Investigating Ionospheric Corruptions in Imaging

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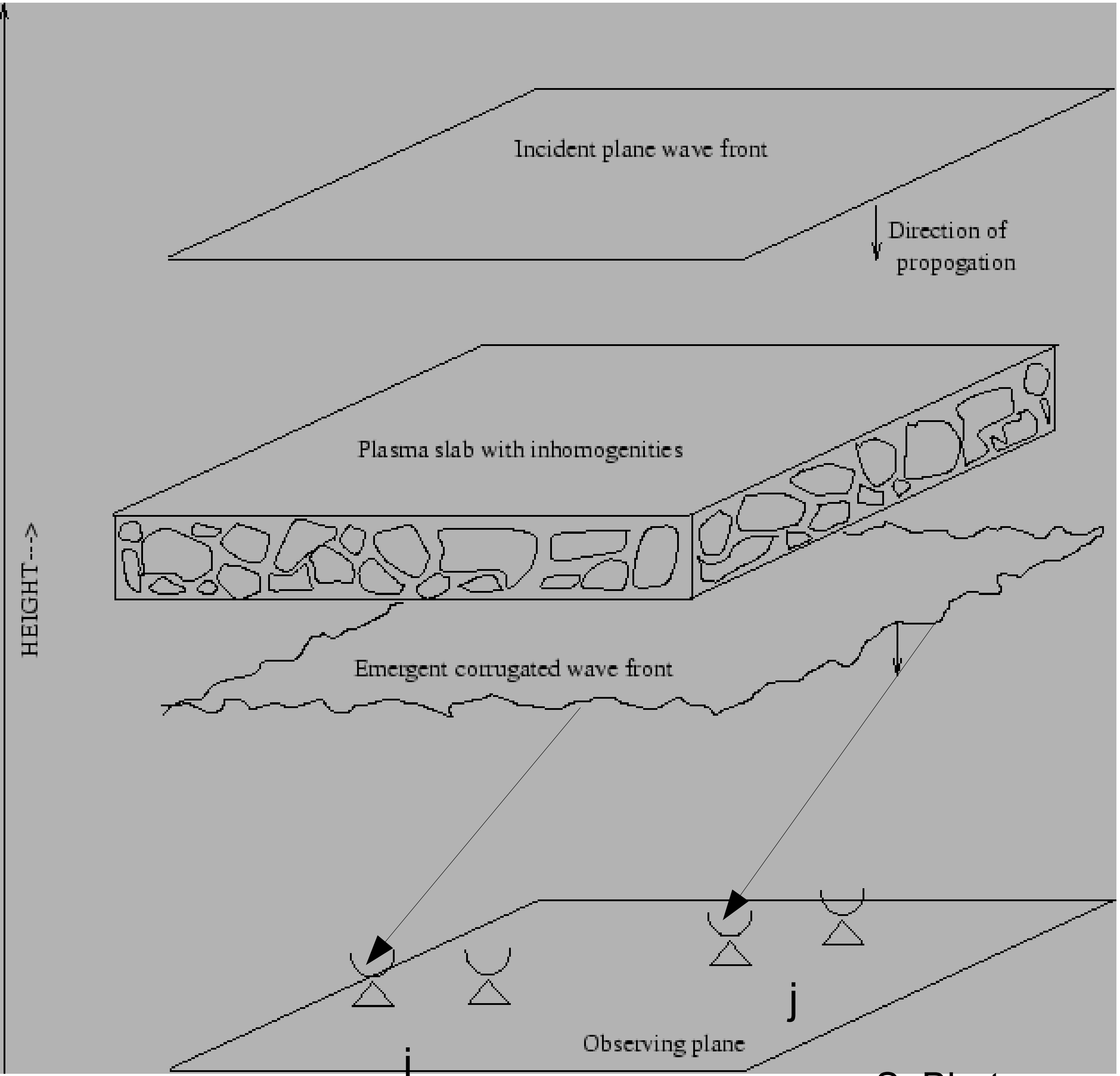
Ionosphere - Basic Geometry



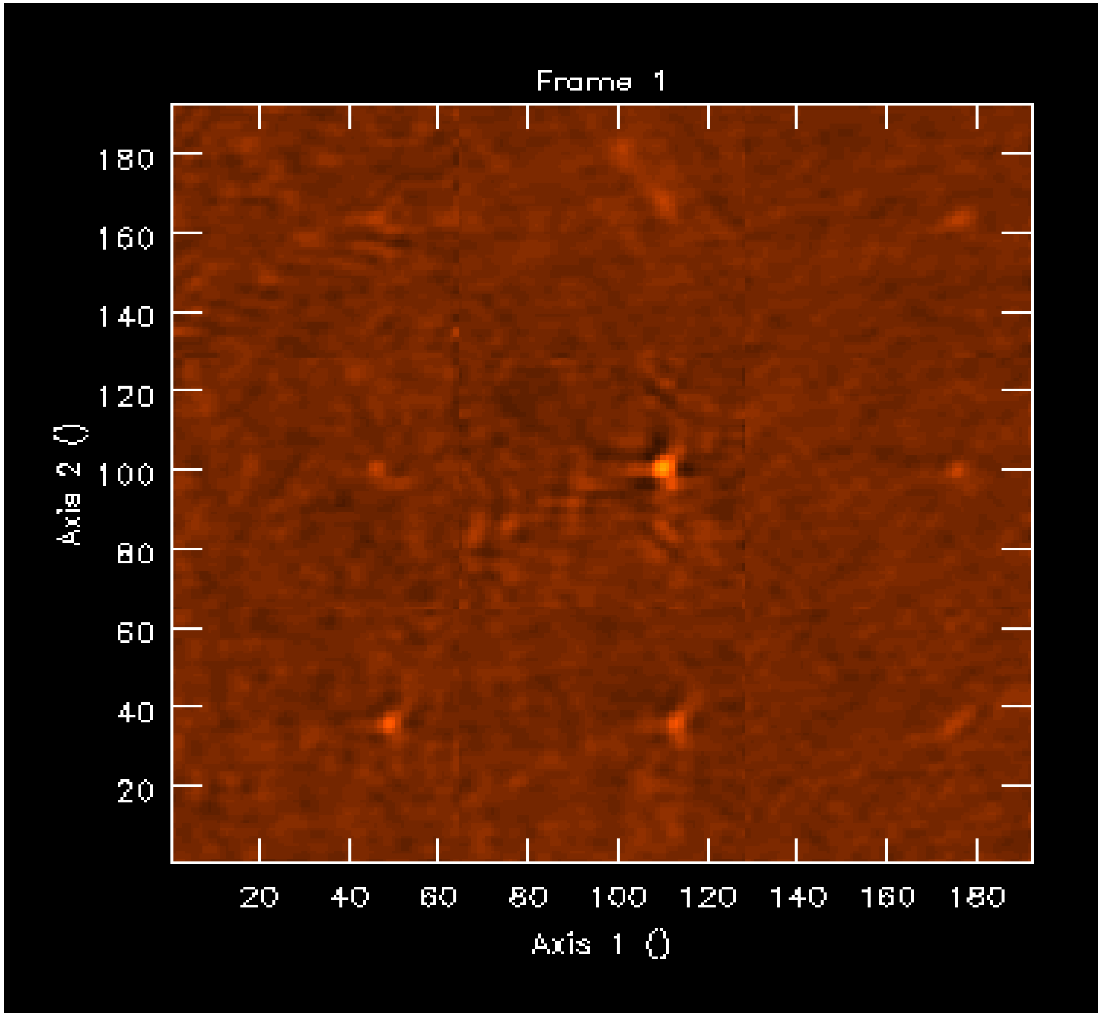
- Altitude ~ 200-1000 Km
- $$TEC = \int n_e dl = 10^{16} m^{-2}$$
- $$\Delta \phi = \lambda r_e \int n_e dl$$
- $$\Delta \phi_{ij} = -8.48 \frac{\delta N_{TEC}}{\nu_{GHz}}$$
- Interferometer sensitive to :-

  $$\delta N_{TEC} = 2 * 10^{-3} \nu_{GHz}$$
- At 74 MHz,

$$\delta N_{TEC} = 1.5 * 10^{-4} TEC$$

S. Bhatnagar

Ionospheric effect on Imaging

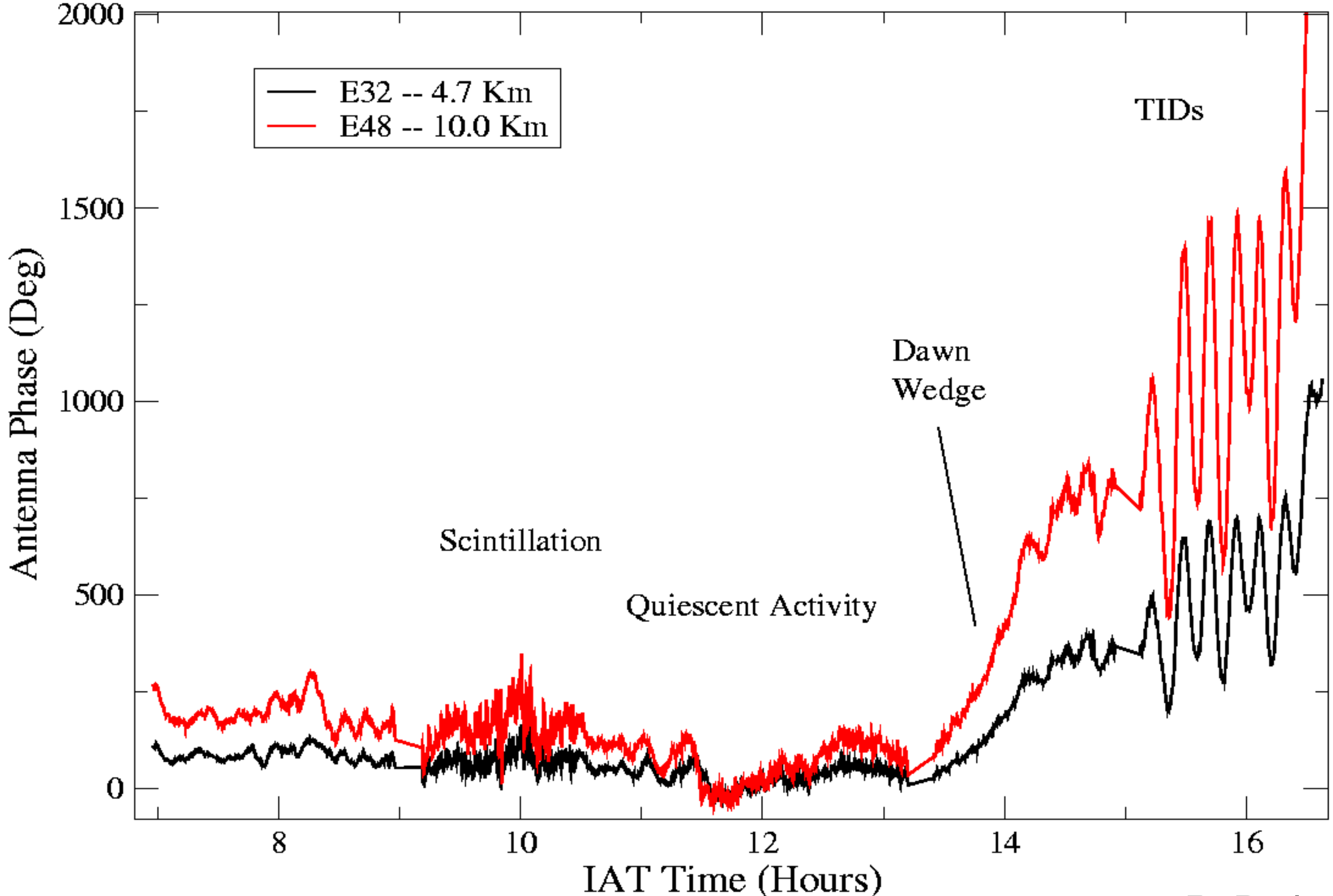


- Nine radio sources from VLSS Survey (74 MHz)
- 30 sec map for total 9 hours over sunrise
- Variation in intensity, side-lobe structure, etc

W.D.Cotton

Virgo A – Ionospheric Phase

- Phase proportional to base-line
- Typical phase gradient ~40 deg/km
- Typical position offsets ~ 10 arcsec



R. Perley

VLA 74 MHz - Ionospheric Probe

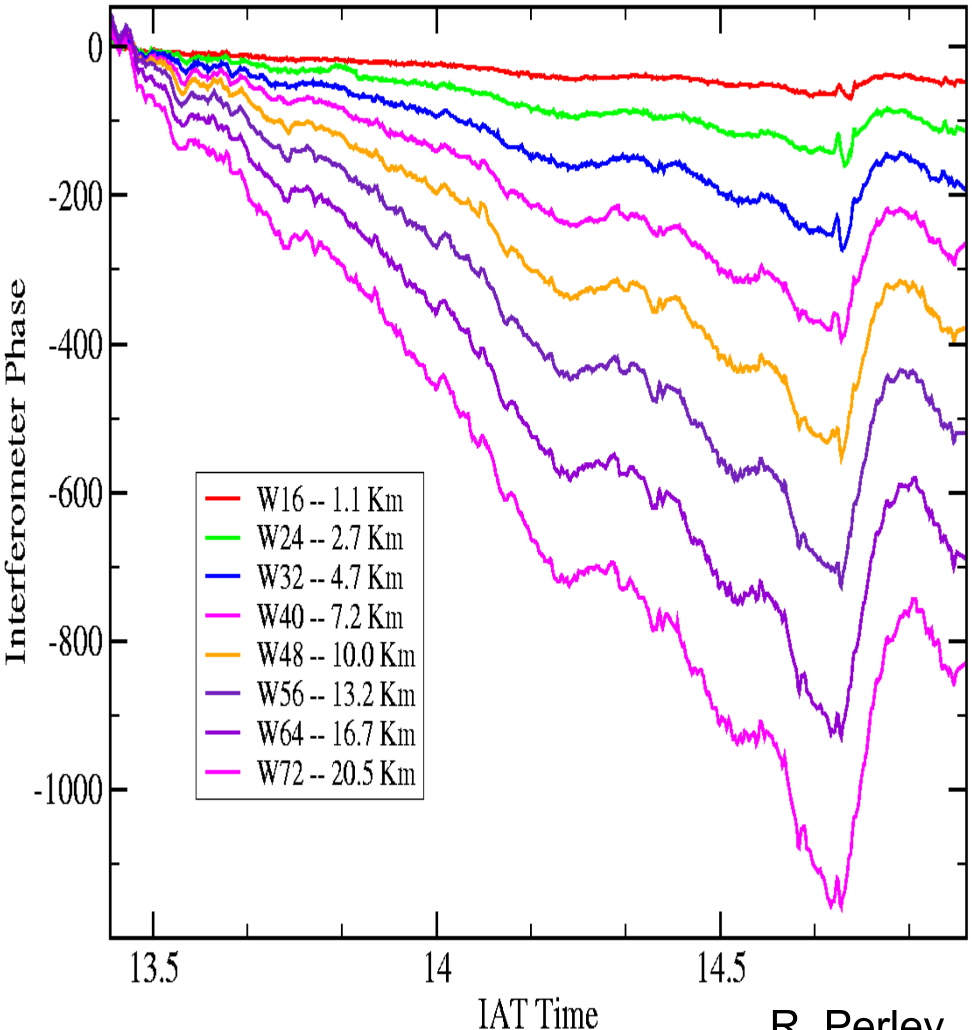
- Faraday Rotation
- Refraction
- Rapid Phase Fluctuation
- TIDs (< 1% fluctuations)

$$T = 750\mathrm{s}, \Delta\phi = 50^{o}\, km^{-1}$$

- Travelling wave model:-

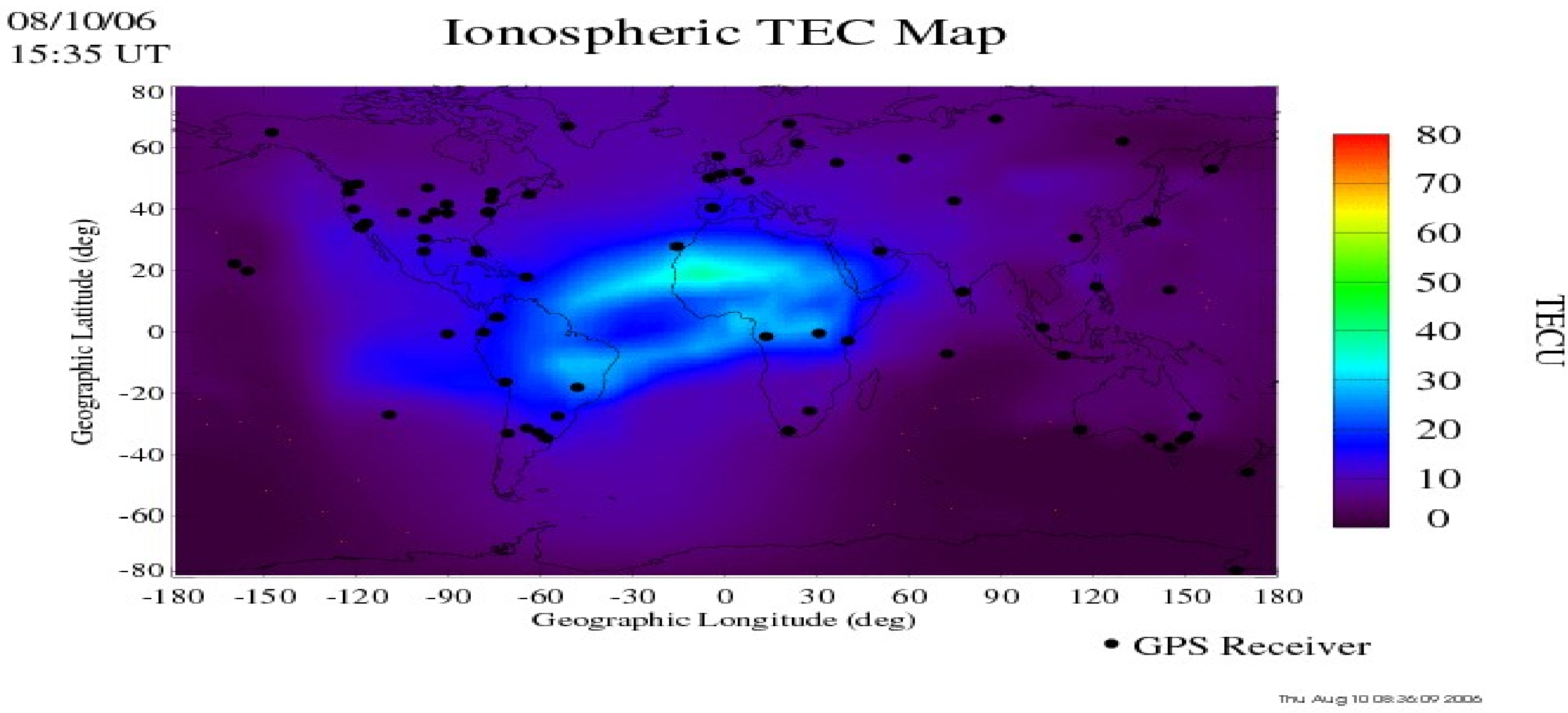
$$V = 200\mathrm{m}\, s^{-1}, \lambda = 750\, km, \delta N_{TEC} = 1.1\, TEC$$

- Dominant curvature term – varies with the location of baseline.



R. Perley

Ionosphere – GPS Observation



- Poor spatial resolution
- No instantaneous Information

http://iono.jpl.nasa.gov/latest_rti_global.html

Problem with Self-Cal

- Fundamental Calibration Equation

$$V_{ij}^{c}(t)=g_i(t)\,g_j{*}(t)\,G_{ij}(t)\,V_{ij}(t)+\epsilon_{ij}(t)$$

-

$$V_{ij}^{Obs}(\nu,t)=\underbrace{G_{ij}}_{\text{Self-Calibration}}(\nu,t)\left(\int\int \underbrace{P_{ij}}_{\text{This cannot be eliminated by Self-Cal}}(l,m,\nu,t)\,\underbrace{I^{M}(l,m)}_{\text{Sky}}\,e^{2\pi\iota(u_{ij}l+v_{ij}m)}\,dl\,dm\right)$$

Visibility Equation

- The full equation including the ionospheric term :-

$$V(u,v,w)=\iint I(l,m)\,\mathrm{e}^{2\pi\iota\left(ul+vm+w\left(\sqrt{1-l^2-m^2}-1\right)-\Phi_{ion}(l,m)\right)}\frac{dl\,dm}{\sqrt{1-l^2-m^2}}$$

- Where

$$\Phi_{ion}(l,m)=\Phi_{ij}(l,m,u,v,t)$$

$$\Phi_{ij}=\Phi_i(\vec{x}_i,t)-\Phi_j(\vec{x}_j,t)$$

$$\vec{x}_i,\vec{x}_j=f(l,m,u,v,t)$$

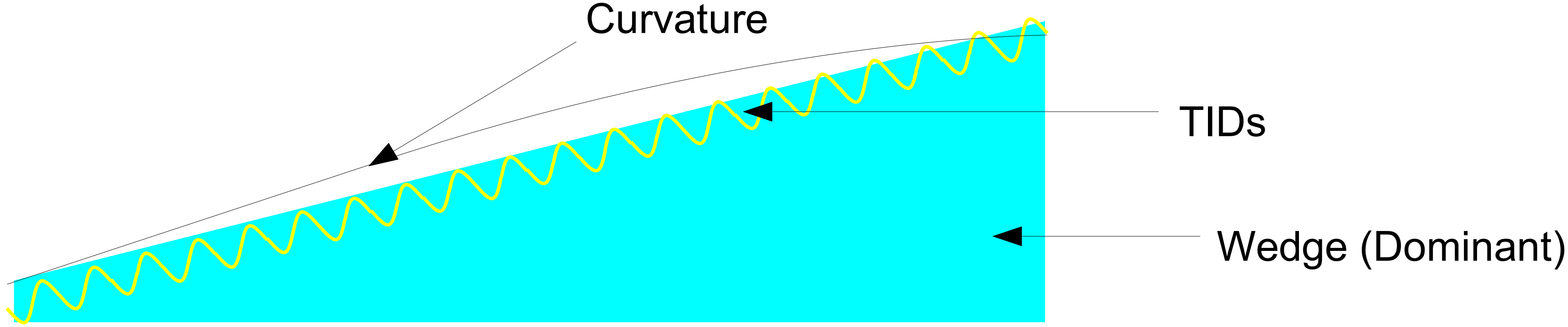
- Expressed in Taylor series :-

$$\Phi_i(\vec{x}_i)=\Phi_i(\vec{x}_i^o)+\Delta\vec{x}_i\nabla\Phi_i+\frac{(\Delta\vec{x}_i)^2}{2!}\nabla^2\Phi_i+\dots$$

Field Based Calibration - W.D.Cotton

- Take snapshot images of bright sources in the field.
- Compare to their know positions (NVSS)
- Record the shift and fit a 2nd order Zernike Polynomial.
- Obtain 2-D phase delay screen for each time interval.
- Use this phase screen to correct the image.
- Implemented in OBIT.
- Works well for smaller arrays and >100 MHz
- But will fail for the larger arrays (LWA, LOFAR,etc).

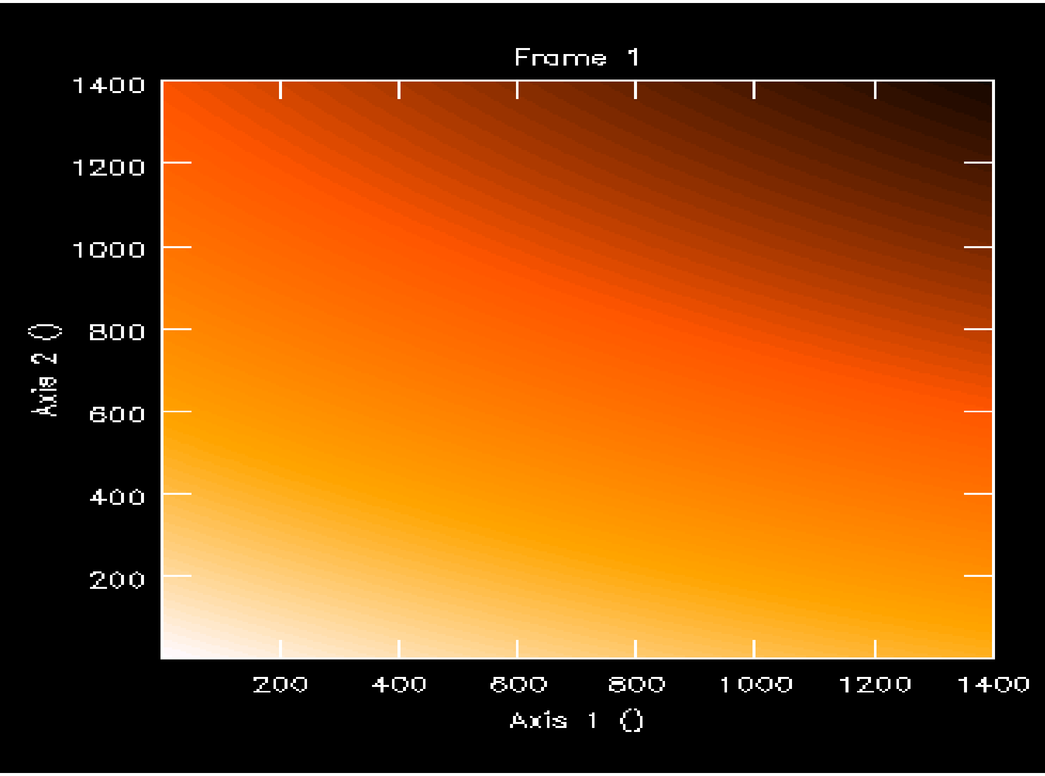
Ionospheric Phase screen



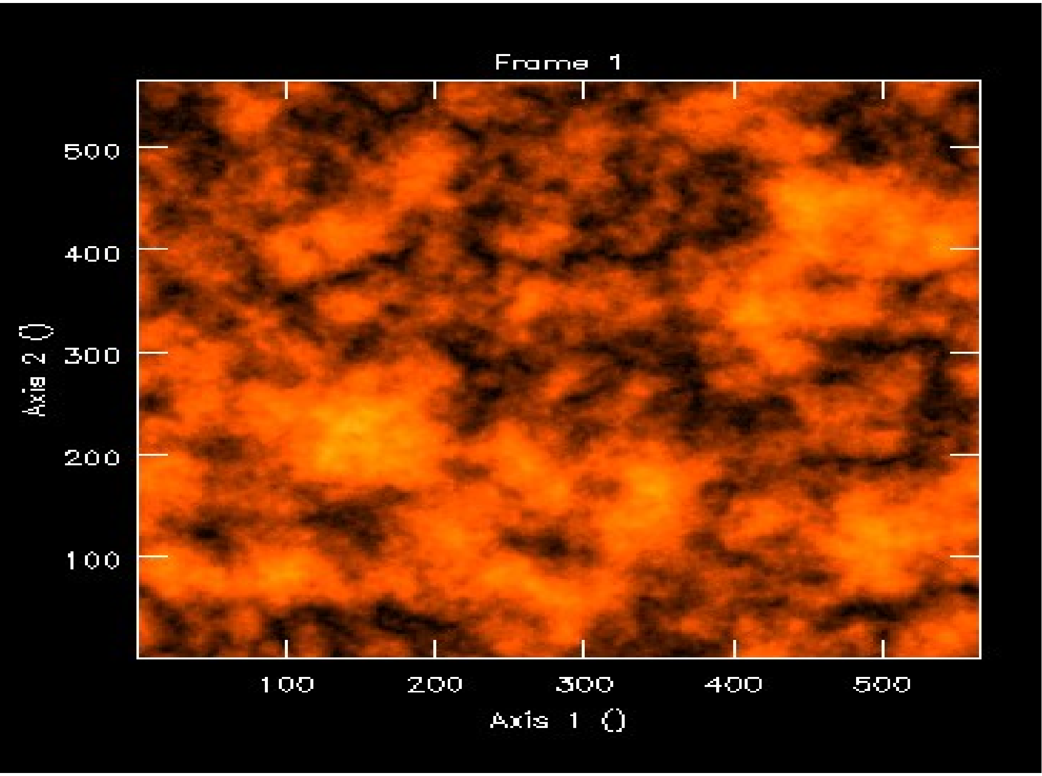
- Single phase gradient => Position Shift of image.
- Time varying phase gradient => Image shifts about a mean position with time.
- Curvature => Distorts the image, defocus.
- TIDs => Can be modelled as superposition of several curvature terms. (?)

Comparison of Phase Screens

Present Screen



Future !!! ??



- Single Gradient (dominant)
- Some random time varying component to the gradient
- Curvature

- Typical turbulent screen

$$P(q, z) = C_N^2(z)(q^2 + q_{min}^2)^{-\beta/2} \exp(-q^2 / q_{max}^2)$$

Work in Progress

- Studying effects of Ionospheric corruptions on the imaging dynamic range.
- How to solve for the first few order deformations ?
- Try to simulate effects for the LWA, LOFAR config.