The Influence of Natural Fractures on Hydraulic Fracture Propagation*

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Abstract

Complex hydraulic fracture geometry has become more evident with the widespread application of improved fracture diagnostic technology. Multi-stranded fracture propagation from vertical wells has been confirmed by coring, while microseismic data in naturally fractured reservoirs such as the Barnett Shale suggests significant diversion of hydraulic fracture paths due to intersection with natural fractures. Mechanical interaction between a propagating hydraulic fracture and pre-existing natural fractures seems to be the key component explaining why some reservoirs exhibit more complex behavior. There are several possibilities for the interaction between hydraulic and natural fractures. The likelihood of intersection between a hydraulic and natural fracture is partly a function of orientation. If the hydraulic and natural fracture directions are parallel, intersection is less likely, but there can still be interaction between close, en echelon overlaps of fractures, and the natural fractures may be reactivated by being within the process zone (region of altered stress) around the crack tip. If the natural fractures are orthogonal to the present-day hydraulic fracture direction, the propagating hydraulic fracture is likely to cross a large number of natural fractures as it propagates through the reservoir. Analytical results are presented to predict whether a hydraulic fracture will arrest, divert or continue across natural fractures when intersected. Numerical results are presented to show potential complex, multi-stranded hydraulic fracture geometries in naturally fractured reservoirs from single or multiple injection points. Examples include cases where the hydraulic fracture direction is sub-parallel to the natural fracture strike as well as perpendicular.

References

Atkinson, B. K., 1987, Introduction to fracture mechanics and its geophysical applications, *in* B. K. Atkinson, ed., Fracture Mechanics of Rock: London, Academic Press, p. 1–26.

Fisher, M.K., J.R. Heinze, C.D. Harris, B.M. Davidson, C.A. Wright, and K.P. Dunn, 2004, Optimizing horizontal completion techniques in the Barnett shale using microseismic fracture mapping: Proceedings of the Society of Petroleum Engineers Annual Technical Conference, Houston, Texas, SPE Paper 90051, 11 p.

Kim , B.H., P.K. Kaiser, and G. Grasselli, 2007, Influence of persistence on behavior of fractured rock masses *in* C. David and M. LeRavalec-Dupin, eds., Rock Physics and Geomechanics in the Study of Reservoirs and Repositories, London Geological Society Special Publications, v. 284, p. 161-173.

Olson, J. E., 1993, Joint pattern development: Effects of subcritical crack-growth and mechanical crack interaction: Journal of Geophysical Research, v. 98, p. 12,251–12,265.

Olson, J. E., 2004, Predicting fracture swarms—The influence of subcritical crack growth and the crack-tip process zone on joint spacing in rock, *in* T. Engelder and J. W. Cosgrove, eds., The Initiation, Propagation, and Arrest of Joints and Other Fractures: Geological Society (London) Special Publication 231, p. 73–87.

Olson, J. E., 2007, Fracture aperture, length and pattern geometry development under biaxial loading: A numerical study with applications to natural, cross-jointed systems, *in* G. Couples and H. Lewis, eds., Fracture-like Damage and Localization: Geological Society (London) Special Publication 289, p. 123–142.

Olson, J.E., S.E Laubach, and R.H. Lander, 2009, Natural fracture characterization in tight gas sandstones: Integrating mechanics and diagenesis: AAPG Bulletin, v. 93/11, p. 1535-1549.

Rijken, P. 2006, Petrographic and chemical controls on subcritical fracture growth: Dissertation Ph.D, University of Texas at Austin, Austin, Texas, 239 p.

Warpinski, N.R., and L.W. Teufel, 1987, Influence of geologic discontinuities on hydraulic fracture propagation: Journal of Petroleum Technology, v. 39/2, p. 209-220.

The Influence of Natural Fractures on Hydraulic Fracture Propagation

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Motivation / Inspiration

- complex hydraulic fractures (HF) are making some plays viable (tight gas ss, shale gas) by maximizing surface area for inflow – Warpinski & Teufel (1987); Fisher et al. (2004)
- complexity in natural fracture (NF) patterns attributed to stress state and subcritical crack growth parameters - Olson et al. (2009)
- multi-frac propagation models can capture HF – NF interaction
- fracturing fluid chemistry may give us tool to influence HF complexity

Fracture Propagation Criteria

- critical propagation at when $K_I=K_{Ic}$ (fracture toughness), propagation accelerates to rupture velocity, velocity ~10^3 m/s
- subcritical propagation (stress corrosion mechanism) occurs when $K_I<K_{Ic}$, velocity $\propto K_I$, velocity $\leq 10^{-3}$ m/s
- hydraulic fracturing velocities in transition zone between subcritical and critical

Propagation Criteria

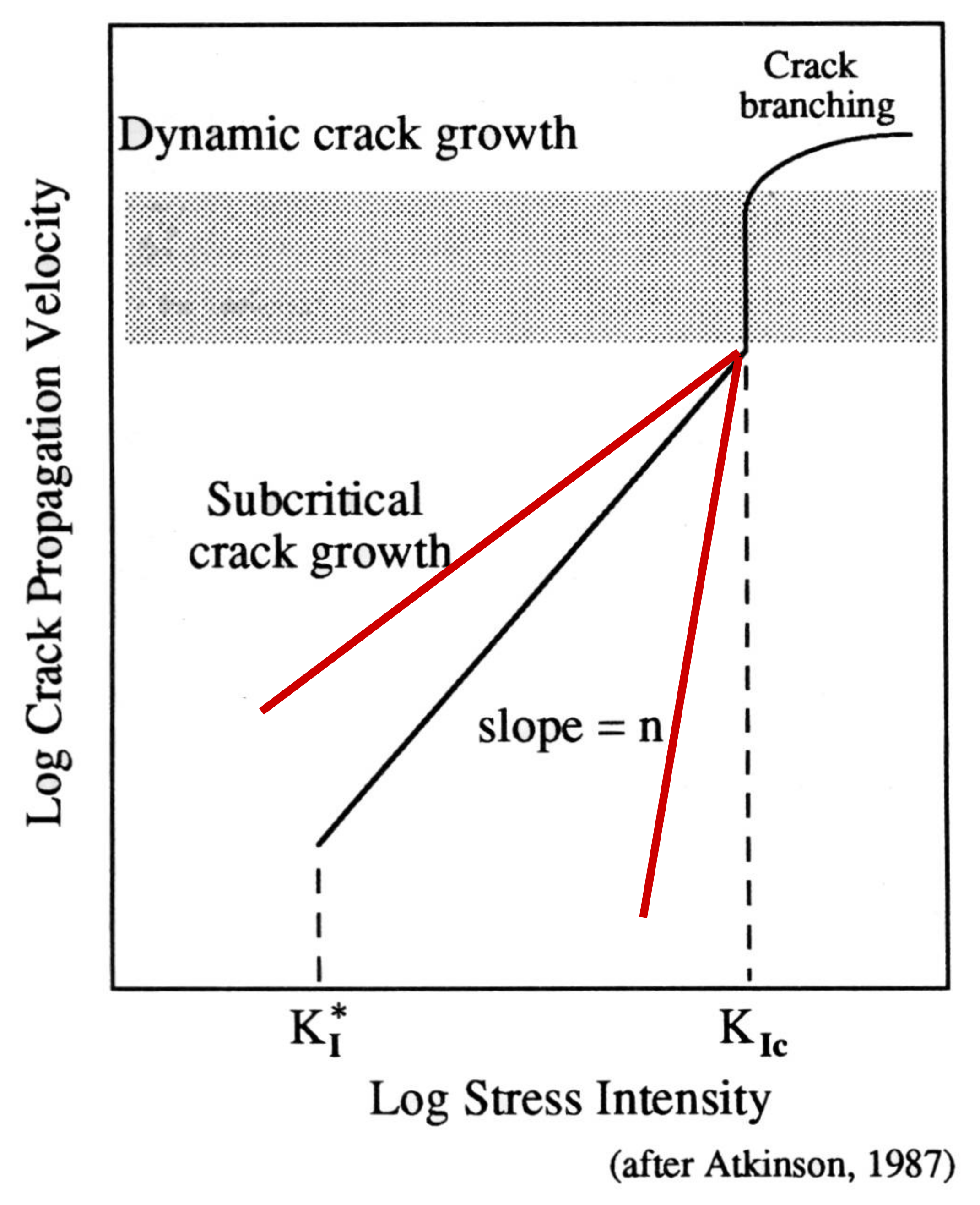
$v \propto (K_I / K_{Ic})^n$

lower n

- less velocity contrast
- more growth at low stress intensity

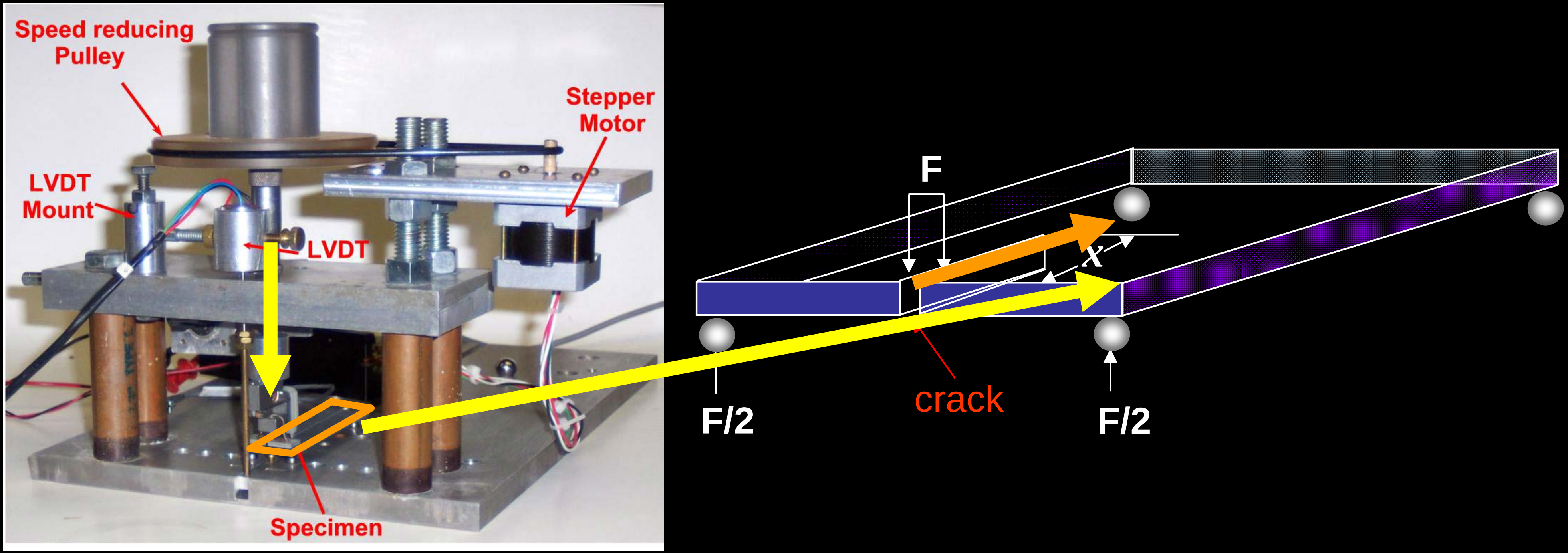
higher n

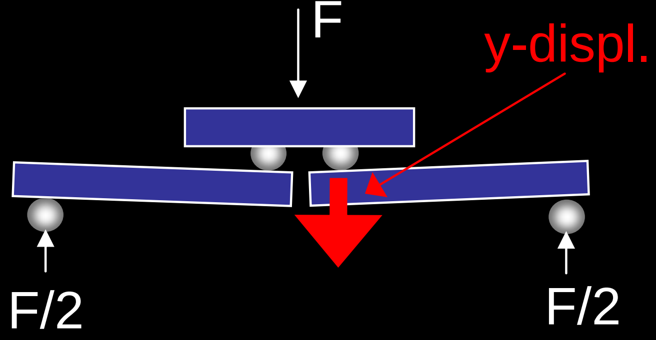
- more velocity contrast
- growth only at high stress intensity
- approaching critical



(after Atkinson, 1987)

Measuring Stress Corrosion Parameters

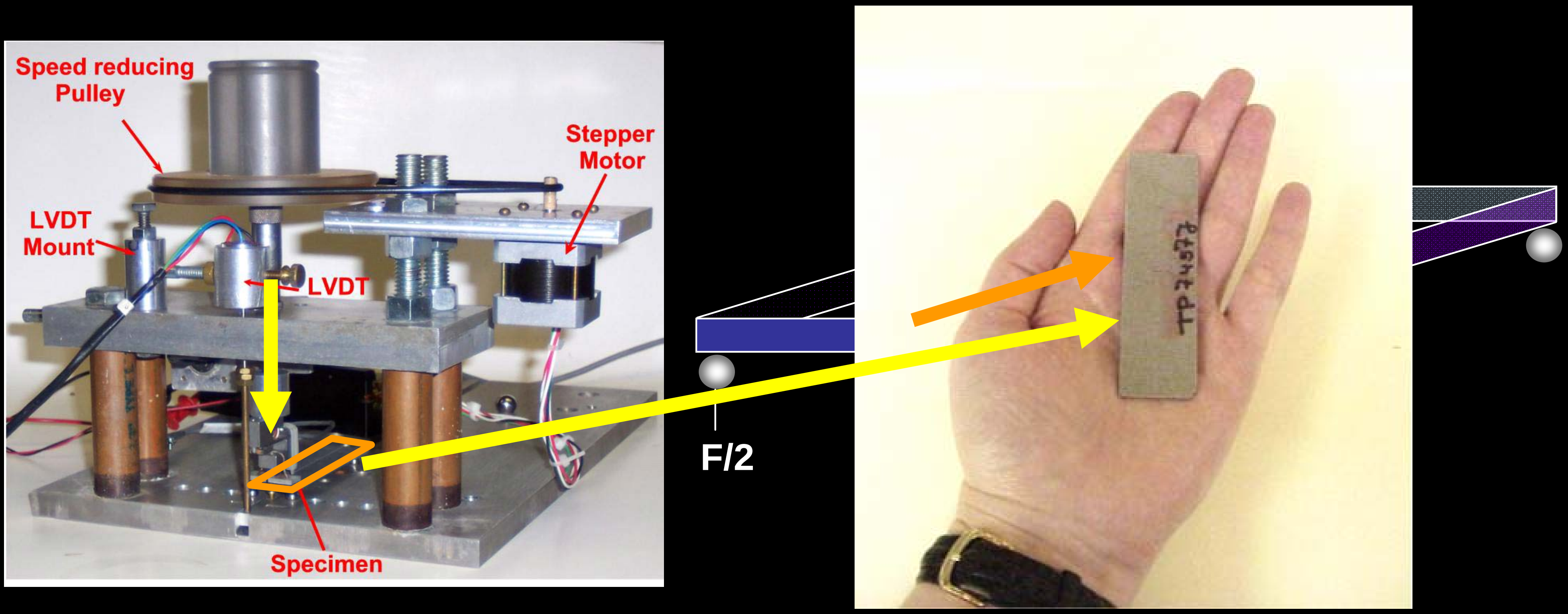


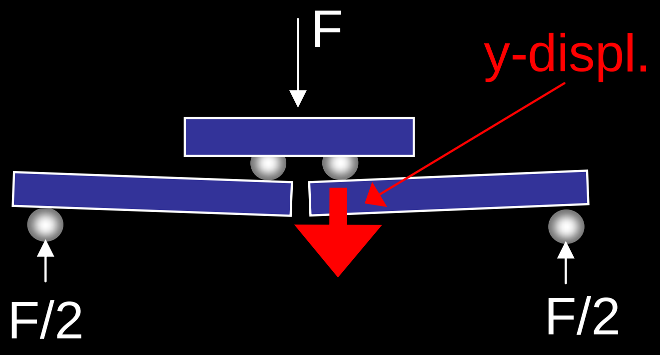


- small samples allow multiple tests per core depth
- measure properties under various environmental conditions

Rijken, 2006

Measuring Stress Corrosion Parameters





- small samples allow multiple tests per core depth
- measure properties under various environmental conditions

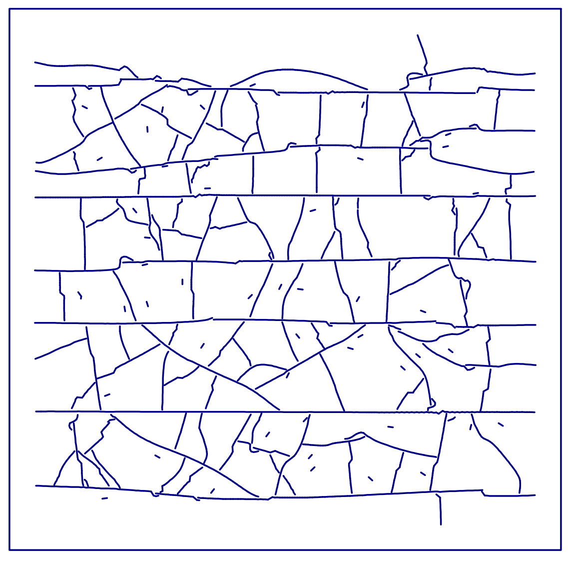
Rijken, 2006

Effect of Subcritical Parameter on NF Patterns (Olson 2007)

- lowering subcritical index increases amount of fracture length created
- 20x20 m area, 10 my, ~10^{-3} biaxial strain

2 m thick

n=20



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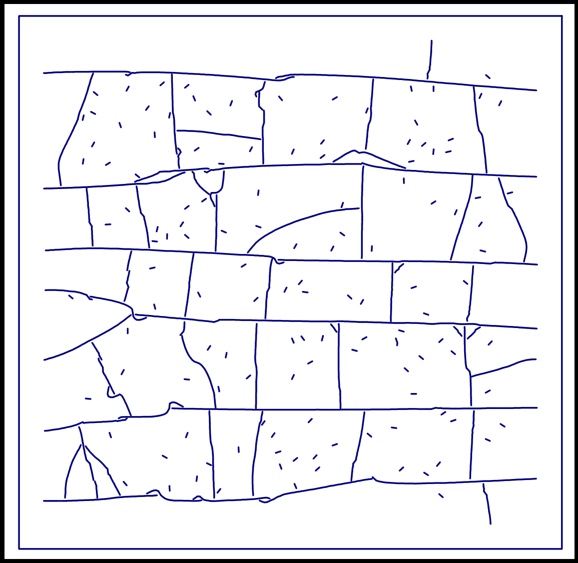
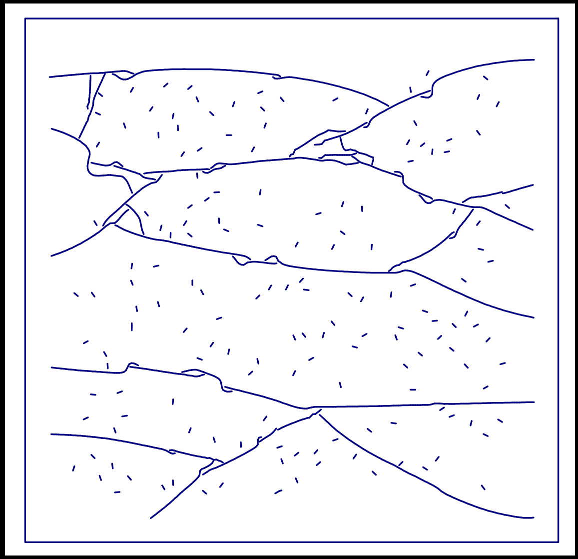


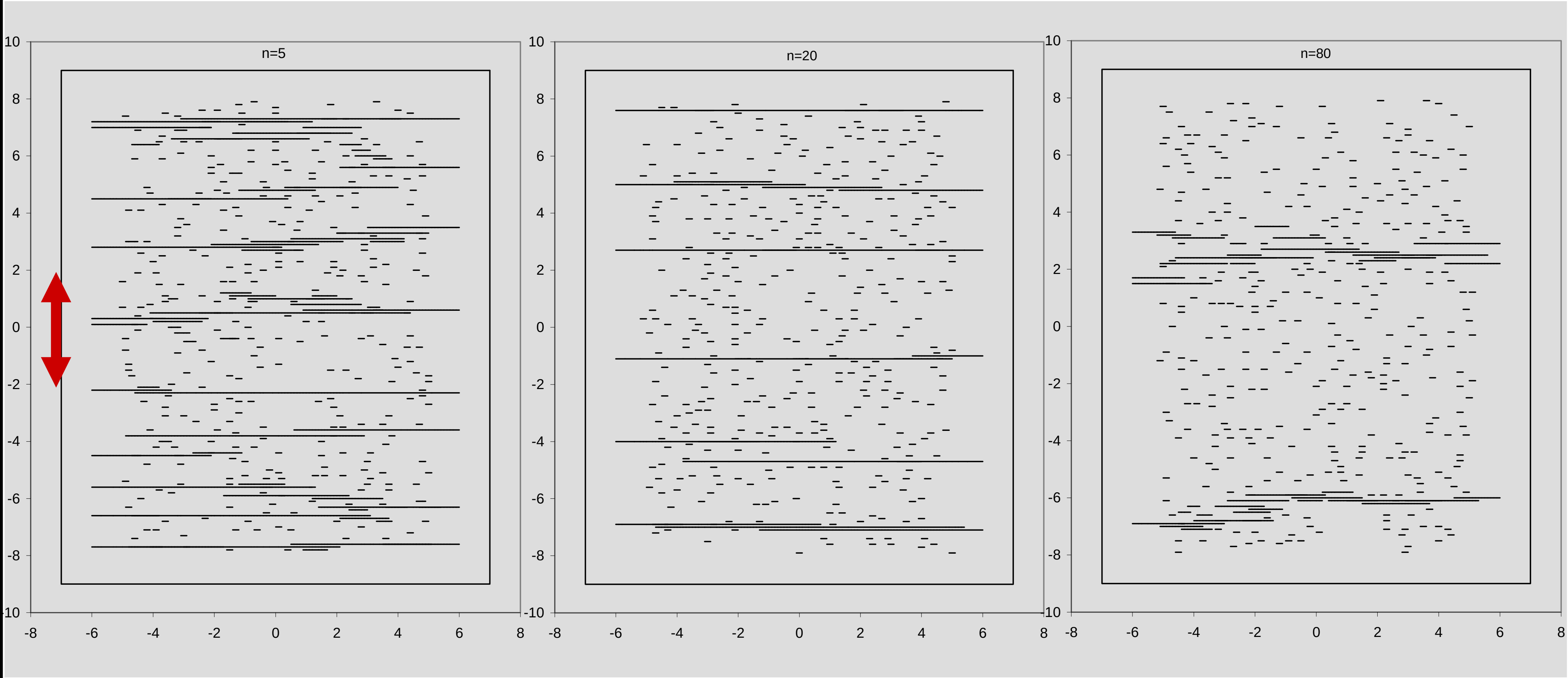
n=80



Subcritical crack growth & clustering

from Olson (1993, 2004)

- low n (1-20), spacing < bed thickness, early subcritical growth
- intermediate n (20-40), regular spacing α bed thickness
- high n (40+), widely spaced clusters, late critical growth



n=5 n=20 n=80

Influence of Stress Anisotropy on NF Patterns

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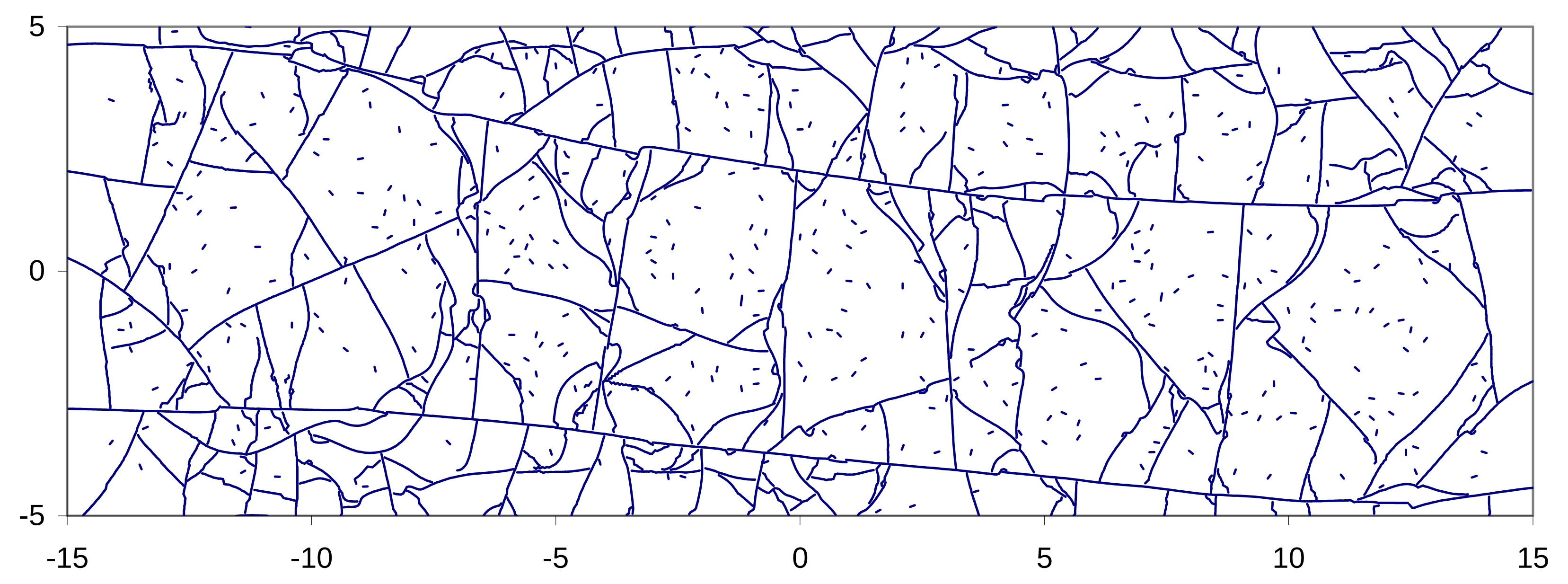
stress
anistropy



strong
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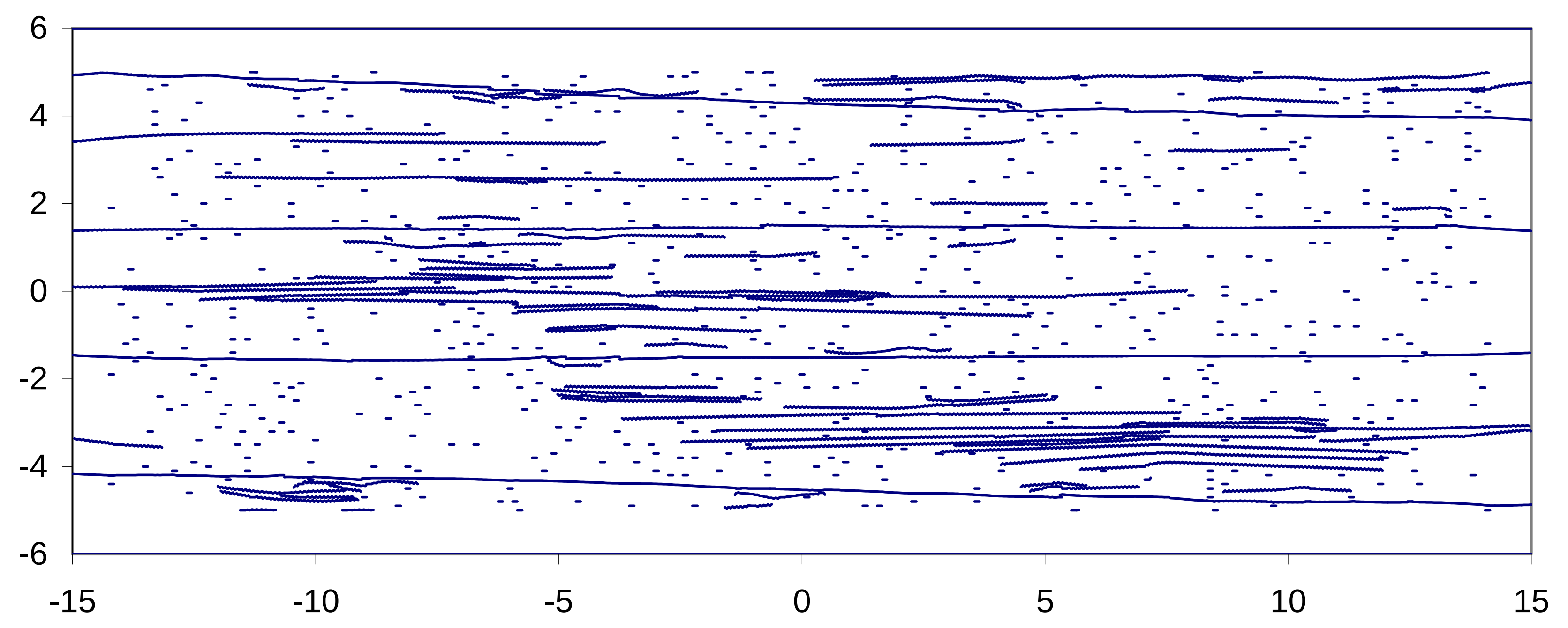
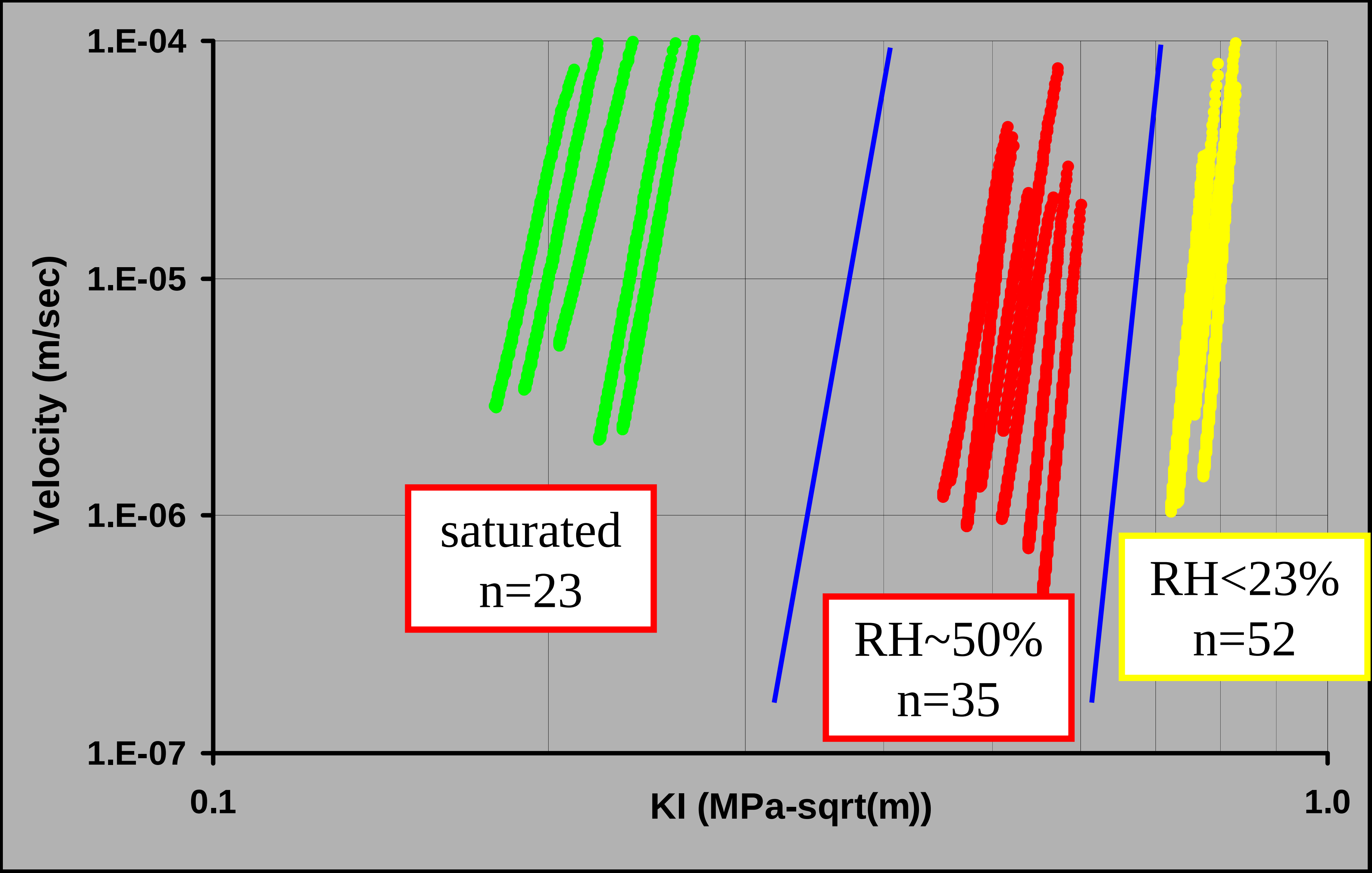
anistropy

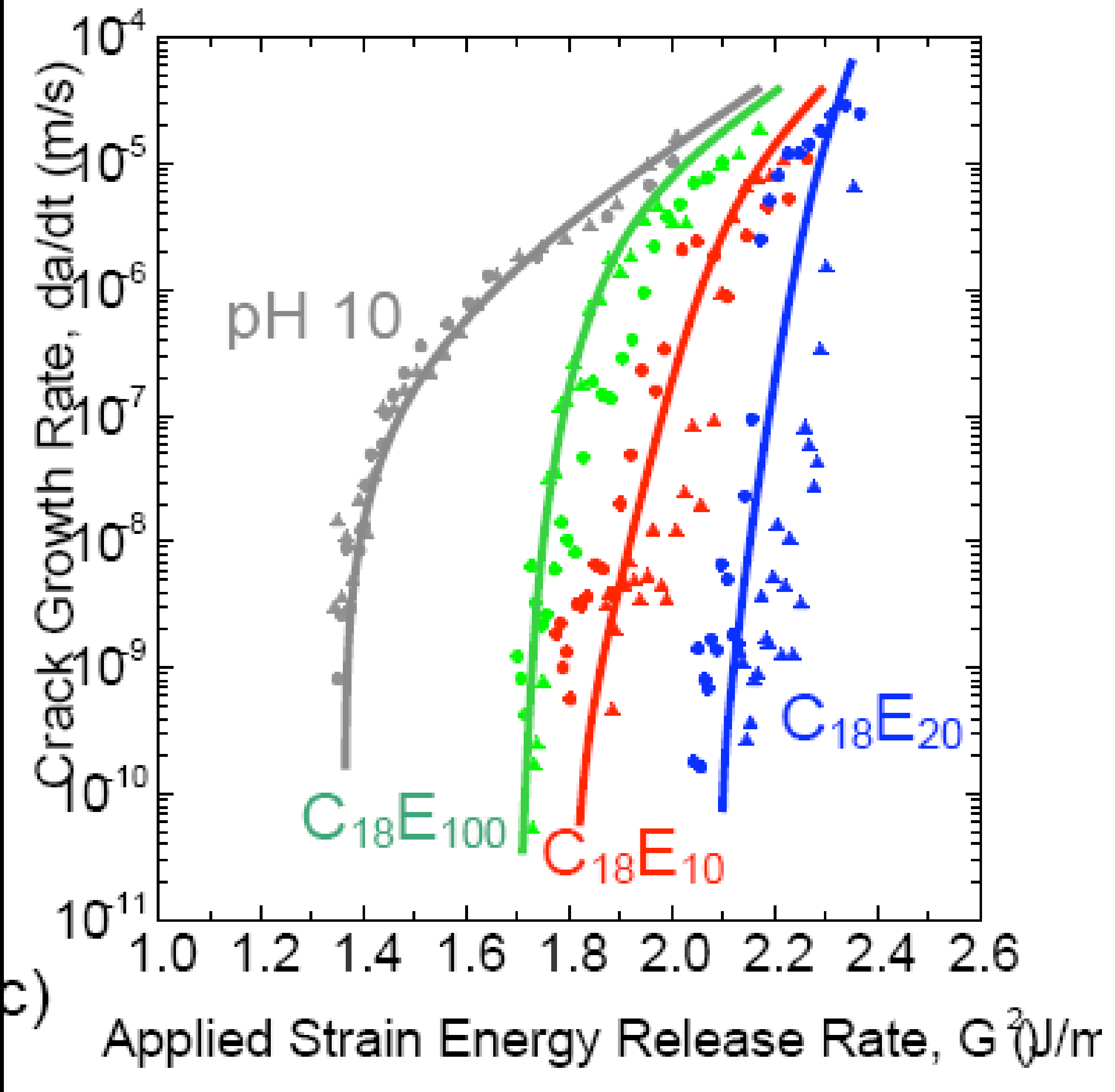


Influence of Water on Fort Union Siltstone (Rijken 2006)



Effect of Surfactants on Fracture Growth

non-porous
thin films



Ref: Kim et. al., (2007)

Numerical Study – HF and NF

- fractures grow from constant pressure source (limiting case of zero viscosity)
- HF and NF have same height
- propagation velocity a power-law of K_I
- HF arrested when intersecting NF, but transmits pressure to NF
- NF can slip in response to HF-induced stress (non-intersecting interaction)

Numerical Method

- Base code => 2-d displacement discontinuity (with 3d extension)
- Propagation accomplished by adding elements at crack tip (according to propagation criterion)

Existing element

New element

Design Parameters Influencing Results

- fracture (layer) thickness and injection point spacing
- propagation velocity exponent (used 2 to 50)

$$v = A\left(K_I\right)^n$$

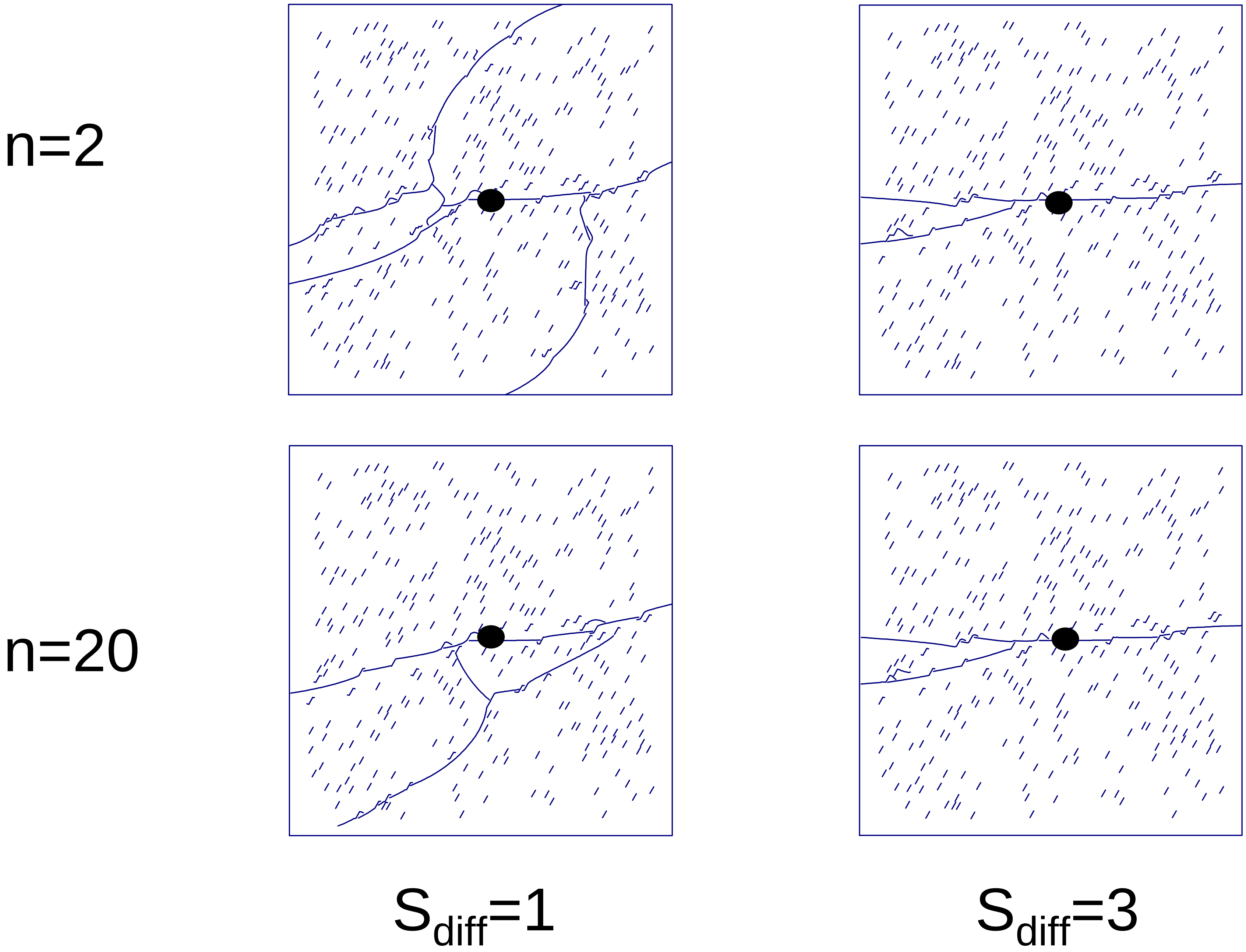
- ratio of net pressure to differential stress

$$R = \frac{\left(P_{frac} - S_{h\min}\right)}{\left(S_{H\max} - S_{h\min}\right)}$$

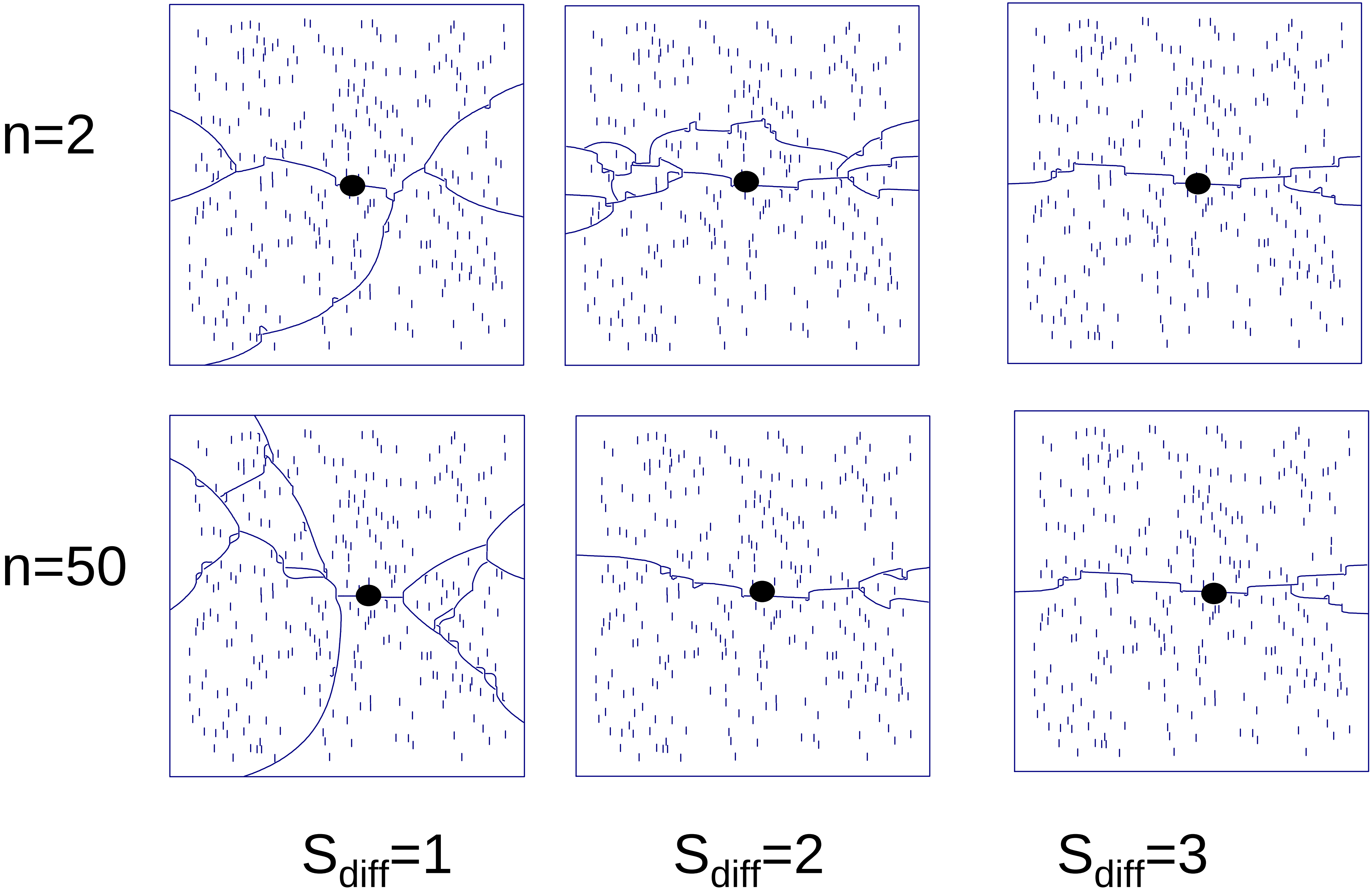
Boundary Conditions – Vertical Well Case

- fracture (layer) thickness 40 m, areal extent of map view is 300 x 300 m
- $S_{yy}=S_{hmin}=10$ MPa
- $S_{xx}=S_{Hmax}=S_{hmin} + S_{diff}$
- 1 MPa $< S_{diff} <$ 3 MPa
- $P_{NF} = 9$ MPa (net closing pressure)
- $P_{HF}=15$ MPa (net opening pressure)
- when HF intersects NF, pressure is propagated (raises NF pressure)

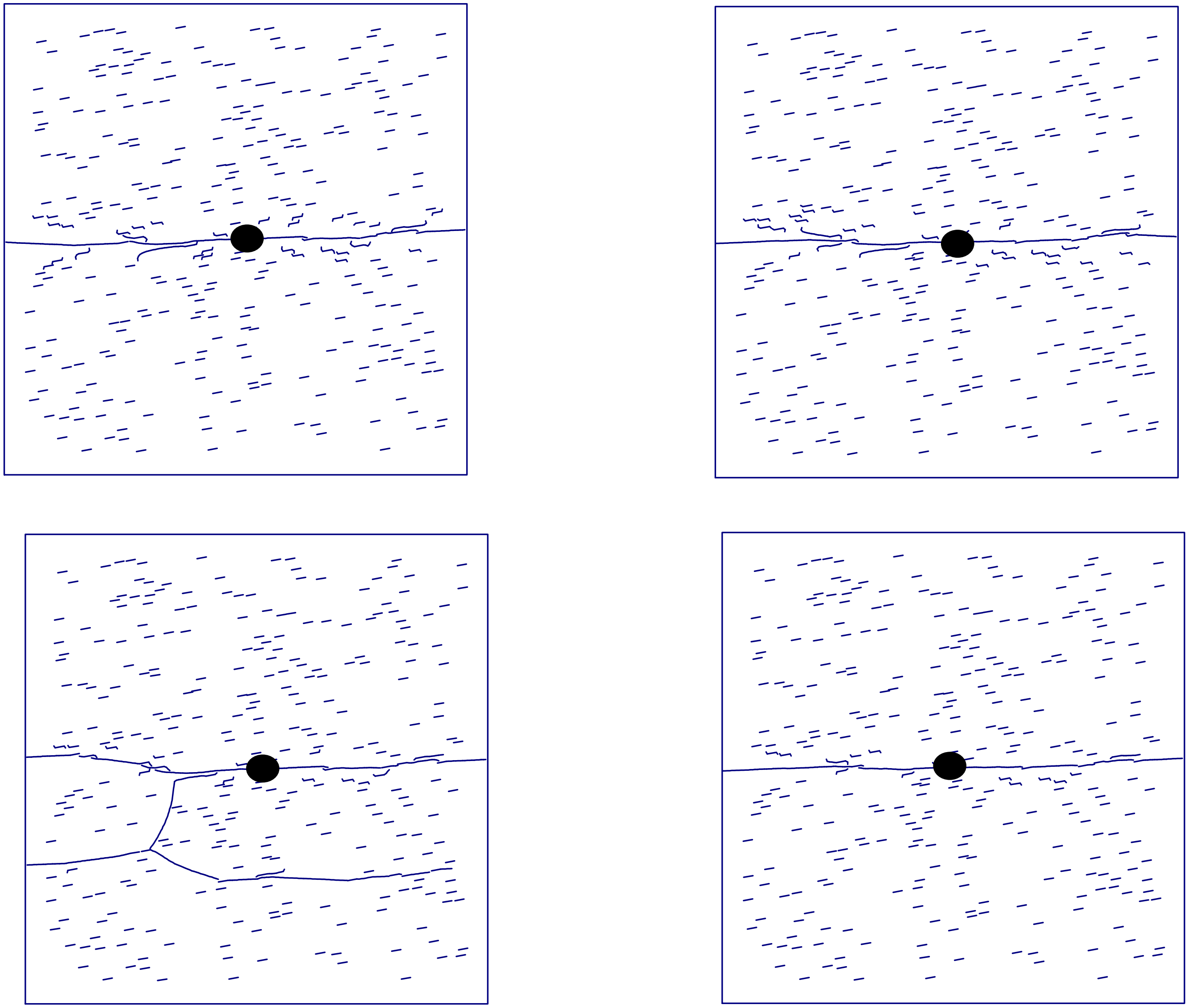
Strike Difference (HF vs NF) = 60°



Strike Difference (HF vs NF) = 90°



Strike Difference (HF vs NF) = 10°



n=2

n=50

S_{diff}=1

S_{diff}=3

Conclusions

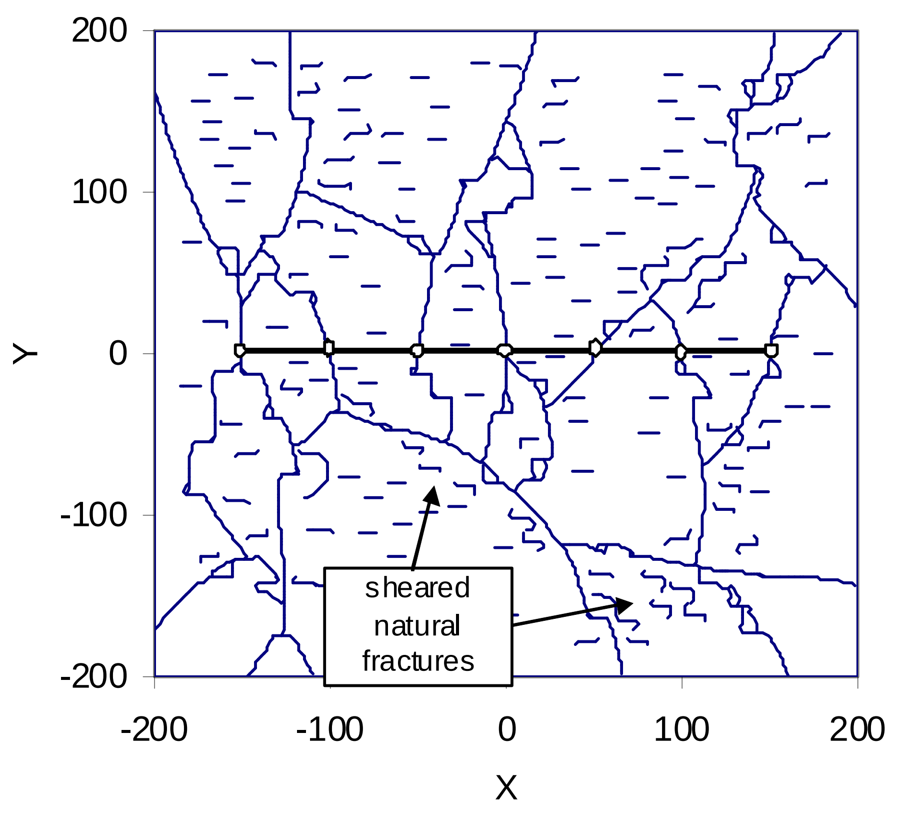
- plausible HF network geometries generated with constant pressure numerical model
- HF/NF interaction complexity influenced by subcritical index and stress ratio
- rock fracture properties influenced by HF fluid chemistry => more experimental work to study best additives
- numerical model allows assessment of complex geometry potential given in situ conditions

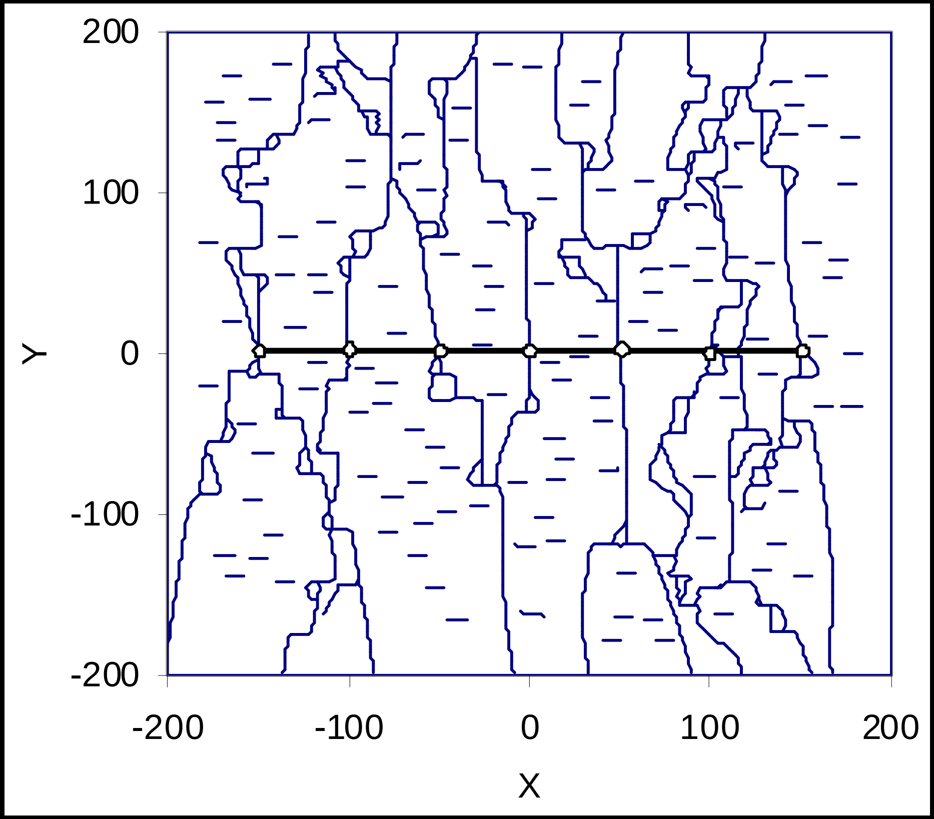
Appendix:

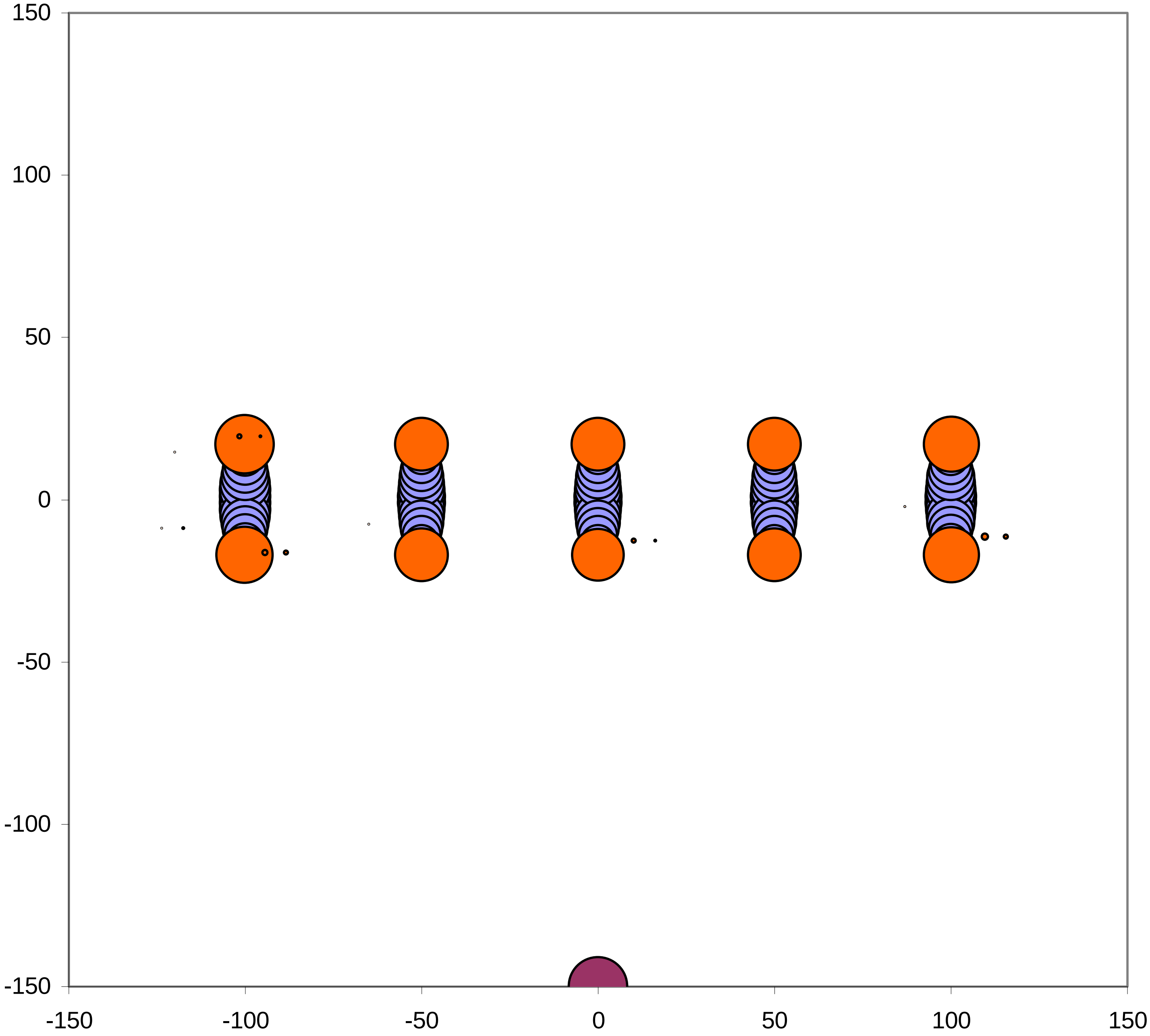
Natural Fractures – Stress Anisotropy
&
Fracture Propagation

NF Interaction & Stress Anisotropy

- randomly located, equal length natural fractures
- weak anisotropy allows unfavorably aligned growth
- stronger differential stress straightens crack paths
- stress induced by hydraulic fracture shears nearby



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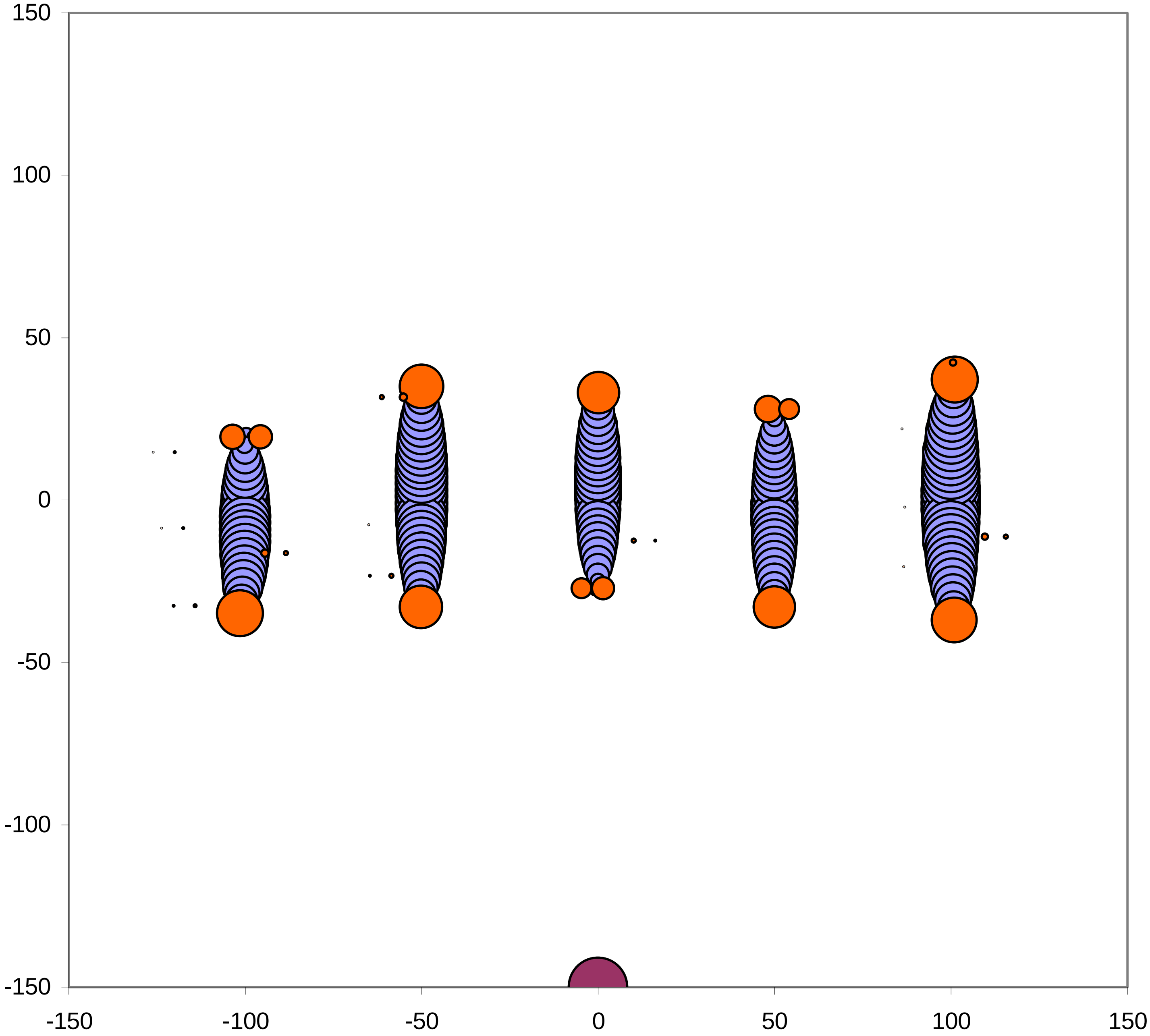
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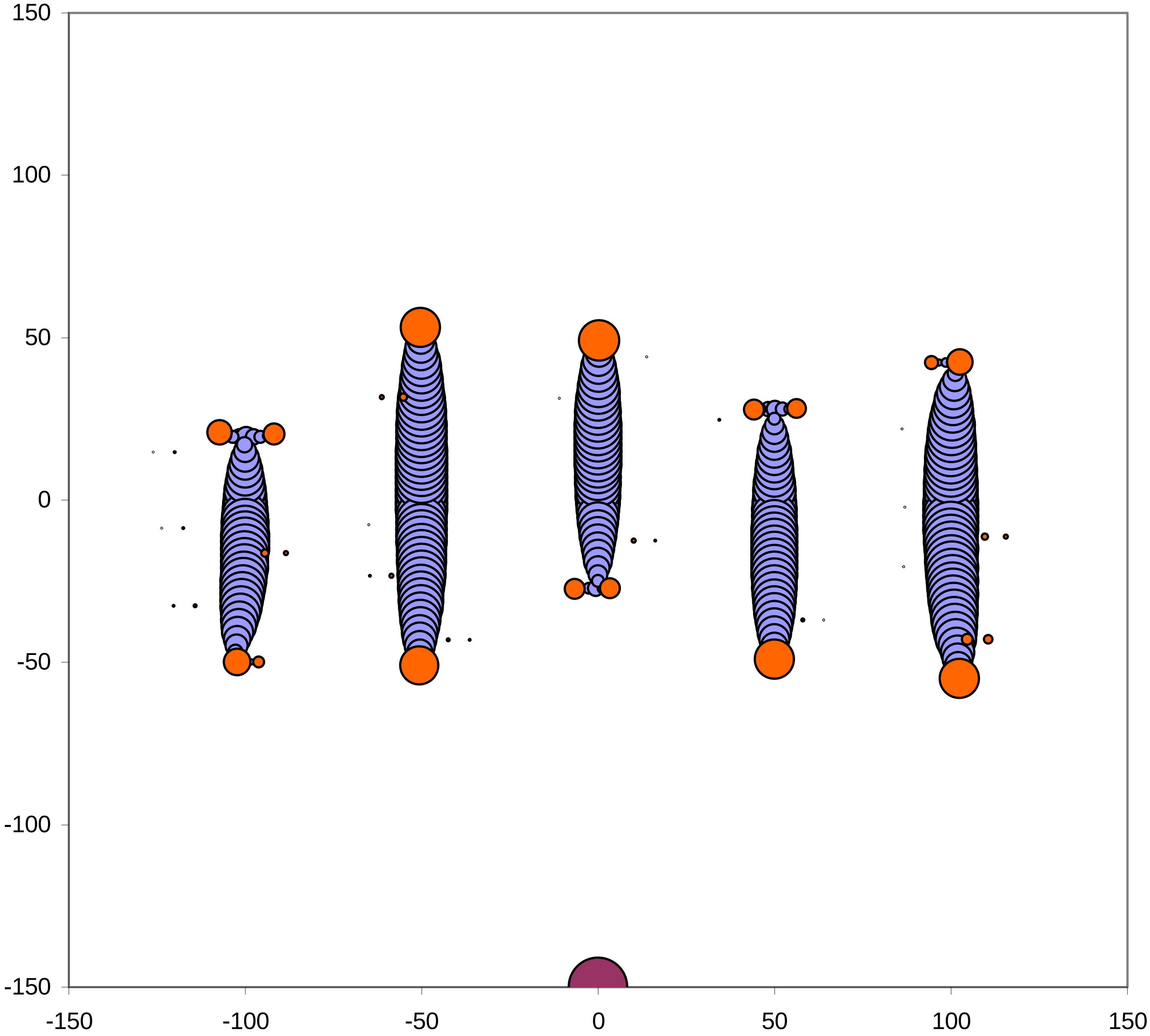
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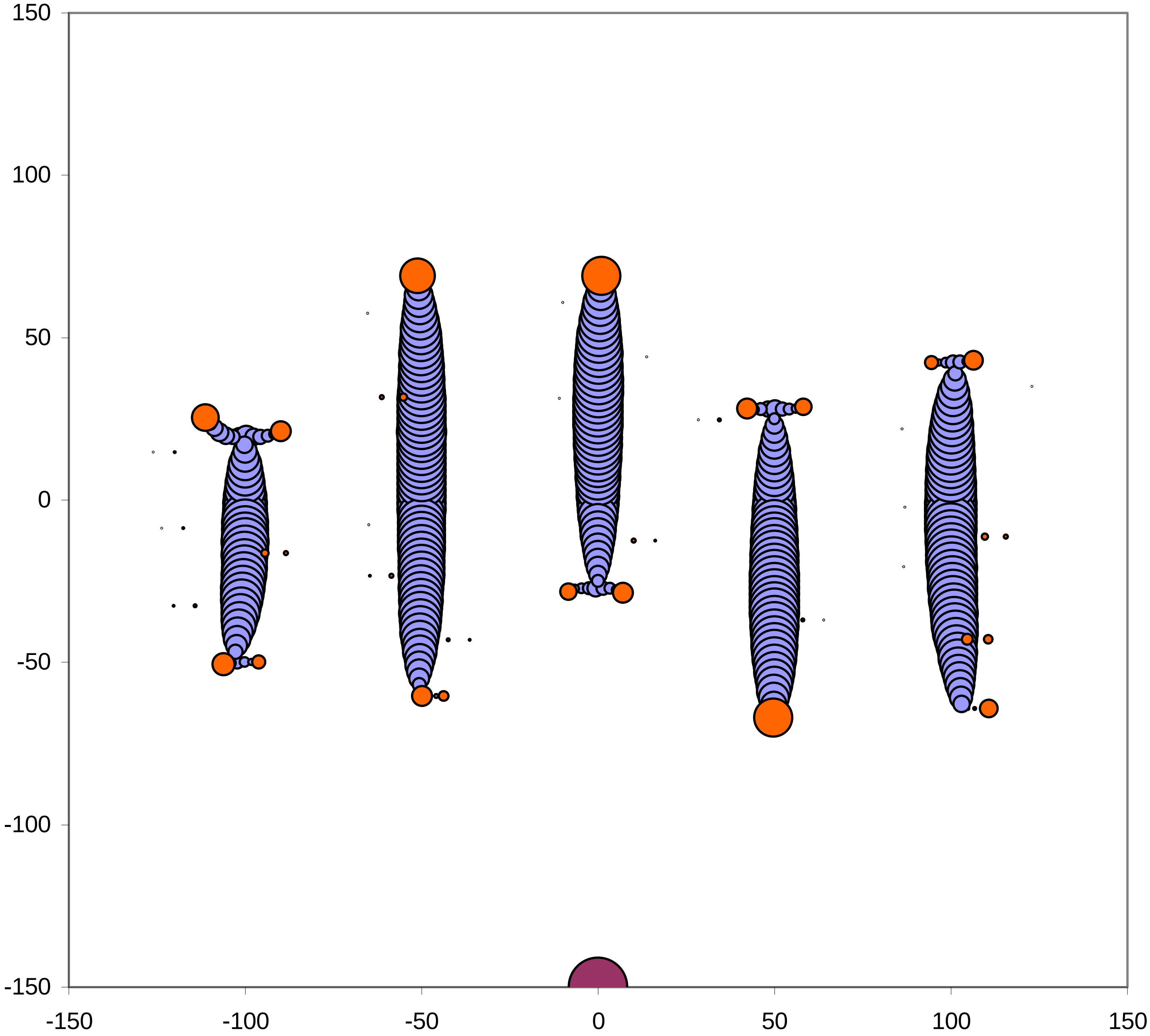
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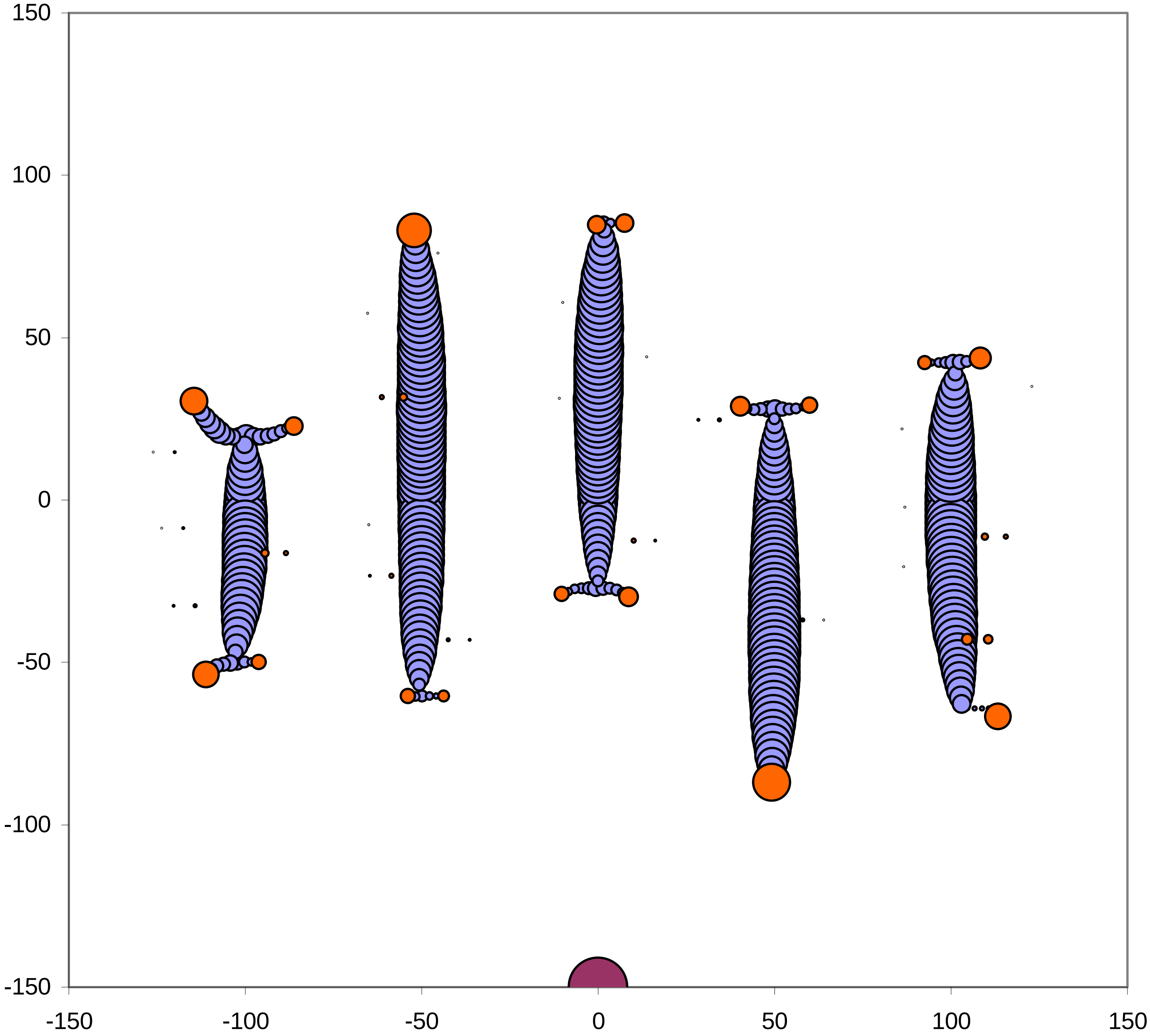
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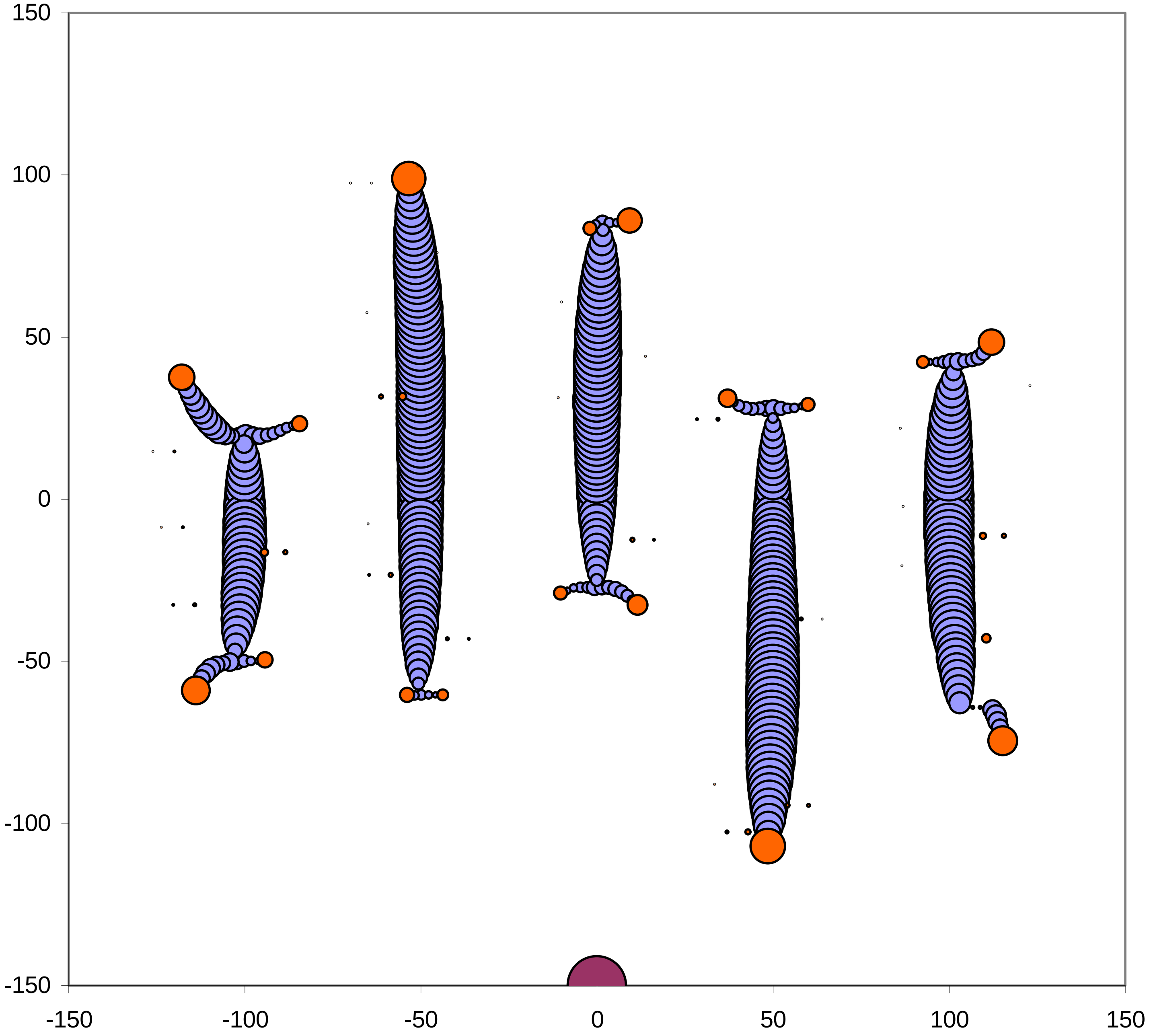
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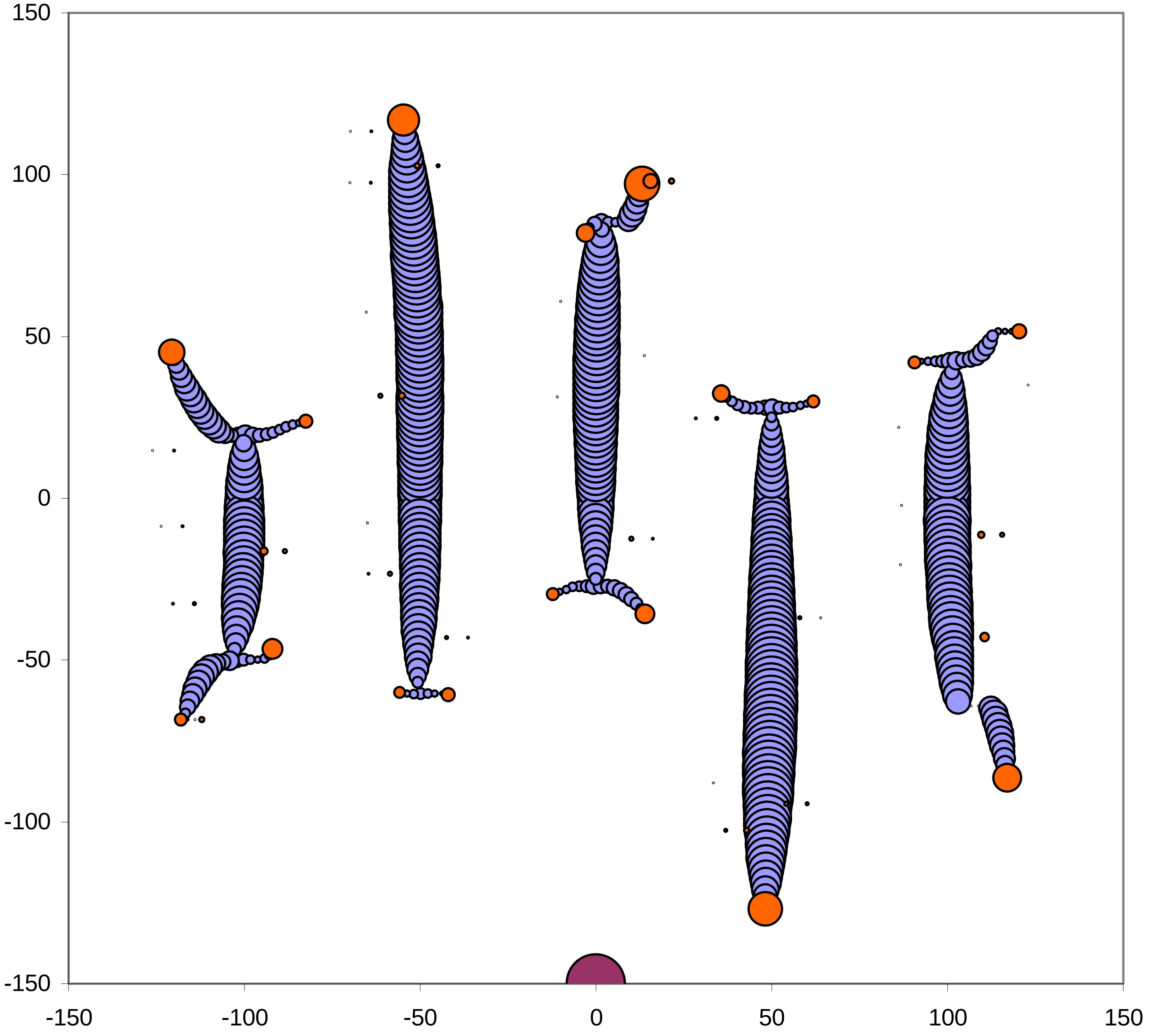
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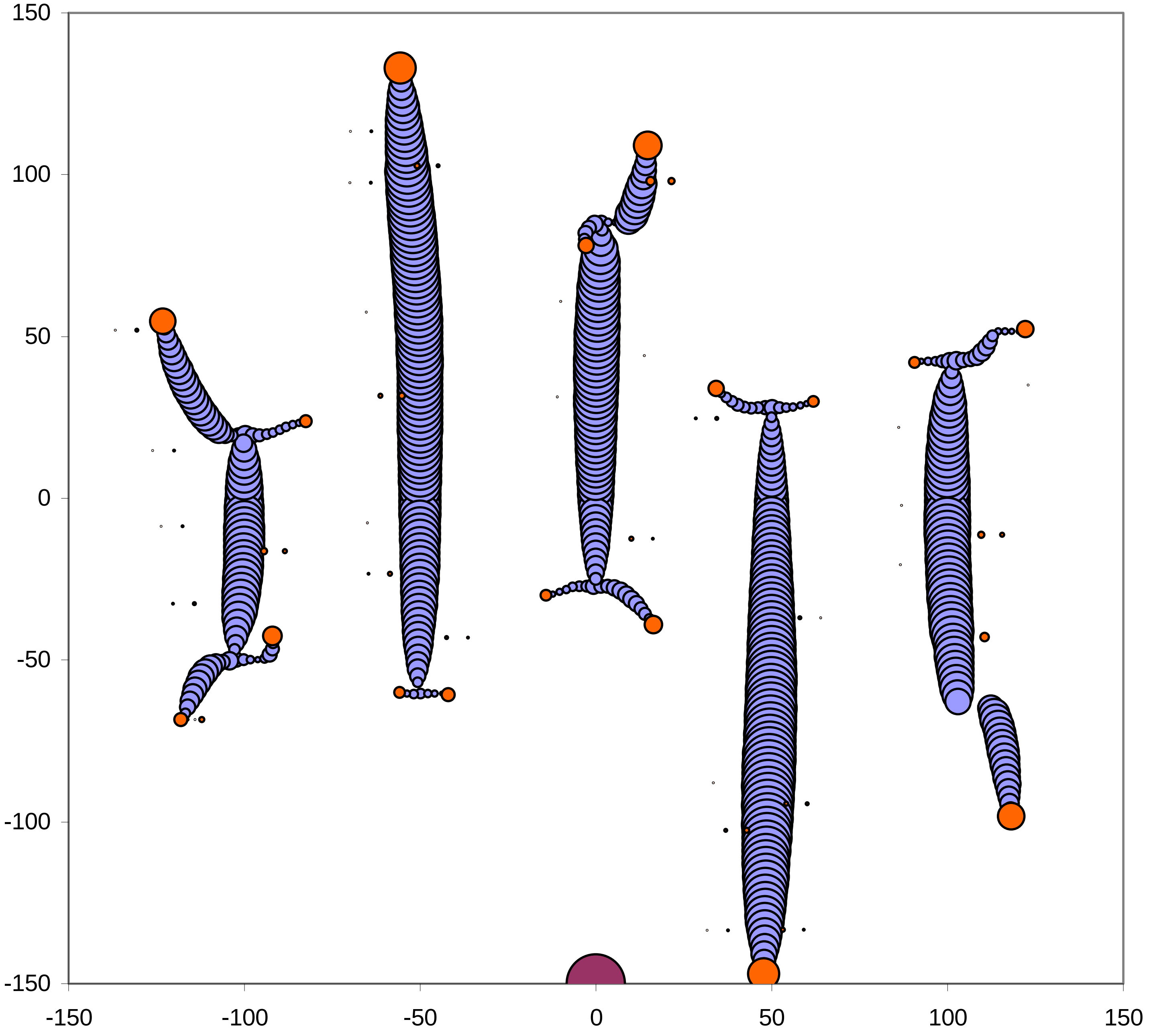

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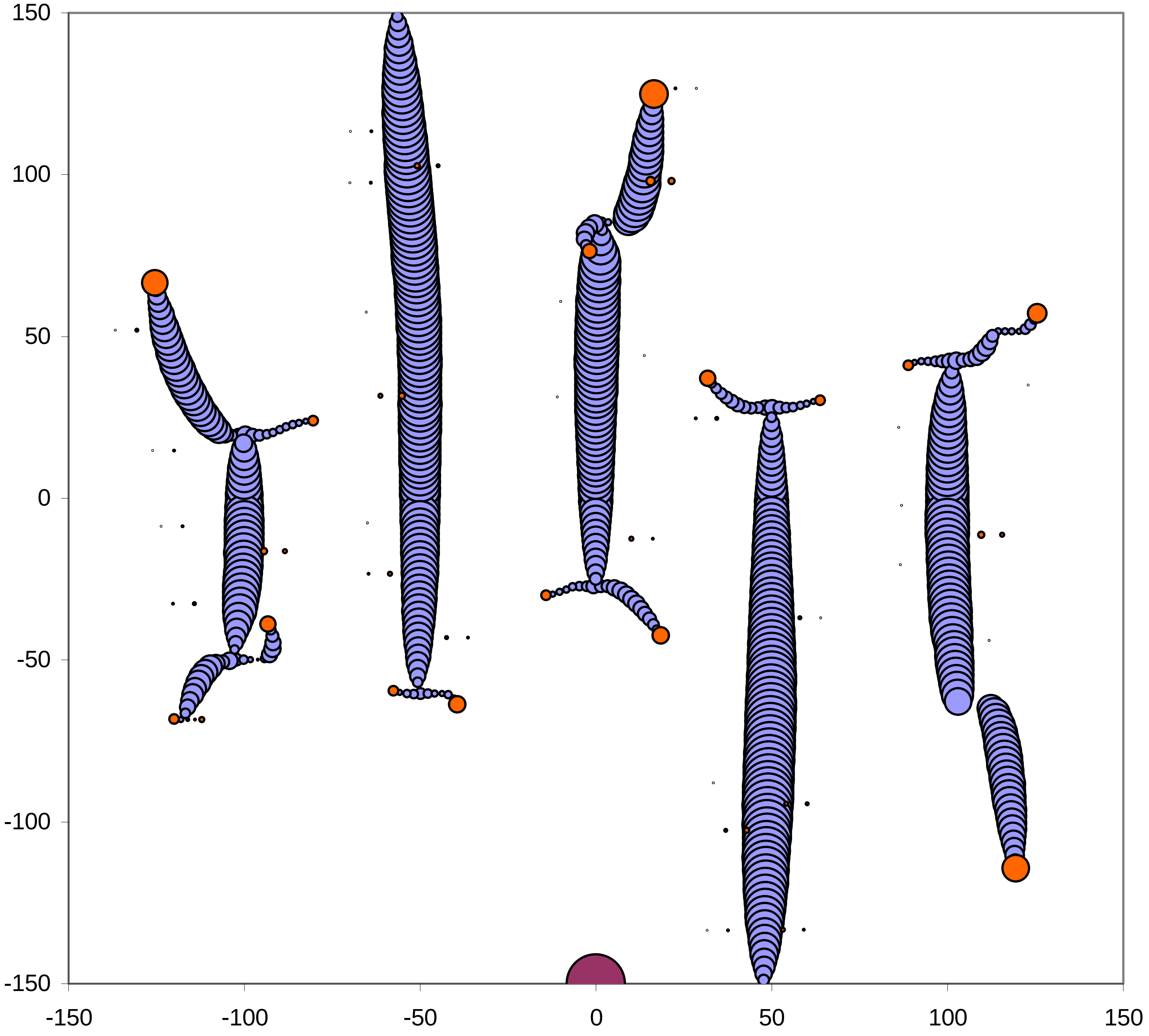
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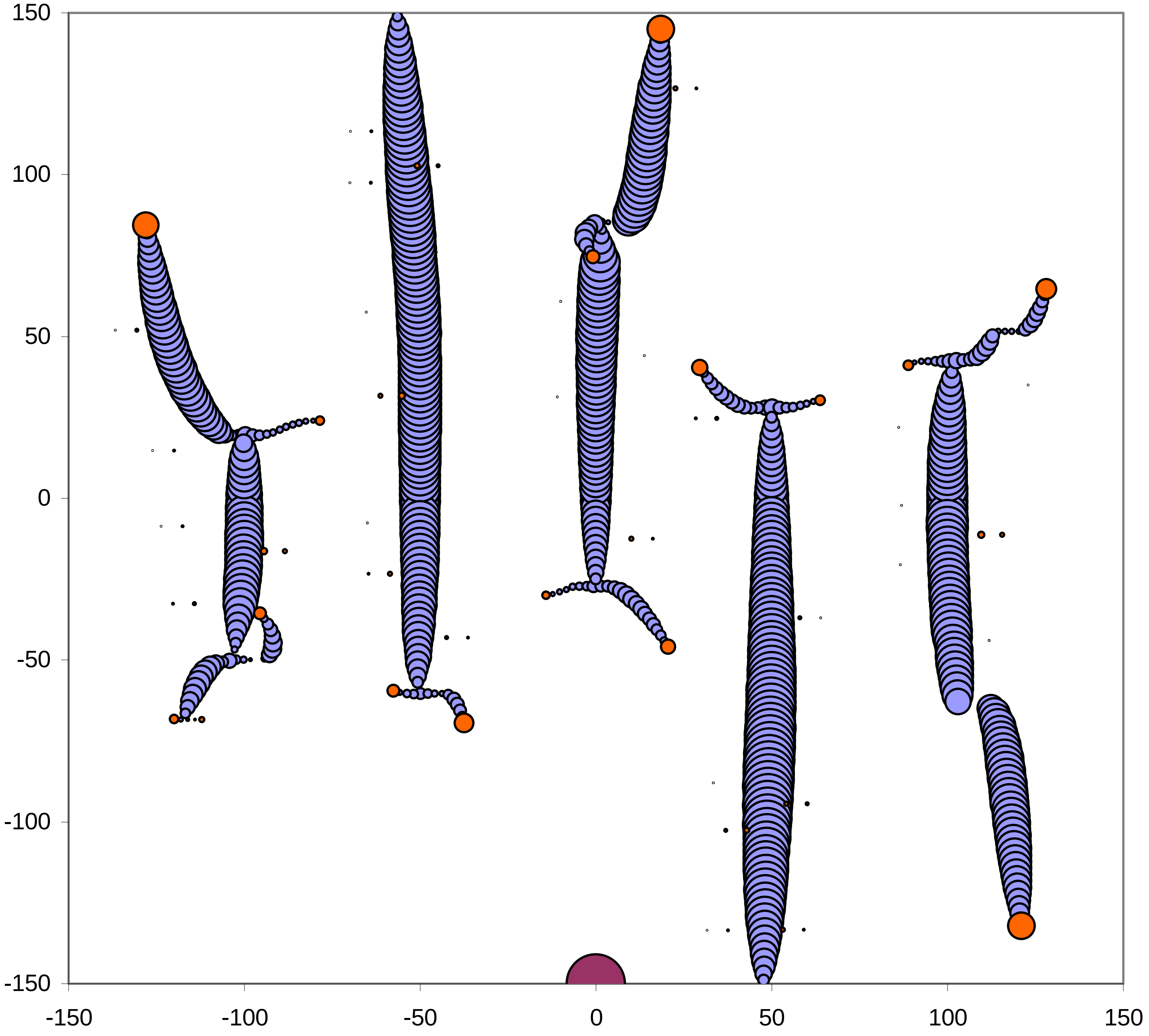
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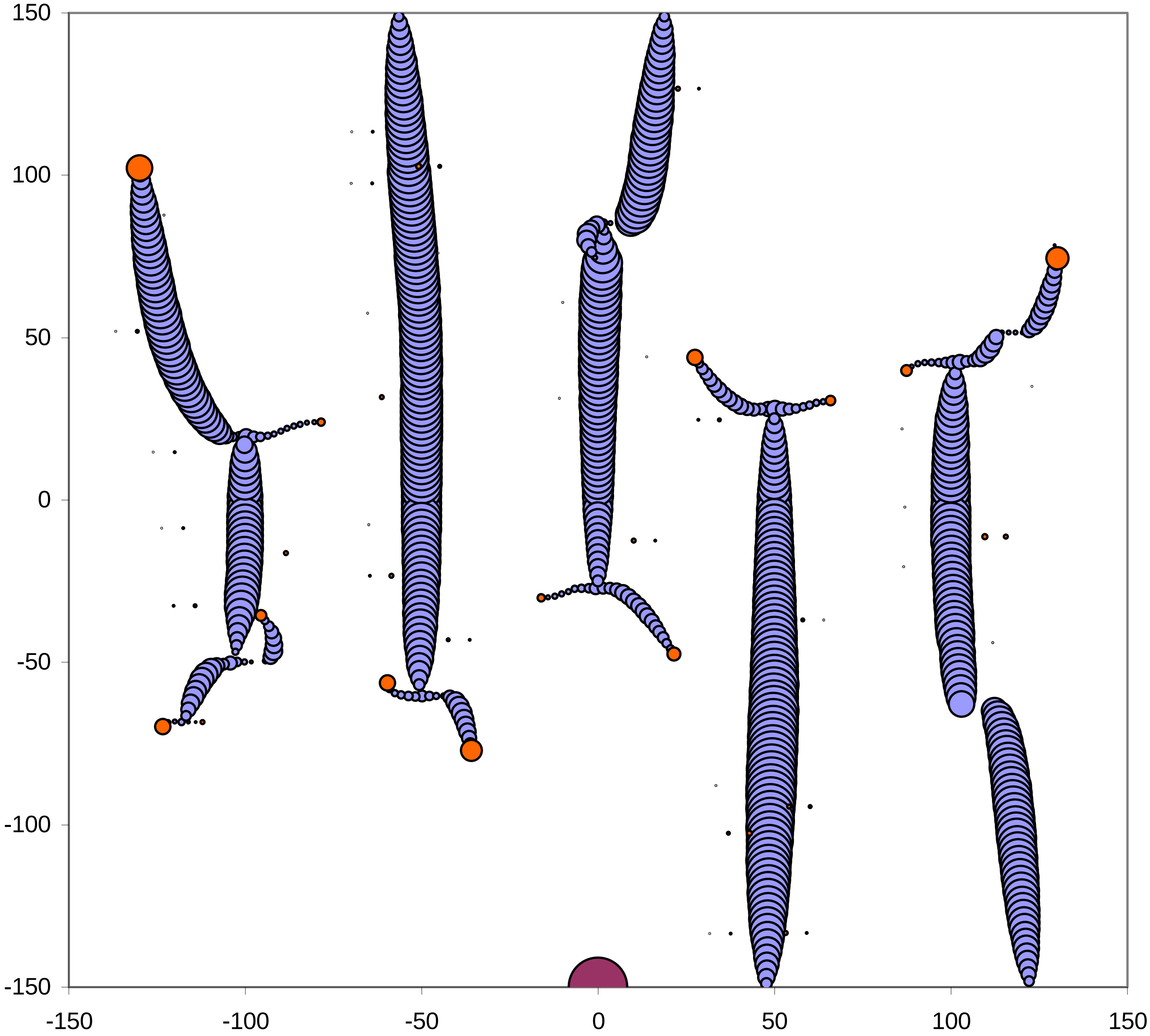
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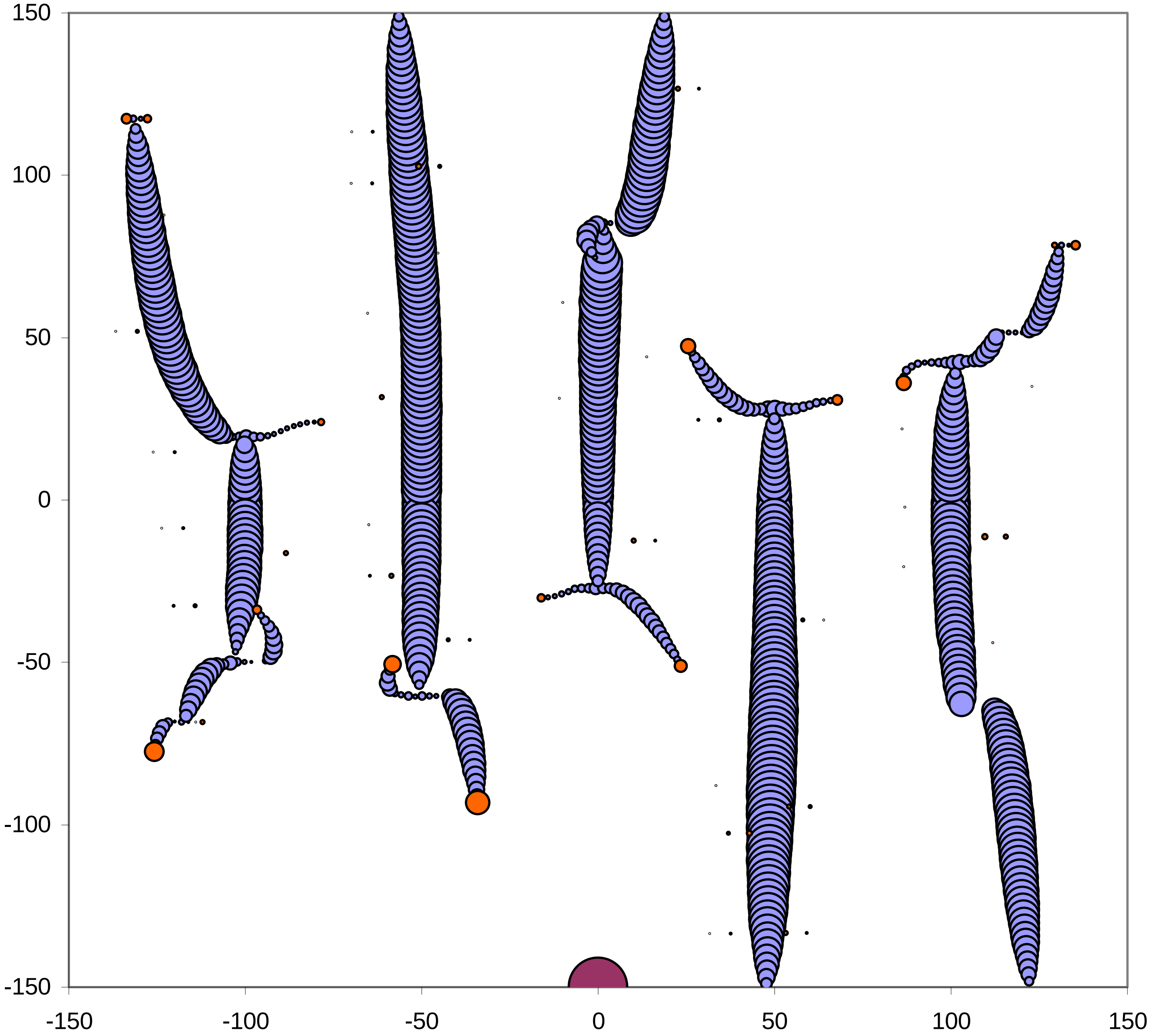
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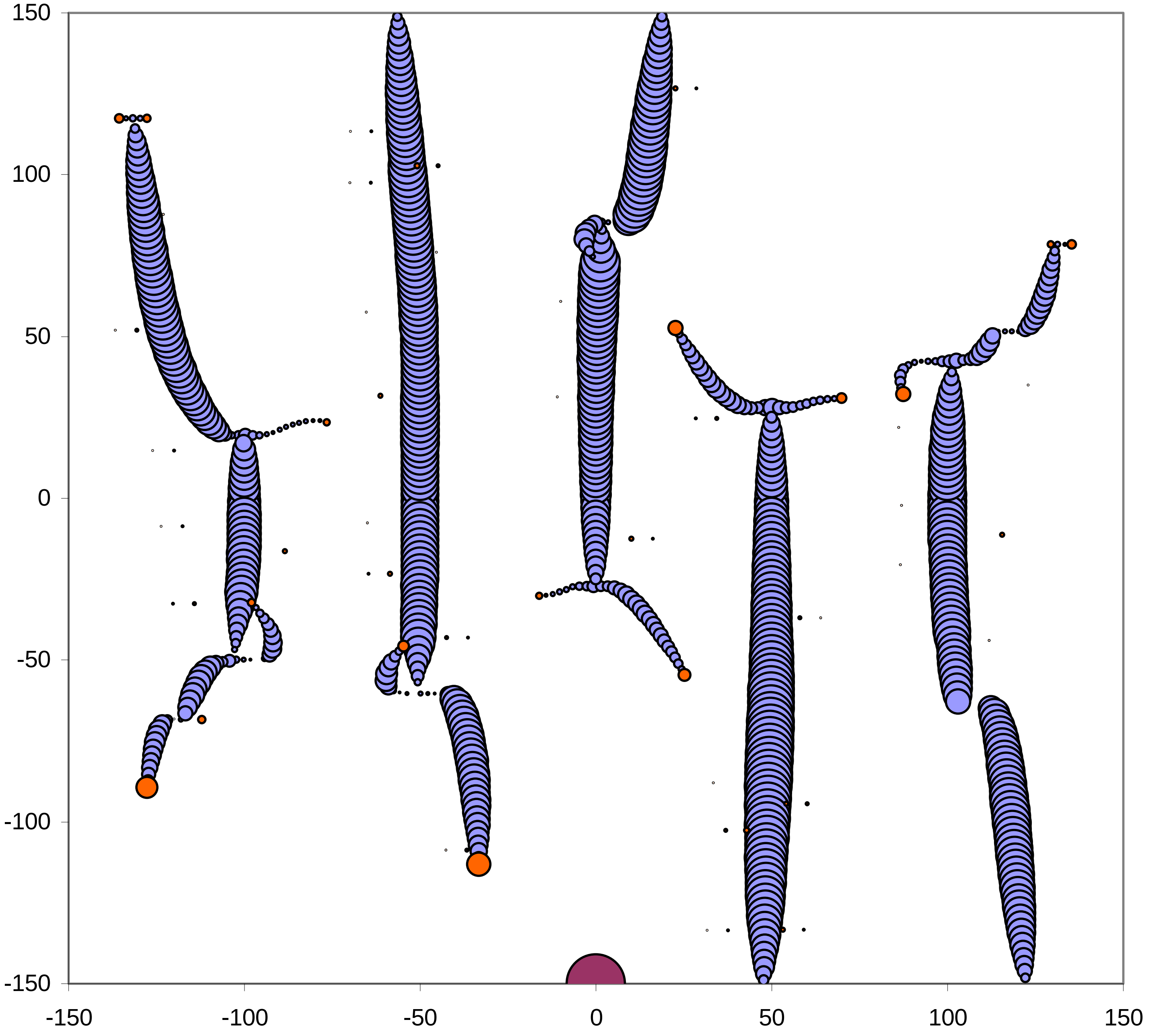
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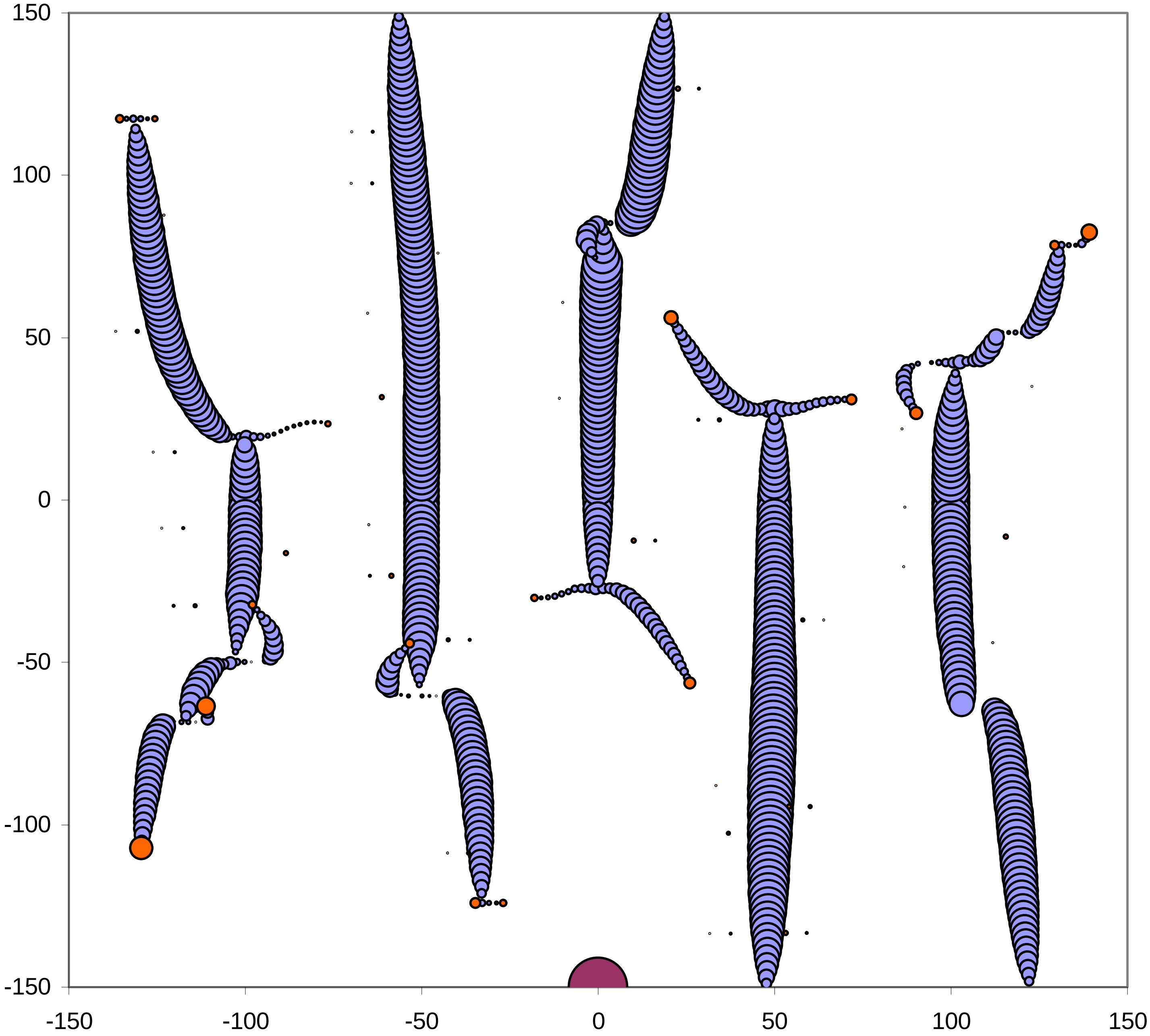
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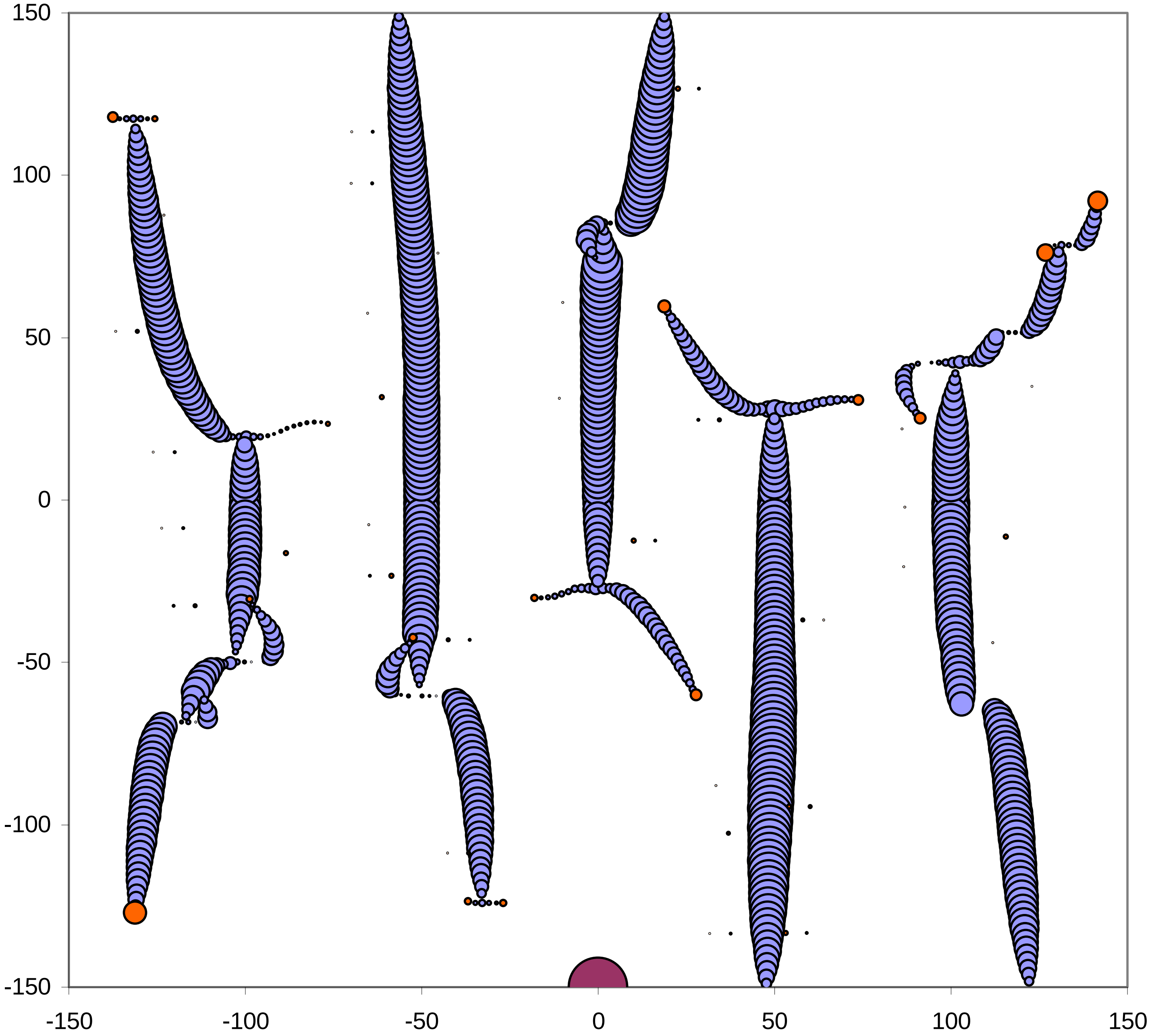
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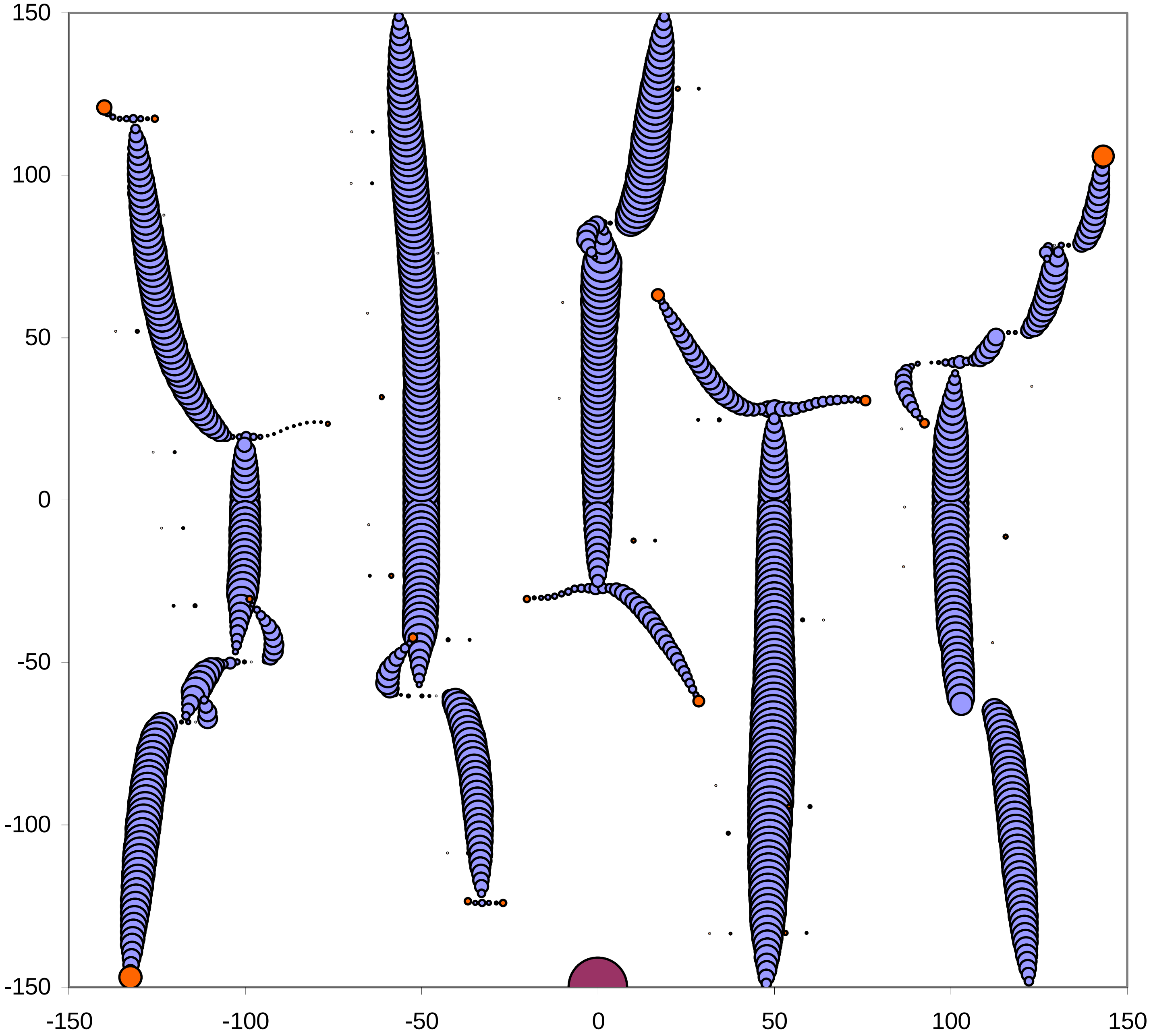
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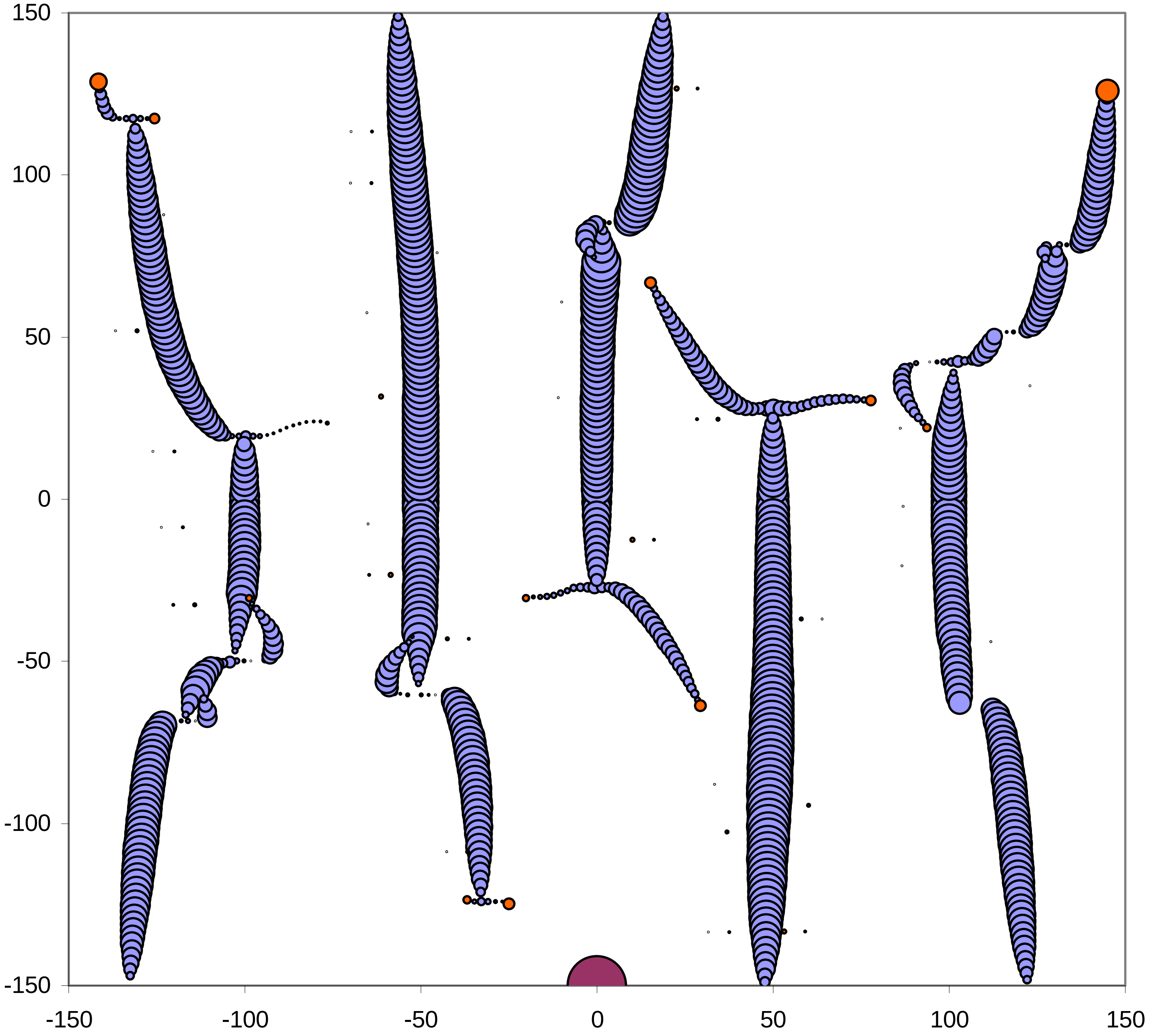
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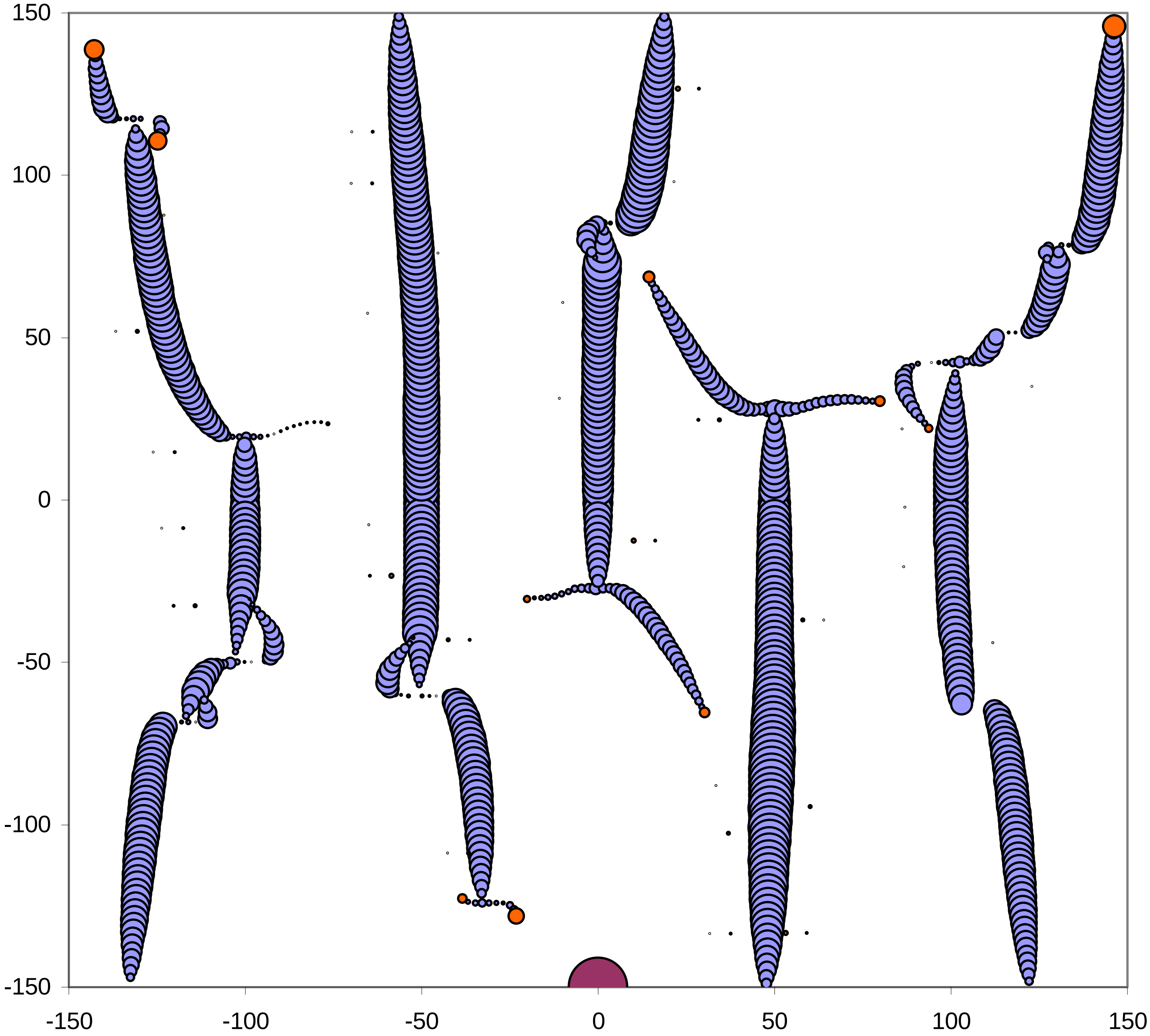
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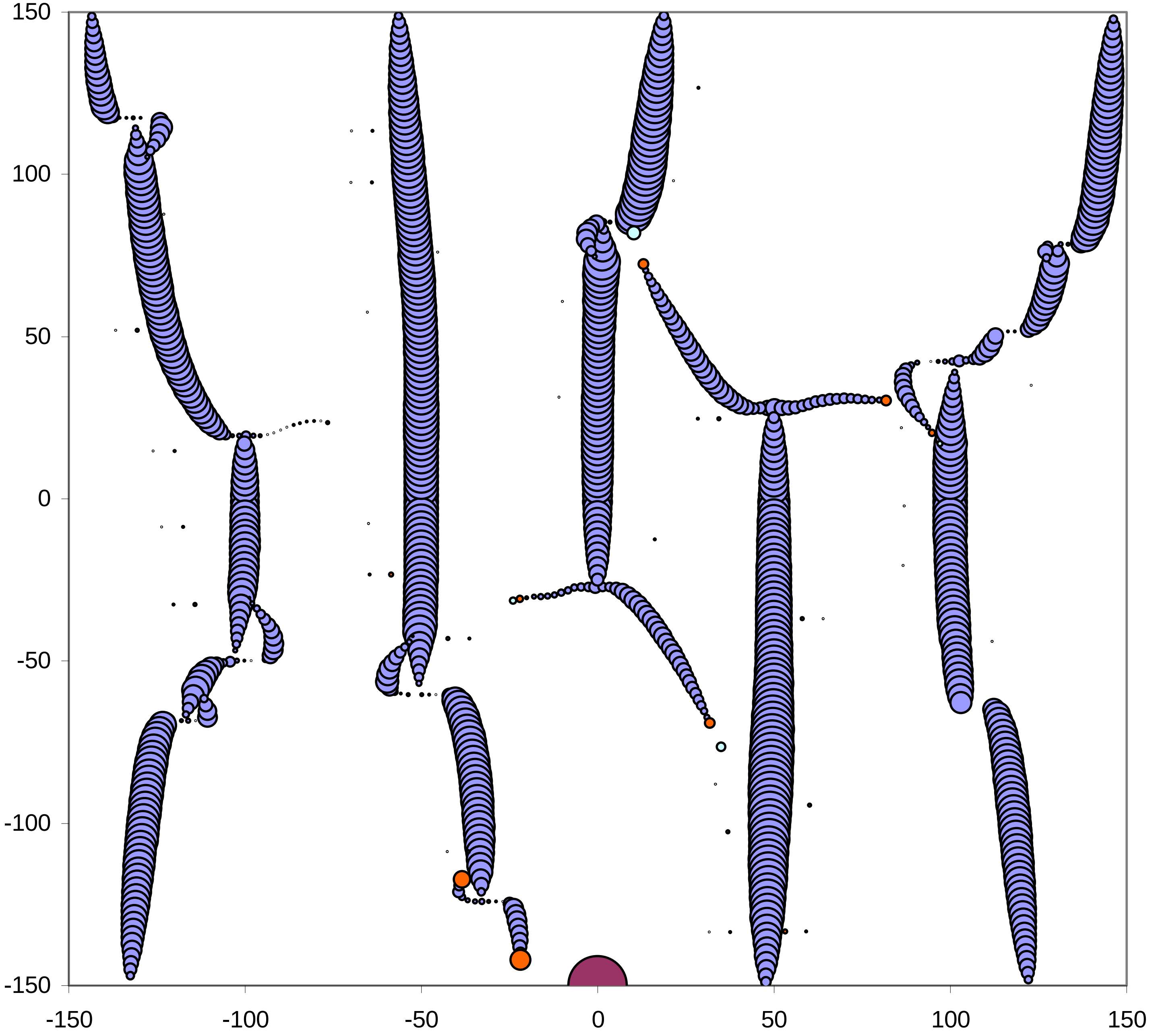
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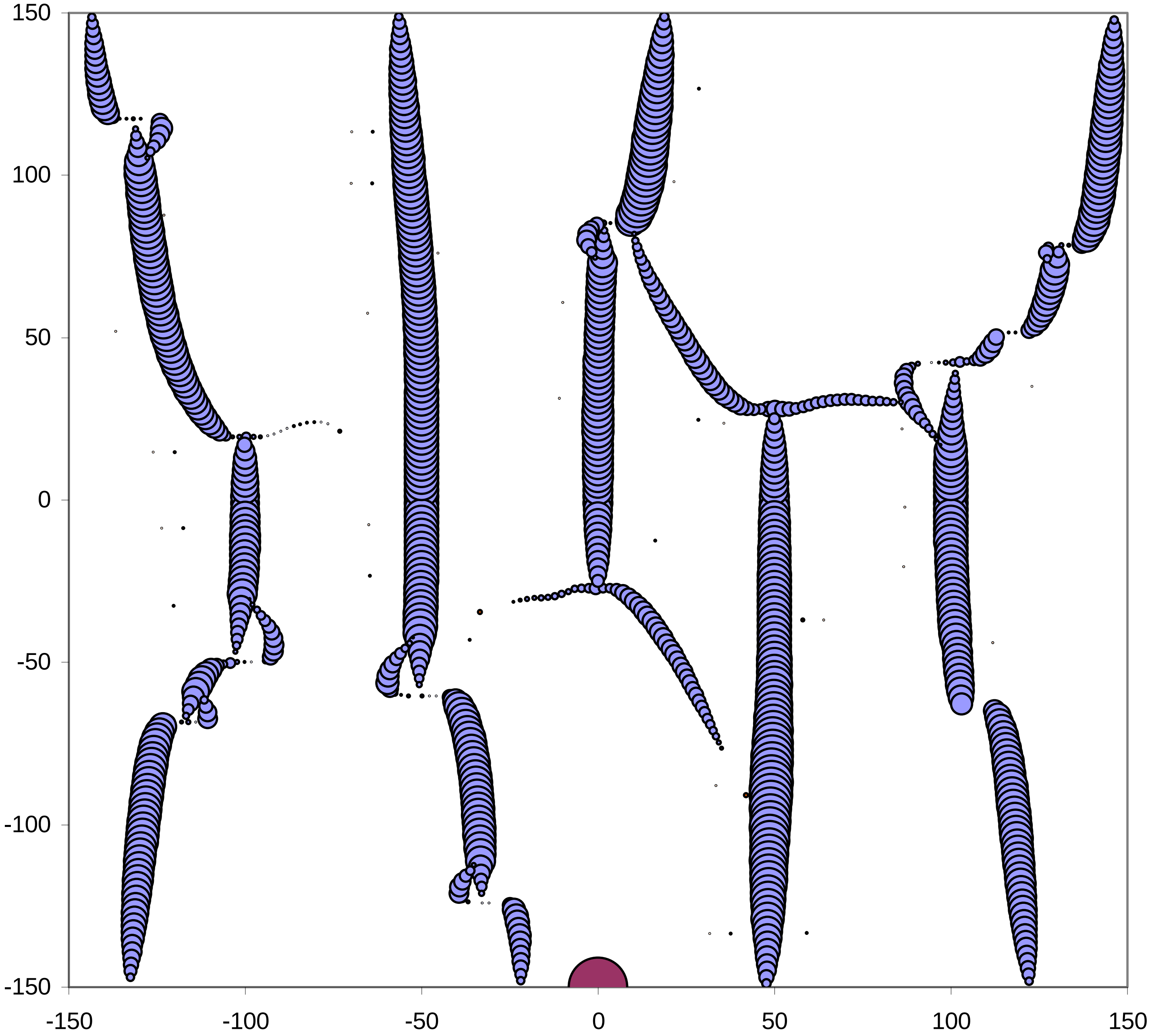
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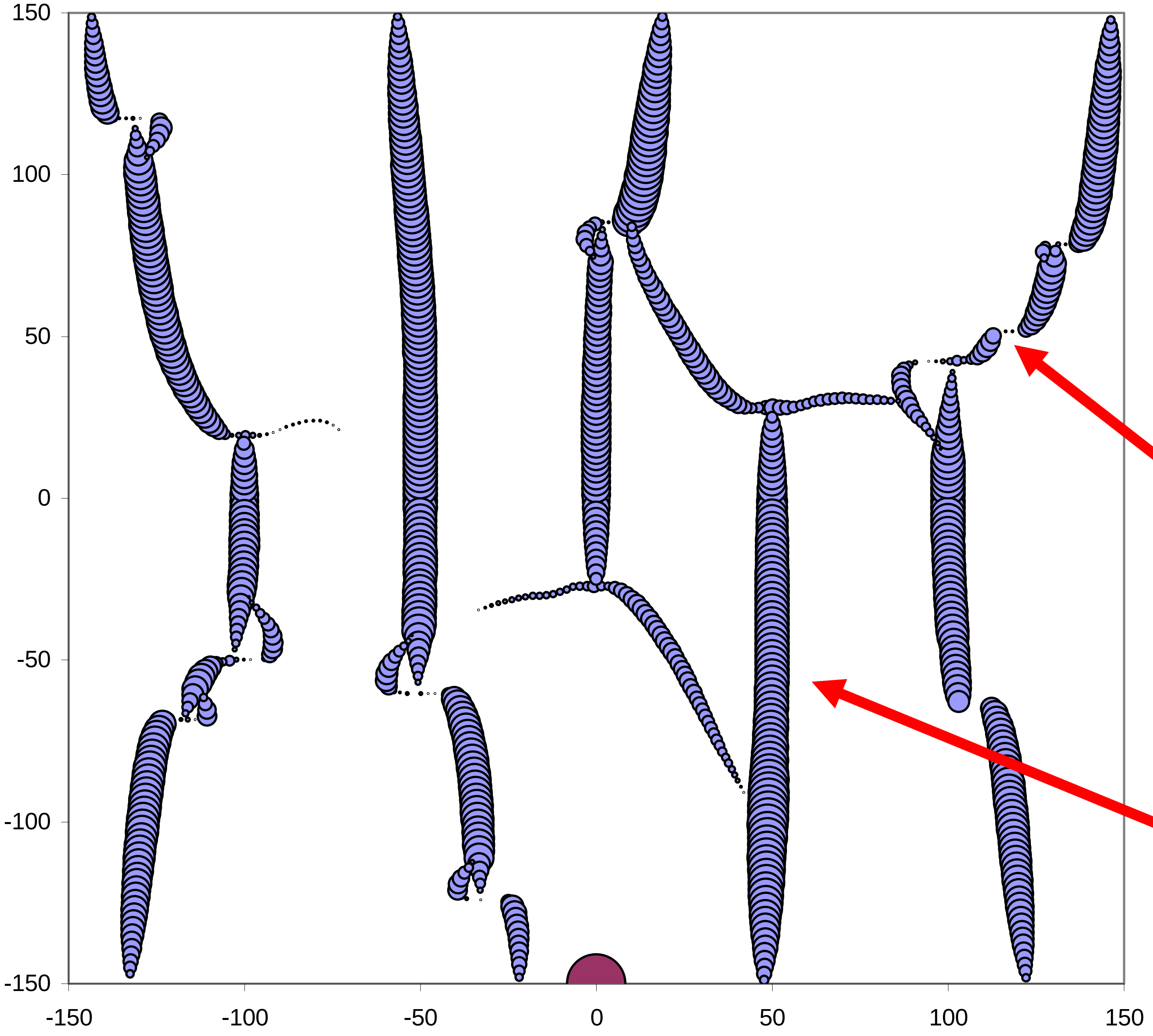

width restriction at overlapped intersections

overall widths reduced due to strong interactions