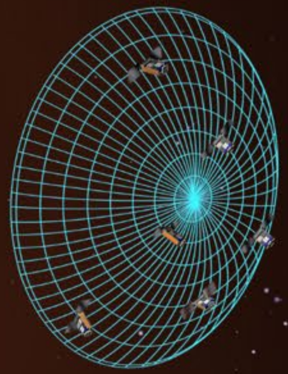
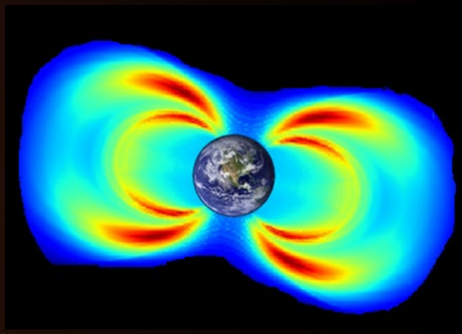
Measuring the Earth's Synchrotron Emission from Radiation Belts with a Lunar Near Side Radio Array





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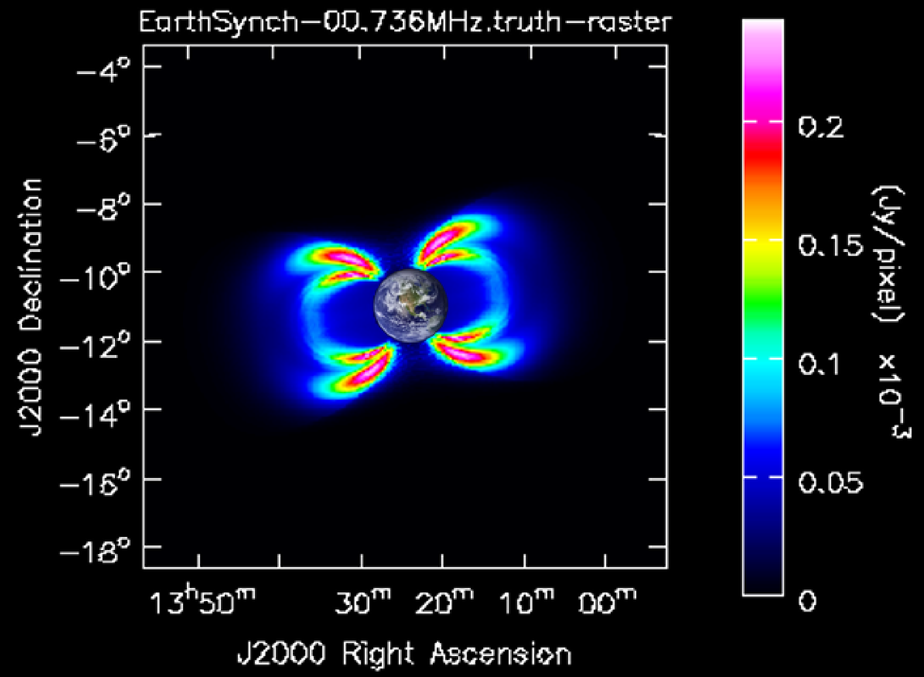
LUNAR ARRAYS AND MAGNETOSPHERIC SCIENCE

- Earth is 1.9 degrees in the Lunar Sky
- Radiation belts go out to 4-6 Earth Radii
  Takes up most of the sky for lower Earth orbits
- Synchrotron Emission is a good target for Lunar Array
- Sensitivity of ~1Jy at 1 MHz needed



LUNAR ARRAY OUTLINE

- Radiation Belt Physics Overview
- Salammbo Electron Code
- Noise Sources
- Array Design & Simulations
- Future Work

RADIATION BELT PHYSICS

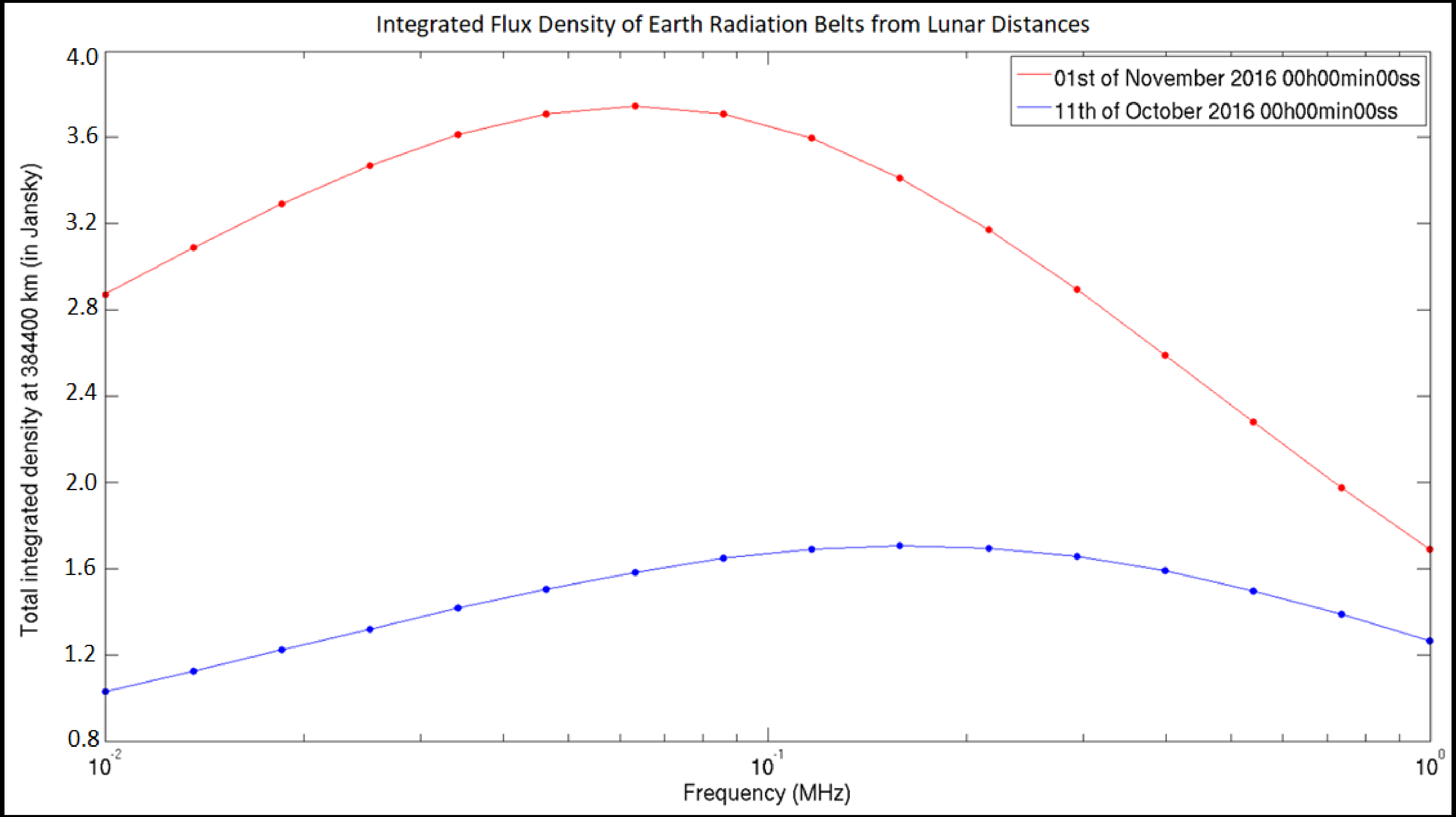
- Caused by high energy electron interaction with magnetic fields
- Brightness of Earth's radiation belts reveal the electron energy distribution
- Varies drastically with Space Weather input
- Real time surveillance would provide unique global measurement of electron environment

$$f_{max} \approx 4.8\, E^2 B \sin\alpha$$

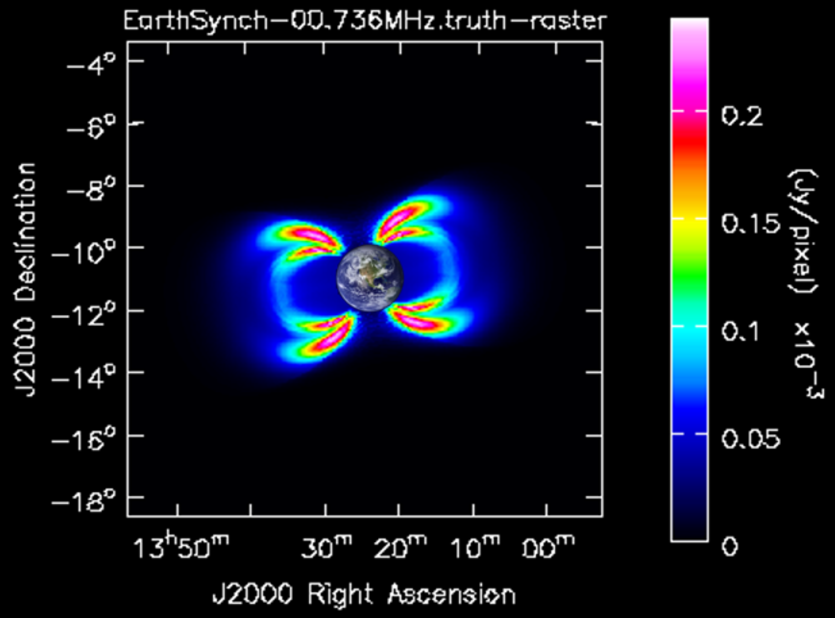
SALAMMBO CODE

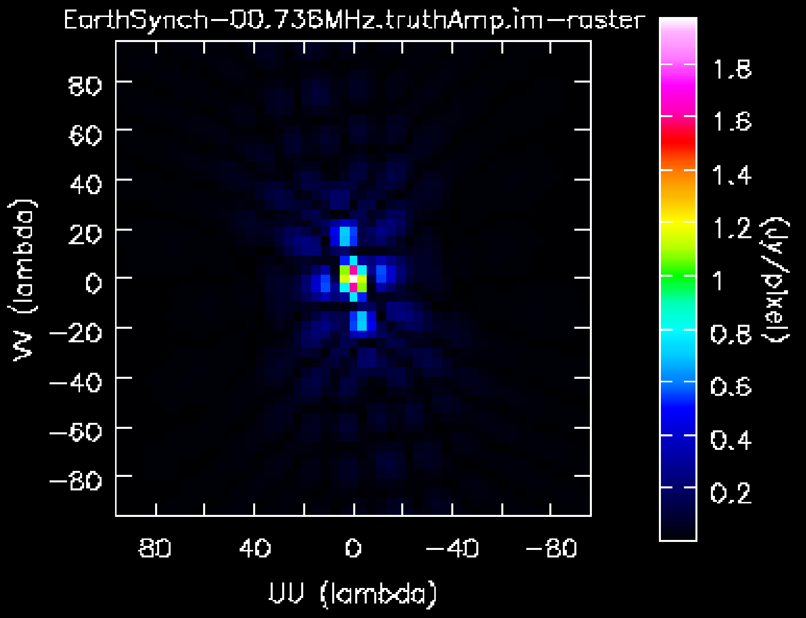
- Input Boundary Conditions
  - THEMIS-SST Electron Distributions
  - Earth's Magnetic Field
  - Kp – Plasmapause Position
- Captures wave–particle interactions
- Globally solves 3-D phase-space diffusion equation
- Convert Electron Distribution & Magnetic Field to Radiation Belt Brightness

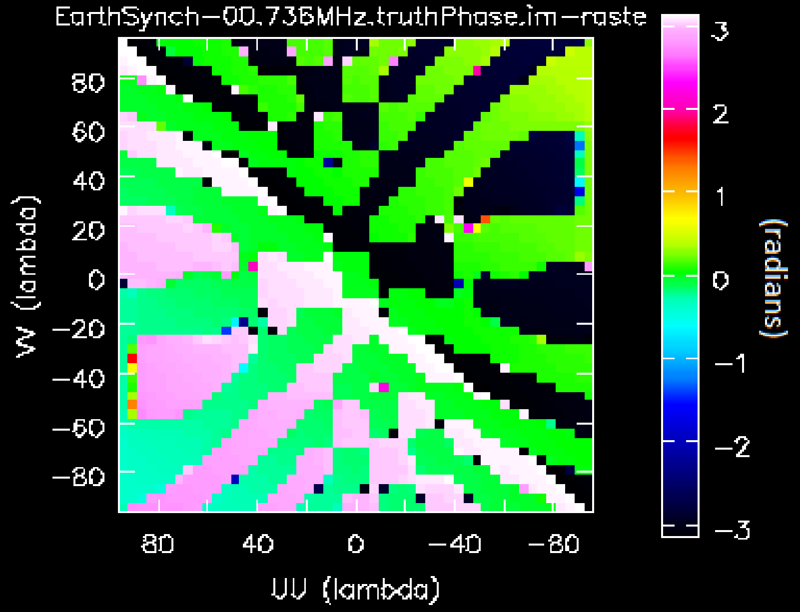
SALAMMBO CALM PERIOD VS STORMY PERIOD



SALAMMBO SIMULATION CODE







Total Brightness 1.5-2.0 Jy

Power mainly with 30 λ
= 9000 m baselines at 1 MHz

Highest Amplitude samples either ~ 0°, -180° ,180°

NOISE SOURCES: REMOVABLE CONSTANTS

Source	Lunar 1 MHz Flux Density	Notes
Galactic Brightness	$5*10^6$ Jy	Acts like correlated noise
Earth Blackbody	$3.04*10^{-2}$ Jy	1.9° circle from Moon 273 K
Lunar Blackbody	38.5 - 144 Jy Night to Day	Added to background noise 100 – 373 K
Solar Blackbody	$4.84*10^{-2}$ Jy	0.5° circular source 5800 K

NOISE SOURCES: TRANSIENTS

Transient Source	Frequency Range	Lunar 1 MHz Flux Density	Occurrence Rate	10 km instantaneous Overresolution
Auroral Kilometric Radiation	50-800 kHz	10^{10} Jy	50% on night side	0.2-0.4 deg at 500 kHz, 10x better
Auroral Hiss	100-600 kHz	$6.1*10^{8}$ Jy	30-50% K_p correlation	0.3 deg at 500 kHz
Medium Frequency Bursts	1.5-4.3 MHz	10^{6} Jy	every 6-20 hours K_p correlation	0.7 deg at 3 MHz
Auroral Roar	2.8-3.0 MHz	10^{6} Jy	every 3-5 hours K_p correlation	0.7 deg at 3 MHz
Terrestrial Continuum Emission	30-200 kHz	10^{5} Jy	60% total, highest near midnight	N/A, low frequency

NOISE SOURCES: TRANSIENTS

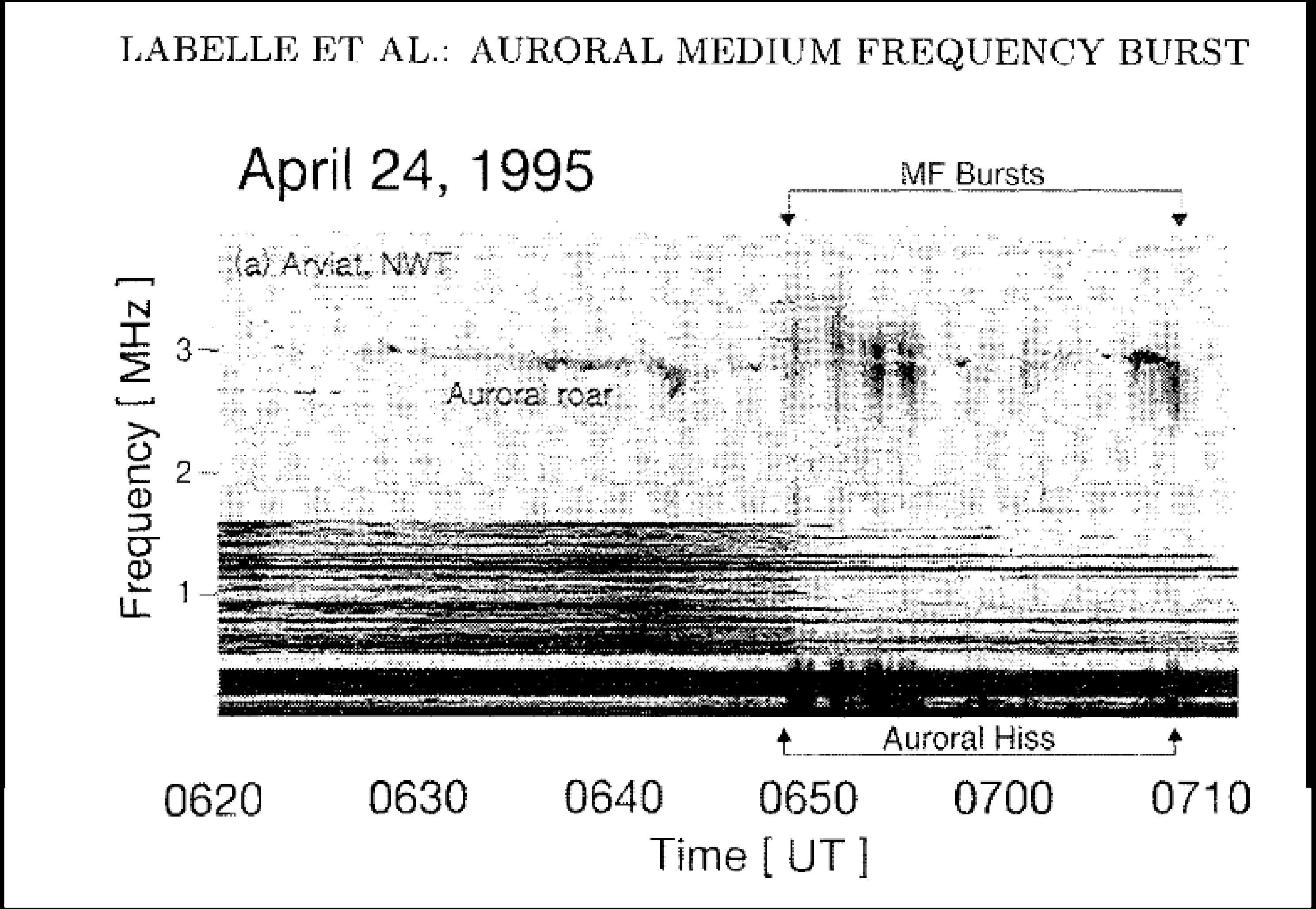
Primary Science Band

0.5 – 1.0 MHz

Marginal Science Band

1.0-1.5 MHz

Avoids most transients



NOISE SOURCES: UNAVOIDABLE

Unavoidable Noise	Lunar 1 MHz Flux Density	Notes
Amplifier Noise	10^7 Jy	Comparable to Wind & SunRISE
Electron QTN Optimal	$3*10^5$ Jy	$n_e = 8/cm^3$
Electron QTN Moderate	10^7 Jy	$n_e = 250/cm^3$
Electron QTN Conservative	$6*10^7$ Jy	$n_e = 1000/cm^3$

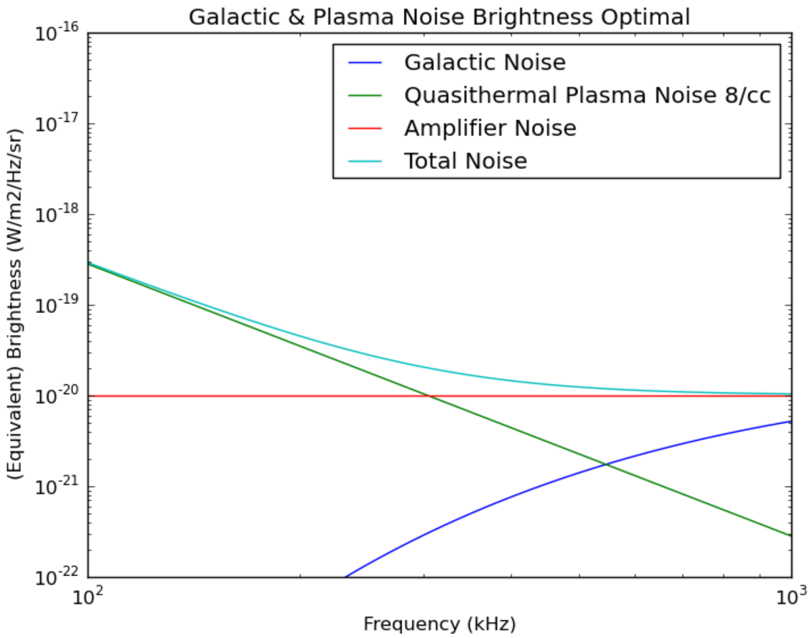
$$\sigma = \frac{2\, k_B\, T_{sys}}{\eta_s\, A_{eff}\, \sqrt{N(N-1)(N_{IF}\, \Delta T\, \Delta\nu)}}$$

$$V_{QTN}^2 \simeq 5.10^{-5}\frac{n_e T_e}{f^3 L},$$

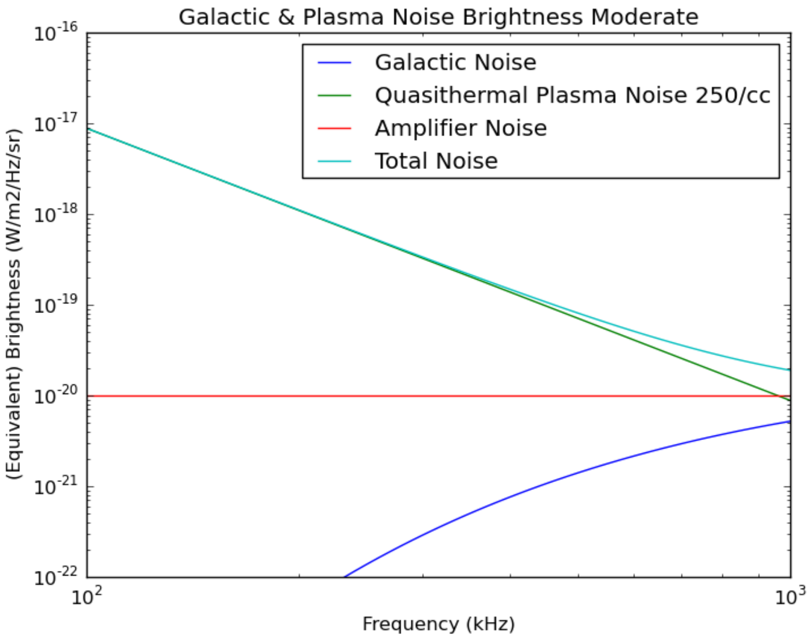
UNAVOIDABLE NOISE BUDGETS

Average noise taken over 500-1000kHz

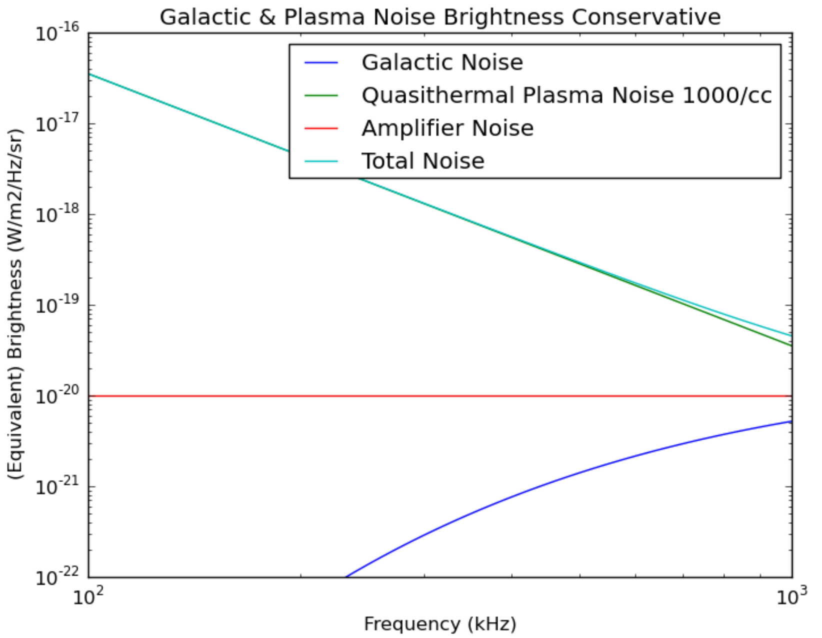
Average = 1.1e-20 W = 1.1e6 Jy



Average = 3.66e-20 W = 3.66e6 Jy

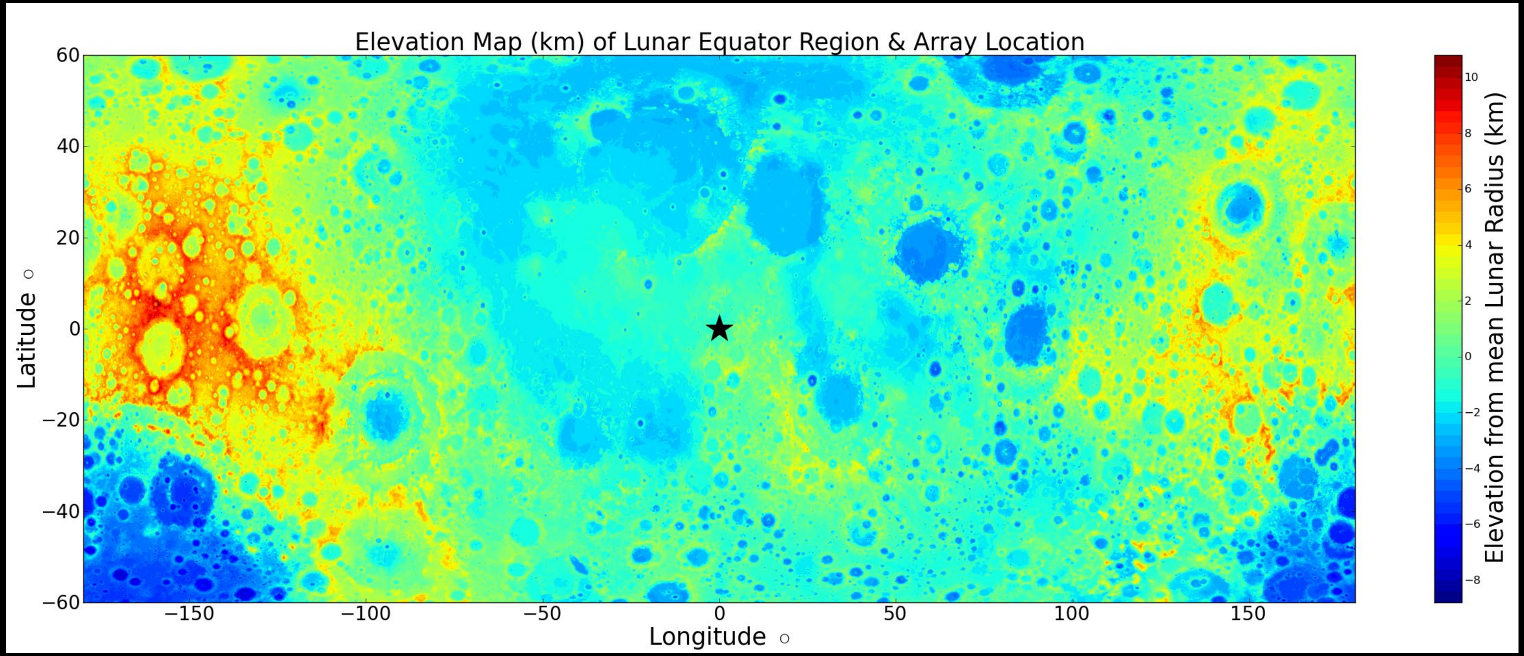


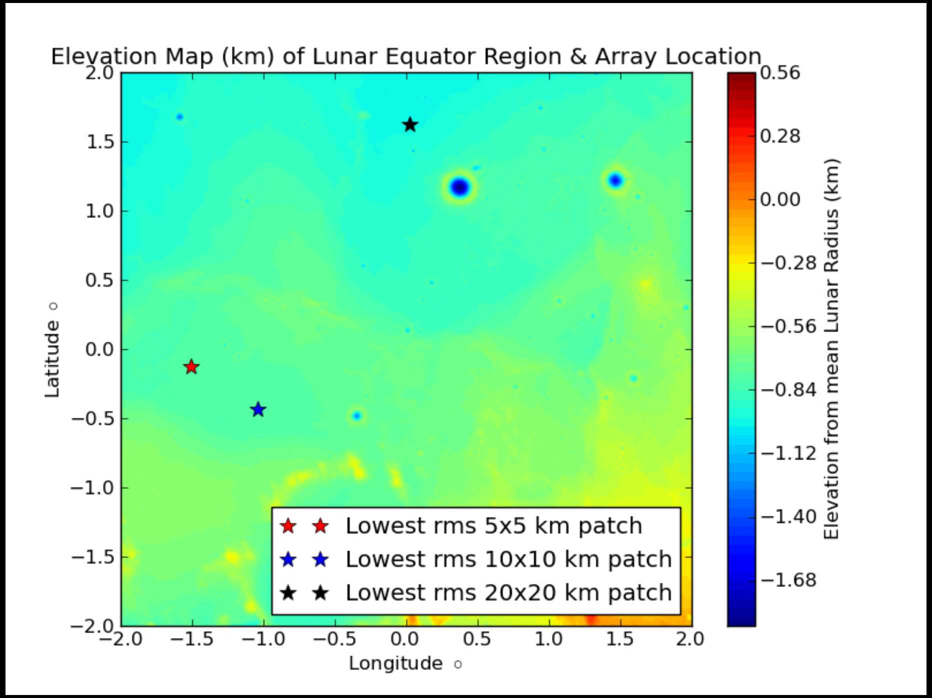
Average = 1.16e-19 W = 1.16e7 Jy



CREATING LUNAR ARRAYS

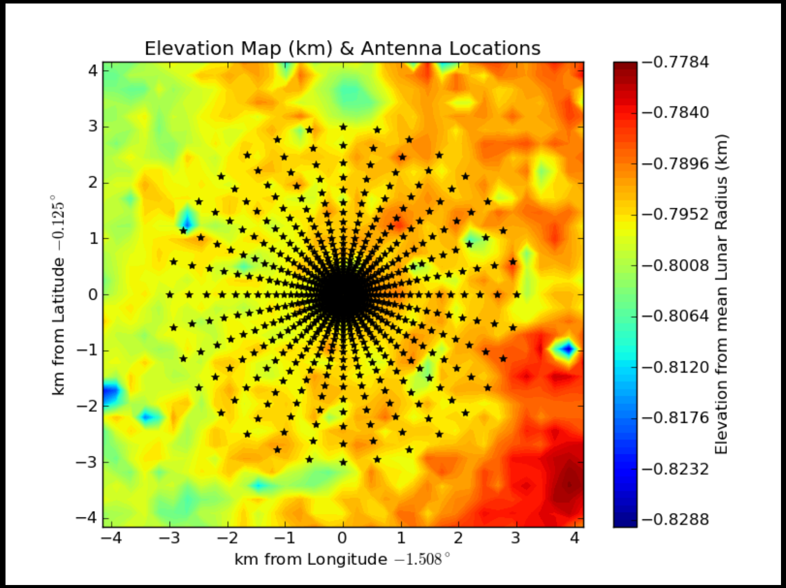
- LRO Laser Altimeter Data for Topography
- SPICE for orientation of Lunar coordinates with Sky and Earth

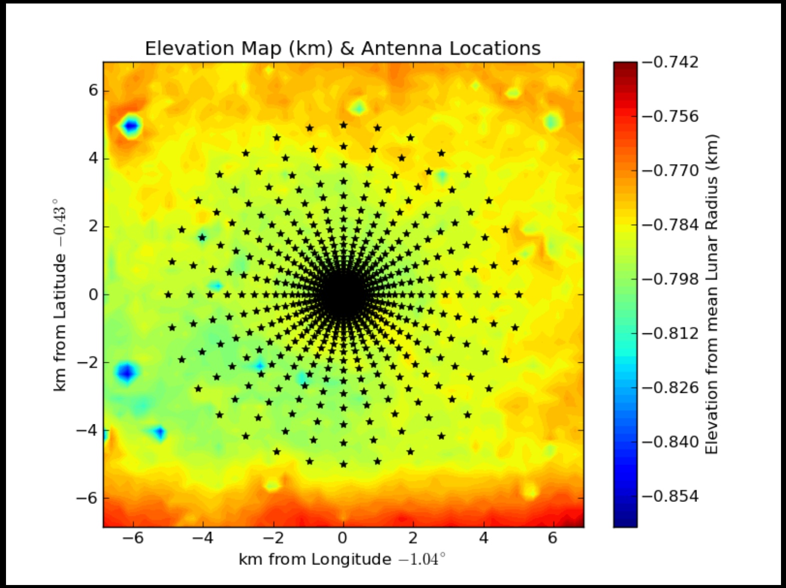


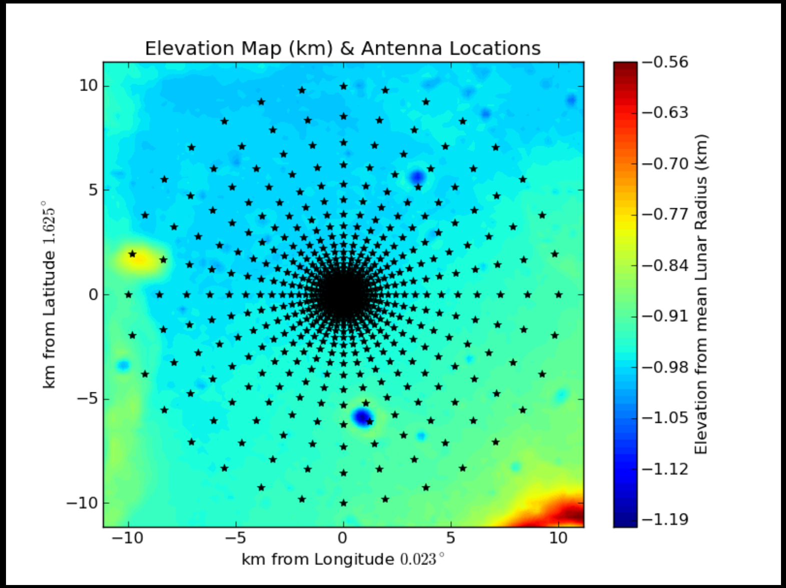


CREATING LUNAR ARRAYS

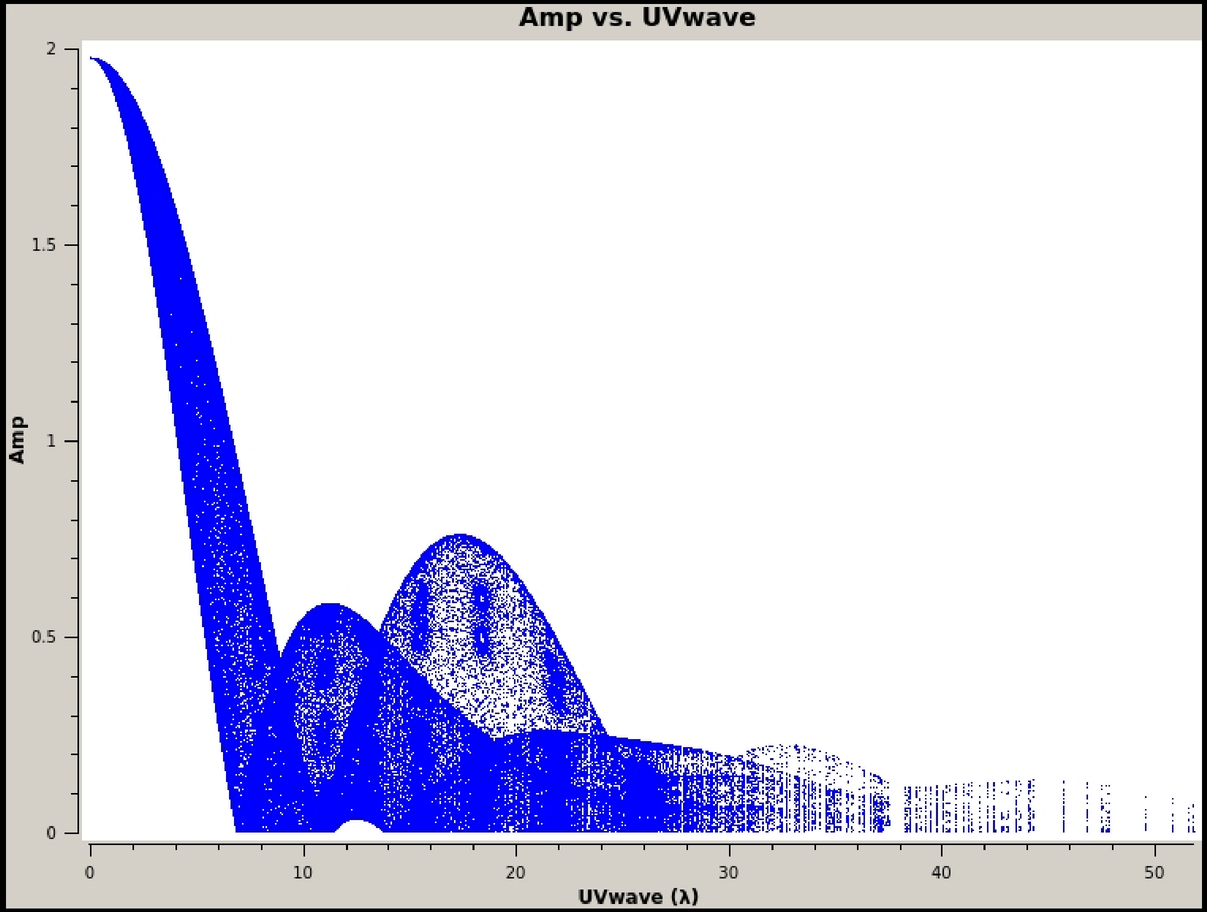
- LRO Laser Altimeter Data for Topography
- SPICE for orientation of Lunar coordinates with Sky and Earth
- Simulate 6, 10, and 20 km diameter arrays

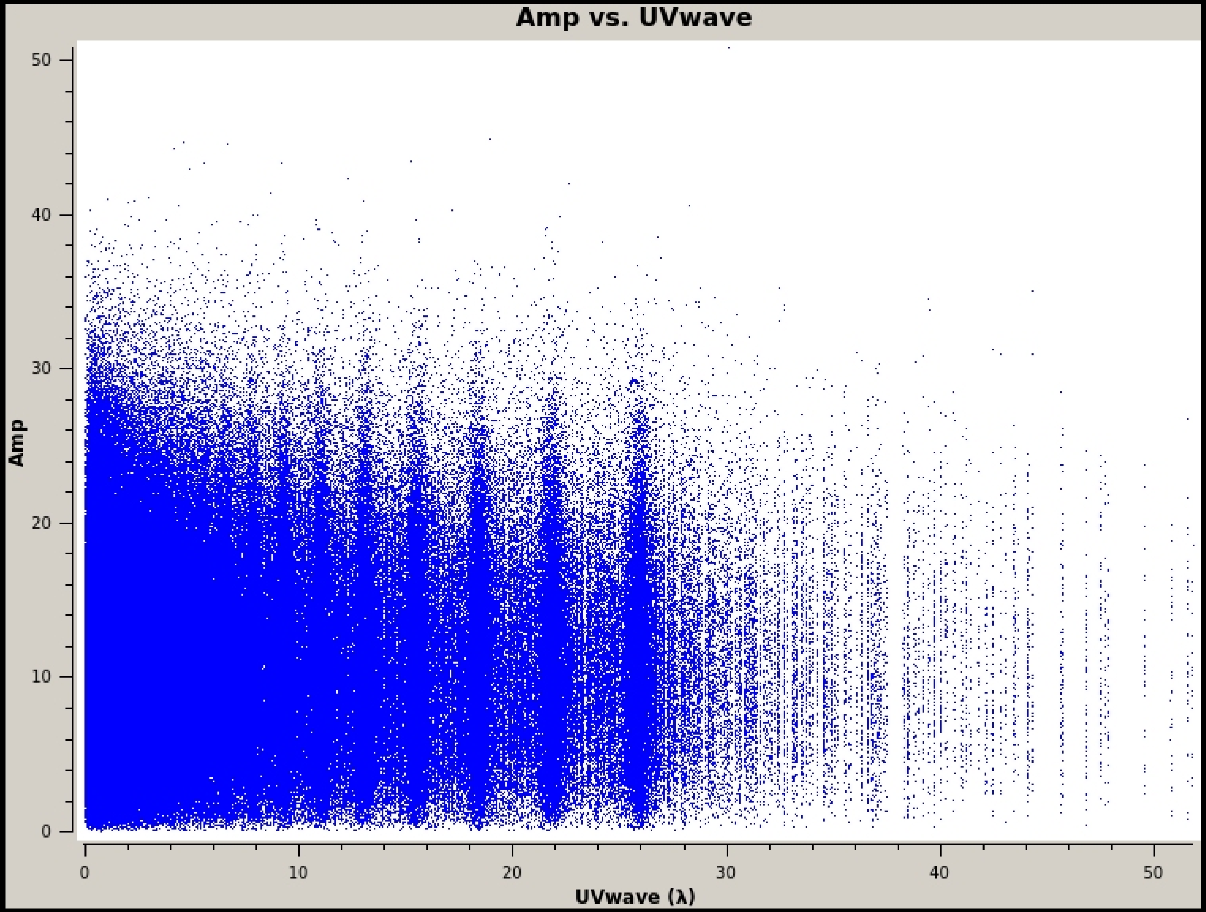


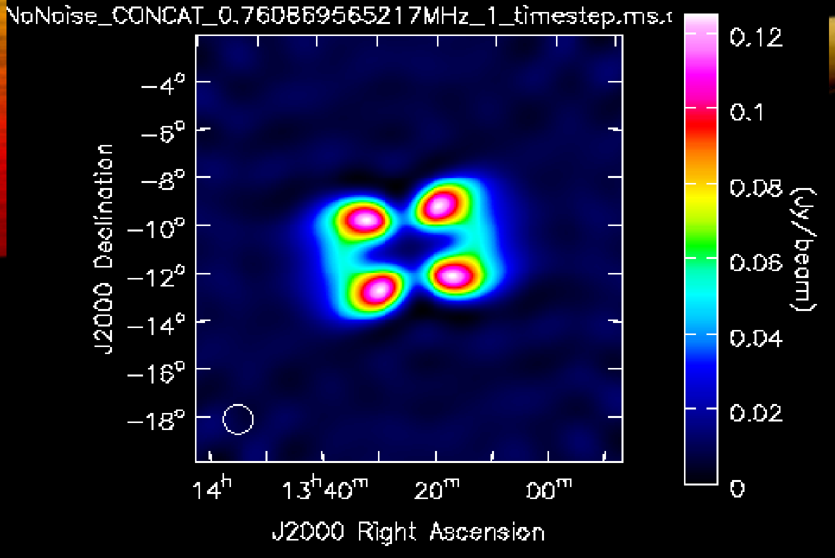




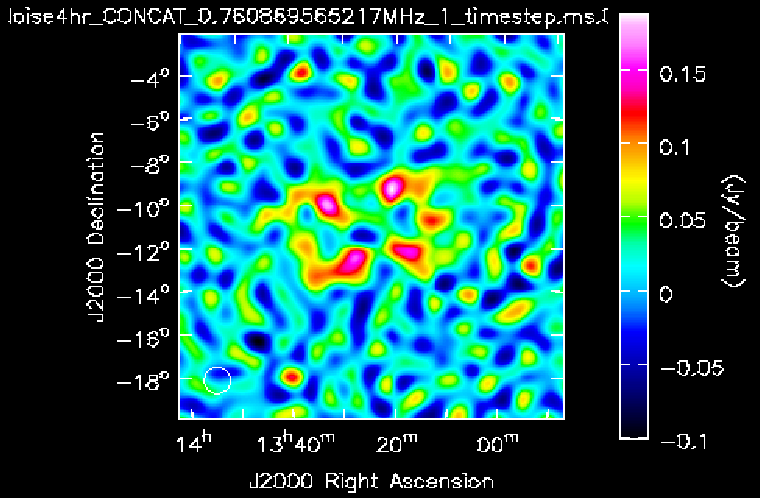
VISIBILITIES BEFORE AND AFTER SEFD NOISE ADDED

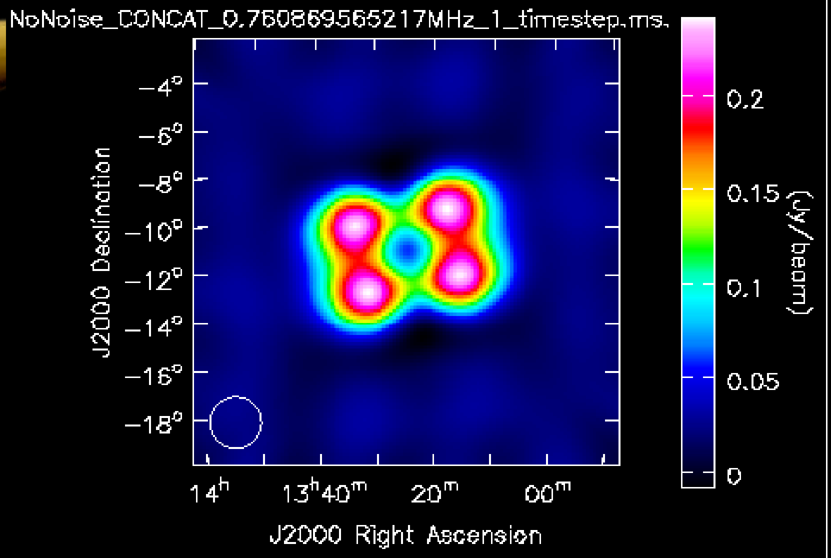




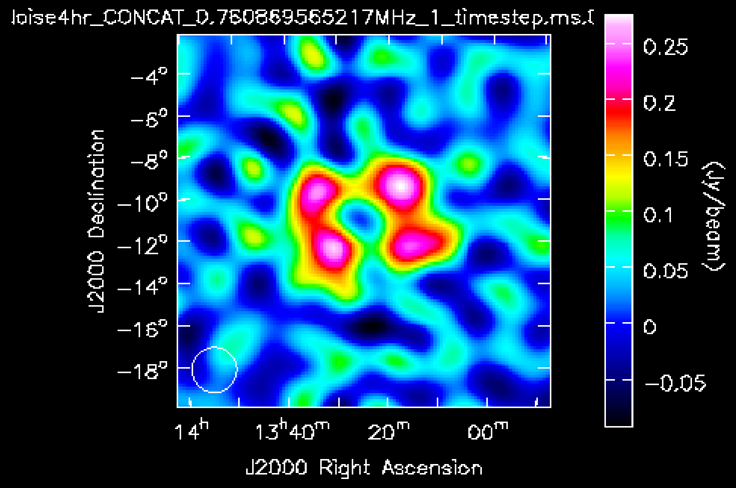


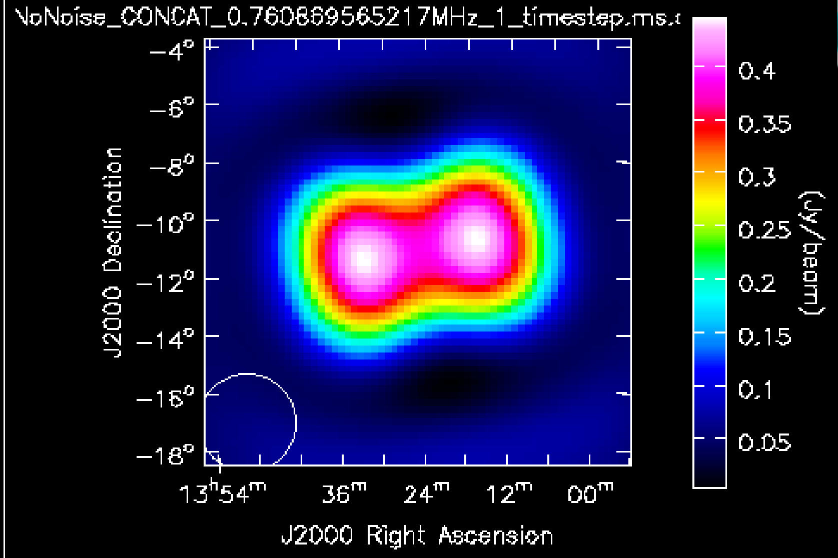
20 km, 4 hours integration optimal noise 16k antenna, rms = .0318
3.93 SNR



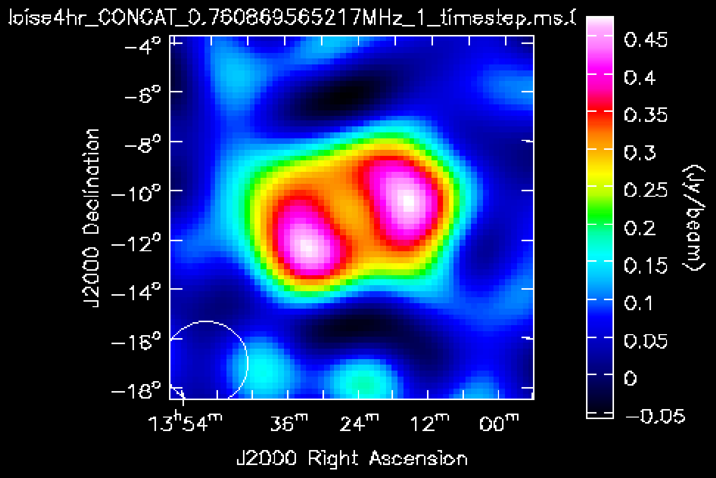


10 km, 4 hours integration optimal noise 16K antenna, rms = .041
5.85 SNR





6 km, 4 hour integration, optimal noise 16K antenna, rms = .073
6.44 SNR



ARRAY INTEGRATION TIMES

Integration Time (minutes) for 16384 Element Array over 500 kHz	6 km array	10 km array	20 km array
Optimal Noise 3 σ Lobe Detection Calm	104	126	280
Optimal Noise 3 σ Lobe Detection Storm	52	63	140
Moderate Noise 3 σ Lobe Detection Calm	1132	1372	3050
Moderate Noise 3 σ Lobe Detection Storm	566	686	1525
Conservative Noise 3 σ Lobe Detection Calm	11096	13442	28873
Conservative Noise 3 σ Lobe Detection Storm	5548	6721	14936

CONCLUSIONS

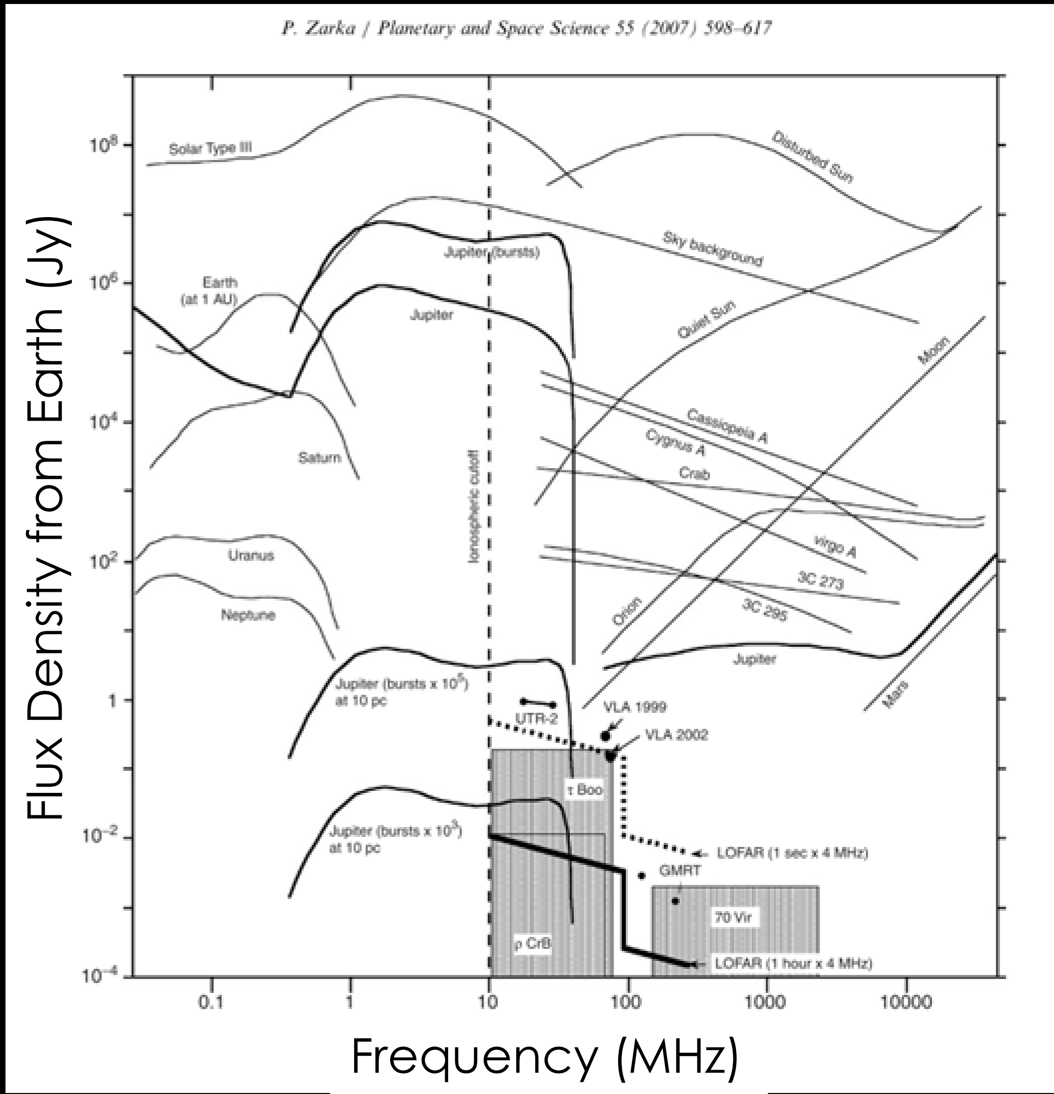
- For a moderate lunar surface electron density of 250/cm^3, **the radiation belts may be detected in 1-2 times a day with a 16384 element array over a 10 km diameter circle.**

- Lunar surface electron densities in the 1000s $\longrightarrow$ too much noise

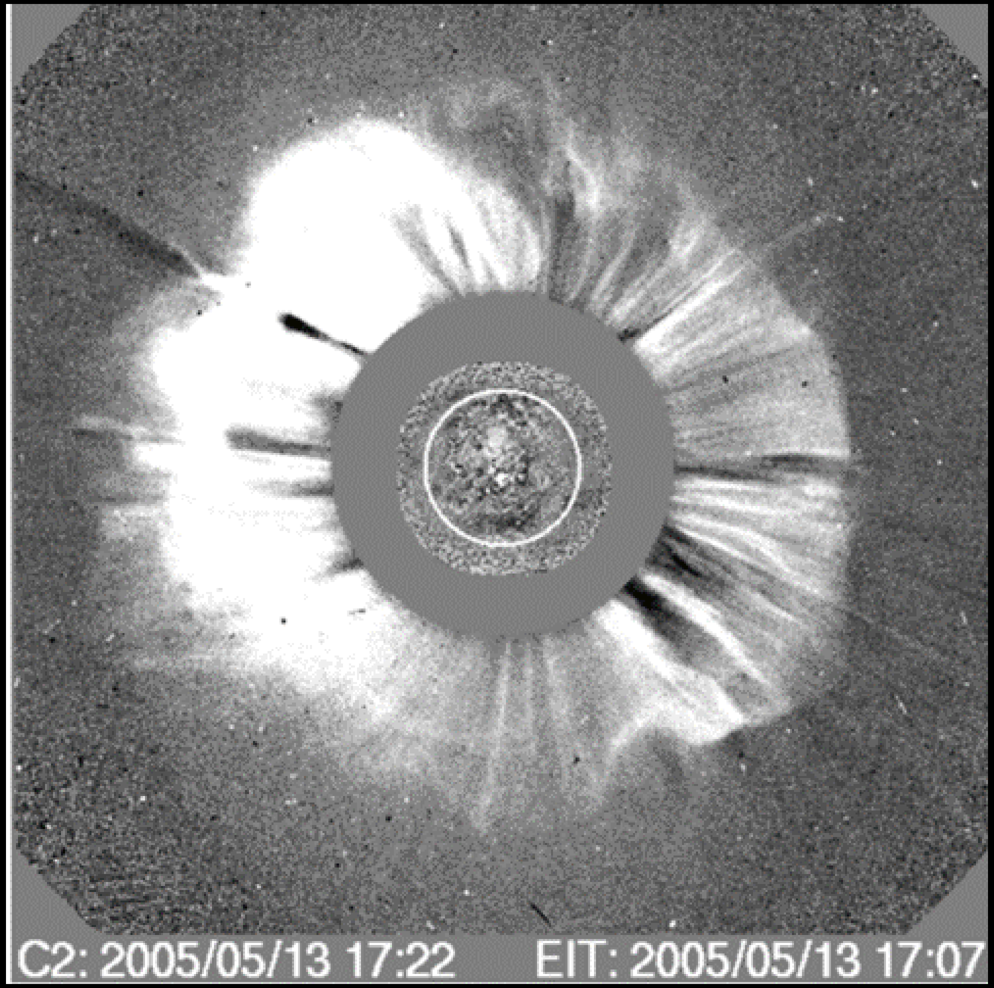
- **If functional at Lunar night/dusk, 10-20 snapshots a day possible**

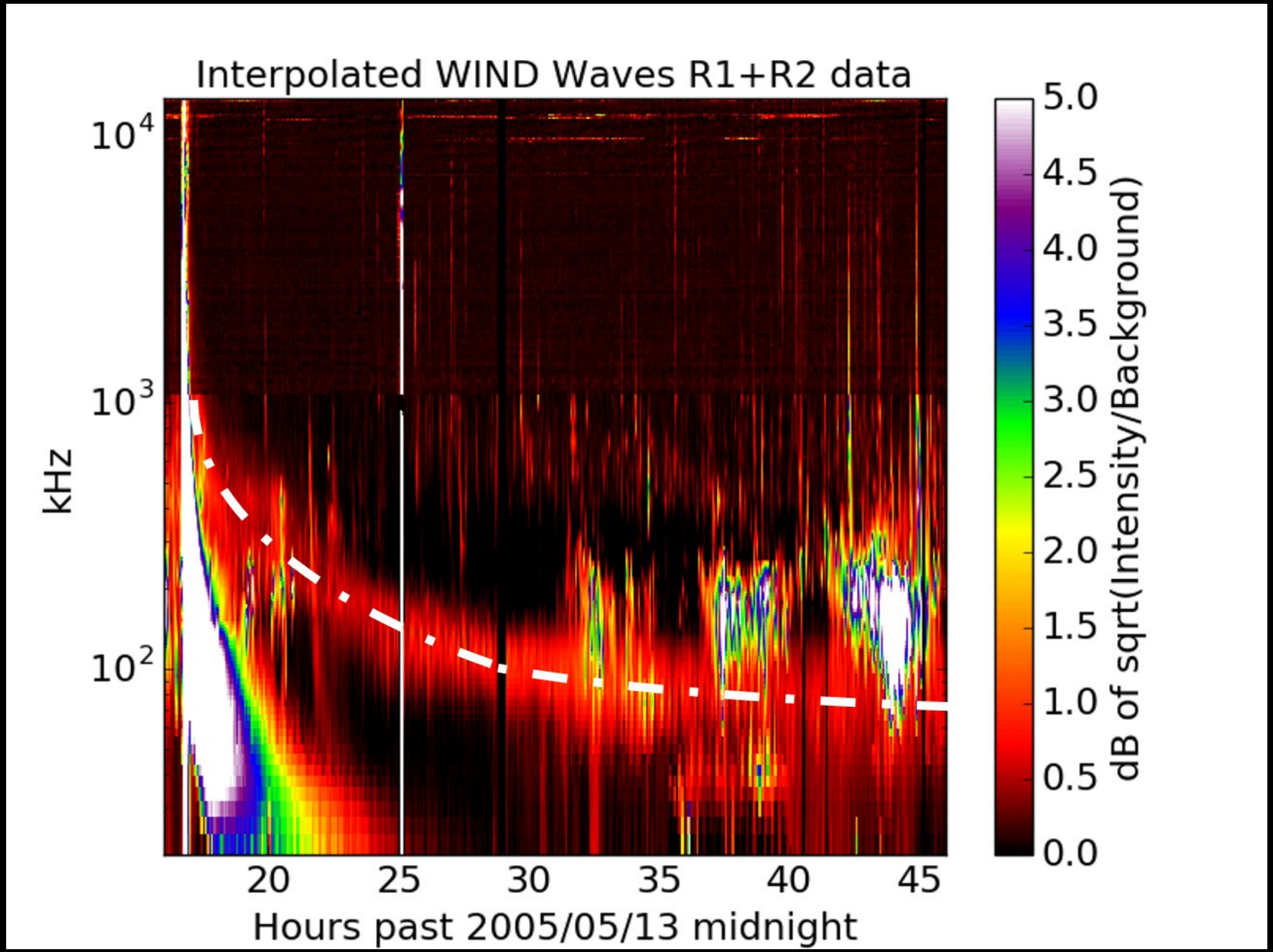
RETROSPECTIVE

- Many low frequency emissions are seen by single antenna in space
- Never been imaged in these low frequencies
- New window to observe the universe
- Exoplanet detections also possible with ~1 Jy Sensitivity
- Heliophysics and Astrophysics also possible



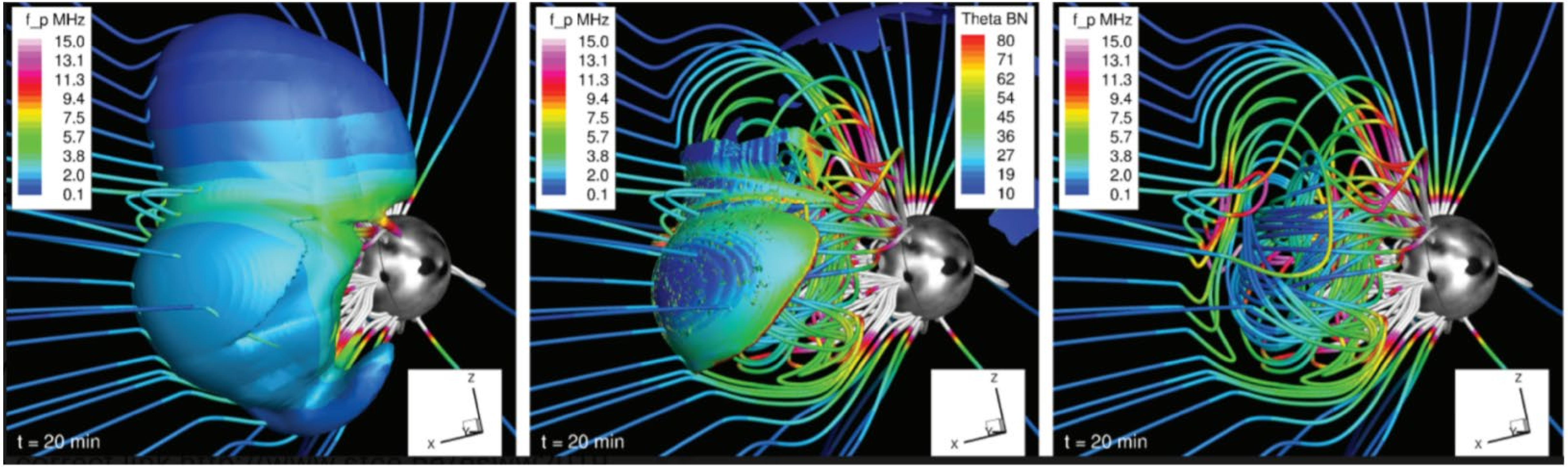
2005/05/13 CME





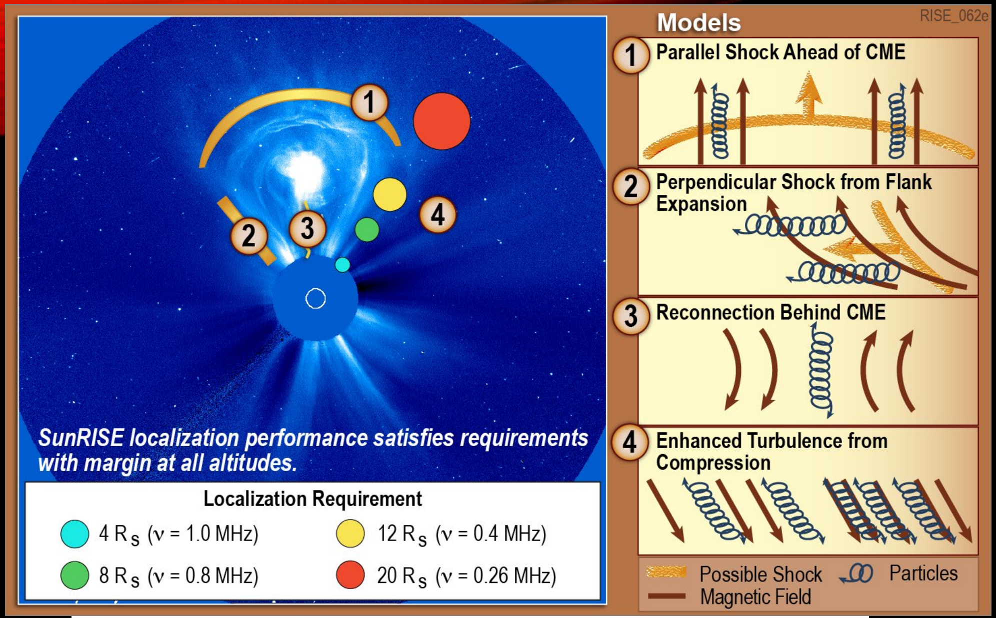
MHD CME SIMULATION

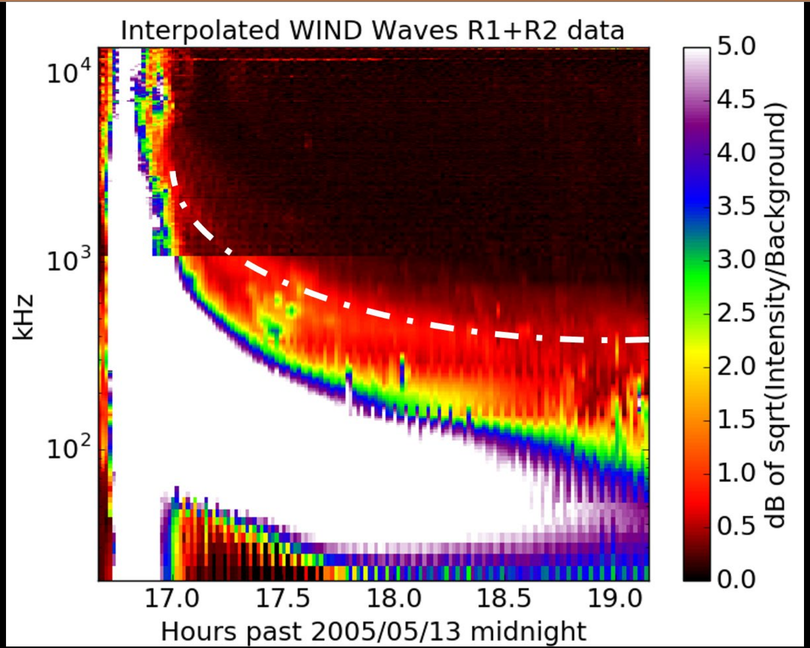
CME Density Enhancement | Entropy Derived Shock | Magnetic Field

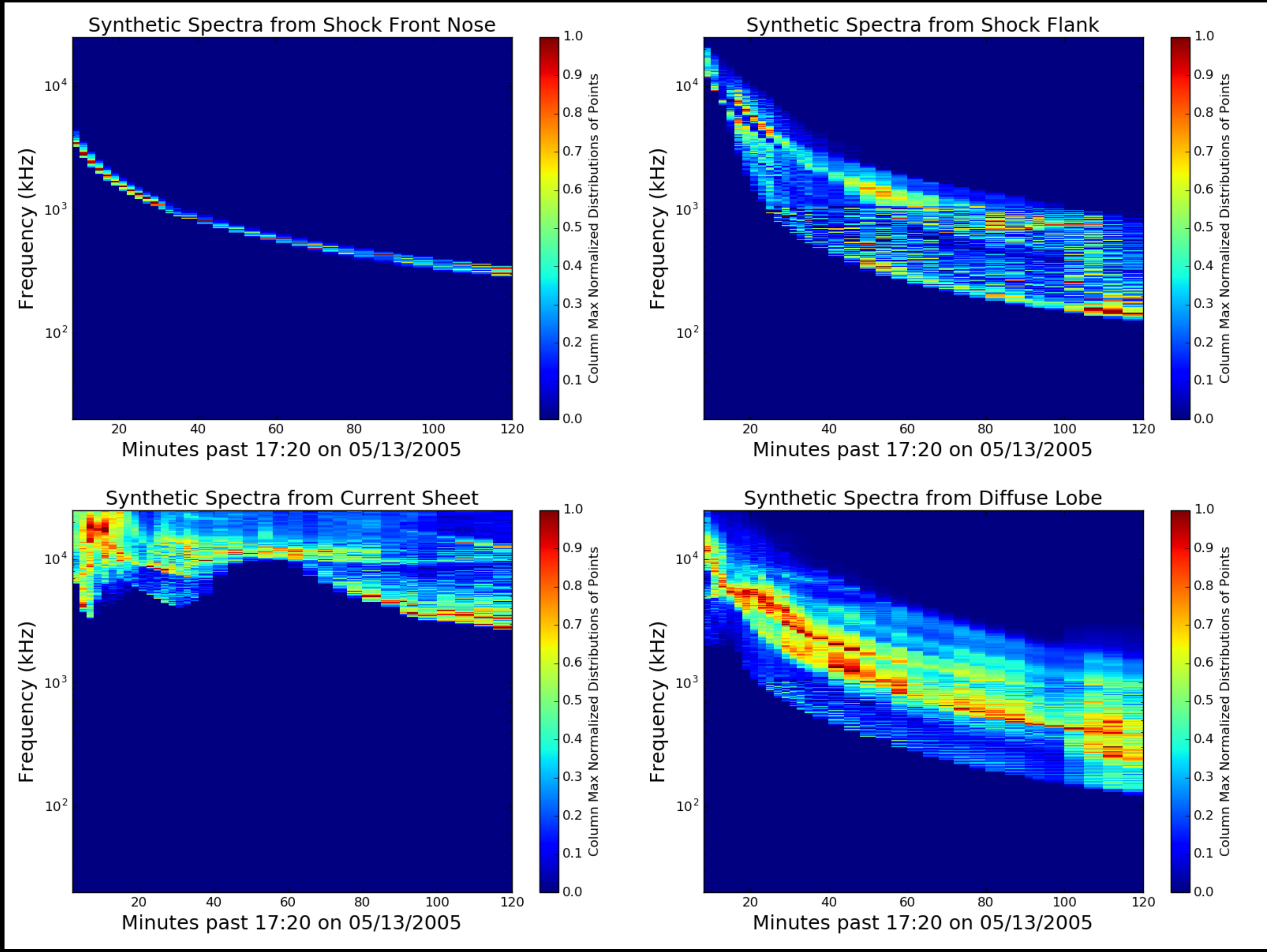


Snapshots from a AWSoM 2-Temperature MHD Simulation of a Radio-Loud CME on May 13, 2005

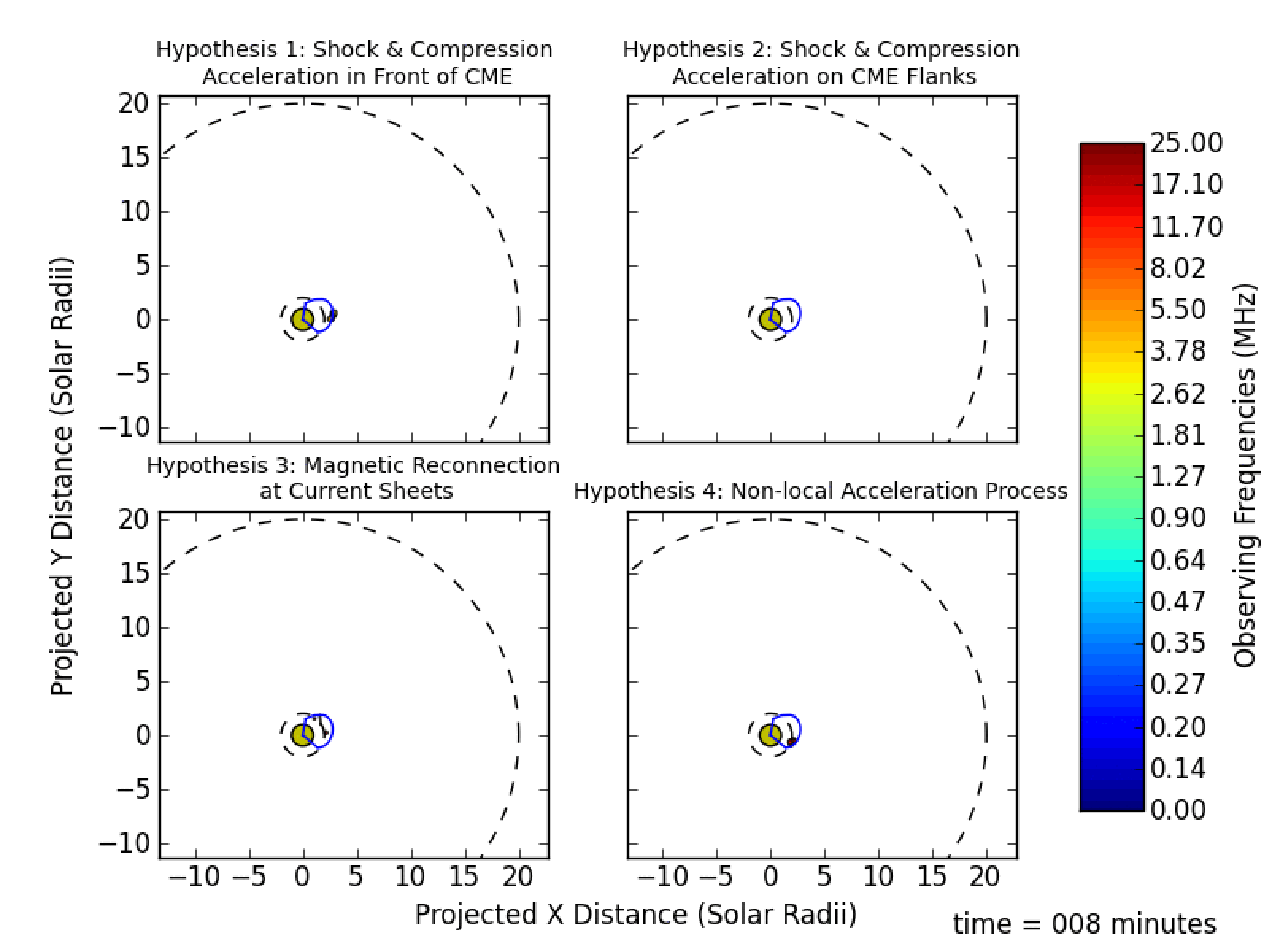
SYNTHETIC SPECTRA FROM MHD







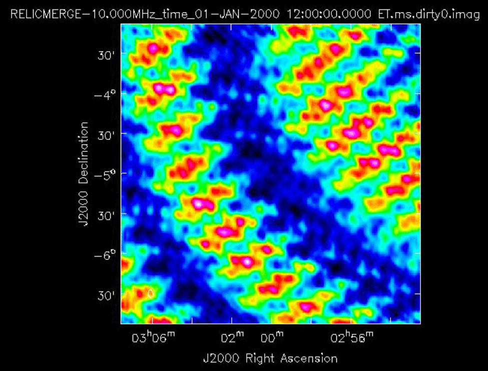
SUNRISE RECOVERED RADIO EMISSION



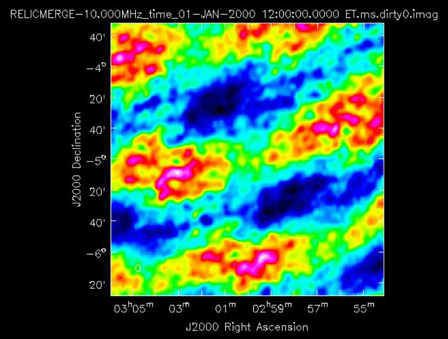
ASTROPHYSICS, RELIC ARRAY VARYING #SPACECRAFT

900 arcsec DRAGN at 10 MHz

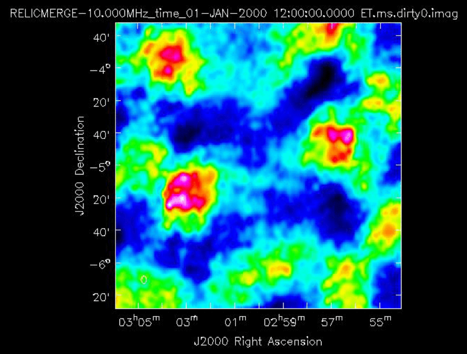
8 Spacecraft



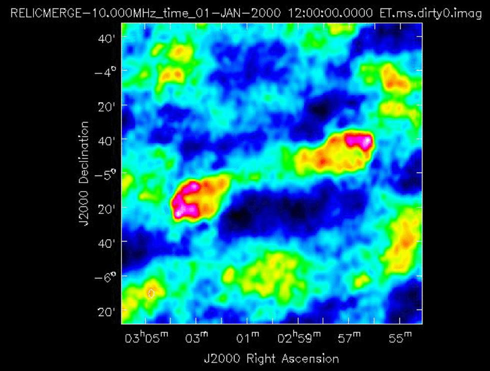
16 Spacecraft



24 Spacecraft



32 Spacecraft



FUTURE WORK

- Fine Tuning Array Shape, now using basic logarithmic spacings
- Optimize shape for shortest cable length, or use tall poll for wireless comms at central station
- Include Active foreground removal in simulations (hard problem for high precision)
- Study possible effects of mutual coupling on Array sensitivity
- Flesh out ideas with data from Radio wave Observations on the Lunar Surface of the photoElectron Sheath (ROLSES)