WORKSHOP

A Strategic Vision for Incoherent Scatter Radar

FACILITIES FOR THE 21ST CENTURY

APRIL 26–28, 2021

http://landau.geo.cornell.edu/workshop.pdf

registration: https://forms.gle/of9WyLtC2iBn1Cvi7

Workshop summary

This online workshop will conduct interactive discussions to define a vision that incorporates community views on the most important objectives for future incoherent scatter (IS) radar facilities and to develop a strategy for pursuing them. The ultimate goal of this workshop is to generate a draft program plan for delivery to U.S. NSF Geospace leadership and the forthcoming US NASEM Decadal Survey. The plan will address key scientific and technical aspects of future IS radar facilities, including those key scientific frontier areas where IS radar techniques and observations are essential for progress. The plan will also discuss the ways future facilities could combine multiple different types of radio and radar observations to address a broad portfolio of scientific investigations.

A high priority for the organizing committee is to include early career researchers and graduate students in the field. Accordingly, we strongly encourage faculty to invite their graduate tudents/postdocs to actively participate in the workshop.

Day 1: Monday, April 26 — start time: 12:00 EDT (16:00 UTC)

12:00–1:10 EDT — **Plenary tutorial: What could future radars observe?**
Roger Varney

This tutorial will overview the conditions needed for a quantity to be observable from radar measurements and discuss how new facilities could observe new parameters not currently accessible to existing facilities. To perform compelling tests of existing theories, enable new discovery science, and have a transformational impact on the field, facilities of the future will need to observe more quantities than the existing facilities. Particular emphasis will be placed on the abilities to unambiguously observe vector and tensor quantities, abilities to observe gradients, and abilities to observe divergences and curls for vector fields. The language of plasma physics theory is the language of vector and tensor calculus, so progress requires the ability to do calculus with the observations without needing restrictive assumptions about spatial uniformity or isotropy of distribution functions. Science requirements for advanced observations will drive technical requirements for the new facilities, possibly including multistatic scattering geometries, transmit frequency diversity, interferometric imaging instead of slow imaging with beam steering, and wide-bandwidth waveforms.

1:10–1:20 Break

1:20–2:30 EDT — **Overarching picture of geospace science: theory and experiment**
Moderators: Roger Varney, Dave Hysell

1:20–1:40 What characteristics should a next-generation geospace radar have in the next decade?
J. Chau, J. Vierinen, D. Hysell, et al.

We define a geospace radar, a radar that can observe from the lower atmosphere through to the solar corona, i.e., troposphere, stratosphere, mesosphere, ionosphere/thermosphere, plasmasphere, planets, solar corona. These observations would rely on different scattering mechanisms, and therefore different radar capabilities. Taking into account past experiences with incoherent scatter radar (ISR) and coherent scatter radars (e.g., MST, meteor, partial reflection, reflection, ionospheric radars), and recent radar developments, we consider the characteristics of a multi-purpose all-in-one geospace radar. Among other concepts, we consider: multi frequency, modular power, spread spectrum, antenna arrays, multistatic, coherent MIMO, aperture synthesis imaging and beamforming, compressed sensing, radio astronomy, etc. These concepts are closely tie to targets of interest, desired spatial and temporal scales as well as accuracies, location, timeline, budget, …

1:40–2:00 Remote sensing geospace dynamics using ISRs
Shasha Zou

Solar wind, magnetosphere, and ionosphere/thermosphere form the highly coupled geospace system. Remote sensing the ionosphere using ISRs provides a valuable way to probe dynamic coupling processes, such as reconnection, convection and plasma-neutral interaction, in the whole geospace system. In this presentation, I will discuss the theoretical foundation of these coupling processes and highlight examples and potentials of ISR applications in deepening our understanding of the geospace dynamics.

2:00–2:30 Open discussion

2:30–2:40 Break

2:40–3:50 EDT	**Data/sensor fusion and data assimilation** ***Moderators: Anthea Coster, Elizabeth Kendall***
2:40–3:00	Data assimilative modeling of volumetric observations *Tomoko Matsuo*

The talk will discuss how data assimilative modeling of volumetric observations can help address outstanding magnetosphere-ionosphere-thermosphere (MIT) science questions.

3:00–3:20	On the role of ISR in the heliophysics system observatory *Joshua Semeter*

The Earth and its habitable atmosphere are enveloped in the expanding solar atmosphere. A defining characteristic of this interaction is the abrupt change in governing physics across specific space-time boundaries. Conditions set at one scale drive processes defined by an entirely different set of equations at another. Prominent examples include magnetic reconnection, auroral acceleration, equatorial spread-F, Alfvenic turbulence, and the kinetic instabilities excited by plasma convection. Developing a predictive understanding of these cross-scale interactions is arguably the core objective of geospace system science. Modern ISR techniques are able to resolve plasma state parameters over a substantial regional volume at rapid cadence, providing critical context for global-scale measurements acquired from sparse or less capable networks. In its recent history, the most celebrated contributions of ISR have come from their collaborative use with other measurements from both ground and space. Current initiatives in heliophysics have focused on the development of a distributed "heliophysics system observatory" (HSO) involving networks of sensors deployed on ground and in space. These efforts call for a critical reexamination of the role of ISR. Such discussions must be informed by advancements in technology — including the use of electronically scanned arrays, software defined radar, low-cost components, and autonomous remote operations — and thus must involve a tight collaboration among scientists and engineers. This talk seeks to initiate discussions on the role of ISR as an enabling element in the emerging heliophysics system observatory.

12:00–1:10 EDT Operational applications and global observations

Moderators: Phil Erickson, Anthea Coster

12:00–12:20 Whole geospace system perspective and future challenges
Naomi Maruyama

ISR data is not necessarily limited to studying the ionosphere. We suggest some creative ways to investigate mutual interactions between the midlatitude ionosphere and inner magnetosphere, the geospace as a whole, in particular, during geomagnetically active periods. ISR plays a key role in allowing us to effectively combine multiple observations and physics based models in geospace.

12:20–12:40 User Community Perspective
Susan Skone

National infrastructure, systems and services are dependent on radio technologies, such as navigation and communication systems, that are vulnerable to space weather. Emerging safety-critical applications are driving needs for greater space weather understanding and risk mitigation. Opportunities to employ ISR for improved knowledge, accuracy and integrity in this context will be presented.

1:10–1:20 Break

1:20–2:30 EDT Radio and space plasma physics

Moderators: Roger Varney, Phil Erickson

1:20–1:40 Multiscale ionospheric plasma physics: Generation of small-scale irregularities in larger-scale density inhomogeneities
M. Zettergren, L. Lamarche, M. Redden, K. Deshpande, A. Spicher, S. Datta-Barua, M. Hirsch, and many others!

Mesoscale density inhomogeneities (hundreds to tens of km) occur at all latitudes and include geophysically important phenomena like polar cap patches, cusp structures, equatorial plasma bubbles, midlatitude troughs, and auroral arc-related enhancements and depletions. These features are often associated with production of smaller scale plasma irregularities (hundreds to tens of m) in plasma density as evidenced, e.g., by GNSS scintillation and high-rate in situ measurements. In many cases the physical mechanism for the irregularities can be traced back to instabilities growing off of the larger scale inhomogeneities or direct influence of the magnetosphere ("stirring" and energetic precipitation). This talk discusses fundamental physical mechanisms behind instabilities and other structuring mechanisms responsible for creation of irregularities. We explore, in particular, the need to include more complete descriptions of the plasma at smaller scales to encapsulate inertial and pressure effects, as well as, impact ionization and localization of unstable modes along geomagnetic fields lines. The state of modeling of irregularity formation and ongoing efforts that apply modeling to analysis of radio data are discussed; current efforts highlight need for (1) more continuous coverage of inhomogeneities, (2) improvements in measurement range resolution, (3) reduced integration times, and (4) better measurements and modeling of effects of E-region.

1:40–2:00 Using radars to probe micro-scale plasma processes
William Longley

Incoherent scatter radars observe plasma waves and density irregularities on the order of the radar's wavelength, effectively creating a laboratory for fundamental plasma physics at the smallest scales. Radar observations of ion-acoustic wave spectra, photoelectron enhanced plasma lines, 150 km echoes, and the Farley-Buneman instability all provide experimental evidence and insight into the micro-scale

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plasma physics in the ionosphere. This talk will highlight recent theoretical research into the physics underlying these observed phenomena, including kinetic effects such as Coulomb collisions, photoelectron populations, magnetized Landau damping, and nonlinear wave coupling.

2:00–2:30 Discussion

2:30–2:40 Break

2:40–3:50 EDT Broader applications for geospace radar and radio arrays

Moderator: David Hysell

2:40–3:00 Astronomy and aeronomy with the Long Wavelength Array
Greg Taylor

For the past decade, we have been operating the Long Wavelength Array (LWA), a radio telescope for exploration of a broad scientific portfolio ranging from the study of Cosmic Dawn when the first stars and galaxies lit up the Universe, to understanding the properties of the Earth's ionosphere. The LWA consists of two dipole arrays with 256 elements each in New Mexico, with two additional stations under construction in New Mexico and California. I will review some of the scientific highlights and discuss opportunities for future work.

3:00–3:20 Broader applications for geospace radars
Juha Vierinen

The ideal future geospace radar system allows experimenters to freely design and execute innovative radio science experiments to validate existing theories and to enable serendipitous discovery. Modern high-power large-aperture radar systems can access a wide spectral bandwidth, utilize all digital phased array antennas in a multi-static observing geometry, and employ a supercomputing architecture for data analysis. For example, in order to validate theories of ionospheric irregularity formation, such a system could be used to study how the governing state parameters of the partially ionized upper atmosphere vary within a volume, while simultaneously observing ionospheric irregularities using a coherent scatter geometry or by measuring ionospheric scintillation of satellite signals and radio stars. A next-generation geospace radar could be used to observe accurate trajectories and masses of micrometeoroids using multi-static time of flight, while observing the scattering wavelength dependence of the radar cross-section to obtain information about the distribution of plasma surrounding the ablating meteoroid. One could even envision using such a system to make a multi-wavelength ground-penetrating radar map of the Moon to study regolith depth and subsurface structure across a range of length scales in hopes of obtaining more clues about the composition and evolution of our our nearest planetary body. With a flexible enough system, it will be feasible to attempt new types of high-risk, high-reward measurements, such as observing radar echoes from the Solar corona. In this talk, we will discuss some selected results from active and passive experiments using existing radars and radio telescopes, and discuss scientific questions that could be addressed using a next-generation geospace radar system.

3:20–3:50 Open discussion

3:50–4:00 Break

4:00–5:00 Workforce training and international collaboration: Open discussion

Day 3: Wednesday, April 28 — start time: 12:00 EDT (16:00 UTC)

12:00–4:00 EDT	**Workshop summary**
12:00–2:00	Open discussion for summarizing major points and defining organizational tasks *All*
2:00–4:00	Writing assignments *All*