Using fully coupled hydro-geomechanical numerical test bed to study reservoir stimulation with low hydraulic pressure

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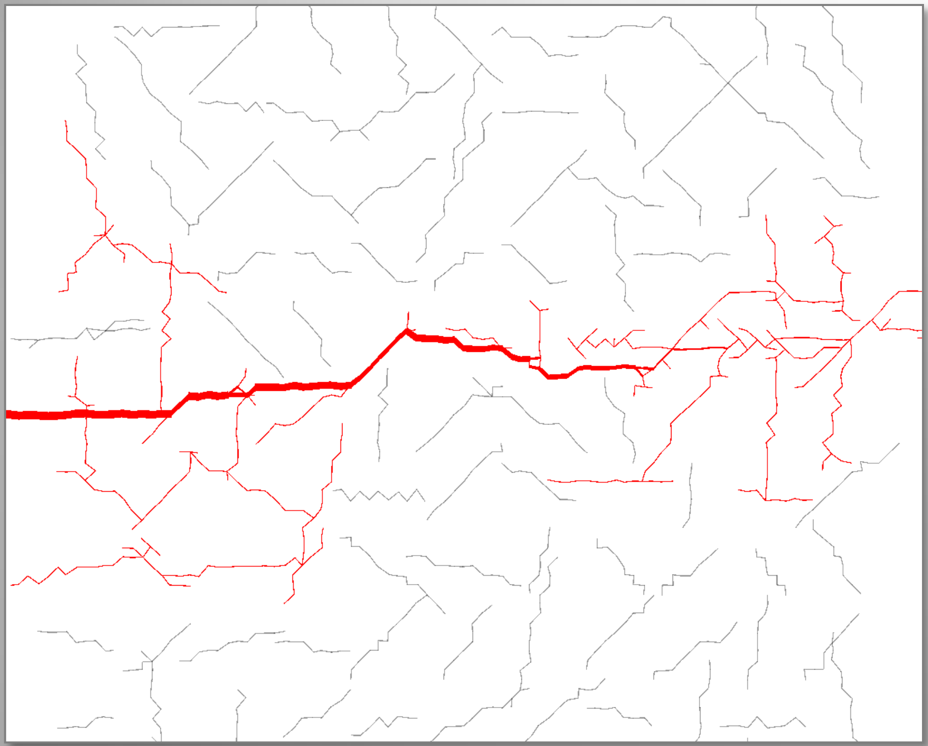
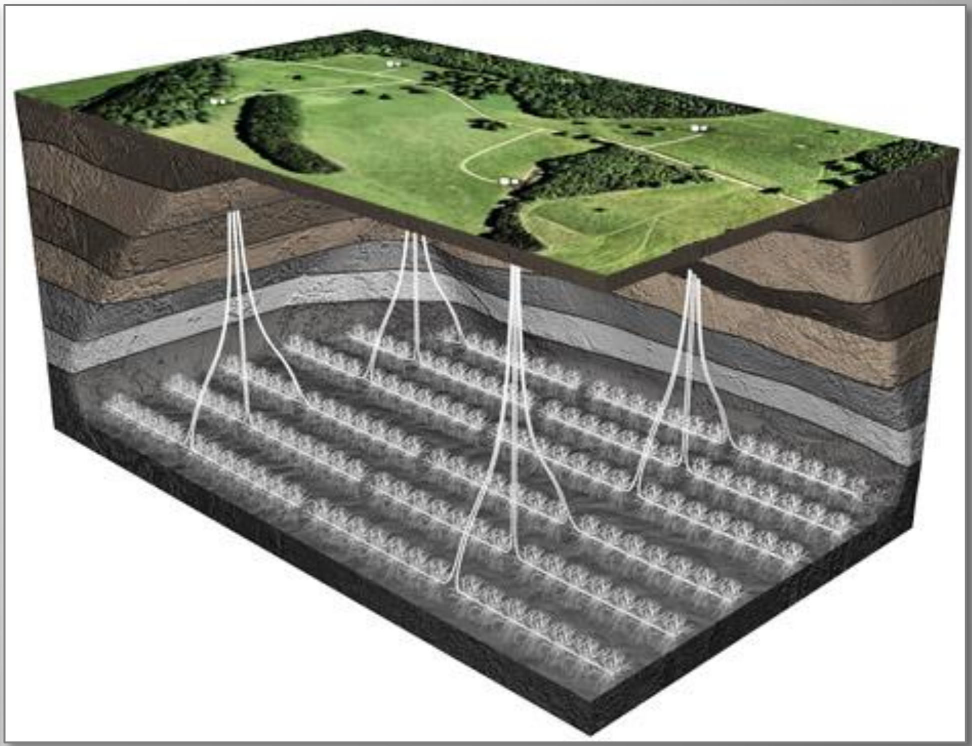
Motivation for low pressure stimulation

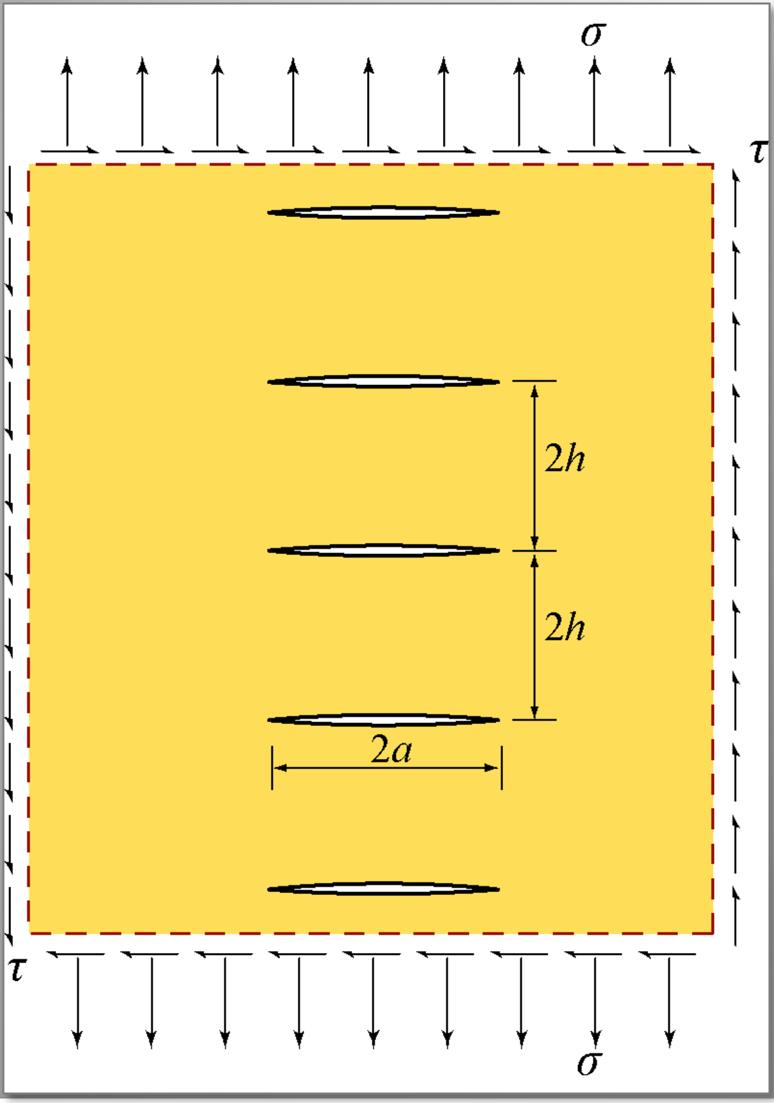


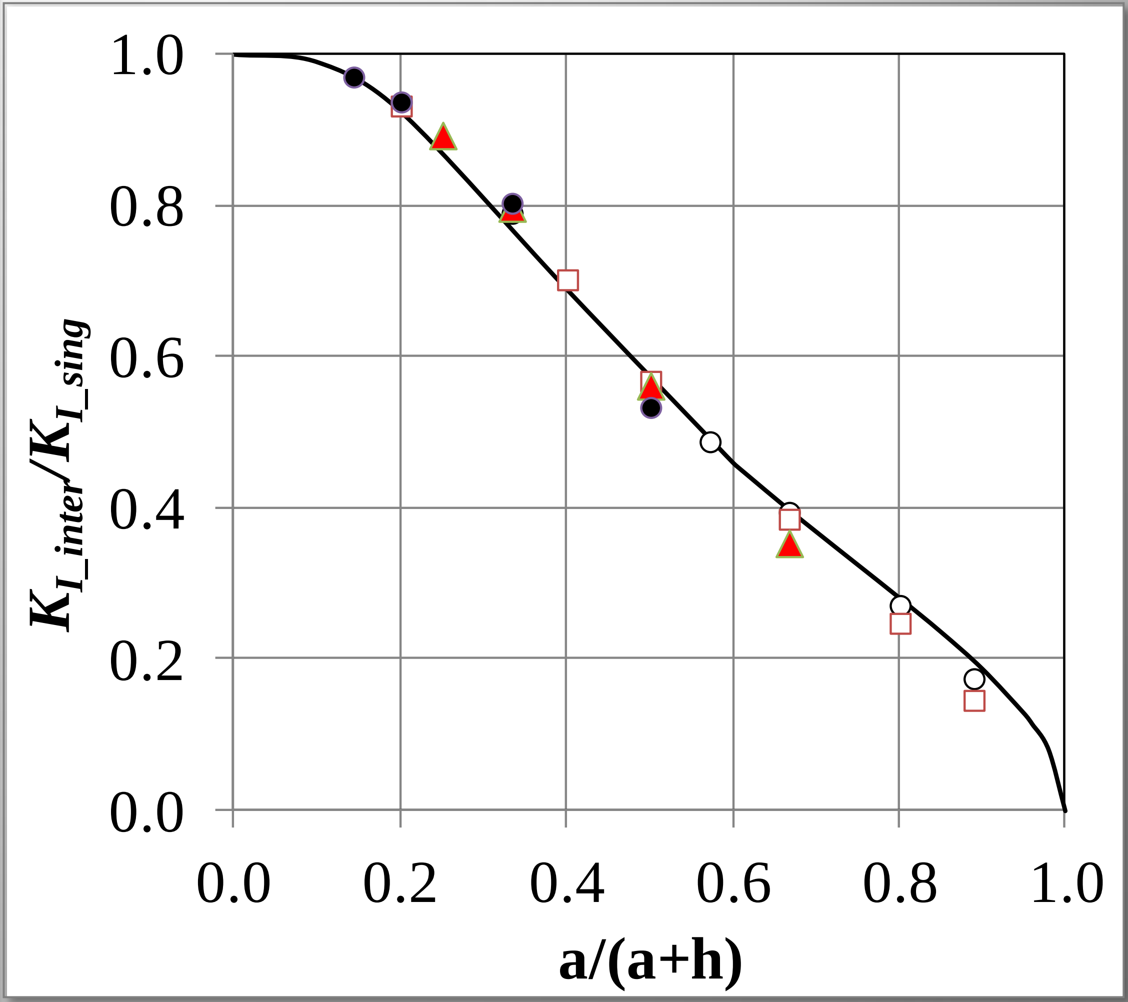


- How can we stimulate a fracture network instead of a single primary fracture?
- Insights gained from a fully coupled numerical test bed.

Interaction between competing fractures

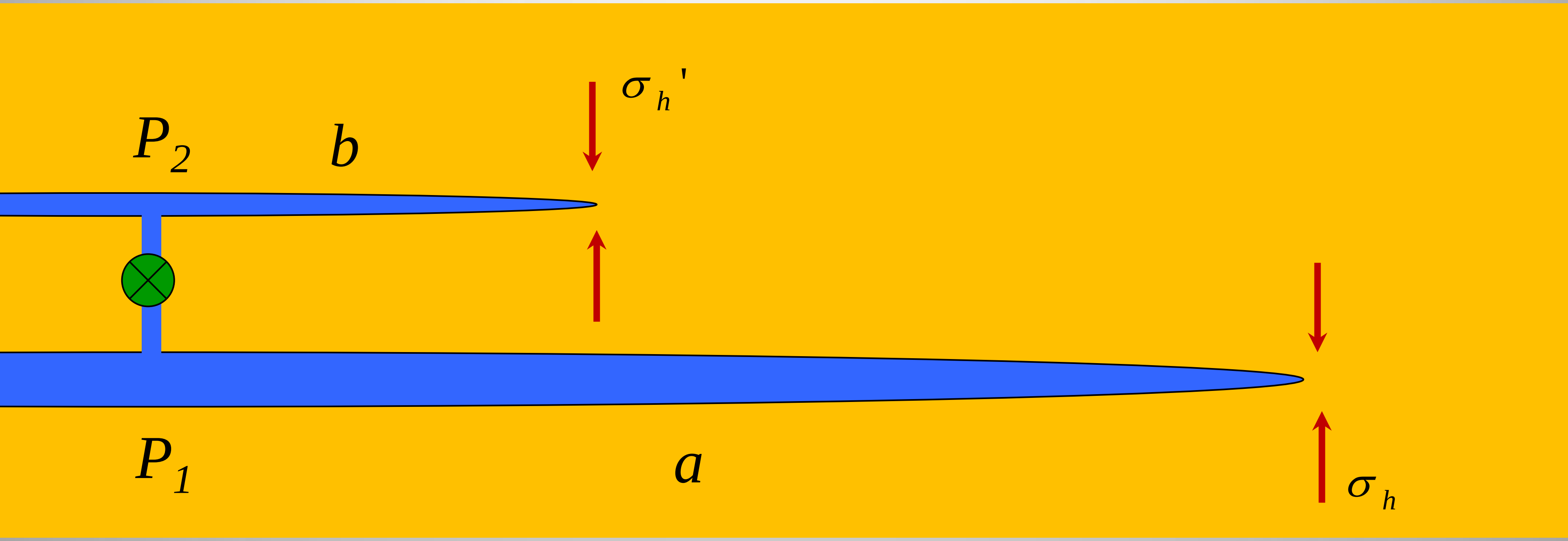
- Parallel fractures weaken SIF of each other





Interaction between competing fractures

- Pressurized fracture creates stress shadow on neighbors



$$\sigma_h < \sigma_h' < P_1$$

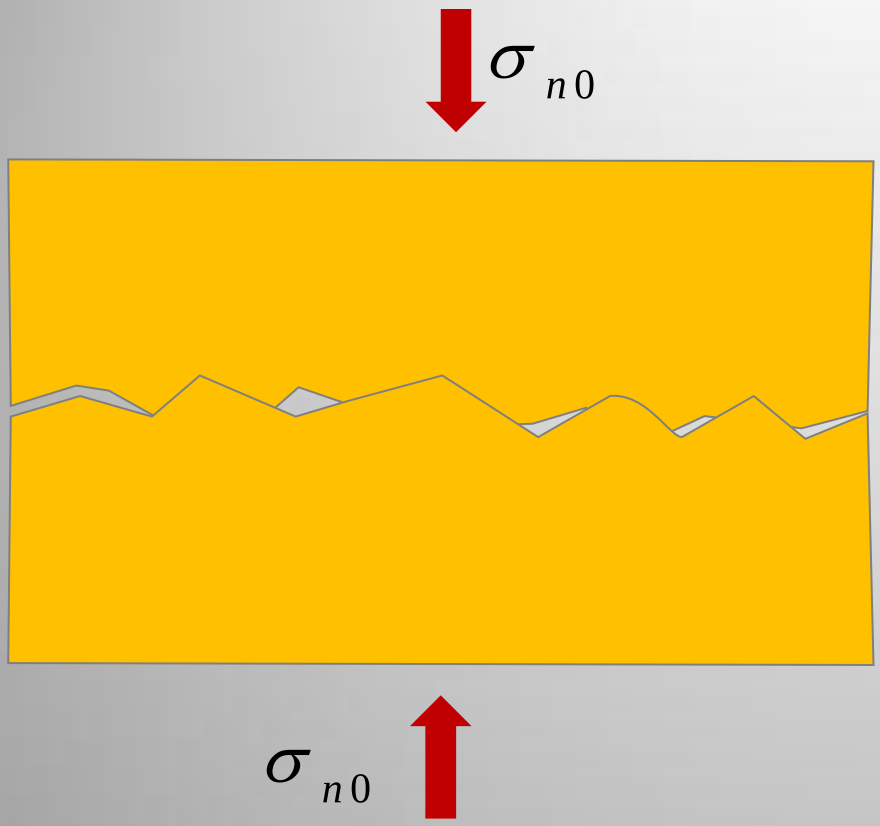
$$(P_1 - \sigma_h)\sqrt{\pi a} \geq K_{I-crit}$$

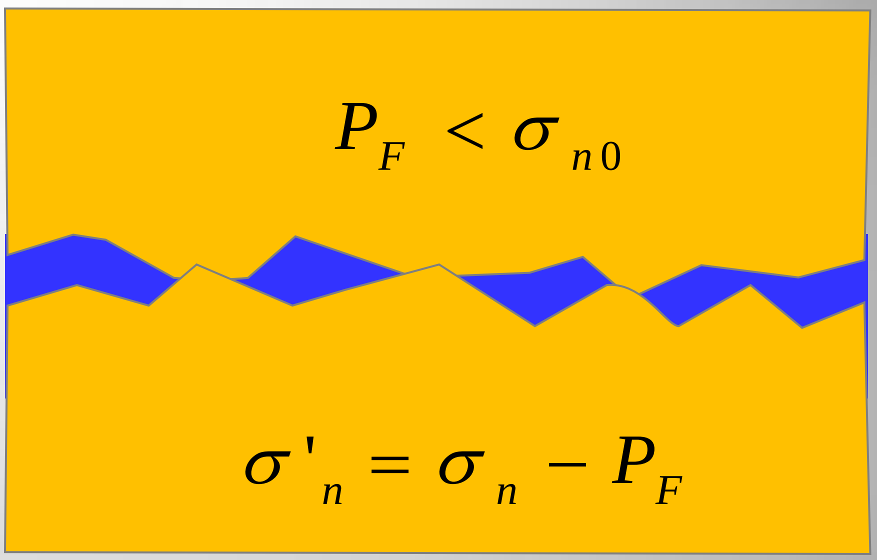
$$(P_2 - \sigma_h')\sqrt{\pi b} \geq K_{I-crit}$$

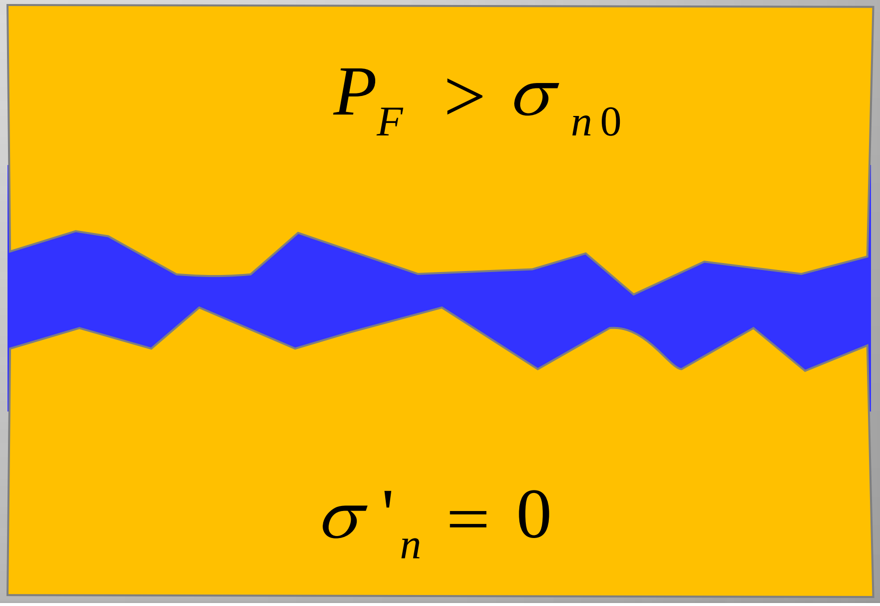
Low pressure stimulation as a potential solution

- Objective of low pressure stimulation:
  - Stimulate a fracture network **covering a large volume of reservoir**, instead of **a single primary fracture**.
  - Permanent permeability enhancement through shear dilation.
- Assumption:
  - An interconnected fracture network already exists.
- Goal of study:
  - Learn about geomechanical behaviors of reservoir subjected to low pressure stimulation.

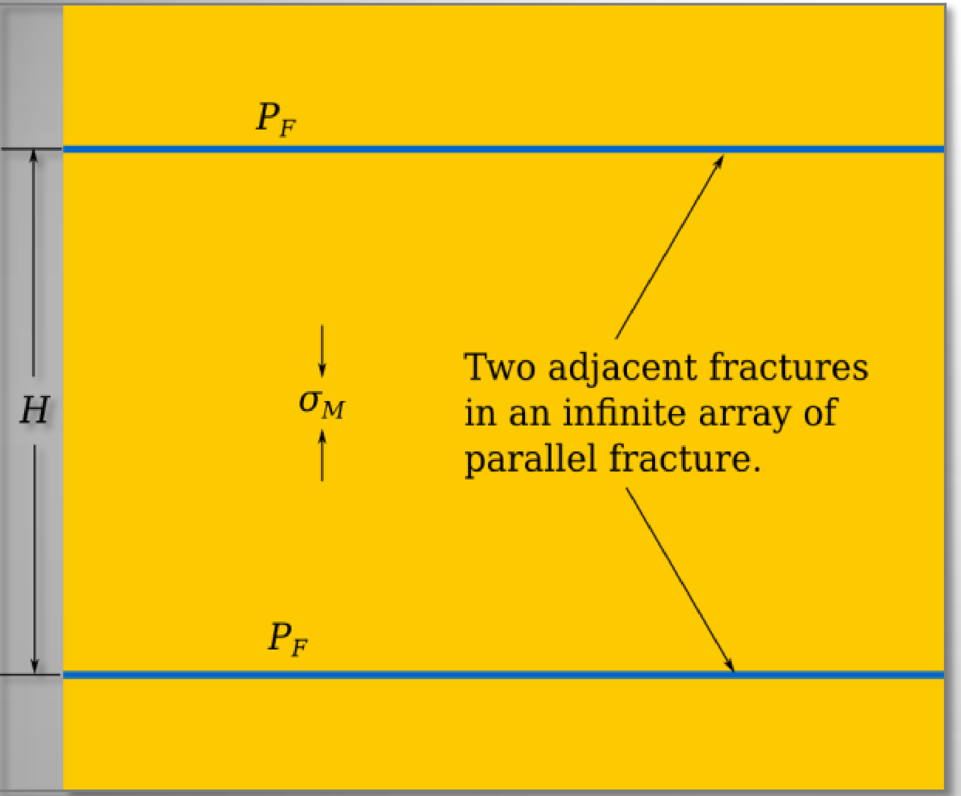
Interaction between rock-joint-fluid

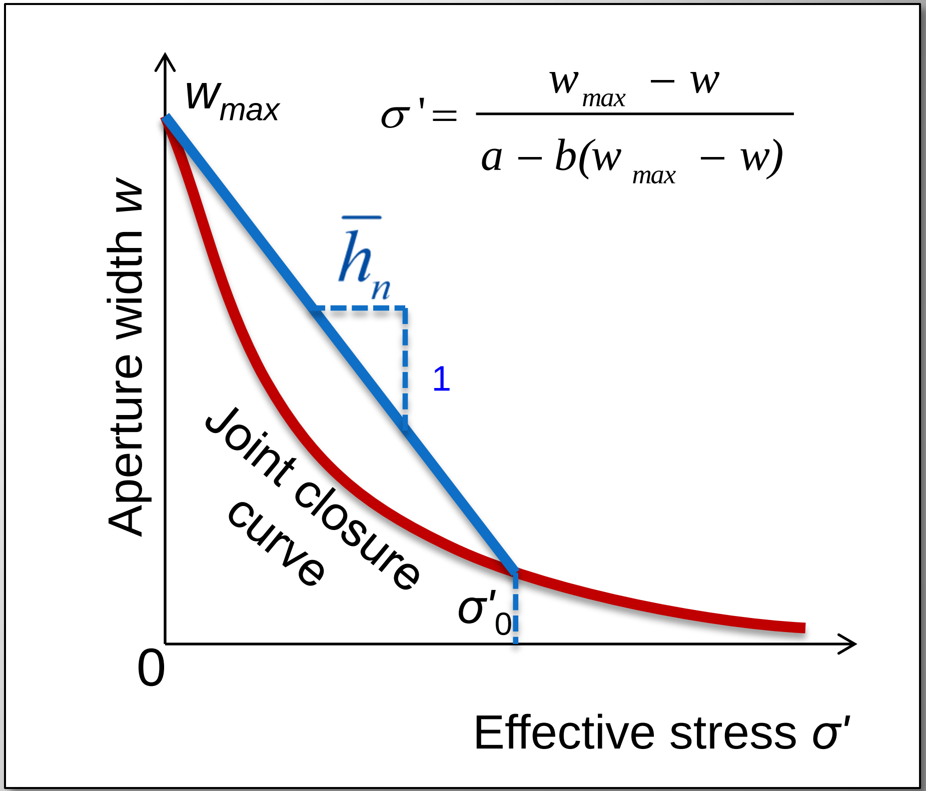






Stress shadow: matrix stress increase due to fluid pressure change

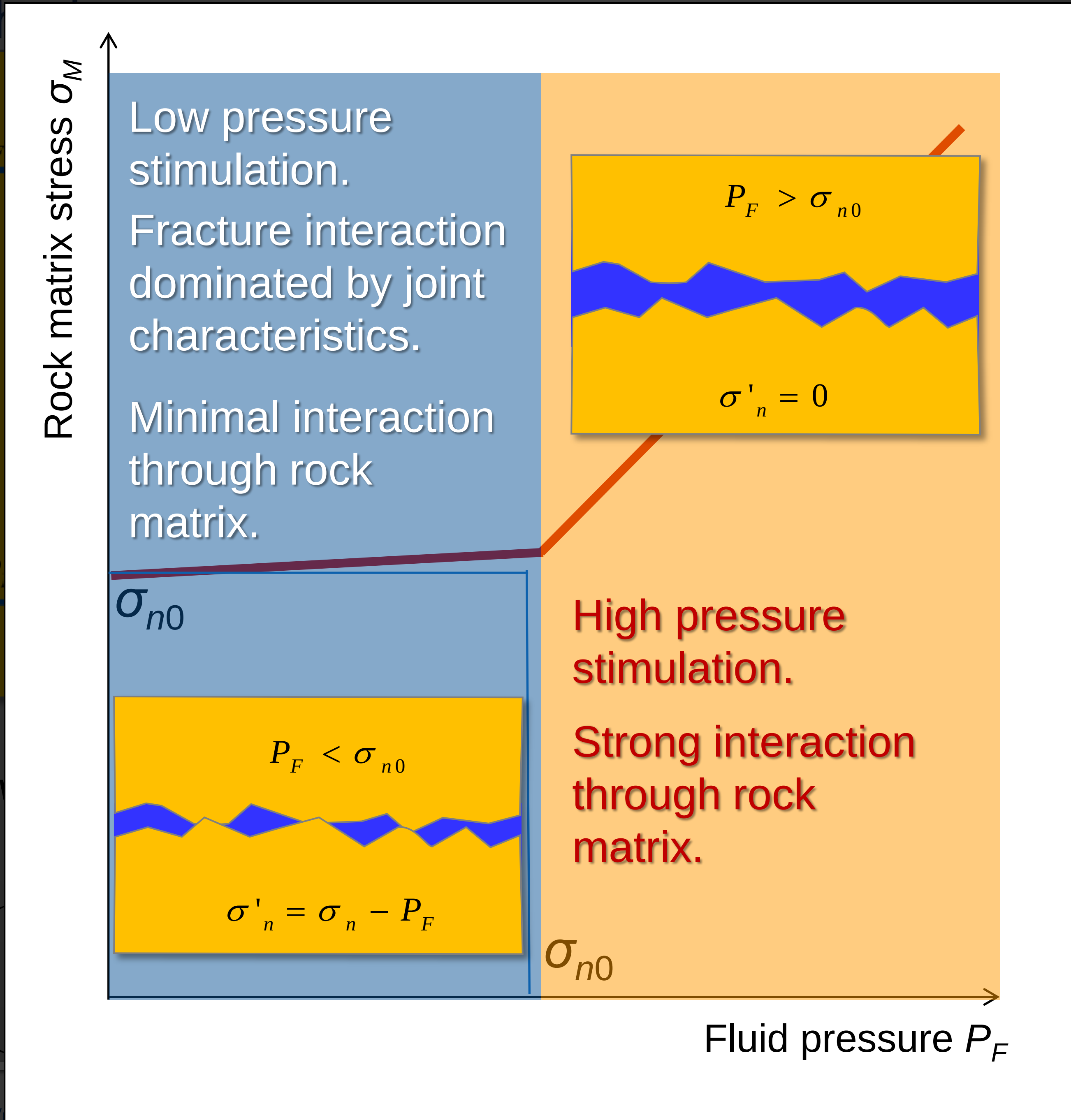




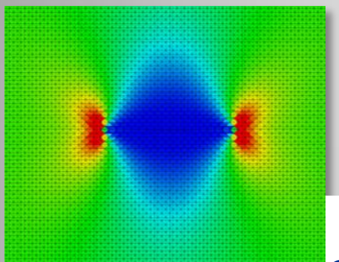
$$w(\sigma'_J) - w_i = \frac{(\sigma_M - \sigma_{Mi})H}{E'}$$

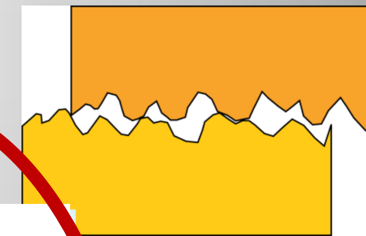
$$\Delta\sigma_M = \begin{cases} P_F / (1 + H/\bar{h}_n) & \text{if } P_F \le \sigma_{Mi}(1 + \bar{h}_n / H) \\ P_F - \sigma_{Mi} & \text{otherwise} \end{cases}$$

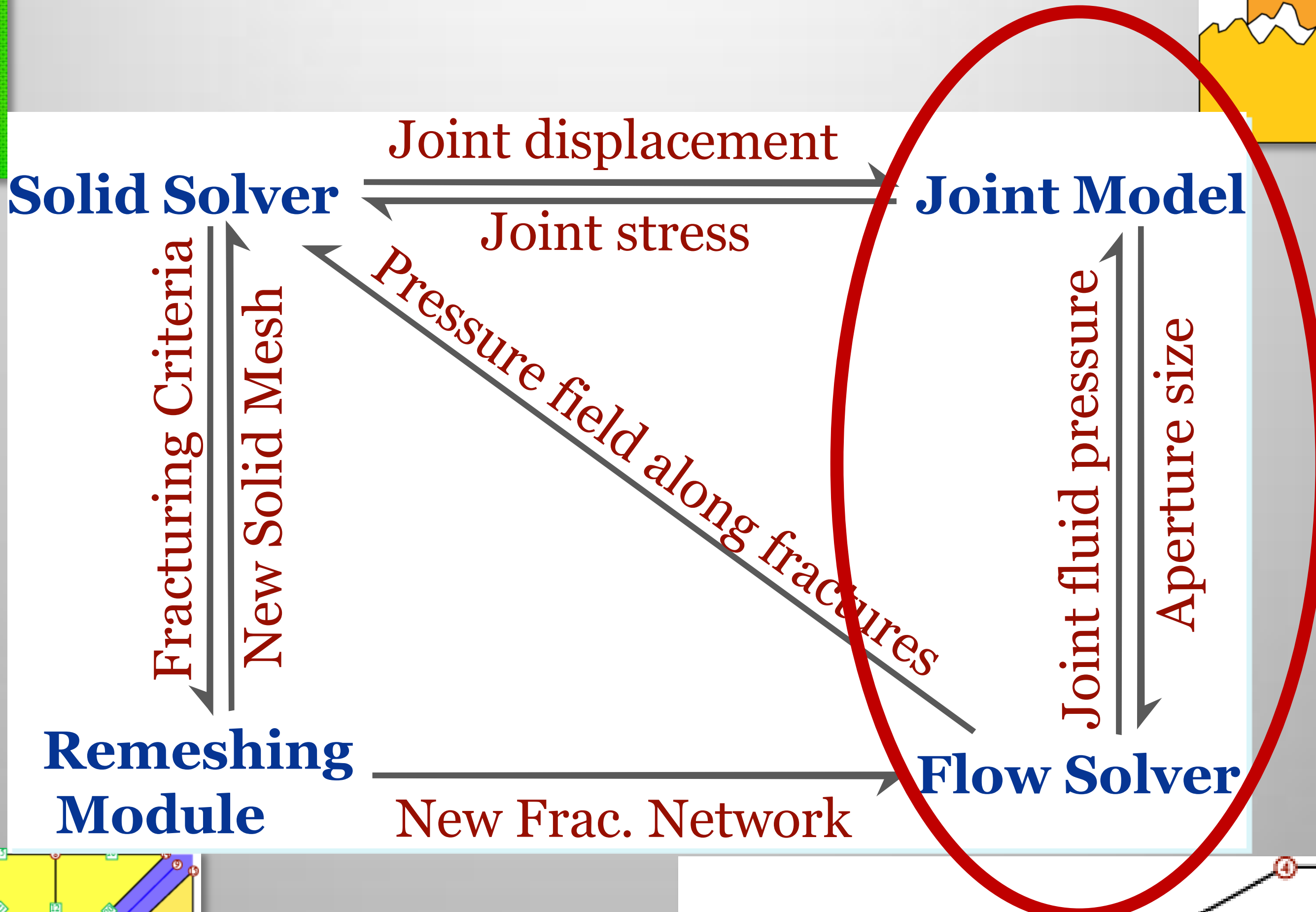
Stress sh… …ange

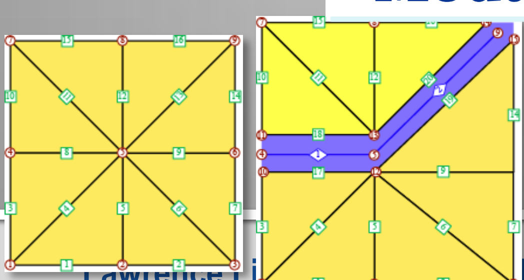


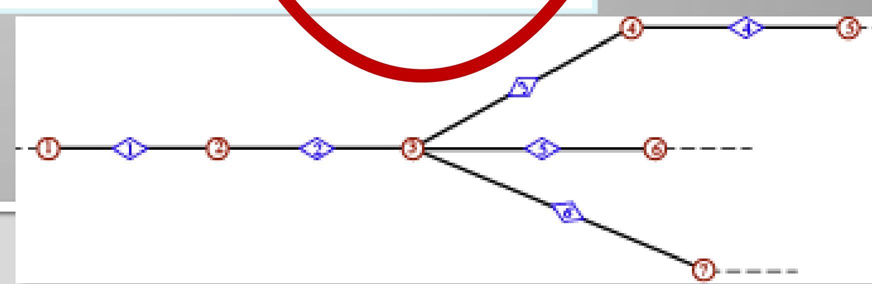
Fluid-solid coupling for high pressure regime





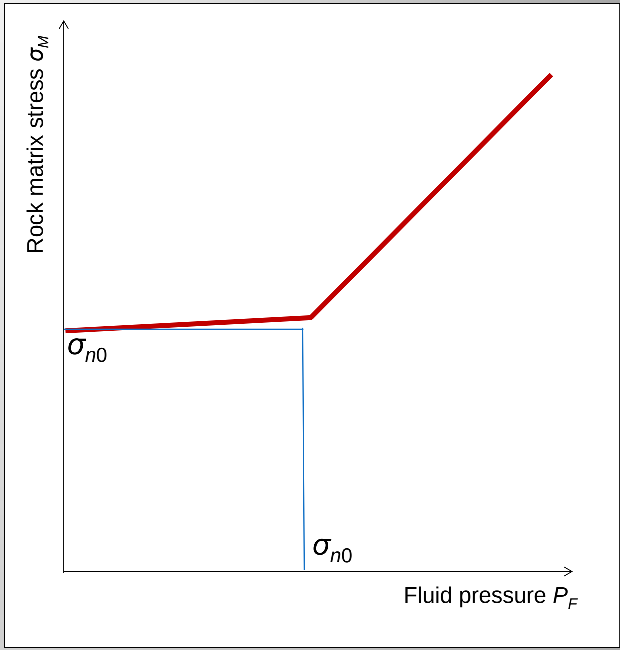






Fluid-solid coupling for low pressure regime

$$P_F = \begin{cases} K_F\left(1 - \dfrac{\rho_{ref} L_C w}{m_C}\right) & \text{if } m_C / L_C w \geq \rho_{ref} \\ P_{vap} & \text{if } m_C / L_C w < \rho_{ref} \end{cases}$$

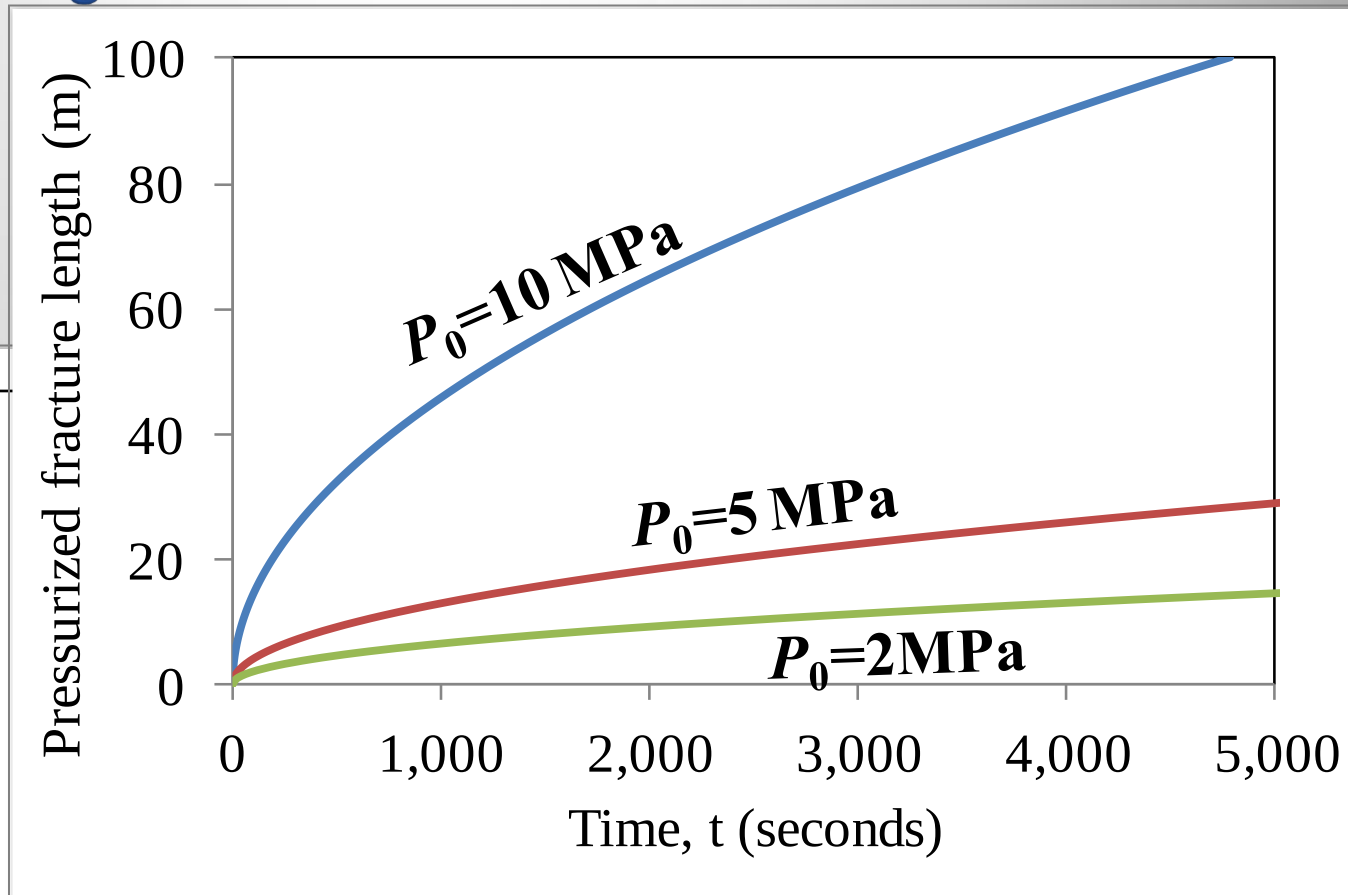


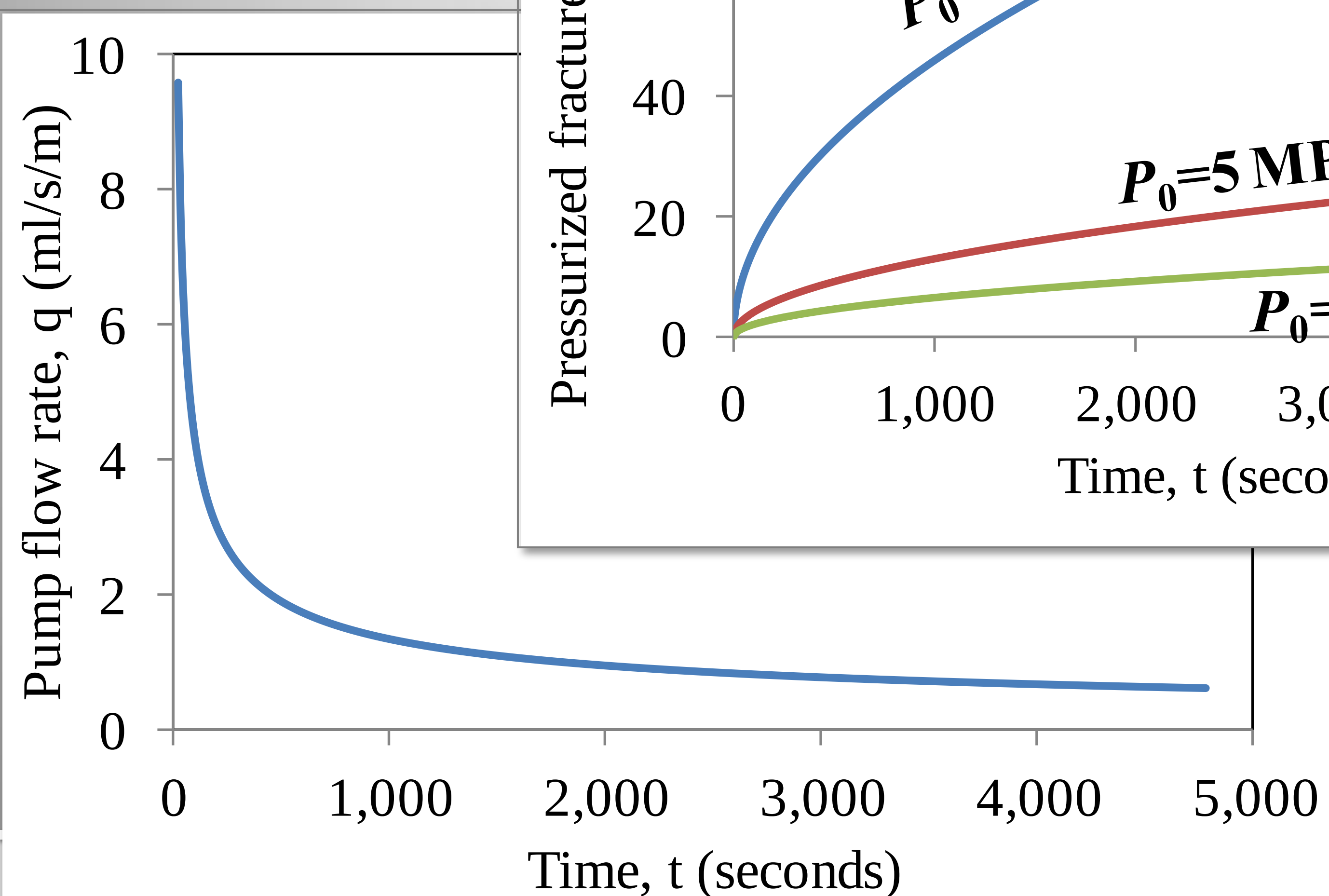
$$\sigma' = \frac{w_{max} - w}{a - b(w_{max} - w)}$$

$$w = w_{max} - \frac{Aa + Bb + 1 - [(Aa + Bb + 1)^2 - 4AaBb]^{0.5}}{2Ab}$$

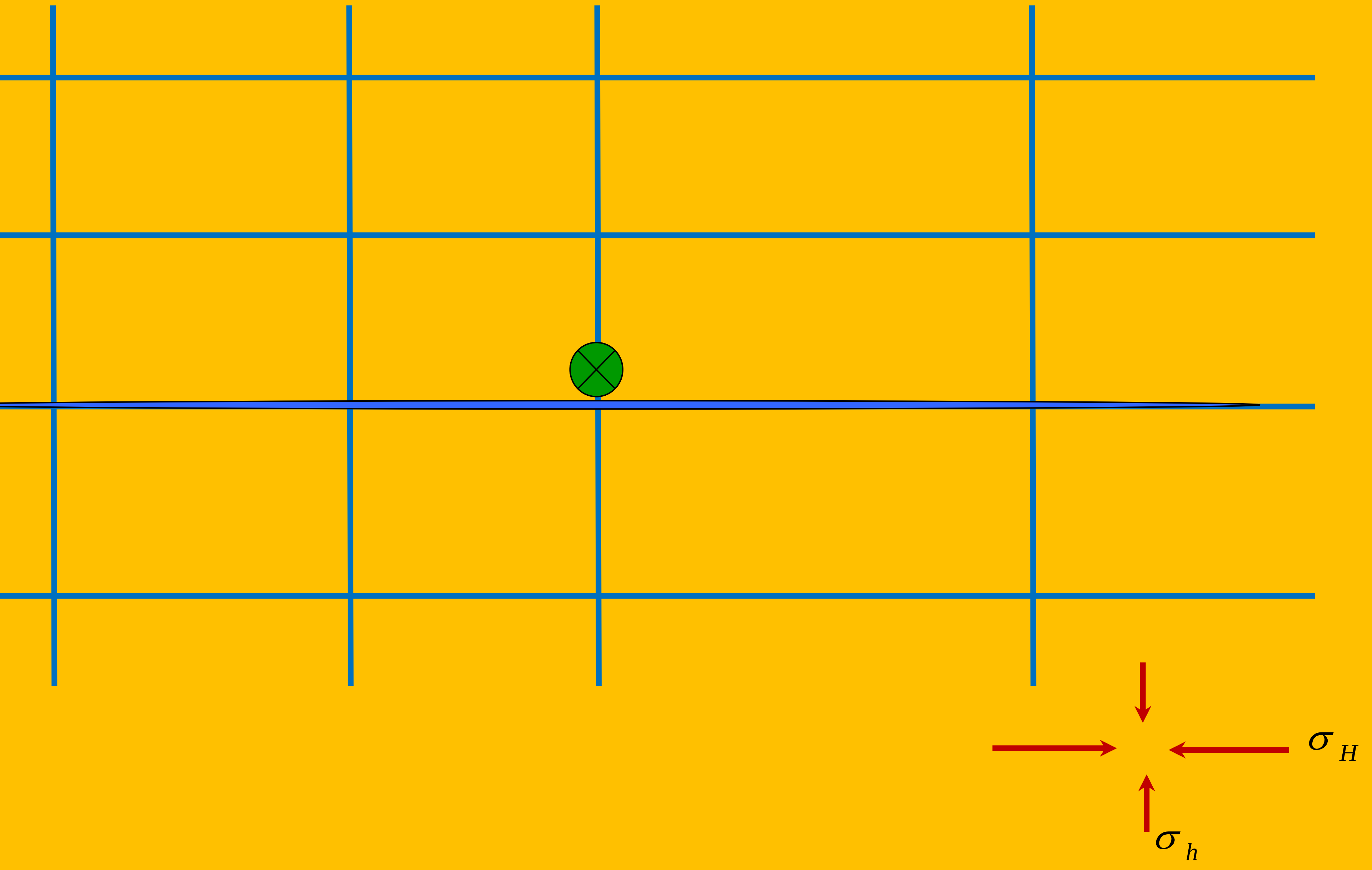
$A = K_F \rho_{ref} L_C / m_C$ and $B = \sigma_M - K_F + A w_{max}$

Behavior of a single fracture: 10 MPa ini. Normal stress

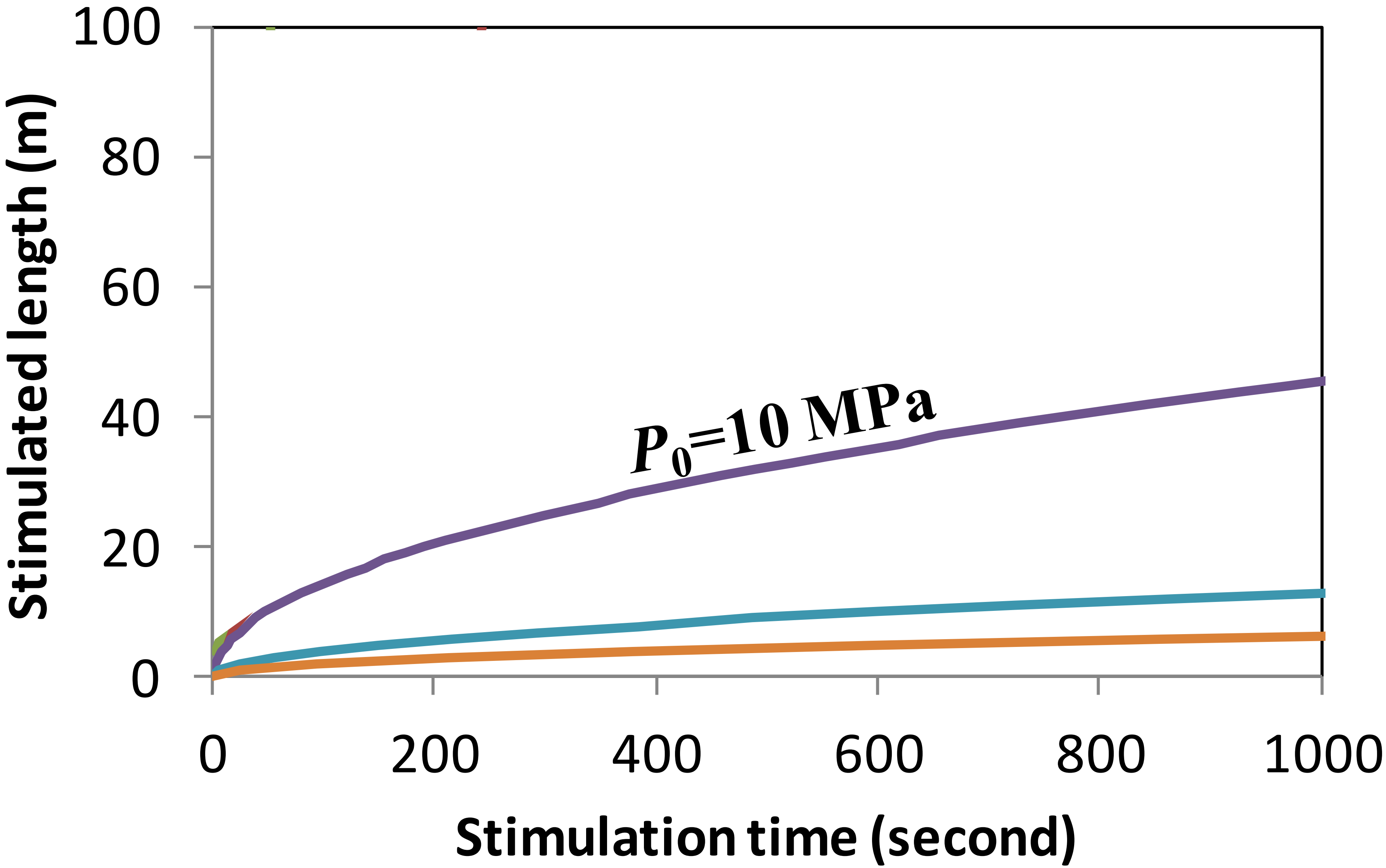




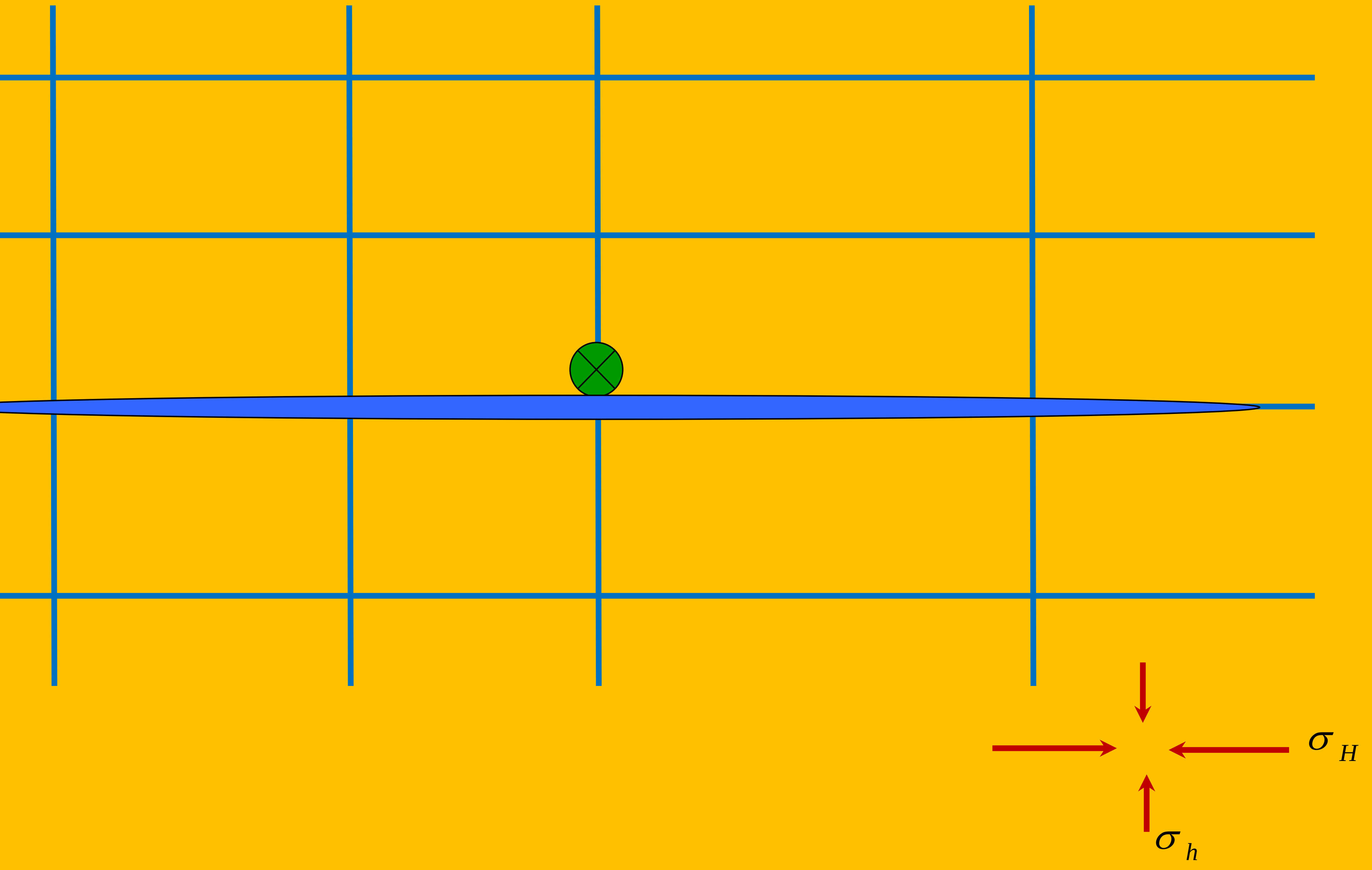
Competition between fractures



What if we pump a little harder?



Competition between fractures

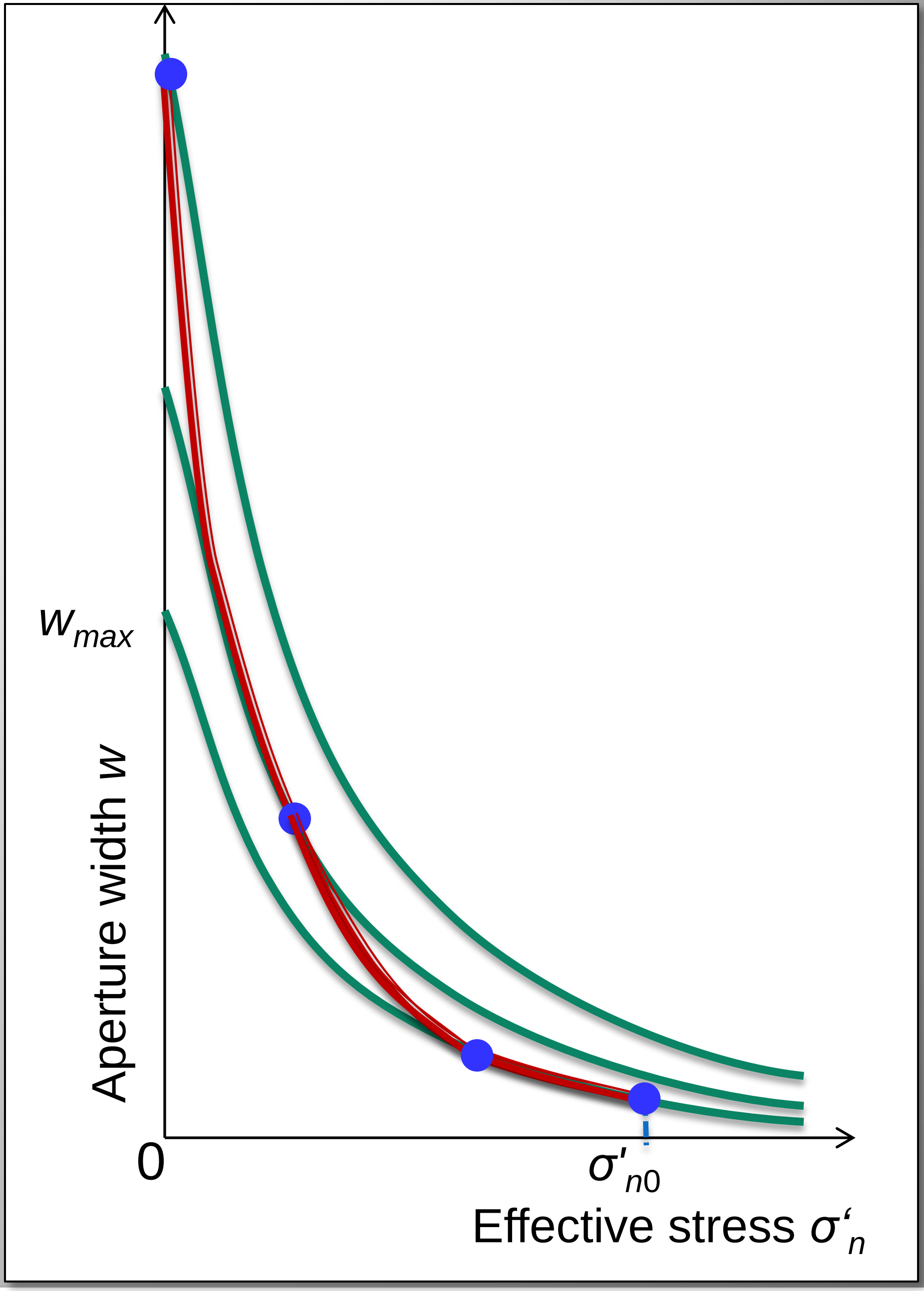


Shear dilation

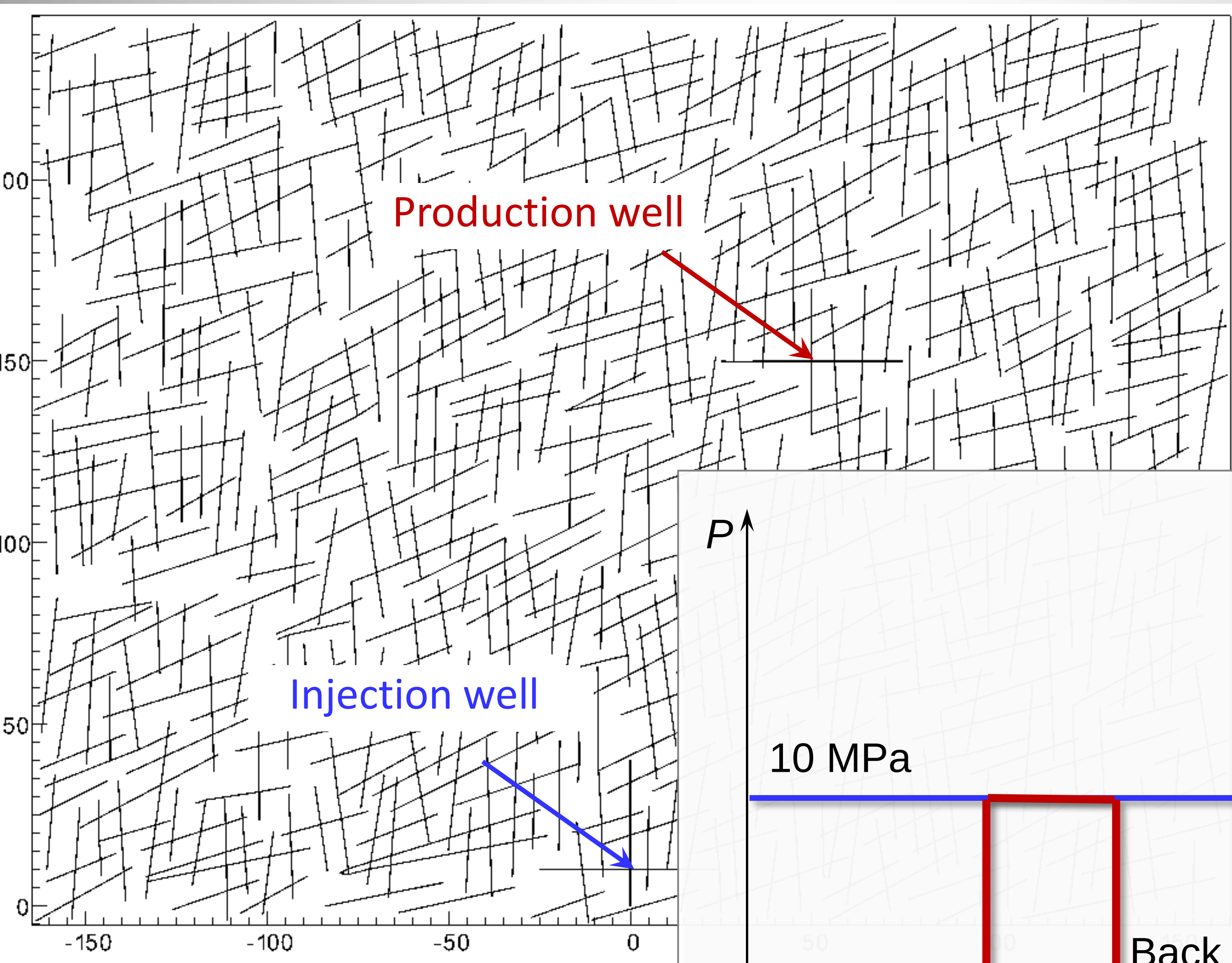
$$\tau' = \tau_0 - \sigma' \mu$$

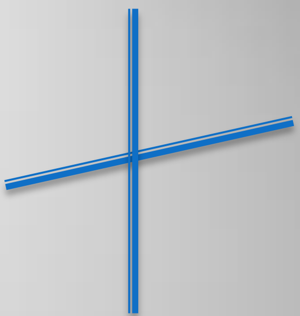
$$w = w(\sigma', S) = S w(\sigma')$$

$$S = \begin{cases} 1 + \tau'_{max} (S_{max} - 1) / \tau'_s \\ \quad \text{if } \tau' \tau'_{max} < \tau'_s \\ S_{max} \\ \quad \text{otherwise} \end{cases}$$



Numerical example: a reservoir

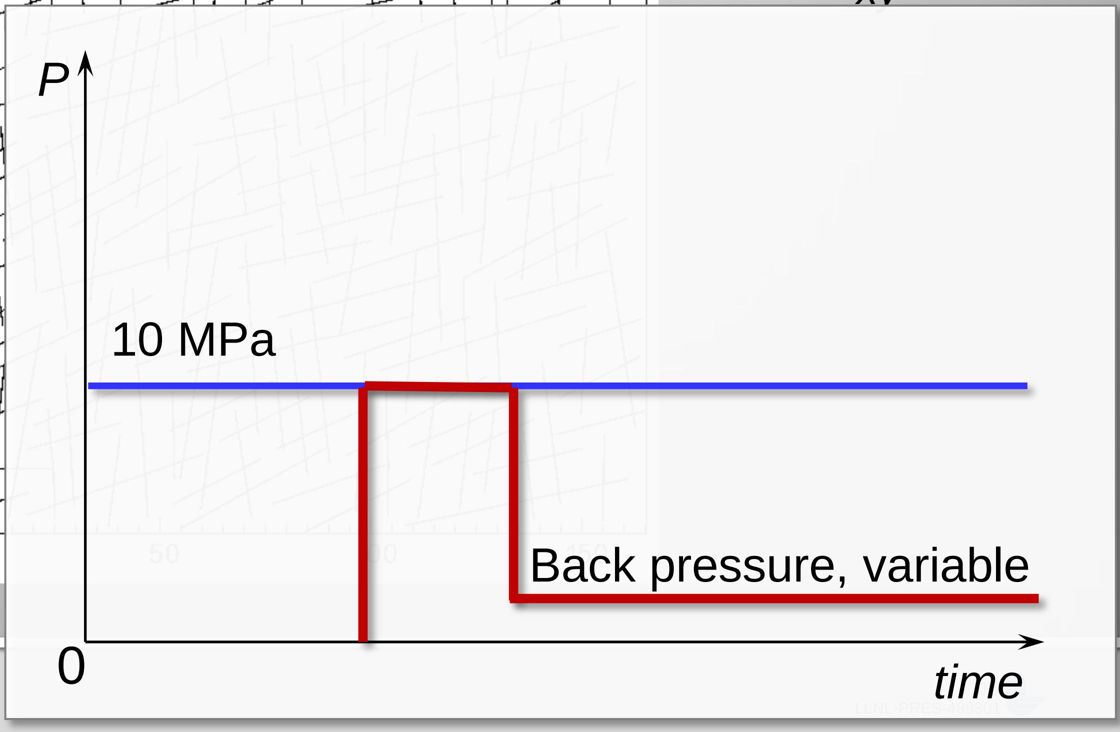


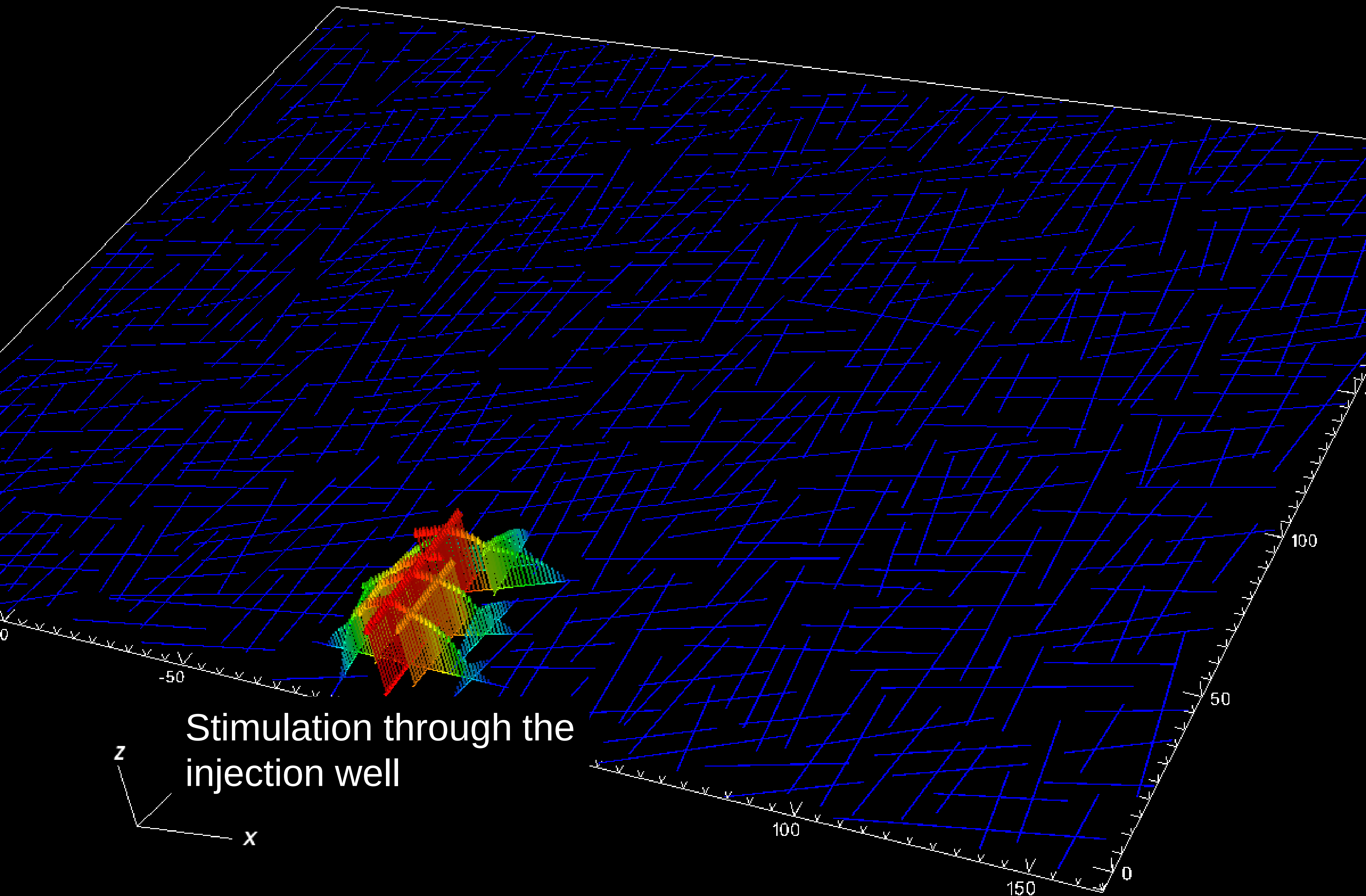


σ_{xx}=10 MPa

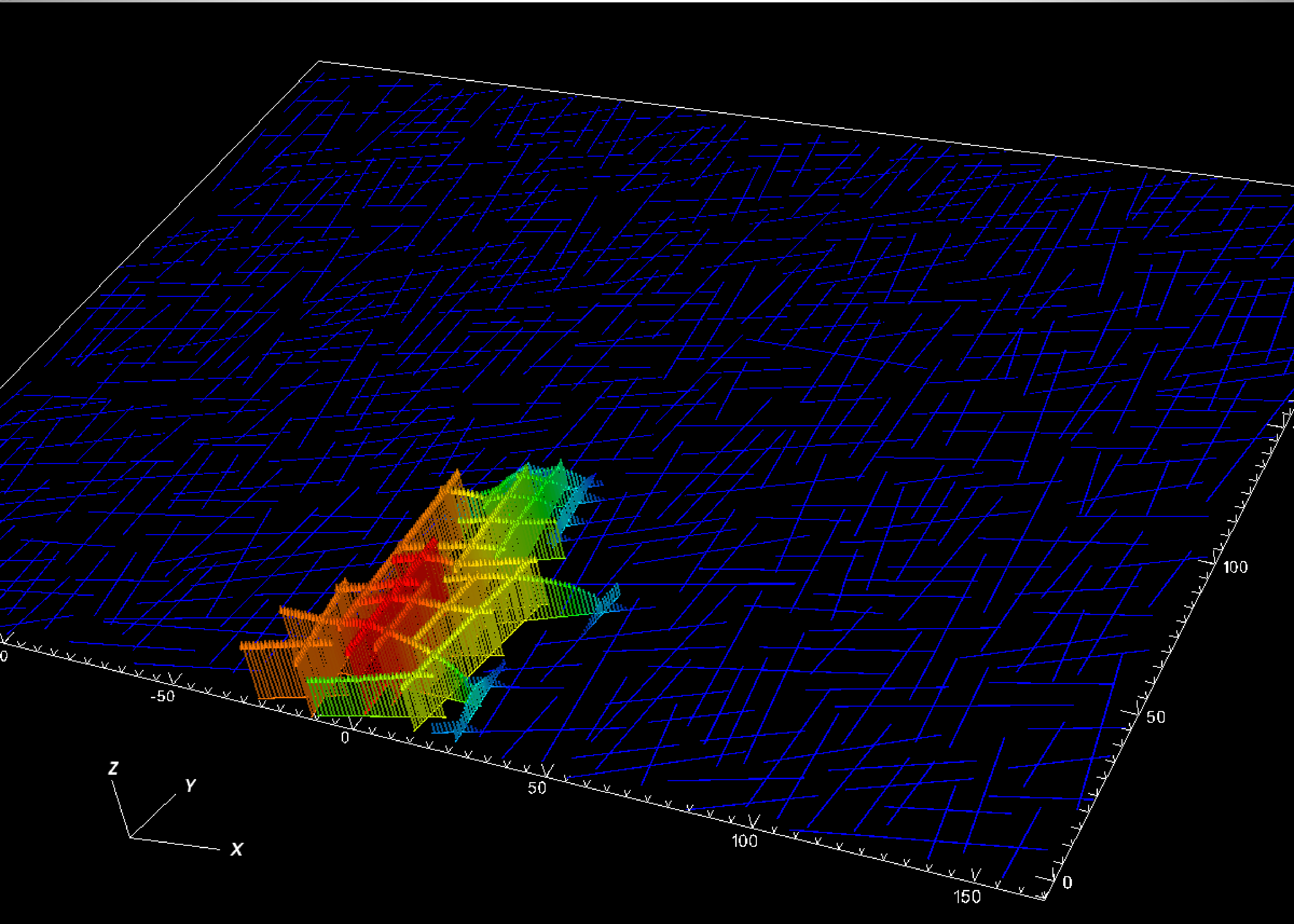
σ_{yy}=14 MPa

and σ_{xy}=0





Stimulation through the injection well



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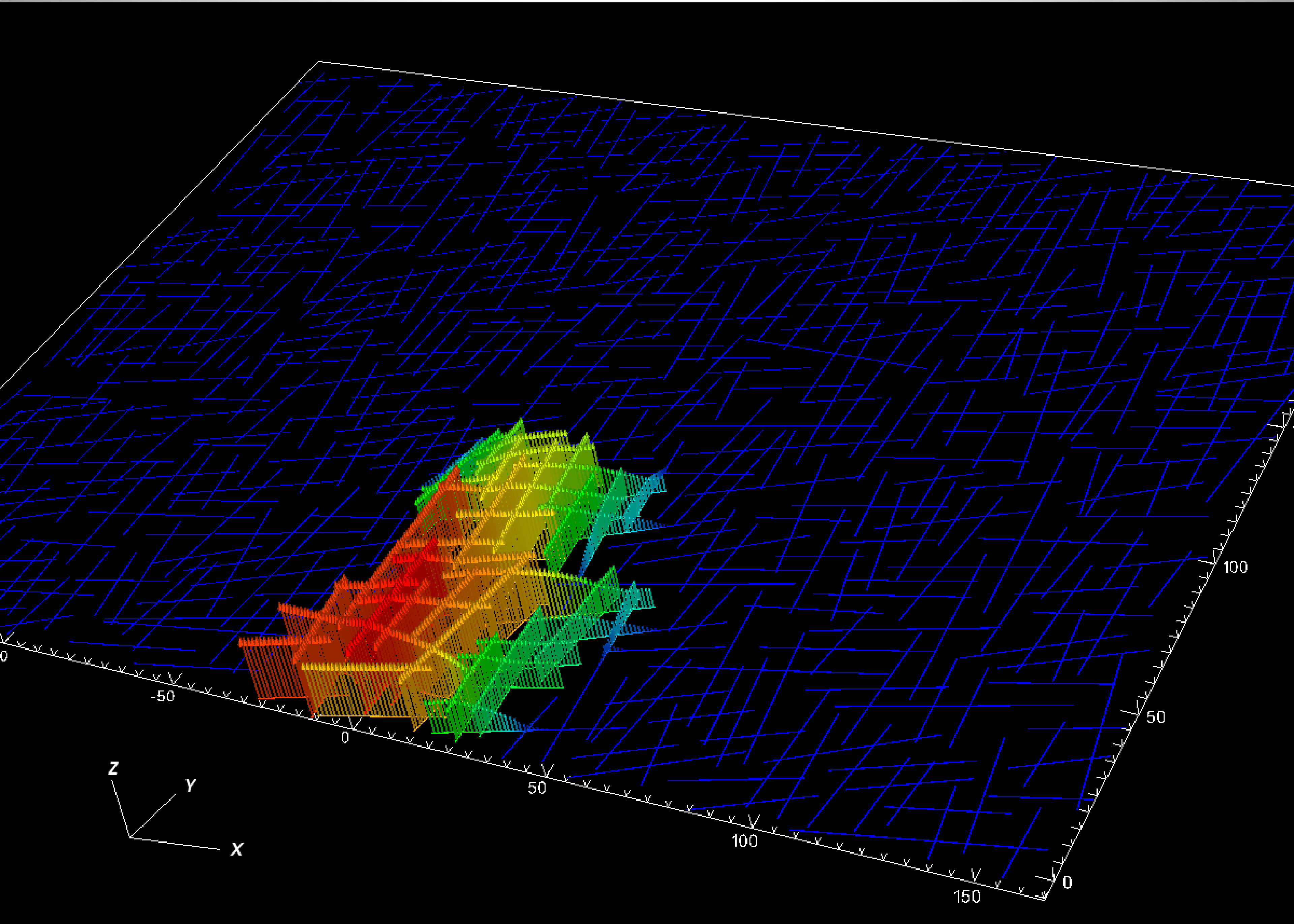

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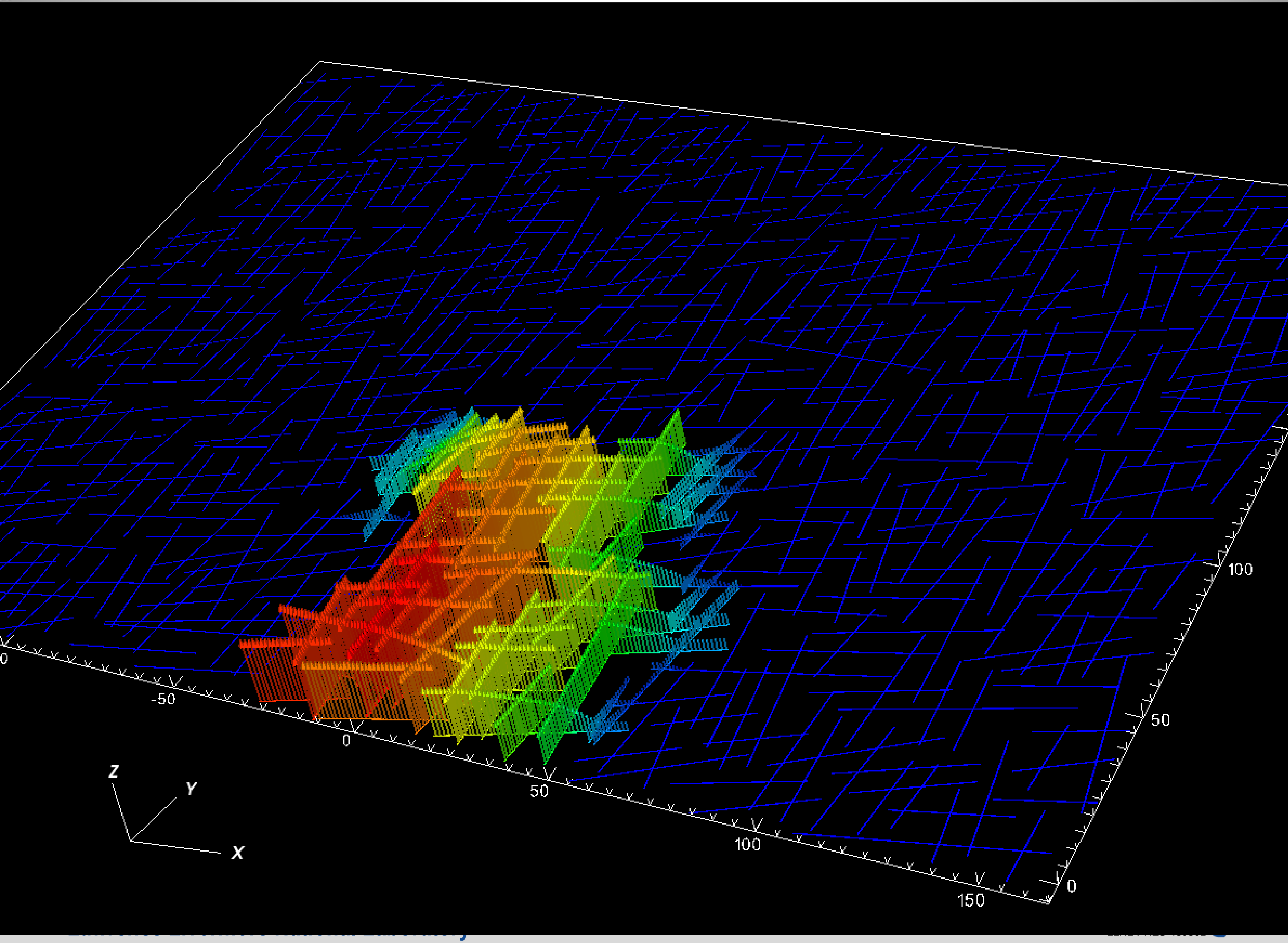
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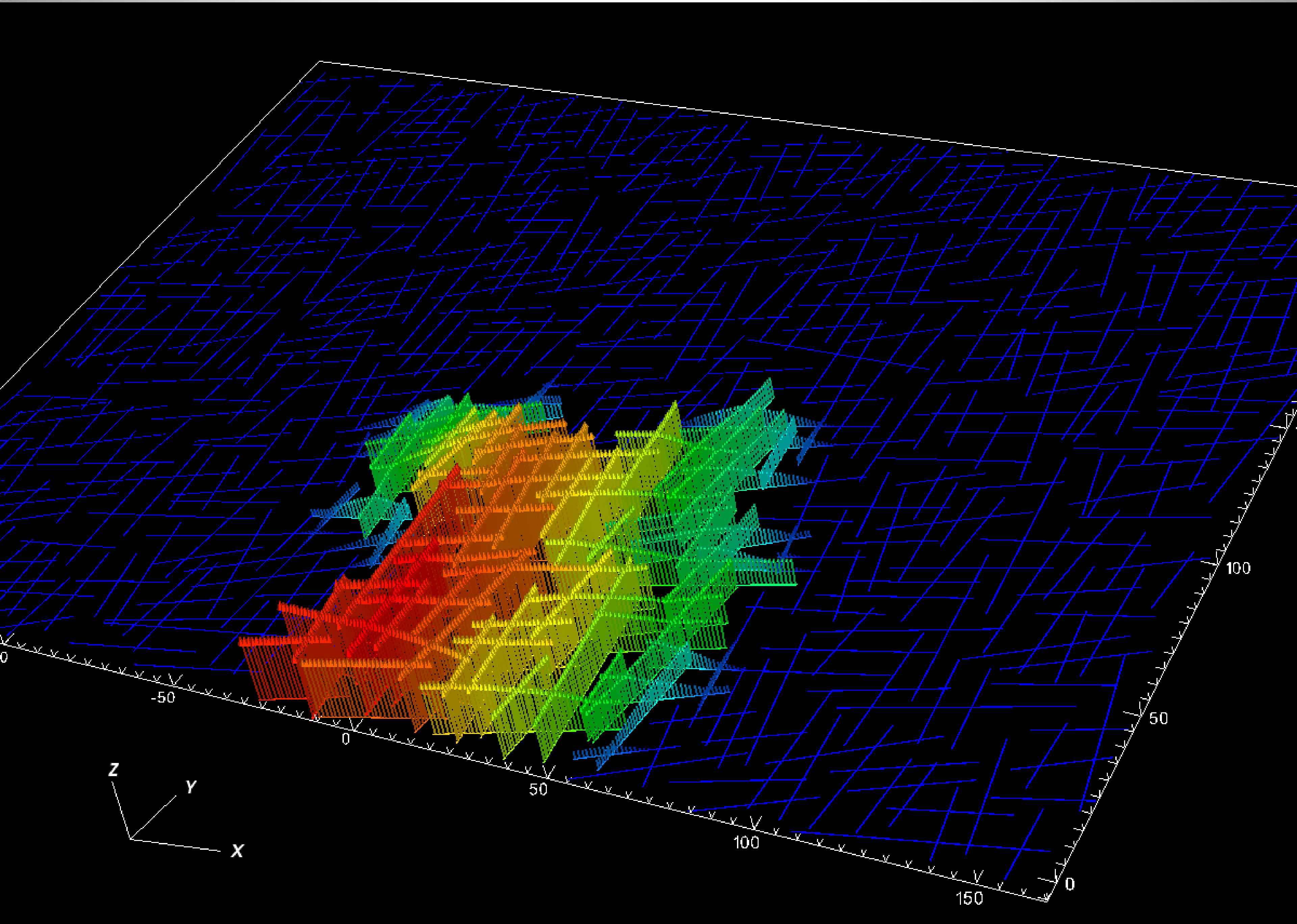

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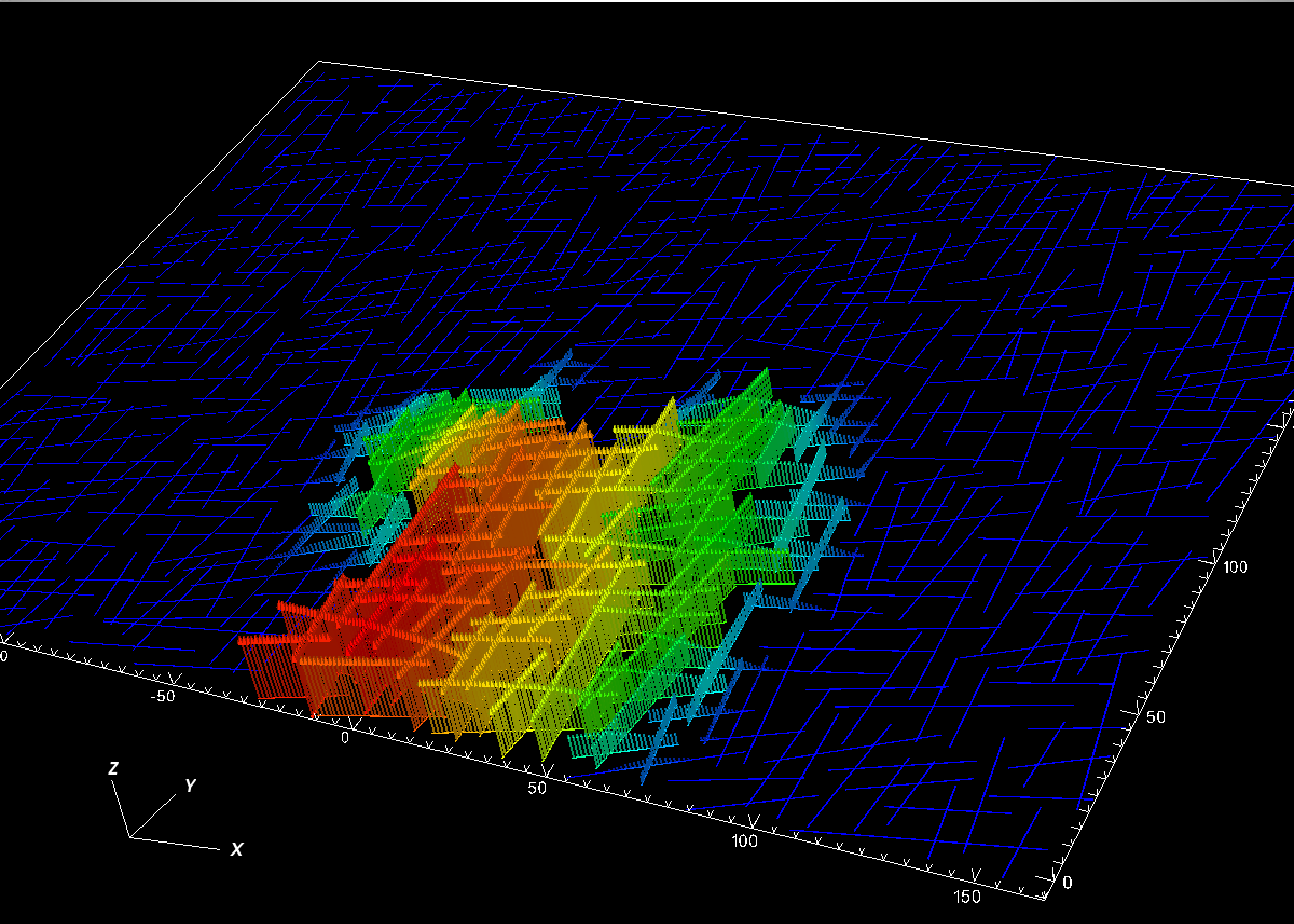

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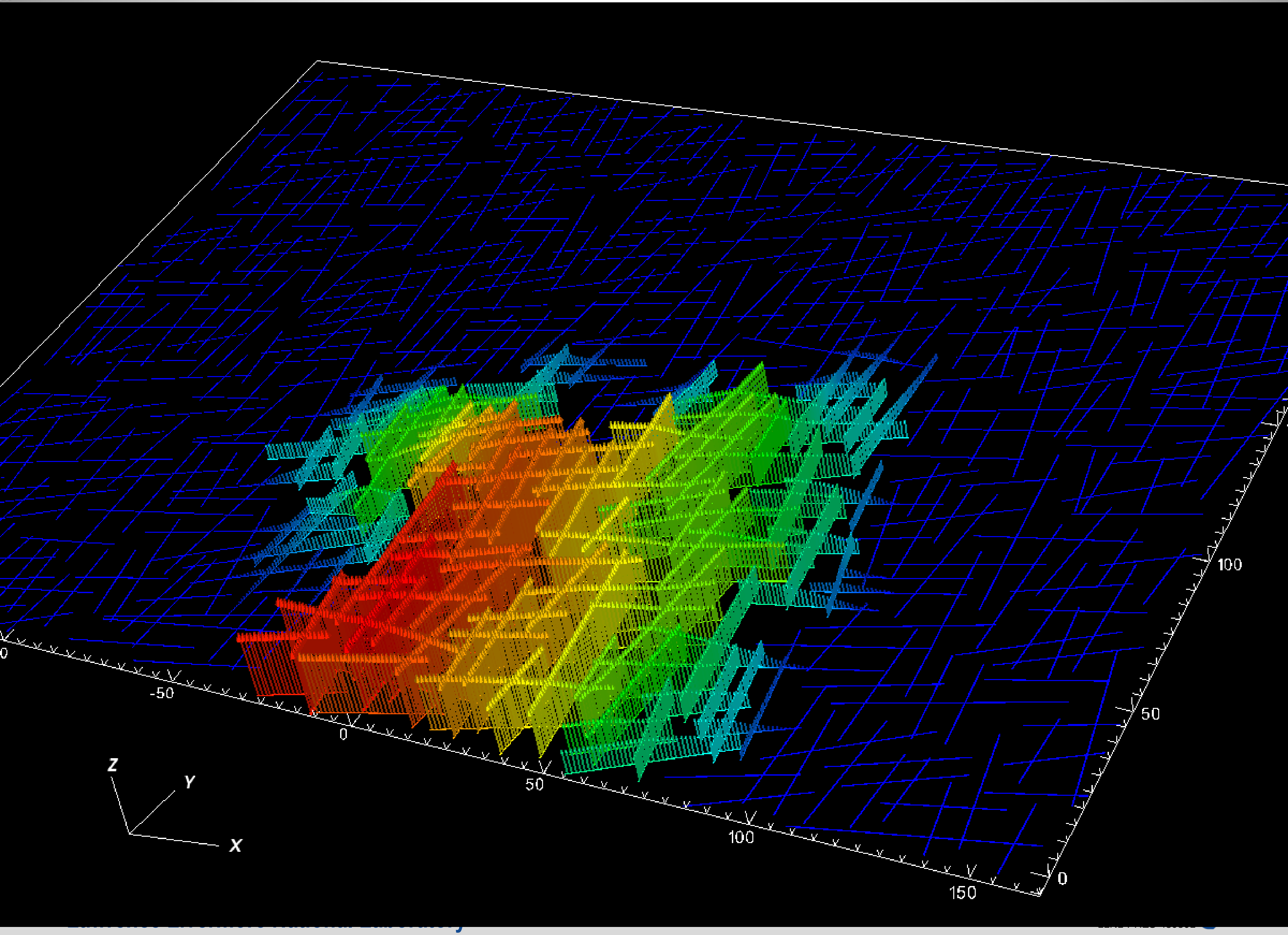

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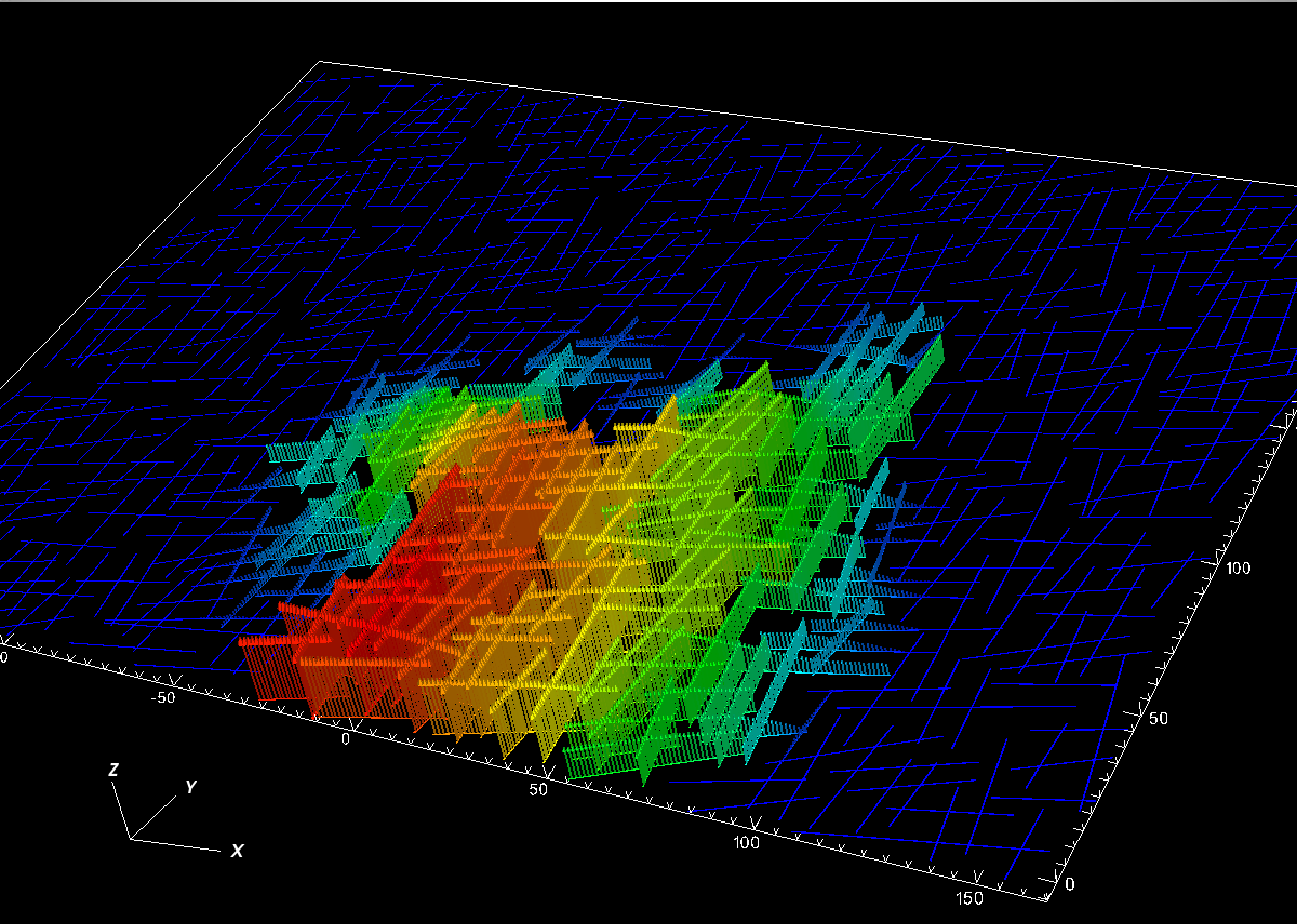

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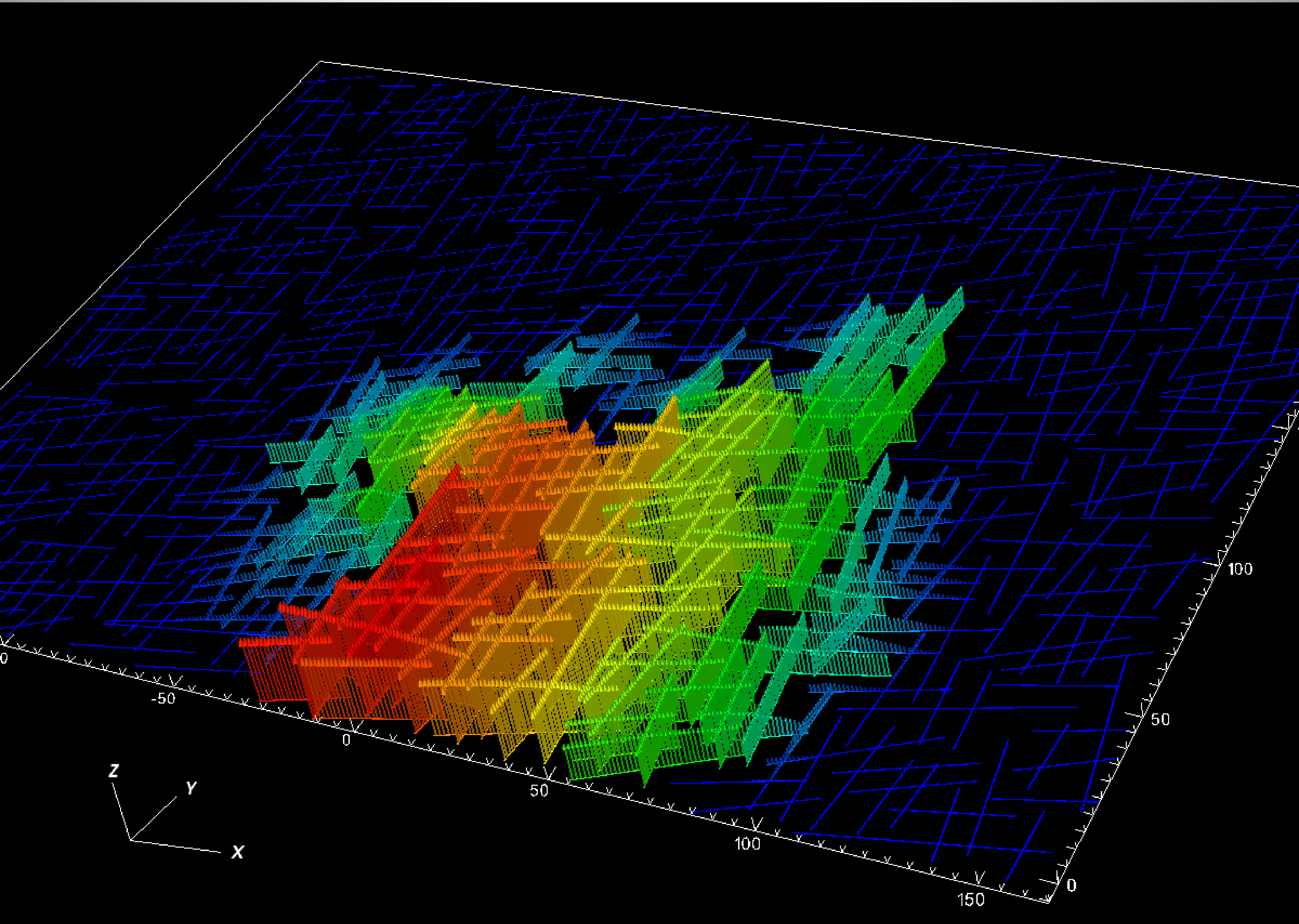
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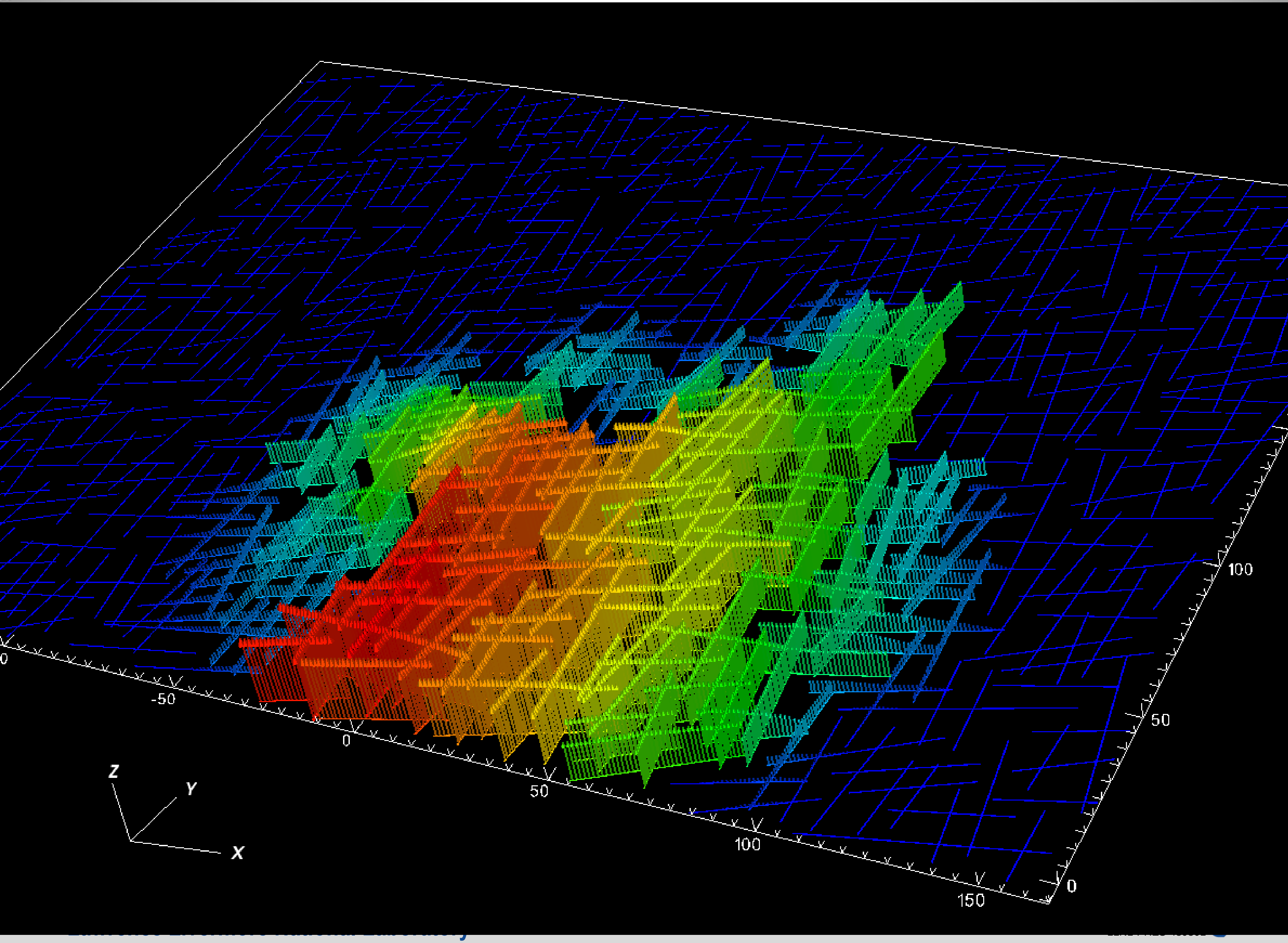
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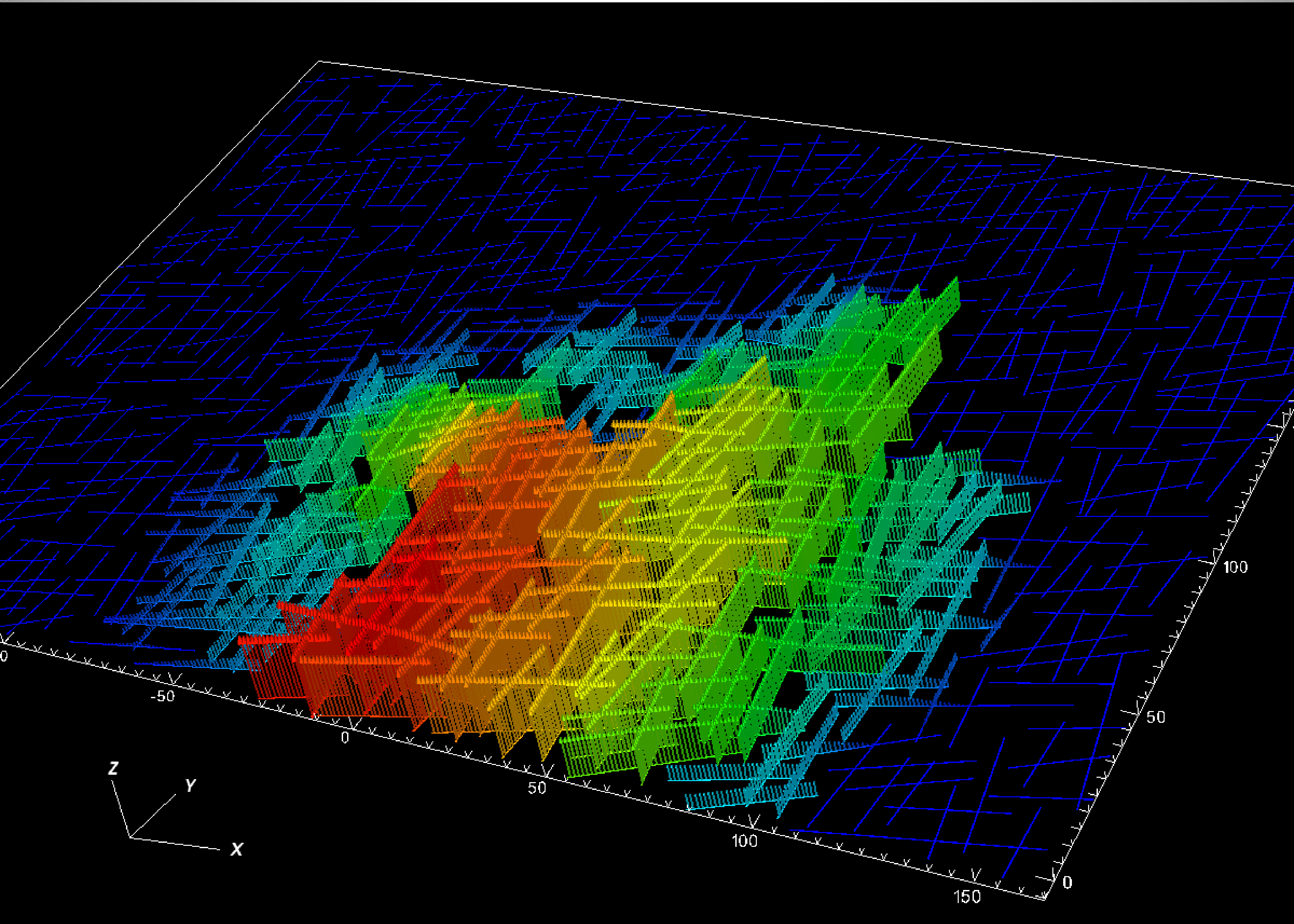

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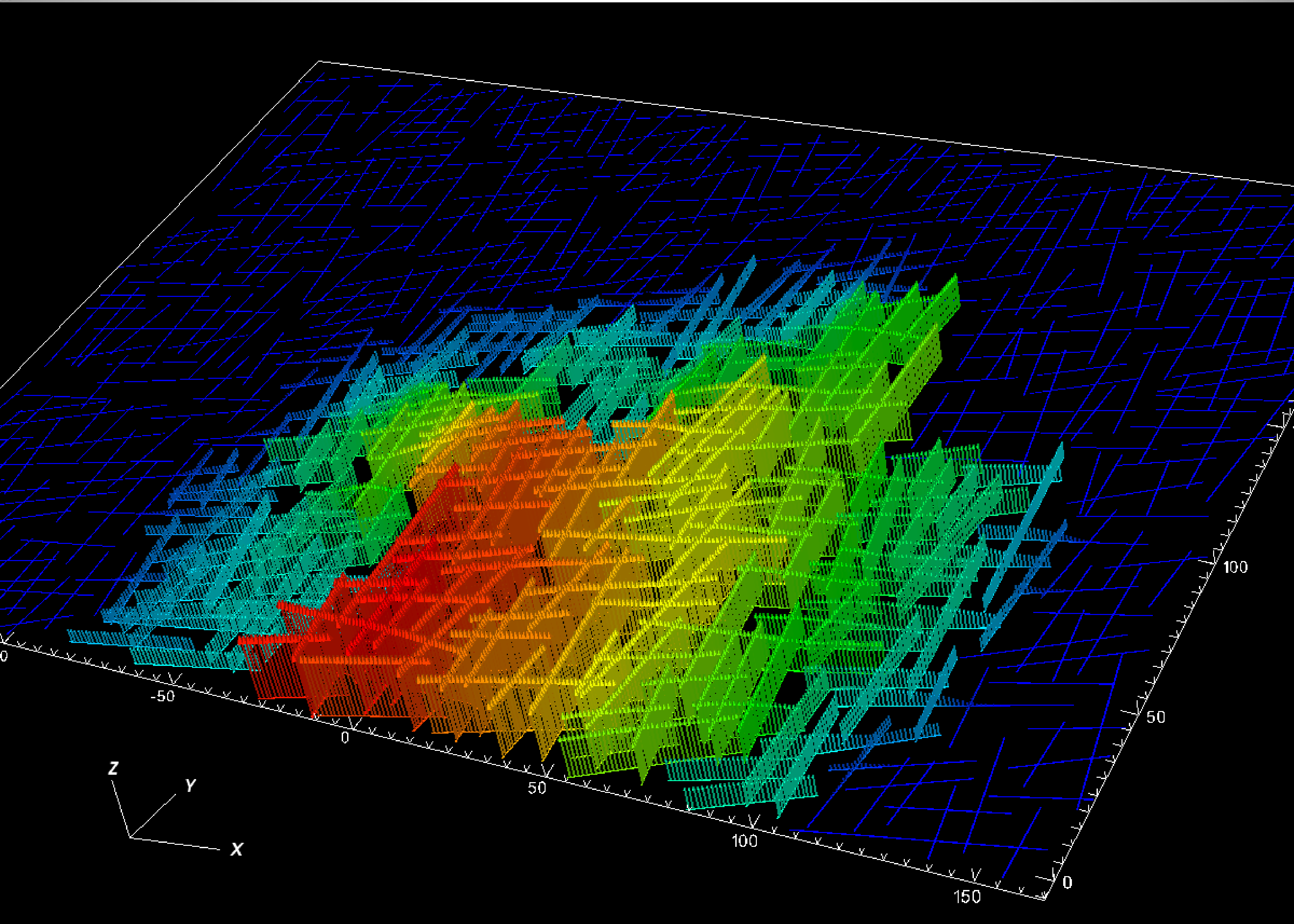

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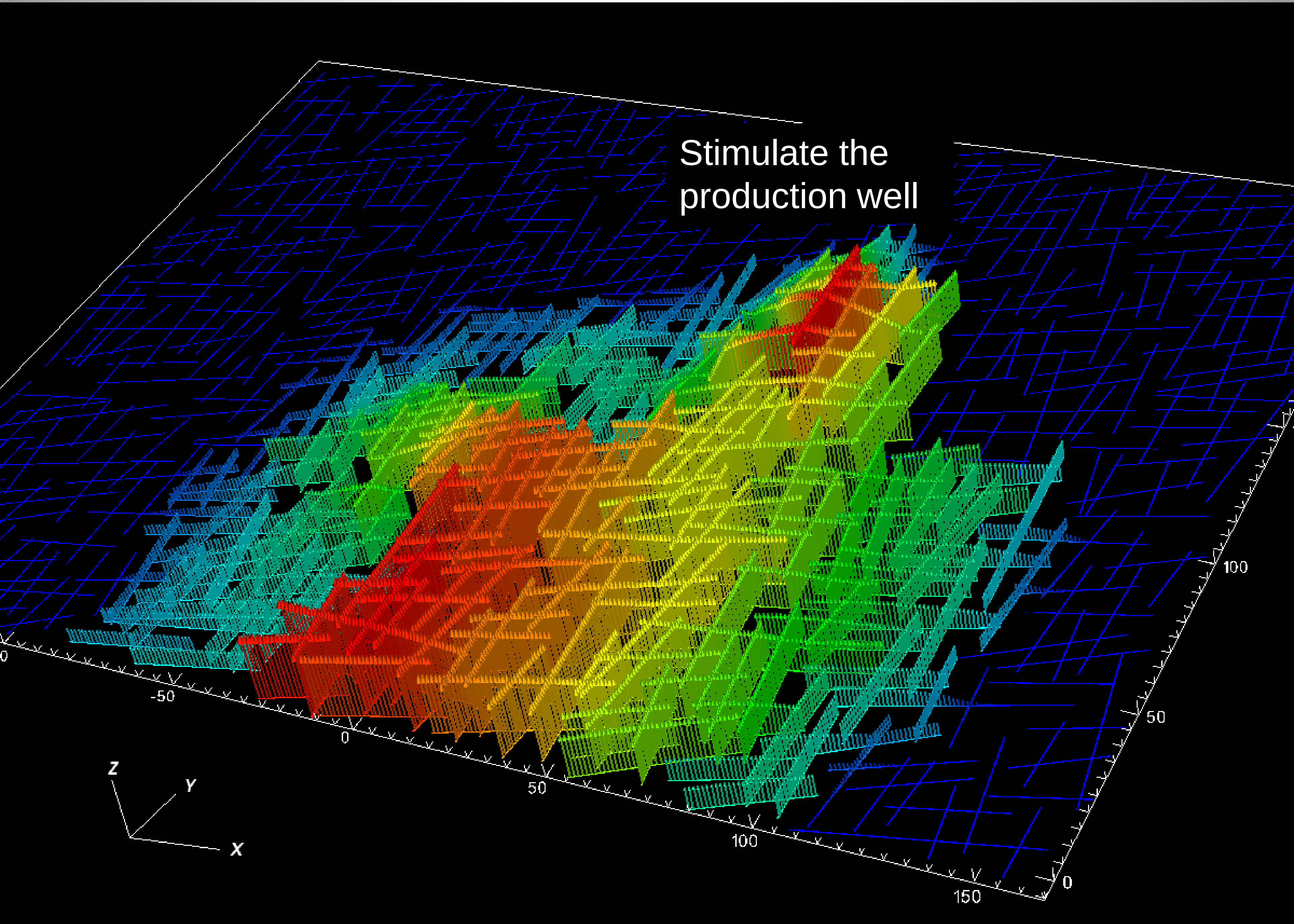
Stimulate the
production well
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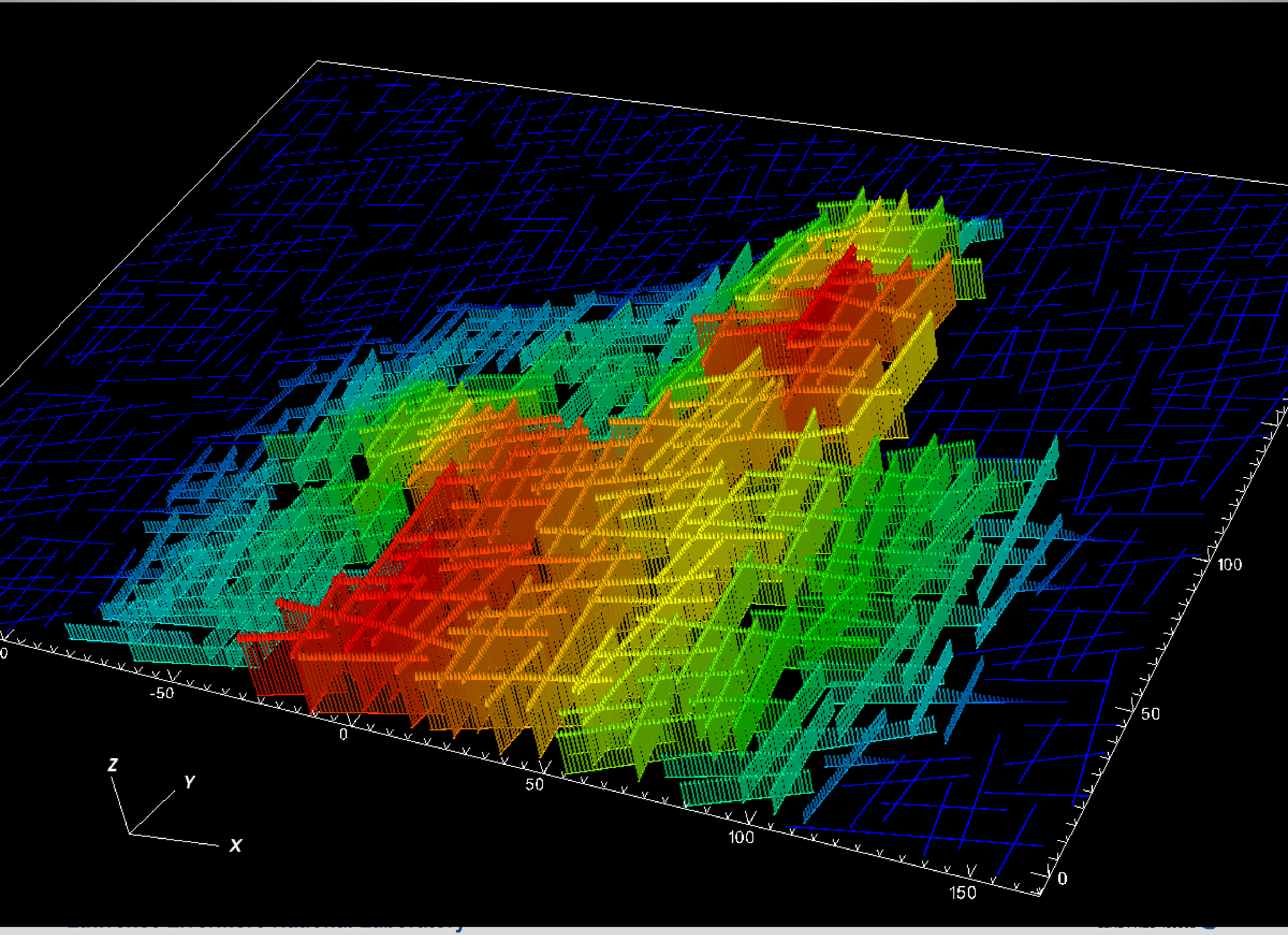

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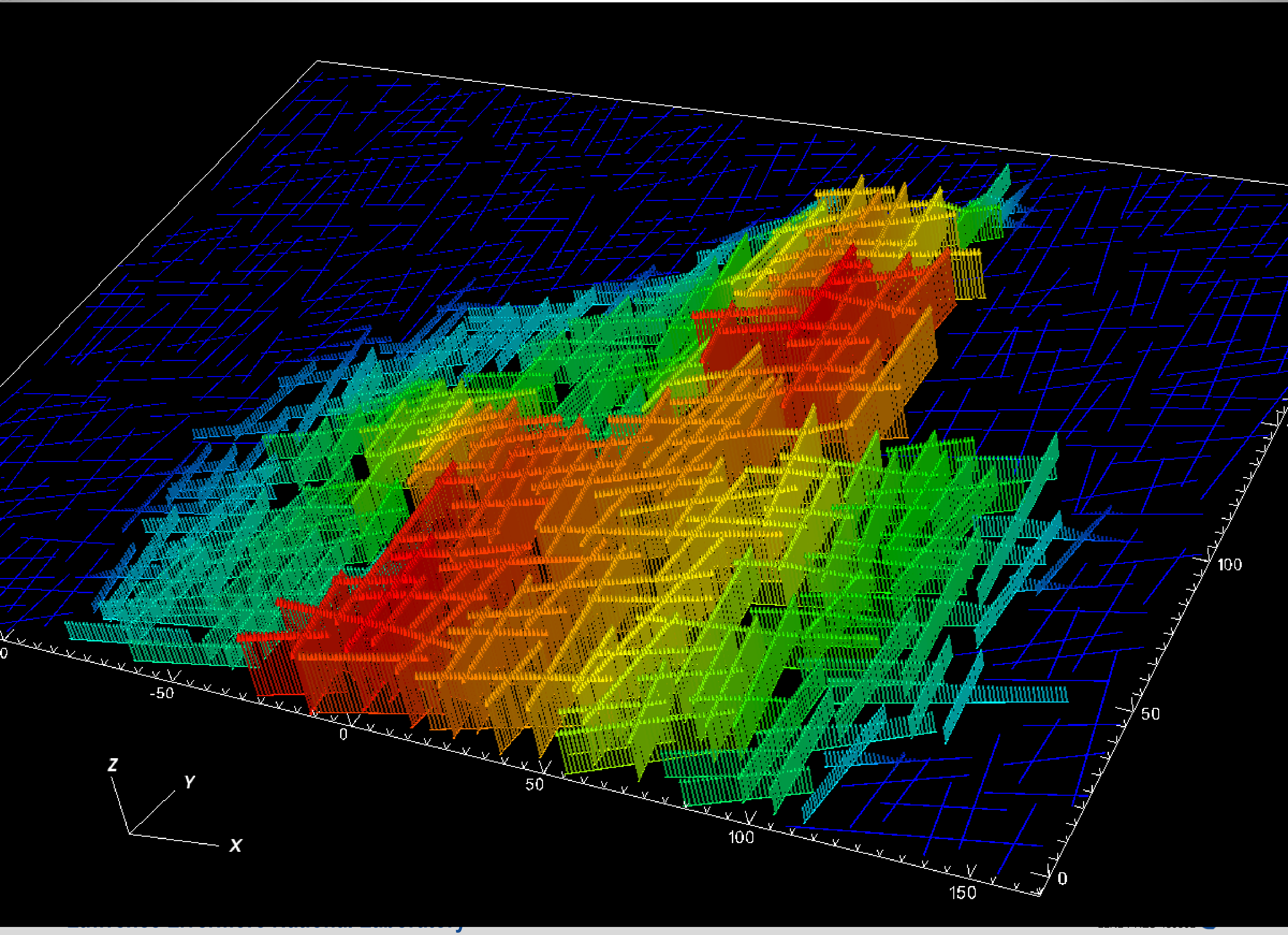
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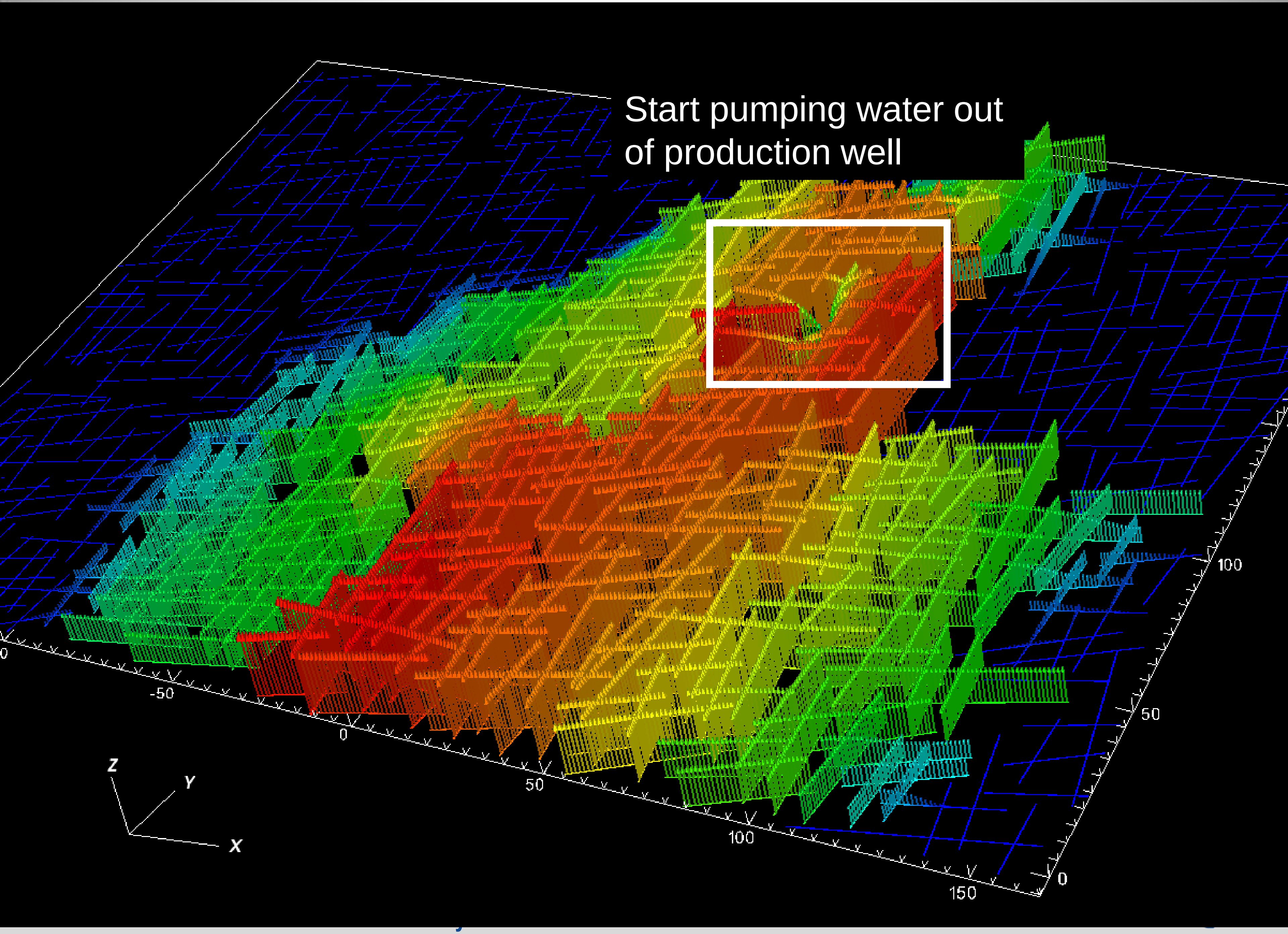

Start pumping water out of production well
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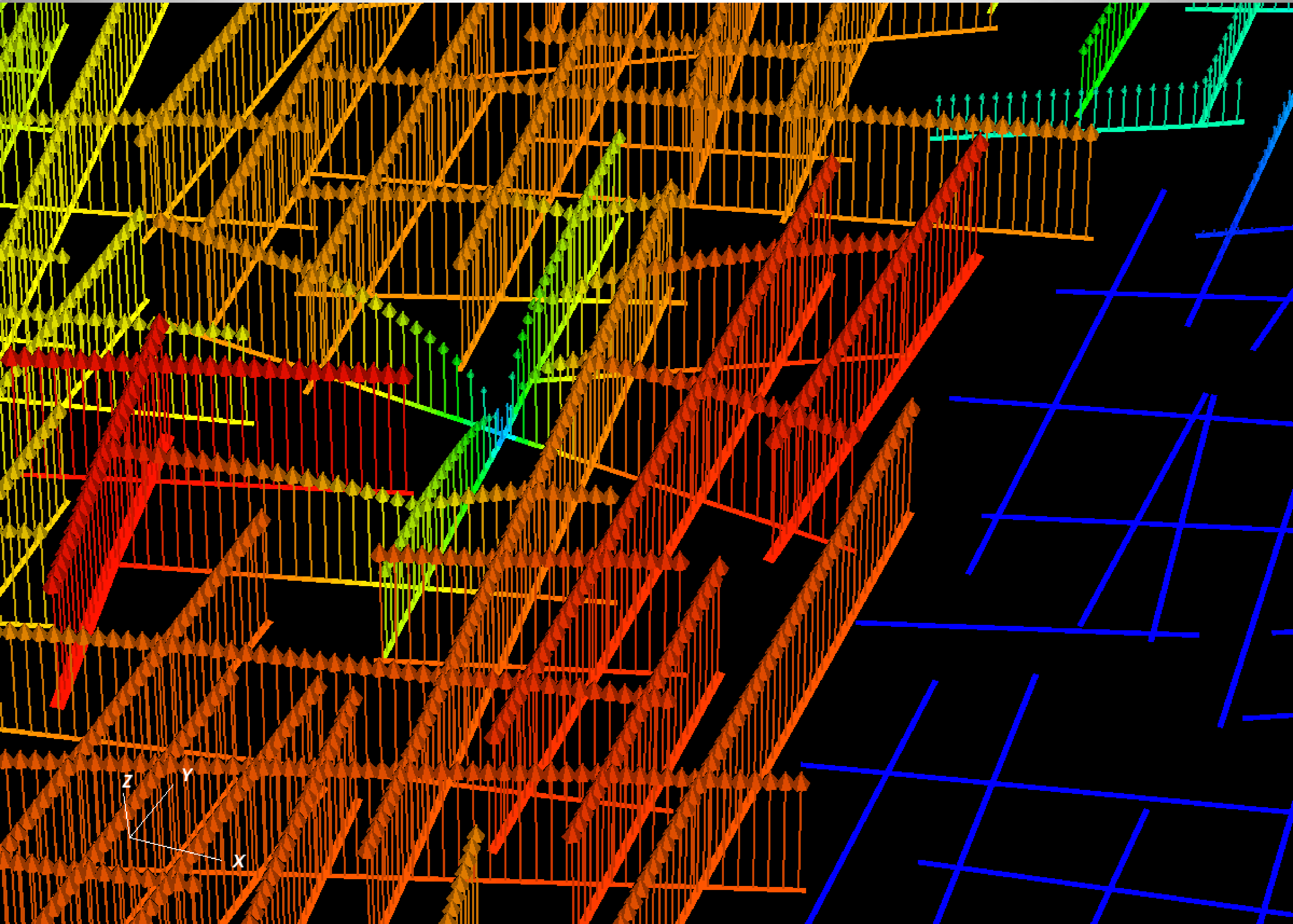
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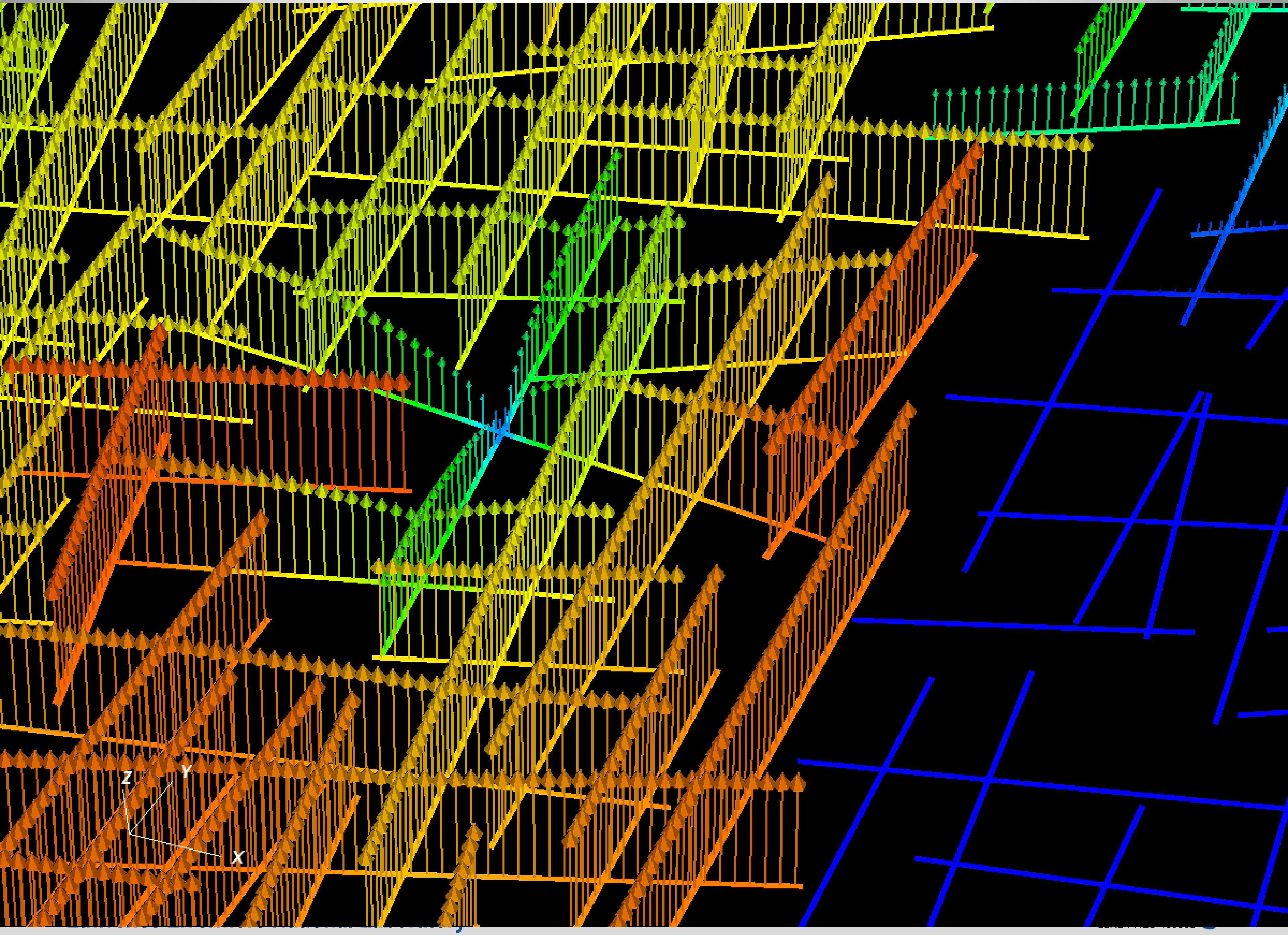
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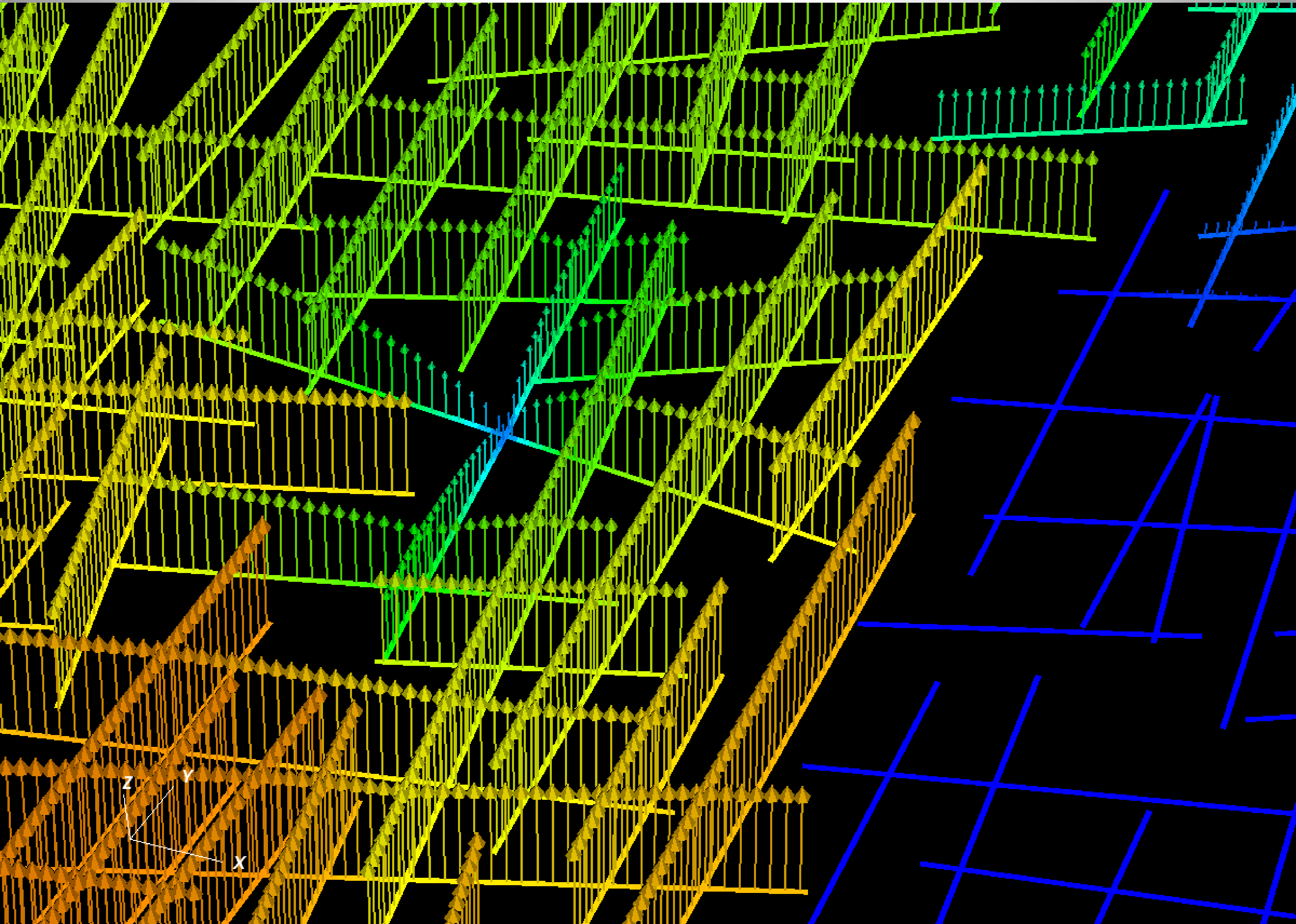
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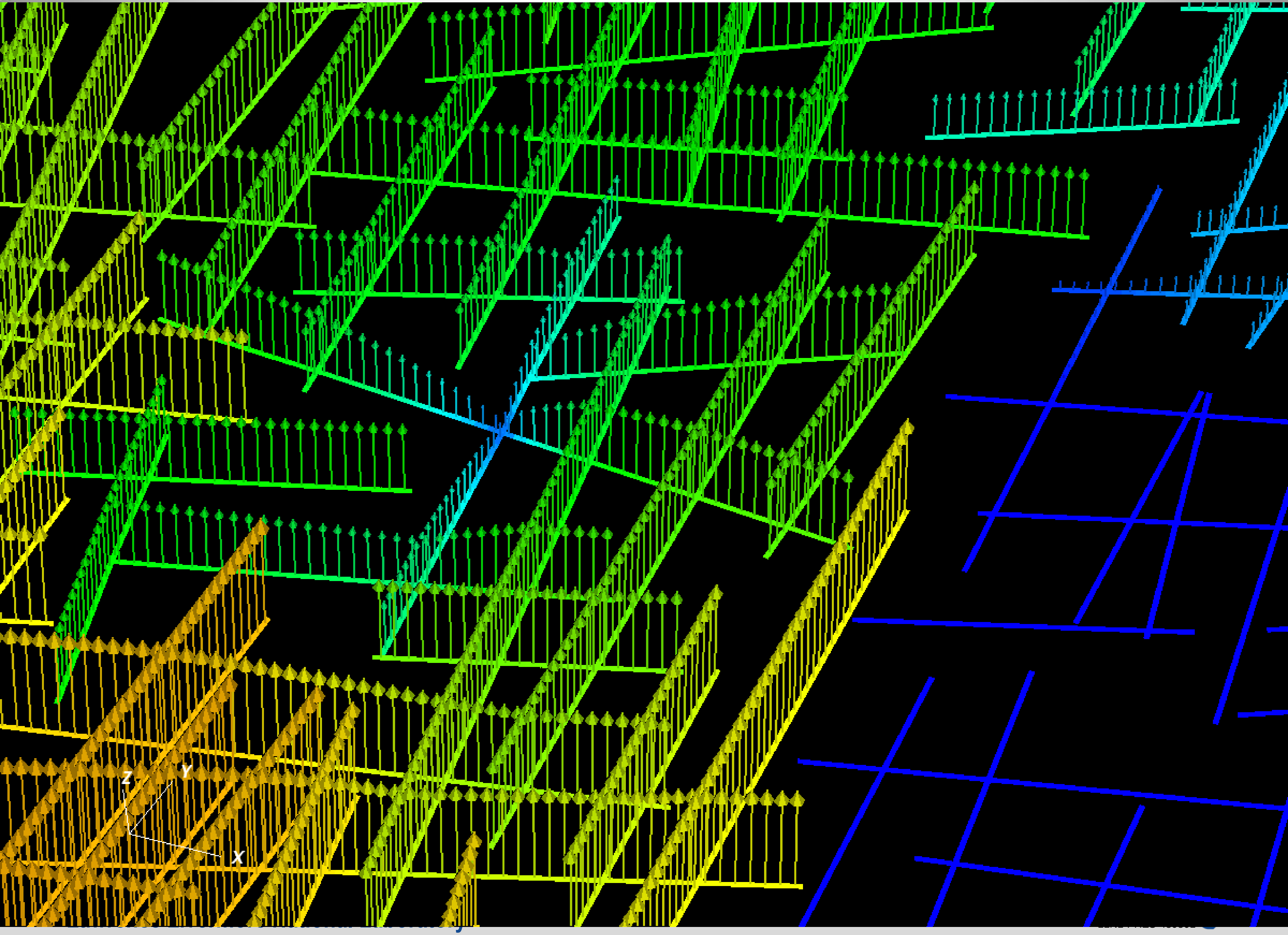
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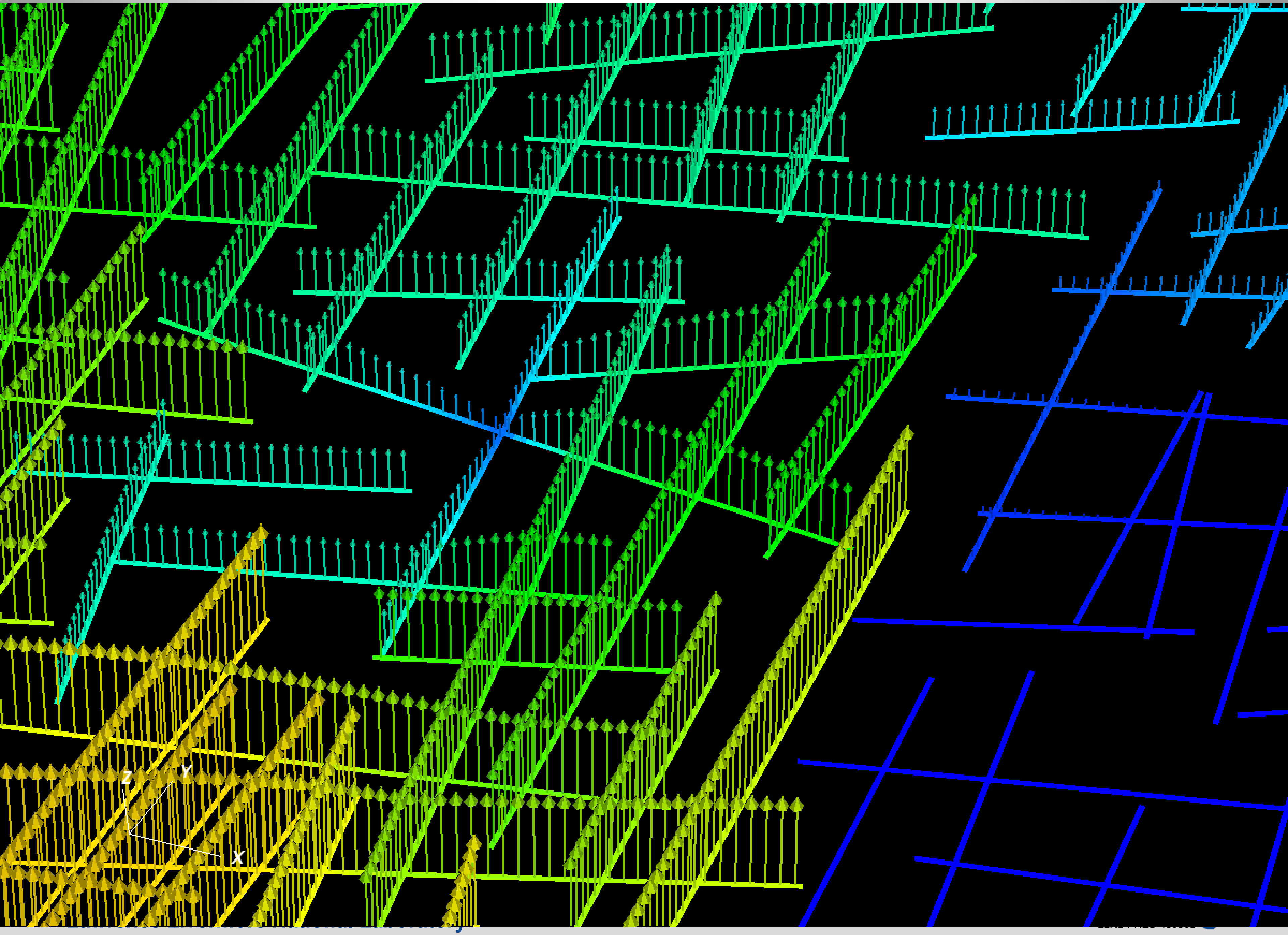
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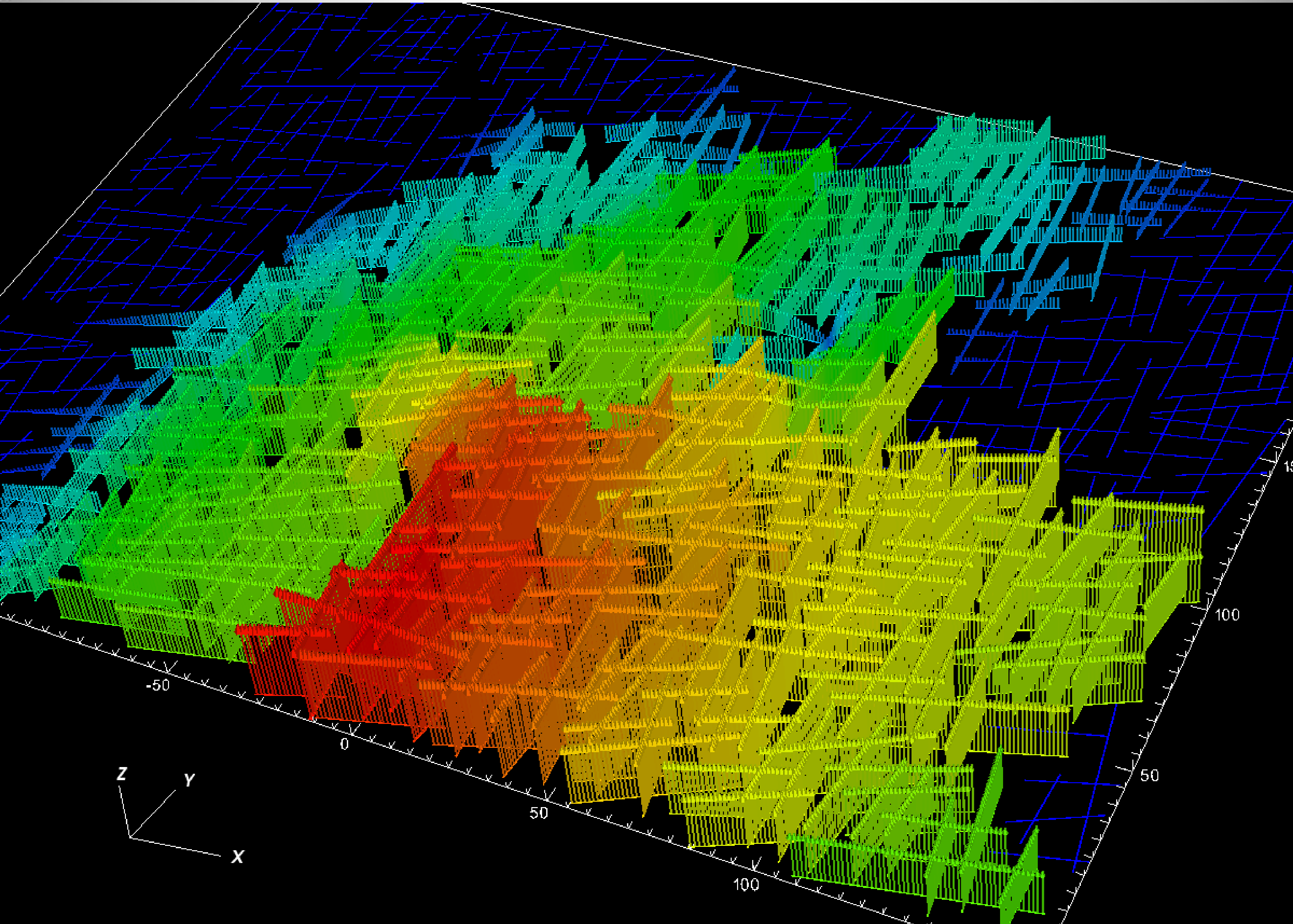

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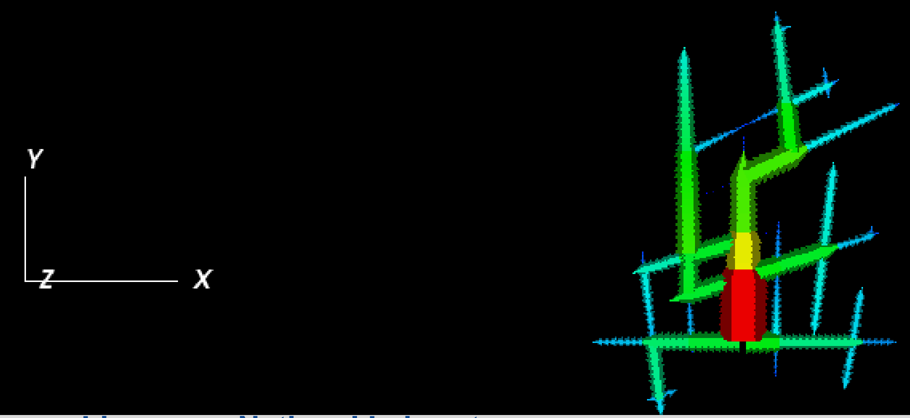
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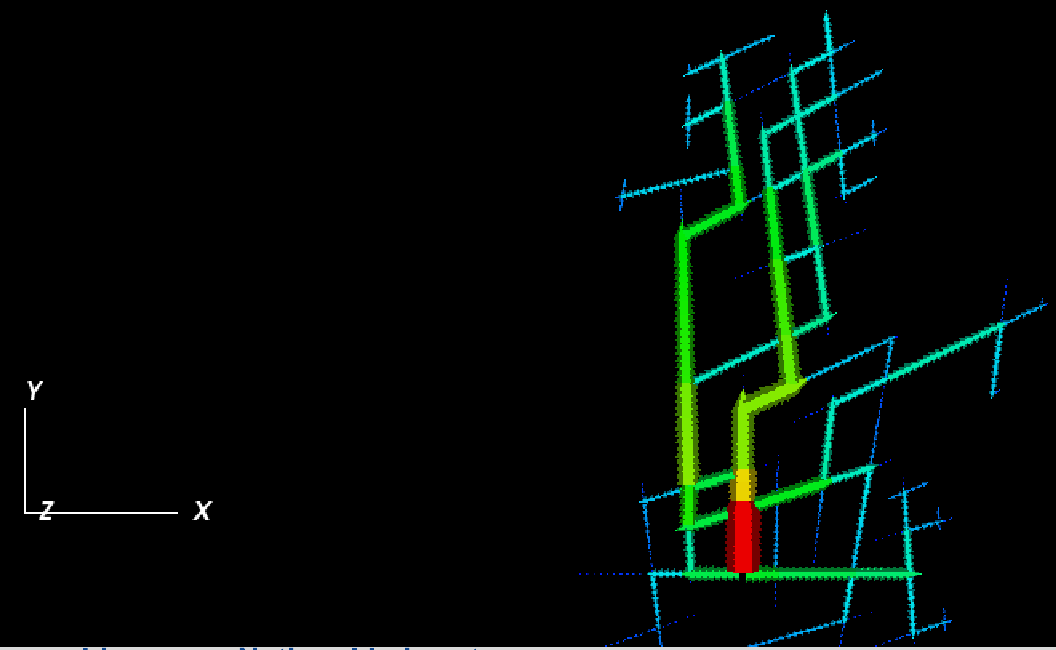
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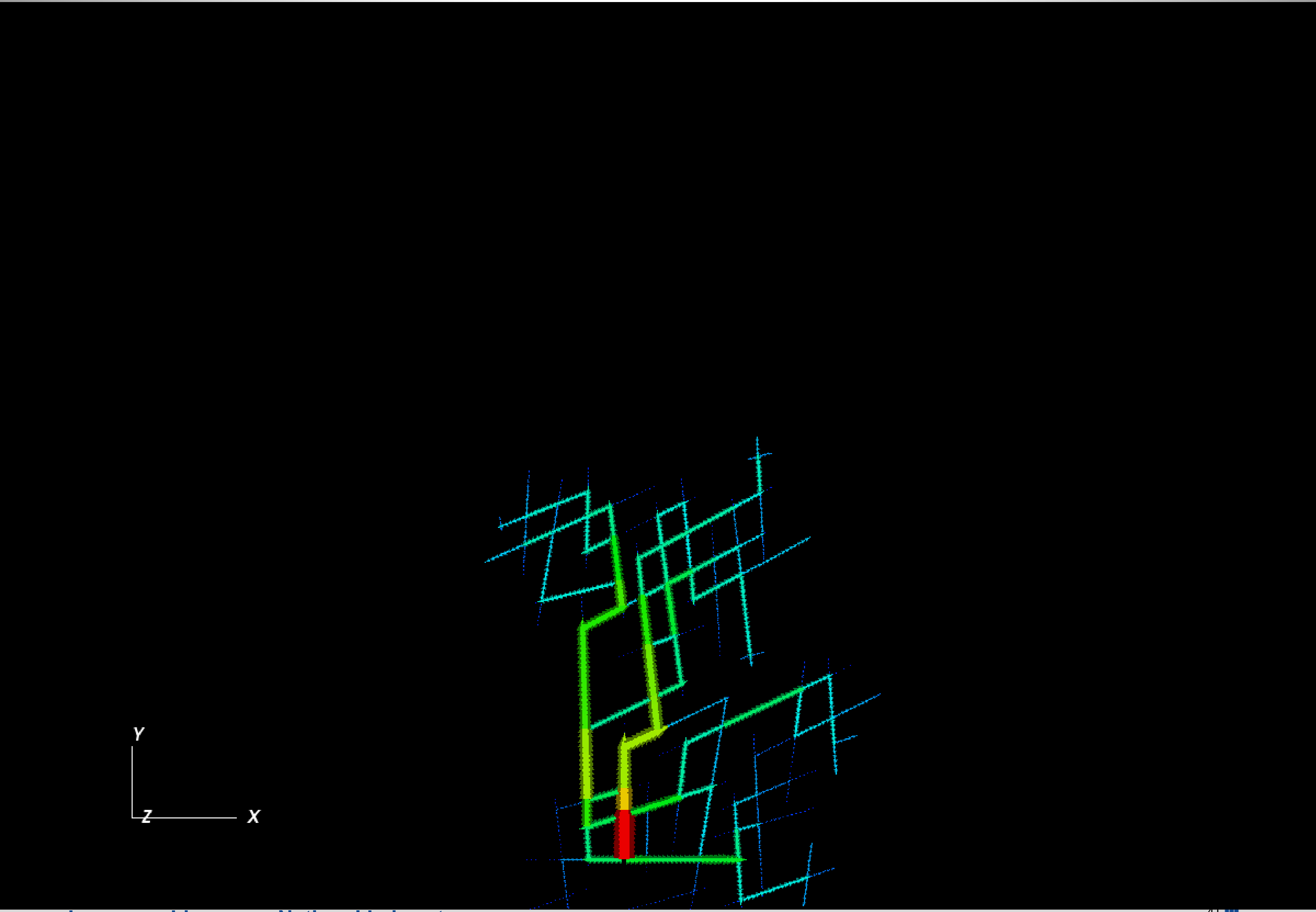
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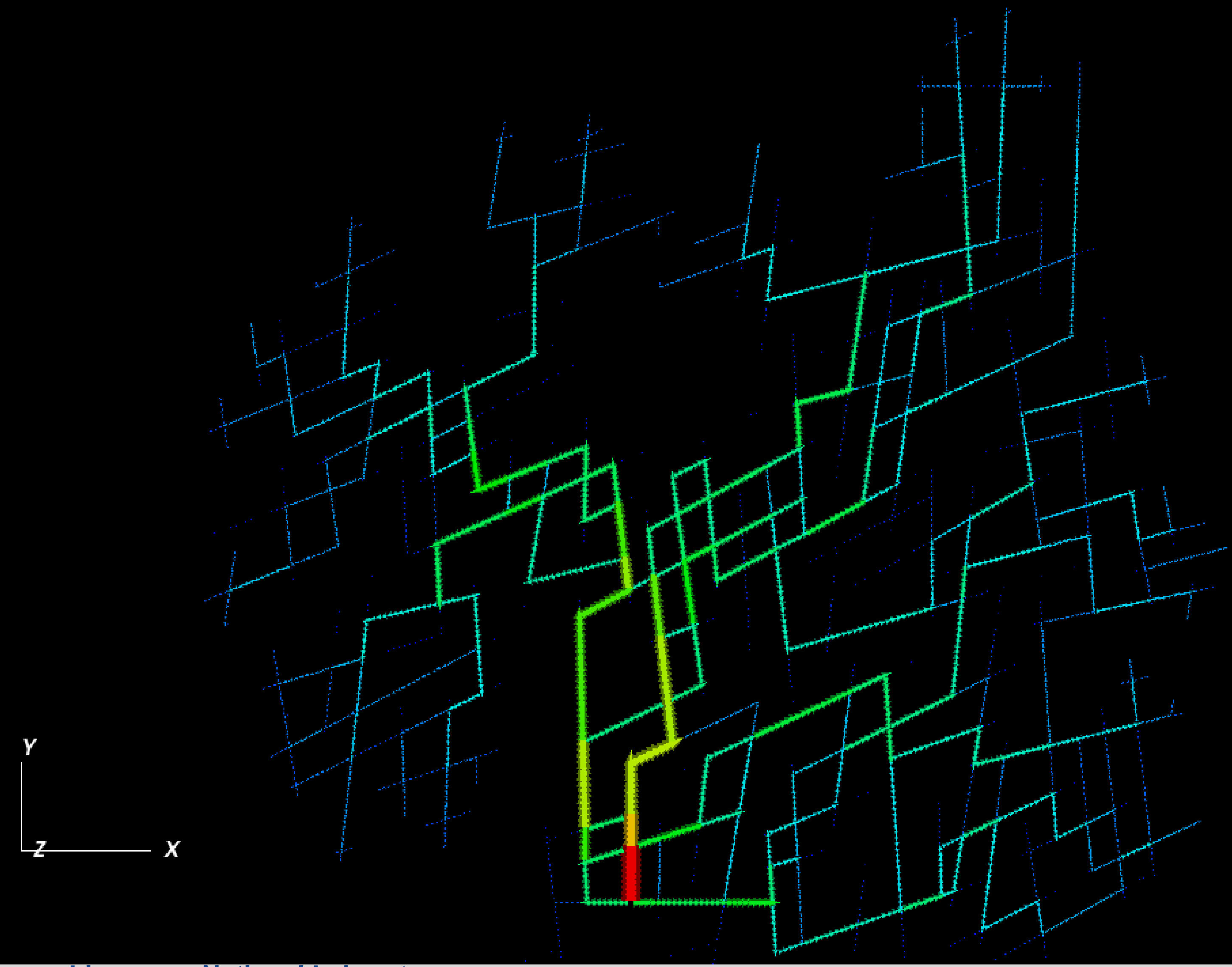
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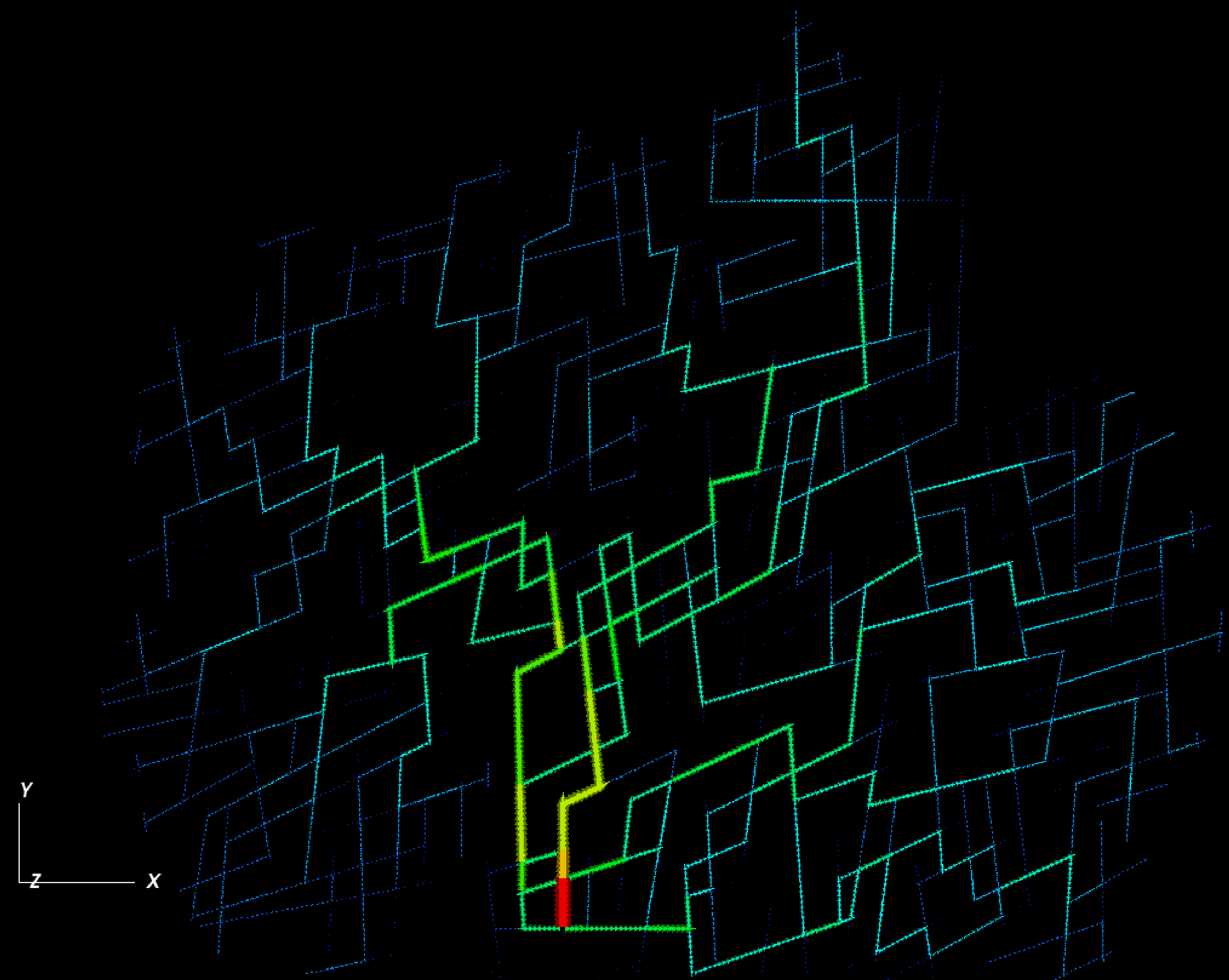
Y
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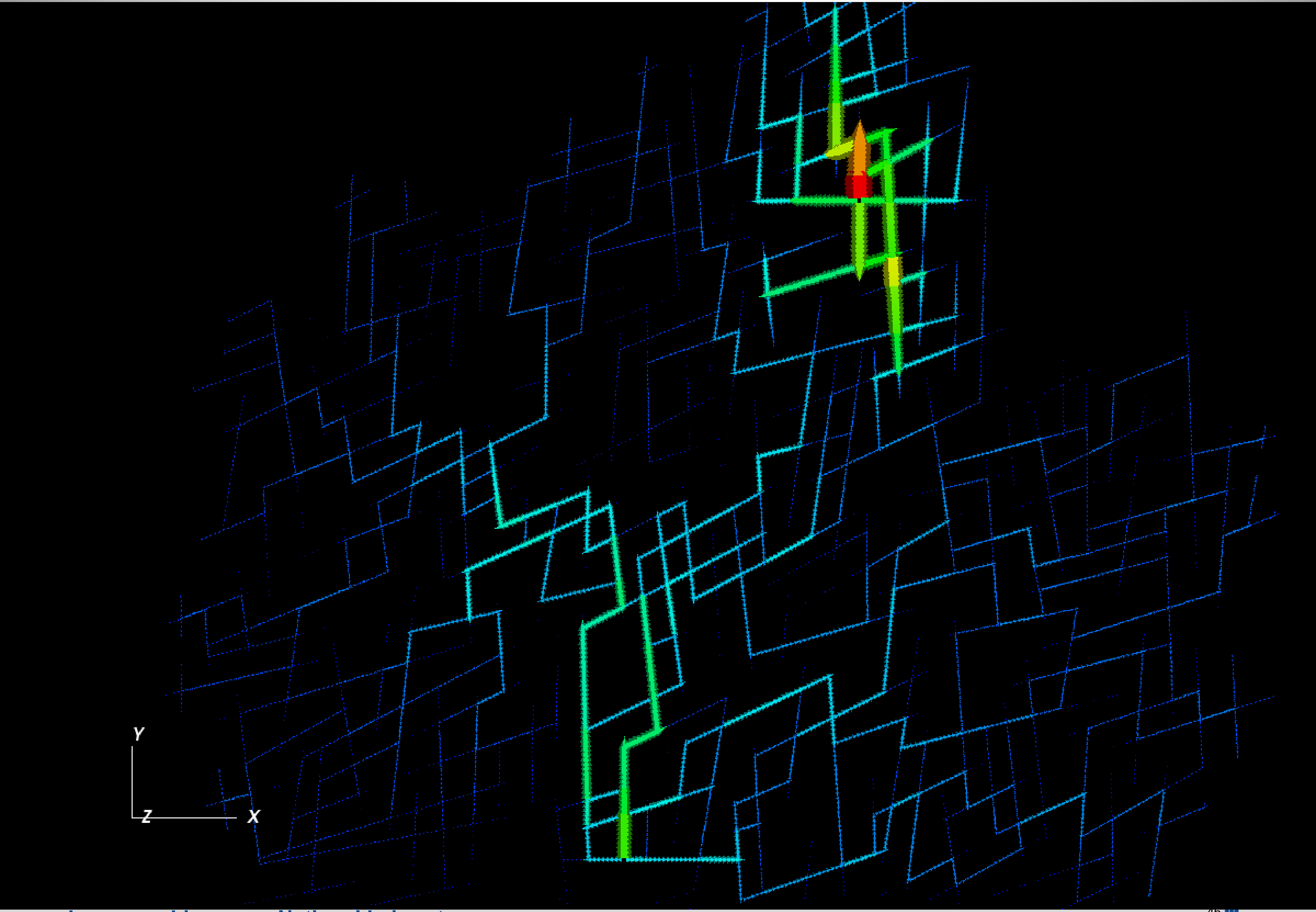
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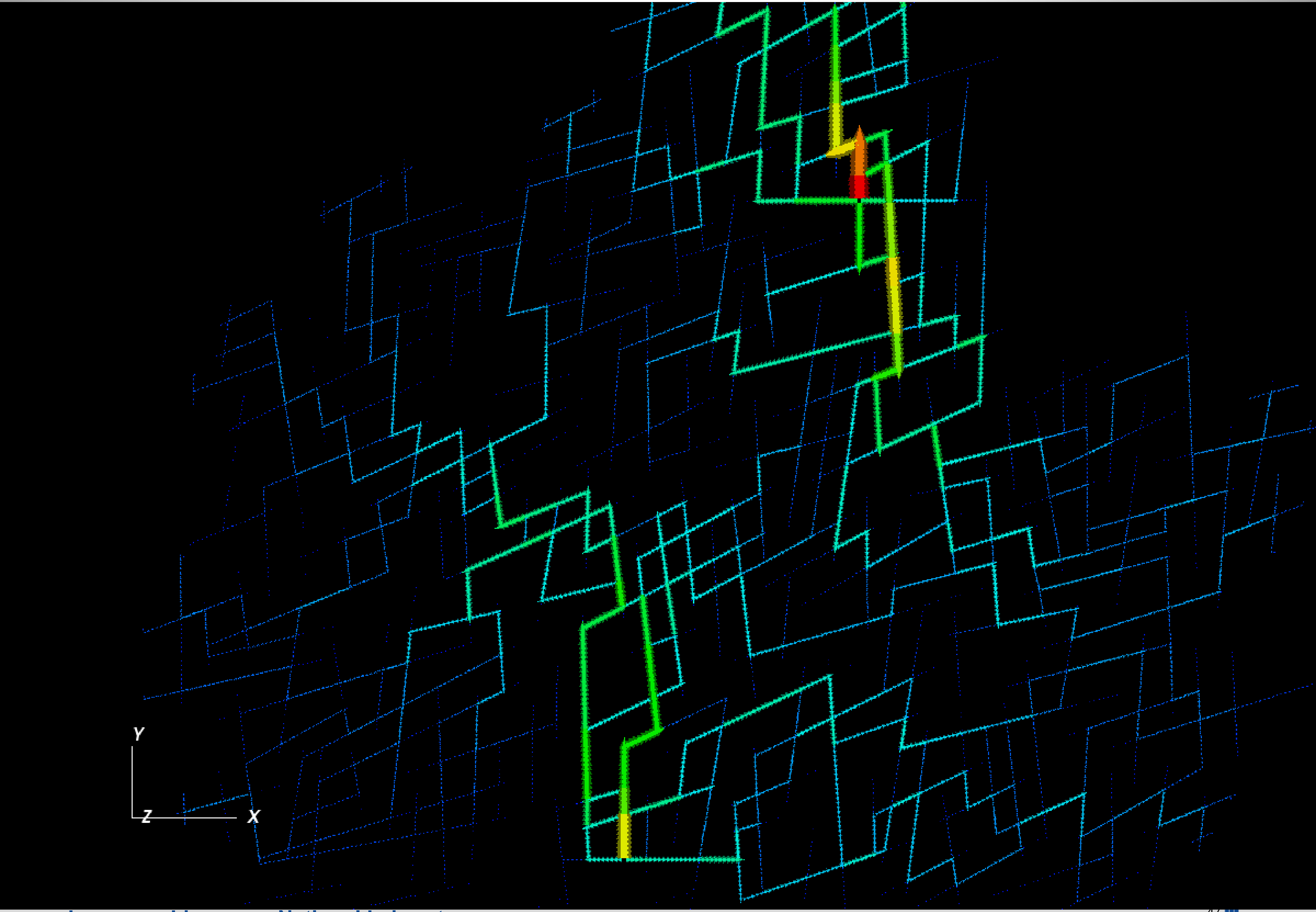
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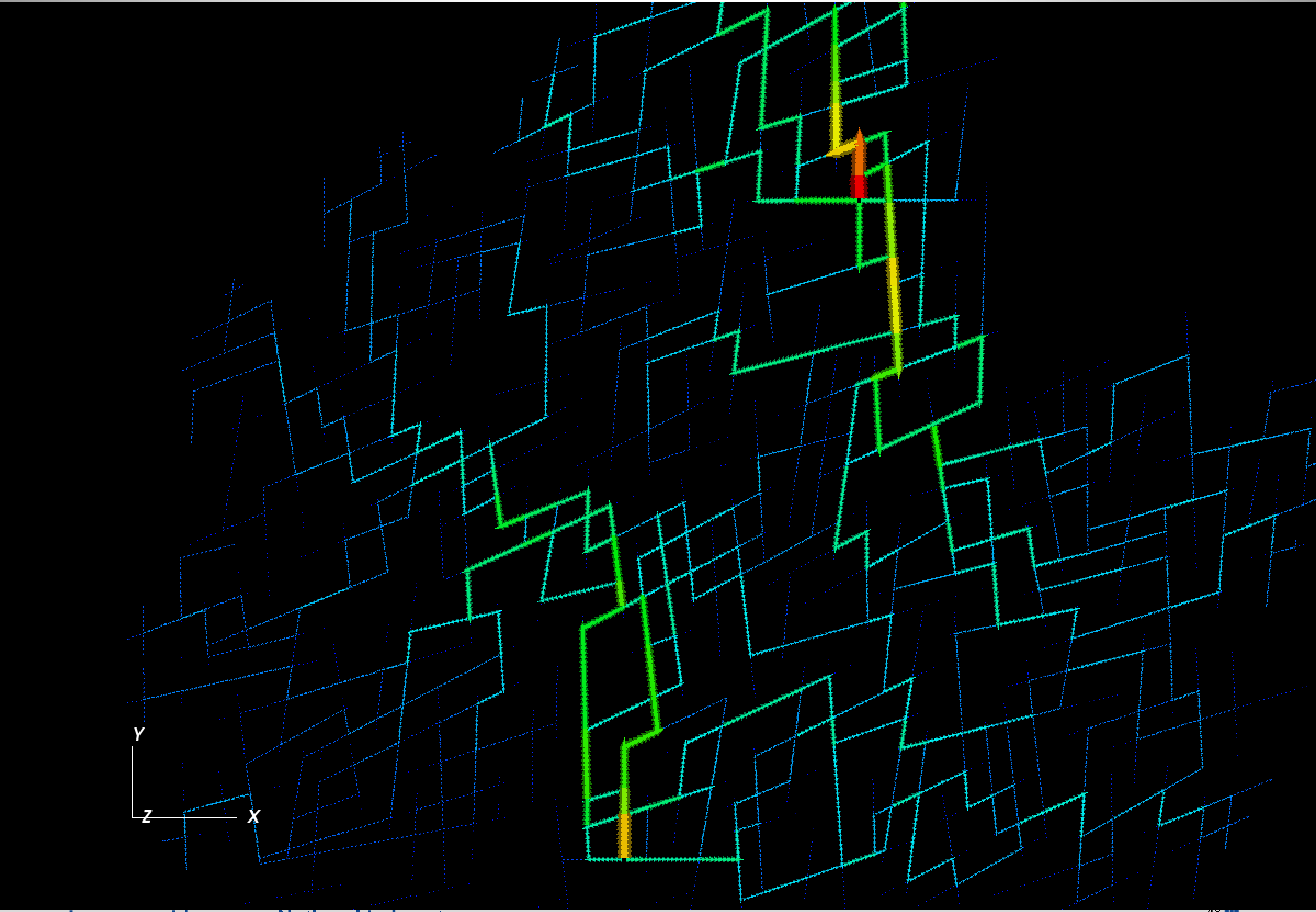
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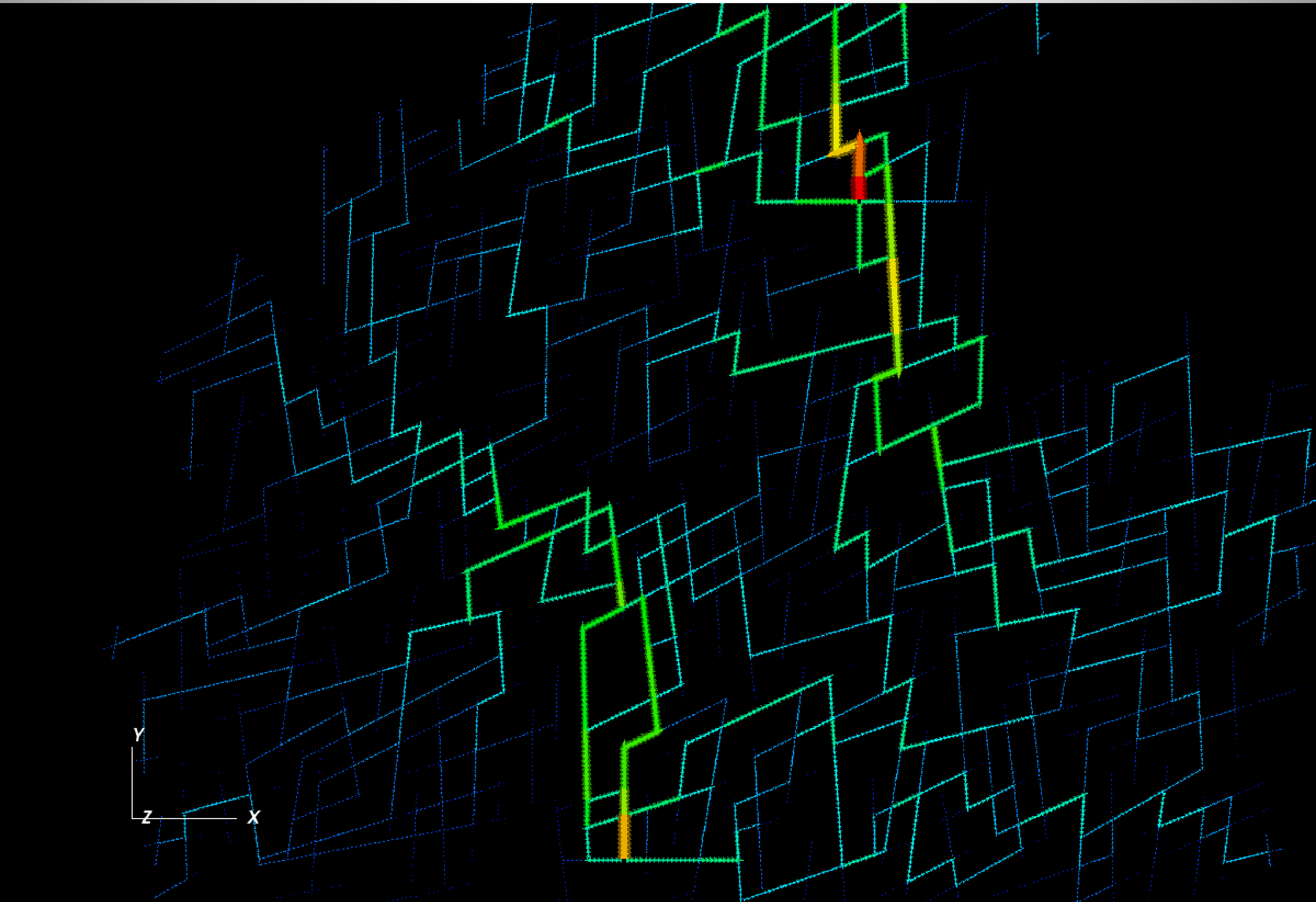
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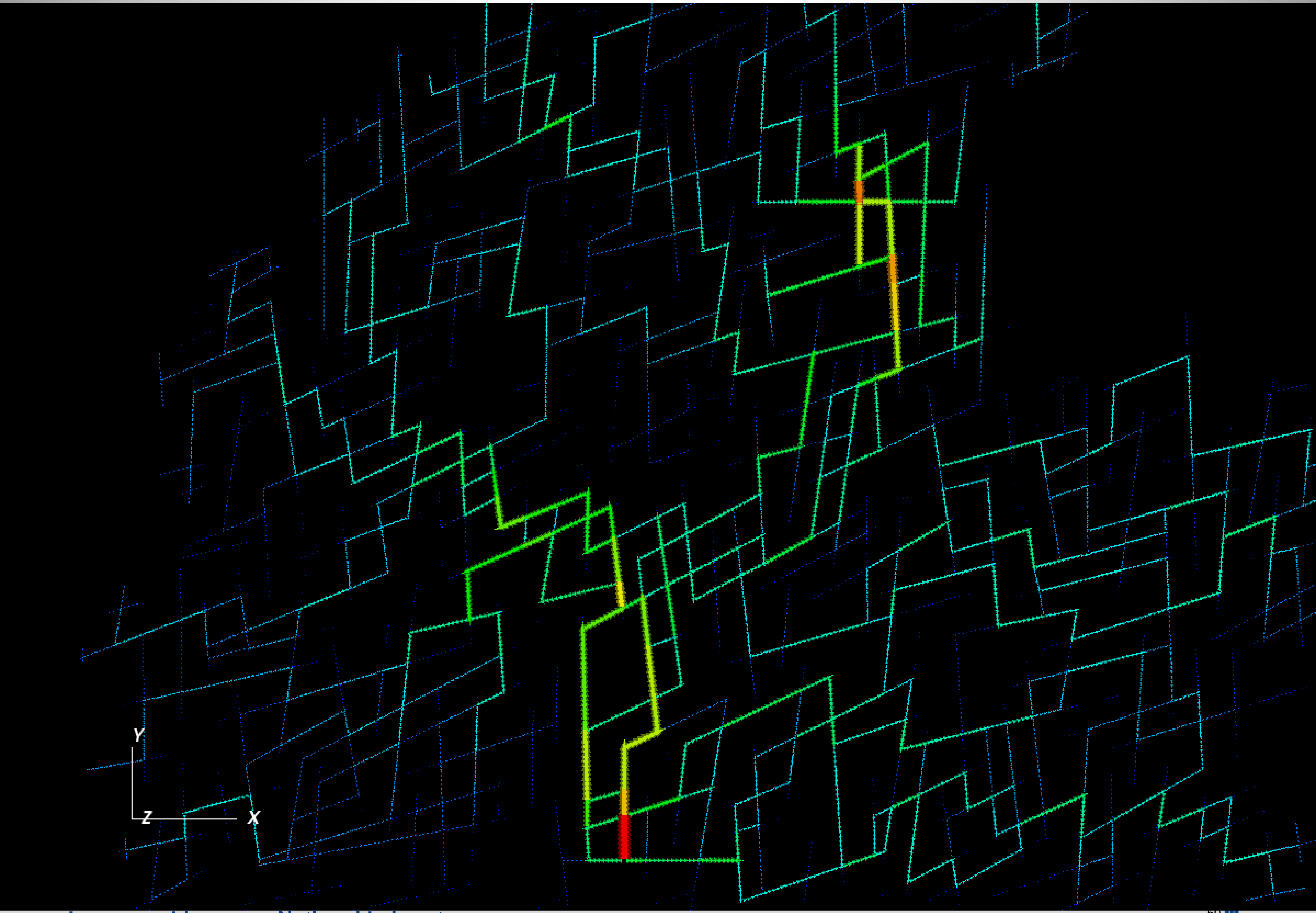
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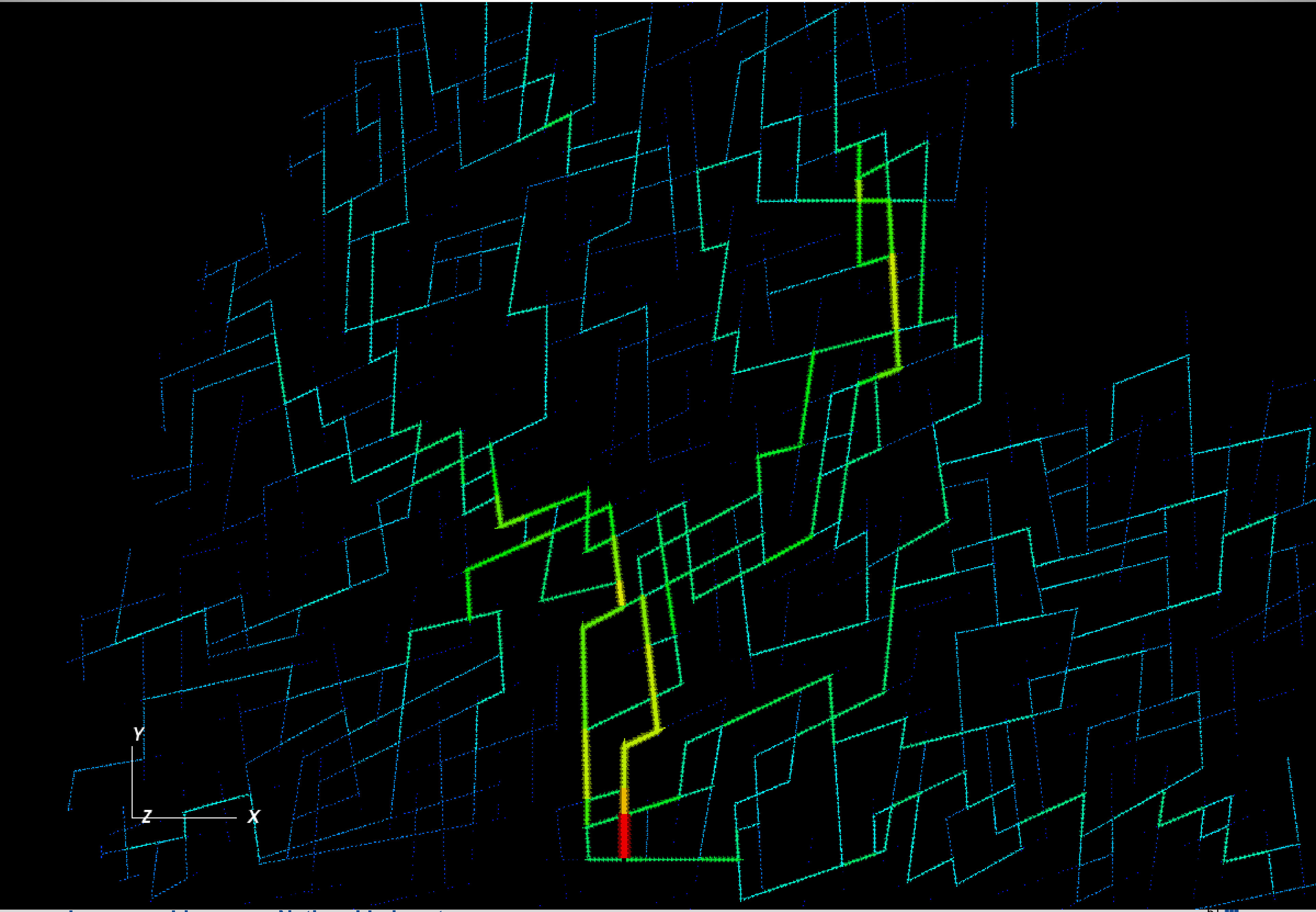
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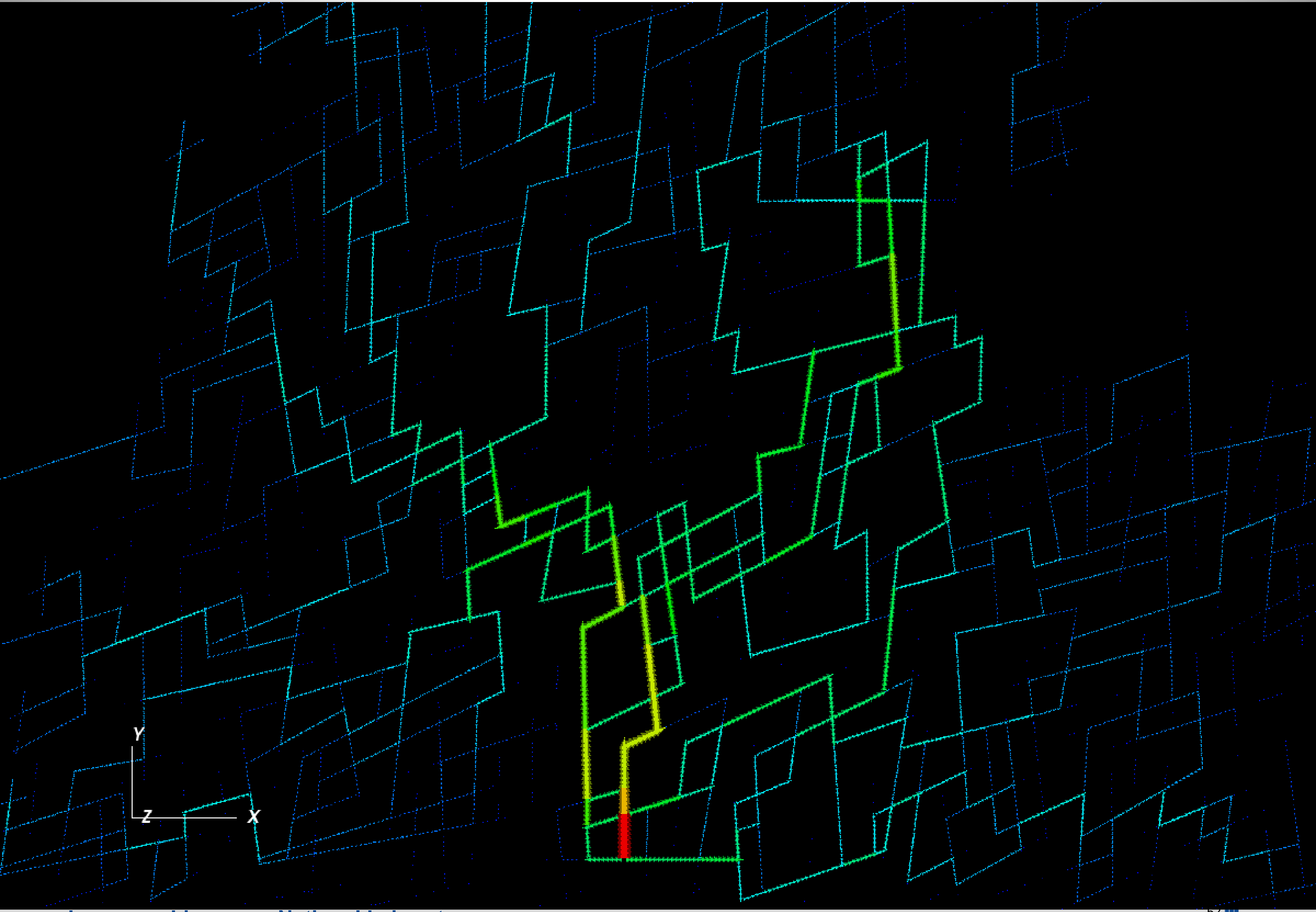
Y
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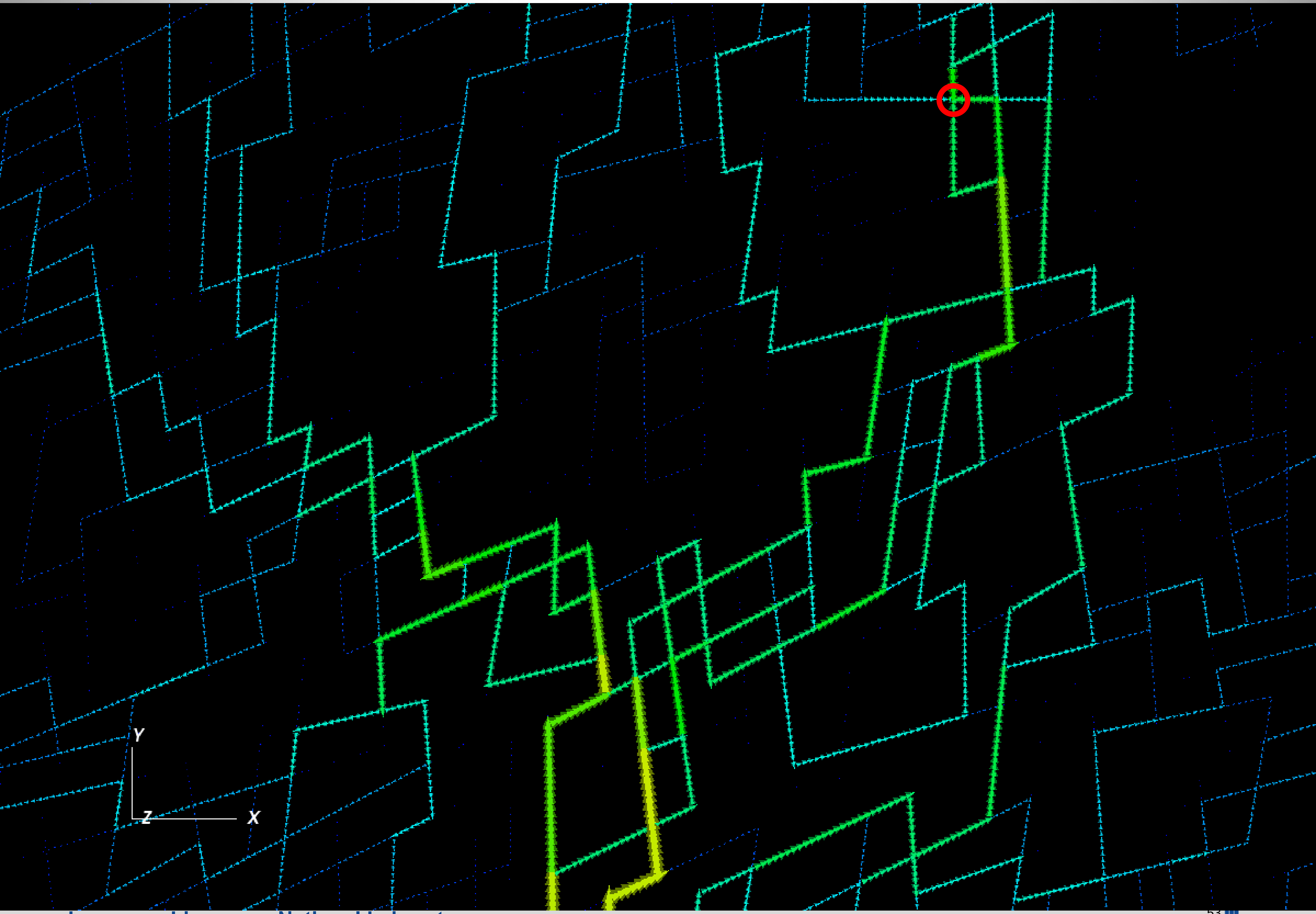
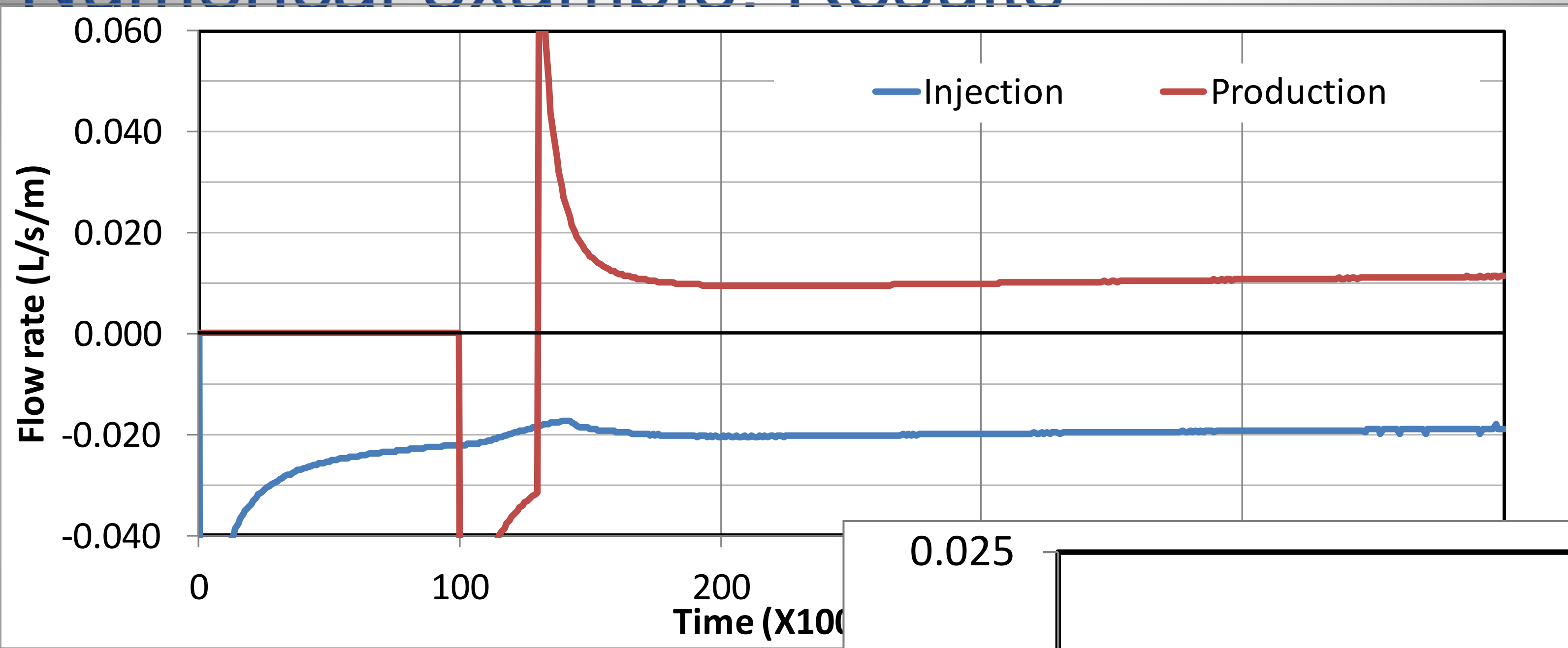
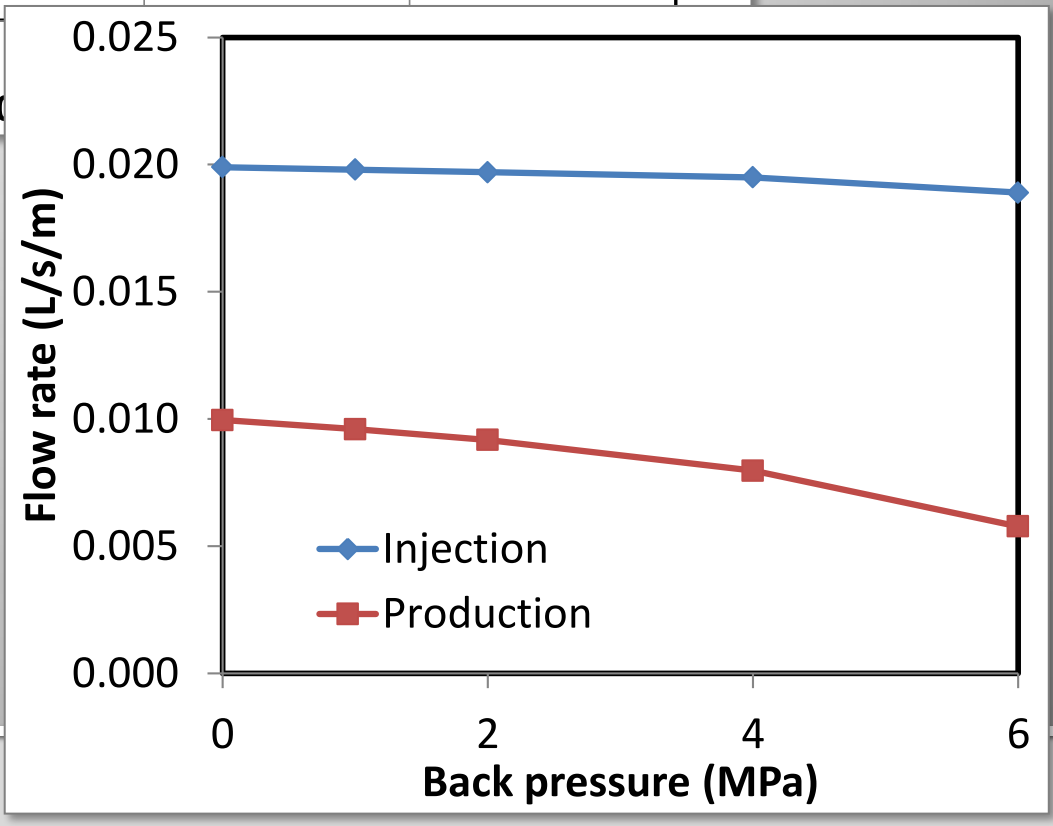
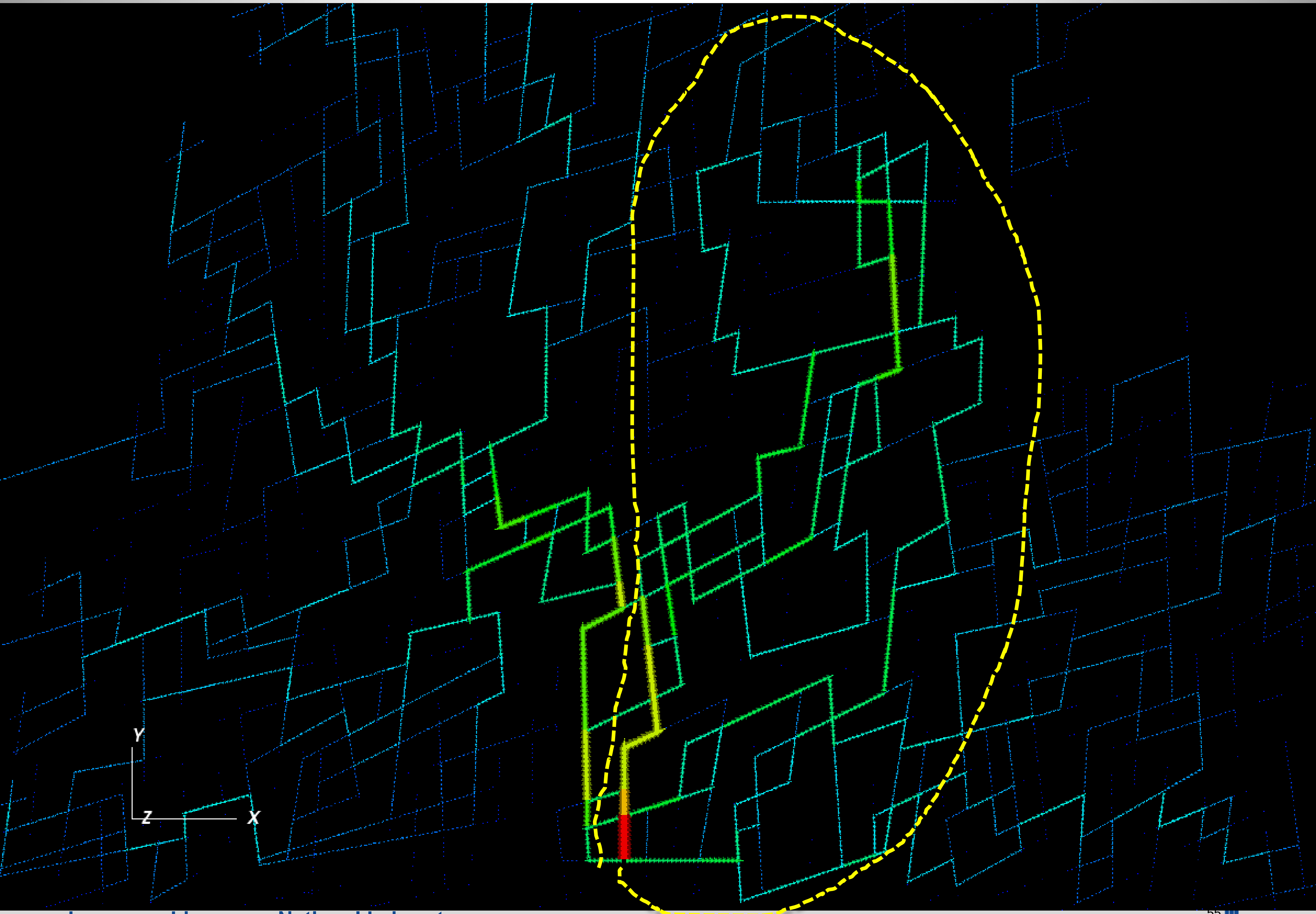
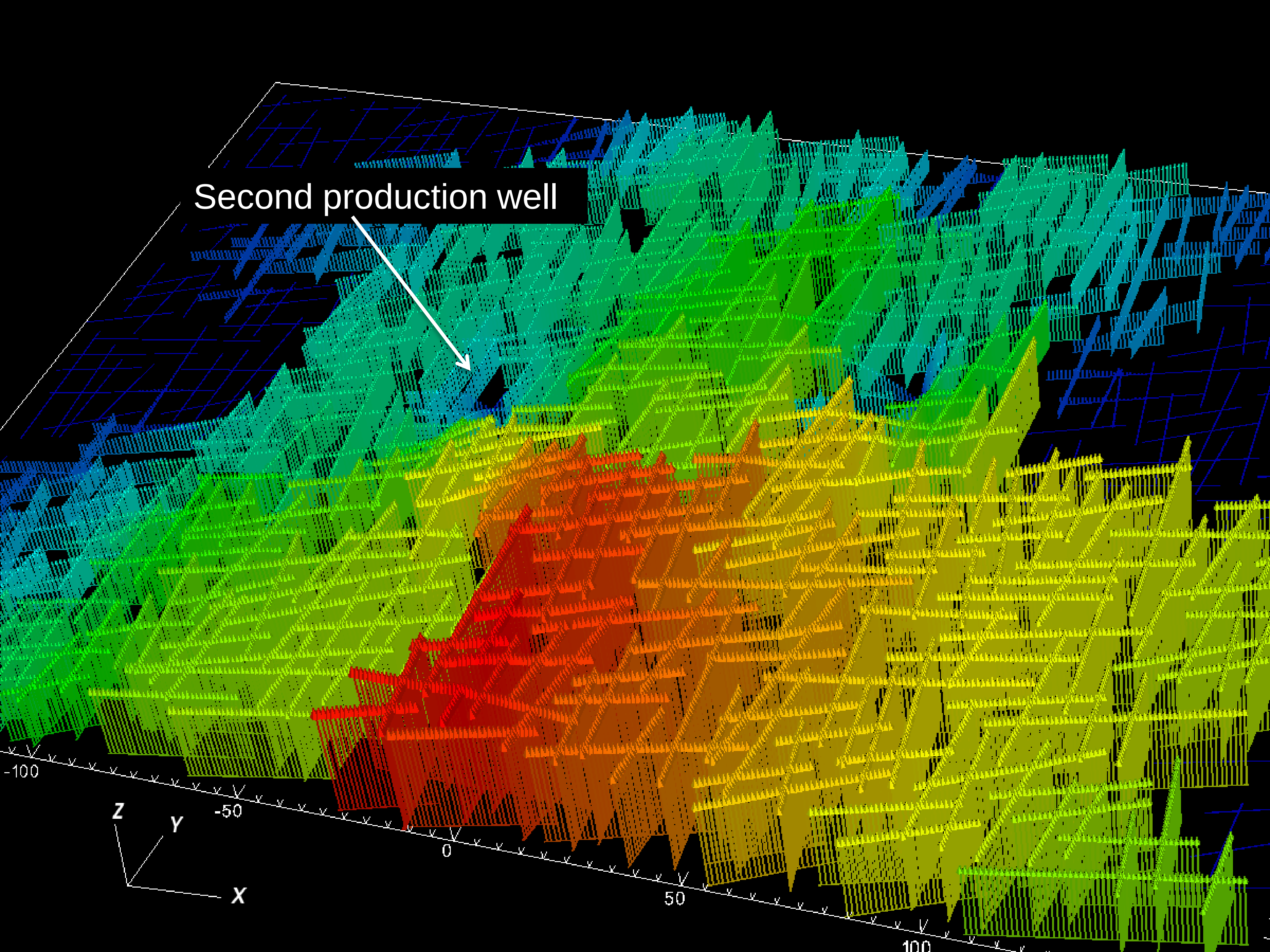

Y
Z
X

Numerical example: Results






Y
Z
X



Second production well
-100
-50
0
50
100
Z
Y
X

Concluding Remarks

- Low pressure stimulation is able to stimulate a fracture network.
  - Very different mechanics than high pressure hydro-fracturing.
- How well it works is sensitive to:
  - Initial connectivity of the natural fracture network
  - *In situ* stress
  - Rock joint characteristics
- Reservoir will infinitely grow, but will be slower and slower
  - It seems to be possible to achieve reasonable circulation with proper well configuration
- Numerical tool can used to study different scenarios
  - Hybrid high pressure – low pressure stimulation?

Acknowledgments

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A companion presentation

"Simulation of Hydraulic Fracture Networks in Three Dimensions" by Settgast et al.

@SESSION 10(B) Modeling 6, Wednesday, 10:45 am