Final Report for Period: 09/2011 - 08/2012
Submitted on: 11/30/2012
Principal Investigator: Bunn, Emory F.
Award ID: 0922748
Organization: University of Richmond
Submitted By:
Bunn, Emory - Principal Investigator
Title:
MRI: Acquisition of a Computing Cluster for Astrophysics and Nuclear Physics Research at the University of Richmond

Project Participants

Senior Personnel

Name: Bunn, Emory
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Gilfoyle, Gerard
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Undergraduate Student

Name: Musalo, Chistopher
Worked for more than 160 Hours: Yes
Contribution to Project:
During the summers of 2010 and 2011 (full-time), as well as during the academic year (part-time), Chris Musalo installed, tested, and benchmarked software to be used in the nuclear physics research program. He has begun using this software to perform simulations of Jefferson Lab accelerator data.

Name: Carbonneau, Joshua
Worked for more than 160 Hours: Yes
Contribution to Project:
During the summers of 2010 and 2011, Josh Carbonneau installed, tested, and benchmarked software to be used in the nuclear physics and astrophysics research programs.

Name: Lee, Robert
Worked for more than 160 Hours: Yes
Contribution to Project:
During the summers of 2011 and 2012 (full-time) and the academic year (part-time), undergraduate Robert Lee has worked on the creation of simulations of cosmic microwave background map-making. He was supported in part by another NSF award.

Name: Sherman, Keegan
Worked for more than 160 Hours: Yes
Contribution to Project:
During the summers of 2011 and 2012, undergraduate Keegan Sherman worked on software development for the nuclear physics program.

Name: Bialt, Spencer

Worked for more than 160 Hours: Yes

Contribution to Project:
Undergraduate Spencer Bialt worked on software development for the nuclear physics program during the summer of 2012.

Name: Murray, Liam

Worked for more than 160 Hours: Yes

Contribution to Project:
Undergraduate Liam Murray worked on software development for the nuclear physics program during the summer of 2012.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Thomas Jefferson National Laboratory
Co-PI Gilfoyle's research involves analysis and simulation of experiments performed at Jefferson Laboratory. His collaborators at the Laboratory are involved in the analysis and will make use of the cluster.

University of Wisconsin-Madison
PI Bunn collaborates with Peter Timbie's group at the University of Wisconsin, Greg Tucker's group at Brown University, and Ben Wandelt's group at the Institut d'Astrophysique (Paris) on the simulation of future CMB observations. The simulations being performed by this collaboration are a large part of the astrophysics portion of the research program supported by this MRI award.

Brown University
PI Bunn collaborates with Peter Timbie's group at the University of Wisconsin, Greg Tucker's group at Brown University, and Ben Wandelt's group at the Institut d'Astrophysique (Paris) on the simulation of future CMB observations. The simulations being performed by this collaboration are a large part of the astrophysics portion of the research program supported by this MRI award.

Institut d'Astrophysique (Paris)
PI Bunn collaborates with Peter Timbie's group at the University of Wisconsin, Greg Tucker's group at Brown University, and Ben Wandelt's group at the Institut d'Astrophysique (Paris) on the simulation of future CMB observations. The simulations being performed by this collaboration are a large part of the astrophysics portion of the research program supported by this MRI award.

Other Collaborators or Contacts

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:
Six undergraduates have worked on all aspects of the work supported by this award (installation and testing of the cluster as well as science activities), supported by other funds. These students gained invaluable experience in high-performance scientific computing.

Outreach Activities:

Journal Publications

P.M. Sutter, B.D. Wandelt, S. Malu, "Bayesian power spectrum analysis of interferometric data", Astrophysical Journal Supplement, p. 9, vol. 202, (2012). Published,

L. Zhang, A. Karakci, P.M. Sutter, E.F. Bunn, A. Korotkov, P. Timbie, G.S. Tucker, and B.D. Wandelt, "Maximum likelihood analysis of systematic errors in interferometric observations of the cosmic microwave background", Astrophysical Journal Supplement, p. , vol. , (2012). Submitted,

A. Karakci, P.M. Sutter, L. Zhang, E.F. Bunn, A. Korotkov, P. Timbie, G.S. Tucker, and B.D. Wandelt, "Bayesian Inference of Polarized CMB Power Spectra from Interferometric Data", Astrophysical Journal Supplement, p. , vol. , (2012). Submitted,

Books or Other One-time Publications

G.P. Gilfoyle, "Measuring the Fifth Structure Function in 2H(e, e'p)n", (2011). Collaboration meeting presentation, Published
Collection: CLAS Collaboration Meeting
Bibliography: CLAS Collaboration Meeting

G.P.Gilfoyle, M.Ungaro, J. Carbonneau, M. Moog, and C. Musalo, "Simulated CLAS12 Neutron Detection Efficiency in the Forward Time-of-Flight System", (2011). Jefferson Lab Collaboration Note, Published
Collection: CLAS Note
Bibliography: CLAS-NOTE-2011-15, September 29, 2011.

C. Musalo, J.Carbonneau, and G.P.Gilfoyle, "Simulation of the CLAS12 dual hydrogen-deuterium target", (2011). Conference presentation, Published
Collection: Abstract of presentation at APS Division of Nuclear Physics meeting
Bibliography: Bull. Am. Phys. Soc., Fall DNP Meeting, EA.00102 (2011).

L. Murray and G.P. Gilfoyle, "Extracting the Fifth Structure Function of the 2H(e,e′p)n Reaction", (2012). Conference contribution, Published
Bibliography: Bull. Am. Phys. Soc., Fall DNP Meeting, EA.00114

G.P. Gilfoyle et al., "Simulation of the Electromagnetic Calorimeter in CLAS12", (2012). Internal collaboration report, Published
Bibliography: CLAS- NOTE 2011-019

K.Sherman and G.P.Gilfoyle, "Simulation of the Scintillator Geometry in the Electromagnetic Calorimeter in the CLAS12 Detector", (2012). Conference contribution, Published
Bibliography: Bull. Am. Phys. Soc., Fall DNP Meet- ing, EA.00115

Sebouh Paul, "Service Oriented Tracking: A Package For CLAS12 Reconstruction Using Clara Framework", (2012). Thesis, Published
Bibliography: Master's thesis, Christopher Newport University

CLAS Collaboration, "CLAS12 Software, Version 1.3", (2012). , Published
Editor(s): D.Weygand and V.Ziegler
Bibliography: Jefferson Lab internal document

L.Elouadrhiri, "12 GeV Upgrade Computing Review", (2012). Internal Jefferson Lab document, Published
Bibliography: 12 GeV Software Review

R. Lee and E.F. Bunn, "Simulation of Cosmic Microwave Background Map Recon- struction with Large Asymmetric Beams", (2012). Conference contribution, Published
Bibliography: American Astronomical Society Meeting Abstracts 220, 436.06

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

The cluster acquired under this grant has been used for simulation and analysis of experiments involving the CLAS12 detector at Jefferson Lab and to simulate interferometric observations of the cosmic microwave background radiation.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Six undergraduates received significant training in high-performance computing.

Contributions to Resources for Research and Education:

In part as a result of the acquisition of the computing cluster supported by this grant, an alumna of the University has given the department funding to develop a separate high-performance computing lab for use in teaching. The new equipment has been acquired and used in our Computational Physics course. The University of Richmond is committed to closely integrating research and teaching, and the new educational computer lab is of great help in our effort to tie our computational research together with our educational efforts.

Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Activities and Findings: Any Outreach Activities

Any Web/Internet Site

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering

Any Conference

Findings

The cluster has been used for several projects in nuclear physics and astrophysics, as described under "Activities." Key results of those projects are summarized here.

Nuclear Physics

- We are nearing completion in the analysis of the nuclear reaction $^2\mathrm{H}(e, e'p)n$ measured in Hall B at Jefferson Lab. We have verified our extraction of the helicity asymmetry using an alternative method [1]. The results were presented at the October, 2012 CLAS Collaboration meeting [2] and a technical report describing the analysis is now under collaboration review (this is the first formal step in submitting a manuscript for publication that is approved by the CLAS Collaboration).

- We have completed a study of the simulated response of the electromagnetic calorimeter in CLAS12 to neutrons and published the work as a CLAS technical report. [3].

- We have completed modifications to the geometry of the simulation of the CLAS12 electromagnetic calorimeter that make the simulation more realistic, but more computationally intensive. The effect on running the simulation in batch mode is modest (less than 10%), but significant (about 30%) when using the graphics-intensive features of the simulation [4].

- The Richmond cluster is being used as a test bench for the CLAS12 software being developed as part of the 12 GeV Upgrade at Jefferson Lab. The software will be used for the simulation, analysis, and reconstruction of CLAS12 data after the Upgrade. Significant progress has been made and external reviews are positive [5, 6]. The cluster was also used in a masters thesis project at Christopher Newport University [7].

Astrophysics

- A simulation pipeline for generating interferometric data sets and analyzing them in both maximum-likelihood and Gibbs sampling frameworks has been developed. Two papers describing our first results quantifying the effects of various systematic errors on interferometric data sets are currently under review for publication [8, 9].

- A paper has been published [10] presenting a Bayesian power spectrum and signal map inference engine for interferometric CMB data sets.

- We have implemented a set of tools for simulating the map-making process for a set of novel possible CMB instrument designs. Preliminary results were presented by undergraduate Robert Lee at the 2012 summer meeting of the American Astronomical Society [11].

References

[1] 'Extracting the Fifth Structure Function of the ^{2}H(e, e′p)n Reaction', L.Murray and G.P.Gilfoyle, Bull. Am. Phys. Soc., Fall DNP Meeting, EA.00114 (2012).

[2] 'Measuring the Fifth Structure Function in ^{2}H$(e, e'p)n$', G.P.Gilfoyle, CLAS Collaboration Meeting, October 12, 2012.

[3] 'Simulation of the Electromagnetic Calorimeter in CLAS12', G.P.Gilfoyle *et al.*, CLAS-NOTE 2011-019, October 31, 2011.

[4] 'Simulation of the Scintillator Geometry in the Electromagnetic Calorimeter in the CLAS12 Detector', K.Sherman and G.P.Gilfoyle, Bull. Am. Phys. Soc., Fall DNP Meeting, EA.00115 (2012).

[5] 'CLAS12 Software, Version 1.3', D.Weygand and V.Ziegler, editors, Jefferson Lab, May 2012.

[6] '12 GeV Upgrade Computing Review', L.Elouadrhiri, 12 GeV Software Review, June 7, 2012.

[7] 'Service Oriented Tracking: A Package For CLAS12 Reconstruction Using Clara Framework', S. Paul, Masters thesis, Christopher Newport University, June, 2012.

[8] L. Zhang, A. Karakci, P.M. Sutter, E.F. Bunn, A. Korotkov, P. Timbie, G.S. Tucker, and B.D. Wandelt, "Maximum likelihood analysis of systematic errors in interferometric observations of the cosmic microwave background," arXiv:1209.2676 (2012).

[9] A. Karakci, P.M. Sutter, L. Zhang, E.F. Bunn, A. Korotkov, P. Timbie, G.S. Tucker, and B.D. Wandelt, "Bayesian Inference of Polarized CMB Power Spectra from Interferometric Data," arXiv: 1209.2930 (2012).

[10] P.M. Sutter, B.D. Wandelt and S. Malu, "Bayesian power spectrum analysis of interferometric data," Astrophysical Journal Supplement, 202, 9 (2012).

[11] R. Lee and E.F. Bunn, "Simulation of Cosmic Microwave Background Map Reconstruction with Large Asymmetric Beams," American Astronomical Society Meeting Abstracts 220, 436.06 (2012).

Activities

The development of the Richmond Research Cluster is complete. The cluster is in heavy use by both the nuclear physics and astrophysics groups.

Nuclear Physics

In nuclear physics, the cluster has been used for three main projects. (1) The analysis of the nuclear reaction $^2\mathrm{H}(e, e'p)n$ measured in Hall B at Jefferson Lab is nearing completion. The goal is to extract the seldom-measured fifth structure function. The structure functions encode the information about the structure of the neutron and proton bound into deuterium. The data are described well by a relativistic calculation of the response functions by Jeschonnek and Van Orden. The data set is large (about 1 GByte) and the analysis is computationally intensive. The use of the cluster dramatically reduces the time needed for an analysis run. The results were presented recently at the October, 2012 CLAS Collaboration meeting [1] and at the fall, 2012 meeting of the Division of Nuclear Physics of the APS [2]. A technical report describing the analysis is now under collaboration review (this is the first formal step in submitting a manuscript for publication that is approved by the CLAS Collaboration).

We have developed a simulation of the CLAS12 detector in collaboration with our colleagues at Jefferson Lab. The CLAS12 detector is a large particle detector being built to take advantage of the new physics opportunities of the 12 GeV Upgrade at Jefferson Lab. We are performing simulations in preparation for an experiment (E12-07-104) that is approved to run in the first five years after the Upgrade entitled 'Measurement of the Neutron Magnetic Form Factor at High Q^2 Using the Ratio Method on Deuterium'. Gilfoyle is the spokesperson and contact person for the experiment. Neutrons will be measured in E12-07-104 with the electromagnetic calorimeter (EC) system in CLAS12 and, using the cluster, we have completed a simulation of the performance of the EC system. We found the performance of the EC to be consistent with previous studies [3]. The EC consists of alternating layers of plastic scintillator and lead. The scintillator layers consists of long strips of material, but the simulation has treated each layer as a single, large slab to reduce the computational load. We have modified the geometry of the EC simulation to replace the slabs with more realistic strips. We find the effect on running the simulation in batch mode is modest (less than 10%), but significant (about 30%) when using the graphics-intensive features of the simulation [4].

The Richmond cluster has been used as a development platform for the CLAS12 software framework. The package, entitled CLARA, is an environment where data processing algorithms filter continuously flowing data. In CLARAs domain of loosely coupled services, data is not stored, but rather flows from one service to another, evolving constantly along the way. The environment can take full advantage of modern, multi-core, multi-threaded processors in a distributed environment. The code is under nearly constant development by researchers at JLab and at Richmond. It has been used for a masters thesis project

at Christopher Newport University [5] and the results are presented in several reports and presentations [6, 7].

Astrophysics

The astrophysics research program focuses on simulation of cosmic microwave background (CMB) data sets.

Bunn is a leading member of a collaboration (funded via another NSF award) that is building a suite of simulation software to assess the viability of interferometric methods in CMB polarimetry. The state of the art in simulating "traditional" imaging telescopes is far more advanced than interferometric simulations. In order to insure that we use the optimal strategy to pursue the goals of CMB polarimetry, we must close that gap.

This project has made rapid progress, due in large part to the work of postdoctoral researcher Le Zhang (based at the University of Wisconsin) and Brown University graduate student Ata Karakci. We have produced software to simulate interferometric skies and to analyze the results with both maximum-likelihood and Gibbs sampling approaches. This software has been run extensively on the Richmond cluster. Two papers detailing our first results are currently under review for publication [8, 9]. These papers quantify the effects of certain systematic errors on mock interferometric observations and compare them with a simple analytic approximation [10].

Ben Wandelt's group at the Institut d'Astrophysique in Paris, particularly postdoc Paul Sutter, have used the cluster funded under this grant for a preliminary analysis of CMB interferometric data via the Gibbs sampling technique. A paper describing this work has recently been submitted for publication [11]

Bunn and undergraduate Robert Lee are working on a separate project involving the simulation of CMB map-making (i.e., deriving sky maps from time-ordered data) in the context of some novel and unusual telescope designs. This work is in an early stage. Lee has successfully written much of the simulation code.

References

[1] 'Measuring the Fifth Structure Function in ^{2}H$(e, e'p)n$', G.P.Gilfoyle, CLAS Collaboration Meeting, October 12, 2012.

[2] 'Extracting the Fifth Structure Function of the ^{2}H(e, e′p)n Reaction', L.Murray and G.P.Gilfoyle, Bull. Am. Phys. Soc., Fall DNP Meeting, EA.00114 (2012).

[3] 'Simulation of the Electromagnetic Calorimeter in CLAS12', G.P.Gilfoyle *et al.*, CLAS-NOTE 2011-019, October 31, 2012.

[4] 'Simulation of the Scintillator Geometry in the Electromagnetic Calorimeter in the CLAS12 Detector', K.Sherman and G.P.Gilfoyle, Bull. Am. Phys. Soc., Fall DNP Meeting, EA.00115 (2012).

[5] 'Service Oriented Tracking: A Package For CLAS12 Reconstruction Using Clara Framework', S. Paul, Masters thesis, Christopher Newport University, June, 2012.

[6] 'CLAS12 Software, Version 1.3', D.Weygand and V.Ziegler, editors, Jefferson Lab, May 2012.

[7] '12 GeV Upgrade Computing Review', L.Elouadrhiri, 12 GeV Software Review, June 7, 2012.

[8] L. Zhang, A. Karakci, P.M. Sutter, E.F. Bunn, A. Korotkov, P. Timbie, G.S. Tucker, and B.D. Wandelt, "Maximum likelihood analysis of systematic errors in interferometric observations of the cosmic microwave background," arXiv:1209.2676 (2012).

[9] A. Karakci, P.M. Sutter, L. Zhang, E.F. Bunn, A. Korotkov, P. Timbie, G.S. Tucker, and B.D. Wandelt, "Bayesian Inference of Polarized CMB Power Spectra from Interferometric Data," arXiv: 1209.2930 (2012).

[10] E.F. Bunn, "Systematic errors in cosmic microwave background interferometry," Physical Review D, 75, 083517 (2007).

[11] P.M. Sutter, B.D. Wandelt and S. Malu, "Bayesian power spectrum analysis of interferometric data," Astrophysical Journal Supplement, 202, 9 (2012).