

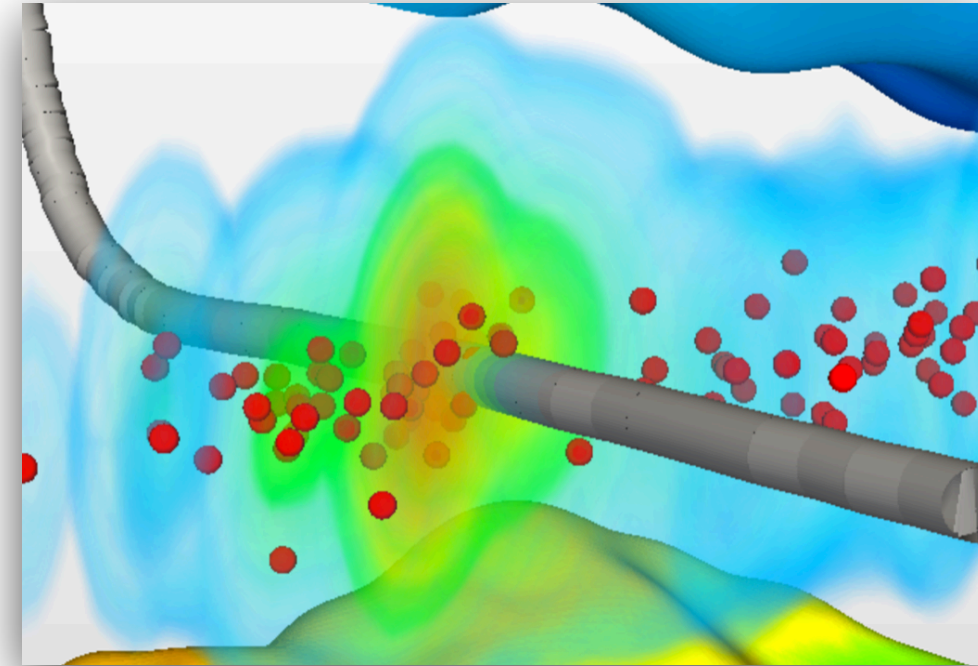
Feasibility of moment tensor inversion for a single-well microseismic data using neural networks

O. Ovcharenko, J. Akram, D. Peter

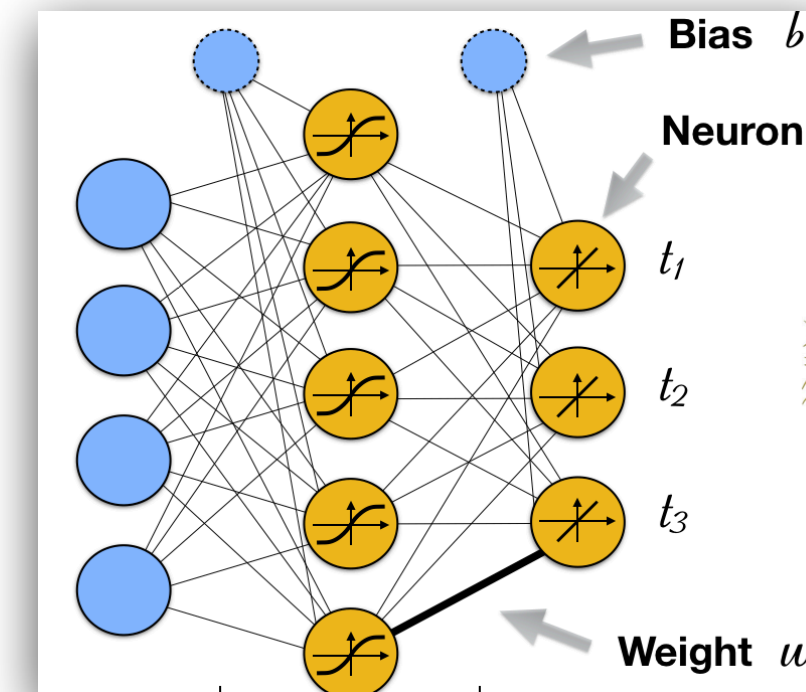
March 6, 2018

Outline

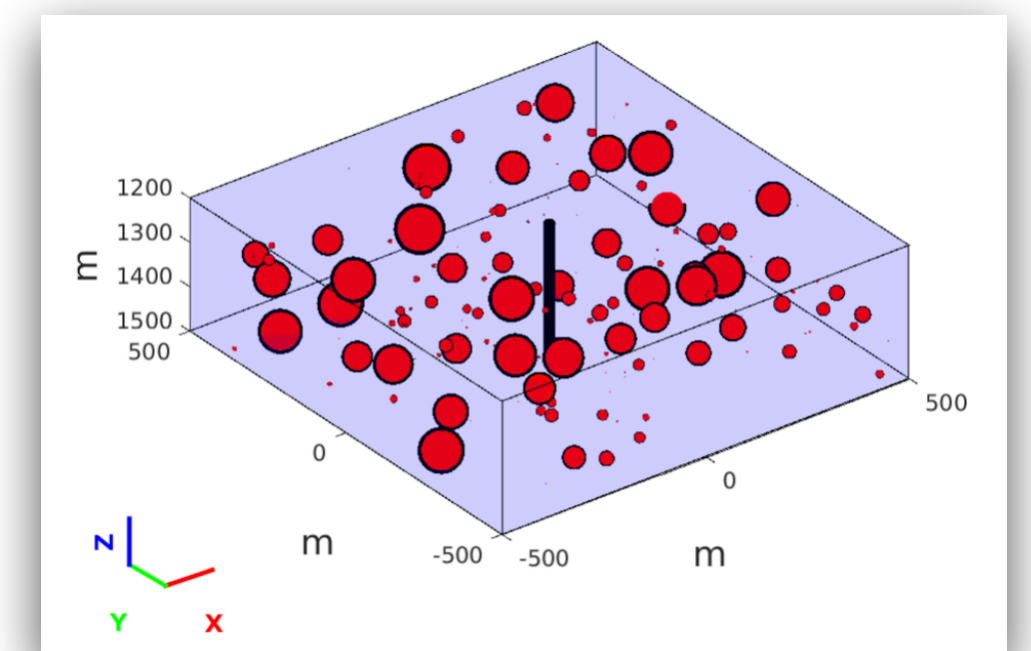
Single-well data



Artificial Neural Network

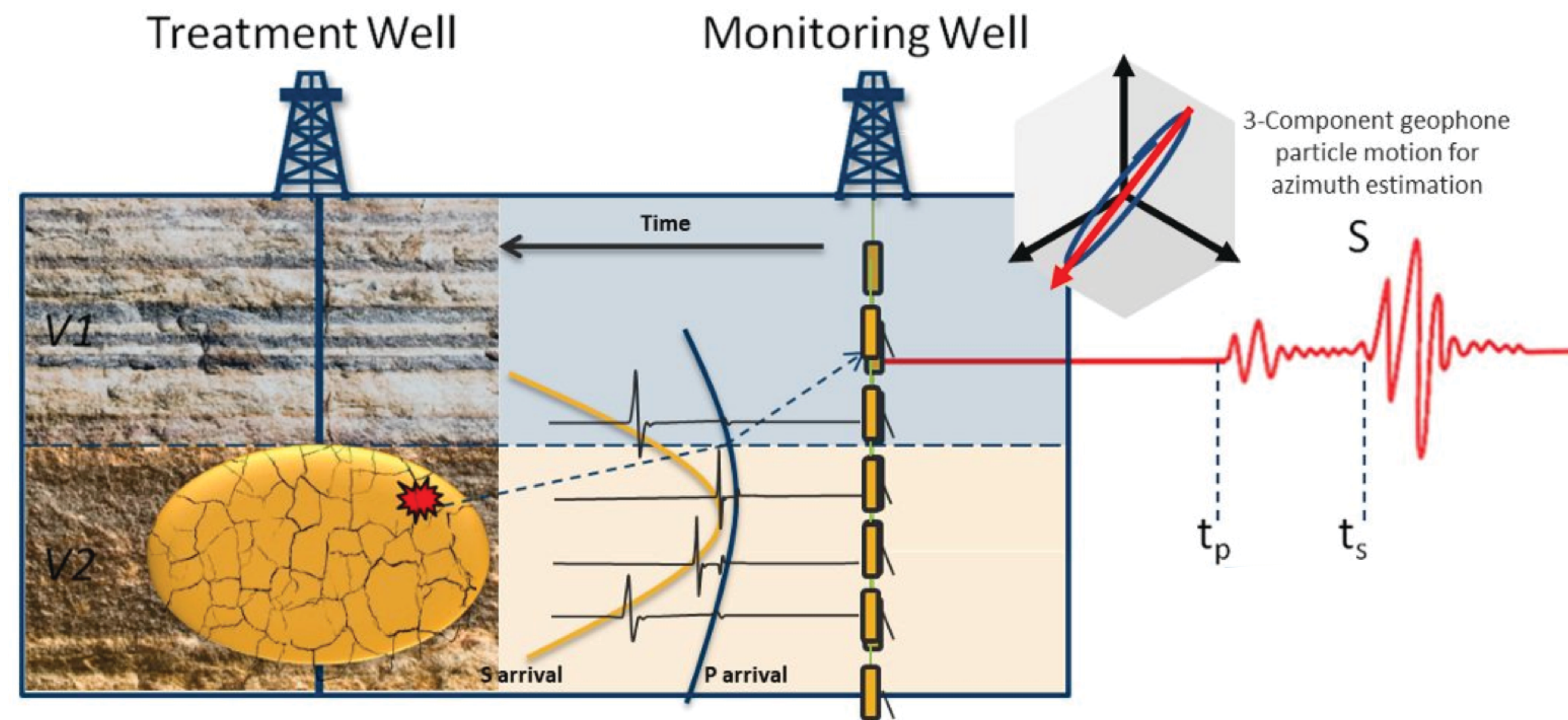


Example in a homogeneous model

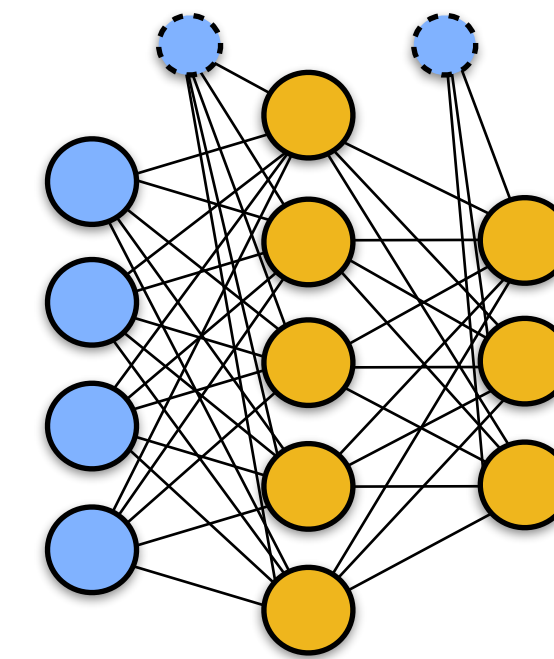


Idea

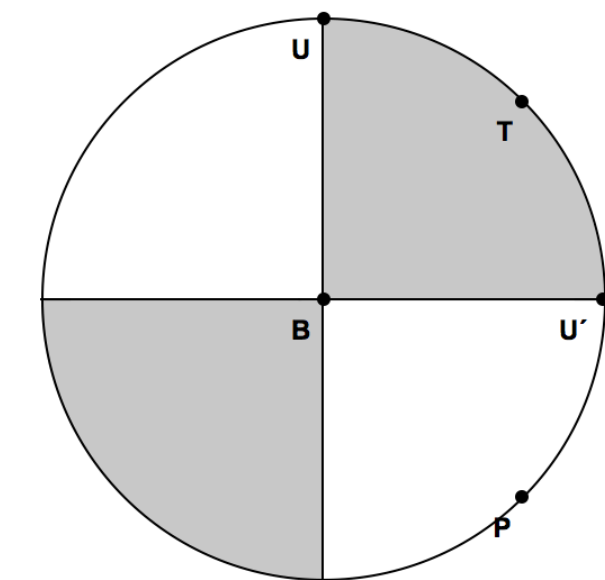
Reconstruct source mechanisms from single-well data using an artificial neural network

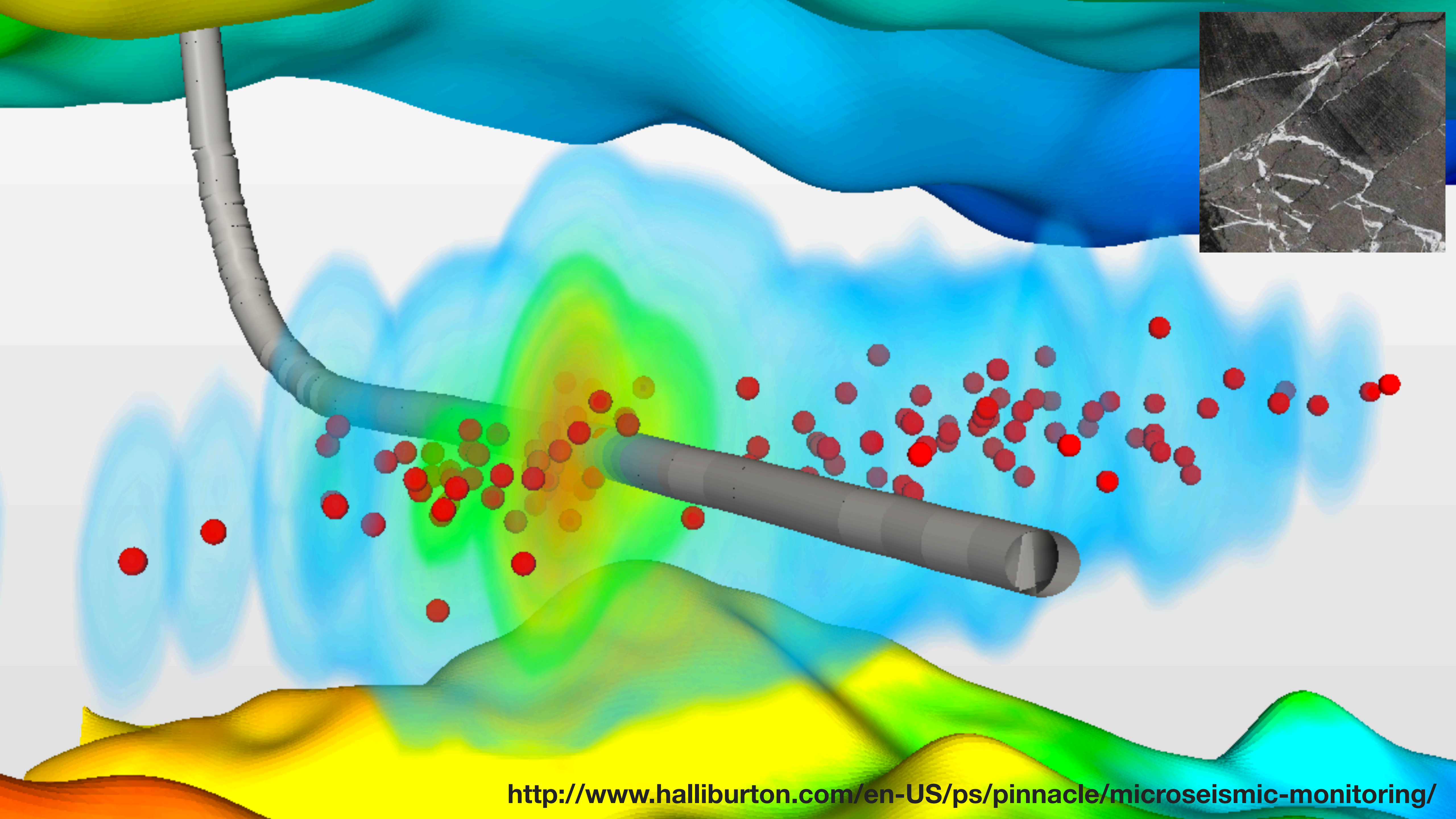


<https://www.geoexpro.com/articles/2017/07/>

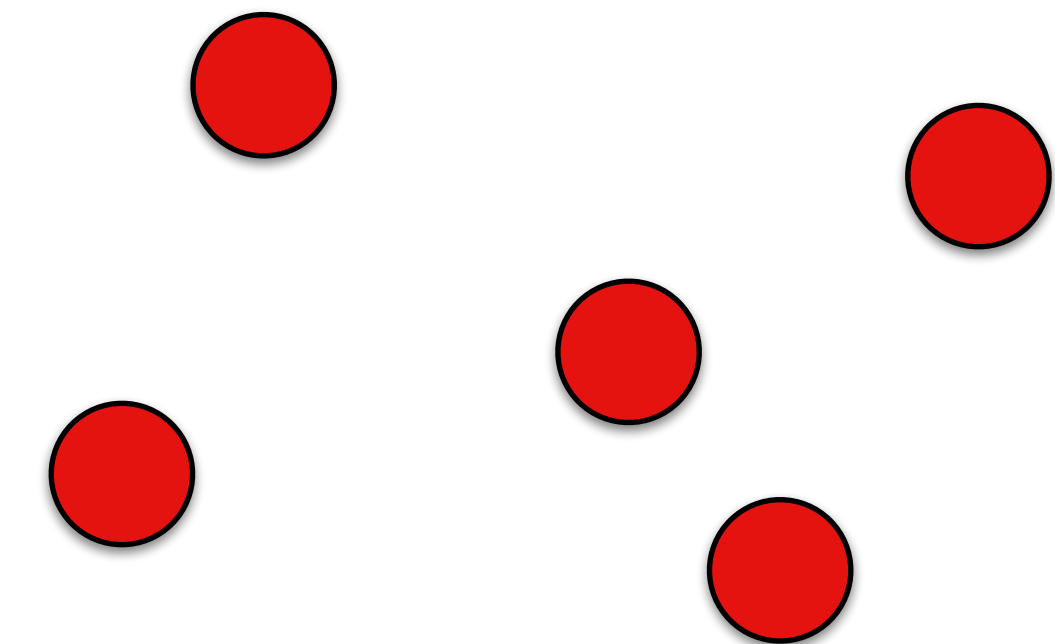


$$\begin{pmatrix} M_{xx} & M_{xy} & M_{xz} \\ & M_{yy} & M_{yz} \\ & & M_{zz} \end{pmatrix}$$

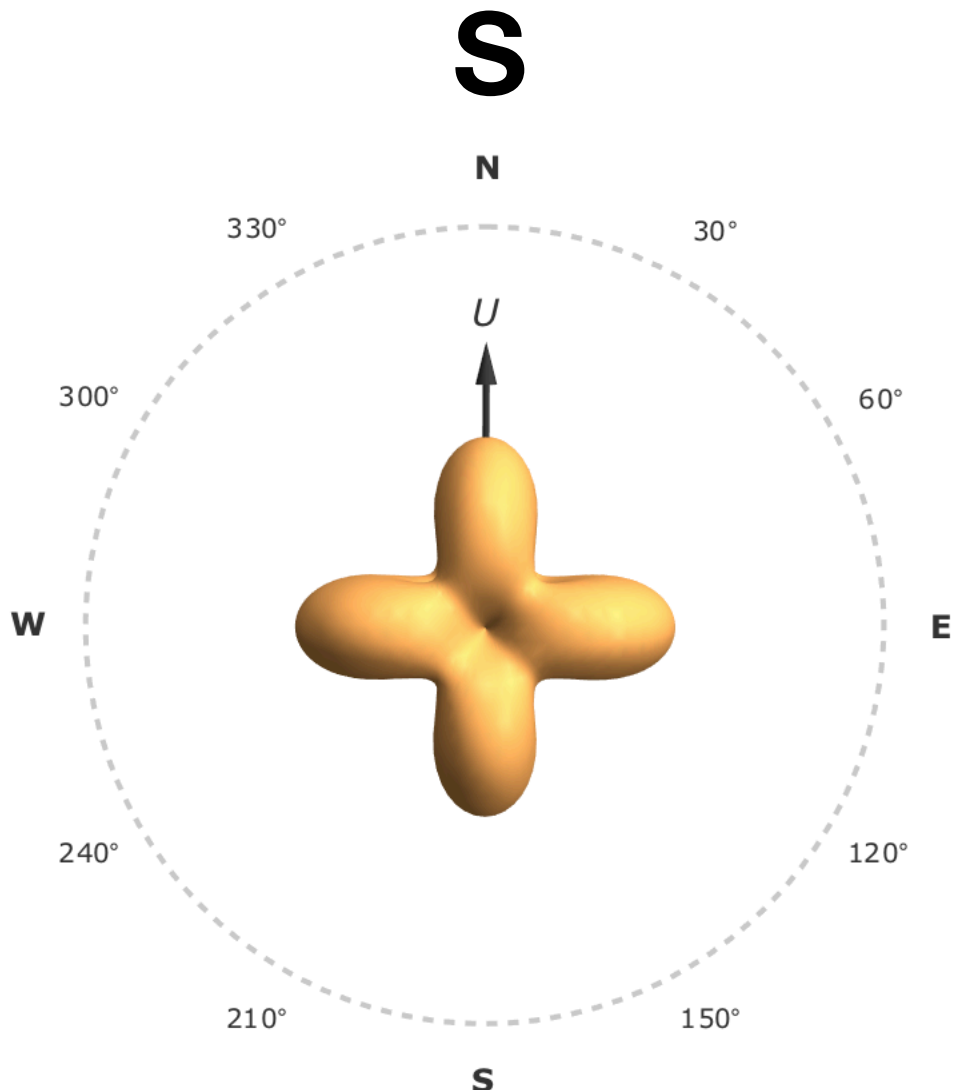
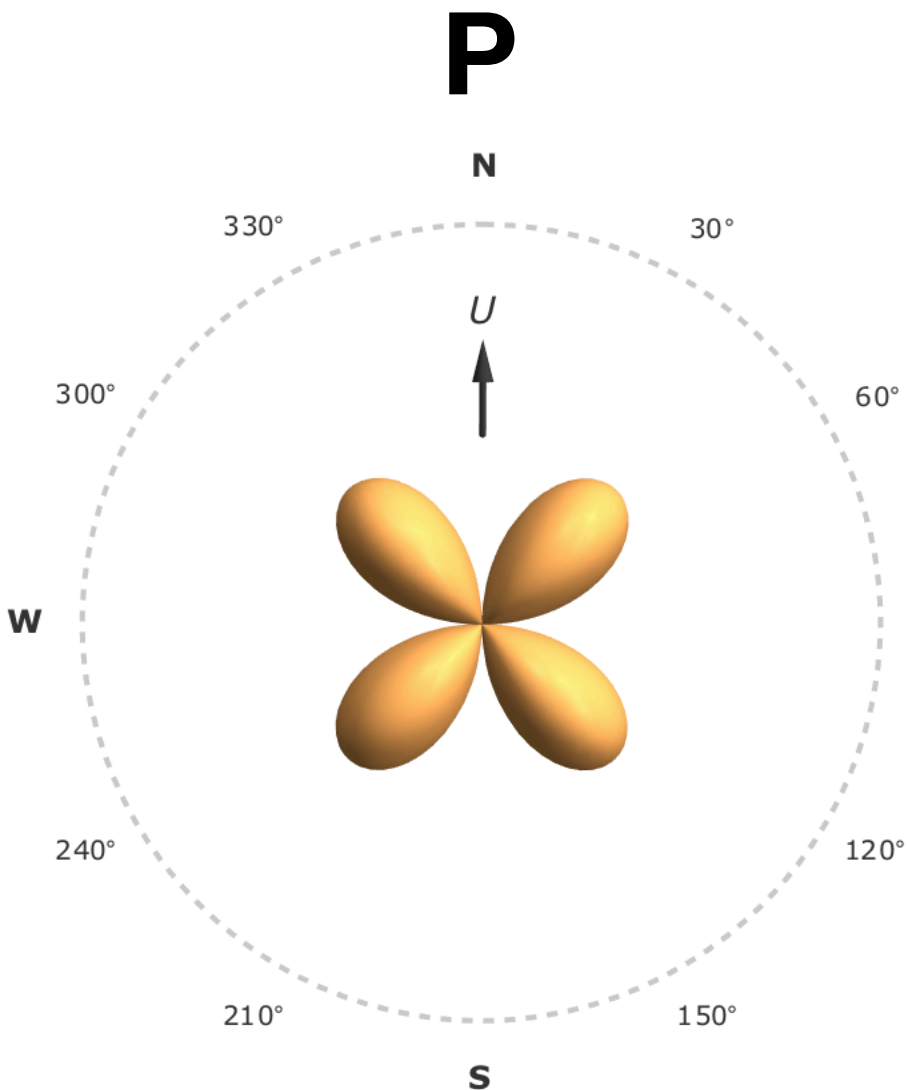
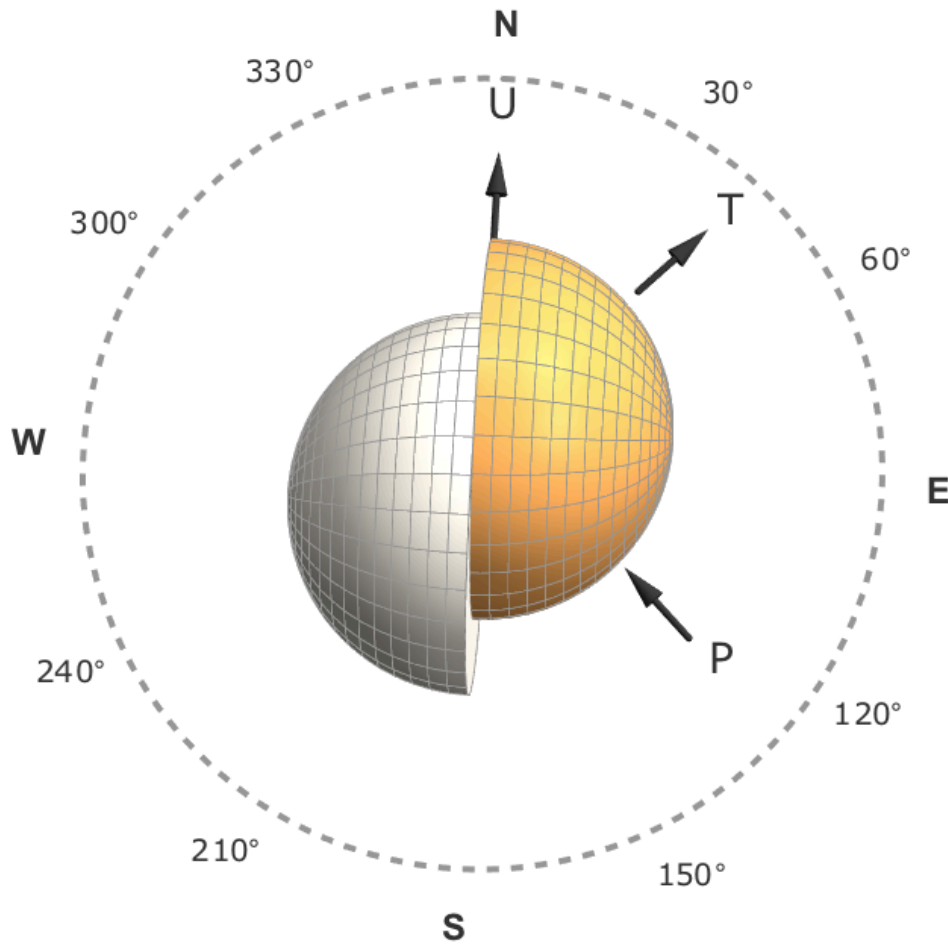
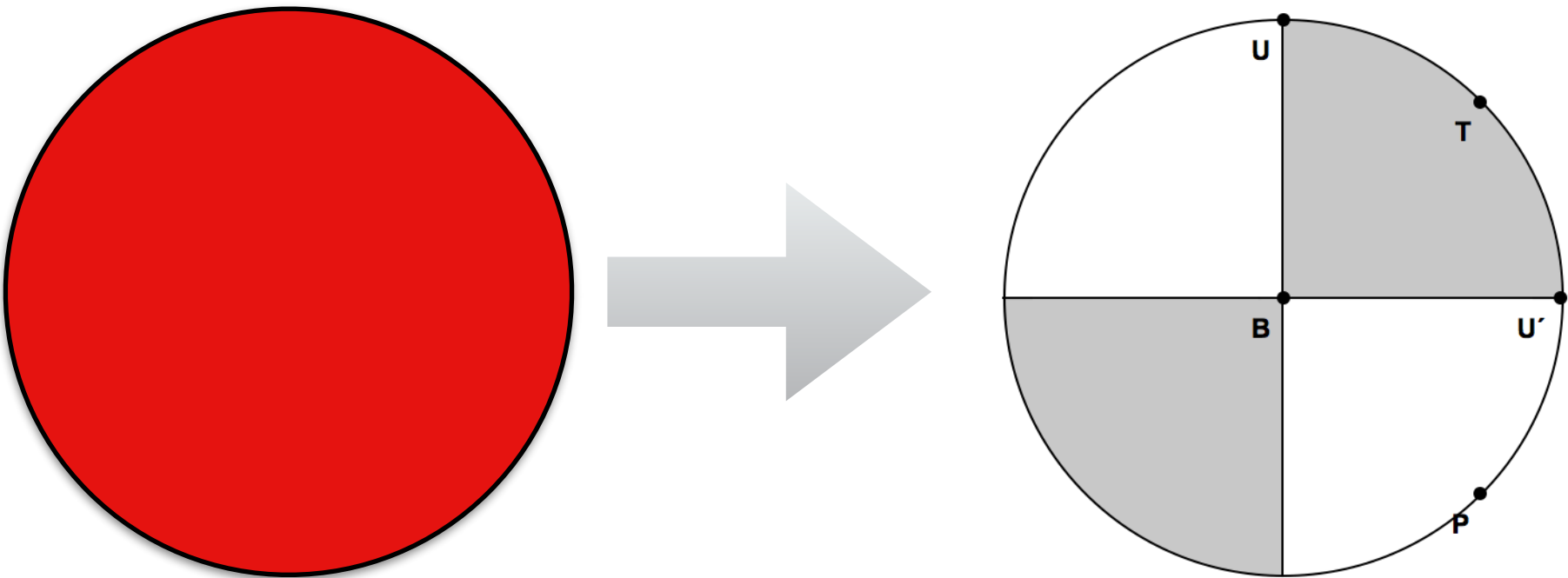




Source mechanism



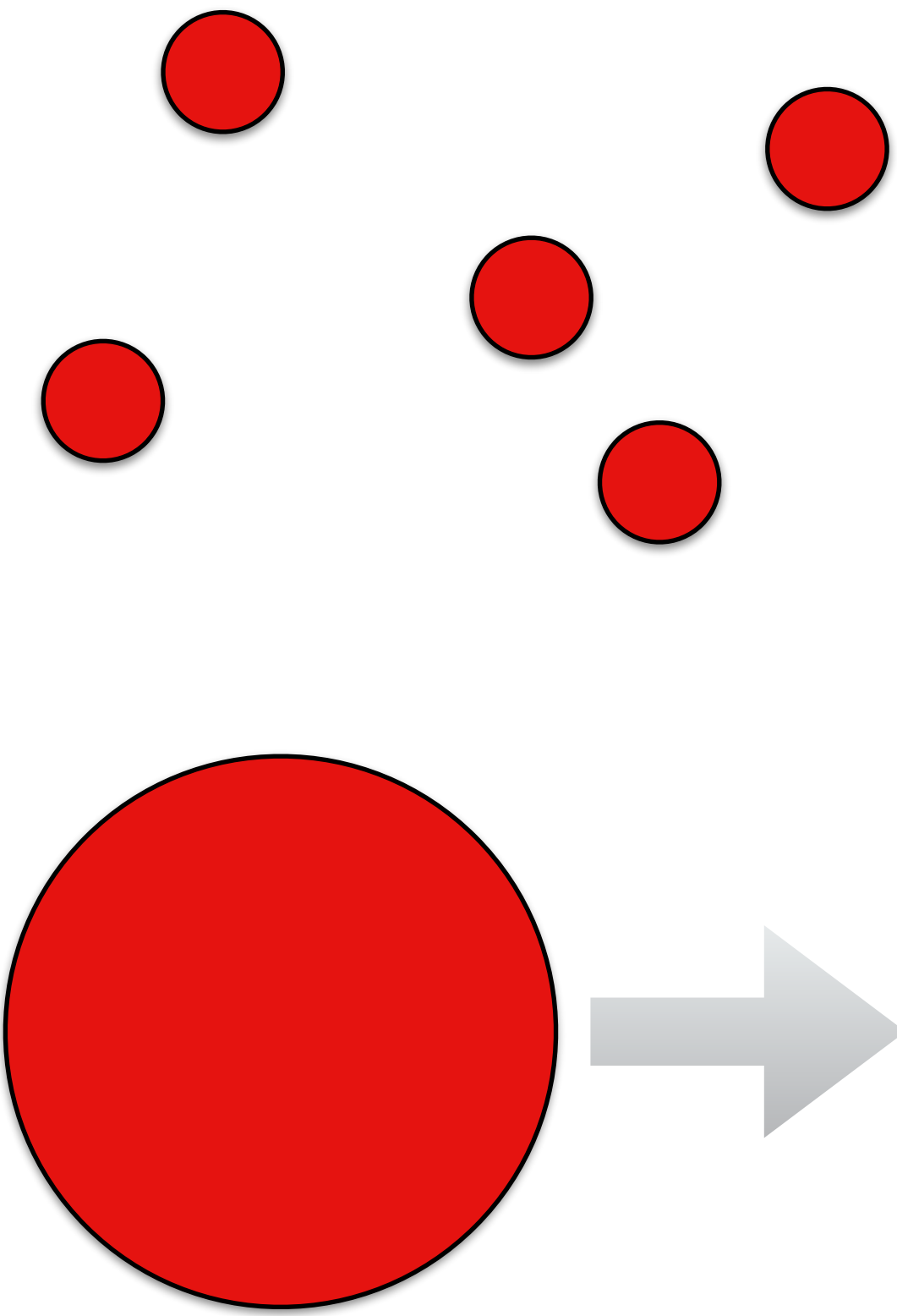
“Beach ball”



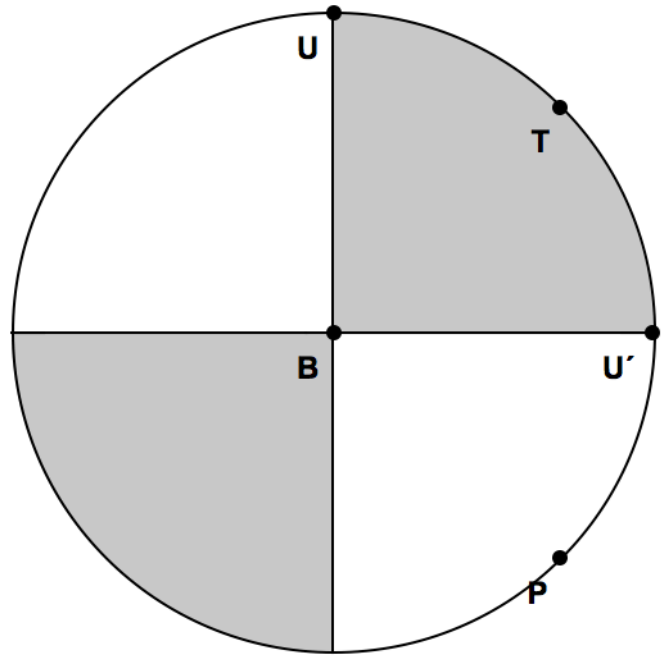
Radiation patterns



Source mechanism



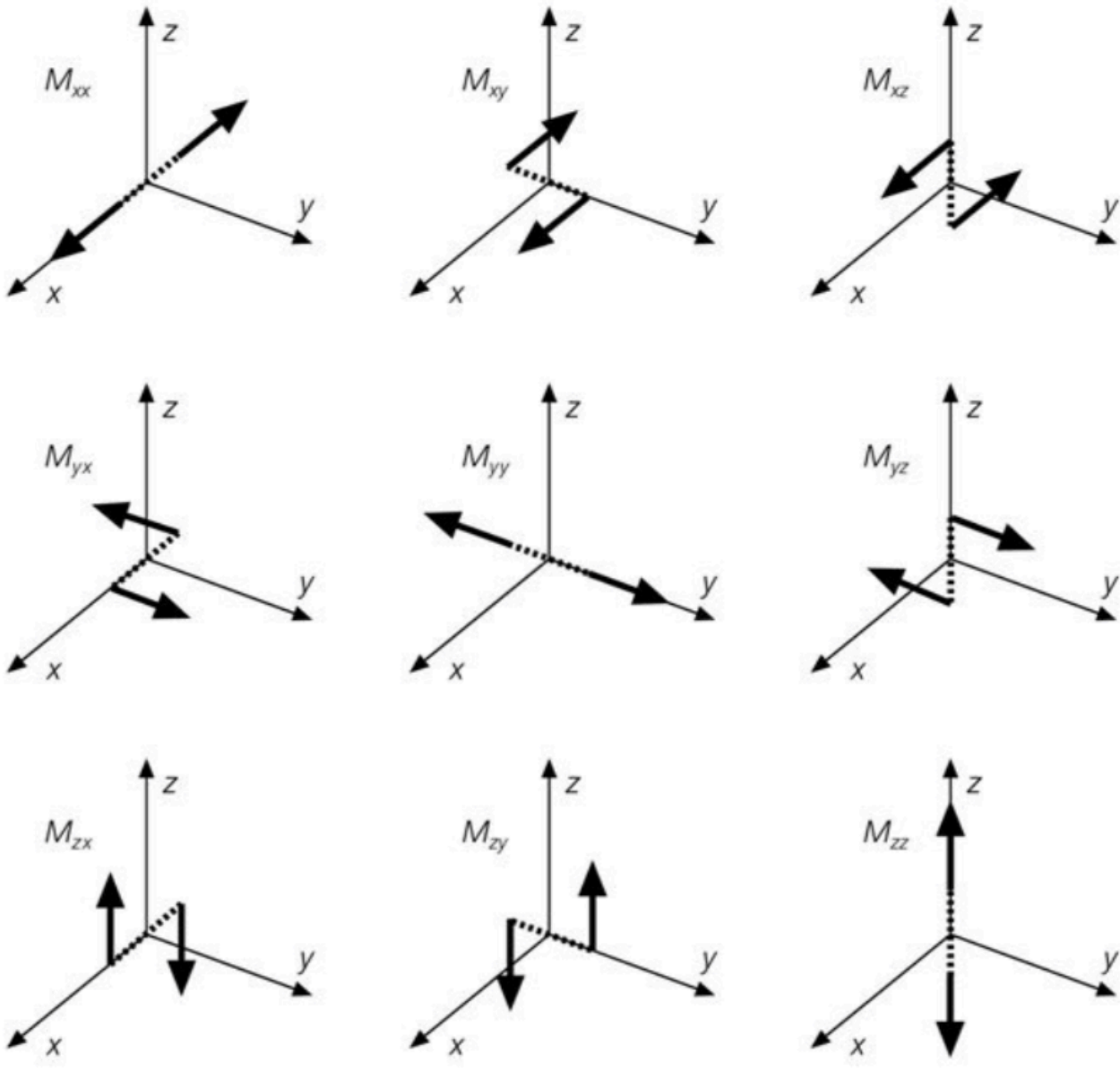
“Beach ball”



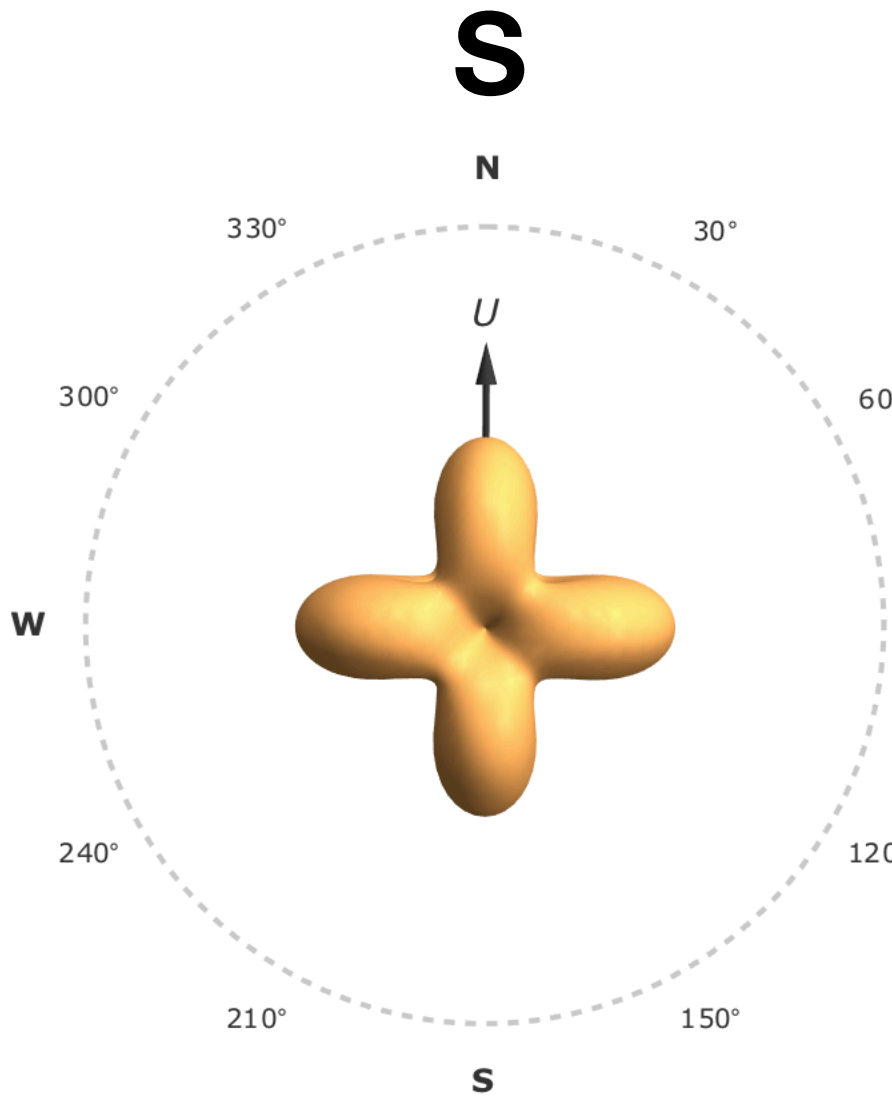
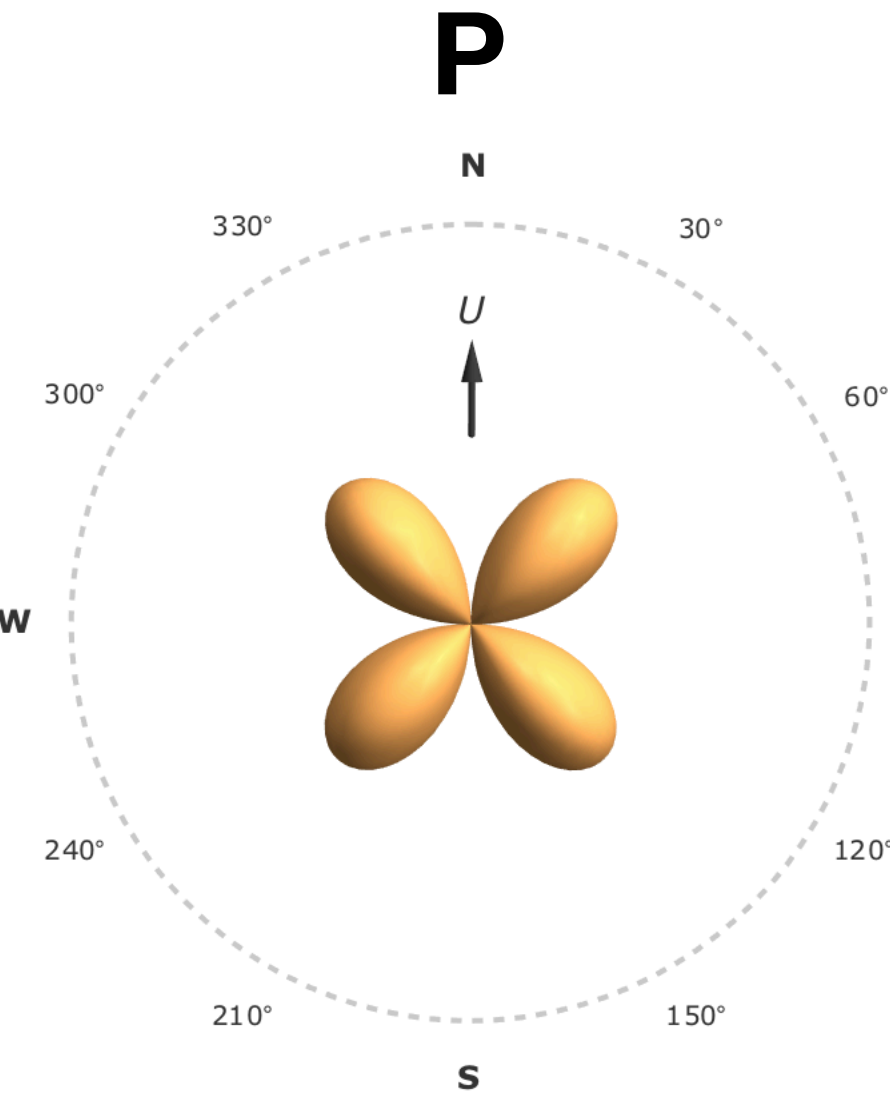
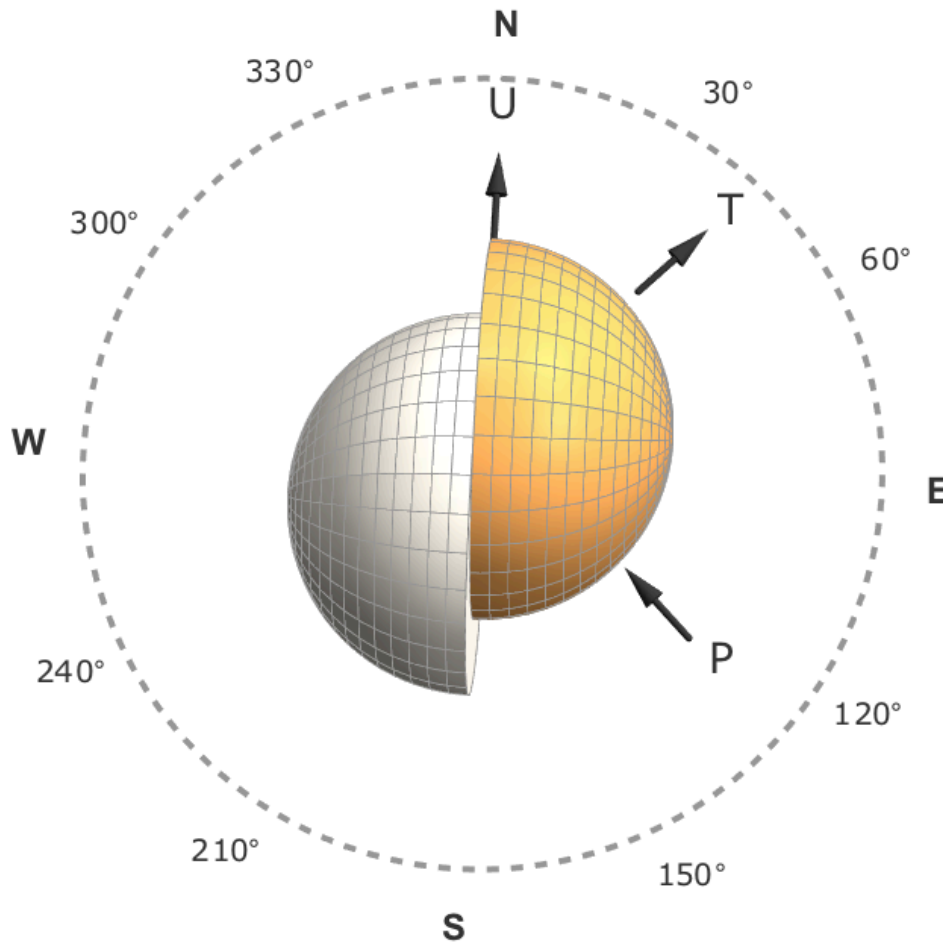
Seismic moment tensor

$$\mathbf{M} = \begin{pmatrix} M_{xx} & M_{xy} & M_{xz} \\ M_{yx} & M_{yy} & M_{yz} \\ M_{zx} & M_{zy} & M_{zz} \end{pmatrix}$$

6 independent components



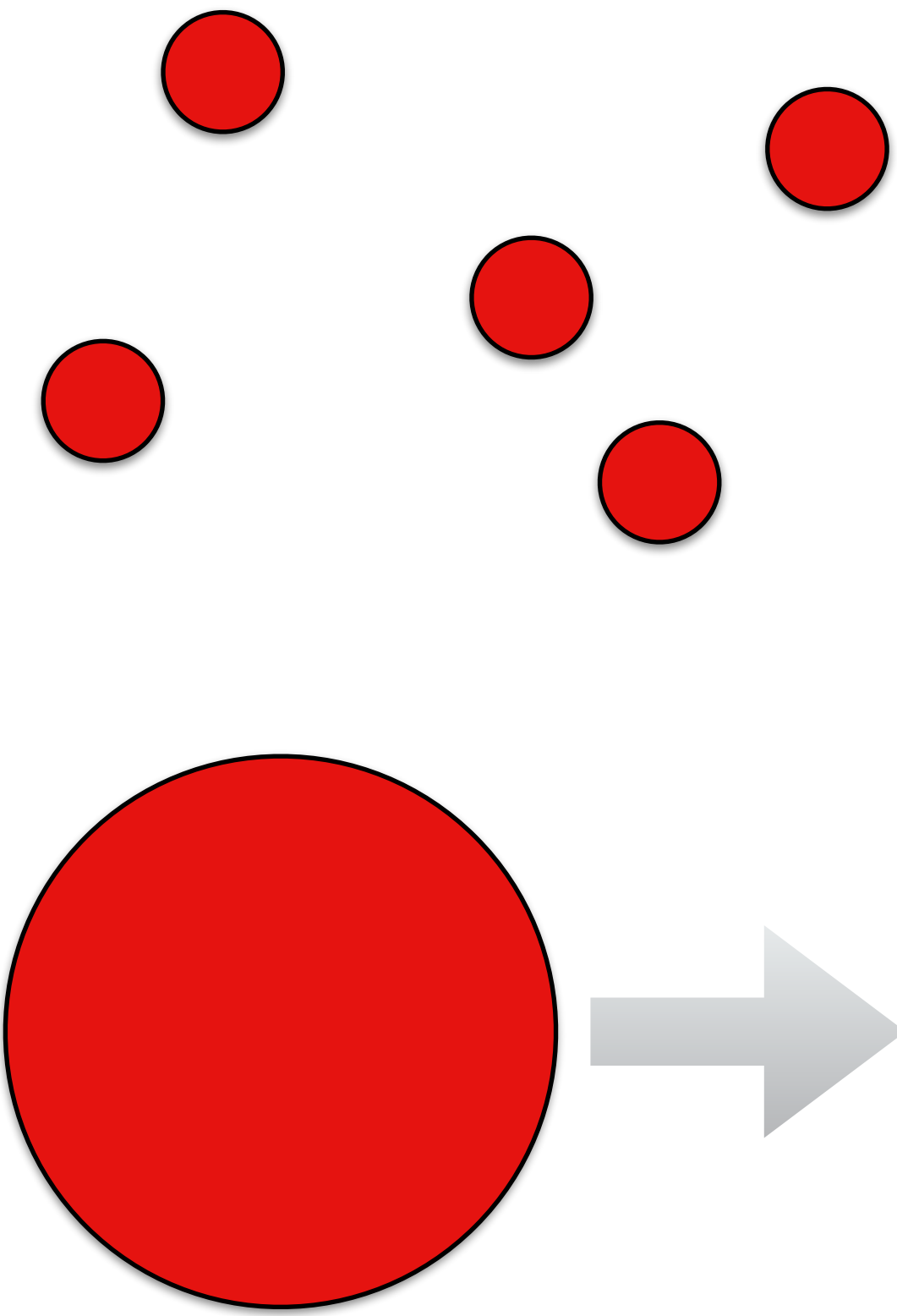
(Stein & Wyssession, 2003)



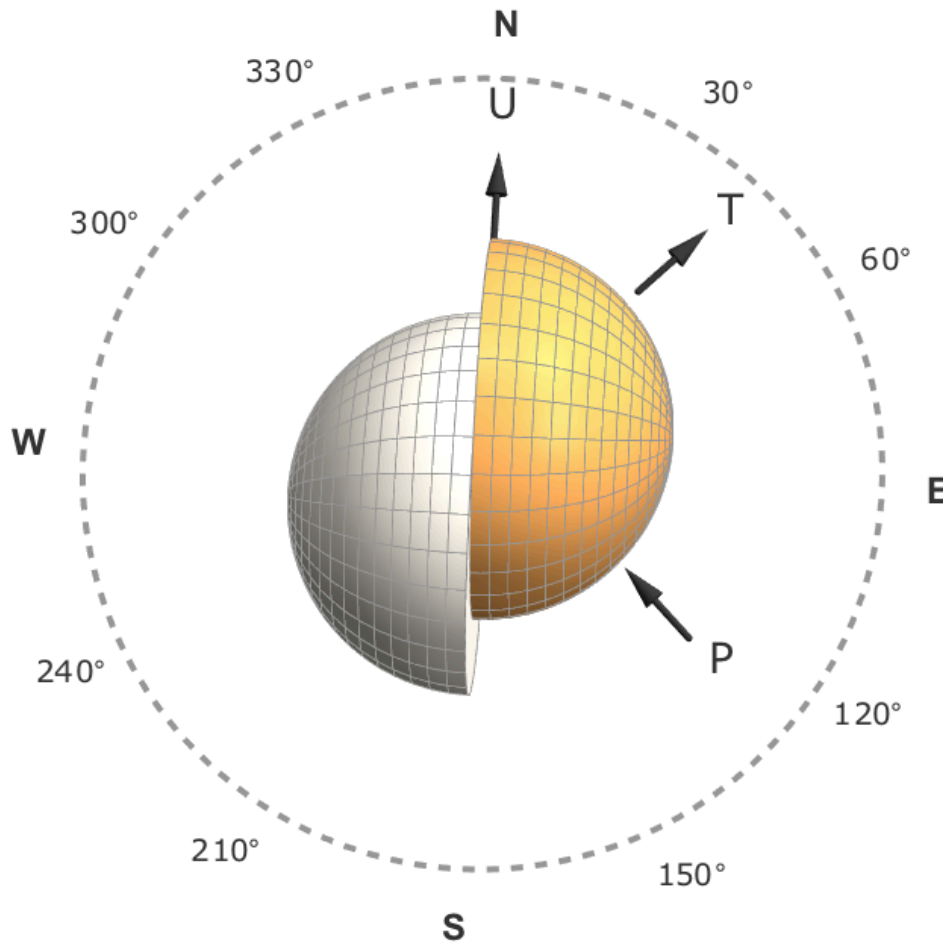
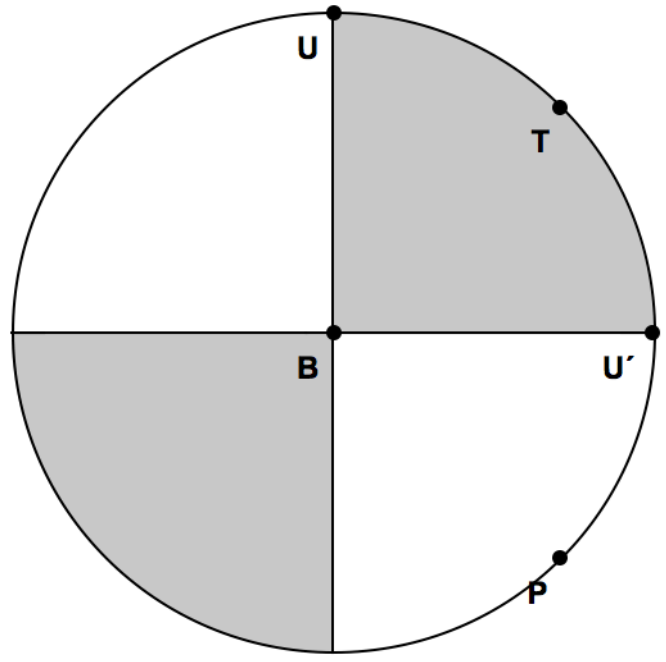
Radiation patterns



Source mechanism



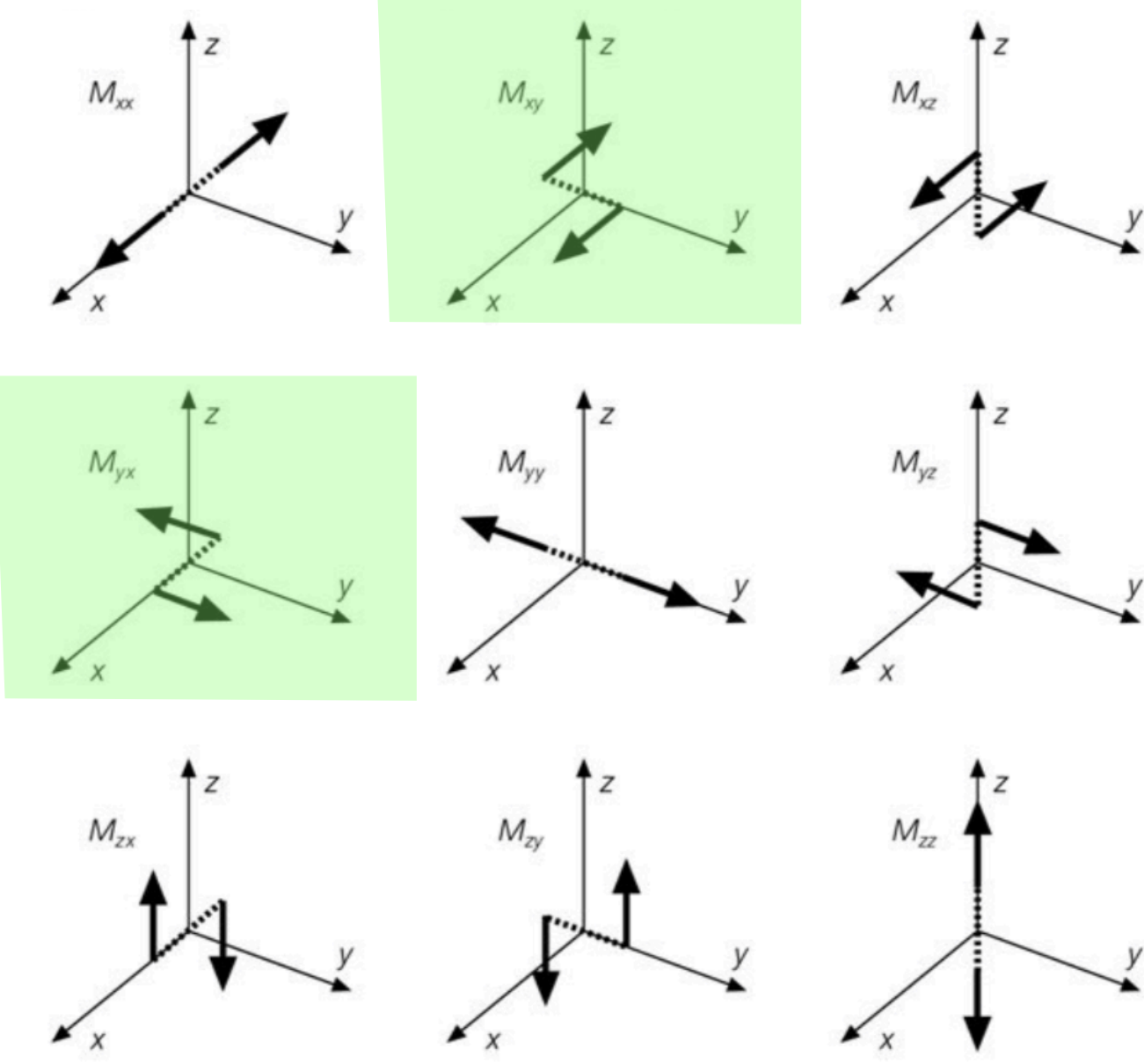
“Beach ball”



Seismic moment tensor

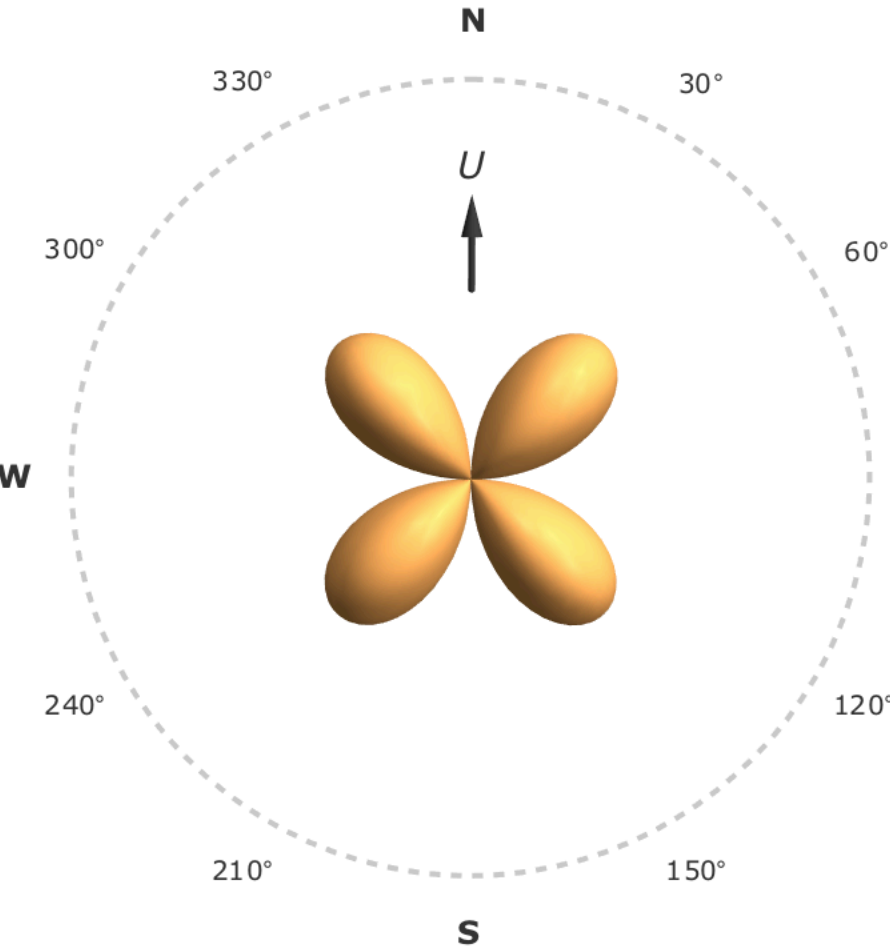
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6 independent components

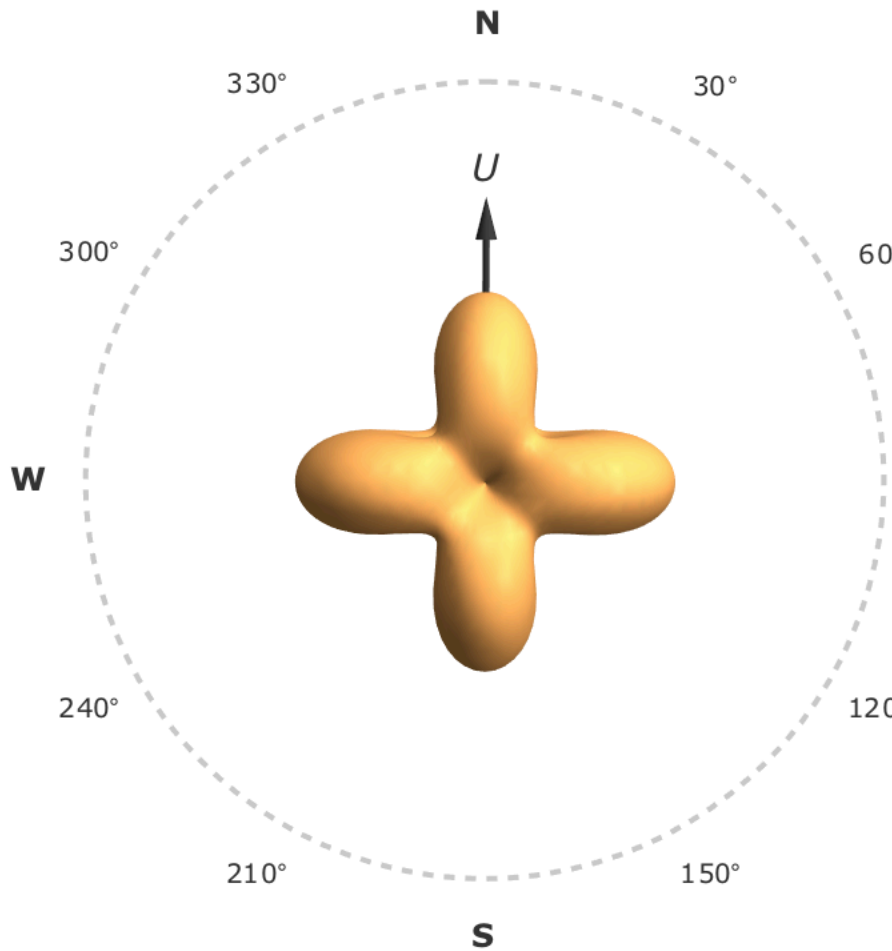


(Stein & Wyssession, 2003)

P



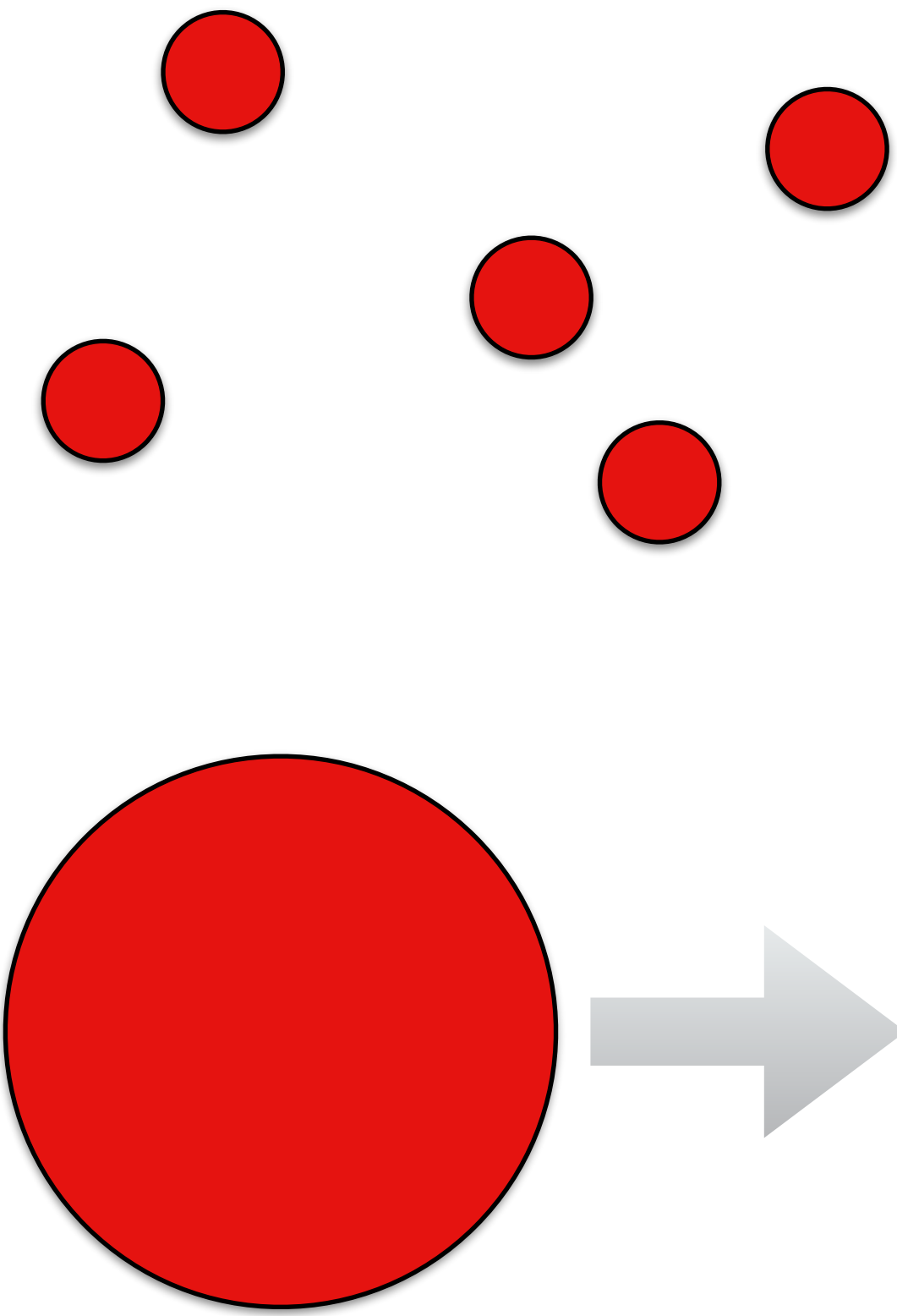
S



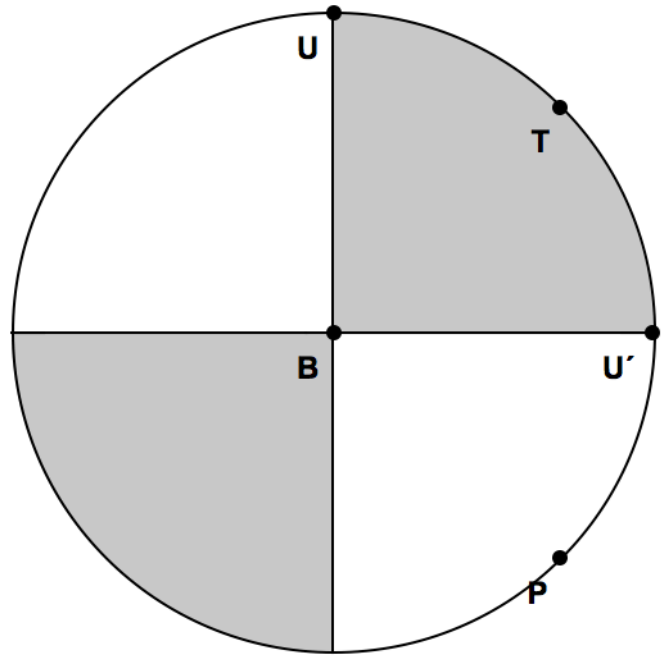
Radiation patterns



Source mechanism



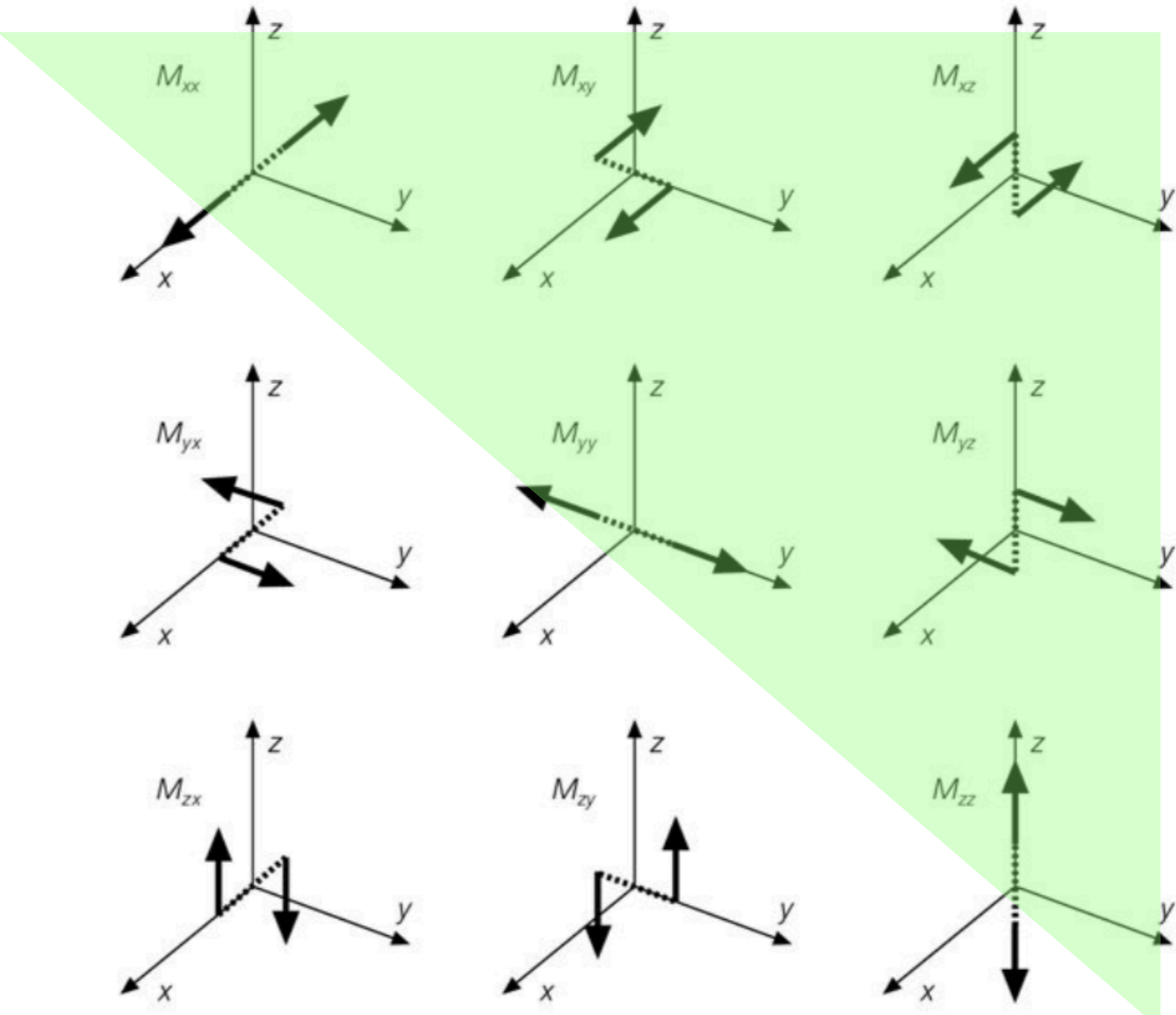
“Beach ball”



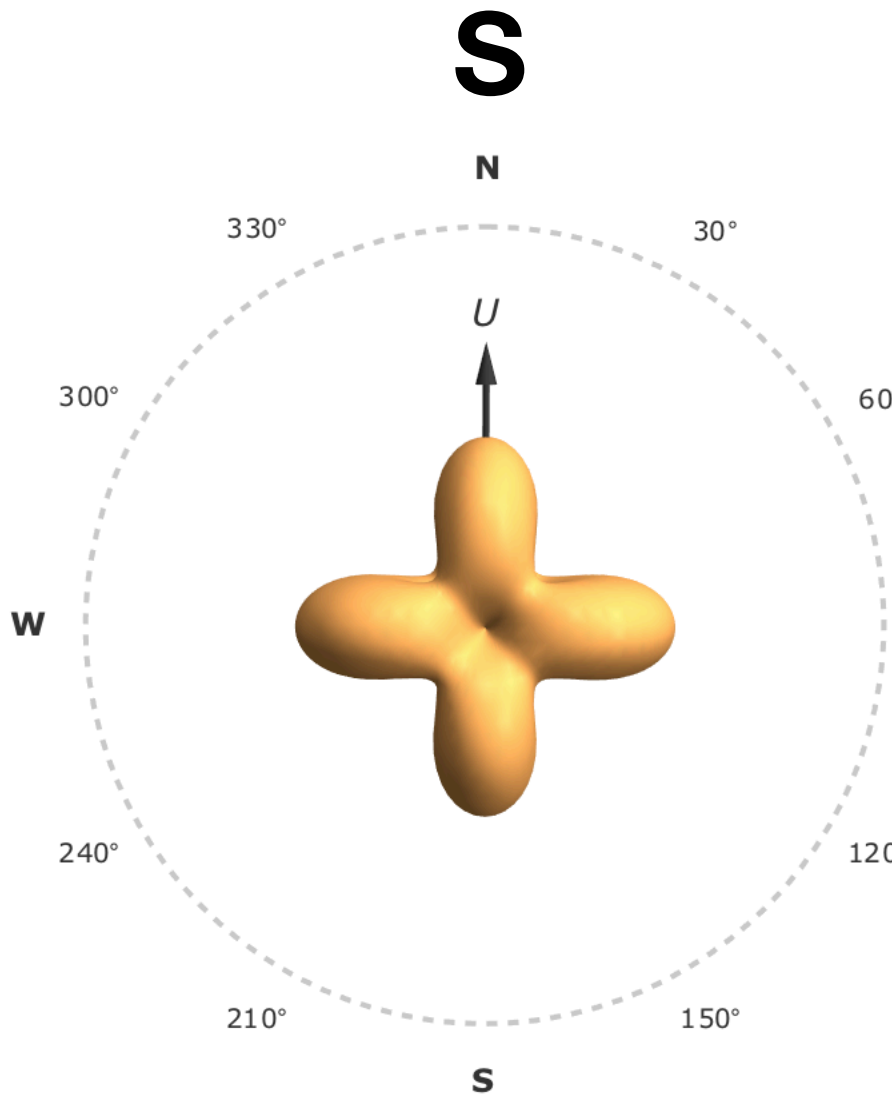
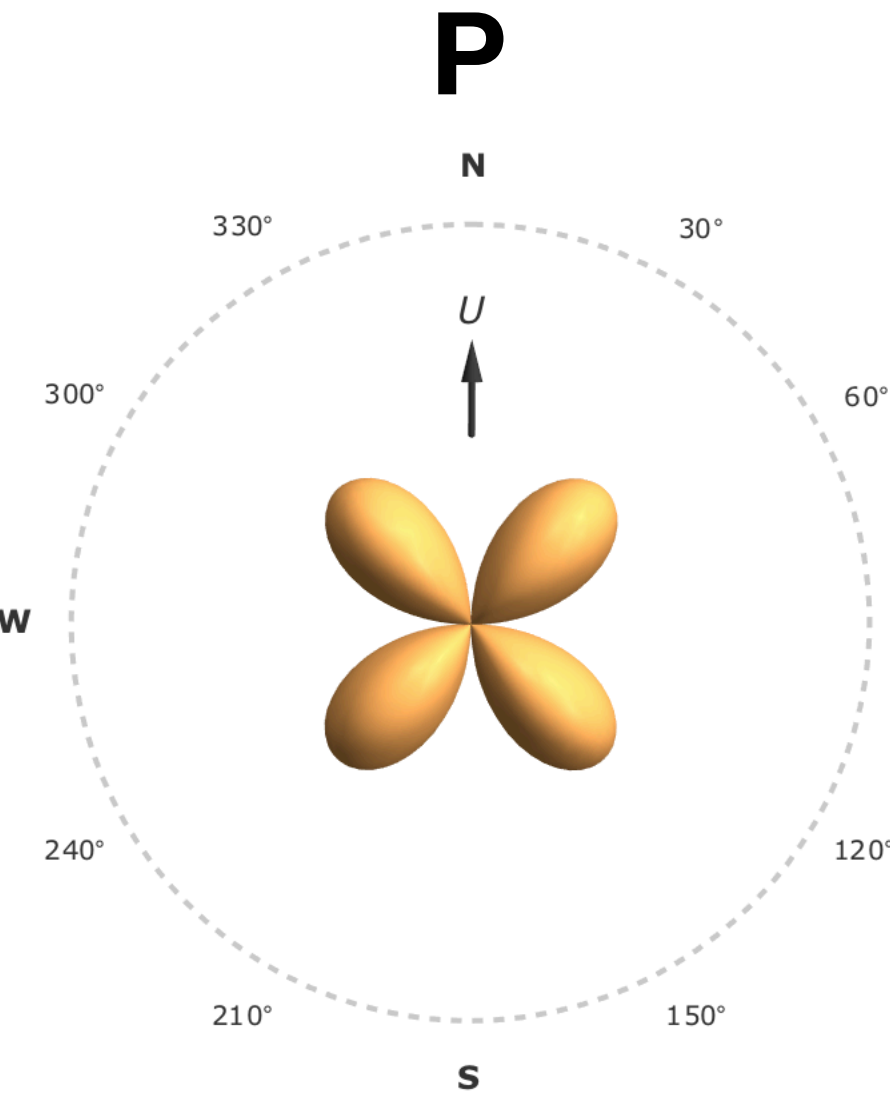
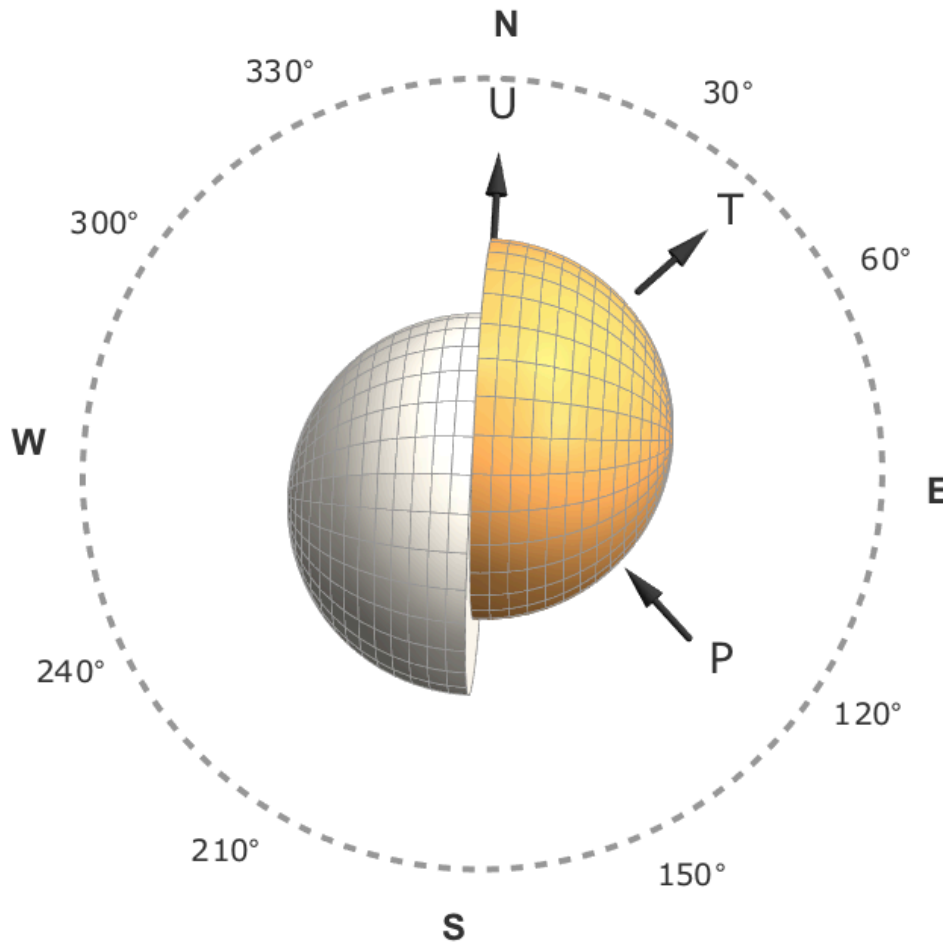
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6 independent components



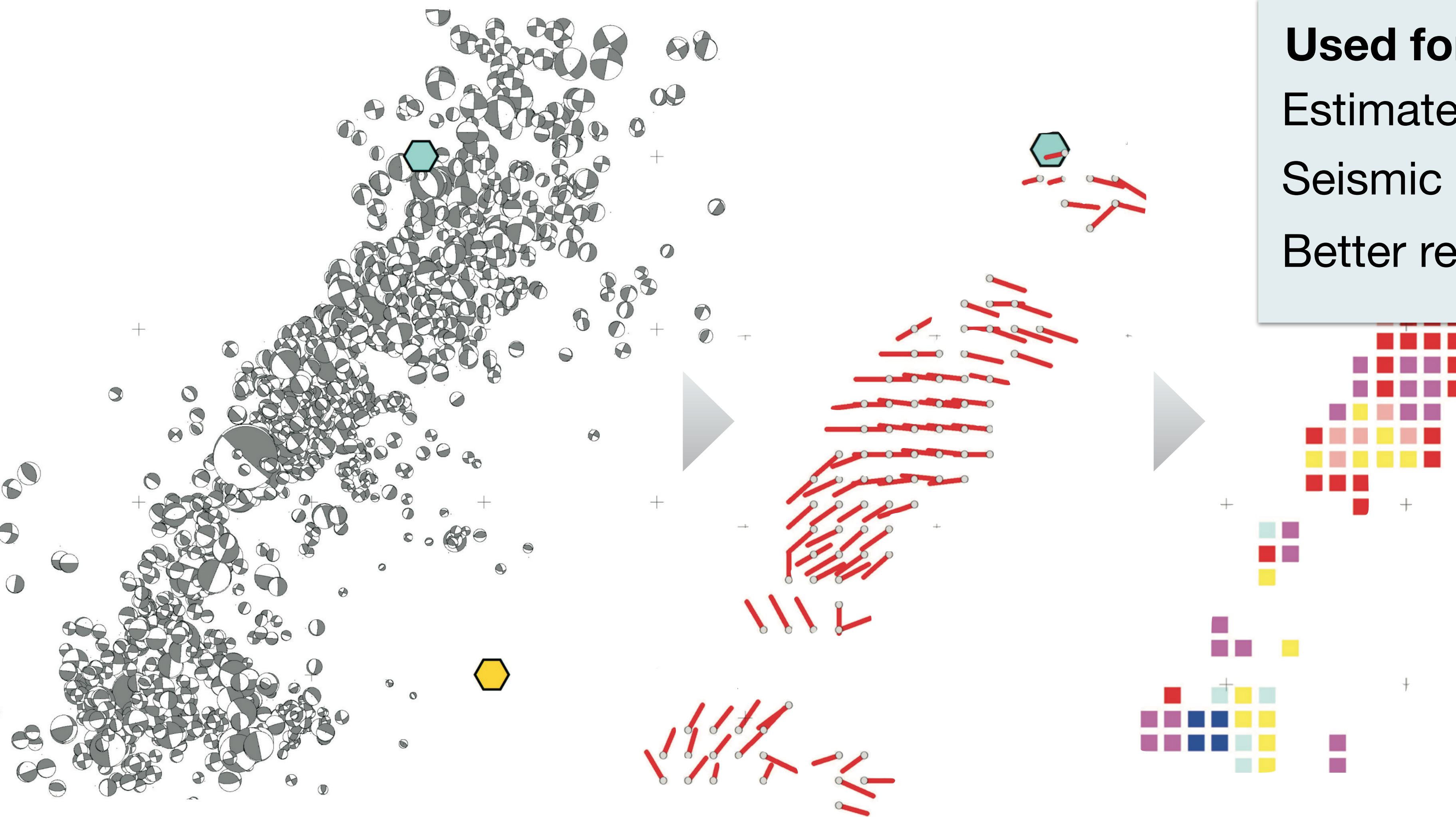
(Stein & Wysession, 2003)



Radiation patterns



Stress state



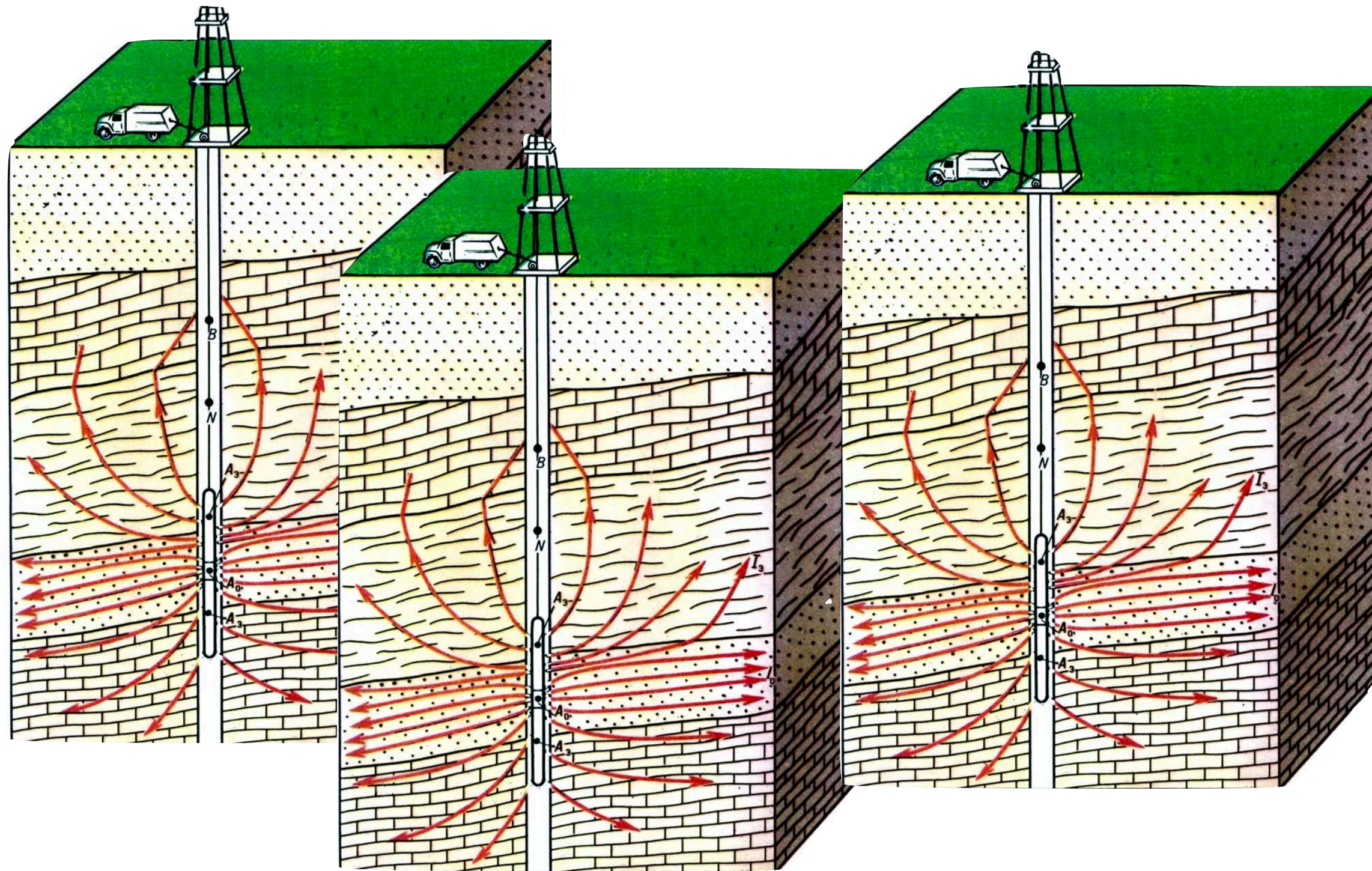
Used for
Estimates of fracturing direction
Seismic hazard assessment
Better reservoir characterization

(Rebetsky et al., 2018 *in preparation*)

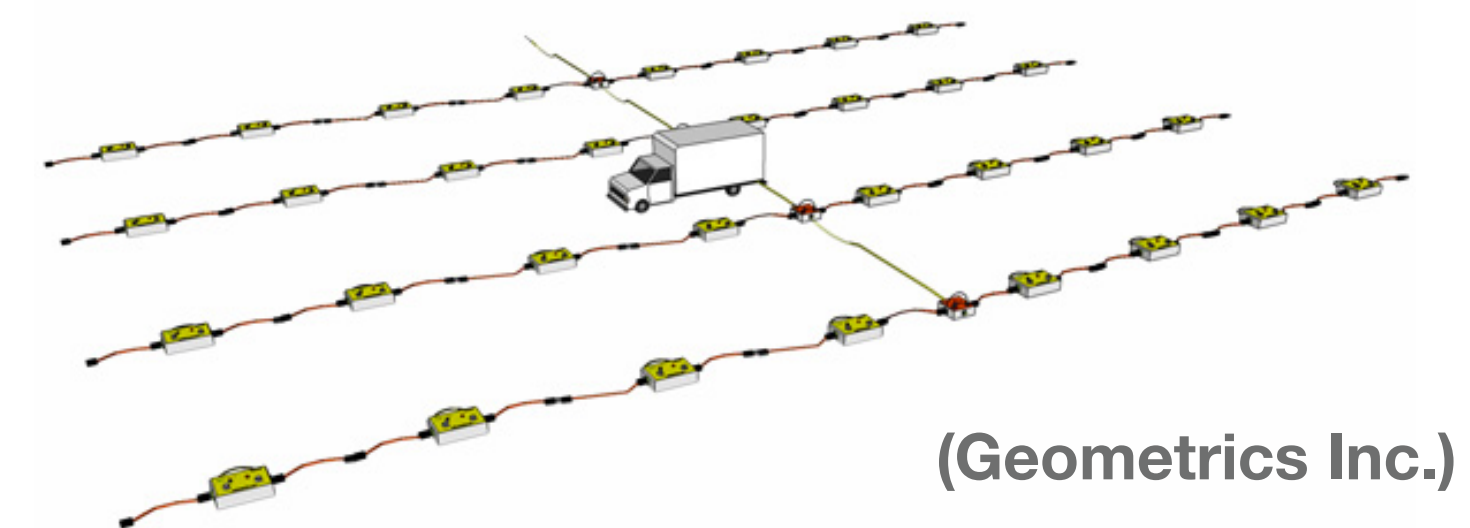
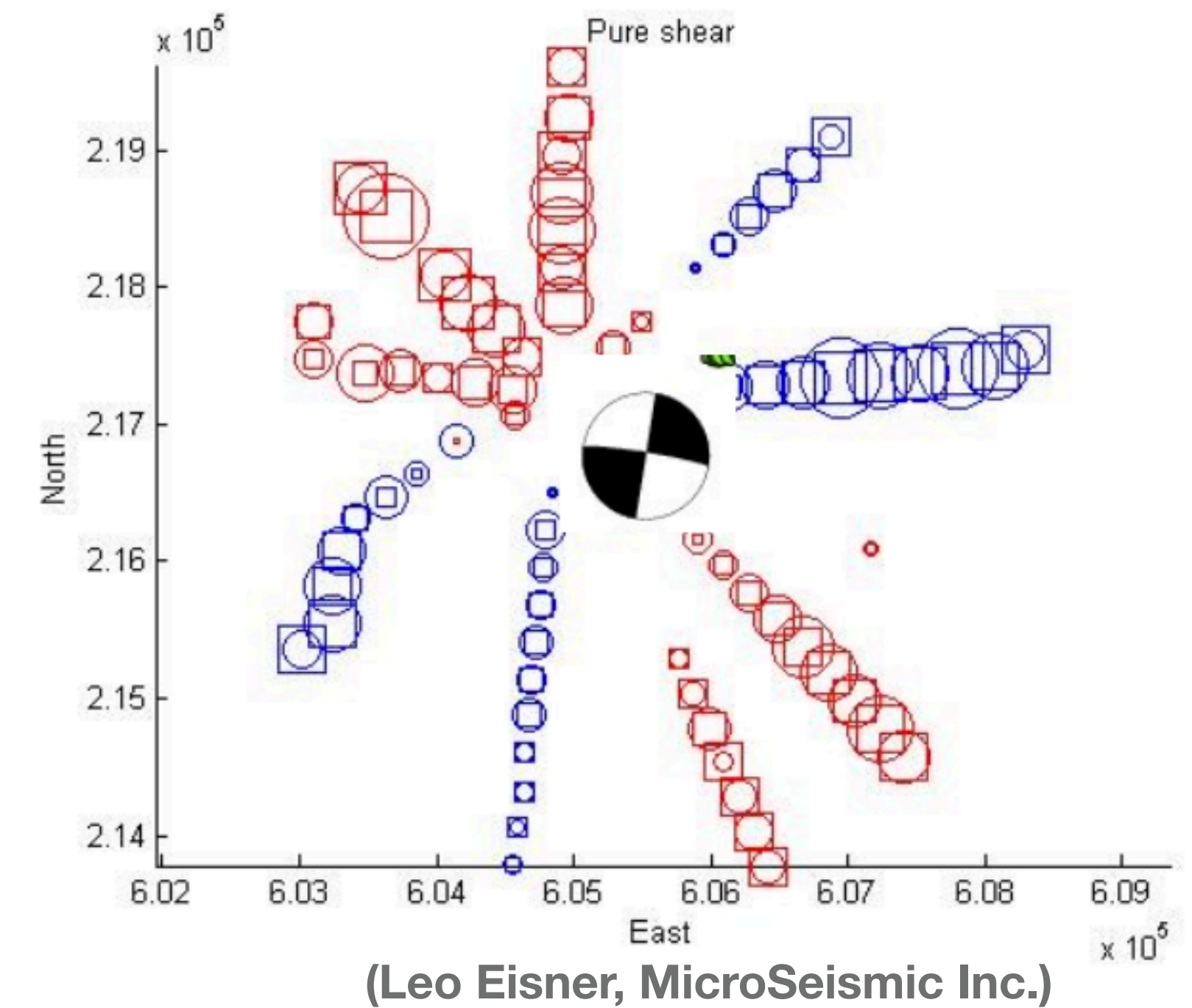


Microseismic acquisition design

Borehole



Surface



Multi-well borehole acquisition

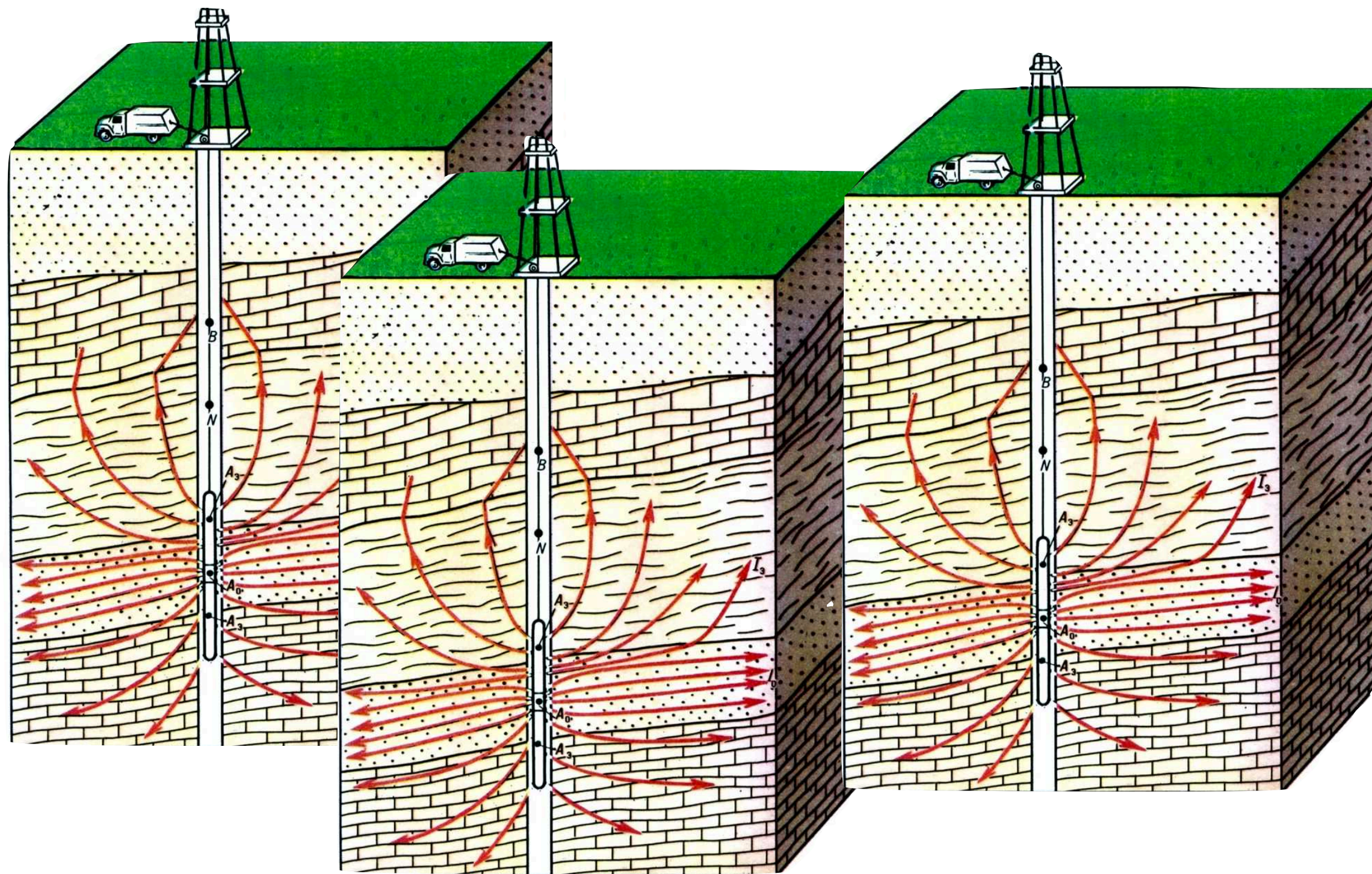


Table 1 Number of components of M recoverable in isotropy

Waves	1 well	2 wells	3 wells or more
P	3	5	6
S	4	5	5
P+S	5	6	6

(Vavryčuk, 2007)



Single-well borehole acquisition

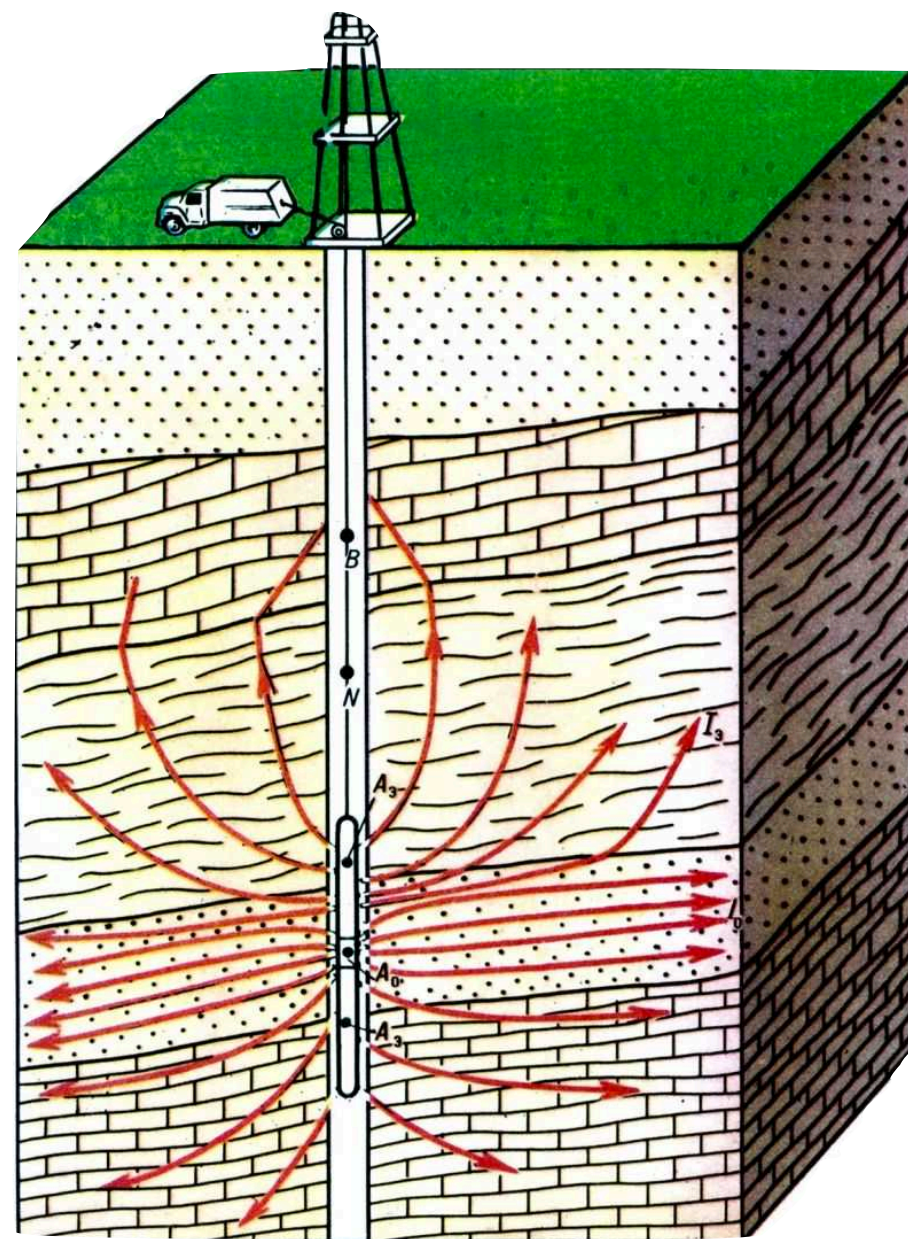


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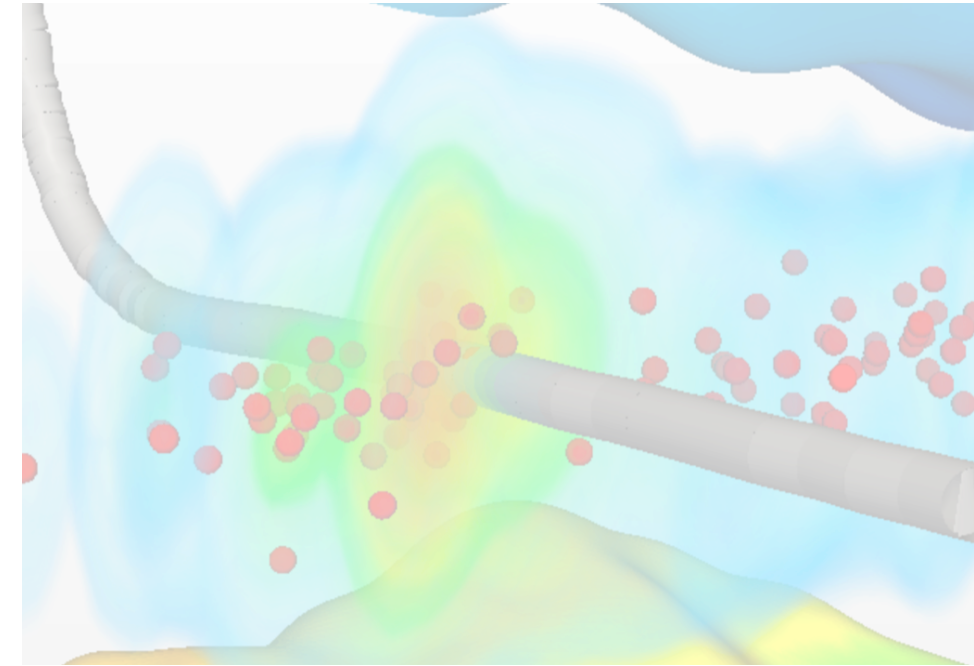
Up to 5 moment tensor components could be resolved with conventional P+S arrival inversions



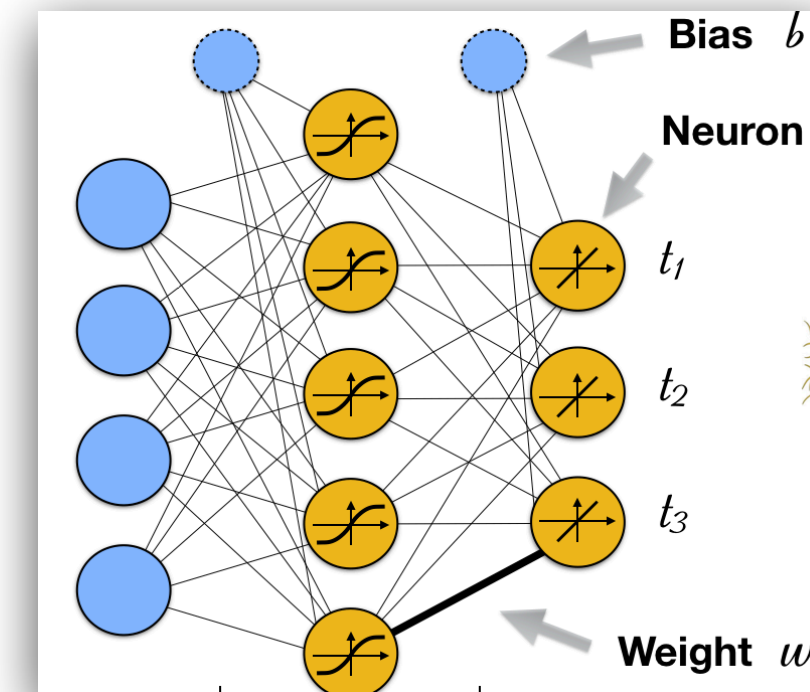
Can we retrieve the full moment tensor from a single-well acquisition using an artificial neural network?



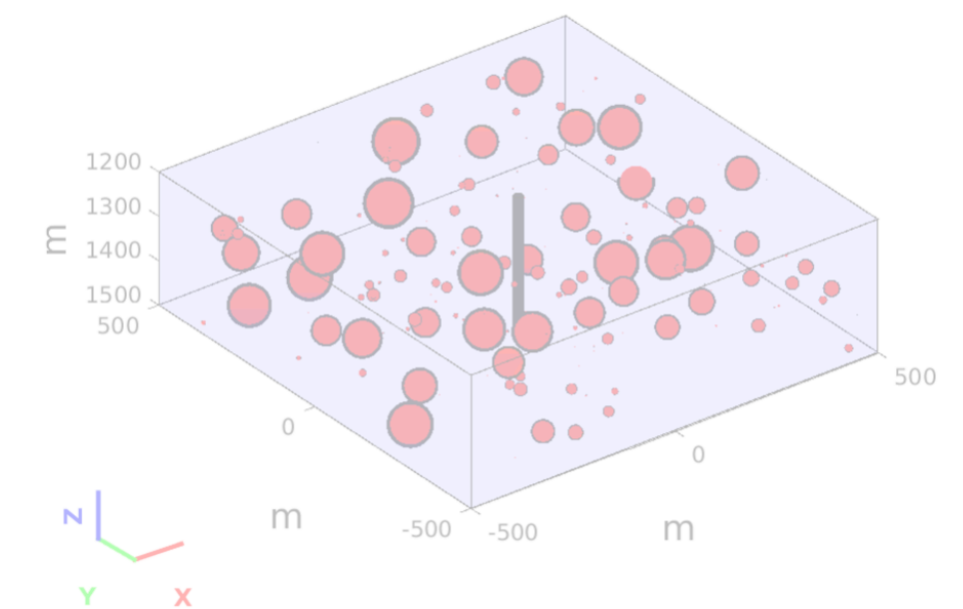
Single-well data



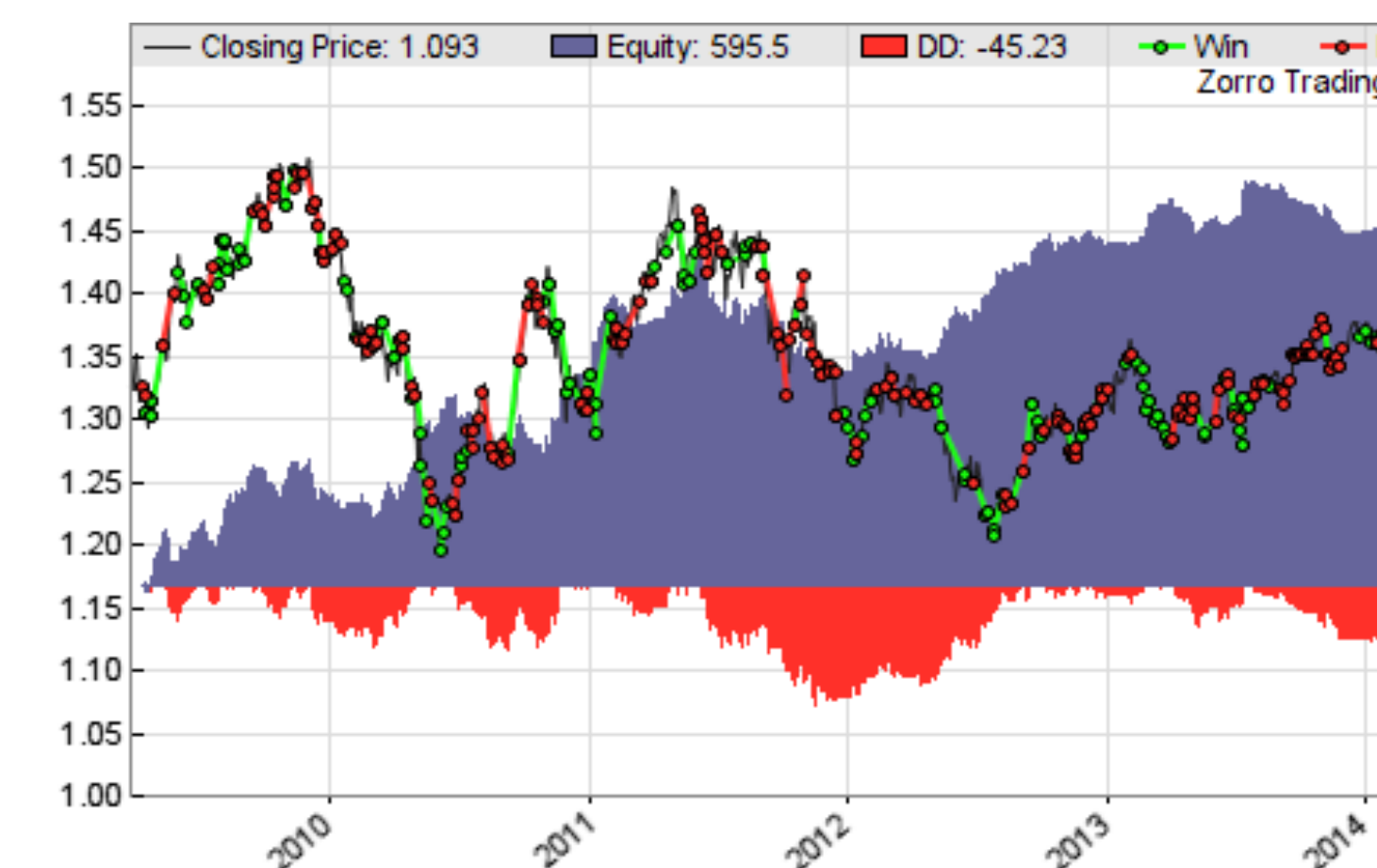
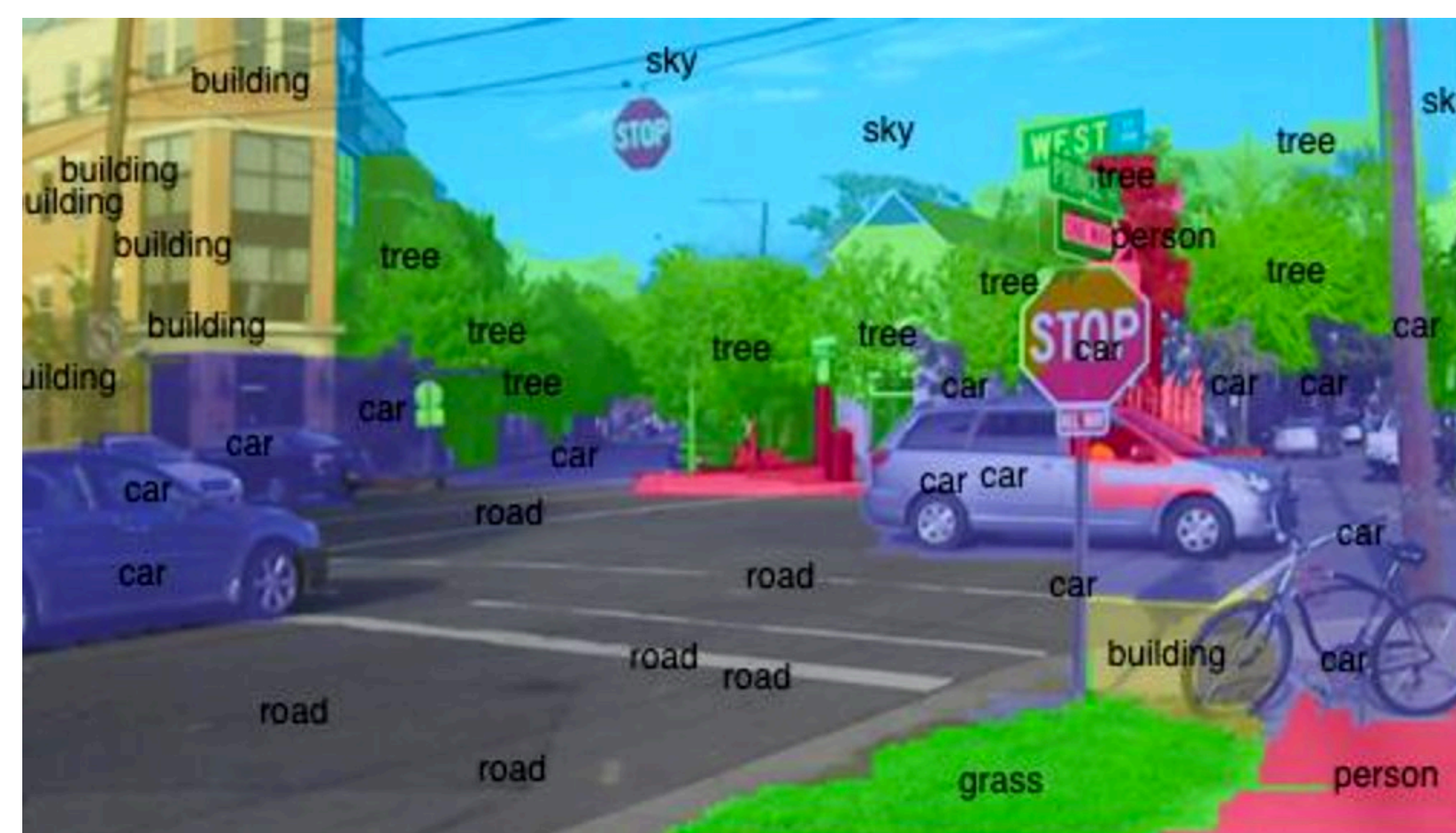
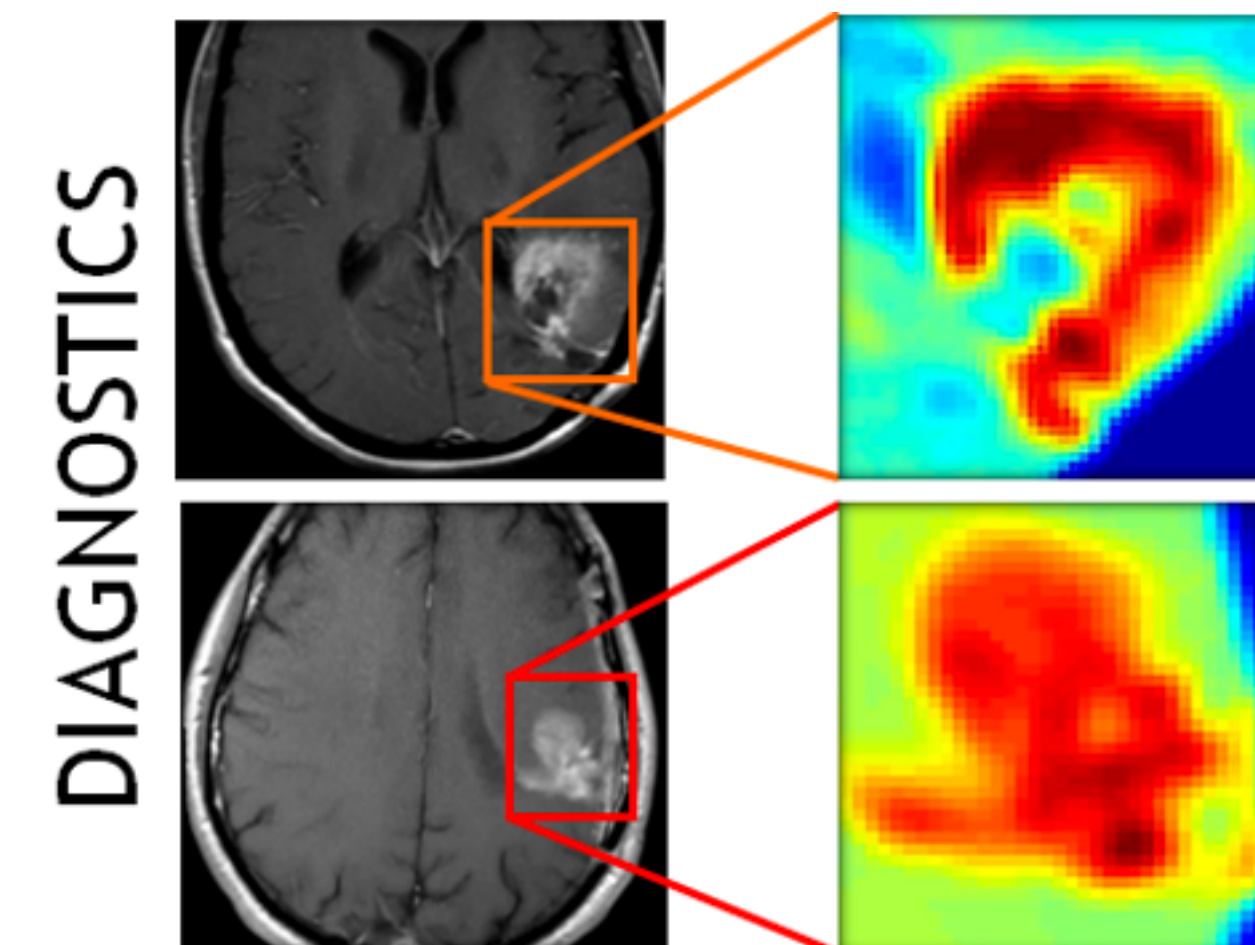
Artificial Neural Network



Example in a homogeneous model



Machine Learning



Neural Networks pros and cons

Pros

- + Good for nonlinear problems
- + Good for large inputs
- + **Data-driven**
- + Easy to implement and parallelize
- + Ability to generalize

Cons

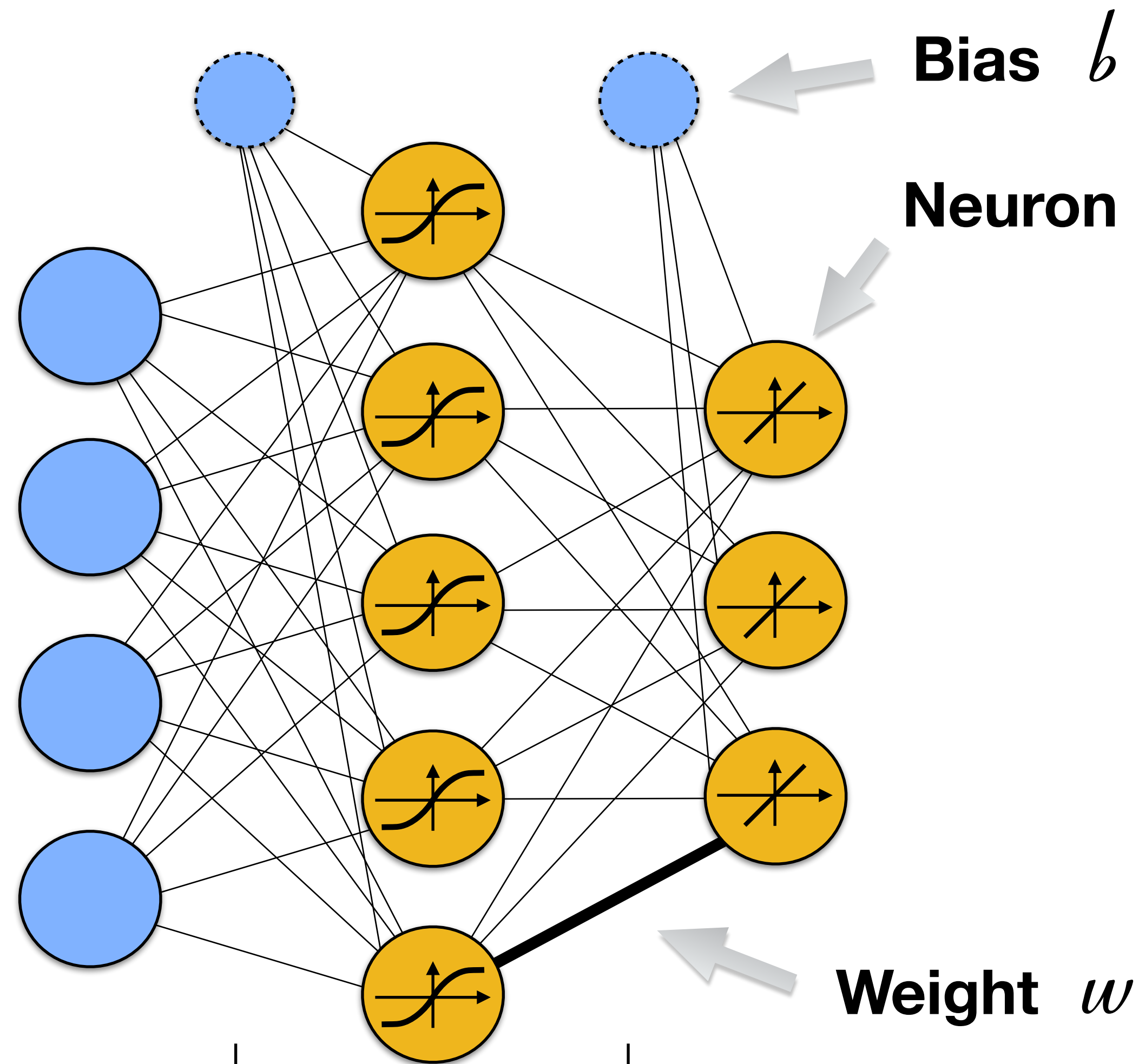
- Lots of parameters
- Hard to interpret
- Computational costs

Not a magic wand, use with care



Neural network architecture

Training
=
tuning up weights w



$$\begin{matrix} W & x & b \\ \boxed{\text{matrix}} & \boxed{\text{vector}} & + \boxed{\text{vector}} \\ & \downarrow \text{activation} & \\ & \boxed{\text{vector}} & = \boxed{\text{vector}} \end{matrix}$$

Layers:

Input

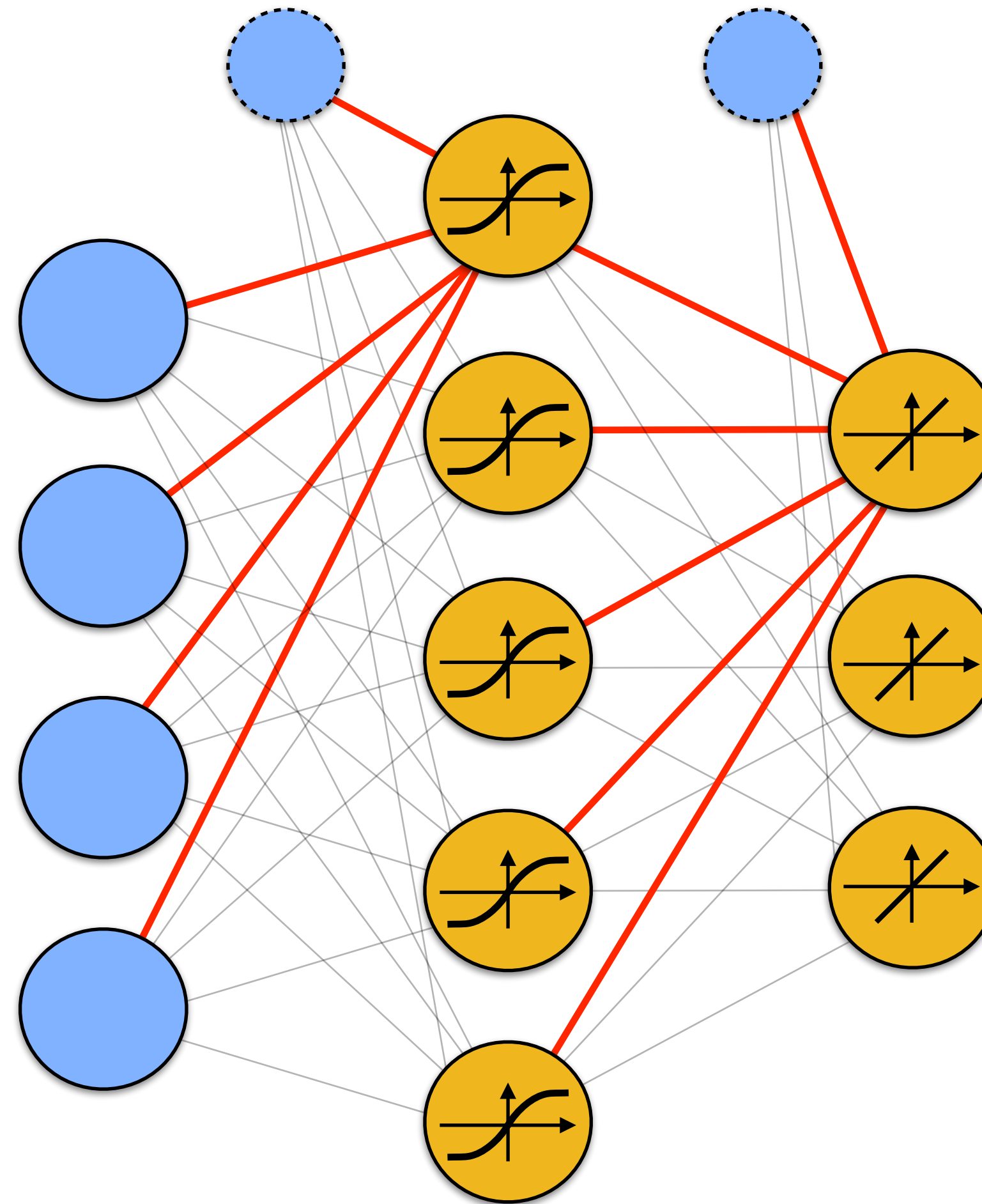
Hidden

Output

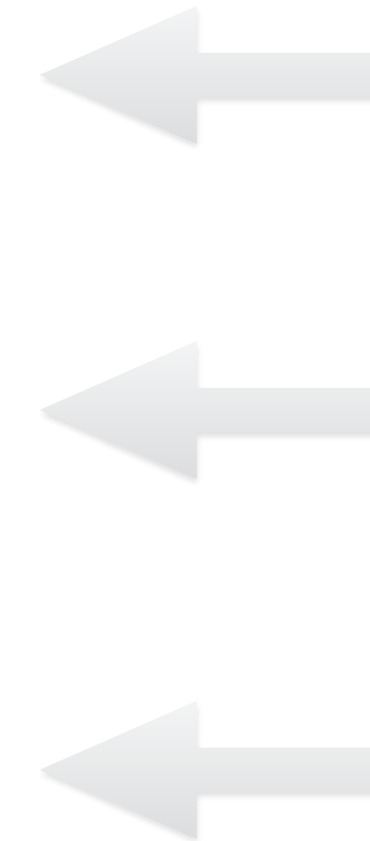
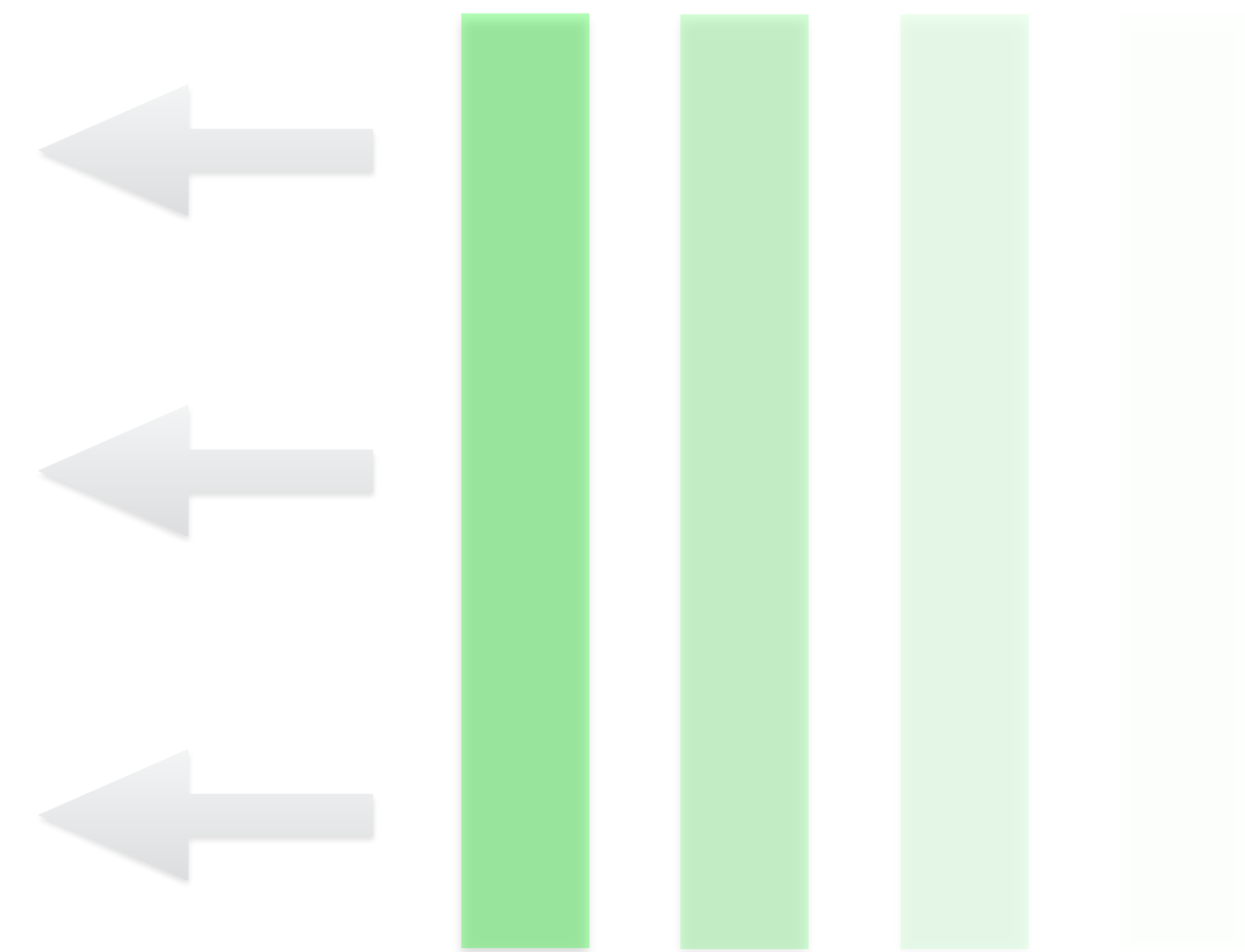


Training

Training inputs



Training outputs

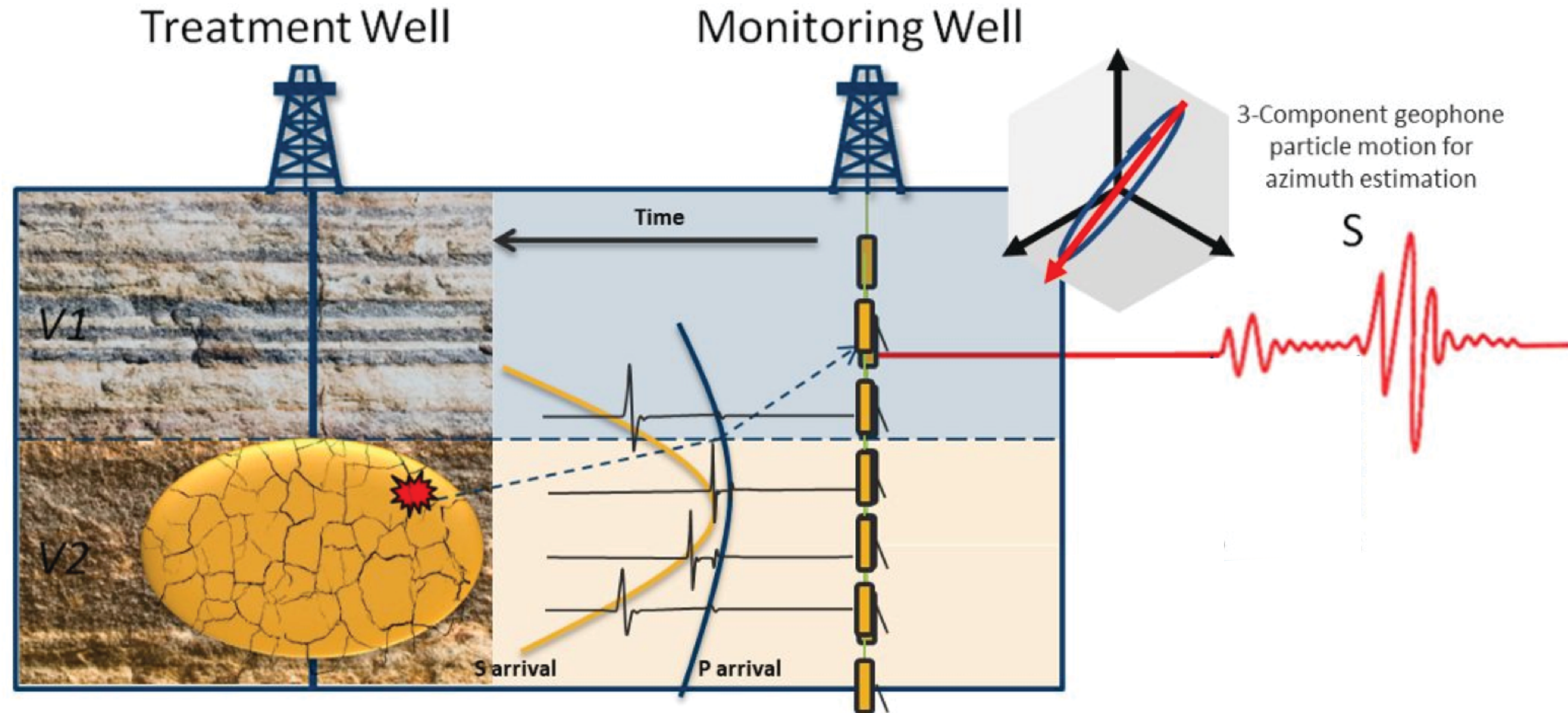


Minimize L_2 norm

Neural networks require training with multiple inputs



Data generation



<https://www.geoexpro.com/articles/2017/07/>

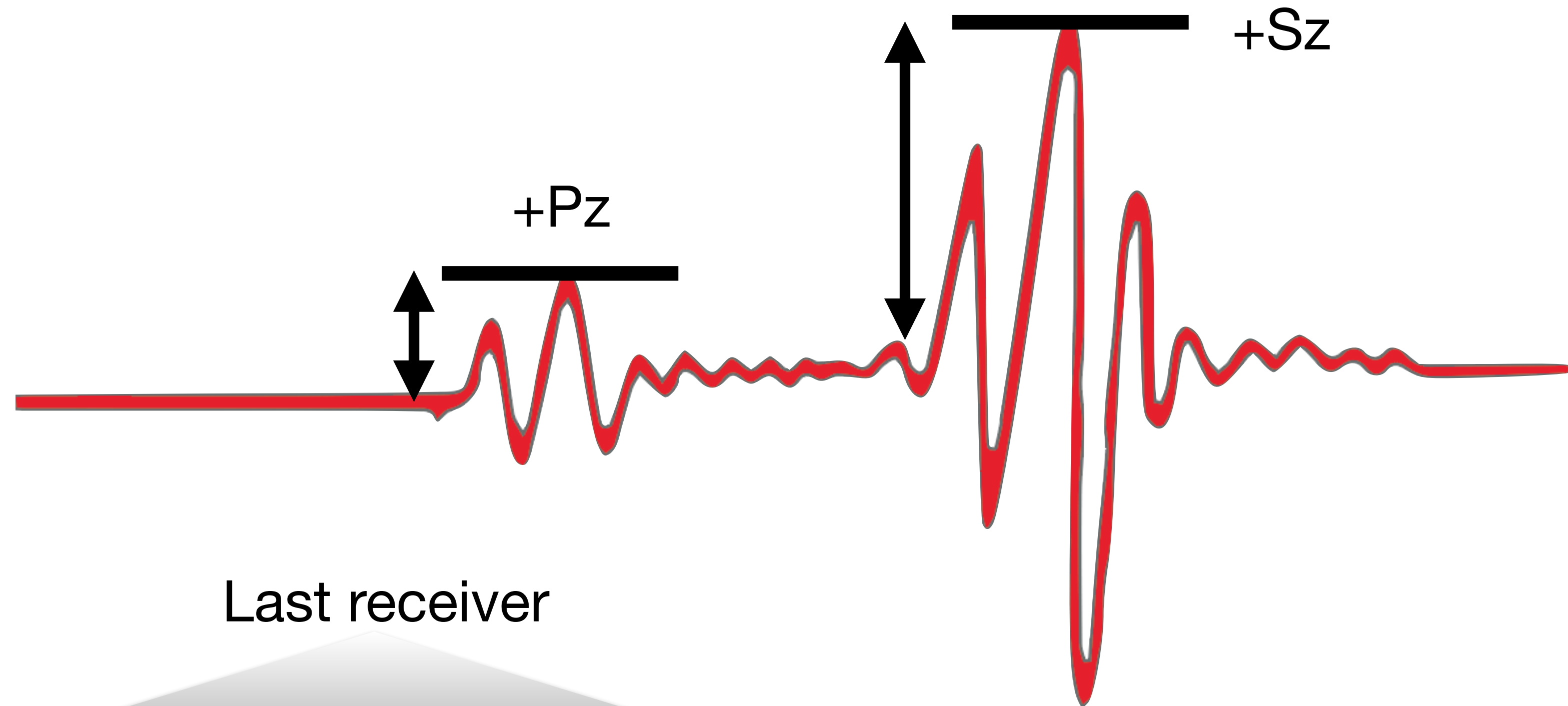


Input data

Maximum amplitudes of P and S waveforms multiplied by their first arrival polarity

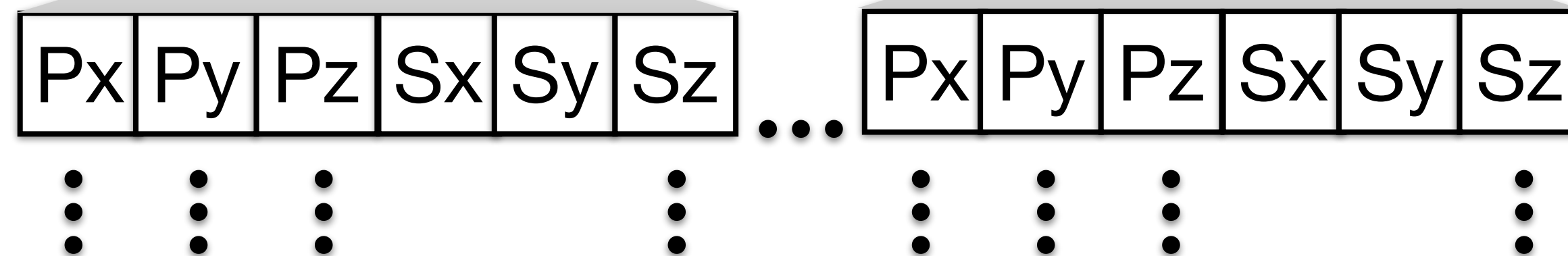
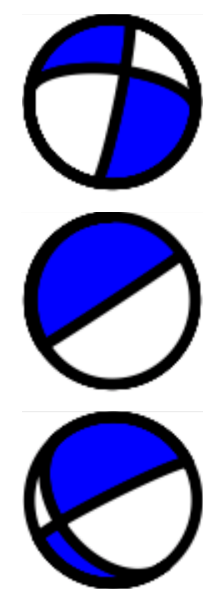
3-component receivers
2 types of waves (P and S)

3 x 2 x NREC



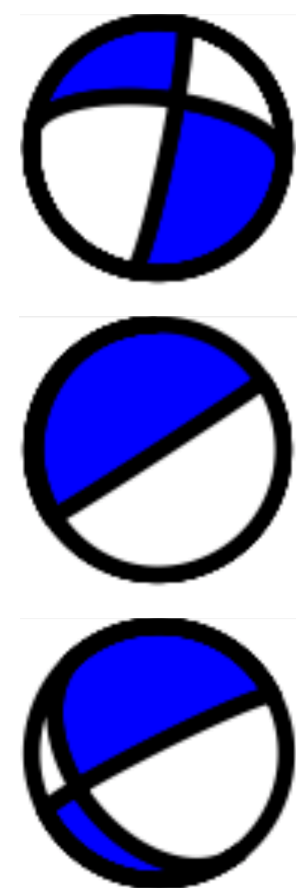
First receiver

Last receiver

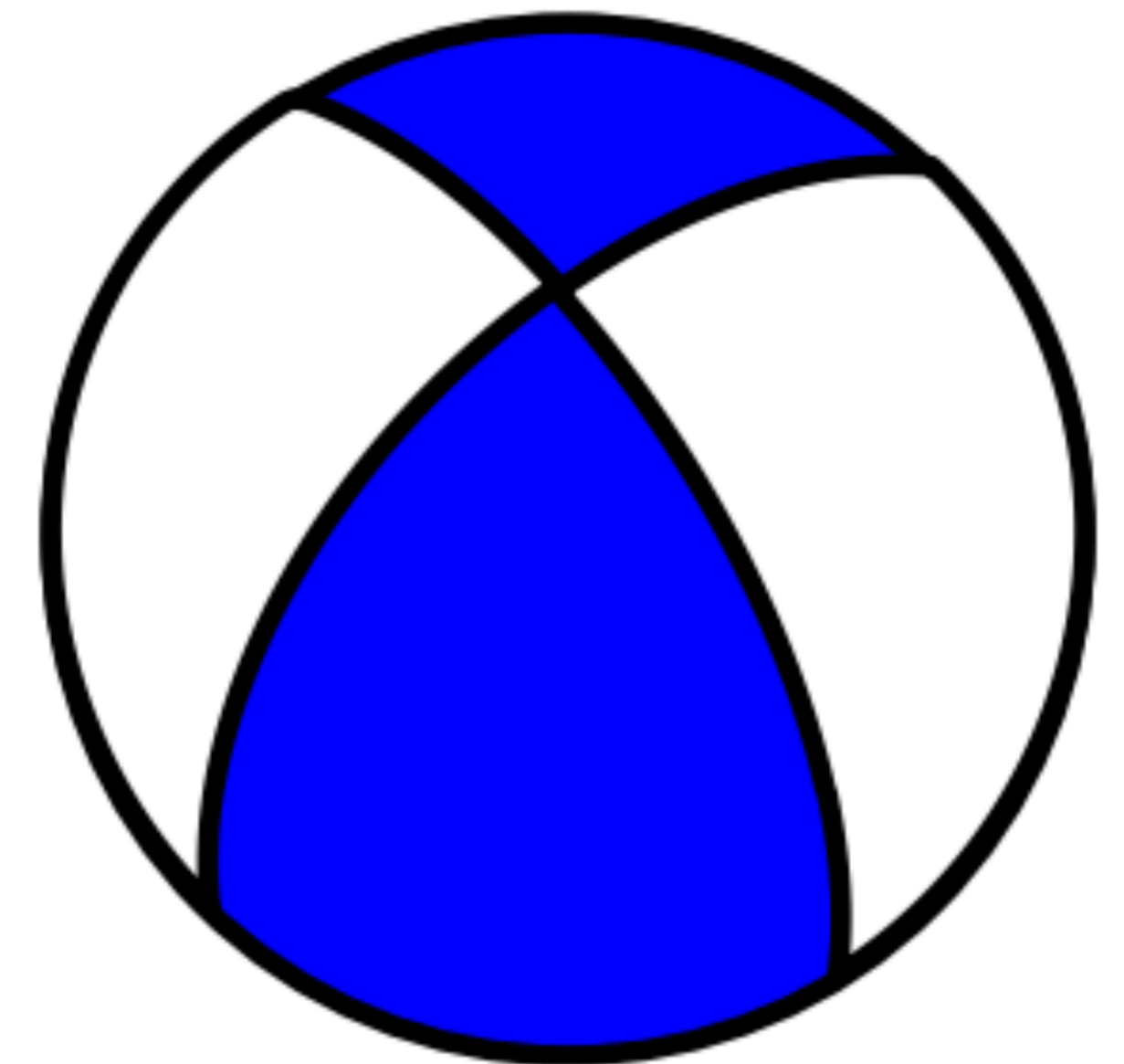


Output data

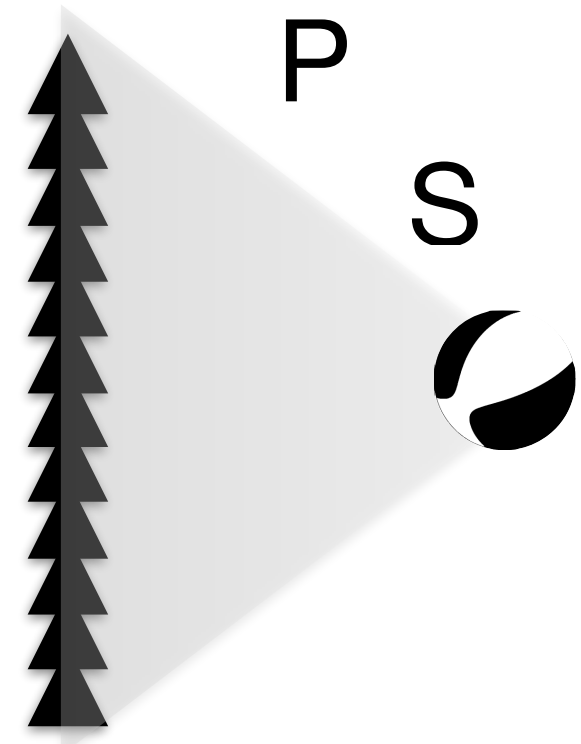
6 components of moment tensor describing source mechanism



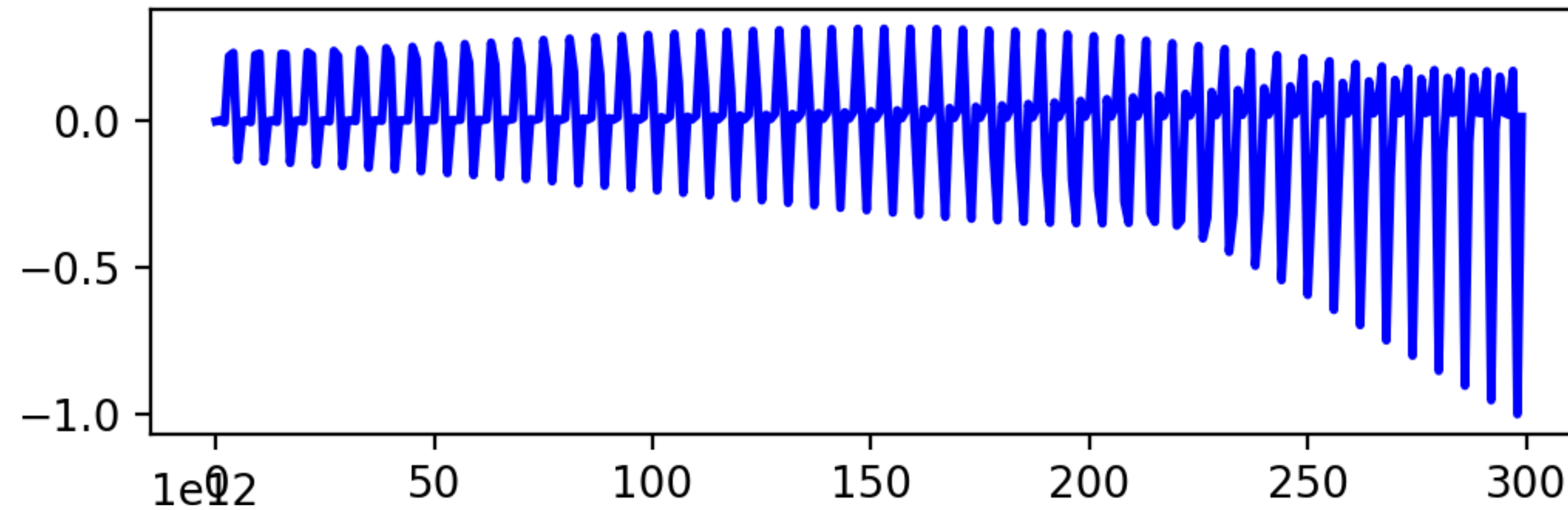
Mxx	Myy	Mzz	Myz	Mxz	Mxy
•	•	•			•
•	•	•			•
•	•	•			•



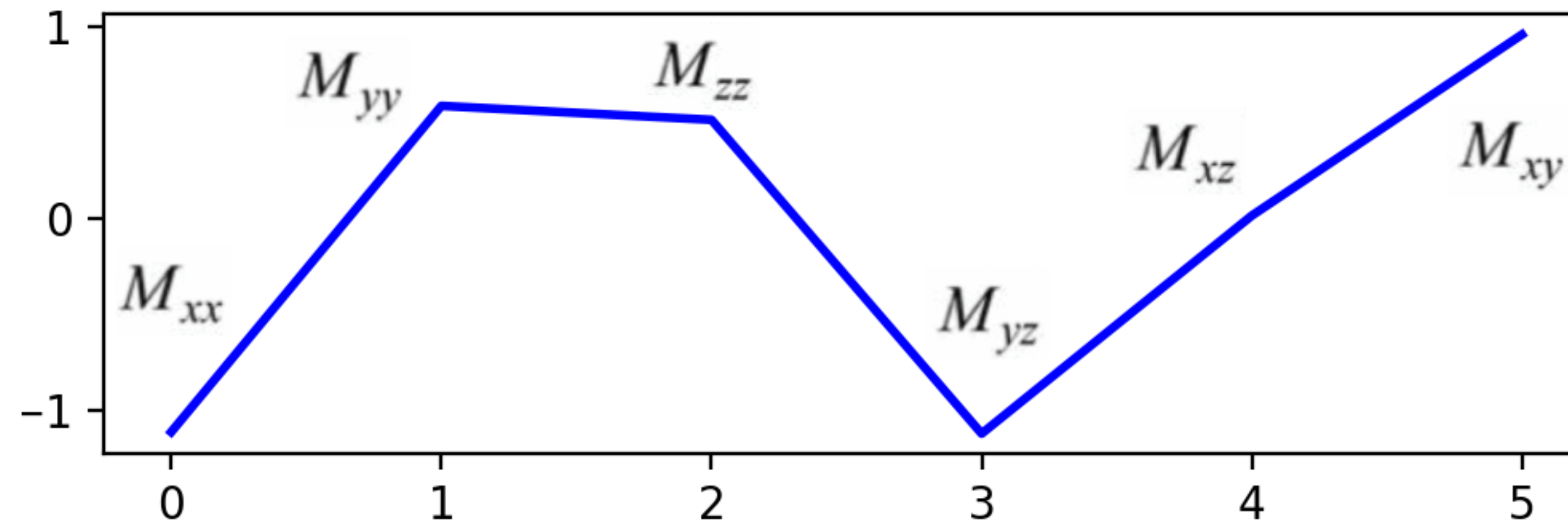
Single pair of training data



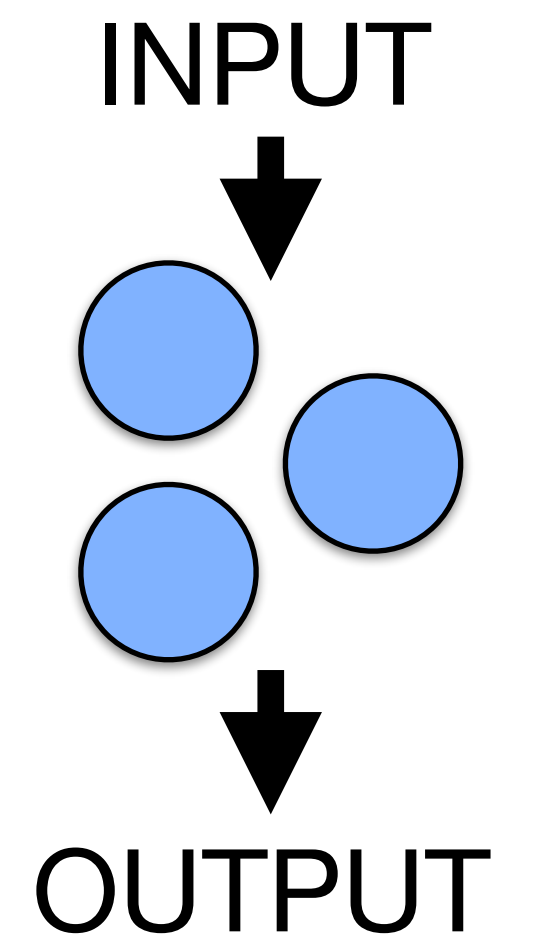
INPUT



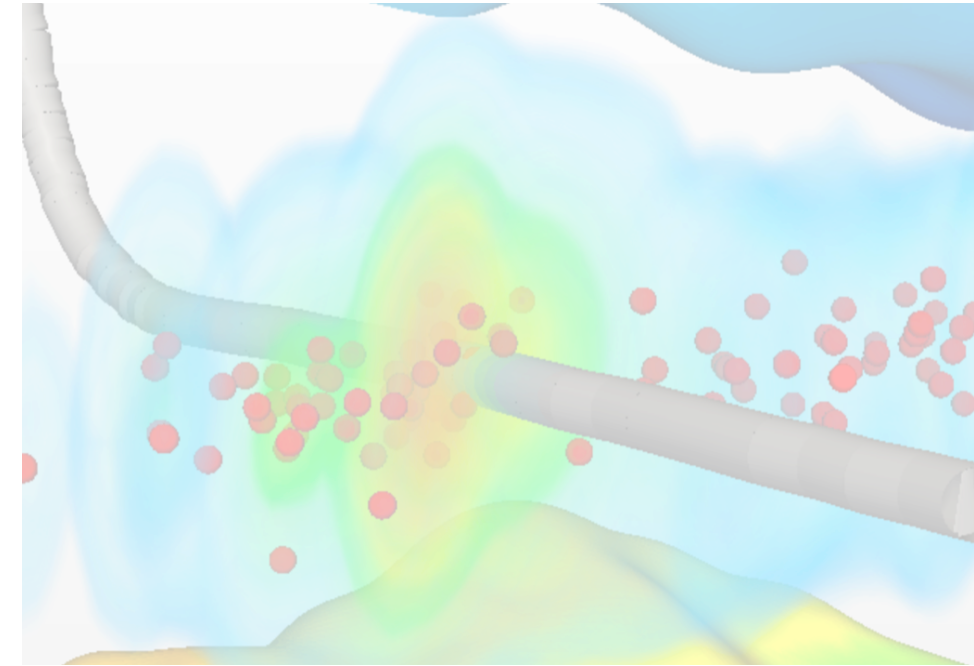
OUTPUT



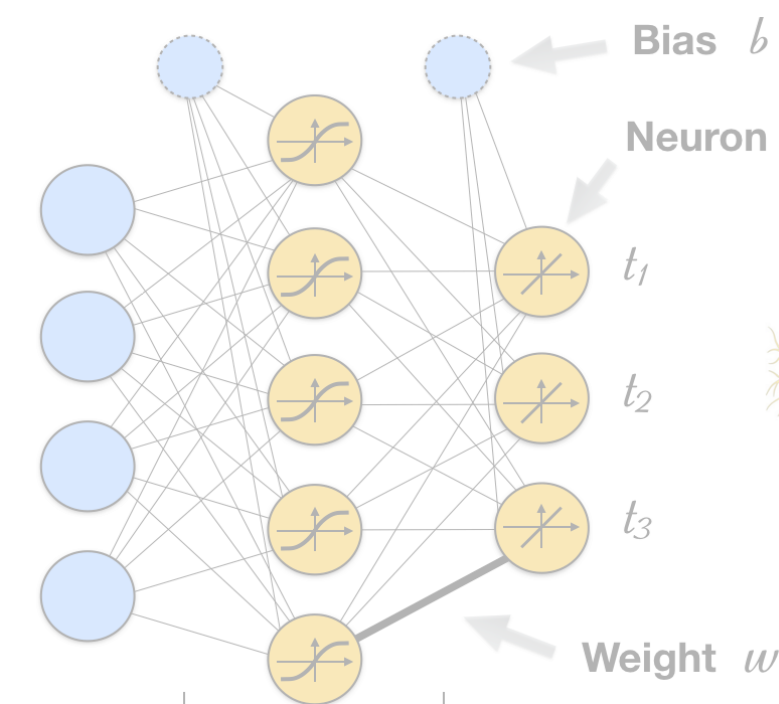
6 components of
moment tensor



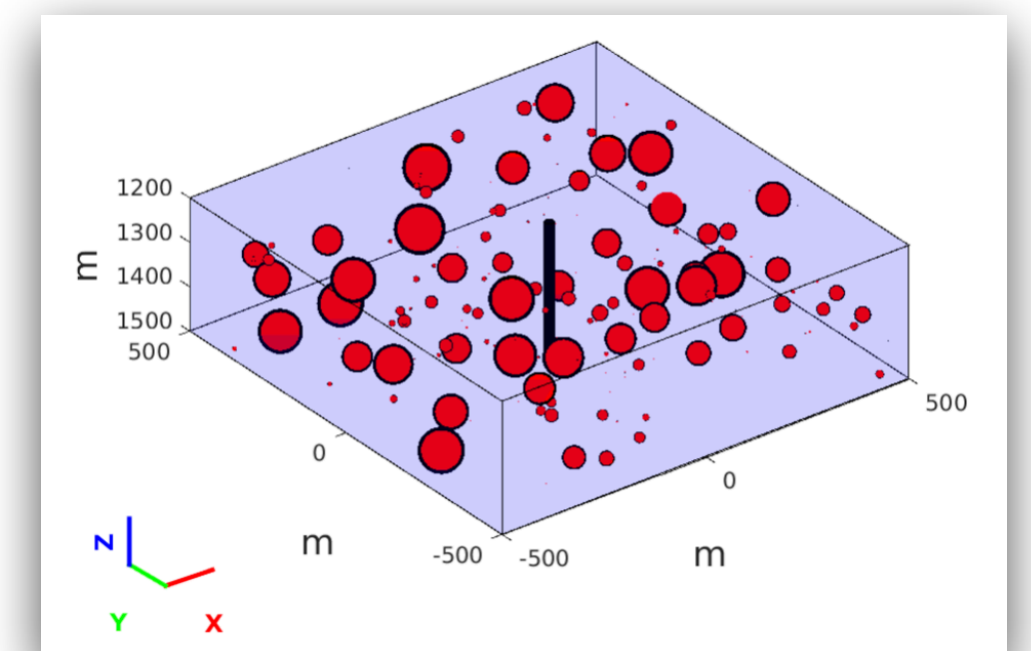
Single-well data



Artificial Neural Network



Example in a homogeneous model

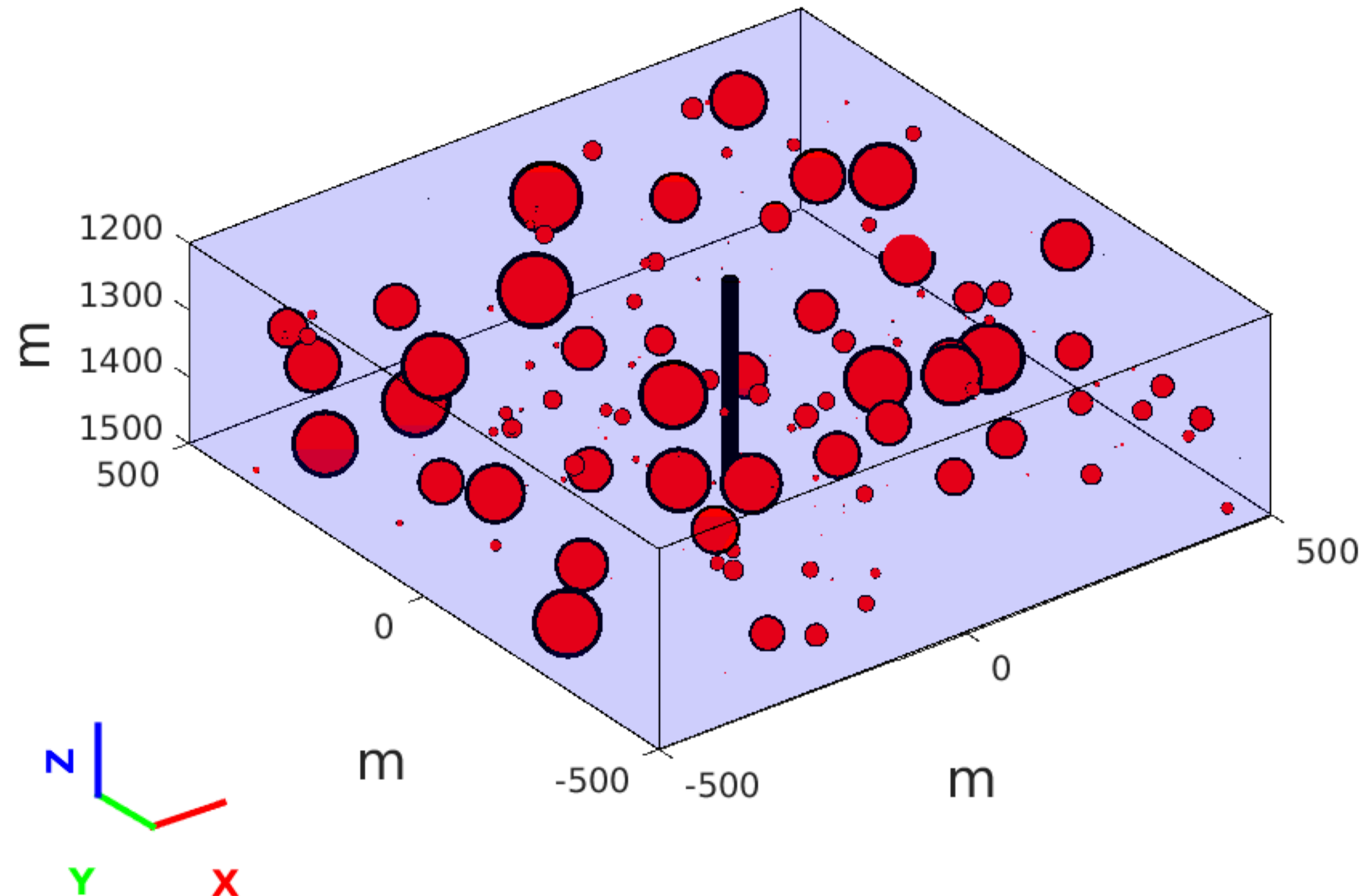


Homogeneous medium

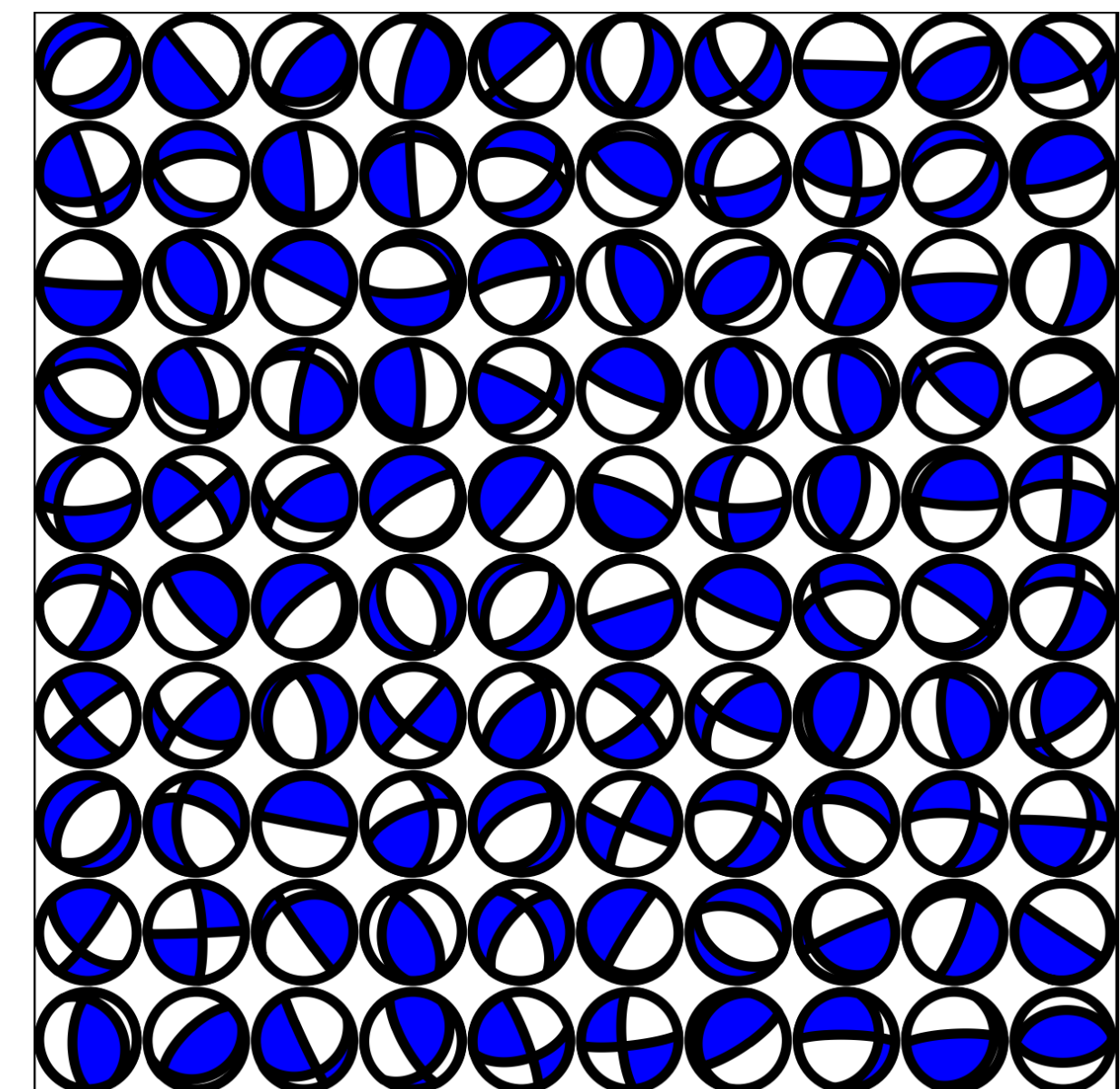
Synthetic data

$N = 8000$ events

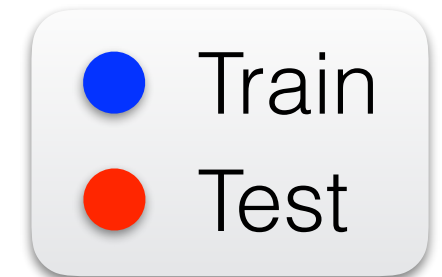
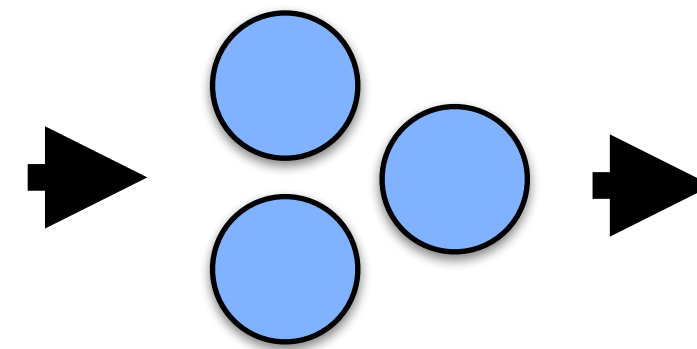
$M = -3 \dots 0$



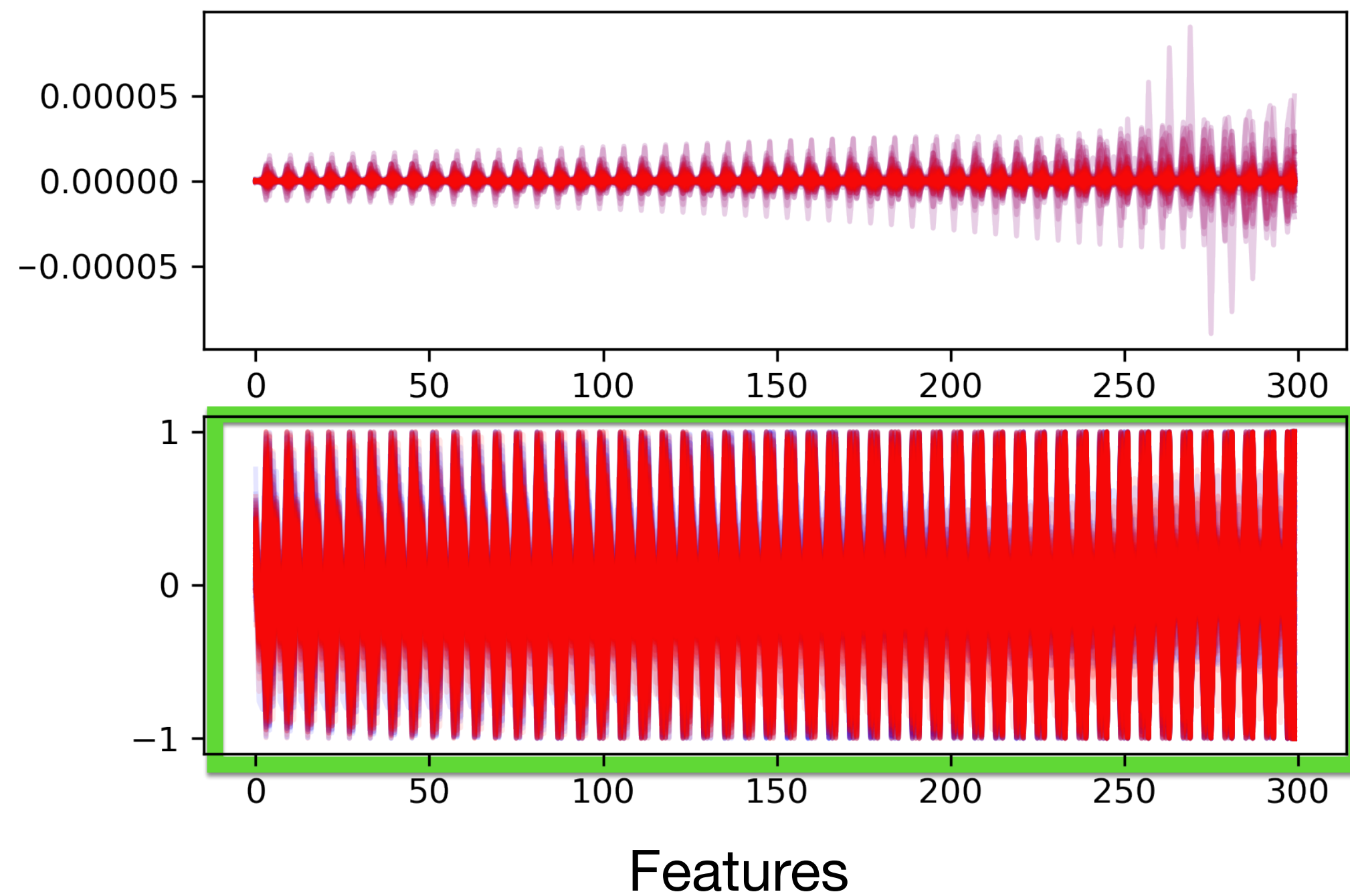
Mostly shear mechanisms



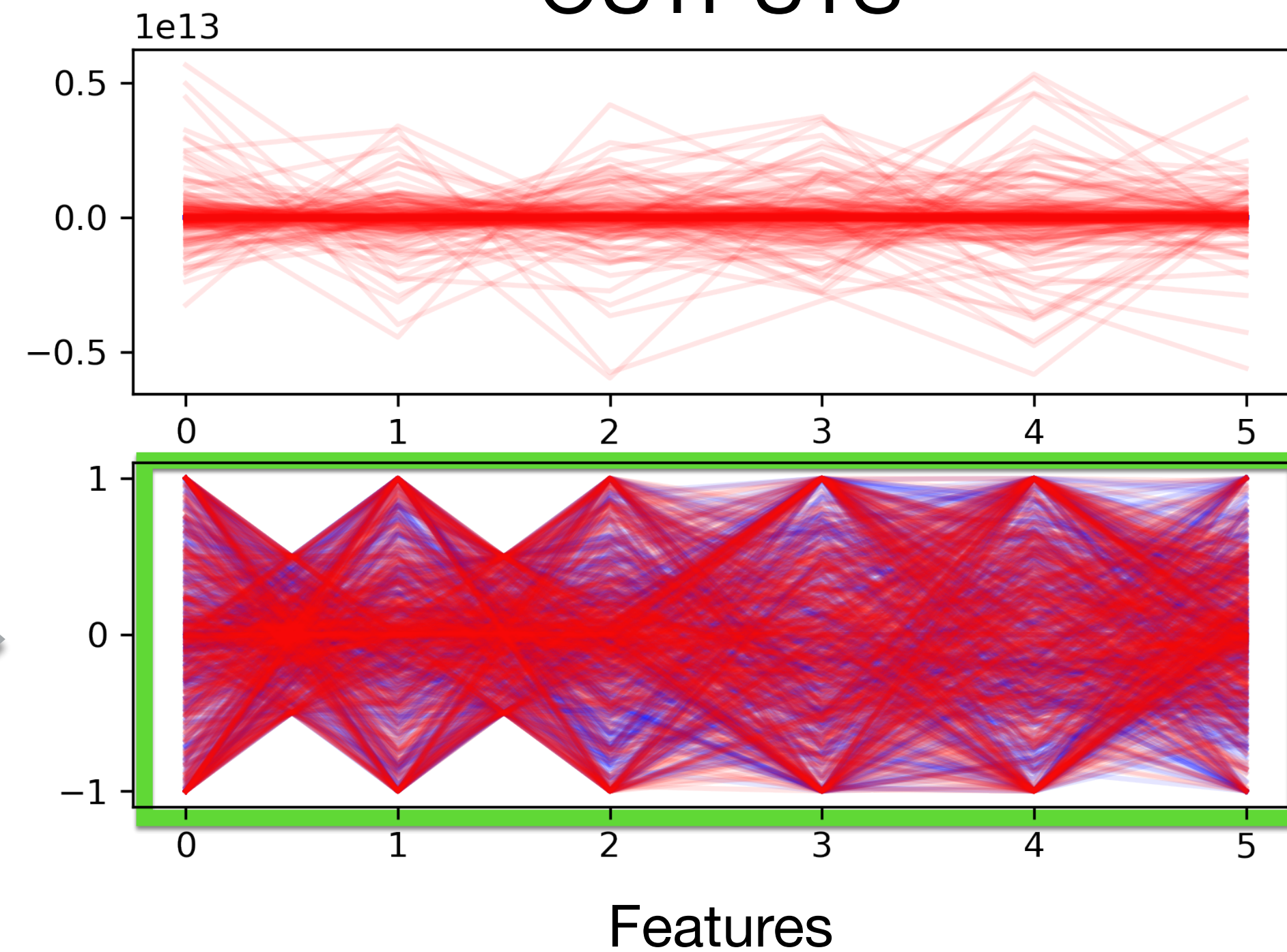
Data normalization



INPUTS



OUTPUTS



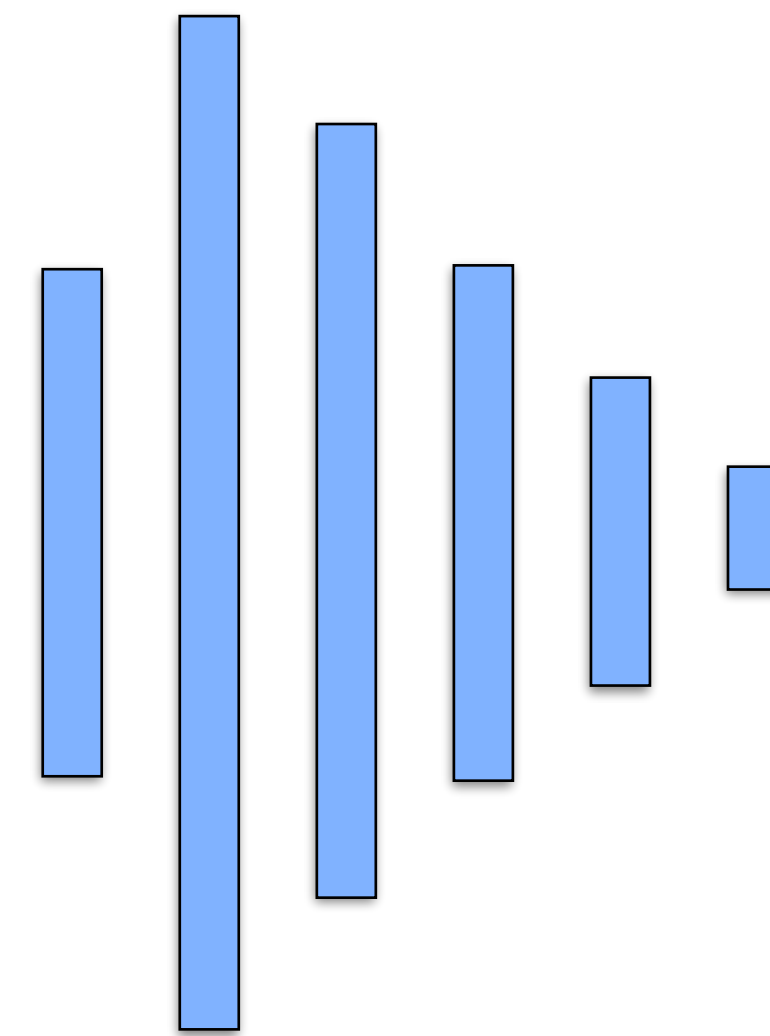
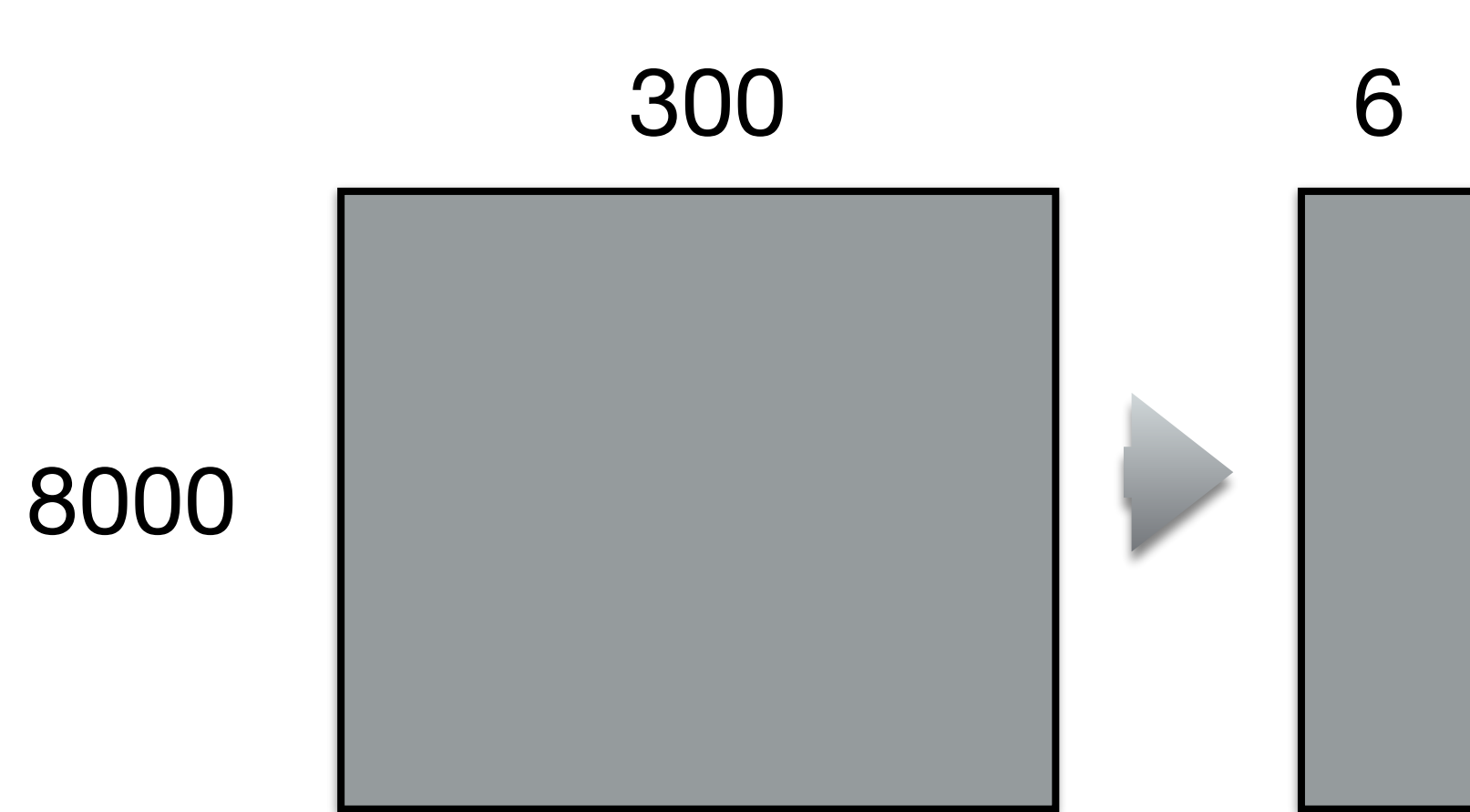
Before

After

Important stage



Computational facts



NN: 5 hidden layers
Batch size: 200
Learning rate: 0.005
Optimizer: Adam
Weight regularization: 0.005

Initialization “xavier”
(Glorot & Bengio, 2010)

Training data generation
~ 2 min on 24 cores

Training time ~ 5 min
Prediction time < 1 sec

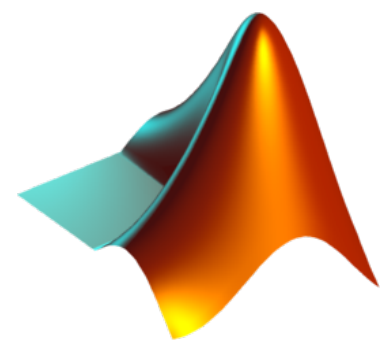
Matlab R2016b

Python 3.6

TensorFlow 1.3.0

Keras 2.0.5

Obspy

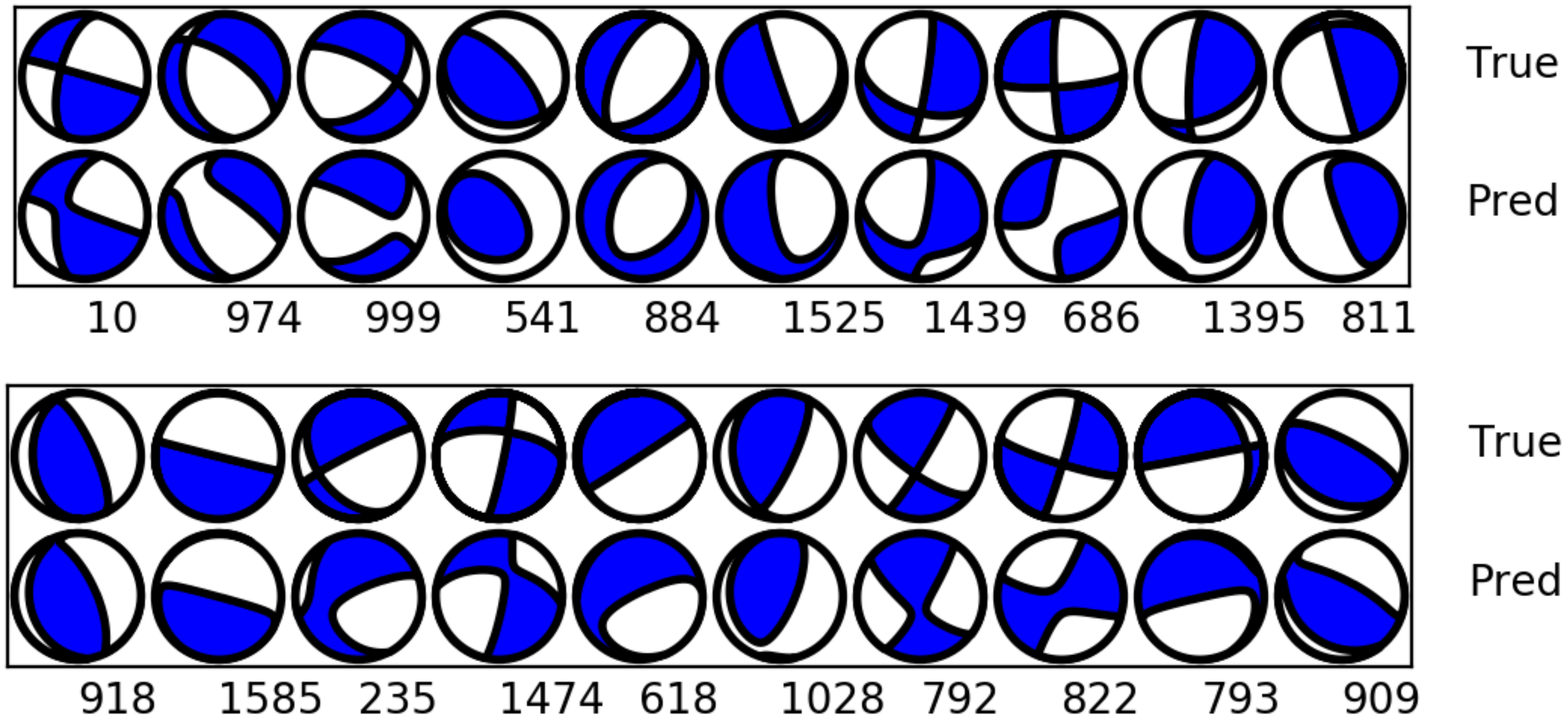


ObsPy
A Python Framework for Seismology

Feasibility of moment tensor inversion using ANN

oleg.ovcharenko@kaust.edu.sa

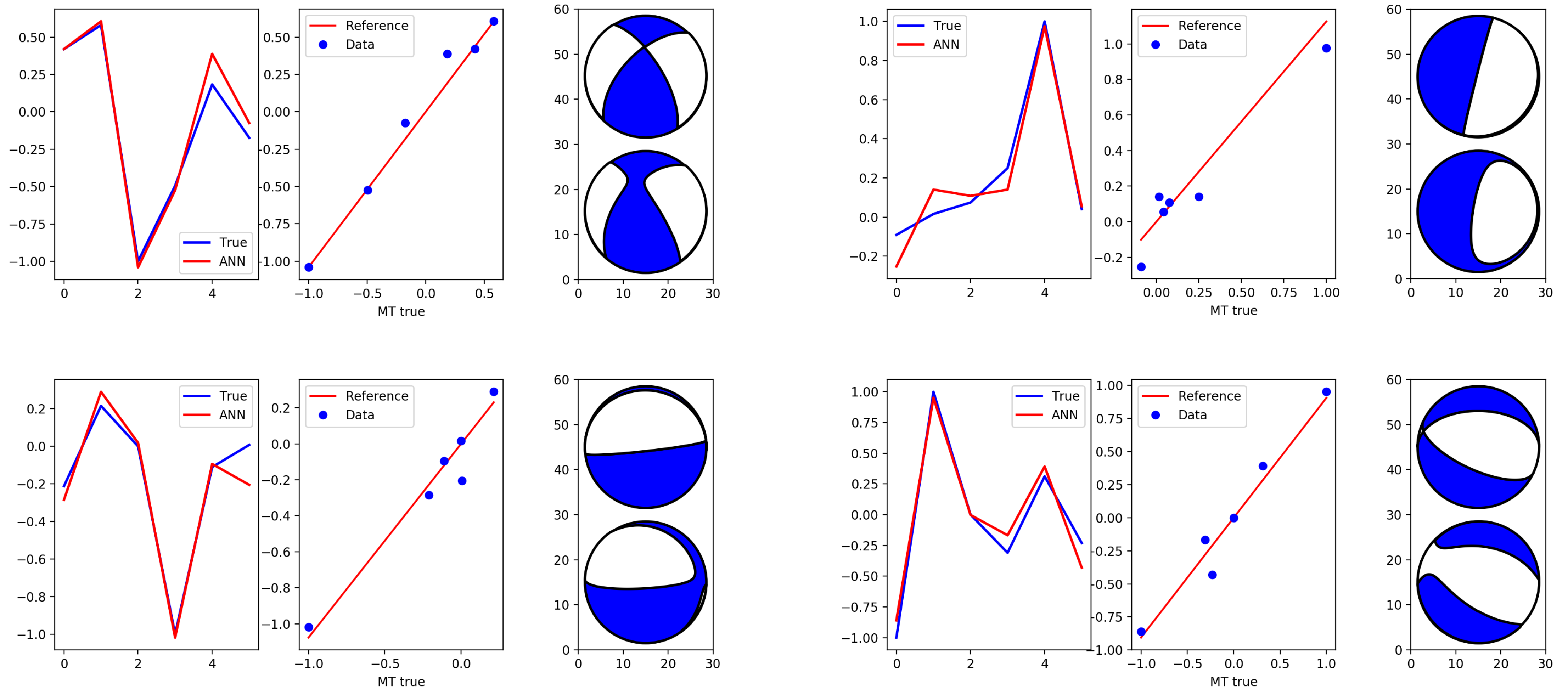
Detected focal mechanisms



Neural network never
seen these data before



Detected focal mechanisms



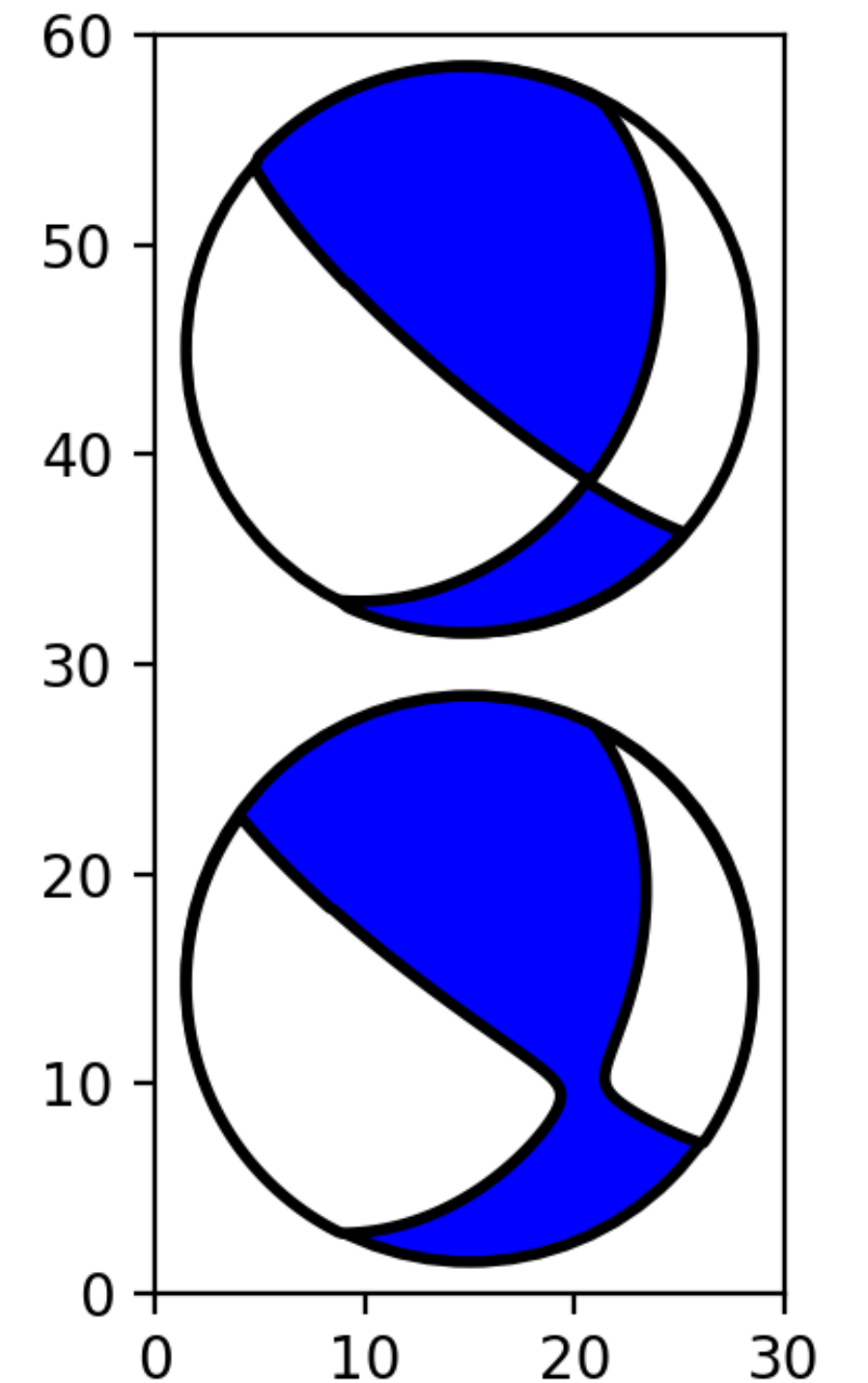
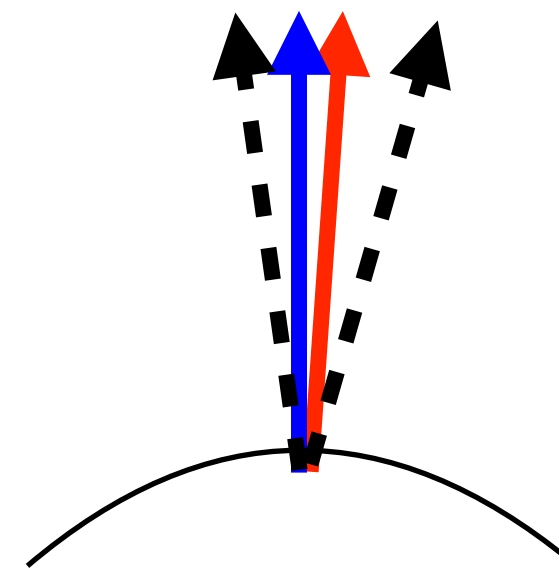
Analysis

17% moment tensors matched with 10% tolerance

80% eigenvalues matched with 5% tolerance

Deviation between detected and true P and T axes

Std 12°



Test data 1600 events

1294 DC

306 DC + ISO

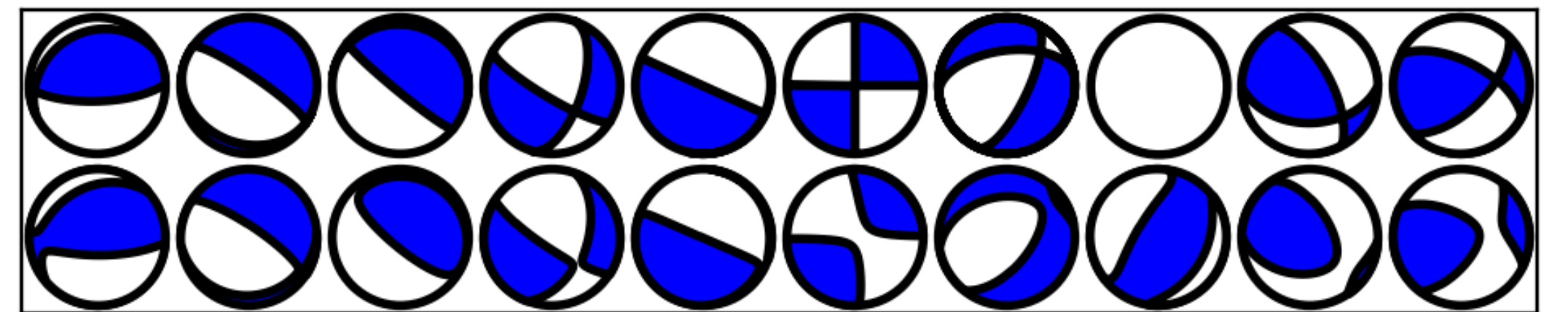


Conclusions

- Used a neural network to extract radiation pattern from a single-well data
- Able to retrieve full moment tensor
- Difficult to match absolute values
- Promising match of eigenvalues and eigenvectors

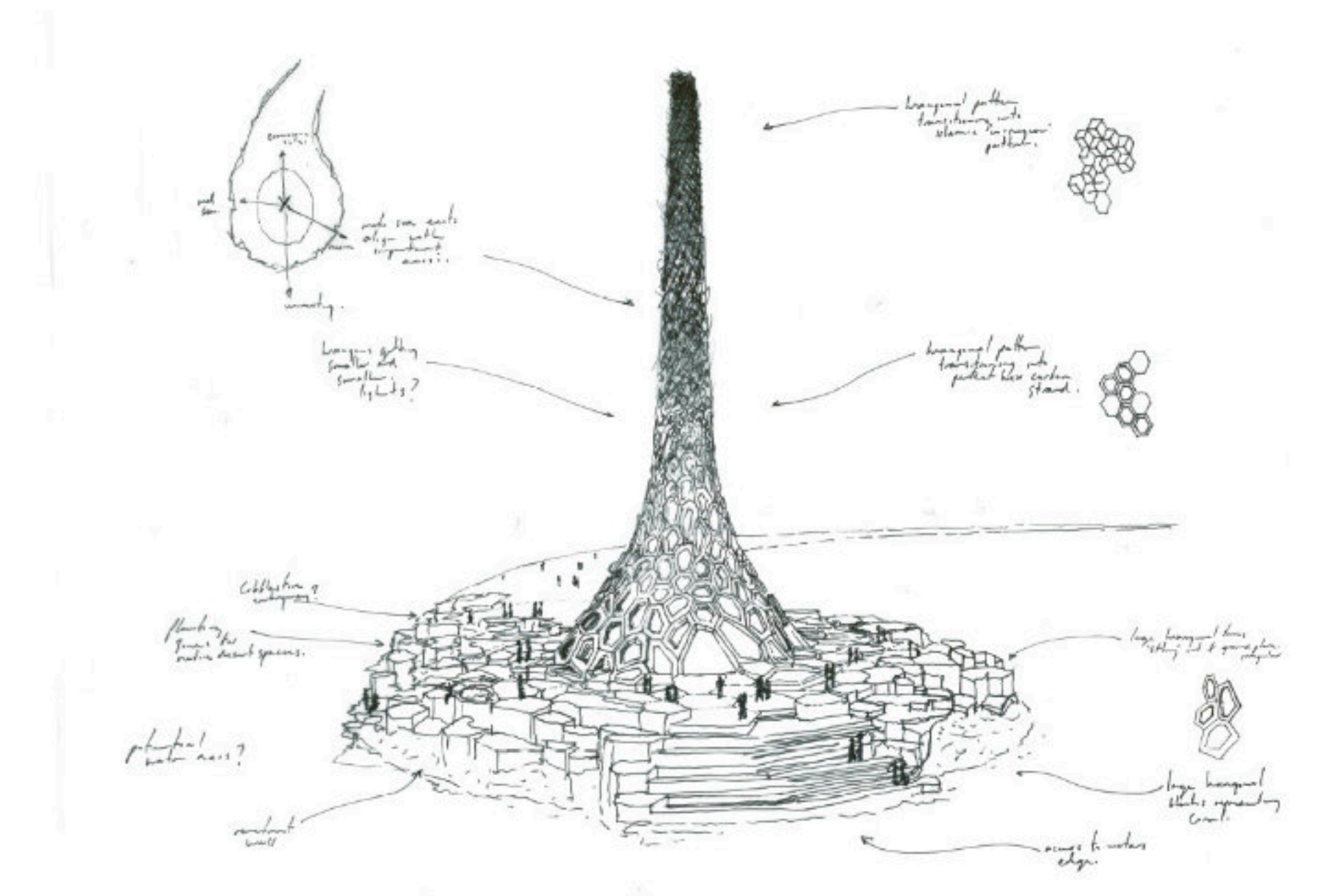
Future work

- Quantitative comparison
- Seismic moment
- Realistic cases



Acknowledgements

We are grateful to Leo Eisner, SMI and SWAG groups at KAUST for fruitful discussions.

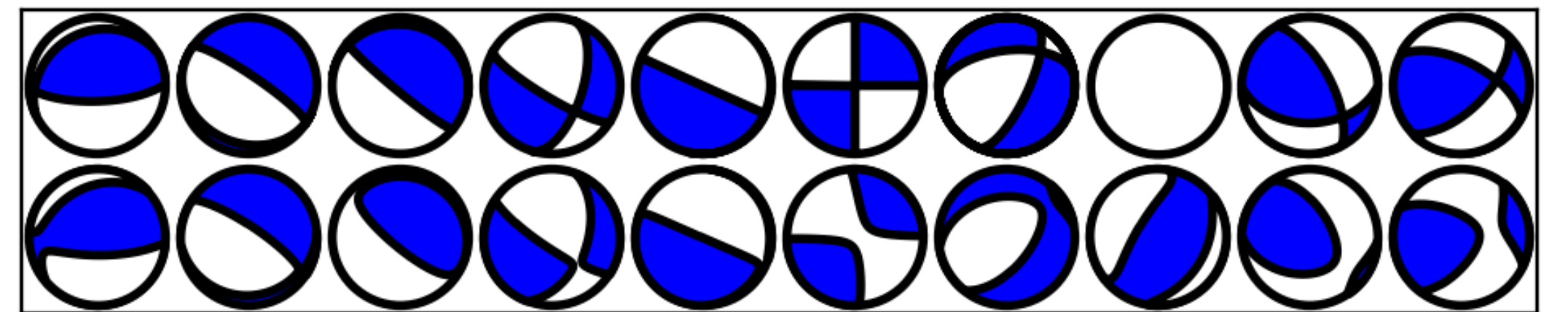


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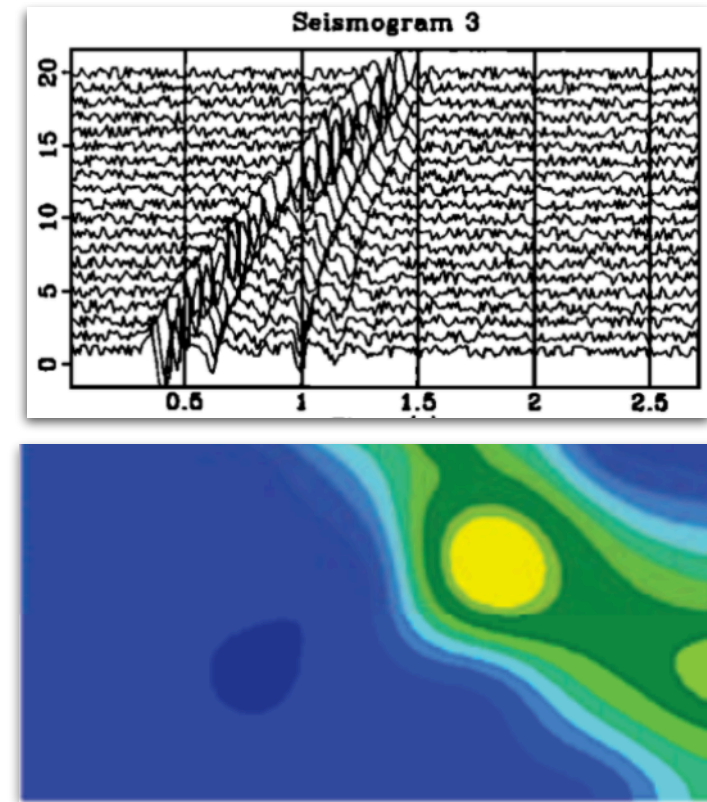
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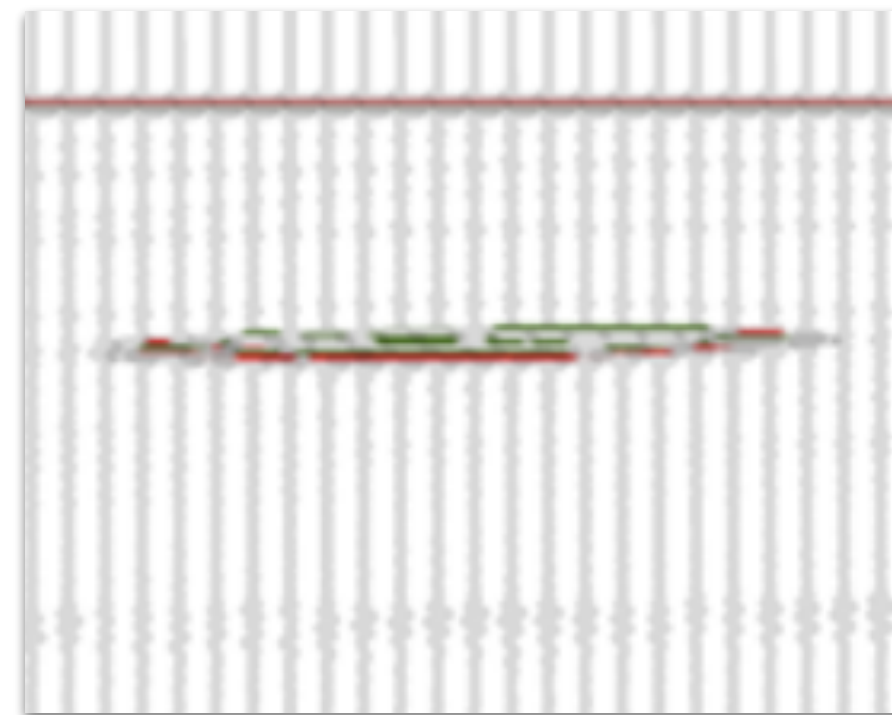


The End

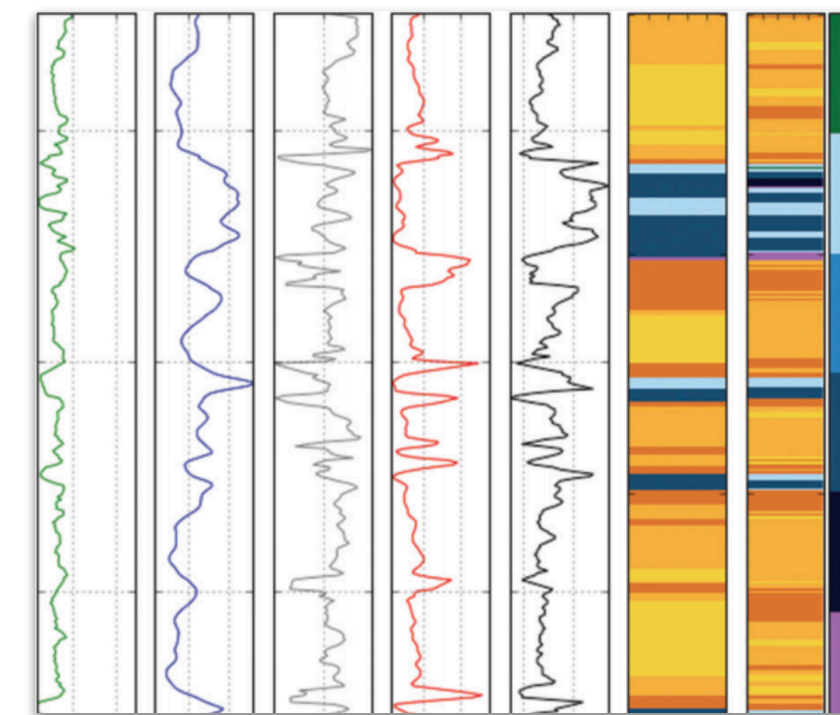
Some NN applications in geophysics



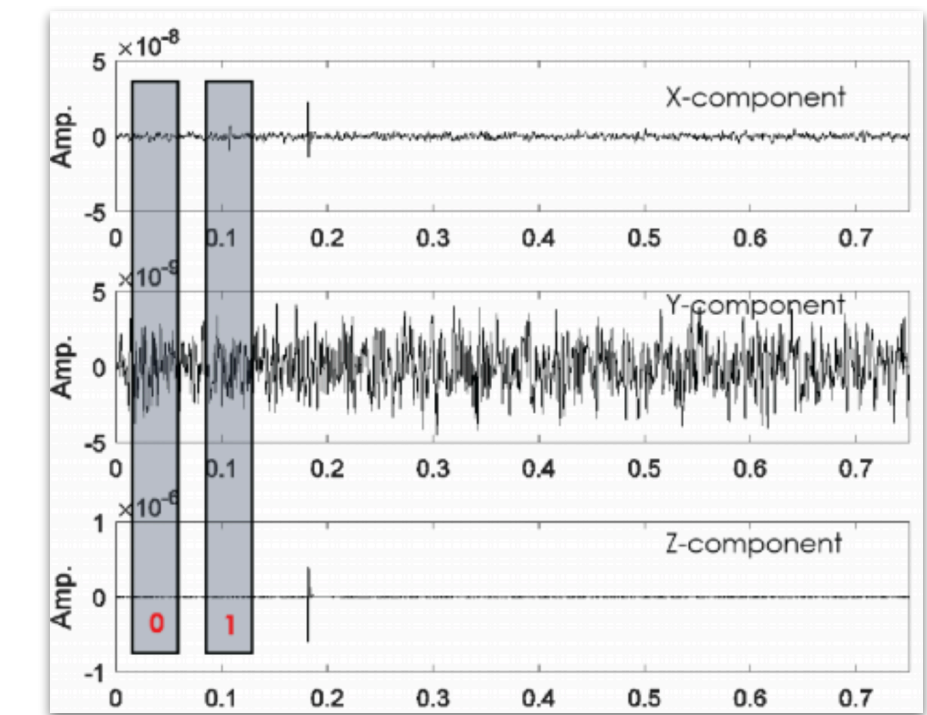
Inversion of seismic, DC data etc.
(Röth, Tarantola, 1994;
Neyamadpour et al., 2009)



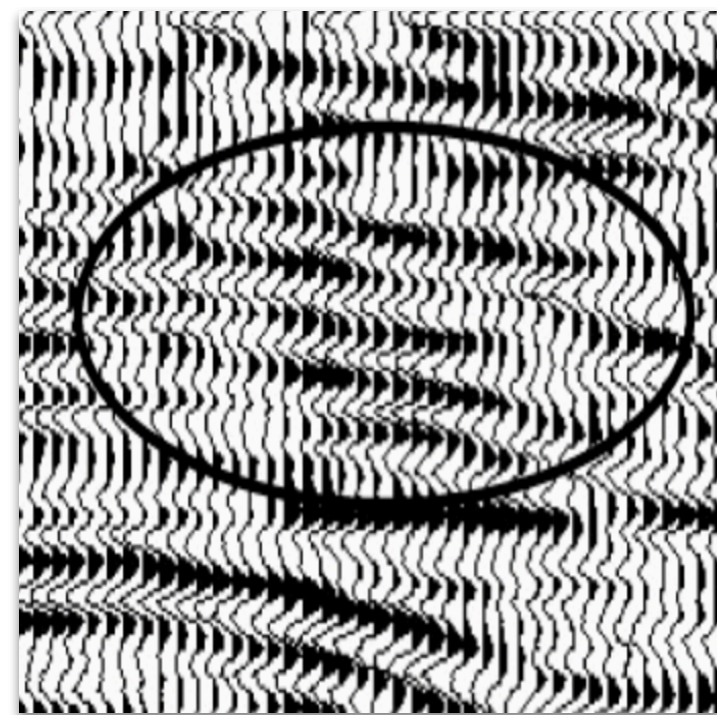
Mapping reservoirs on
migrated seismic
(Bougher, 2016)



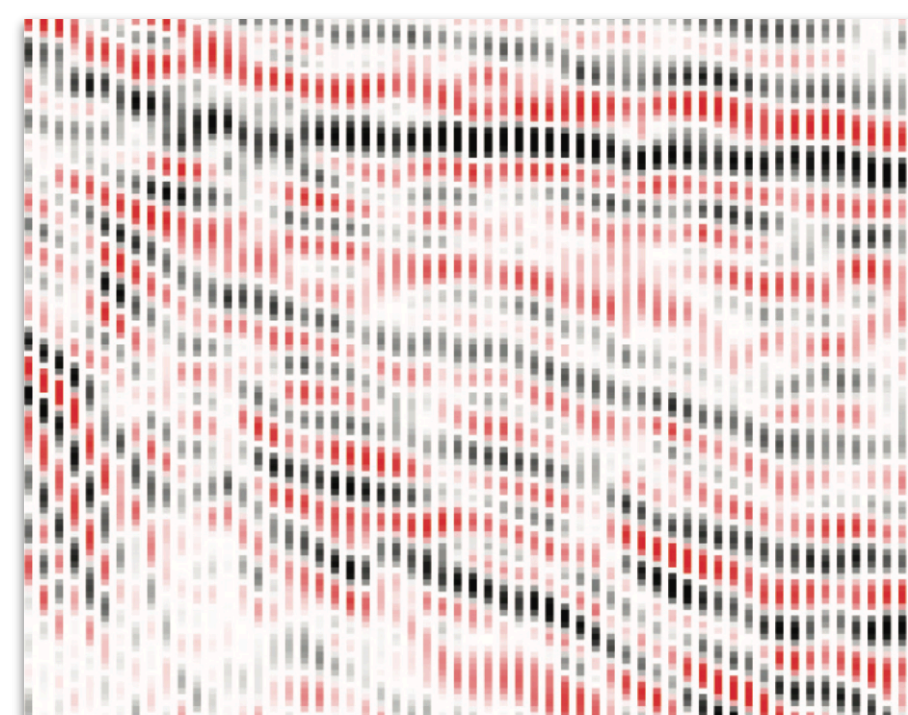
Facies classification
and reservoir properties prediction
(Hall, 2017; Ahmed et al., 2010)



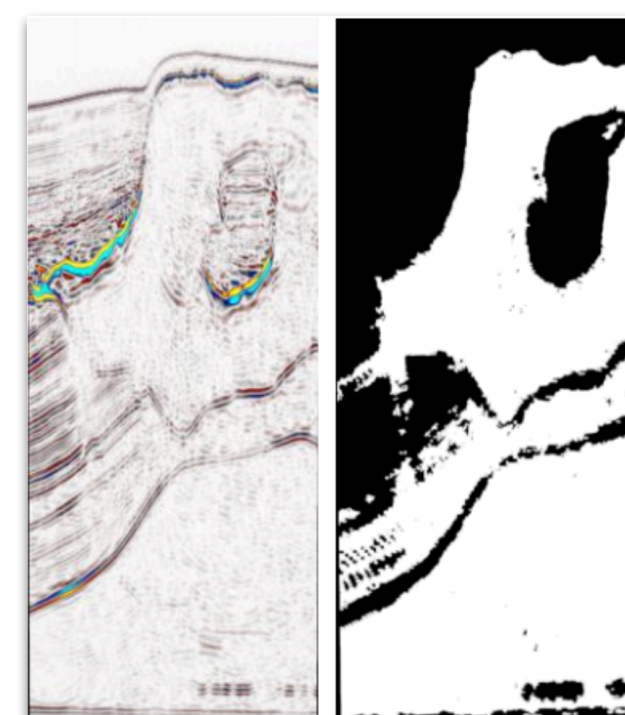
Event detection
(Akram et al., 2017)



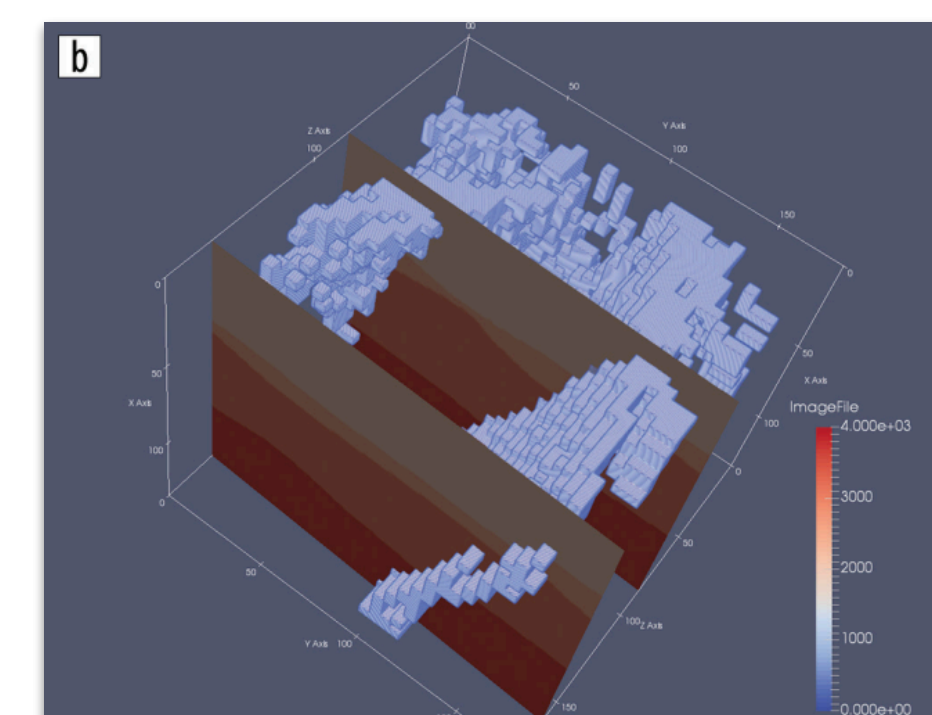
Denoising
(Zhang et al, 2017)



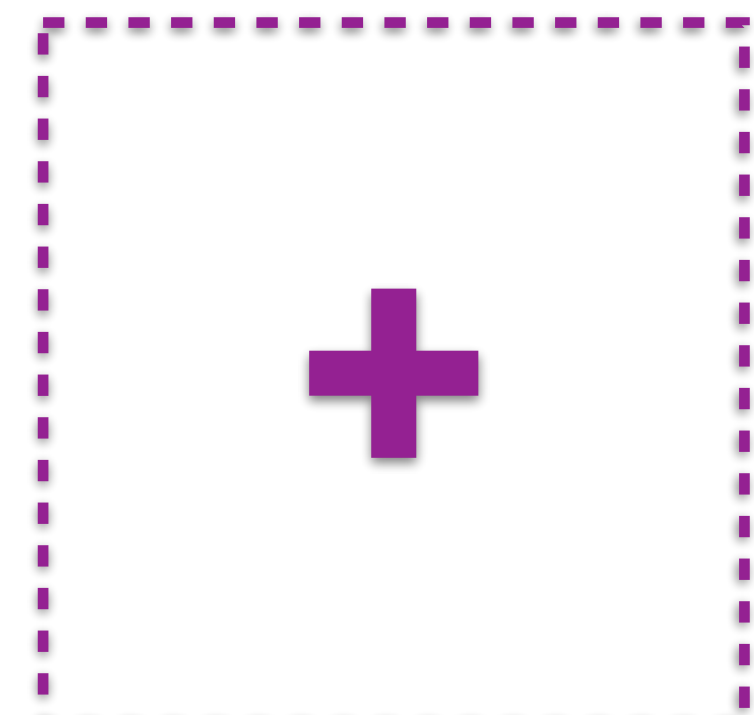
Interpolation of missing data
(Jia and Ma, 2017)



Salt body picking
(Guillen et al., 2017)



Automated fault detection
(Araya-Polo et al., 2017)



Bonus

