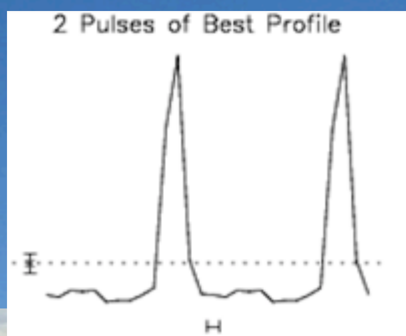
So you got a Million Dollars …

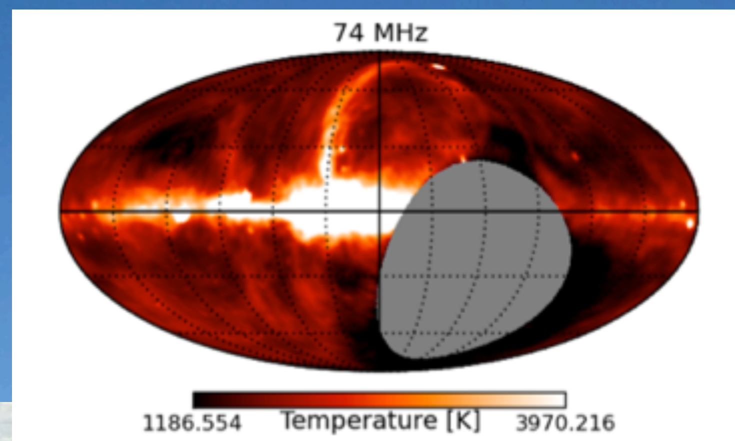
Greg Taylor (UNM)
On behalf of the LWA Collaboration

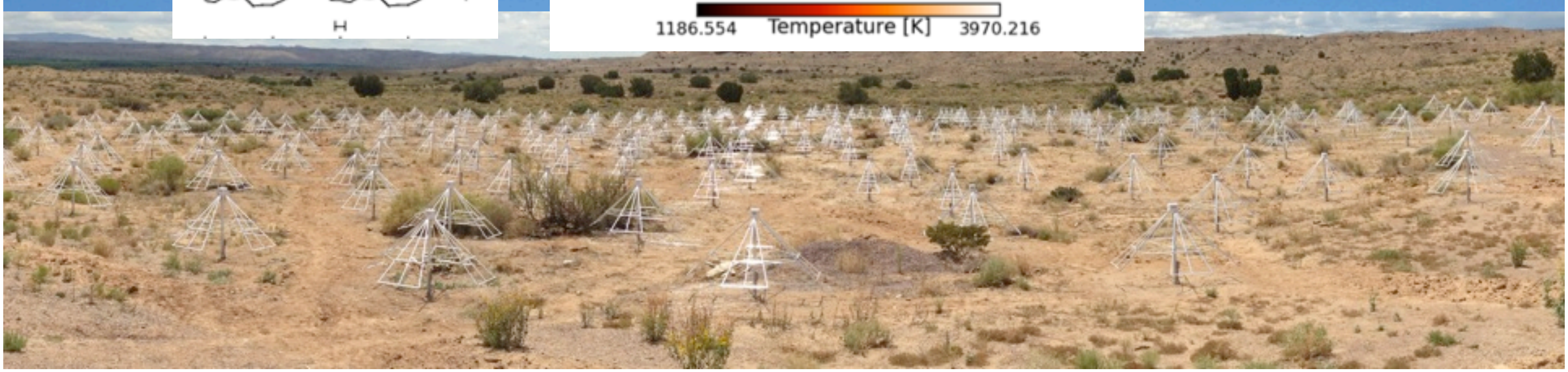
ASU, 3/30/2017

LWA-ASU station

- New station as part of the Long Wavelength Array
- 257 dual polarization LWA dipoles
- 20 MHz bandwidth beamforming
- 20 MHz bandwidth all-sky imaging (TBN)
- 400 km baseline provides 2" resolution in conjunction with LWA1





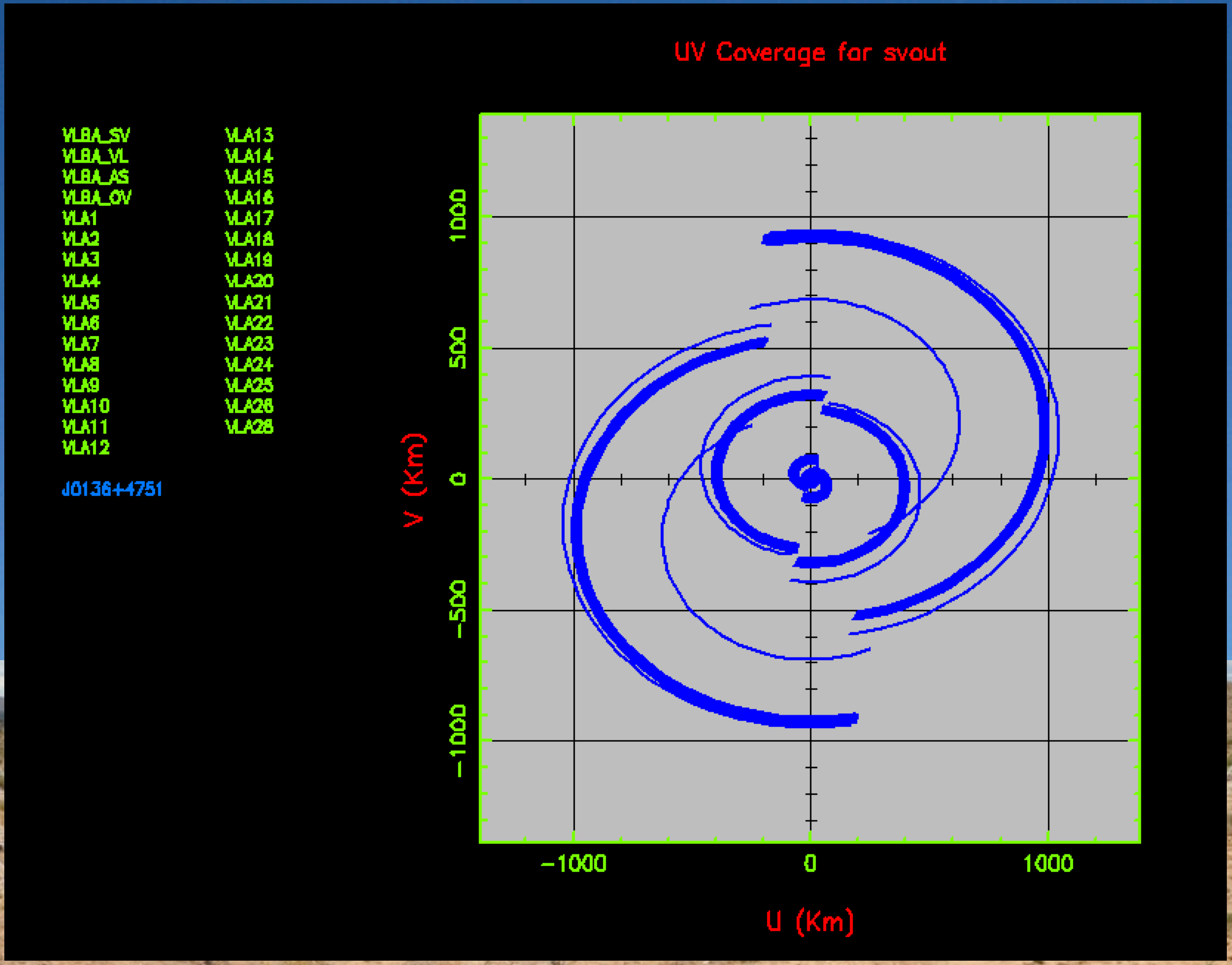


LWA-ASU station

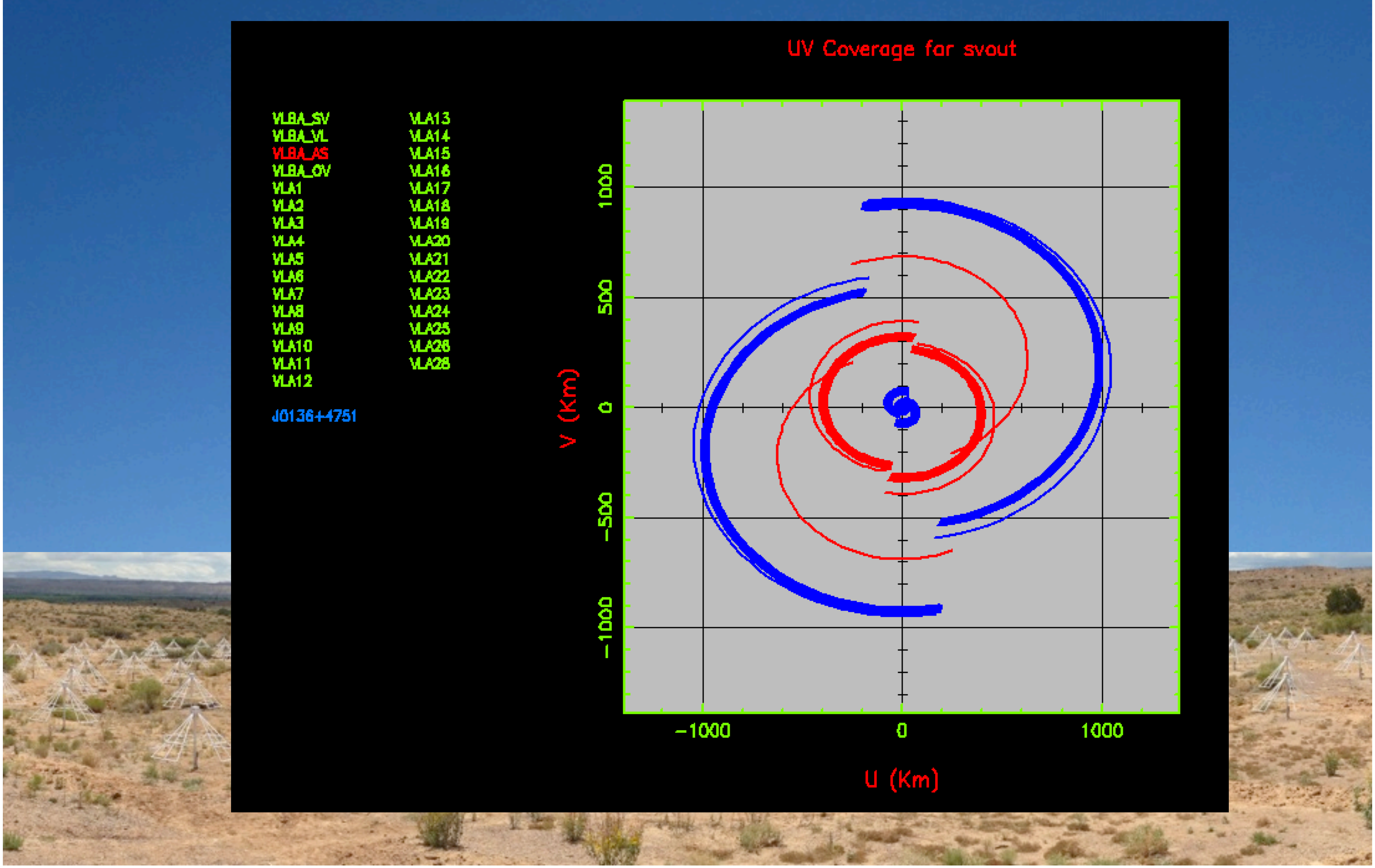
700 km ASU-OVRO

400 km ASU-LWA1

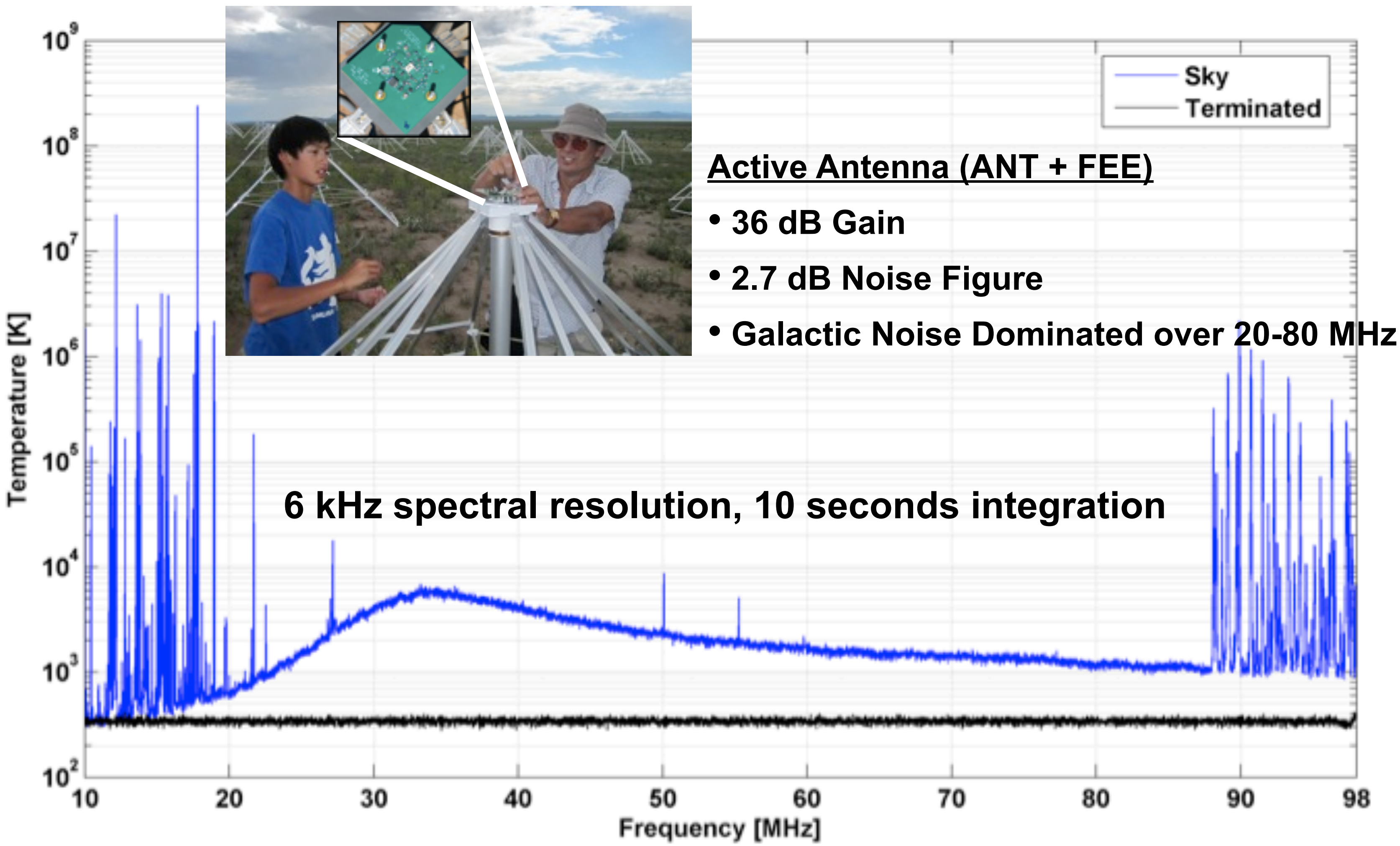
LWA-ASU station



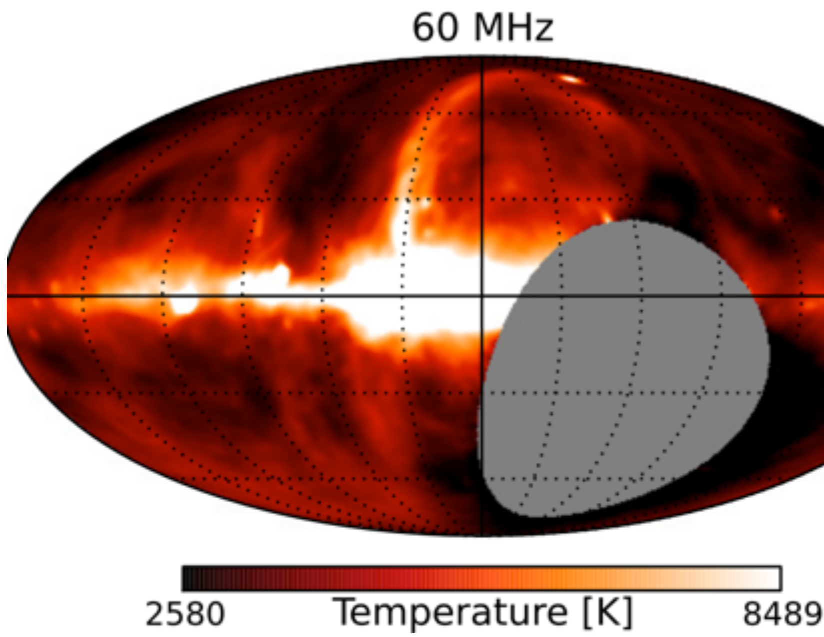
LWA-ASU station



Active Antenna Temperature



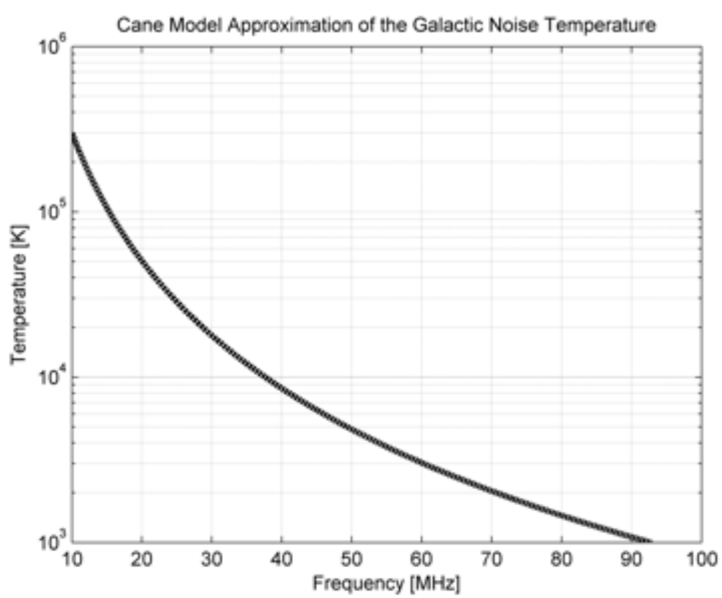
LF Sky Temperature

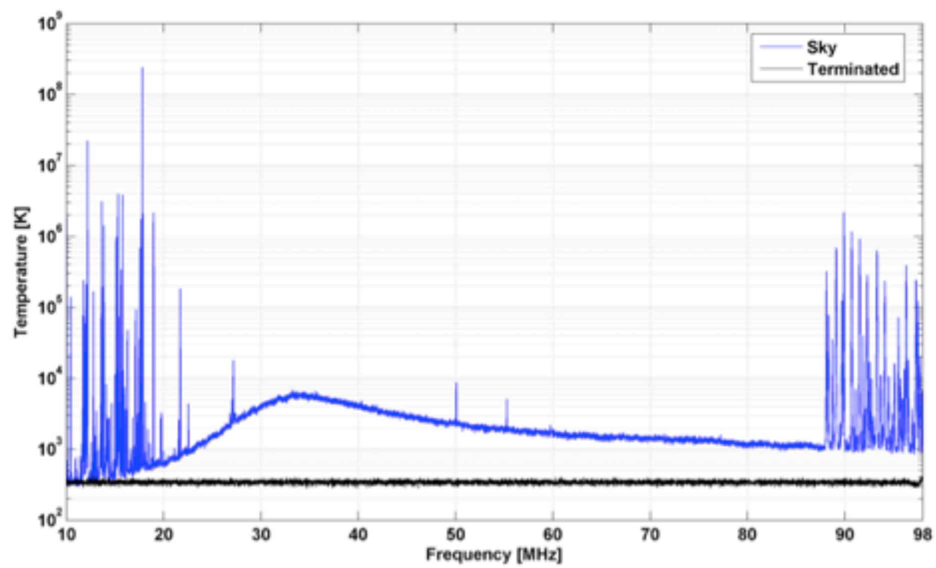


Sky is very bright at low frequencies

- Captured with production antenna thru digitizer, 12-bits @ 196 MSPS
- 10 seconds of integration captured between 12:30 PM and 2:30 PM (local time)... worst time for RFI below 30 MHz
- 6 kHz spectral resolution

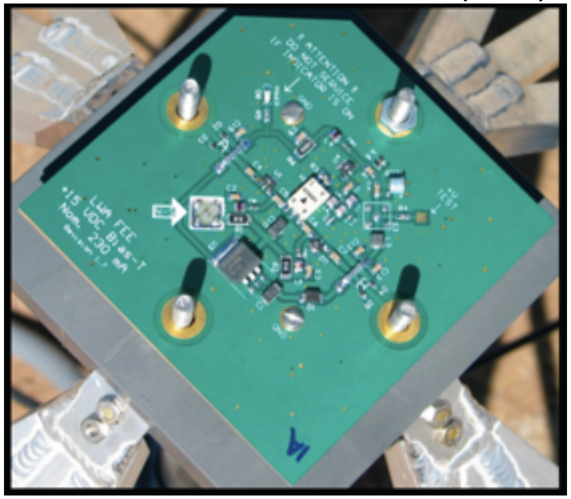
↓



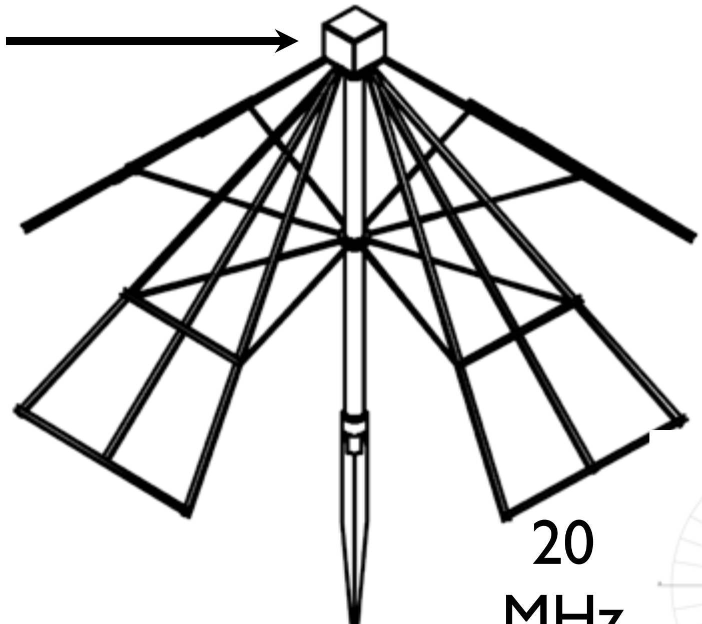


Active Antenna

Front-End Electronics (FEE)



- 36 dB Gain
- 2.7 dB Noise Figure (250 K)
- Galactic Noise Dominated over 20-80 MHz

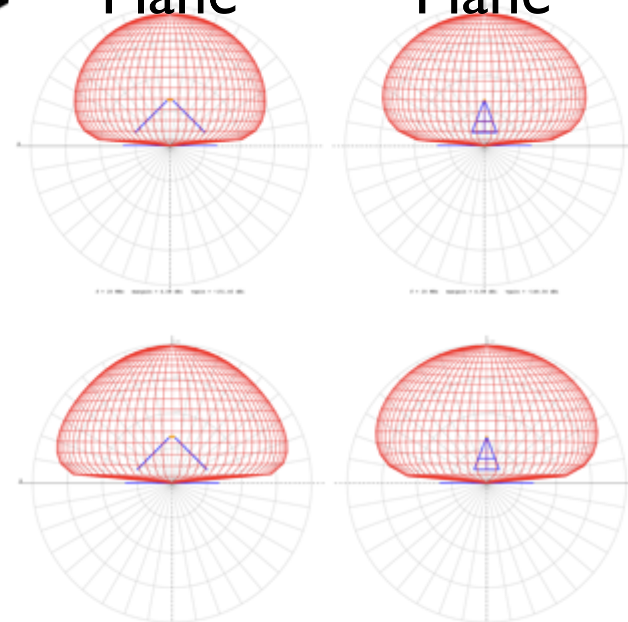


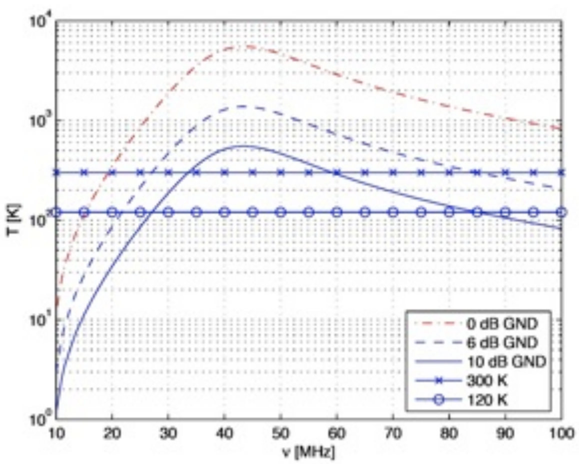
Inverted-Vee Dipoles to broaden the antenna pattern

E-Plane H-Plane

20 MHz

80 MHz

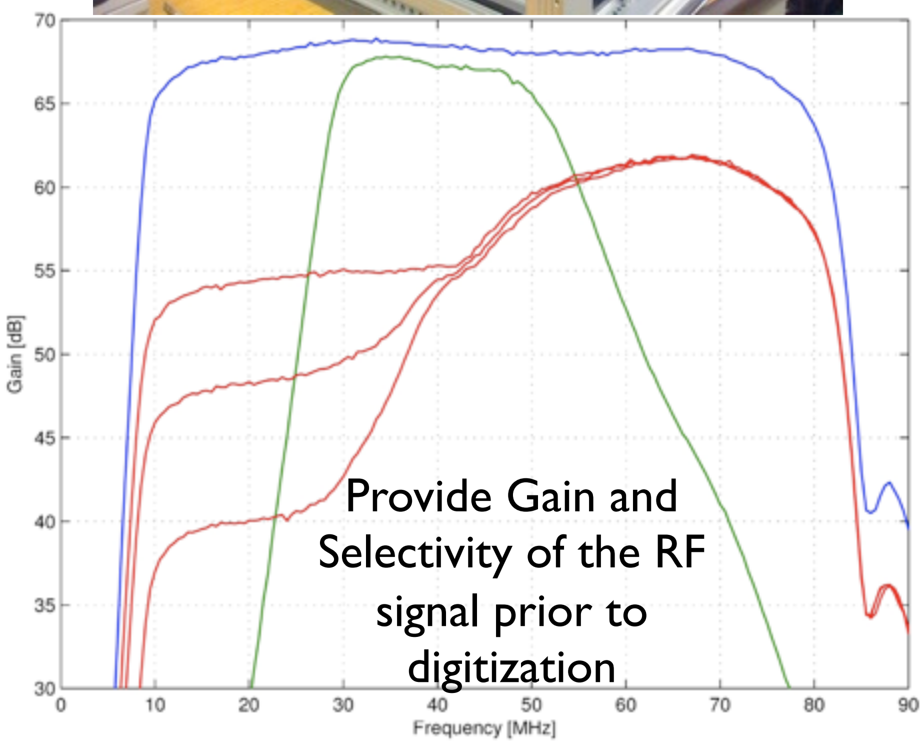




Front-End Noise Temperatures required to achieve Galactic Noise Dominance (GND)

Analog Receiver (ARX)

- 8 - 68 dB Gain (2 dB steps)
- Filterbank with 3 configurations
  - Full Bandwidth: 10 - 88 MHz
  - Reduced Bandwidth: 28 - 54 MHz
  - Split Bandwidth: 10 - 88 MHz, 30 dB of gain control over the low-frequency portion of the passband (equalizer)
- Integrated bias-tee to power FEE



Provide Gain and Selectivity of the RF signal prior to digitization

32 ARX boards per station

HAL:
Heuristic Automation for LWA1

HAL

```
HAL has successfully created the following schedule for UTC 2014/09/04:

Schedule:
  * 2014/09/04 00:04:00 /home/op1/MCS/exec/acquireTBWAndProcess.py
  * 2014/09/04 01:30:00 /home/op1/LO001/runLO001_split.py 14280
  * 2014/09/04 05:39:00 /home/op1/MCS/sch/INIdp.sh
  * 2014/09/04 05:54:00 /home/op1/MCS/exec/setASP_LS003.sh
  * 2014/09/04 05:59:03 LS003001, session 1806 starts on beam 2
  * 2014/09/04 05:59:03 LS003001, session 1807 starts on beam 1
  * 2014/09/04 05:59:03 LS003001, session 1808 starts on beam 4
  * 2014/09/04 05:59:03 LS003001, session 1809 starts on beam 3
  * 2014/09/04 06:59:13 LS003001, session 1806 stops on beam 2
  * 2014/09/04 06:59:13 LS003001, session 1807 stops on beam 1
  * 2014/09/04 06:59:13 LS003001, session 1808 stops on beam 4
  * 2014/09/04 06:59:13 LS003001, session 1809 stops on beam 3
  * 2014/09/04 07:01:00 /home/op1/MCS/sch/INIdp.sh
  * 2014/09/04 07:02:00 /home/op1/MCS/exec/setLEDA64_split.sh
  * 2014/09/04 07:20:00 /home/op1/MCS/sch/startTBN_split38.sh
  * 2014/09/04 07:24:00 /home/op1/MCS/exec/acquireTBWAndProcess.py
  * 2014/09/04 08:31:00 /home/op1/MCS/sch/INIdp.sh
  * 2014/09/04 08:51:55 LS006, session 112 starts on beam 2
  * 2014/09/04 08:51:55 LS006, session 113 starts on beam 4
  * 2014/09/04 09:52:05 LS006, session 112 stops on beam 2
  * 2014/09/04 09:52:05 LS006, session 113 stops on beam 4
  * 2014/09/04 09:54:00 /home/op1/MCS/sch/INIdp.sh
  * 2014/09/04 10:59:55 LH011, session 121 starts on TBN/TBW
  * 2014/09/04 12:00:05 LH011, session 121 stops on TBN/TBW
  * 2014/09/04 12:04:00 /home/op1/MCS/sch/startTBN_split38.sh
  * 2014/09/04 12:08:00 /home/op1/MCS/exec/acquireTBWAndProcess.py
  * 2014/09/04 12:52:00 /home/op1/MCS/sch/startTBN_split38.sh
  * 2014/09/04 16:11:00 /home/op1/MCS/exec/acquireTBWAndProcess.py
  * 2014/09/04 20:26:00 /home/op1/MCS/exec/acquireTBWAndProcess.py
  * 2014/09/04 20:52:00 /home/op1/MCS/sch/INIdp.sh
  * 2014/09/04 21:12:30 LS006, session 114 starts on beam 2
  * 2014/09/04 21:12:30 LS006, session 115 starts on beam 4
  * 2014/09/04 22:12:40 LS006, session 114 stops on beam 2
  * 2014/09/04 22:12:40 LS006, session 115 stops on beam 4
  * 2014/09/04 22:14:00 /home/op1/MCS/sch/INIdp.sh
  * 2014/09/04 22:34:00 /home/op1/MCS/sch/startTBN_split38.sh
```

Fully autonomous operation of LWA1

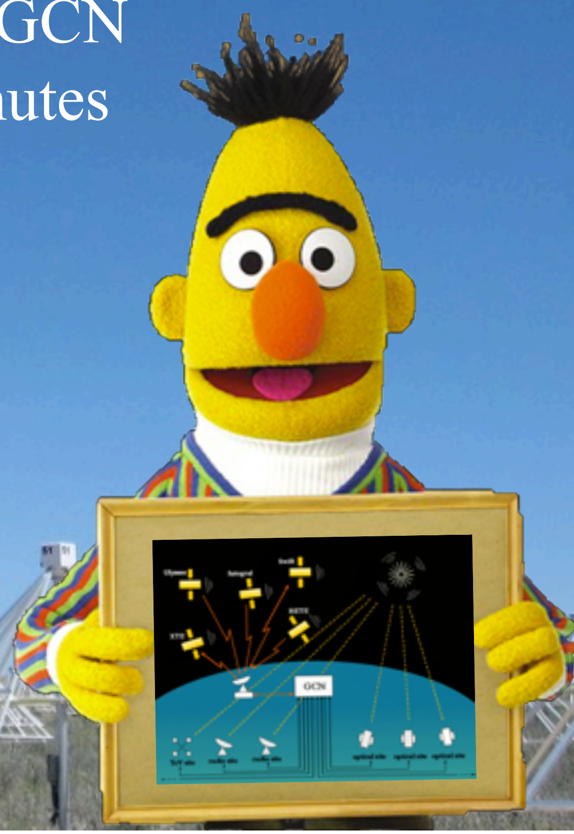
- Generation of static schedule
- Dynamic scheduling of filler observations
- Accepts automatic triggering of observations
- Reacts on environmental issues:
  - Electronics overheating
  - Lightning protection mode
- Automatic station health checks

```
HAL is taking control of LWA1 in order to protect ASP and DP by shutting both
systems down.  Observations will be canceled until the lightning has cleared the
area.

The following 'at' commands have been canceled:
  * 5920
  * 5921
```

BERT – Burst Early Response Triggering System

- Currently Running:
  - GRB follow-up observations
  - LIGO follow-up obser
  - VLA+LWA observations
  - BERT is the interface between HAL and GCN with LWA1 getting on the sky within minutes of a trigger

```
HAL is taking control of LWA1 in order to observe the trigger
'Fermi_GBM_GRB #431039250' which occured at 2014-08-29
21:07:27.469993.  Observations will start at 2014-08-29
21:09:54 (0:02:26.530007 after the event) and continue until
2014-08-30 00:09:54 on beams #2, #3, #4, #1

The following 'at' commands have been canceled:
  * 5968
```



LWA1 vs. LWA-SV

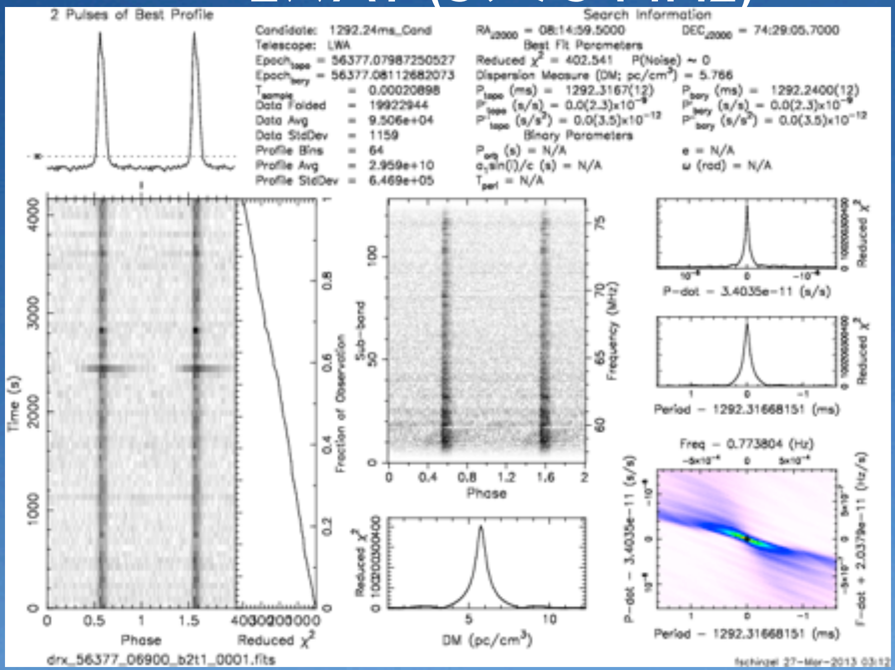
- Similar layout, antennas, analog receivers, and M&C systems
- HAL & SAL
- Beamformer
- TBN (all-sky) mode with 100 kHz of bandwidth

- Different digital backend
  - DP at LWA1
  - ADP at LWA-SV
- LWA-SV has only one beam but allows for simultaneous real-time correlation over a wide bandwidth

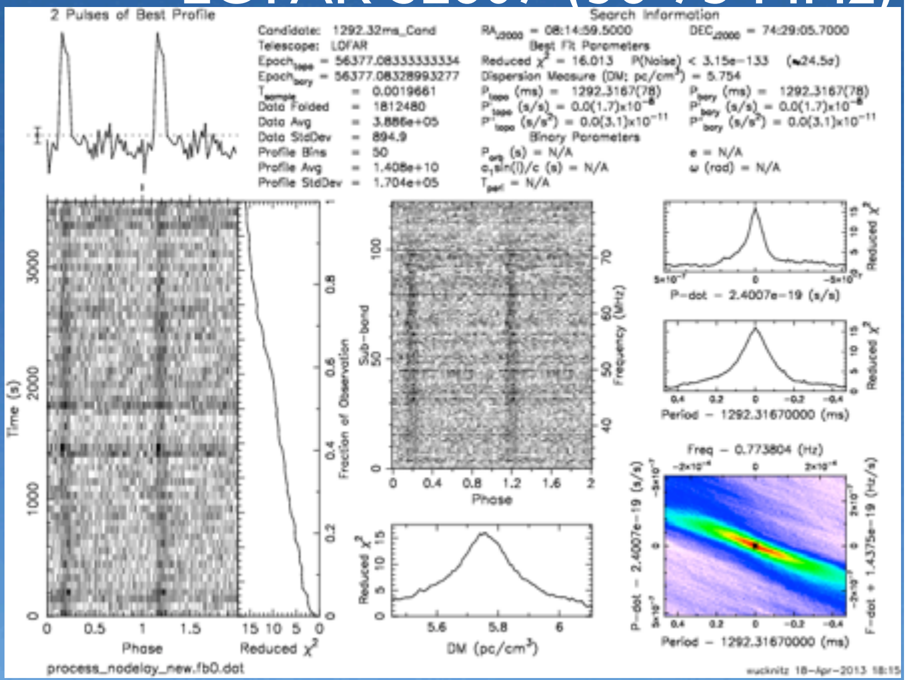
Using Pulsars to compare sensitivity

LWA1 Compared to LOFAR Int'l Station

LWA1 (59-75 MHz)



LOFAR SE607 (36-75 MHz)

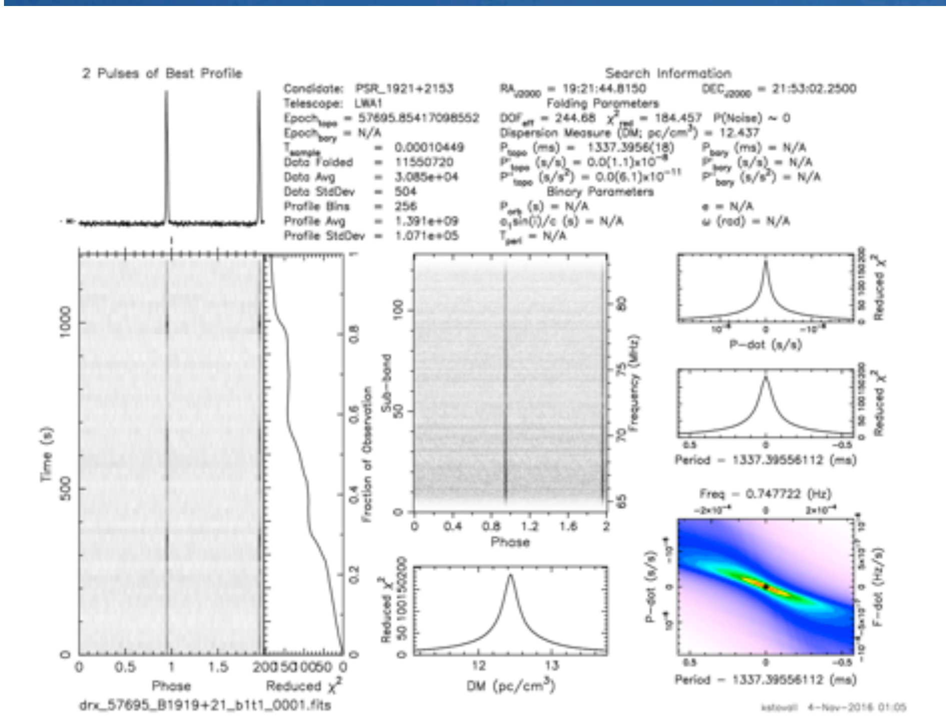


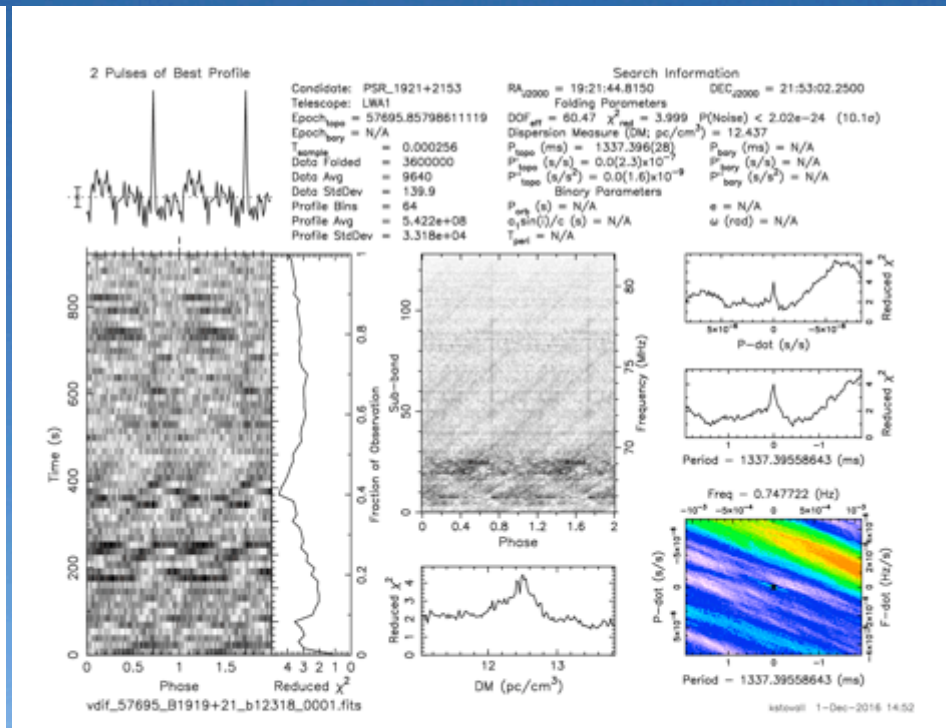
256 dipoles vs 96 dipoles

PSR B0809+74 (Wucknitz, Schinzel, McKay, Carozzi)

PSR B1919+21

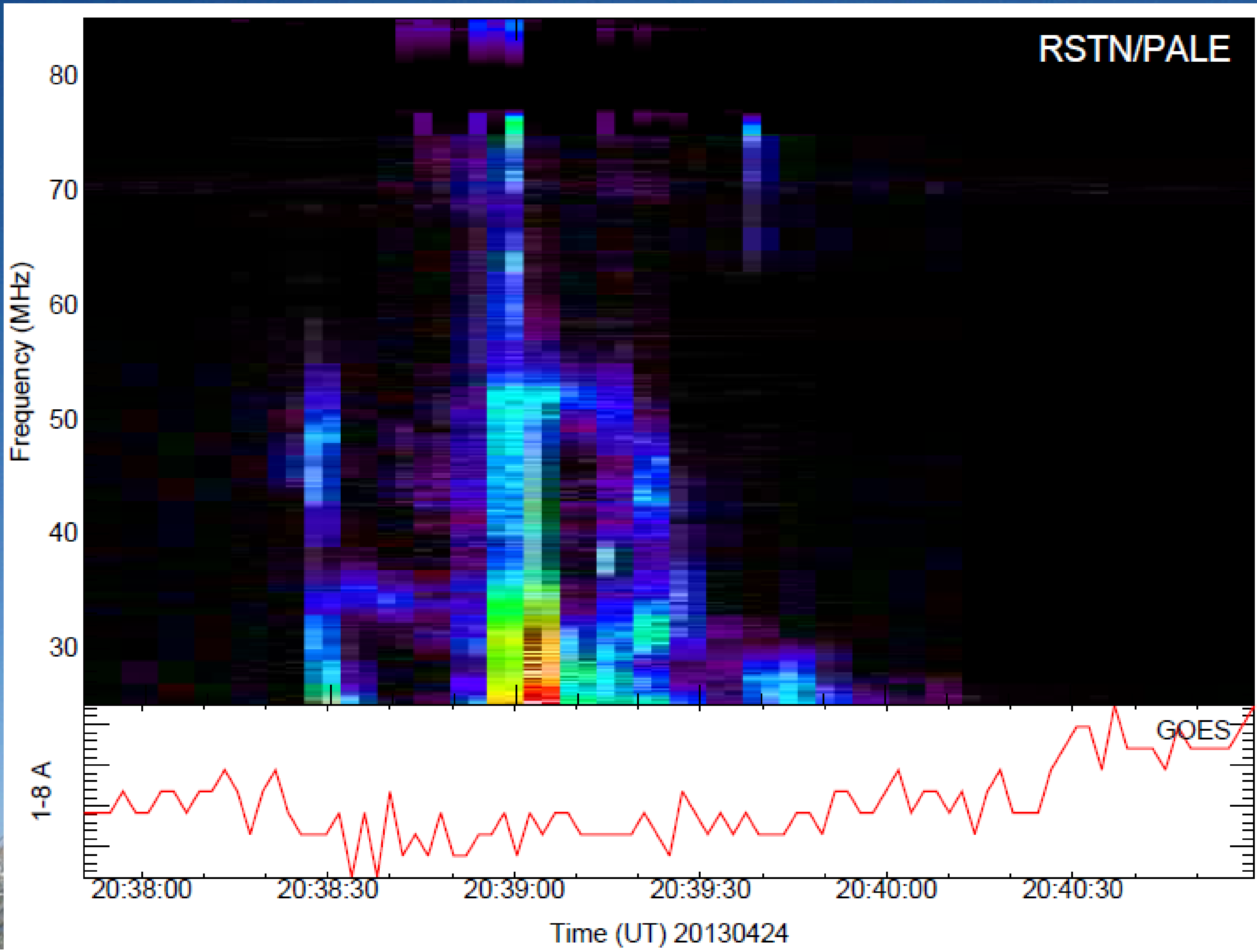
- Test observation on Nov 03rd 2016, 20 min
- 12 antennas (A config.) + LWA1
- 16 MHz bandwidth/4 bit

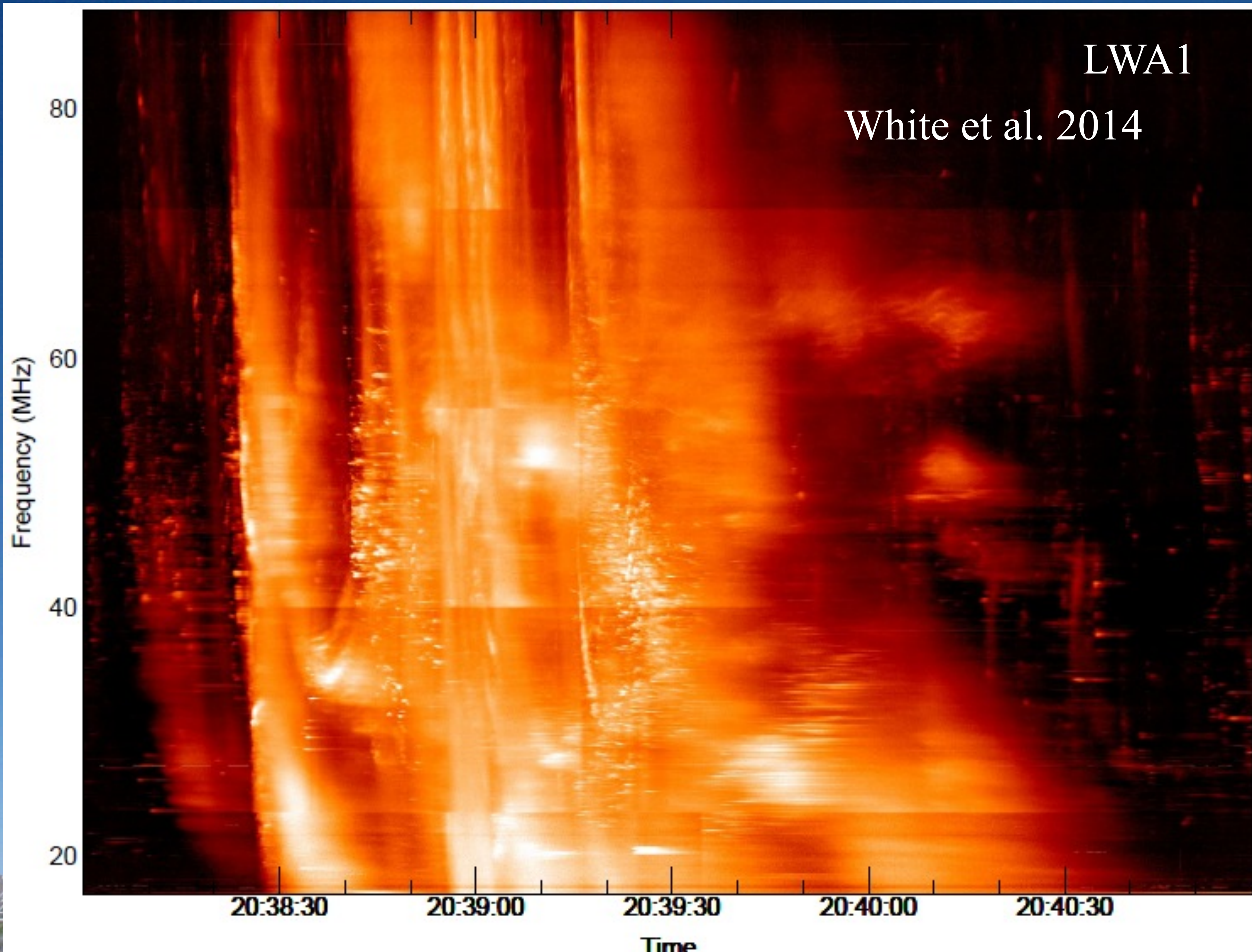




LWA1 256 dipoles vs. VLA ant18, a 25m dish with MJP

“Type III” burst at RSTN (3 seconds, 0.15 MHz)





LWA1
White et al. 2014
Frequency (MHz)
80
60
40
20
20:38:30
20:39:00
20:39:30
20:40:00
20:40:30
Time

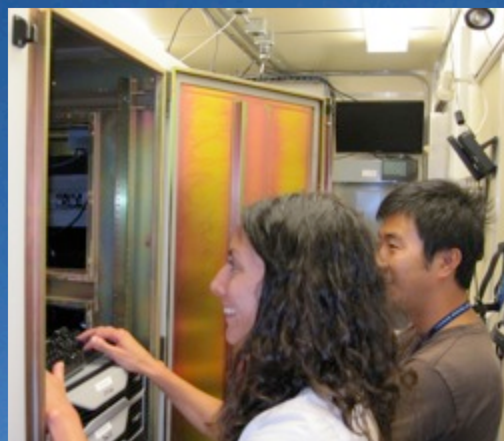
Construction

- Site/Power/Coms/Shelter
- Trenching & Conduit for Cabling
- Antenna Installation
- Cable Installation

- Receivers, Digital Processor, Data Recorders, Electronics








Remember to start with a Fence!

Overview

- 35 publications to date
  - Pulsars
  - Ionospheric research and space weather
  - The Sun
  - Jupiter
  - Meteors

LWA Science

Astrophysics

- **Cosmology**
  Observing cosmic dawn through redshift 30 absorption of the 21 cm line. High redshift radio galaxies, containing the earliest black holes

- **Acceleration, Propagation & Turbulence in the ISM**
  Origin, spectrum & distribution of Galactic cosmic rays, Supernova remnants & Galactic evolution, Pulsars and their environments

- **Solar Science & Space Weather**
  Jupiter, Radio heliography of solar bursts & coronal mass ejections, Solar magnetic fields

- **Exploration of the Transient Universe**
  New coherent sources, GRB prompt emission, poorly explored parameters space …

- **Meteors**
  Self-emission and reflections of man-made signals

Iono- & Atmospheric Physics

- Unprecedented continuous spatial & temporal imaging of the ionosphere

- Test and improve global ionospheric models

- High-time-resolution Imaging of Lightning

Cosmic Ray Physics

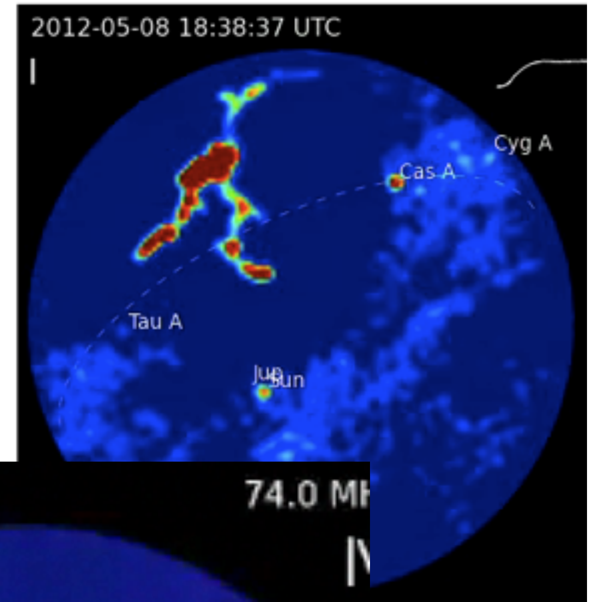
Your ideas?

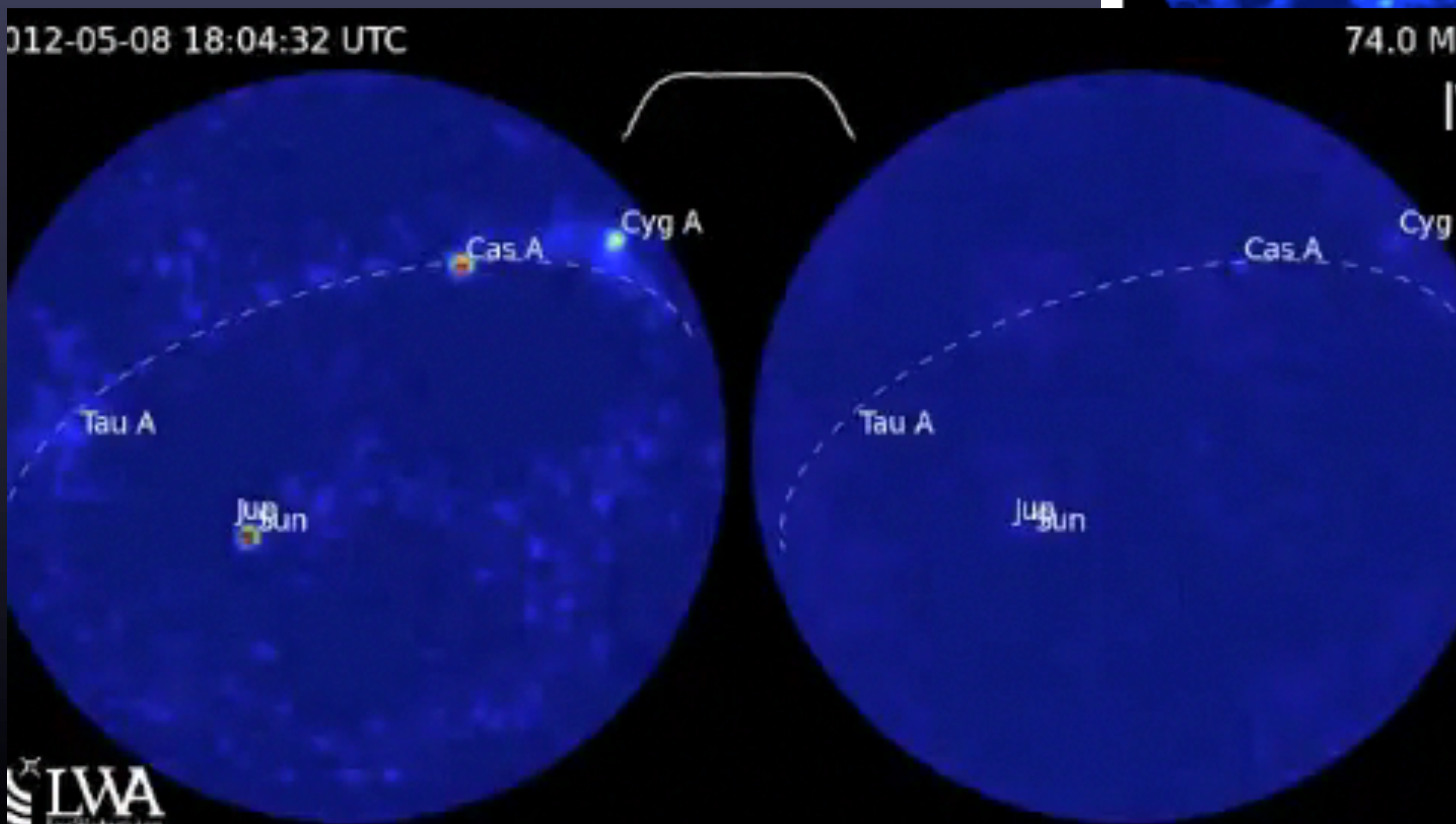
All of LWA1 time is open skies.

Your observing proposals are welcome!

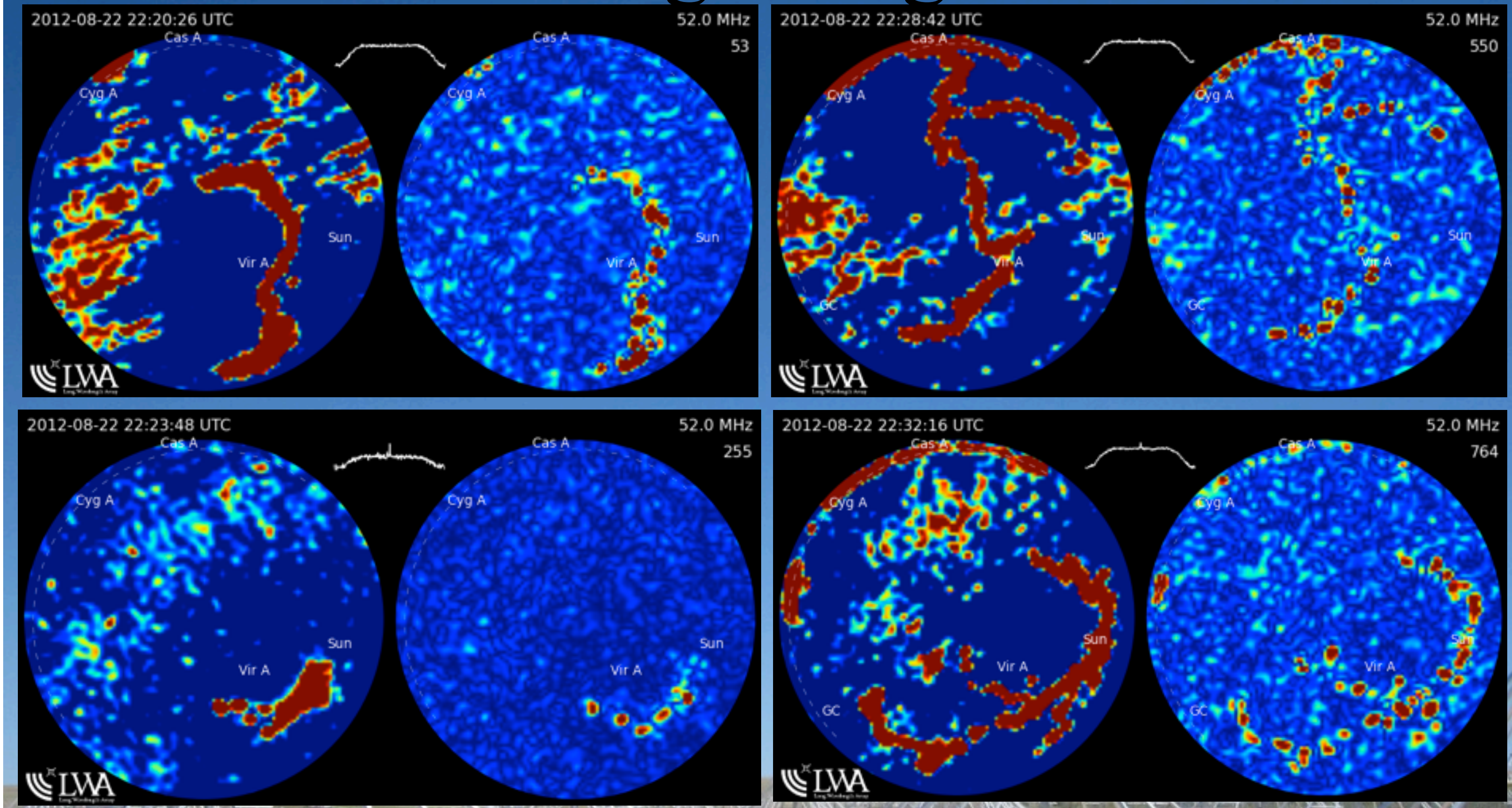
Lightning

Thunderstorm season on the Plains ...



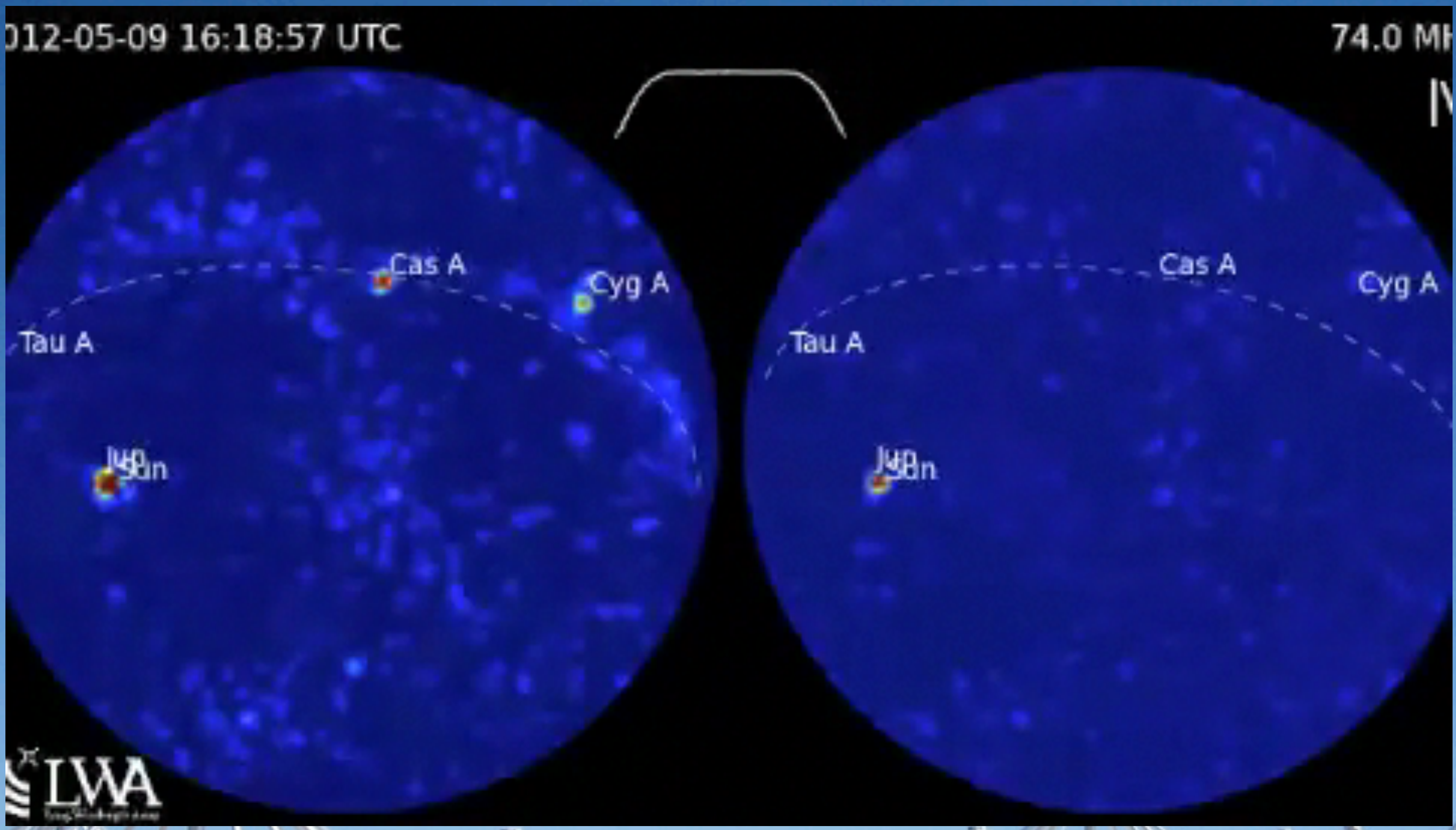


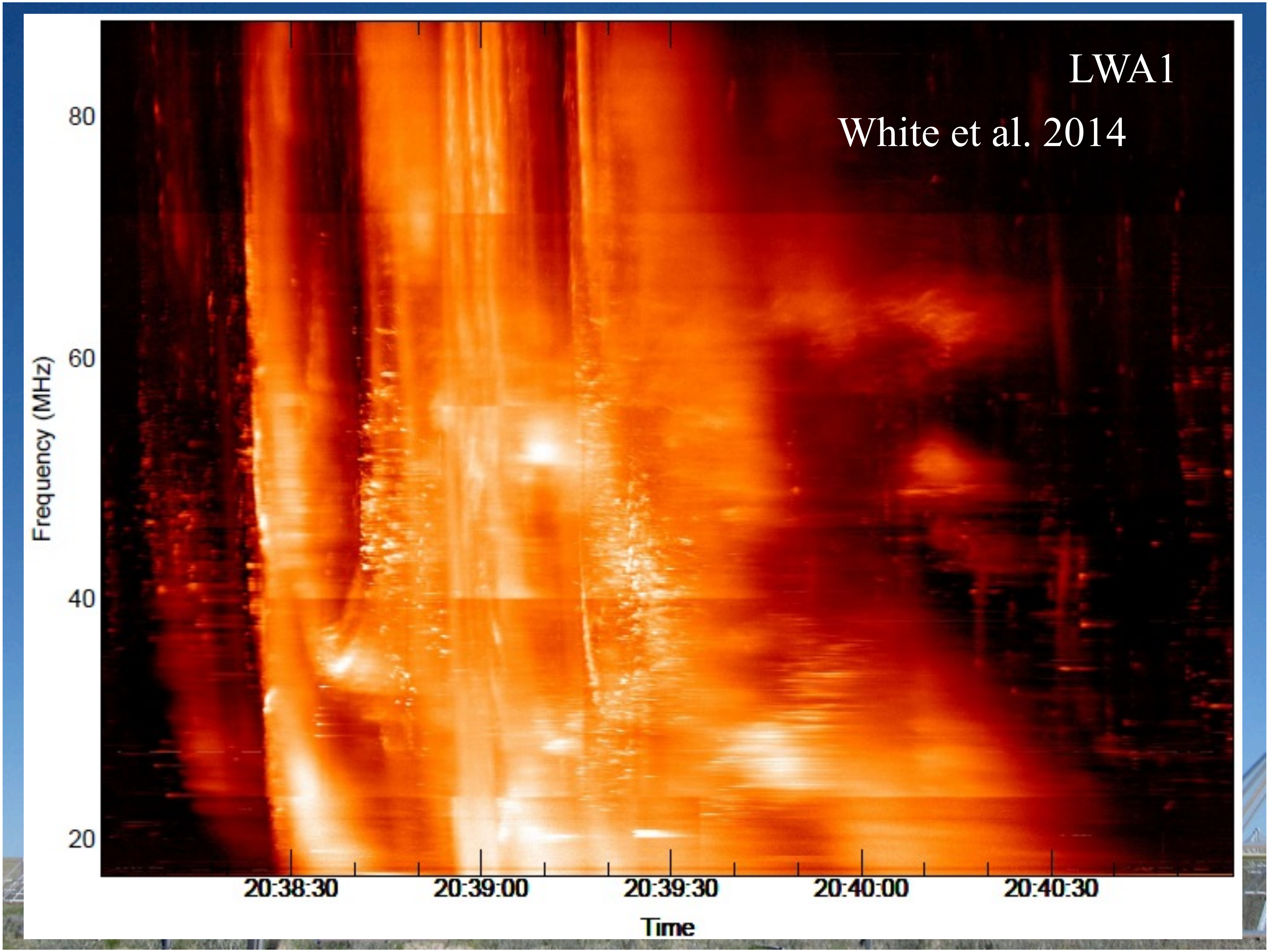
Lightning


2012-08-22 22:20:26 UTC
52.0 MHz
53
2012-08-22 22:28:42 UTC
52.0 MHz
550
2012-08-22 22:23:48 UTC
52.0 MHz
255
2012-08-22 22:32:16 UTC
52.0 MHz
764
Cas A
Cyg A
Sun
Vir A
GC
LWA

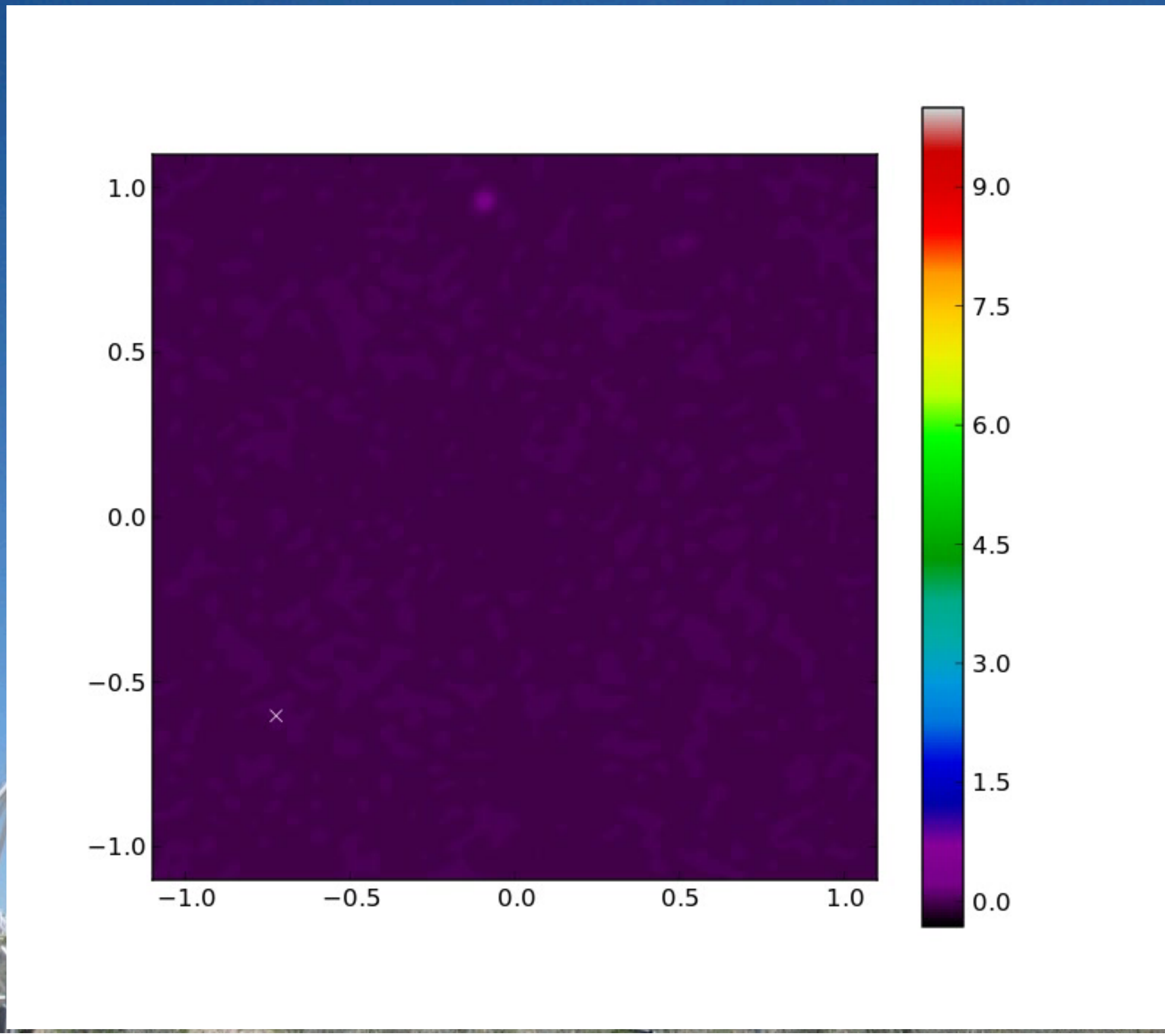
Solar Interference

Watch out for the Active Sun




LWA1
White et al. 2014
Frequency (MHz)
80
60
40
20
20:38:30
20:39:00
20:39:30
20:40:00
20:40:30
Time

International Space Station
July 2013



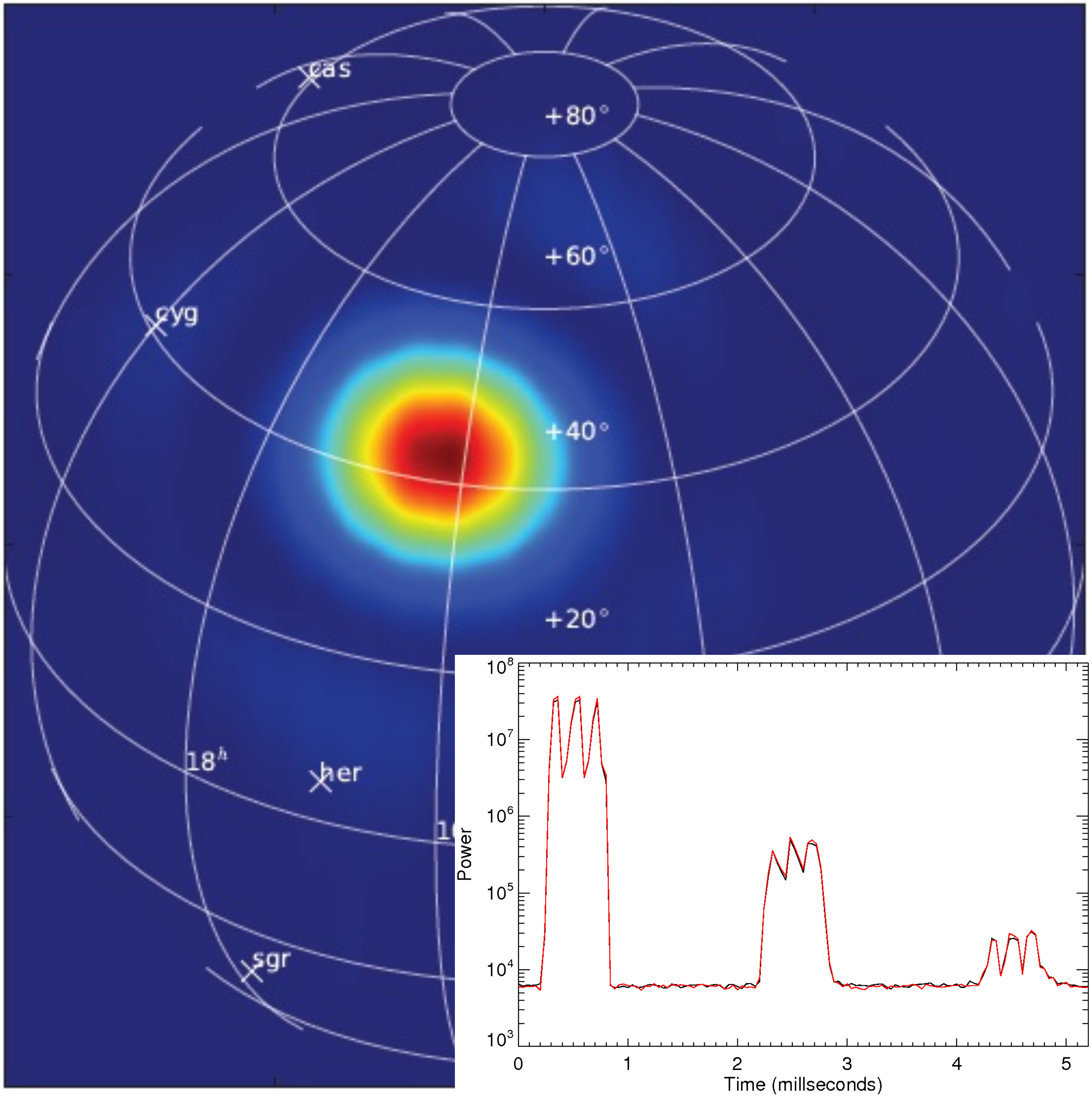


Image of the Kirtland digisonde reflecting off the ionosphere

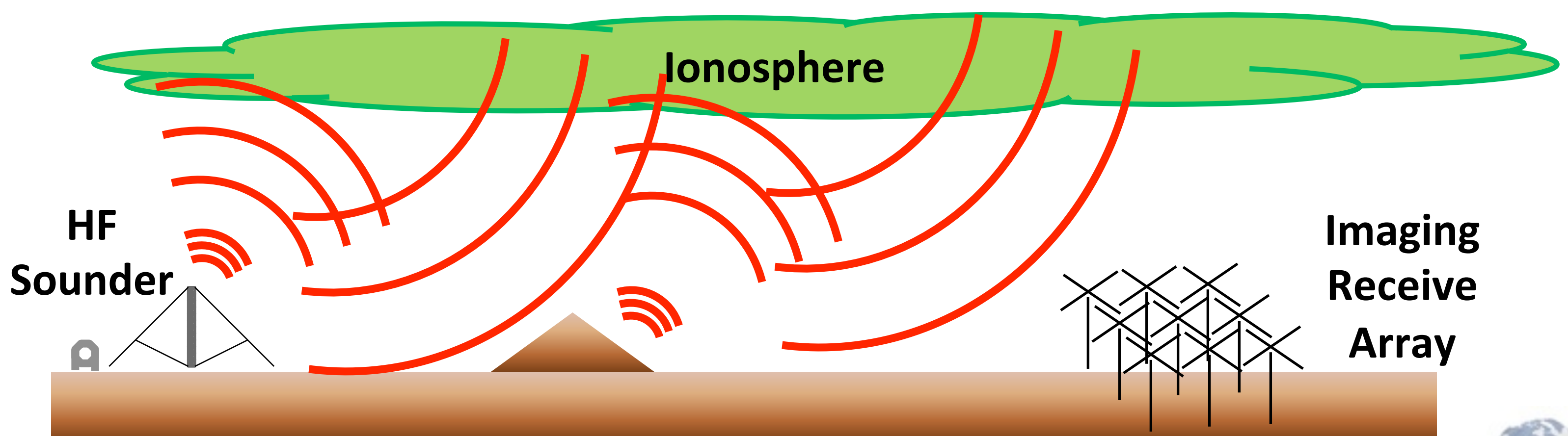
(astronom-ical coords)

+

Pulse train at 40 micro-seconds resolution

Bottomside Ionosphere and Terrain Mapping

- In addition to transmitter direct echoes, terrain features illuminated by sounder also potential control points for ionospheric reconstruction
  - Appear as "2nd-hop" echoes
  - Echo strength depends on surface tilt and roughness
    - Readily computed from digital elevation models



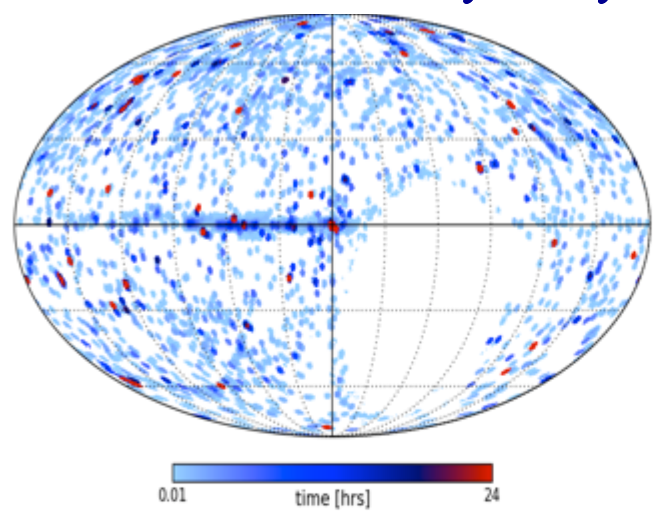
Beyond eLWA: ngVLA and ngLOBO

- The Next Generation VLA is an opportunity for a low frequency "ride along"
  - Builds off VLITE at P-band and eLWA at 4-band
  - Infrastructure sharing saves costs and has interesting baseline lengths (~300 km)
  - ngLOBO commensal system 150-800 MHz

ngVLA Option: Commensal Low Frequency Science

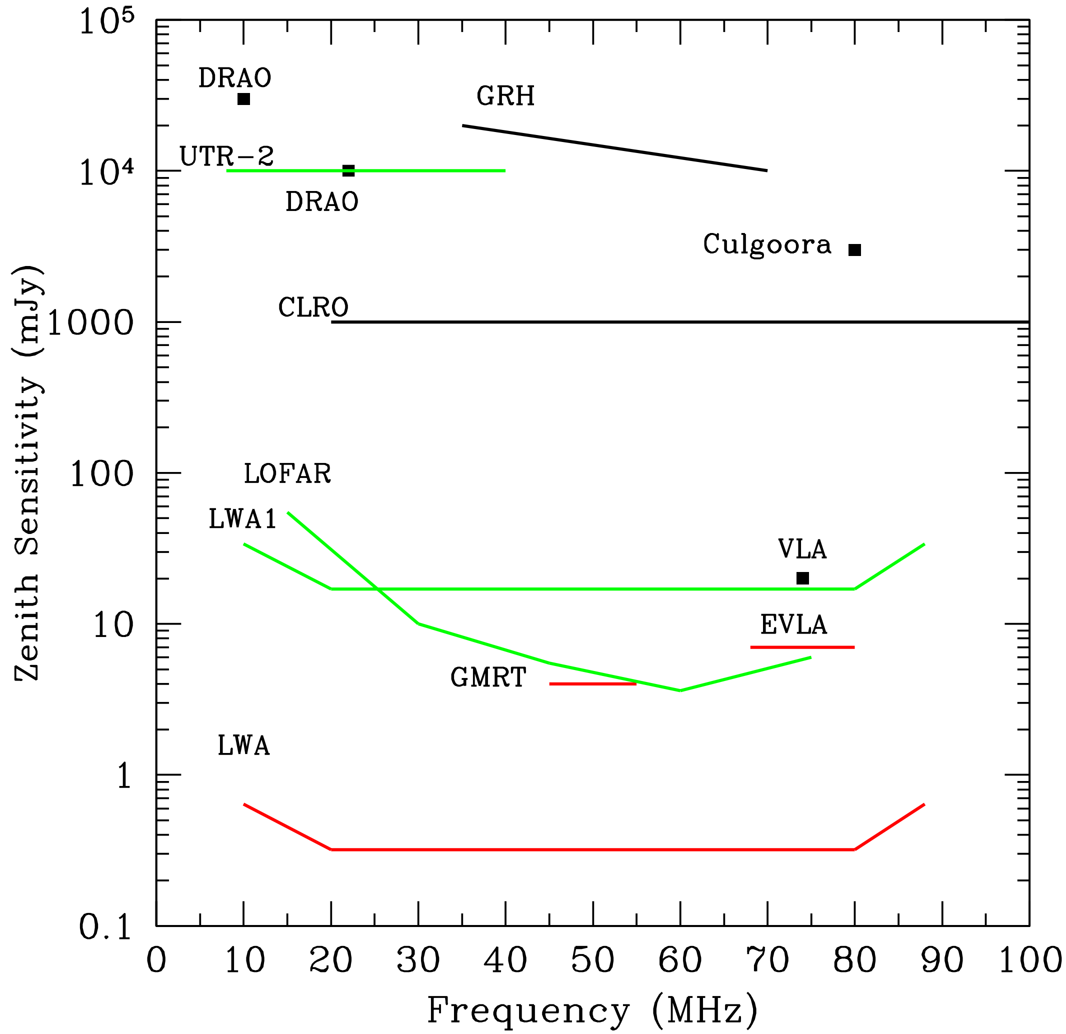
LWA: all sky plus beams

VLITE: >50% of sky in 1 year



- Current infrastructure:
  - VLITE + LWA => Low Band Observatory (LOBO)
- Future: Leverage ngVLA infrastructure (land/ fiber/power) for commensal low frequency capabilities (ngLOBO)
- 5 – 150 MHz: multi-beam dipole arrays alongside ngVLA long-baseline stations (e.g., LWA style).
- 150 – 800 MHz commensal prime focus feeds on ngVLA antennas (e.g., VLITE style)
- Science: efficiently exploring the entire low frequency Universe with (almost) “free photons” so transients, pulsars, space weather, exo-planets, …

Comparison to other instruments



	Declination Range	Δν (MHz)
UTR2:	-30° to +60°	33
LOFAR:	-11° to +90°	16
Y=VLA:	-35° to +90°	3
LWA1:	-30° to +90°	16
GMRT:	-53° to +90°	10

LWA1 has sensitivity ~25% of all of LOFAR

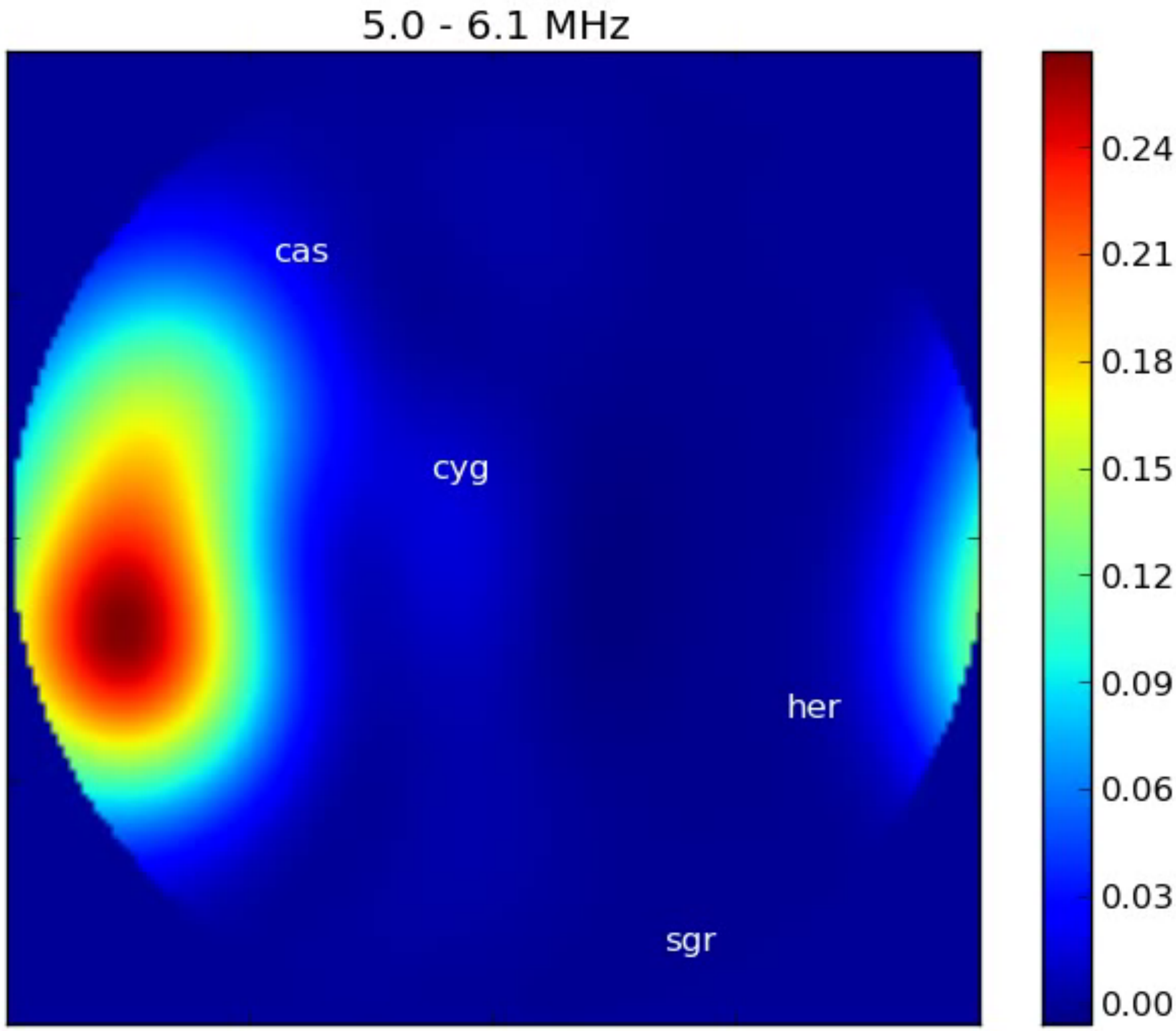
Adding another station and the VLA would about equal LOFAR

Summary

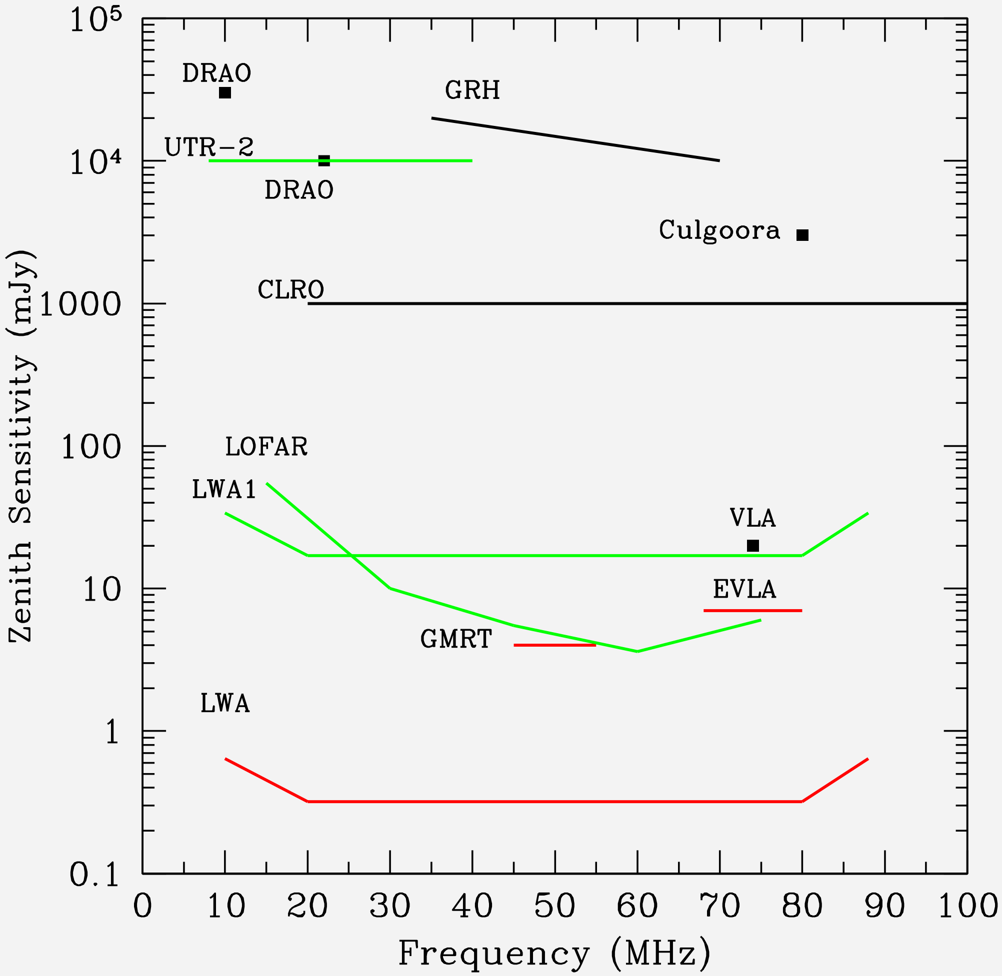
- LWA1 has demonstrated technical feasibility and scientific results
- Lots of exciting science at low frequencies. Progress requires:
  - High temporal, spectral, and spatial resolution
  - Sensitivity
  - Software development
- Current experiments are providing new hardware and software, and a better understanding of the sky at long wavelengths
- We have begun the next phase – interferometry with LWA and VLA stations

LWA
Long Wavelength Array

Extra Slides


5.0 - 6.1 MHz
cas
cyg
her
sgr
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00

Comparison to other instruments



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LWA1 has sensitivity ~25% of all of LOFAR-LBA