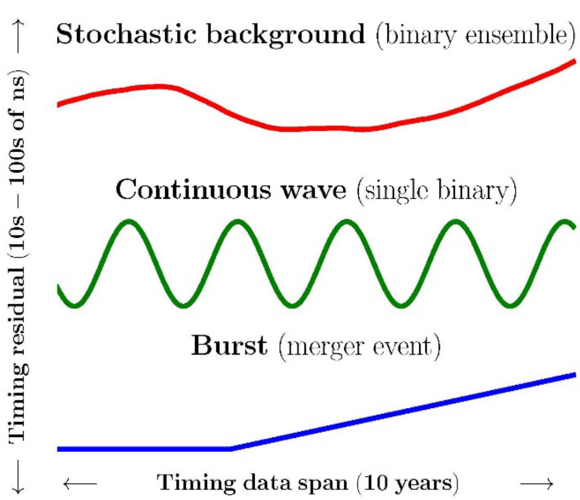

Fig. 2 Pulsar timing signatures expected for different types of GW signals. The vertical axis is the difference between measured and expected pulsar arrival times, and the horizontal axis is time. There are three expected manifestations of supermassive black hole binaries in pulsar timing data. The first 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)

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 2). Because these systems 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 2). GWs at the very low frequencies to which PTAs are sensitive are 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 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 times of arrival with a particular focus on effects of interstellar scattering and dispersion and pulse jitter. 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 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, 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 pulsar timing residuals as priors 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. 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 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 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. Currently, there is no existing effort to incorporate non-GW dynamics in PTA searches. Therefore, contributions from McLaughlin and McWilliams will introduce critical institutional knowledge of the novel methods under development.

This research 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). 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 Fall 2014, and part of the WVU investment in this research area. Such searches will then be run on Advanced LIGO detector data using the LIGO Data Grid and NSF XSEDE computing resources. Likewise, we will make use of existing GW-dedicated supercomputing resources managed by McWilliams as part of WVU's Spruce Knob cluster in combination with the dedicated data server that will be supported locally at WVU through this 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.

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 class of objects: 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 in the LIGO Algorithm Library (Huerta *et al.* 2014). Furthermore, a non-template-based method was recently developed (Tai, McWilliams, and Pretorius 2014) that mitigates sensitivity to systematic template errors that are intrinsically larger for eccentric sources. For this proposal, we will take development a step farther to create an optimized template-free search and parameter estimation algorithm. 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. 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 sequence of GW bursts from an eccentric source instead of an instrument artifact. It will 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 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: Parameteric and nonparametric models for noise and interference in PTA data and GW detections. Application and analysis of suitable data-driven and universal priors used in support of Bayesian and BayesWave approaches. Parallelizable software implementation of the proposed algorithms.
Infrastructure: High-capacity storage system for NANOGrav data.

<u>Research Focus 2.b: Gravitational wave signals and populations</u>

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 different parameters influence the signal. With 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 complex. In this research, we will establish WV as a leading center for signal characterization, source signal and population modeling, and numerical simulations. In addition to the 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 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. After the 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. Etienne 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 (WV Wesleyan College - WVWC), Saken (MU) and WVU faculty hire who will initiate a new research area, and a WVU post doc. The new hire will be mentored by WVU faculty members 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: Advanced numerical relativity, general relativistic magnetohydrodynamics, and EM radiation transport 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 number of MSPs, making this the dominant contribution (Siemens et al. 2013). For individual sources, sensitivity is dominated by 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.

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 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 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, WVWC, and Shepherd University (SU). With astronomers Lorimer and McLaughlin and a graduate student, a hire in the WVU Department 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 Department of Physics and Astronomy as well as shared Mountaineer and Spruce Knob clusters developed through the previous RII. This team with another graduate student will also develop methods for automated inspection of diagnostic plots (Fig. 3). 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 participated in development of automated candidate inspection (Lee *et al.*, 2013, Zhu *et al.*, 2014), butthese 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 handles 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. Schmid and Goseva-Popstojanova will combine their expertise in machine learning algorithms, big data, and stochastic modeling, and algorithms with the expertise of Lorimer and McLaughlin. A set of fully automated optimized algorithms for detecting candidate pulsars implemented in software is the main 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 searches and analysis of LIGO data and will host the analysis software and data repository for educational programs associated with GW and water research.

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 post docs 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.

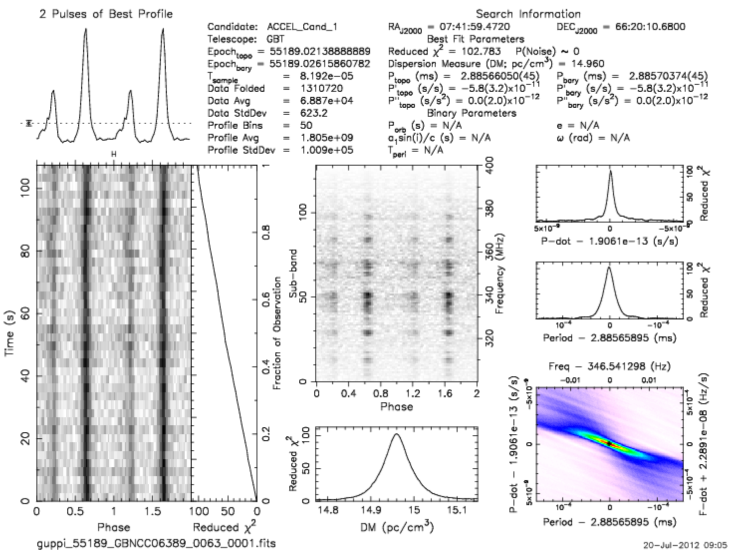

Fig 3. Example periodicity search output plot showing data folded in time (lower left) and radio frequency (upper center) as well as the integrated pulse profile (upper left) and optimal DM search (lower center). The statistical significance of the signal in each of these diagrams is measured in terms of the reduced chi-squared value computed from the integrated pulse profiles.

A large number of middle school, high school, and undergraduate students will participate in 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, WVWC, and SU 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 IPTA partners throughout the world to middle-school students.

Tools: New algorithms for pulsar searching and pulsar candidate classification.
Infrastructure: Hardware implementations of algorithms, new hire in CSEE, and statewide outreach program based on analysis of GBT data.

4.3.1 Workforce Development Plan

Through this RII, WV seeks to build a diverse workforce in key STEM fields, including 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 a multi-tiered strategy by 15%. The program ranges 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.

Broader Impacts: This project's broader impacts include: (1) increasing research competitiveness in the state of WV. The AFI-GW research will create new knowledge, advance societal needs and derive economic value. Significant potential exists to leverage the commercial potential of the AFI initiative as well as establish WV, WVU in particular, as a driving force in the field of nHz gravitational wave detection through pulsar timing arrays. The transformative nature of both initiatives positions the state to develop competitive advantages in terms of research excellence and technology commercialization; (2) impacting national and international scientific communities and general public. Improving water quality is a grand challenge given its central importance to sustaining life. Similarly, the strong team seeking GW discoveries will enhance the prestige of WV, excite students and public, and draw the best and brightest students to our state. Output of AFI will not only impact the citizens of the WV, but also people in the Chesapeake Bay watershed and downstream into the Ohio and Mississippi Rivers. Similarly, a direct GW detection will be a milestone in contemporary astrophysics and fundamental physics, testing one of the central predictions of Einstein's General Relativity, and opening a completely new window on the Universe.; (3) impacting the STEM workforce. Waves of the Future will have a marked impact on development of the STEM workforce. Students, teachers and the general public engaged in water quality research and pulsar searching will create interest in STEM careers and improve the quality of K-12 STEM teaching as a direct result of early exposure. Engagement of the public with displays, planetaria shows, videos, The Neuron will contribute to increased scientific literacy. We estimate thousands will be impacted by this work.

Technology and Economic Development Program. Regional competitiveness will be enhanced by providing support and expertise to the technology business sector. WVU and MU Technology Transfer Offices will create a webinar series to guide faculty 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 on how to bridge the technology commercialization "valley of death," which exists between discovery and a mature product with commercial application. To bridge this gap, university tech transfer offices will proactively seek technologies with the highest commercial potential, and work to find funding from sources such as SBIR and STTR awards or through strategic partnership formation. Coaching and hands-on support from mentors, industry partners and service providers will also be provided.

Mountain State Graduate Fellowship Program. Each year, a cohort of 6 students from historically underrepresented groups will receive two-year graduate fellowship stipends for supported AFI and GW research. As WV is an unusually ethnically homogenous state (~ 5% minority), its underrepresented (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 (Sec. 4.7.1).

PROMISE and HEG Scholarships. Recognizing that cost and access are two significant barriers to STEM-centered educational achievement, WV 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 Sec. 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 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 (NRAO), trains undergraduate students 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 in 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 undergraduates to the NRAO facility in Green Bank, WV to receive training during summers.

Citizen Science – Engagement of Students and the Public in Research. A broad range of participants - high school and middle school teachers, students, and the public - will be involved in actual performance of AFI-GW research. AFI: This RII will expand implementation of standards-based, self-contained, classroom science modules using existing GLOBE curricula to develop an outreach effort that targets Appalachian water quality issues. *Water in Appalachia: Testing, Extraction, and Remediation* (WATER) will engage K-12 students, providing professional training for teachers, and hands-on experiments led by university students and faculty. The program will target vocational schools in WV, those with training for students pursuing careers in mining, drilling and forestry industries. Each year will focus on a different facet of water science. Results from student-led measurements will be incorporated into statewide models of existing watershed water quality. An already established network of citizen scientists around the world use the GLOBE curriculum, which will allow rapid expansion of state, national and international data and interactions for our citizens. GW: The NSF-ITEST Pulsar Search Collaboratory (PSC) program has involved over 2000 high-school students over the past 7 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 6 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 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 and expanding its reach throughout WV and beyond. Finally, WVU Physics and Astronomy researchers will work with education 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 the project. Examples include the recent chemical spill in the Elk River in Charleston, WV or 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 provide 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 NSF CAREER award; and (4) innovative educational/research alliances with industry. Themes of 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 second year renewal is warranted. 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. 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 fully participate in fundamental scientific research. The research 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 to WV postsecondary students. Through administration and stewardship of the PROMISE Scholarship, Higher Education Grant

(HEG), Higher Education Adult Part-Time Student Grant, Engineering, Science and Technology Scholarship, and Underwood-Smith Teacher Scholarship programs, HEPC incentivized 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 and partnership with the HEPC GEAR-UP program 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 student retention so WV can capitalize on its 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 first-year retention rate of full-time, first-time degree-seeking freshmen to 80%; increase first-year retention rate of part-time, first-time degree-seeking freshmen to 50%; increase first-year retention rate of low-income, first-time degree-seeking freshmen to 75%; increase first-year retention rate of first-time degree-seeking freshmen from underrepresented racial/ethnic minority groups to 75%; increase one-year retention rate of returning adult degree-seeking students to 65%; and increase 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). Disaggregated retention rates will be acquired from the statewide HEPC database for tracking from 2014 through the course of the grant. Racial/ethnic STEM graduates in 2014 were 16.5%, 22.0% and 13.7% of total STEM graduates at MU, WVSU and WVU respectively. For the 2013-2014 academic year, overall URM STEM majors in WV were 2,325 or 18.2% of all STEM majors.

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. Those best practices include: 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 Sec.4.8.

4.5 PARTNERSHIPS and COLLABORATION

Multiple partnerships and collaborations build upon the contributions and connections the partner institutions have with their communities. While the initial group includes WVU, MU and WVSU, there are smaller, undergraduate institutions that are active participants in this proposal, e.g., Best (SU) and Delaney

(WVWC). As a result of these collaborations, **PUI** faculty can also leverage research support funds from the NASA WVEPSCoR 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** in WV are also partners in this RII's research and education activities. The National Energy Technology Laboratory (Morgantown) 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 to AFI researchers. The US Geological Survey (USGS) National Water Quality Laboratory, USGS Water Science Center, and the Leetown Science Center are important partners and collaborators 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. AFI 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. Similarly, 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 (Fairmont) is an active collaborator 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 work 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 and strengthen education and research capacity. Proposed activities include: 1) Communicating importance and benefits of STEM research by continuing publication of *The Neuron* and video projects, which highlight WV STEM research and related economic development. 2) Publishing the *Neurite* which targets 7th grade science students to introduce them to WV scientists. 3) Hosting 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 10 planetaria within WV as well as at the NRAO Education Center (visited by >50,000 people each year). Schools can request the program to accompany the portable Starlab planetarium available through the NASA Educator Resource Center in Fairmont. This program will describe 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) Developing an interactive watershed display for the WVU Natural History Museum. 5) Using the Summit Bechtel Reserve, Boy Scout Camp (on the Upper New River— with a whitewater rafting section 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 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) Burns will engage the public by measuring WV residents' perceptions of the water quality, quality of life, and perceptions of the impacts of global climate change in WV. 8 Focusing on educating industry, legislators, the public, and other stakeholders about the value of new practices (e.g. preventative measures). 9) Public website about the project – publications, talks, student work, videos. 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 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 stakeholders.

4.7 SUSTAINABILITY PLAN

Investments of past RIIs (faculty hires and Shared Facilities) have been sustained and upgraded through shared facilities user fees, university and state funding. These investments will be similarly sustained by targeting 8 key organizational and contextual domains (PSAT domains,sustaintool.org) 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 post doc 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 the AFI, the largest risk is in the modeling effort. If data from 1a and 1 b are delayed or unusable, modeling efforts would be in danger. However, untapped resources of data in public repositories would allow useful preliminary modeling which would partially compensate for delay of new data. For astrophysics, the greatest risk is loss of access to the GBT, which was recommended for divestment in the recent NSF Portfolio Review. If the GBT is lost, 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 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 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 loss of onsite GBT workshops and relevance of working with data acquired in WV.

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. Teacher retention is a major issue in WV and nationwide; 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 prior experience with veteran high school science teachers and high school students, and focus on engaging pre-service (PS), early career (EC) science teachers and in-service teachers (IS) in authentic research experiences and early career support, which will occur at all 3 partner institutions. To partly address critical needs of EC teachers, we propose a support system for PS and EC science teacher engagement in further development of content knowledge, pedagogical skill, and pedagogical content knowledge. The goals of ***The Preparation and Early Career Support of Science Teachers (PECS)*** program are to: 1) enhance the training of high quality science teachers entering the teaching field, 2) support EC teachers to increase retention during a period in the teacher's career that is most difficult and most susceptible to attrition, and 3) engage PS, EC teachers in authentic research experiences that are 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 ongoing work to restructure science teacher preparation. PS teachers will engage in authentic research experiences during the academic year which are required under the NSTA 2012 standards for science teacher preparation. PS and EC teachers will interact with IS teachers via face-to-face and online programming at each institution. The scientific research 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 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. 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 revised science education programs 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 help of scientific staff, that can form new citizen science research activities, similar to the PSC. These new activities will be aligned with Next Generation Science Standards (NGSS). Incoming WVU faculty hire G. Stewart served as a critical reviewer of NGSS for the American Association of Physics Teachers. She will vet developed activities to make assure they meet both the letter and spirit of the NGSS.

For the AFI, each fall there will be an orientation workshop where new and continuing students and postdocs 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 orientation. In addition, a 2-week summer trainee academy will be held on at WVU 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 AFI will record a 2 minute video about themselves and their research during their first year. Videos will be shared with the all research teams. These activities will serve to increase camaraderie and technical expertise of participants. Similarly, student researchers in GW astrophysics will meet yearly at the GBT for a training session which involves instruction in gravitational waves and data analysis and also in observing with the GBT. The yearly meeting, held each fall, will include talks by researchers in their specialties. In the spring, a symposium at WVU will be held where students, from undergraduate to postdoctoral level, will present results of their research. This will coincide with the Capstone event for the PSC program as high school students will benefit from hearing about research of more advanced students, and more advanced students can be judges of high school student posters.

Early Career Faculty and Junior Researcher Mentoring Program: The lead institutions provide a wide range of mentoring and career development programs for early career faculty, junior researchers, and graduate students. Programs include “Faculty Success Program”, available through the National Center for Faculty Diversity and Development, an intensive 12-week on-line program 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.

4.7.2 Post RII Extramural Funding: The decision to invest in these research consortia was based on the expectation that these research areas have tremendous potential for significant future non-EPSCoR funding from NSF, other federal agencies, and regional industries and/or national laboratories. The AFI-GW 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. WVU, MU and WVSU has developed comprehensive support infrastructure for research active faculty, including project management staff, grant writing, mentoring and external pre-submission proposal review for all faculty; WVU has embarked on a new effort to incentivize creation of large research Centers by allocating a fixed fraction of facilities and administrative costs for investment in Center development. Research teams are expected to develop large, center-level proposals by the end of the project period. The seed funding/emerging areas program will play a critical role in developing and growing new research programs aligned with the core research and support junior faculty. We expect young faculty to apply for CAREER grants as well as individual and collaborative grants, and in the latter years of the grant, we will target the I/UCRC program and other Center grant programs

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) serves as the EPSCoR Committee, and d) directs state research programs in concert with WV strategic objectives. 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). ELT is the senior management team and will meet quarterly to insure that project milestones are met and will utilize evaluation feedback (4.8.2) 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 who oversees all project activity. Drs. Maura McLaughlin and James Anderson are responsible for daily management of 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 campus 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. Succession for project leadership is assured by the SRC and institutional leaders. The SRC will provide NSF with qualified names of replacements for current leadership should they no longer be available for service. WVEPSCoR will hire a Deputy Director/Education & Diversity Coordinator to assist in project management and lead education and diversity programs.

Campus Management. Each research consortium and the education program have a technical director. Technical directors hold quarterly meetings with the technical coordinators to assure progress with research goals and will report to the ELT. Research consortia have 3 research focus areas, each with a coordinator (bold in the management chart). Technical coordinators are responsible for organizing monthly focus area meetings where progress will be shared and graduate students will give presentations on their work. Technical directors are responsible for allocating budgets, student and post doctoral positions and reporting to the PI and external advisory board. Leadership who will assure that the milestones of each overarching project goal are met are: 1) Advancing fundamental science – McLaughlin and Anderson; 2) Developing STEM pipeline-Carver; and 3) Improving diversity – Maher, King and Toledo; 4) Building technology transfer foundation – Harbaugh. Milestones, statements of work, meeting minutes, and scientific results will be kept on a project page on the DSR website.

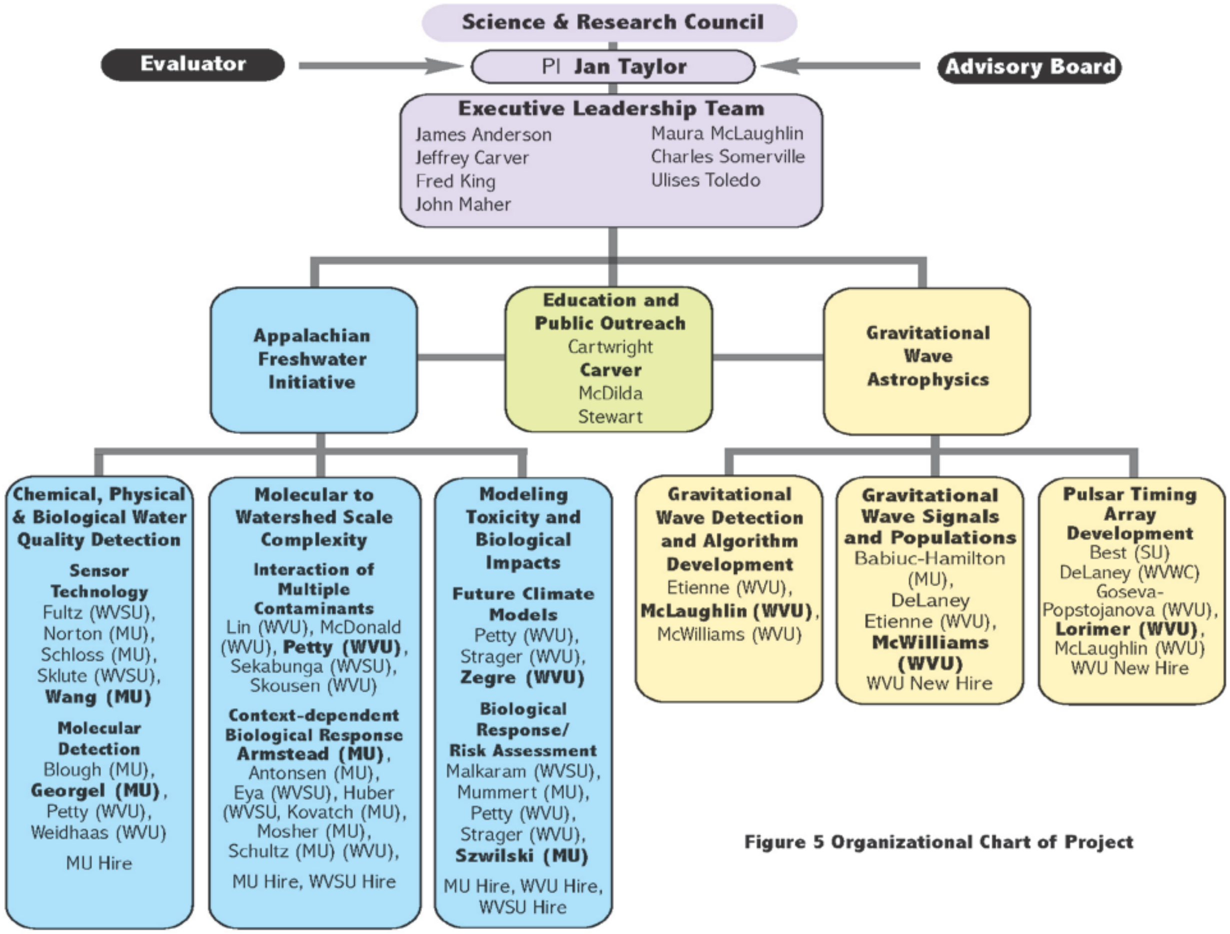

Figure 5 Organizational Chart of Project

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 the AFI-GW research areas. Managed by campus specific technical and educational coordinators, these activities 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. 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 ELT will also meet quarterly with the PI to review and evaluate progress. In each research consortium, communication and partnerships are maintained through meetings and monthly progress reporting. Research focus team leaders will meet weekly with their technical coordinators to discuss project needs, advances and challenges. Biannually, all 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, RII PI, will visit all 3 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 composed of national experts in the research areas. Drs. Shane Larson (Northwestern U.), Kelly Holley-Bockelmann (Vanderbilt), Robert Findlay (Alabama),Louis Kaplan (Stroud Water Res. Ctr, PA, and Scott Little (SC EPSCoR), The Board: (a) reviews annual progress reports, provides advice for strengthening the RII Program to the PI and to Research Consortia Directors and; (b) makes two on-campus review visits during the grant period and to advise on strengths, weaknesses and progress.

4.8.2 Evaluation and Assessment

[redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

[redacted]

4.8.3 Jurisdictional and Other Support

Cost Share. WVEPSCoR institutions commit $4M in cost share to support this RII.

Table 2. Research Support Levels

Awardee	Year 1 ($K)	Year 2 ($K)	Year 3 ($K)	Year 4 ($K)	Year 5 ($K)	5-yr Total	%
WVU	1,930	1,930	1,930	1,930	1,930	$9,650	48.3
MU	1,120	1,120	1,120	1,120	1,120	$5,600	28.0
WVSU	540	500	500	500	500	$2,500	13.5
Shepherd	20.2	20.2	20.2	20.2	20.2	$100,945	0.5
WV Wesleyan	11.6	11.6	11.6	11.6	11.6	$57,980	0.3
WVHEPC	378.2	378.2	378.2	378.2	378.2	$1,891,000	9.5
Total	4,000	4,000	4,000	4,000	4,000	$20,000,000	100

4.8.4 Milestones and Outcome Metrics:

Gravitational Wave Astrophysics

Appalachian Freshwater Initiative

Education and Outreach

Diversity

[redacted]