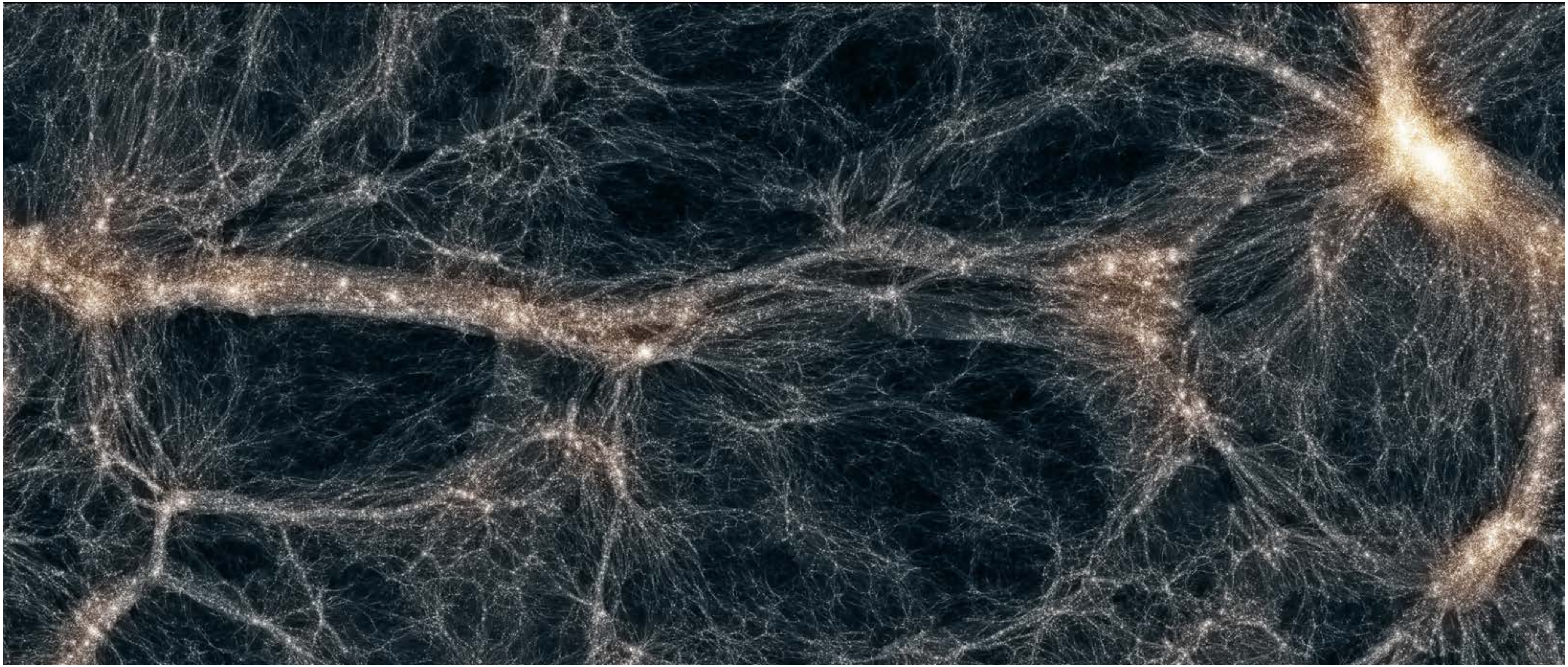
Evolution of the Small Galaxy Population



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Outline

- Scientific background (Why it matters)
- Need for high resolution (Key Challenges)
- Project goals (Why Blue Waters)
- Charm++ and ChaNGa (Key Challenges)
- Preliminary results (Accomplishments)
- Work from the PAID program
- STEM education/training (Broader Impacts)

Galaxy formation: can this...

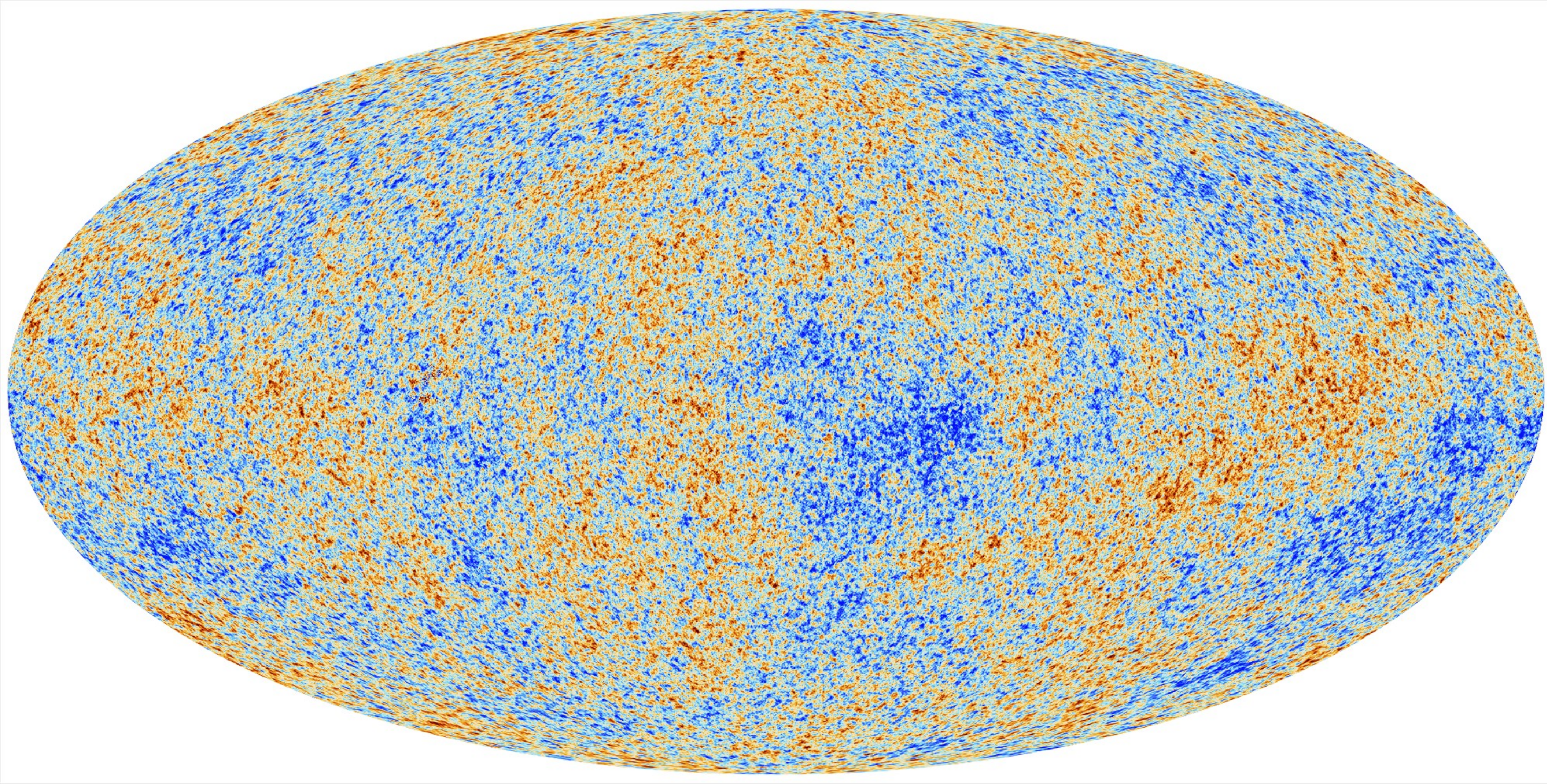
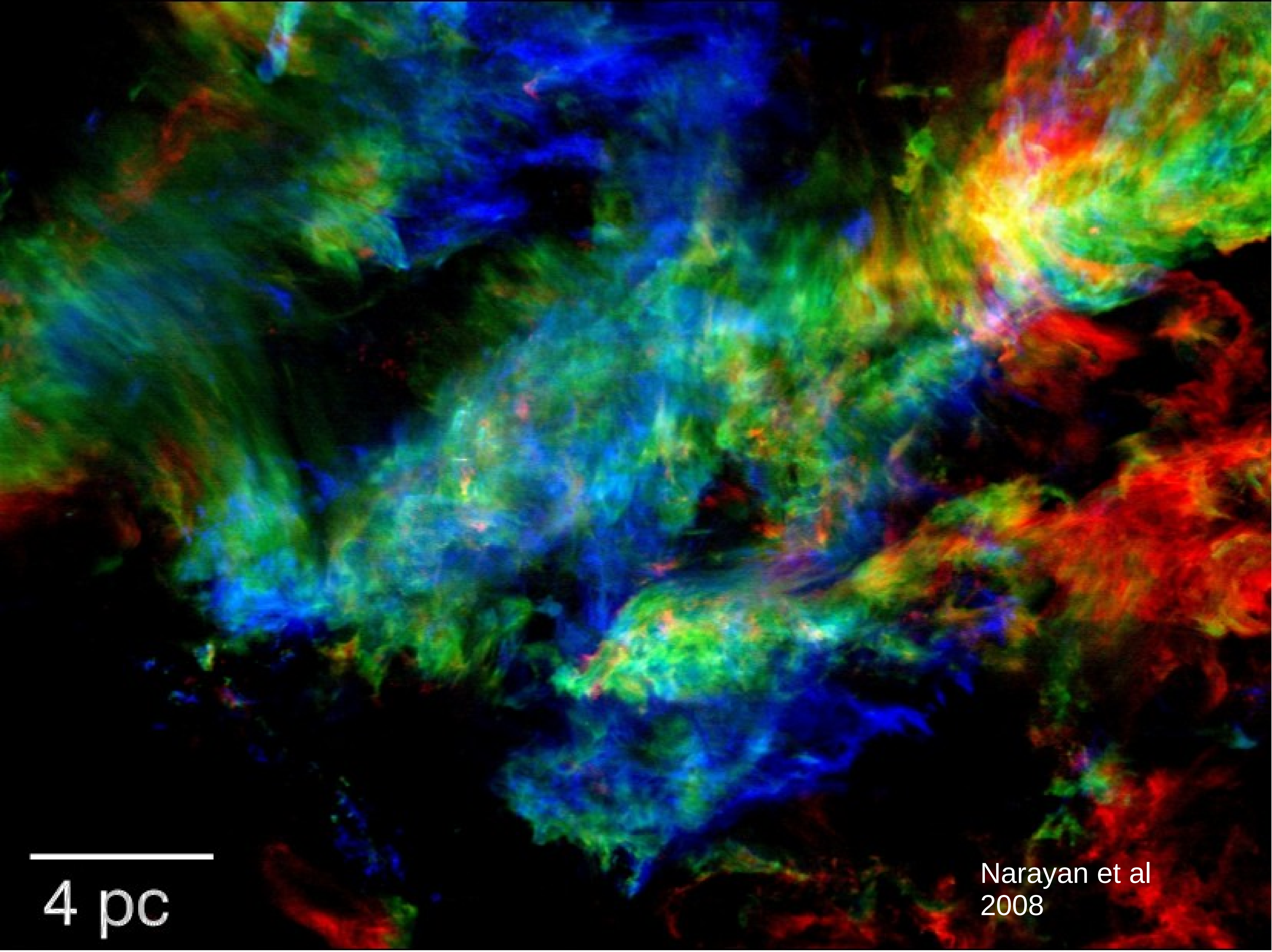


Image courtesy ESA/Planck

... turn into this?

Modeling Star Formation: it's hard

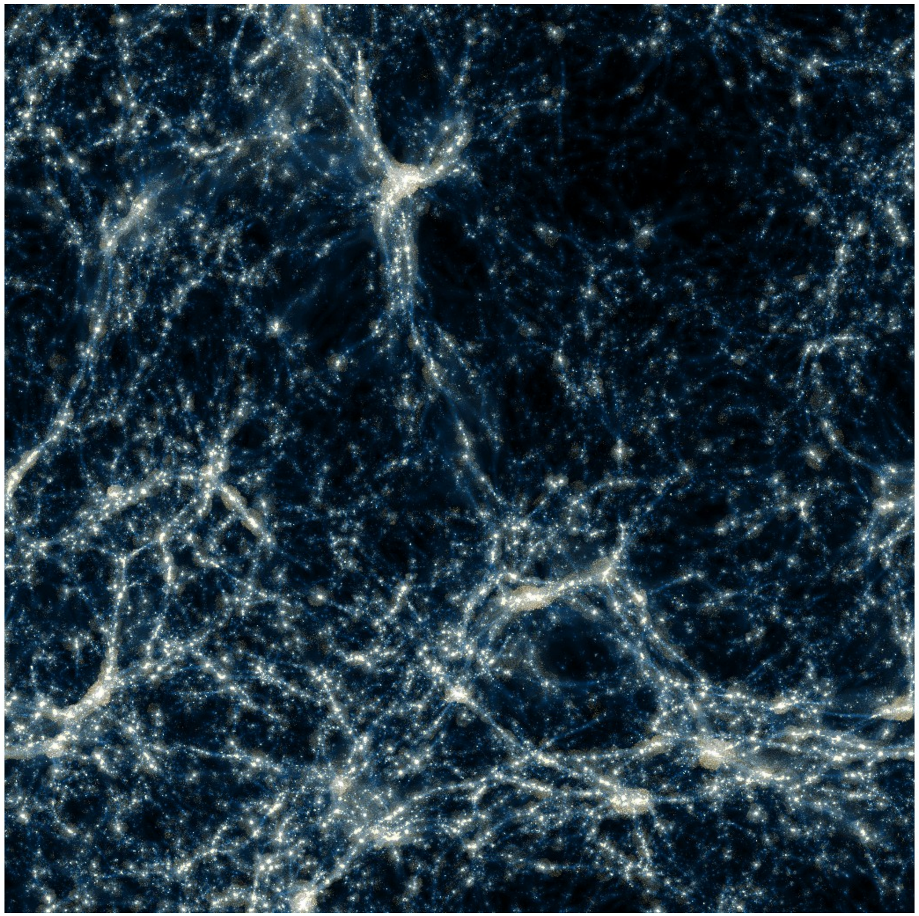
- Gravitational Instabilities
- Magnetic Fields
- Radiative Transfer
- Molecular/Dust Chemistry
- Driven at large scales: differential rotation
- Driven at small scales: Supernovea and Stellar Winds
- Scales unresolvable in cosmological simulations


4 pc
Narayan et al
2008

Resolution and Subgrid Models

- Maximize Simulation Resolution
  - Capture tidal torques/accretion history (20+ Mpc)
  - Adapt resolution to galaxy (sub-Kpc)
- Capture Star Formation in a sub-grid model
  - Stars form in high density environments
  - Supernovea/stellar winds/radiation regulate star formation
  - Mitigate issues with poor resolution (overcooling)
  - Tune to match present day stellar populations

Blue Waters: High Redshift Galaxies



- 25 Mpc Volume
- Few million particles/galaxy
- Goals:
  - Models to compare with HST Frontier fields
  - Physical properties of high z galaxies and connection to the present day

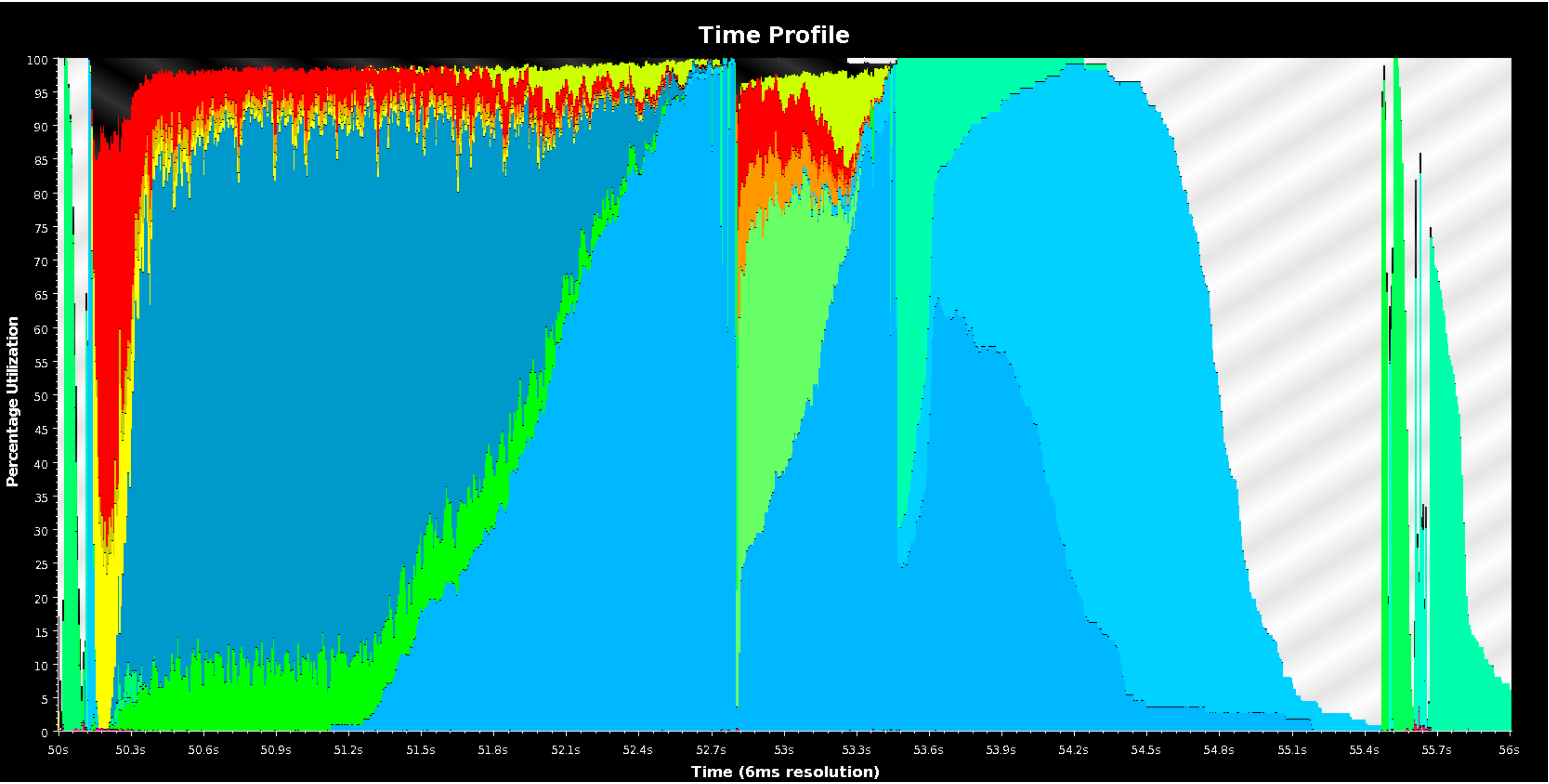
Charm++

- C++-based parallel runtime system
  - Composed of a set of globally-visible parallel objects that interact
  - The objects interact by asynchronously invoking methods on each other
- Charm++ runtime
  - Manages the parallel objects and (re)maps them to processes
  - Provides scheduling, load balancing, and a host of other features, requiring little user intervention

Charm Nbody GrAvity solver

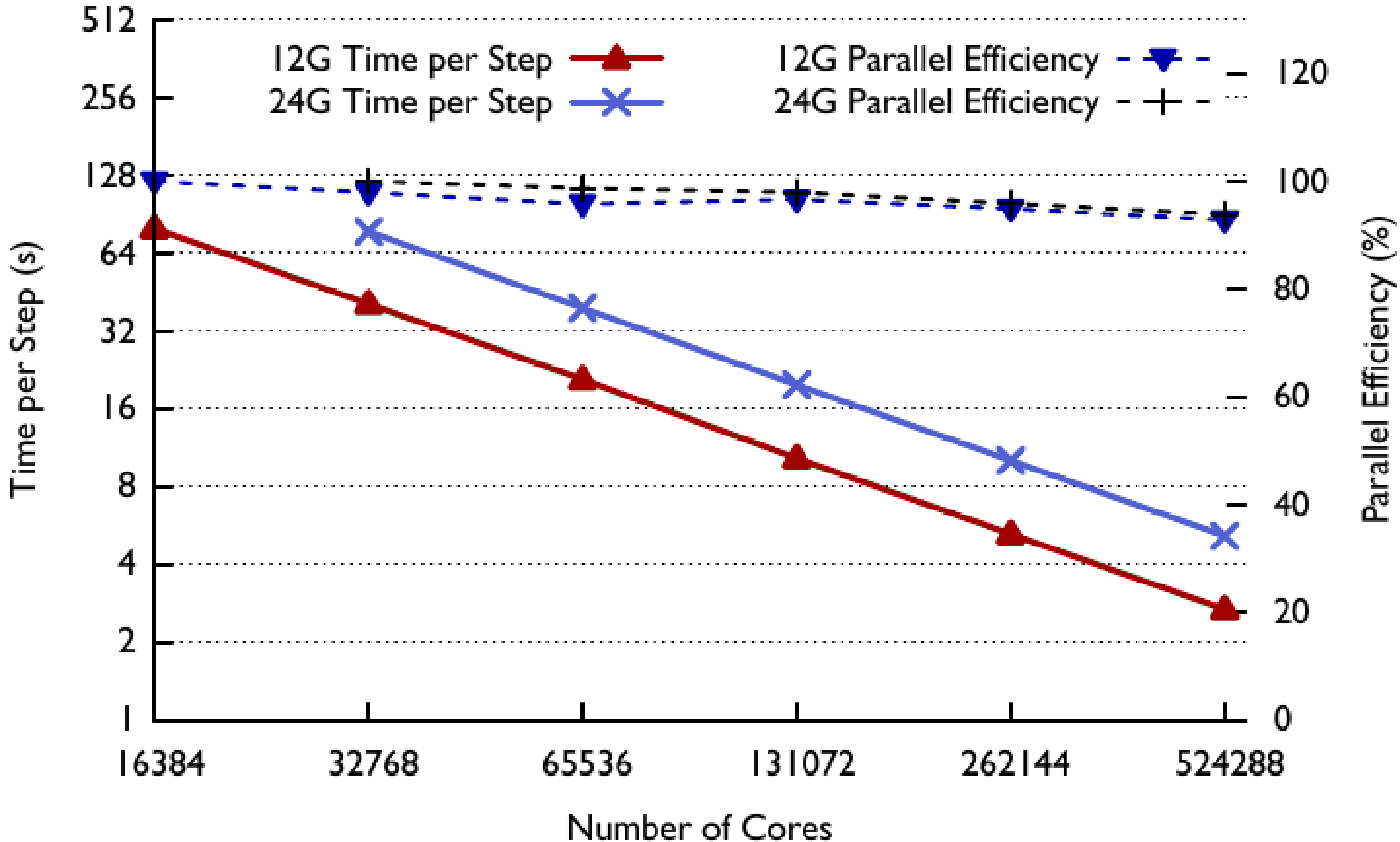
- Massively parallel SPH
- SNe feedback creating realistic outflows
- SF linked to shielded gas
- SMBHs
- Optimized SF parameters

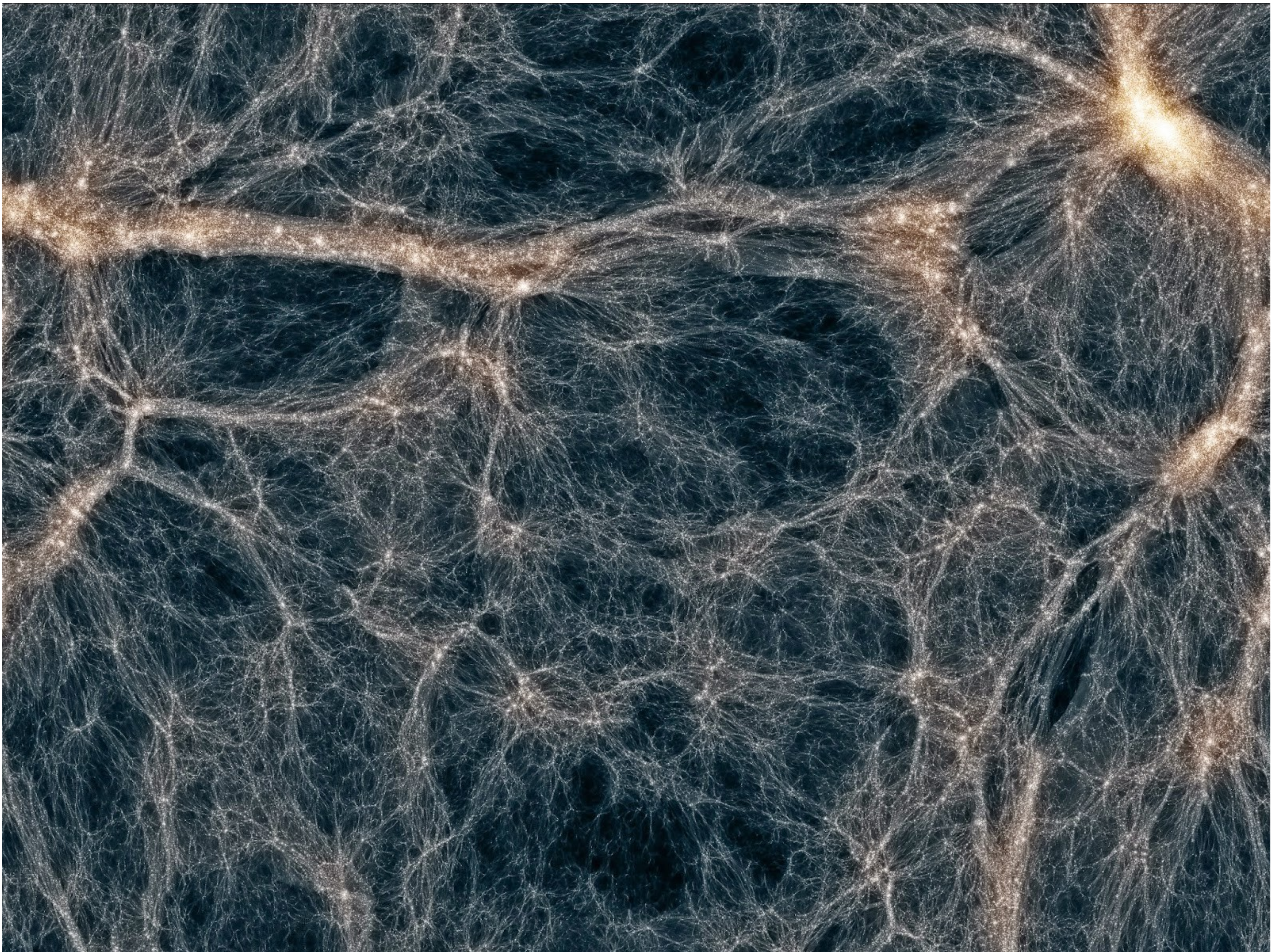
Overlap of Phases



Gravity Hydrodynamics

Scaling to .5M cores

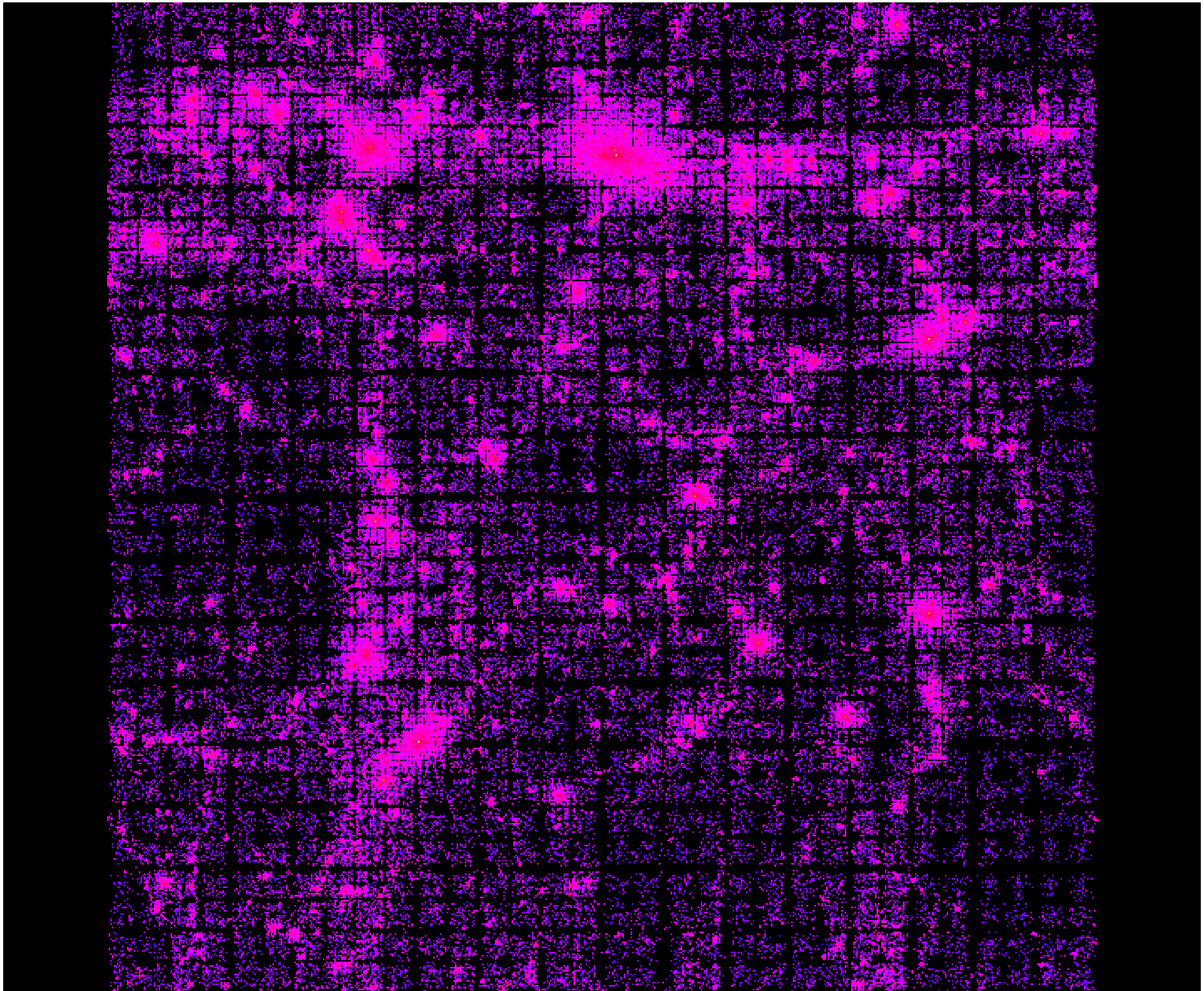




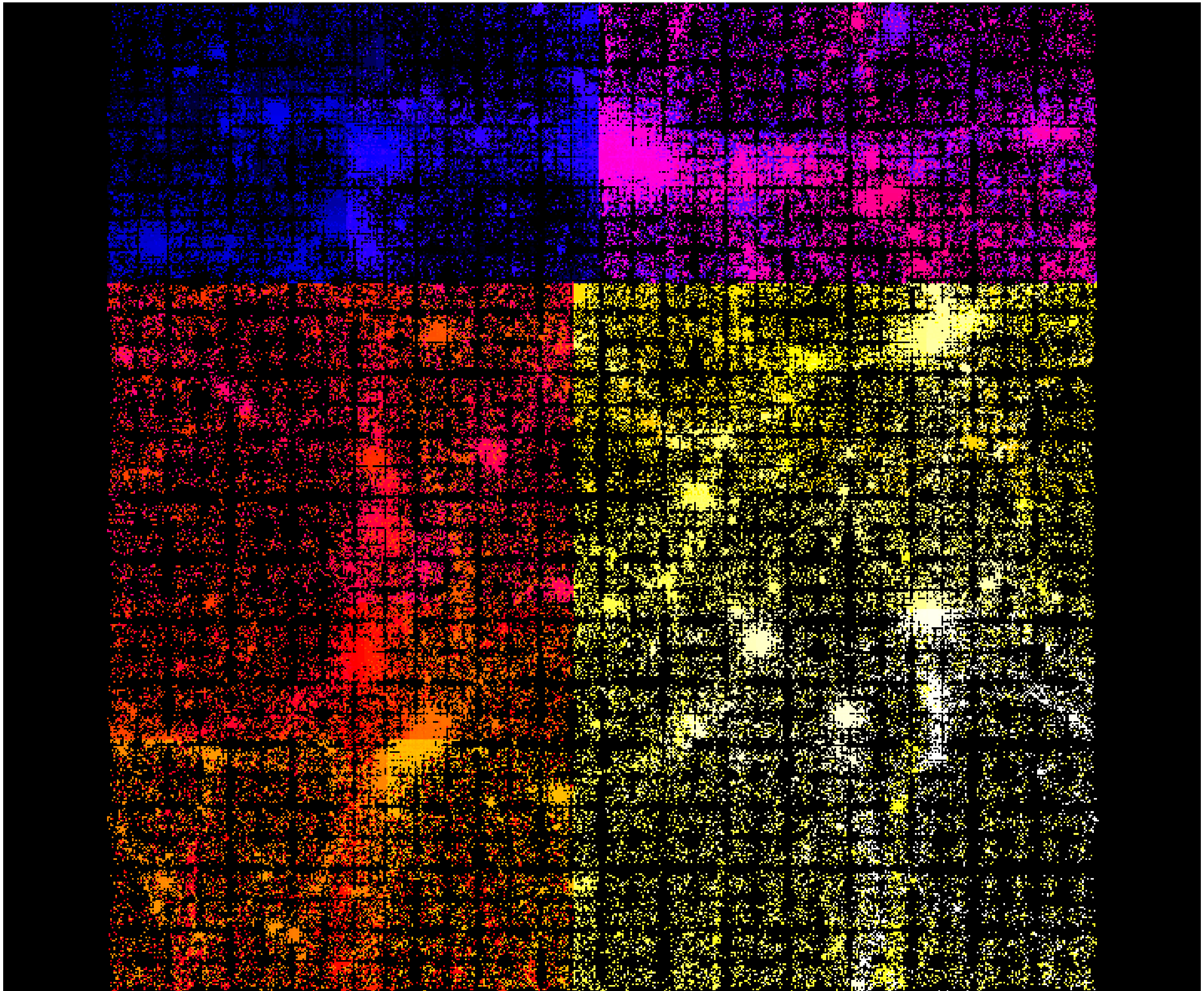
Clustered/Multistepping Challenges

- Load/particle imbalance
- Communication imbalance
- Fixed costs:
  - Domain Decomposition
  - Load balancing
  - Tree build

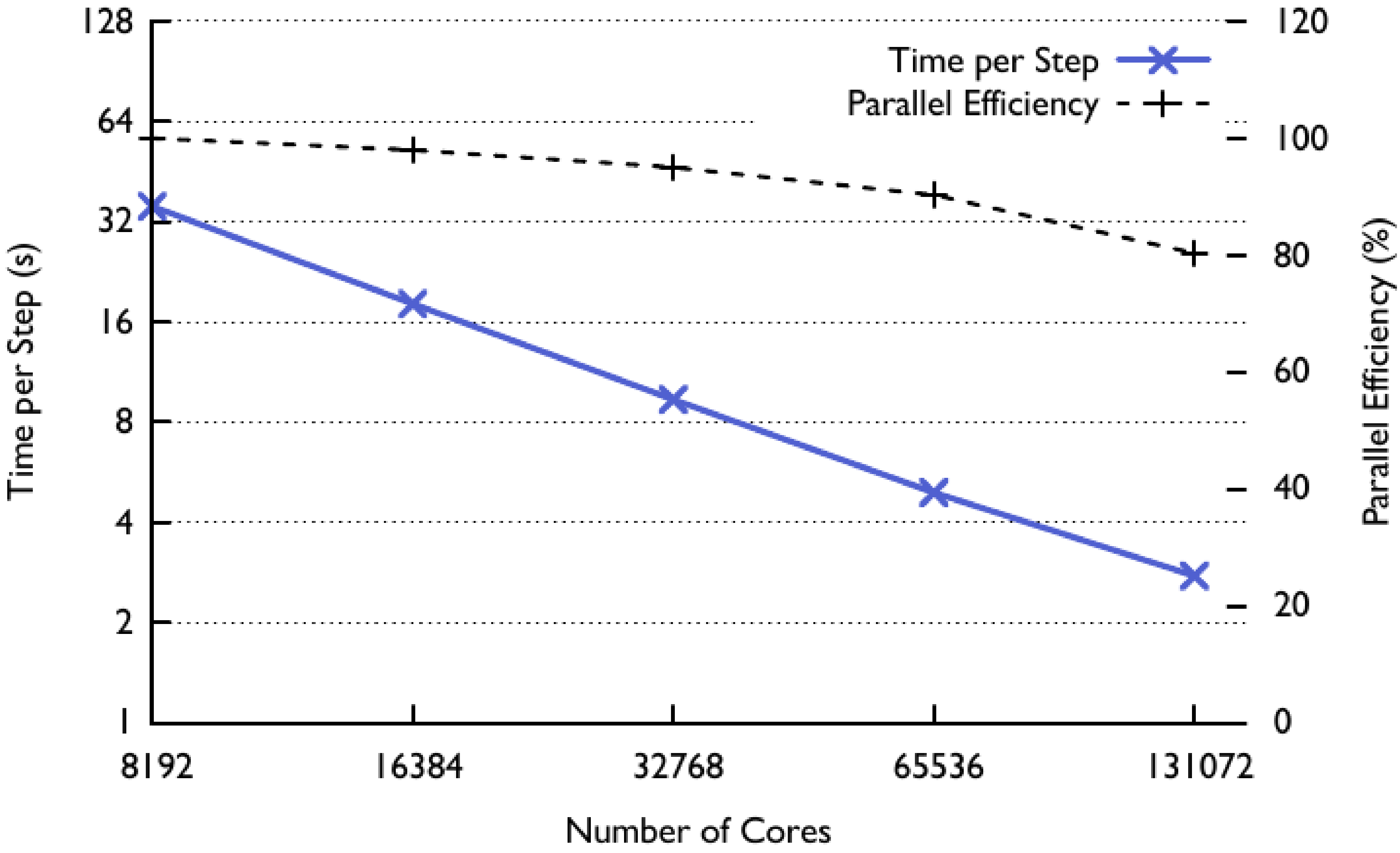
Load Variance



ORB Load Balancing

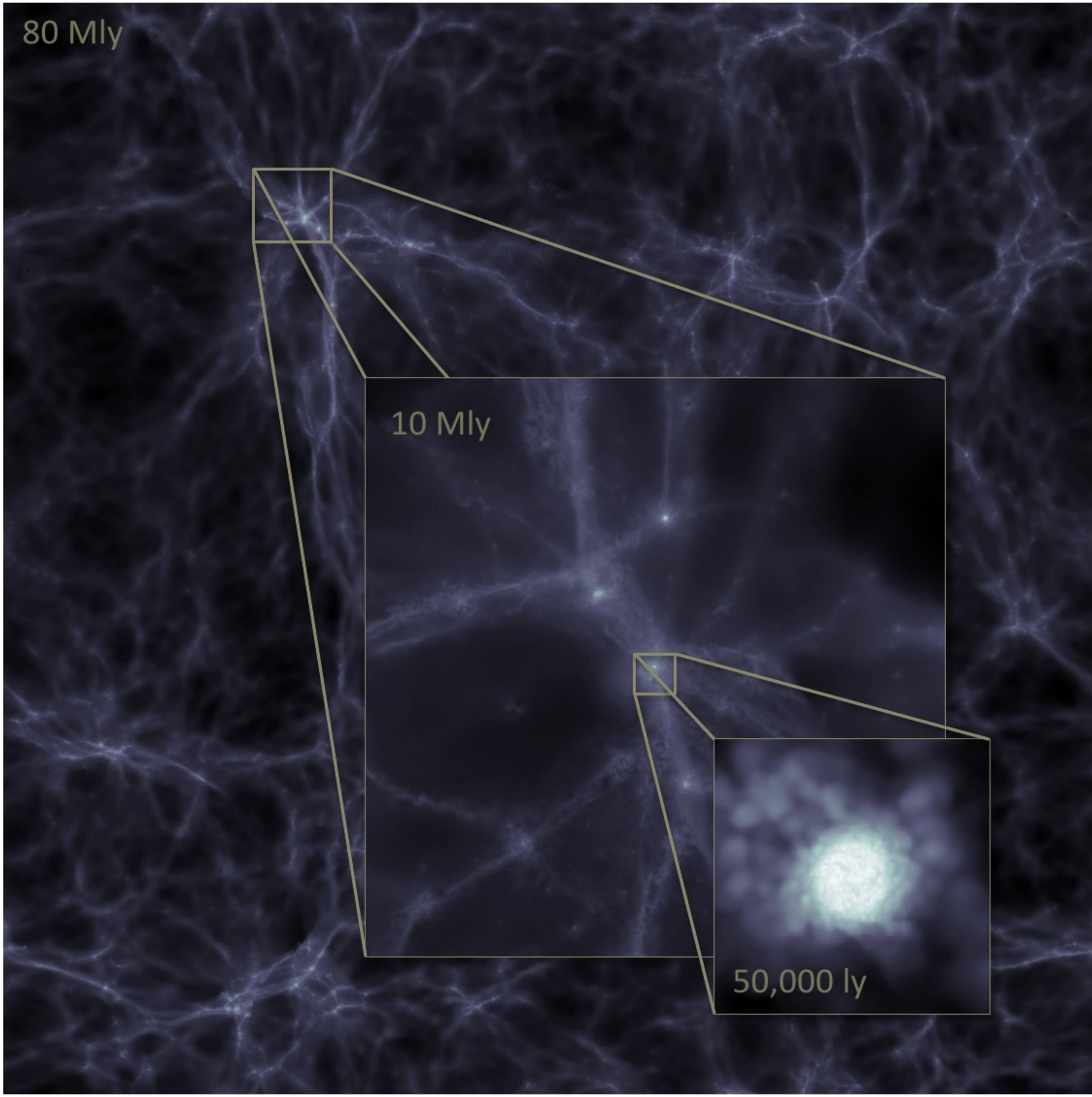


Multistep speedups for 2 billion clustered particles



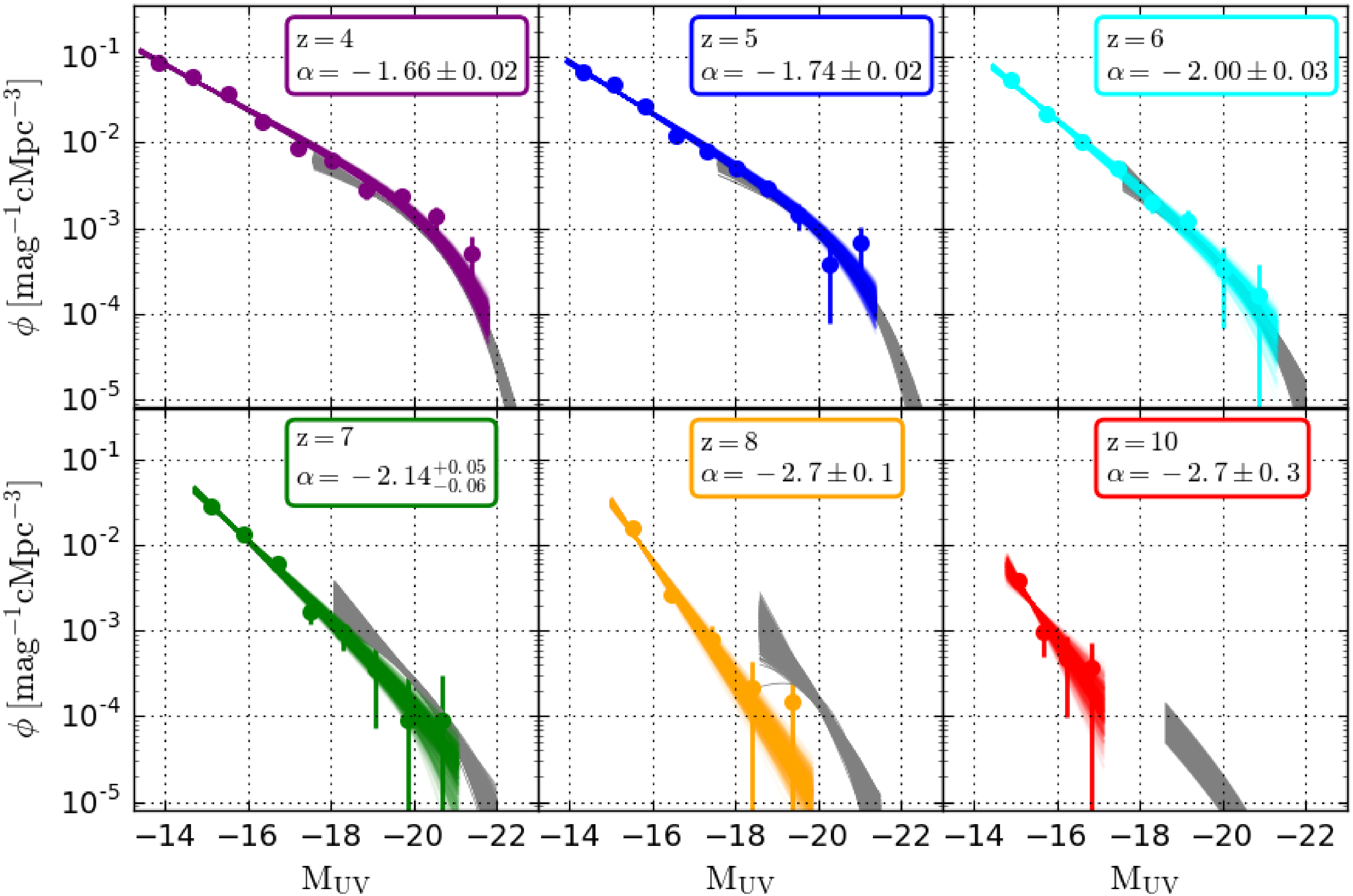
The Vulcan

- 2 billion particles
- (25 Mpc)^3
- Forces ~ 350pc
- SPH ~ 40 pc
- 100s of galaxies
- 5 TB dataset



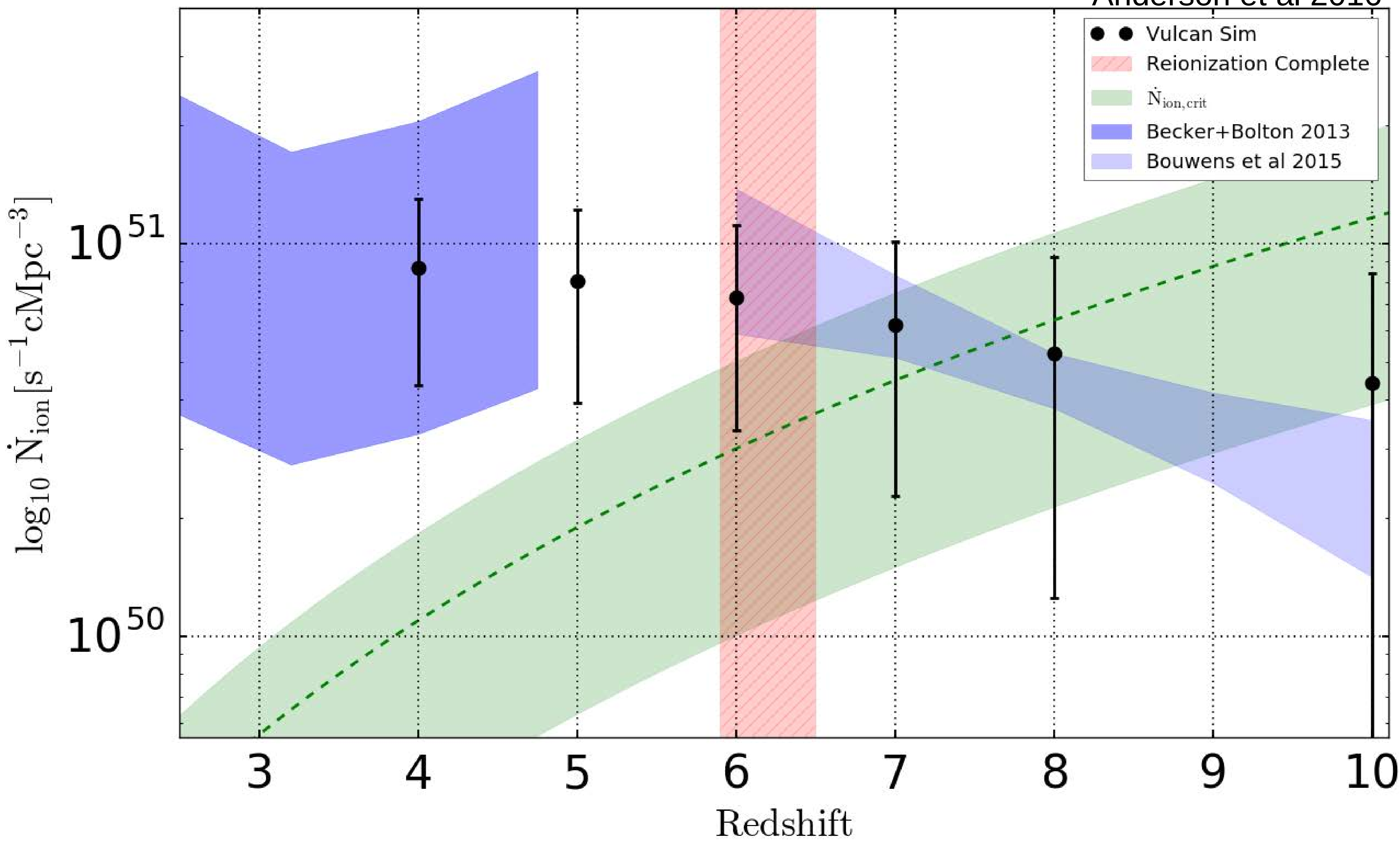
Luminosity Function

Anderson, et al 2016



Faint galaxies reionize the Universe

Anderson et al 2016



Faint galaxies reionize the Universe

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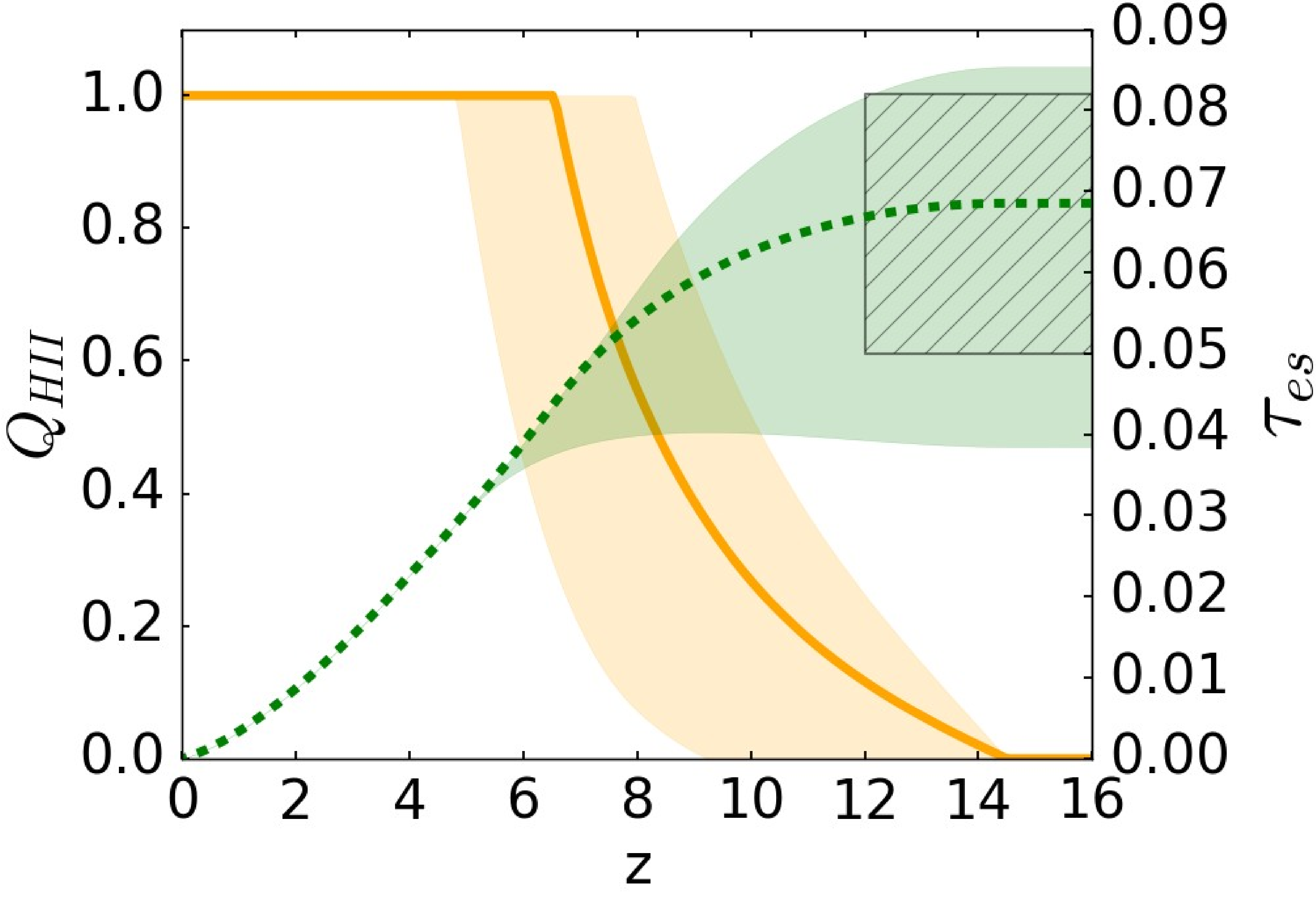
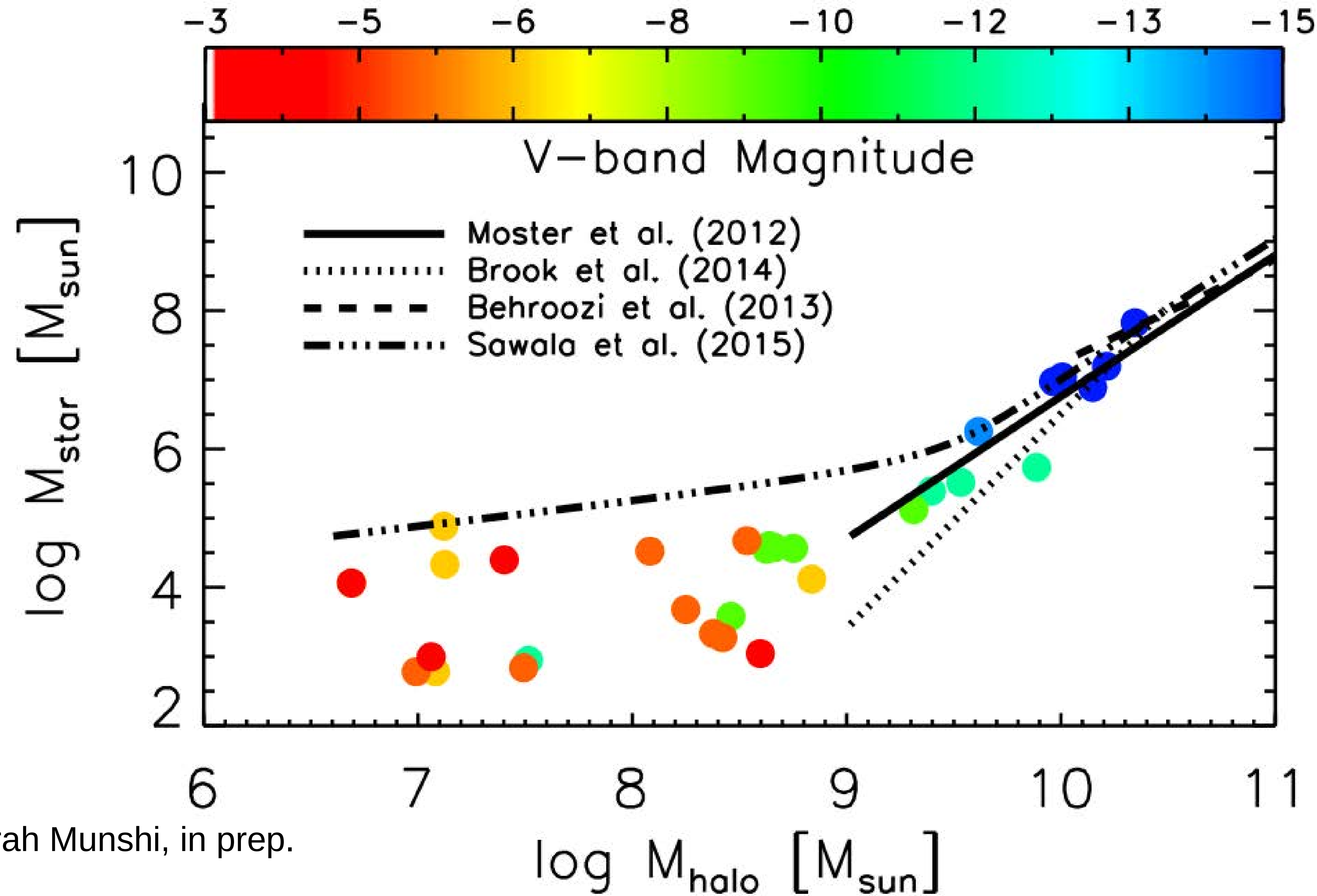


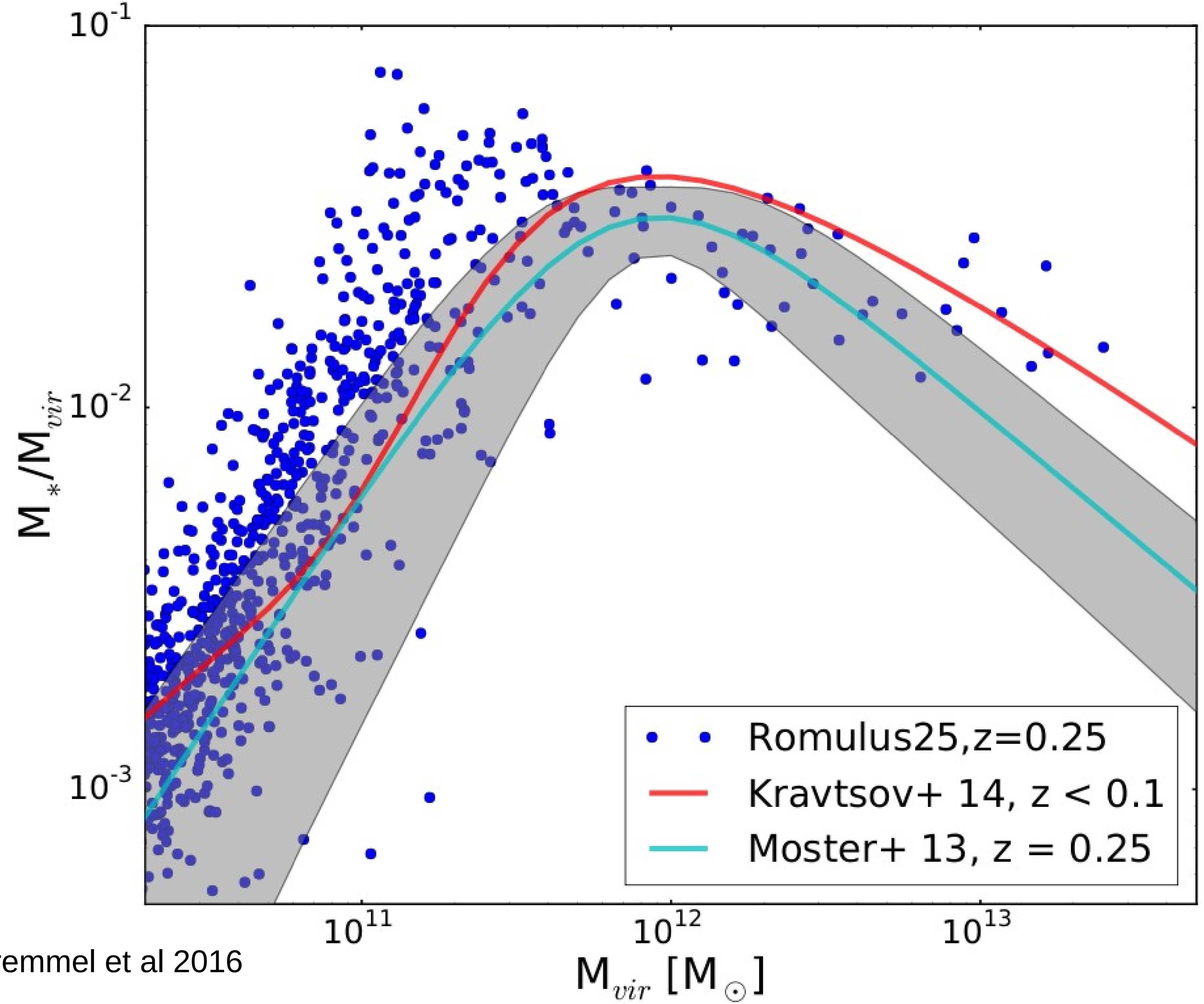
Scatter in Stellar Mass/Luminosity



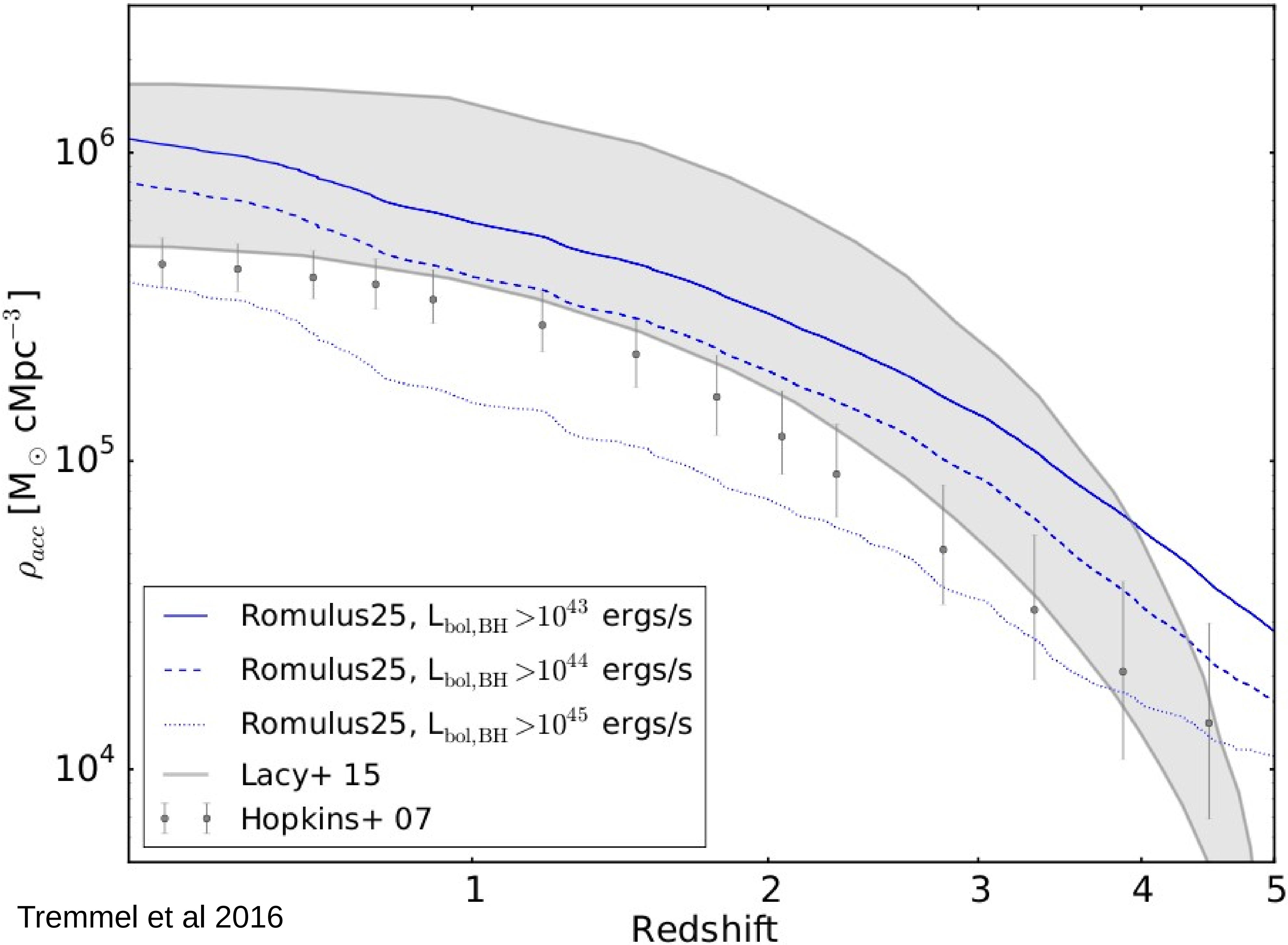
Ferah Munshi, in prep.

Black hole/AGN feedback

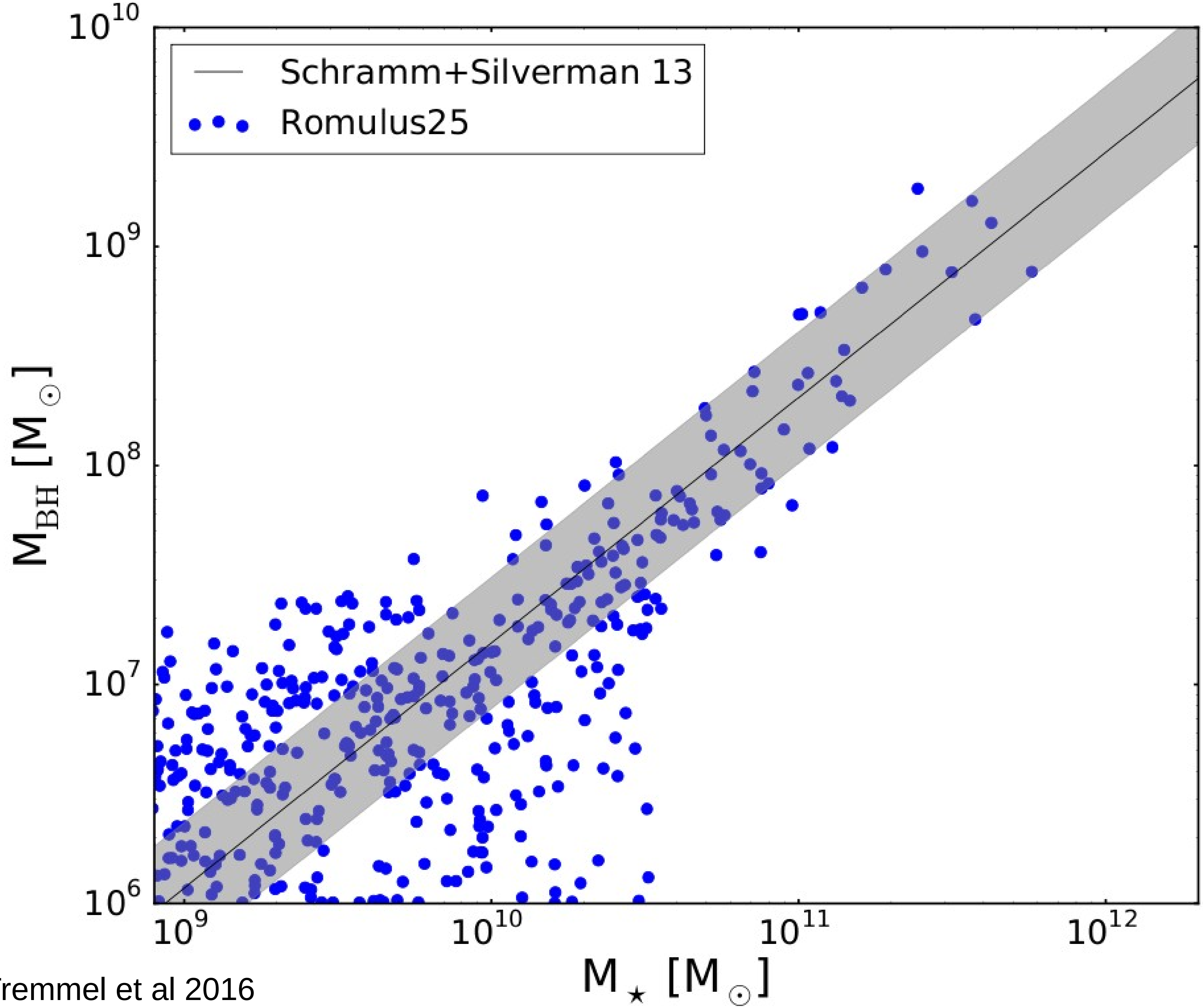
- Supernova feedback doesn't suppress star formation in massive galaxies
  - Modeling of more energetic feedback required
- Components of AGN modeling:
  - Seed (1e6 Msun) BH form in dense, low metallicity gas
  - BH grow from accreting gas, and release energy into the surrounding gas (Active Galactic Nuclei)
  - BH in merging galaxies sink to the center and merge (LIGO, eLISA)



Tremmel et al 2016

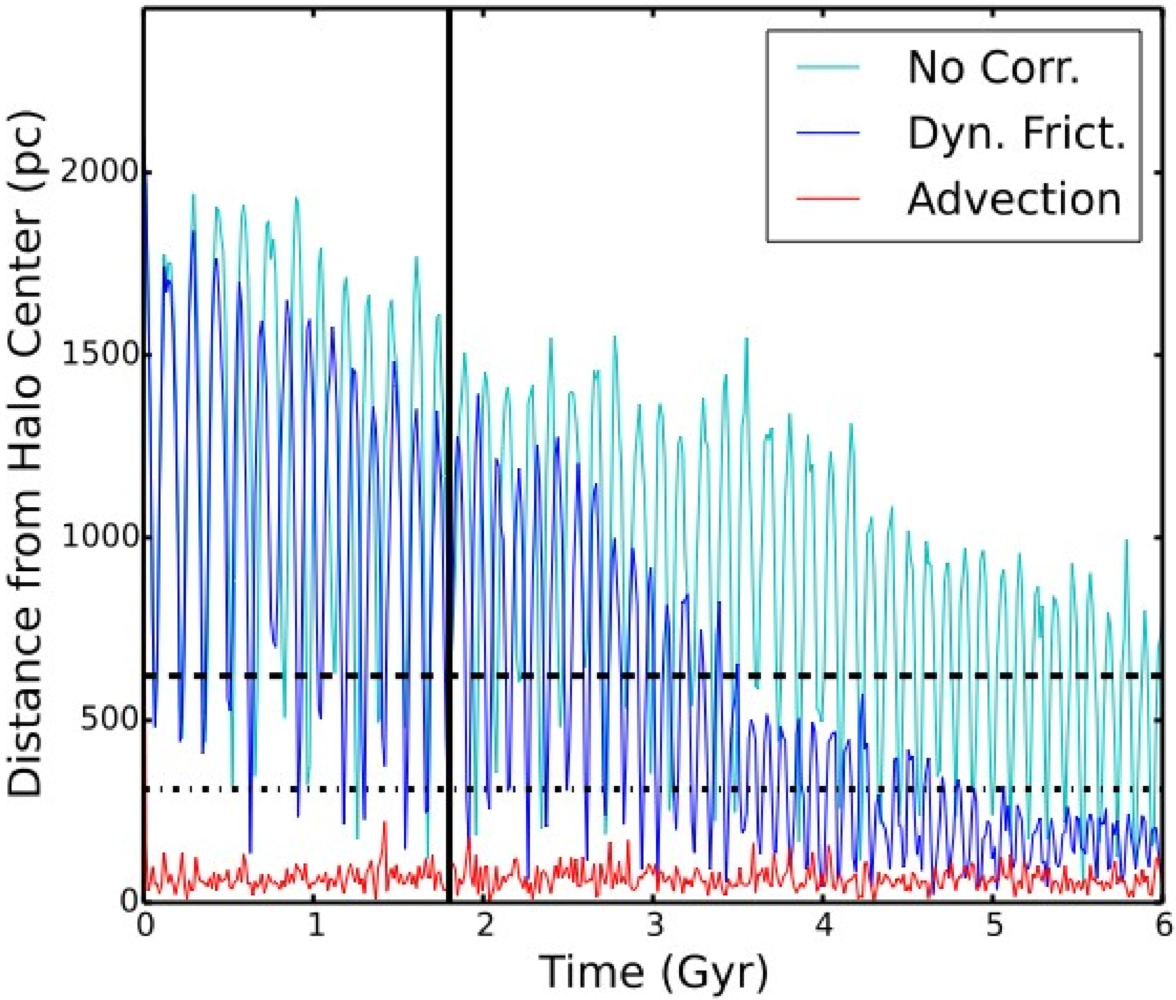


Tremmel et al 2016



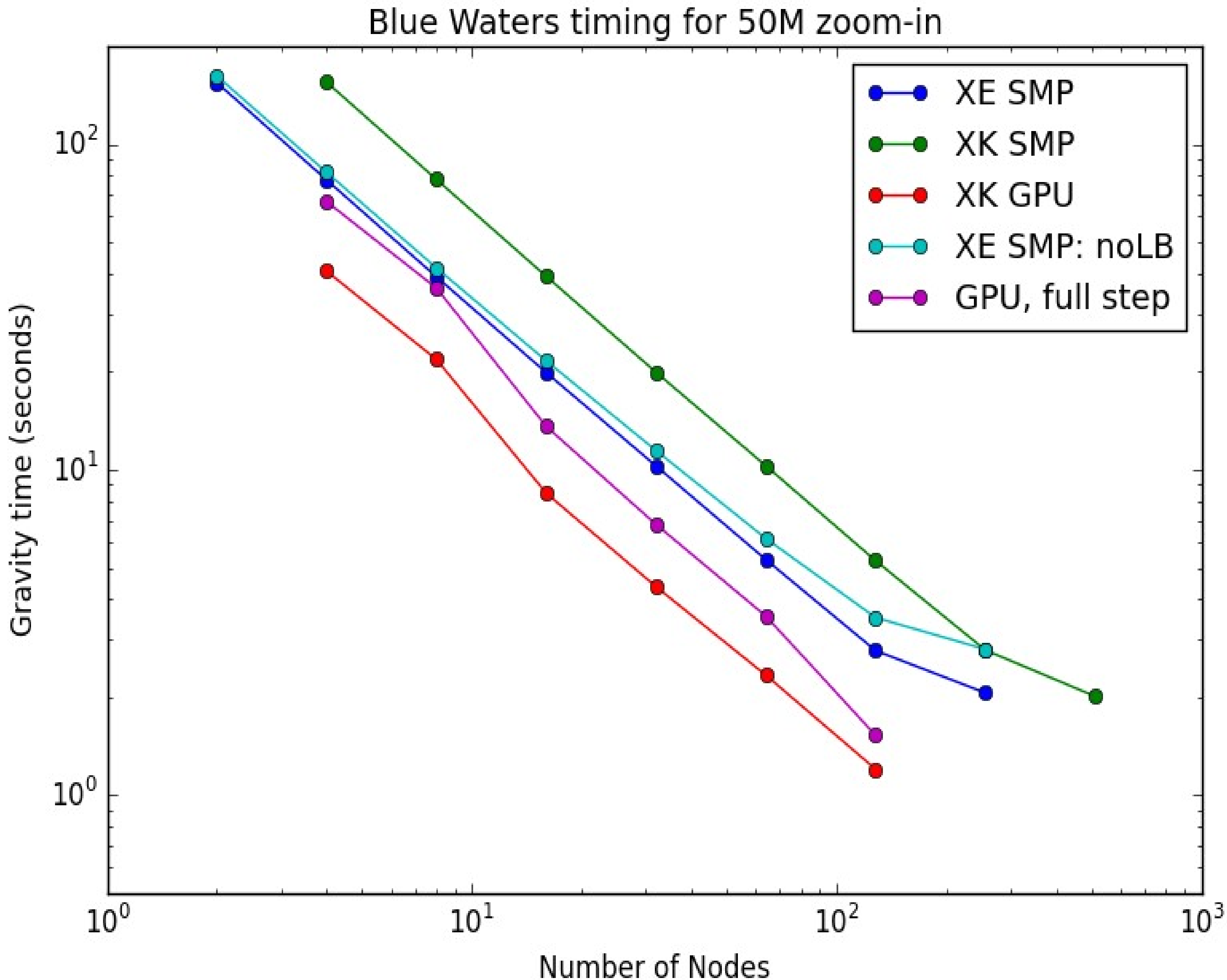
Tremmel et al 2016

Black Hole Dynamics



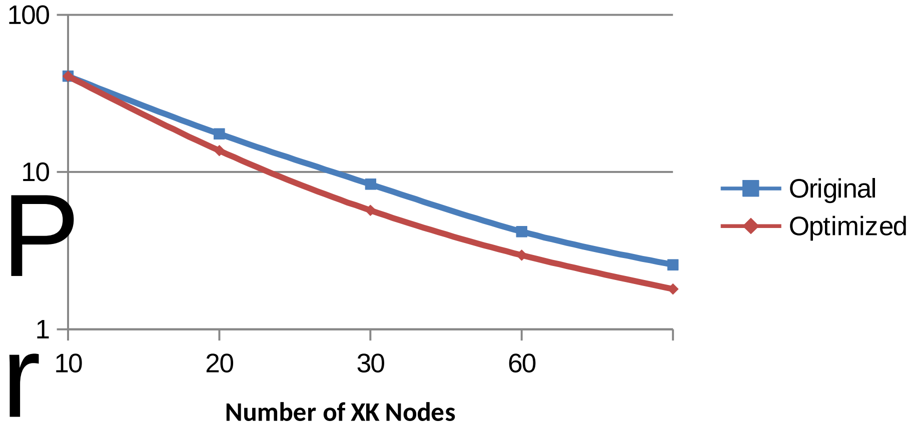
PAID: ChaNGa GPU Scaling

- ChaNGa has a prelimary GPU implementation
- Goals of PAID:
  - Tesla → Kepler optimization
  - SMP optimization
  - Multistep Optimization
  - Load balancing
- Personnel:
  - Simon Garcia de Gonzalo, NCSA
  - Michael Robson, Harshitha Menon, PPL UIUC
  - Peng Wang, Tom Gibbs (NVIDIA)

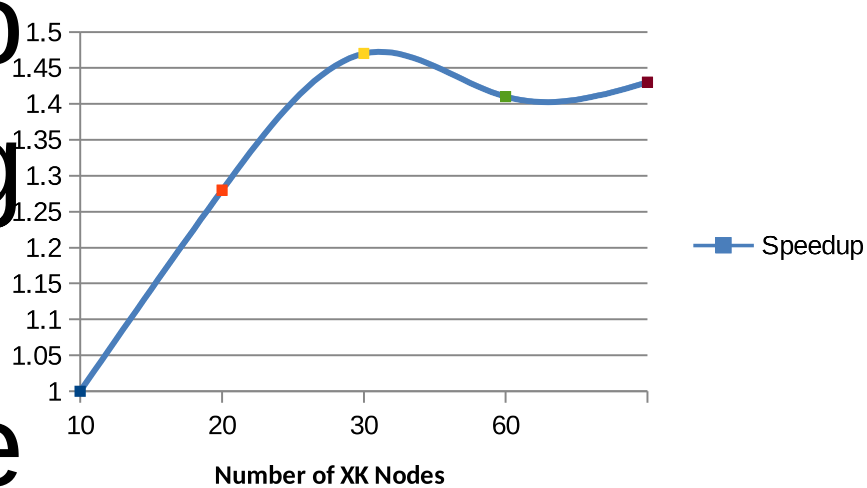


Blue Waters timing for 50M zoom-in
XE SMP
XK SMP
XK GPU
XE SMP: noLB
GPU, full step
Gravity time (seconds)
Number of Nodes
10^0
10^1
10^2
10^3

NGa



Progres



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Kepler

speci

PAID GPU Progress

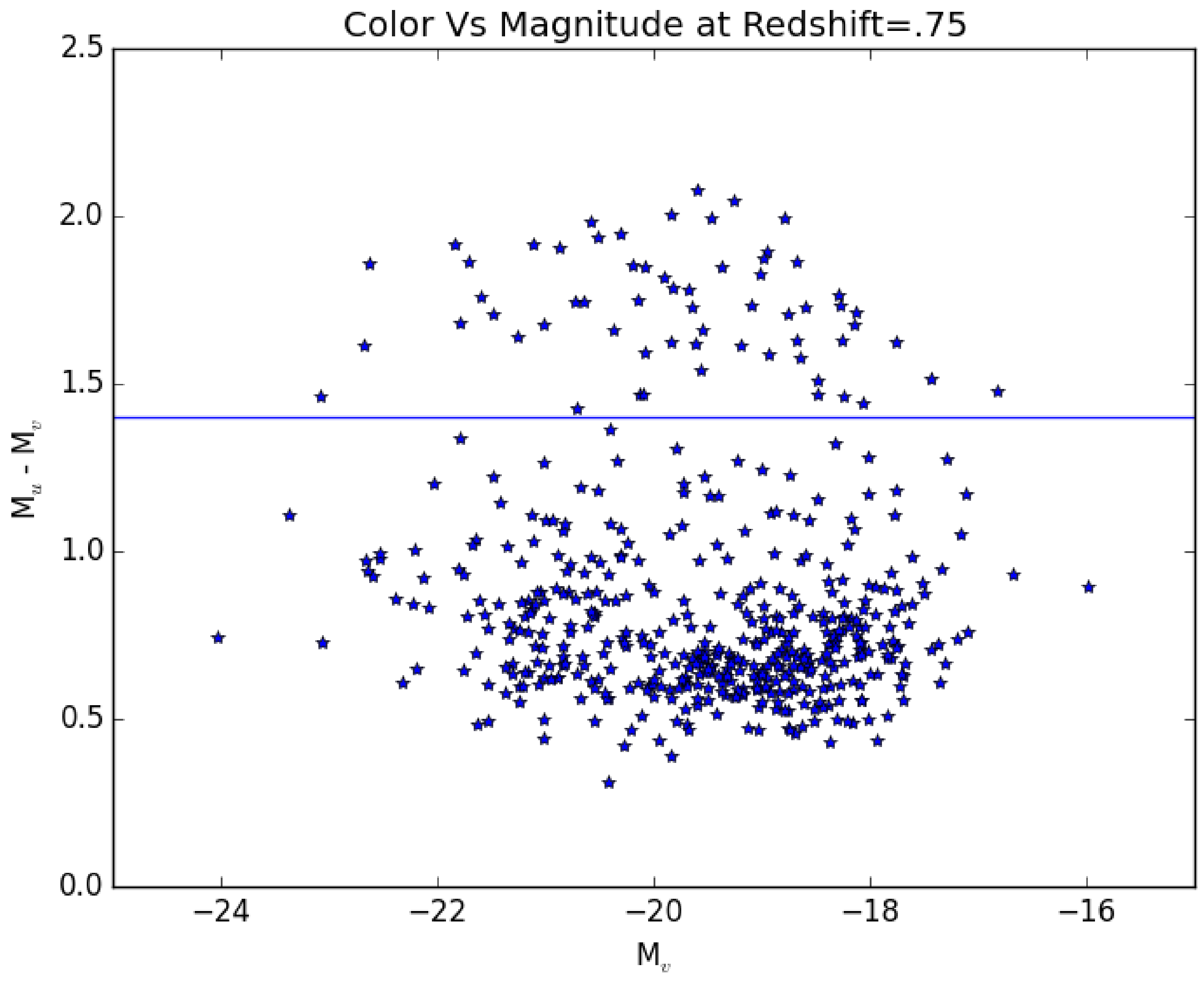
- 2X speed up of main gravity kernel; 1.4X speedup of 2nd gravity kernel
  - Interwarp communication
  - Caching of multipole data
  - Higher GPU occupancy
  - Overall speedup of 60%
- SMP queuing of GPU requests
  - Reduced memory use, allowing more host threads
  - GPU memory management still an issue

Broader Impacts: Pre-Majors and Supercomputing

- UW Pre-Major in Astronomy Program:
  - Engage underrepresented populations in research early
  - Establish a cohort
  - Plug major leak in the STEM education pipeline
- Simulation data analysis is ideal for this research
  - Science and images are compelling
  - Similarity to Astronomical data reduction

Simulated Galaxy Catalogs

Zoe Deford
Joshua Smith
(UW Freshman)



Simulated Images

Danielle Skinner, UW 3rd year

Take Aways

- Scaling is necessary, but hard
  - Need all the help we can get
- “Break through” results are unexpected
- “Simulated observations” enable broad impact

Acknowledgments

- NSF ITR
- NSF Astronomy
- NSF XSEDE program for computing
- BlueWaters Petascale Computing
- Blue Waters PAID Program
- NASA HST
- NASA Advanced Supercomuting