Blue Tides
On BlueWaters

"The first galaxies and quasars"

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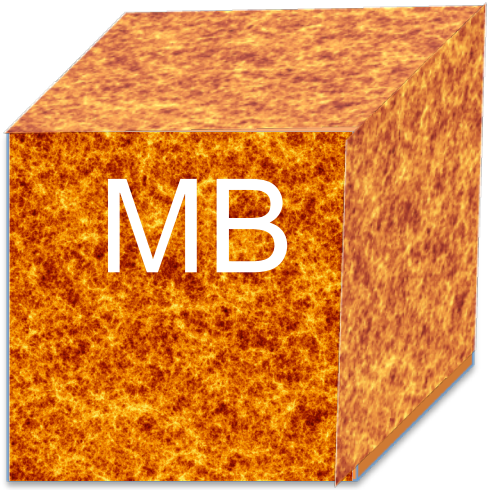
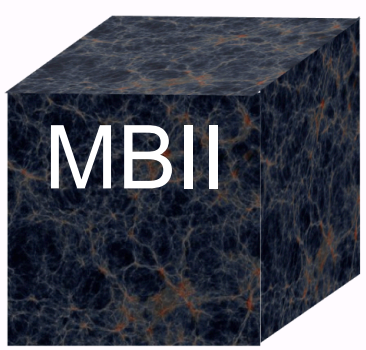
Rupert Croft (CMU)
Nick Battaglia (Princeton)
Mark Straka (NCSA)

http://bluetides- project.org

Cosmological Hydro Simulations:



-Code used: PetaGadget (Petapps Cosmology)
-Physics: gravity, SPH, cooling, star formation, feedback, black holes.



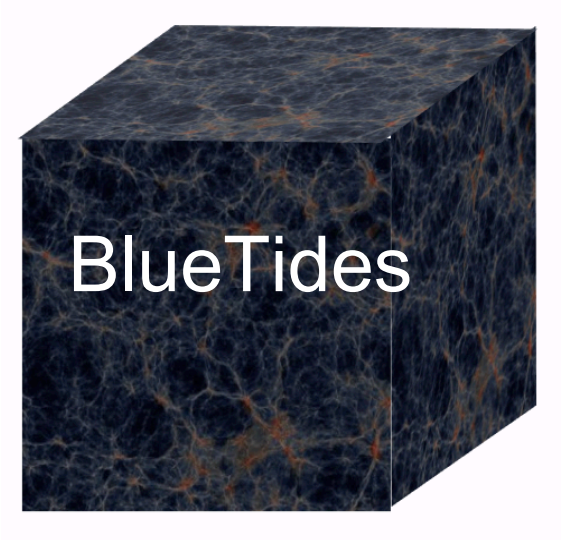
-Particle number:	$2x3200^3$ =64 billion
-Box size:	533 h^{-1} Mpc
- z_{final} =	4.75

$2x1800^3$ =11.5 billion
100 h^{-1} Mpc
- z_{final} = 0 (biggest SPH vol)

- Runs using Kraken at NICS (>100k compute cores).

Team: N. Khandai,Y. Feng, C.DeGraf R. Croft, V. Springel, E. Tucker

Cosmological Hydro Simulations:



-Code used: MPGadget (Petapps Cosmology)
-Physics: p-SPH, H2 +cooling, star formation, feedback, black holes, Patchy Reionization.

WHOLE BW run

-Particle number: $2x7040^3$ = 0.7triillion
-Box size: 400 h^{-1} Mpc
- z_{final} = 7 (8)

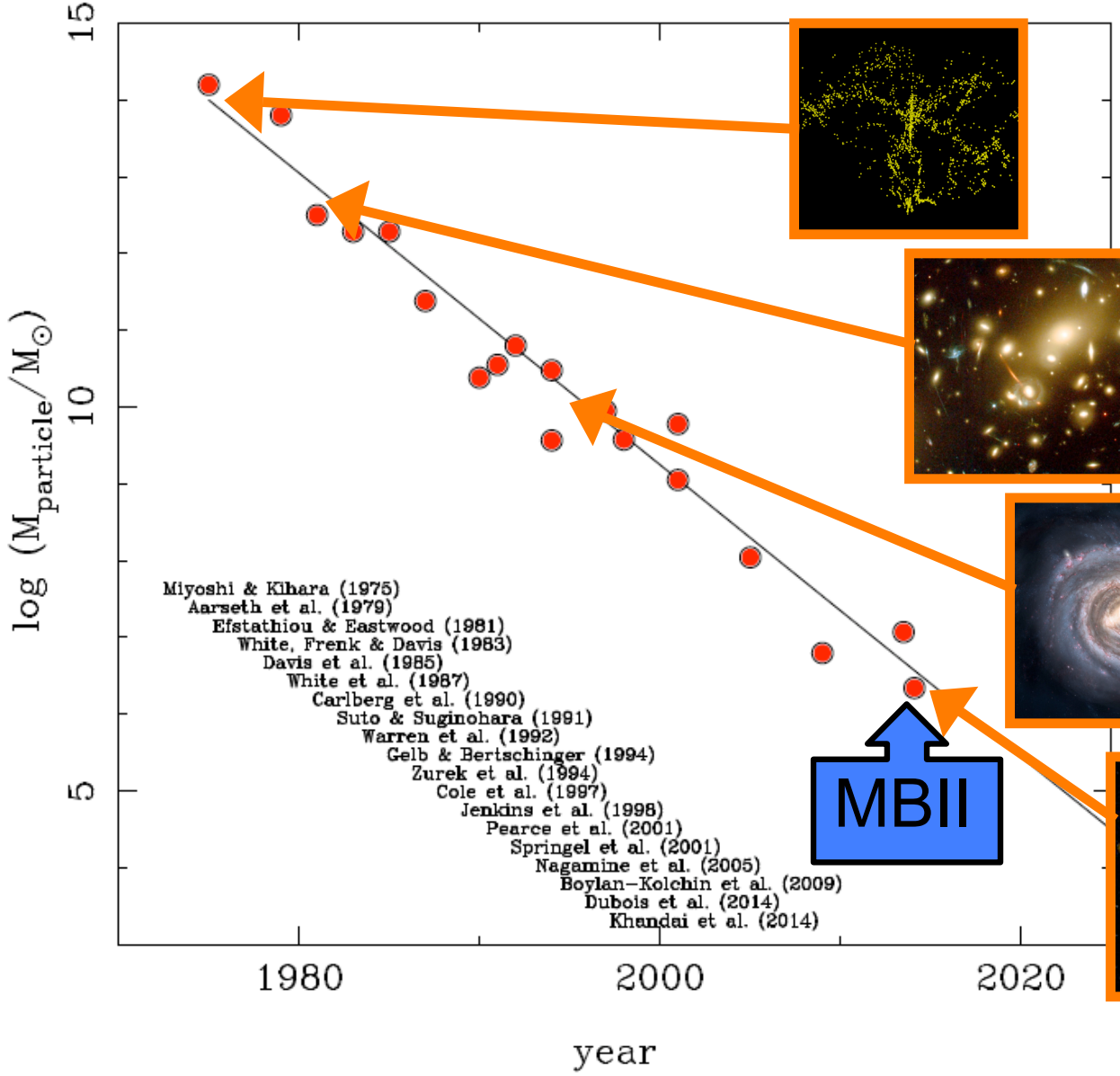
-Snapshots: 86 x (47 TB each)

- Run using BlueWater at NCSA (648k compute cores).

Team:, Y. Feng, DM, R. Croft, S. Bird, Battaglia

We resolve galaxies across the full mass function

What we can resolve with 100 particles:



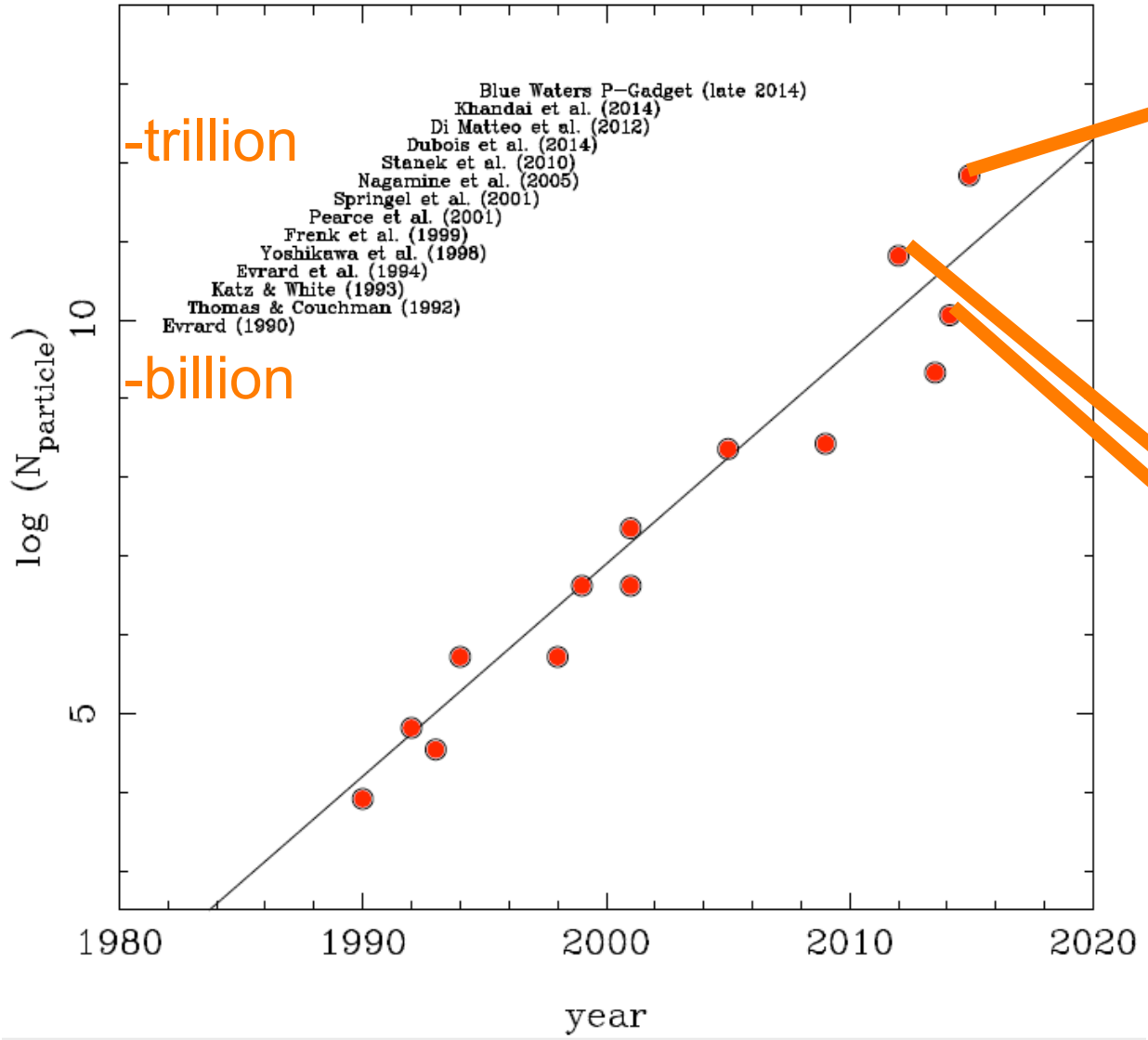
Superclusters of galaxies

Clusters of galaxies

Milky way-sized galaxies

Dwarf galaxies

Algorithms keep up with computational power
Hydro simulations:



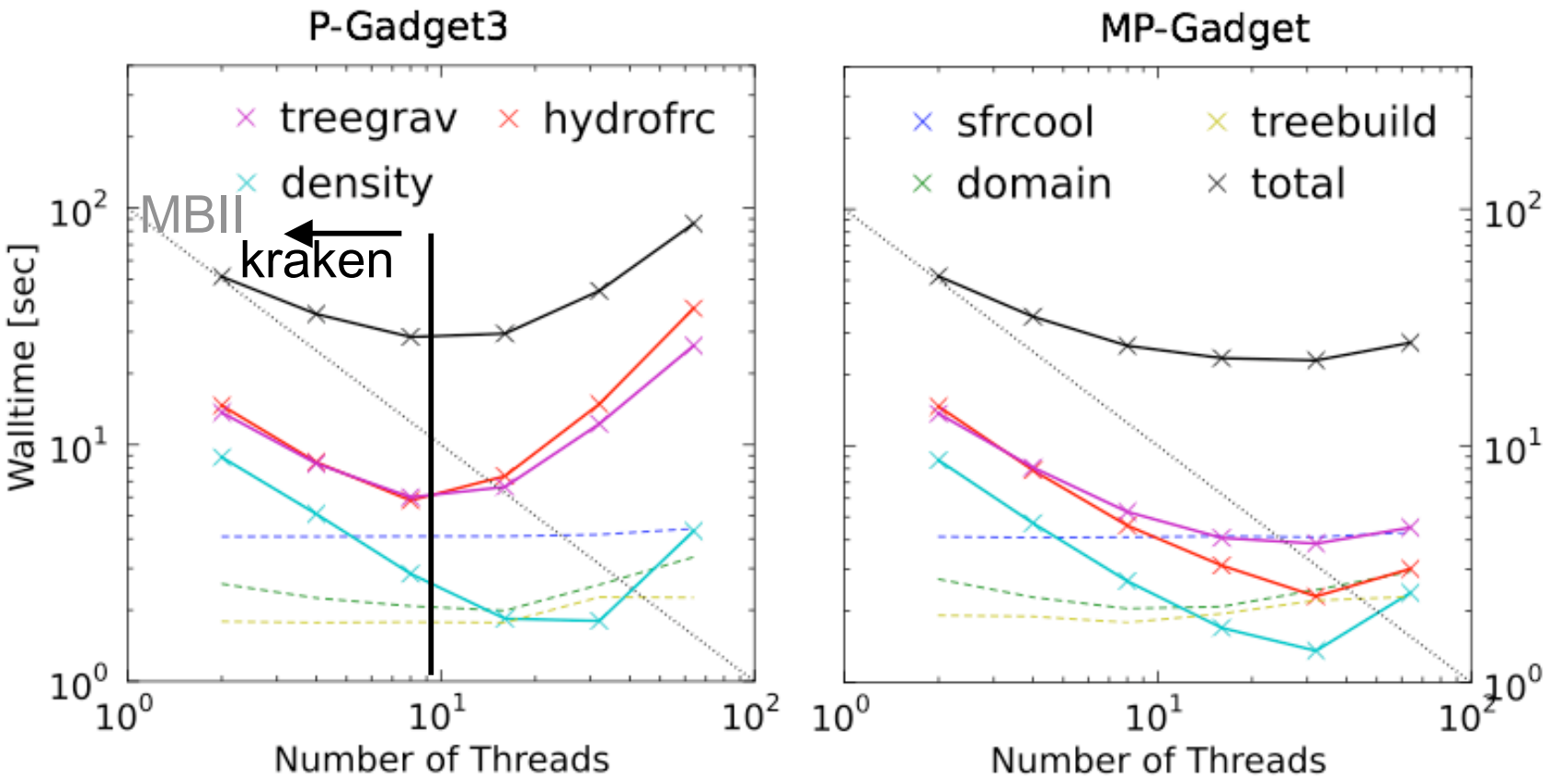
On 0.72m cores
NCSA Cray XE6
Blue Waters

On 112k cores
NICS Cray XT5
Kraken

MP-Gadget:
Petascale cosmological code (P-Gadget3)

Feng et al. 2015a,b, Code paper, in prep.

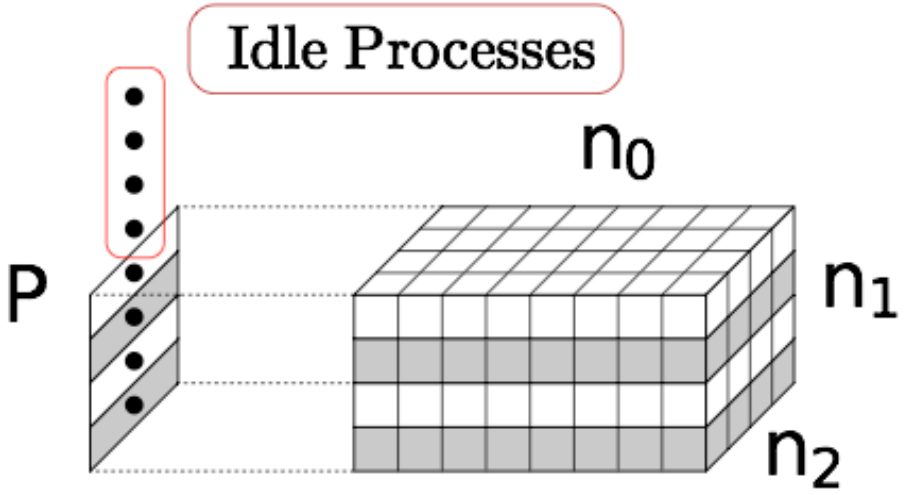
Short range force calculation: increased threading efficiency



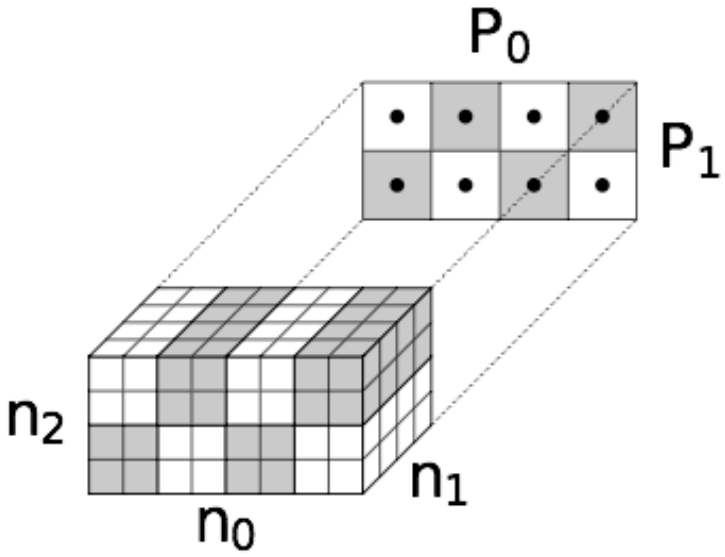
replaced global critical sections with spinlocks (per particle lock) and atomic increment operations → 2 x speed-up

Long range force calculation (PM): New solver:

E.g. 8 processes:



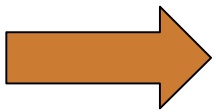
FFTW/P-Gadget3



PFFT/MP-Gadget

Figure from M.Pippig 2013

Blue Tides:
N= 10000 slabs
on 81000 MPI ranks

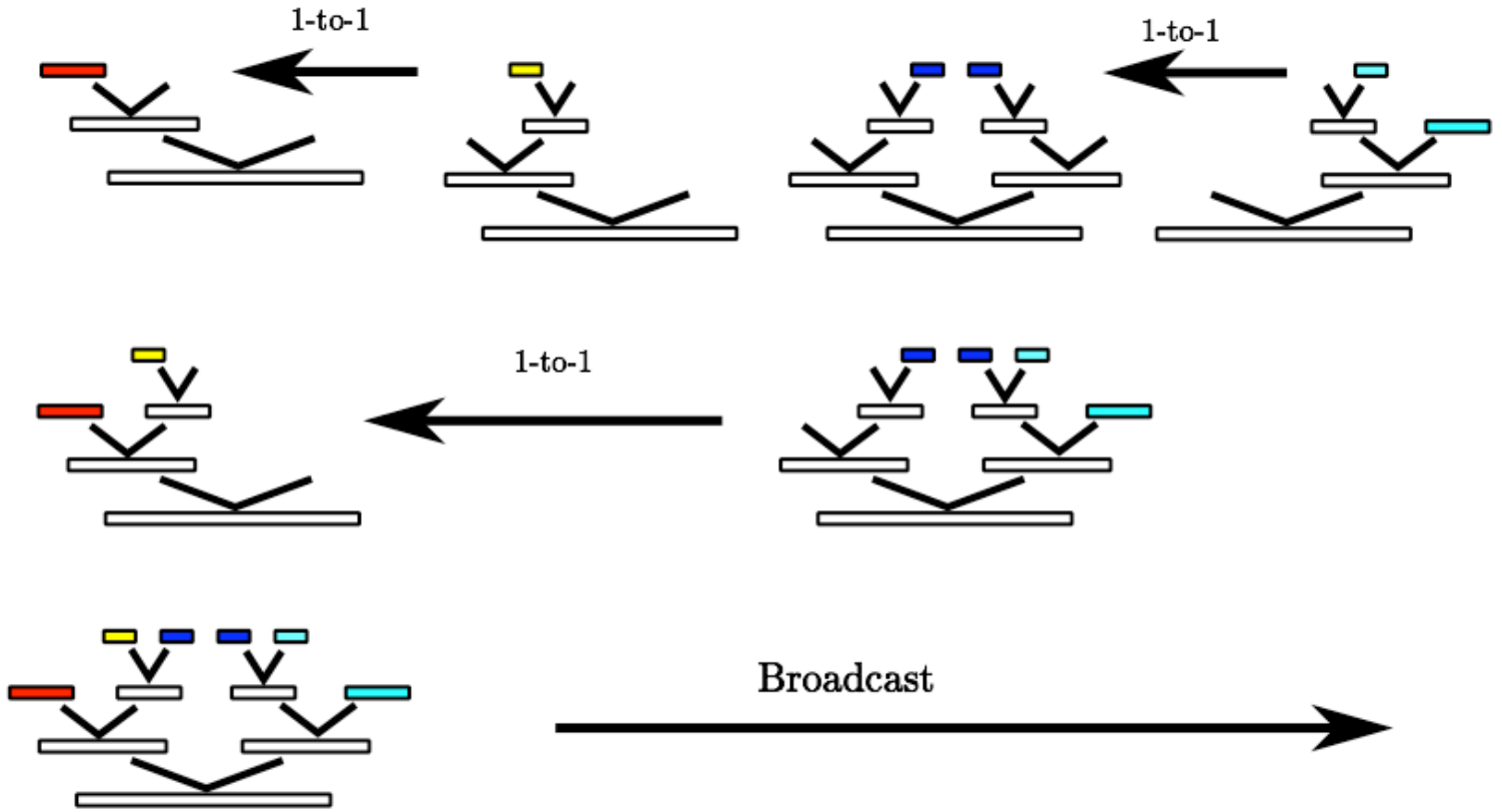


Pencil beam domain decomposition

8 x speed-up

Open Source: Added new Array-execution interface and python binding to PFFT (http://github.com/mpip/pfft)

Domain decomposition: New global domain tree built on root rank.



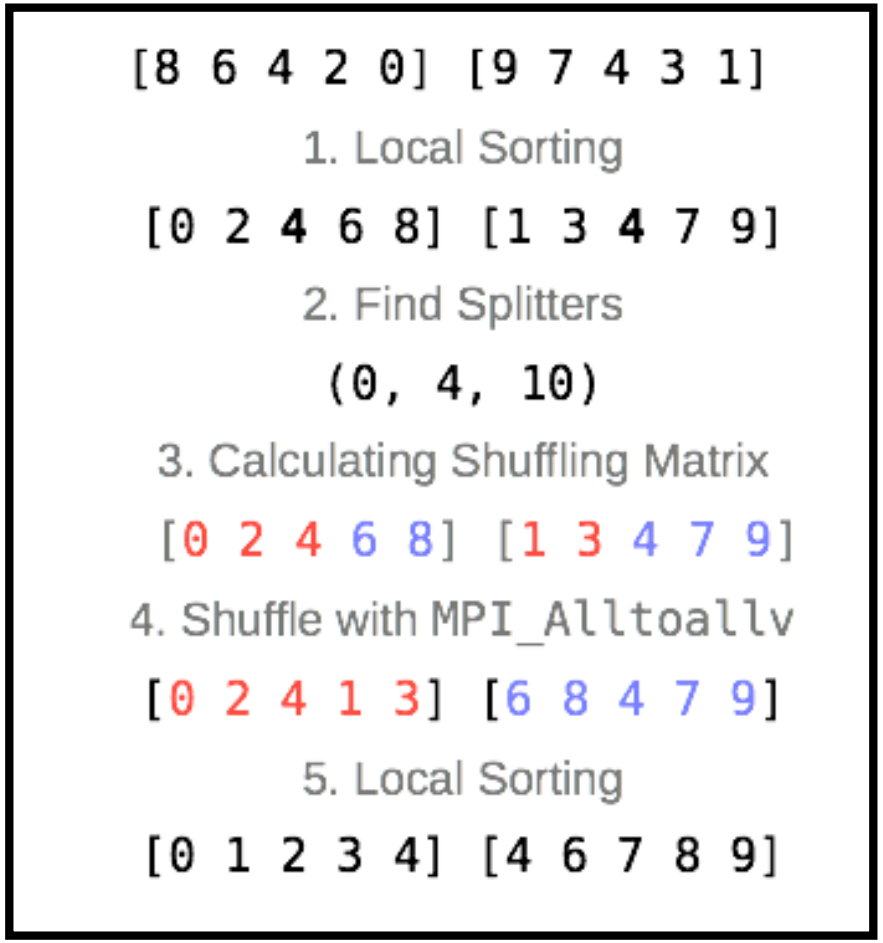
The communication is minimium, with one direction communication from children to root-ranks in each sub-communicator, followed by a global broadcast of the fully merged tree to all computing ranks.

10 x speed-up (comunication)

New parellel sorting module:
MP-Sort: histogram based Sorting: exchange 1 data item exactly once:

Large impact on IO, FoF/galaxy catalogues

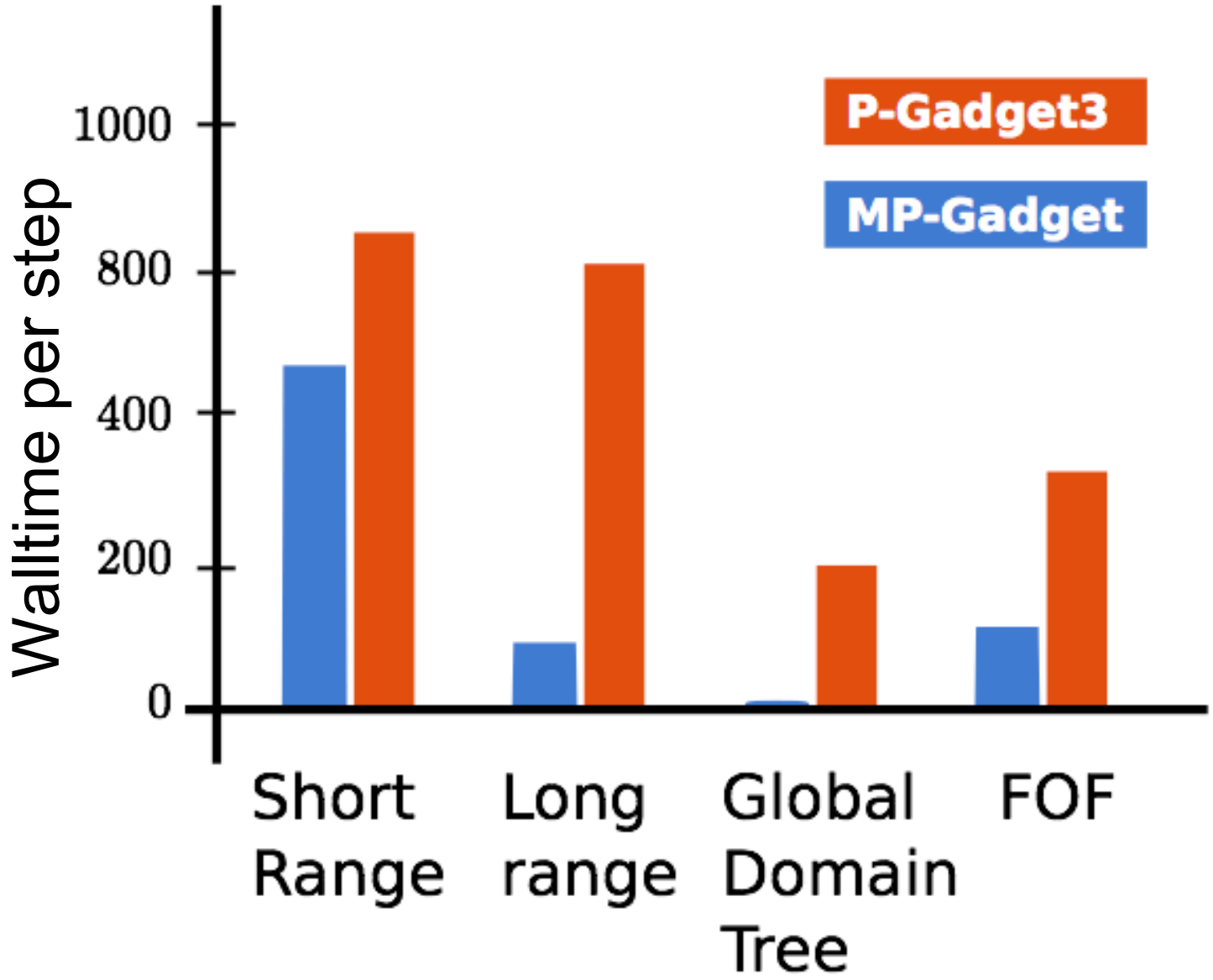
E.g sort 10 items on 2 MPI tasks



"Sorting At Scale on BlueWaters"
Y. Feng, M. Straka, R. Croft, TDM, 2015, CUG2015; Finalist of Best Paper.

Open Source:
http://github.com/rainwoodman/MP- sort

Code performance improvement for BlueTides



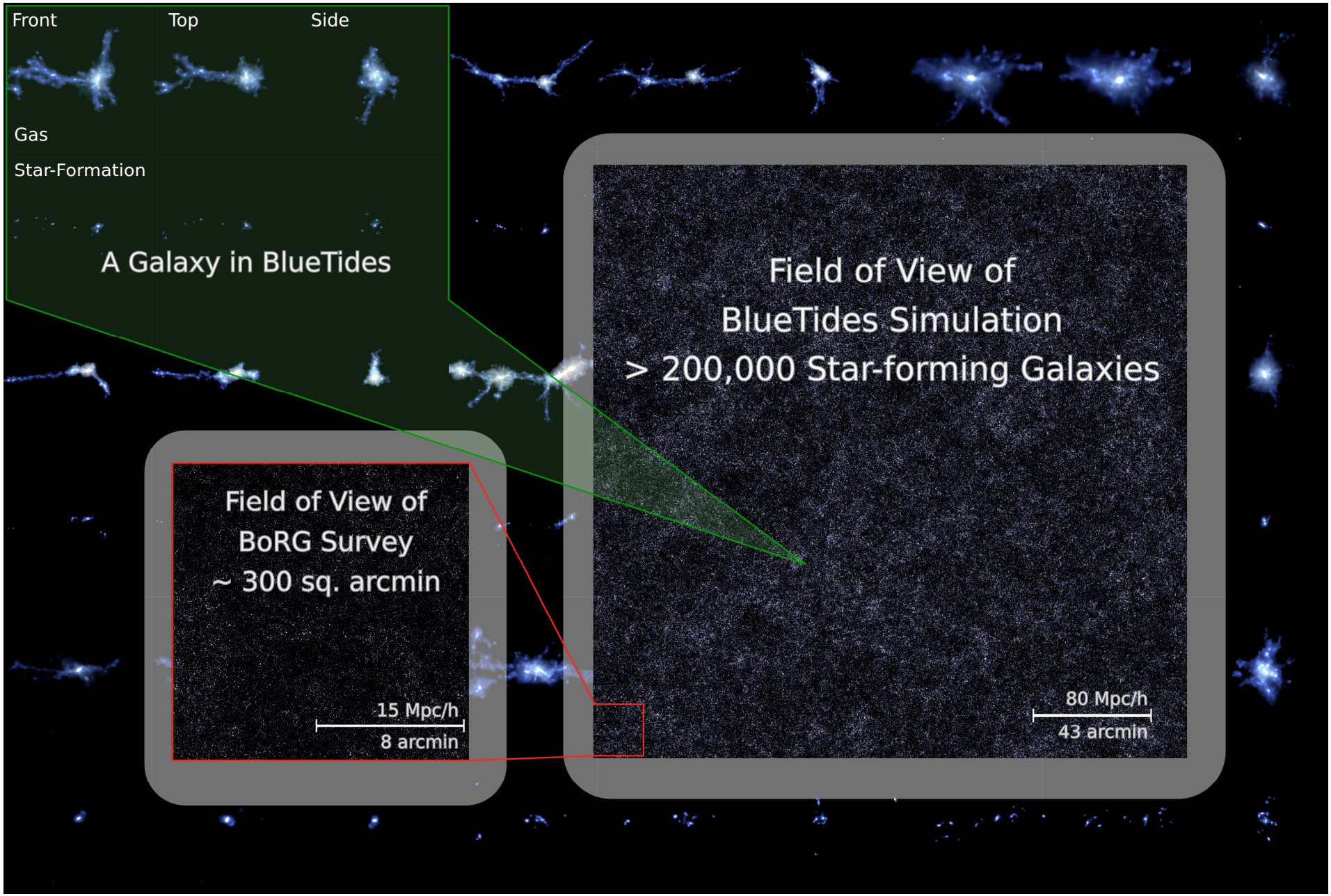
New Physical Modeling

- P-SPH formulation
- H2 Molecular cooling/ star formation
- Patchy Reionization (introducing spatially dependent UV field, Battaglia et al. ,2013)
- Mass dependent Supernova Wind

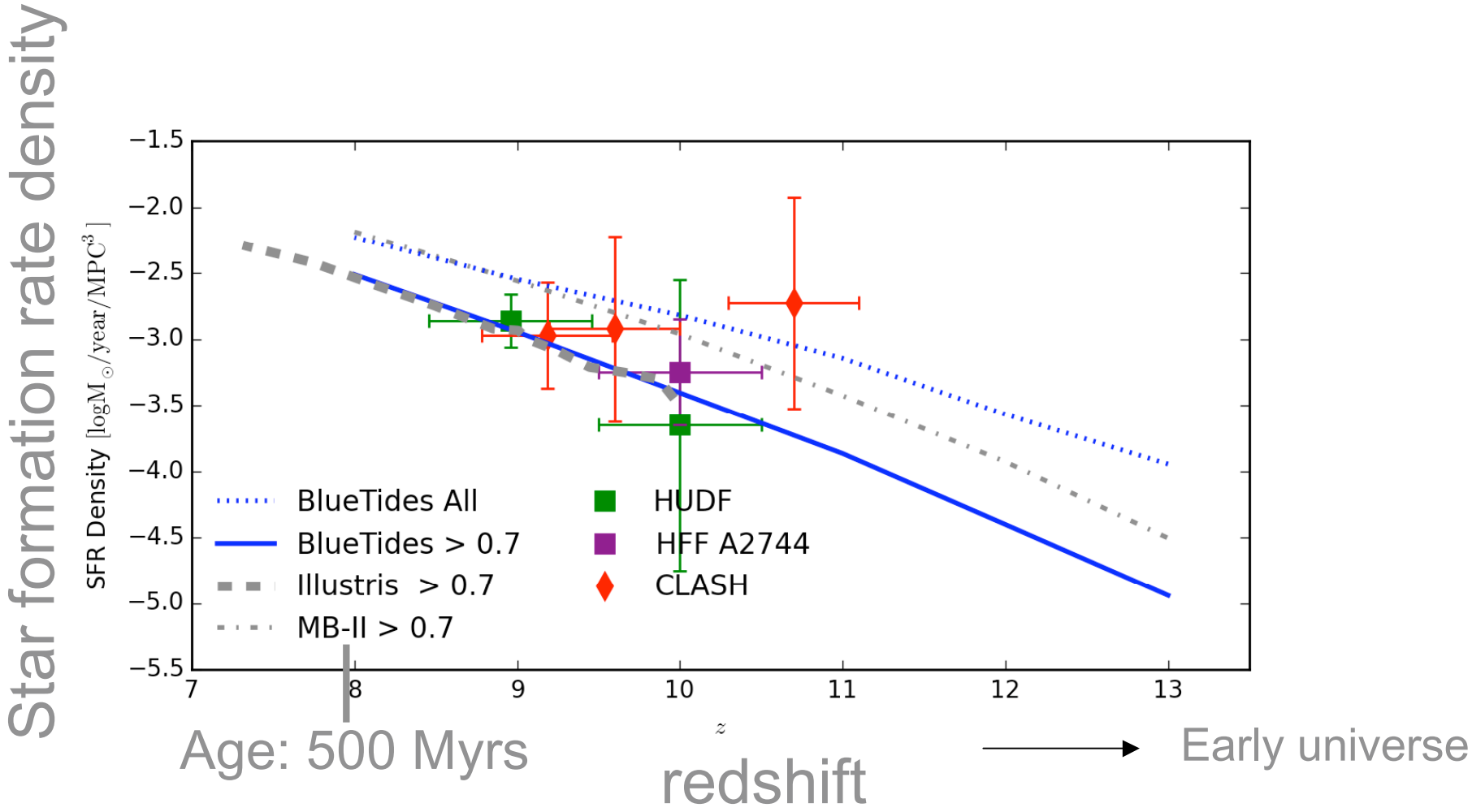
An example Problem :
What are the first galaxies like?

Hubble Legacy Deep Fields: galaxies at z=8-10

Current Hubble Legacy Deep Fields probe tiny regions



BlueTides Simulation: Global SFRD is consistent with current observations.



Feng et al., 2015a

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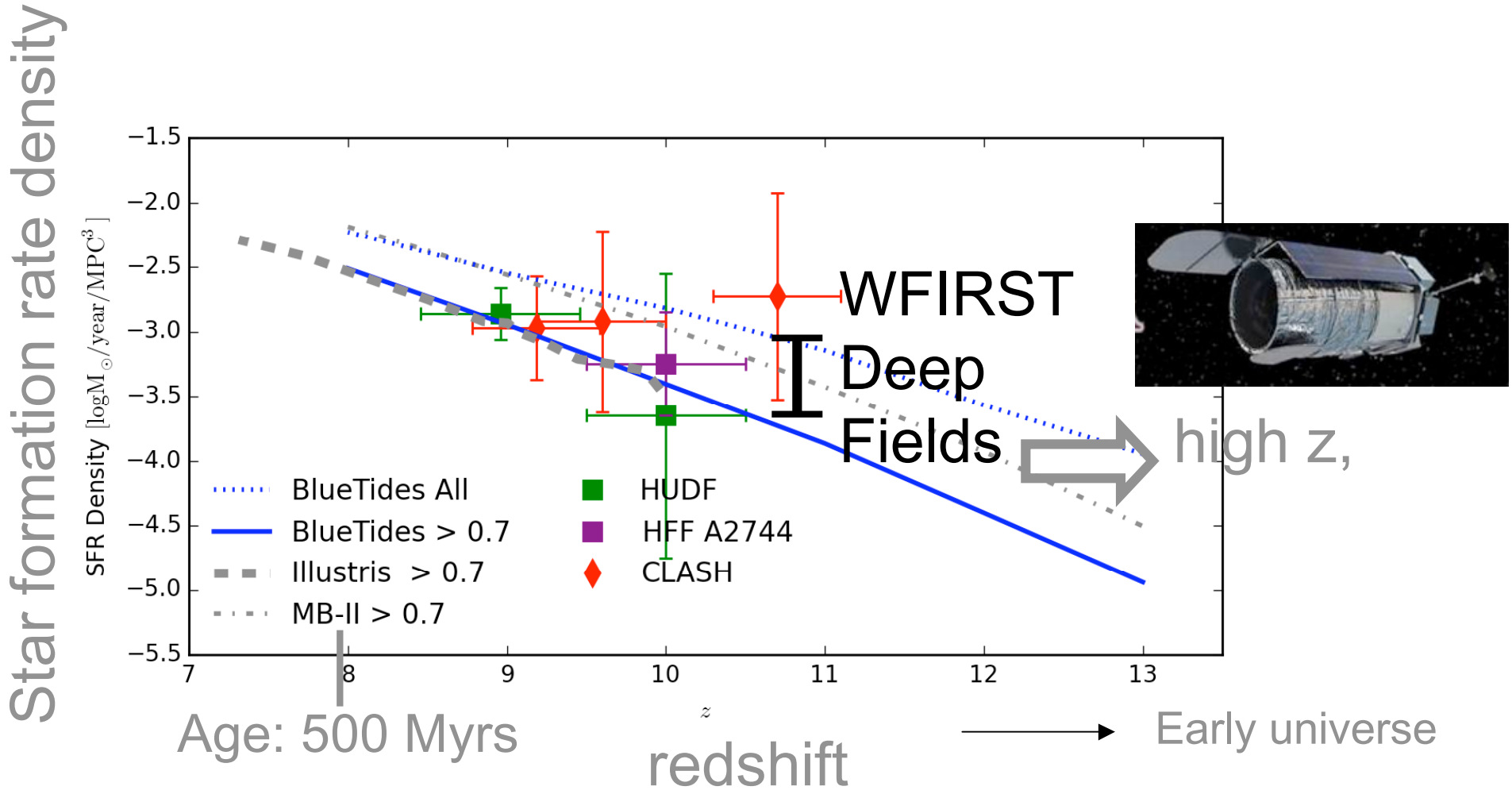
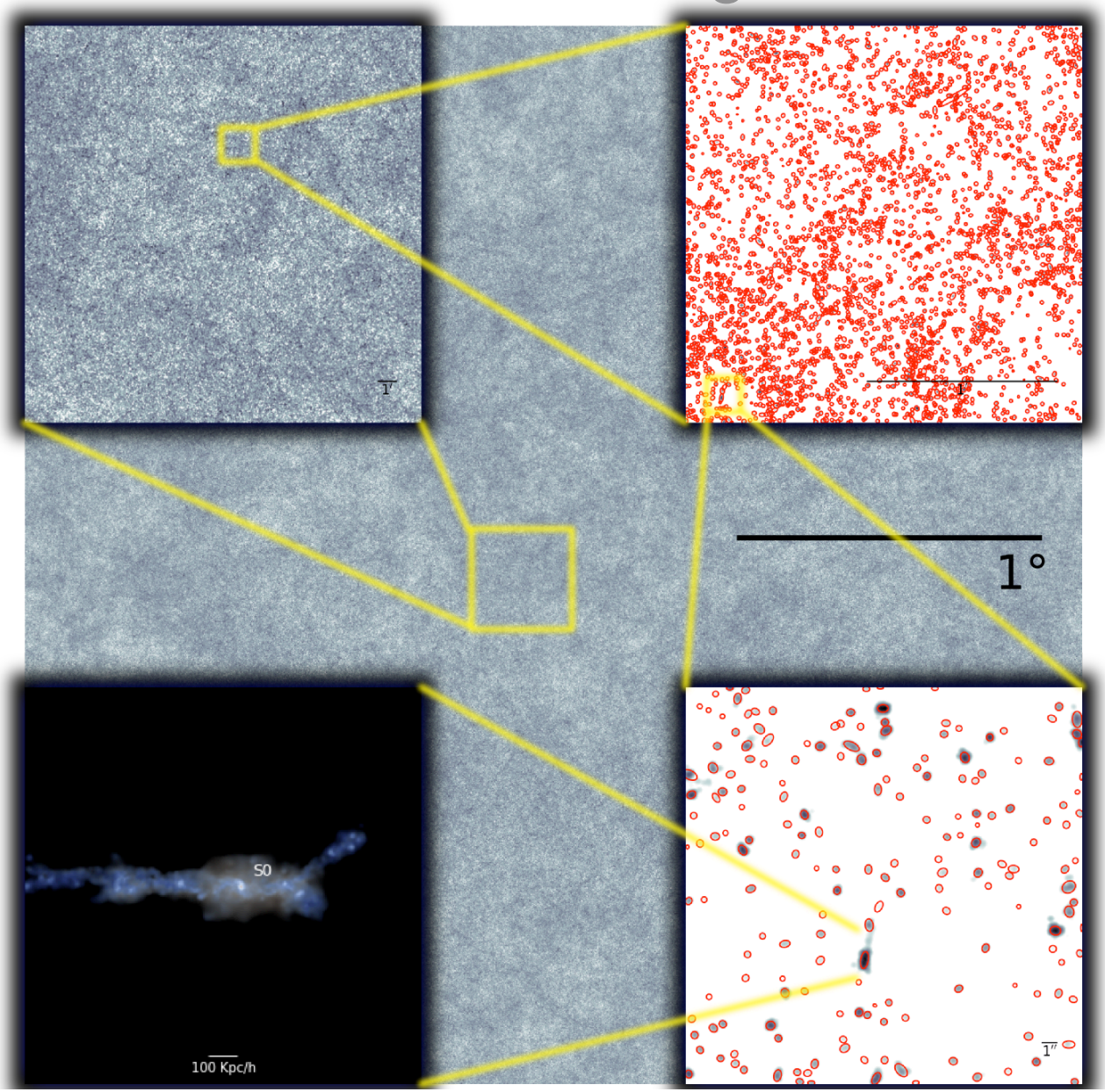
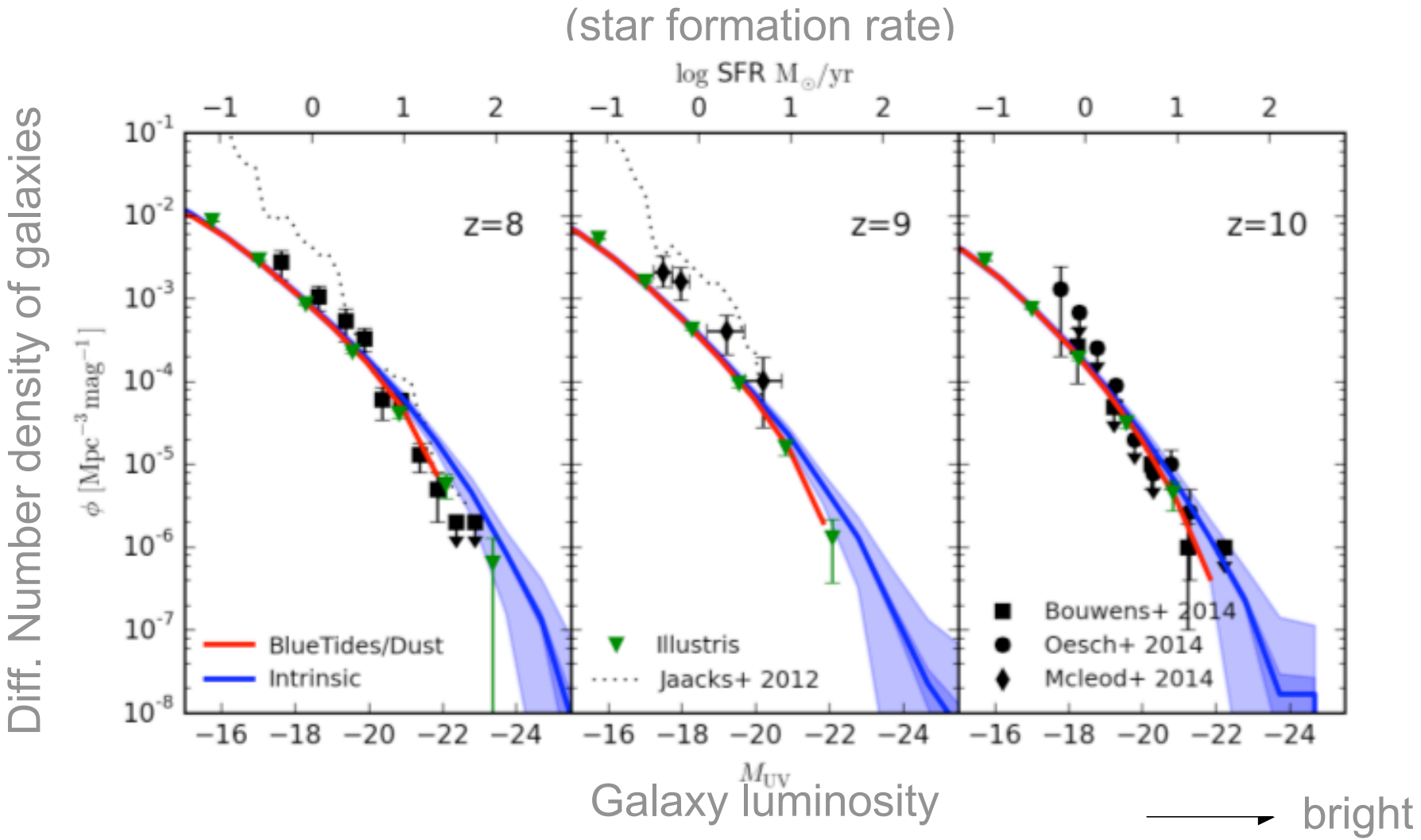


Simulations like Observations: Create Mock Fields. Source extract detection to find galaxies



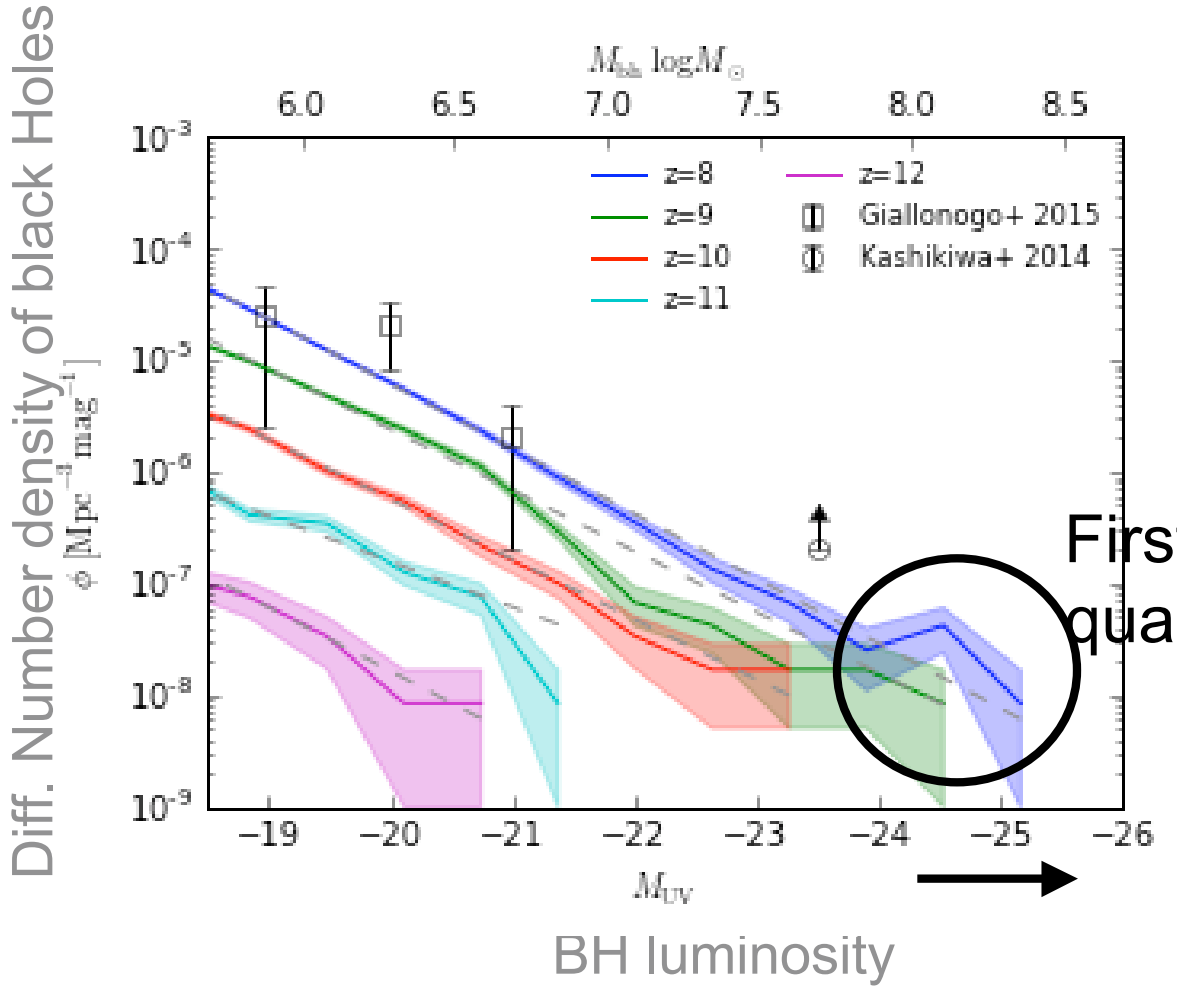
Galaxy Luminosity Function in BlueTides consistent with Hubble Legacy Fields



Feng et al., 2015a

Black Hole/AGN Luminosity Function in BlueTides

Consistent → Predictions for first quasars

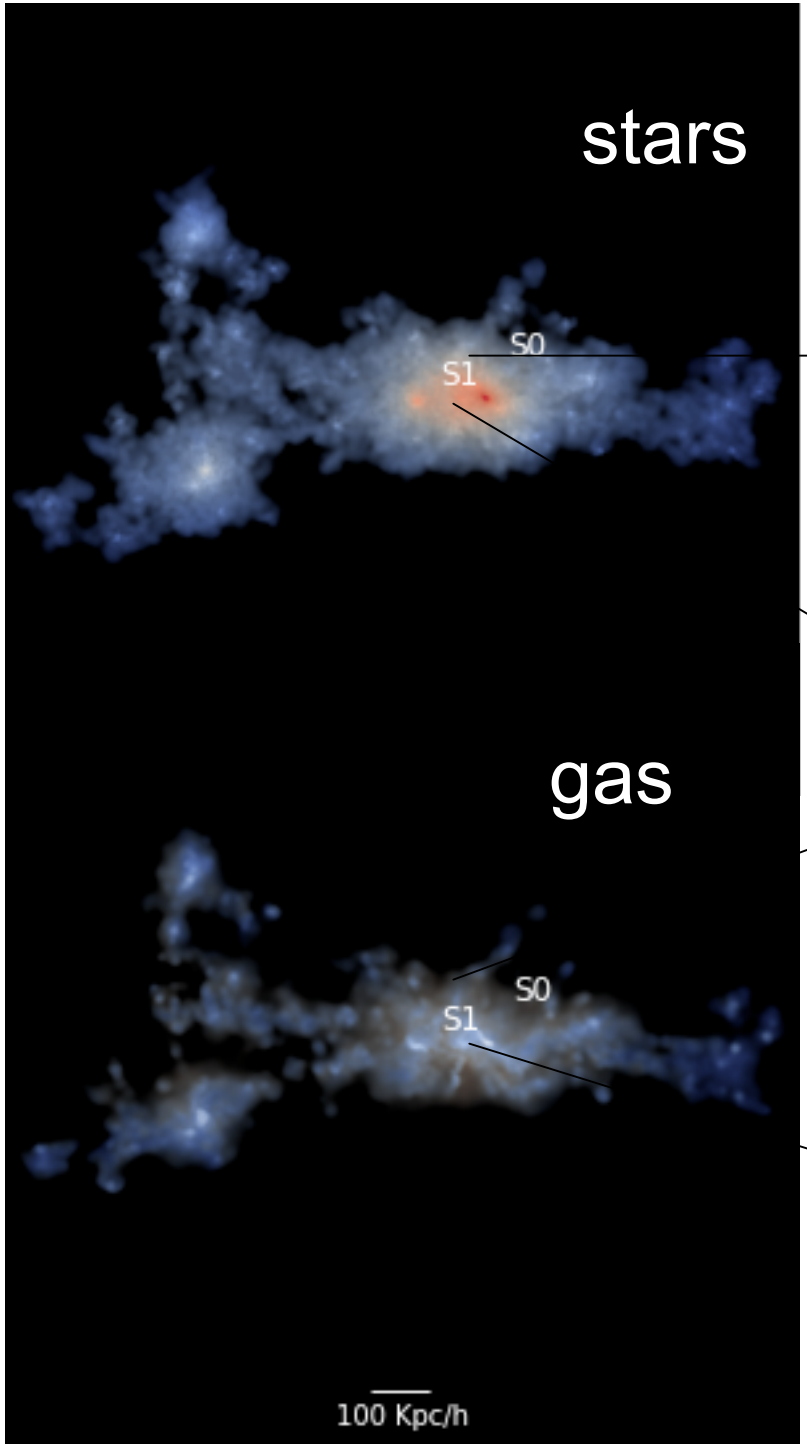


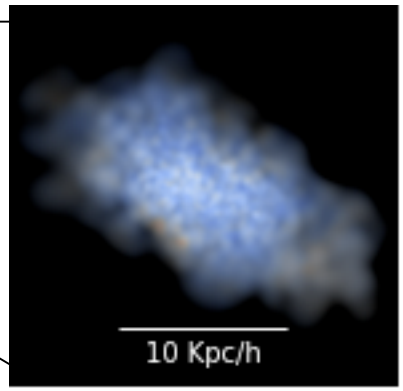
First super-bright quasars

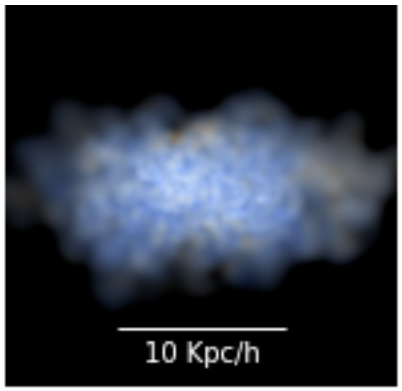
Feng et al., 2015a

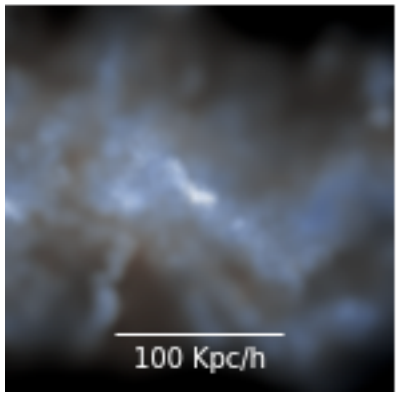
What are the first galaxies like?

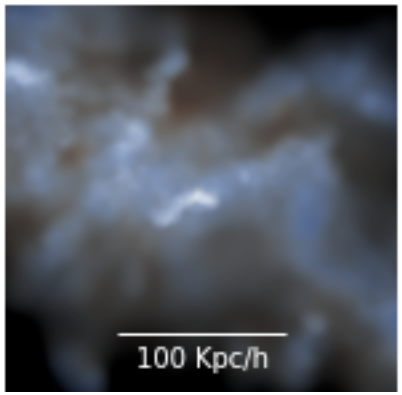
First galaxies are messy….



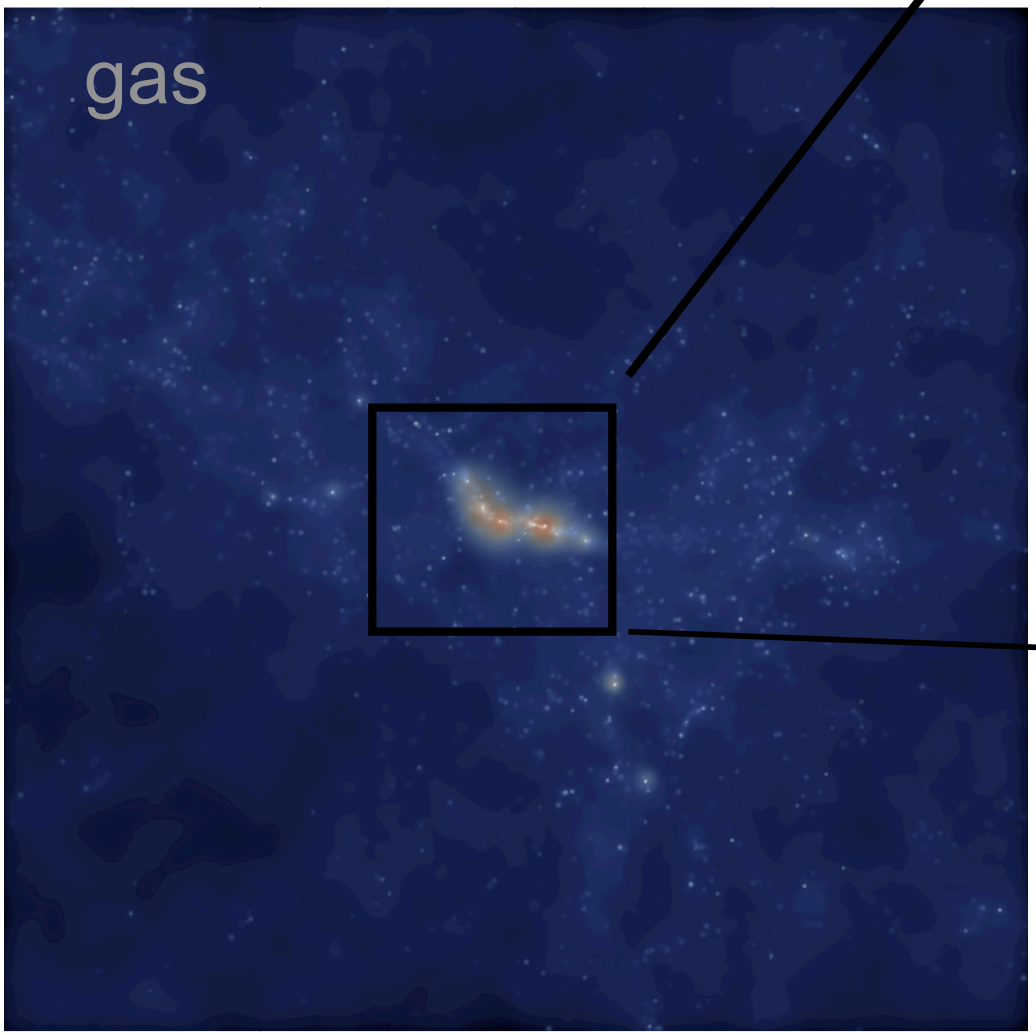


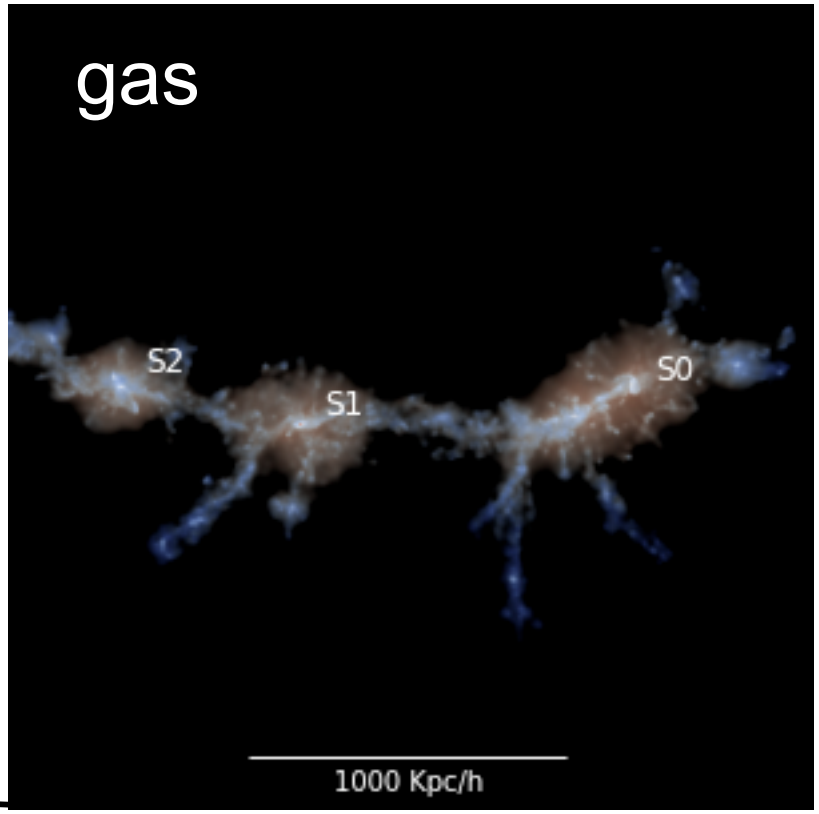


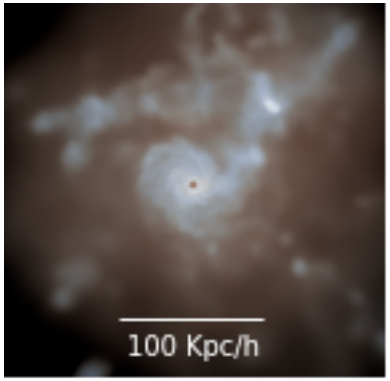


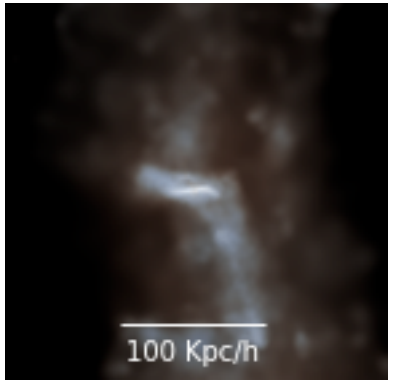


z=8 Most massive (Milky Way) galaxies

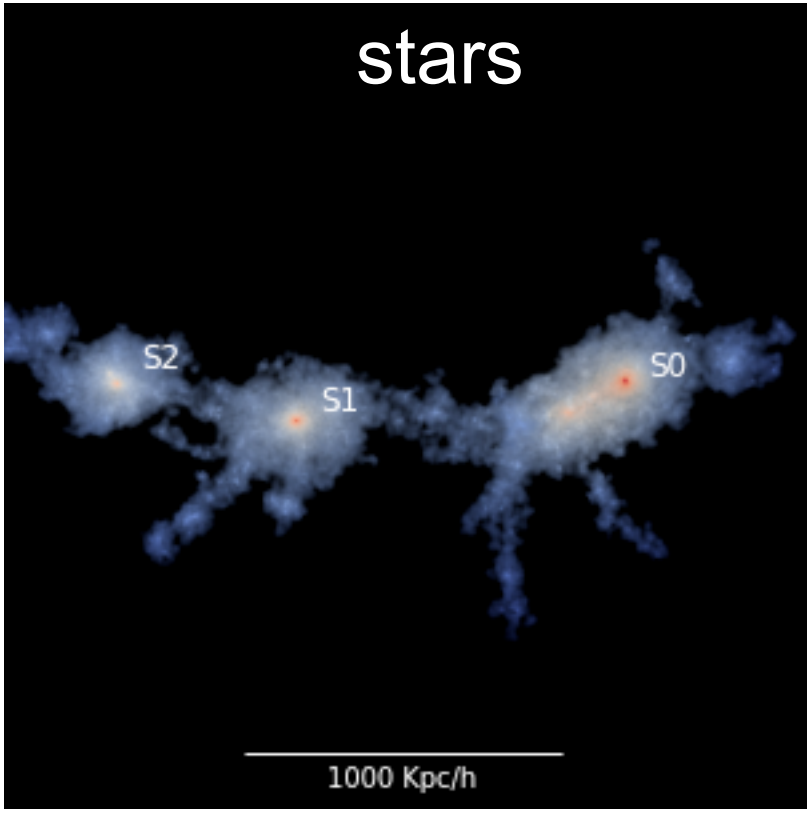


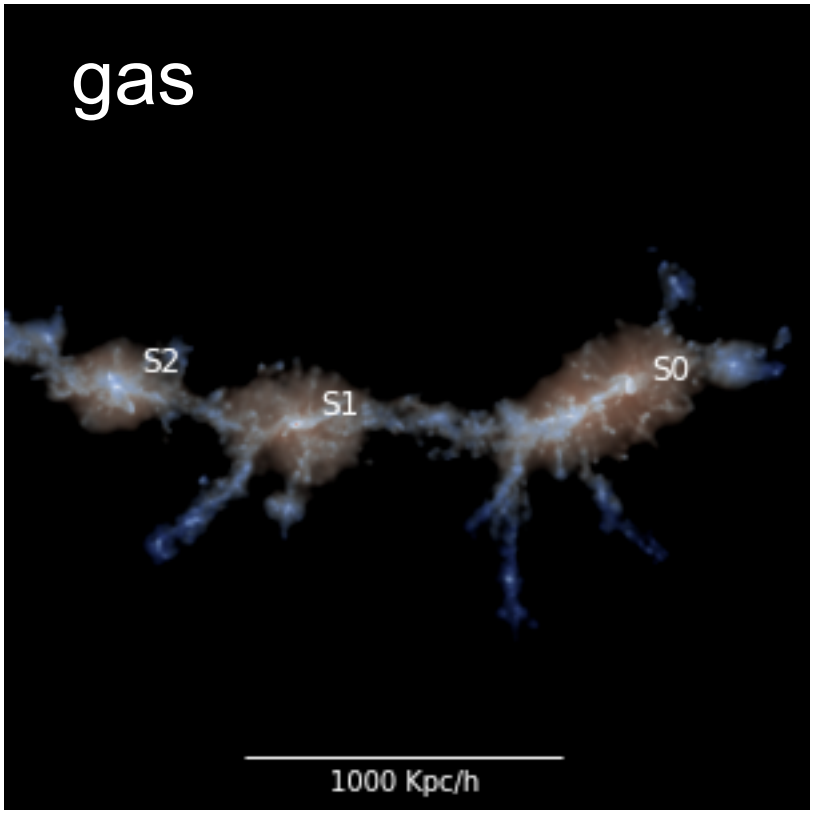


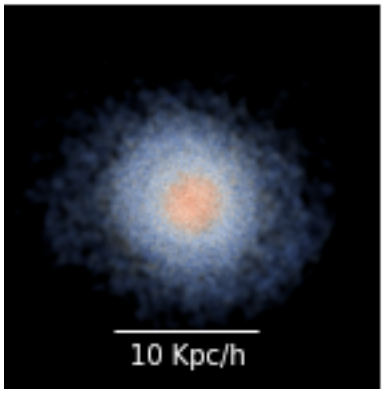


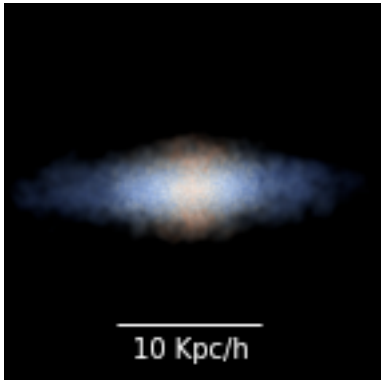


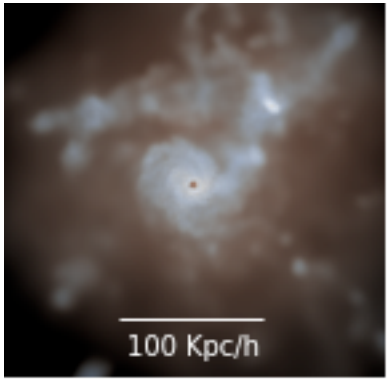
z=8 Most massive (Milky Way) galaxies are disks!

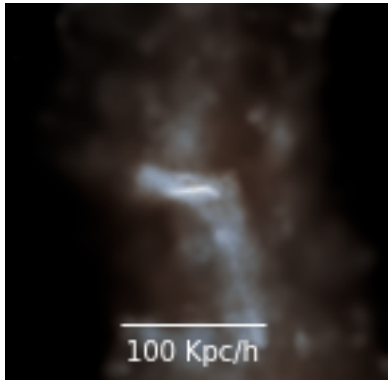




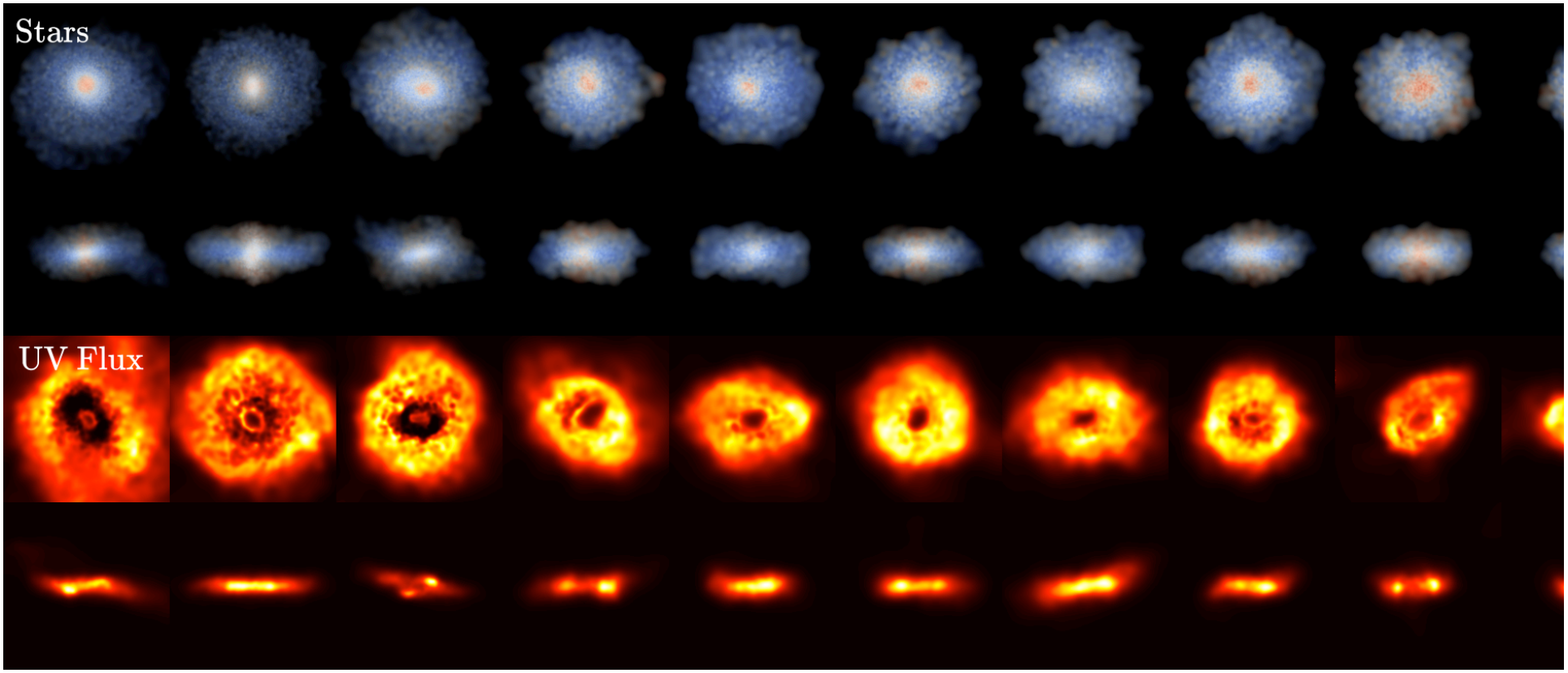




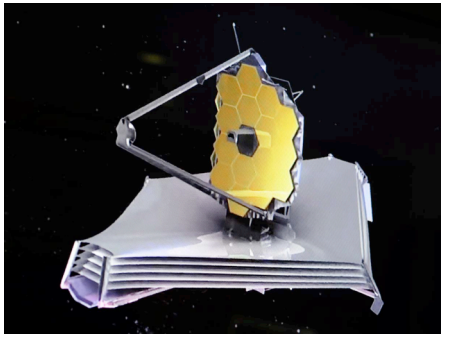




z=8 Milky Way (/Massive) Halos look like disks!



JWST



Feng et al., 2015b

Star formation in BlueTides (subgrid):

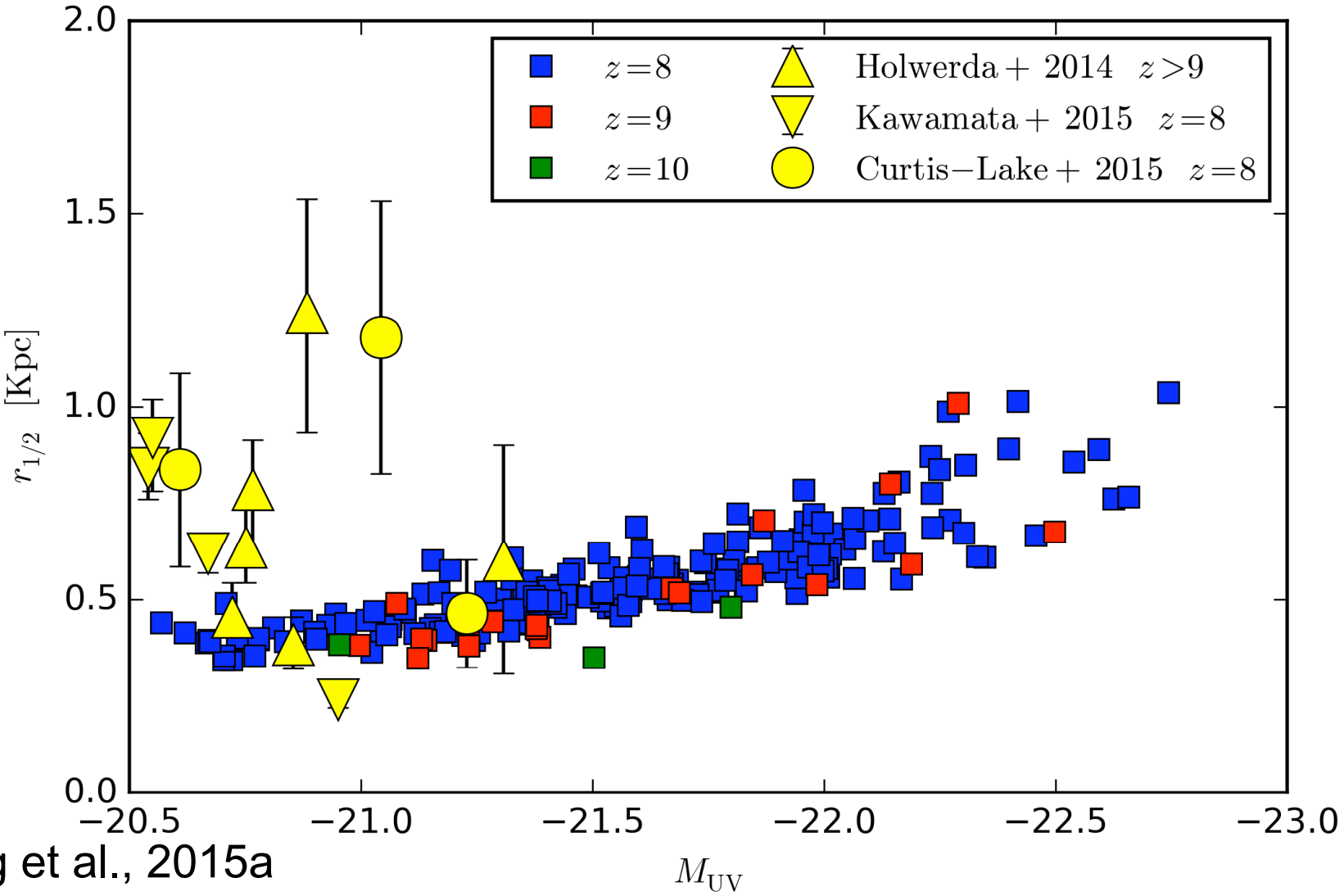
- Multiphase ISM (Springel 2003)

- SFR depends on Metallicity/Molecular Hydrogen (Krumolz &Gnedin 2011)

- Supernova Feedback/wind depends on Halo Mass (e.g. Okamoto 2010)

BH subgrid model as before

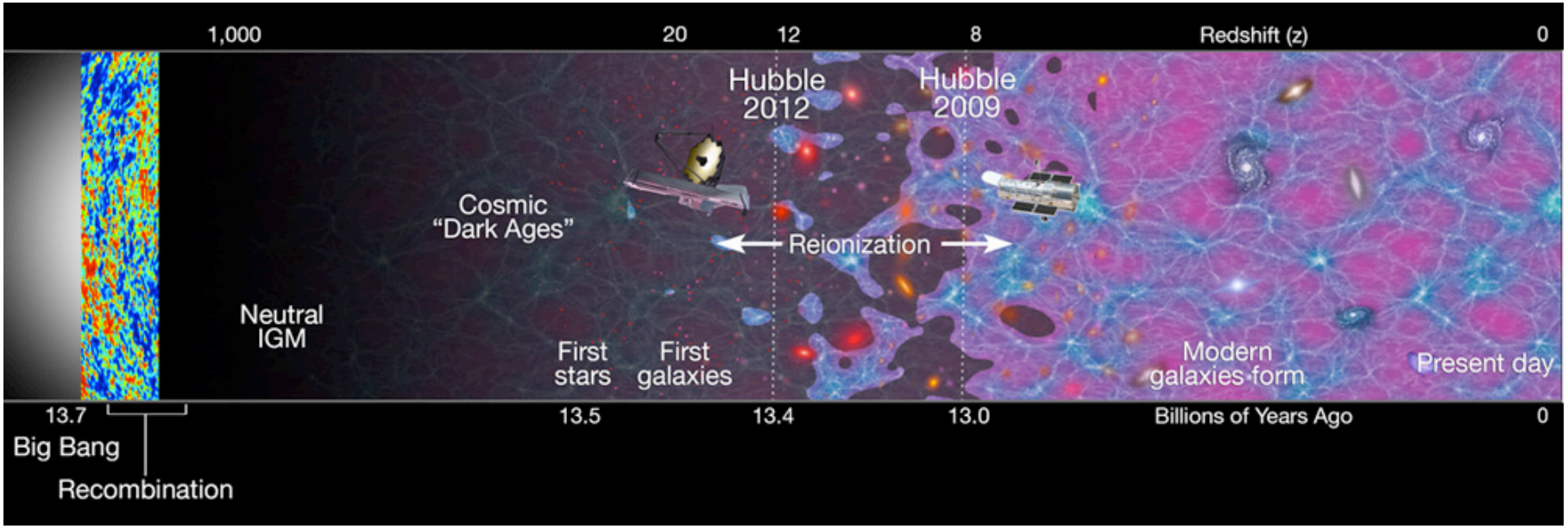
The sizes of galaxies in BlueTides are consistent with HST observations --> larger disks in bright galaxies



Feng et al., 2015a

What sources reionize the Universe?

Galaxies and AGNs in BlueTides



BlueTides and Re-ionization history of the Universe

Galaxies can reionize the universe for high escape photon fractions. But AGNs can contribute (very?) significantly