Modeling Fluid Structure Interaction with Multi-GPU Enabled Software

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Agenda

- Types of Fluid Solvers
- Multi GPU Processing
- SPH Examples
- Under Development

Types of Fluid Solvers

- Smoothed Particle Hydrodynamics
- CFD (Full Navier-Stokes)
- ALE – Arbitrary Lagrangian-Eulerian

Smoothed Particle Hydrodynamics

Why SPH over other Fluid Solvers?

- ❑ Conceptually Simple
- ❑ Robust
- ❑ Easily applied to 3D
- ❑ Arbitrary Deformation in a Lagrangian Frame
- ❑ Exact Local Conservation of Momentum
- ❑ Ideally Suited for Fluid Structure Impact

What makes an SPH Solver ideal for Fluid Structure Interaction?

- Simple particle to structure “penalty” based Contact Algorithm
- Scales easily to 10’s of millions of particles on GPUs
- High particle resolution
- Does not require remeshing during computation

IMPETUS Afea Next Generation SPH Solver - γSPH

Resolves Inherent Problems with Classic SPH

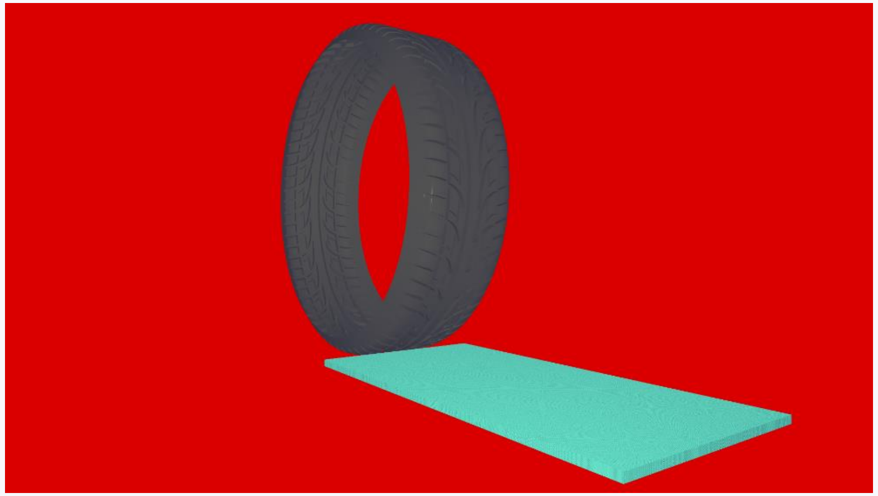
- ❑ Accurate Pressure Computation
- ❑ Eliminated the classic SPH tensile instability problem

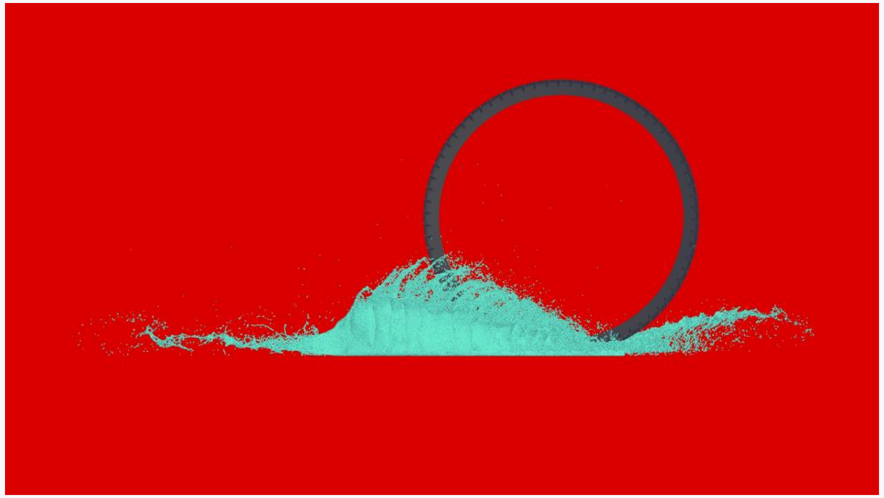
GPU Based Solver

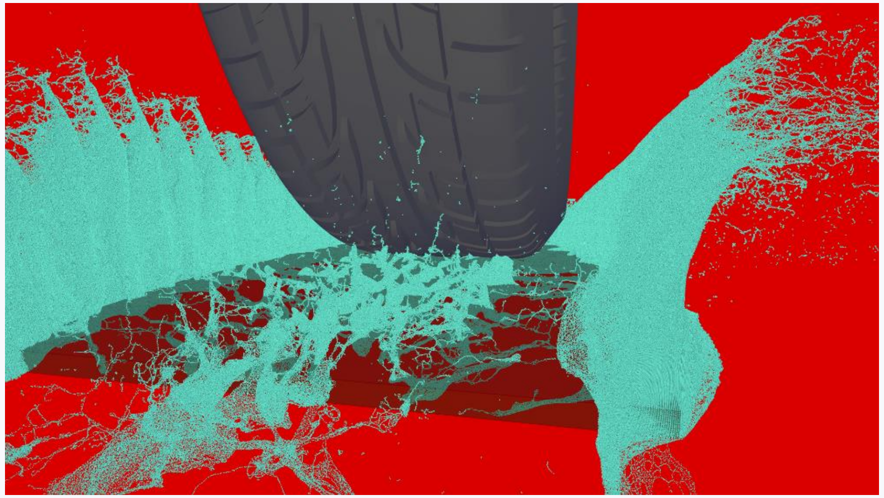
- ❑ Developed Specifically for GPU parallelization
- ❑ Requires only single precision for accurate solution
- ❑ Very scalable to many CUDA cores

Example: Tire Hydroplaning

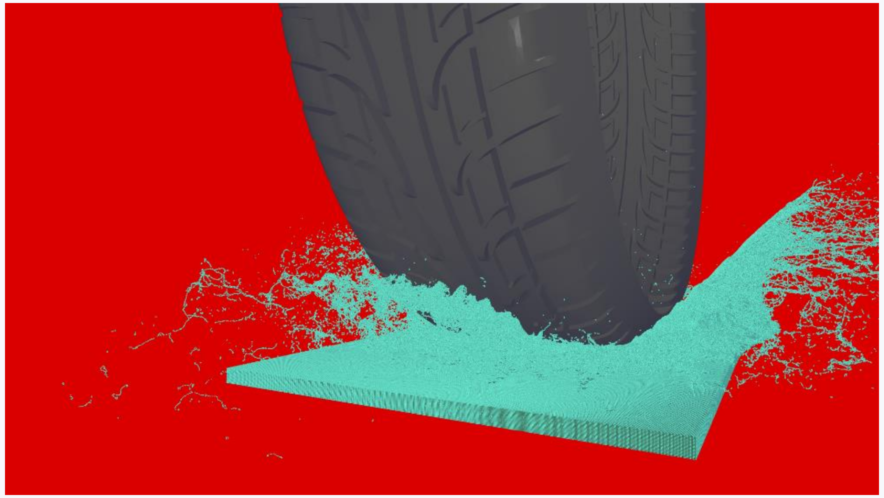
Tire Hydroplaning **14.76 Million Fluid Particles**





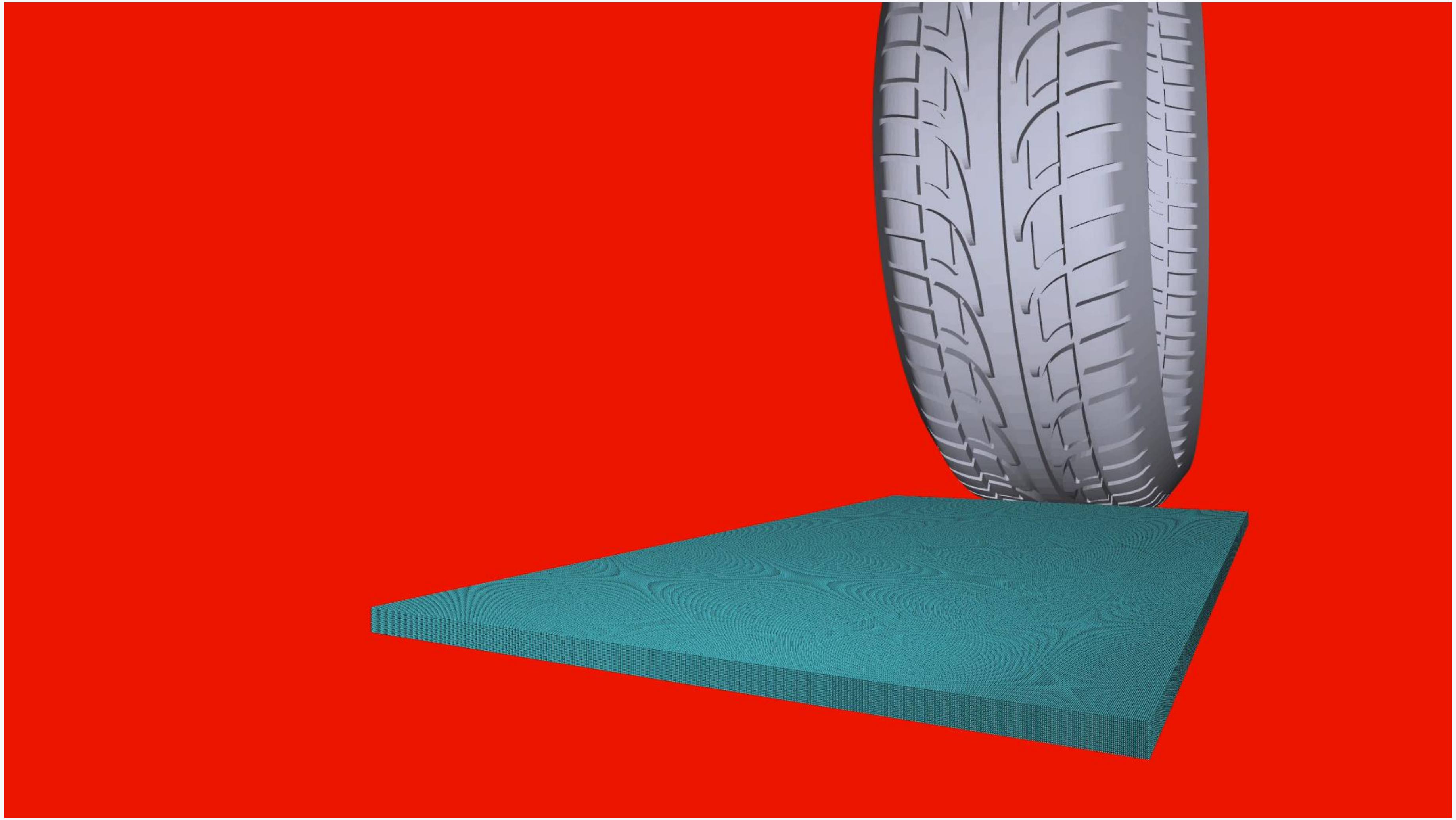


Back View

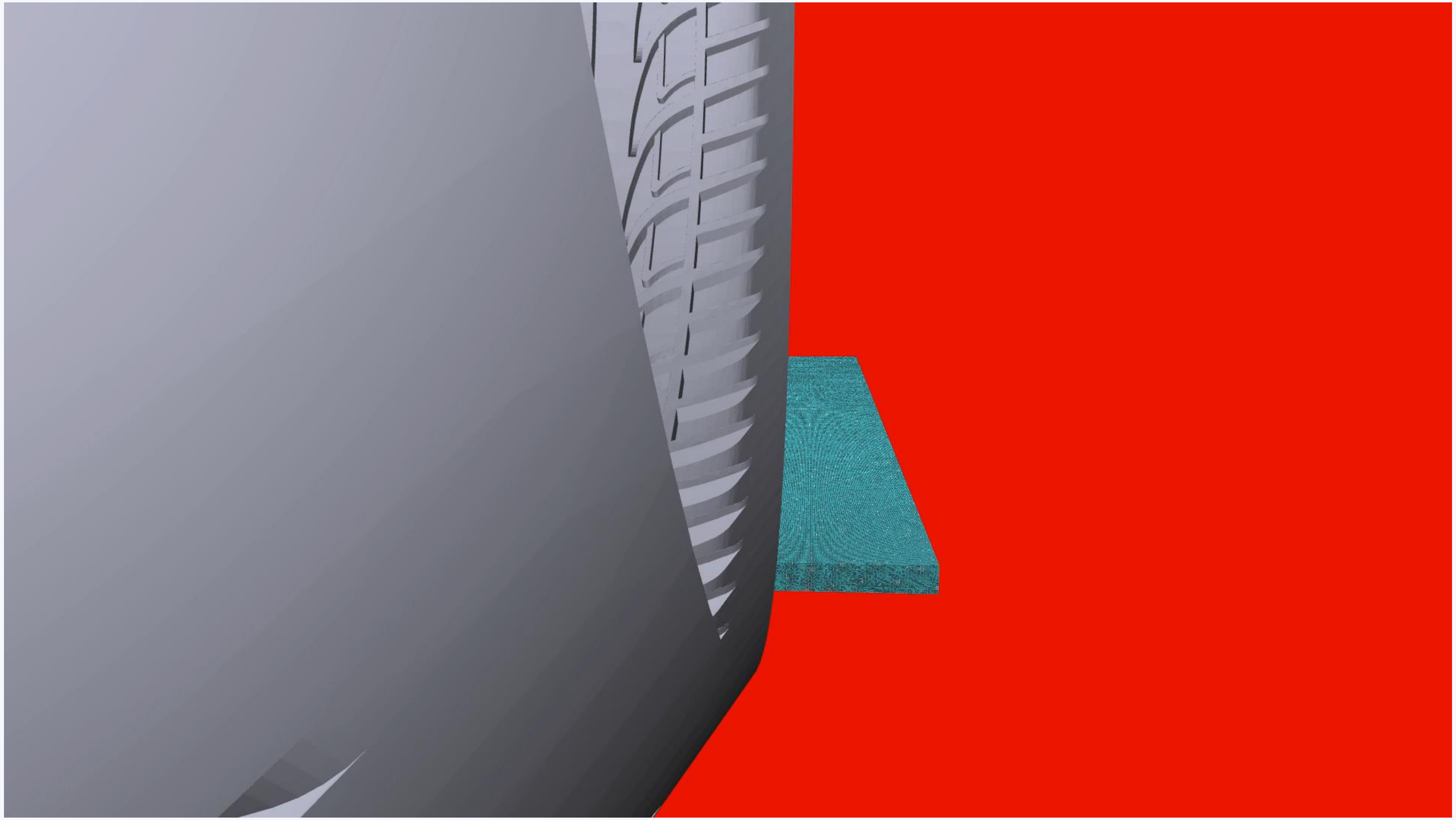


Front View

Tire Hydroplaning 14.76 Million Fluid Particles



Tire Hydroplaning 14.76 Million Fluid Particles



Multi GPU Processing – Procedure

❑ Methods for Multi-GPU Implementation

- ❑ Duplicate the Model on both GPUs
    - ➢ Easier to implement (Fully Functional)
- ❑ Divide the Model into 2 parts
    - ➢ Allows for larger models to run
    - ➢ More difficult to implement (In Alpha Testing)

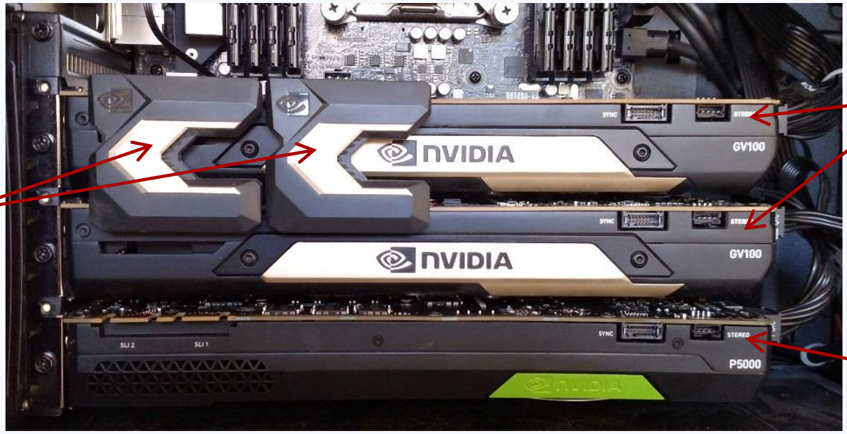
Hardware Configuration – Single Workstation with Dual GPUs

KRONOS 840-G4
Ciara Technologies

- ❑ **Dual GPUs can be used with and without NVLINK**
- ❑ **NVLINK provides a Direct connection between 2 GPUs**

- ❑ **QUADRO GV100 – Flagship Workstation GPU**
  - ❑ Requires that both GPUs be in TCC Mode
  - ❑ Only for Computation in this mode

NVLINK

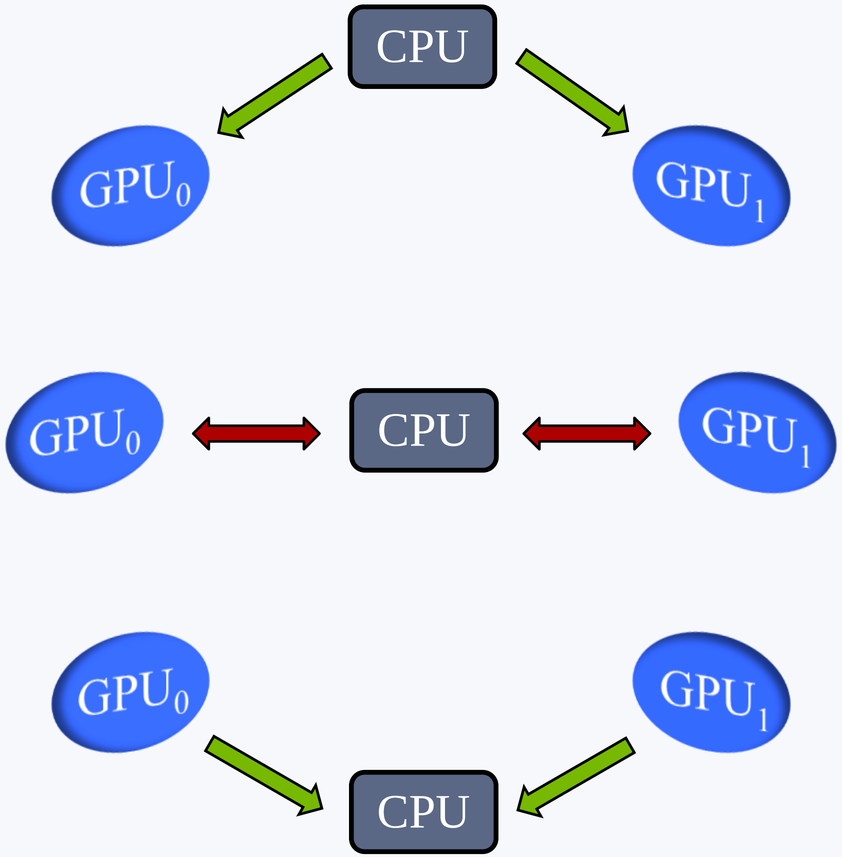


NVIDIA
QUADRO GV100
(For Computing)

NVIDIA
QUADRO P5000
(For Visualization)

Method 1: Multi GPU Processing Algorithm – No NVLINK

<u>One iteration</u>

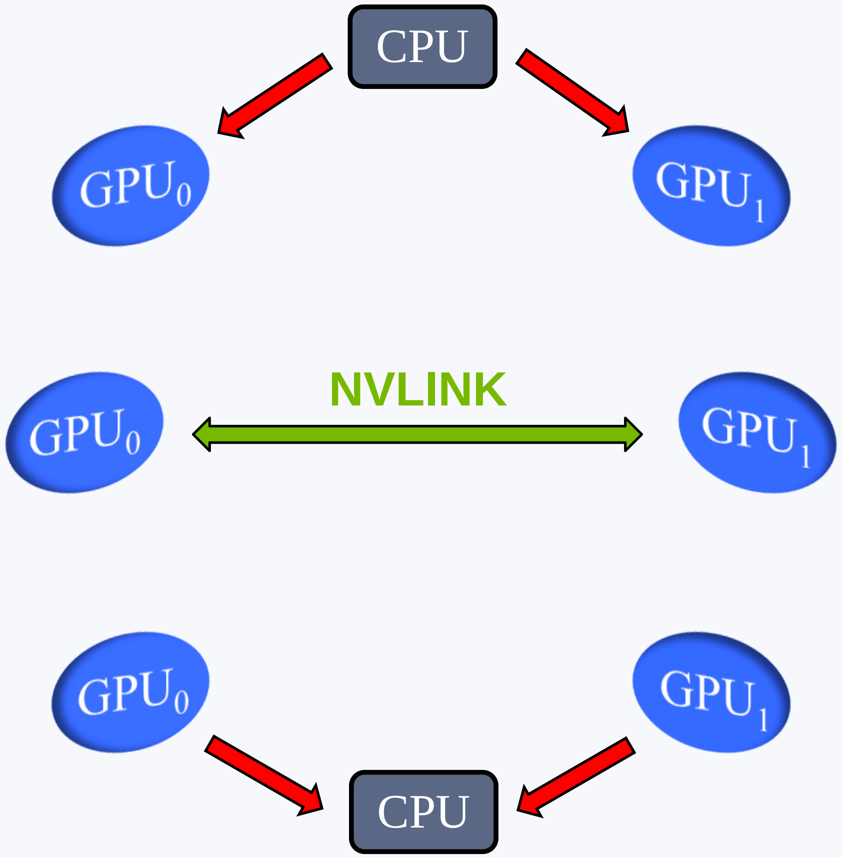


1st Leapfrog Integration
Both GPUs

Collision Computations
Shared between GPUs
by way of the CPU

2nd Leapfrog Integration
Both GPUs

Method 1: Multi GPU Processing Algorithm – NVLINK



One iteration

1st Leapfrog Integration
Both GPUs

Collision Computations Shared directly between GPUs with NVLINK

2nd Leapfrog Integration
Both GPUs

SPH Example: Hypervelocity Impact

What is meant by Hypervelocity?

- Velocity > 2.5 km/sec

- Metal behaves like a fluid when impacted at these velocities
  - A particle based method such as the SPH method is necessary to model the structures

- Deformation is very large so classic Finite Elements(FE) cannot handle the deformation

Hypervelocity Oblique Impact

Reference Experiment

Thiot Ingenierie Test Lab

Projectile: ***Aluminum Sphere***

Target: ***Aluminium Plate***

Simulation

IMPETUS Afea Solver®

γSPH Module

Material Model: ***Elastic Perfectly Plastic + Mie-Gruneisen EOS***

Hypervelocity Oblique Impact

Modeling Hypervelocity Impact

Protecting Satellite Impact from Space Debris

Obilque Impact of a Sphere on a Plate

Impact Velocity 4050 m/s

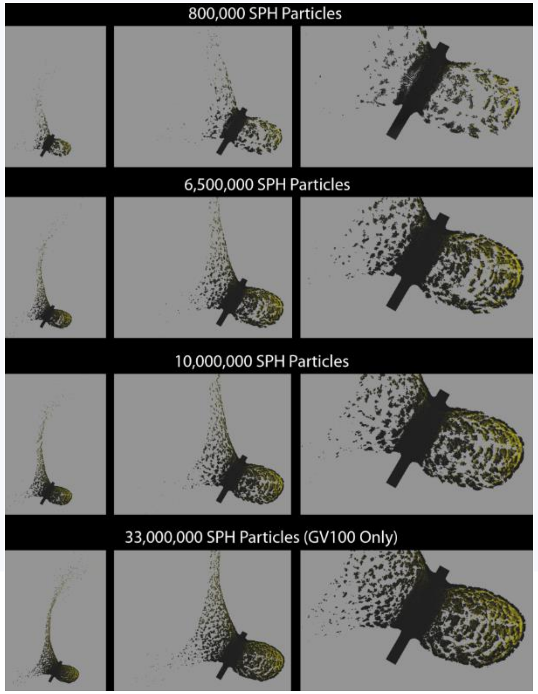
Sphere Diameter 3.0 mm

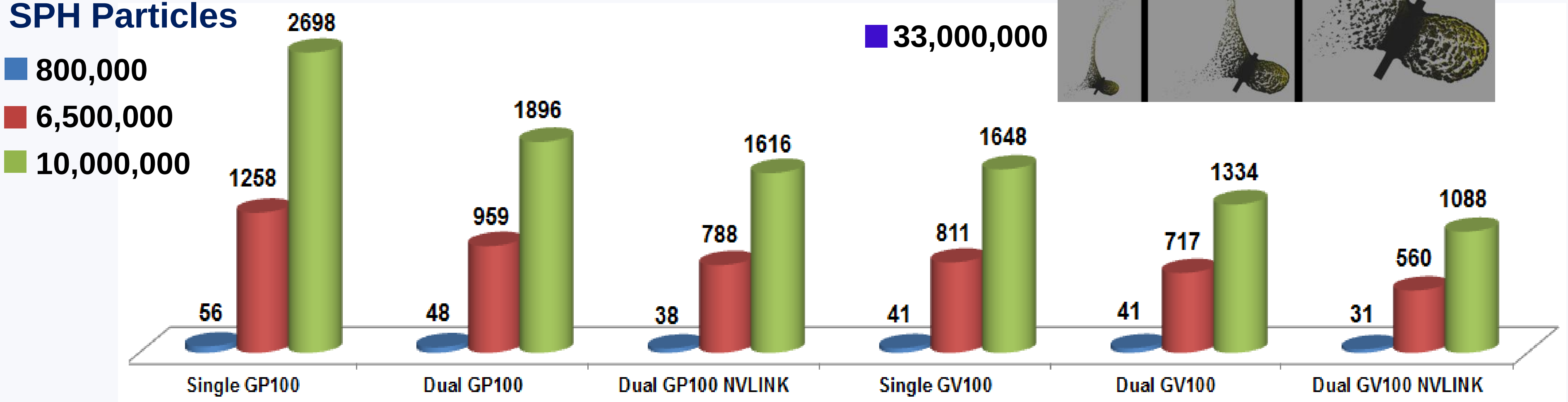
800,000

6,500,000

10,000,000

33,000,000

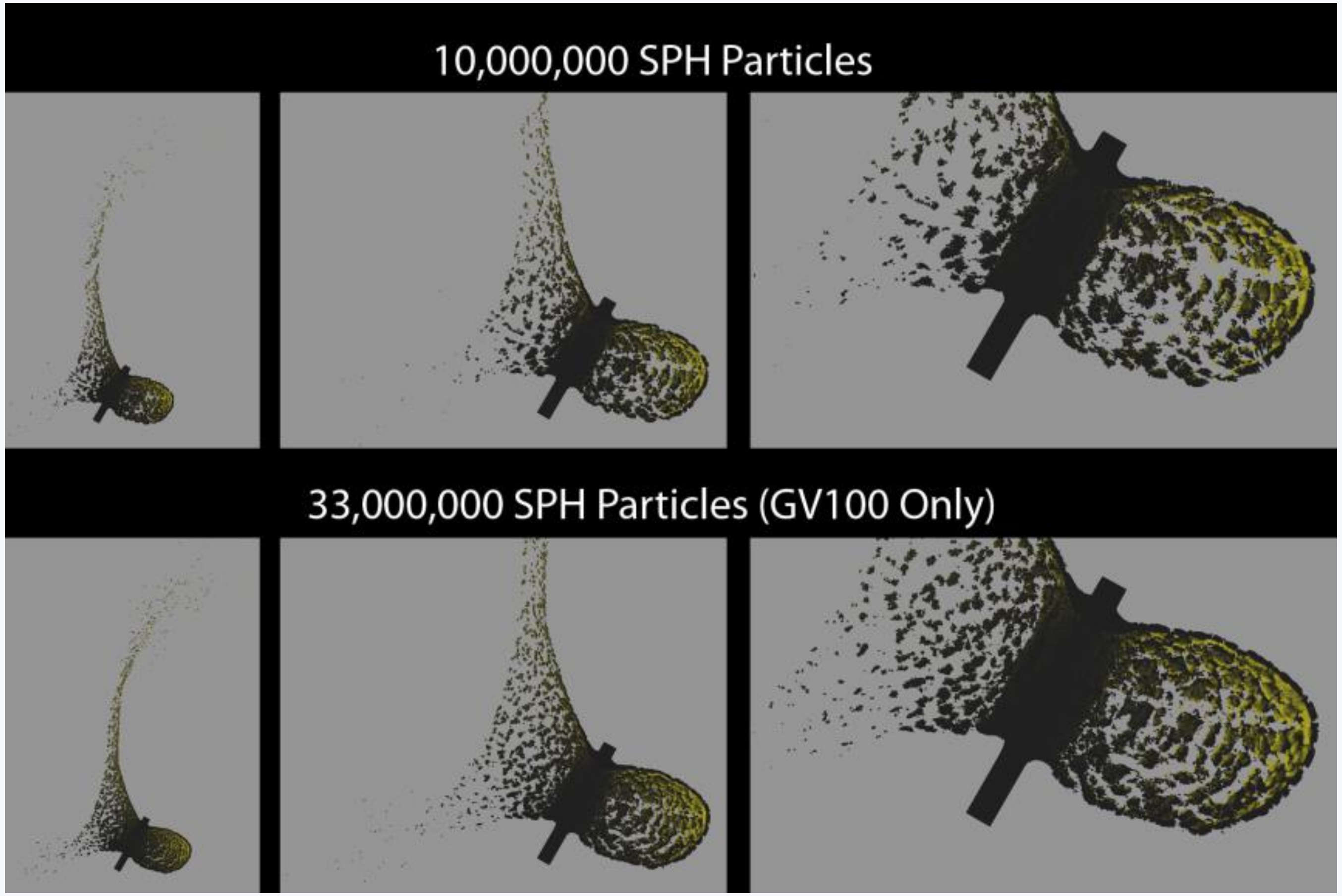




Simulation Time (sec)

Hypervelocity Oblique Impact

<u>Every Particle Counts:</u> High resolution is necessary to track debris formation



Comparison – 800K Model for Hypervelocity Impact

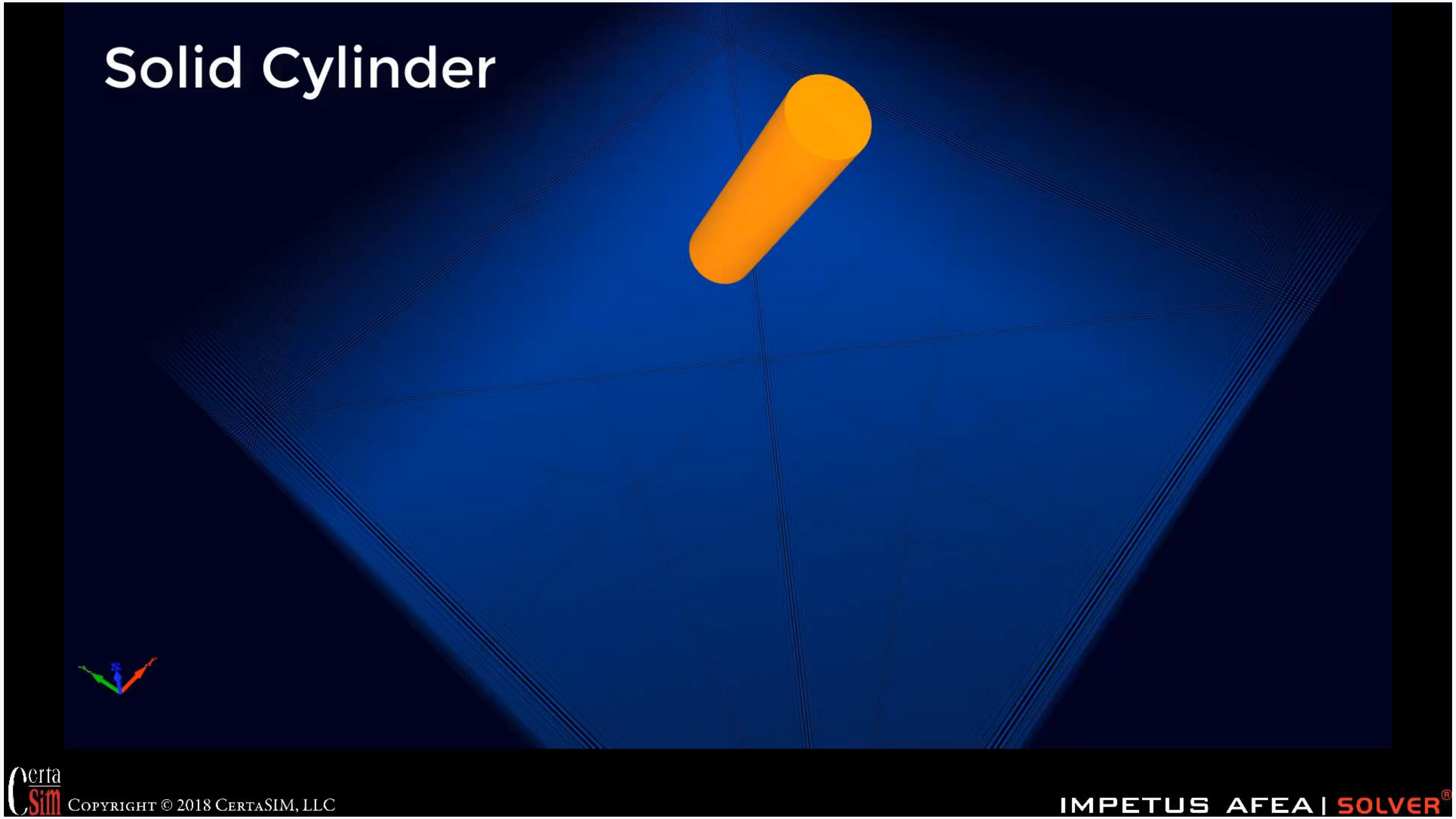
- **"Legacy MPP Solver"**
  - Standard Intel Cluster Configuration
    - 36 cores
    - Runtime 20 mins

- **GPU Massively Parallel Processing**
  - GV100 – Standalone Workstation
    - Single GV100 --------------- 41 sec
    - Dual GV100 --------------- 41 sec
    - Dual GV100 NVLINK--- 31 sec

IMPETUS Afea Next Generation SPH Solver - γSPH

Example: Cylinder Impacting Water

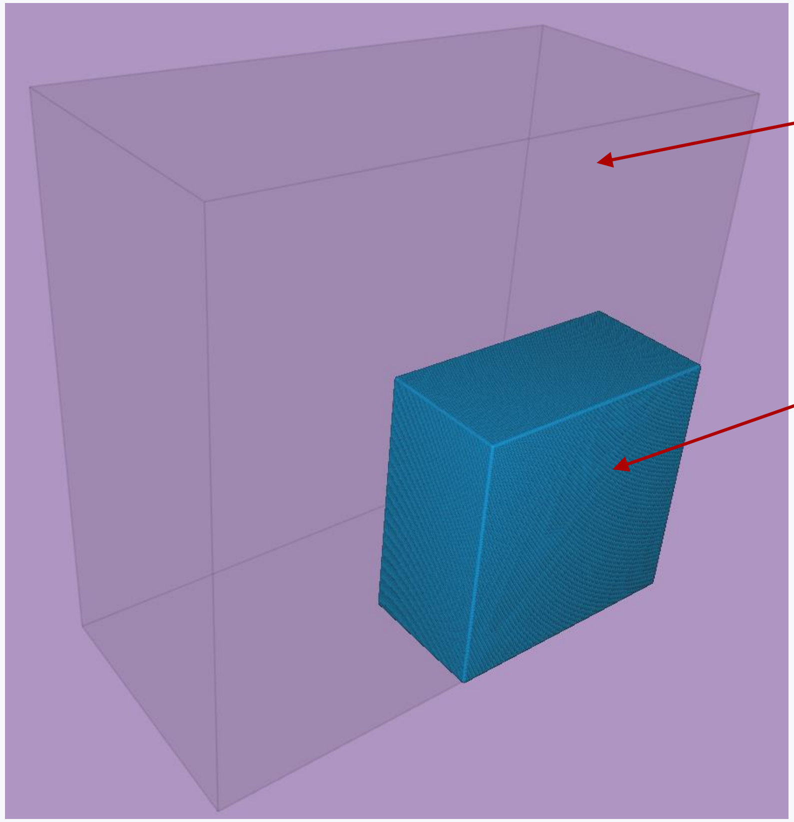
Cylinder Drop in Water



Example: Dam Break

Dam Break: 6 Test Cases with varying number of Particles

Fluid Under a Gravity Load at time = 0.



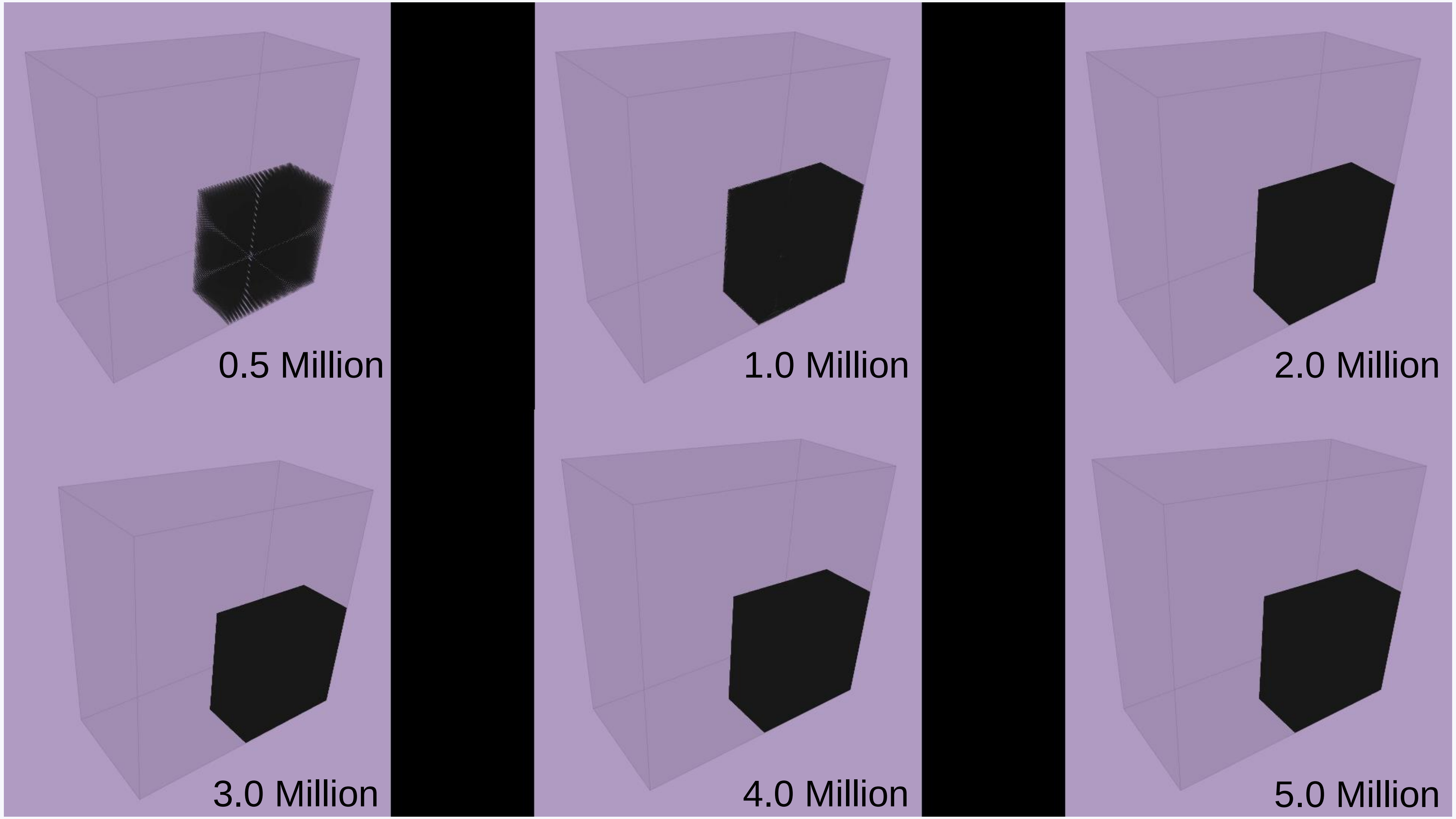
Closed Tank

Length = 2m, Height = 2m, Width = 1m

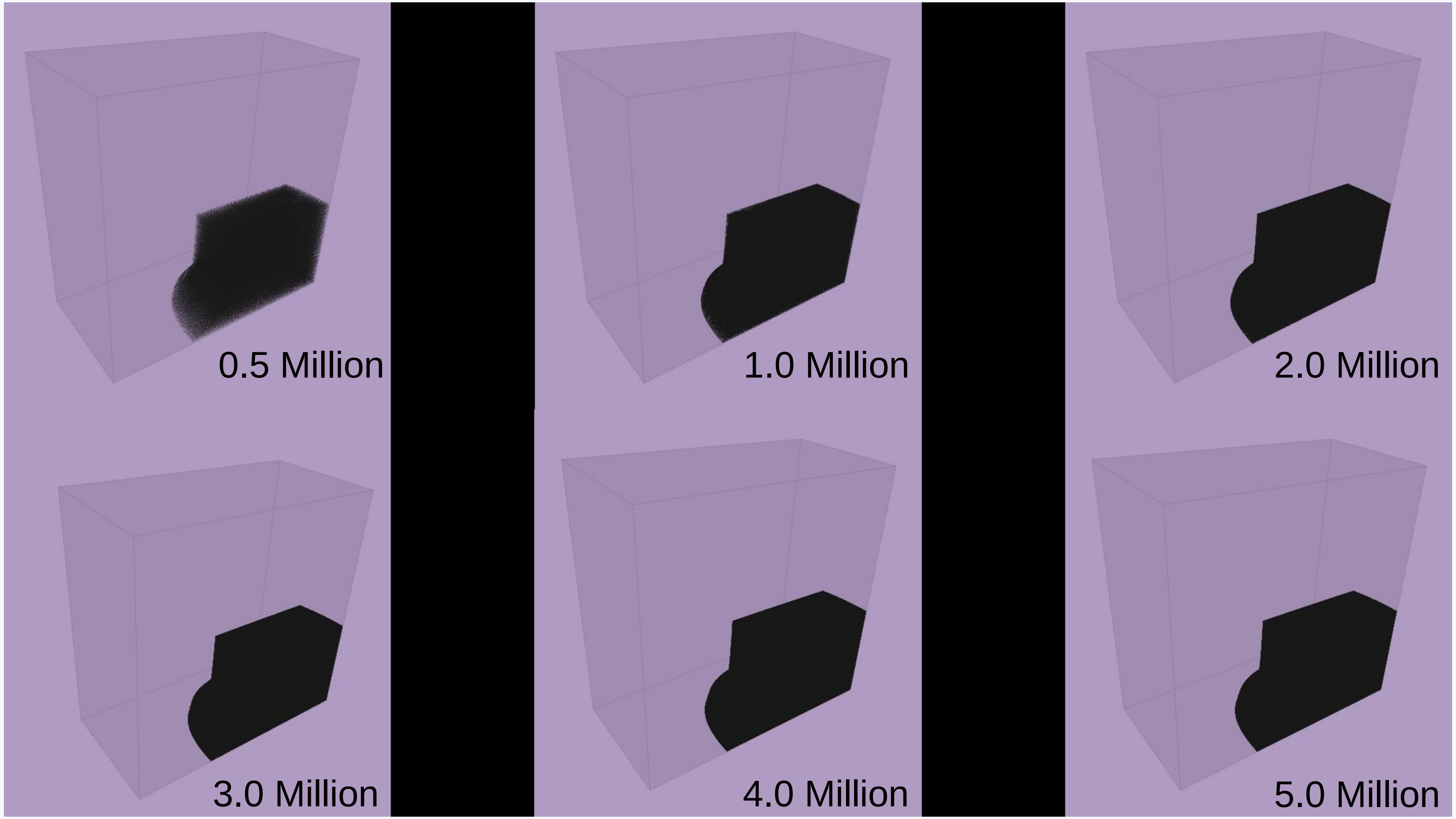
Block of Water

Length = 1m, Height = 1m, Width = 0.5m

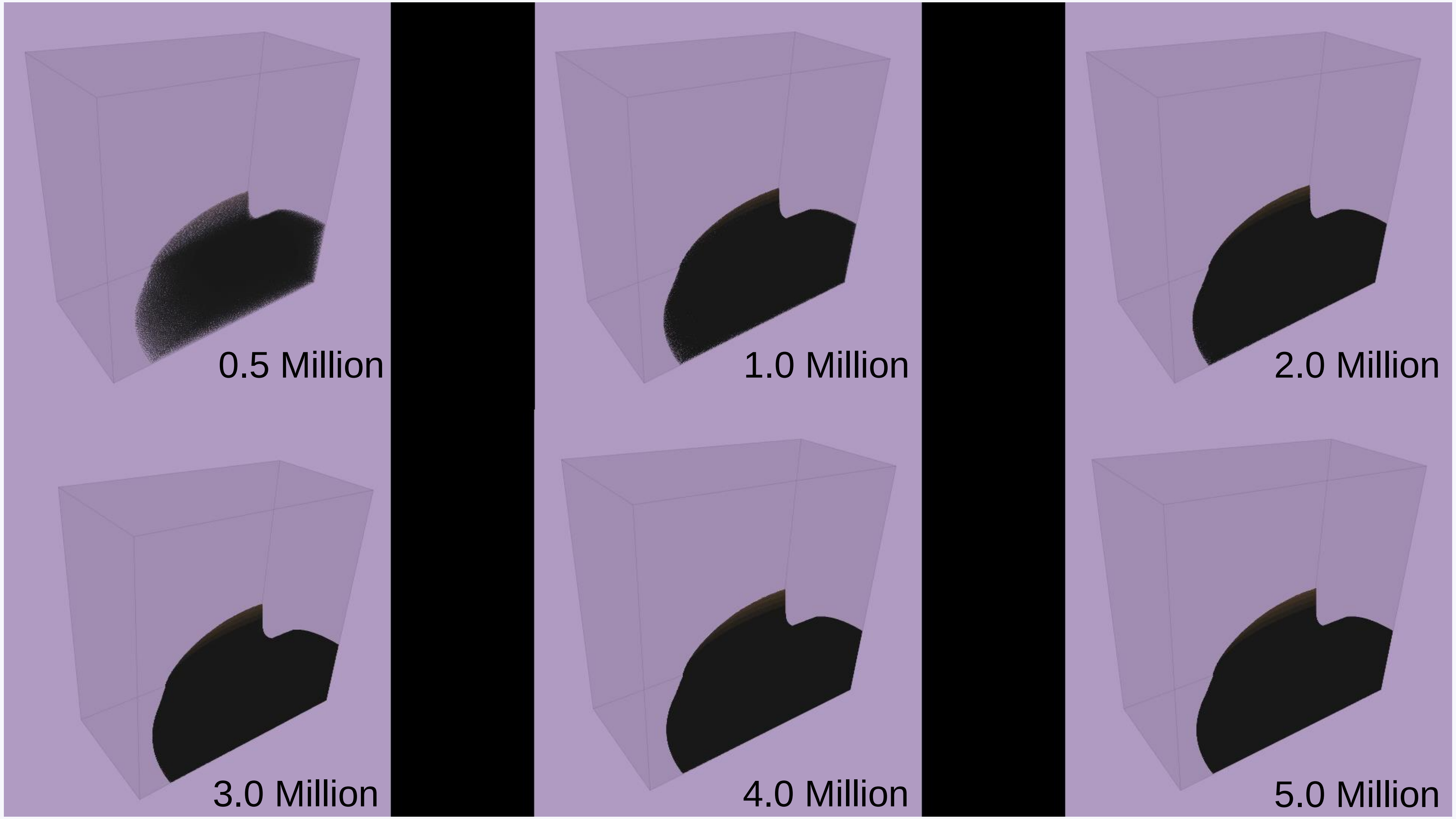
Dam Break: 6 Test Cases with varying number of Particles



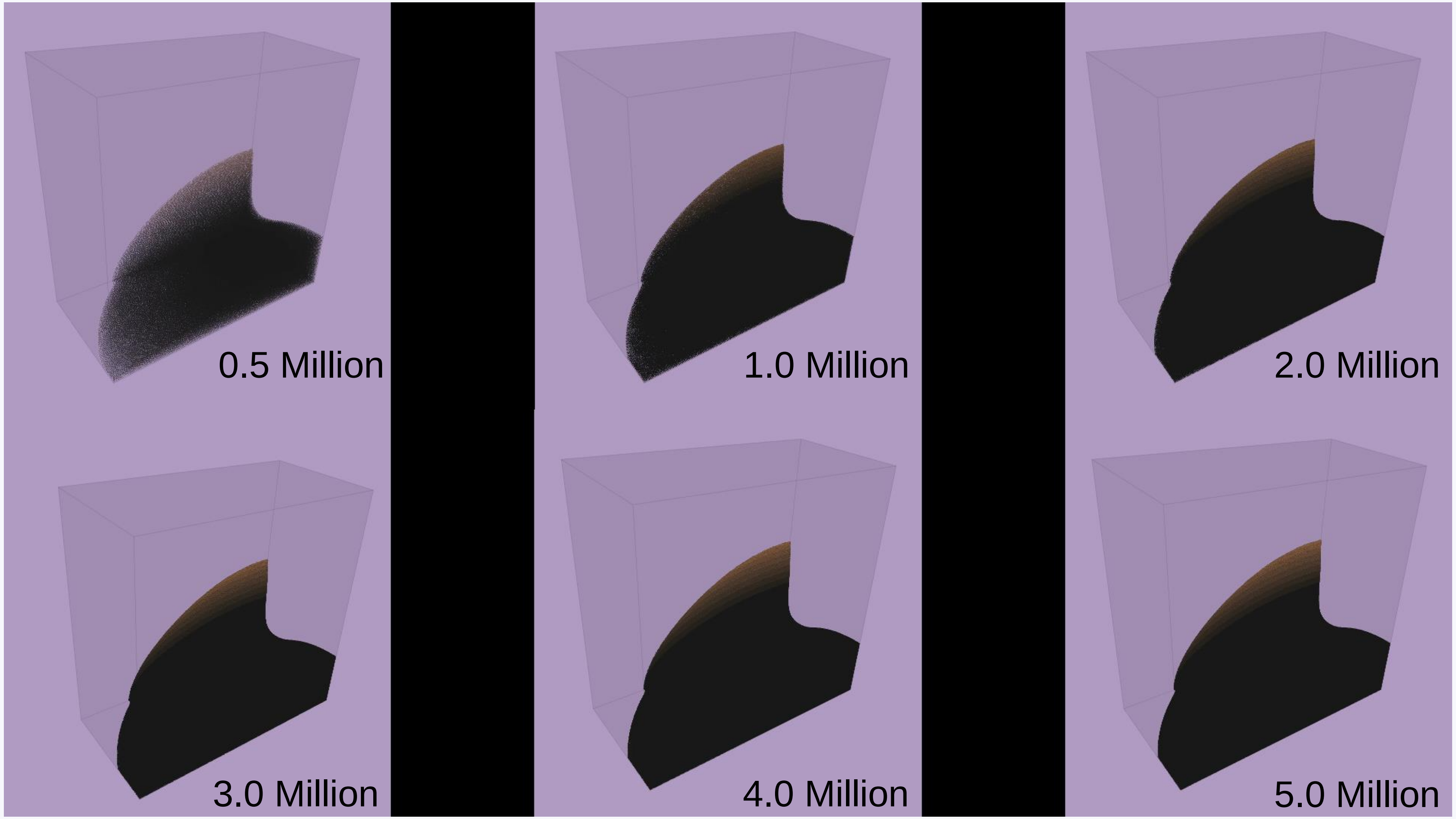
Dam Break: 6 Test Cases with varying number of Particles



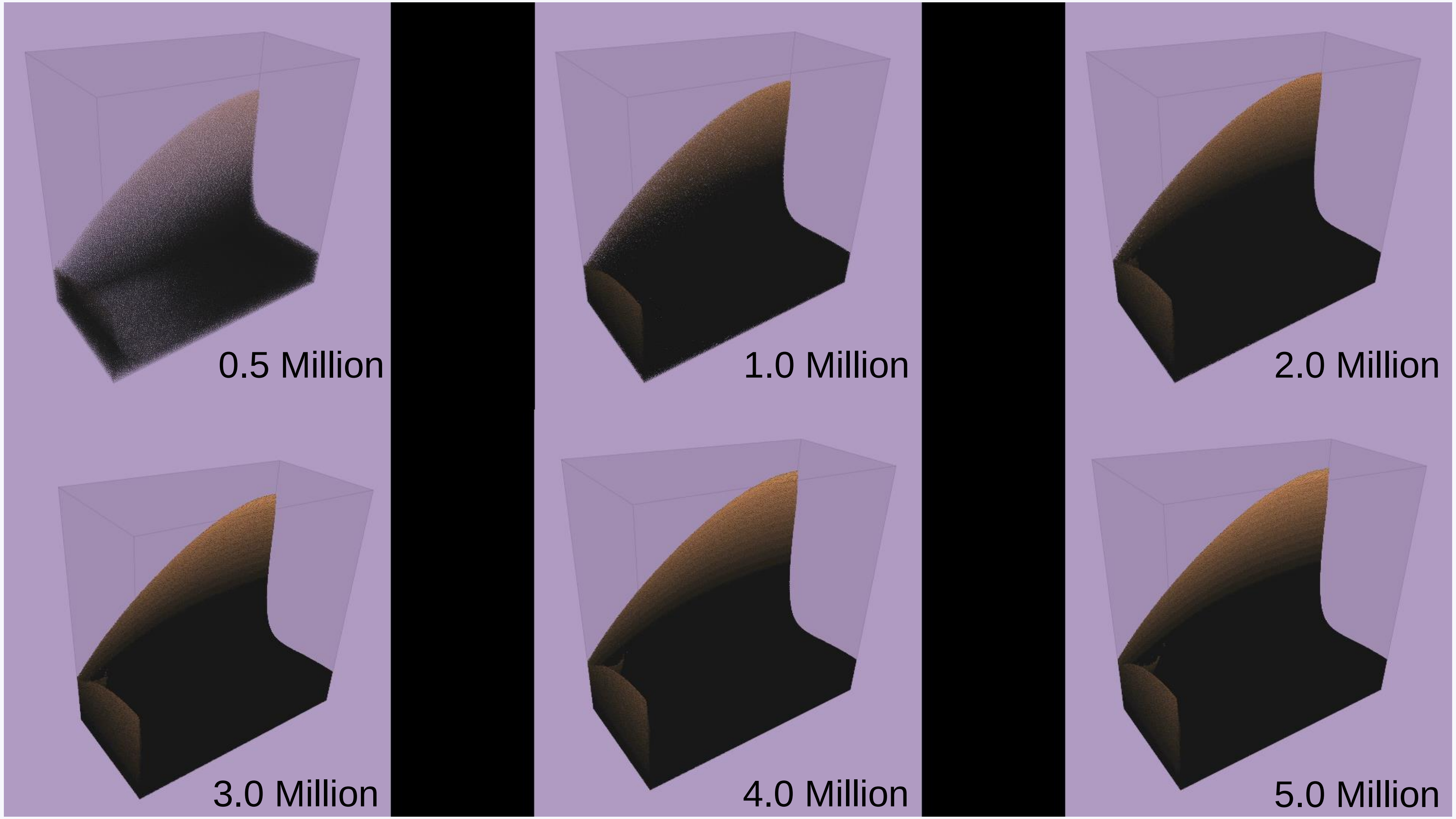
Dam Break: 6 Test Cases with varying number of Particles



Dam Break: 6 Test Cases with varying number of Particles



Dam Break: 6 Test Cases with varying number of Particles



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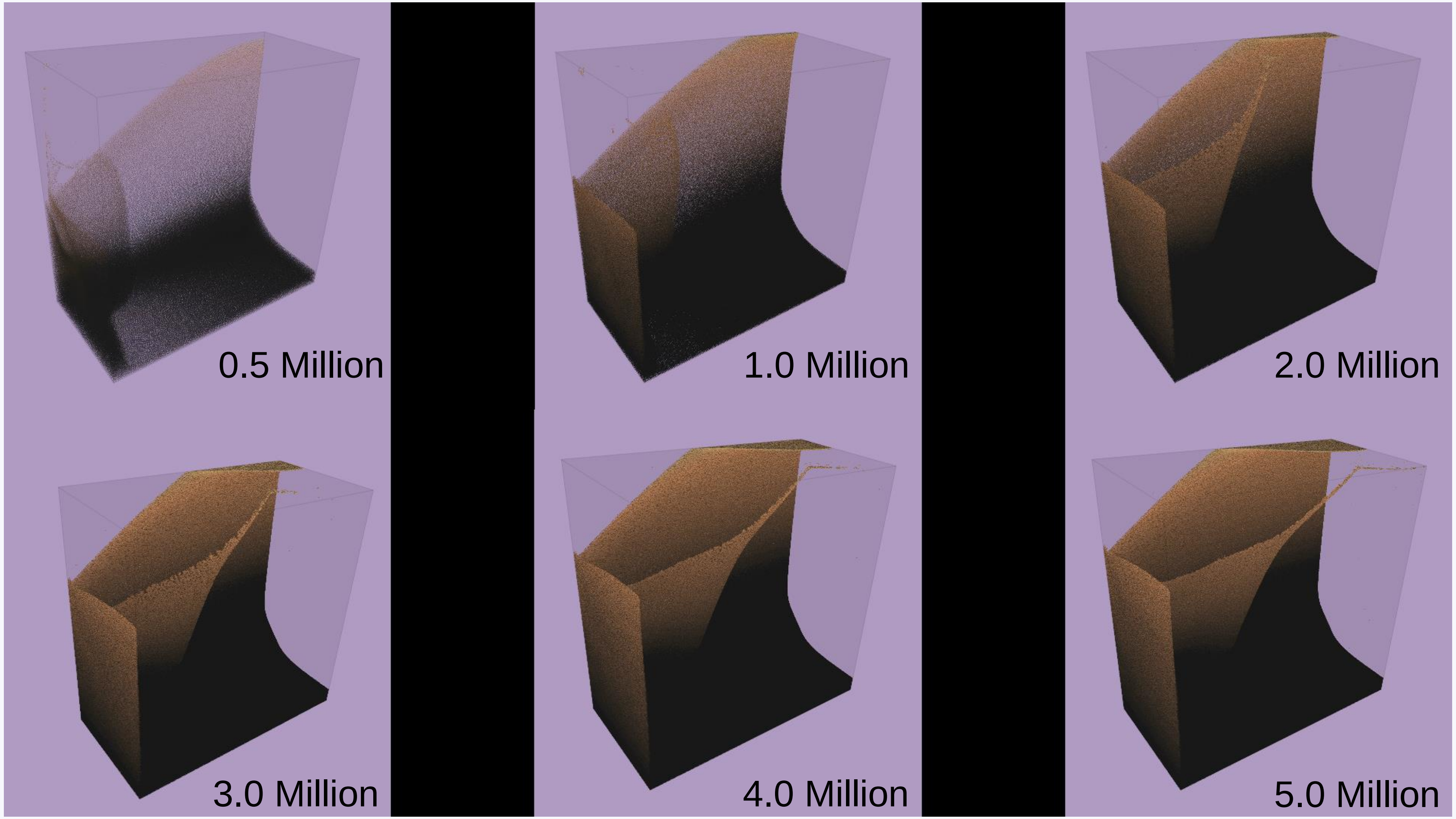
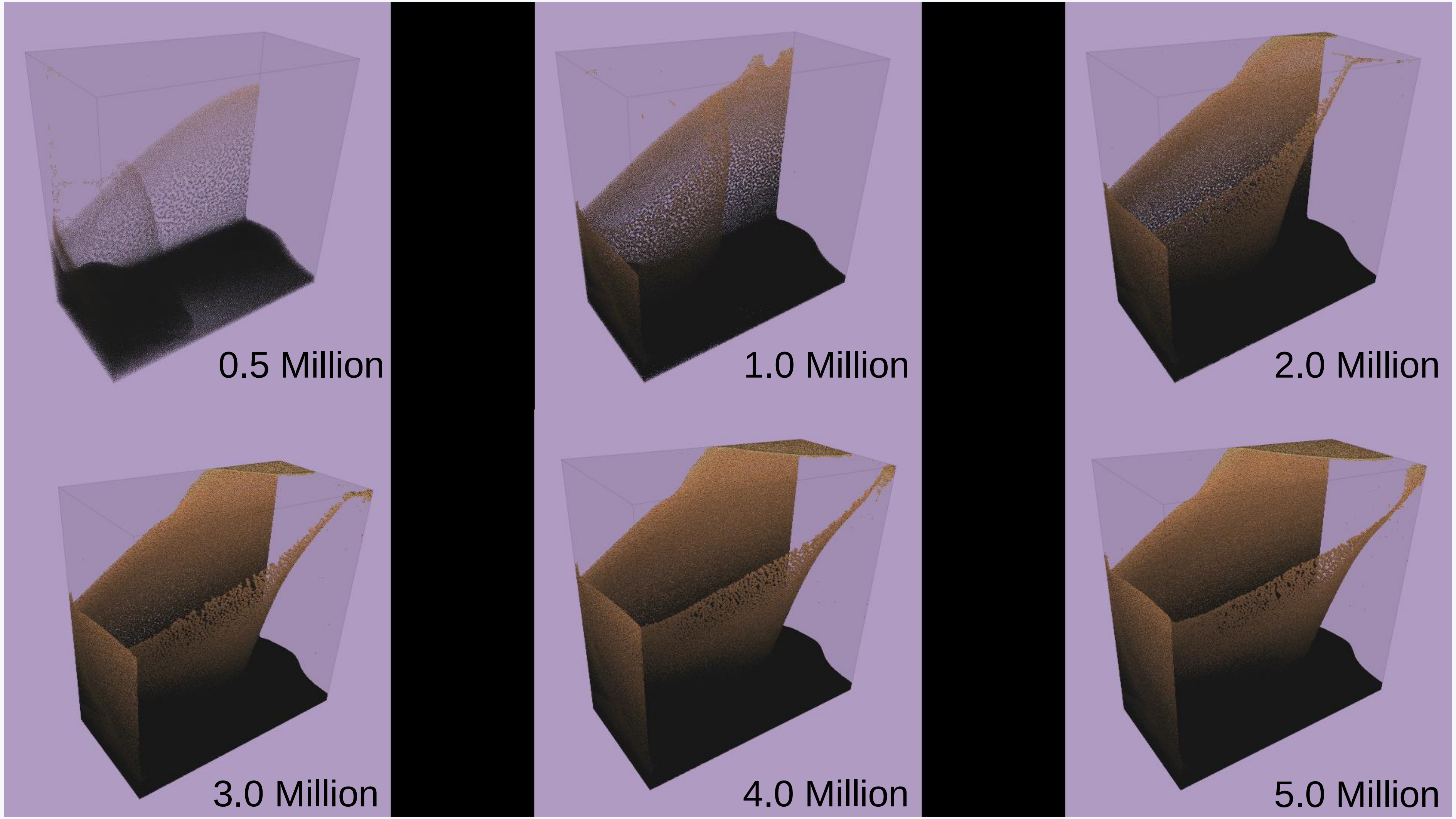


Dam Break: 6 Test Cases with varying number of Particles



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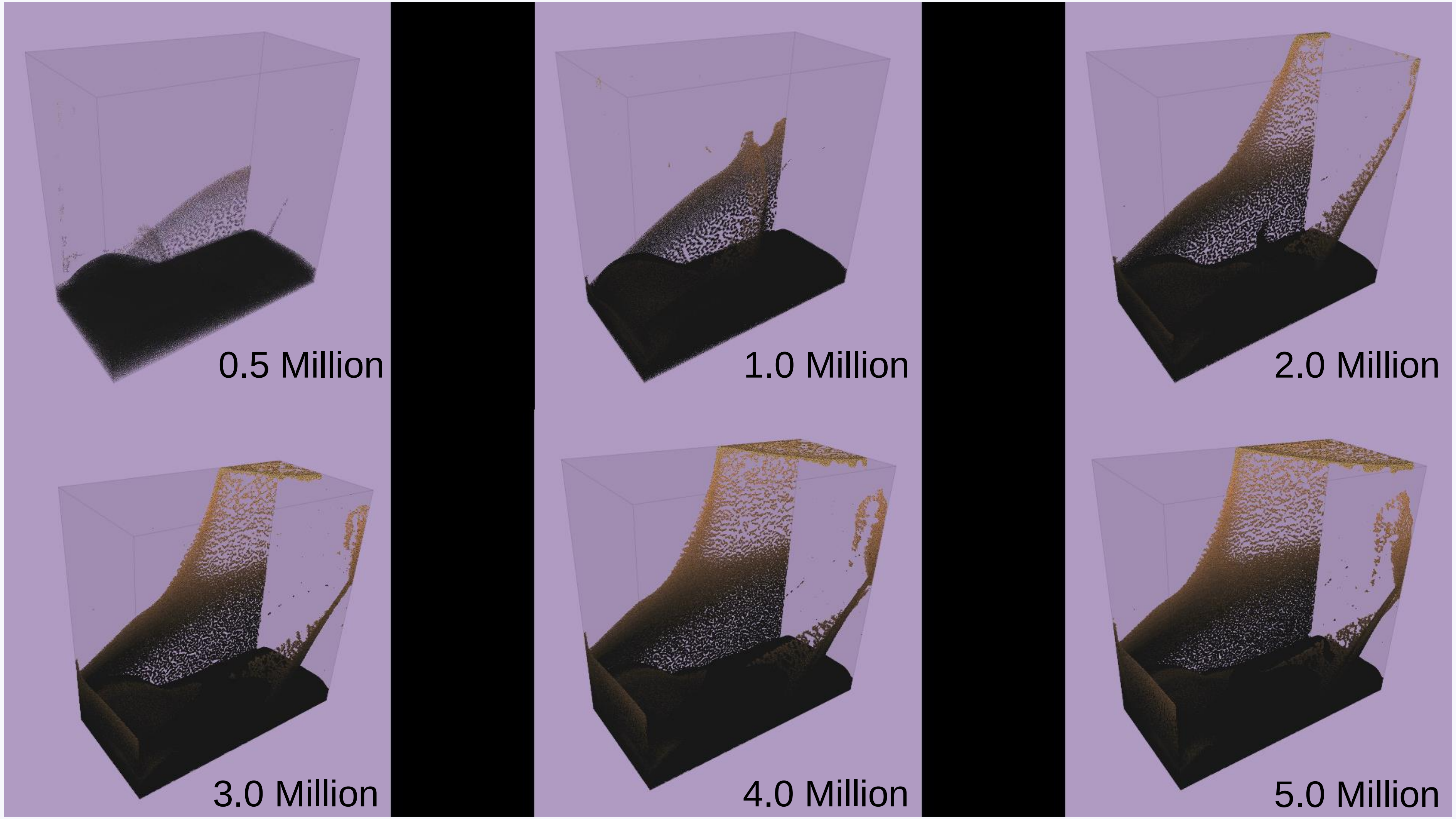

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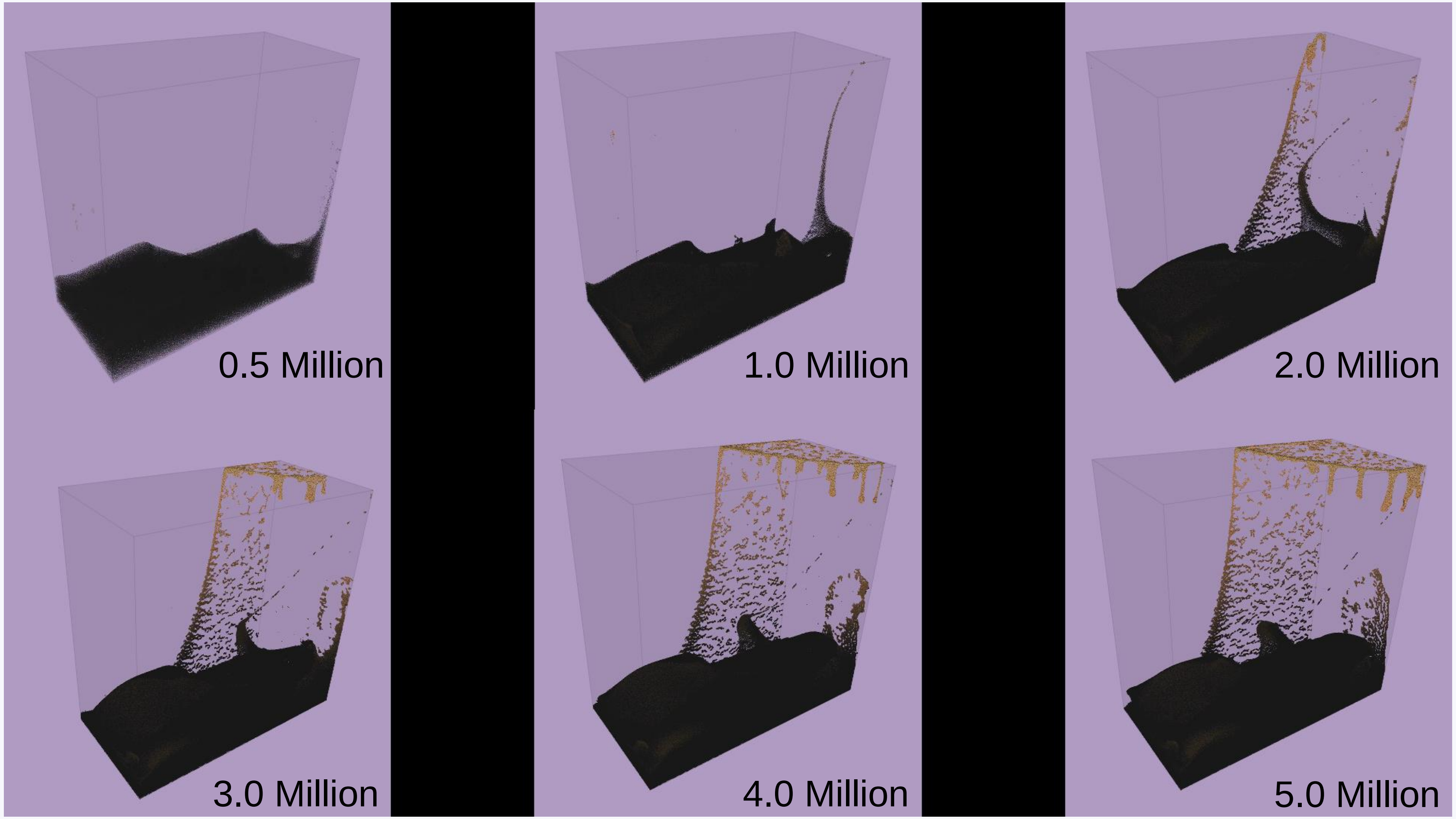
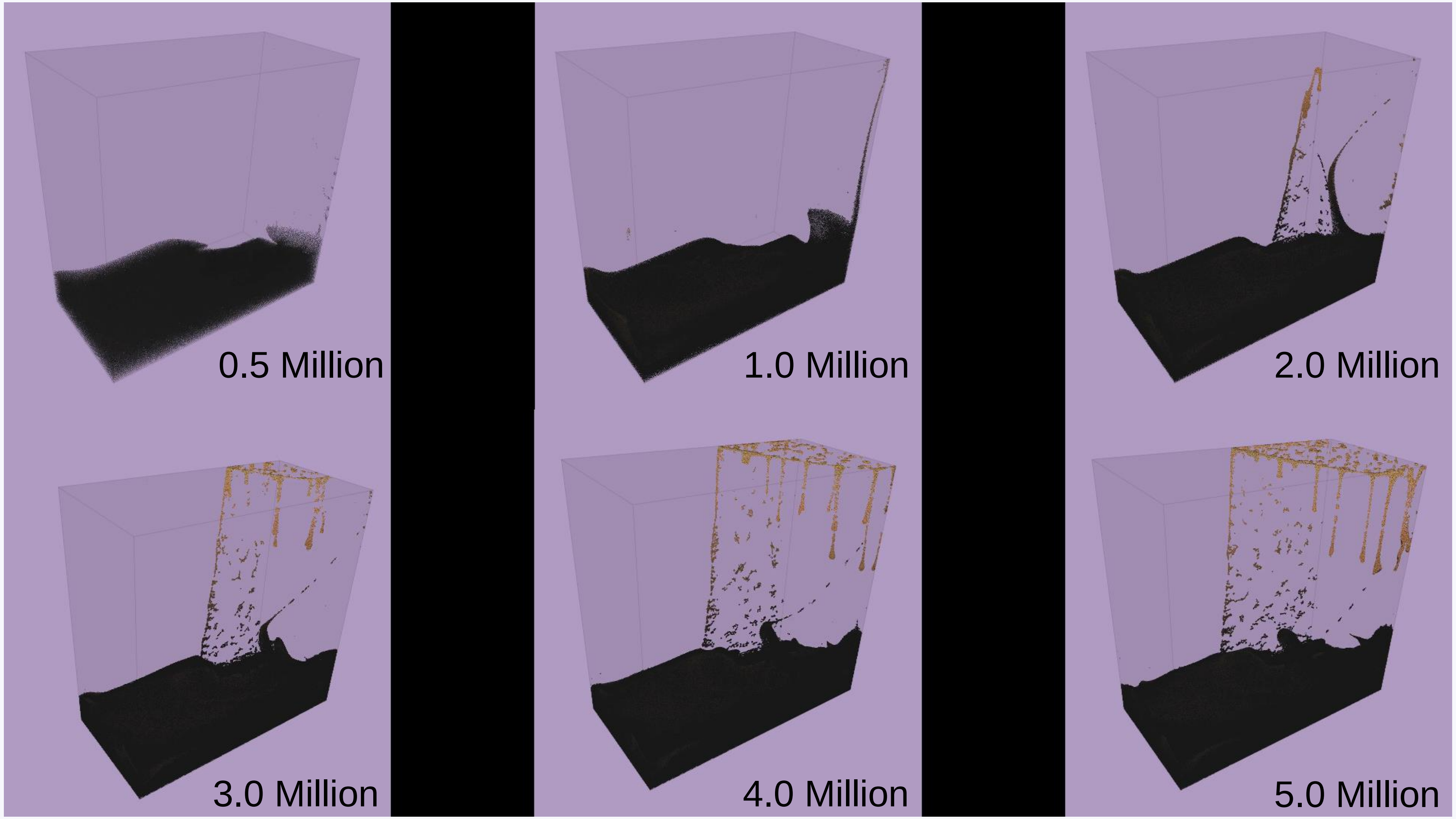


Dam Break: 6 Test Cases with varying number of Particles



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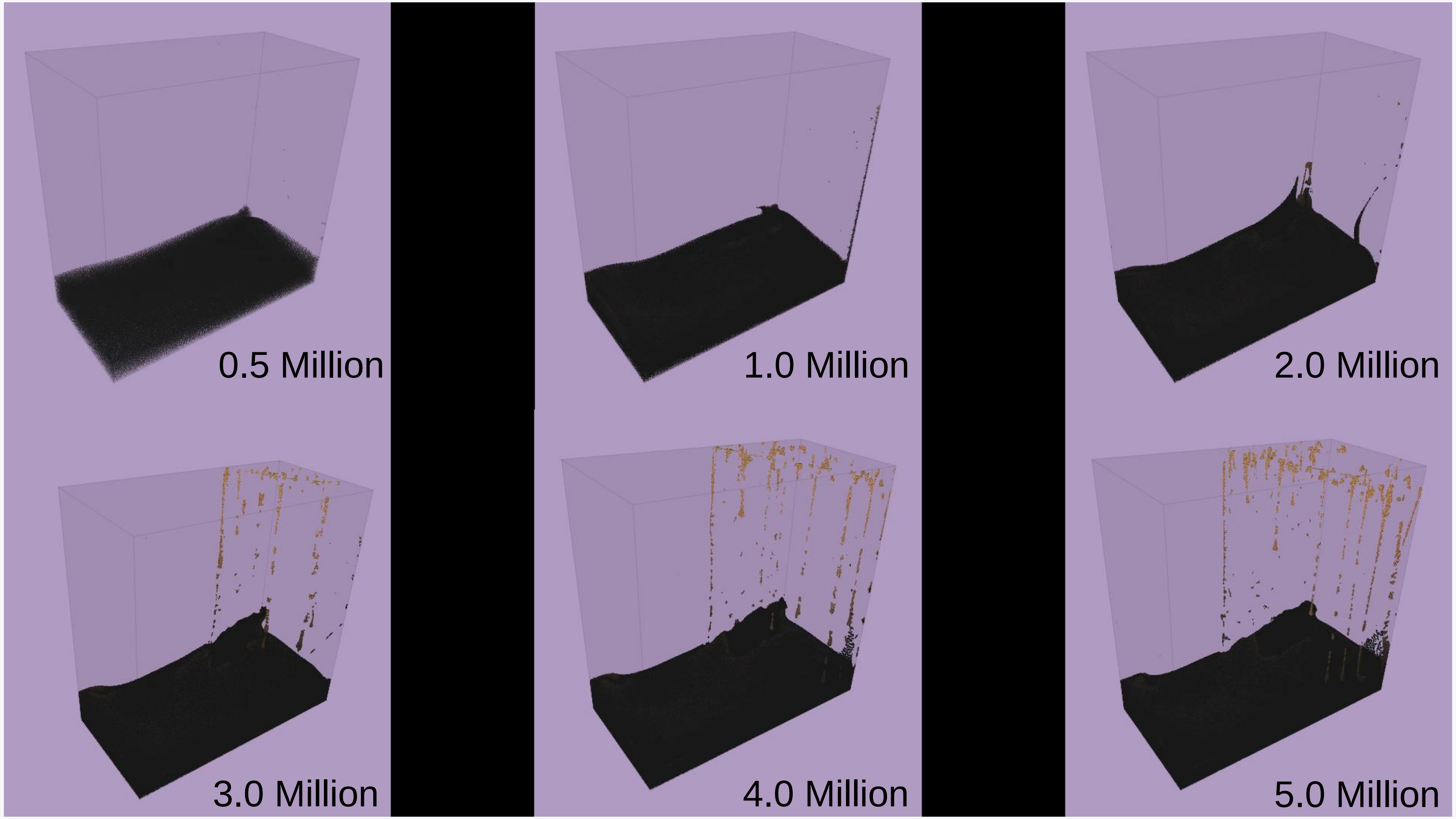

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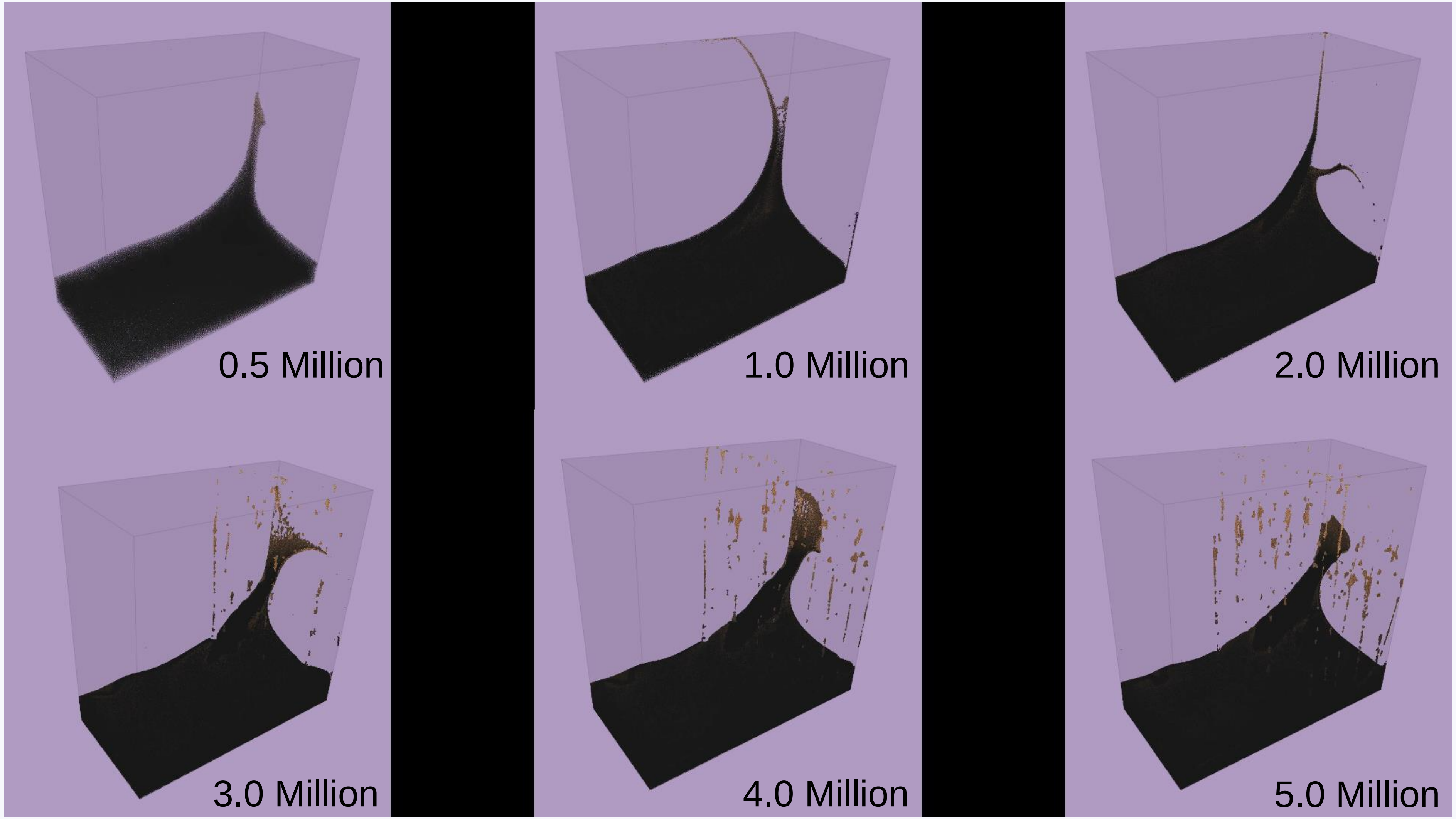
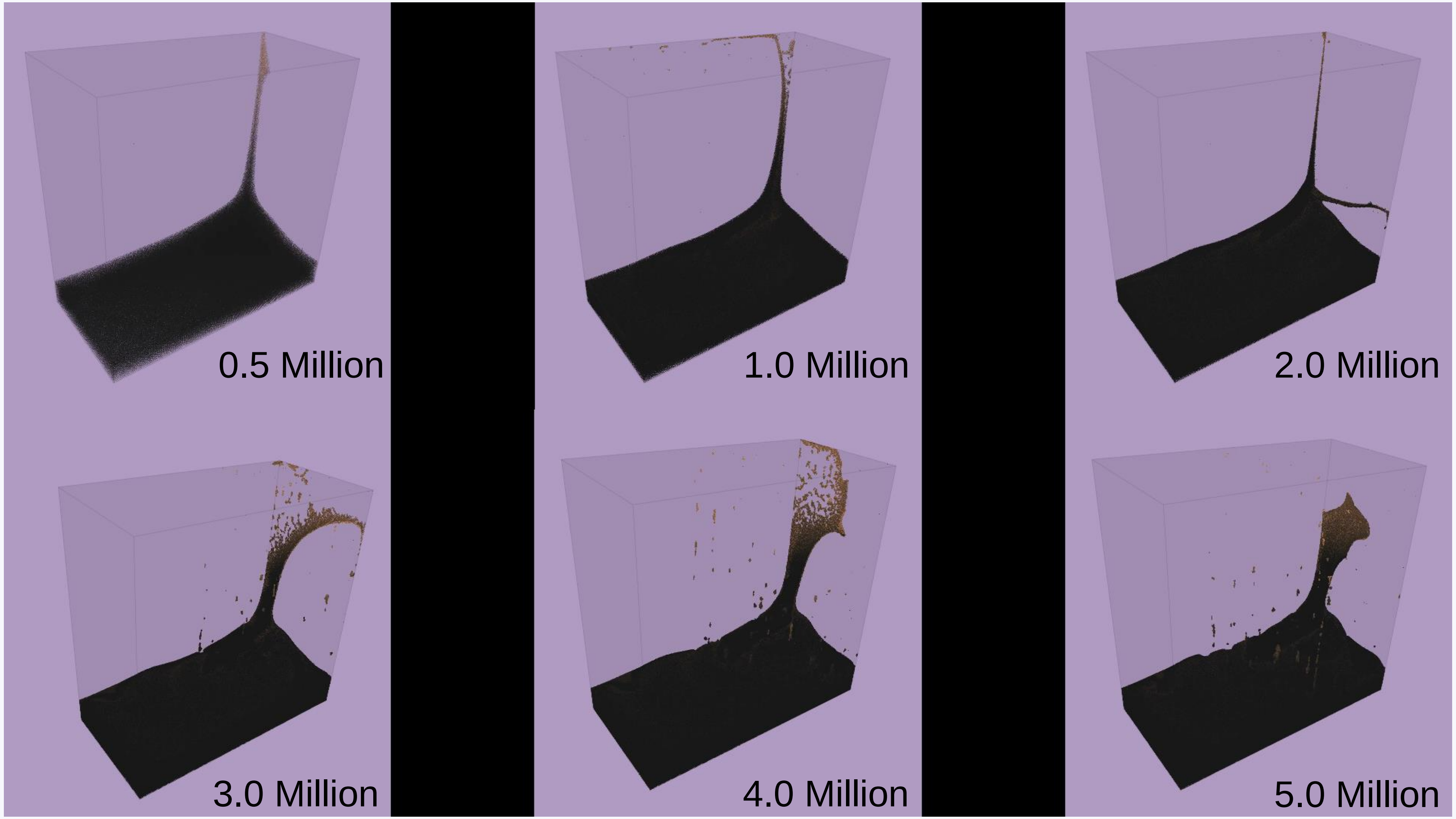


Dam Break: 6 Test Cases with varying number of Particles



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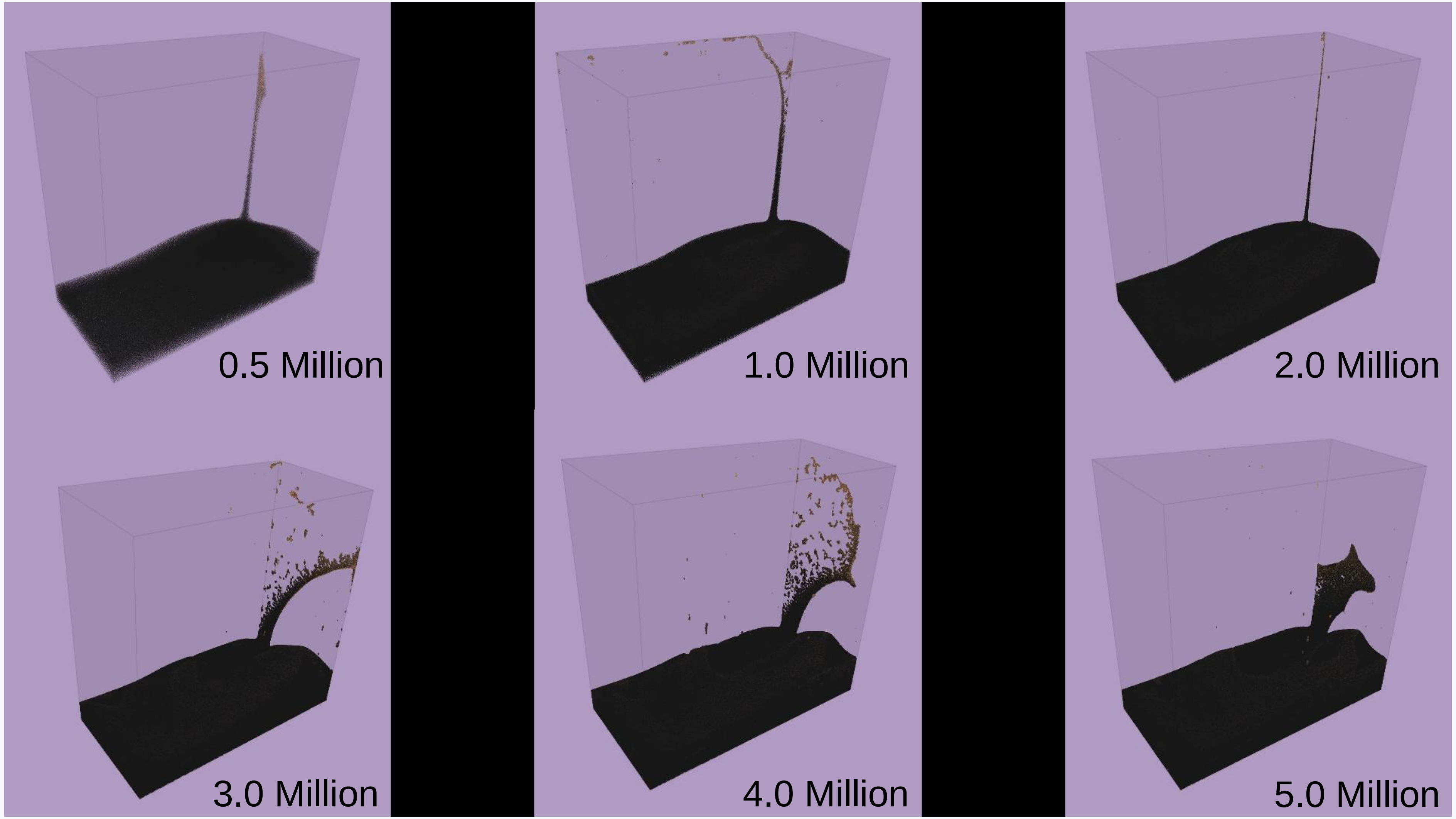

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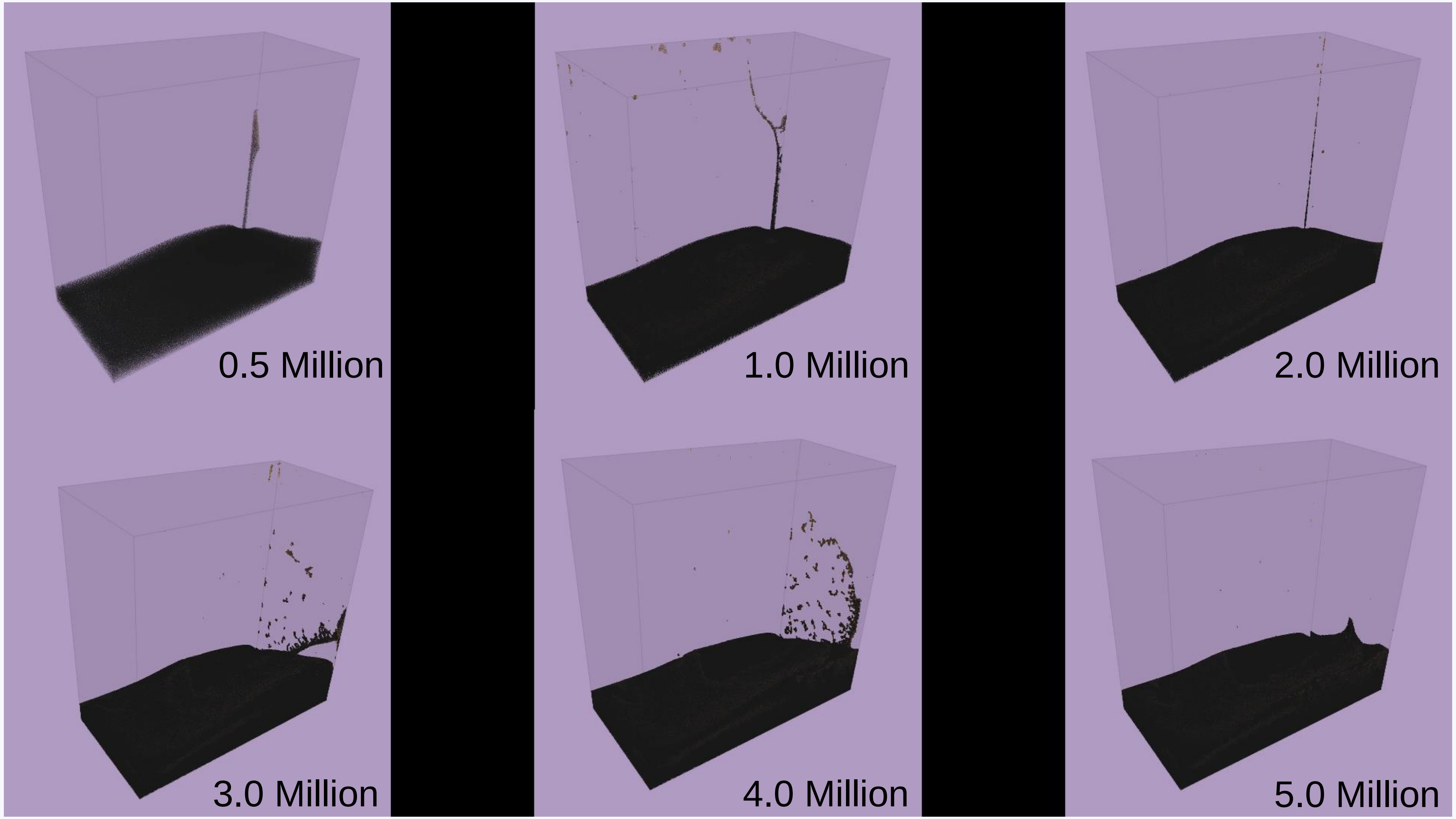
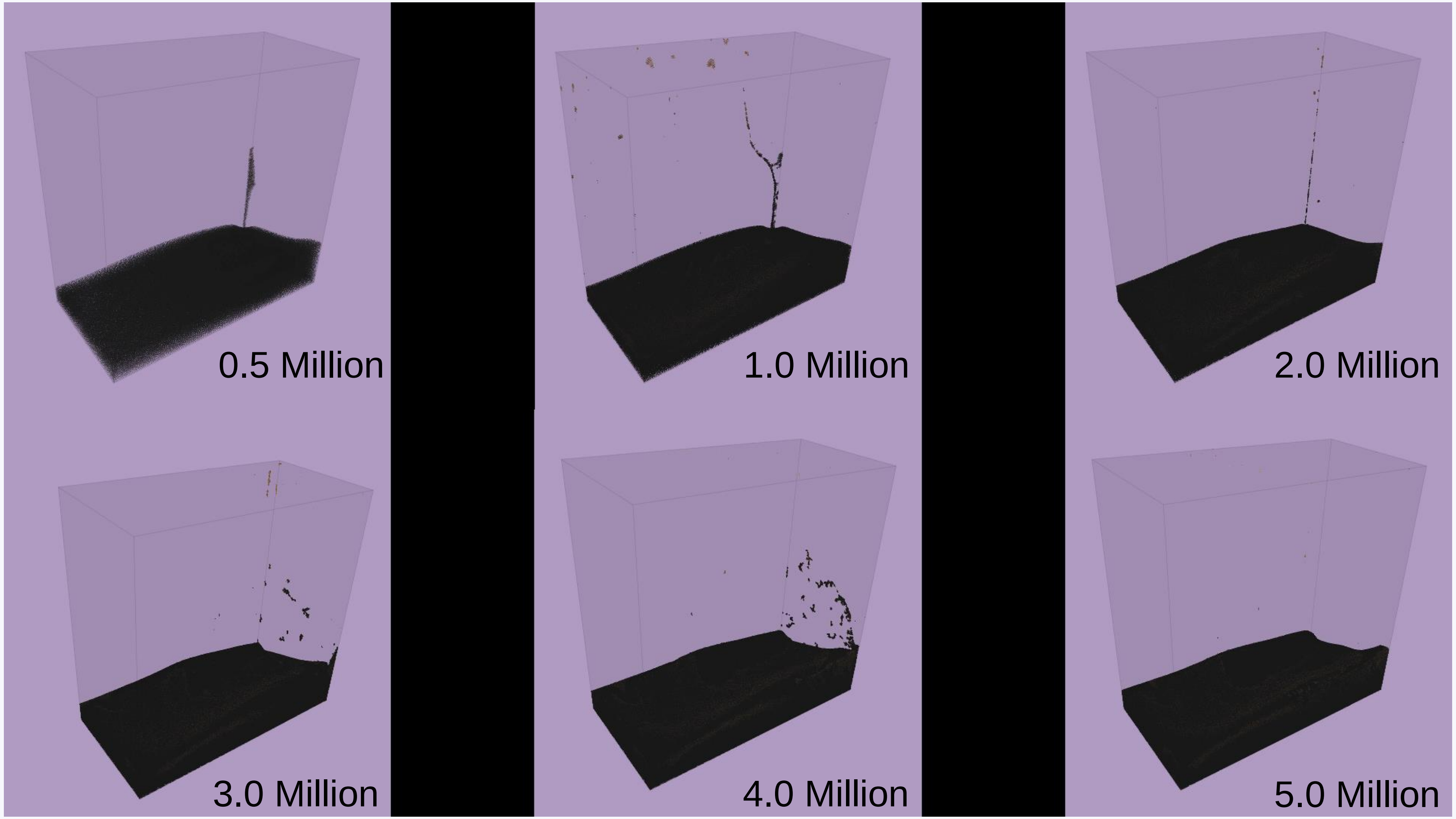


Dam Break: 6 Test Cases with varying number of Particles



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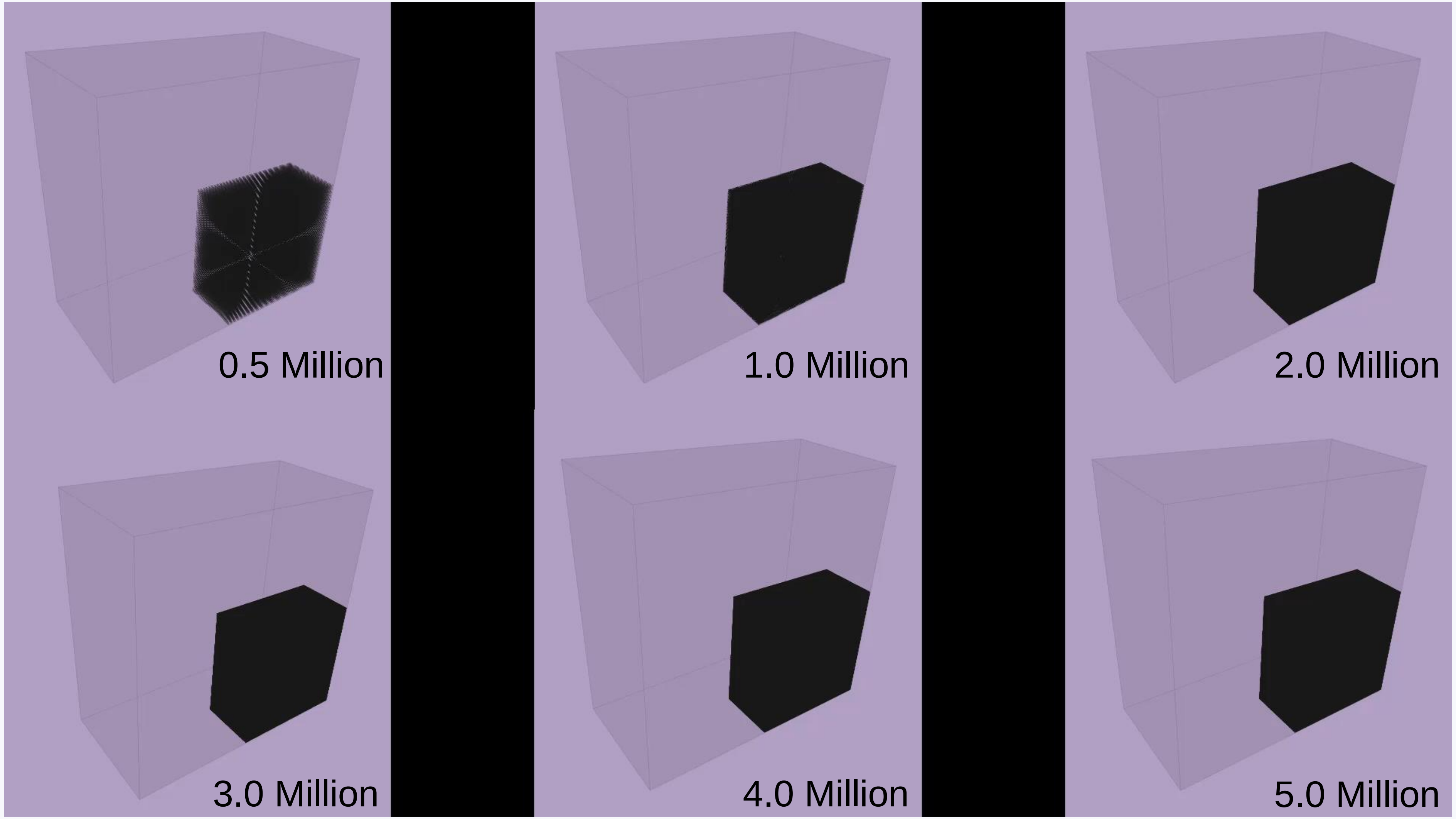
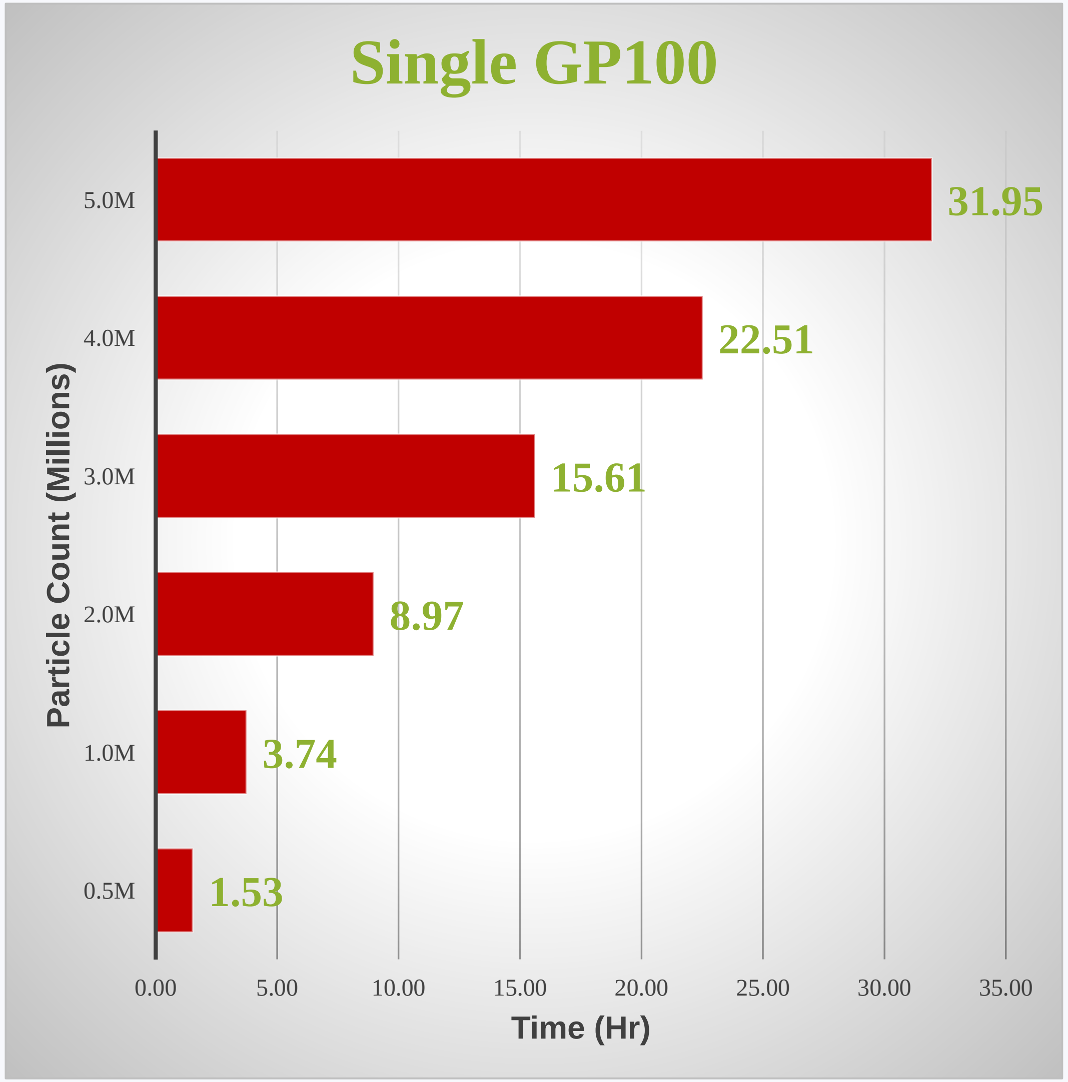
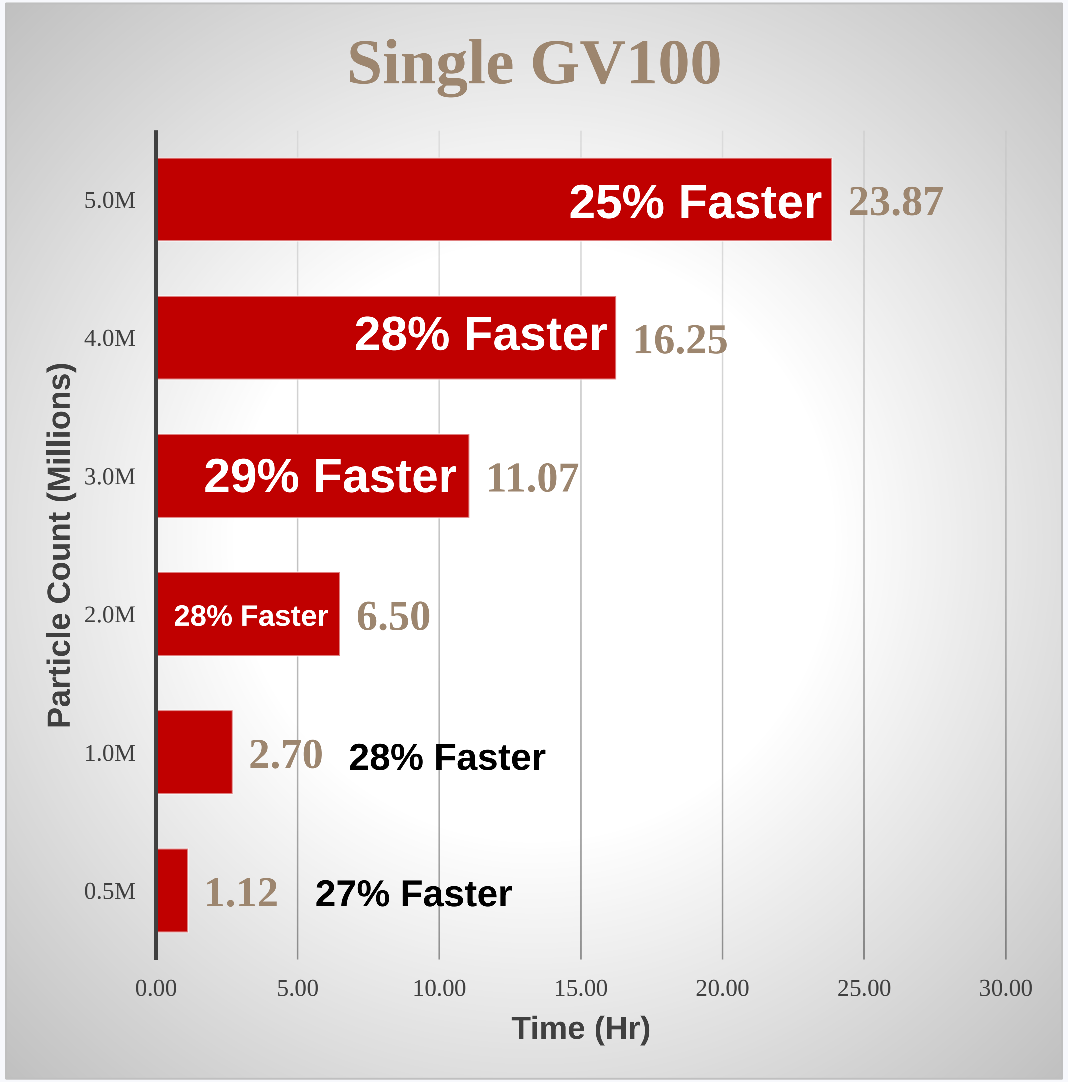
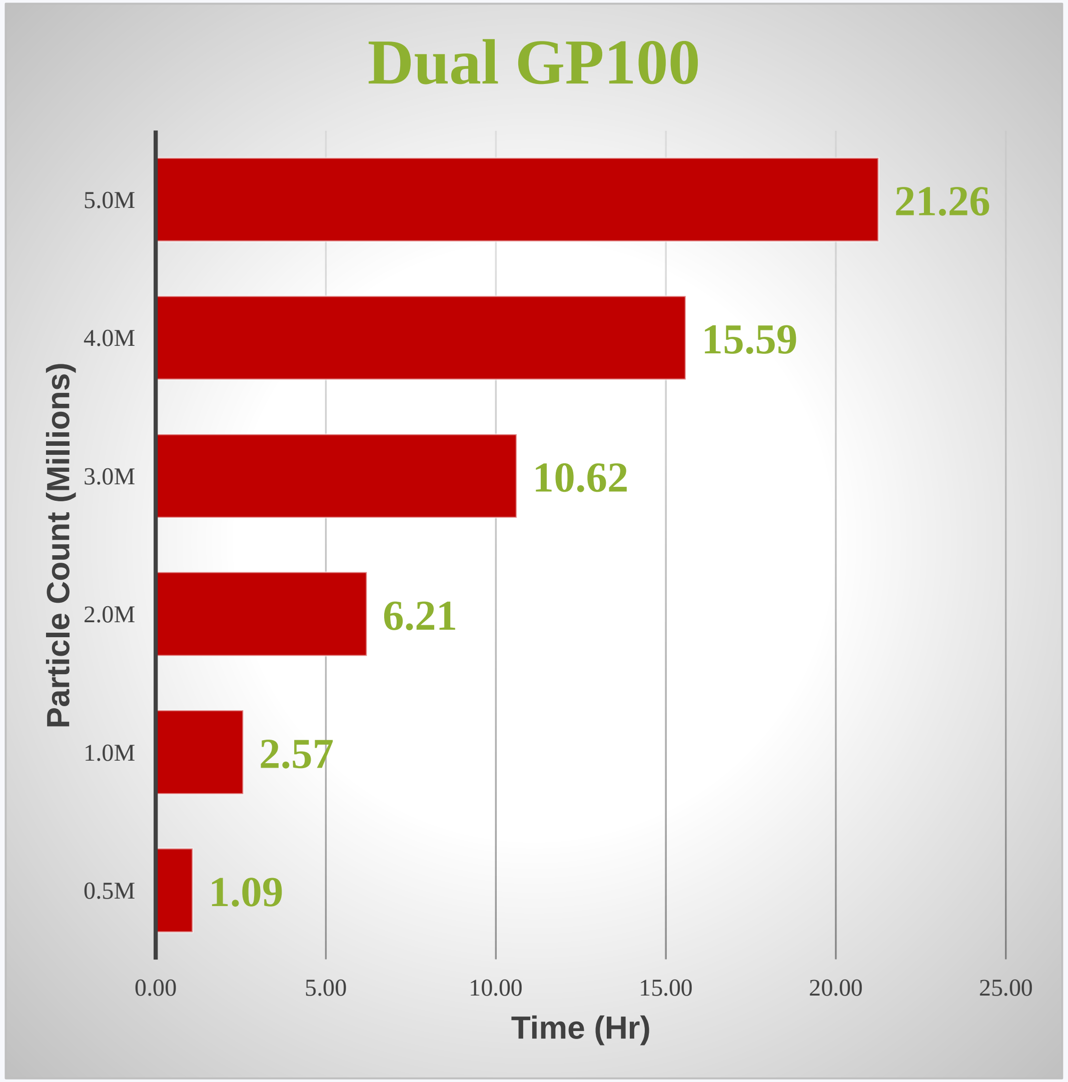


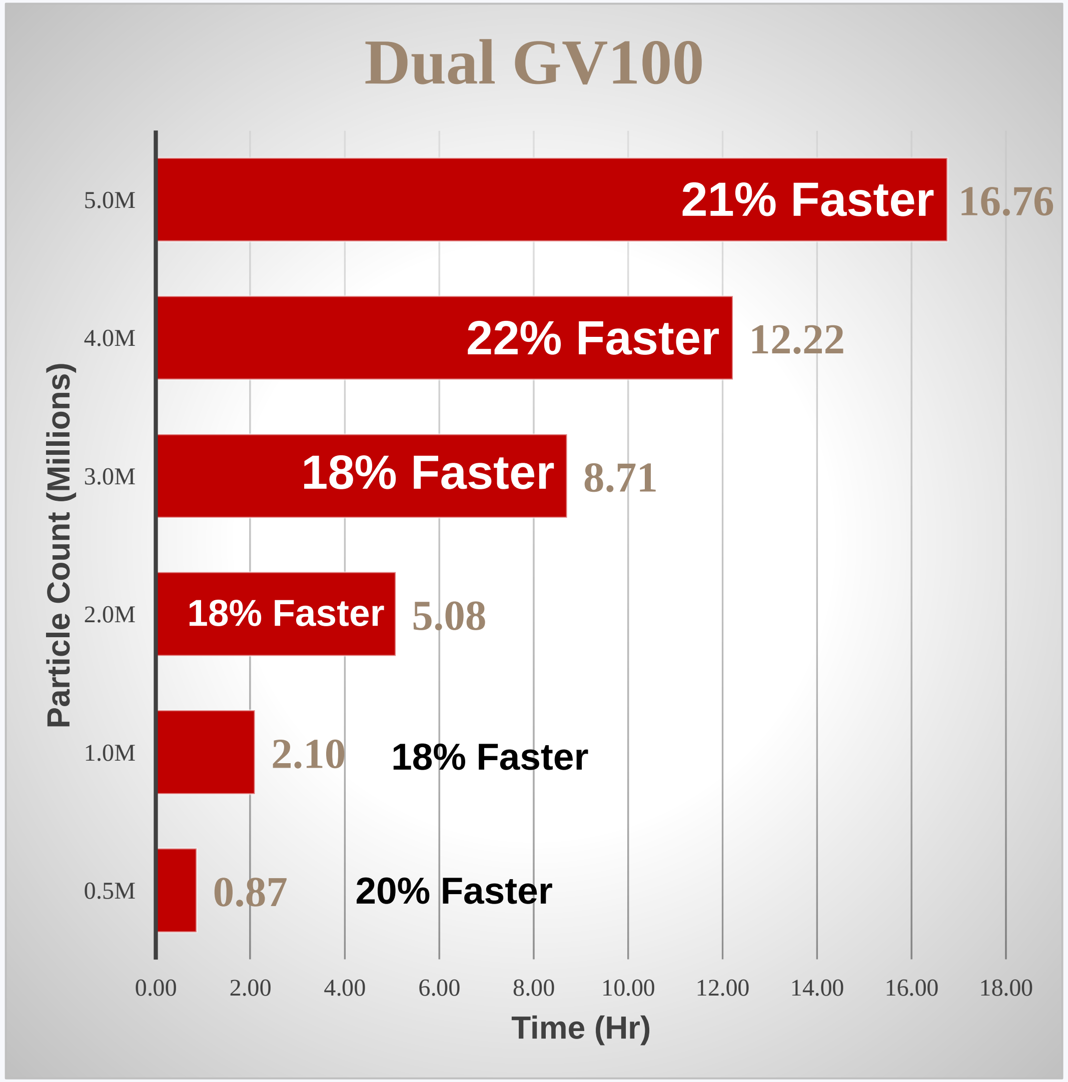
Dam Break – Scaling and Timing for Single GPU



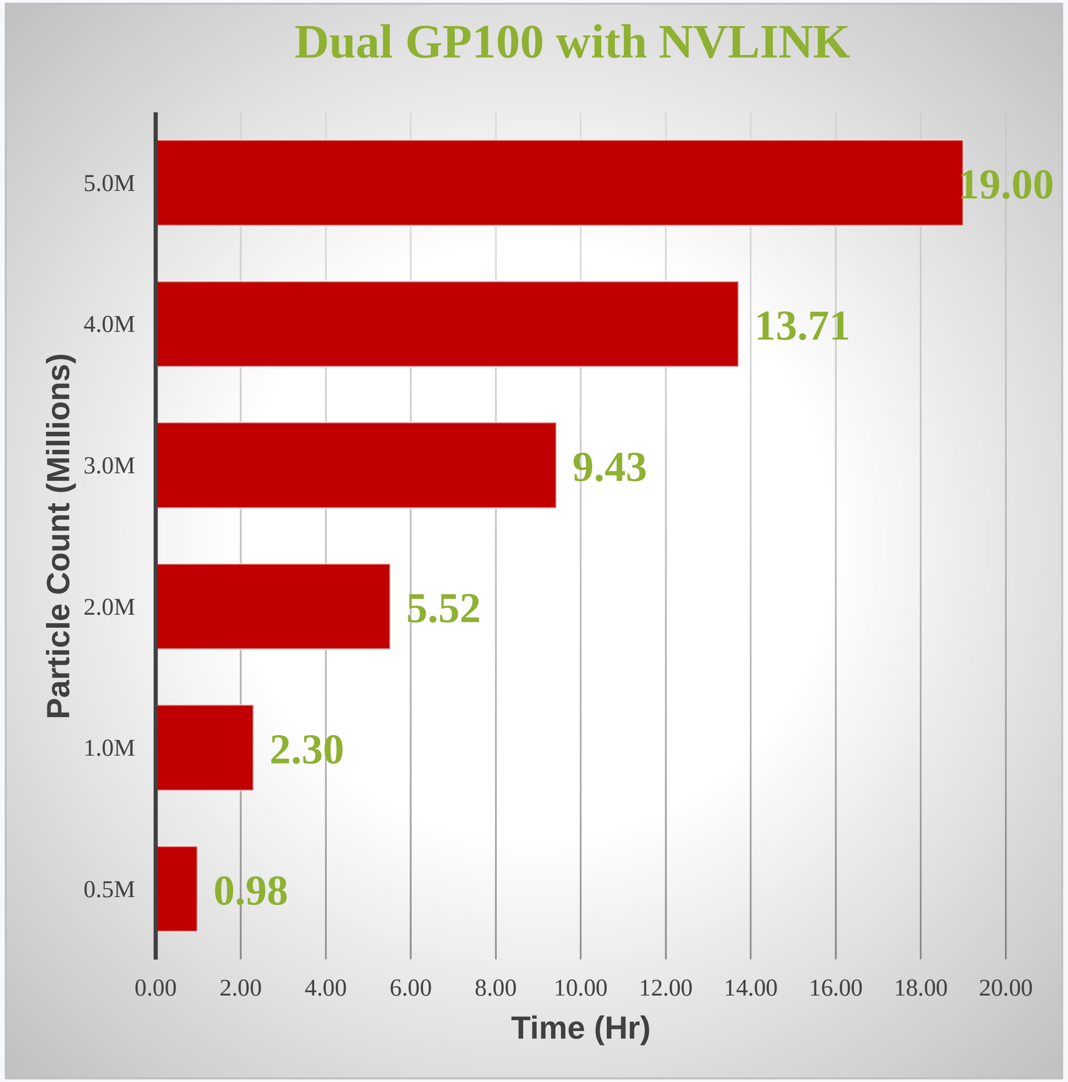


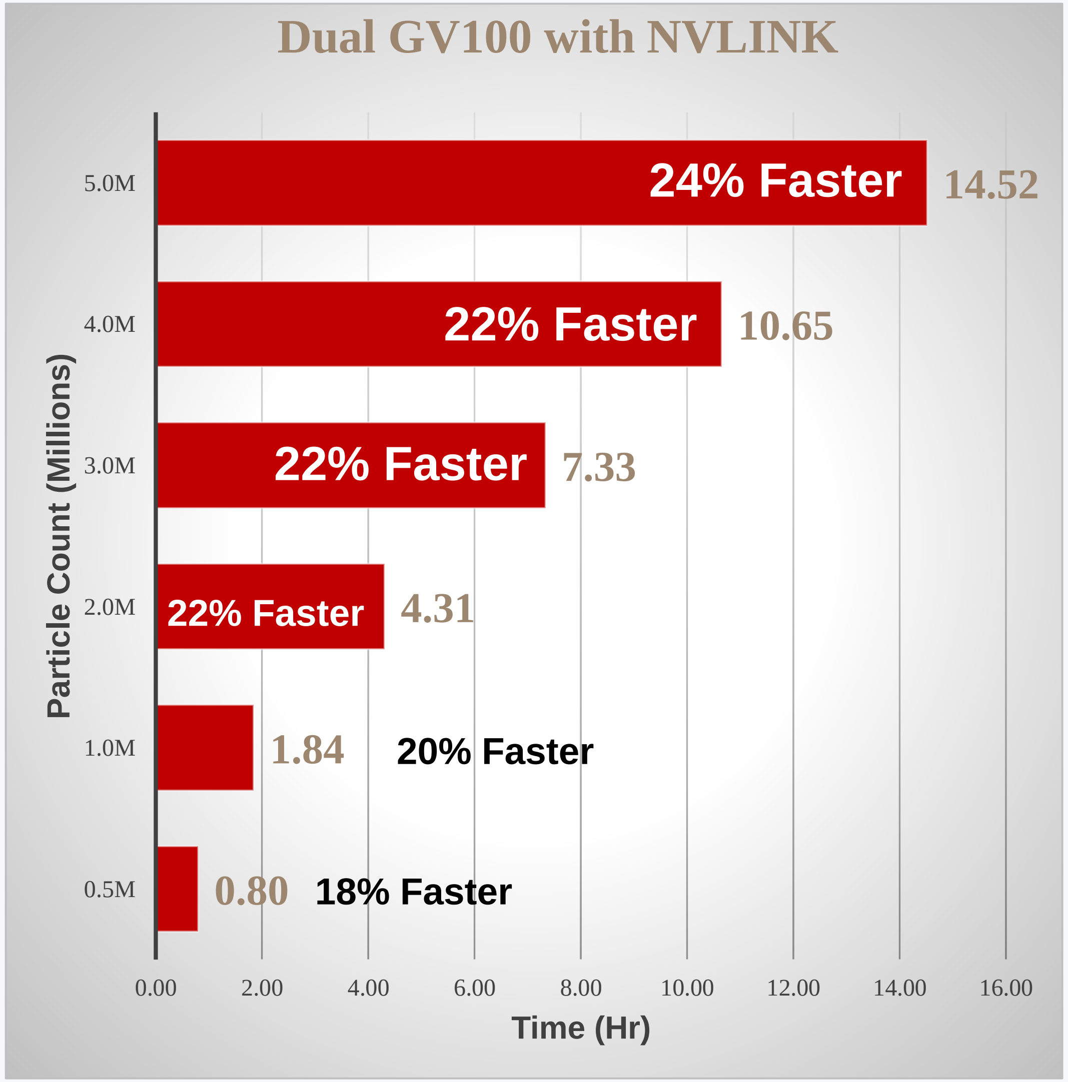
Dam Break – Scaling and Timing for Dual GPU



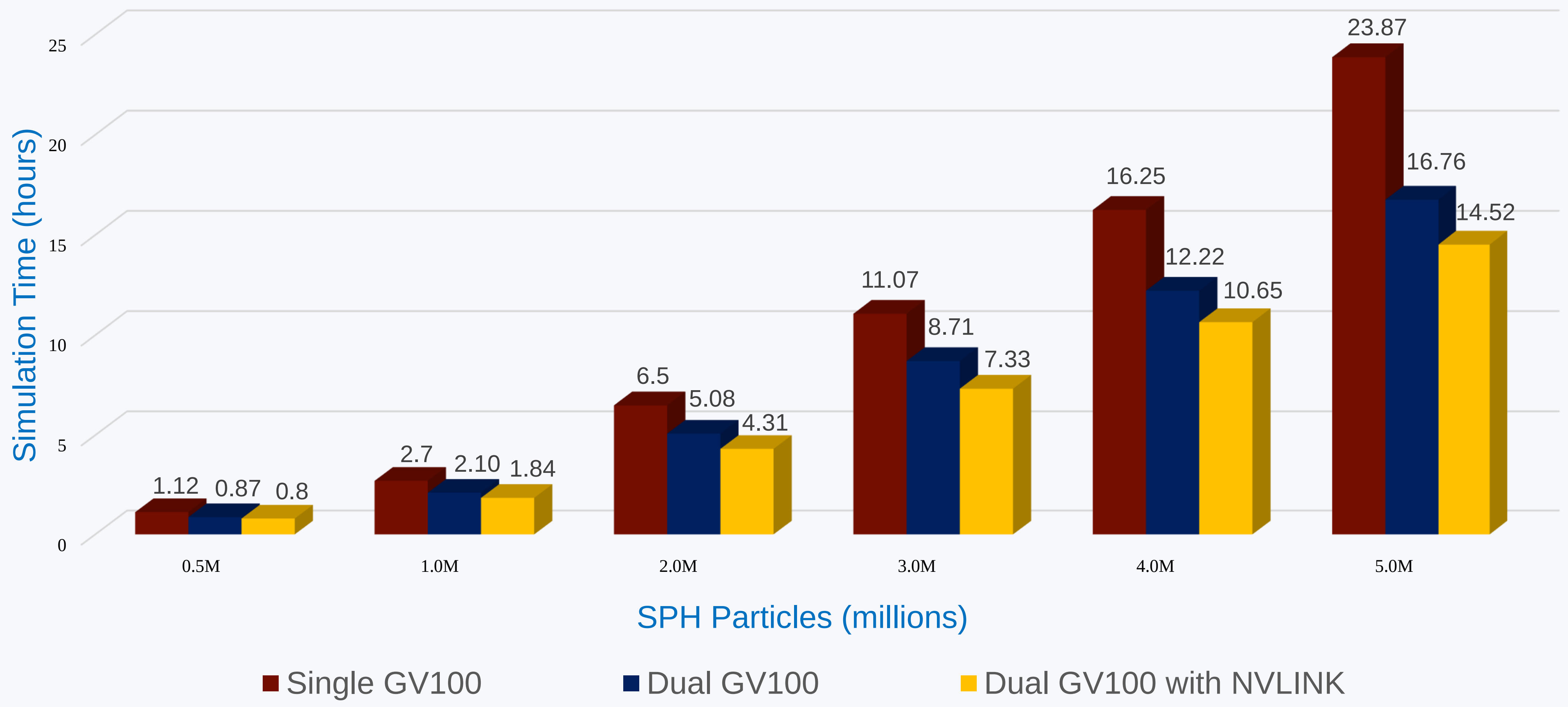


Dam Break – Scaling and Timing for Dual GPU NVLINK





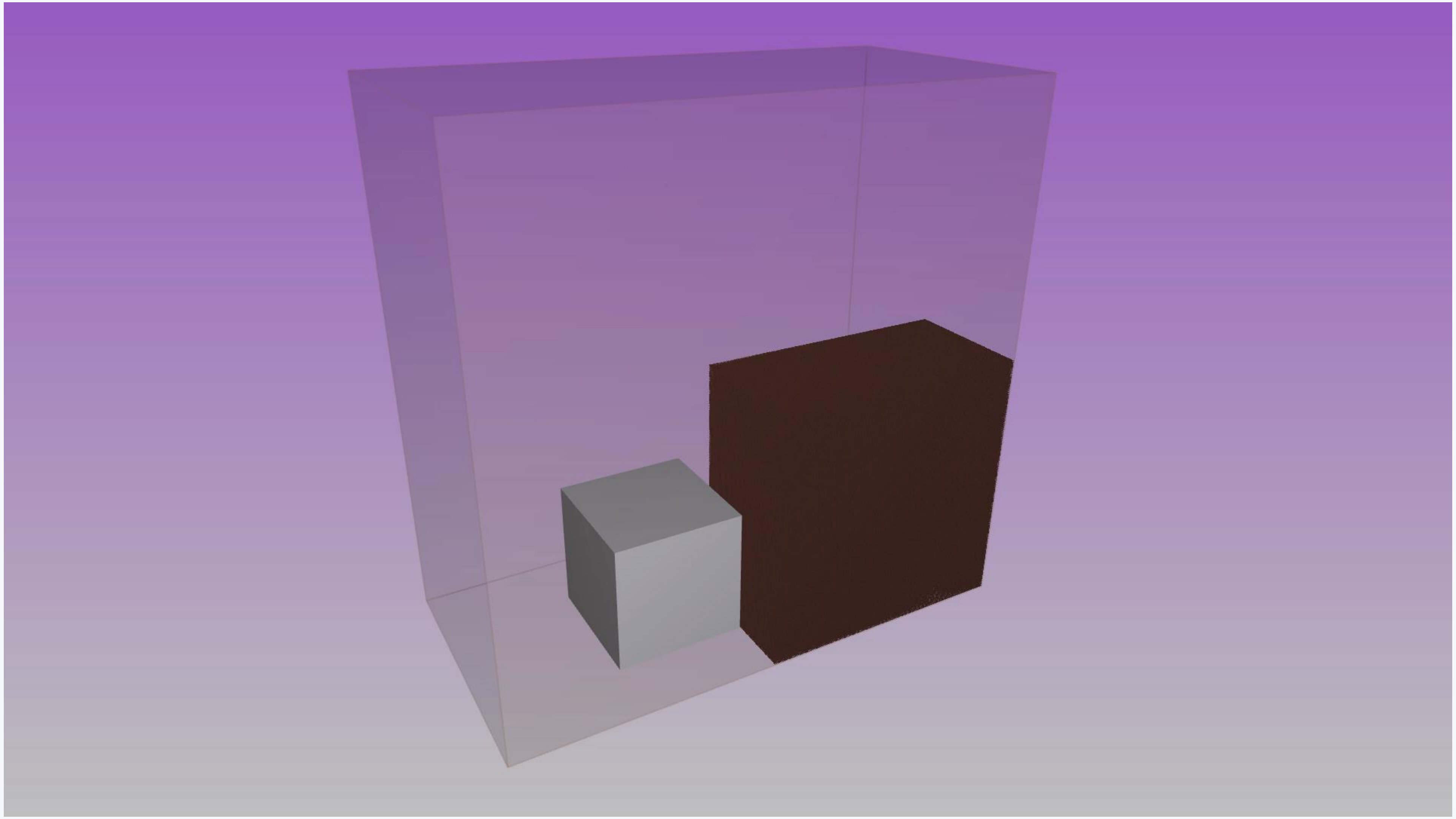
Dam Break – GV100 Timing Comparison



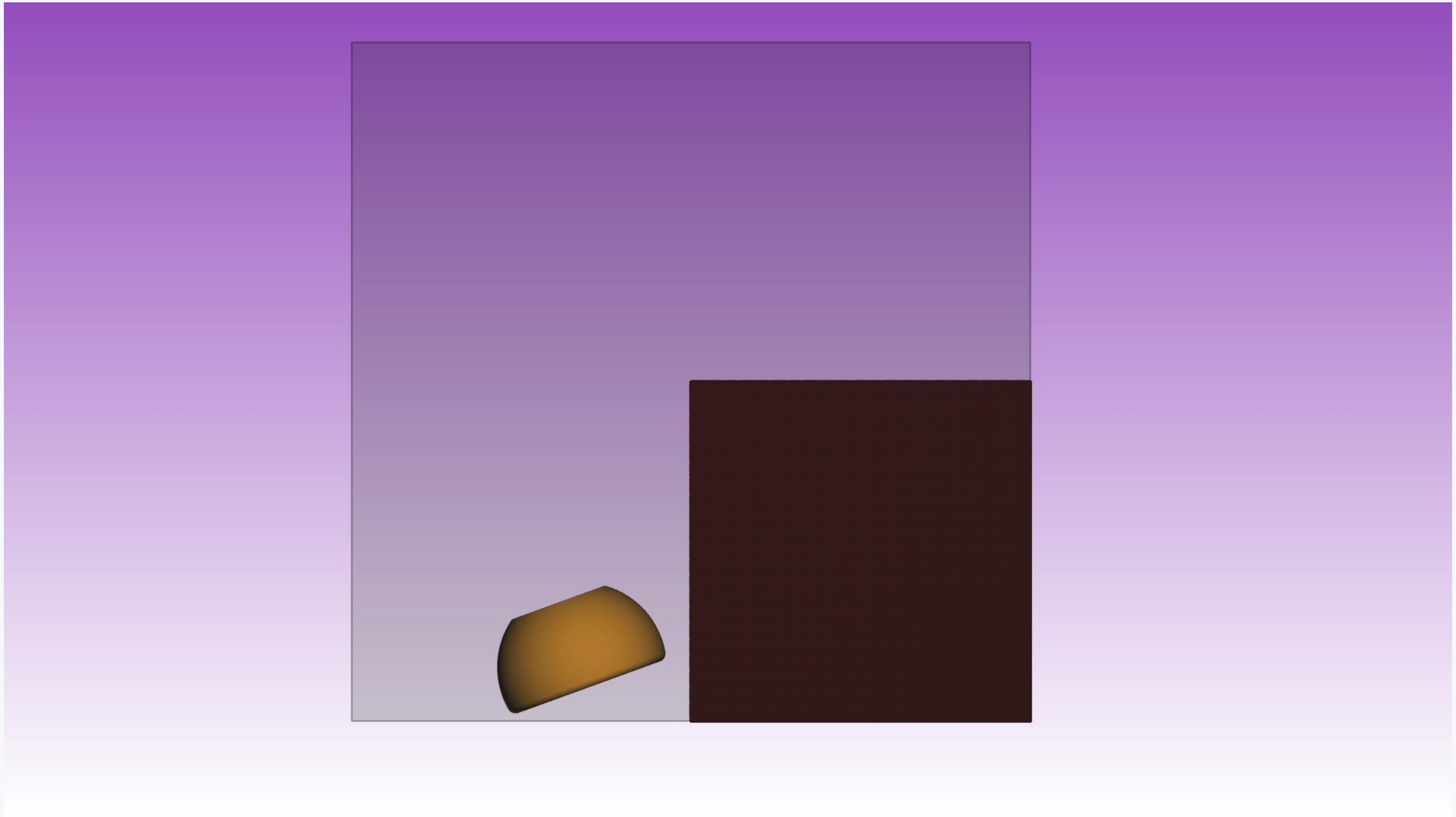
Dam Break with Objects in Tank

- Objects can be Rigid or Deformable
  - Adds a significant increase in computation time
  - Deformable Objects add even more

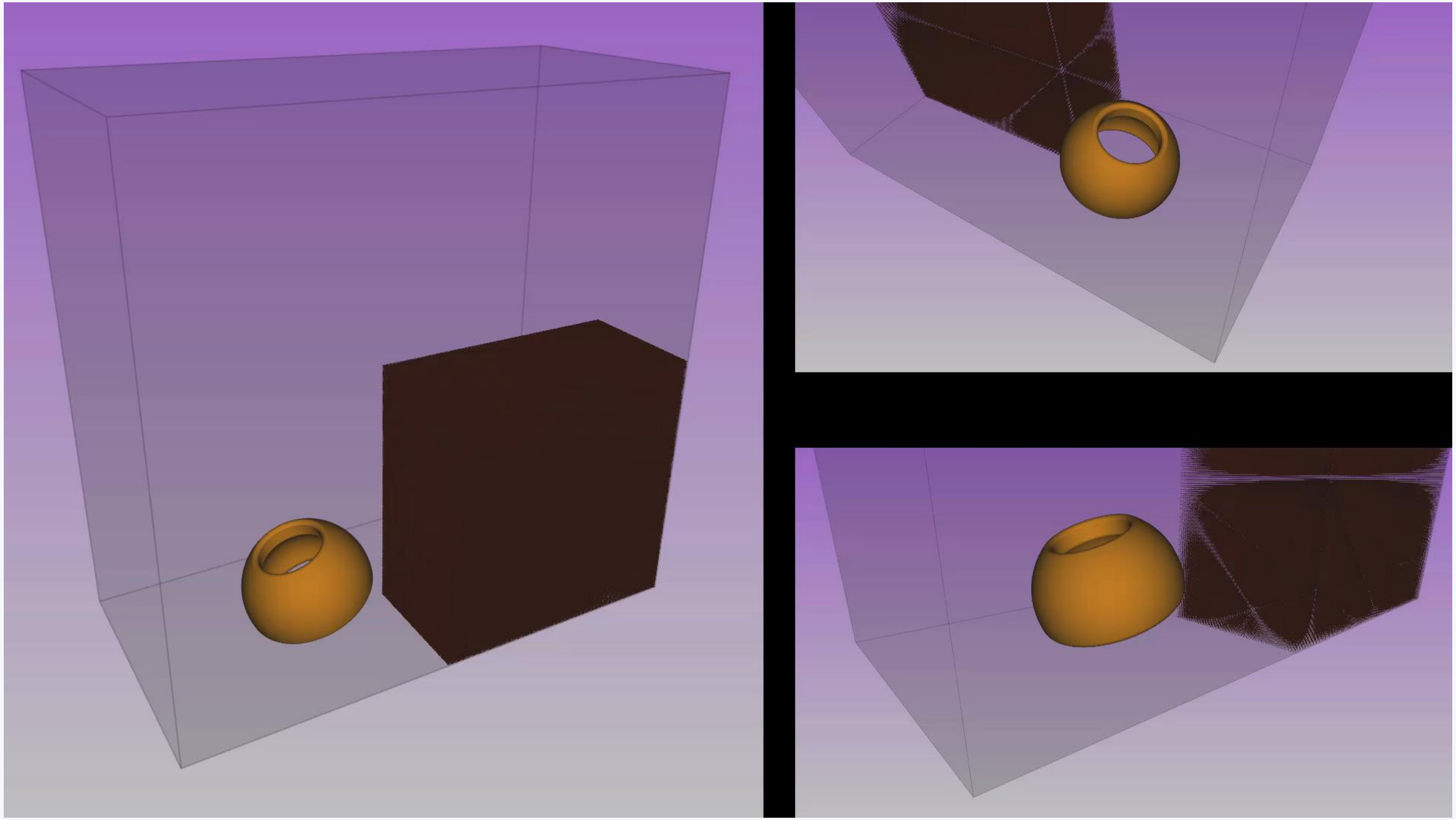
Dam Break with Rigid Box



Dam Break with Rigid Complex Geometry



Dam Break with Rigid Complex Geometry



Under Current Development

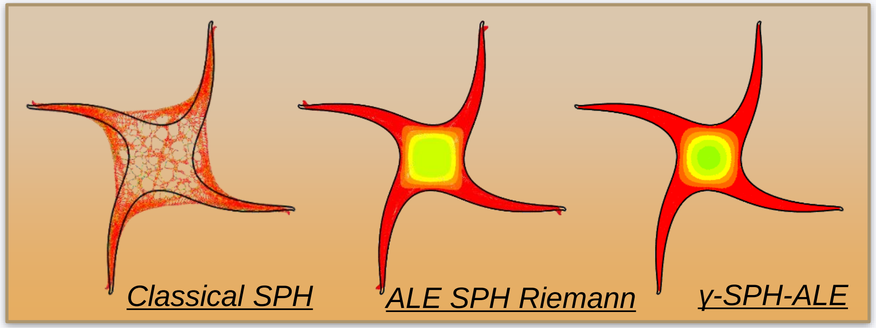
SPH-ALE formulation: Described by **Vila [1]**

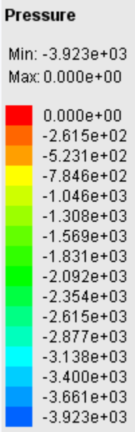
- Combination of **Eulerian** and **Lagrangian** descriptions
  - Eulerian : *Large deformations*
  - Lagrangian : *Interface tracking*

[1] J. P. Vila, On particle weighted methods and SPH, M3AS, 1999

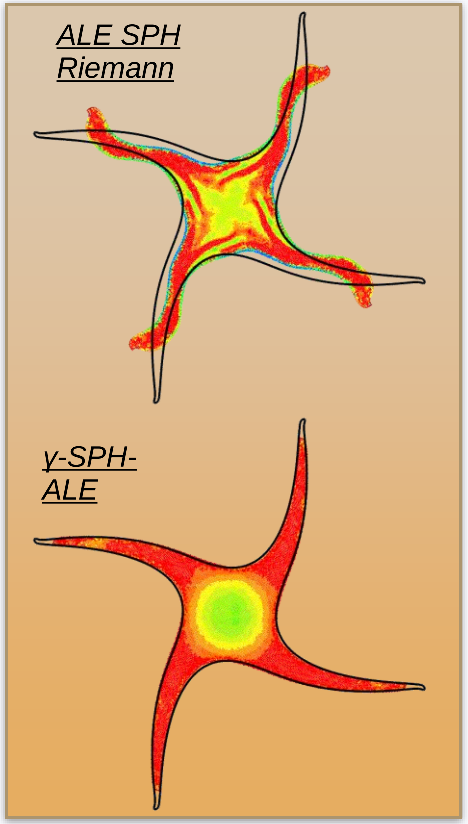
γSPH-ALE Solver- Rotating Square Patch of fluid

Pressure field at M=0,1

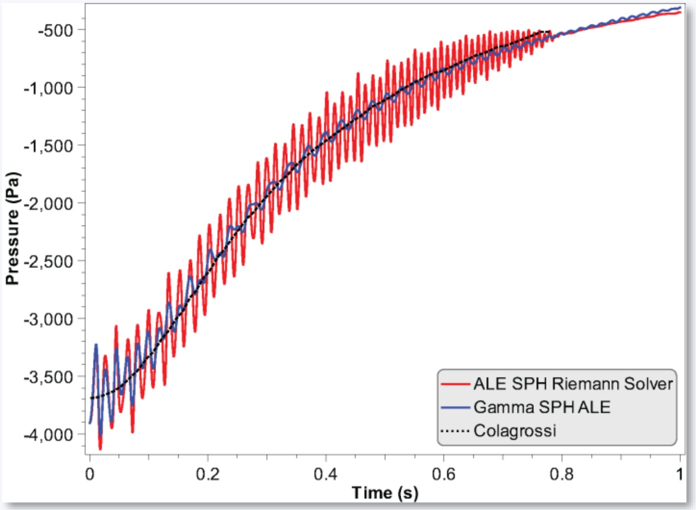




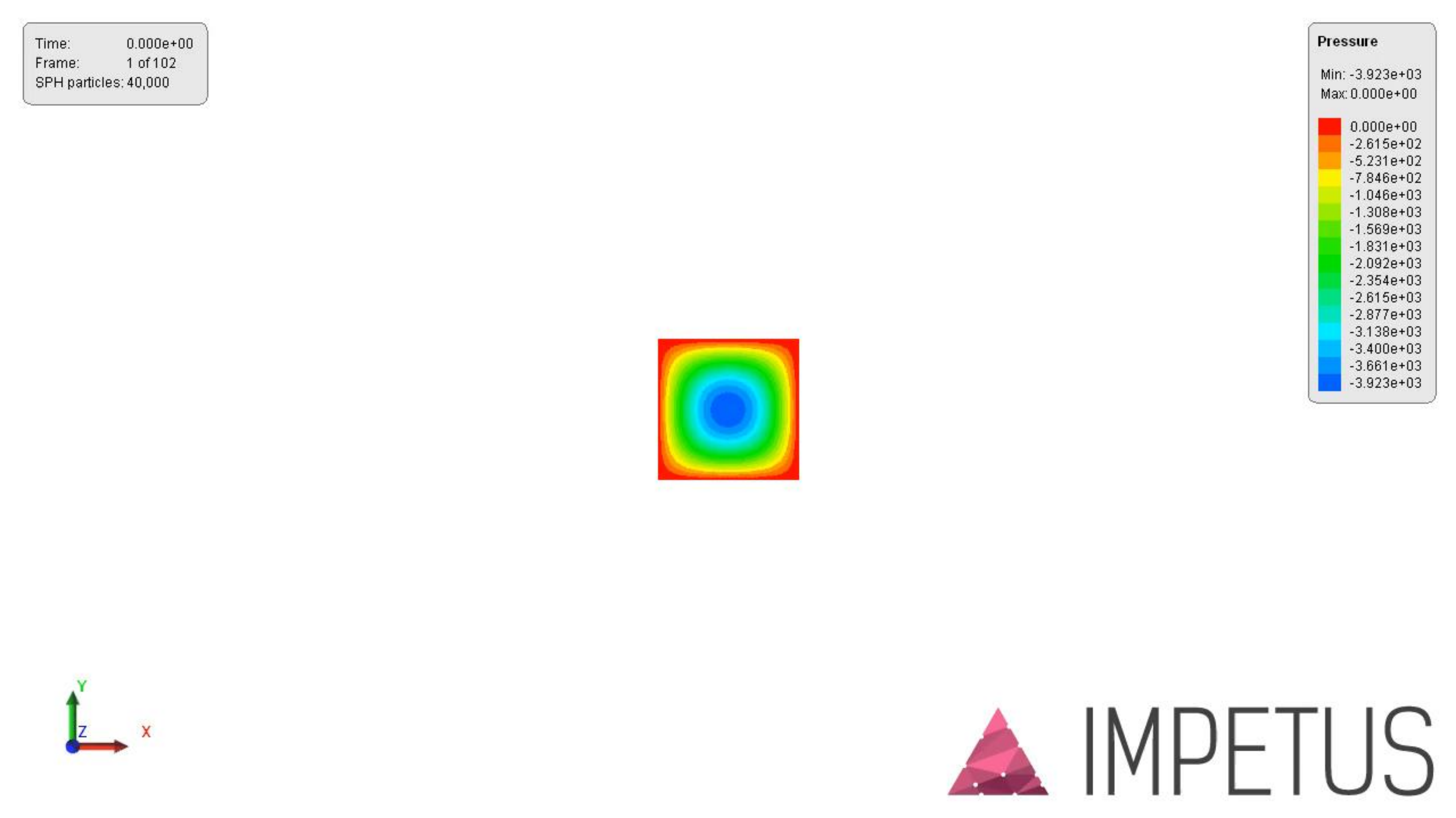
Pressure field at M=0,01



Pressure at the center of the Patch



γSPH-ALE - Rotating Square Patch of fluid



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