Approximating Q propagation to speed up finite differences

Robert Clapp

Standard single shot migration

Outline

Motivation

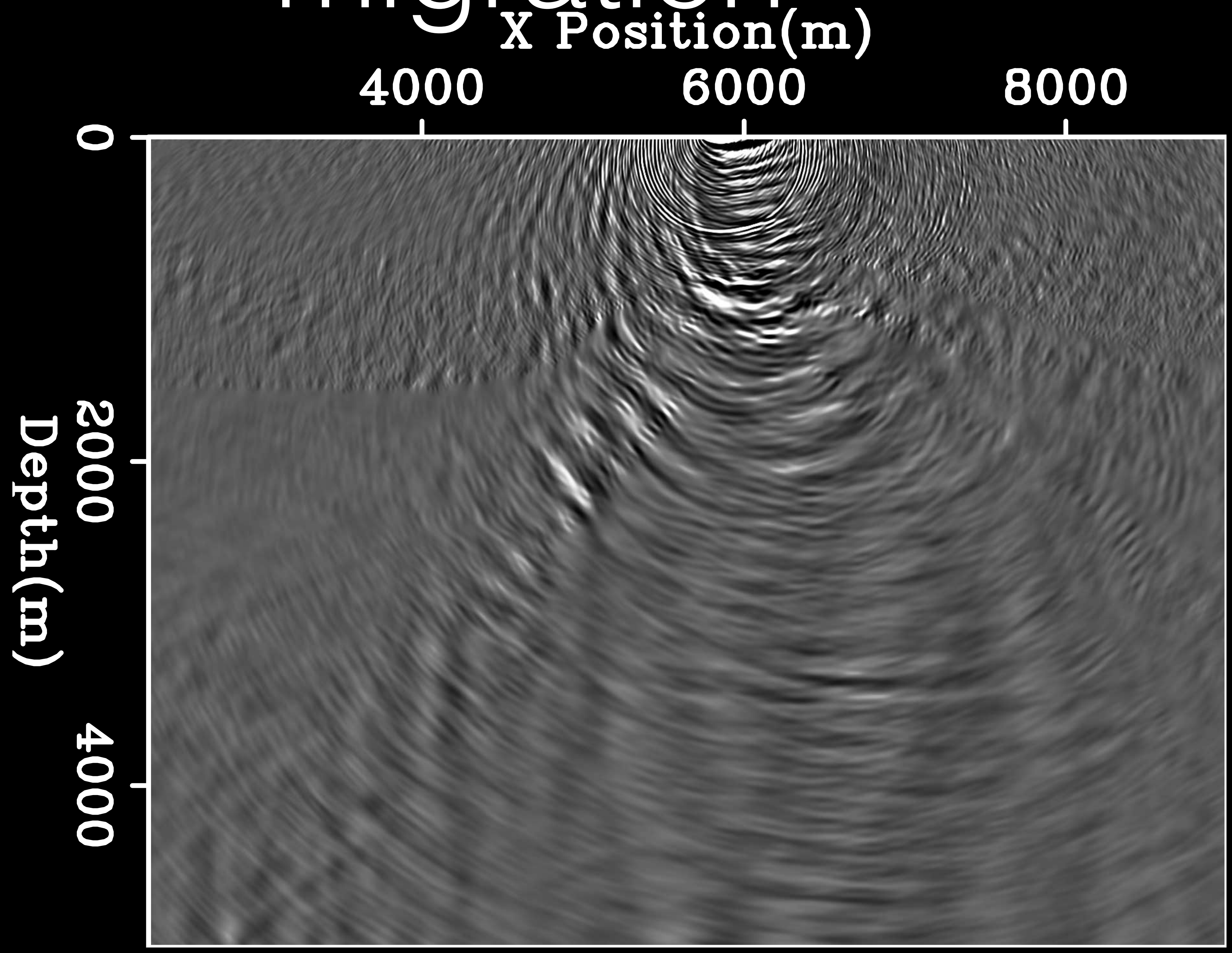
Accelerating migration

Approximating Q

Speedup

Implementation

Migration examples



Variable single shot migration

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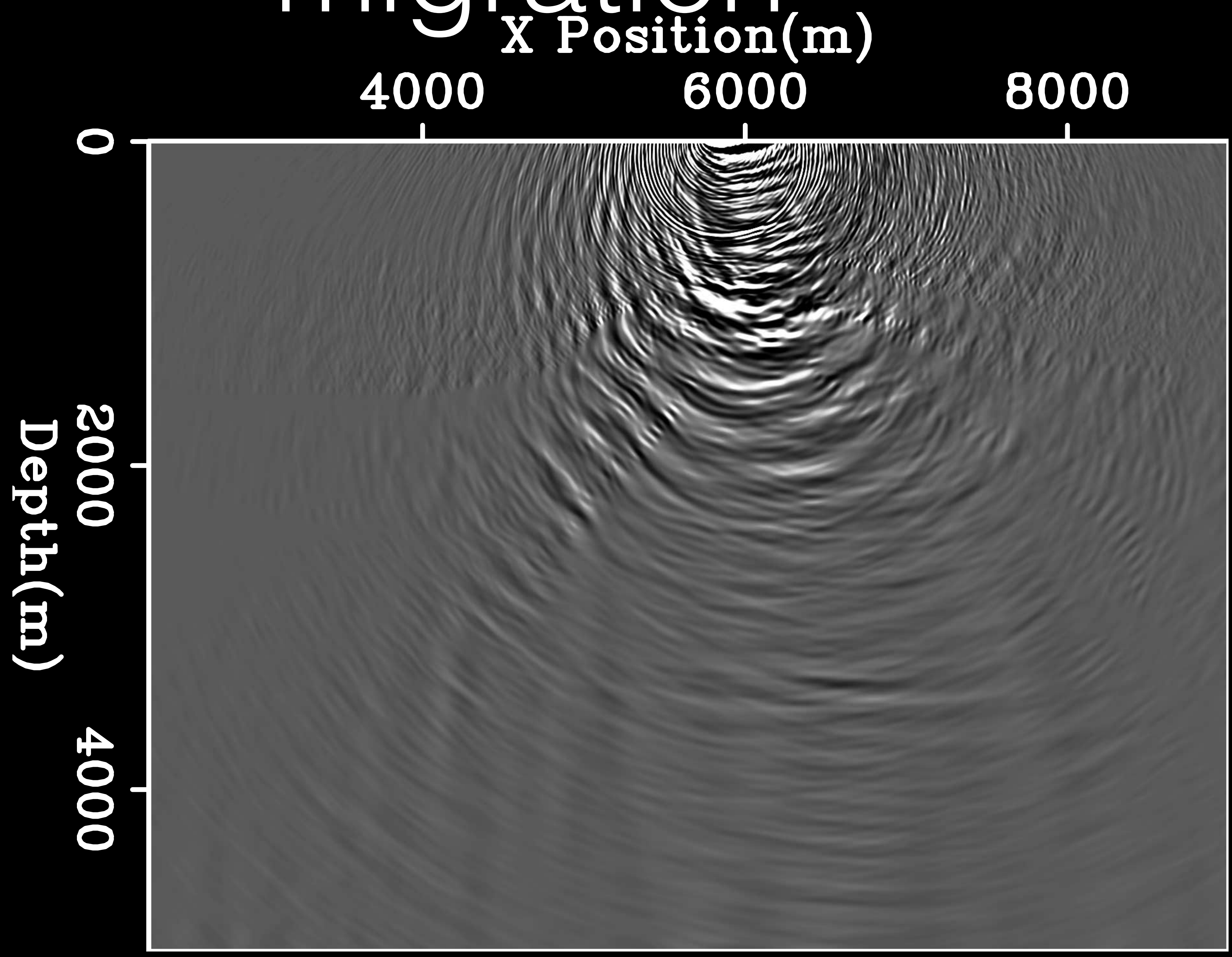

Finite-difference constraints

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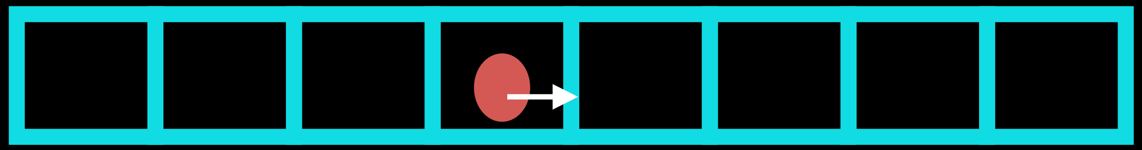
Stability: $v_{max}\frac{dt}{d_{min}} < .5$



Grid dispersion:

Finite-difference constraints

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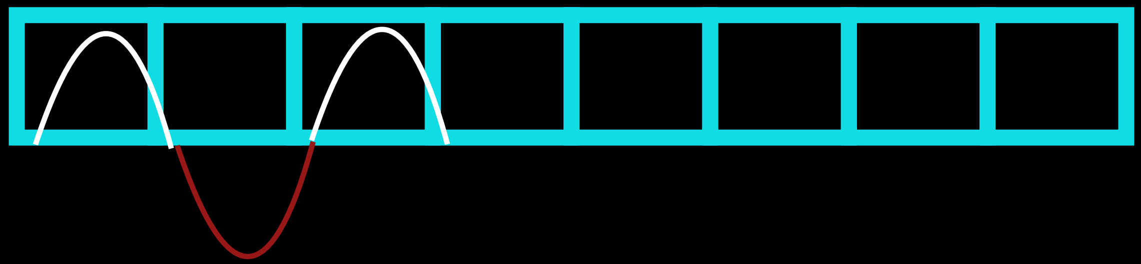
Stability: $v_{max}\frac{dt}{d_{min}} < .5$



Grid dispersion: $\frac{v_{min}}{f_{max}d_{max}} > 3.2$

Finite-difference constraints

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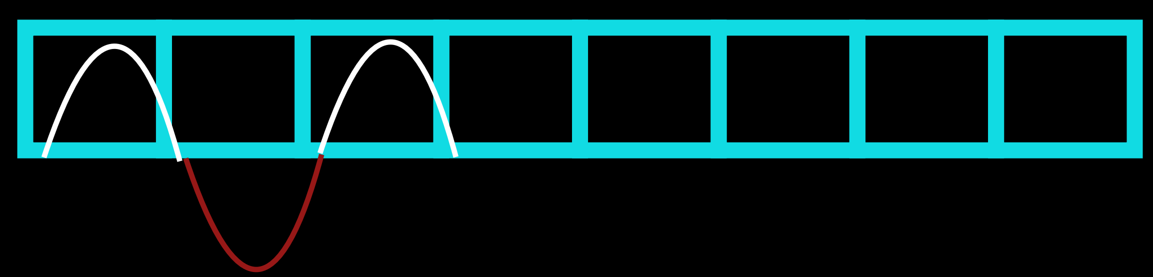
Stability: $v_{max} \frac{dt}{d_{min}} < .5$



Grid dispersion: $\frac{v_{min}}{f_{max} d_{max}} > 3.2$

Higher order stencil less grid dispersion error

Go through data using a pencil pattern

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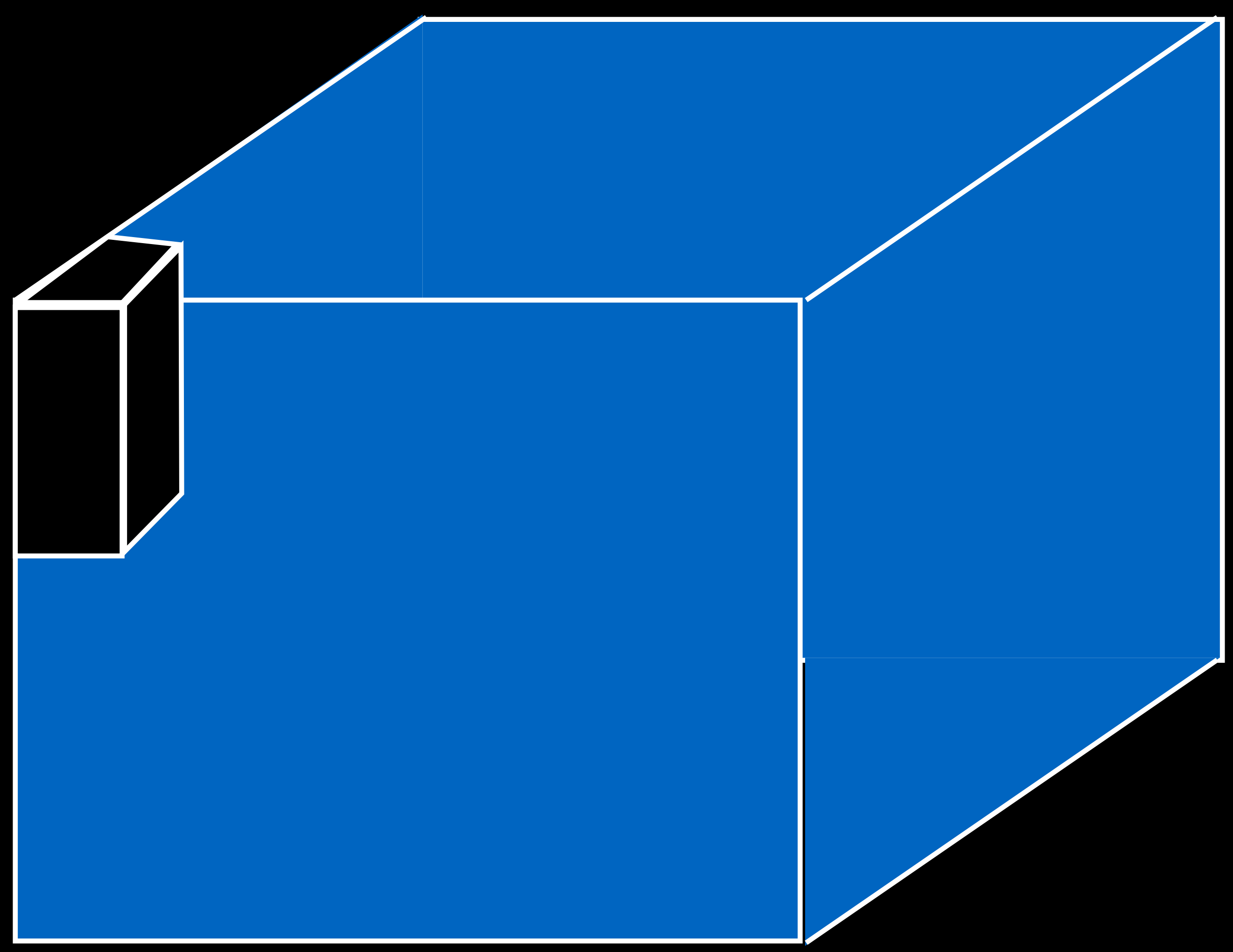

Vectorize your code

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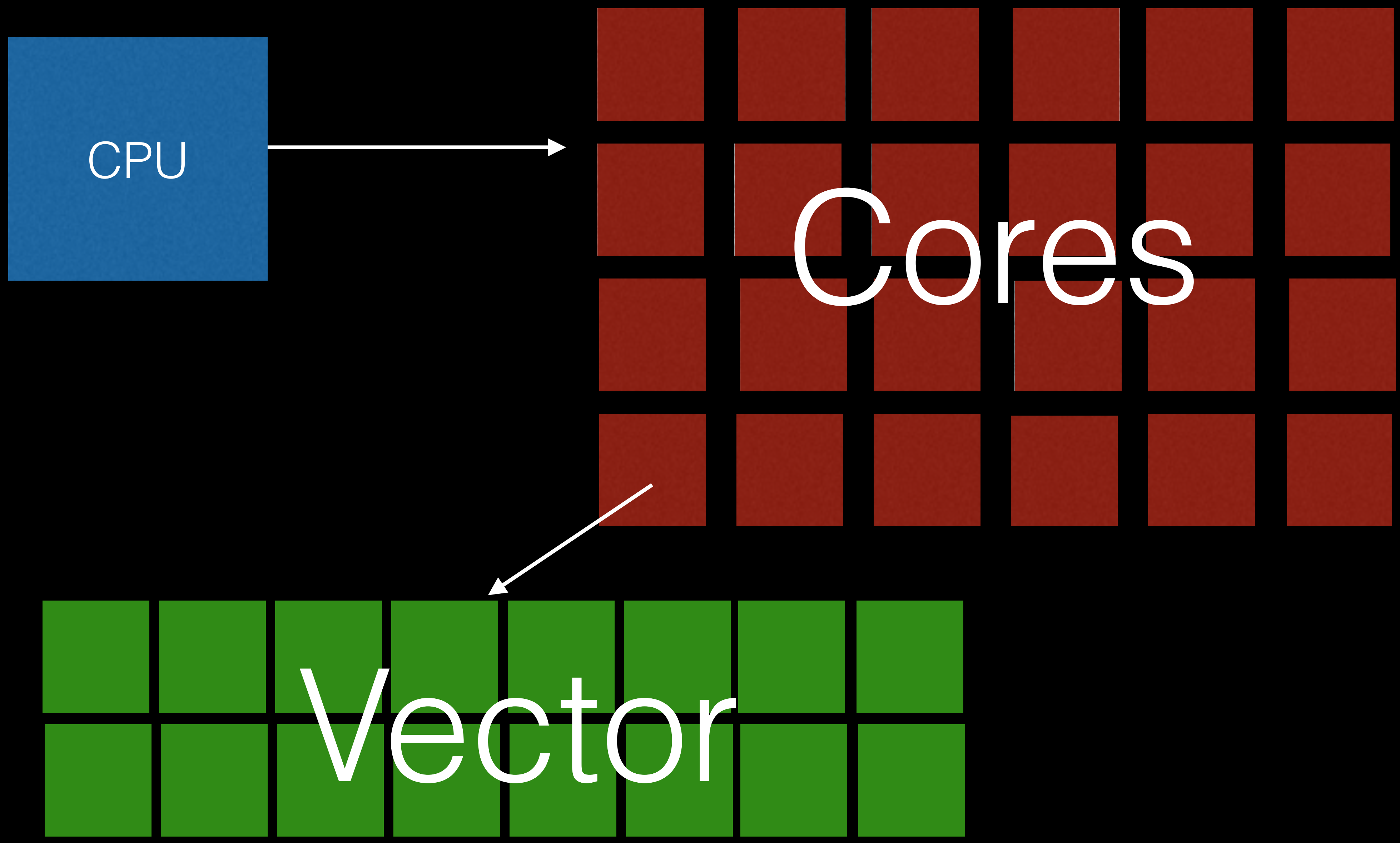

Pencils less bandwidth contention on multi-core

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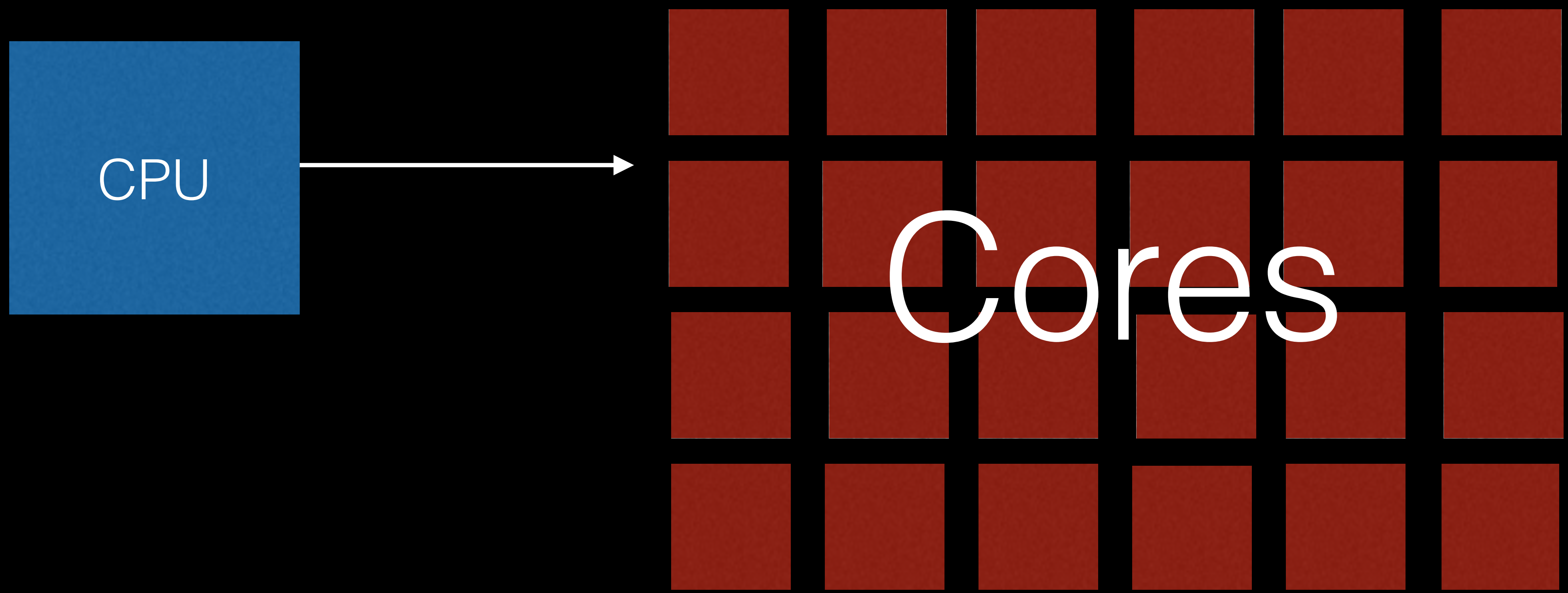

Follow the wave-field

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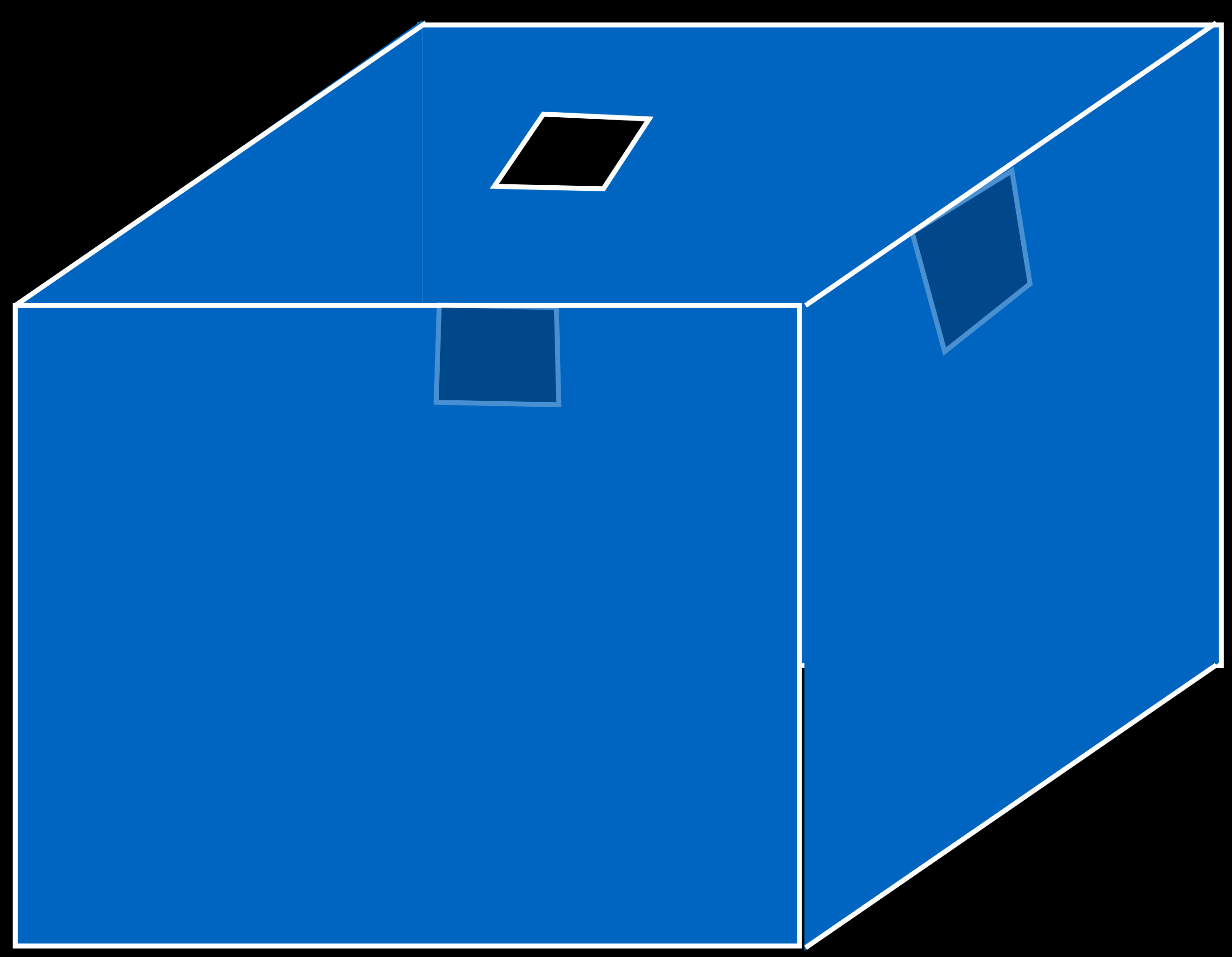

Follow the wave-field

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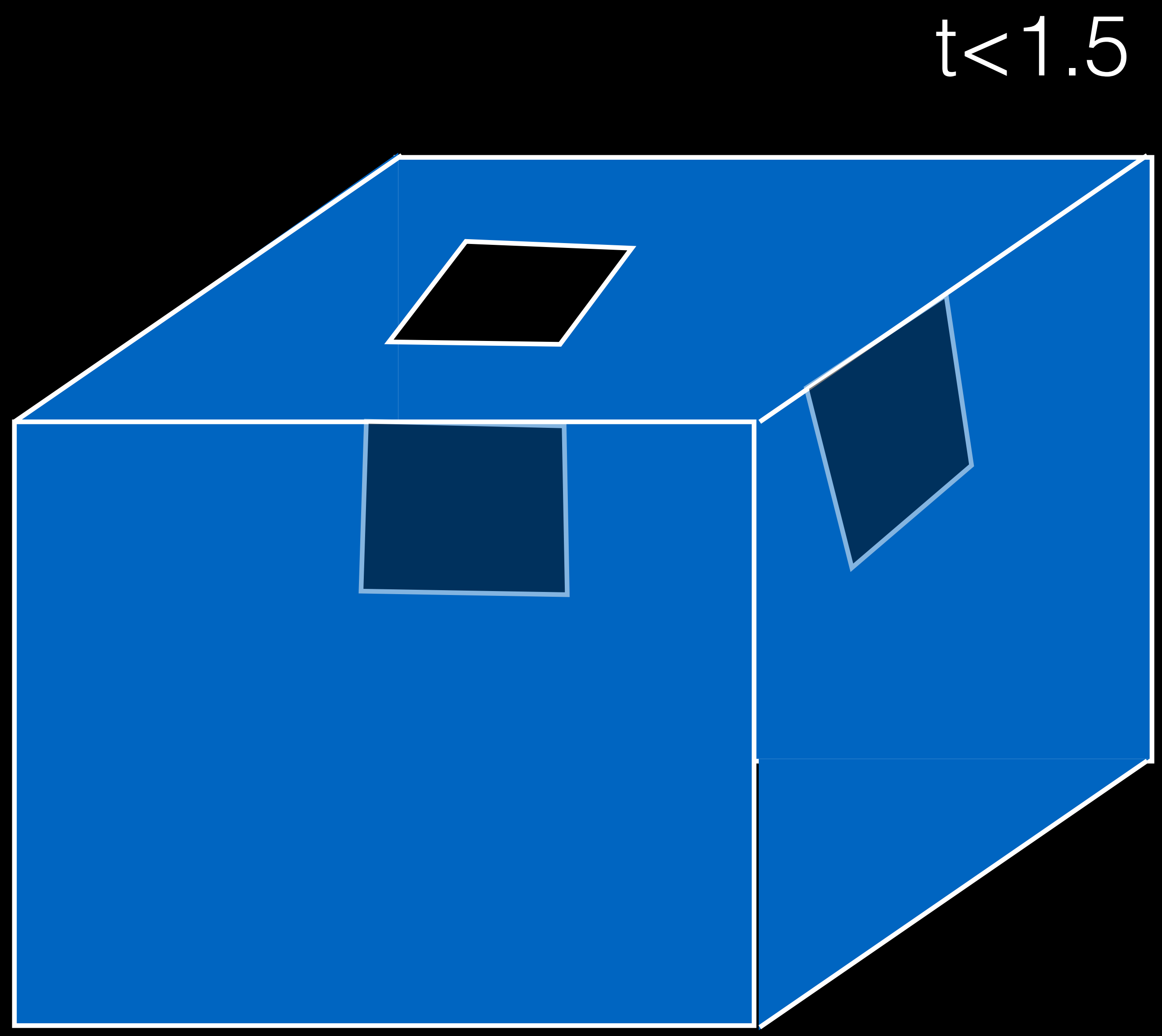

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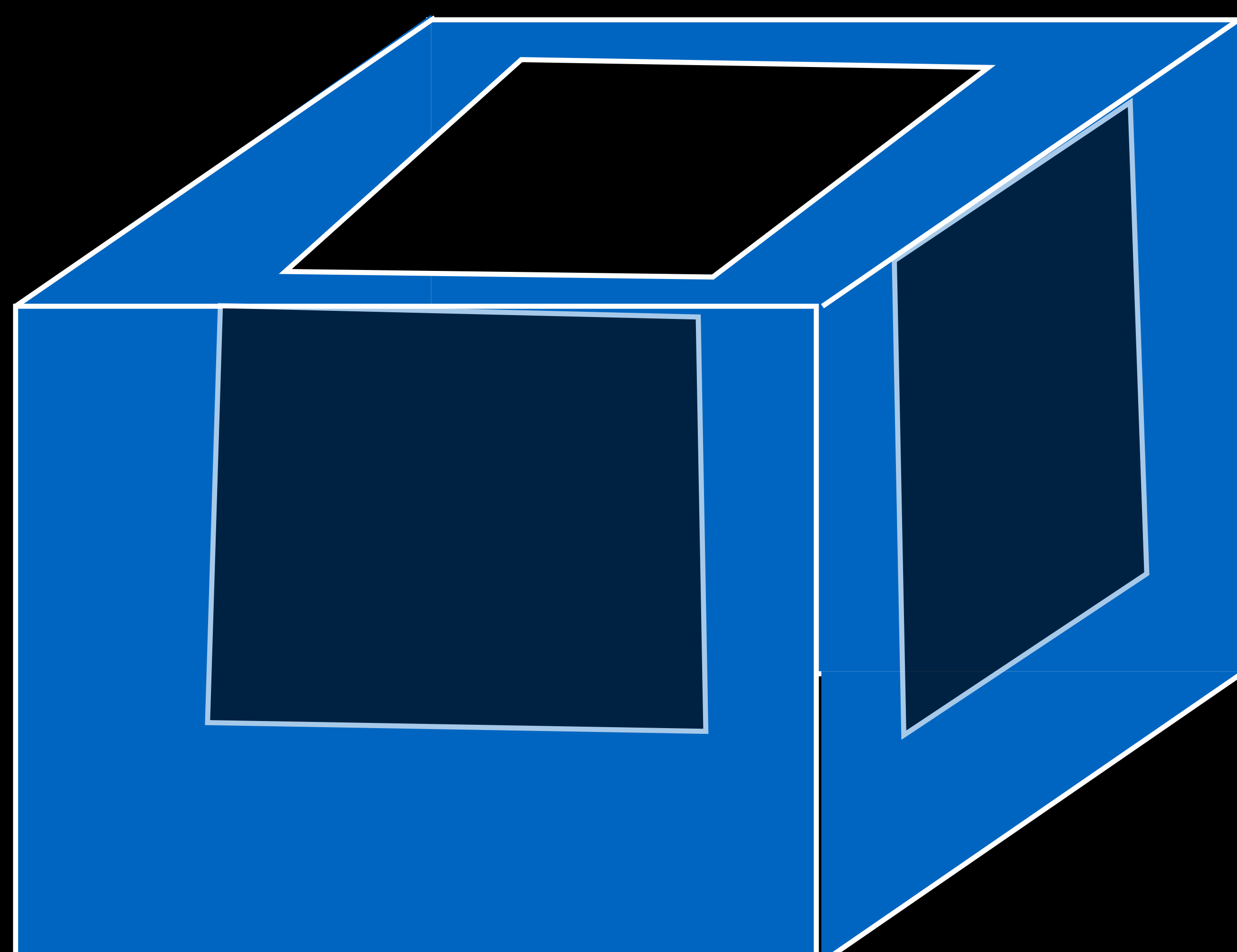
t<3.



Speeding up RTM

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- High-order stencils
  - Space domain 12-30th order
  - 4th order in time
- Go through grid in pencil shapes
- Vectorize the code
- Follow the wave-field

Speeding up Downward continuation

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- FFD and/or smart choice of reference velocities
- Follow the wave-field
- Use different grid sampling at different frequencies (large cells at larger frequencies)
- Stop downward continuing higher frequencies at certain depths

Speeding up Downward continuation

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- Use different grid sampling at different frequencies (large cells at larger frequencies)
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Models of Q

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- Q varies as a function of frequency and material (spatially)
- Q is constant as a function of frequency and varies spatially
- As we increase in depth frequencies have decayed to the point of being unimportant
- As we increase in time useful frequencies decrease

Fractional Laplacian

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$$\left[\eta\mathbf{L} + \tau\mathbf{H}\frac{\mathbf{d}}{\mathbf{dt}} - \mathbf{v}^{-2}\frac{\partial^2}{\partial\mathbf{t}^2}\right]P(t) = f(t)$$

$$\mathbf{L} = (-\nabla^2)^{\gamma+1} \qquad \mathbf{H} = (-\nabla^2)^{\gamma+\frac{1}{2}}$$

$$\eta = -v^{2\gamma}w_0^{-2\gamma}\cos\pi\gamma \qquad \tau = -v^{2\gamma-1}w_0^{-2\gamma}\sin\pi\gamma$$

$$\gamma = \frac{1}{\tan^{-1}\frac{1}{Q}}$$

Zhu(2014)

Fractional Laplacian

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$$\left[\eta \mathbf{L} + \tau \mathbf{H}\frac{\mathbf{d}}{\mathbf{dt}} - \mathbf{v}^{-2}\frac{\partial^{\mathbf{2}}}{\partial \mathbf{t}^{\mathbf{2}}}\right]P(t) = f(t)$$

Dispersion component from attenuation

$$\mathbf{H} = \left(-\nabla^{\mathbf{2}}\right)^{\gamma+\frac{1}{2}}$$

os $\pi\gamma$

$$\tau = -v^{2\gamma-1}w_0^{-2\gamma}\sin\pi\gamma$$

$$\gamma = \frac{1}{\tan^{-1}\frac{1}{Q}}$$

Zhu(2014)

Fractional Laplacian

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$$\left[\eta \mathbf{L} + \tau \mathbf{H}\frac{\mathbf{d}}{\mathbf{dt}} - \mathbf{v}^{-2}\frac{\partial^2}{\partial \mathbf{t}^2}\right] P(t) = f(t)$$

Amplitude decay term

$$\mathbf{L} = (-\nabla$$

$$\mathbf{H} = (-\nabla^2)^{\gamma+\frac{1}{2}}$$

$$\eta = -v^{2\gamma} w_0^{-2\gamma} \cos \pi\gamma \qquad \tau = -v^{2\gamma-1} w_0^{-2\gamma} \sin \pi\gamma$$

$$\gamma = \frac{1}{\tan^{-1}\frac{1}{Q}}$$

Zhu(2014)

Fractional Laplacian

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$$\left(\nabla^2 - \tau\nabla^2\frac{d}{dt} - v^{-2}\frac{\partial^2}{\partial t^2}\right)P(t) = f(t)$$

$$\tau = -v^{2\gamma-1}w_0^{-2\gamma}\sin\pi\gamma$$

$$\gamma = \frac{1}{\tan^{-1}\frac{1}{Q}}$$

Zhu(2014)

RTM imaging condition

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$$(\mathbf{Ps}) * (\mathbf{Pd})$$

s,**d** - Source and data

P - Propagation

- Standard approach
  - Higher frequencies don't exist because absent from data at larger times
- Approximate Q approach
  - Higher frequencies don't exist, absent from source and data

Standard propagation

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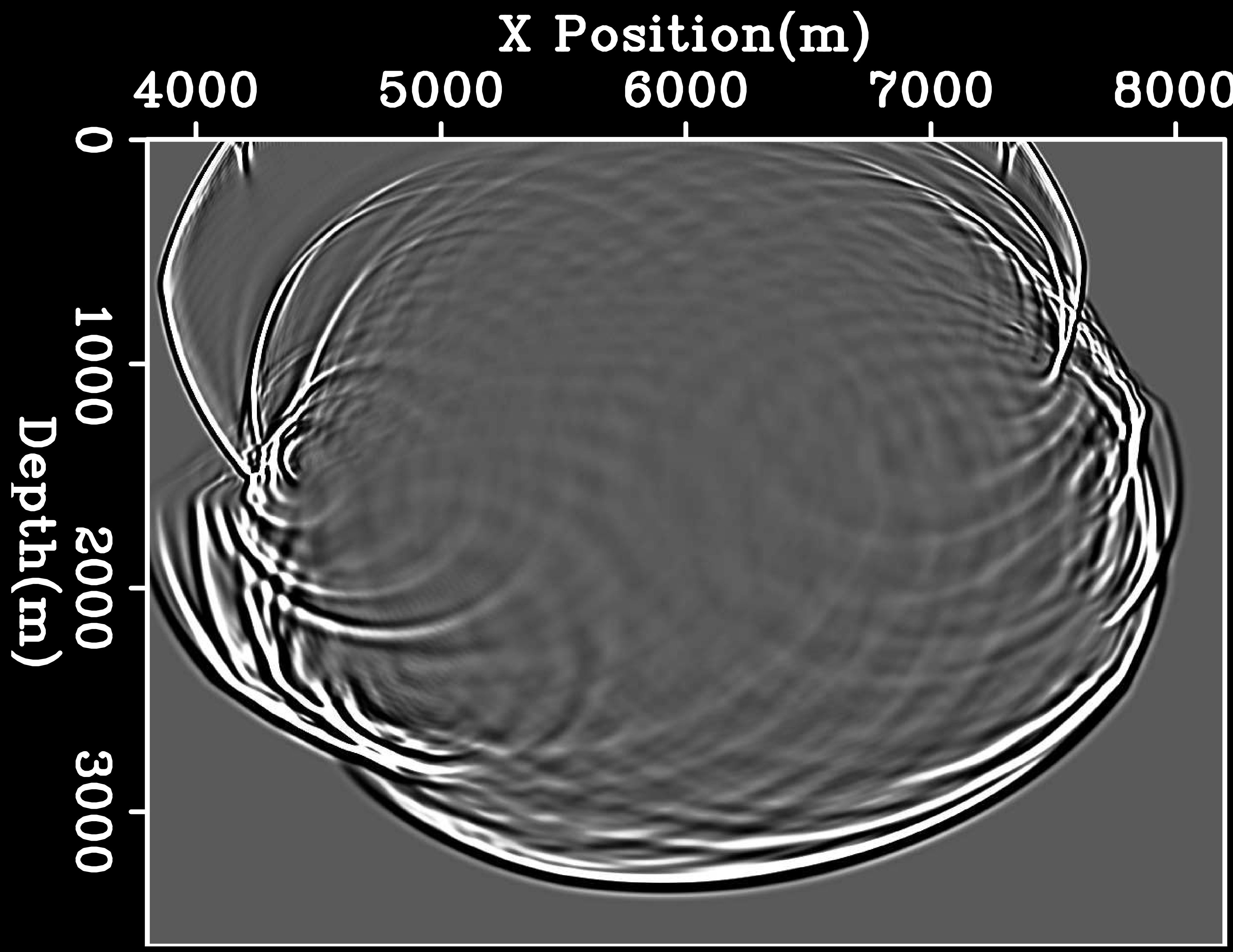

Q with changing grid

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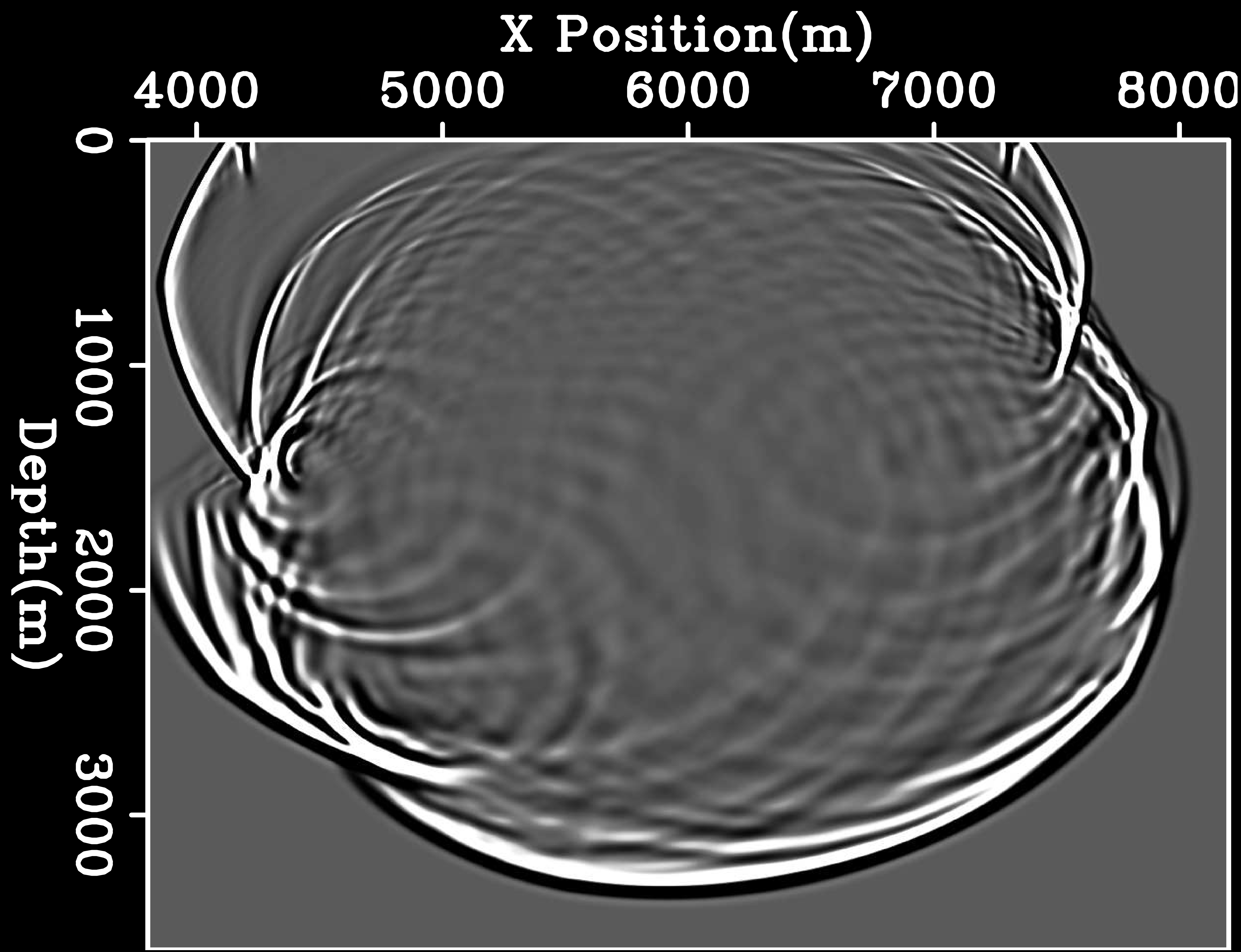

Frequency change over time

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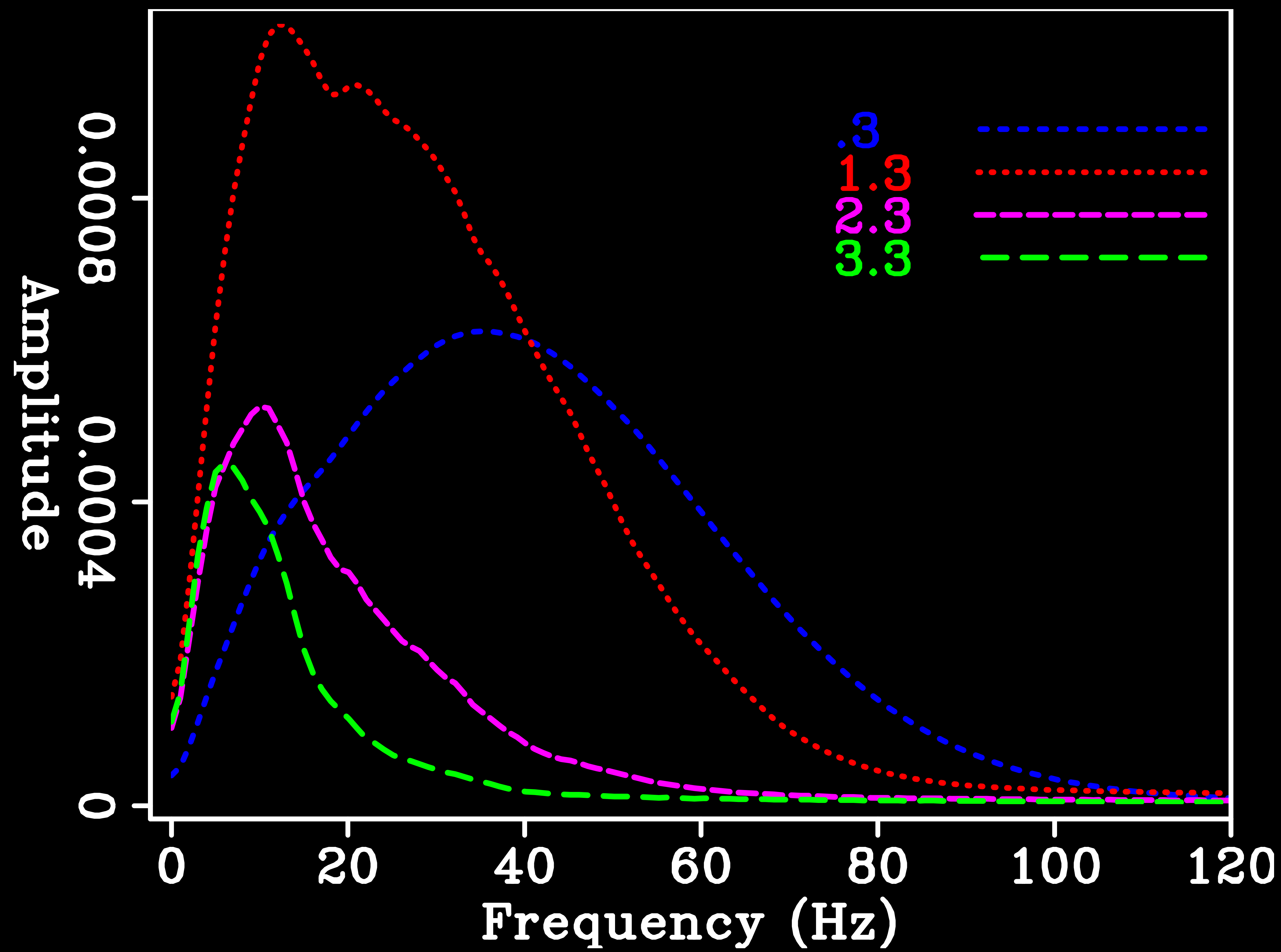

Speedup vs Q

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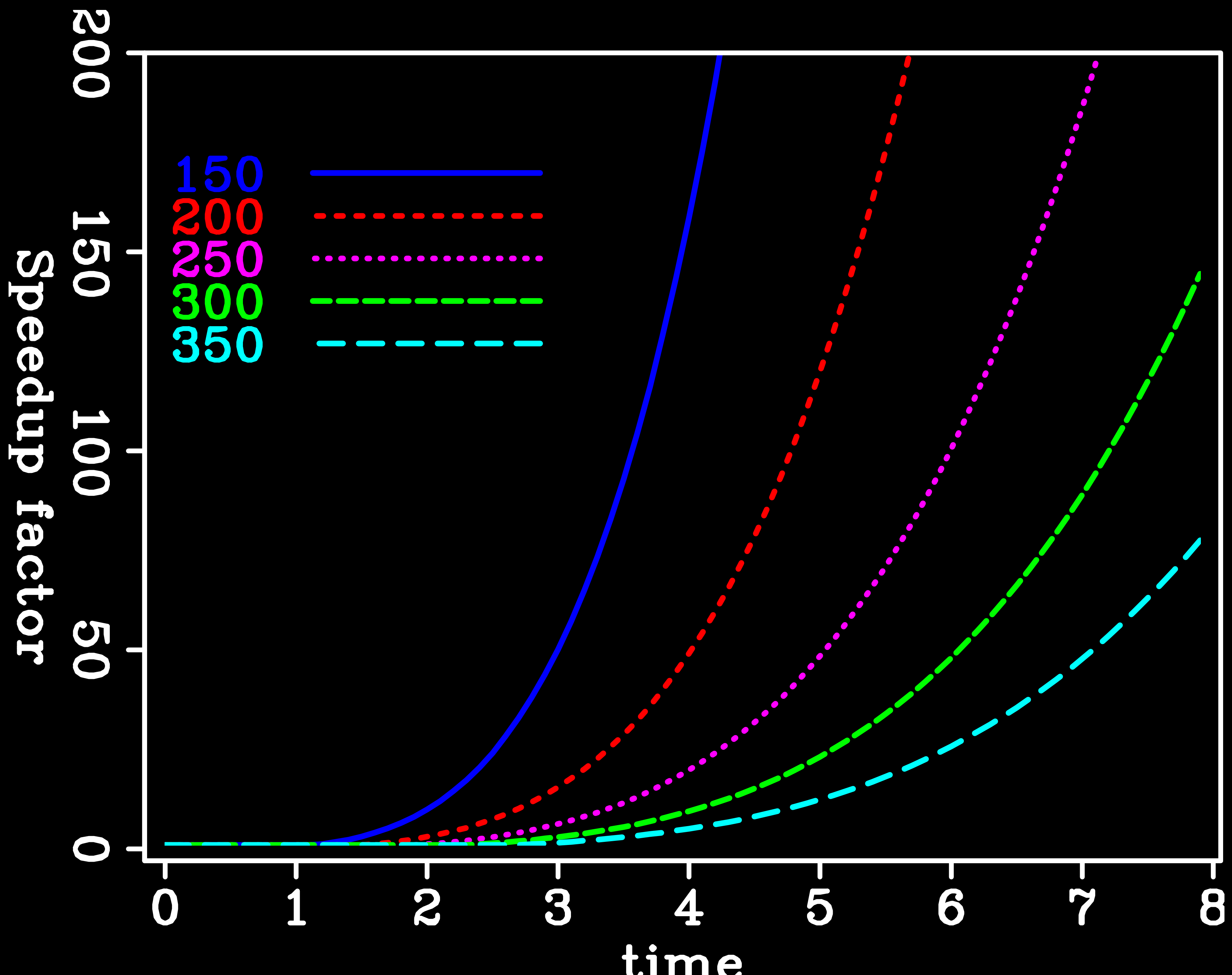

Following wave-field

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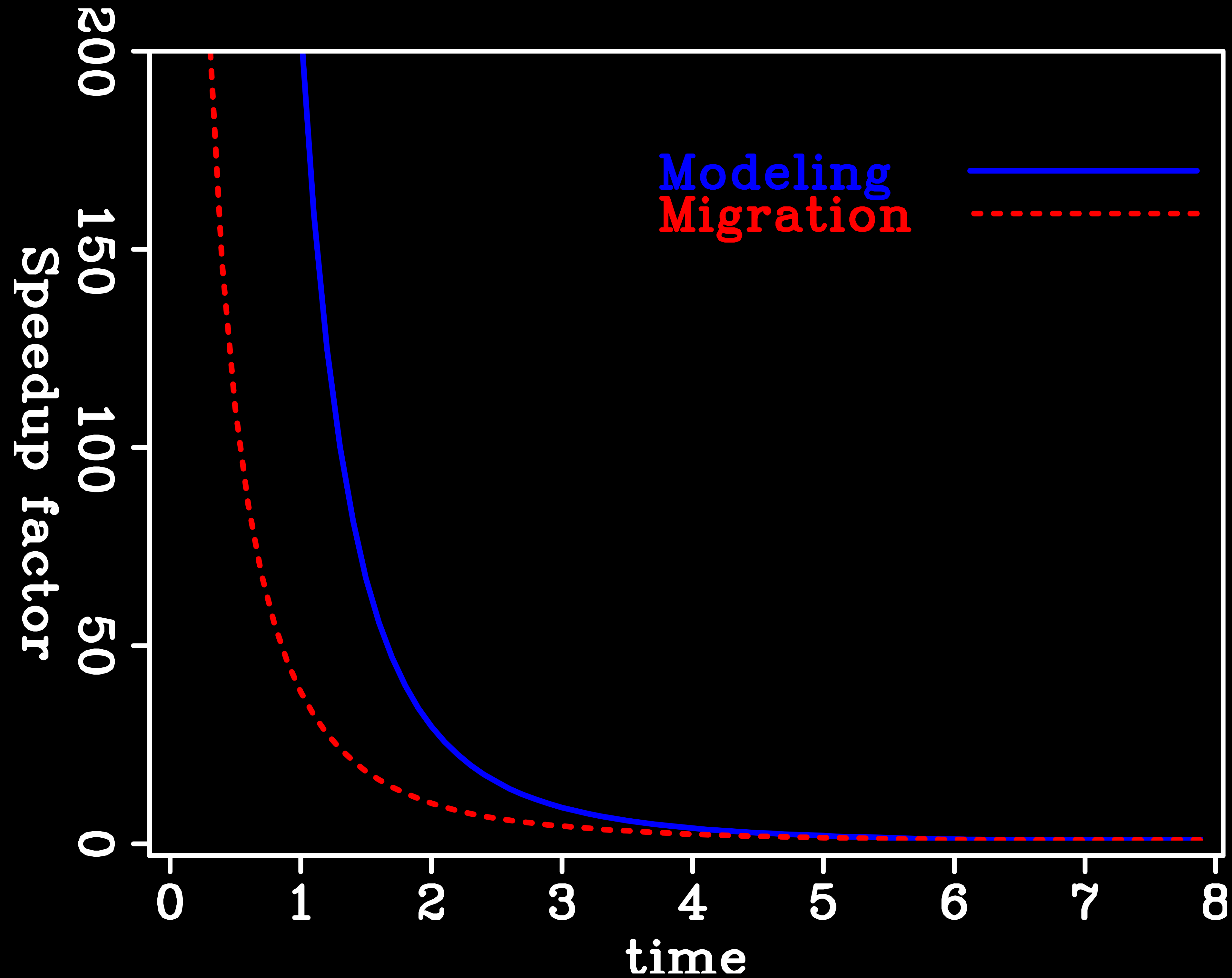

Speedup over time

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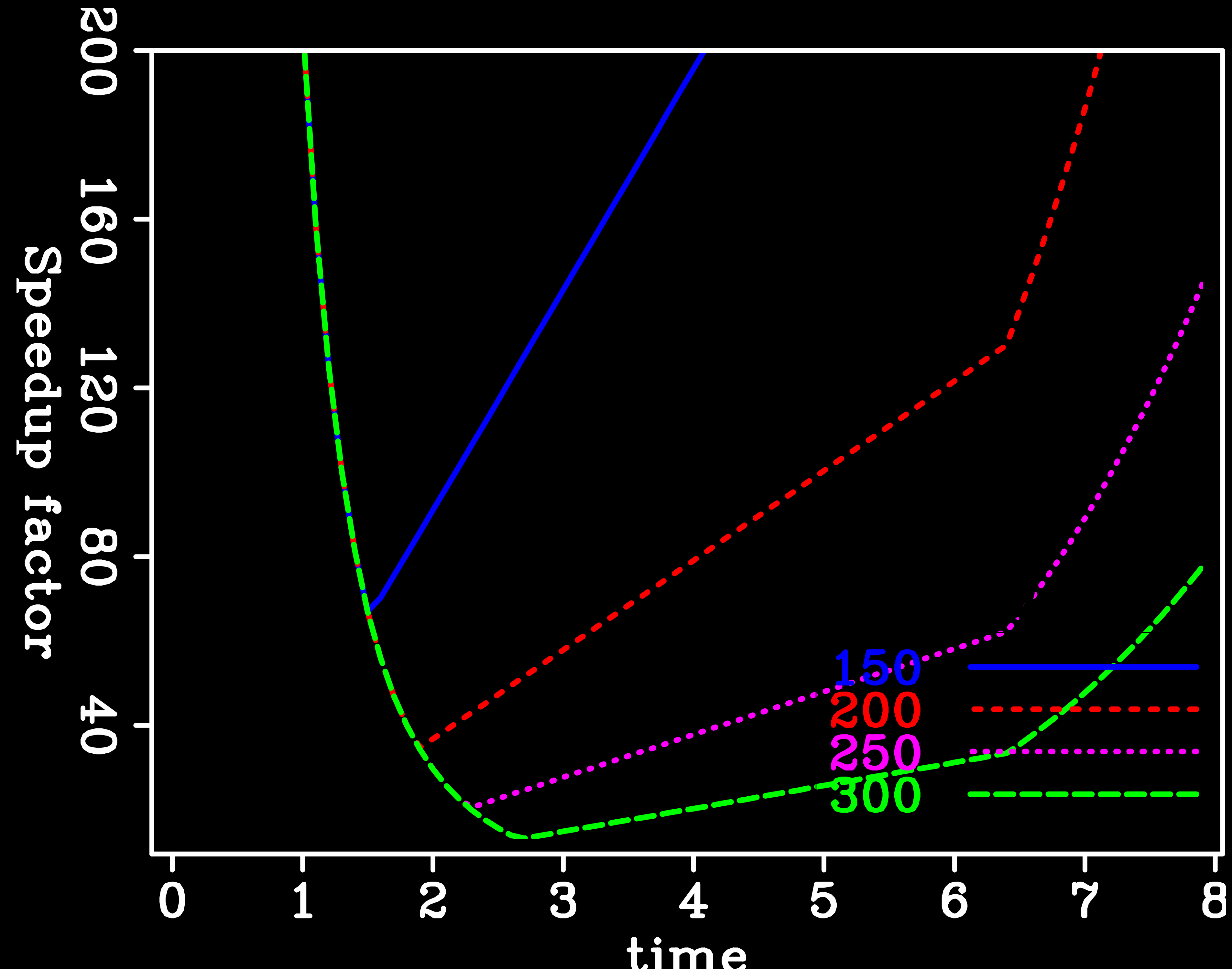

Total speedup

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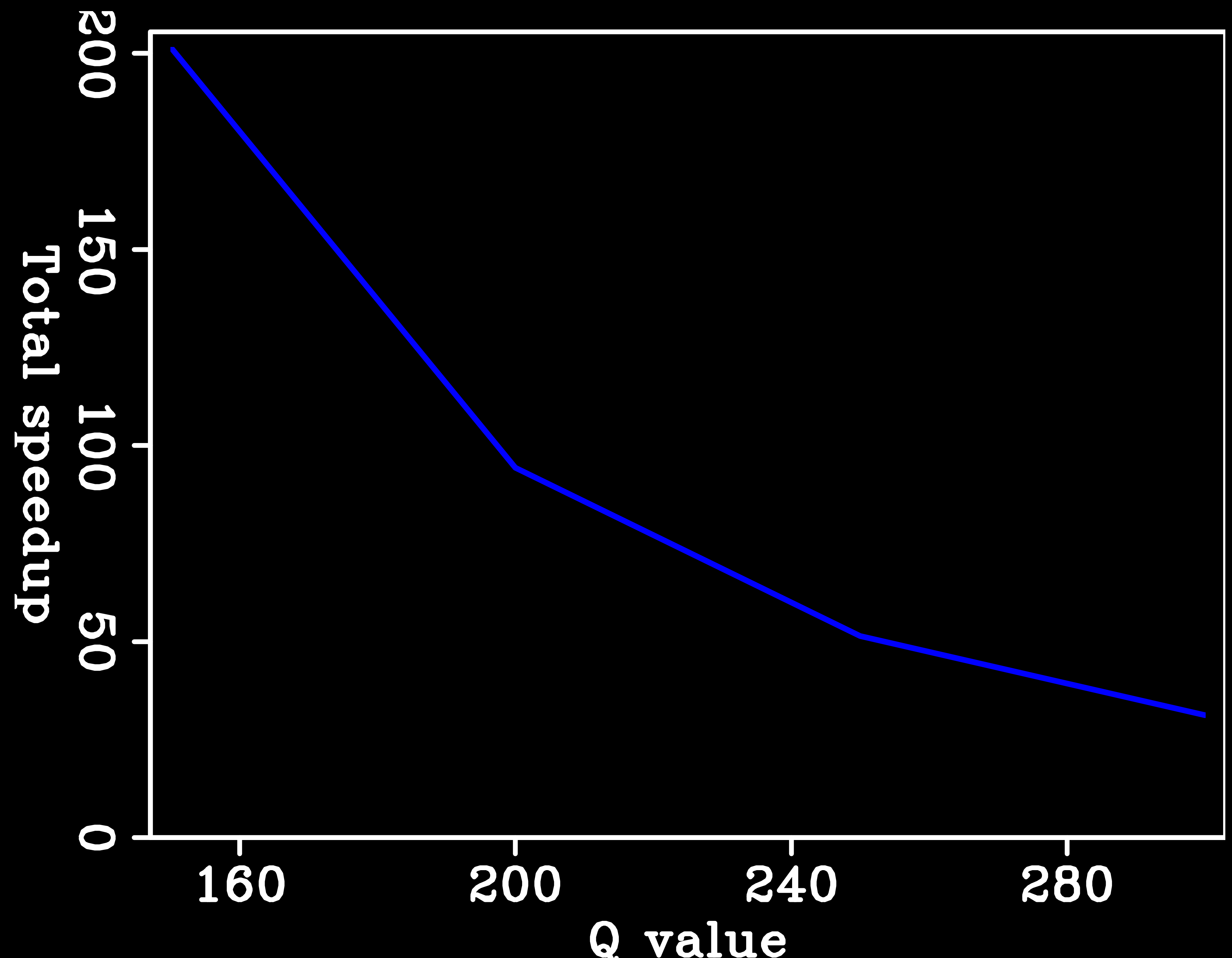

Modified RTM algorithm

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Pre-calculation

For each source:

Source specific initialization

Forward propagate source

Back propagate source

RTM: Pre-calculation

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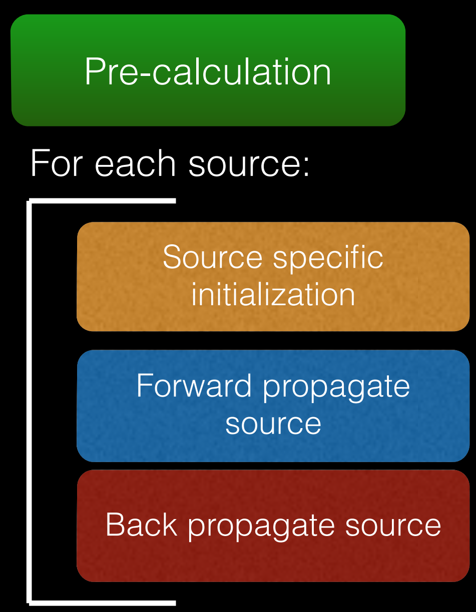

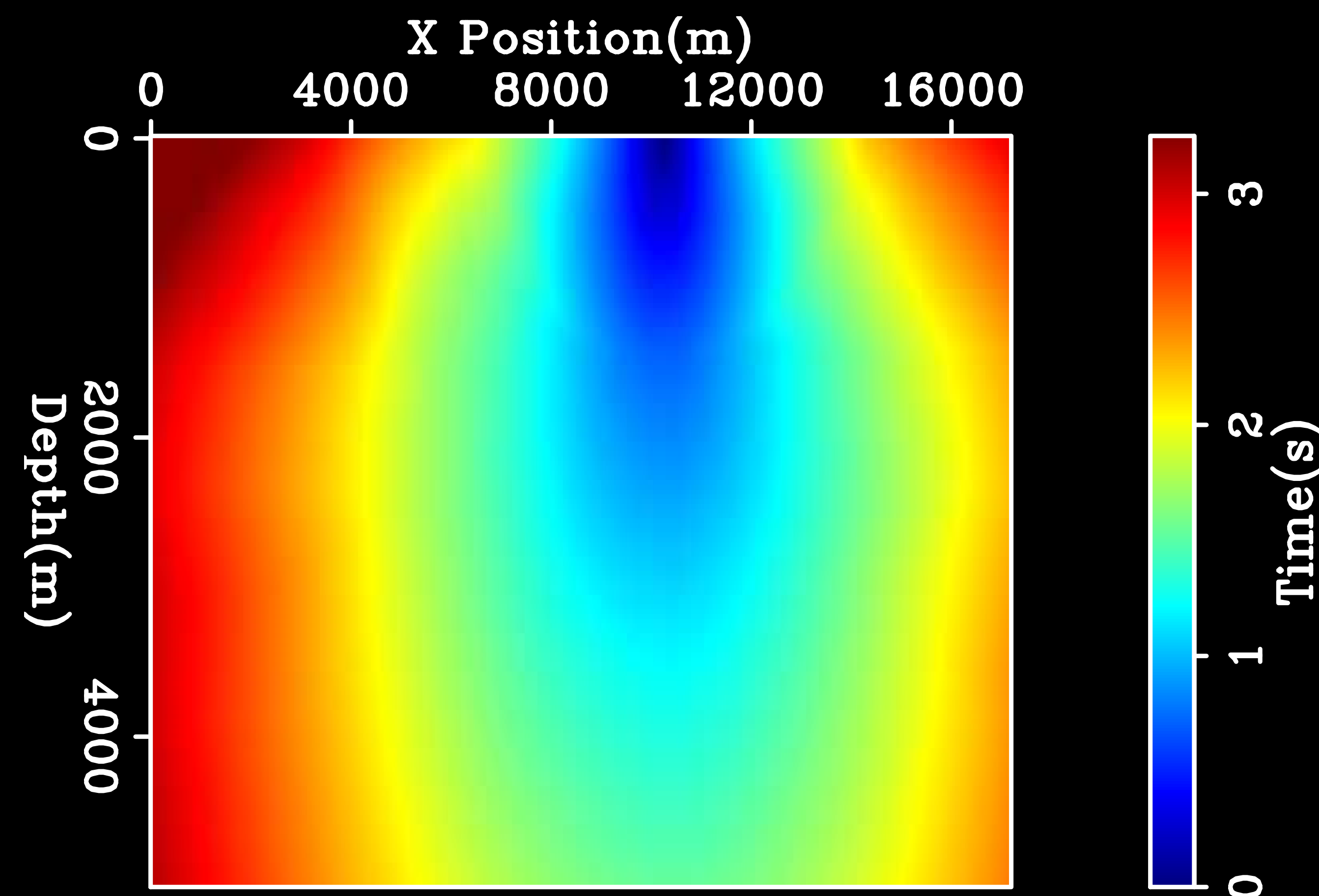

Calculate first arrival travel time maps from every source/ receiver position to every model point

RTM: Source initialization

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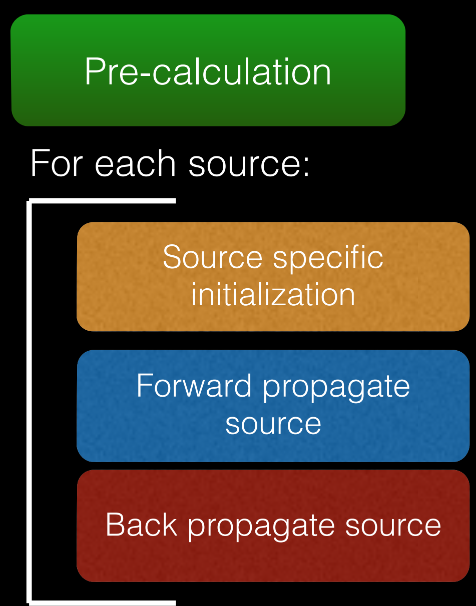

- Break time axis into block
- For each time block
  - Find max propagation location for end of time block
  - Find max frequency which hasn't decayed below noise level
  - Calculate dt, damp based on max freq, min/max vel

RTM:
Forward propagate source

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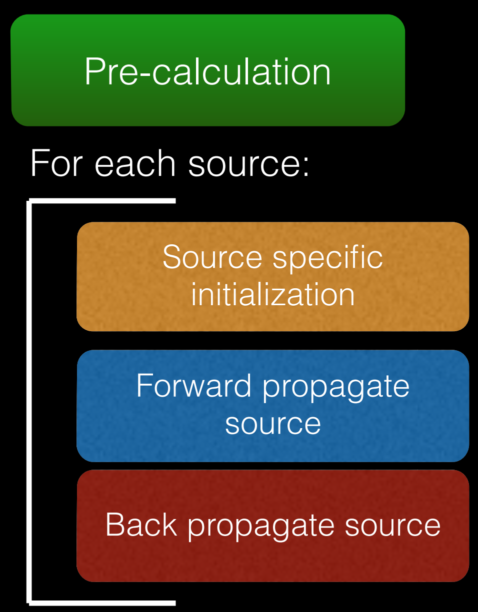

- For each time block
  - Resample wave-fields,velocity to current sampling
  - Loop over time in block
    - Forward wave-fields using attenuated wave equation
    - Store source wave-field at imaging times

RTM: Backward propagate receiver

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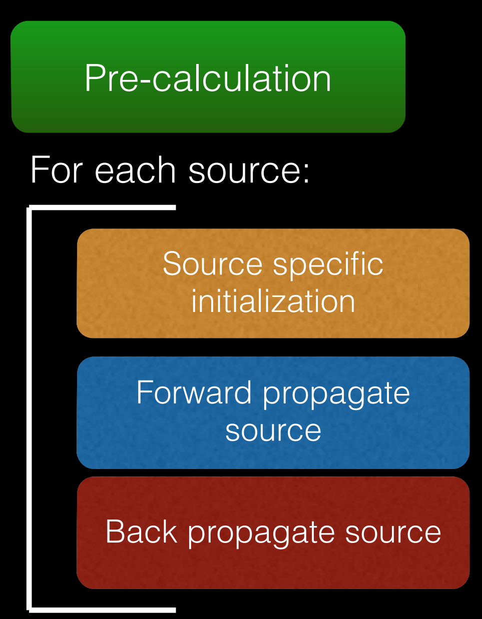

- For each time block
  - Resample wave-fields,velocity,image to current sampling
  - Loop over time in block
    - Backward propagate receiver using standard wave equation
    - Apply imaging condition using stored source wave-field and current receiver wave-field

Standard single shot migration

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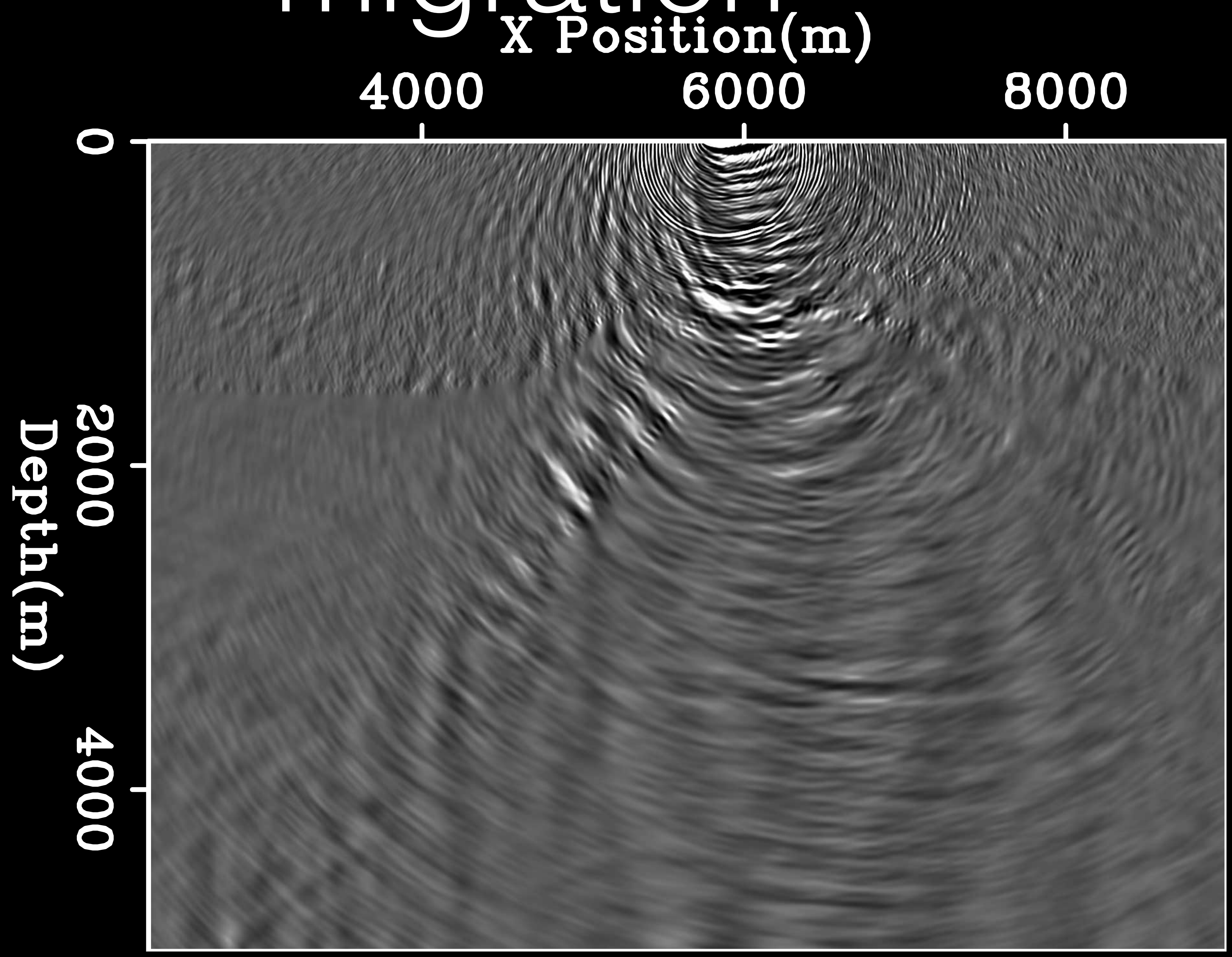

Variable single shot migration

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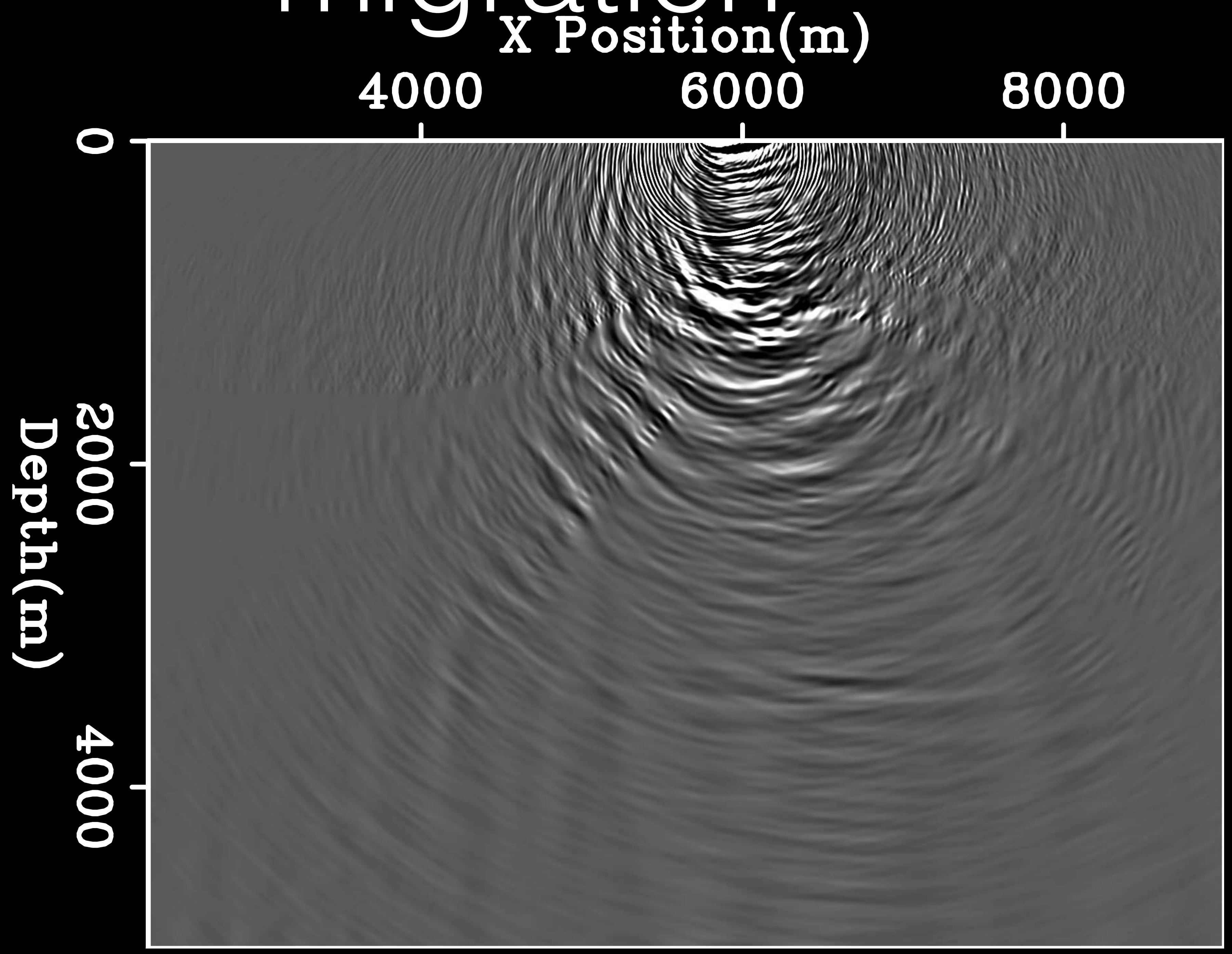

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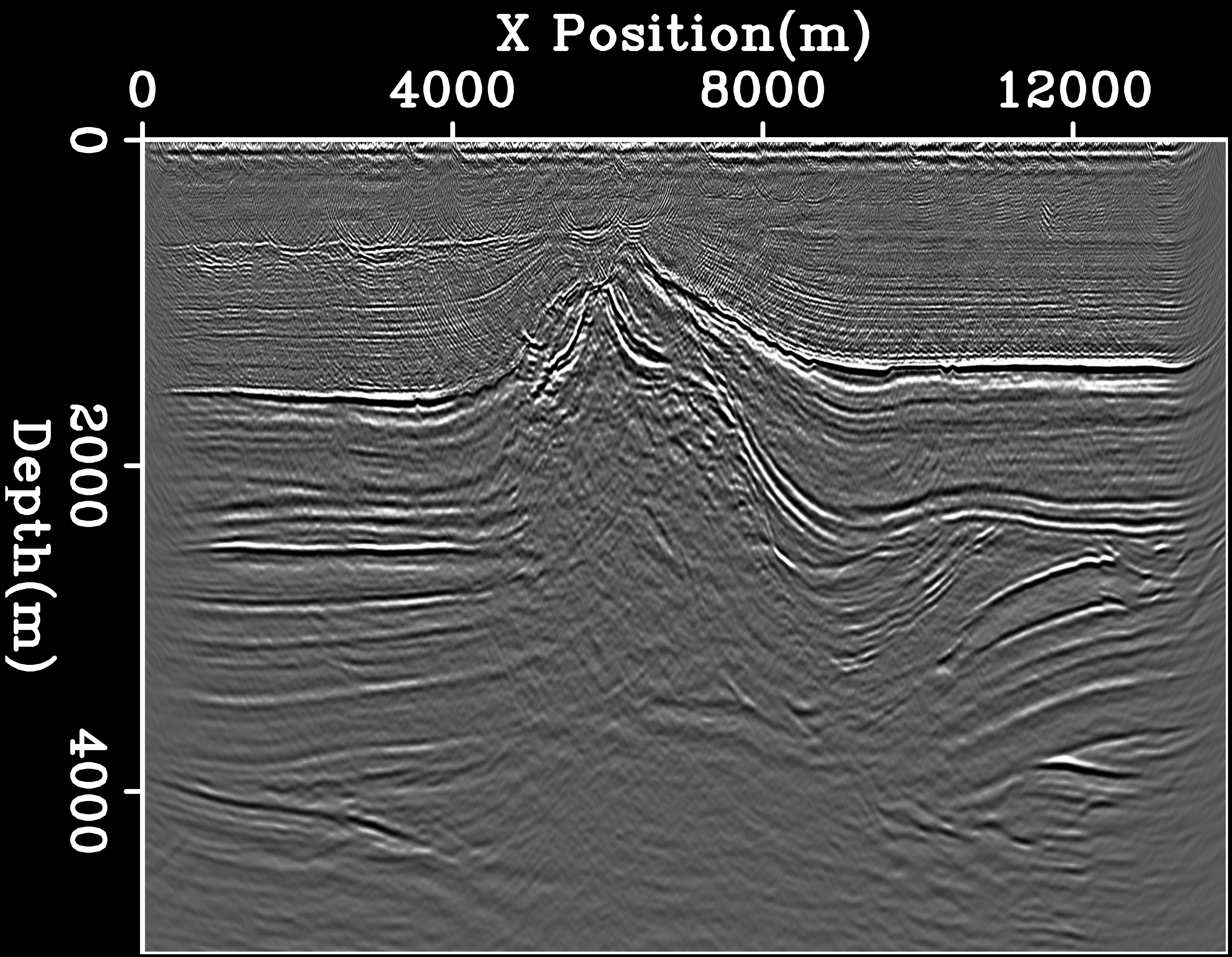

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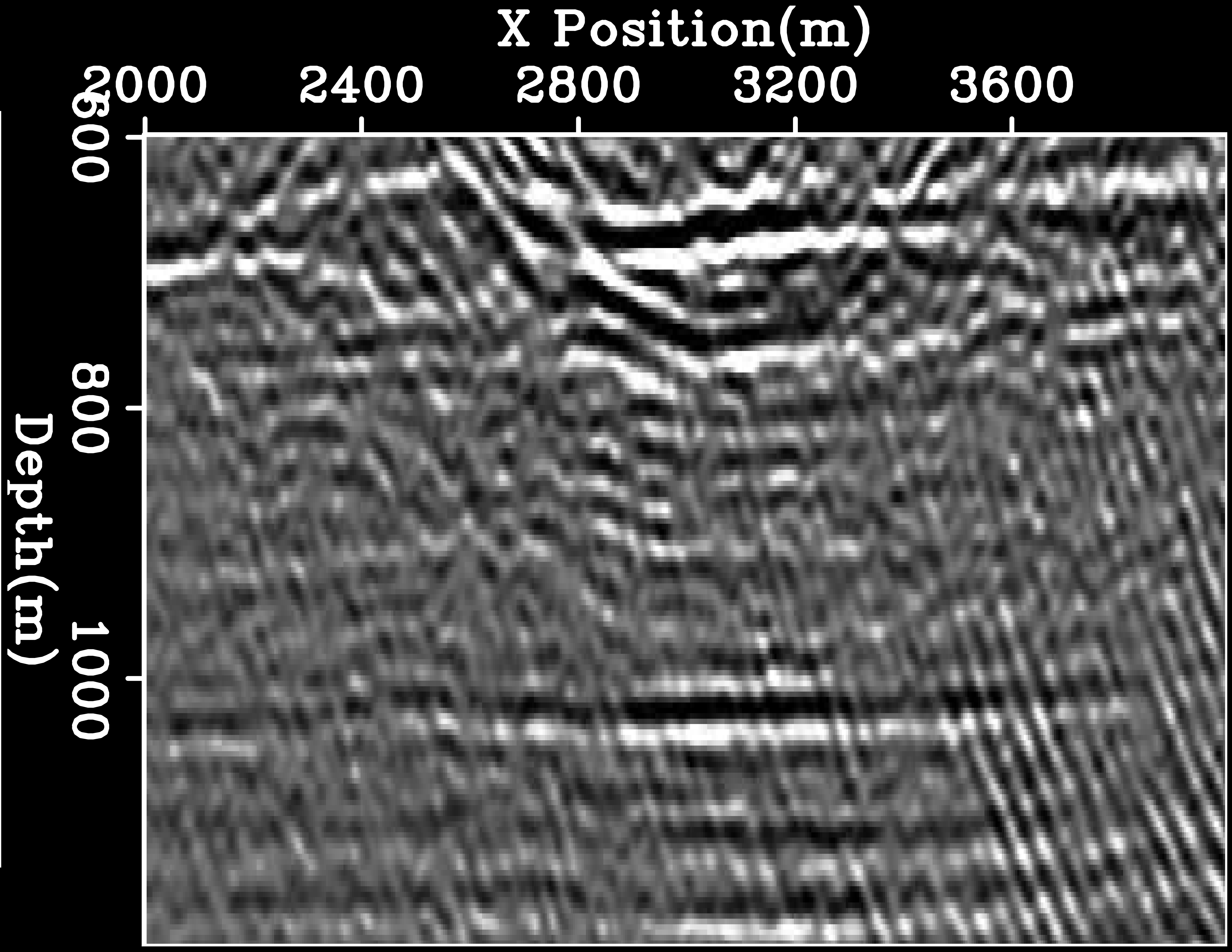

Conclusions

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- Constant Q can be cheaply approximated into a standard time/space domain propagation
- Approach allows for larger grid cells at later times
- Combined with following the wave-field it can lead to significant speedups
- ***Messing with the wavelet***