Structural Monitoring of Ionospheric Absorption Events

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Long Wavelength Array

University of New Mexico
<http://lwa.unm.edu/>

Developing High-Resolution Structural Monitoring of Ionospheric Absorption Events

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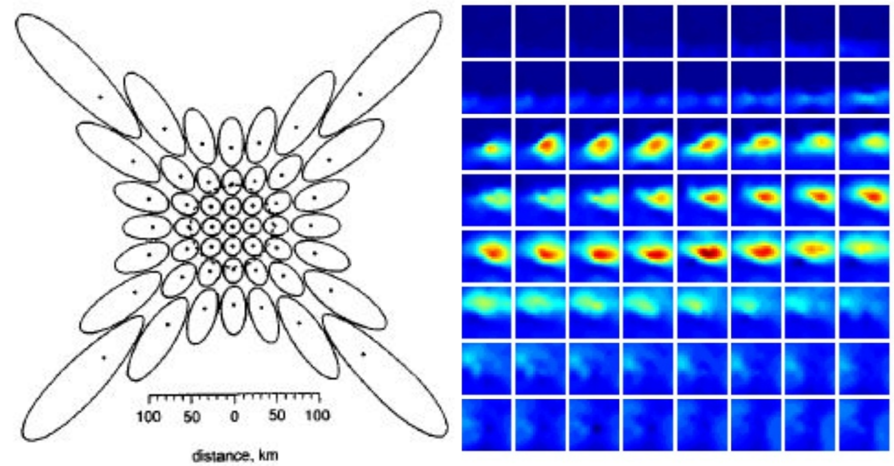
Objective: Develop interferometric capability to resolve the fine-scale structure in anomalous ionospheric absorption events triggered by precipitation of particles from radiation belts.

Relevance: Provide instrument to improve scientific understanding of mechanisms that control the decay of artificial radiation belts, with a view to mitigation or instigation.



Absorption event measured at Kilpisjarvi with 8-element array

Approach: Develop 'outrigger' for interferometric correlation with first station of Long Wavelength Array, to provide high angular resolution, broad spectral range (20 – 80 MHz), all-sky riometric measurements.

Personnel Support: Two Ph. D. scientists, one engineer, and one graduate student in first year (two graduate students in second year).

Tasks: Year 1: Acquire and install equipment to produce a 16-element array near LWA-1 station, including data link for real-time correlation. Measure and validate riometric data, and correlate with relevant phenomena.

Year 2: Measure and validate riometric improvement from enhanced resolution of background and reduced confusion noise.

Funding: Year 1: FY10-$485K, Year 2: FY11-$338K

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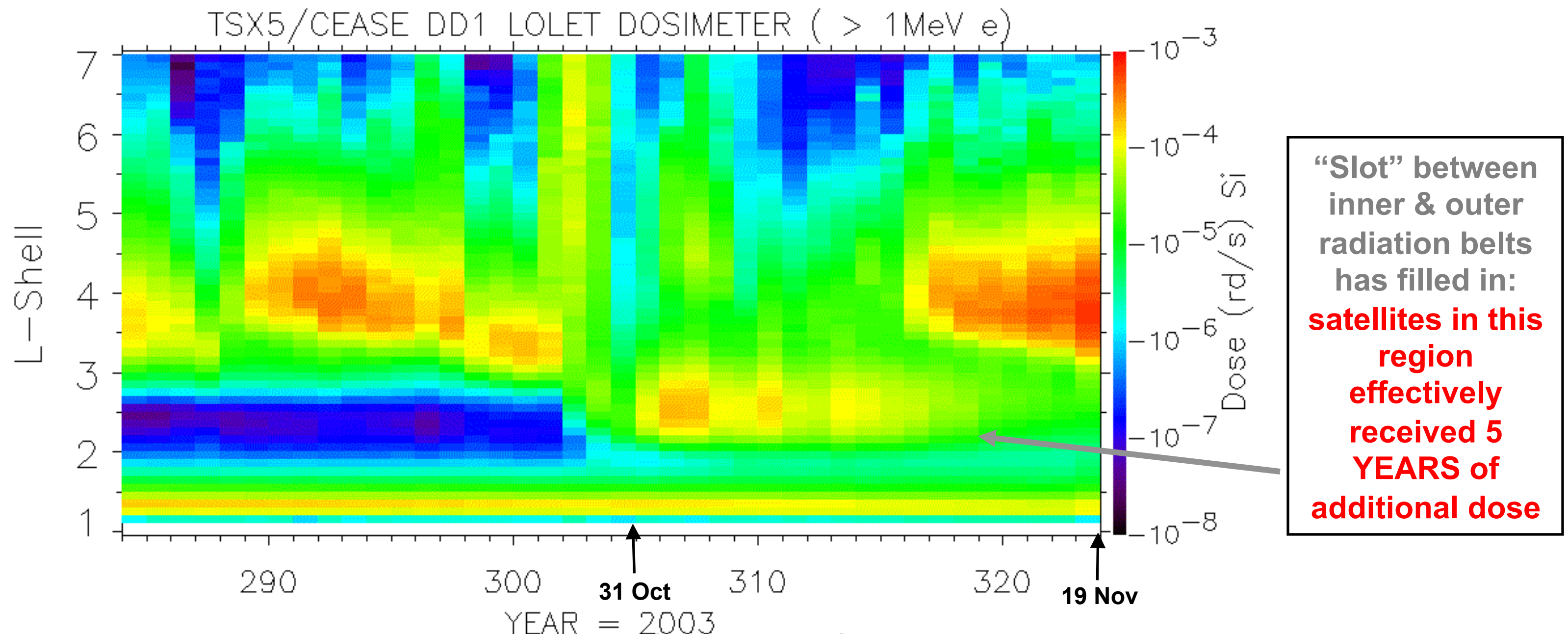
Space Weather System Impacts Oct/Nov 2003 (Courtesy AFRL)



Impacts (partial list)

- Military comms impacted (HF / UHF SATCOM) / Over The Horizon (OTH) comms
- High latitude GPS receiver outages
- Multiple satellite anomalies (DMSP F16 / MIDORI-2 / CHANDRA / GOES / KODAMA / …)
- NASA ISS operations affected / ***astronauts retreated to service module***
- NASA/NOAA ACE satellite damaged (SW low-energy proton sensor)
- Commercial airlines re-routed / loss of HF comm / ***radiation warnings posted***
- Power outages affected 20,000 Scandinavians / ***multiple power utilities react pro-actively***

Purpose of Work
(top down)

- Evaluate prospects for monitoring, and perhaps instigating, decay of artificial radiation belts.

↑

- Clarify triggering mechanisms for precipitation events in natural radiation belts.

↑

- Associate specific phenomena (solar flares/CMEs, lightning, earthquakes) with ionospheric absorption events caused by particle precipitation from radiation belts.

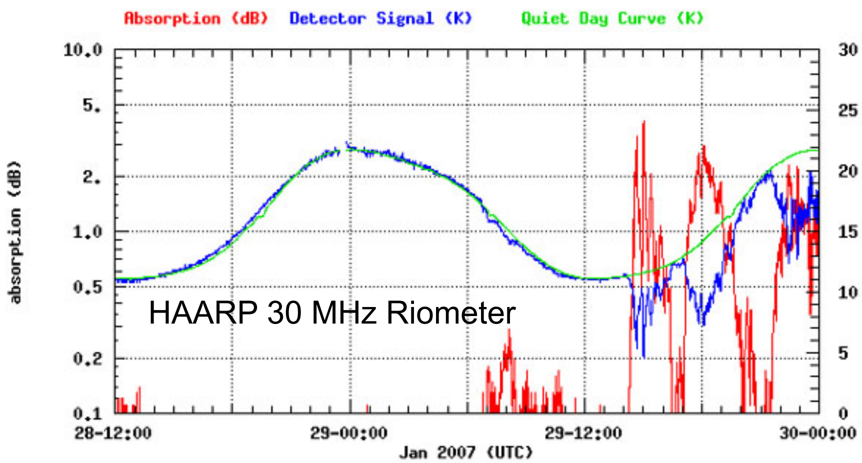
Description of Work
(top down)

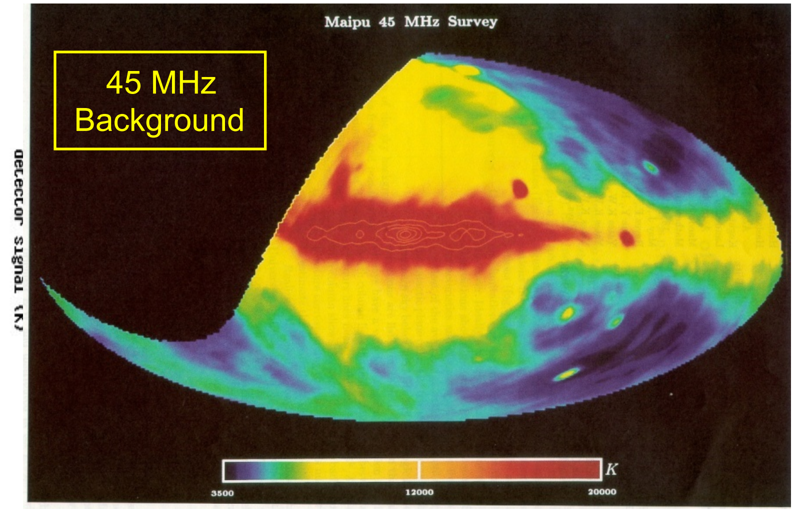
- Correlate solar/interplanetary/terrestrial phenomena with ionospheric enhanced-absorption events.

- Use LWA-1 to acquire synoptic views of ionospheric enhanced-absorption events.

- Augment LWA-1 with small ‘outlier’ at NA to improve performance.

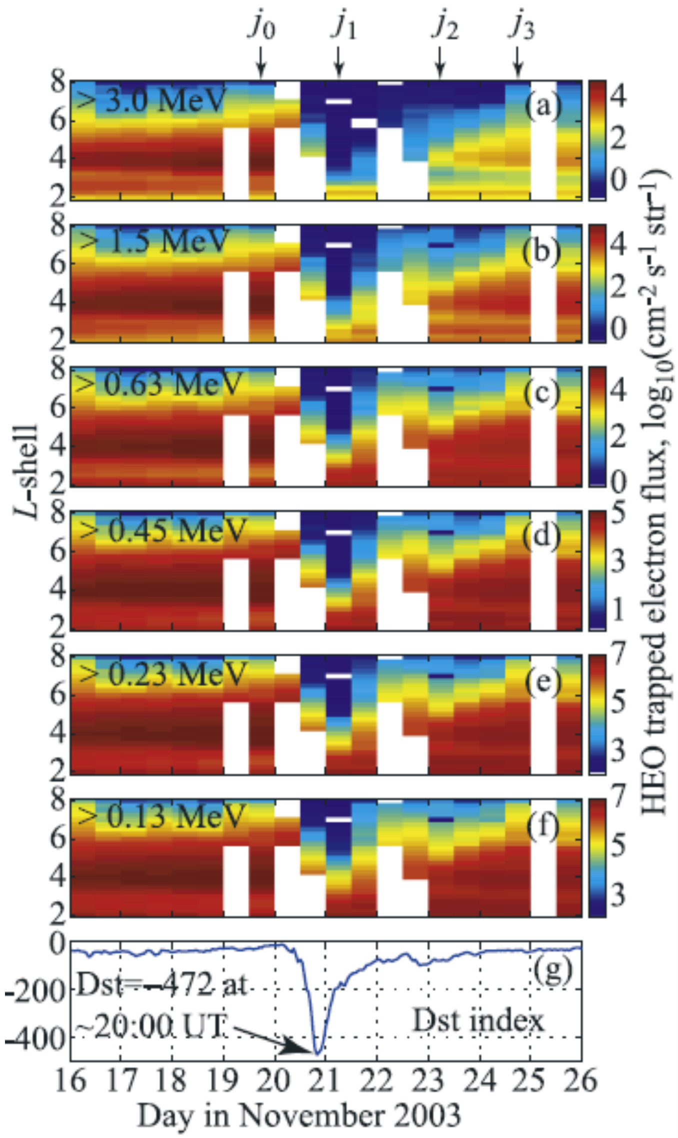
Riometry
(Relative Ionospheric Opacity Measurements)

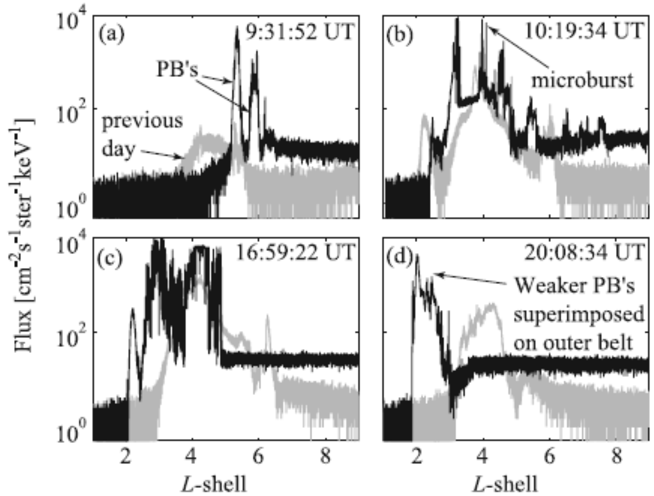




- Relative Ionospheric Opacity
  - Determine 'quiet background level', from sky seen through quiet ionosphere, empirically.
  - Measure deviations from the quiet level: drops due to ionospheric attenuation – enhanced absorption in lower (D-region) ionosphere.
- Absorption events are related to particle precipitation events
  - Magnetospheric perturbations from solar storms/CMEs
  - Lightning-generated whistler-mode waves
  - Seismic events generating ULF/VLF waves?
- Could be done better
  - Calibrated determination of background (and convolution with instrument response)
  - Wide-field simultaneous measurements at multiple frequencies

Correlation of Event with Loss from Radiation Belt



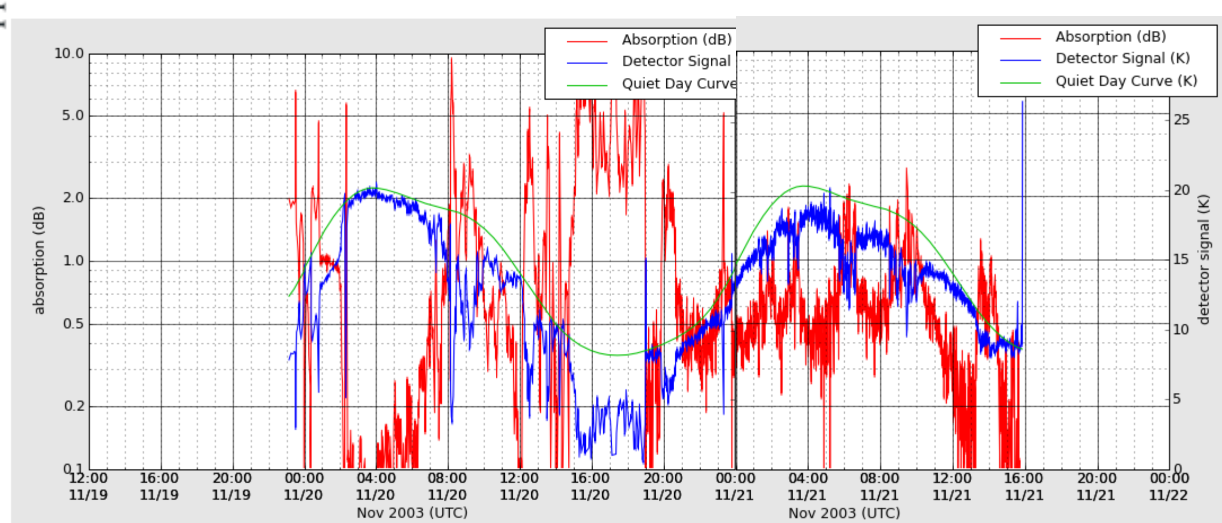


Precipitation actually occurs in bursts.

(Bortnik *et al.* 2006 *JGR*)

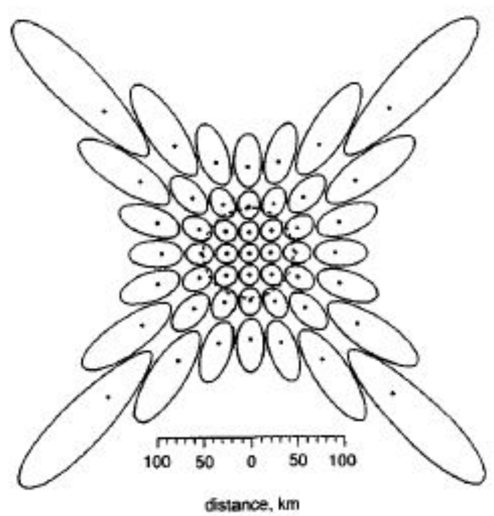
Attempt to match a precipitation event to a riometric event – the 20 November 2003 storm.

HAARP 30 MHz Riometer

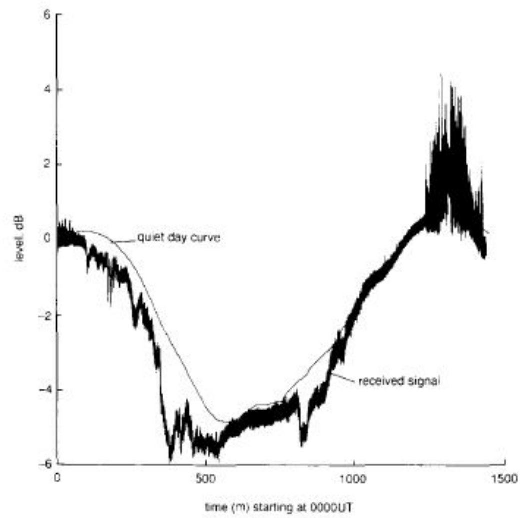


Imaging Riometry

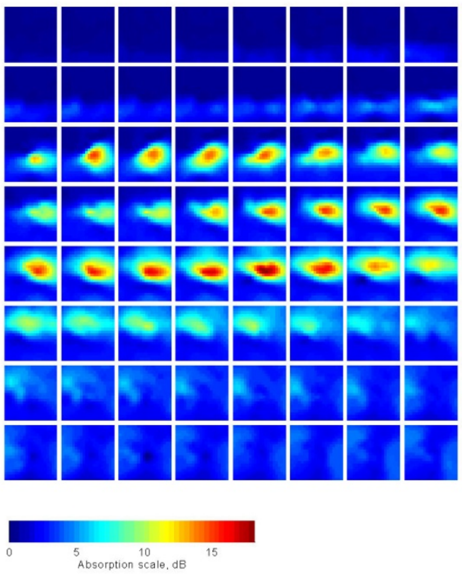
- Traditional imaging riometers use analog beam combination of small arrays.
- They show the onset and evolution of absorption events, although not with much structural resolution.



IRIS 8x8 Array produces 49 beams, here projected to 90 km altitude



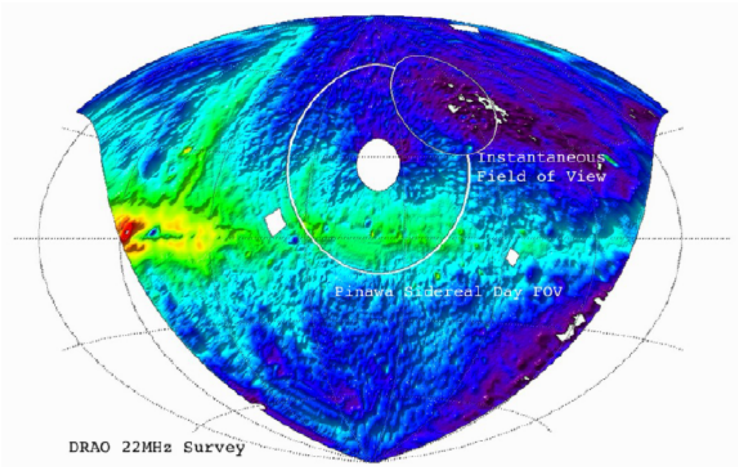
Single-beam measurements at Kilpisjärvi; Frequency = 38 MHz



7x7 maps of evolving absorption event at Kilpisjärvi – note that, even with this resolution, there is much structure.

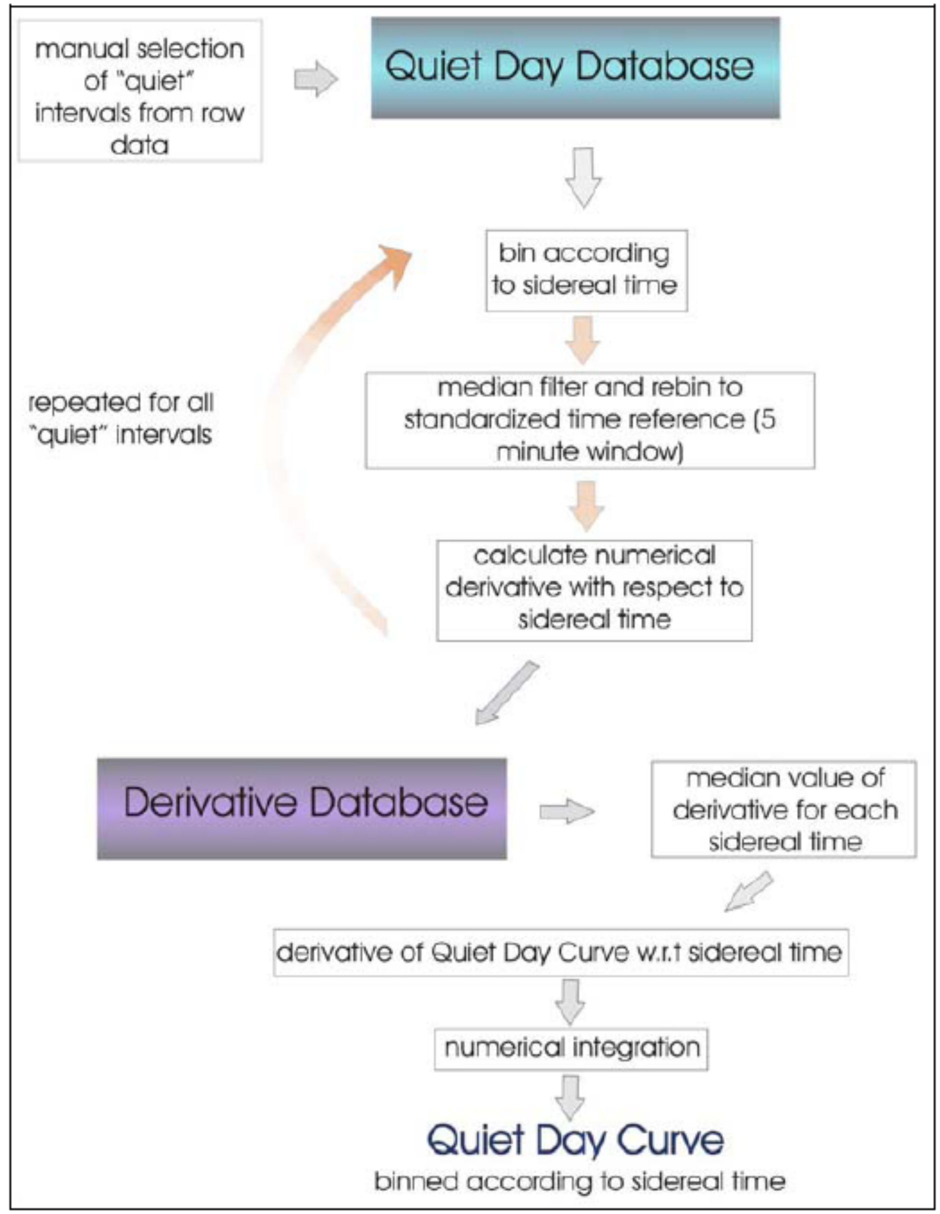
Current Riometric Methodology

U. Calgary scheme for CANOPUS riometers



DRAO 22 MHz Galactic Survey (courtesy of Tom Landecker). The sidereal day path of the Pinawa riometer (large circle), along with the instantaneous FOV (small circle).

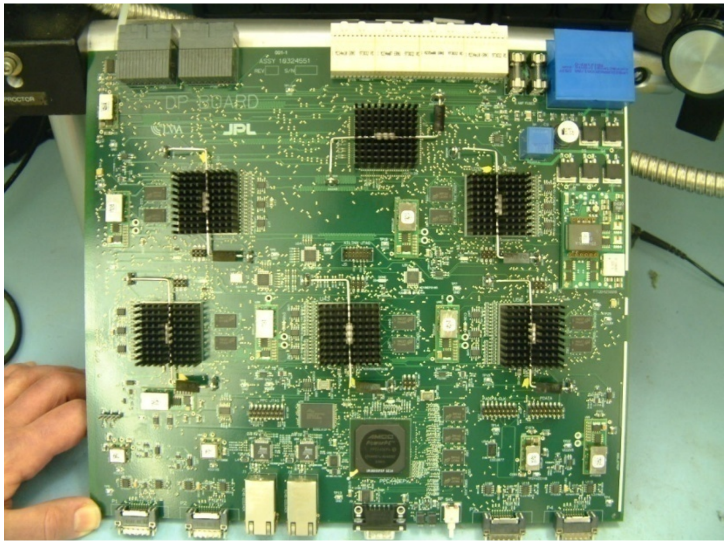
- Empirical derivation of "Quiet Day Curve is quite complicated.
  - Requires lots of data so that RFI and solar bursts can be edited out.
  - Can be improved by expanded spectral coverage, in the sense that one could implement automated identification and removal of RFI and typical bursts. But that's more software to do.



Digital Processing Advantages

- **12-bit x 196 MSPS digitization**
  (“direct sampling” architecture)
  – Sample rate selected to alias FM broadcast band onto itself
- **Output Modes**
  (available simultaneously)
  – Digital Receiver (DRX): 4 beams (x 2 pol x 2 tunings x 19 MHz, with 4096 channels/beam)
    - Full RF delay & sum beamforming, including subsample “fine” delays

  – Wideband Transient Buffer (TBW): Full RF from all 512 antennas in a 57 ms-long burst
  – Narrowband Transient Buffer (TBN): 100 kHz from all 512 antennas, continuously in time



One of 26 ATCA-based “DP” boards
5 Xilinx XC5VSX50T FPGAs

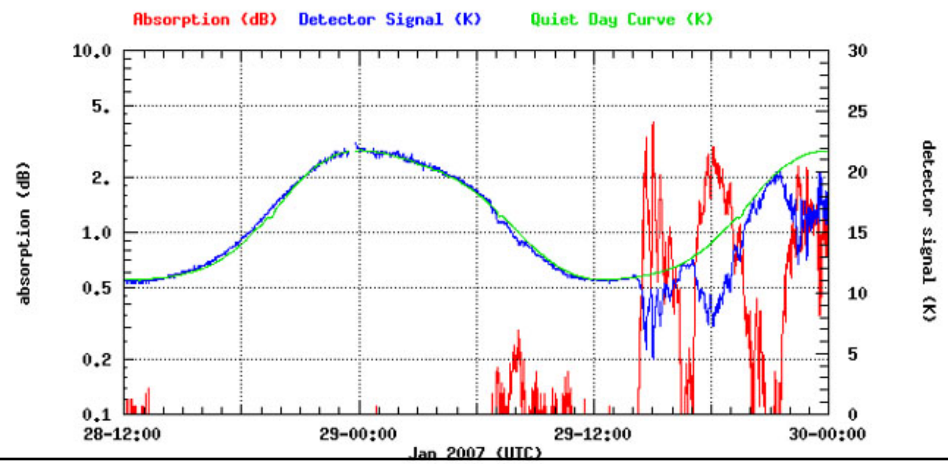
Enable correlation of all station antennas to produce ‘all-sky’ images.

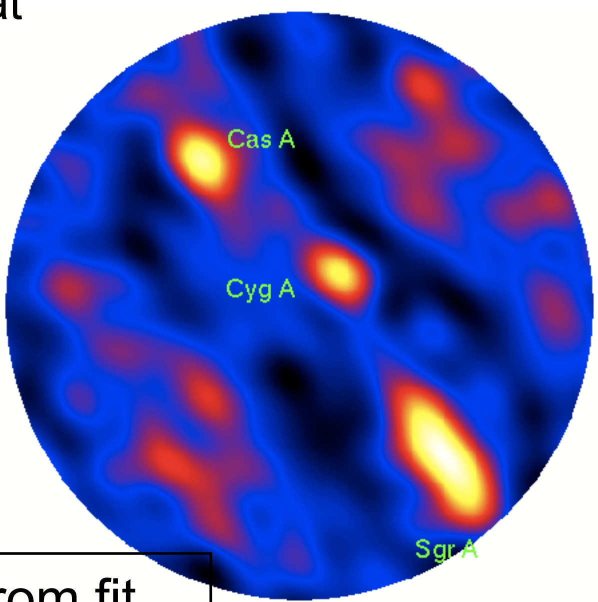
TBN Analysis Scheme

TBN → Edit; mask → Fit: $T_{sky} = \tau_o(\text{ionosphere})\,sec(\text{z.a.})\,T_{sky\ model}$

time-variable

Assume instantaneously flat ionosphere over station





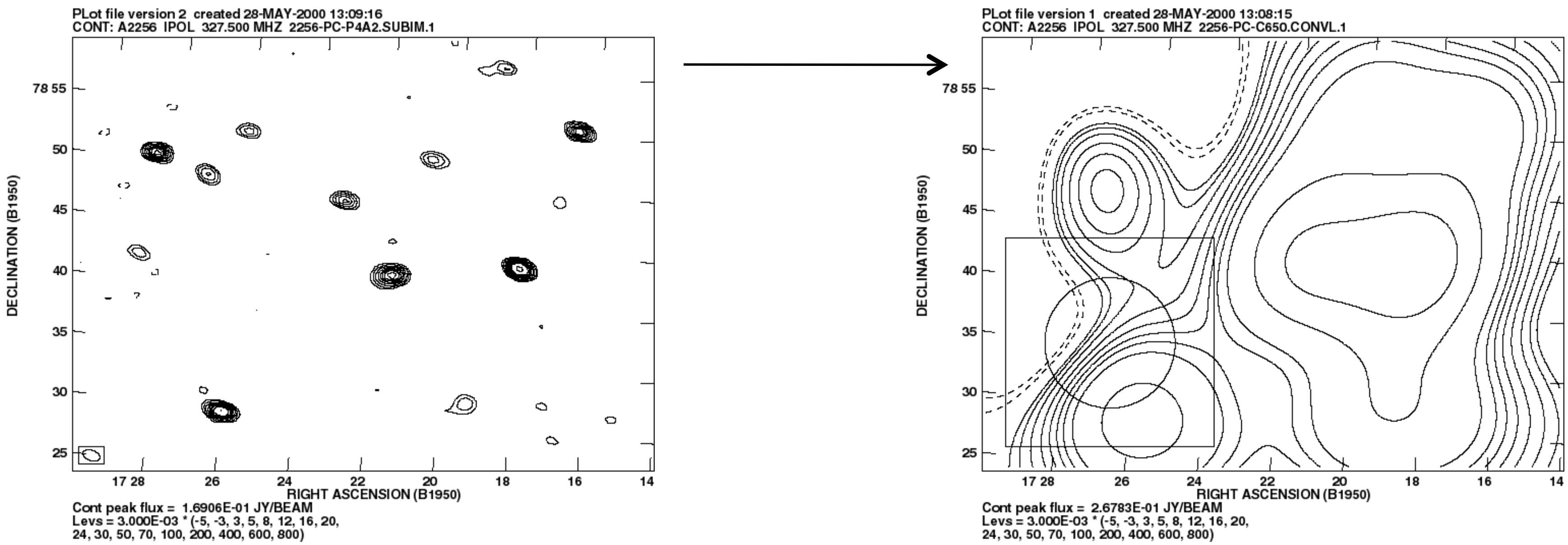
Absorption events should be obvious deviations from fit.

Low Angular Resolution Limits Sensitivity Because of Source Confusion

$\theta \sim 8^{o}\ (20\ \mathrm{MHz}/\nu)$

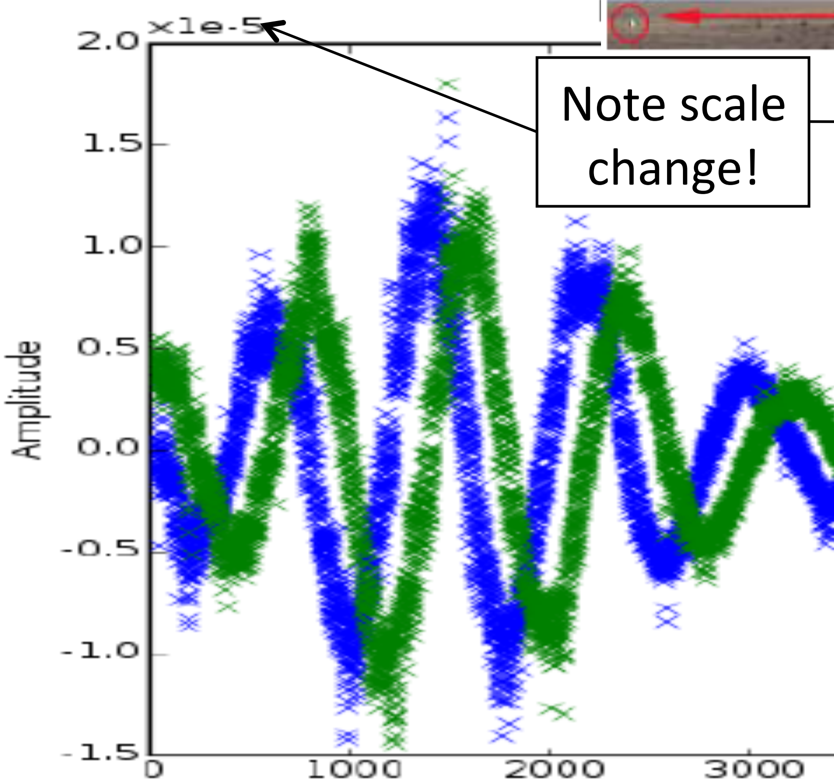
confusion rms ~ 25 Jy/beam at 74 MHz at zenith

So TBN @ 100 kHz will reach confusion limit in 80 msec.

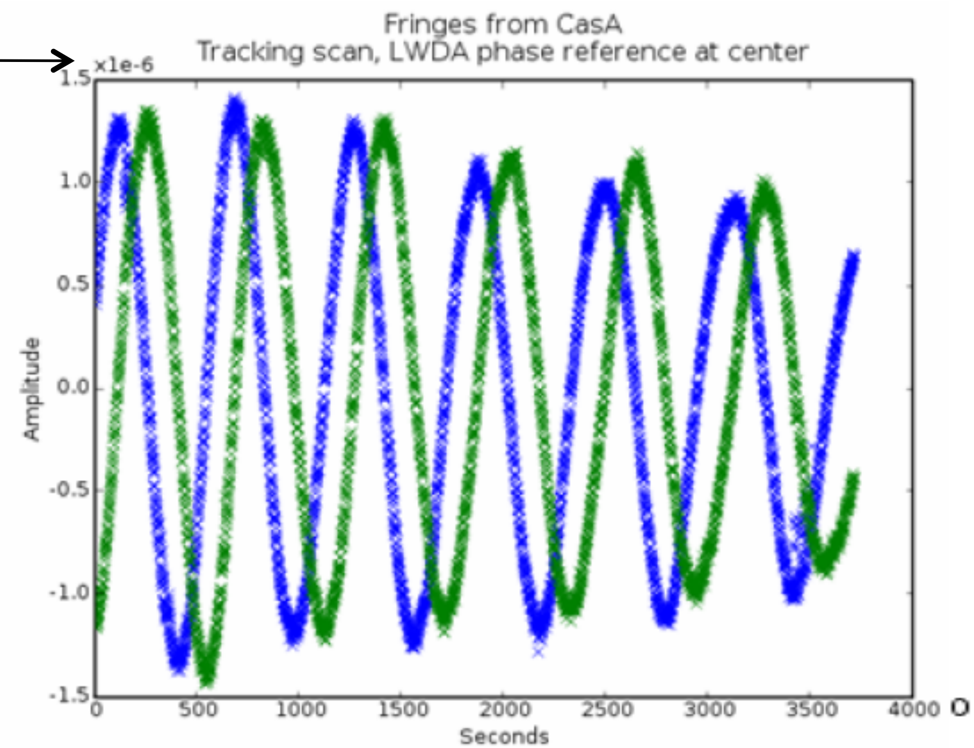


Use of 'Outrigger' Improves SNR

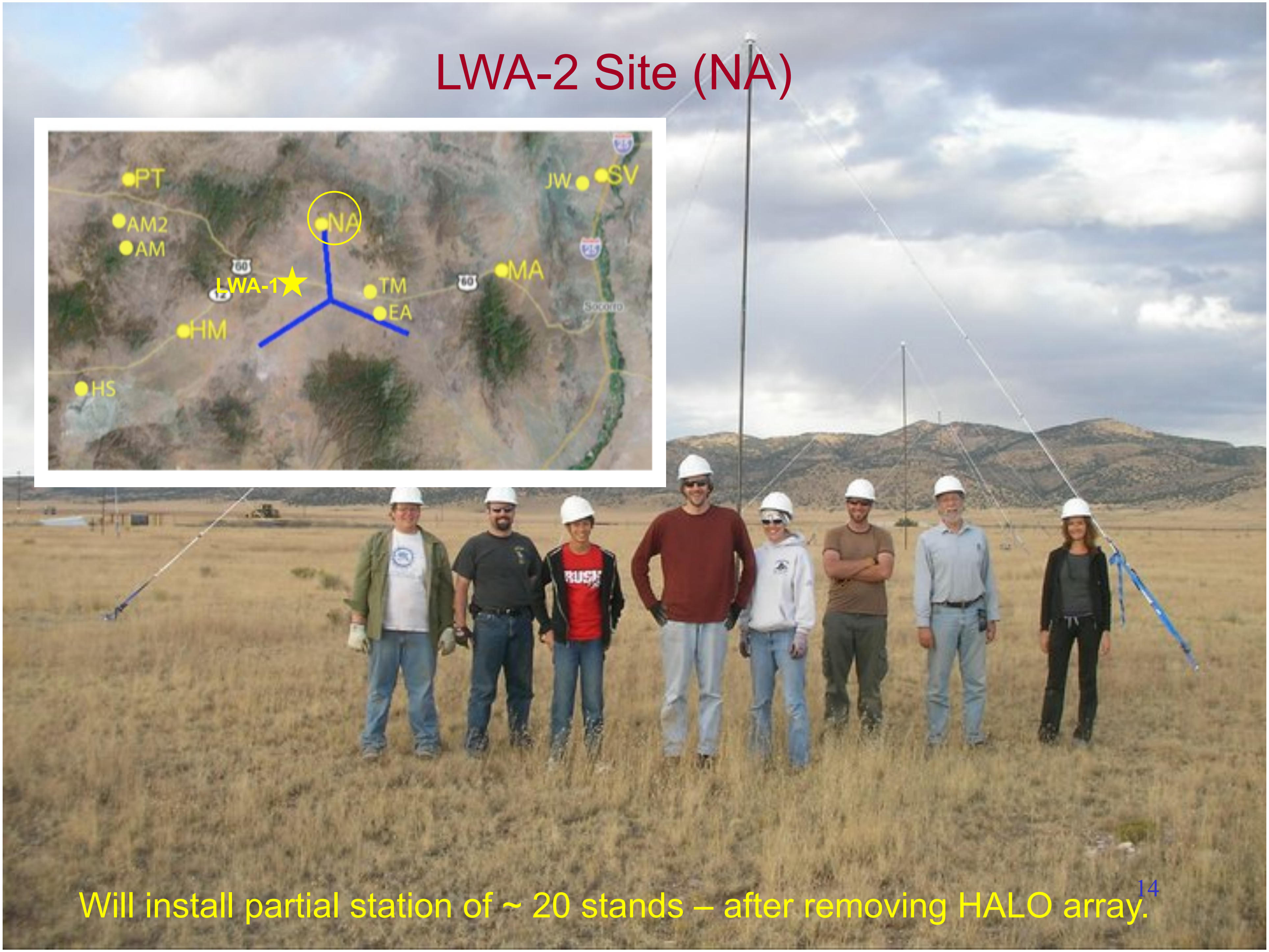
(demonstration array built by NRL and UT/ARL)



Note scale change!

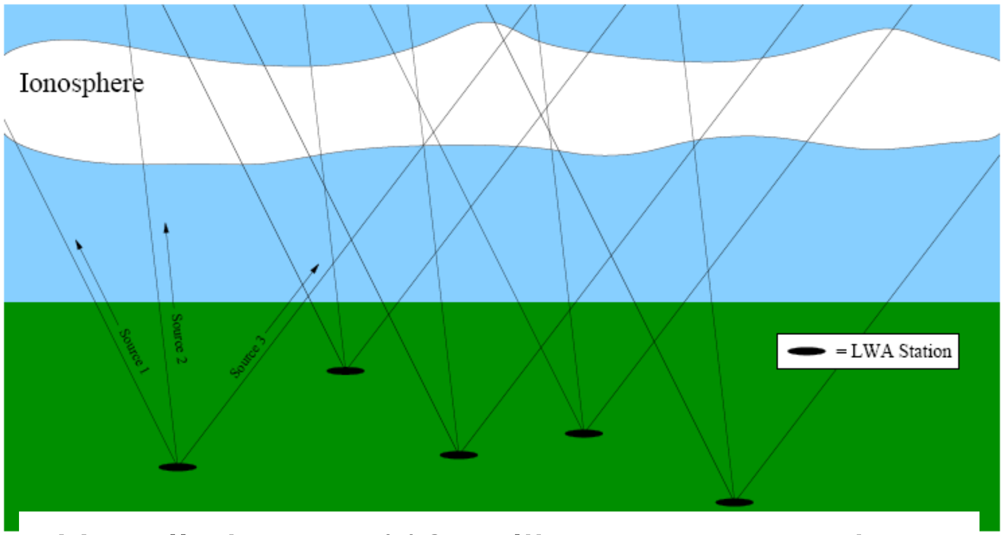


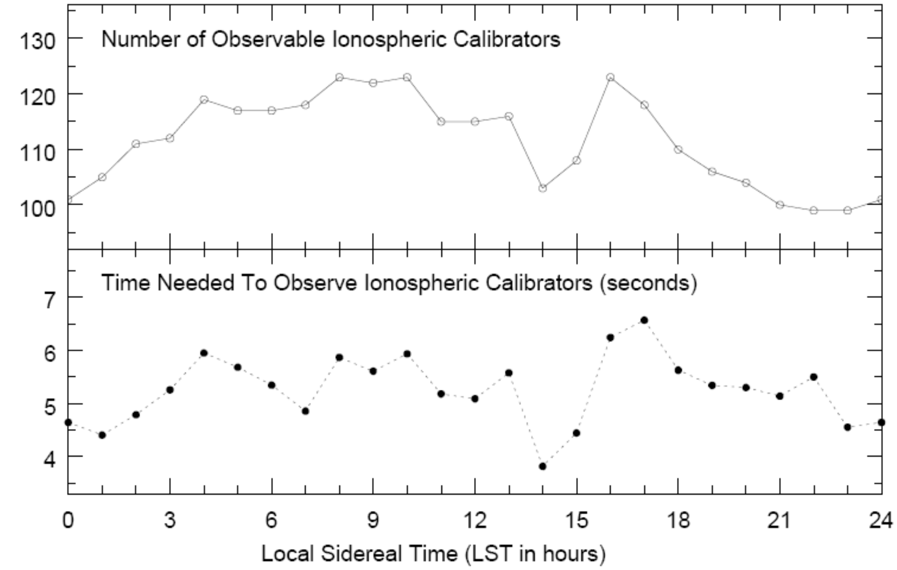
LWA-2 Site (NA)



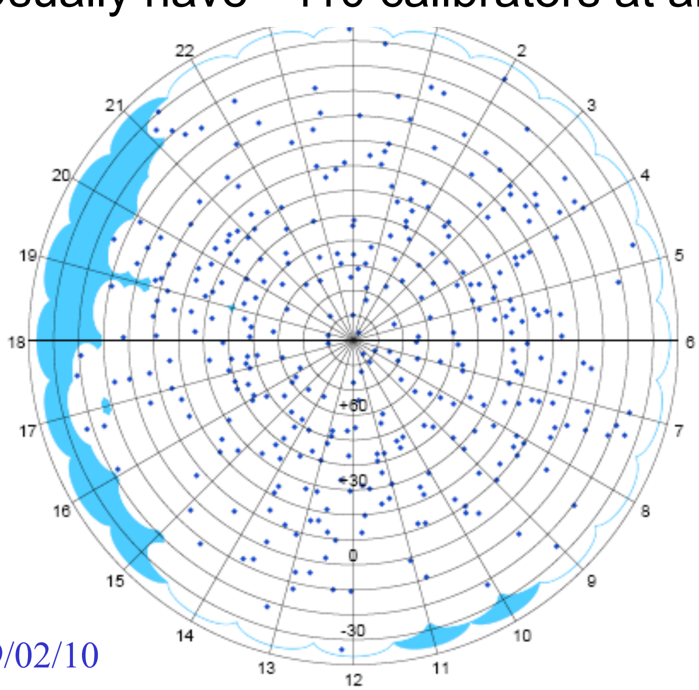
Will install partial station of ~ 20 stands – after removing HALO array.

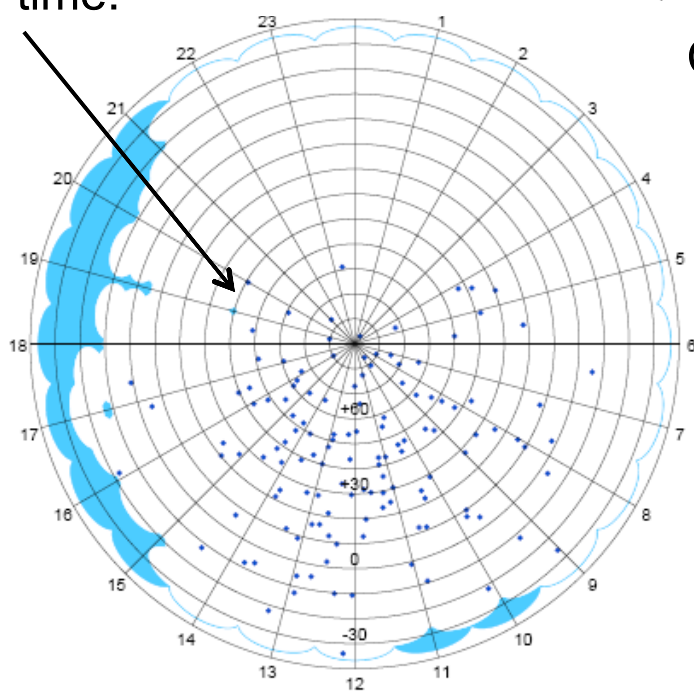
LWA-1 Calibration by 'Flickering'





Usually have ~110 calibrators at any time.





Can cycle through in ~ 6 sec with ~50 msec per calibrator.

Can thus do calibration of multiple lines of sight to derive absorption.

Summary Task Description

- Task 1: Acquire baseline hardware, primarily for outrigger.
- Task 2: Develop riometric analysis for TBN data.
- Task 3: Collect riometric data (a continuing operation).
- Task 4: Install outrigger.
- Task 5: Develop software for correlating LWA-1 with outrigger.
- Task 6: Develop riometric analysis for beamed data.
- Task 7: Collect beamed riometric data.
- Task 8: Validate riometric data and correlate with phenomena reported by other systems.