Neutrino Tomography and LLSVPs

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Collaborators

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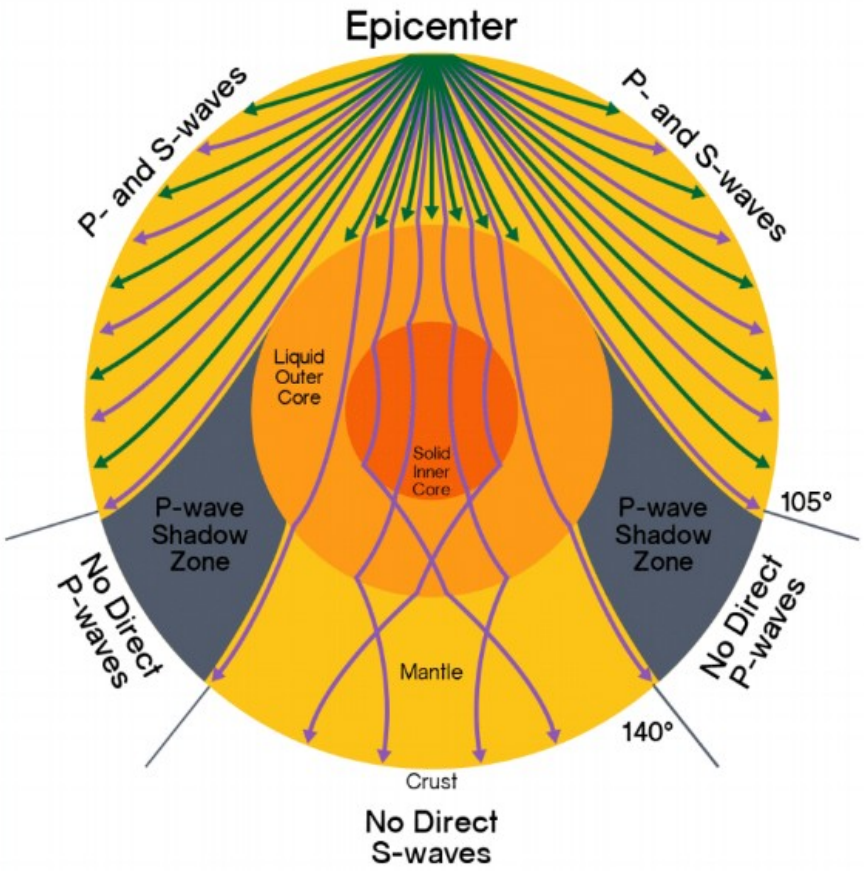
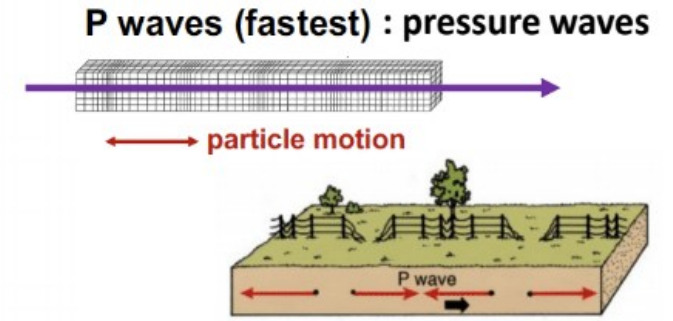
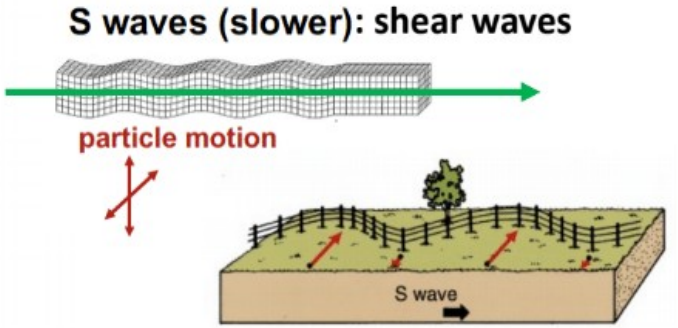
Inside the Earth: Seismology

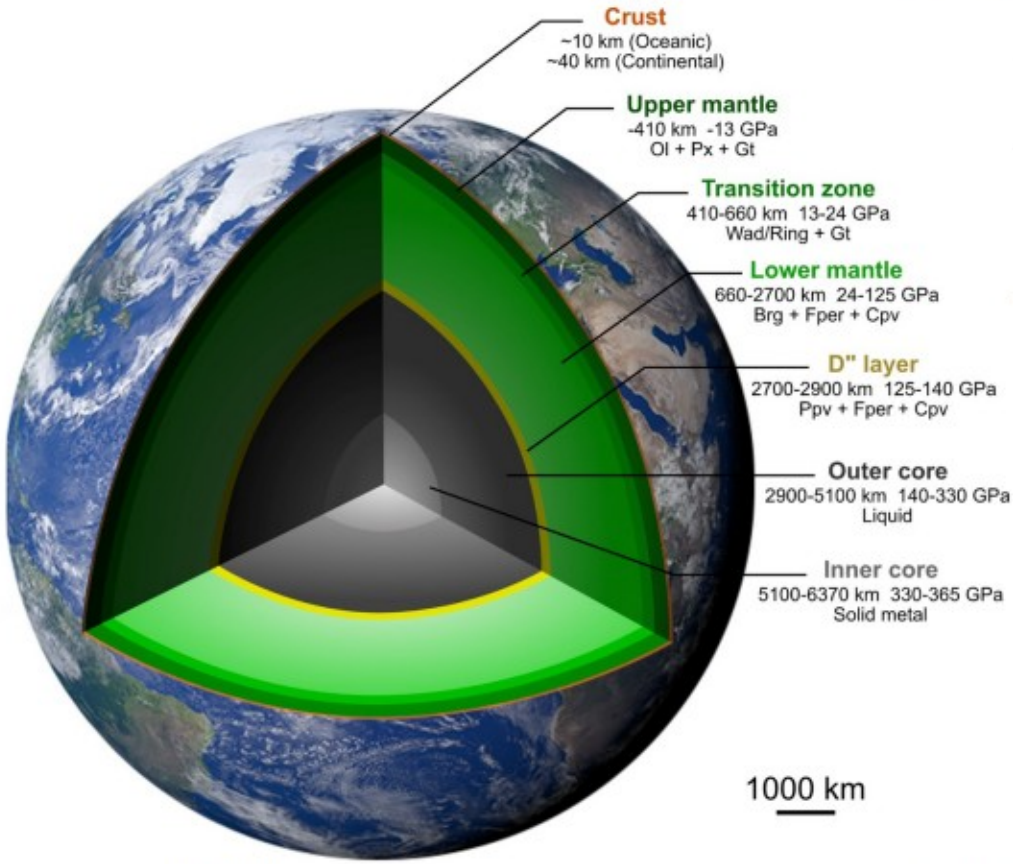




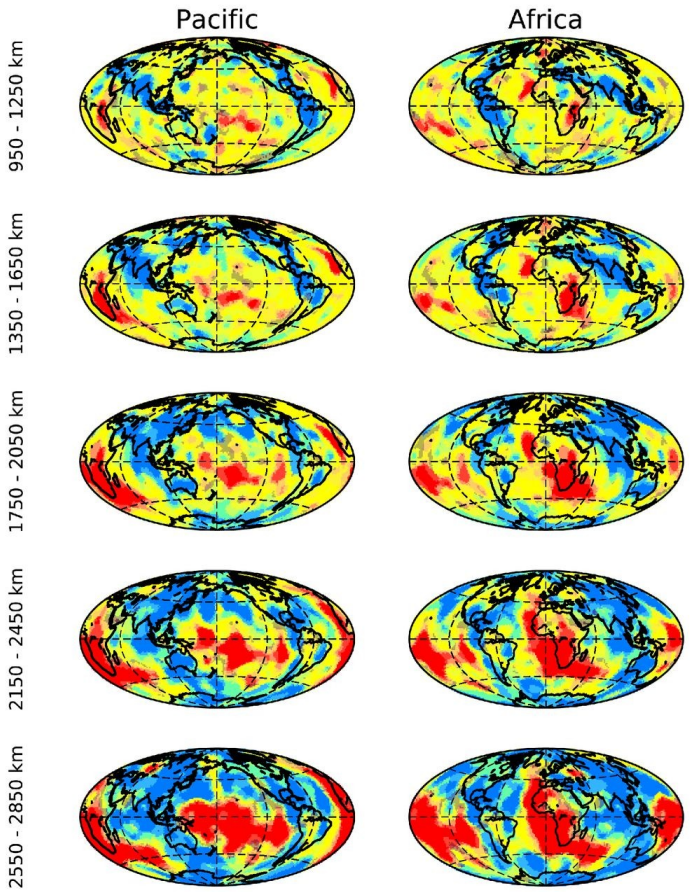


Inside the Earth: Some Questions

- Inner/Outer Core Boundary
  - Where is it?
  - How big is the density change?
- Core Composition
  - Light element percentage?
  - Is there any hydrogen?
- Asymmetries
  - What are LLSVPs?



Large Low-Shear-Velocity Provinces (LLSVPs)

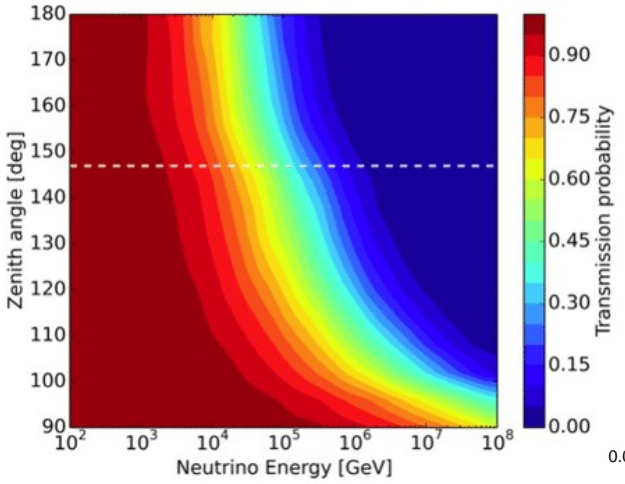


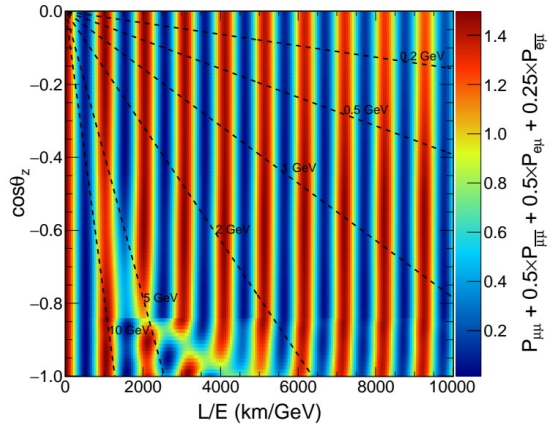
- Large regions in the lower mantle where seismic waves have a lower shear velocity
  - Sharp boundaries
  - Stable
- Makeup
  - Chemical?
  - Thermal?

https://doi.org/10.1093/gji/ggw324 (S. Cottaar, V. Lekic)

Neutrino Tomography

- Neutrinos interact with matter
  - High energy neutrinos have higher cross sections
    - Absorption profiles tell us about density
  - Low energy neutrinos' oscillation patterns are affected by matter
    - Oscillation profiles tell us about density





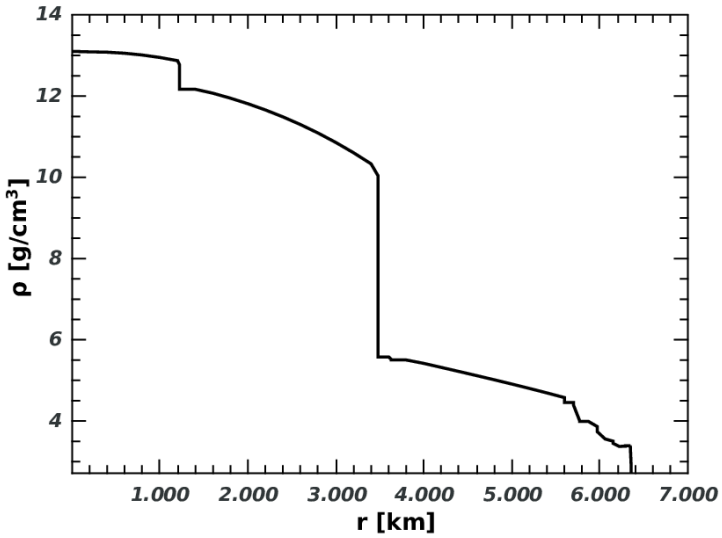
Neutrino Oscillation Tomography

$$H = \frac{1}{2E}\left(U^{\dagger} \begin{bmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{bmatrix} U + 2\sqrt{2} G_F N_e E \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \right)$$

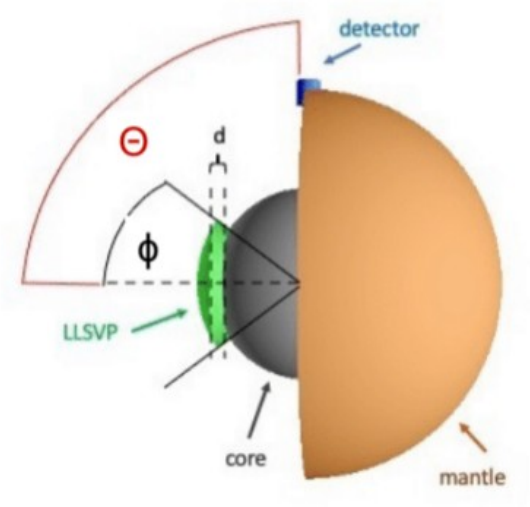
- With matter effect, neutrino oscillation is sensitive to electron number density

$$N_E = \rho(Z/A)$$

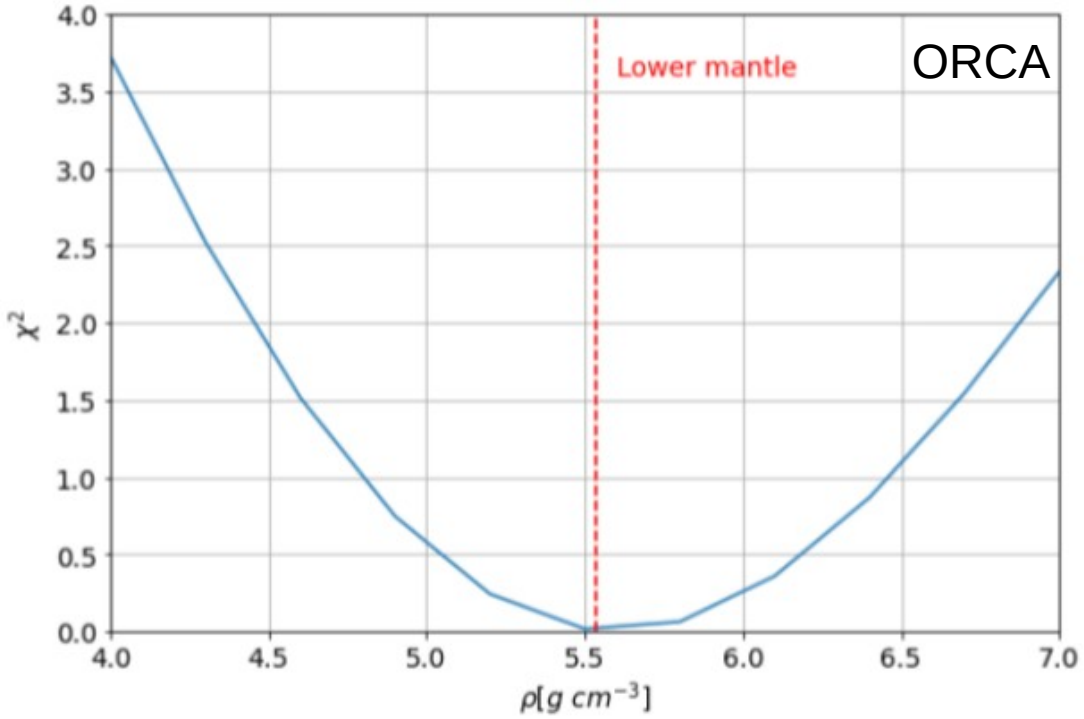
  - Depends on density and composition
- Use atmospheric neutrinos to study Earth



Neutrino Oscillation Tomography with LLSVPs



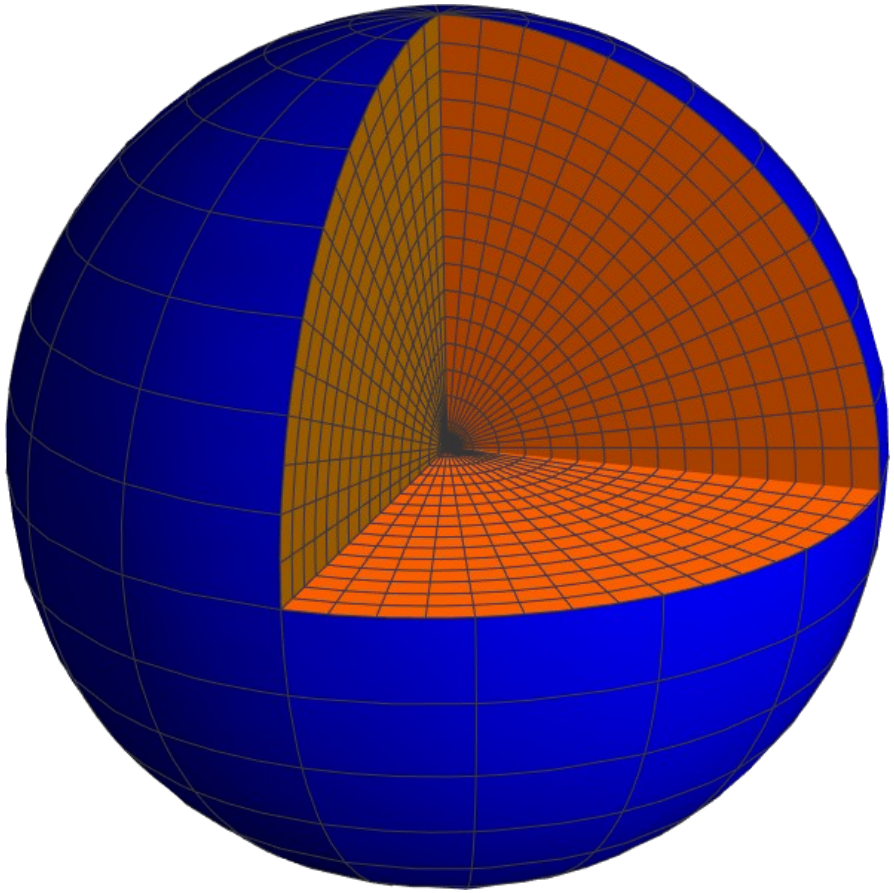
LLSVP model with *ROOT:TGeoManager*

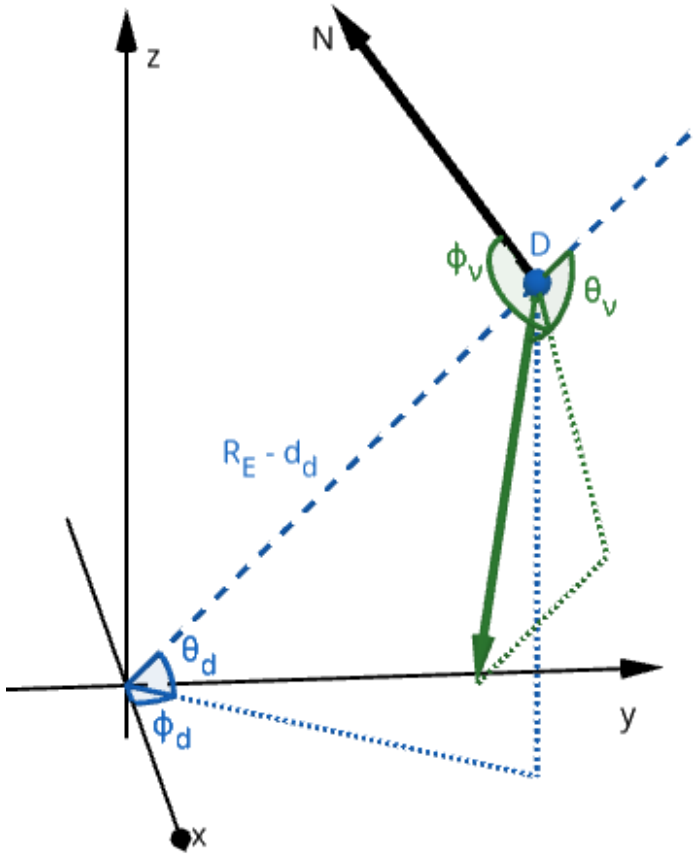


L. Maderer, et al.

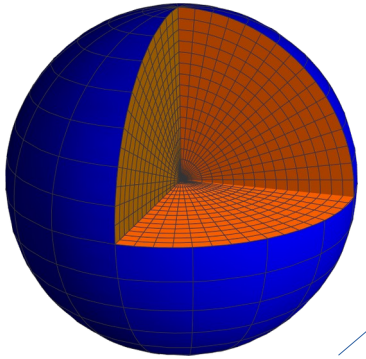
- PREM -> Model with LLSVP
- Constrain density of LLSVP

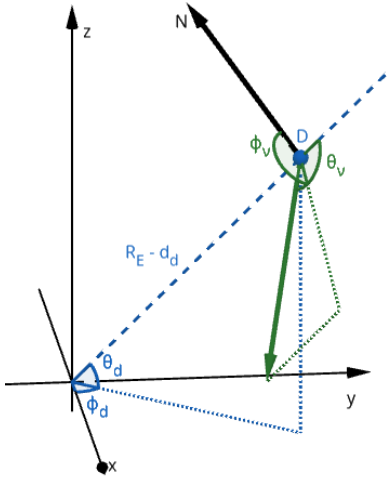
Using a Binned Earth





Using a Binned Earth

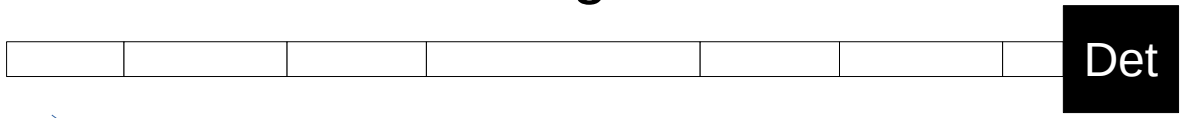




- Find equations for distance from detector with respect to each coordinate

$$x(r) \qquad x(\theta) \qquad x(\phi)$$

- Determine neutrino path segments
  - Bin information + length



- Neutrino Oscillation Probability Calculation (e.g. OscProb)

Next Steps

- Optimize code
- Test abilities of atmospheric neutrino experiments to discriminate between competing realistic LLSVP models
- Use combinations of atmospheric neutrino experiments
- Look into other potential asymmetries in the Earth
- Investigate possibility of joint analysis with seismic data and others

Thank you!

Questions?

Backup Slides

Equations: Coordinates

- Depth:

$$d = R_E - \sqrt{R_E^2 + x^2 + 2R_E x\cos(\theta_\nu)}$$

- Latitude:

$$\sin(\theta) = \frac{(R_E + x\cos(\theta_\nu))\sin(\theta_d) + x\sin(\theta_\nu)\cos(\phi_\nu)\cos(\theta_d)}{\sqrt{R_E^2 + x^2 + 2R_E x\cos(\theta_\nu)}}$$

- Longitude:

$$\tan(\phi) = \frac{(R_E + x\cos(\theta_\nu))\cos(\theta_d)\sin(\phi_d) - x\sin(\theta_\nu)(\cos(\phi_\nu)\sin(\theta_d)\sin(\phi_d) + \sin(\phi_\nu)\cos(\phi_d))}{(R_E + x\cos(\theta_\nu))\cos(\theta_d)\cos(\phi_d) - x\sin(\theta_\nu)(\cos(\phi_\nu)\sin(\theta_d)\cos(\phi_d) - \sin(\phi_\nu)\sin(\phi_d))}$$

Equations: Distance from Detector in term of...

- Depth:

$$x = -R_E \cos(\theta_\nu) \pm \sqrt{R_E^2 \cos^2(\theta_\nu) - 2R_E d + d^2}$$

- Latitude:

$$\frac{x}{R_E} = \frac{\cos(\theta_\nu)\left(\sin^2(\theta) - \sin^2(\theta_d)\right) - \sin(\theta_\nu)\left[\cos(\phi_\nu)\sin(\theta_d)\cos(\theta_d) \mp \sin(\theta)\sqrt{\cos^2(\theta) - \sin^2(\phi_\nu)\cos^2(\theta_d)}\right]}{\left(\sin(\theta_\nu)\cos(\phi_\nu)\cos(\theta_d) + \cos(\theta_\nu)\sin(\theta_d)\right)^2 - \sin^2(\theta)}$$

- Longitude:

$$\frac{x}{R_E} = \frac{\cos(\theta_d)(\tan(\phi_d) - \tan(\phi))}{[\sin(\theta_\nu)\cos(\phi_\nu)\sin(\theta_d) - \cos(\theta_\nu)\cos(\theta_d)](\tan(\phi_d) - \tan(\phi)) + \sin(\theta_\nu)\sin(\phi_\nu)(1 - \tan(\phi_d)\tan(\phi))}$$