Curved edge diffraction modeling

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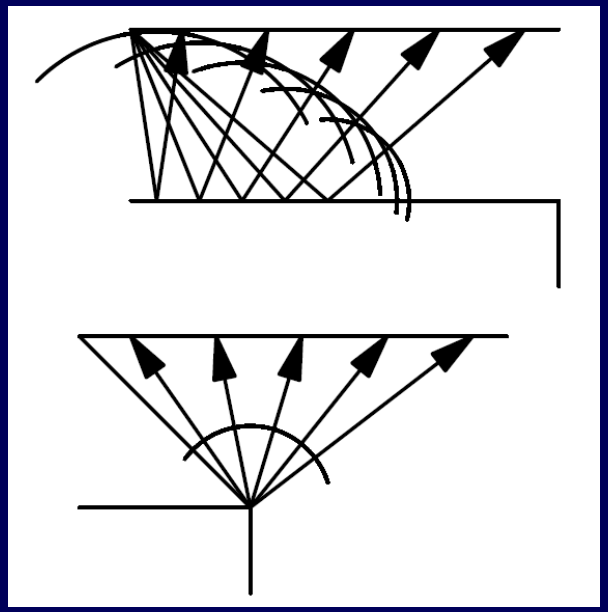
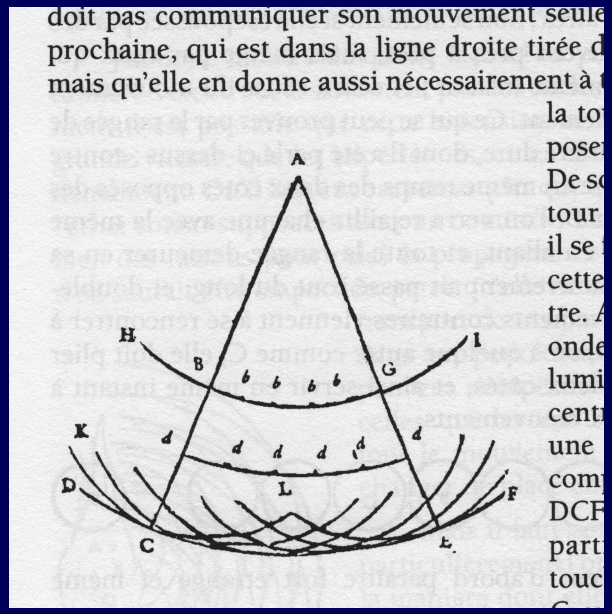
Outline

- Diffractions - introduction
- Diffraction - analysis, imaging, modeling, inversion
- Diffraction modeling - ray-Born
- Edge and tip diffractions
- Curved edge diffraction modeling
- Examples – synthetic, GOM-B

Diffractions – introduction

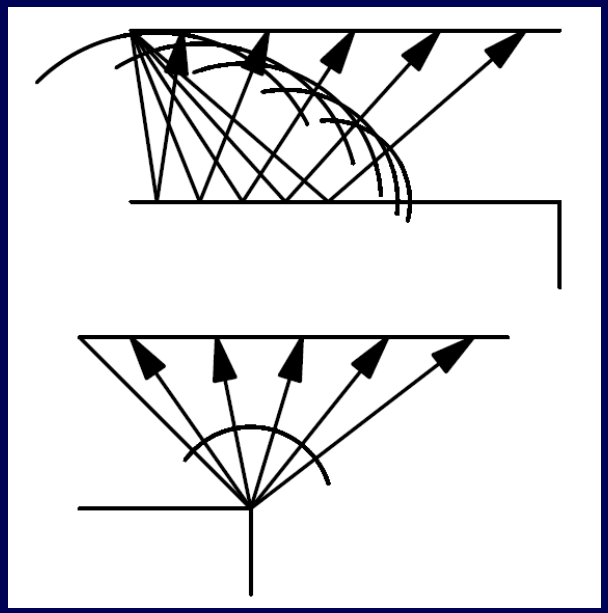


Reflections vs. Diffractions



Traité de la Lumière, Christiaan Huygens ('s-Gravenhage, 1629-95)

Diffractions – introduction



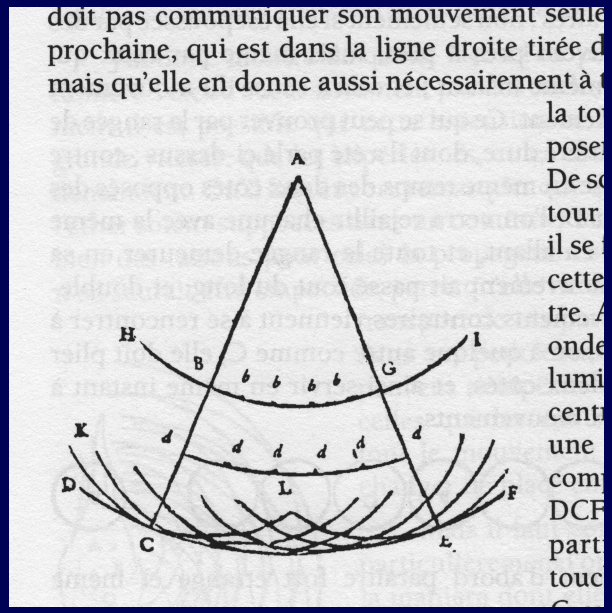
Why diffractions?

Geology – structural interpretation, super-resolution: faults, pinch-outs, small-size scattering objects

Physics – conventional processing/imaging flow uses specular reflections, diffractions are not well preserved

"Diffractions are the abandoned stepchildren of traditional seismic processing and imaging!" (Khaidukov, Landa & Moser, Geophysics, 2004)

Diffractions – analysis, imaging, modeling, inversion



What can we do with diffractions?

Diffraction ...

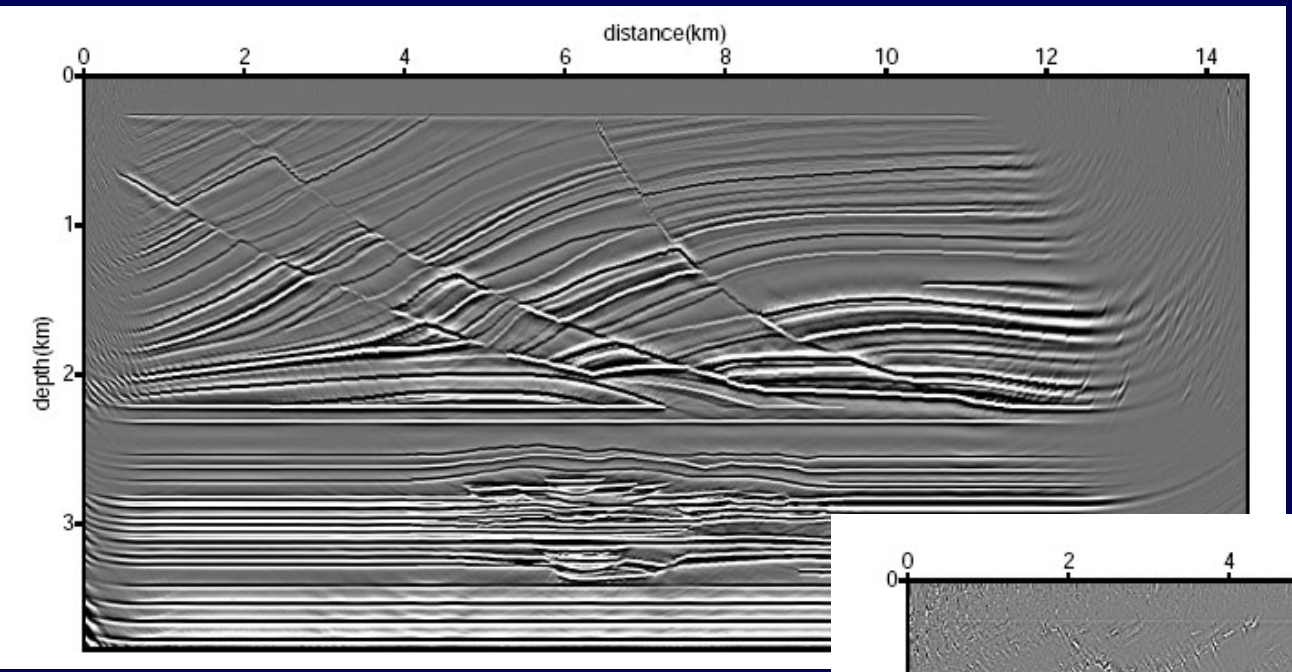
... *Analysis*

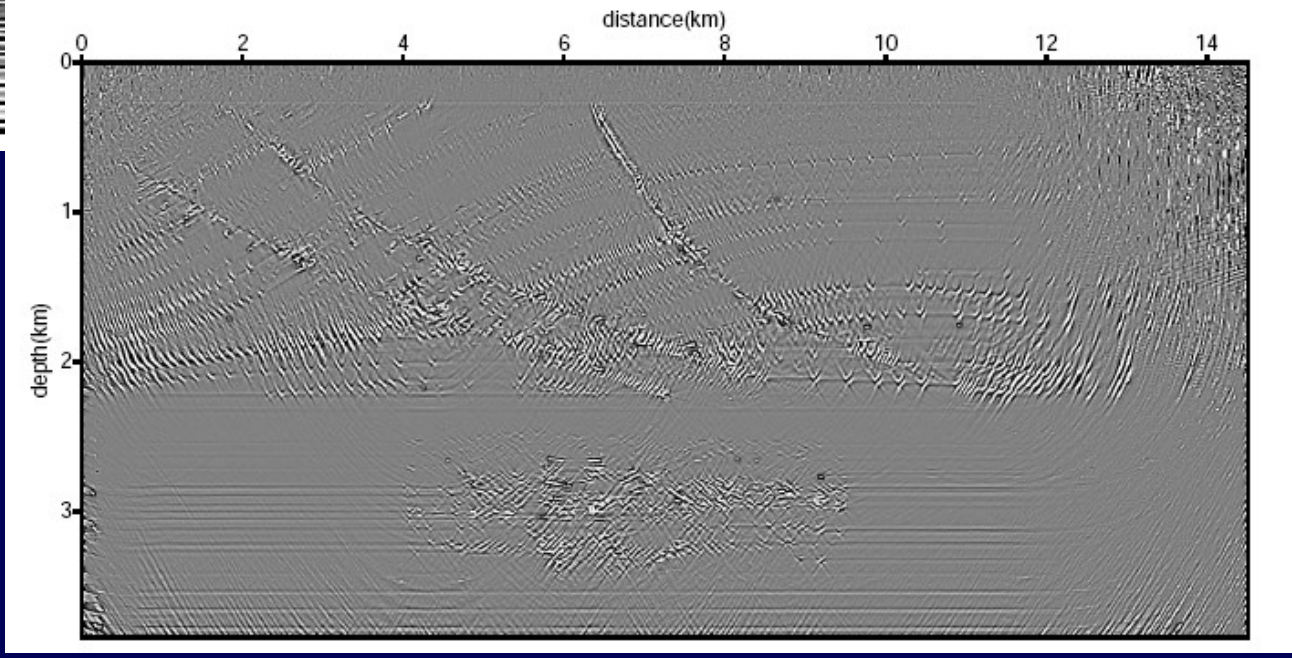
... *Imaging*

... *Modeling*

... *Inversion*

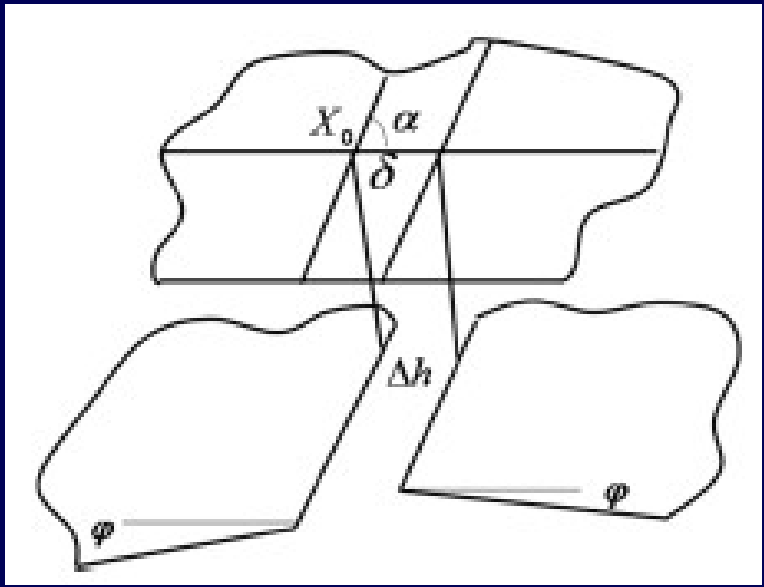
Diffractions – analysis, imaging, modeling, inversion

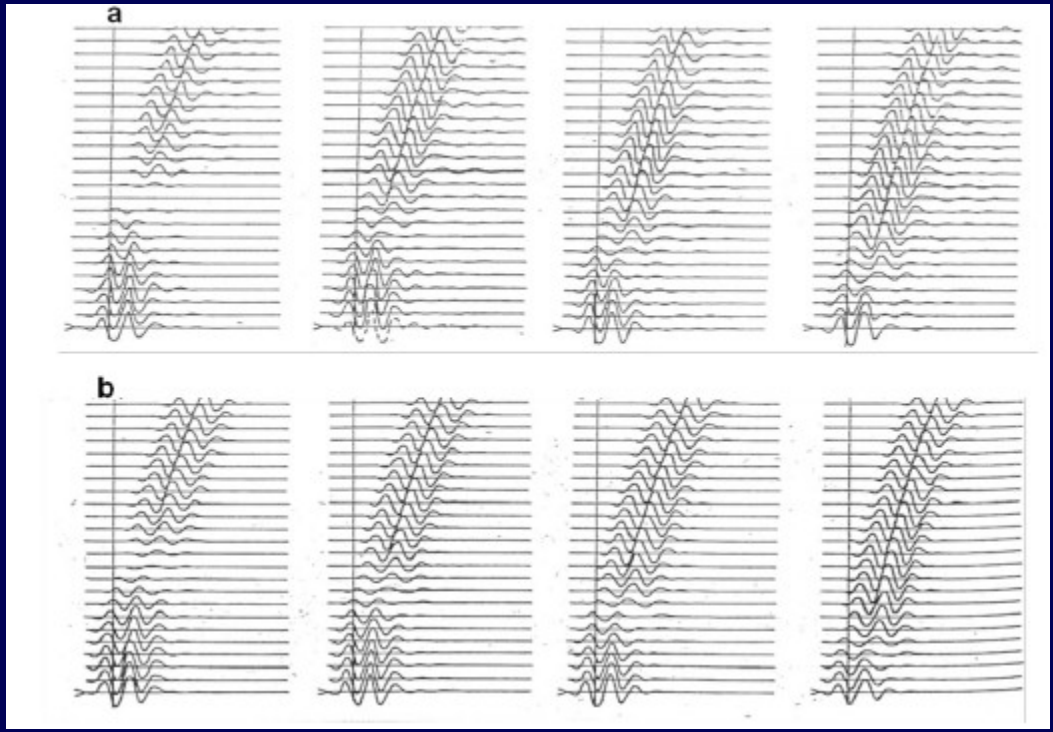




(Moser and Howard, 2008, data courtesy R. Baina, OPERA)

Diffractions – analysis, imaging, modeling, inversion





X_0 hor. position, α fault azimuth, δ hor. shift, Δh fault amplitude, φ reflector dip
a) modeled b) observed seismograms

(Landa & Maximov, 1980)

Diffraction modeling

modeling - Ray-Born integral

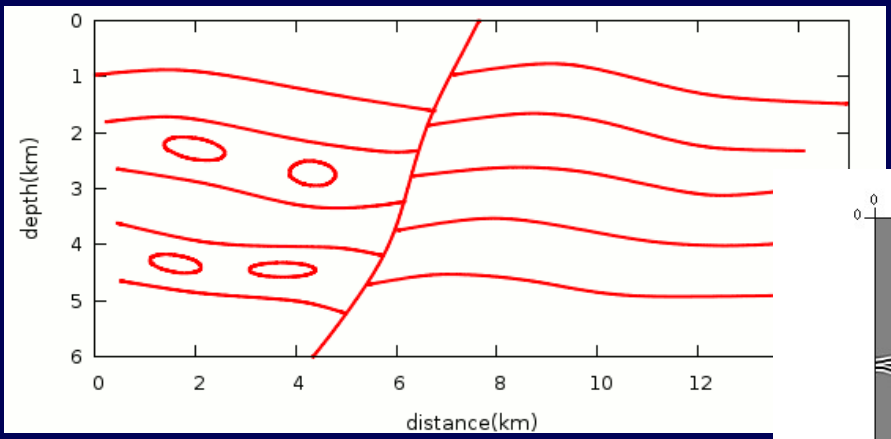
$$U(\mathbf{s},\mathbf{r},t) = \int A(\mathbf{s},\mathbf{x},\mathbf{r})V(\mathbf{x})w(t - T(\mathbf{s},\mathbf{x},\mathbf{r}))\mathrm{d}\mathbf{x}$$

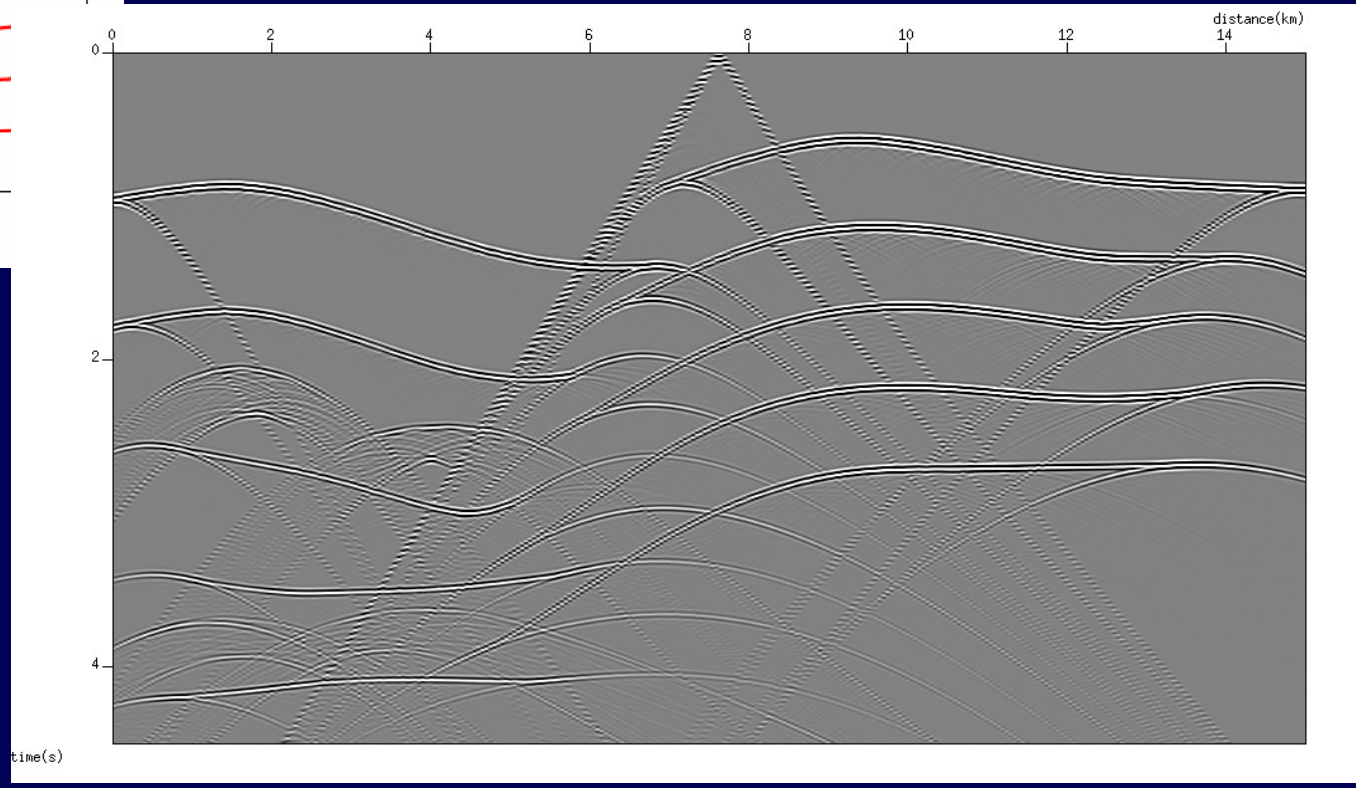
- **Linear — Inversion, migration + primaries only**
- **Ray-theory travel time T(s,x,r) and amplitude A(s,x,r) in smooth background**
- **Volume integral over scattering potential V(x)**
- **No smoothness constraints for V(x), only integrability**

  → *Diffractions*

Diffraction modeling

Ray-Born modeling - example





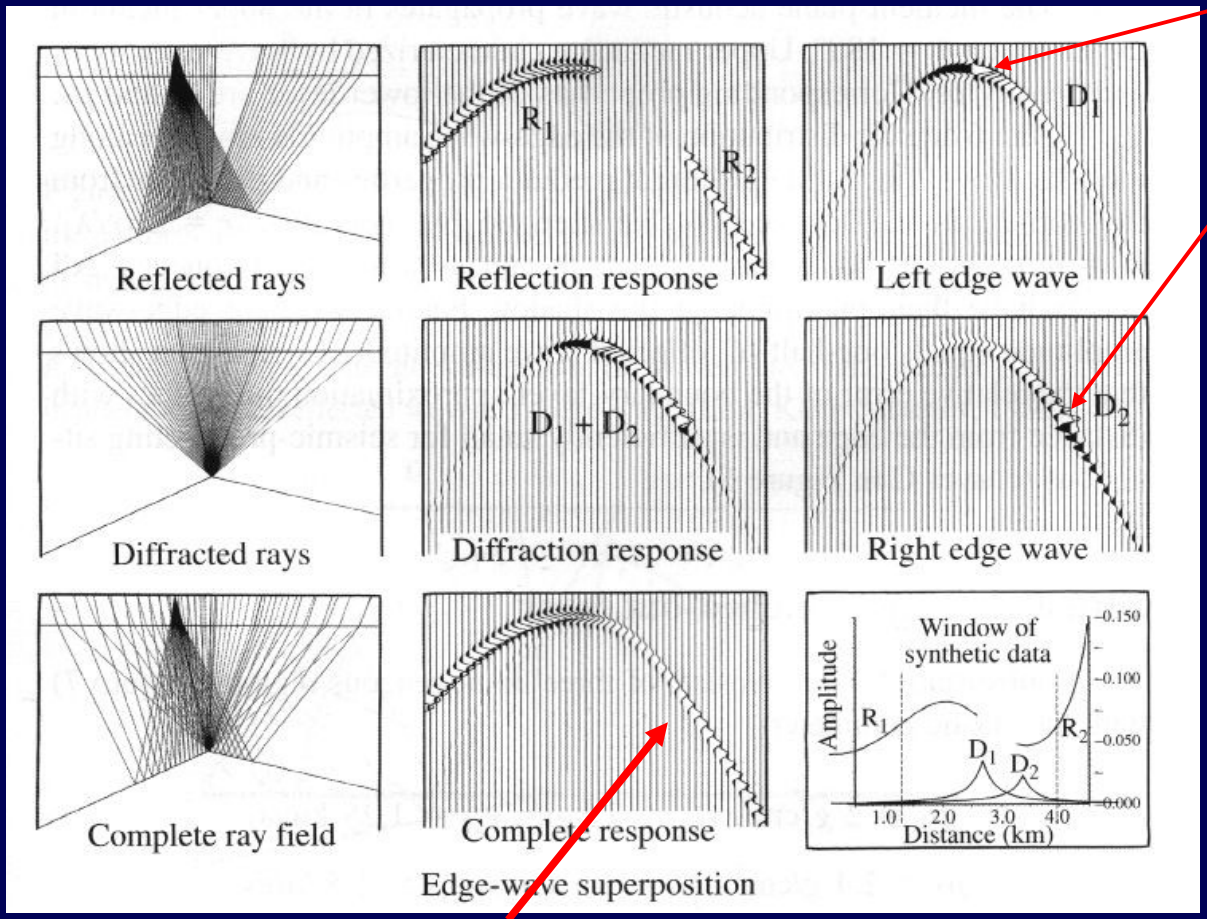
Complicated fault model

→ *Edge diffractions + Caustic diffractions*

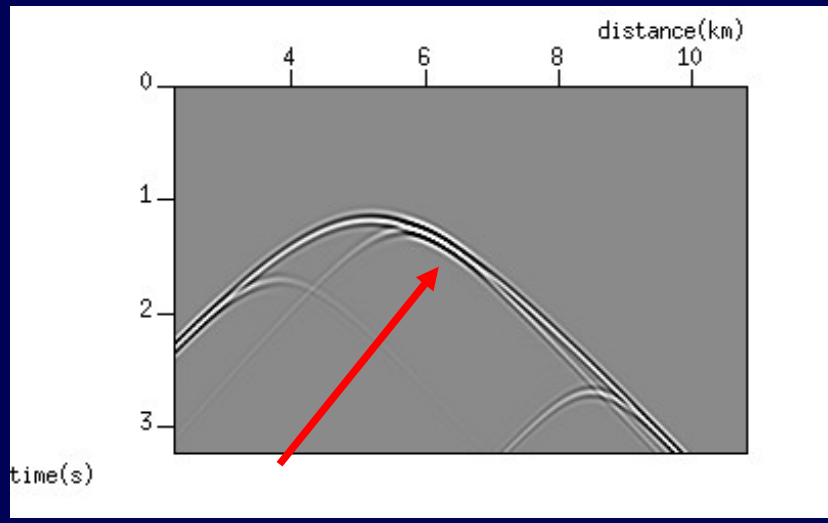
(Moser, 2012)

Edge and tip diffractions

Edge wave theory



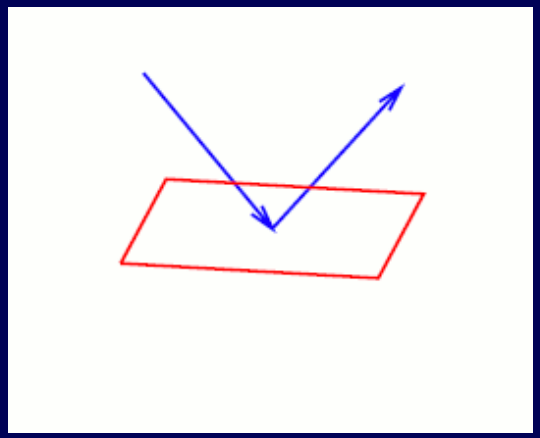
Polarity change across reflection tangent point



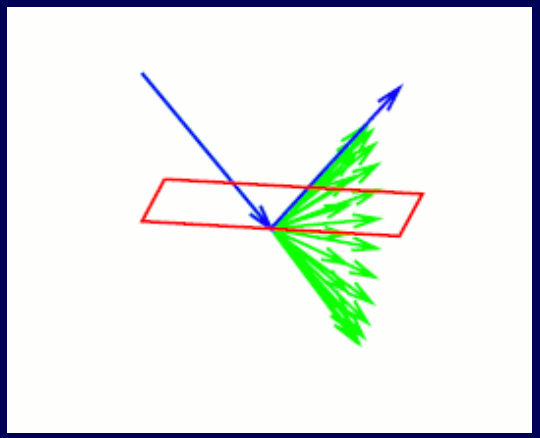
ray-Born (shot at 4km)

(Klem-Musatov & al, 1976, 2008)

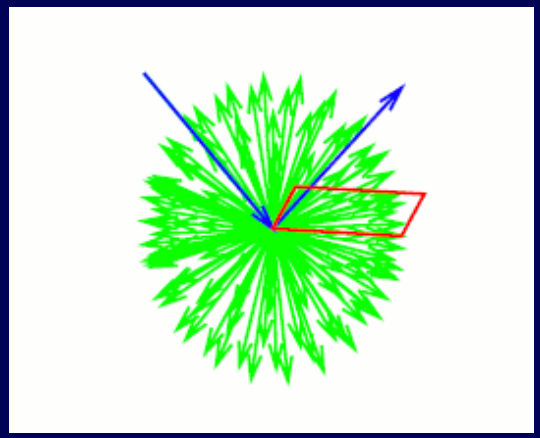
Edge and tip diffractions



Plane reflection



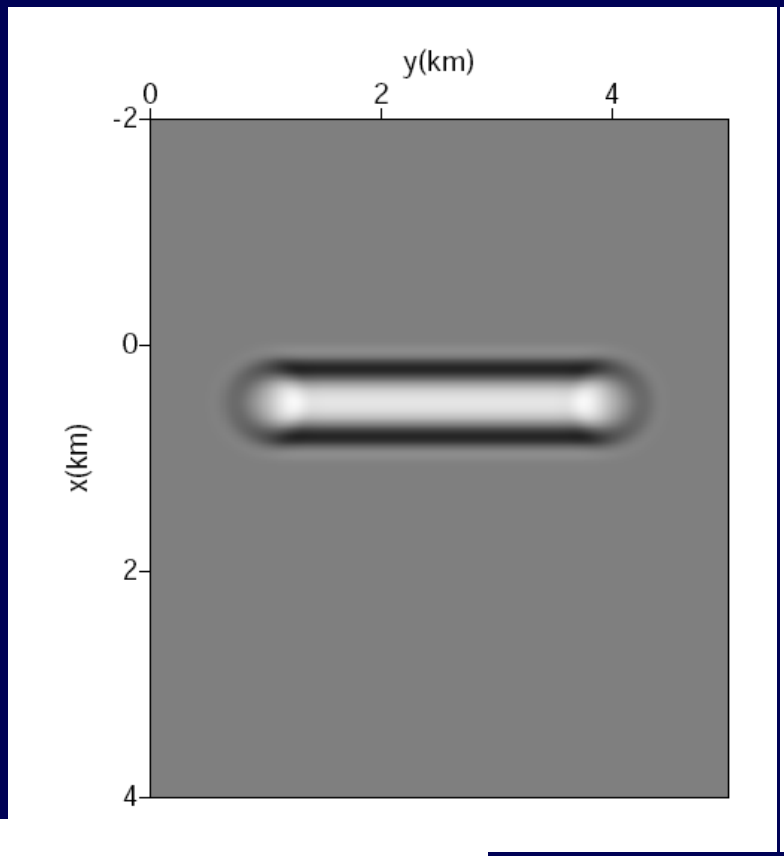
Edge diffraction

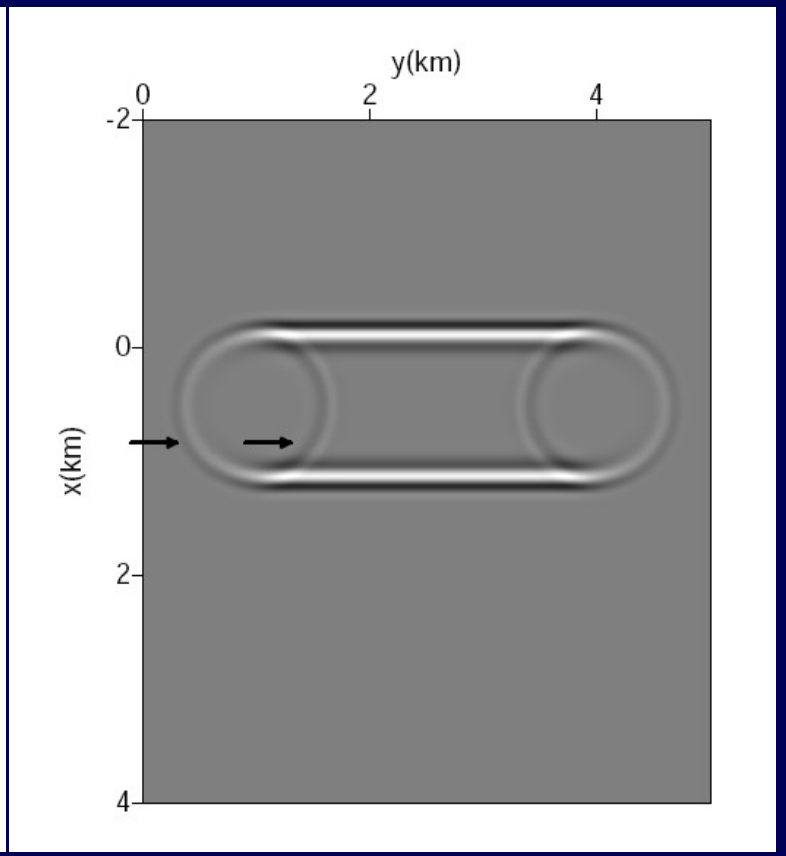


Tip diffraction

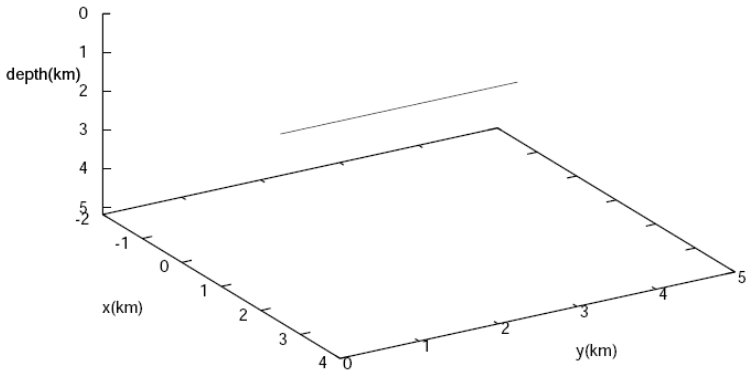
Edge and tip diffractions

3D line/tip diffraction



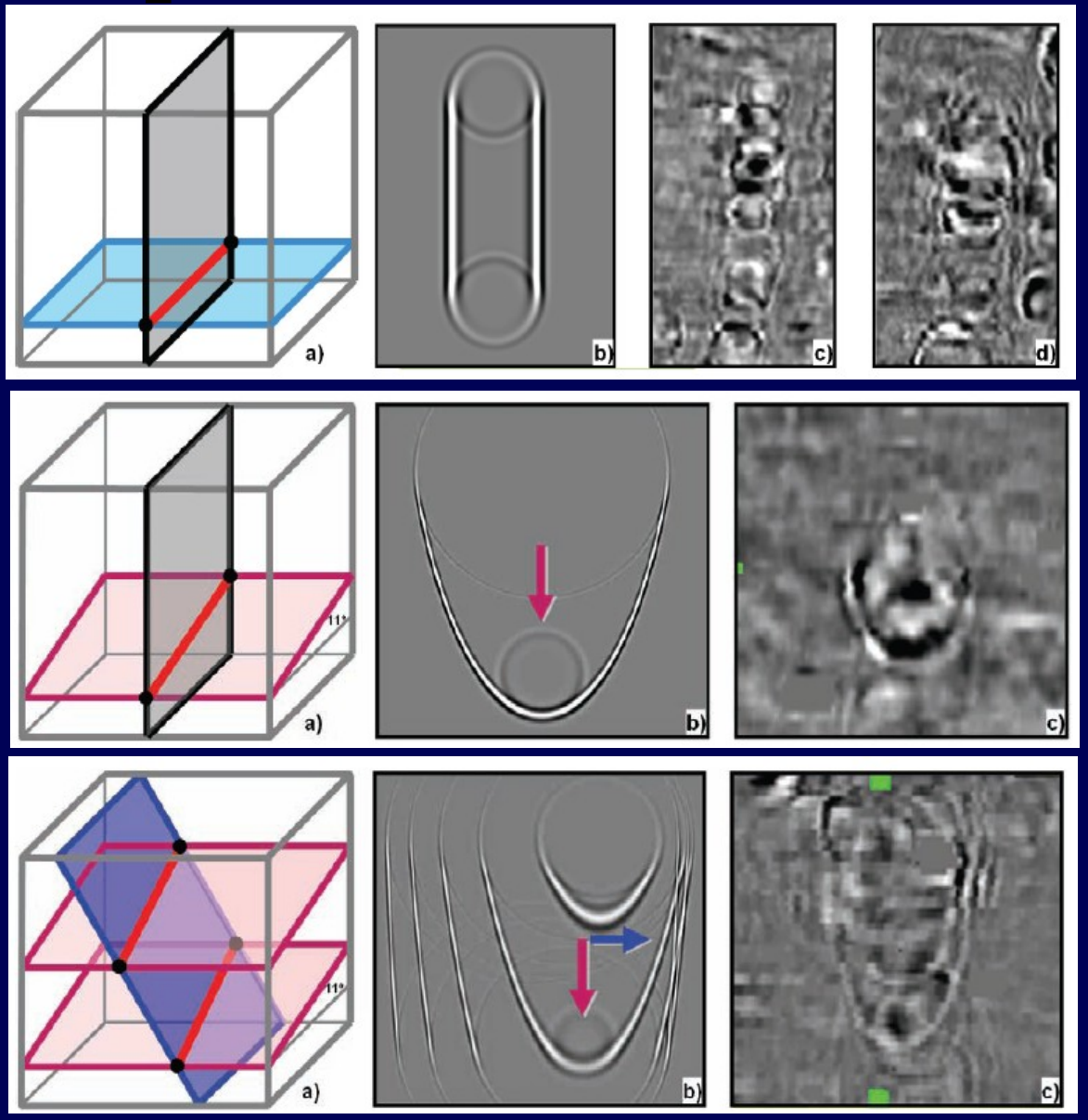


Time slices t=2.0, 2.2s



Line diffractor

Edge and tip diffractions

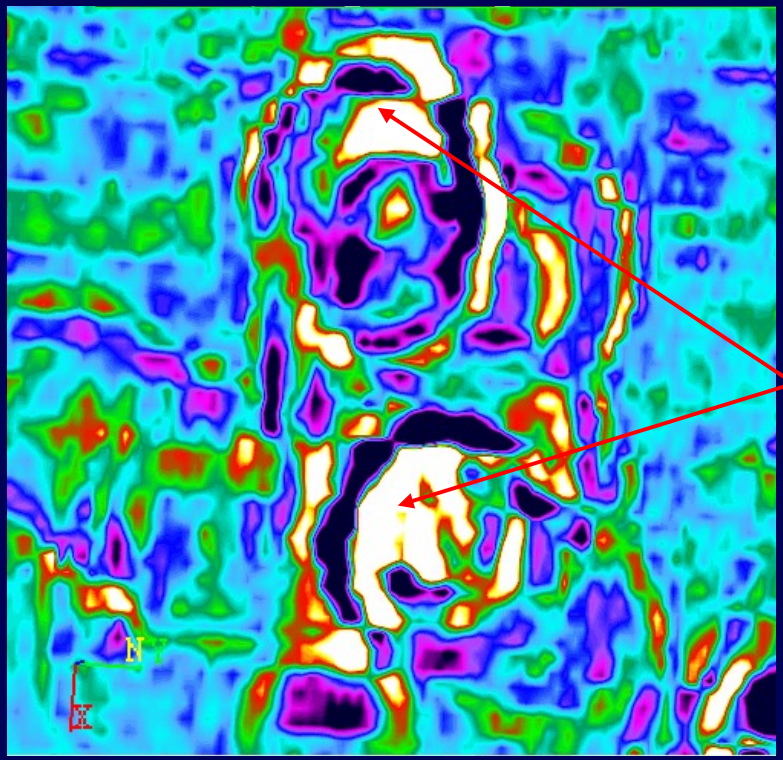


(Grasmueck, Moser and Pelissier 2011, CSL report)

GPR data over Cassis quarry (fracture and karst network)

Edge and tip diffractions

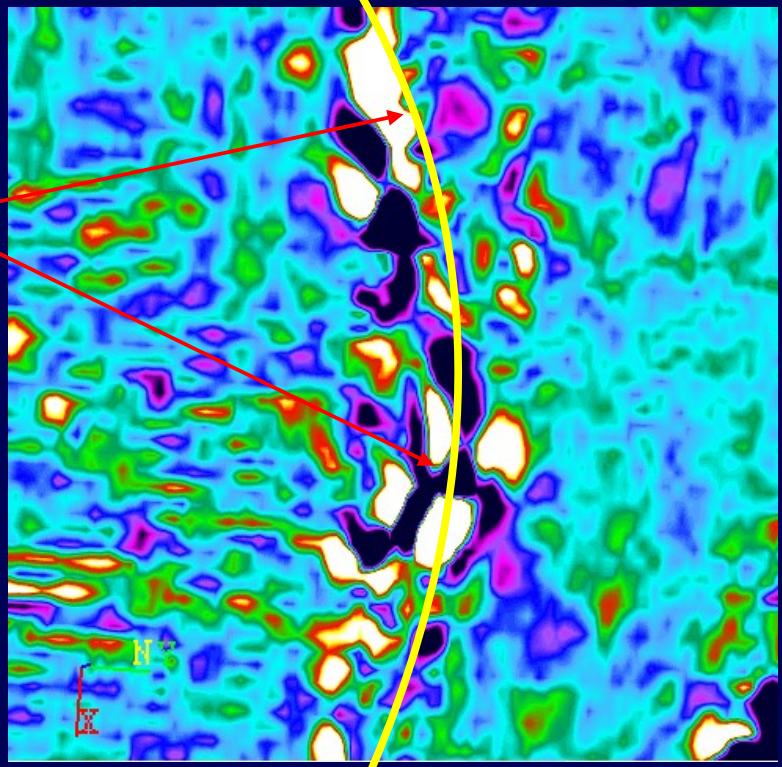
GPR data time slice (zero offset)



Fractures

Semi-circles

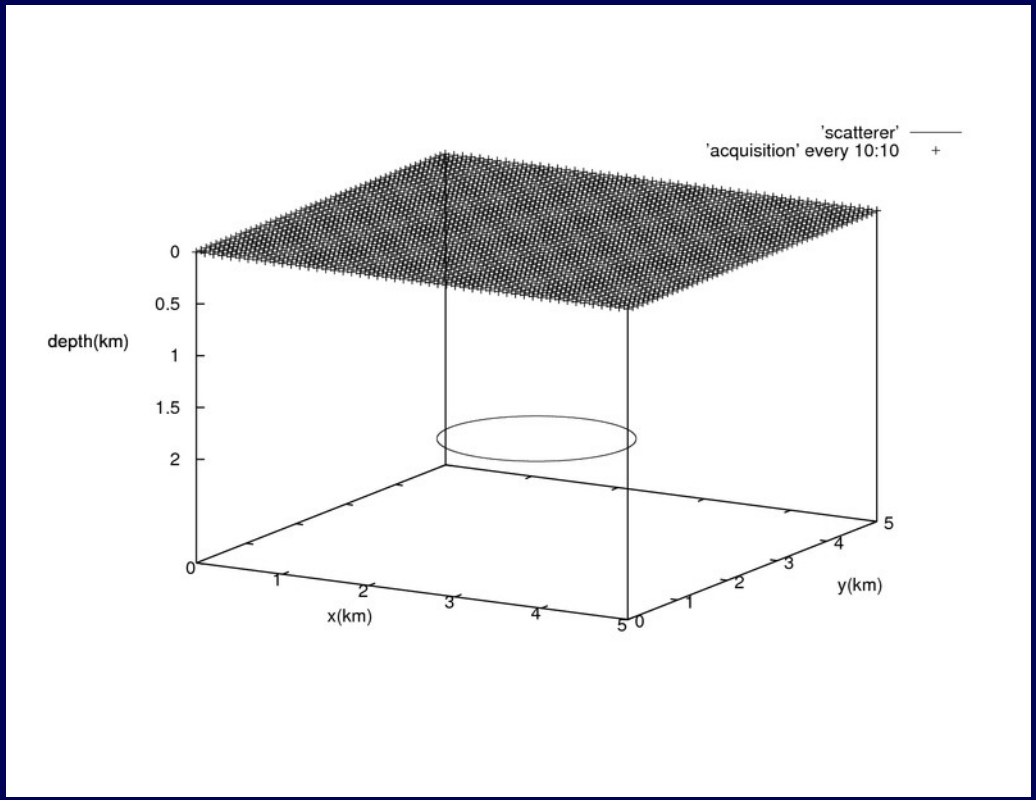
… migrated



Curved edge

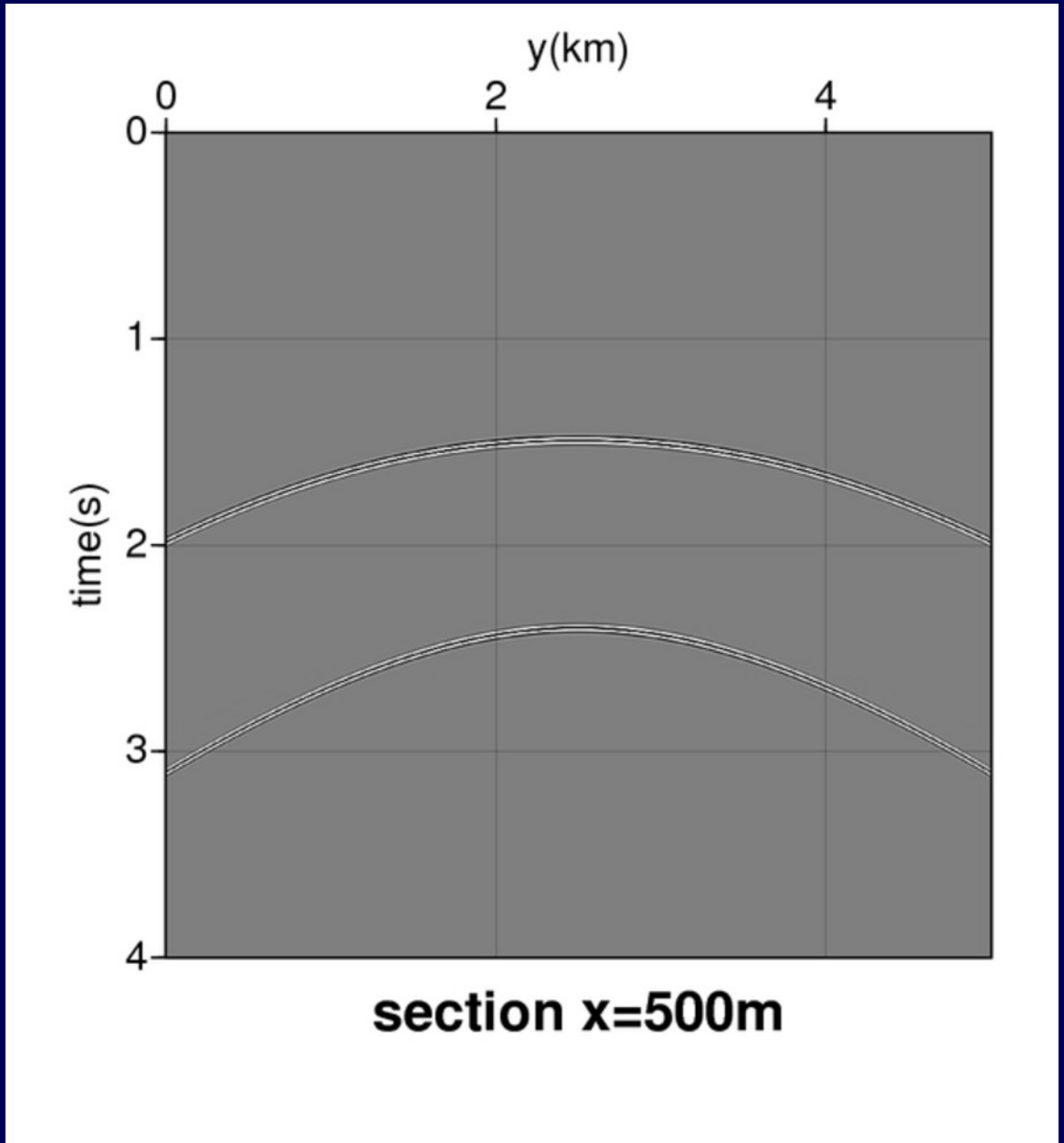
(Grasmueck & al, 2010)

Curved edge diffractions – synthetic – plane circle



Zero offset → Stacked section

Curved edge diffractions – synthetic – plane circle



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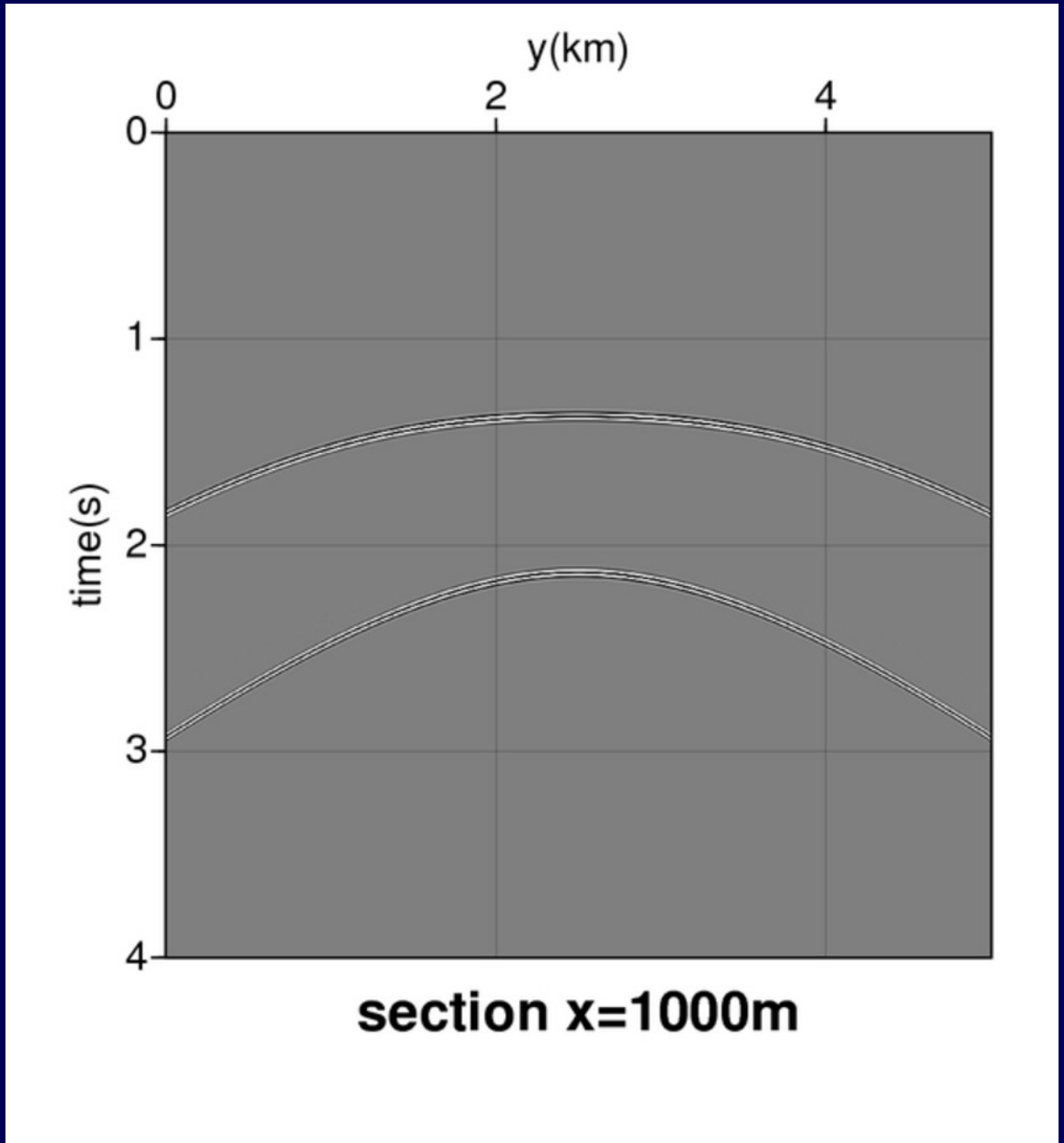

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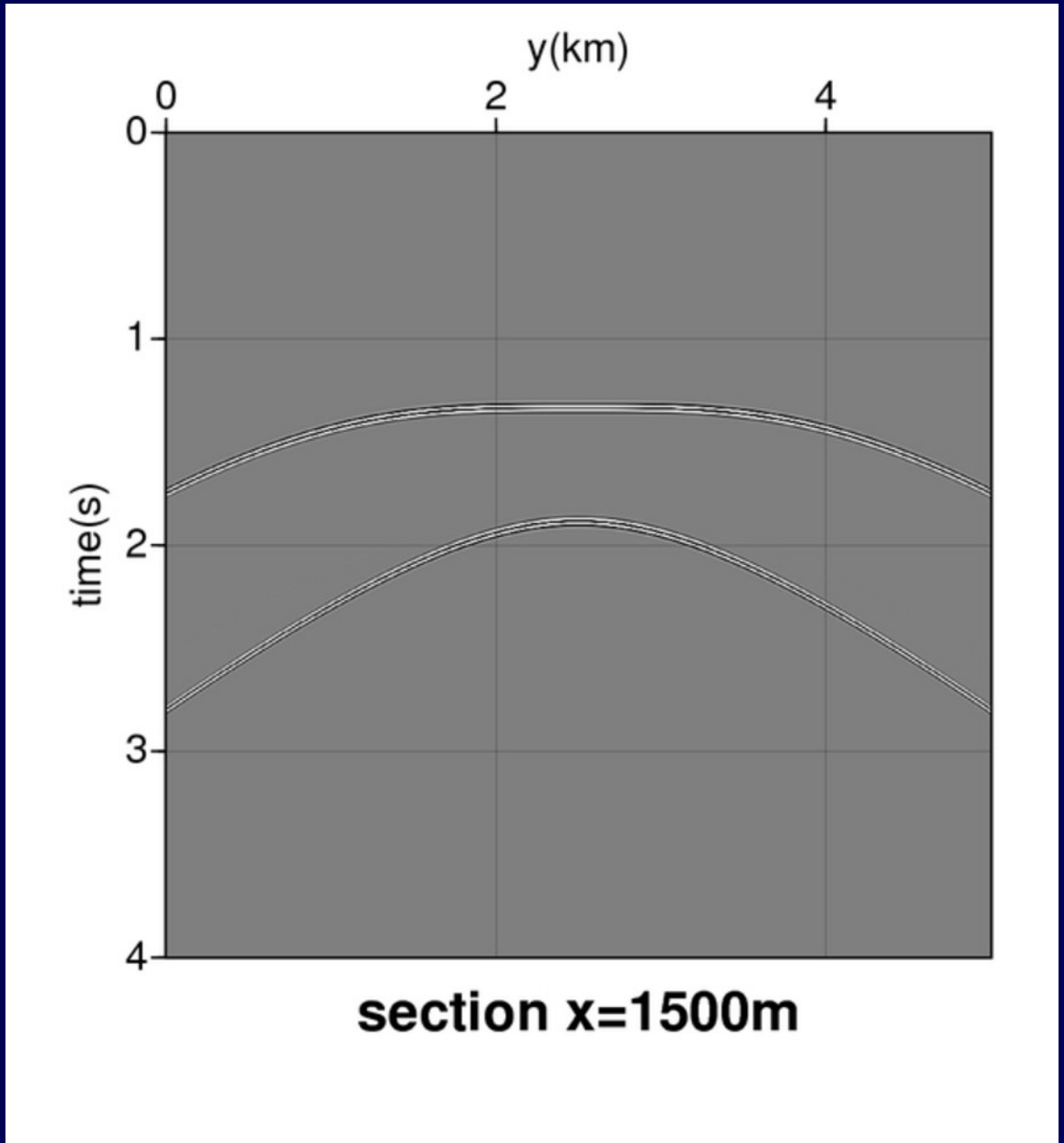

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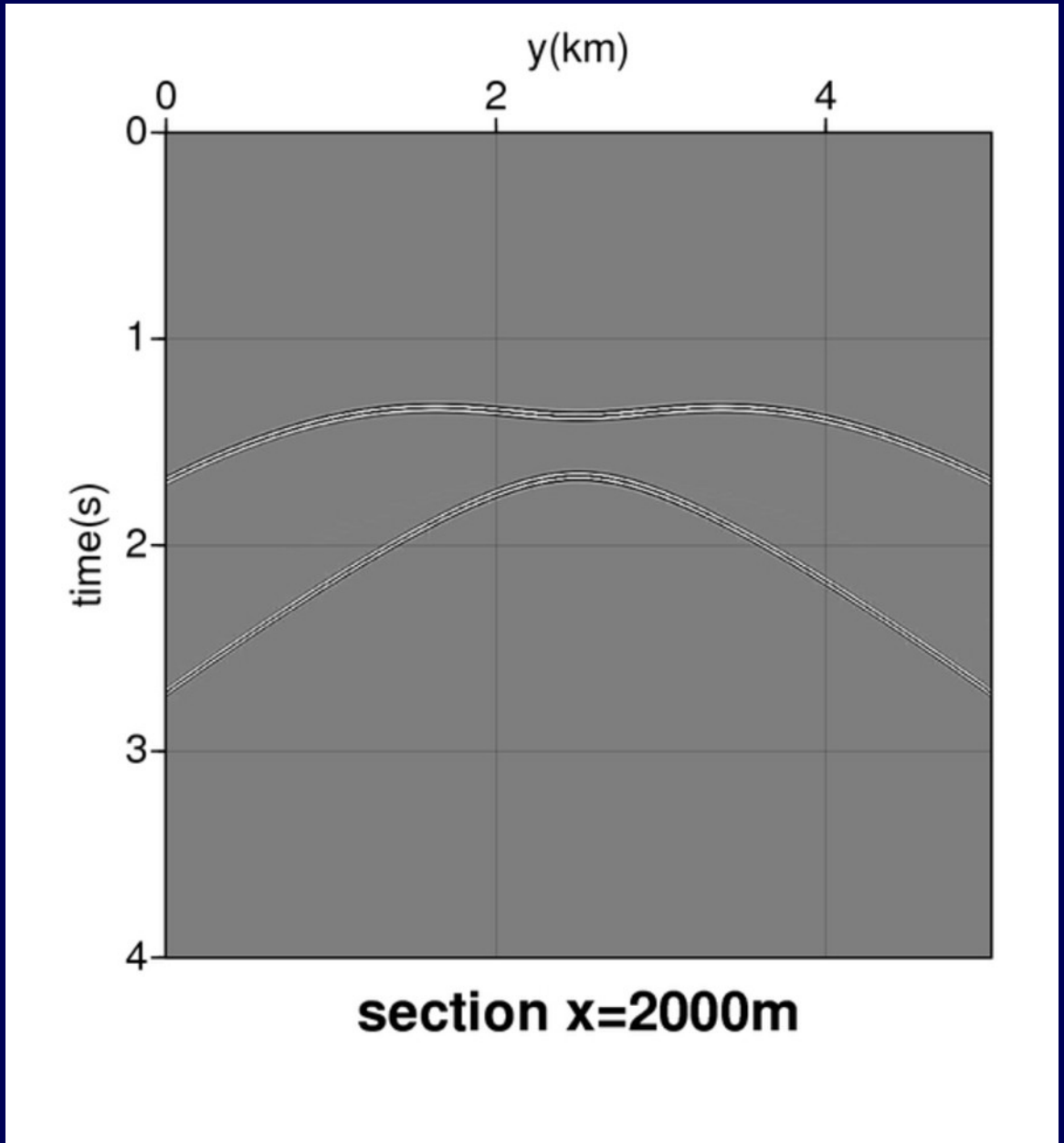
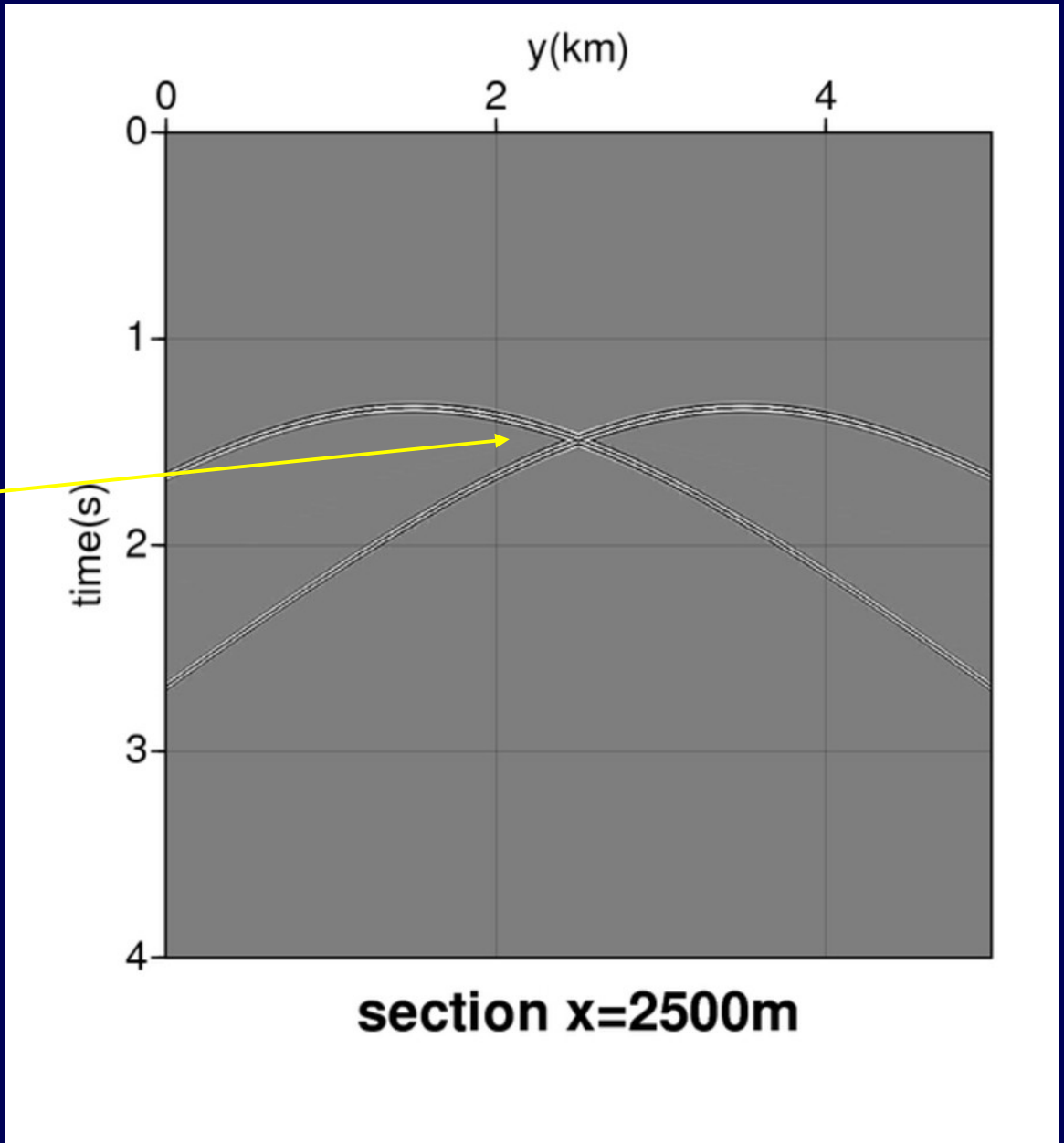


Curved edge diffractions – synthetic – plane circle

Two branches crossing over



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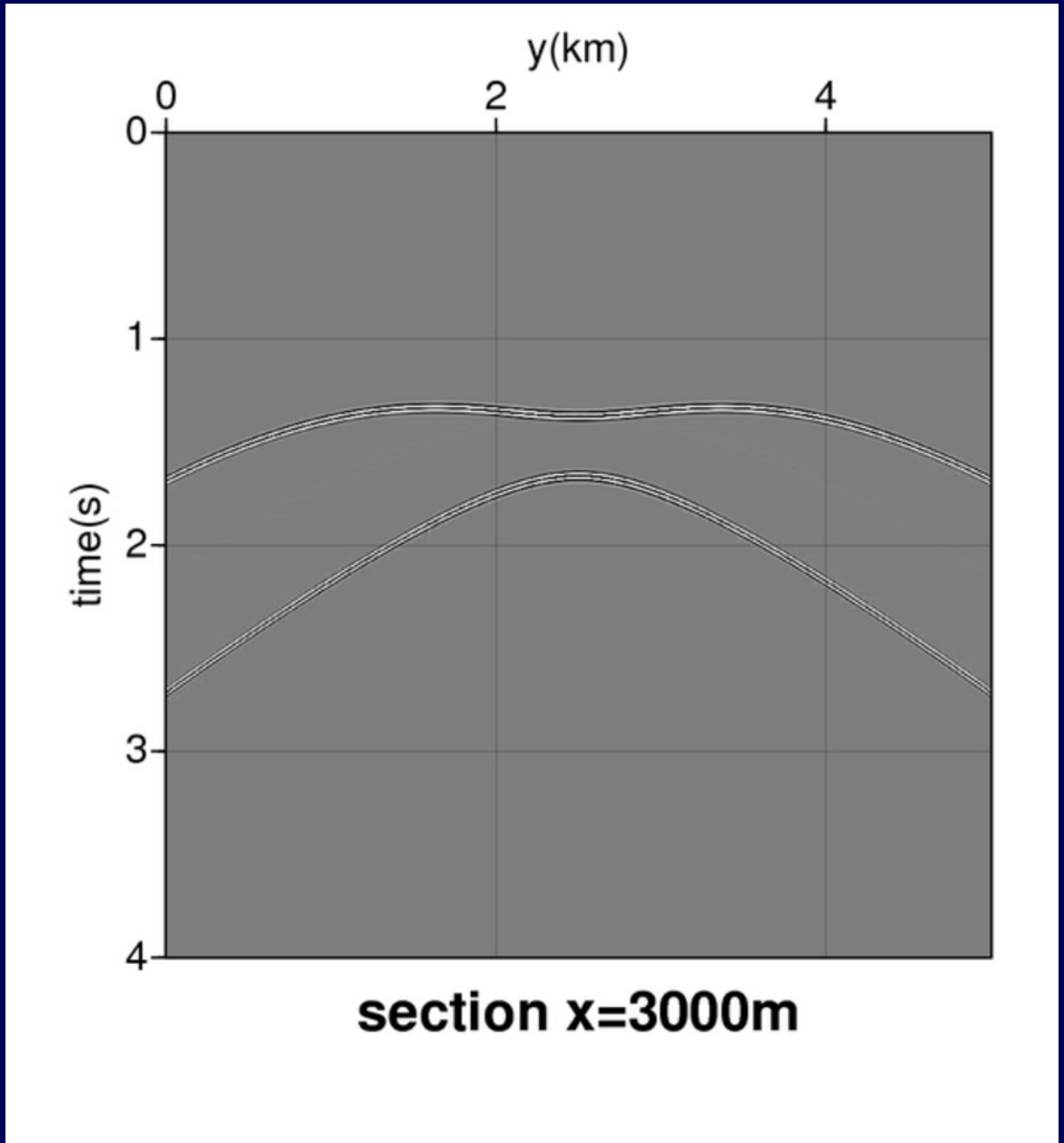

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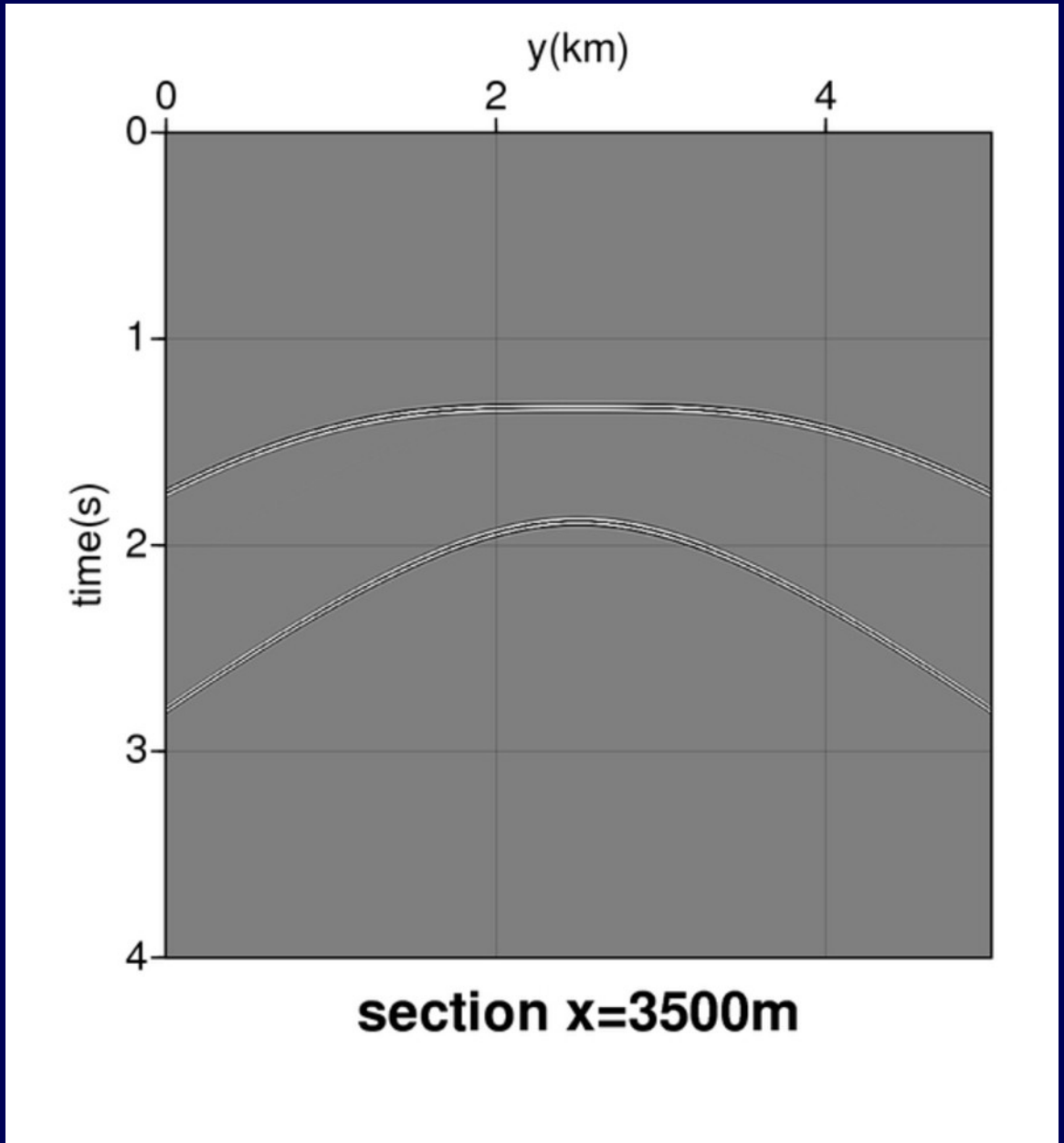

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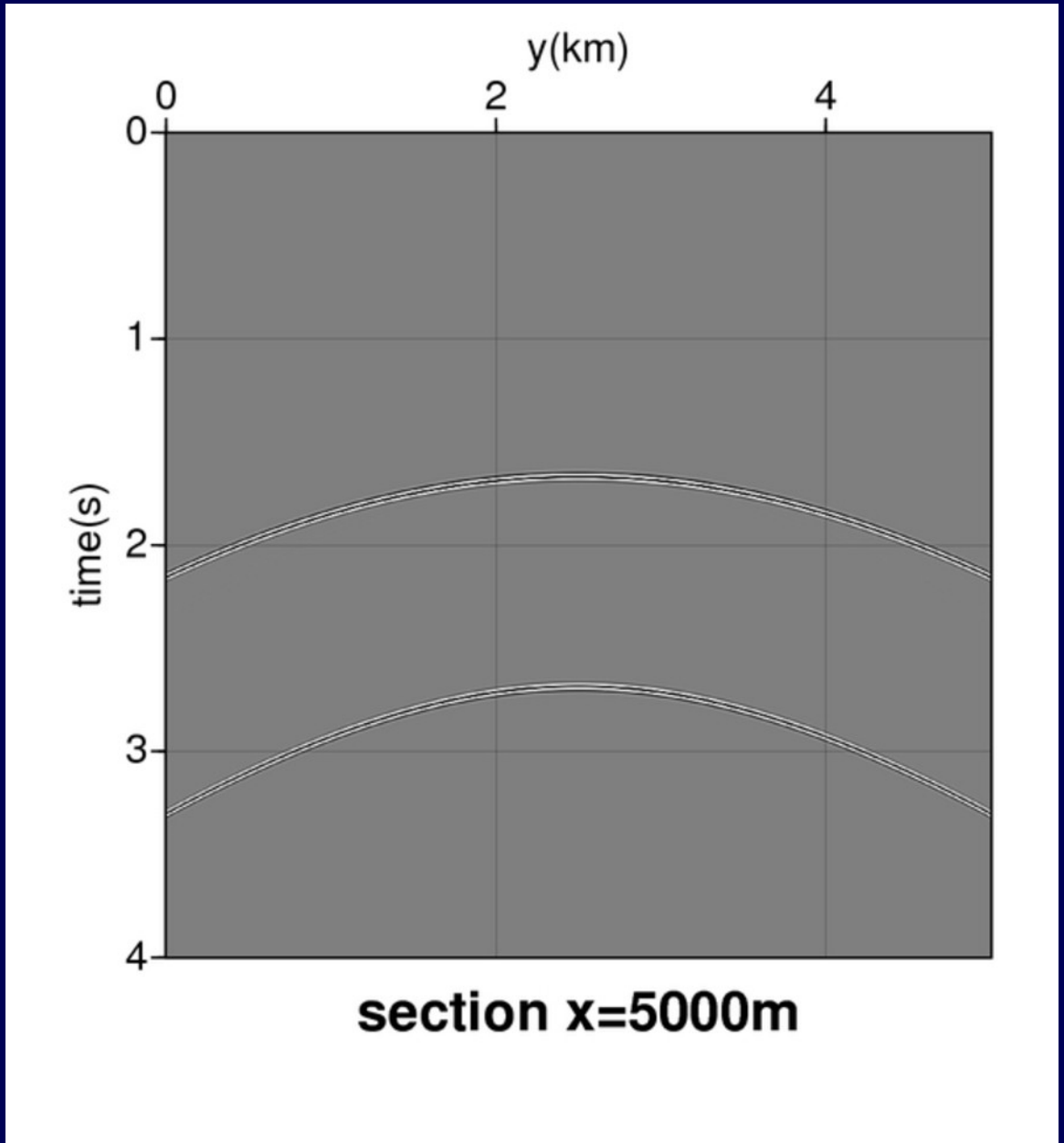

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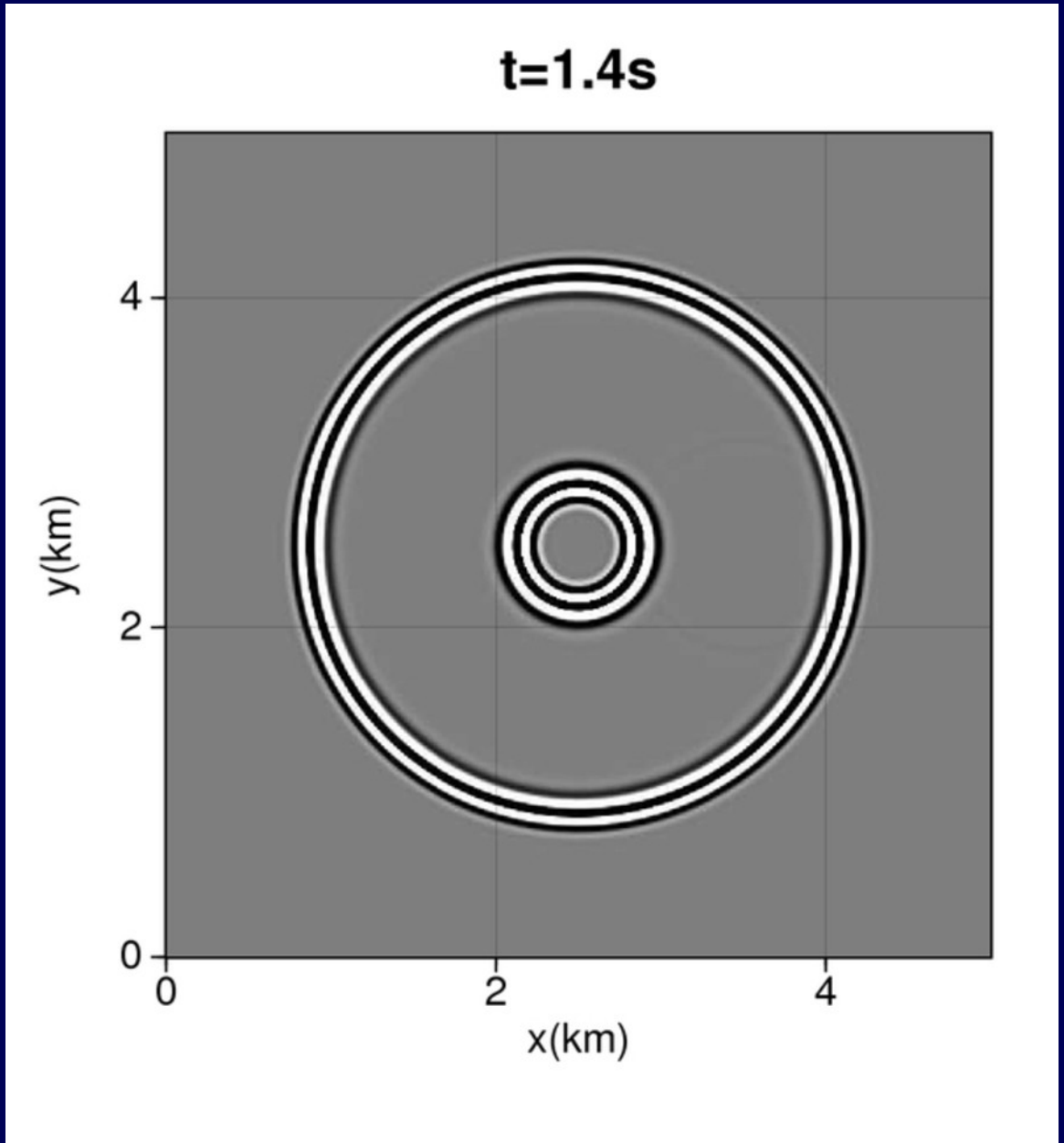
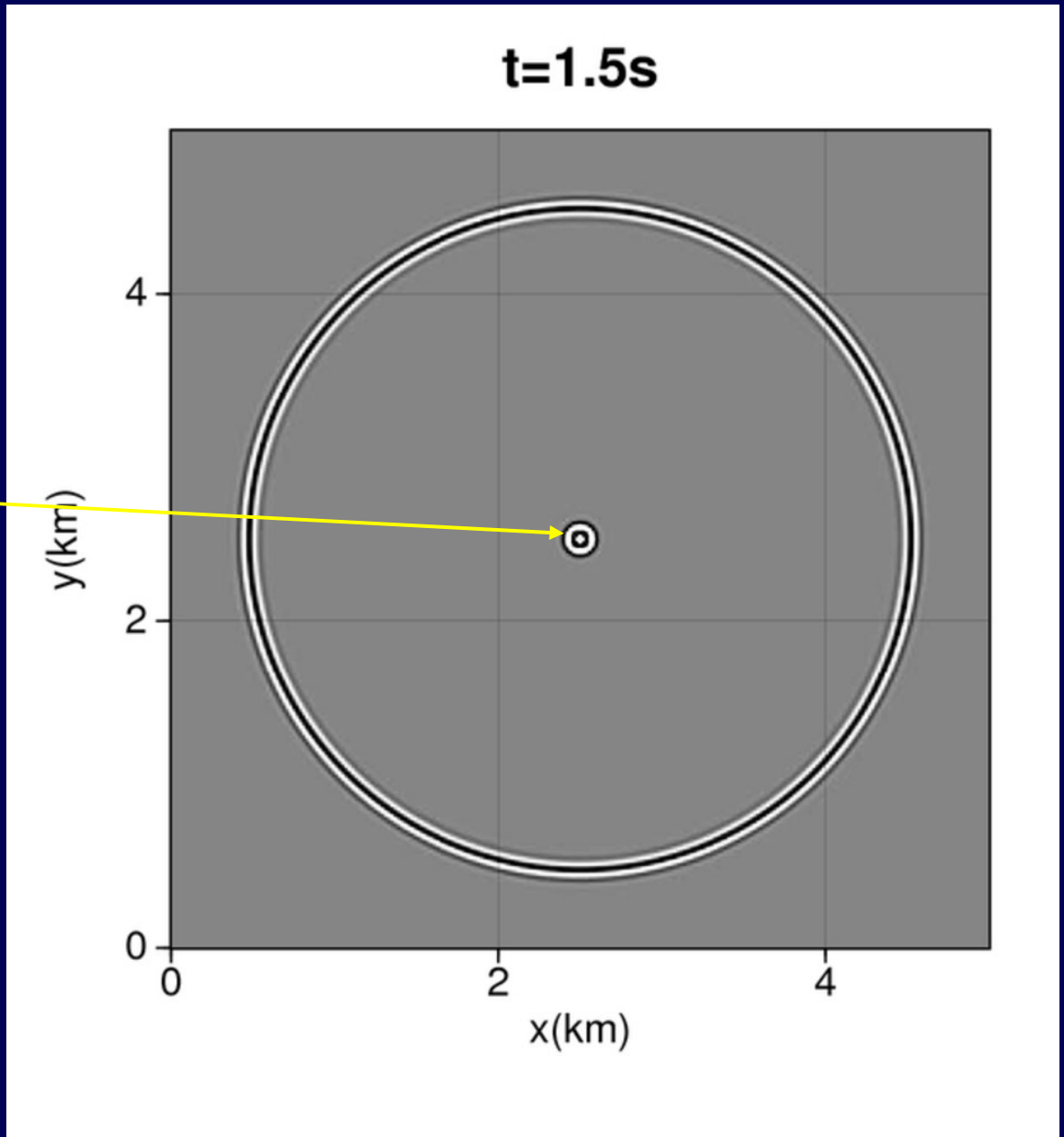
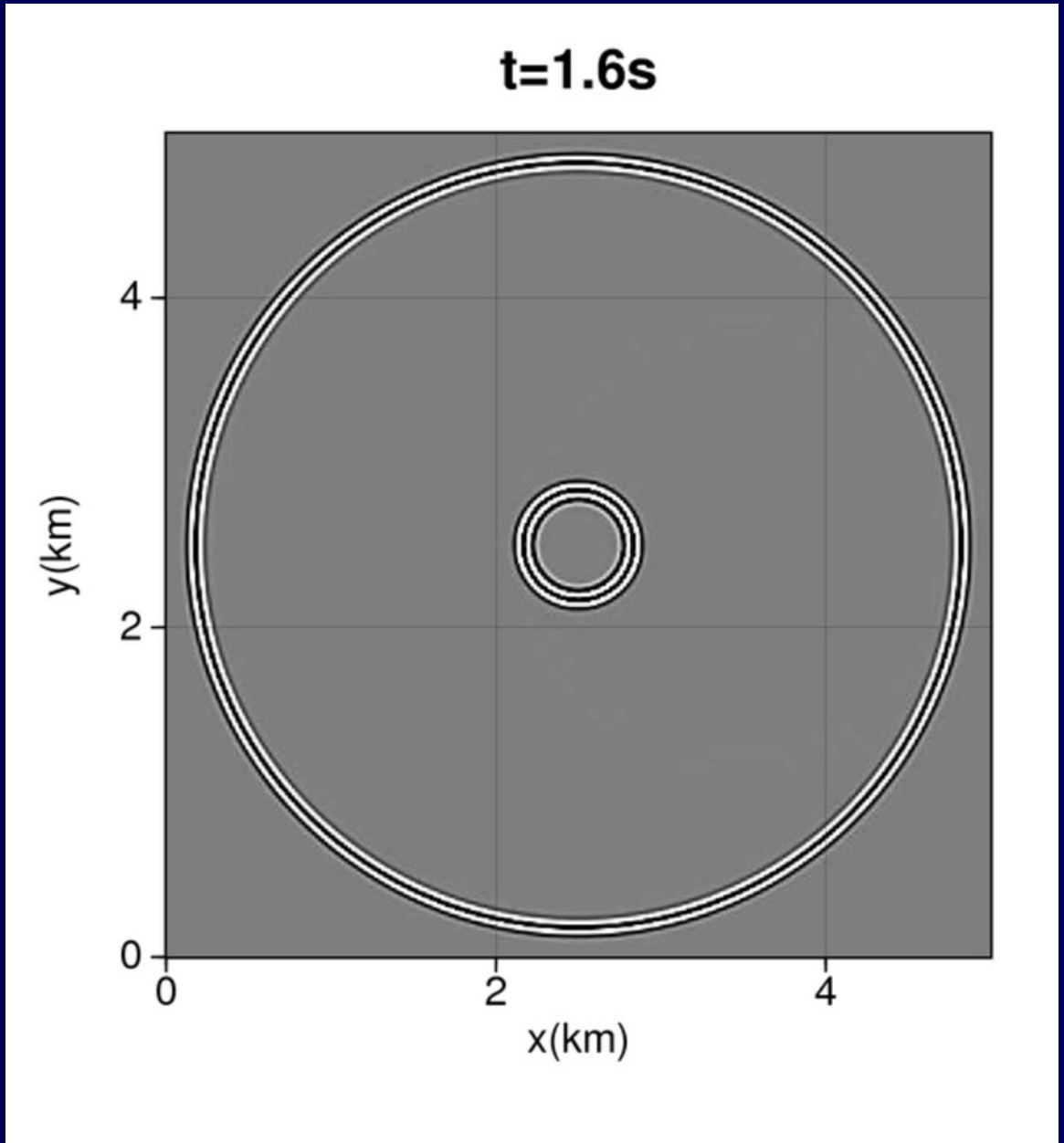


Curved edge diffractions – synthetic – plane circle

Two branches crossing over



Curved edge diffractions – synthetic – plane circle



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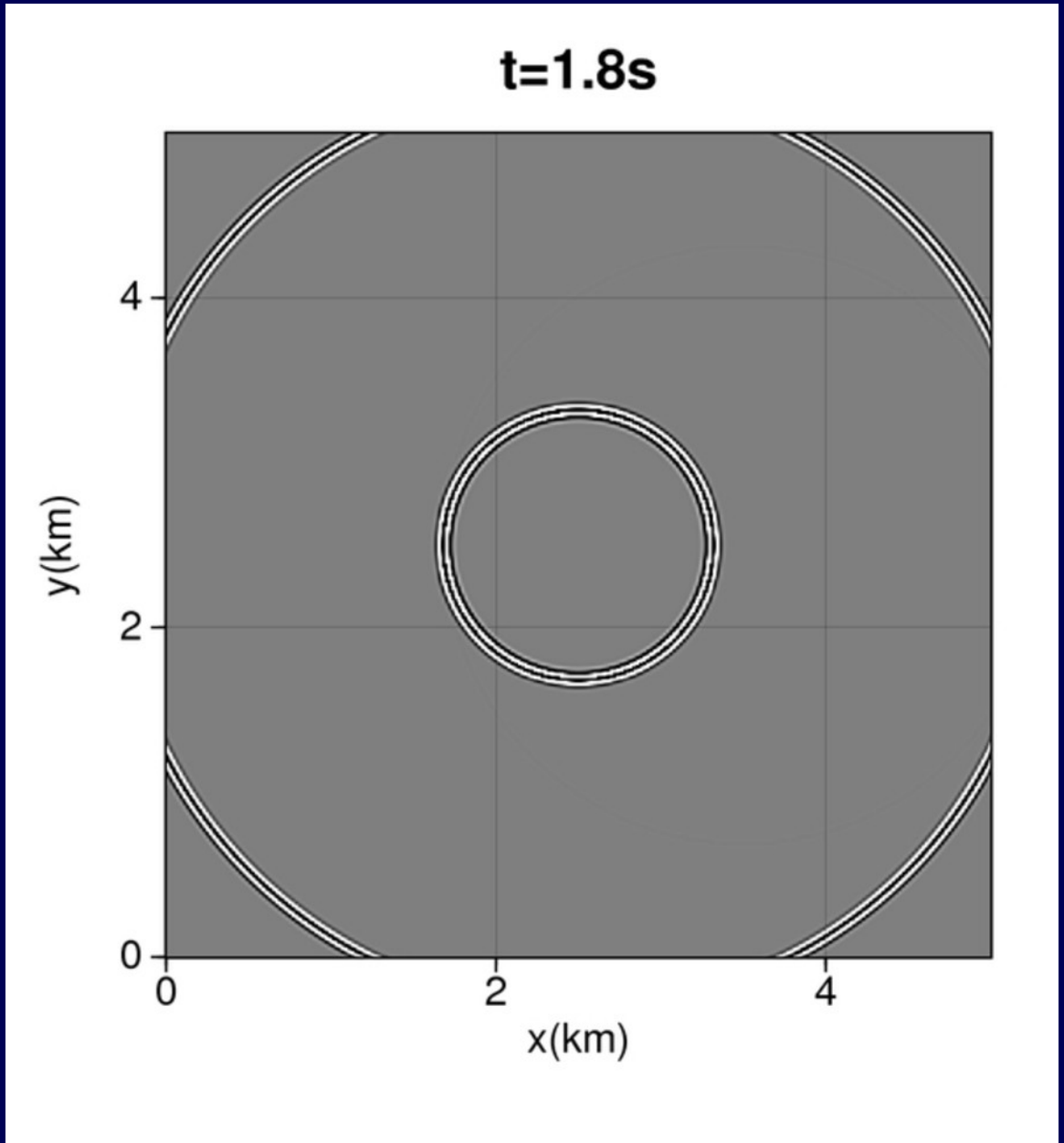

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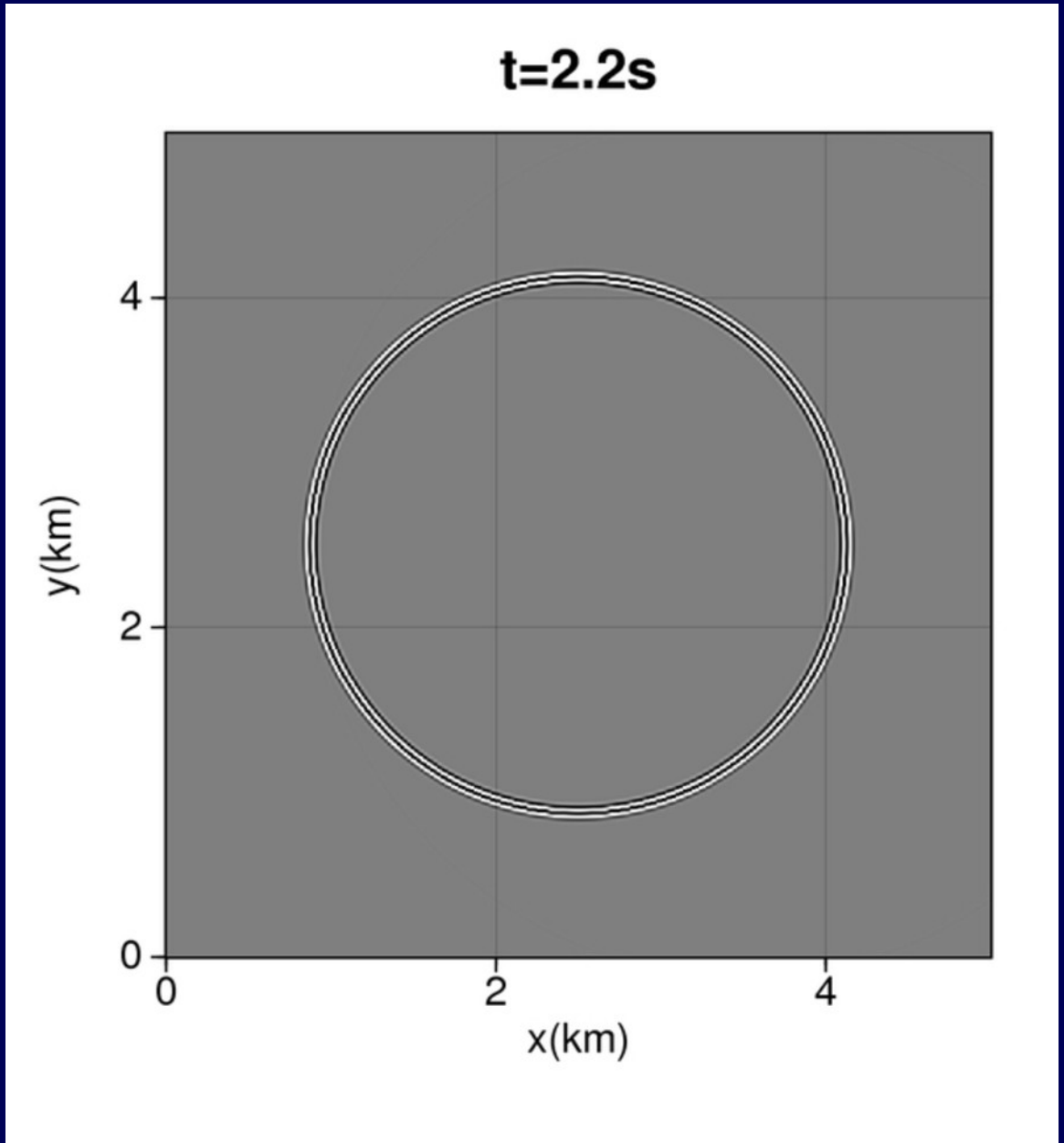
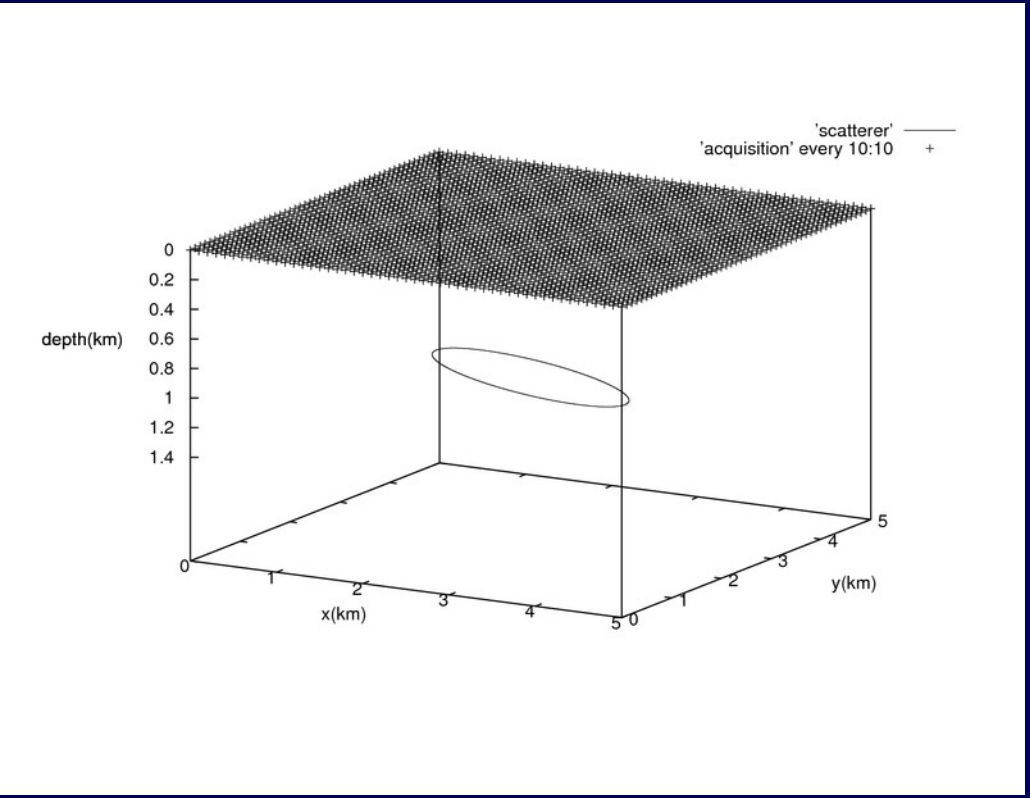


Curved edge diffractions – synthetic – dipping circle



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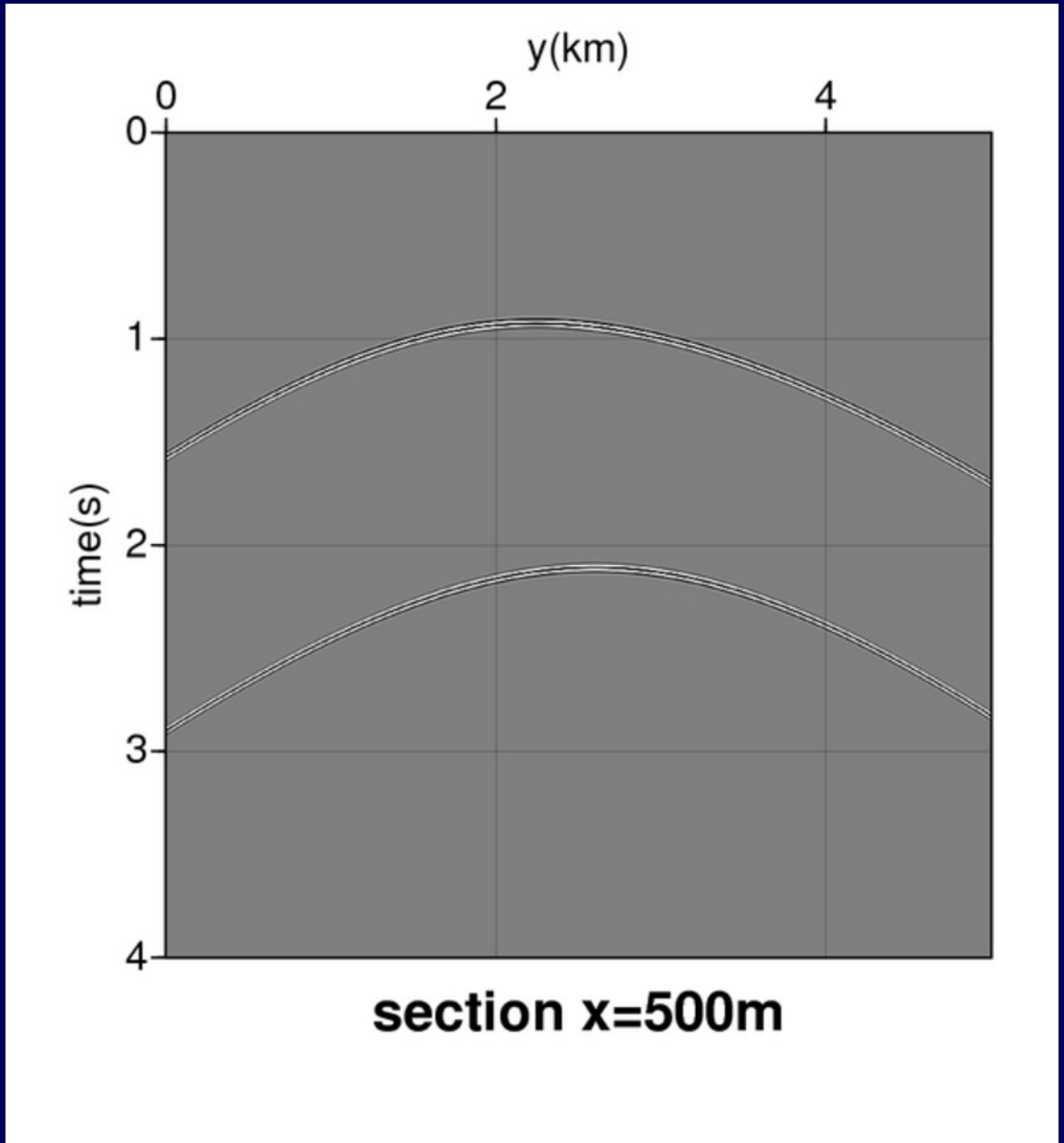

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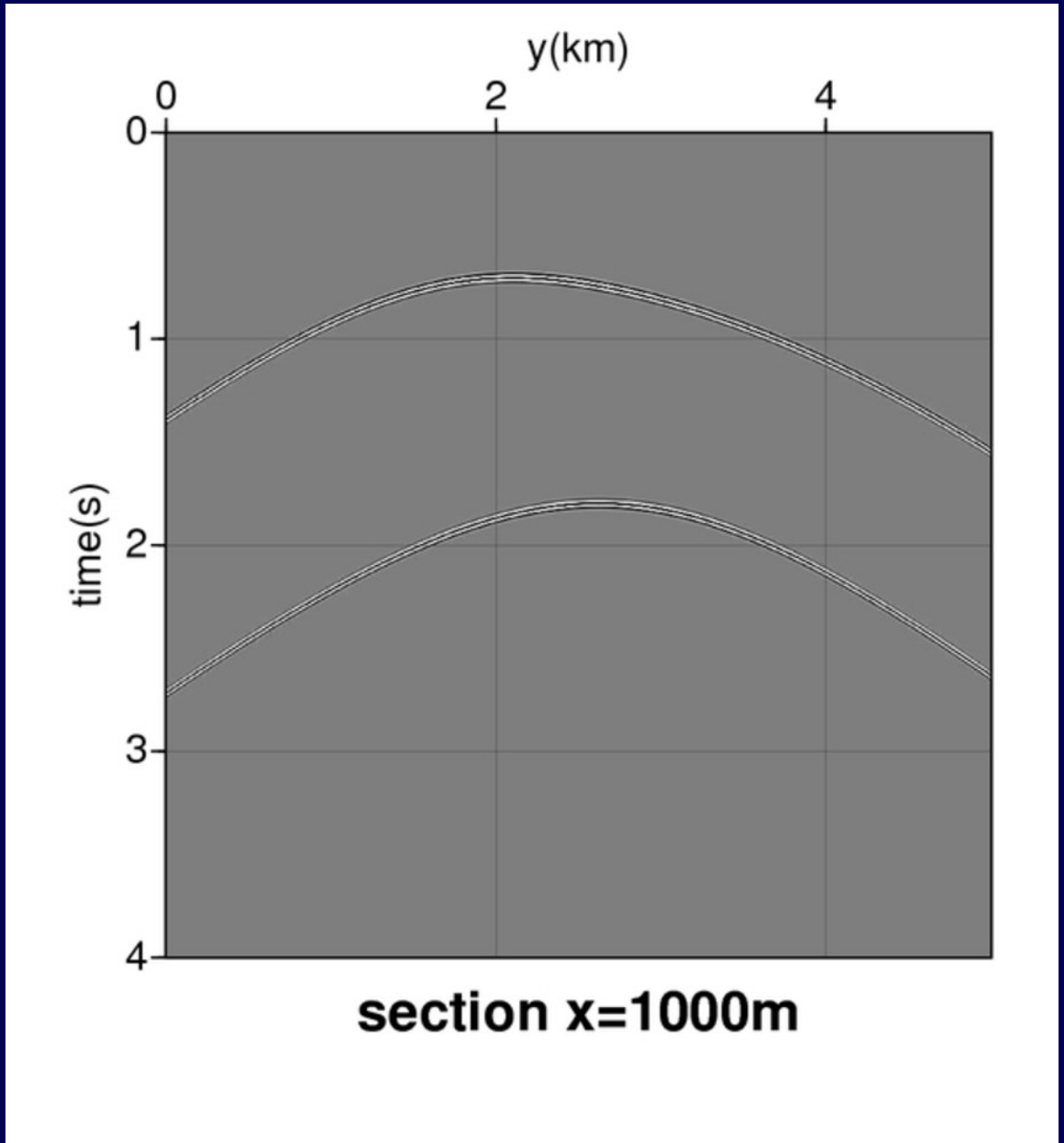

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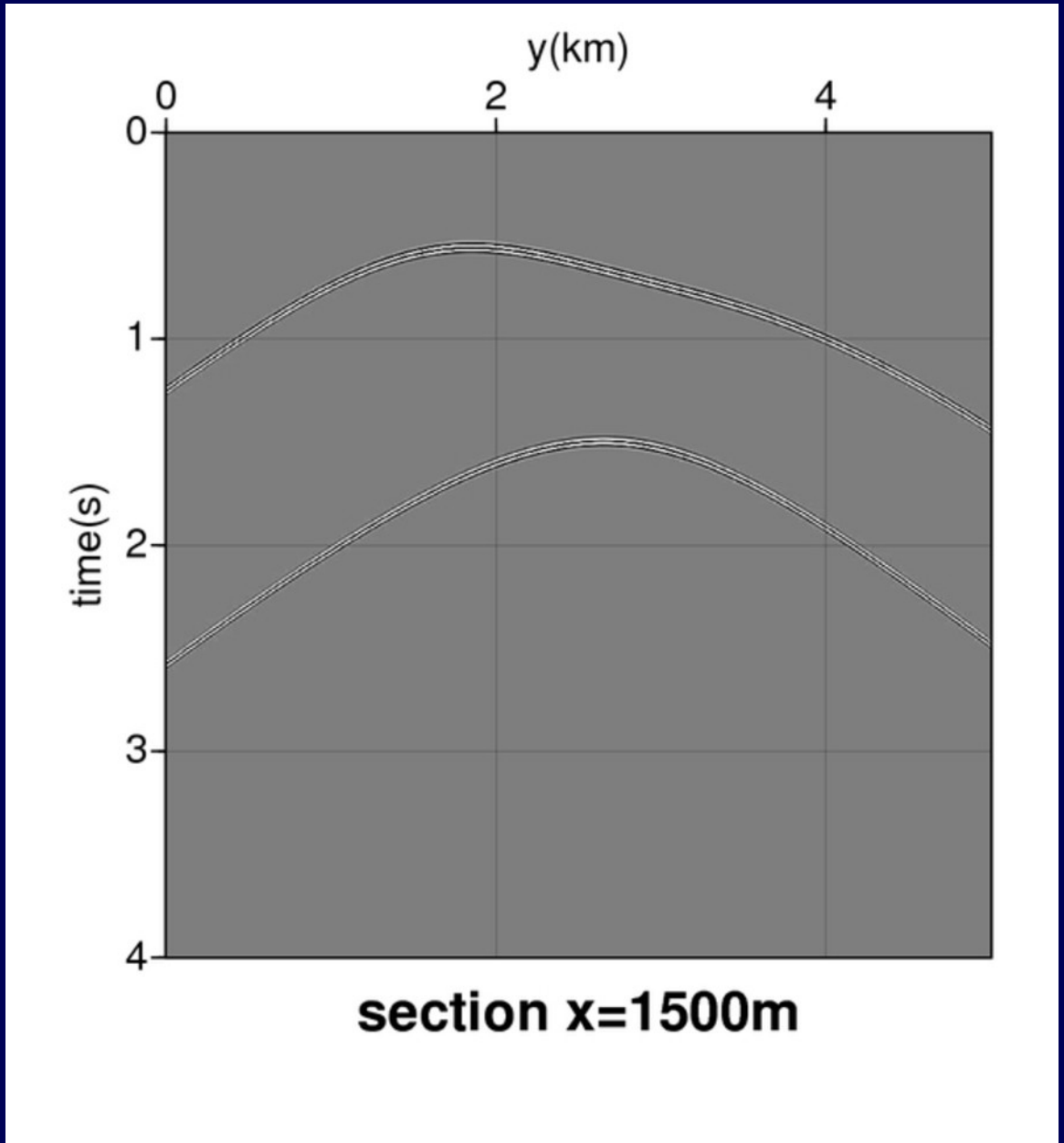

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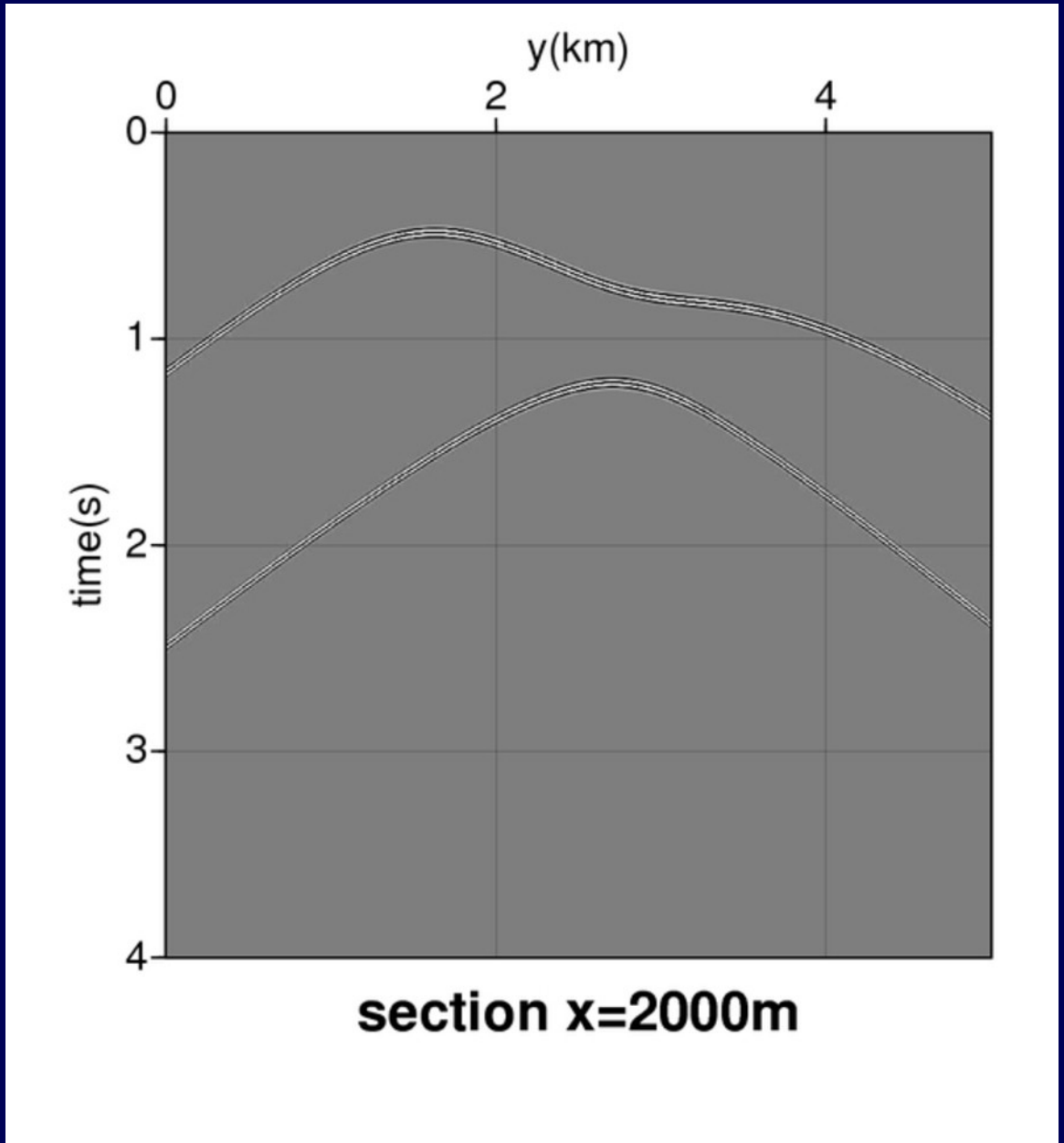
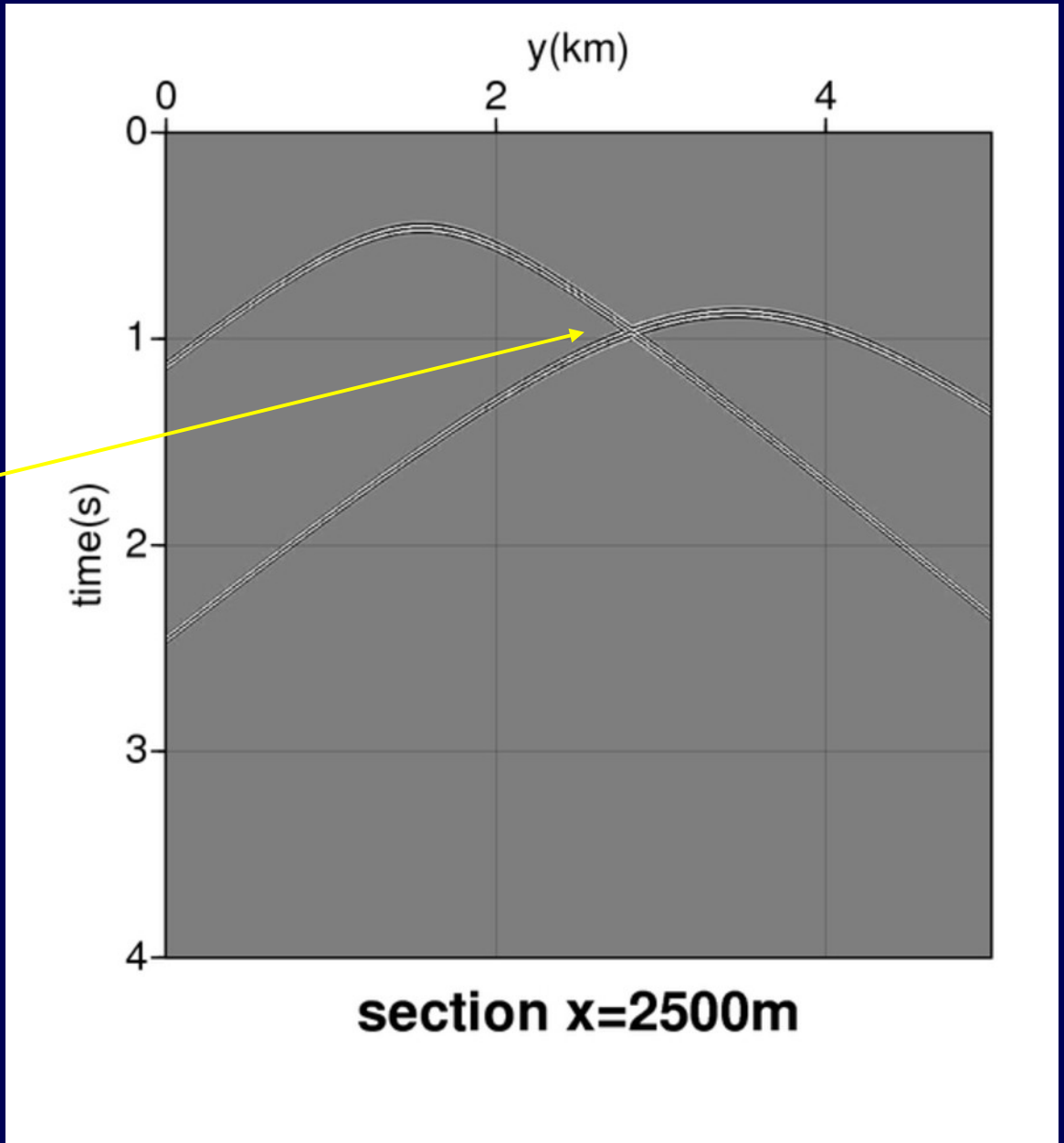


Curved edge diffractions – synthetic – dipping circle

Two branches crossing over



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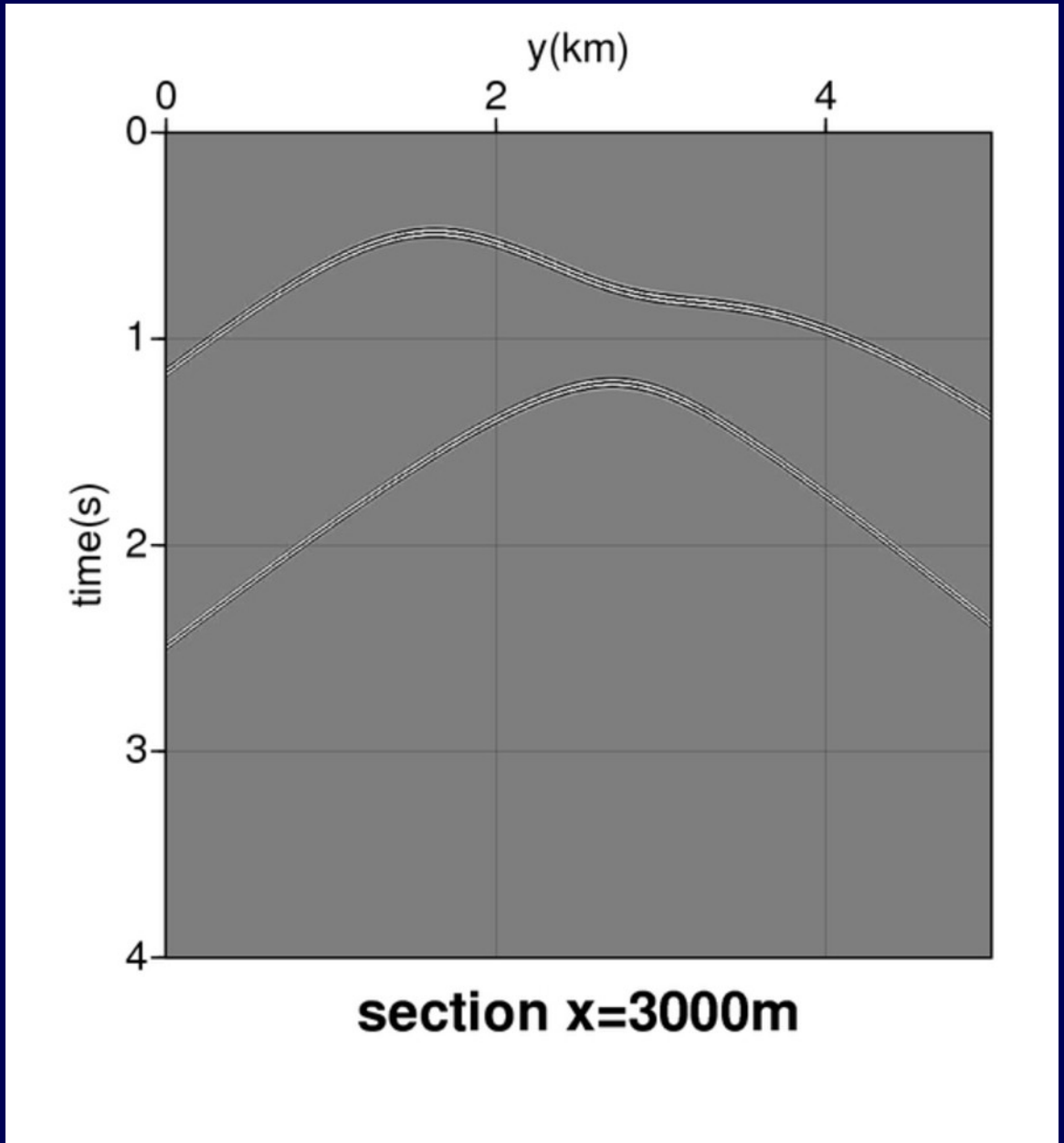

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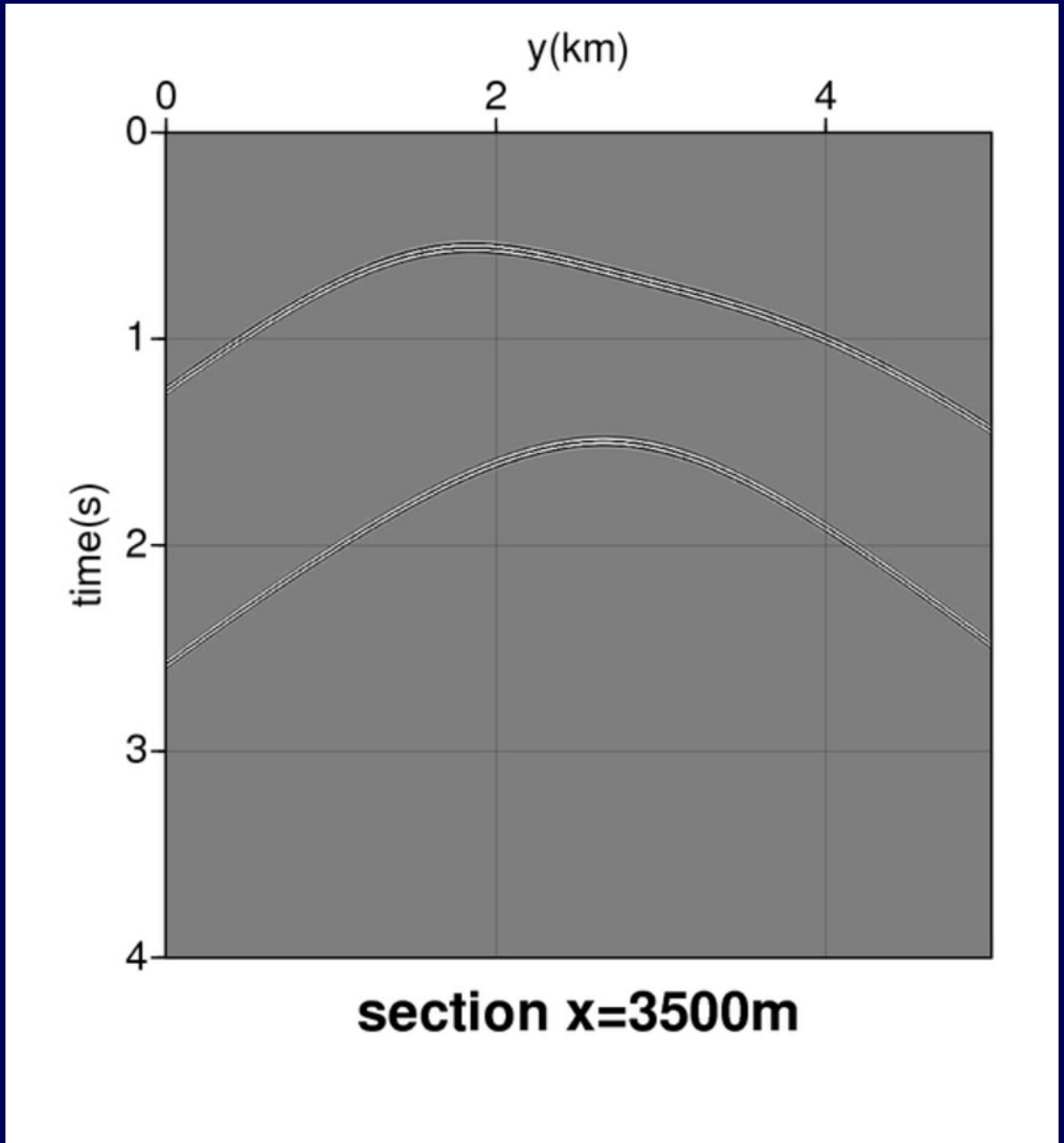

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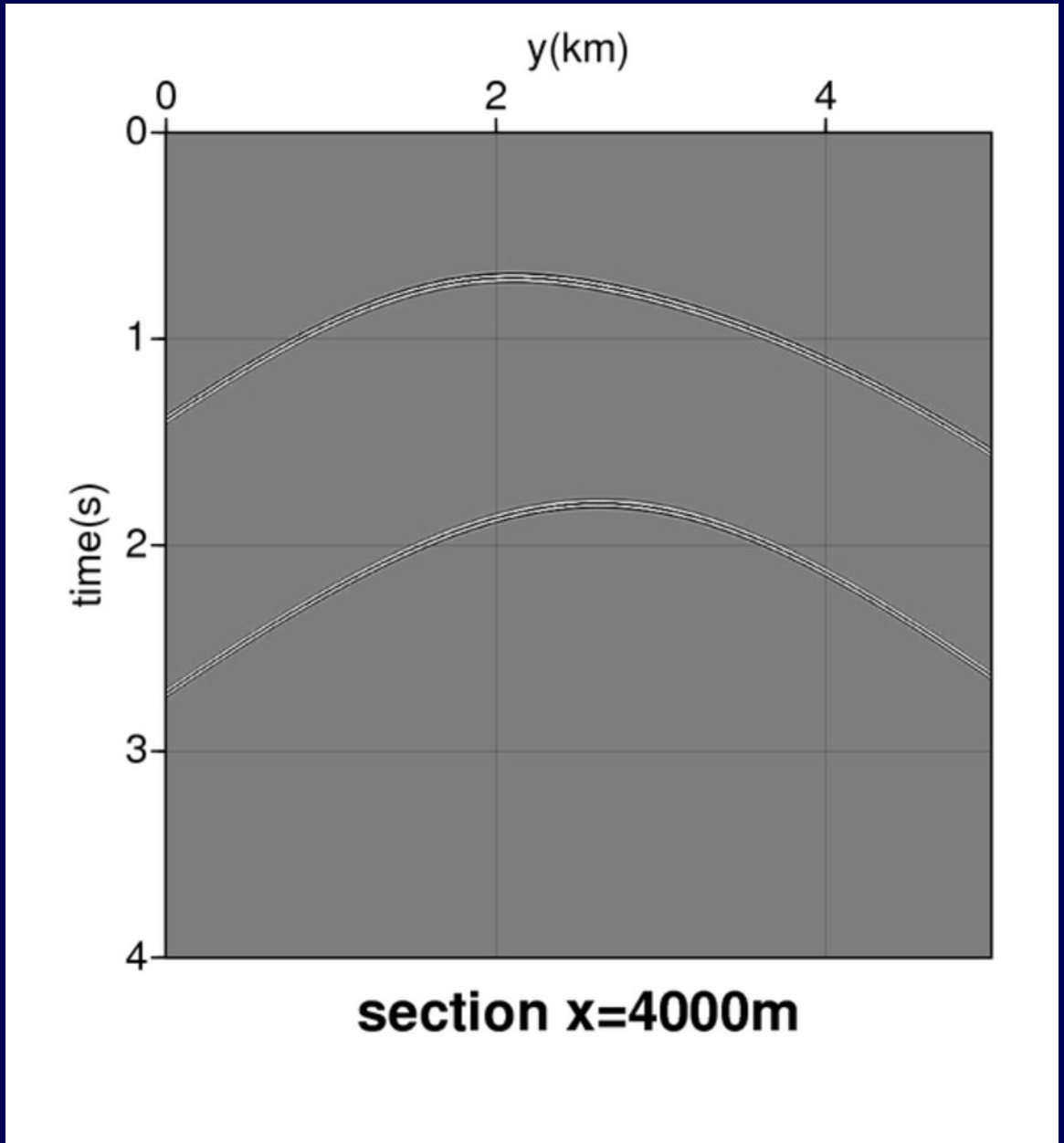

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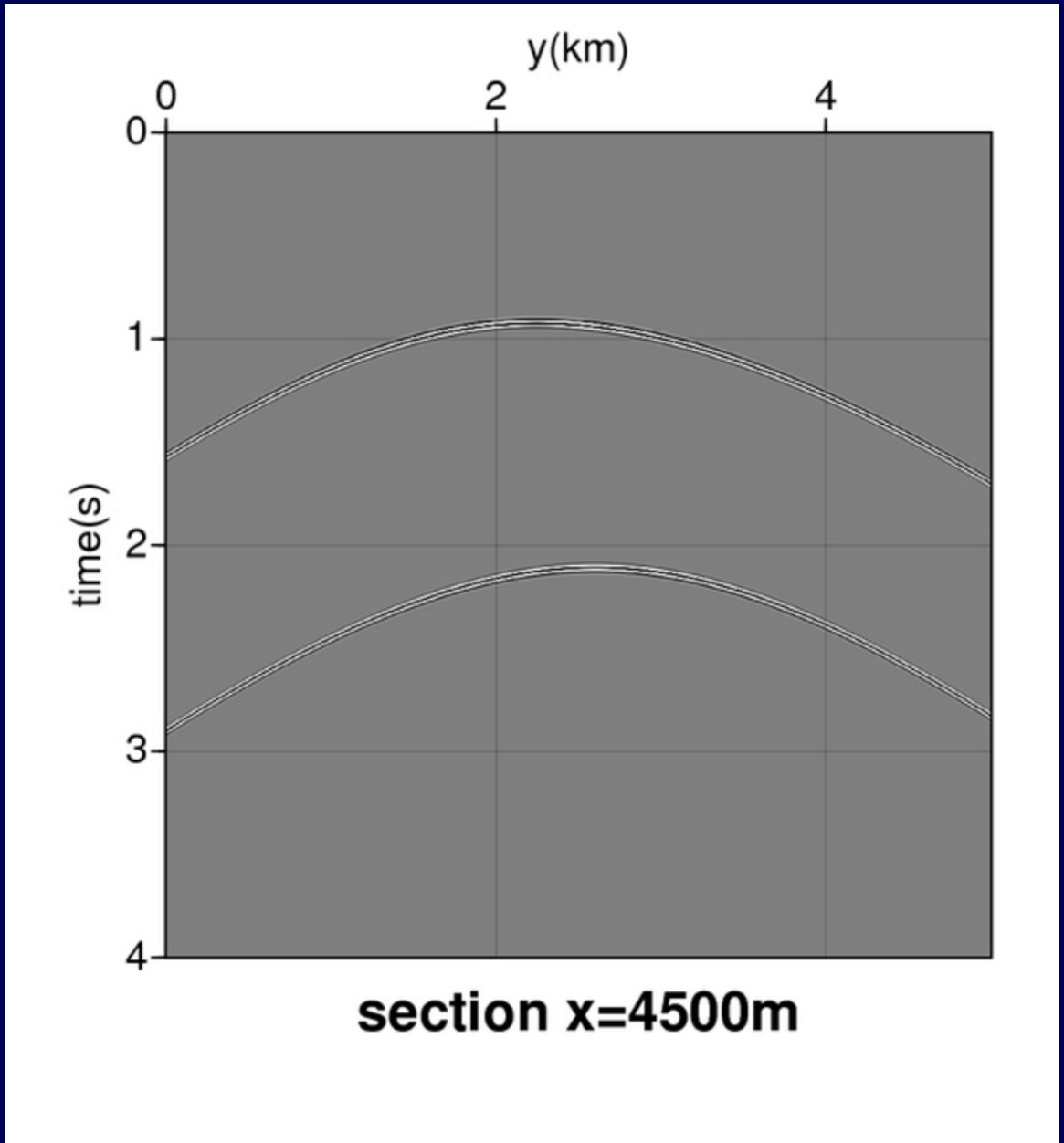

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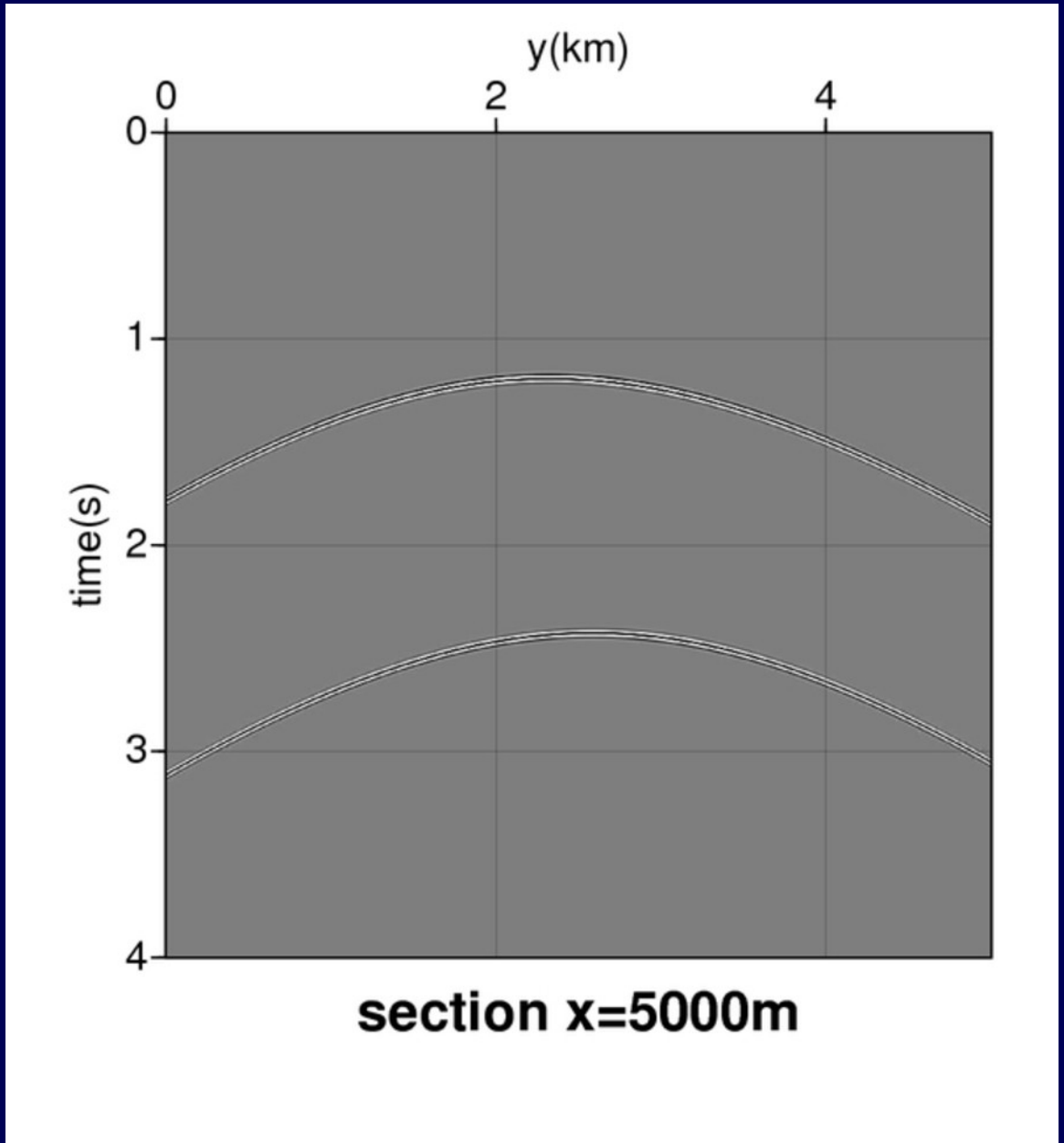

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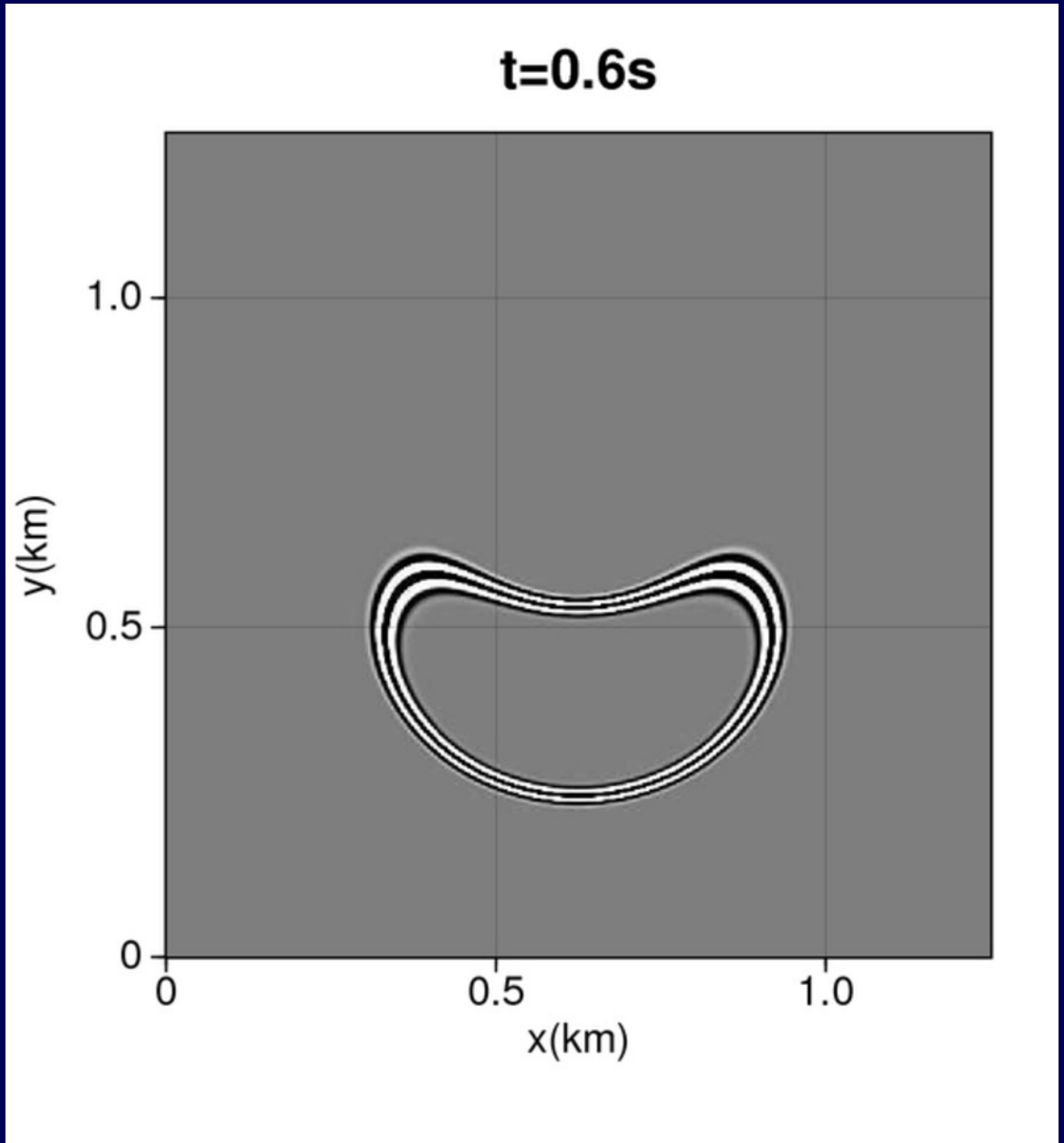

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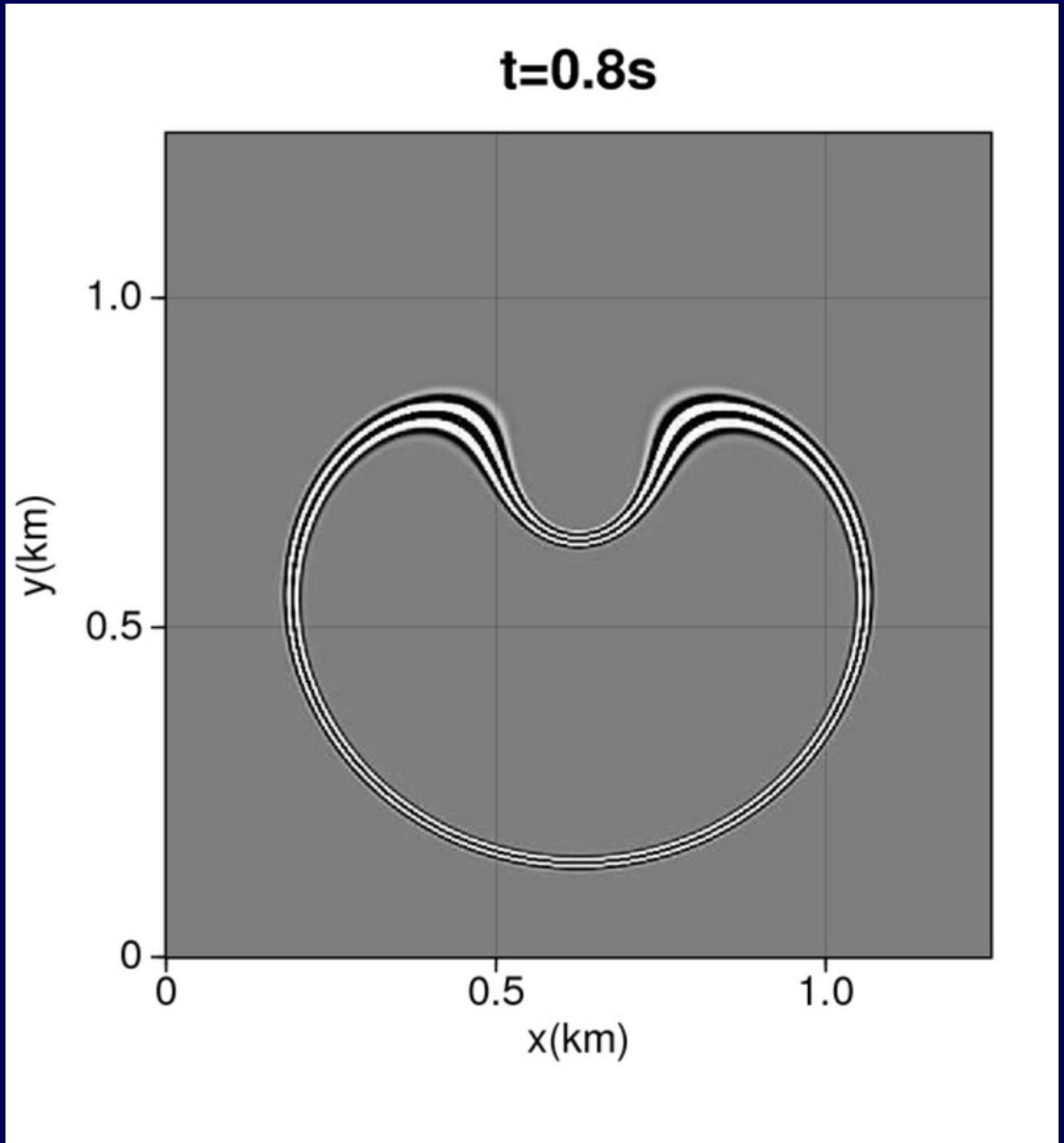

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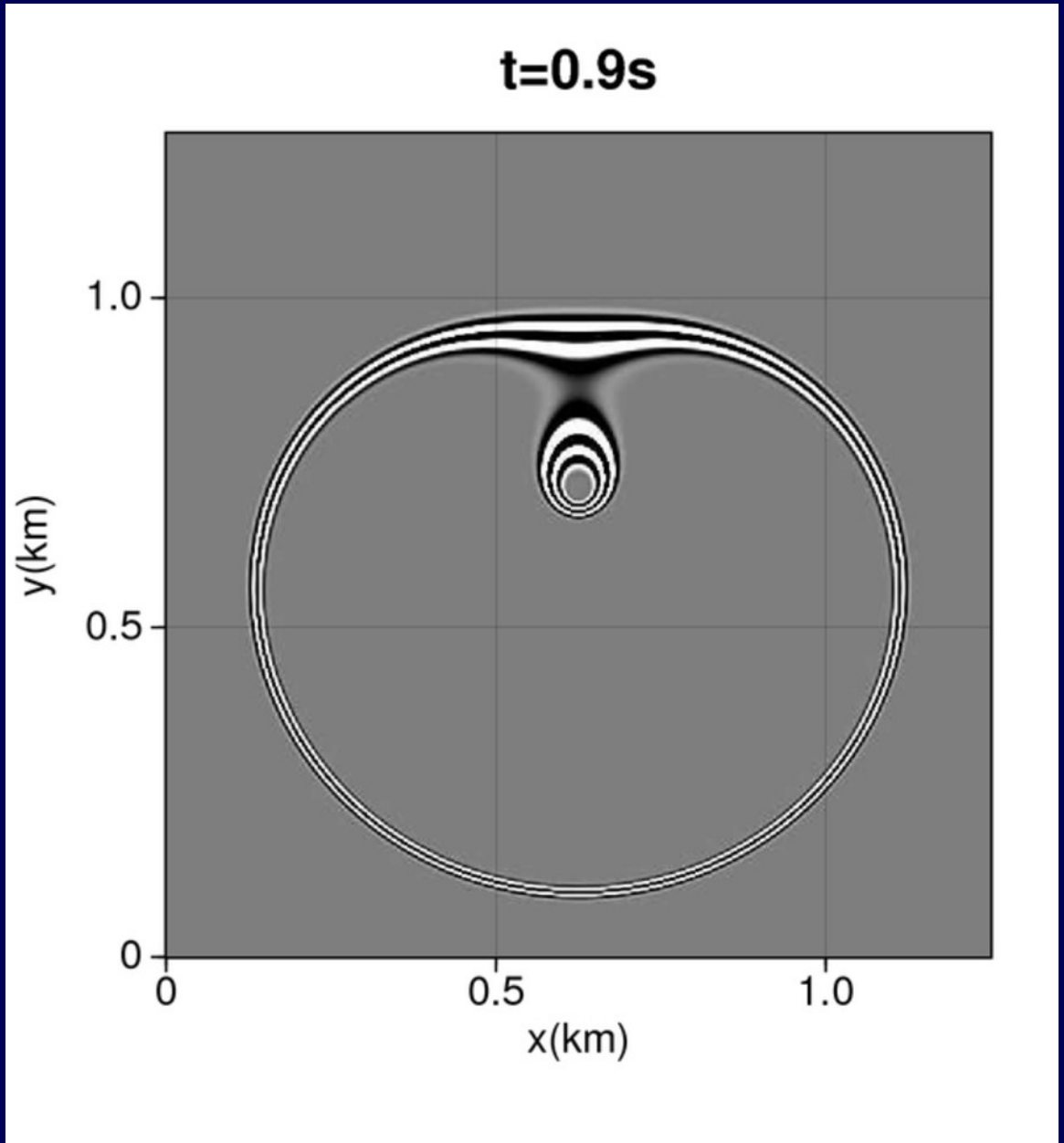

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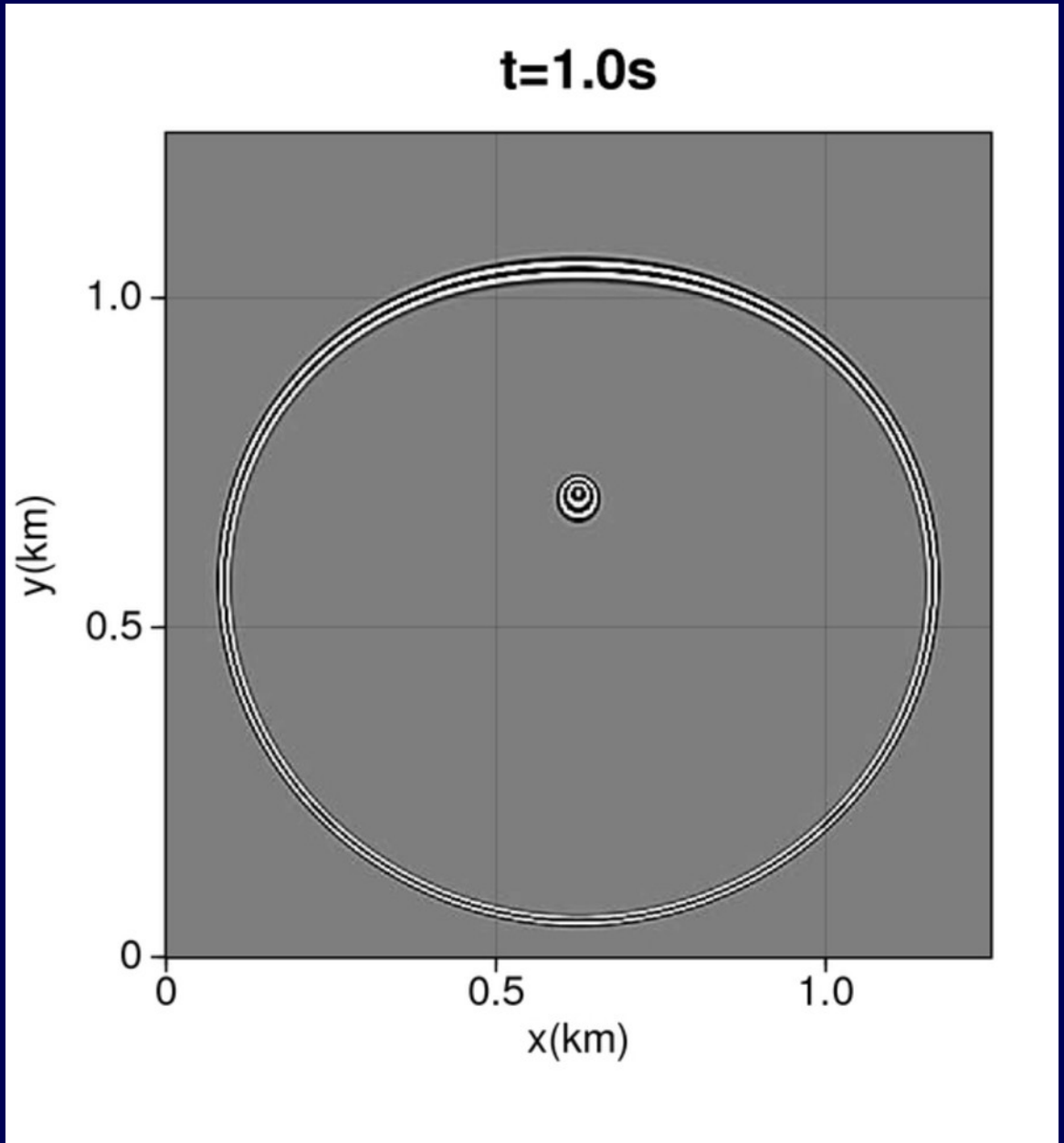

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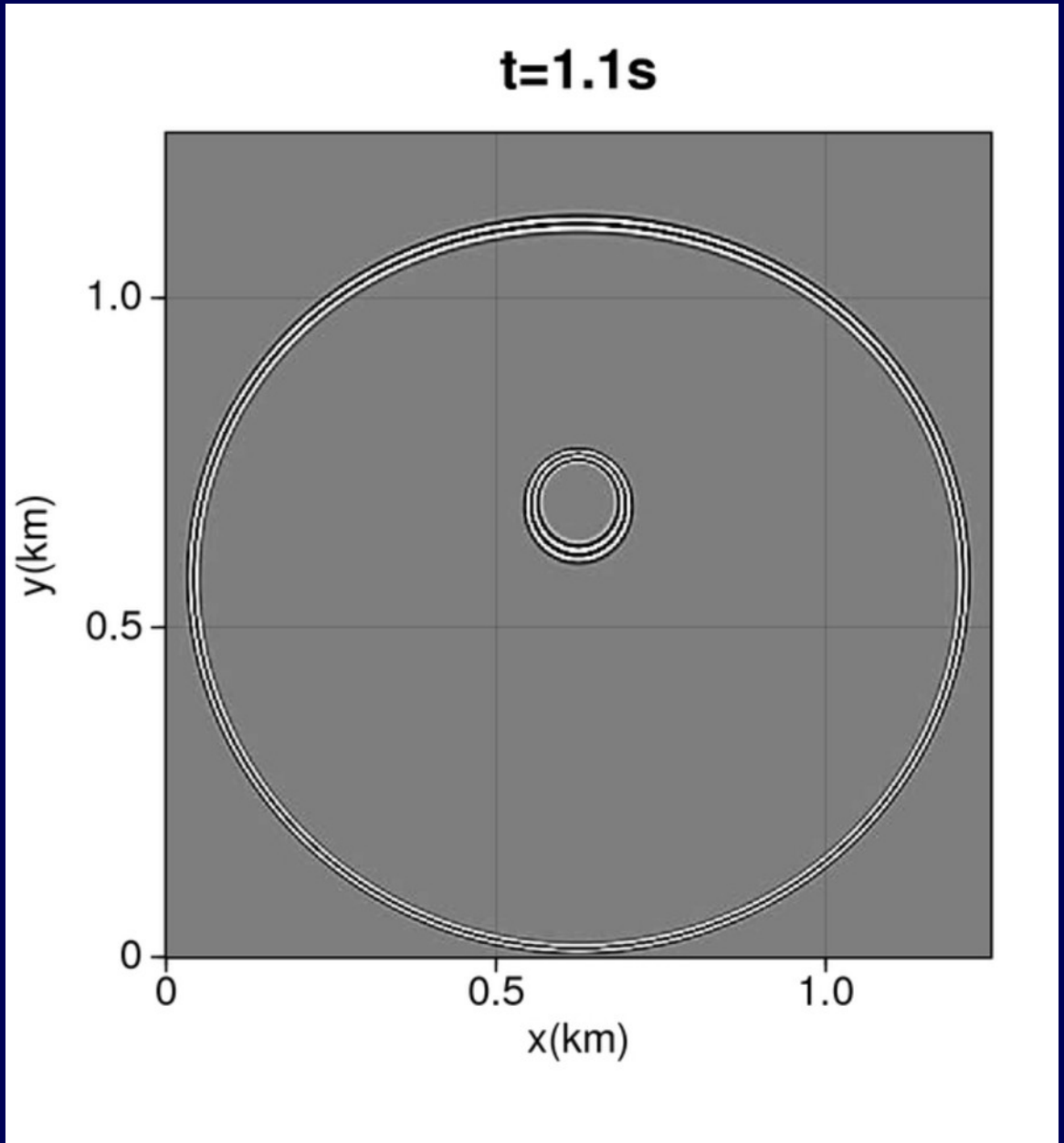
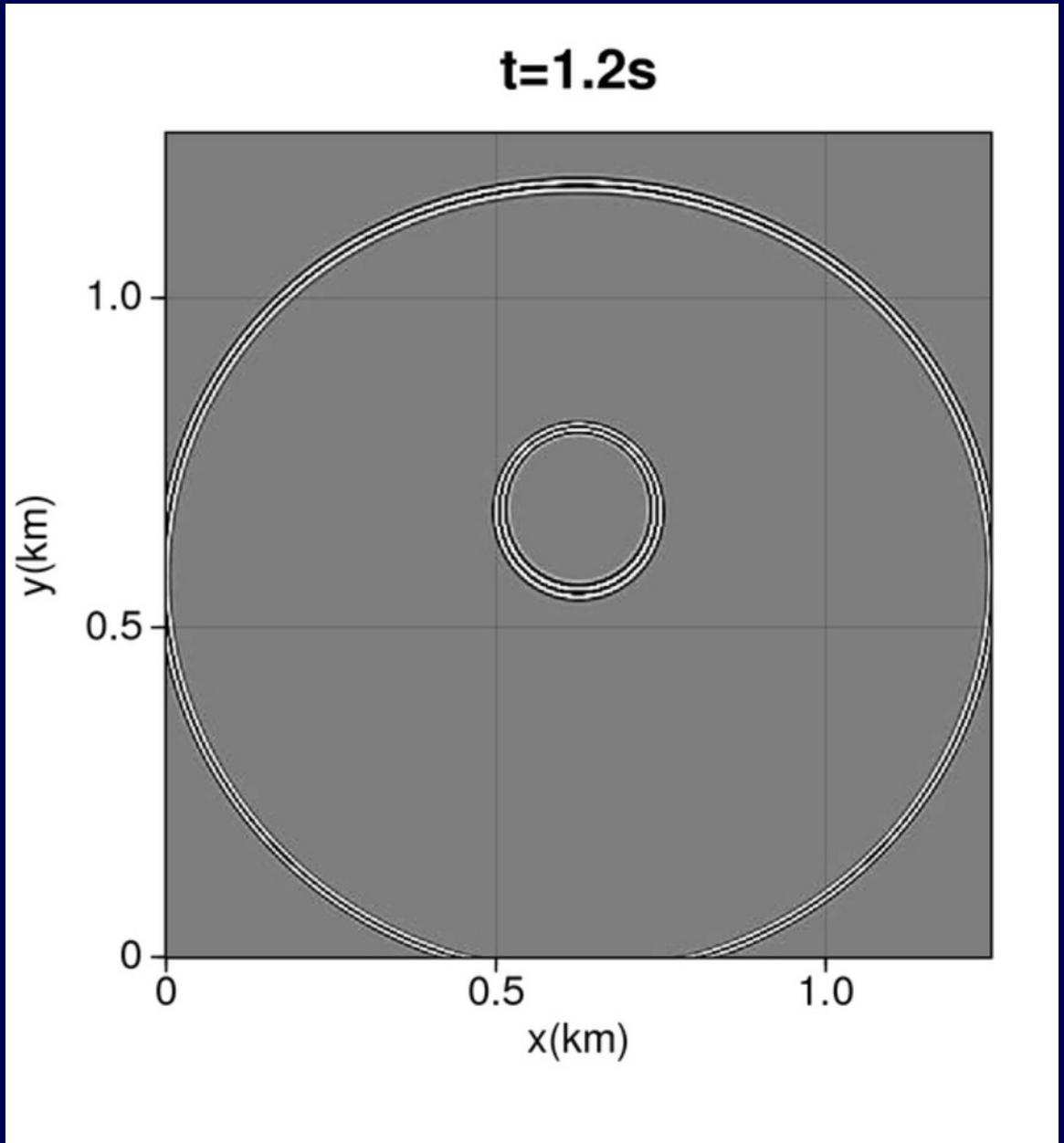
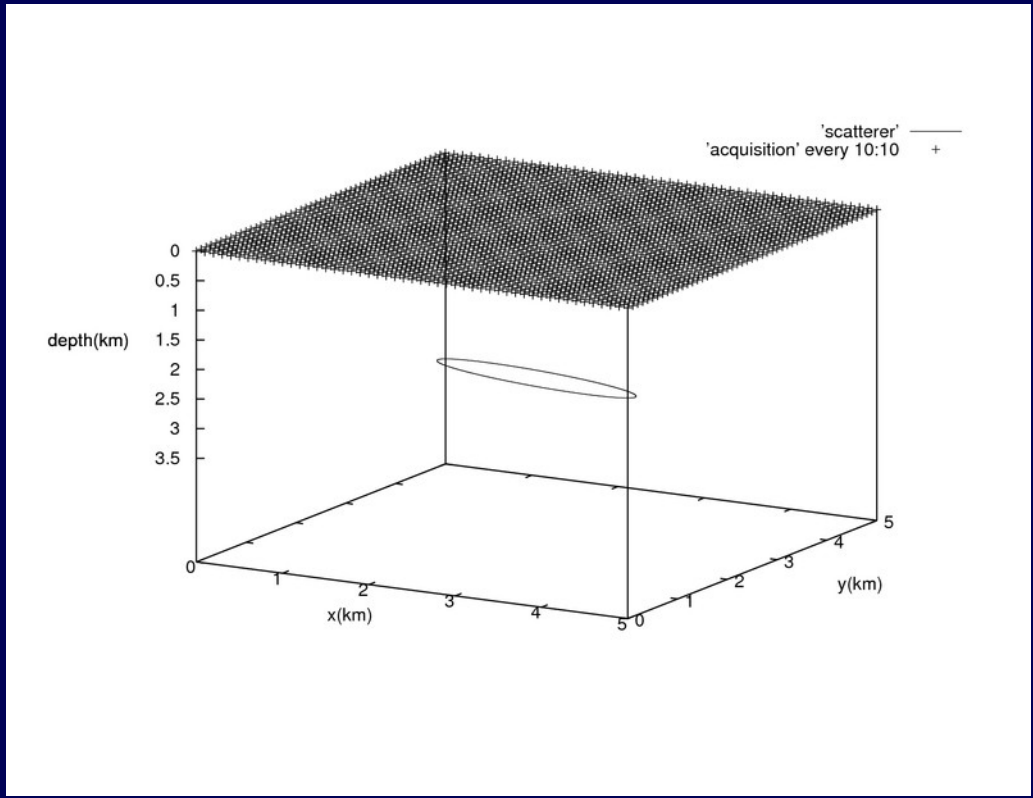


Curved edge diffractions – synthetic – dipping circle



Curved edge diffractions – synthetic – dipping ellipse



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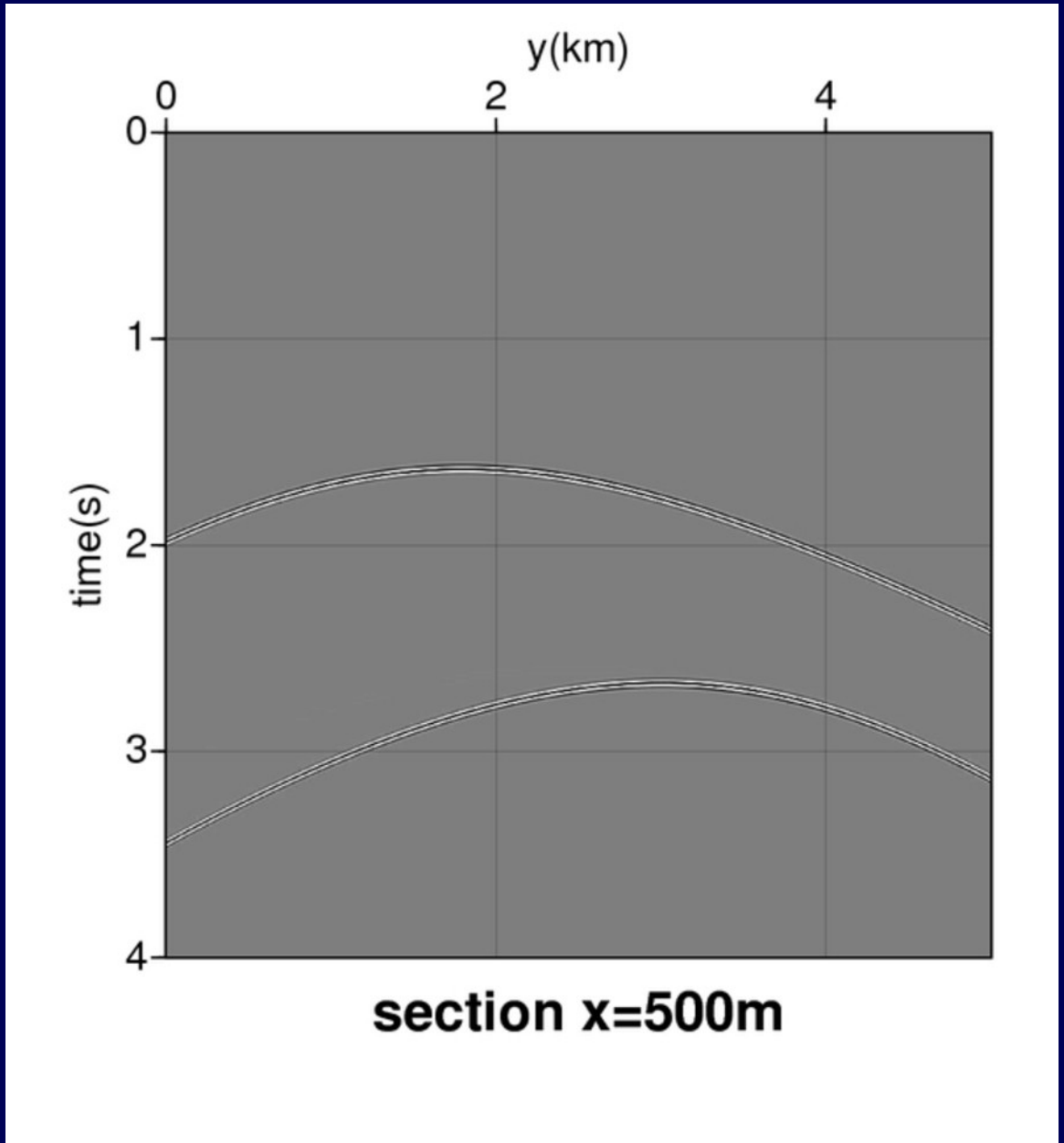

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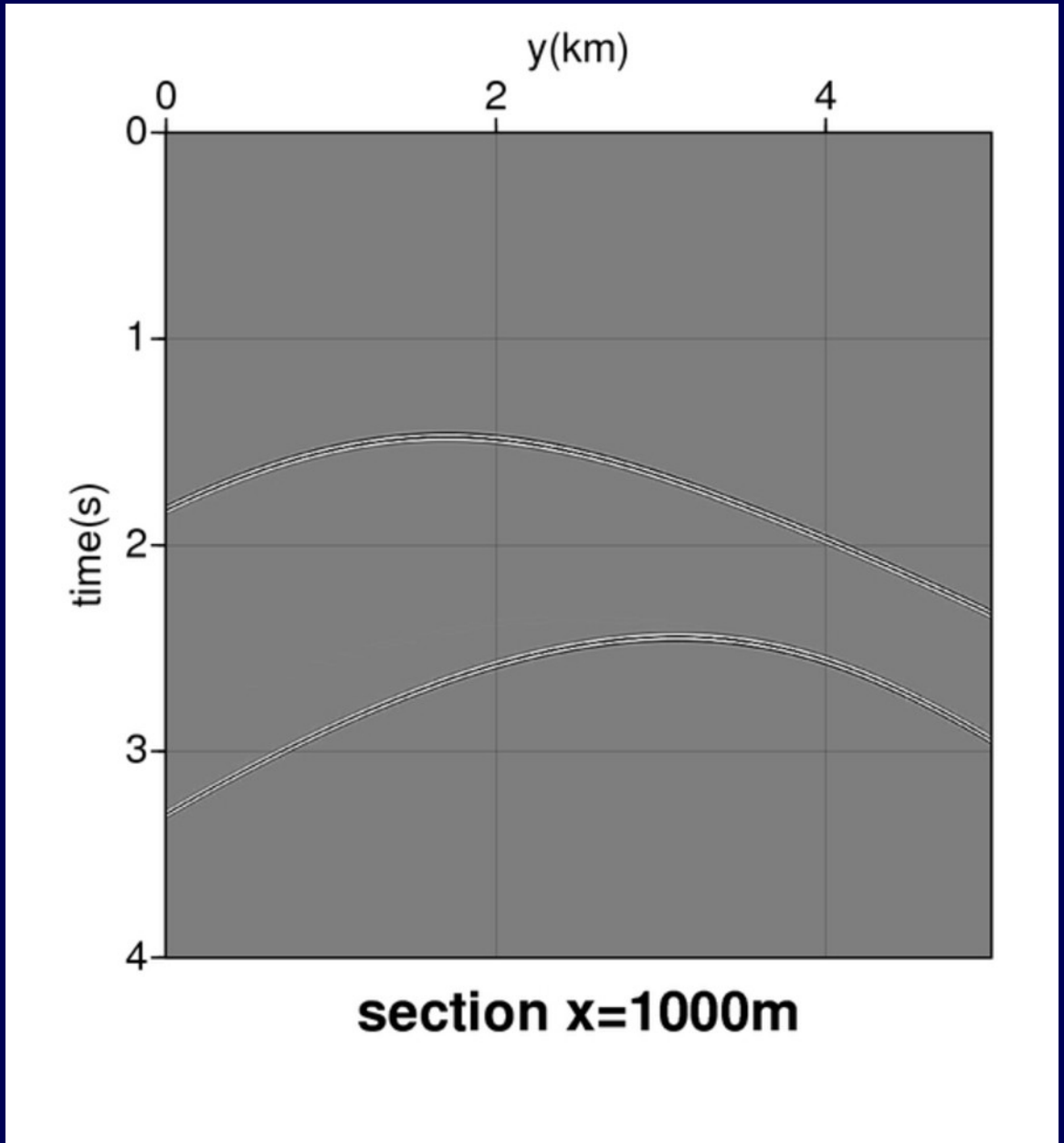
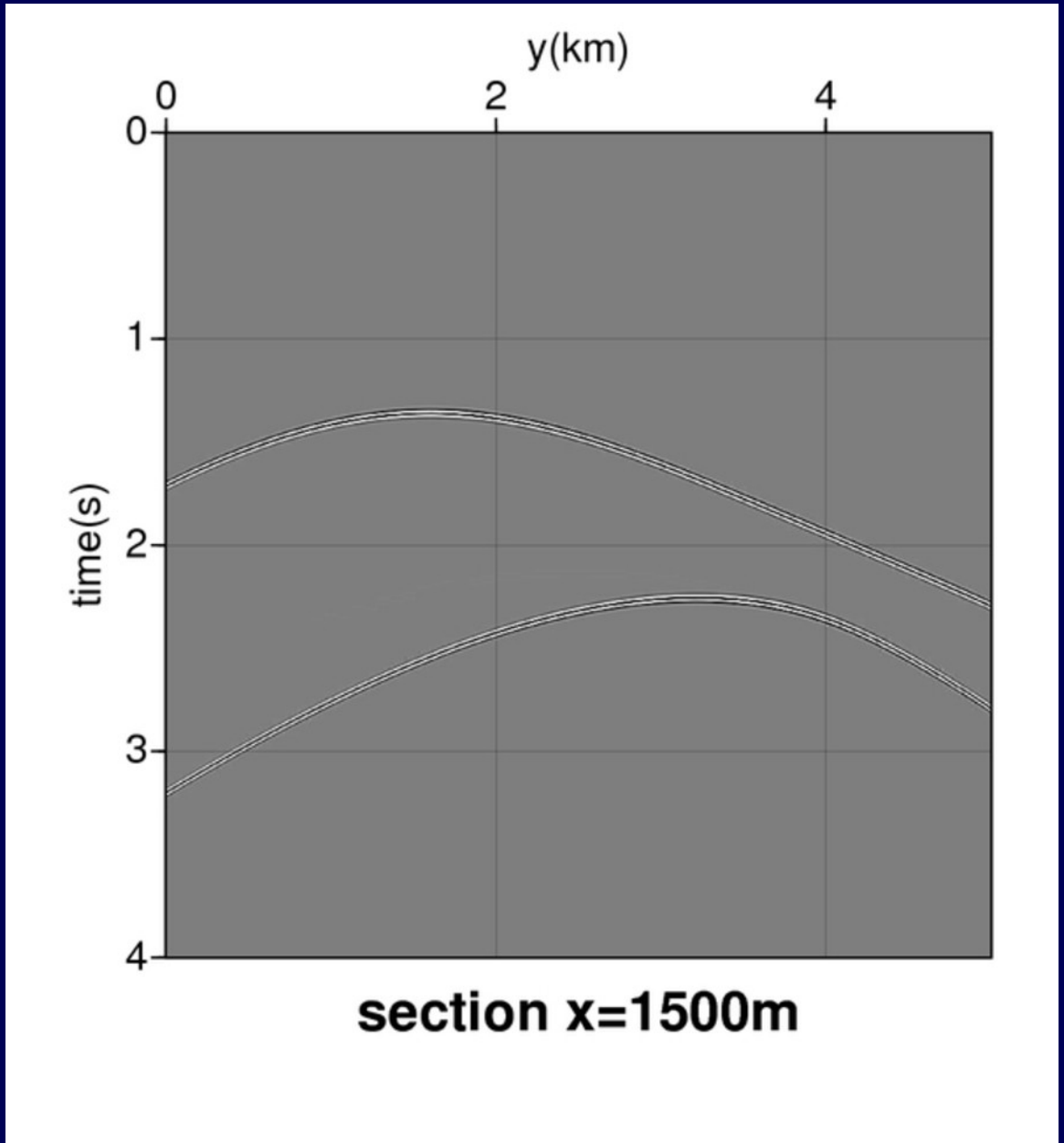
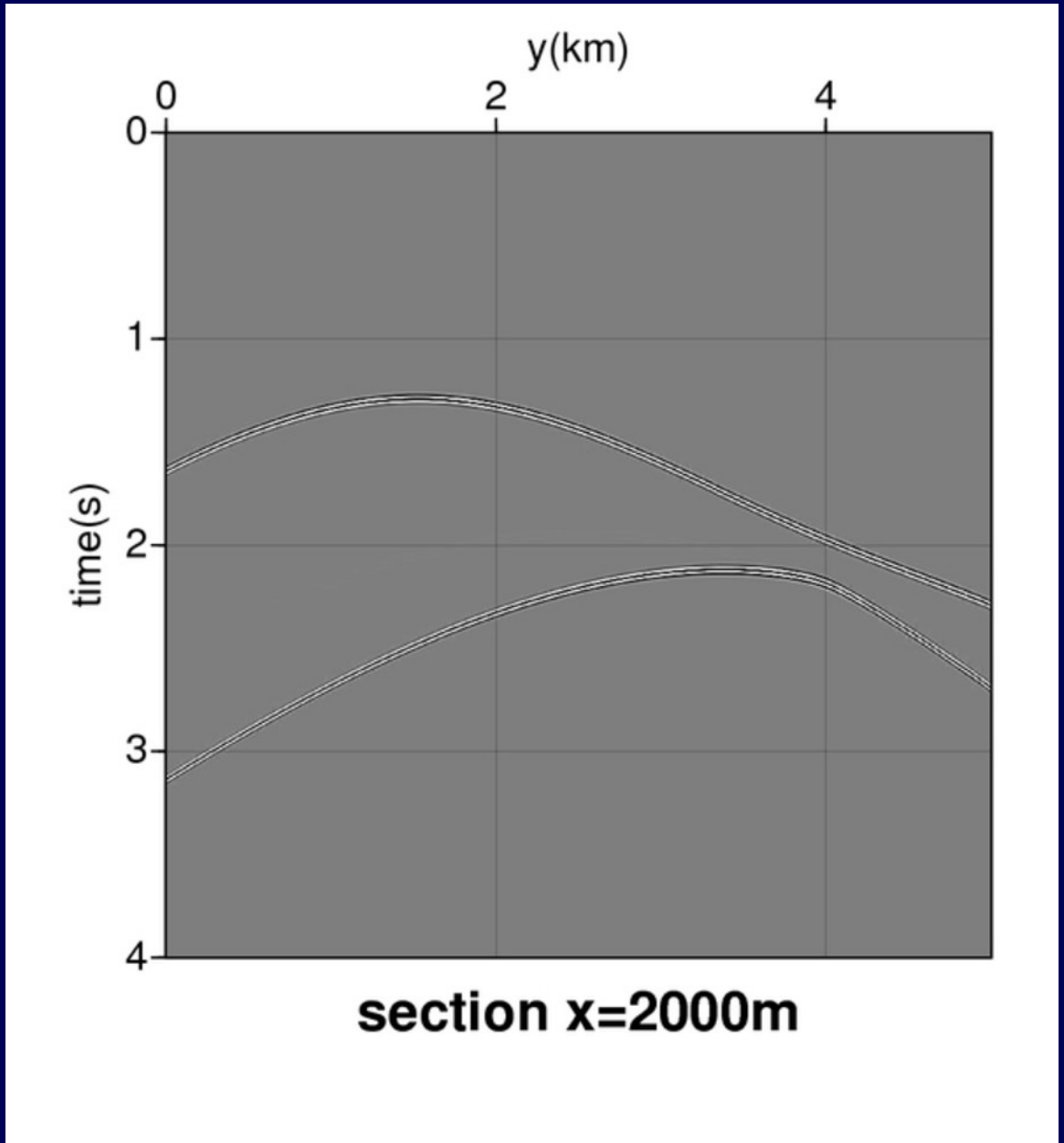


Curved edge diffractions – synthetic – dipping ellipse

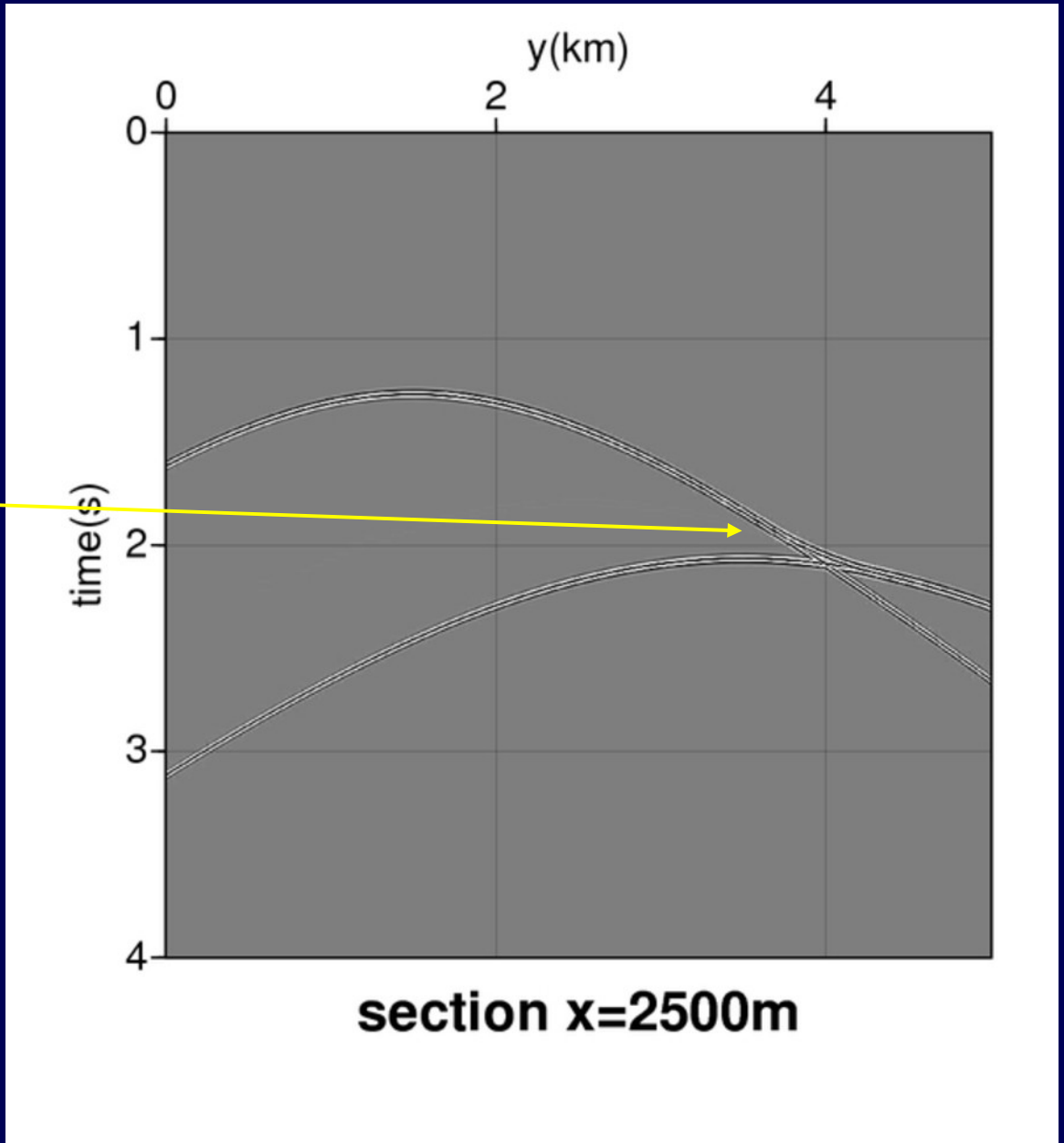


Curved edge diffractions – synthetic – dipping ellipse

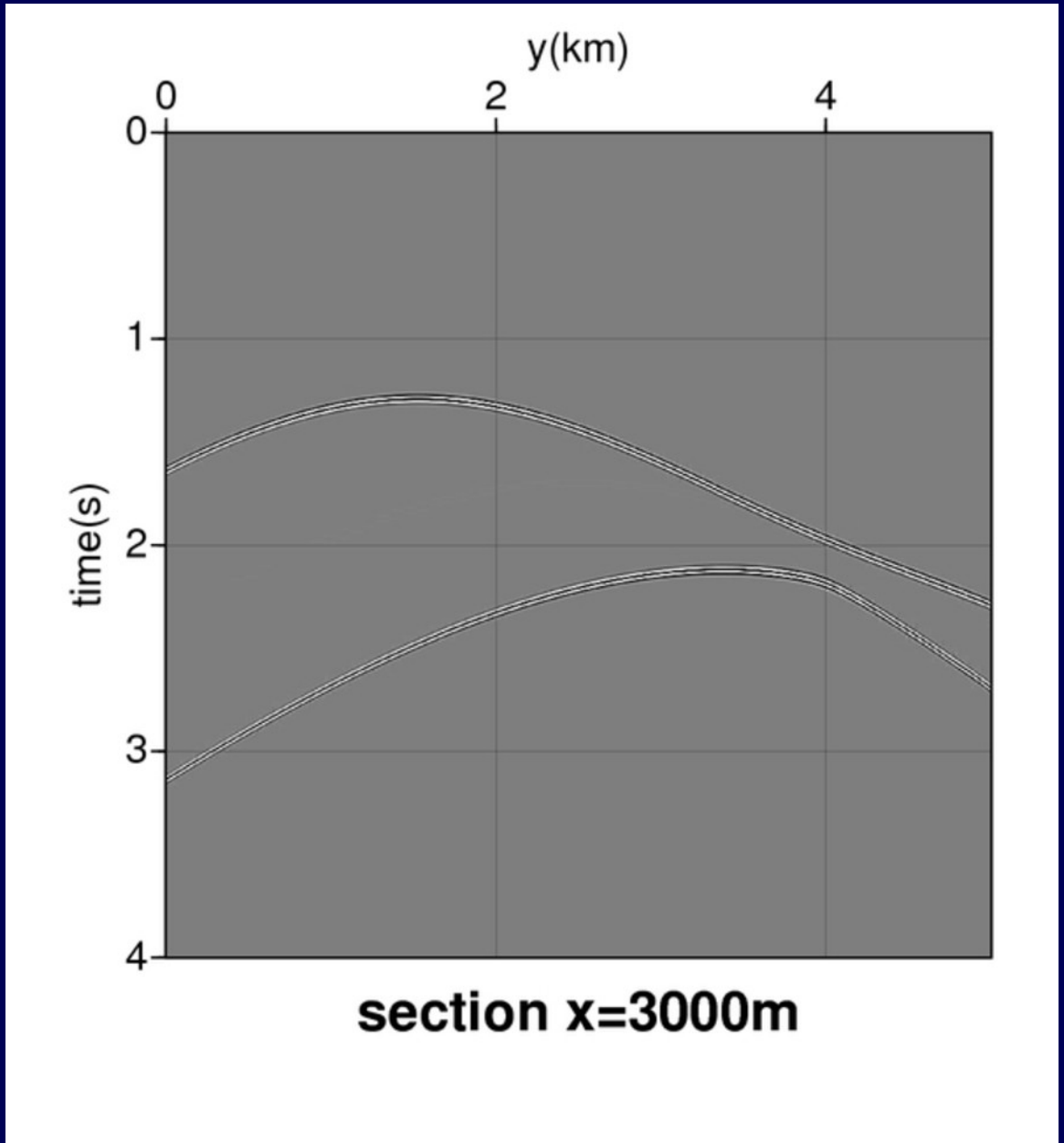


Curved edge diffractions – synthetic – dipping ellipse

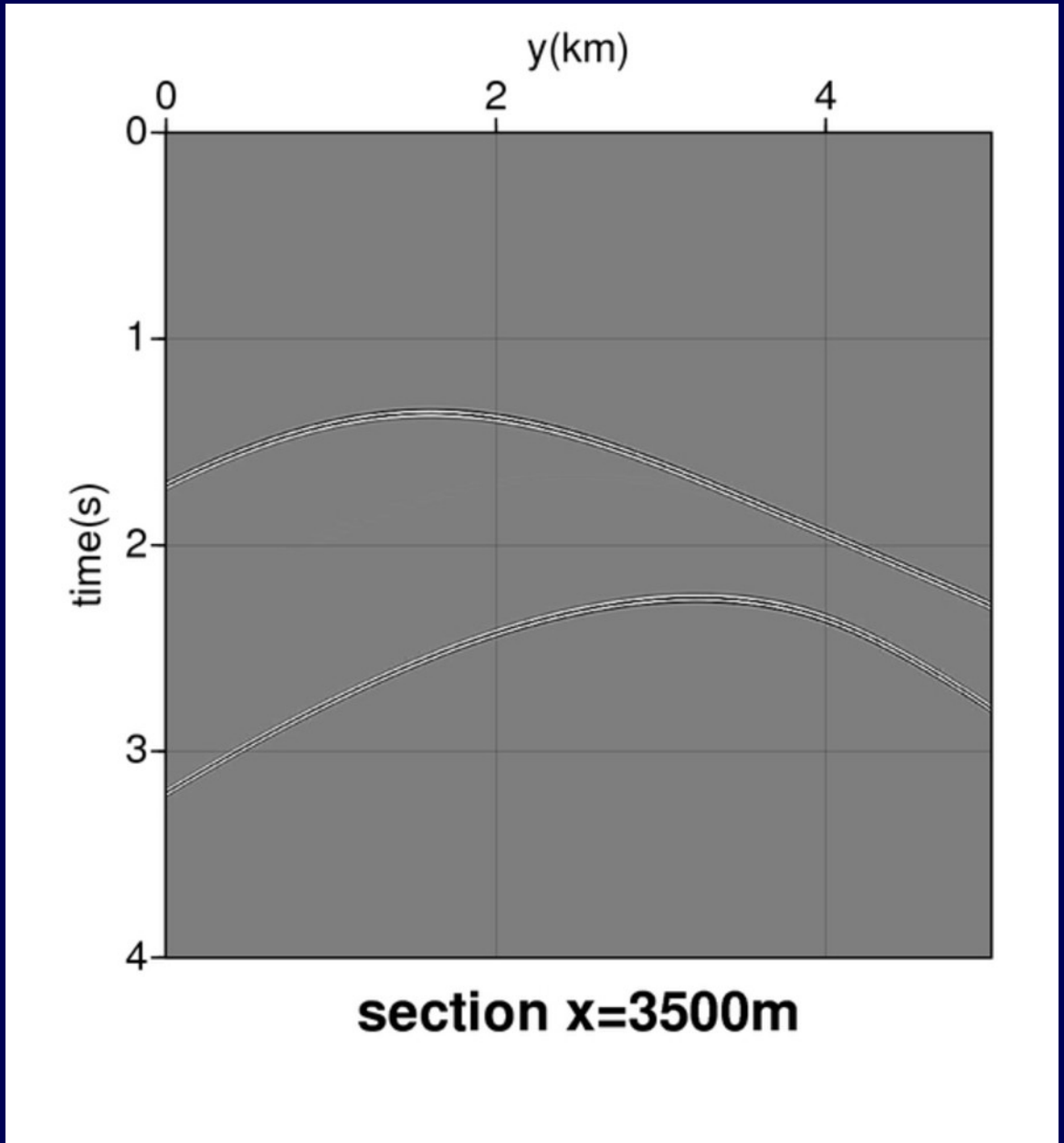
Triplicated branch + Caustic



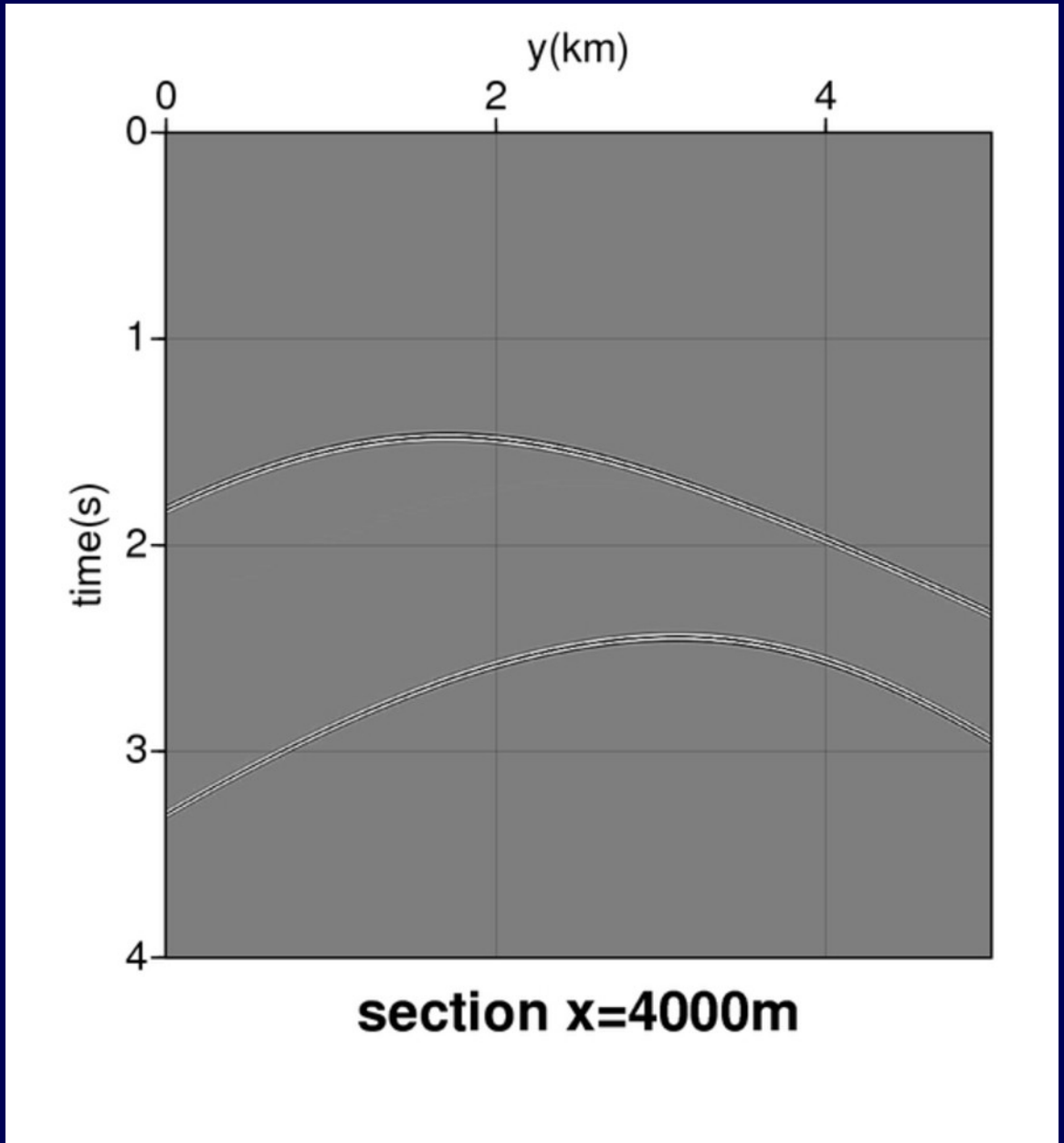
Curved edge diffractions – synthetic – dipping ellipse



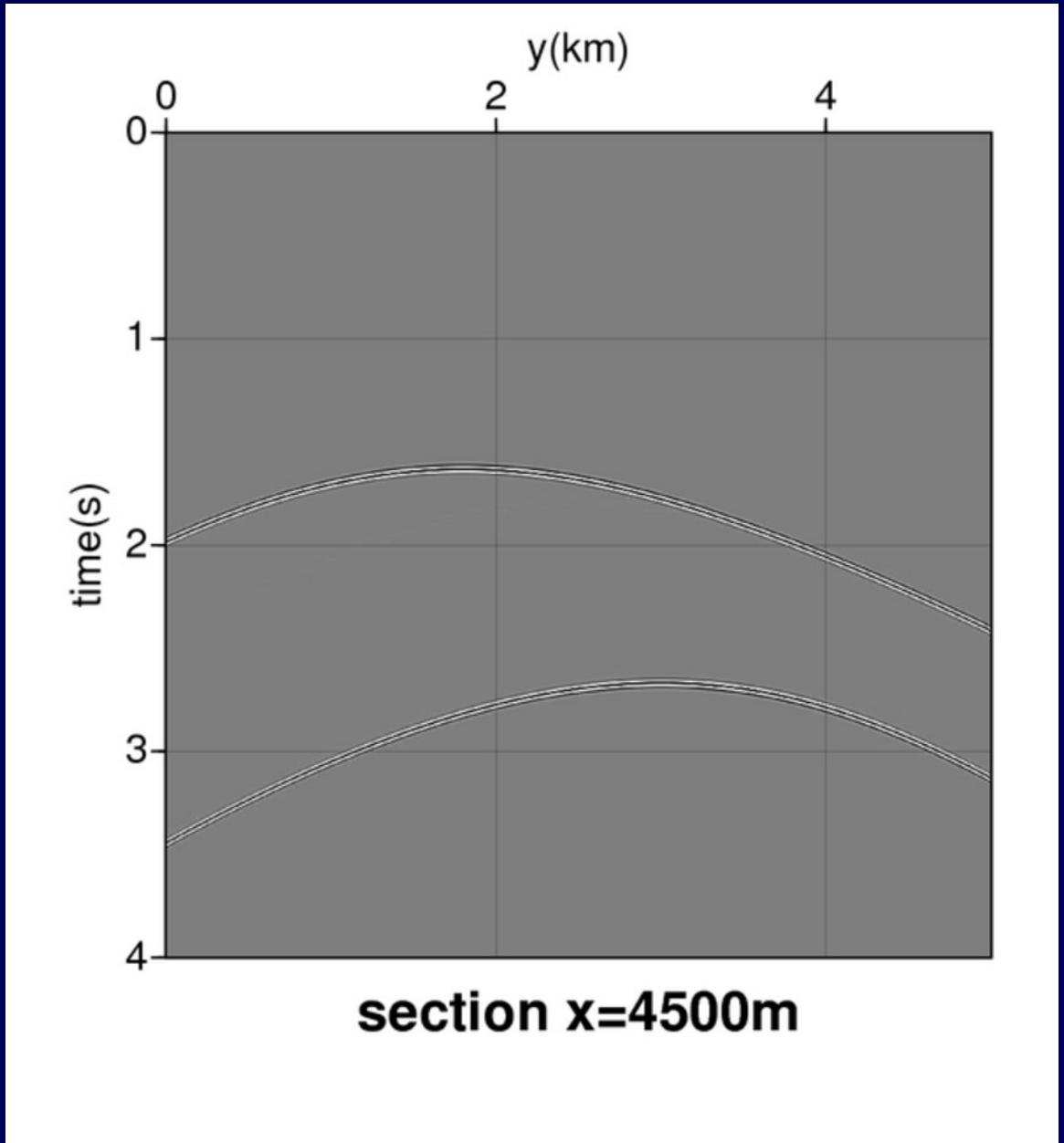
Curved edge diffractions – synthetic – dipping ellipse



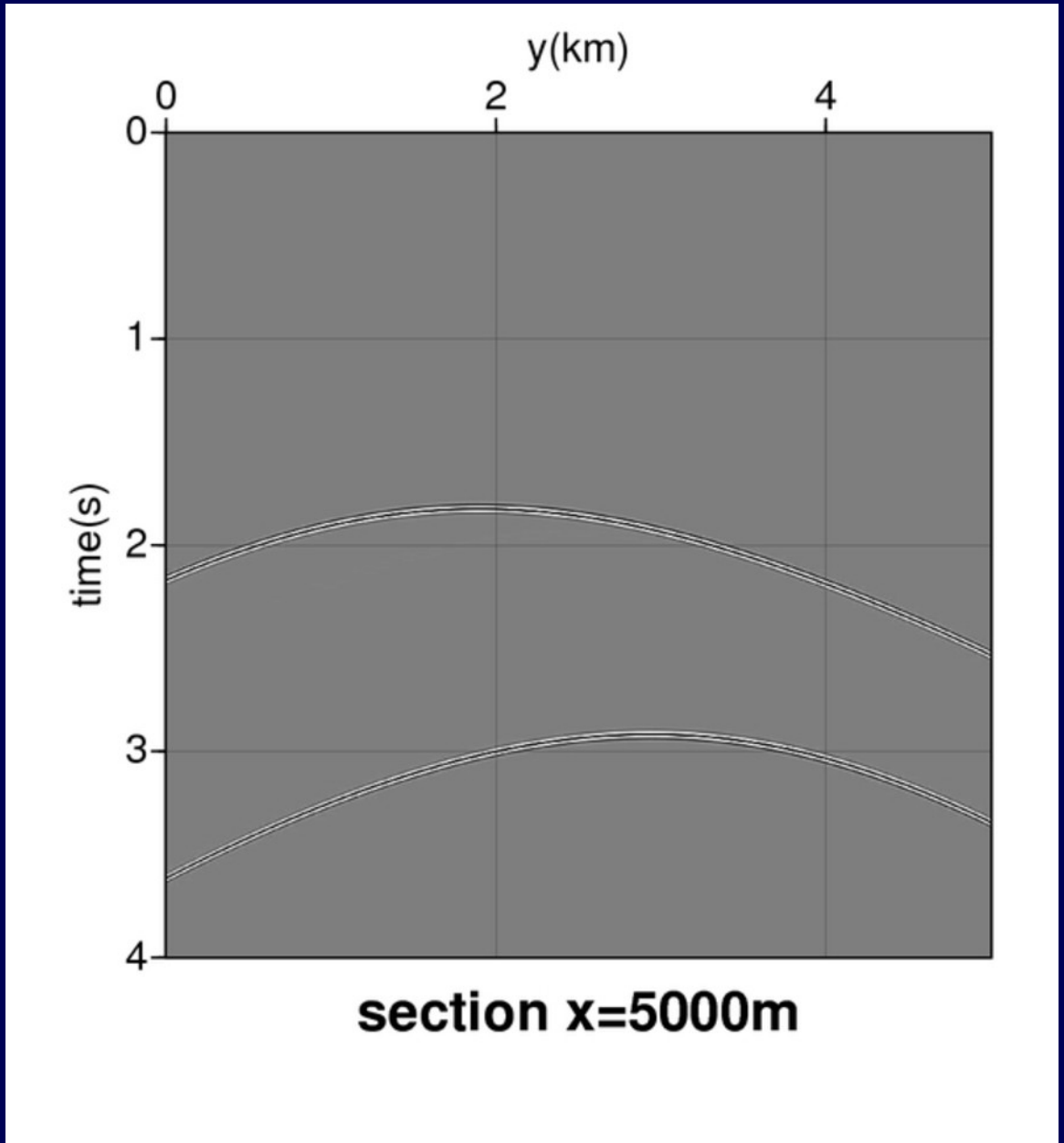
Curved edge diffractions – synthetic – dipping ellipse



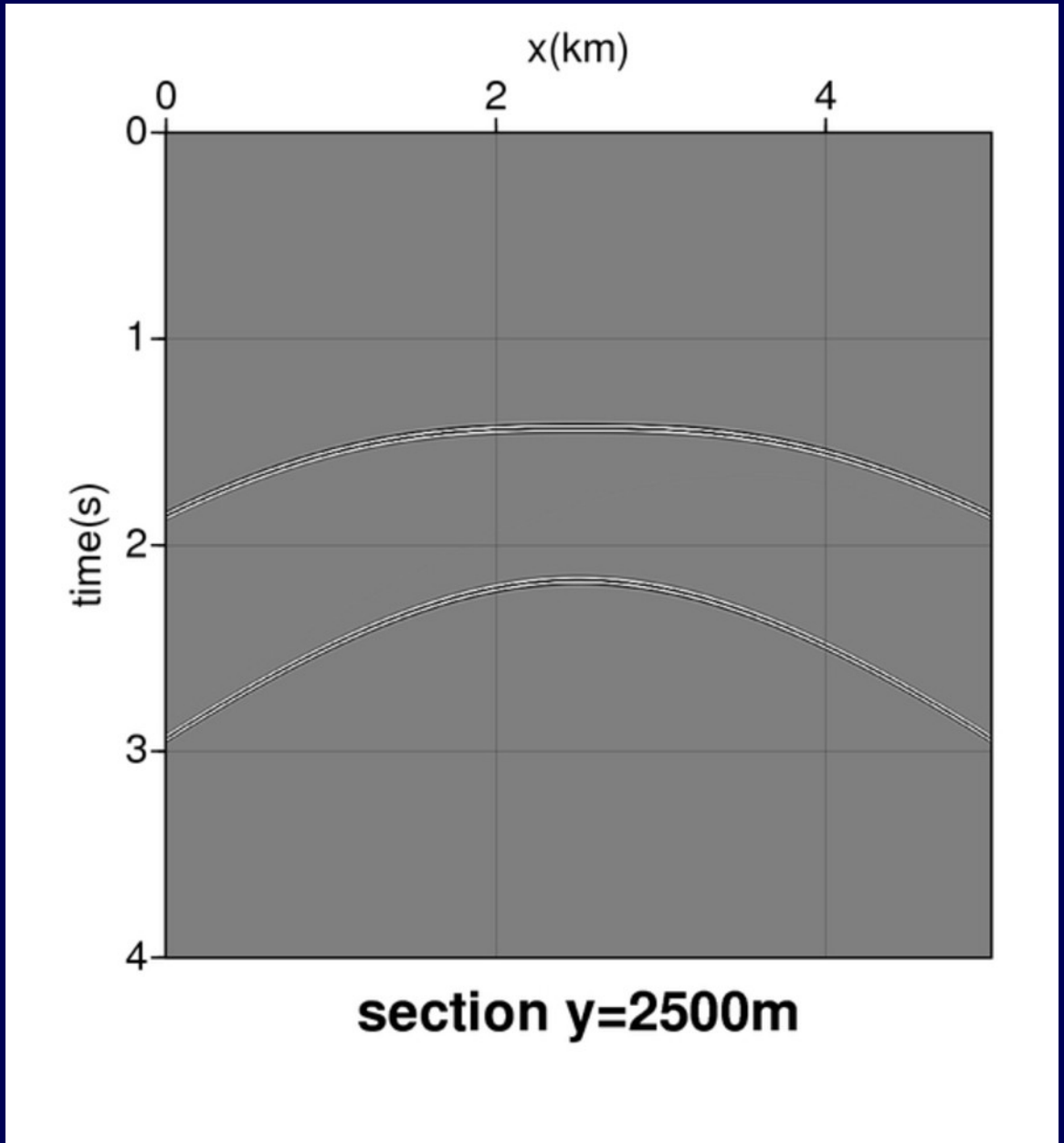
Curved edge diffractions – synthetic – dipping ellipse



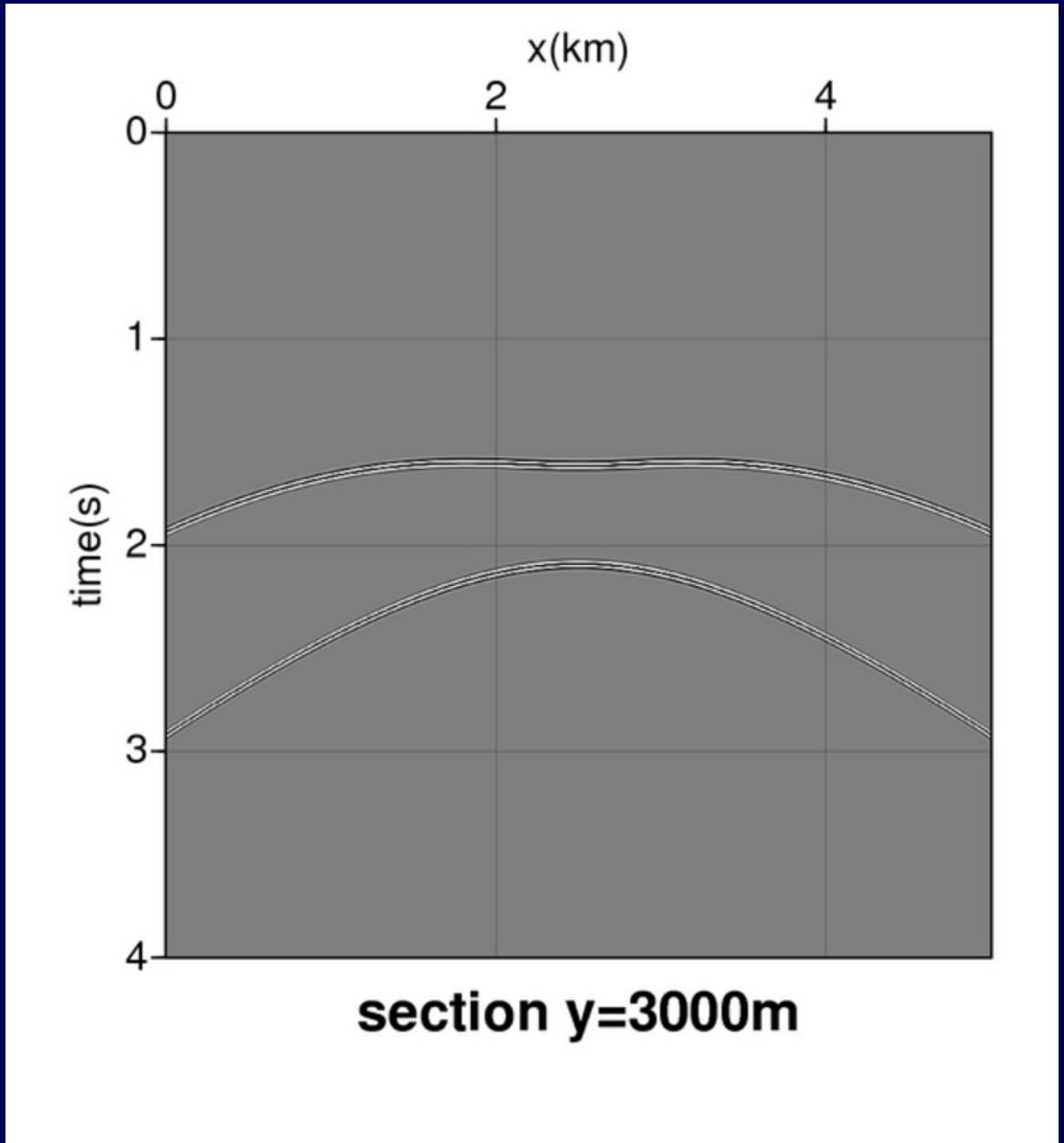
Curved edge diffractions – synthetic – dipping ellipse



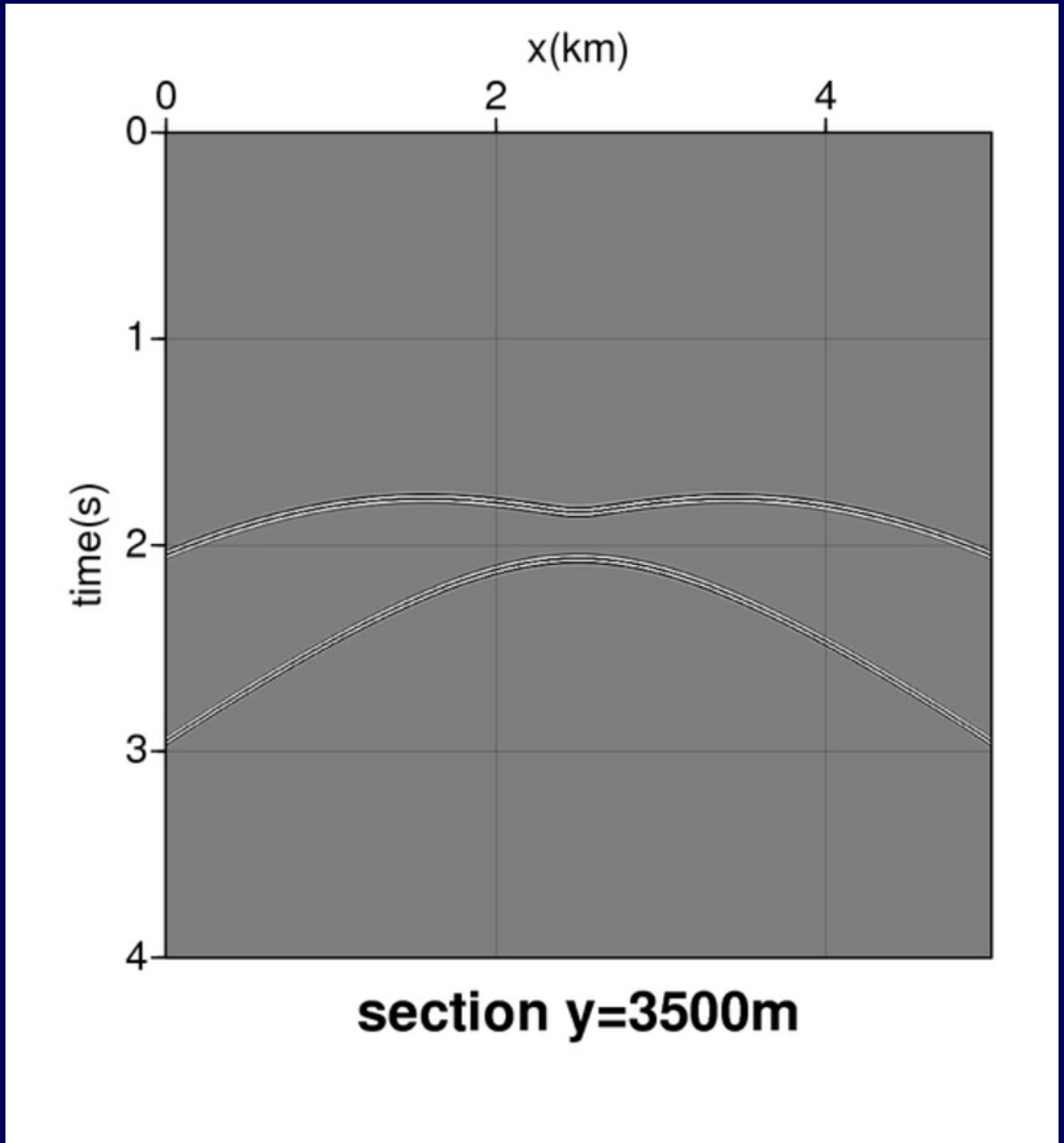
Curved edge diffractions – synthetic – dipping ellipse



Curved edge diffractions – synthetic – dipping ellipse

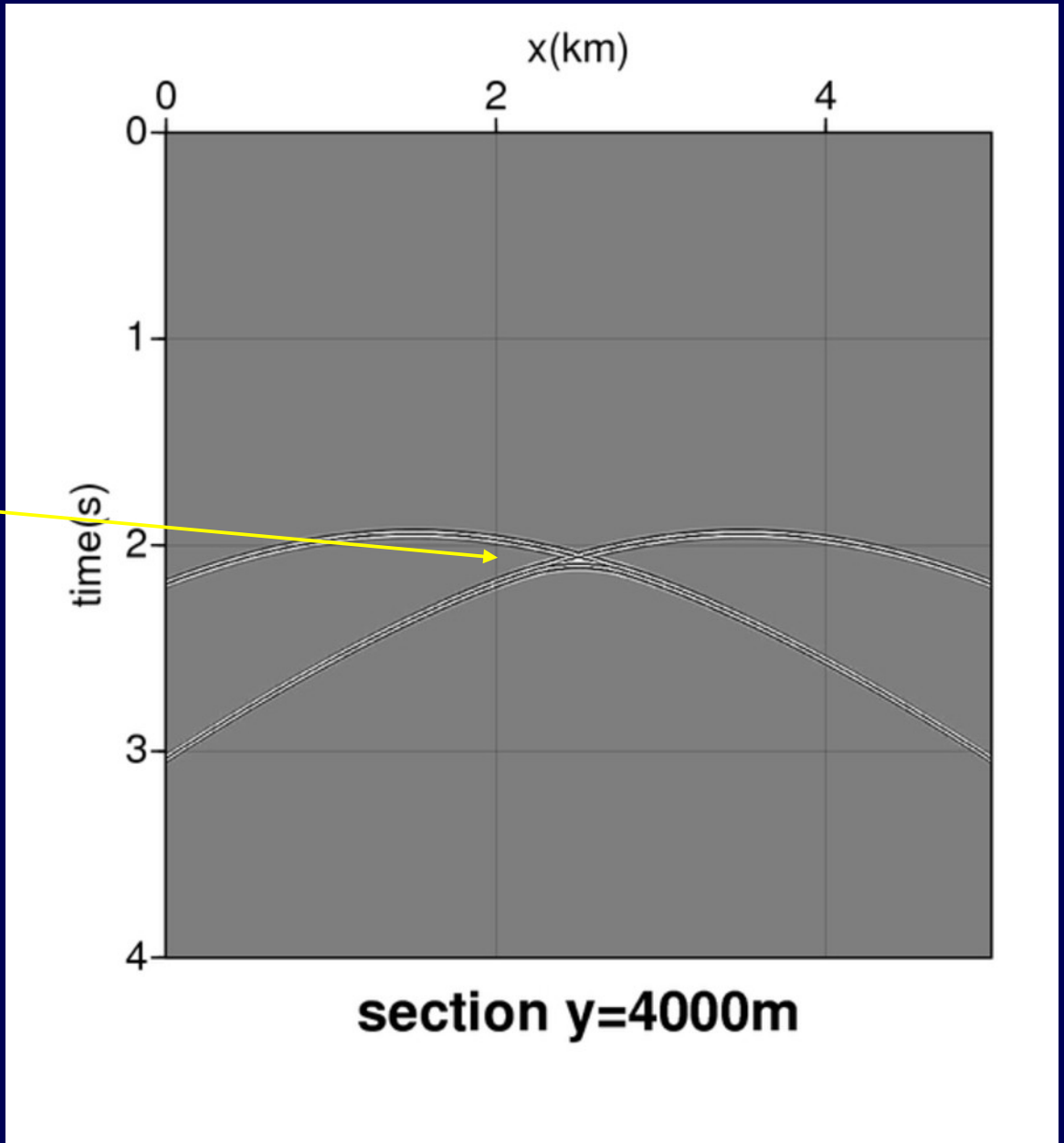


Curved edge diffractions – synthetic – dipping ellipse

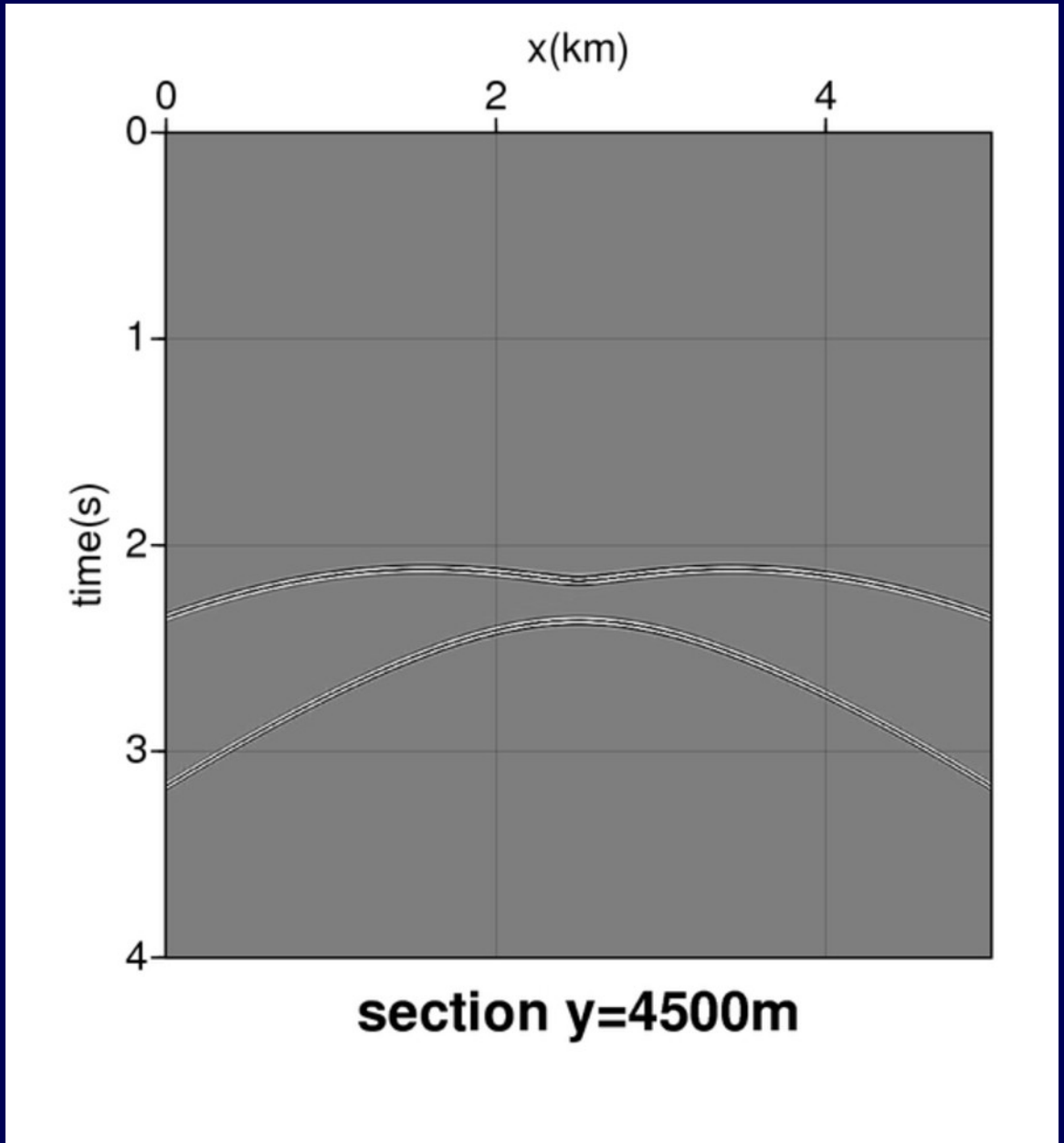


Curved edge diffractions – synthetic – dipping ellipse

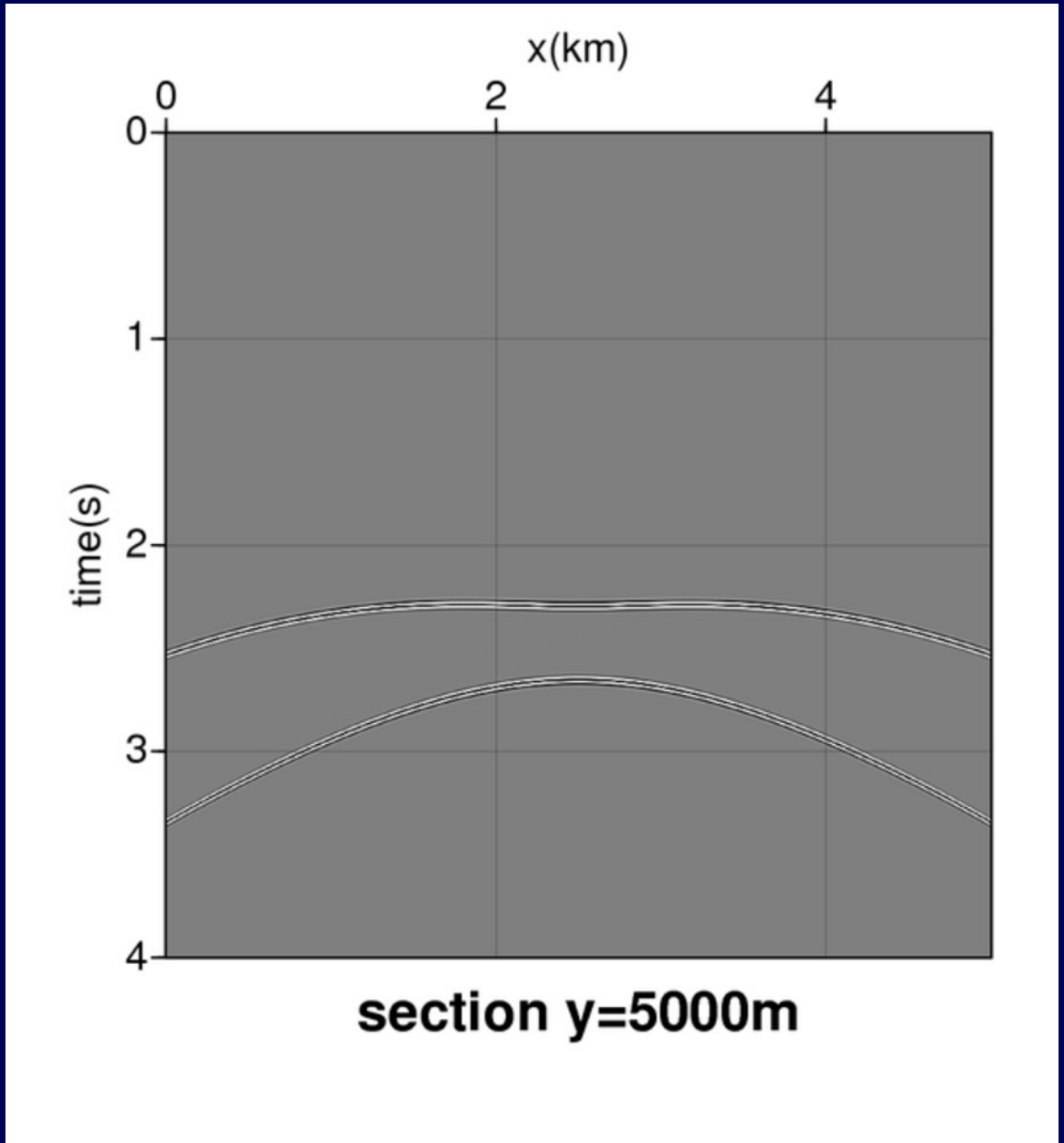
Triplicated branch + Caustic



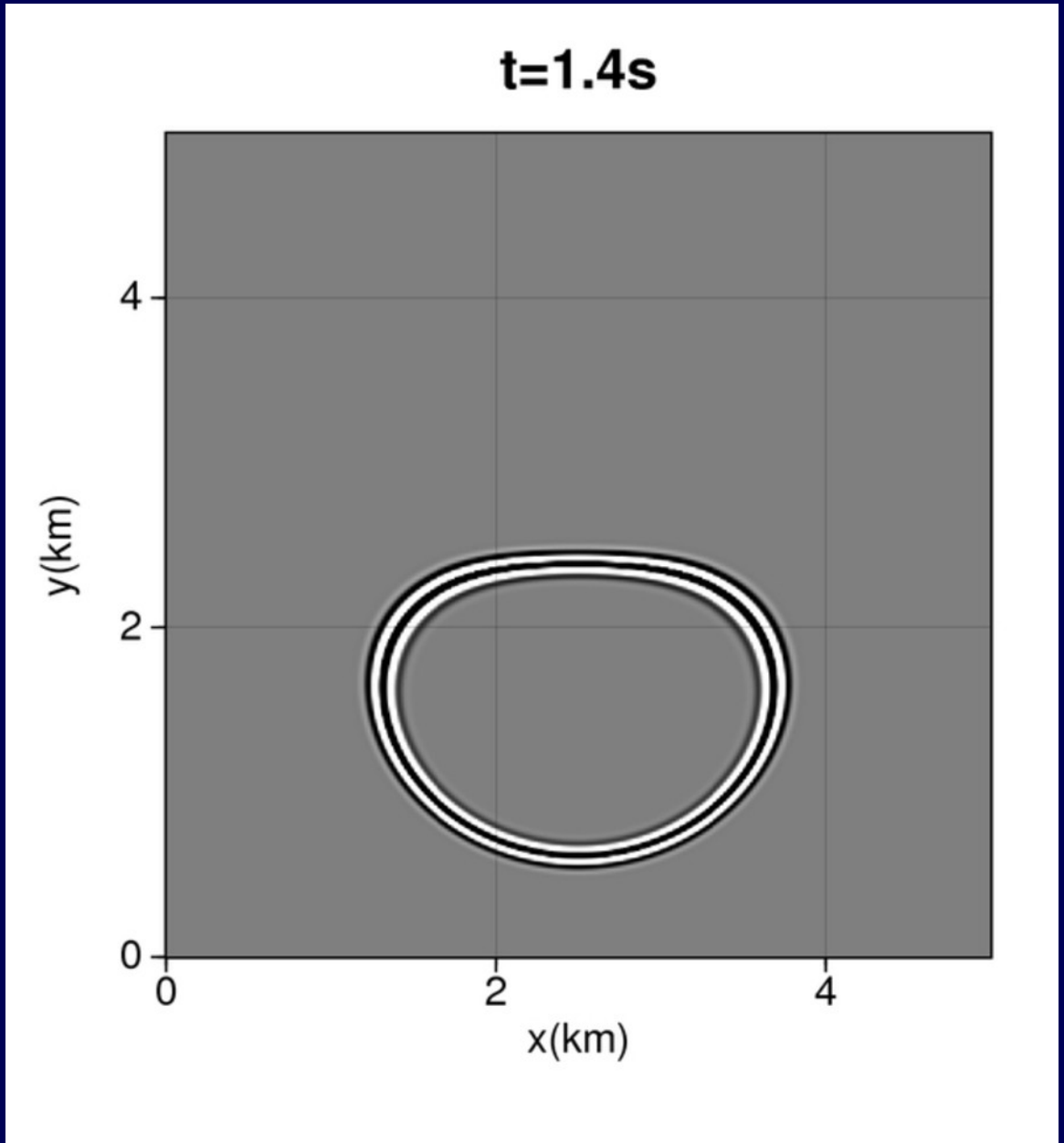
Curved edge diffractions – synthetic – dipping ellipse



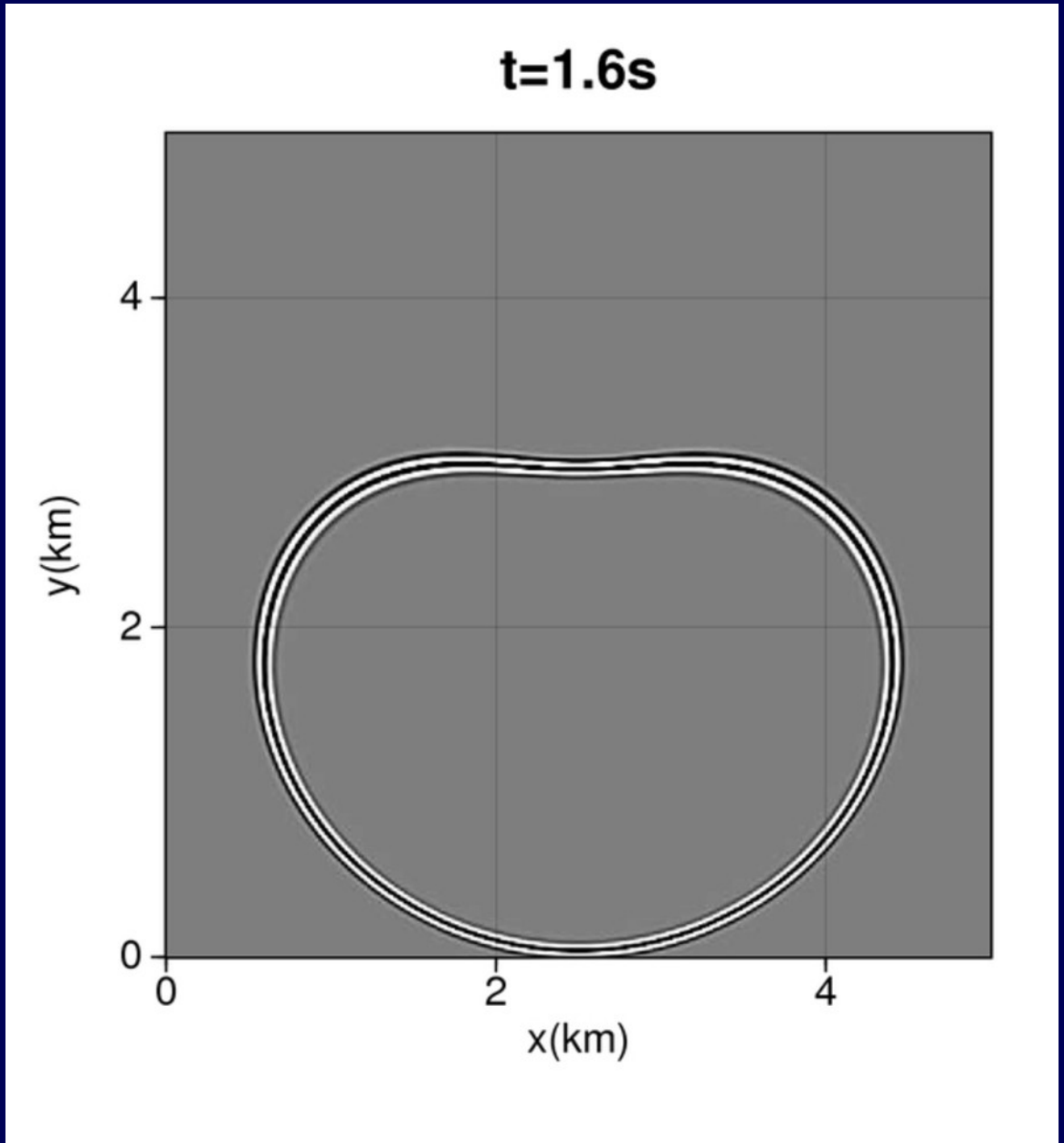
Curved edge diffractions – synthetic – dipping ellipse



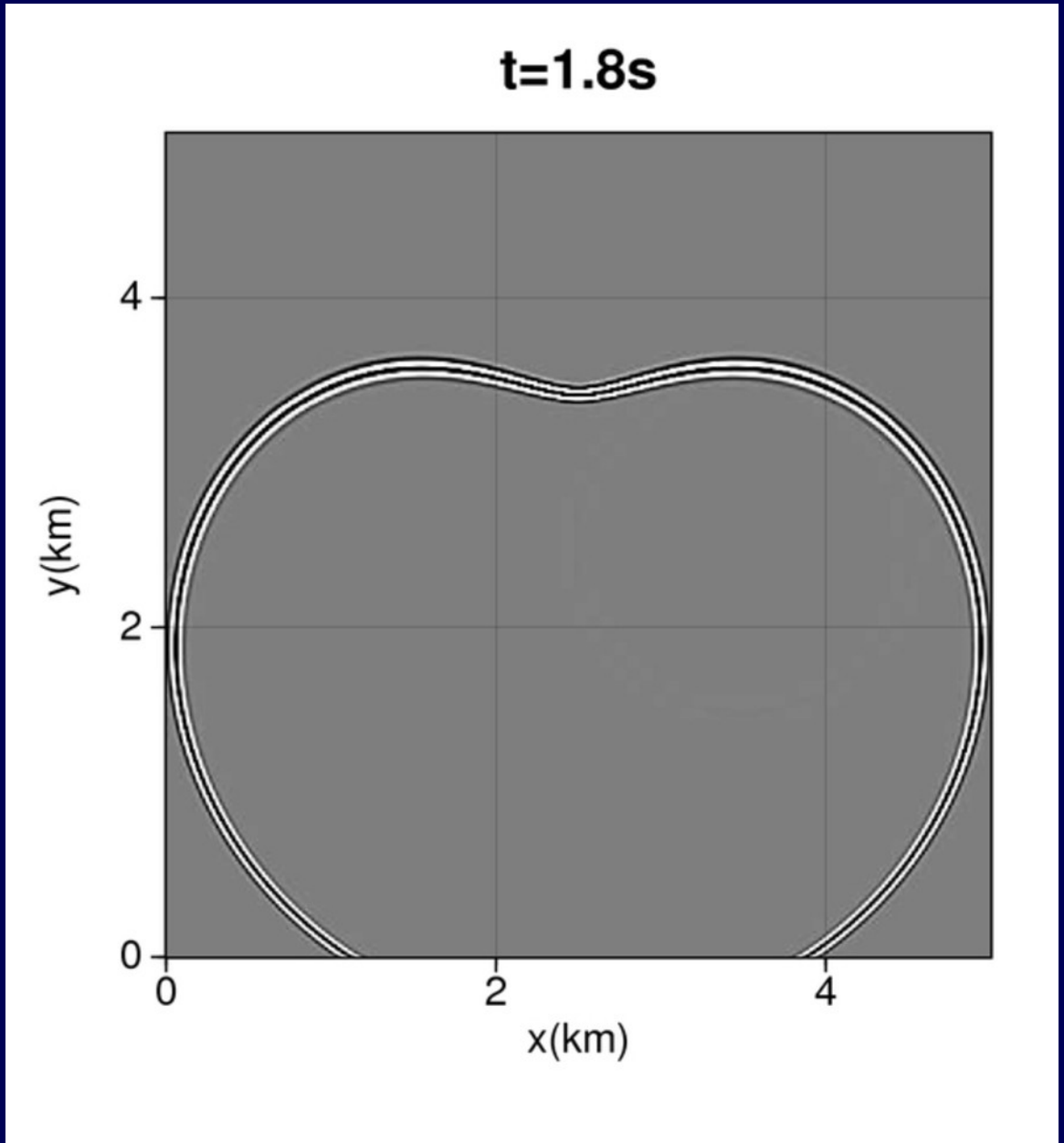
Curved edge diffractions – synthetic – dipping ellipse



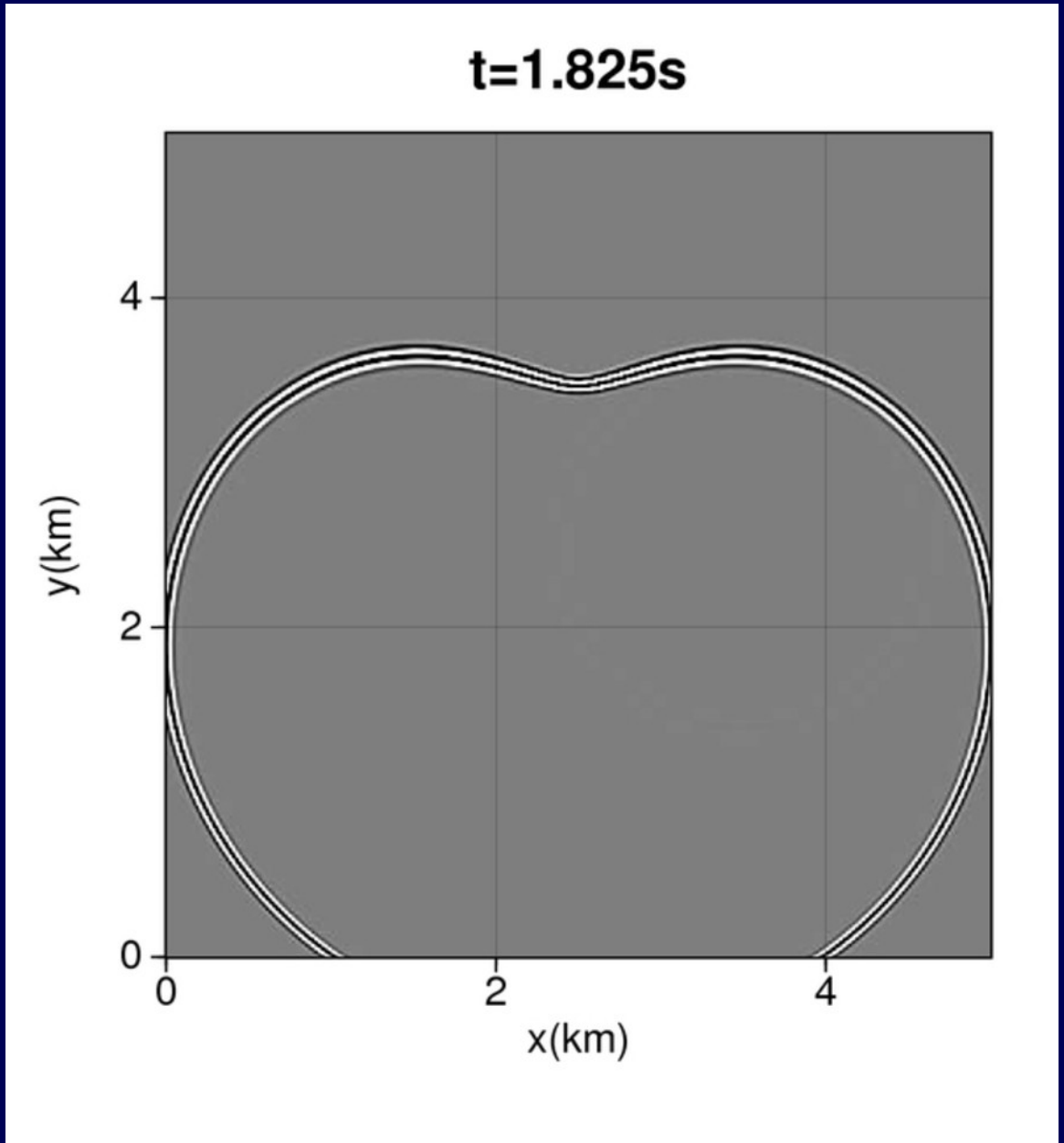
Curved edge diffractions – synthetic – dipping ellipse



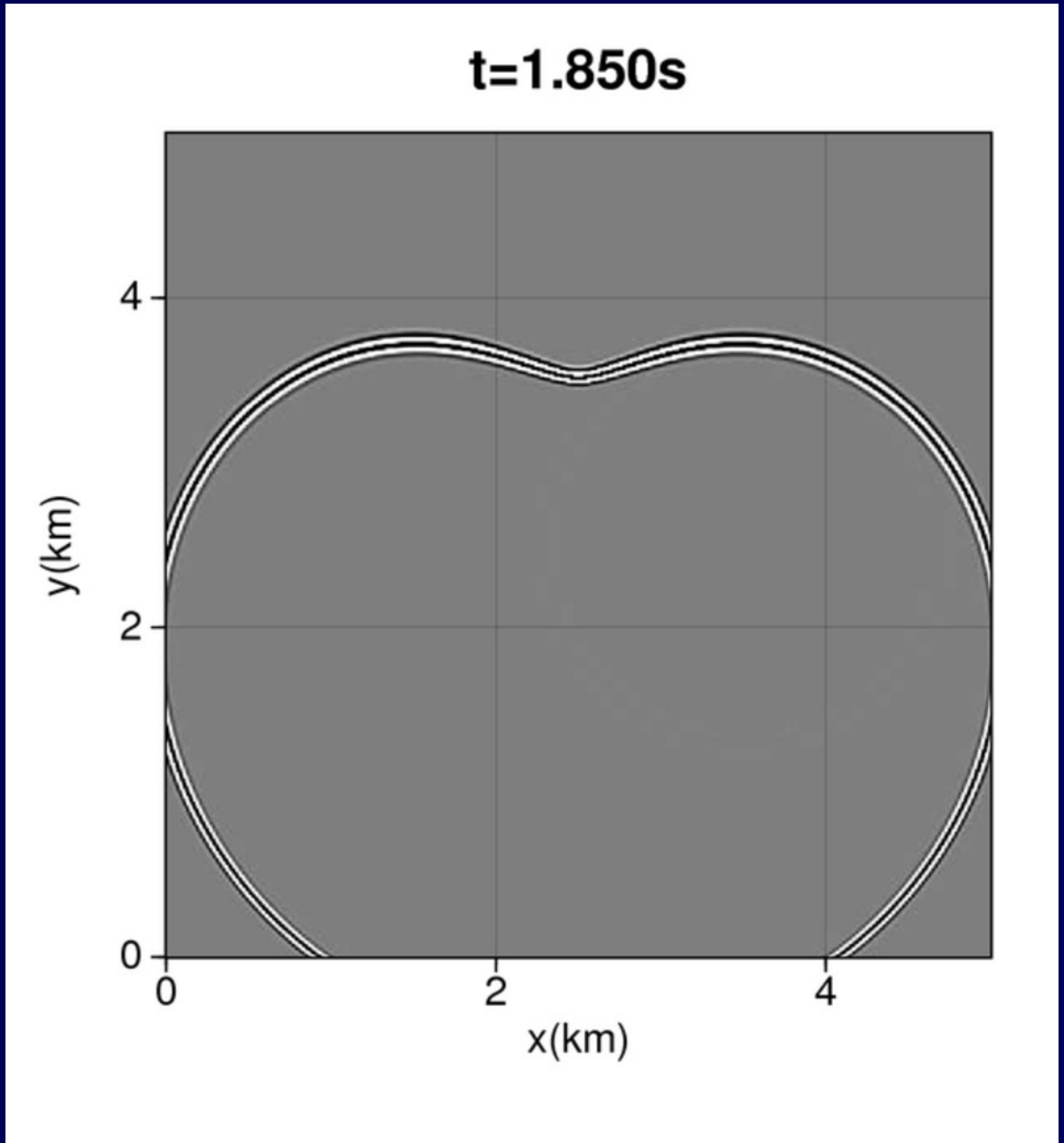
Curved edge diffractions – synthetic – dipping ellipse



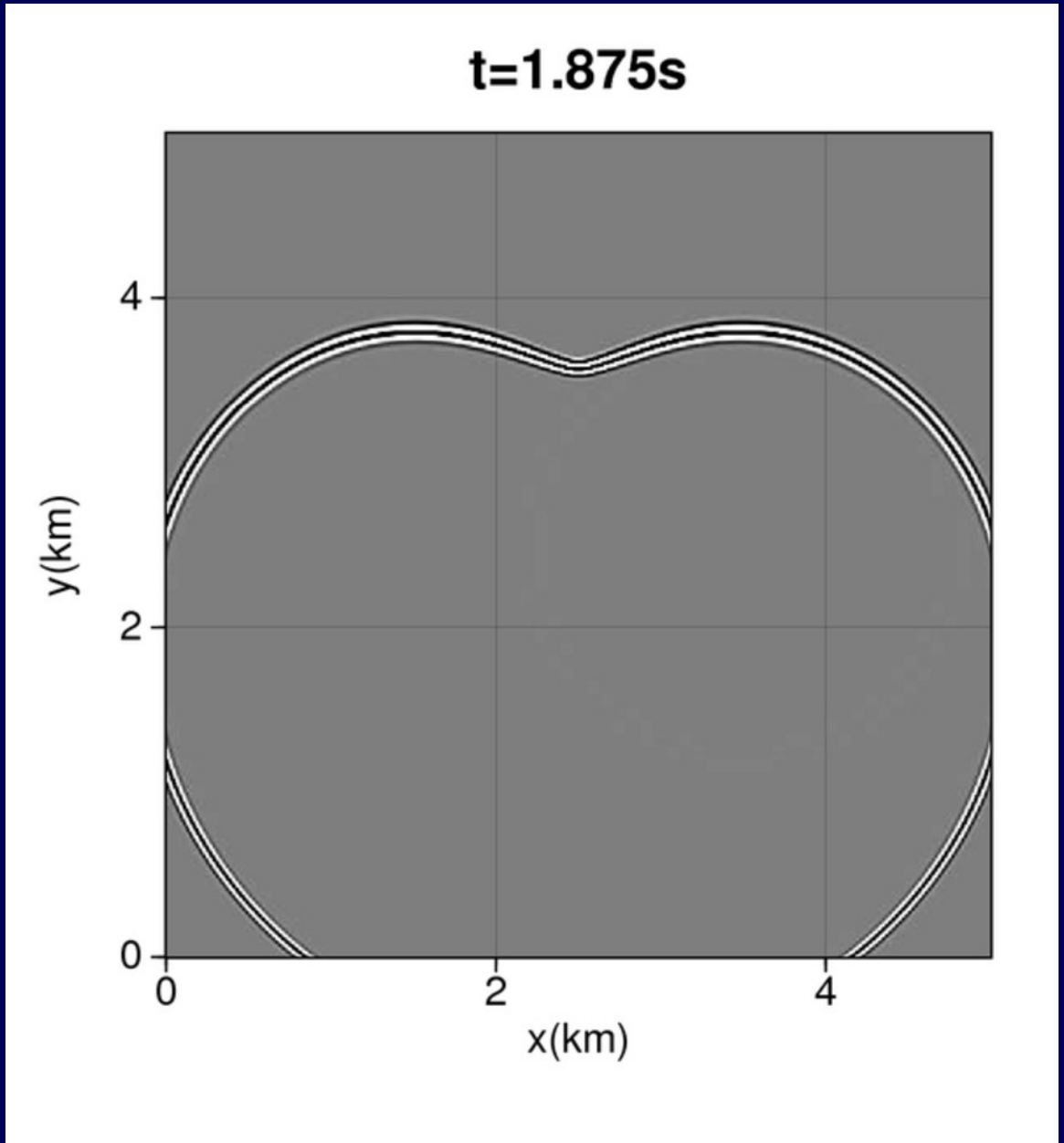
Curved edge diffractions – synthetic – dipping ellipse



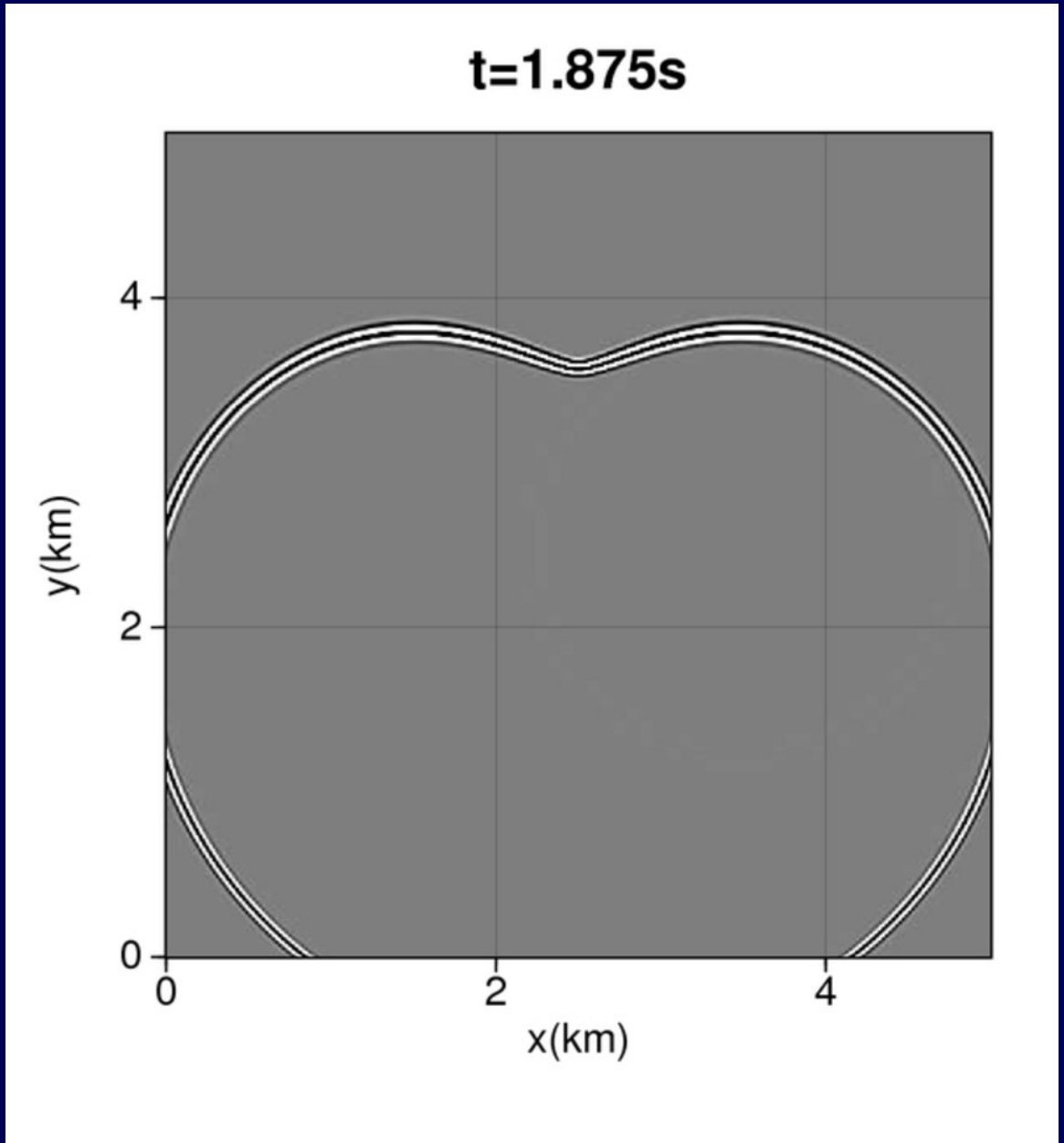
Curved edge diffractions – synthetic – dipping ellipse



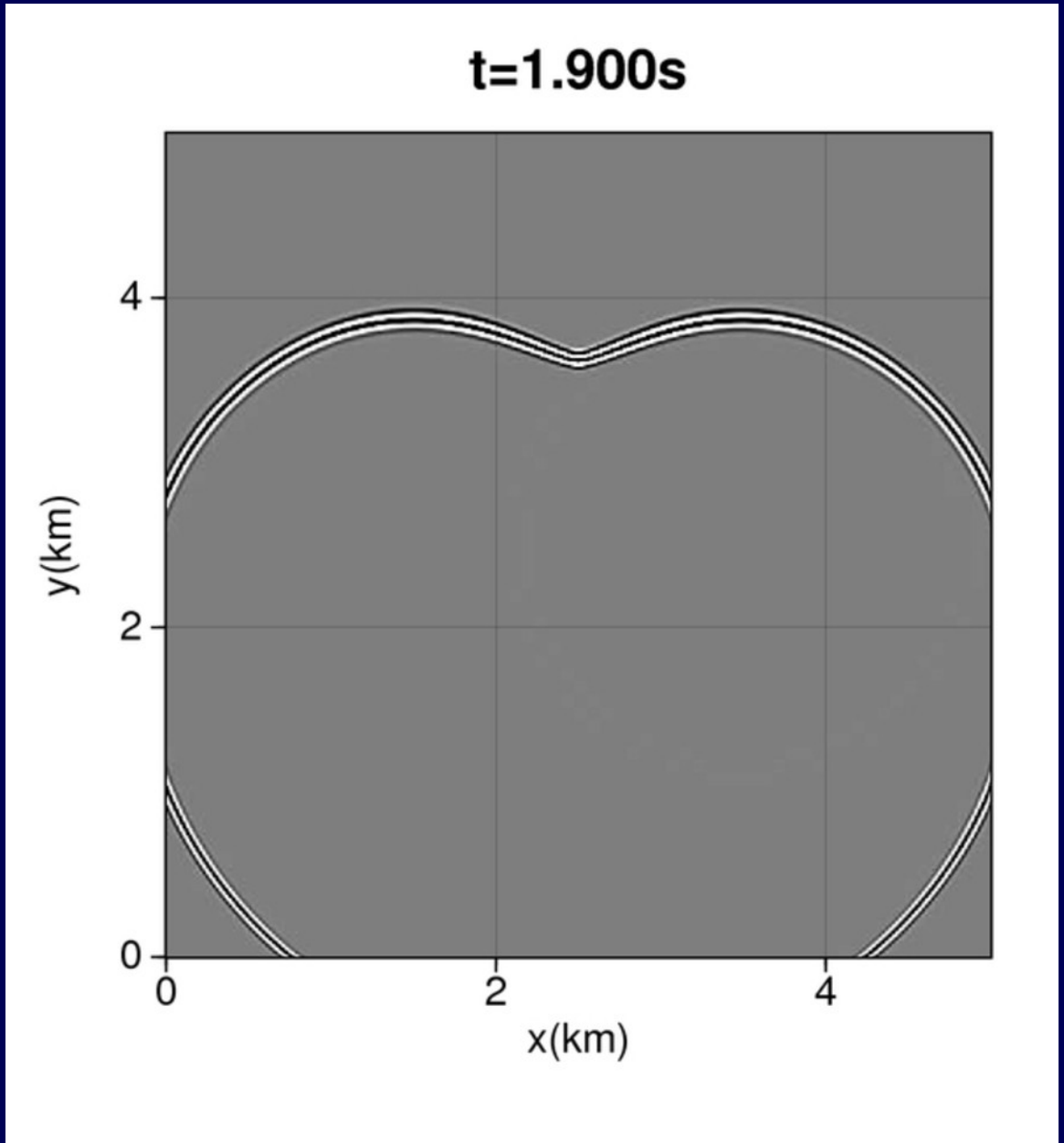
Curved edge diffractions – synthetic – dipping ellipse



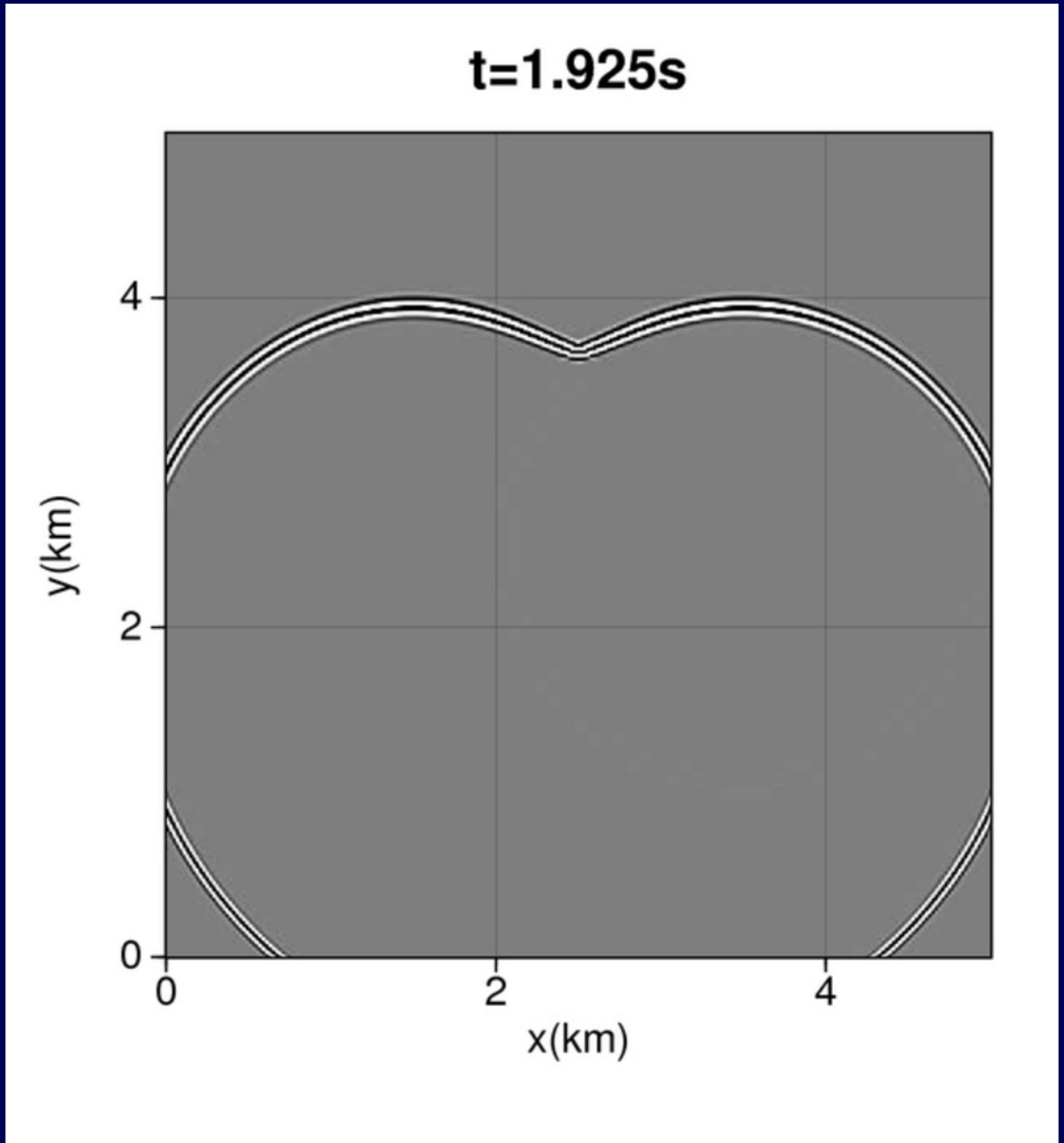
Curved edge diffractions – synthetic – dipping ellipse



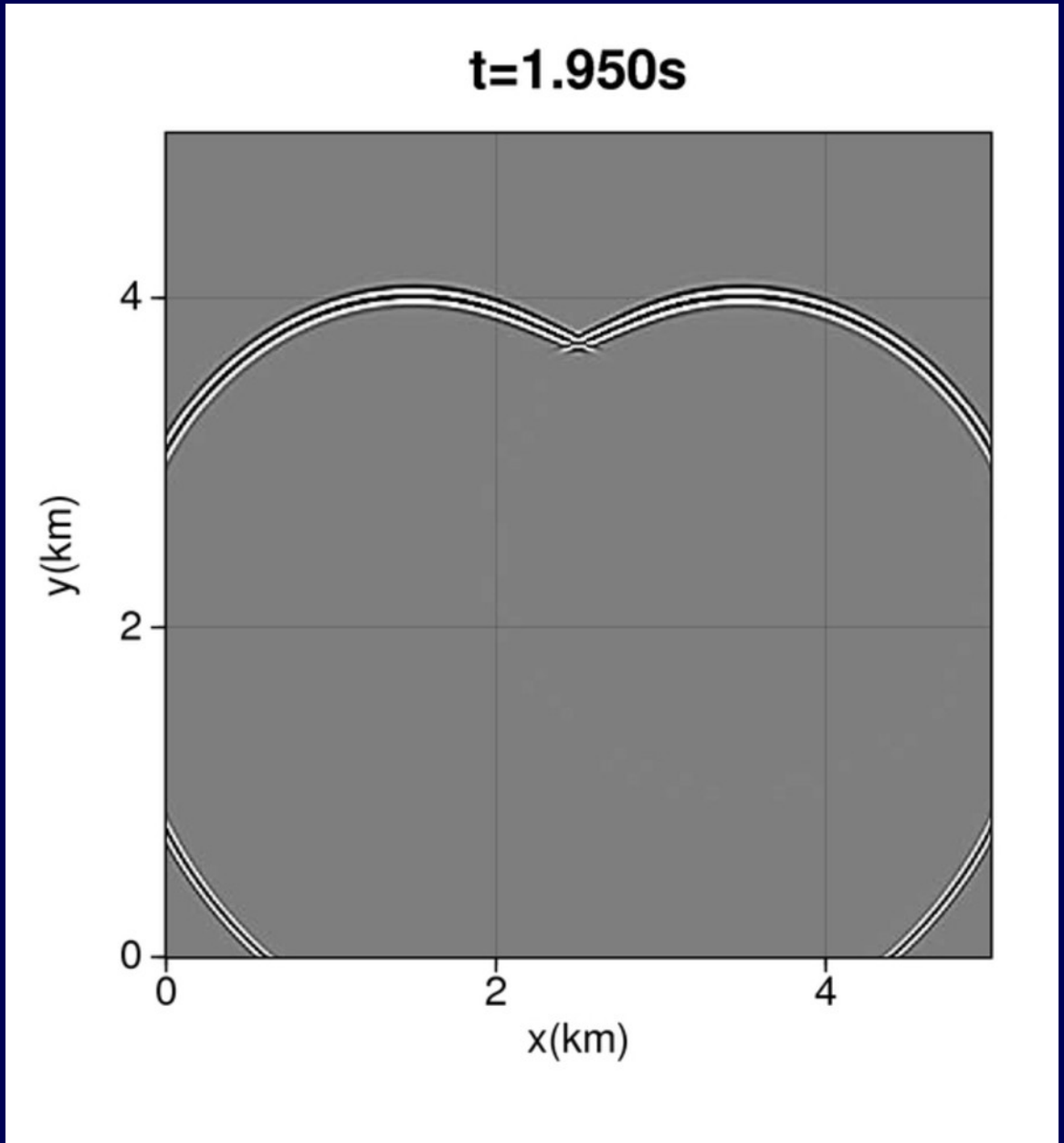
Curved edge diffractions – synthetic – dipping ellipse



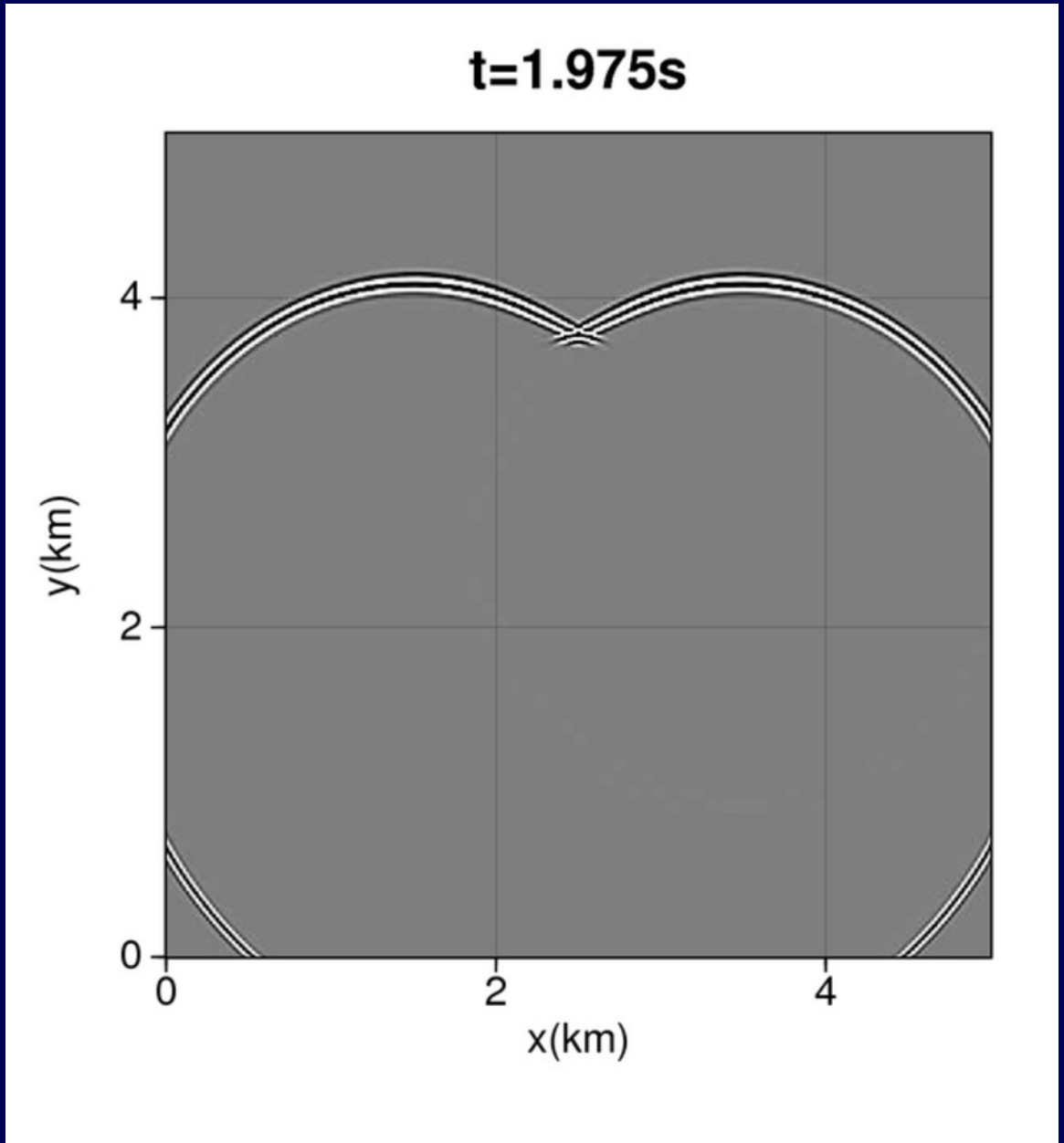
Curved edge diffractions – synthetic – dipping ellipse



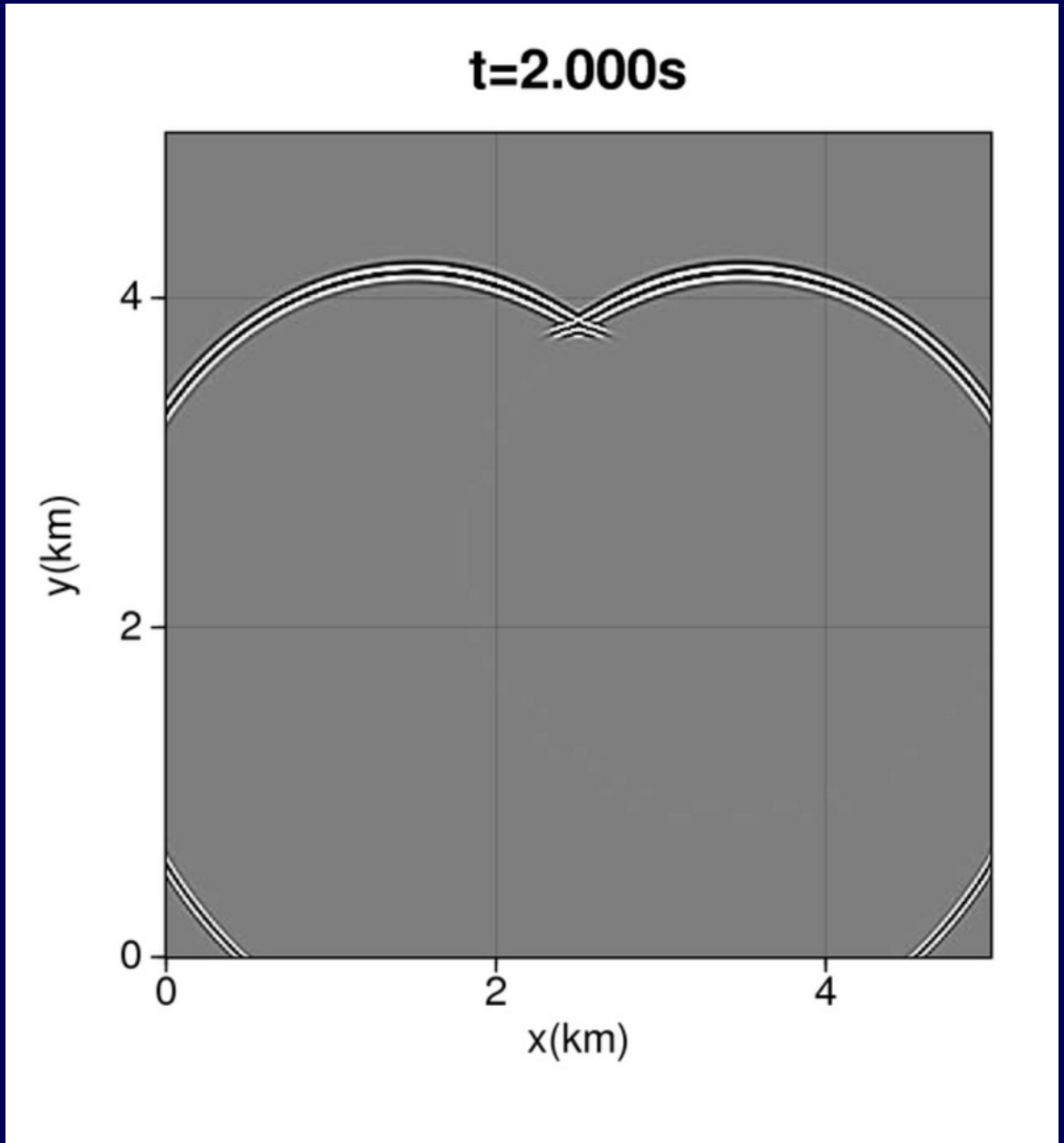
Curved edge diffractions – synthetic – dipping ellipse



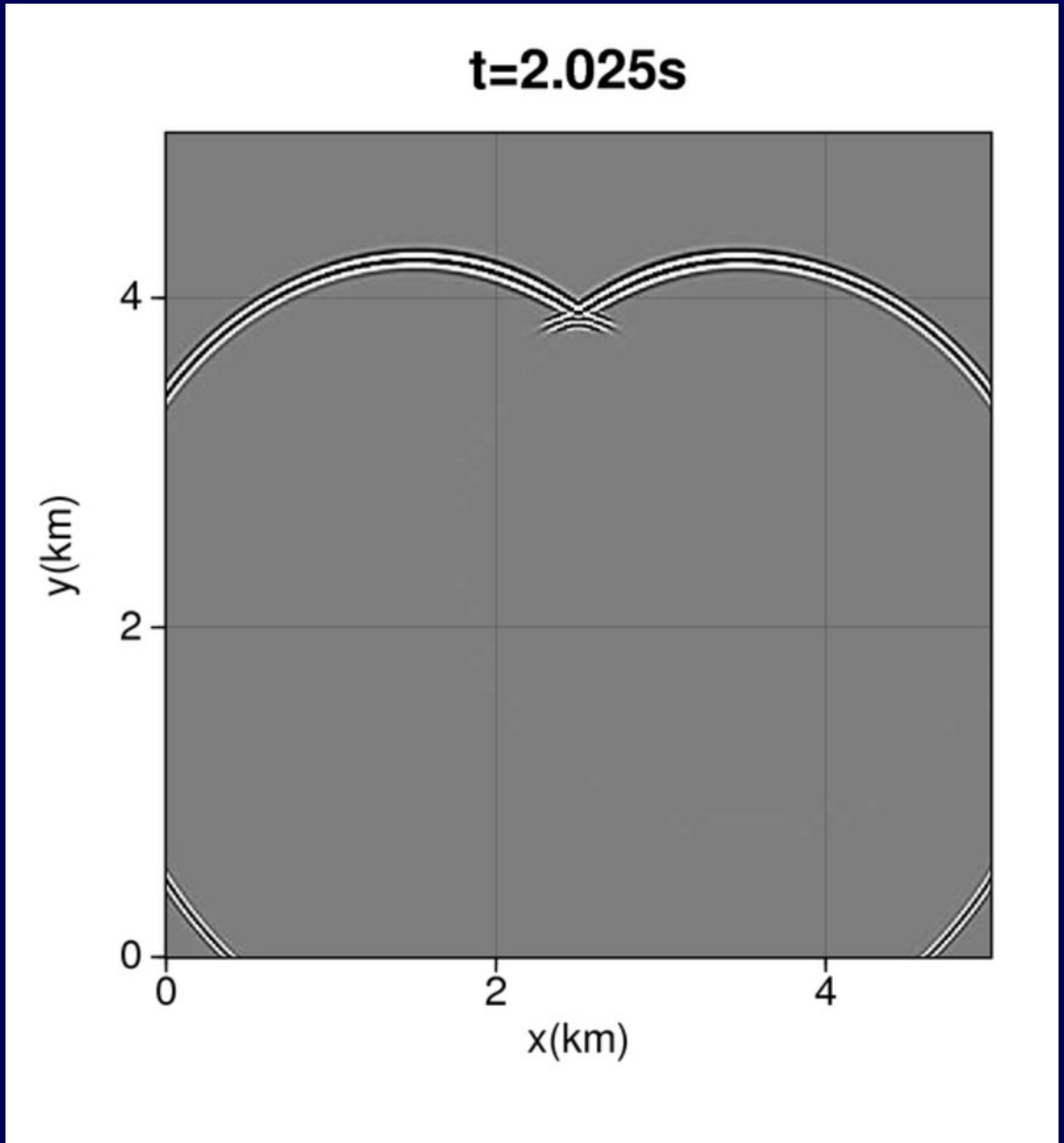
Curved edge diffractions – synthetic – dipping ellipse



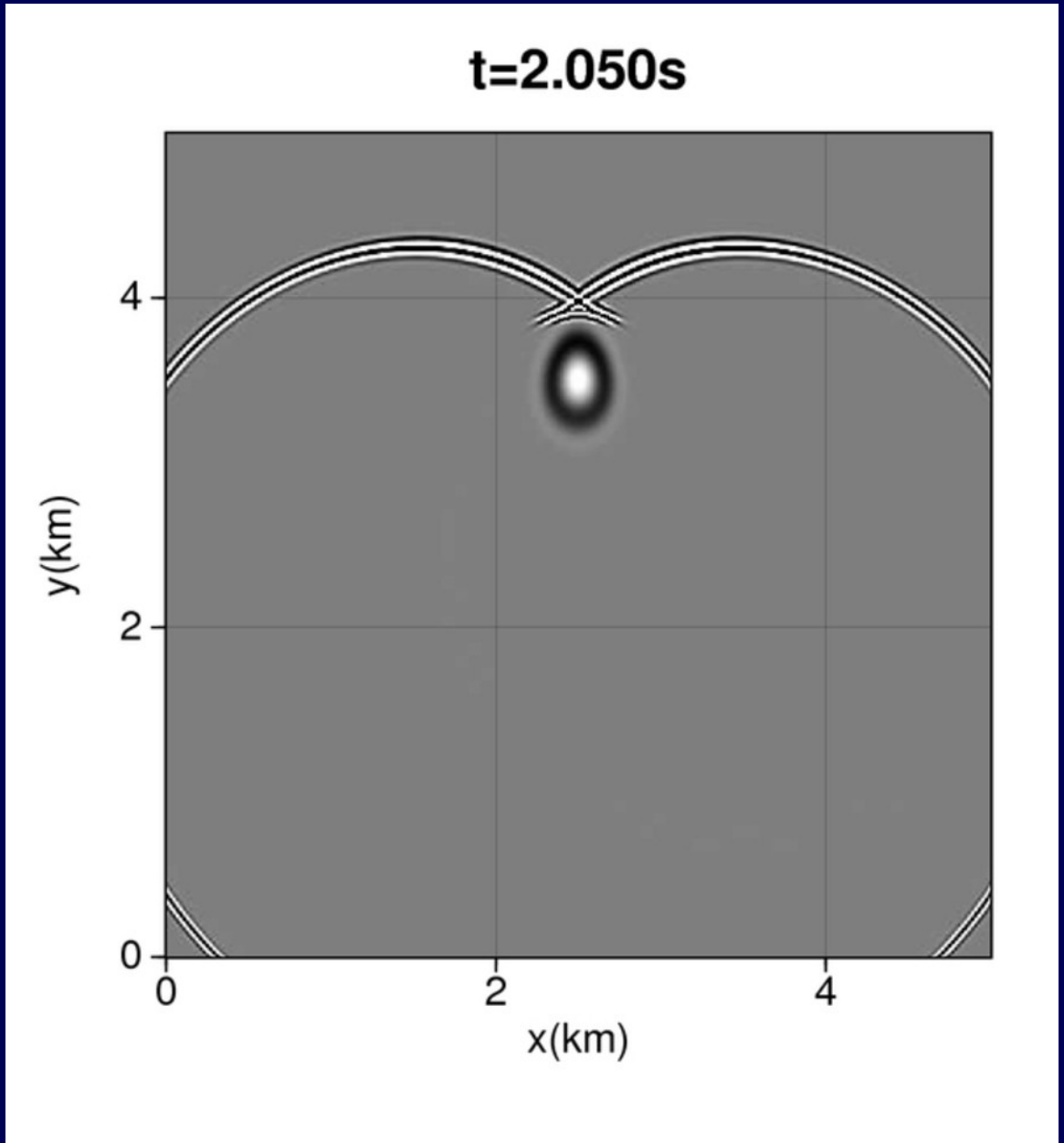
Curved edge diffractions – synthetic – dipping ellipse



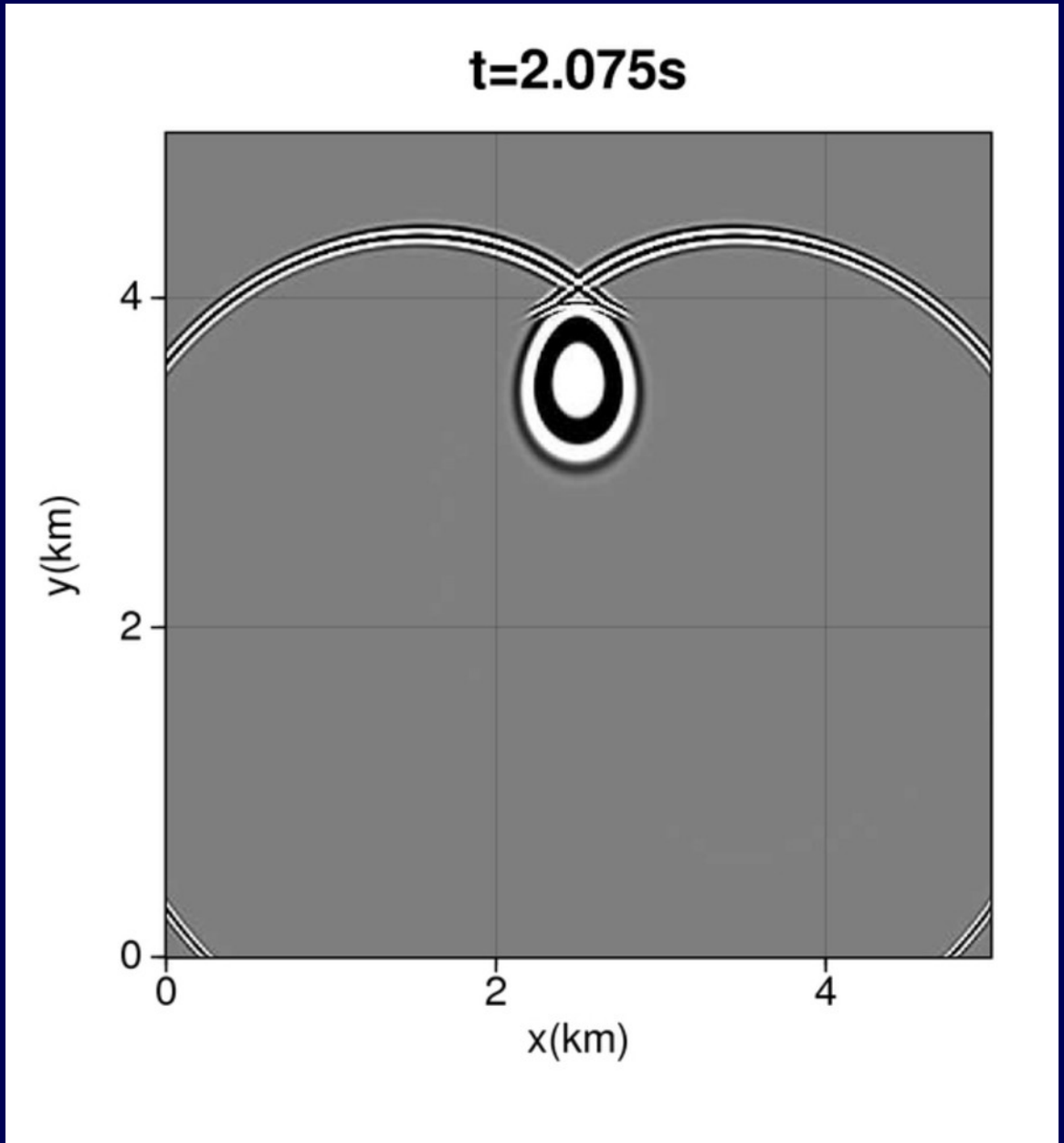
Curved edge diffractions – synthetic – dipping ellipse



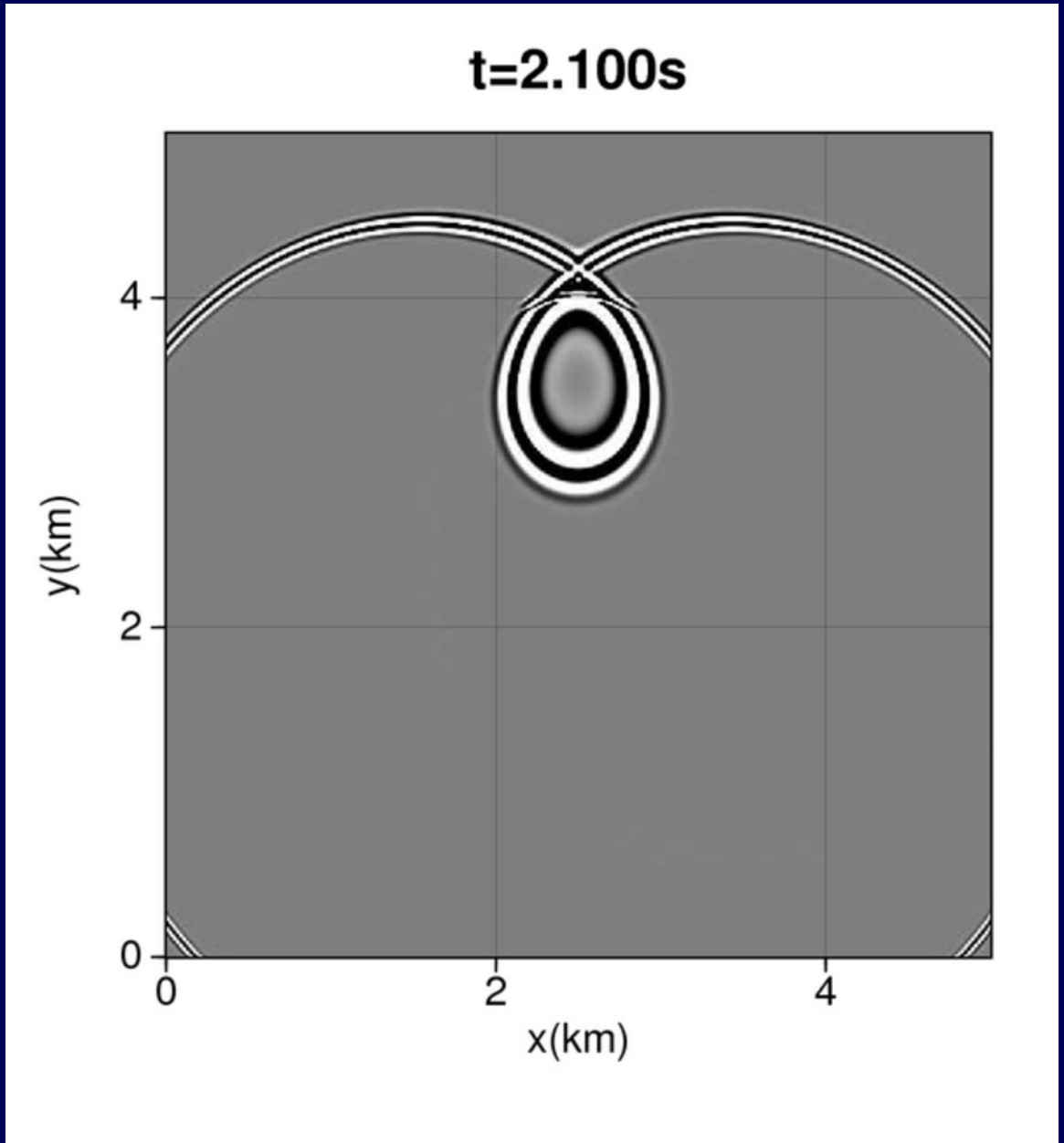
Curved edge diffractions – synthetic – dipping ellipse



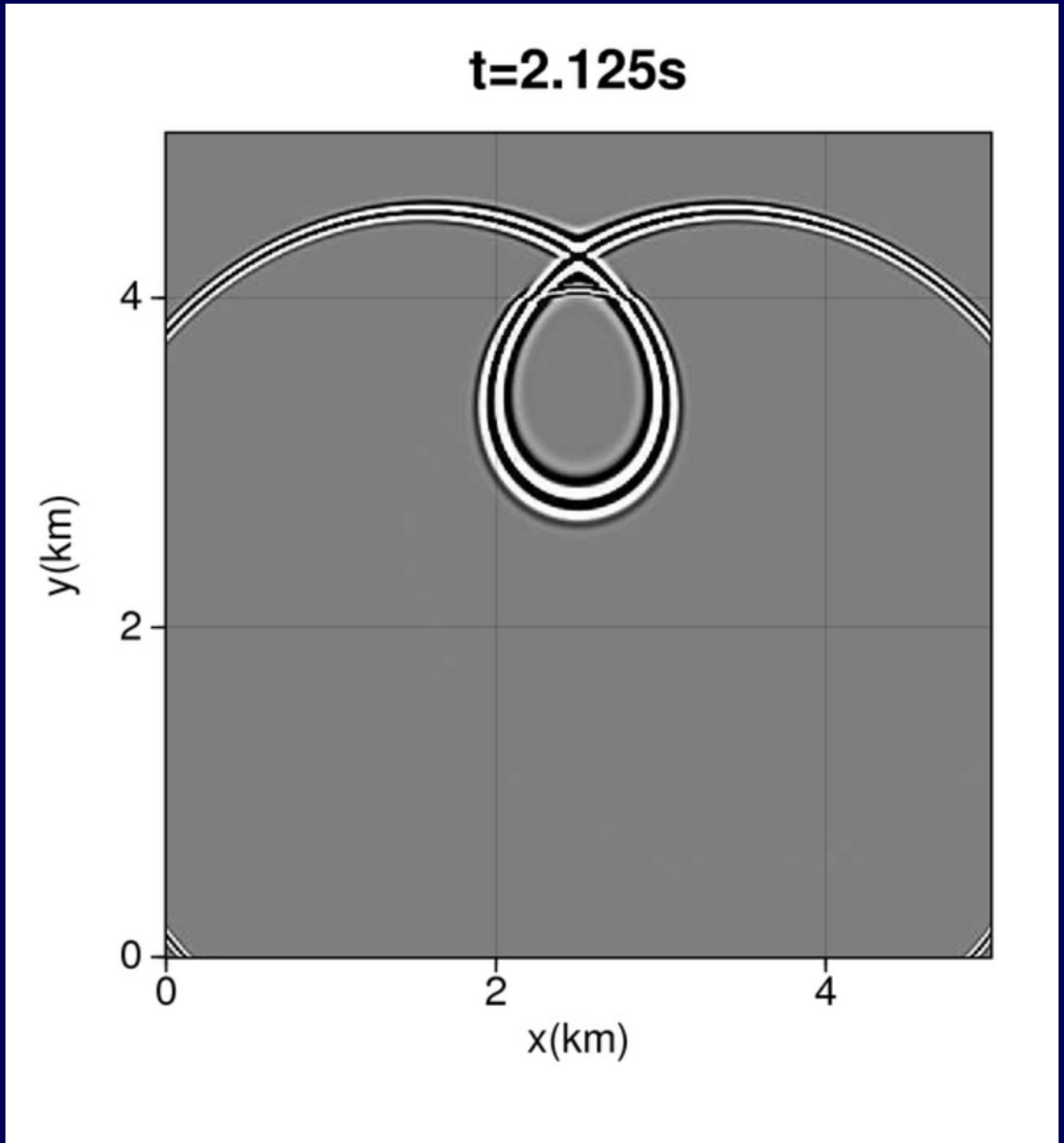
Curved edge diffractions – synthetic – dipping ellipse



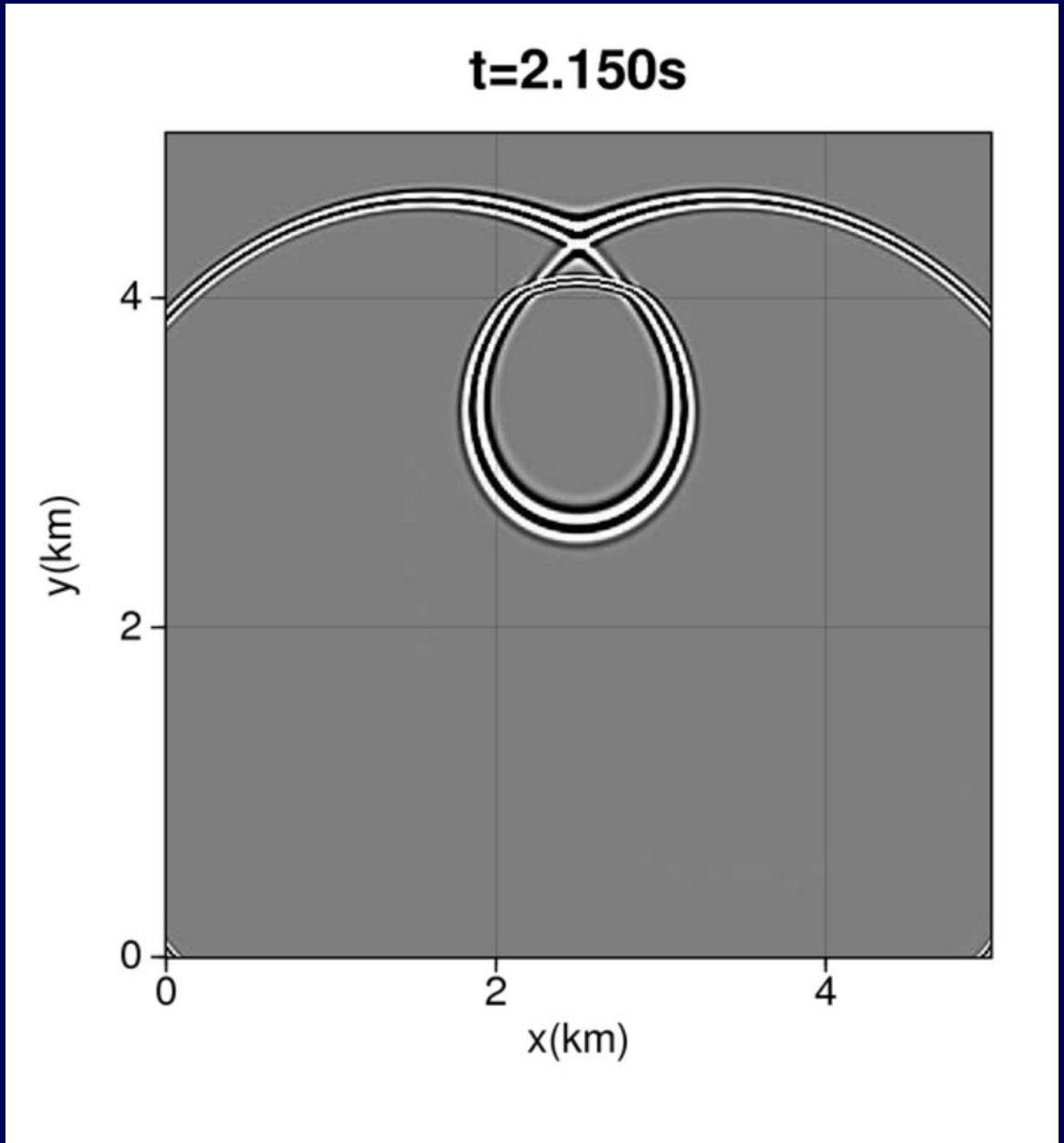
Curved edge diffractions – synthetic – dipping ellipse



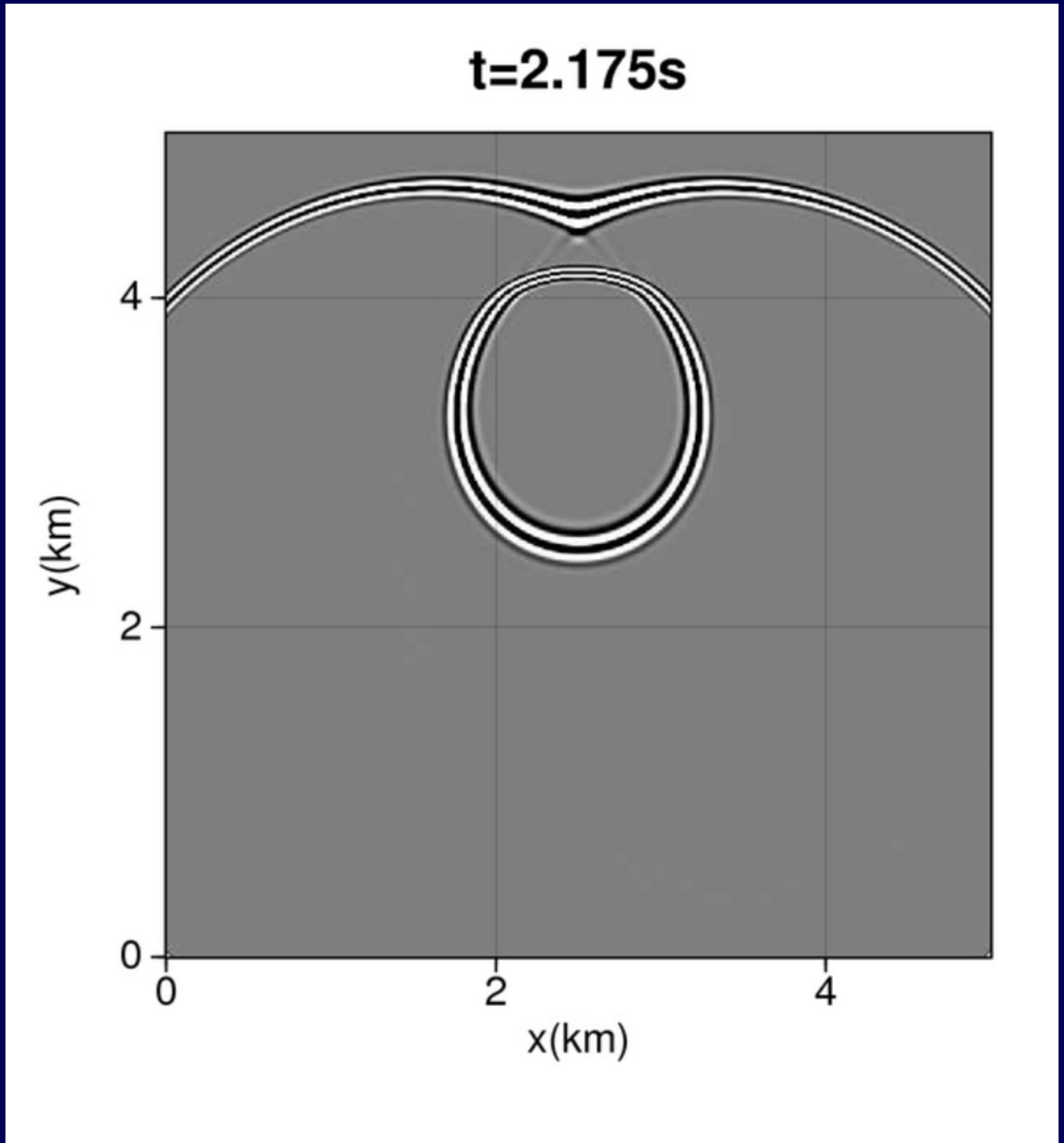
Curved edge diffractions – synthetic – dipping ellipse



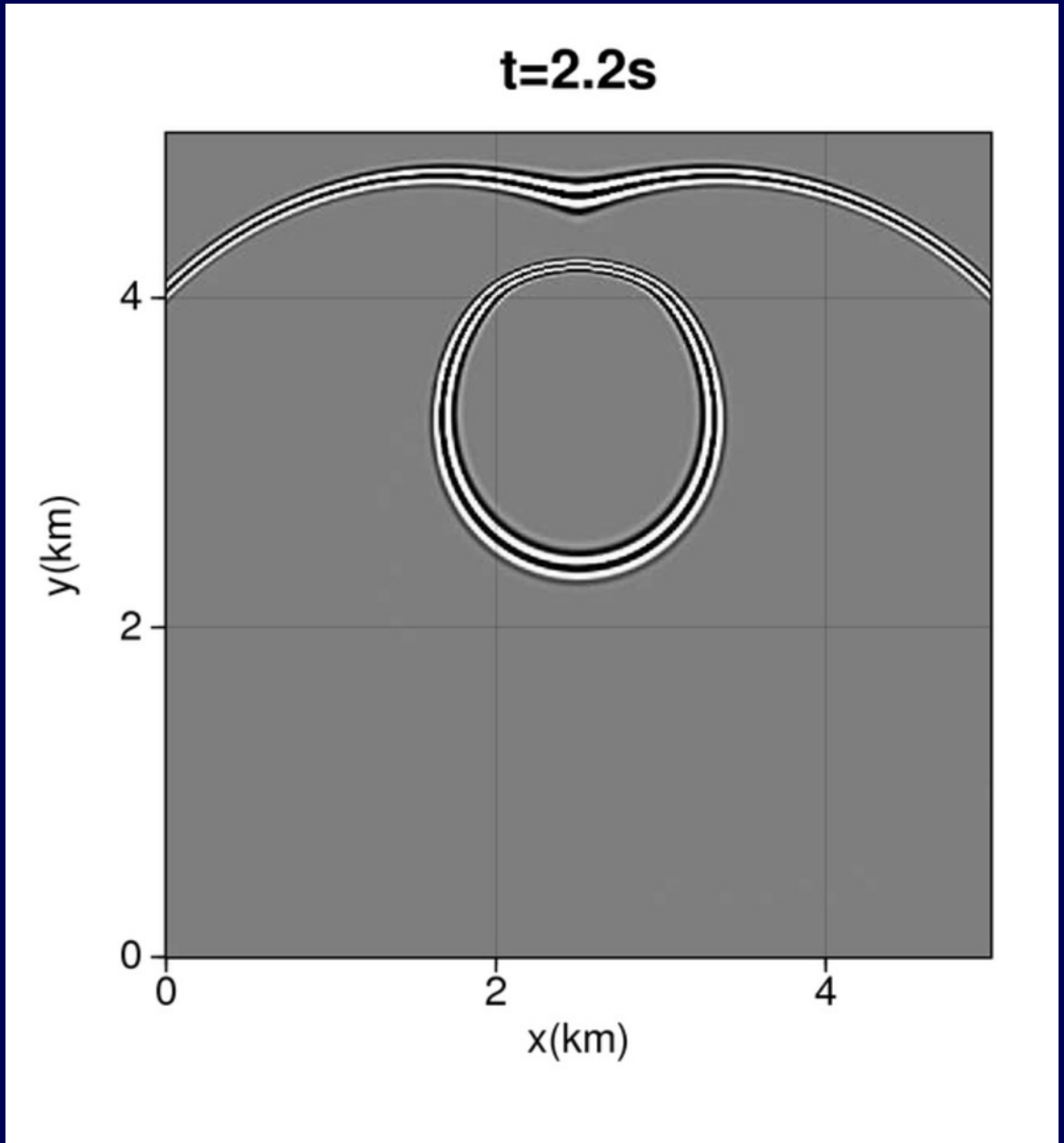
Curved edge diffractions – synthetic – dipping ellipse



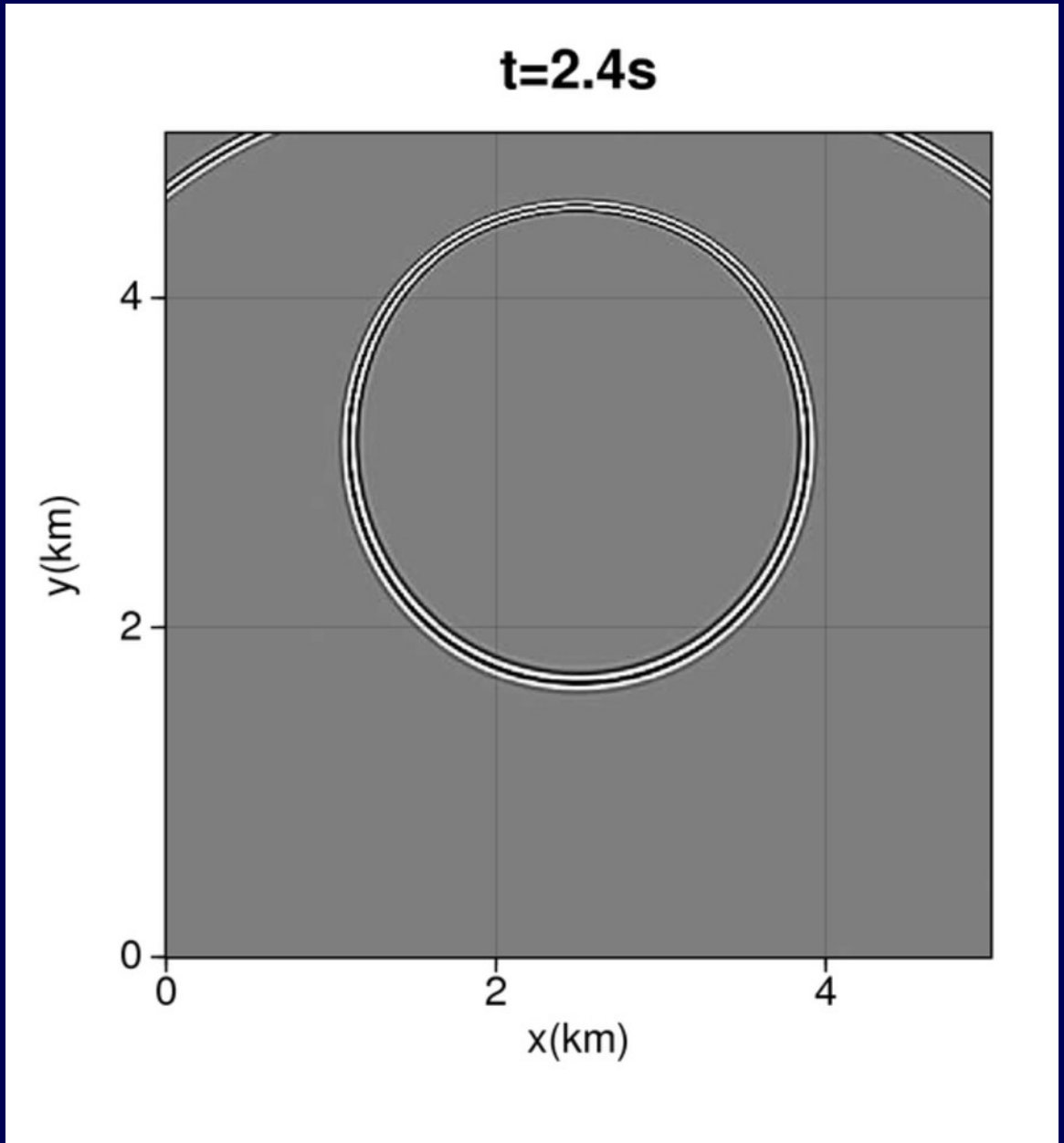
Curved edge diffractions – synthetic – dipping ellipse



Curved edge diffractions – synthetic – dipping ellipse



Curved edge diffractions – synthetic – dipping ellipse



Curved edge diffractions – analytic

Envelope of diffraction hyperboloids

Consider a 3D line diffractor given by the curve

$$\mathbf{x}(q) = (x_1(q), x_2(q), x_3(q))^T \ , \tag{1}$$

where q is a parameter along the curve and $\mathbf{x}$ the spatial location. We assume a constant model with velocity equal to one. Then, point diffraction surfaces at each point q are given by the hyperboloids

$$\mathbf{h}(u,v,q) = \begin{bmatrix} h_1(u,v,q) \\ h_2(u,v,q) \\ h_3(u,v,q) \end{bmatrix} = \begin{bmatrix} x_1(q) + u \\ x_2(q) + v \\ \sqrt{u^2 + v^2 + x_3(q)^2} \end{bmatrix} \ . \tag{2}$$

In (2), u, v are parameters pointing in x_1, x_2-direction. The apices of the hyperboloids are located at the line diffractor: $\mathbf{h}(0,0,q) = \mathbf{x}(q)$.

$\mathbf{h}(u,v,q)$ is a one-parameter family of 3D surfaces for parameter q. Its envelope is given by combinations of u, v, q satisfying

$$\det[\mathbf{h}_u \ \mathbf{h}_v \ \mathbf{h}_q] = 0 \ . \tag{3}$$

Curved edge diffractions – analytic

Envelope of diffraction hyperboloids

Expanding (3) gives

$$0 = \det[\mathbf{h}_u\ \mathbf{h}_v\ \mathbf{h}_q] = \det\begin{vmatrix} h_{1u} & h_{1v} & h_{1q} \\ h_{2u} & h_{2v} & h_{2q} \\ h_{3u} & h_{3v} & h_{3q} \end{vmatrix} = \det\begin{vmatrix} 1 & 0 & x_1' \\ 0 & 1 & x_2' \\ u/h_3 & v/h_3 & x_3 x_3'/h_3 \end{vmatrix}$$

$$= (x_3 x_3' - v x_2' - u x_1')/h_3 \ , \tag{4}$$

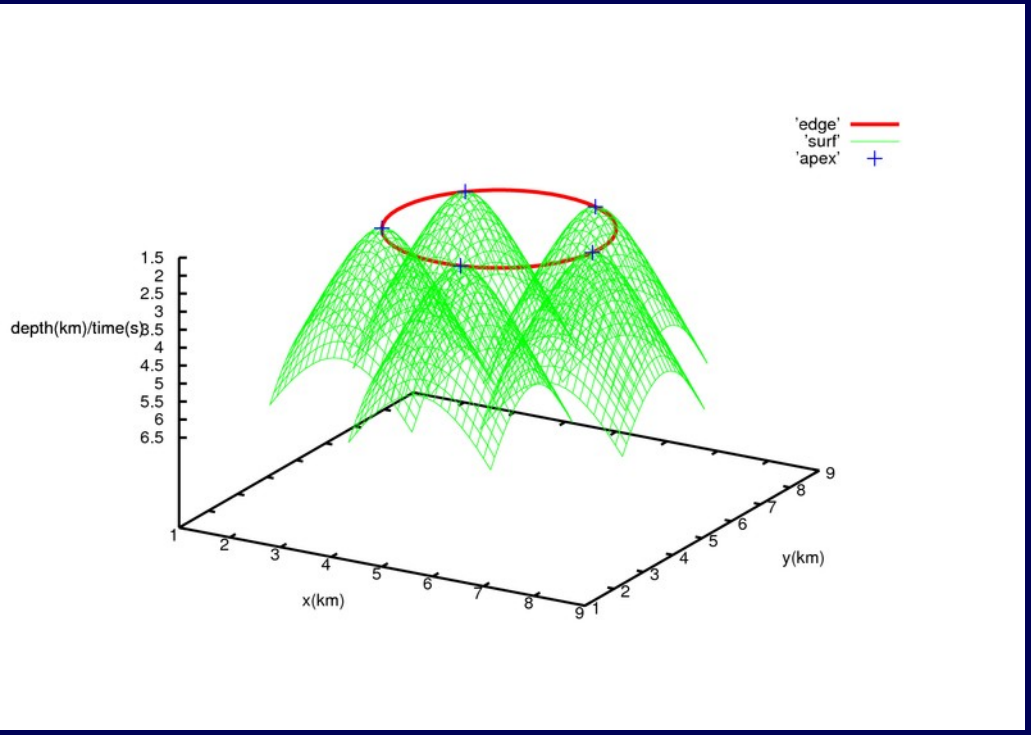
where $x_i' = \mathrm{d}x_i/\mathrm{d}q$ $(i = 1, 2, 3)$. Therefore for fixed q, (3) is a line in the u, v-plane. By parametrizing it as

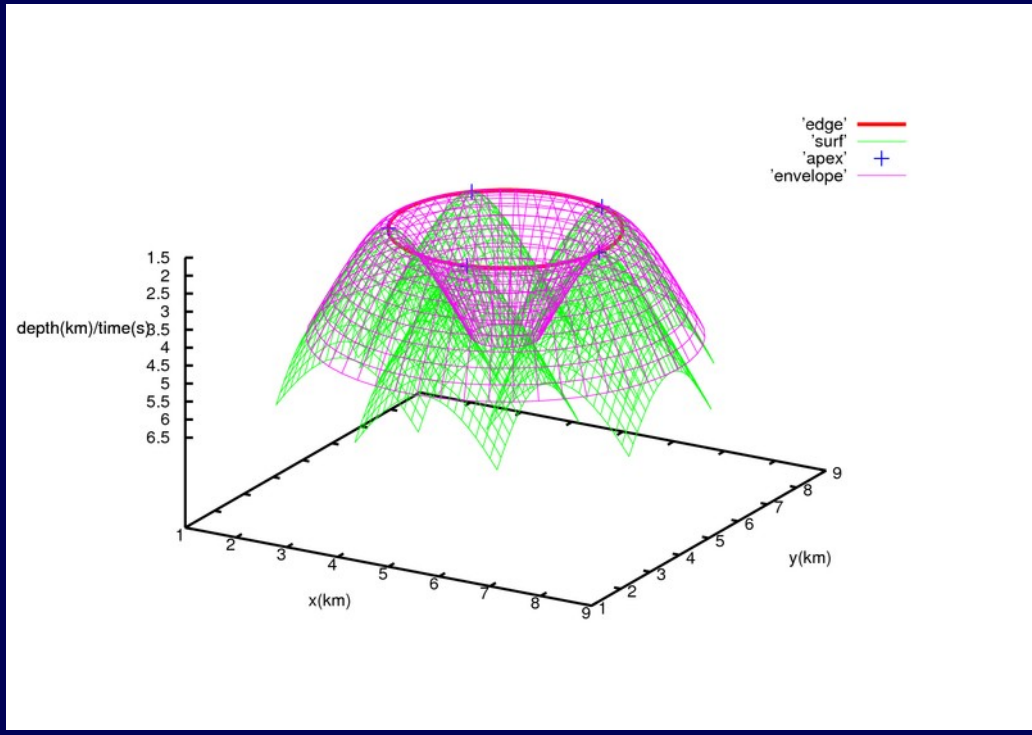
$$u(w) = x_1' x_3 x_3'/x_n + w x_2' \ , \quad v(w) = x_2' x_3 x_3'/x_n - w x_1' \ , \quad x_n = {x_1'}^2 + {x_2'}^2, \tag{5}$$

the line diffraction surface is given by $\mathbf{h}(u(w), v(w), q)$ and (5).

For a fixed q, $\mathbf{h}(u(w), v(w), q)$ is a hyperbola as function of w. For a horizontal line diffractor, $x_3' = 0$, and the hyperbola has its apex $w = 0$ on the diffraction line. For a dipping line diffractor this is not the case.

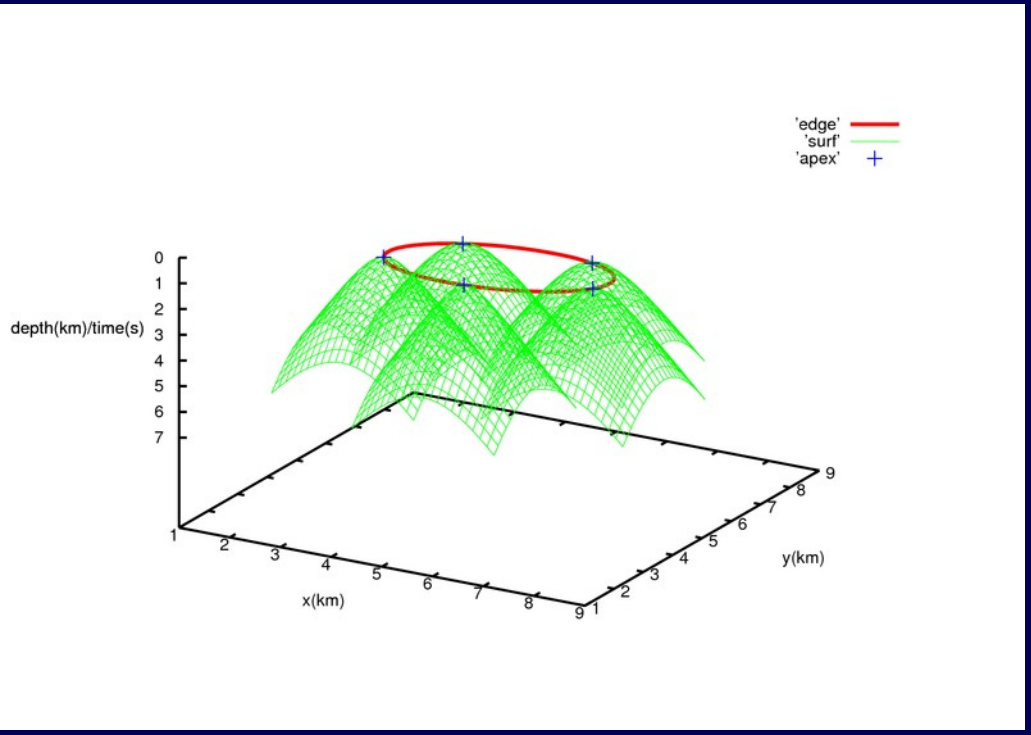
Curved edge diffractions – analytic

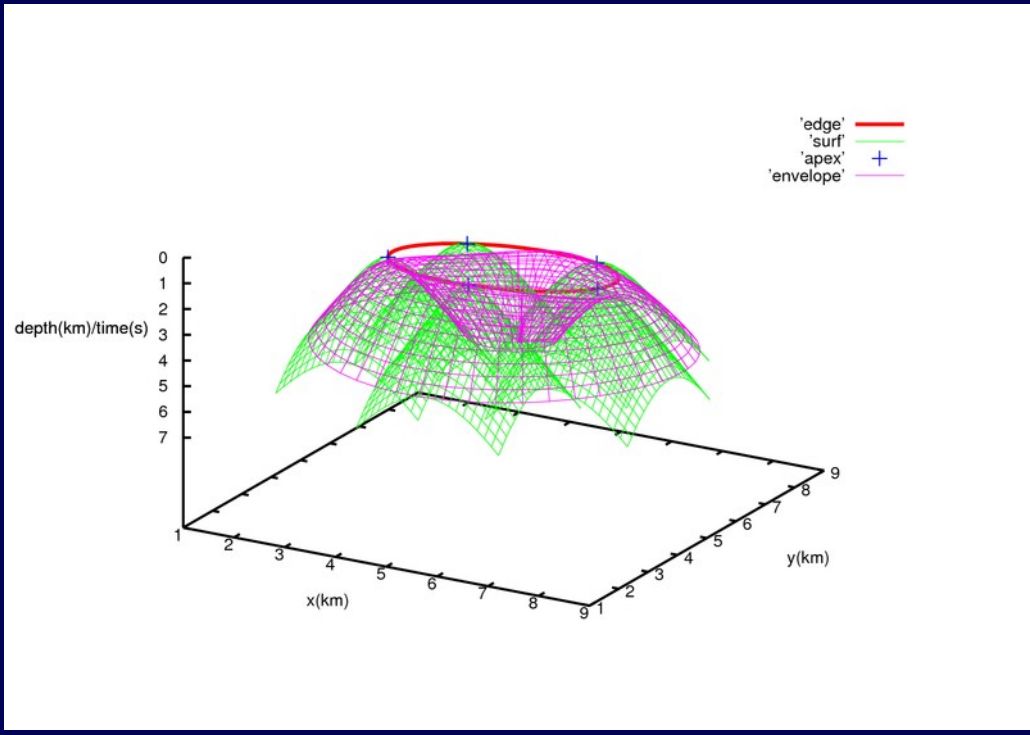




Flat circular edge

Curved edge diffractions – analytic

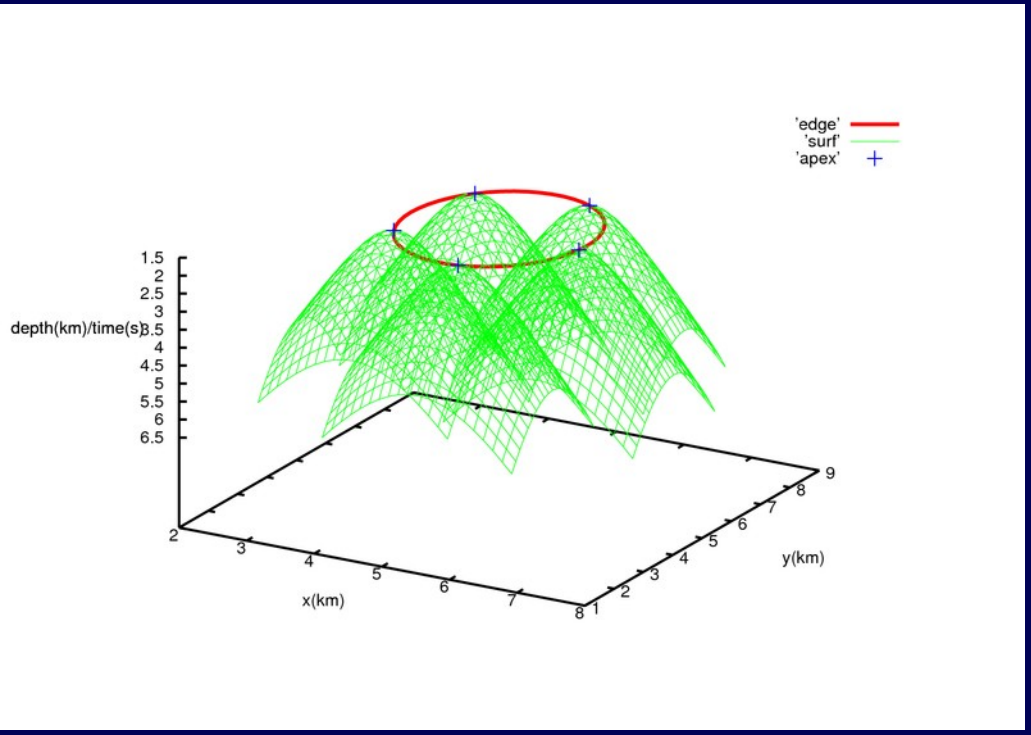


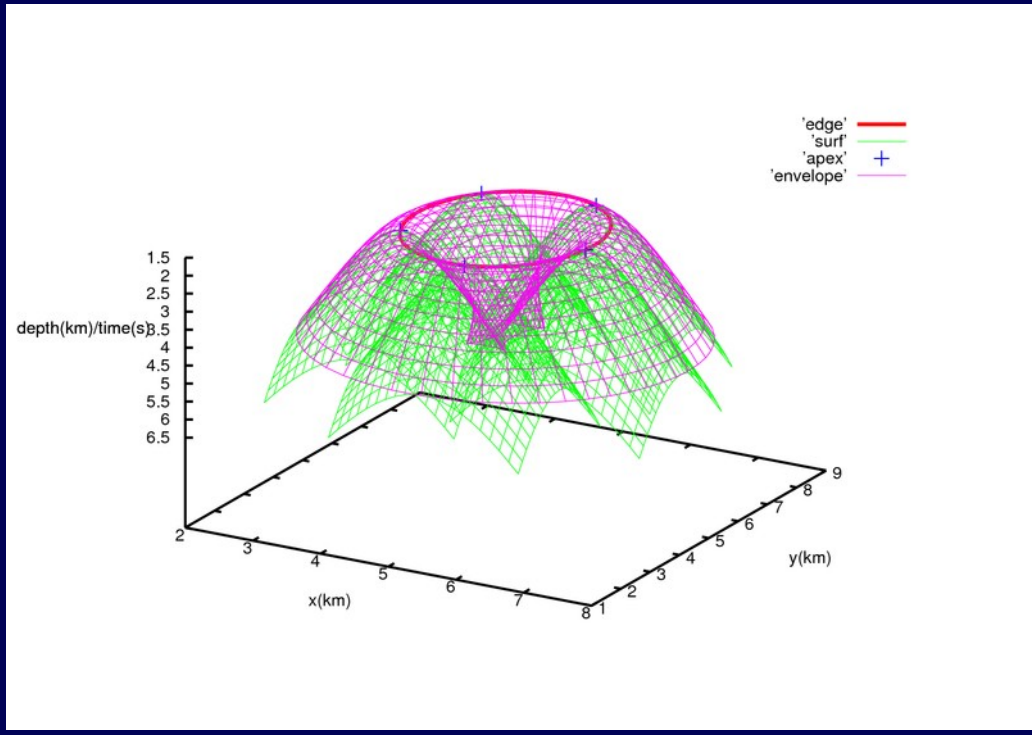


Note: envelope does not contain diffractor

Dipping circular edge

Curved edge diffractions – analytic

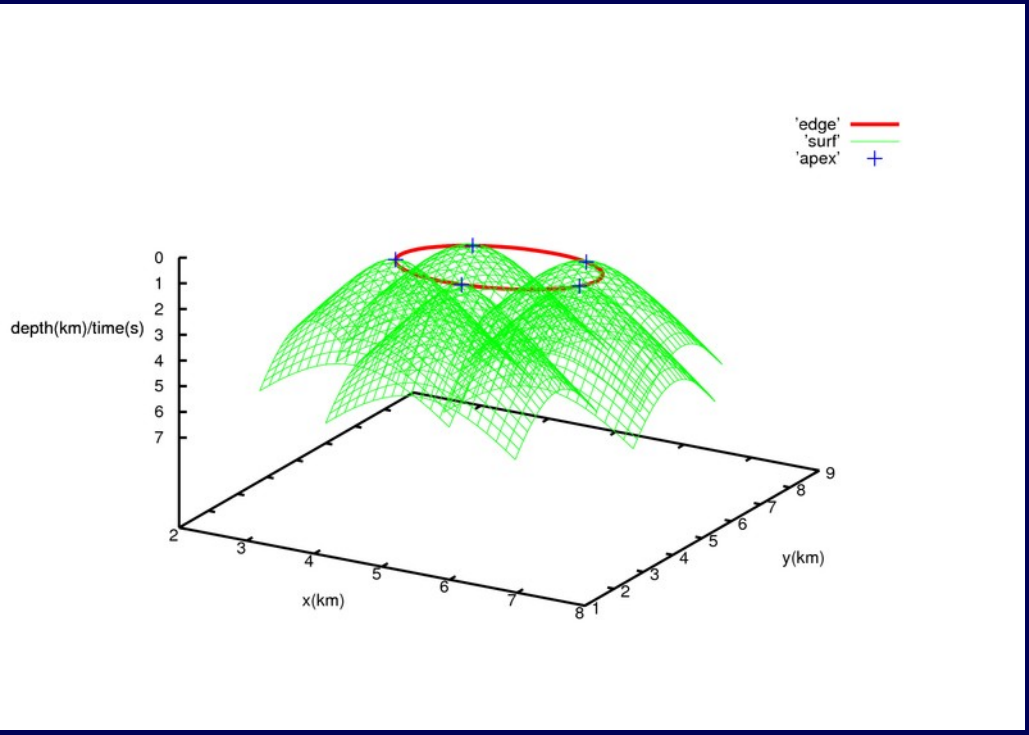


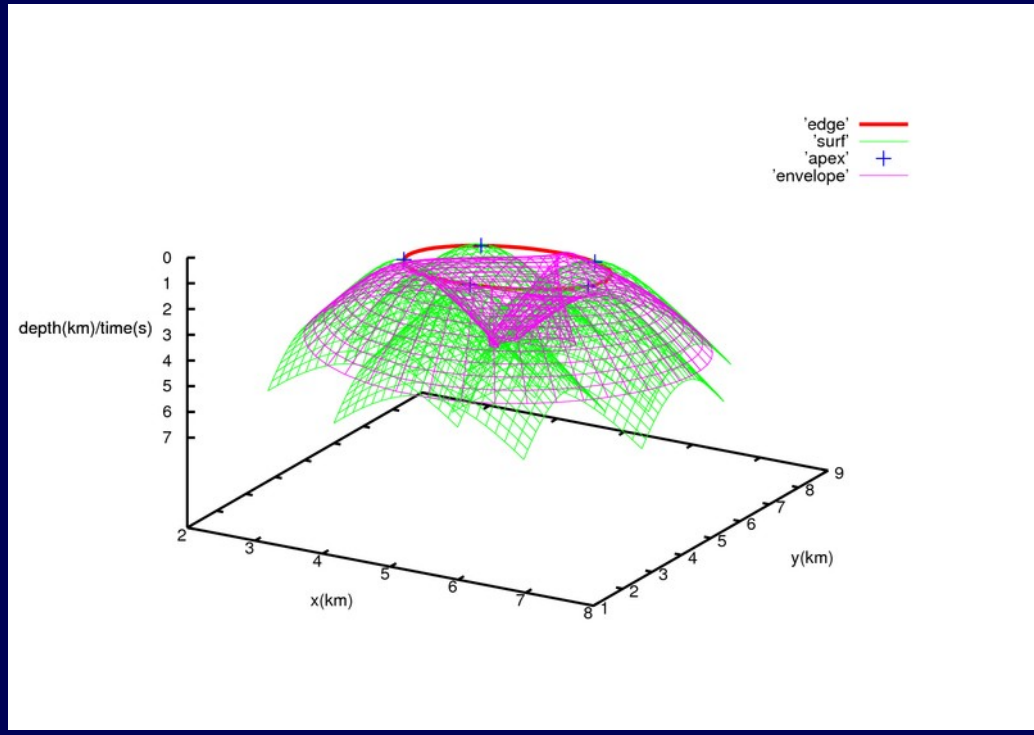


Note: caustics

Flat elliptical edge

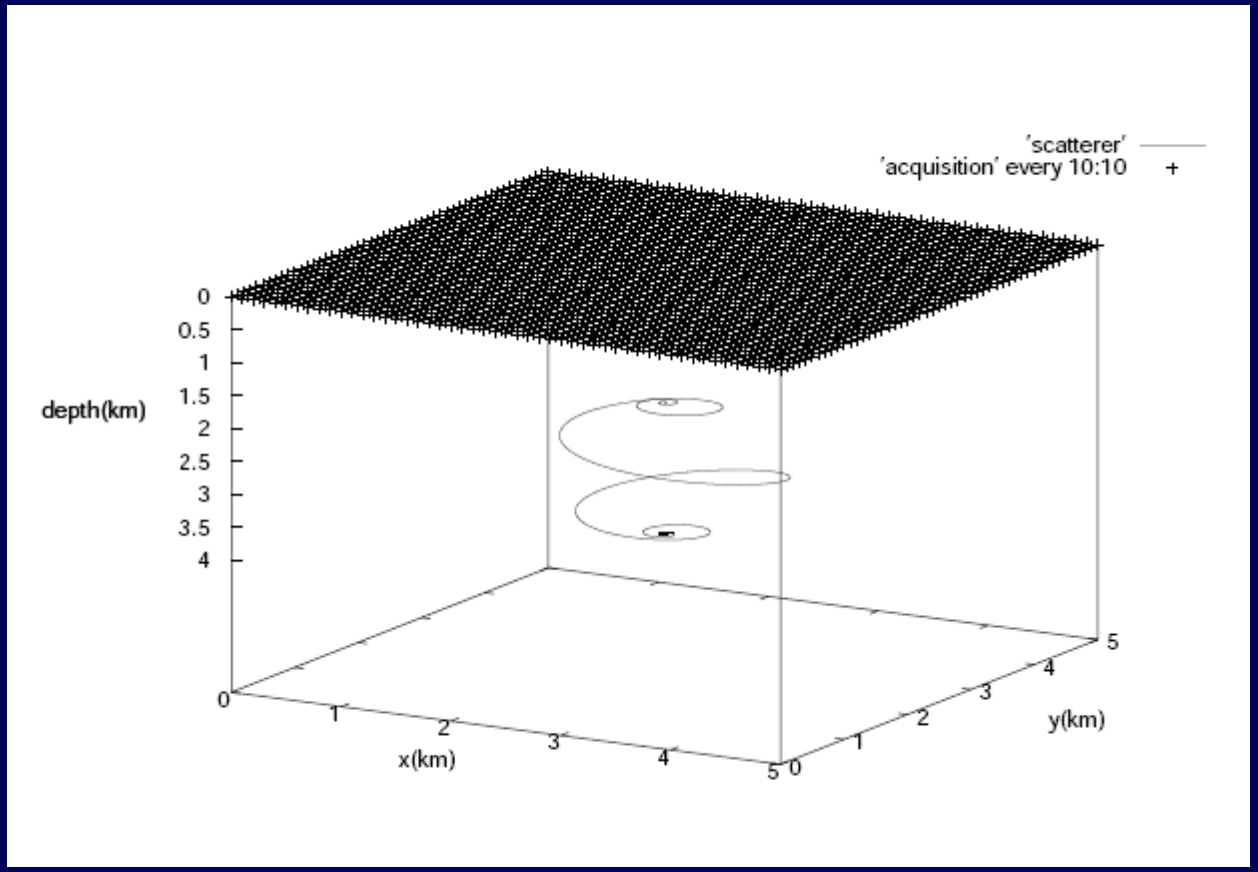
Curved edge diffractions – analytic





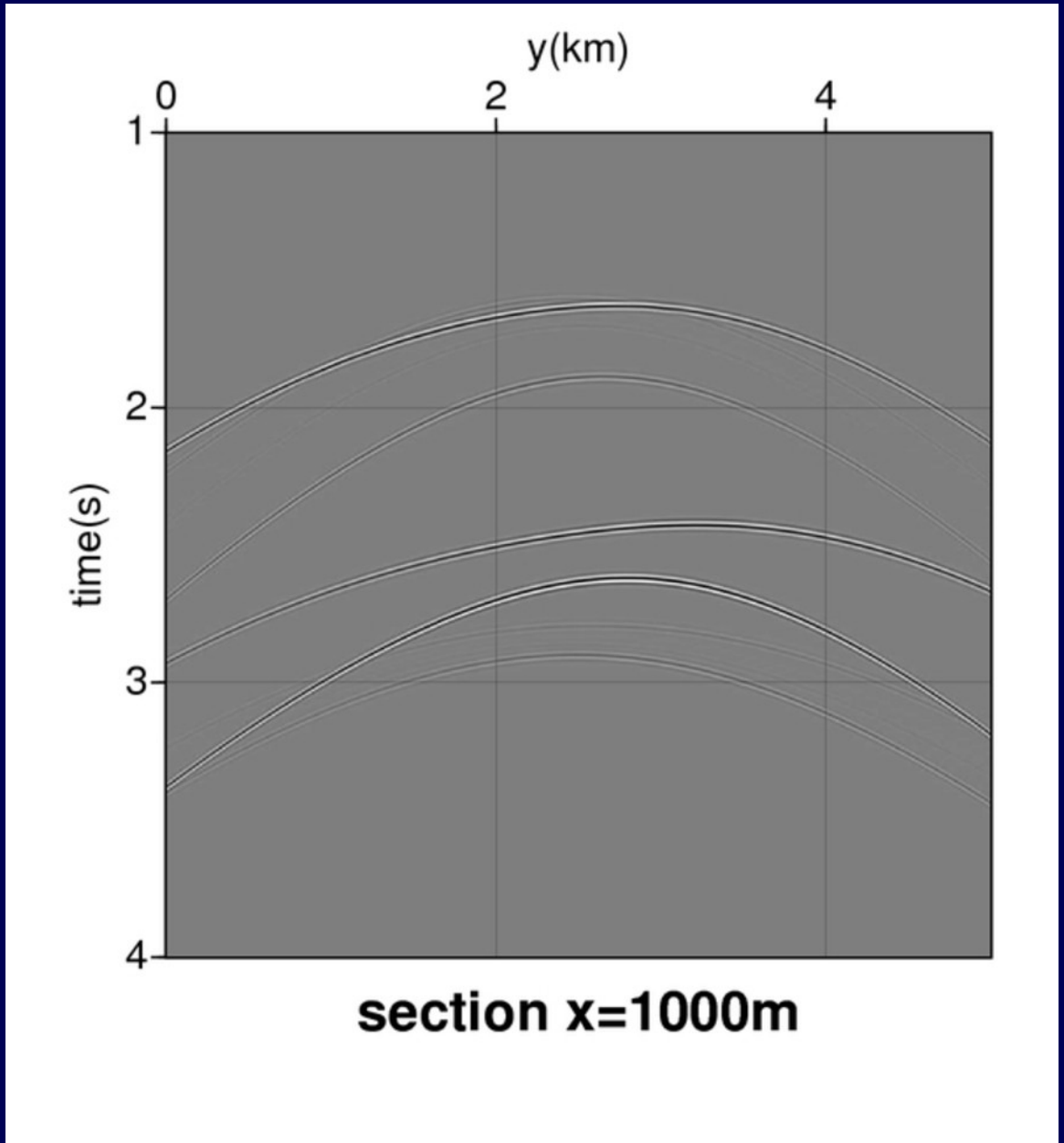
Dipping elliptical edge

Curved edge diffractions – synthetic – spherical spiral

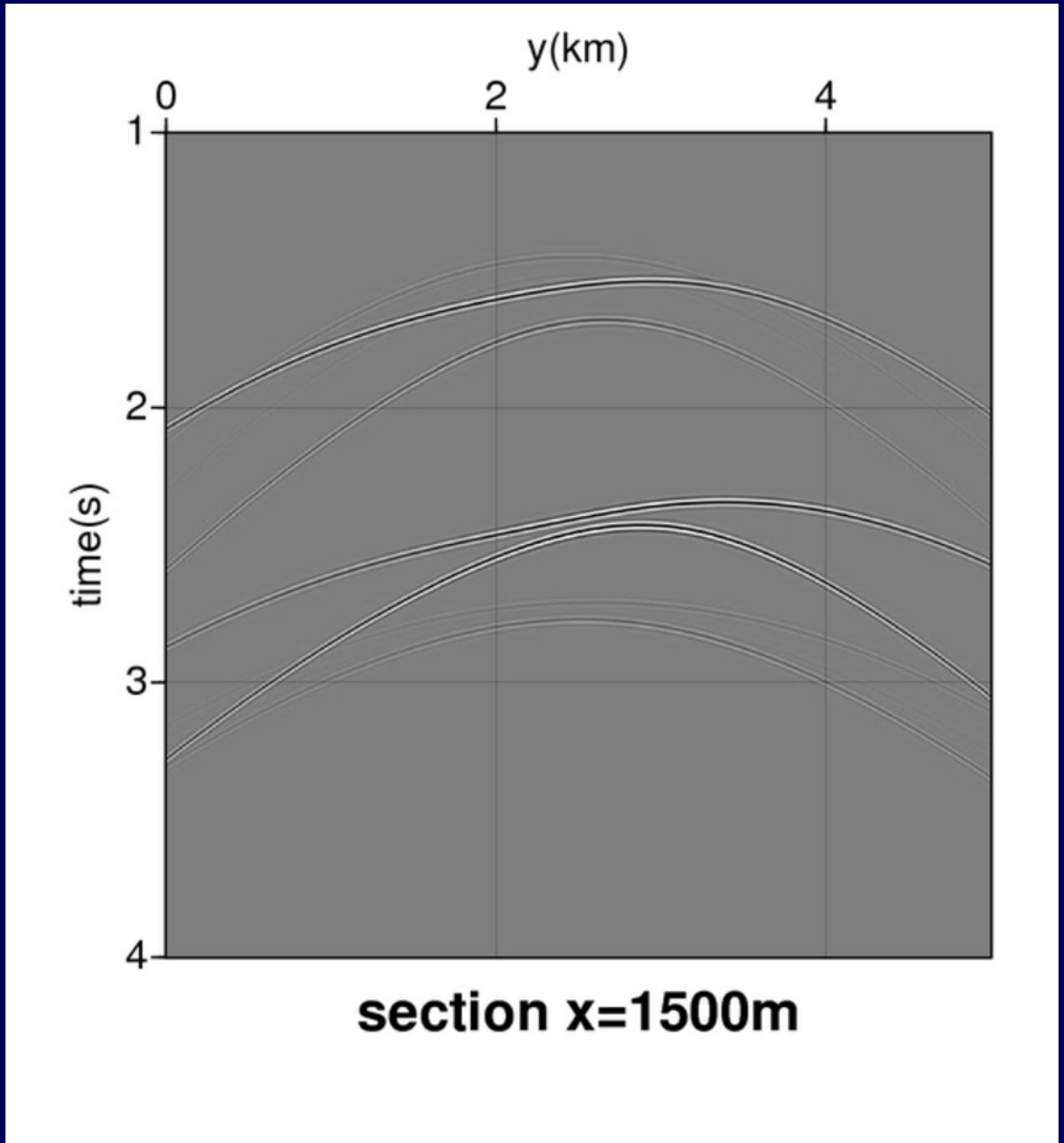


Curvature going to infinity + introducing torsion

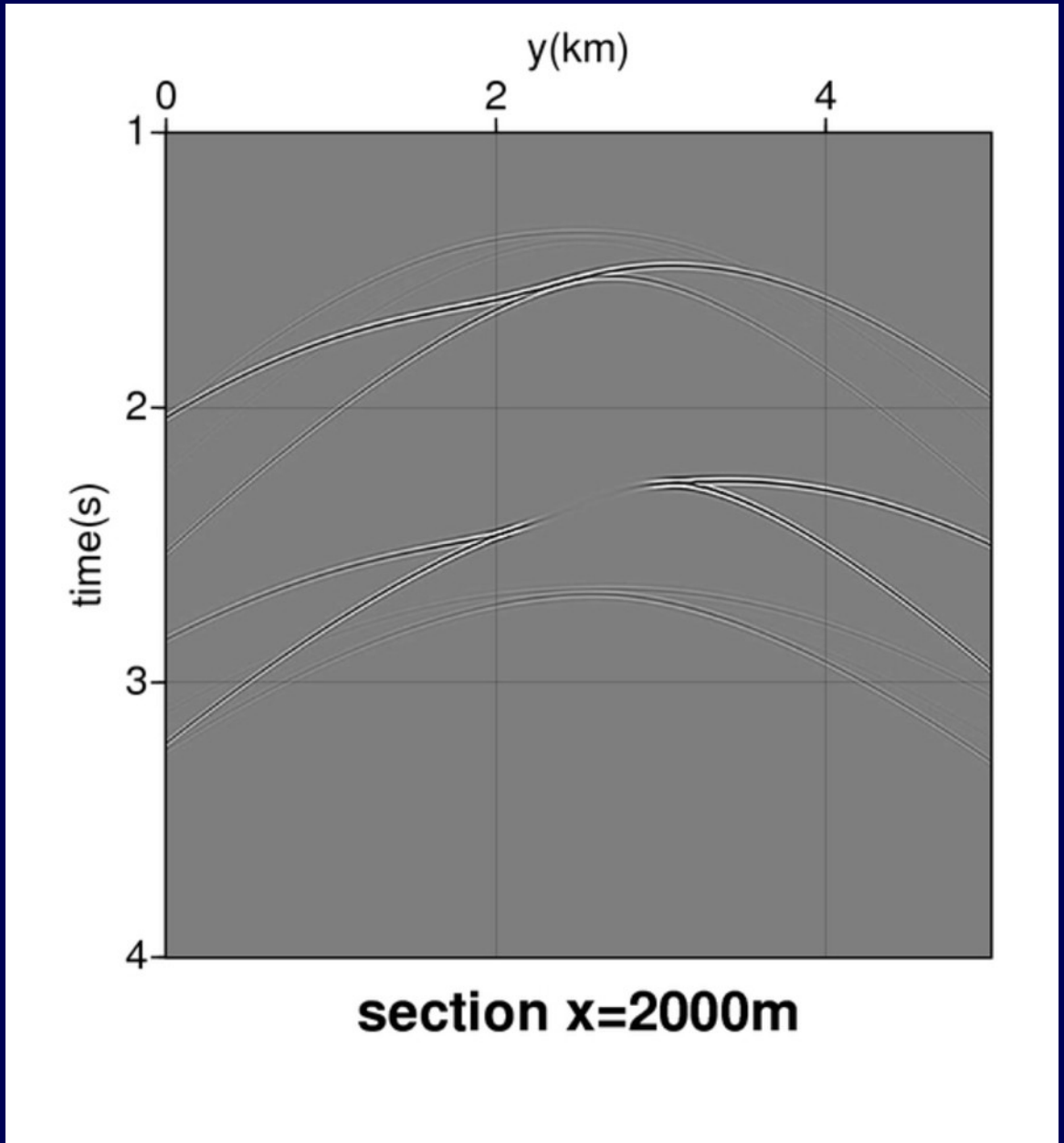
Curved edge diffractions – synthetic – spherical spiral



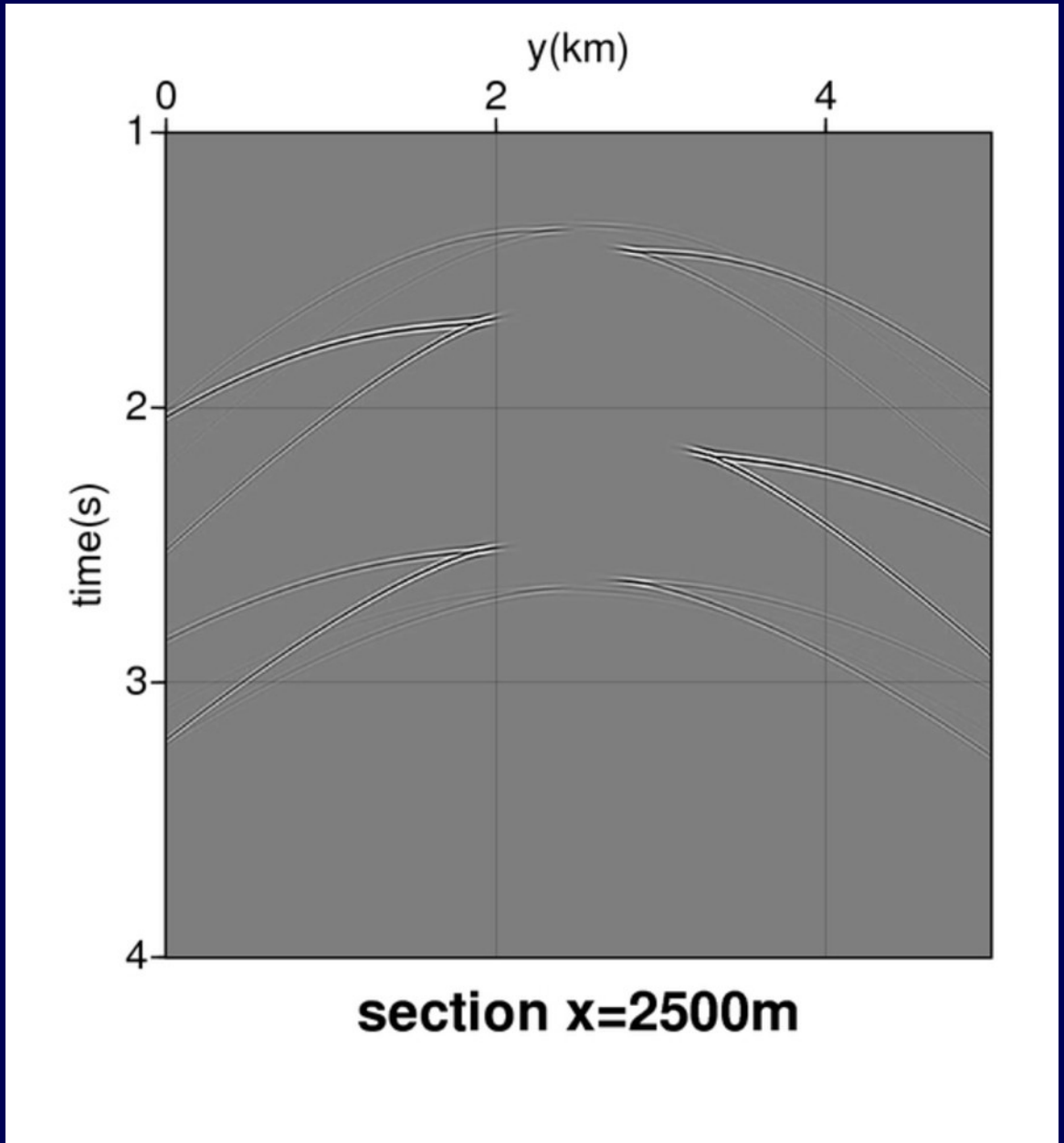
Curved edge diffractions – synthetic – spherical spiral



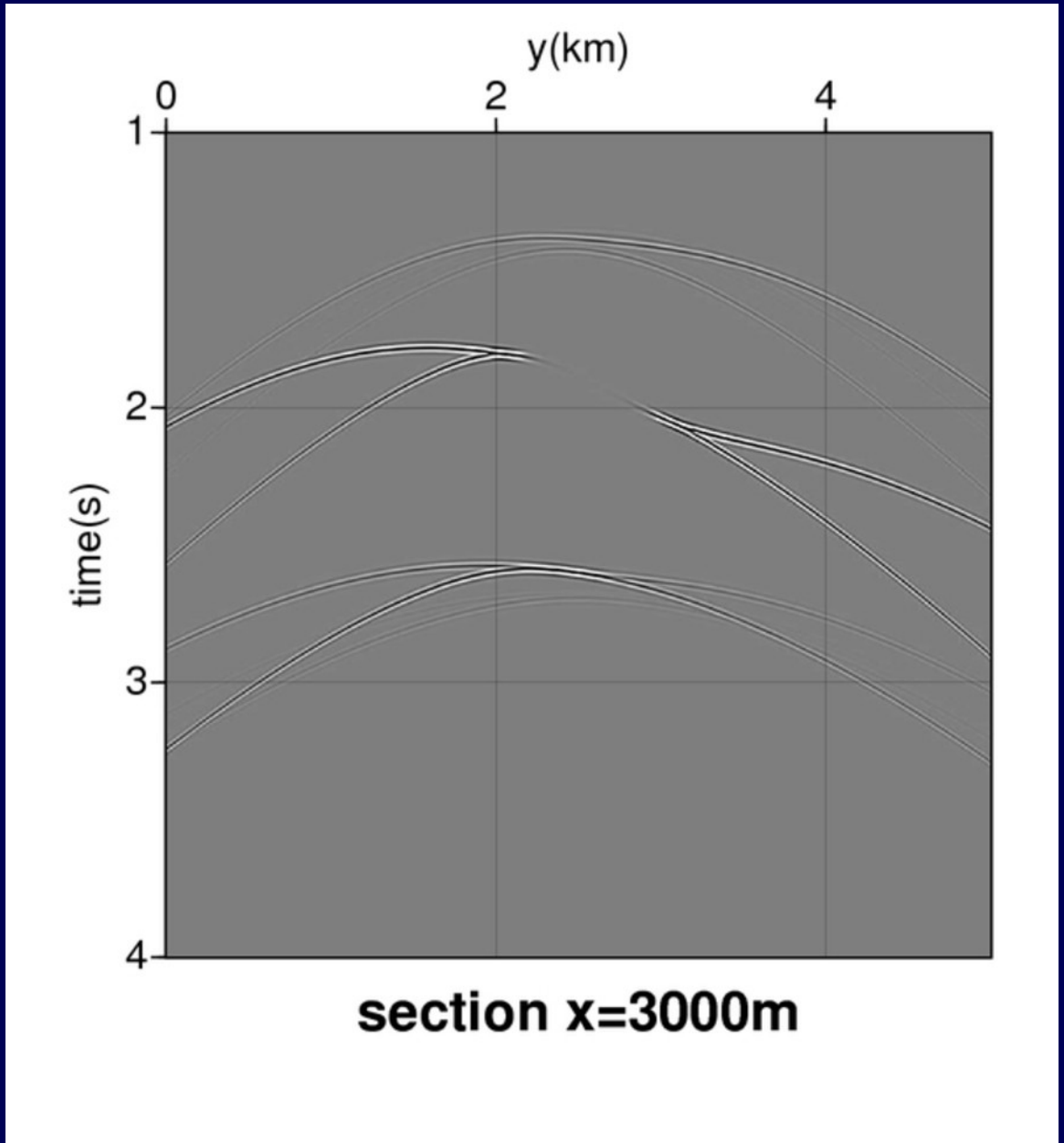
Curved edge diffractions – synthetic – spherical spiral



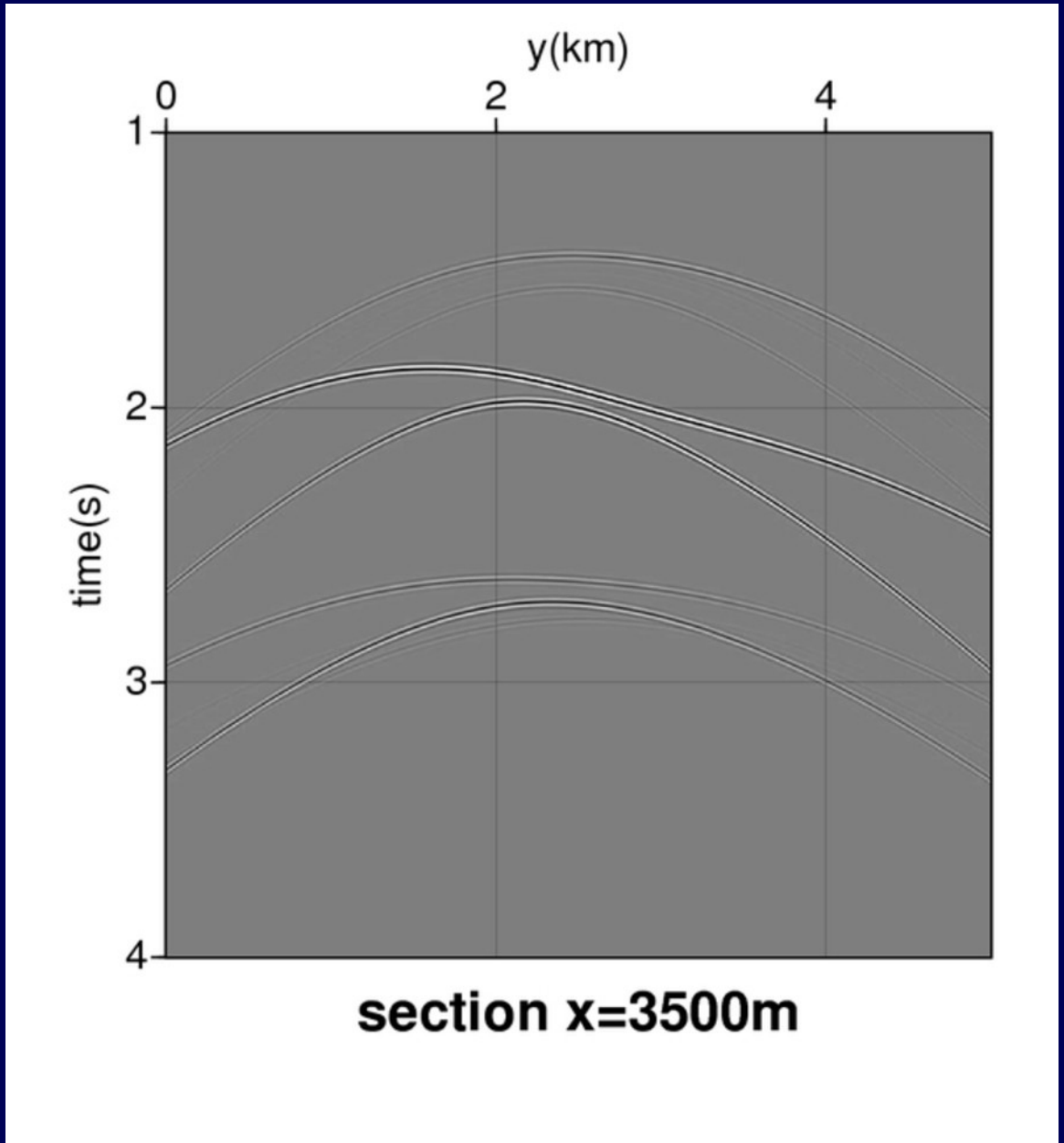
Curved edge diffractions – synthetic – spherical spiral



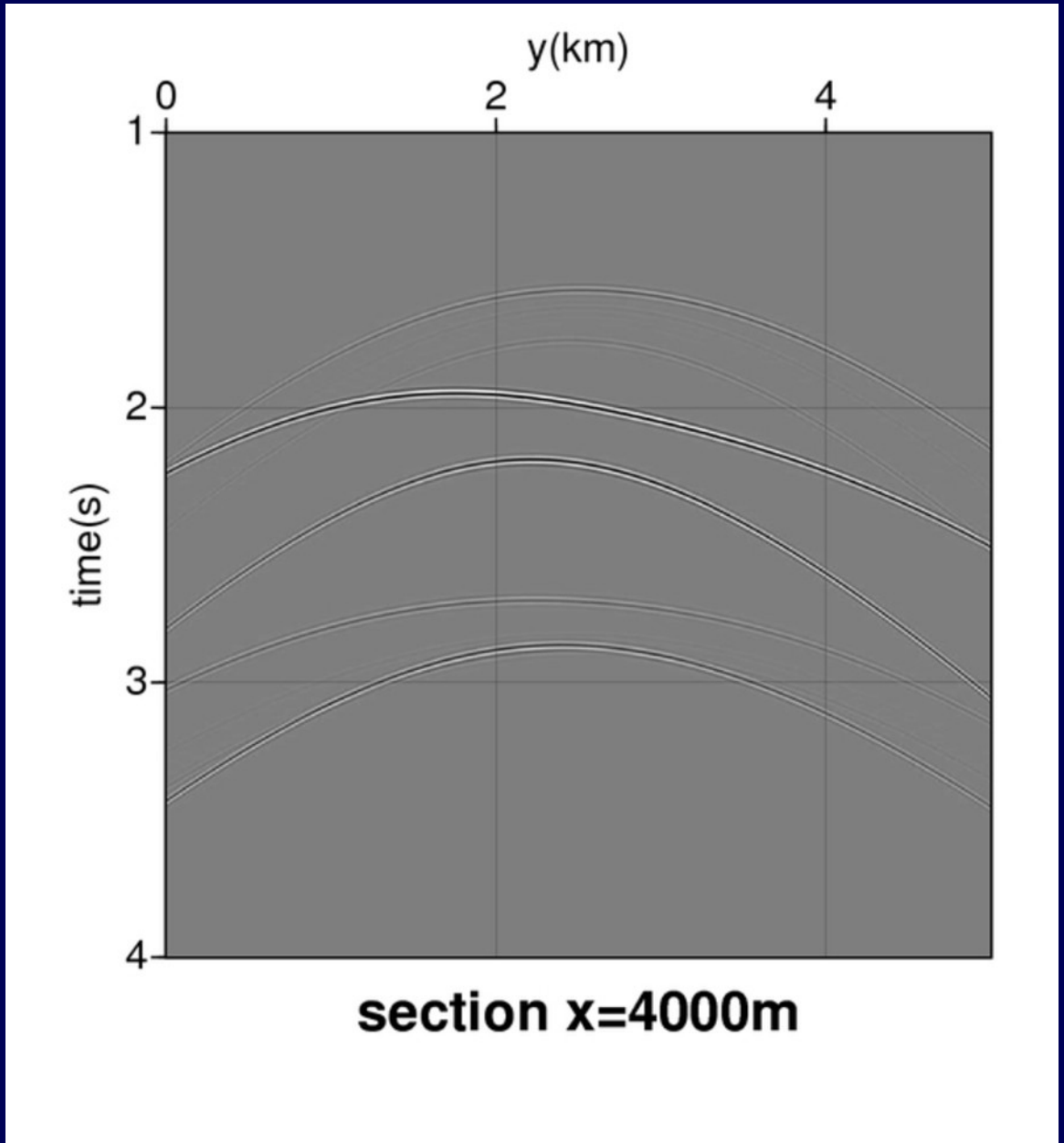
Curved edge diffractions – synthetic – spherical spiral



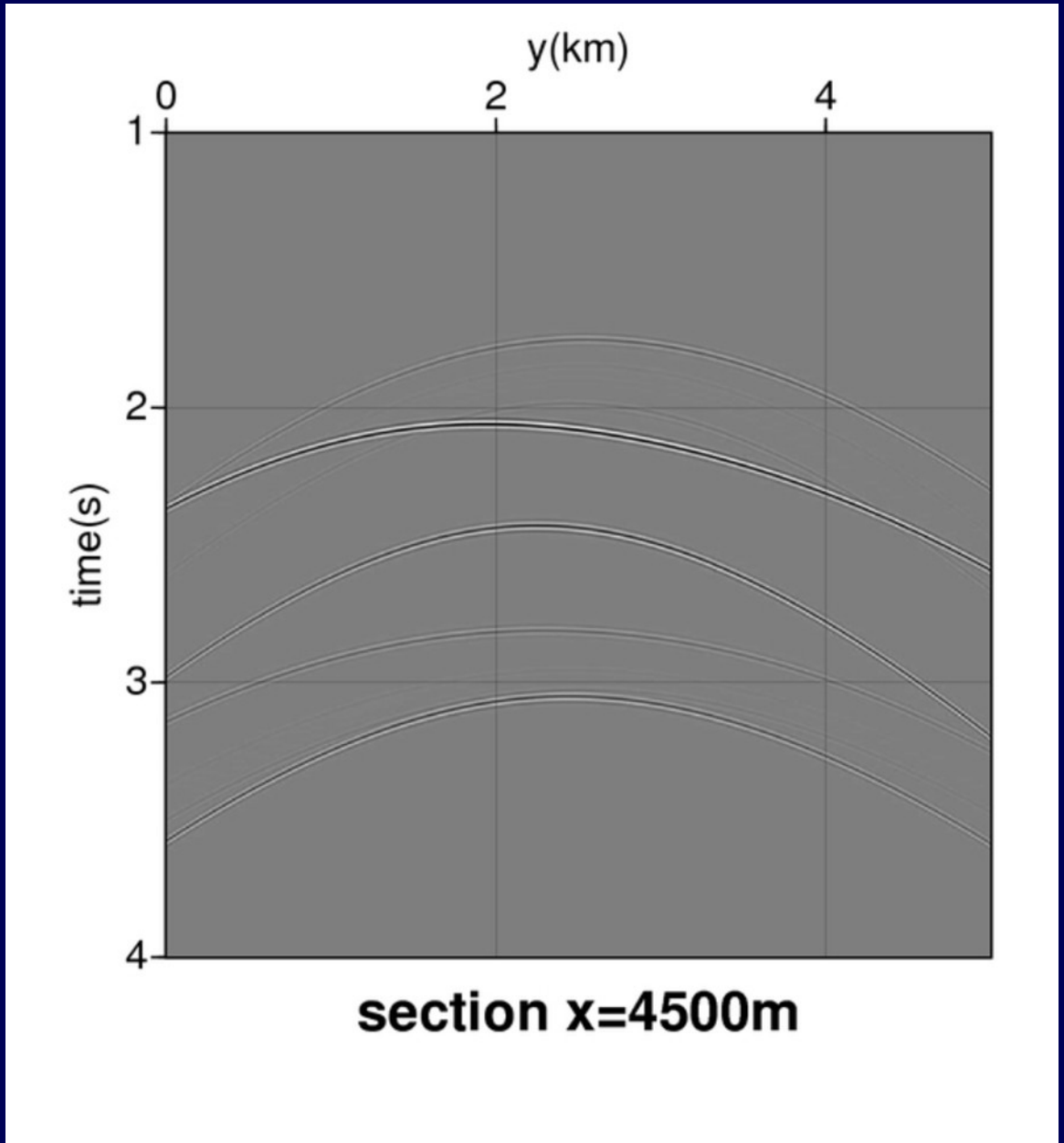
Curved edge diffractions – synthetic – spherical spiral



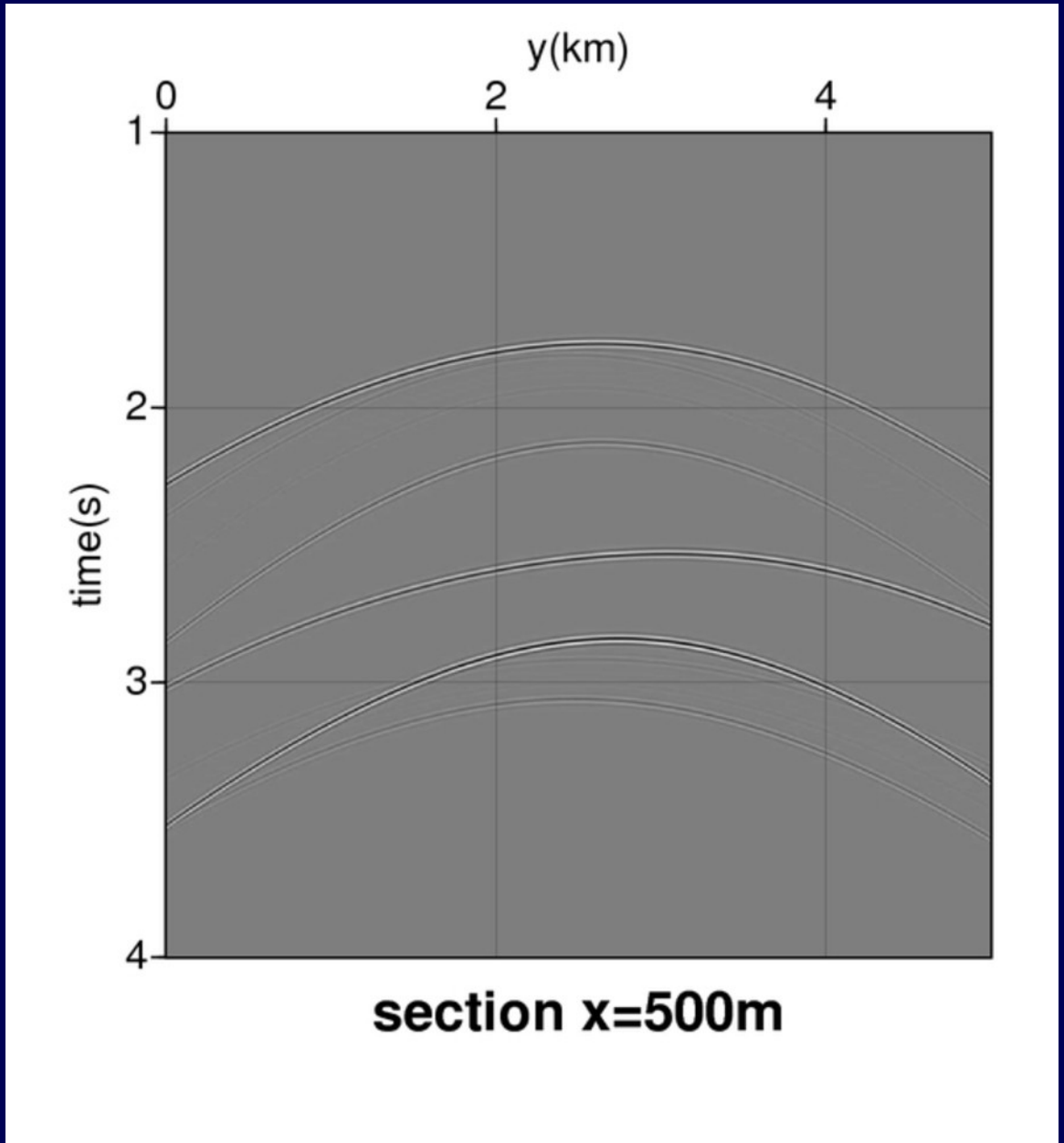
Curved edge diffractions – synthetic – spherical spiral



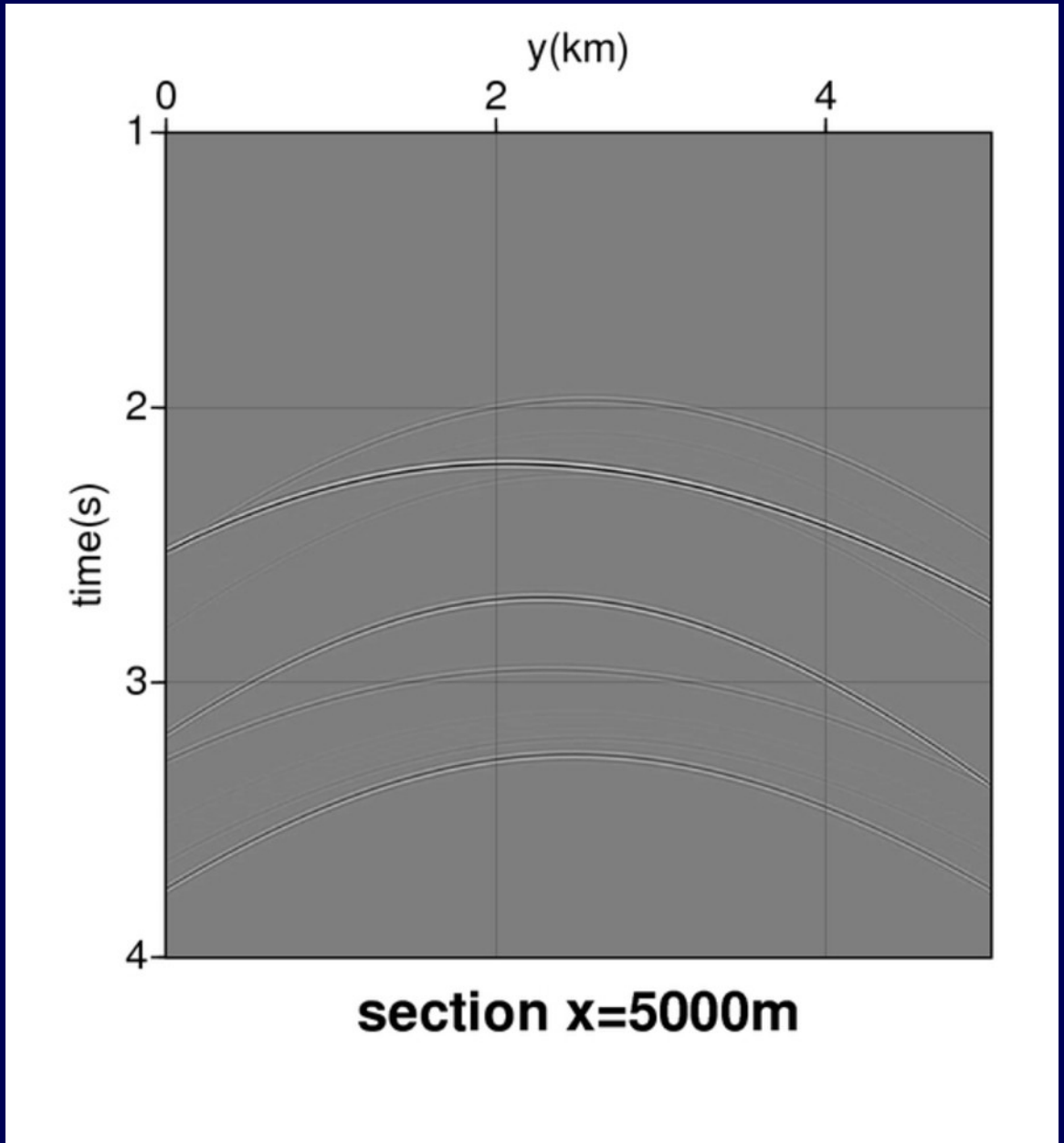
Curved edge diffractions – synthetic – spherical spiral



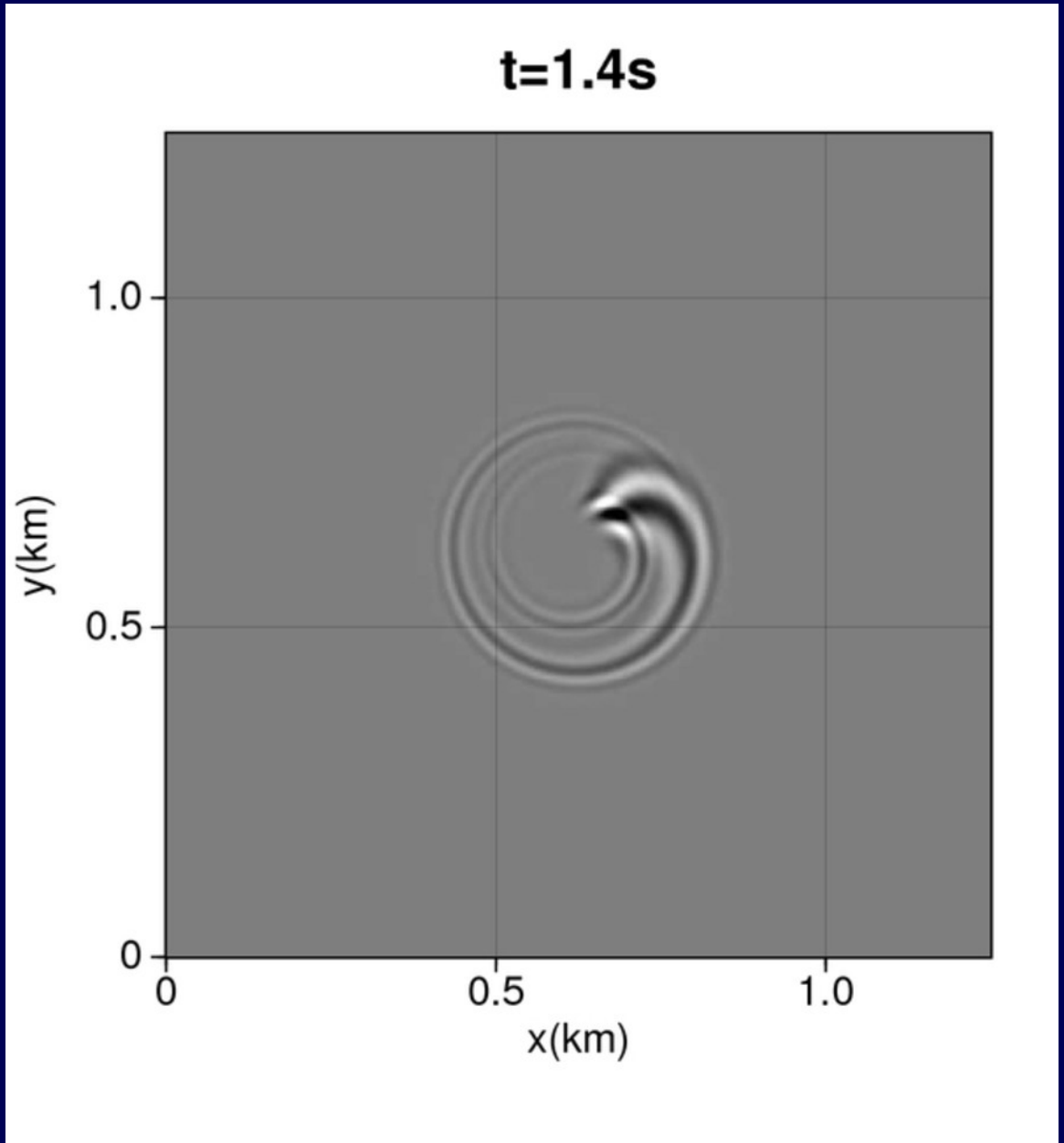
Curved edge diffractions – synthetic – spherical spiral



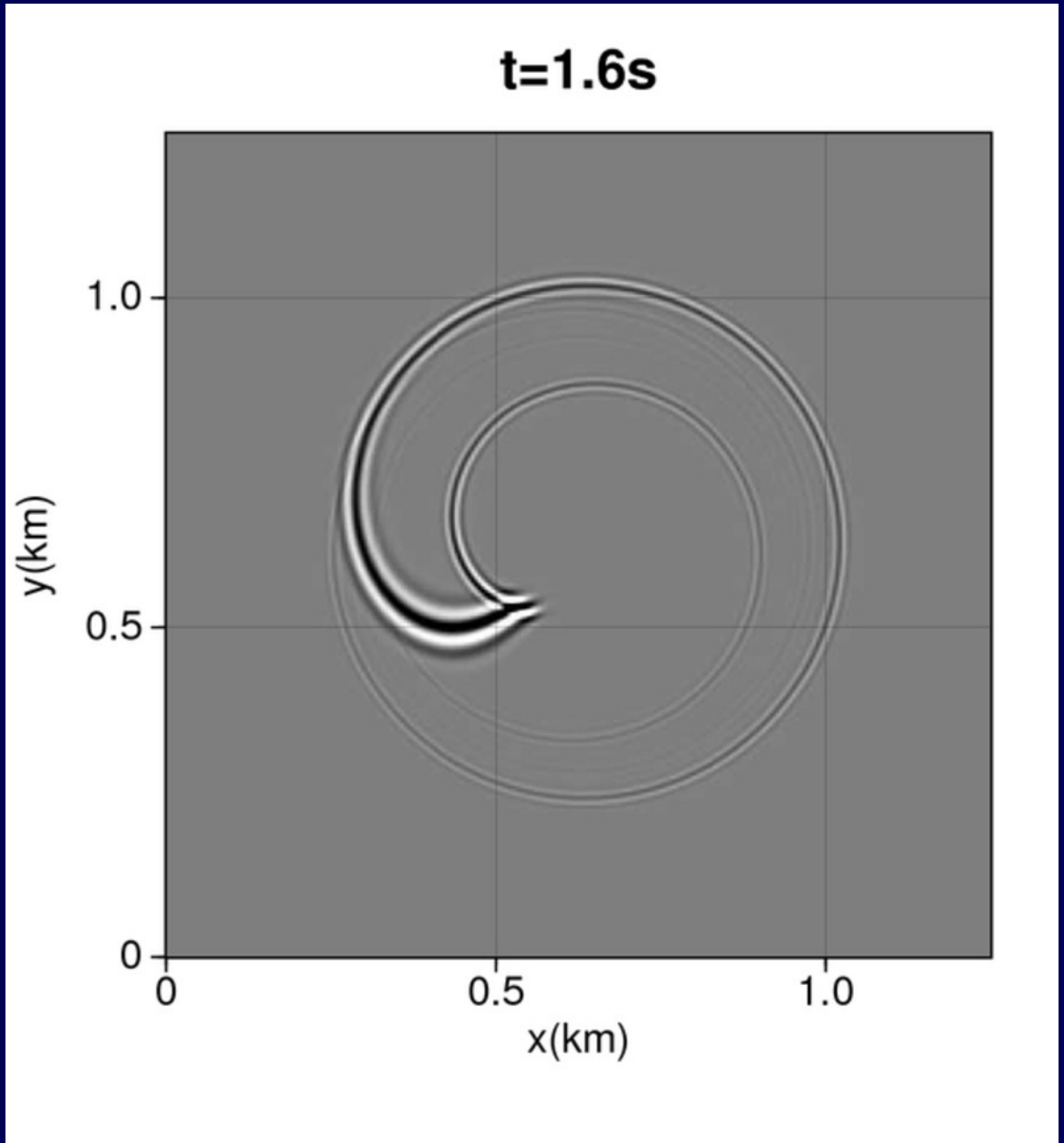
Curved edge diffractions – synthetic – spherical spiral



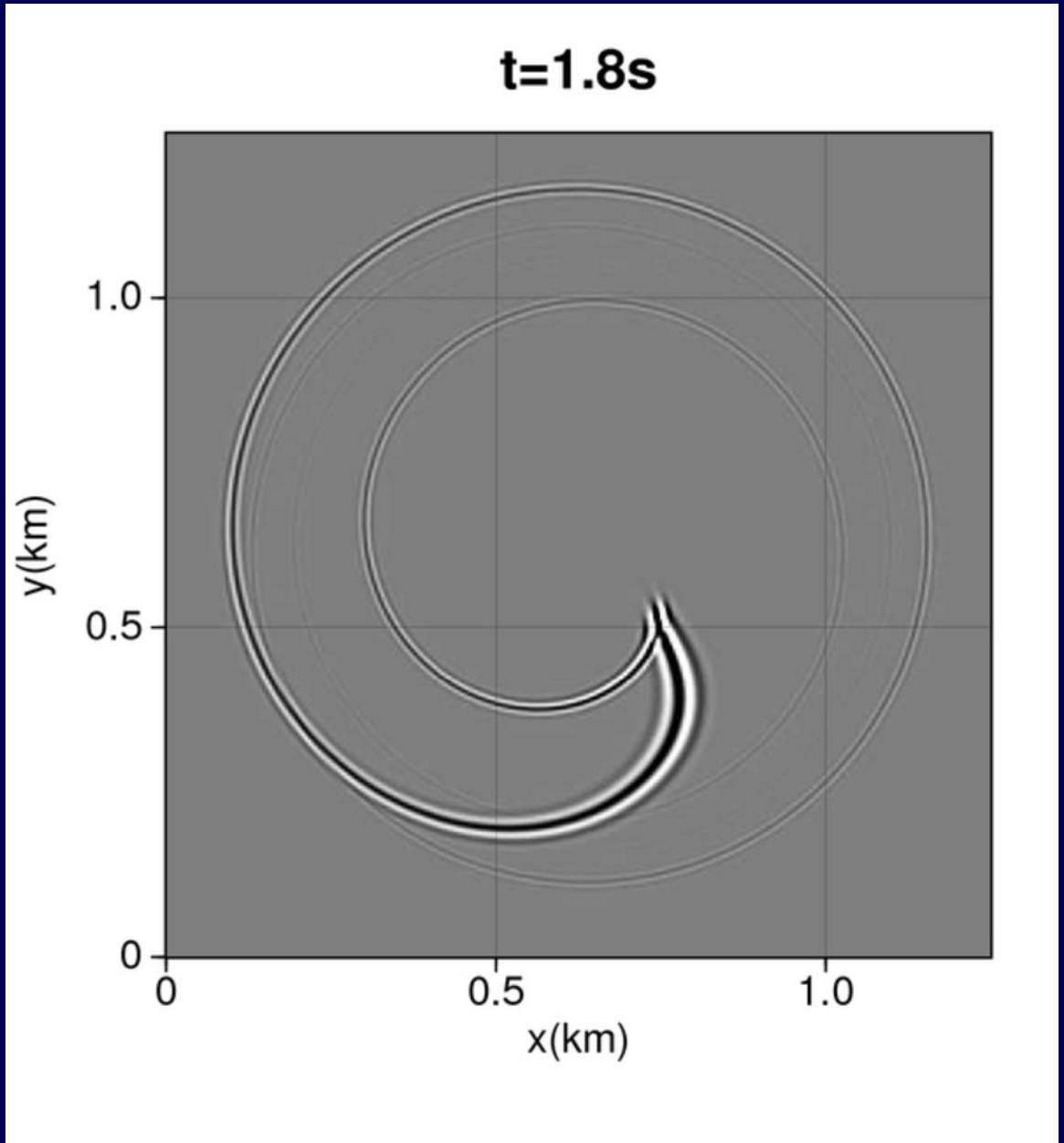
Curved edge diffractions – synthetic – spherical spiral



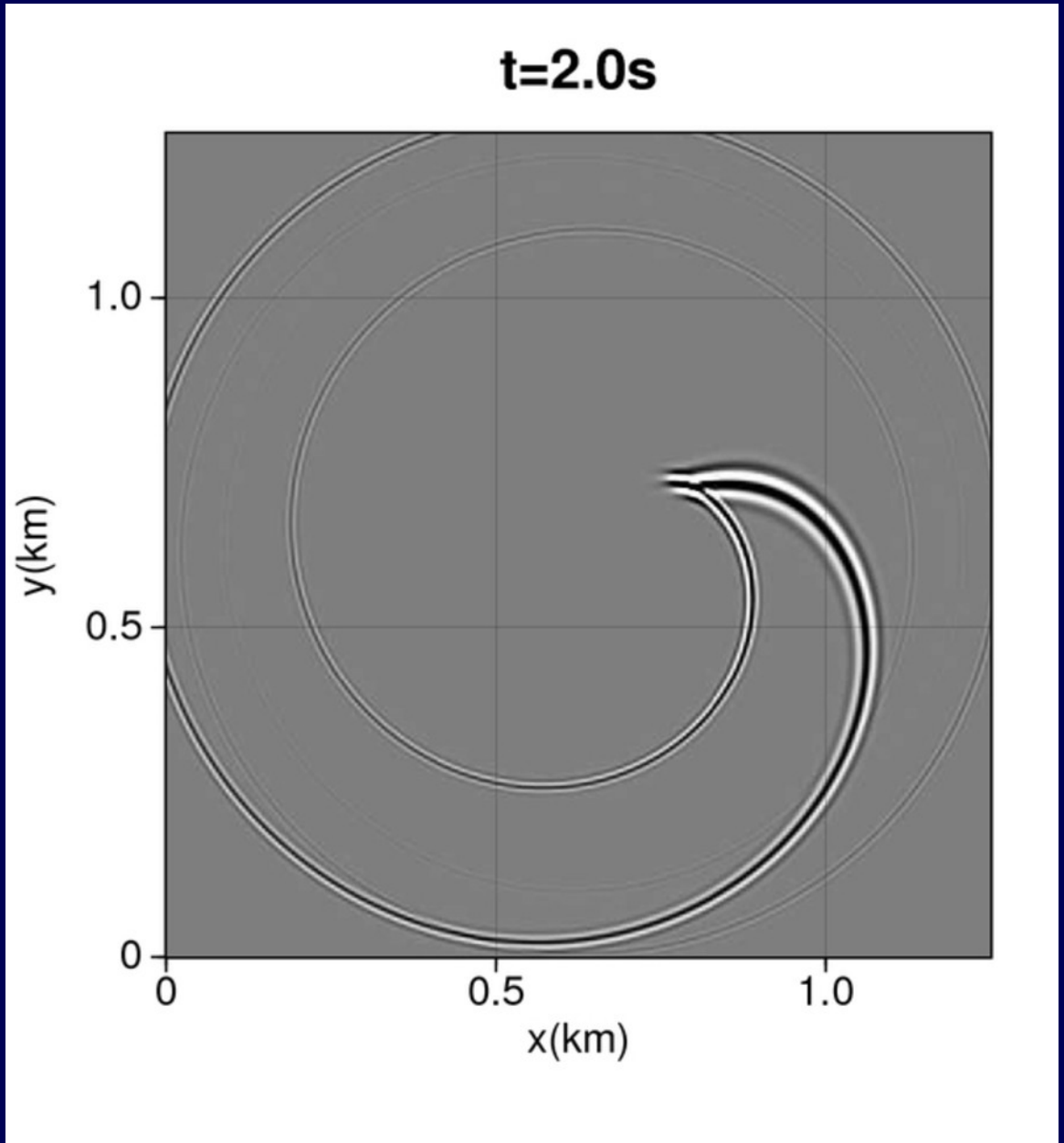
Curved edge diffractions – synthetic – spherical spiral



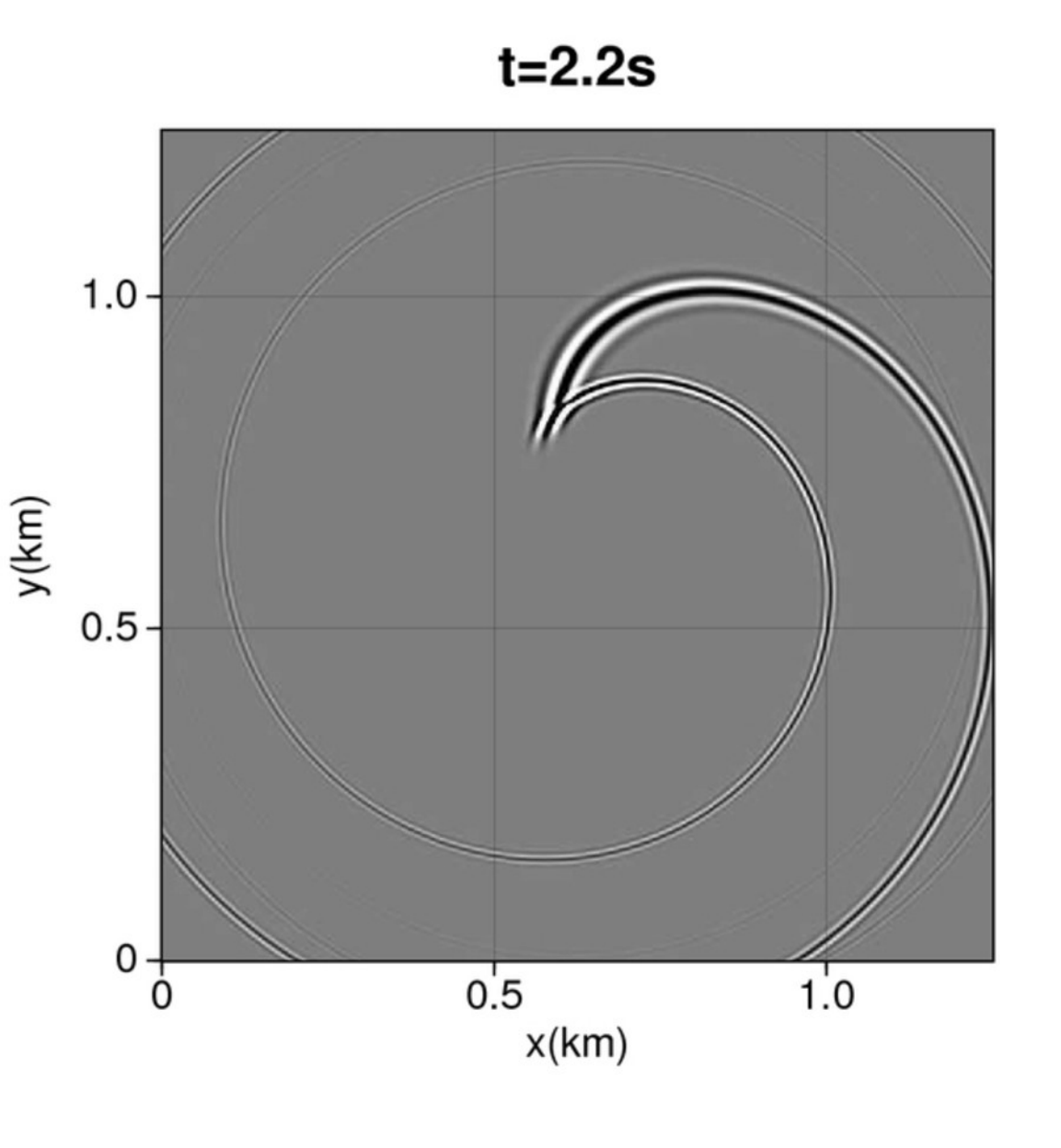
Curved edge diffractions – synthetic – spherical spiral



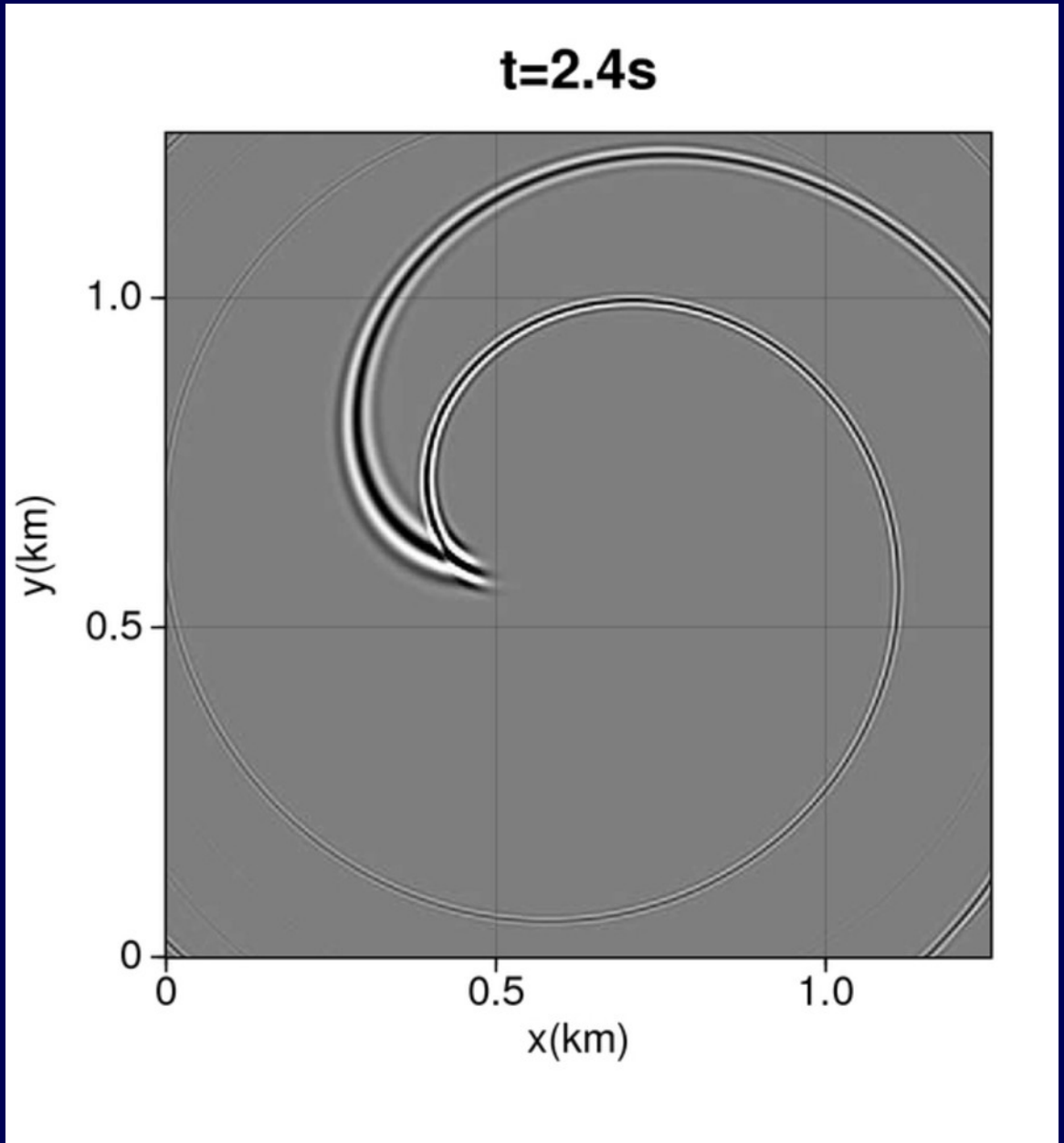
Curved edge diffractions – synthetic – spherical spiral



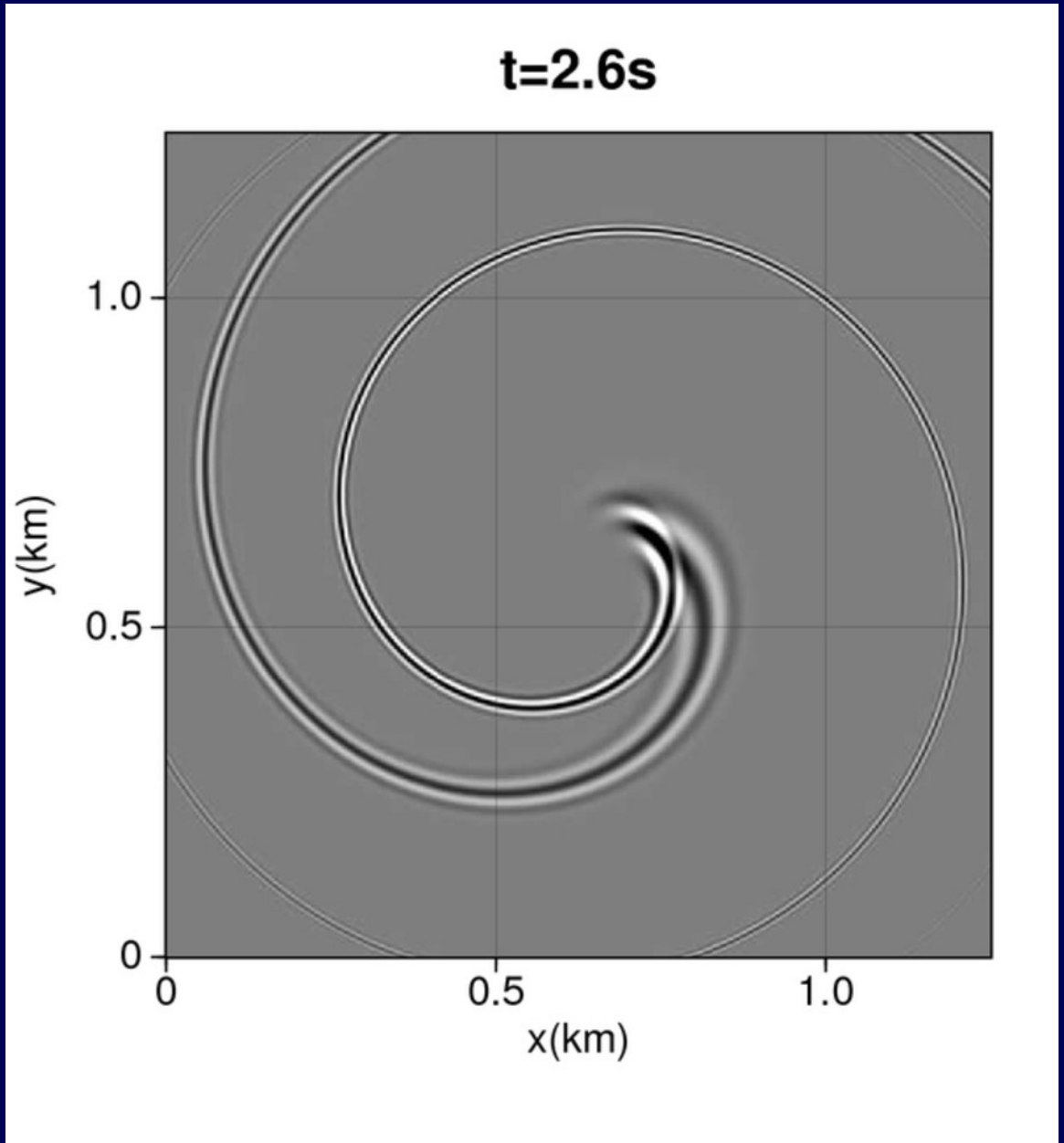
Curved edge diffractions – synthetic – spherical spiral



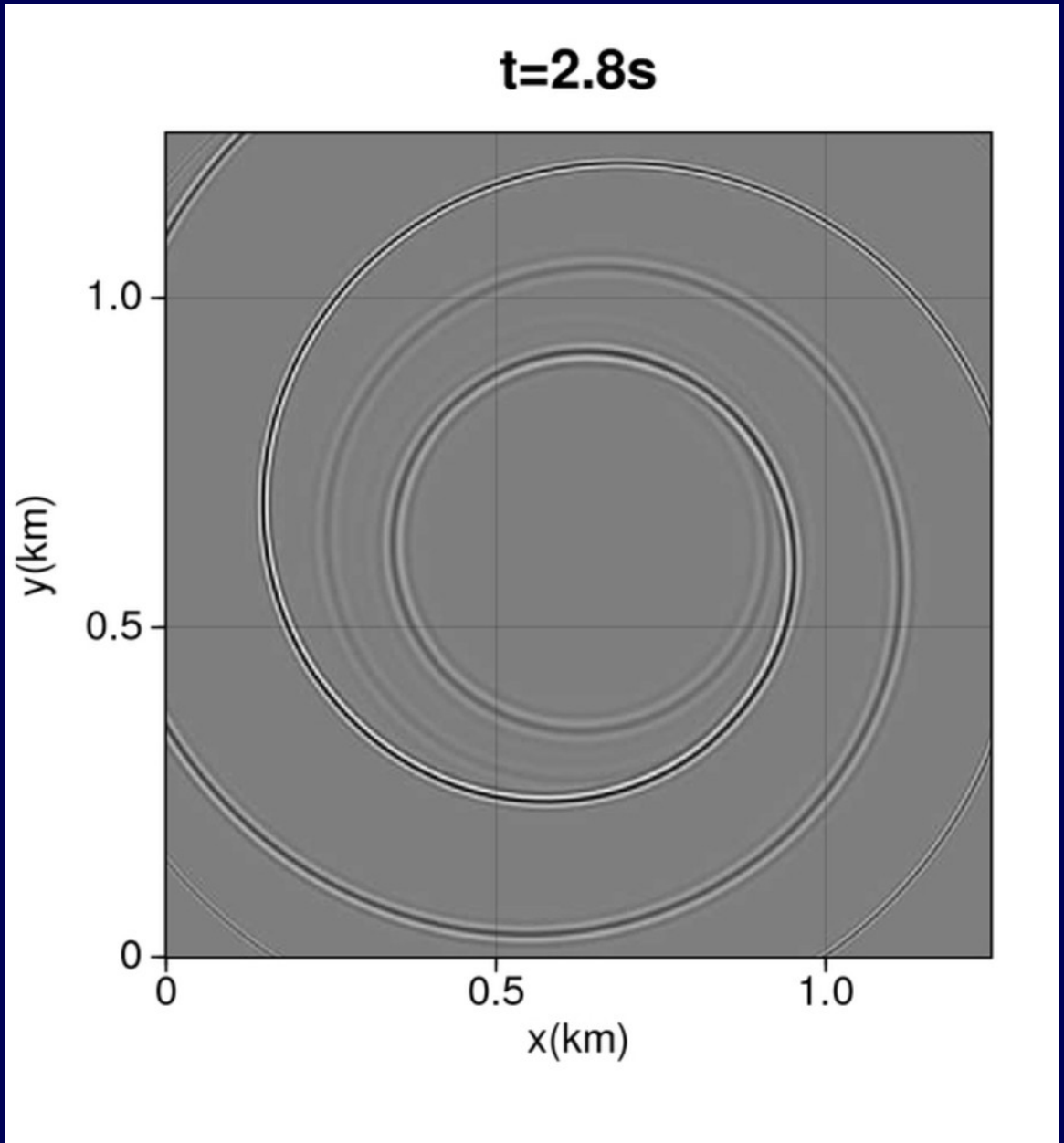
Curved edge diffractions – synthetic – spherical spiral



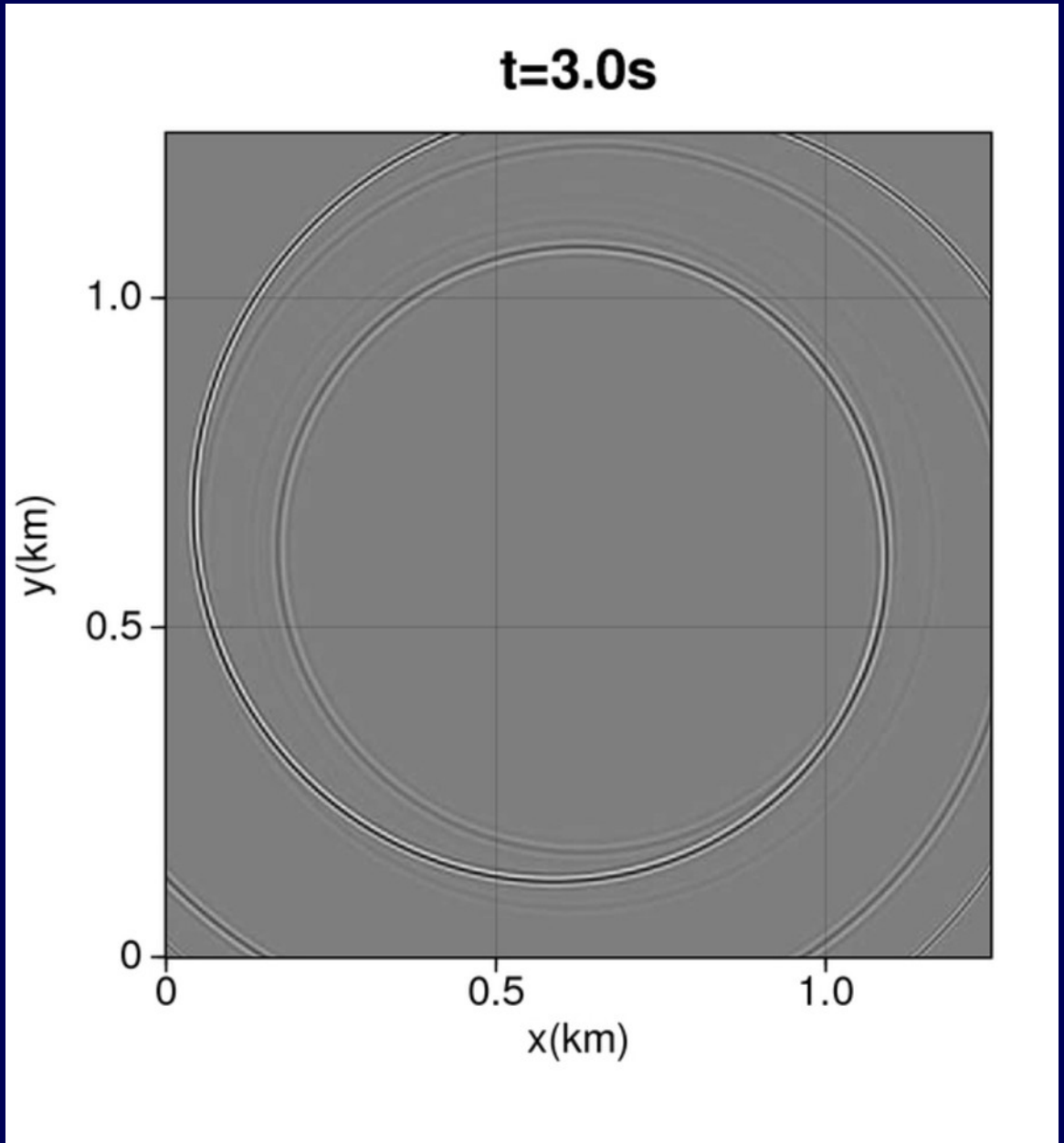
Curved edge diffractions – synthetic – spherical spiral



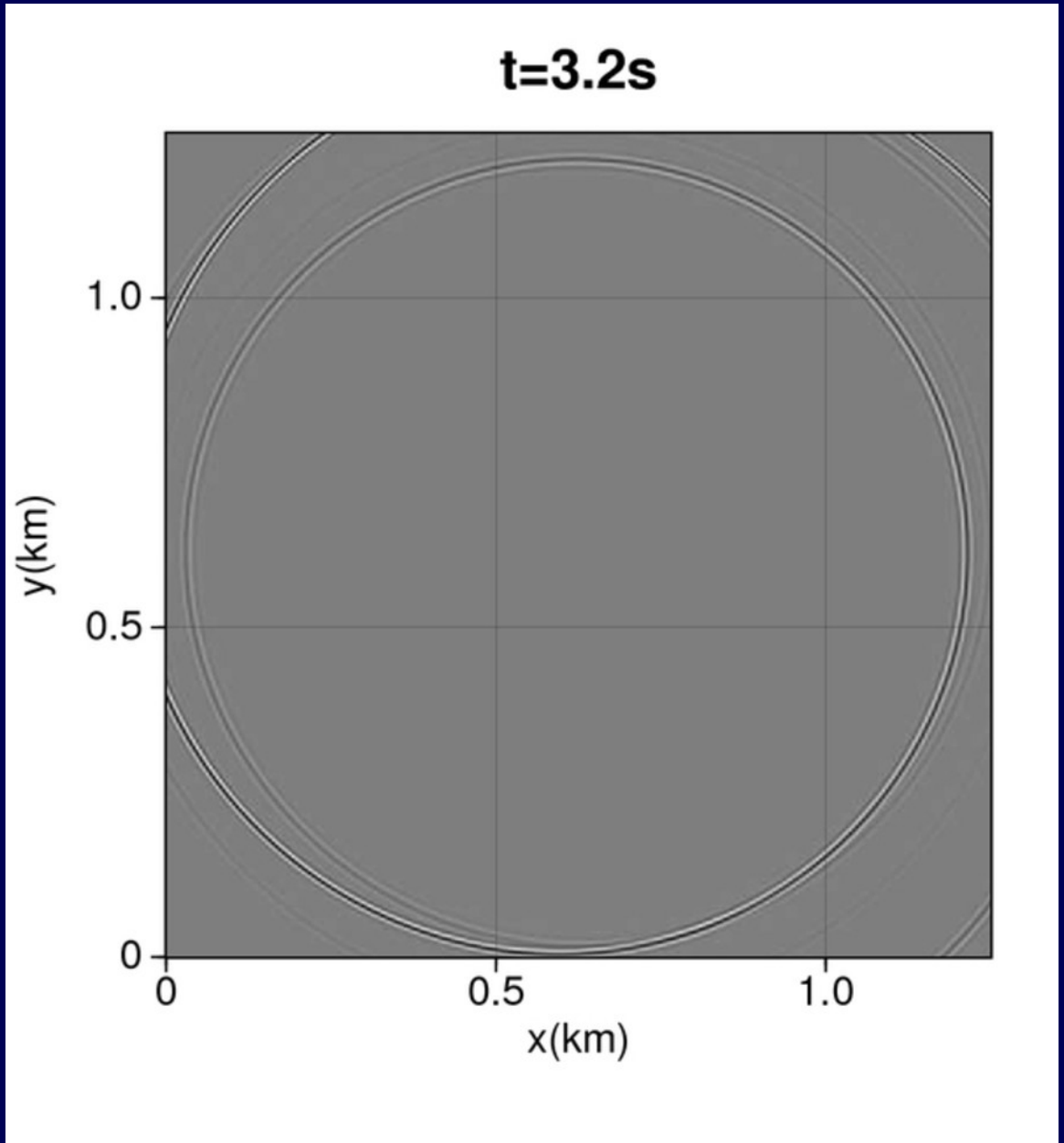
Curved edge diffractions – synthetic – spherical spiral



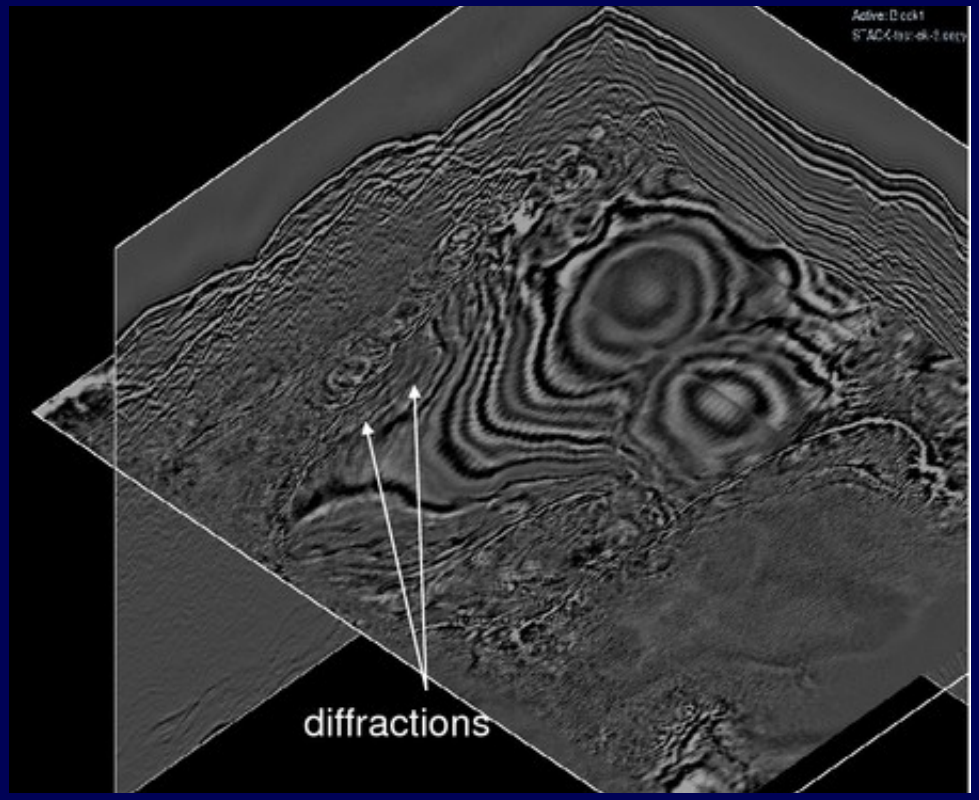
Curved edge diffractions – synthetic – spherical spiral



Curved edge diffractions – synthetic – spherical spiral



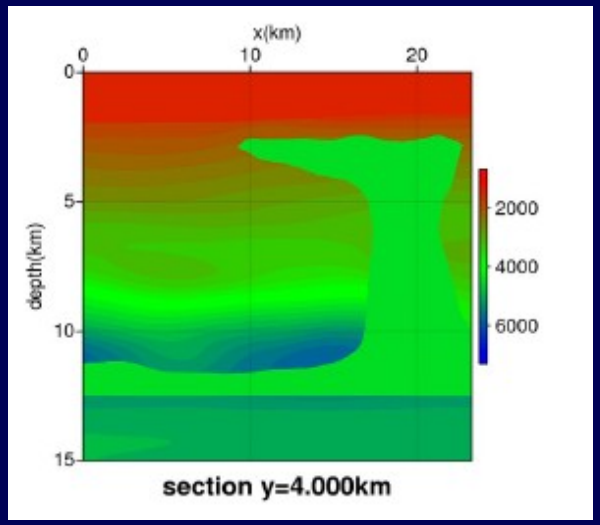
Curved edge diffractions – Salt diapirs

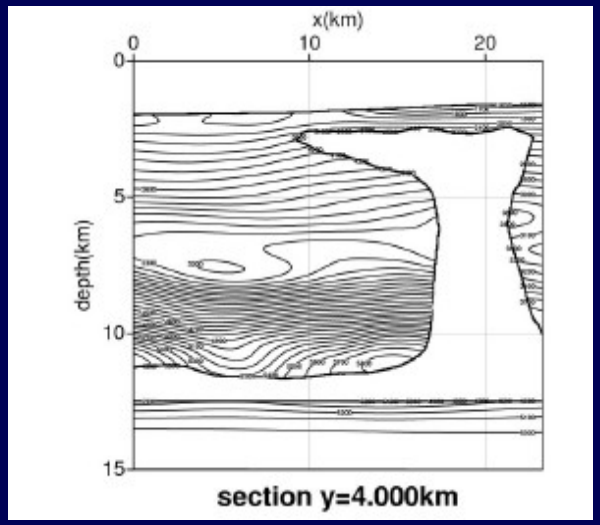


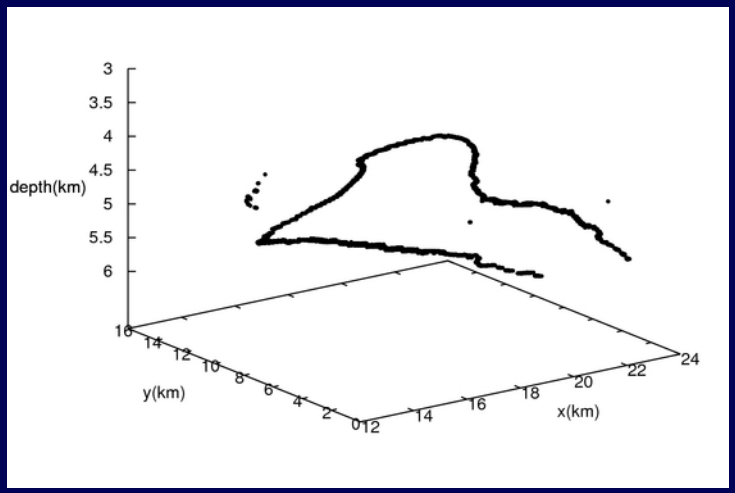
Diffractions from salt diapirs:

- **How to model them?**
- **Can they support interpretation ?**
- **Can they distinguish between:**
  - **Edge/tip diffractions - fault tectonic**
  - **Convex bodies - erosional tectonic**

Curved edge diffractions – GOM-B Salt diapir model

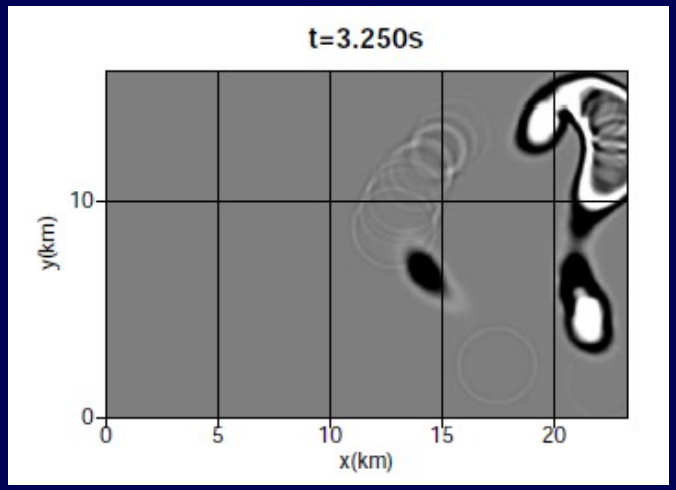


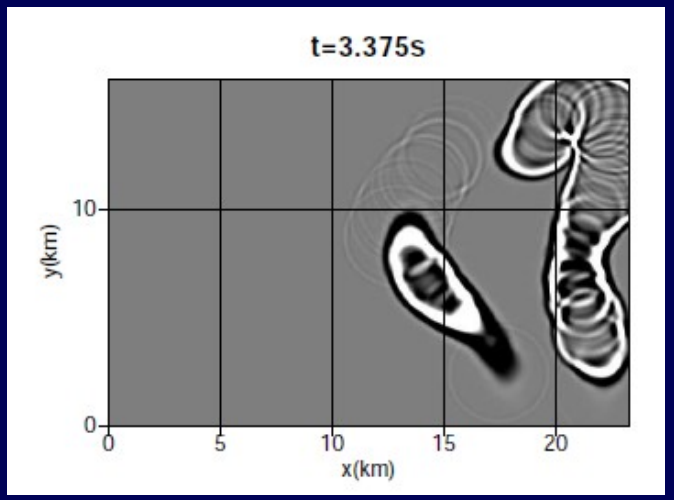


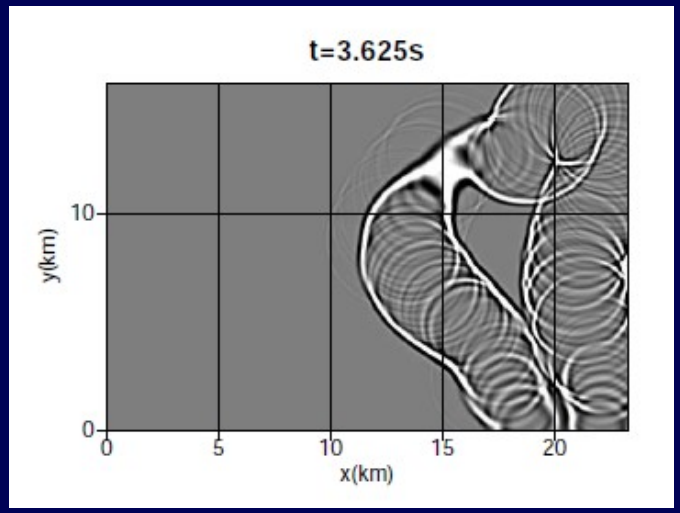


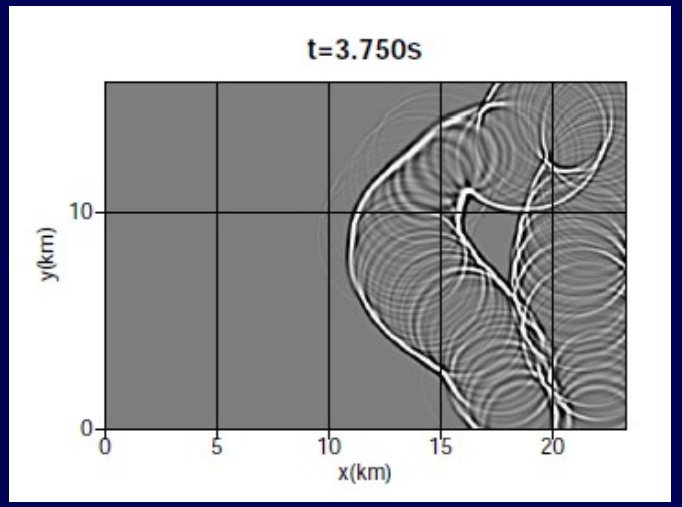
Extraction of intersection of salt dome with 3km/s iso-velocity surface

Curved edge diffractions – GOM-B Salt diapir model









Time slices

Note caustics resembling elliptical edge modeling

Curved edge diffraction modeling – Conclusions

- Ray-Born versatile modeling tool for diffractions
- Diffraction-based workflow as a complement to reflection-based workflow
- Edge and tip diffractions elementary building elements for composite diffractions
- Importance of curved edge modeling (GPR, Salt diapir, …)
- Impact on interpretation

Acknowledgments

We thank Statoil for permission to show the GOM-B data and model.

We thank Mark Grasmueck (Miami Univ. Comparative Sedimentology Lab) for making available the GPR data.

Events

Dedicated session 'Case Studies in Diffraction Imaging and Interpretation', EAGE Copenhagen 2012

Workshop 'Diffraction Methods for Fault and Fracture Detection', SEG Las Vegas 2012