Exploring dwarf galaxy evolution around Milky Way mass galaxies

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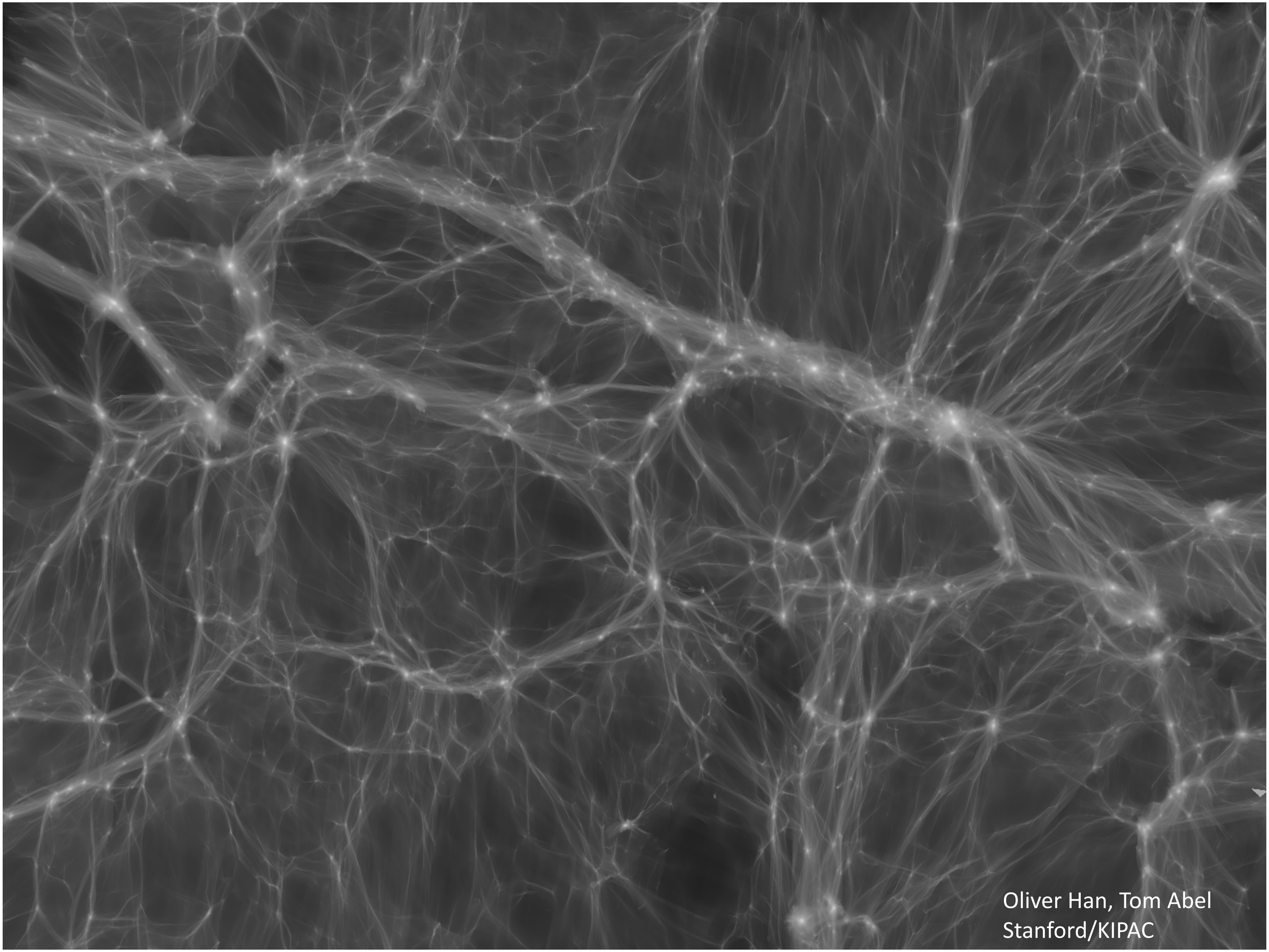
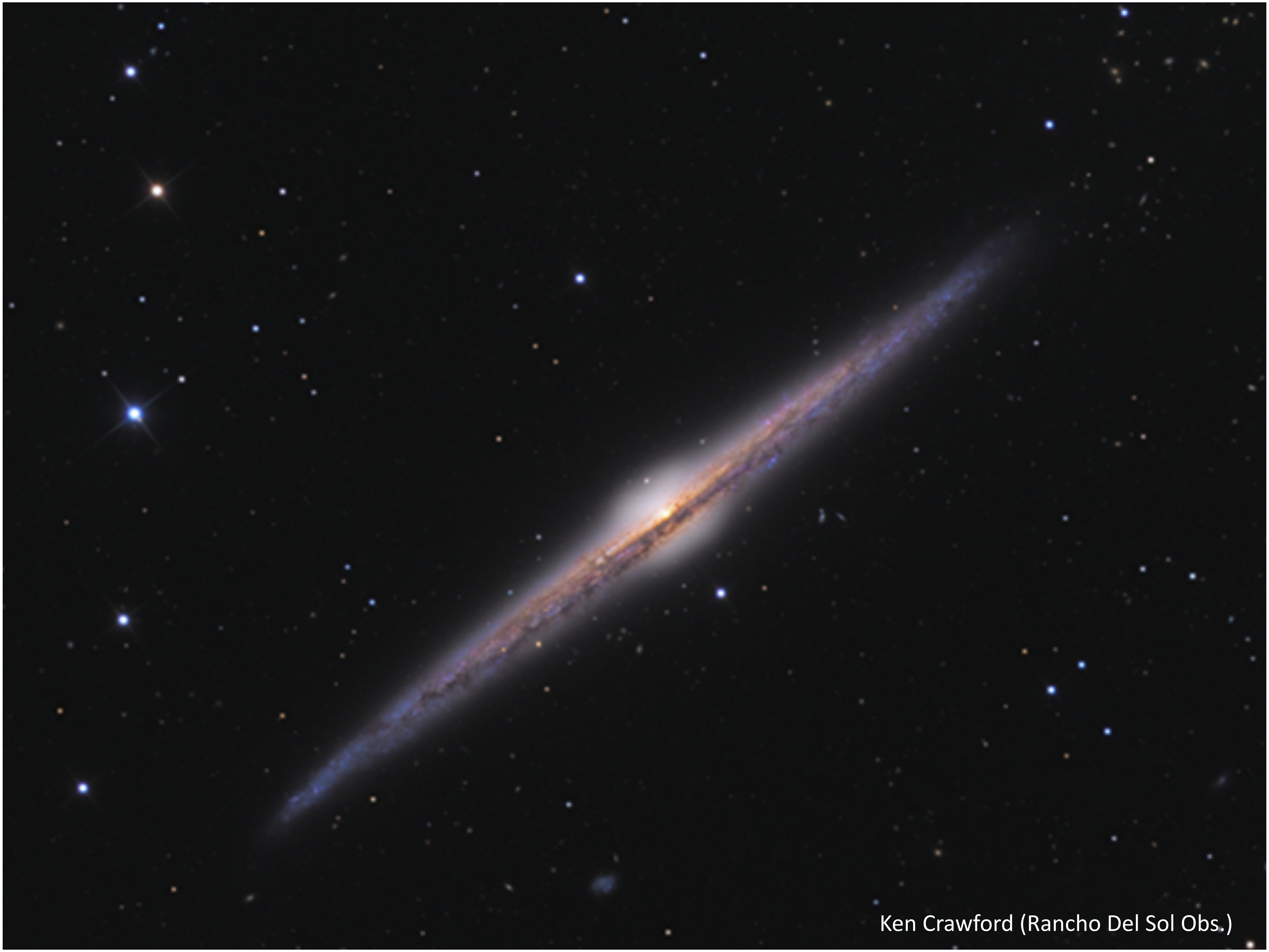
Understanding galaxy evolution

M31 Robert Gendler

Key Challenges

- Understanding galaxy evolution requires:
  - large volume
  - high spatial resolution
  - long time span
  - good time resolution
  - following of dark matter particles
  - creation of stars and treatment of feedback
  - following gas flows
- Understanding dwarf galaxy evolution requires:
  - even higher spatial resolution
  - large, well resolved volumes


Oliver Han, Tom Abel
Stanford/KIPAC


Ken Crawford (Rancho Del Sol Obs.)

Why it Matters

- Still are discrepancies between theory predictions and observations on small (galaxy) scales
- Gain a better understanding of:
  - how dwarf galaxies build up their mass
  - how many satellite dwarf galaxies there are
  - morphological types of dwarf galaxies as evolution
  - how satellite and isolated dwarf galaxies differ
  - what dwarf galaxies central densities depend on
  - how dwarf galaxies impact their host galaxy
  - where the other 50% of gas mass is around our galaxy
  - what observations are required to find this gas

Project Goals

- Create galaxies that are:
  - realistic - match observations on a variety of tests
  - high resolution - able to examine these small scales
- Use them to learn about dwarf galaxies
  - isolated and satellite galaxies
  - abundances
  - star formation rates
  - central densities
  - morphological changes
  - tidal disruption and mass loss
  - influence on gas around galaxies

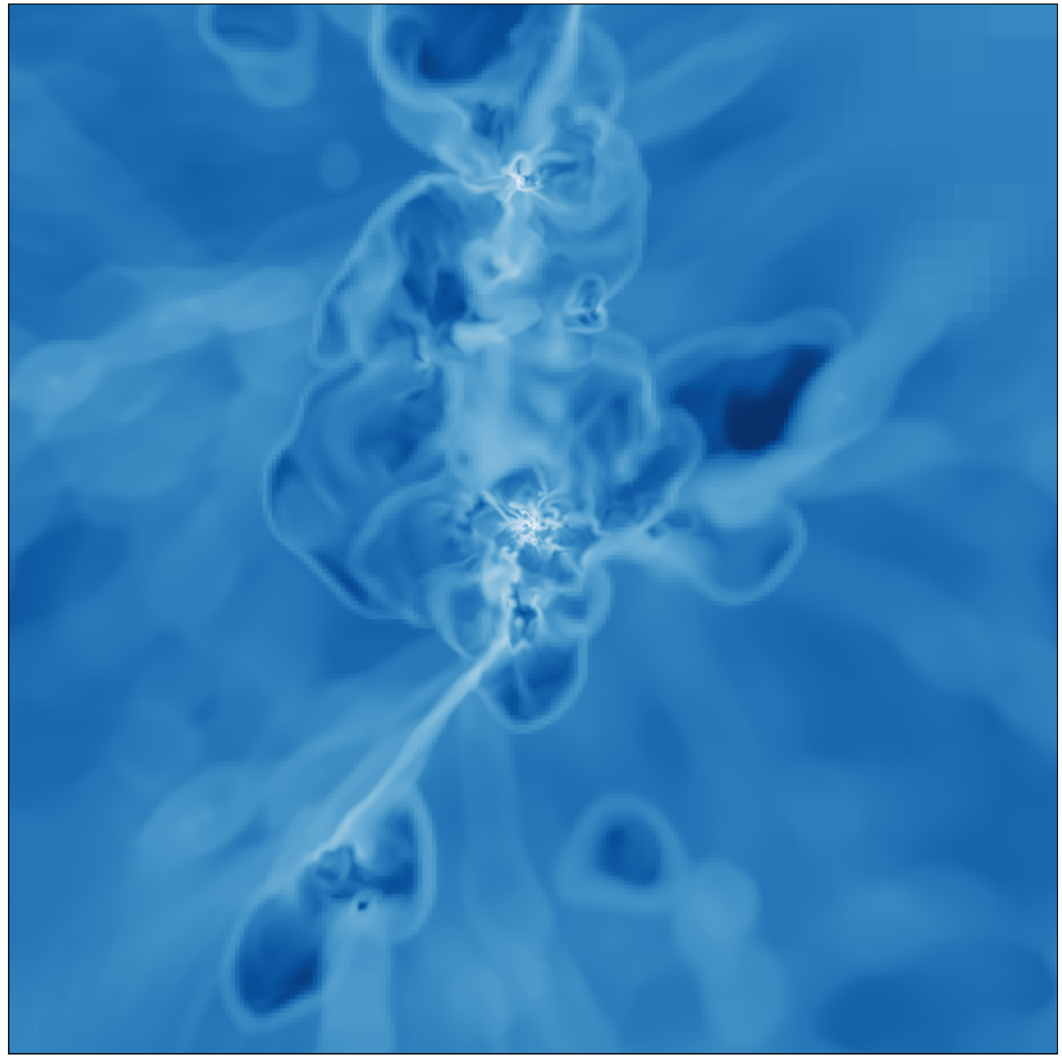
Simulations

Run by Daniel Ceverino
hydrodynamical ART code

Box length = 20 /h Mpc
DM mass = $8x10^4$ M_{sun}
Resolution = 17 pc

N cells = 67 million
N particles = 30 million

Stellar winds
Supernovae feedback
Radiation pressure (τ_{IR}=0)



Simulations

10 VELA host galaxies

Possible MW progenitors

No specific environmental selection

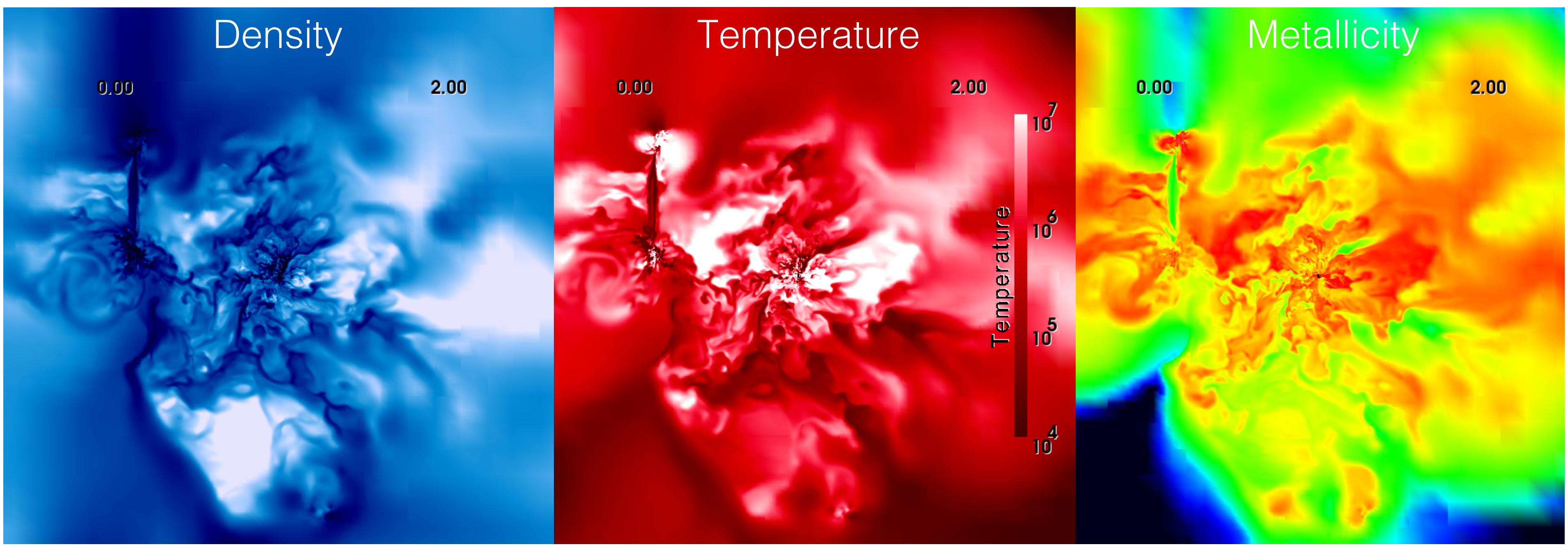
Range of merger histories and M_{vir}

Results from redshift one

$M_{vir} = 2x10^{11} – 1.2x10^{12}\ M_{sun}$

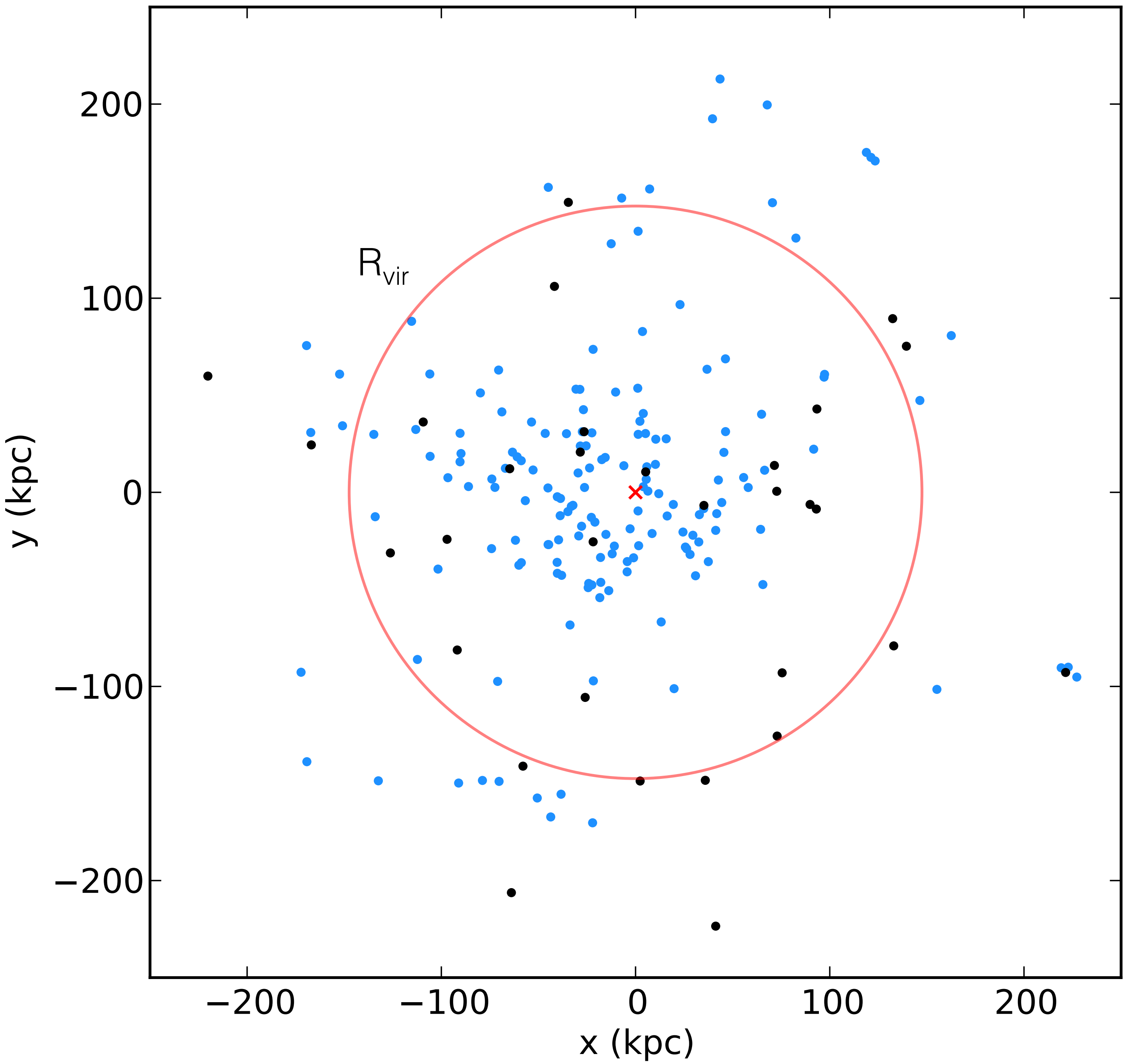
$M_{star} = 6x10^{9} – 8x10^{10}\ M_{sun}$

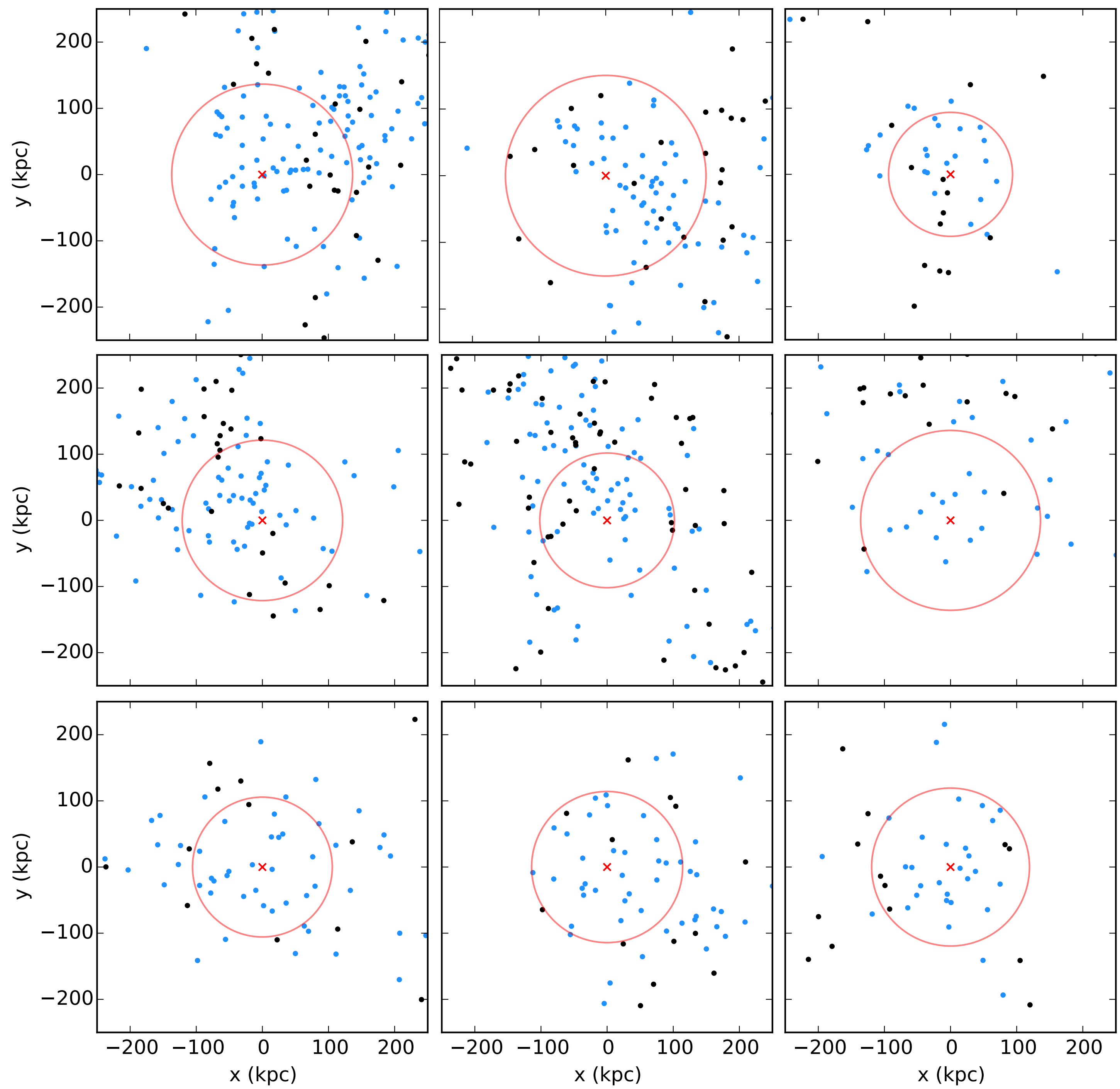
$R_{vir} = 92 – 147$ kpc



Distribution of galaxies around main halo

- **Red "x"** marks the center of main halo
- **Red circle** marks the 'edge' of the main galaxy
- **Blue dots** are luminous dwarf galaxies
- **Black dots** are dwarf galaxies without any stars (dark galaxies)

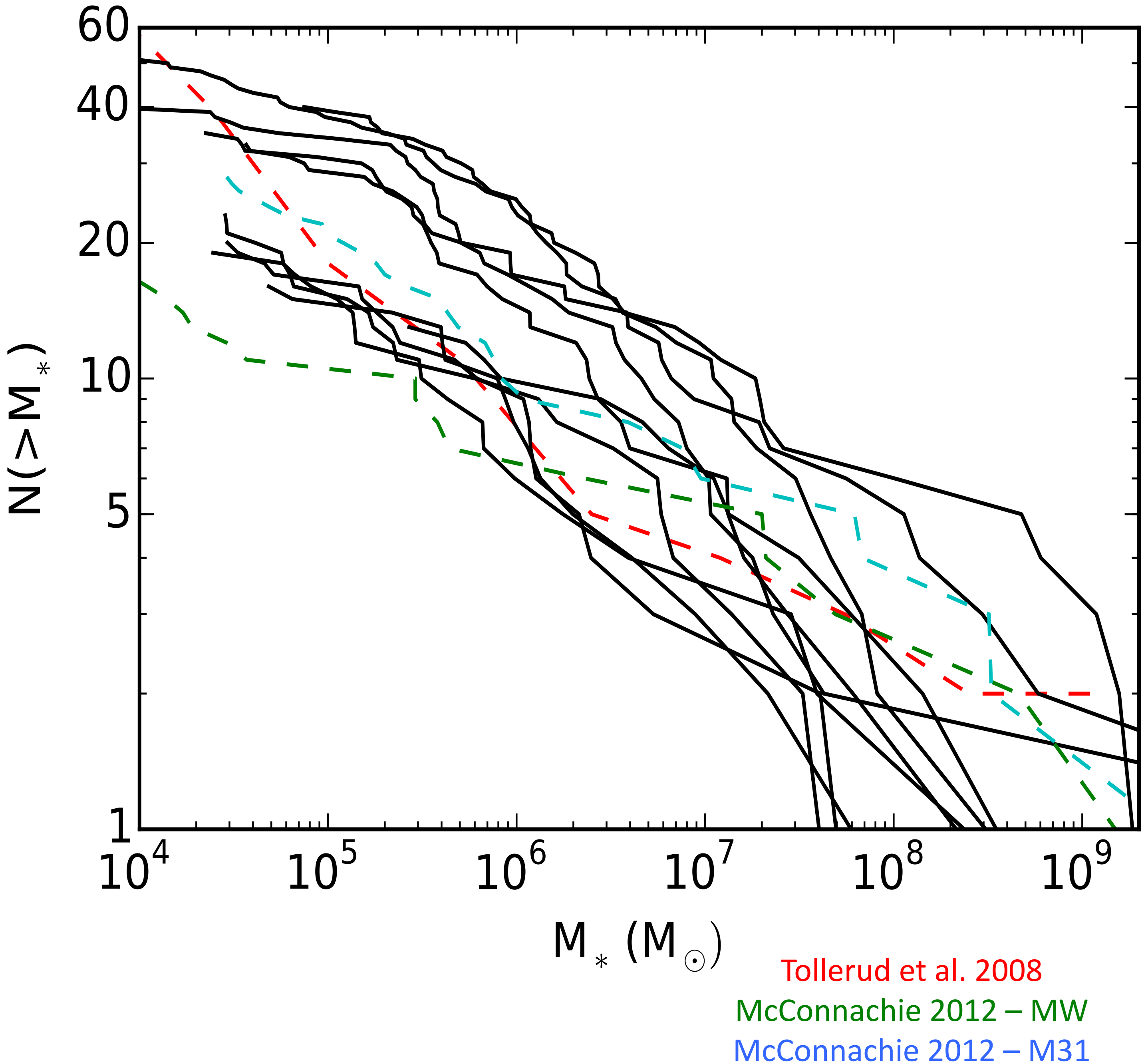


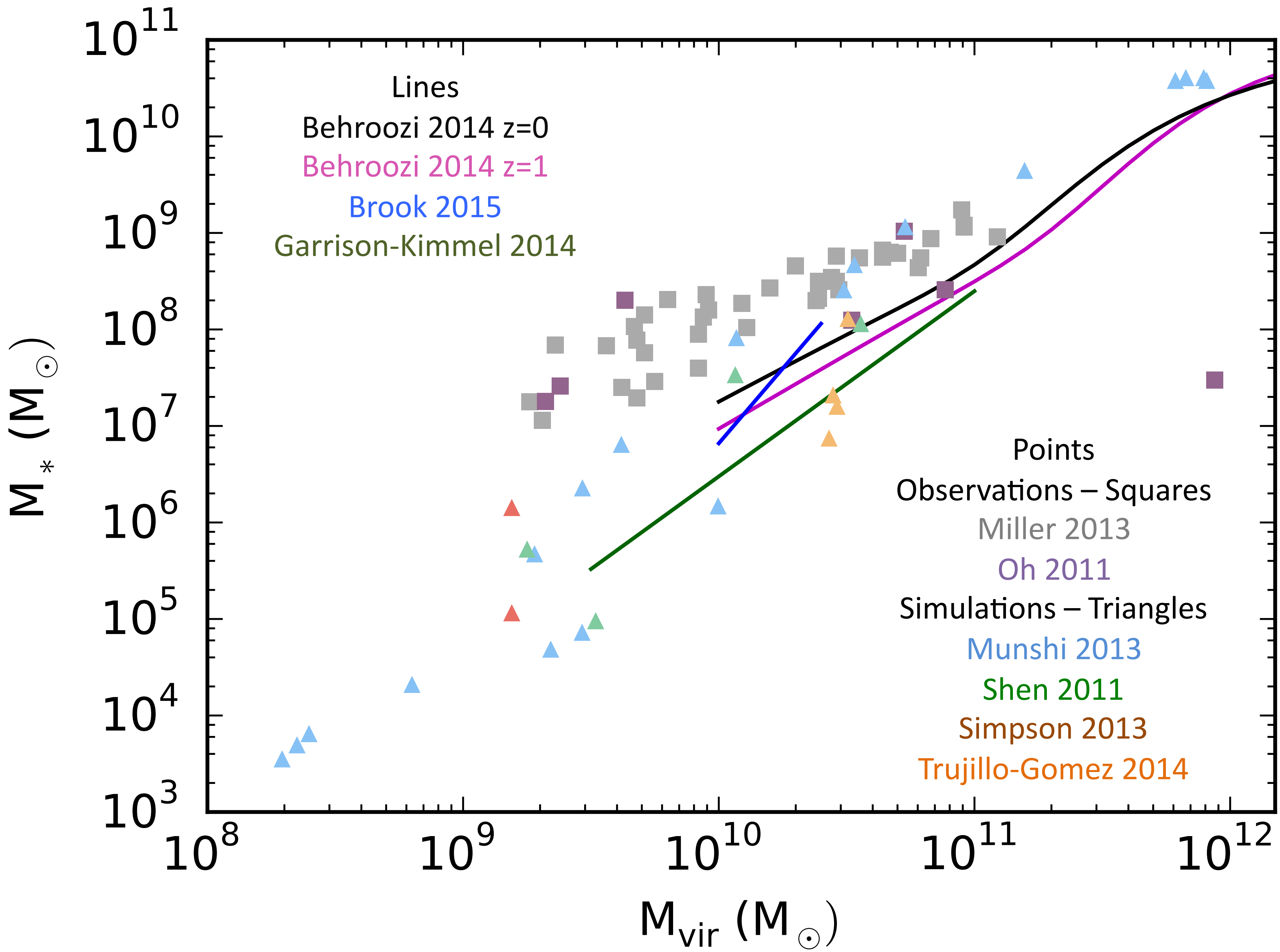


y (kpc)
y (kpc)
y (kpc)
200
100
0
−100
−200
−200 −100 0 100 200
x (kpc)
x (kpc)
x (kpc)

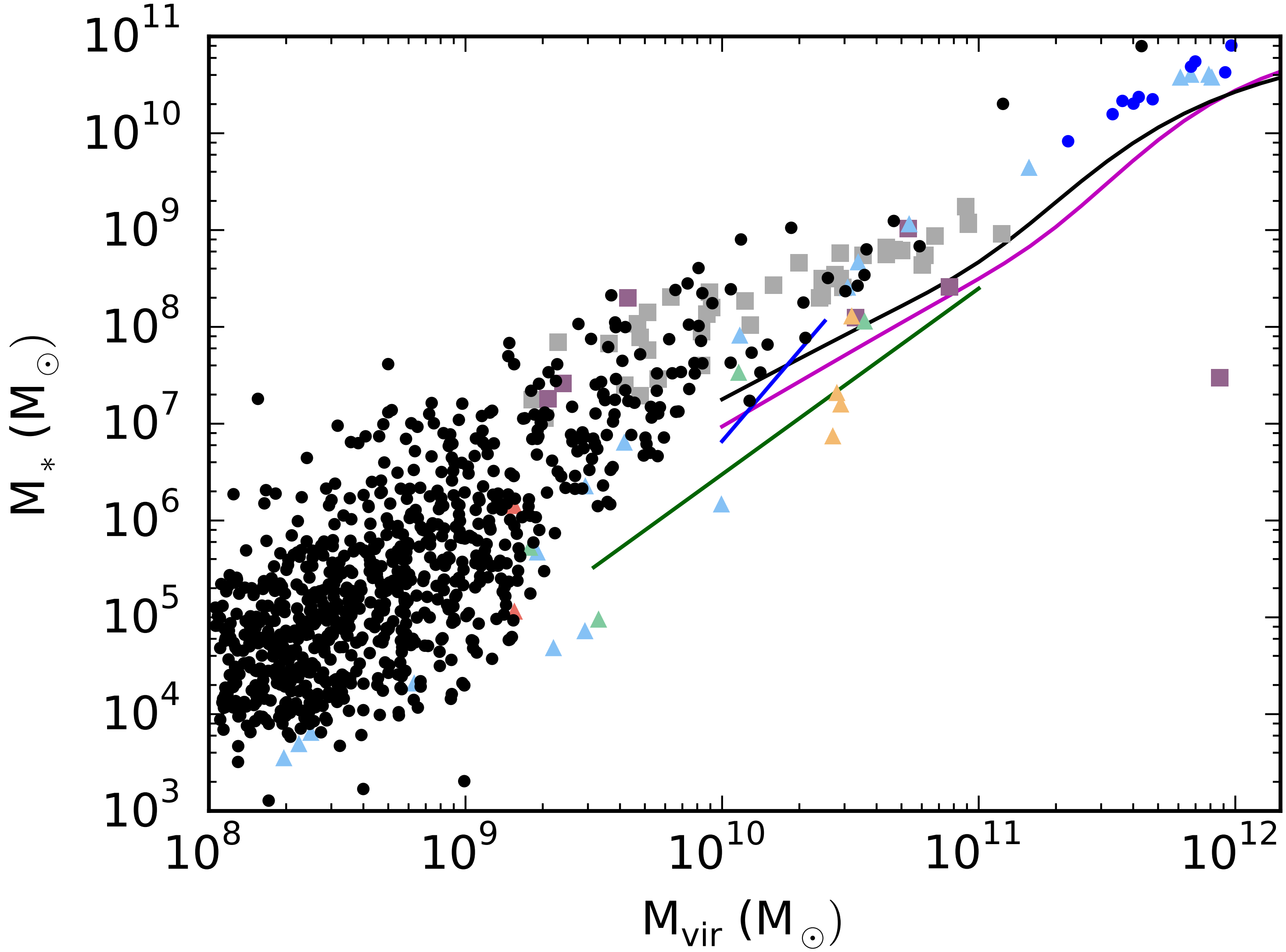
Stellar Mass Functions

- All normalized to a halo mass of 10^{12} M_{sun}
- Half of the halos are similar to observations




Lines
Behroozi 2014 z=0
Behroozi 2014 z=1
Brook 2015
Garrison-Kimmel 2014
Points
Observations – Squares
Miller 2013
Oh 2011
Simulations – Triangles
Munshi 2013
Shen 2011
Simpson 2013
Trujillo-Gomez 2014
M_* ($M_\odot$)
M_{vir} ($M_\odot$)
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}

Stellar-Mass Halo-Mass Relation

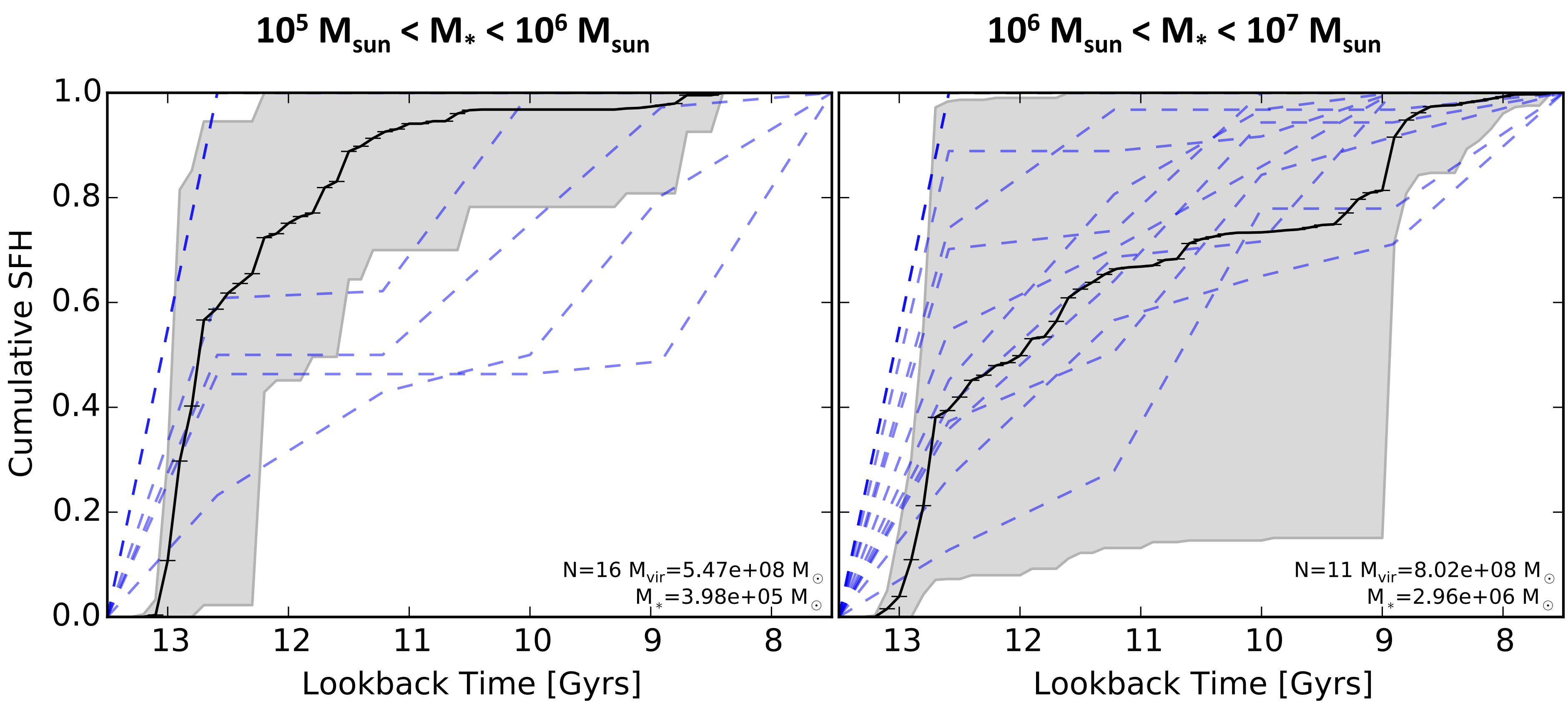


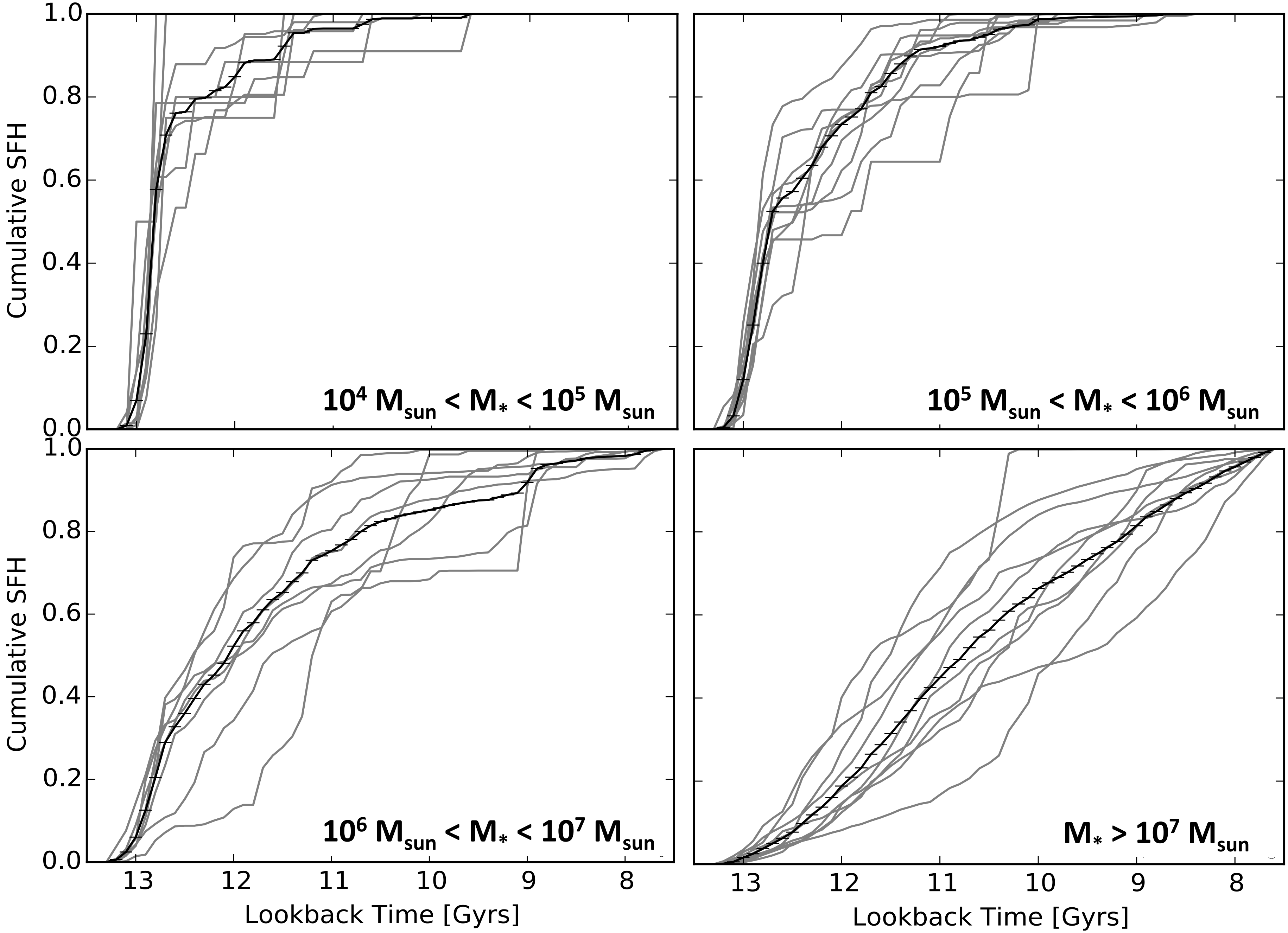
- There is lots of scatter in M_* and M_{vir}
- In agreement with other simulations, observations, and expected low-mass abundance matching relations

Star Formation Histories (SFH)

Cumulative SFH of dwarf galaxies
- Gray area is range of SFHs
- Black line is the average SFH

Weisz 2014 observations of Local Group dwarfs in the same mass range





Cumulative SFH
Lookback Time [Gyrs]
10^4 M_{sun} < M_* < 10^5 M_{sun}
10^5 M_{sun} < M_* < 10^6 M_{sun}
10^6 M_{sun} < M_* < 10^7 M_{sun}
M_* > 10^7 M_{sun}

New initial conditions run with ART by Anatoly Klypin and Kenza Arraki

All implemented physics is included:
Supernovae
Radiation Pressure
Photoionization

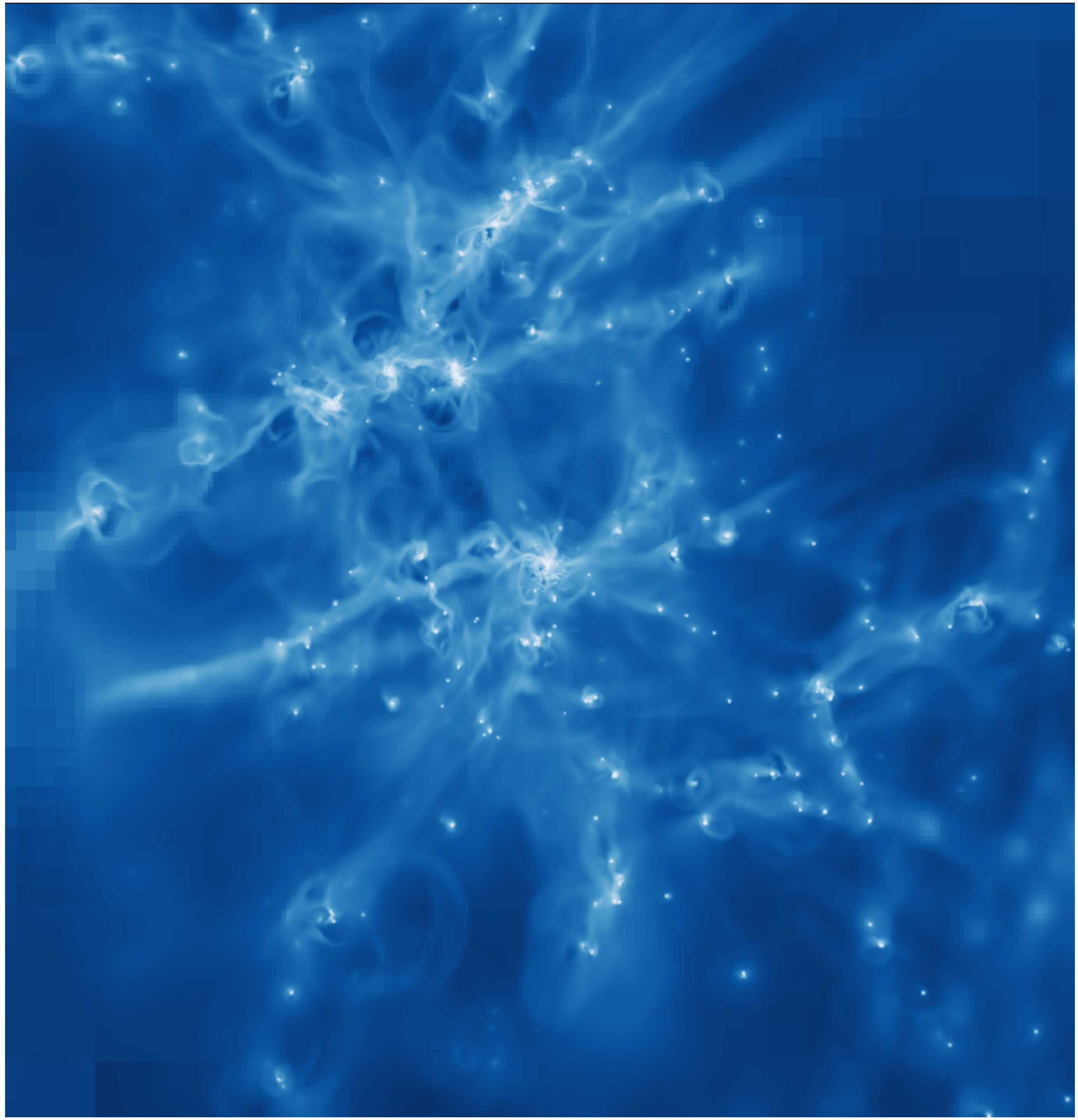
Box = 100 /h Mpc

DM mass = $2x10^5$ M_{sun}

Resolution = 60 pc

No specific environmental selection

Run down to z=0



Conclusions

- Vela simulations are high-resolution hydro runs of MW-mass galaxies and their satellites down to redshift one
- Including Radiation Pressure (RP) and Photoionization (PH) physics produces a realistic dwarf galaxy population
- Slightly over produces luminous satellites
- Stellar-Mass Halo-Mass function has a large spread in M_*

Upcoming:

Vela4 simulations including SNe, RP, & PH
New ICs, larger box, run down to z=0

Thanks to the Blue Waters Graduate Fellowship and the yt project