

Simulations of the Structure of Magnetic Fields in Galaxy Clusters

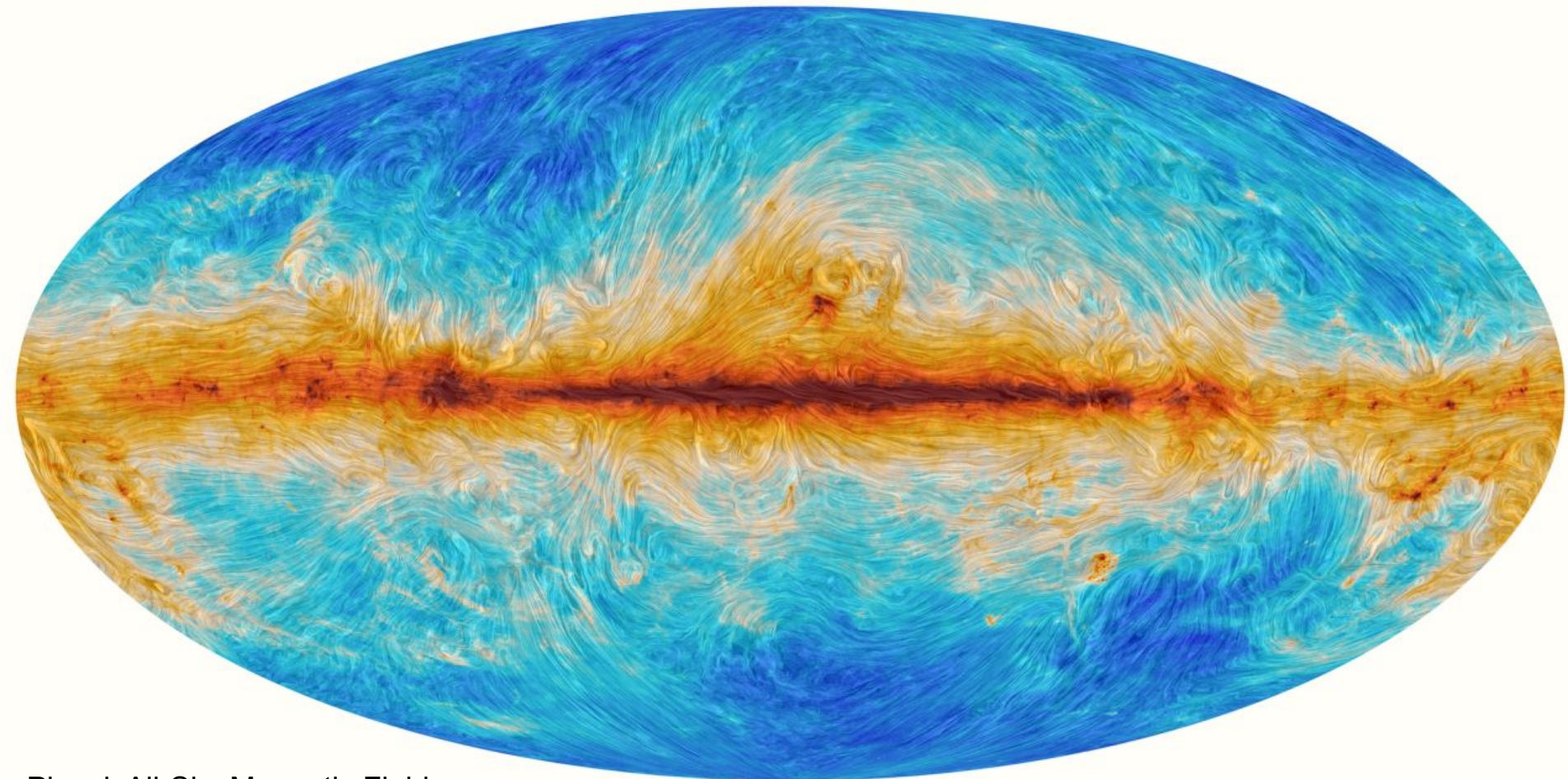
Forrest W. Glines^{1,2},
Brian W. O'Shea^{1,2}, Philipp Grete¹



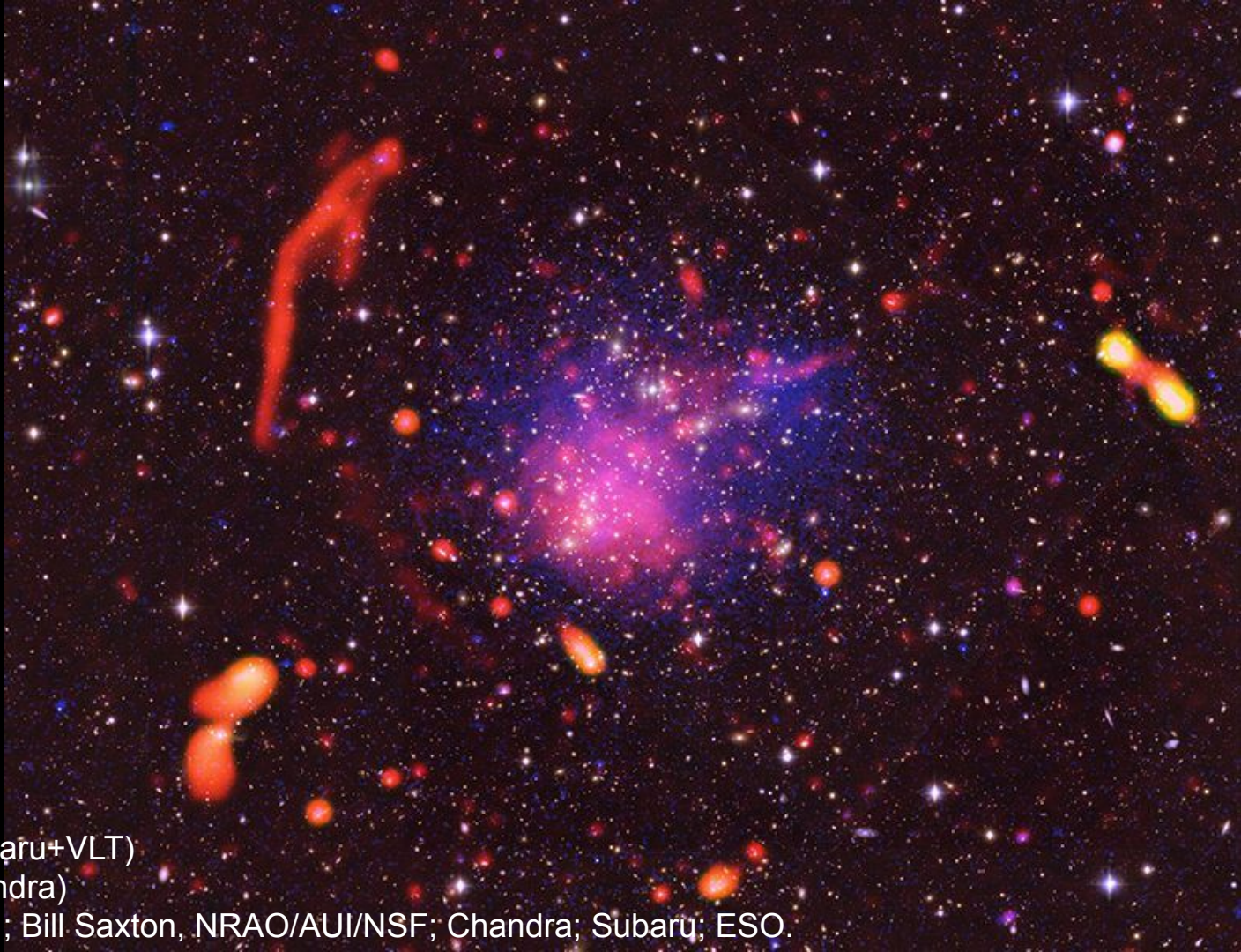
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Planck All-Sky Magnetic Field



Abell 2744

Radio (VLA)

Optical (Subaru+VLT)

X-Ray (Chandra)

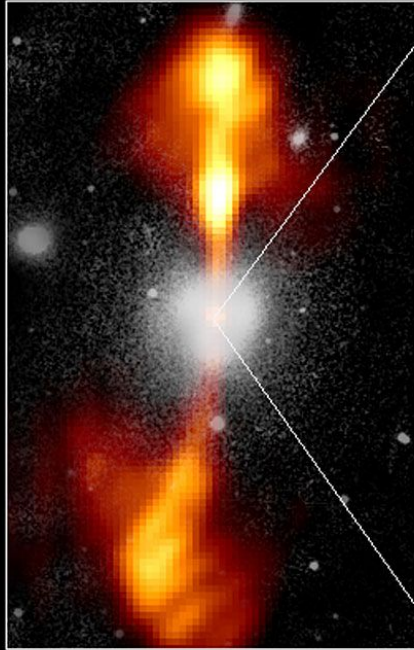
Pearce et al.; Bill Saxton, NRAO/AUI/NSF; Chandra; Subaru; ESO.

Core of Galaxy NGC 4261

Hubble Space Telescope

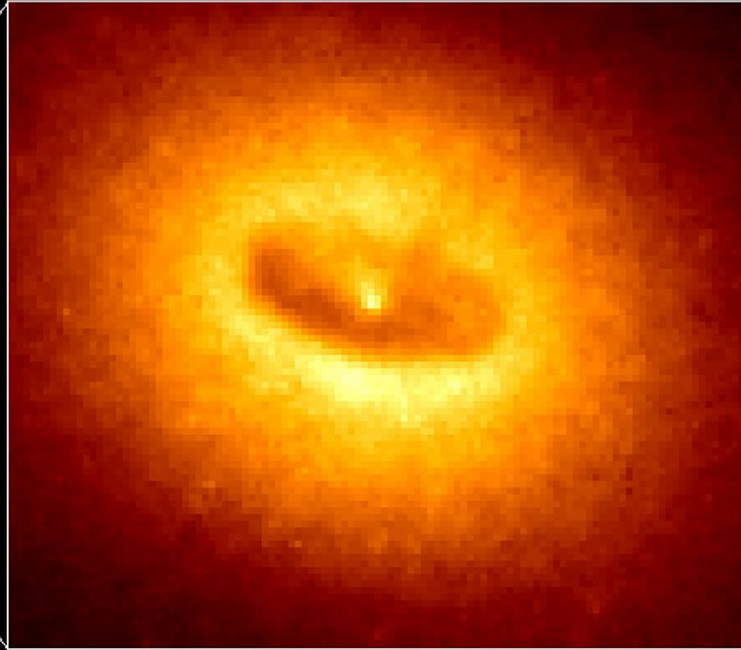
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image



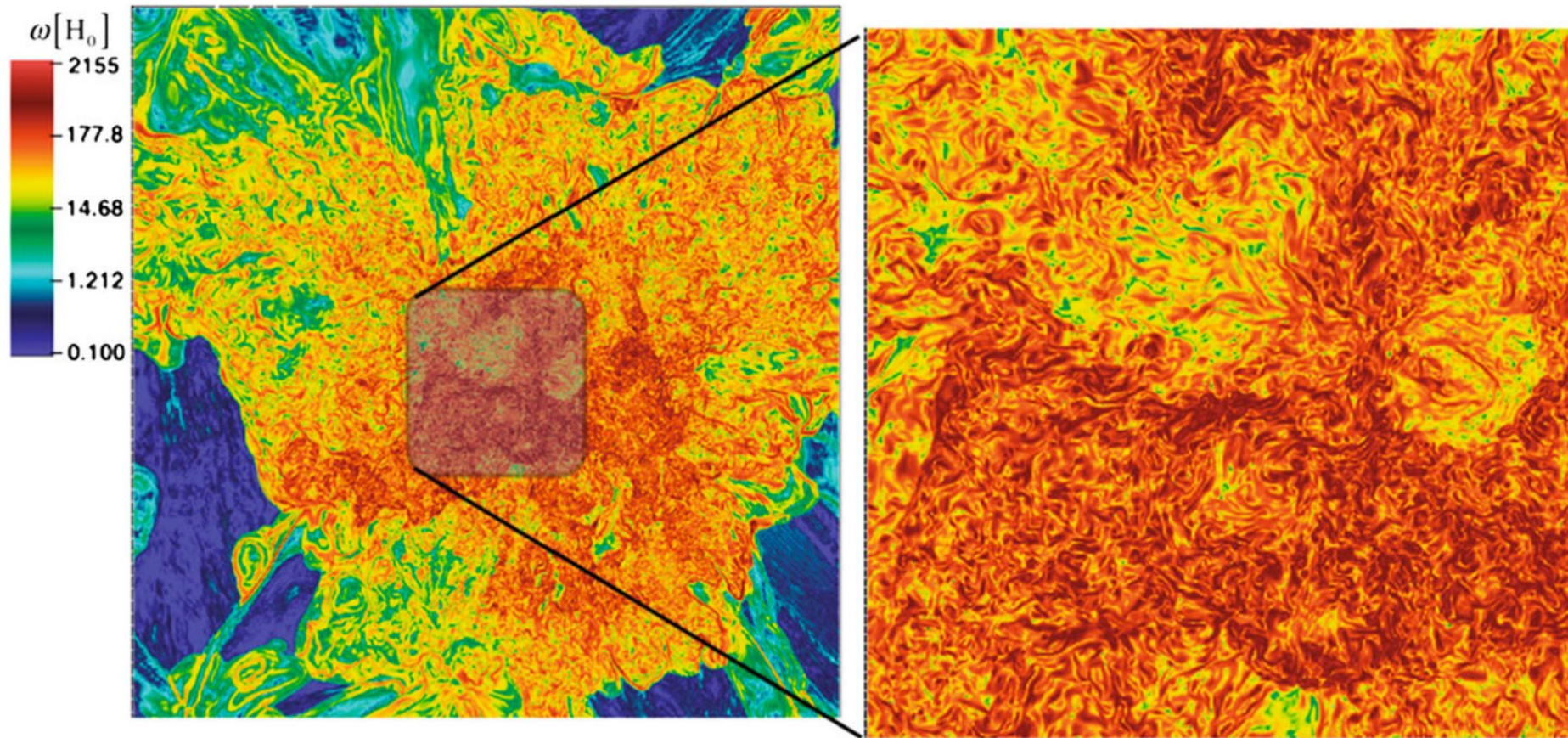
380 Arc Seconds
88,000 LIGHTYEARS

HST Image of a Gas and Dust Disk



17 Arc Seconds
400 LIGHTYEARS

NASA



Miniati 2014

CPU



Xeon Phi



Stampede 2



Cori (12)
LBNL



NVIDIA

BLUE WATERS
SUSTAINED PETASCALE COMPUTING



Summit (1)



Perlmutter

GPU



Aurora
ANL



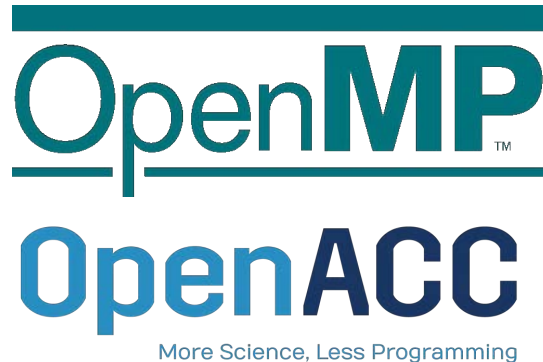
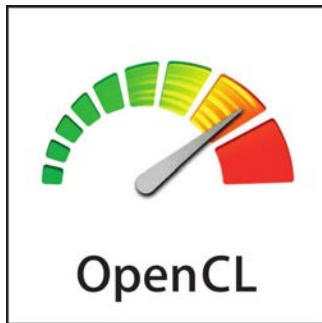
AMD



Performance Portability APIs

Typical Solutions

- OpenCL
- OpenACC
- OpenMP 4.5, 5.0



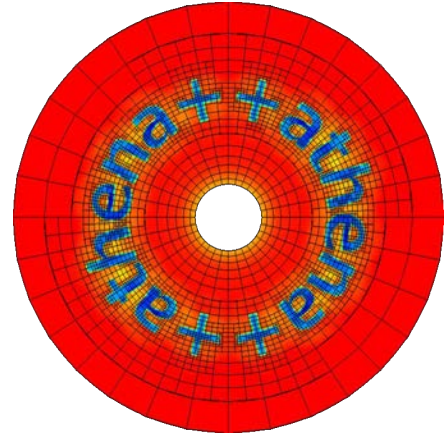
Abstraction Layers

- OCCA
- RAJA
- Kokkos



K-Athena: Performance Portable MHD

- Partial Conversion of astrophysical MHD code Athena++ using Kokkos library
- Minimal code changes
- Performance Portable
 - Ready for CPUs, GPUs
- Freely available on GitLab



<https://gitlab.com/pgrete/kathena>

<https://arxiv.org/abs/1905.04341>

Kokkos Conversion

Athena++

```
for( int k = ks; k < ke; k++){  
  for( int j = js; j < je; j++){  
    #pragma omp simd  
    for( int i = is; i < ie; i++){  
      /* Loop Body */  
      u(k, j, i) = ...  
    }  
  }  
}
```

K-Athena

```
using namespace Kokkos;  
parallel_for( MDRangePolicy<Rank<3>>  
  ({ks, js, is}, {ke, je, ie}),  
  KOKKOS_LAMBDA(int k, int j, int i){  
    /* Loop Body */  
    u(k, j, i) = ...  
  });
```

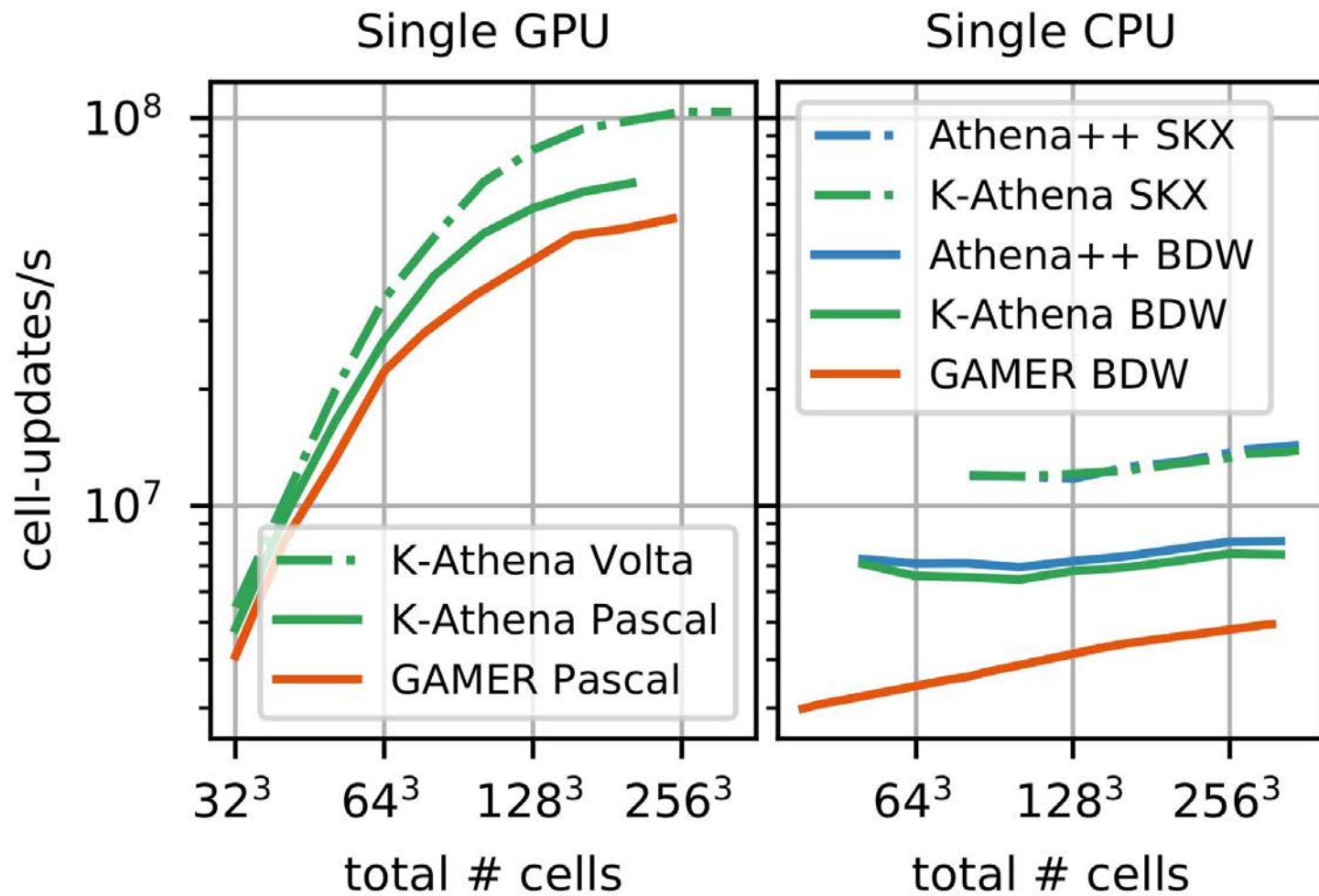
Parallelism Flexibility

Flat Parallelism

```
using namespace Kokkos;  
parallel_for( MDRangePolicy<Rank<3>>  
  ({{ks, js, is}, {ke, je, ie}},  
  KOKKOS_LAMBDA(int k, int j, int i){  
    /* Loop Body */  
    u(k, j, i) = ...  
  });
```

Hierarchical Parallelism

```
using namespace Kokkos;  
parallel_for(team_policy(nk*nj, AUTO),  
  KOKKOS_LAMBDA(member_type team_mem){  
    int lr = team_mem.league_rank();  
    int k = lr / nj + ks;  
    int j = lr % nj + js;  
    parallel_for(  
      TeamThreadRange<>(team_mem, is, ie),  
      [&](int i) {  
        /* Loop Body */  
        u(k, j, i) = ...  
      });  
  });
```

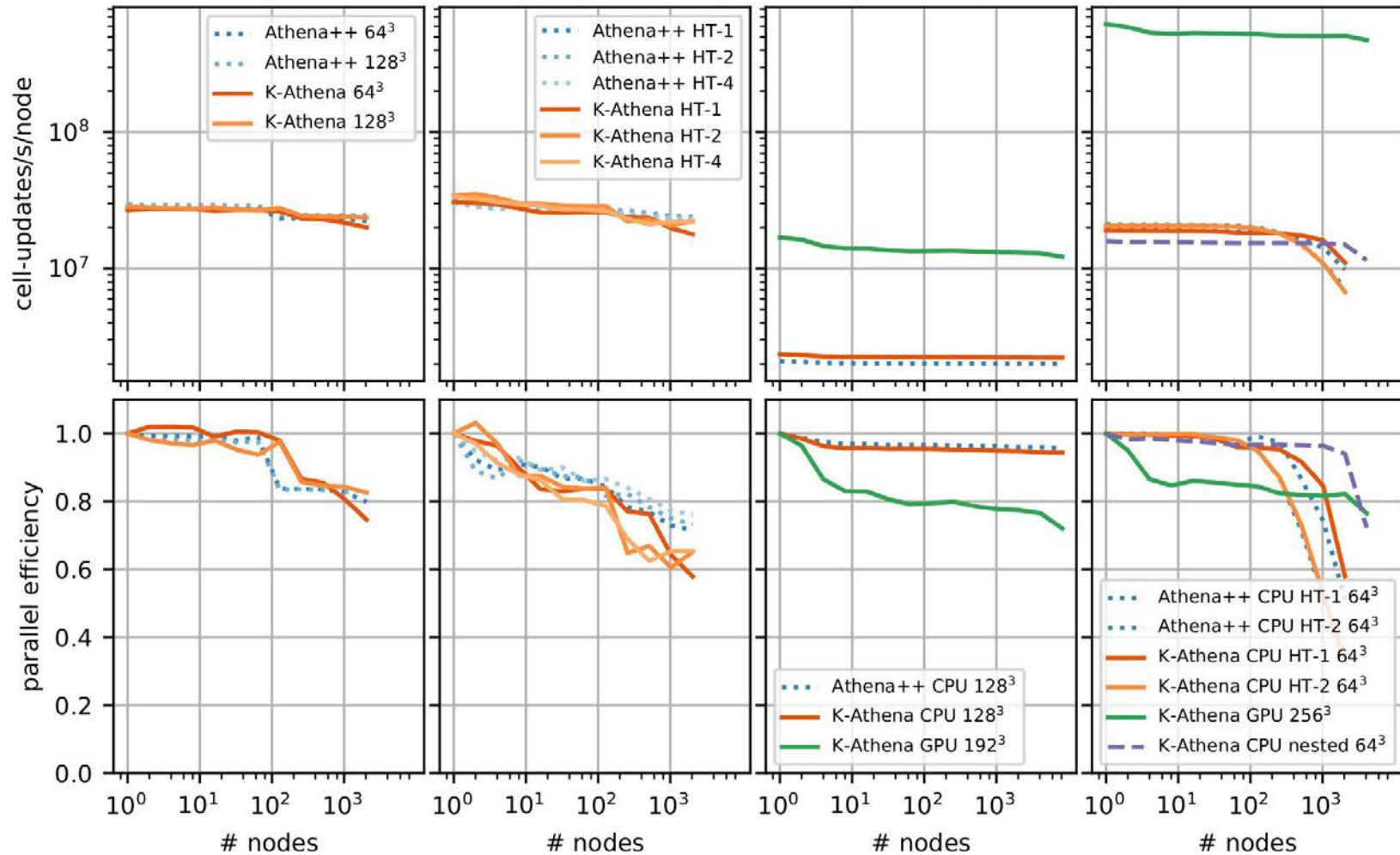


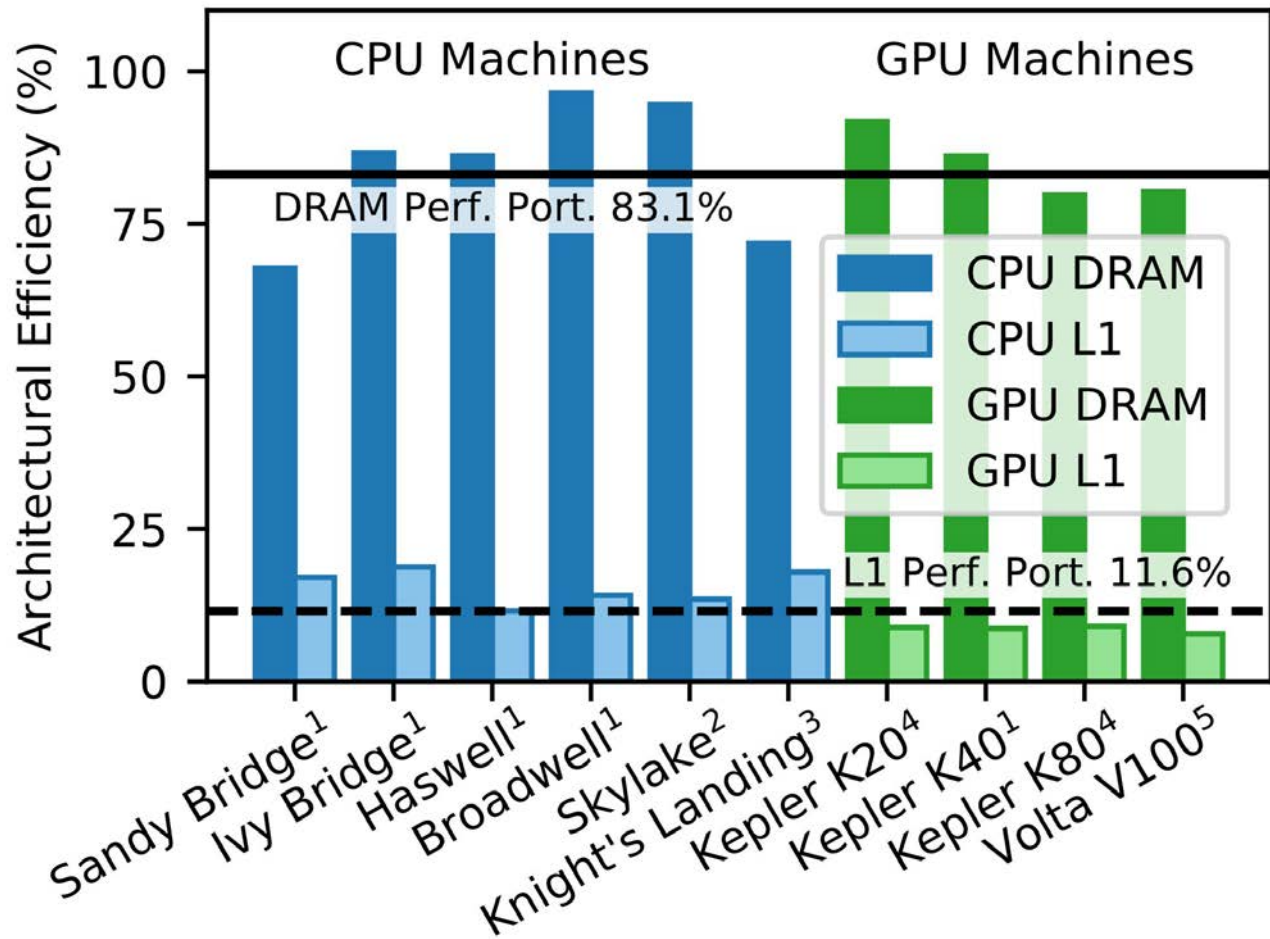
Electra Skylake CPU

Theta Knights Landing

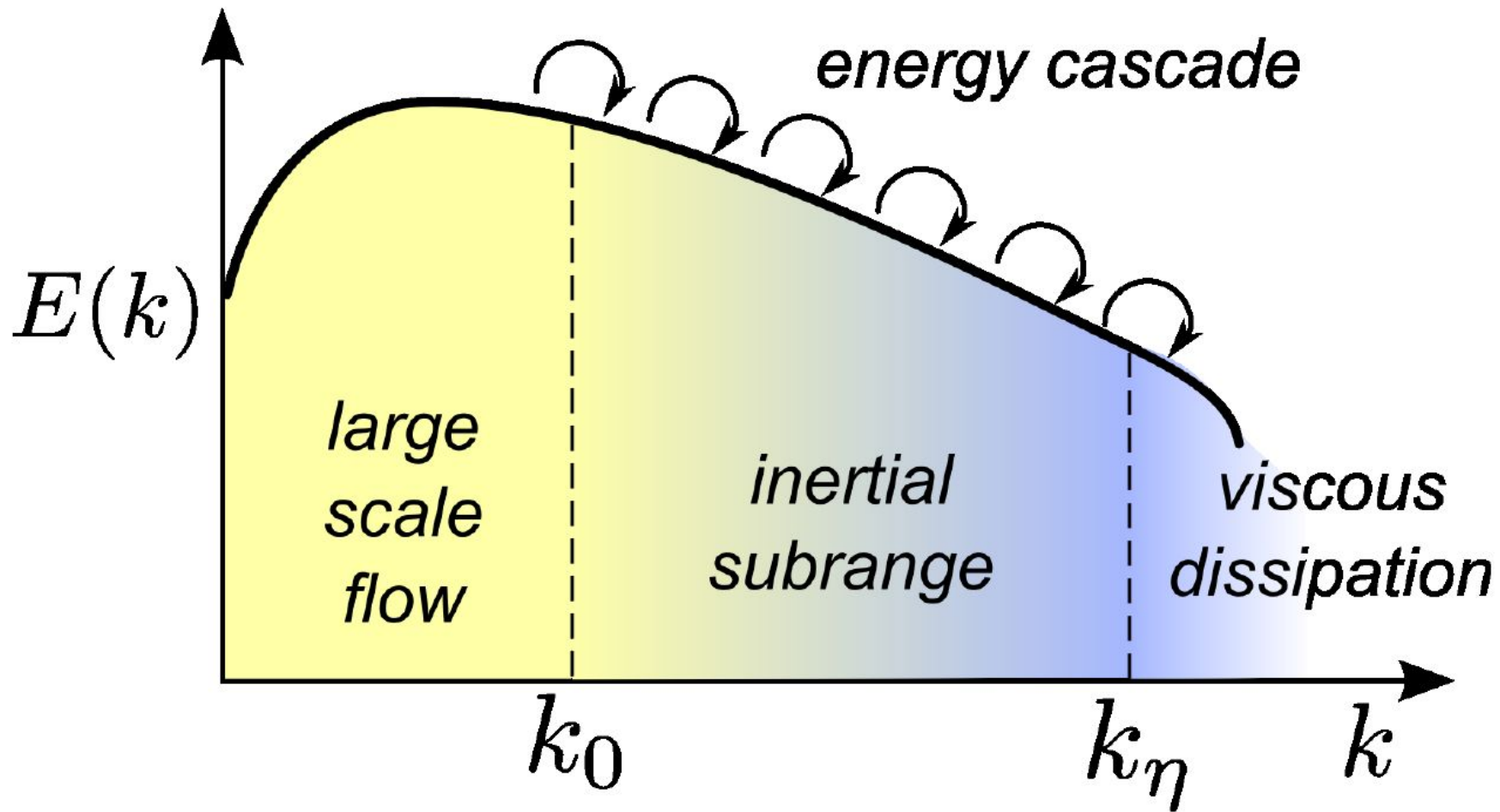
Titan Opteron/Kepler GPU

Summit Power9/Volta GPU

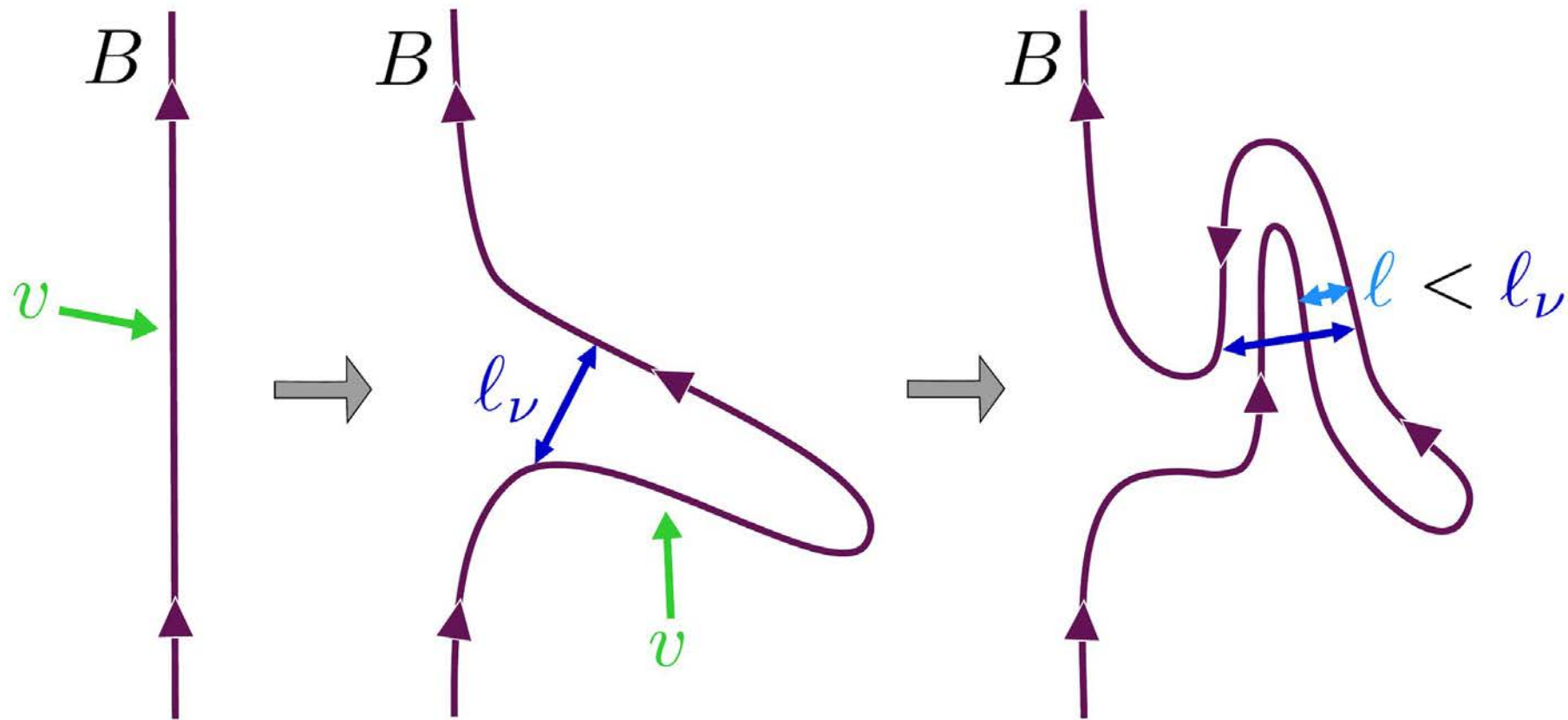


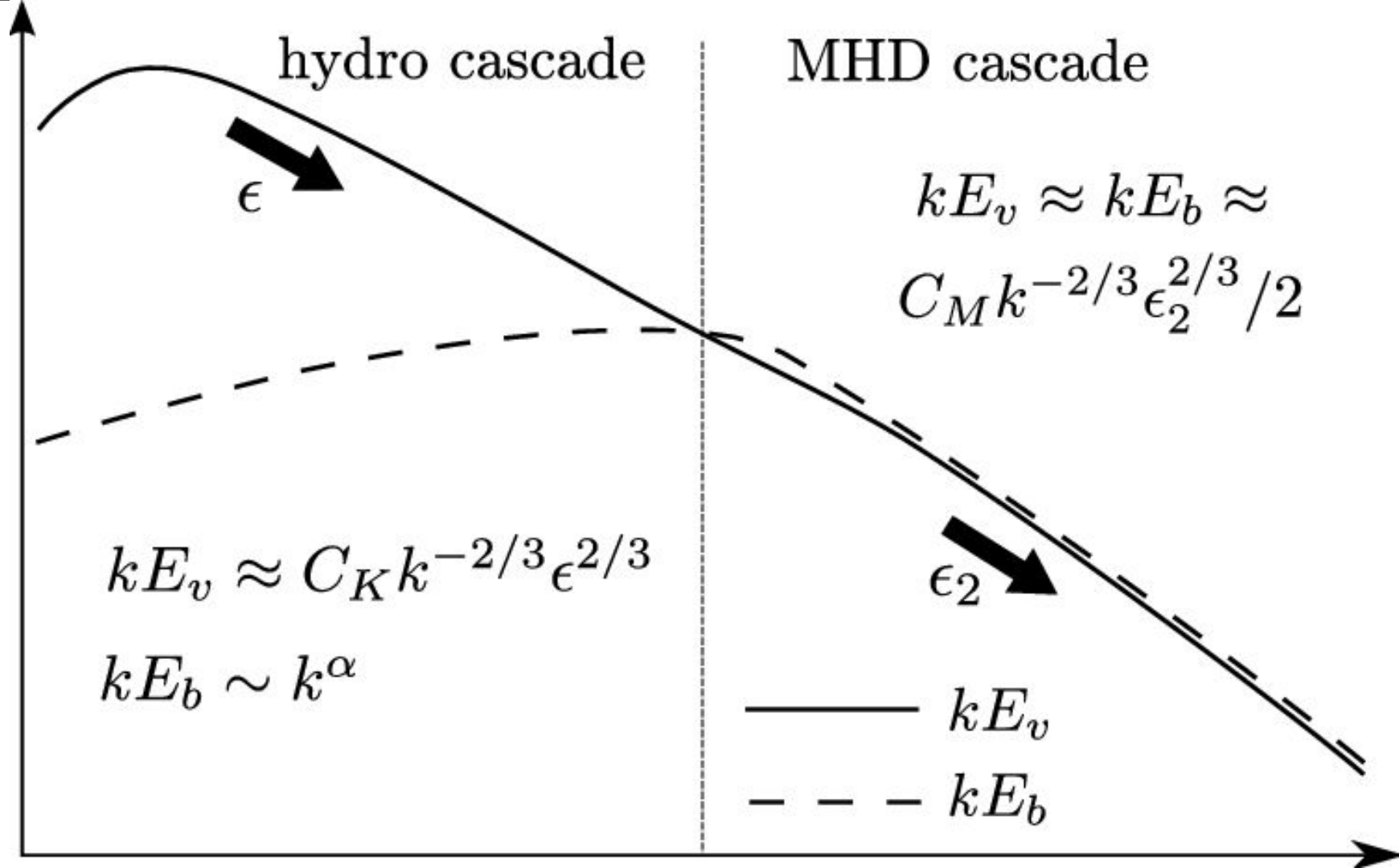


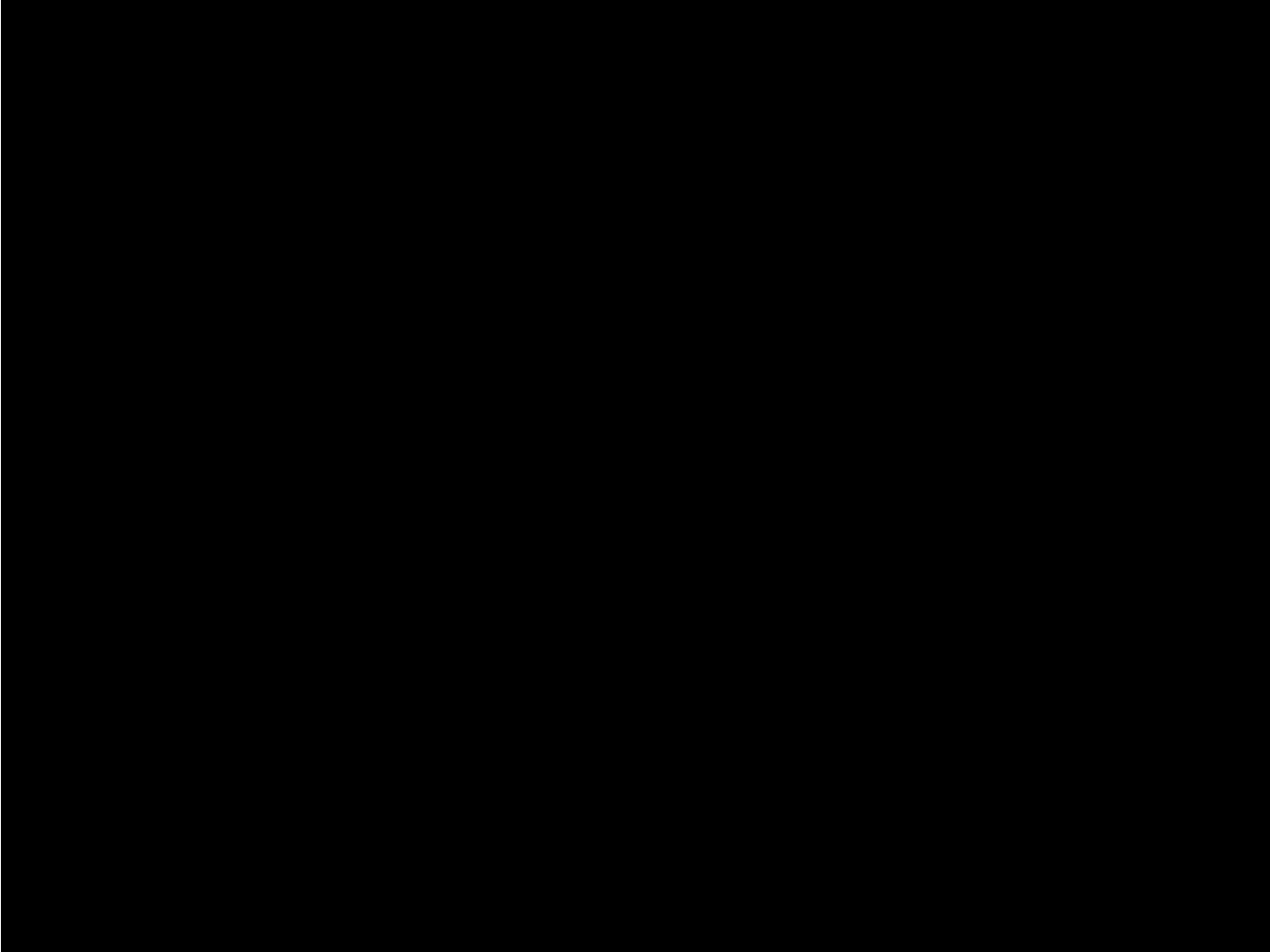
¹Pleiades, ²Electra, ³Stampede 2, ⁴MSU HPCC, ⁵Summit



Small Scale Turbulent Dynamo

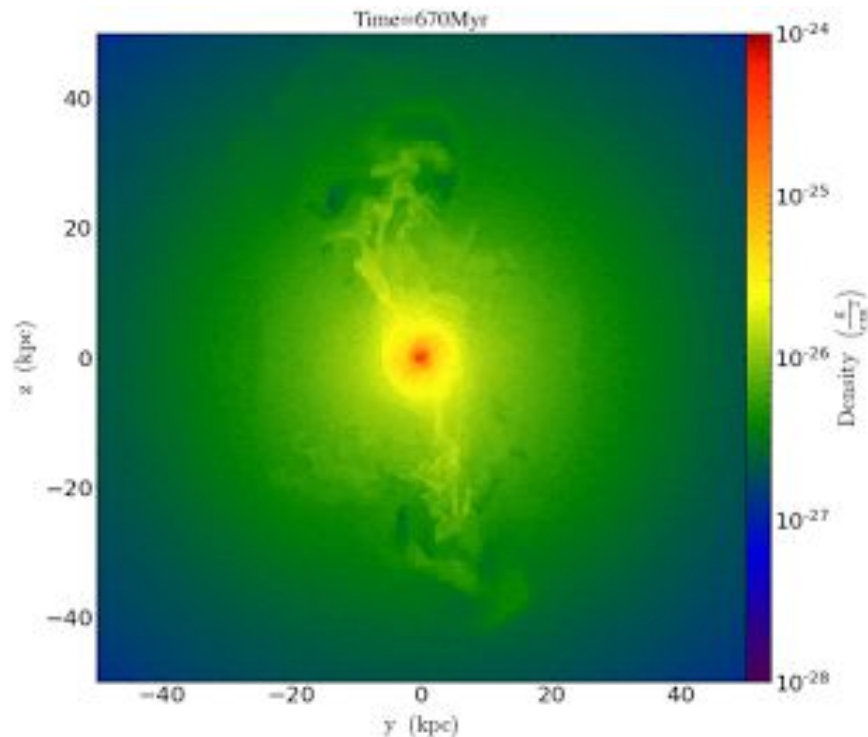






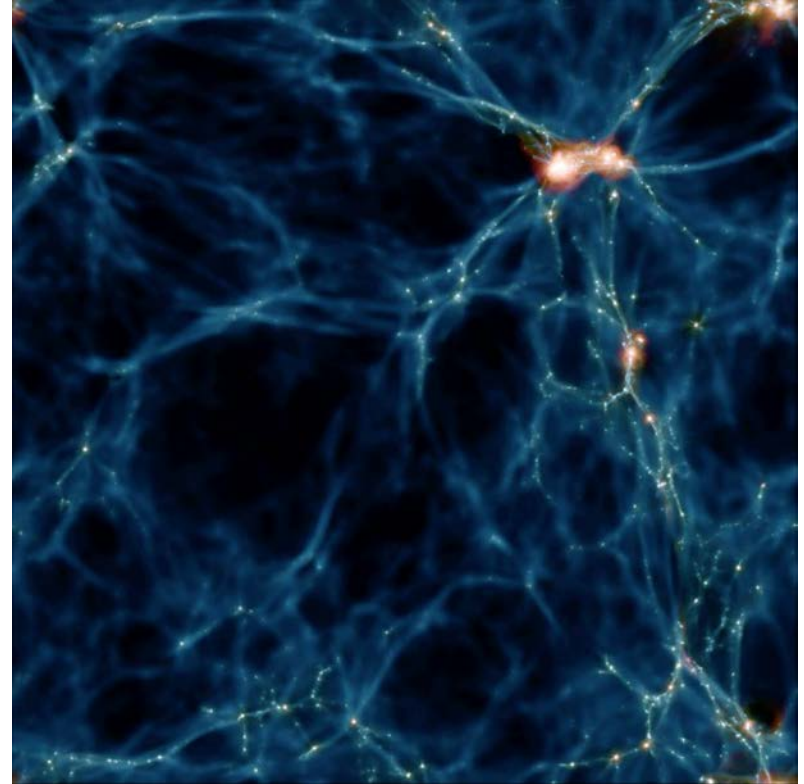
Isolated Galaxy Cluster Simulations with K-Athena

- Physics rich cluster simulation
 - MHD
 - Magnetic AGN feedback
 - Tabulated Cooling
 - Cosmic Ray model
 - Viscosity and Conduction
- How does the ISM behave?
- How does AGN feedback thermalize?



Cosmological Simulations with Enzo-E

- How does rich plasma physics change cosmological simulations?
- How do cool core clusters emerge, and how are they maintained?
- How do AGN affect star formation and the evolution of galaxies within the cluster?
- With all the plasma physics, do we get realistic cool core clusters?



Romulus C Simulation [Tremmel 2018]

References

K-Athena: <https://gitlab.com/pgrete/kathena>

References

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