

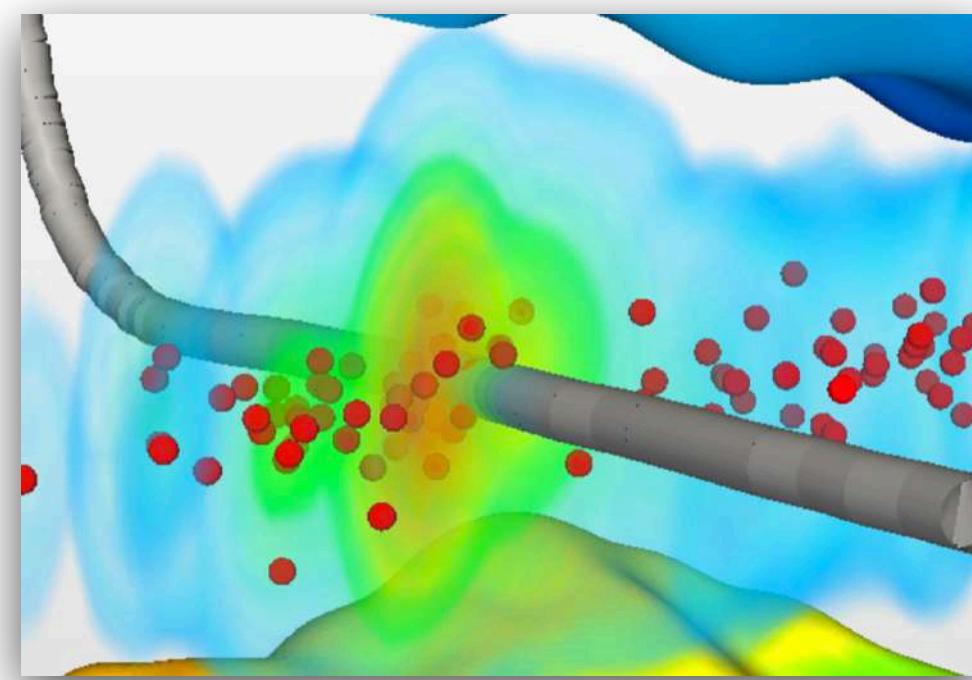
Feasibility of moment tensor inversion for a single-well microseismic data using neural networks

O. Ovcharenko, J. Akram, D. Peter

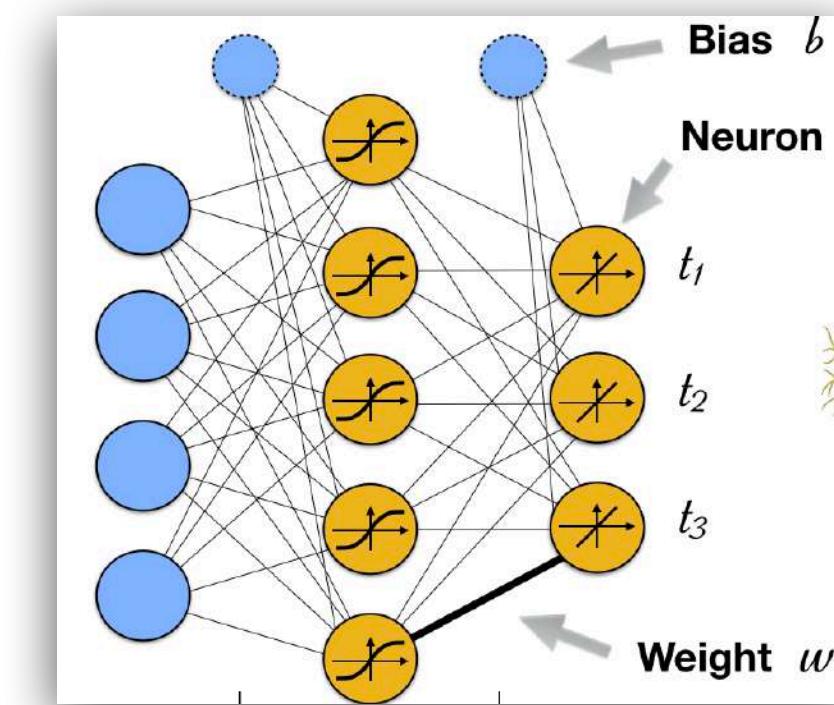
March 6, 2018

Outline

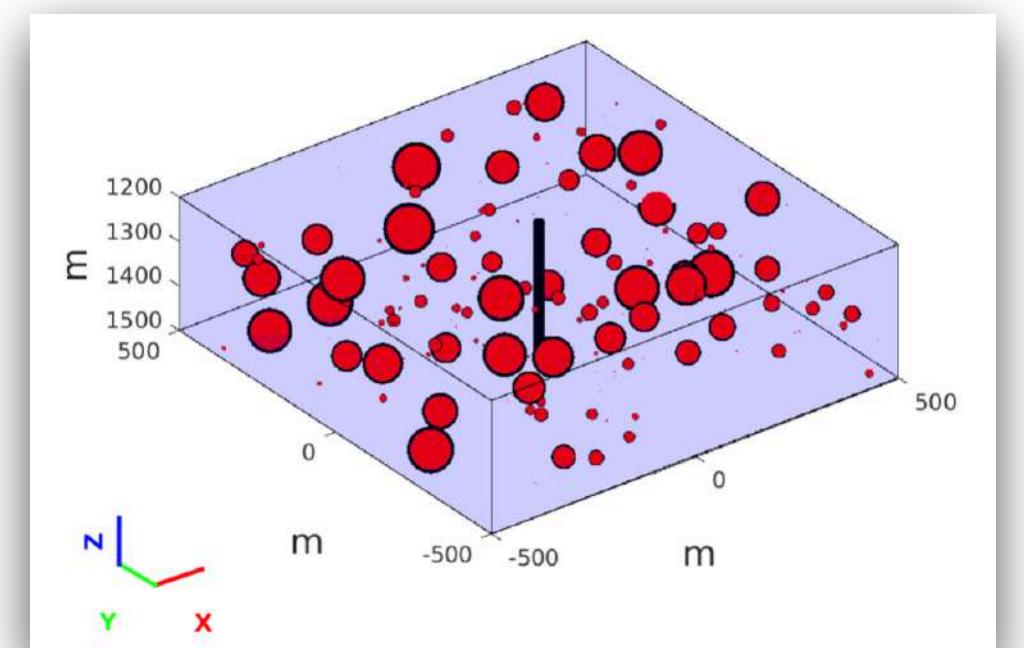
Single-well data



Artificial Neural Network

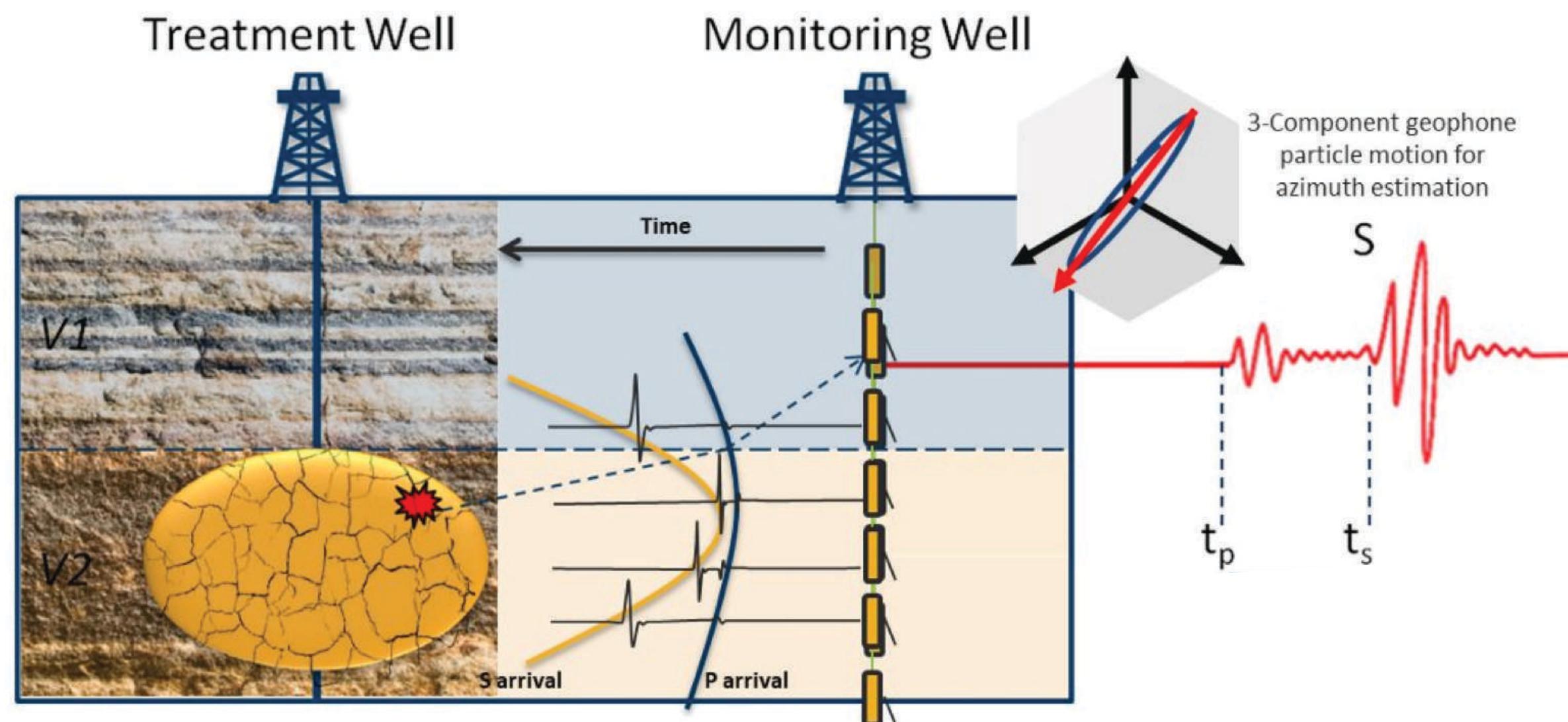


Example in a homogeneous model



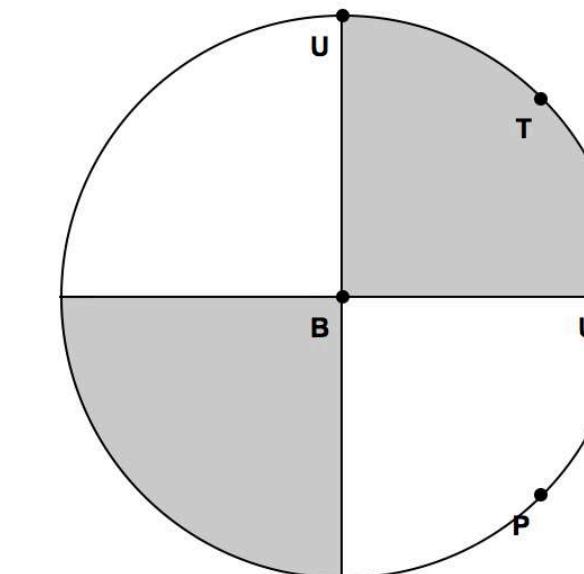
Idea

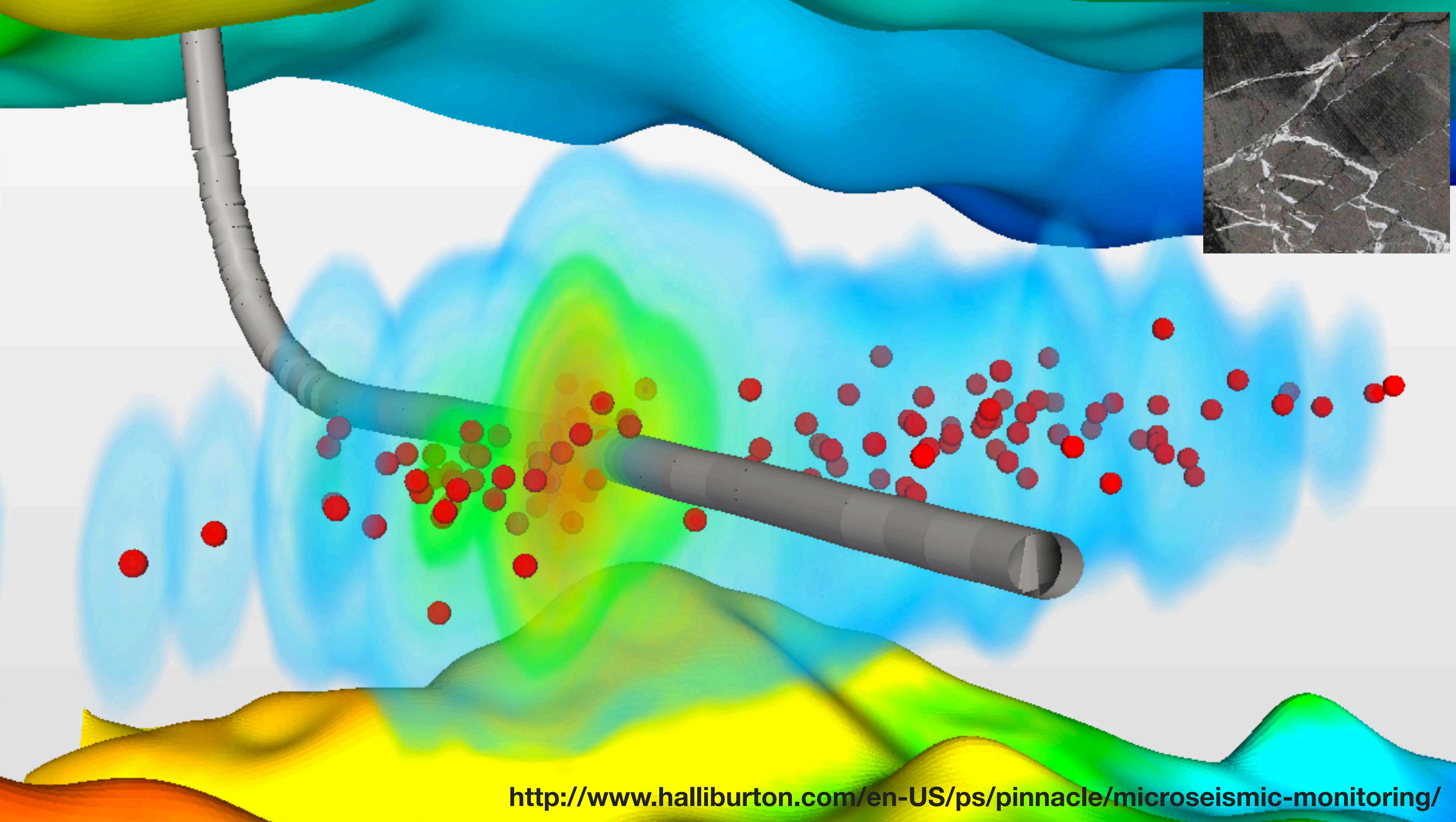
Reconstruct source mechanisms from single-well data using an artificial neural network



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

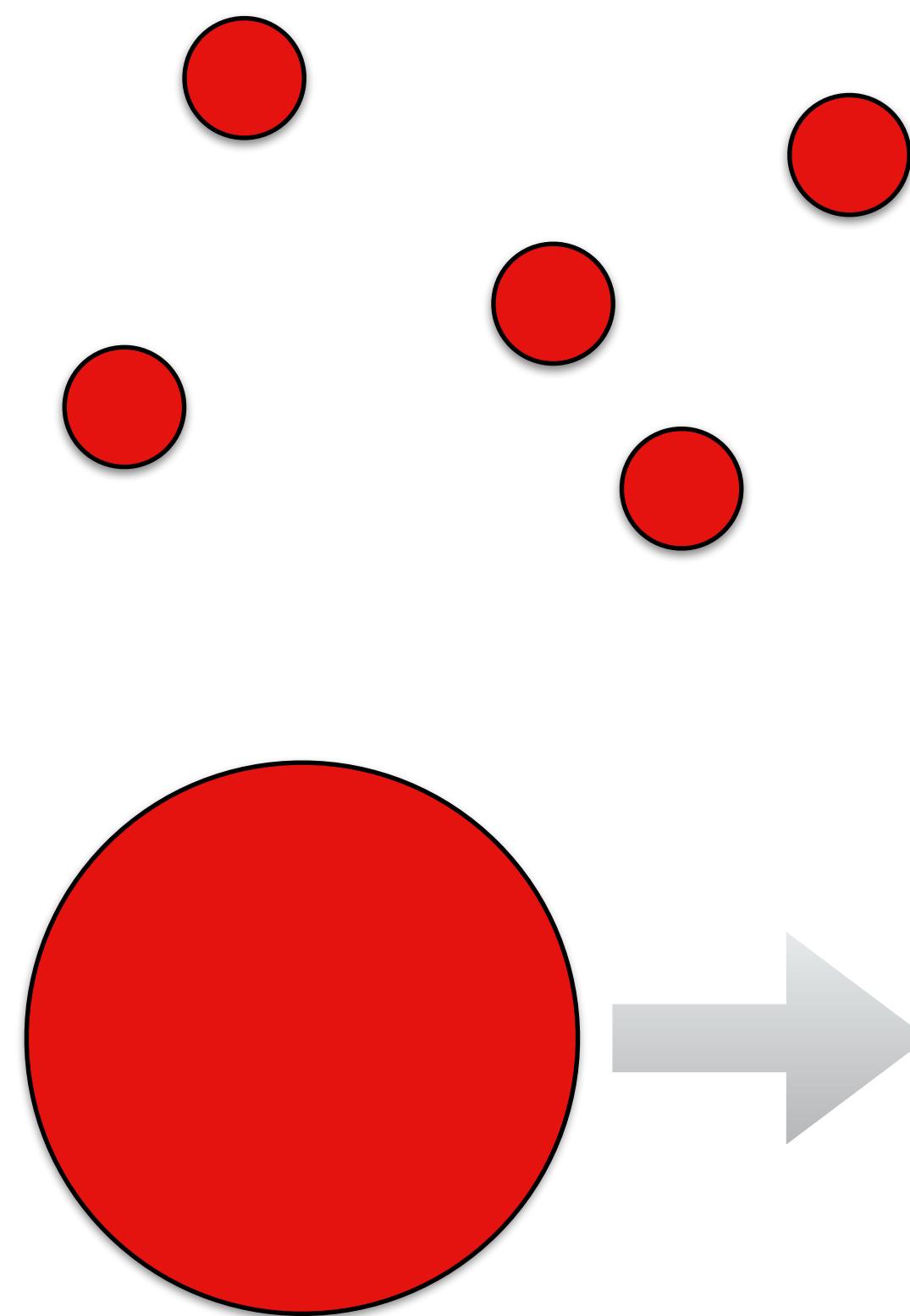
$$\begin{pmatrix} M_{xx} & M_{xy} & M_{xz} \\ M_{yy} & M_{yz} & \\ M_{zz} & & \end{pmatrix}$$



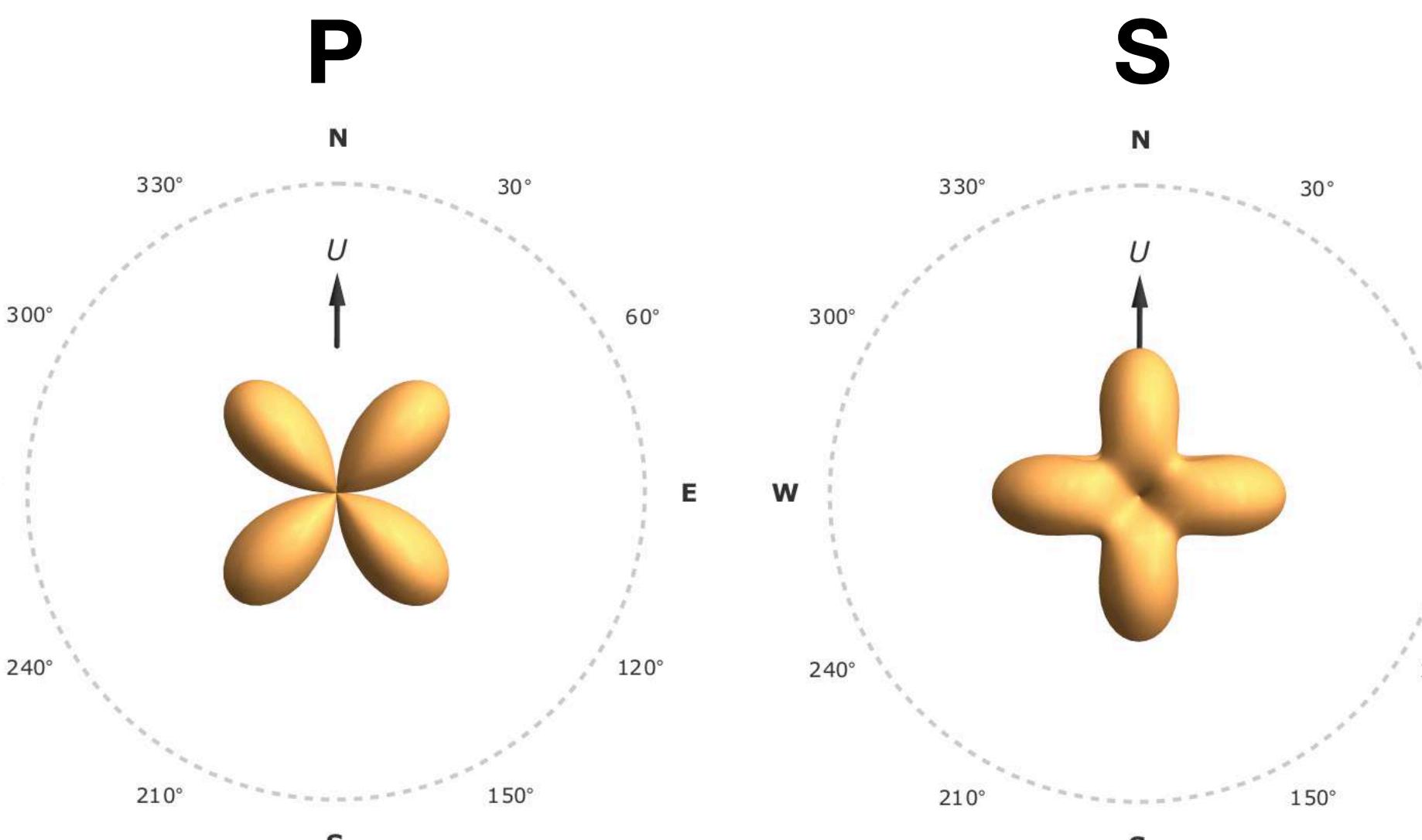
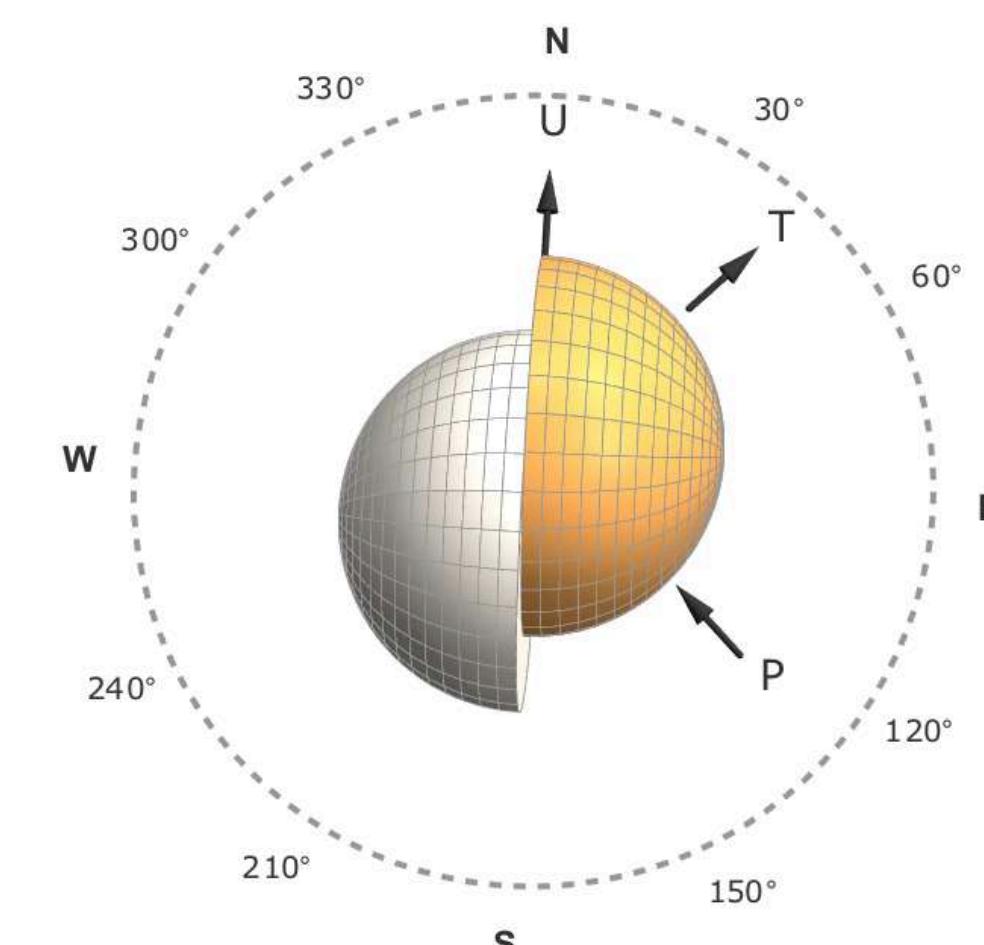
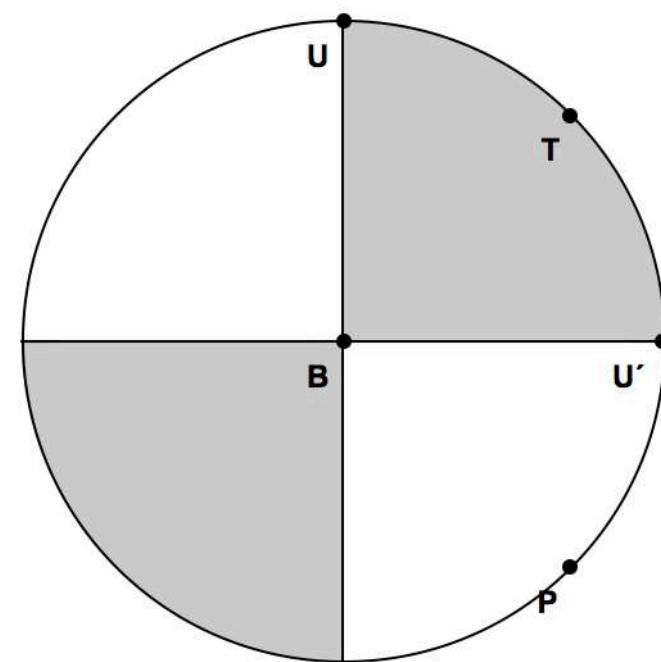


<http://www.halliburton.com/en-US/ps/pinnacle/microseismic-monitoring/>

Source mechanism



“Beach ball”



Radiation
patterns

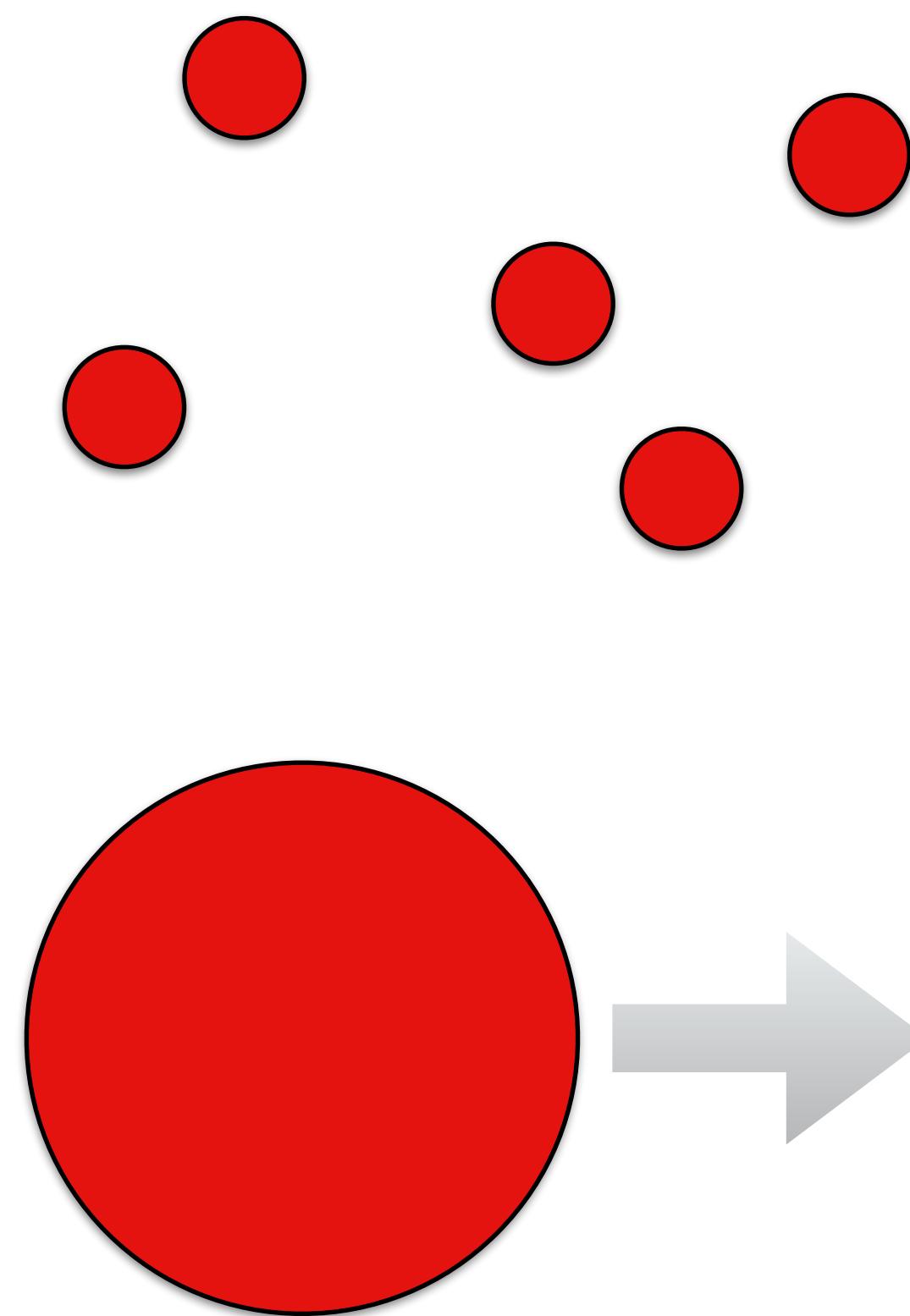


<http://demonstrations.wolfram.com/author.html?author=Frank+Scherbaum%2C+Nicolas+Kuehn%2C+and+Bj%C3%BCrn+Zimmermann>

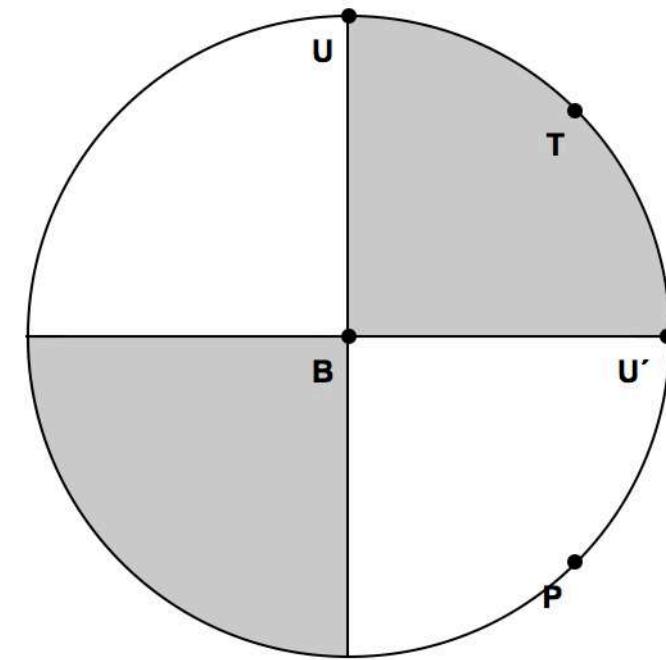
Feasibility of moment tensor inversion using ANN

oleg.ovcharenko@kaust.edu.sa

Source mechanism



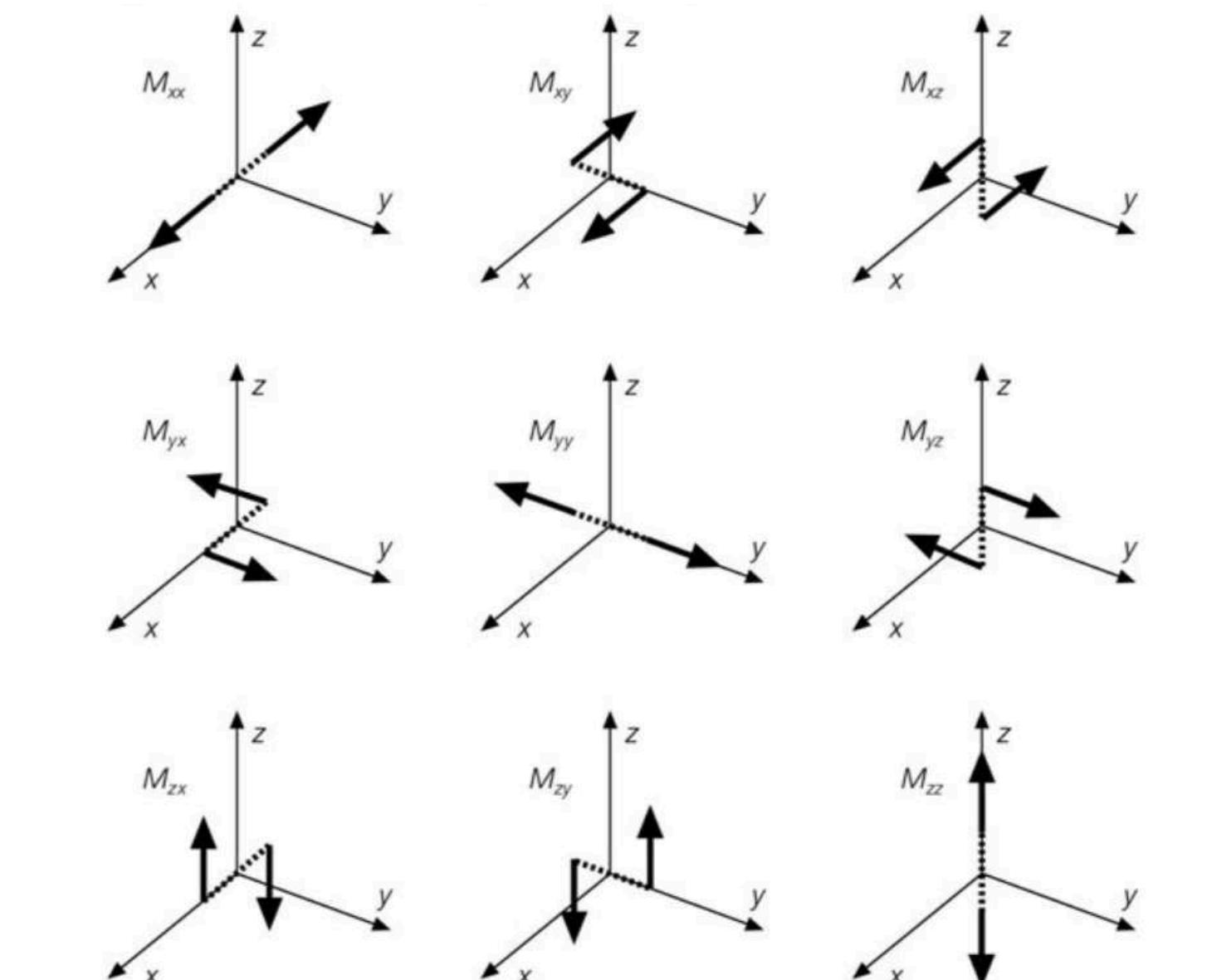
“Beach ball”



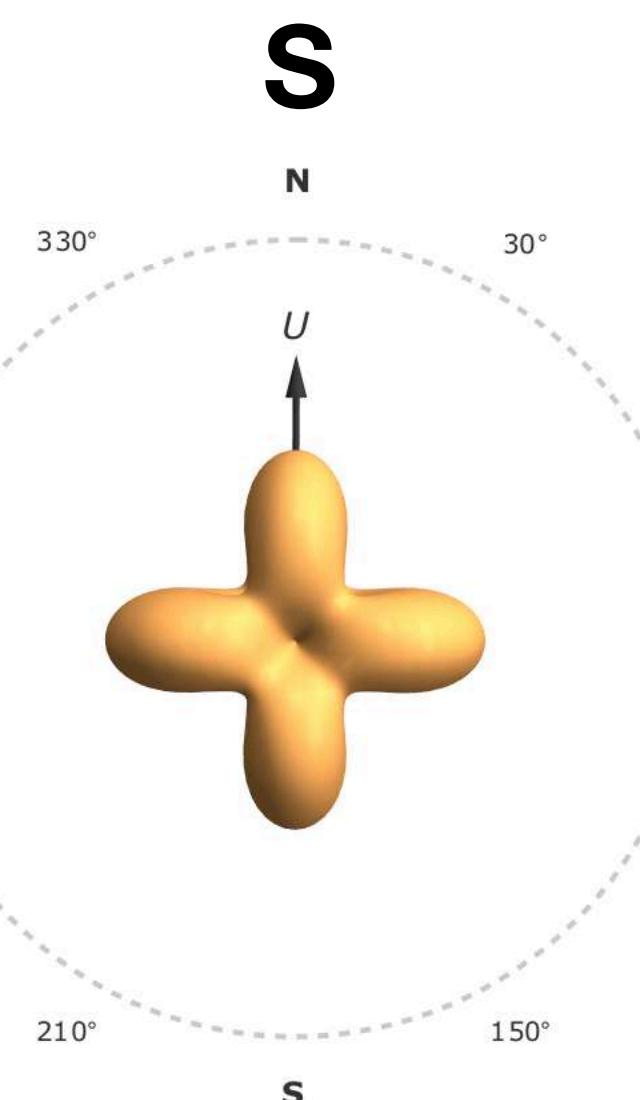
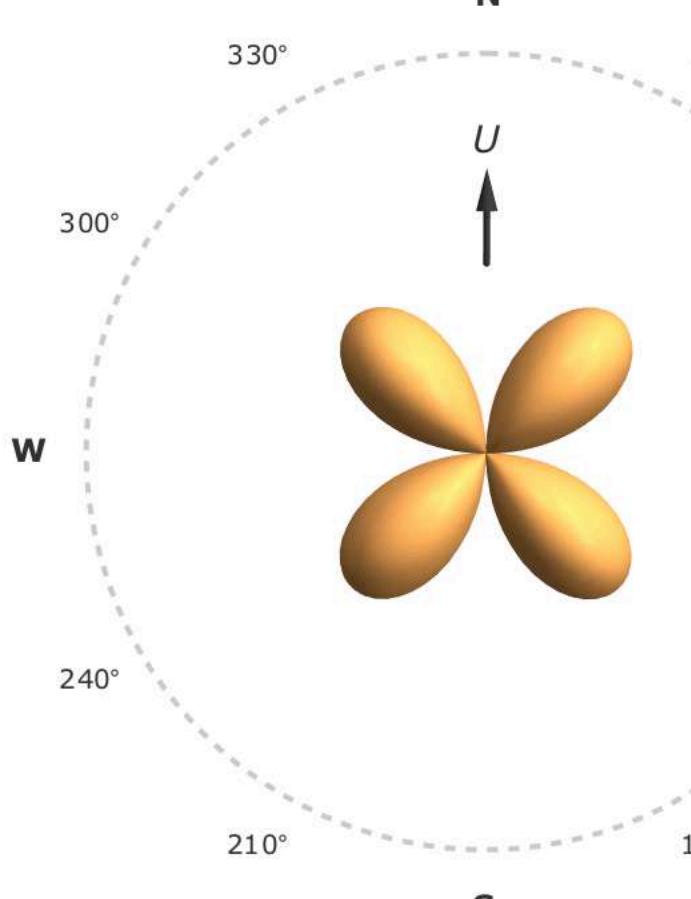
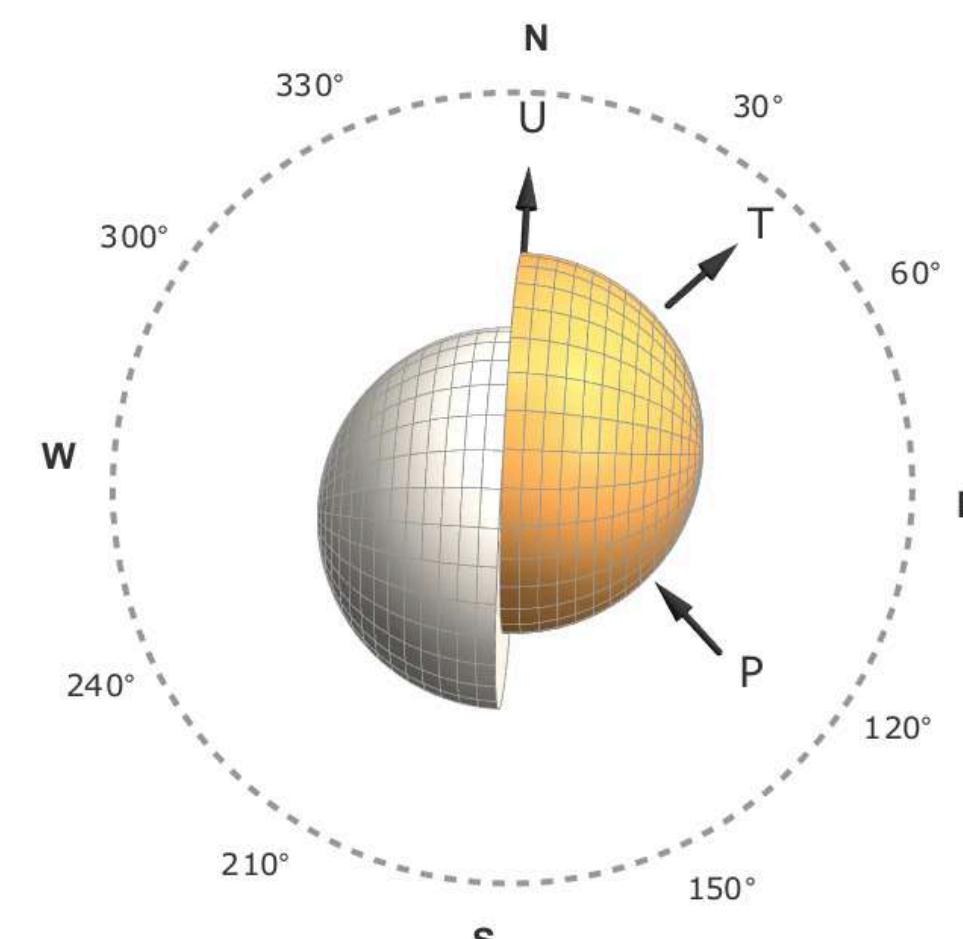
Seismic moment tensor

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

6 independent components



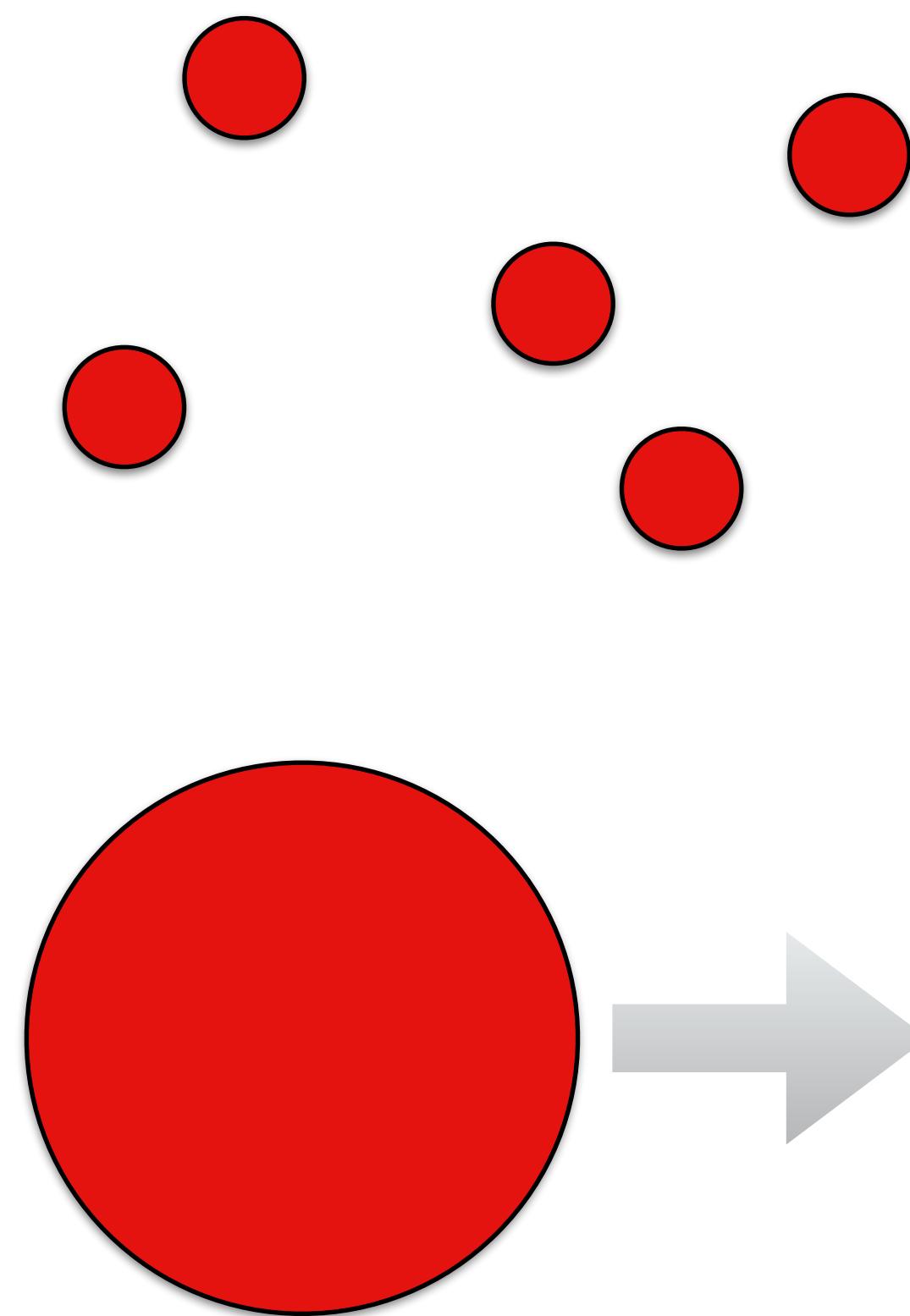
(Stein & Wysession, 2003)



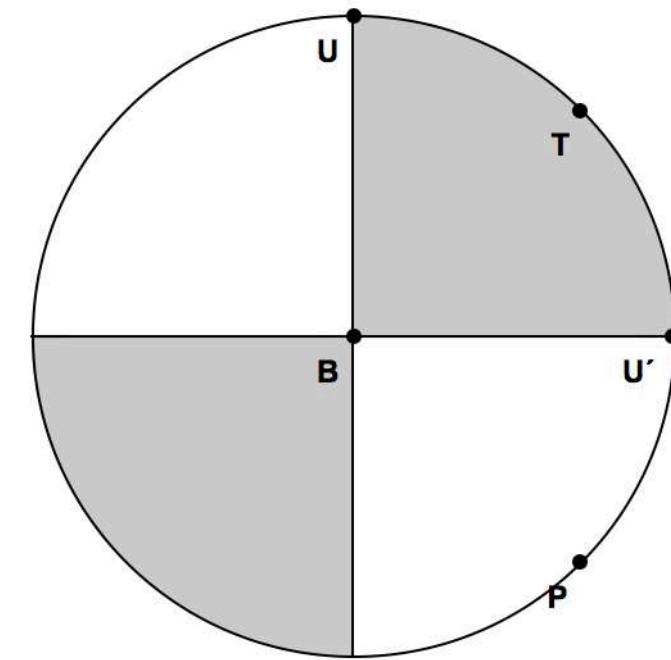
Radiation patterns



Source mechanism



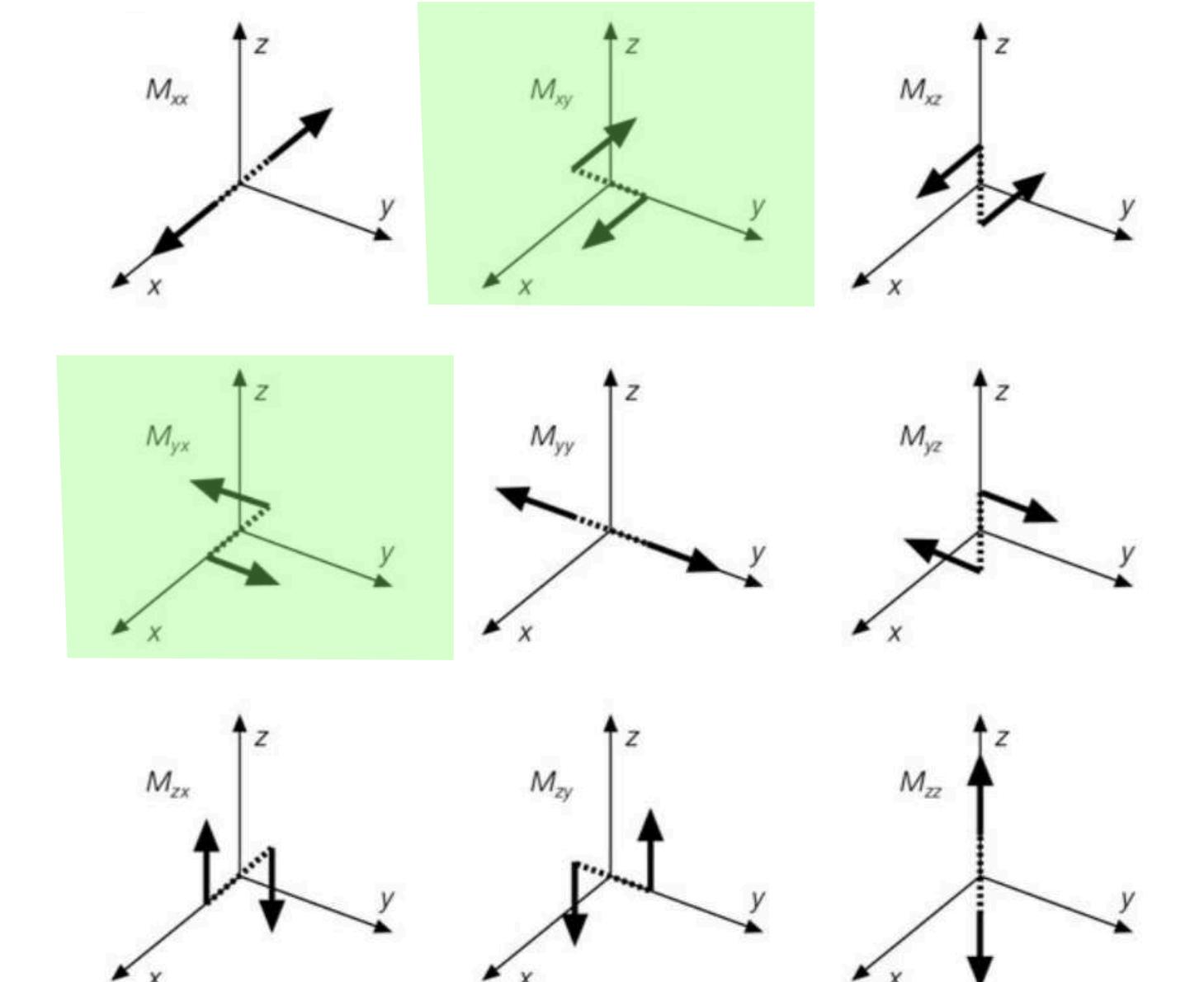
“Beach ball”



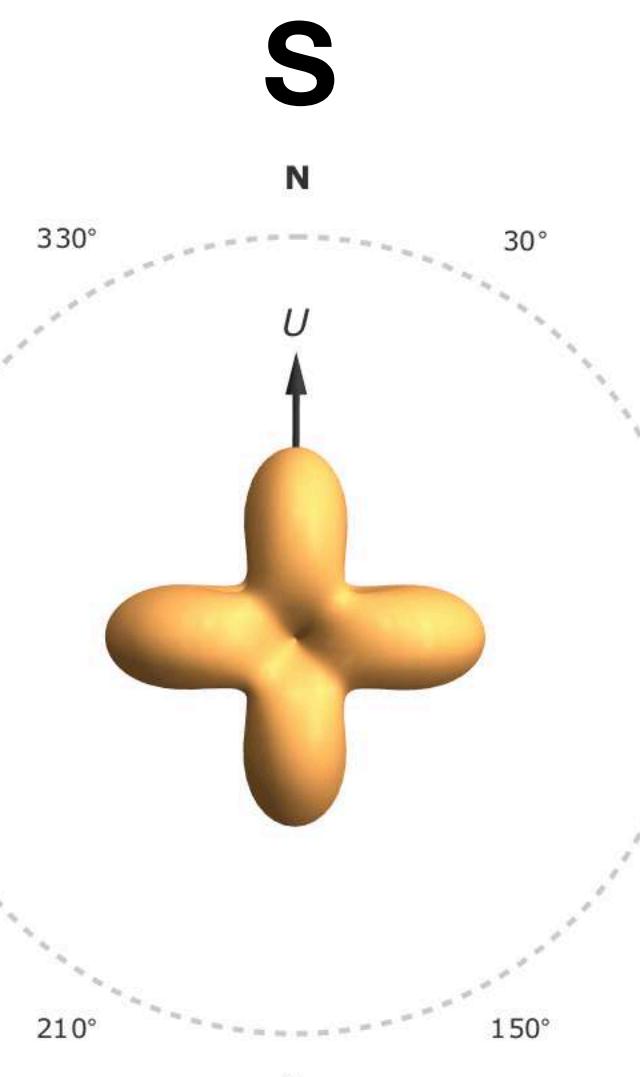
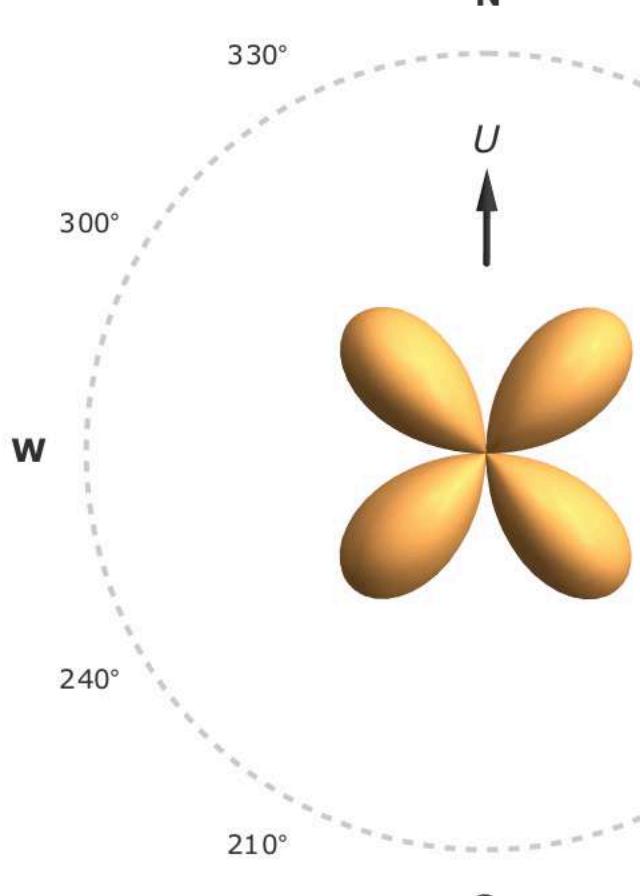
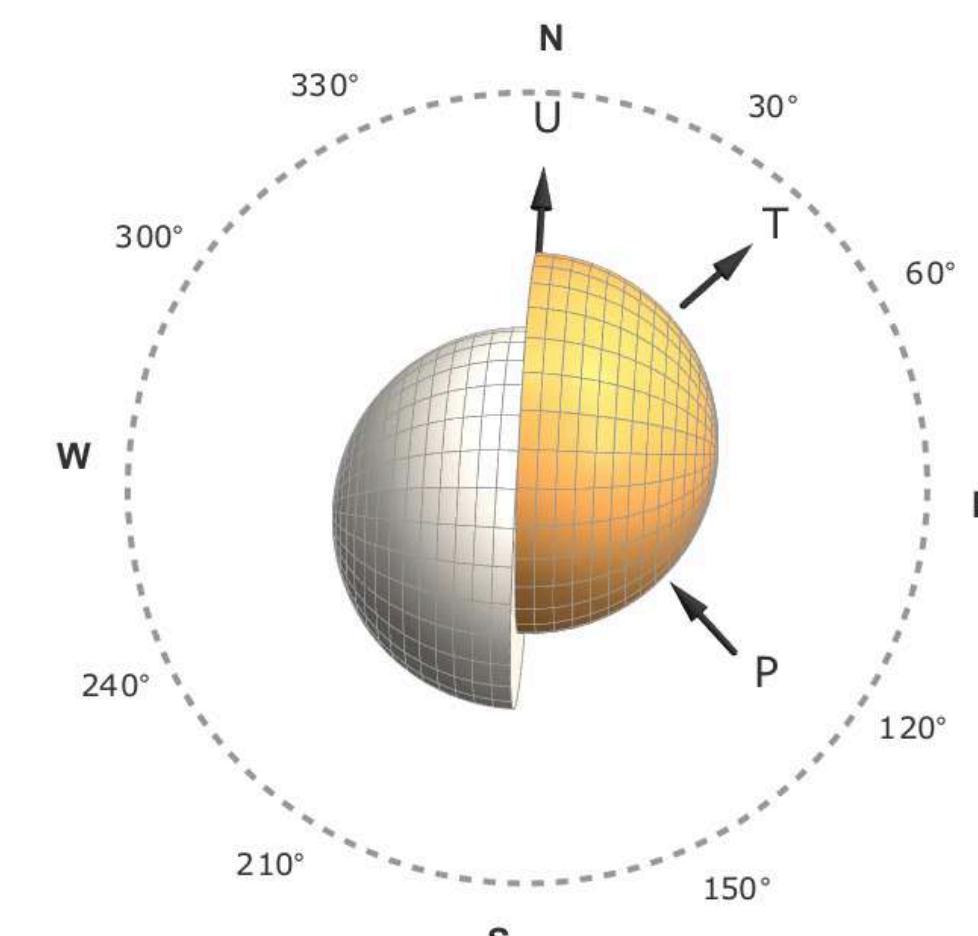
Seismic moment tensor

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6 independent components



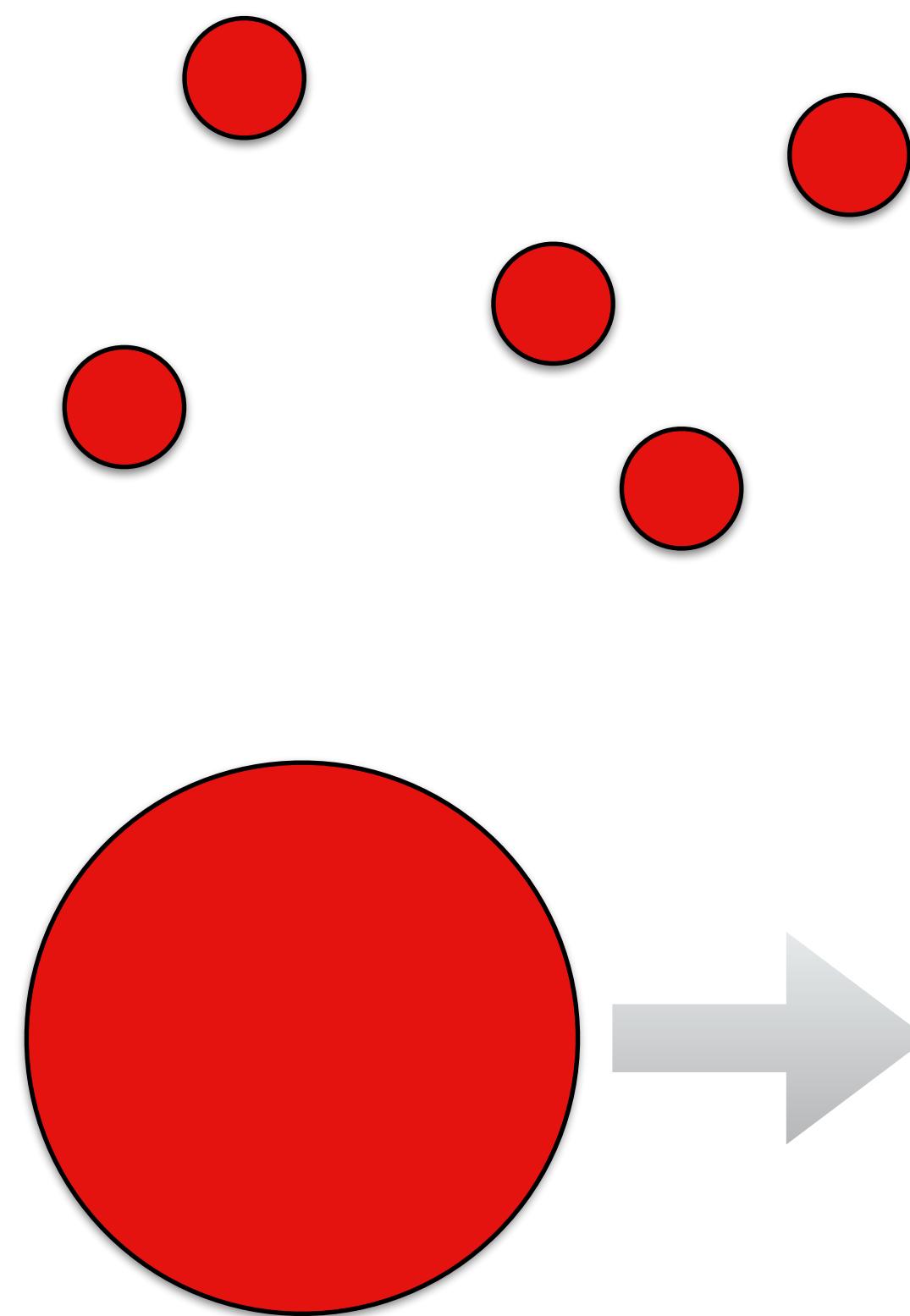
(Stein & Wysession, 2003)



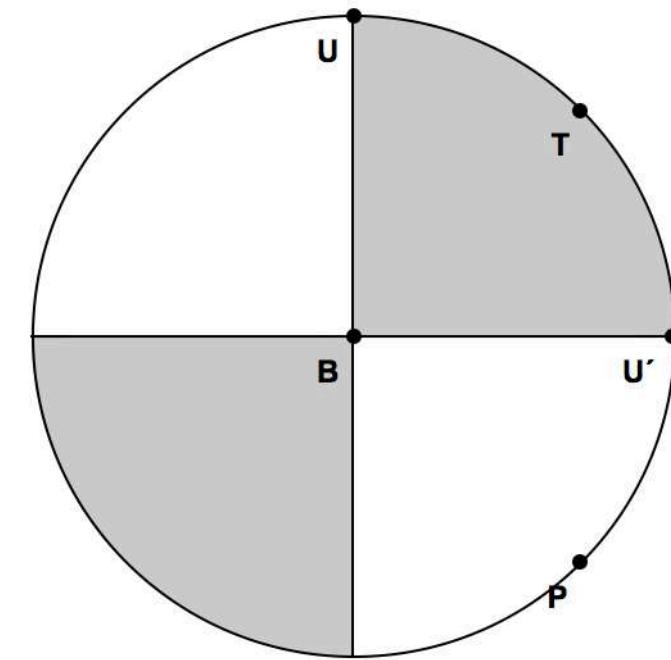
Radiation patterns



Source mechanism



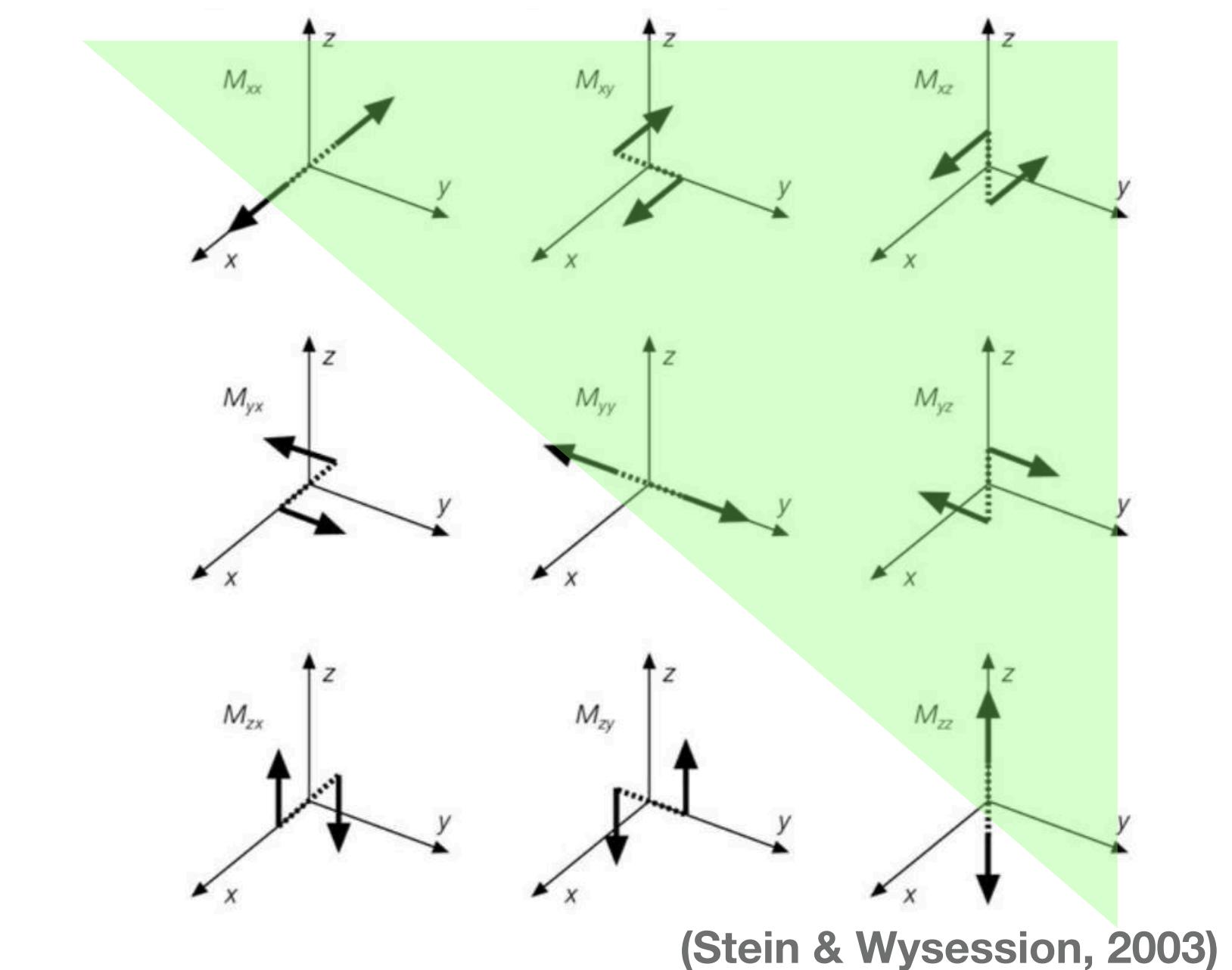
“Beach ball”



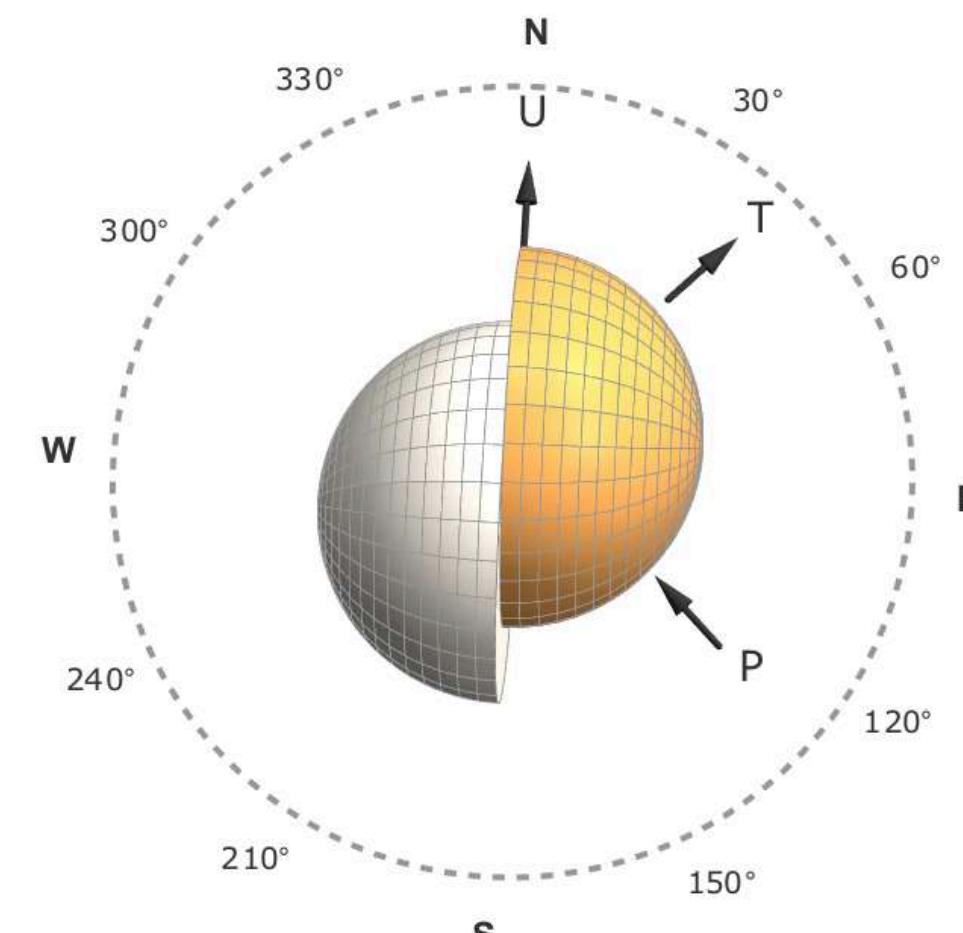
Seismic moment tensor

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

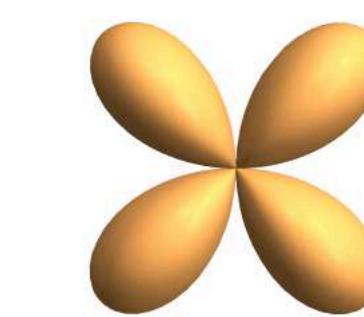
6 independent components



P

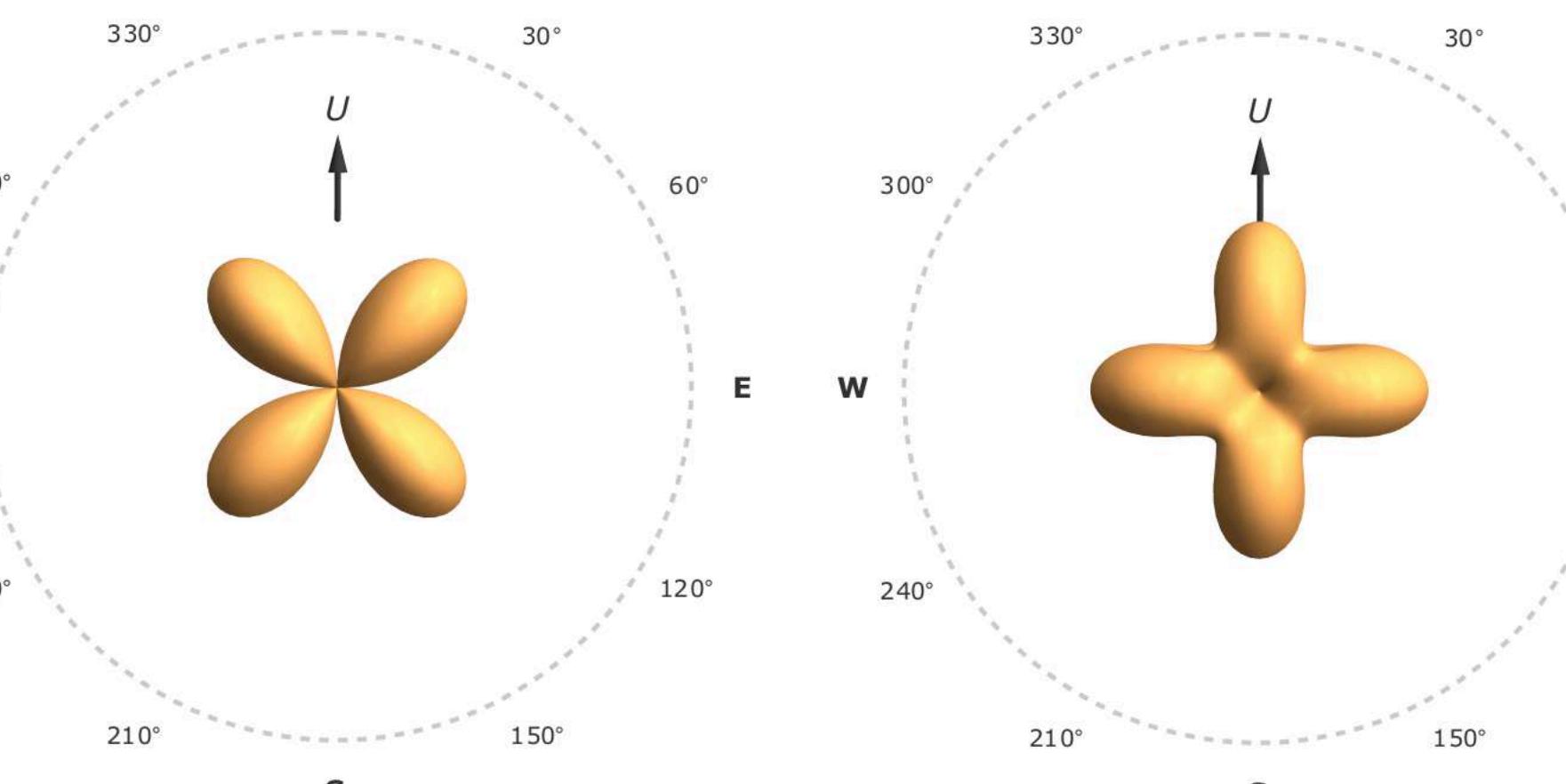


N



S

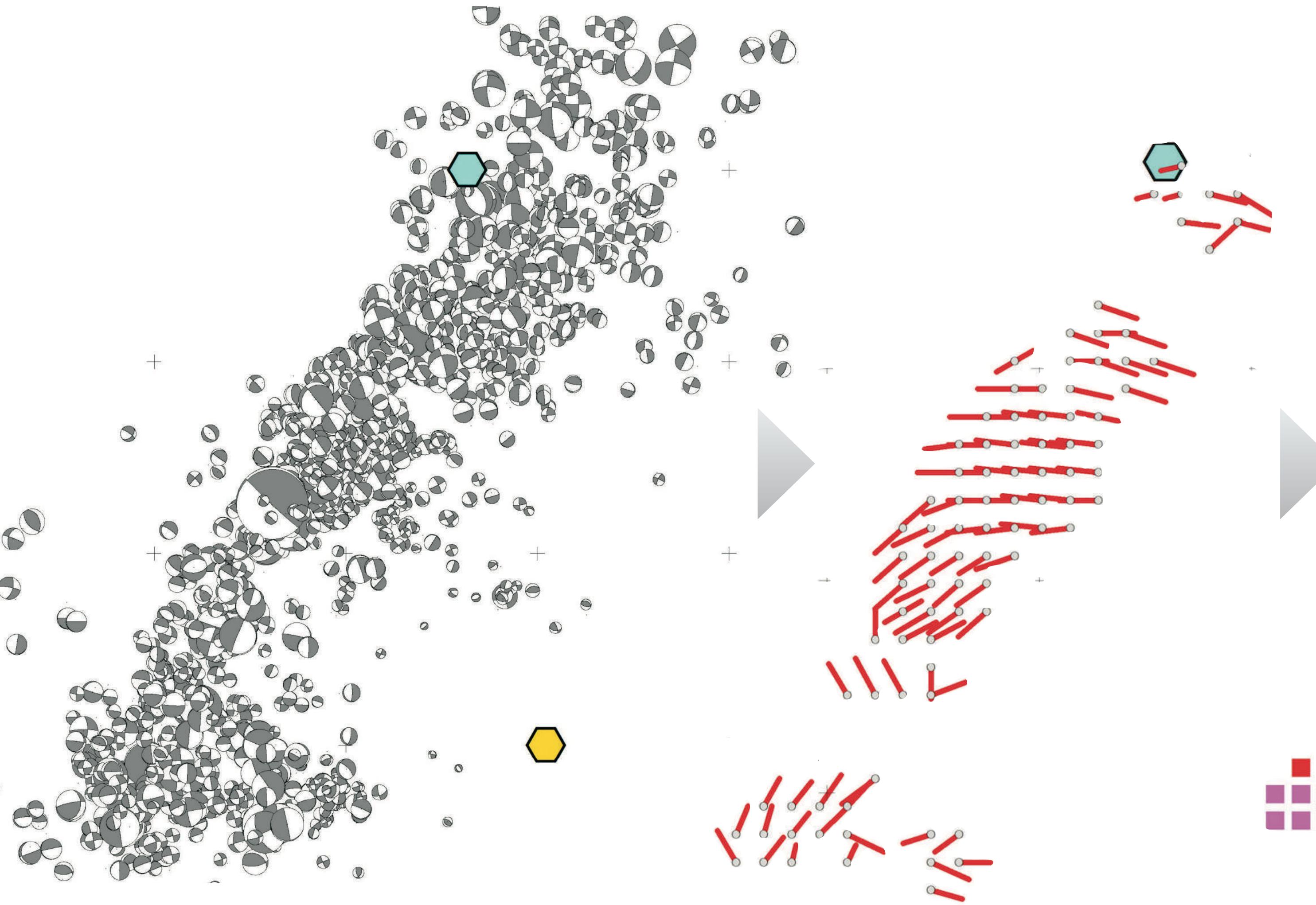
S



Radiation patterns



Stress state



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

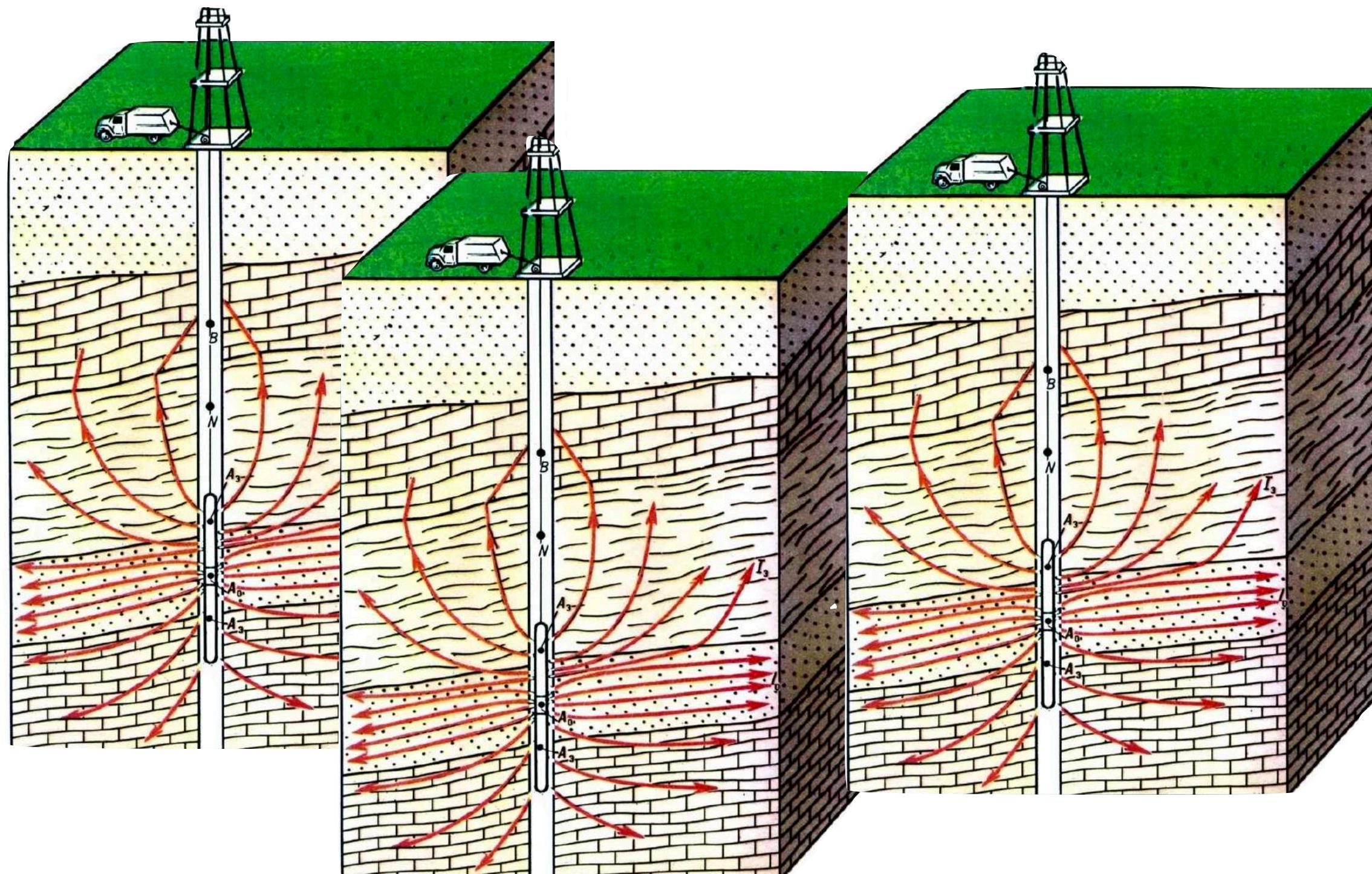
Used for

- Estimates of fracturing direction
- Seismic hazard assessment
- Better reservoir characterization

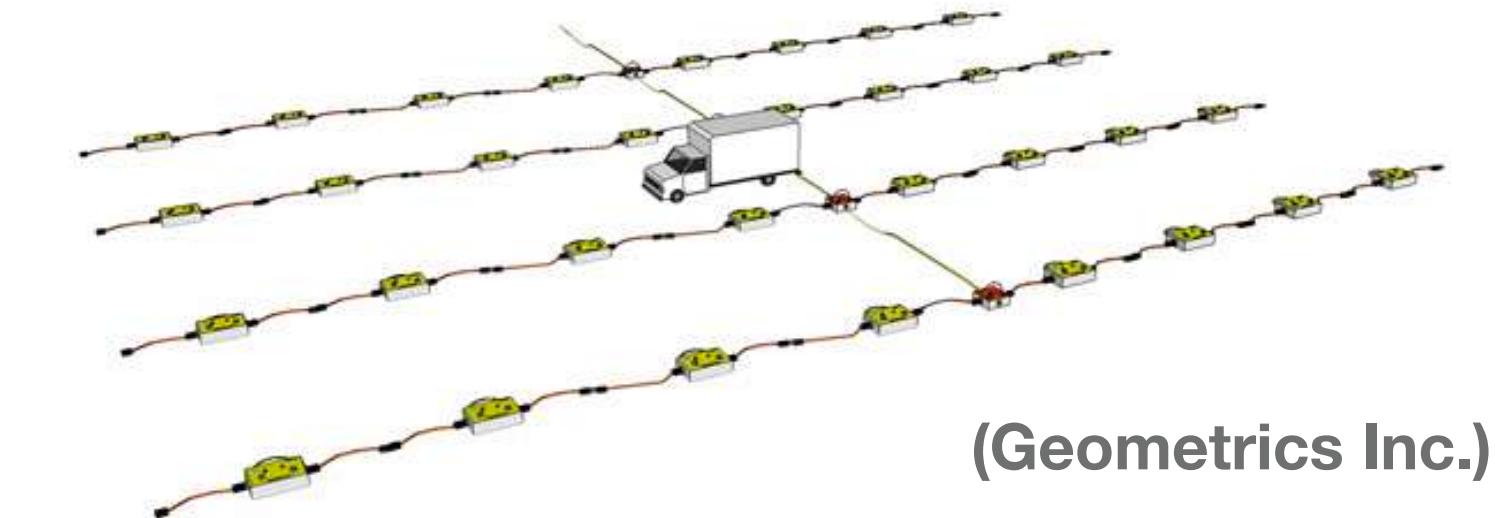
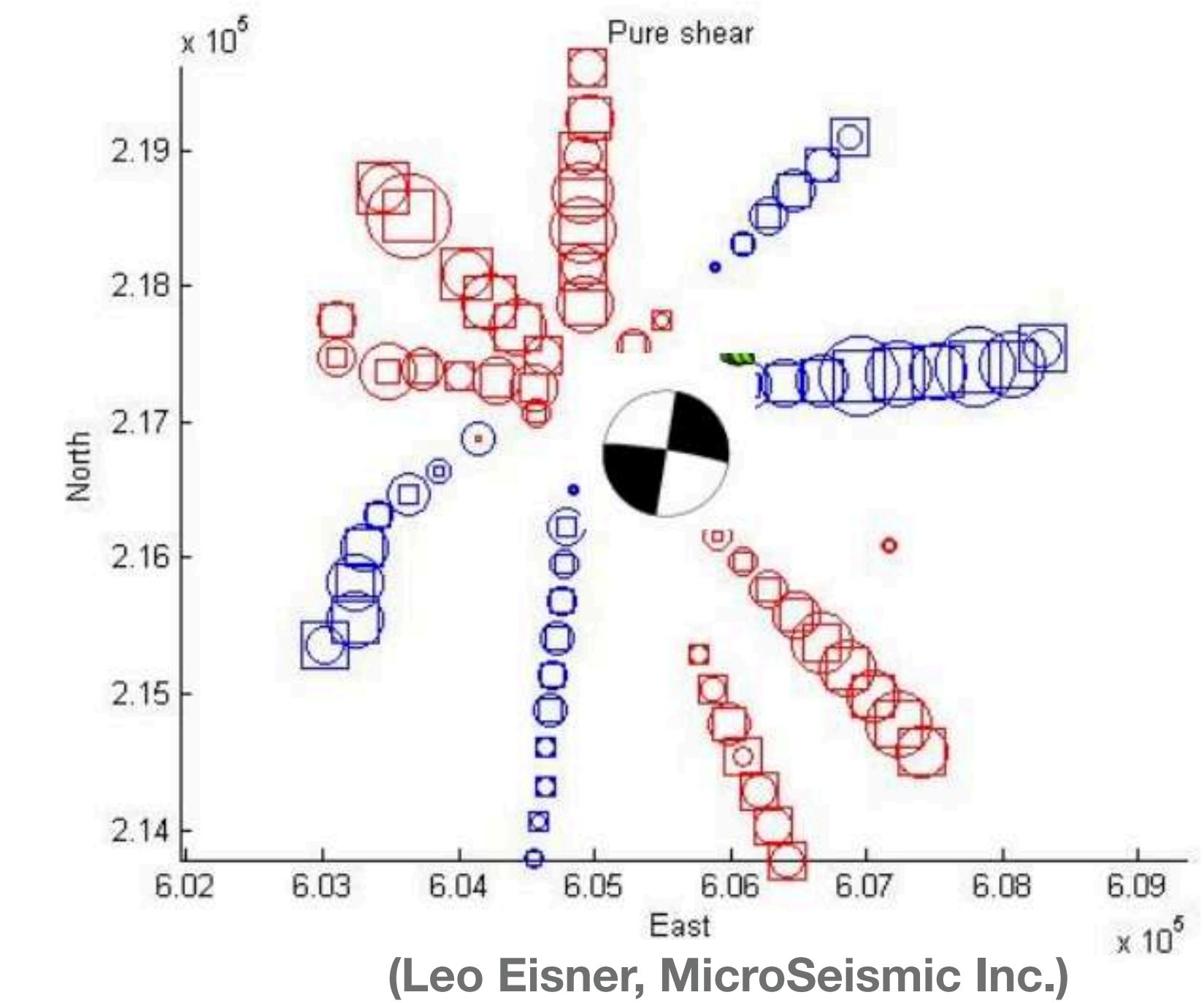


Microseismic acquisition design

Borehole



Surface



Multi-well borehole acquisition

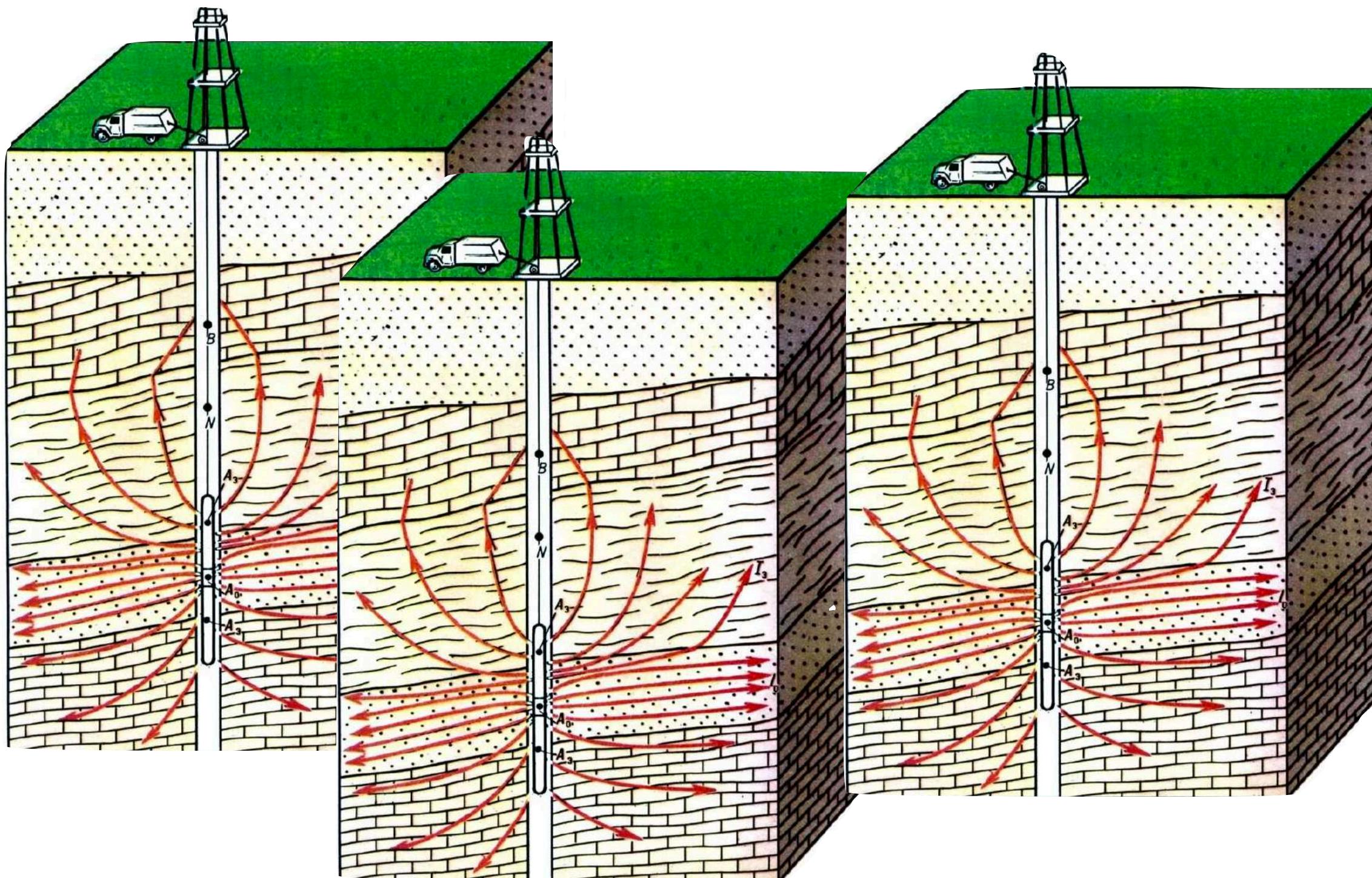


Table 1 Number of components of M recoverable in isotropy

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

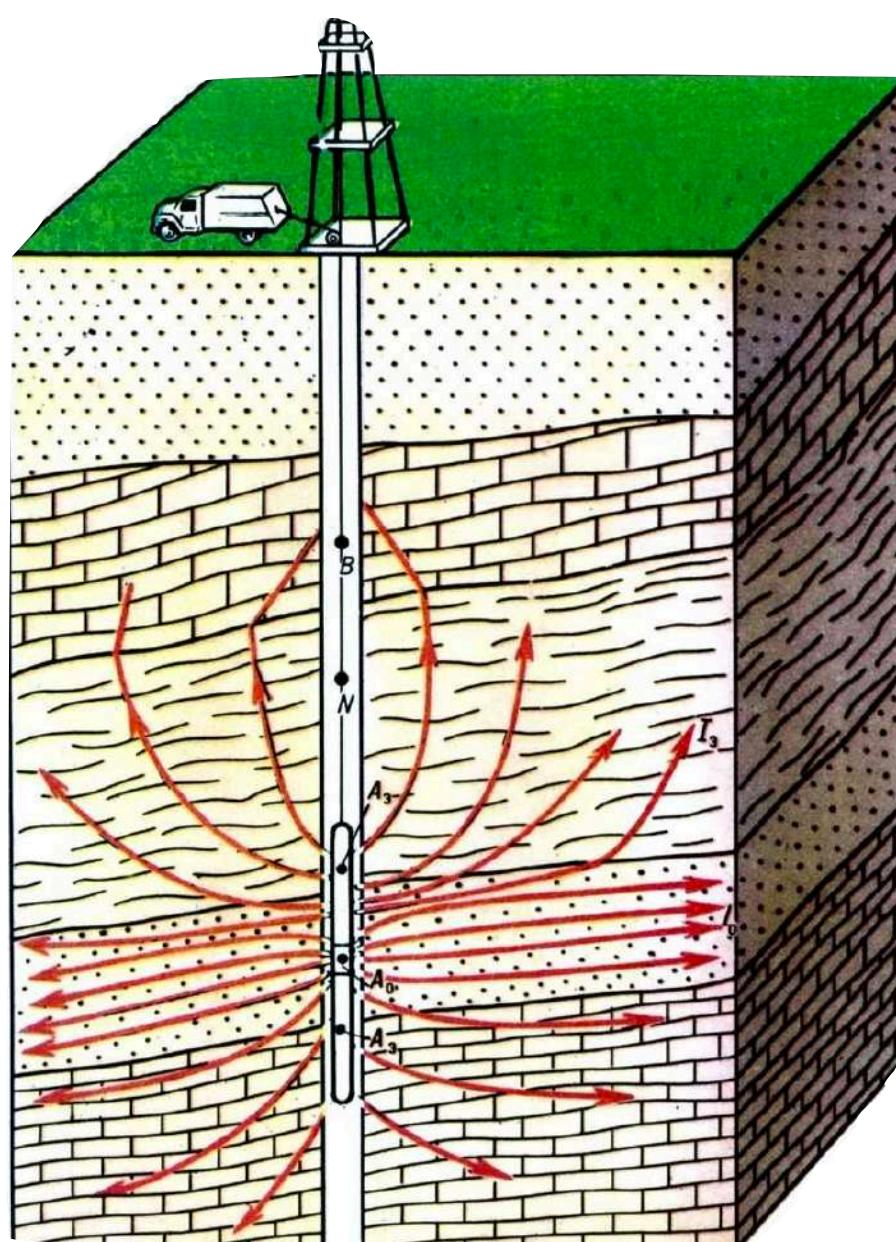


Table 1 Number of components of \mathbf{M} recoverable in isotropy

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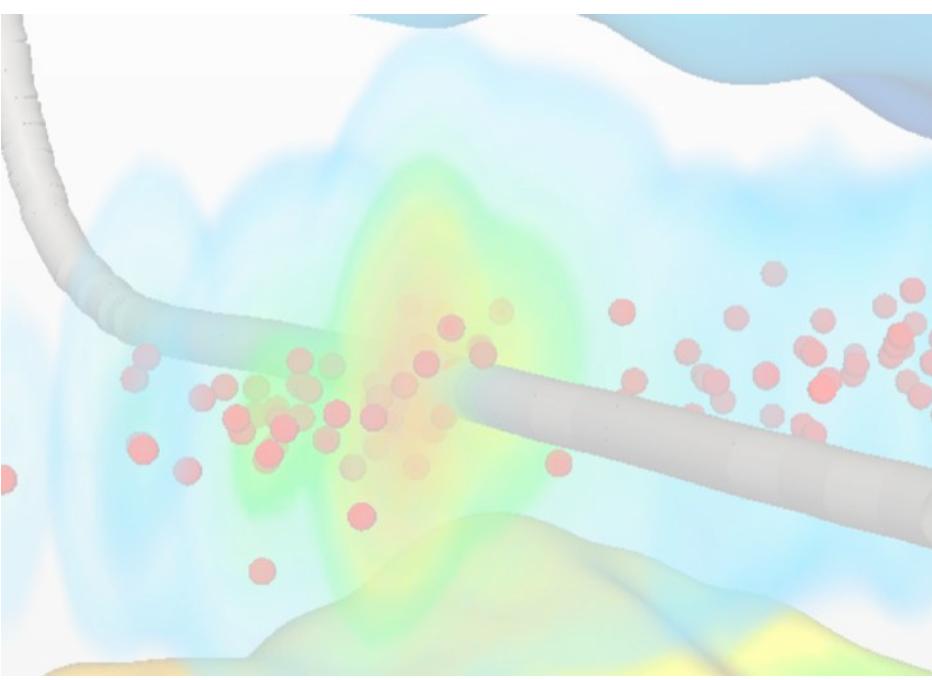
Up to 5 moment tensor components could be resolved with conventional P+S arrival inversions



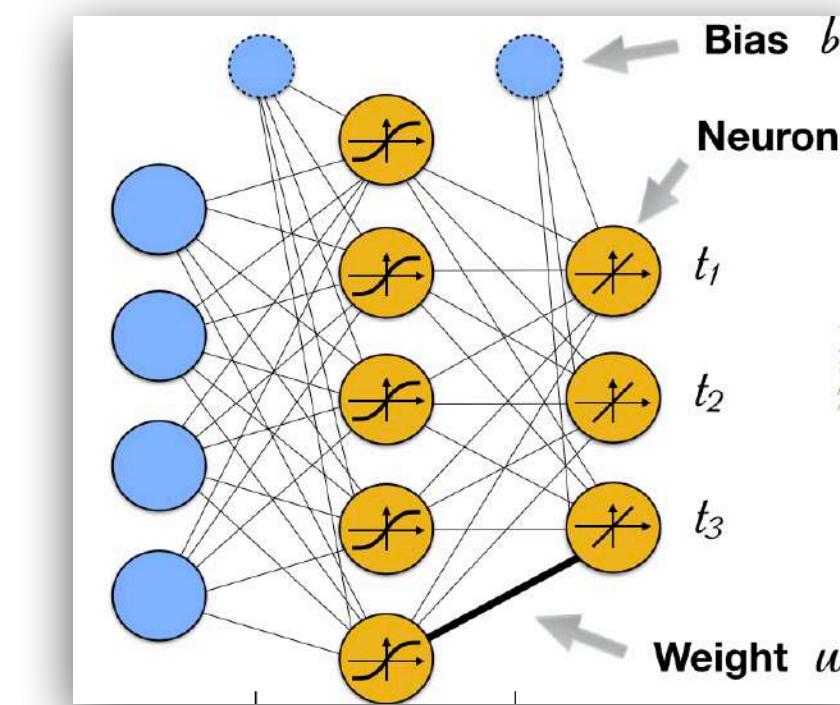
Can we retrieve the full moment tensor from a single-well acquisition
using an artificial neural network?



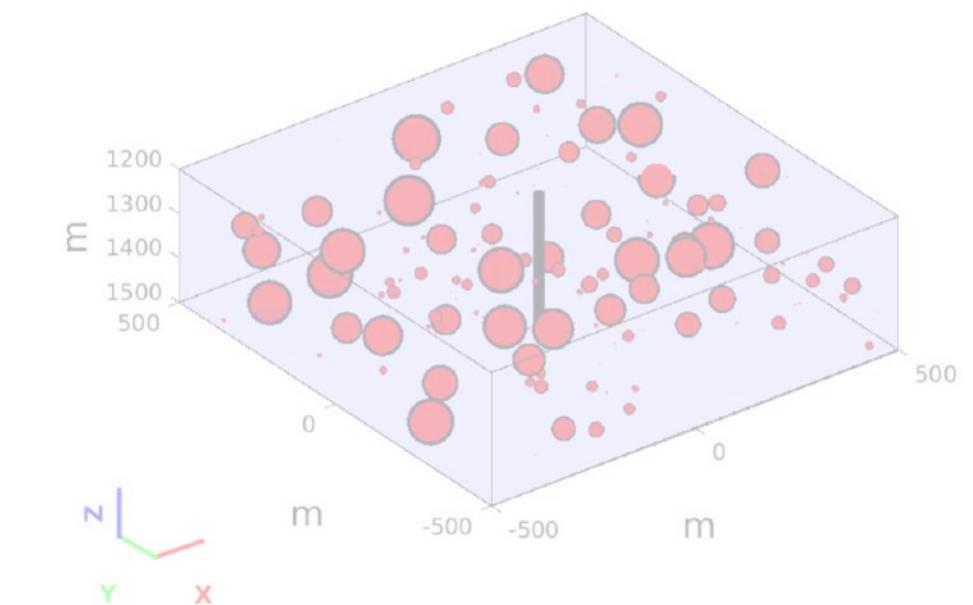
Single-well data



Artificial Neural Network



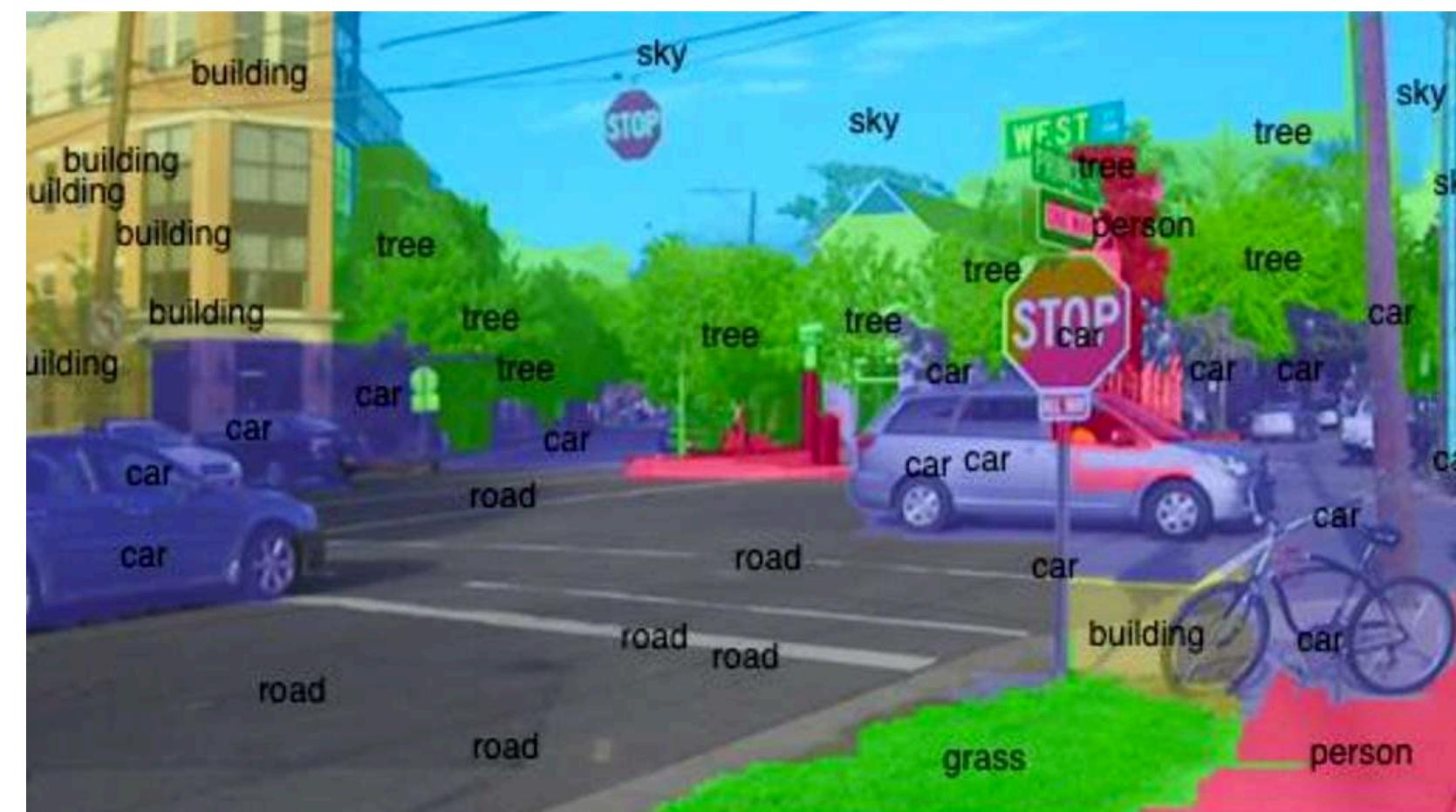
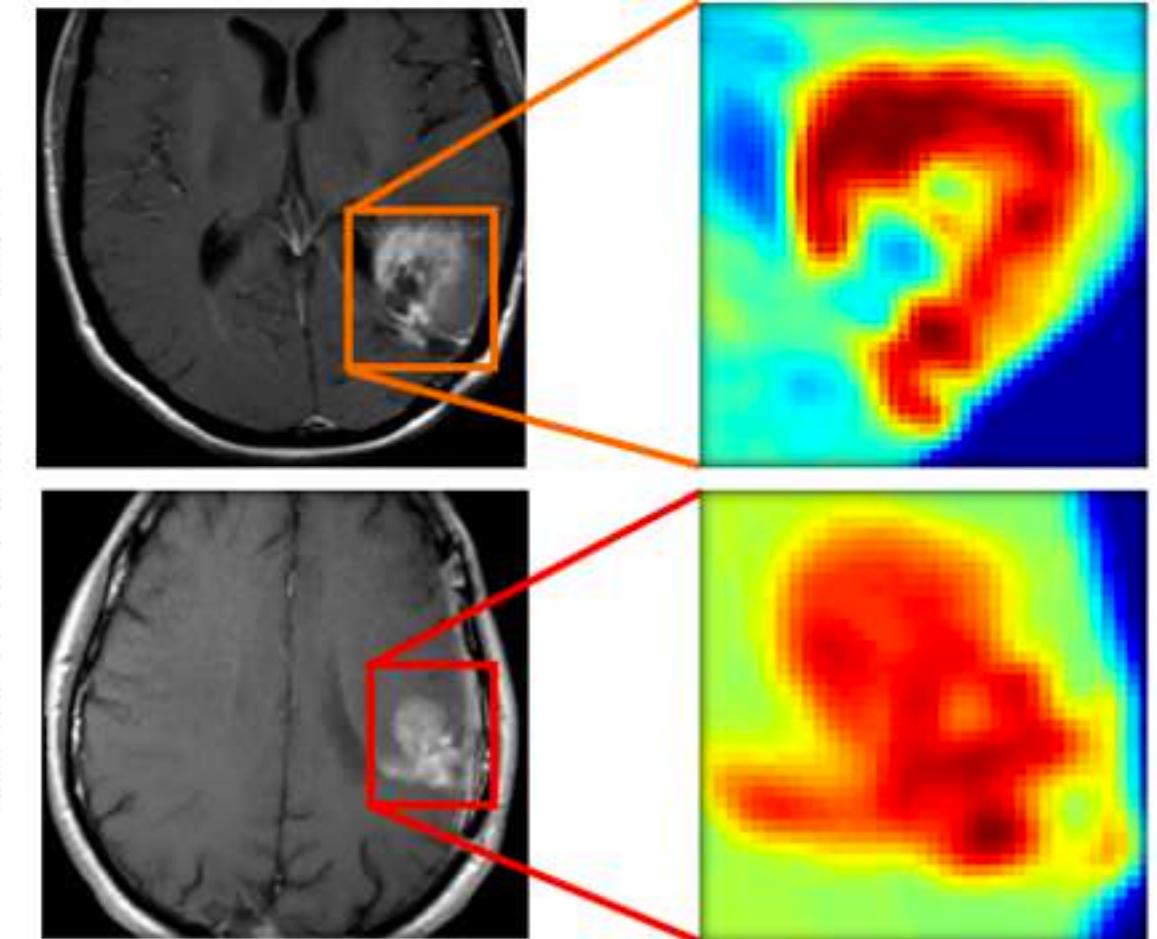
Example in a homogeneous model



Machine Learning



DIAGNOSTICS



Neural Networks pros and cons

Pros

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

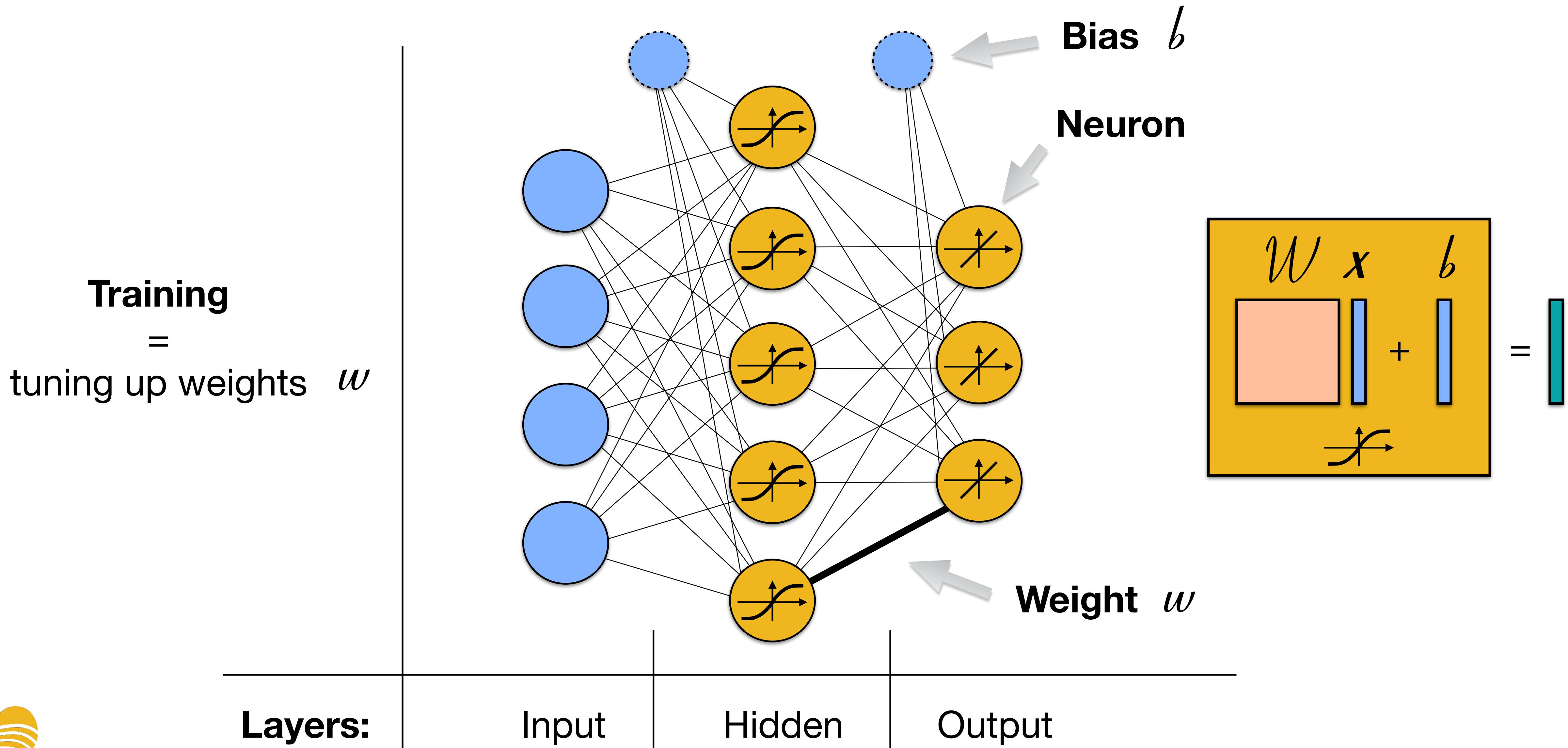
Cons

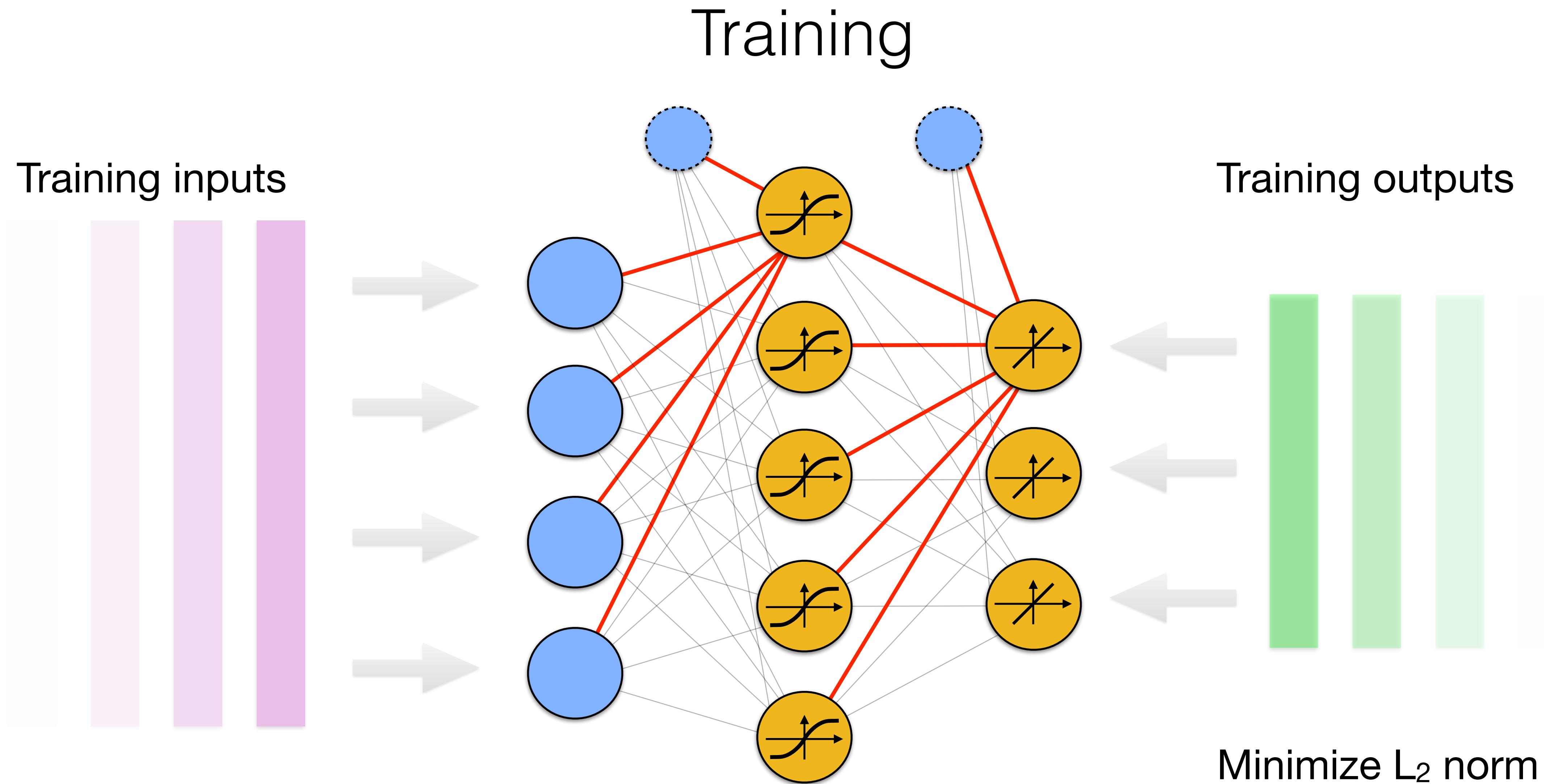
- Lots of parameters
- Hard to interpret
- Computational costs

Not a magic wand, use with care



Neural network architecture

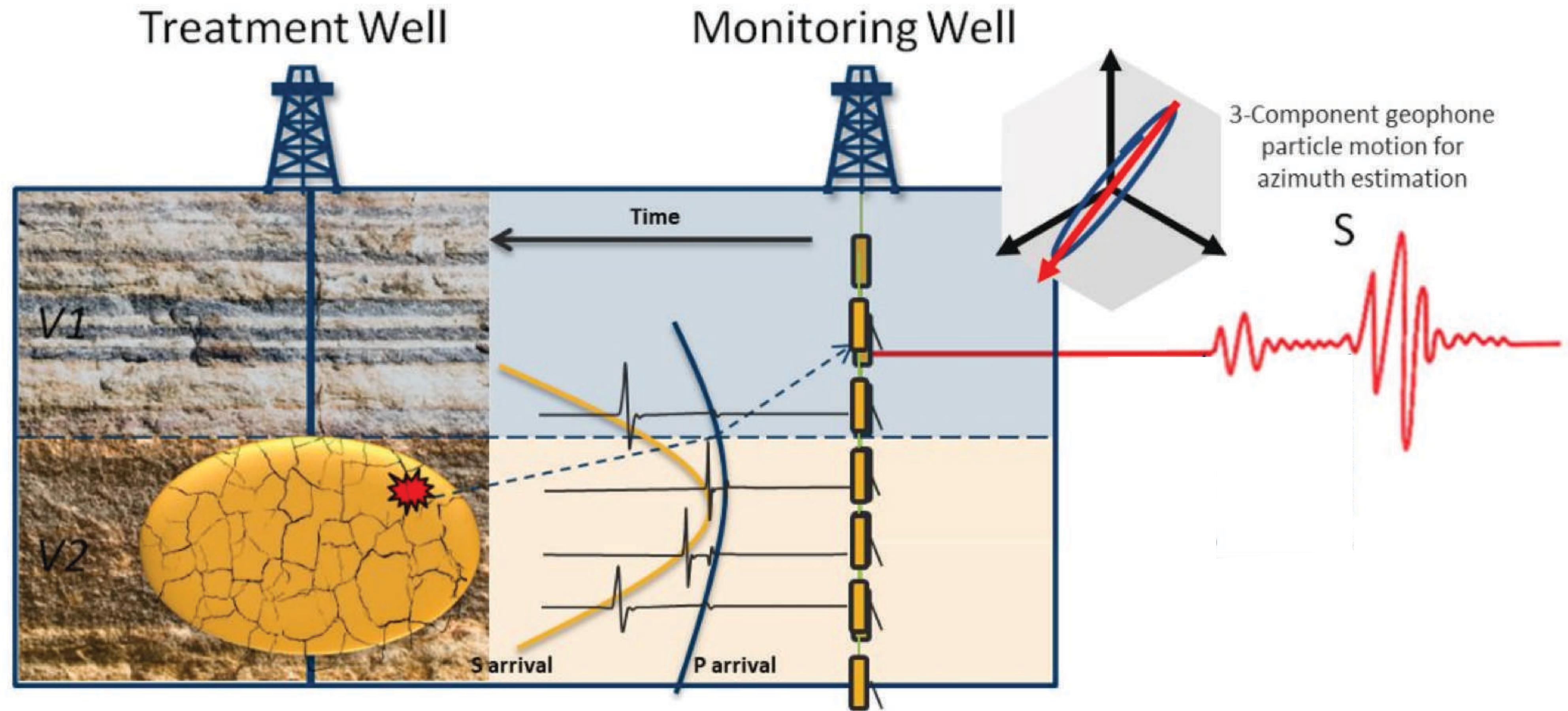




Neural networks require training with multiple inputs



Data generation



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



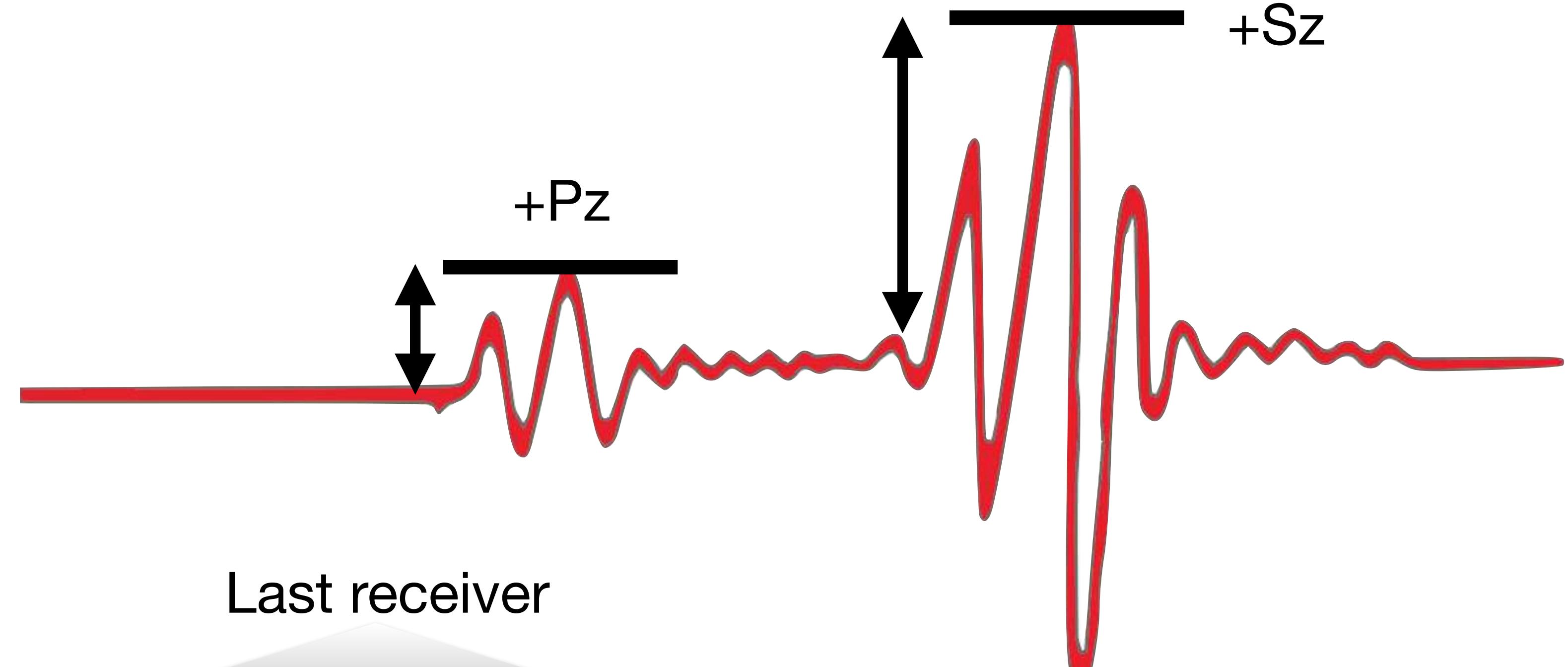
Input data

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

3-component receivers

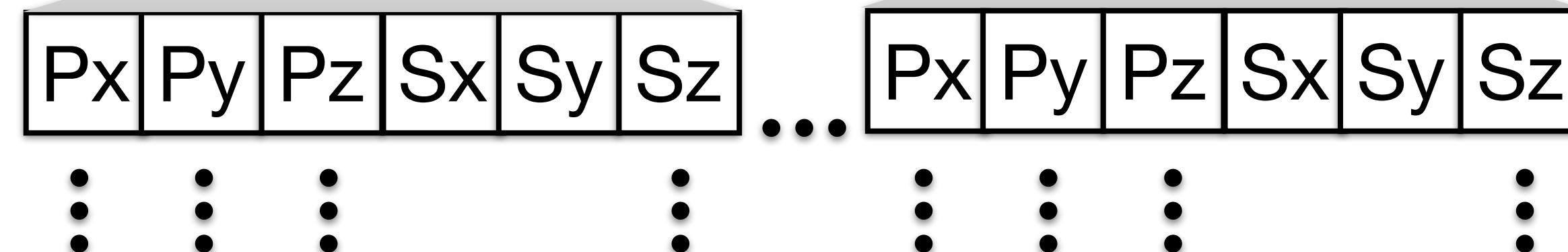
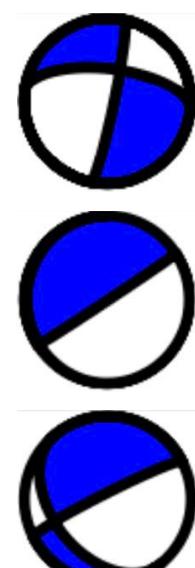
2 types of waves (P and S)

$3 \times 2 \times NREC$



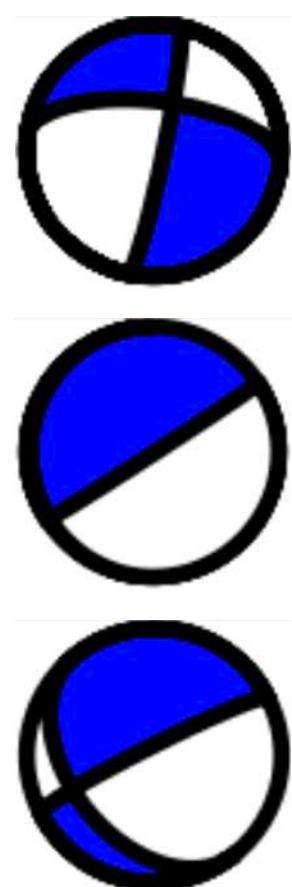
First receiver

Last receiver

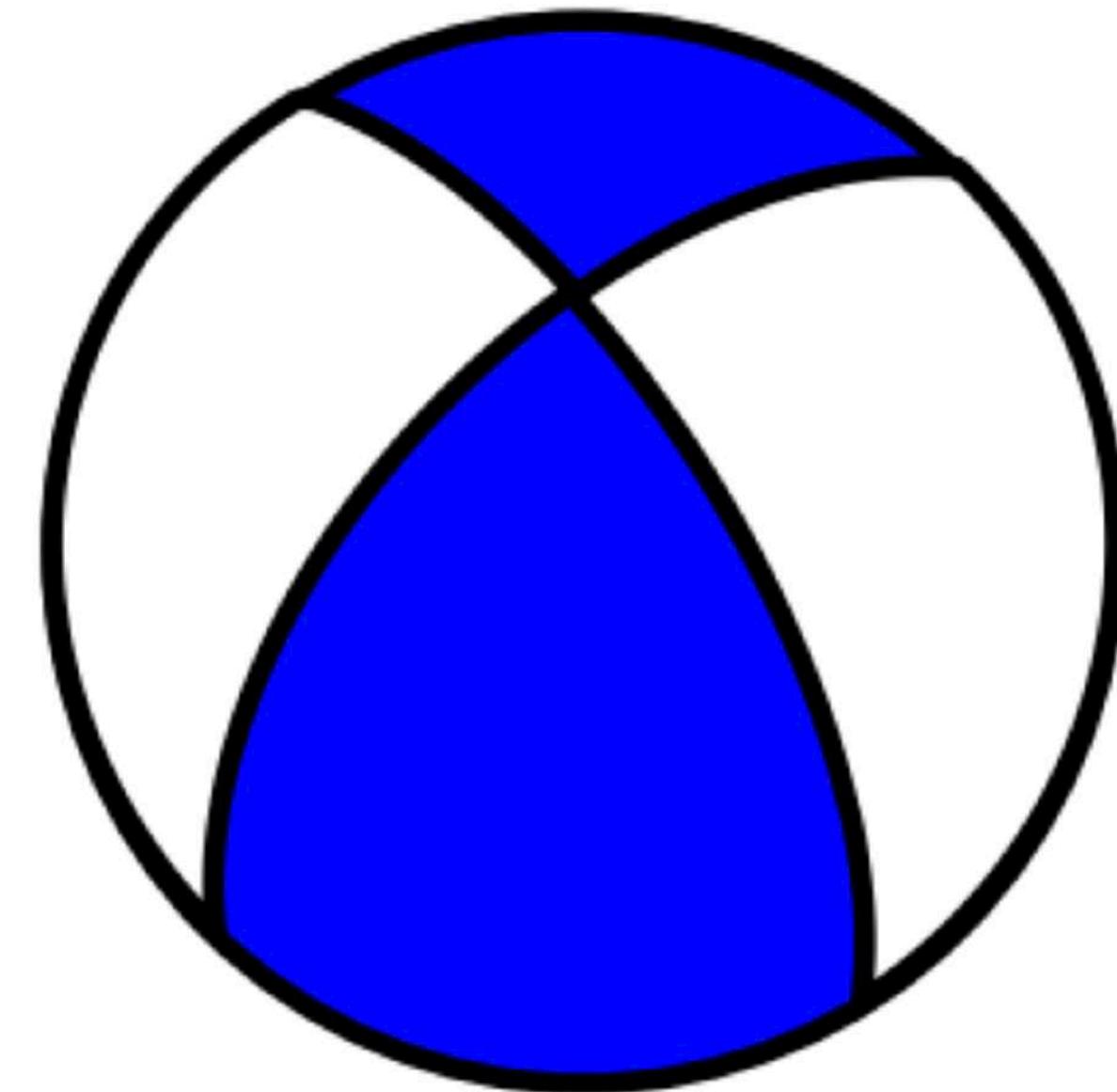


Output data

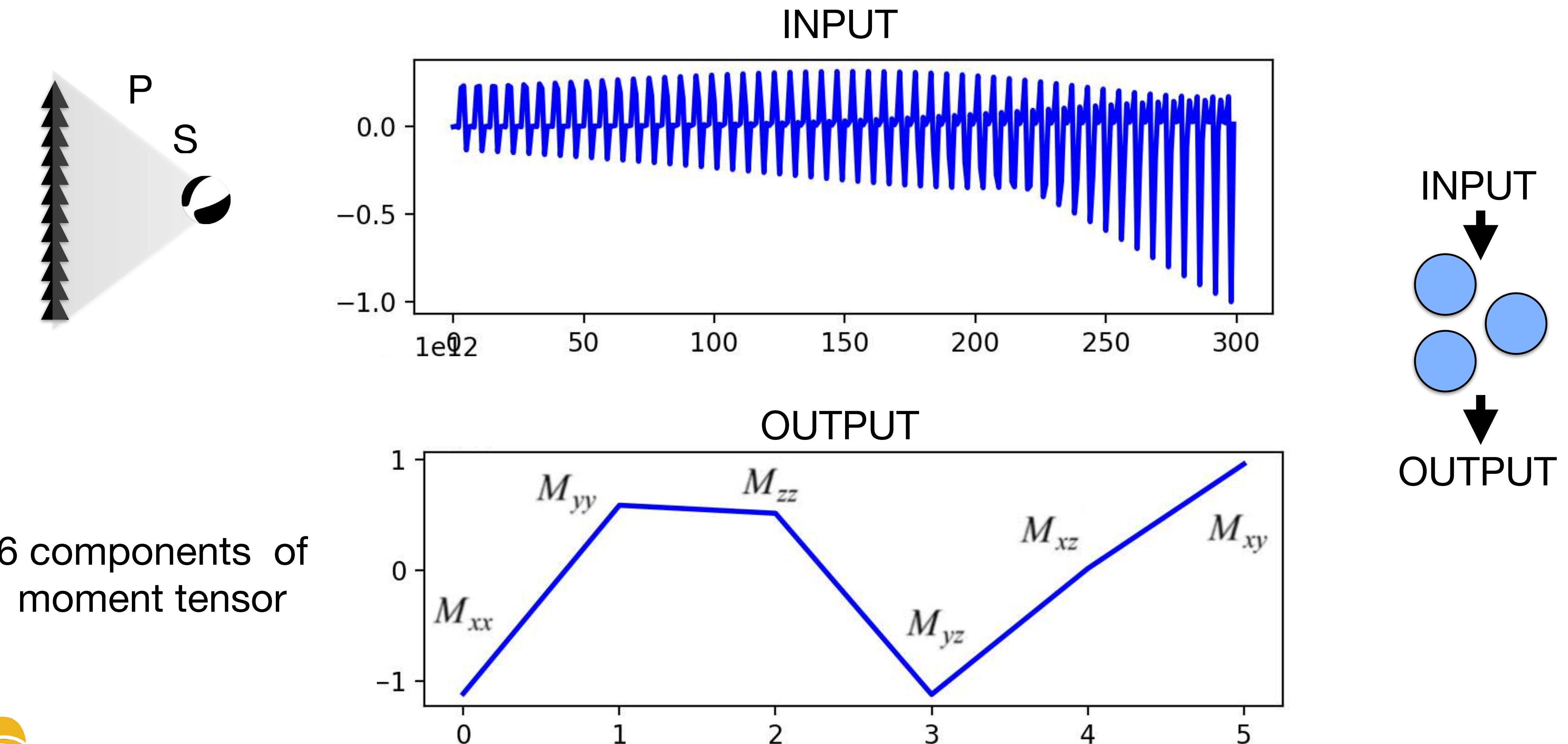
6 components of moment tensor describing source mechanism



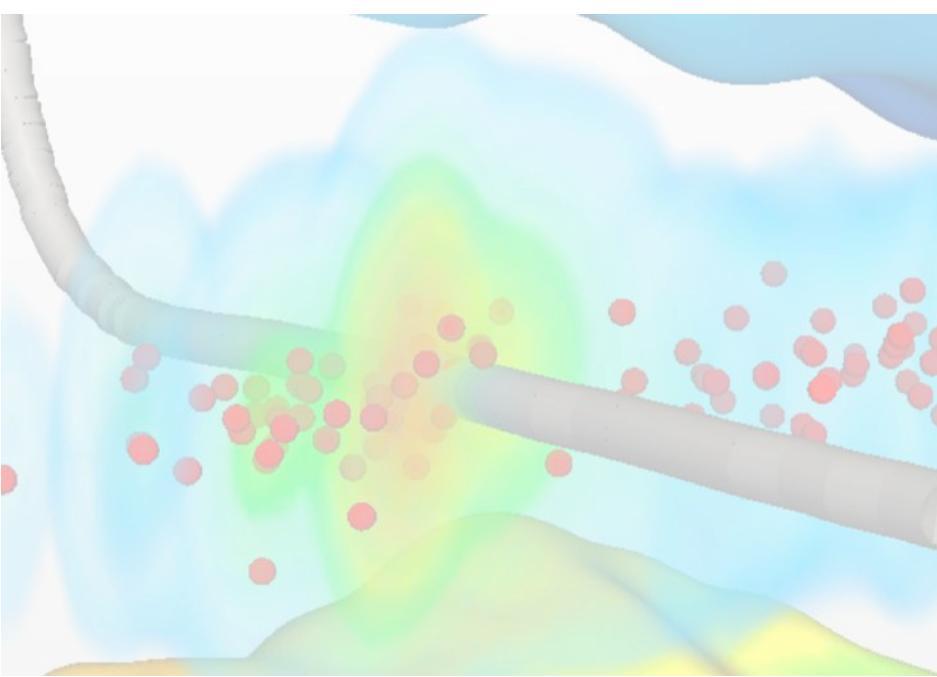
Mxx	Myy	Mzz	Myz	Mxz	Mxy
⋮	⋮	⋮		⋮	⋮



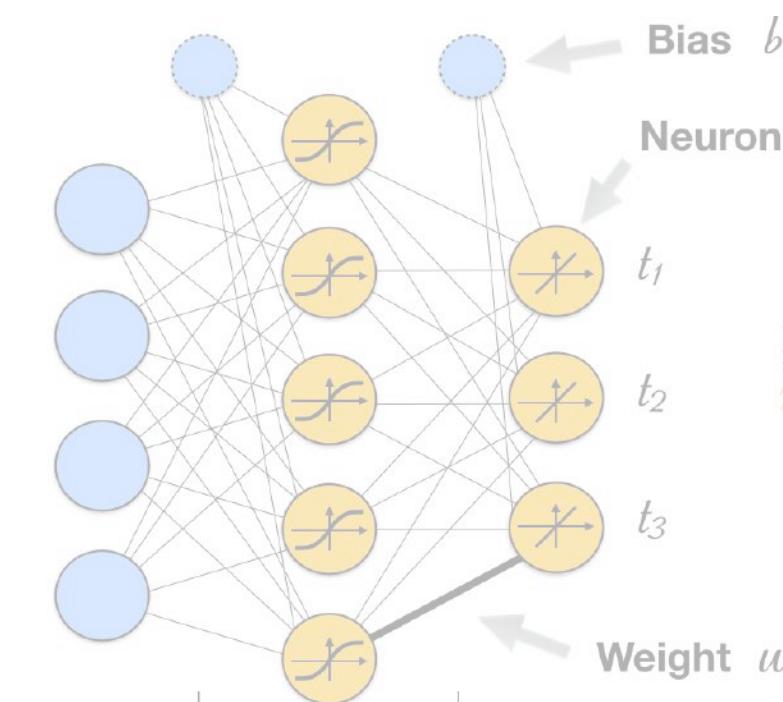
Single pair of training data



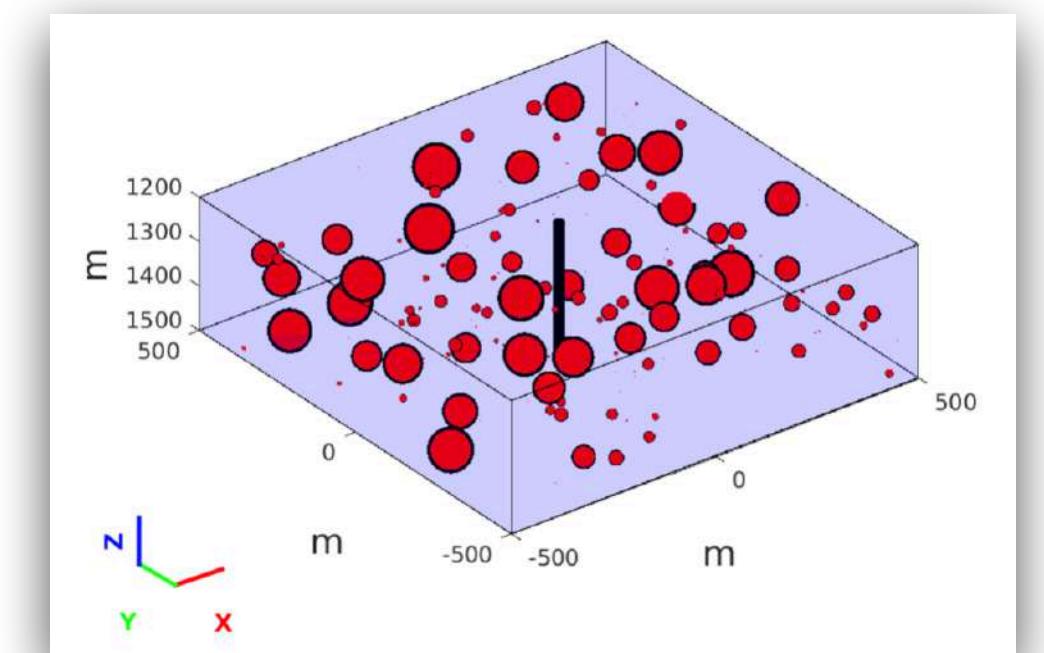
Single-well data



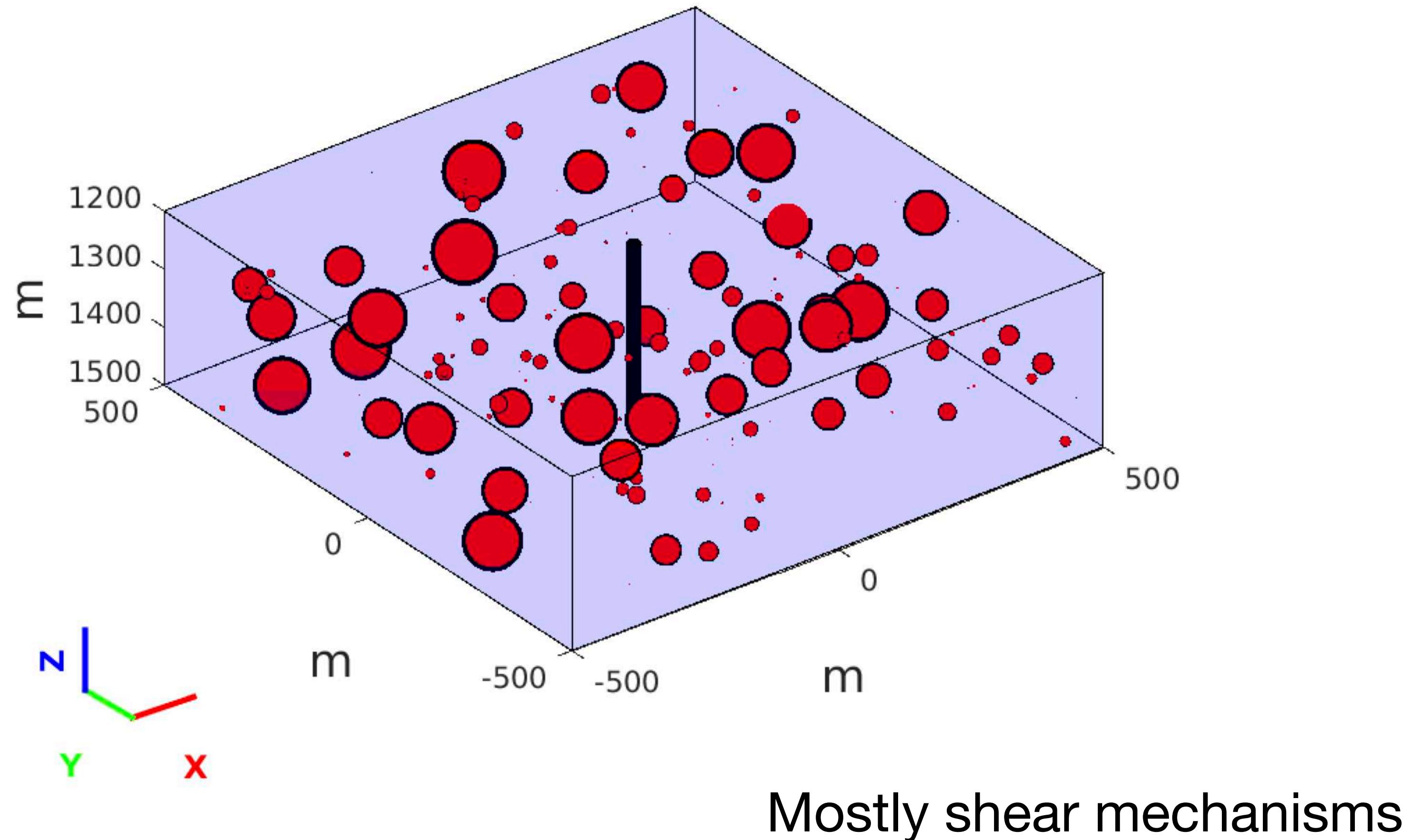
Artificial Neural Network



Example in a homogeneous model



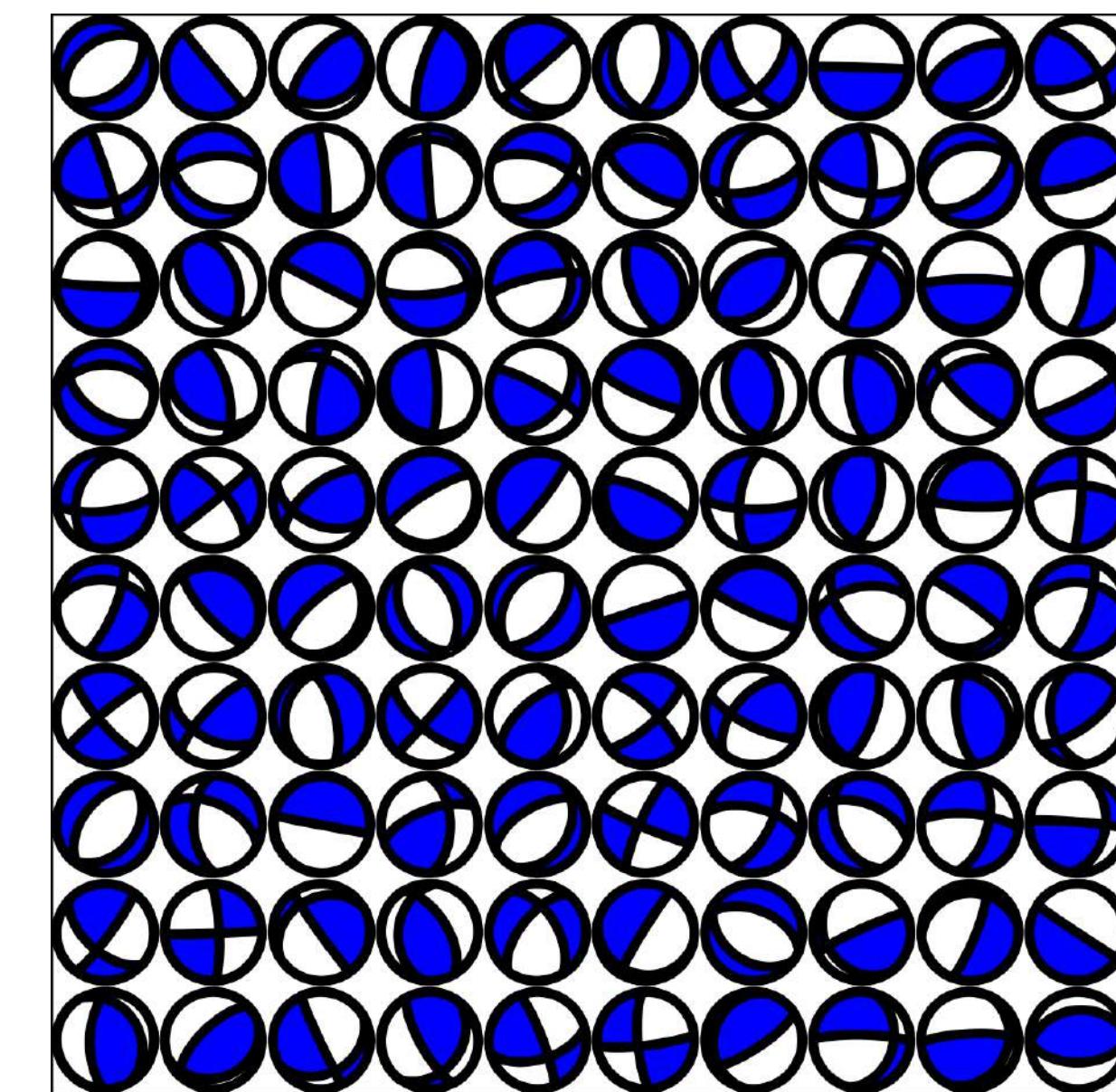
Homogeneous medium



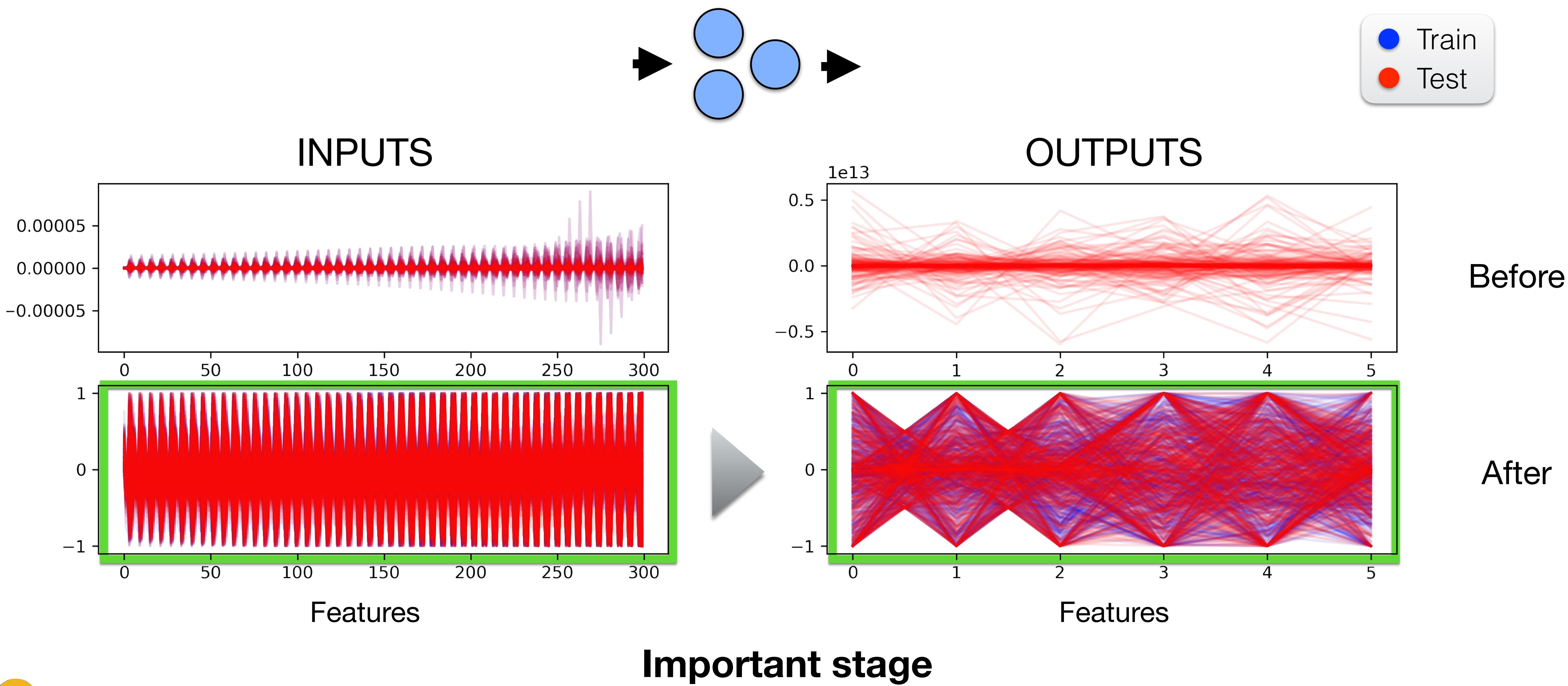
Synthetic data

$N = 8000$ events

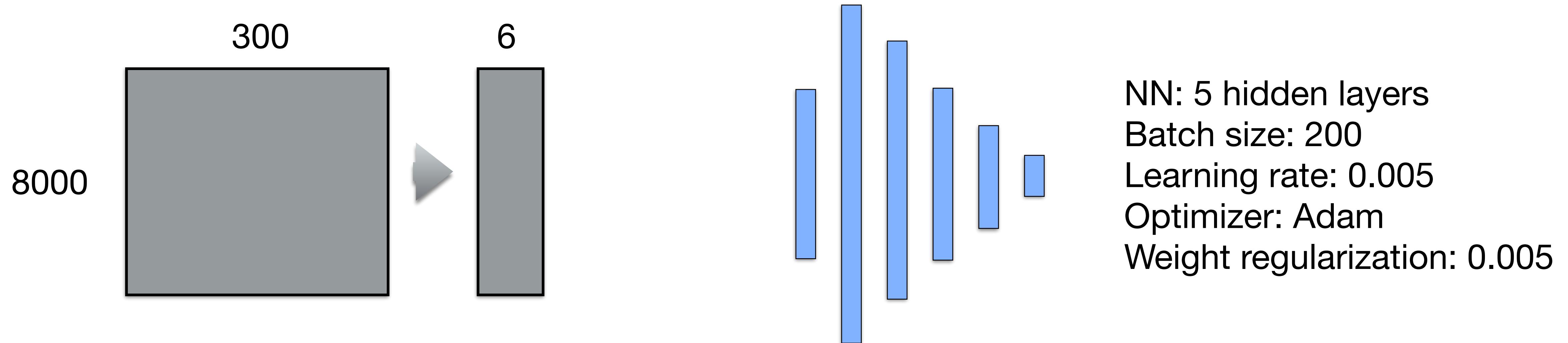
$M = -3 \dots 0$



Data normalization



Computational facts



Initialization “xavier”
(Glorot & Bengio, 2010)

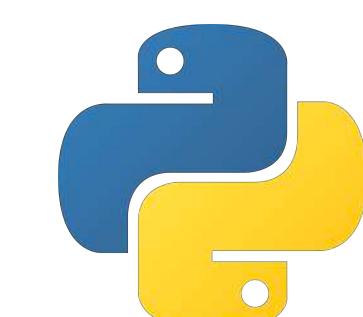
Training data generation
~ 2 min on 24 cores

Training time ~ 5 min
Prediction time < 1 sec

Matlab R2016b



Python 3.6



TensorFlow 1.3.0



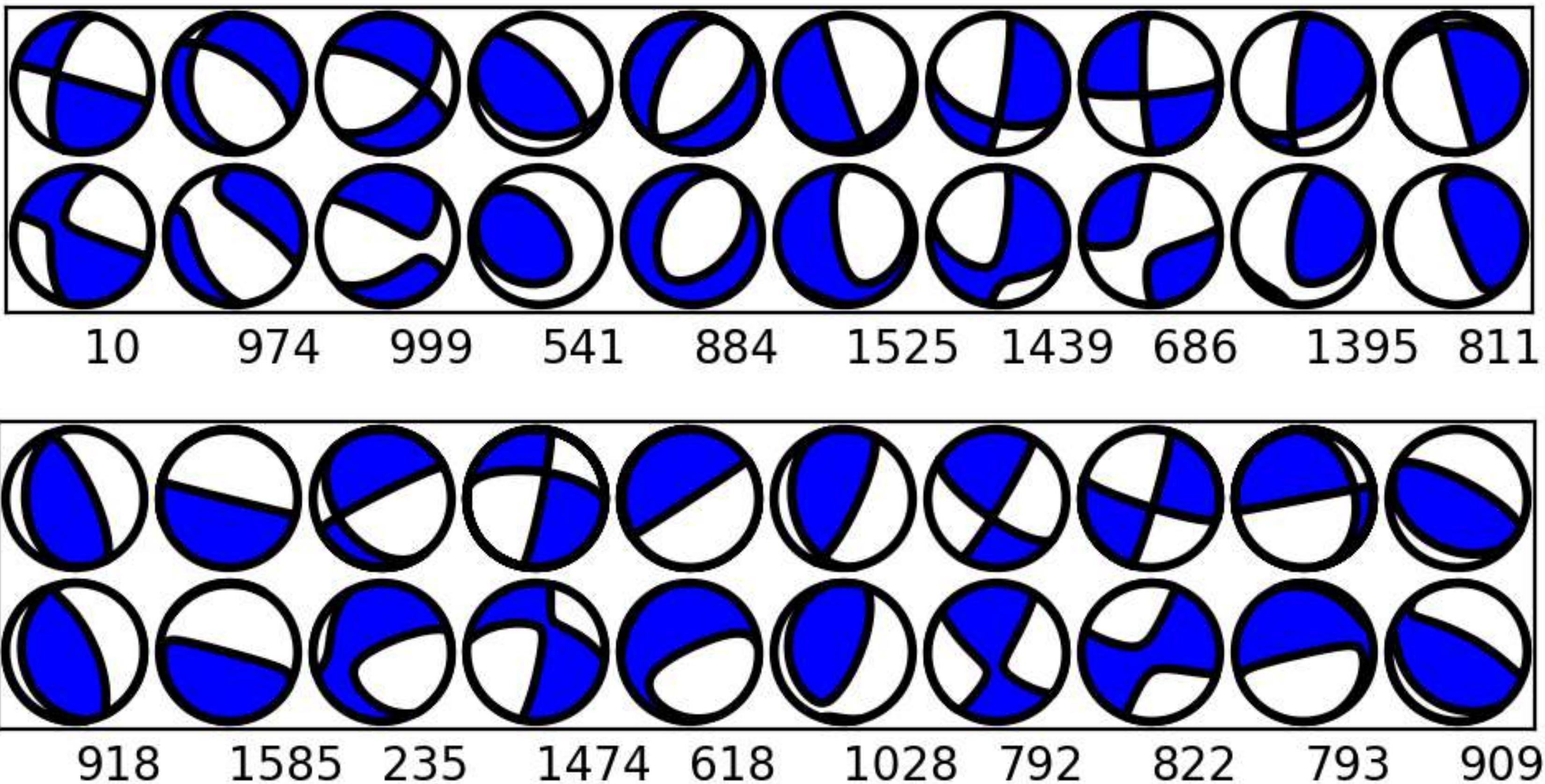
Keras 2.0.5



Obspy



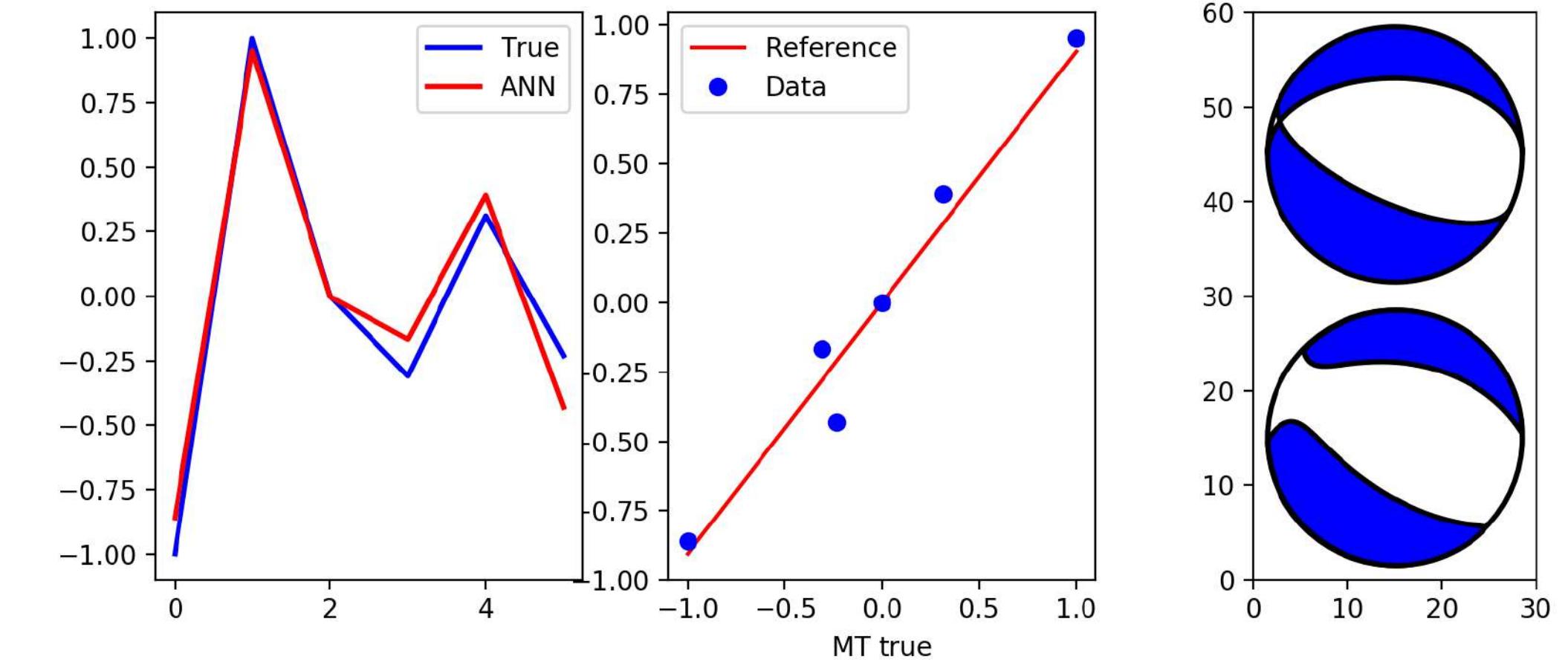
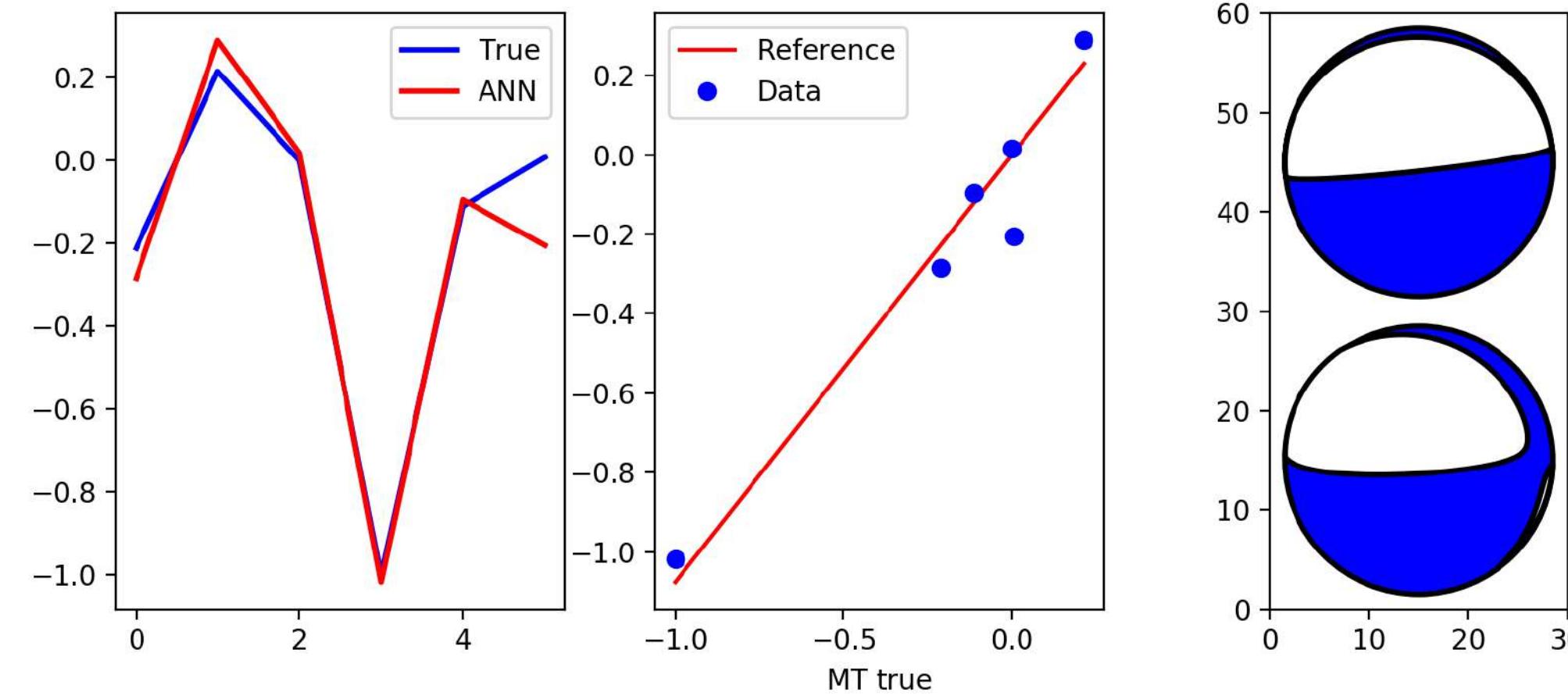
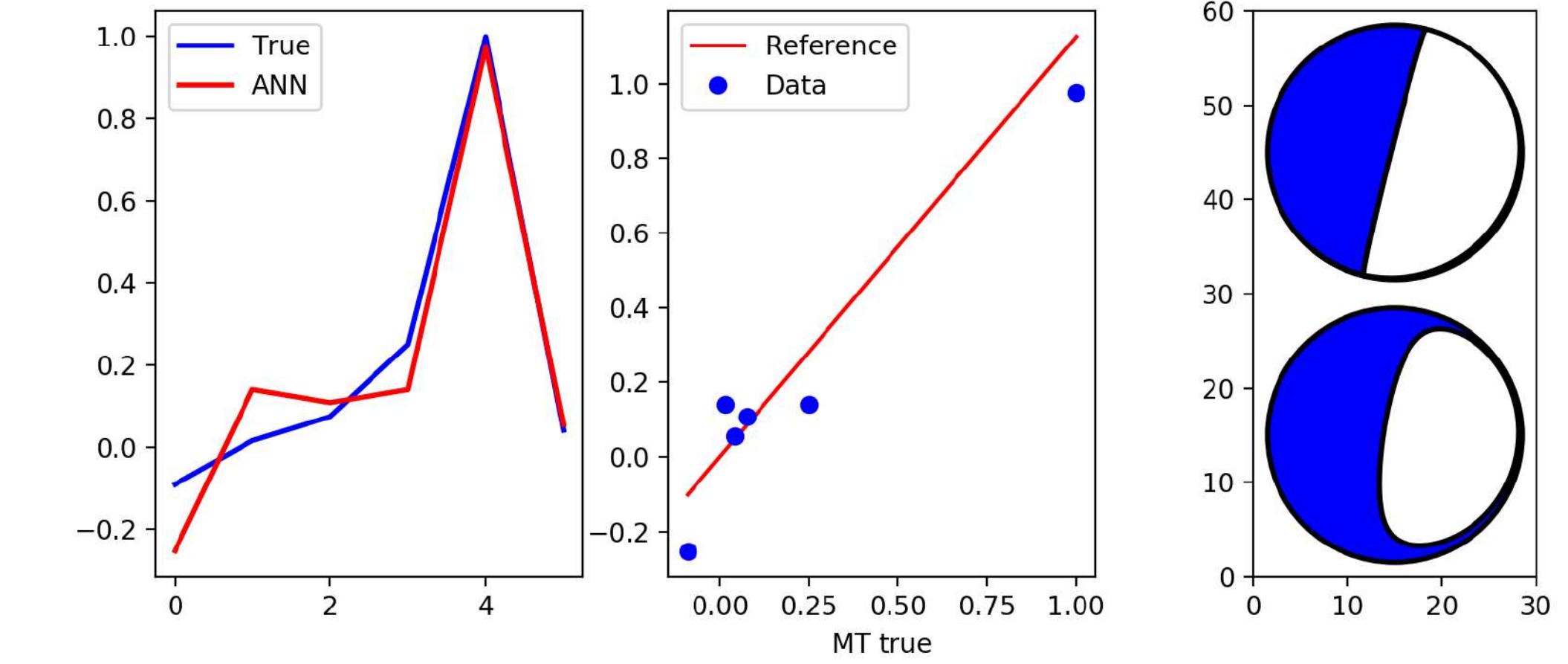
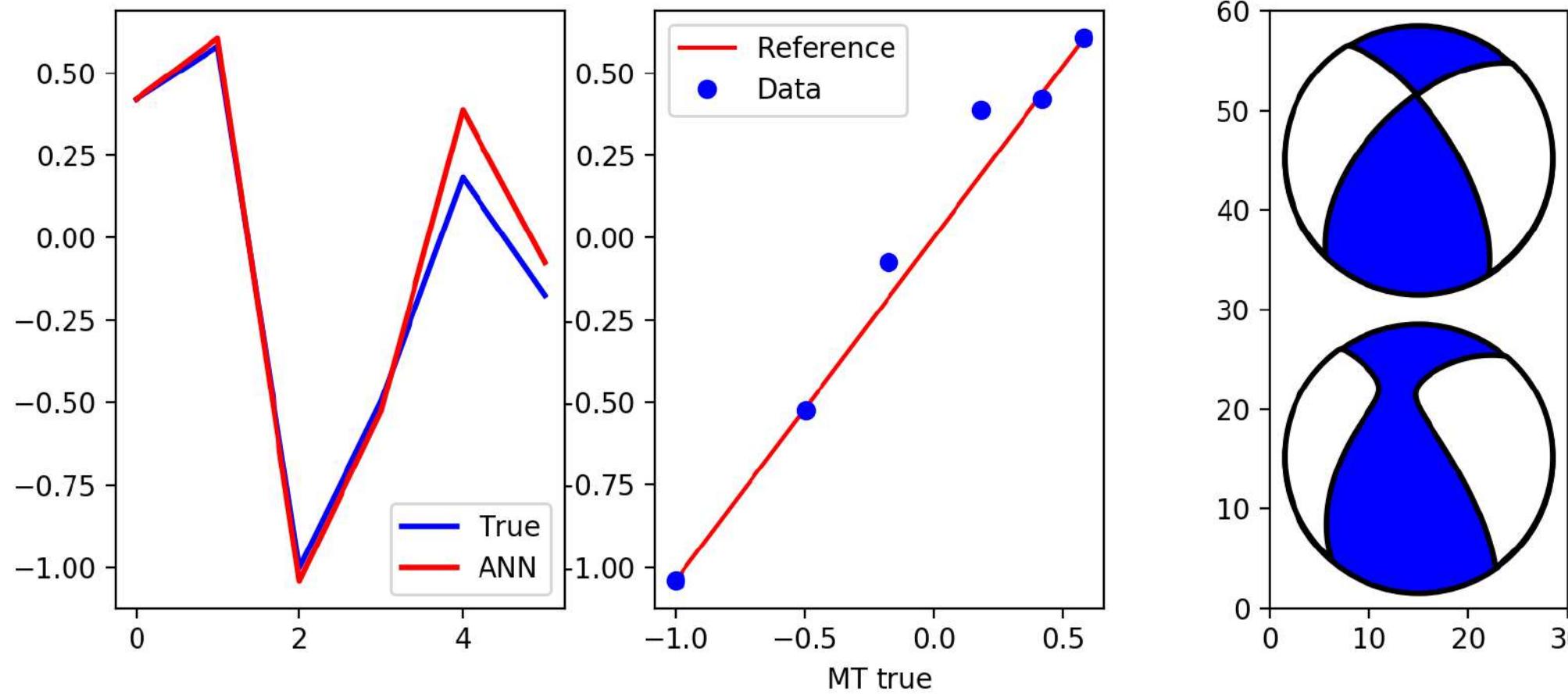
Detected focal mechanisms



Neural network never
seen these data before



Detected focal mechanisms



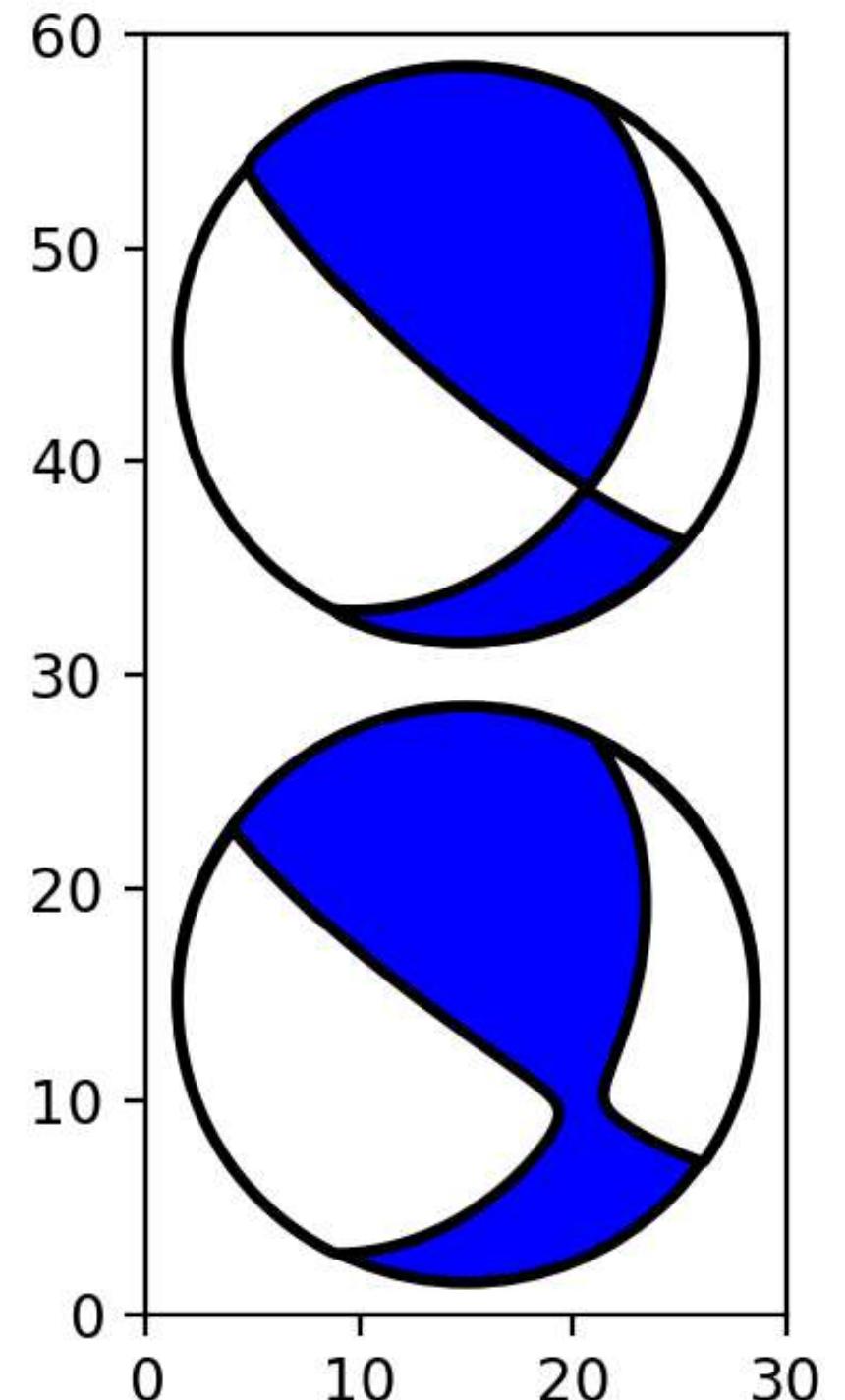
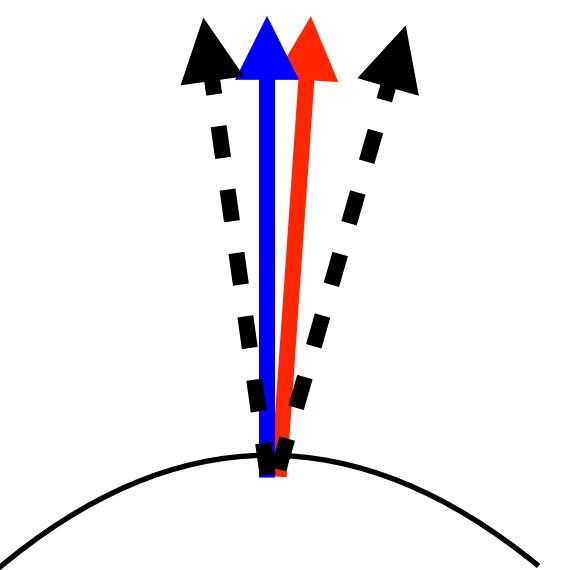
Analysis

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

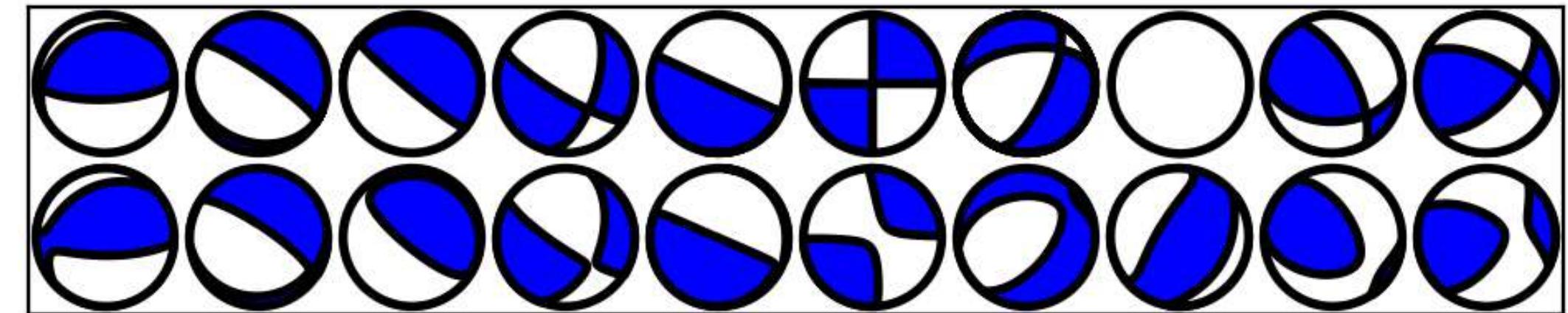


Conclusions

- 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

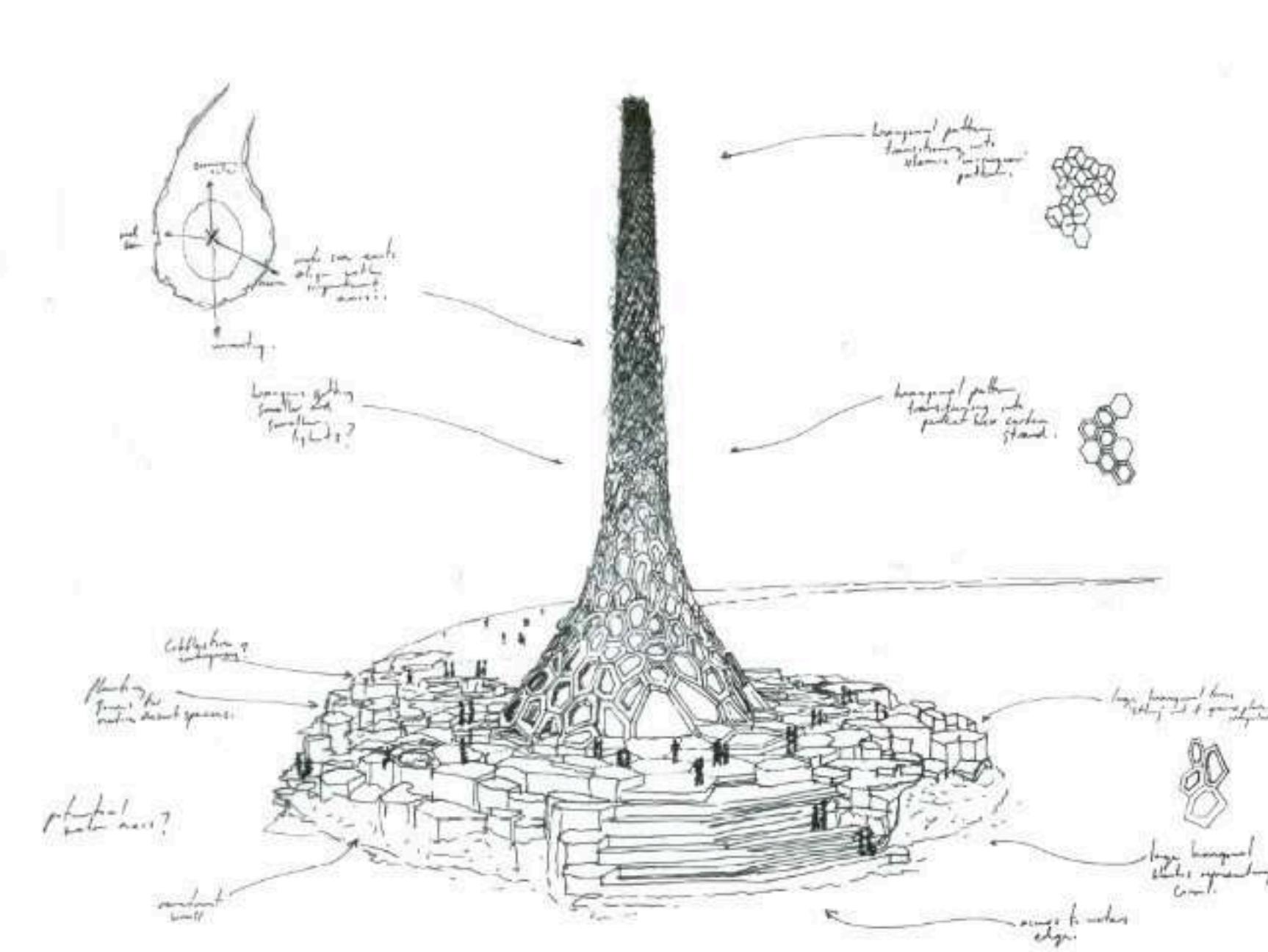
Future work

- Quantitative comparison
- Seismic moment
- Realistic cases



Acknowledgements

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

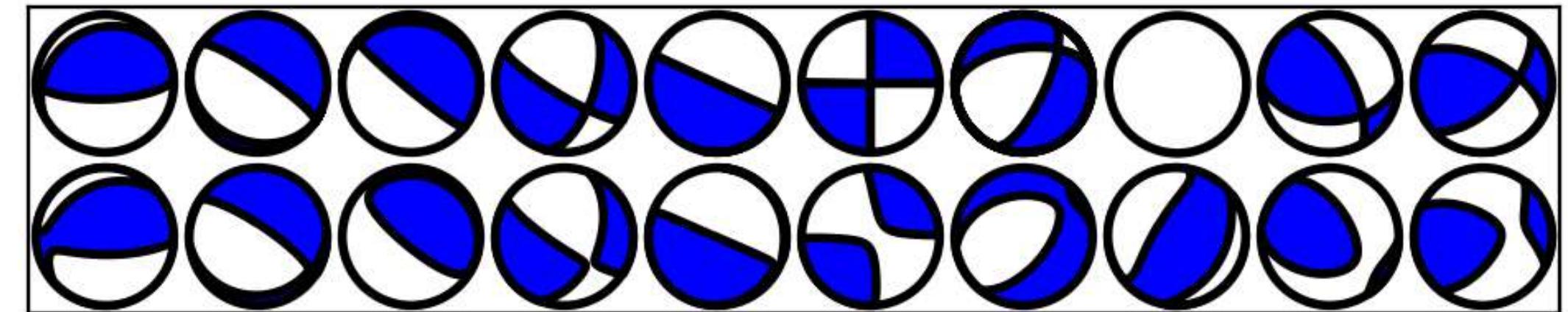


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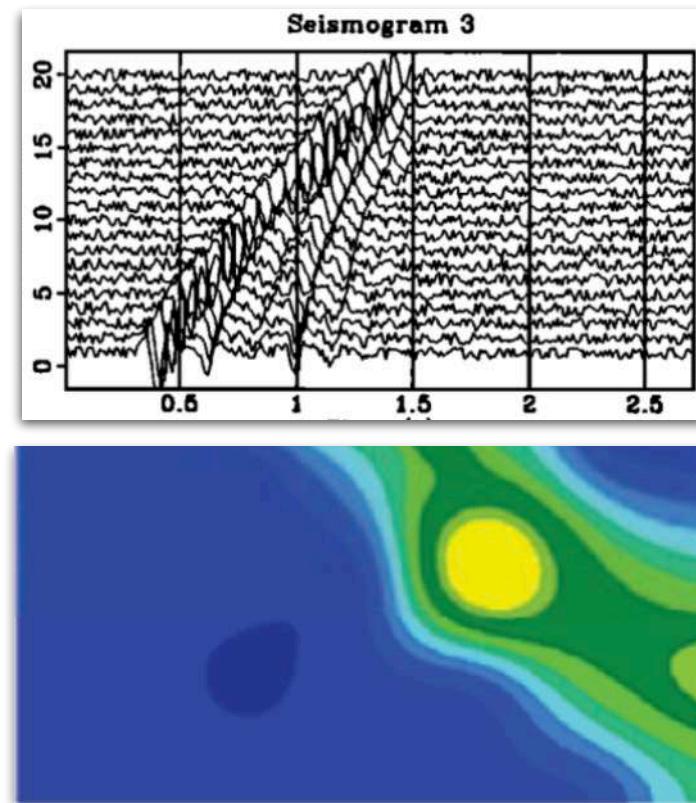
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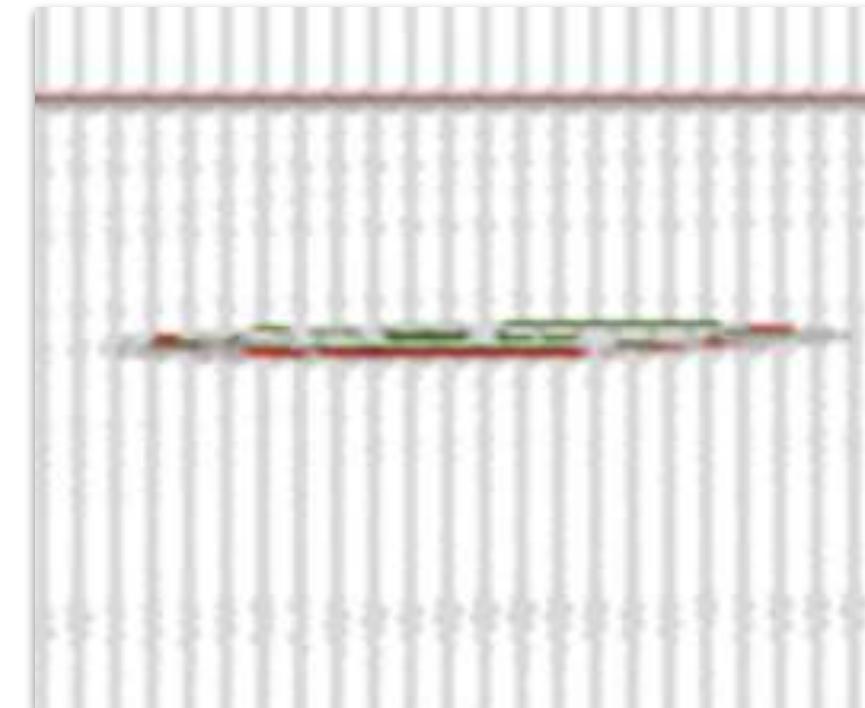


The End

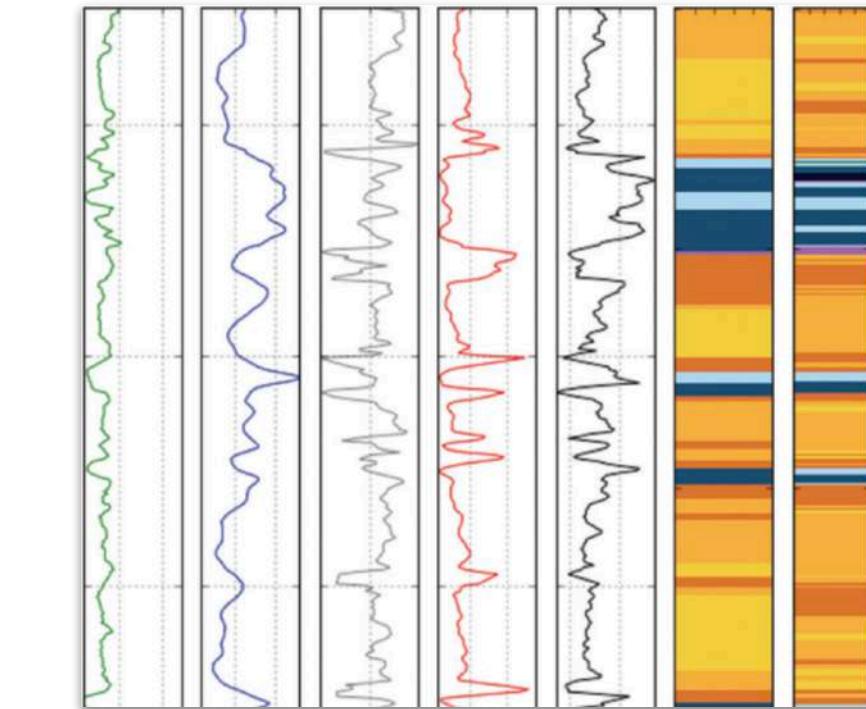
Some NN applications in geophysics



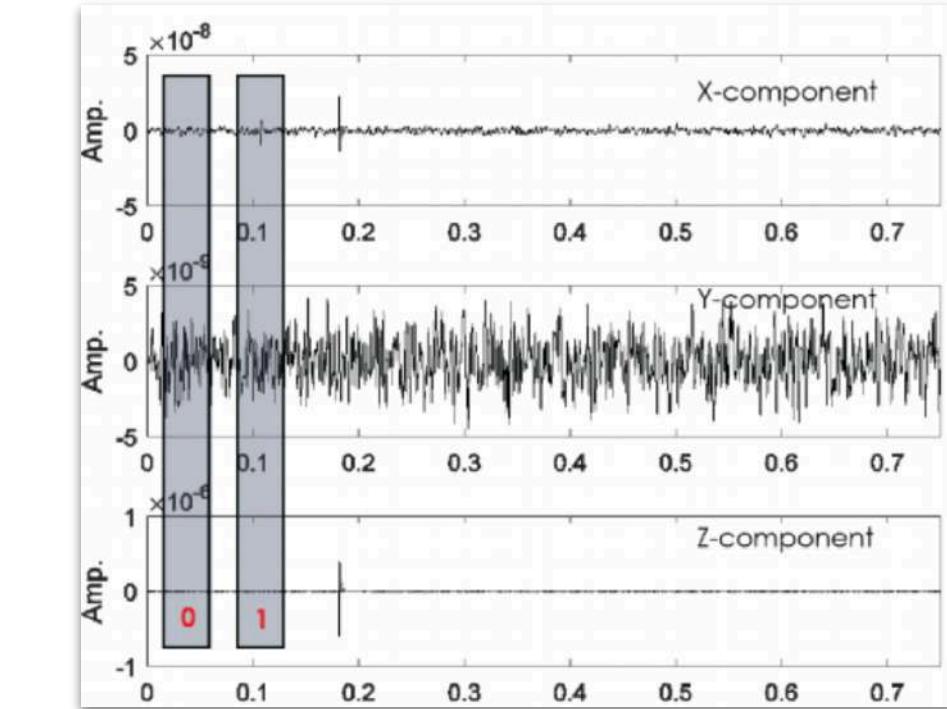
Inversion of seismic, DC data etc.
(Röth, Tarantola, 1994;
Neyamadpour et al., 2009)



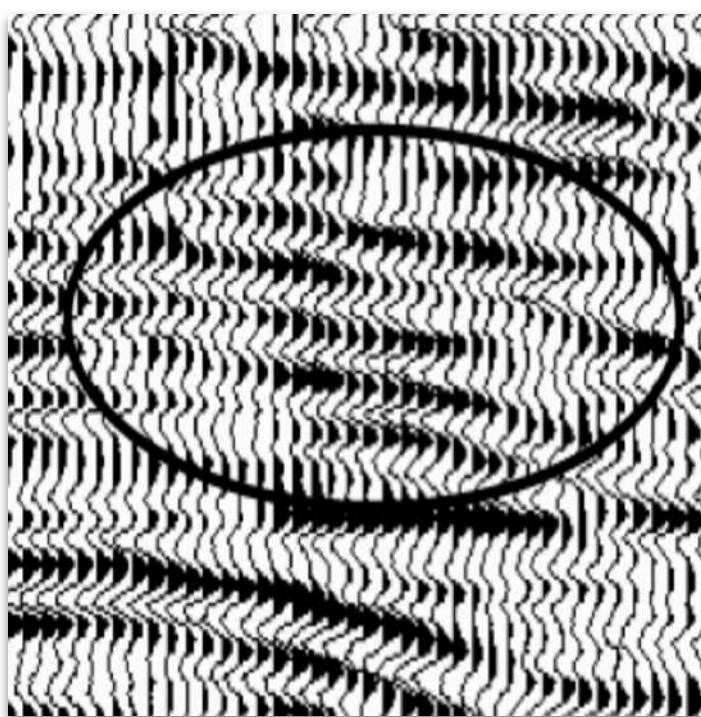
Mapping reservoirs on
migrated seismic
(Bouger, 2016)



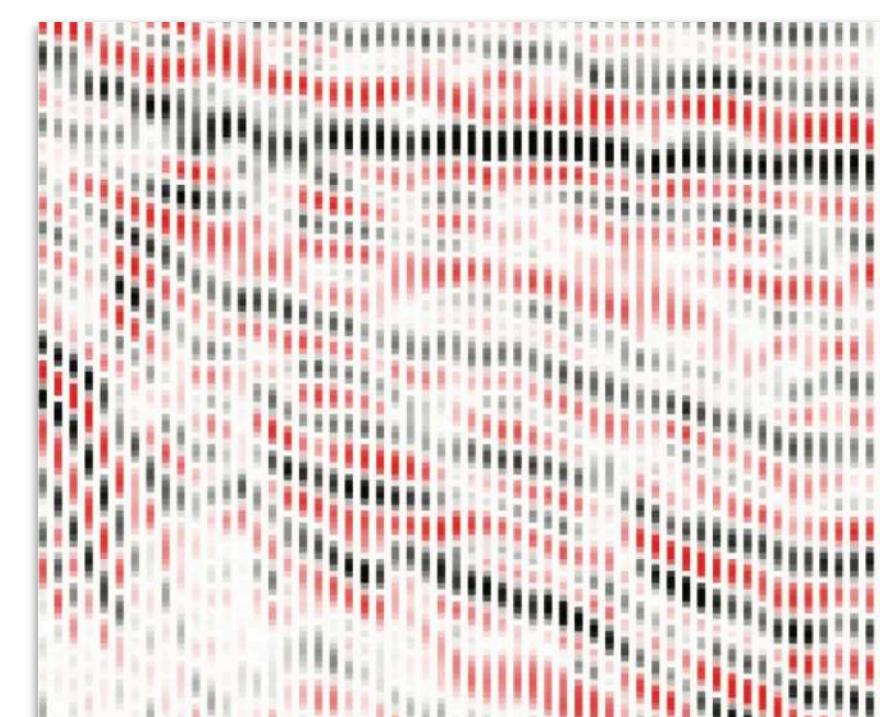
Facies classification
and reservoir properties prediction
(Hall, 2017; Ahmed et al., 2010)



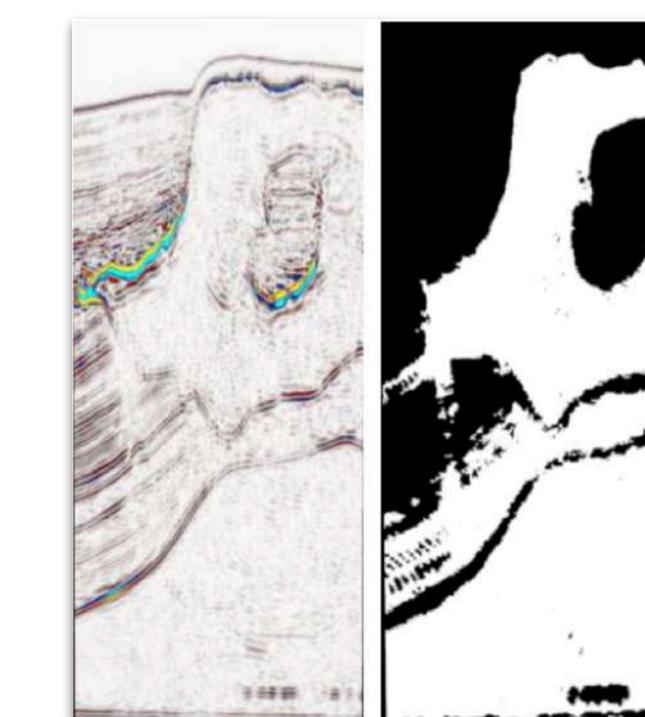
Event detection
(Akram et al., 2017)



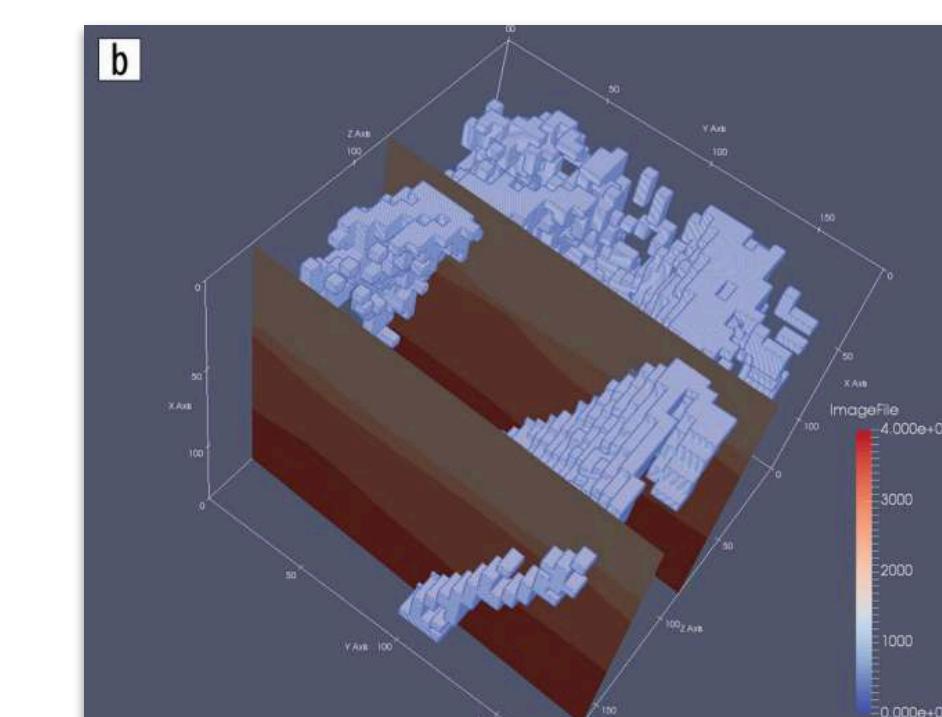
Denoising
(Zhang et al, 2017)



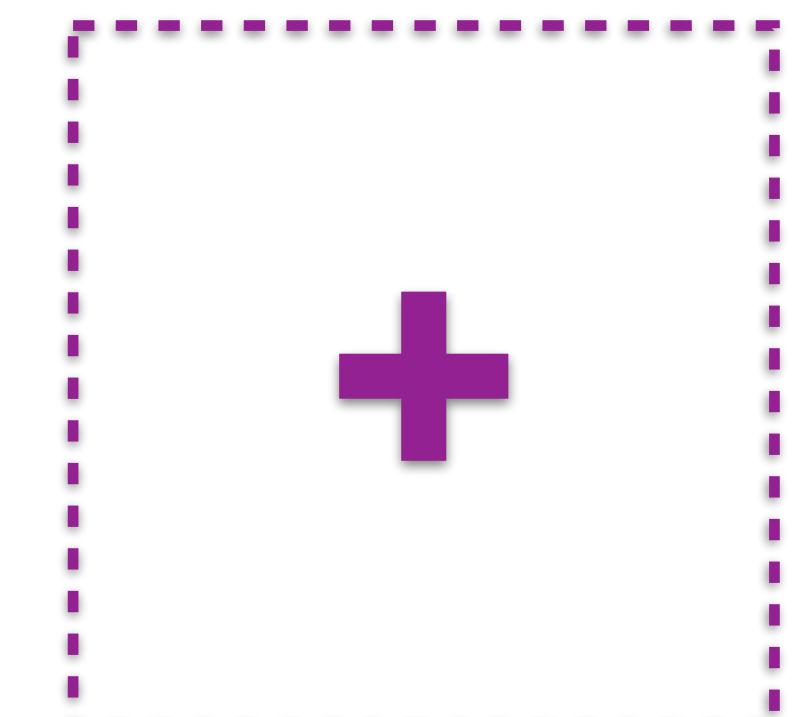
Interpolation of missing data
(Jia and Ma, 2017)



Salt body picking
(Guillen et al., 2017)



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



Bonus

