White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***June 15, 2015***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	S
• Interactions of plasmas and waves	P
• Plasma self-organization	
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	X
Poster	
Either Oral or Poster	
Will not attend	

Title:	Controlled Wave-Wave, Wave-Particle Interactions Experiments at Arecibo Observatory in Puerto Rico
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**(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)**

- ***Describe the research frontier* and importance of the scientific challenge.**

Controlled study of wave-wave, wave-particle interactions, as well as EM wave-induced large-scale plasma turbulence in the ionosphere by injecting VLF waves/whistler waves (40.75 kHz), HF waves (a few MHz), and microwave (2.38 GHz) from the ground at Arecibo, Puerto Rico. Some results have been crosschecked in laboratory experiments.

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

We propose to conduct continuing "wave-wave, wave-particle interactions experiments at Arecibo Observatory, Puerto Rico", aimed at investigating radio wave-induced plasma turbulence, electron and ion acceleration caused by radio wave excited electrostatic plasma waves, and whistler wave interactions with inner radiation belts at L = 1.35. Radio waves injected from three ground-based transmitters for experiments are in the frequency range of VLF (40.75 kHz), HF (a few MHz), and microwaves (2.38 GHz). Remote diagnostic instruments include NSF-funded Arecibo radar at 430 MHz and optical facilities, GPS satellites as well as

our own BU/MIT's All-Sky Imaging System, CADI Ionosonde (1-10 MHz), Ionospheic Radar Integrated System (10-60 MHz), and VLF receiving system.

In the paper presented at the Arecibo Observatory 50th Anniversary Scientific Symposium held on October 28-29, 2013 [see http://www.naic.edu/fifty/agenda.shtml], we reported our whistler wave injection experiments, which have been conducted at Arecibo Observatory in the past 25+ years, starting with the joint US-USSR Active Space Plasma Program experiment on December 24, 1989. In this experiment a satellite-borne VLF transmitter injected radio waves at the frequency and power of 10 kHz and 10 kW. A series of controlled whistler wave experiments with Arecibo HF heater were subsequently carried out during 1990 - 1998. In these ionospheric HF heating experiments, 28.5 kHz whistler waves were launched from the nearby Naval transmitter (code-named NAU) located at Aguadilla, Puerto Rico. HF heater waves were used to create ionospheric ducts (in the form of large parallel-plate waveguides) to facilitate the entering of NAU whistler waves from the neutral atmosphere into the ionosphere. Conjugate whistler wave propagation experiments were conducted between Arecibo, Puerto Rico and Trelew, Argentina in 1997. Some of our Arecibo experimental results were successfully reproduced in our laboratory experiments [Lee et al., GRL, 1997; M.C. Lee et al., JATP, 1998].

In the next 15 years or so (1999 - ongoing), we conducted whistler wave experiments in the absence of an HF heater. Naturally-occurring large-scale ionospheric turbulence [in the form of filed-aligned ionospheric plasma density irregularities (due to spread F or TIDs)] were relied on to guide NAU launched 40.75 kHz whistler waves to propagate from the ionosphere further into the inner radiation belts. There are indications in our January 2015 experiments that large-scale background ionospheric plasma turbulence can facilitate the entering of NAU-launched 40.75 kHz whistler waves into the ionosphere [M.C. Lee et al., long-term proposal]. Our current plan is to use the newly built Arecibo HF heater and NAU VLF transmitter together with Arecibo UHF and microwave radars, for further study of whistler wave interacting with ionospheric plasmas and inner radiation belts, involving wave-wave and wave-particle interactions processes.

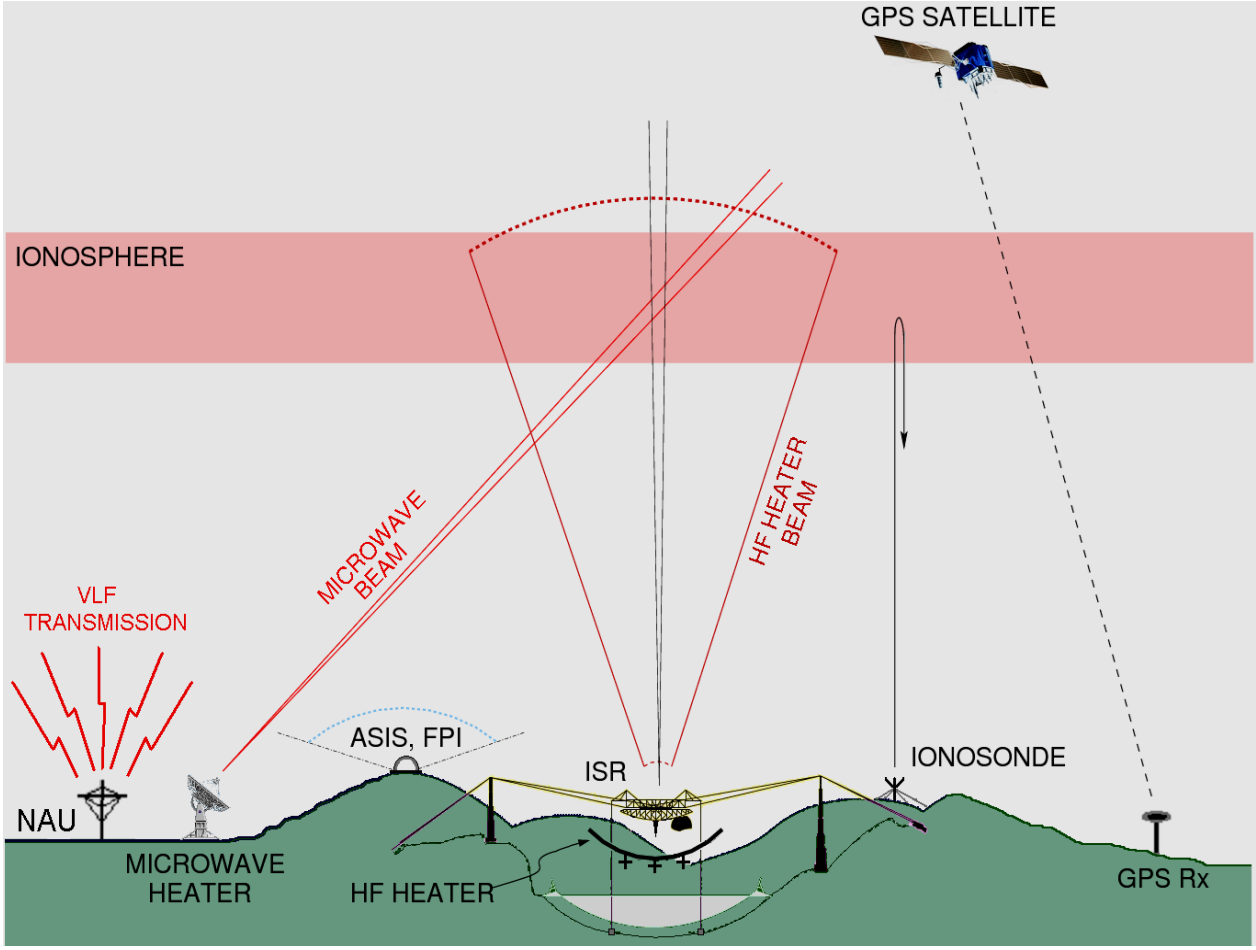
- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit.***

Controlled field experiments at Arecibo Observatory can advance our knowledge in wave-wave and wave-particle interactions, electron and ion accelerations, and plasma turbulence. Some of these processes can occur in magnetic and laser fusion (e.g., EM wave-excited parametric instabilities and plasma turbulence). Aforementioned radio and optical facilities at Arecibo Observatory are funded by NSF and accessible to the users.

References (Maximum 1 page)

Several references have been cited in this form and see http://www.naic.edu/fifty/agenda.shtml].

Figures (maximum 1 page)



Planned experiments in Puerto Rico using Arecibo HF heater, UHF and microwave radars and optical instruments, NAU VLF transmitter, together with our own optical and radio instruments as well as GPS satellites for diagnostics.