Ionospheric Propagation Effects on Wide Bandwidth Signals

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2008 URSI General Assembly
Chicago, August 2008

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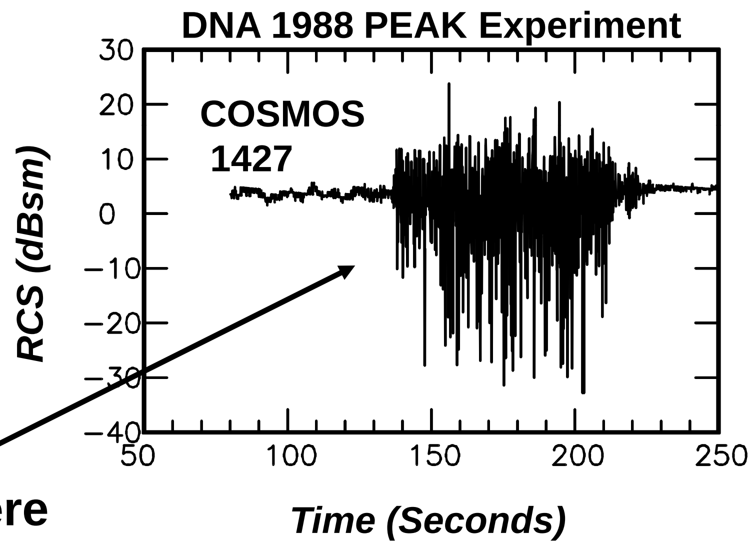
Ionospheric Effects on Propagating Signals

Mean effects:
- **Dispersion**
- **Faraday rotation**
- **Refraction**

Scintillation:
- **Amplitude fading**
- **Phase scintillation**
- **Waveform distortion**
- **Angle-of-arrival jitter**



Scintillation observed during track of Russian calibration sphere

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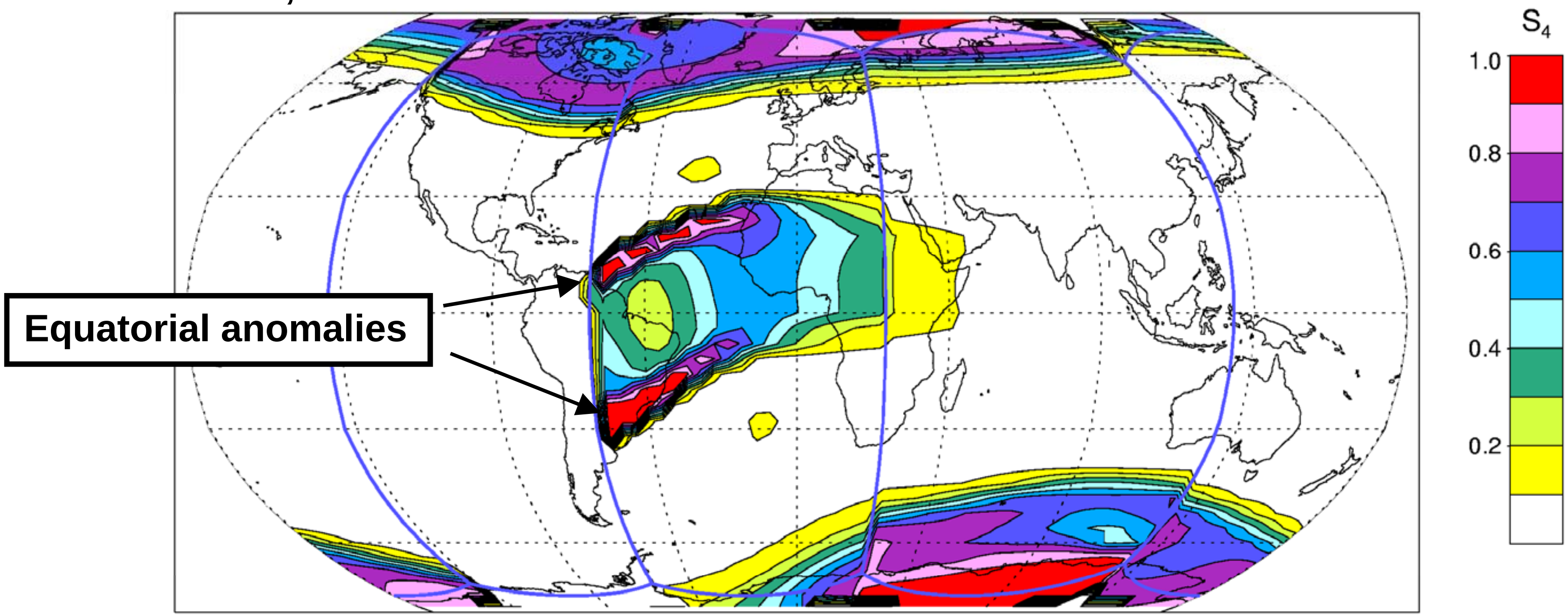
Scintillation is Most Severe in the Equatorial Region

Time = 00 GMT, 90th Percentile calculation



- **PROPMOD code calculation of scintillation severity for a UHF comm system from 4 synchronous satellites to users on the earth's surface**
- **Scintillation severity varies with year, day, time of day, sunspot number, and solar magnetic activity**
- **Animation shows an example of RMS amplitude variation for 24 hours in March 2001 (High sunspot number)**

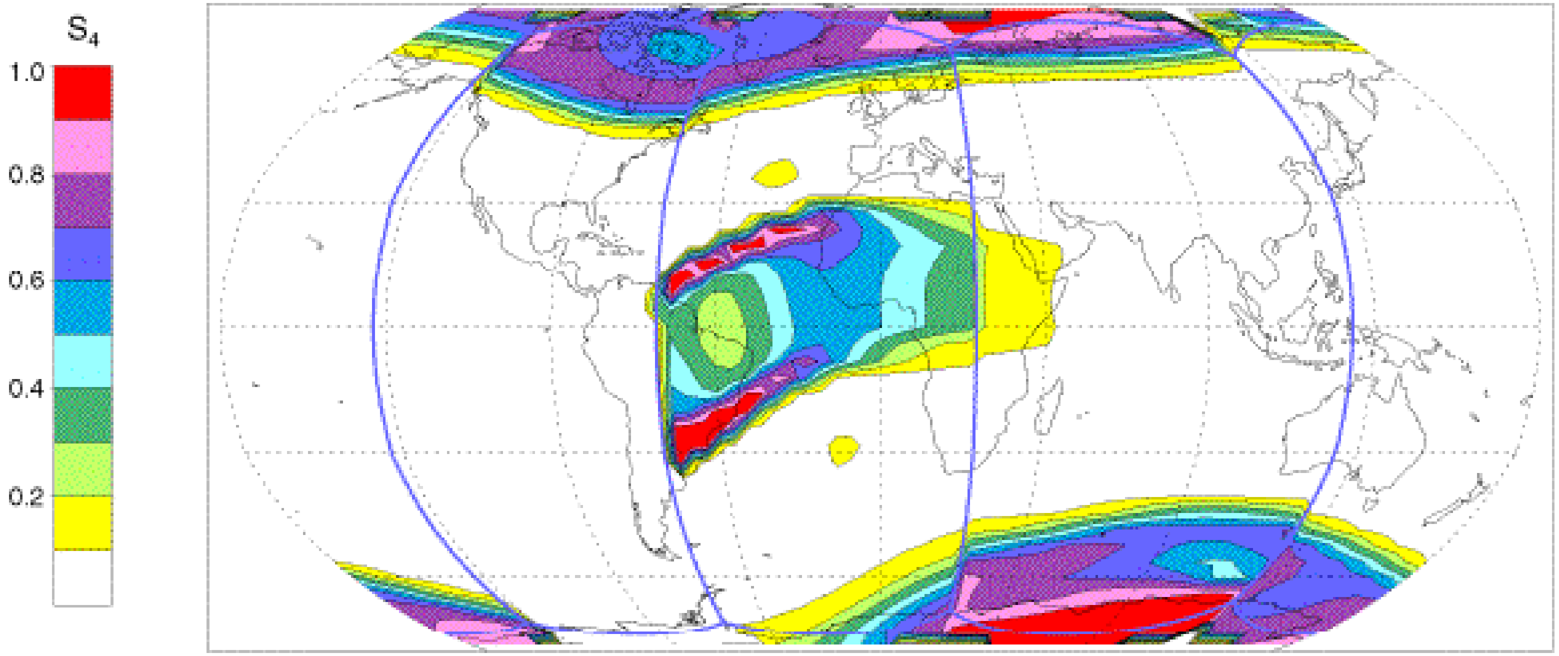
S_4 at 90% Level,

to Closest MUOS location

Signal freq = 310 MHz

SSN = 150, K_p = 6

March, UT = 0000



Ionospheric Propagation Effects on Ground and Space Based Radars

Outline

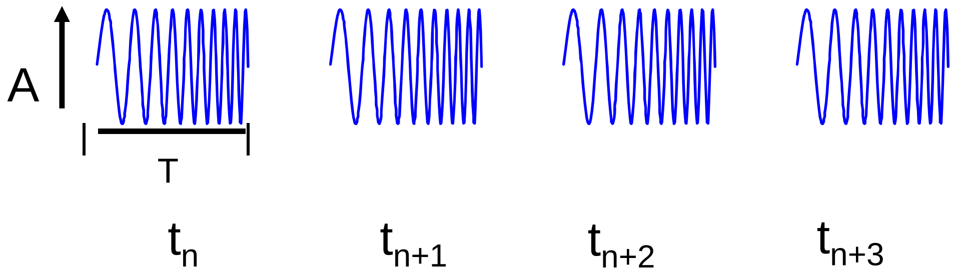
- **Propagation effects on radar**
  - **Scintillation – ionospheric multipath**
- **Three data collection experiments**
  - **DNA PEAK (Propagation Effects Assessment-Kwajalein)**
    - > **Knepp, et al. 1991**
  - **US-UK WIDE (Wideband Ionospheric Distortion Experiment)**
    - > **Cannon, et al., 2006**
  - **DNA Wideband Satellite Experiment – Analysis of 1977 data**
- **Measurements of frequency selective scintillation**
- **Coherent integration performance during scintillation**
- **Conclusions**

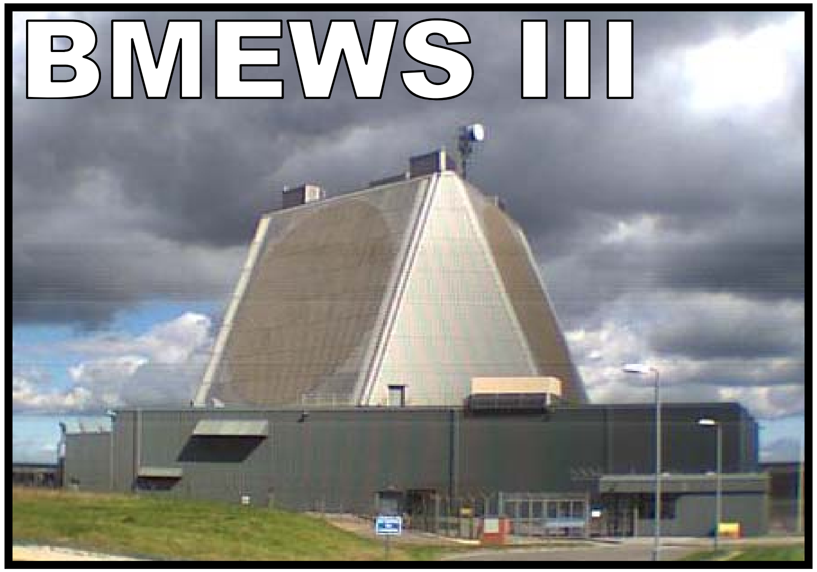
Propagation Disturbances Cause Scintillation of Received Signal

Radar transmits a train of chirp pulses:

$$S(t) = A \cos(\pi \alpha t^2)$$

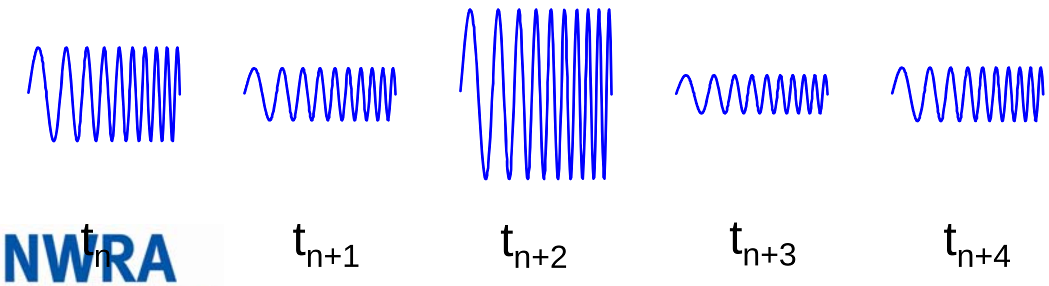
Example of transmitted waveform:



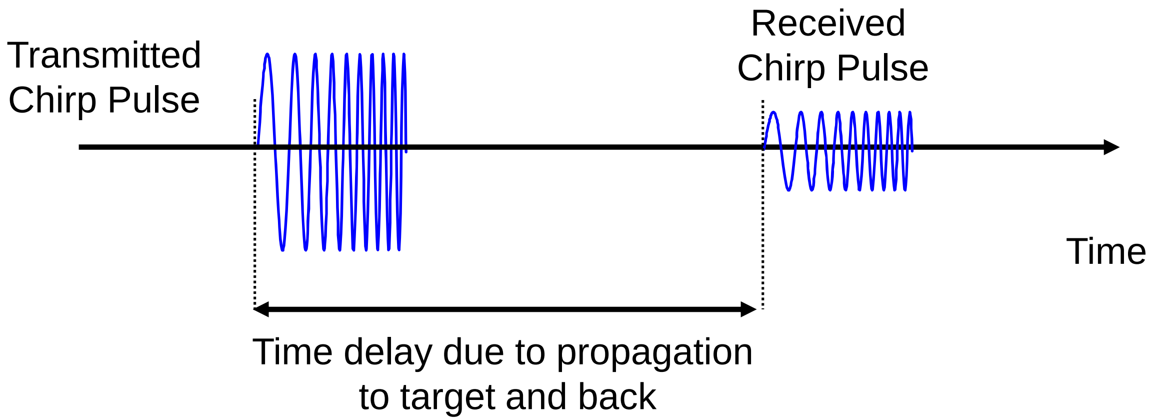


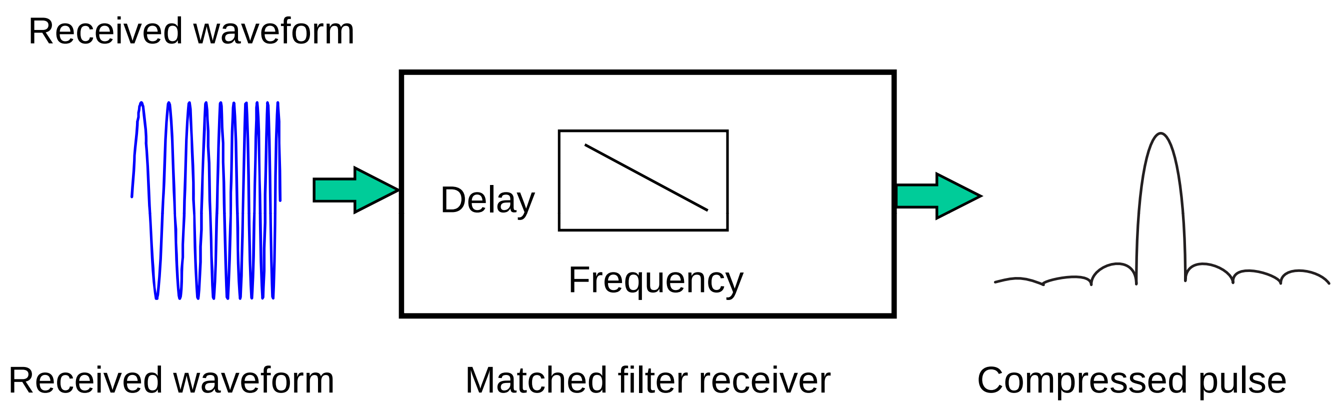
Fading (or rapid amplitude variation) is caused by angular scattering from the structure in the ionisphere. Example of received waveform:

All long-range radars use chirp waveforms



Effects of Disturbances on Received Compressed Pulse





Pulse compression is a standard technique used in long-range radar to improve range resolution and signal-to-noise ratio

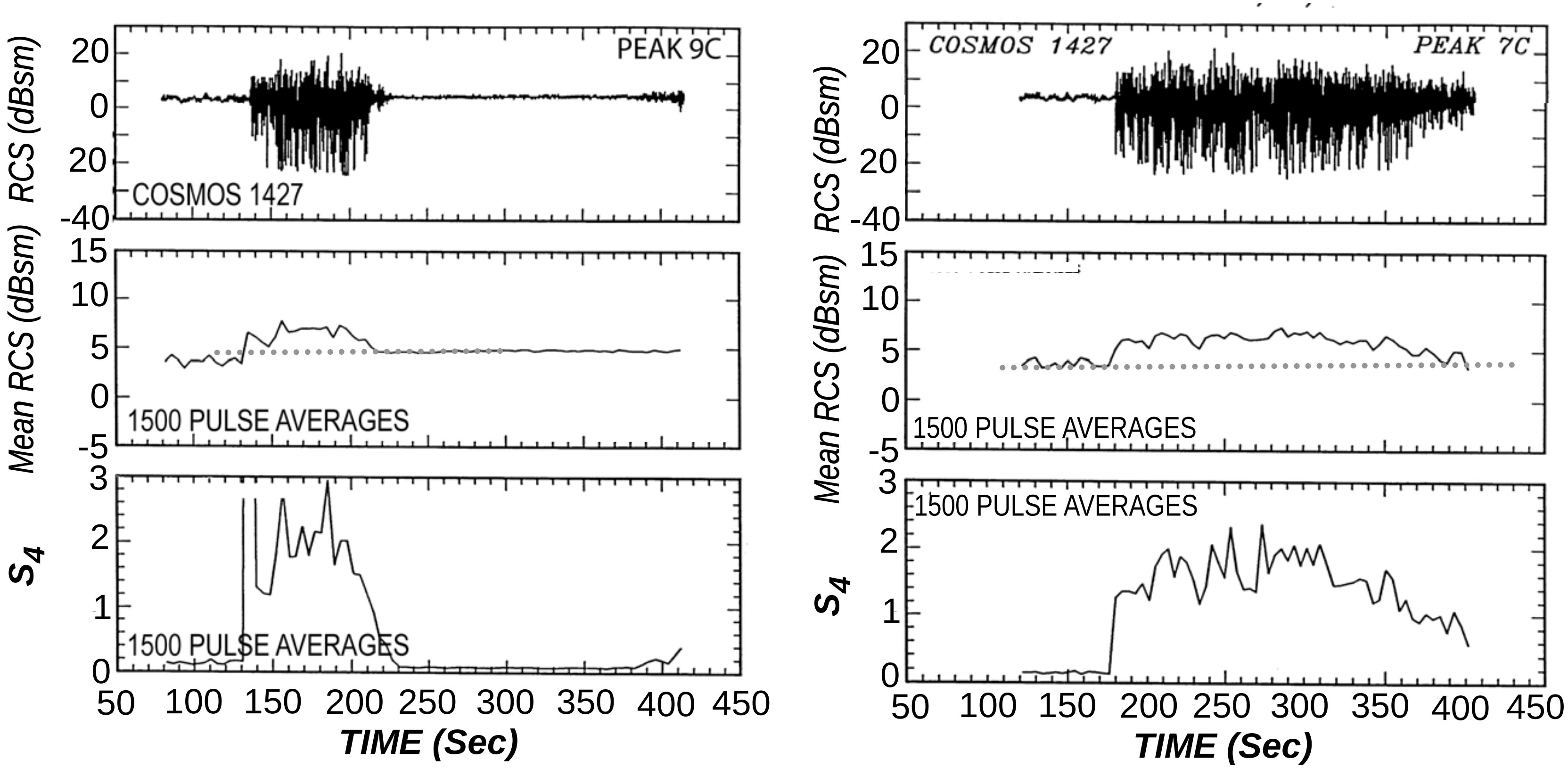
PEAK and WIDE Ionospheric Radar Experiments

- **PEAK - Propagation Effects Experiment – Kwajalein**
  - **August 1988, two years prior to solar maximum**
  - **ALTAIR radar used to track calibration spheres and other satellites of opportunity to help understand radar performance during scintillation**
- **WIDE – Wideband Ionospheric Distortion Experiment**
  - **Characterize the impulse response function of the equatorial ionosphere**
  - **January 2005, four years after solar maximum**
- ***Both experiments* collected high pulse repetition data (350 Hz) coherent I&Q data during passes of calibration spheres in orbits above the peak of the ionosphere**
  - **Simultaneous VHF and UHF pulses**

Primary Accomplishments of the PEAK and WIDE Experiments

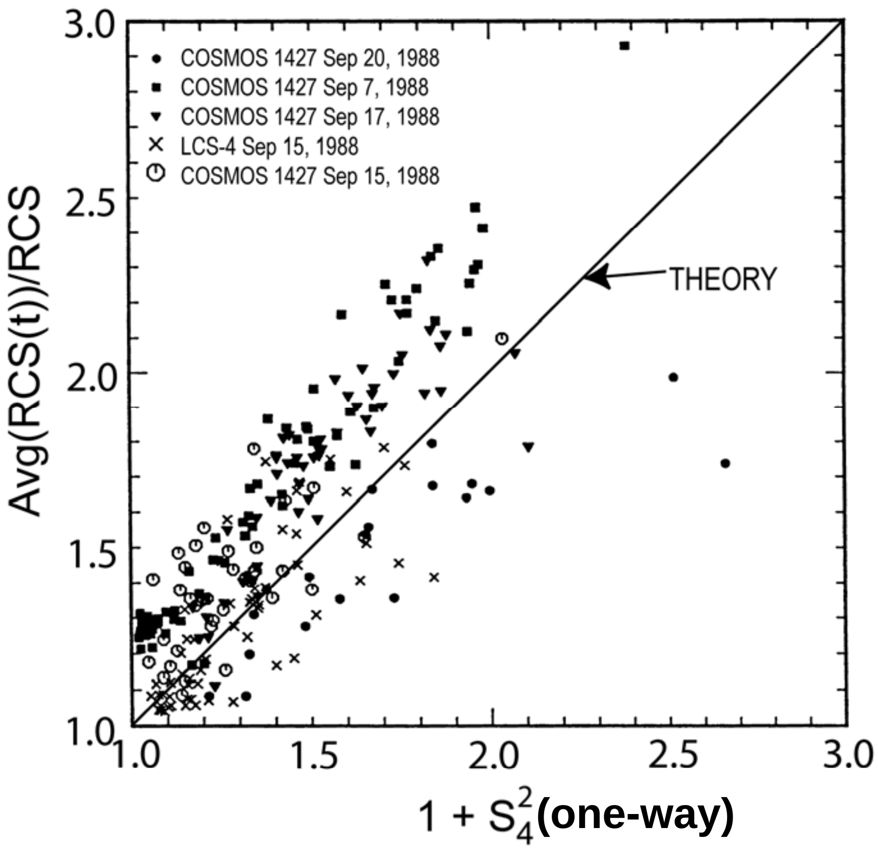
- **Measured the statistics of received power for two-way (radar) propagation**
  - **Prior to PEAK, the community disagreed on some aspects of two-way propagation theory**
  - **PEAK had the first observations of the enhancement in average received radar power from monostatic radar**
- **WIDE additionally measured the coupled channel impulse response function (range-doppler power spectra) and showed serious scintillation near the middle of the solar cycle**

UHF Scintillation Observed During ALTAIR Radar Track of a Large Russian Calibration Sphere



- **Notice the increase in average measured RCS coincident with the presence of severe multipath fading**

Comparison of Average RCS Enhancement and Theory



- **The ALTAIR data give a good fit to theory**

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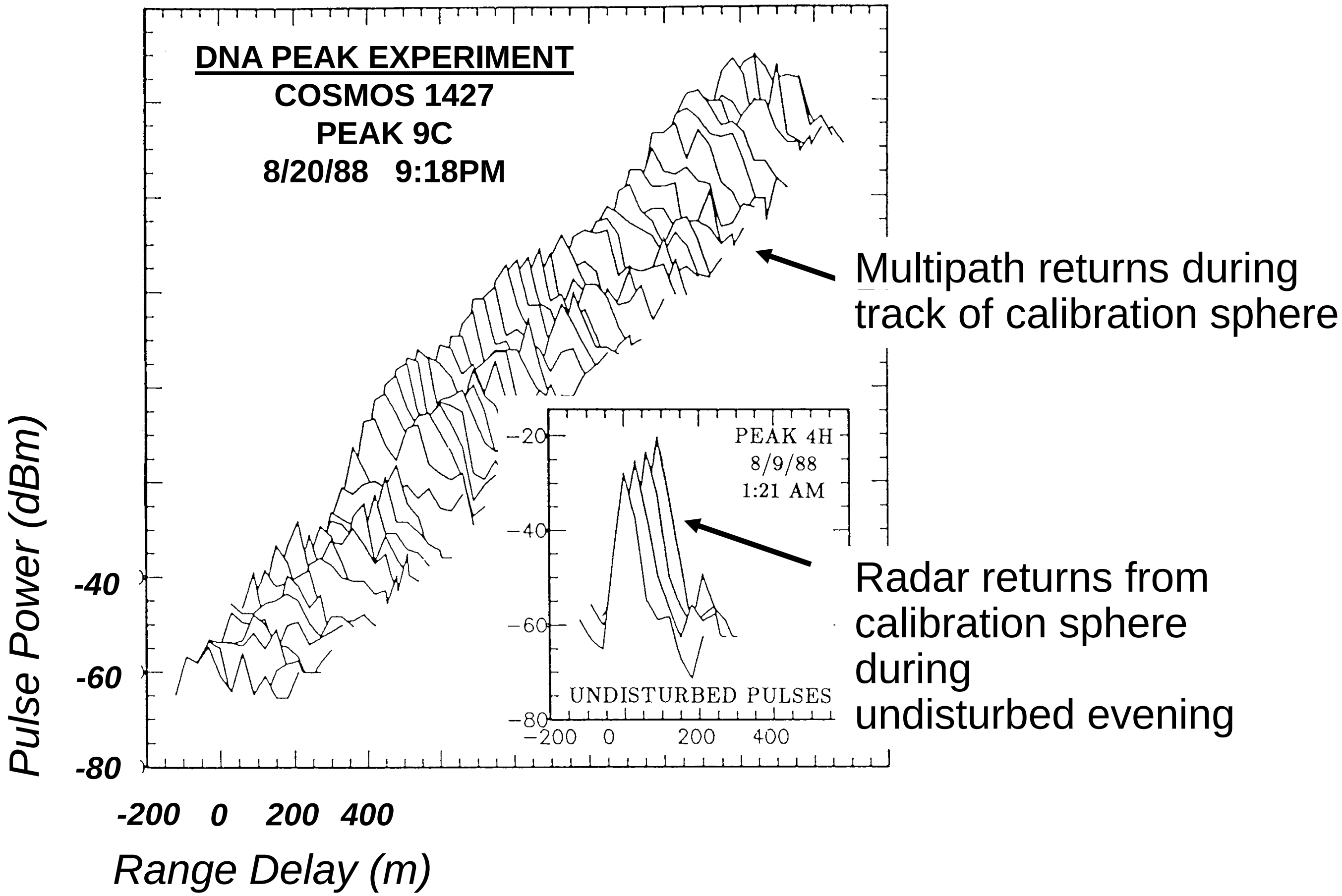
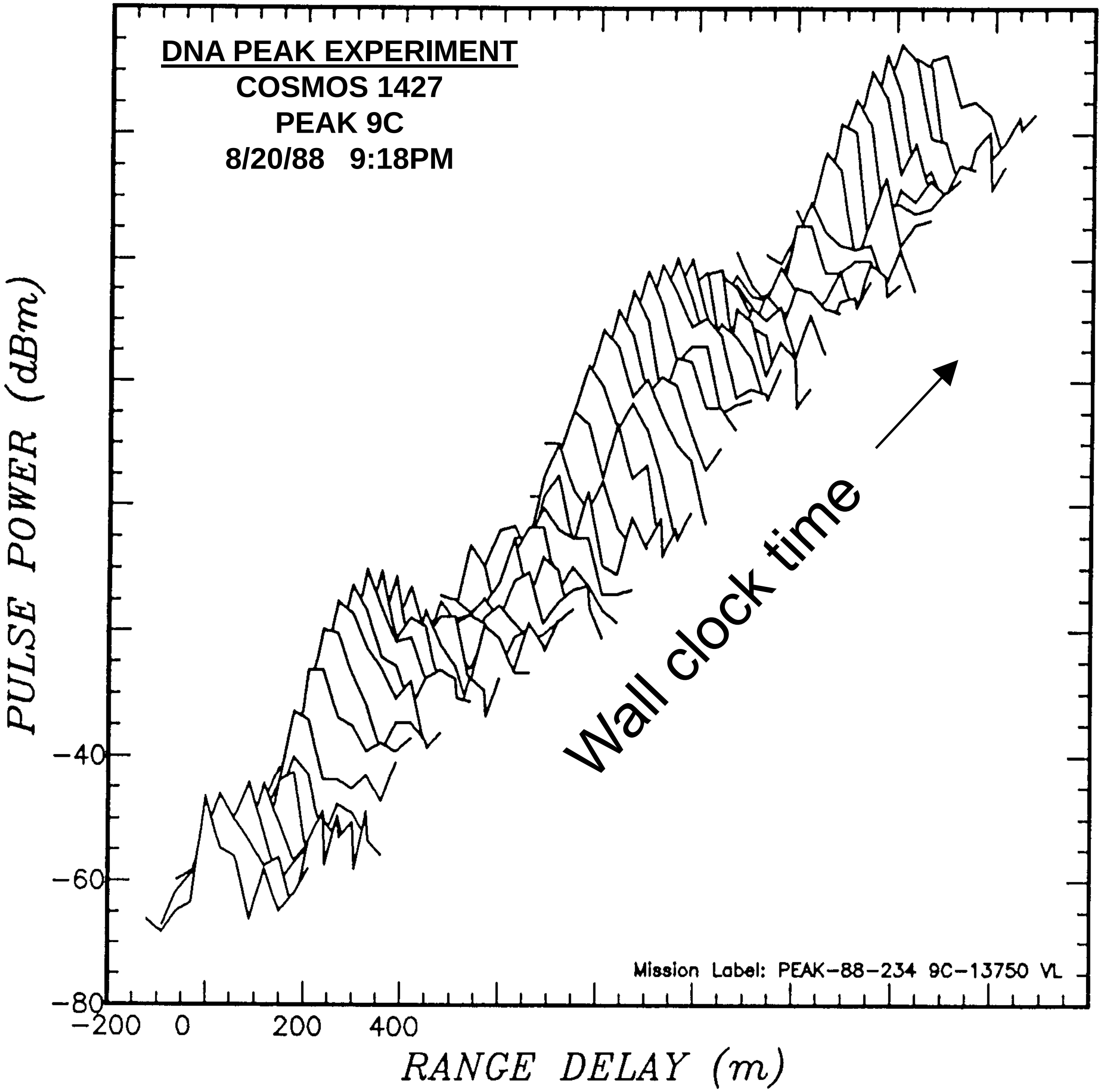
ALTAIR Measurements of Frequency-Selective Scintillation

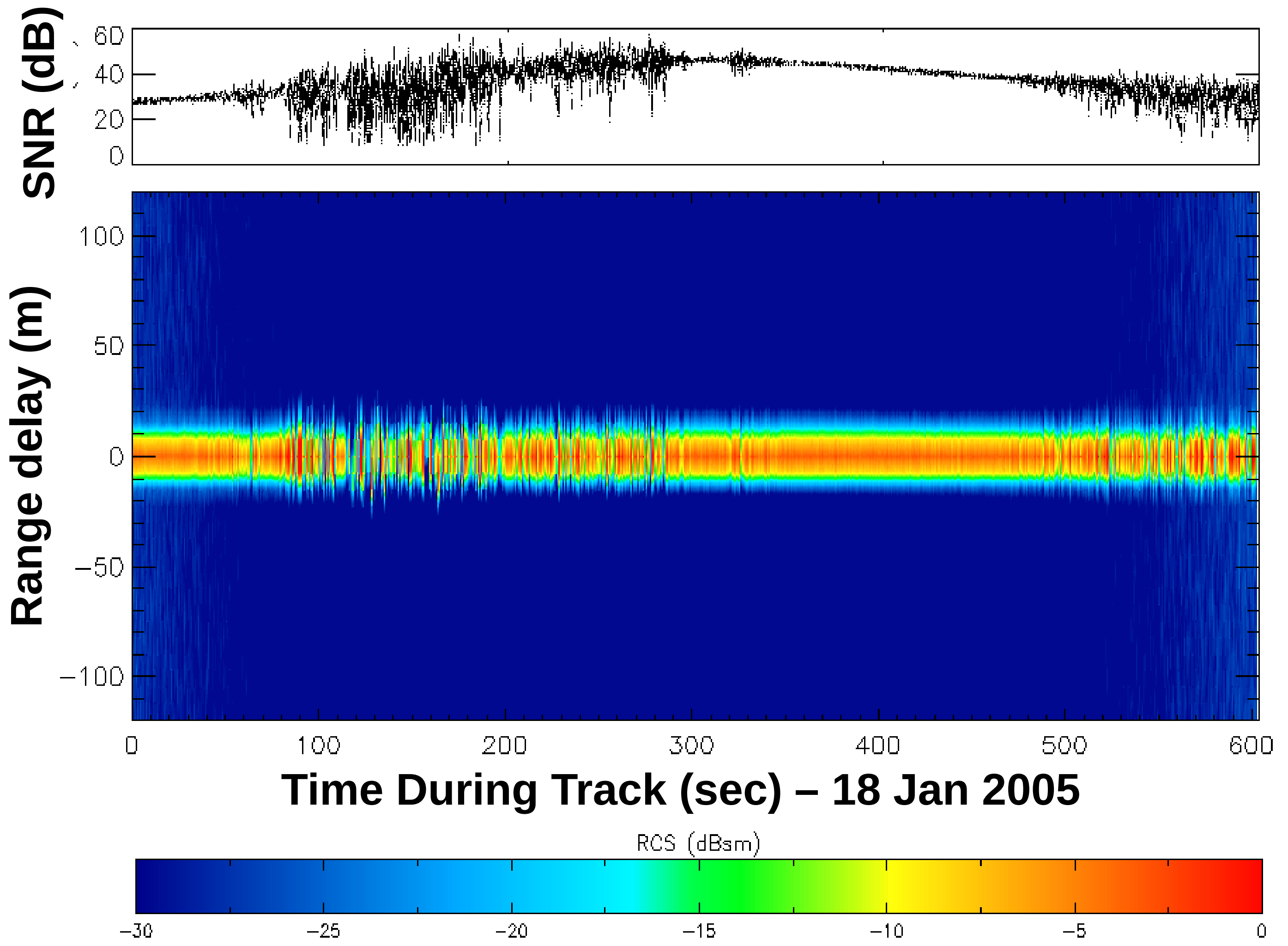


Multipath from frequency-selective scintillation can severely degrade radar performance

ALTAIR Measurements of Frequency-Selective Scintillation



SNR and Range Delay During Track of Calibration Sphere – UHF – 422 MHz



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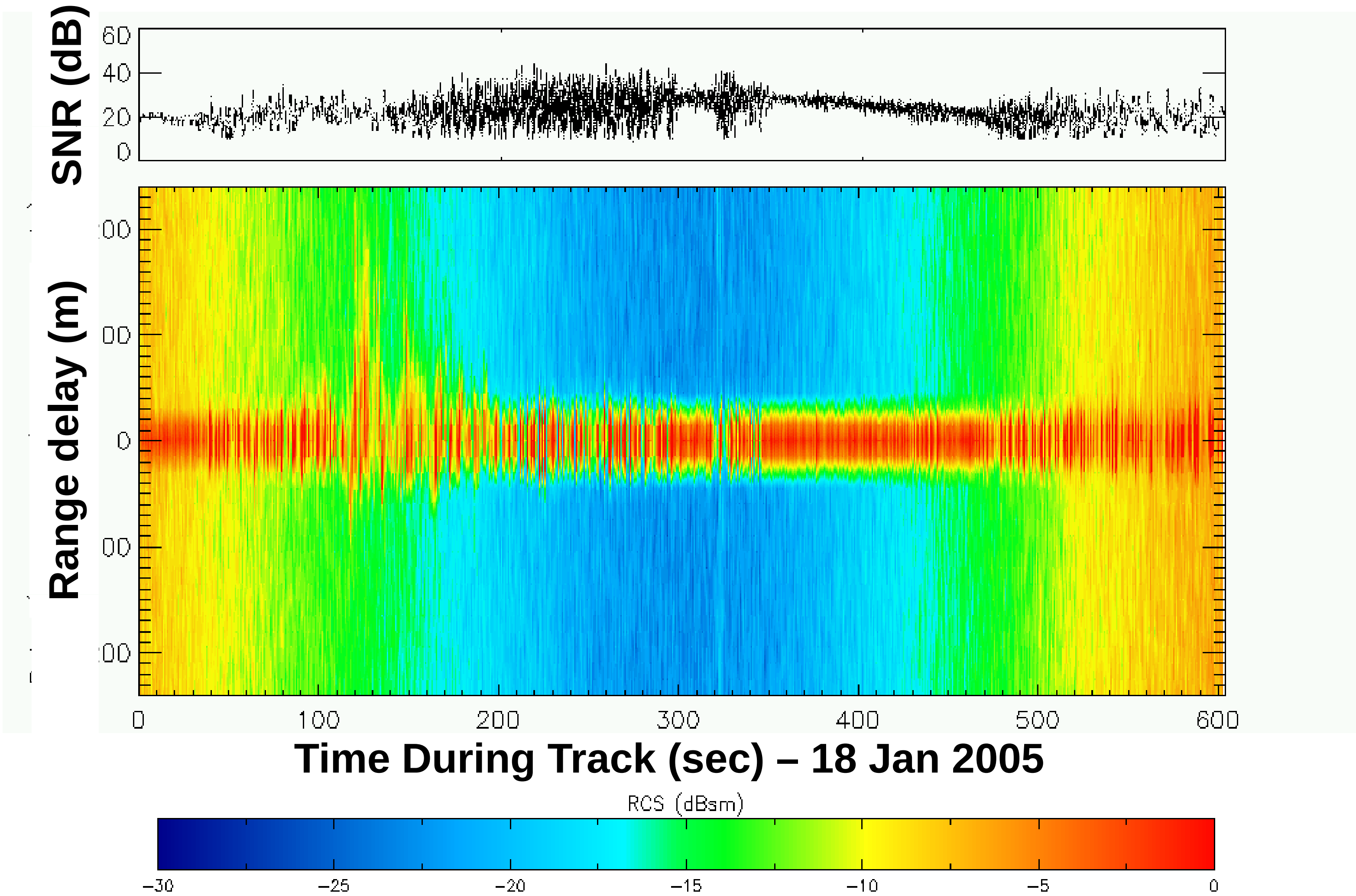
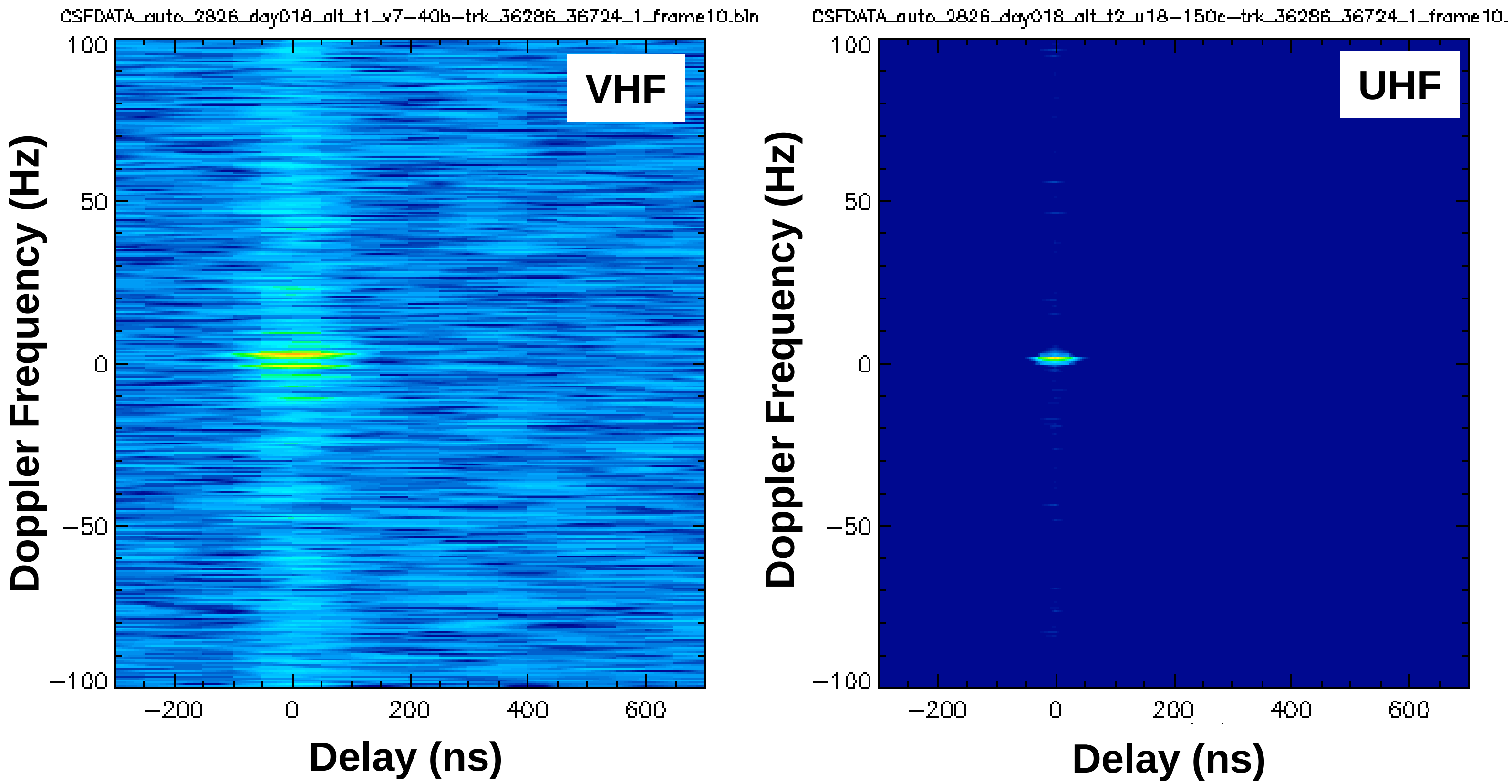
SNR and Range Delay During Track of Calibration Sphere – VHF – 158 MHz

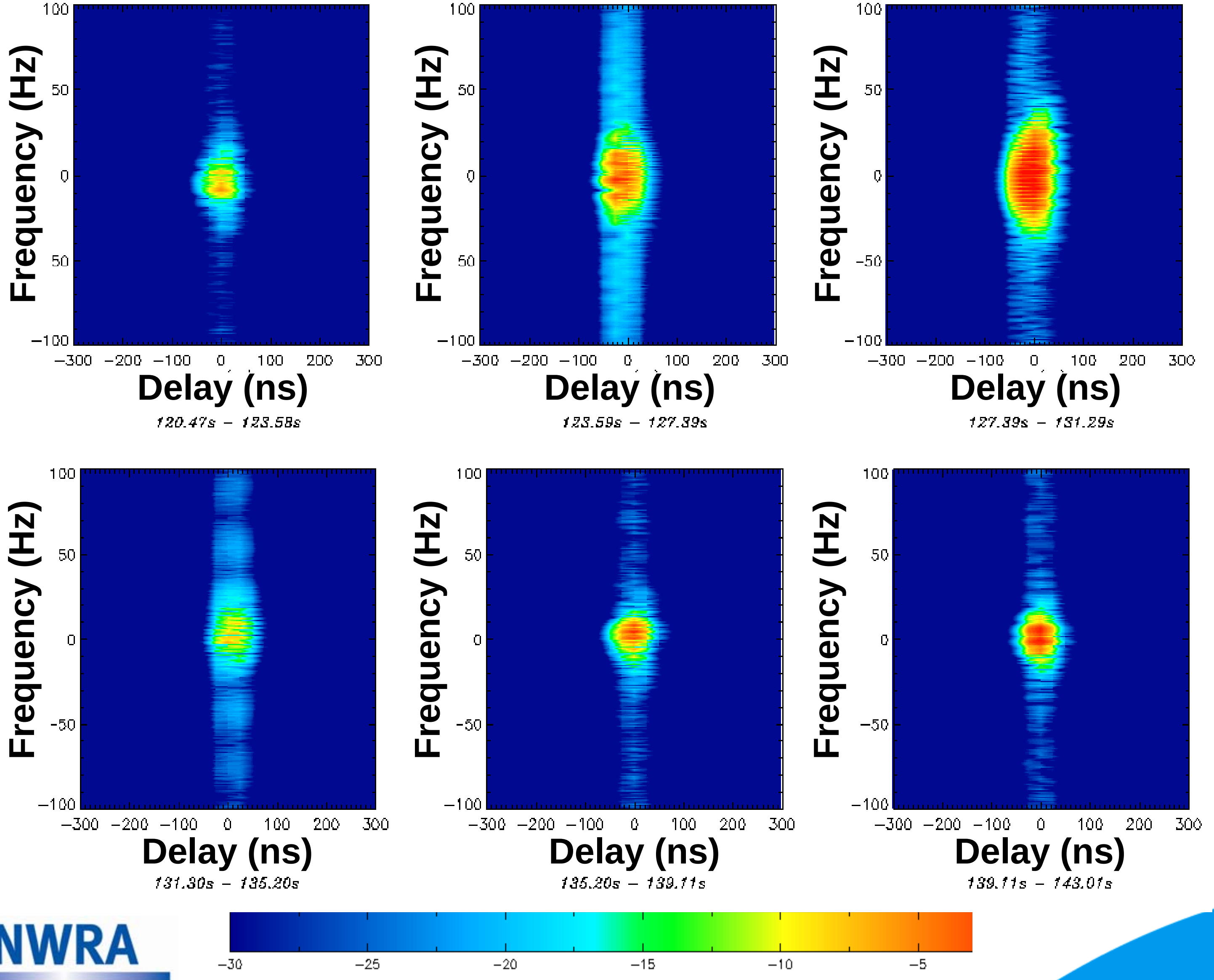


Delay-Doppler Power Spectra
Case of No Scintillation



Delay-Doppler power spectra for the case of no scintillation – shows the radar resolution

Delay-Doppler Power Spectra during Track of Calibration Sphere – UHF – 422 MHz



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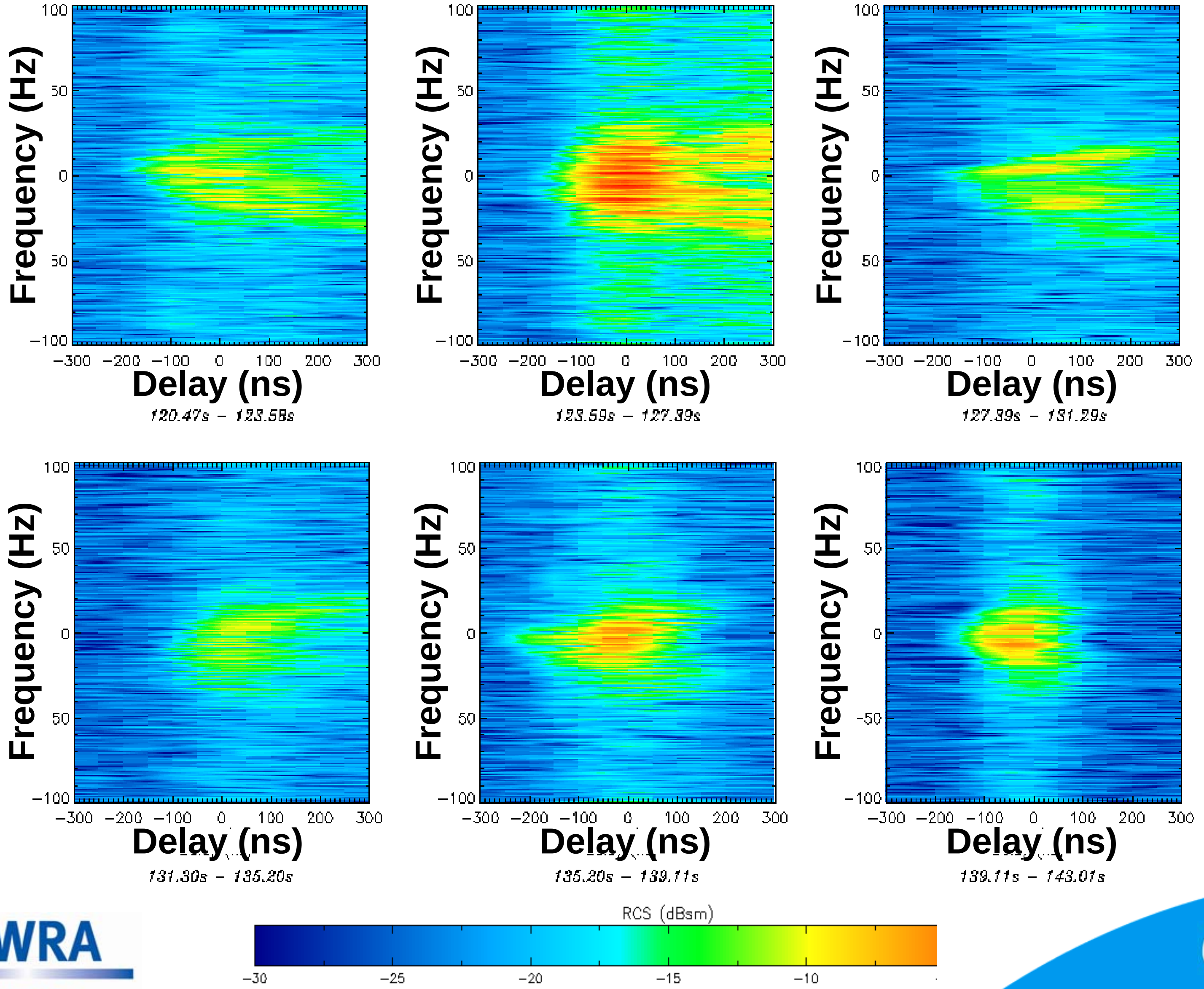
Delay-Doppler Power Spectra during Track of Calibration Sphere – VHF – 158 MHz



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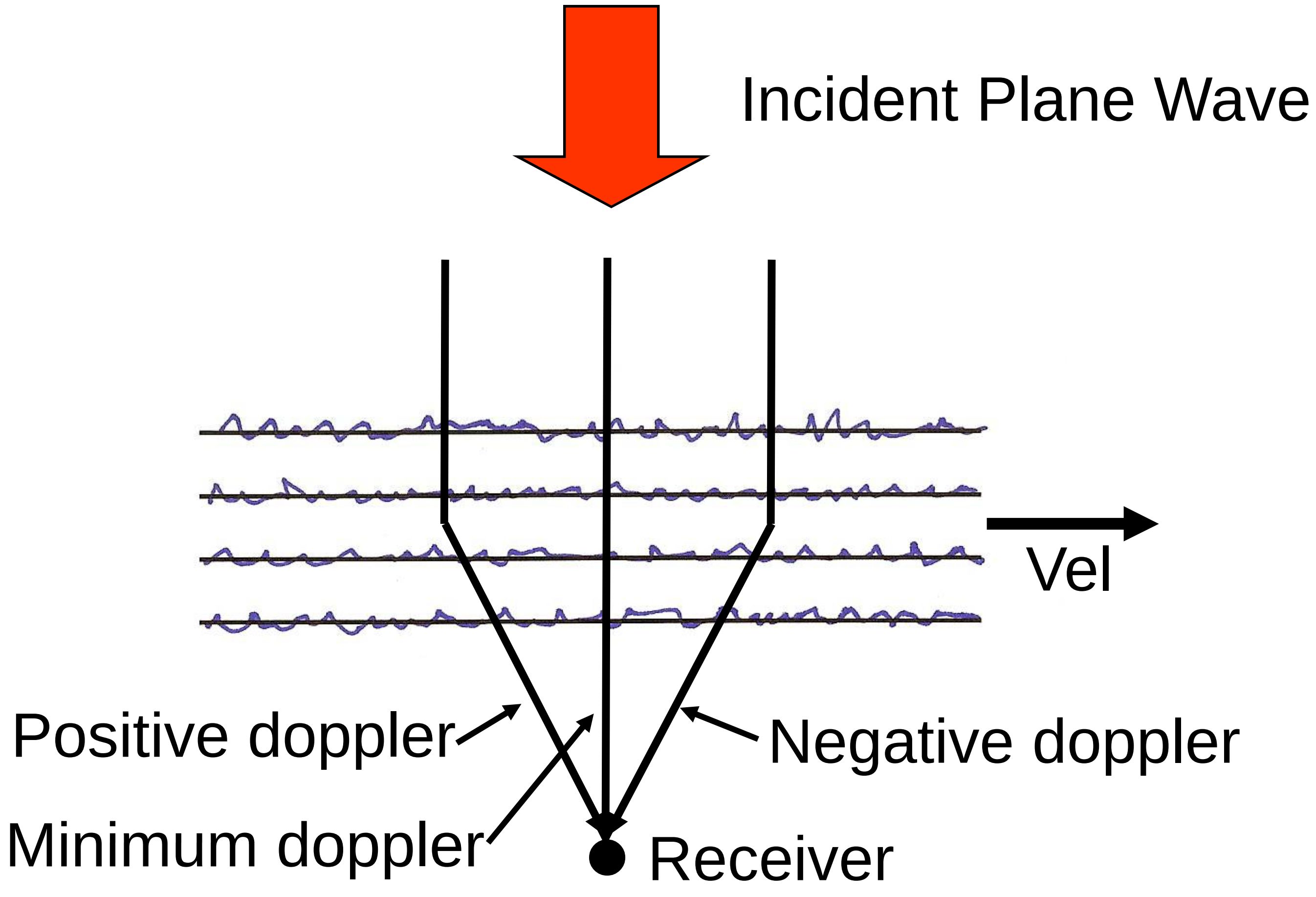
Explanation of Horseshoe Shape of the Delay-Doppler Power Spectrum



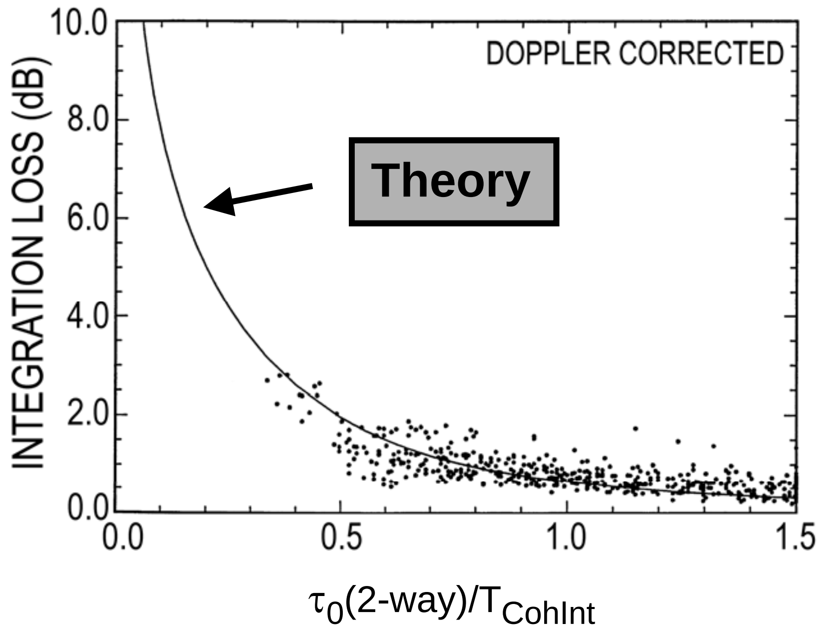
A Space-Based Radar Must Perform Coherent Integration

- **Synthetic aperture radar:**
  - Synthetic aperture radars (SARs) always perform coherent integration
  - SARs are vulnerable to phase fluctuations (which can be accompanied by amplitude scintillation)
  - Wideband SAR at low frequencies may experience dispersion
- **MTI radar:**
  - The radar generally is limited in transmit power
  - Space based MTI radars use Doppler processing to separate target returns from the return from the earth return
  - The radar return from the earth is large but appears at a known Doppler
  - Interesting targets are generally small – coherent integration is needed to increase the signal-to-noise ratio

Wideband Satellite Data

- Defense Nuclear Agency Wideband Satellite: 1976-1979
- Sun synchronous polar orbit, 1000 km altitude
- Passed over Marshall Islands near midnight, every night
- Transmitted coherent CW tones
  - VHF (155 MHz)
  - 7 UHF tones (378, 390, 402, 413, 425, 436, 447 MHz)
  - L-band (1239 MHz)
  - S-band (2891 MHz, used as the phase reference)
- Wideband measured the amplitude and phase of transionospheric signals at a 250 Hz rate
- Total of 2170 passes observed. Many passes were collected from receivers at Kwajalein, Marshall Islands and Ancon, Peru

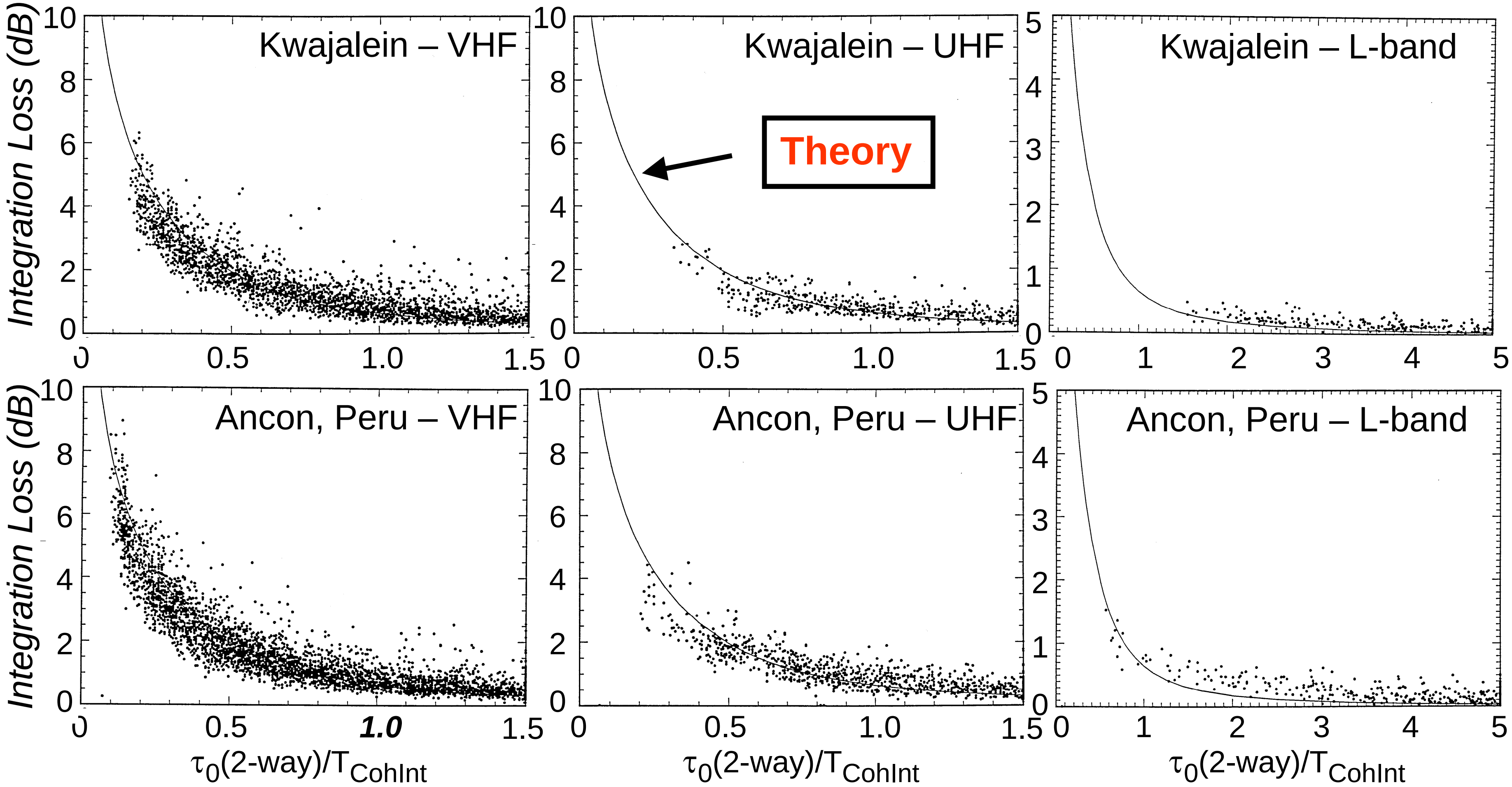
Calculated Coherent Integration Loss from Collected Wideband Satellite Data



Loss is always accompanied by doppler spread and increased sidelobe levels

- **Collected Wideband data was squared to simulate monostatic radar and then analyzed to obtain the coherent integration performance as a function of the propagation channel decorrelation time**
- **Figure shows results of the analysis of the UHF data from 19 passes as observed from Kwajalein (here T_{CI} = 0.256 seconds)**

Calculated Coherent Integration Loss in SNR from Collected Wideband Satellite Data



- *Results generated from collection of 41 of the most seriously disturbed passes in 1977, 3 years prior to solar max*

Conclusions

- The natural ionosphere can be important for ground and space based radar for frequencies from VHF through GHz
- Ionospheric scintillation is most severe for lower frequencies (VHF/UHF) but can also be significant for higher frequencies (L-band through X-band), depending on the radar system requirements
- Synthetic aperture radars
  - Techniques are available to correct for phase fluctuations due to platform motion, where all range cells in a pulse experience the same phase deviation (with no amplitude variation)
  - Ionospheric amplitude and phase fluctuations will require more advanced compensation techniques
  - Wide bandwidth UHF SAR systems may be affected by ionospheric dispersion. Mitigation will be needed to restore range resolution
- The 2012 solar maximum offers an opportunity to collect important data