Wavefield-continuation Angle Domain Common Image Gathers for Migration Velocity Analysis

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SEG 2003 - Dallas

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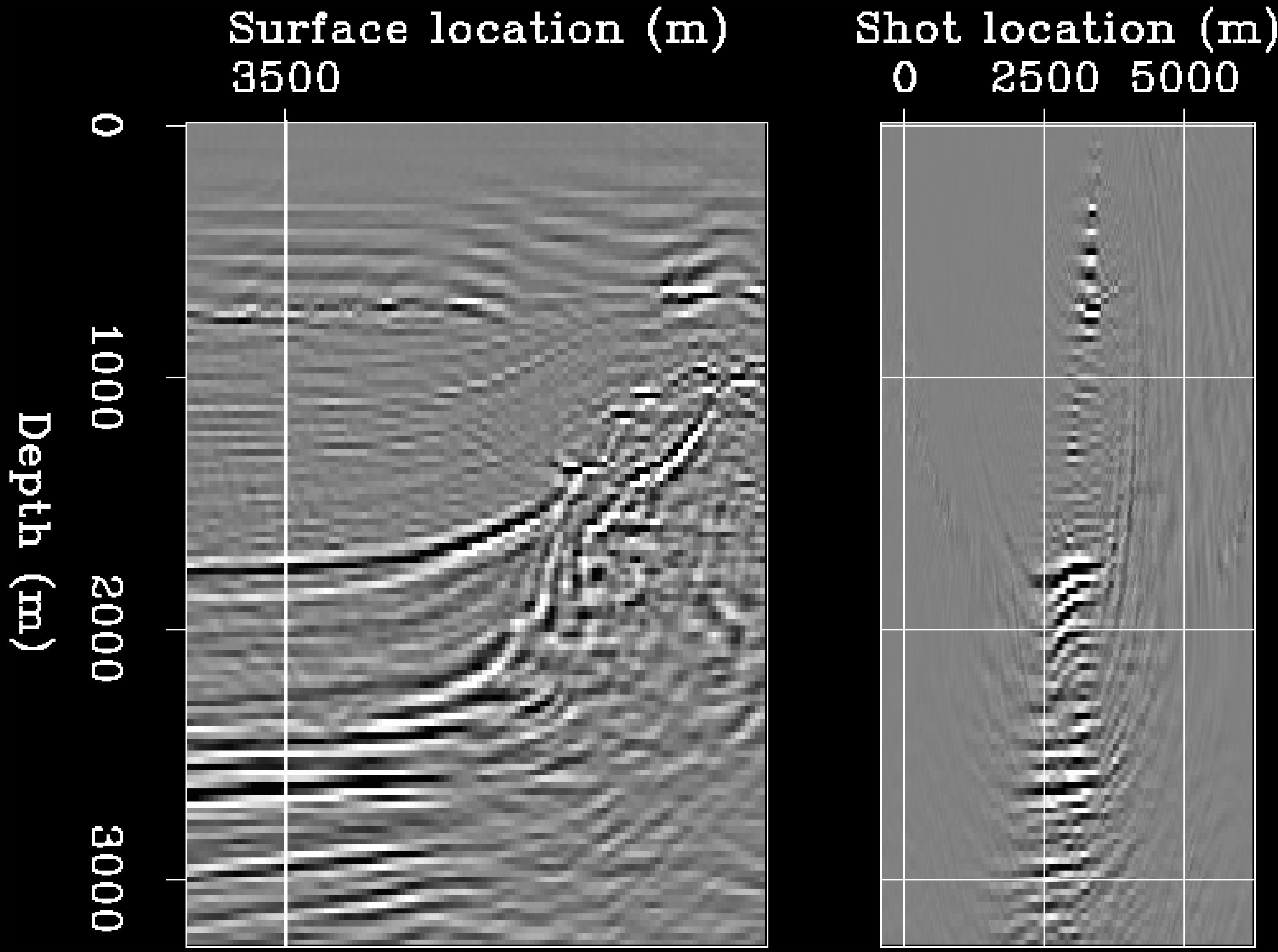
Surface-offset CIGs in simple structure



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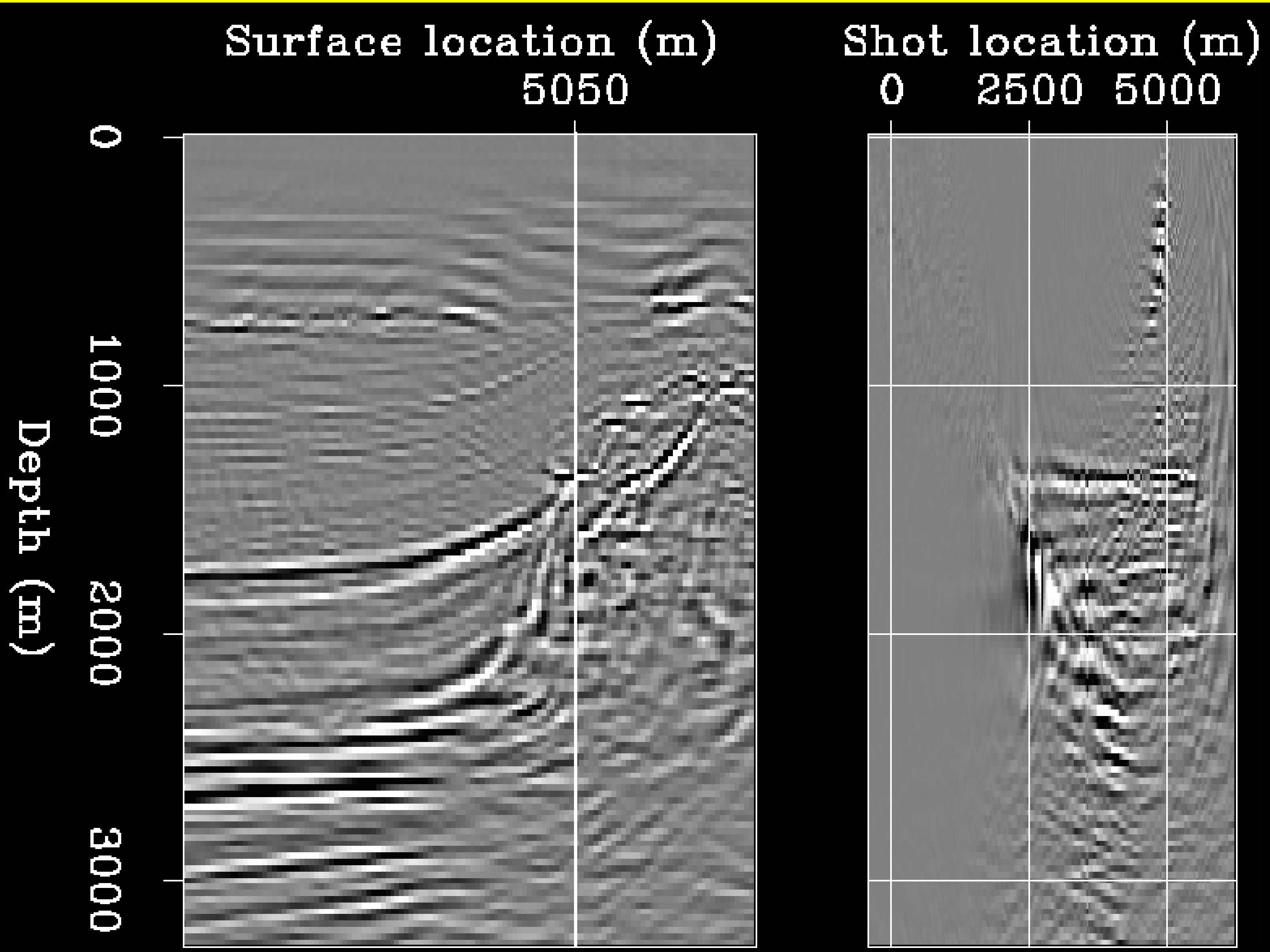
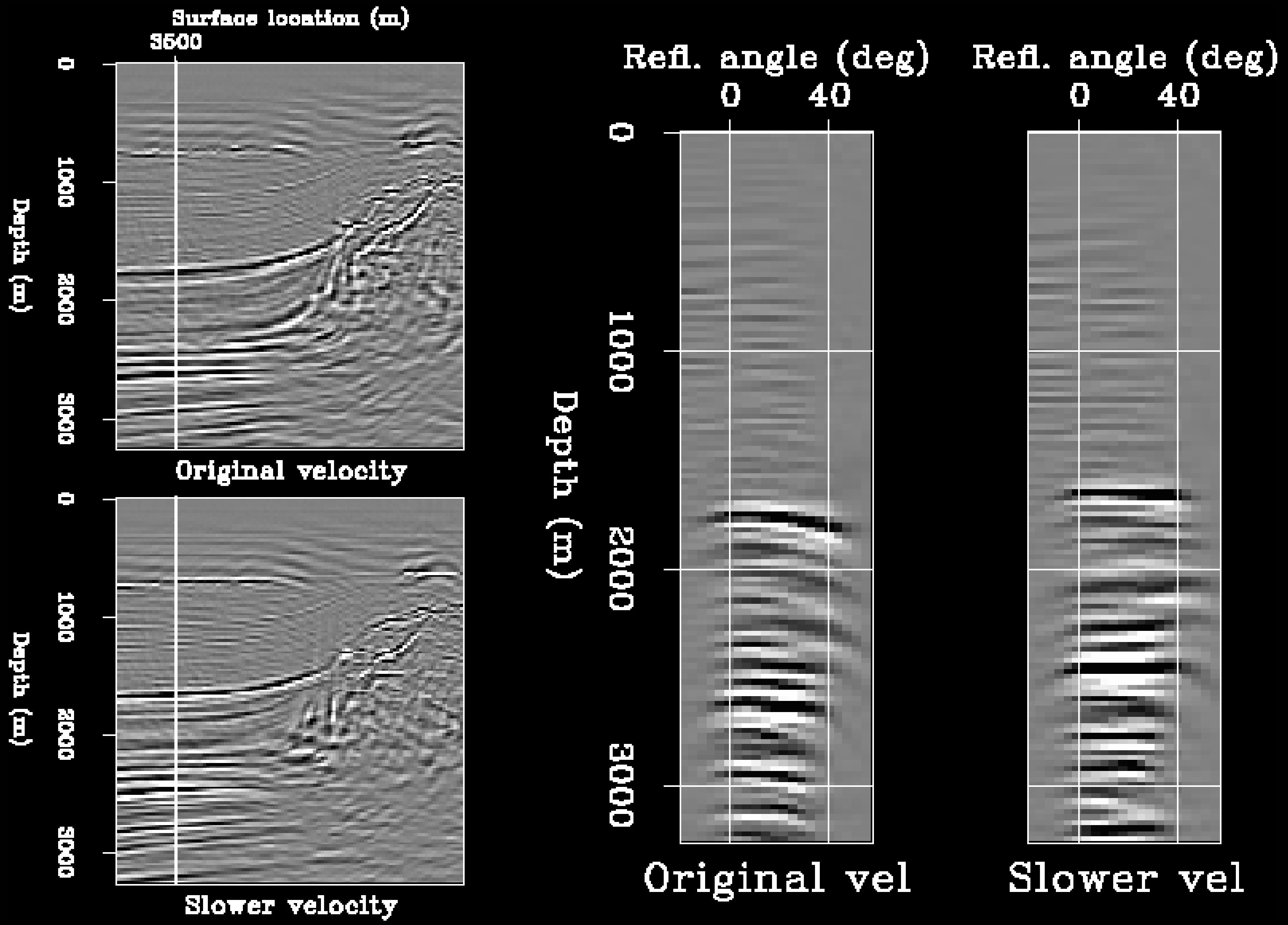
Surface-offset CIGs in complex structure



ADCIGs and velocity in simple structure



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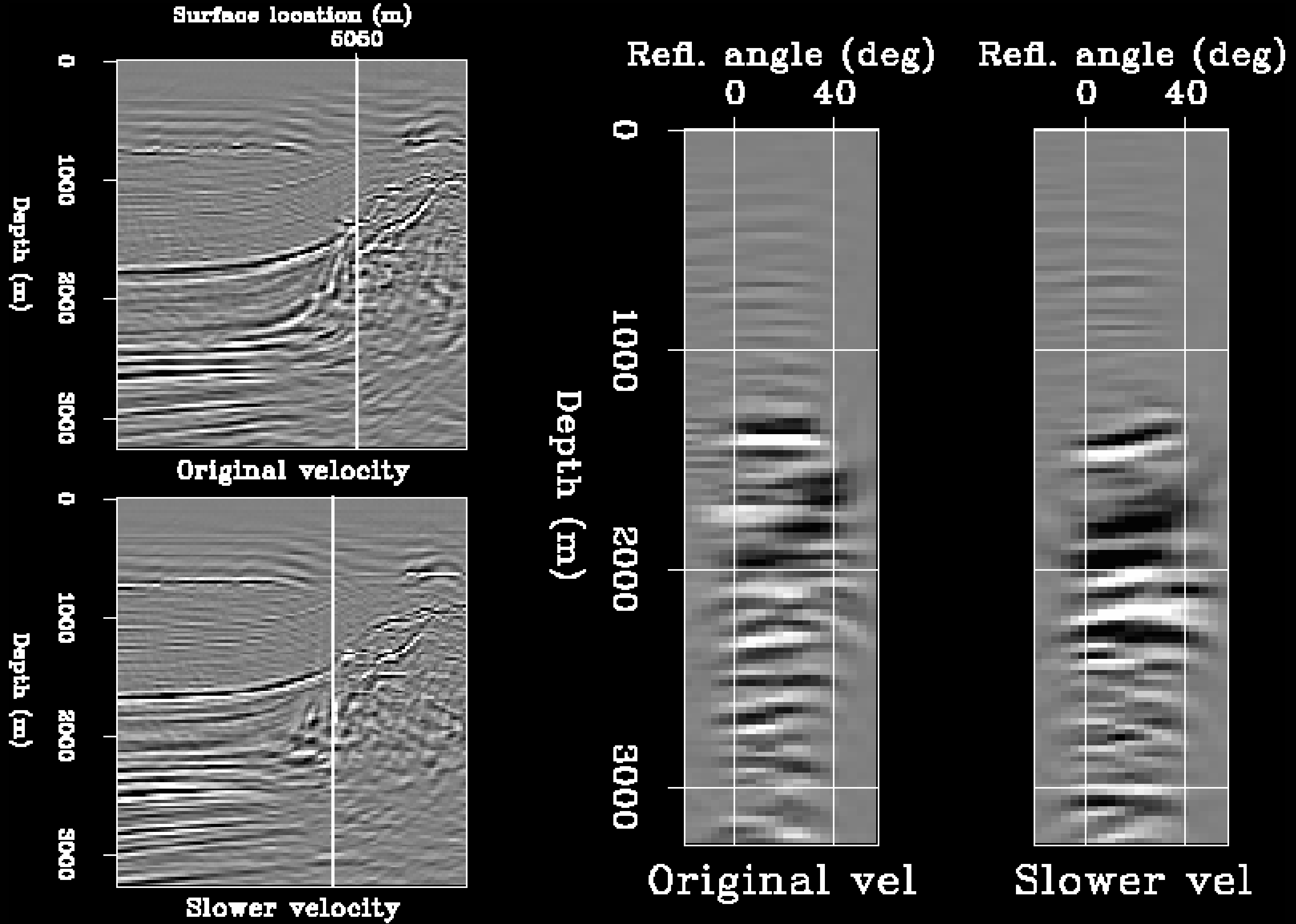

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Outline

- **Review of ADCIGs fundamentals (2-D)**
- **Analyze ADCIGs ⇔ velocity (2-D)**
  - Small errors (unperturbed raypaths ⇔ fixed γ)
  - Large errors (perturbed raypaths ⇔ varying γ)
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- Offset-domain CIGs (Rickett and Sava, 2001)

$$I(z,x,h_x)=\sum_s\sum_t S_s\left(t,z,x+\frac{h_x}{2}\right)R_s\left(t,z,x-\frac{h_x}{2}\right)$$

- Angle-domain CIGs (Sava et al., 2001)

$$I(z,x,h_x)\xrightarrow{\text{Slant Stack}} I(z,x,\tan\gamma)$$

where : I – Image

S_s – Source wavefield

R_s – Receivers wavefield

Common Image Gathers (CIGs => ADCIGS)

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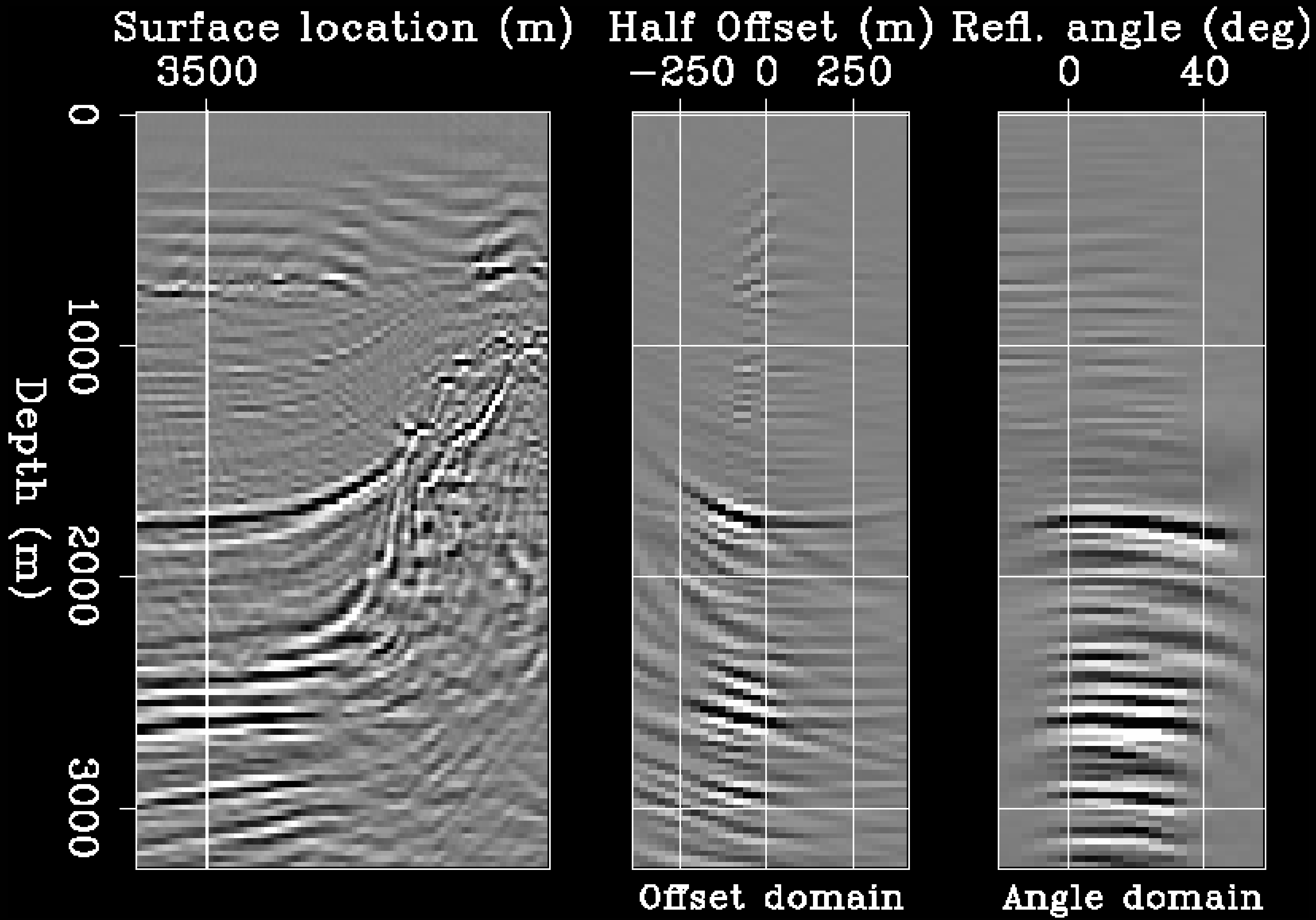
$$I(z,x,k_{hx}) \xrightarrow{k_{hx}=-k_z\tan\gamma} I(z,x,\tan\gamma)$$

- **No dependency on V(z,x)**
- **Dip-decomposition only in offsets**

Transformation from Offset to Angle-Domain



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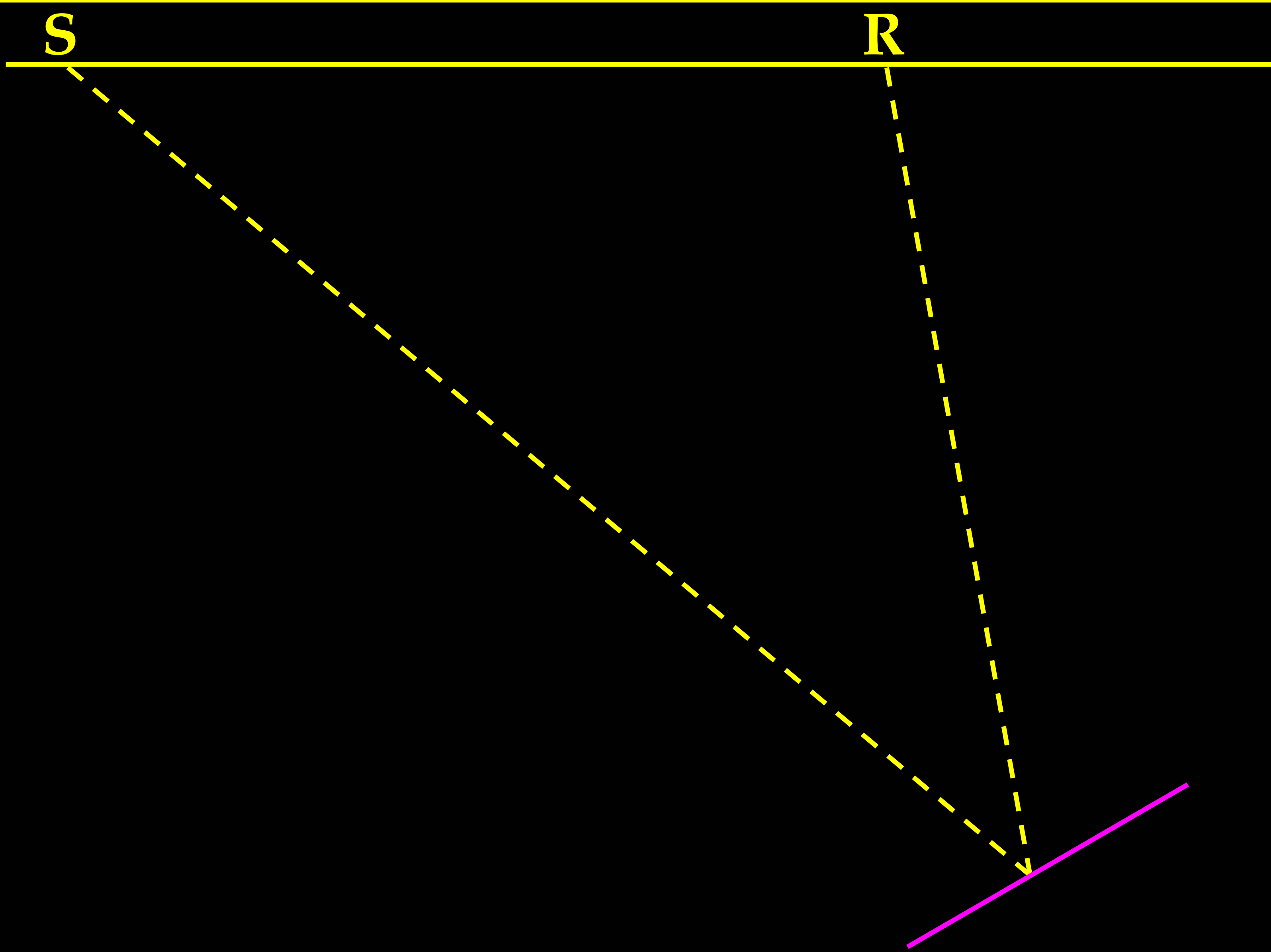
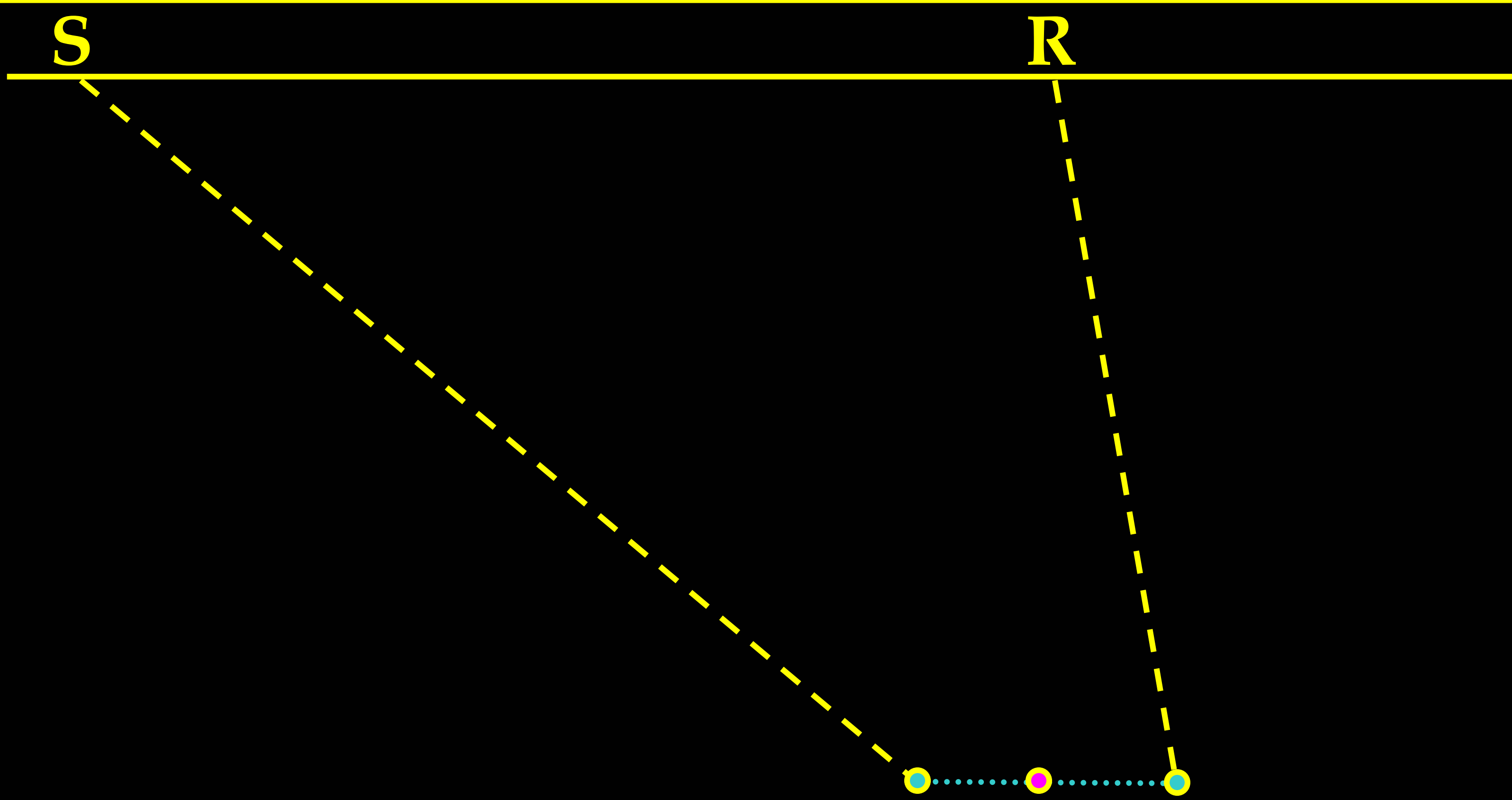
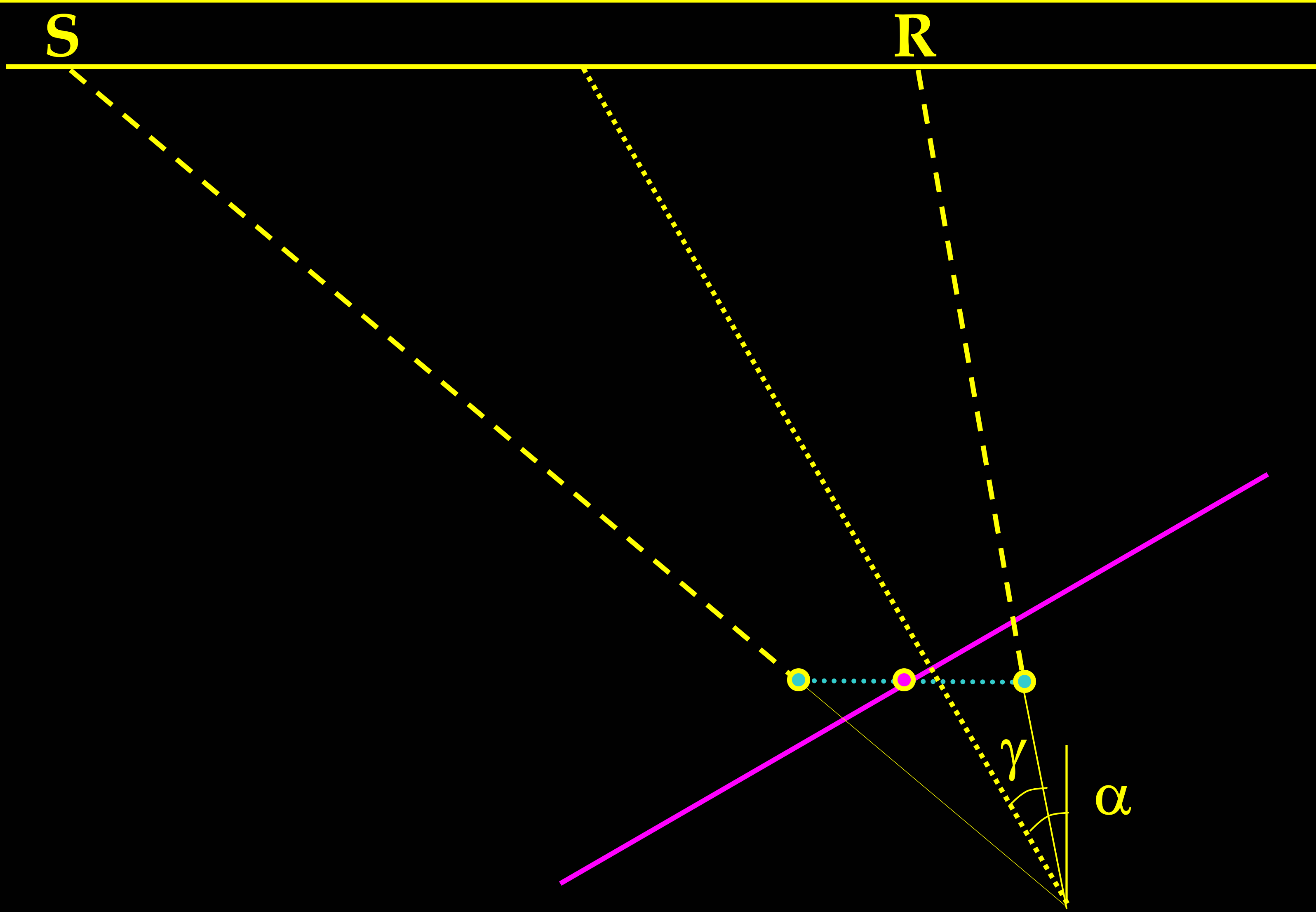
Schematic of recording a data event



Schematic of migrating data event - low velocity

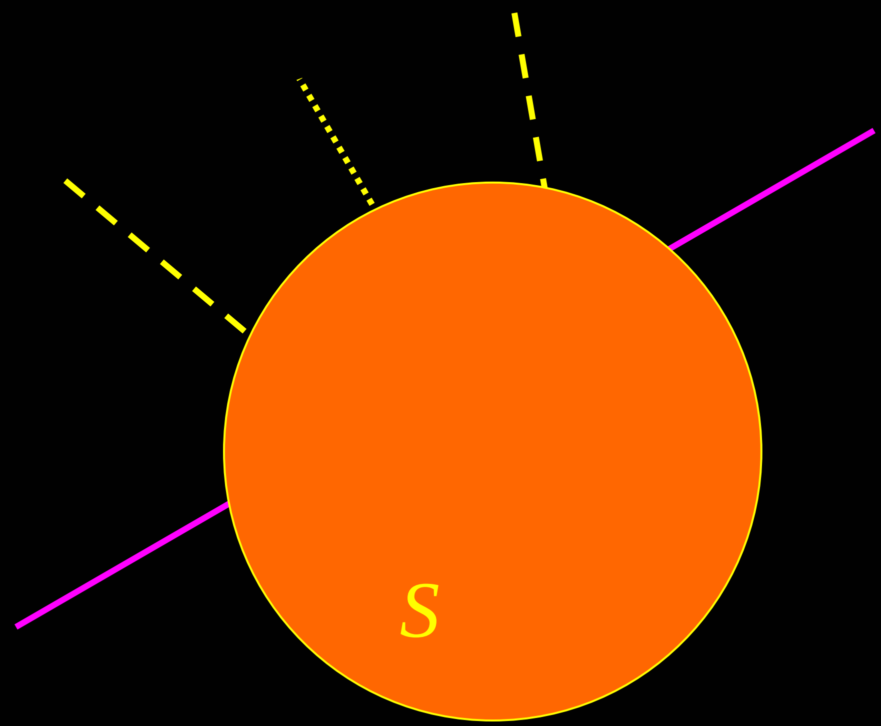


Offset Common Image Gather



Offset Common Image Gather

S = Locally constant slowness



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S = Locally constant slowness

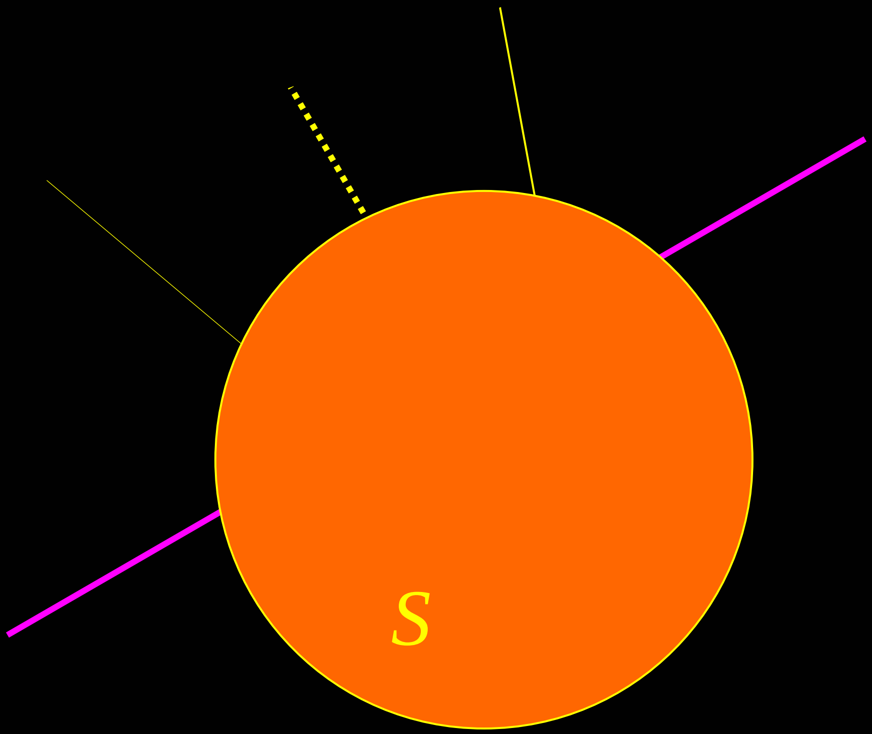


Image point movements in ADCIGs

S = Locally constant slowness

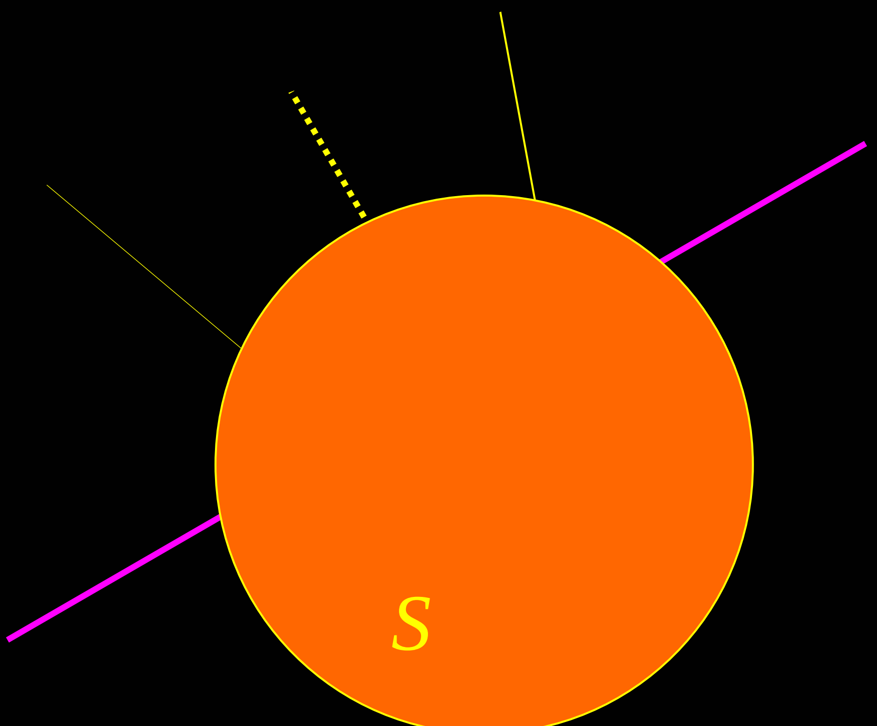


Image point movements in ADCIGs

$$\Delta n = h_o \tan^2 \gamma$$

S = Locally constant slowness

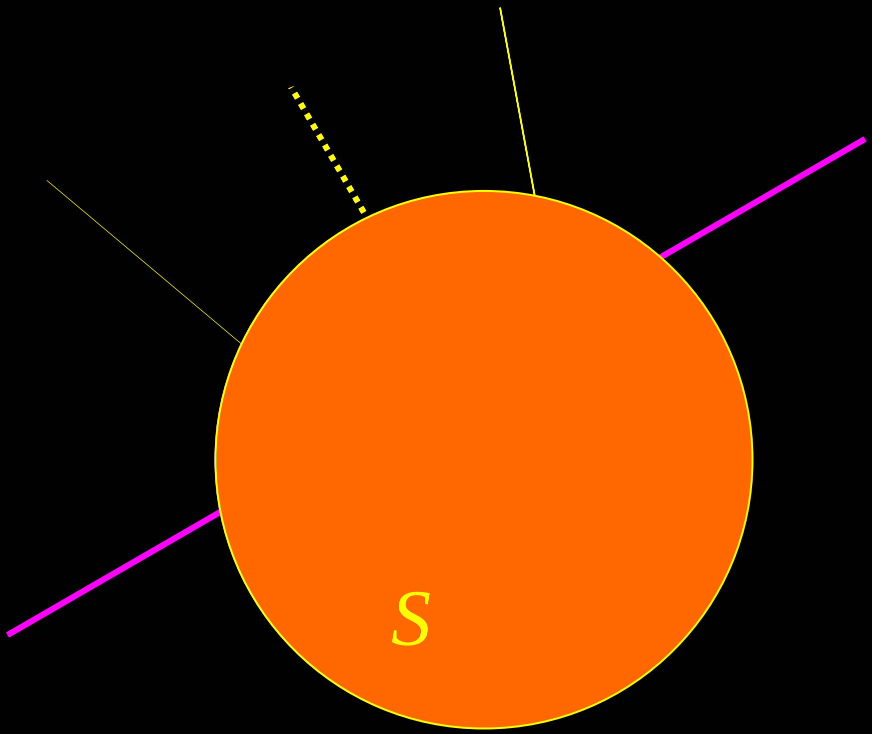
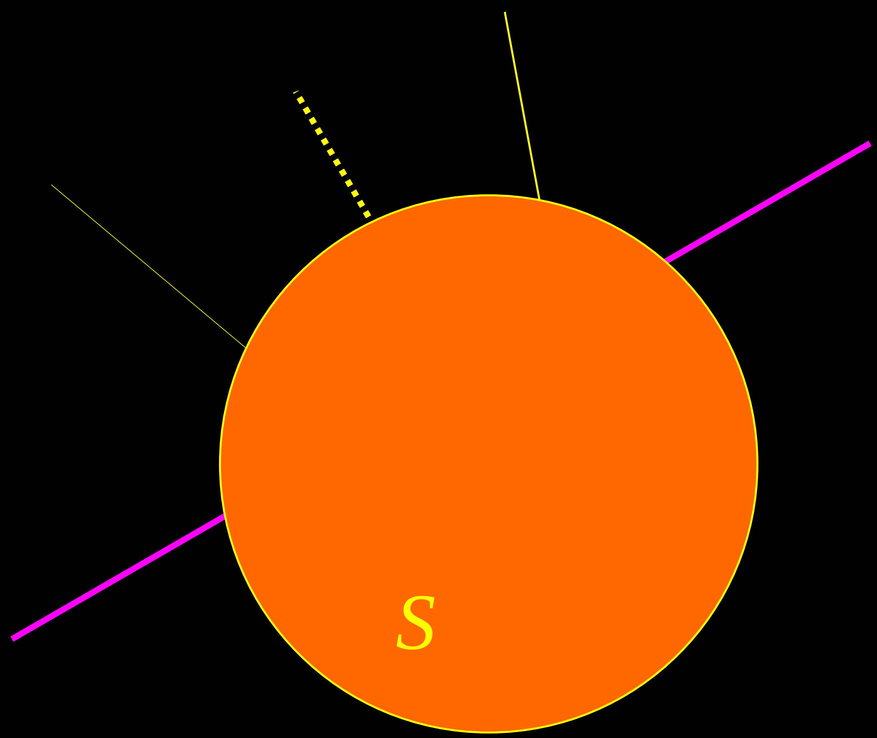


Image point movements ⇔ Vel. perturbations

$$\Delta n = h_o \tan^2 \gamma$$

$$\Delta n = -\frac{\Delta t}{2S \cos \gamma}$$

S = Locally constant slowness



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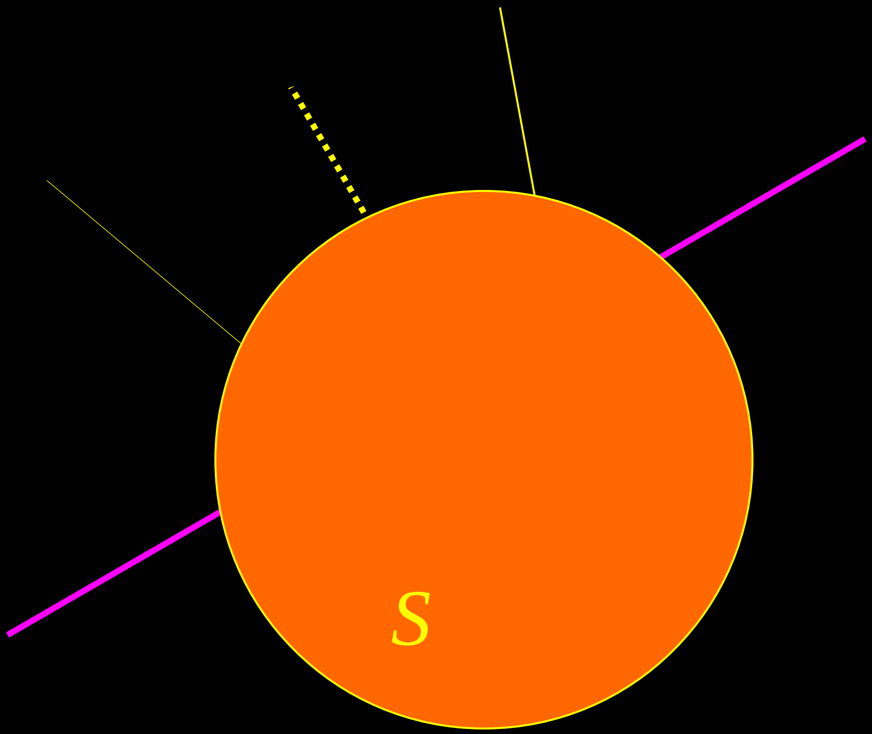
$$\Delta n = h_o \tan^2 \gamma$$

$$\Delta n = -\frac{\Delta t}{2S \cos \gamma}$$

$$\Delta t \Leftrightarrow V(z,x,y)??$$

S = Locally constant slowness



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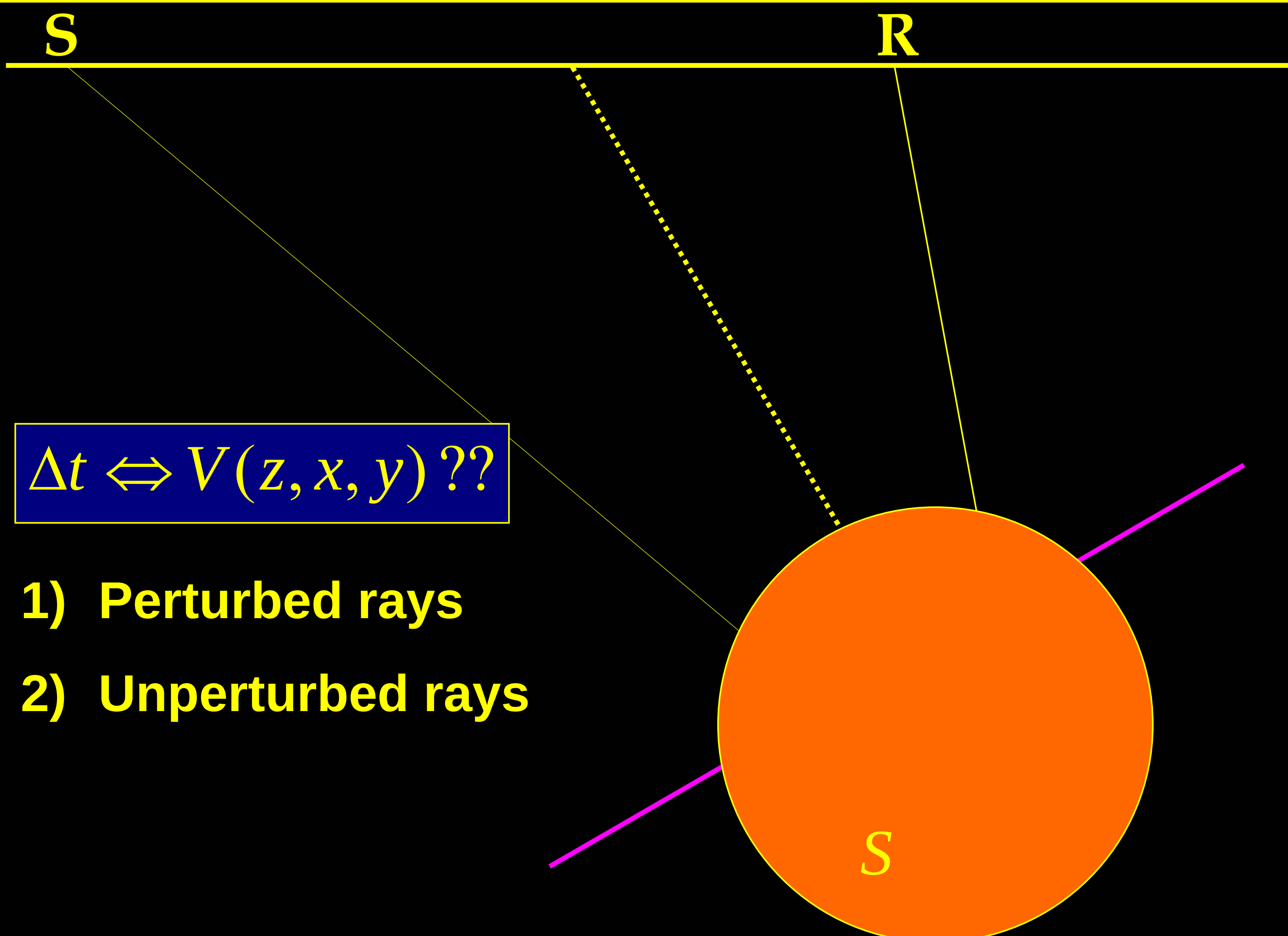
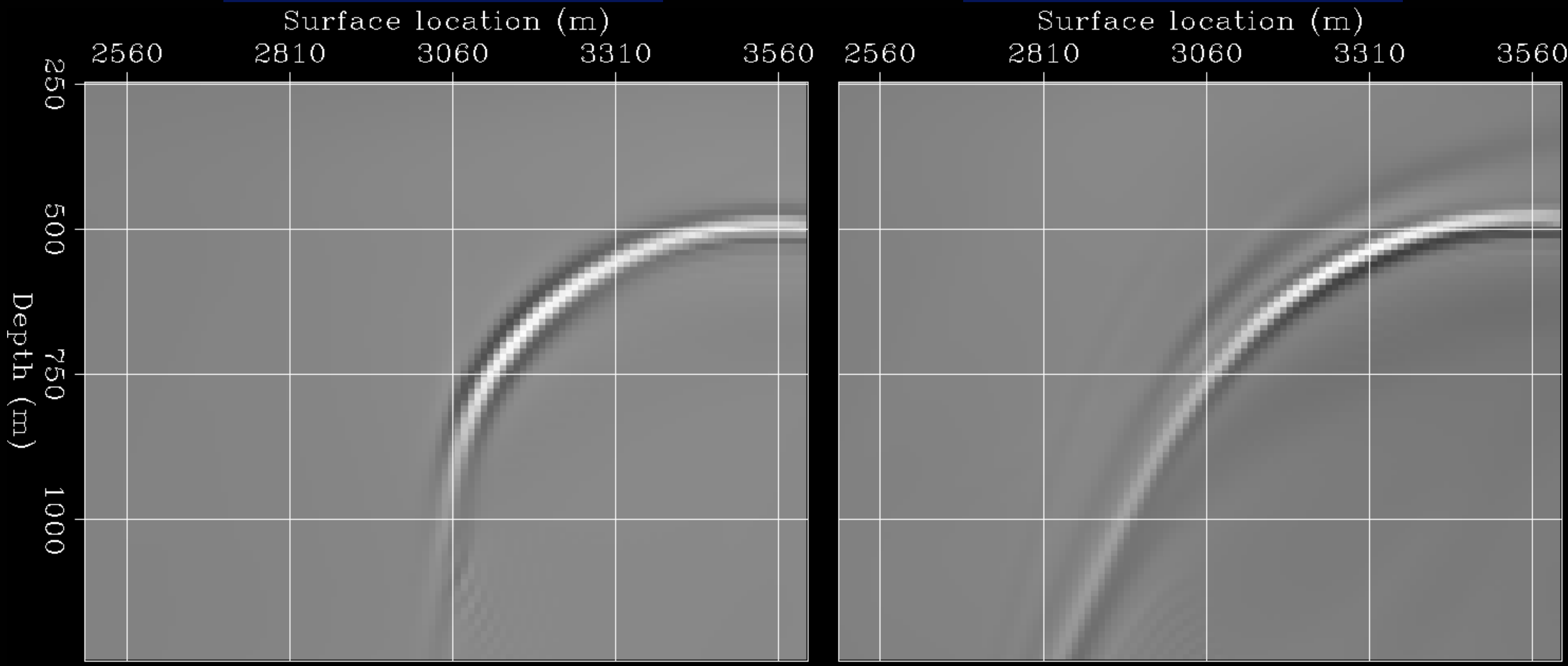


$$\Delta t \Leftrightarrow V(z,x,y)\,??$$

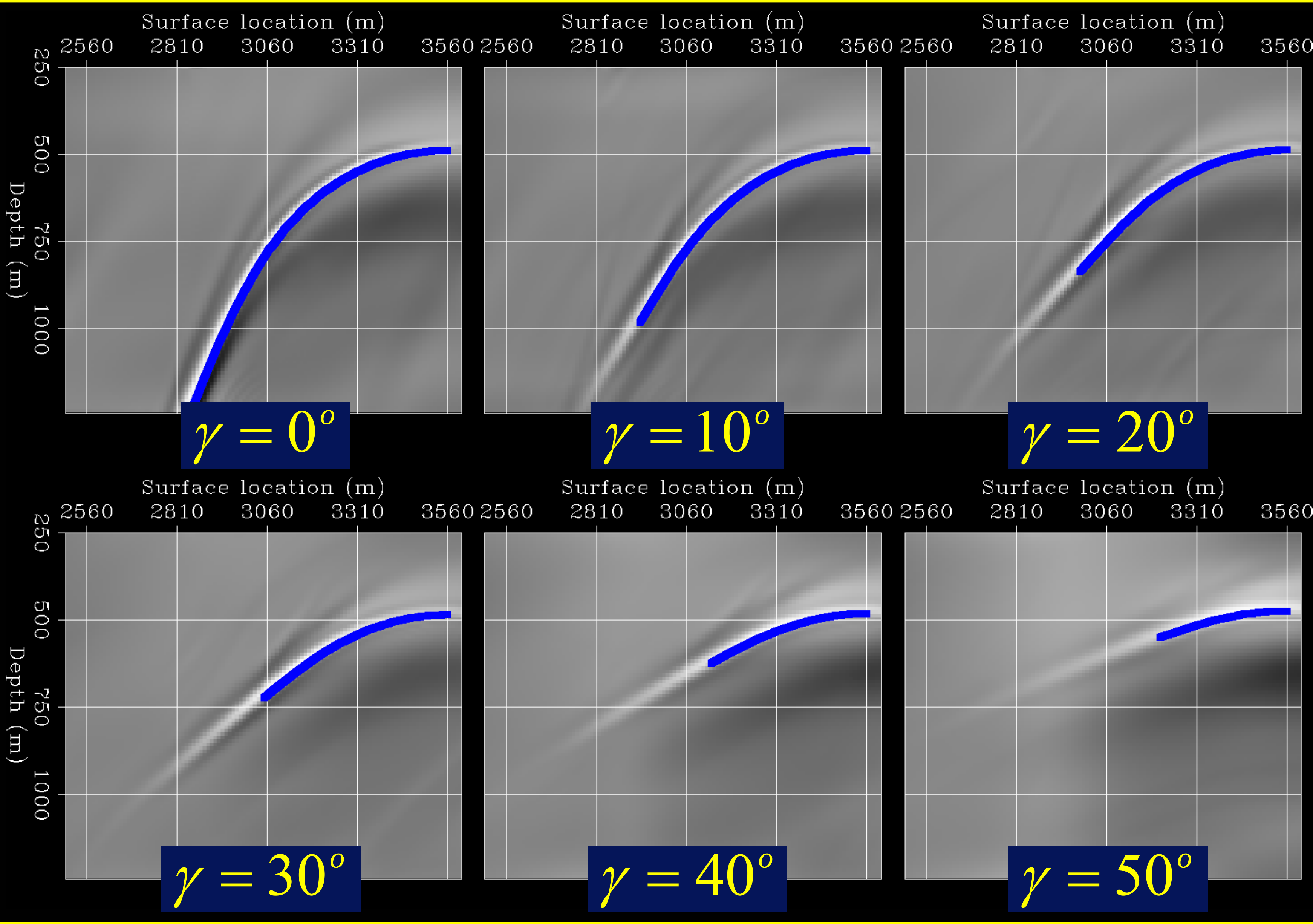
1) **Perturbed rays**
2) **Unperturbed rays**

Test on synthetic data

Correct Velocity | **Slow Velocity (4%)**



Reflector movements in ADCIG (synthetic test)



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Residual Moveout functions for ADCIG

- Dip-dependent Residual Moveout (RMO)

$$\Delta n_{\mathrm{RMO}} = z_0 \frac{1-\rho}{1-\rho\left(1-\cos\alpha\right)} \frac{\sin^2\gamma}{\left(\cos^2\alpha - \sin^2\gamma\right)}$$

- Flat-reflector Residual Moveout (RMO)

$$\Delta n_{\mathrm{RMO}} = z_0\left(1-\rho\right)\tan^2\gamma$$

where $\rho = -\frac{S_0}{S_m}$

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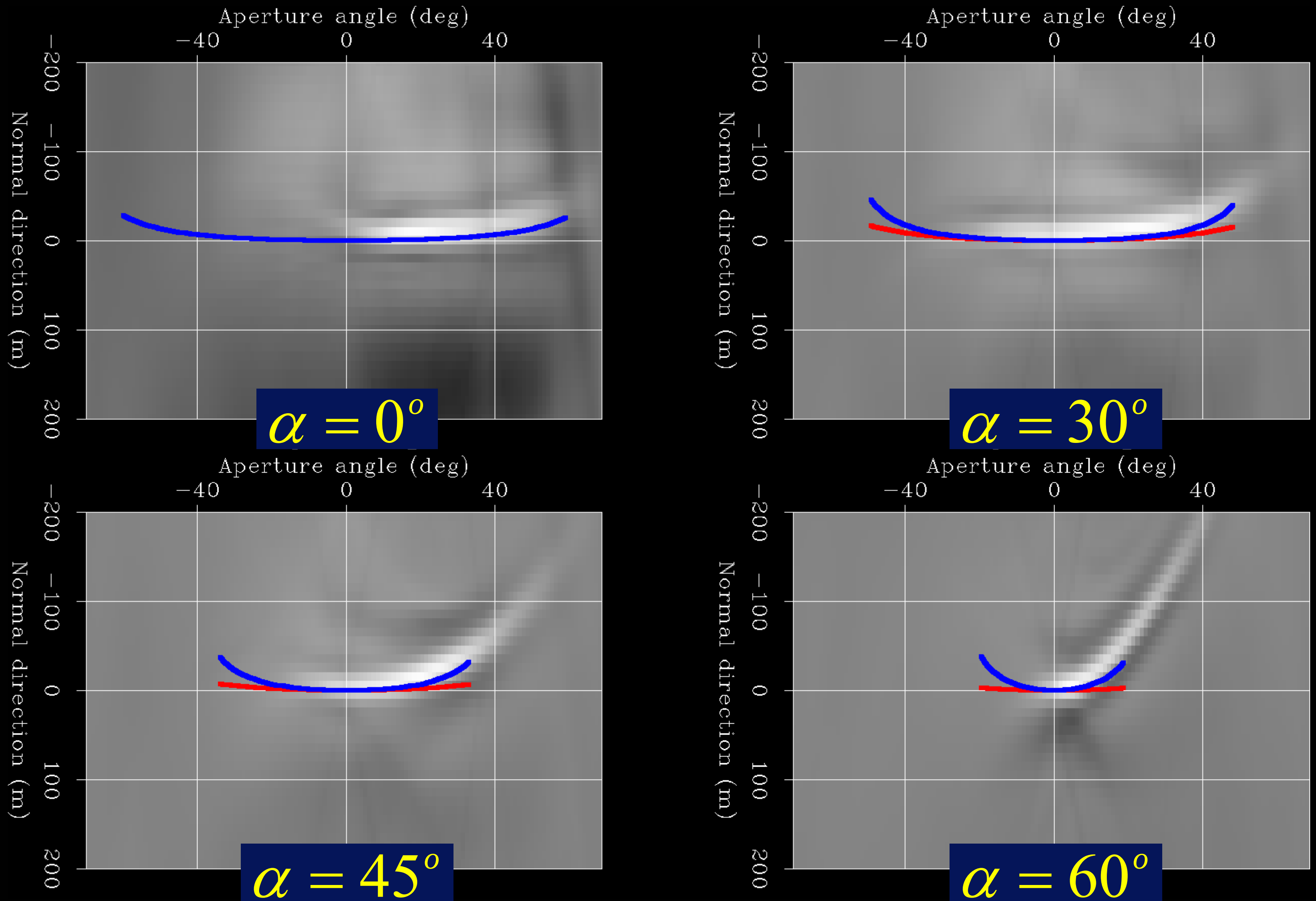
RMO functions in ADCIG (synthetic test)



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Common Image Gathers (2-D)

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- Angle-domain CIGs (Sava et al., 2001)

$$I(z,x,h_x) \xrightarrow{\textit{Slant Stack}} I(z,x,\tan\gamma)$$

where : γ – Reflection opening angle

Common Image Gathers (3-D)

- Offset-domain CIGs

$$I\left(z,\vec{\mathbf{x}},\vec{\mathbf{h}}\right)=\sum_{s}\sum_{t} S_s\left(t,z,\vec{\mathbf{x}}+\frac{\vec{\mathbf{h}}}{2}\right)R_s\left(t,z,\vec{\mathbf{x}}-\frac{\vec{\mathbf{h}}}{2}\right)$$

- Angle-domain CIGs (Biondi and Tisserant, 2003)

$$I\left(z,\vec{\mathbf{x}},\vec{\mathbf{h}}\right)\xrightarrow{\textit{Slant Stack + Coplanarity Condition}} I\left(z,\vec{\mathbf{x}},\gamma,\phi\right)$$

where : γ – Reflection opening angle

ϕ – Reflection azimuth

Common Image Gathers (3-D)

- Offset-domain CIGs

$$I\left(z,\vec{\mathbf{x}},\vec{\mathbf{h}}\right)=\sum_{s}\sum_{t} S_s\left(t,z,\vec{\mathbf{x}}+\frac{\vec{\mathbf{h}}}{2}\right) R_s\left(t,z,\vec{\mathbf{x}}-\frac{\vec{\mathbf{h}}}{2}\right)$$

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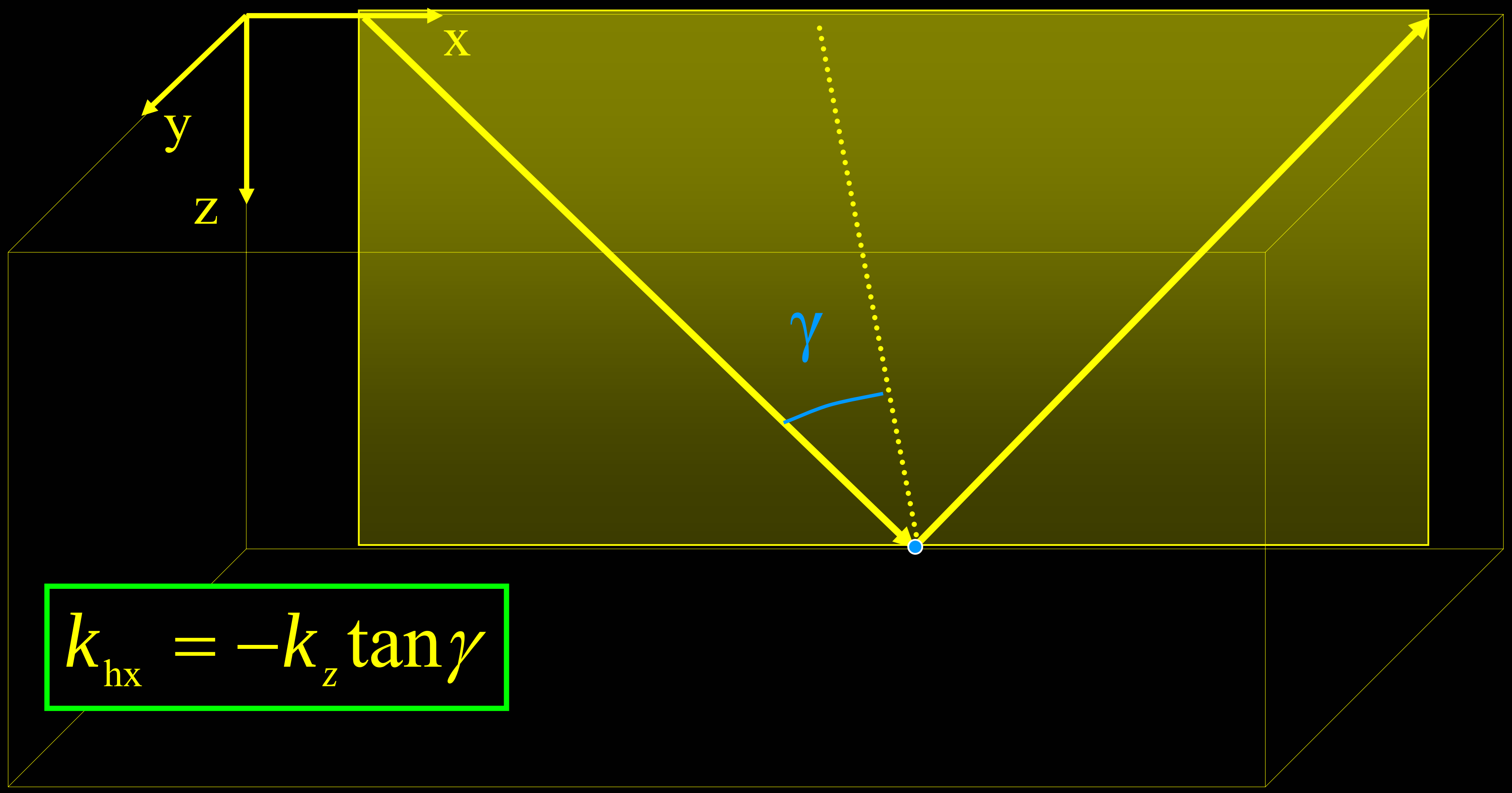
3-D ADCIGs along vertical local plane



$$k_{hx} = -k_z \tan\gamma$$

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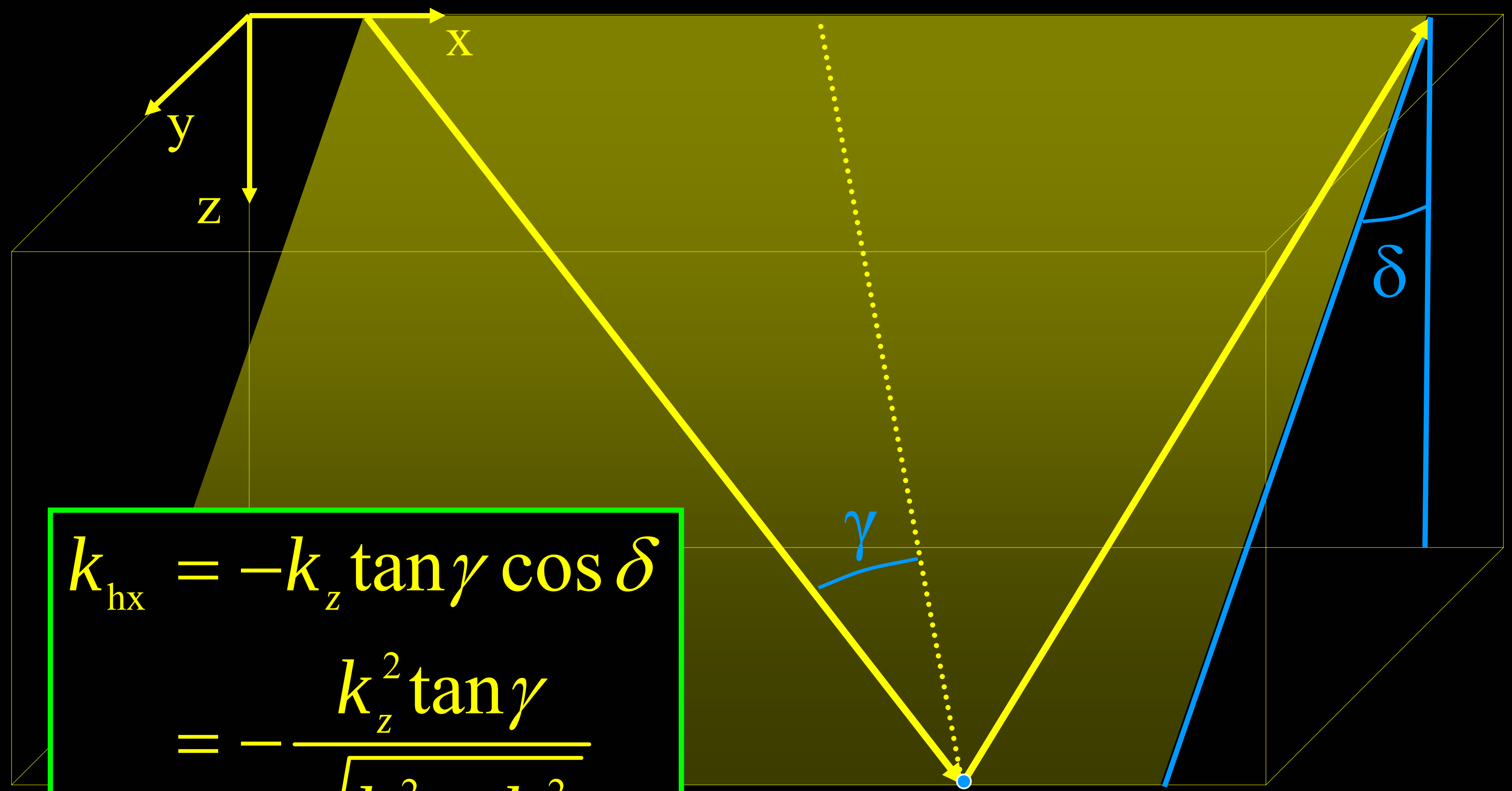
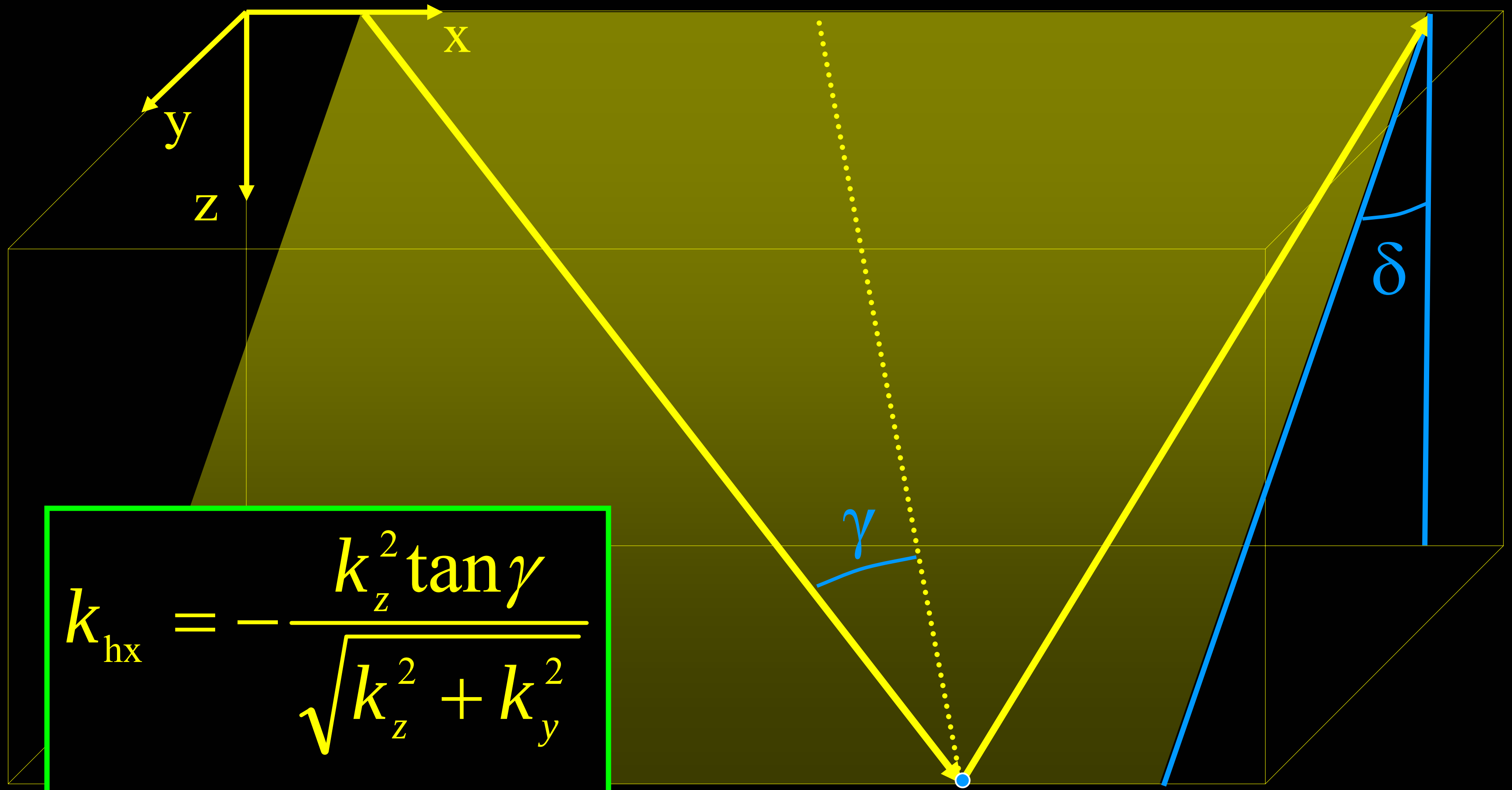
3-D ADCIGs along slanted local plane



$$k_{hx} = -k_z \tan\gamma \cos\delta$$

$$= -\frac{k_z^2 \tan\gamma}{\sqrt{k_z^2 + k_y^2}}$$

3-D ADCIGs along slanted local plane



$$k_{hx} = -\frac{k_z^2 \tan\gamma}{\sqrt{k_z^2 + k_y^2}}$$

$$k_{hy} = -\frac{k_{mx} k_{my} k_{hx}}{k_z^2 + k_{my}^2}$$

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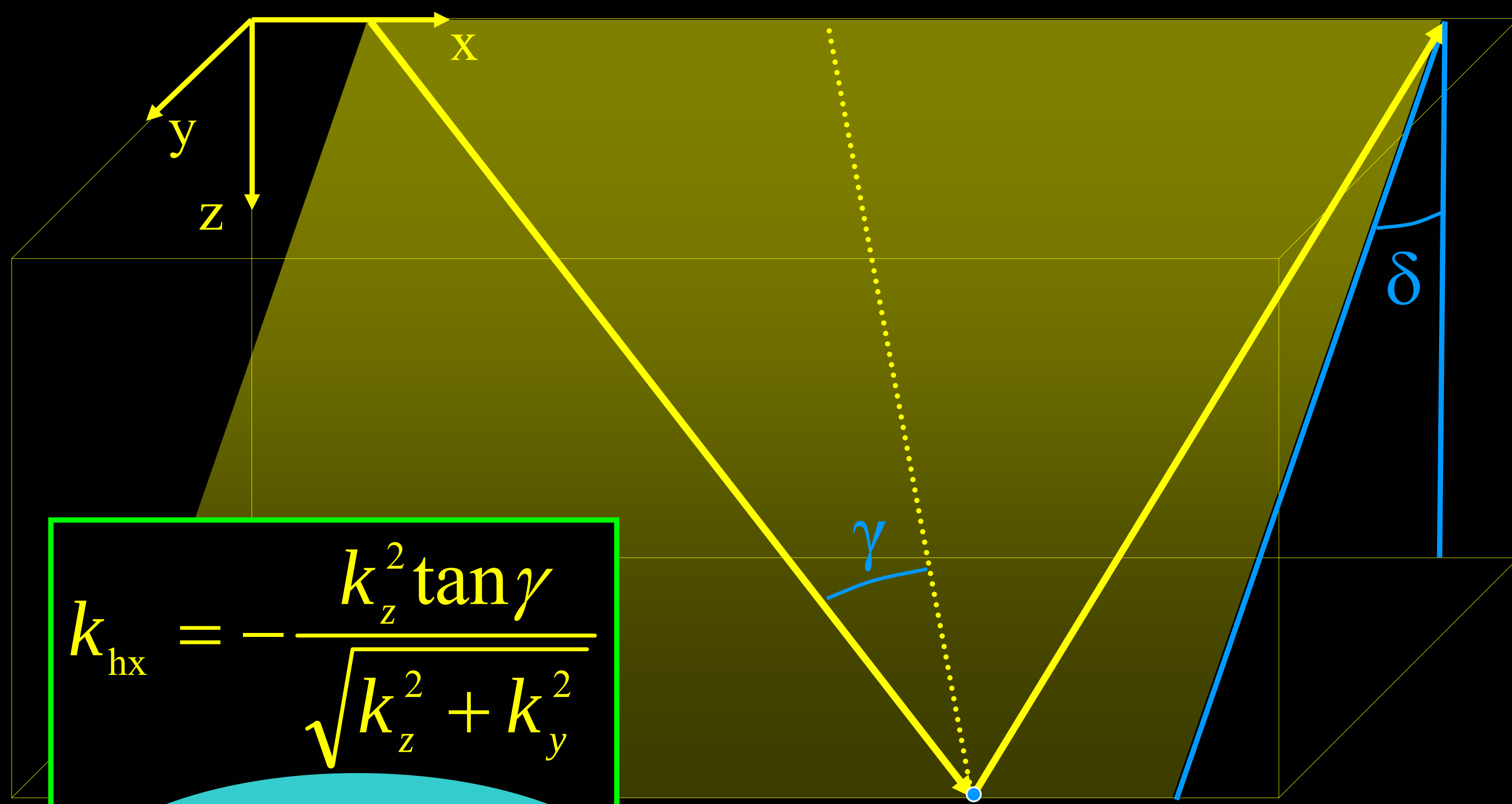
3-D ADCIGs along slanted local plane



$$k_{hx} = -\frac{k_z^2 \tan\gamma}{\sqrt{k_z^2 + k_y^2}}$$

Coplanarity condition

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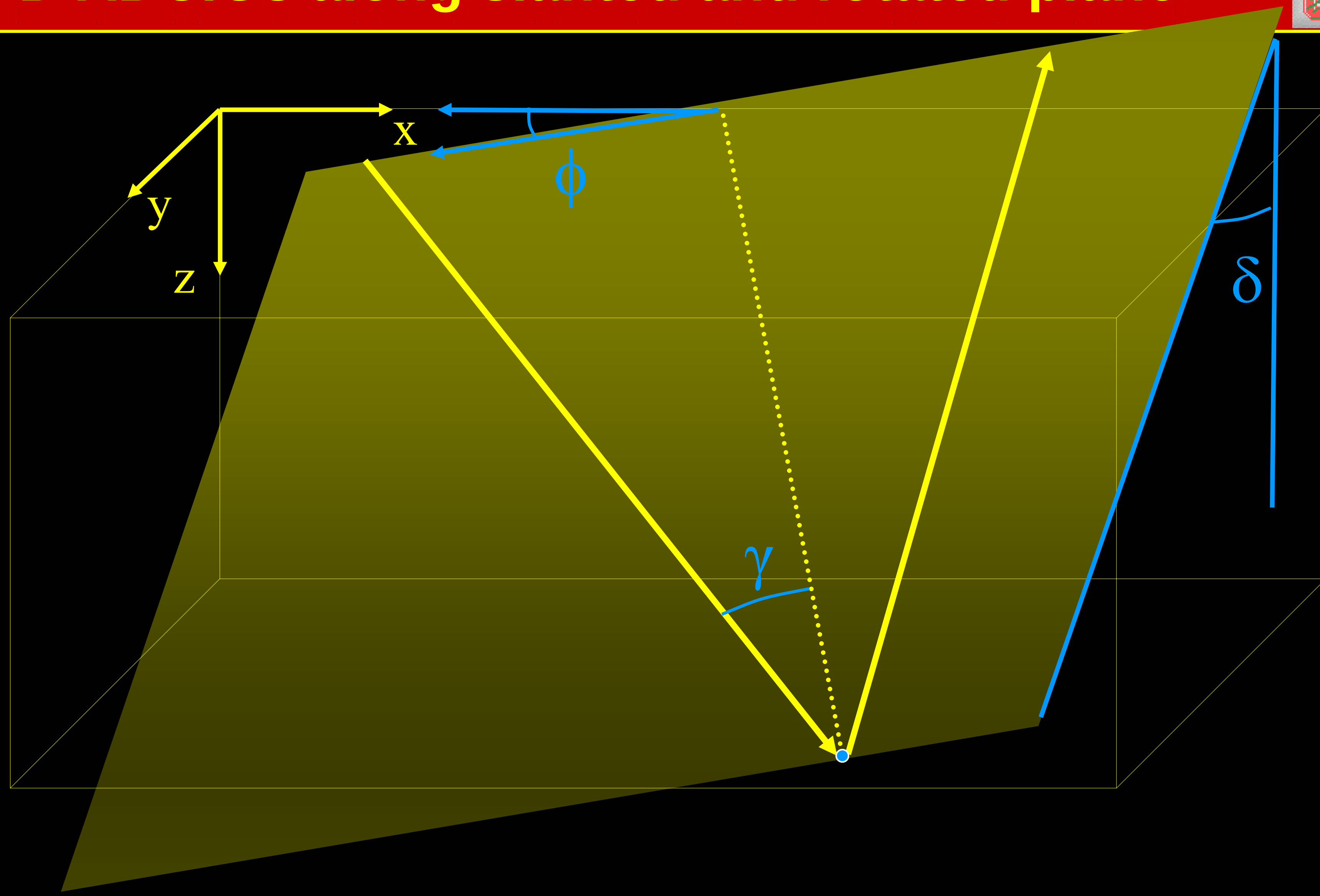
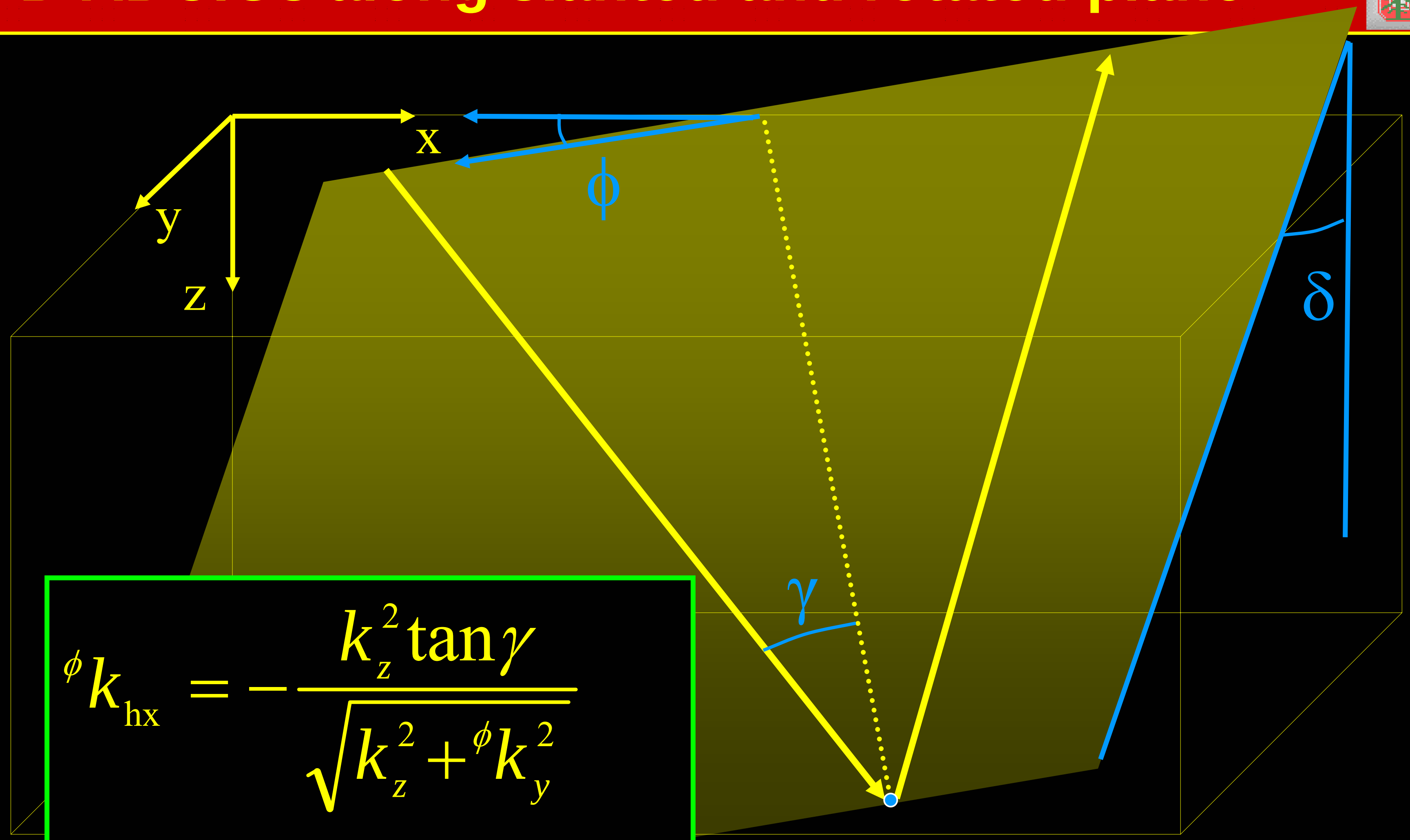
3-D ADCIGs along slanted and rotated plane



3-D ADCIGs along slanted and rotated plane



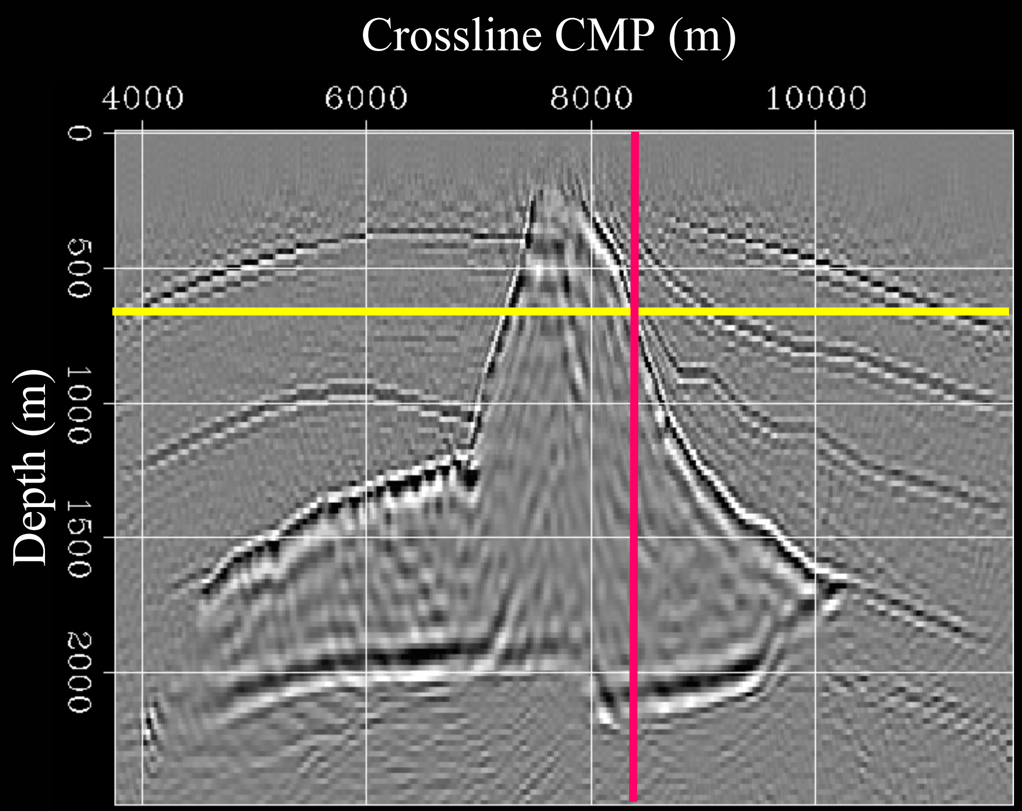
$$^{\phi}k_{hx} = -\frac{k_z^2 \tan\gamma}{\sqrt{k_z^2 + {}^{\phi}k_y^2}}$$

$$^{\phi}k_{hy} = -\frac{^{\phi}k_{mx}\, {}^{\phi}k_{my}\, {}^{\phi}k_{hx}}{k_z^2 + {}^{\phi}k_{my}^2}$$

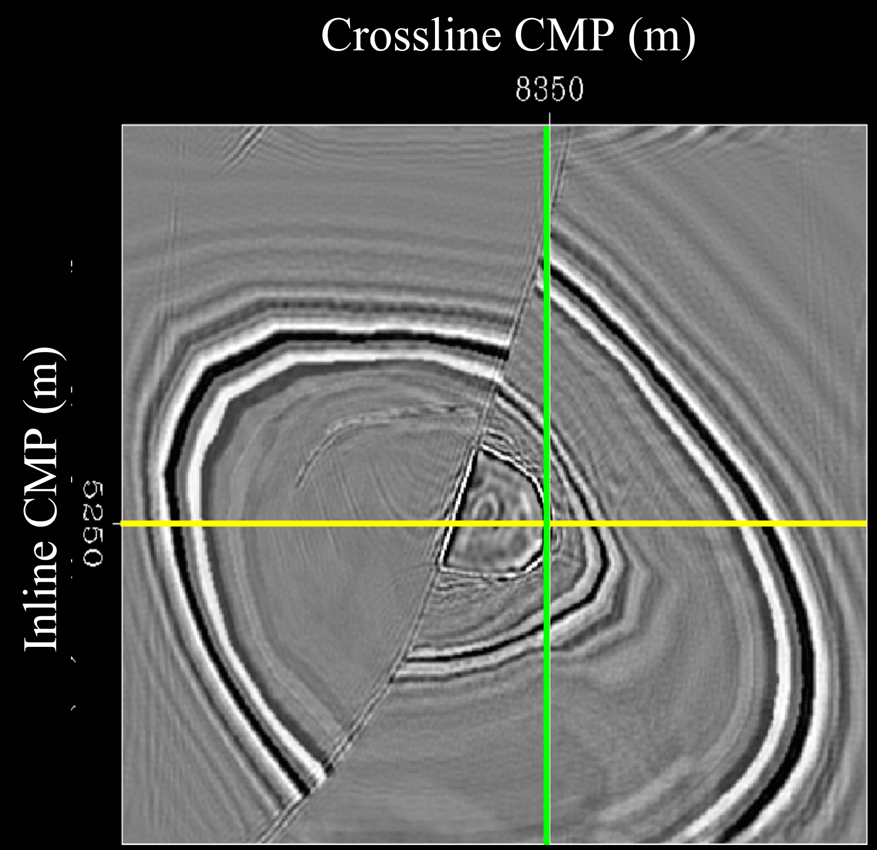
where : $^{\phi}k_{mx}, {}^{\phi}k_{my}, {}^{\phi}k_{hx}, {}^{\phi}k_{hy}$

Rotated wavenumbers

Example of 3-D ADCIGs – SEG-EAGE salt data



Migrated crossline section



Migrated depth slice

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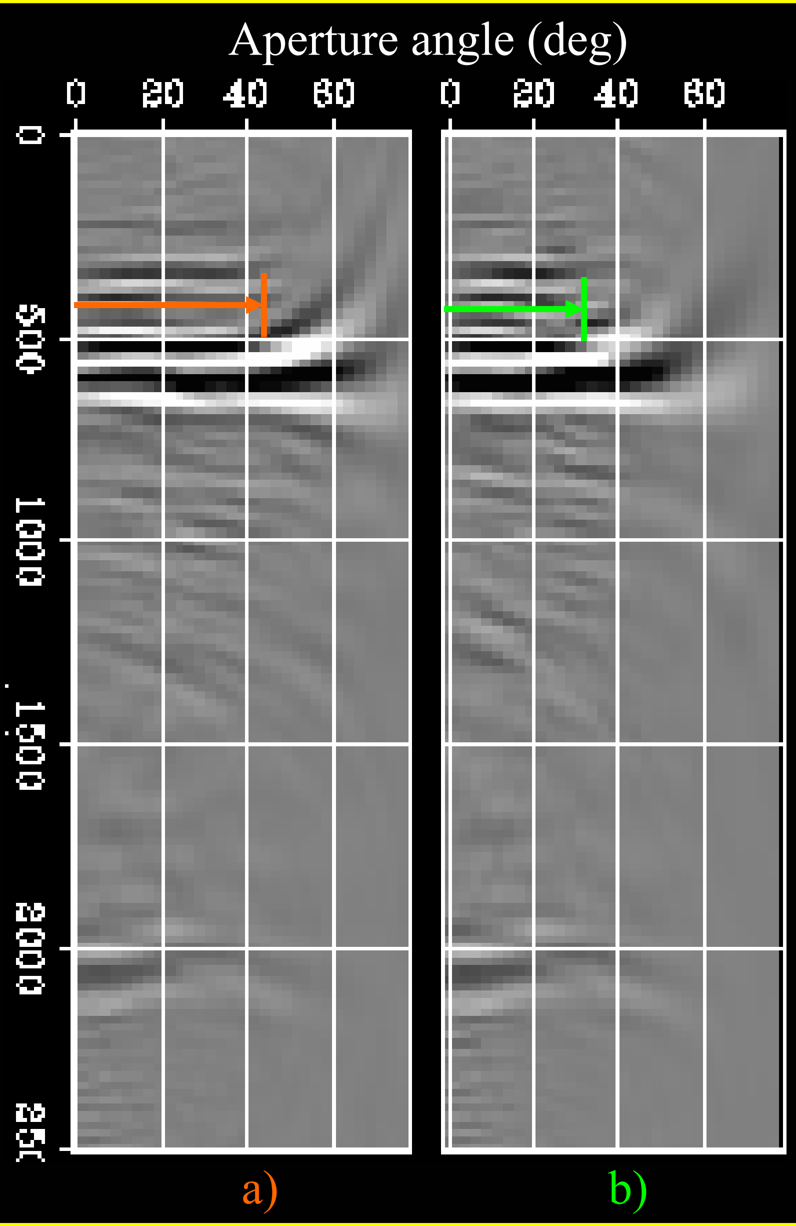
Effect of crossline dips on 3-D ADCIGs

a) $k_{hx} = -k_z \tan\gamma$

b) $k_{hx} = -\frac{k_z^2 \tan\gamma}{\sqrt{k_z^2 + k_y^2}}$



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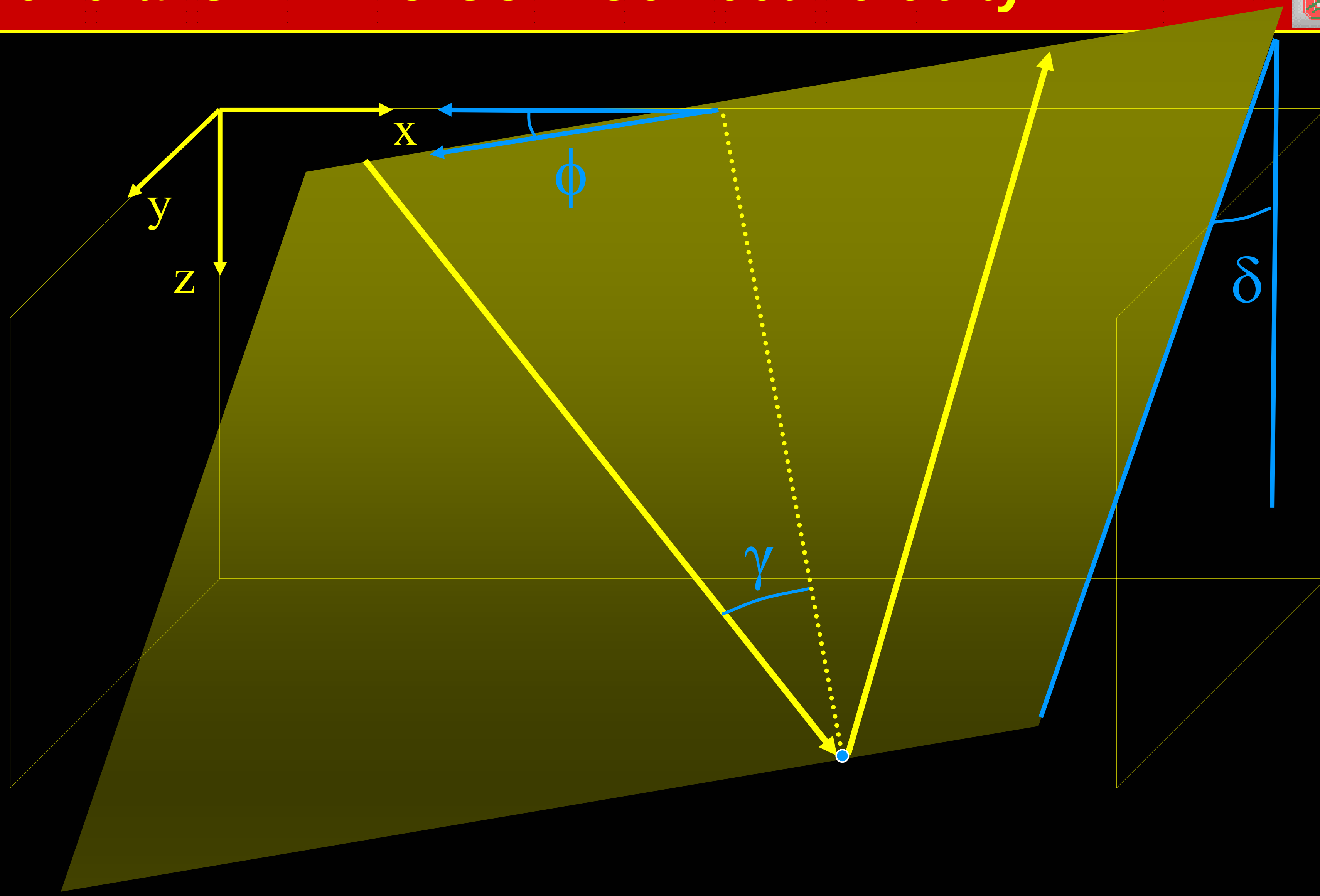
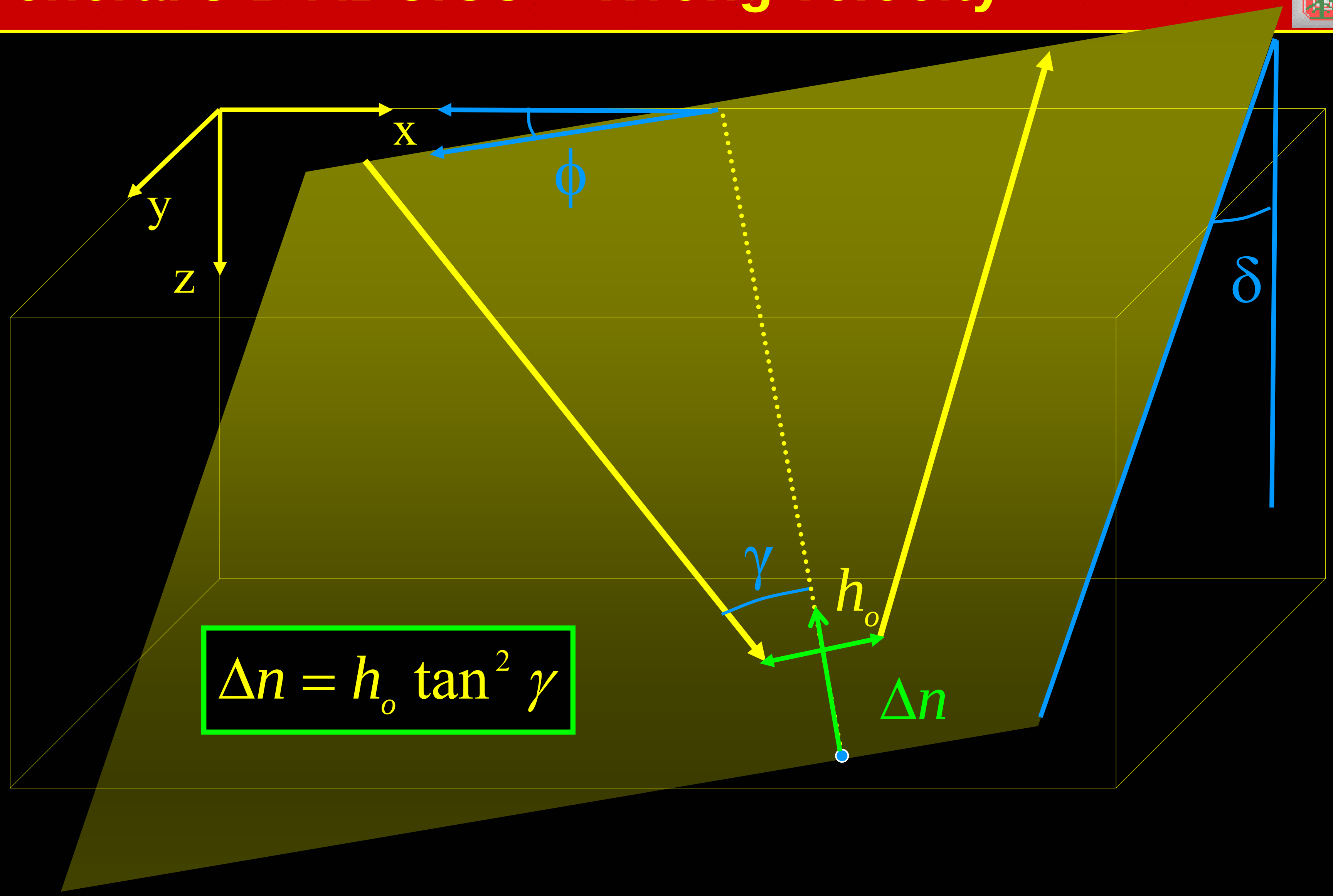
General 3-D ADCIGs - Correct velocity



General 3-D ADCIGs - Wrong velocity



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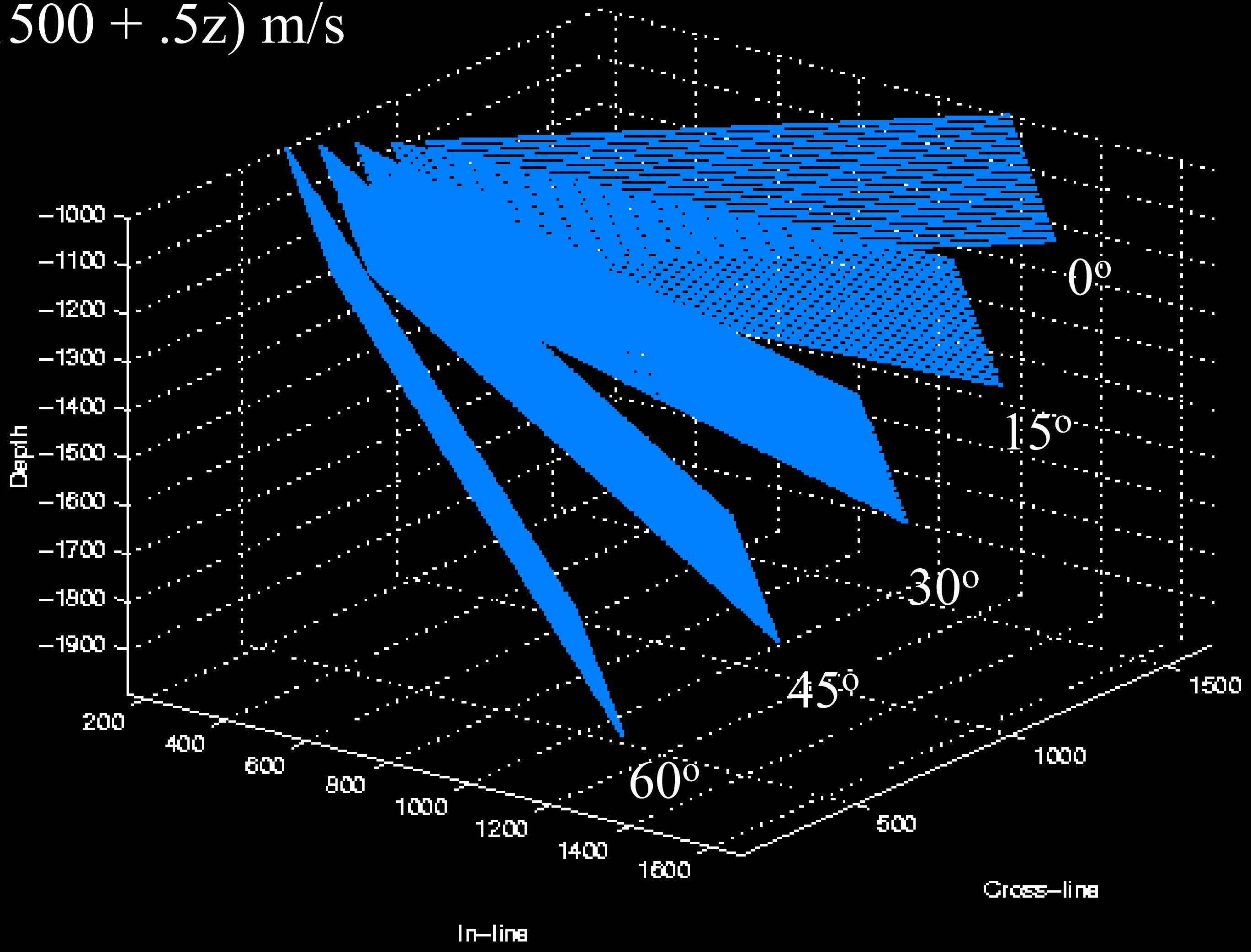
Synthetic dataset with 5 planes oriented at 45°

V(z) = (1500 + .5z) m/s



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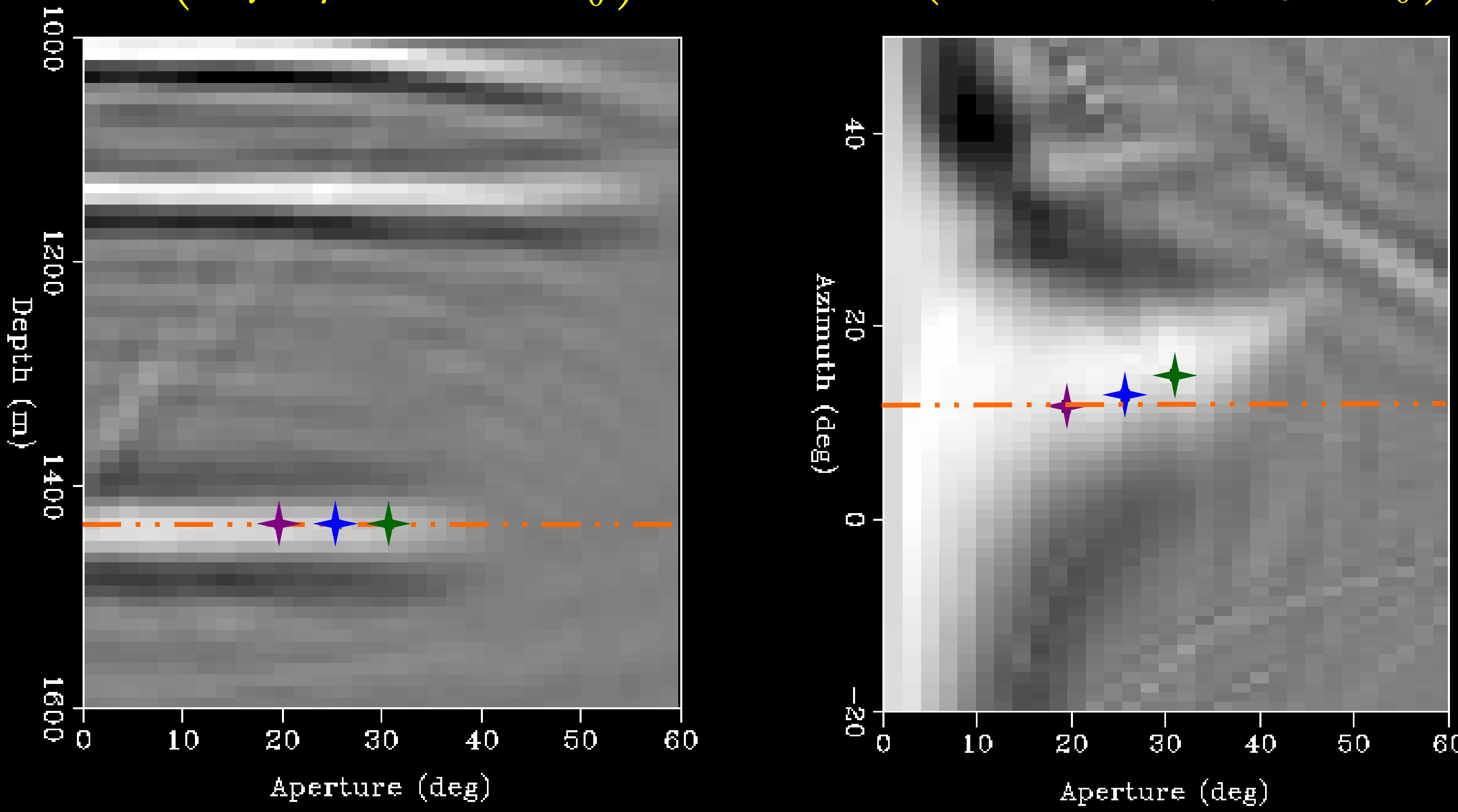
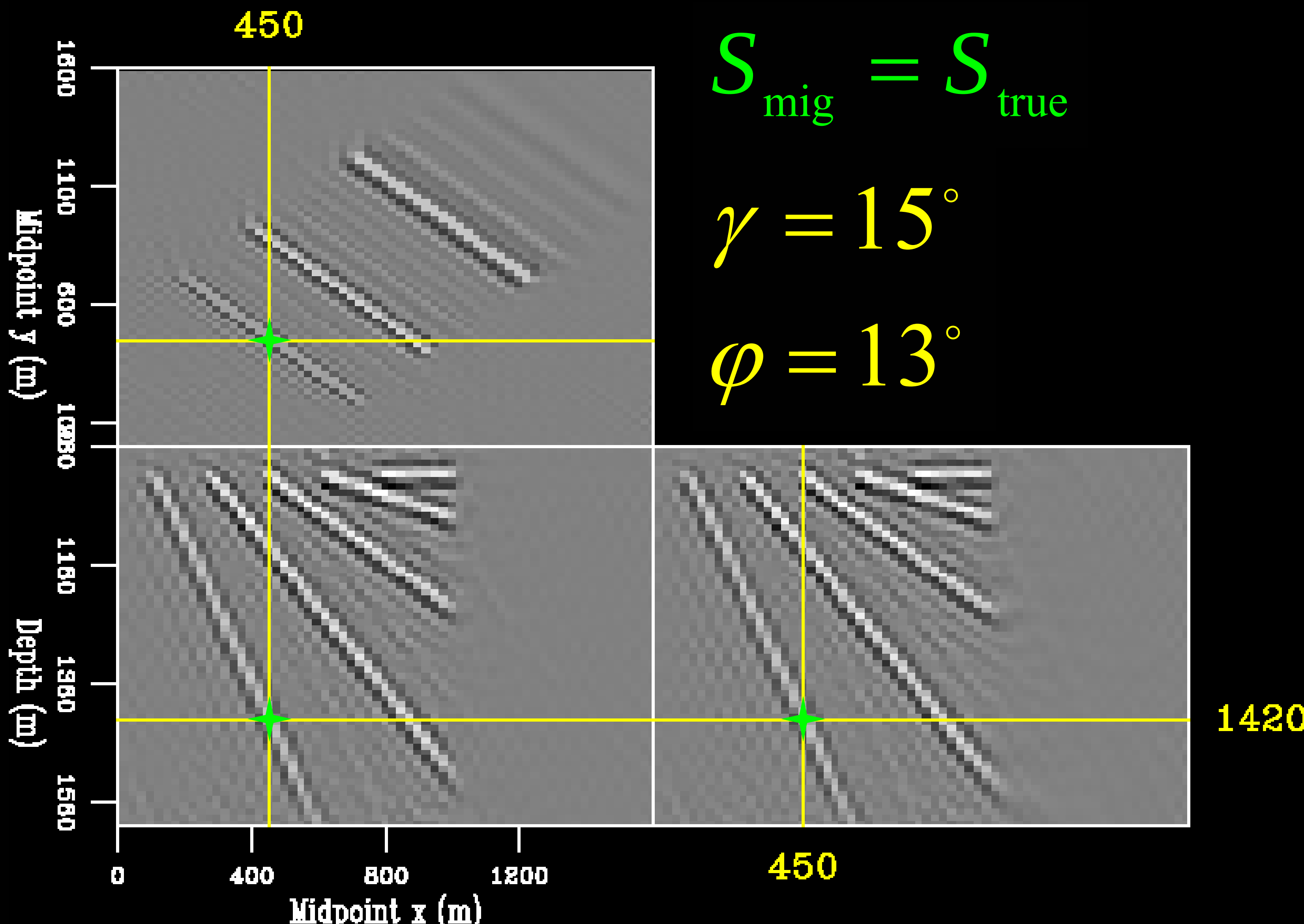
3-D ADCIG with correct velocity

$$I\left(z, \gamma, \varphi = 13^\circ; \vec{\mathbf{x}}_0\right) \qquad I\left(z = 1420, \gamma, \varphi; \vec{\mathbf{x}}_0\right)$$



Constant (γ,ϕ) cube with correct velocity



$$S_{mig} = S_{true}$$

$$\gamma = 15^\circ$$

$$\varphi = 13^\circ$$

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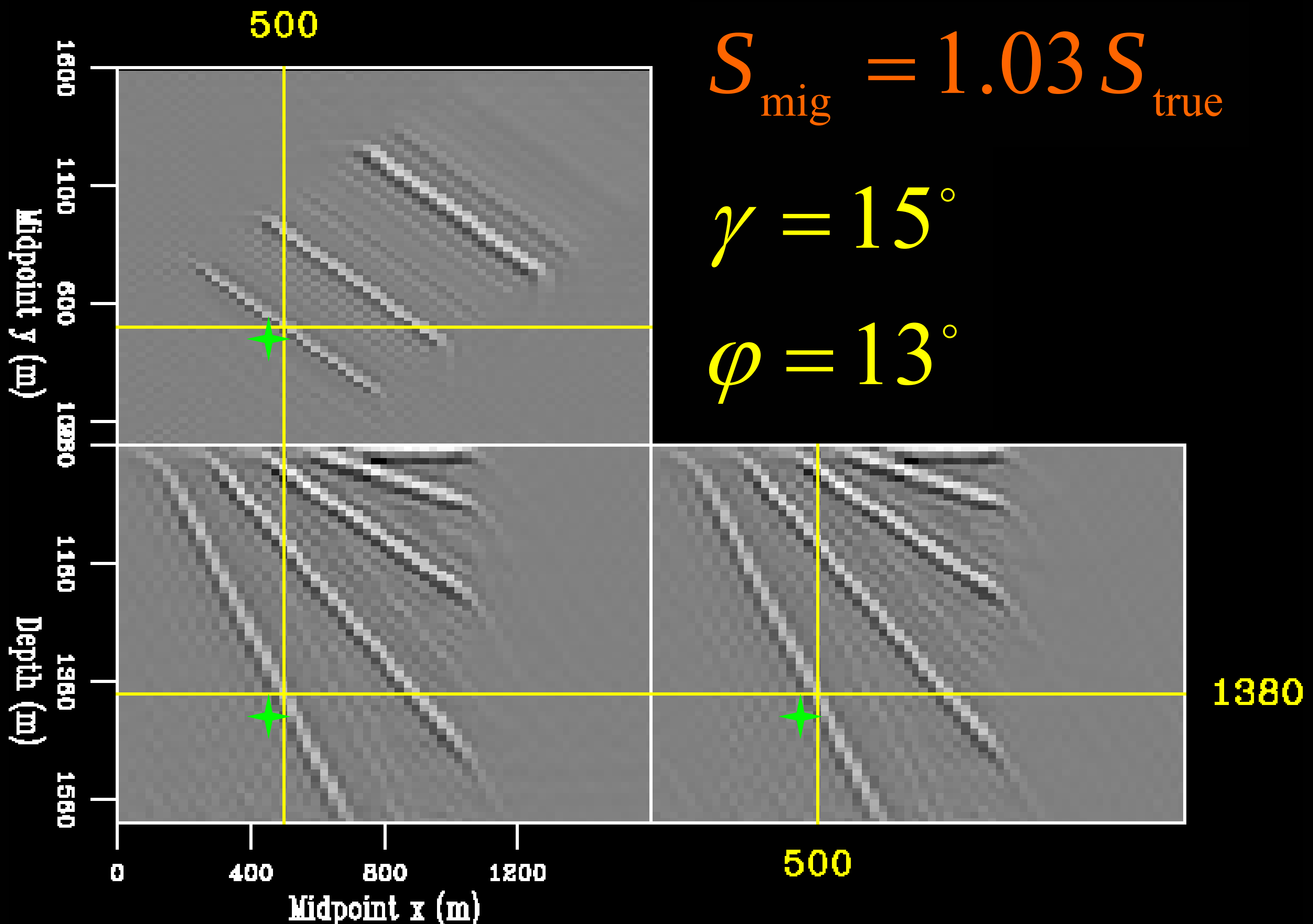
Tracking reflector movement - unperturbed rays



$$S_{mig} = 1.03\,S_{true}$$

$$\gamma = 15^{\circ}$$

$$\varphi = 13^{\circ}$$

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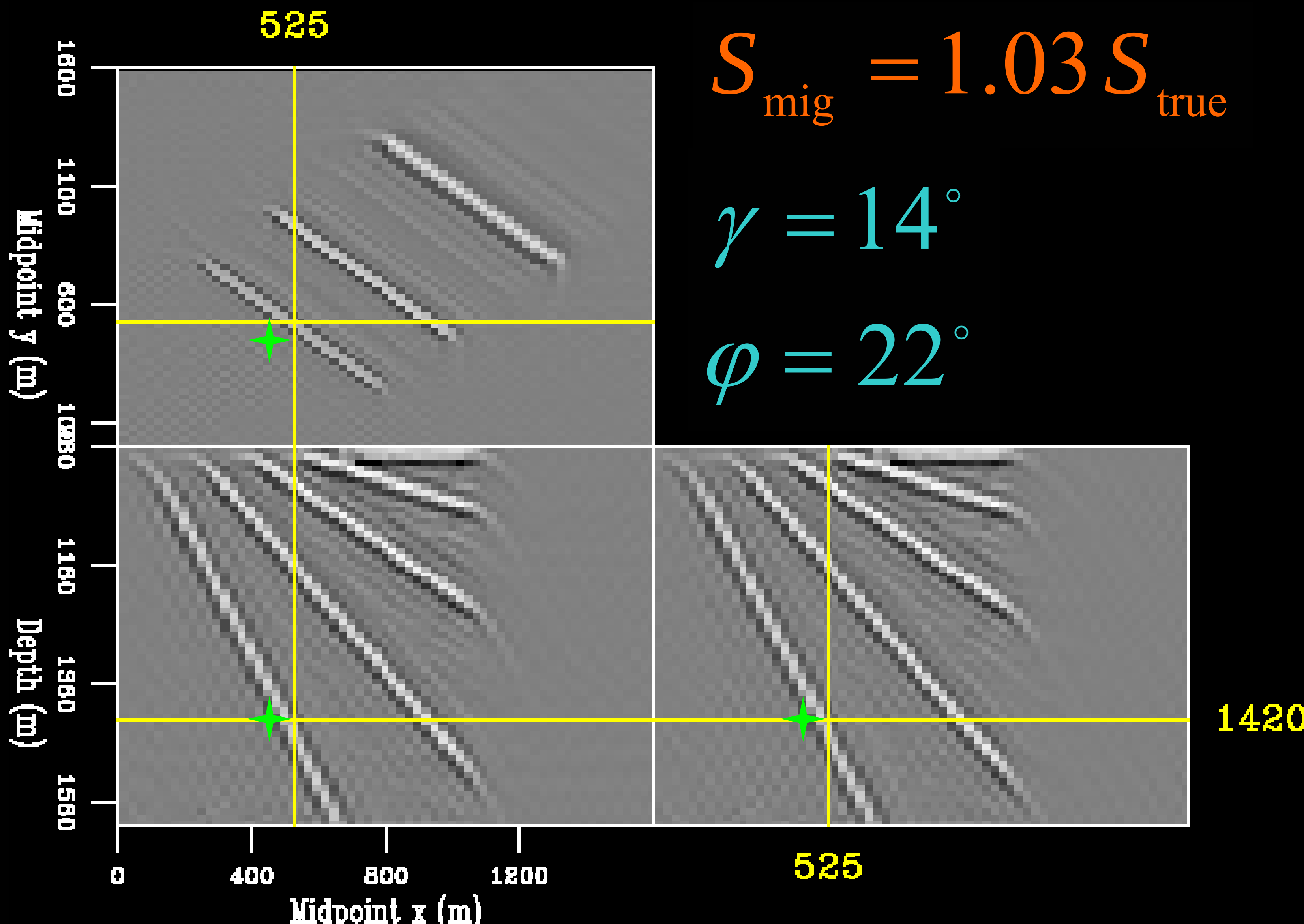
Tracking reflector movement - perturbed rays

$$S_{\mathrm{mig}} = 1.03\, S_{\mathrm{true}}$$

$$\gamma = 14^{\circ}$$

$$\varphi = 22^{\circ}$$



Conclusions

- ADCIGs provide accurate velocity information even in presence of steep dips.
- The kinematic analysis of ADCIGs when reflections are not focused at zero offsets leads to the derivation of accurate Residual Moveout functions in both 2-D and 3-D.
- ADCIGs in 3-D are 5-D objects, function of both the aperture angle γ and the reflection azimuth ϕ.
- In 3-D, large errors in velocity cause not only perturbations in γ but also perturbations in ϕ.

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Acknowledgments

❖ Total for North Sea data set.

❖ SEP sponsors for financial support.