Background: Program Purpose

The "Expanding Collaborative Opportunities for Research in Archaeo-Geomatics and Archaeo-Geophysics" project, referred to as the **SP**atial **A**rchaeometry **R**esearch **C**ollaborations (SPARC) Program, began in August 2013 through the support of a grant from the NSF Archaeometry / Archaeology Program (http://sparc.cast.uark.edu/about/grant). The initial proposal laid out the need for a national center for spatial archaeometry, the importance of a formal, open, and competitive system for the submission and selection of research proposals, and the benefits of collaboration for both individual research projects and methodological advancement in research quality and productivity. SPARC was established with the idea that the growing availability and sophistication of digital technologies, particularly in the geospatial realm, has begun to profoundly affect how archaeologists and other scholars work. The things archaeologists study—from artifacts to sites to landscapes—almost always have a spatial component and for many decades space has been viewed as one of the central dimensions of archeological study (Spaulding 1960; Willey 1953; Ashmore 2002; Ashmore & Knapp 1999; Clarke & Chapman 1978; Cowgill 1993; Kvamme 2003). The capabilities of geospatial technologies to enhance the discovery and interpretation of these things not only offers new data, but creates entirely novel means of engaging with the archaeological record. Building on these principles, the SPARC Program's initial aims were to:

1. promote the effective application of advanced geospatial methods in archaeology by acting as a center of expertise.
2. Enhance the research productivity of archaeological projects by making geospatial technologies available to researchers who would not otherwise have access to the tools or skills needed to collect and analyze these data.
3. directly generate high value archaeological data by participating in fieldwork and analytical projects to efficiently collect and analyze geospatial data.
4. provide training opportunities for students and professionals seeking to use geospatial techniques in their own research.
5. promote the development of new geospatial methods and applications in archaeology and the visibility of these innovations in the broader archaeological community.
6. support good practice and promote innovation in archiving and publication of digital geospatial data.

SPARC provides a model for increasing access to a variety of specialist skills and technologies, and goes beyond the simple (but important) promotion of geospatial techniques in archaeology, by demonstrating that research outcomes and the allocation of resources can be improved through the creation of centers of expertise housing researchers who will work as active and engaged collaborators. The formal, collaborative approach taken by this project supports the development of multi-institutional and interdisciplinary teams - a mode of working increasingly necessary for successful research in archaeology, a discipline that draws on many disparate techniques and skillsets. Further, by democratizing access to specialist technologies and expertise, this project spreads the benefits of advances in practice. Establishing recognized centers of expertise with programs explicitly dedicated to outreach and collaborative research, like the one developing through this project, is particularly beneficial for

archaeologists working at smaller institutions, exploring new sub-disciplines, or at early career stages when identifying good collaborators is challenging and is especially valuable for researchers located at institutions focused on underserved communities. In parallel, connecting specialist researchers at the Center for Advanced Spatial Technologies (CAST) with senior researchers through this program creates opportunities for methodological advancement and innovative research projects, promoting development in the field of spatial archaeometry and creating key case studies that serve as examples of emerging methods and applications.

Background: Original Application Motivations

Over the past two decades, researchers at the University of Arkansas have made substantial investments in the development of capacities (equipment and software, analytical practices, staff, expertise, etc.) in geospatial technologies and promoted their use in archaeological research through ongoing collaborations between geomatics specialists and archaeologists. Today CAST continues to be a global leader in geospatial research across a variety of disciplines and applications, and is widely regarded among the best places for the application of these technologies in archaeology, particularly in a North American context. The SPARC program is the embodiment of this leadership role, serving as a visible center of expertise for geospatial methods in archaeology.

The program was created with the aim of supporting projects with research needs in three primary areas of expertise: 1) site-based archaeo-geophysics and mapping, 2) three-dimensional scanning, photogrammetry, visualization, and morphometrics; and 3) aerial and satellite remote sensing, regional survey, and spatial analysis. The program is intended to make the extensive suite of instruments (see equipment details in the facilities section. Many of these instruments were obtained with prior NSF support – esp. BCS 0321286 and ESP 0918070*)* and, perhaps more importantly, expertise available on a collaborative basis to researchers with US institutional affiliations working around the world, leading to increased productivity for a wide range of individual research projects. The aim was to help projects integrate geospatial techniques and, at the community level, to achieve the "tipping point" that moves these research approaches from being viewed as "intriguing" or "potential" to essential parts of archeological study, and at the project level to help individual researchers achieve their research goals by facilitating the effective use of geospatial methods.

Motives for Continuation of the Program

This proposal requests continued funding to sustain and expand the role CAST (and the University of Arkansas generally) is increasingly playing through the SPARC Program, directly supporting archaeological research projects external to CAST, providing ongoing access to CAST facilities and expertise for a broader audience of projects, and providing training and educational opportunities in topics related to geospatial applications in archaeology.

The first 18 months of activity have demonstrated the substantial value provided to the archaeological community by the SPARC program, as discussed in detail below. Importantly, the support of ten (10) full projects and three (3) collaborative projects through the first two rounds of awards demonstrates that medium and long term commitment to these projects, often through intermittent, but intensive, engagement as the larger project moves forward, is needed

to help researchers achieve the best results in their projects. The need for ongoing, timely engagement with a project highlights the necessity of a stable, dedicated program that can make commitments beyond a fixed period of initial data acquisition or scope of analysis, operating outside the constraints of contract or project specific grant supported work - models that don't provide the combination of longevity and flexibility needed for researchers to feel confident in investing effort to integrate new technologies or methods into their research agendas.

Renewed support from the NSF Archaeometry program will allow us to build on a program that is increasingly **visible** - capable of attracting top research projects; **efficient** - as project staff build on their experience carrying out a variety of types of collaborations; **high impact** – as pilot projects build skills in research teams and the results of small scale projects supported through SPARC awards are integrated into larger research programs; and **innovative** – as broader collaborations with the potential to lead to significant methodological advancements are established through SPARC supported projects.

The program will continue to aid researchers with their own grant funding by making their money go further, by offering essential geospatial "consulting," field data collection, and post-collection data processing and analysis. Beyond the direct and immediate impacts on archaeological research through support of individual projects, the training and outreach activities and methodological work supported through this program are essential to the continued integration of geospatial applications into archaeological research, creating an environment for future innovation.

Guiding the uptake of new methods and guiding projects as they attempt innovative work in spatial archaeometry is particularly important now. While over the past twenty years the majority of instrumentation for the acquisition of geospatial data has been prohibitively expensive, we are currently experiencing an explosion of low-cost alternative instruments. This situation poses two challenges for the archaeological community. First, many researchers and organizations are considering investing in equipment, as it is now within their budget, but are uncertain how to integrate the instruments into their education and research programs. Second, and perhaps more important, the quality of the data produced by these instruments is variable (cf. Manferdini and Remondino 2012; Poli et al. 2014; Mechelke et al. 2007). Many archaeological acquisitions are 'one time only' affairs, where the material is difficult to access or destroyed shortly after the moment of discovery. If we are to rely on the digital data captured by these devices as the primary or sole record, we have an obligation to collect the best possible information. The differences between data captured by different sensors of the same type require expertise in the fundamentals of the techniques, and broad, practical experience across projects and through a full project lifecycle. There is a strong need for training and expert consultation as an expanding constituency of researchers and projects acquire instrumentation and begin to collect their own data. SPARC, as a center of expertise in geospatial applications in archaeology, can play a role toward fulfilling this need through consultations and professional development training targeted for senior researchers.

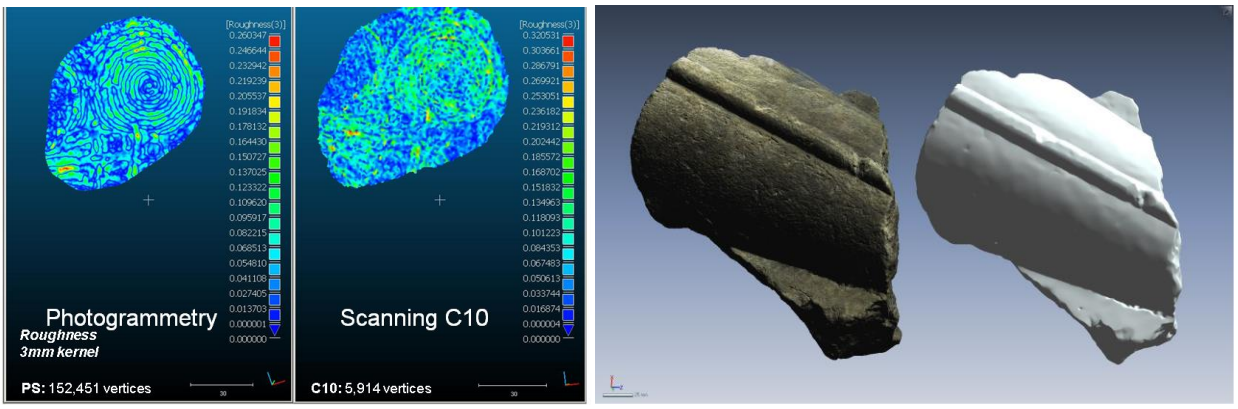

Figure 1 (Left images): Data density and the visibility and recognition of small scale features, like the rock art shown here, are dependent on the quality of data derived from different instruments; in this case (left)DSLR images processed using Agisoft Photoscan and (right) the Leica C10 scanner. (Right images): Breuckmann SmartScan-HE (left) and Atos GOM (right) are both structured light scanners with similar capabilities, but operator choices on scanning parameters result in more metric detail and higher quality model appearance (left), illustrating the importance of not only the instrument but expertise in data collection.

Program Goals 2015-2017

In addition to continued pursuit of our initial goals in 2015-2017 we aim to:

- Promote geospatial methods and approaches in research communities where uptake remains limited.
- Expand awareness of opportunities for collaboration and support through the SPARC Program.
- Increase the number of supported archaeological research projects.
- Increase our commitment/contribution to high research value projects, notably at the publication phase.
- Promote methodological innovation by CAST researchers through participation in projects.
- Expand program of workshops, online seminars, and published training materials.

Management Changes for 2015-2017

In the second phase of the SPARC program the PIs will be Drs. Jesse Casana, Jackson Cothren, David Frederick, W. Fred Limp, and Rachel Opitz. Dr. Kenneth Kvamme will remain involved in the project as a supporting faculty member, but will not serve as a PI in order to devote more time to bringing his other research projects to completion.

Based on the first phase of the program several changes will be made to the application and review process. The criteria for the reviews will remain the same in principle, following NSF merit criteria, but in the second phase of the program the set of specific questions will be reduced and simplified to expedite the review process. This will, in turn, allow a quicker turnaround time between the close of applications and the notification of projects that they will receive support through SPARC.

In the course of the first phase of the program we have expanded our distinguished advisory and review board. This expansion adds new scholars with new areas of geographic and period expertise, and makes available more reviewers for each project. In the second phase of the program, we anticipate a continuing expansion of the review board, adding specialists for regions in Asia, Africa and the Pacific. We are particularly pleased that all but one member of

SPARC's current advisory board have agreed to continue to serve during the second phase of the project.

Spatial Archaeometry Research Collaborations Advisory Board

The initial SPARC project benefited from the support and time of members of our advisory board, including: **Sue Alcock**, Brown University, Director of Joukowsky Institute for Archaeology and the Ancient World; **Alex Barker**, University of Missouri, Director of the Museum of Art and Archaeology; **Brad Chase**, Albion College, Assistant Professor of Anthropology; **Michael Chazan**, University of Toronto, Professor, St. George Campus and Director, Archaeology Center; **Meg Conkey**, UC Berkley, Class of 1960 Emerita Professor of Anthropology; **Charles R. Ewen**, East Carolina University, Professor, Department of Anthropology; **Gary Feinman**, University of Illinois at Chicago Field Museum, Curator of Mesoamerican, Central American, and East Asian Anthropology; **Michael Hardgrave**, US Army Corps of Engineers, Construction Engineering Research Laboratory; **Matthew Johnson**, Northwestern University, Professor of Anthropology**; Simon Keay**; University of Southampton, Head of Archaeology; **Bernard Means**, Virginia Commonwealth University, Director of Virtual Curation Laboratory and Instructor of Anthropology; **Margaret M. Miles**, UC Irvine and American School of Classical Studies in Athens, Professor of Art History, School of Humanities, Classics School of Humanities; **Martin Millett**, Cambridge, University, Laurence Professor of Classical Archaeology; **Eduardo Góes Neves**, Universidade de São Paulo, Laboratório de Arqueologia dos Trópicos Museu de Arqueologia e Etnologia; **Christina B. Rieth**, State Archaeologist and Director of the Cultural Resource Survey Program New York State Museum; **Nicola Terrenato**, Professor of Classics, University of Michigan; **Willeke Wendrich**, UCLA, Professor of Egyptian Archaeology/Digital Humanities.

Analytical Development Priorities 2015-2017

In addition to maintaining expertise in our core areas of site-based archaeo-geophysics and mapping, three-dimensional scanning, photogrammetry, visualization, and morphometrics; aerial and satellite remote sensing, regional survey, and spatial analysis, we anticipate that the next phase of projects will facilitate research in spatial archaeometry topics including:

- **UAVs:** UAV have emerged as an important source of site scale airborne data, and CAST has developed expertise in the acquisition of thermal and color imagery, as well as 3D data using these platforms (Casana et al. 2014) and in the complex legal and regulatory structures emerging from the FAA and others.
- **SfM:** Structure from Motion has emerged as the primary low cost means of acquiring 3D models of objects and stratigraphy. While the creation of general models suitable for visualization is straightforward, the collection of metric models, high quality image textures, and the management and scholarly publication of these data are developing areas. The strengths and weaknesses of this approach especially when compared to alternatives such as "laser" scanning are not widely understood in archaeology (Koutsoudis et al. 2014). CAST is strongly positioned, based on a long history of work in SFM, scanning, metric survey, metatdata and archiving, to provide guidance and support in this growing area.

- **Satellite systems:** New satellite platforms relevant for archaeologists have been and will be coming online over the next 1-5 years, notably the Sentinel system (https://sentinel.esa.int/web/sentinel/home). These sensors, with their combination of high temporal, spectral and spatial resolution, will greatly increase the utility of satellite sensors in archaeological applications (Agapiou et al. 2014). The Center will promote the awareness and use of these new sensors within the archaeological community
- **LiDAR:** The increasing availability of airborne lidar data for locations across the Western Hemisphere has increased interest in these data for a range of US based researchers. The challenges of exploiting this data in Meso- and South America are different from those found in Europe (Chase et al. 2012). In particular the detection of standing remains and terraced field systems in dense vegetation are essential. CAST has the expertise to provide specialist advice to a range of projects using these data.
- **Big Data:** Big Digital- Data Publication is increasingly a concern as large scale born digital data proliferates in archaeology (Richards et al. 2013). Further, an increasing number of data publication venues, e.g. *The Journal of Open Archaeological Data*, are encouraging this trend. CAST's expertise in data management and publication, and established relationships with organizations like the Archaeology Data Service (ADS) and the Digital Archaeological Record (tDAR) allow us to support projects pursuing these goals.

Results of Previous Support for this Program

Establishing and Promoting SPARC

The first phase of the SPARC Program established three lines of activity: **education and training**, **research project advancement through collaboration**, and **methodological development.** In addition to initiating activities in these areas, the program's infrastructure and operations were organized. In developing the program's framework we prioritized providing equal opportunity to researchers at all career stages and types of institutions, particularly those outside traditional users of geospatial technologies in archaeology, in order to maximize our impact on the discipline as a whole. To accomplish this, we invested time in establishing a clear application and review process, and disseminated the advertisement of the opportunity for research support awards repeatedly, including direct mailing, presence at conferences, and through social media. Significant time was invested in developing the application and review framework, expanding the review board, and raising awareness of the availability of the research support awards. The program's framework is summarized below.

Information and Training Resources

The SPARC Program carries out training and outreach activities, primarily through online seminars, research residencies, and workshops at conferences. The aim of the online seminars and conference workshops is to provide an introduction to key topics in geospatial applications in archaeology, while residencies are intended to provide more in-depth or intensive training. During residencies, individual researchers undertake a period of concentrated study or project development at CAST in collaboration with resident staff. Workshops at international, national and regional meetings provide opportunities to reach

members of the archaeological community who might not otherwise seek out training in geospatial applications and give them hands-on experience with one or more methods, with the aim of inspiring them to pursue further training

Application and Review Process

Applications for SPARC Awards are accepted twice a year, in December and June. Notifications of research support award opportunities are disseminated to over 800 institutions and individuals. Application procedures are detailed on the SPARC website (http://sparc.cast.uark.edu/apply/fieldwork) and SPARC staff are available to discuss project ideas and provide early feedback on application materials for a month before each application period opens. Applicants are asked to address both the intellectual merit and broader impacts of their research and the value added through geospatial methods in a short (~5 pages) application. Projects are reviewed by the Program's Advisory Board and ranked broadly following NSF Merit Criteria. Projects are assigned for review based on the region/period expertise of reviewers and at least two reviewers (preferably three) are sought for each project. These rankings are the basis for project selection by the Program's staff, in consultation with the advisory board, taking into account scheduling and budgetary constraints.

Technical Support and Selection of Projects

Stage	External Researcher Involvement	SPARC Resources and Support
Stage 1 "Information Seeking"	• Initial exploration	• GMV Website • On-line inquiry System • Web accessible FAQ • Remote consultations
Stage 2 "Evaluation of Alternatives"	• Focused information gathering • Review of comparable efforts • Cost/benefit assessments	• Workshops • Webinars • Consultation at Center • Advice in proposal development
Stage 3 "Initial Pilot Studies"	• Active collaboration in field and data analysis • Active collaboration in publication and reporting	• Center staff and equipment in field • Data processing • Ongoing consulting • Intermediate Center residency
Stage 4 "Integration into Practice"	• Full implementation in current and future project(s)	• Continuing field participation as needed • Continuing advice as needed • Graduate residency

Table 1: Stages, or levels, of support

Collaborative Project Development

In addition to projects receiving full support through SPARC Awards, collaborative projects are supported through the Program. In these projects more direct costs, notably travel and equipment transport, are typically covered by the external collaborator, with staff time, instrument use and expertise supported through SPARC. These projects are typically more open ended, and planned to run over a longer period than projects supported through Awards (typically 2-4 weeks duration), and intended to develop sustained collaborative projects supported through external funding, with greater scope for methodological innovation.

Applicants and Projects

In the first two rounds of Awards (12 month period), SPARC received 24 project submissions, of which 10 were awarded support, a success rate of 41.6%. As the visibility of the Program increases, we expect more applications for the available awards. For 2015-2017 our aim is to increase the number of applications received by 25% in order to continue to support high quality research. In the first two rounds of awards the distribution of PIs between senior, early career and doctoral researchers was fairly even, often with junior and senior scholars applying together as co-PIs. We plan to continue to support high quality research across these career stages as the Program expands. To date, the vast majority of applications have been received from university affiliated researchers, going forward we will expand awareness of the program and engagement with archaeologists working in the public sector.

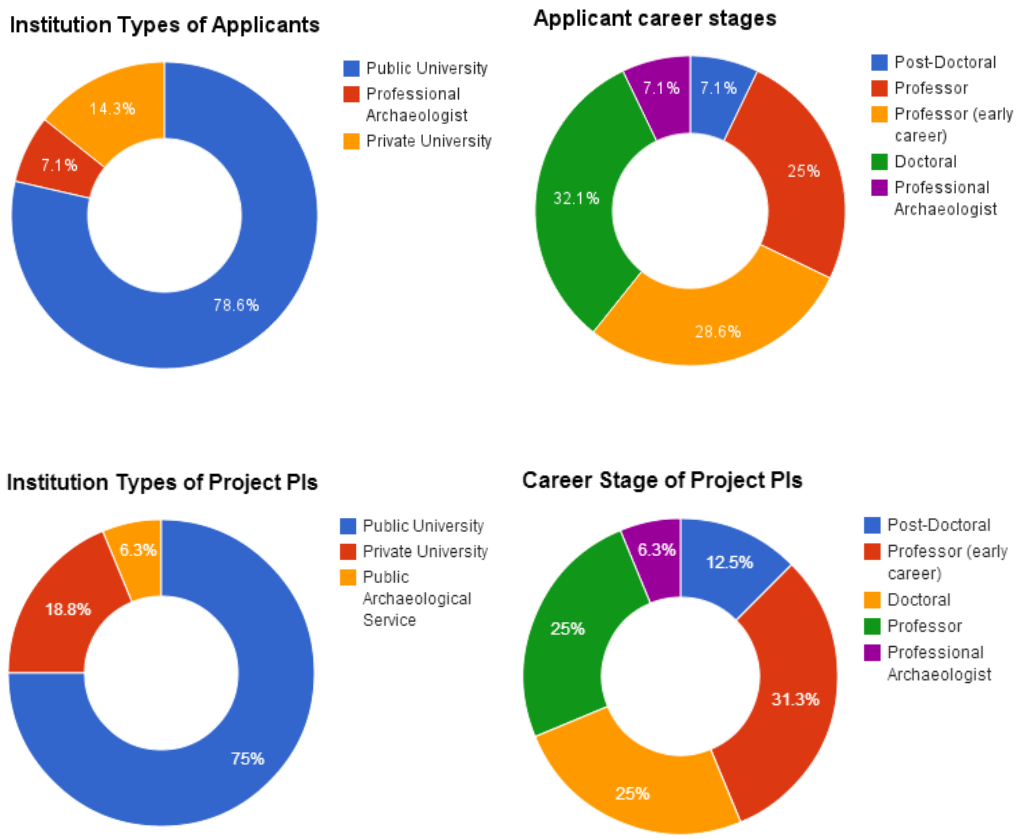

Figure 2: (top) Applicant demographics and (bottom) Project PI demographics.

Researcher	Career Stage	Institution Type	Institution Location	Project Location	Collaboration Type
Klehm	Post-Doctoral	Private University	Missouri	Botswana	Fieldwork
Ernenwein	Prof. (early career)	Public University	Tennessee	Botswana	Fieldwork
Soroush	Doctoral	Private University	New York	Iran	Analysis
King	Prof. (early career)	Public University	Indiana	Mexico	Analysis
Dolan	Doctoral	Public University	Washington	Canada	Fieldwork
Ryzewski	Prof. (early career)	Public University	Michigan	Montserrat	Analysis
Cherry	Professor	Private University	Rhode Island	Montserrat	Analysis
Cerasuolo	Post-Doctoral	Public University	New York	Italy	Analysis
Warford	Doctoral	Public University	New York	Italy	Analysis
Grier	Professor	Public University	Washington	Canada	Fieldwork
Safi	Doctoral	Public University	Washington	USA	Fieldwork
Creekmore	Professor	Public University	Colorado	Kurdistan	Fieldwork
Bauer	Prof. (early career)	Public University	Indiana	India	Fieldwork
Porter	Prof. (early career)	Public University	California	Jordan	Fieldwork
Boytner	Independent Researcher	Non-profit research center	California	Peru	Fieldwork
Bagley	Prof. Archaeologist	Arch. Service	Massachusetts	USA	Analysis

Table 2: Summary of supported project PI career stages, affiliations, and project types.

Research Productivity Enhancements for Supported Projects

Data has been collected and/or analyzed for projects through SPARC research support awards as follows, for projects currently completed or underway:

PIs Cherry & Ryzewski (SLAM Project): Approximately 24 km^2 of raw airborne lidar was processed and interpreted. This data and maps and a short report on initial interpretation was delivered to PIs Cherry & Ryzewski. The data and maps were the basis for fieldwork carried out on Montserrat from May 20 to June 5, 2014, through which approximately 98 new landscape features and locations of interest were identified. Secondary analysis is underway and publication preparation has commenced [submission to the *Journal of Field Archaeology*, December 2014].

PIs Dolan & Grier (Dionisio Point Project): 1,500+ sq. m. of archaeo-geophysical survey was performed over the interior and immediate exterior of architectural feature spaces in the densely vegetated site of Dionisio Point Provincial Park. The expertise of CAST staff was key in generating a data set that successfully located unknown features, providing new evidence of the layout and internal organization of these post-and-beam houses. This data has been processed, fused, and analyzed. It was delivered to Dolan & Grier on 29 August 2014.

PI Safi (Largo Gap Project): 4,000 sq. m. of geophysical survey was conducted using the GSSI 400 MHz antenna. Airborne thermography survey was carried out over the same area. This GPR and thermal data has been preliminarily processed and initial analysis is in process. An initial report was delivered to PI Safi.

PIs Klehm & Ernenwein (Bosutswe Landscapes Project): Multiple airborne thermography surveys were carried out over an area of 4,400 sq. m. An initial report will be delivered to the PIs by 31 December 2014.

PI Cerasuolo (Vulci Landscapes Project): A basic webmapping and data entry interface has been designed for this landscape analysis. Datasets available from regional and national

government agencies in Italy have been compiled in this interface, and data from an initial set of three archaeological surveys has been integrated, including reprojection and standardization of terms.

PI King (Tavela Community Museums Project): During a week-long residency at CAST in March 2014 King established a protocol for the 3D modeling of artifacts using low cost and open source software, appropriate for use in rural Mexico. In May 2014 SPARC staff traveled to Bloomington, IN to lead a three day workshop titled "Build your own Digital Museum: An Introductory Workshop". A complete workshop package was provided to participants.

PI Soroush (Modeling Long-Term Water Management Strategies on the Irrigated Plain of Miān-āb): SPARC supported the acquisition of 191 Aerial photos of Khuzistan (Miān-āb Plain) acquired in 1975 and 17 aerial photos acquired in 1956. These were purchased on March 1st, 2014, in Tehran, from the National Cartographic Center (NCC). The analysis of these photos including processing into a DEM appropriate for hydrological modeling was carried out during a residency at CAST in September and October 2014.

PIs Bagley and Poulsen (Identification of Coarse Earthenware Potters on Production and Consumption Sites in Charlestown, Massachusetts Using Fingerprint Biometric Identification): In October 2014 SPARC Staff travelled to Boston, MA to acquire high resolution 3D scans of fingerprints on ceramic vessels from the Parker-Harris Kiln and Three Cranes Tavern sites. Over sixty prints were scanned using the Breuckmann smartScan-HE. These data will be used in subsequent analysis of the production of the ceramics and exchange between the two groups, carried out during 2015. An initial presentation is planned for the SHA 2015 conference.

PI Porter (Measuring Household Economies in Iron Age Southwest Jordan: An Archaeological Case Study from Edomite Busayra): Program researchers will conduct geophysical survey in Spring 2015 to map sub-surface features in order to characterize the overall architectural layout of the settlement as well as identify domestic residences for additional sampling.

PI Bauer (Biodiversity as a Social Process: Land Use, Resource Consumption, and Near-surface Geophysical Explorations at South Indian Iron Age-Early Historic Settlements): Program researchers will conduct geophysical survey in Spring 2015 to identify structures and activity spaces for forthcoming excavations of habitation and metals production locales at two sites, Kadebakele and Maski, where artifact surface distributions and early textual sources suggest specialized extraction and production of iron and gold occurred.

Collaborative Projects: In summer 2014 we undertook a collaborative project with PIs Schwarz & Creekmore, supporting the acquisition of kite aerial photography and SFM using this imagery for the Kurd Qaburstan Project. Two further collaborative projects are planned, with PI Boytner, carrying out extensive documentation and survey work at Huari in Peru, and with PI Piscitelli at the Caballete site in Peru, carrying out geophysical survey. The collaborative project with Boytner has initial fieldwork planned for January 2015, with subsequent work based on the results of the initial survey. The collaborative project with Piscitelli has recently been awarded a NatGeo Waitts grant, and initial fieldwork is planned for summer 2015.

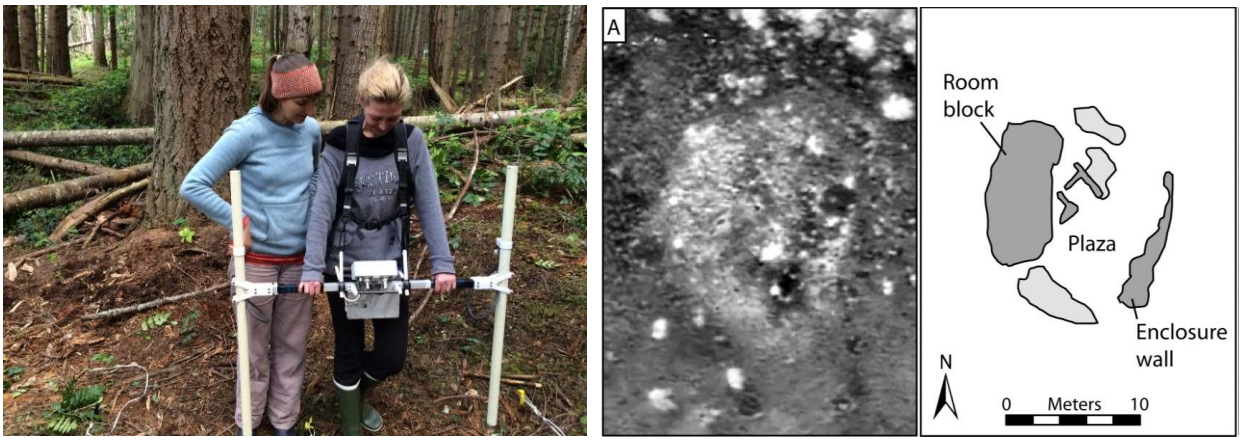

Figure 3 (left): Geophysical survey in challenging conditions such as woodlands is supported through SPARC. Data collection at Dionisio Point (BC) required careful planning in the field and the interpretation of small data blocks. (right): Airborne thermography using UAVs allows the detection of sub-surface features. Collecting data with maximum contrast, here at BlueJ (NM), required repeated flights (Casana et al. 2014).

Research Outcomes from Supported Projects

Presentations and Publications; Theses; Workshops; Data

Research through projects supported during the initial 18 months of the SPARC program has led to 5 journal articles, 1 conference proceedings publication, 13 conference papers and presentations, substantive contributions to two doctoral theses, and 9 datasets – with many more of all planned. Details on these products are provided in the references section of this proposal.

Subsequent Grants and Proposals Based on SPARC Pilot Projects

Two SPARC projects have resulted in applications for further funding. Dr. Stacie King is submitting a NEH proposal to further develop her project, using 3D models in virtual museum environments to promote the heritage of communities in Tavela, Mexico. CAST staff will participate in this project as an adviser. Drs. John Cherry and Krysta Ryzewski have submitted an application to the National Geographic Society to support further fieldwork in 2015 to continue to exploit the results of the lidar analysis on Montserrat.

Completed and Planned Residencies

SPARC is supporting 5 researchers in residence, providing access to the computing and software resources available at the center and mentorship. Past residencies include pre-doctoral Researcher Castillo, looking at settlement patterns in the American southwest and gaining experience in geophysical survey and imagery-based GIS analysis; doctoral researcher Soroush, working with CAST staff to derive DEMs from historic imagery from Iran; and Dr. Glatz, a researcher at Glasgow University, learning structure from motion for objects. Future planned residencies for Spring 2015 include extended stays by doctoral researchers Hanus (Poznan) and Vurpillot (Besancon), respectively pursuing projects in diffuse urbanism and spatial analysis of cityscapes, and perceptual studies of historic cultic environments through game interfaces.

CAST Professional Development and Graduate Student Advancement

CAST staff and affiliates working on SPARC projects advance their own work through methodologically oriented publications and presentations, and through opportunities created during collaborative projects to work under challenging conditions or in new environments. Program researchers (publications based in SPARC-affiliated work detailed in the references document) have developed: improved field data collection strategies and UAV thermographic imagery over complex sites; improvement in strategies for low cost and open source software based solutions to SfM problems traditionally solved using commercial products and new strategies to assess and process a wider variety of historic imagery with atypical or unknown camera/mission properties. Participation in SPARC projects will continue to act as a driver for methodological and technical advancement for key staff on the project.

Graduate students collaborating on SPARC projects have been and will be given opportunities to increase their field and processing experience. Wiewel (PhD student U. Arkansas) and Markussen (Phd Student LBI / U. Vienna) contributed substantively to geophysical and UAV thermographic surveys, broadening their experience in terms of environments and types of sites studied. Fletcher and Cool (MA students- U. Arkansas) gained experience in UAV survey and field project planning in a variety of environments.

Methodological Advances

Methodological advances made through SPARC collaborative projects have primarily been in the deployment of UAV-based thermography, used on Klehm & Ernenwein's project in Botswana and on Safi's project in New Mexico. These projects provided opportunities for testing and refinement of the UAV thermography protocol.

Work on SPARC projects has contributed to an ongoing program of comparative assessment of costs, performance and results of SfM and "laser" scanning with the aim of providing best practices guidelines and real-world assessments of the quality of data acquired and effort required under a variety of conditions.

Through work on the Montserrat SLAM lidar project new approaches to the detailed characterization of standing architecture as represented in ALS point cloud data are under development. The problem of characterization and visual representation of archaeological remains in the 3D point cloud environment has not been addressed elsewhere, and conventions are lacking for the communication of basic metrics and relationships using these data. The work on this project forms a key part of a broader effort toward the development of a new set of appropriate visual conventions.

Broader Impacts of the First Phase of the Program

Online Seminars and Workshops

SPARC has hosted three official online seminars on geospatial technologies. The first seminar was led by Dr. Fred Limp, the second by Katie Simon and Adam Barnes, and the third by Dr. Eileen Ernenwein. Limp offered two additional on-line seminars dealing with spatial archaeometry as part of the Society for American Archaeology's seminar series and Dr. Rachel Opitz offered an on-line seminar in the same series. Both SAA online seminars were viewed at

25 locations, the maximum supported by the SAA. Further online seminars are planned for Spring 2015. In its first 18 months, the SPARC Program has also supported four (4) workshops: *3D Digital Data Publication* (Digital Heritage Conference, Marseilles, October 2013), *Airborne Laser scanning* (3DScotland Conference, Edinburgh, October 2013 and Space2Place, Durham, NC, October 2014) and *Digital Excavation Documentation* (Space2Place, Durham, NC, October 2014).

Participation and Leadership in Interest Groups and Professional Organizations

In order to promote geospatial approaches in archaeology and to continue to increase awareness of the SPARC program, researchers from SPARC have taken up leadership roles in relevant professional organizations, and continue to actively contribute to the organization of conference sessions, workshops, and forums. Opitz and Simon joined the board of the Computing Applications in Archaeology North America Chapter (CAA-NA) in 2014 as secretary and vice president respectively, both one year appointments. Limp was appointed to the Board of Directors of the National Center for Preservation Technology and Training. Opitz took up the chair of the Aerial Archaeology Research Group (AARG), a three year appointment. SPARC research staff have worked to promote the issues of spatial archaeometry at national and international meetings through the organization of discussion based sessions. Notably, at the SAA 2014 meeting in Austin SPARC organized a forum on "Debating Spatial Archaeometry". At the UNESCO sponsored Space2Place Conference SPARC staff were involved in multiple workshops and presentations. A joint forum with DDIG on "Diverse Digital Archaeologies" is planned for the SAA in 2015 in San Francisco.

Institutional Collaborations

Institutional collaborations with groups specializing in complementary methods, particularly those located in regions where there is high demand for fieldwork support, have been established with the aim of expanding and improving the range of technologies and expertise available through the Program.

Researchers at the *Universite de Franche-Comte*, located in eastern France, have core expertise in woodland and large scale geophysical survey, environmental and palynological survey and modeling, airborne lidar processing, and agent-based modeling. A formal collaboration between CAST and the MSHE (*Maison de l'Science l'Homme et l'Environnement*) at the UFC was established in 2014, including support for researcher exchange and collaborative project development. This institutional collaboration will provide further opportunities for SPARC project collaborators, through the combined expertise and resources of CAST and the MSHE.

The Tesseract Lab, led by Dr. Frederick at the University of Arkansas, will be partnering with CAST in the upcoming phase of this program to expand support for the use of games, game design, and immersive environments for heritage analysis, exploration and communication. The Tesseract Lab provides access to software, computing workstations, and substantial expertise in modeling for the web, user-interface design, and the Unity3D environment.

Continuing Impact in the Research Community

Ongoing support from the NSF Archaeometry/Archaeology program will allow us to build on the program's current success in increasing the effective use of geospatial methods in archaeological research and education. The value of the program is cumulative, impacting researchers and students involved directly in SPARC supported projects and training activities, and through them the broader community. Continued funding will sustain our efforts in promoting new knowledge across the discipline, teaching and mentoring, and developing high-impact research, as we grow an interdisciplinary and collaborative program that advances contemporary archaeology.

Results of Previous NSF Support

There have been five prior NSF projects that have directly supported the research activities described here. In addition to the directly funded projects, the research activities discussed in this proposal have supported two other NSF projects.

BCS 1321443. Expanding Collaborative Opportunities for Research in Archaeo-Geomatics and Archaeo-Geophysics at CAST/AIL. PIs: Cothren, J., Limp, F., Frederick, D., Casana, J. and Kvamme, K. Award: $249,986. With National Science Foundation support the University of Arkansas' Center for Advanced Spatial Technologies (CAST) and the Archaeo-Imaging Laboratory (AIL) are providing next-generation 3D measurement, analysis and remote sensing technologies to archaeological research projects around the world. The project focuses on three primary areas of established expertise: 1) site-based archaeo-geophysics and mapping, 2) three-dimensional scanning, photogrammetry, visualization, and morphometrics; and 3) aerial and satellite remote sensing, regional survey, and mapping.

BCS 0321286. Acquisition of a High Accuracy/Resolution Landscape and Structure Characterization System (HARLS-CS) for Anthropology, Archaeology, Architecture, Biology and Geosciences. PI: Limp, W. F. Co-PIs: Kvamme, K., Beaupre, S., Burian, S., Bajwa, S. Award: $349,452. 2003-2006. The High Accuracy/Resolution Landscape and Structure Characterization System (HARLS-CS) provides coordinated three dimensional, multi-spectral and metric image-based measurements necessary for a wide range of mensuration, classification, and quantitative characterization analyses. The system is comprised of an Optech ILRIS 3D laser profiler, a Konica Minolta Vivid 9i laser scanner, TerraVerde's TerraHawk airborne multispectral imaging platform, the ASDI field spectroradiometer, three Nikon digital cameras with calibrated lens, a Trimble 5700/5800 GPS survey system, a Trimble 5600 Robotic total station, supporting software (e.g. Innovmetric PolyWorks, Trimble Geomatics Office and EOS PhotoModeler) and a Genie TZ-50 towable boom.

IIS 0431070 Computing and Retrieving 3D Archaeological Structures from Subsurface Surveying. PI: Daniilidis, Kostas. Co-PIs: Limp, W. F., Vranich, A., Shi, J. Biros, G. University of Pennsylvania. Award. $1,068,000. 2004-2007. CAST was involved in a multi-year collaboration with Dr. Alexei Vranich and the University of Pennsylvania GRASP lab to scan and document the Pre-Incan site of Tiwanaku, Bolivia. The field research at this site was conducted in 2005 and 2006 and involved an extraordinarily broad range of instruments and methodologies. Aerial photographs from 1972 and 1992 were used to create two separate digital elevation models (DEM). Two laser-scanning systems (TLS and object) were used to acquire high-resolution data

for monumental structures, excavation areas, and artifacts. Ground-penetrating radar, magnetometery, magnetic susceptibility, and electrical conductivity surveys were conducted in the monumental core area, revealing unexcavated building foundations, paved surfaces, water conduits, and revetments. Results from the photogrammetry, laser scanning, and geophysical surveys were merged into one software environment that allows all these and other multi-scale, multi-temporal datasets to be integrated.

ESP 0918070 Collaborative Research: Cyberinfrastructure for Transformational Scientific Discovery in Arkansas and West Virginia (CI TRAIN). PI Cothren, Jackson, Co-PIs, Limp, W. F. Ramaswamy, S. Bellaiche, L., Spearot, D. Award: $3,370,951. 2009-2013. The CI-TRAIN project was designed to create a self-sustaining environment in which cyberinfrastructure is used to develop and deploy a multi-faceted workforce that is empowered to apply, sustain, and create cyber-based systems, tools, and services over the long term; develop a nationally competitive computational and visualization environment shared across the partnership, featuring shared and new supercomputing clusters for computation, visualization support, and training; develop visualization display resources; procure and develop software and new high-end data capture devices in support of the creation of new digital content. The project has allowed the acquisition of a number of instruments of direct relevance to the archaeometry proposed effort (see the Facilities section for a full listing).

BCS 917732. Collaborative Research: the Kalavasos and Maroni Built Environments Project. Investigating Social Transformation in Late Bronze Age Cyprus. PI Manning, S., Co-PI Fisher, K. Cornell University. Award $107,570. 2009-2013. The Kalavasos and Maroni Built Environments (KAMBE) Project is a continuing interdisciplinary and collaborative effort by Cornell University and Ithaca College to investigate the relationships between architecture, social interaction and social change in Late Bronze Age (c. 1650-1100 BCE) Cyprus. This important period saw the island of Cyprus shift from a relatively insular and egalitarian, village-based society to an urbanized, cosmopolitan civilization. Using large-scale, multi-dimensional archaeo-geophysics, the KAMBE Project is investigating these processes at the sites of Kalavasos-Ayios Dhimitrios and Maroni (Fisher et al. in press). After the project was underway, the important role of TLS for recording the sites' extant architecture as a basis for modeling and visualization was also realized. Initial fieldwork was conducted with CAST staff and equipment in 2011 and more extensive efforts conduced in summer 2012.