# Solar Imaging and Space Weather using MWA and RAPID

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MIT Haystack Observatory

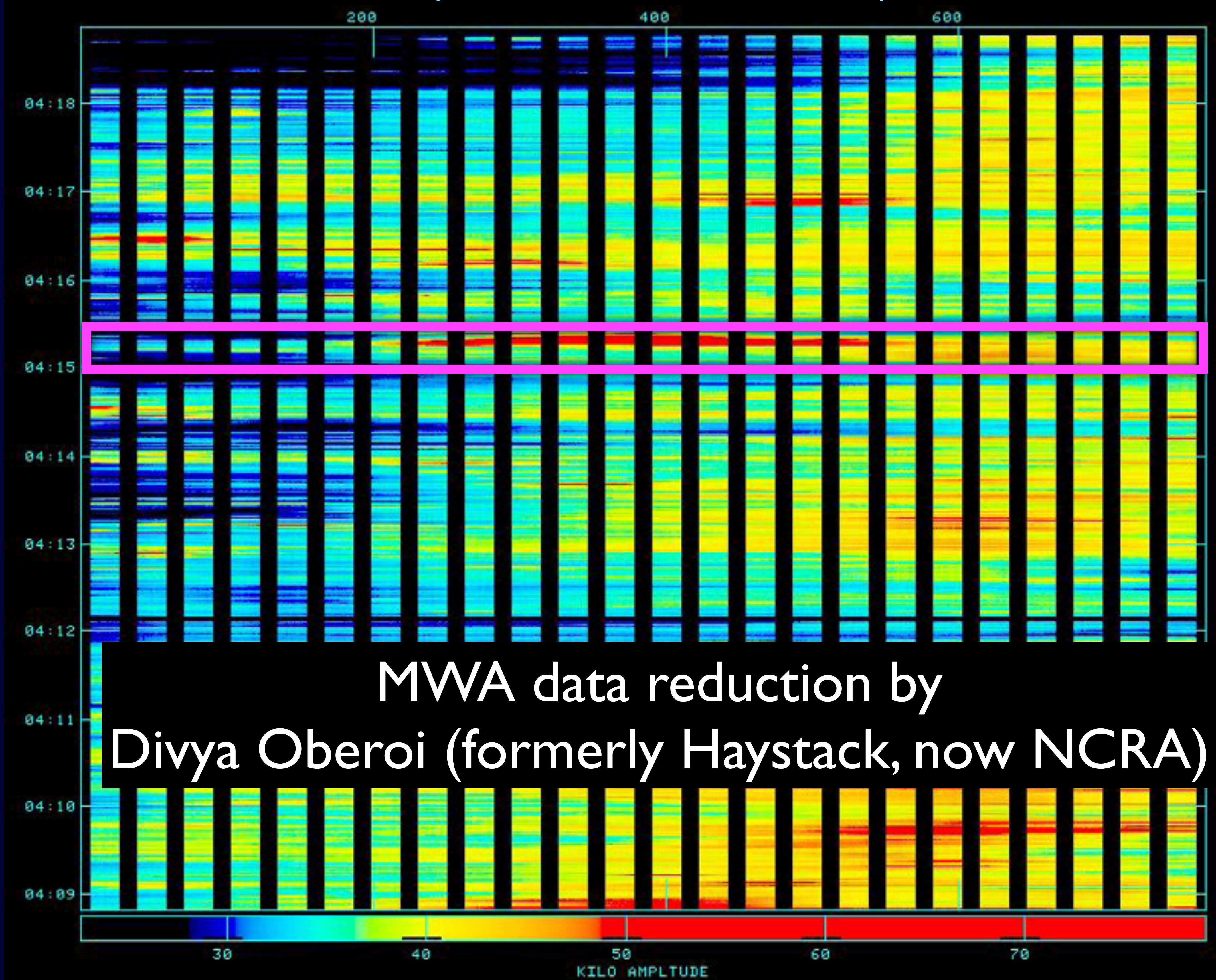
Gerfeest, 5 November 2013

# MWA - The Finished Array



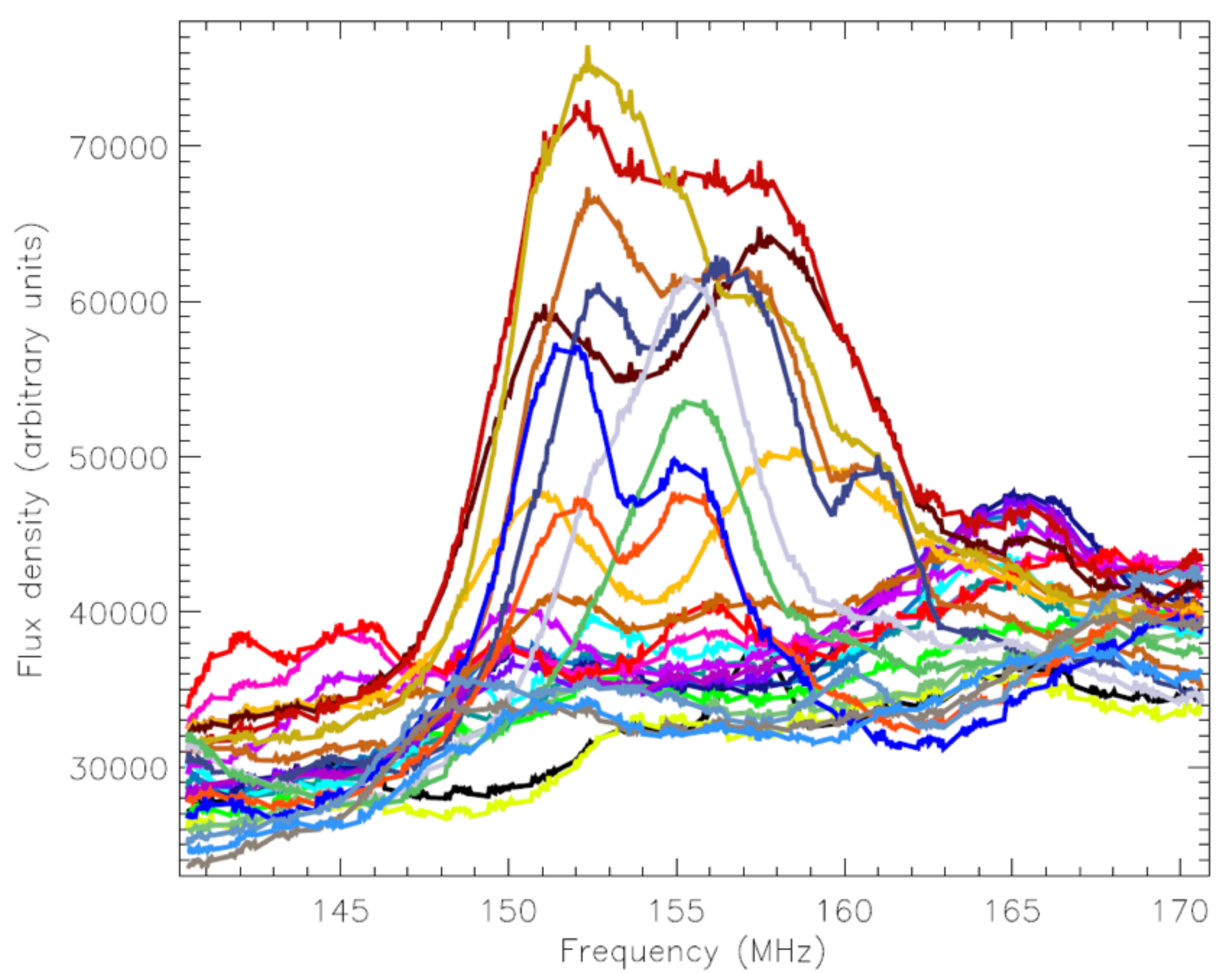

# Dynamic Spectrum

(One MWA baseline)

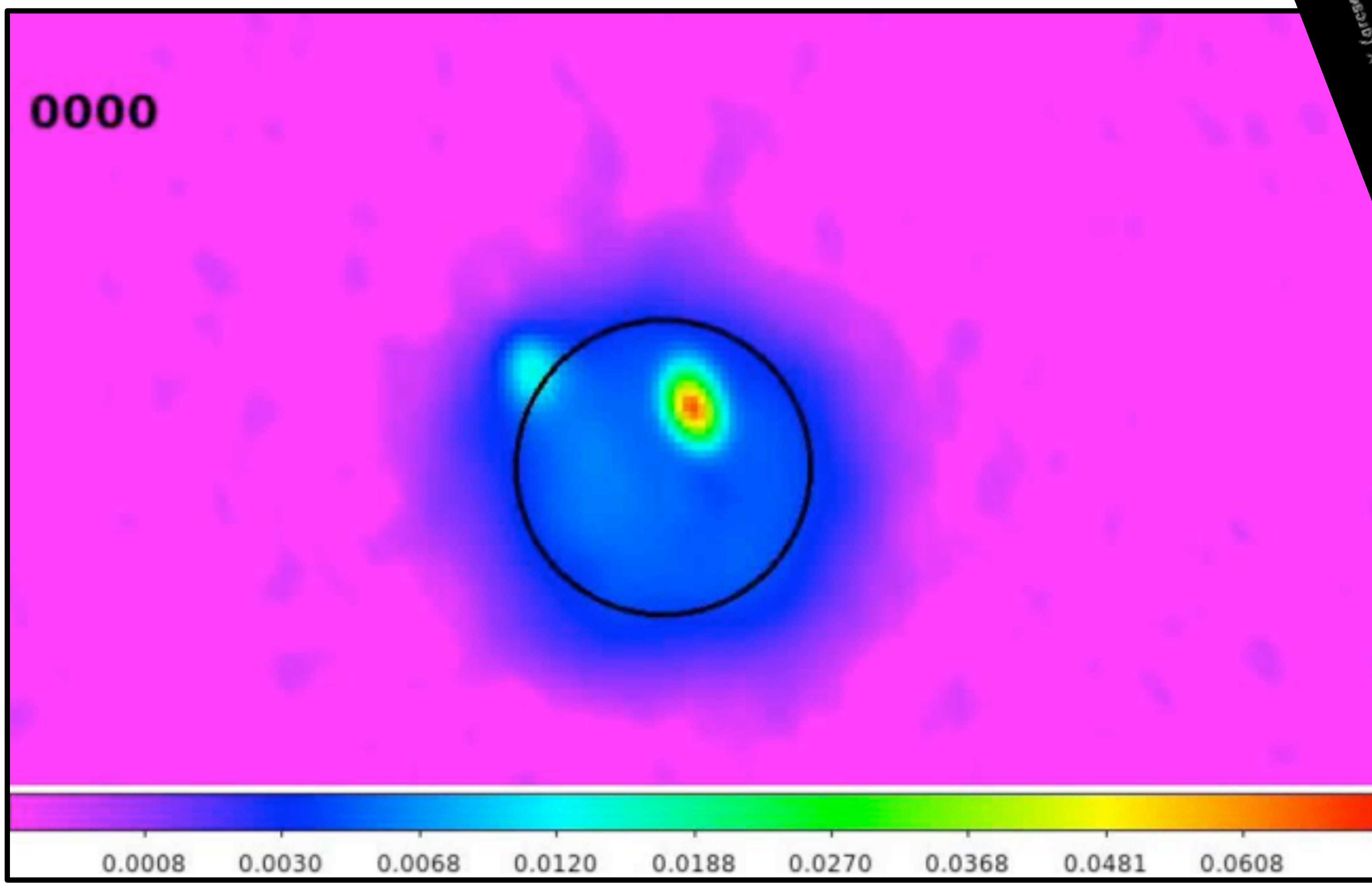


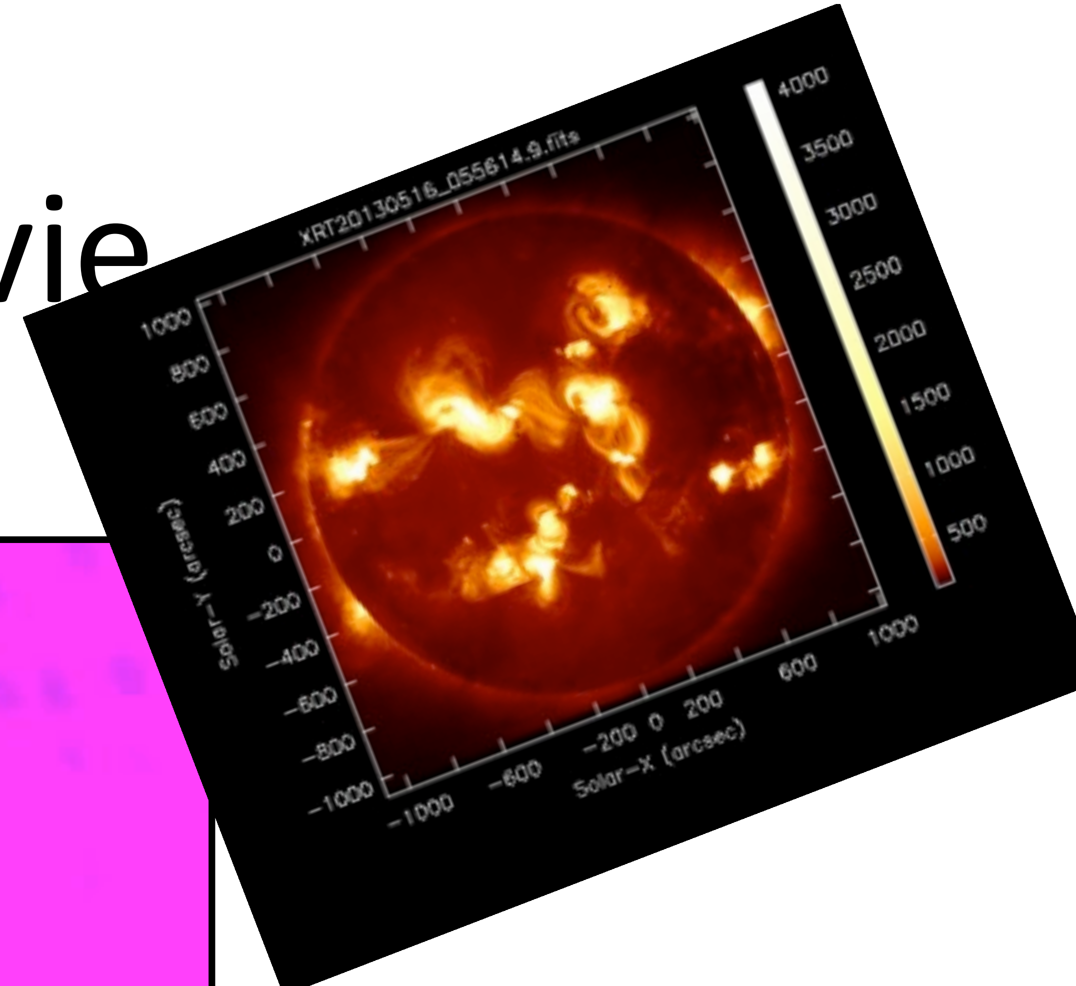

MWA data reduction by
Divya Oberoi (formerly Haystack, now NCRA)

# Extreme Spectral Variability



# Radio Movie



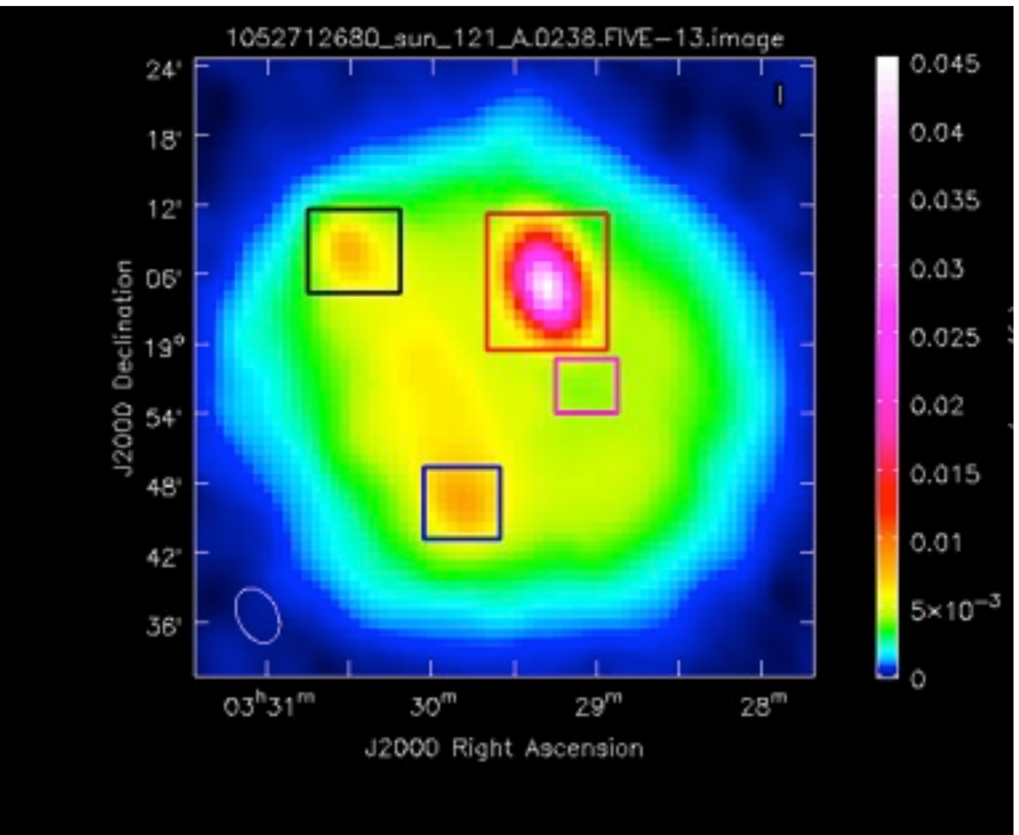



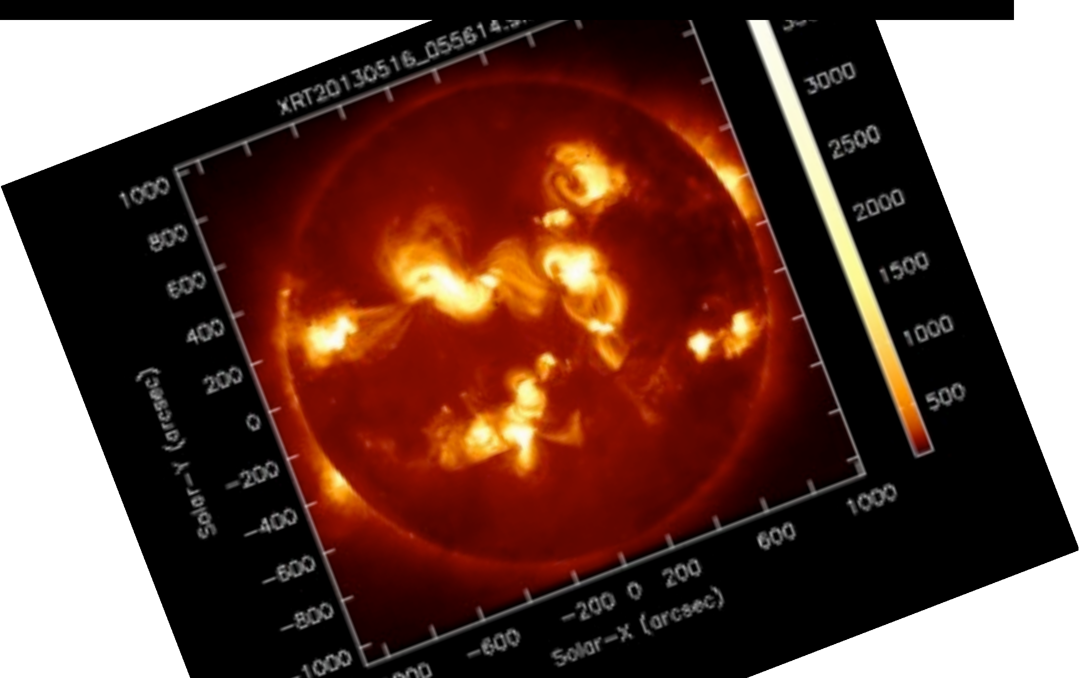

16 May, 2013
04:11:04 – 04:16:00 UT

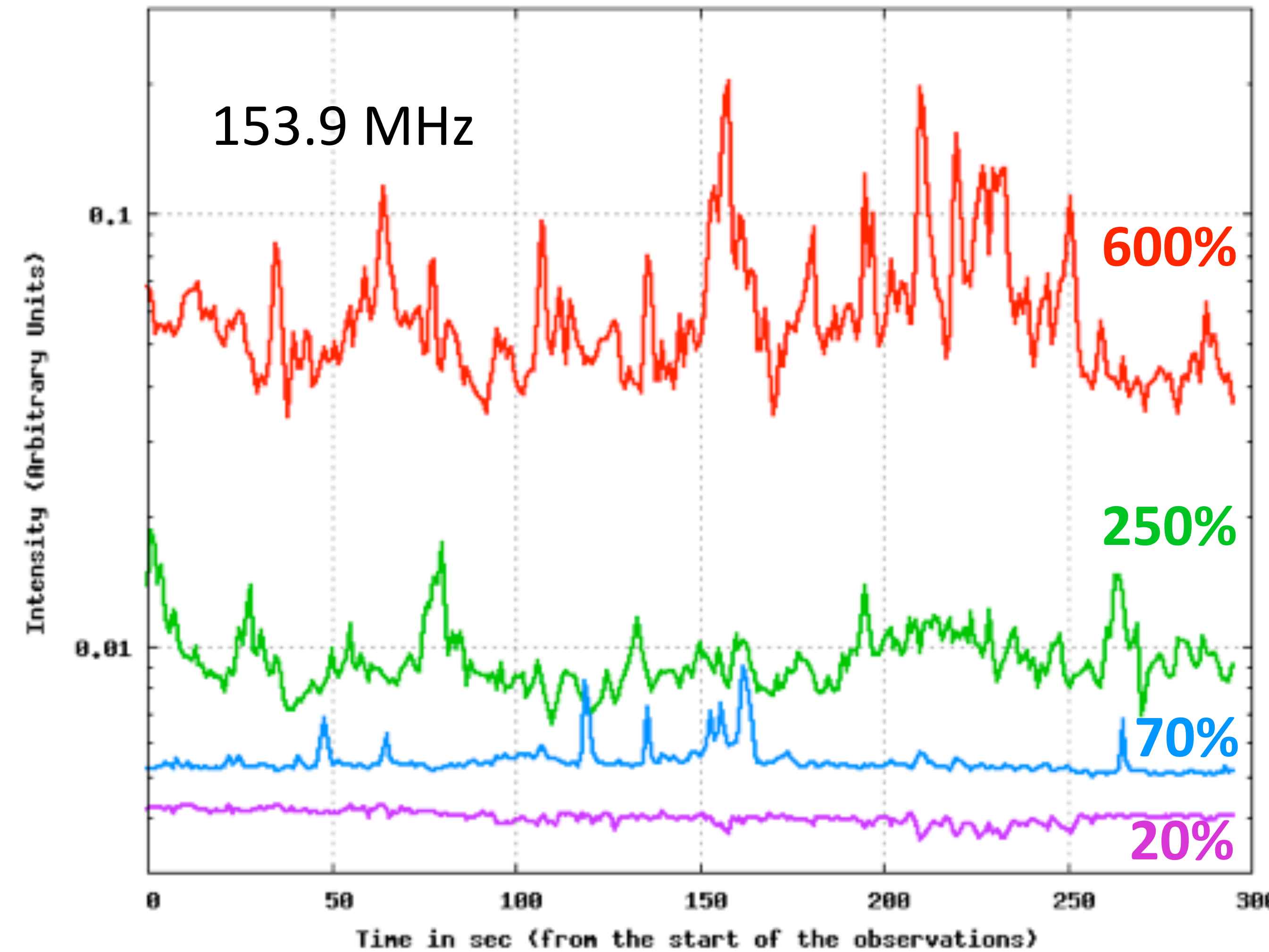
$\nu_0$=153.905 MHz
$\Delta\nu$=640 kHz

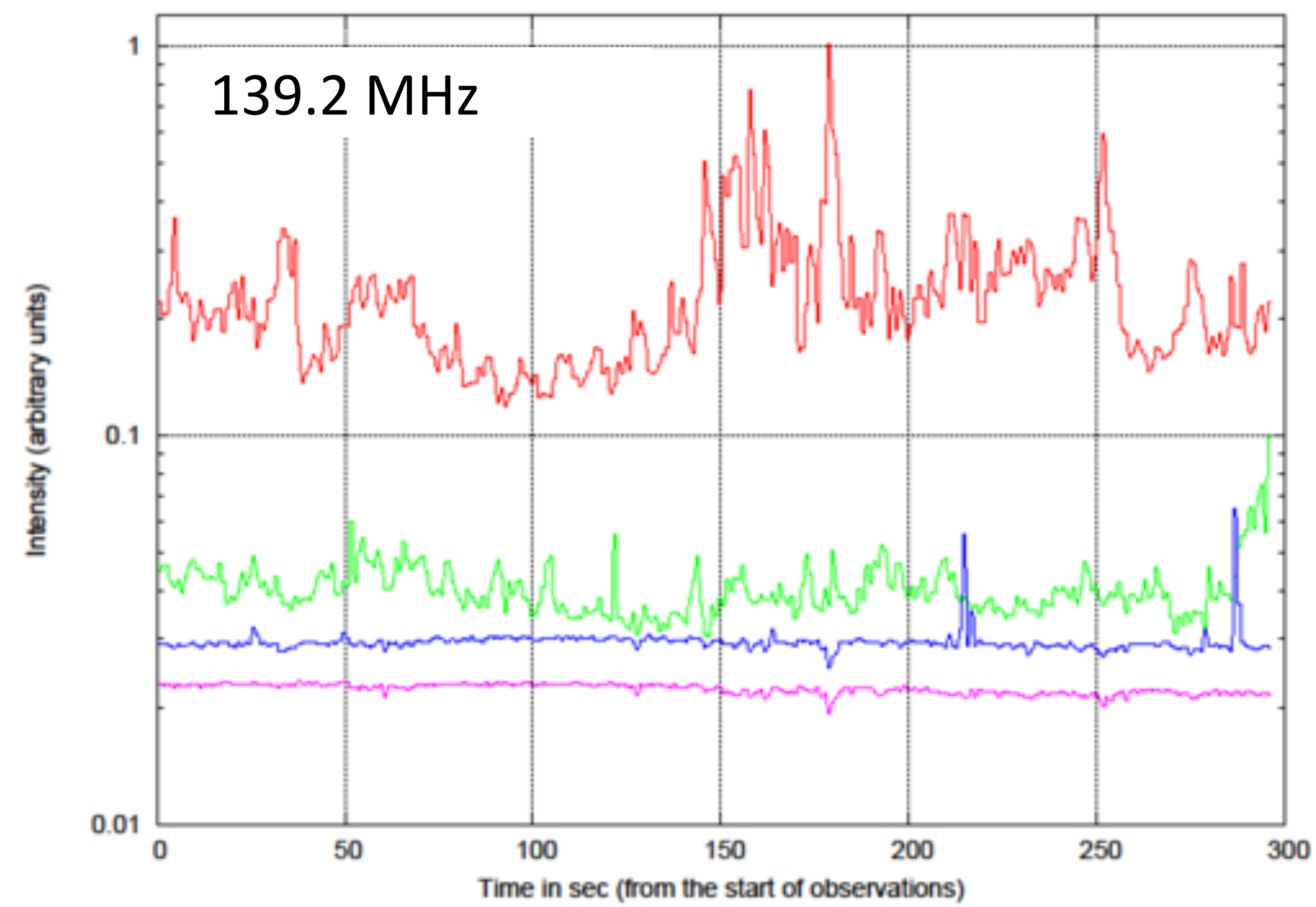
$\Delta t$=1 second

Imaging Dynamic Range ~1500


1052712680_sun_121_A.0238.FIVE-13.image
J2000 Declination
J2000 Right Ascension
24'
18'
12'
06'
19°
54'
48'
42'
36'
03h31m
30m
29m
28m
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
5×10−3
0


Solar-Y (arcsec)
Solar-X (arcsec)
3000
2500
2000
1500
1000
500


153.9 MHz
600%
250%
70%
20%
Intensity (Arbitrary Units)
0.1
0.01
0
50
100
150
200
250
300
Time in sec (from the start of the observations)


139.2 MHz
Intensity (arbitrary units)
1
0.1
0.01
0
50
100
150
200
250
300
Time in sec (from the start of observations)

# The ‘Carrington Event’: Aug 27 - Sep 7, 1859

Boston MA to Portland ME telegraph line
Sept 2, 1859

“We observed the influence upon the lines at the time of commencing business — 8 o’clock — and it continued so strong up to 9 1/2 as to prevent any business from being done, excepting *by throwing off the batteries at each end of the line and working by the atmospheric current entirely!*”

NY Times

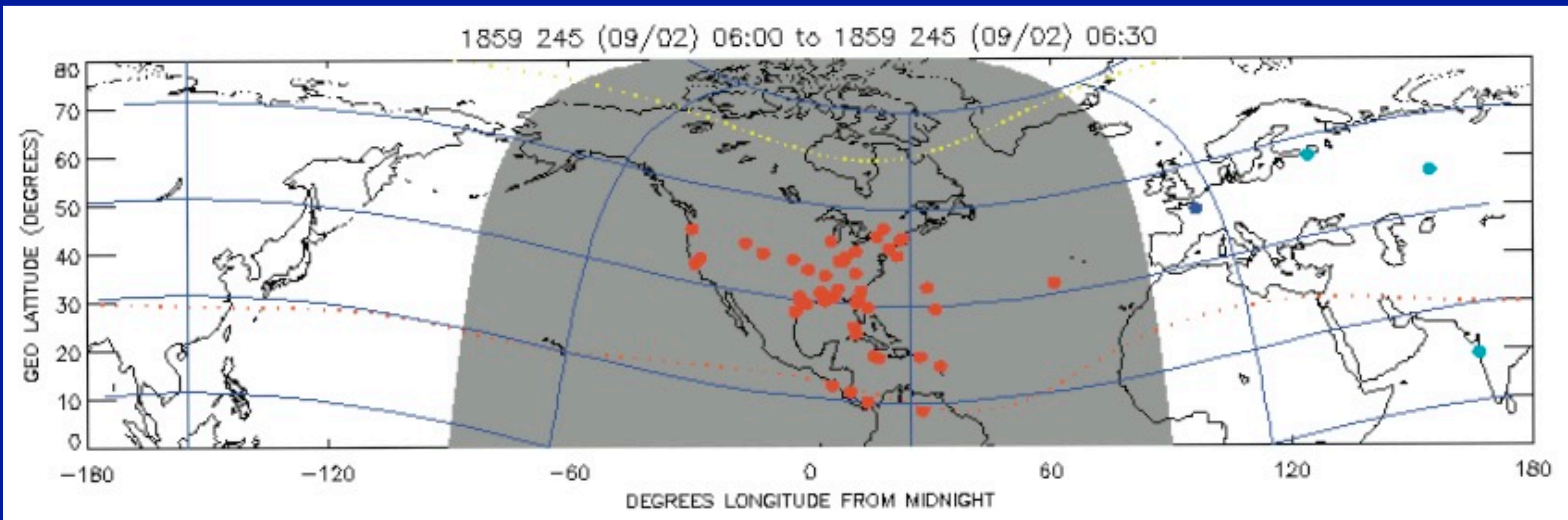
Operator exchange:

**BOS**: Mine is also disconnected, and we are working with the auroral current. How do you receive my writing?

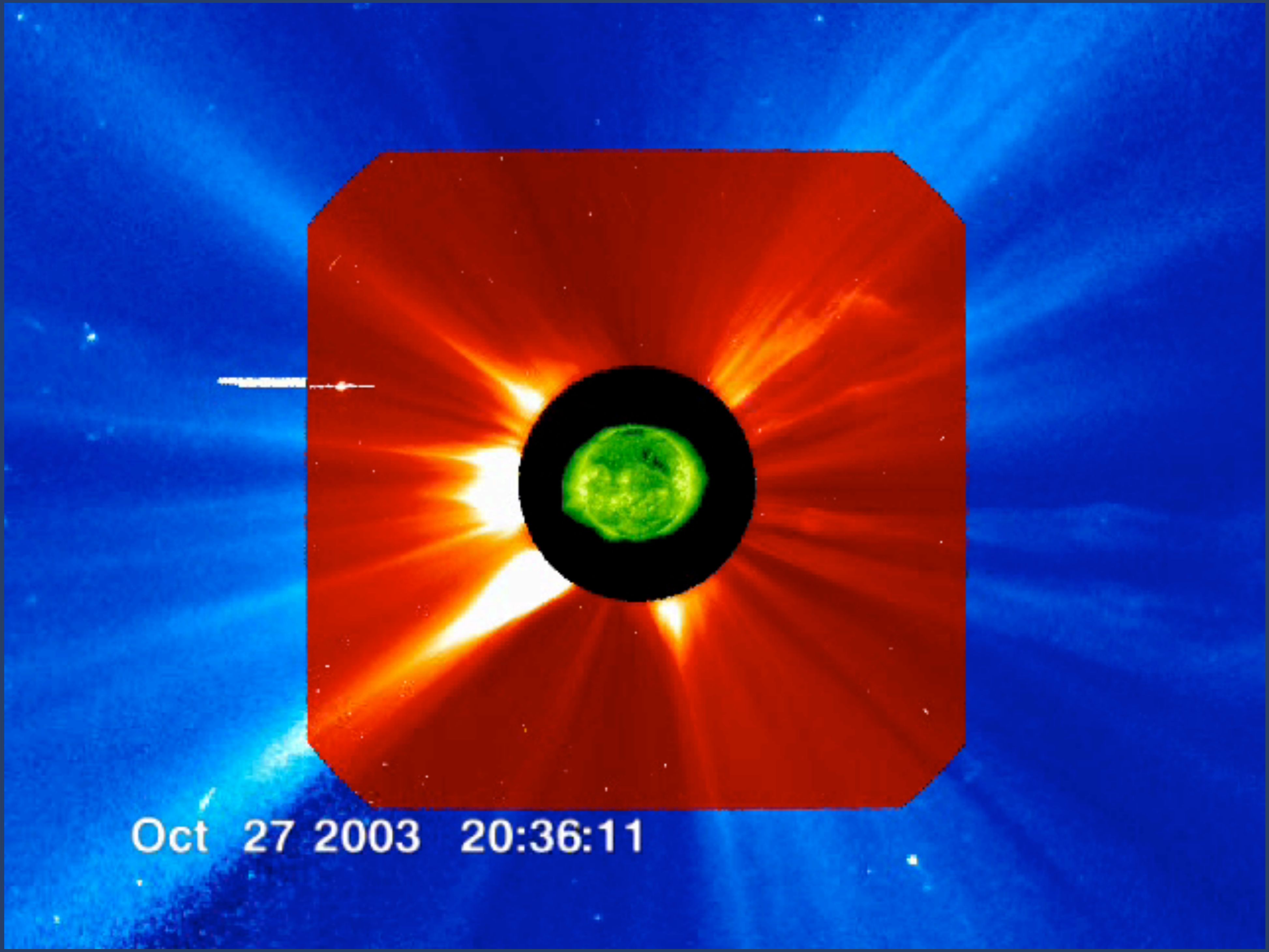
**POR**: Better than with our batteries on..

Very well. Shall I go ahead with business?

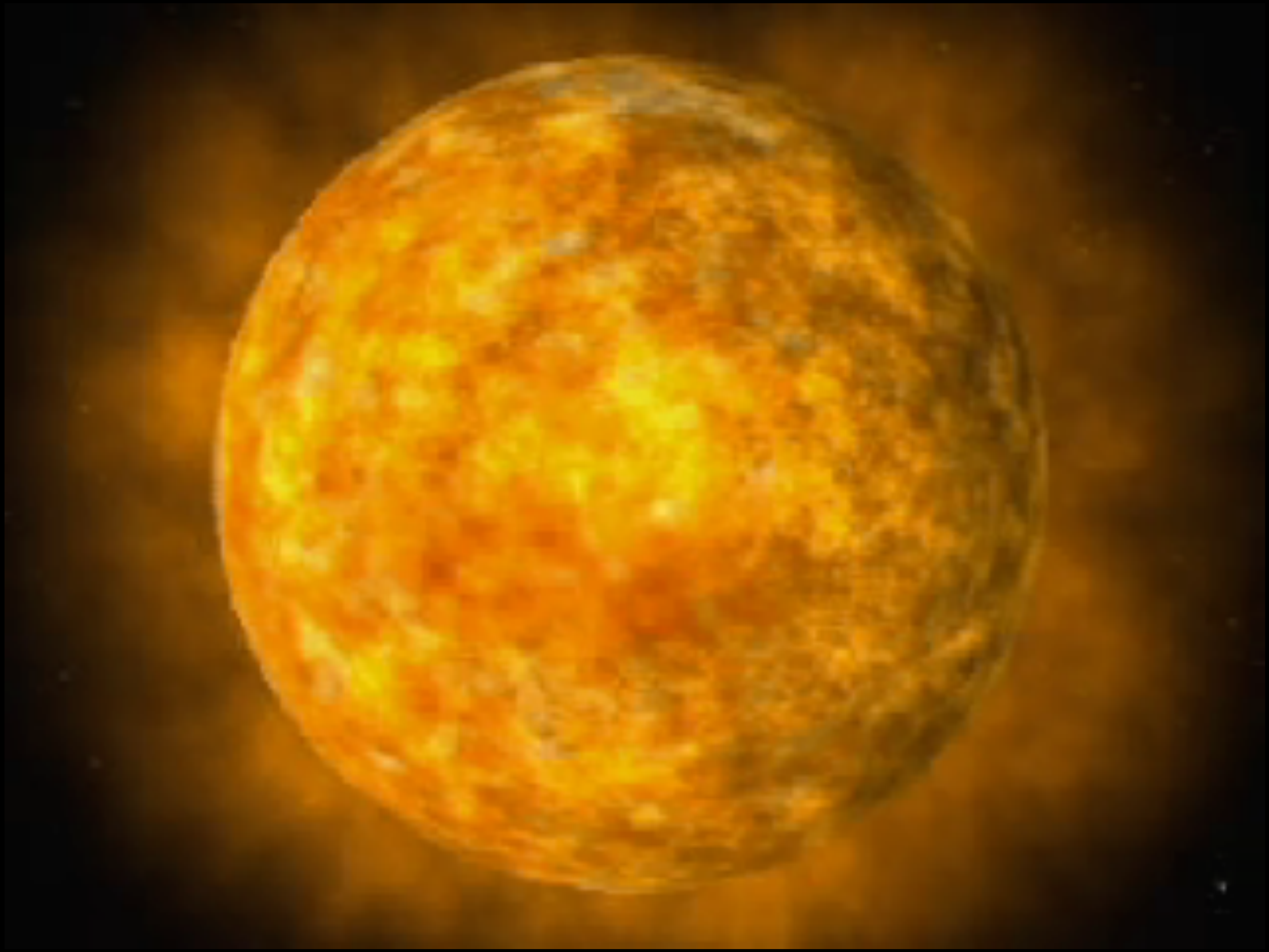
# The ‘Carrington Event’: Aug 27 - Sep 7, 1859




Locations where aurora was visible
(Green, 2008)


Oct 27 2003 20:36:11

# Solar and Heliospheric Science



# CME Synchrotron

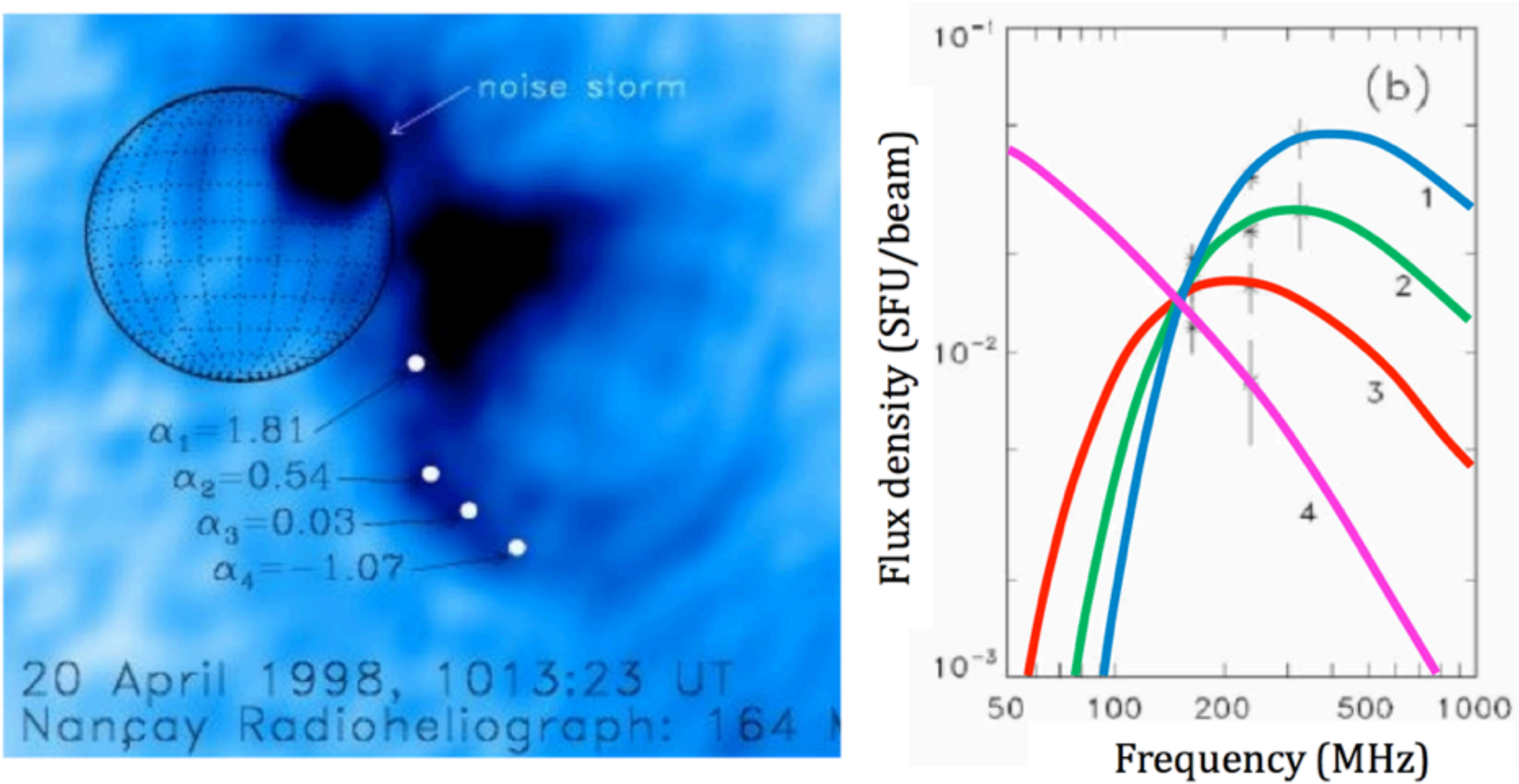
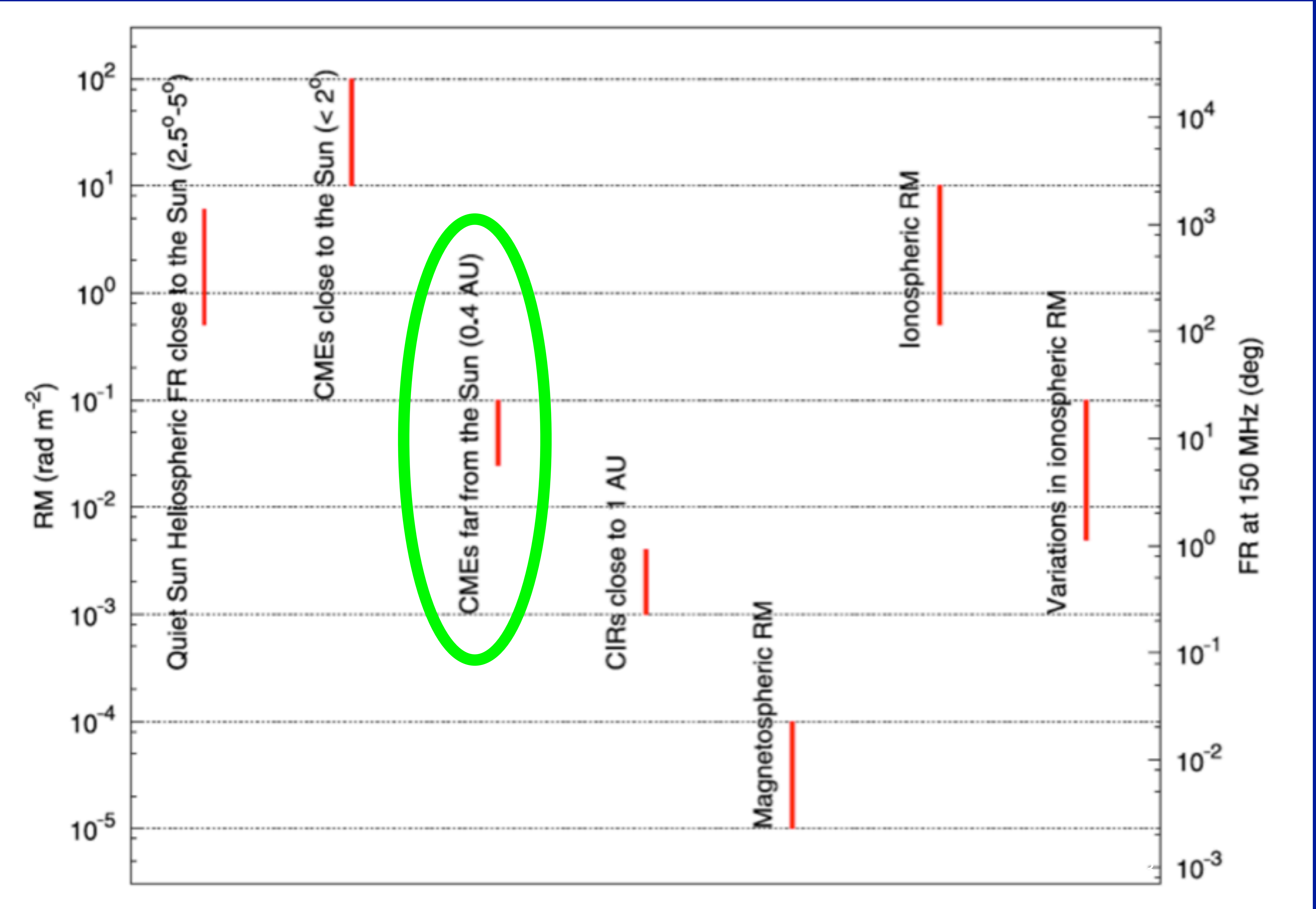


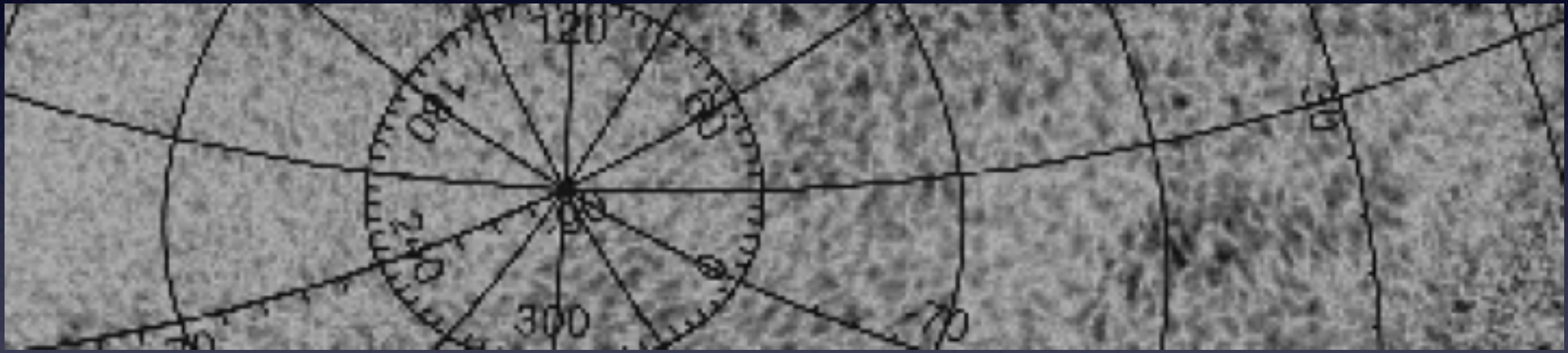

***Figure** 7 - the left panel shows a snapshot of the radio CME at 164 MHz at the time of maximum flux. The background emission from the Sun has been subtracted. Time variable radio emission from a noise storm is present to the northwest. The image has been saturated at 0.04 SFU/beam, corresponding to a brightness temperature of $2.6x10^5$ K. The spectral index measured between 164 MHz and 236.6 MHz at a few locations is also shown. The right panel shows the spectra measured at the four points marked in the left panel in SFU/beam. Model spectra fits based on optically thin synchrotron radiation are also shown. (adapted from Bastian et al. 2001).*

# Sources of Faraday Rotation



# Galactic Synchrotron Polarimetry

- MWA 32-tile prototype data at 189 MHz
- Bernardi et al. 2013



# RAPID

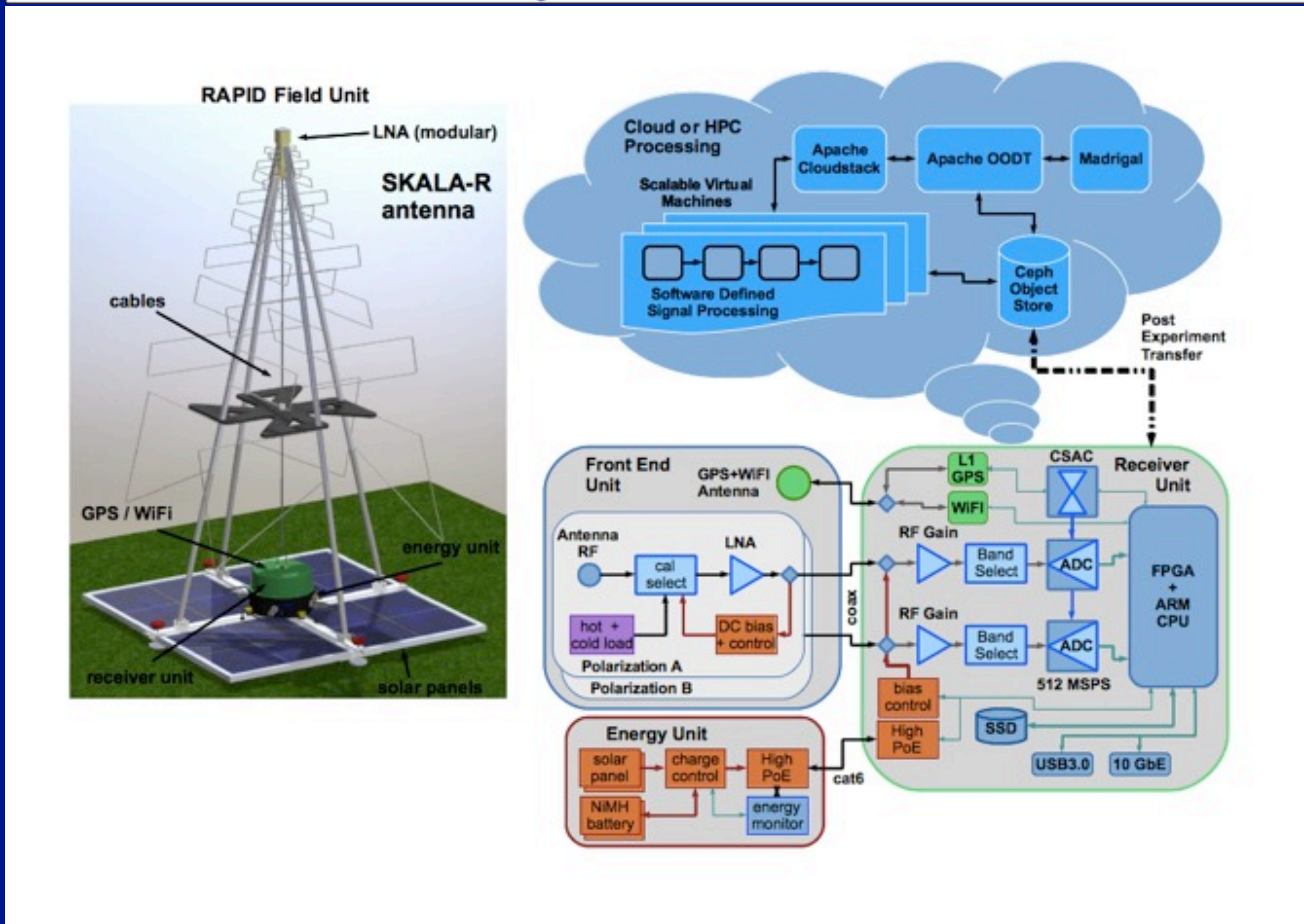
## Radio Array of Portable Interferometric Detectors

HAYSTACK OBSERVATORY

UNIVERSITY OF CAMBRIDGE

JPL

NSF



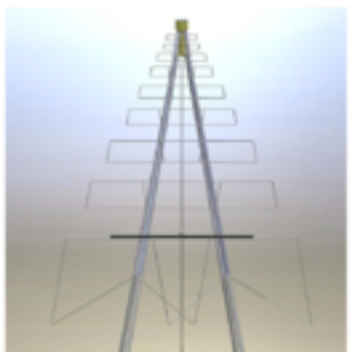

× 100

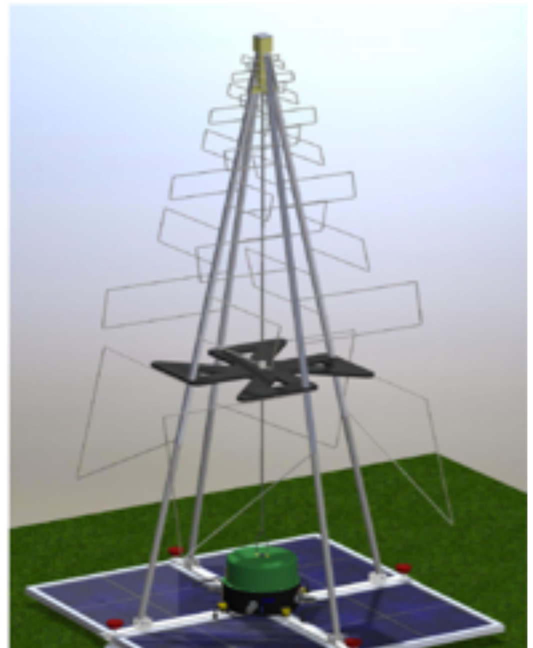
# RAPID - What is it?

- Low frequency radio array, 48-600 MHz
- ~100 solar-powered, portable antennas
- No copper **<u>or</u>** fiber connections
- Local storage of voltage samples at each antenna
- Imaging interferometry performed offline
- Low-cost setup and breakdown
- Highly portable and reconfigurable
- <u>Extreme flexibility</u> for targeted science experiments

## SKALA-R Antenna General Architecture

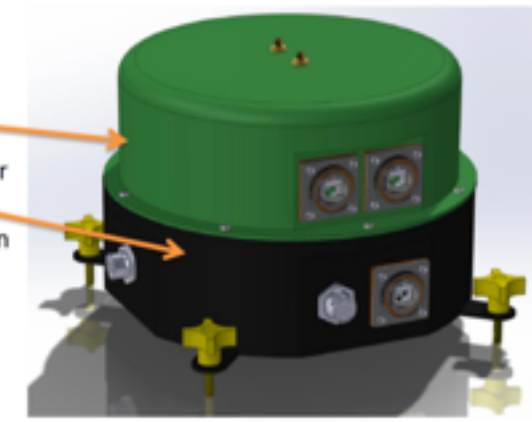
- Element Supported
  (no central support structure)
- Modular top section
  (Contains antenna top elements and LNA housing)
- Base mounted power and recording sub systems
- Centrally routed RF cables

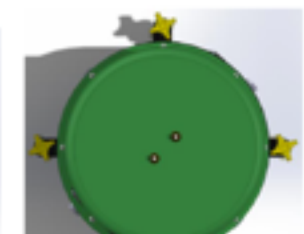




## Rapid Recorder System General Architecture

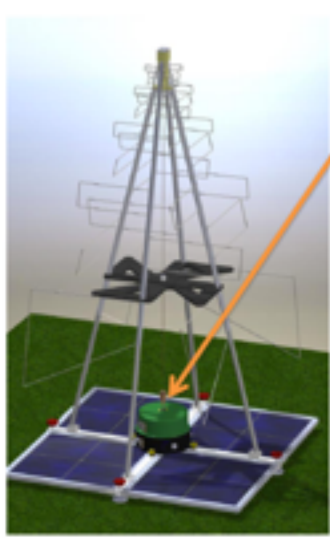
- Data recording system is split into two part;
  - Upper section (green) houses the recording hardware
  - Lower section (black) houses the power controller and battery pack.
- Data recording system has 2 data connection ports (either USB or Ethernet with PEO) and 2 SMA quick connect fittings.
- Power controller section includes 4 solar panel connection points and two Ethernet ports that are POE compatible.

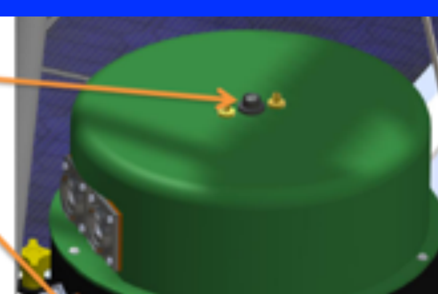


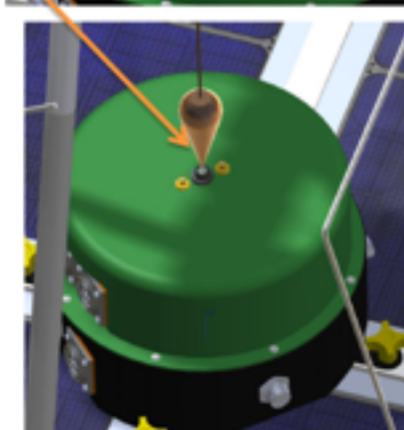


# Portable and Reconfigurable

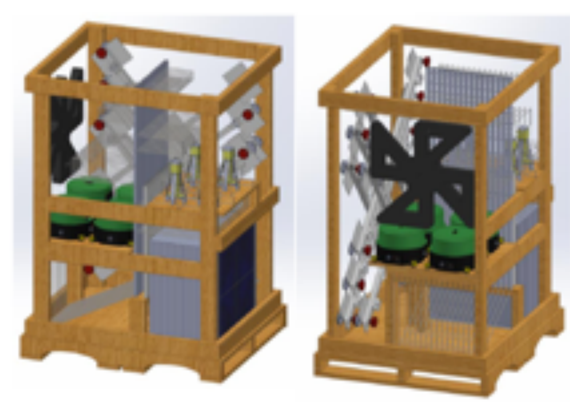
- Use the built in bubble level and the red leveling knobs to coarsely level the system.
- Hang the plum bob from the antenna top section and use it to finely level the system.

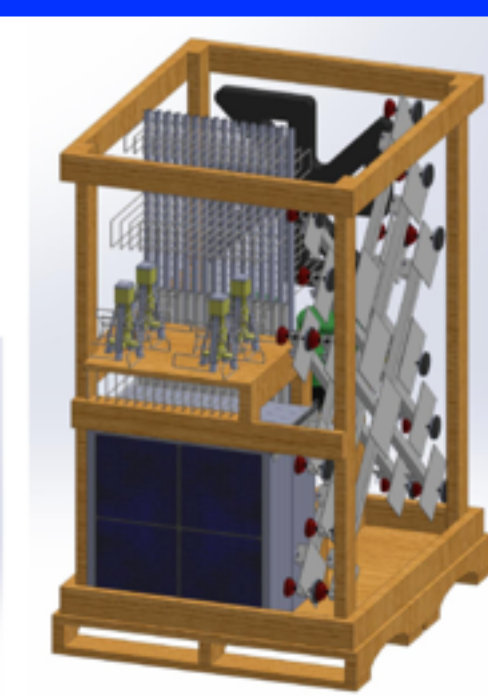






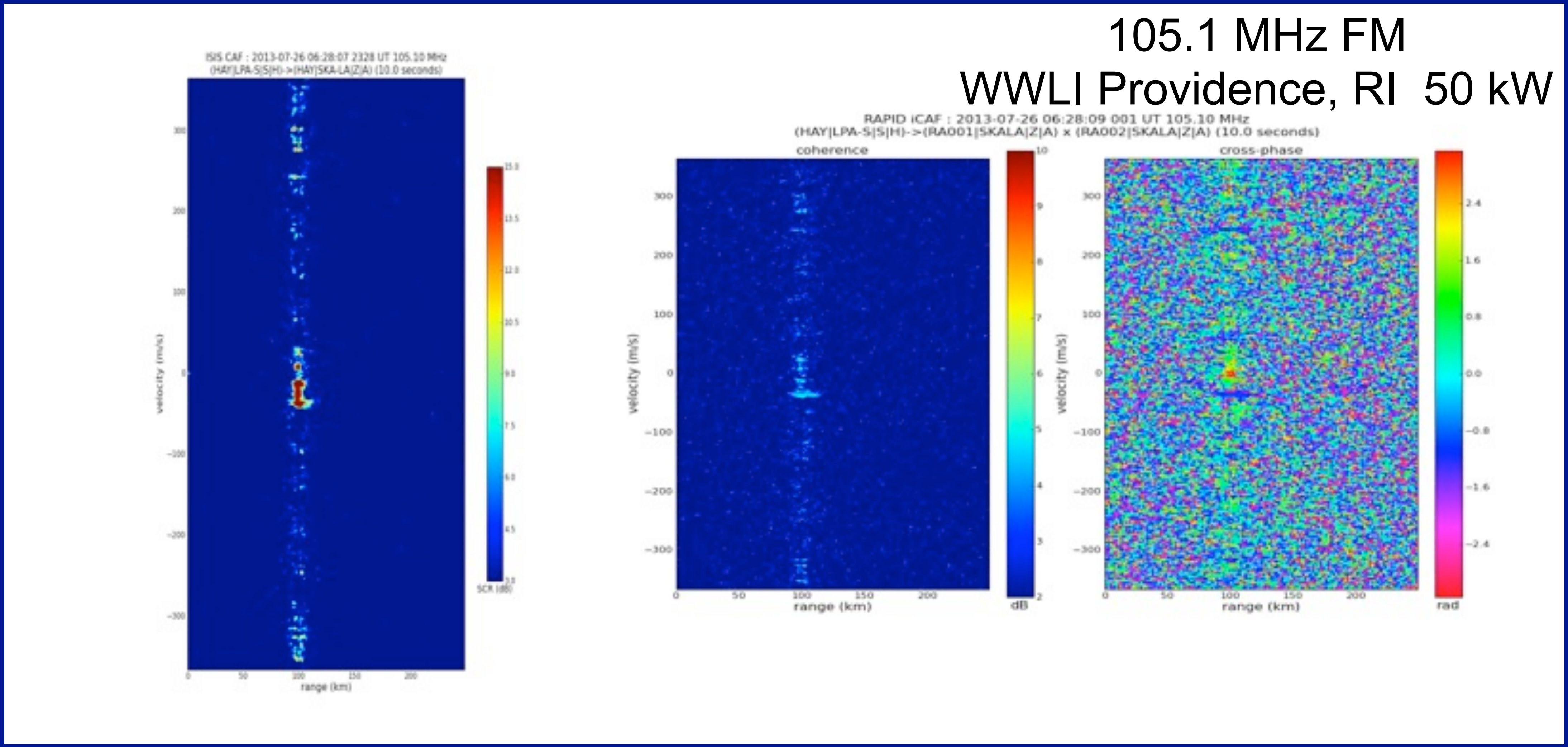
- Rapid systems will be shipped in purpose built crates.
- 4 rapid systems per crate
- Crate meets UPS and Fedex guidelines for shipping
- Each crate will be 60'H 40'W 47'D which meets the standard shipping size for most countries. (larger crates can be used if willing to pay oversize pallet charges)





# RAPID Prototype Development

## Passive Radar Interferometry and Imaging




Meteor Trail Detection, Coherence, and Cross phase

Two Antenna Passive Radar Interferometry for RAPID prototyping activities

Imaging with 16 SKALA antenna elements is next!

# Signal-to-Noise

- Sample calculation at 150 MHz:
  - At 150 MHz, quiet sun ~$10^5$ Jy
  - With 1000 pixels (~30x30, ~1 arcmin), each pixel has ~100 Jy
  - MWA noise in 1 sec, 1 MHz ~1Jy
  - RAPID gain will be ~10% of MWA gain
  - SNR on quiet solar disk ~10 in 1 sec
- RAPID can see thermal solar disk at 1 arcmin resolution in 1 second with 1 MHz bandwidth
- Active solar features are ***much*** brighter, and are localized, high SNR in <<1 sec, <<1 MHz

**At 1 arcminute, 100 RAPID antennas have enough sensitivity for good solar imaging**

# Resolution

- Solar disk is 30-60 arcmin at upper/lower freqs
  - Information on >1 degree scales not needed
- Coronal scattering smears images at arcmin level
  - But scattering is asymmetric
  - Very compact structures can and do exist
- 1 arcminute resolution is scientifically valuable across the RAPID frequency range
- Implied array extents range from ~1.7km at 600MHz to ~20km at 50 MHz
  - These are large, logistically challenging configurations

# Full uv-plane Sampling

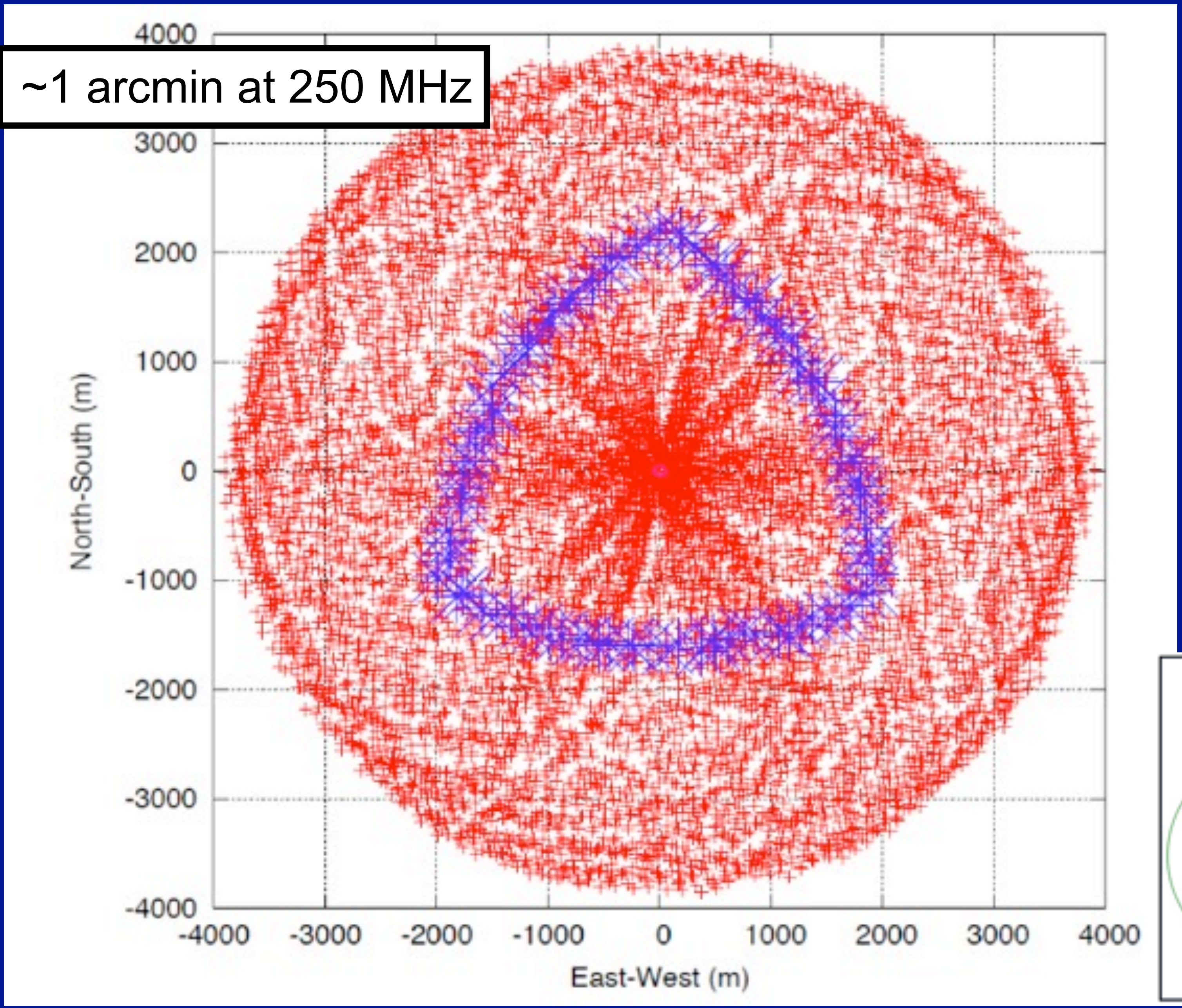
- Solar emission can be very complex
  - in individual time/frequency segments
  - uv coverage required instantaneously and monochromatically

- For ~1 arcmin resolution, need each uv sample from a ~100 element array to be independent on a ~60$\lambda$ grid (1º FOV)
  - 4950 independent visibilities on 3600 grid points
  - Ensures proper over-constraint for precision imaging

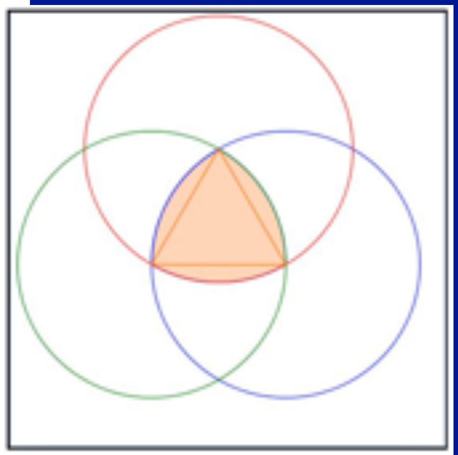
- Configurations with strong central condensation on the ground or in the uv plane are not favored

# RAPID configuration for solar imaging

- Custom solution:
  - Reuleaux triangle with "dither"
  - Scale with frequency as needed
  - Tapering (apodizing) an option as needed




⇒ extraordinary uv plane sampling, high DR imaging at optimum resolution



# Summary

- The MWA works
  - and it works really well for solar imaging
- The Sun is a really interesting radio source
  - Spectrally and temporally complex
  - Rich phenomenology
  - Important contributions possible from low frequency radio
- Space weather is a big deal (and source of $$)
  - Polarized galactic background is key
- RAPID allows new levels of array optimization
  - Very potent for solar studies
  - Can also be used for galactic synchrotron imaging