Theoretical Cosmology and Galaxy Formation at UMD

Massimo Ricotti (Associate Professor, Dept. of Astronomy)

Current group members:
Owen Parry (Postdoc)
Sam Leithner (CTC postdoc)
Emil Polisensky (PhD student)
Kari Helgason (PhD student)
Harley Katz (undergraduate student)
Previous PhD students:
KwangHo Park (Postdoc, Carnegie Mellon University)
Mia Bovill (Postdoc, U of Texas, Austin)

Computational/Theoretical Astrophysics

- **Main scientific interest:** understanding the beginning of structure formation in the universe and the effects on the subsequent cosmic evolution.
- **Some of the questions my research is focusing on:** How small and numerous were the the first galaxies? How many survived to the present? What is the origin of today's supermassive black holes? What is the origin of globular clusters? What reionized the universe?

Topics and Subtopics:

1. **Galaxy Formation/Early Universe/First Stars and BHs**
   - Radiative/chemical feedback
   - Dark matter simulations
   - NIR background fluctuations
2. **Connection to Near Field Cosmology**
3. **Reionization of the Intergalactic Medium**
   - Ly-alpha forest
   - Sources of reionization: role of GCs and X-rays
   - Primordial BHs and CMB, etc

Sample of past/ongoing research projects

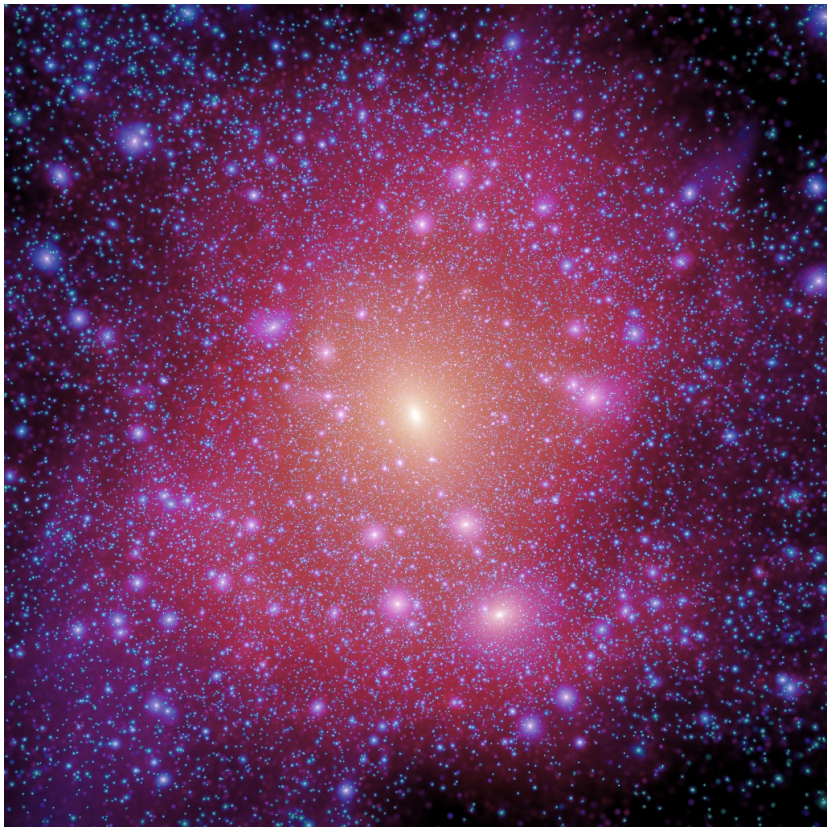
- **Emil Polinsesky: Testing CDM.** Simulations of the Milky Way in CDM and WDM; minihalos in voids at z=0
- **Kari Helgason: Detecting the First Light.** NIR background fluctuations, in collaboration with Alexander Kashlinsky
- **Owen Parry: The ISM in the First Galaxies**

Previous students:

- **Mia Bovill**: **The Quest for the Fossils of the first galaxies** (postdoc @ UT Austin, U Cattolica)
- **KwangHo Park**: **Growth of the First Seed Black Holes.** Simulations of accretion onto IMBH with rad. transfer (postdoc @ Carnegie Mellon)

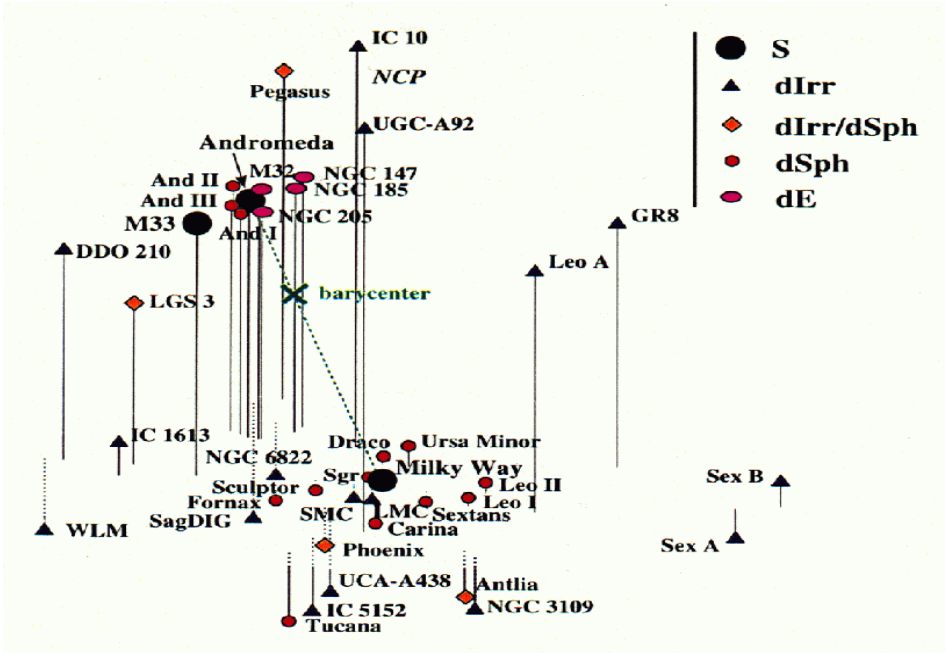
The Missing Satellites

Klypin et al 1999, More et al 1999



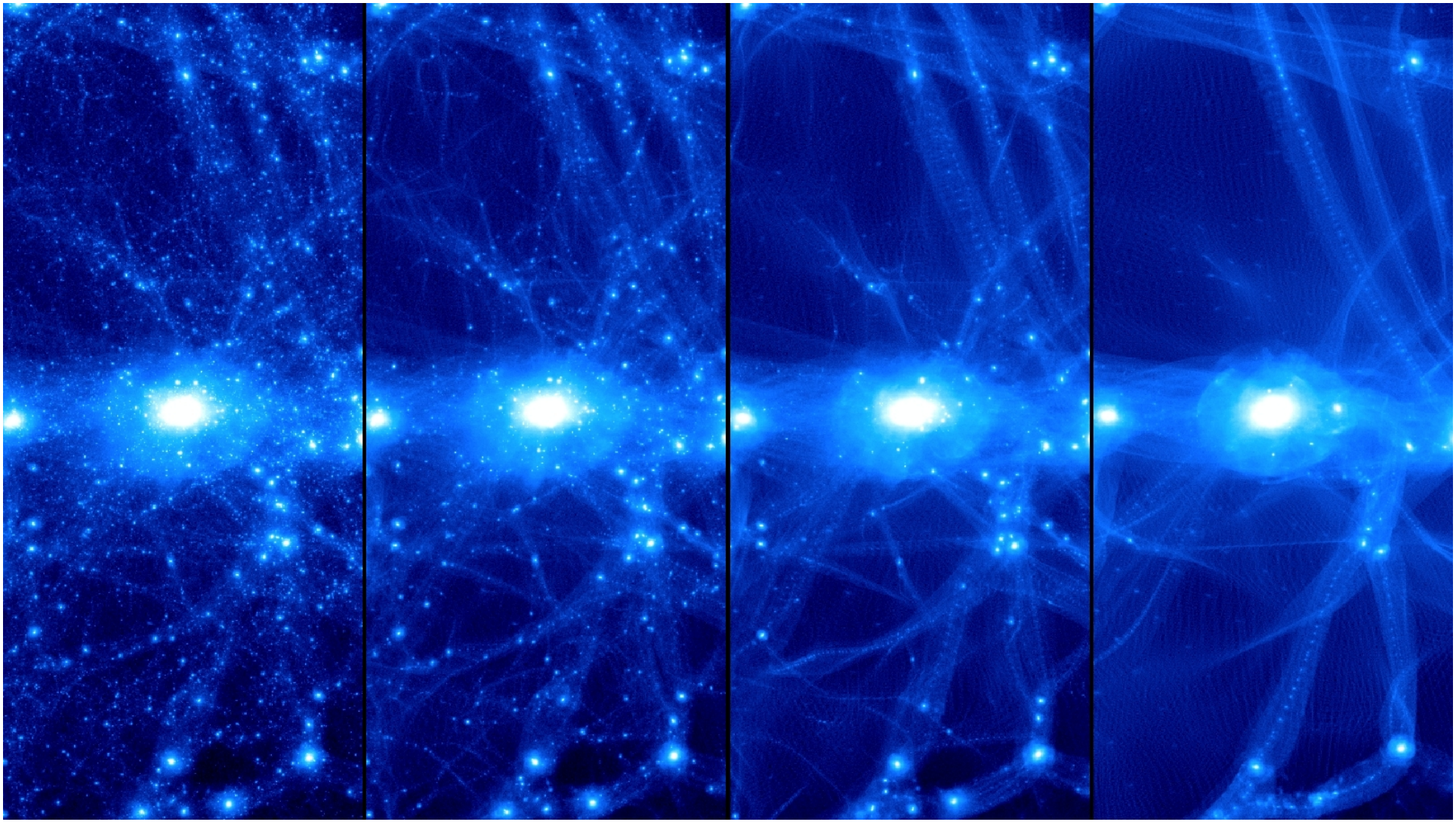
Aquarius Simulation (Springel et al, 2008)

Figure credit: Grebel

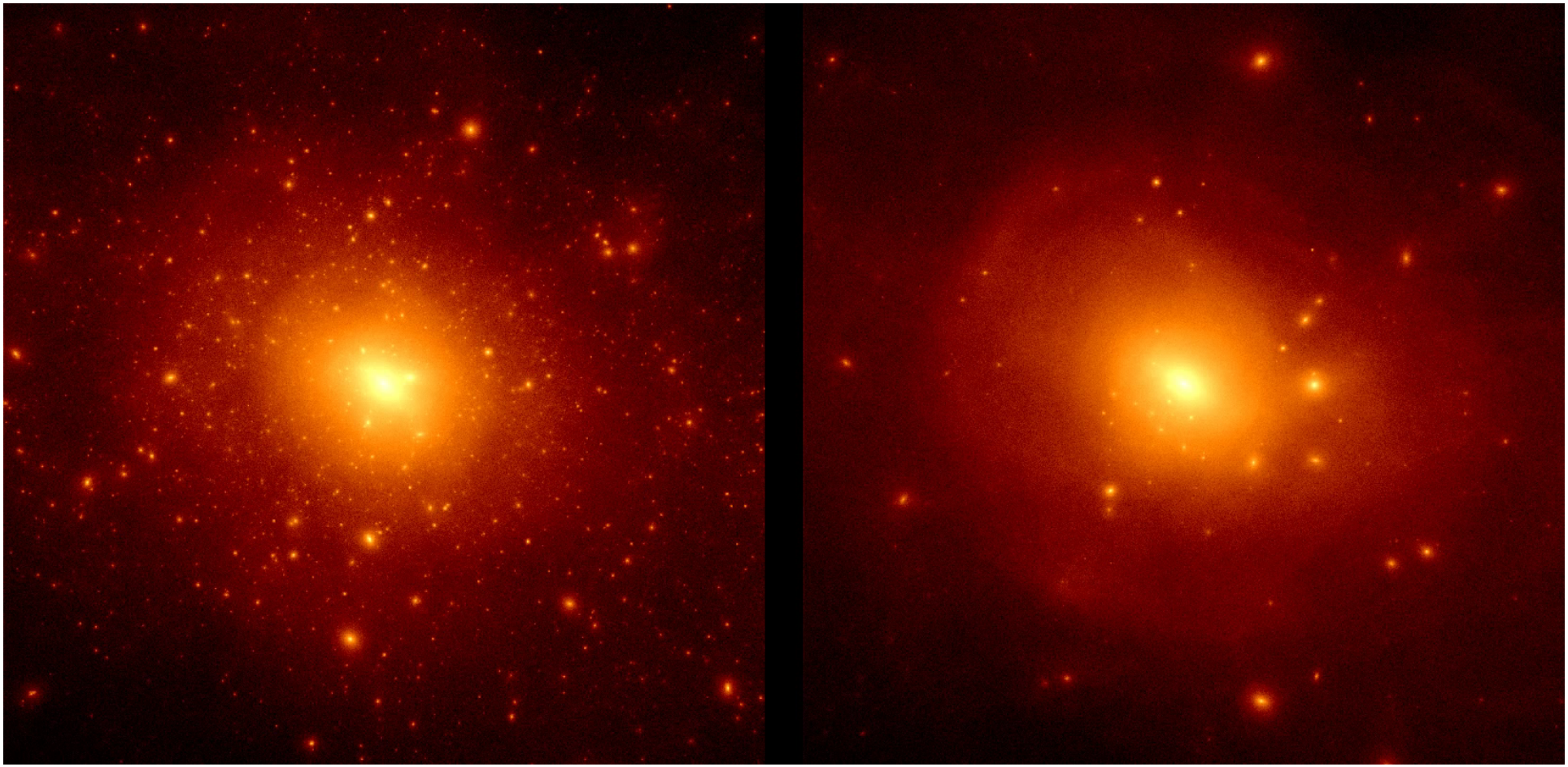


*There should be **thousands** of dwarf satellites around the Milky Way. However, as of 2005 only about 30 satellites known in LG.*

Warm Dark Matter

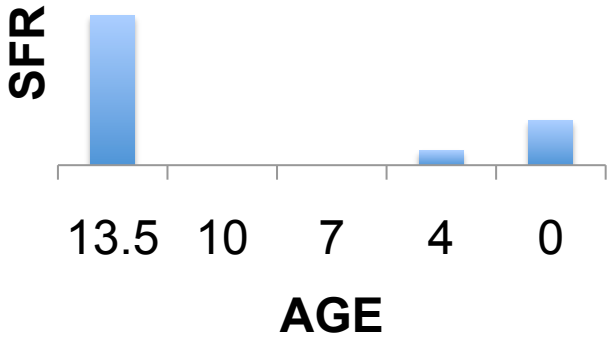


Cold Warmer Warmer yet Warmest

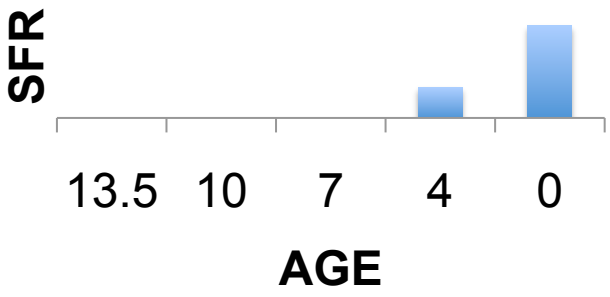


Reionization feedback on dwarf galaxy formation

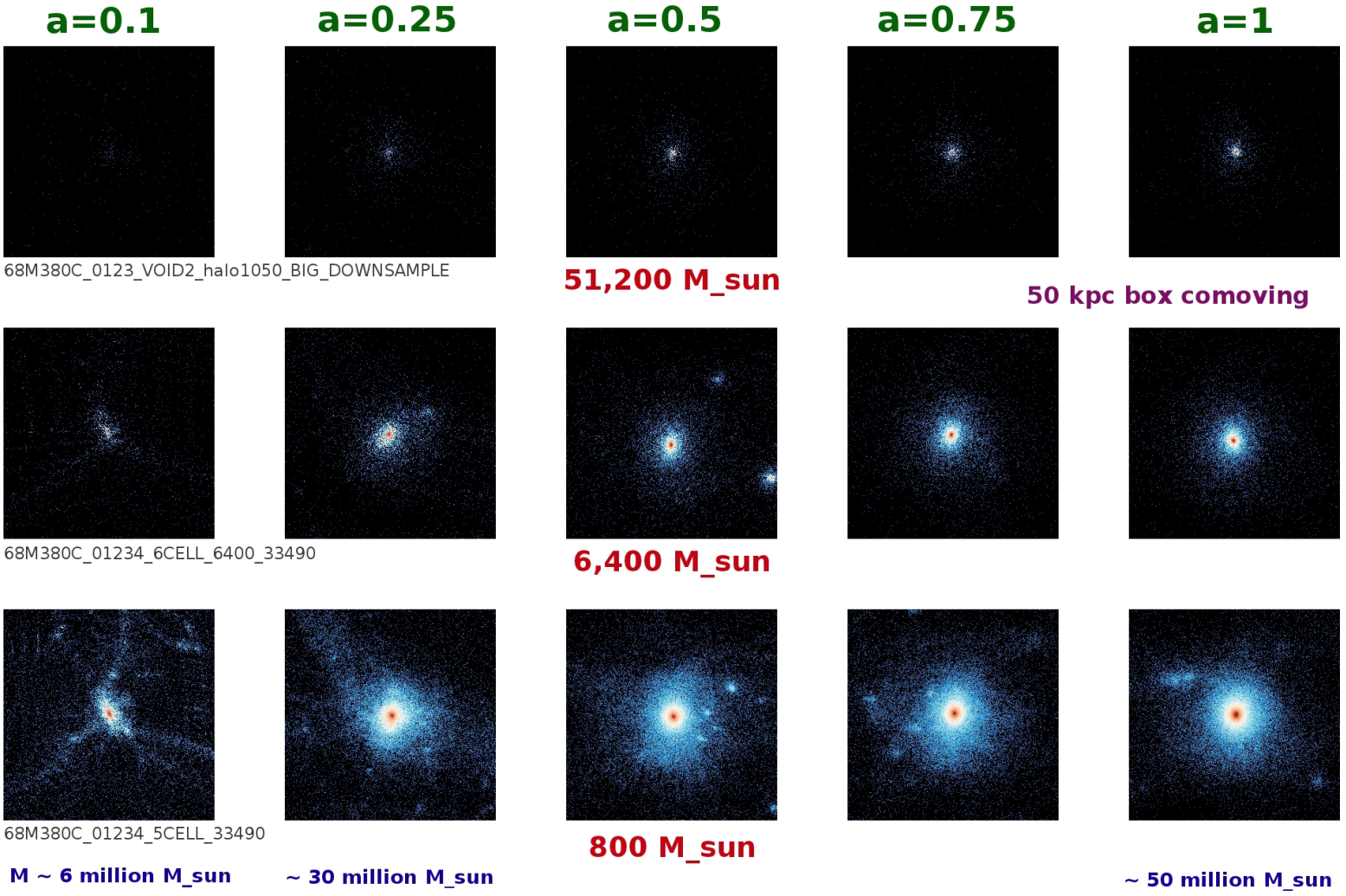
- The reionization feedback idea is valid but fails at z<2 if the halo is highly concentrated
- Minihalos virialized before reionization, that evolve to z=0 in the low-density IGM, have a late phase of gas accretion and possibly star formation



Do these objects exist?



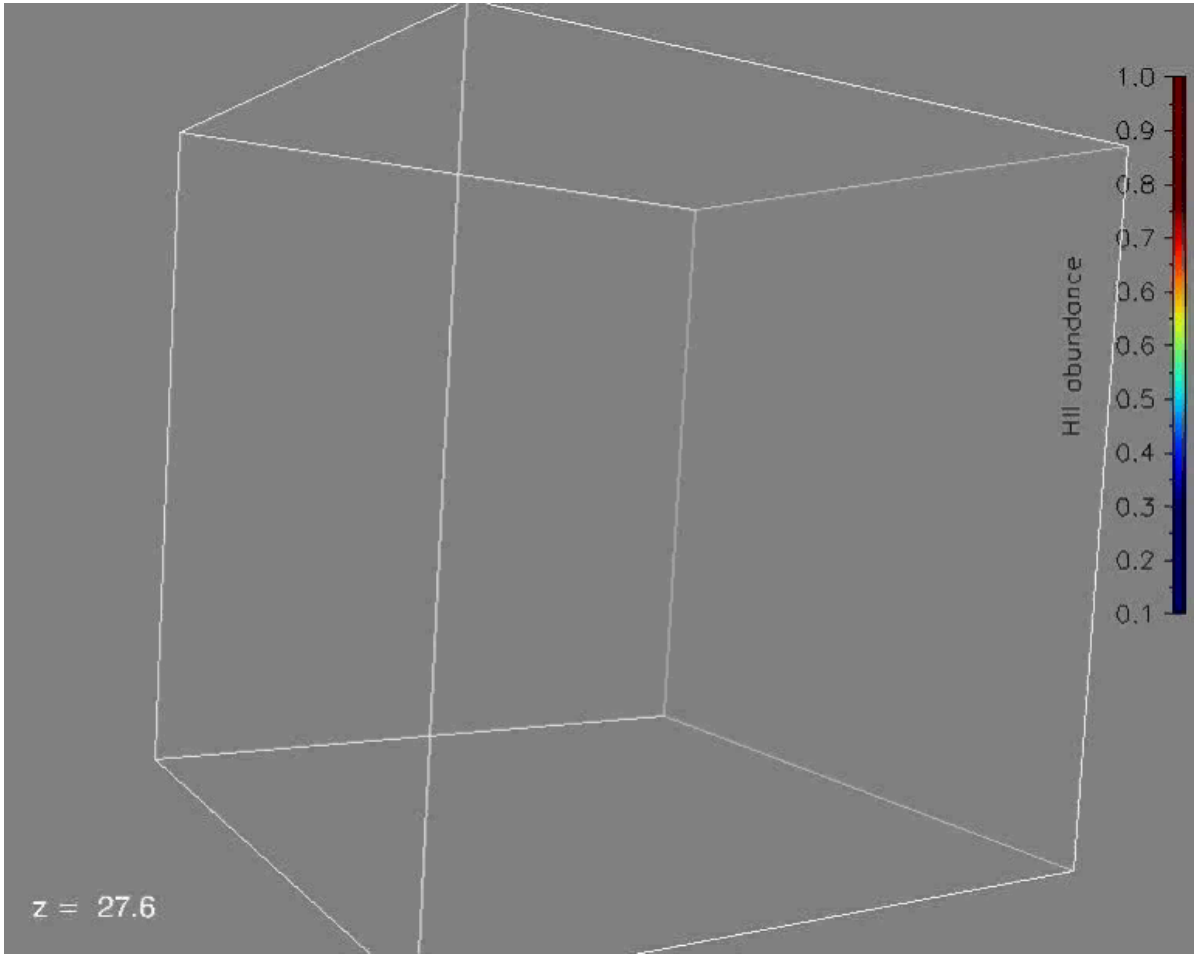
Detecting minihalos in voids



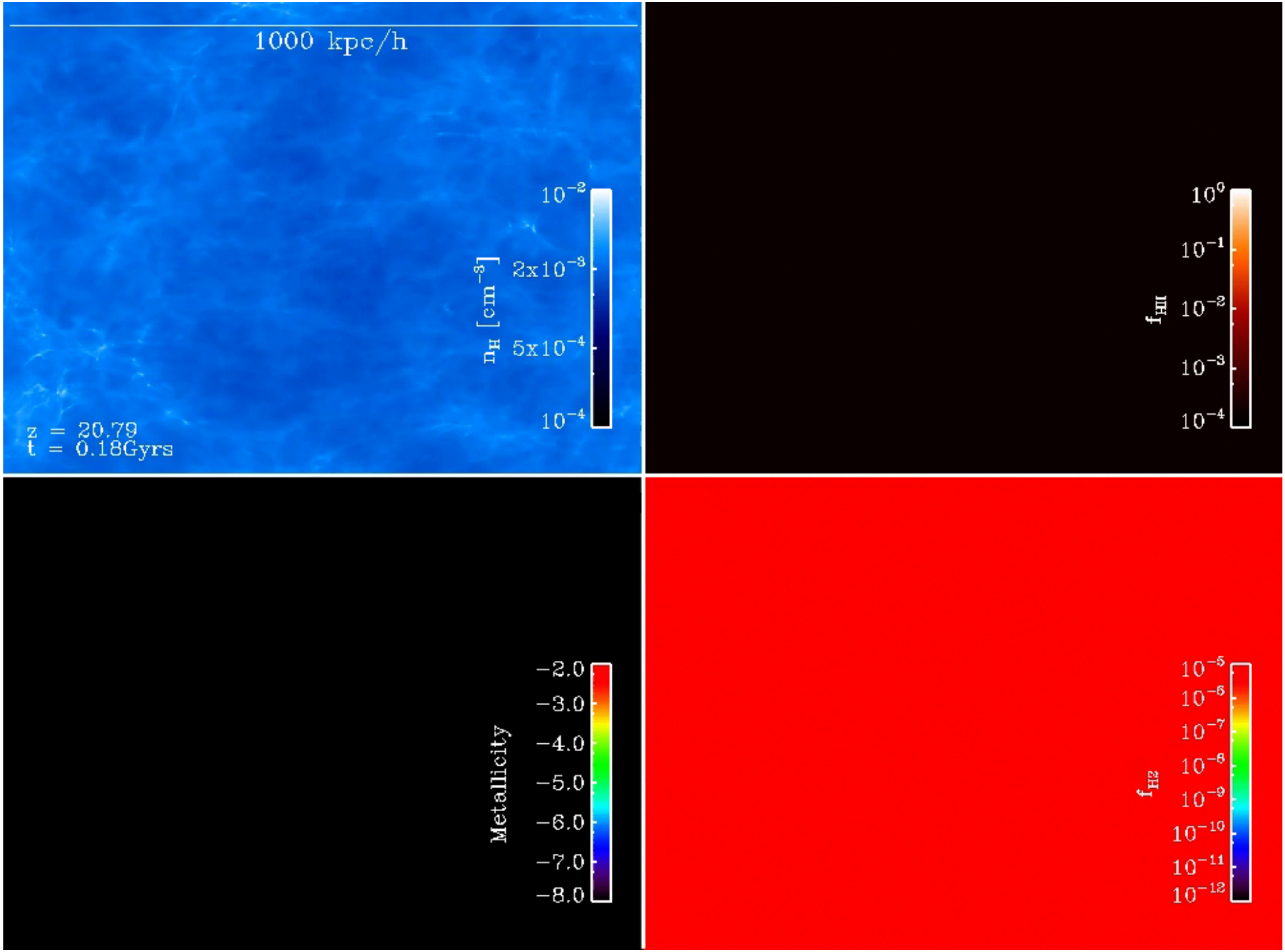
Simulations of the first galaxies

Feedback-regulated galaxy formation

- 1 Mpc box size
- 10^3 M_{sun} mass res.
- 3D radiative transfer
- Run ends at redshift of reionization



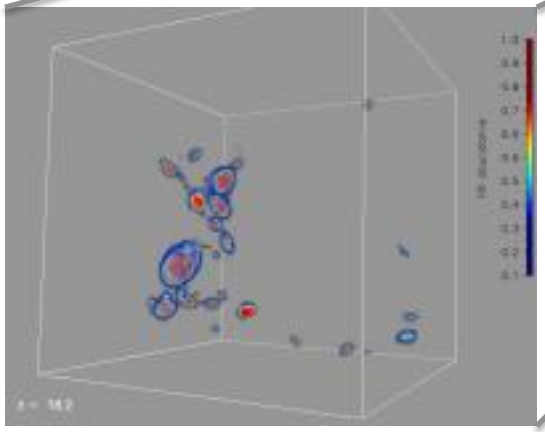
Ref: Ricotti, Gnedin & Shull 2002

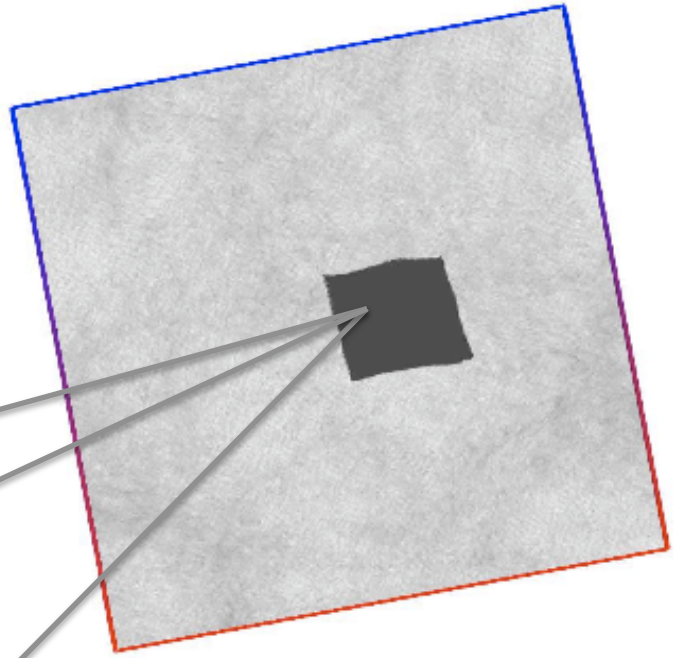

1000 kpc/h
10^{-2}
$2x10^{-3}$
$5x10^{-4}$
10^{-4}
n_H [cm^{-3}]
z = 20.79
t = 0.18Gyrs
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
f_{HII}
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
−8.0
Metallicity
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
f_{H2}

Simulating Fossils of First Galaxies

The final pre-reionization output is transformed in a 1 Mpc^3 box of particles.

We duplicate this box, adding perturbations to account for density variations with $l > 1$ Mpc.

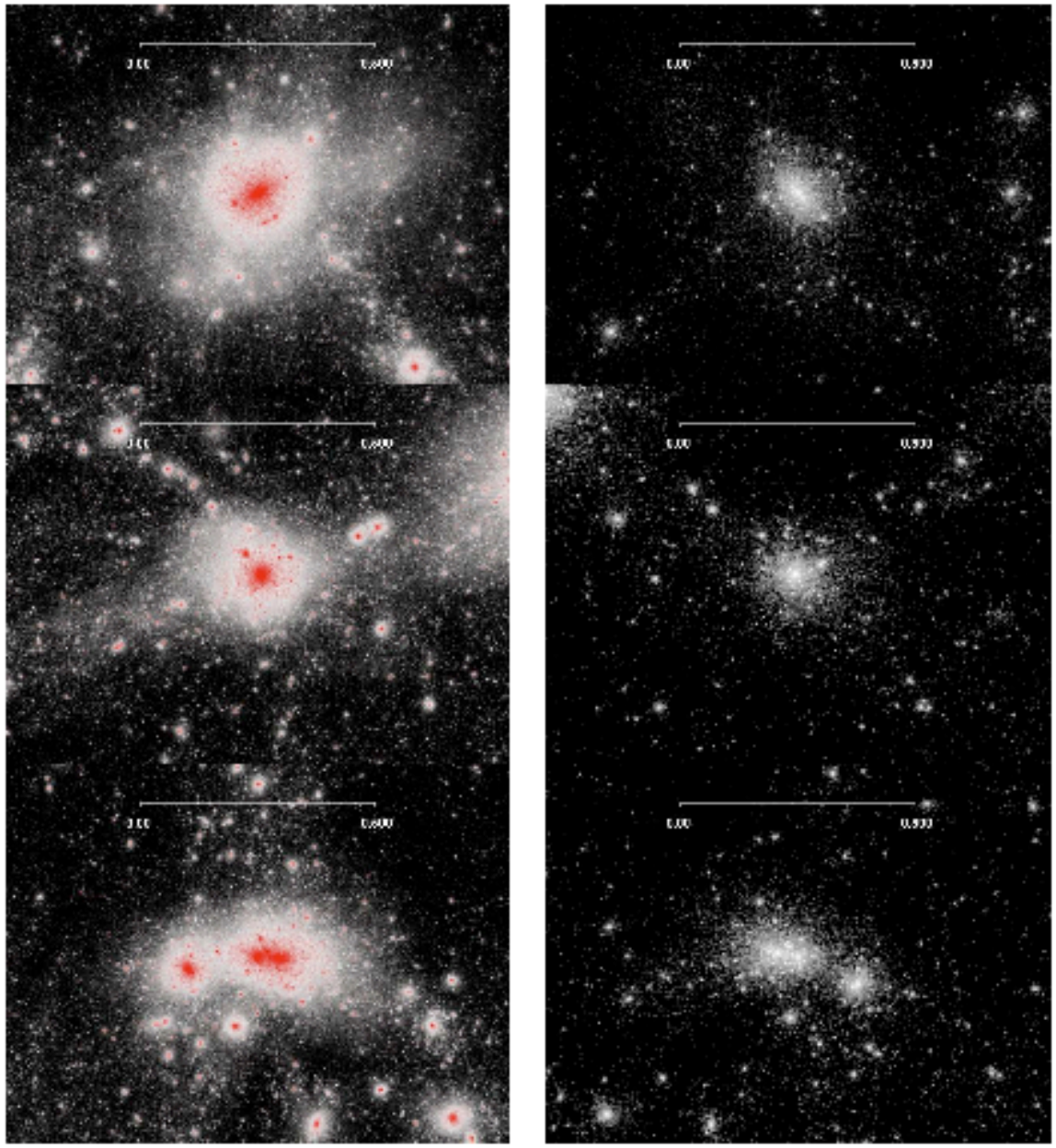




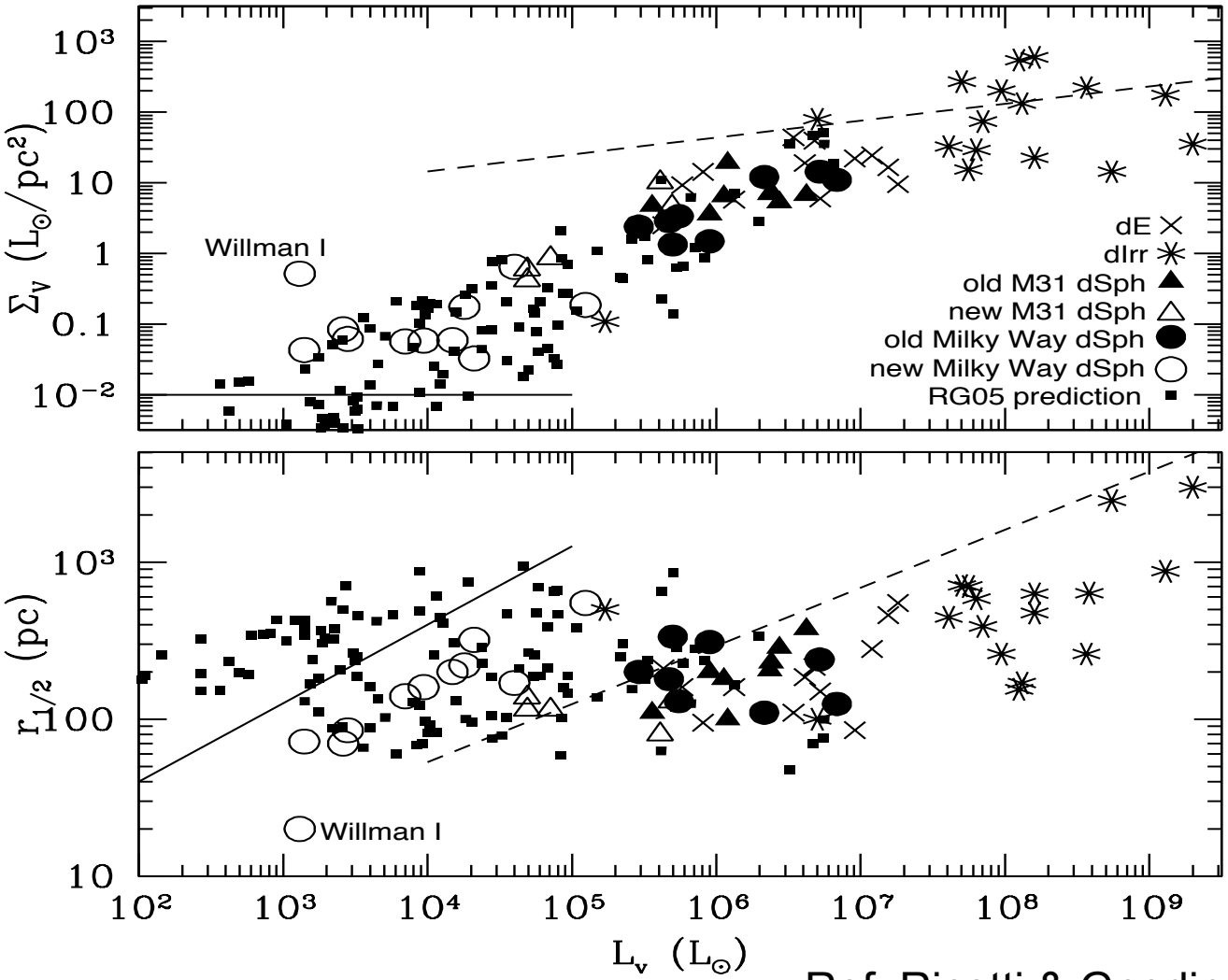
Each HR particle in the resulting N-body simulation represents a pre-reionization halo.

Unique IDs allow us to retrieve the stellar properties at $z = 0$.

Where are the fossil Galaxies today?



Pre-reionization fossils and ultra-faint dSphs: a model prediction!

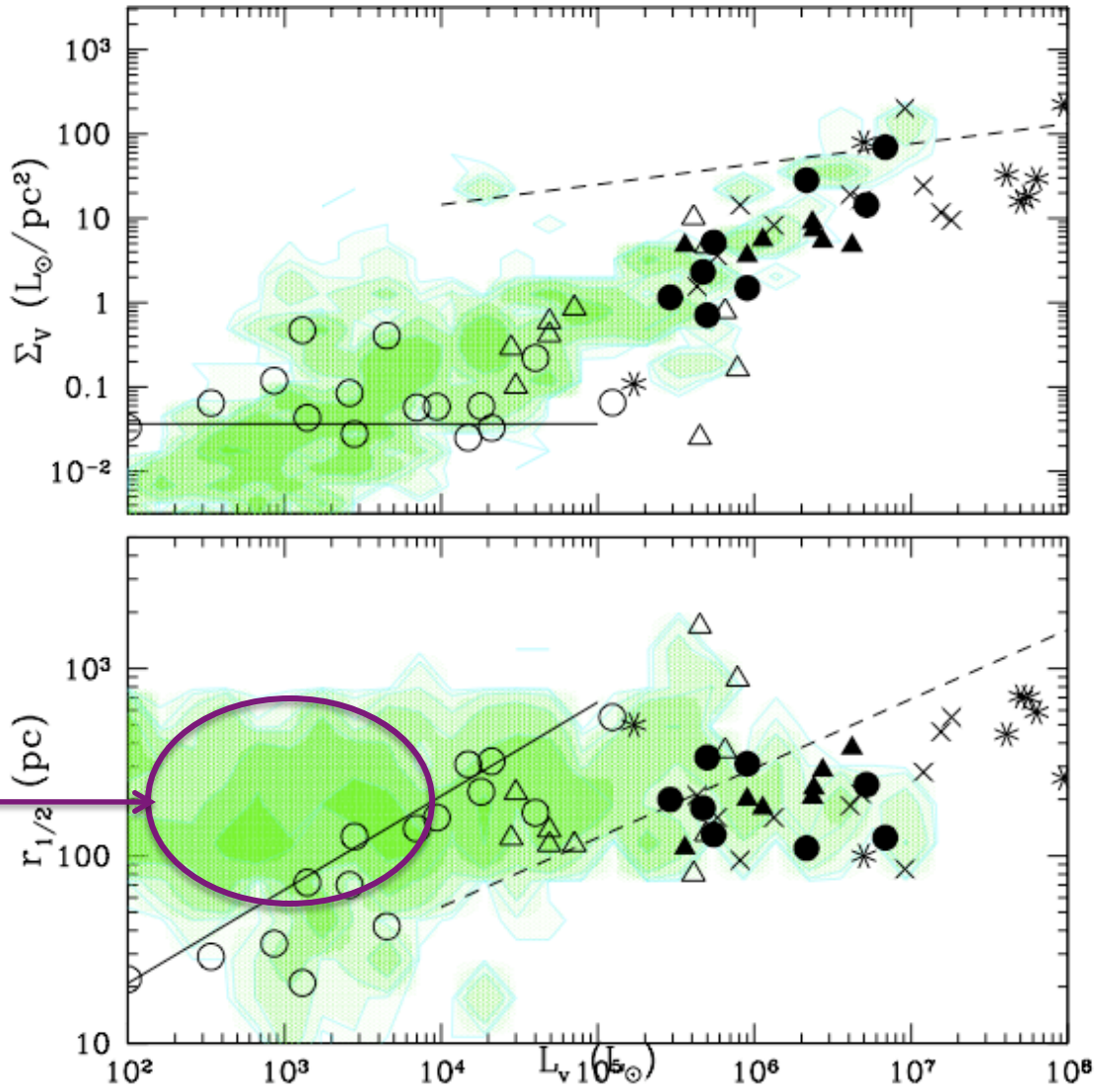


Ref: Ricotti & Gnedin 05, Bovill & Ricotti 09

More work with LSST

We now have z=0 halos which reproduce the faintest and smallest ultra-faints!

Yet undiscovered population



Sources of Reionization

1. Role of globular clusters (with **Harley Katz**, undergraduate)
2. Constraints from IR background fluctuations (**Kari Helgason**)
3. X-ray pre-ionization: redshifted X-ray background
   - Accretion onto intermediate mass black holes with radiation feedback (**KwangHo Park**)
4. Primordial black holes

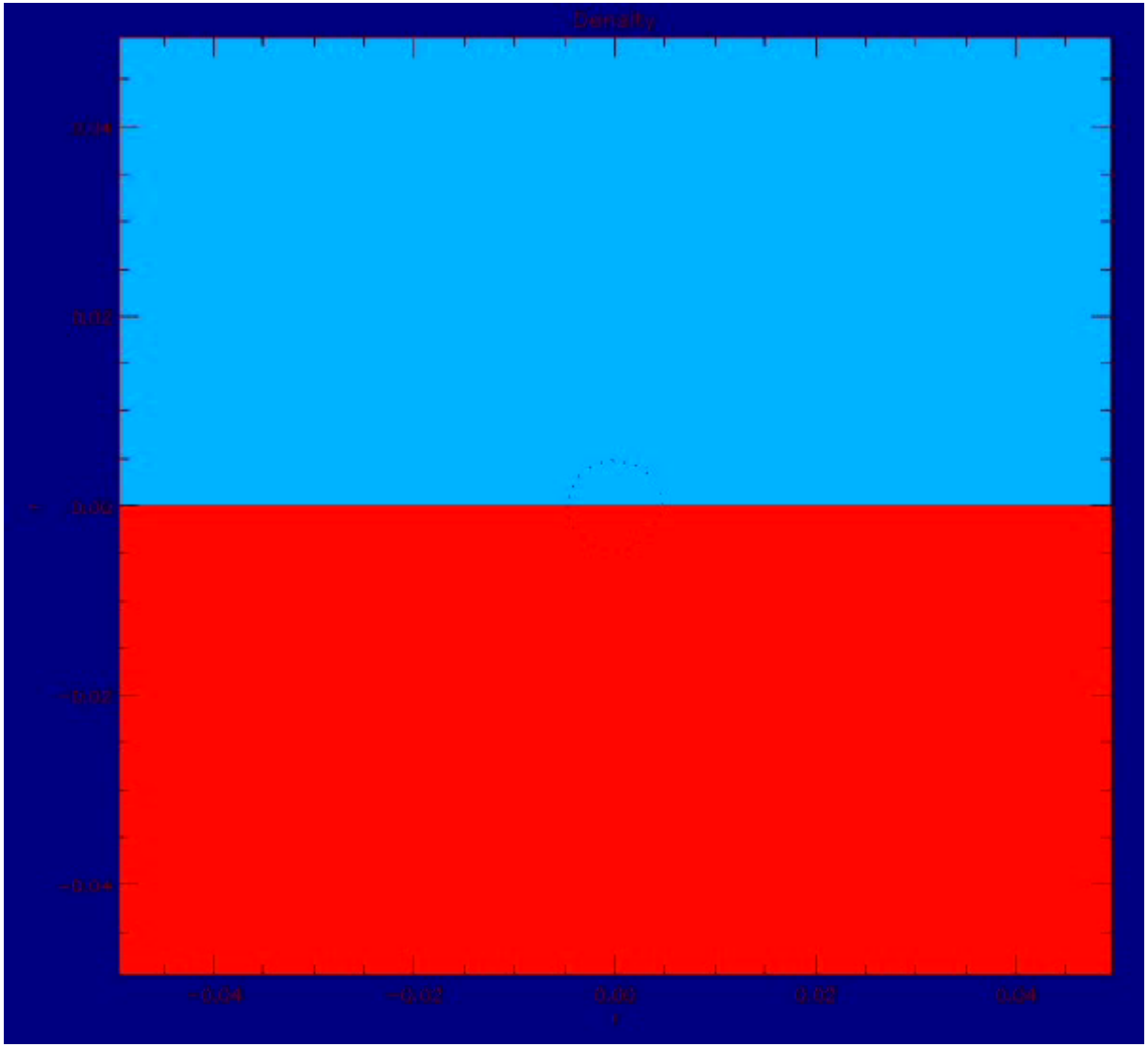
Bondi accretion with radiation feedback

Park & Ricotti 2011

100 M_{solar} IMBH

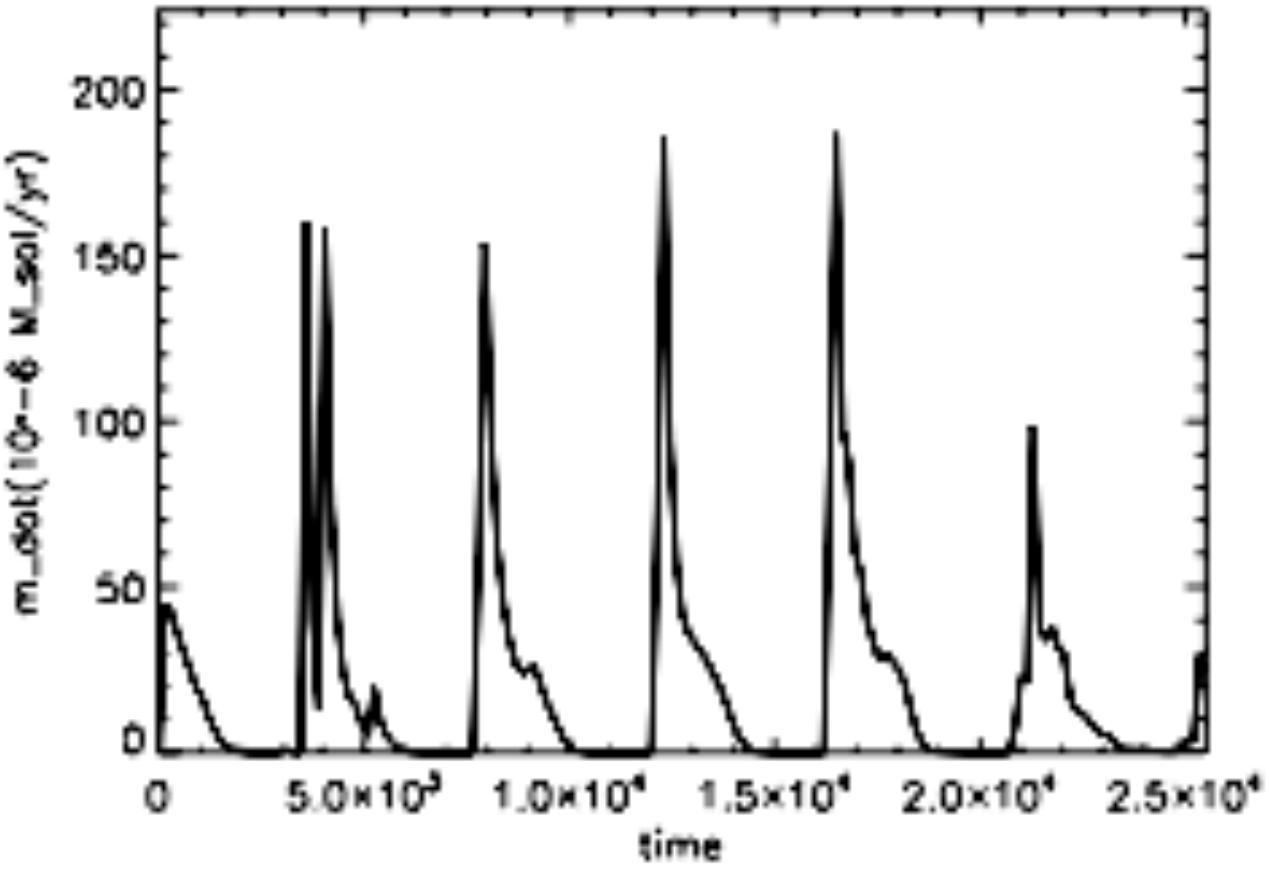
Gas density

Ionization fraction



Accretion rate

Park & Ricotti 2011



See also Milosavljevic et al 2008

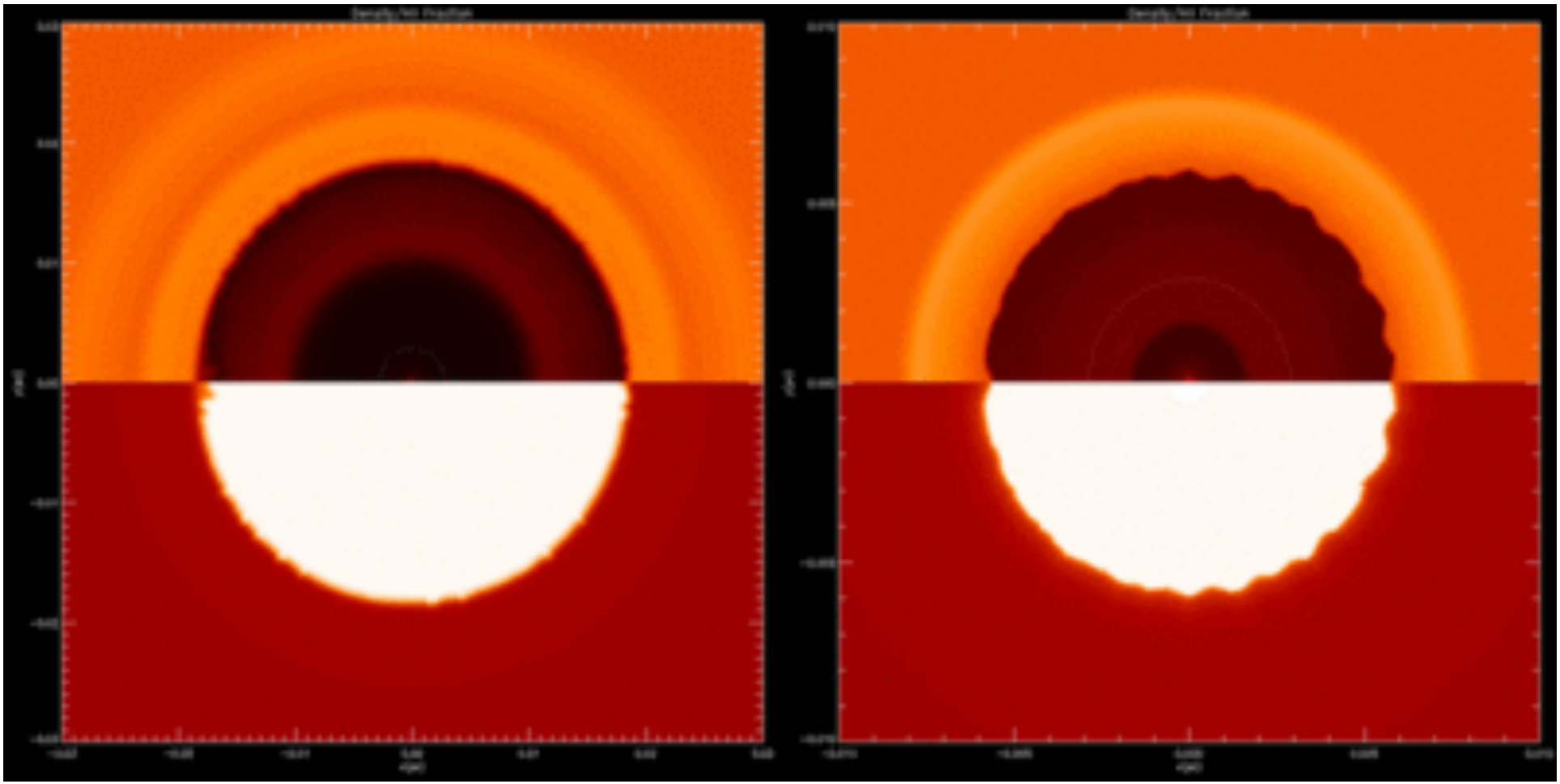
Two Distinct Modes of Oscillations

Mode-I

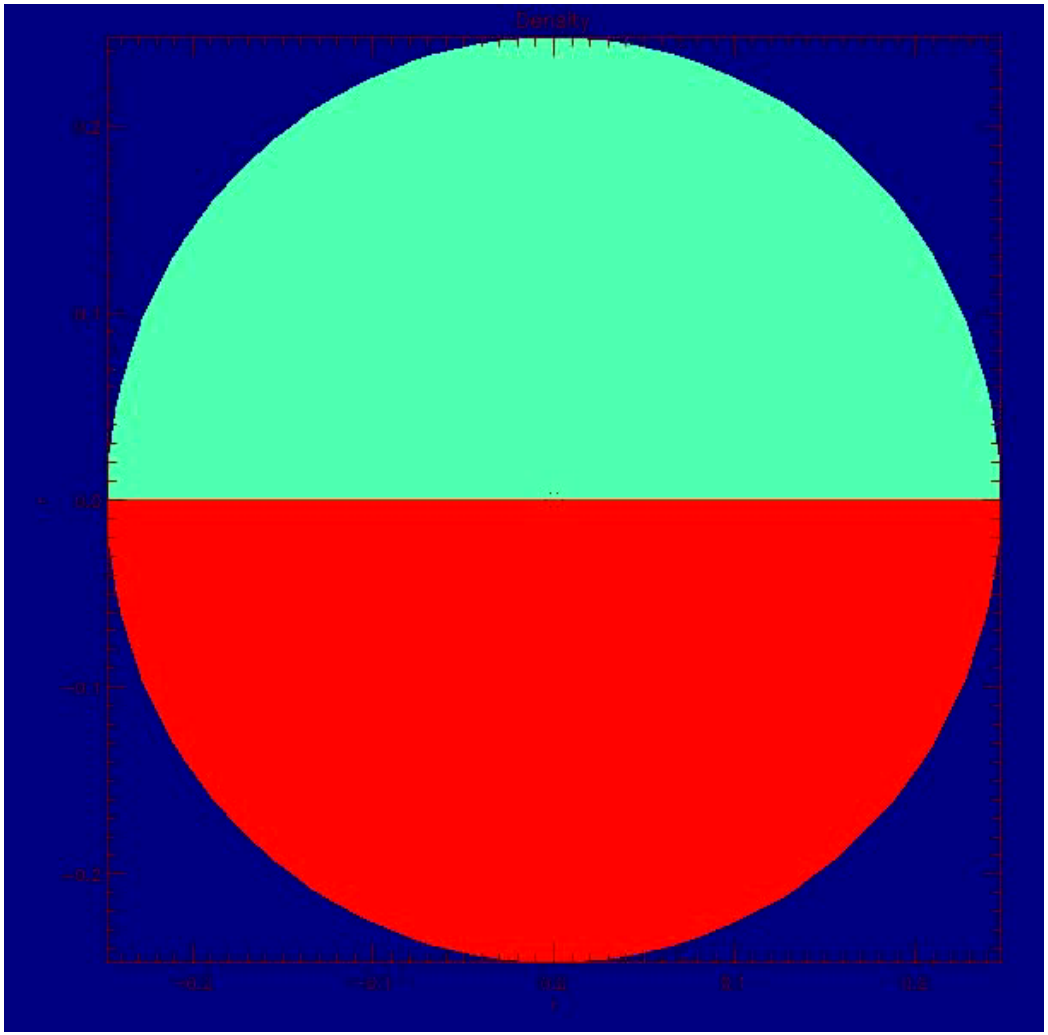
$n = 10^6\ cm^{-3}$

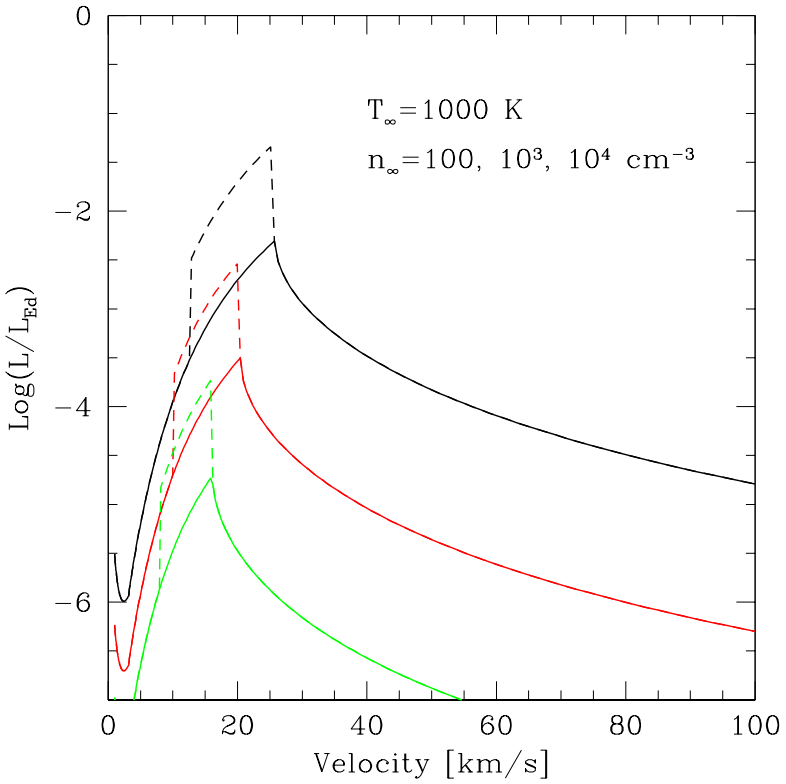
Mode-II

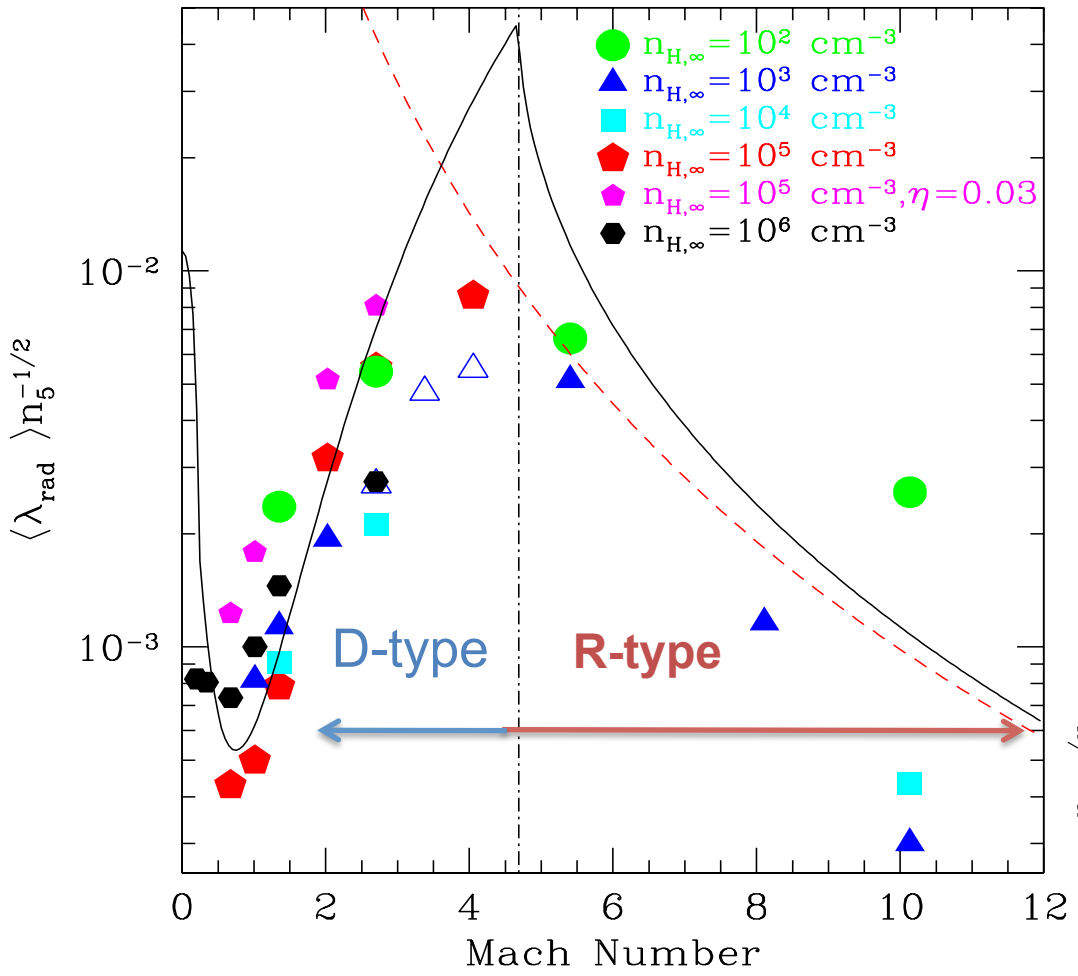
$n = 10^7\ cm^{-3}$



Moving BH + Radiative Feedback

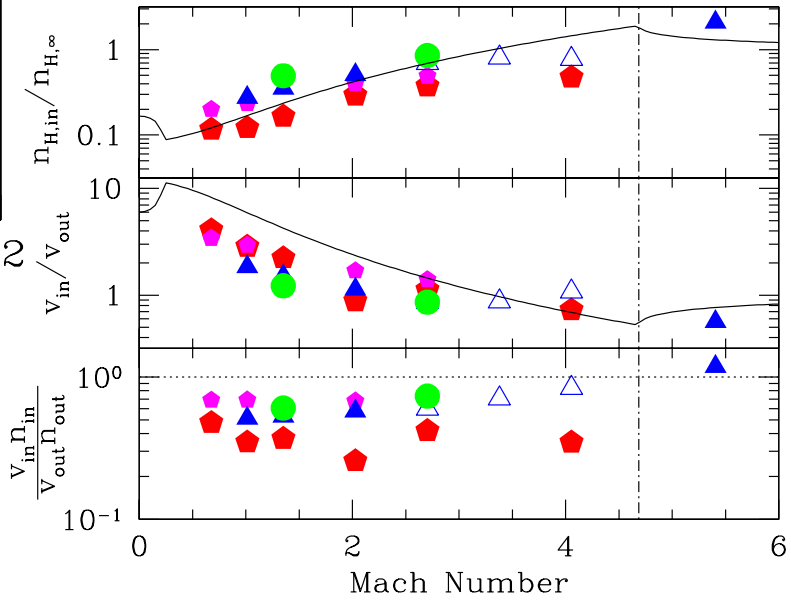






Modeling based on Simulations:

1. Transition from R-type to D-type ionization front
2. Isothermal bow-shock
3. Thin shell instability produce periodic accretion rate



Shell instability and periodic oscillations