Ionospheric Applications of the Murchison Widefield Array (MWA)

Anthea Coster, Phil Erickson, David Herne, Divya Oberoi, Joseph Salah

**** M. Salem, Cornell U**

MIT Haystack Observatory
Curtin University of Technology

Outline

- Murchison Widefield Array – low frequency radio astronomy
- Ionospheric Research with MWA Measurements

Murchison Widefield Array

- Primary Science Objectives
  - Red-shifted 21cm neutral hydrogen signals from the Epoch of Re-ionization (EOR)
  - Transience of radio observations in the universe
  - Solar, Heliospheric and Ionospheric Science
- Collaborating Institutions
  - MIT Haystack, MKI, CfA (NSF Ast and Atm, AFOSR)
  - 7 Australian Institutions
  - Raman Research Institute, India

Why is low freq radio astronomy suddenly so hot?

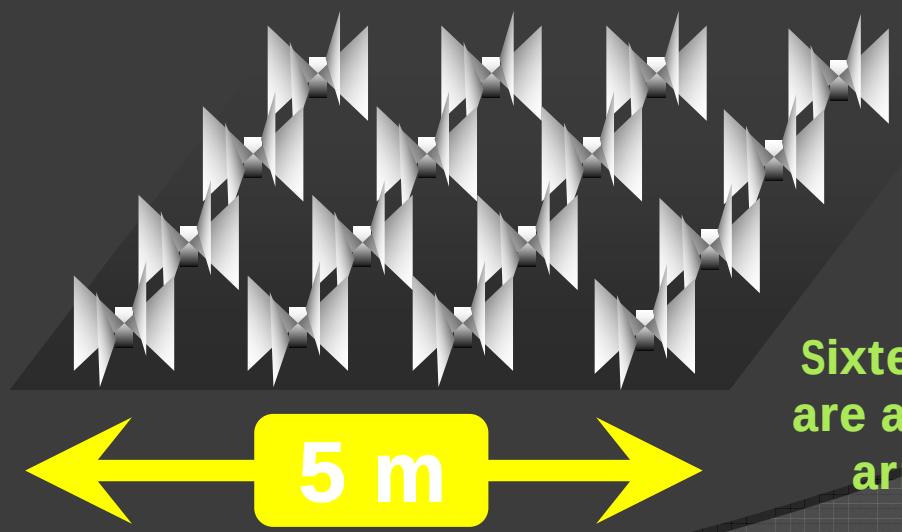
- Huge advances in digital hardware $\Rightarrow$ affordability of capable instrumentation
- Enormous increase in affordability of computing (considering a few Tflops machine for MWA)
- Considerable and continuing effort in development of calibration algorithms and techniques

Murchison Widefield Array

Frequency range	80-300 MHz
Number of receptors	8192 dual polarization dipoles
Number of tiles	512
Collecting area	~8000 m^2 (at 200 MHz)
Field of View	~15°-50° (1000 deg^2 at 200 MHz)
Configuration	Core array ~1.5 km diameter (95%, 3.4') + extended array ~3 km diameter (5%, 1.7')
Bandwidth	220 MHz (Sampled); 31 MHz (Processed)
# Spectral channels	1024
Temporal resolution	8 sec
Polarization	Full Stokes
Point source sensitivity	20mJy in 1 sec (32 MHz, 200 MHz) 0.34mJy in 1 hr
Multi-beam capability	32, single polarization
Number of baselines	130,816 (VLA: 351, GMRT: 435, ATA: 861)

what does it look like?

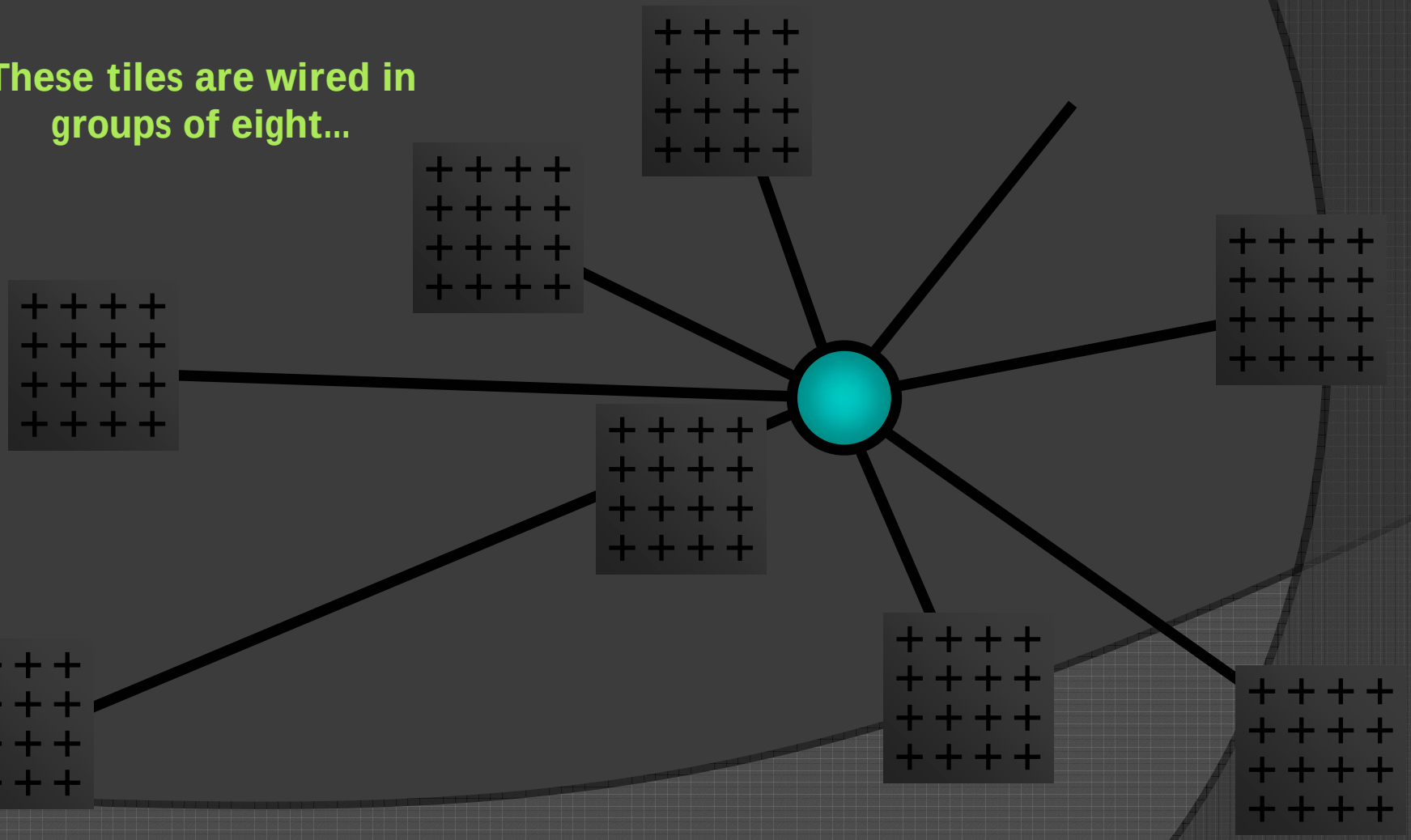
- The array is a massive collection of antennas
- Has both regular geometry, and random distribution:



Sixteen bowtie antennas are arranged In a 4x4 tile array on wire mesh.

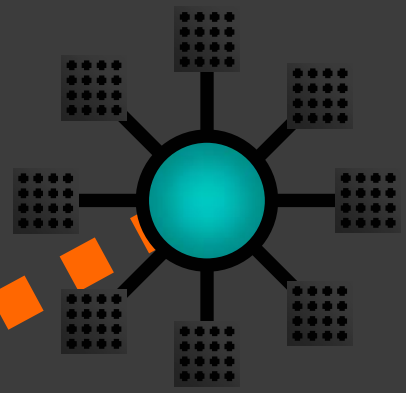
what does it look like?

These tiles are wired in groups of eight...



what does it look like?

... and there are 64 such groups of eight... for a total of 512 tiles...



x 64

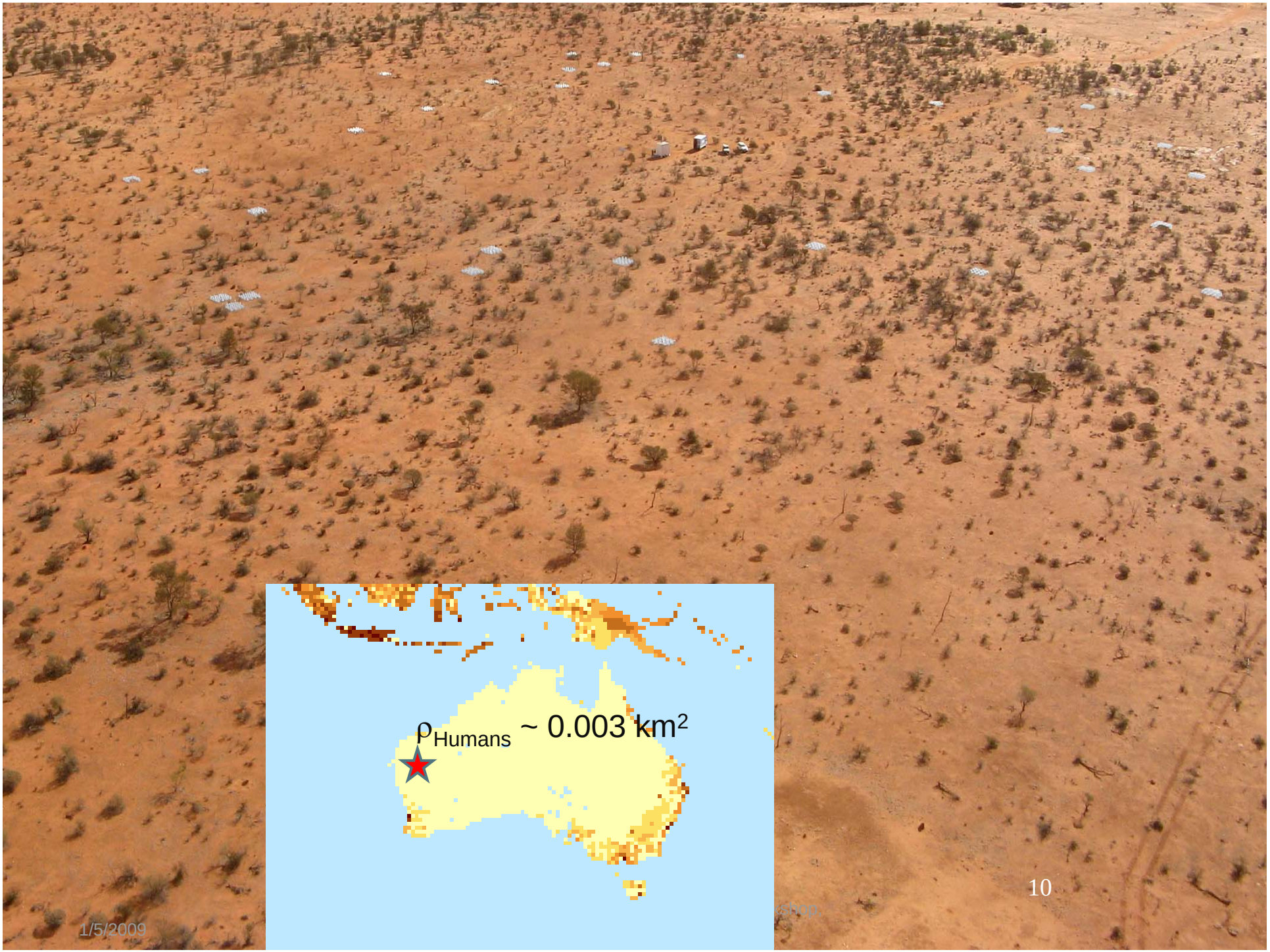
... all of which report data back to a central, on site processing unit

MWA's Correlator

what does it look like?

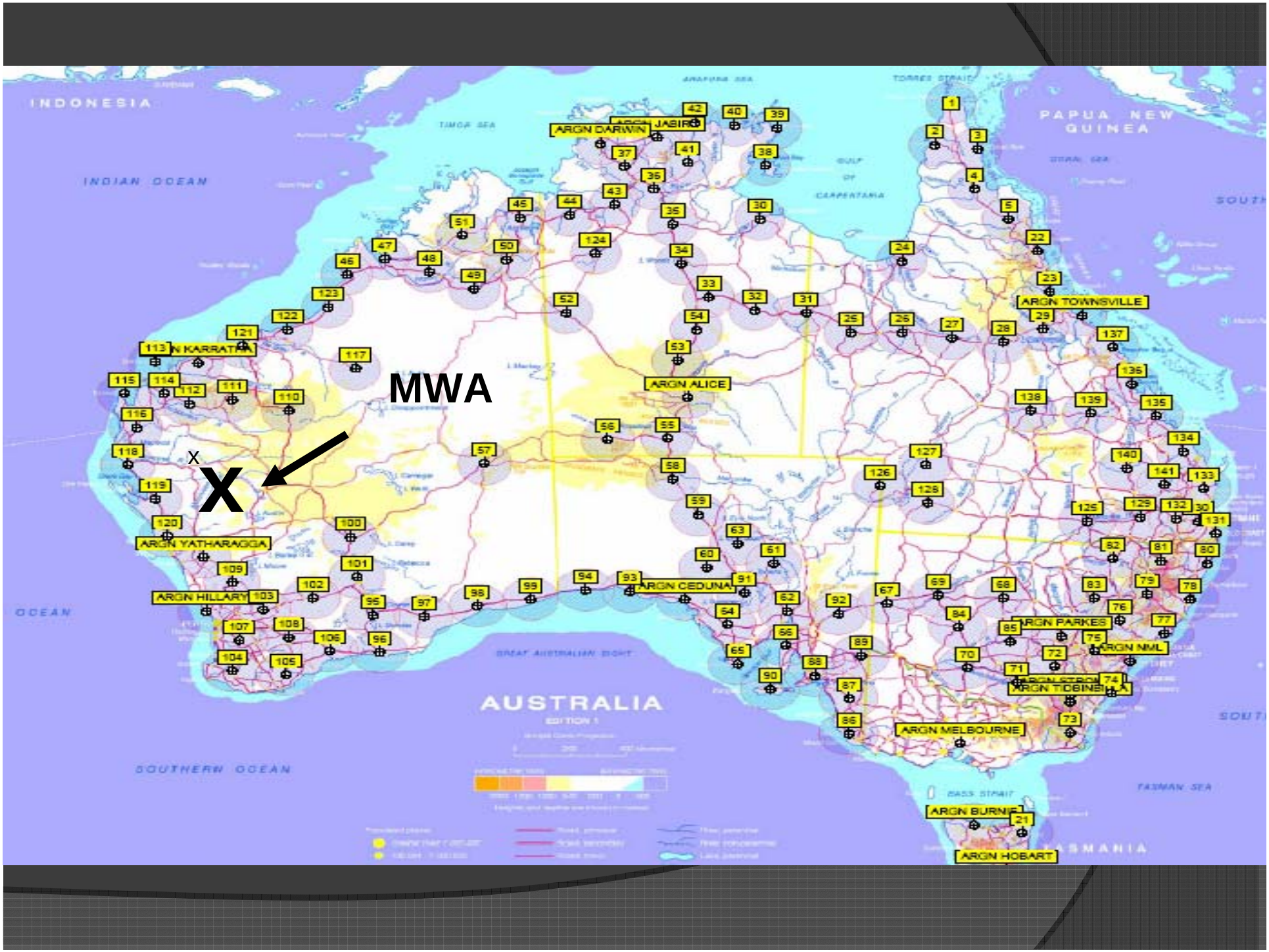
1.5 km

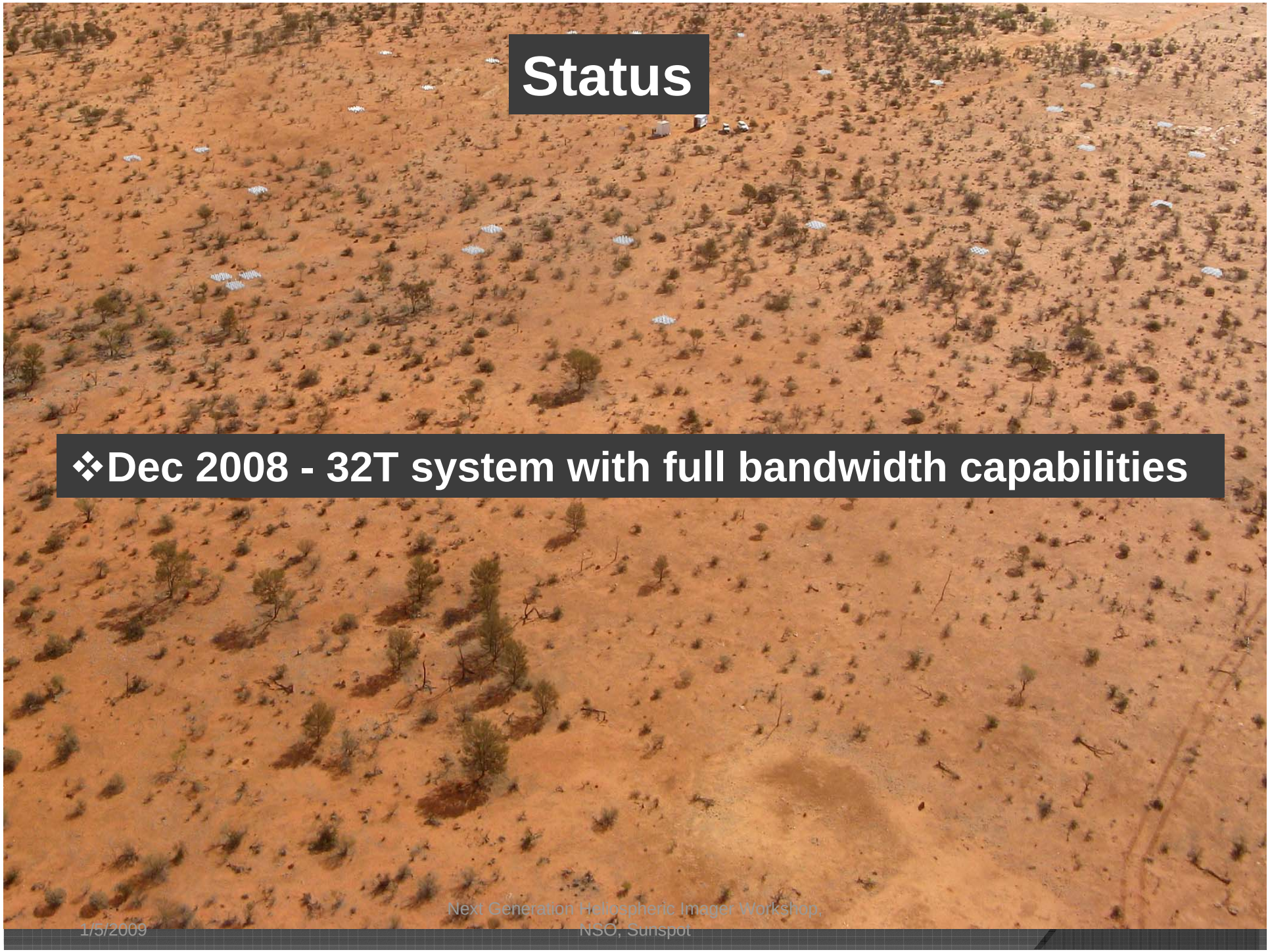
MWA's r/t software


ρ_{Humans} ~ 0.003 km^2

Three GPS Scinda receivers

Dr. Keith Groves AFRL


INDONESIA
INDIAN OCEAN
TIMOR SEA
ARAFURA SEA
TORRES STRAIT
PAPUA NEW GUINEA
GULF OF CARPENTARIA
ARGN DARWIN
JABIRU
ARGN KARRATHA
ARGN ALICE
ARGN TOWNSVILLE
ARGN YATHARAGGIA
ARGN HILLARY
ARGN CEDUNA
ARGN PARKES
ARGN NML
ARGN TIDBINBILLA
ARGN MELBOURNE
ARGN BURNIE
ARGN HOBART
MWA
X
X
AUSTRALIA
EDITION 1
GREAT AUSTRALIAN BIGHT
SOUTHERN OCEAN
TASMAN SEA
BASS STRAIT
TASMANIA



Status

- Dec 2008 - 32T system with full bandwidth capabilities

step 1: form a beam!

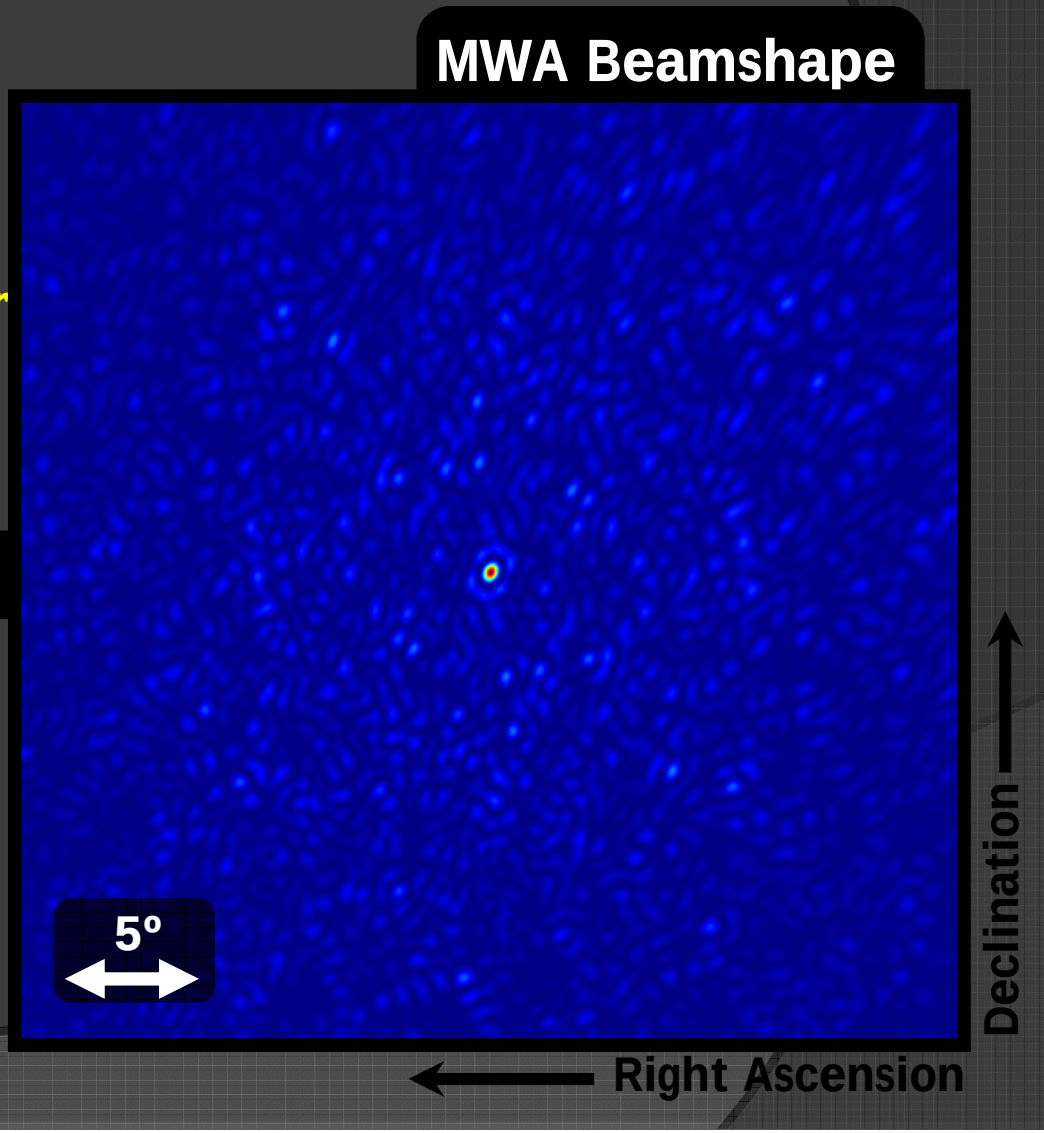
a single full tile of 16 antennas gives a large, squat bump. Adding more tiles, like adding more antennas, provides further structure: longer baselines give thinner central peaks, meaning higher resolution.

1 tile (16 antennas)

6 tiles (current data)

32 tiles (coming soon!)

512 tiles (full MWA array)

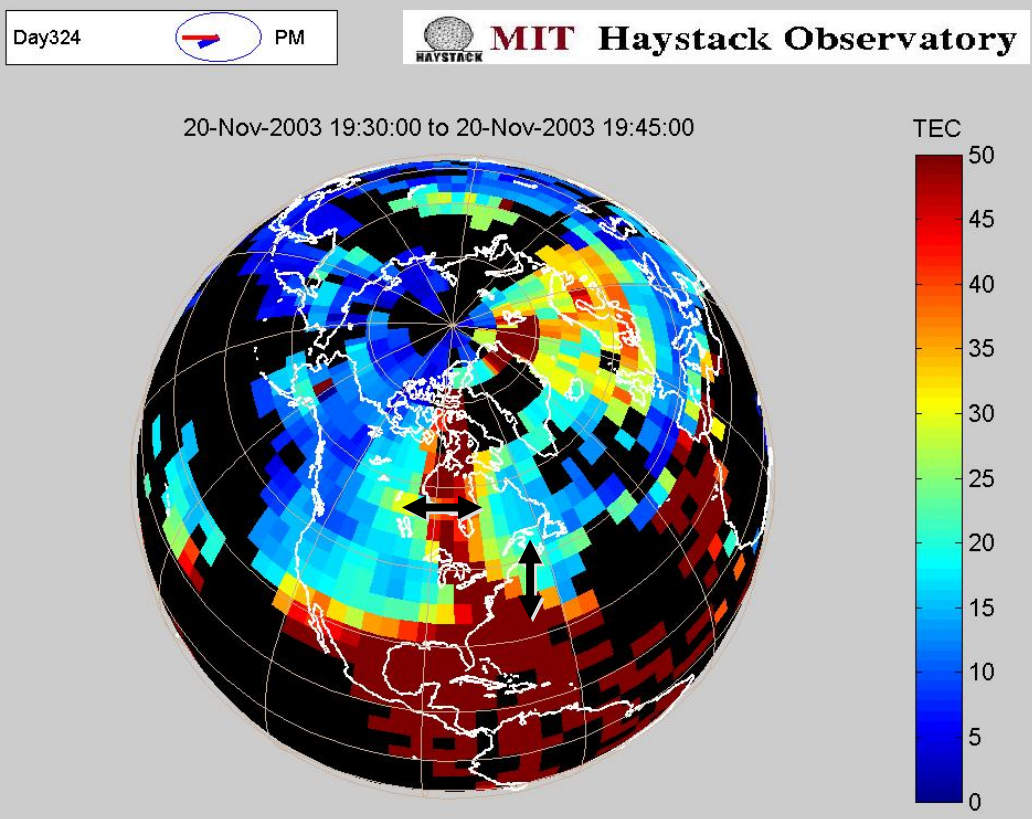


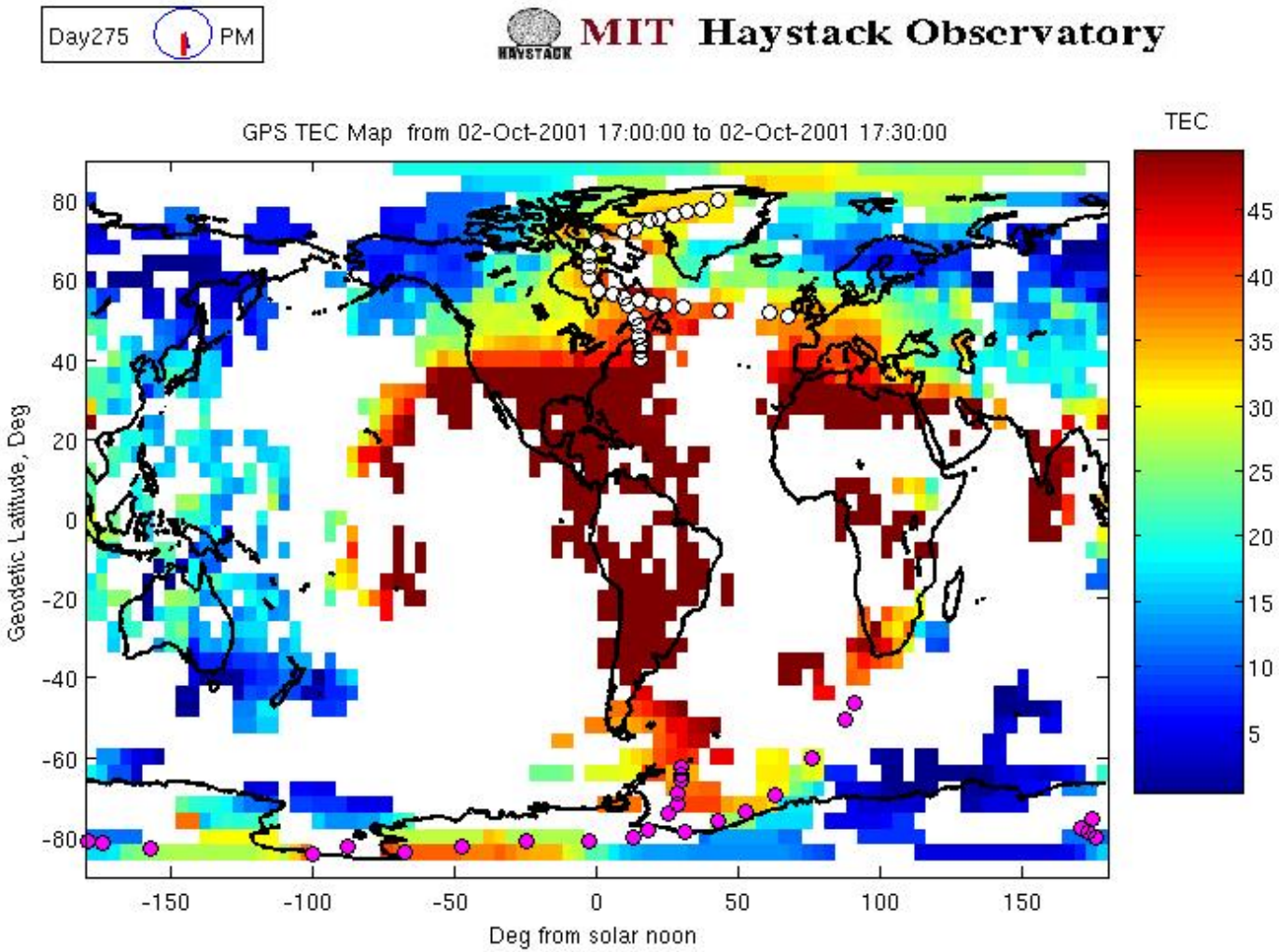
Ionospheric Science at the MWA

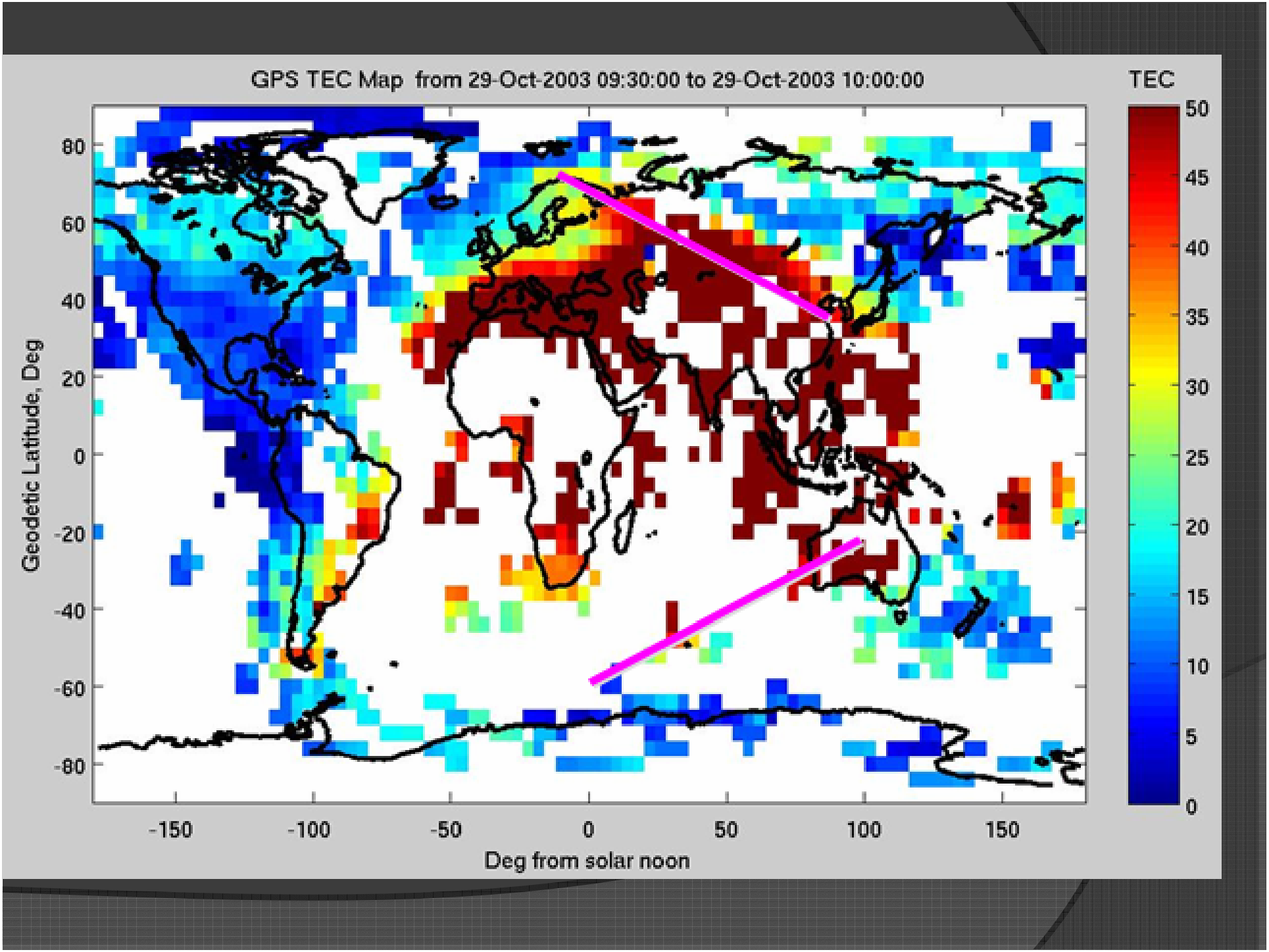
- Ionospheric Science
  - Storm Enhanced Density in Southern Hemisphere
  - Traveling ionospheric disturbances (TIDs)
  - Scintillation and ionospheric irregularities

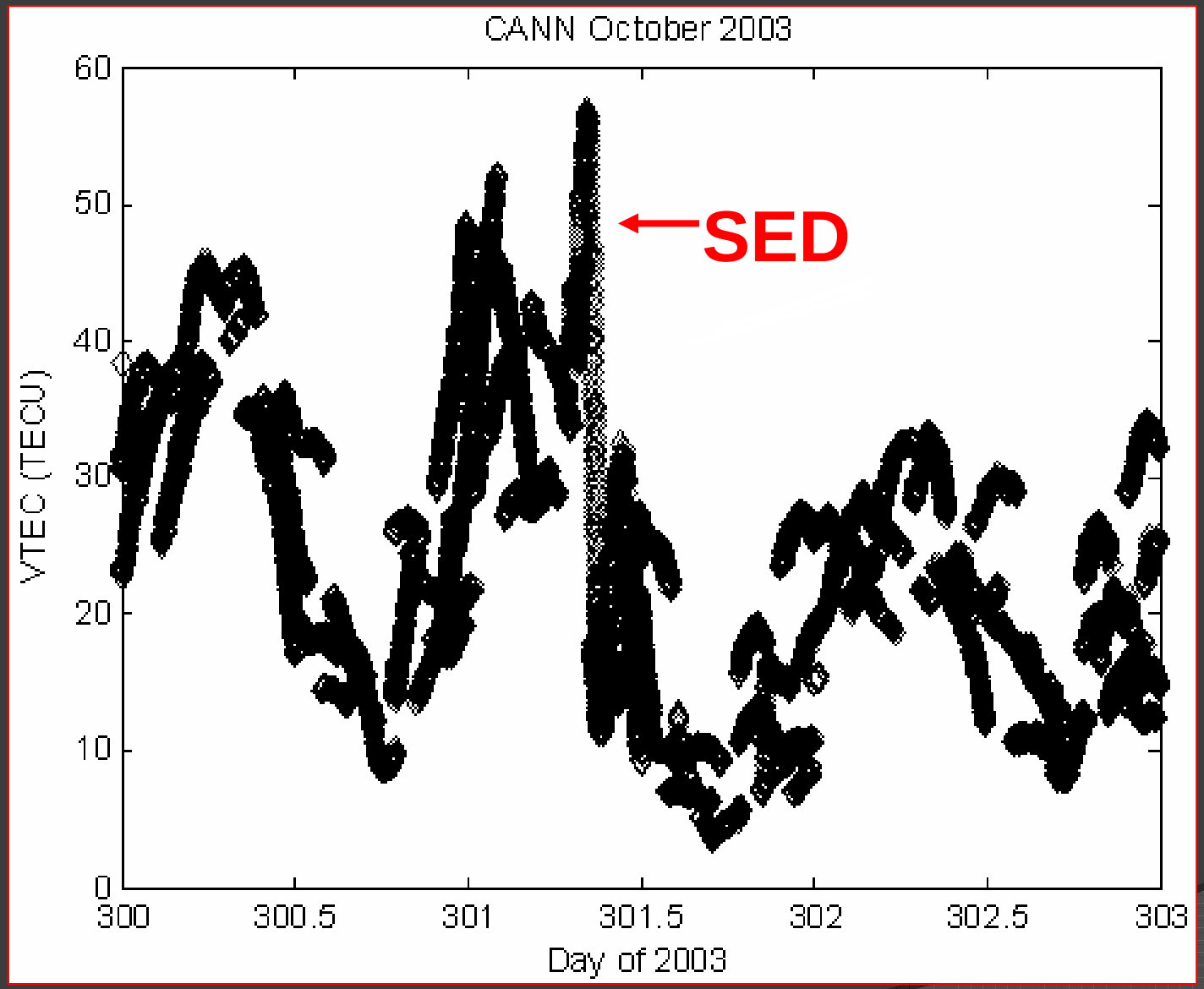
Storm-Enhanced Density

- **Plume extends 1000 km E-W**
- **Gradients of 30-50 ppm near edges of plume (E-W) and base of plume (N-S)**
- **Structures within the plume edges**

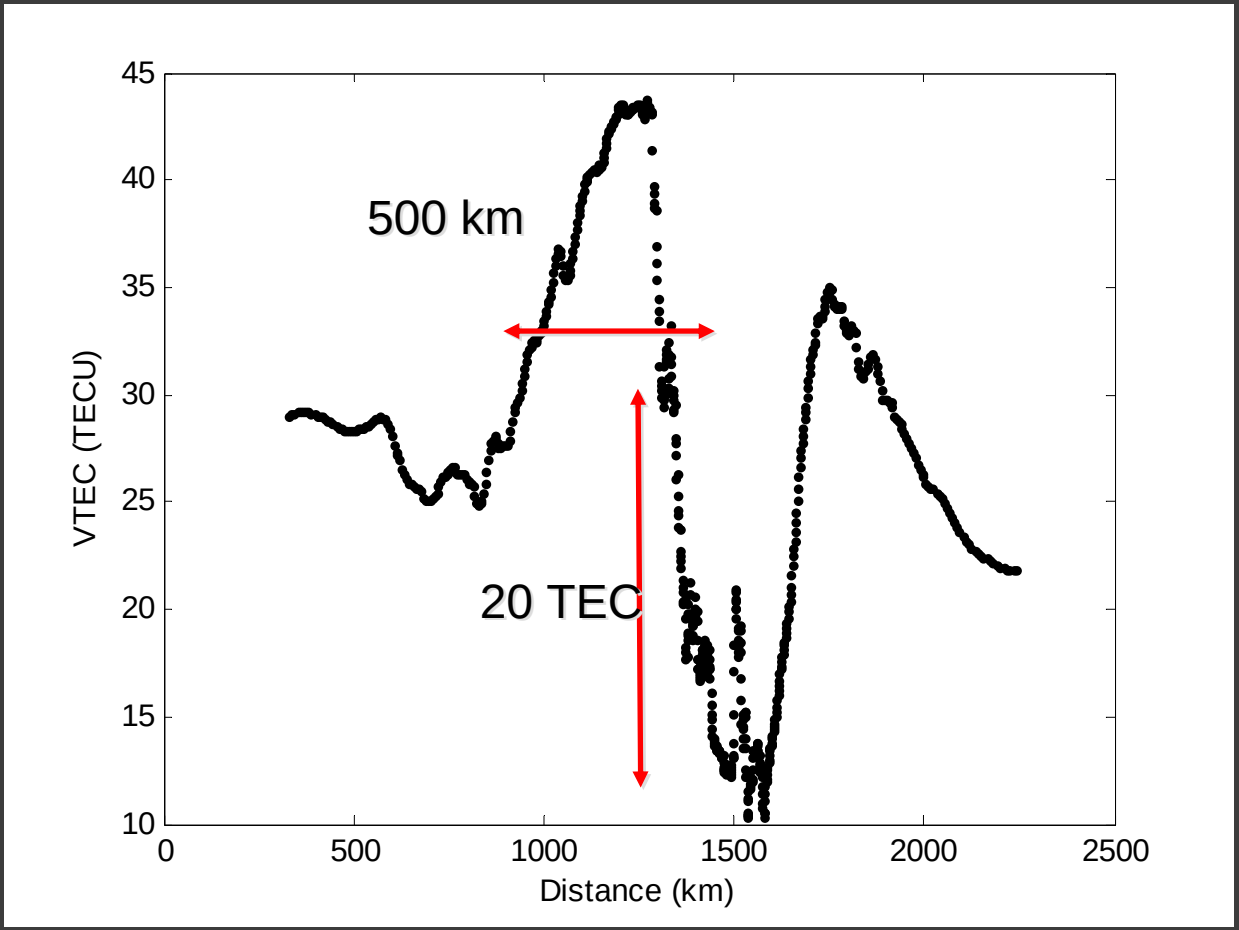



Day275
PM
MIT Haystack Observatory
GPS TEC Map from 02-Oct-2001 17:00:00 to 02-Oct-2001 17:30:00
TEC
Geodetic Latitude, Deg
Deg from solar noon
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
45
40
35
30
25
20
15
10
5

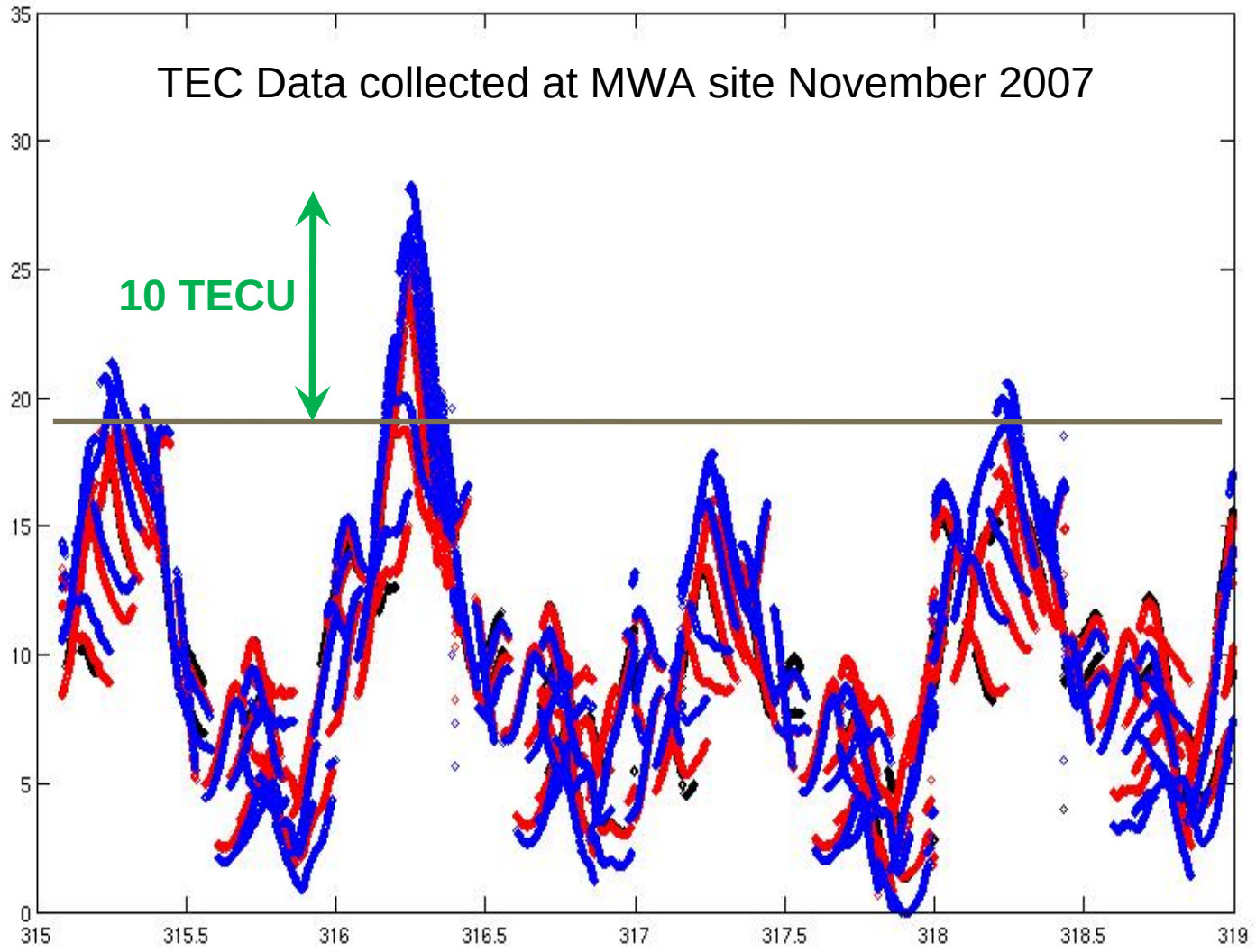

GPS TEC Map from 29-Oct-2003 09:30:00 to 29-Oct-2003 10:00:00
TEC
50
45
40
35
30
25
20
15
10
5
0
Geodetic Latitude, Deg
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
Deg from solar noon


CANN October 2003
SED
VTEC (TECU)
Day of 2003
0
10
20
30
40
50
60
300
300.5
301
301.5
302
302.5
303

IRYM: PRN 16



- Structure with amplitudes of 20 TEC and scale size of 500 km


TEC Data collected at MWA site November 2007
10 TECU
35
30
25
20
15
10
5
0
315
315.5
316
316.5
317
317.5
318
318.5
319

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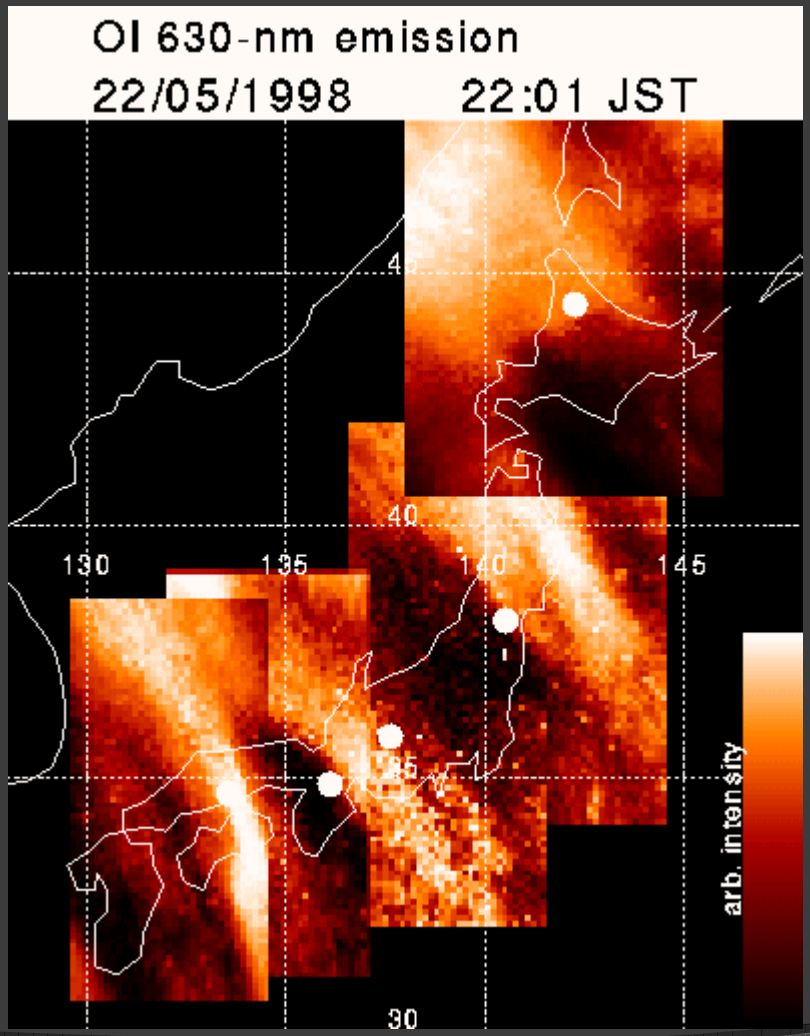
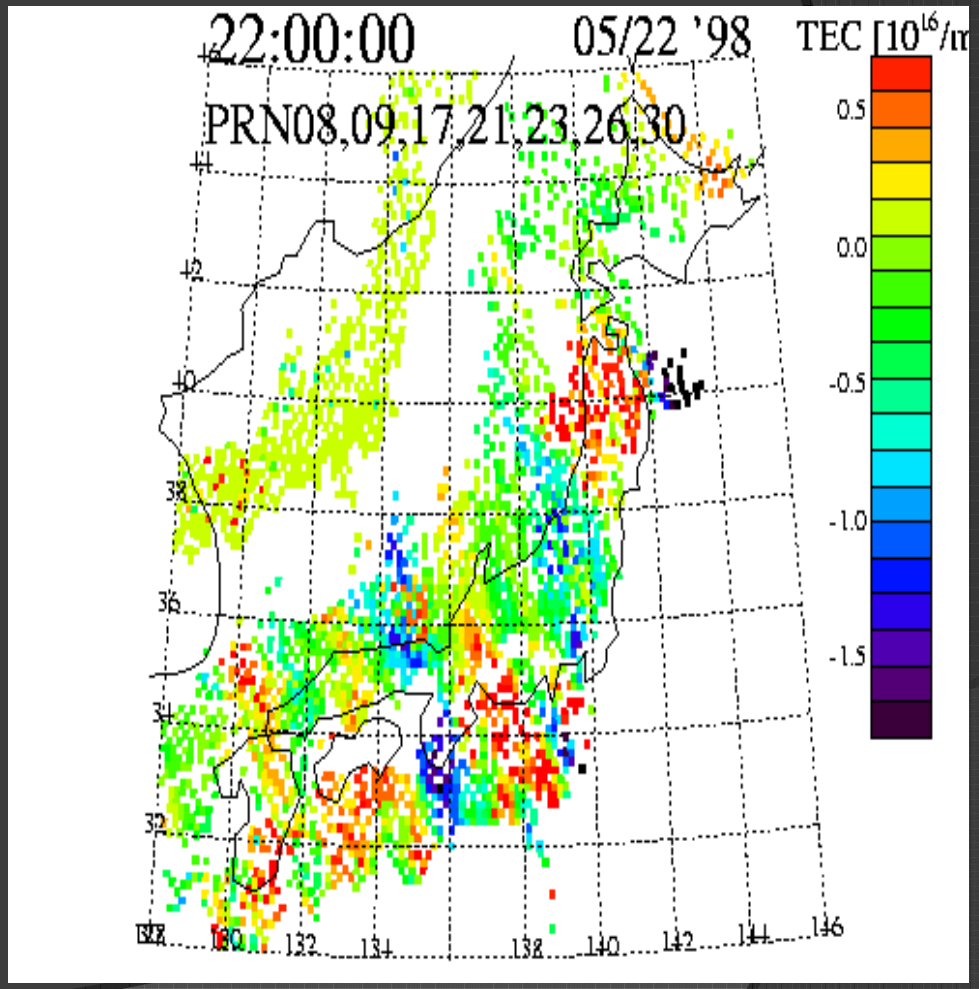
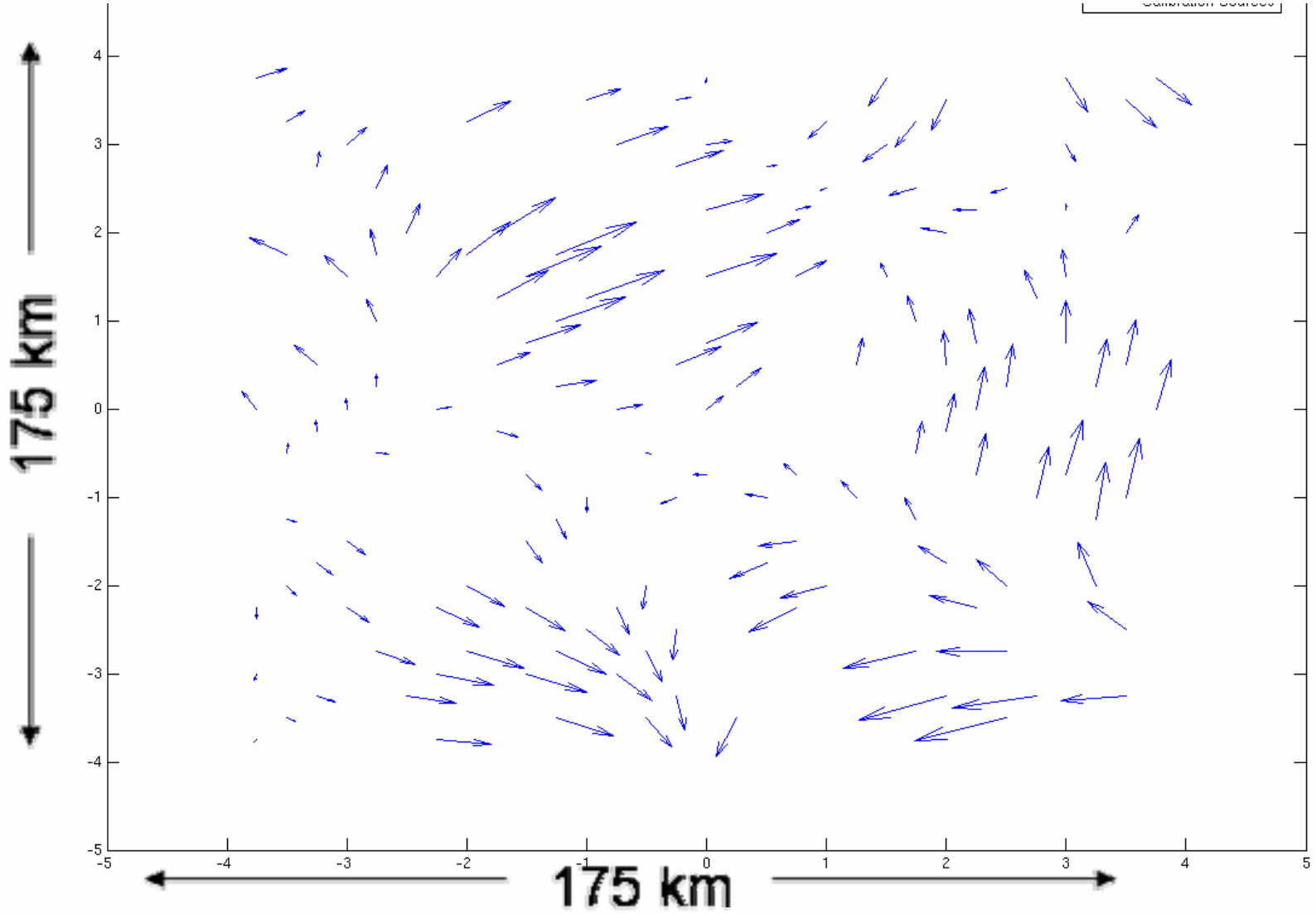
Nighttime MSTID Observations (TEC, Airglow) **[*Saito et al*., 2001]**





Differential TEC derived from Measured Offsets of Radio Sources



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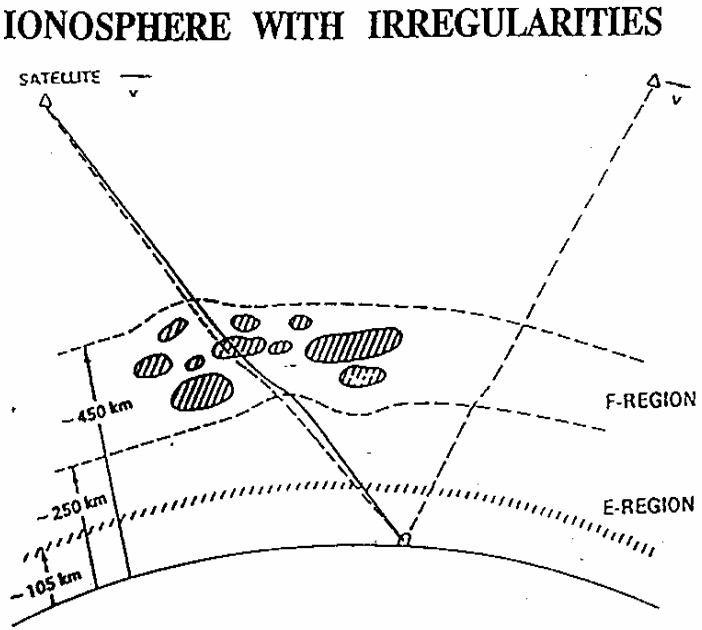
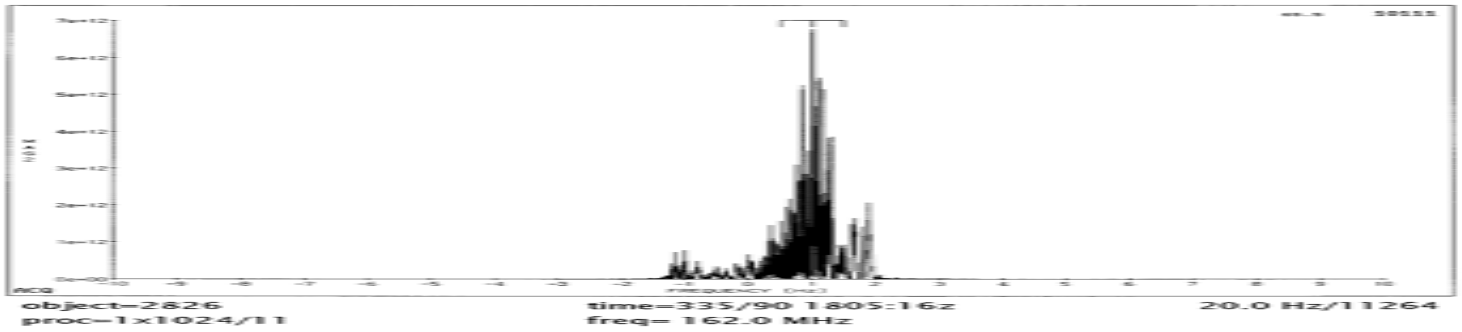
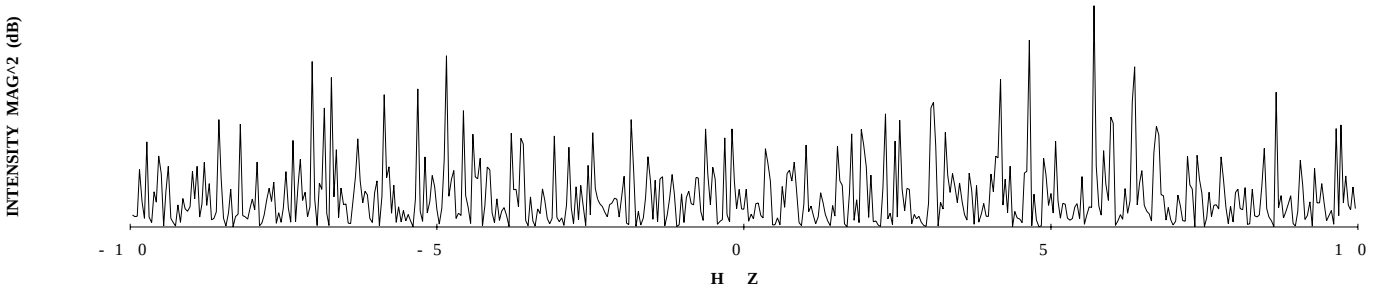
Scintillation

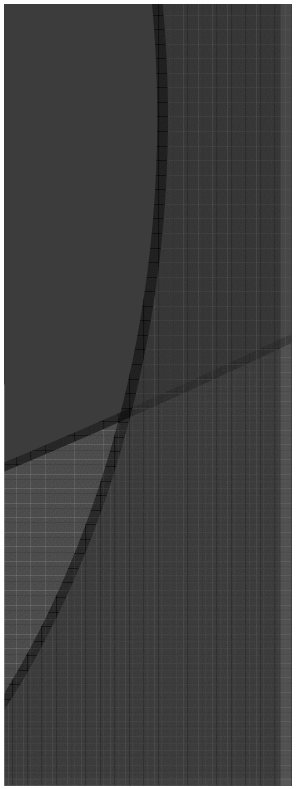
- Amplitude and Phase Scintillation

ALTAIR VHF Calibration Sphere Pass

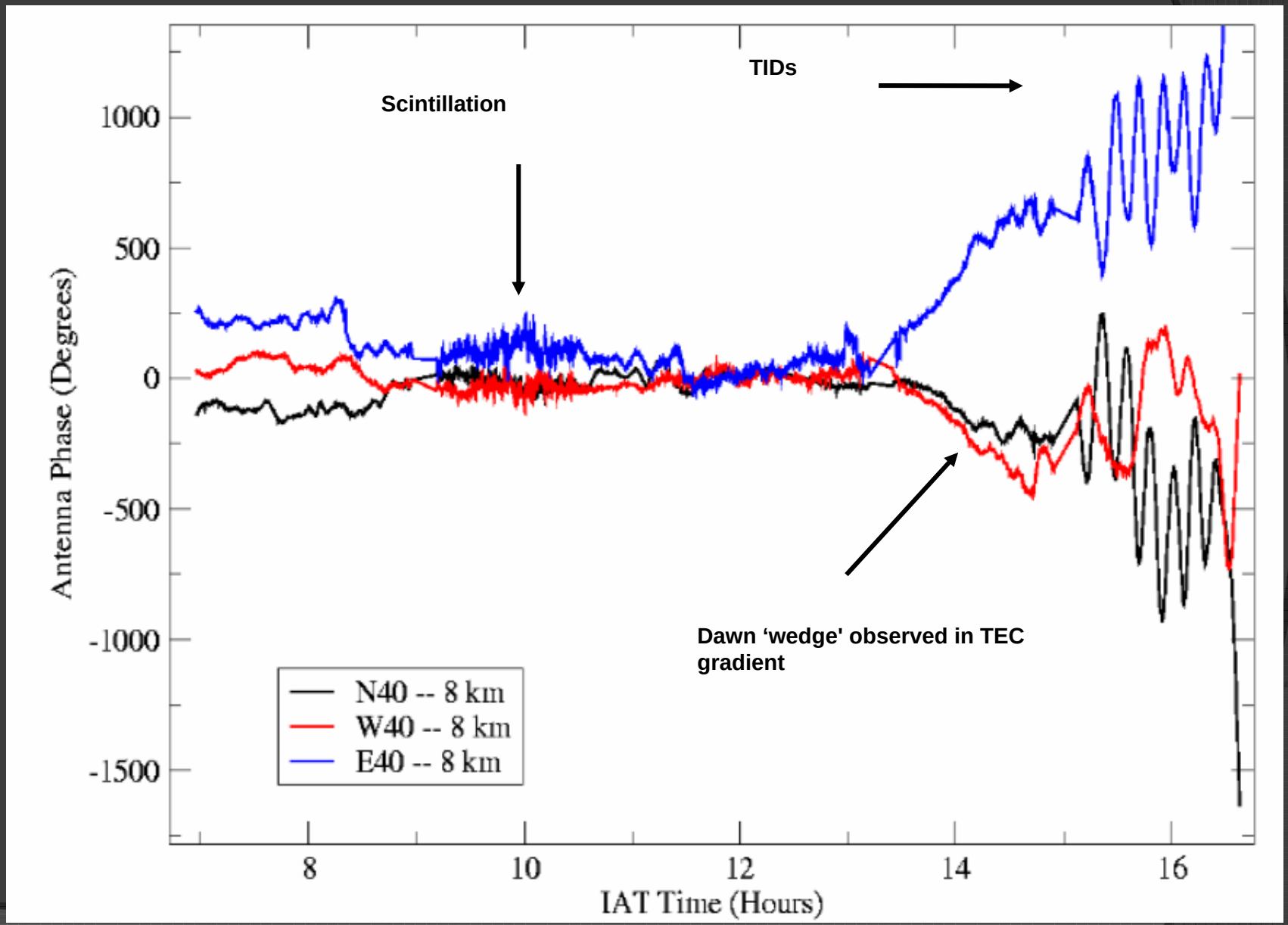




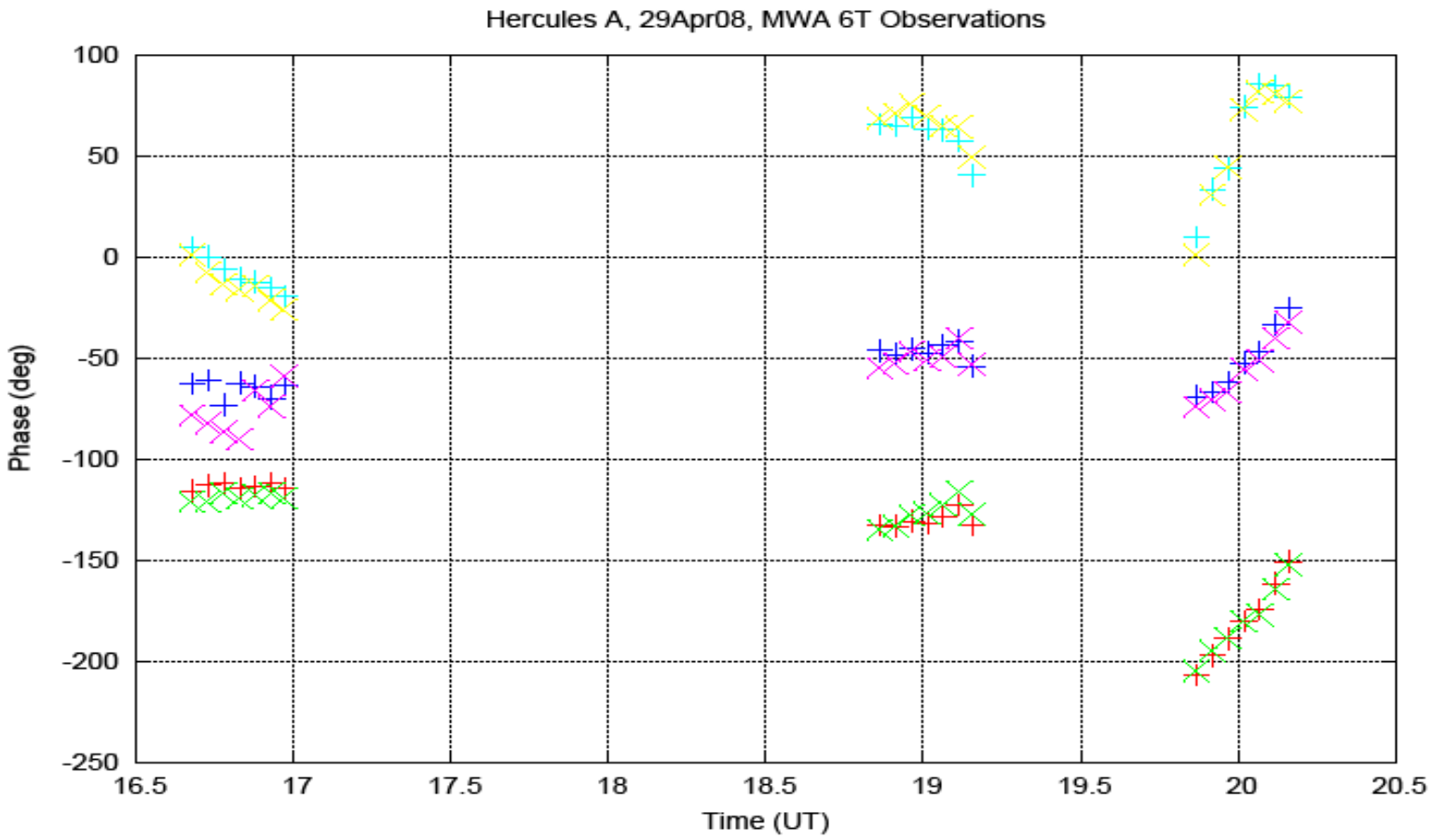




Observations collected at VLA (Perley and Bust, URSI) GA,



MWA phase measurements – 3 tiles



MWA: A New Ionospheric Sensor