Next Generation Radio Arrays

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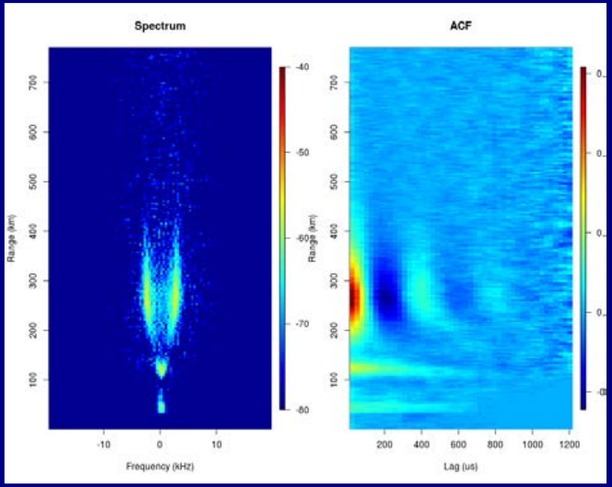
(with acknowledgement to my colleagues who contribute to these efforts...)



[McKay-Bukowski, et al., 2014]

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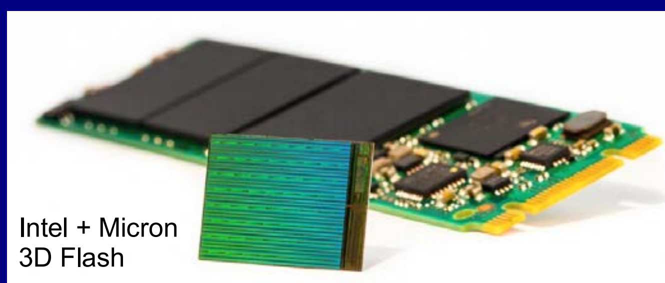
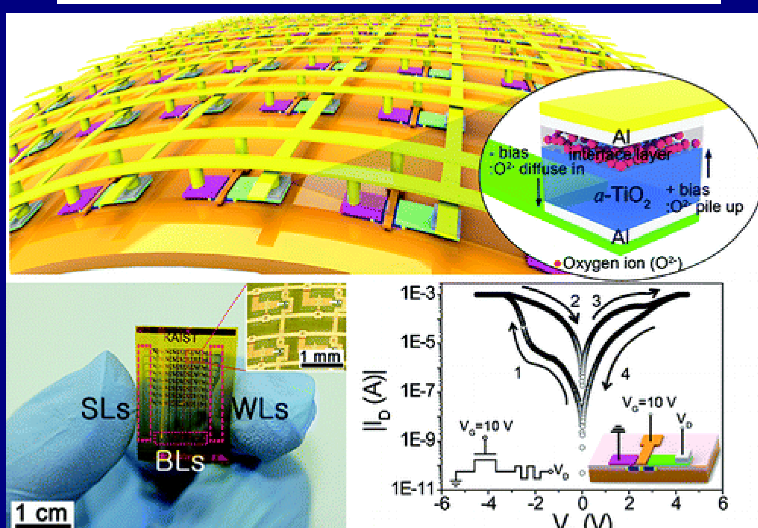
Deep Memory

Solid state memory capacity will exceed our data storage requirements.

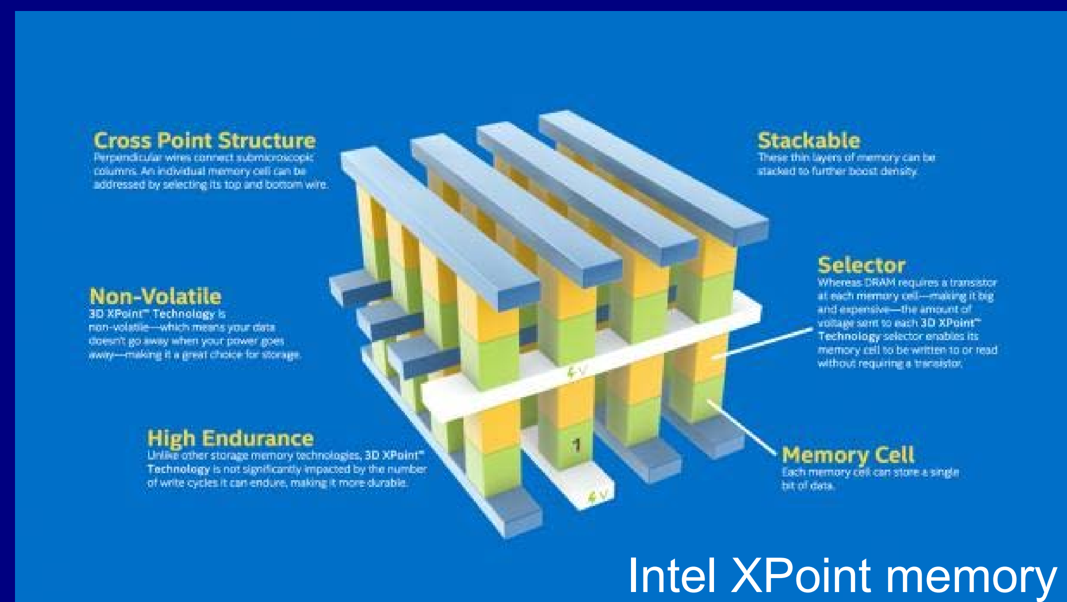
Deep memory instruments will become possible.

Store all data from every element for the life of a radio array...





Keon Jae Lee of the Korea Advanced Institute of Science and Technology (KAIST)

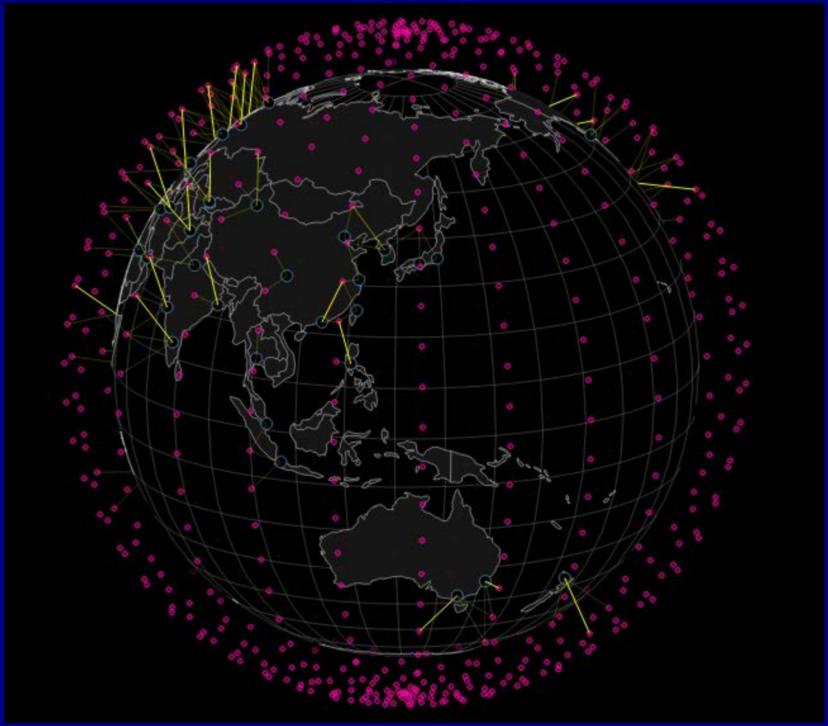


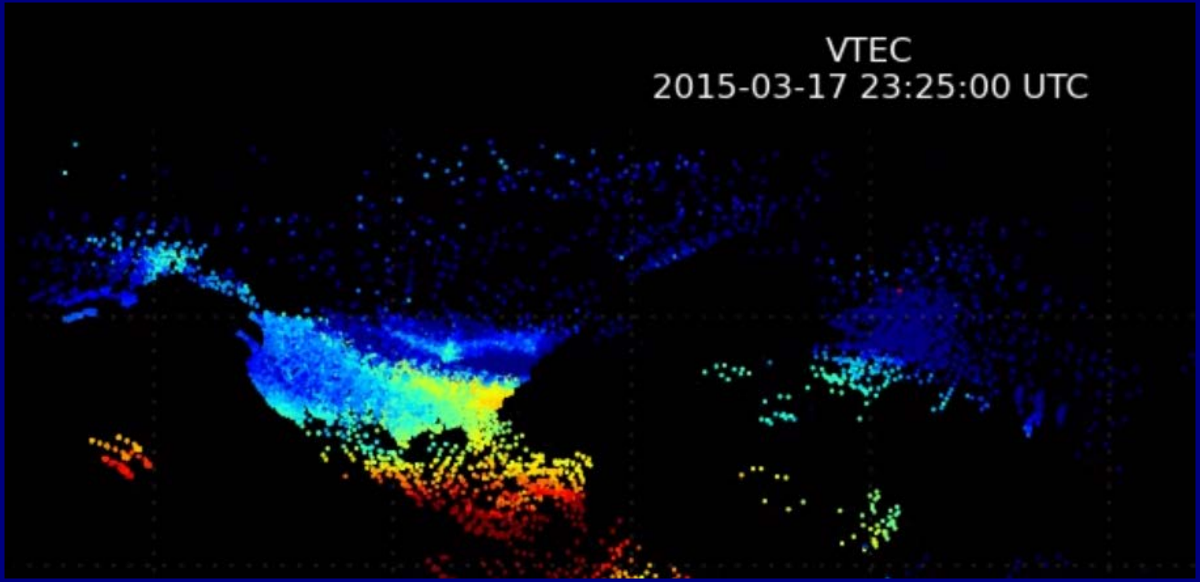
Connected World

Wireless networks will be global and even replace the wires.

Disconnected, self networking, and software realized instrumentation

Sparse global radio arrays, deployable dense arrays, and ad-hoc arrays





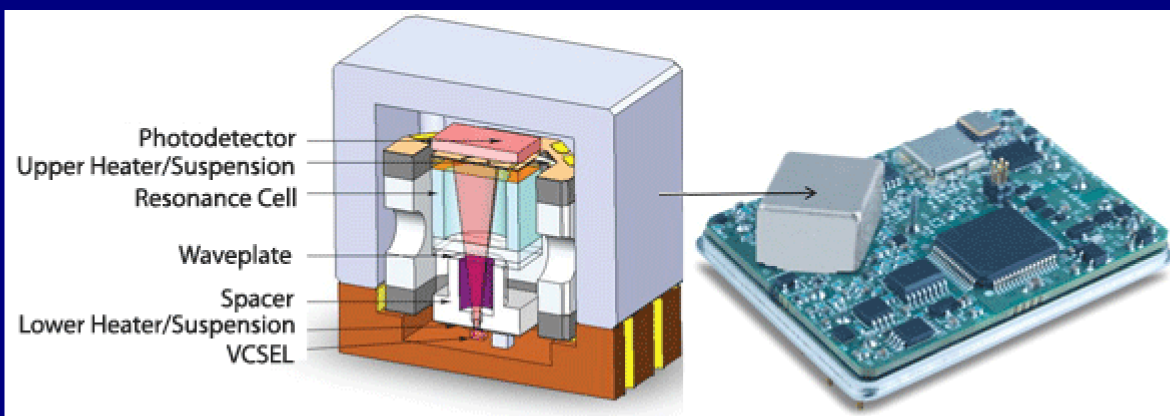
Disappearing Sensors

Integration will become extreme and include quantum referenced sensors

Receivers in connectors, cloud computers on a chip, <u>really</u> good clocks

Energy harvesting and low power near field wireless data

Self coherent arrays, personal passive radar, the ionosphere as a sensor

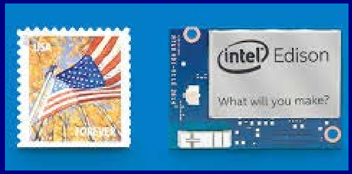


The physics package in the Symmetricom atomic clock has a microwave oscillator on the PCB (printed-circuit board) that modulates a VCSEL (vertical-cavity surface-emitting laser). The Q (quality factor) of the cesium resonance cell is greater than 10 million.

Deployable Low Power Radio Platforms

Mahali Array (during build out)

Mahali Box Generation 2



Low Power Embedded Computing

Instruments in ~ 10W power envelopes.
Future systems will use ~ 1W of power total.

Zero infrastructure radio science instrumentation

- Software radio and radar technology
- Solar and battery power
- Low power computing for data acquisition
- Intelligent control software
- Deep local solid state data storage
- Wireless communications (WiFI, 4G, Satellite)

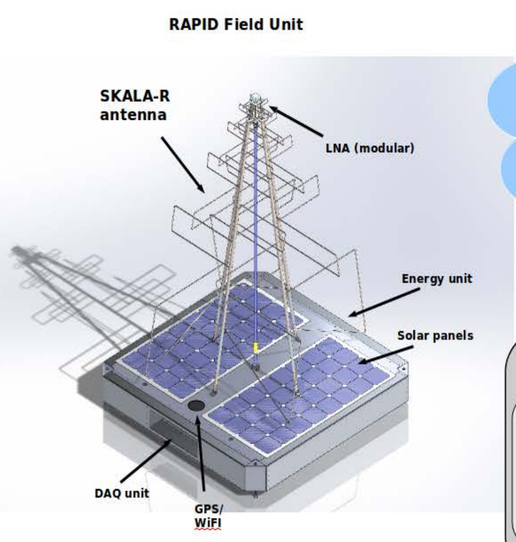
Cloud scale data collection, analysis, application

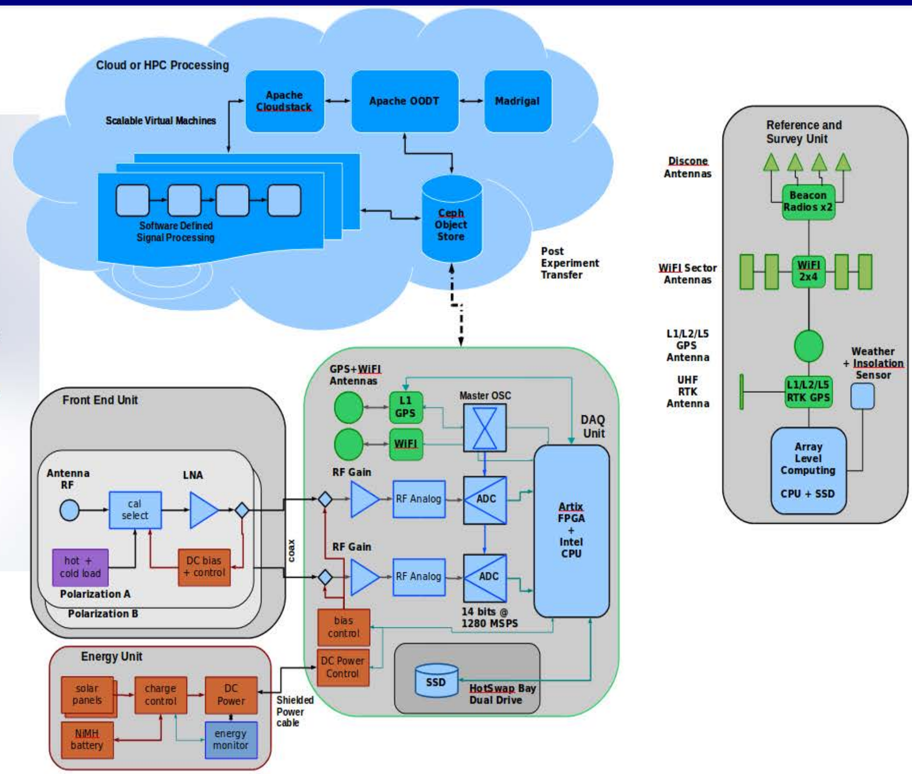
Generic instrument envelopes and APIs

- Array Radar (active + passive ; RAPID)
- GPS TEC / Scintillation (Mahali)
- Satellite Beacon (jitter)
- HF Radar / Sounders
- Spectral and propagation monitoring
- AM propagation monitoring

RAPID

Radio Array of Portable Interferometric Detectors

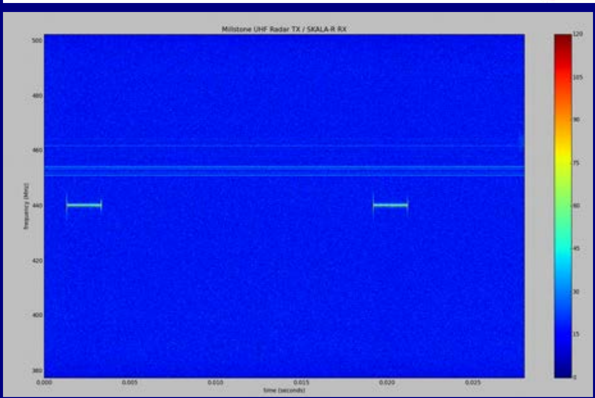


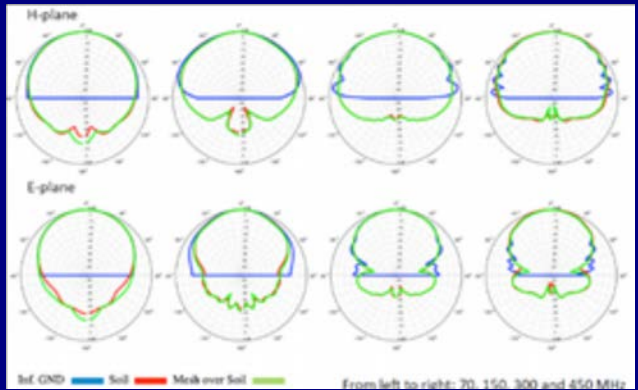


Go Where the Science is Best!
Deploy Easily and Anywhere
Reconfigure as Necessary
Capture the Radio Environment

~ 64 Element Demonstrator

A Partnership with
University of Cambridge
Square Kilometer Array Efforts



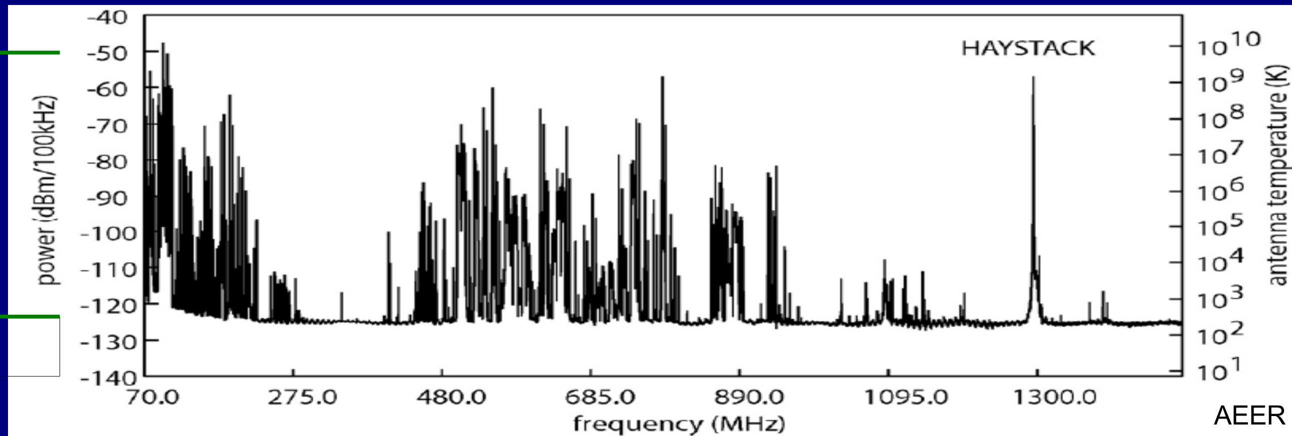


RAPID Electromagnetic Coverage

Strongest Signals

~ 70 – 85 dB

Geospace Scatters + Astronomy Sources



Typical Strong Signal Environment

10 MHz | 48 MHz | 615 MHz | 2000 MHz

RAPID Baseline Coverage (48 MHz – 615 MHz)

RAPID Extended Coverage (10 – 48 MHz; 615 – 2000 MHz)

HF | VHF | UHF | L-Band

49-50 MHz

54-108 MHz

174 - 240 MHz

420-450 MHz

500 MHz

470-862 MHz

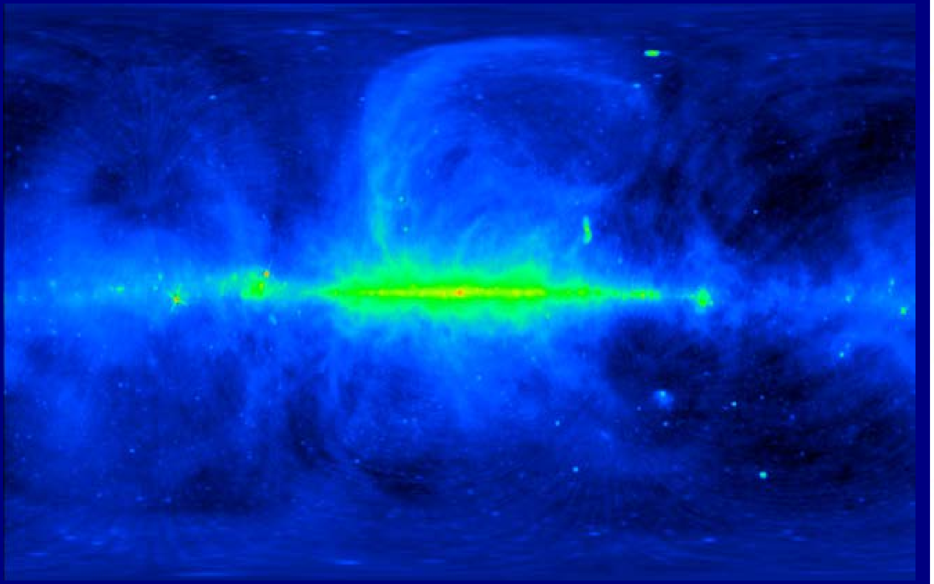
1280-1300 MHz

1176-1575 MHz

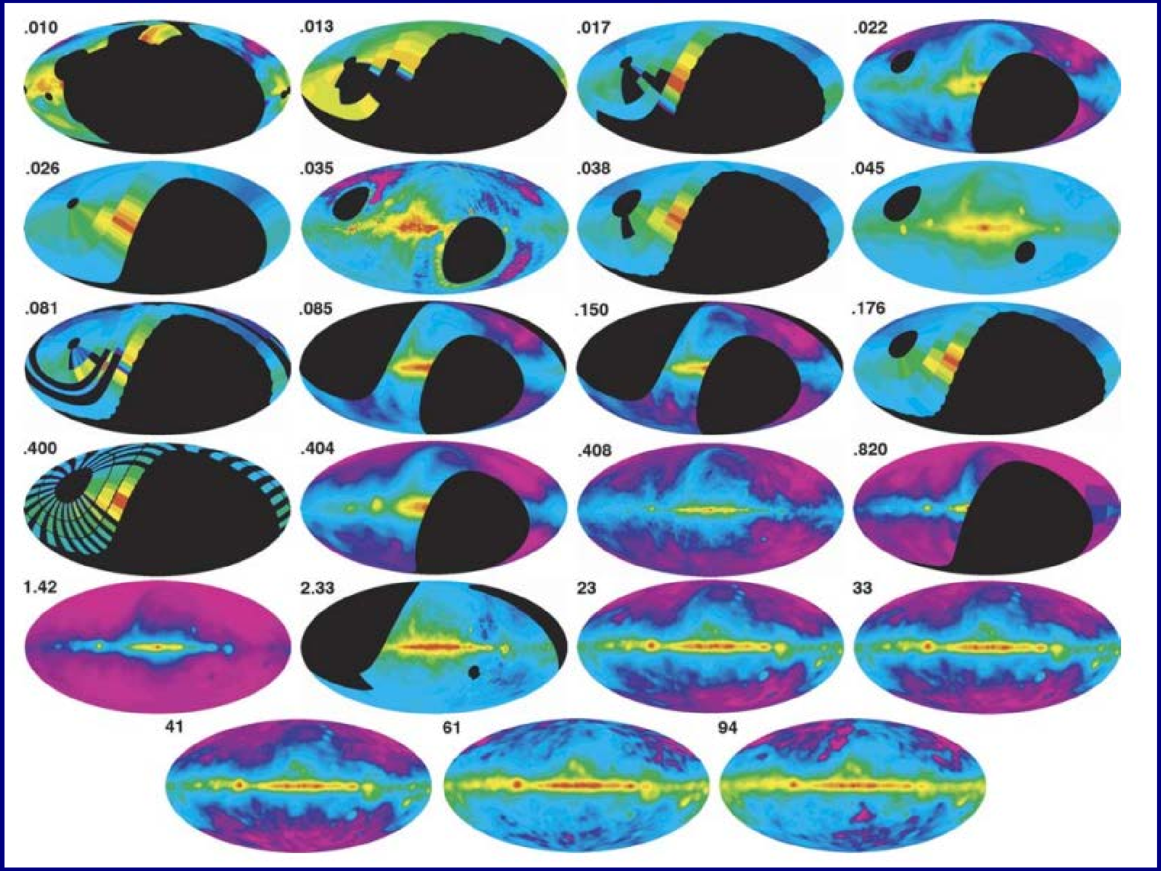
Geospace radar transmissions
- 50 to 1295 MHz, Narrow bandwidth (< 6 MHz)
- 2-3 MW (6 – 20 % duty cycle)
- Aeff ~ 1000 to 2000 m^2 @ UHF

Signals of opportunity (i.e. Passive Radar)
- HF to L-band, Moderate bandwidth (< 20 MHz)
- 100 kW to 1 MW ERP + GPS

RAPID for Galactic Synchrotron Mapping



408 MHz Galactic Synchrotron Emission [Haslam, 1982]

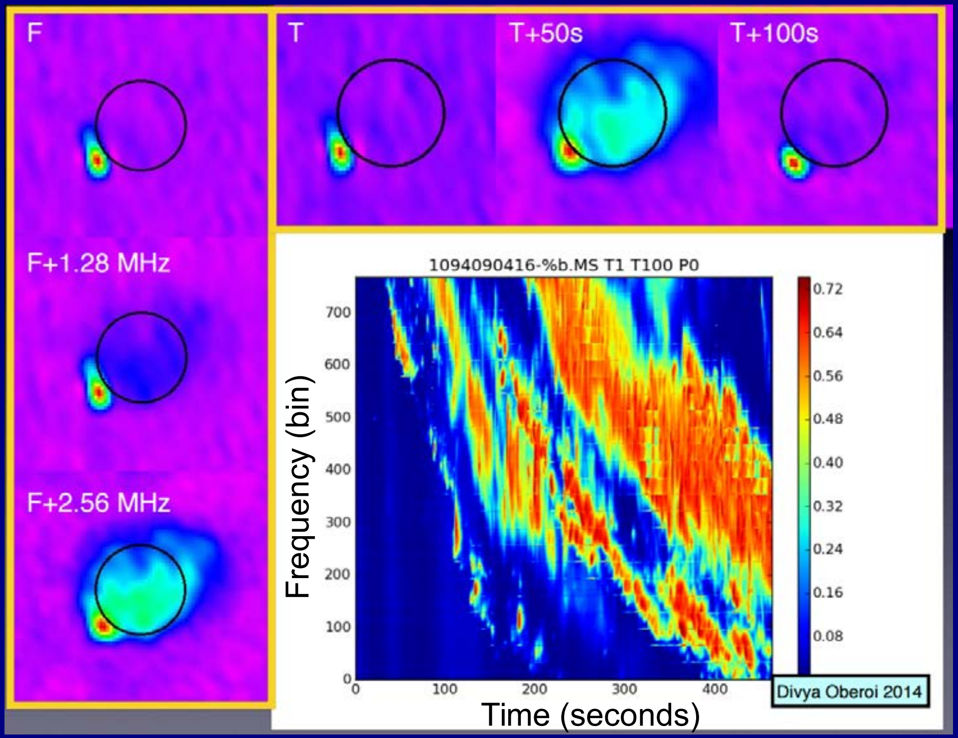


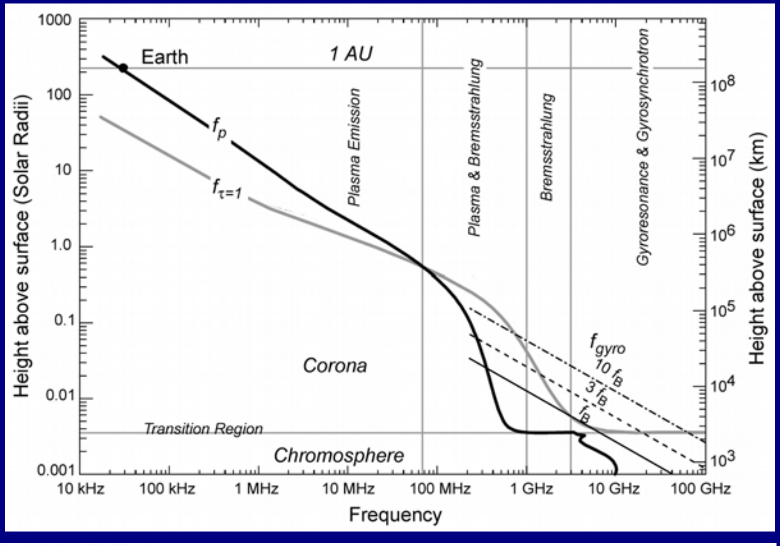
Galactic Synchrotron Empirical Model [Oliveira-Costa et al, 2008]

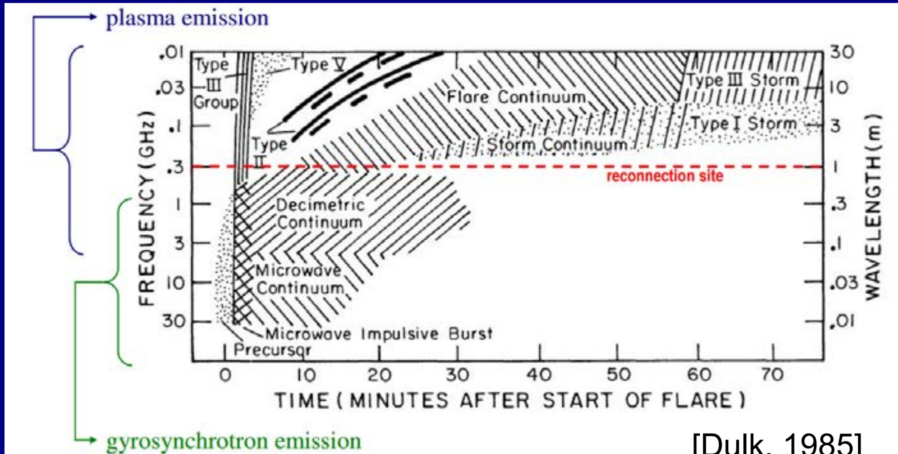
Synchrotron Emission of the Interstellar Medium
- Spectral index of ~ -2.5 with about 170K @ 200 MHz (relatively strong!)
- A factor of 5 to 10 in flux between galactic plane and high latitudes
- Ionospheric effects below 70 MHz or so (condition dependent)

RAPID can be applied for each frequency range (~ 35 hours of data per map for 0.3% error)
- Reconfigure as needed for additional baselines, frequencies, and polarizations, ~ 85λ)
- Calibration will be key to produce a highly consistent set of maps

RAPID for Solar Imaging







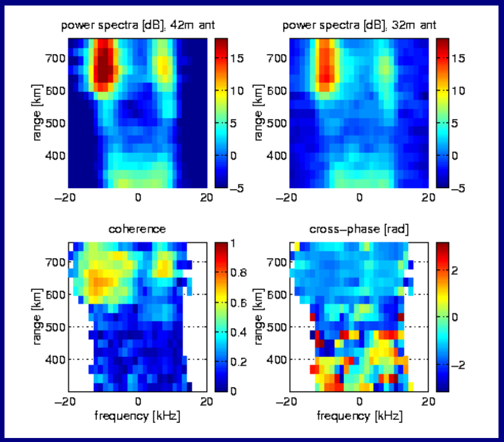
[Dulk, 1985]

MWA – 16 May, 2013 – Type II radio burst
04:11:04 UT v0=153.905 MHz Δv=640 kHz
Δt= 1 sec Image Dynamic Range ~ 1000

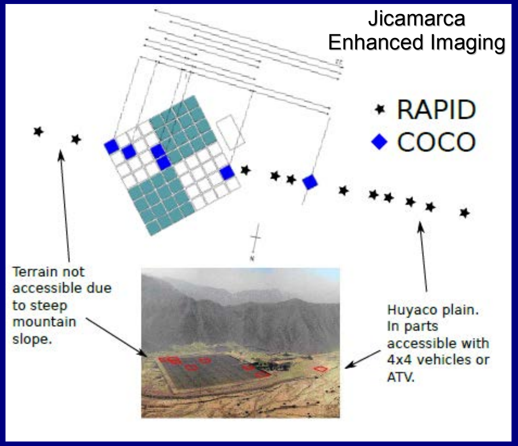
Radio bursts associated with solar reconnection processes and coronal mass ejection events

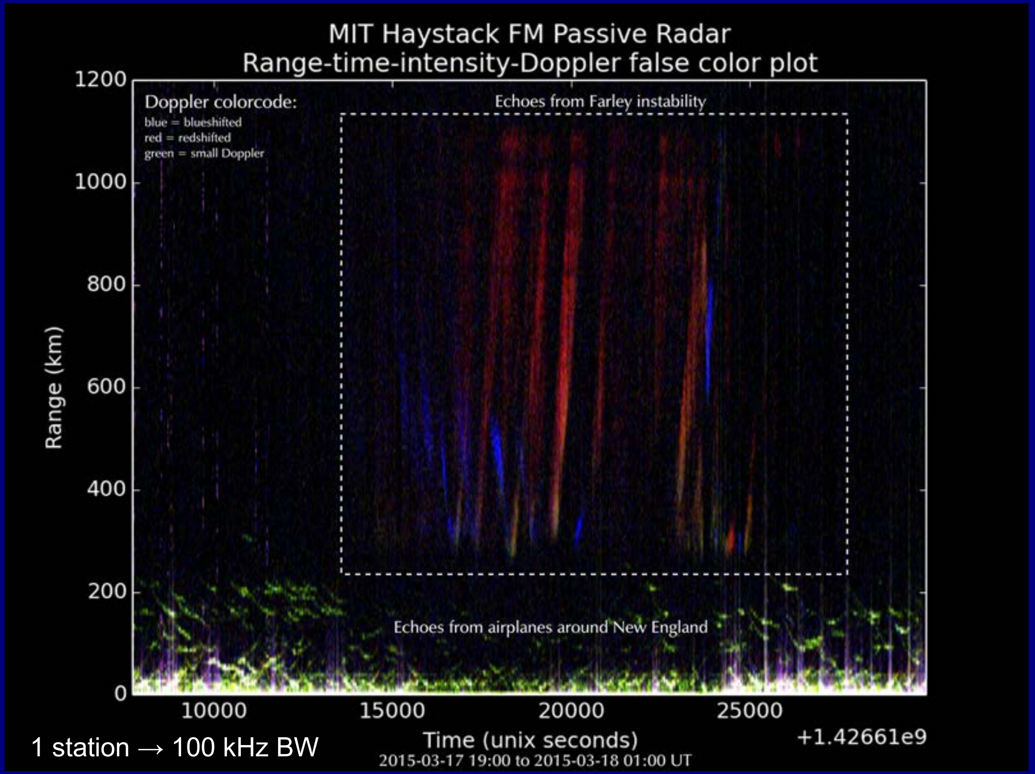
Select baselines for uniform UV sampling of solar disk
SNR is high (~ 10 in 1 sec for thermal disk) → enables fast imaging of bright structures
Raw data enables post experiment time / bandwidth trade-offs and analysis
Large instantaneous bandwidths allow for tracking dynamics in frequency
Optimal spatial sampling leads to high dynamic range and high resolution (~ 1 arcmin)
Logistically challenging configuration (~1.7 km at 600 MHz to 20 km at 50 MHz)

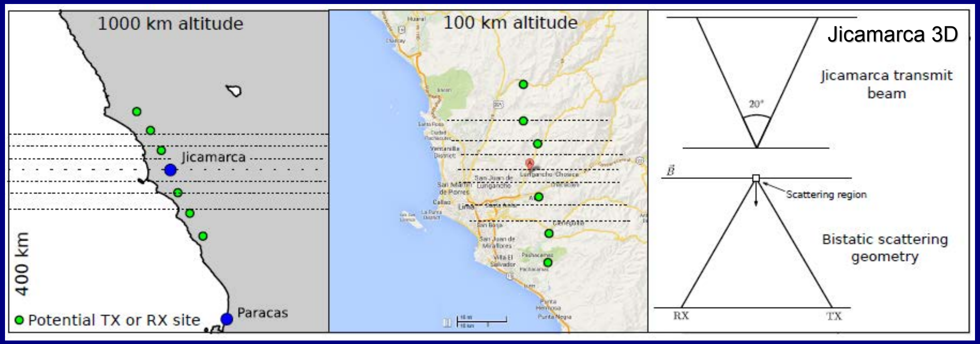
RAPID for Geospace Radar



[Svalbard NEILs, Grydeland, et. al, 2004]







Coherent scatter using existing Facilities and Broadband Passive Radar (FM / HDTV for HF → UHF)

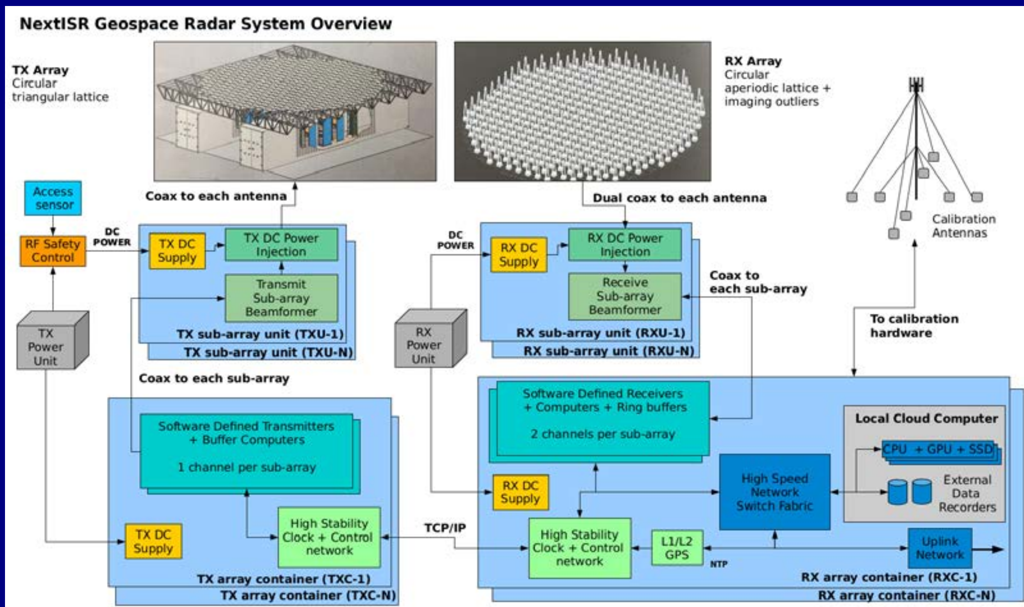
E-region irregularities, naturally enhanced ion acoustic lines, RF heater generated irregularities

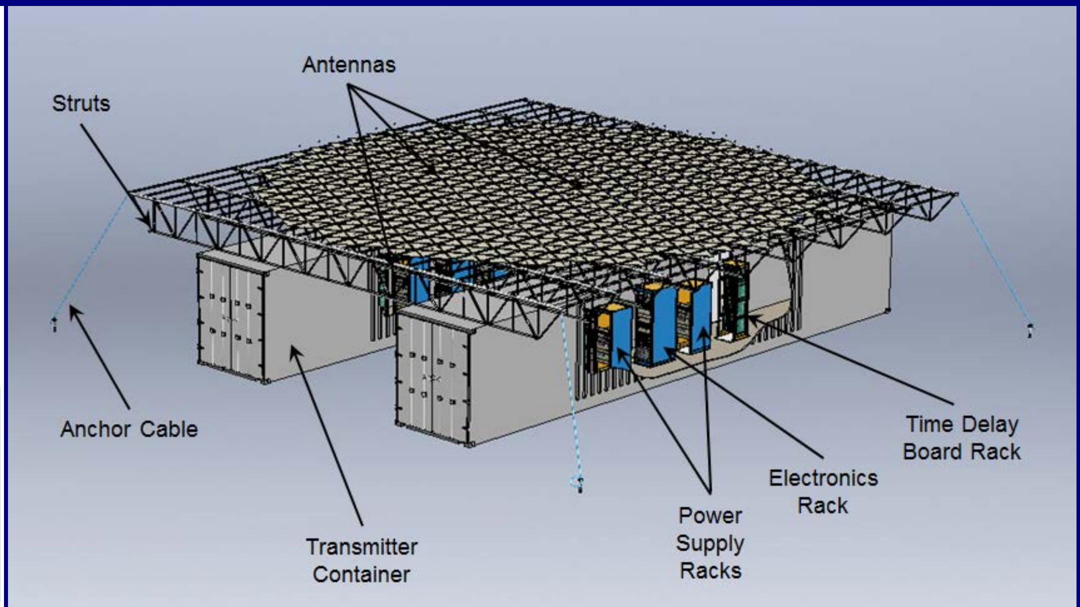
Configurable interferometric imaging array for any RX application (48 to 2 GHz)

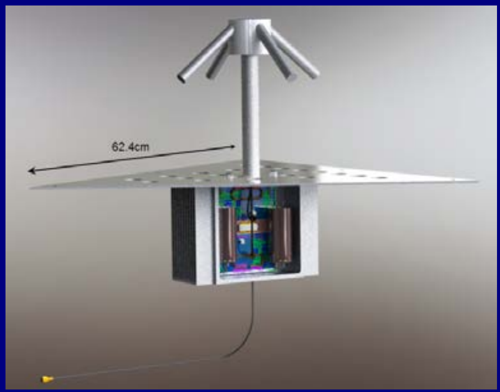
SKALA-R antennas or alternate antennas as needed (e.g. HF for meteor radar, GPS, etc.)

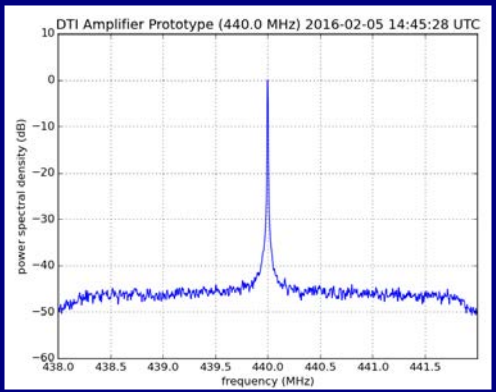
Deployable facility asset for use by the community

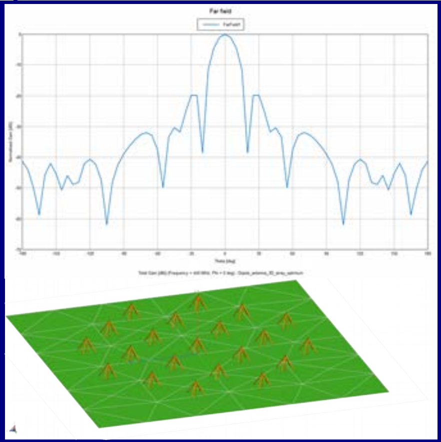
NextISR Geospace Radar System

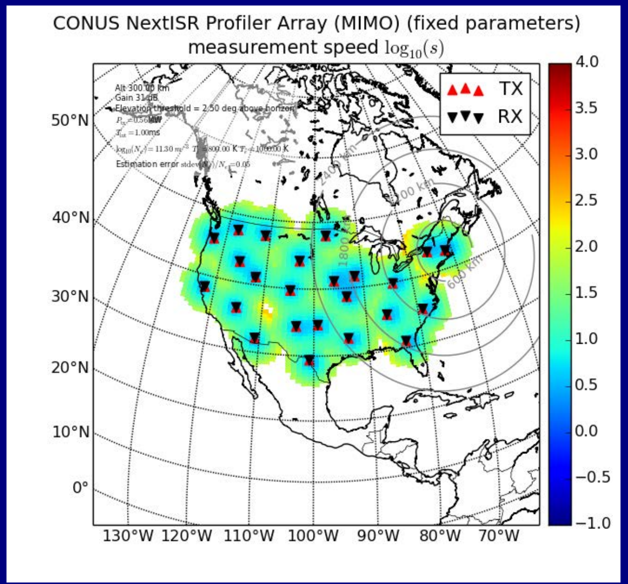












Low Cost Geospace Radar System (806 elements / 1.0 MW to 1806 el / 2.3 MW)

Enable radar networks for Space Weather monitoring

Locally Bi-static Radar Architecture (separate TX and RX)

1.25 kW per element, simultaneous TX and RX, broadband RX capability

Time delay beamforming with digital waveforms per sub-array

The Most Science for the Aperture