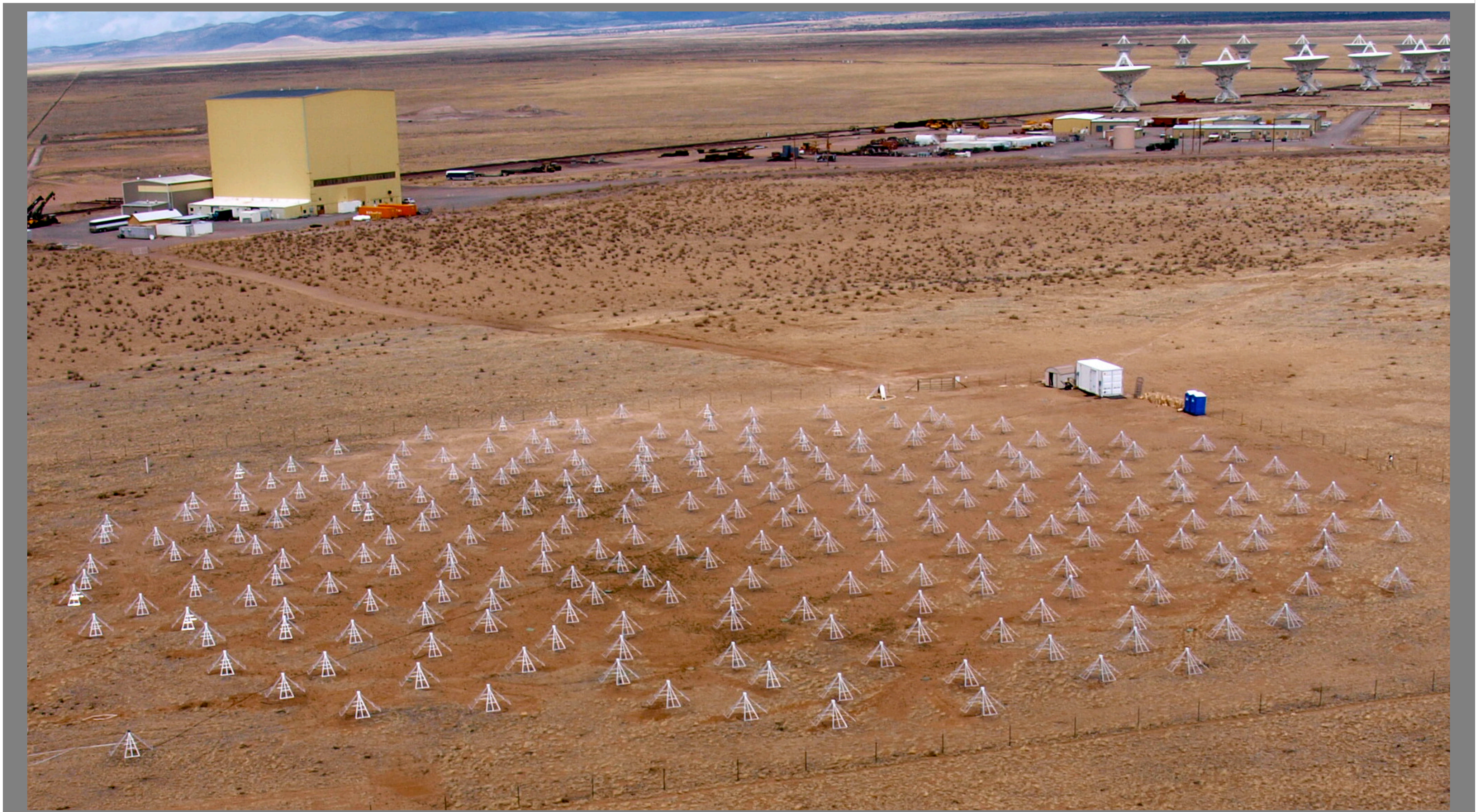
Long Wavelength Interferometry

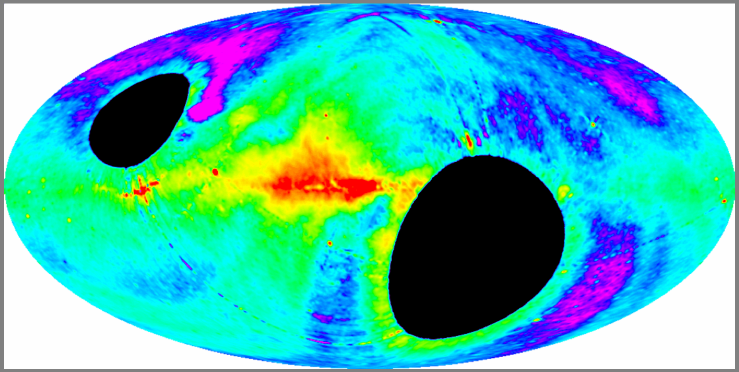


ASTR 423 Radio Astronomy

Announcements – The Sprint to the Finish

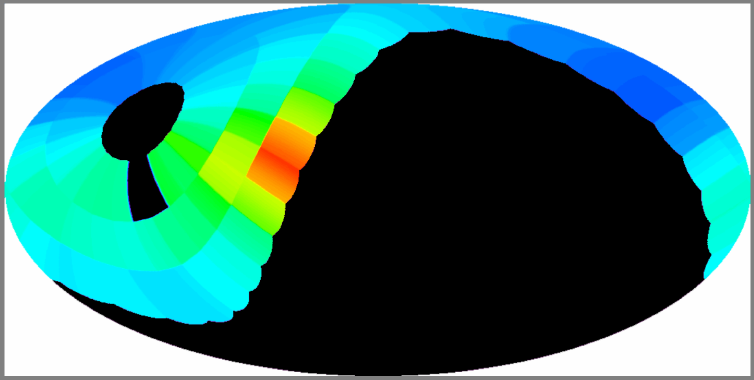
- Exam2 average: 87% – good job
- Course evaluations: 15% – not as good, but not too late
- May 3; teams 421 and 422 (VLA projects)
- May 5; teams 423 and 424 (LWA projects)
- Presentations should use slides (powerpoint, keynote, etc.) and aim for 21+10 (talk + Q&A) Everybody in the group needs to take a turn speaking
- May 7 - Written reports due

Science - All-Sky Survey



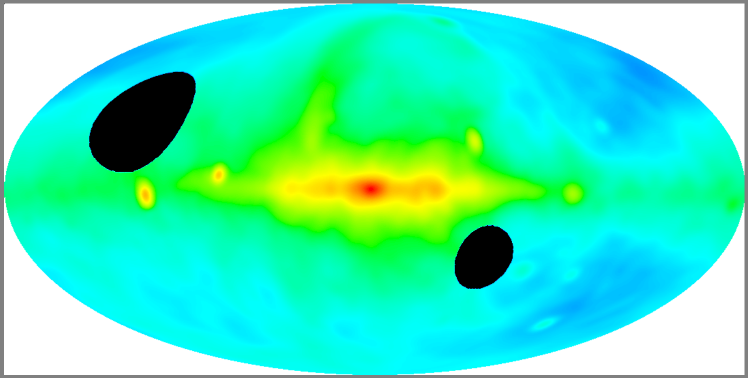
35 MHz

Dwarakanath et al. 1990



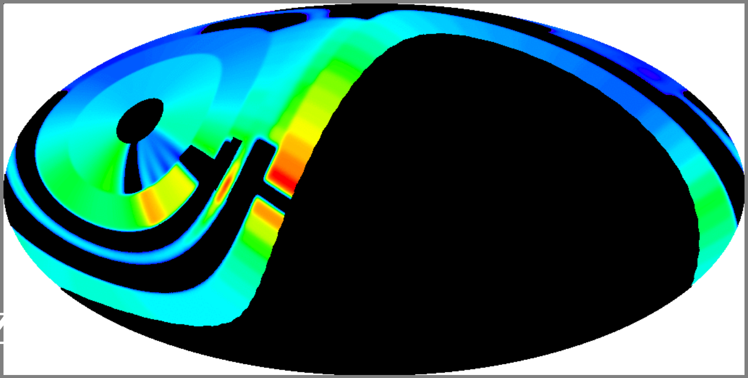
38 MHz

Turtle et al. 1962



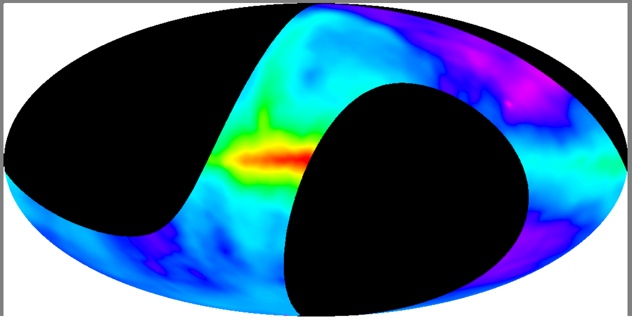
45 MHz

Alvarez et al. 1997;
Maeda et al. 1999



81 MHz

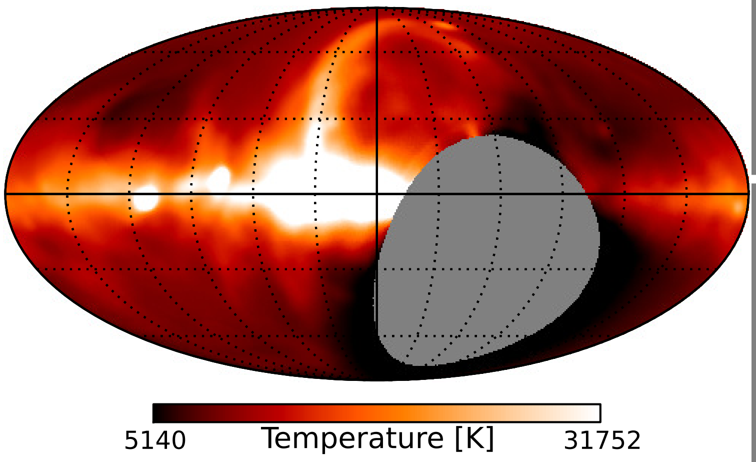
Bridle 1967



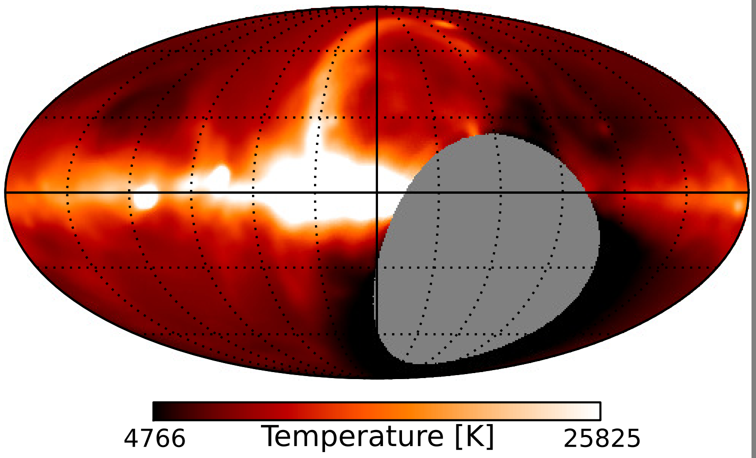
85 MHz

Landecker & Wielebinski 1970

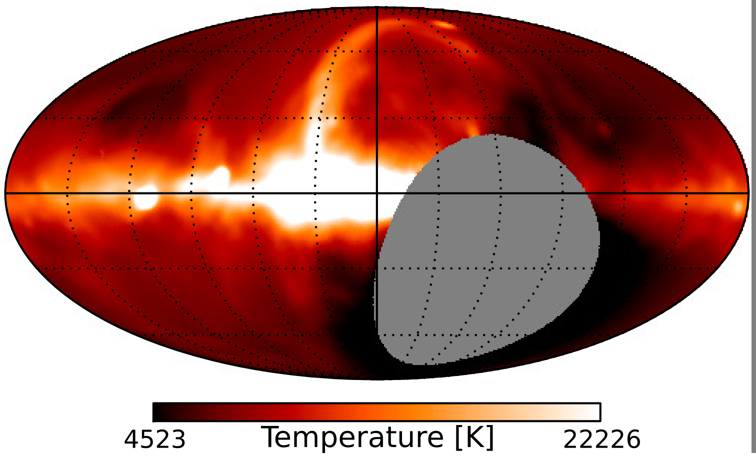
35 MHz



38 MHz



40 MHz

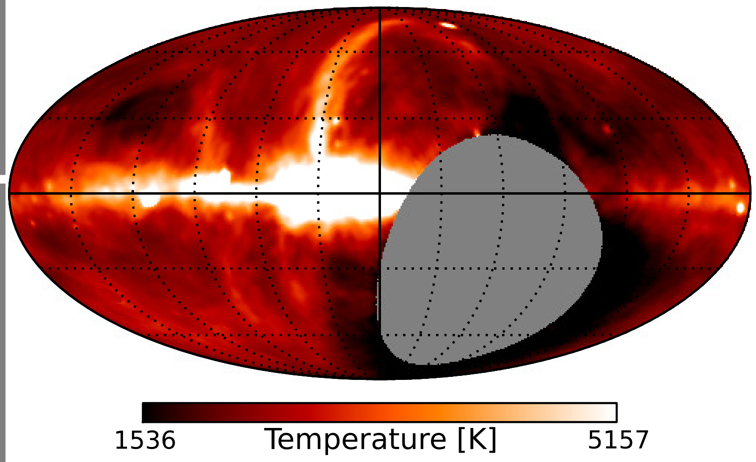


The Sky
35-80 MHz

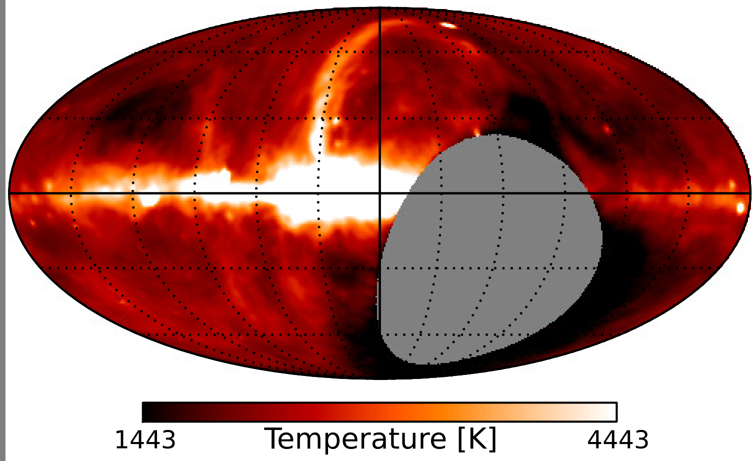
Dowell et al.
2017

+ New Low
Frequency Sky
Model generator

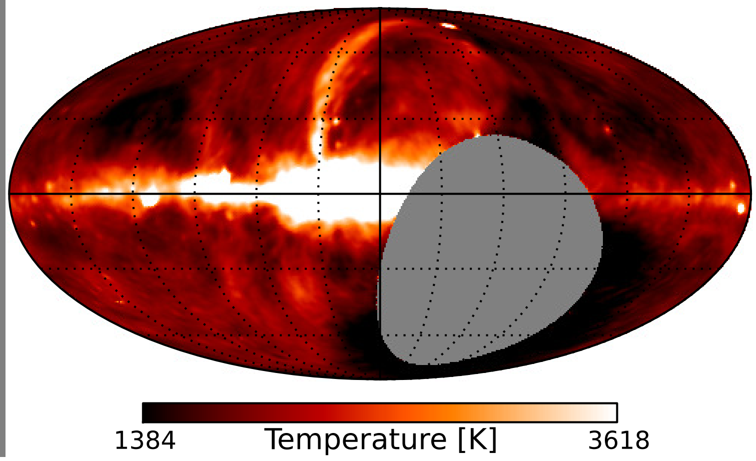
70 MHz



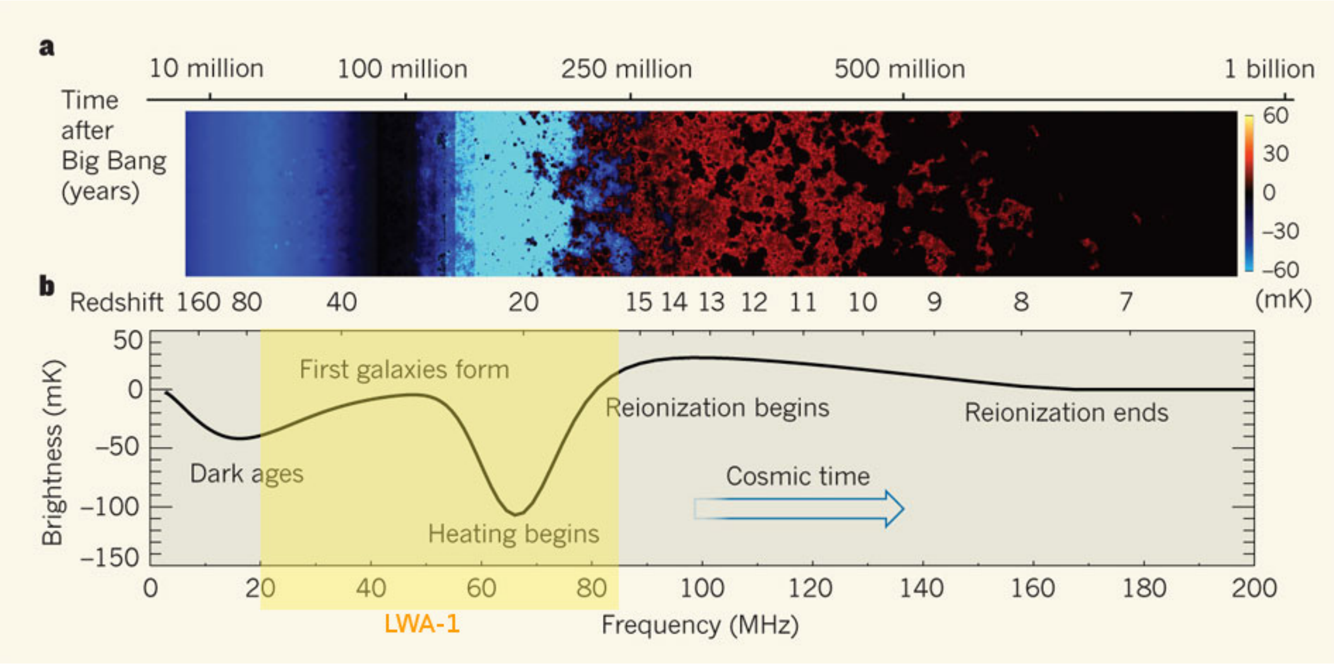
74 MHz



80 MHz



Cosmic Dawn



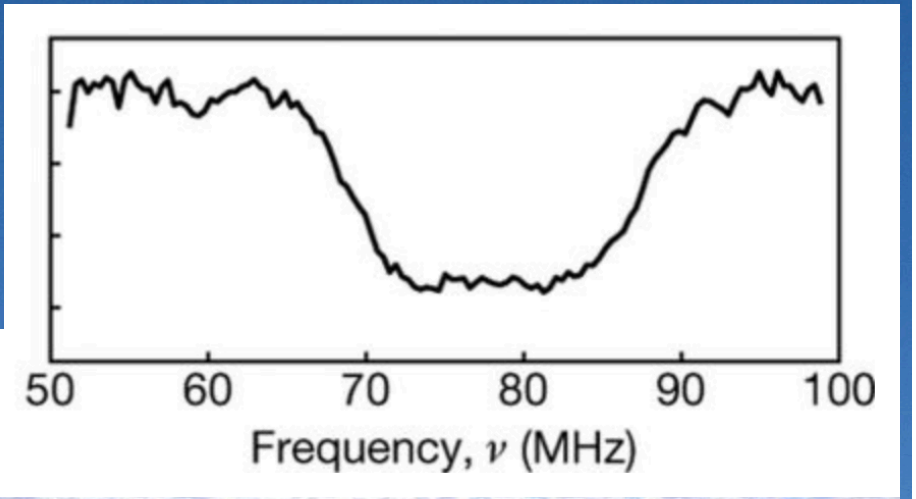
The predicted brightness temperature of the 21cm line from the HI gas is displayed as a function of time, redshift & frequency.

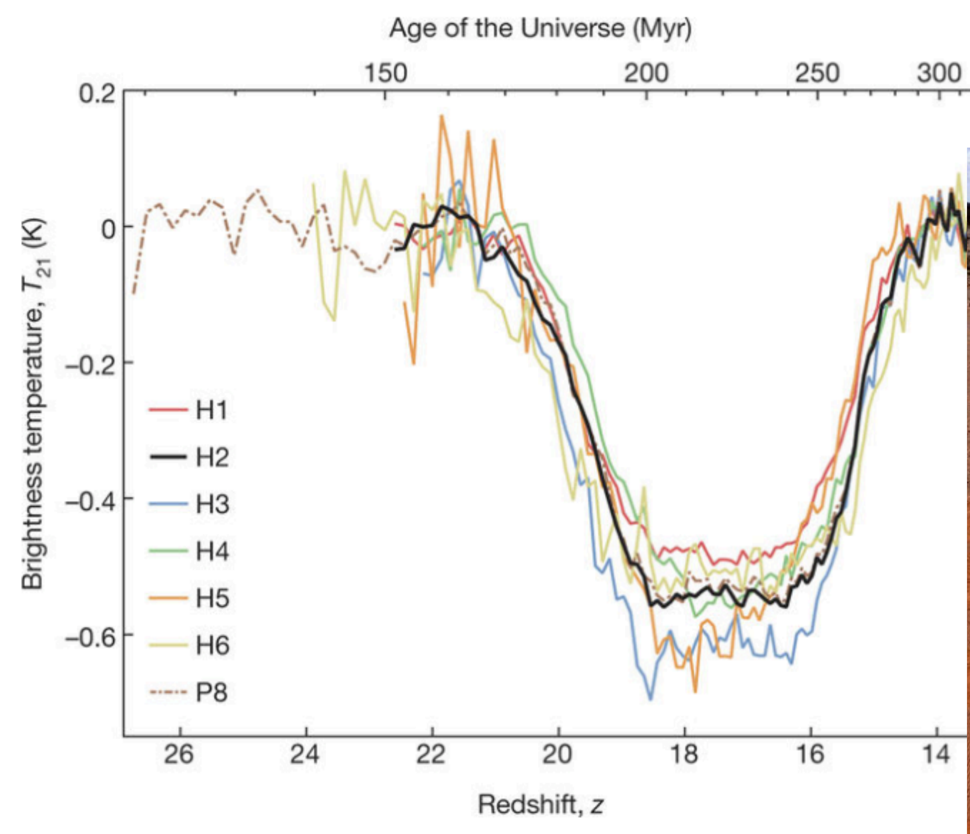
Figure 1 from Pritchard & Loeb, 2010 Nature 469 772

The Dark Ages through Cosmic Dawn encompasses the formation of the 1st galaxies & black holes. The LWA offers a window into this era.

Detection of HI at z=17

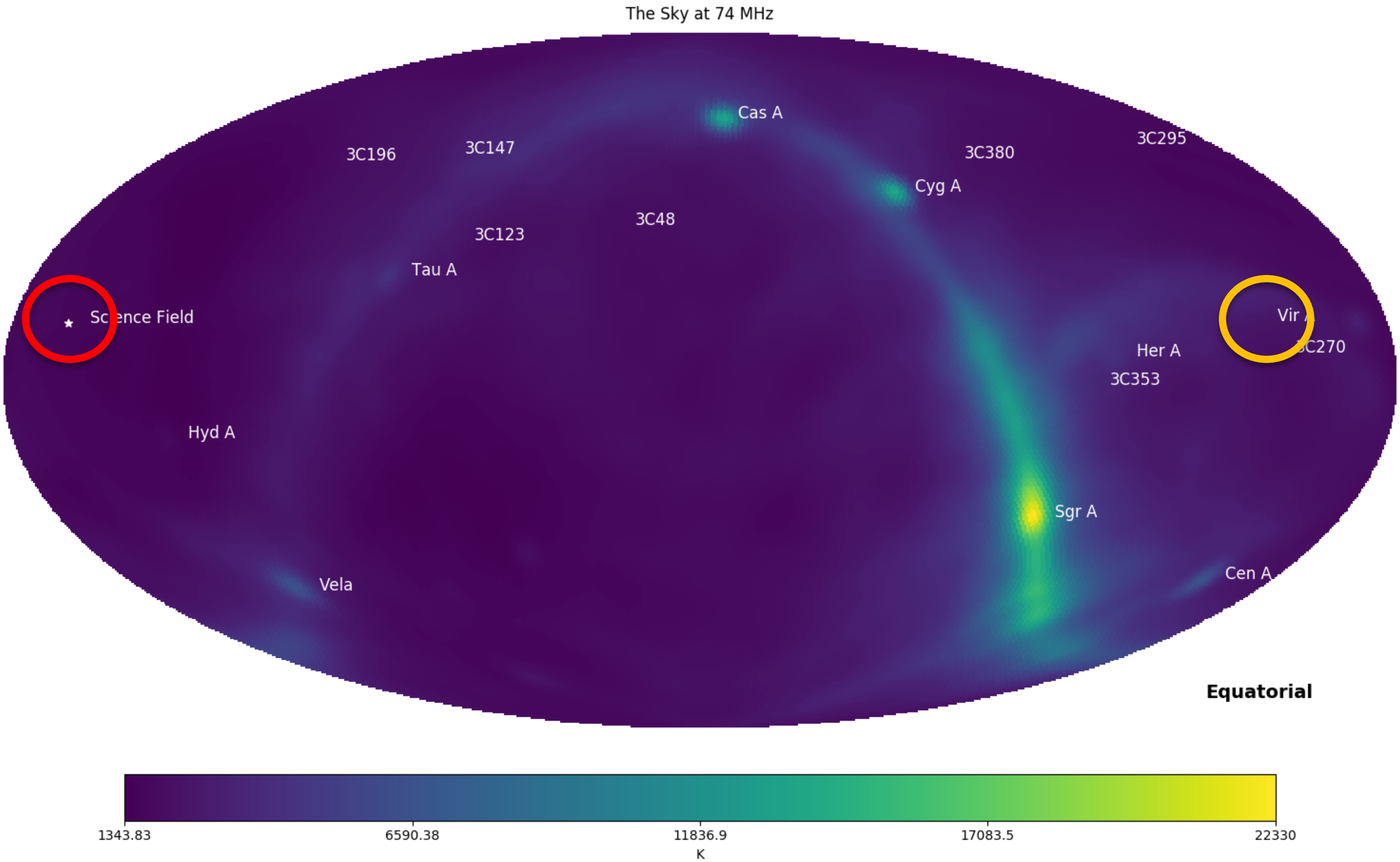
Bowman et al. 2018



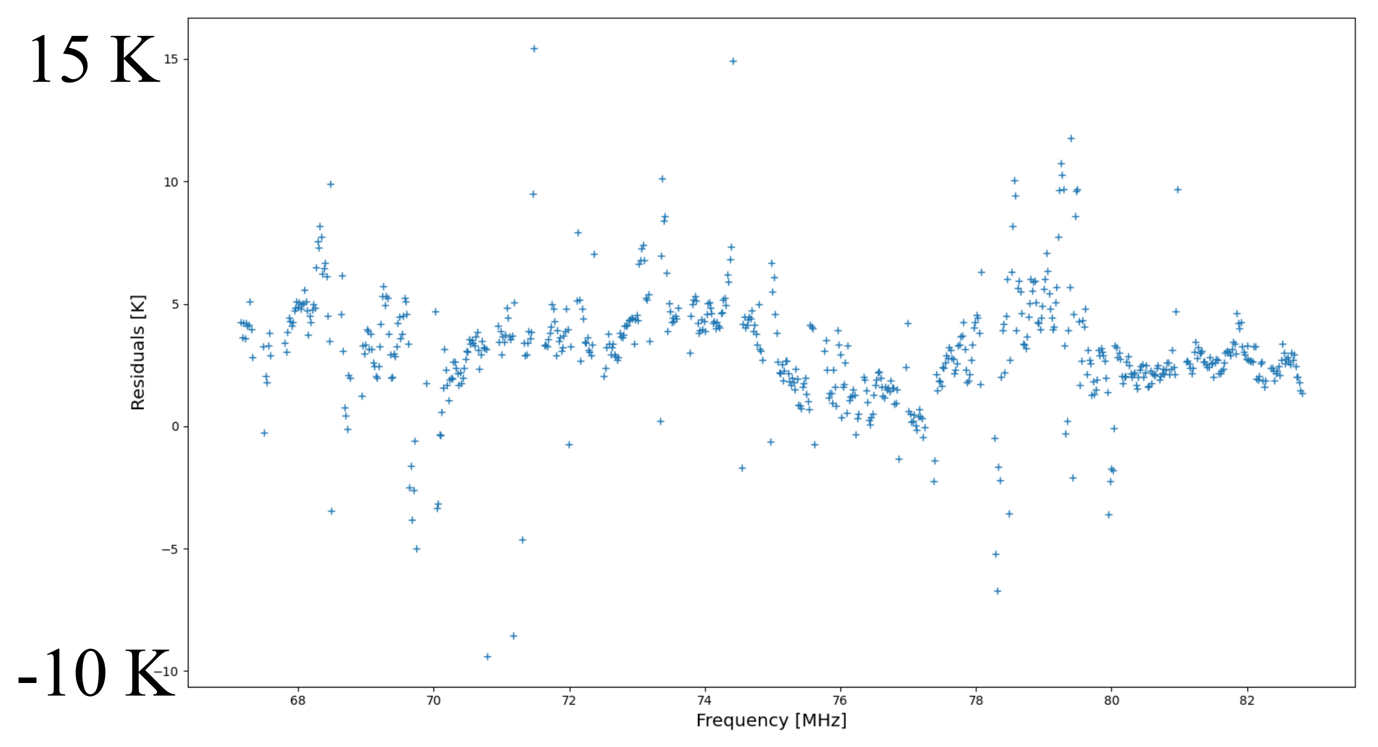


EDGES, Australia

LWA-SV Efforts



LWA-SV Efforts



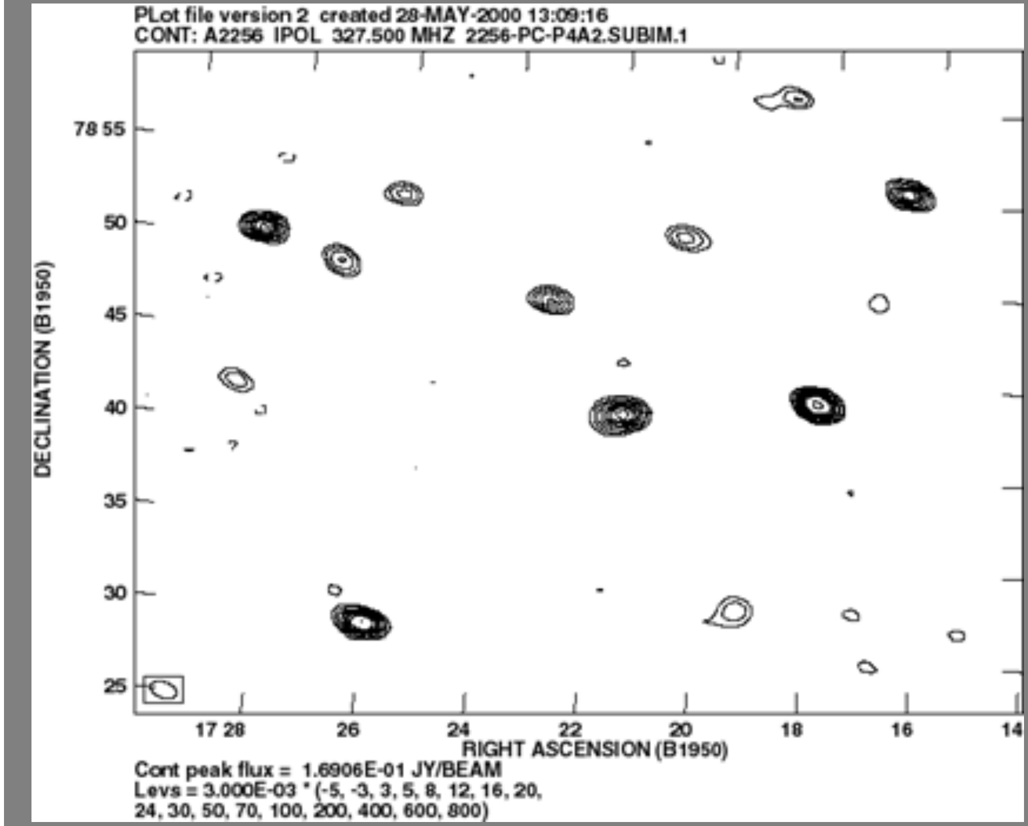
rms ~3 K
5 minute integration

DiLullo et al. 2020
DiLullo et al, in prep

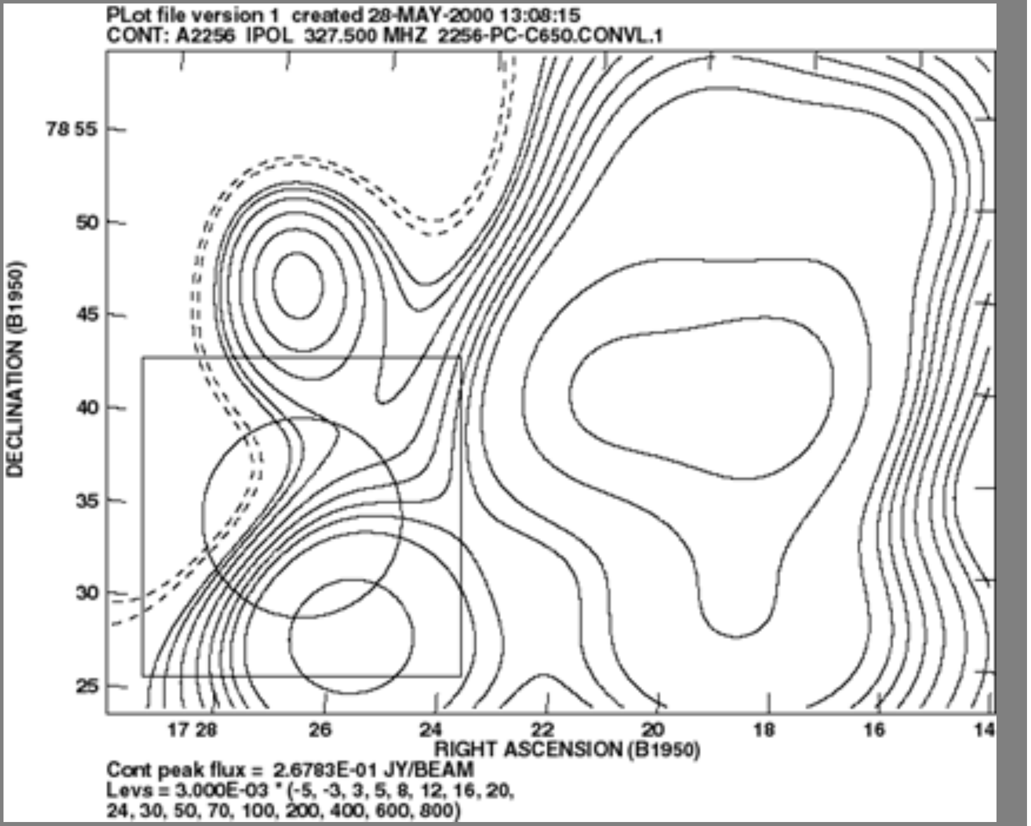
Confusion

- First radio telescopes operated at long wavelengths with low spatial resolution and very high system temperatures
- Radio astronomy quickly moved to higher frequencies with better spatial resolution and lower system temperatures

$\theta \sim 1'$, rms $\sim$ 3 mJy/beam



$\theta \sim 10'$, rms $\sim$ 30 mJy/beam



Low Frequency In Practice: Not Easy!

- Bandwidth smearing

Distortion of sources with distance from phase center

- Interference:

Can be severe below 5 GHz

- Phase coherence through ionosphere

Corruption of coherence of phase on longer baselines

- Finite Isoplanatic Patch Problem:

Calibration changes as a function of position

- Large Fields of View:

Non-coplanar array (*u*,*v*, & *w*)

Large number of sources requiring deconvolution

Calibrators

- Time-variable primary beam
- Lots of sources - Large Number of elements required

Large Fields of View (FOV) I

Noncoplanar baselines: *(u,v, **and w)*** ***- Cotton, SI ch 17***

- Important if FOV is large compared to resolution

  => in AIPS multi-facet imaging, each facet with its own θ_{synth}

- Essential for all observations below 1 GHz and for high resolution, high dynamic range even at 1.4 GHz

- Requires lots of computing power and disk space

- AIPS: IMAGR (DO3DIMAG=1, NFIELD=N, OVERLAP=2), CASA (aka AIPS++): w-projection

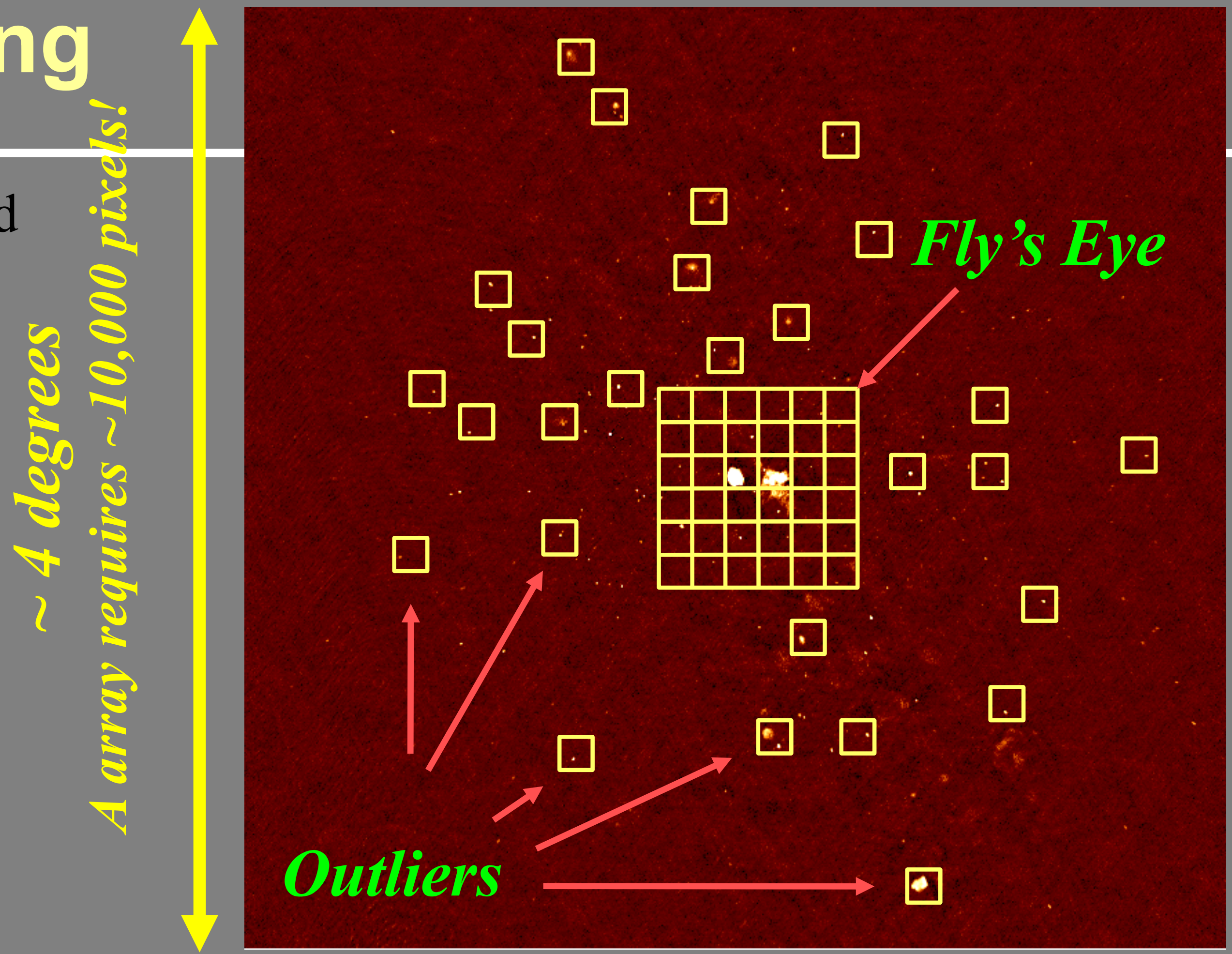
Example: VLA B array 74 MHz:
~325 facets

A array requires 10X more:
~ 3000 facets
~10^8 pixels

Targeted Faceting

- enormous processing required to image entire FOV
- reduce processing by targeting facets on selected sources (still large number!)
- overlap a fly's eye of the central region and add individual outliers

- AIPS: SETFC



AIPS Tip:

- Experience suggests that cleaning progresses more accurately and efficiently if EVERY facet has a source in it.

- Best not to have extended sources spread over too many facets

=> often must compromise

Large Fields of View (FOV) II

Calibra

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ba s a
sin

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- A o which
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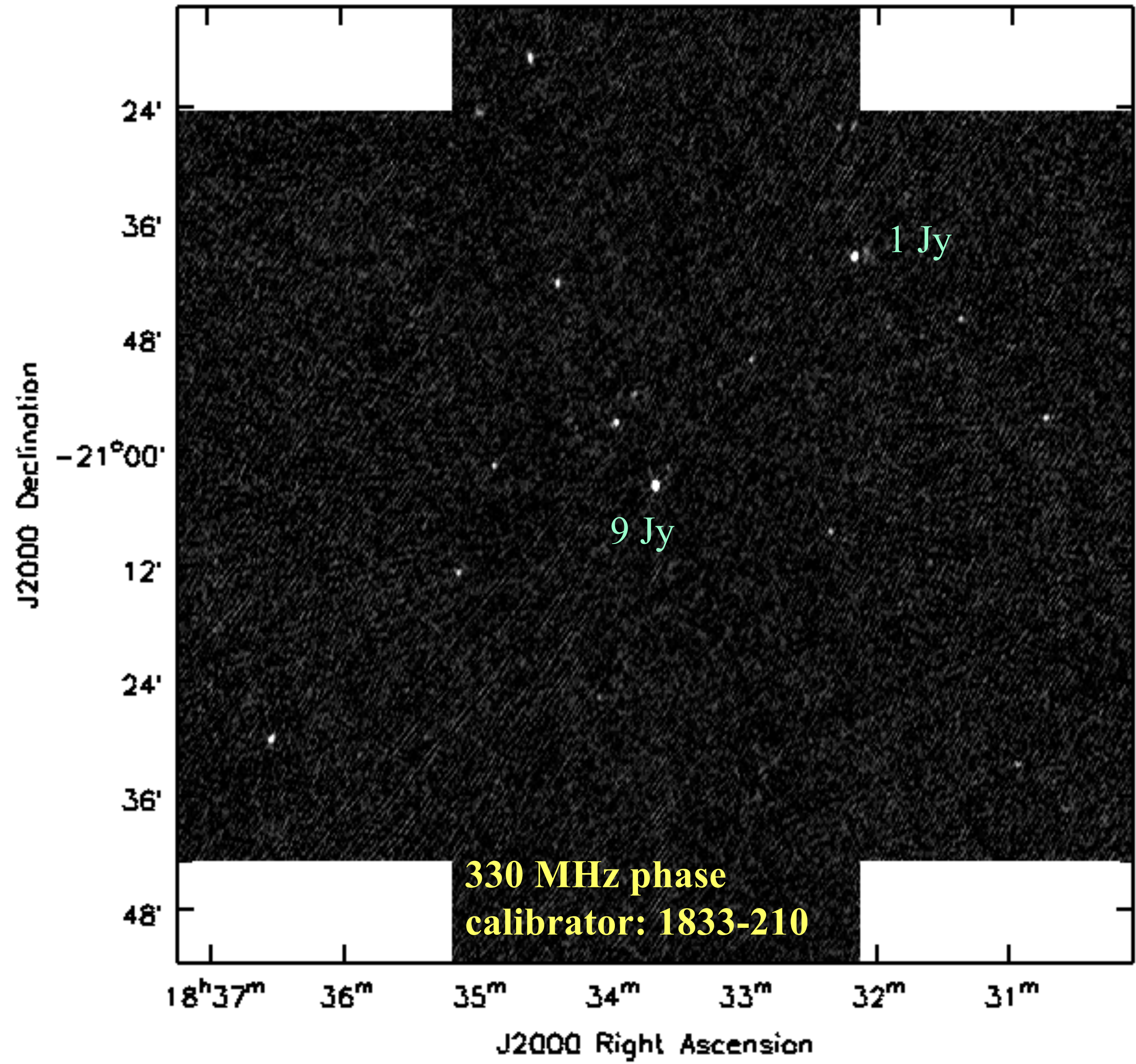
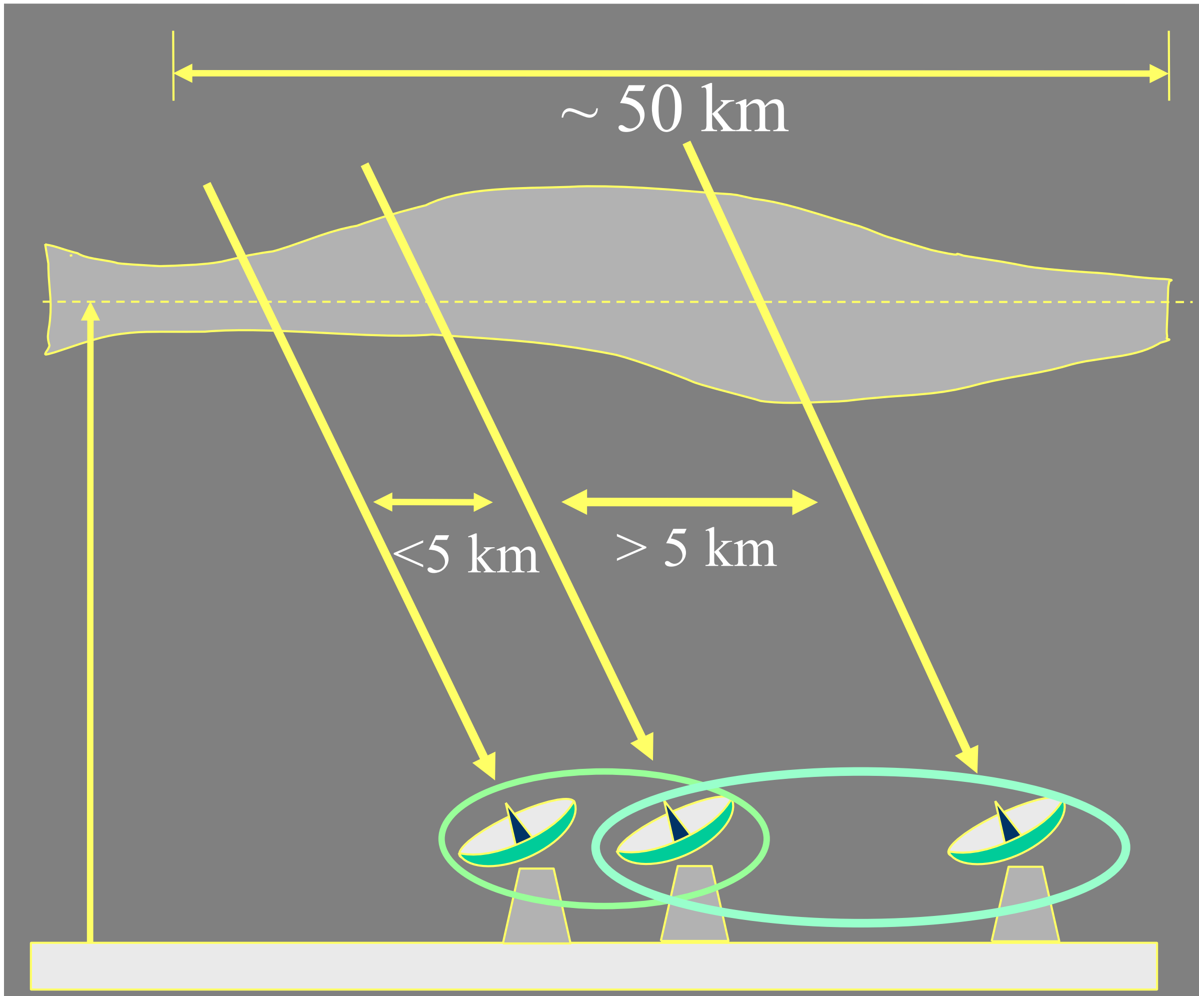
g phase
cal

- M al



330 MHz phase calibrator: 1833-210

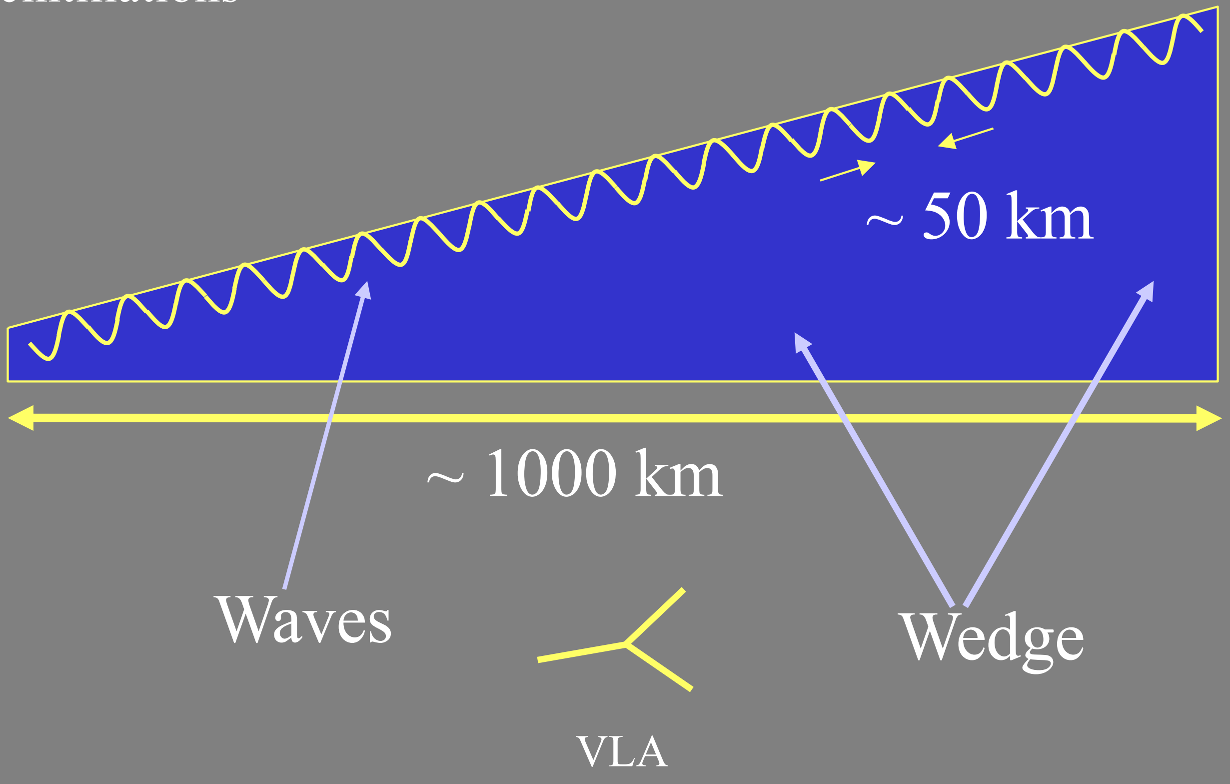
Ionospheric Structure:



- Waves in the ionosphere introduce rapid phase variations (~1°/s on 35 km BL)
- Phase coherence is preserved on BL < 5km
- BL > 5 km have limited coherence times
- Historically limited capabilities of low frequency instruments

Ionospheric Effects

Wedge Effects: Faraday rotation, refraction, absorption below ~ 5 MHz (atmospheric cutoff)
Wave and Turbulence Effects: Rapid phase winding, differential refraction, source distortion, scintillations



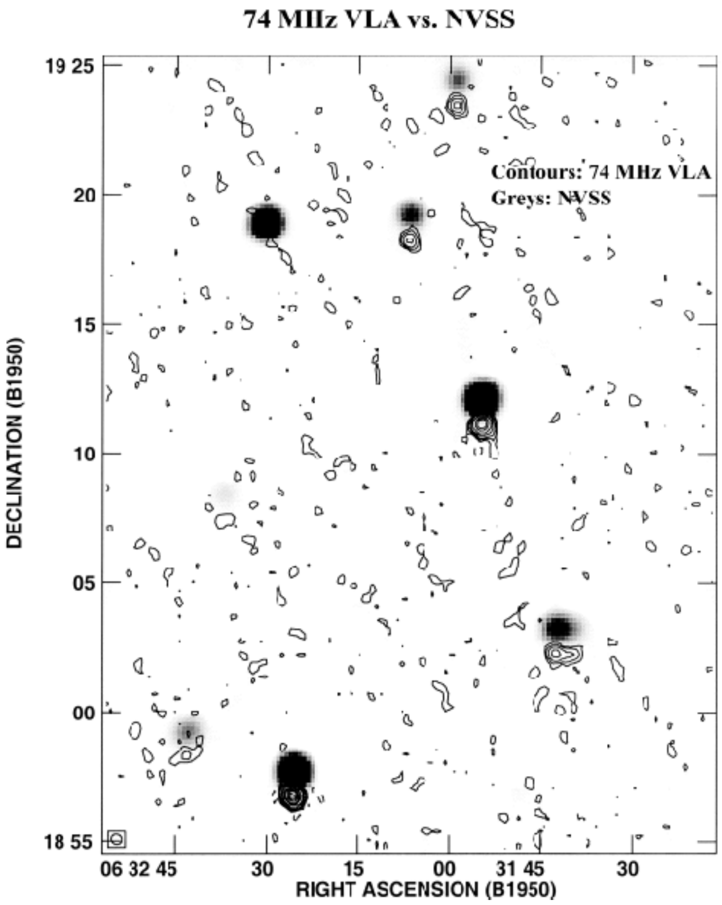
Wedge: characterized by
$\text{TEC} = \int n_e dl \sim 10^{17}\ \text{m}^{-2}$

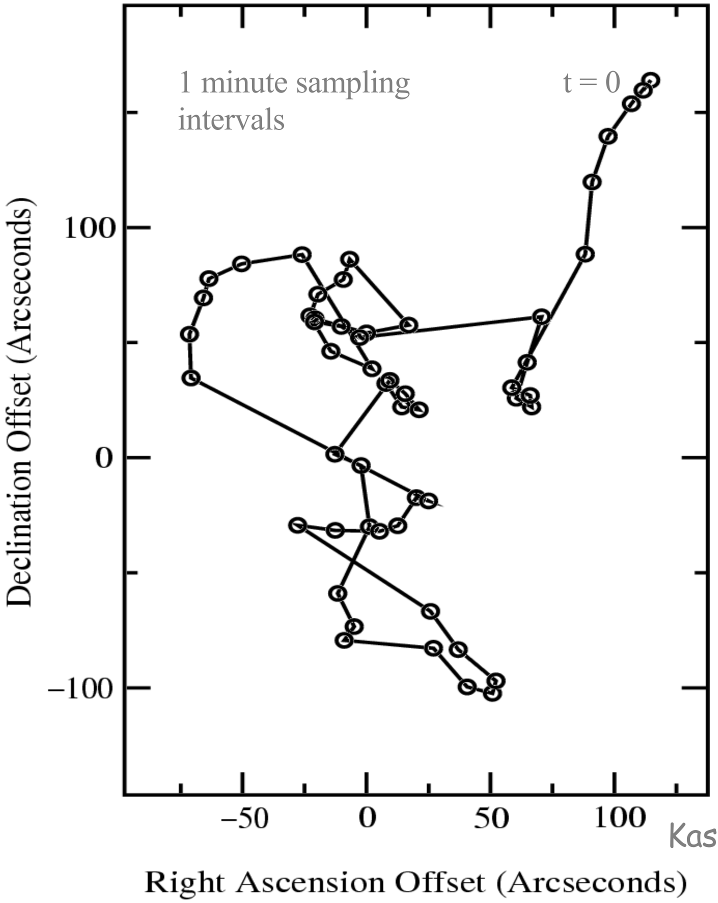
Extra path length adds extra phase
$\Delta L \propto \lambda^2 * \text{TEC}$
$\Delta\phi \sim \Delta L/\lambda \sim \lambda * \text{TEC}$

Waves: tiny (<1%) fluctuations superimposed on the wedge

- The wedge introduces thousands of turns of phase at 74 MHz
- Interferometers are particularly sensitive to difference in phase (wave/turbulence component)

0th Order Correction: Refractive Wander



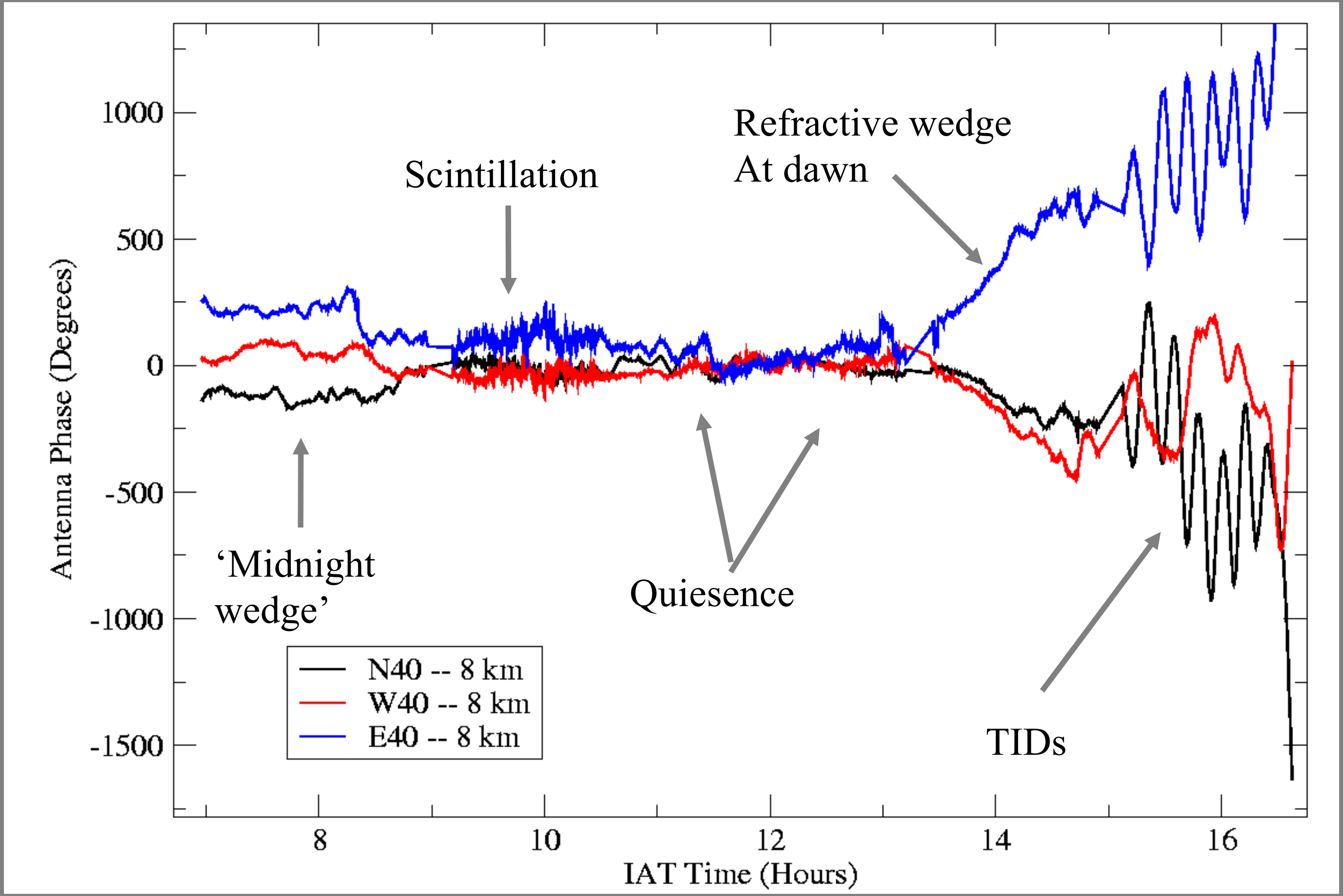


Kassim et al. 2007

- The large-scale ionospheric refraction shows considerable variability
  - Shown at the left 74MHz referenced to 1400MHz images
- Large Scale Ionospheric Structure -> simple phase shift
- Solution – use known phase centers to shift images to compensate

Antenna Phase as a Function of Time

Phase on three 8-km baselines



Scintillation

Refractive wedge
At dawn

'Midnight
wedge'

Quiesence

TIDs

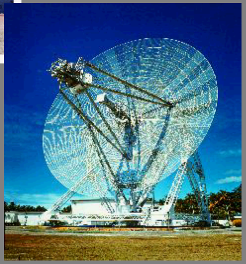
A wide range of phenomena were observed over the 12-hour observation

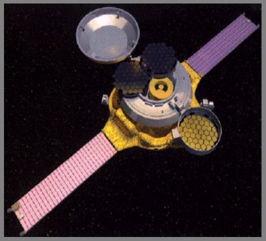
=> MYTH: Low freq. observing is better at night.

Often daytime (but not dawn) has the best conditions

Ionosphere Overview

- What is the ionosphere?
  - Partially ionized gas (i.e. a plasma) that envelops the earth and forms the interface between the atmosphere and space:
    - ***Plasma***: quasineutral gas of charged and neutral particles
    - ***Ionizing source***: UV light, x-rays and cosmic rays
- Why do we care about the ionosphere?
  - Many reasons, but for our purposes today, it affects radio wave propagation
- How do we detect the ionosphere?
  - Sounders (i.e. ionosondes)
    - Ground-based
    - Space-based
  - Radar
    - Coherent
    - Incoherent Scatter Radar (ISR)
  - Satellites (GPS, etc.)
  - Rockets
  - Etc.

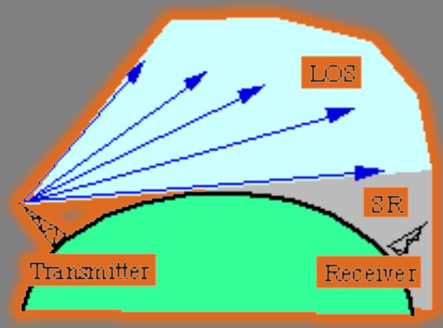




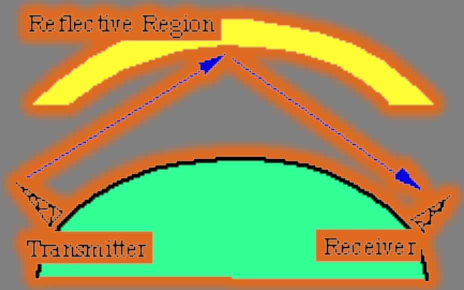
History

- On December 12, 1901, Marconi received a signal in St. John's Newfoundland that had been sent from Cornwall, England (500 kHz): Nobel Prize in physics in 1909 for using EM radiation for radio communication

  - **Problem: EM radiation travels in straight lines and maximum distance determined by Line-of-Sight (LOS). How could Marconi have "heard" the signal?**



  - **Solution: Heaviside and Kennely in 1902 proposed that a conducting layer existed in upper atmosphere that reflects EM signals**



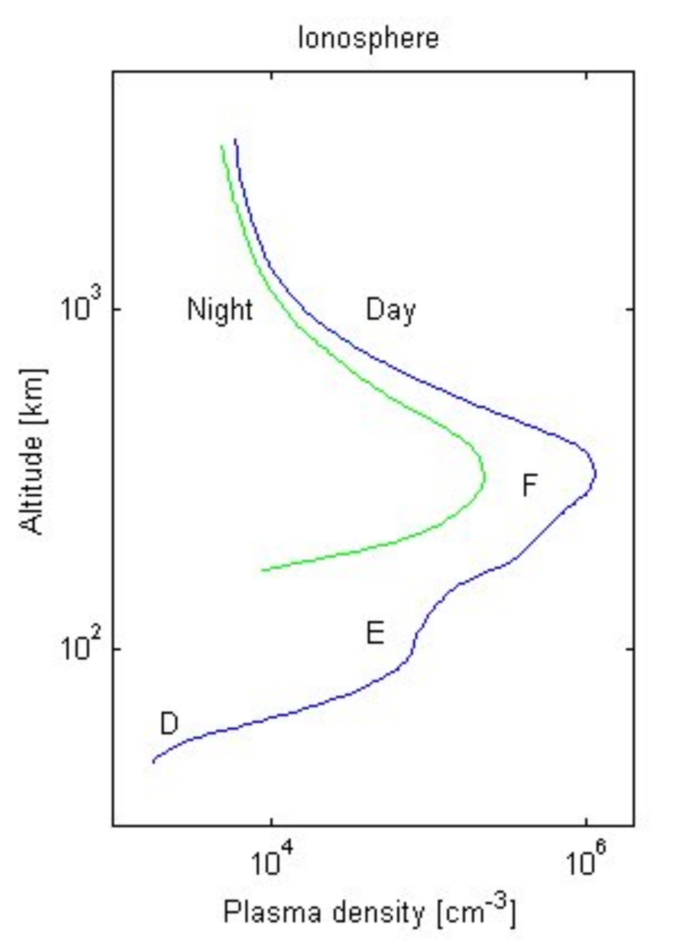
  - **In 1924, Appleton developed the ionosonde (ground-based sounding) and proved existence of <u>ionosphere</u>. Awarded Nobel Prize in physics in 1947**

Ionospheric Layers

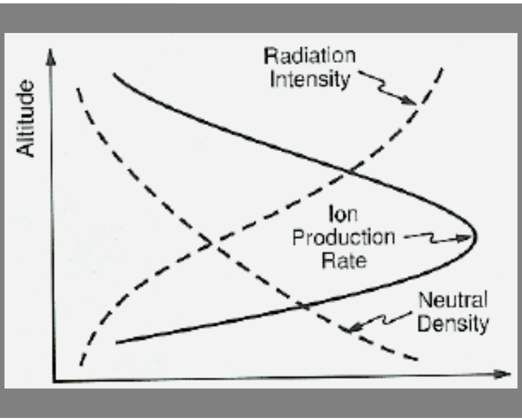
- Ionospheric layers independently produced by absorption of solar radiation by specific constituents of neutral atmosphere

- **D region**
  - **60-90 km, dynamics dominated by neutral atmosphere**
  - **Ions are NO^+ produced by radiation at 121.5 nm**
- **E region**
  - **90-130 km, peak near 110 km**
  - **Ions are O_2^+ and NO^+ produced by UV radiation in the 100-150 nm range, and solar X-rays in the 1-10 nm range**
- **F region (F_1 and F_2)**
  - **Above 130 km (typically caps at 2000 km)**

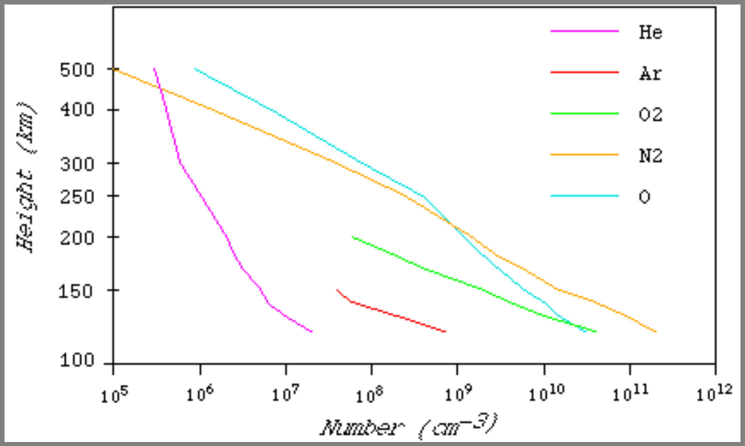
    F_1 peaks near 170 km, F_2 peaks near 250 km
  - **Ions are mainly O^+ from photons in the 17-91 nm range**



Ion Production - Photoionization



- Ionospheric peaks generated by:
  - Incoming solar radiation intensity increases with height
  - Neutral density decreases with height

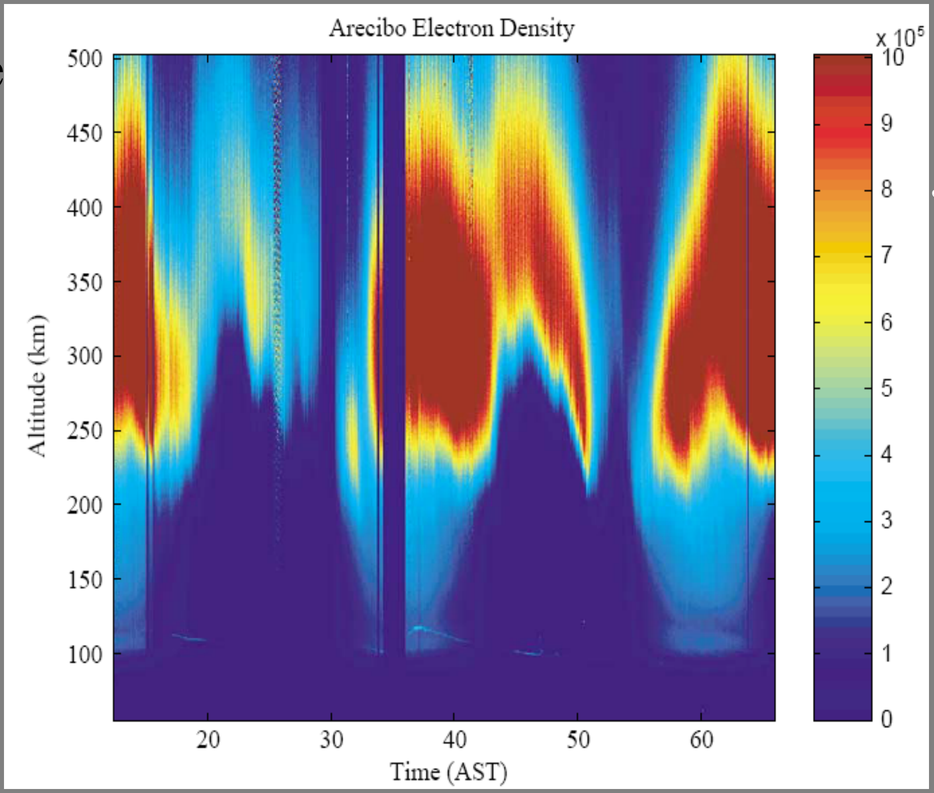


- Ionospheric layers generated by solar radiation acting on different compositions of atmosphere with height

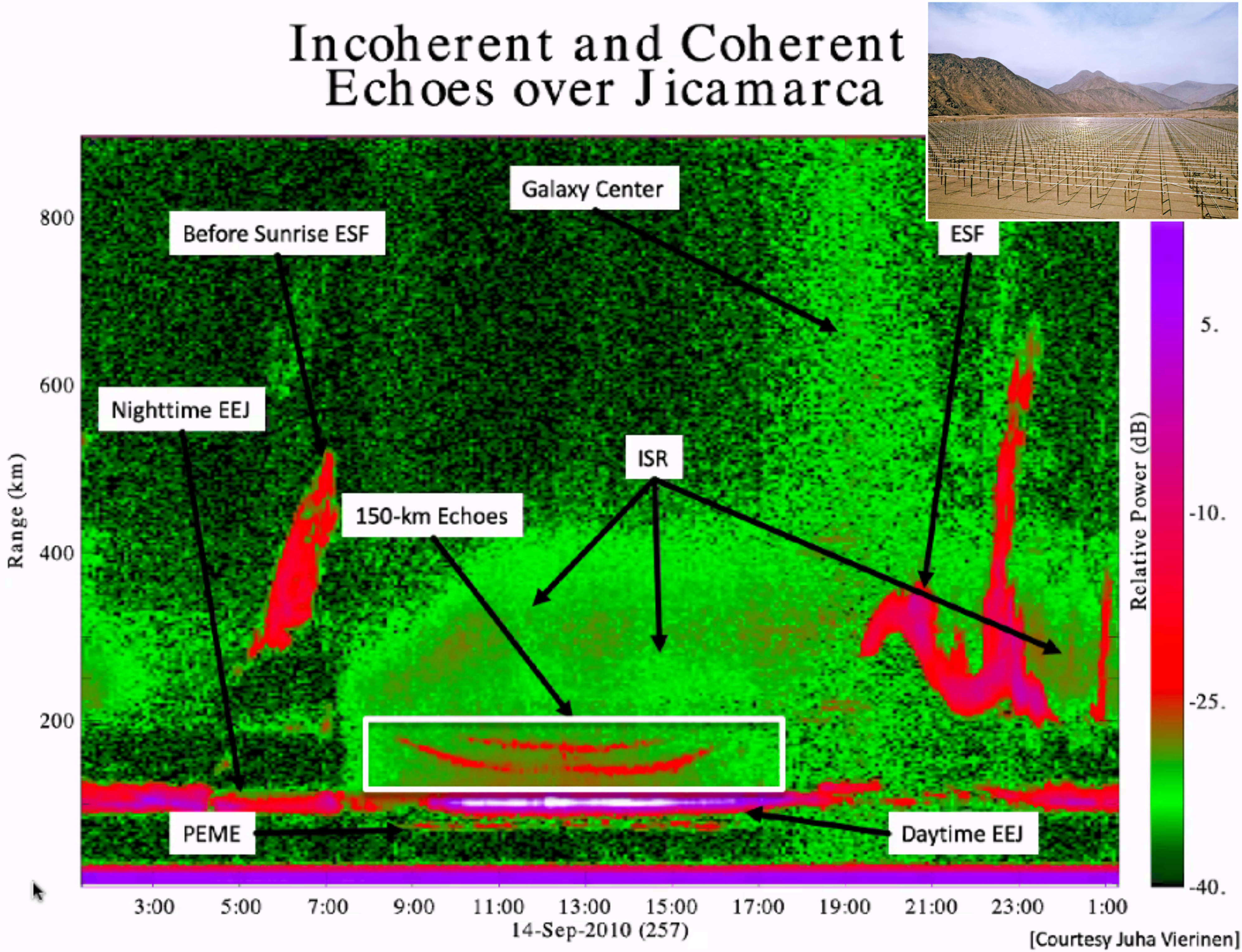
- Chapman theory (developed in 1927) describes ion production as a function of height assuming:
  - Details of photon absorption hidden in a radiative-absorption cross section, σ
  - Ion production depends only on amount of radiative energy absorbed

Density from Ion Loss and Production

- Ion loss
  - Ionospheric electrons disappear by thre types of recombination:
    - 1) Radiative: $e + X^+ \rightarrow X + h\nu$
    - 2) Dissociative: $e + XY^+ \rightarrow X + Y$
    - 3) Attachment: $e + Z \rightarrow Z^-$
  - Recombination rates depend upon:
  - Loss = $L = \alpha n_e n_i$, where α is a recombination coef. determined by empirical and theoretical models



Incoherent and Coherent Echoes over Jicamarca



[Courtesy Juha Vierinen]

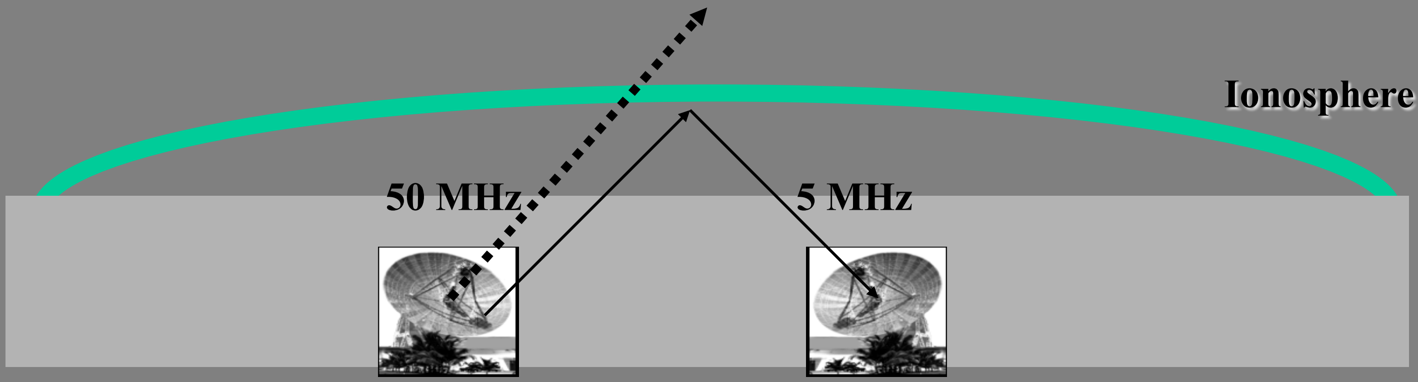
When does a Radio Wave get Reflected by Plasma?

- Dispersion relation for EM wave: $\boxed{\omega^2 = \omega_p^2 + k^2c^2}$
  - **If in a vacuum, you get light waves:** $\omega^2 = k^2c^2$
  - **If k → 0, you have a cutoff:** $\omega^2 = \omega_p^2$

    A cutoff point leads to reflection, so <u>this</u> is how you determine what radio frequency you need to transmit through the ionosphere

$$\omega^2 = \omega_p{}^2 = \frac{e^2 n_o}{\varepsilon_o m}$$ **or** $f_{critical} \sim 9 \times 10^{-3}(n^{1/2})$

where n = electron density per cm^3 and $f_{critical}$ is in MHz.



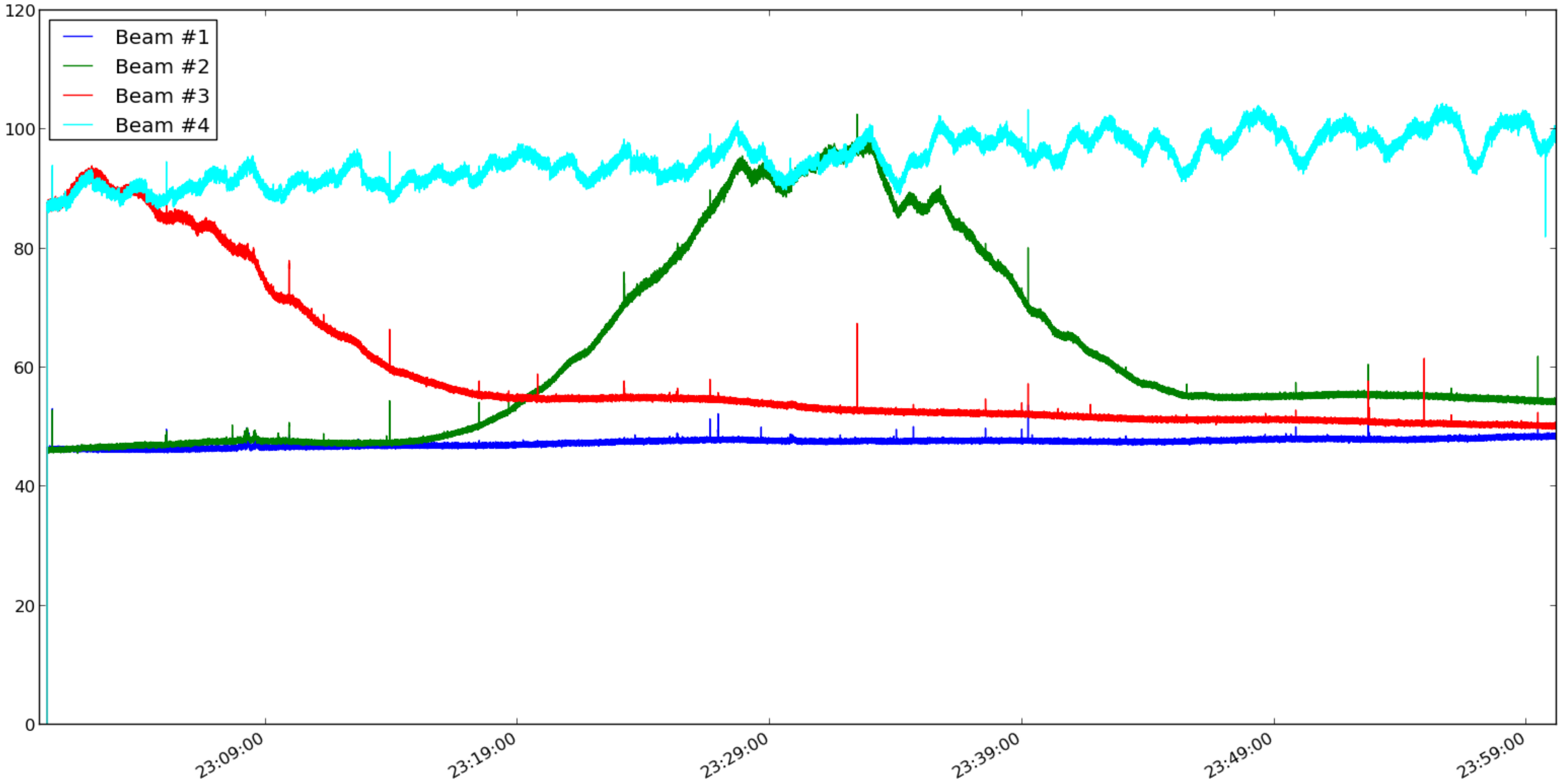
  - **Real-world examples**

    You need a radio frequency of 2 MHz to reflect from the E-region (10^5 el/cm^3)

    You need a radio frequency of 9 MHz to reflect from the F-region (10^6 el/cm^3)

    But these are <u>gross</u> over-simplifications, as the ionosphere is extremely dynamic and variable!

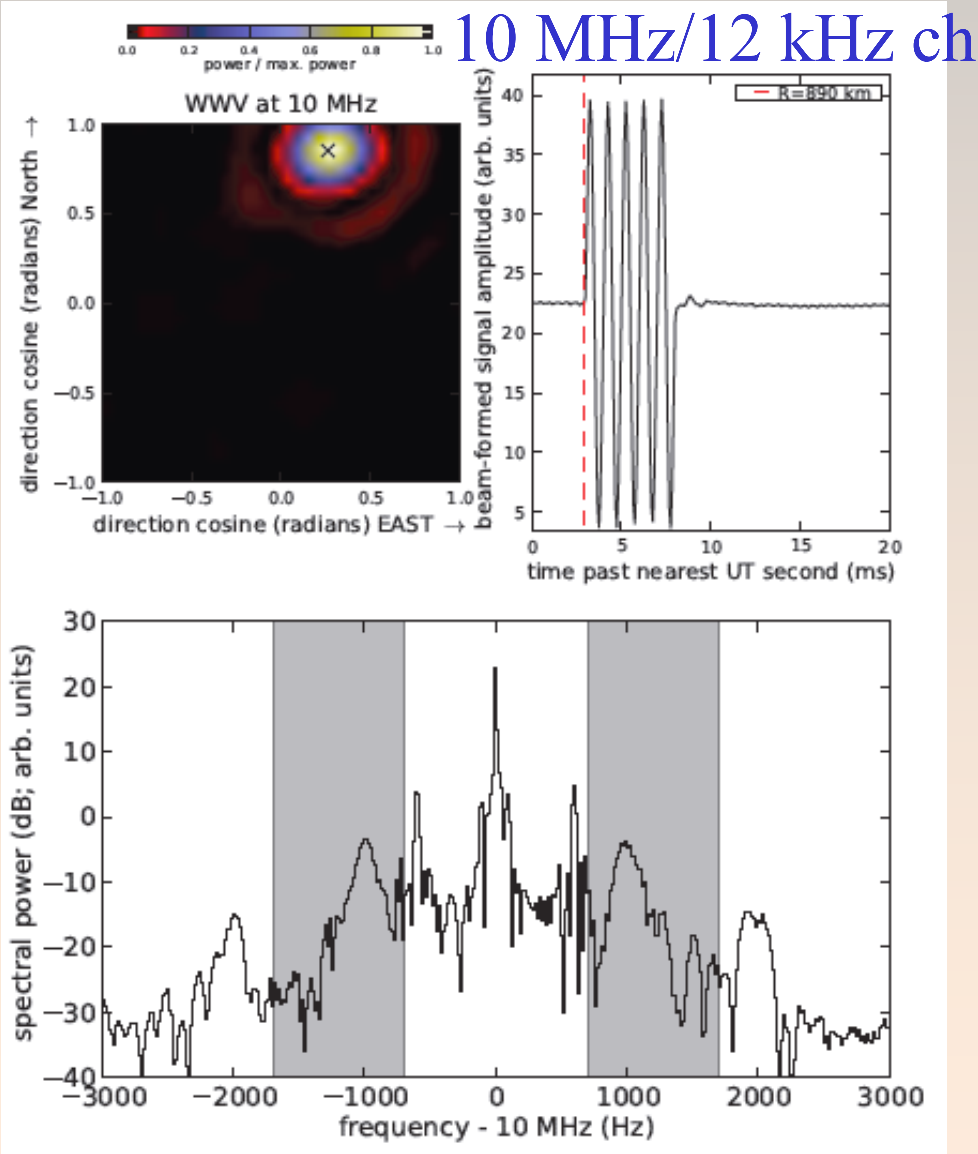
Ionospheric Absorption



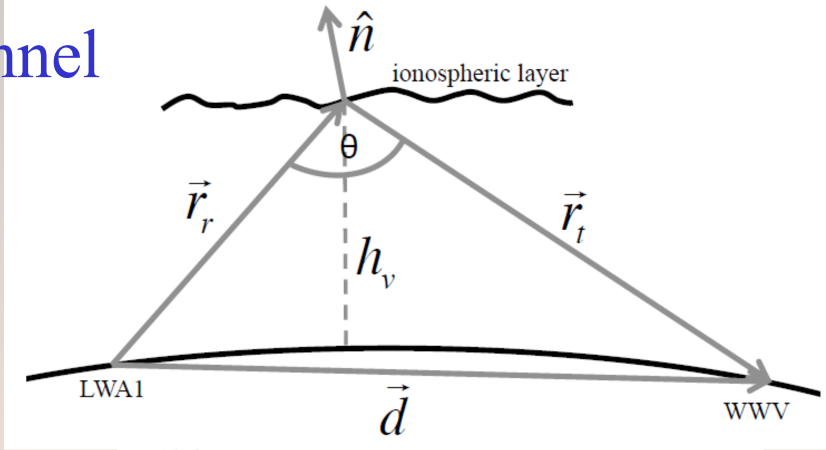
beam 1: off-source, pointed at north celestial pole
beam 2 and 3: fixed points along Cyg A track
beam 4: tracking Cyg A

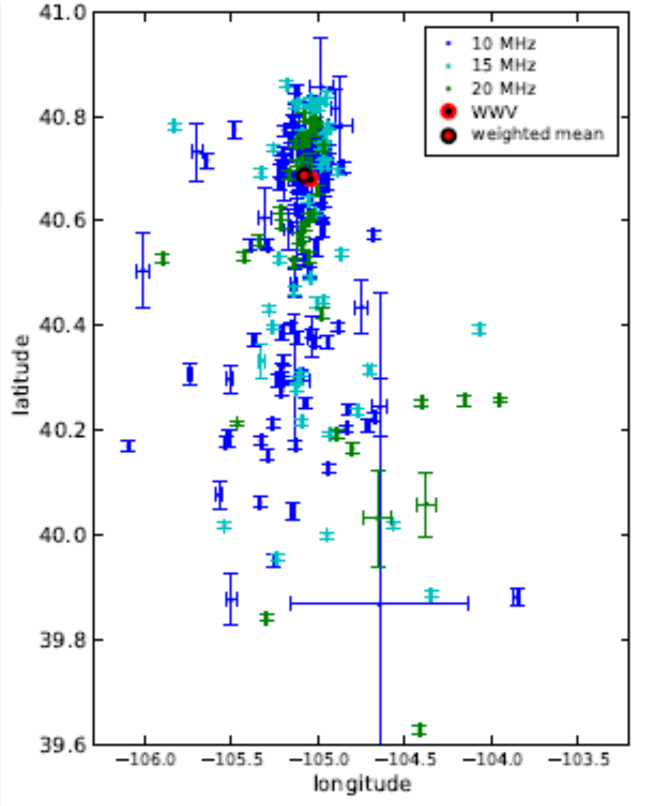
LWA
Long Wavelength Array

Passive Over the Horizon Radar



10 MHz/12 kHz channel



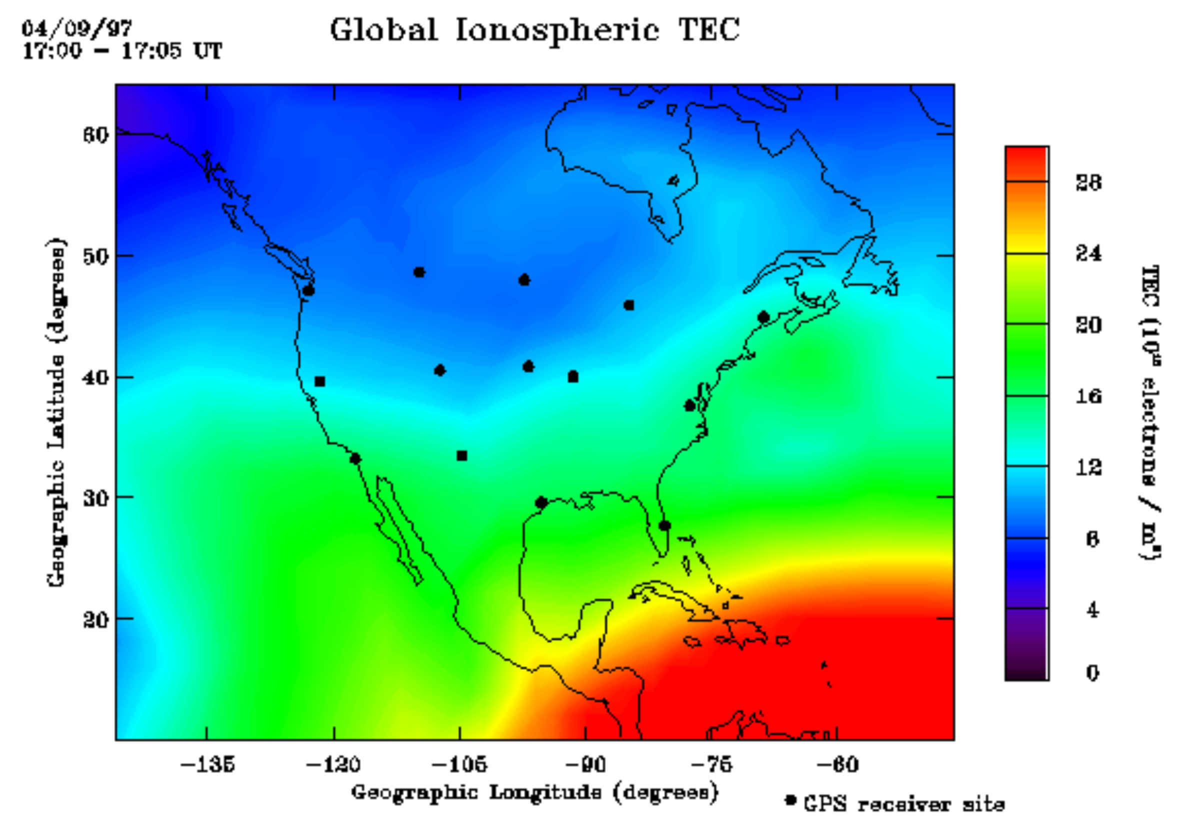


Helmboldt et al. 2013

LWA1 (Schinzel)

Ionospheric GPS Data

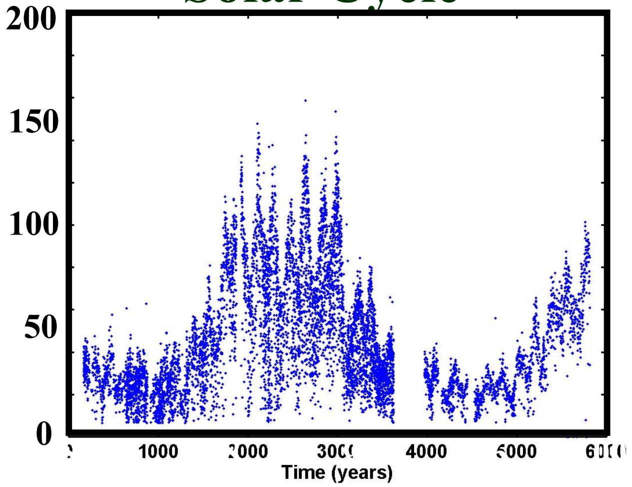
- Recall that GPS satellites can “probe” ionosphere by transmitting at two different frequencie simultaneously
  - Total Electron Content (TEC) is integrated density along line of sight: $TEC = \int_0^s n_e ds$



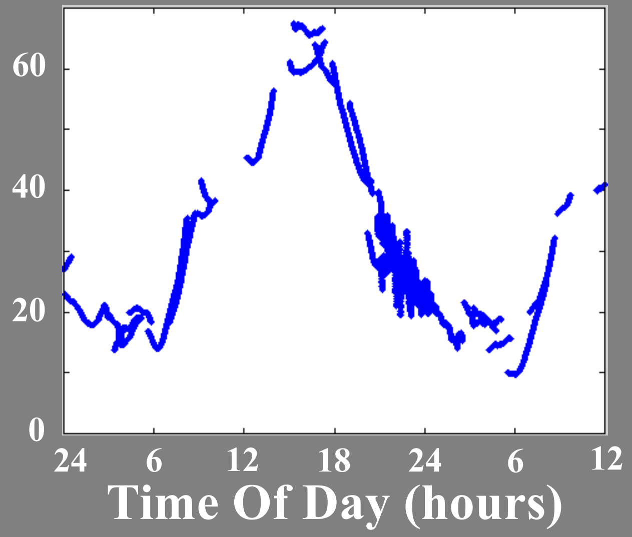
Ionospheric Variability - Time

Vertical TEC

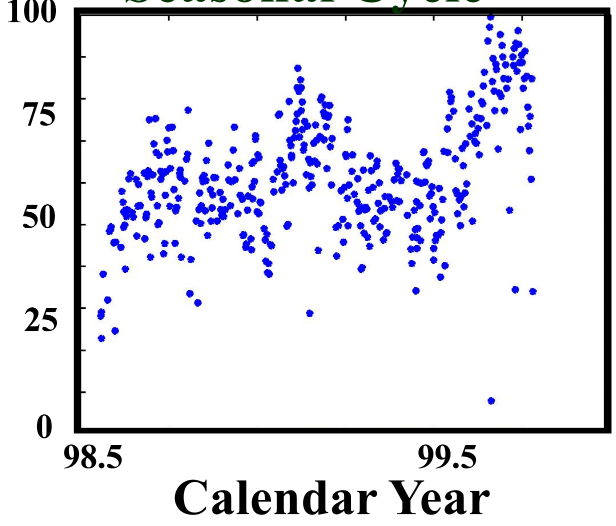
Solar Cycle



Diurnal Variation

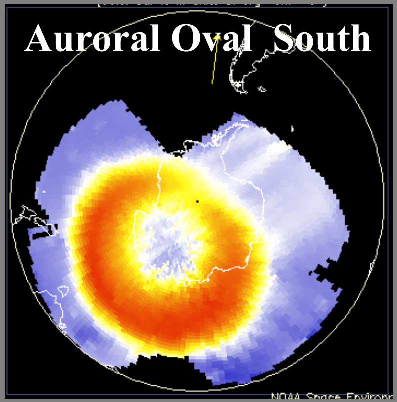


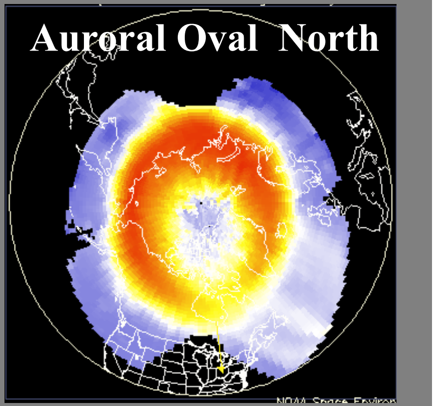
Seasonal Cycle



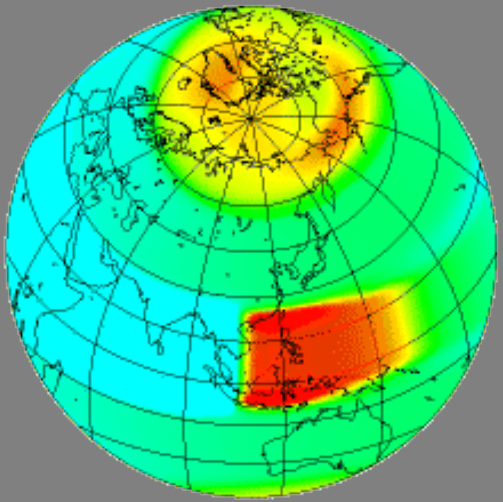
Ionospheric Variability - Location

- Auroral
  - Field lines coupled to magnetosphere
  - B_z field perpendicular to Earth





- **Equatorial**
  - **B_x field parallel to Earth**
    - **E_z → zonal drifts (large)**
    - **E_y → vertical drifts (small but important)**



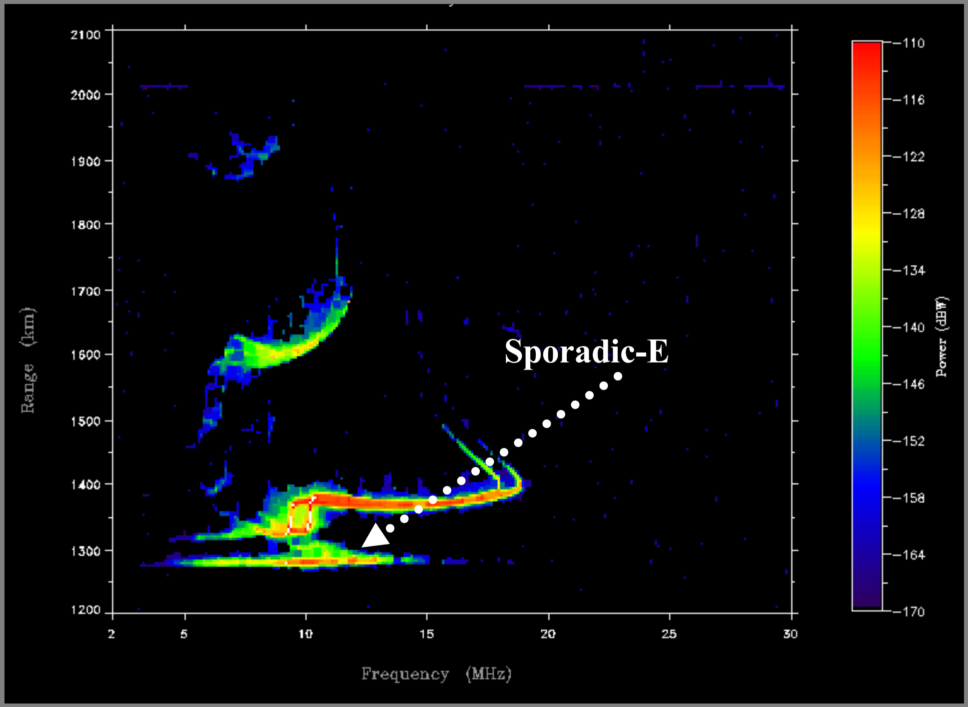
Copyright 1995, Northwest Research Associates, Inc.

- **Mid-Latitudes**
  - **Buffer between low- and high-latitude processes (both E fields and neutral winds penetrate here, as well as equatorial plasma streams)**

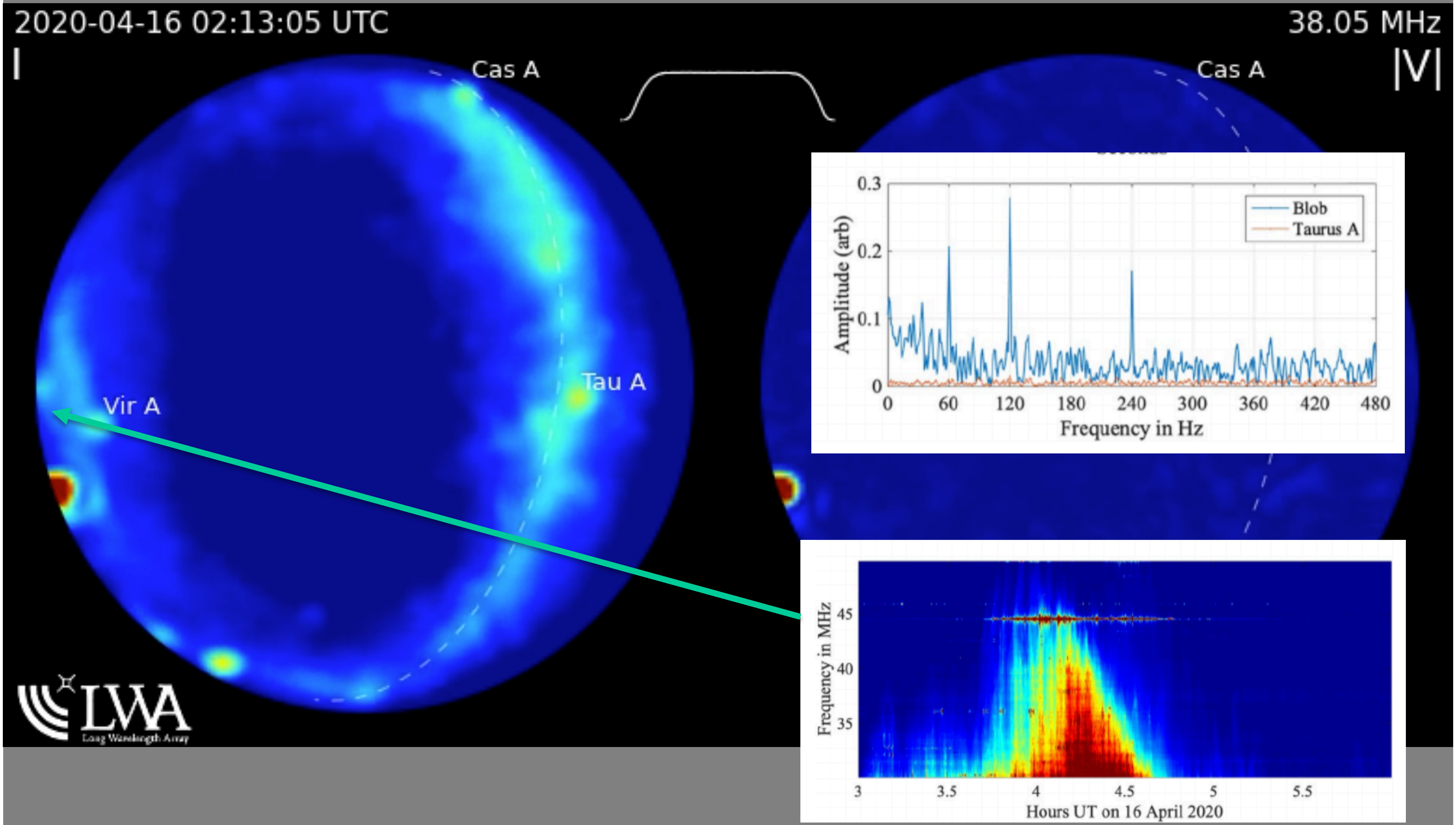
Current Research - Sporadic-E

- **<u>Sporadic-E:</u>** **dense layer of ionization in E-region that can reflect radio frequencies up to 225 MHz**
  - **Why is it most prevalent in summer?**
  - **What causes intermediate sporadic-E?**
  - **What causes long-lived intense sporadic-E layer? (heavy metals deposited by meteoroids?)**

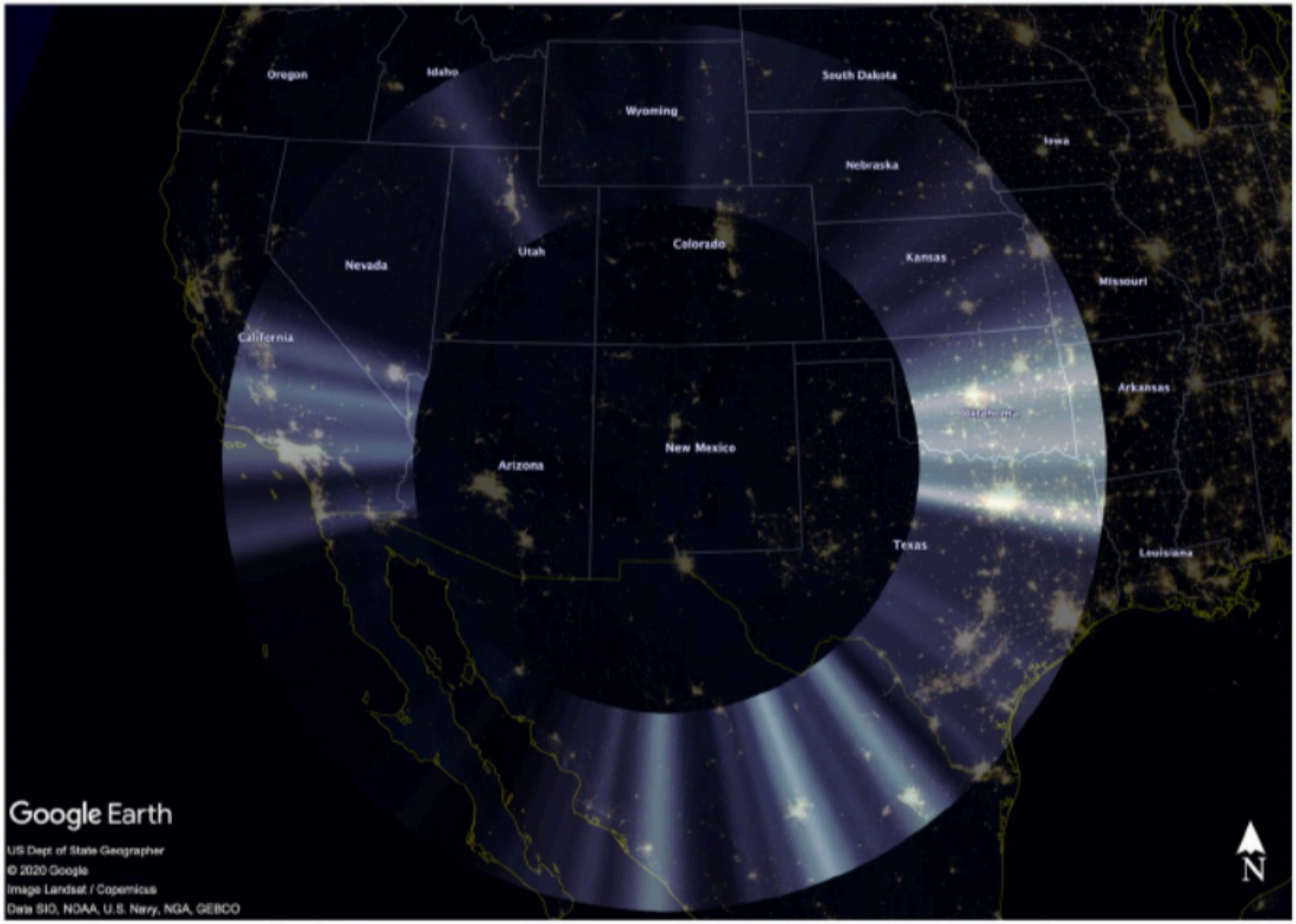
Ionosonde Data



Sporadic E

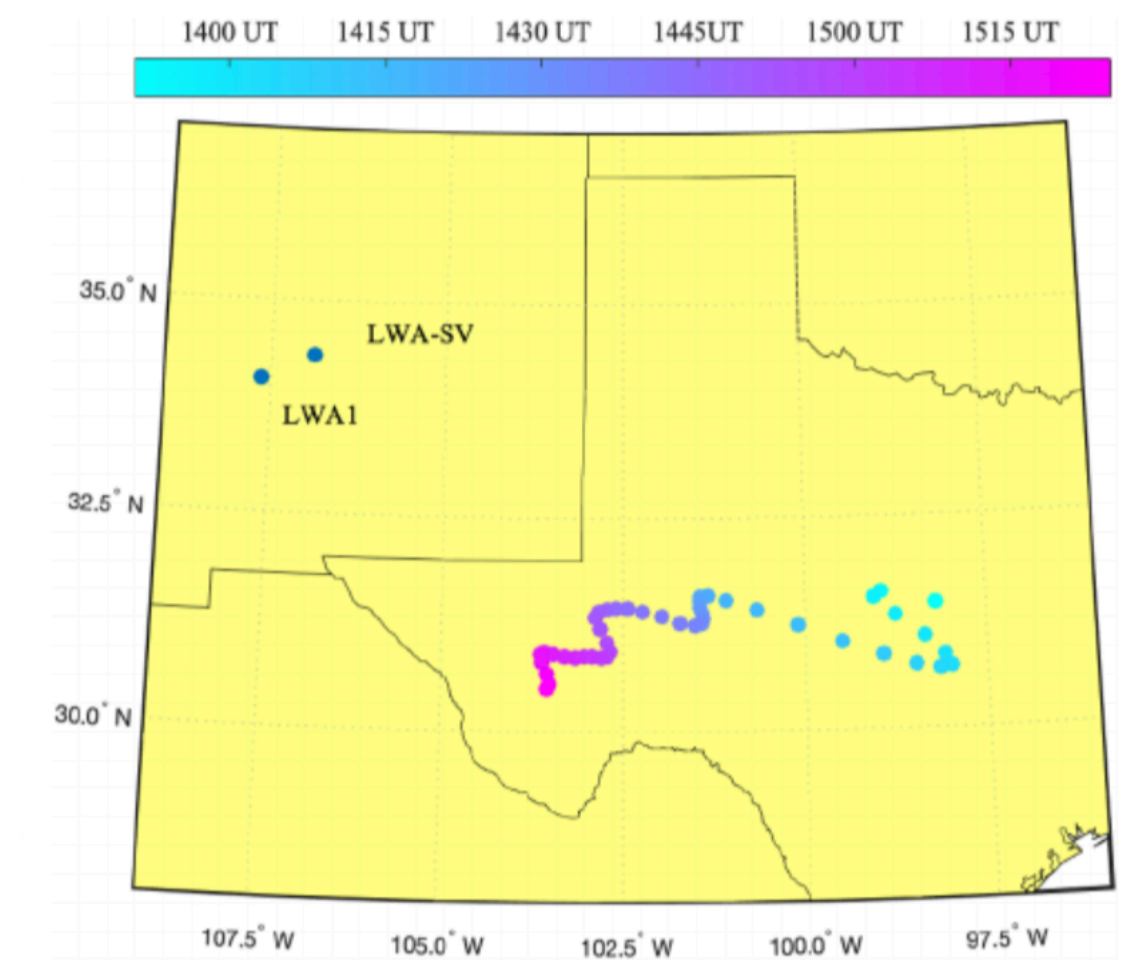

2020-04-16 02:13:05 UTC
38.05 MHz
I
|V|
Cas A
Tau A
Vir A
Cas A
LWA
Long Wavelength Array
Amplitude (arb)
0.3
0.2
0.1
0
0
60
120
180
240
300
360
420
480
Frequency in Hz
Blob
Taurus A
Frequency in MHz
45
40
35
3
3.5
4
4.5
5
5.5
Hours UT on 16 April 2020

Sporadic E



Obenberger et al. 2021

Sporadic E

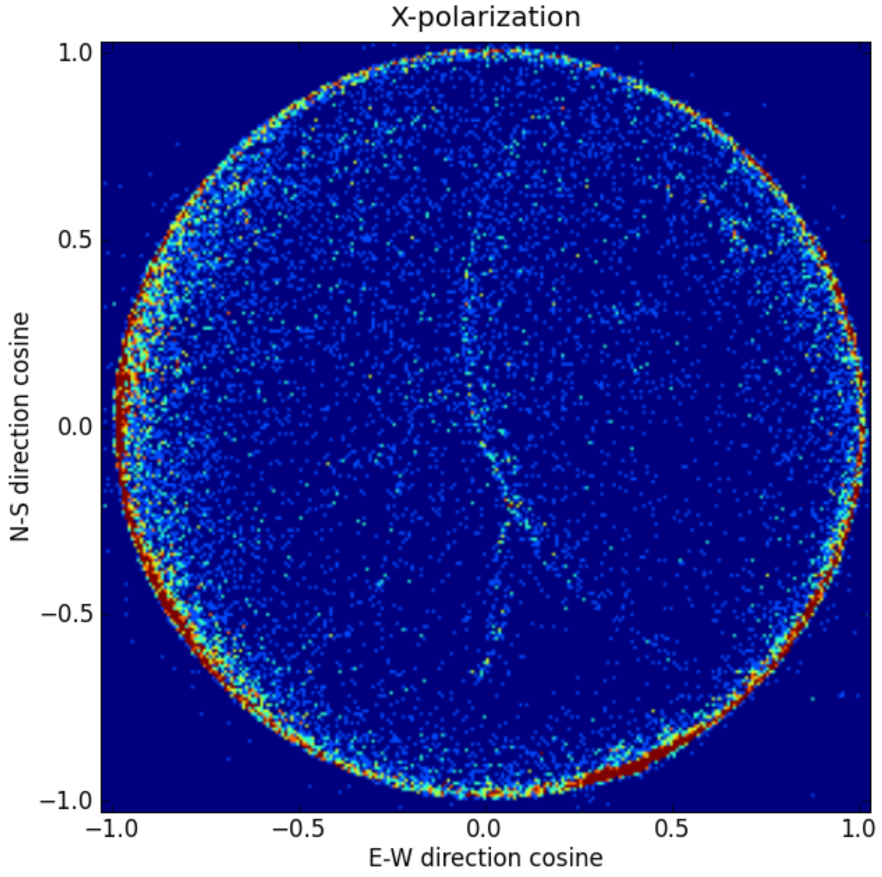


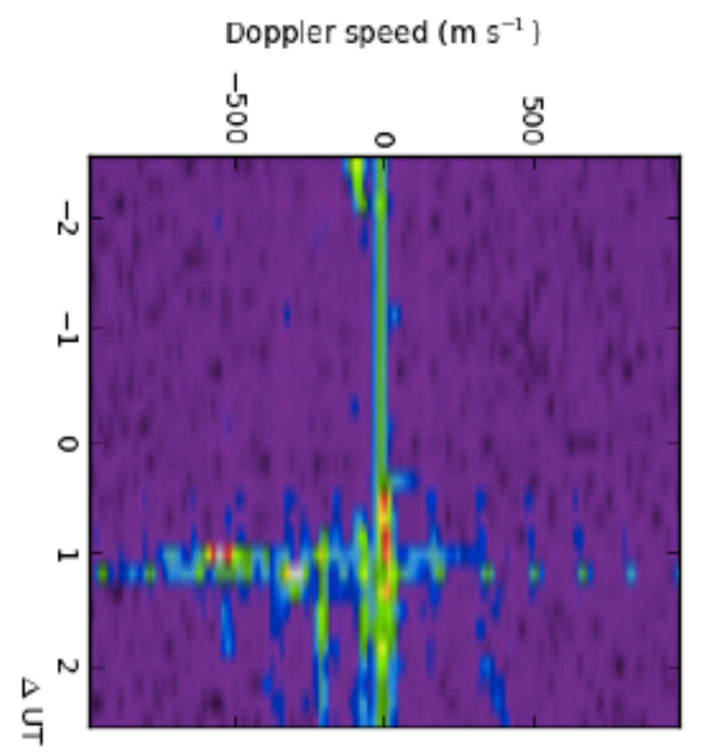
Obenberger et al. 2021

Current Research - Meteors

- **<u>Meteor</u>: Strong ionization (up to 4 orders of magnitude greater than background ionosphere!) formed in the E-region by meteoroid ablation**
- **More than 100 billion meteoroids enter Earth’s atmosphere daily (tons)**

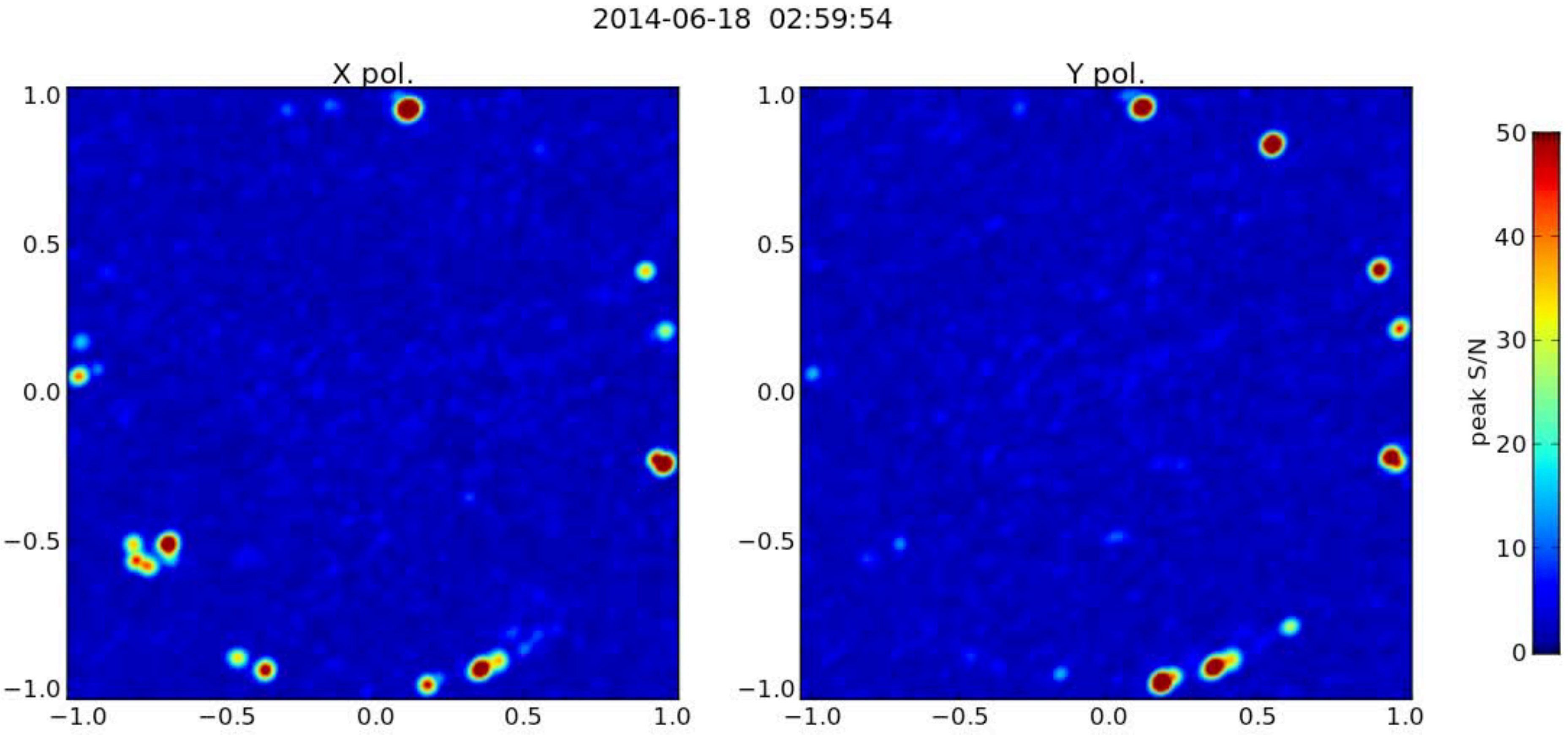
- Mapping the wind profile via meteor trails (Helmbolt et al. 2014)



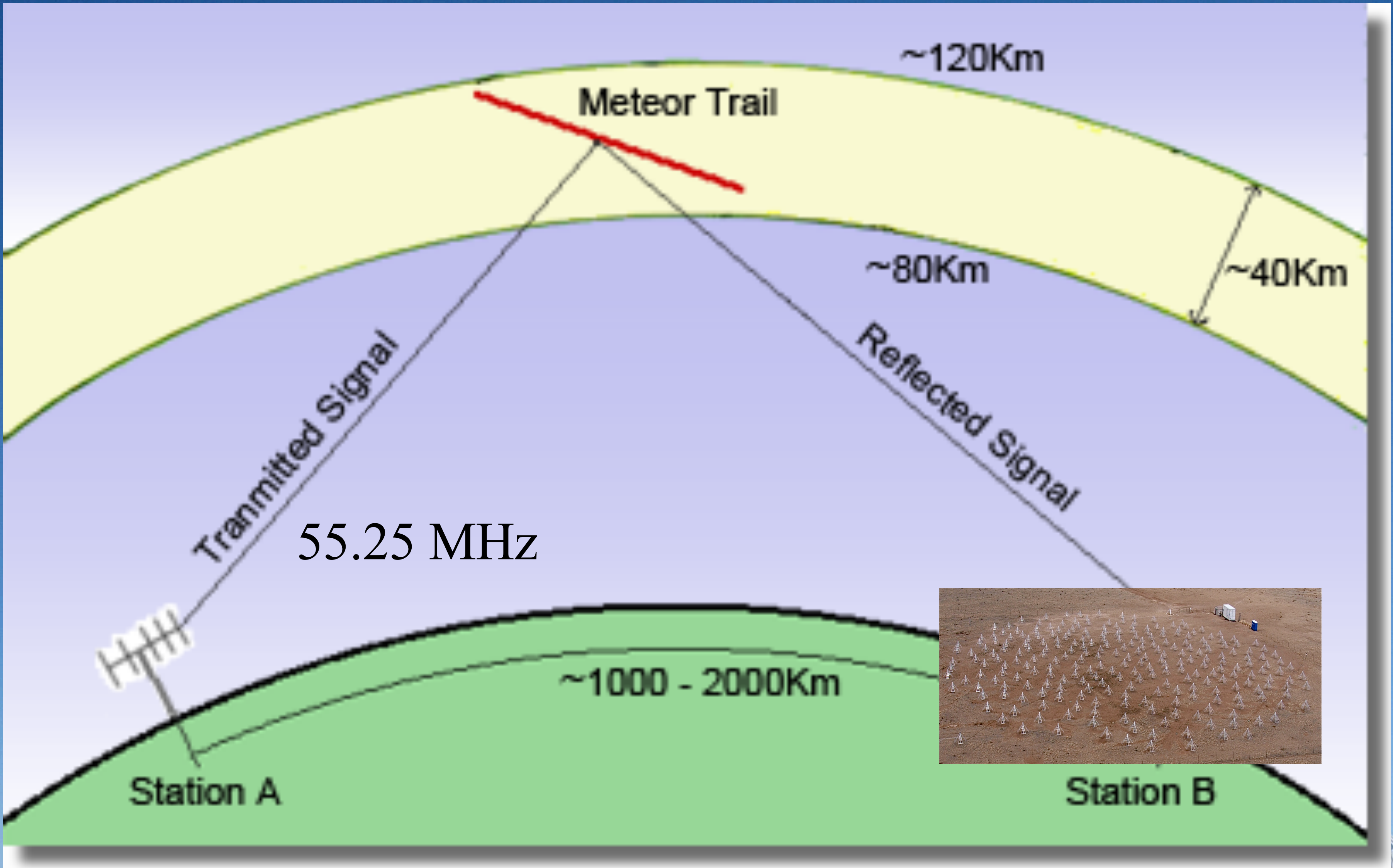


~10,000 events/hr

Meteors – by reflection

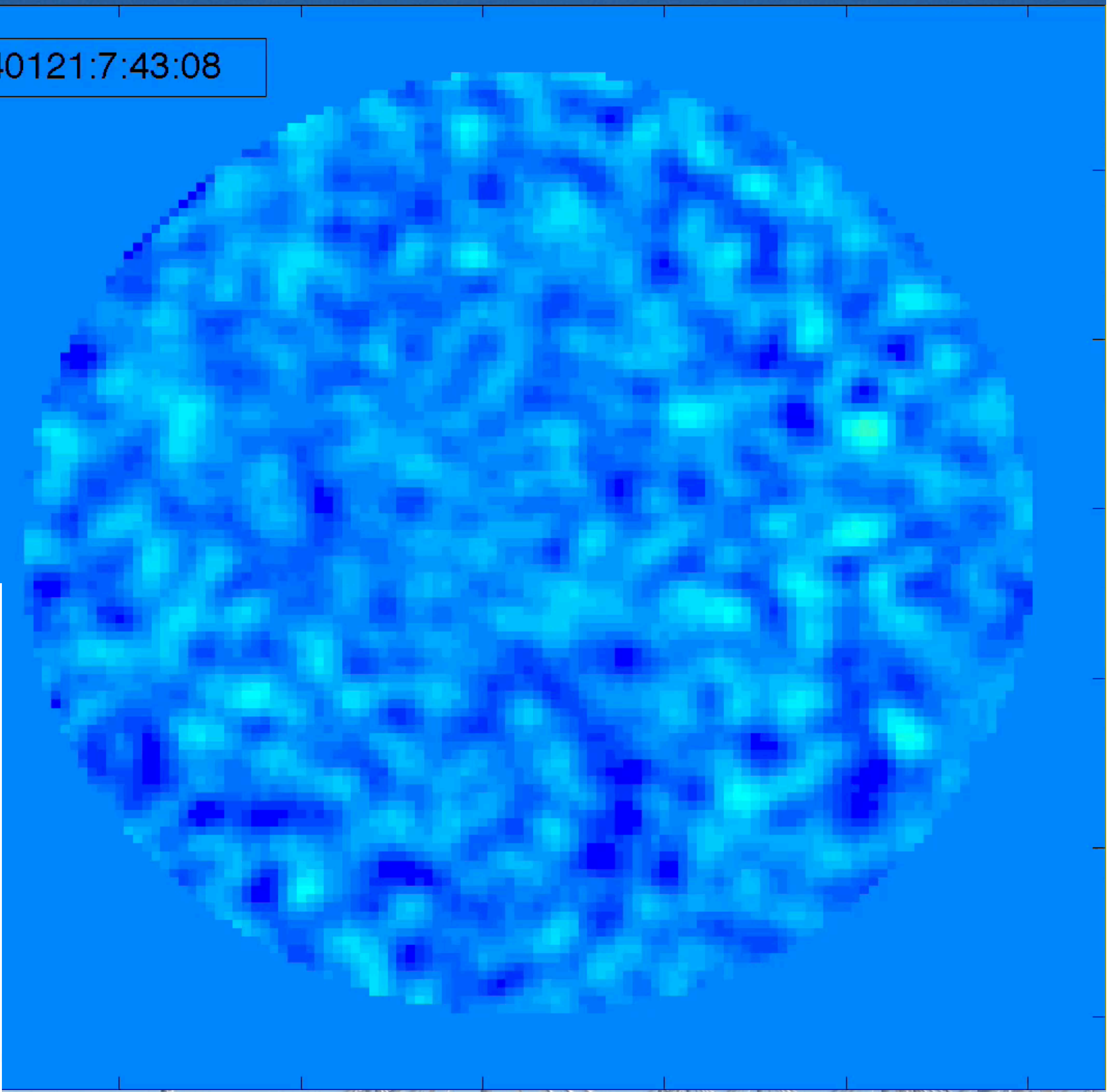


Meteors – by reflection



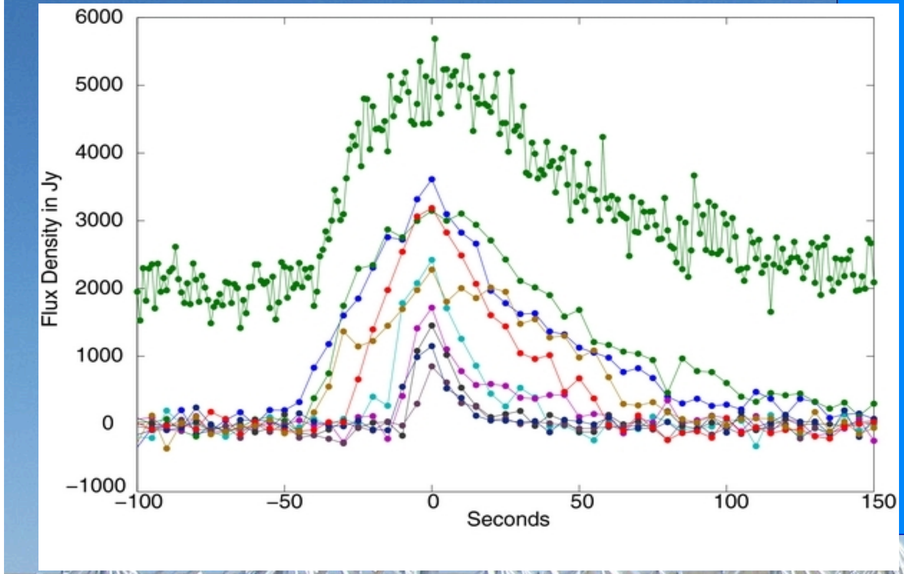
Great Balls of Fire!

Obenberger et al. 2014, 2016

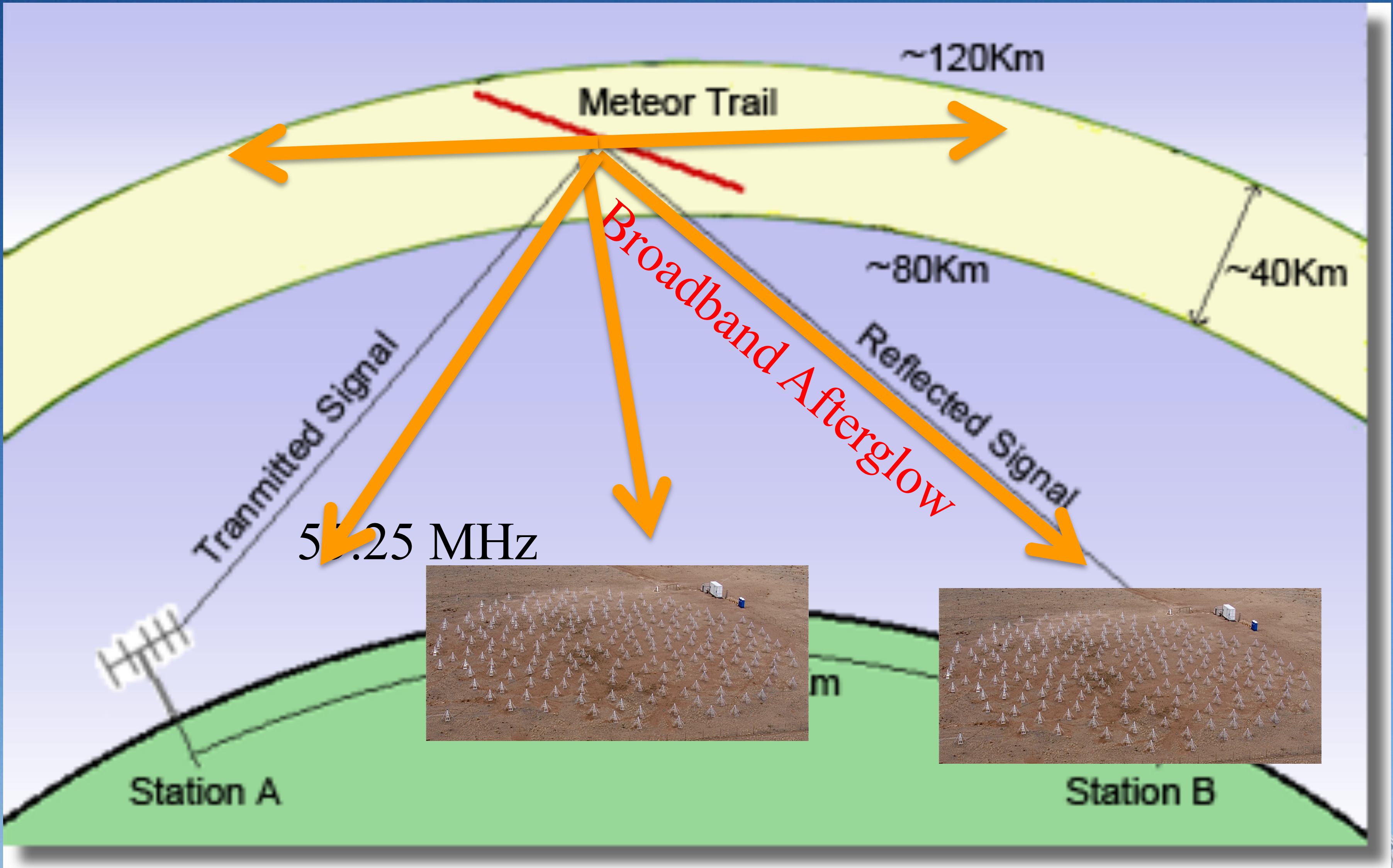


140121:7:43:08

Light curves of the brightest transients



Meteors – by Emission

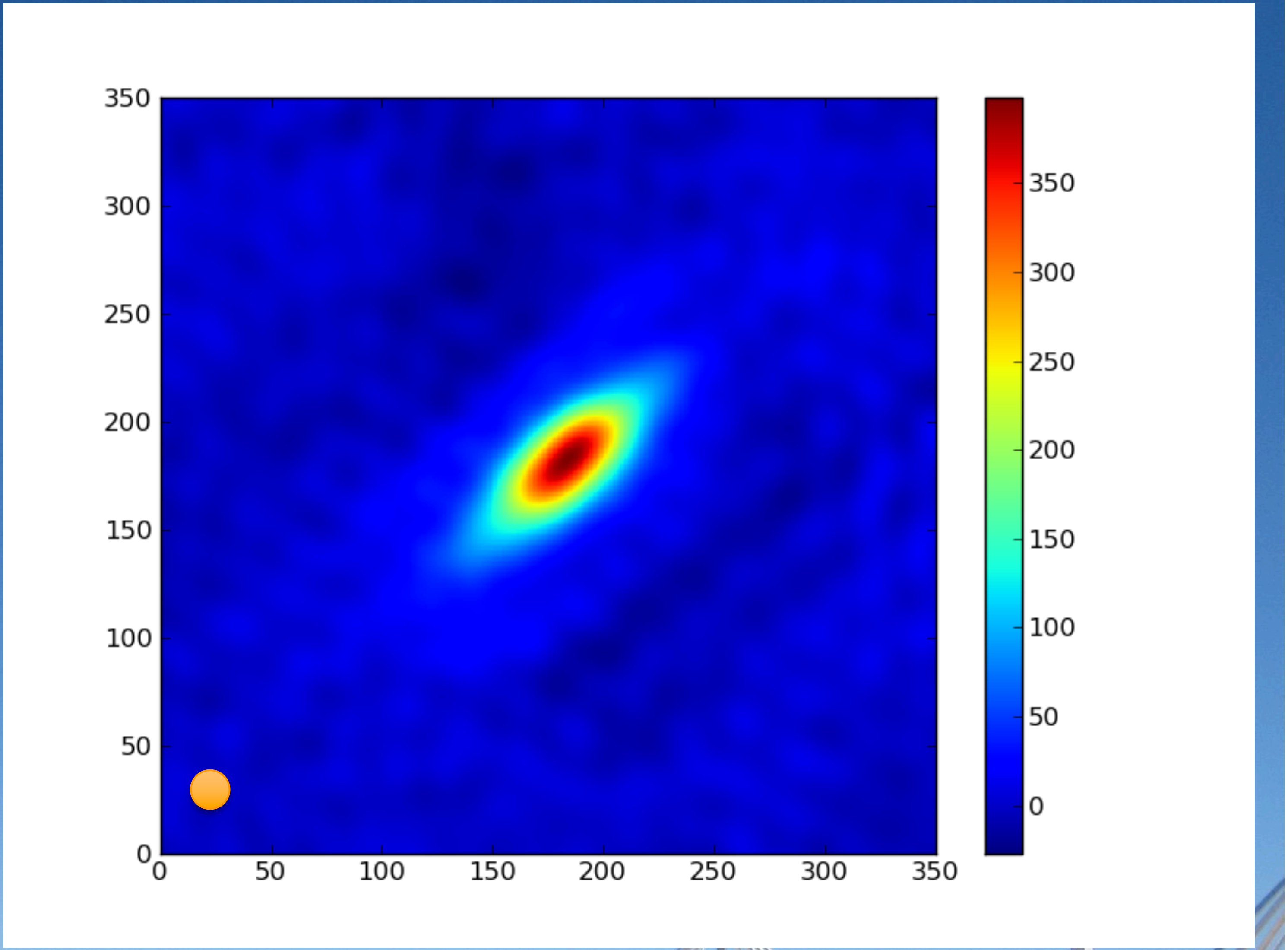


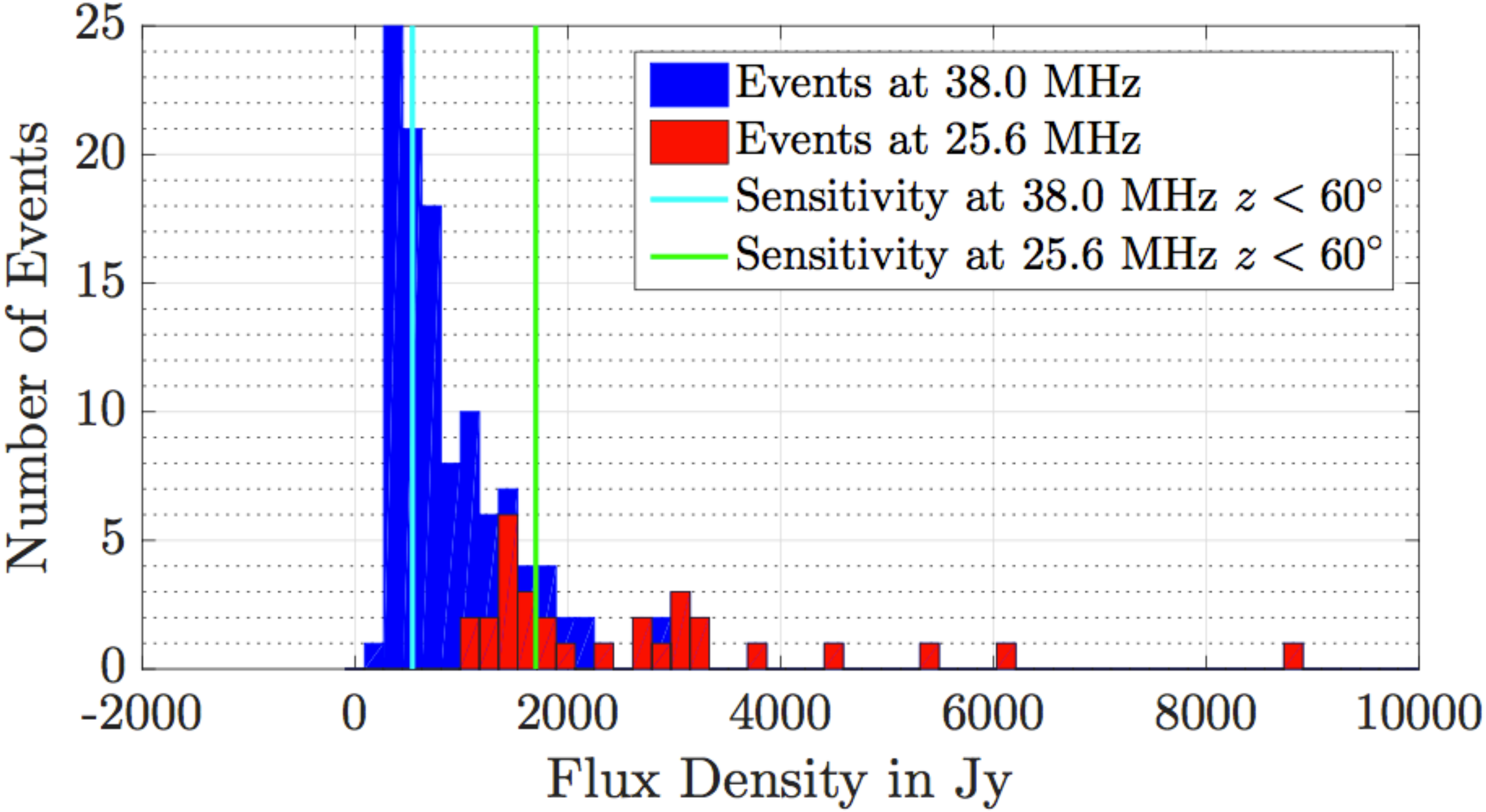
Great Balls of Fire!

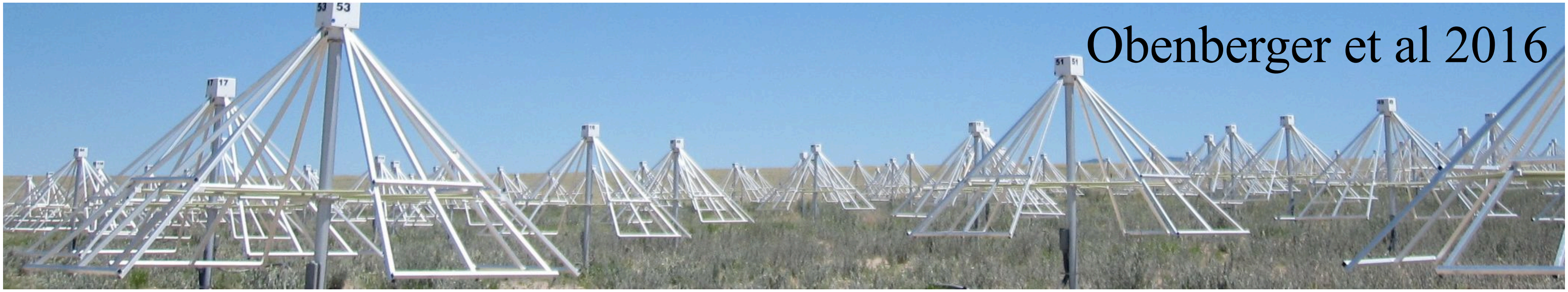
Varghese et al. in prep
Using OVRO-LWA

Resolution 20’

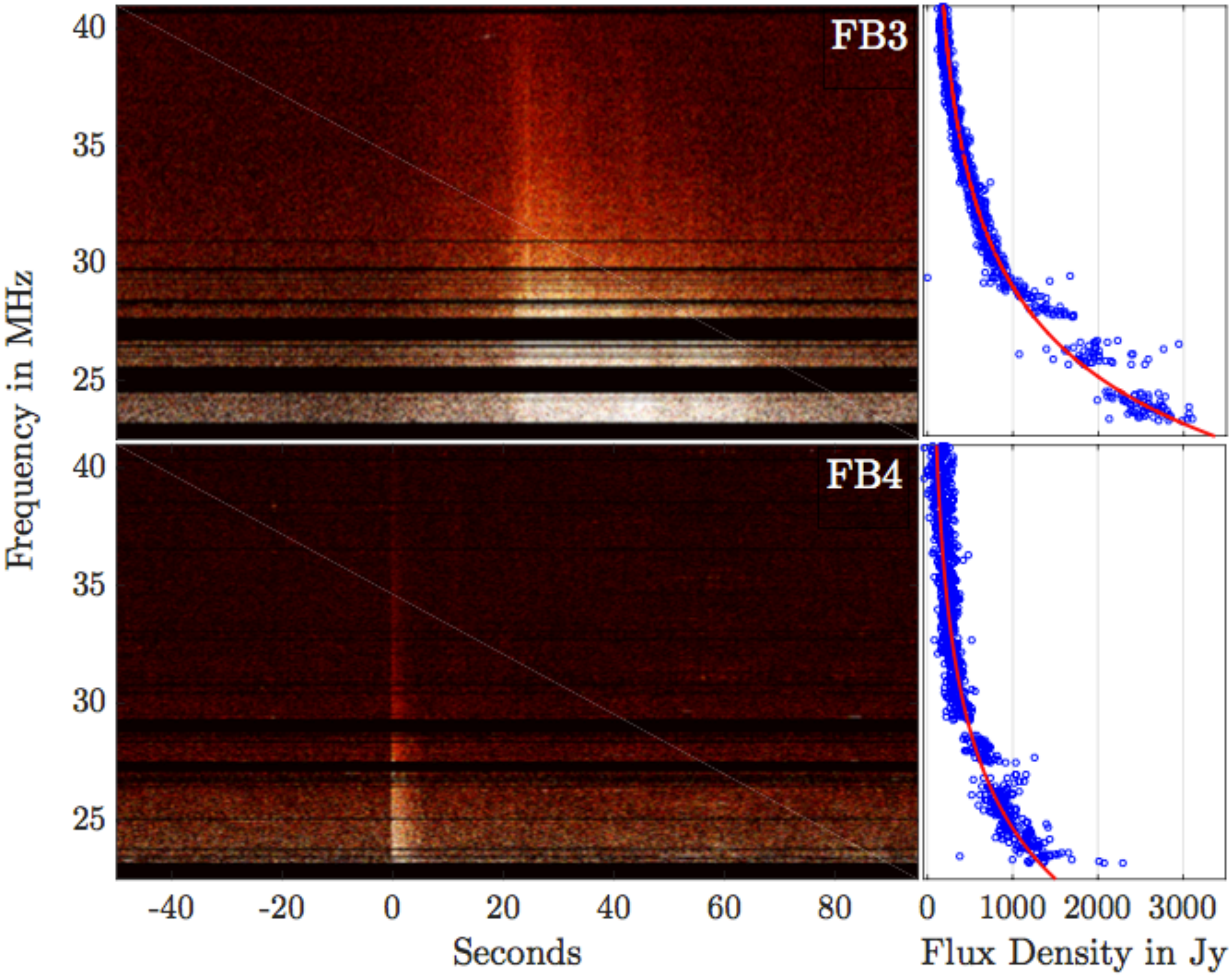
~0.6 km at 100 km elevaltion







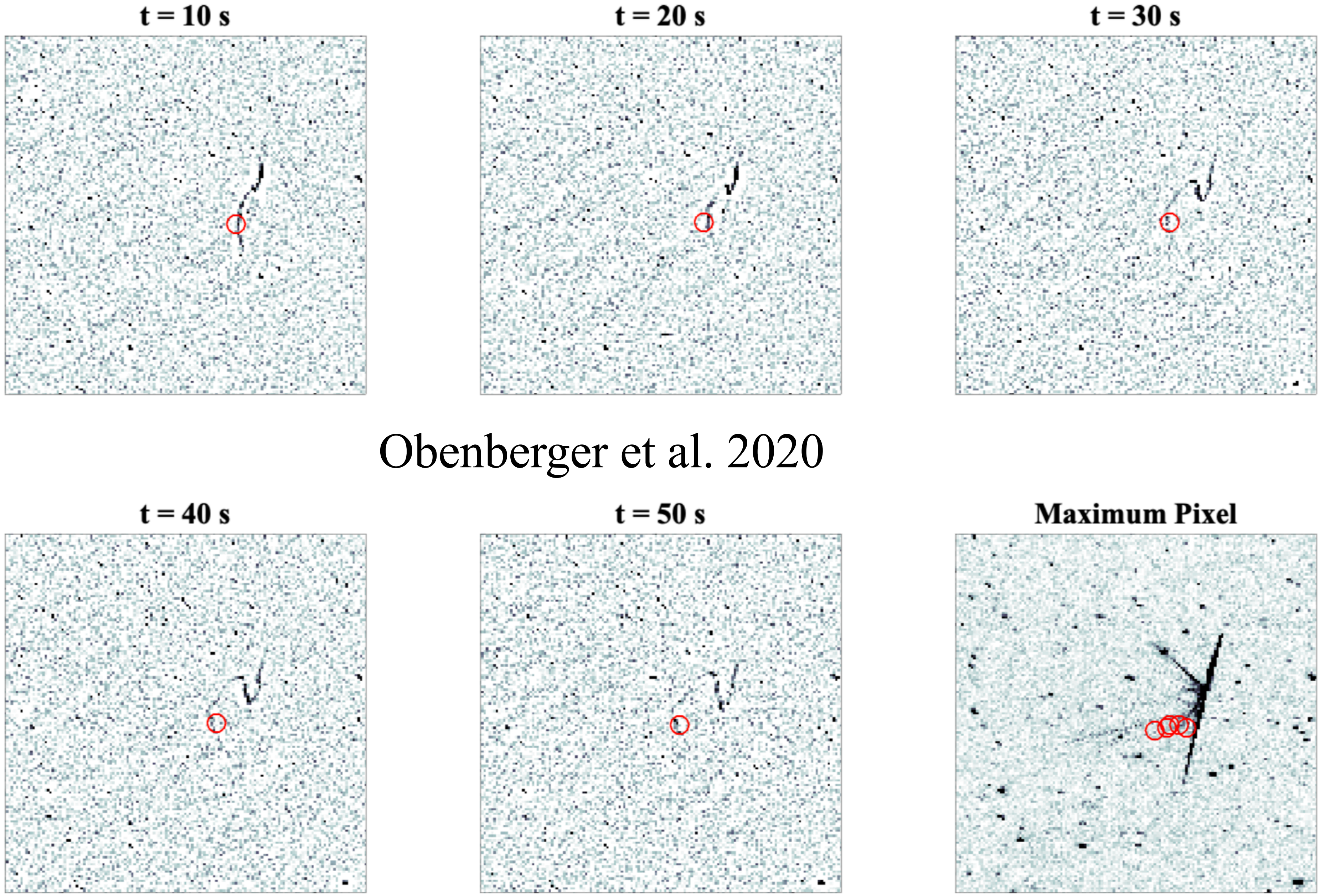
Obenberger et al 2016


FB3
FB4
Frequency in MHz
40
35
30
25
-40
-20
0
20
40
60
80
Seconds
0
1000
2000
3000
Flux Density in Jy

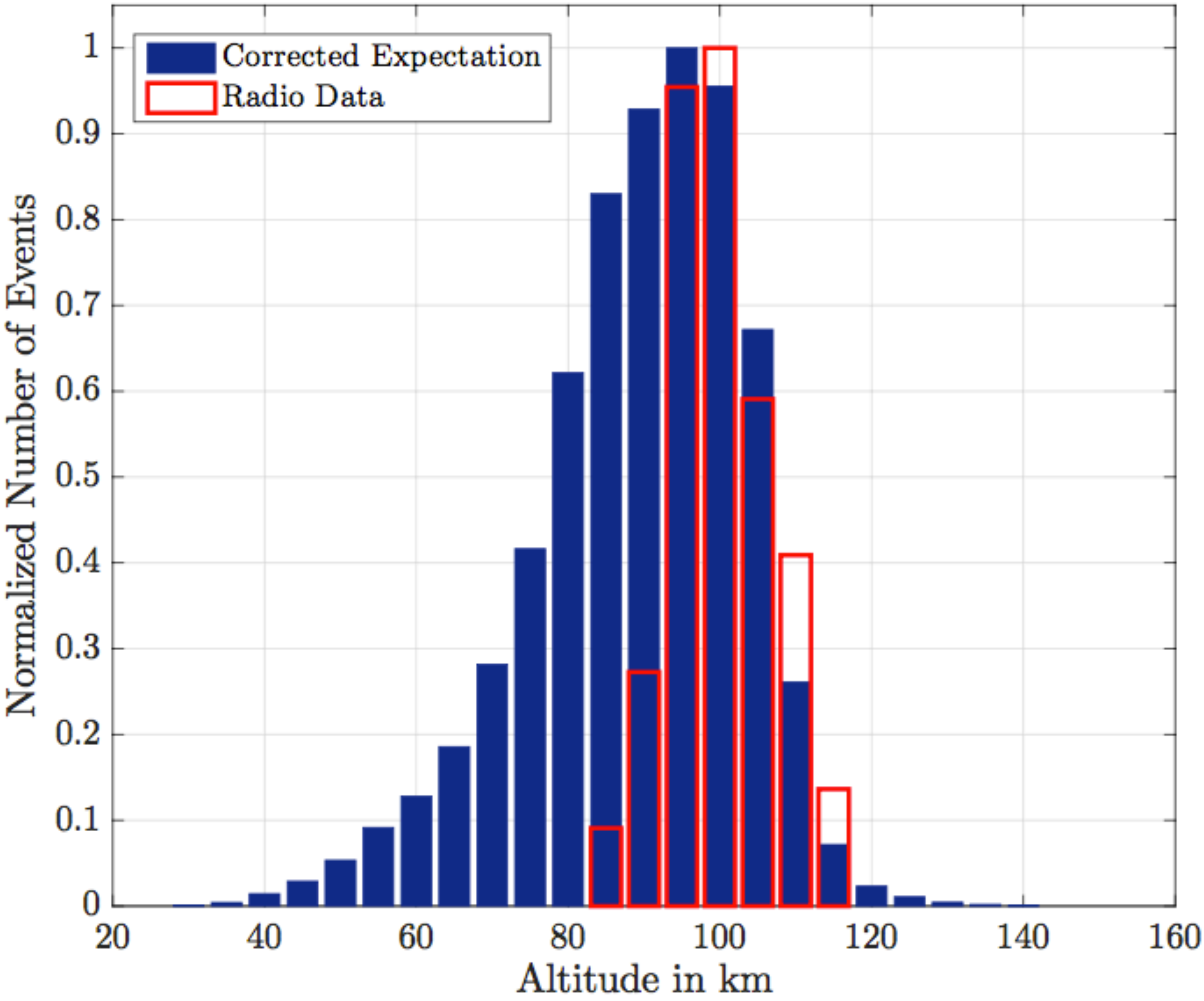
Fireballs – Persistent Trains

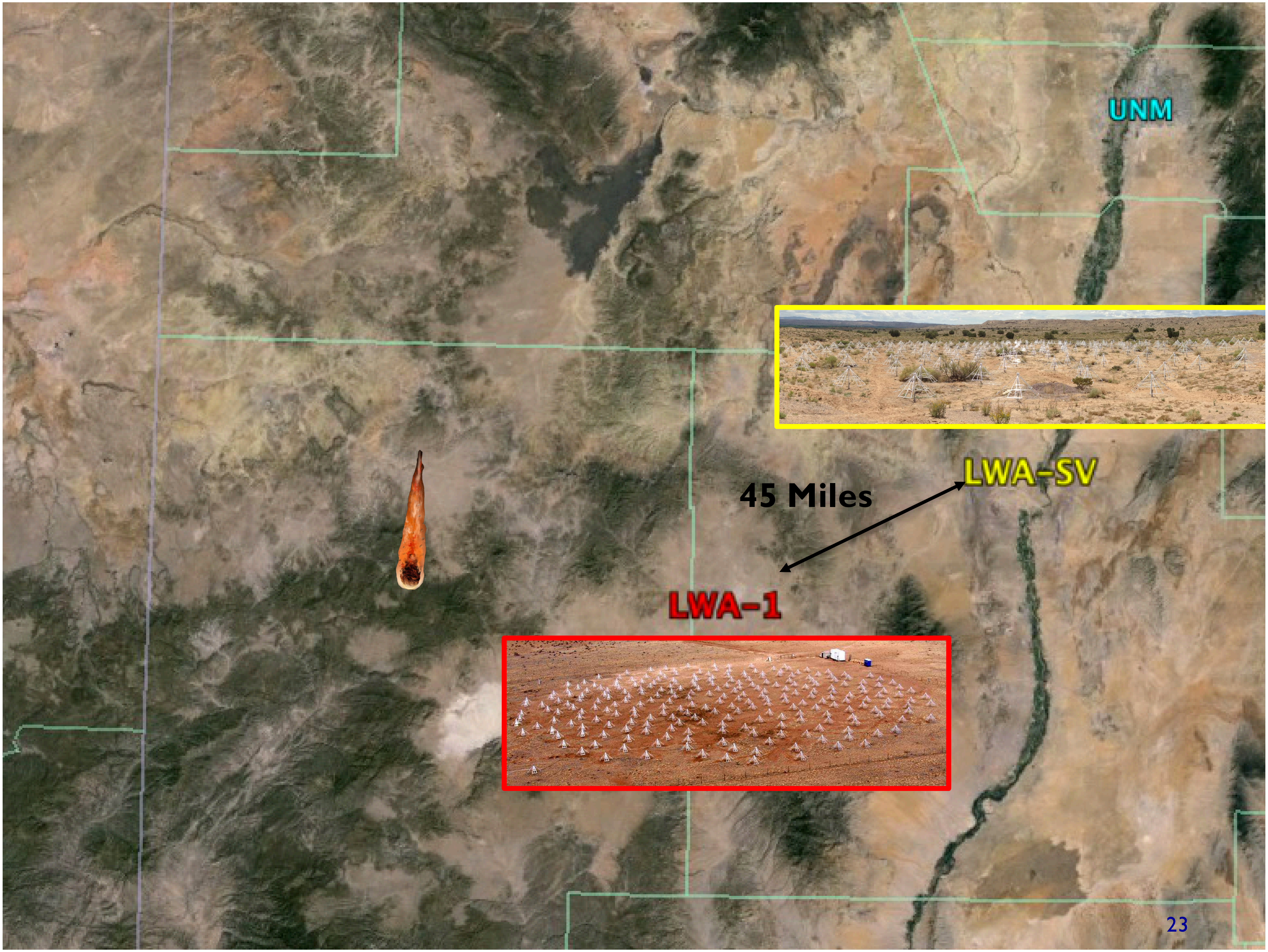
Fireballs – Persistent Trains

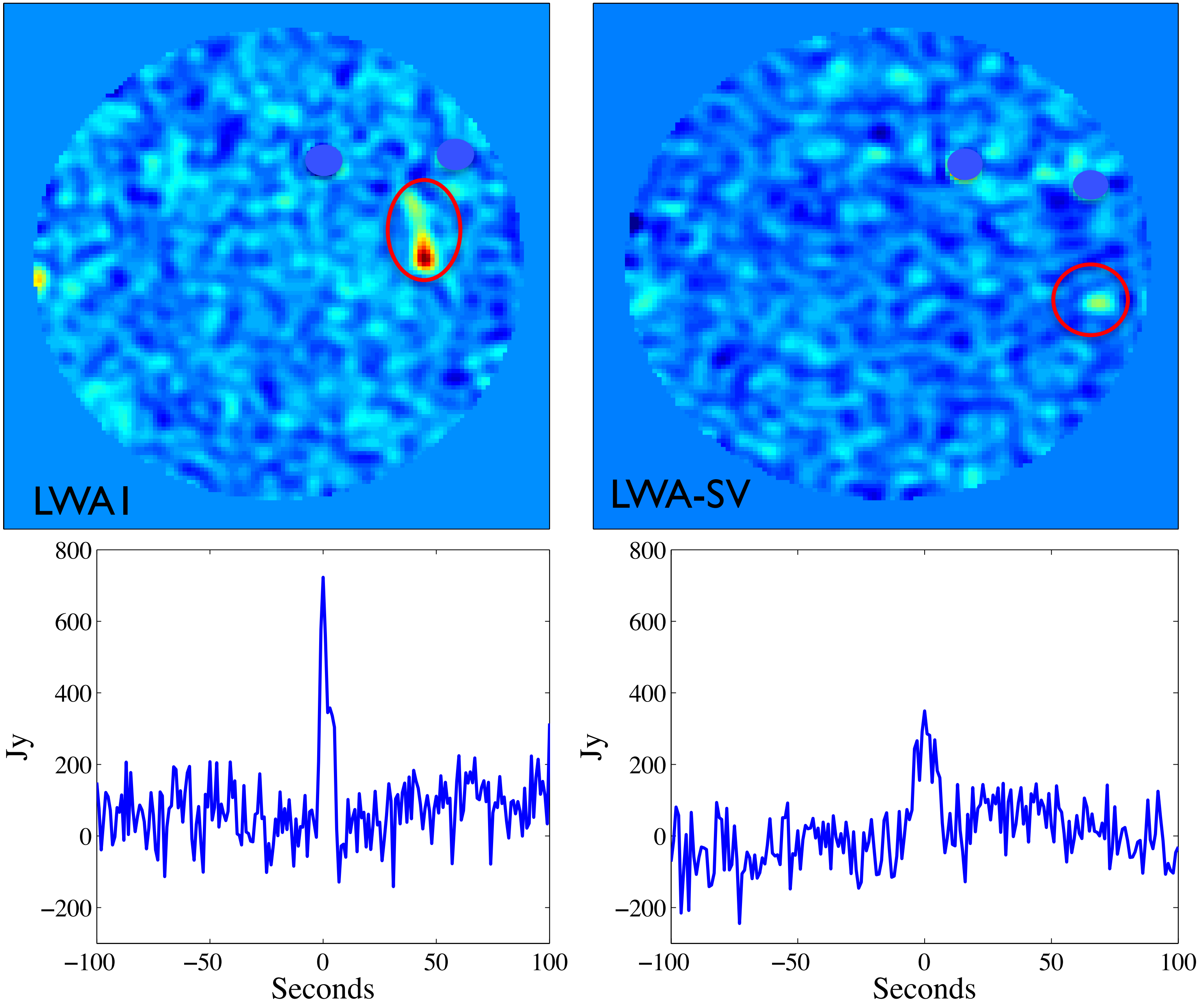
Fireballs – Persistent Trains



Obenberger et al. 2020

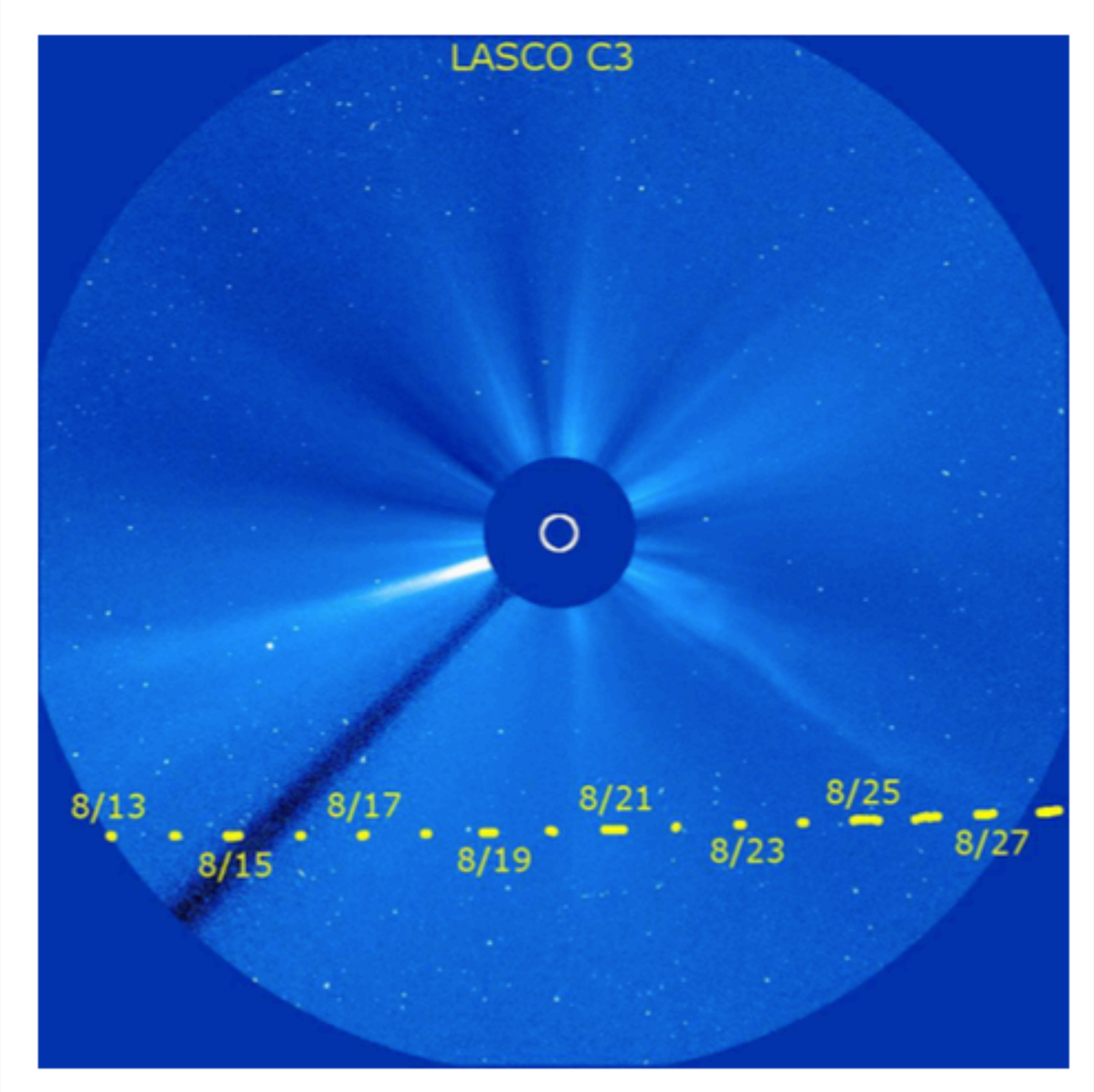

Corrected Expectation
Radio Data
Normalized Number of Events
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
20
40
60
80
100
120
140
160
Altitude in km


UNM
LWA-SV
45 Miles
LWA-1


LWA1
LWA-SV
800
600
400
200
0
−200
Jy
−100
−50
0
50
100
Seconds

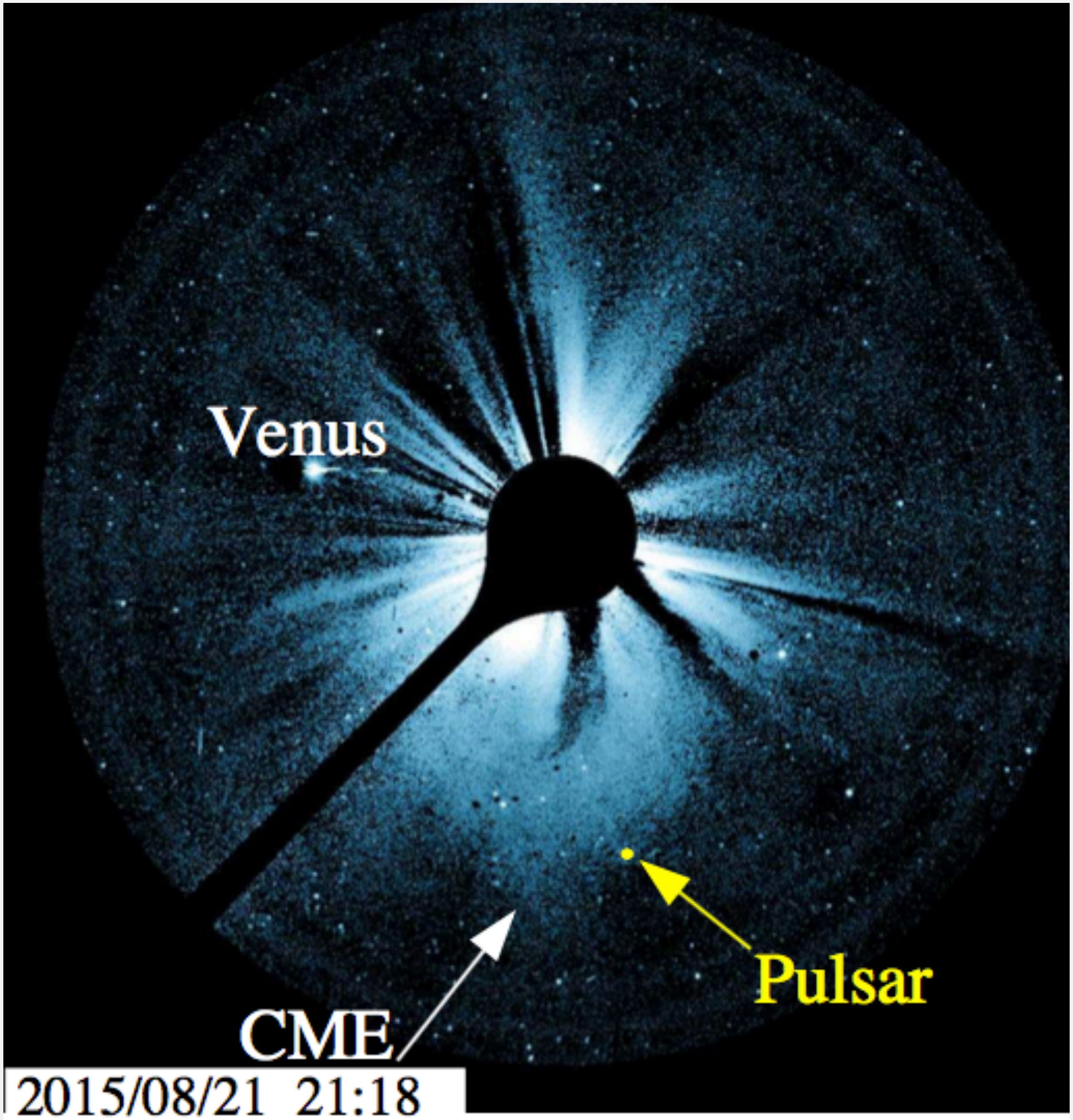
Coronal Mass Ejection

Catching a Coronal Mass Ejection

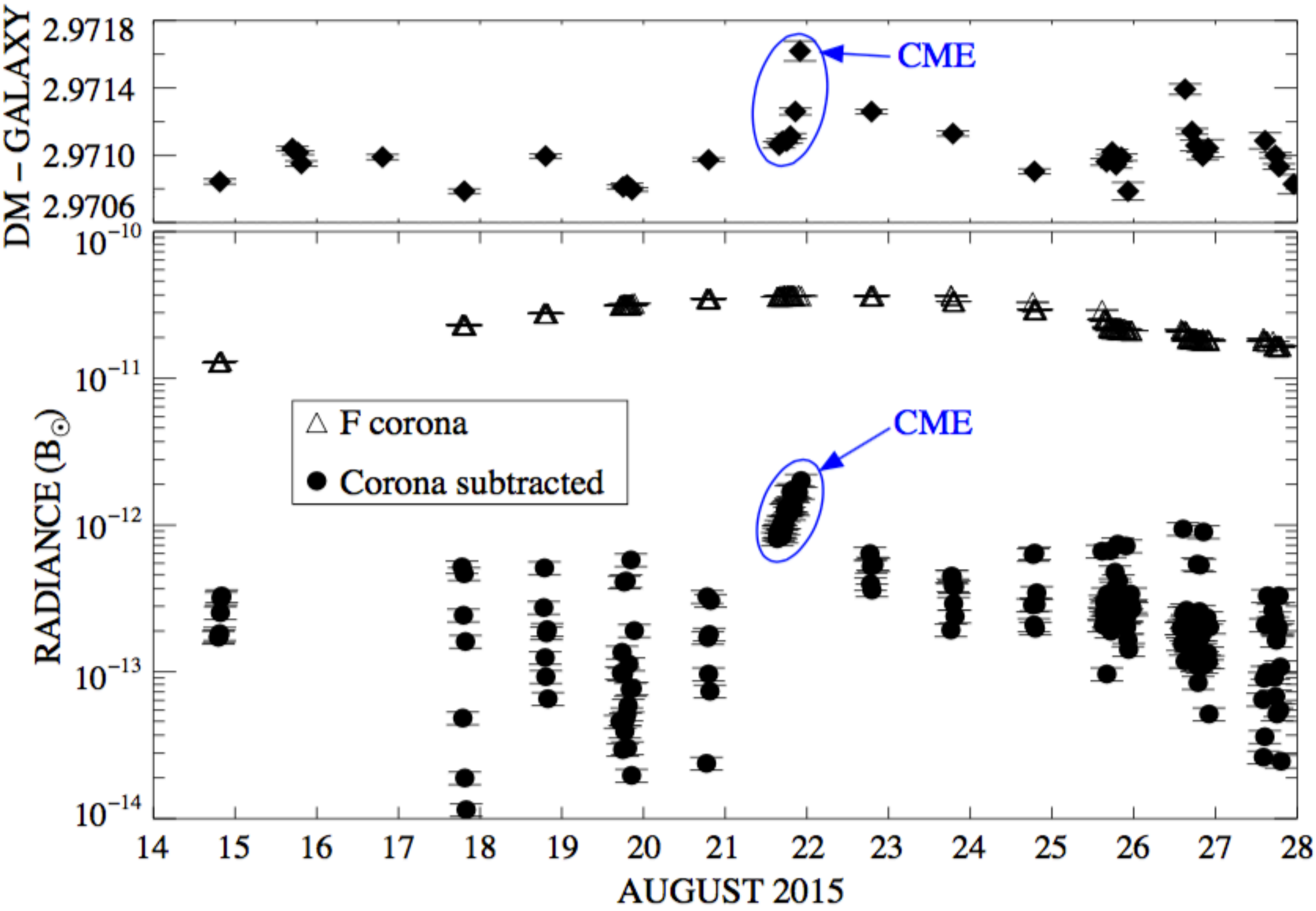


Howard et al 2016

Catching a Coronal Mass Ejection



Catching a Coronal Mass Ejection



Current Low Frequency Interferometers: UTR

- Ukranian T-shaped Radio telescope

- 2040 array elements

- 8-40 MHz tunable

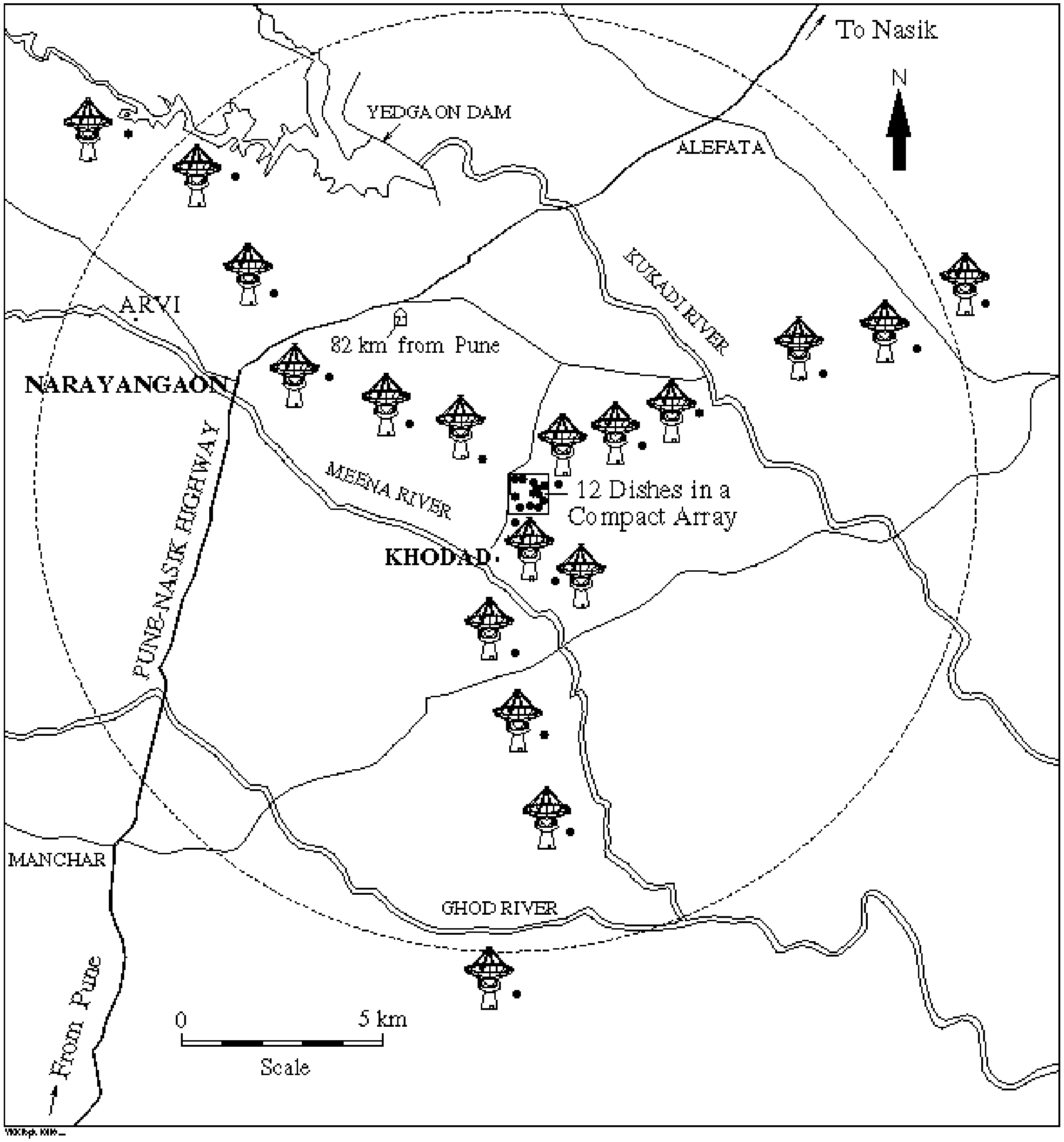
At 17 MHz

res ~ 0.6^O

Area ~ 0.15 km**2

Current Lo rs: GMRT

PRIME FOCUS FEEDS



Receivers:

Hz = 190cm

3.8^{O} (res ~ 20")

Hz = 128cm

2.5^{O} (res ~ 12")

Hz = 90cm

1.8^{O} (res ~ 9")

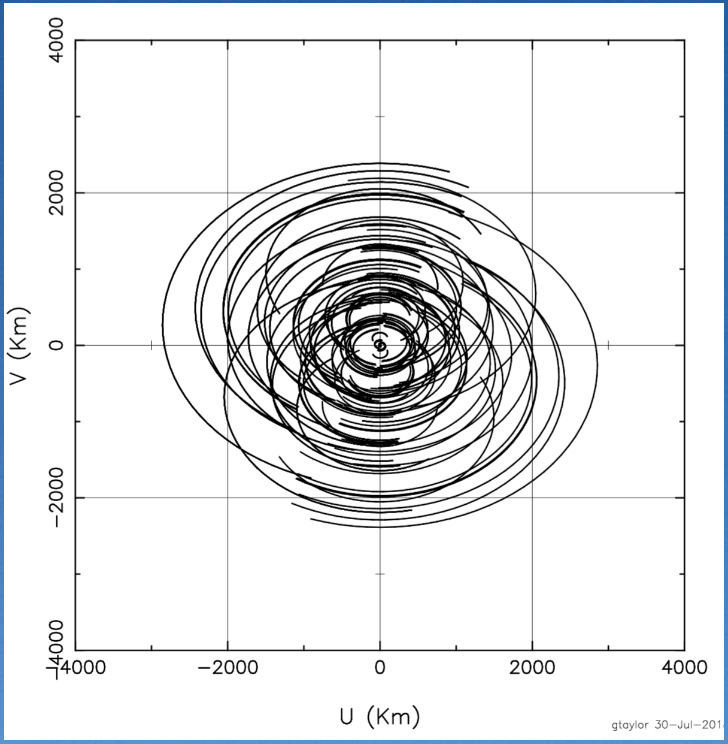
Hz = 50cm

0.9^{O} (res ~ 5")

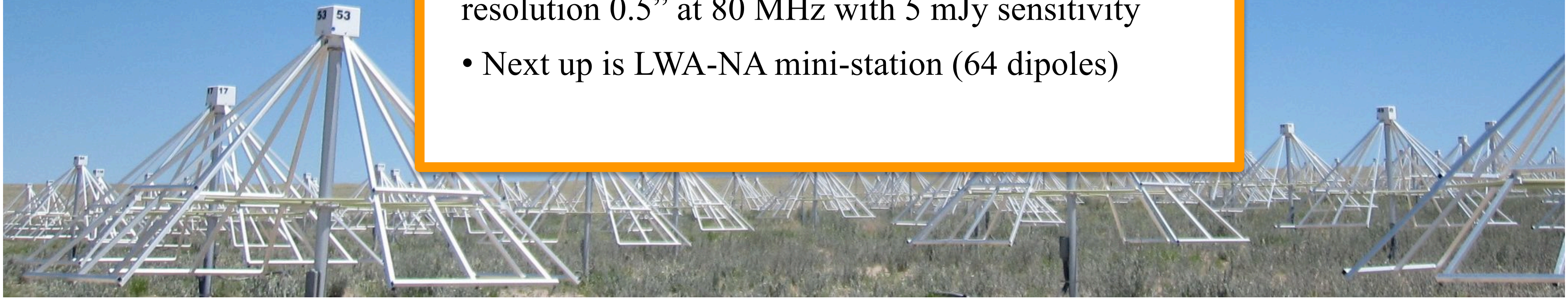
LWA1

LWA Swarm Concept

↔



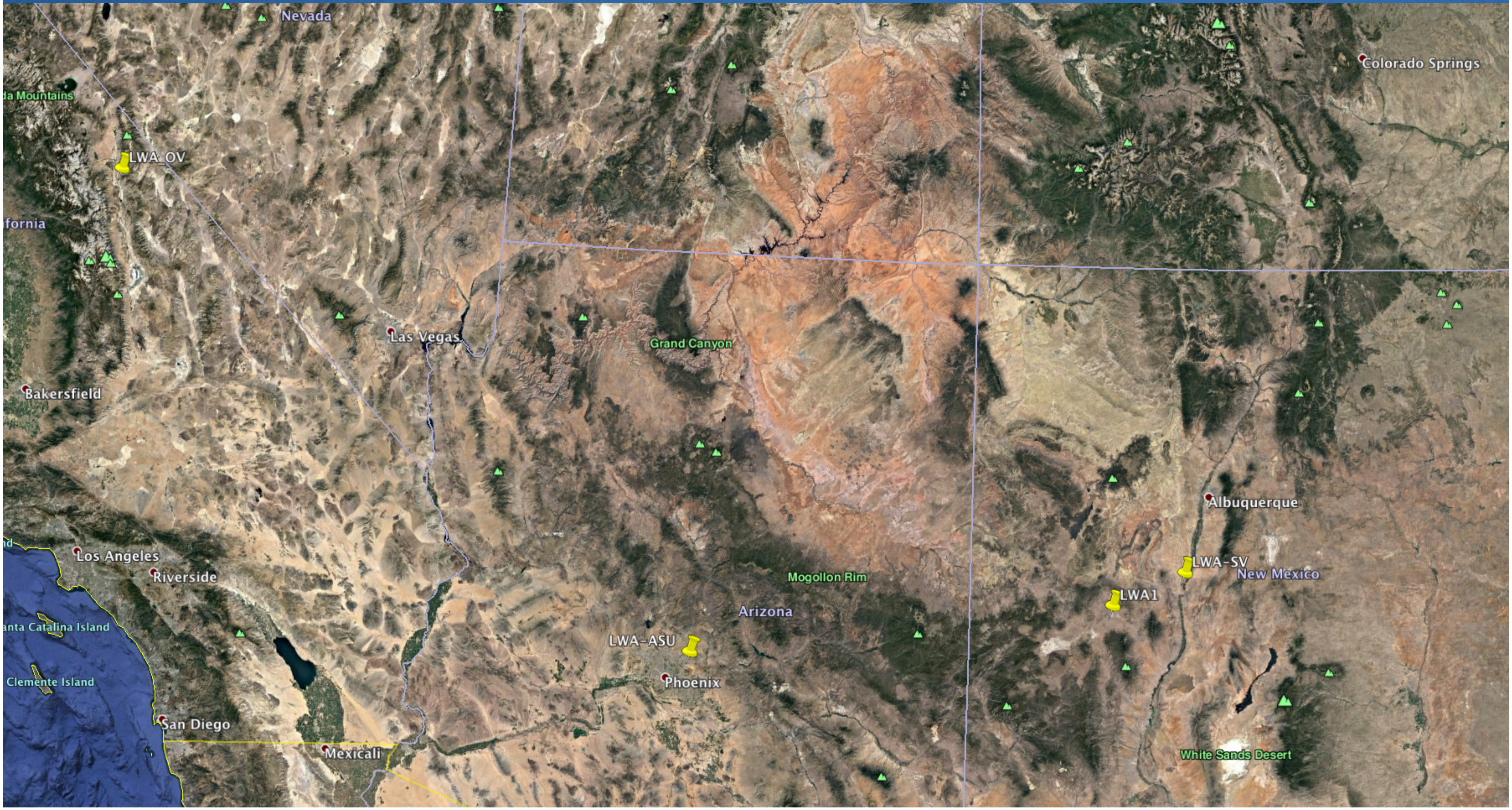
- Goal of 3 existing full stations (●) plus ~10 LWA mini stations (●), baselines up to 2500 km for resolution 0.5” at 80 MHz with 5 mJy sensitivity
- Next up is LWA-NA mini-station (64 dipoles)



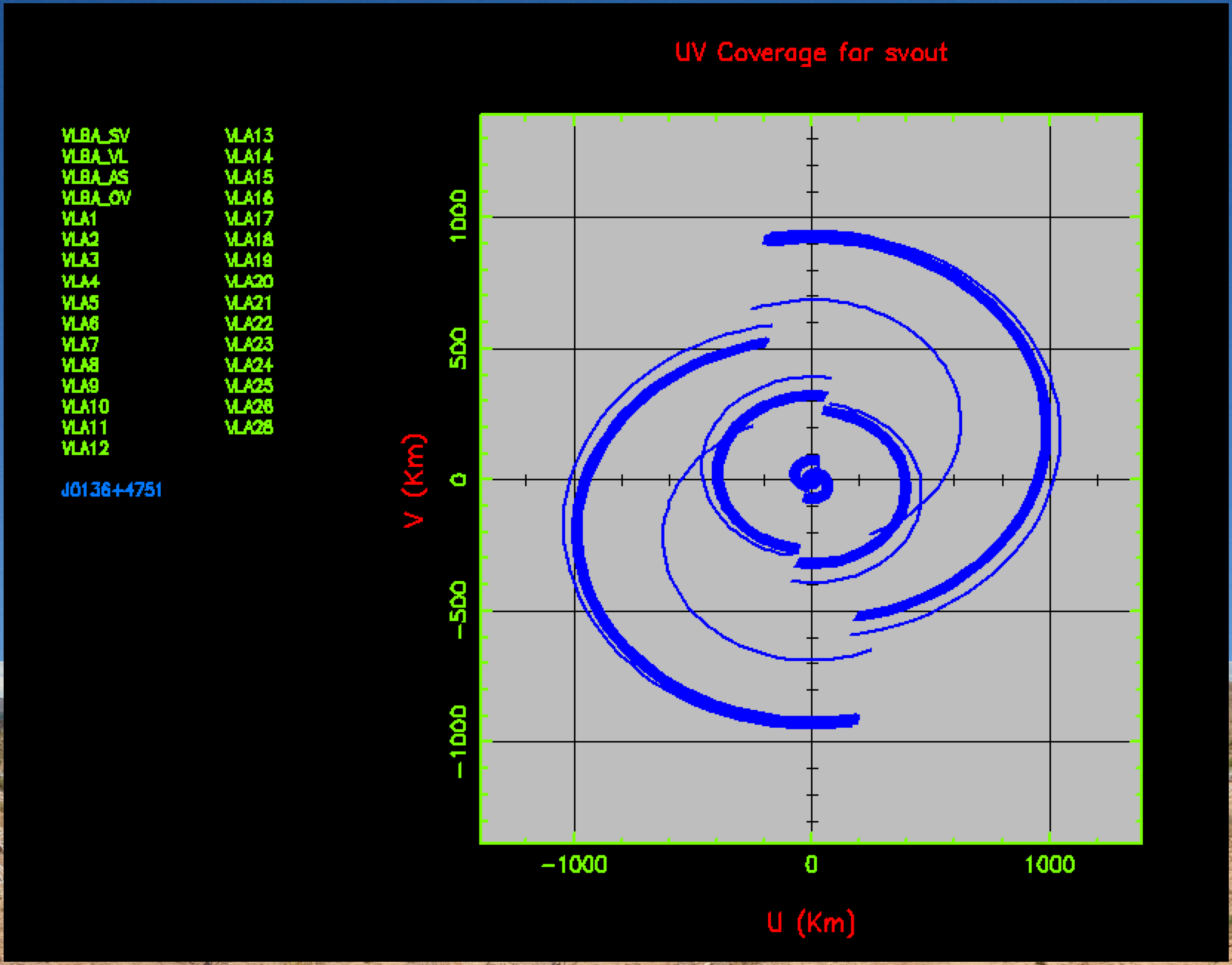
LWA-ASU station

700 km ASU-OVRO

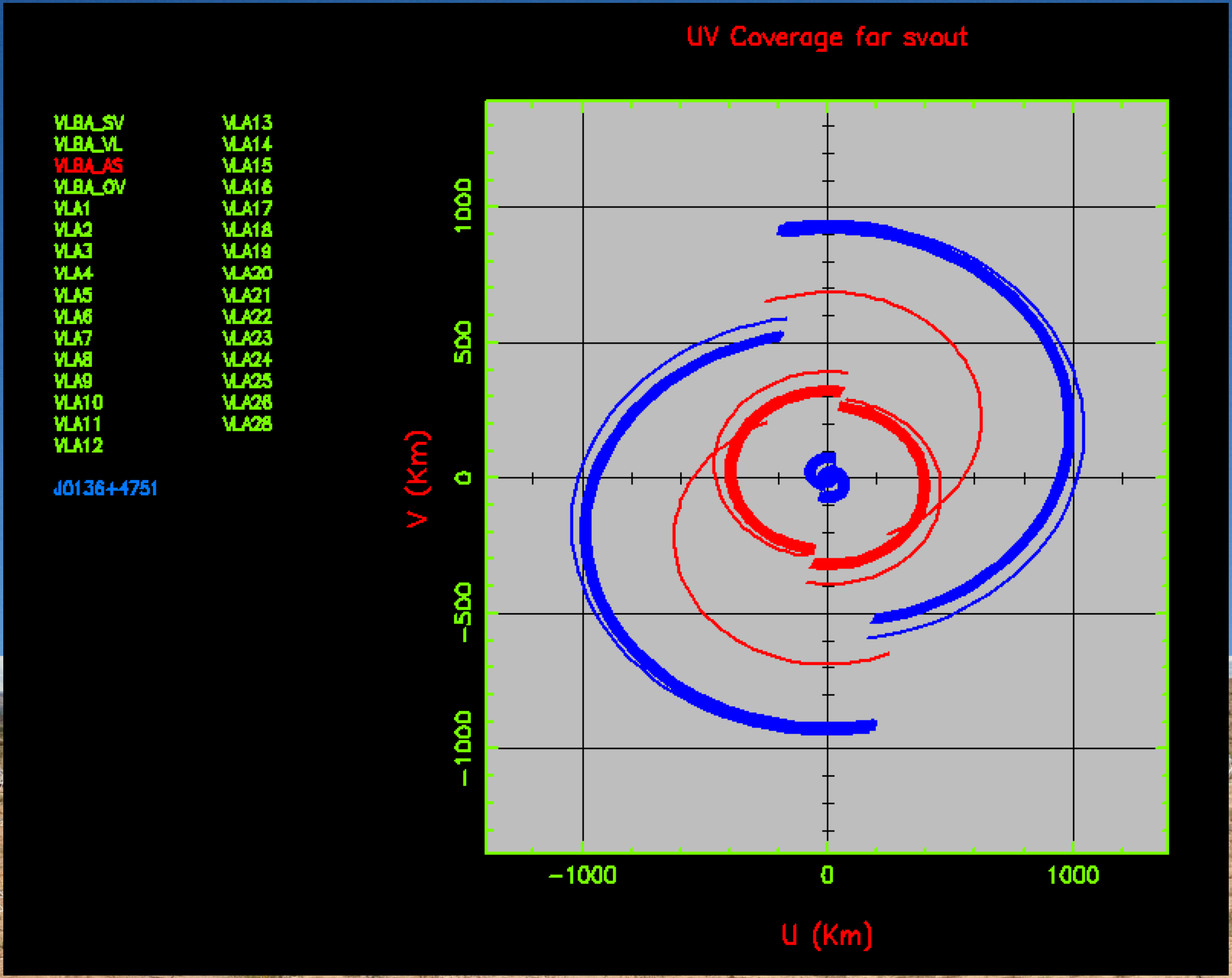
400 km ASU-LWA1



LWA-ASU station



LWA-ASU station



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?

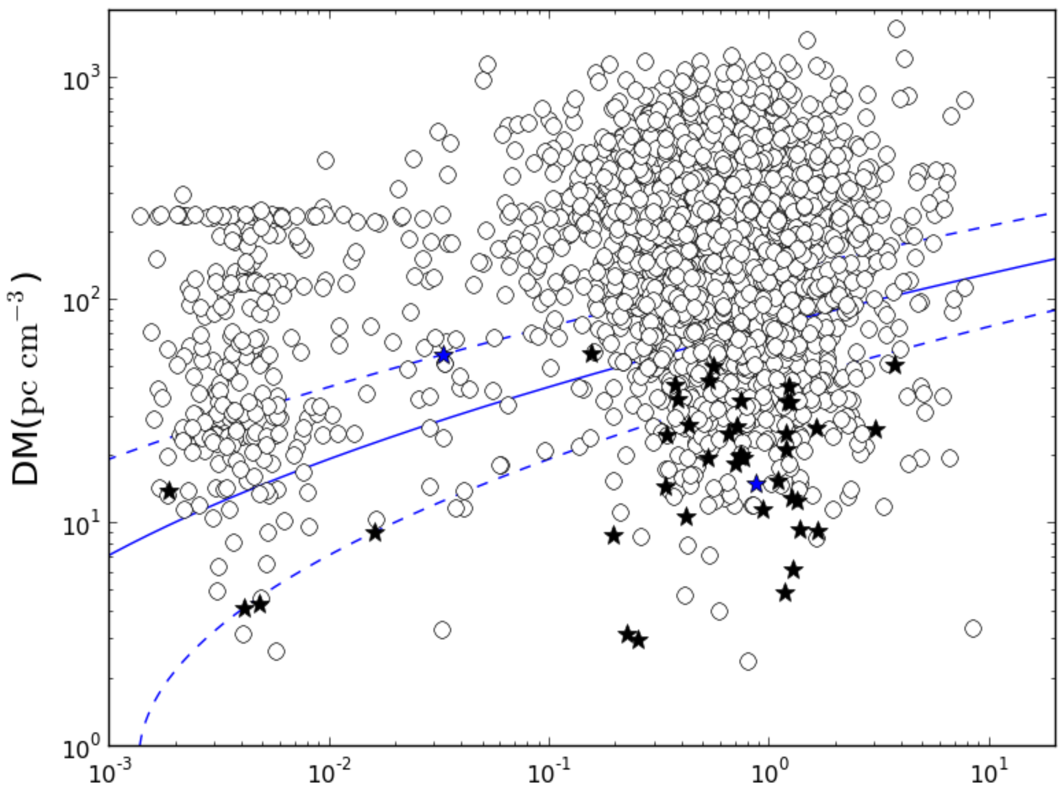
All of LWA1 time is open skies. Your observing proposals are welcome!

LWA1 Pulsar Detections

J0030+0451
B0031-07
J0034-0534
B0138+59
J0203+70
B0320+39
B0329+54
B0355+54
B0450+55
B0525+21
B0531+21*
B0628-28
B0655+64
B0809+74
B0818-13
B0823+26
B0834+06
B0919+06
B0943+10
B0950+08
B1112+50

B1133+16
B1237+25
J1327+34
B1508+55
B1540-06
B1541+09
B1604-00
B1612+07
B1642-03
B1706-16
B1749-28
B1822-09
B1839+56
B1842+14
B1919+21
B1929+10
B2020+28
B2110+27
J2145-0750
B2217+47
J2324-05

- 102 Pulsars detected (58 through pulsations, 2 through single pulses)
- 7 MSPs detected
- Periods from 1.9ms to 3.7s

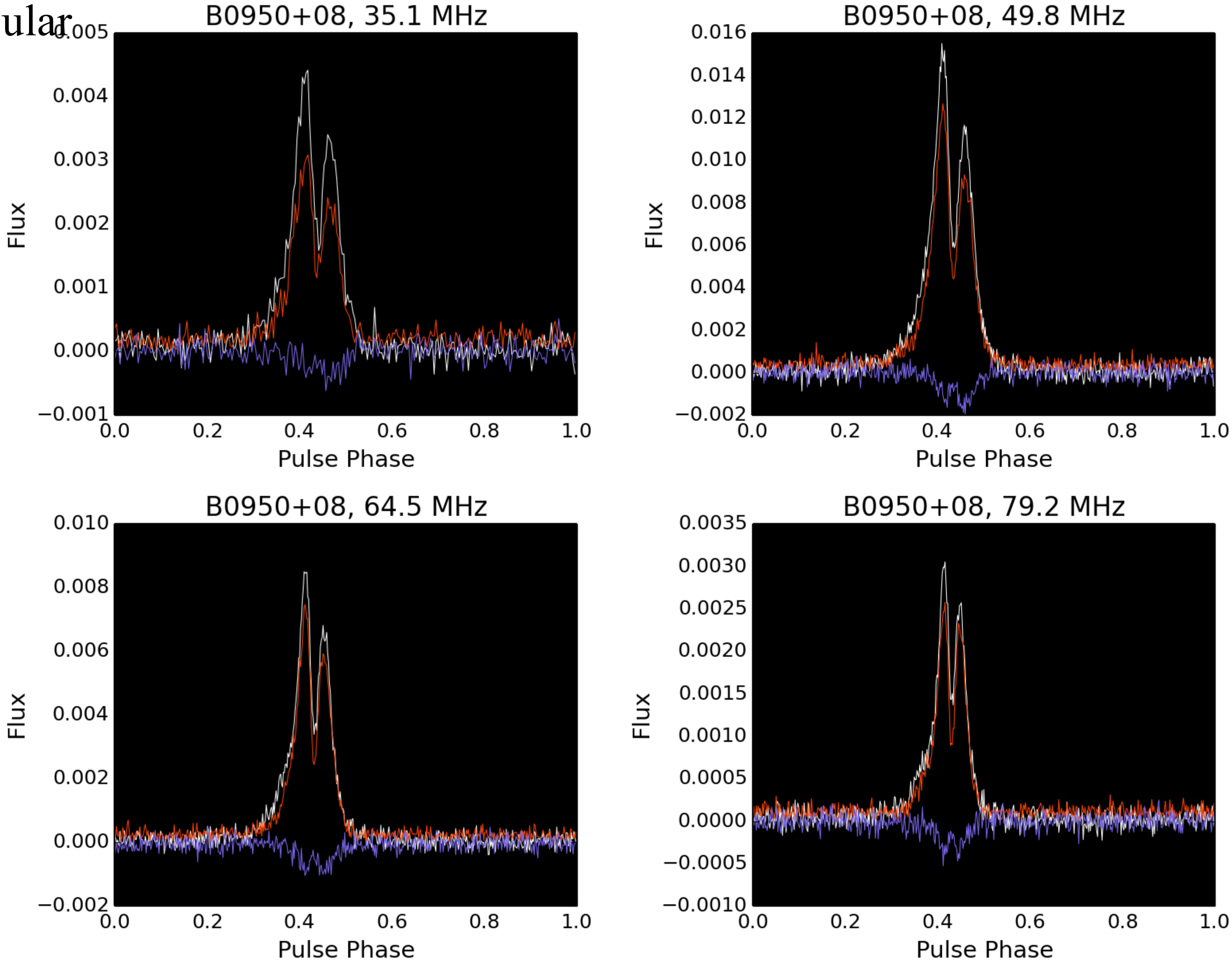


Stovall et al. (2014)

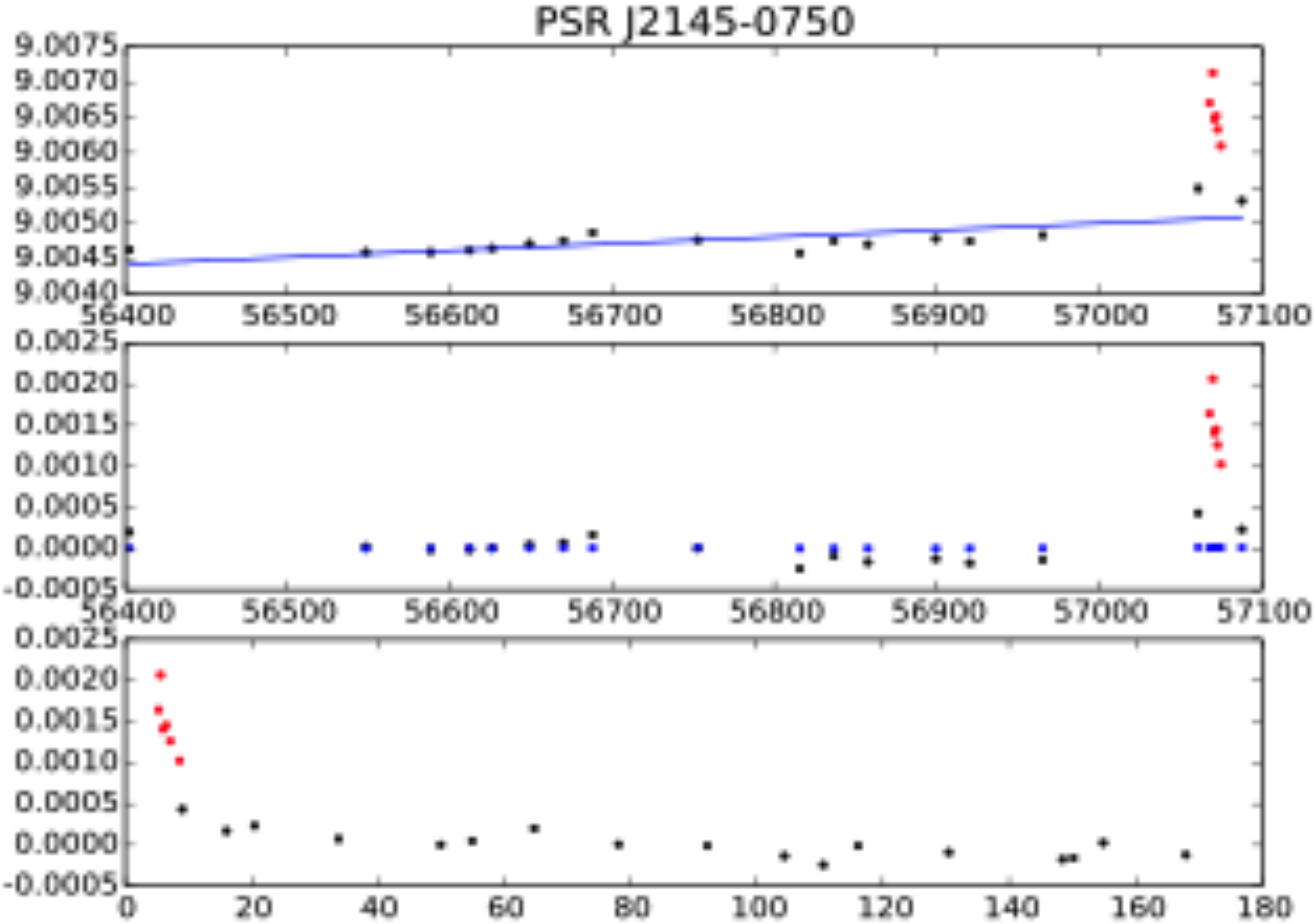
White=Total
Red=Linear
Blue=Circular

Dike et al.
2021

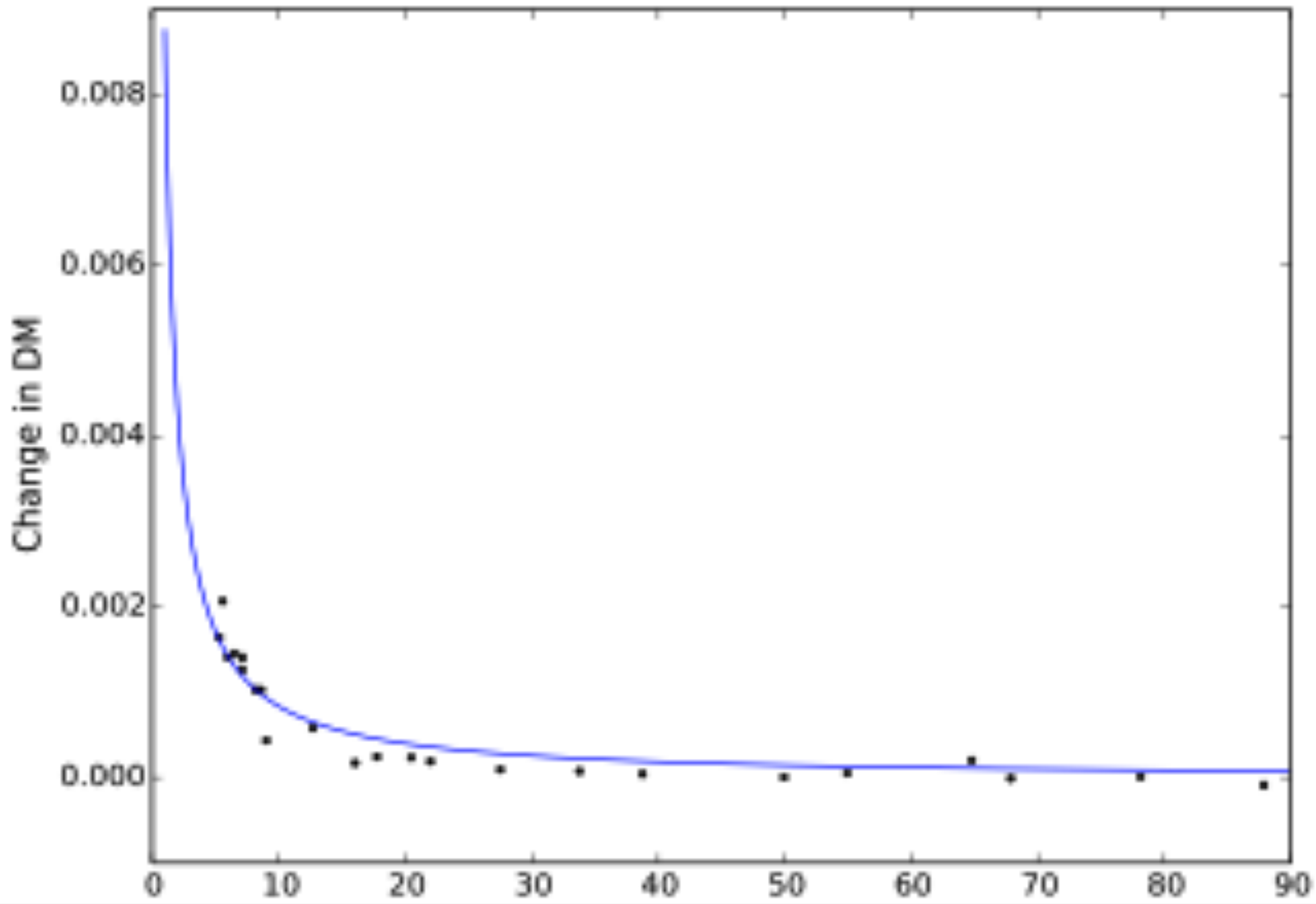
Polarized Pulse Profiles



DM Variations



Solar System Electron Density



Rotation Measure Fitting

PSR B0950+08

$RM_{Meas} = 2.36(4)$

$RM_{Ion} = 1.2(1)$

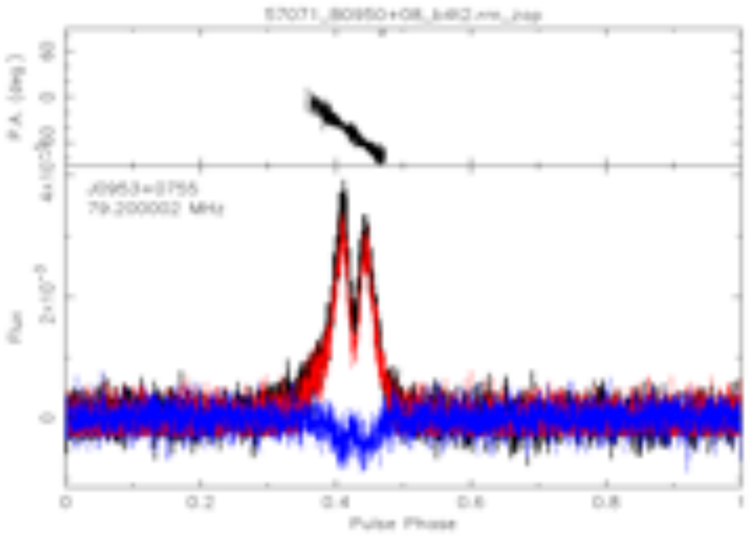
$RM_{corr} = 1.2(2)$

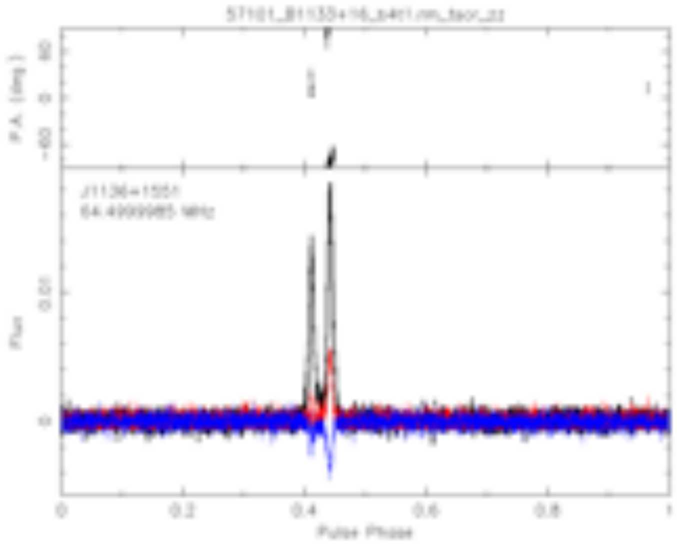
PSR B1133+16

$RM_{Meas} = 4.61(1)$

$RM_{Ion} = 0.84(4)$

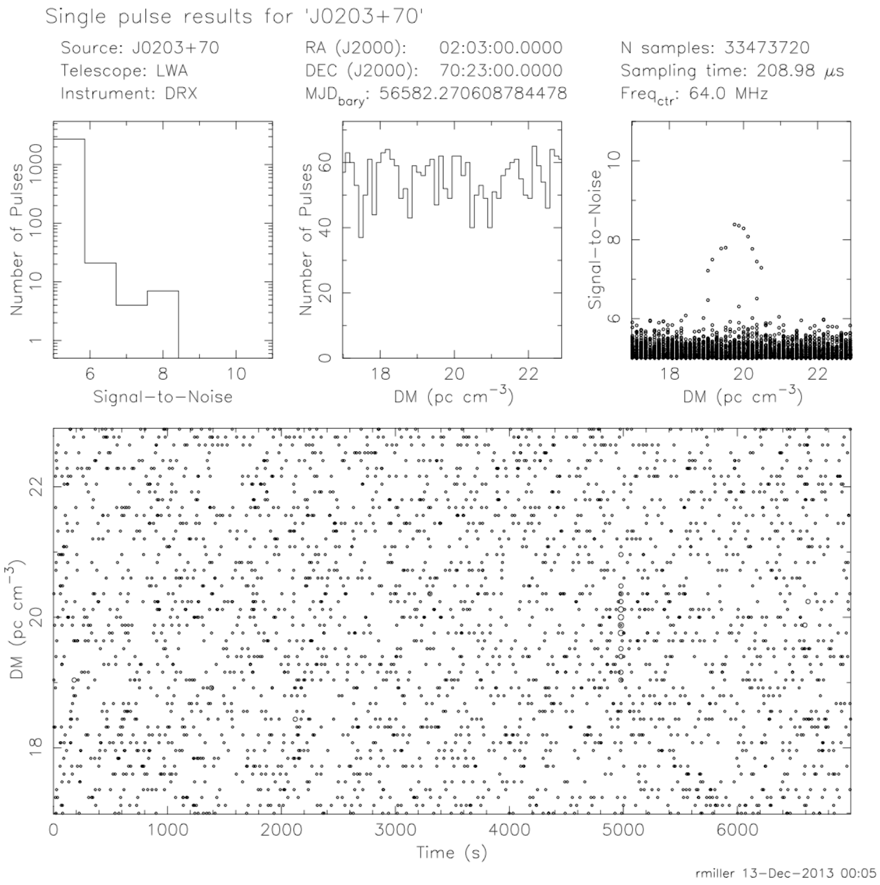
$RM_{corr} = 3.77(5)$





Rotating Radio Transients (RRATs)

J0203+70



Single pulse results for 'J0203+70'

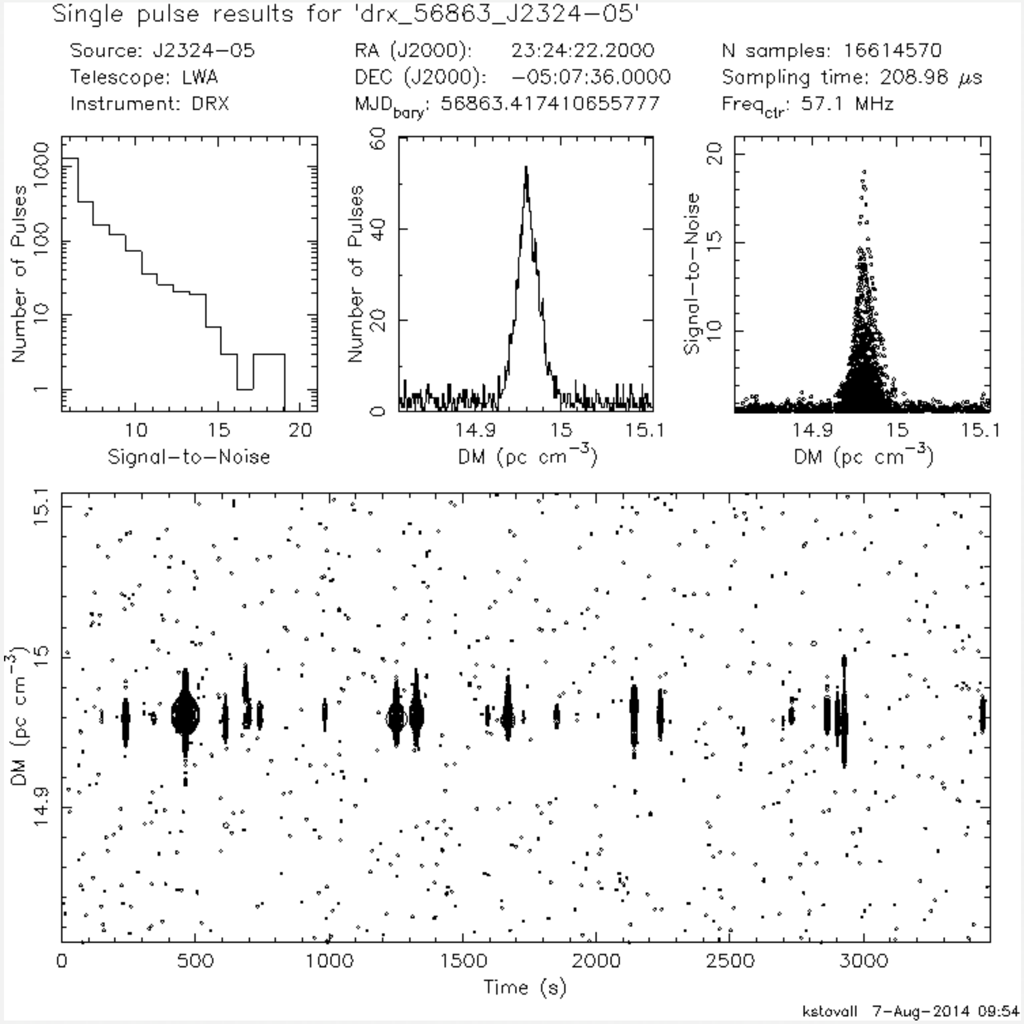
Source: J0203+70
Telescope: LWA
Instrument: DRX

RA (J2000): 02:03:00.0000
DEC (J2000): 70:23:00.0000
$\mathrm{MJD}_{\mathrm{bary}}$: 56582.270608784478

N samples: 33473720
Sampling time: 208.98 μs
$\mathrm{Freq}_{\mathrm{ctr}}$: 64.0 MHz

rmiller 13−Dec−2013 00:05

J2324-05



Single pulse results for 'drx_56863_J2324−05'

Source: J2324−05
Telescope: LWA
Instrument: DRX

RA (J2000): 23:24:22.2000
DEC (J2000): −05:07:36.0000
$\mathrm{MJD}_{\mathrm{bary}}$: 56863.417410655777

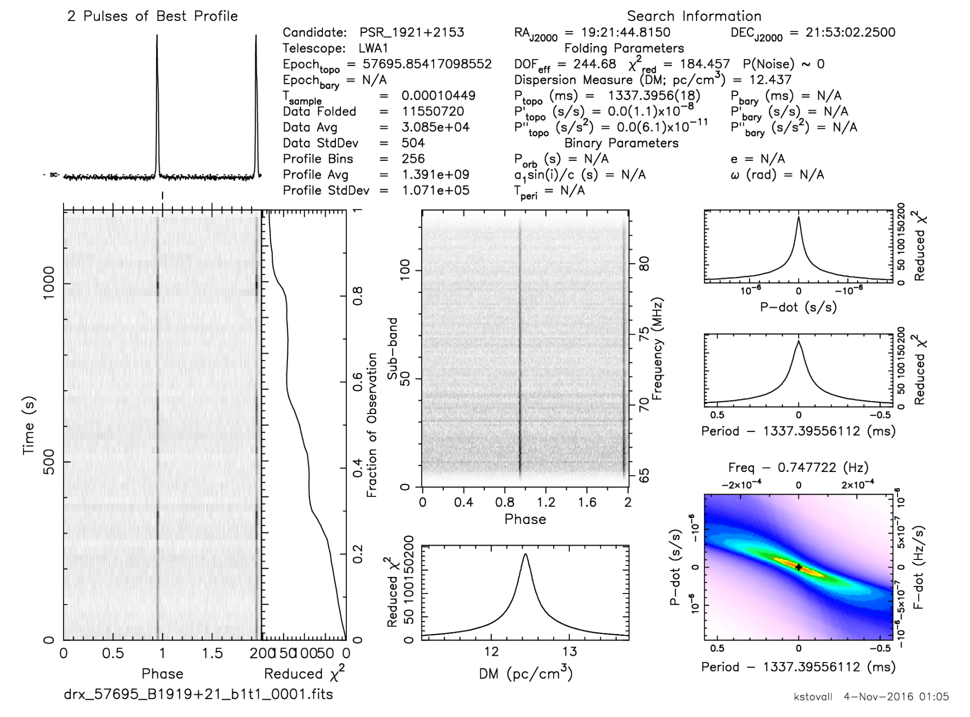
N samples: 16614570
Sampling time: 208.98 μs
$\mathrm{Freq}_{\mathrm{ctr}}$: 57.1 MHz

kstovall 7−Aug−2014 09:54

3 detected so far, search is ongoing

PSR B1919+21

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



Search Information

Candidate: PSR_1921+2153
Telescope: LWA1
$\mathrm{Epoch_{topo}}$ = 57695.85417098552
$\mathrm{Epoch_{bary}}$ = N/A
T_{sample} = 0.00010449
Data Folded = 11550720
Data Avg = 3.085e+04
Data StdDev = 504
Profile Bins = 256
Profile Avg = 1.391e+09
Profile StdDev = 1.071e+05

RA_{J2000} = 19:21:44.8150
DEC_{J2000} = 21:53:02.2500

Folding Parameters

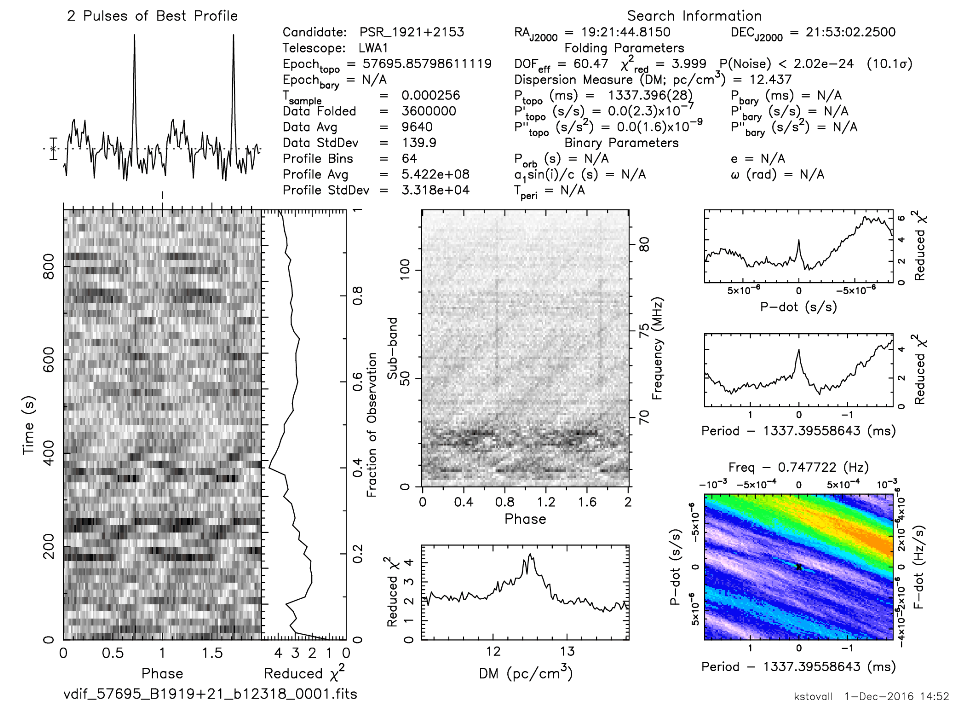
DOF_{eff} = 244.68 χ^2_{red} = 184.457 P(Noise) ~ 0
Dispersion Measure (DM; pc/cm^3) = 12.437
P_{topo} (ms) = 1337.3956(18)
P_{bary} (ms) = N/A
P'_{topo} (s/s) = 0.0(1.1)x10^{-8}
P'_{bary} (s/s) = N/A
P''_{topo} (s/s^2) = 0.0(6.1)x10^{-11}
P''_{bary} (s/s^2) = N/A

Binary Parameters

P_{orb} (s) = N/A
$a_1\sin(i)/c$ (s) = N/A
T_{peri} = N/A
e = N/A
ω (rad) = N/A

drx_57695_B1919+21_b1t1_0001.fits

kstovall 4−Nov−2016 01:05



Search Information

Candidate: PSR_1921+2153
Telescope: LWA1
$\mathrm{Epoch_{topo}}$ = 57695.85798611119
$\mathrm{Epoch_{bary}}$ = N/A
T_{sample} = 0.000256
Data Folded = 3600000
Data Avg = 9640
Data StdDev = 139.9
Profile Bins = 64
Profile Avg = 5.422e+08
Profile StdDev = 3.318e+04

RA_{J2000} = 19:21:44.8150
DEC_{J2000} = 21:53:02.2500

Folding Parameters

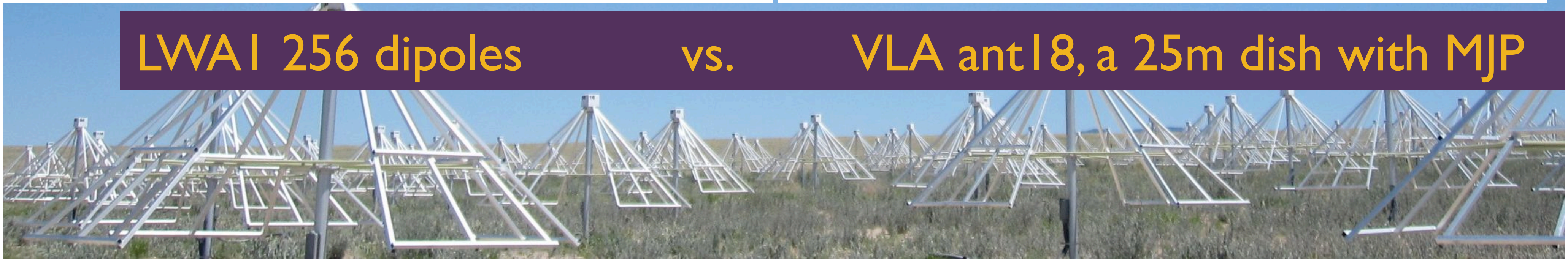
DOF_{eff} = 60.47 χ^2_{red} = 3.999 P(Noise) < 2.02e−24 (10.1σ)
Dispersion Measure (DM; pc/cm^3) = 12.437
P_{topo} (ms) = 1337.396(28)
P_{bary} (ms) = N/A
P'_{topo} (s/s) = 0.0(2.3)x10^{-7}
P'_{bary} (s/s) = N/A
P''_{topo} (s/s^2) = 0.0(1.6)x10^{-9}
P''_{bary} (s/s^2) = N/A

Binary Parameters

P_{orb} (s) = N/A
$a_1\sin(i)/c$ (s) = N/A
T_{peri} = N/A
e = N/A
ω (rad) = N/A

vdif_57695_B1919+21_b12318_0001.fits

kstovall 1−Dec−2016 14:52

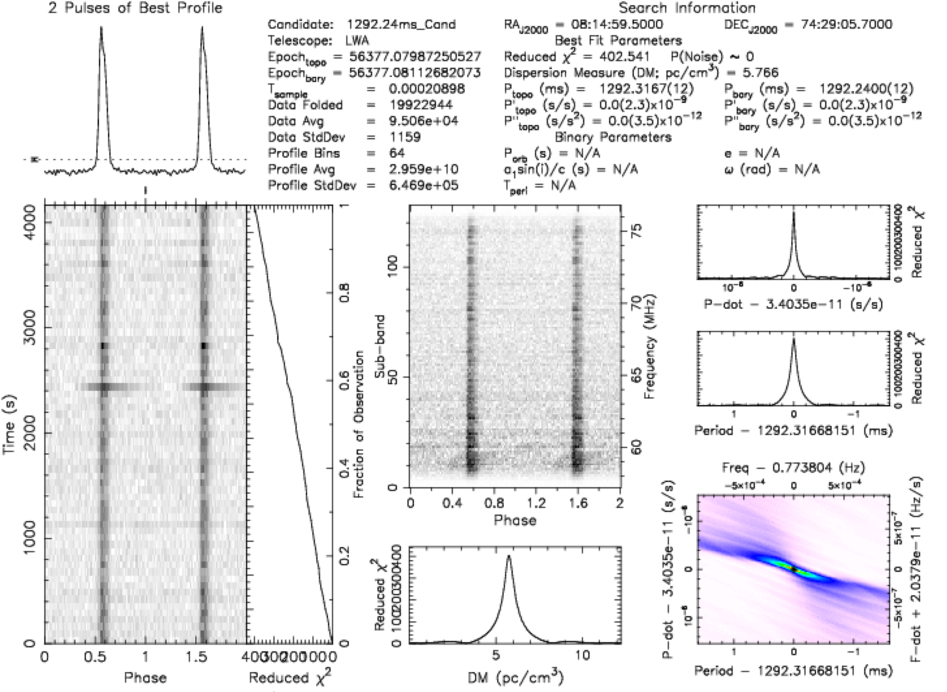


LWA1 256 dipoles vs. VLA ant18, a 25m dish with MJP

Using Pulsars to compare sensitivity

LWA1 Compared to LOFAR Int'l Station

LWA1 (59-75 MHz)



Search Information

Candidate: 1292.24ms_Cand
Telescope: LWA
$\mathrm{Epoch_{topo}}$ = 56377.07987250527
$\mathrm{Epoch_{bary}}$ = 56377.08112682073
$\mathrm{T_{sample}}$ = 0.00020898
Data Folded = 19922944
Data Avg = 9.506e+04
Data StdDev = 1159
Profile Bins = 64
Profile Avg = 2.959e+10
Profile StdDev = 6.469e+05

$\mathrm{RA_{J2000}}$ = 08:14:59.5000
$\mathrm{DEC_{J2000}}$ = 74:29:05.7000

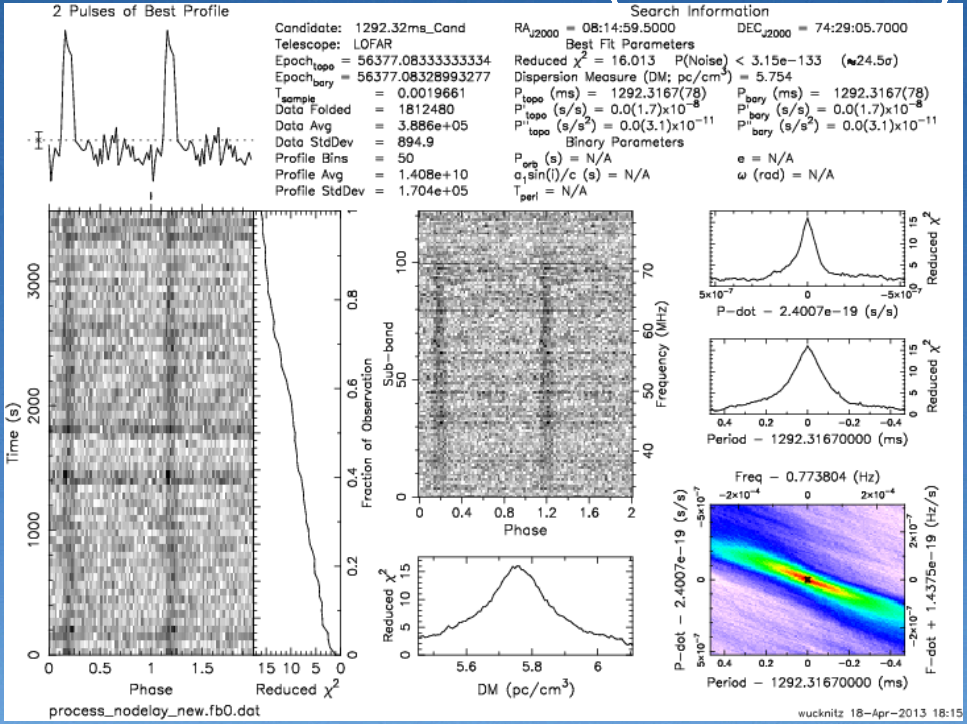
Best Fit Parameters

Reduced χ^2 = 402.541 P(Noise) ~ 0
Dispersion Measure (DM; pc/cm^3) = 5.766
$\mathrm{P_{topo}}$ (ms) = 1292.3167(12)
$\mathrm{P_{bary}}$ (ms) = 1292.2400(12)
$\mathrm{P'_{topo}}$ (s/s) = $0.0(2.3)\times10^{-9}$
$\mathrm{P'_{bary}}$ (s/s) = $0.0(2.3)\times10^{-9}$
$\mathrm{P''_{topo}}$ (s/s^2) = $0.0(3.5)\times10^{-12}$
$\mathrm{P''_{bary}}$ (s/s^2) = $0.0(3.5)\times10^{-12}$

Binary Parameters

$\mathrm{P_{orb}}$ (s) = N/A
e = N/A
$a_1\sin(i)/c$ (s) = N/A
ω (rad) = N/A
$\mathrm{T_{peri}}$ = N/A

LOFAR SE607 (36-75 MHz)



Search Information

Candidate: 1292.32ms_Cand
Telescope: LOFAR
$\mathrm{Epoch_{topo}}$ = 56377.08333333334
$\mathrm{Epoch_{bary}}$ = 56377.08328993277
$\mathrm{T_{sample}}$ = 0.0019661
Data Folded = 1812480
Data Avg = 3.886e+05
Data StdDev = 894.9
Profile Bins = 50
Profile Avg = 1.408e+10
Profile StdDev = 1.704e+05

$\mathrm{RA_{J2000}}$ = 08:14:59.5000
$\mathrm{DEC_{J2000}}$ = 74:29:05.7000

Best Fit Parameters

Reduced χ^2 = 16.013 P(Noise) < 3.15e−133 (≈24.5σ)
Dispersion Measure (DM; pc/cm^3) = 5.754
$\mathrm{P_{topo}}$ (ms) = 1292.3167(78)
$\mathrm{P_{bary}}$ (ms) = 1292.3167(78)
$\mathrm{P'_{topo}}$ (s/s) = $0.0(1.7)\times10^{-8}$
$\mathrm{P'_{bary}}$ (s/s) = $0.0(1.7)\times10^{-8}$
$\mathrm{P''_{topo}}$ (s/s^2) = $0.0(3.1)\times10^{-11}$
$\mathrm{P''_{bary}}$ (s/s^2) = $0.0(3.1)\times10^{-11}$

Binary Parameters

$\mathrm{P_{orb}}$ (s) = N/A
e = N/A
$a_1\sin(i)/c$ (s) = N/A
ω (rad) = N/A
$\mathrm{T_{peri}}$ = N/A

256 dipoles vs 96 dipoles

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