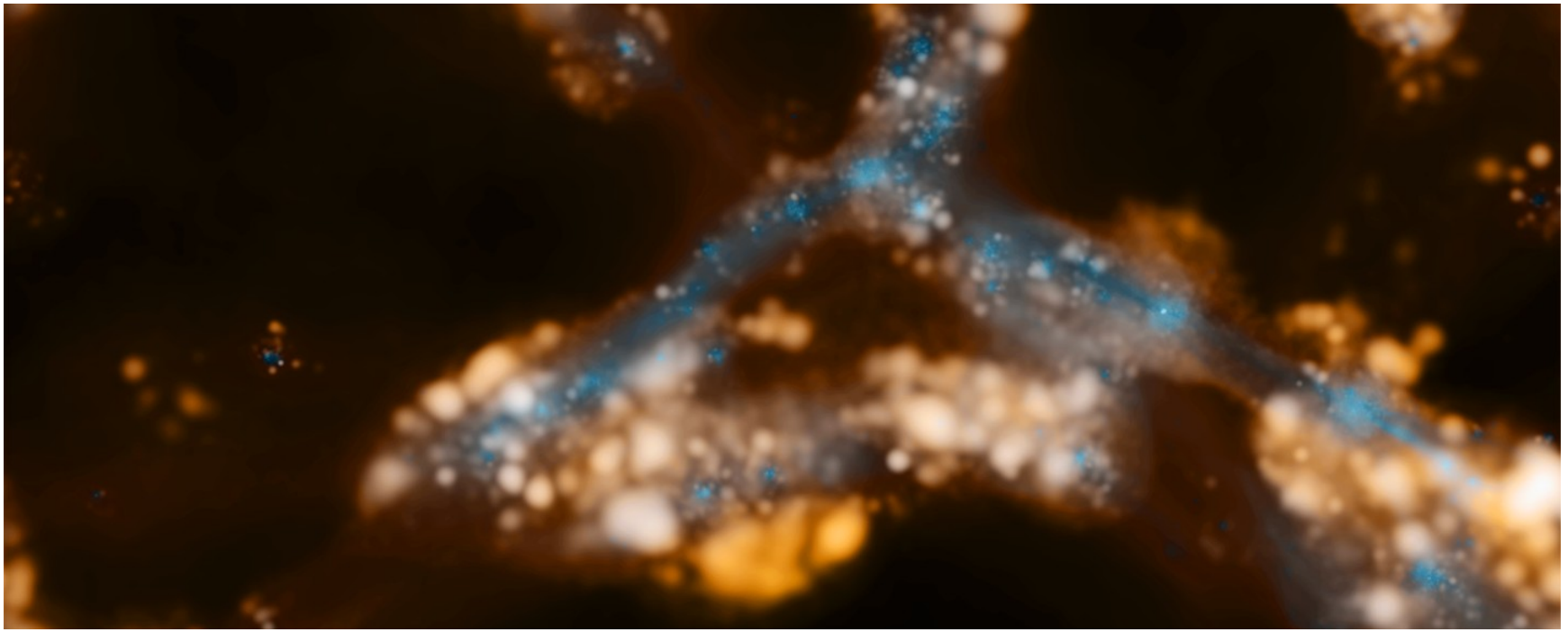
# Evolution of the Small Galaxy Population



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Orion Lawlor

# Galaxy formation:can this...

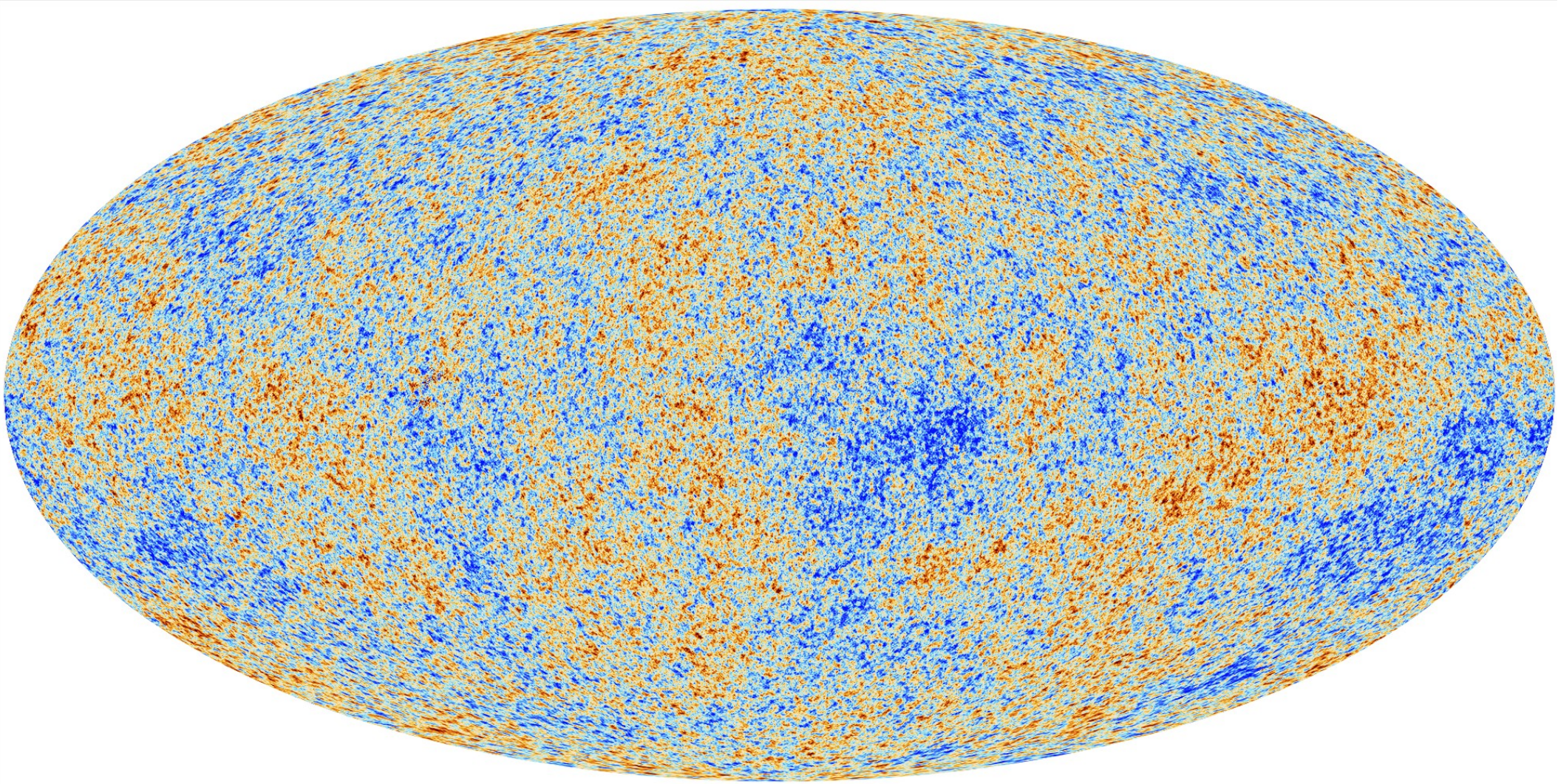
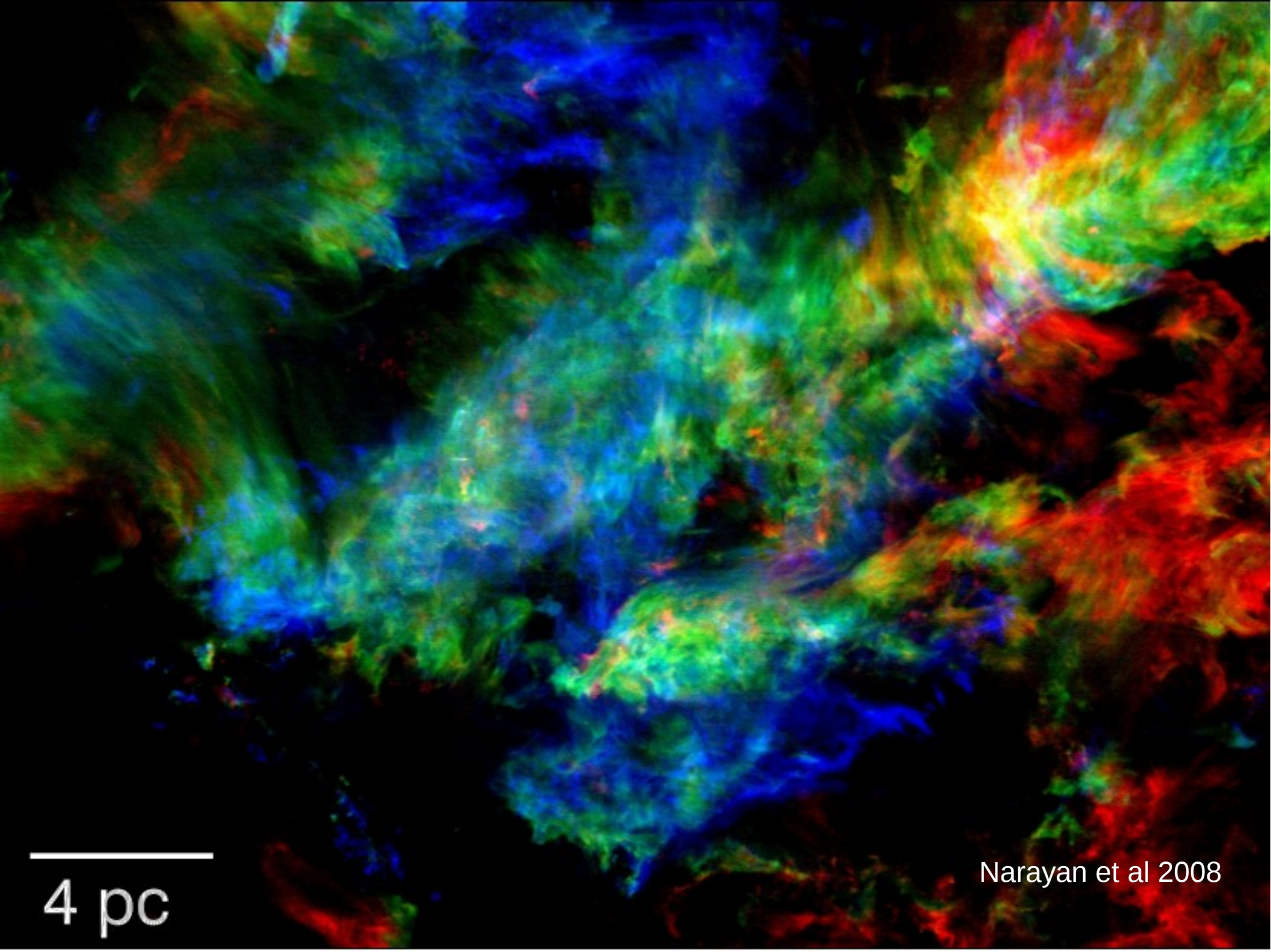


Image courtesy ESA/Planck

... turn into this?

# Modeling Star Formation: it's hard

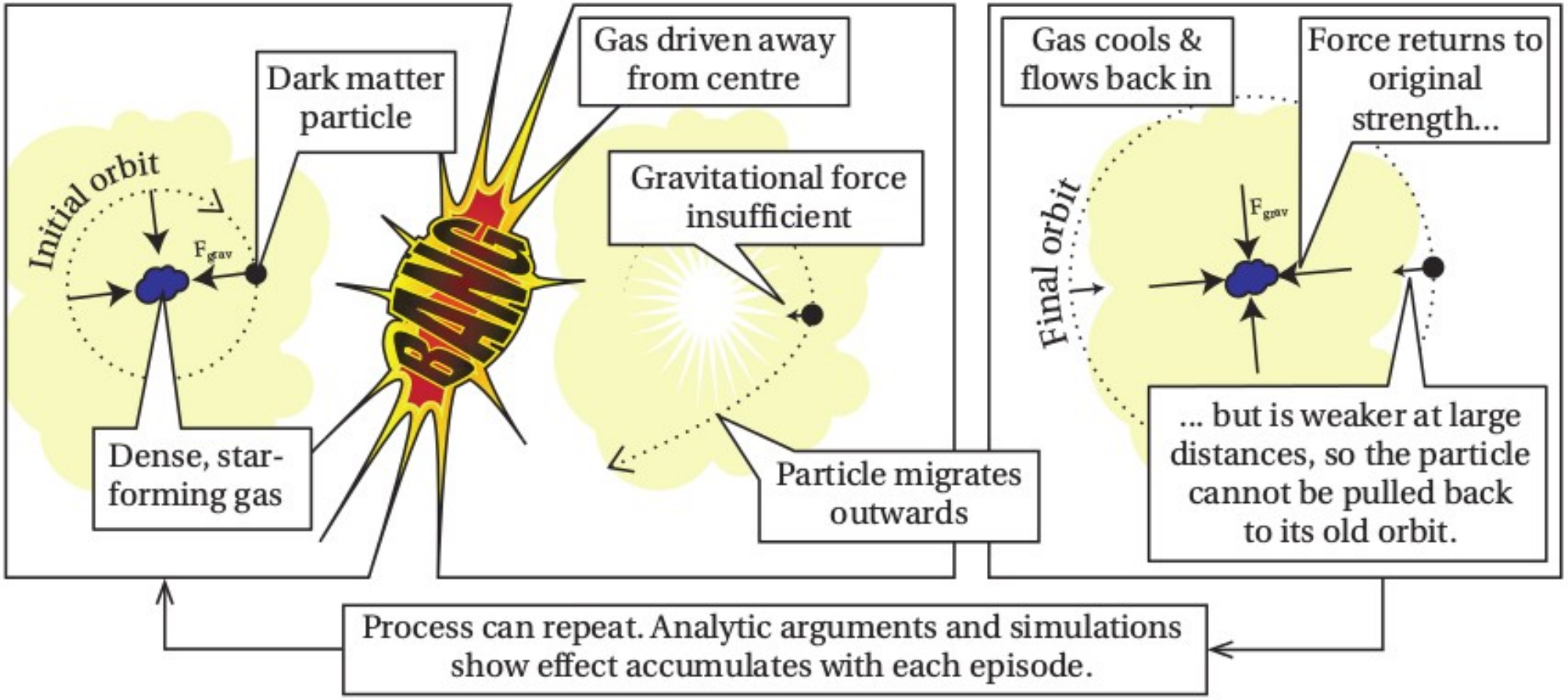
- Gravitational Instabilities
- Magnetic Fields
- Radiative Transfer
- Molecular/Dust Chemistry
- Driven at large scales: differential rotation
- Driven at small scales: Supernovea and Stellar Winds
- Scales unresolvable in cosmological simulations


4 pc
Narayan et al 2008

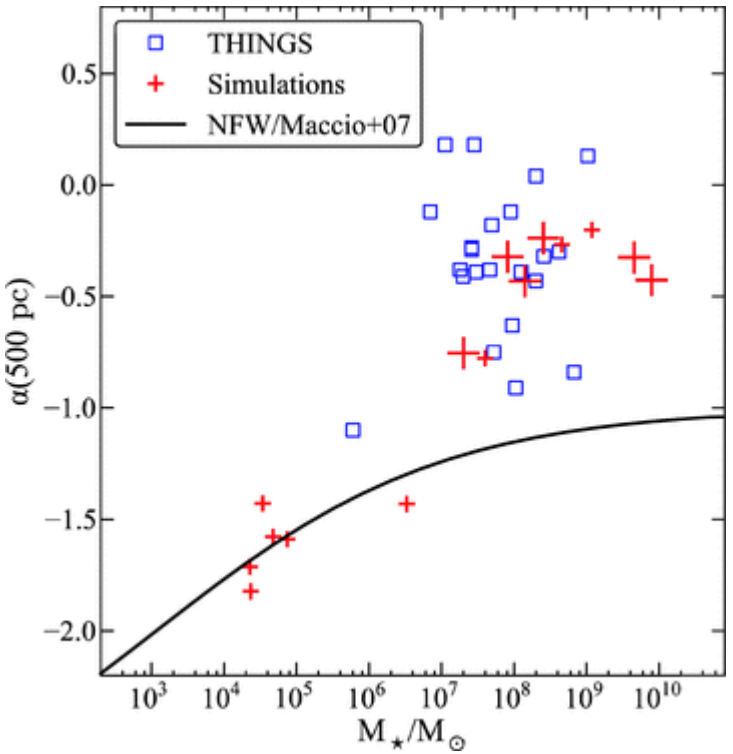
# Resolution and Subgrid Models

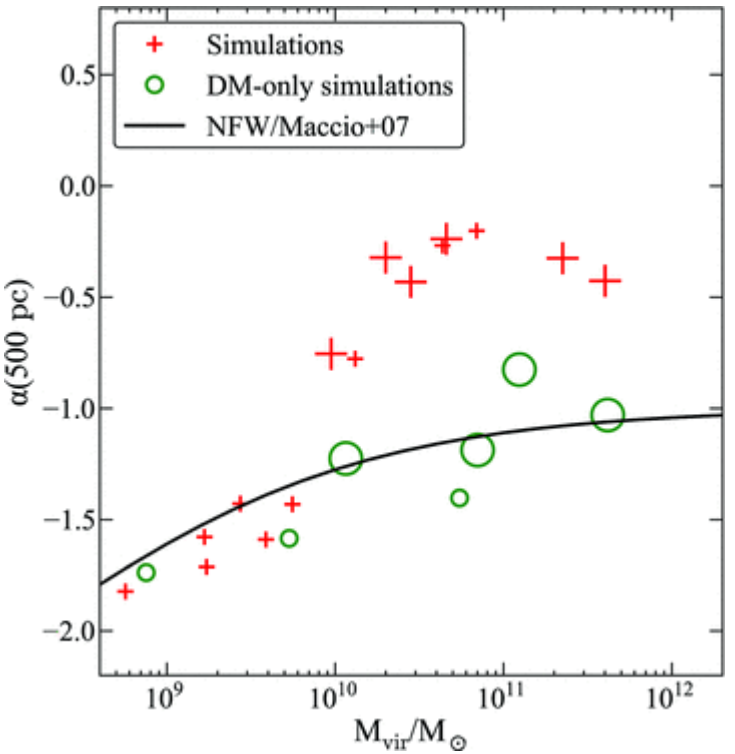
- Maximize Simulation Resolution
  - Capture tidal torques/accretion history (20+ Mpc)
  - Adapt resolution to galaxy (sub-Kpc)
- Capture Star Formation in a sub-grid model
  - Stars form in high density environments
  - Supernovea/stellar winds/radiation regulate star formation
  - Mitigate issues with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

# Star Formation and Dark Matter



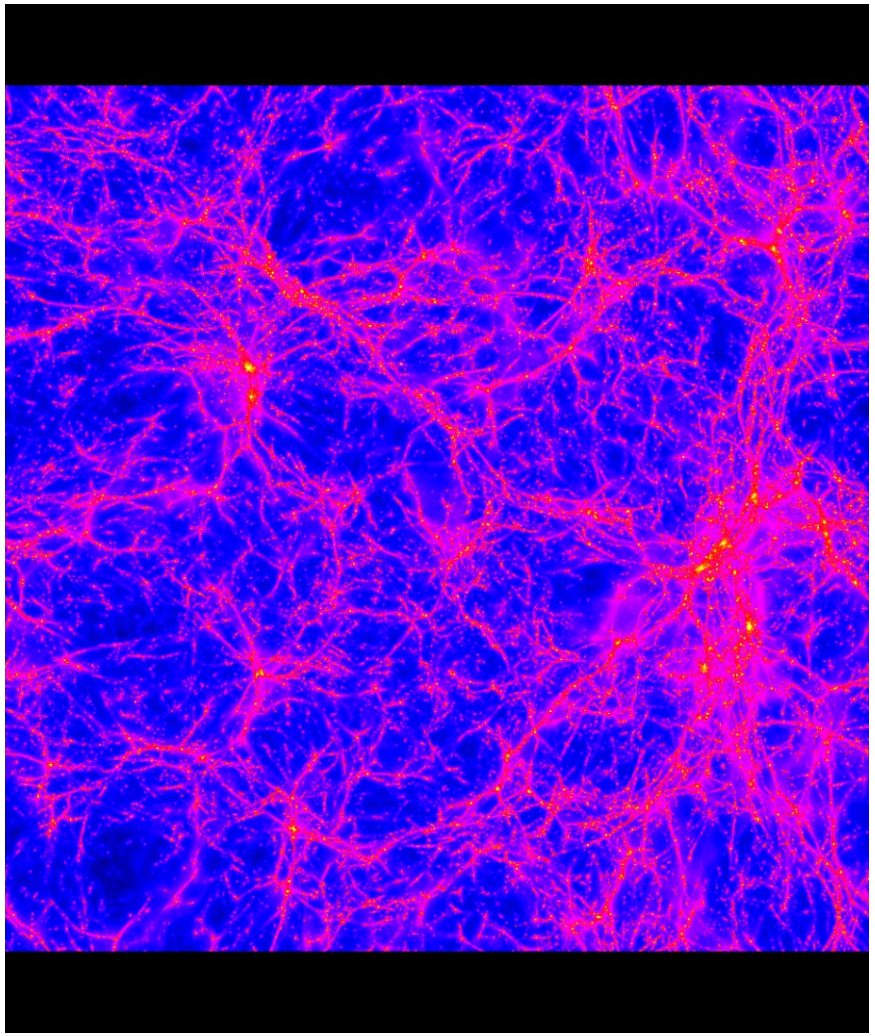
# Inner Profile Slopes vs Mass




Governato, Zolotov etal 2012

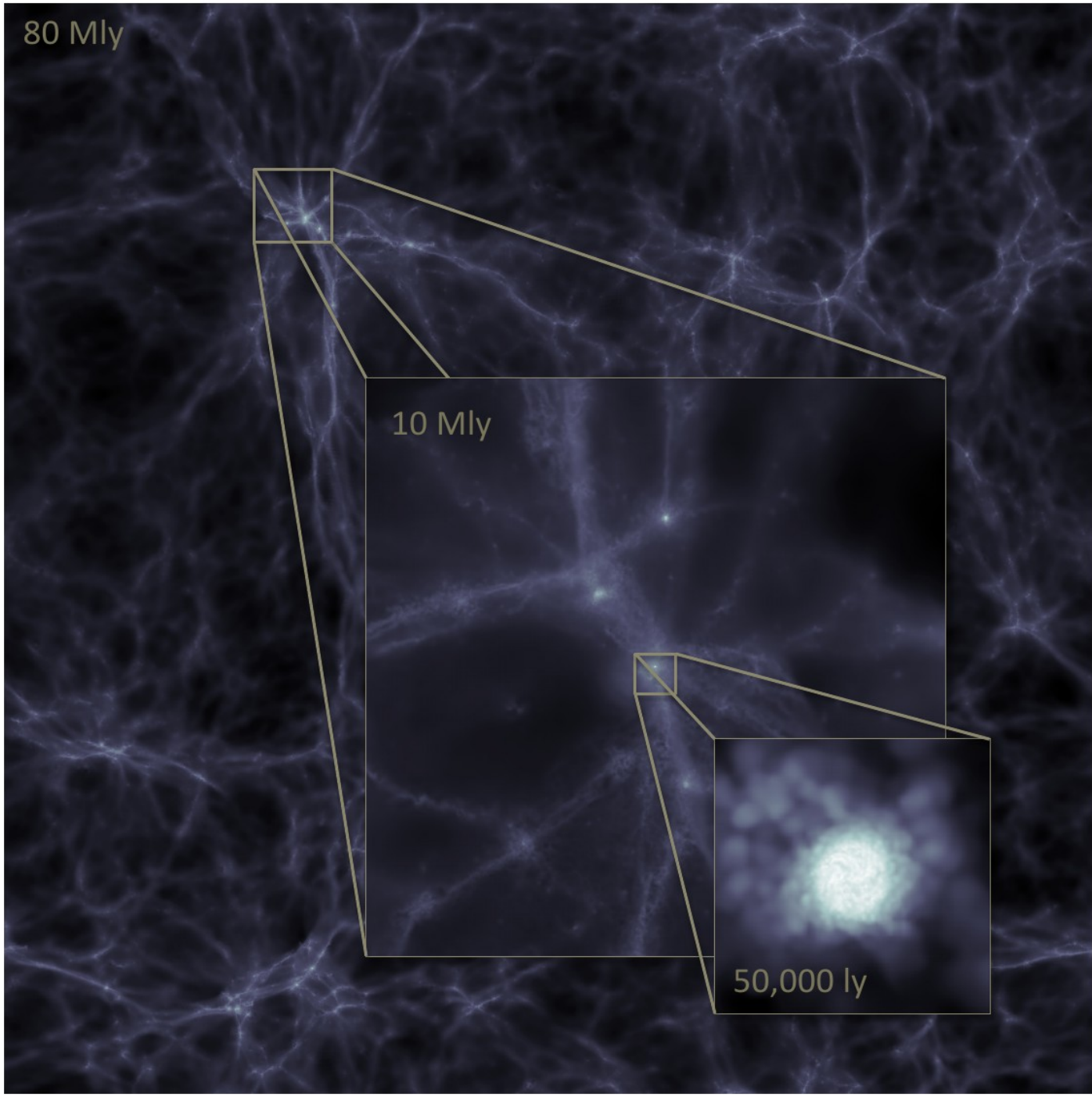
# Blue Waters: High Redshift Galaxies



- 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

# Cosmo25

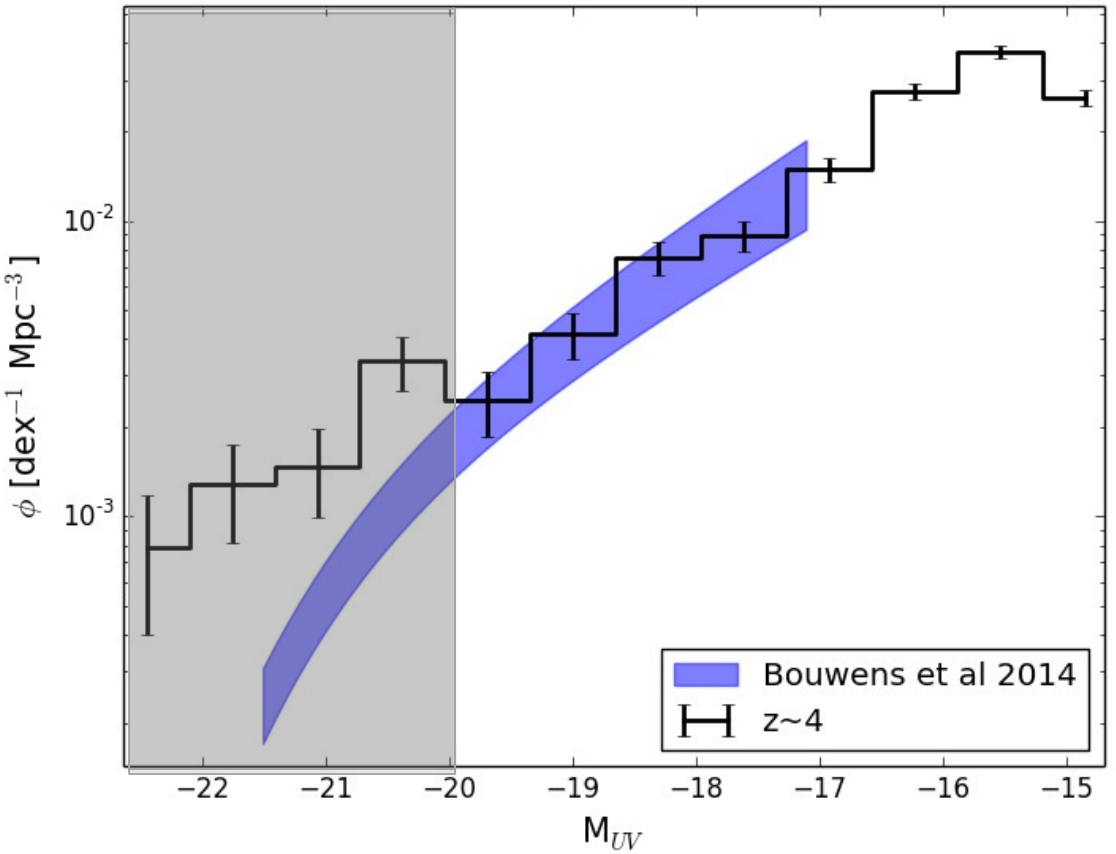
- 2 billion particles
- (25 Mpc)^3
- Forces ~ 350pc
- SPH ~ 40 pc
- 100s of galaxies
- 5 TB dataset



# Luminosity Function: Faint end slope

Fit Schechter Function at bright end and project to dimmer magnitudes

Faint end essential to assessing the impact of galaxies on the reionization of the universe




L. Anderson, in prep.

Better constraint on galaxy contribution to reionization

# Charm++

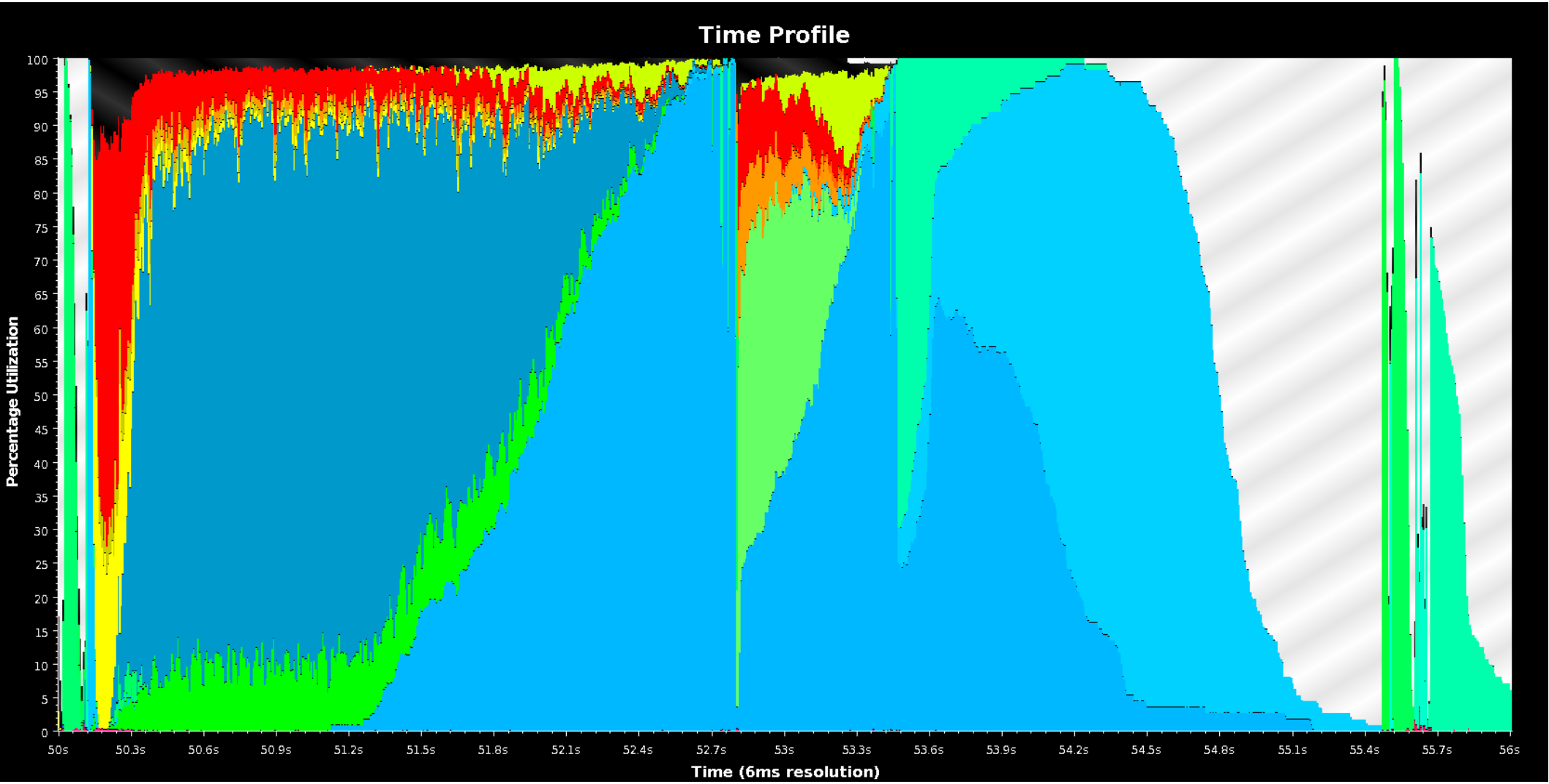
- C++-based parallel runtime system
  - Composed of a set of globally-visible parallel objects that interact
  - The objects interact by asynchronously invoking methods on each other
- Charm++ runtime
  - Manages the parallel objects and (re)maps them to processes
  - Provides scheduling, load balancing,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

# ChaNGa: Charm Nbody GrAvity solver

Massively parallel SPH+nbody code, including:

- SNe feedback creating realistic outflows
- H2 based star formation
- SMBH formation, growth, and energy feedback
- Optimized parameters regulating star formation

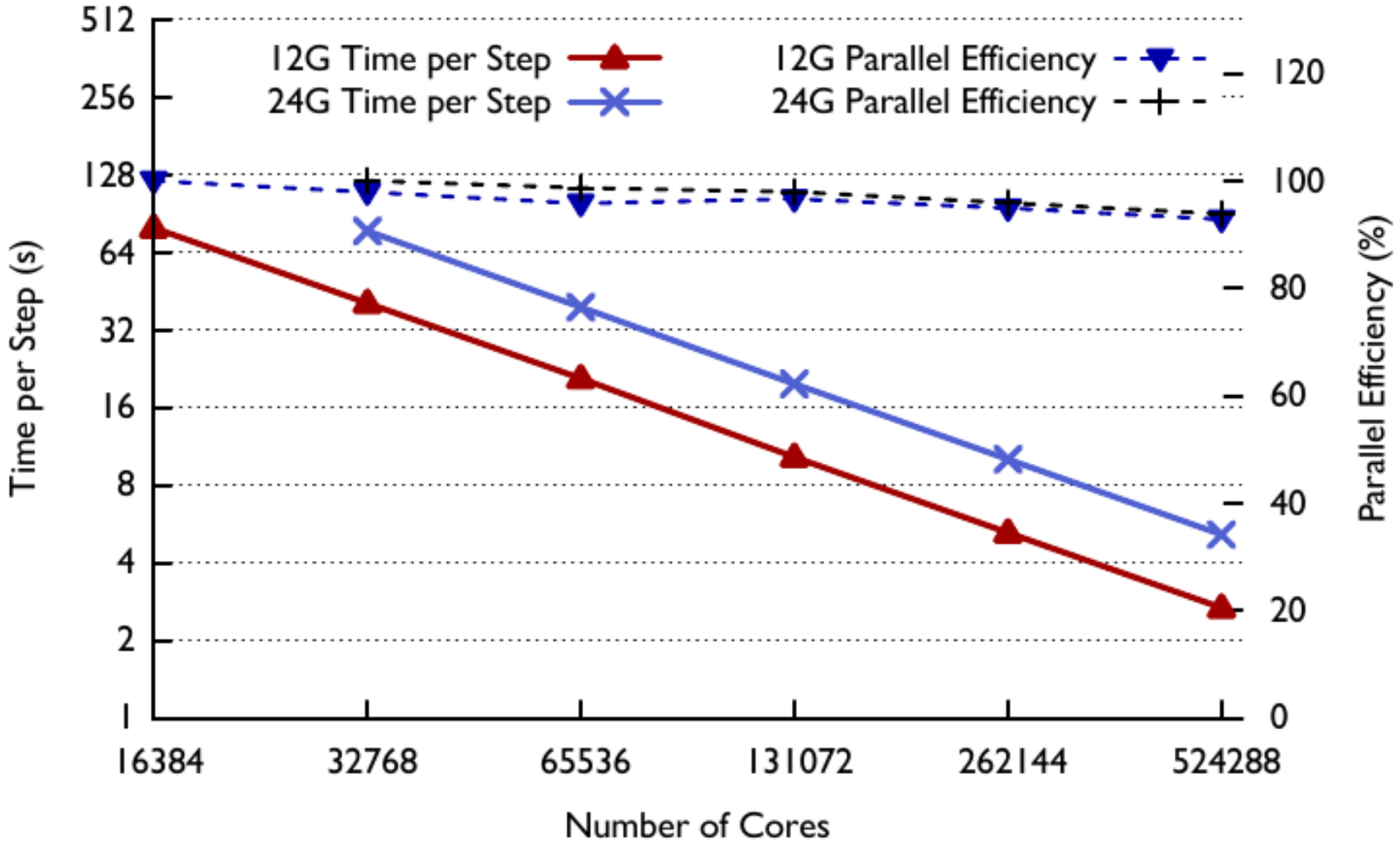
# Overlap of Phases






Gravity Hydrodynamics

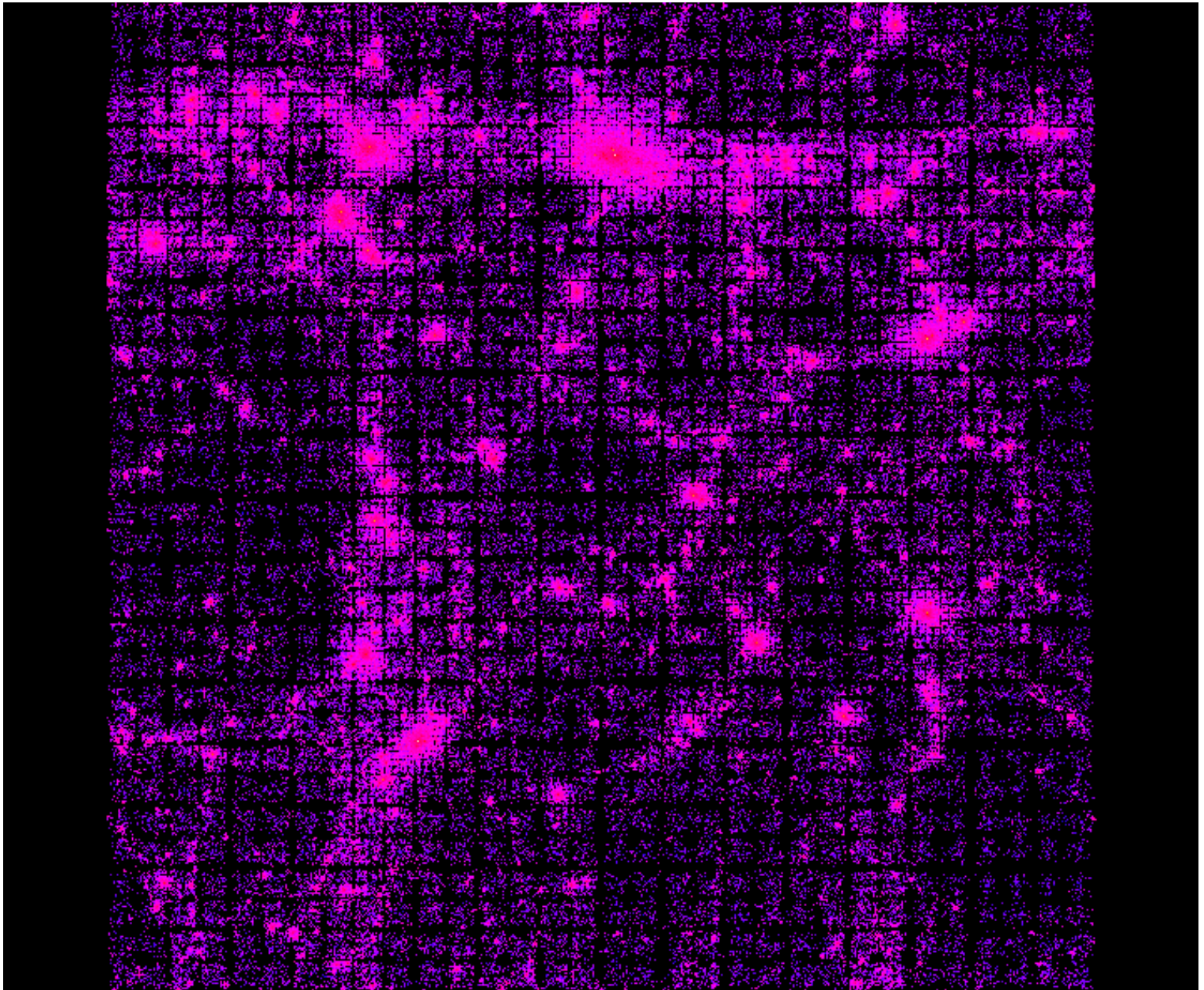
# Scaling to .5M cores



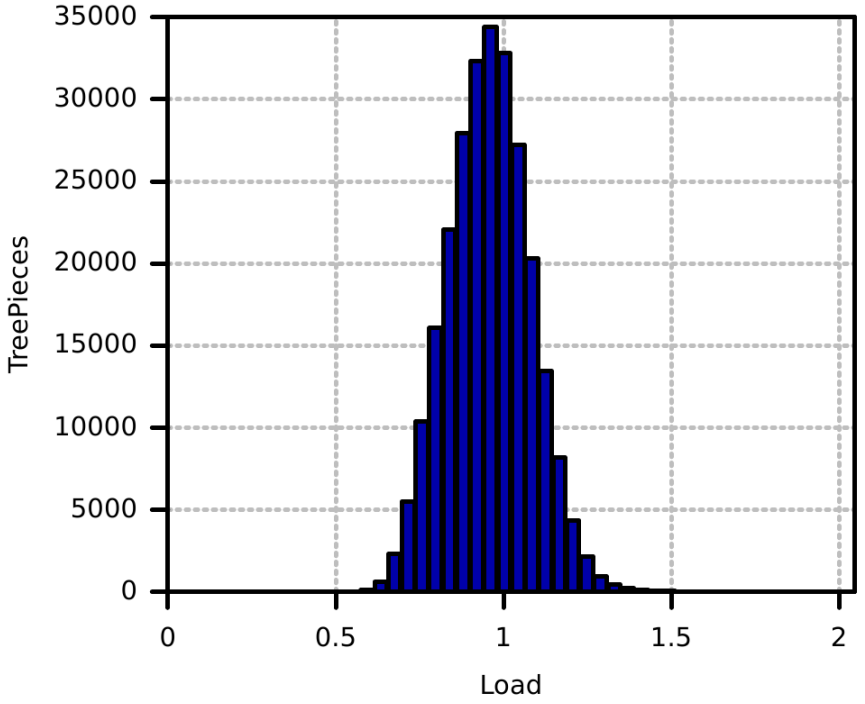
# Clustered/Multistepping Challenges

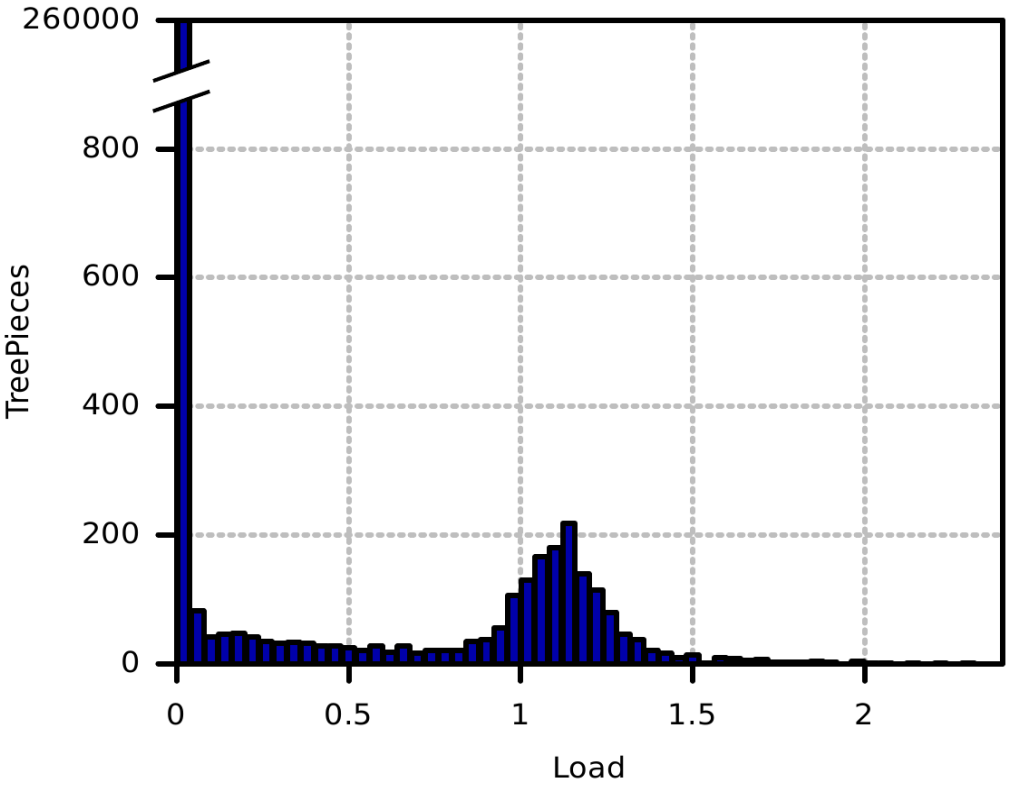
- Load/particle imbalance
- Communication imbalance
- Fixed costs:
  - Domain Decomposition
  - Load balancing
  - Tree build

# Load Variance

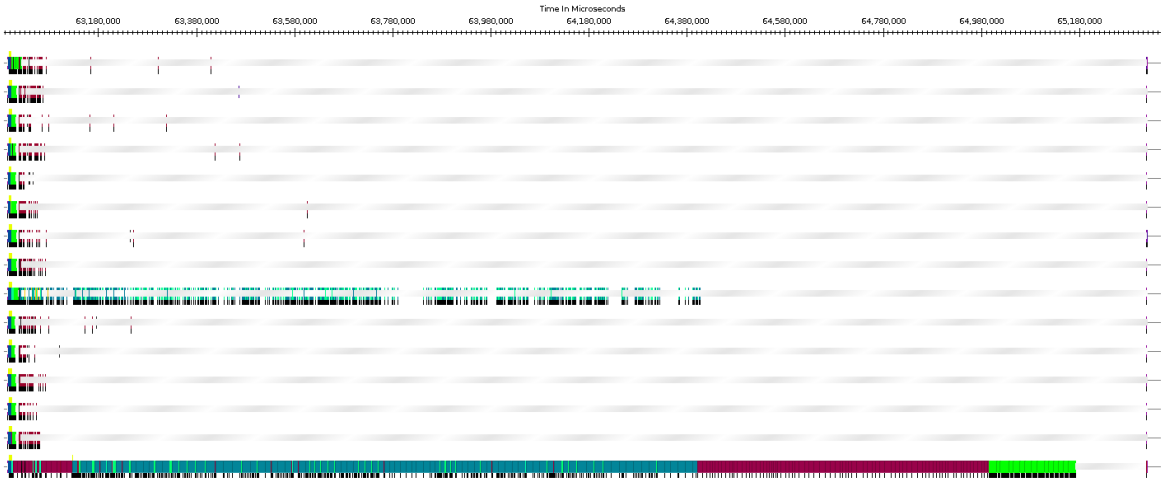


# Load distributions

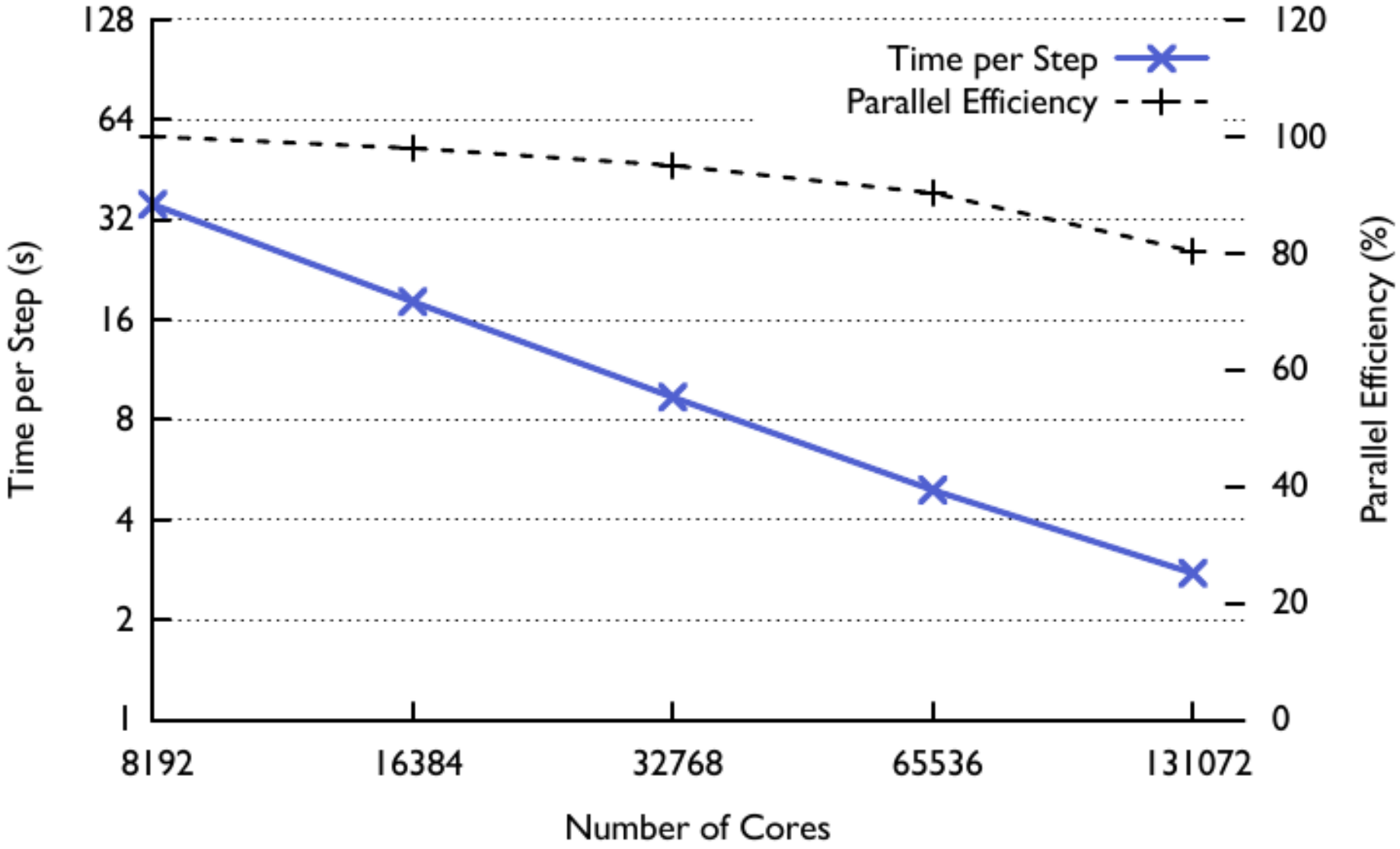


# Intra-node work balancing




# Multistep speedups for 2 billion clustered particles



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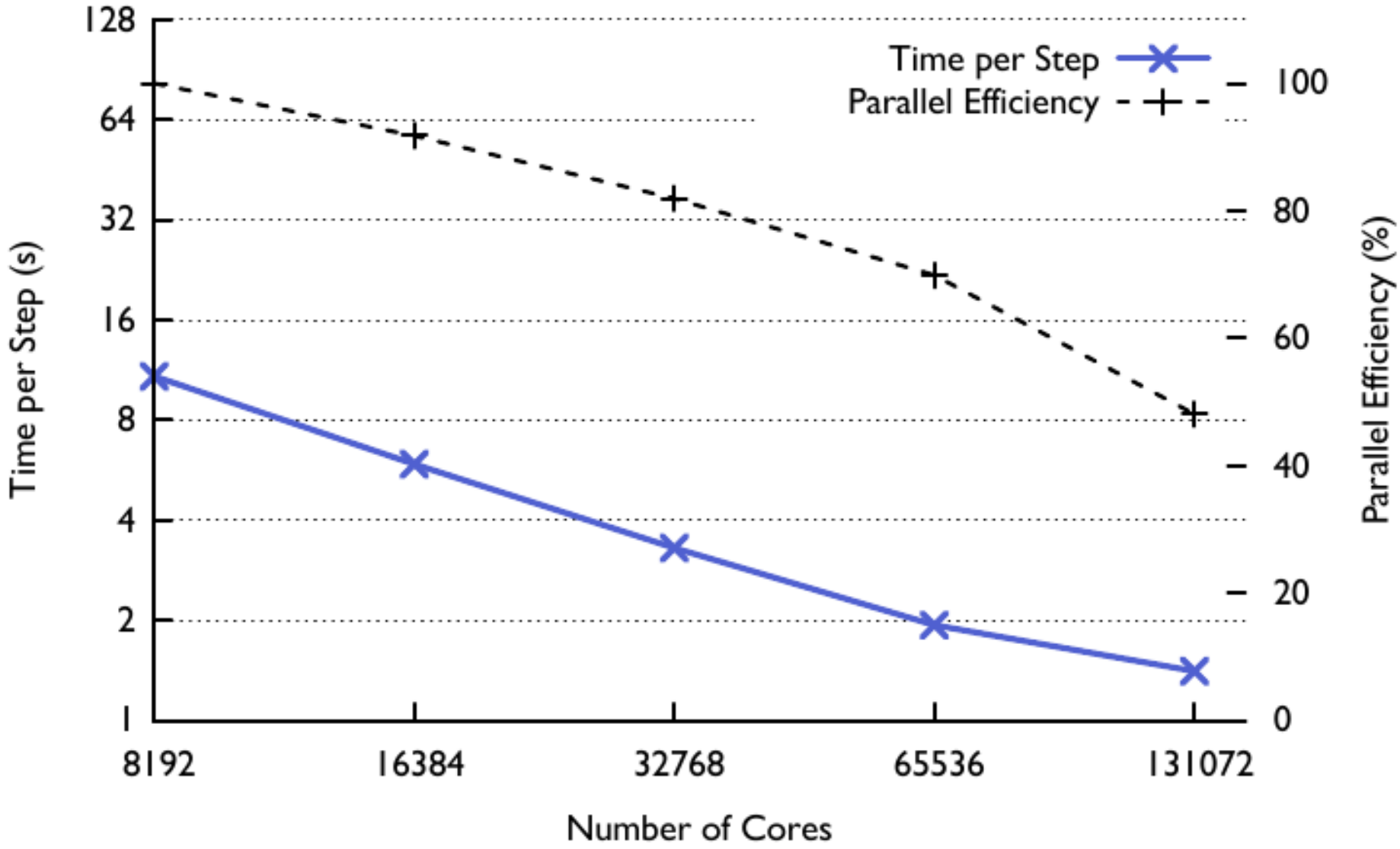
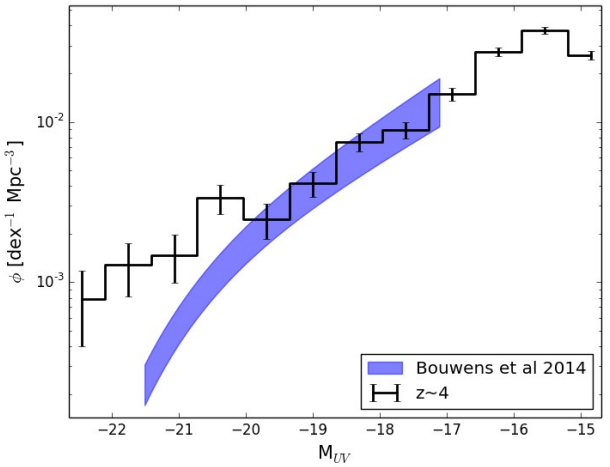


# Future Simulations

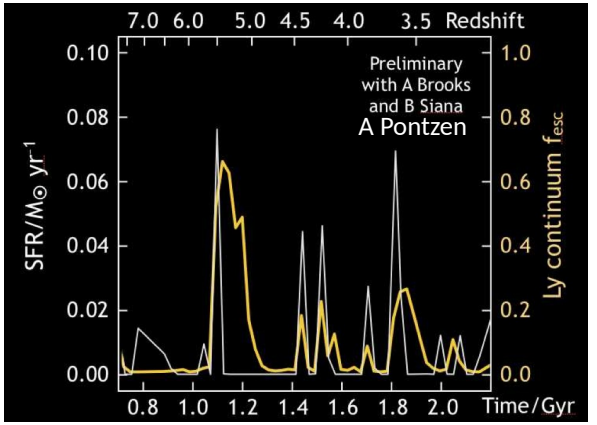
| | First Stage | Near Future |
|---|---|---|
| | Vulcan | Enterprise |
| Timeline | February 2014 | Summer 2014 |
| Size | $(25\ \mathrm{Mpc})^3$ | $(25\ \mathrm{Mpc})^3$ |
| Nparticles | 2 billion | 25 billion |
| Duration in z | 100-4 | 100-0 |
| Force Resolution | 350 pc | 175 pc |
| Morphologies | 5e10 $M_{tot}$ (1e9 $M_*$) | 5e9 $M_{tot}$ |
| Size | 5 TB | 500 TB |
| Extra Physics | | Black hole feedback<br>H2 regulated star formation |

# Future Results

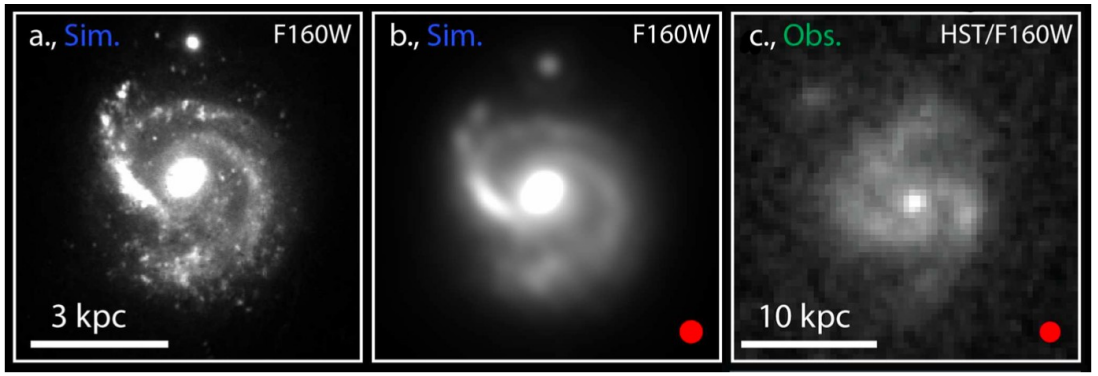
Predict faint end slope of LF




Measure escape fraction f(z, M, sfr, Z)




Morphologies of ~ 100 (1000) systems in Vulcan (Enterprise)




Law+ 2013

Evolution of SFR-$M_*$-Z relation