Plans and possibilities for fielding HF receivers at HAARP

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Collaborators

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Digital radio receivers – multi-purpose

SEE

- spectra
- polarization
- direction angle
- imaging

Radio phase modes – photon orbital angular momentum (OAM)

Pump wave – verify transmission (time, frequency)

Radar receiver – HF, ionosonde

Satellite beacon scintillation receiver – VHF/UHF

Natural radio emissions – unclamped pump, wide bandwidth

Digital radio receivers

Wide band
high-speed data transfer

Multi-channel
four or eight channels

Coherent
coherent operation at multiple sites

Low-maintenance
easily configurable, unattended operation, remotely controllable
modular, identical swapable parts

Radio emission measurements

Single site
- stimulated radio emissions (SEE)
- power (time, frequency)
- polarization (time, frequency)

Single site – coherent receivers
- direction angle

Multiple sites
- aspect angle dependence

Multiple sites – coherent receivers
- imaging
- radio phase modes (photon orbital angular momentum)

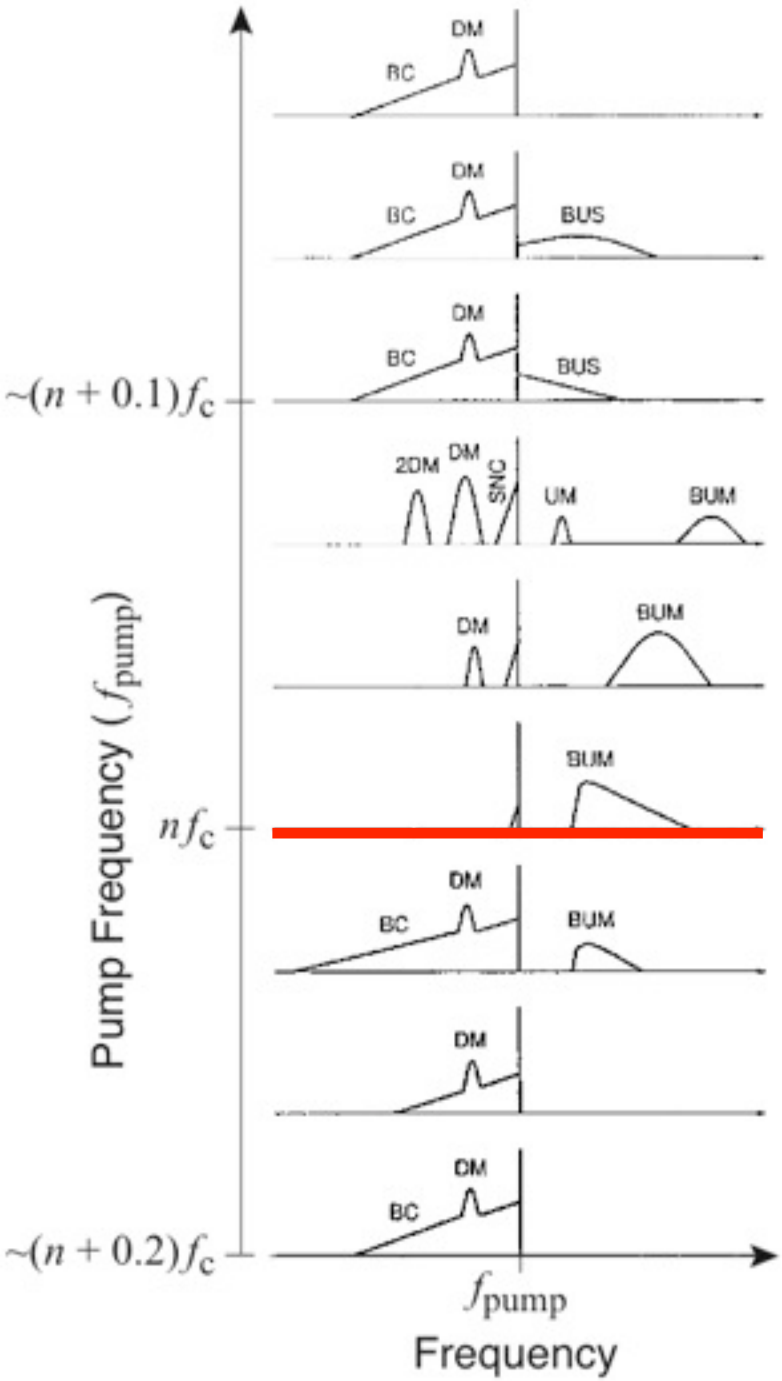
Collaborations for receiver development

Swedish Institute of Space Physics (Bo Thidé et al., 2006-present)

12 receivers
4 channels per receiver
16-bit ADC, 125-MHz sampling
control and data via Ethernet (two 1-Gbps lines)
coherence via GPS with advanced processing (Thidé et al.)
produced by BitSim AB, Stockholm, Sweden

Scion Associates (Bob Livingston et al., 2010-present)

8 receivers
8 channels per receiver
16-bit ADC, 100-MHz sampling
control via USB-2, data via USB-3 (5 Gbps) or Thunderbolt (2x10 Gbps)
coherence via GPS-disciplined rubidium (frequency accuracy $\pm 1\times10^{-8}$)
produced by Scion Associates, Port Townsend, Washington, USA



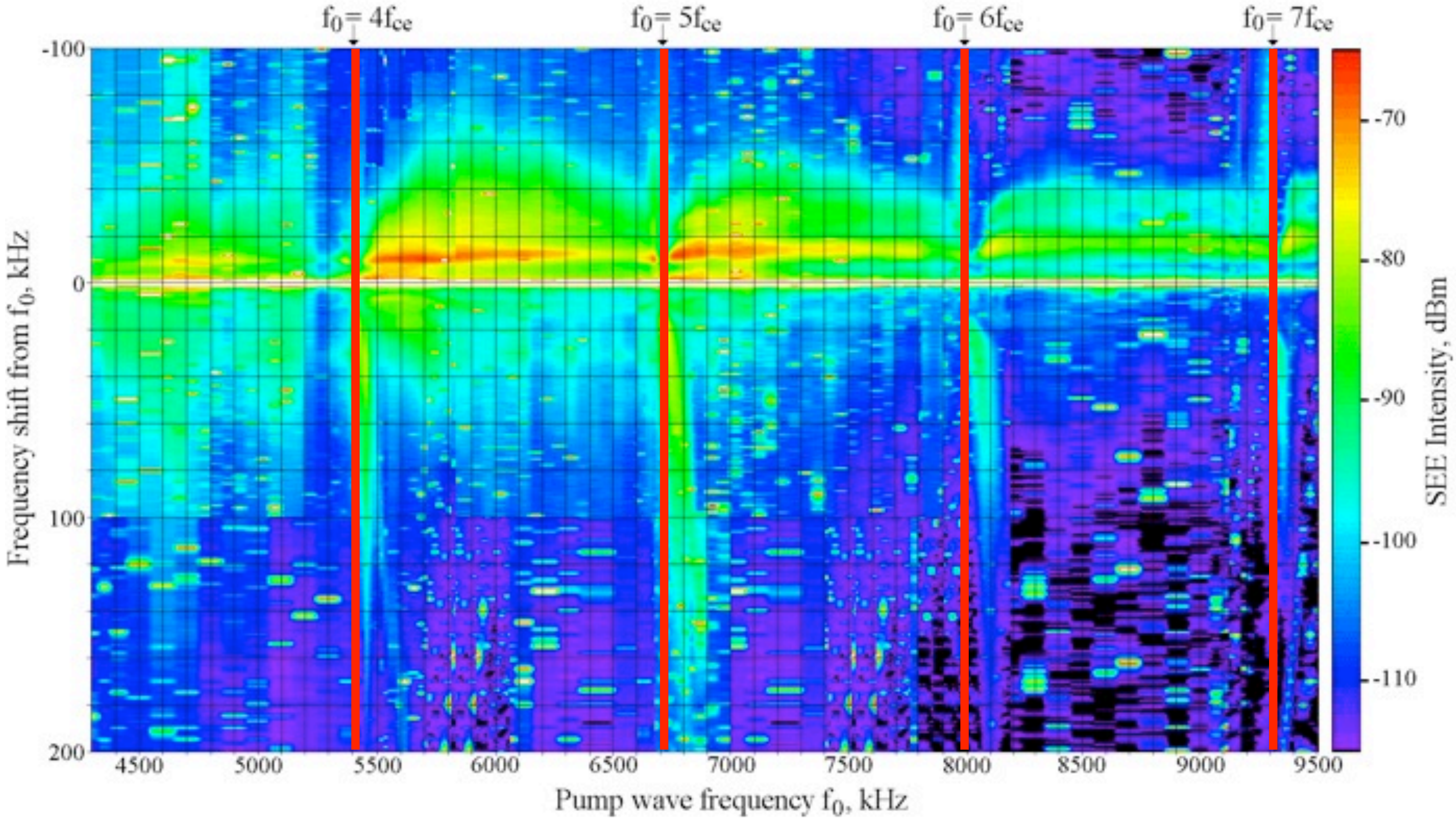
Schematic of SEE spectra

Schematic diagram of SEE spectra for variations in HF pump frequency relative to the gyroharmonic frequencies (n > 3).

Note the asymmetries in the individual spectra as well as in spectra above and below the gyroharmonics.

Adapted from Leyser (2001)

SEE spectra observed at Sura



Frolov et al. (2001)

SEE features close to the pump

SBS (stimulated Brillouin scatter)

EM => IA + EM

few Hz offset from pump frequency

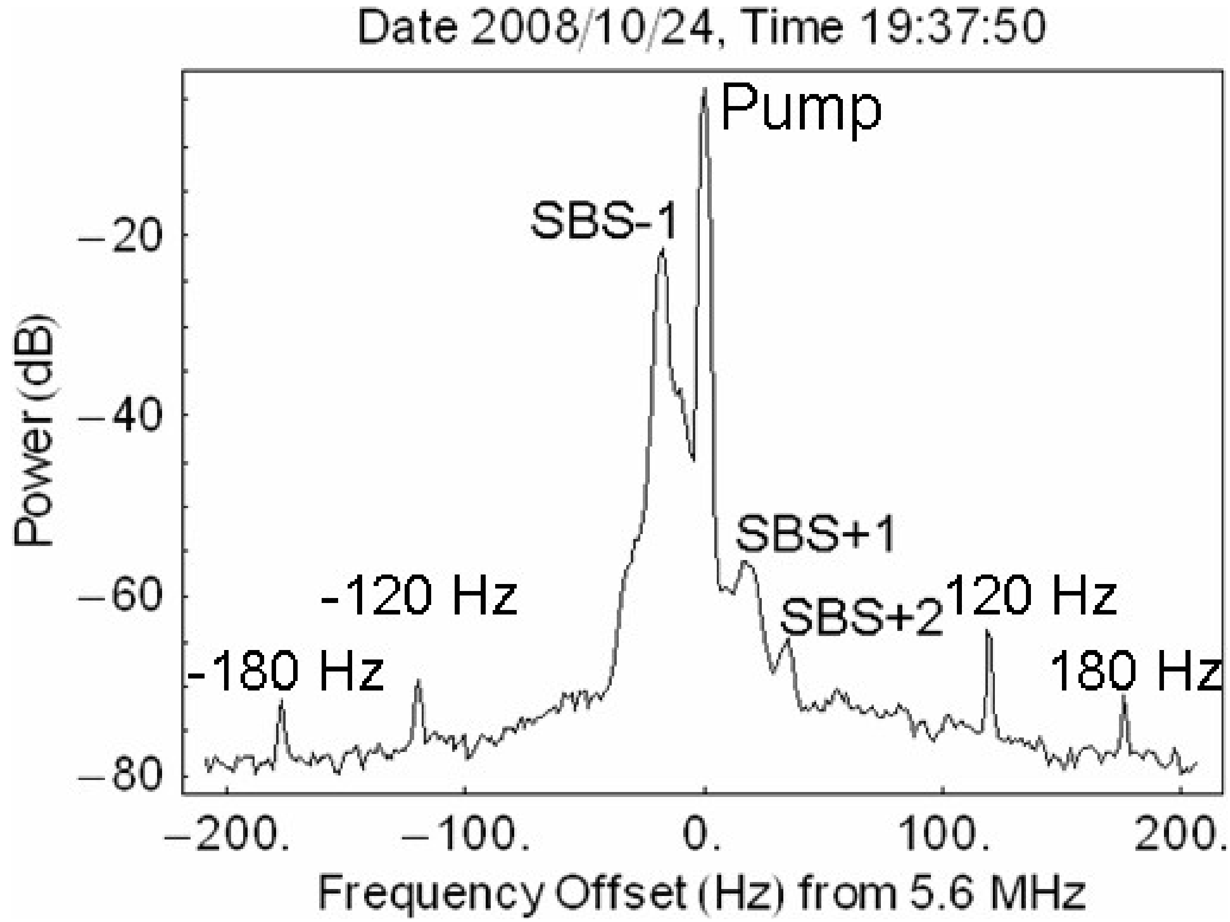


Fig. 4. Stimulated electromagnetic emission spectra for a 5.6 MHz pump wave pointed toward the magnetic zenith from HAARP. A down shifted SBS-2 line may be masked by the low-frequency side of the strong SBS-1 line.

Norin et al. (2009), Bernhardt et al. (2009)

Comparison with theory: Results and predictions

New simulation codes include EM emission

fluid, kinetic, particle, hybrid, ...

1-D, 2-D, and 3-D

Few if any citable predictions, e.g.:

Scales et al. (1997): qualitative similarity with observations

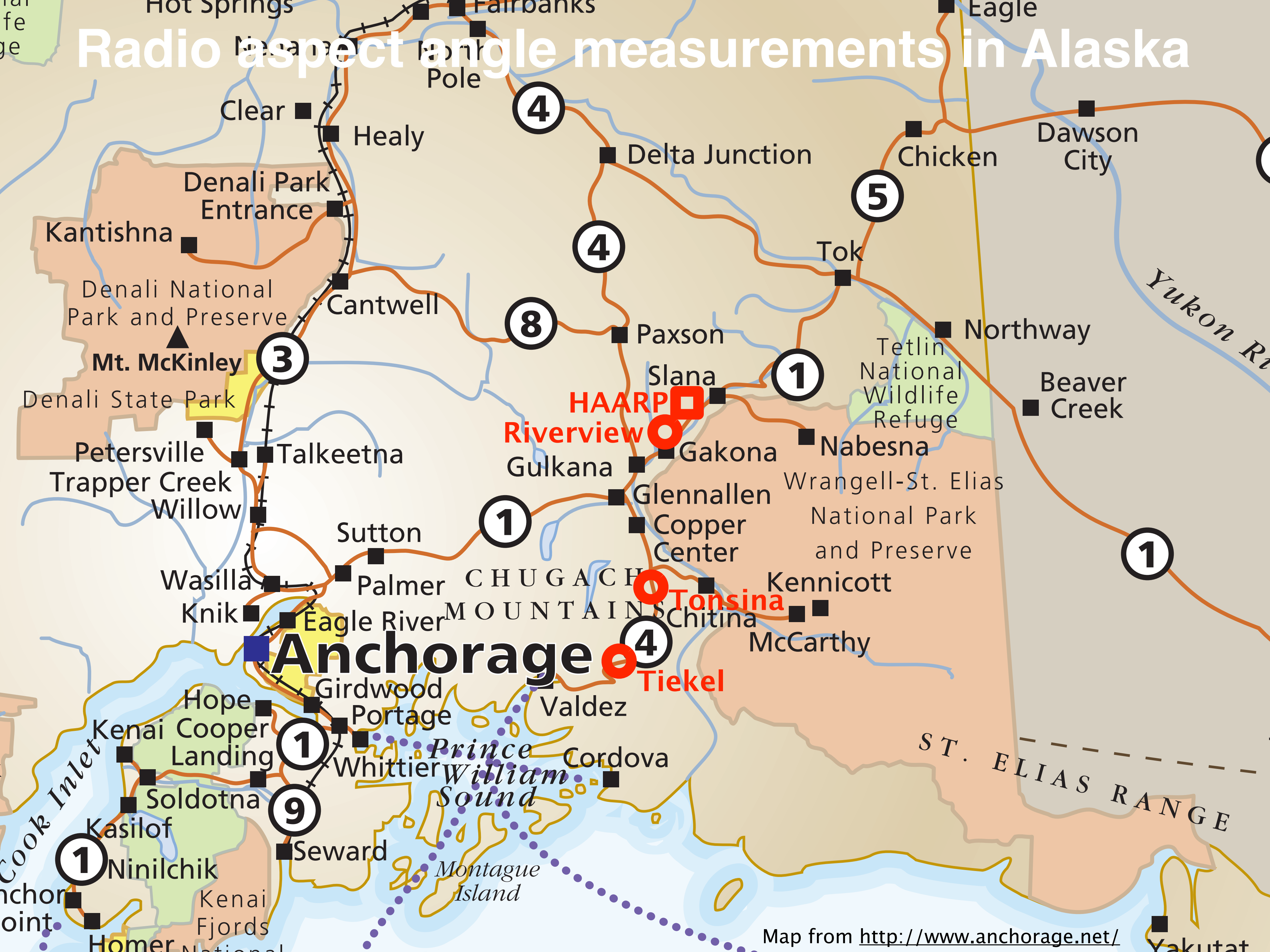
Mjølhus (1998): consistent with observations

Xi and Scales (2001): exhibit many properties of observations

Eliasson and Stenflo (2010): spectra agree with observations

SEE experiments lead theory...

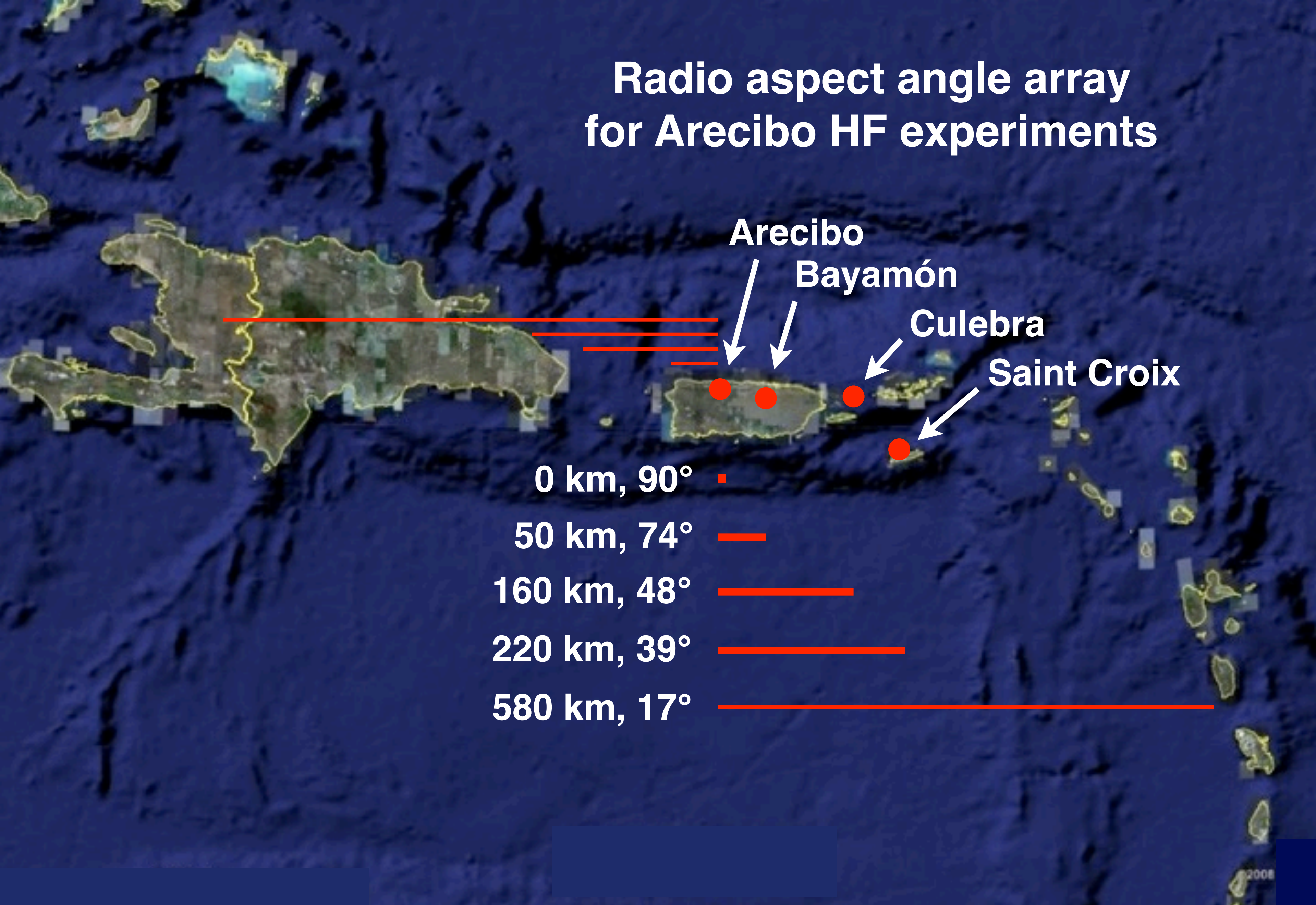
Radio aspect angle measurements in Alaska



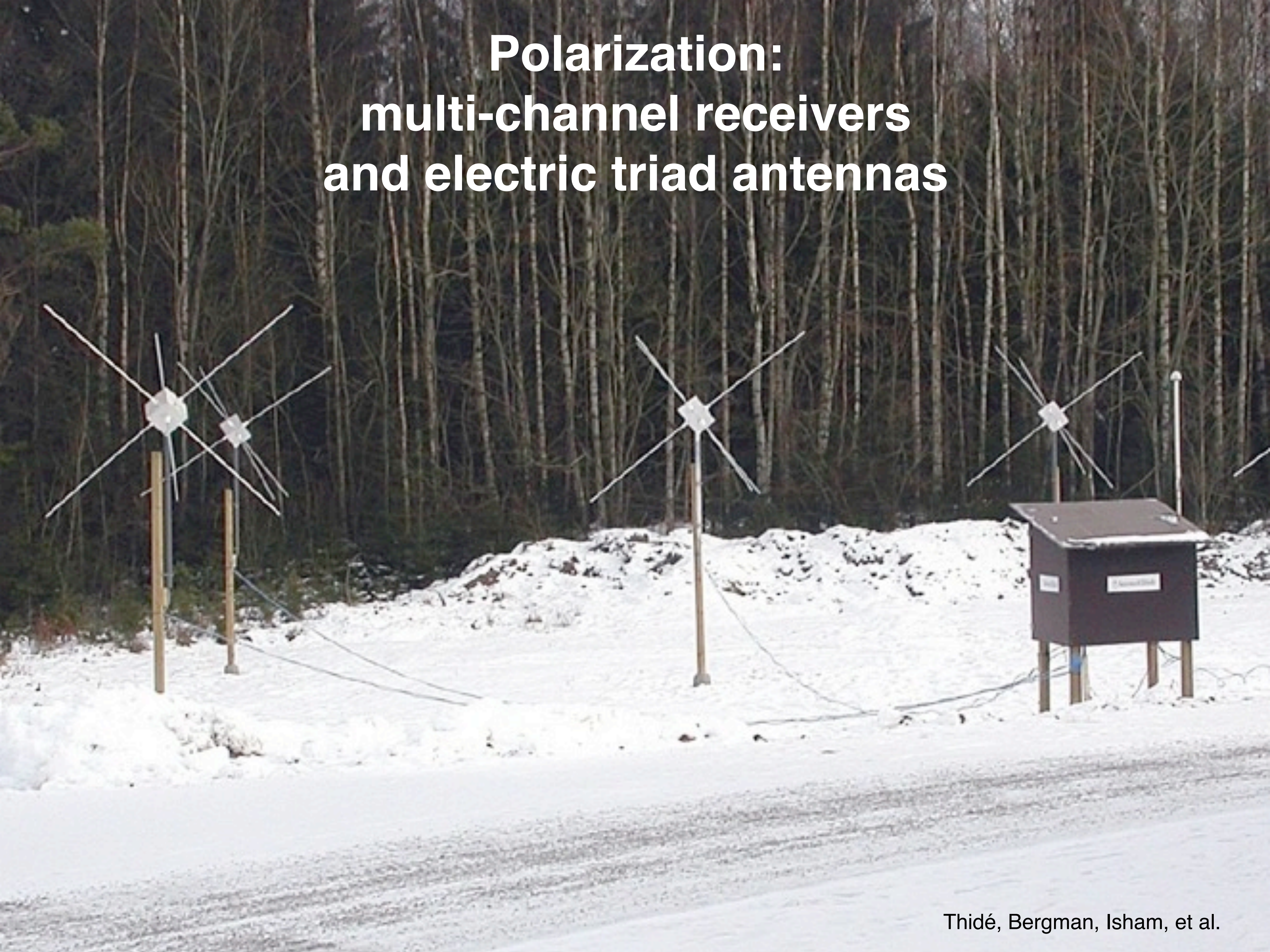
Map from http://www.anchorage.net/

Radio observations with new Arecibo HF

Radio aspect angle array for Arecibo HF experiments



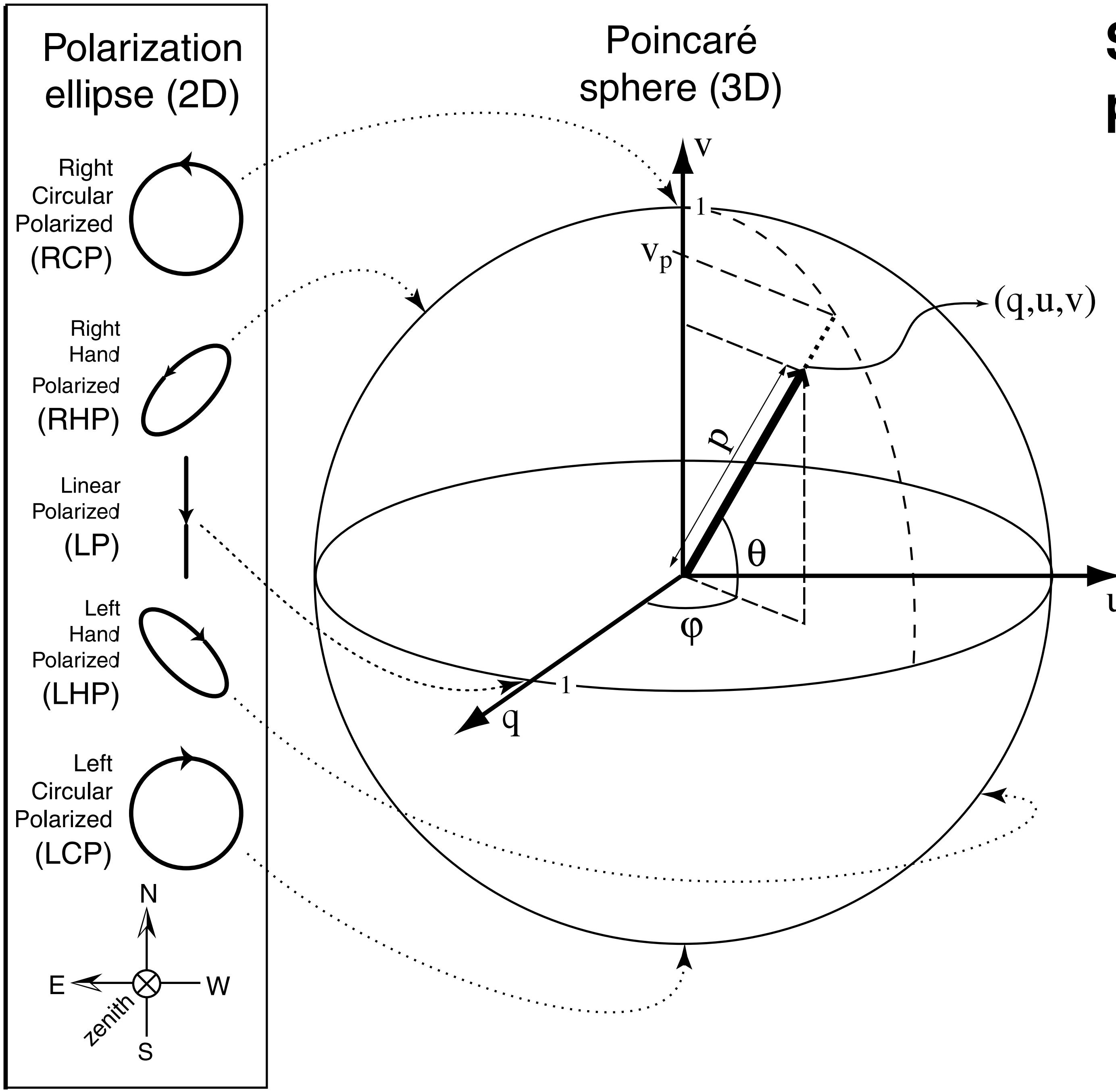
Polarization: multi-channel receivers and electric triad antennas



Thidé, Bergman, Isham, et al.


Magnetic
triad
antenna
Thidé, Bergman, Isham, et al.

SEE polarimetry

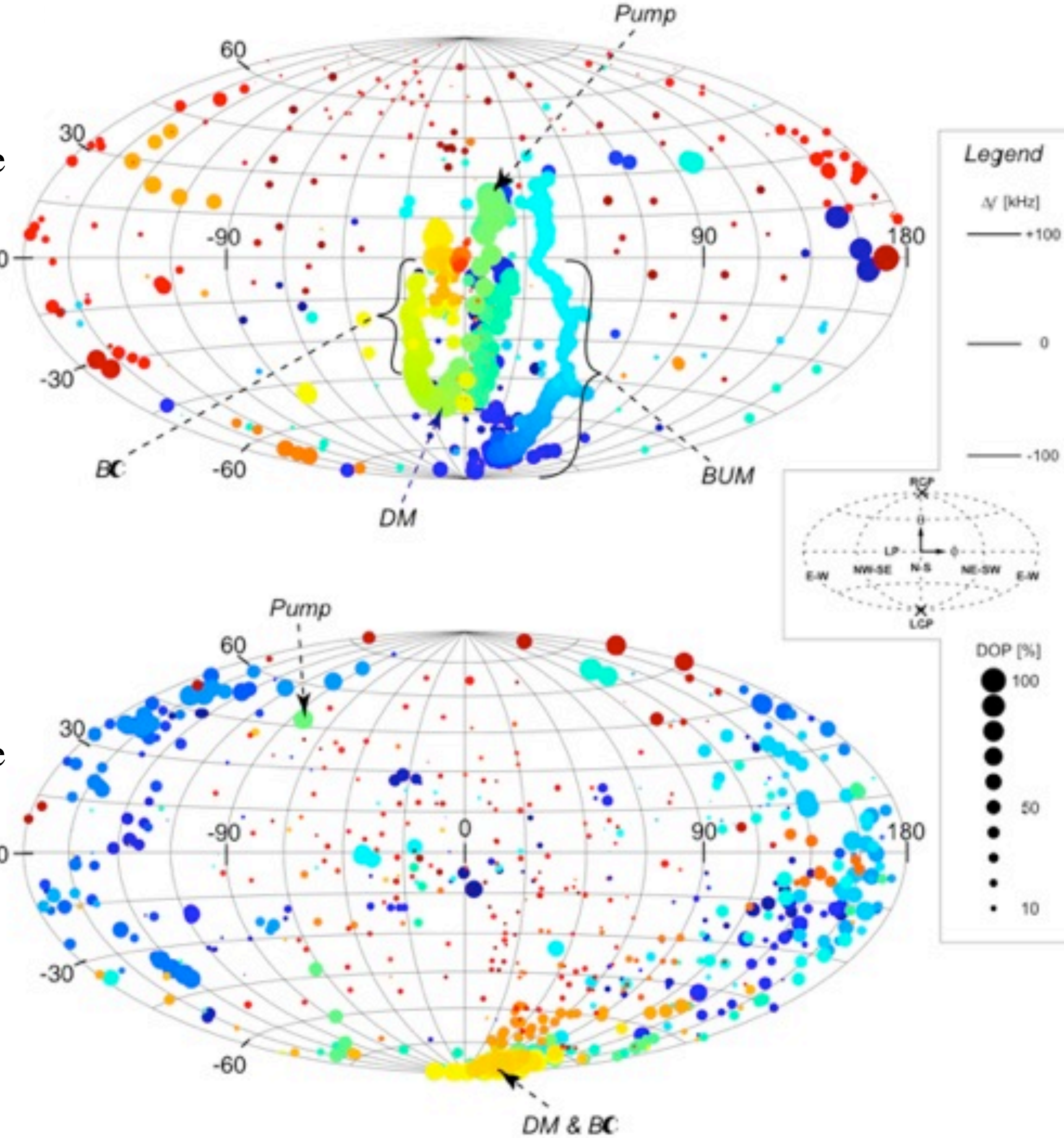


Carozzi et al. (2001) figure 1

SEE polarimetry measurements at Sura

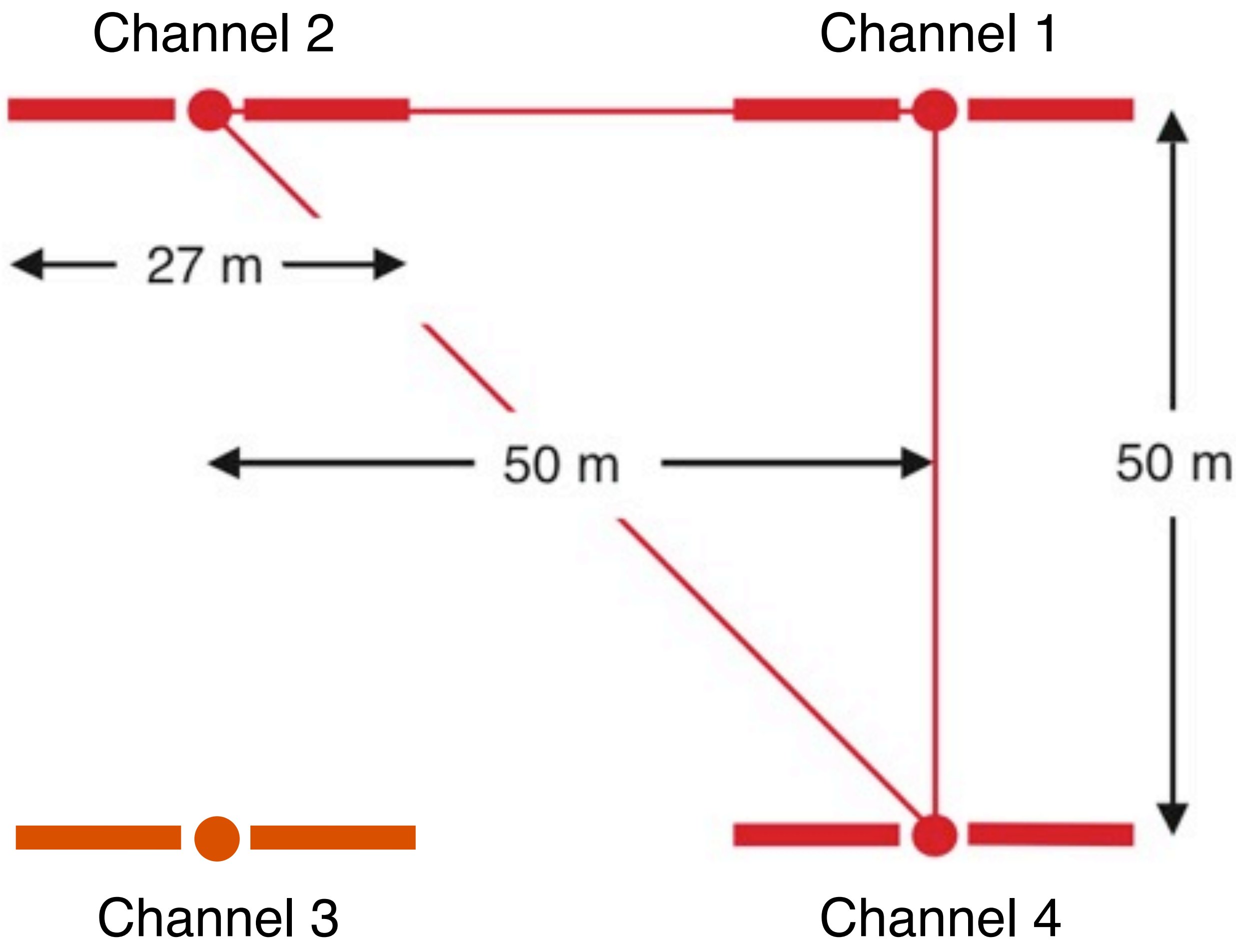
$f_{\mathrm{pump}} > 4 f_{\mathrm{ce}}$

$f_{\mathrm{pump}} < 4 f_{\mathrm{ce}}$



Carozzi et al. (2001) figure 12

Radio direction-finding




Dartmouth College
direction-finding array
Toolik Lake, Alaska
August 2006
(photo by Nick Bunch)

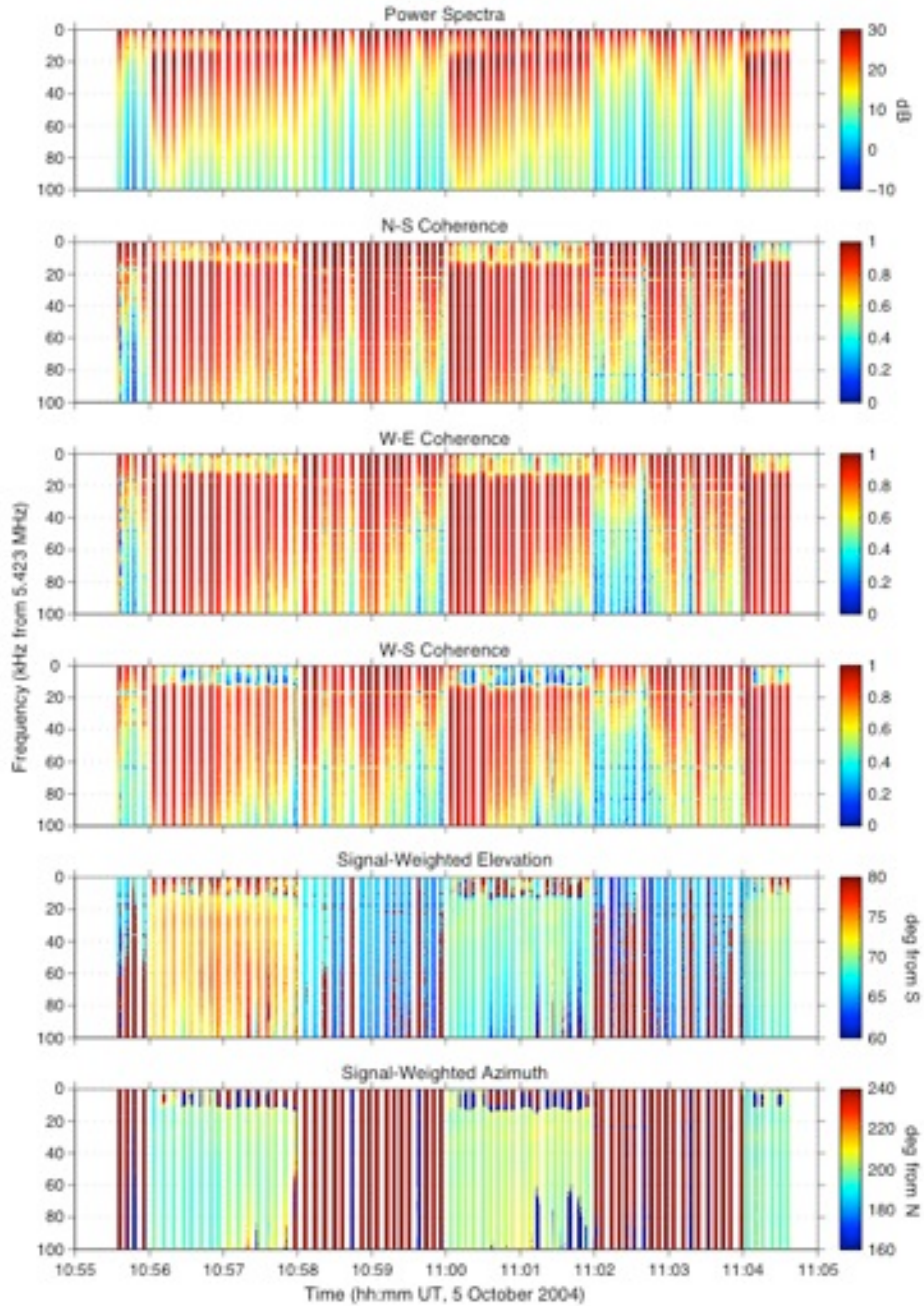
Direction angle of stimulated radio emissions (SEE)

Broad upshifted maximum (BUM1)

0 to +100 kHz from 5.423-MHz pump ($\sim 4\, f_{ce}$)
2 min on, 2 min off

HF: 14.0°S, 17.5°S
BUM1: 16°S, 20°S

Ramfjordmoen
5 October 2004
10:55 to 11:05 UT



Power

Coherence North-South

Coherence West-East

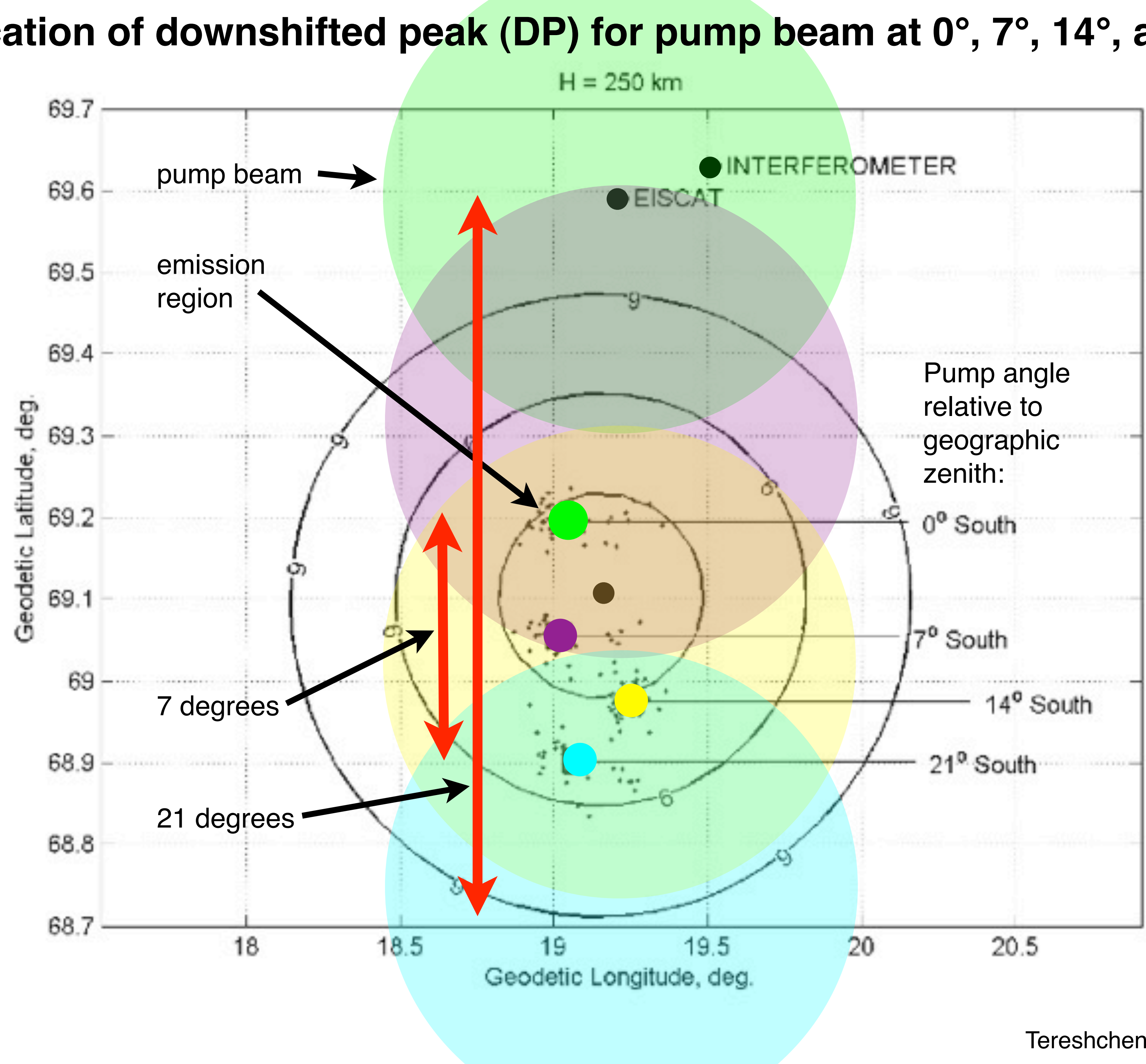
Coherence West-South

Elevation

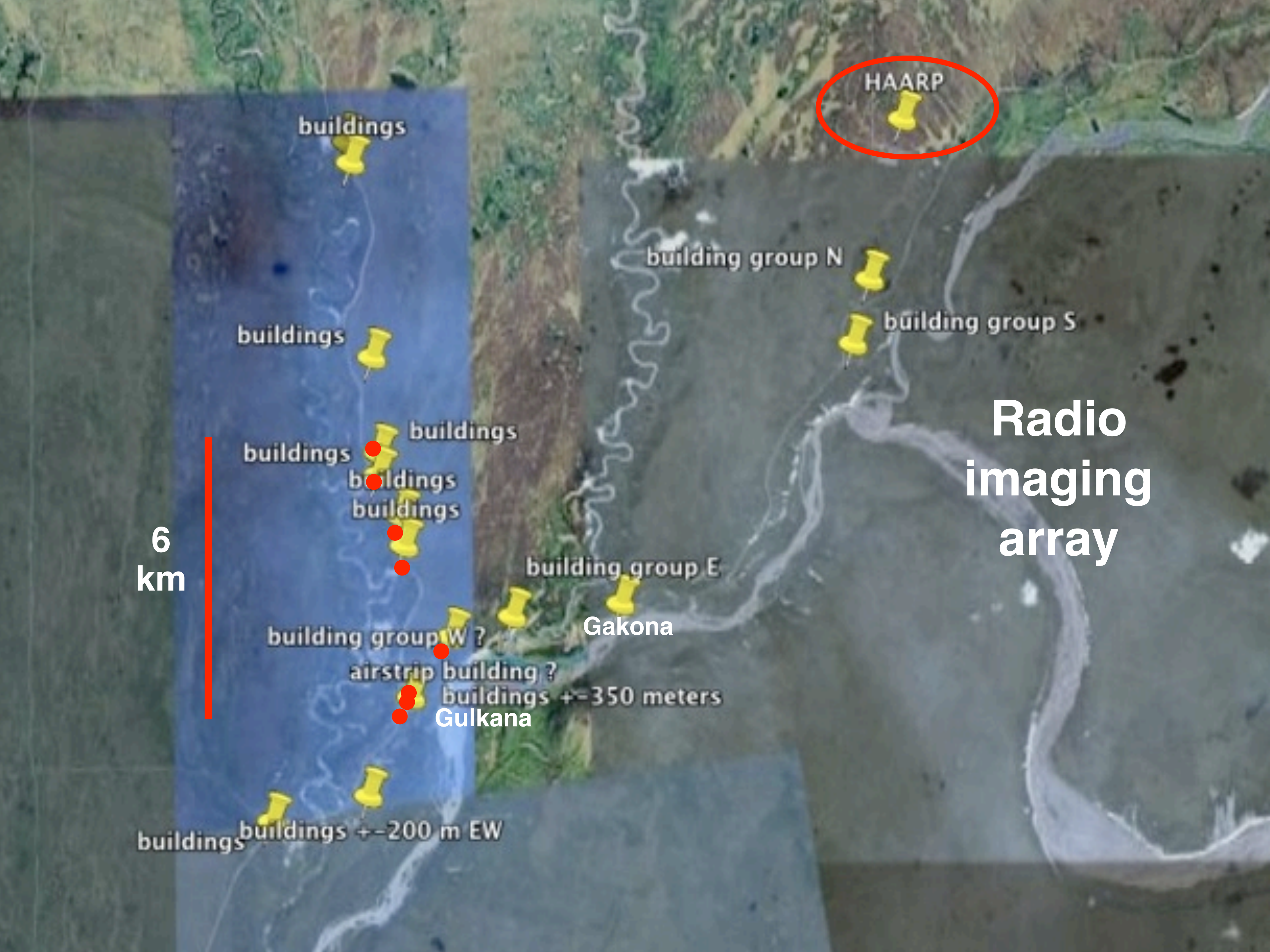
Azimuth

Isham et al. (2005)

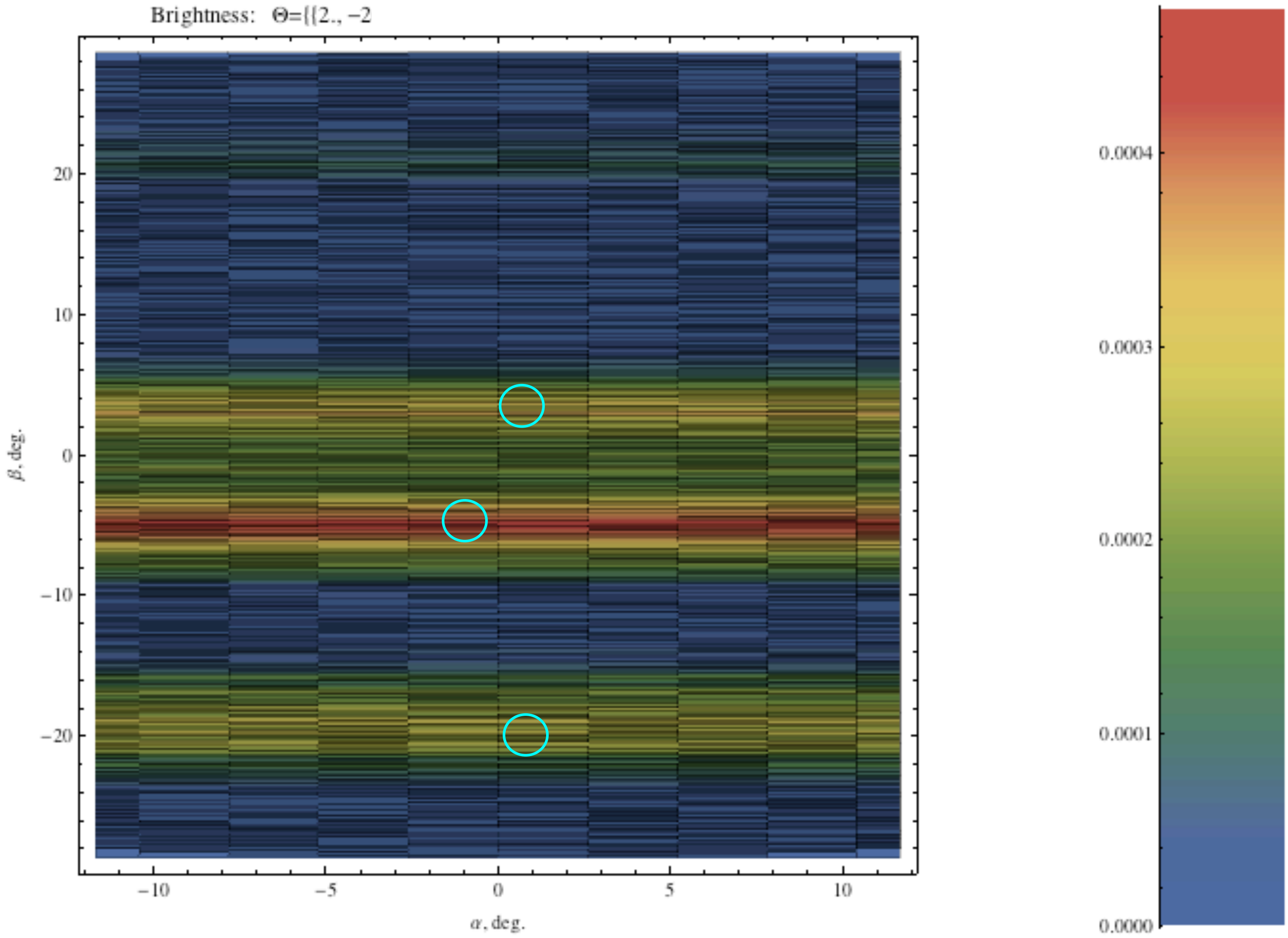
Location of downshifted peak (DP) for pump beam at 0°, 7°, 14°, and 21° S



Tereshchenko et al. (2006)

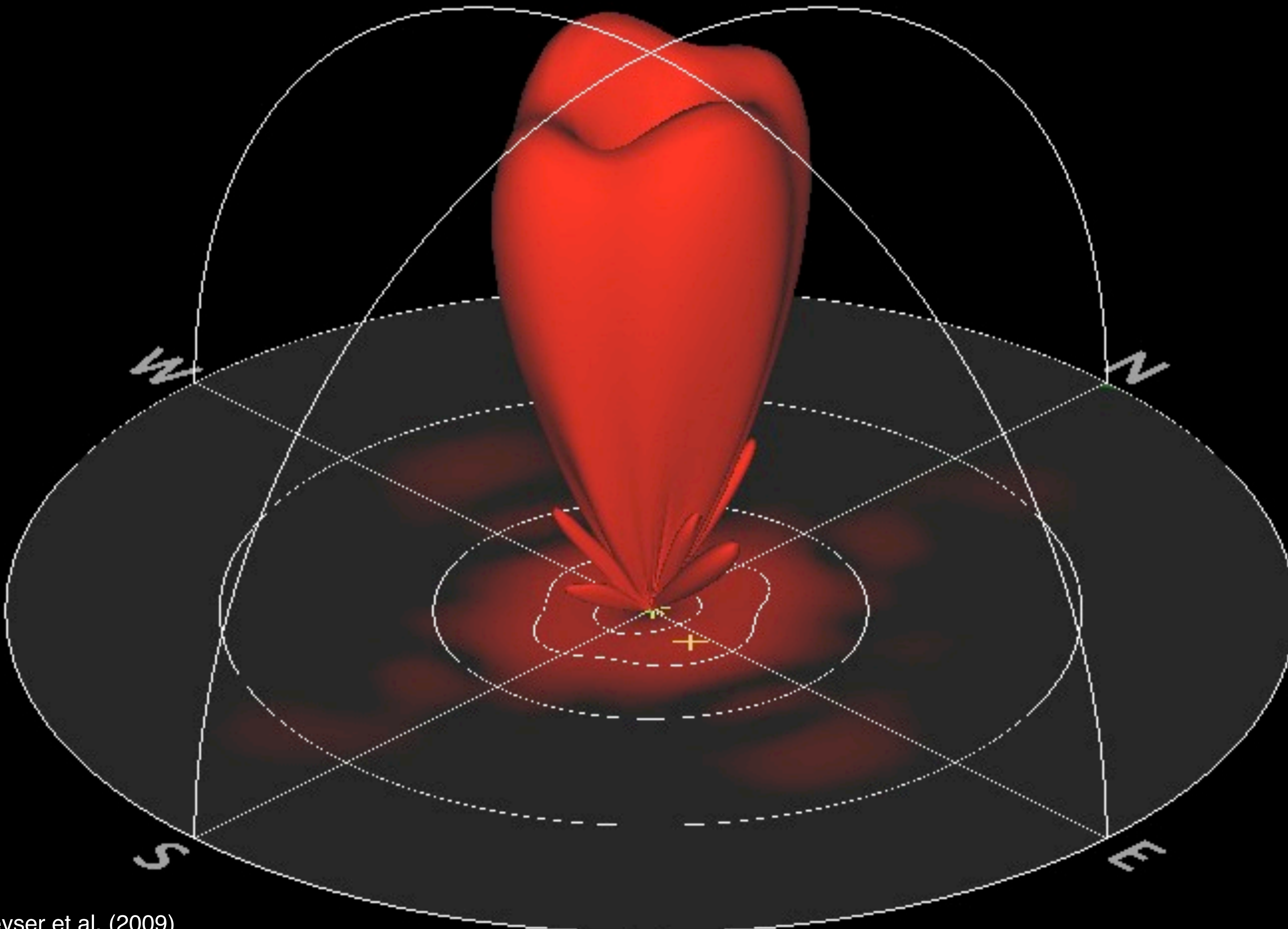

HAARP
buildings
building group N
building group S
buildings
Radio imaging array
buildings
buildings
buildings
buildings
6 km
building group E
Gakona
building group W ?
airstrip building ?
buildings +-350 meters
Gulkana
buildings
buildings +-200 m EW

Simulated 1-D radio image



Belyey and Isham

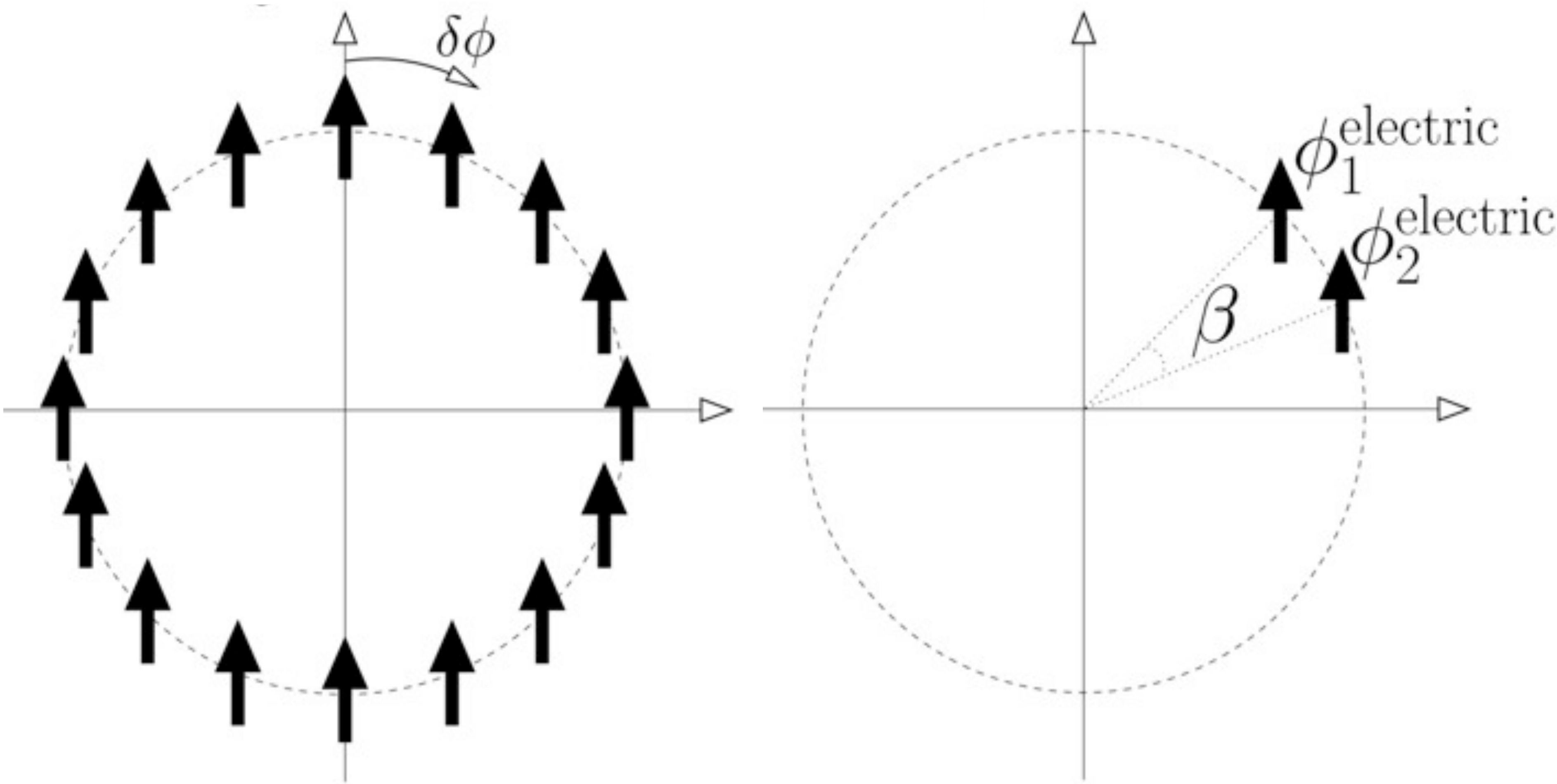
Photon orbital angular momentum (radio phase modes) at HAARP



Leyser et al. (2009)

Radio Phase Modes

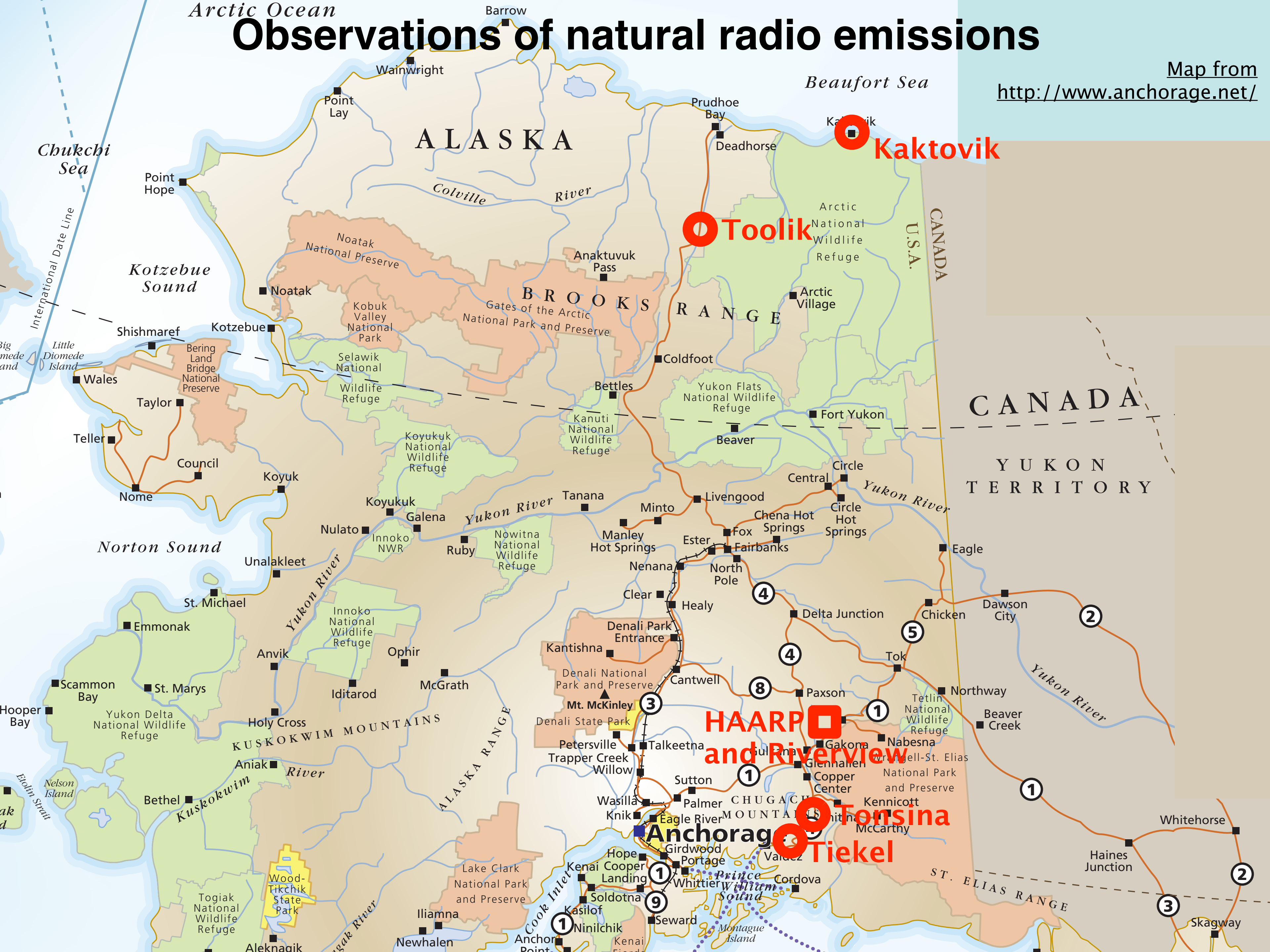
Transmission | **Measurement**



Mohammadi et al. (2010)

Observations of natural radio emissions

Map from
http://www.anchorage.net/



Summary

New digital receivers

Aspect angle

Polarization

Direction finding

Imaging

Radio phase modes

Start simply, add complexity

Outside of HF campaigns, extend Dartmouth network

Collaborations in the use of the receivers are welcome!

Contact Brett Isham at <brettisham@gmail.com>