Towards a New Arecibo Radar Telescope for Incoherent Scatter and All Radar Science

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URSI GASS, 28 August – 4 September 2021, Rome, Italy

Acknowledgment: The participation of B.I. was supported in part by U.S. National Science Foundation award 1618691

The collapse of the Arecibo instrument platform

10 August 2020
Newer (mid 1990s) main cable slips from socket
Falls from SE tower into dish

7 November 2020
Older (early 1960s) main cable parts in two
Falls from SE tower into dish

1 December 2020
Remaining four cables at SE tower fail
900-ton instrument platform falls into 305-meter dish

Arecibo Observatory
2019


Arecibo Observatory
December 2020


Arecibo Observatory
March 2021

Criteria for a new Arecibo telescope

Multidisciplinary

Unique

Better

Revolutionary

— Noemí Pinilla-Alonso
Arecibo Observatory Deputy Principal Scientist
10 December 2020

I would add

Inspiring

Inspiring is not completely different than multidisciplinary, unique, better, and revolutionary

But "inspiring" speaks to a goal equally important for the future

Arecibo Observatory has three core science areas

Atmospheric and geospace science
Instrumentation: Pulsed UHF radar, HF transmitter, lidar, optical

Planetary science
Instrumentation: CW S-band radar

Astronomy
Instrumentation: Wideband radio telescope

No observatory could match Arecibo in these areas

The enormous dish provided unrivaled receiving sensitivity

The radar systems were unique in the world

The collapse of the platform is an opportunity to improve

Of the three major AO science areas
atmospheric and geospace science
has the largest number of potential telescope options and parameters
that can contribute to science goals
e.g. multiple scale lengths and vector measurements

Planetary radar benefits from multiple wavelengths
e.g. for surface penetration

All proposed AO2 radars
could be productively used for both atmospheric and planetary science
if they are designed with that goal in mind

Lessons from EISCAT
– Tristatic vector measurements
– Dual k vectors

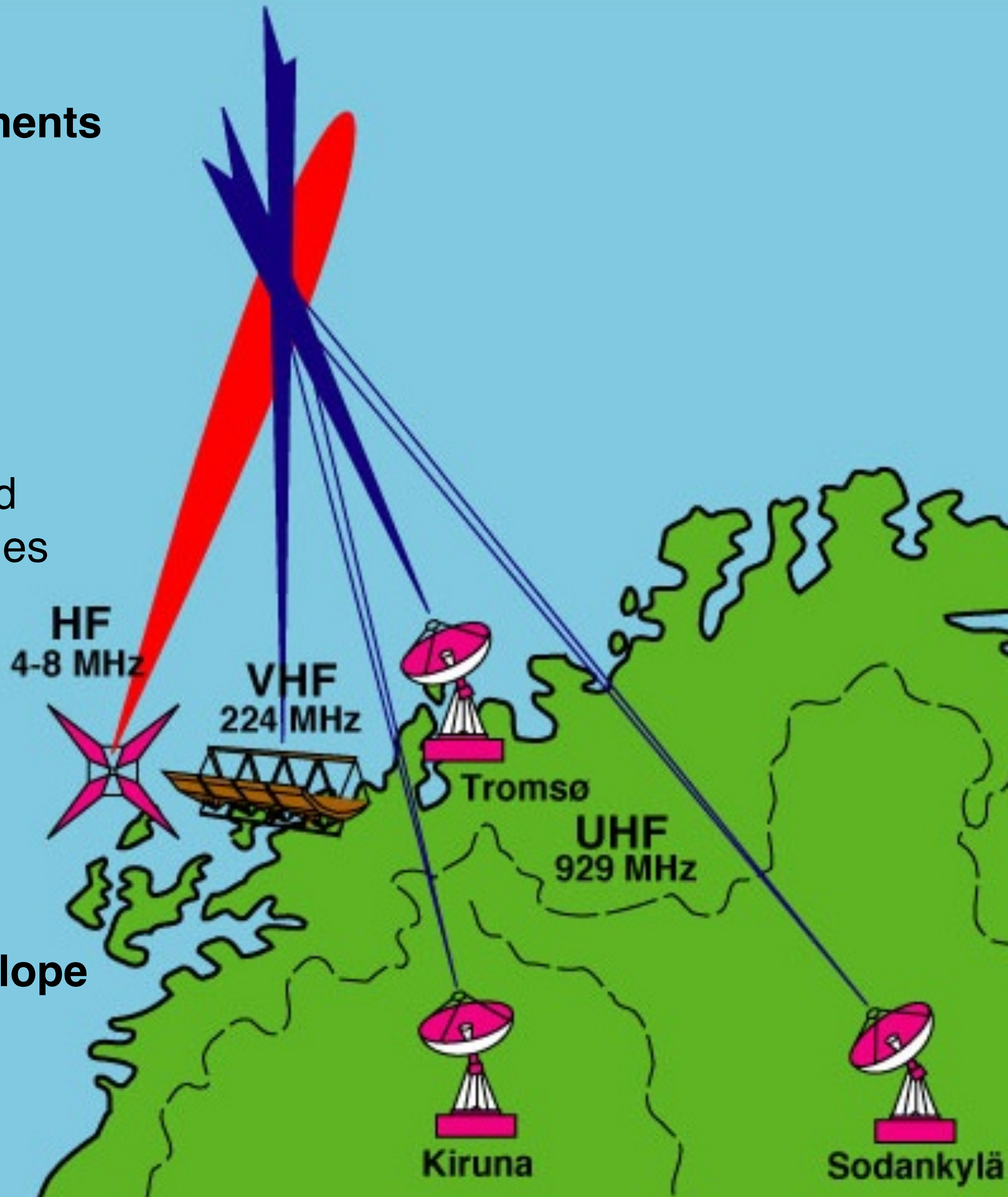
EISCAT initially also had
– Limited bandwidth
– Limited dynamic range

Both of which when expanded lead to fundamental discoveries in ionospheric physics

All can be done better now

There will be technology limits and tradeoffs

It's worth pushing the envelope



We must consider
1 What we want — science
2 How to do it — technology
3 How to pay for it — community and politics

Each affects the other
But focus on that order of priority
With inspiring science goals driving the rest

1 Science: Keep discovery science at the top of it all
2 Technology: **Keep maximum instrumental flexibility a top priority**

New measurement windows will show new and unexpected things
Including some we can't predict or imagine
That's a real inspiration, for me at least

Proposed AO2 NGAT systems

Atmospheric and geospace science

10-MW pulsed radar at 430 MHz

Potentially also at 220 MHz

Planetary science

5-MW CW radar from 2 to 6 GHz

Increased transmitter power for greater sensitivity and greater range

Maximum zenith angle 48 degrees (versus 20 degrees for AO1)

Reference:

The Future of the Arecibo Observatory: The Next Generation Arecibo Telescope

Roshi et al. (2021), https://arxiv.org/abs/2103.01367

Clues from AO1

Incoherent scatter (VHF and low UHF)

Extremely powerful for remote sensing in the ionosphere

Original Arecibo radar: ***430-MHz pulsed radar for "incoherent scatter"***

But it was used to

– Make the first maps of Venus

– Determine the rotation rate of Mercury

Coherent scatter (MF through X band)

Important throughout the atmosphere

And over a much broader frequency range

First Arecibo upgrade: ***2380-MHz CW radar for "planetary science"***

But it was used to

– Make the highest-ever-resolution observations of the stratosphere

What if the radars were actually designed for multiple purposes?

Technology driving science or science driving technology?

"Science" is often understood to mean that you know what you will study

Science includes not only current science and our best guess at near-future science, but also future science that is impossible to predict.

That is the scientific future towards which we can aim the technical capabilities desired for AO2.

Discovery science is what you don't know

When a new window is opened new discoveries will be made

Not just better: ***better, revolutionary, inspiring***

Revolutionary means different than before

Out-of-box thinking

For radar science this means

All radars for all purposes

Simultaneous and flexible use

Multiple receiver sites

Multiple transmitter sites

For the future this means

Green power

Discovery science

All radars for all purposes

Coherent and incoherent
Atmospheric and planetary

Simultaneous and flexible use

Collinear transmitter and receiver feeds
– simultaneous multi-k-vector (multi-scale) measurements
Wide transmitter tuning bands
– choice of k vector, potential multi-frequency operation of each radar
Wide transmitter coding bandwidths
– high range resolution
Variable beam width
– beam widening and shaping

Multiple receiver sites

High resolution vector measurements
Interferometric and imaging resolution
Potential use of many small passive receivers
Resolve planetary radar N/S ambiguity
MIMO

Multiple transmitter sites

Bistatic CW radar operation
MIMO

Many capabilities could potentially be included in the proposed NGAT AO2 radars

Simultaneous collinear operation of all radars

Selectable radar frequencies within wide bandwidths

Operation of each radar at simultaneous multiple frequencies

Wide instantaneous bandwidth (range resolution, multi-frequency)

Multiple radar beams (local area and mesoscale measurements)

Variable beam width (beam widening and shaping)

CW bistatic operation at all radar frequencies

These would allow all AO2 radars to be used in all science areas

Don't let past practice and technology limit flexibility

Let flexibility drive technology

The collapse of the platform is an opportunity for out-of-box thinking

Other capabilities that might be included

Multiple bistatic receiving sites
Vector velocities, interferometry
Resolution, MIMO
CW radar

Multiple bistatic transmitting sites
MIMO, CW radar

Radar frequencies between 2 and 200 MHz

These could be significant additions to the white paper proposal

Flexibility is a traditional strength of Arecibo Observatory

Let flexibility for discovery science drive the technology

Important for education as well as for discovery

Important for achieving
a multidisciplinary, unique, better, revolutionary, and inspiring AO

Path to transition to AO2

Make good use of remaining assets of AO1
Restore some previous capabilities
Seek new instruments

Rebuild with new capabilities

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Make good use of remaining assets of AO1
Restore some previous capabilities
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Rebuild with new capabilities

A strategy for a new Arecibo Observatory

Receive-only dish (or planar array)
For all frequencies
Larger than 305-meters (compete with FAST)
If a dish: Lightweight secondary, perhaps prime focus under dish
Challenge: 48-degree pointing
Receiving rings for high spacial resolution?

Bistatic radar transmitting arrays
2-10 GHz (S, C, X-band) – *planetary and atmospheric small scales*
200-800 MHz (UHF) – *planetary/atmospheric medium scales and ISR*
40-160 MHz (low VHF) – *solar radar, planetary/atmospheric long scales*
2-20 MHz (HF) – *ionosphere and very long scales*

Additional receiving arrays
Low VHF deep space radar
Sensitivity at low VHF for radio astronomy
Multiple-site coherent/incoherent atmospheric vector measurements

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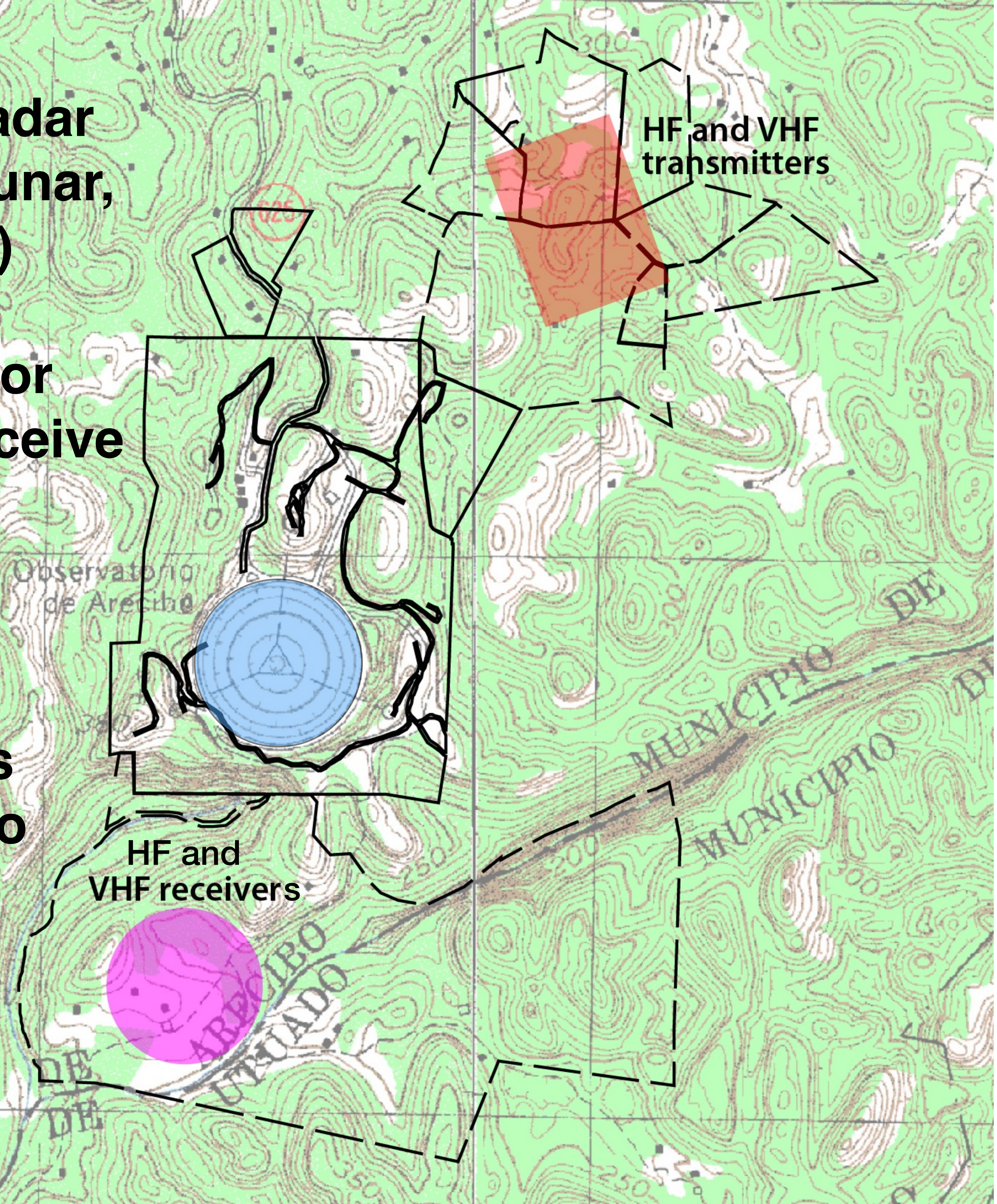
Additional receiving arrays
Low VHF deep space radar
Sensitivity at low VHF for radio astronomy
Multiple-site coherent/incoherent atmospheric vector measurements

An idea
for a low VHF radar
(geospace, cislunar,
planetary, solar)

Potential sites for
transmit and receive
arrays

Separate sites
will not conflict
with other plans
for main Arecibo
dish



A low VHF geospace / deep space radar has been a decades-long dream

In part inspired by past radar observatories including Jicamarca, Arecibo, El Campo

Efforts towards this goal have periodically been made

HiScat International Radio Observatory
Thidé, Boström, et al. (1994)
http://doi.org/10.13140/2.1.3915.8560

Radio Studies of Solar-Terrestrial Relationships
Thidé et al. (2002)
http://doi.org/10.13140/RG.2.2.16990.54084

The Case for Combining a Large Low-Band Very High Frequency Transmitter With Multiple Receiving Arrays for Geospace Research: A Geospace Radar
Hysell et al. (2019)
http://doi.org/10.1029/2018RS006688

Why now?

Technology and techniques are better

Supporting instrumentation and science are better

Geospace science needs an inspirational and capable new facility

A low VHF radar would have multiple science uses

Neutral atmosphere
Coherent scatter from the troposphere to the thermosphere
Structure and dynamics

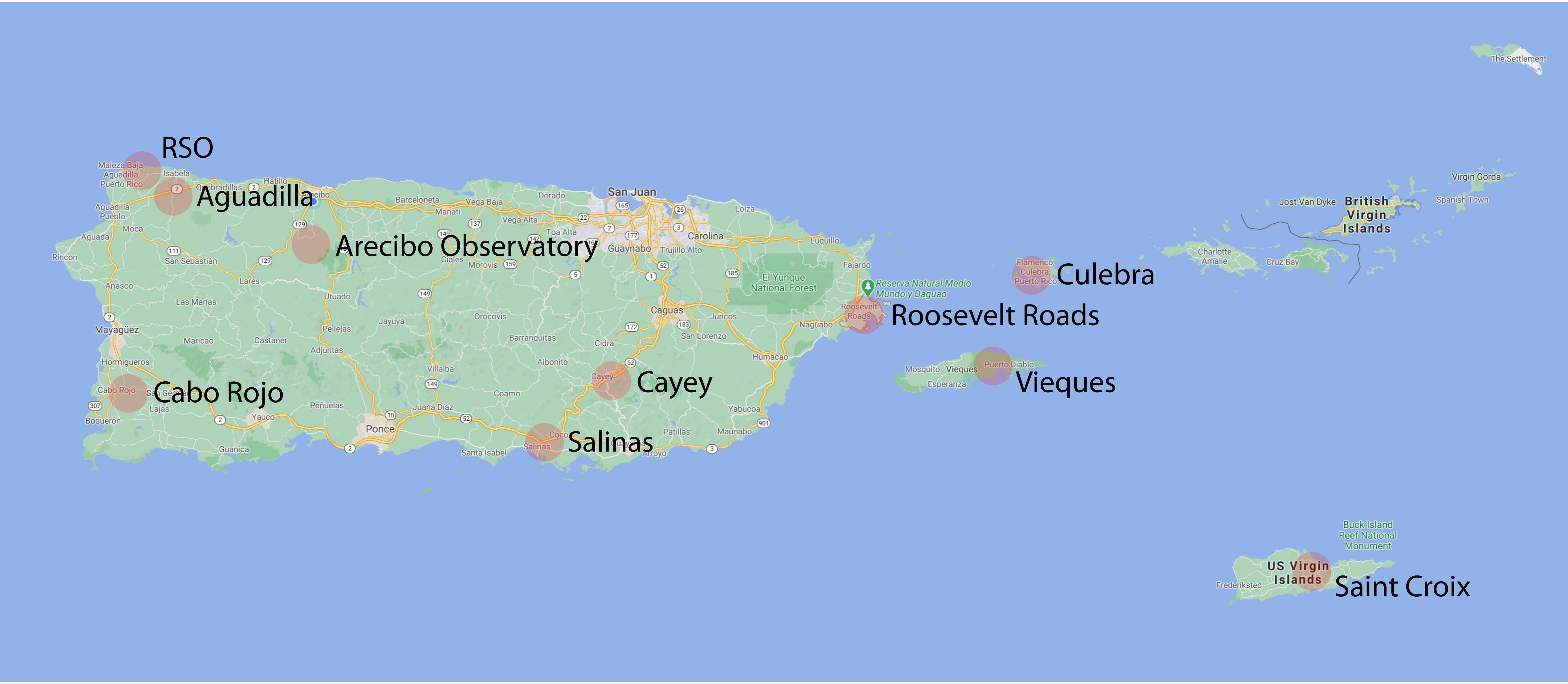
Ionospheric physics
Underdense heating
Diagnostics for natural ionosphere and HF modification experiments
Incoherent scatter vector velocities
Coherent scatter to the plasmapause
Parameters, structure, irregularities, instabilities

Planetary radar
Subsurface structure of asteroids, the moon, and terrestrial planets
Asteroid tracking and tomography in collaboration with spacecraft radar

Solar corona, solar wind, zodiacal dust
Coronal mass ejections

Radio astronomy
Magnetized extra-solar planets

Potential transmitting and receiving sites for a vector/MIMO radar array in Puerto Rico and the US Virgin Islands



Opportunity for global collaboration

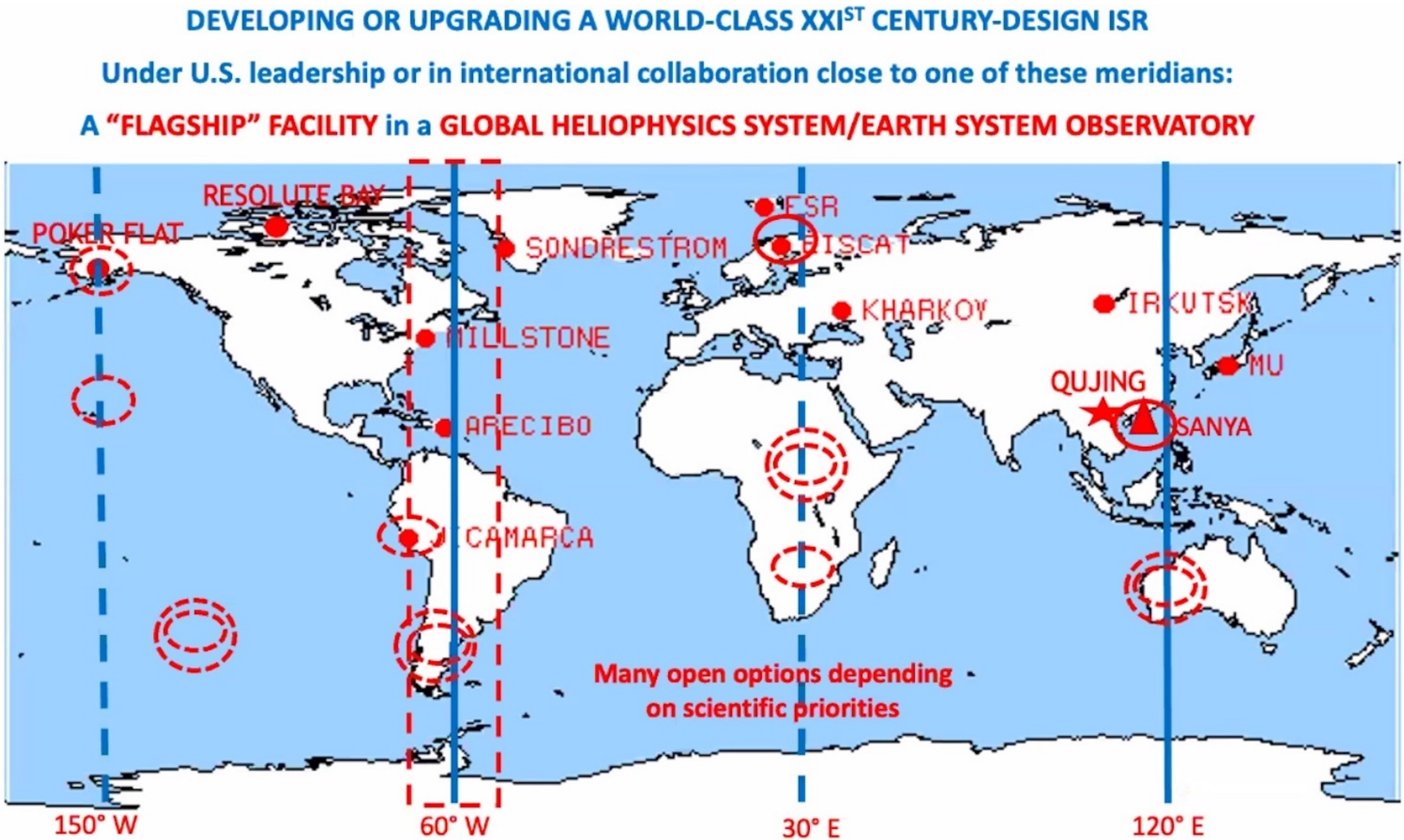


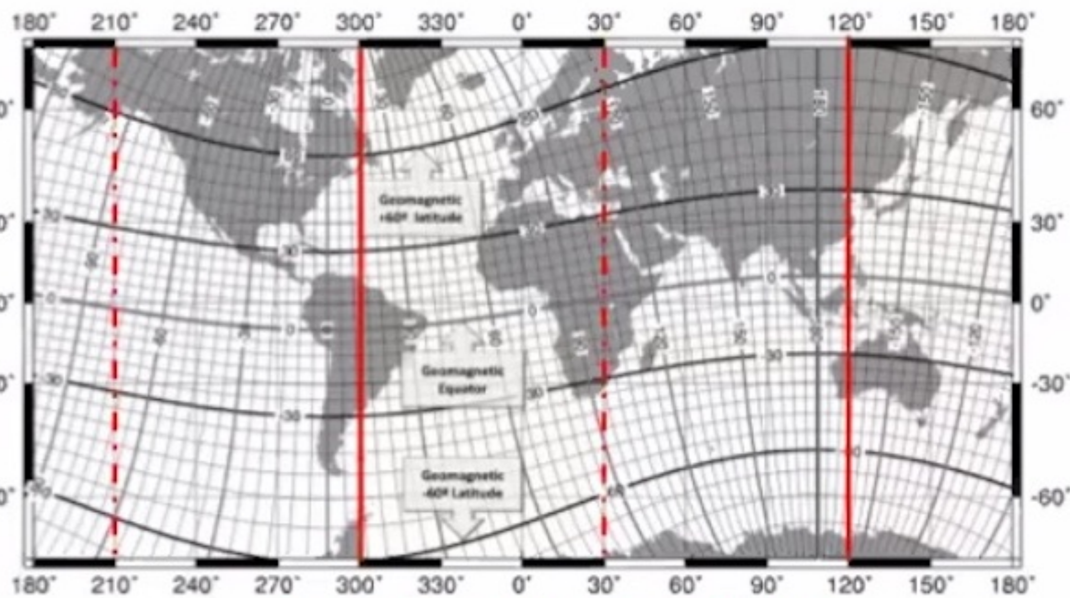
Figure courtesy of Michel Blanc.

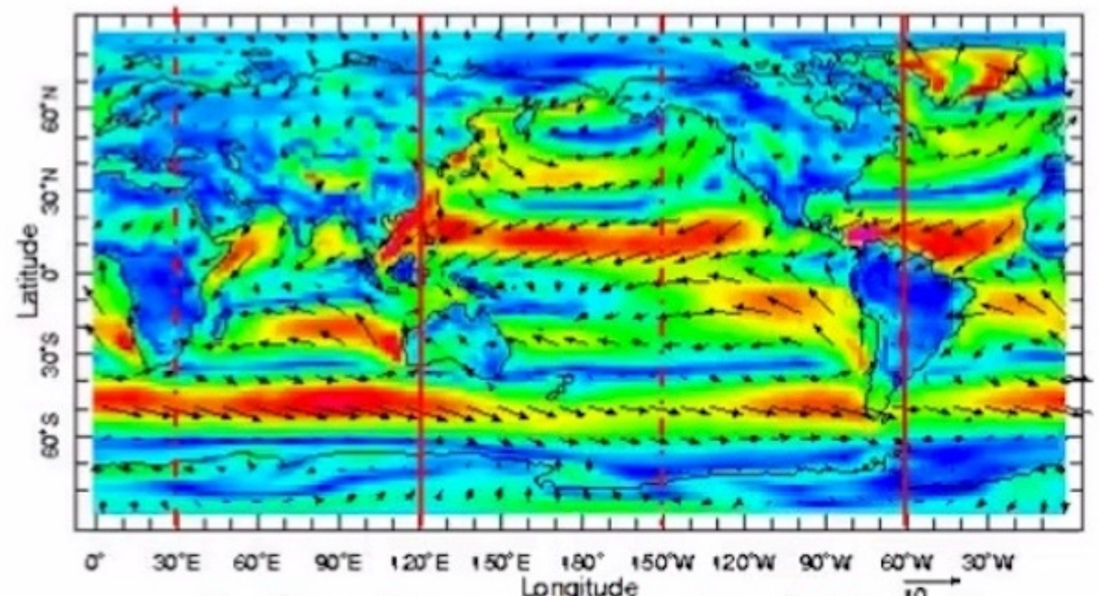
Opportunity for global collaboration

A COMBINATION OF TWO GREAT CIRCLES IN QUADRATURE OFFERS THE OPTIMAL CONFIGURATION:

120° E – 60° W (Americas-east Asia) ———— 30° E – 150° W (Europe/Africa – Alaska/Hawaii - - - - - - - -

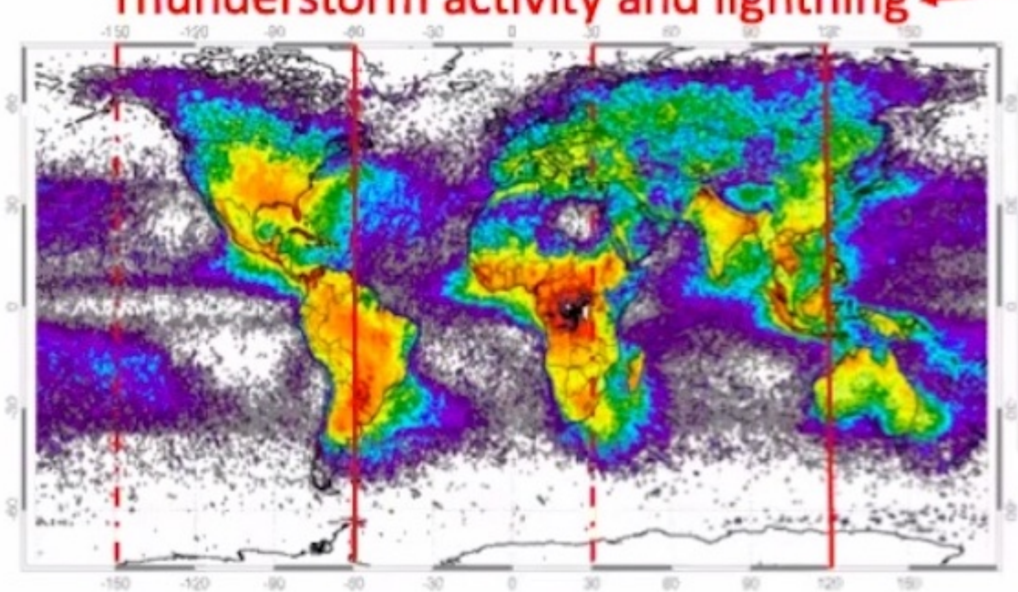
E)

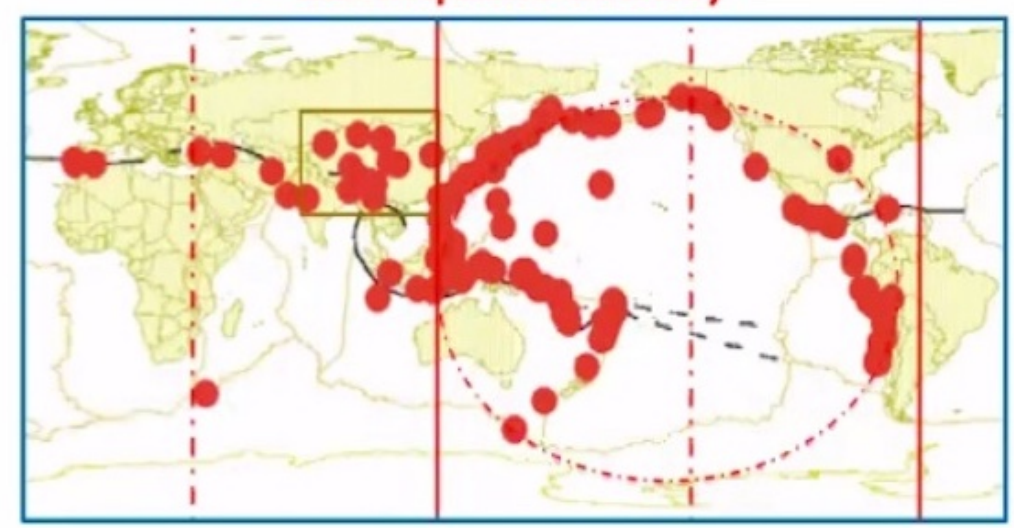




Geomagnetic coordinates ← **WORLD MAPS OF** → Surface tropospheric circulation

Thunderstorm activity and lightning ← → Earthquake activity

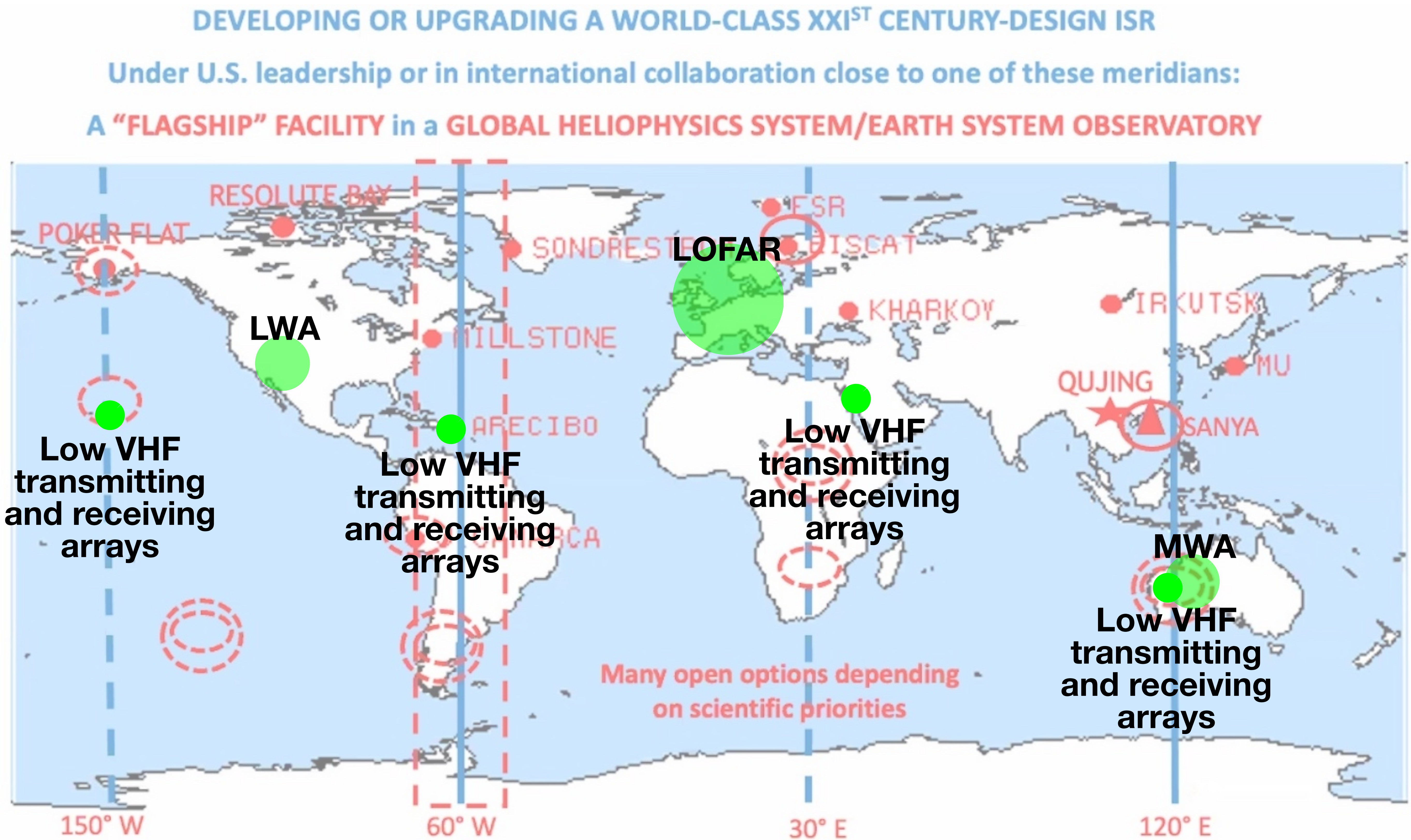




(W. Liu et al., 2021)

Figure courtesy of Michel Blanc.

A Distributed Geospace, Planetary, and Solar Radar System



Original figure courtesy of Michel Blanc.

Ideas for a new Arecibo radar/radio telescope

Multidisciplinary, Unique, Better, Revolutionary, Inspiring

For science this means

All radars for all purposes

Simultaneous and flexible use

Multiple transmitter and receiver sites

For the future this means

Green power

Expand discussion

beyond AO staff and interested volunteers

to broader AO user and science community

Particularly important for atmospheric and geospace sciences

Some Arecibo-related projects and proposals

The Next Generation Arecibo Telescope (NGAT)
White paper published on arXiv February 2021

Restoration of the Arecibo HF transmitter (heating facility)
Ready to implement using existing funding

Development of an HF ionospheric radar (ionosonde and interferometric radar)
Proposal to NSF submitted January 2021

A remote radio facility at the former Air Force Solar Observatory (RSO)
Proposal to AFRL submitted July 2021

Acquisition of an ngVLA antenna for VLBA (VLBA-11)
Proposal to NSF submitted March 2021

Acquisition of an eight-element ngVLA phased array (AO-8)
Pre-proposal accepted by NSF; full proposal due September 2021

Acquisition of a UHF incoherent scatter radar (two full AMISR faces)
Pre-proposal accepted by NSF; full proposal due September 2021

Design of a low VHF geospace, cislunar, planetary, and solar radar
Pre-proposal accepted by DARPA; full proposal due May 2022

Related Presentations — URSI GASS 2021

Plans for a Restored HF Heating Facility at the Arecibo Observatory
Isham et al. (2021), Mo-G13-AM2-3 — Monday 10:10, RM0031 Room 24

The Arecibo Observatory: Current State and Future Visions for the Site
Córdova (2021), Tu-J10-AM1-1 — Tuesday 09:00, RM0033 Room 40

Next Generation Arecibo Telescope: A Powerful Instrument for Redshifted Molecular Line Surveys
Roshi et al. (2021), We-J03-AM2-1 — Wednesday 10:10, RM0033 Room 39

Reconstructing the Arecibo Observatory with an Upgraded Design of the High-Power HF System
Bernhardt et al. (2021), Th-HG-AM2-1 — Thursday 10:10, RM0031 Chiostro

Towards a New Arecibo Radar Telescope for Incoherent Scatter and All Radar Science
Isham et al. (2021), Th-G06-PM2-2 — Thursday 15:00, RM0031 Room 24

Some Related Publications

The Future of the Arecibo Observatory: The Next Generation Arecibo Telescope
Roshi et al. (2021), https://arxiv.org/abs/2103.01367

The Case for Combining a Large Low-Band Very High Frequency Transmitter with Multiple Receiving Arrays for Geospace Research: A Geospace Radar
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