

Instrumentation and Digital Signal Processing Topics From Passive Radar and Radio Astronomy

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Outline



- Passive Radar Data
 - Nulling, Stability, Mobility
- Radio Astronomy
 - Interferometry, Dirty Beam
 - Single Dish
 - Phased Arrays

Motivation



- Passive Radar is stealthy, cost-effective and uses transmitters of opportunity



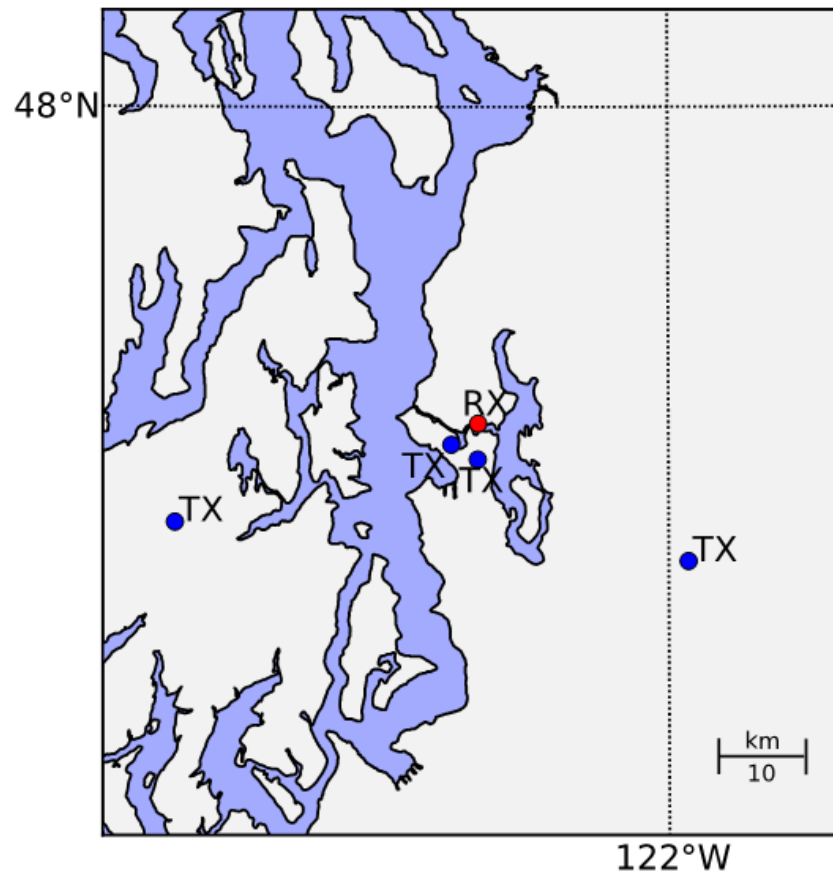
- Receivers combine these signals to detect ground clutter, aircraft, coastline ship traffic, meteor trails, the aurora, and security surveillance

Focus of initial experiments

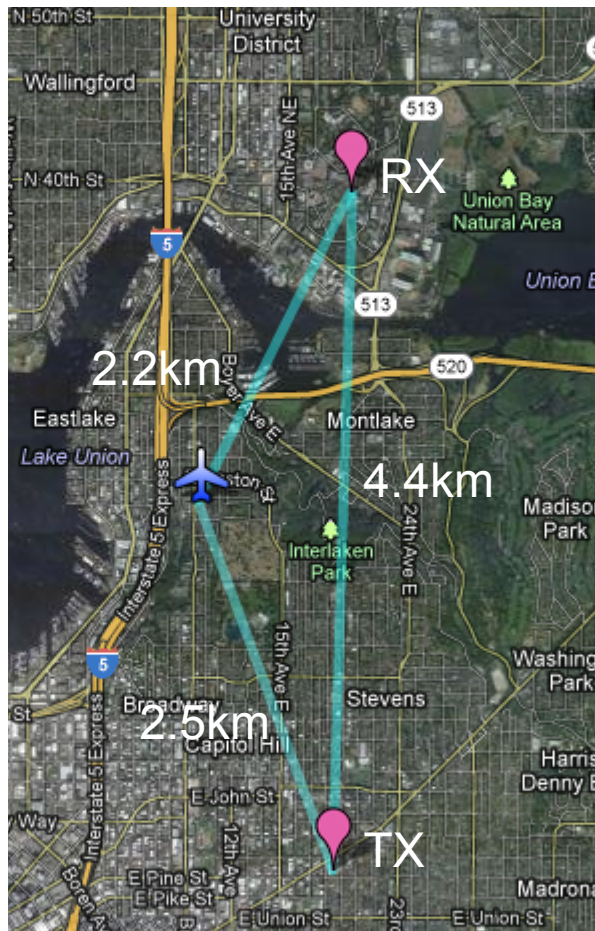


- DTV for aircraft detection

DTV Transmitters in Seattle and Surrounding Area

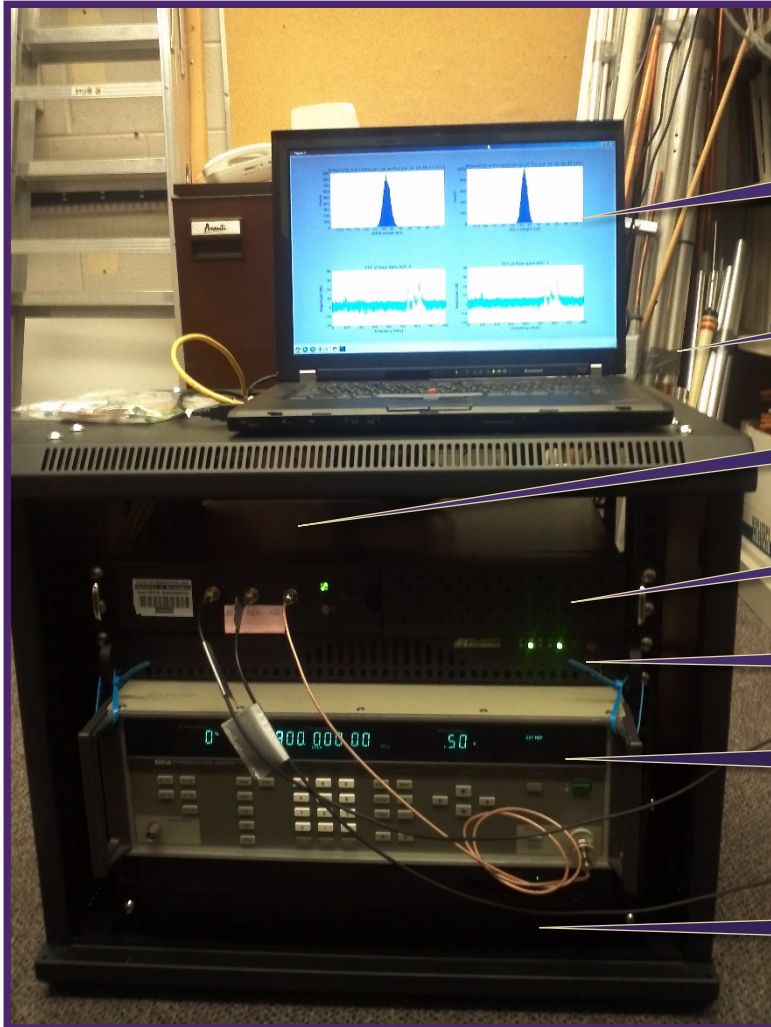


The SCR and Dynamic Range



- Isolation of transmit and received signal
 - Monostatic, time separation
 - Manastash Ridge Radar, geographic separation
 - New system: computational separation
- We are **not limited by noise**, but by the large signal strength of the direct path propagation from the transmitter – the largest clutter component in our received signal
- After digitizer: using estimates for DTV, aircraft, 50 ohm load, 126 MHz analog BP filters
 - SCR = -85 dB ← DR must exceed 85 dB
 - Quant. Noise Power -47.2 dBm
 - To compete with $q \approx 25 M K$ is analog system temp must be

Passive Radar Receiver using ROACH



Laptop for control and Real-Time display

12 U, 18" Rack

Inputs: 4 RF, 1 Sample Clock

ROACH with 2 KATADCs

"Thorex" host computer, absorbs data via 10Gbe, SSD

800 MHz from sig. gen. (replaced by oscillator)

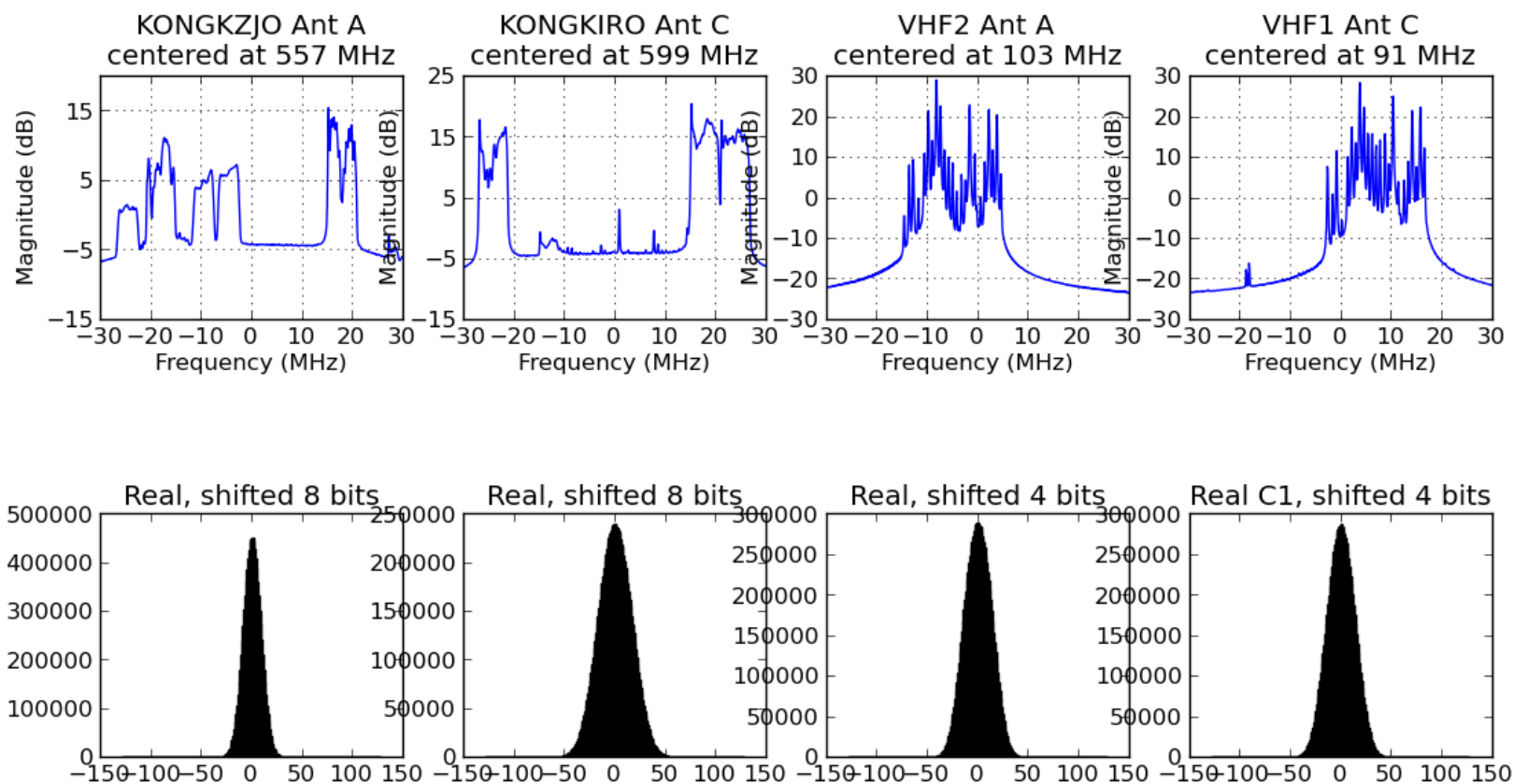
UPS for mobile operation
~50min operation (50 pounds)

Intro

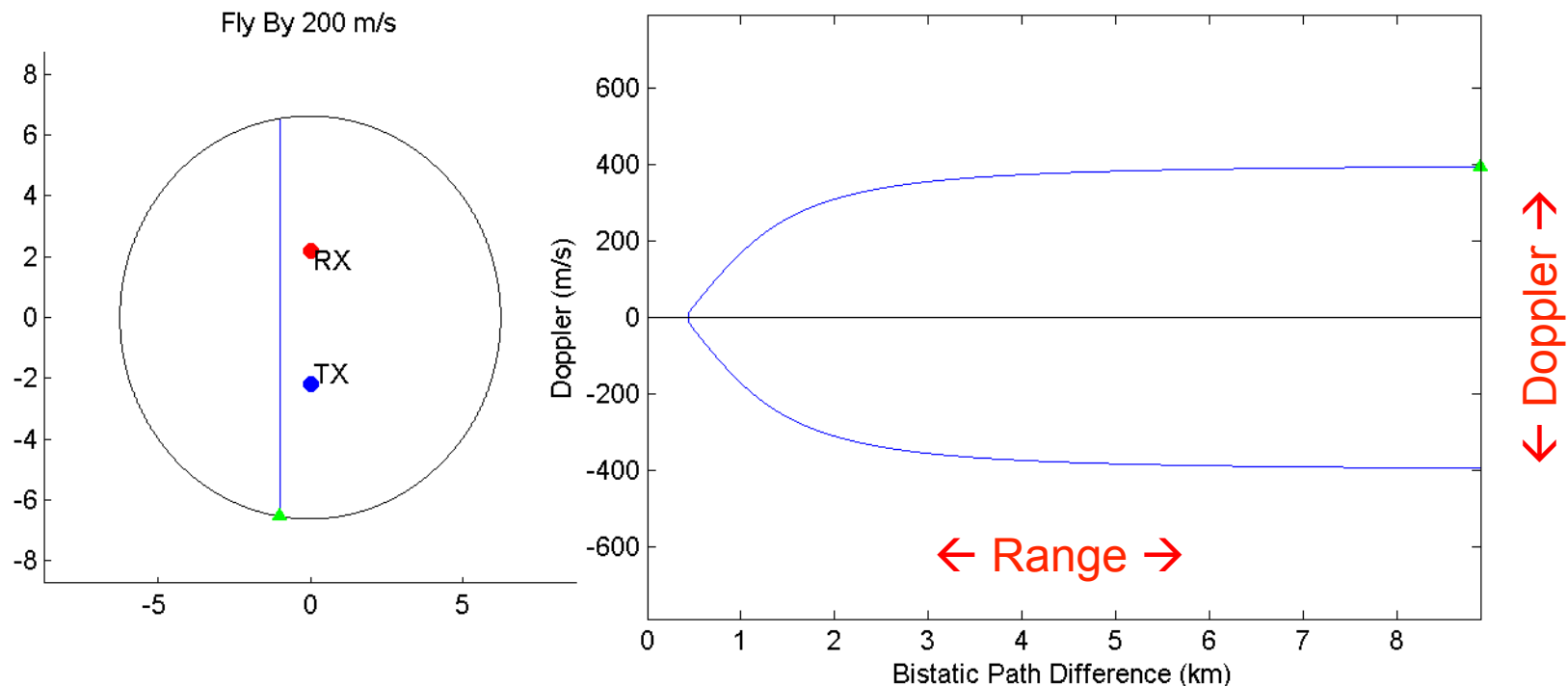
Design

Results

1.6 GSps, digital split to VHF and DTV



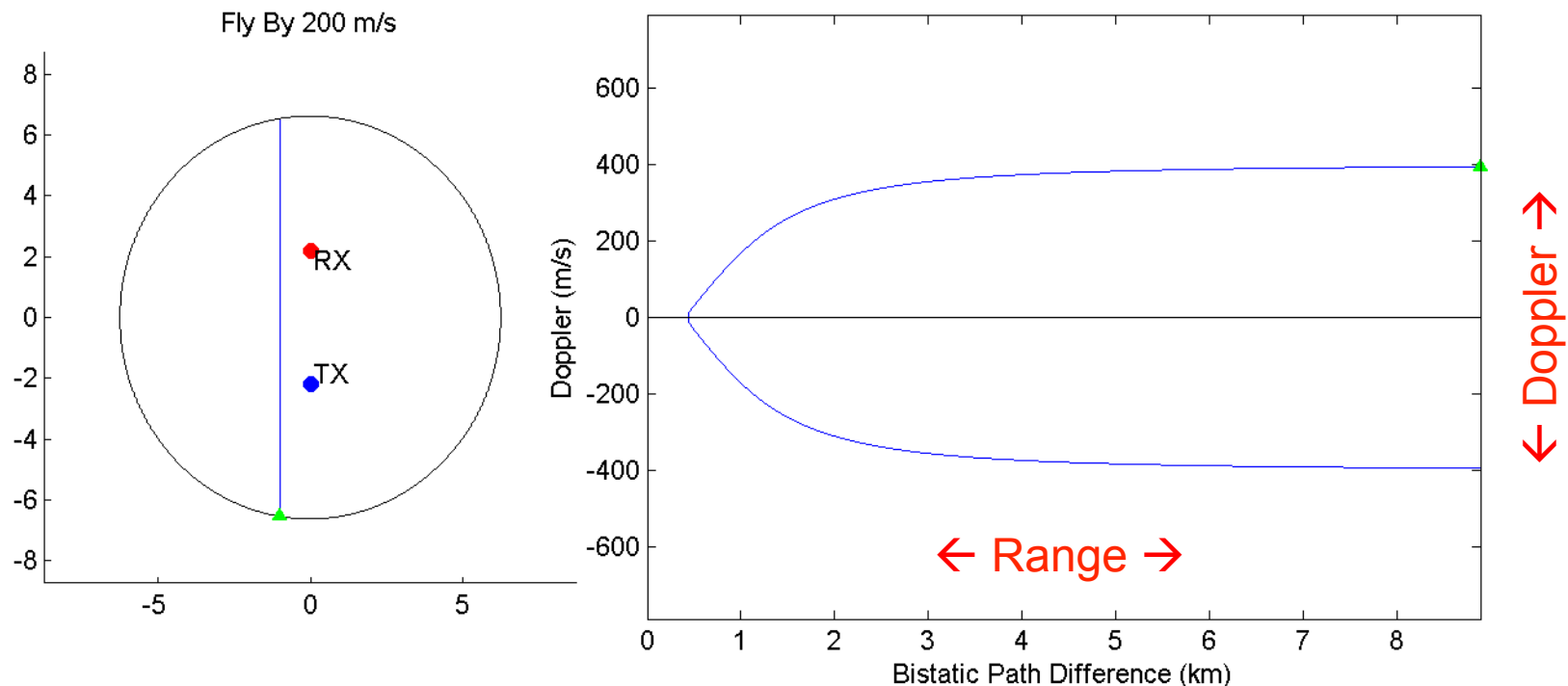
Demo of range and doppler



Range begins large, still has a positive minimum range, then travels back out, symmetry

Doppler shift large and positive, indicating coming towards us, goes to 0 at closest approach, and then goes negative

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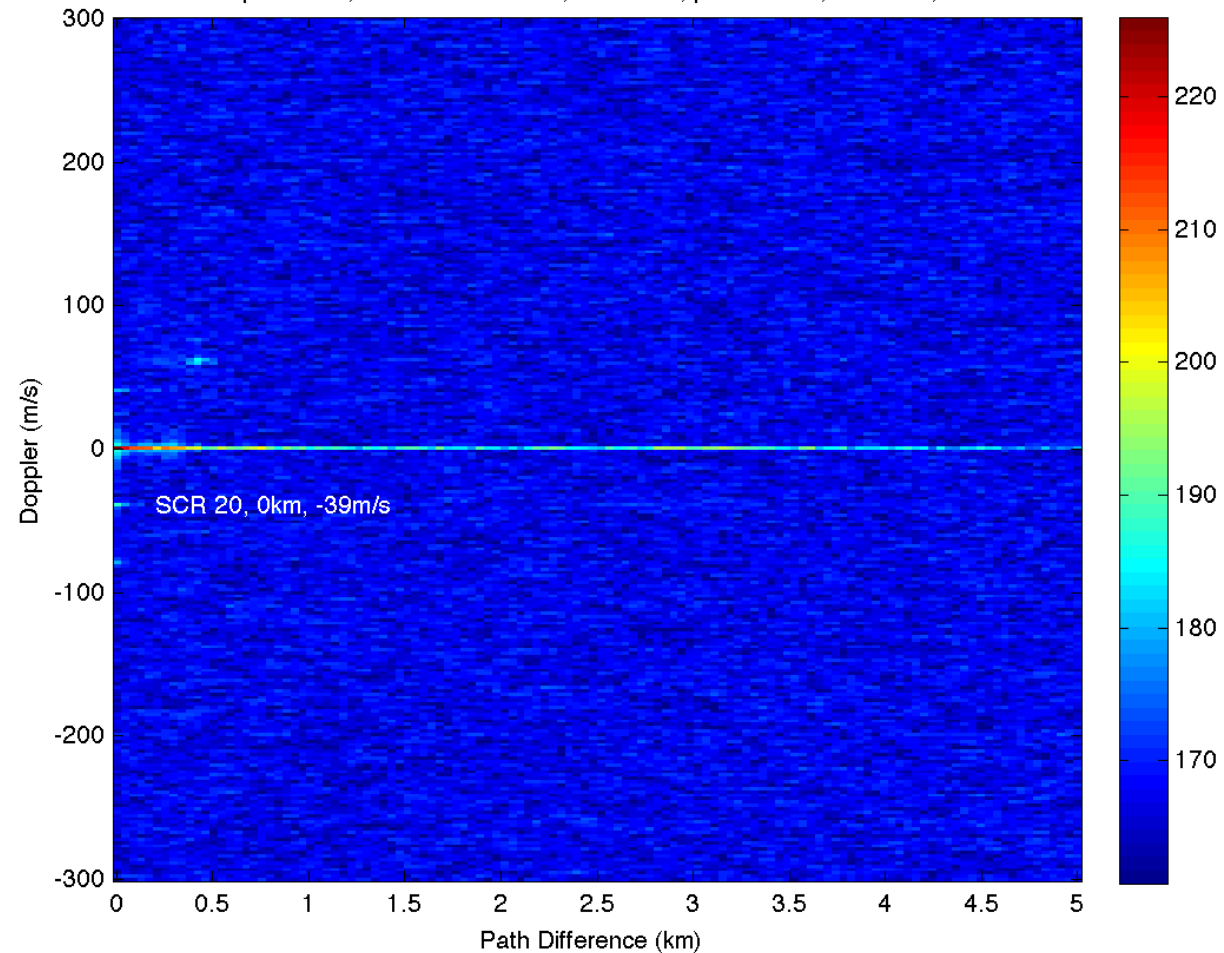
Stationary detection of Helicopter

9 s of data, 1s per frame, 40s to compute a single frame

Cross part 1: 1s, total int time 0.24s, 6626 dec, peak = 226, floor 167, DR 59

KZJO no nulling

We had noticed a
 helicopter flying
 from South to
 North, about to
 fly right over
 receiver at the
 UW



Stationary detection of Helicopter

9 s of data, 1s per frame, 40s to compute a single frame

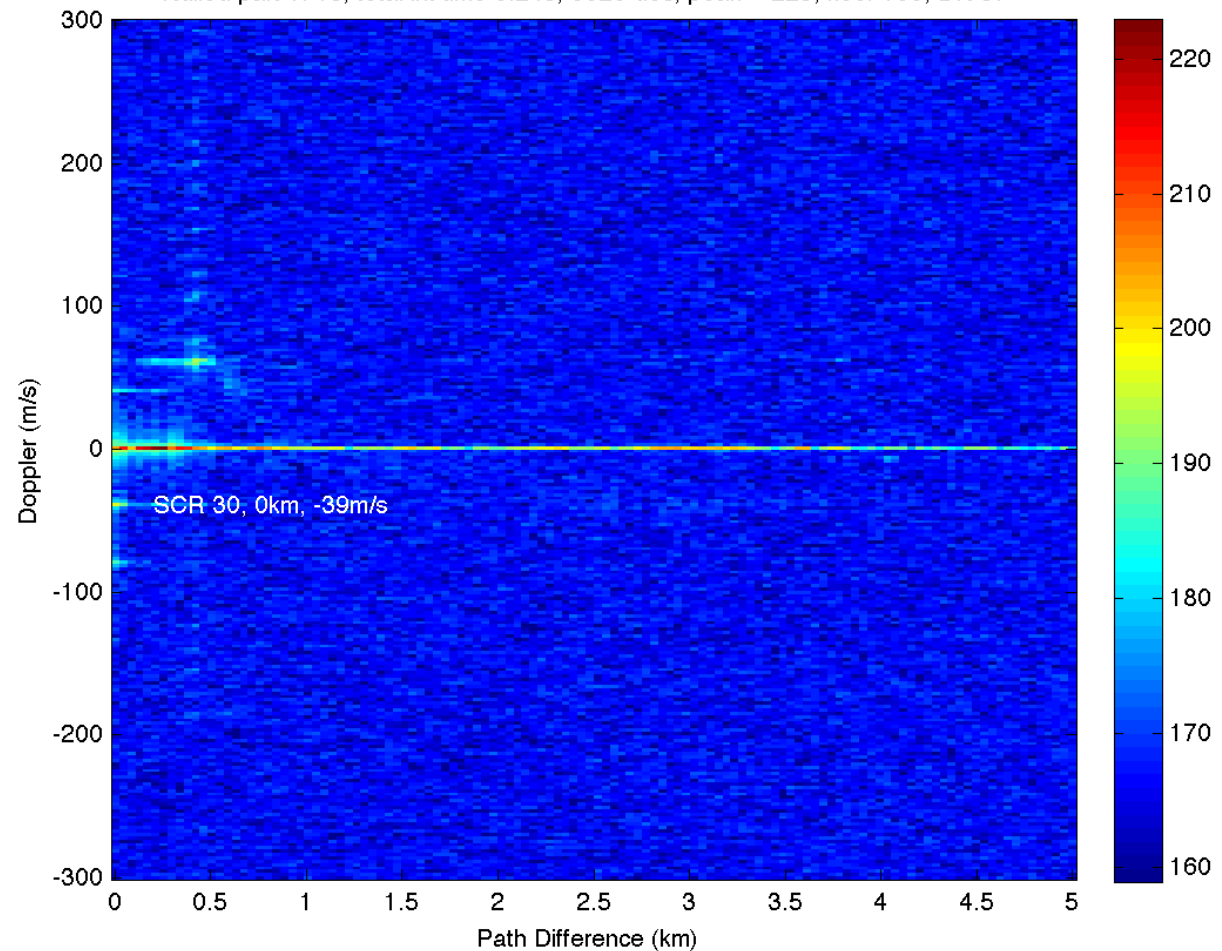
Nullled part 1: 1s, total int time 0.24s, 6626 dec, peak = 223, floor 166, DR 57

KZJO with nulling

Blade modulation
of helicopter

5m blade, 55 cm
wavelength ~ 10
Lambda

Other targets
emerge



Mobile Data



Intro

Design

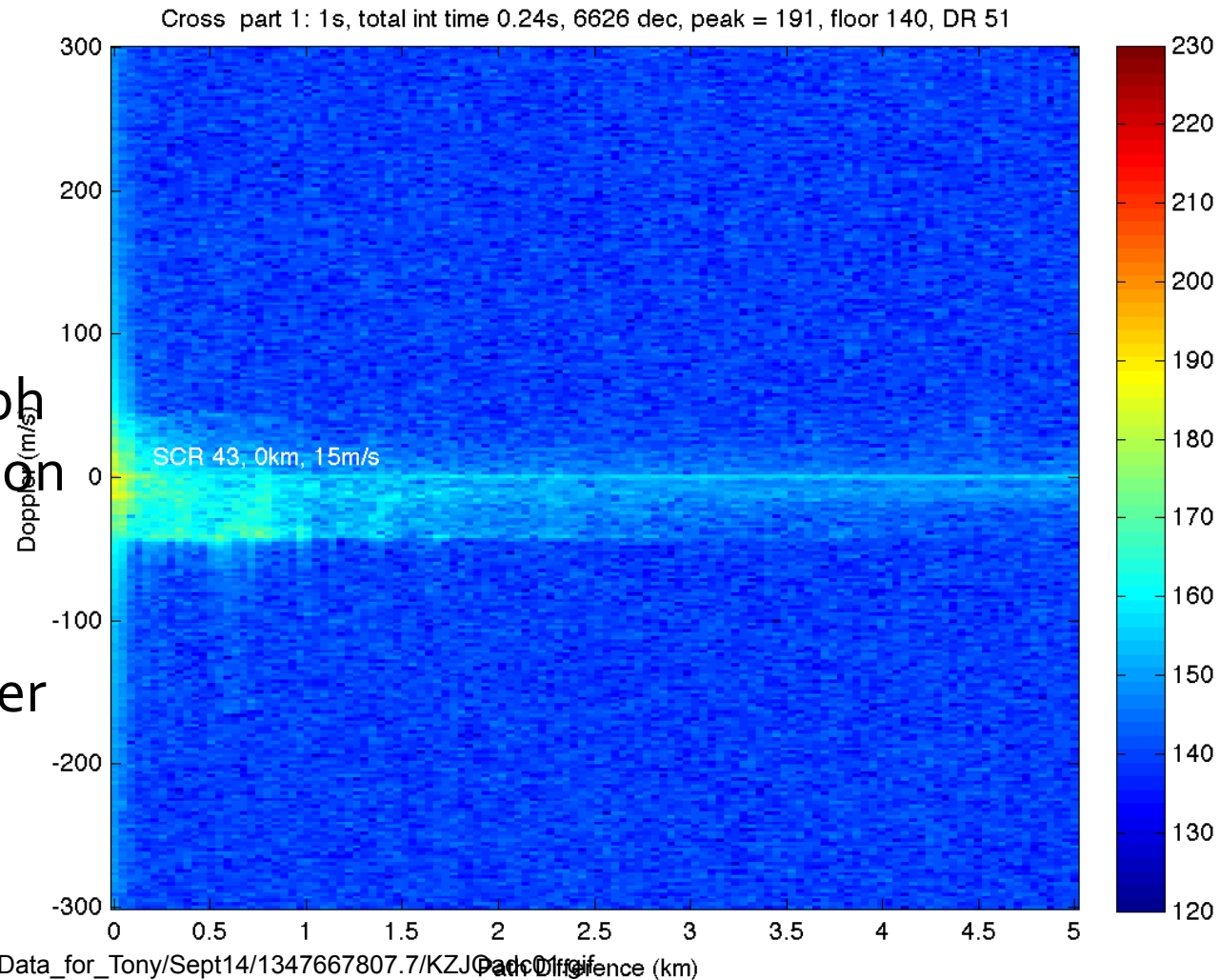
Results

Mobile Data



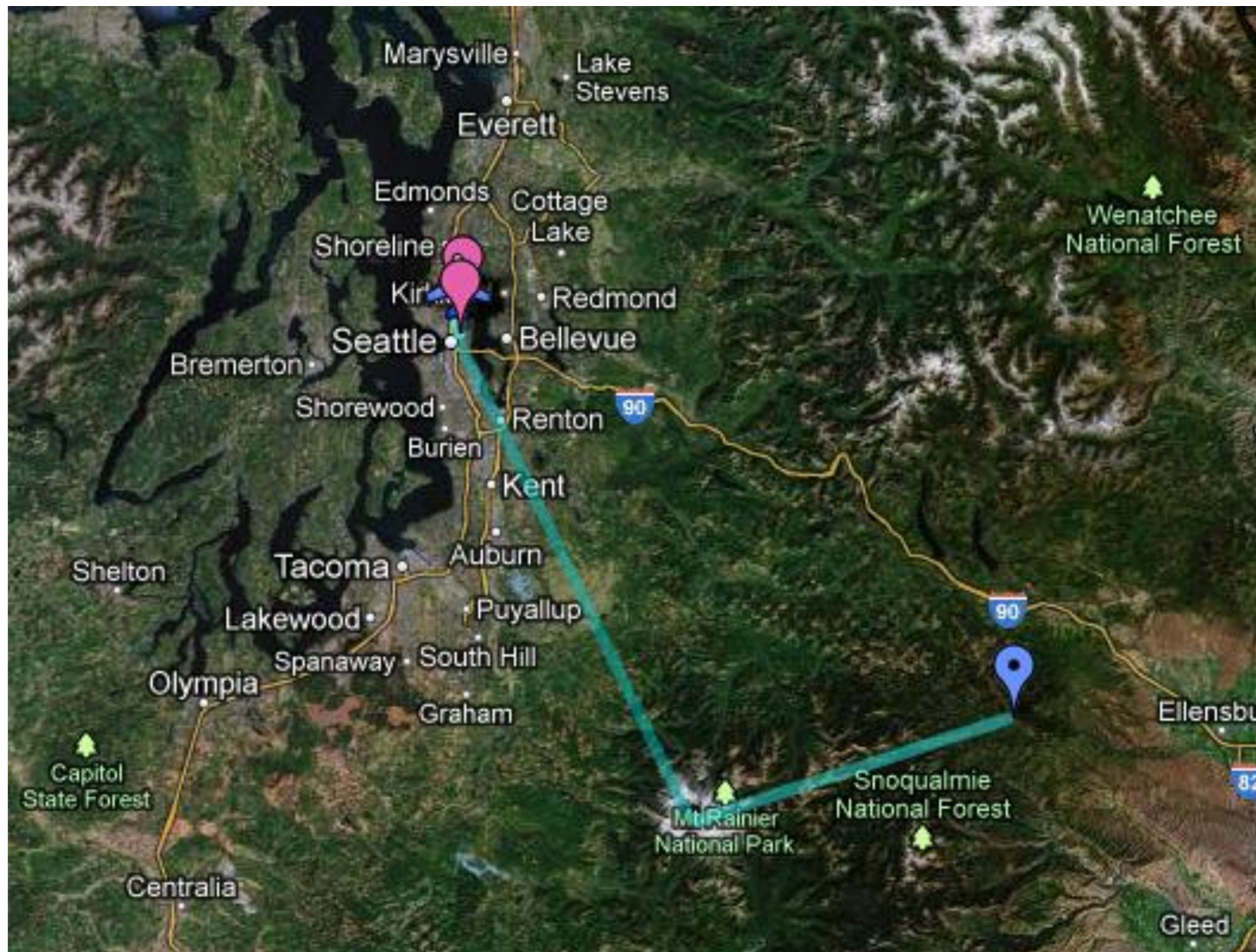
KZJO, with
transmitter
nulling

38s of data
moving ~60 mph
southbound on
I-5, about 10
km north of
the city center



http://rrsl.ee.washington.edu/Data_for_Tony/Sept14/1347667807.7/KZJO_Pad01.gif

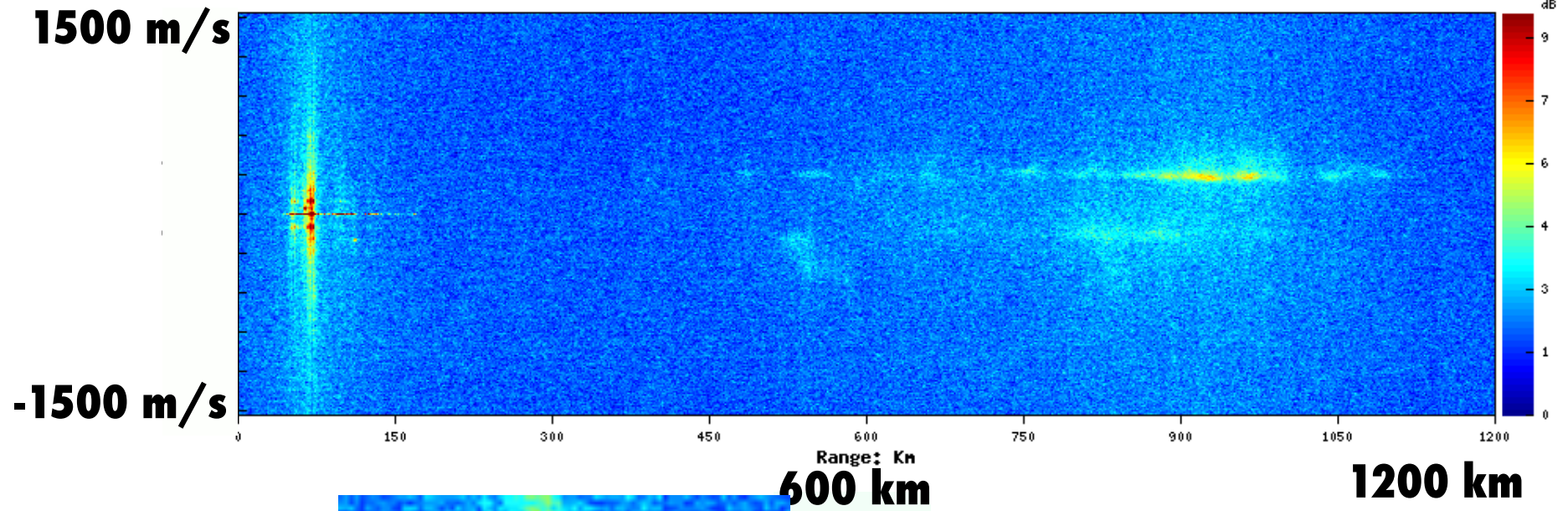
Distributed, Receiver over Mtns



MRR example



UT20031029_102300_F965_D560_B100_u0_h1



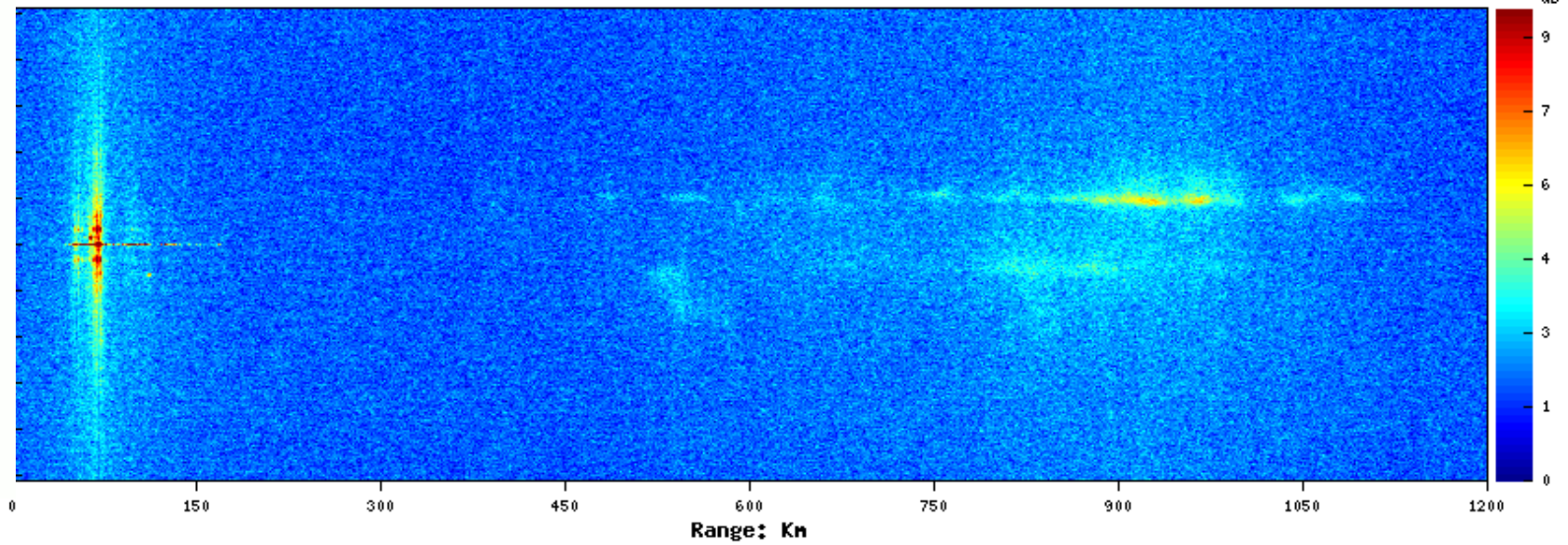
Ground clutter

airplanes

00 m/s



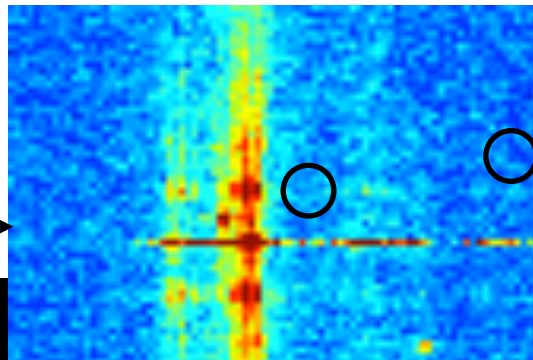
UT20031029_102300_F965_D560_B100_u0_h1



1500 m/s

600 km

Ground clutter

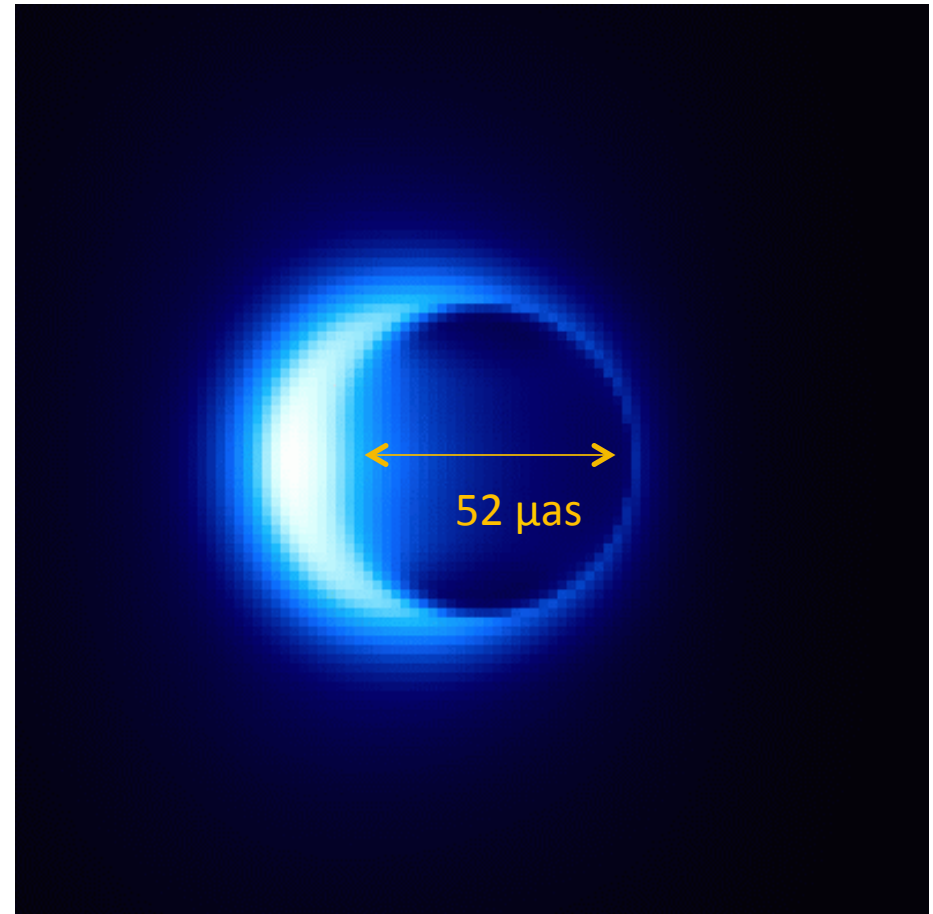


airborne

Black Holes

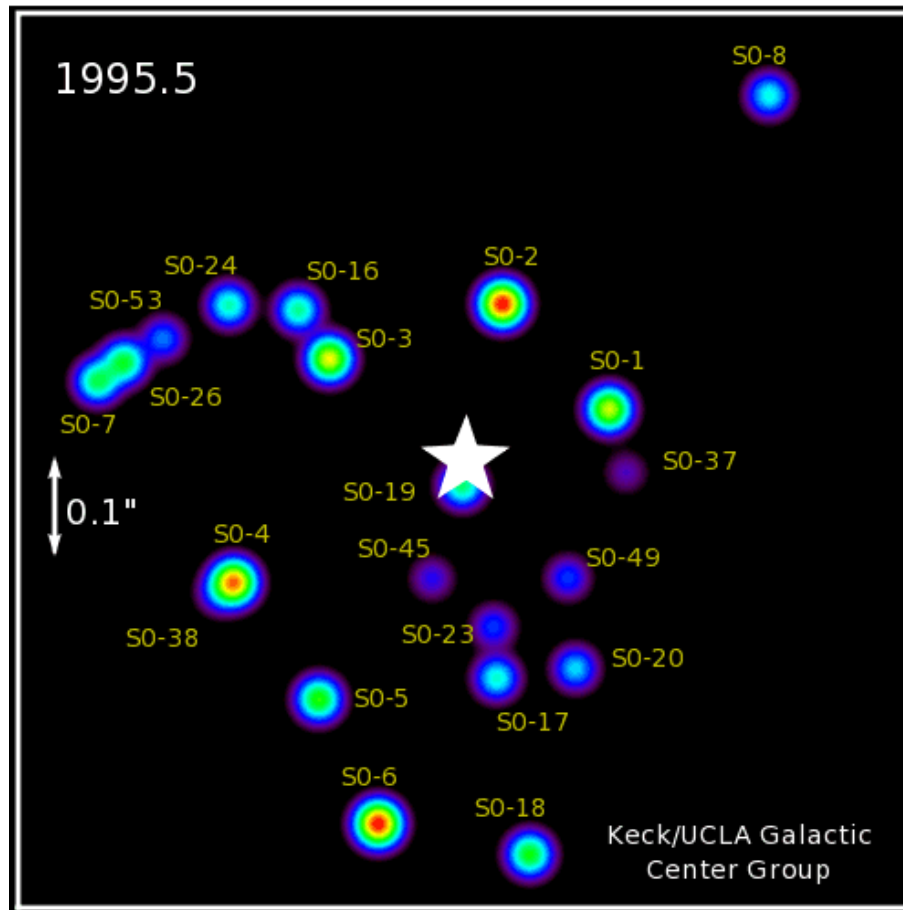


- Supermassive black holes are thought to be found at the center of galaxies
- Observations of a black hole on the angular scale of the event horizon is a long-standing challenge in astrophysics that the EHT intends to meet
- Black hole candidates with large enough angular scale (tiny!) to observe are found at Sgr A* and M87
- Shadow the size of an orange sitting on the surface of the moon

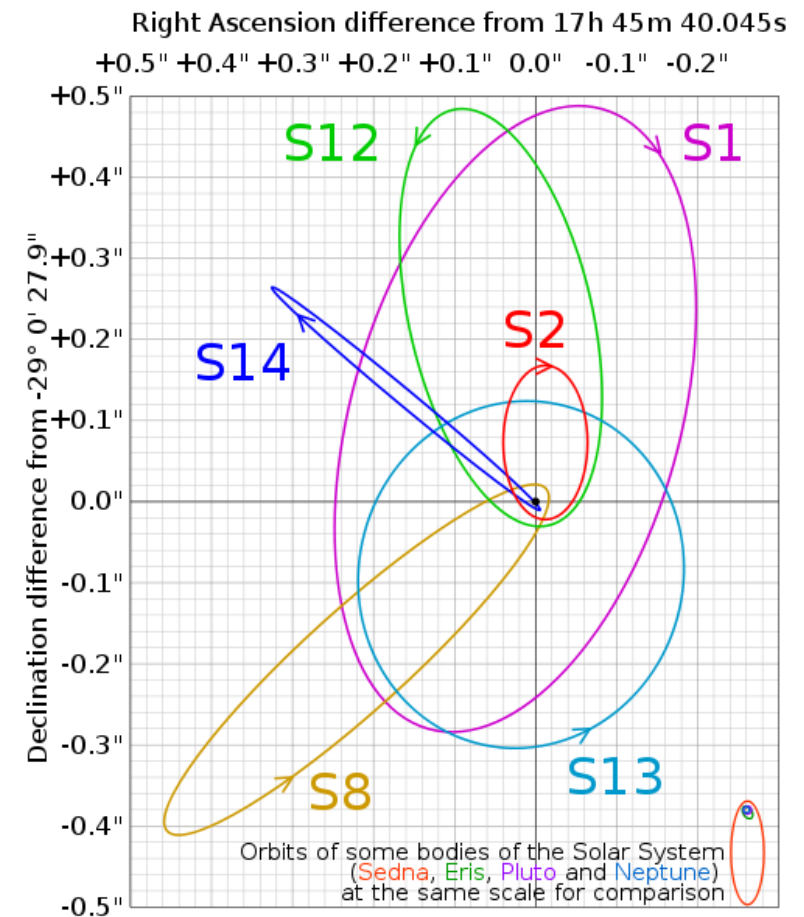


courtesy D. Psaltis and A. Broderick: http://www.eventhorizontelescope.org/science/general_relativity.html

Case for the Galactic Center



Animation showing the orbits of stars around the black hole at the center of our galaxy (marked with a star). Images/animations created by Prof. Andrea Ghez and her research team at UCLA and are from data sets obtained with the W. M. Keck Telescopes.



Eisenhauer, Frank, et al. "SINFONI in the Galactic center: young stars and infrared flares in the Central Light-Month." *The Astrophysical Journal* 628.1 (2005): 246.

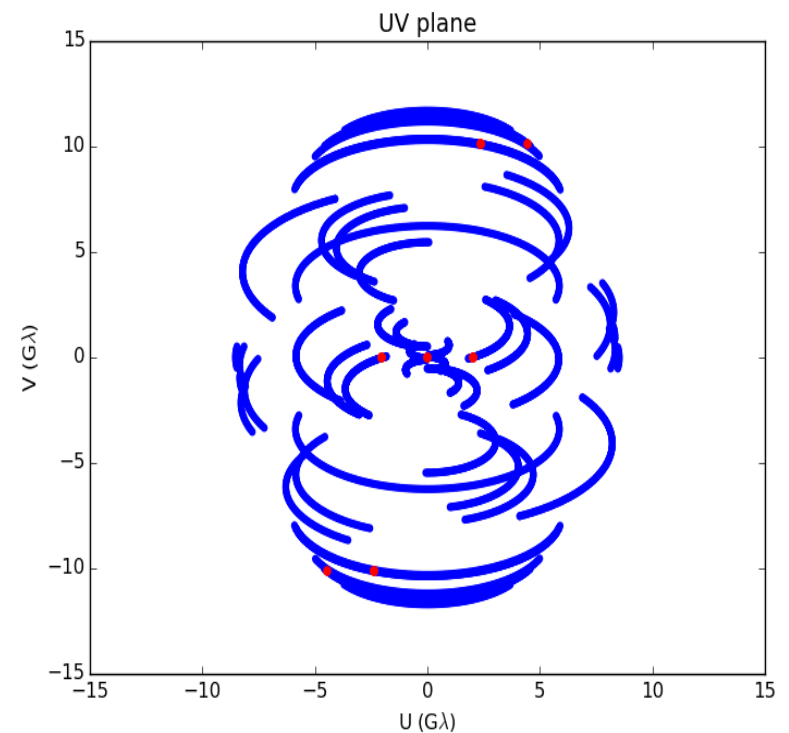
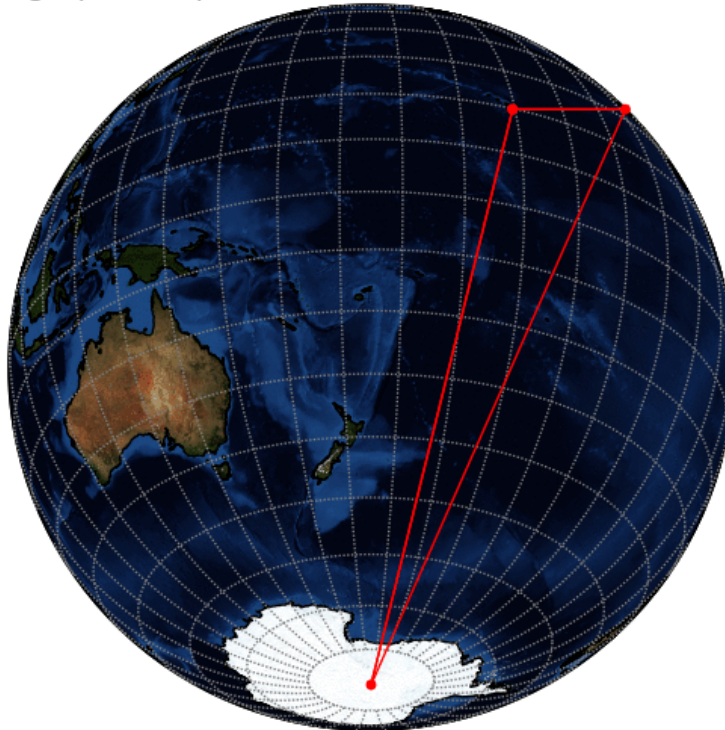
EHT, seen by Sgr A* near future



For 1 mm

Orthographic Map Centered on Lon=180, Lat=-29.00778

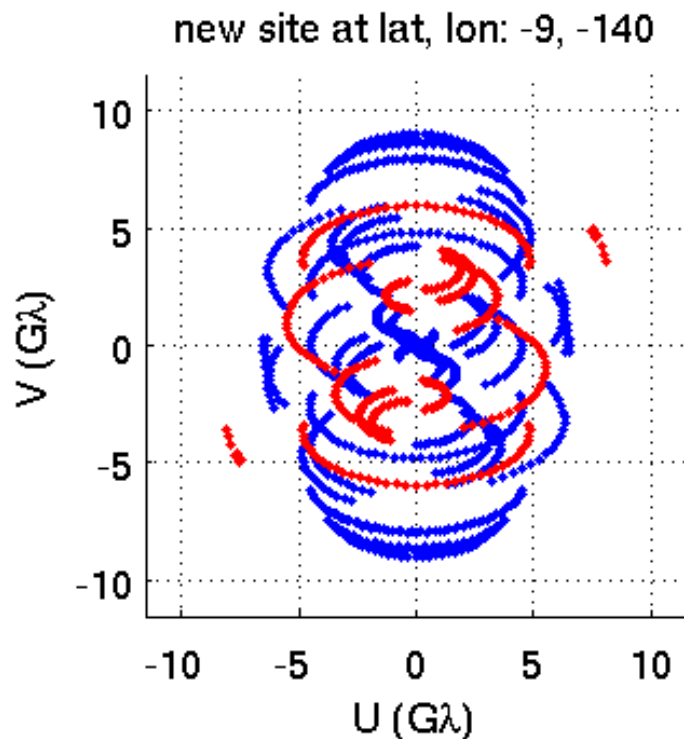
Hawaii
Chile
California
Arizona
Spain
France
South Pole
Mexico



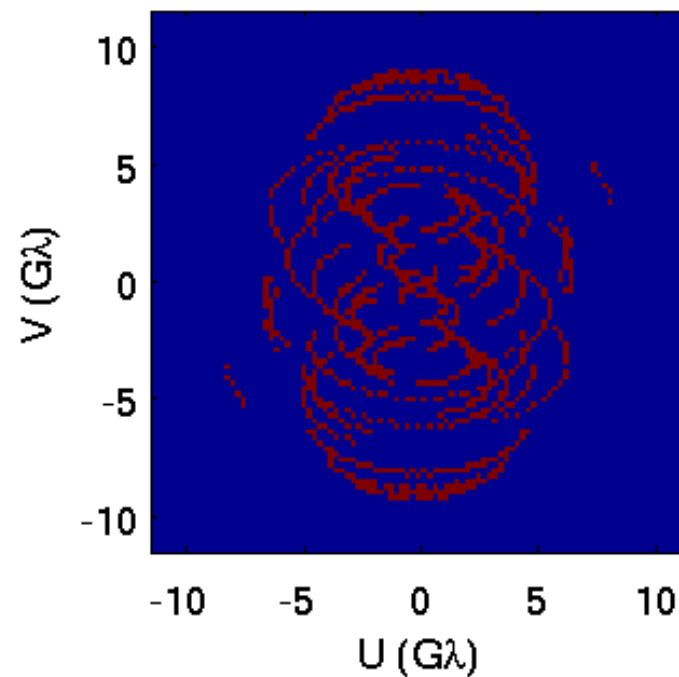
Lat-Lon and UV-plane: Sgr A*



- How much information can be gained from one more site?



Quantized to UV grid,
into 100 bins in u (same in v)

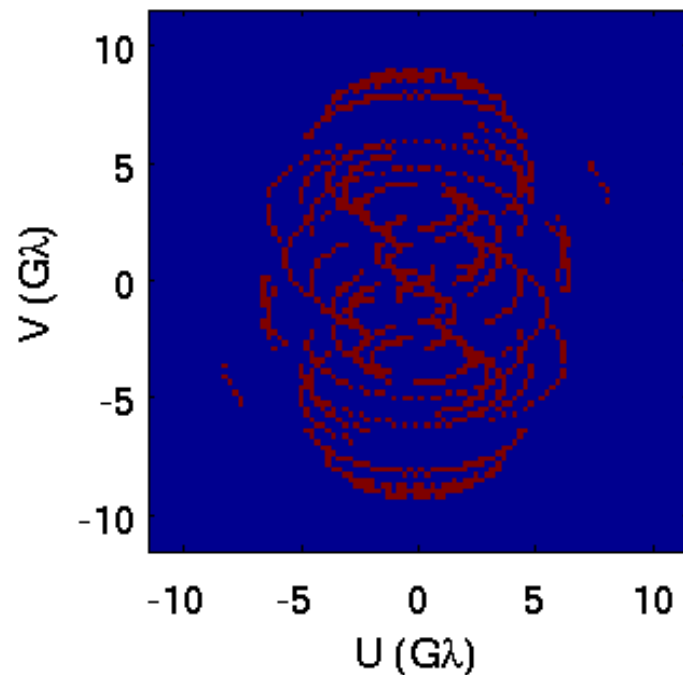


matrix of
ones and
zeroes

Lat-Lon and UV-plane



Quantized to UV grid,
into 100 bins in u (same in v)



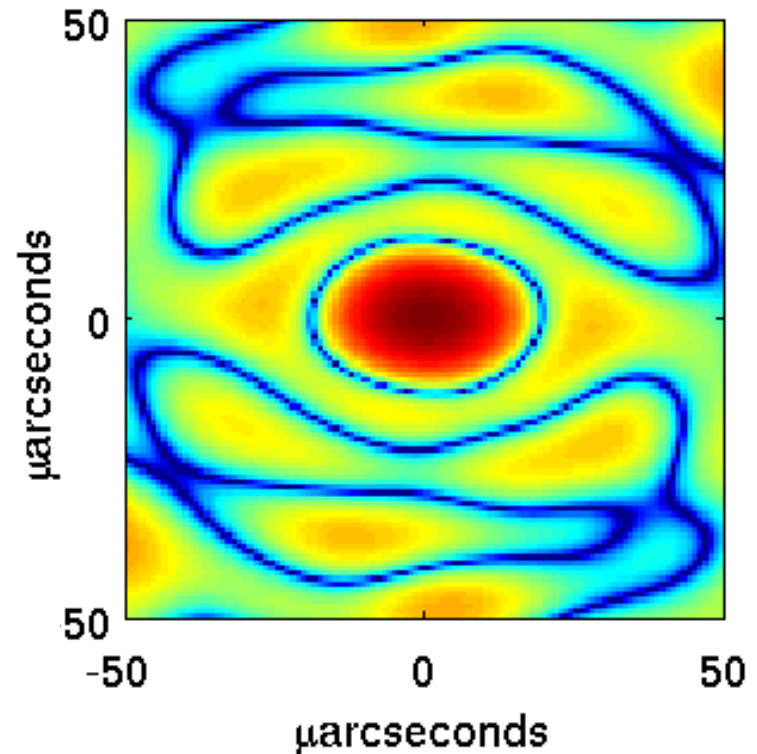
$20 \log_{10} |\text{fft}|$

Point Spread Function

colors -80 to -30 dB

$\lambda = 1.3\text{mm}$

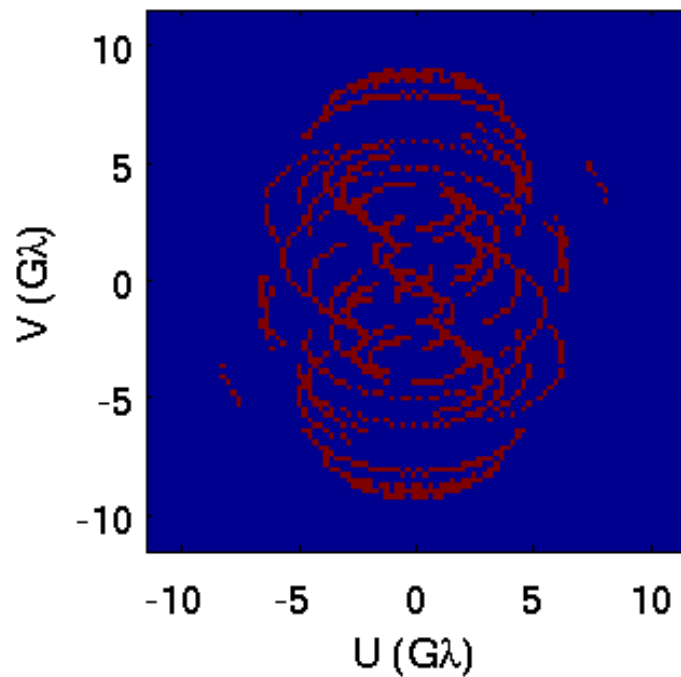
Lat, Lon: -9, -140



Lat-Lon and UV-plane



Quantized to UV grid,
into 100 bins in u (same in v)



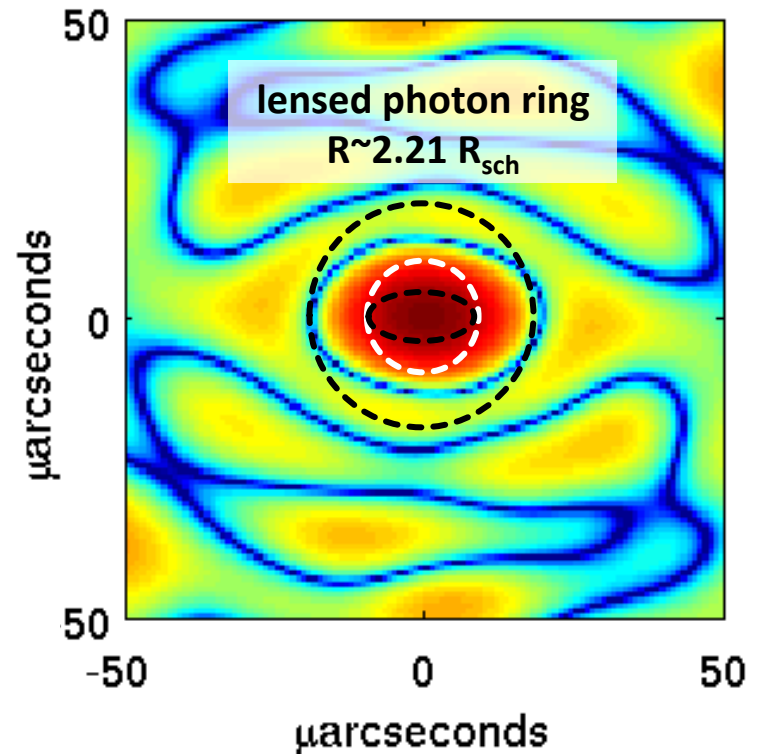
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Point Spread Function

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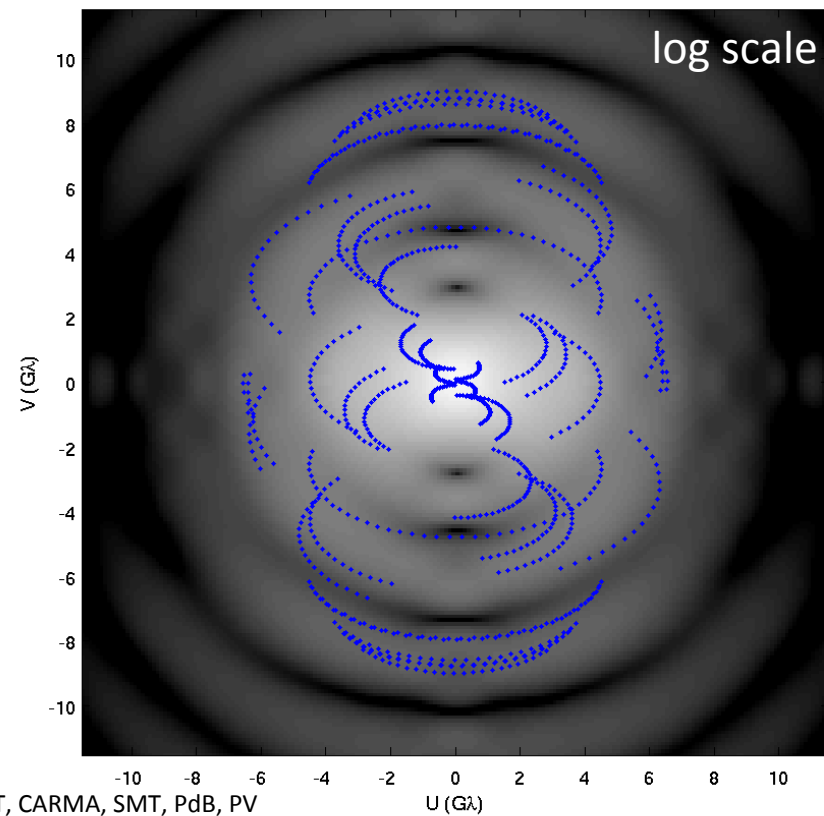
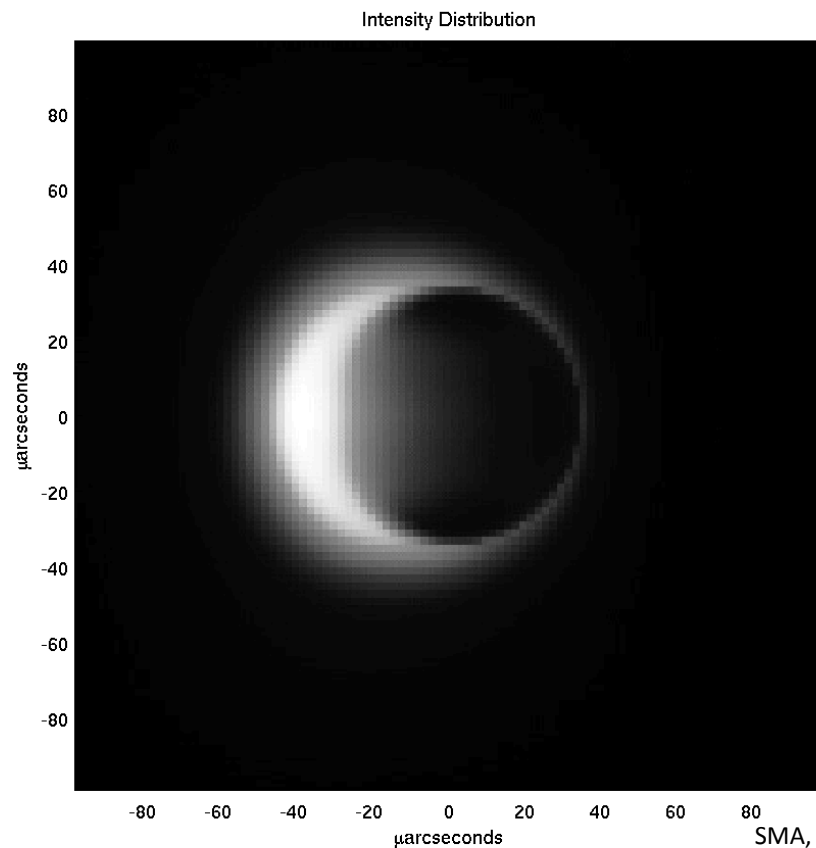


Current model of Sgr A*



■ No Scattering

Hawaii, California, Arizona, Spain, France
+ Chile
+ South Pole, Mexico



SMA, JCMT, CARMA, SMT, PdB, PV
+ APEX (ALMA)
+ SPT, LMT

Lat-Lon and UV-plane: Sgr A*



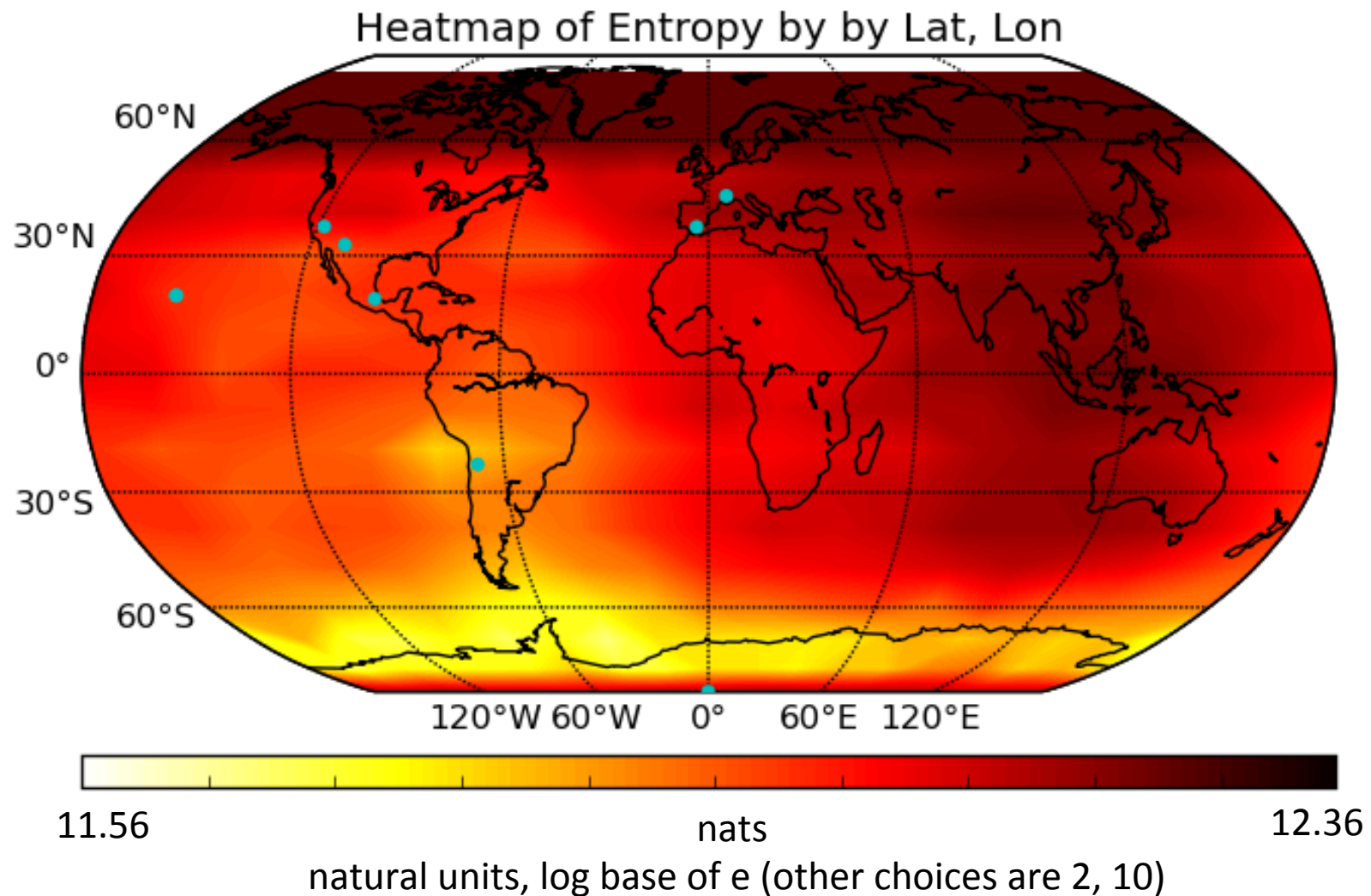
- This unequal sampling in the UV plane can be treated as "windowing"
- Convolution with image
 - Ideal "window" is perfect Dirac delta
- Do this for every lat, lon, compare with metric

- Compare entropy $-\sum_i p_i \ln p_i$
 - Small entropy means the point spread function is closer to a delta function
 - Lower entropy implies better "window"

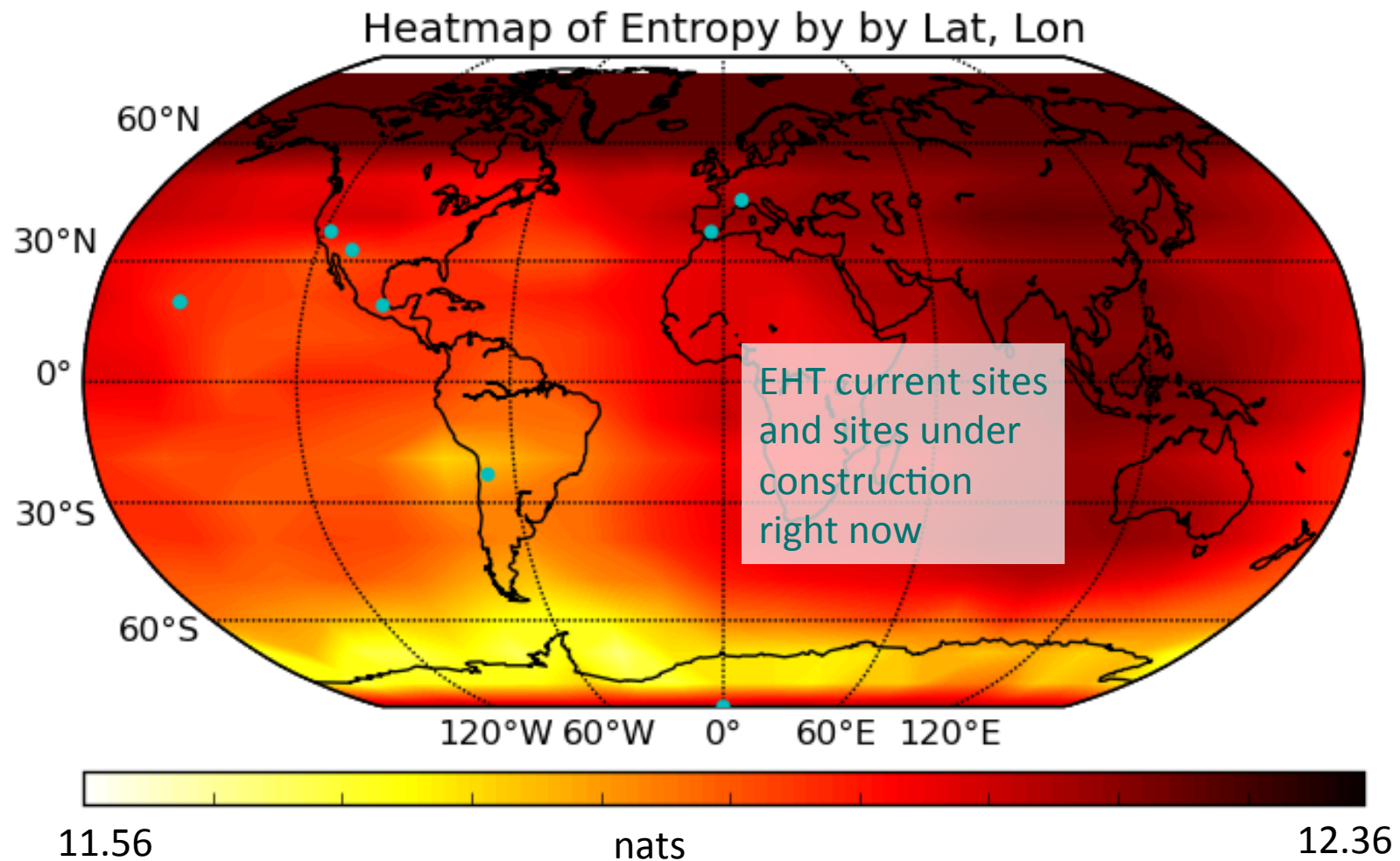
Better  Worse

- Emphasis: this is just one metric
 - Perhaps more important when placing a new telescope are things like weather, cost, existing infrastructure, land mass, etc
 - This is just a tool to build intuition between the effective window created by sites

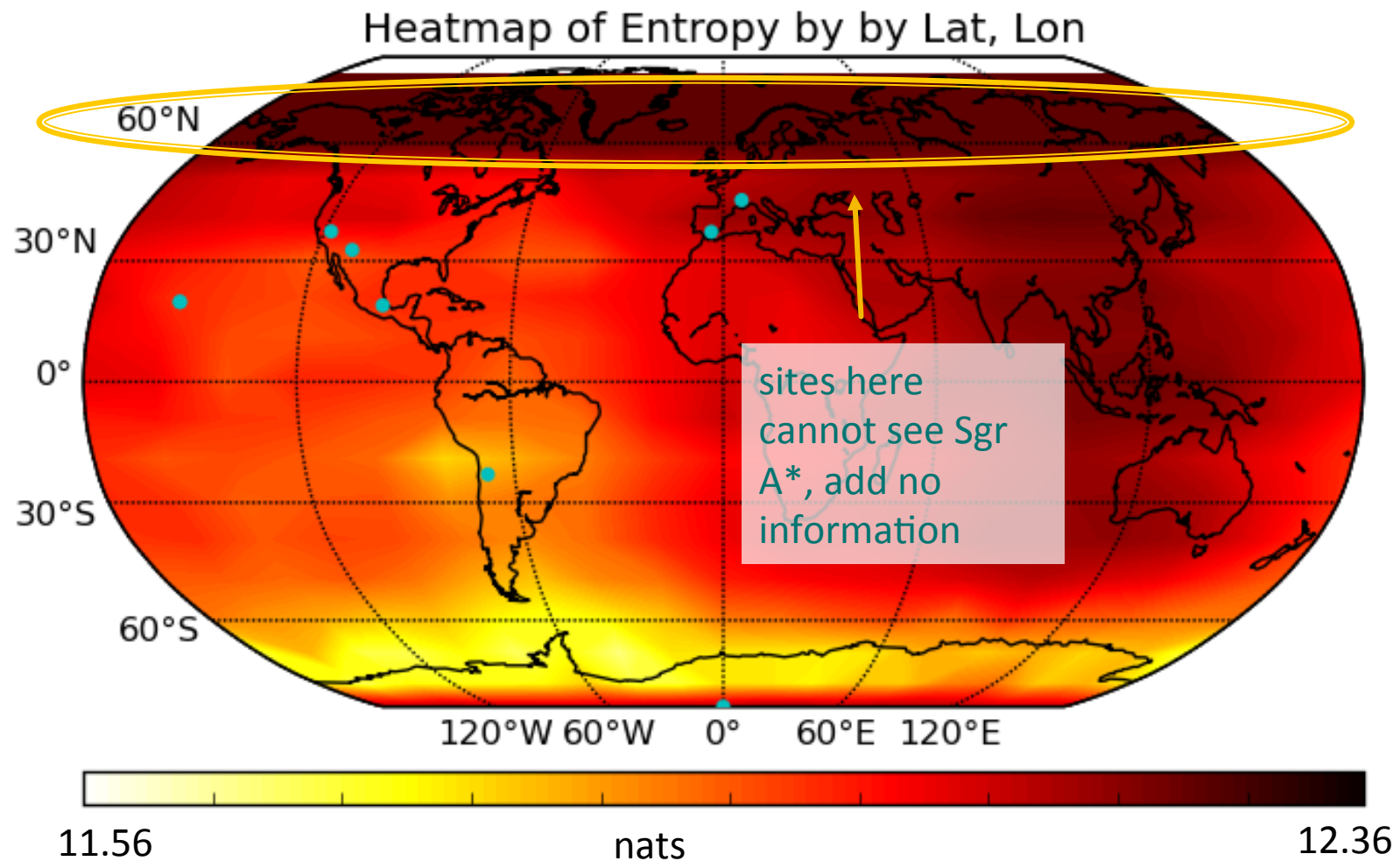
Lat-Lon and UV-plane



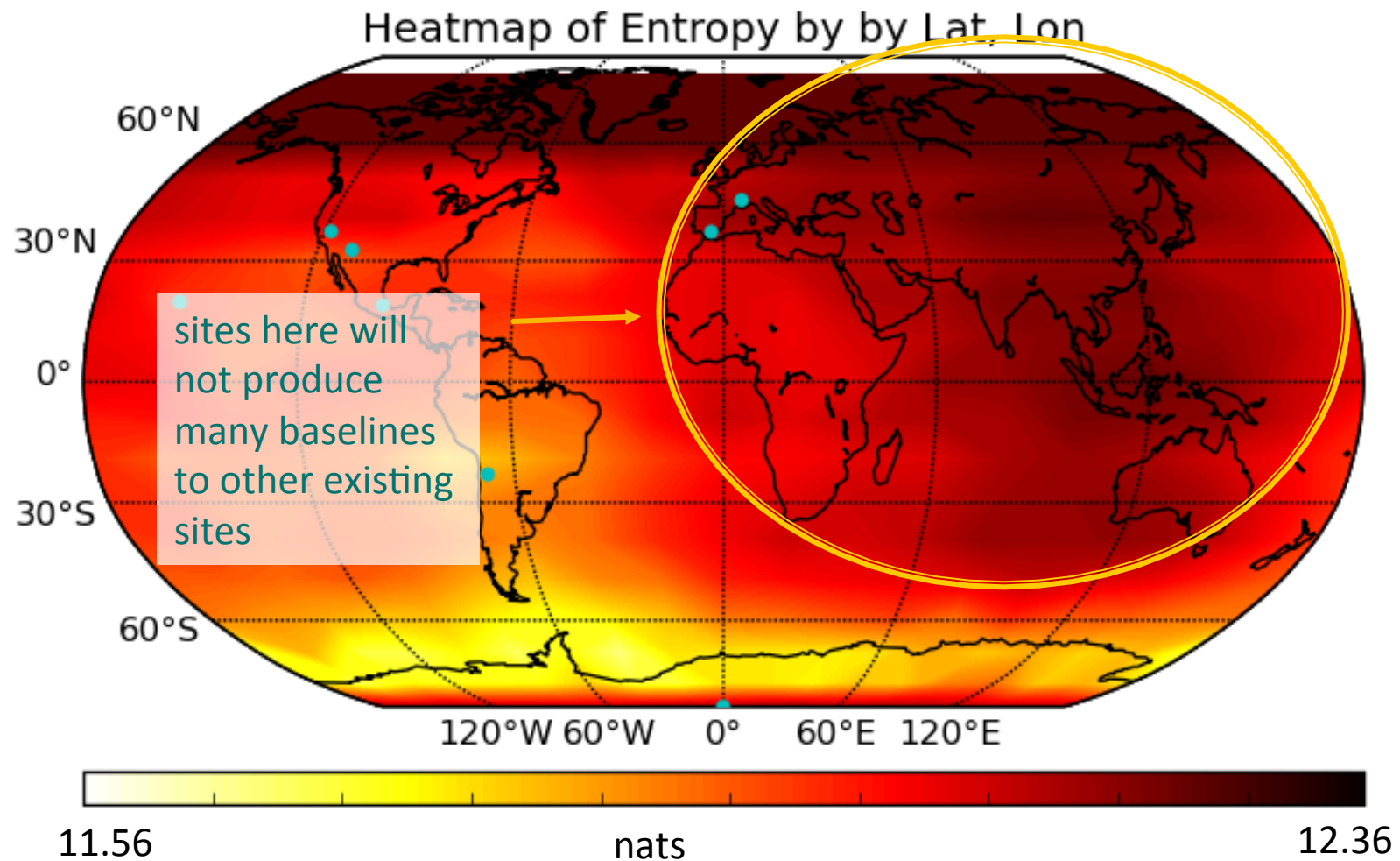
Lat-Lon and UV-plane



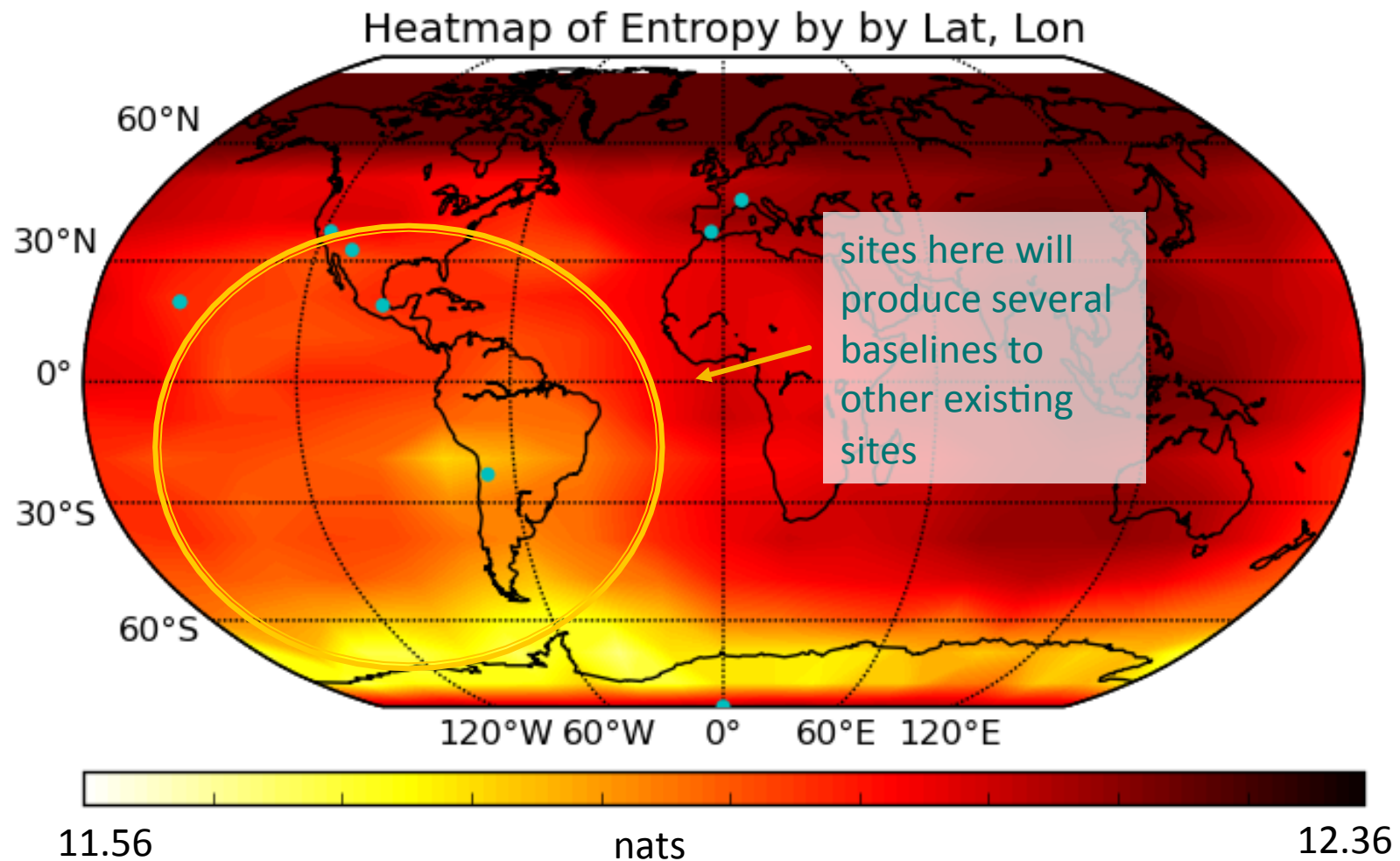
Lat-Lon and UV-plane



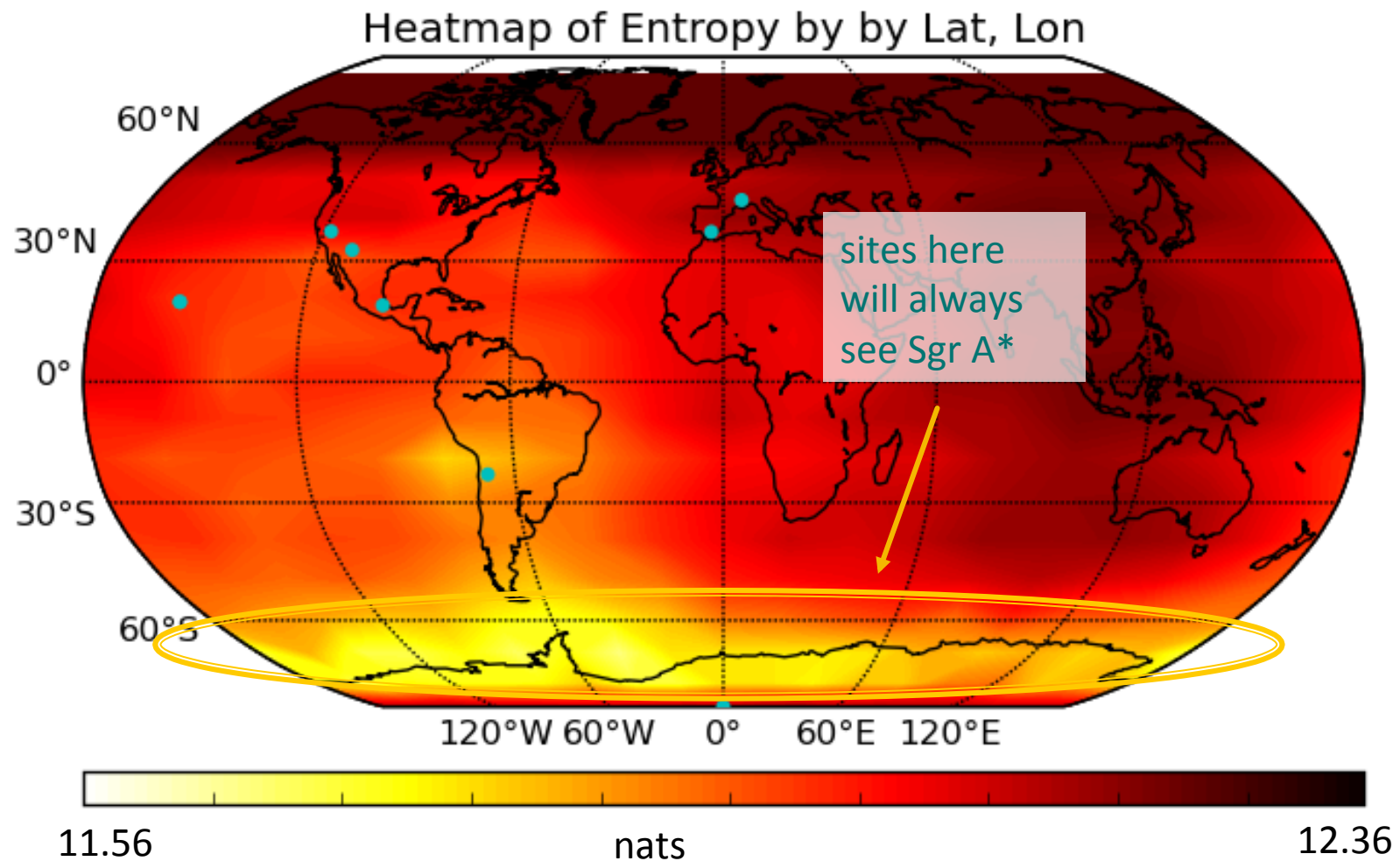
Lat-Lon and UV-plane



Lat-Lon and UV-plane



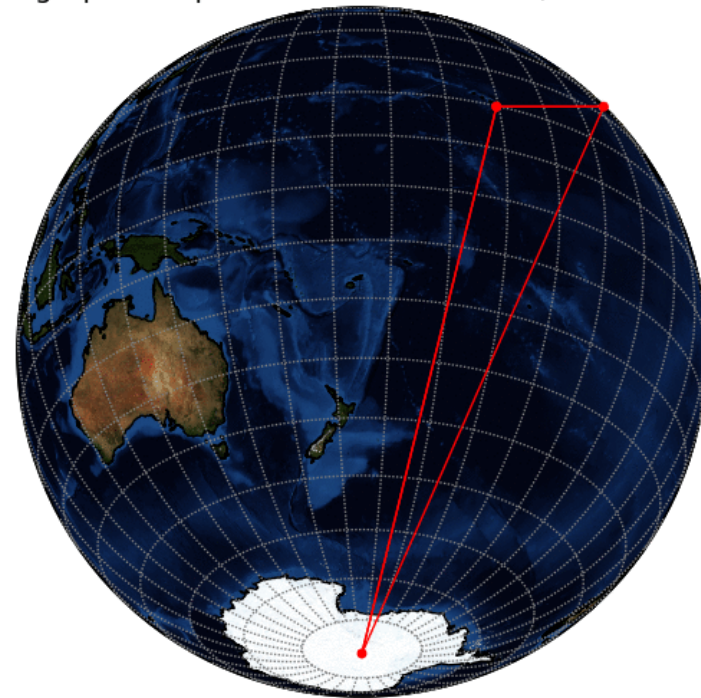
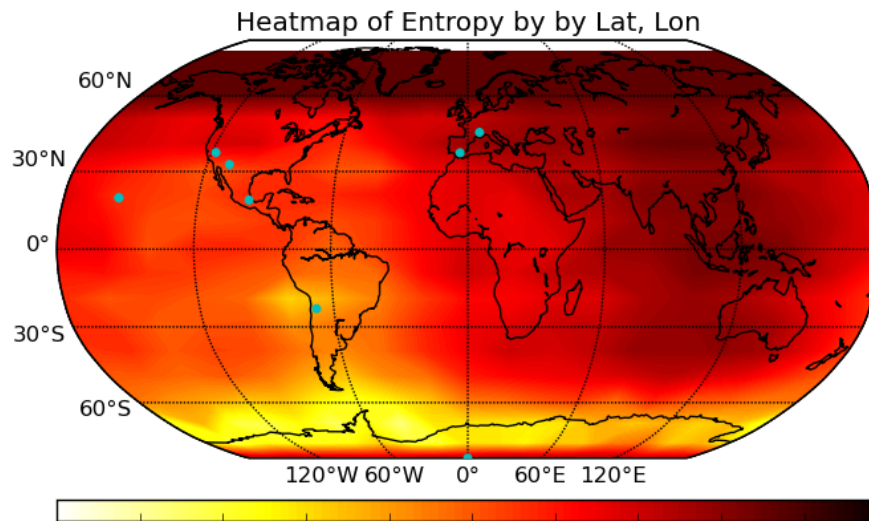
Lat-Lon and UV-plane



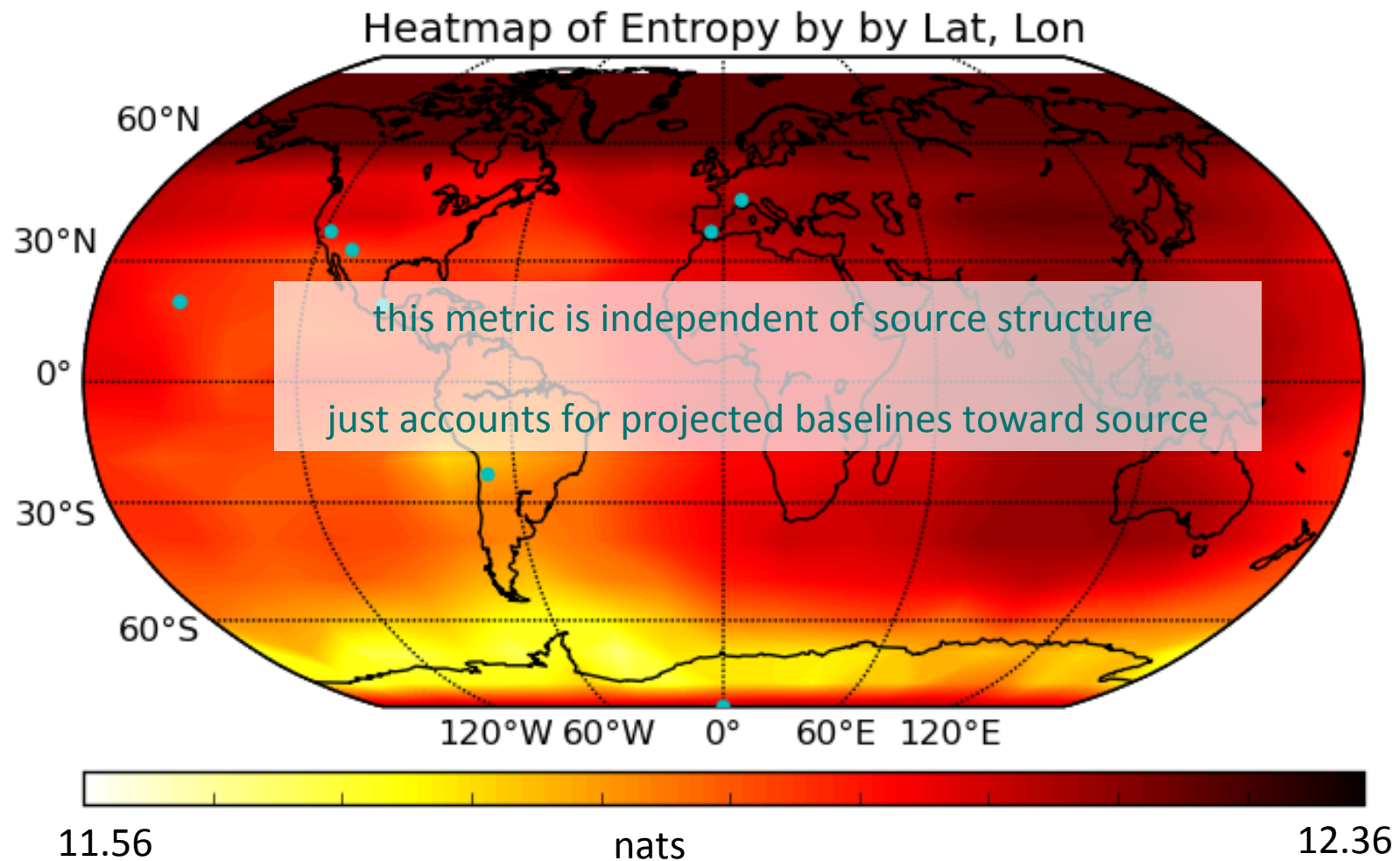
Lat-Lon and UV-plane



Orthographic Map Centered on Lon=180, Lat=-29.00778



Lat-Lon and UV-plane

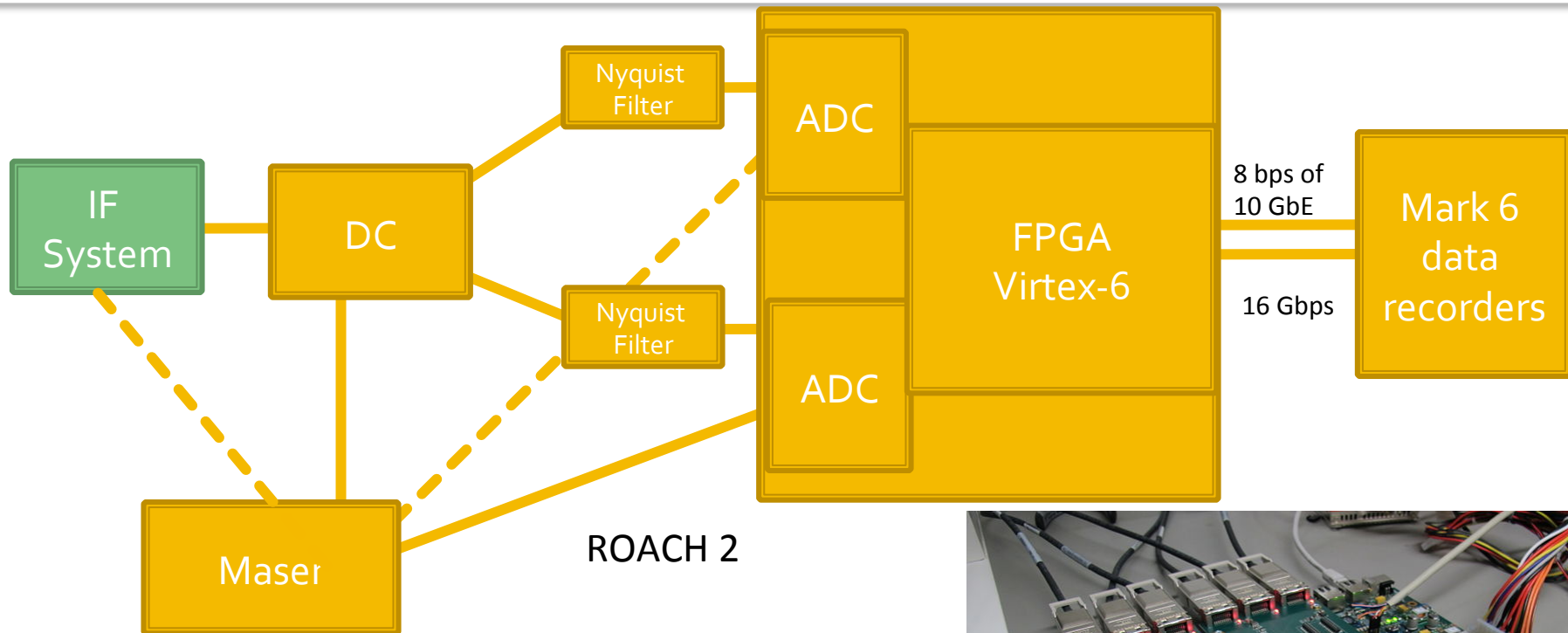


Maser

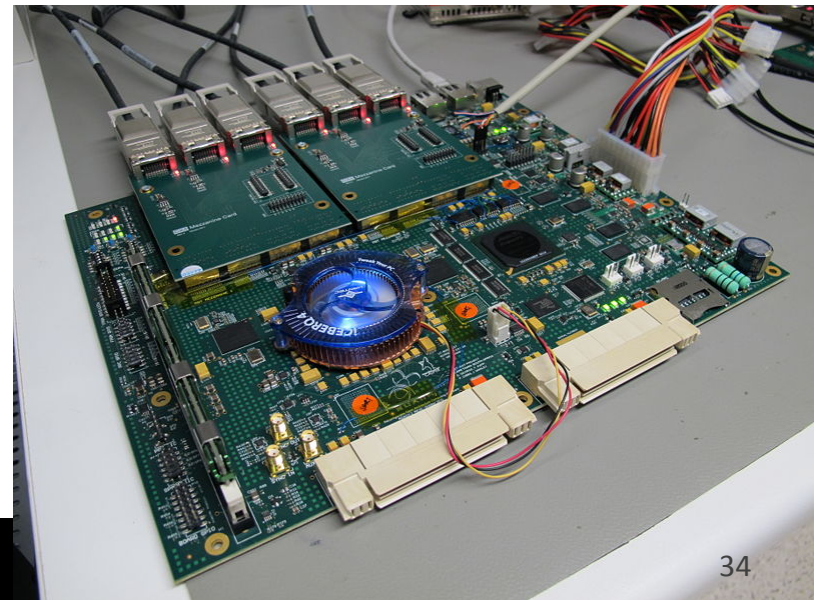


- Maser references all local oscillators in the system, and the sampling clock.
- Stability requirements are most stringent in respect of the sky LO, at around 230 GHz or 345 GHz, a few parts in 10^{14} needed on 10 s time scales.
- Absolute time at stations controlled by locking a maser locked 1pps to GPS. Residual error delay removed by post correlation fringe search.

Block Diagram of R2DBE



Roach2 system + ASIAA ADCs used to digitize widebandwidth, channelize data, quantize data product, format for VLBI, and send out to data recorders



Site Investigation: Phased ALMA



(Credit: C. Padilla, NRAO/AUI/NSF)



Imagery ©2014 NASA, TerraMetrics, Map data ©2014 Google, INEGI

Results

Global Instrumentation

Site Comparison

ALMA Phasing Project

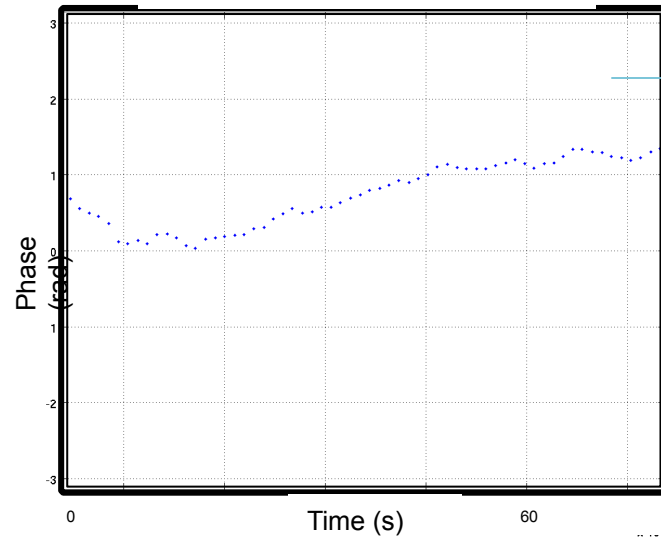


- ALMA Phased Array
- Live, accurate phased estimates needed for phased array
- Major limitation for ground-based (sub)mm VLBI is weather
- Adaptive Phasing
 - Fast Loop: Water Vapor Radiometer measurements
 - Slow Loop: Real-Time Self-Calibration
 - Use models of science targets, imaging methods (such as CLEAN), allow phases of individual elements to be free parameters

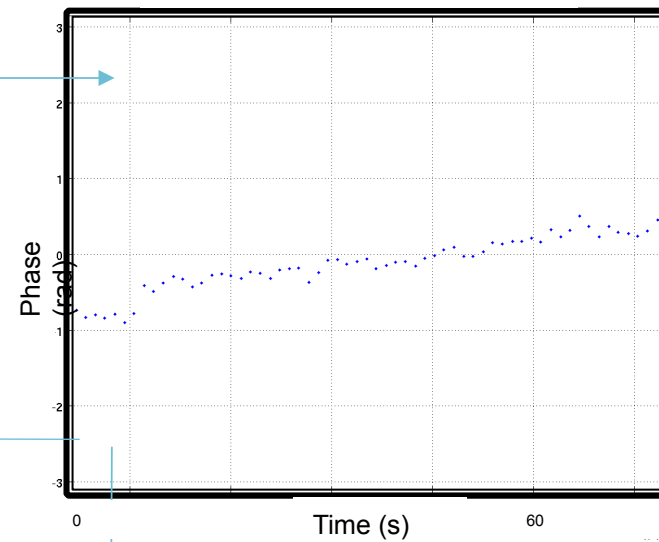
Correct for Water, what now?



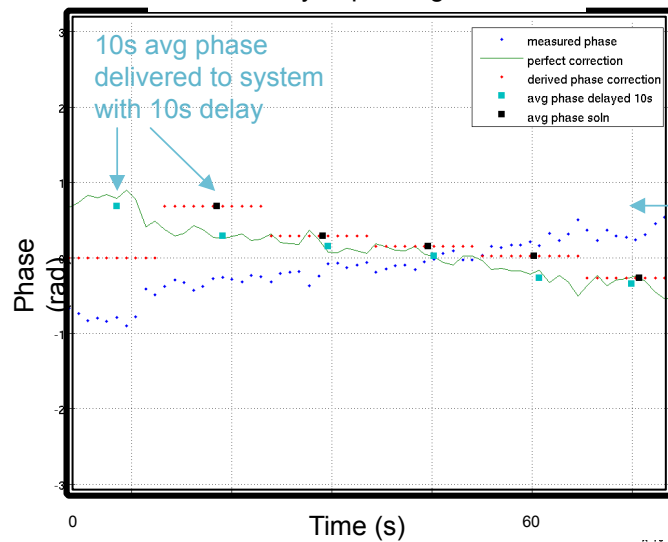
Raw Data, on 2km (long) baseline



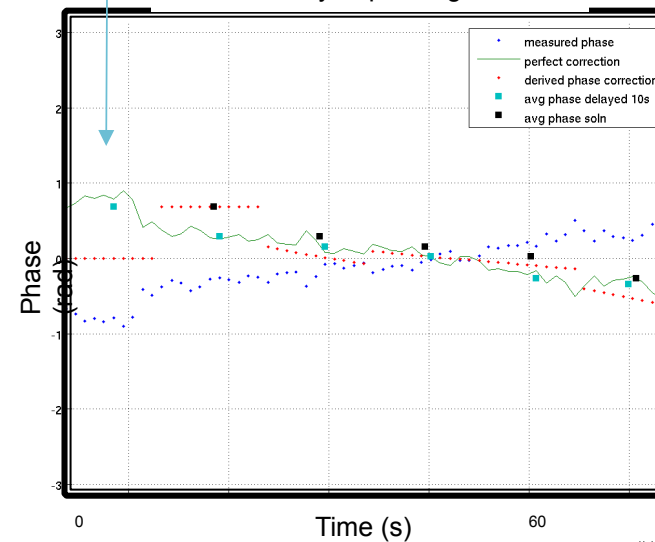
WVR-corrected Data



Flat, delayed phasing solution



Linear, delayed phasing solution



Thank you!



- Questions