Internal Project Number:
External Project Number: 800139

Project Start: **01/01/2019** **Project Duration (in years):** **Year 1 of 3**

Please indicate status of external funding.

1)	**Active Award?**	**Yes** [X]	**No** [ ]	*(If yes, skip to next section.)*
2)	**Pending Proposal?**	**Yes** [ ]	**No** [X]	*(If yes, complete the following questions.)*

a) Has a Director's Questionnaire been submitted? **Yes** [ ] **No** [ ]
b) Is funding likely[1]? **Yes** [ ] **No** [ ] **Unsure** [ ]

[1] If an award is likely or unsure, please notify the Grants Office and obtain an external project number to enter at the top of this form.

Please indicate if proposal includes requests for any of the following (mark all that apply).

[ ]	[ ]	[ ]	[ ]	[ ]
Ship Time	**ROV**	**AUV**	**Wave Glider**	**Mini ROV**

Please indicate what type of project is being proposed (mark only one).

[ ]	[X]	[X]	[ ]	[ ]	[ ]
Feasibility/Scoping [Less than 100 days effort]	**Development**	**Research**	**Infrastructure**	**Education**	**Time Series**

Project Manager/PI: TBD/Kakani Katija

Project Title: EyeRIS (Remote Imaging System)

Please indicate which category best describes the project theme (mark only one).

[ ]	[ ]	[X]	[ ]
Ocean biogeochemistry	**Ecosystem dynamics**	**Ocean visualization**	**Exploration & discovery**

Please indicate percentage of effort on this project anticipated for 2018 toward these three highest institutional goals (percentage total should equal 100%).

Goal	Developing/adapting innovative technologies	Utilizing developments to explore and understand ocean systems	Technology/knowledge transfer[1]
Percentage	80%	10%	10%

[1] This category includes transfer of hardware, know-how, publications, presentations, etc.

1) ABSTRACT (new projects only)

All processes in the ocean (e.g., biogeochemical, biological, and ecological) are governed by the physics of fluid motion. However, the oceanographic community currently does not have instrumentation to characterize fluid motions at spatial and temporal scales relevant to many critical oceanographic processes. Robust, high resolution, volumetric fluid-flow measurements are needed to answer a wide array of science questions that include: fluid fluxes along the seafloor for validation of biogeochemical flux models in active seafloor environments, direct measurement of organismal feeding interactions, and monitoring complex flows that impact the health of coral reefs and other benthic systems. Without direct *in situ* measurements, the oceanographic community is currently limited to using laboratory studies and numerical modeling to address many of these issues. Some *in situ* flow instruments exist, but at their current state (e.g.; limited to 2D, requiring bright laser illumination, etc.), their utility is restricted to a narrow spectrum of situations in ideal conditions.

Visualization of fluid motion alone is nearly impossible because water is transparent. In order to infer motion of fluids, scientists and engineers rely on the motion of proxies like suspended microbubbles or particles. In the ocean, particles can be found at all depths, and they range in size, shape, and composition. While their presence can enable visualization of fluid motion *in situ*, particles and aggregates also play a critical role in our understanding of how deep sea inhabitants survive, and how the ocean regulates climate. Ocean biology helps regulate the amount of carbon dioxide in the Earth's atmosphere through the biological carbon pump. This pump operates by capturing carbon dioxide in the upper-most part of the ocean via photosynthesis and subsequent generation of additional biomass. This biomass (and carbon) can eventually form marine snow, and particles that sink to the deep sea may remove carbon from the atmosphere for thousands of years. Marine snow is the primary food source for many marine animals. The magnitude and mechanisms of the biological pump are still hotly debated due to the lack of observational tools that can resolve particle/aggregate fields and fluxes, which leads to uncertainty in how much carbon is sequestered by the ocean globally.

To address this need, we propose to develop an optical imaging system called *EyeRIS* (Remote Imaging System). This development effort can be broken into two phases:

1. ***Phase 1****:* Design and build an *EyeRIS* instrument suitable for cabled platforms (e.g., ROVs and deep-sea cabled observatories) down to 4000 m. This instrument will be tested using an ROV, and validated with the DeepPIV instrument and an empirical flow using a vortex generator. Develop automated data handling workflows to synthesize *EyeRIS* data. These efforts will take place in years 1 and 2.
2. ***Phase 2***: Design and build an autonomous *EyeRIS* instrument that is rated down to 1500 m. This instrument will be tested and validated by using the *LRAUV*. To demonstrate the utility of the instrument, we will quantify the particle field during a horizontal transect and background fluid turbulence levels during pre-planned

transect and Lagrangian missions with *LRAUV*. These efforts will take place in years 2 and 3.

This instrument will be capable of quantifying three-dimensional fluid motions and the size-and type distribution of particles (and living organisms) throughout the water column. If successful, this instrument will enable quantitative observations in midwater and the benthos, and will inform nearly all fields in oceanography and marine science.

Fundamental Problem

Here we propose to develop imaging technology that can have broad applicability to the geochemical and biological oceanography communities that utilize both remote and autonomous observation platforms. The ability to directly measure three-dimensional particle dynamics, fluid physics, and temporally varying surface reconstructions have applicability to topics from feeding of benthic, deep sea coral communities to the biological pump and carbon sequestration. In addition, being able to image larger volumes in higher temporal and spatial resolution than other structured light imagers and the subsequent characterization of larger sinking objects (e.g., larvacean houses and corpses) could finally enable quantification of episodic deposition events of carbon to the seafloor. If successful, this instrument will contribute to all four of MBARI's research themes (exploration and discovery, ocean visualization, ecosystem dynamics, and ocean biogeochemistry), and all three of MBARI's engineering activities in our Technology Roadmap (taking the laboratory into the ocean, enabling targeted sampling, and advancing a persistent presence).

Technology

This proposal builds from a successful and recently completed, three-year MBARI development project to design, construct, and deploy a 2D particle and flow measurement instrument called *DeepPIV*. To progress to resolving particles or surfaces in 3D, computer vision algorithms and optical arrangements with single or multiple cameras can be used. Here we propose using a single camera solution with a plenoptic (or lightfield) camera, which utilizes a micro array of lenses placed between the image sensor and camera lens. This micro-lens array functionally subdivides the image on the camera sensor, where each lens in the microarray is carefully selected to have a different focal plane. Computer vision algorithms then use each subimage to reconstruct the data such that every object in the imaging volume is in focus. By using a lightfield camera and LED illumination, we can build a system that will fully resolve 3D particle fields and fluid motions, while also simultaneously reconstructing stationary and/or moving surfaces in *situ*. The initial *EyeRIS* development will result in a 4000 m depth-rated cabled instrument that can be deployed from all of MBARI's ROV platforms. The lessons learned from the cabled ROV deployments will inform iterations of *EyeRIS* and our efforts to automate the operation of the instrument. The final development will be an untethered instrument, with a local controller, battery pack, and on-board data storage, to enable deployments in a range of environments where persistent measurements are needed to characterize particle fields and flow behavior. The autonomous *EyeRIS*

instrument will be rated to 1000 m depths, and will be demonstrated by deployment on *LRAUV*.

Data

As part of the instrument development process, we expect to generate small quantities of imaging data used for validation of the imaging technique, and it will be stored on the Atlas Project Library. As the instrument is validated, and our efforts transition into science use cases, we expect to generate on the order of 1-3 TB of data per year.

Impact

The development of *EyeRIS* will enable high temporal and spatial resolution characterizations of *in situ* volumetric particle fields, large objects, and fluid motion, yielding a novel, autonomous instrument that can be deployed for either short- or long-term durations. International organizations such as the IPCC and the oceanographic research community will be interested in both our scientific results and our improved capability for observing the marine environment in a cost-effective way when compared to ship-based measurements. By integrating *EyeRIS* on a wide range of autonomous observation platforms, our efforts will enable volumetric imaging and fluid flow measurements that could be used for marine science applications from directly monitoring animal-fluid-particle interactions and transfer of energy through food webs to the understanding of fine-scale turbulence throughout the ocean's depths to inform mixing and biogeochemical models. By utilizing a cabled system on ROVs for targeted investigations, deployments can inform efforts such as the Deep Sea Coral Observatory (Barry) and deep sea coral ecology at MBNMS and other MPAs.

2) PROPOSAL

Research activities (brief overview of activities to take place in 2019)

Not applicable.

Engineering/technology developments (describe tasks in 2019 for shared labor resources)

See milestone table below.

Field programs in 2019 that use MBARI marine assets (must provide schedule for AUVs/mini ROV, including any necessary time for shipping)

Not applicable.

For work that involves using MBARI marine assets, please respond to the following, as applicable.

Isotope Usage
Project teams must provide details regarding any planned isotope use on shore, on ships, in the Sanctuary, etc. Please review the guidance on isotope usage at http://www.mbari.org/at-sea/cruise-planning/hazardous-materials/ and policy at http://mww.mbari.org/safety/SafetyManual/Isotope_Use_Policy.pdf, and then provide details on plans below.

Not applicable.

R/V *Paragon* Requests
If the project team will be requesting time for the R/V Paragon, please specify the operators in the group and provide estimates of their availability to operate the vessel.

Not applicable.

Milestones for 2019

Due Date	***Act / Ind***	***Description***
06/01/2019	***Output 1.1:*** Procurance and testing of new imaging hardware in the laboratory.	
	1.1.1	Purchase imaging hardware (cameras and lighting) and set up in laboratory.
	1.1.2	Collect/construct moving targets for in-lab imaging evaluation.
	1.1.3	Synthesize data using purchased and in-house software.
12/31/2019	***Output 1.2:*** Packaging of instrument hardware suitable for deploying the imaging device to 4000 m depth on a cabled platform.	
	1.2.1	Design mechanical, electrical, and software system for imaging device.
	1.2.2	Conduct design review and address concerns and incorporate suggestions into design.
	1.2.3	Build instrument using mechanical, electrical, and software design.

2019 Budget Projection for MBARI's Portion of the External Grant

Grant Expenses (e.g., supplies, travel)

See table below.

Grant Labor (labor requests paid by grant)

BUDGET ITEMS	**YEAR 1 (months)**	**YEAR 2 (months)**	**YEAR 3 (months)**	**TOTAL**

Personnel Salary				
Kakani Katija (PI)	0	0	0	-
Henry Ruhl (Co-PI)	1.00	1	1	-
Alana Sherman (Co-PI)	1.00	1	1	-
Denis Klimov (EE)	1.00	1	0	-
Jon Erickson (ME)	1.00	1	0.25	-
Rich Henthorn (SE)	1	2	1	-
TBD (Research Engineer)	12.00	12	12	-
Tom Marion (EE Tech)	0.5	0.5	0.5	-
Frank Flores (ME Tech)	0.5	0.5	0.5	-
Intern	3	3	3	-
Materials + Equipment				
Materials (incl. travel + publications)	32,340	31,990	10,650	74,980
Equipment	110,000	66,000	-	176,000
Ship time				
Rachel Carson + Ventana		(1 day, cost-share)	(1 day, cost-share)	-
Paragon + LRAUV			20,000	20,000

Grant-funded Ship Requests

Not applicable for 2019.

Note: All projections for grant-related expenses should be entered into the Budget System. If cost-sharing is expected (i.e., using MBARI expenses to supplement grant activities), any such expense or labor requests should be associated with an internal project # and identified in that project budget.

Export Regulation
Does the project team anticipate any foreign collaborations or international travel? If so, please identify collaborators by name, institution, and country.

Not applicable.

Does the project team plan or anticipate export-controlled purchases, shipments, or transfers of items (e.g., research instruments, proprietary data, hand-carried tools or samples) outside the U.S. temporarily or permanently? If yes, please identify country or countries and indicate whether these items will remain under MBARI control while abroad or controlled by others. Will the items be exported to more than one country? Please include foreign collaborator information as described above.

Not applicable.

Will the externally funded project include any restrictions on the publication of the information resulting from the research, other than limited prepublication reviews by research sponsors to prevent inadvertent divulging of proprietary information or to insure that publication will not compromise patent rights of the sponsor?

No, we are not aware of any restrictions.

Is the research federally funded and will specific access or dissemination controls regarding the resulting information be accepted by MBARI or the researcher?

Not applicable.

Monterey Bay National Marine Sanctuary (MBNMS)

General Permit
Projects teams need to indicate if any work will be performed that is either: (1) currently authorized under our general permit; or (2) will require that we obtain authorization. The current permit can be viewed at http://mww.mbari.org/pco/permits/mbnms-2015-002_feb2015.pdf. Please see Mandy Allen for questions.

Is a permit with MBNMS required for your work?

Not applicable.

SESAs (General map)
Projects will need to indicate whether or not work will be conducted within one of the Monterey Bay National Marine Sanctuary's Ecologically Significant Areas (SESAs). An interactive map can be found on the Sanctuary's SIMoN webpages at https://sanctuarysimon.org/regional_sections/maps/mpaviewer/. If your work will be conducted in one of these areas, please indicate which area by number or name (zoom in to see names of MPAs).

Not applicable.

California Department of Fish & Wildlife
A Scientific Collecting Permit will be required for biological and geological sample collections offshore California (even in Federal waters and beyond), and for many activities in State Marine Protected Areas. Please see Mandy Allen for questions.

Will you be collecting samples that require a permit?

Not applicable.

Will you be working in a State Marine Protected Area?

Not applicable.

Authorizations/Permits from other Agencies or Organizations
Is the project team aware of any other permits or authorizations that will be necessary to perform the proposed work? If so, please list below along with status of authorizations (obtained, pending, need to apply, etc.). Please see Mandy Allen if you have questions.

Not applicable.

Active Acoustics
We are keeping an inventory of acoustic instrumentation. The current list is posted here: https://mww.mbari.org/resources/2019_Proposal_Process/documents/mbari_acoustic_instruments_2018-05-29_ver_11.pdf. If you have or plan to use equipment that is not already on this list, please be sure to include that information here.

Not applicable.