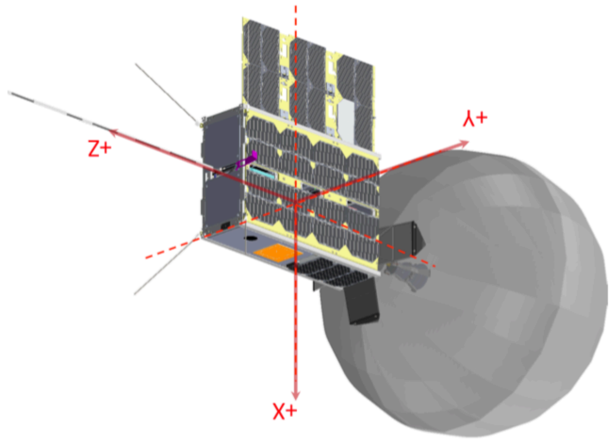

CatSat HF Experiment and Long Wavelength Astronomy Possibilities

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LWA Users Meeting

Aug.16, 2021

Summary

- Who
  - University of Arizona (It's their satellite)
  - UofA Steward Observatory (It's their ground station)
  - Rincon Research Corp. (The HF experiment and AstroSDR)
  - Freefall Aerospace (Inflatable antenna)
  - NASA (Providing launch)
- What
  - 6U CubeSat in 555 km high orbit (sun synchronous)
  - Flexible HF receivers time/freq. referenced to GPS
  - 0.5 meter whip receives HF
  - Store and dump data collection scheme
  - 6.2 meter dishes receive the downlink
  - All data collected will be available via internet

Summary (continued)

Firefly Alpha
Maiden launch
scheduled
In 2 weeks.

- When
  - Launch summer 2022
- Where
  - Worldwide data collection
  - Dump to antennas near Tucson
- Why
  - Education
  - Ham Radio WSPR and FT-8 known signal sourcess available for propagation experiments
  - Technology development

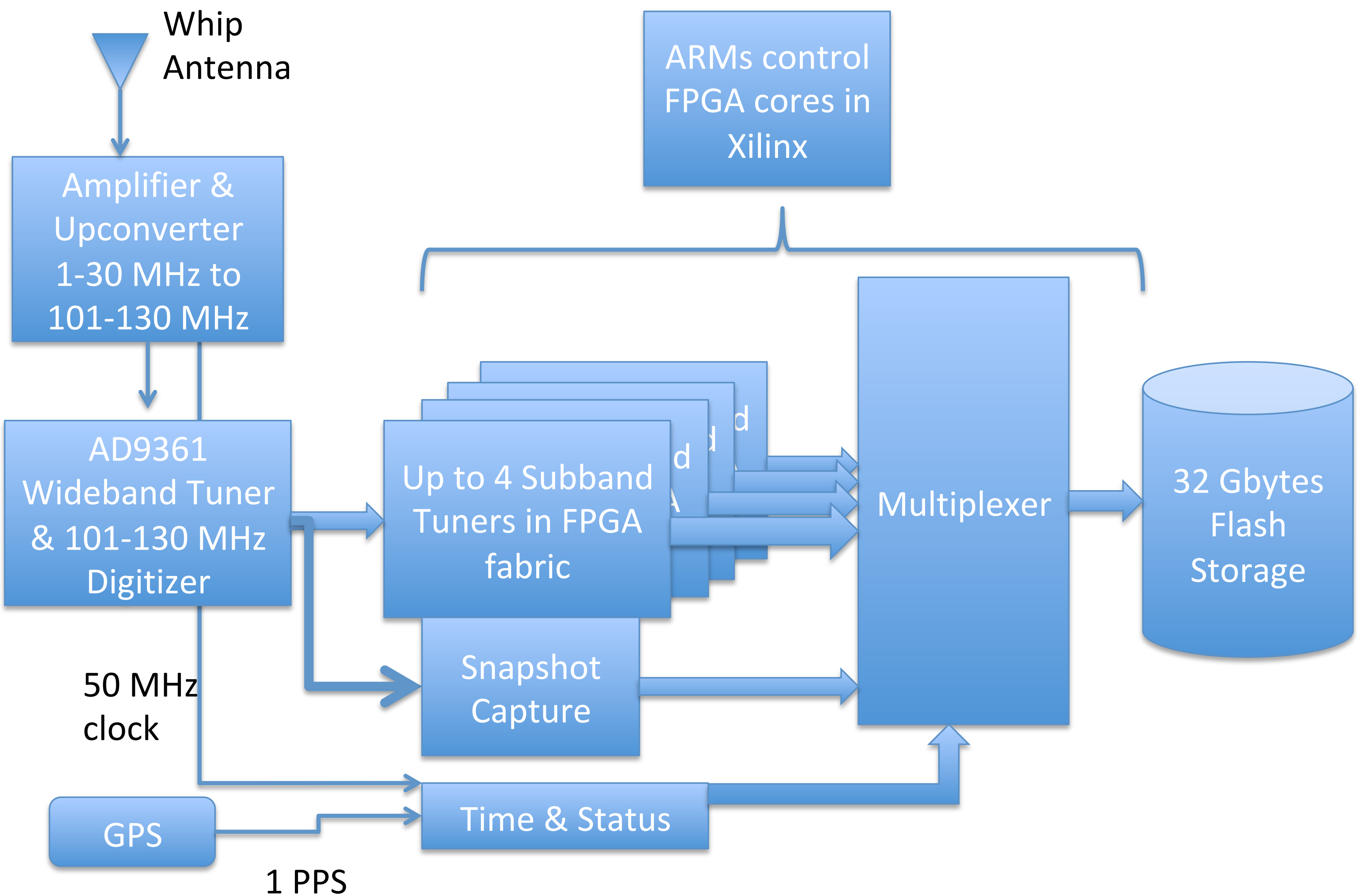
Purpose of this Talk

- Inform you of the opportunity
- Illustrate what is possible
- Solicit partners
  - To help plan collects, schedule time on telescopes, process and analyze data, write papers, or whatever you want to do.

Store and Dump is Fundamental Plan

- Data is acquired from anywhere on earth
  - Data rate is reduced using snapshots or narrowband tuners and then multiplexed into a single stream for storage on flash memory.
- When over ground station, data is dumped to ground
- Ground software de-multiplexes into original streams and stores for analysis.

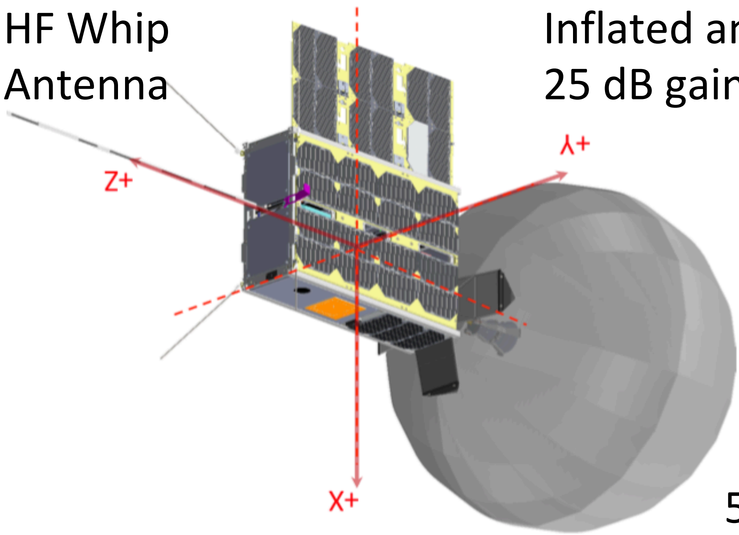
Data Acquisition Block Diagram



Satellite and Ground during High Speed Data Dump

HF Whip
Antenna

Inflated antenna
25 dB gain at 10 GHz

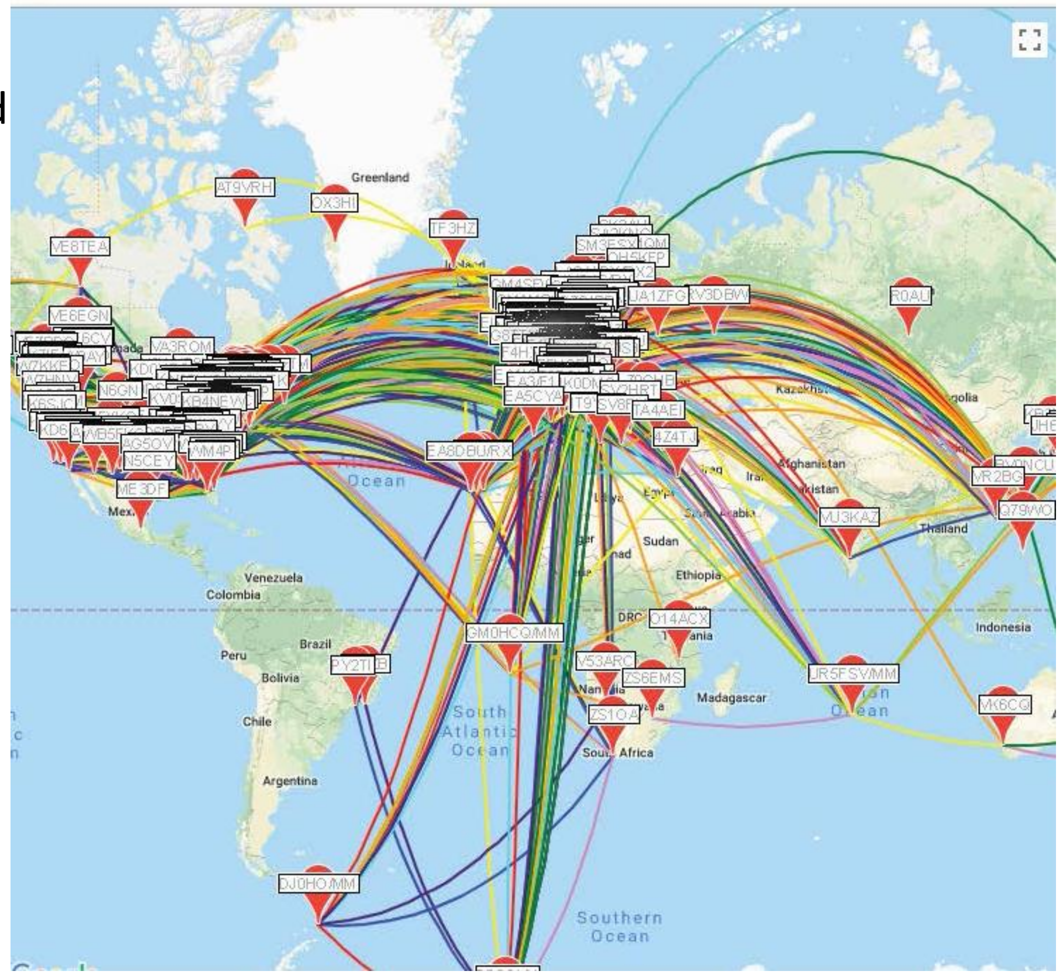


50 Mbps
DVB-S2
modulation

Antenna provided by UofA
Steward Observatory

Ham signals solve the problem of not knowing transmitter info

We plan to use WSPR and FT-8 signals to as source of transmitter data for ionospheric experiments.

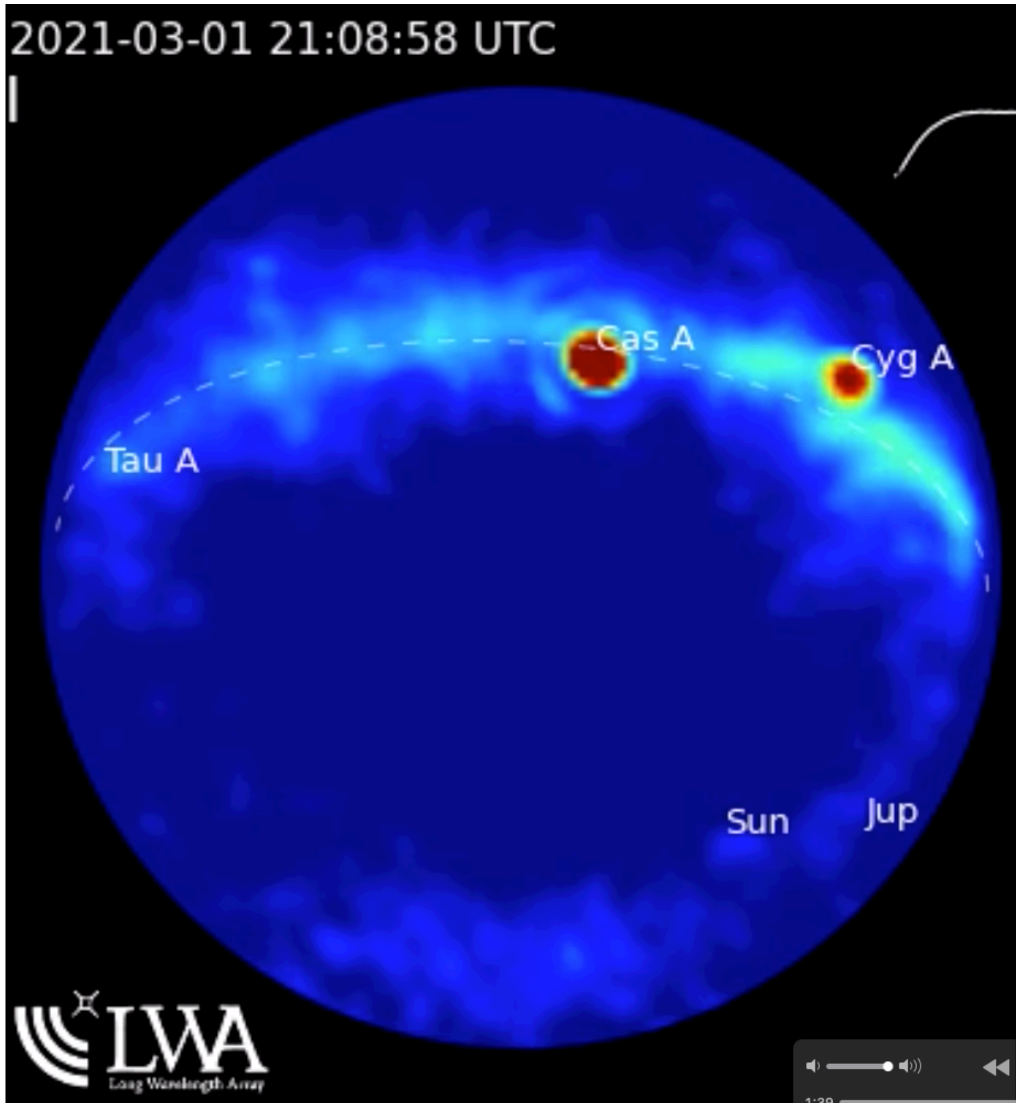


But can it be used for astronomy?

- Computation of a 2 dimensional cross-ambiguity function with variables of delay and Doppler is well known
  - For a particular space direction and time TDOA and FDOA can be calculated and this allows TDOA and FDOA to be mapped into a spatial direction
  - It's a little more complicated since TDOA and FDOA are changing with time
- Potential sources to image
  - Jupiter, Cass-A, Pulsars, sun
    - Sizes for comparison
      - Moon and sun = 30 arcmin
      - Cass A = 5 arcmin
      - Jupiter = 40 to 50 arcsec

All sky intensity from LWA TV

38.10 MHz. lwalab.unm.edu



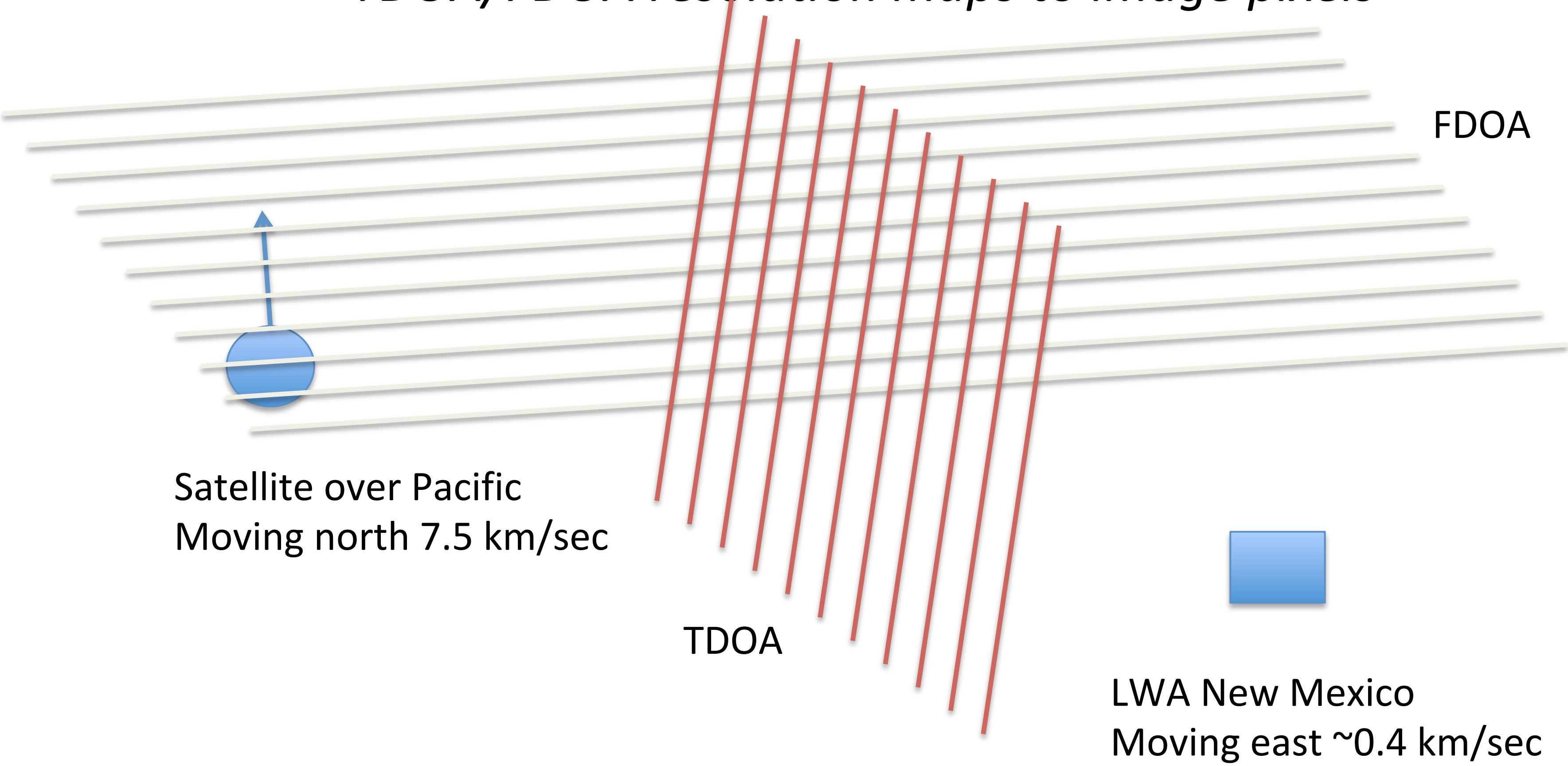
Consider a two-station interferometer

TDOA=Time Difference of Arrival => hyperbola with stations at foci

FDOA=Frequency Difference of Arrival => approx. cones about velocity vector

Sketch of outward view from earth's center

TDOA/FDOA resolution maps to image pixels



How good will the image be?

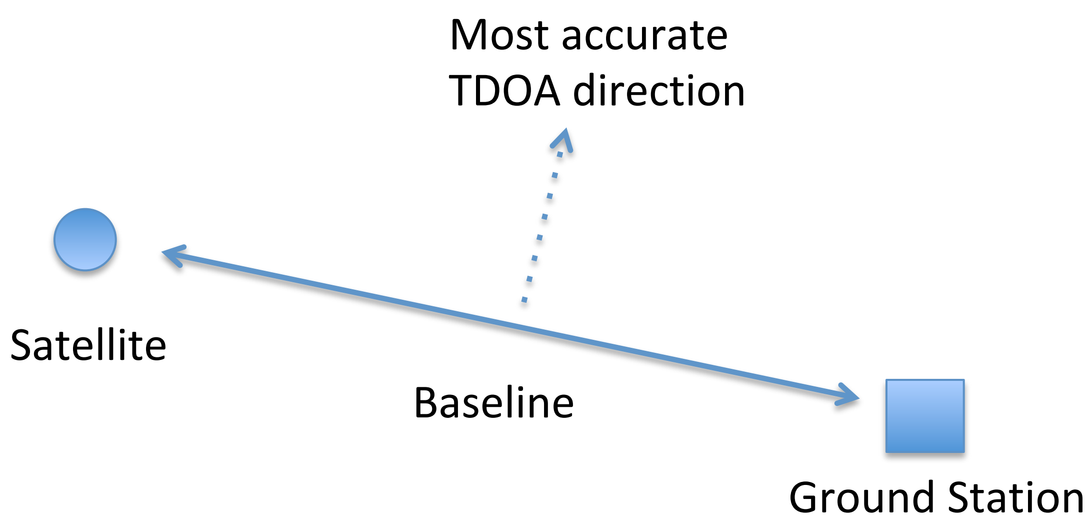
- Limited by the ionosphere
  - If we maintain coherence over 10 seconds, image resolution on the order of 40 arcseconds is possible
  - And a new image might be formed every 10 seconds
- Details in next two slides will be skipped…..ask if you want to know

FDOA (or Array Synthesis) Accuracy

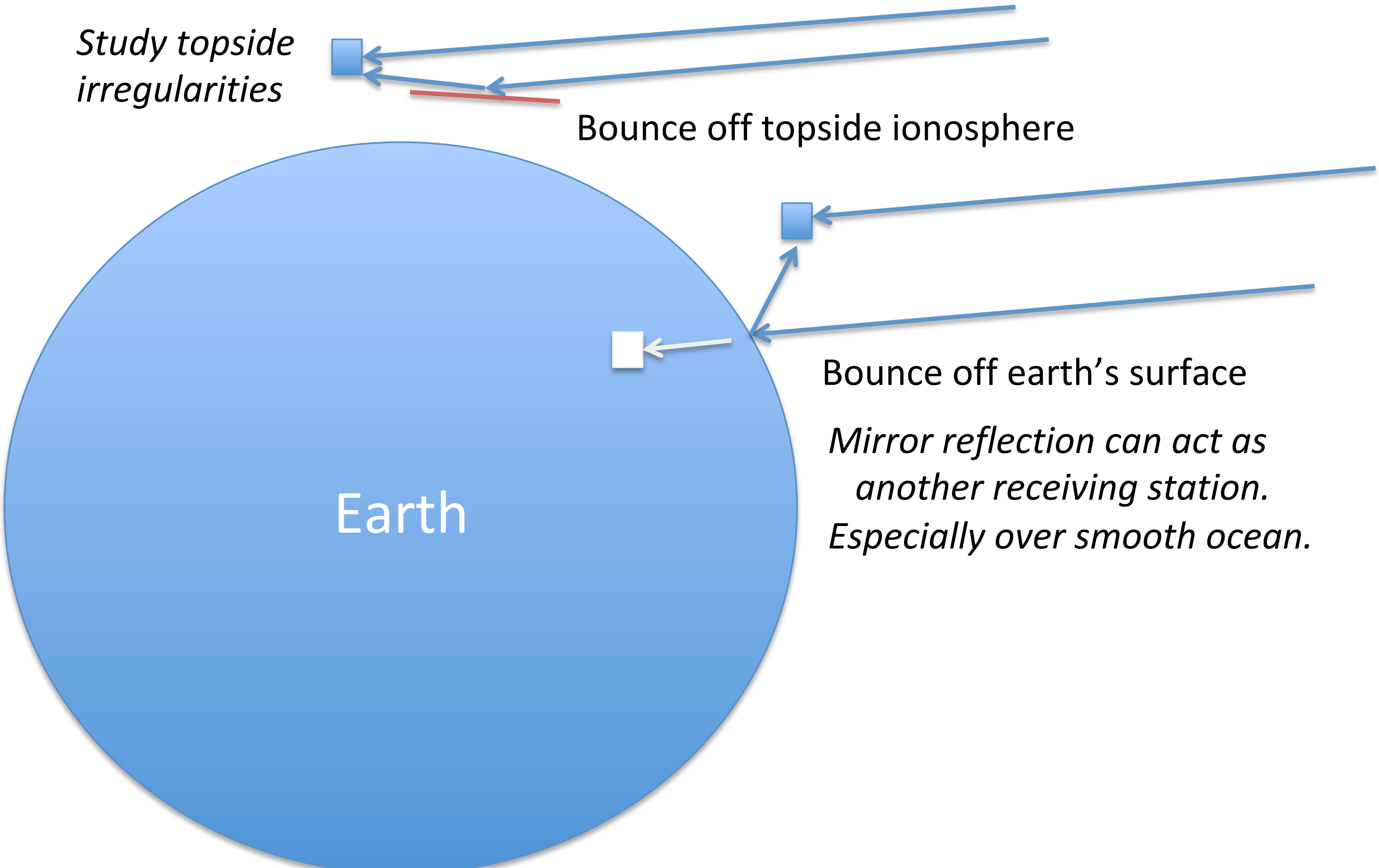
- How accurately can one measure FDOA?
  - Longer coherent observation time implies more accurate FDOA
  - How long can we coherently integrate? Seconds?
    - Remember, we are above the F layer
    - On the other hand, we are traveling very fast
- You may prefer to think in terms of phase difference between the stations since you know that FDOA=rate of phase difference change.
  - So you will realize that motion of the satellite (neglecting the ground motion) synthesizes an aperture
    - 10 seconds x 7.5 km/second = 75 km long synthetic aperture
    - 75000m/15(m/wavelength) = 5000 wavelength long aperture or 1/5000 radian ~41 arcsec resolution

Resolution in the Time Difference of Arrival (TDOA) Direction

Speed of radio wave = 300 meters per microsecond
Baseline 3000 km produces angle resolution of 10^{-4} radians = 0.0057 deg
= 0.34 arcmin = 2 arcsec
But if you are only recording or processing 100 kHz of signal bandwidth at a time
TDOA resolution ~ 10 microsec which translates to 20 arcsec with 3000 km baseline.



Interesting Propagation Paths Interference or additional data?



Observable Phenomena
(not everything needs a complicated station)

- Measurements
  - Frequency shift
    - Example: Frequency shift of WWV and WWVH at 5, 10, 15, & 20 MHz.
    - Example: Frequency shift of WSPR and FT8 Ham Transmitters
  - Time-of-Arrival
    - Example: CODARs
  - Time-Difference-of-Arrival (TDOA)
  - Frequency-Difference-of-Arrival (FDOA)
  - Amplitude fade rate (special case of FDOA)
- Phenomena
  - Free-Space propagation (line-of-sight)
    - Location a function of TDOA & FDOA
  - Reflection of celestial sources off earth surface
    - Additional paths
  - Reflection of celestial sources off top of ionosphere
    - Waves in the topside ionosphere
  - Group delay in ionosphere function of Total Electron Content (TEC)

Conclusions

- Under good geometry and ionospheric conditions TDOA/FDOA ambiguity function calculation might produce an image every 10 seconds
  – Pixel resolution might be on the order of 40 arcsec
    - Sizes for comparison
      – Moon and sun = 30 arcmin
      – Cass A = 5 arcmin
      – Jupiter = 40 to 50 arcsec
- One person's interference is another person's signal
  – Multiple propagation paths and effect of ionosphere on them offer additional experiment opportunities
- Contact me if you want to get involved
  – Mike Parker, airarray@gmail.com, (520) 444-9704 cell

End of Presentation