Jicamarca Beacon Processing using Open Source Beacon Recording and Processing Package

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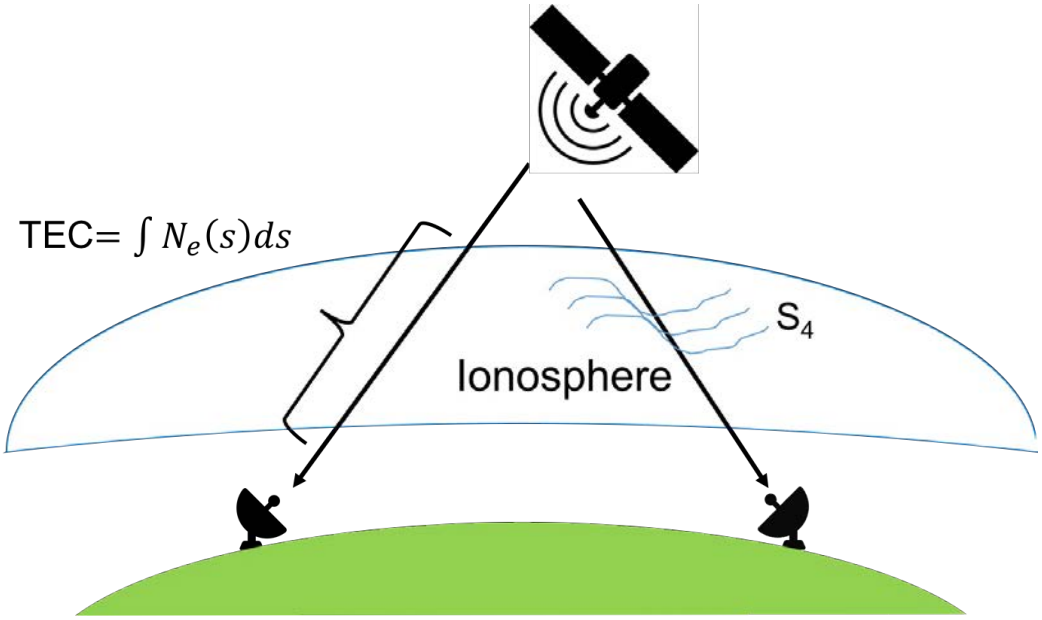
Beacon Receiver

- Total Electron Content (TEC), the number of electrons integrated along a line – a columnar measurement (el/m²)

- S4, σ_ϕ : Indices that measure scintillation



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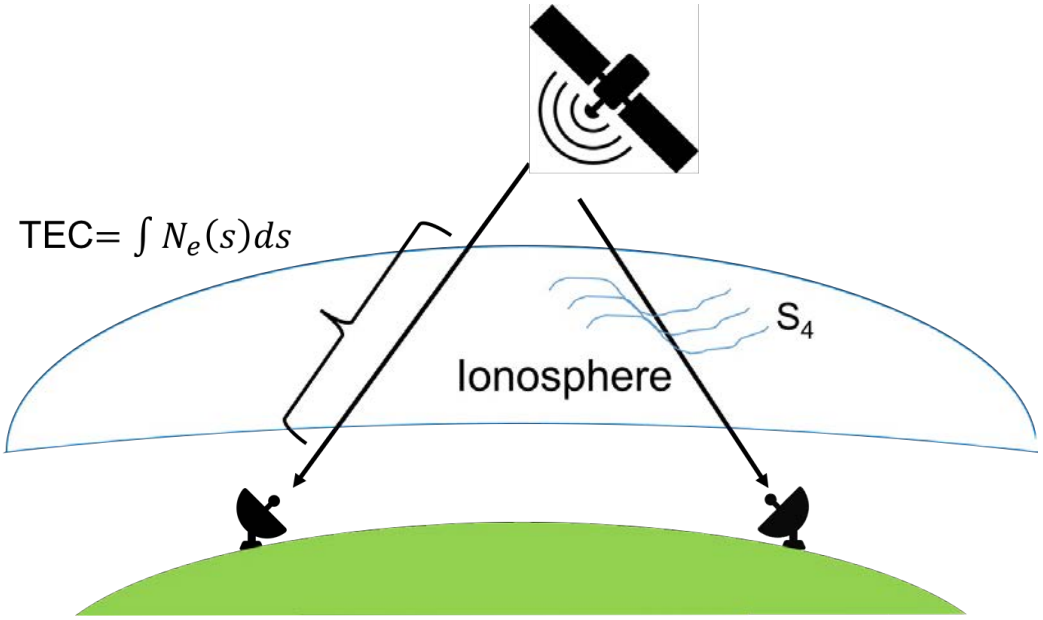
Beacon Receiver

- Signal Model
  - $x(t) = e^{j\omega_0 t + \phi_0(t)}$
  - $\phi_0(t) = \frac{\omega_0}{c}\int_0^{L(t)} N_e(s)ds$



- Need two signals

$$\left(\frac{\omega_1}{\omega_0}\phi_0(t) - \phi_1(t)\right)\frac{1}{a}\left(\frac{\omega_1}{\omega_0^2} - \frac{1}{\omega_1}\right)^{-1} = \int_{L_0(t)}^{L(t)} N_e(s)ds + const.$$

$$a = \frac{q^2}{2\epsilon_0 m_e c}$$

Vierinen et al. 2013

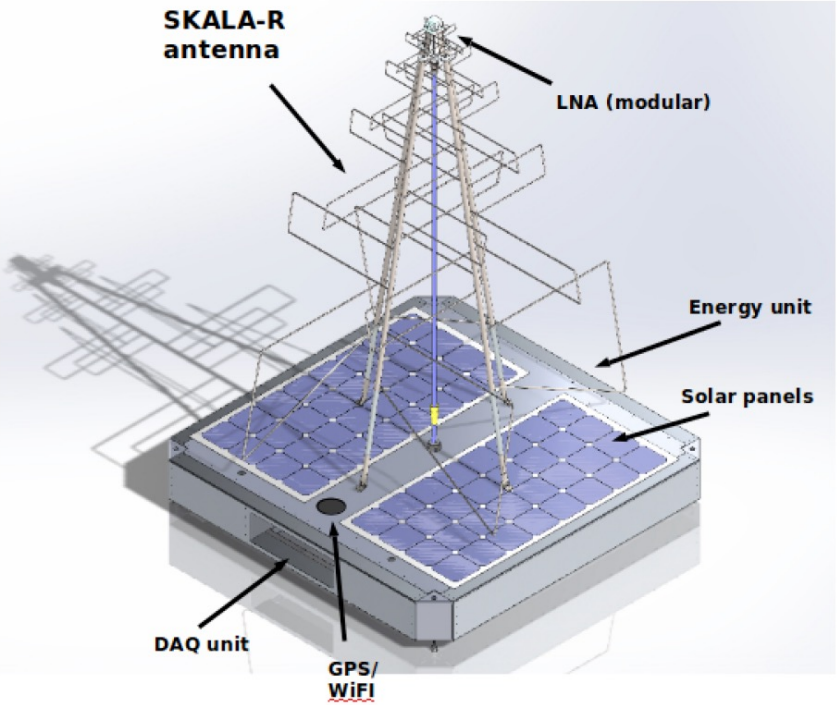
Siefring et al. 2011

Bernhardt et al. 2006

Data Collection

- RAPID: Radio Array of Portable Interferometric Devices

- SKALA: Square Kilometer Array Low-Frequency Antenna



RAPID antenna and base

Lind et al. 2013

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Data Collection Sites

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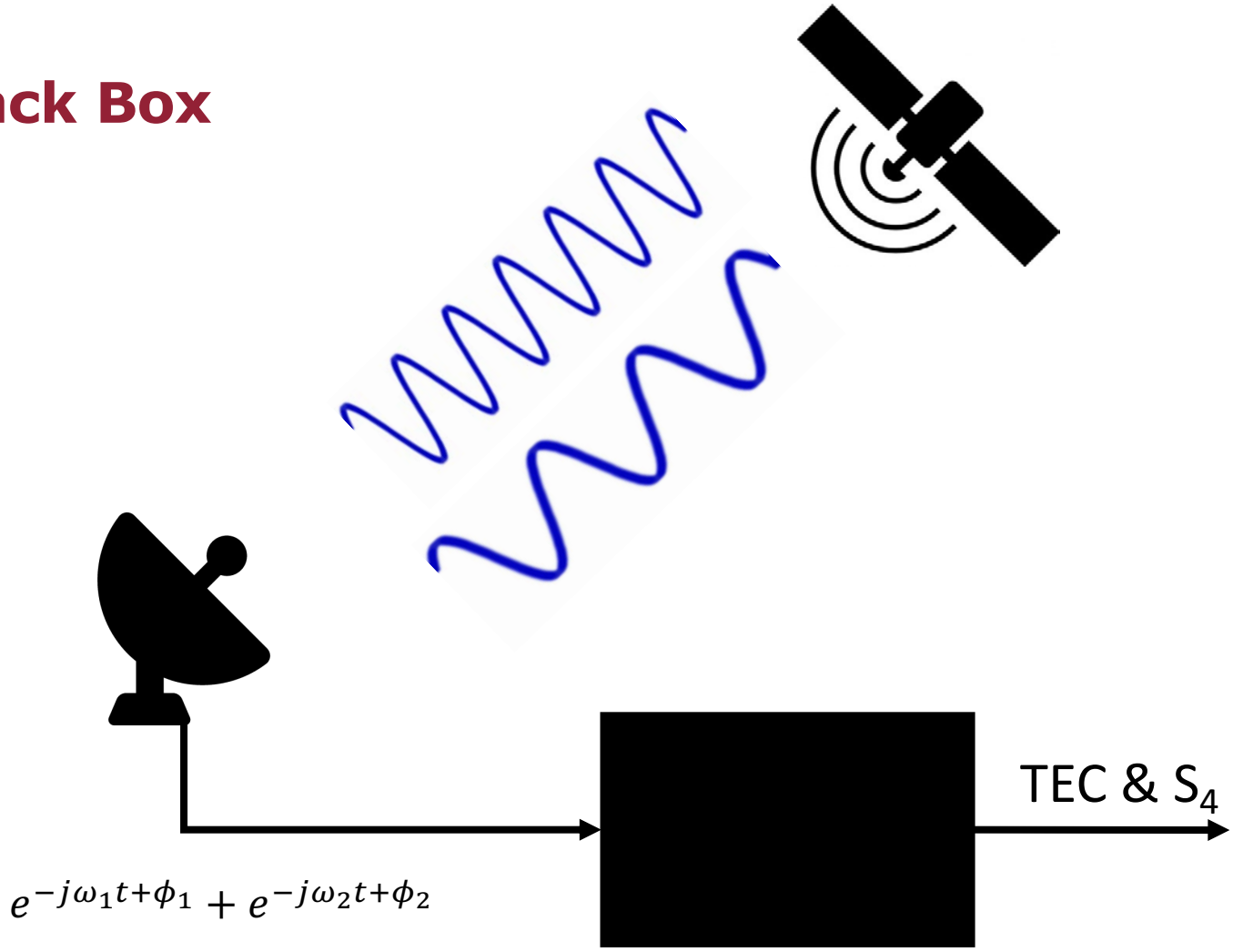
Black Box



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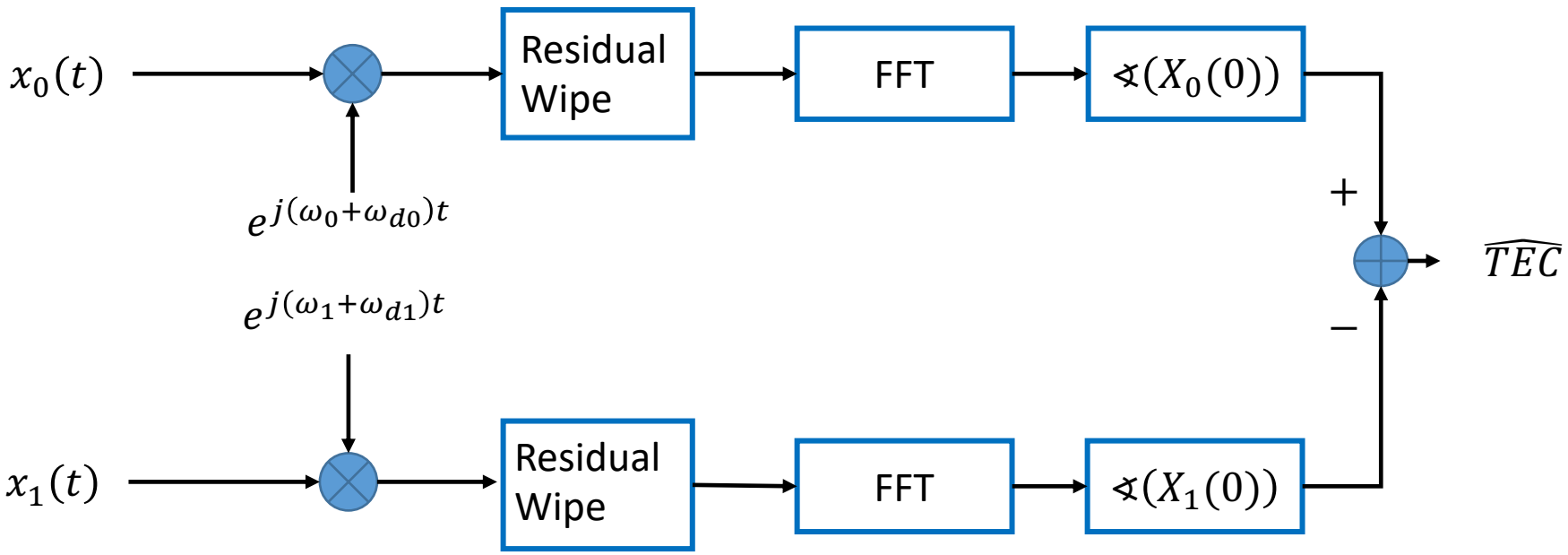
Signal Processing



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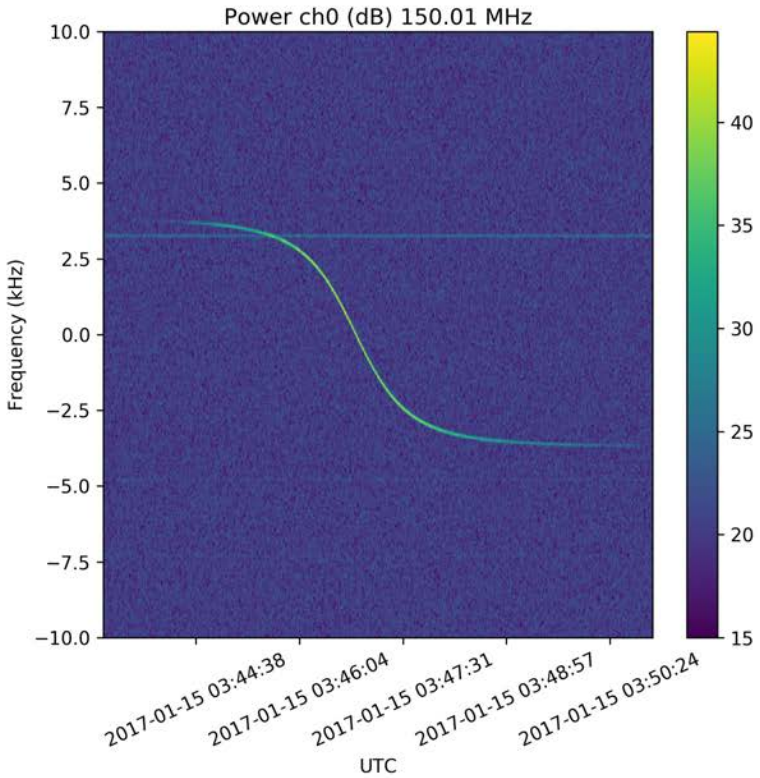
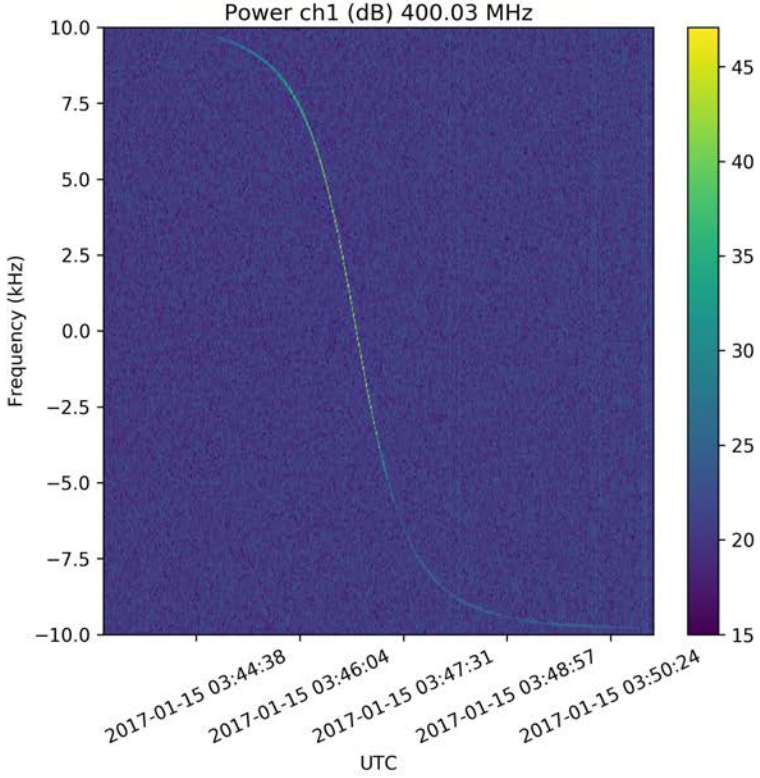
Data Example: 2017-01-15 ~03:45 UT





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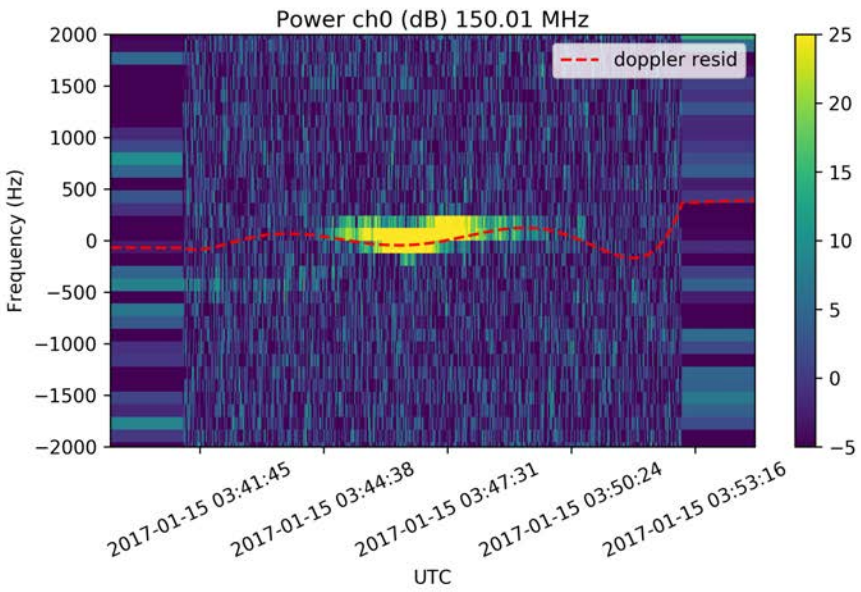
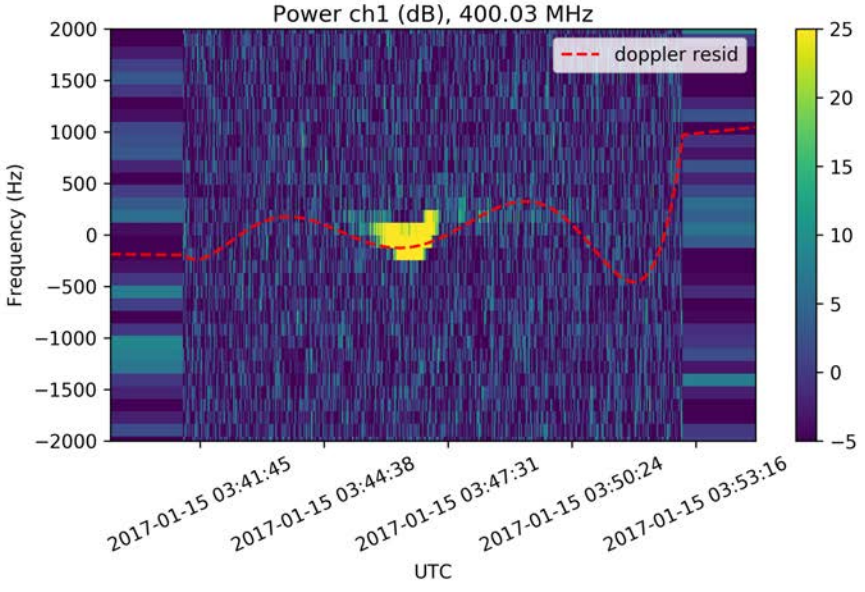
Residual Example: 2017-01-15 ~03:45 UT





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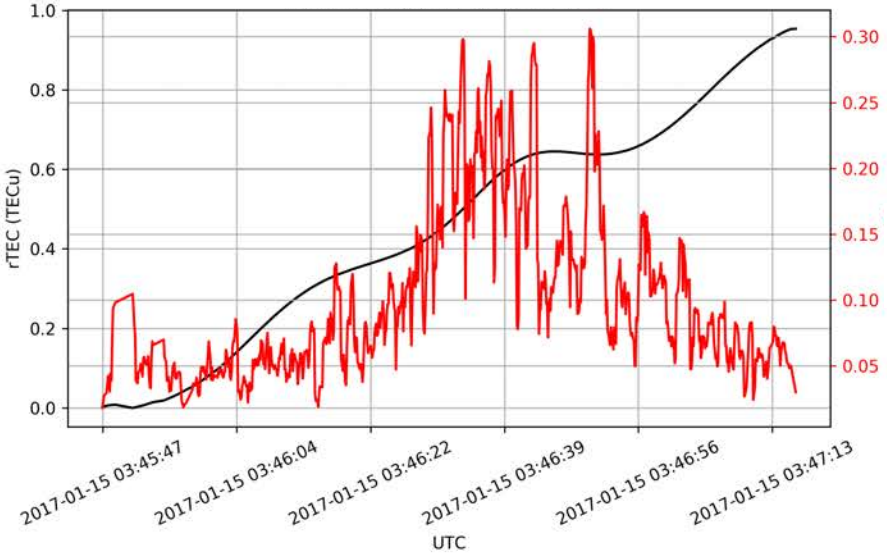
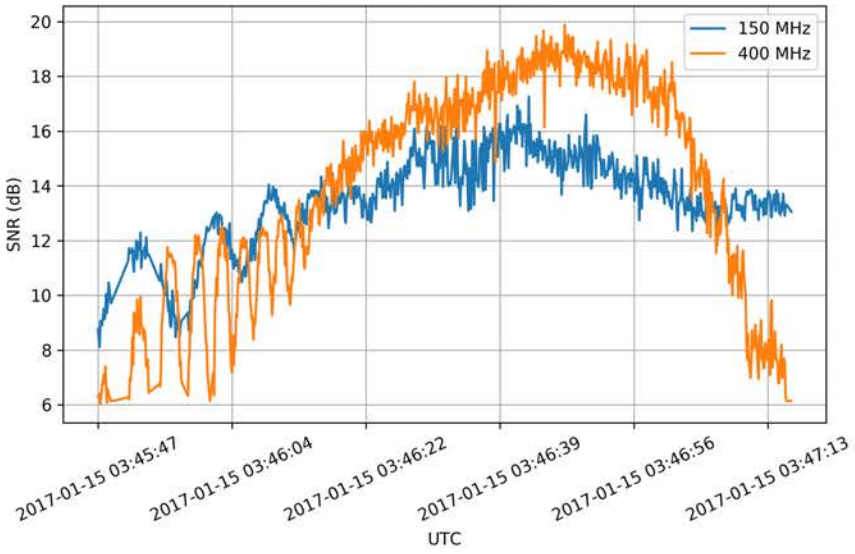
Final TEC Measurement: 2017-01-15 ~03:45 UT

Relative TEC (rTEC - Black Line)



SNR for Both Channels



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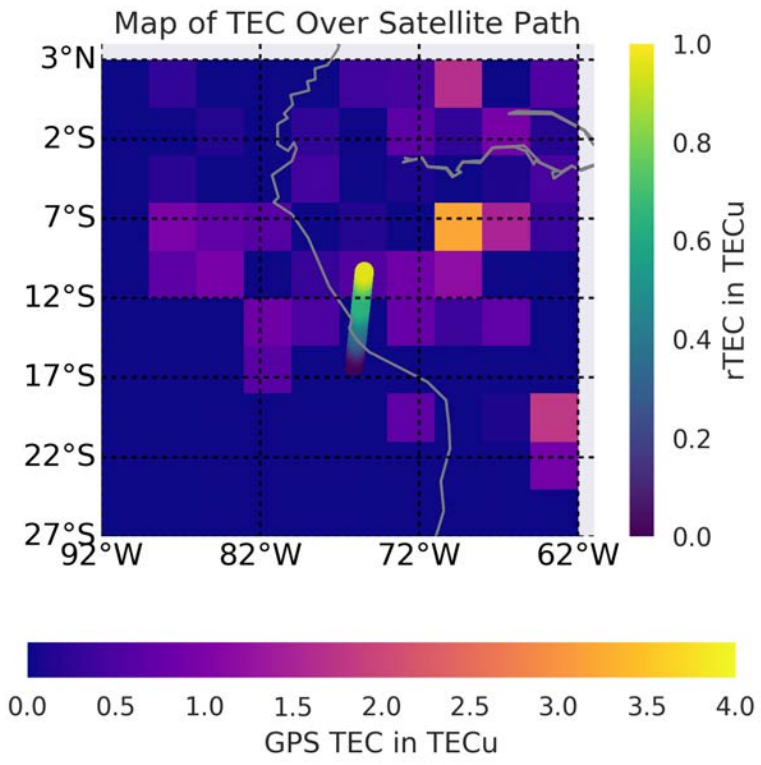
Final TEC Measurement



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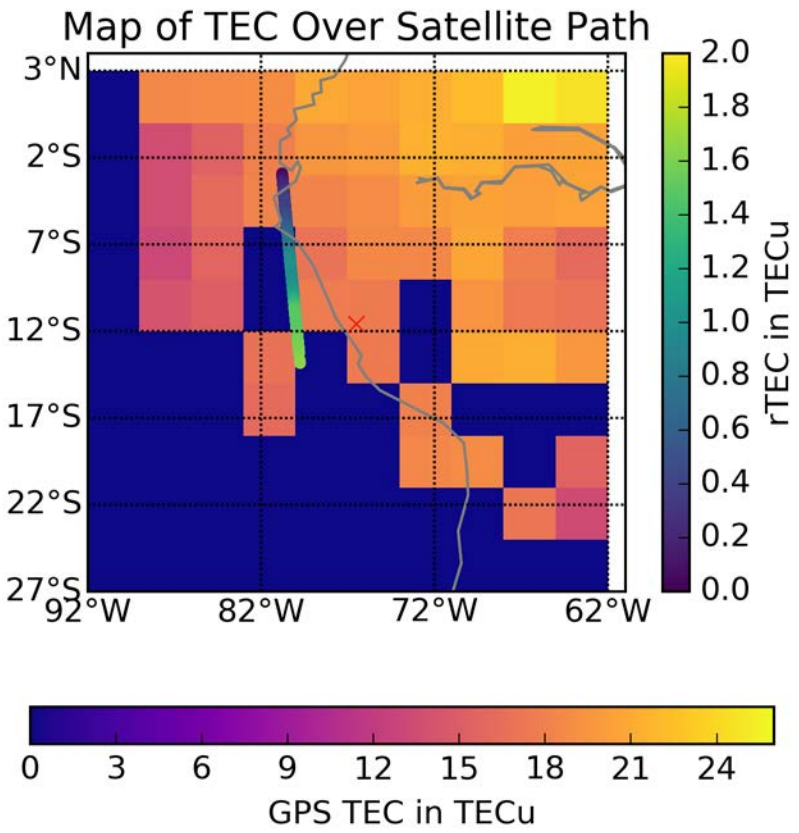
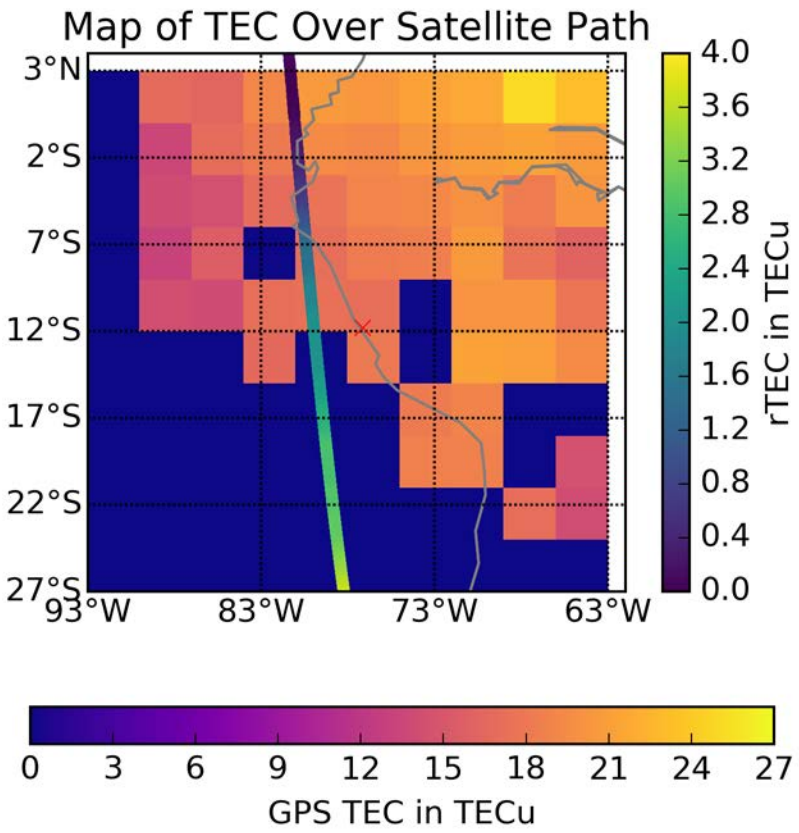
Comparison of Two Sites – Feb 9, 2017

Meriwether Hill



Ancon



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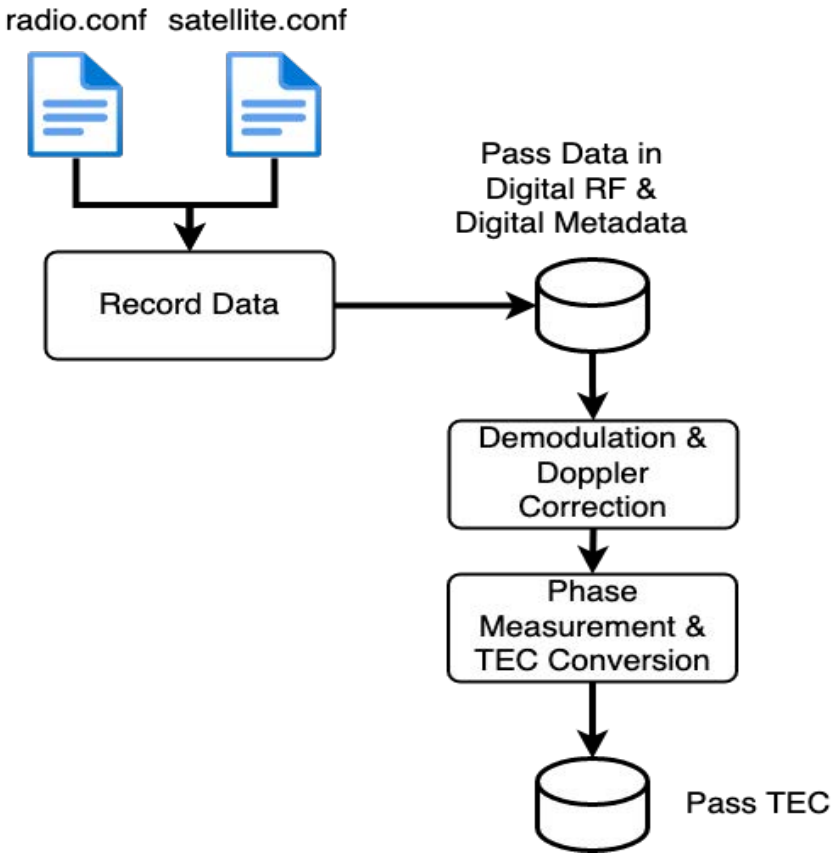
February 9th Data

Beacon Processing Flow

- Radio config contains
  - Center Frequencies,
  - BW,
  - Radio type
  - Number of frequencies
  - Antenna
- Satellite config uses TLEs
  - Used to derive Doppler
- Recording creates metadata and sets up recording processes when satellite is in view



- Recorded data kept for reprocessing purposes
  - Digital RF and Digital Metadata formats allow for long term archival
- If coded wave form can add pluggin as part of Doppler correction
- TEC derived from N channels
  - N >= 2

Current Status/Future

- Processing chain is available with the Digital RF software package
- Develop ways of correlating measurements from different sources
- Extend software for use on inexpensive software defined radios
- Possible future work with cube-sats to get more transmitters

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References

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- P. A. Bernhardt and C. L. Siefring, "New satellite-based systems for ionospheric tomography and scintillation region imaging," *Radio Science*, vol. 41, no. 5, pp. 299–14, 2006.
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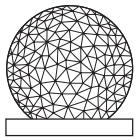
- F. D. Lind, C. J. Lonsdale, A. J. Faulkner, P. Alexander, and C. Mattmann, "Radio array of portable interferometric detectors (RAPID)," presented at the 2013 IEEE International Symposium on Phased Array Systems and Technology (ARRAY 2013), 2013, pp. 676–683.



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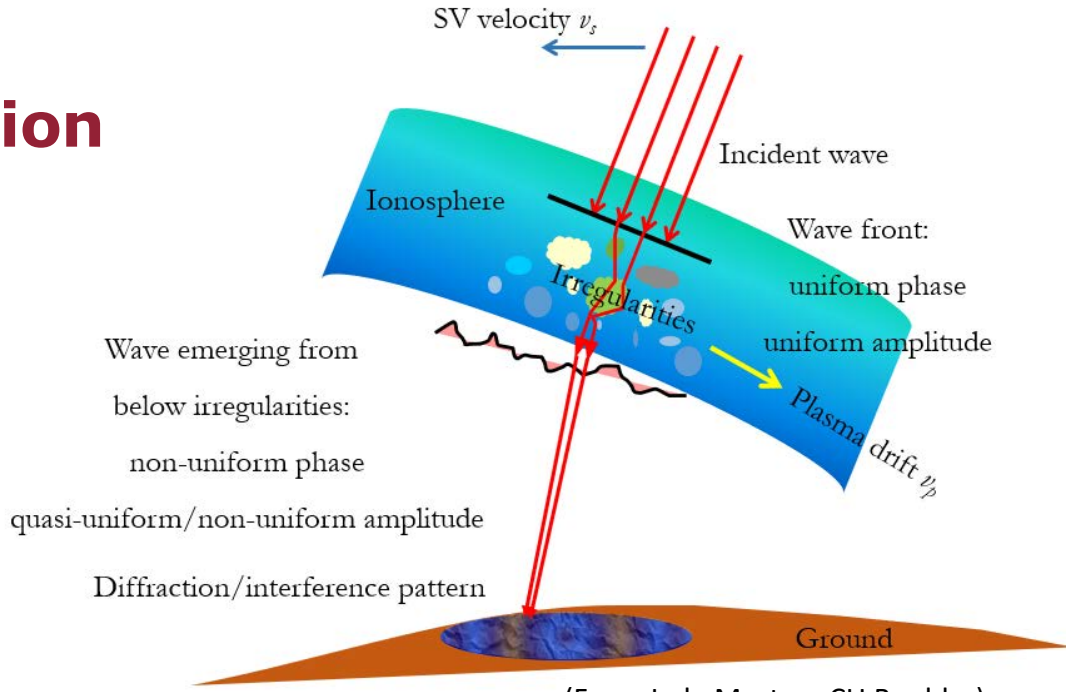
The Science: Scintillation

- Amplitude Scintillation (S4)
  - Root mean square of the intensity of the signal, <> is the ensemble mean,

$$S_4^2 = \left(\langle I^2 \rangle - \langle I \rangle^2\right) / \langle I \rangle^2.$$

- Phase Scintillation (σ_ϕ)
  - The phase shift of a radio wave as it passes through small-scale irregularities in the ionosphere



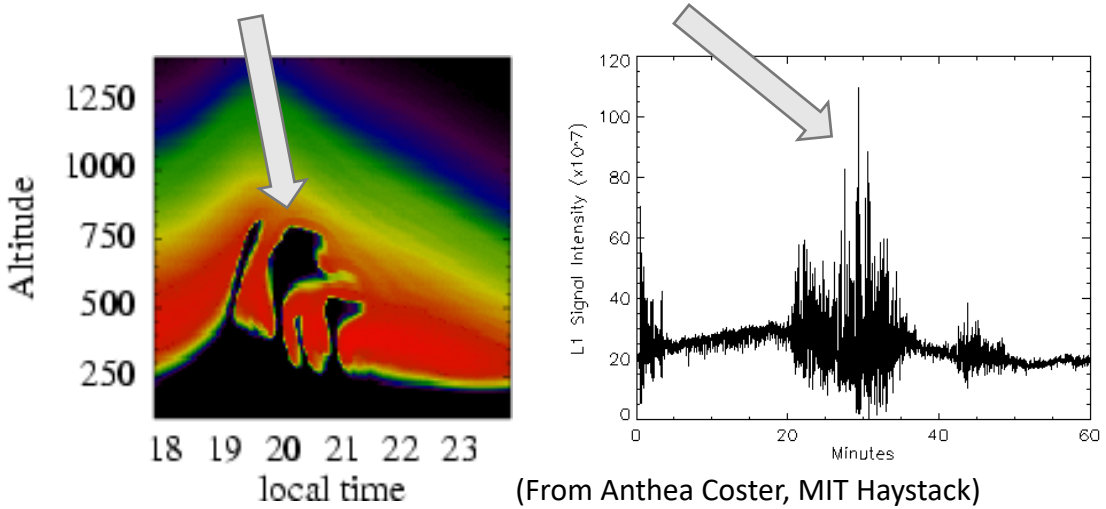
(From Jade Morton, CU Boulder)

$$\sigma_\phi = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2}$$

standard deviation of the signal phase

irregularity

spike in scintillation



(From Anthea Coster, MIT Haystack)

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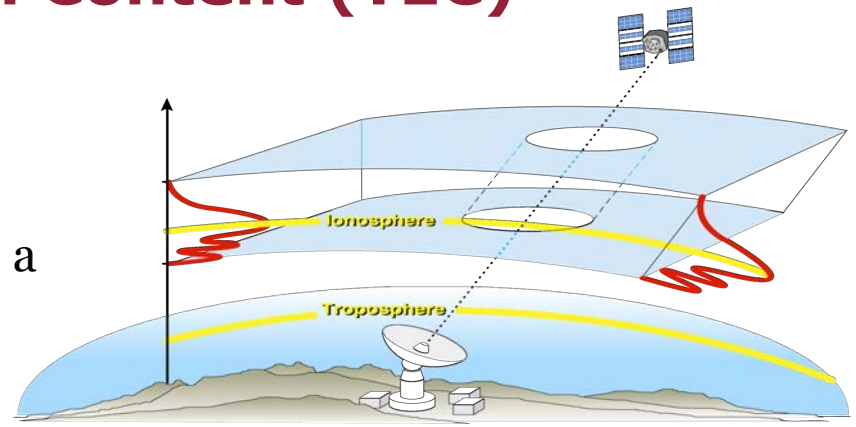
The Science: Total Electron Content (TEC)

- Total Electron Content (TEC)
  - Electron density along a path between a receiver and a satellite
  - Units: 10^{16} electrons/m^2 (1 TECU)



(From Attila Komjathy, JPL)

$$\Delta\phi_{12} = c + \mathrm{b}\int_{L_0(t)}^{L(t)} N_e(z)dz$$

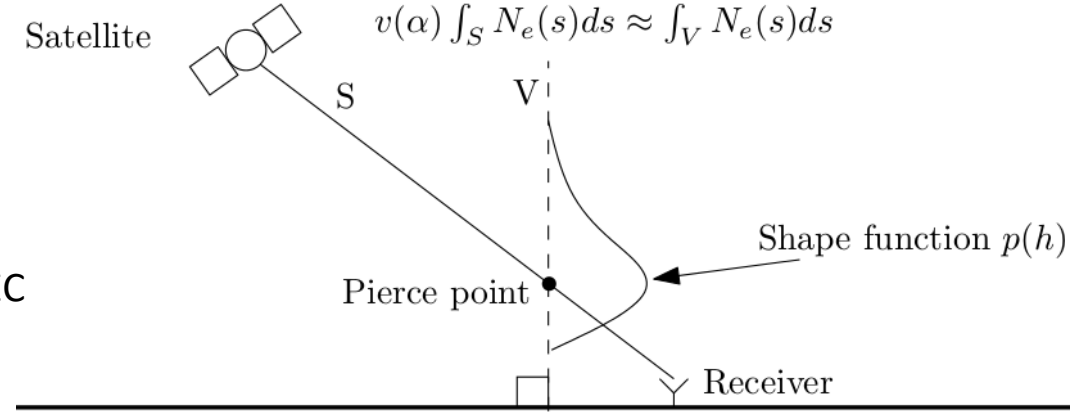
difference in frequency phases of 2 frequencies

phase ambiguity constant

slant TEC

mapping function

$$v(\alpha)\int_S N_e(s)ds \approx \int_V N_e(s)ds$$



(From Vierinen et al. 2016)

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