**Cover Page ROSF 2025**

**Title:** SRD-ROSF2025: Optimization of a novel harmonic radar system and applications for tracking insects other small organisms

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Tan Wong, Electrical and Computer Engineering Department, College of Engineering

Jasmeet Judge, Agricultural and Biological Engineering, College of Agriculture

Isaac Esquivel, Entomology and Nematology Department, North Florida Research and Education Center, College of Agriculture

Marcelo Wallau, Agronomy Department, College of Agriculture

Emilio Bruna, Wildlife Ecology and Conservation, College of Agriculture

**Project Start Date:** (June 1st, 2025)

**Total Budget Requested:** ($98,747)

Please check all that are applicable:

☐**X** This proposal/parts of this proposal have been submitted for funding through other seed programs at UF (CTSI, UF Informatics Institute, UF Biodiversity Institute, MBI, Water Institute, Cancer Center, Invasive Species Research Institute, etc.) The proposal/parts of this proposal:

☐**X** Are currently under consideration for funding (funded in 2024, $49,398)

☐**X** Is the proposal multidisciplinary? 4 academic departments and one REC)

☐**X** Has the proposal been previously submitted for ROSF funding? If yes, please include previous ROSF reviews and the Review Resubmission materials in the application Appendix (see RFP FAQ for requirements) (submitted in 2023 for 2024 funding)

☐**X** Is this a new collaboration? If yes, describe your plans for collaboration; if no, discuss what is new and unique about your continued collaboration. (describe in Key Personnel section)

☐**X** Does the proposal have potential for return on investment? (describe in Plans for continued support and/or return on investment section)

**Abstract:**

The proposed project is an unprecedented opportunity to quantify the movement of pest and beneficial insects and other small organisms. A main goal of the project is to develop and use a new harmonic radar system to automate the collection of a sufficient amount of validated experimental data to facilitate the development of AI-based behavioral models for the target organisms. The new prototype system could become the first commercially available harmonic radar for a wide range of important applications. Initially, we will demonstrate its effectiveness by tracking the movement of a small parasitoid wasp, *Larra bicolor*, that attacks invasive *Neoscapteriscus spp*. mole crickets in pastures. Mole crickets infest millions of hectares of pasture across the Southeast and cause severe damage in some areas. The harmonic radar system will enable us to identify the most attractive plants and determine the maximum distance the wasps fly from nectar plants to hunt mole crickets. Eventually, a predictive model will be generated in a subsequent project and used to design landscapes that increase wasp populations and maintain mole crickets below damage thresholds. After the system is optimized, it will have many important applications, for instance determining the frequency and duration of visits by commercial honeybees and bumblebees to certain crops and confirm their effectiveness. Capturing, tagging, releasing, and tracking invasive pests, such as the yellow-legged Asian hornet, with harmonic radar could enable them to be located and eliminated. Another application for this technology would be to track predatory insects and determine if they successfully locate and consume damaging crop pests. Additionally, it could enable early detection of invasive organisms of economic significance to human and animal health. Our project combines the knowledge and expertise of UF faculty members from Electrical and Computer Engineering, Agricultural and Biological Engineering, Entomology and Nematology, and Agronomy Departments. This is a truly multi-disciplinary team that will extend the project from component development to in-field application of knowledge gained and transferred to stakeholders. Moreover, two of the Co-PIs are early-career faculty members who, along with two graduate students, will receive multi-disciplinary training as next generation scientists.

**Project Description:**

*Specific Aims/Objectives*

* 1. We intend for this initial project to be a major breakthrough in the ability to track insects and other small organisms. The three main objectives of the proposed research are to: 1) optimize a novel harmonic radar system we are constructing for tracking various invasive insect species, 2) demonstrate the ability of the system to follow a small 2.2 cm long *Larra* wasp, as a model organism, and 3) collect a sufficient amount of validated experimental data using the radar for a potential follow-up project to build unique machine learning (ML) models that predict insect movement. To track the insects, we are improving a novel harmonic radar system by increasing its portability, decreasing the size of the transponders, and exploring AI and ML to process the captured radar data. The novel harmonic radar system will enable scientists to follow highly mobile species to determine the ecological services they provide, such as pollination or biological control of pests, as well as spatial responses to climate change, other changes in their habitats, and reductions in biodiversity. It also will make it possible to track social insects, such as native and invasive hornets (Gill et al. 2020), to locate their nests where they can be eliminated. Moreover, it can determine how far a pest organism is able to disperse over time to invade new geographical areas and infest crops, urban environments or natural areas. Invasions occur constantly and the ML models could assist in delimiting an organism’s pathway and predict its probable time of arrival. This technology would thereby facilitate monitoring and interdiction of new pests by regulatory authorities. If commercialized, the system could be used routinely to determine the size of floral resource patches needed within a landscape to support diverse pollinator populations and bolster the ecosystem services they provide. Additionally, scientists would find the equipment especially useful for studying animal behavior that involves movement of small organisms over considerable distances and at night.
  2. *Background and Significance*
  3. Until the mid-20th Century, animal locomotion was studied in the field primarily by direct observation during daylight hours. The advent of portable UV lights, radio telemetry, IR photography, and other innovations extended observations into nighttime hours. Large populations of migratory organisms were tracked in flight using vertically-oriented radar equipment. However, the continuous movement of single, small organisms could only be observed by physically following them throughout their active periods. These constraints were overcome for insects weighing more than 50 mg by developing an harmonic radar system and transponder tags small enough to be carried by these insects without impeding their flight. The system has major advantages over conventional visual and video methods of observing low-flying insects. Its range of operation is hundreds of meters, spatial resolution is ∼5 m, it measures range as well as direction, and the tagged insects can be located even in the presence of very strong clutter, radar echoes reflected from ground features such as vegetation. It works equally well by day and night and provides dynamic records of insect horizontal flight. Thus, harmonic radar has introduced a new era in the study of insect flight at low altitude (Riley and Smith 2002). However, “Development of a true harmonic radar is technically demanding and until recently only a single unit has been available” (Chapman et al. 2011). The equipment is only semi-mobile, expensive, and not practical for use by biologists (Fig. 1A). Nevertheless, a range of insect species, such as bumblebees, honeybees, and butterflies, have been studied by combining harmonic radar with observations of natural flight behavior.

The proposed interdisciplinary research will bring together engineering and biological expertise to make significant progress in enabling the movement of small terrestrial or flying organisms to be tracked. Our goal is to create a new portable harmonic radar system based on known principles and demonstrate its capabilities. The system will have the potential to advance knowledge of small animal locomotion in unconfined field settings. An affordable ”off-the-shelf” harmonic radar system would enable biologists to gain an invaluable understanding of animal behavior relative to a range of biotic and abiotic stimuli. Examples include attraction and conservation of pollinators, detection and elimination of invasive species, manipulation of predators and parasites, local observation and tracking of migratory species, locating beneficial and detrimental habitats, and quantifying a myriad of other currently unknown behaviors. The movement of organisms is fundamental to their survival and reproduction, determines habitat utilization, and enables adjustments to changing climatic conditions. These factors shape the structure and dynamics of populations, community composition, and ecosystem processes. The pathway, distance, and duration of dispersal events affect the spread and potential establishment of an invasive species. Initially, we will use our prototype harmonic radar system to follow Larra bicolor, a wasp that parasitizes invasive mole crickets. Mole crickets cause extensive damage to vegetable seedlings, turfgrass, and pastures in Florida and other southern states.







Figure 1 (L-R). Current harmonic radar system, Larra wasp on false buttonweed, Larra wasp attacking a mole cricket and laying an egg.

* 1. *Preliminary Data*
  2. Our new interdisciplinary team of three entomologists, an agronomist, an agricultural engineer, two electrical and computer engineers, and an ecologist, including two graduate students, is already yielding novel ideas and approaches. Based on previous research, we anticipate the harmonic radar system will achieve a resolution of two meters in the radial direction and a few degrees in the azimuth direction (angle of horizontal change), and will be capable of operating over a duration of several hours. Some advanced signal processing will be required to continuously record the trajectory of a wasp and compare this data with a survey of the landscape and vegetation. In anticipation of obtaining adequate funding for our collaborative project, we applied for FCC site permit that will allow us to transmit anywhere on UF property. We purchased a weather station and located sources of harmonic radar and wideband horn antenna components. We investigated potential field sites and established an experimental plot at the UF Beef Research Unit. Buckwheat (*Fagopyrum esculentum*) was planted to attract Larra wasps and shrubby false buttonweed, *Spermacoce verticillata*, seeds were obtained from an Extension agent.

Research has been conducted on the Larra wasp by UF Entomology and Nematology Department faculty members since it was introduced into Florida in the 1980s. It is established throughout the Southeast and parasitizes up to 90% of the two main species of pest mole crickets in the laboratory (Castner 1984). However, its effectiveness in controlling mole crickets in the field is limited by the availability of nectar-producing plants. It feeds on at least 10 species of flowering plants but is often most abundant on shrubby false buttonweed (Arevalo and Frank 2005). Therefore, before it was banned by the Florida Invasive Species Council, we recommended shrubby false buttonweed be distributed throughout Florida to increase populations of the wasp for mole cricket control. Unfortunately, we have been unable to follow the movement of wasps among flowering plants to determine the best alternative nectar sources. The optimum range and spatial distribution of foraging is unknown.

* 1. *Innovation/Potential Impact of Research*

“Harmonic radar represents a major step forward in the capacity to study insect flight” (Riley and Smith 2002). Previous approaches to following flying insects, such as image-based tracking and radio telemetry, have limited application for insects. For example, the radio tracking equipment currently used for monitoring hornet species in North America depends on a sizable VHF transmitter that could not be carried by smaller insects (Wilson et al. 2000, Nuñez-Penichet et al. 2021, Looney et al 2023). The mass of a hornet worker ranges from 0.36 g to 1.41 g and they are about 5.08 cm long (Gill et al. 2020). Conversely, harmonic radar uses a passive lightweight transponder to double the fundamental frequency of the signal transmitted from the radar and uses it as the receiving signal to resolve the problem of ground clutter. Our unique system incorporates four main features: 1) a sturdy ground platform to provide a solid foundation and power to the radar, 2) a digital control platform responsible for signal generation, processing, and storage, 3) transmit and receive electronically steered by phased-array antennas, and 4) a suitable horn/marine-based radar system that will serve for comparison. Commercial, off-the-shelf parts are used when available; however, most of the antenna prototyping and design is being performed by our team. We will continually test and improve the harmonic radar system during the project.

Initially, we will use the new harmonic radar system to address the devastating mole cricket problem in pastures across Florida. The harmonic radar system will be tested by tracking *Larra* wasps as they feed on plant nectar and search for mole crickets. The maximum distance between nectar source plants must be specified to gain full control of an infested area. The plants are to be distributed near mole crickets and in a density that maximizes feeding by the wasps. Producers will be informed about the best plants to use and how to deploy them for maintaining pest mole crickets below the economic threshold. Specific outcomes include: 1) identifying the best plant species to attract *Larra* wasps and enhance parasitism of the mole crickets by tracking wasps in association with the nectar plants in mole cricket habitats, 2) determining the distribution of nectar sources that maximizes the abundance and effectiveness of the wasps in managing mole crickets in pastures, and 3) measuring the impacts of mole cricket biological control on pasture grass density and growth. As with the harmonic radar system developed by Riley and Smith (2002), our system will enable biologists to track a wide range of small insects and other organisms. This innovative instrumentation and associated methods will address a clearly defined gap in biologists’ ability to observe biological phenomena and has the potential to be broadly applicable in biology.

*Approach/Research Design/Expected outcomes, Challenges, Alternative Strategies*

Our approach to tracking *Larra* wasps is to develop, test and improve a novel harmonic radar system based on a unique ground platform (Fig. 2). This requires specialized expertise

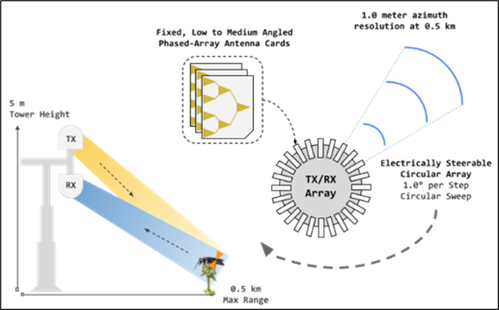


Figure 2. Harmonic radar transmits and receives radomes attached to a telescopic mast and the TX or RX array platform composed of a phase control board and separate vertical riser cards.

contributed by team members from the UF Electrical and Computer Engineering Department. The system consists of a telescopic mast, capable of supporting up to 250 pounds of equipment, that can extend up to 6.3 meters into the air using a hand crank. A comparable horn antenna system is being developed to aid in the calibration and fine-tuning of our azimuth and electronically steerable array (AESA) system. An X-band horn system will provide data similar to that observed in entomological publications (Chapman et al. 2011) and help in judging the benefits and costs of our AESA approach. The platform can be supported by four legs that are leveled and supported with weight to create a structure resistant to wind or wildlife. A 12V DC lithium-ion polymer battery serves as the main power source for the radar’s operation; rated for 100 amp-hours, allowing the radar to operate continuously for several days. The duty cycle can be scaled down to significantly extend battery life. Additional power regulators and conditioners ensure the digital and radio-frequency (RF) equipment have clean operating power. Advancements will be made in analyzing captured radar data with more signal processing and machine learning. We also intend to extend the range of the radar by developing more advanced radar processing techniques and perhaps track multiple targets by deliberately introducing component variations in transponders. If we can develop smaller transponders, we will be able to follow smaller insects than is currently possible.

The harmonic radar system will be deployed first at the UF Beef Research Unit that has been infested with mole crickets for several years. Landscapes will be designed in the pastures, including combinations of nectar sources, such as buckwheat, with shrubby false buttonweed for comparison. These plants were selected based on previous observations of high attraction for *Larra* wasps and buckwheat meeting the required criteria for use in pastures. The plants must be available, non-invasive, reasonably inexpensive, and capable of attracting large numbers of wasps. They also must be easy to establish in Florida agricultural areas and produce abundant flowers for long periods during mid to late summer when mole cricket activity is the highest. Areas of the pastures without nectar plants will be maintained in bahiagrass. The nectar plant seeds will be planted with a no-till drill, and bahiagrass chemically suppressed to reduce competition during establishment. The plantings will be separated by 400 meters, determined to be the estimated distance *Larra* wasps search for mole crickets (Portman et al. 2010). Linear pitfall traps will be placed five meters from each planting (Lawrence 1982). This will enable collection of mole crickets to determine the population size and wasp parasitism rates in the vicinity of the plantings. We will use the harmonic radar to track the wasps beginning when the plants start flowering and continuing each week during the study period. Wasps will be captured at or near the treatment plots and a transponder will be glued to the back of each of them before they are released and tracked for a minimum of 24 hours. Data will include at least the average maximum hunting distance of the wasps from the flowering plants, hunting and nectar foraging time each day, time spent on the experimental nectar plants versus other plants in the area, and percent parasitism of captured mole crickets.

We will develop Kalman filter-based trajectory tracking techniques for the radar target to account for missing or corrupted radar data, a problem that is common to the proposed application scenario. We plan to use the harmonic radar to obtain data and correlate it with

information from vegetation surveys and empirical observations to build a database for training ML models that can predict wasp feeding habits, such as preferred nectar plants and how far from alternative nectar sources they will hunt mole crickets in areas with specific vegetation patterns. Researchers and producers may then be able to use these ML models to design vegetation plans for increasing wasp populations in pastures. We also plan to capture movement data from *Larra* wasp trajectories and comparative empirical observations to train ML models that predict wasp movement and spread. In all, the proposed research aims to develop an optimal set of procedures and tools, including radar hardware, signal processing algorithms, and training databases for ML model development that are generally applicable to behavioral studies of flying insects and can be applied for pest prevention and management.

* 1. *Timeline for Completion*
  2. The project can be completed in two years because mole crickets are abundant in North Florida pastures from about April until December. This will enable us to optimize the harmonic radar system and obtain enough data on nectar plant utilization by *Larra* wasps and their impact on mole crickets. The budget is adequate to achieve these goals.

Year 1: (July 2025- June 2026) Establish experimental plantings of nectar plants, grow plants to flowering, test and refine the prototype harmonic radar system in the laboratory, refine the prototype, design experimental protocols, deploy the system to track *Larra* wasps in the experimental plantings, refine the system in the field, track *Larra* wasps and generate preliminary data, analyze wasp tracking data, develop data collection software, evaluate results, and refine experimental methods.

Year 2: (July 2026-June 2027) Repeat year 1 study (spring and fall mole cricket seasons), expand the study to include additional variables (e.g., light, sound, multiple *Larra* wasps, staggered planting, additional plant species, etc.), finalize data collection software, analyze data and submit the first report (June 2027), write a publication, possibly submit a patent application, prepare and apply for grants, deploy harmonic radar system to track other organisms, submit the second (final) report (August 2030).

**Plans for continued support and/or return on investment:**

The new harmonic radar system, as well as its antenna components, have significant technology transfer and commercialization potential. Therefore, we plan to work with the UF Innovate Office to explore patenting and marketing of the radar technology. It could be a major advancement in the capability to precisely track important insects and other small organisms and observe their behavior under previously impossible conditions in the field (Woodgate et al. 2021). For example, at what distance does a nocturnal insect respond to specific wavelengths of light, what is its natural circadian rhythm, and does it avoid insecticides or traps? Are there times and conditions when pollinators, predators and parasitoids could be less affected by insecticide applications? The harmonic radar system also could be used to predict potential pathways of invasion and spread and aid in mitigating and eradicating new invasive pests that threaten agriculture and human health. For this purpose, a prototype harmonic radar tracking system was developed with improved miniaturization and range measurement (Tahir and Brooker 2011). This radar technique was configured to cover a large field of view in elevation and used to track the yellow-legged Asian hornet, *Vespa velutina*, in Europe (Milanesio 2017, Maggiora et al. 2019). The hornet is spreading across Europe and has recently been detected in the state of Georgia. This serious pest of honey bees kills adults and consumes larvae and pupae. The estimated annual cost of controlling this hornet in Europe is $34.4 million (Alaniz et al. 2021).

Our research could attract considerable grant funding because the prototype system will be unique; nothing like it is available commercially. The ROSF grant funding is needed to construct, test and optimize the system under a variety of conditions. The next step will be to develop a much larger project for the NSF engineering core program. NSF funded a $1.1 million award in 2015-2019 for a team of computer scientists and entomologists to develop sensors and software that allowed them to classify flying insects (<https://grantome.com/grant/NSF/IIS-1510741> ). The investigators stated that “Recent advances in sensor technology and machine learning are just beginning to enable development of advanced algorithms that will help usher in a new era of computational entomology.” Similarly, our proposed radar system will enable us to automate the data collection process based on scientific experimental design. This automated data collection approach/paradigm supports the collection of a sufficiently large volume of data required for training ML models. This may provide us a competitive advantage in pursuing grants for applying ML techniques in biological and agricultural research.

The output of our research could open up new lines of inquiry in tracking small invasive species. We plan to continue our collaboration for the foreseeable future and seek funding for our research from the USDA Invasive Pests and Diseases grants program (<https://www.nifa.usda.gov/topics/invasive-pests-diseases>). A target will be the USDA, NIFA, CPPM, Applied Research and Development Program (ARDP) in the category of “Plant Protection Tools and Tactics – the discovery, development, and introduction of new pest management tools for use in IPM systems”. Another potential source for continued external support is the USDA, Agriculture and Food Research Initiative (AFRI) Sustainable Agricultural Systems (SAS) Program. The category is “protecting yield losses from stresses, diseases, and pests”. The Specialty Crop Research Initiative (SCRI) fits our work, as well. The focus priority will be “Efforts to identify and address threats from pests and diseases, including threats to specialty crop pollinators”. This work also is suitable for specialty crop block grant and farm bill funding, and the NASA-Applied Science Program. Our research is appropriate for the ROSF program because it is “Guided by the philosophy that diverse partnerships across the disciplines drive groundbreaking research and winning proposals”. The collaborators think that the new harmonic radar system will enhance UF’s research capability and create new research opportunities. We have access to different sources of funding based on our disciplines and anticipated synergy.

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**Key Personnel:**

Norman Leppla (Entomology and Nematology)- UF/IFAS Professor of Entomology and Program Director, IPM will serve as projector director (PD) for the project, cooperatively draft and submit the ROSF research proposal, supervise MS student William Piwowarek as co-chair of his graduate committee, with the student and other Co-PIs design the experimental landscapes and field testing of the harmonic radar system, participate in the field work and Extension activities, maintain the IPM Laboratory and vehicles used for the project, manage the project funds, assist in preparing grant proposals, and lead preparation of reports and publications. (.05 FE)

Tan Wong (Electrical and Computer Engineering)- UF Professor of Electrical and Computer Engineering will continue to advise the engineering process of designing, assembling, testing, and calibrating the prototype harmonic radar and transponder tags, work with other Co-PIs to optimize the radar system, and develop proposals to external funding agencies. (0.02 FTE)

Jasmeet Judge (Agricultural and Biological Engineering)- UF/IFAS Professor of Microwave remote sensing and Director, Center for Remote Sensing, will provide expertise in algorithm development to help with analyzing and interpreting tracking signals. She will also collaborate with the Co-PIs to seek external funding for wider applicability of the proposed project. (0.02 FTE)

Isaac Esquivel (Entomology and Nematology)- UF/IFAS Assistant Professor of Entomology, Agroecosystems, will provide guidance for MS student Piwowarek and assist with experimental design and analysis methodology. Further, he will be involved with the other Co-PIs in bringing this information to our producer clientele. (0.03 FTE)

Marcelo Wallau (Agronomy)- UF/IFAS Assistant Professor of Agronomy and Forage Extension Specialist, will provide guidance for MS student Piwowarek, coordinate the field trials, and provide assistance in designing and maintaining the experiments. Furthermore, along with Co-PI Esquivel, be responsible for the Extension component of the project, taking the findings to stakeholders via direct communication, newsletter, related field days, and other diffusion strategies. (0.03 FTE)

Emilio Bruna (Wildlife Ecology and Conservation)- UF/IFAS Professor of Wildlife Ecology and Conservation, specialty: ecosystems and conservation, rainforests, Amazonia.

David Greene (Electrical and Computer Engineering)- UF/ECE graduate student (Ph.D.) is designing and assembling the prototype harmonic radar system and will test, and calibrate the system and transponder tags. Supervised by Dr. Tan Wong, he will be responsible for delivering the radar, post-processing software, and a brief operator’s manual. Time and resources permitting, David will assist with laboratory and field setup and post-processing the obtained datasets. (0.25 FTE)

William Piwowarek (Entomology and Nematology)- MS graduate student fall 2024 (currently OPS) will carry out data collection for the duration of the project, including setting up and running the experiments, performing wasp counts, collecting and surveying mole crickets, determining rates of parasitism, conducting plant surveys, and operating the harmonic radar tracking system. Following data collection, he will perform data analysis, write a master’s thesis, and draft manuscripts for publication. (0.5 FTE graduate assistantship)

All the investigators will be fully engaged in the research but with different responsibilities based on their expertise. This will enable us to learn from each other as we optimize the instrumentation while conducting entomological research.

**Budget:**

a. Budget Table

|  |  |  |
| --- | --- | --- |
| 1. **Budget Item** | 1. **Description** | 1. **Cost** |
| 1. A. Personnel | 1. Student salary | 1. $60,900 |
| 1. B. Fringe | 1. Student fringe | 1. 7,064 |
| 1. Total Personnel | 1. Salary plus fringe | 1. 67,964 |
| 1. C. Materials and supplies | 1. Field tests and studies | 1. 8,000 |
| 1. D. Travel | 1. Travel to two field sites | 1. 2,169 |
| 1. E. Tuition | 1. Resident graduate tuition | 1. 21,540 |
|  | 1. **Total Project Cost** | 1. **$99,673** |

* 1. b. Budget Justification

Most of the requested funding is for the salary, fringe benefits and tuition for a 2-year graduate assistantship ($89,504). Materials and supplies will be needed for minor improvements to the harmonic radar system and disposable materials for use in the field ($8,000). Funding for constructing the harmonic radar system prototype is provided by an ISRI grant. Field materials include seeds, plants, fertilizer, mole cricket trap construction, collection containers, electrical supplies, batteries, and other disposable materials. Vehicles and equipment are provided by other grants. Travel from the UF campus to the BRU research site (26 mi) and other study sites (20 mi) will be weekly from April to December (36 trips each, 3312 mi for 2 years x 0.655 = $2,169). See Key Personnel for project activities and FTEs.

**Biosketch and Current and Pending Support:**

a. Biosketch for PI and Co-PIs (Norm Leppla, Jasmeet Judge, Tan Wong, Marcelo Wallau, Isaac Esquivel, and Emilio Bruna); Other Personnel (David Greene and Vilheim Piwowarek).

b. Current and Pending Support for PI and Co-PIs (Norm Leppla, Jasmeet Judge, Tan Wong, Marcelo Wallau, Isaac Esquivel, and Emilio Bruna).