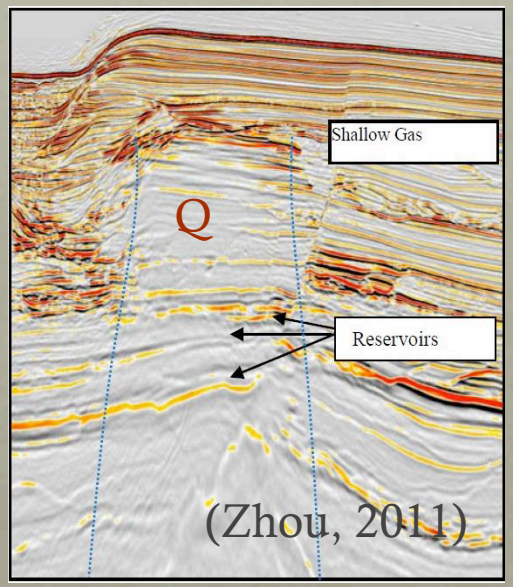
WAVE-EQUATION MIGRATION Q ANALYSIS (WEMQA)

Yi Shen

SEP149 P317-330



Stanford Exploration Project

OUTLINE

- **Introduction:**
  - **Why estimate Q?**
  - **Current methods and new method**
- **Theory**
  - **Image space method**
  - **Wave-equation based tomography**
  - **Inversion**
- **Numerical tests**
- **Conclusion**

INTRODUCTION

- **In seismic imaging**
  - Enhances image quality/sharpness
  - Improves velocity analysis
  - Better interprets the effects of AVO and anisotropy
- **In seismic-acquisition design**
  - Helps determine how much signal may reach the target
- **In reservoir characterization**
  - Determines the contents of a reservoir (e.g. gas saturation)

INTRODUCTION

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INTRODUCTION

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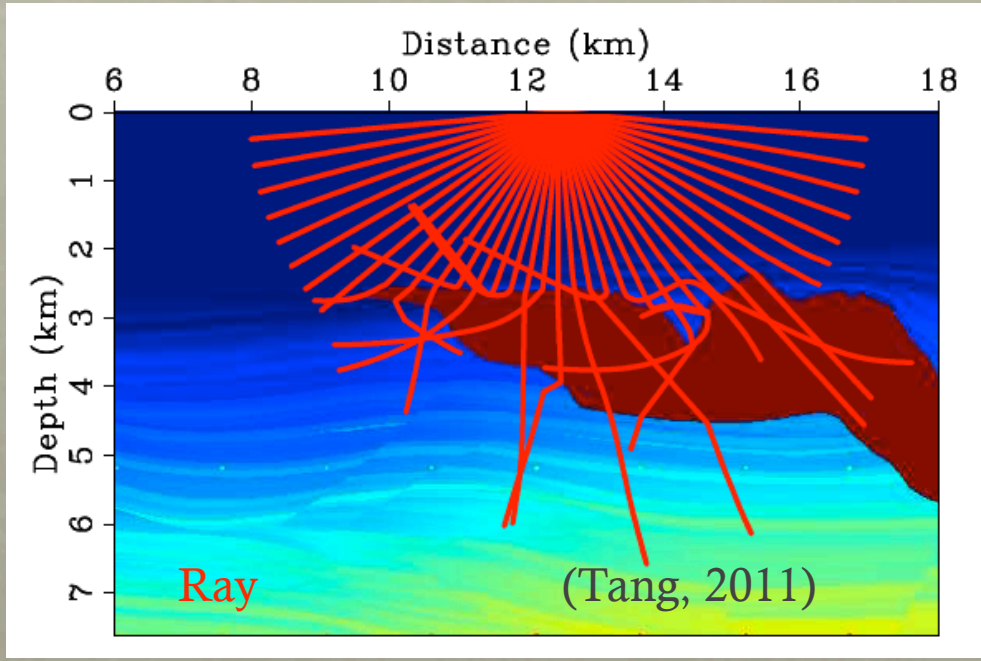
  - Helps determine how much signal may reach the target
- **In reservoir characterization**
  - Determines the contents of a reservoir (e.g. gas saturation)

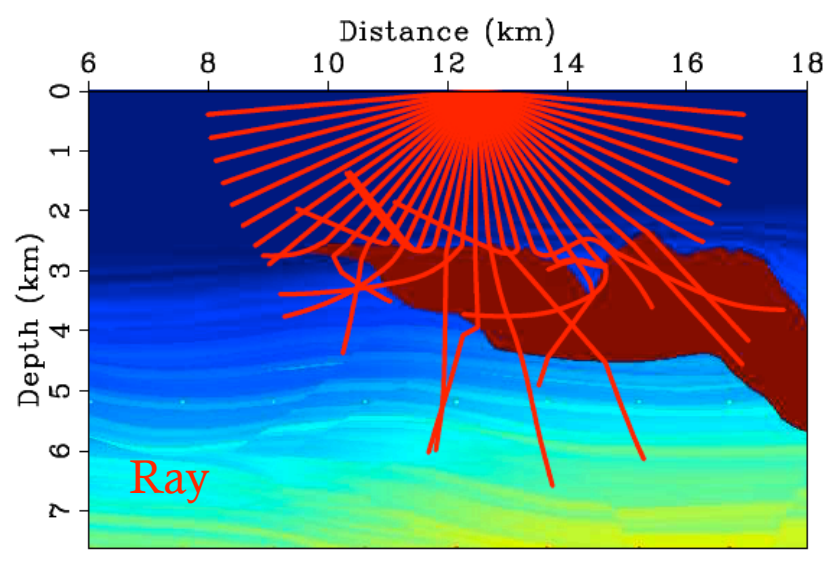
CONVENTIONAL METHODS

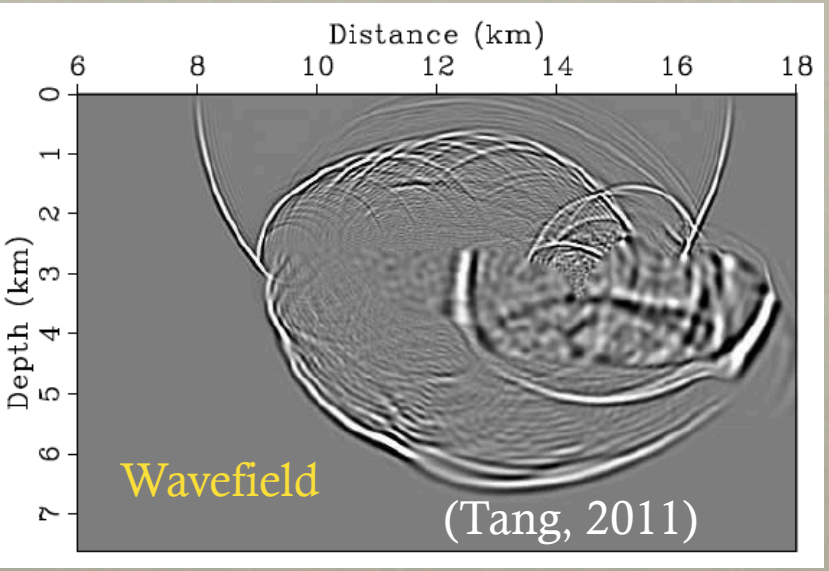
- **Ray-based method** (Tonn 1991, Quan and Harris 1997, Dasgupta and Clark 1998, Leaney 1999, Mateeva 2003, Plessix 2006, Reine et al. 2012)
  - **Difficulty handling complex subsurface structure, e.g. sharp boundary, multi-pathing, etc.**



NEW METHOD

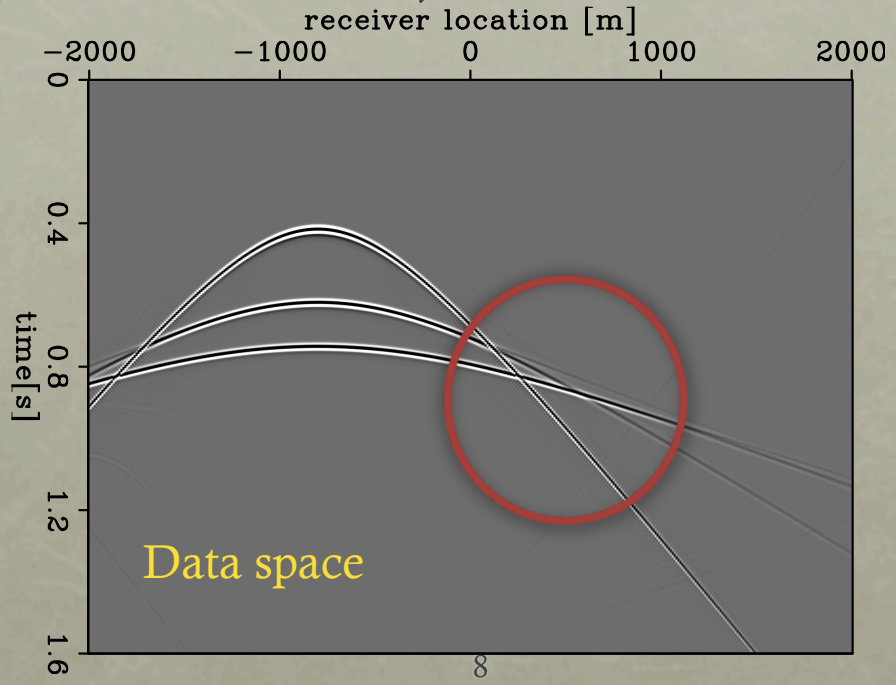
- **Wave-equation based method**
  - **Handle complex subsurface structure**





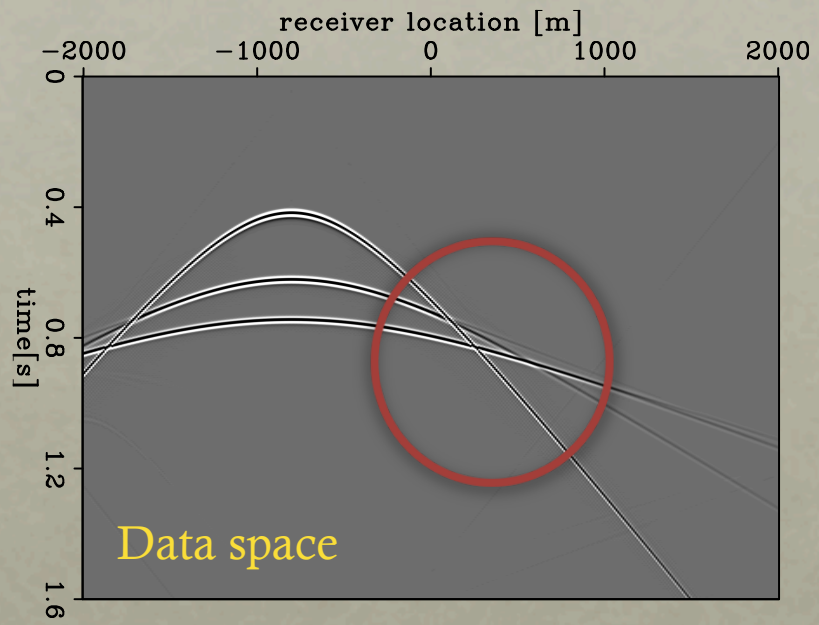
CONVENTIONAL METHODS

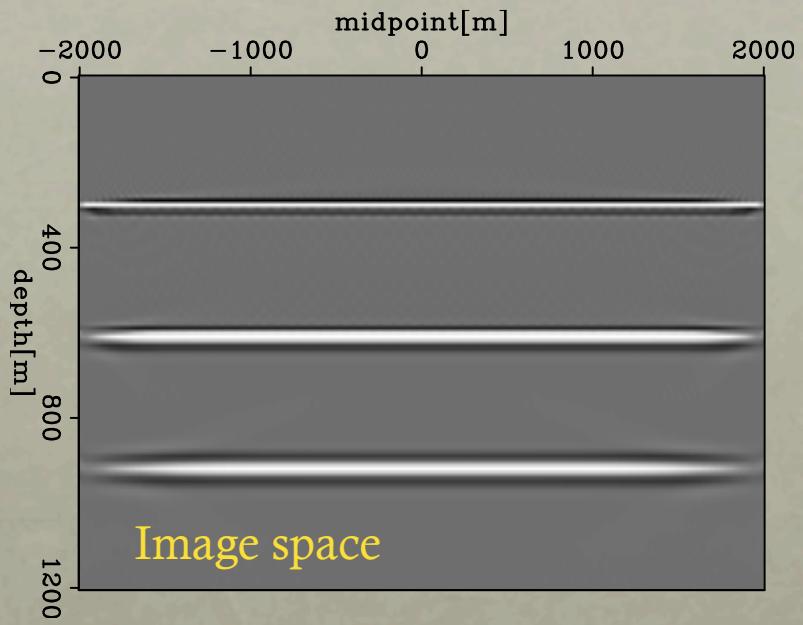
- **Data space** (Tonn 1991, Quan and Harris 1997, Dasgupta and Clark 1998, Leaney 1999, Mateeva 2003, Plessix 2006, Reine et al. 2012)
  - **Noise**
  - **Complex: diffractions, close or even crossing events**



NEW METHOD

- Image space
  - Suppresses the noise
  - Simplifies and focuses the events (e.g. crossing events)





THEORY

- **Image space**
- **Wave-equation based tomography**
- **Inversion**

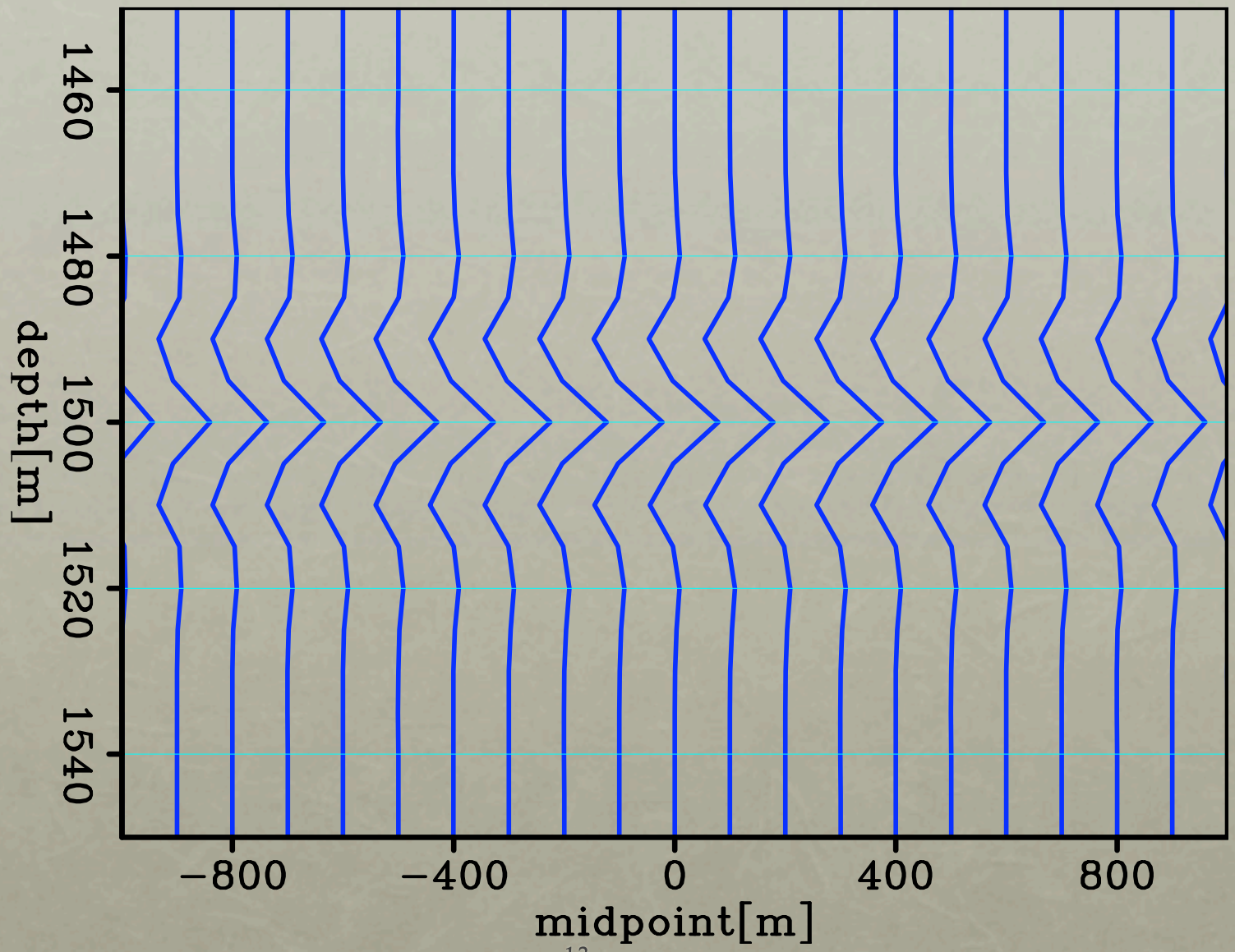
THEORY

- **Image space**
- **Wave-equation based tomography**
- **Inversion**

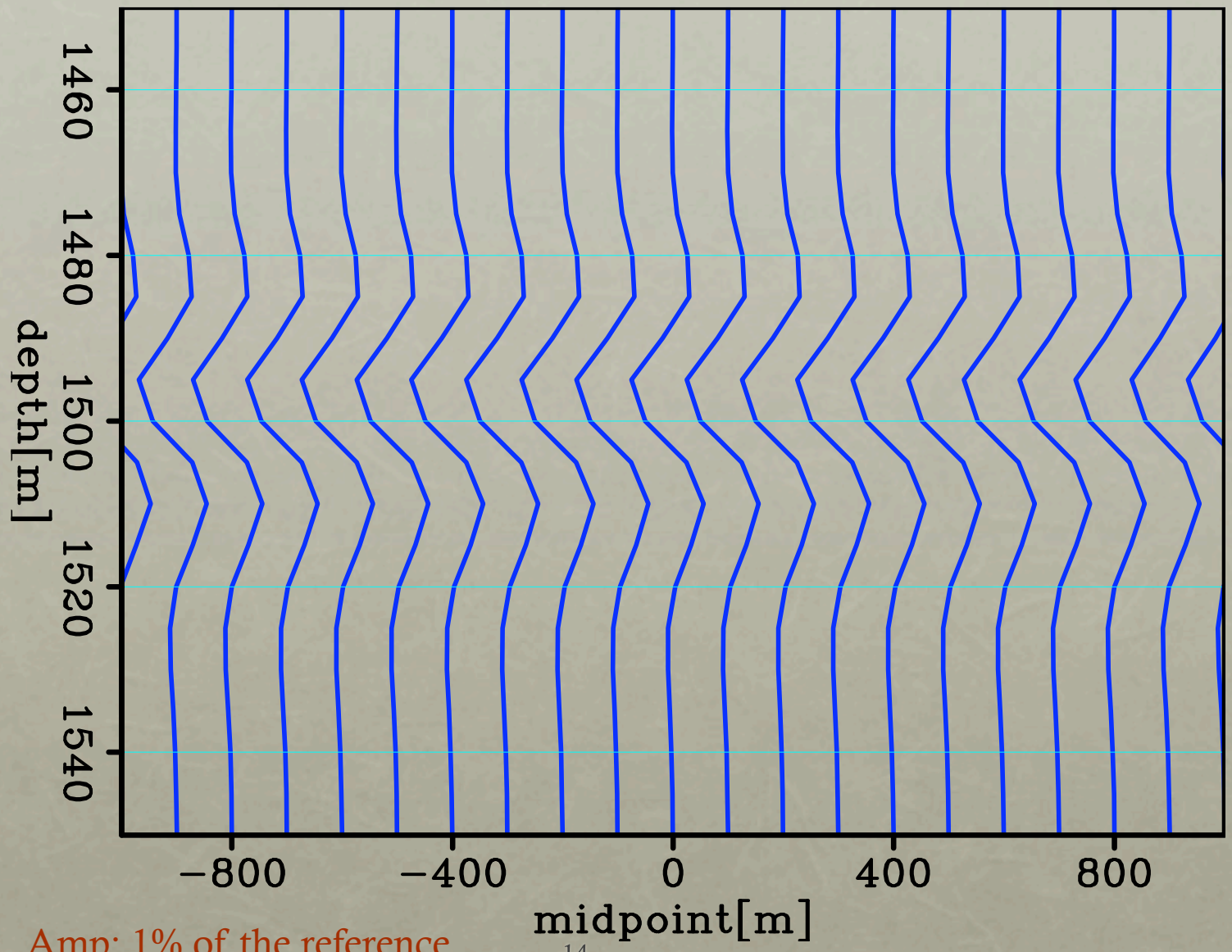
IMAGING WITH Q: ALGORITHM

- Migration with Q compensation
  - Downward continuation with one-way wave equation
    - Fourier Finite Differences (Valenciano et al. 2011)
    - **Extended split-step**
      - Less frequency dispersion

REFERENCE (**NO** ATTENUATION)

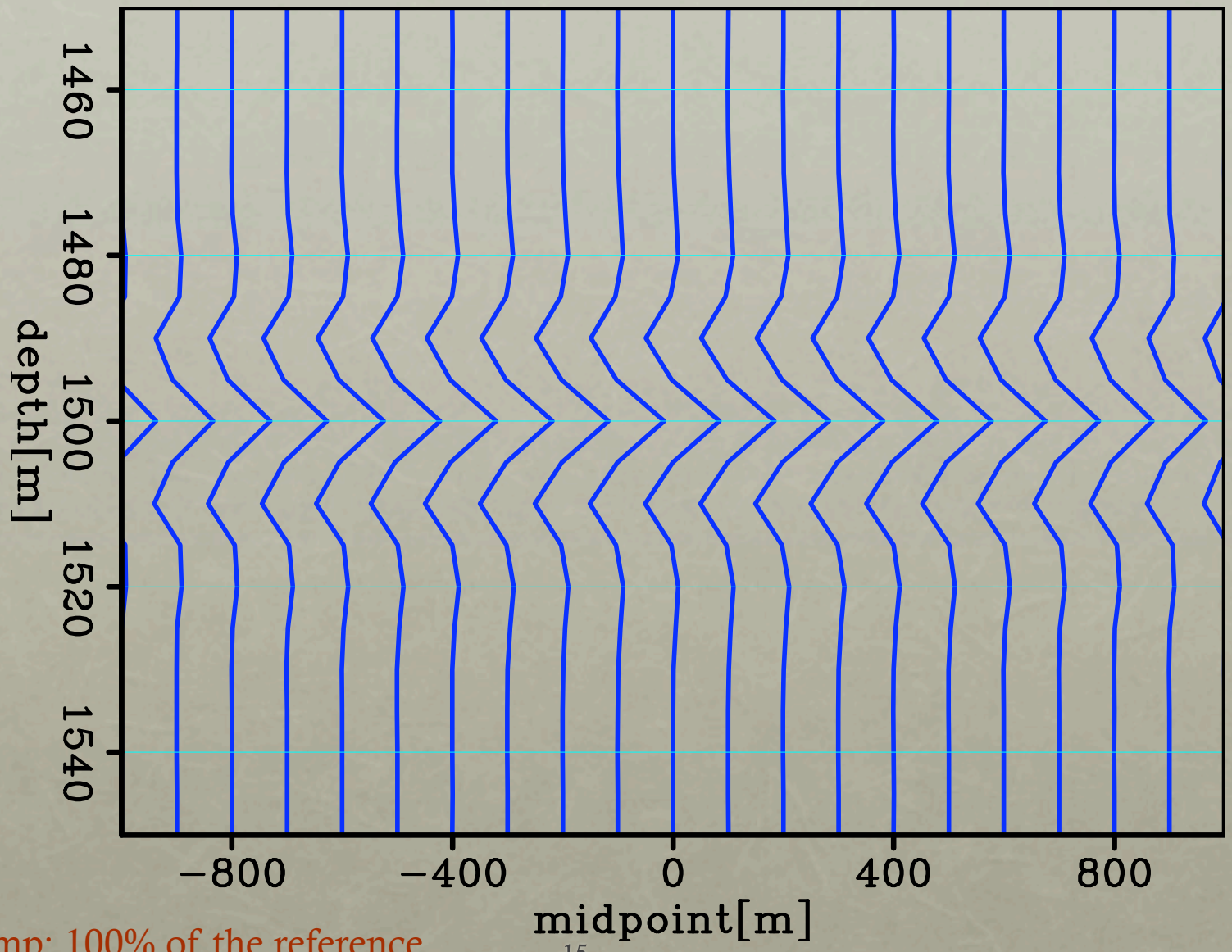


CONVENTIONAL MIGRATION



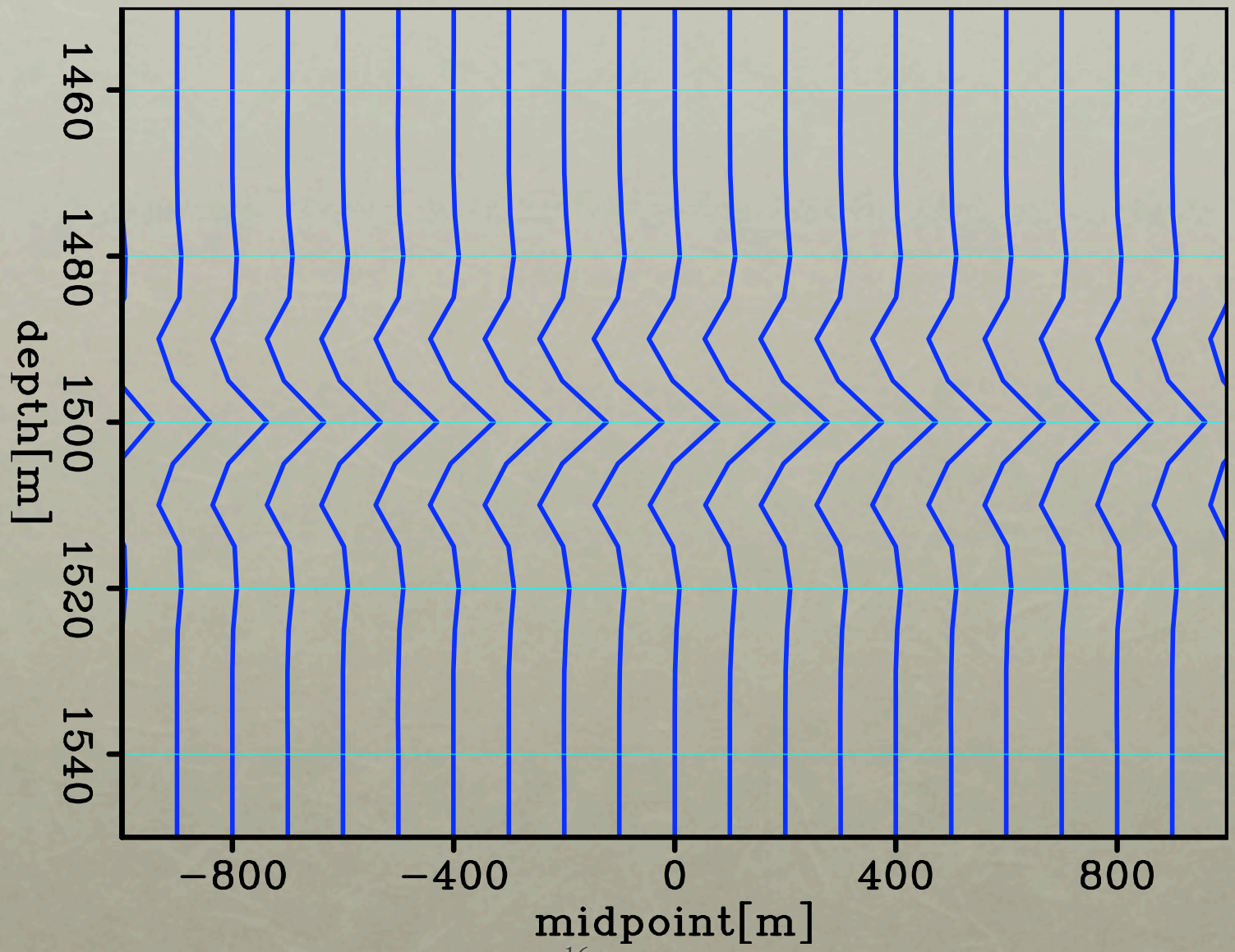
Amp: 1% of the reference

MIGRATION WITH Q COMPENSATION



Amp: 100% of the reference

REFERENCE (**NO** ATTENUATION)



THEORY

- Image space
- **Wave-equation based tomography**
- Inversion

TOMOGRAPHIC OPERATOR

$$\Delta \mathbf{I} = \mathbf{T}\Delta \mathbf{Q}$$

$$\Delta \mathbf{Q} = \mathbf{T}^{*}\Delta \mathbf{I}$$

where

$\Delta \mathbf{Q}$ is the model perturbation

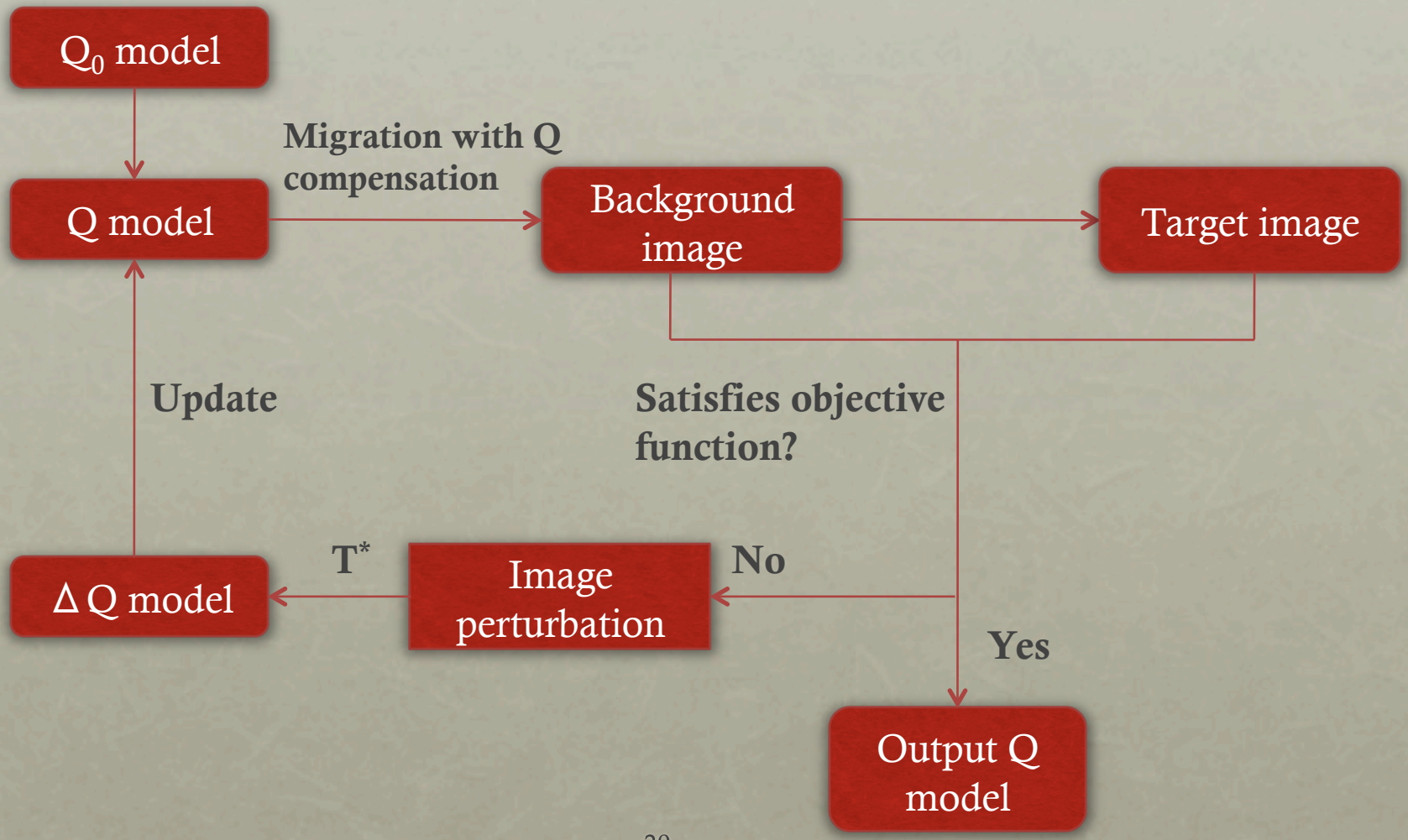
$\Delta \mathbf{I}$ is the image perturbation

$\mathbf{T}$ is the tomographic operator

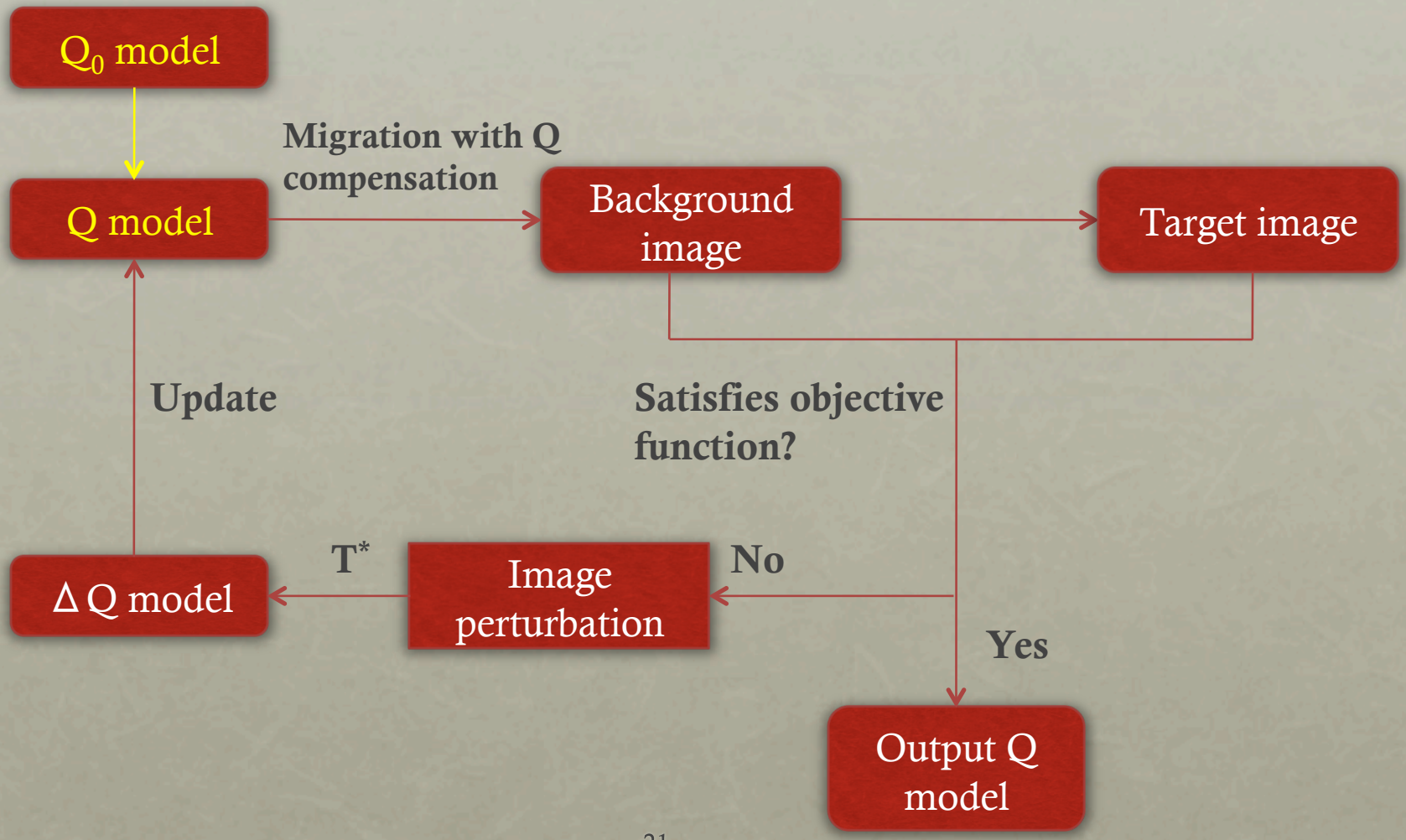
THEORY

- Image-based method
- Wave-equation based tomography
- **Inversion**

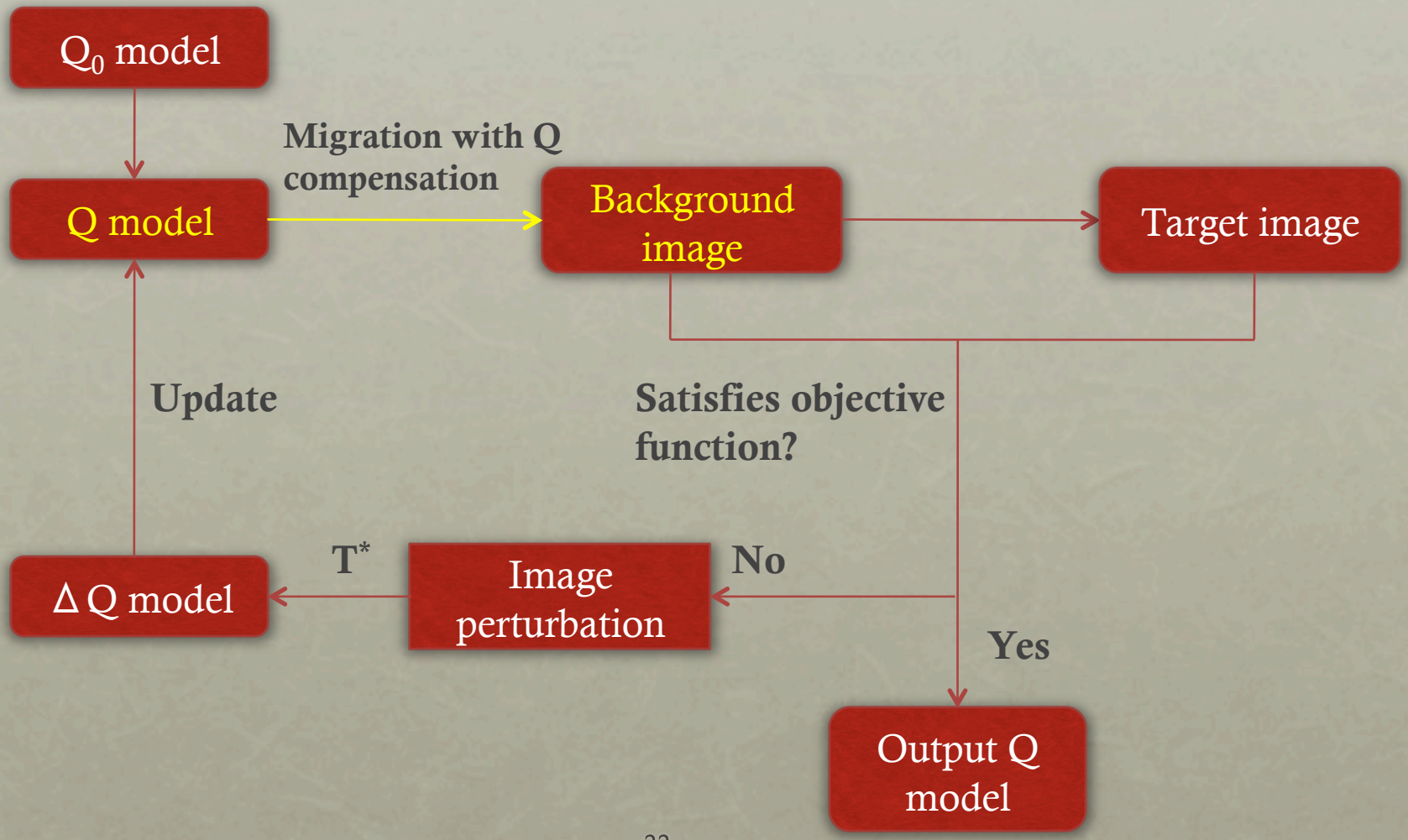
INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
T*
ΔQ model
Image perturbation
No
Yes
Output Q model

INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
T^*
No
Δ Q model
Image perturbation
Yes
Output Q model

INVERSION


Q_0 model
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Satisfies objective function?
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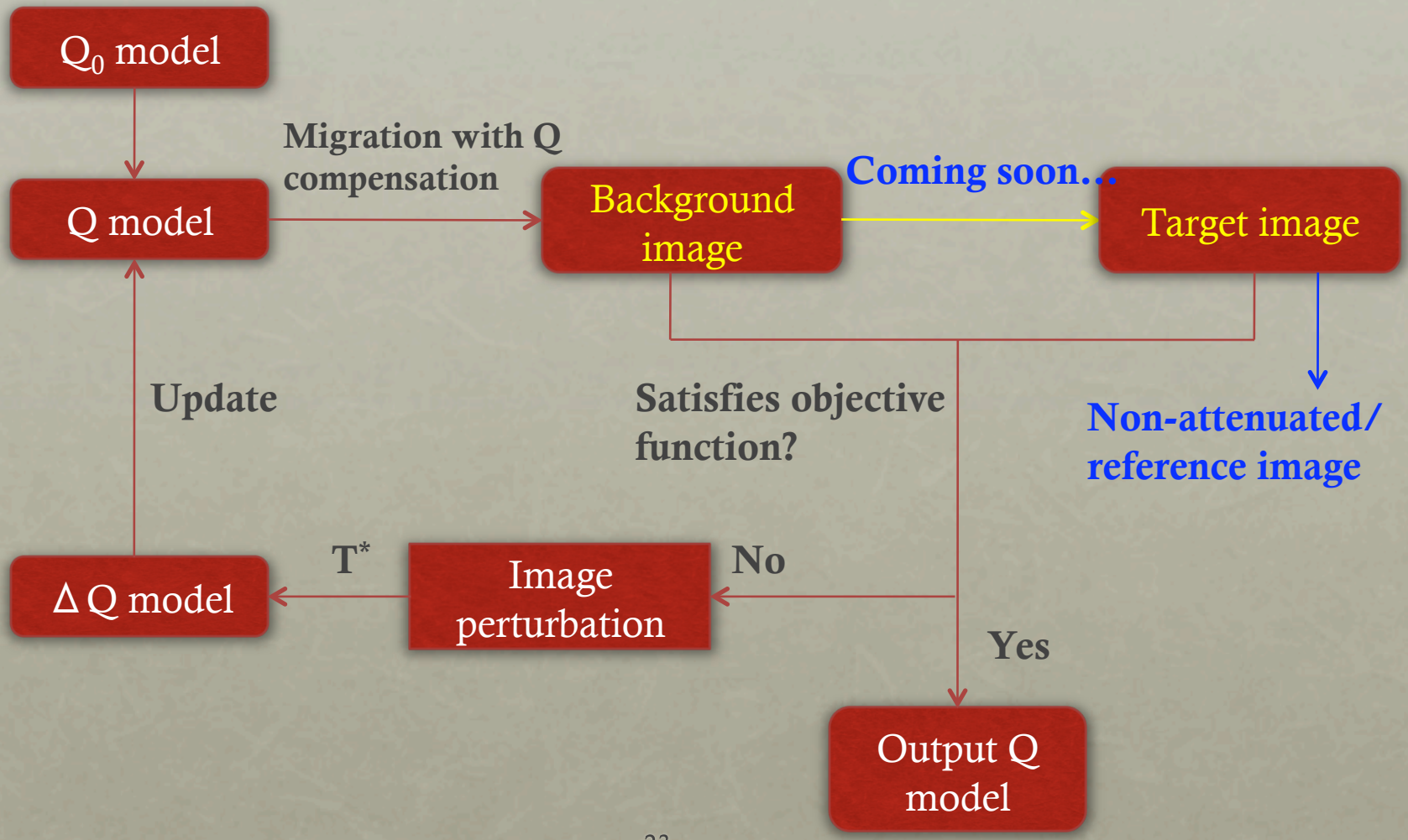
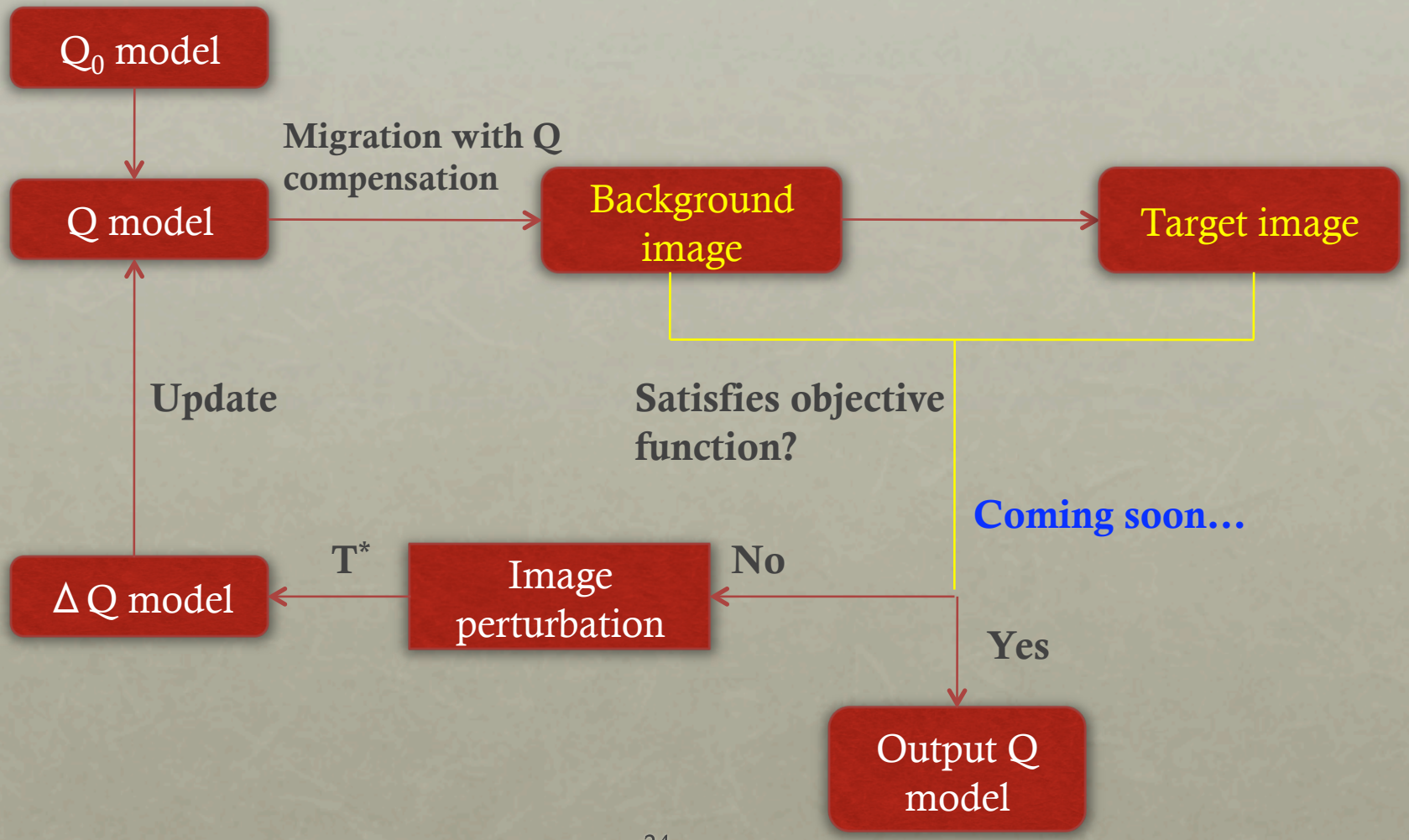
ΔQ model
Image perturbation
No
Yes
Output Q model

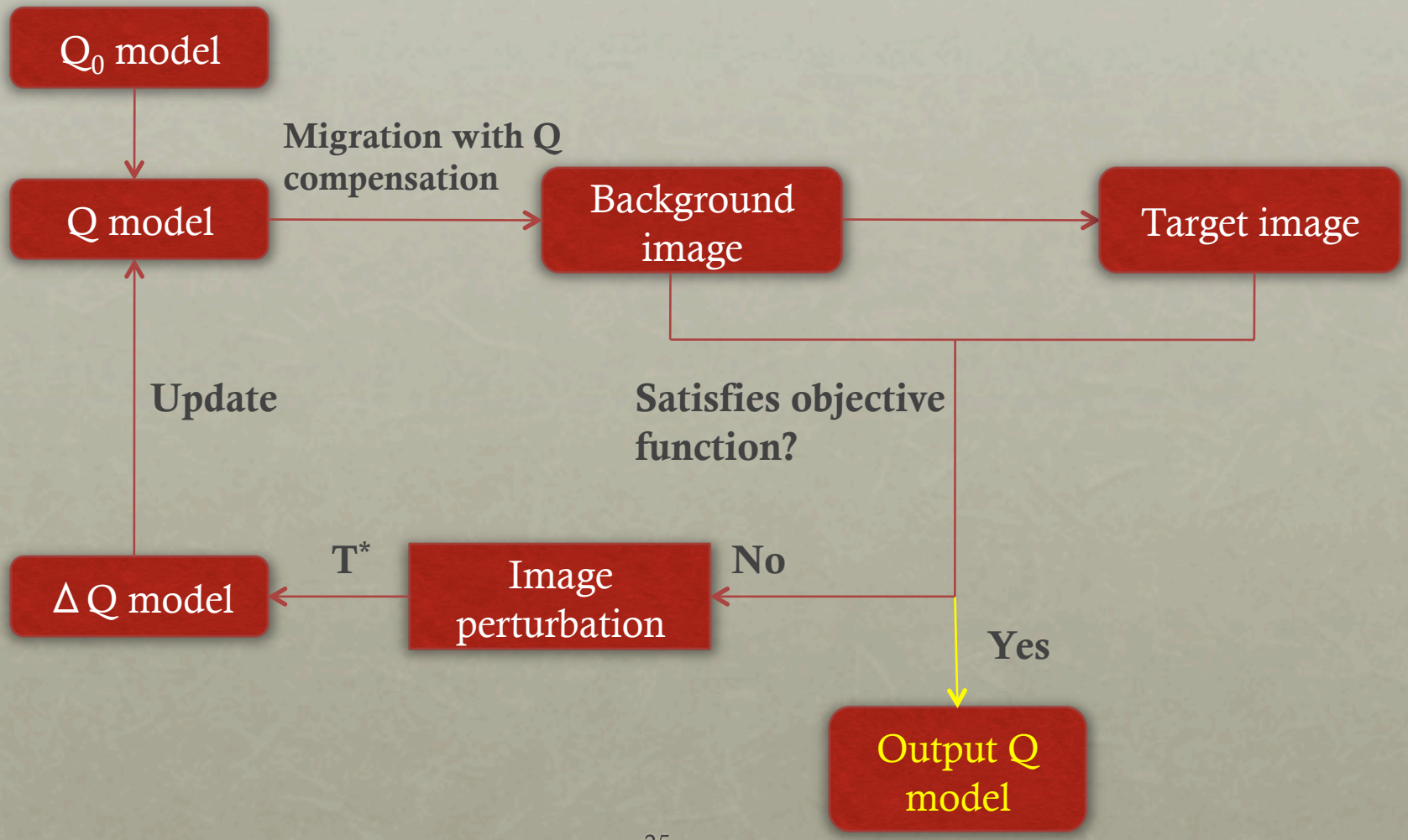
INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Coming soon…
Target image
Update
Satisfies objective function?
Non-attenuated/ reference image
T^*
No
ΔQ model
Image perturbation
Yes
Output Q model

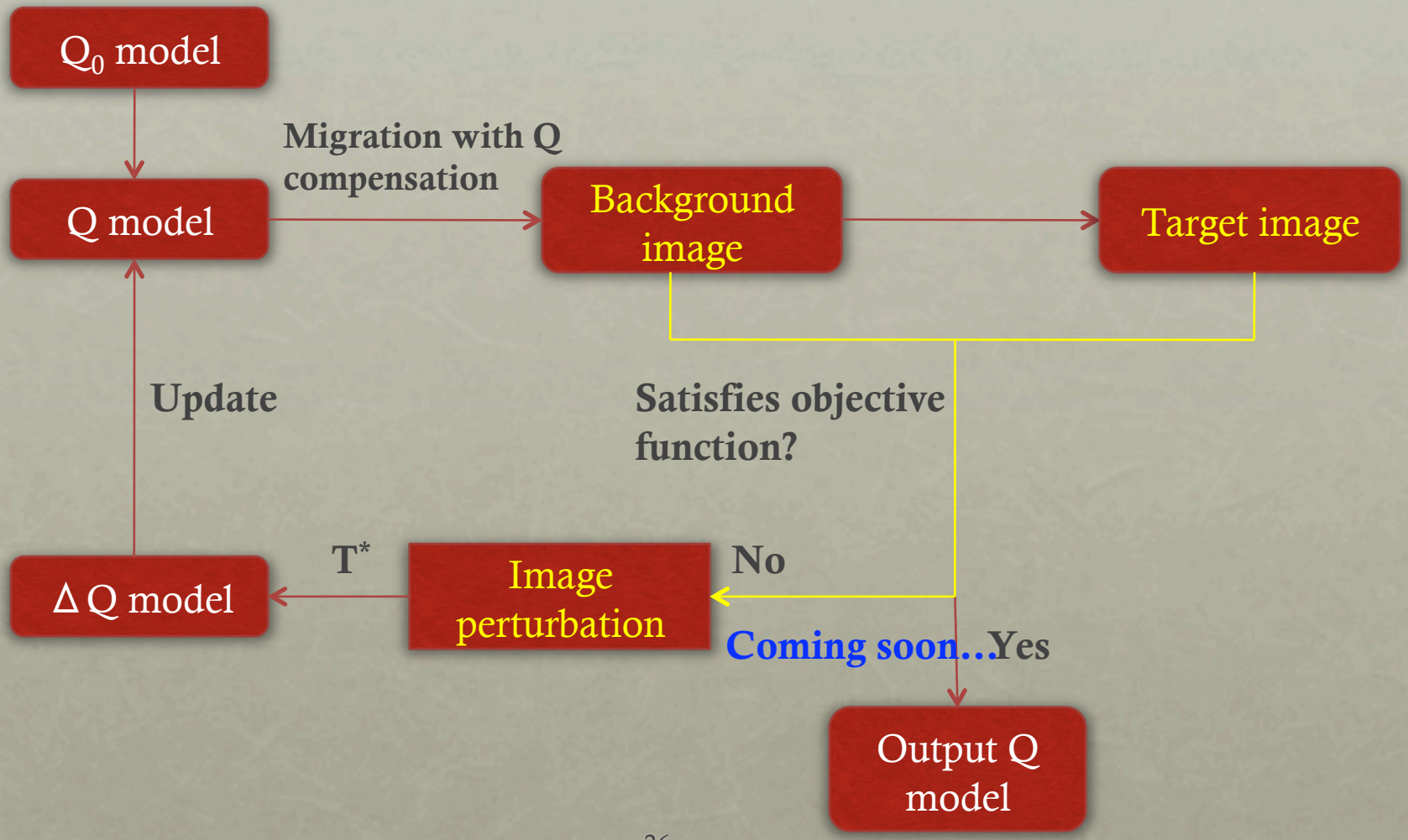
INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
Coming soon…
T*
Image perturbation
No
ΔQ model
Yes
Output Q model

INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
T*
ΔQ model
Image perturbation
No
Yes
Output Q model

INVERSION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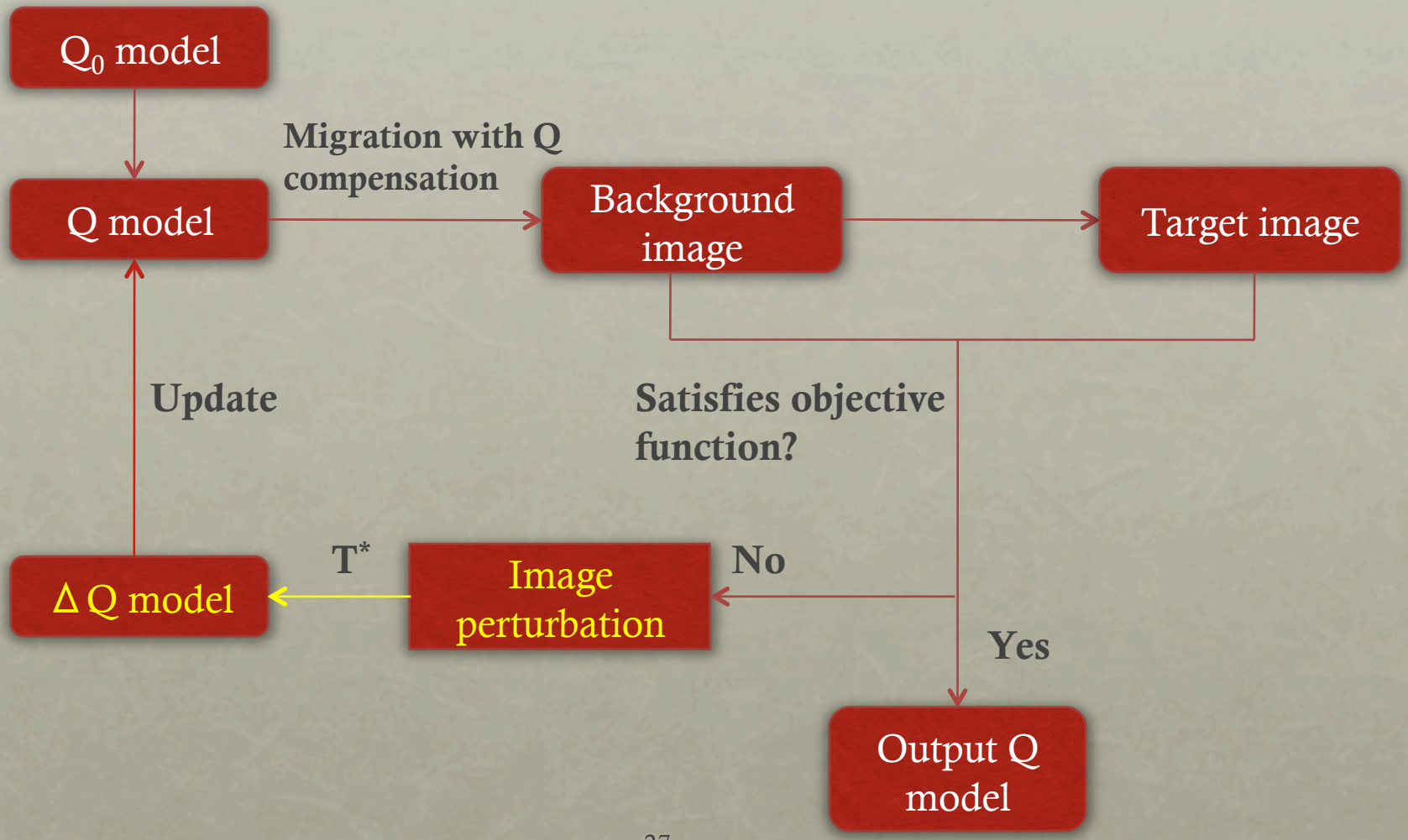
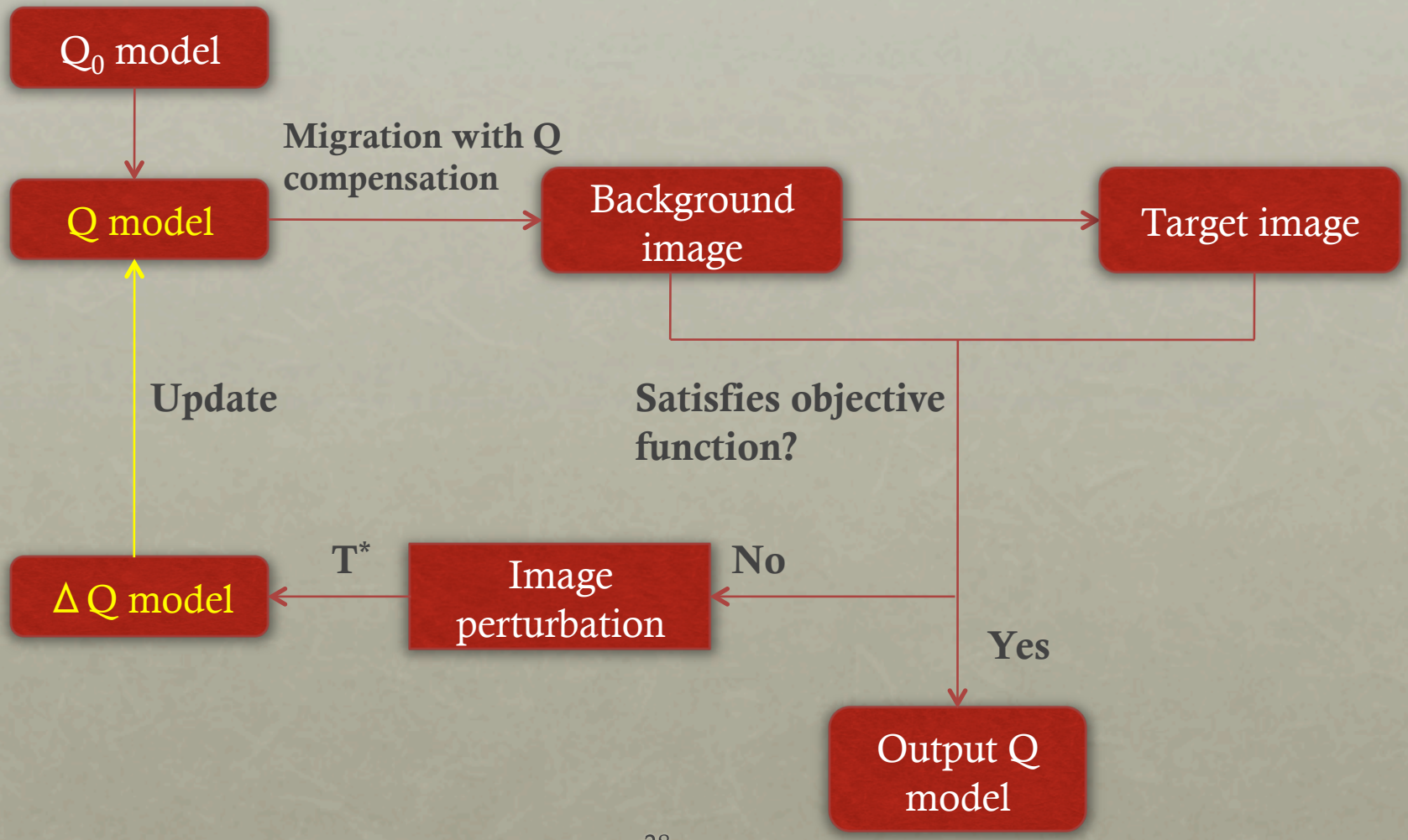
ΔQ model
Image perturbation
No
Coming soon…Yes
Output Q model

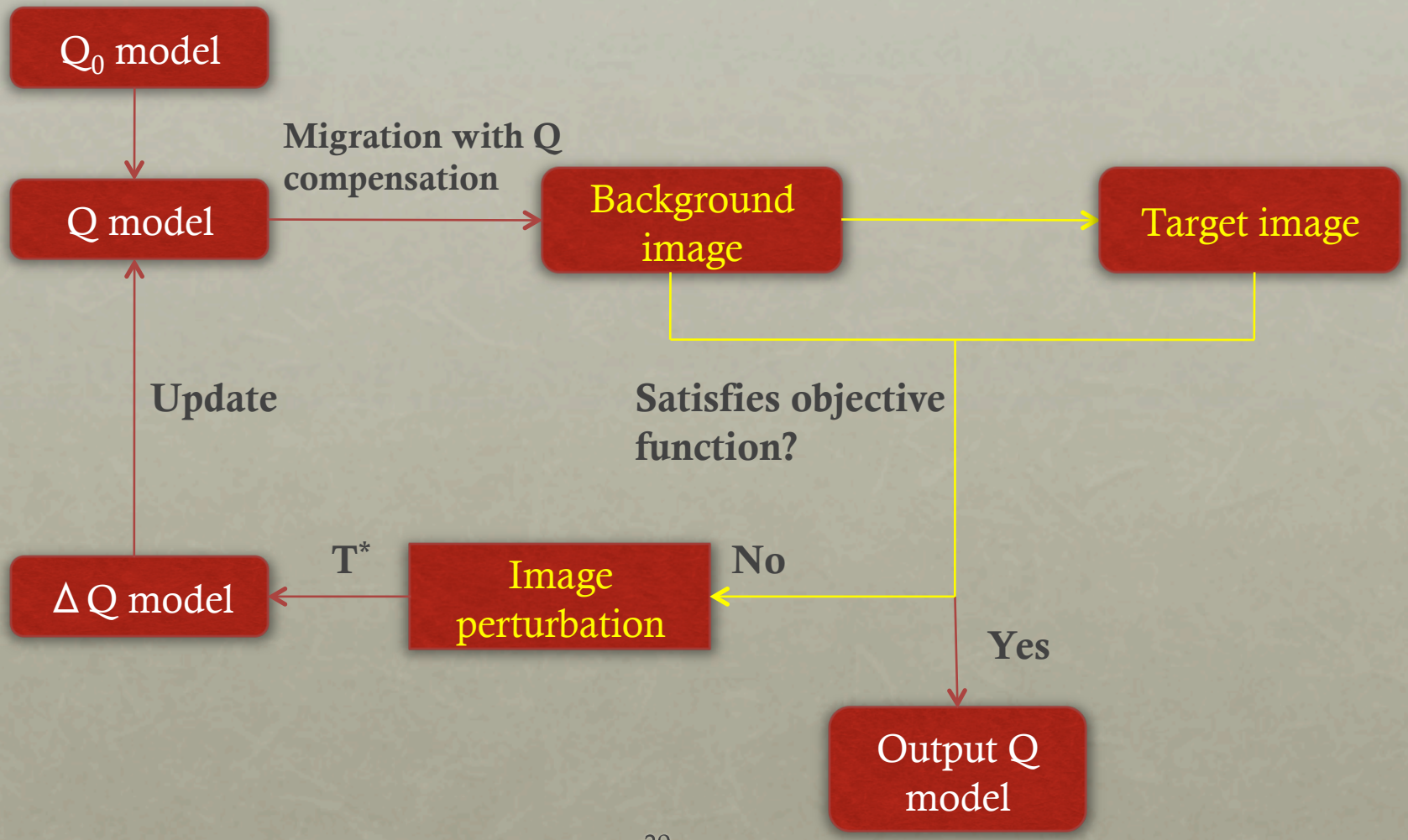
INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
T*
ΔQ model
Image perturbation
No
Yes
Output Q model

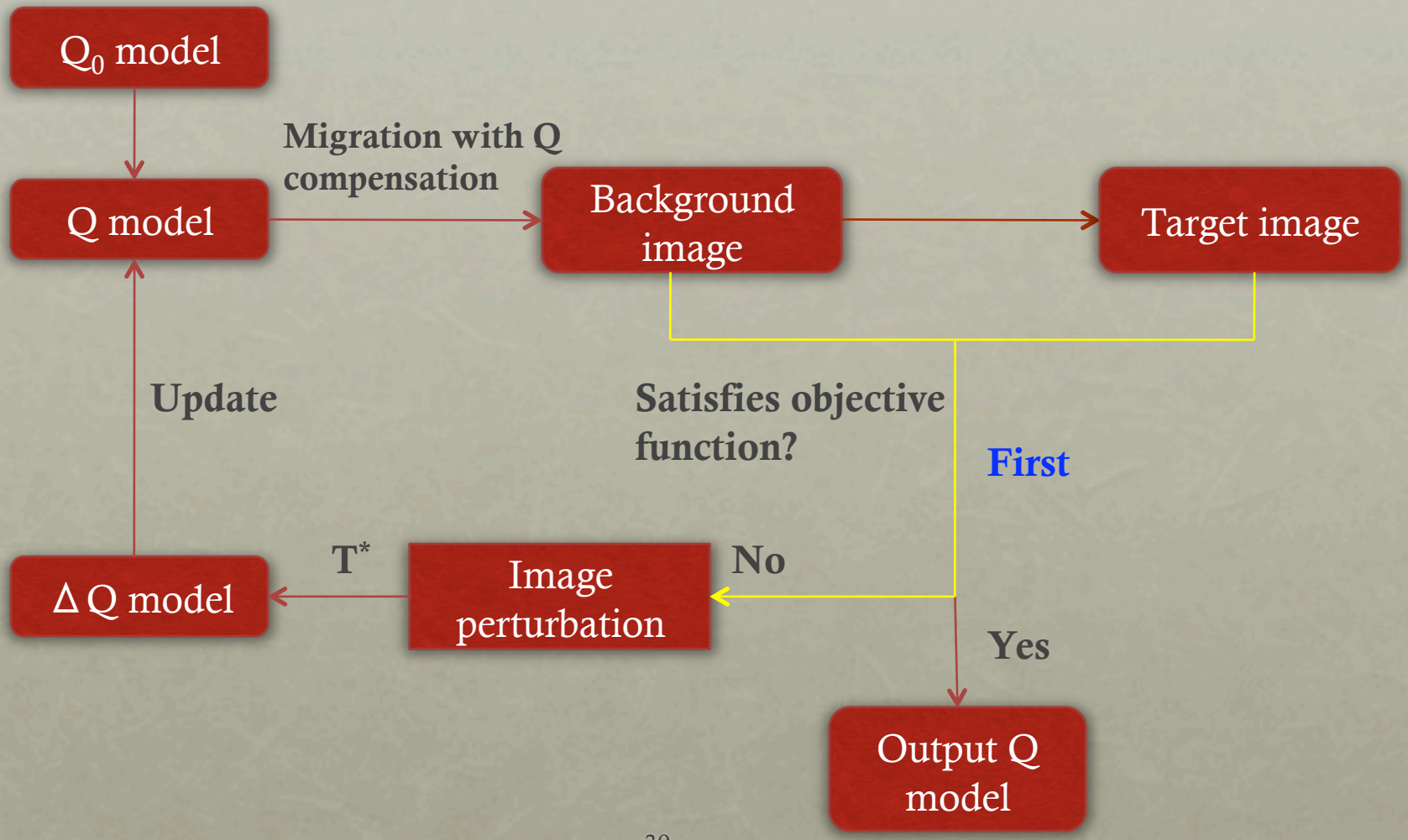
INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
T^*
Image perturbation
No
ΔQ model
Yes
Output Q model

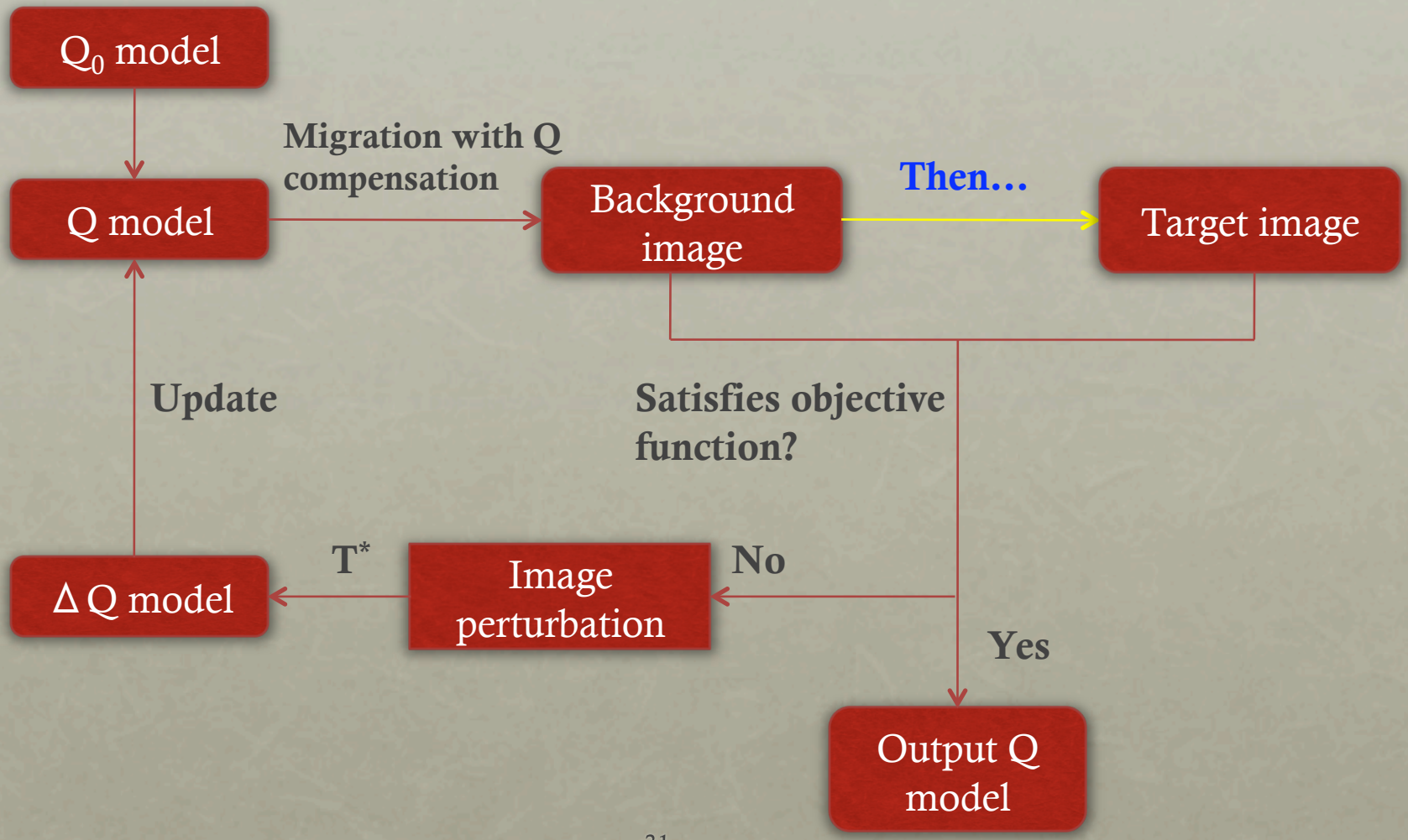
INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
T*
ΔQ model
Image perturbation
No
Yes
Output Q model

INVERSION

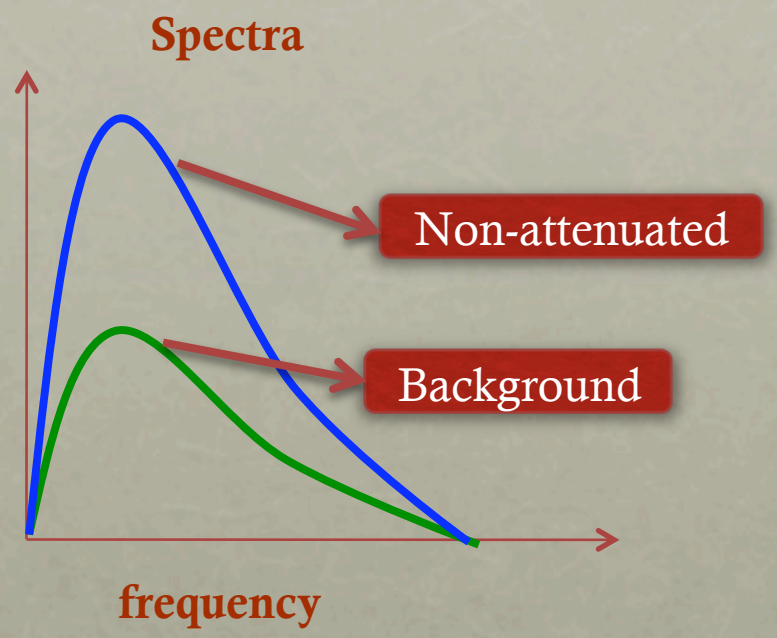

Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
First
T^*
No
Δ Q model
Image perturbation
Yes
Output Q model

INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Then…
Target image
Update
Satisfies objective function?
T^*
No
Δ Q model
Image perturbation
Yes
Output Q model

OBJECTIVE FUNCTION

- Spectral ratio method（Tonn, 1991);



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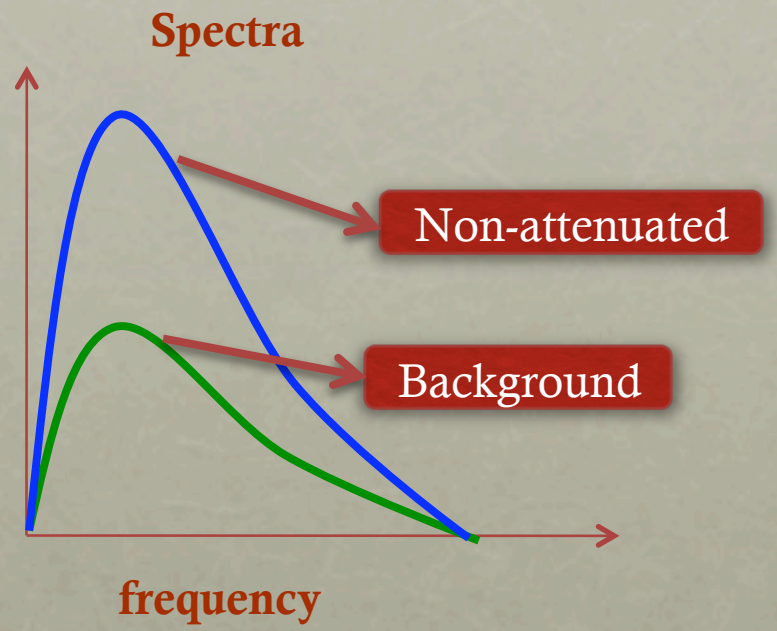

$$\text{Ratio} = \frac{\text{Background spectra}}{\text{Non-attenuated spectra}}$$

OBJECTIVE FUNCTION

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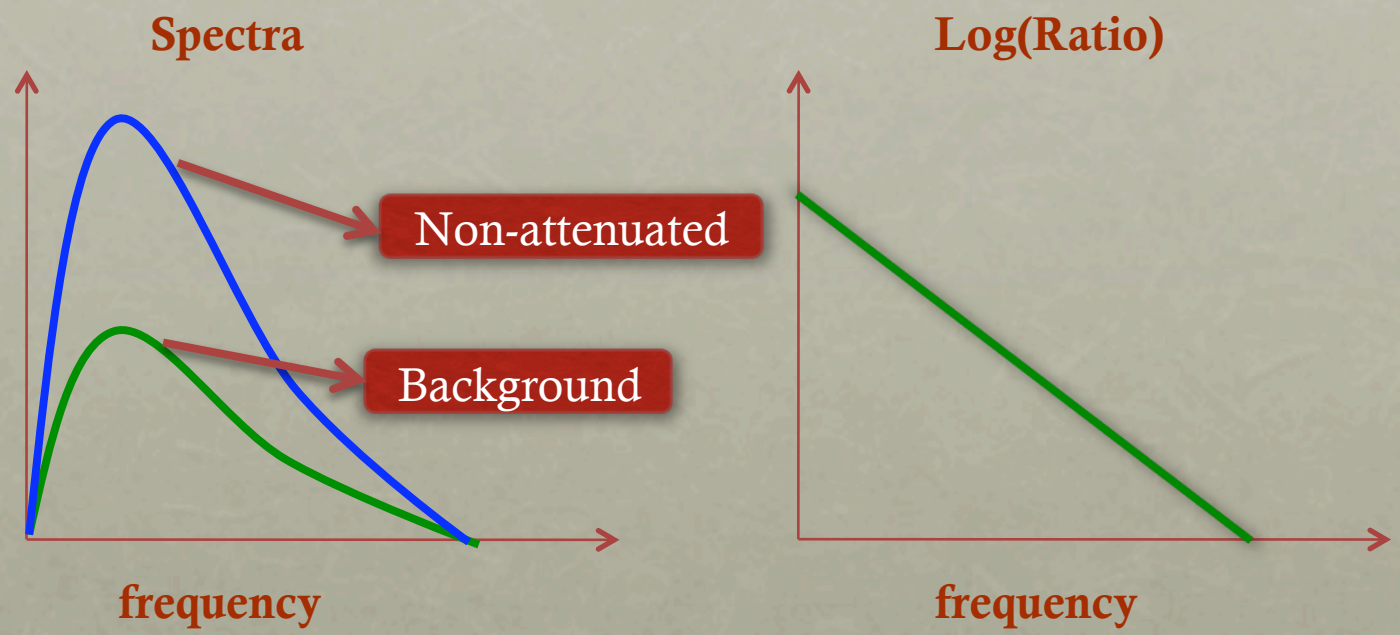

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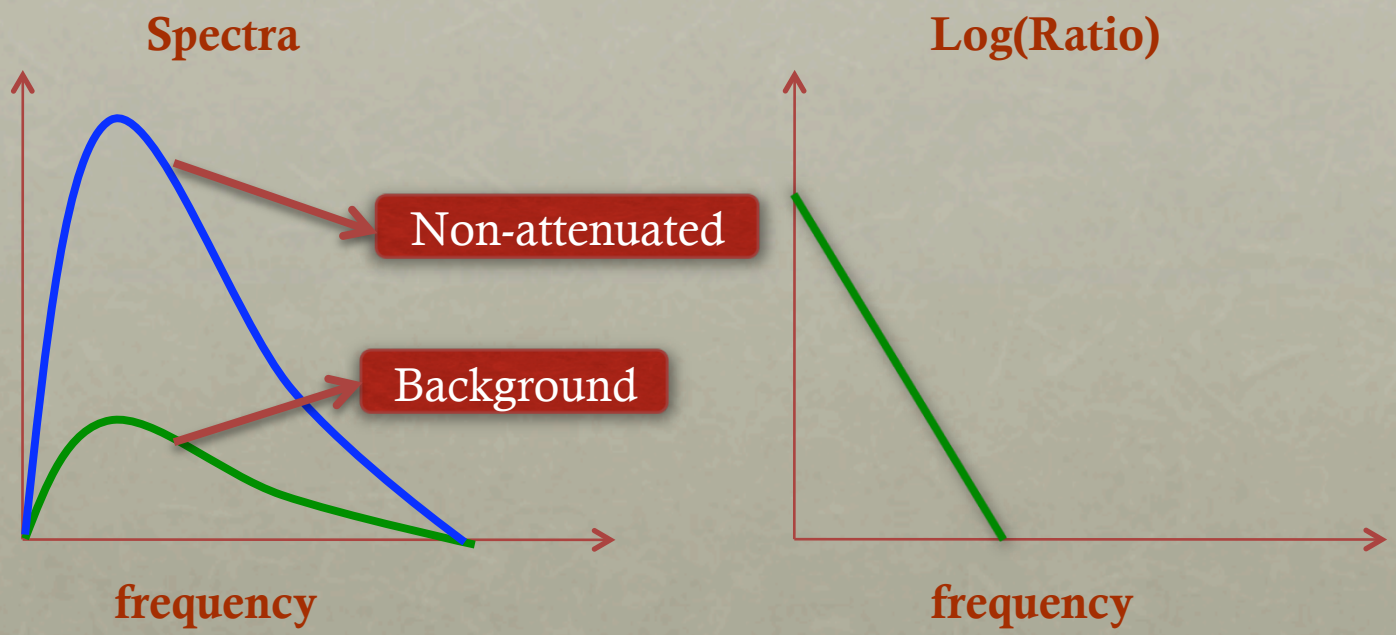

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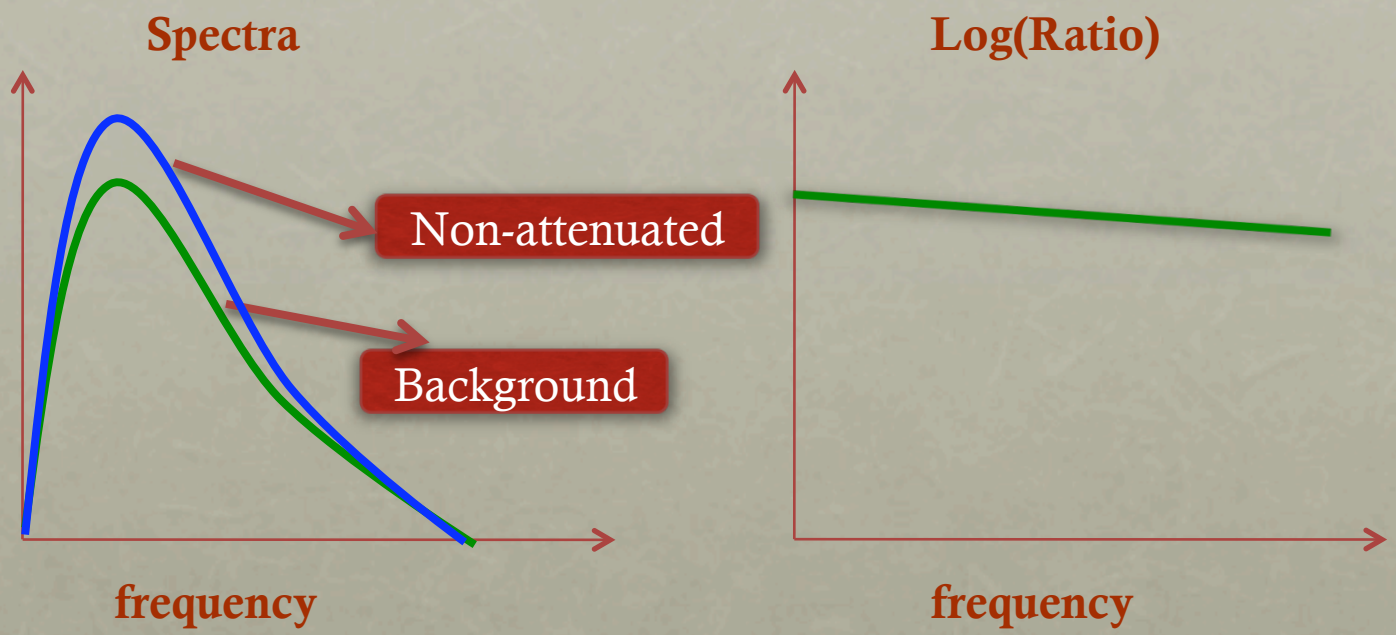

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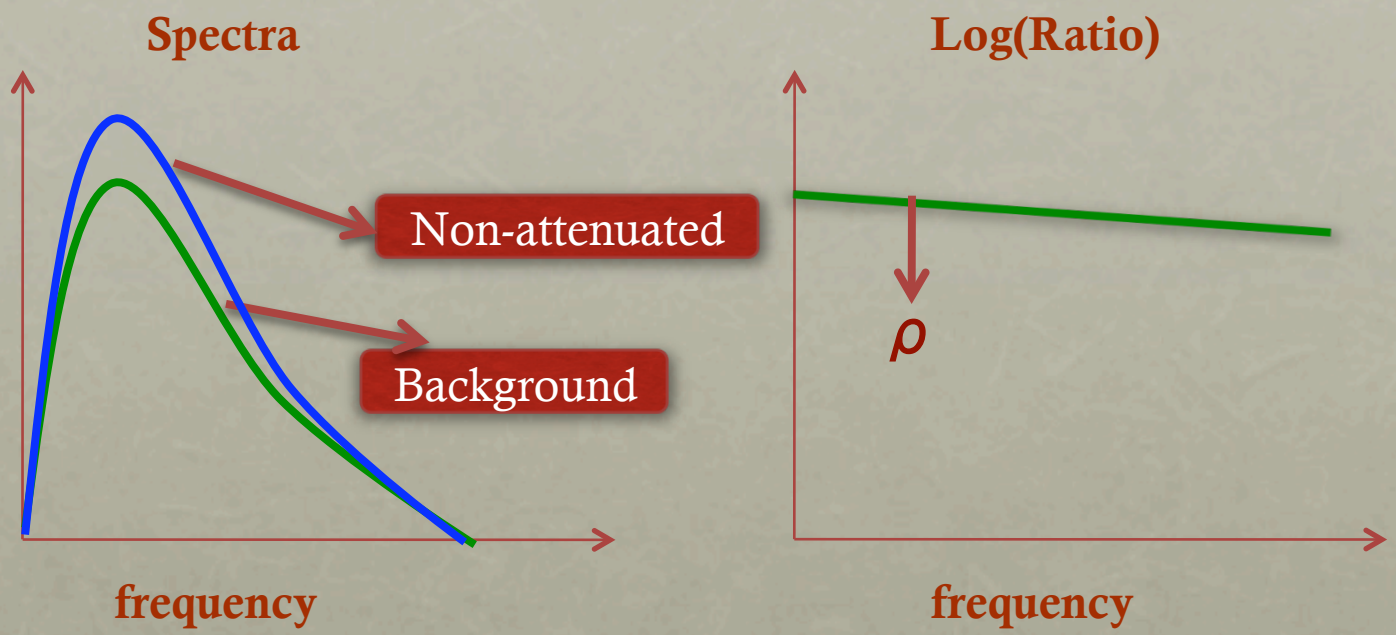

OBJECTIVE FUNCTION

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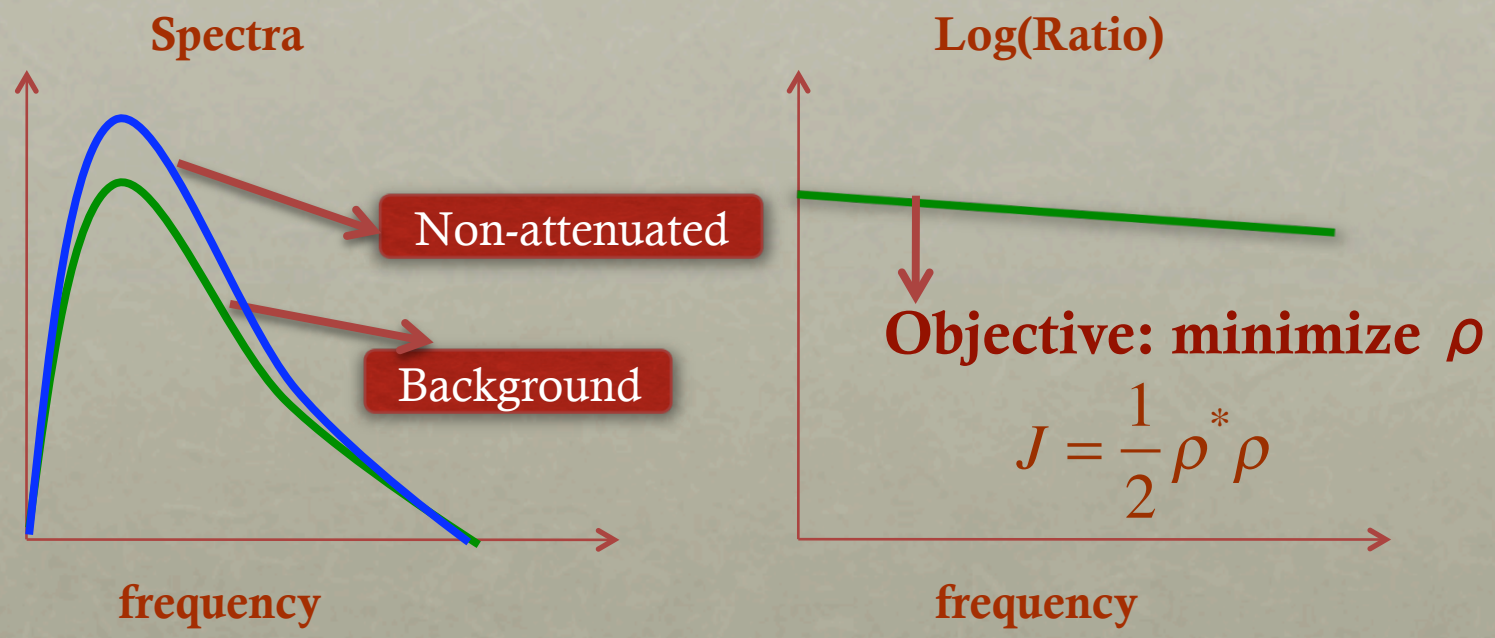

OBJECTIVE FUNCTION

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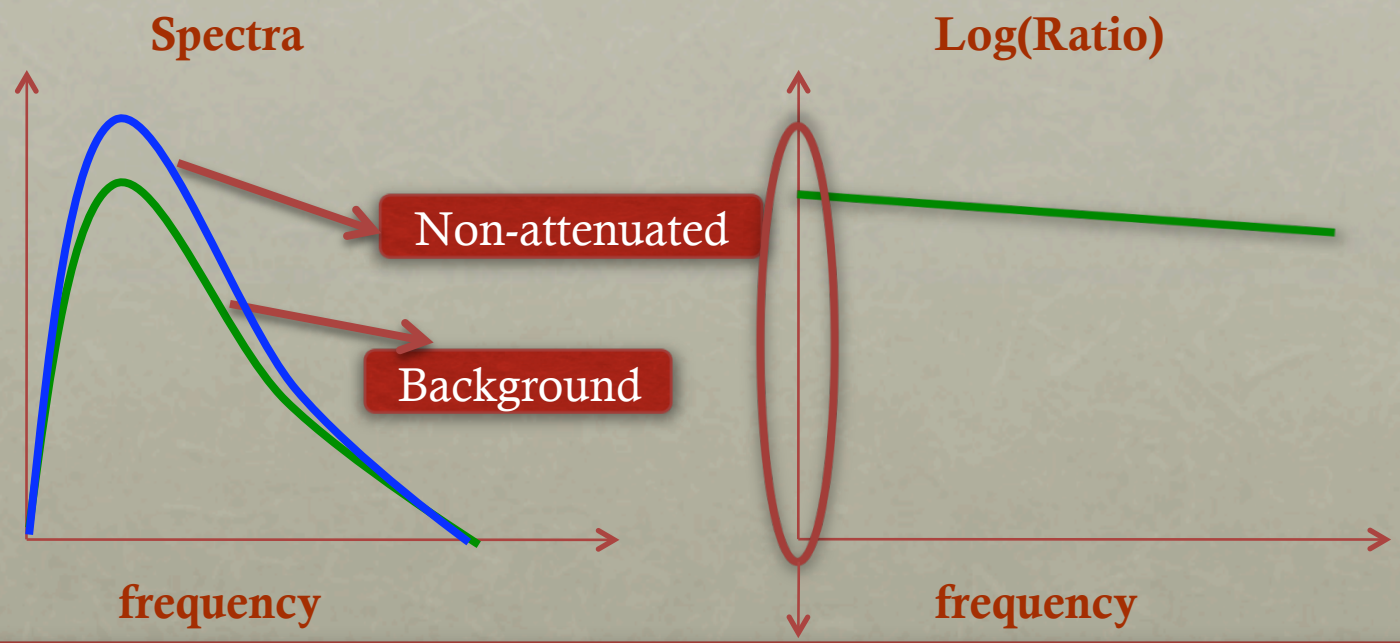


Frequency-independent amplitude effects: geometric spreading; reflectivities; etc

OBJECTIVE FUNCTION

- Spectral ratio method (Tonn, 1991);

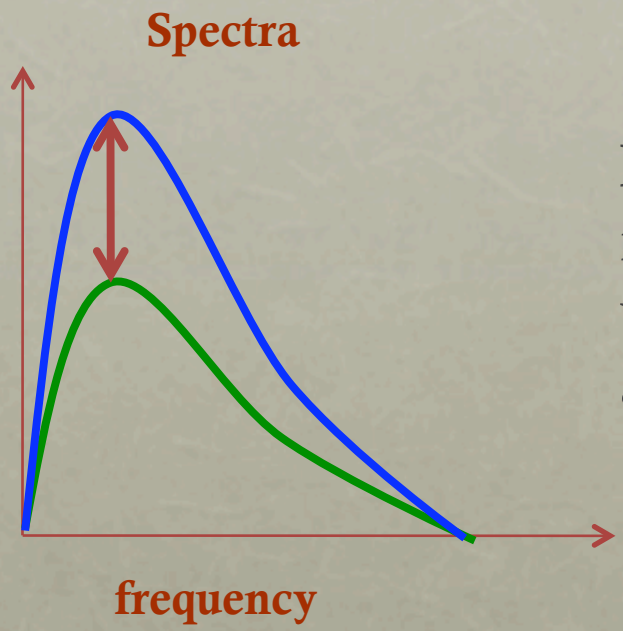
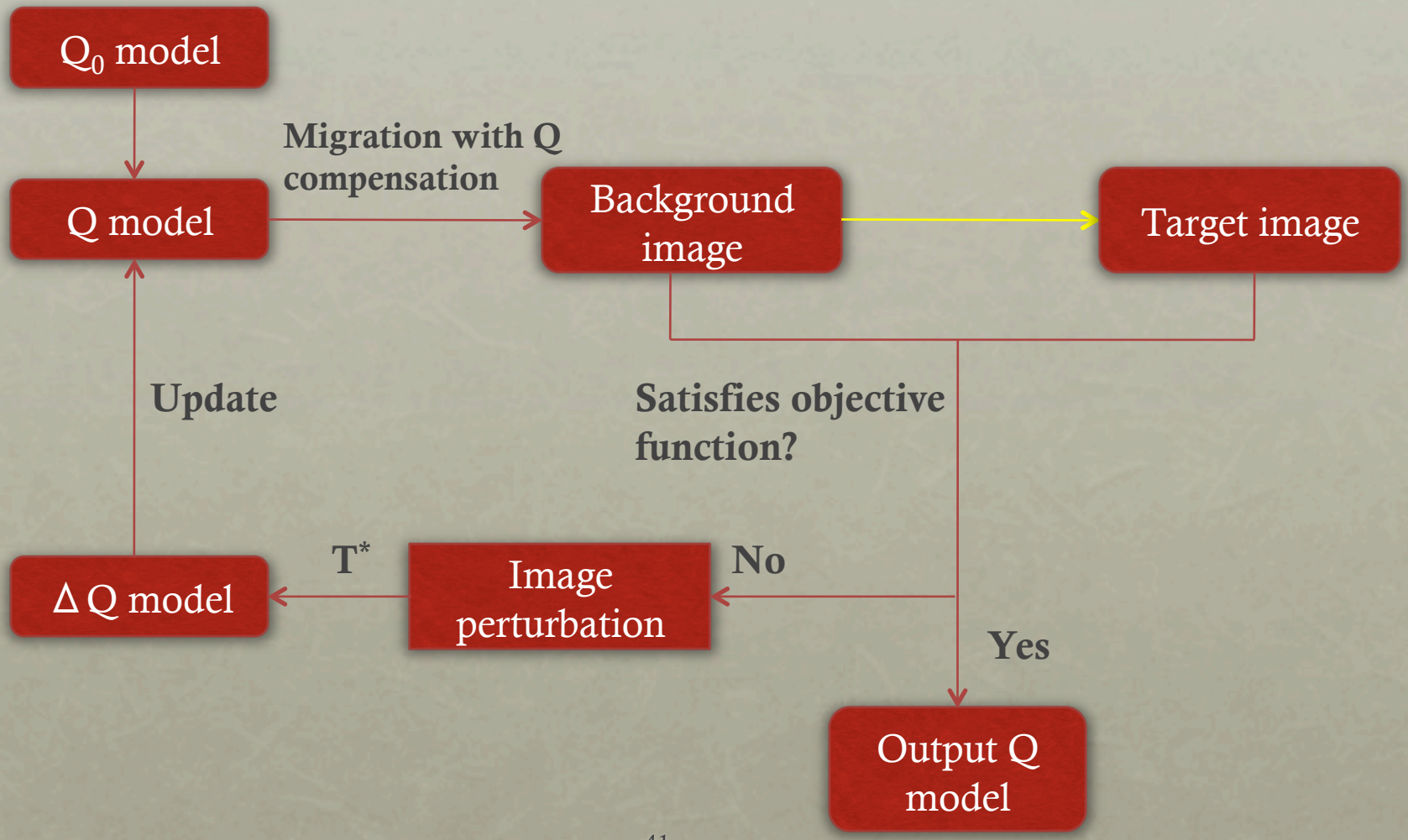


Image perturbation:
from the relative spectral difference without frequency-independent amplitude effects

INVERSION


Q_0 model
Migration with Q compensation
Q model
Background image
Target image
Update
Satisfies objective function?
T*
Image perturbation
No
ΔQ model
Yes
Output Q model

TARGET IMAGE

- **Choice of the target image**
  - Model with sparse reflectors
  - Model with dense reflectors

NUMERICAL TESTS

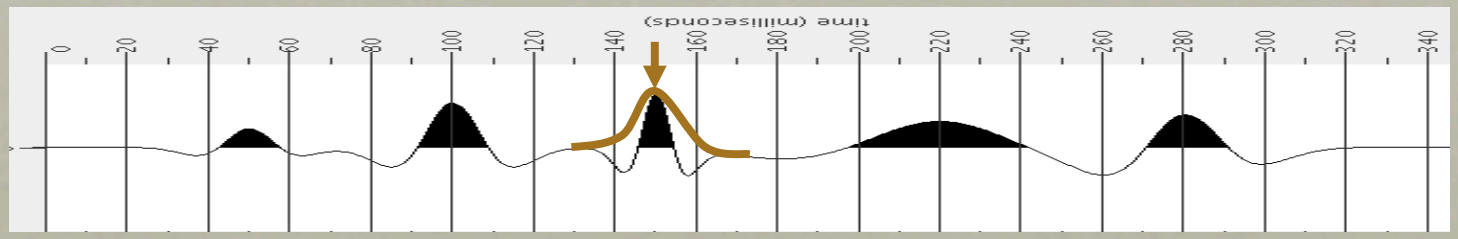
- **Model with sparse reflectors**
  - 2D test I
  - 2D test II
- **Model with dense reflectors**
  - SEAM model

NUMERICAL TESTS

- **Model with sparse reflectors**
  - 2D test I
  - 2D test II
- **Model with dense reflectors**
  - SEAM model

MODEL WITH SPARSE REFLECTORS

- The target image
  - Pick reflectors



MODEL WITH SPARSE REFLECTORS

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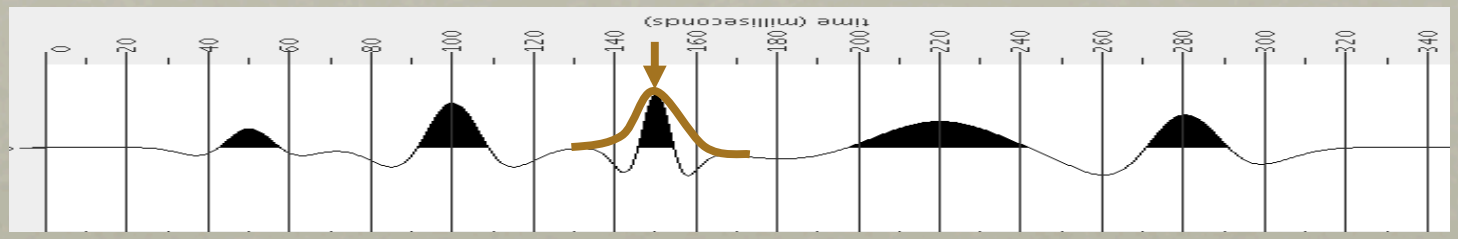
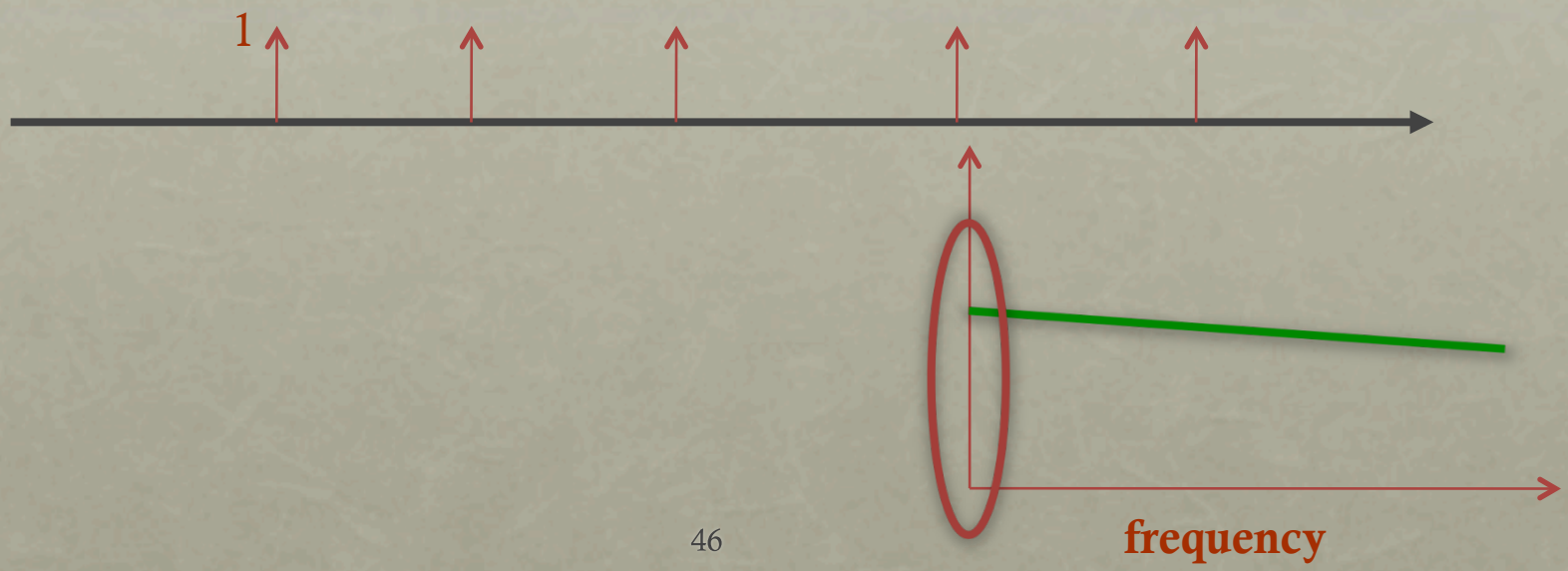
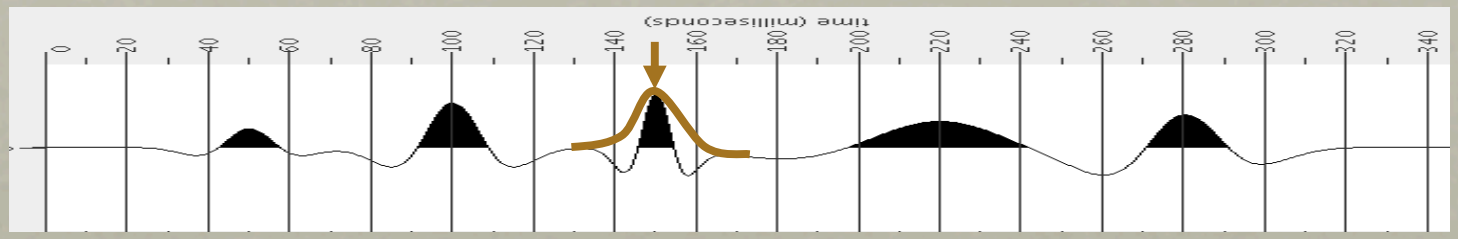
  - Pick reflectors





MODEL WITH SPARSE REFLECTORS

- The target image
  - Pick reflectors



  - Generate non-attenuated dataset
  - Migrate this dataset to obtain the non-attenuated target image

NUMERICAL TESTS

- **Model with sparse reflectors**
  - 2D test I
  - 2D test II
- **Model with dense reflectors**
  - SEAM model

TRUE MODEL – LOW Q ANOMALY

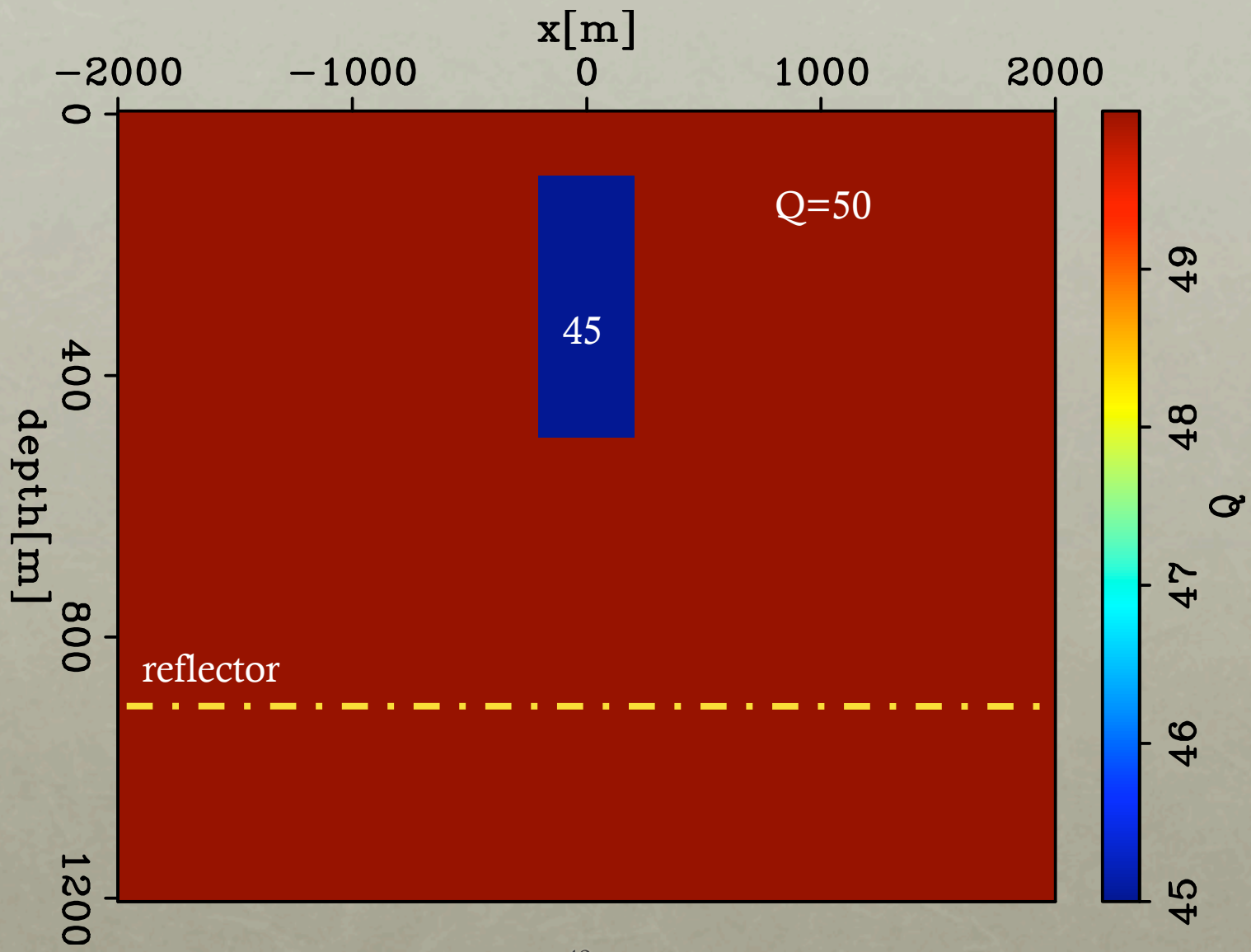
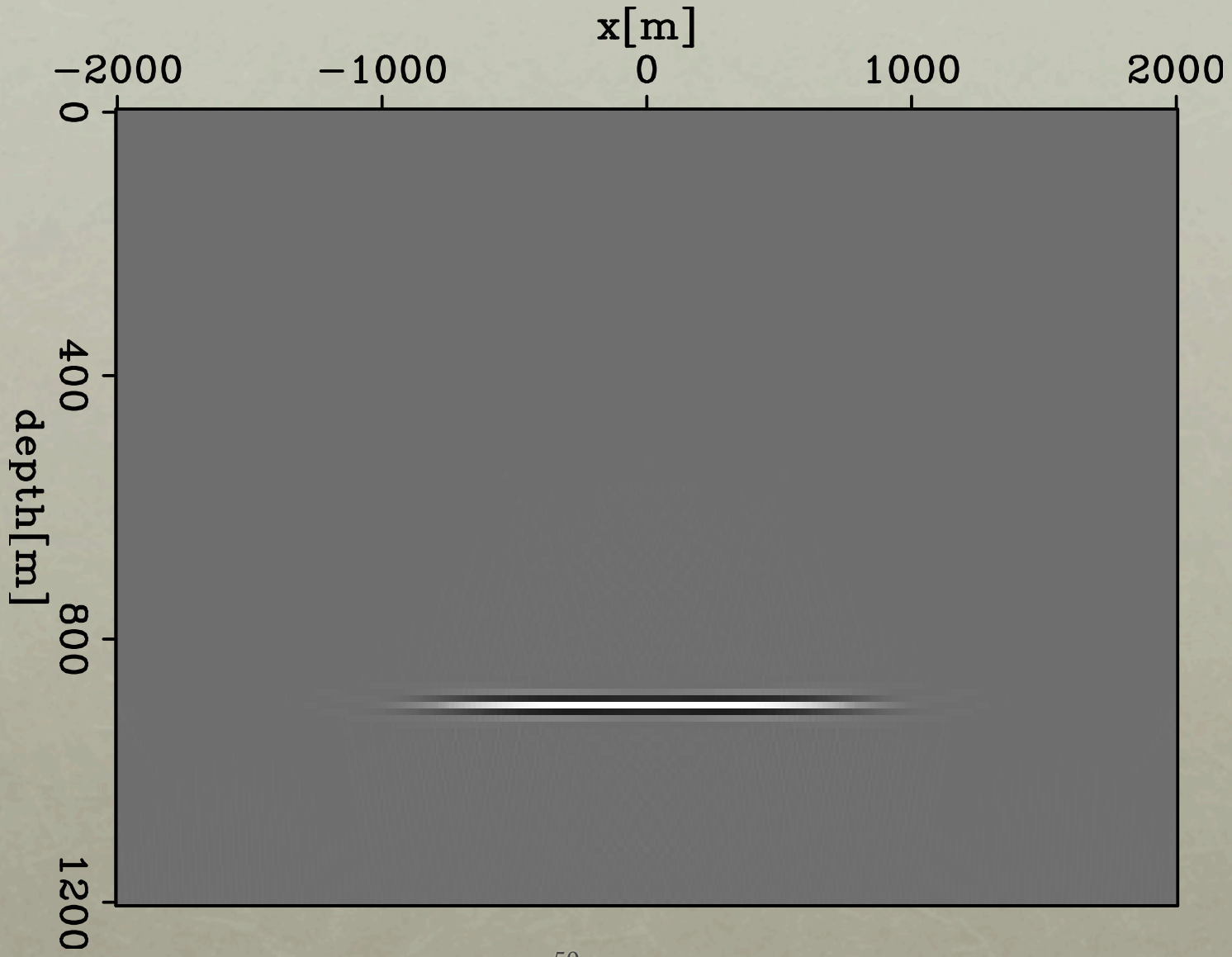
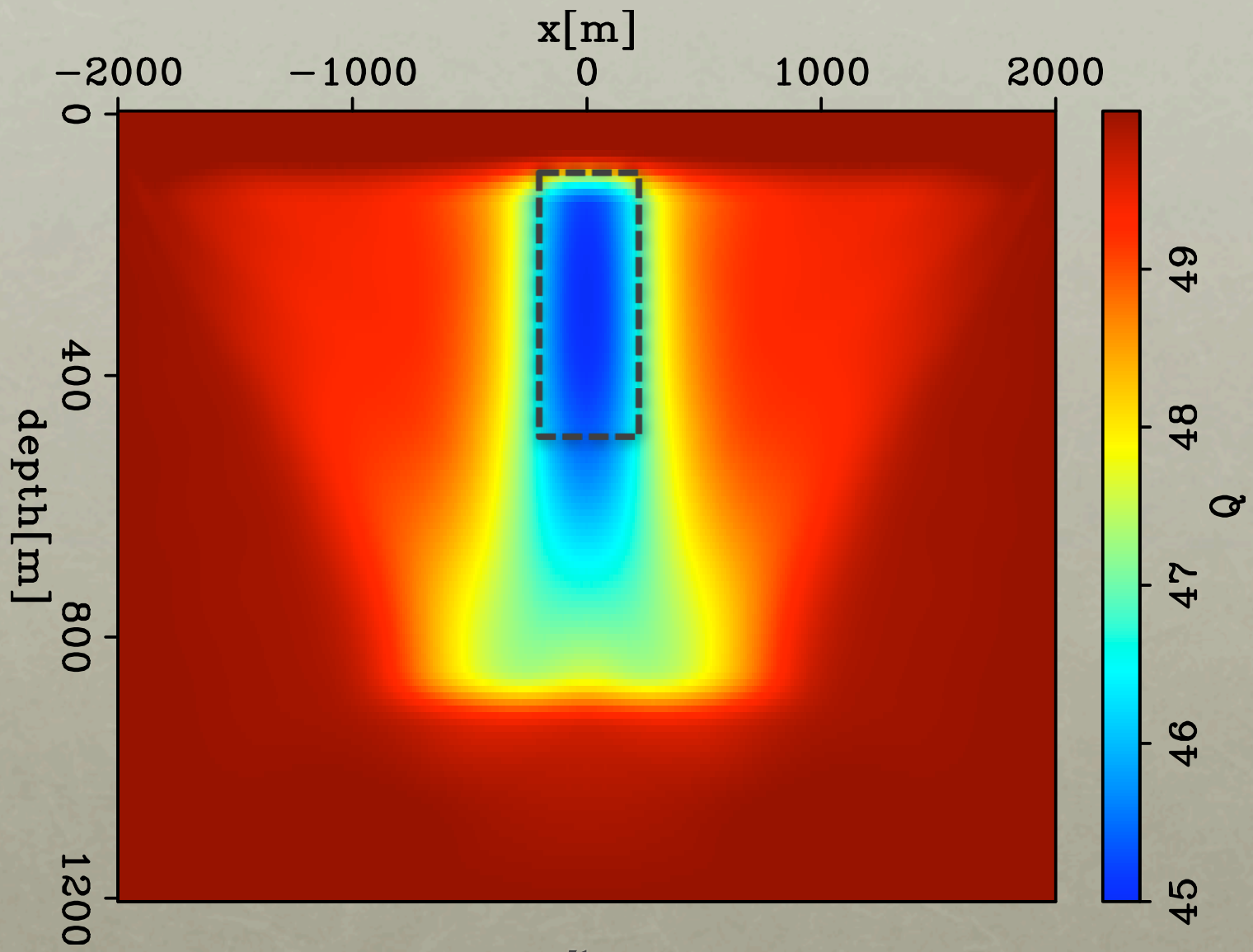


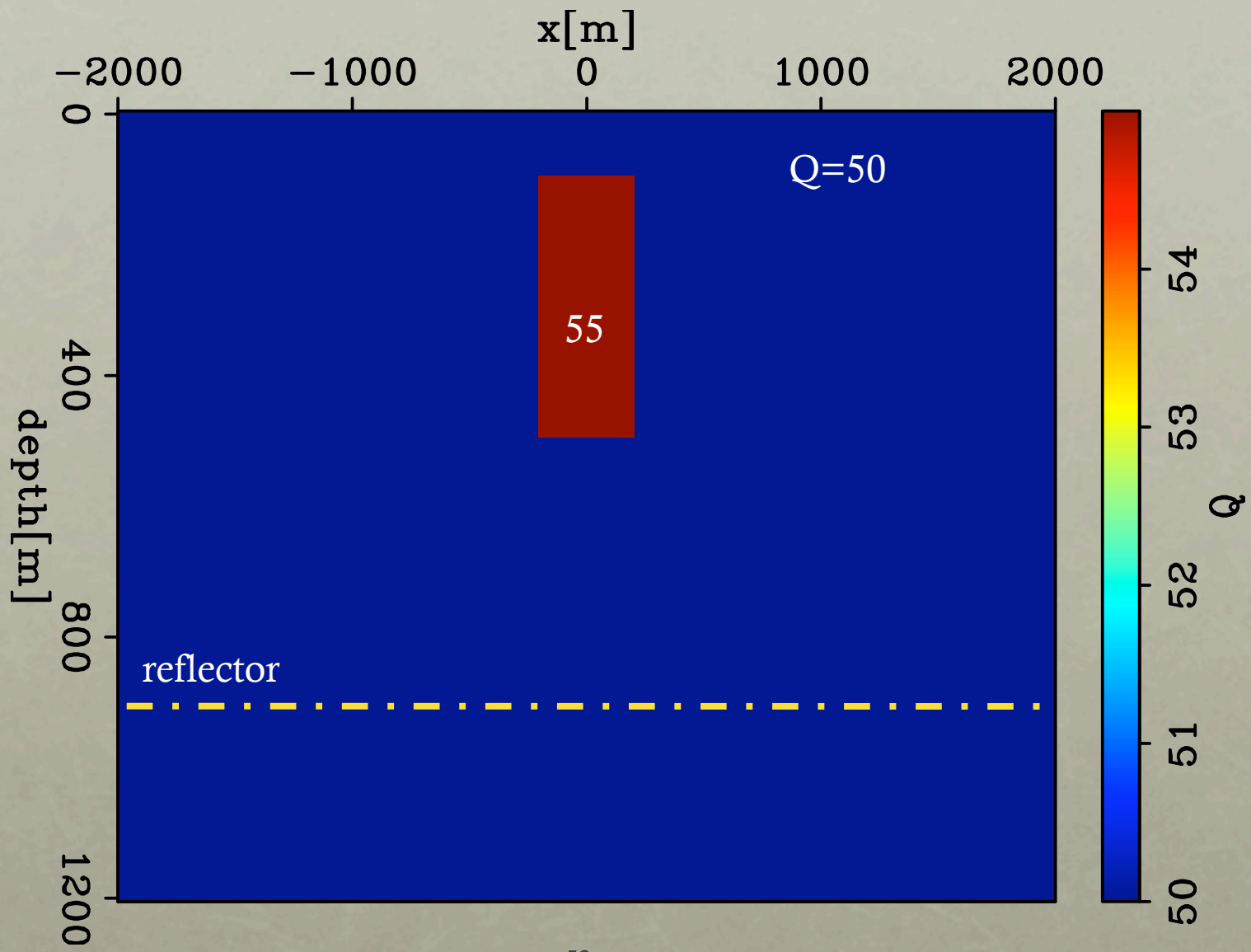
IMAGE PERTURBATION



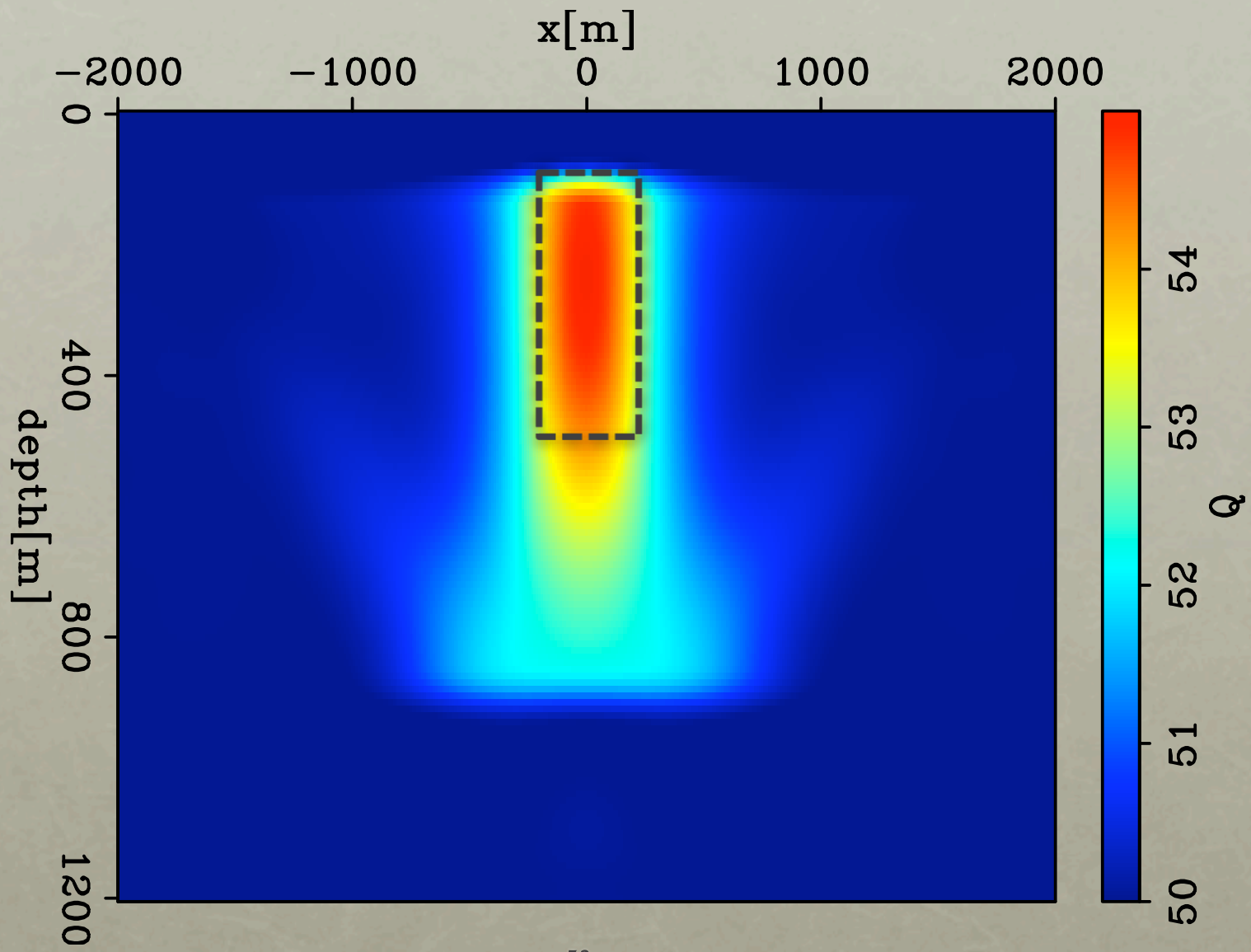
INVERSION (3RD ITERATION)



TRUE MODEL – HIGH Q ANOMALY



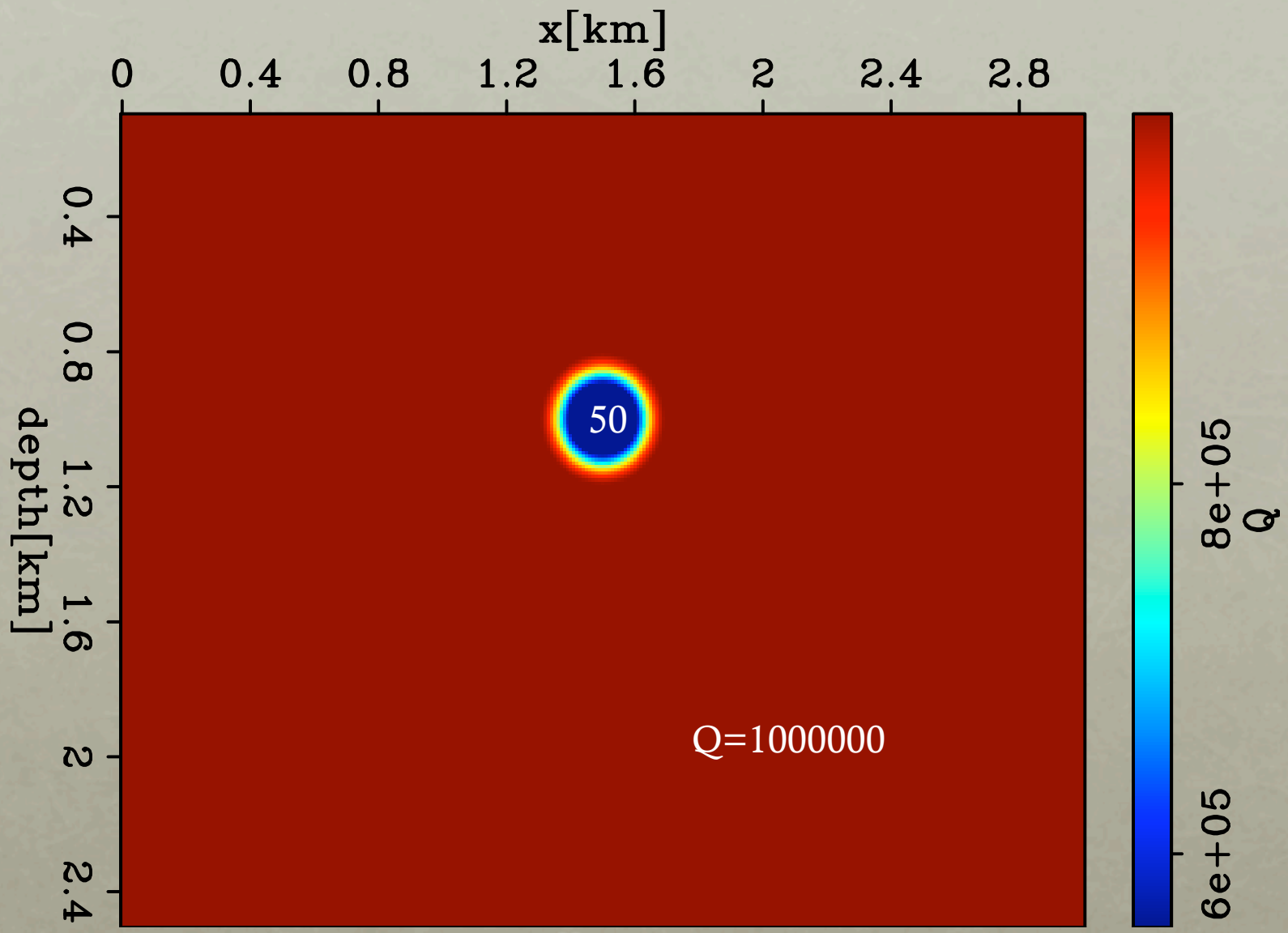
INVERSION (3RD ITERATION)



NUMERICAL TESTS

- **Model with sparse reflectors**
  - 2D test I
  - 2D test II
- **Model with dense reflectors**
  - SEAM model

TRUE Q MODEL


x[km]
0
0.4
0.8
1.2
1.6
2
2.4
2.8
depth[km]
0.4
0.8
1.2
1.6
2
2.4
50
Q=1000000
Q
8e+05
6e+05

TRUE VELOCITY MODEL

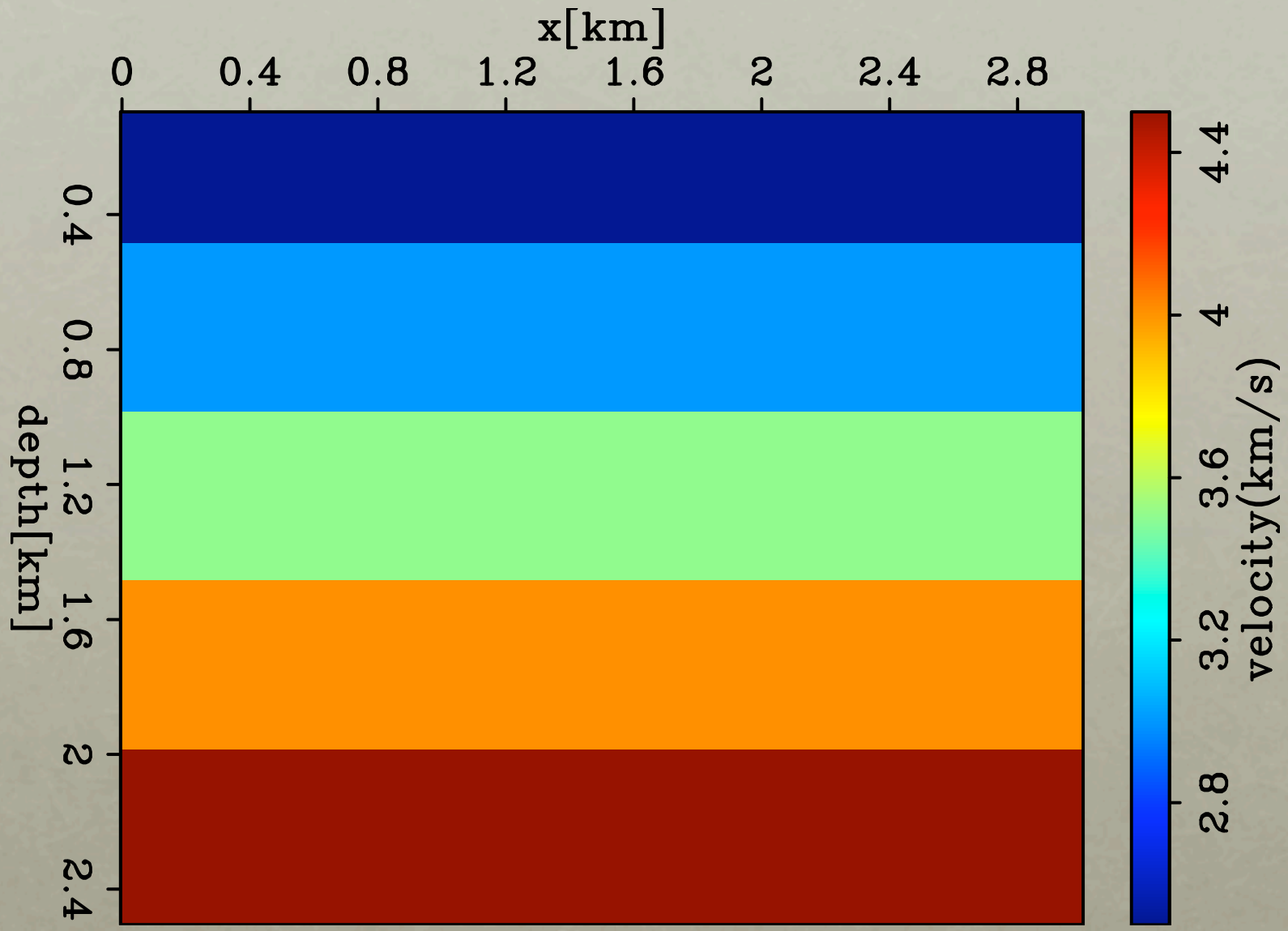
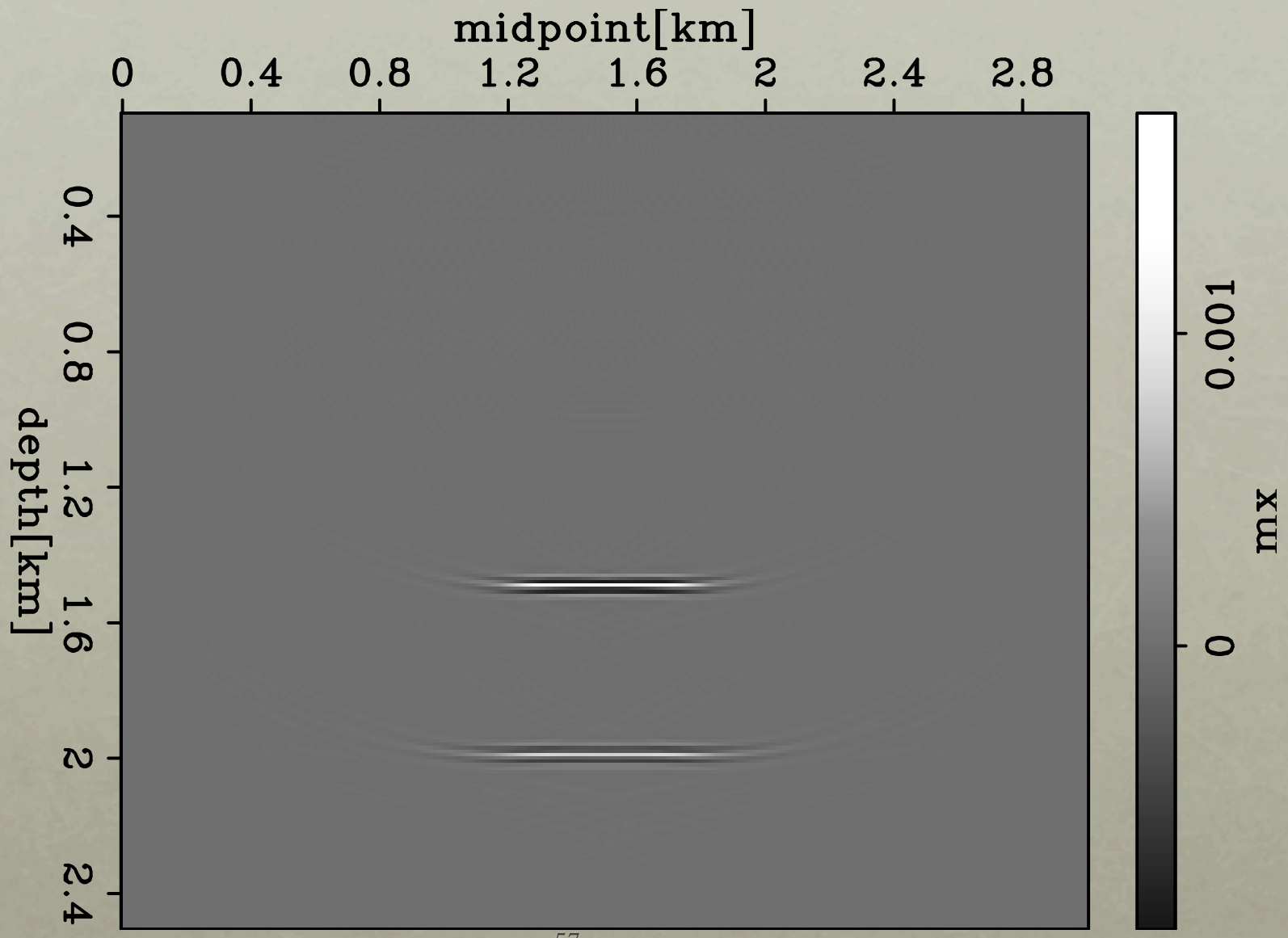
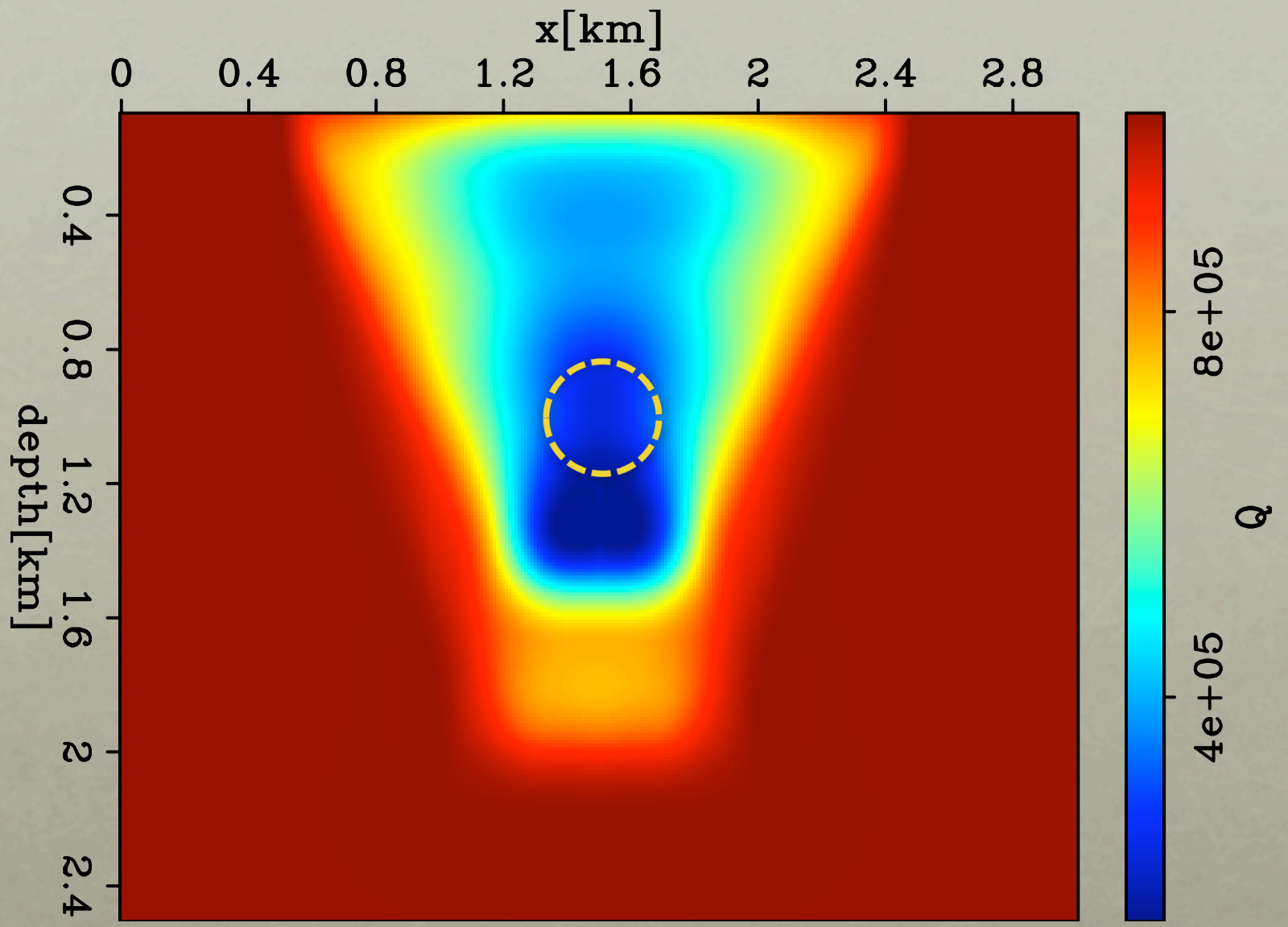


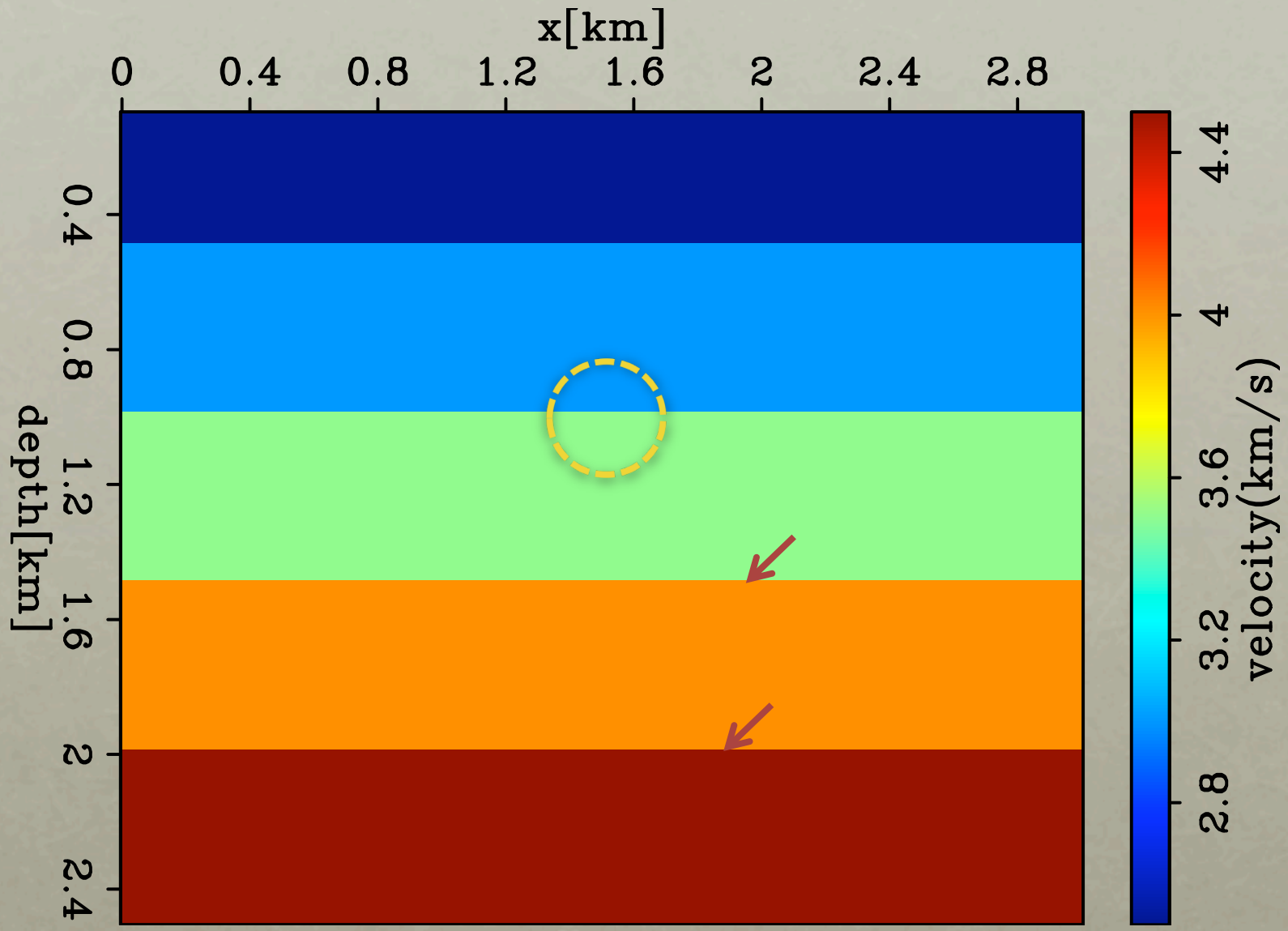
IMAGE PERTURBATION



INVERSION (4TH ITERATION)



TRUE VELOCITY MODEL

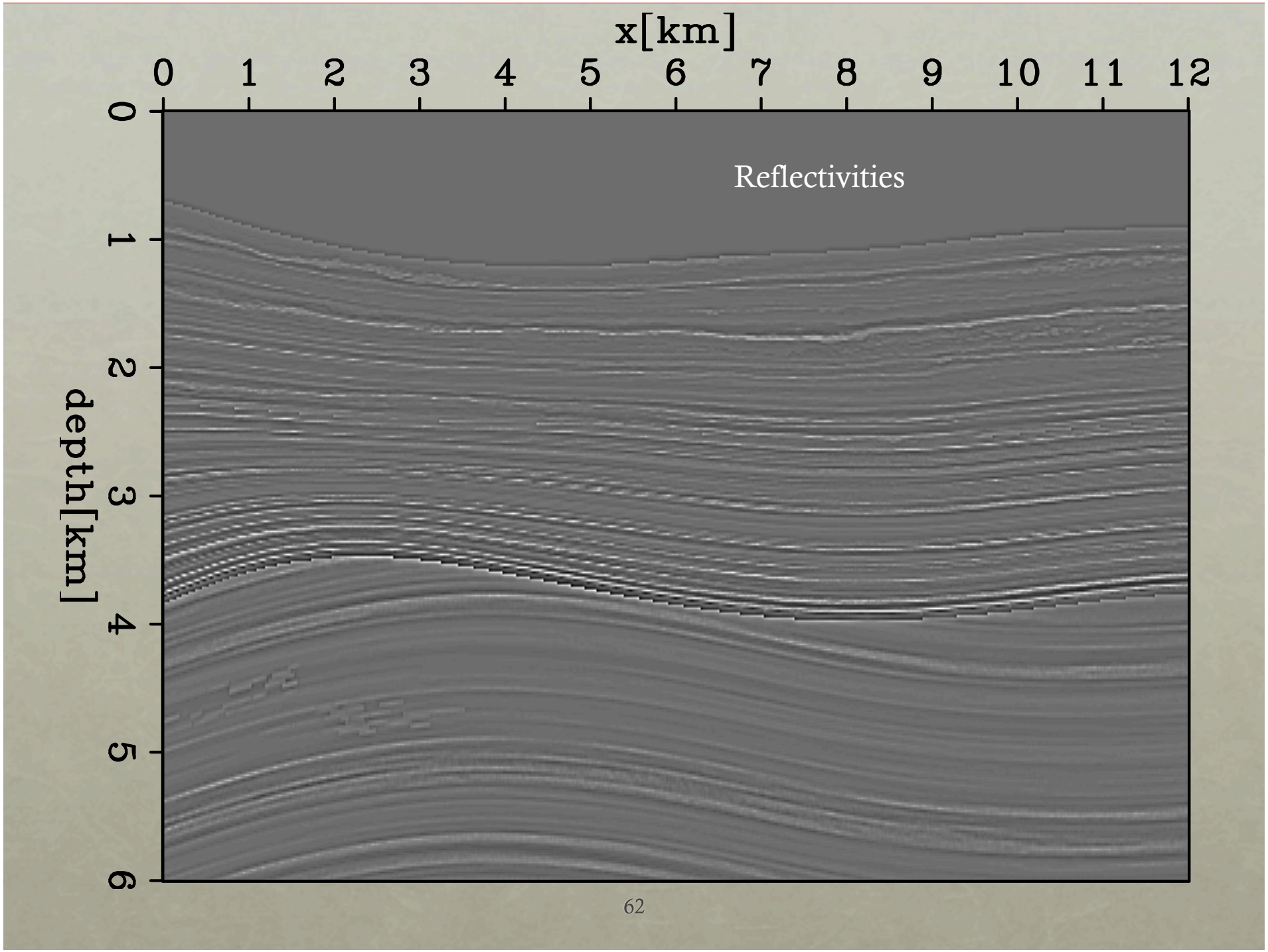


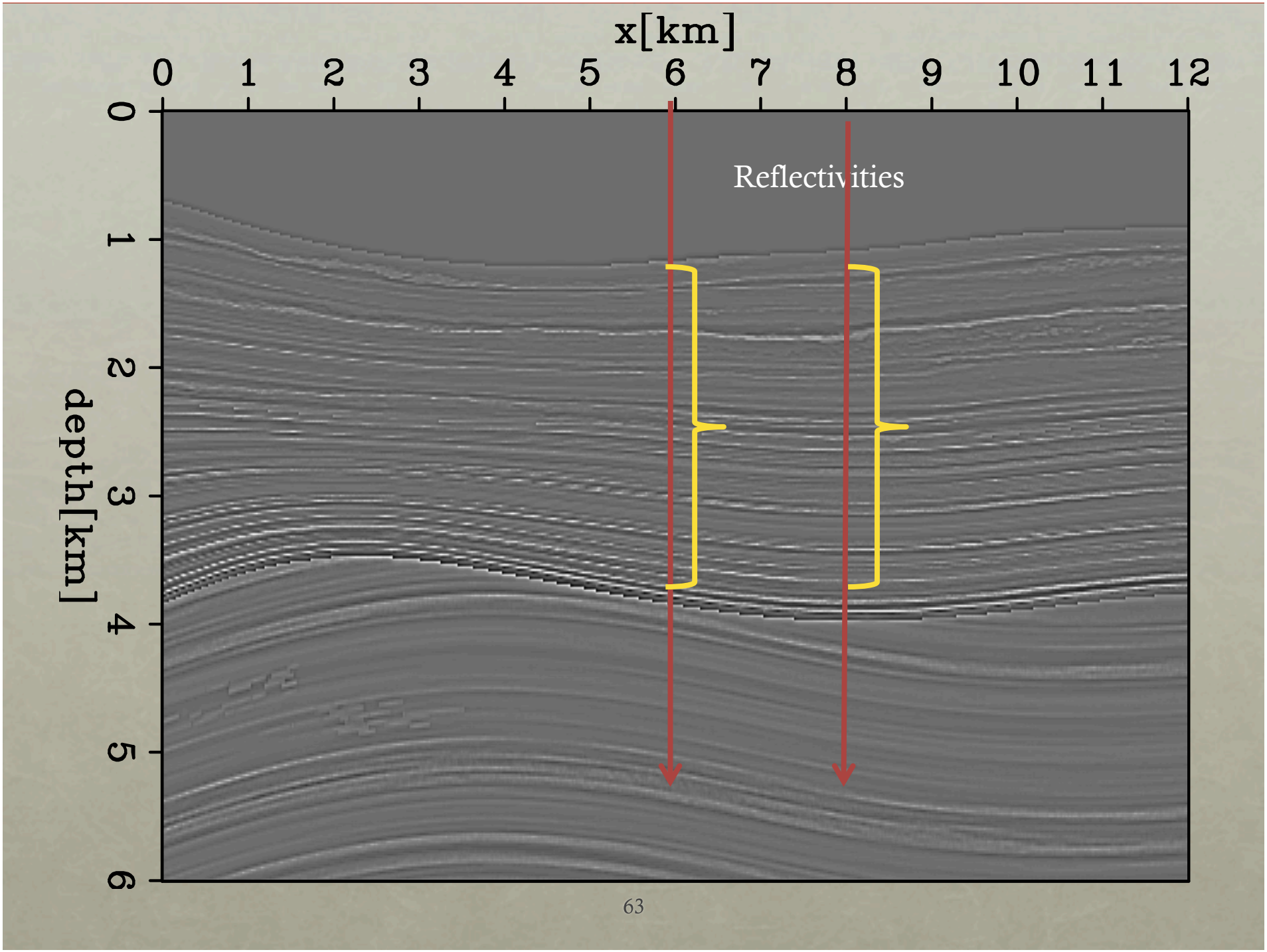
NUMERICAL TESTS

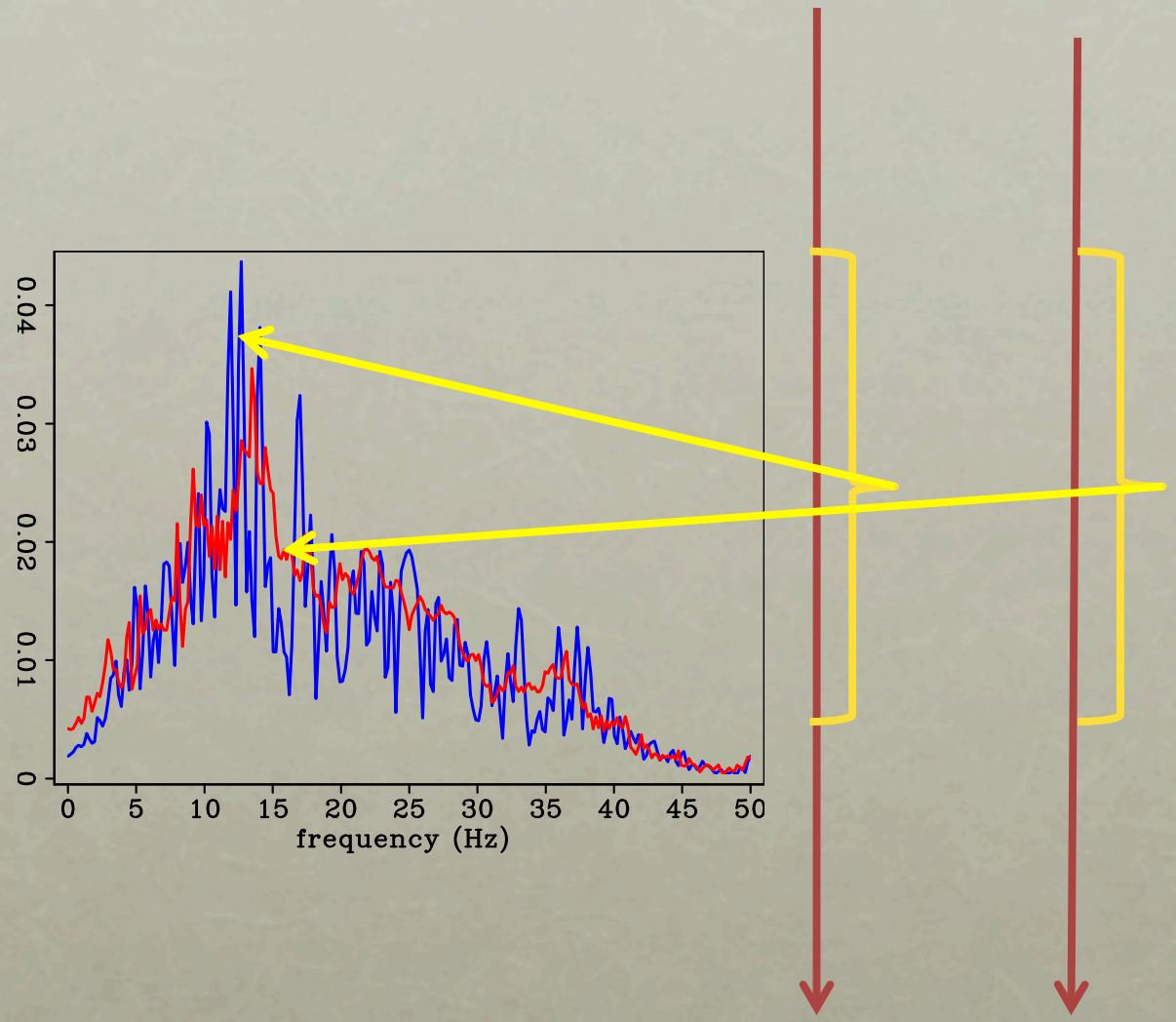
- Model with sparse reflectors
  - 2D test I
  - 2D test II
- **Model with dense reflectors**
  - SEAM model

MODEL WITH DENSE REFLECTORS

- **Assumption(1)**:
  - The spectra of the reflectivities are statistically the same, within each large window

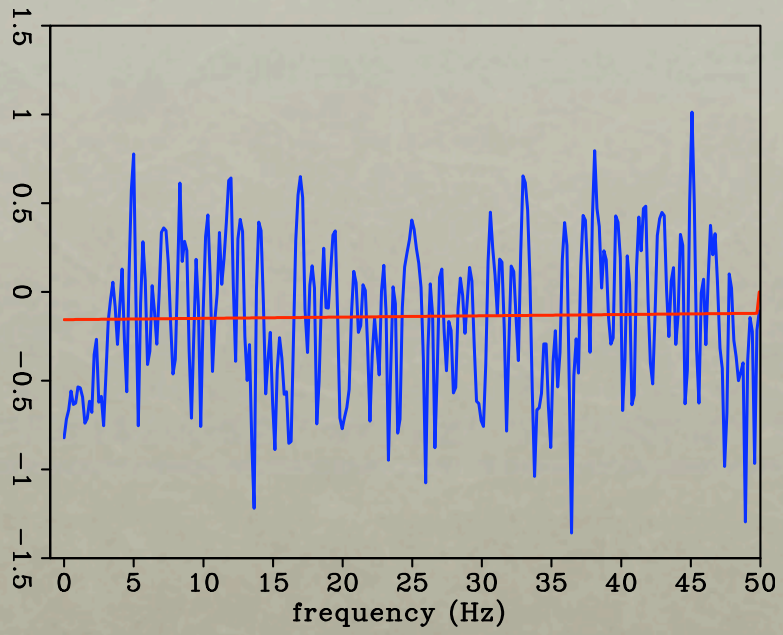

x[km]
0 1 2 3 4 5 6 7 8 9 10 11 12
depth[km]
0 1 2 3 4 5 6
Reflectivities

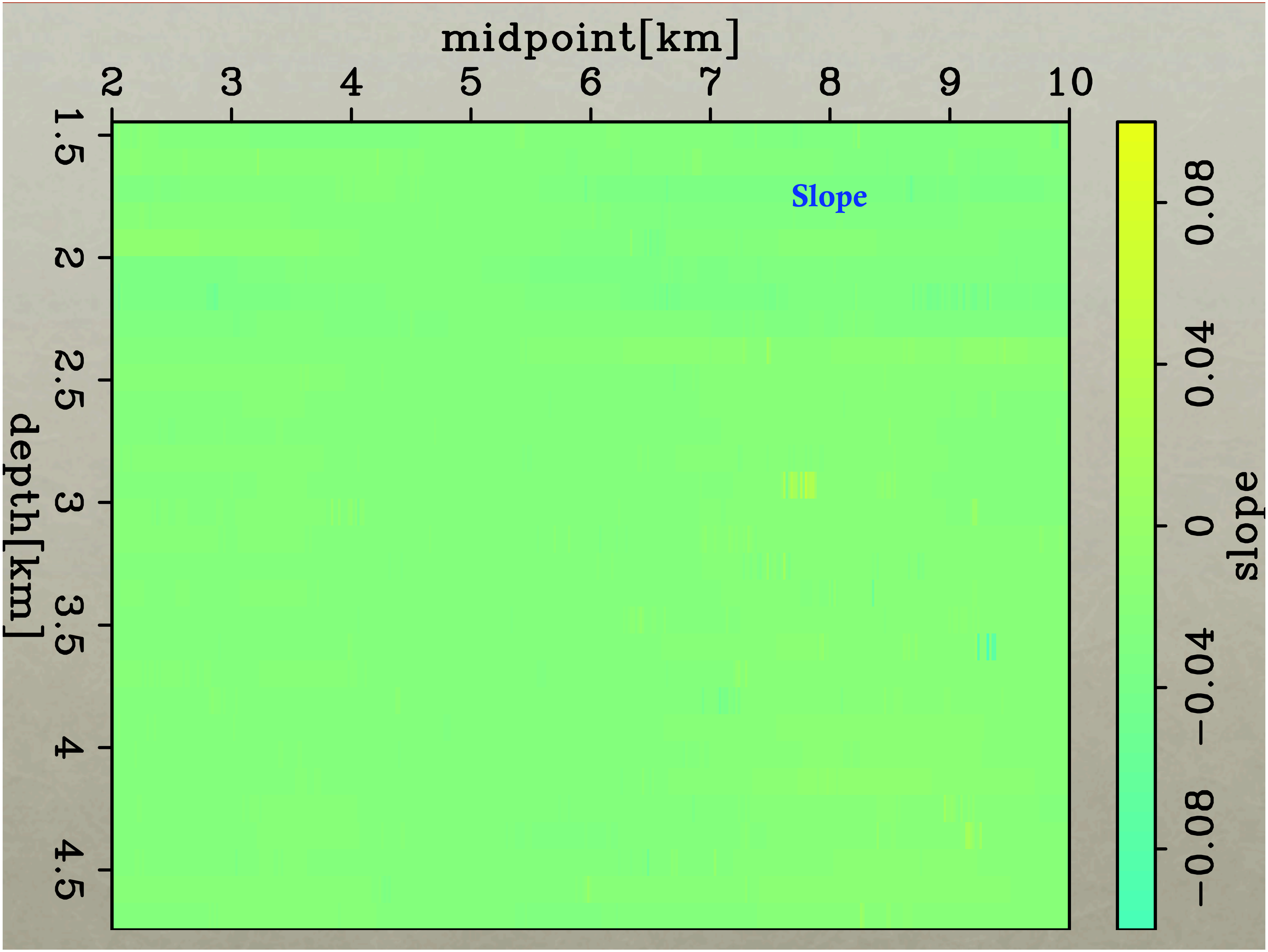

x[km]
0
1
2
3
4
5
6
7
8
9
10
11
12
depth[km]
0
1
2
3
4
5
6
Reflectivities


0.04
0.03
0.02
0.01
0
0
5
10
15
20
25
30
35
40
45
50
frequency (Hz)

Blue: Log(Ratio)

Red: fitted line

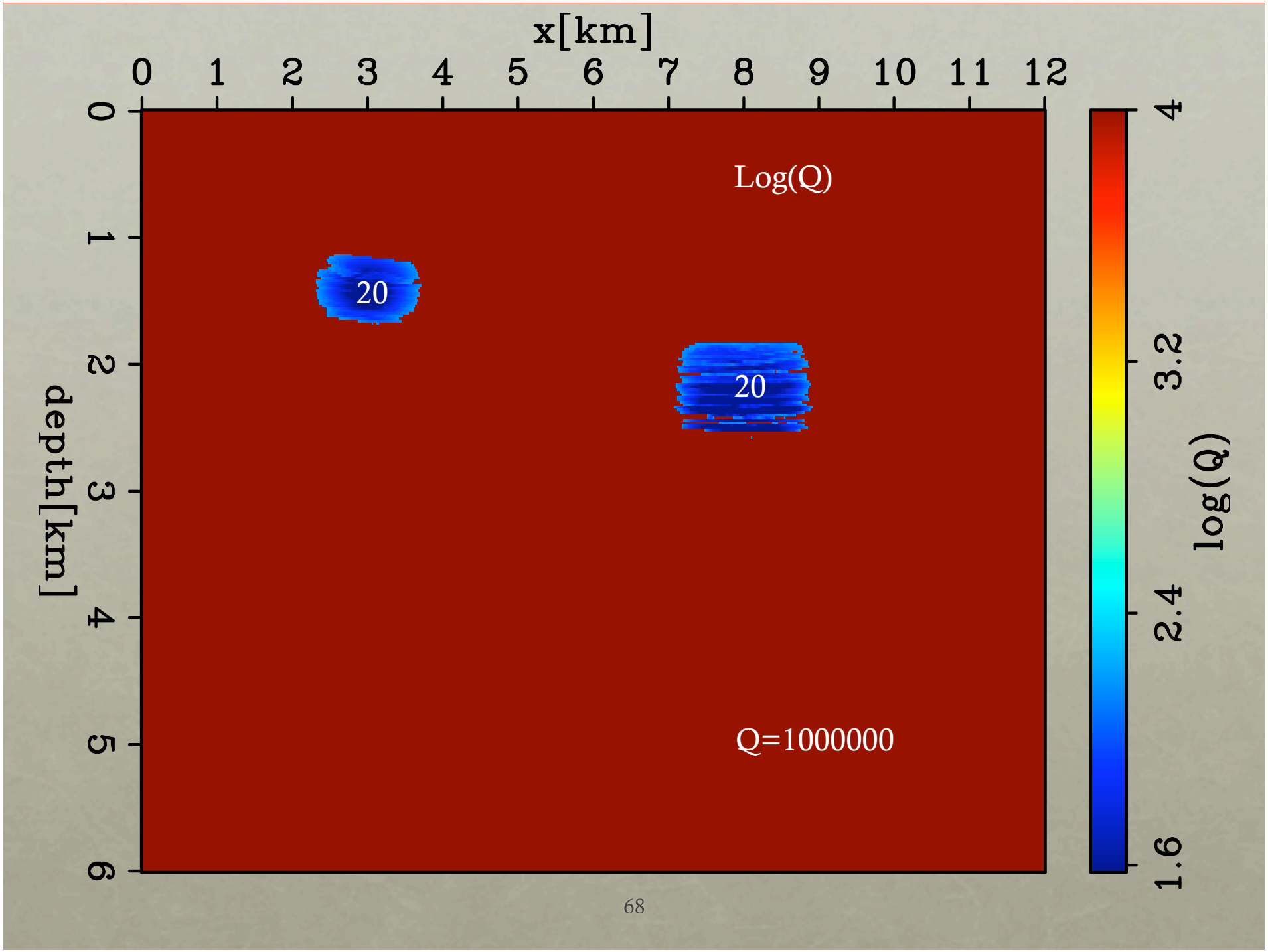


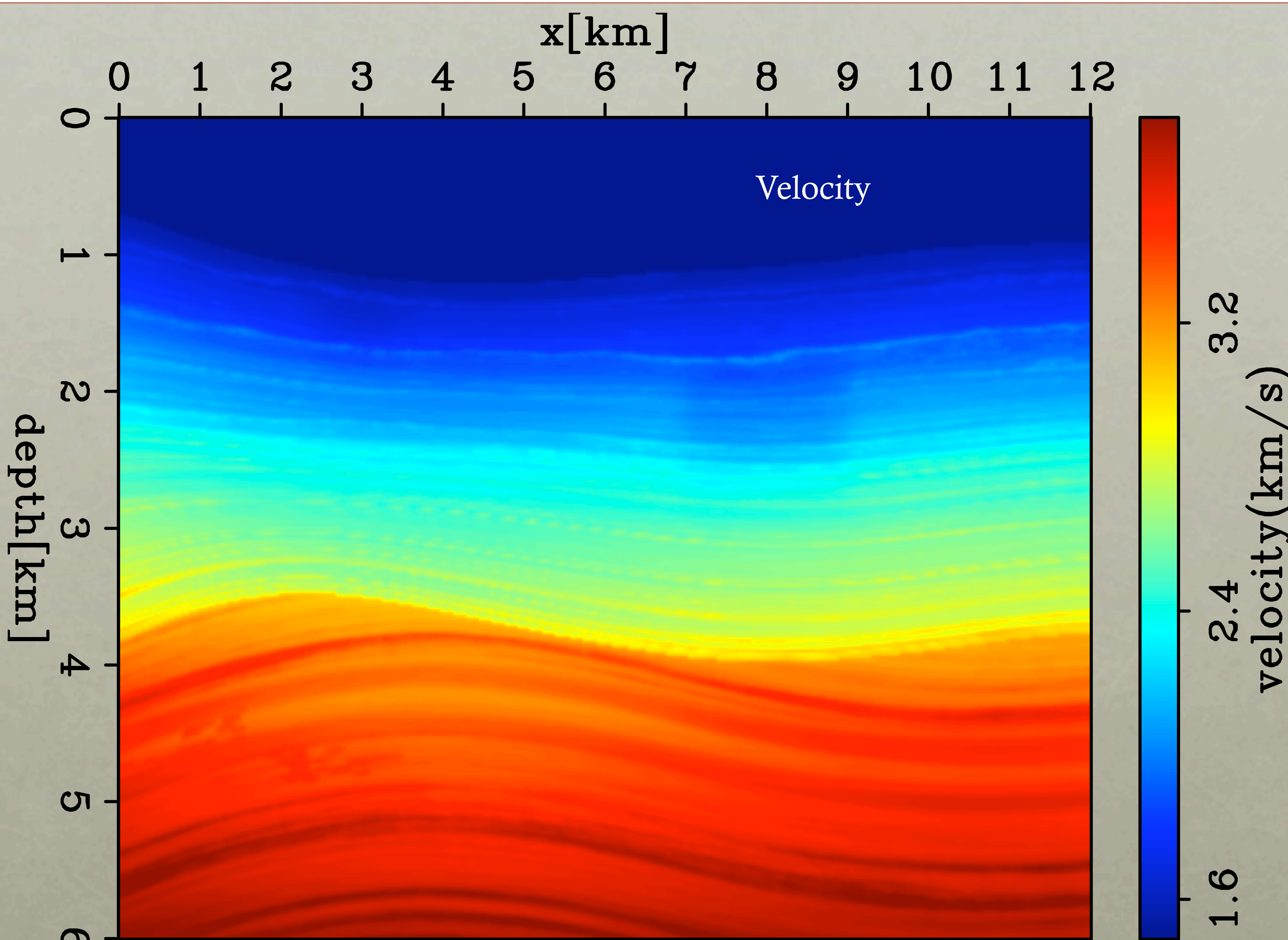


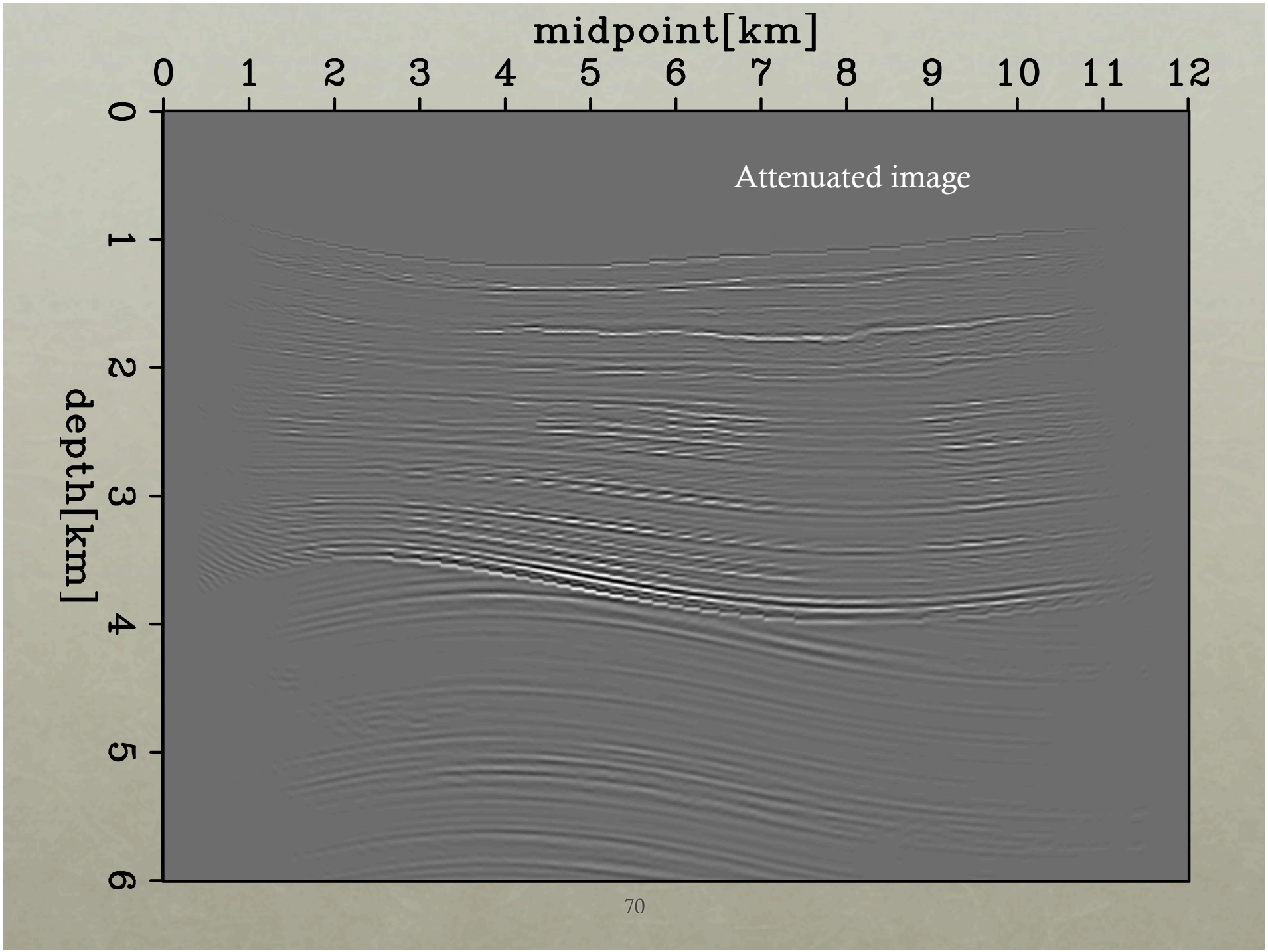
midpoint[km]
2
3
4
5
6
7
8
9
10
depth[km]
1.5
2
2.5
3
3.5
4
4.5
Slope
slope
0.08
0.04
0
−0.04
−0.08

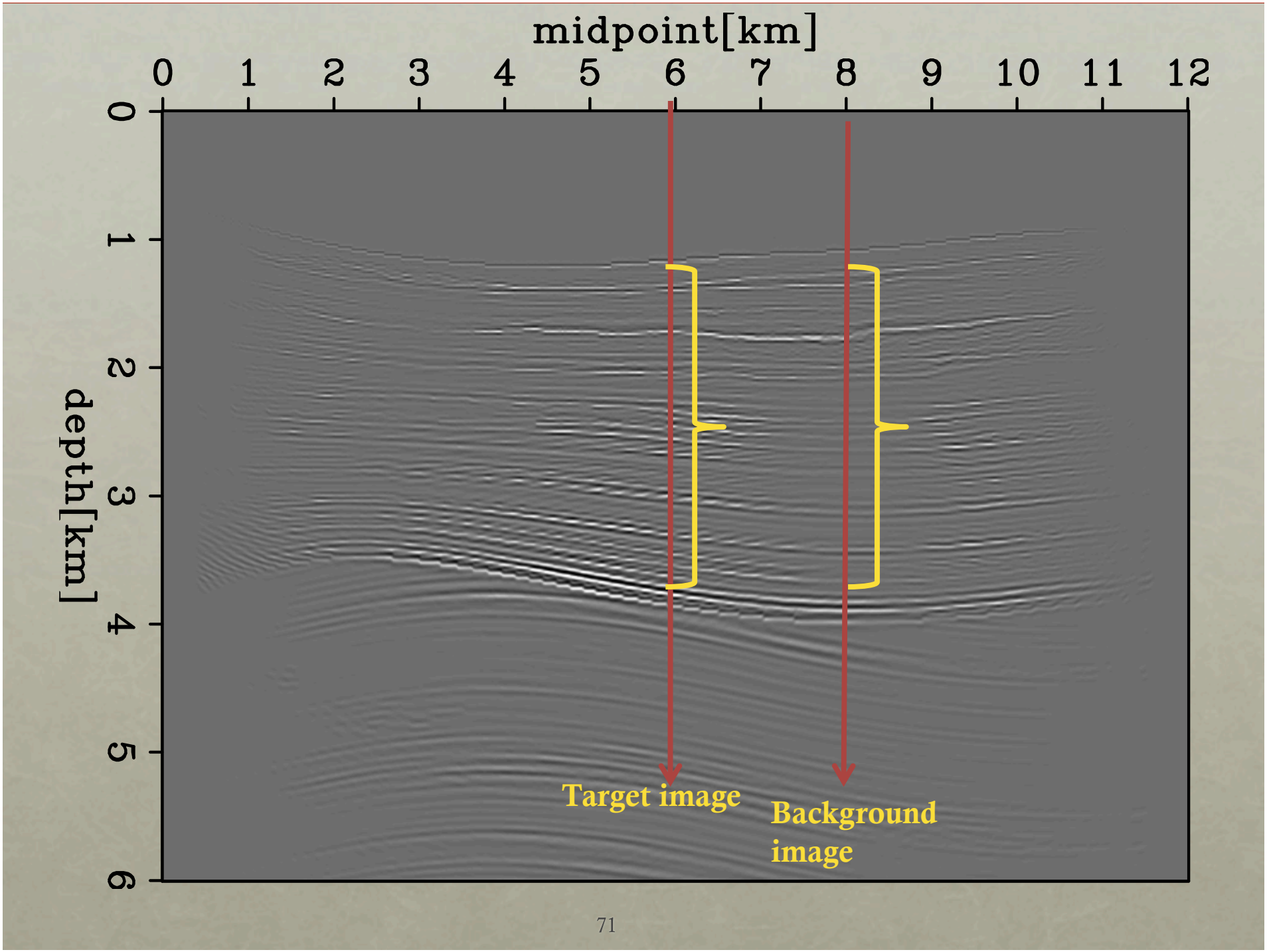
MODEL WITH DENSE REFLECTORS

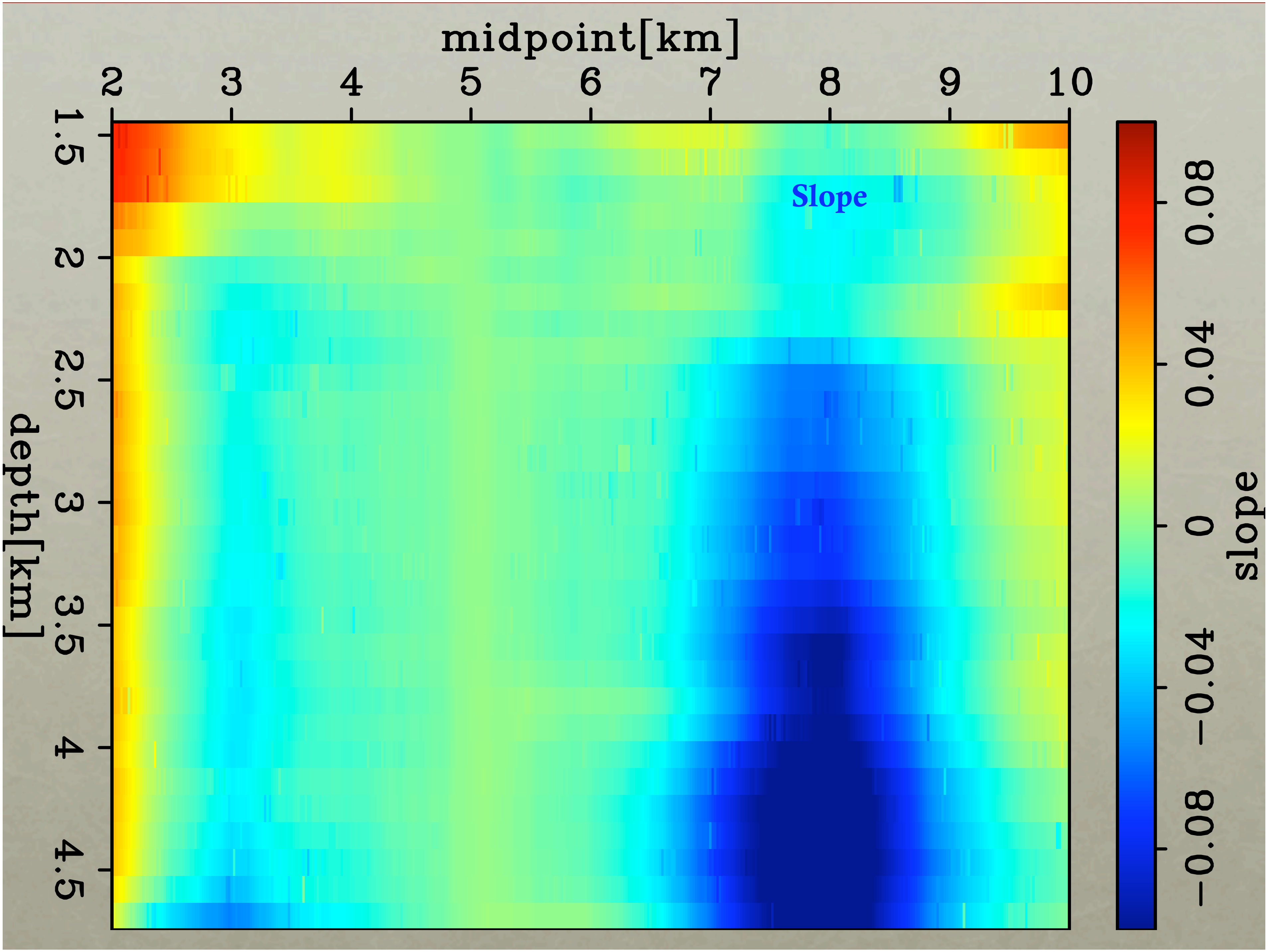
- **Assumption(2)**:
  - The spectral differences between these windows in the background image mainly come from attenuation (no scattering)

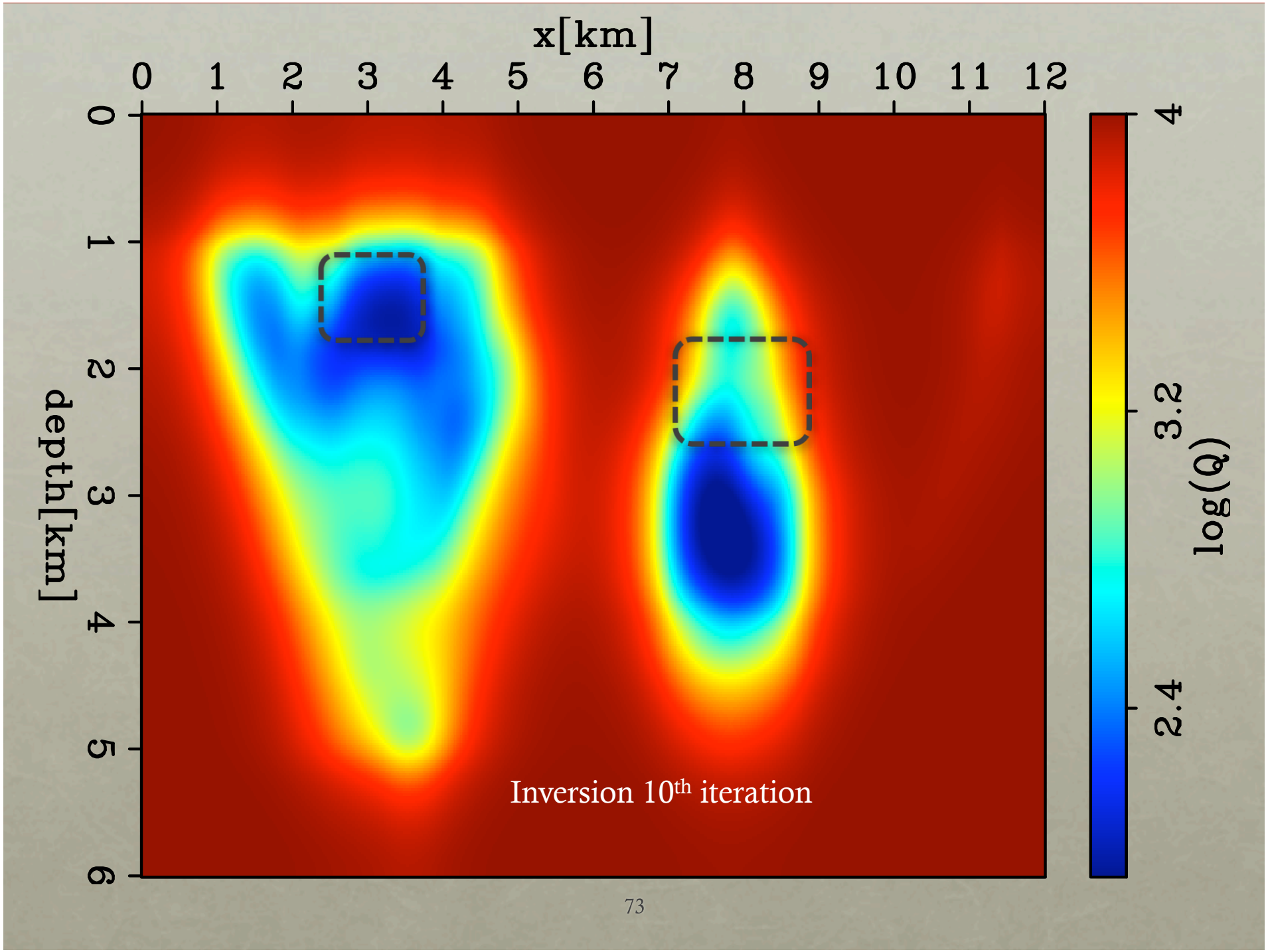

x[km]
0 1 2 3 4 5 6 7 8 9 10 11 12
depth[km]
0 1 2 3 4 5 6
Log(Q)
20
20
Q=1000000
log(Q)
4 3.2 2.4 1.6


x[km]
0 1 2 3 4 5 6 7 8 9 10 11 12
depth[km]
0 1 2 3 4 5 6
Velocity
velocity(km/s)
1.6 2.4 3.2


midpoint[km]
0
1
2
3
4
5
6
7
8
9
10
11
12
depth[km]
0
1
2
3
4
5
6
Attenuated image


midpoint[km]
0
1
2
3
4
5
6
7
8
9
10
11
12
depth[km]
0
1
2
3
4
5
6
Target image
Background image


midpoint[km]
2
3
4
5
6
7
8
9
10
depth[km]
1.5
2
2.5
3
3.5
4
4.5
Slope
slope
0.08
0.04
0
−0.04
−0.08


x[km]
0 1 2 3 4 5 6 7 8 9 10 11 12
depth[km]
0 1 2 3 4 5 6
log(Q)
4
3.2
2.4
Inversion 10th iteration

CONCLUSION

- WEMQA
  - Image space method: suppresses the noise; simplifies and focuses the events
  - Wave-equation based method: better handle complex subsurface structure

- Tests with three 2D models demonstrate the feasibility for the model with sparse events and dense events

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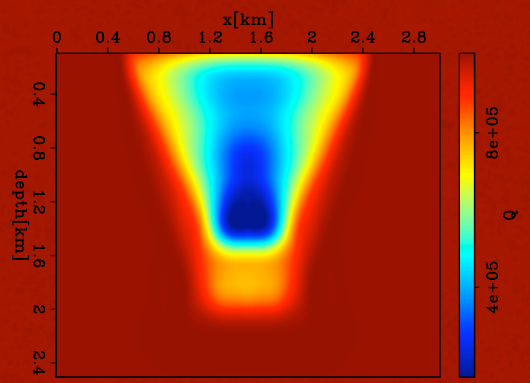
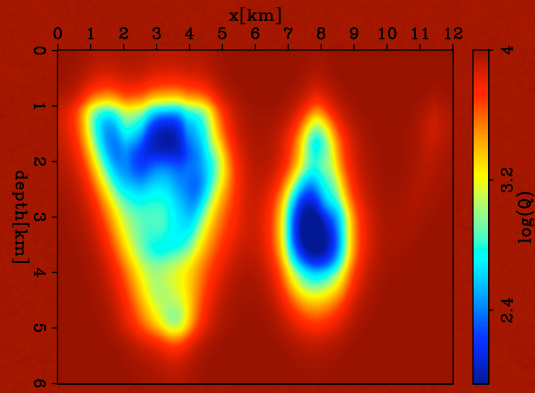
- Thanks Yaxun for WEMVA code
- Thanks all SEPers





THANQ AND Q?

Yi Shen