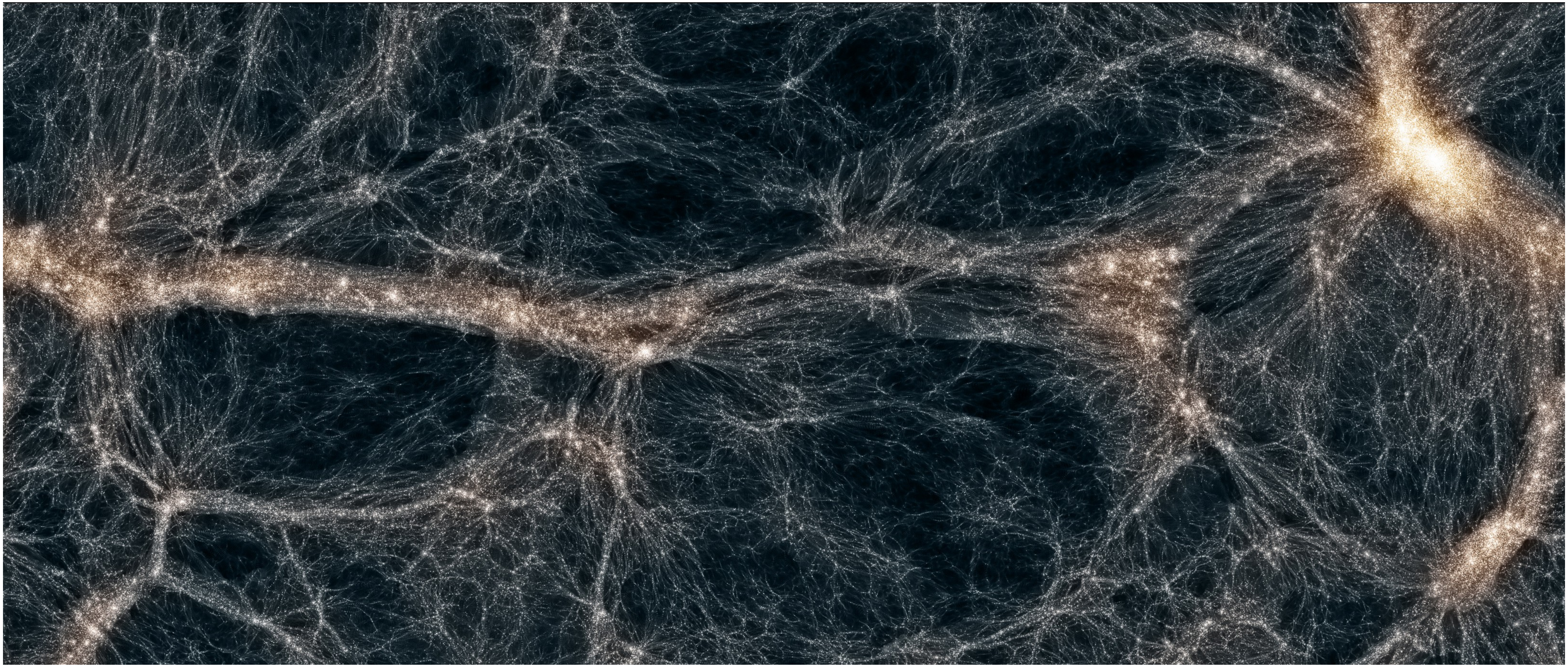
A Universe of ChaNGa Applications



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THE N-BODY SHOP

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Joachim Stadel
James Wadsley
Charlotte Christensen
Spencer Wallace

PPL PARALLEL PROGRAMMING LAB
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Ronak Buch

Others:
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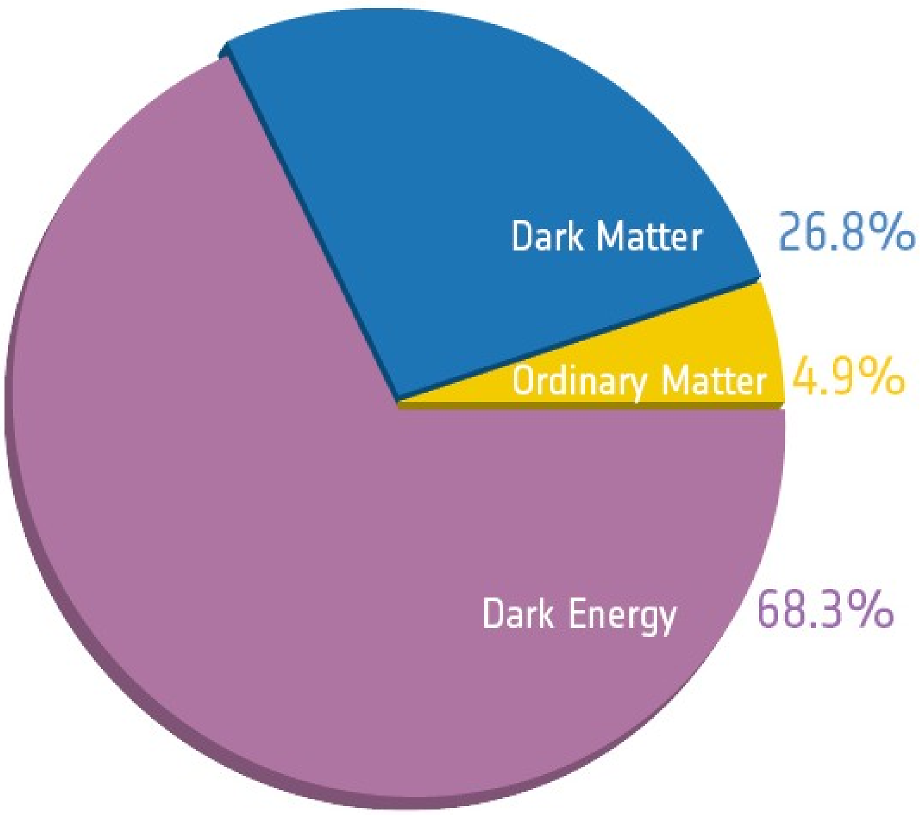
Tim Haines, UW-Madison
Phil Chang, UW-Milwaukee

Fundamental Problem: Dark Matter and Energy: What is it?

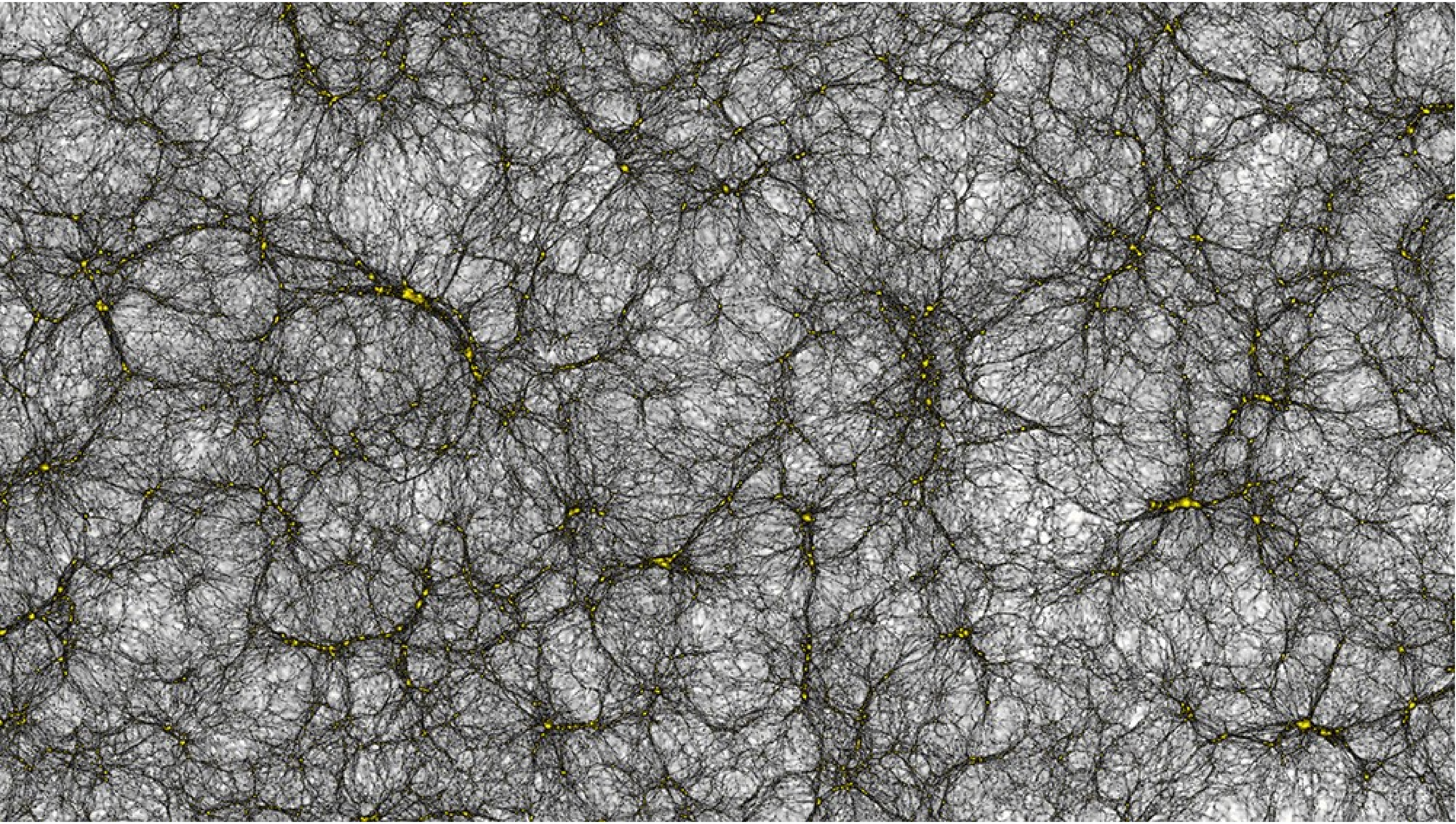
- Not baryons
- Gravitates!
- Simulations show: not known neutrinos
- Candidates:
  - Sterile Neutrinos
  - Axions
  - Lightest SUSY Particle (LSP)



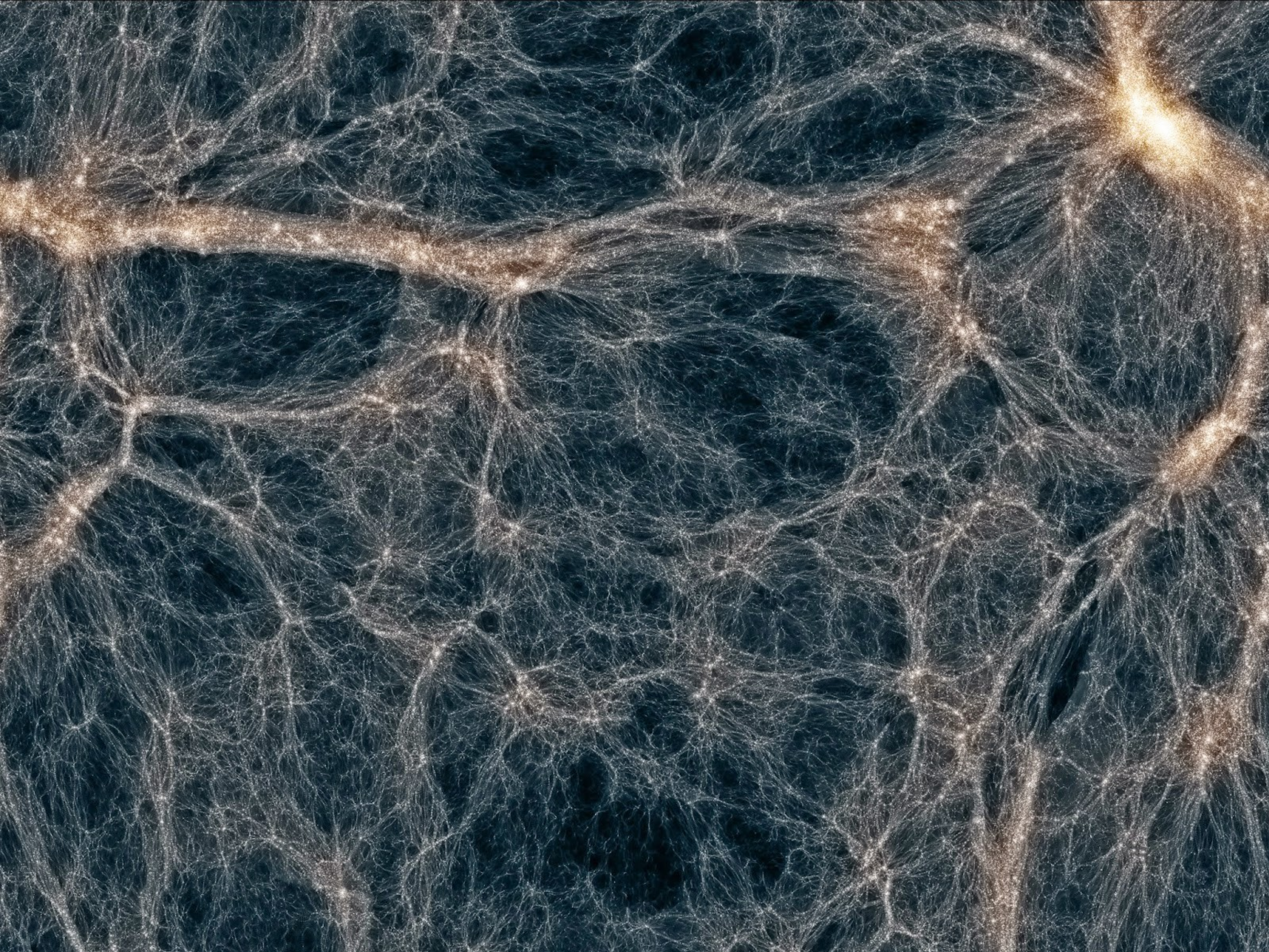
Modeling Dark Matter

- Physics is simple: Newton's Laws
- Computation is challenging: Naively order N^2
- Large spacial dynamic range: > 100 Mpc to < 1 kpc
  - Hierarchical, adaptive gravity solver is needed
- Large temporal dynamic range: 10 Gyr to < 1 Myr
  - Multiple timestep algorithm is needed
- Gravity is a long range force
  - Hierarchical information needs to go across processor domains

Gigaparsecs: the Cosmic Web



Potter & Stadel, 2017

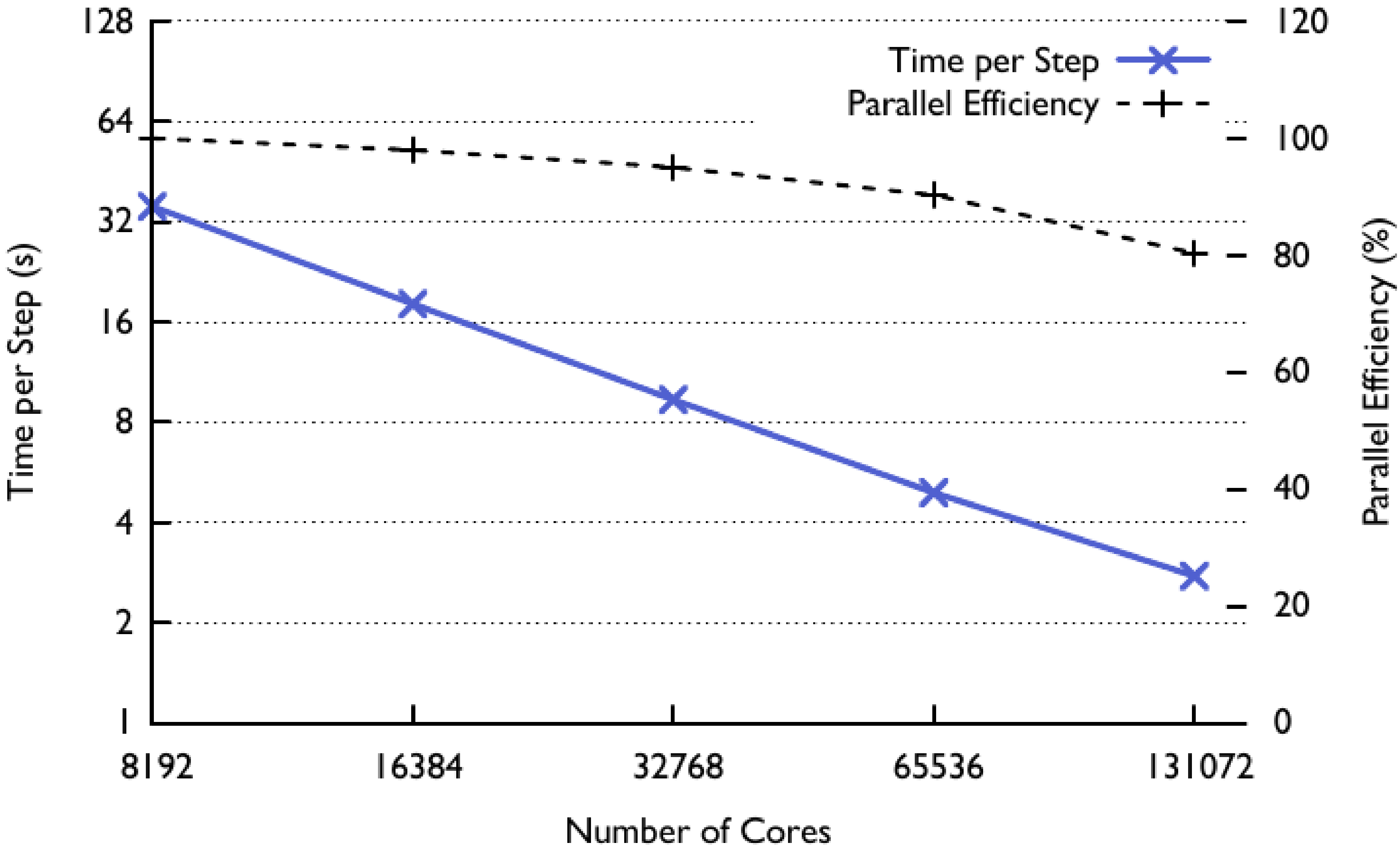


Charm Nbody GrAvity solver

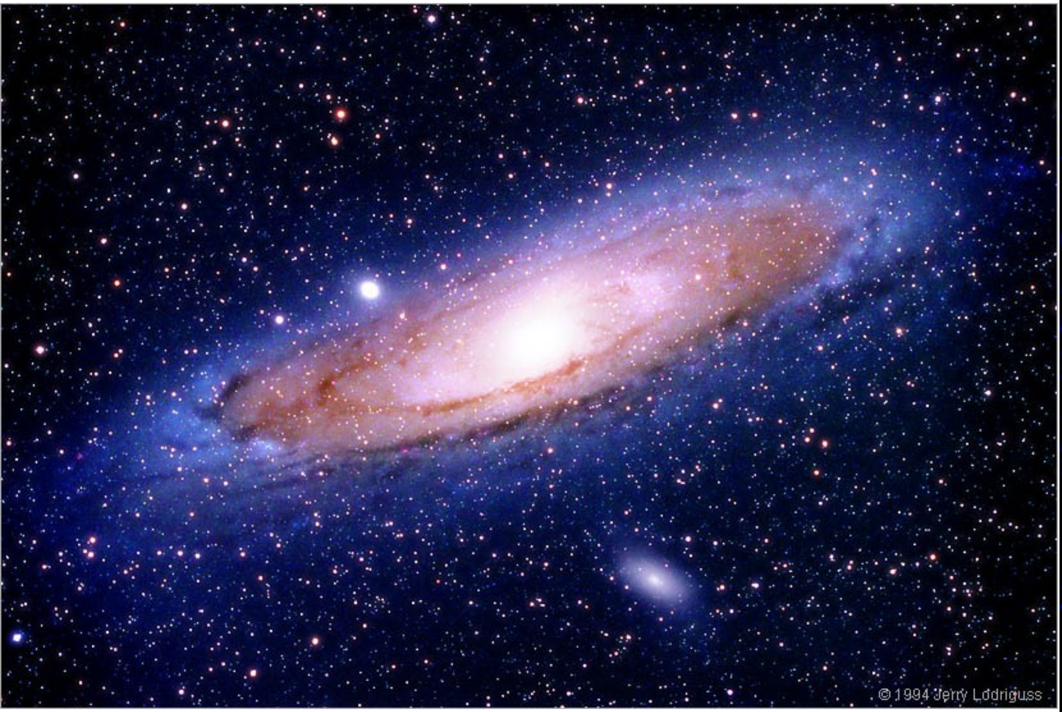
- Massively parallel Tree-code
- Framework for Gravity and Neighbor Finding
  - K-nearest
  - Fixed radius
- Large number of Astrophysics models

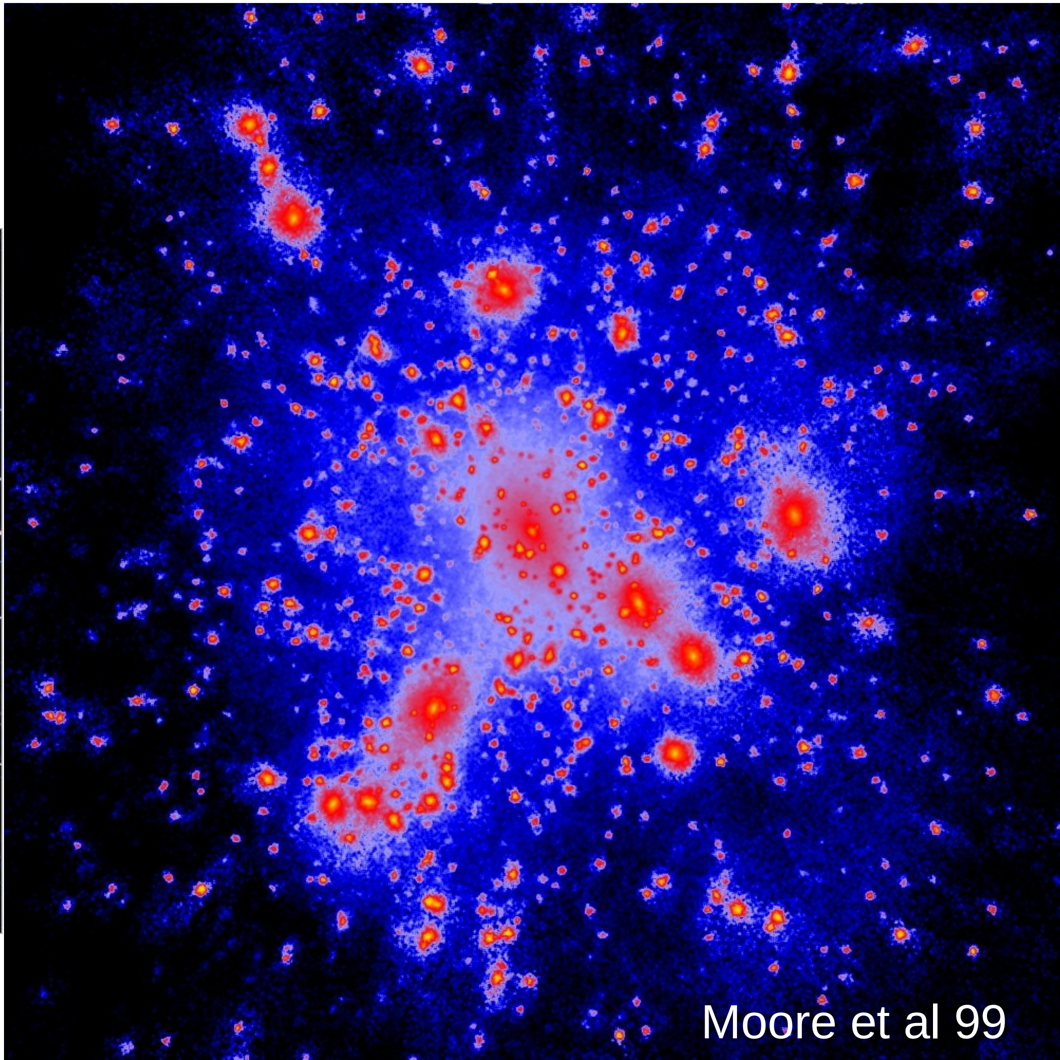
Menon+ 2014, Jetley+2008

Speedups
for 2 billion clustered particles



Light vs. Matter

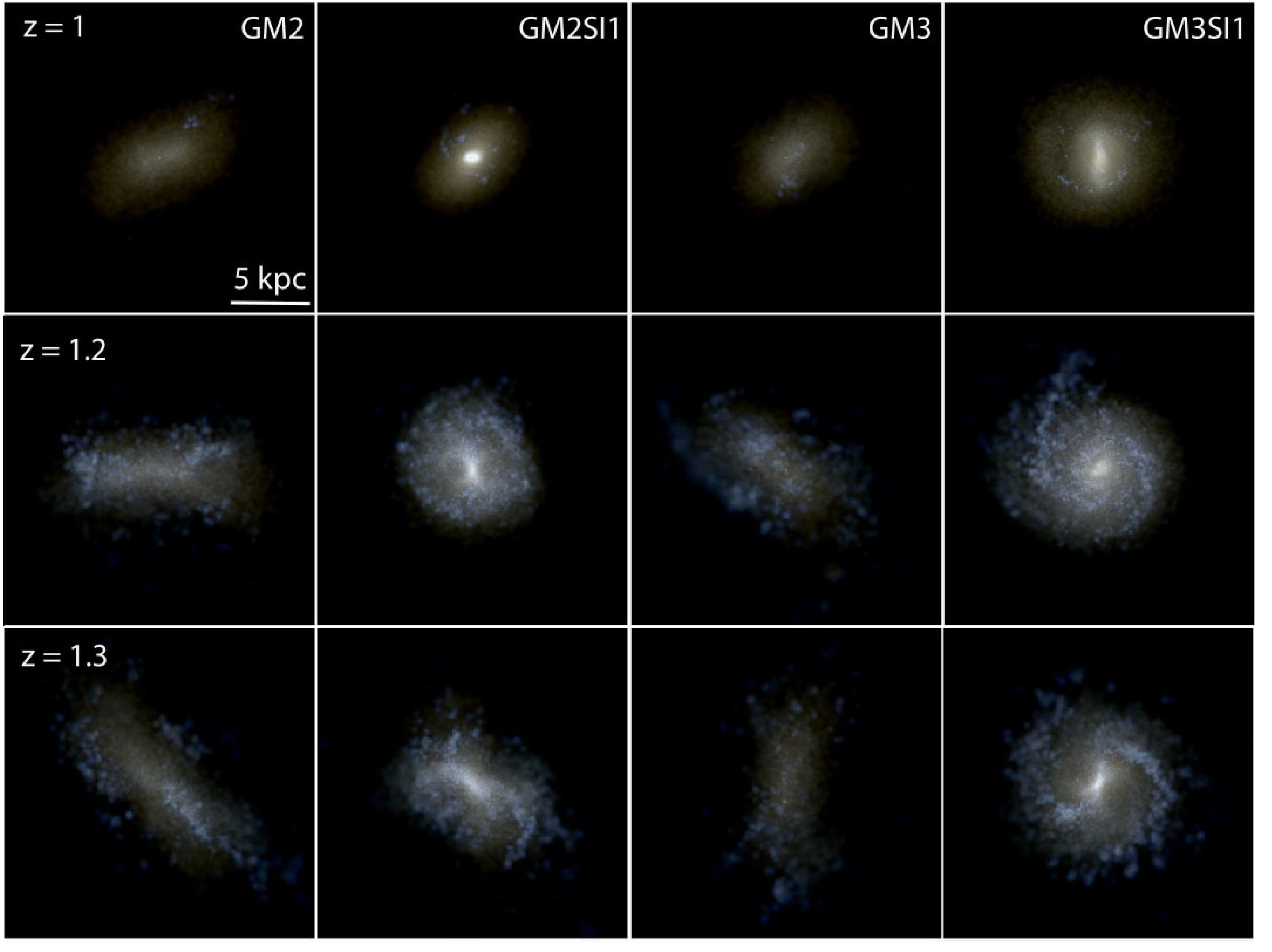




Smooth Particle Hydrodynamics

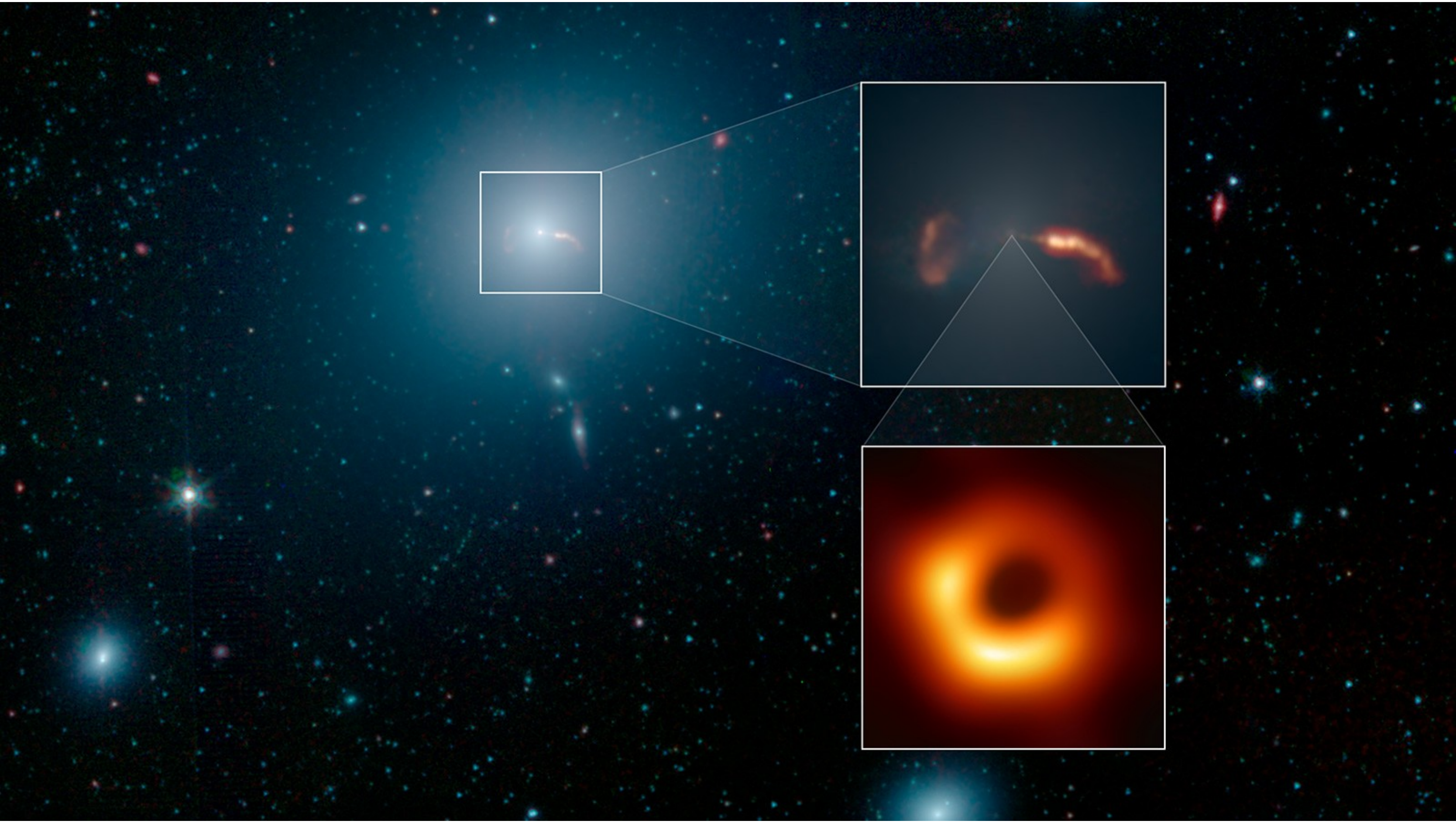
- Making testable predictions needs Gastrophysics
  - High Mach number
  - Large density contrasts
- Gridless, Lagrangian method
- Galilean invariant
- Monte-Carlo Method for solving Navier-Stokes equation.
- Natural extension of particle method for gravity.

Testing Dark Matter Models



Cruz et al, 2021

Black Holes!



NASA, JPL, Event Horizon Telescope

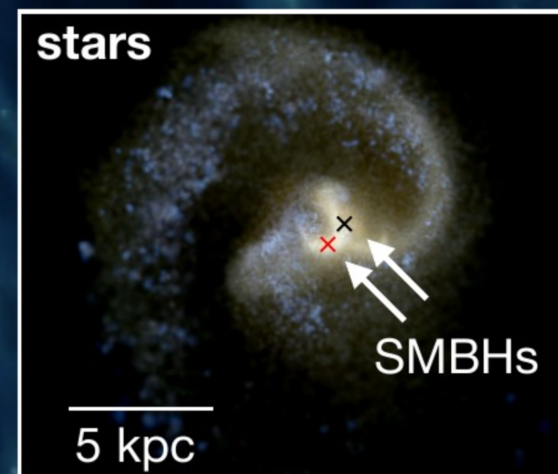
The ROMULUS Simulations

Certified organic, free-range, locally grown supermassive black holes

- ✓ Early Seeding in low mass halos
- ✓ Self-consistent and physically motivated dynamics, growth, and feedback
- ✓ Naturally produces large-scale outflows
- ✓ **No unnecessary additives or assumptions**

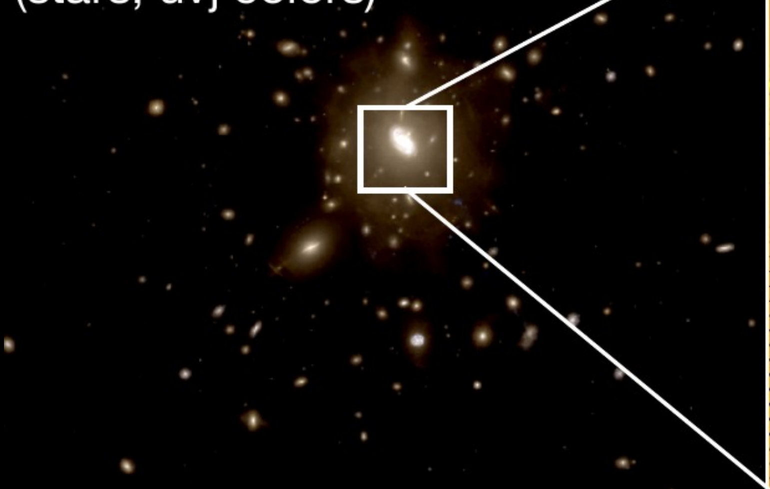
ROMULUS25

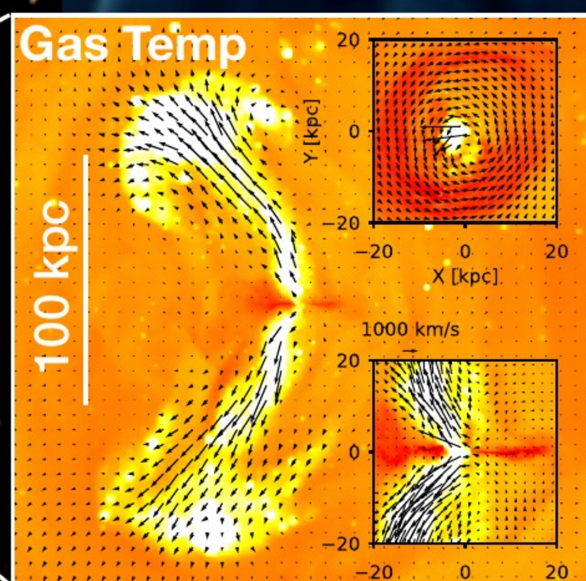
25 Mpc Volume
Tremmel+ 2017
(gas temp)



ROMULUSC

10^{14} M_{sun} Galaxy Cluster
Tremmel+ submitted
(stars, uvj colors)

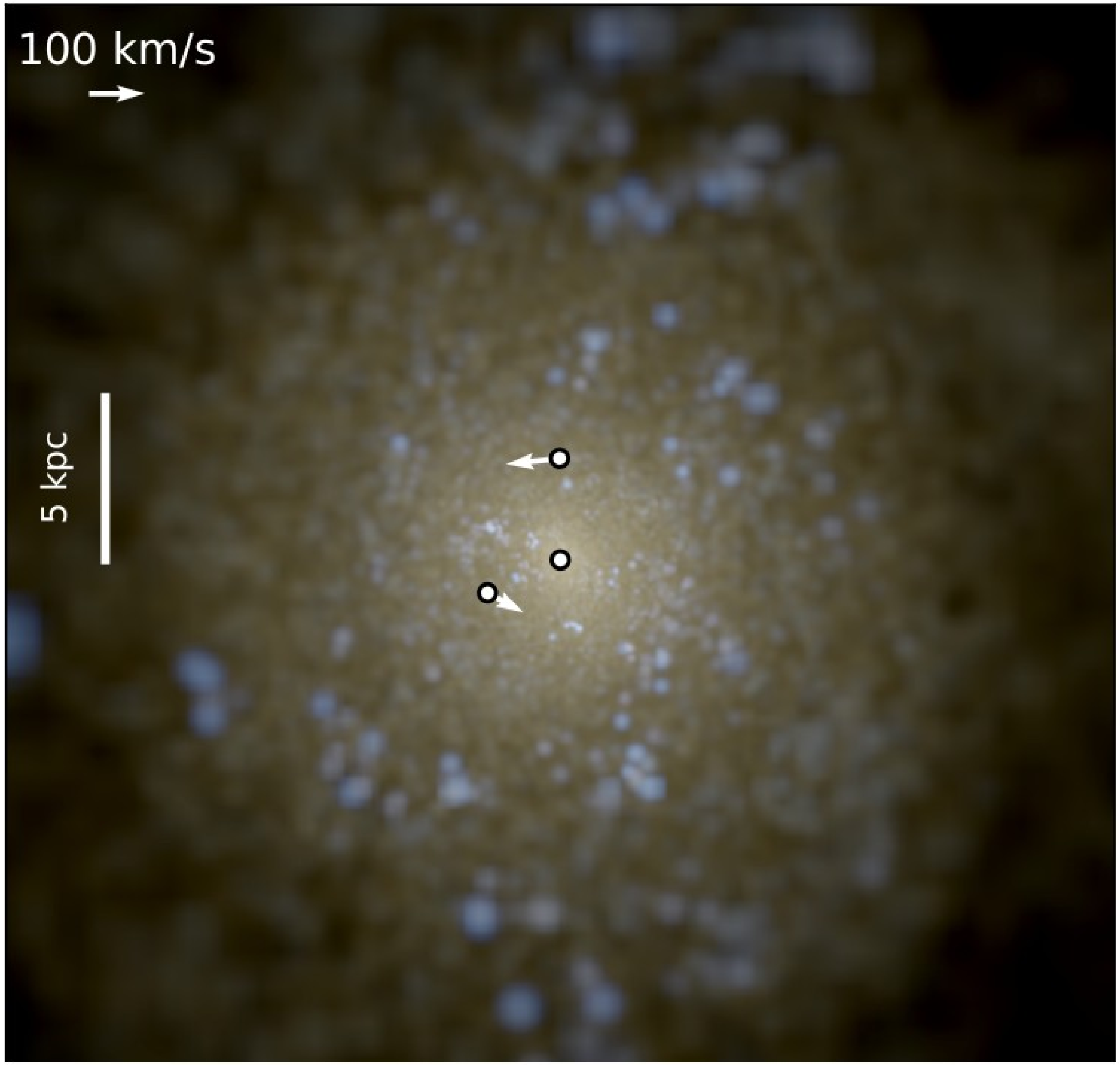




Resolution:
250 pc (grav)
50 pc (hydro)
~1e5 M_{sun}

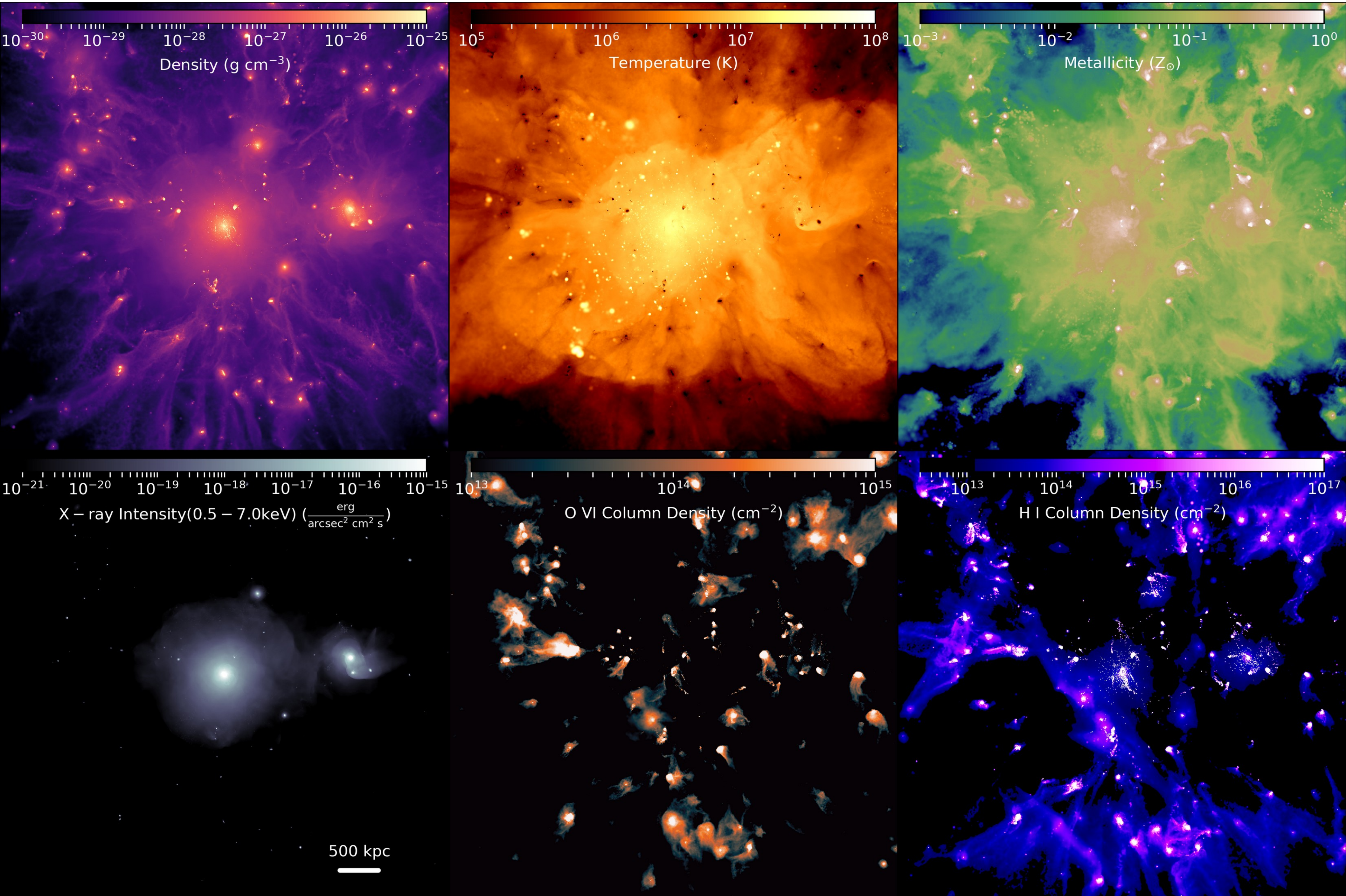
CHANGA

Wandering Black Holes?

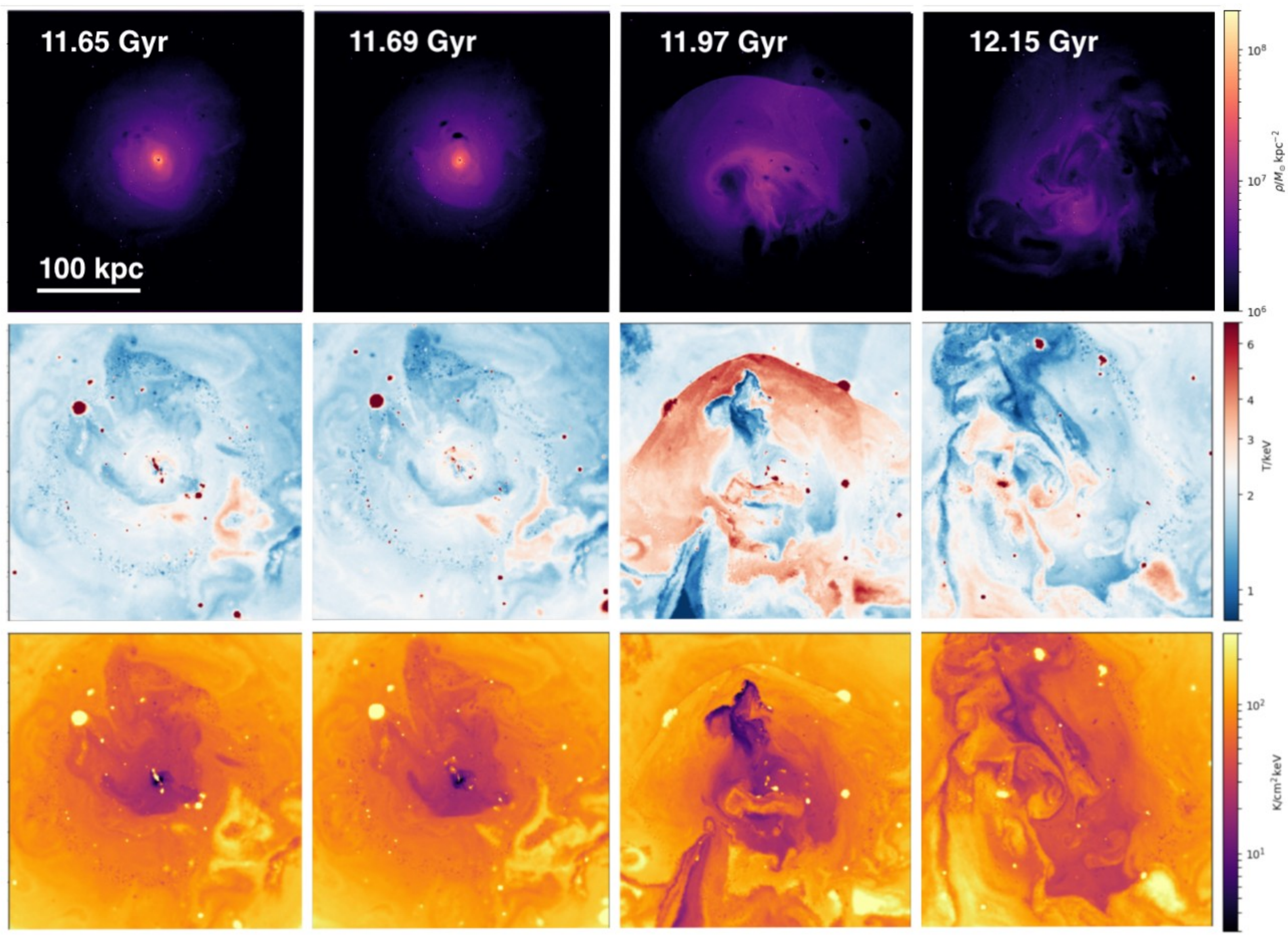


Ricarte et al 2021

Galaxy Cluster

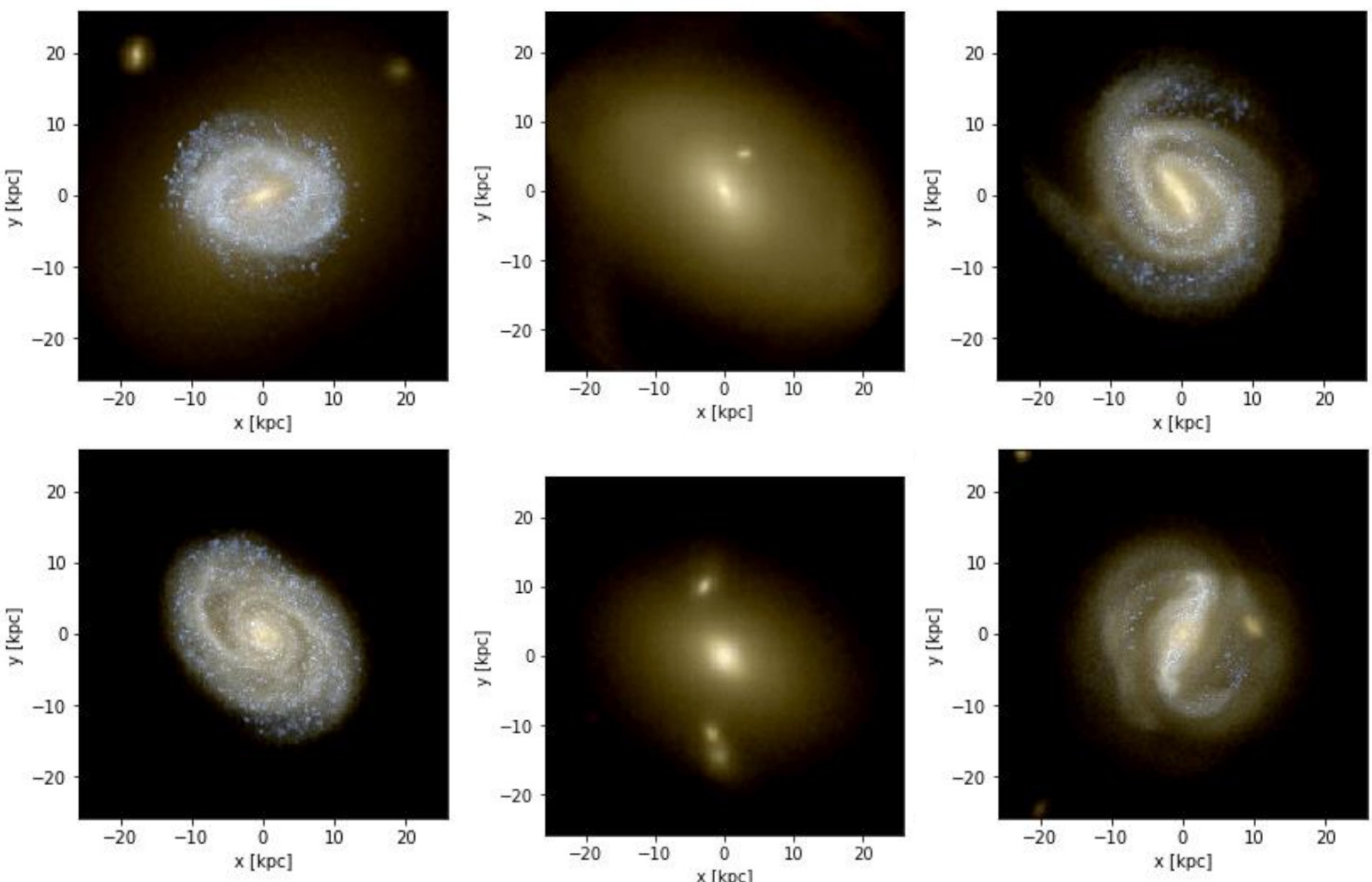


Galaxy Cluster Cores

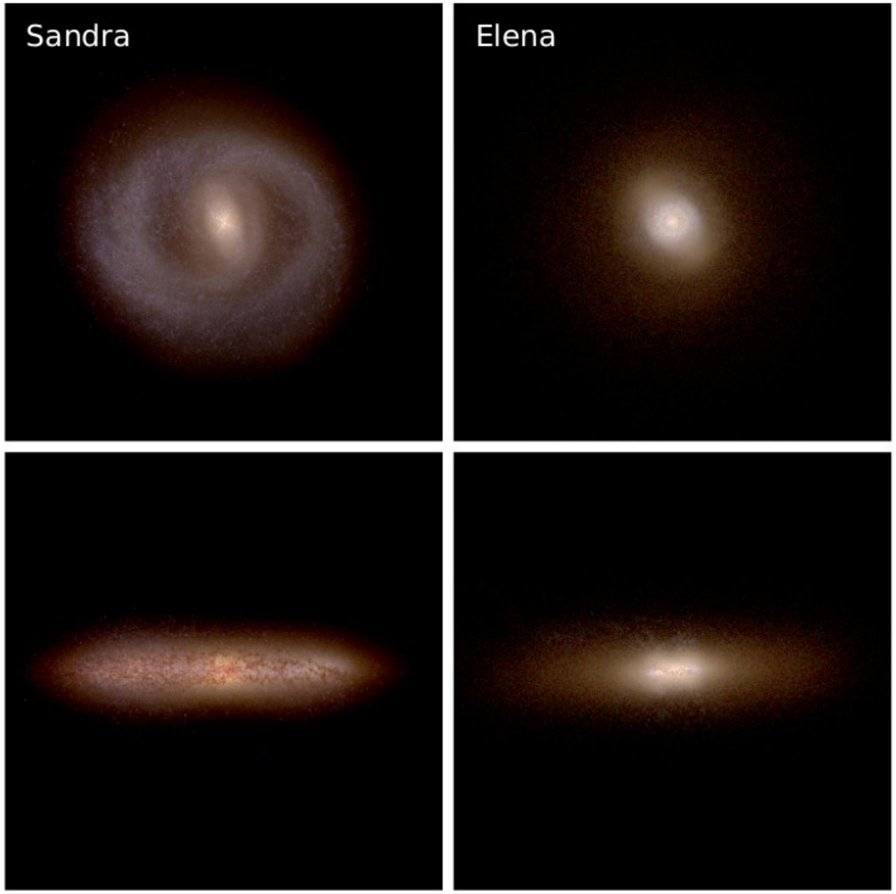


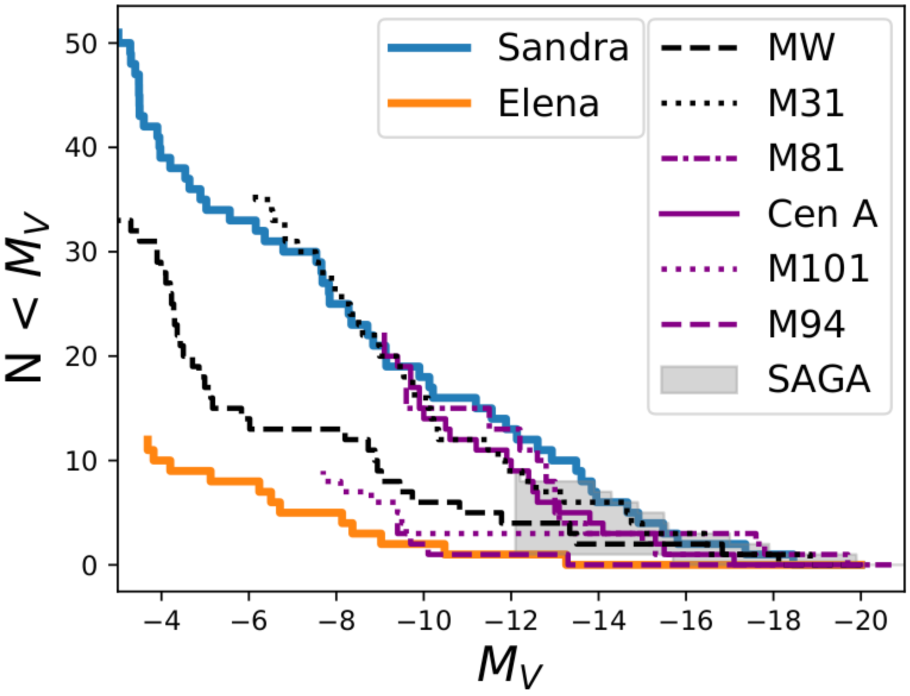
Chadayammuri, et al, 2021

Galaxy populations



Faint Satellites of Galaxies

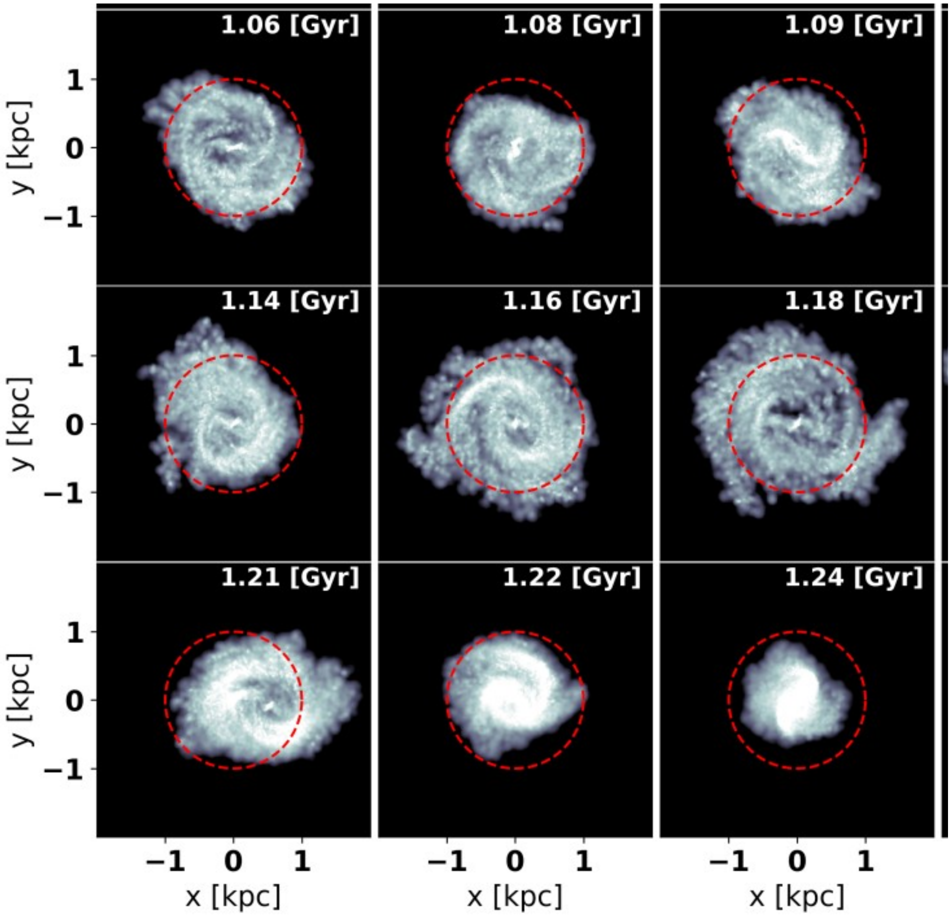


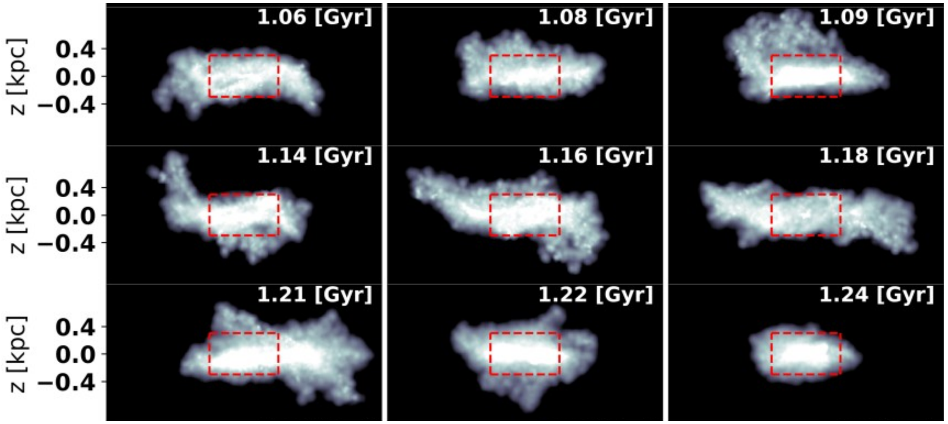


DC Justice League Galaxies running on Frontera

Applebaum et al 2021

Early Disk Formation

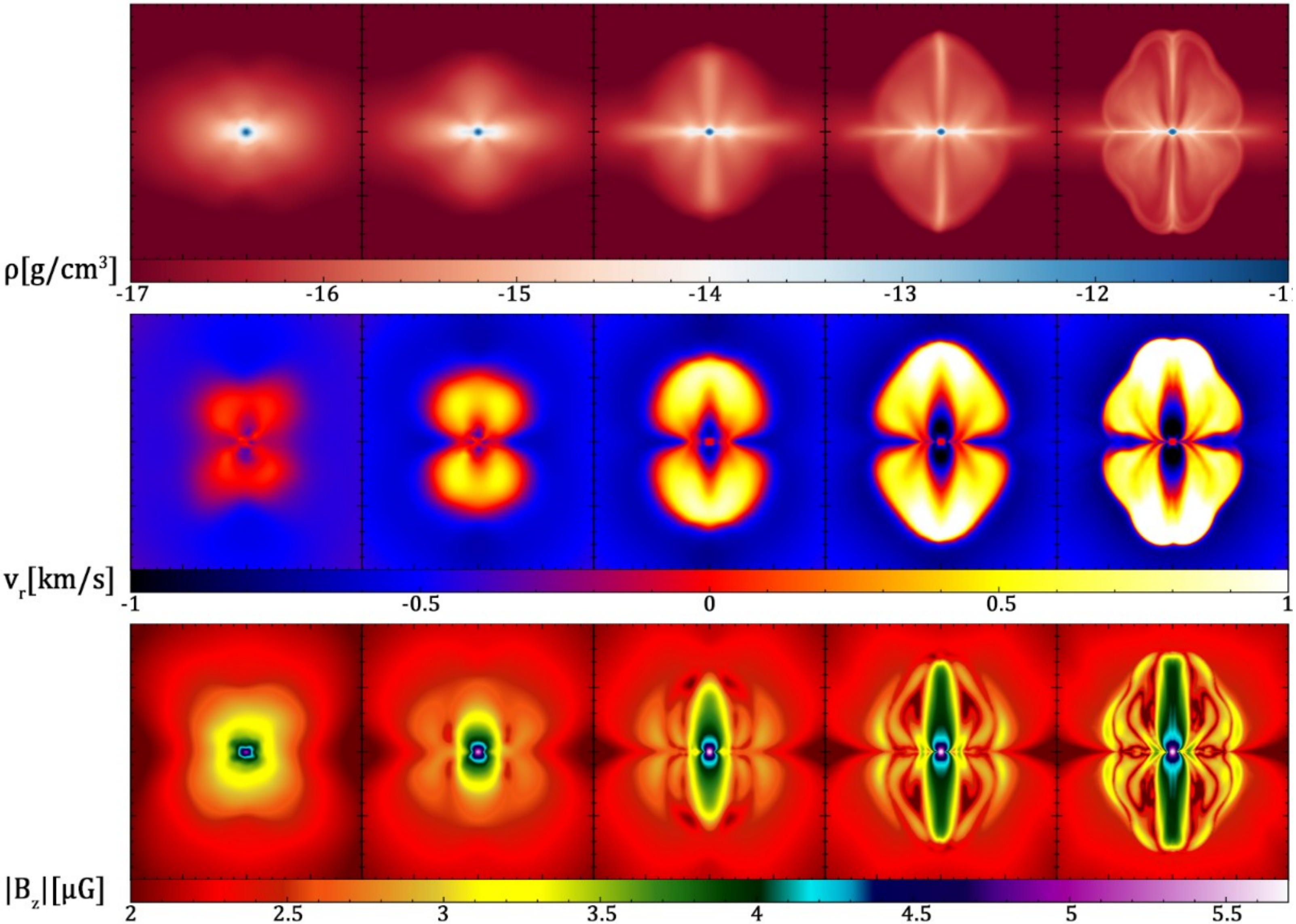




Galactic Disks form thin: Billion particle simulation on Piz Daint

Tamfal et al, 2021

MHD Protostellar Cloud Collapse

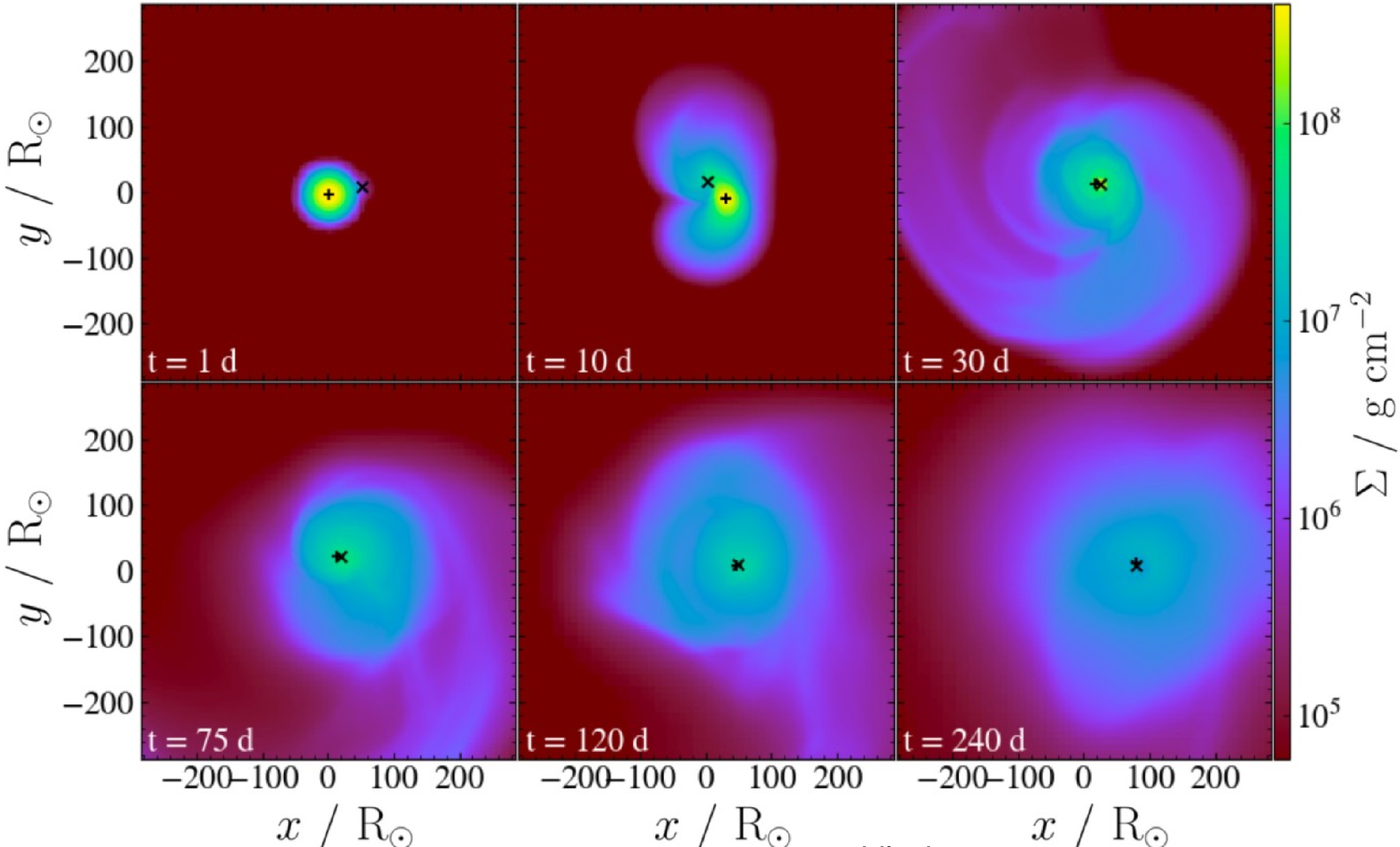


Wissing & Shen, 2020

Moving Mesh Hydrodynamics

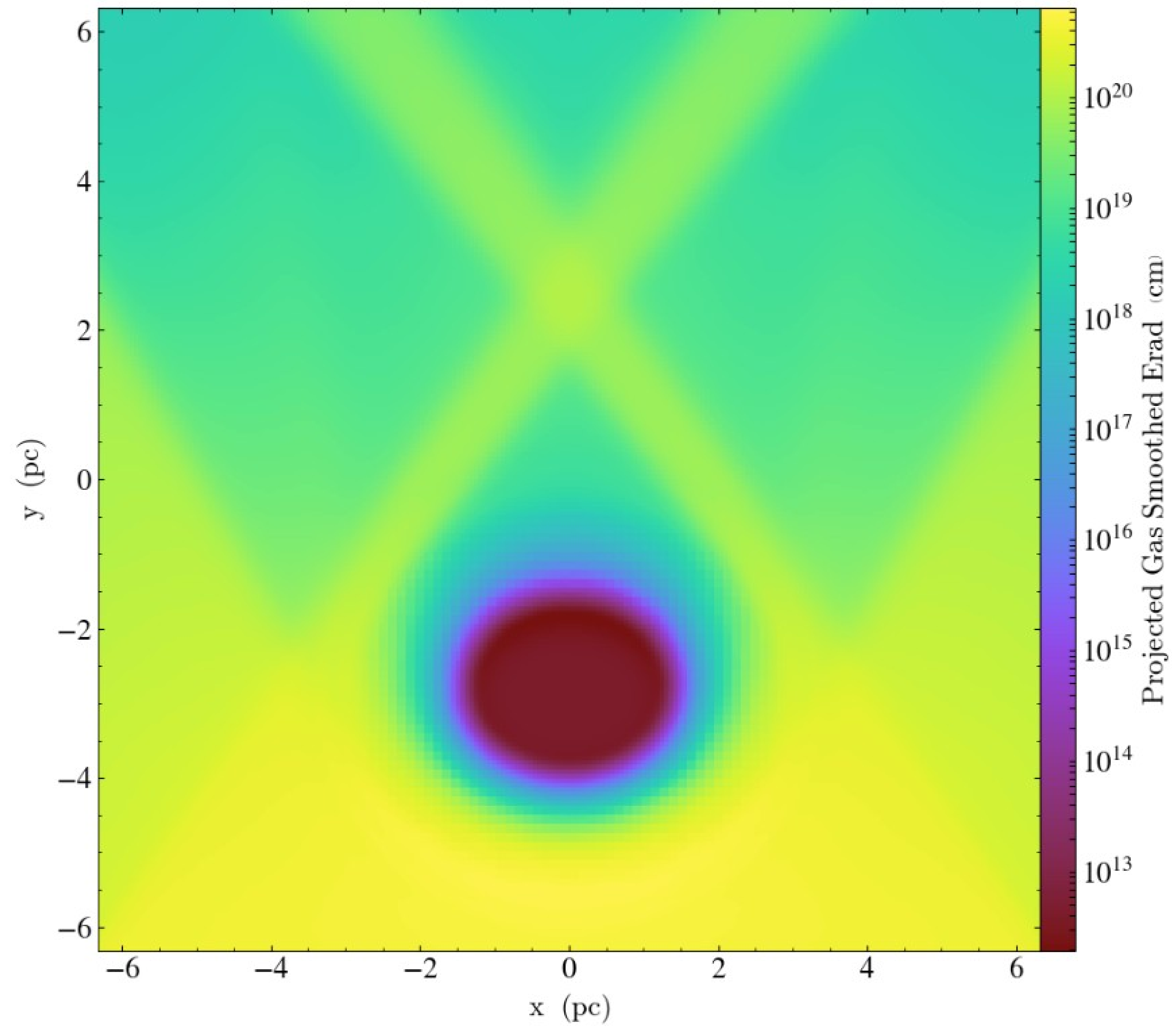
- More accurate hydrodynamics requires Riemann solvers
- Galilean invariance: mesh needs to follow the fluid flow
- Mesh needs to have arbitrary geometry
- Need a fast Voronoi mesh generator: ChaNGa (MANGA)

Binary Stars with MaNGa



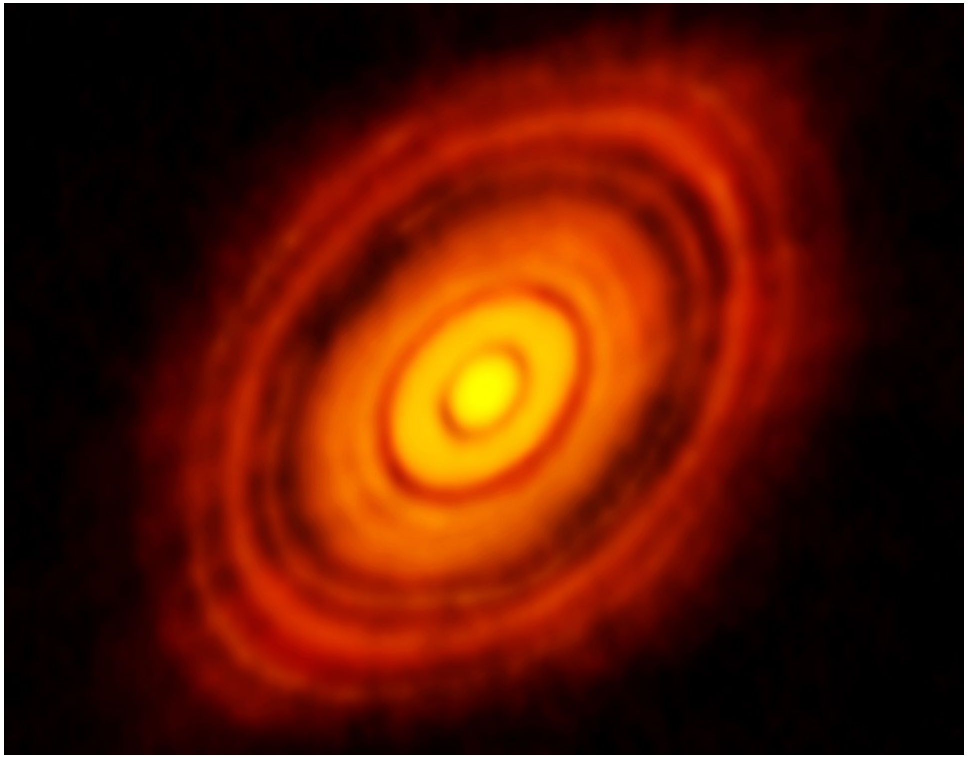
Phil Chang

Radiation Hydrodynamics with MaNGa

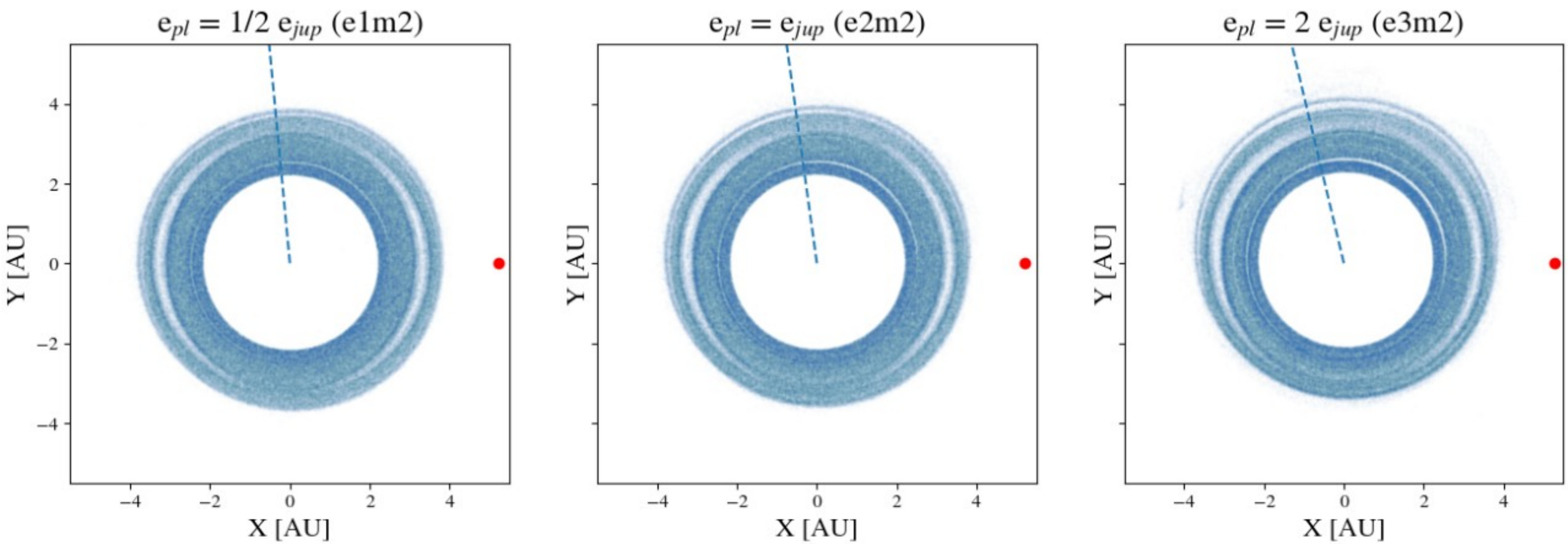


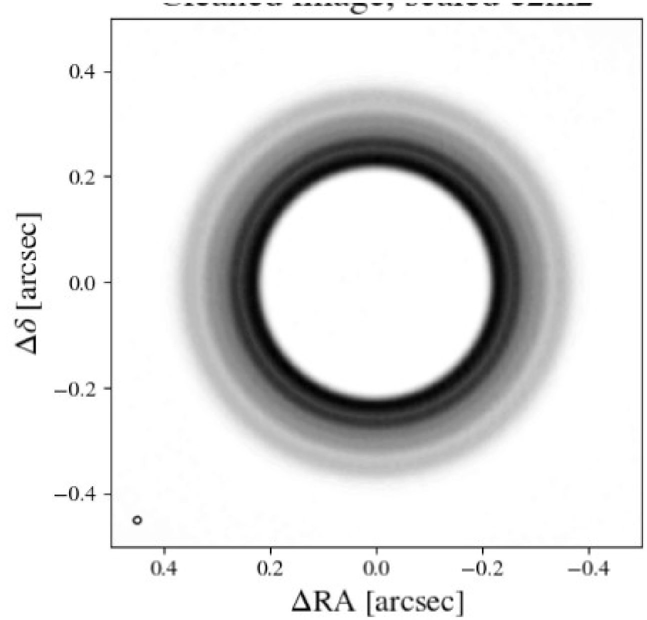
Protoplanetary Disks

- Likely result of cloud collapse with conserved angular momentum
- Disks can be gravitationally unstable
- Fragmentation depends on details of gas dynamics



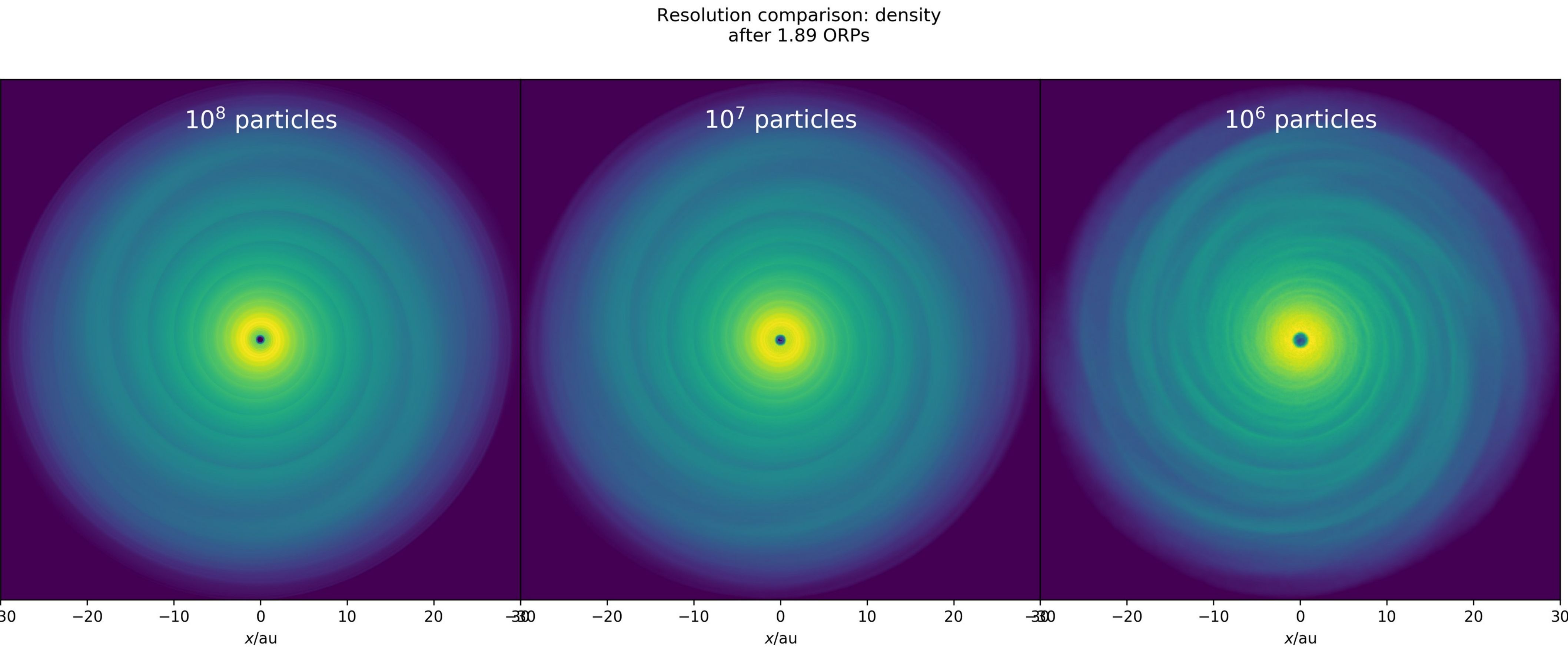
Dust from Collisions?





Wallace et al 2021

Resolution and Disks

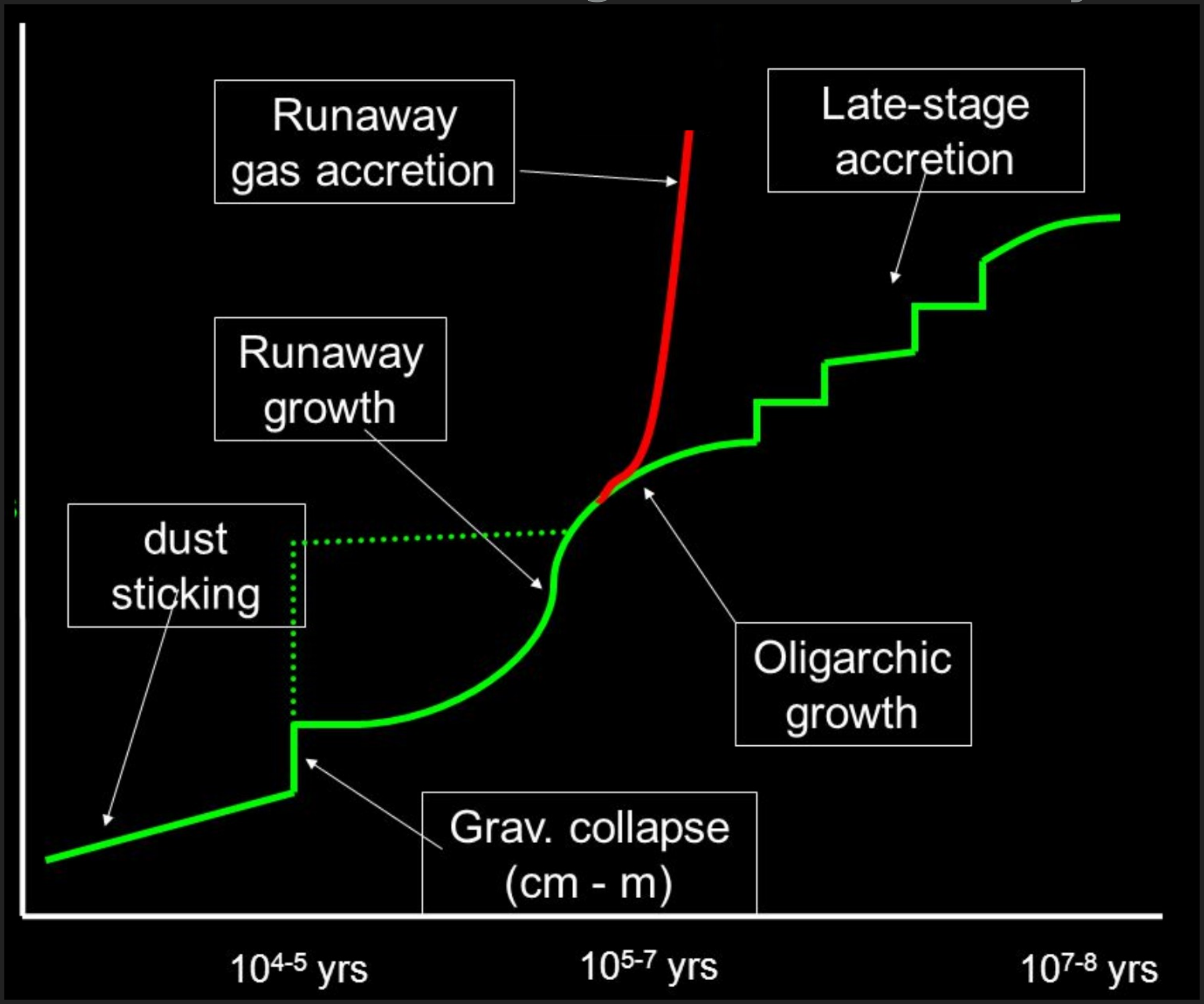


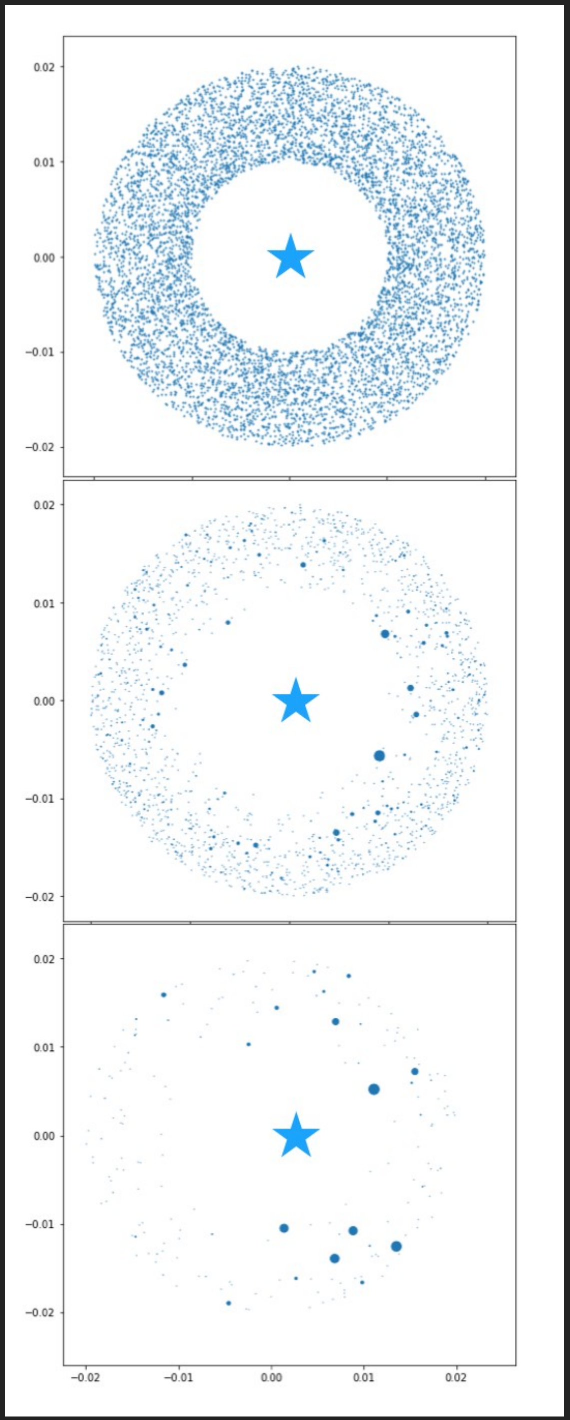
Isaac Backus, Ph. D. Thesis

FROM DUST TO PLANETS

Image credit: Sean Raymond

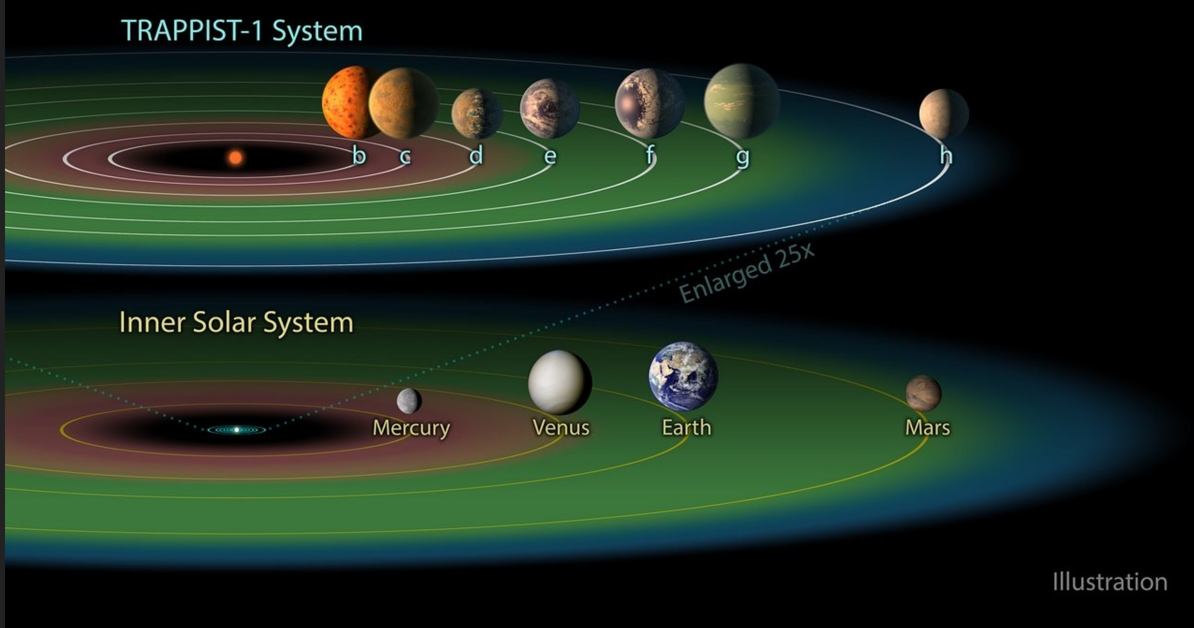
More Particles

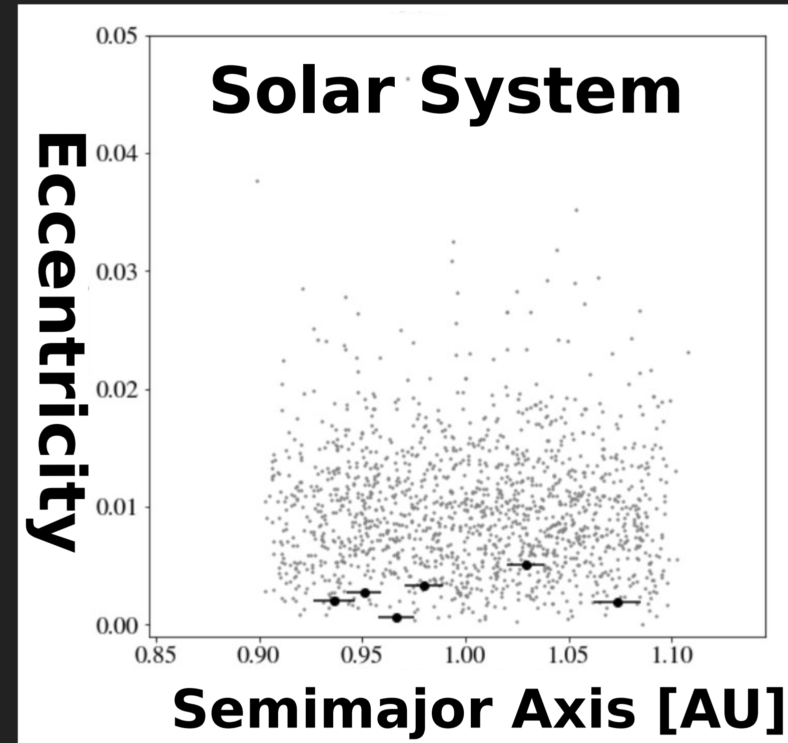


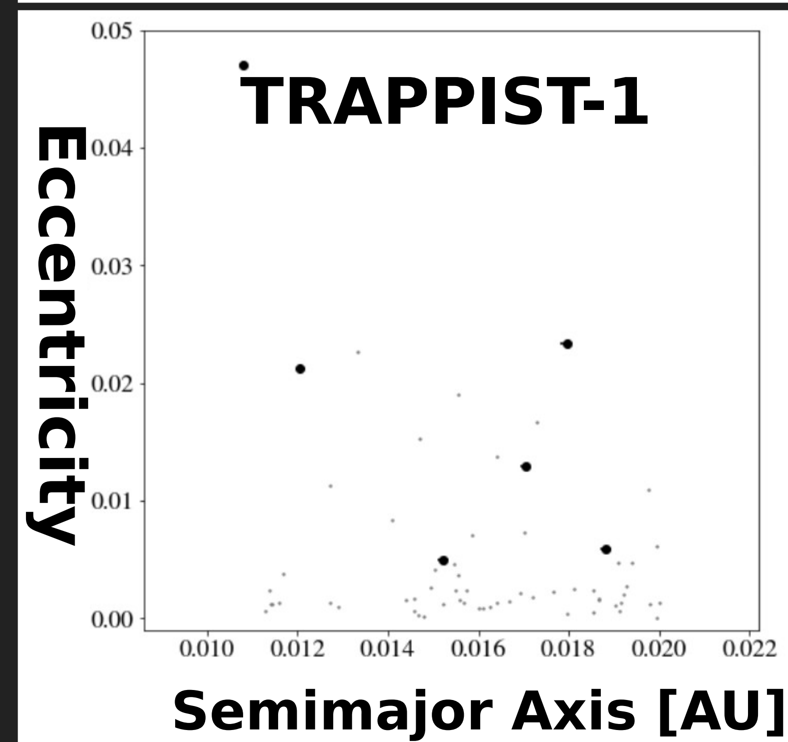


- ChaNGa can directly simulate accretion of planetesimals, test planetesimal formation models

SYSTEMS OF TIGHTLY PACKED INNER PLANETS



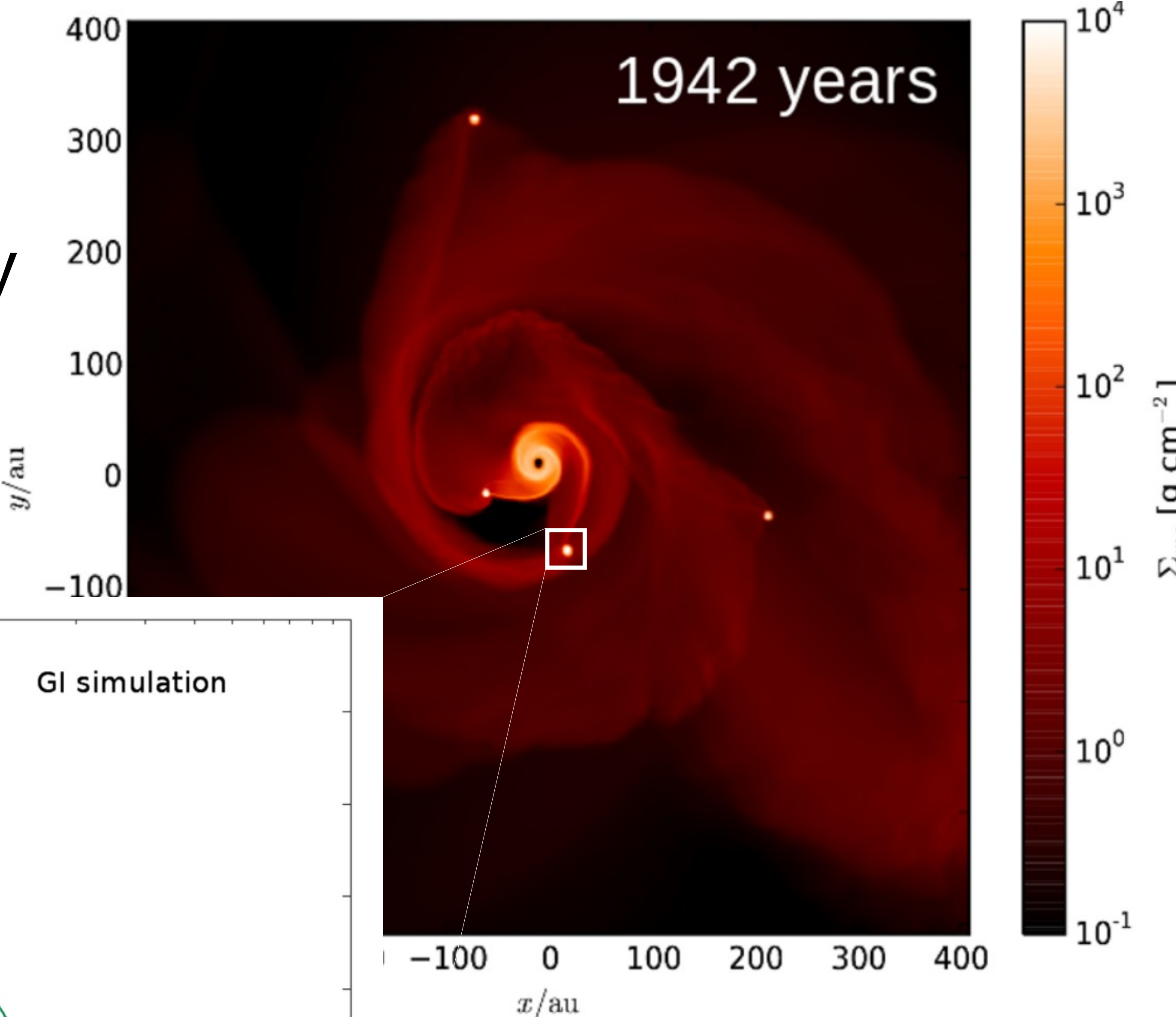


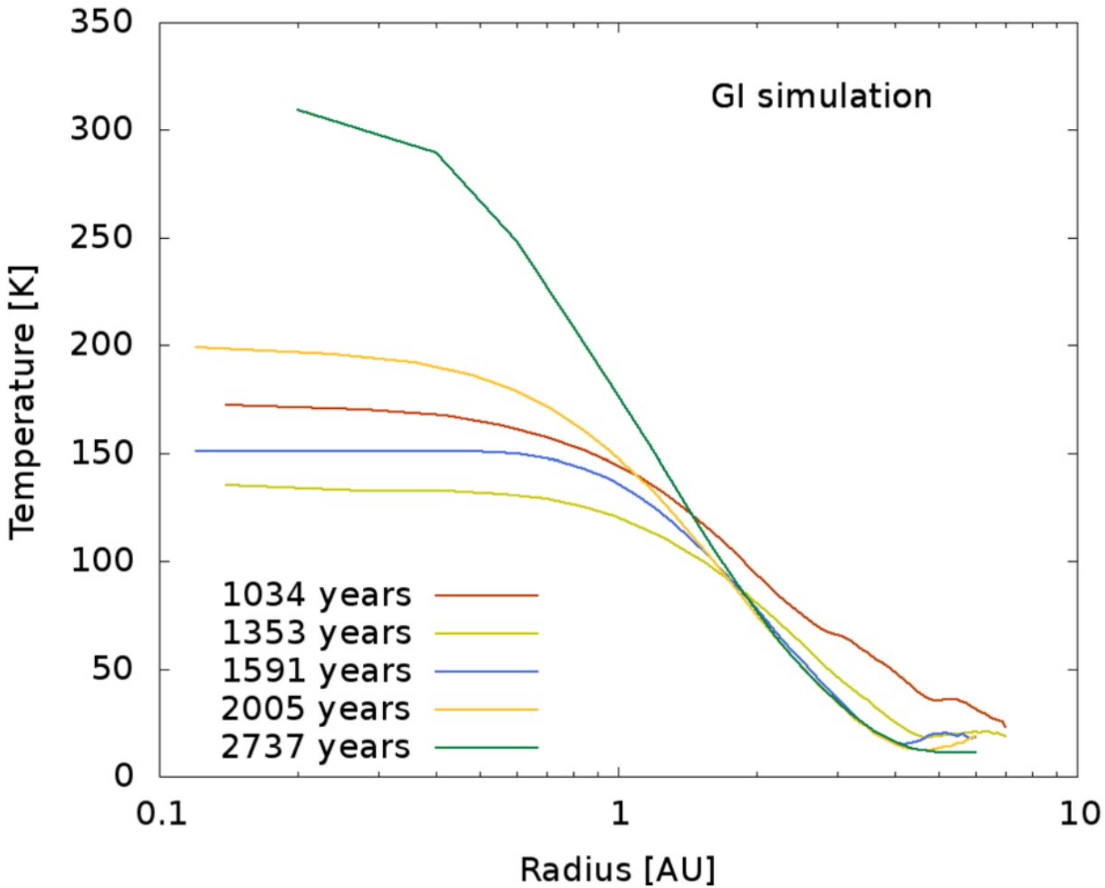


- High surface density, short dynamical timescale close to star
- Does the runaway + oligarchic growth model still apply?

Wallace, in prep.

Circum-Planetary Disks





Szulagy et al 2017

Summary

- Astrophysical simulations provide a challenges to parallel implementations
  - Non-local data dependencies
  - Hierarchical in space and time
- ChaNGa has been successful in addressing these challenges using Charm++ features
  - Computation/Communication overlap
  - Message priorities
  - Load Balancing
  - Modularity to add new Physics

Availability

- ChaNGa: http://github.com/N-bodyShop/changa
  - See the Wiki for a developer's guide
- Paratreet: http://github.com/paratreet
  - Some design discussion and sample code

User Community:

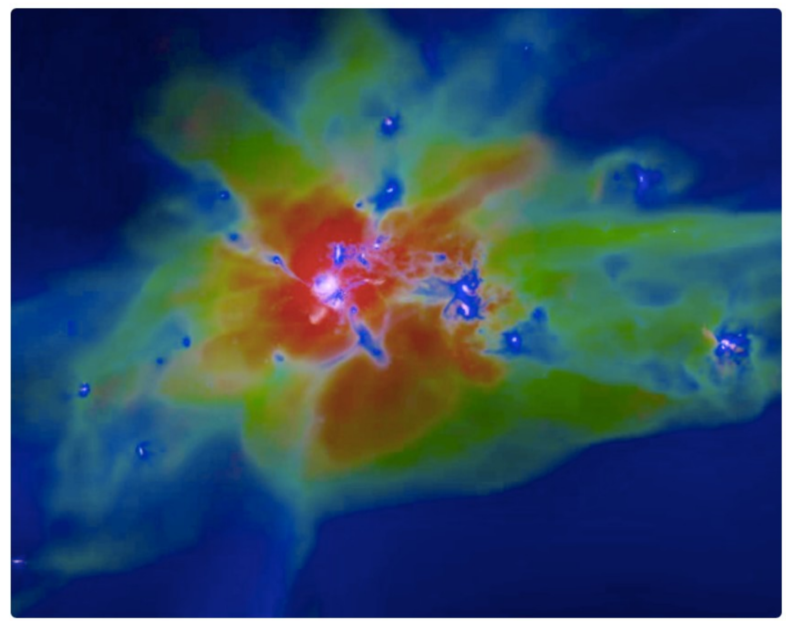
https://nbody.shop

The N-Body Shop Conference

N-Body Shop Excellence Conference 2021

A VIRTUAL COLLABORATION CONFERENCE

LEARN MORE



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