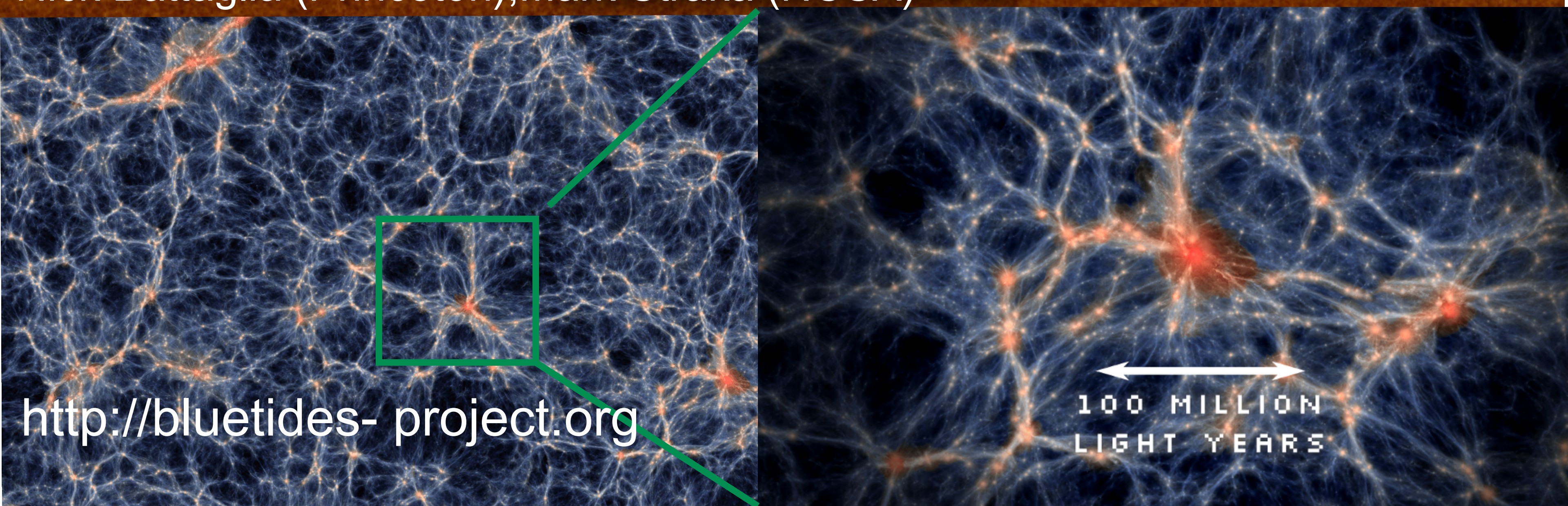
The next quasars and massive galaxies frontier:

The bluetides simulation

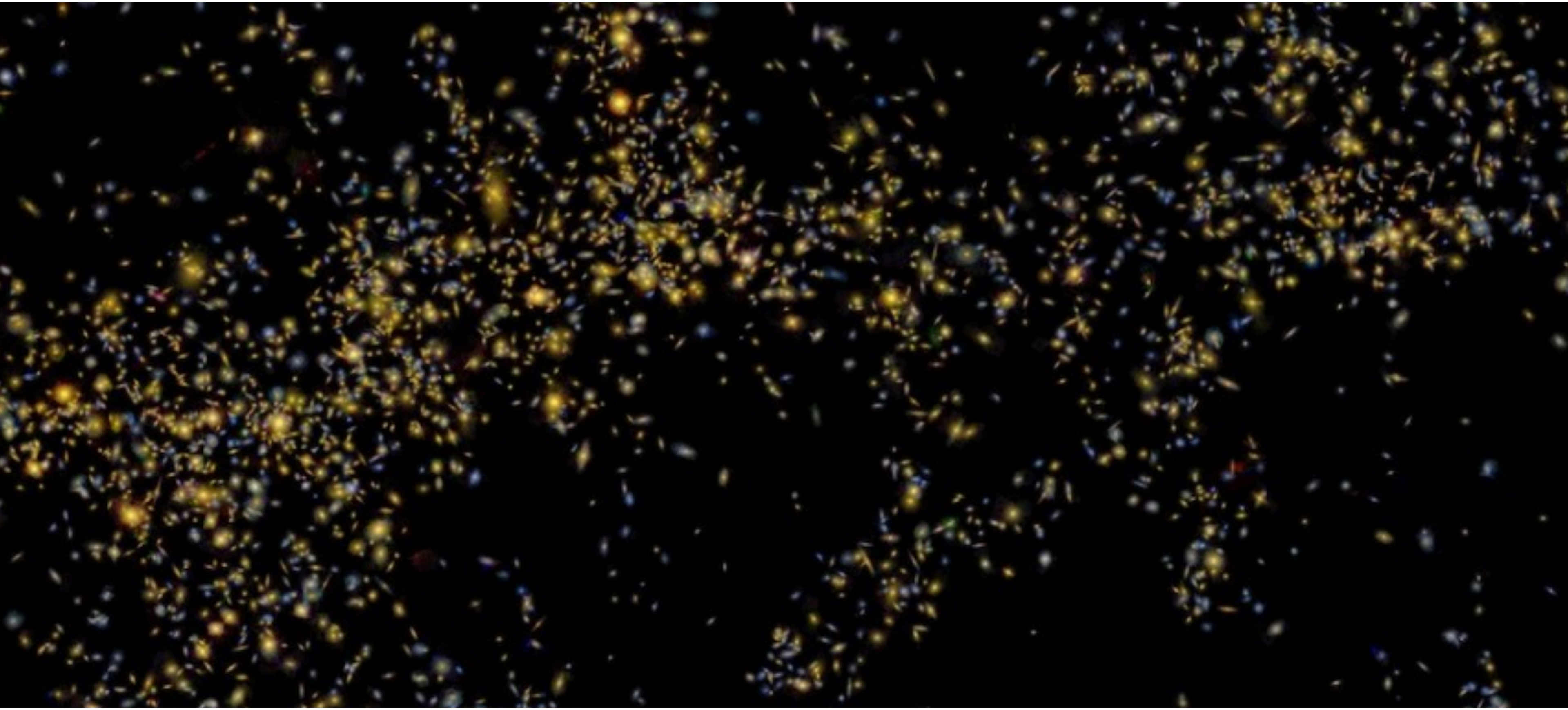
Tiziana DiMatteo (CMU)

Yu Feng (Berkeley), Rupert Croft (CMU), Aklant Bhowmick, Kuan-Wei Hunag, (CMU) Simeon Bird (JHU), Steve Wilkins (Sussex),Ananth Tenneti (CMU) Nick Battaglia (Princeton),Mark Straka (NCSA)



http://bluetides- project.org

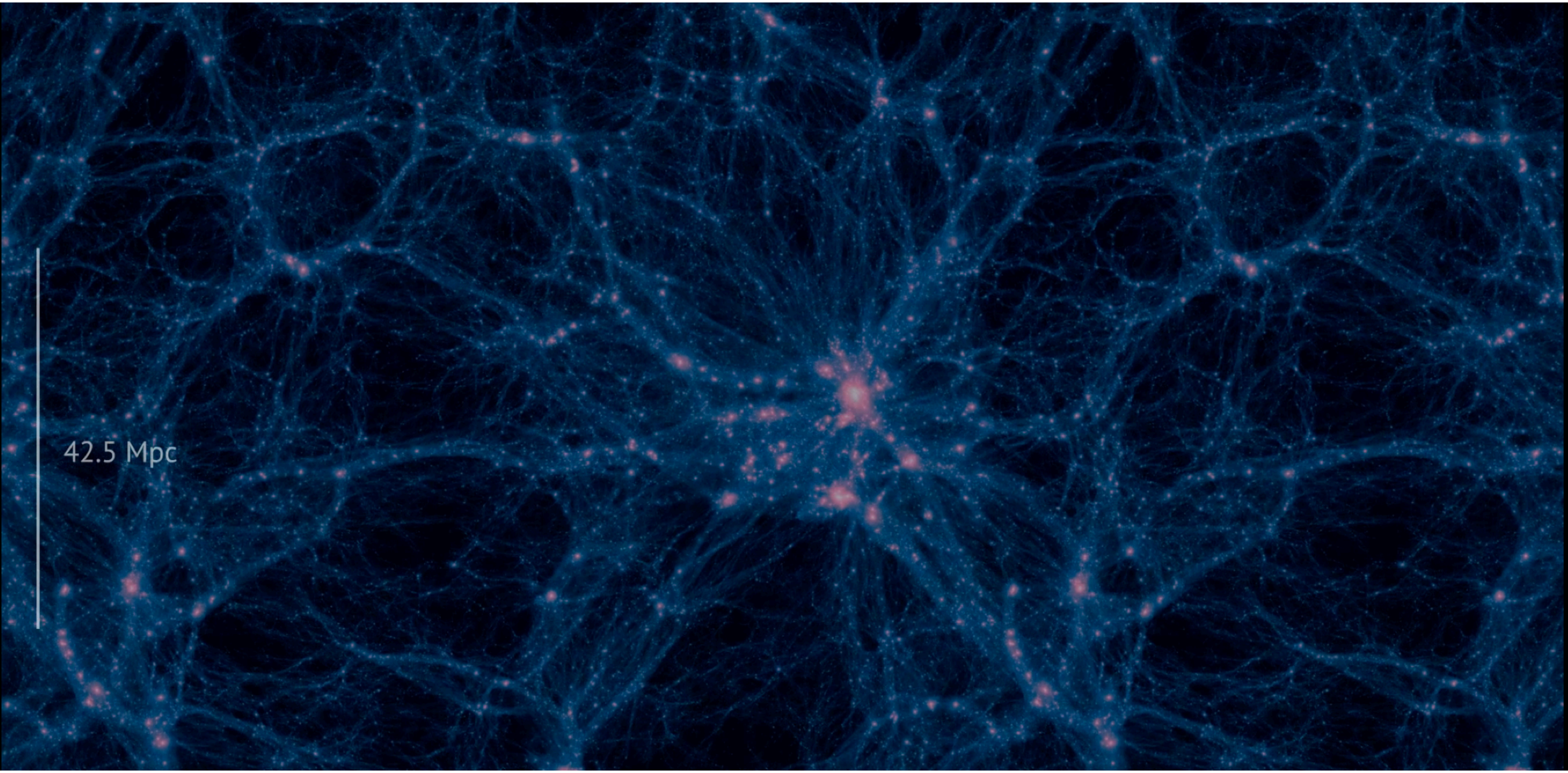
Structure in the Universe



Observations:

Large Sky Surveys

Structure in the Universe

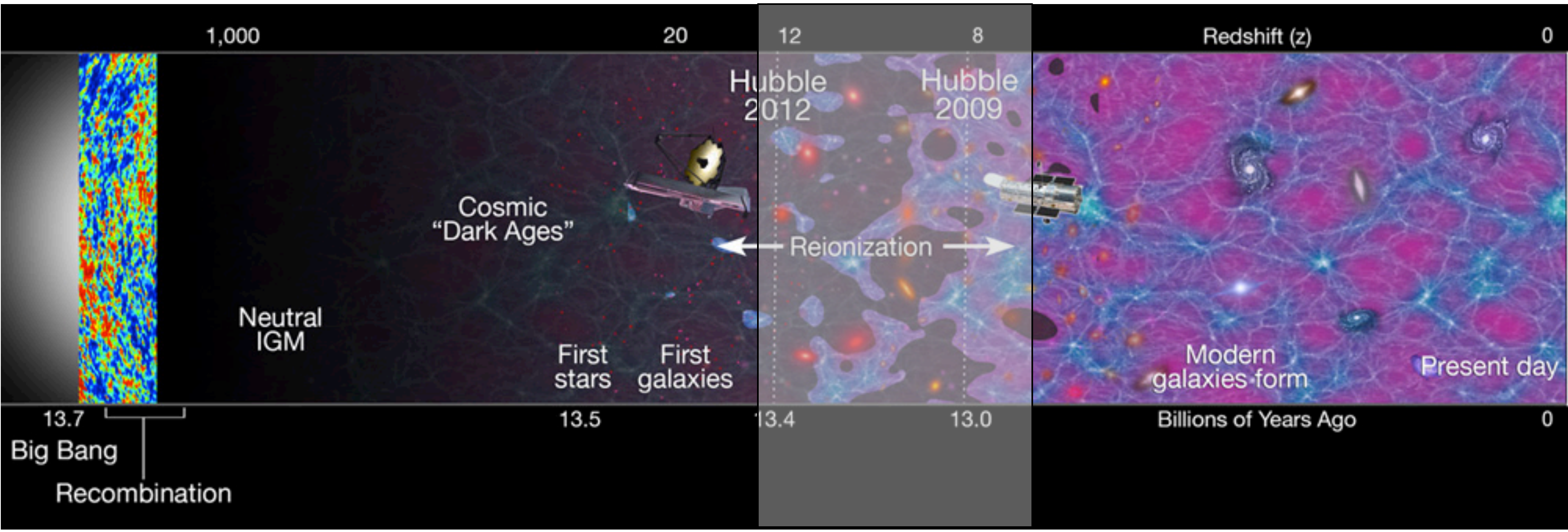


Simulations: 'real' structure

Structure in the Universe

Observations meet simulations

A sketch of Cosmic History



300Myrs 800Myrs

z =8 **z =7**

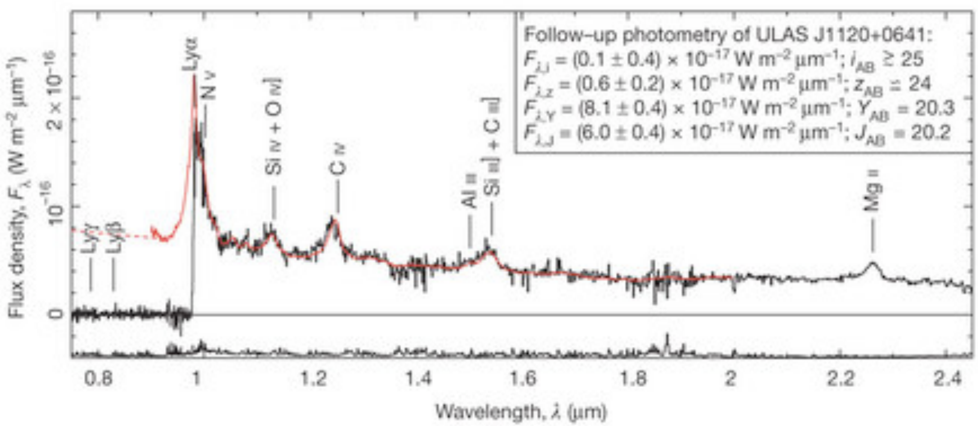
Z > 7

Observations

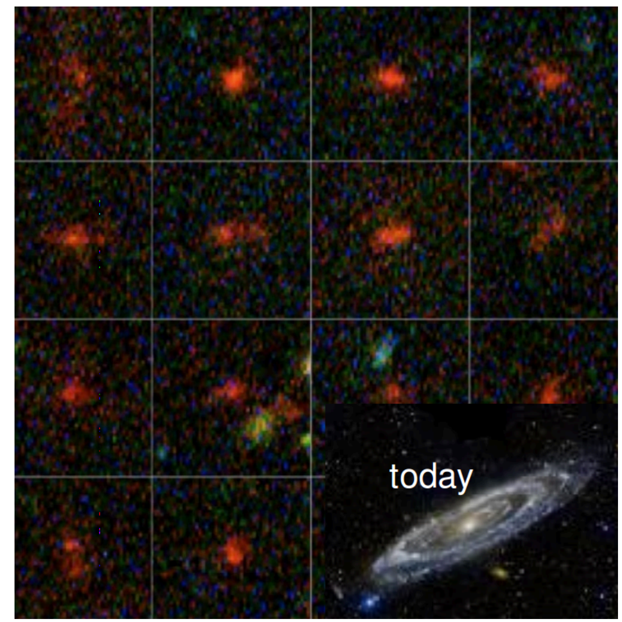
The first 800 million years

Z > 7

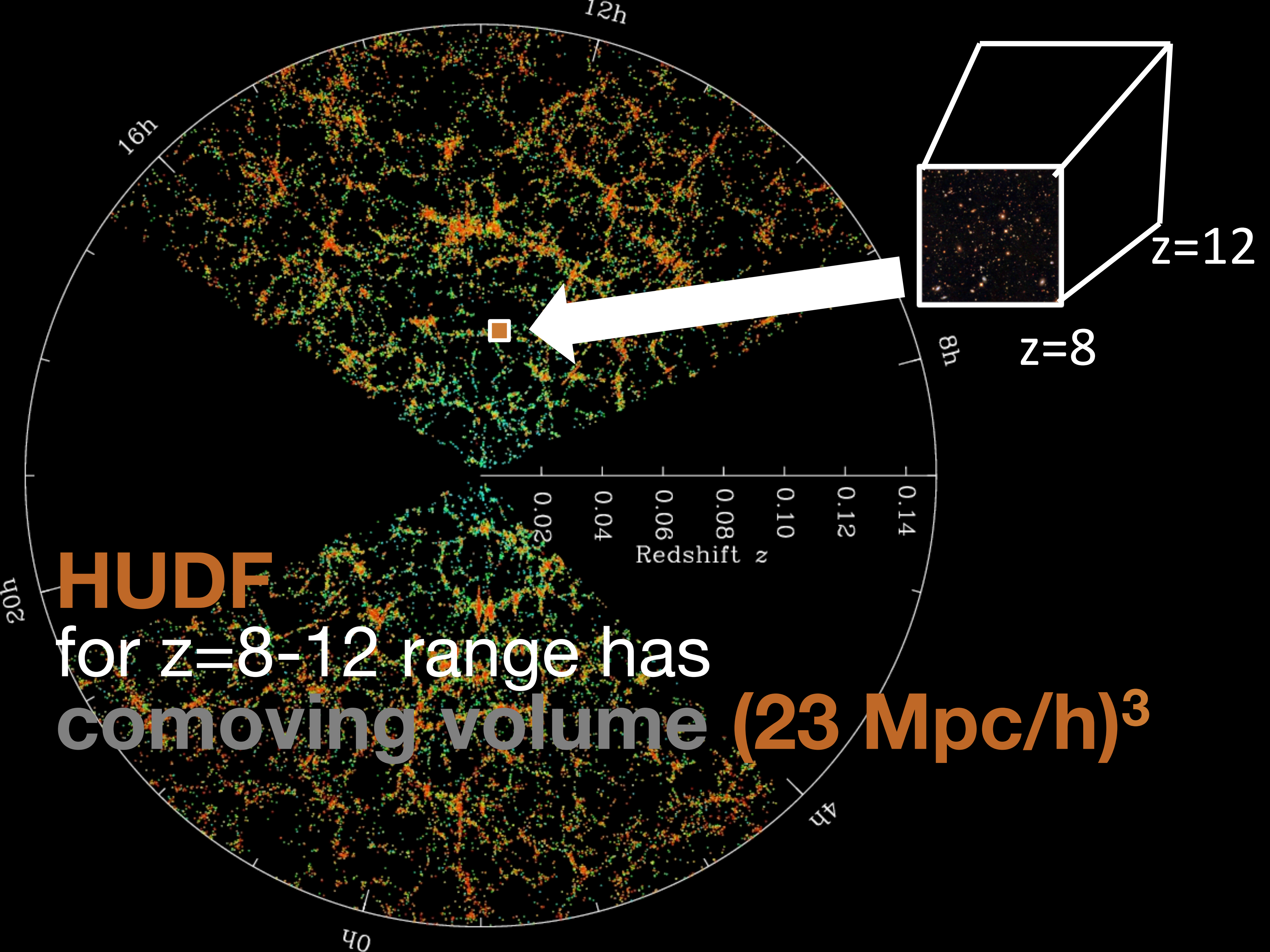
One quasar



A few (tens) of compact, clumpy irregular galaxies



Z > 7

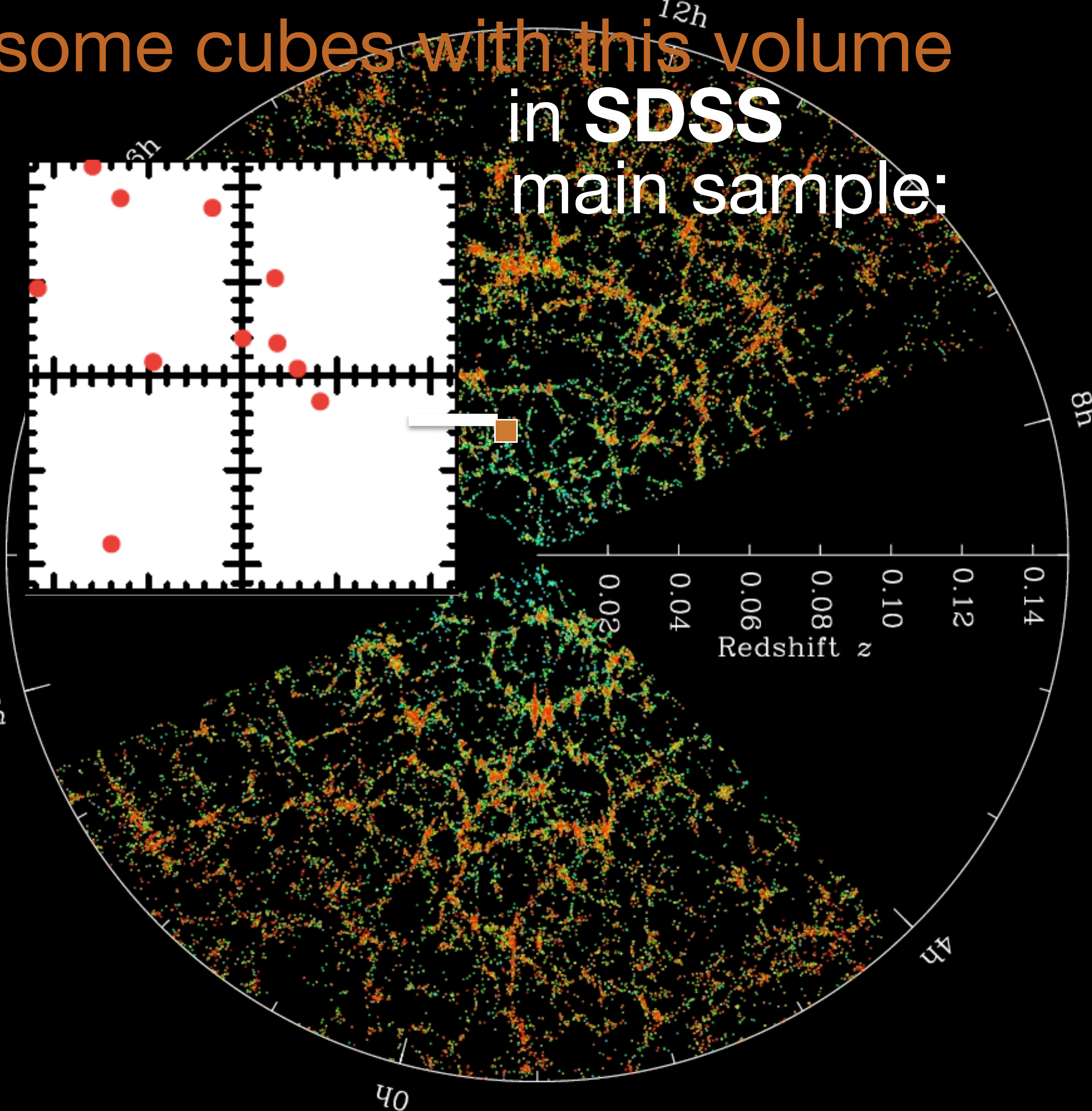


HUDF
for z=8-12 range has
comoving volume (23 Mpc/h)^3

some cubes with this volume

in **SDSS**

main sample:



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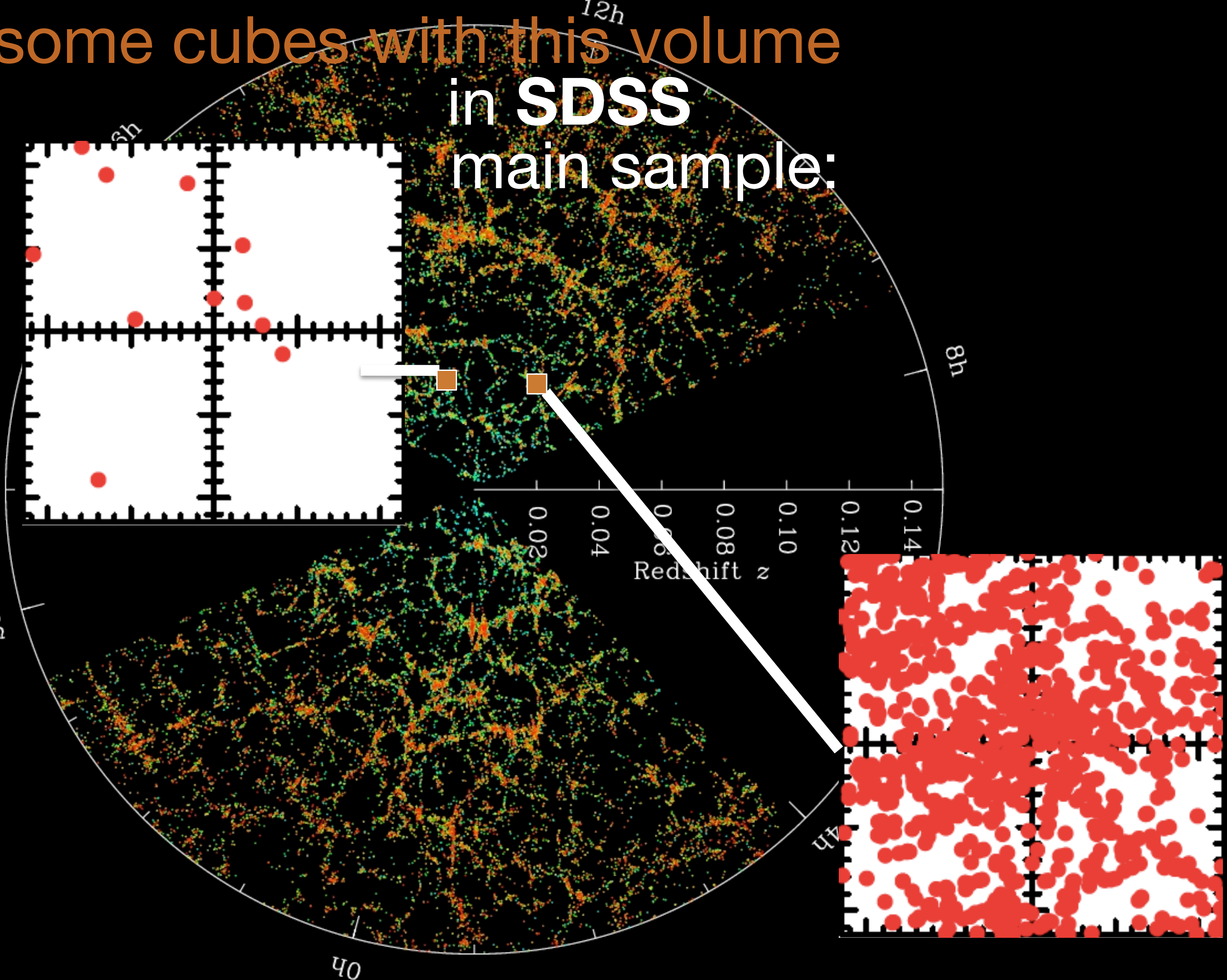
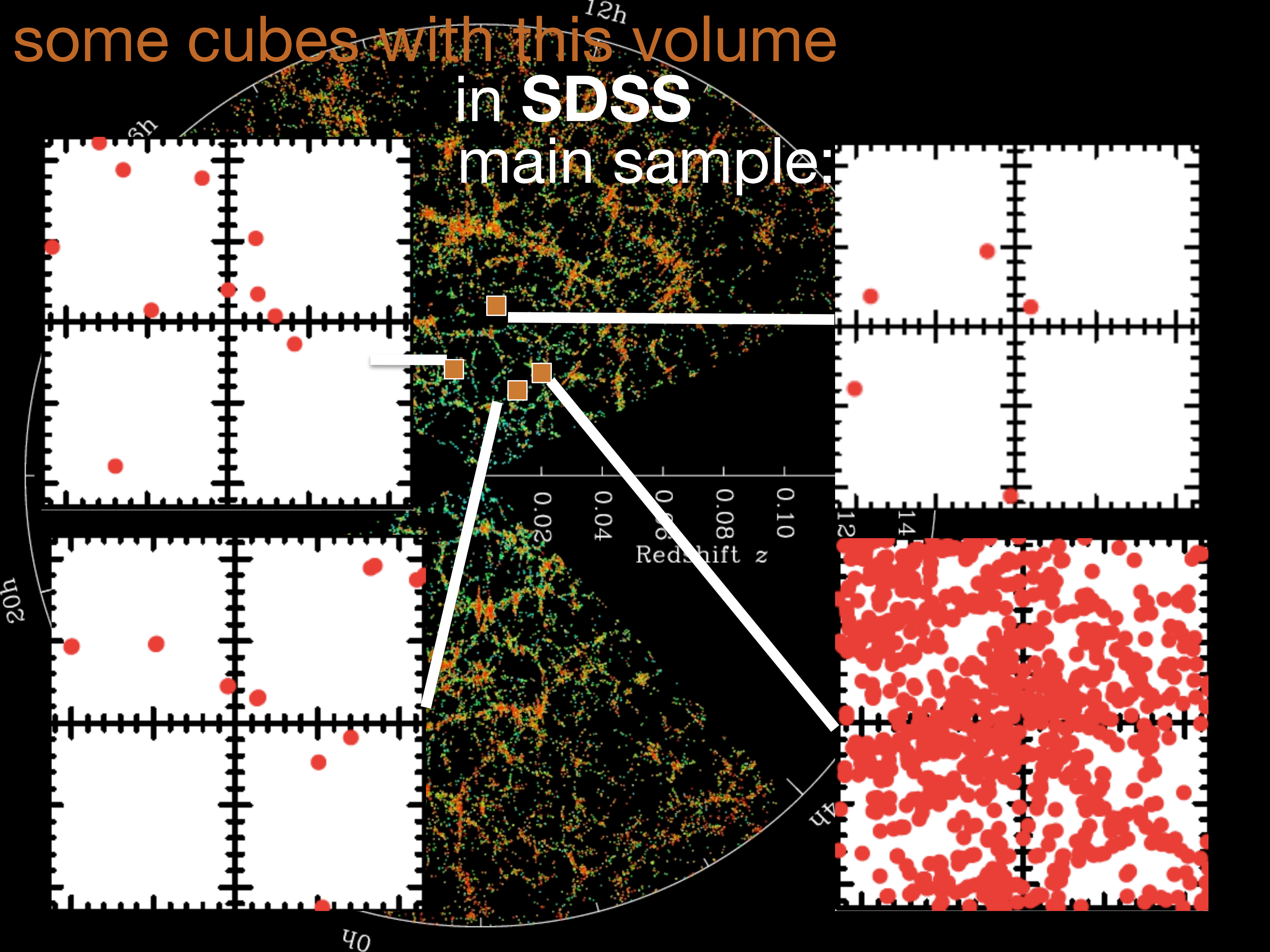
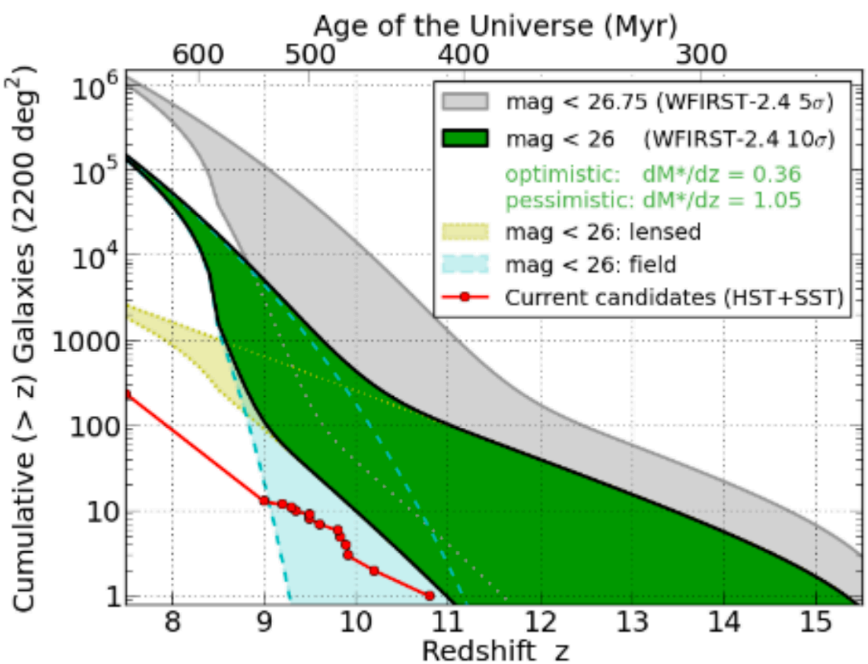


some cubes with this volume in **SDSS** main sample:



Z > 7

room for discovery

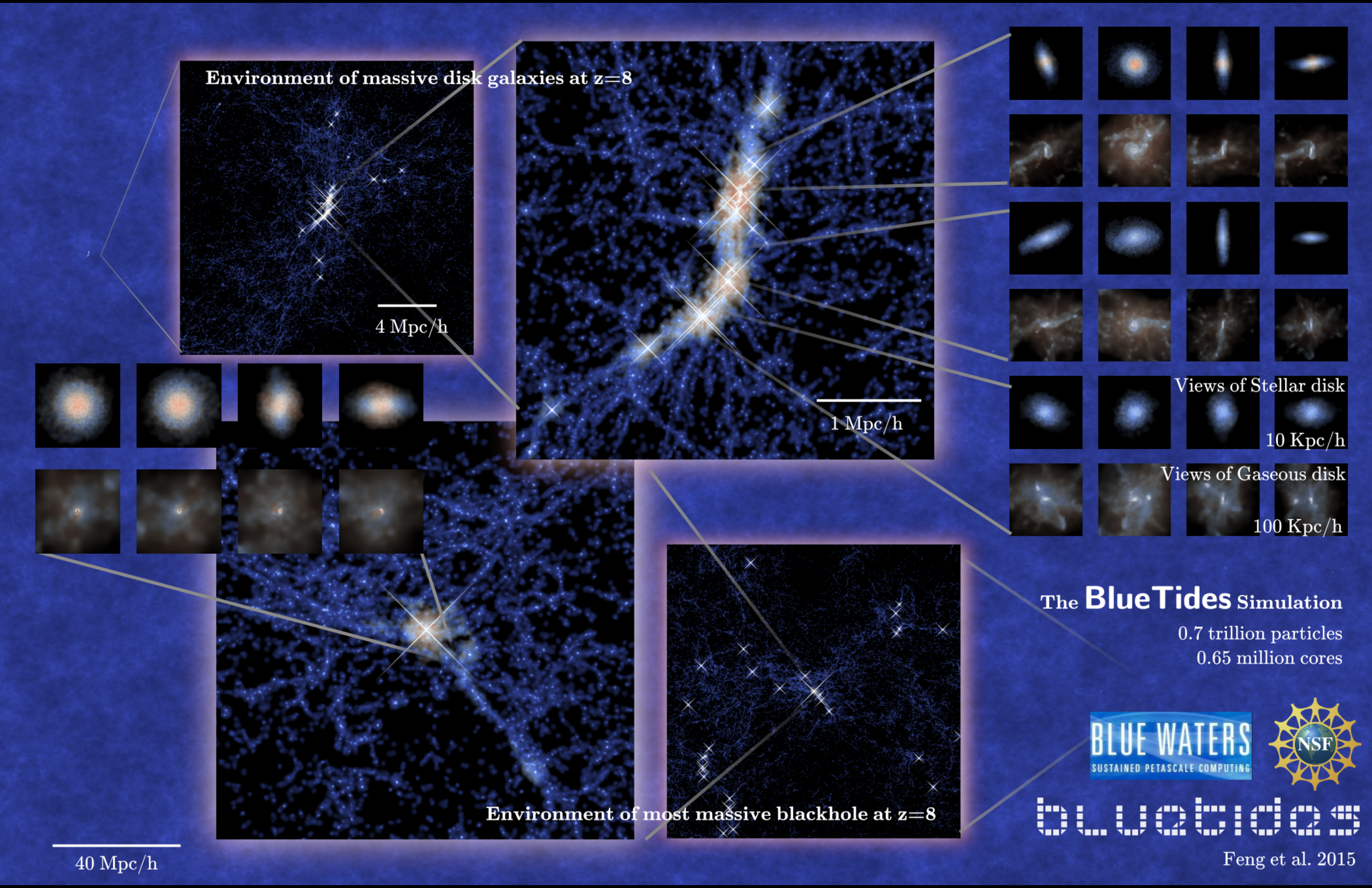


Z > 7

Predictions:

The first 800 million years

http://bluetides-project.org/


Environment of massive disk galaxies at z=8
4 Mpc/h
1 Mpc/h
Views of Stellar disk
10 Kpc/h
Views of Gaseous disk
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The BlueTides Simulation
0.7 trillion particles
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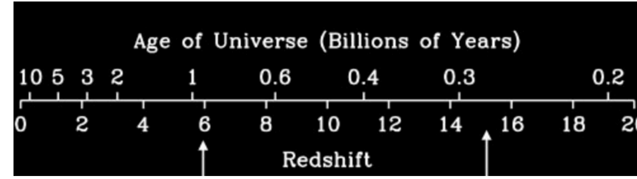
BLUE WATERS
SUSTAINED PETASCALE COMPUTING
NSF
bluetides
Environment of most massive blackhole at z=8
40 Mpc/h
Feng et al. 2015



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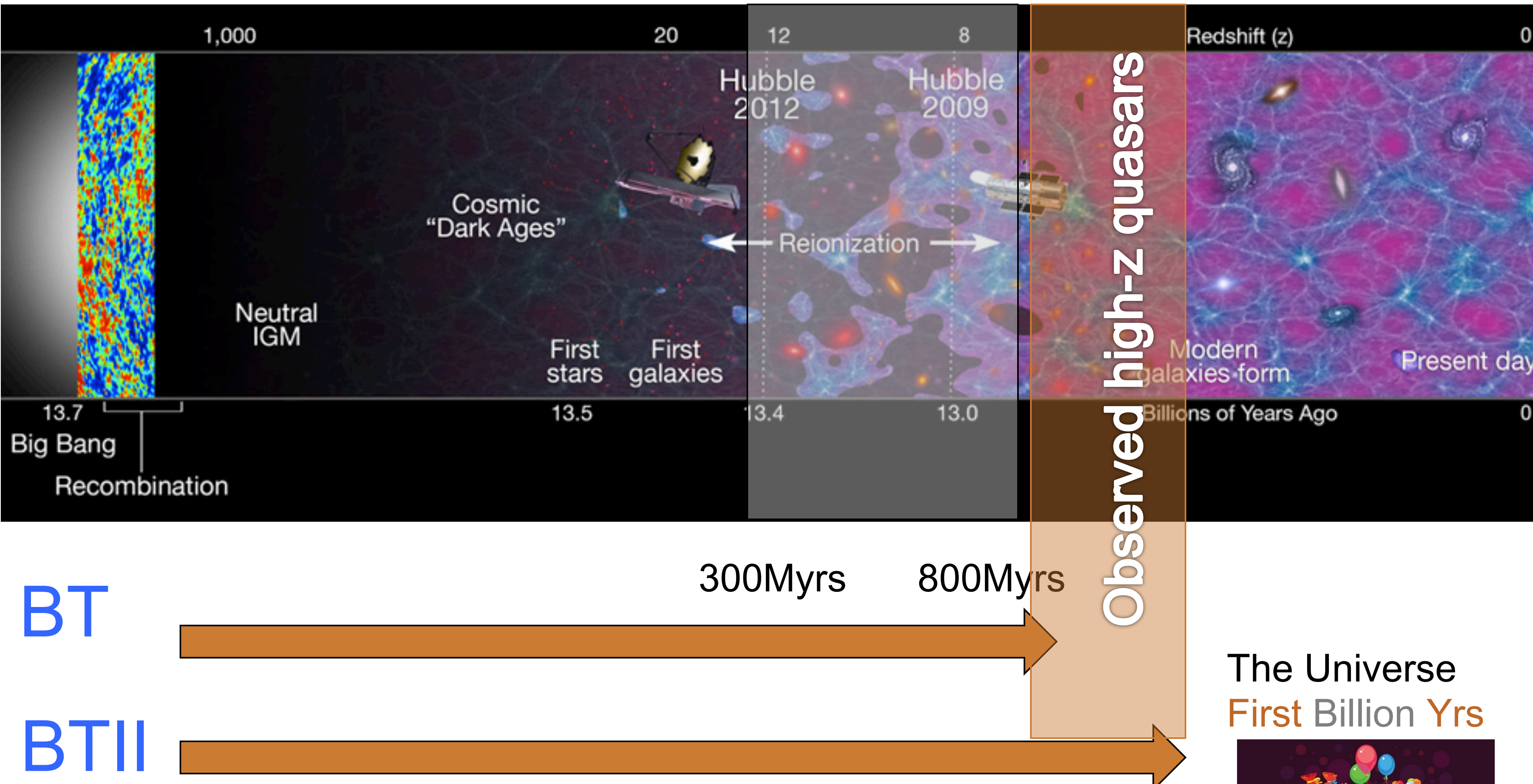
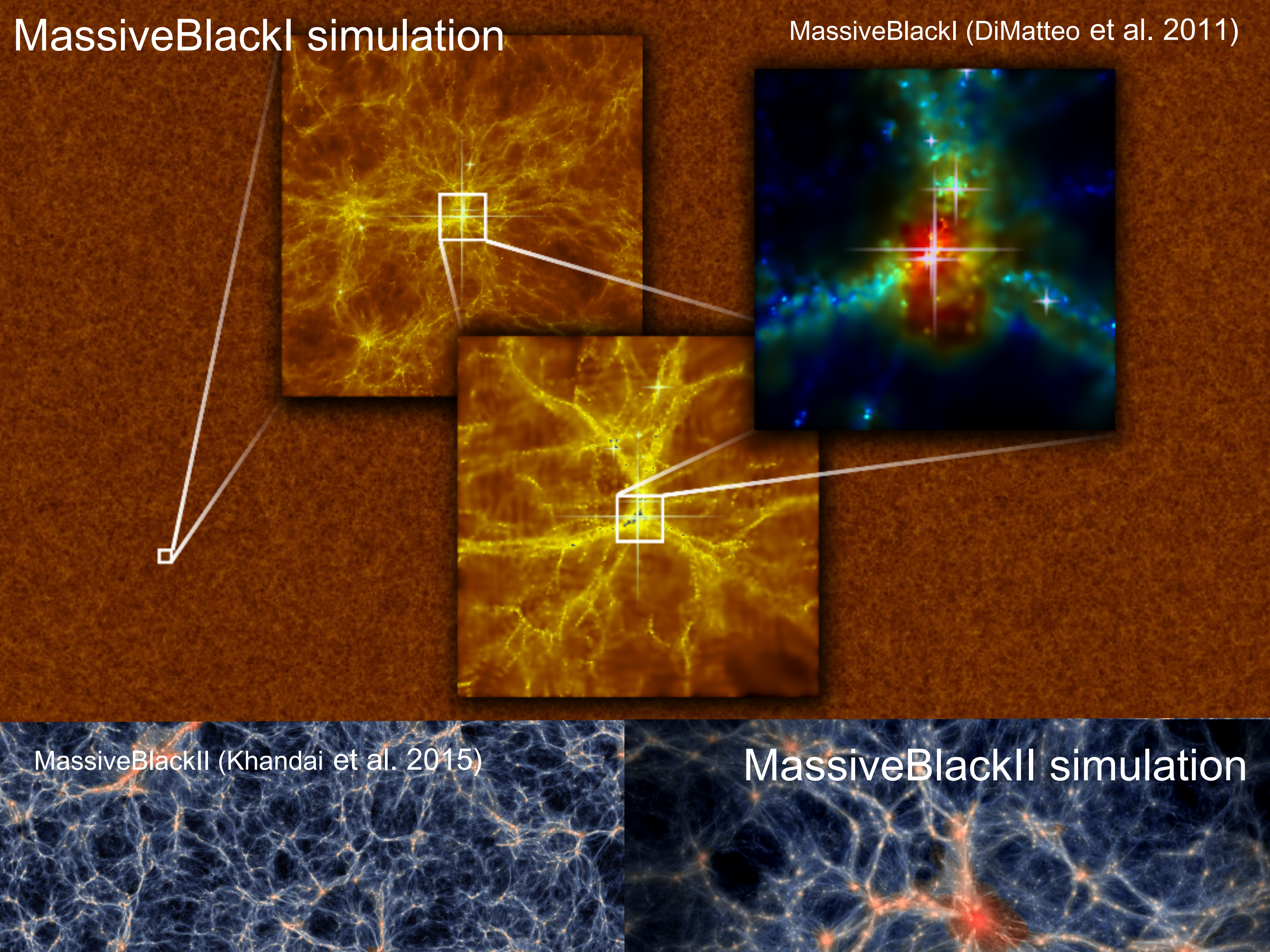
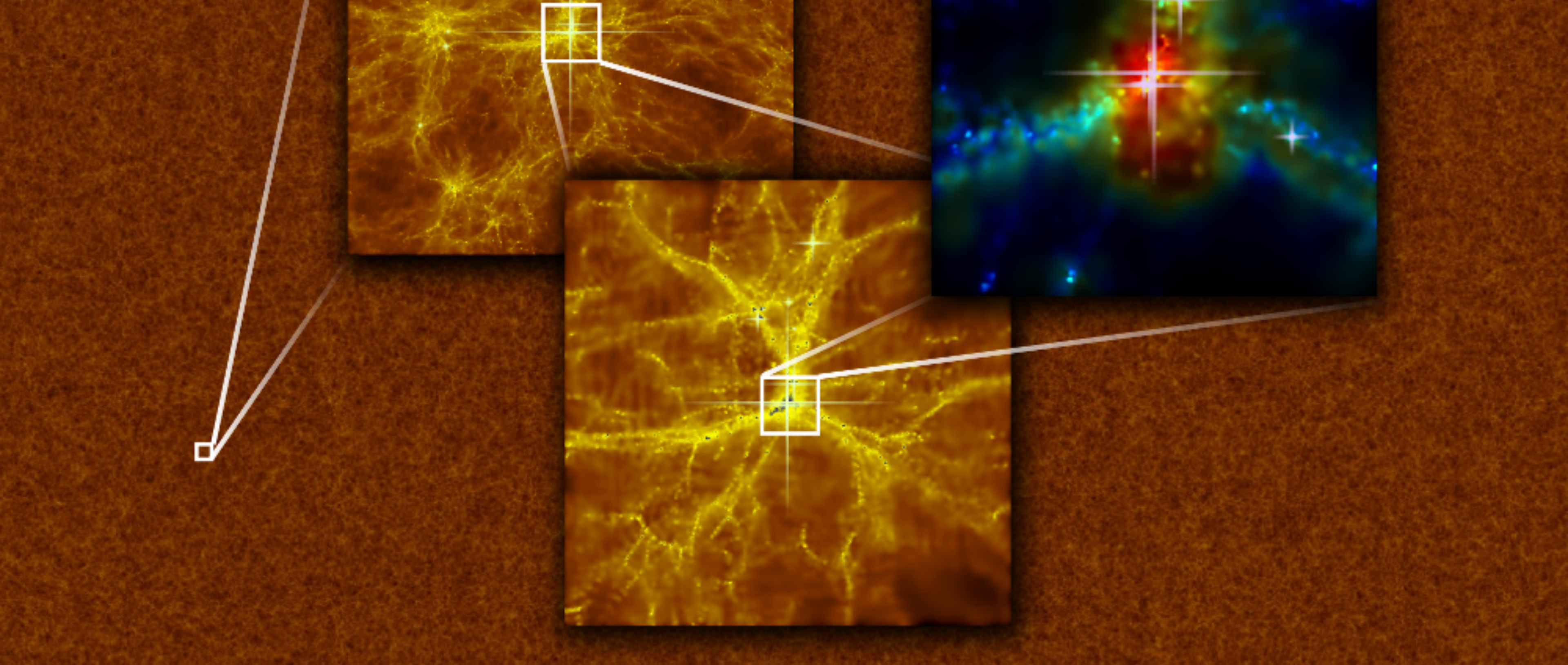
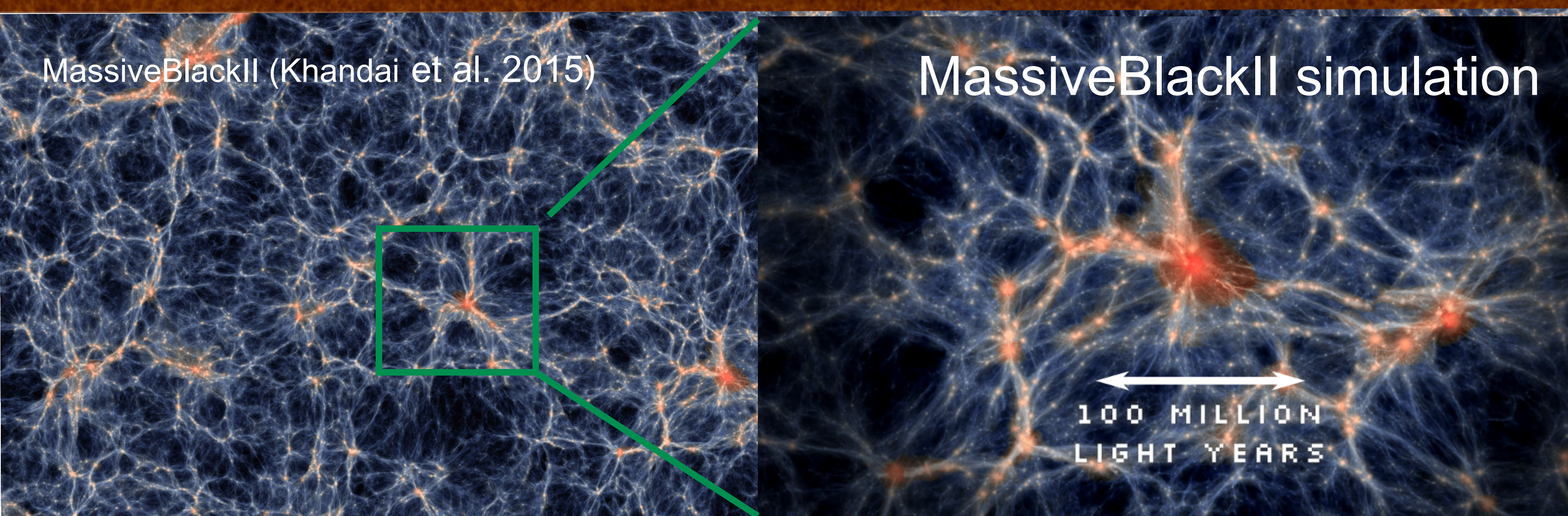
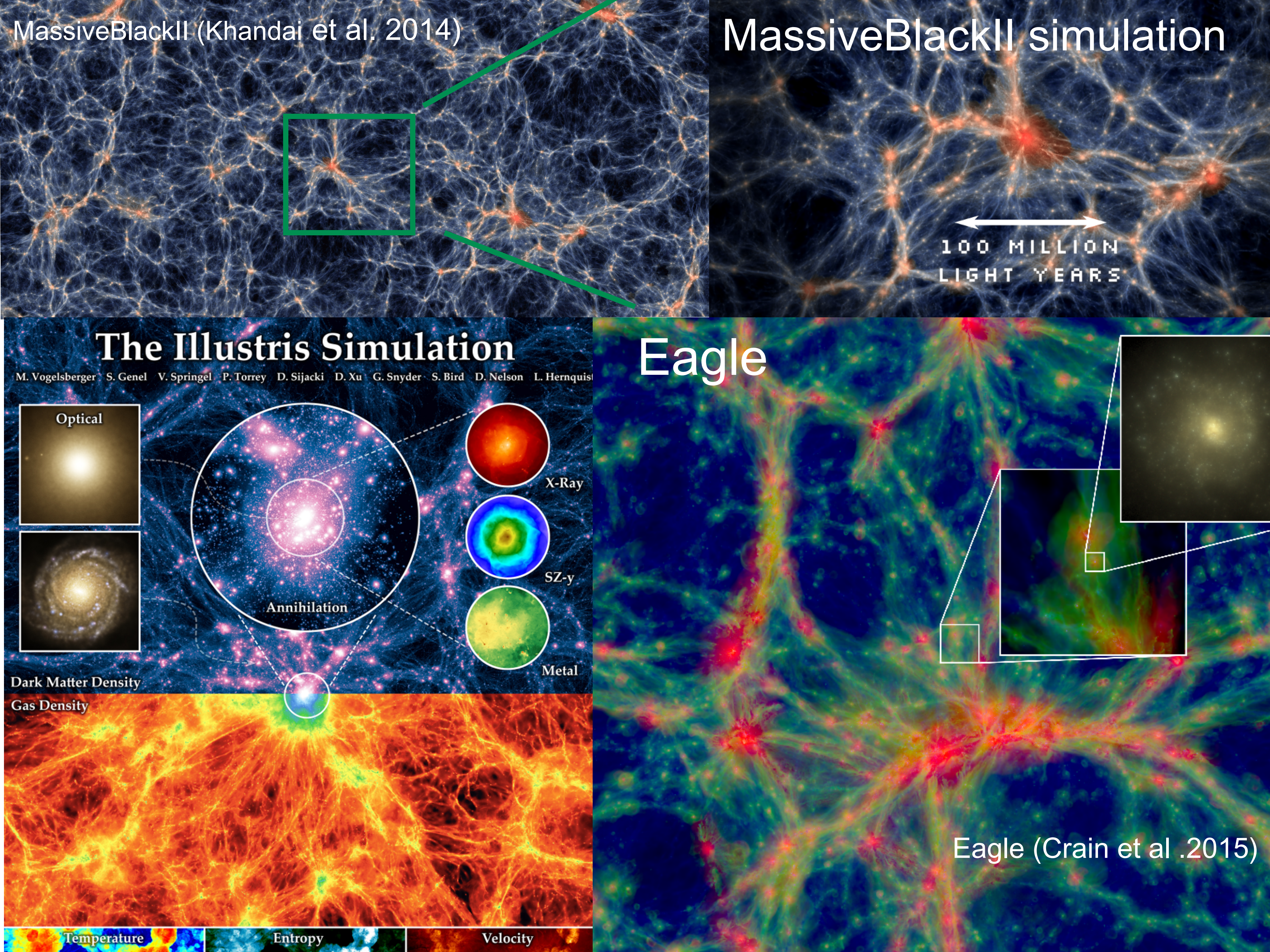


The Universe
First Billion Yrs

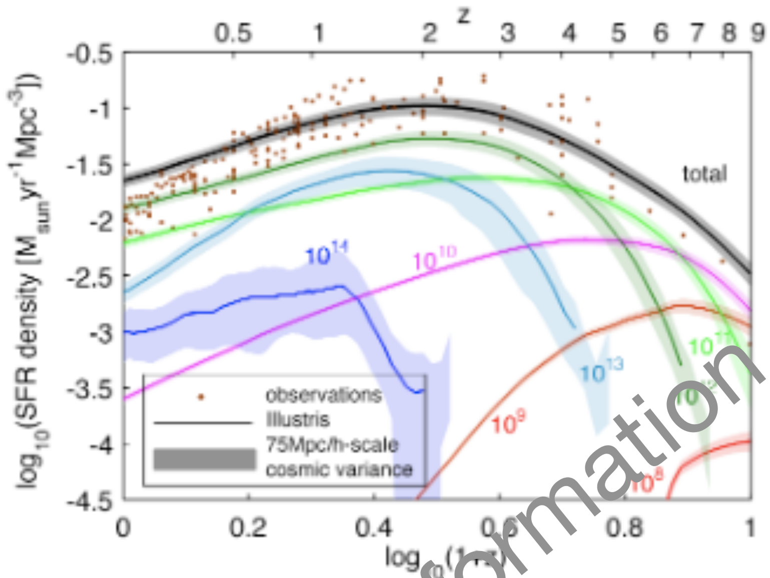

MassiveBlackI simulation
MassiveBlackI (DiMatteo et al. 2011)
MassiveBlackII (Khandai et al. 2015)
MassiveBlackII simulation



MassiveBlackII (Khandai et al. 2015)
MassiveBlackII simulation
100 MILLION
LIGHT YEARS

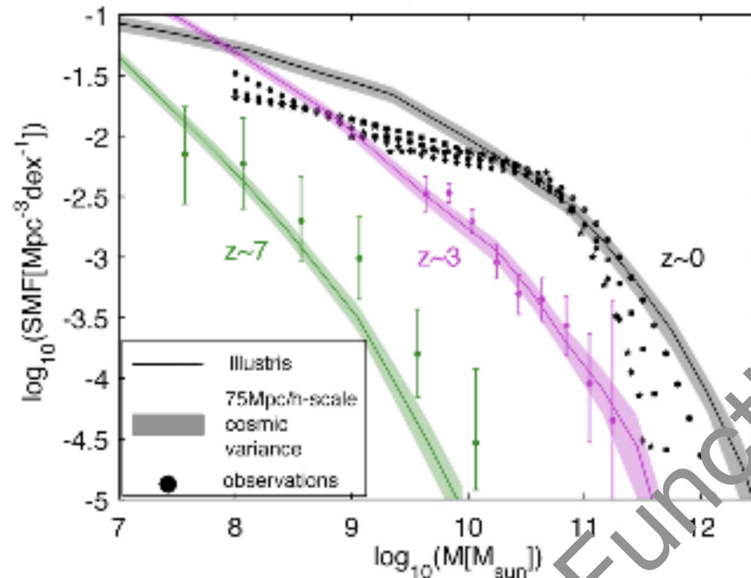


MassiveBlackII (Khandai et al. 2014)
MassiveBlackII simulation
100 MILLION
LIGHT YEARS
The Illustris Simulation
M. Vogelsberger S. Genel V. Springel P. Torrey D. Sijacki D. Xu G. Snyder S. Bird D. Nelson L. Hernquist
Optical
X-Ray
SZ-y
Annihilation
Metal
Dark Matter Density
Gas Density
Temperature
Entropy
Velocity
Eagle
Eagle (Crain et al .2015)

Simulations reproduce statistics of galaxy formation



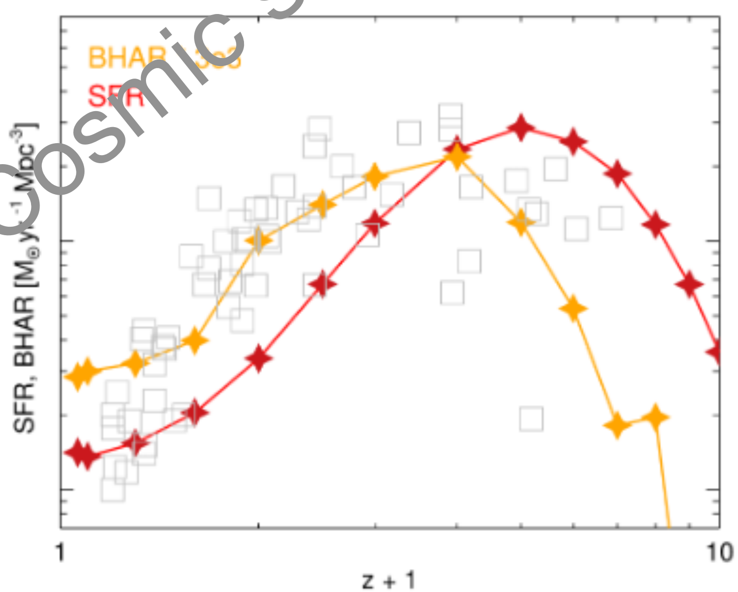
(c) Cosmic SFR density, 106.5 Mpc cosmic variance

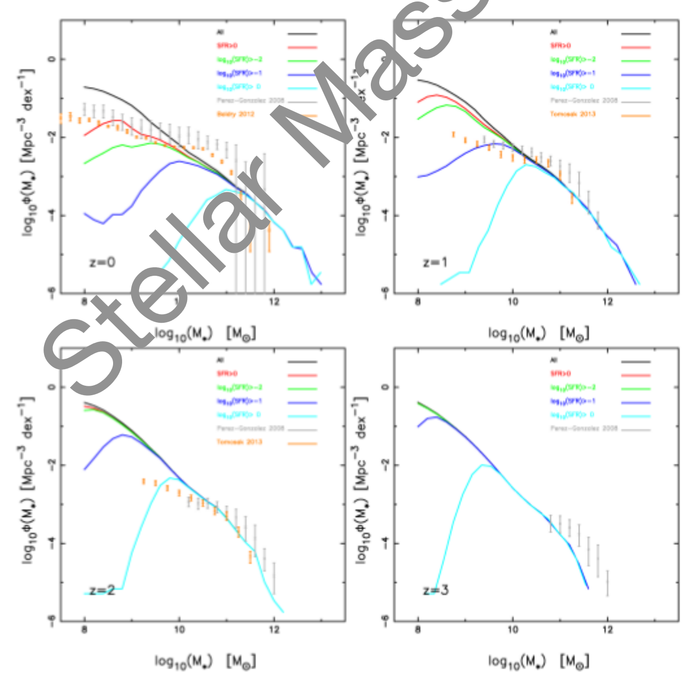


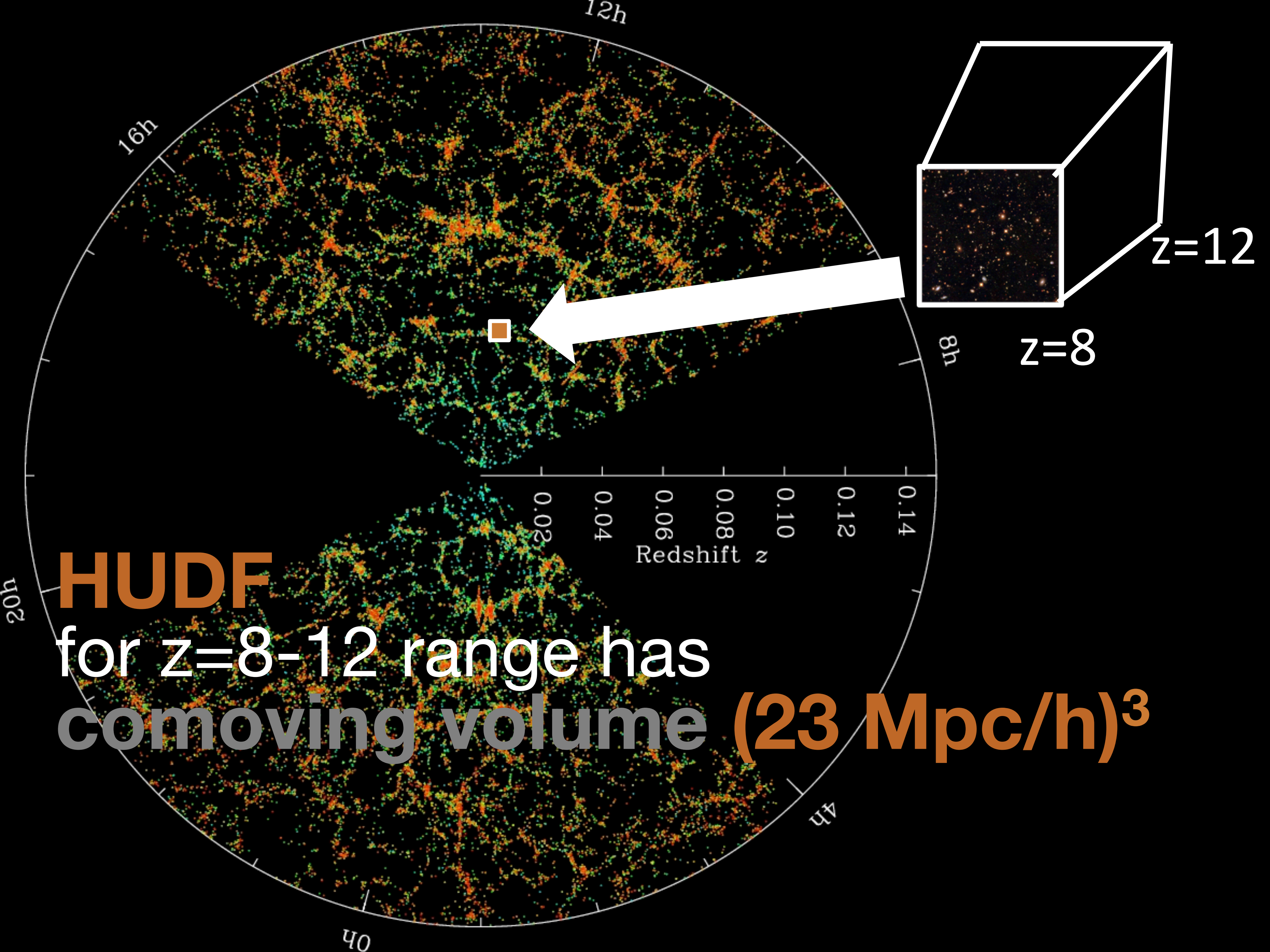
(d) Stellar mass functions, 106.5 Mpc cosmic variance

Cosmic star formation

Stellar Mass Functions



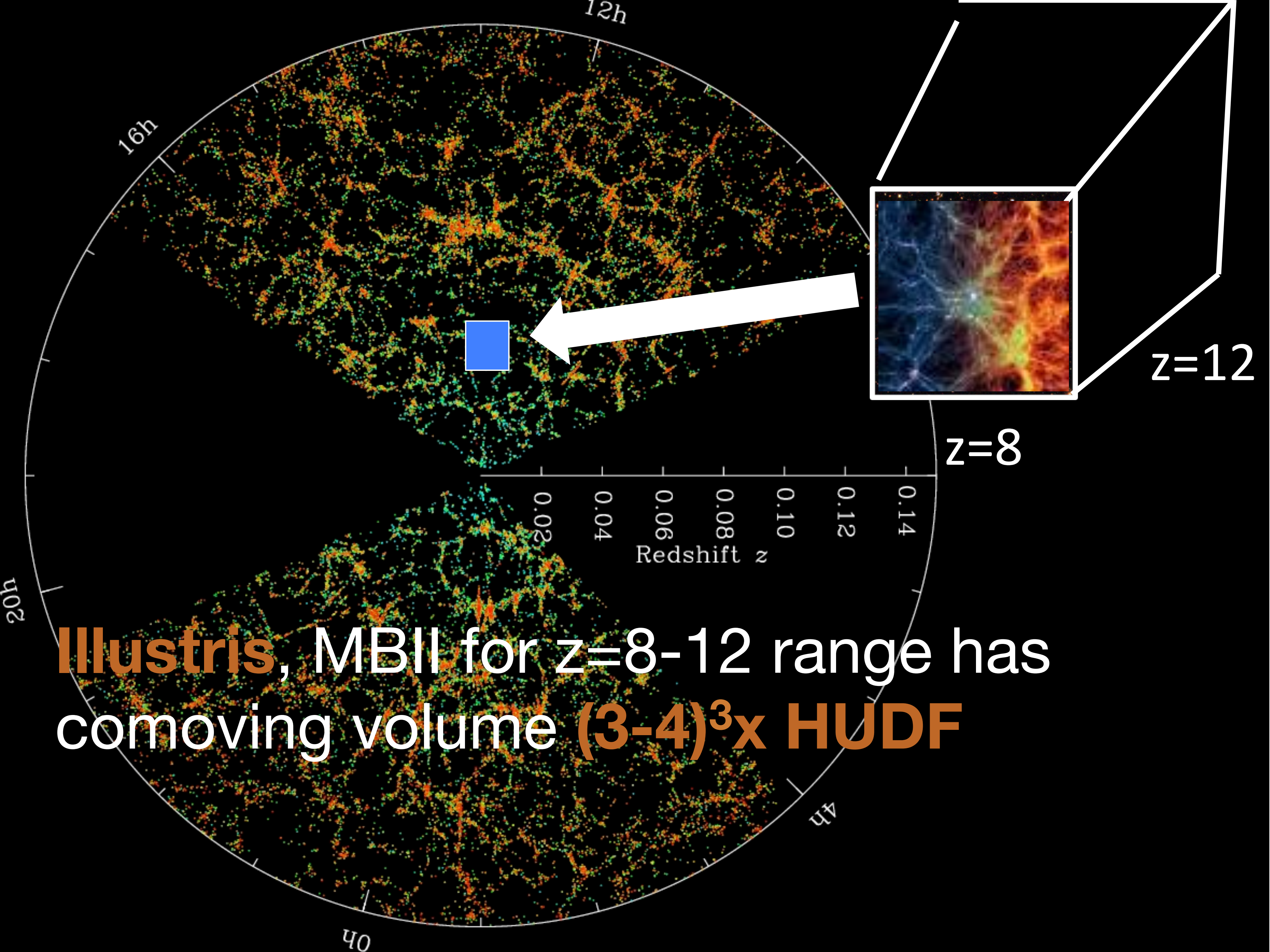




HUDF

for z=8-12 range has

comoving volume (23 Mpc/h)^3

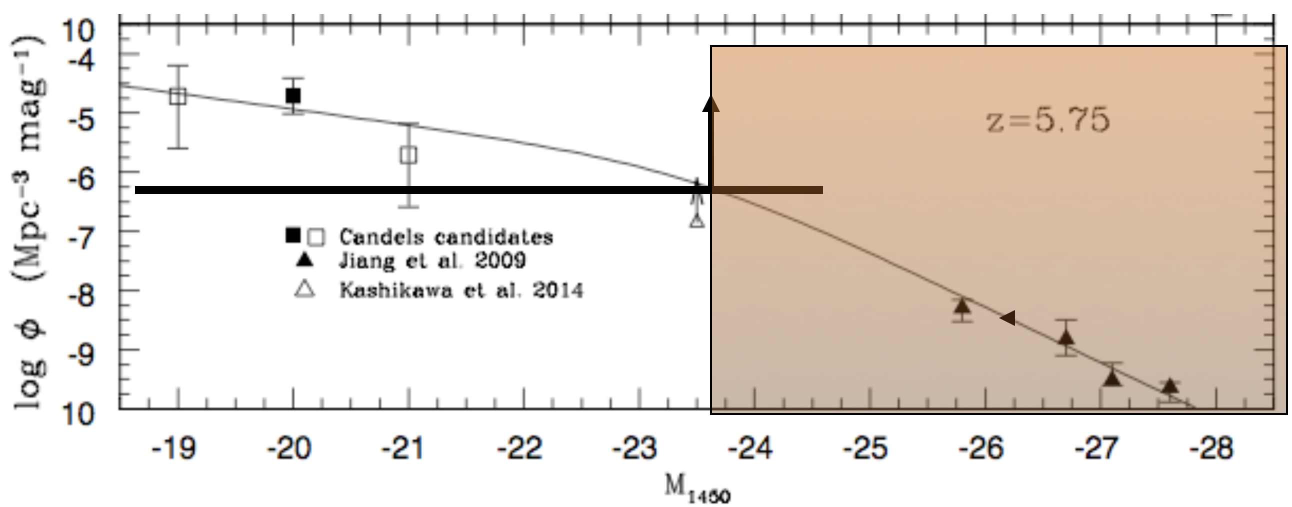


Illustris, MBII for z=8-12 range has comoving volume **$(3\text{-}4)^3$x HUDF**

Theoretical predictions lacking at z=7+
simulations have either:
insufficient resolution or too small volumes for
massive objects/high density regions

Illustris

e.g: High-z
QSO lum. Function
(Giallongo 15)



BlueTides Simulation:

NCSA BlueWaters
0.7 million cores
0.7 trillion particles
full hydrodynamics

Resolves galaxies **and** large-scale structure of the Universe

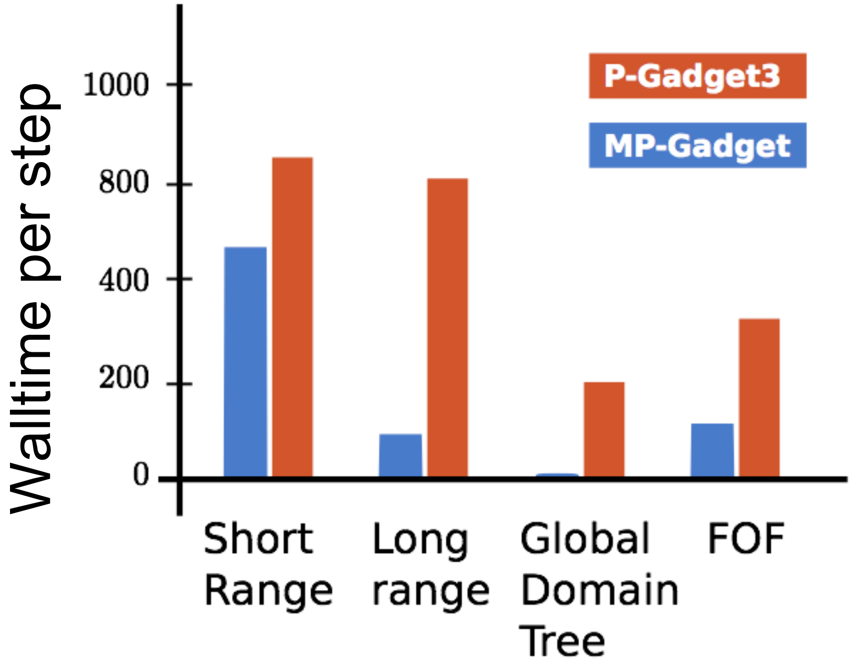
BlueTides Simulation: Technology

Gadget3+ MPGadget

Old
100,000 lines

New
22,000 lines
low redundancy
better sustainability

BlueTides Simulation: Technology



efficient: 32 threads/rank
large: 81000 rank FFT

Open-source spinoffs:
new hierarchical file format
MP-sort algorithm
parallel data analysis tools
PencilFFT interface & binding

8x speedup

BlueTides Simulation: Science

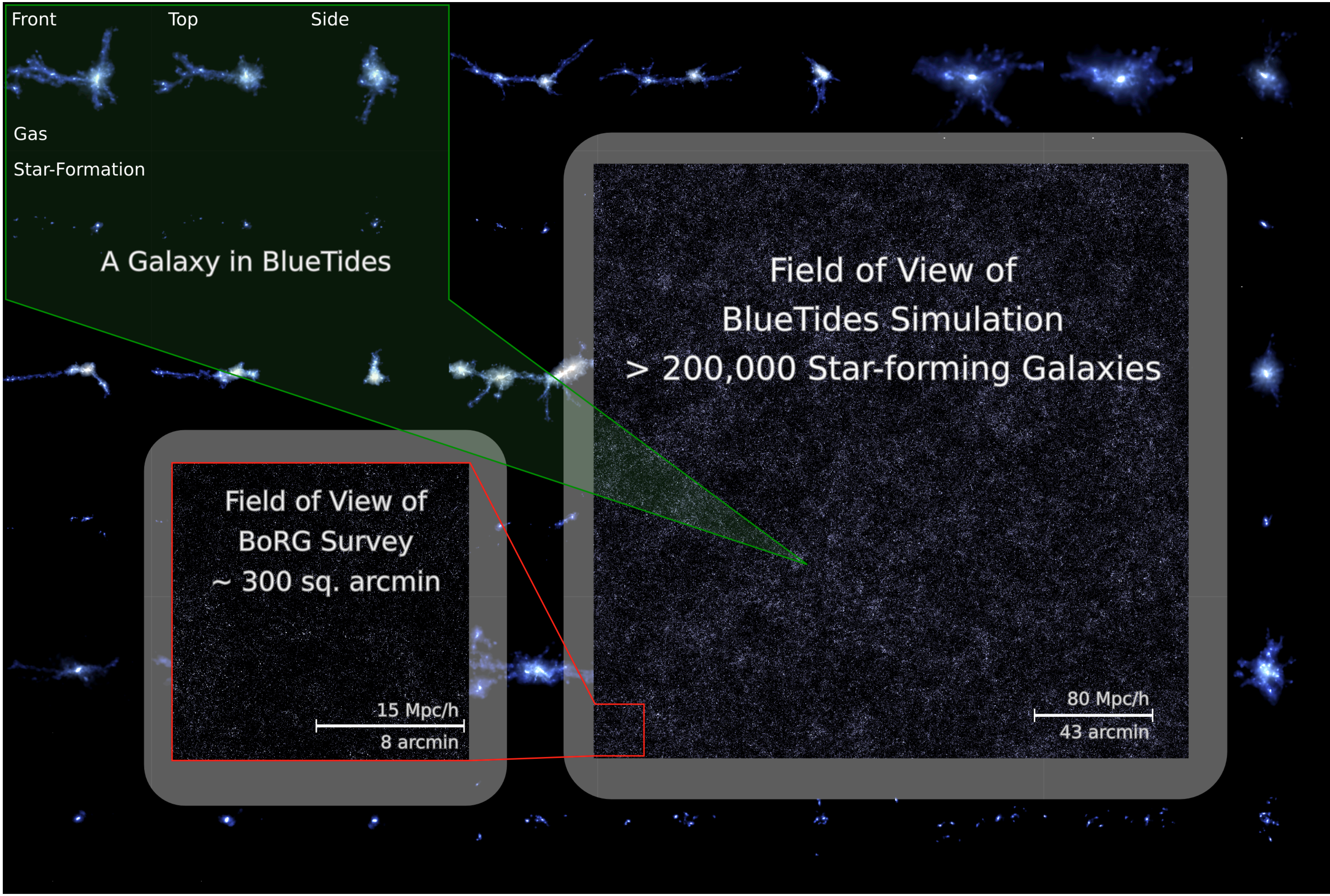
Physics modelling in BlueTides

- Hydrodynamics (pSPH)
- Primodial cooling
- Multi-phase medium star-formation
- SN wind feedback
- H2 molecule fraction
- AGN feedback
- Metal enrichment and cooling
- Non-uniform UV background calibrated from rad. Hydro sims (Battaglia+13)

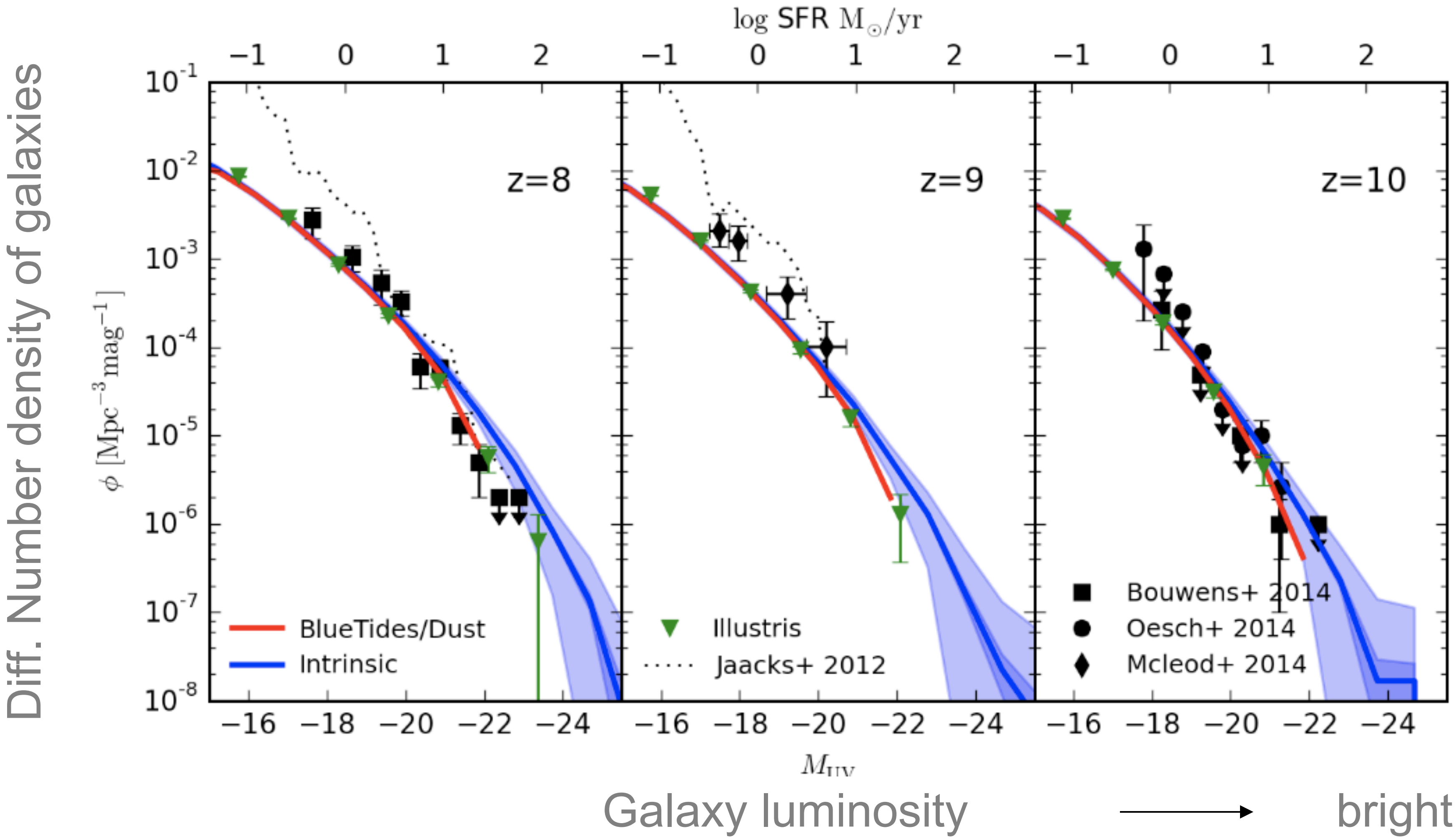
Science of high redshift galaxy

- a statistical sample of high redshift galaxies, accessible only via uniform simulations
- reionization
- morphology
- mock surveys
- high redshift AGNs
- ....

BlueTides 400 x volume of HUDF



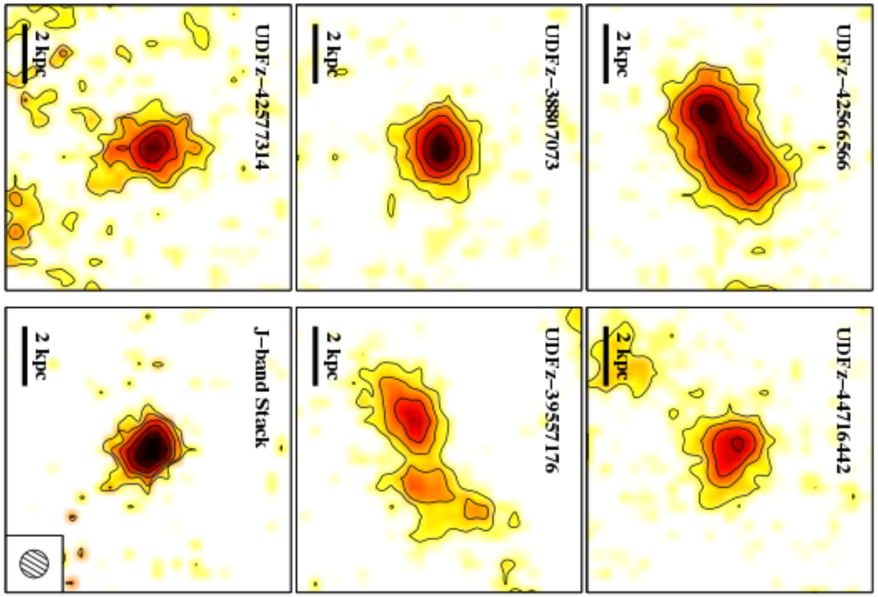
Galaxy Luminosity Function in BlueTides consistent with Hubble Legacy Fields



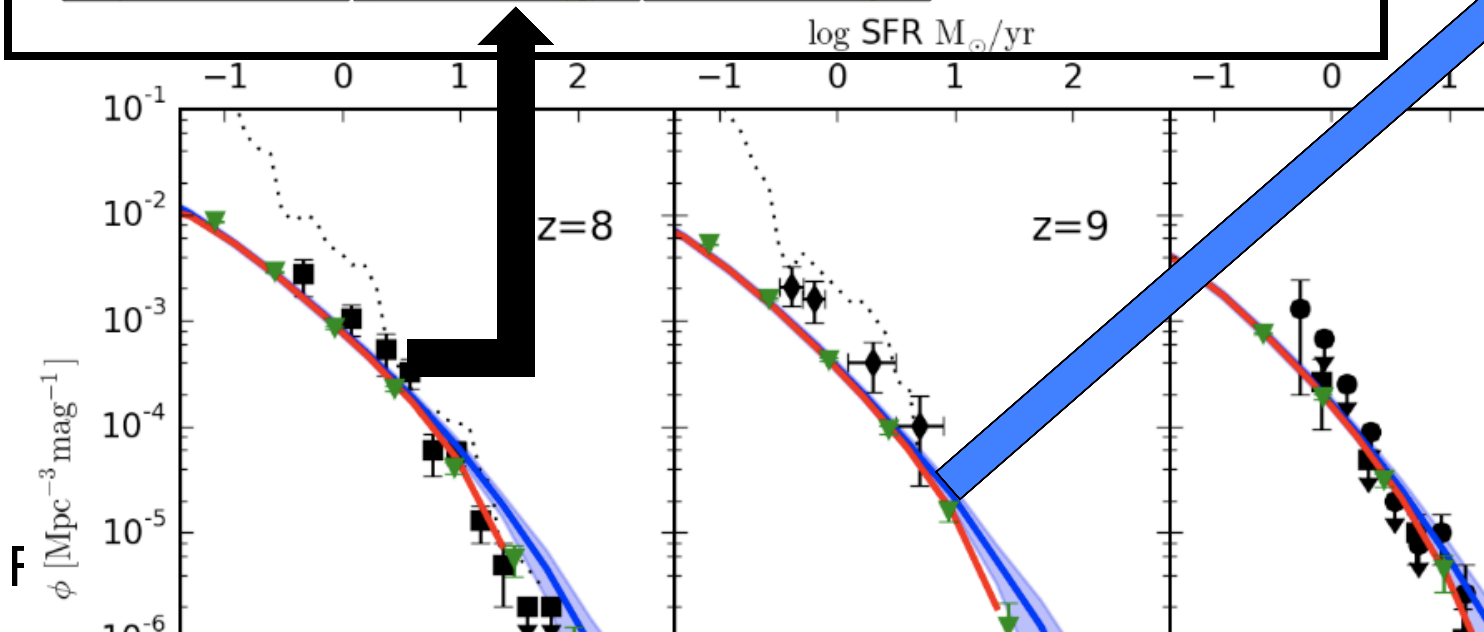
Feng et al., 2015a

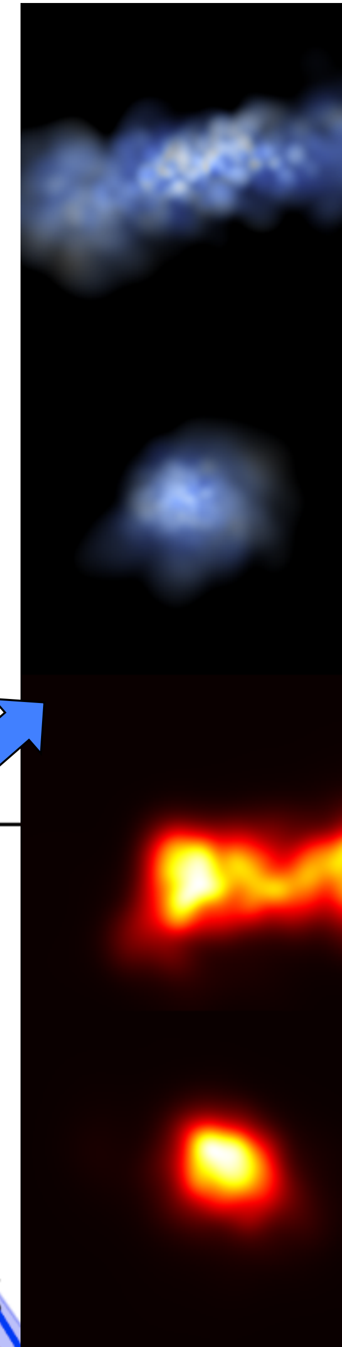
Galaxy Luminosity Function in consistent with Hubble Legacy Fields

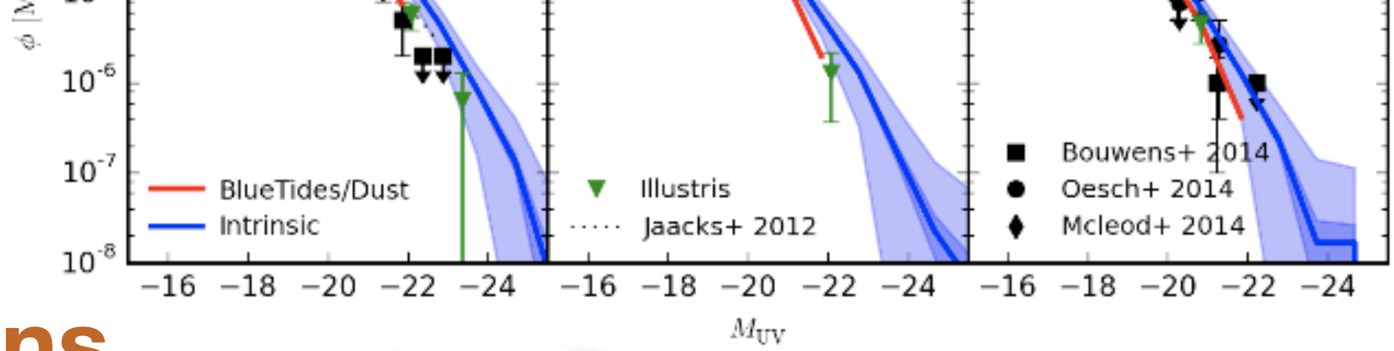
BlueTides



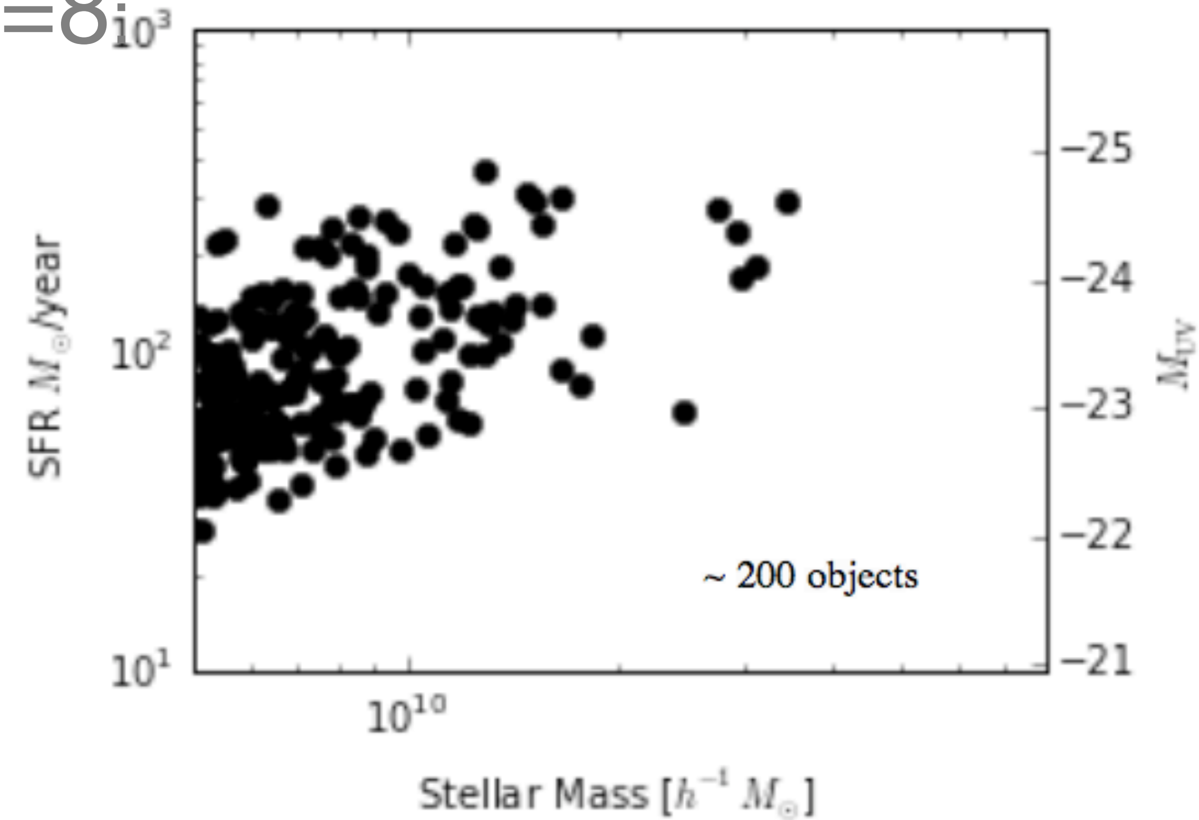
Compact, irregular

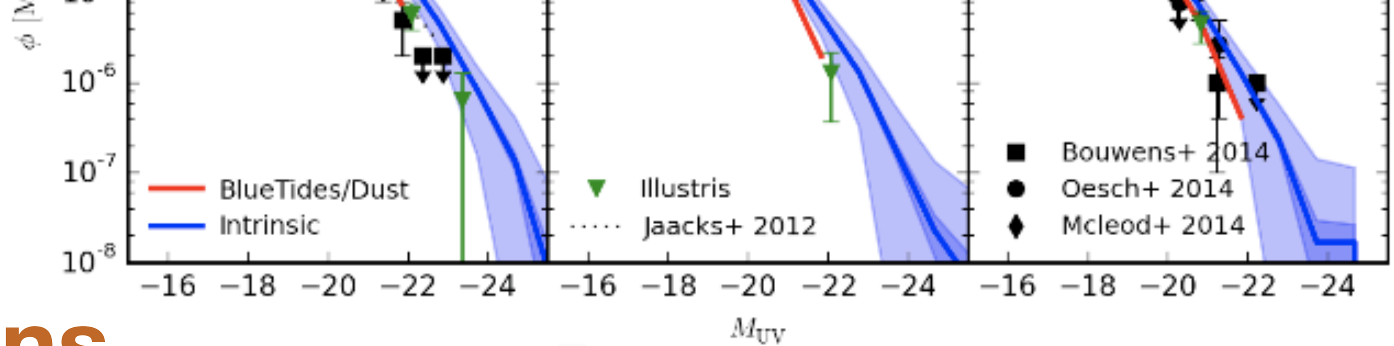






Predictions
for the brightest
galaxies at z=8





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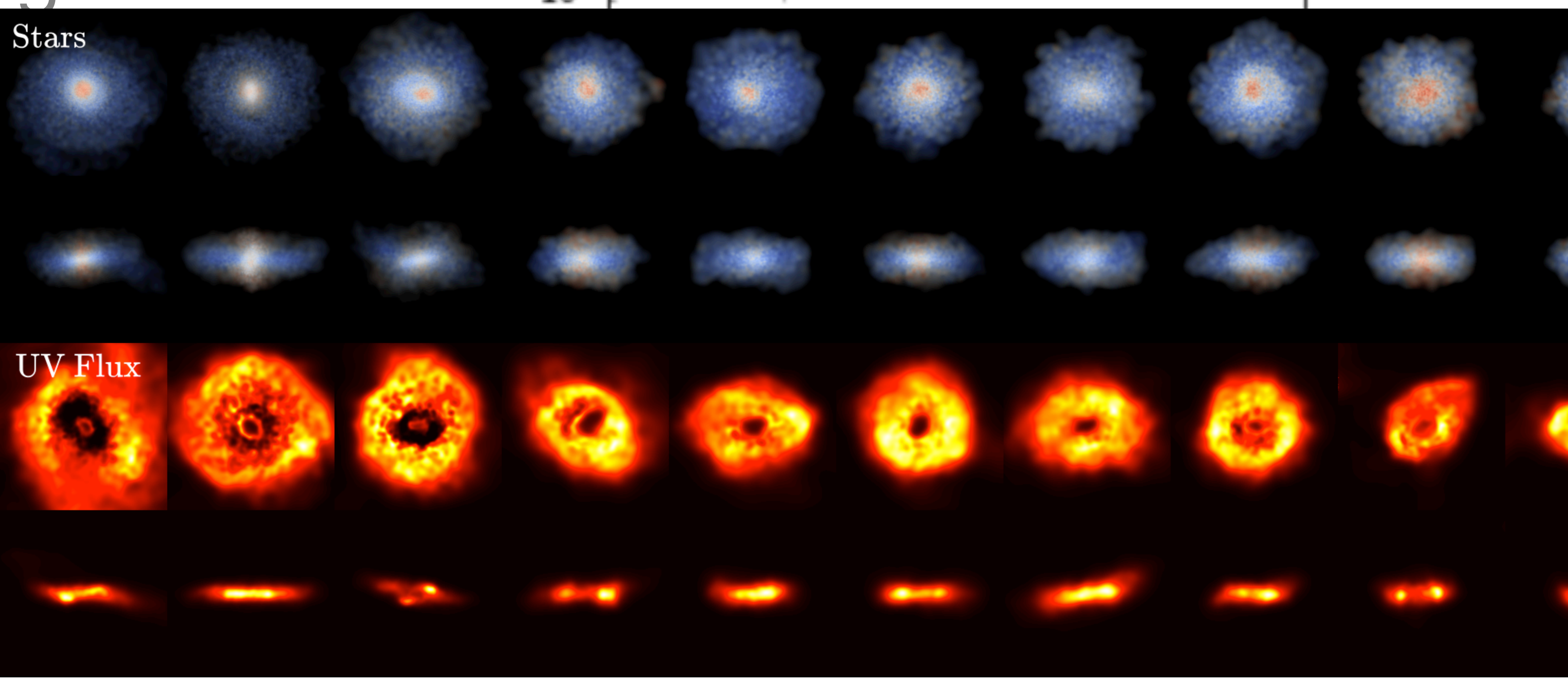
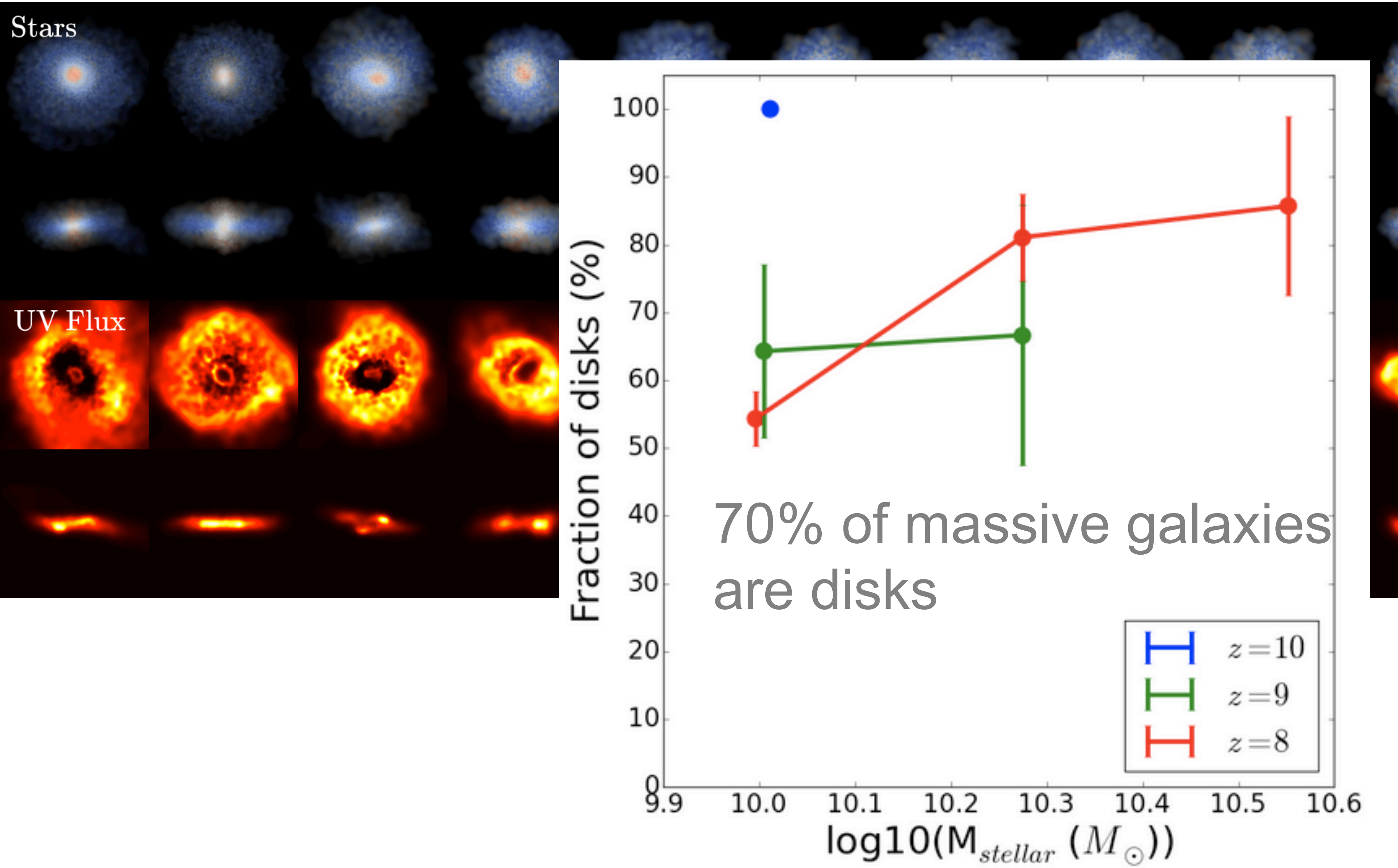
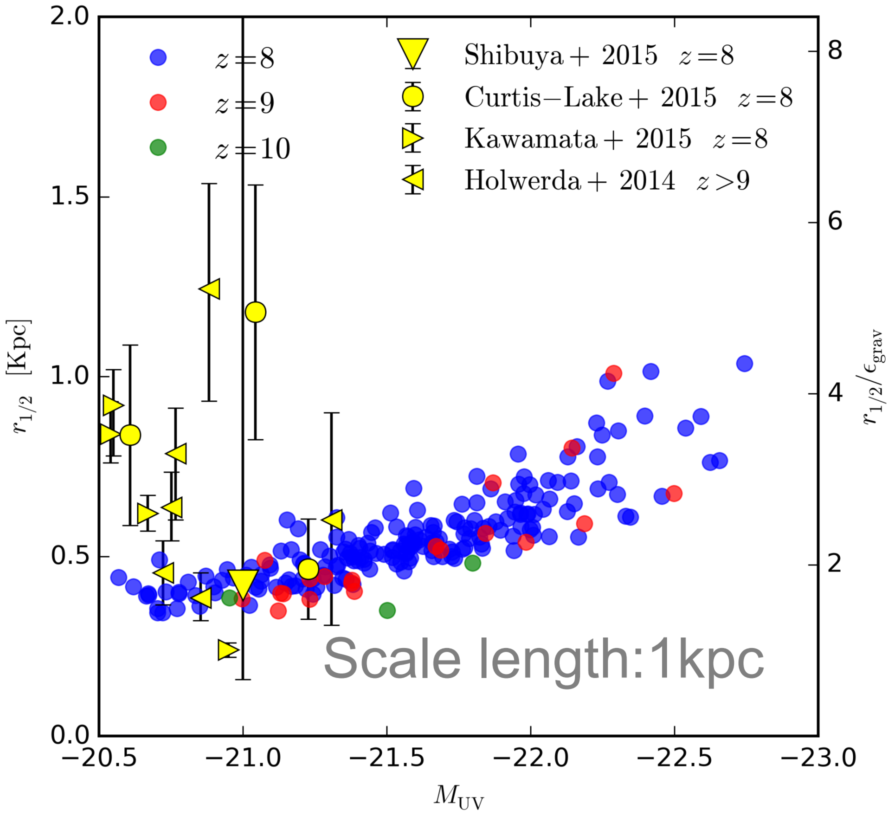


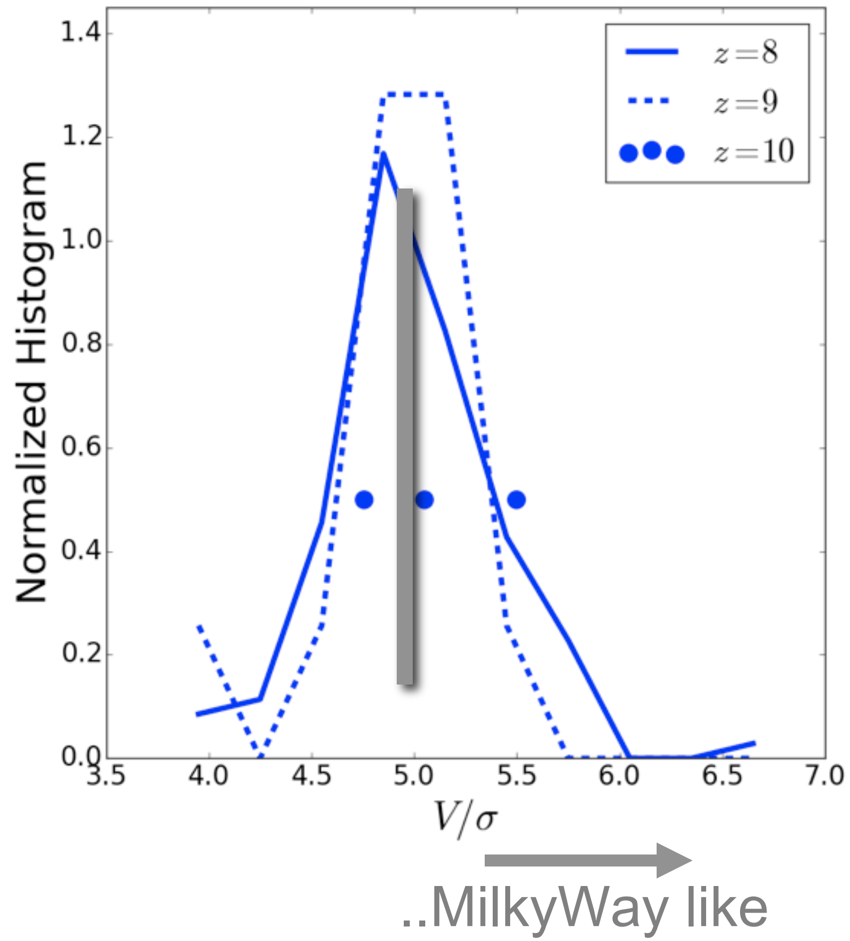
z=8, Milky Way(Mass) galaxies are disks!



The sizes of galaxies in BlueTides are consistent with HST observations --> 'massive' disks in bright galaxies are compact rotationally supported

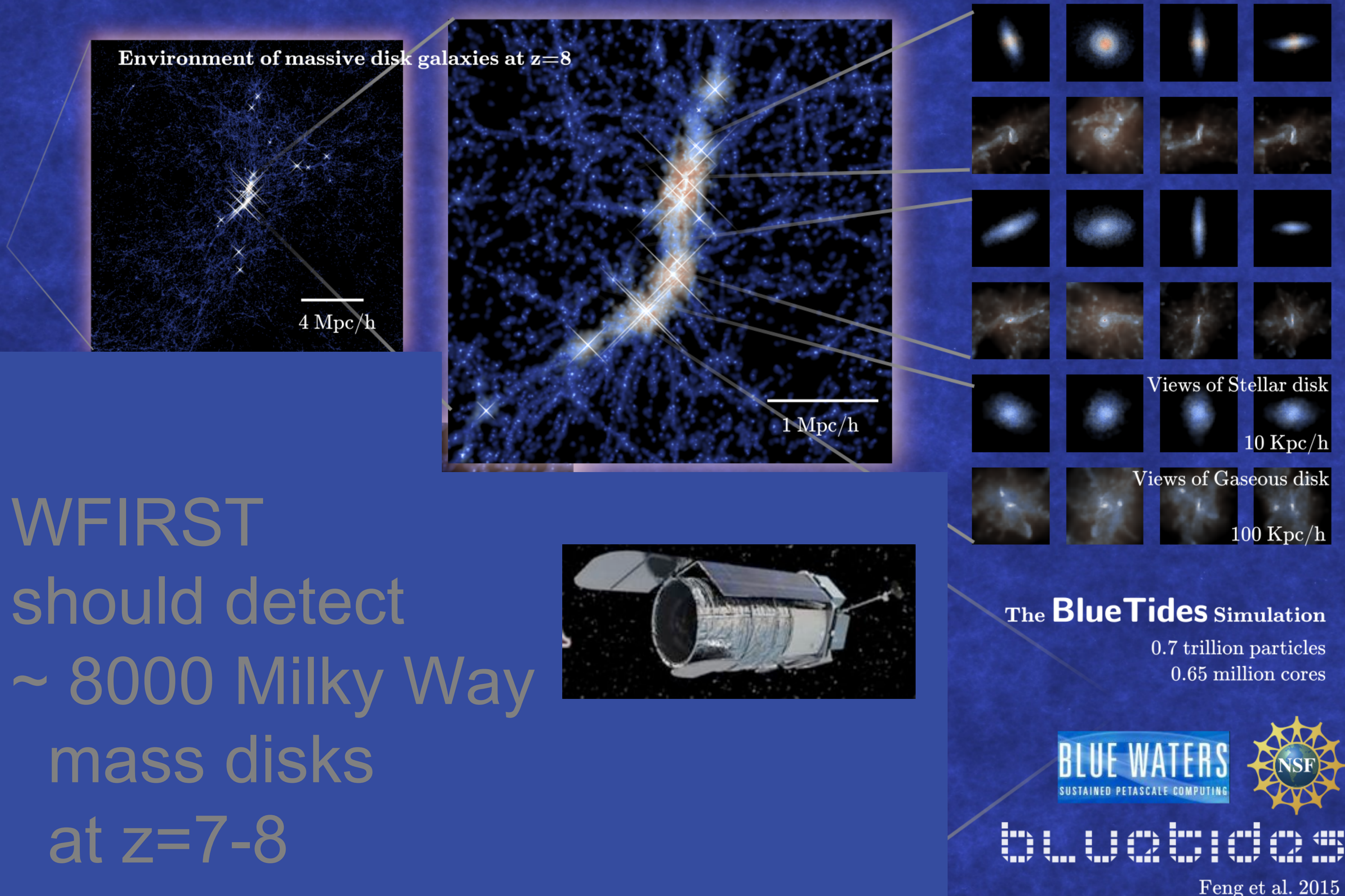
z=8





Feng et al., 2015a

WFIRST
should detect
~ 8000 Milky Way
mass disks
at z=7-8



BT: predicts the ‘bright’ 400 million years old galaxy

News Release Number: STScI-2016-07 *March 3, 2016 12:00 PM (ES*

Hubble Team Breaks Cosmic Distance Record

Introduction | The Full Story | Release Images | Release Videos | Fast Facts | Related Links

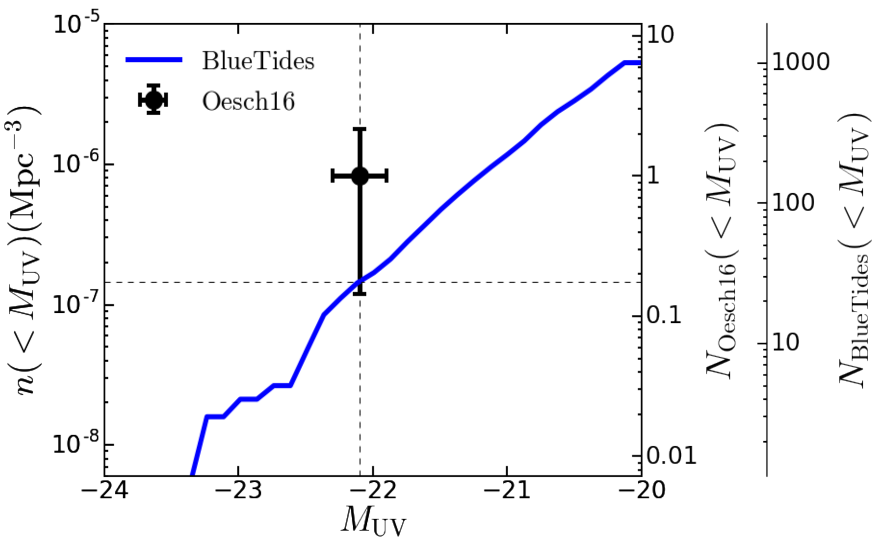
The full news release story:

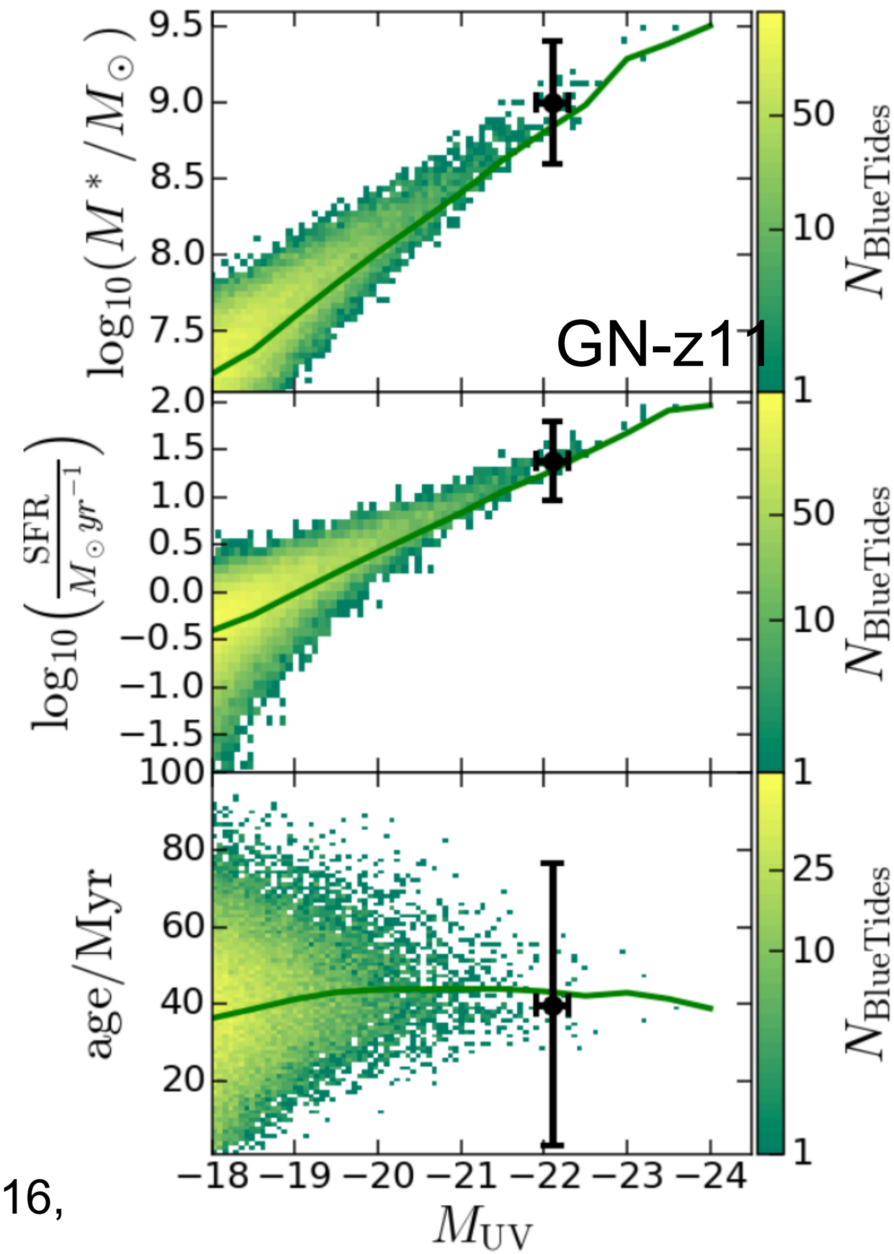
By pushing NASA's Hubble Space Telescope to its limits, an international team of astronomers has shattered the cosmic distance record by measuring the farthest galaxy ever seen in the universe. This surprisingly bright, infant galaxy, named GN-z11, is seen as it was 13.4 billion years in the past, just 400 million years after the big bang. GN-z11 is located in the direction of the constellation of Ursa Major.

Ultra bright galaxy GNz-11
400 Myr after big bang??

The end of the dark ages is bright!

BT: z=11, GN-z11 cosmic distance record is in Bluetides.

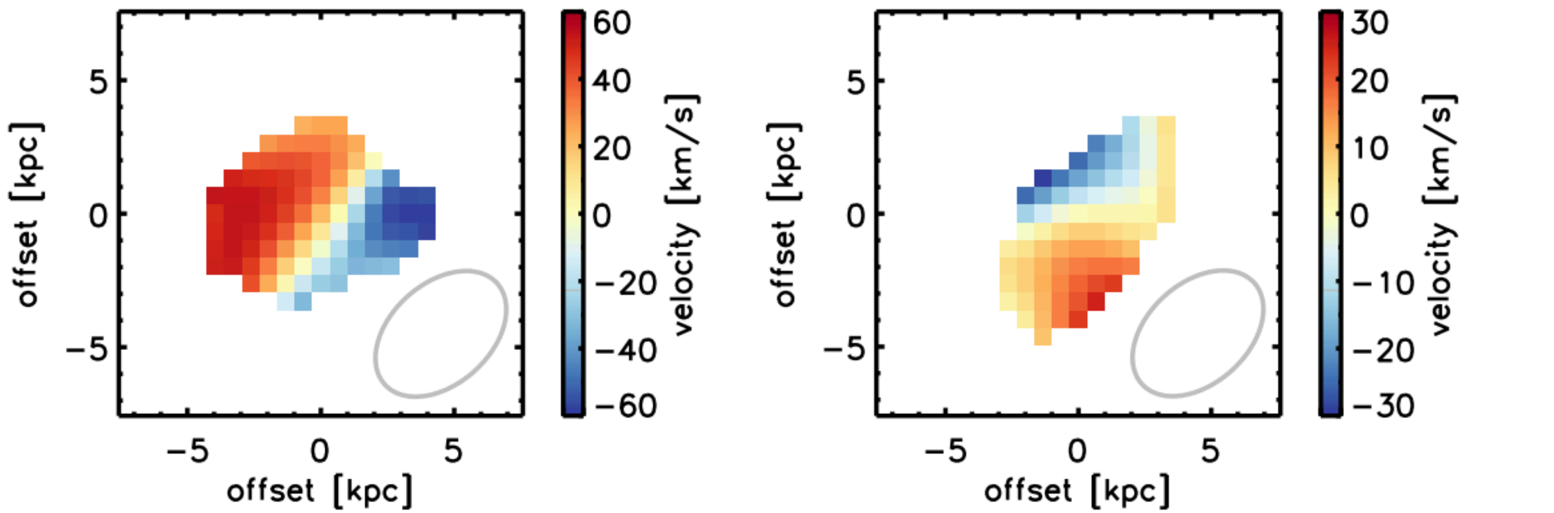




Waters, DM+, 16,

Measurement of rotation in two galaxies in the Epoch of Reionization from ALMA-detected [CII] emission

Renske Smit[1,2], Rychard J. Bouwens[3], Stefano Carniani[1,2], Pascal A. Oesch[4], Ivo Labbé[3], Garth D. Illingworth[5], Paul van der Werf[3], Larry D. Bradley[7], Valentino Gonzalez[7,8], Jacqueline A. Hodge[3], Benne W. Holwerda[9], Roberto Maiolino[1,2]



arXiv:1706.04614v1

The luminous and extended [C II] detections reveal clear velocity gradients and suggest these galaxies have turbulent, yet rotation-dominated disks, with similar stellar to-dynamical mass fractions as observed for Hα emitting galaxies 2 Gyr later at cosmic noon.

First quasars beyond z=7

First 600 million years: The first (and only) billion solar mass Black Holes

LETTER TO NATURE

At z=7, 1 in a Gpc^3

A luminous quasar at a redshift of $z = 7.085$

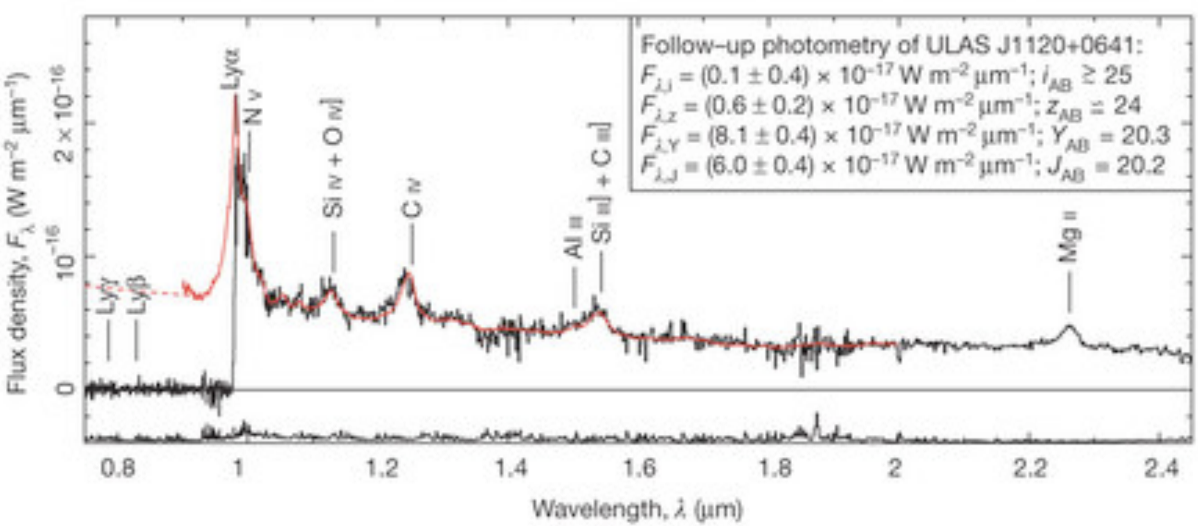
Daniel J. Mortlock[1], Stephen J. Warren[1], Bram P. Venemans[2], Mitesh Patel[1], Paul C. Hewett[3], Richard G. McMahon[3], Chris Simpson[4], Tom Theuns[5,6], Eduardo A. Gonzáles-Solares[3], Andy Adamson[7], Simon Dye[8], Nigel C. Hambly[9], Paul Hirst[10], Mike J. Irwin[3], Ernst Kuiper[11], Andy Lawrence[9] & Huub J. A. Röttgering[11]

$M_{BH}=10^9 M_{sun}$

30 Jun 2011

The intergalactic medium was not completely reionized until approximately a billion years after the Big Bang, as revealed[1] by observations of quasars with redshifts of less than 6.5. It has been difficult to probe to higher redshifts, however, because quasars have historically been identified[2–4] in optical surveys, which are insensitive to sources at redshifts exceeding 6.5. Here we report observations of a quasar (ULAS J112001.48+064124.3) at a red-

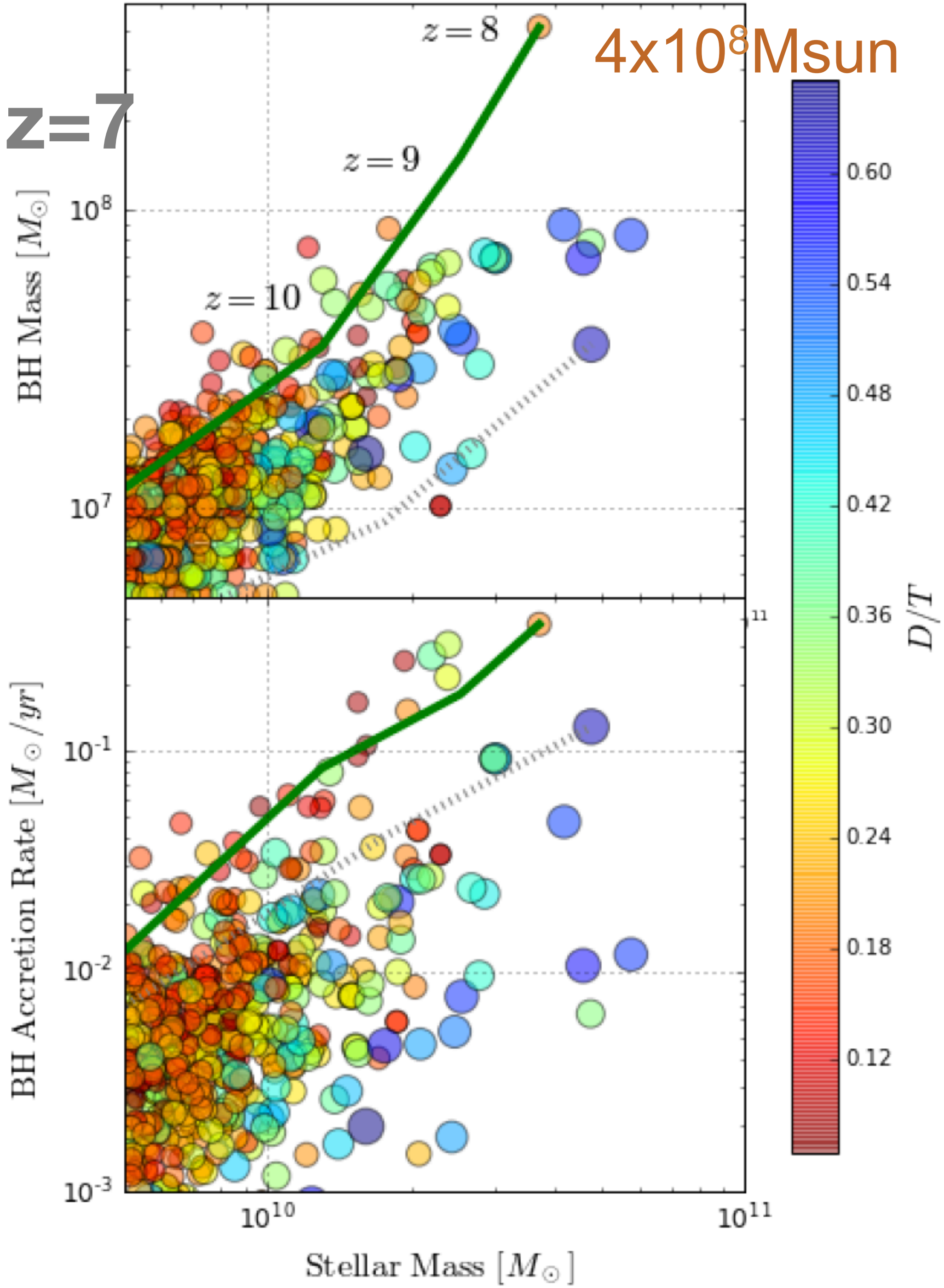
troscopically confirmed to have even higher redshifts, two are faint $J_{AB} \gtrsim 26$ galaxies[10,11] and the other is a γ-ray burst which has since faded[12]. Indeed, it has not been possible to obtain high signal-to-noise ratio spectroscopy of any sources beyond the most distant quasars previously known: CFHQS J0210−0456[13] ($z = 6.44$), SDSS 1148+5251[3] ($z = 6.42$) and CFHQS J2329+0301[14] ($z = 6.42$). Follow-up measurements of ULAS J1120+0641 will provide the first opportunity to explore the 0.1 Gyr between $z = 7.08$ and $z = 6.44$,



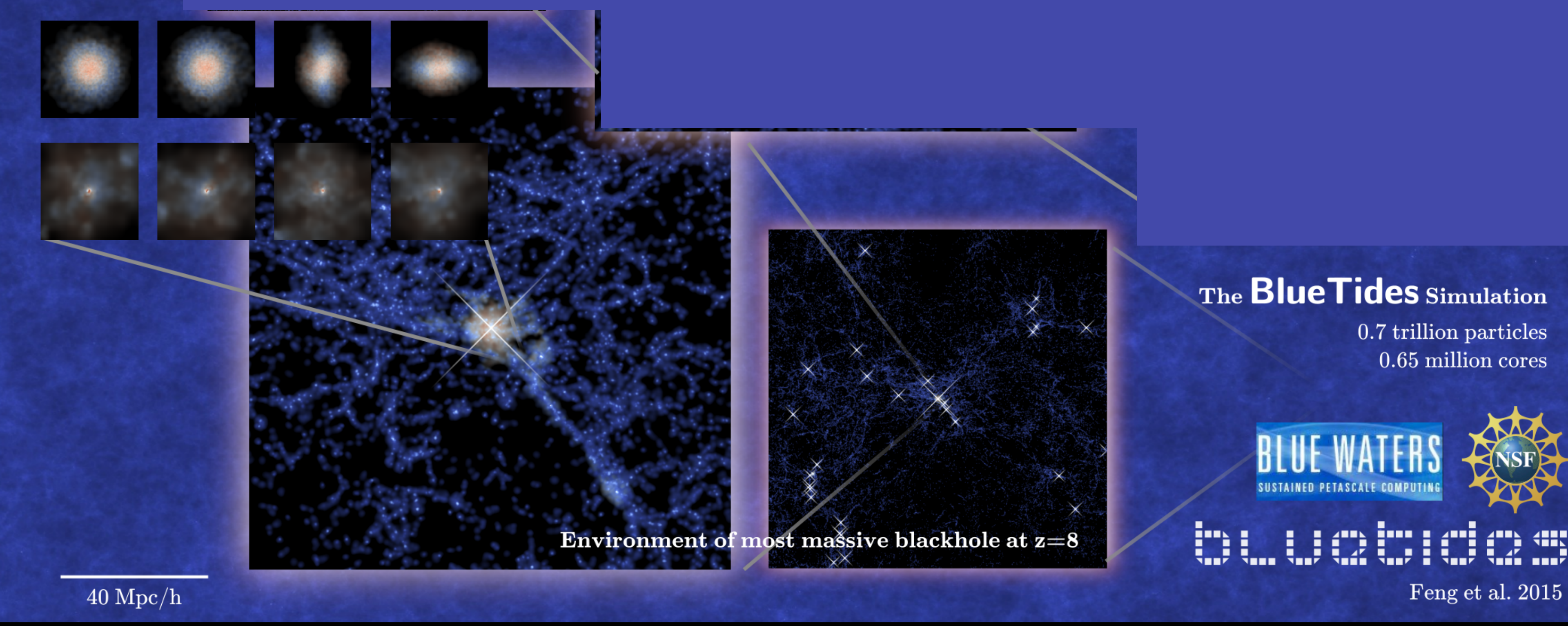
Example III:
First quasars beyond z=7

Most massive BHs
at z=8, $M \sim 10^8 M_{sun}$

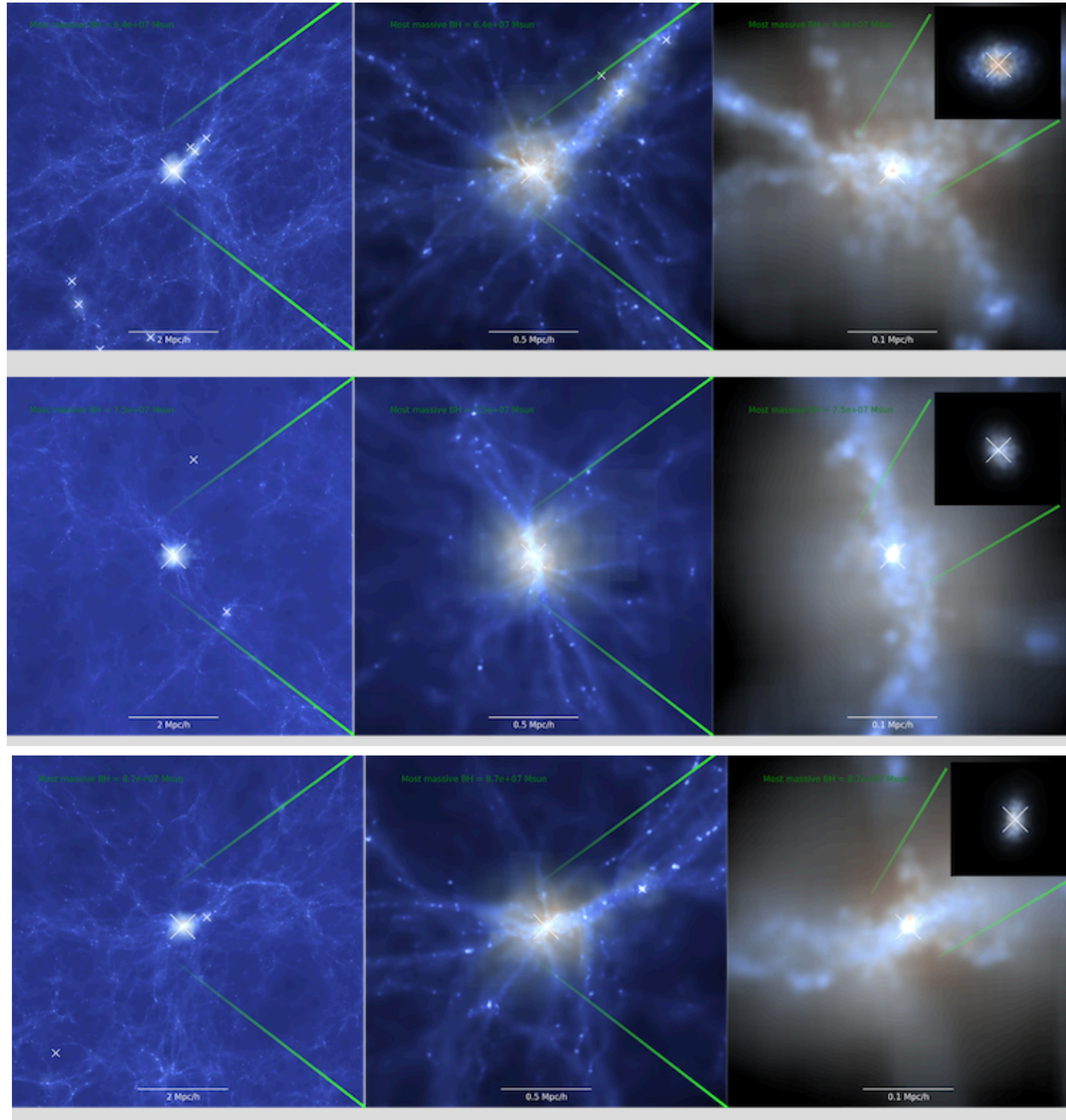
Fastest growing,
massive black holes
are not in disky galaxies!

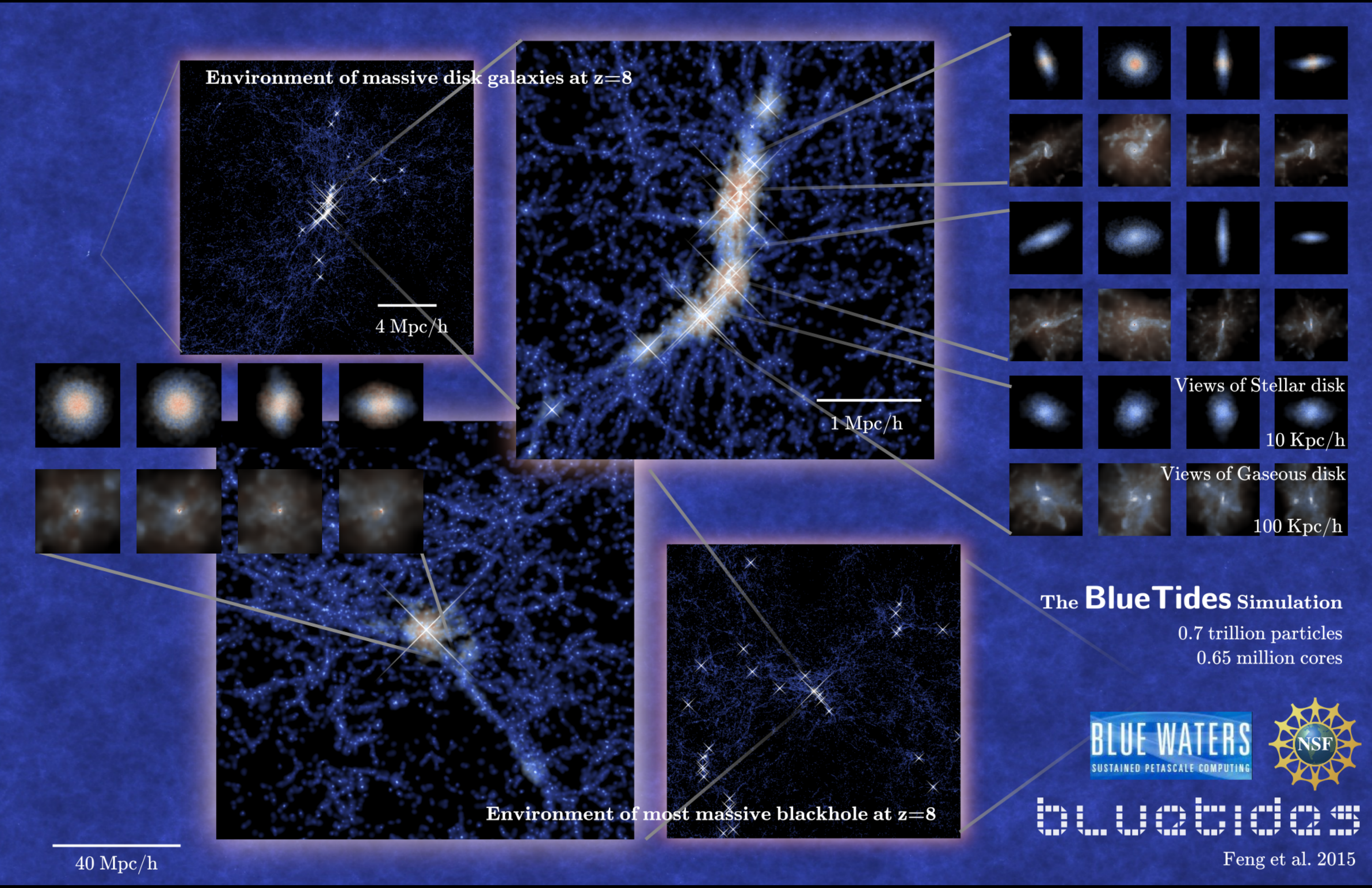


The environment of the most massive BH: compact, spheroidal host galaxy with strong radial inflows



Massive BHs
reside in isolated
overdensities
in supercompact
spheroidal hosts

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40 Mpc/h
Feng et al. 2015

tidal tensor

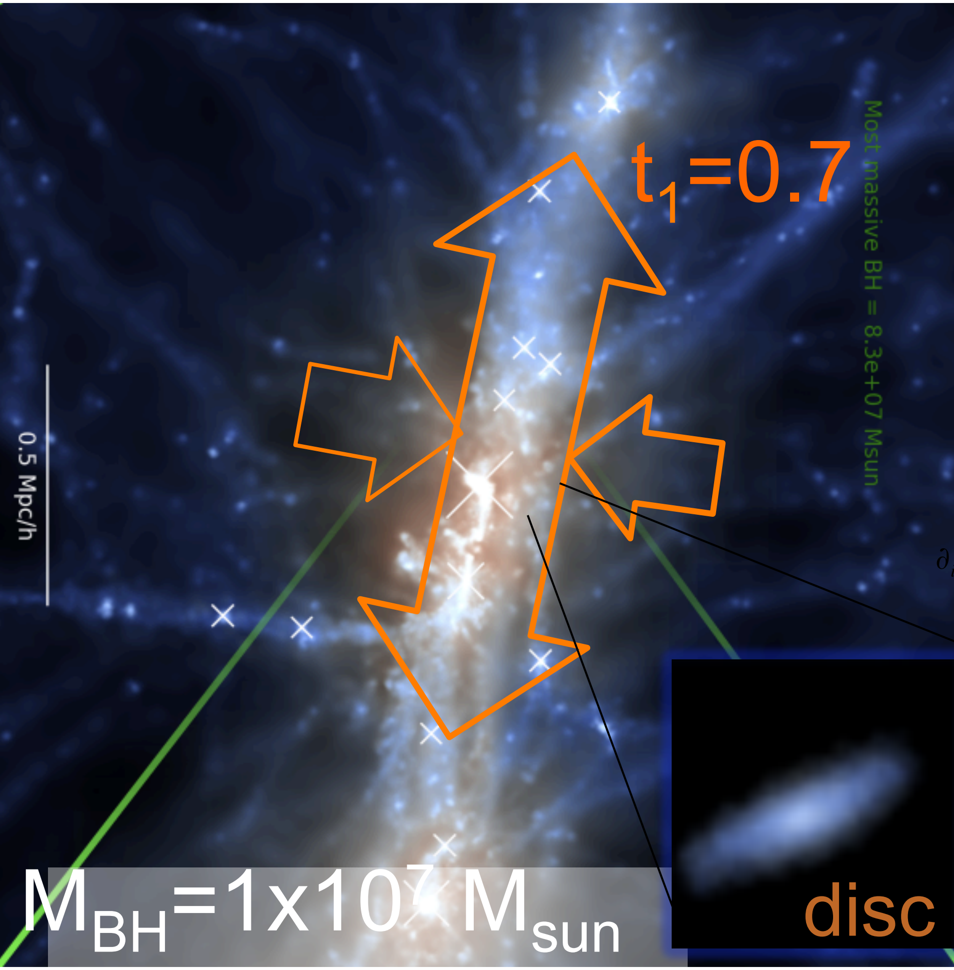
$$T_{ij}(\boldsymbol{x}) = \frac{\partial^2 \phi}{\partial x_i \partial x_j},$$

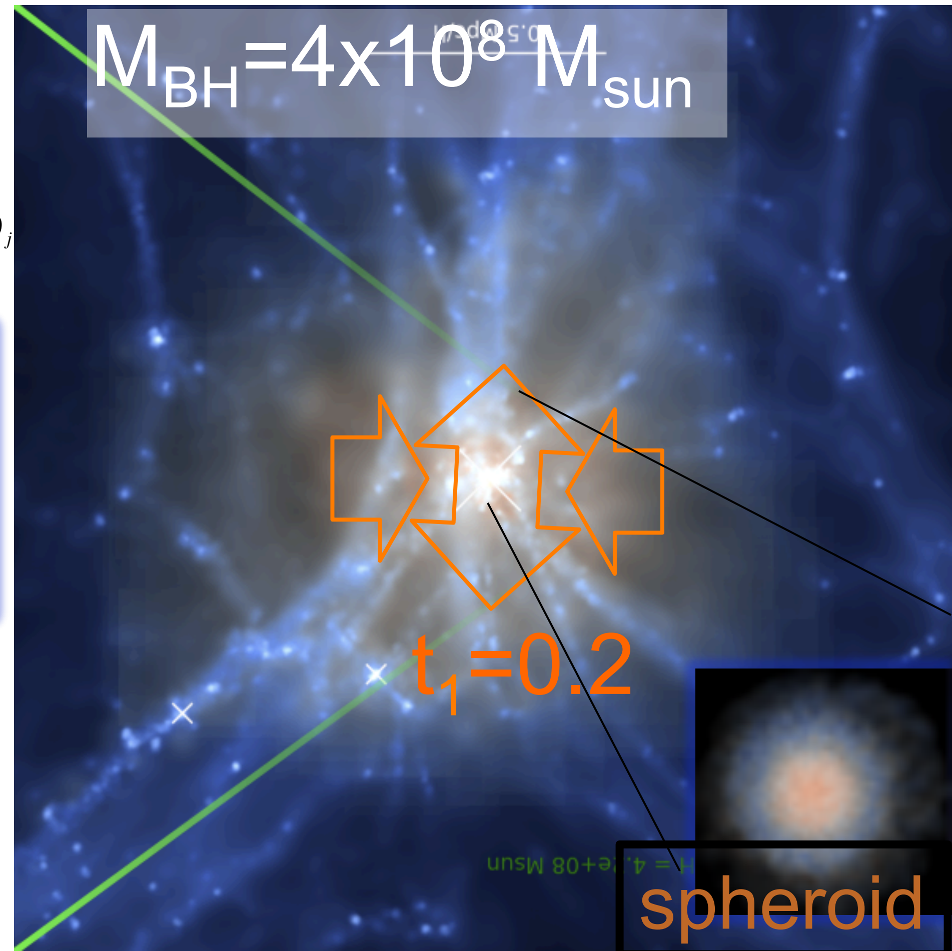
weak tidal field:

Thin filaments

radial motions along t1,

cold accretion





Large tidal field:

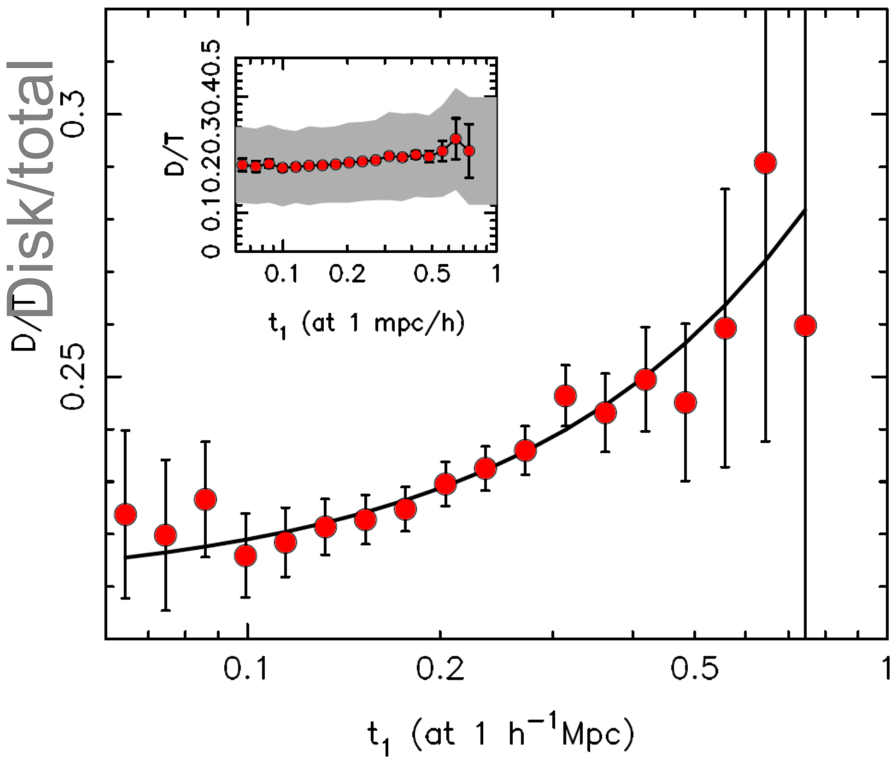
Large filaments,

Accretion perp. to t1, /coherent

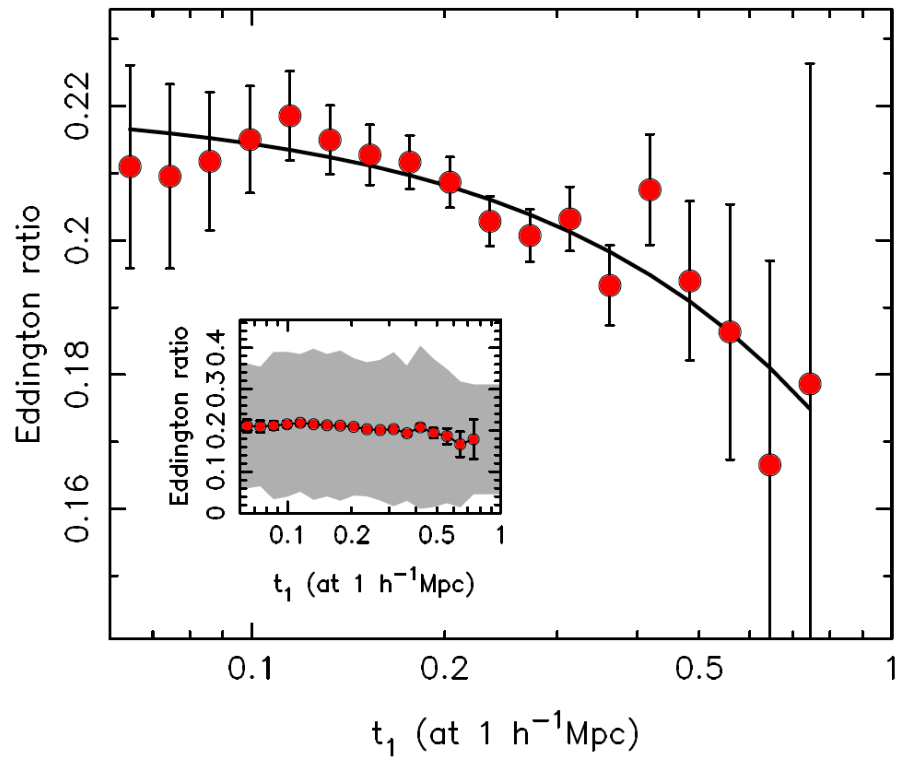
ang. momentum

Large tidal field:
→discs

weak tidal field:
→massive BHs
in spheroids



Tidal field strength

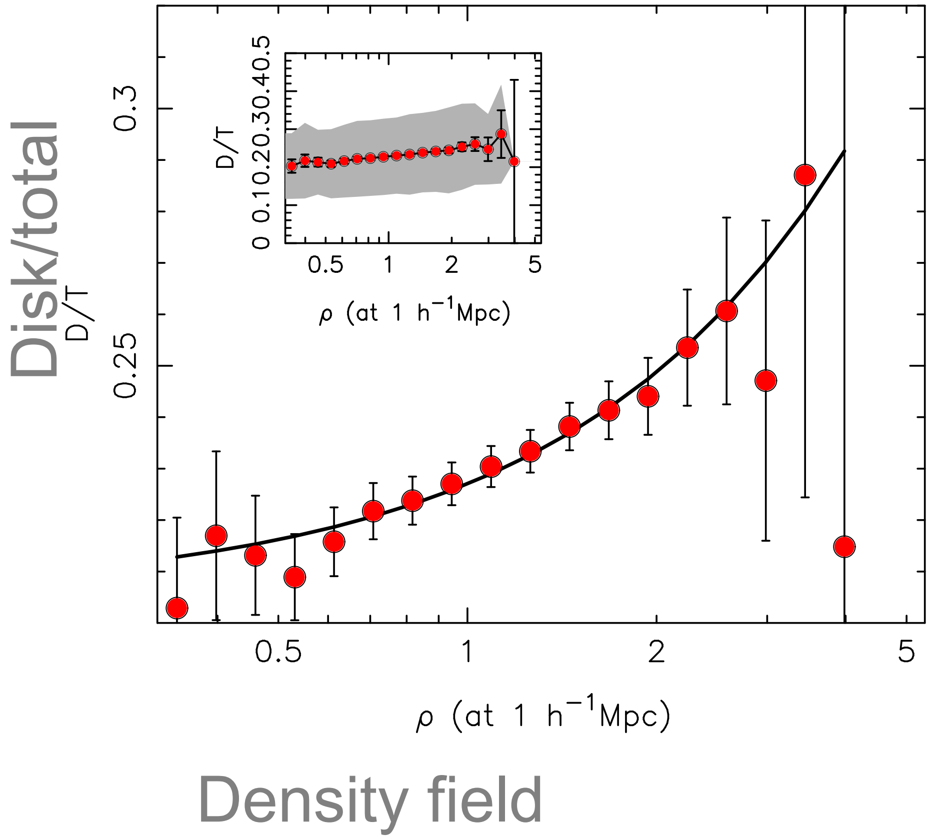


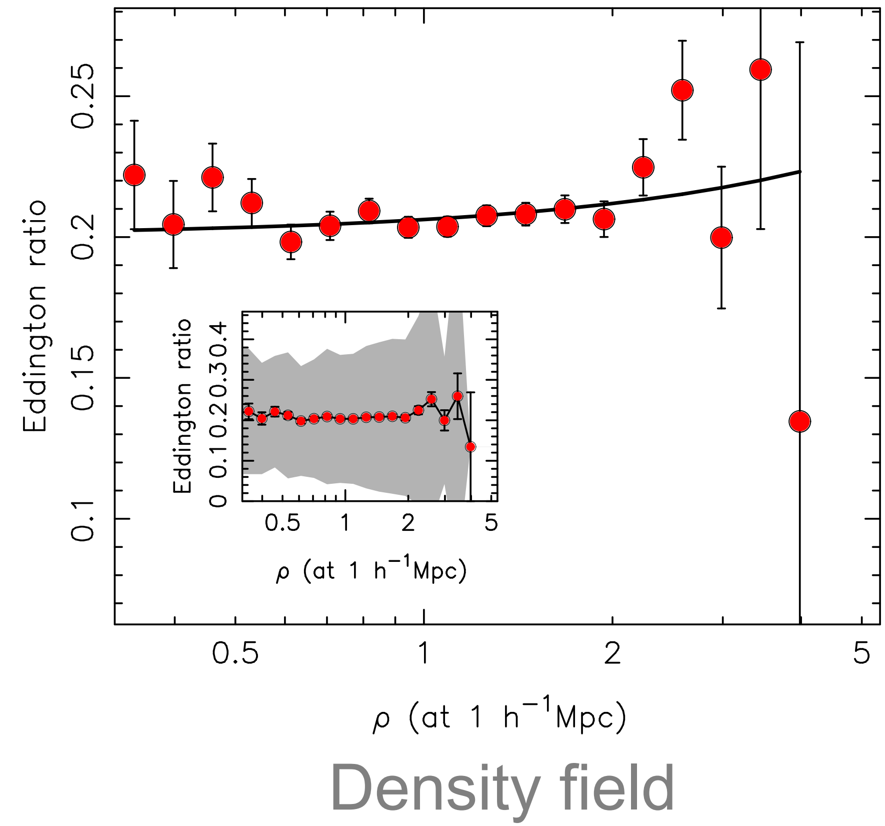
Tidal field strength

TDM et al. 17

→discs

→massive BHs in spheroids

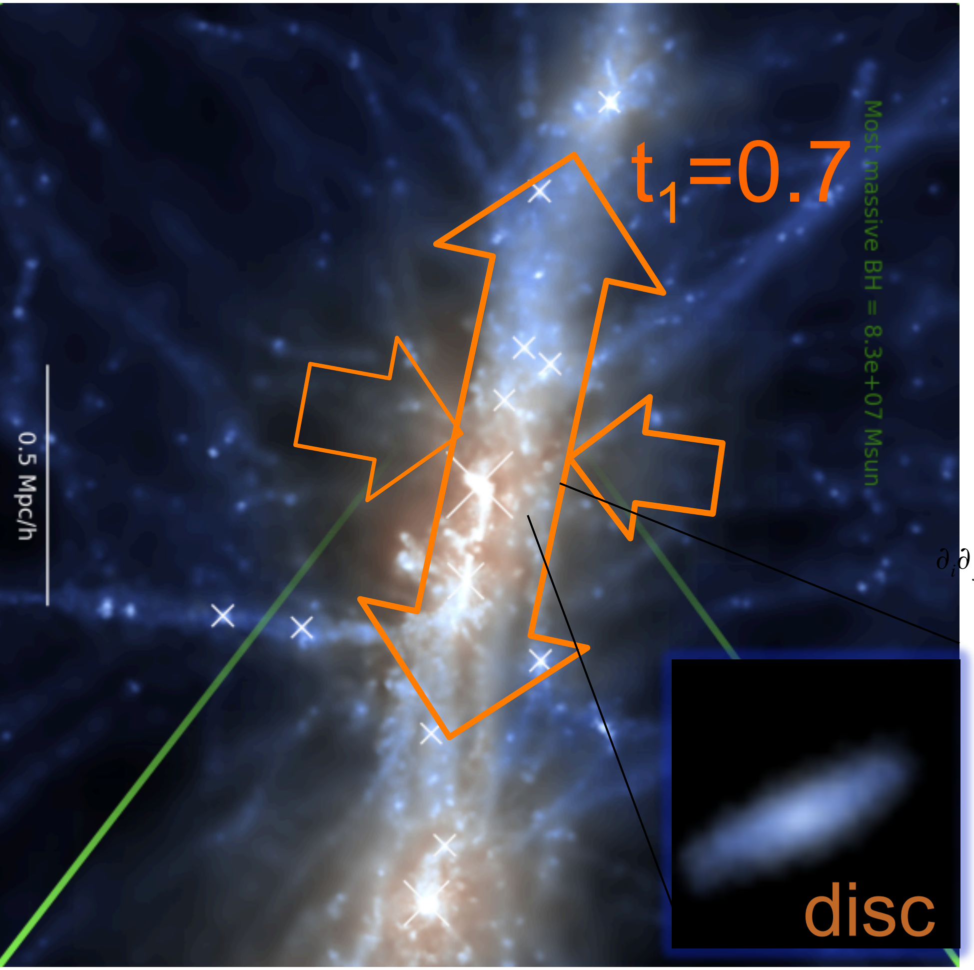




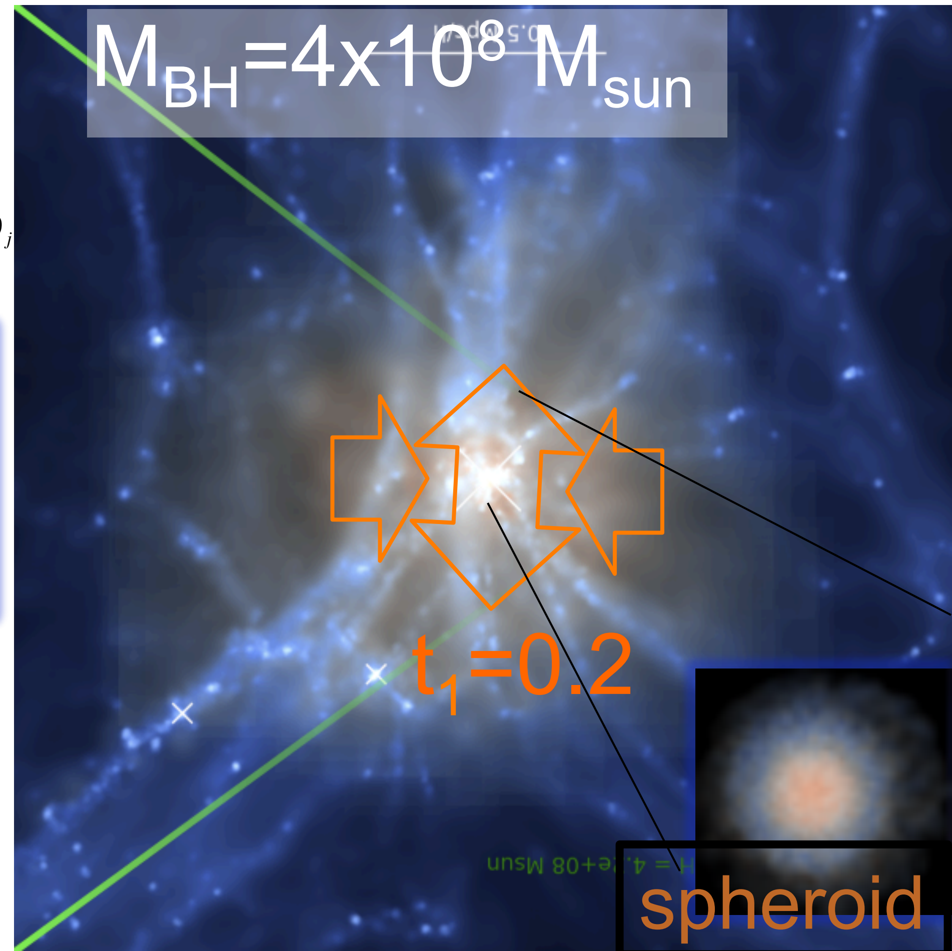
Not correlated to density

TDM et al. 17

BT: First Massive stuff...

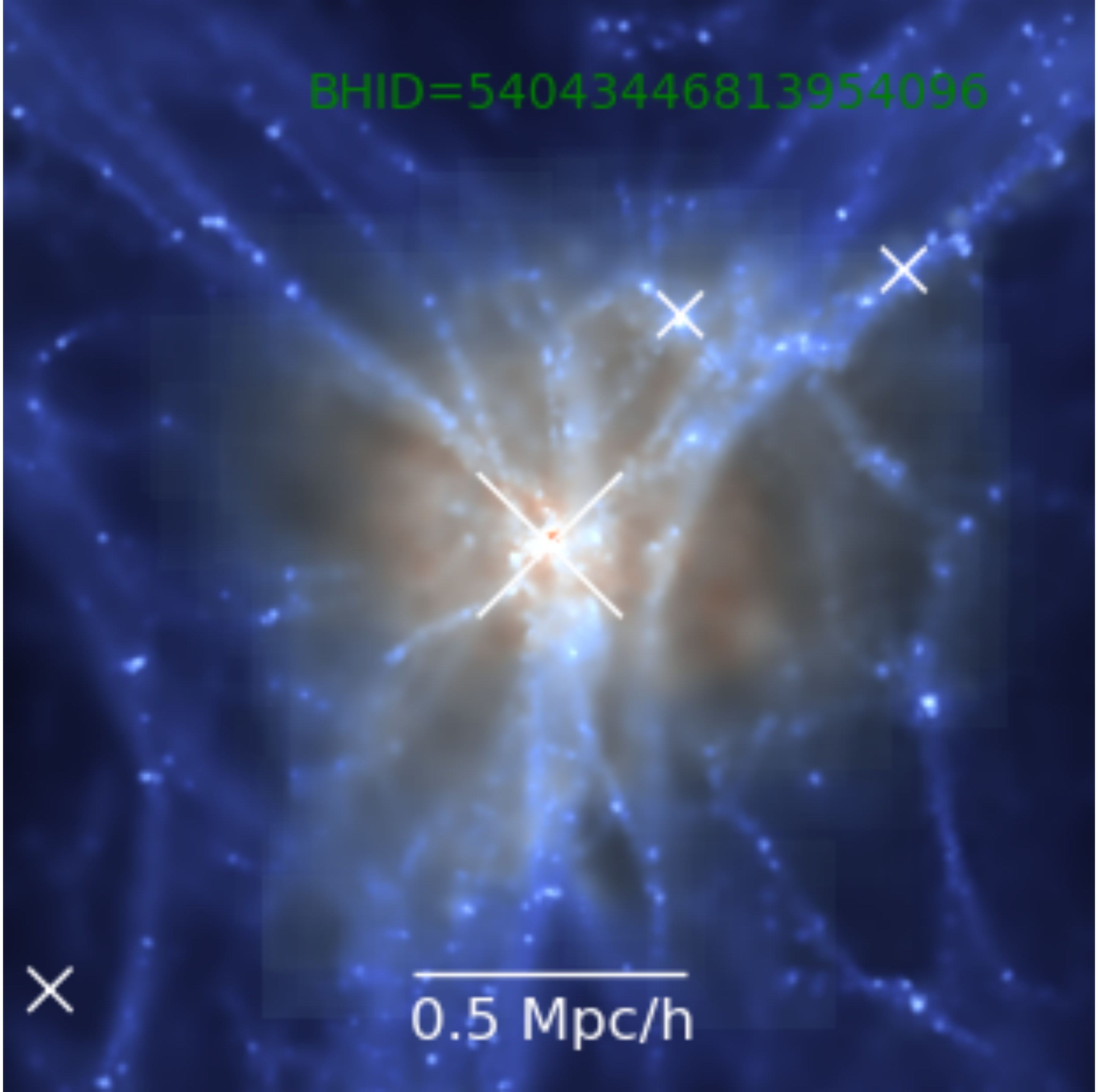


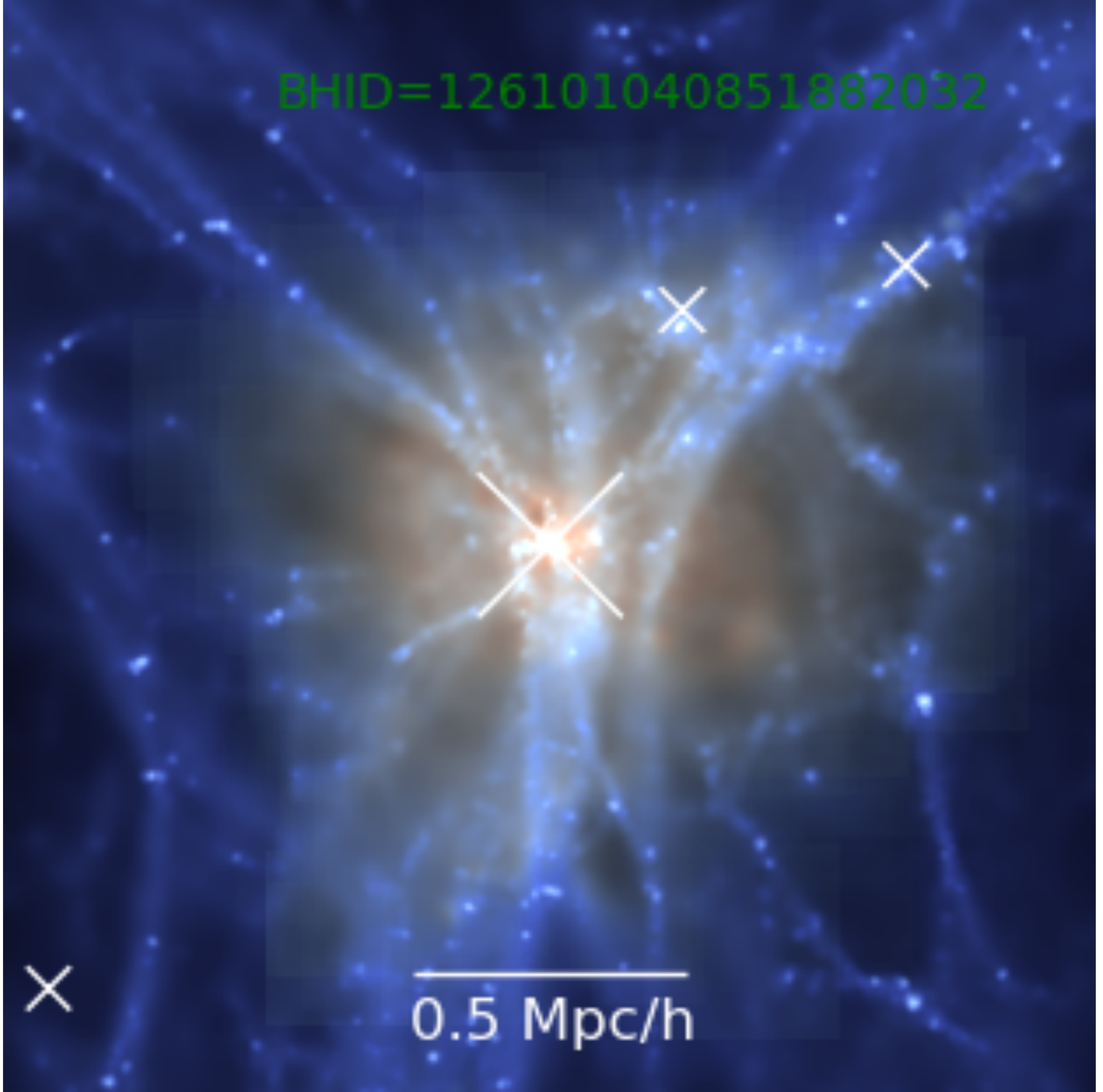
First billion solar mass BHs

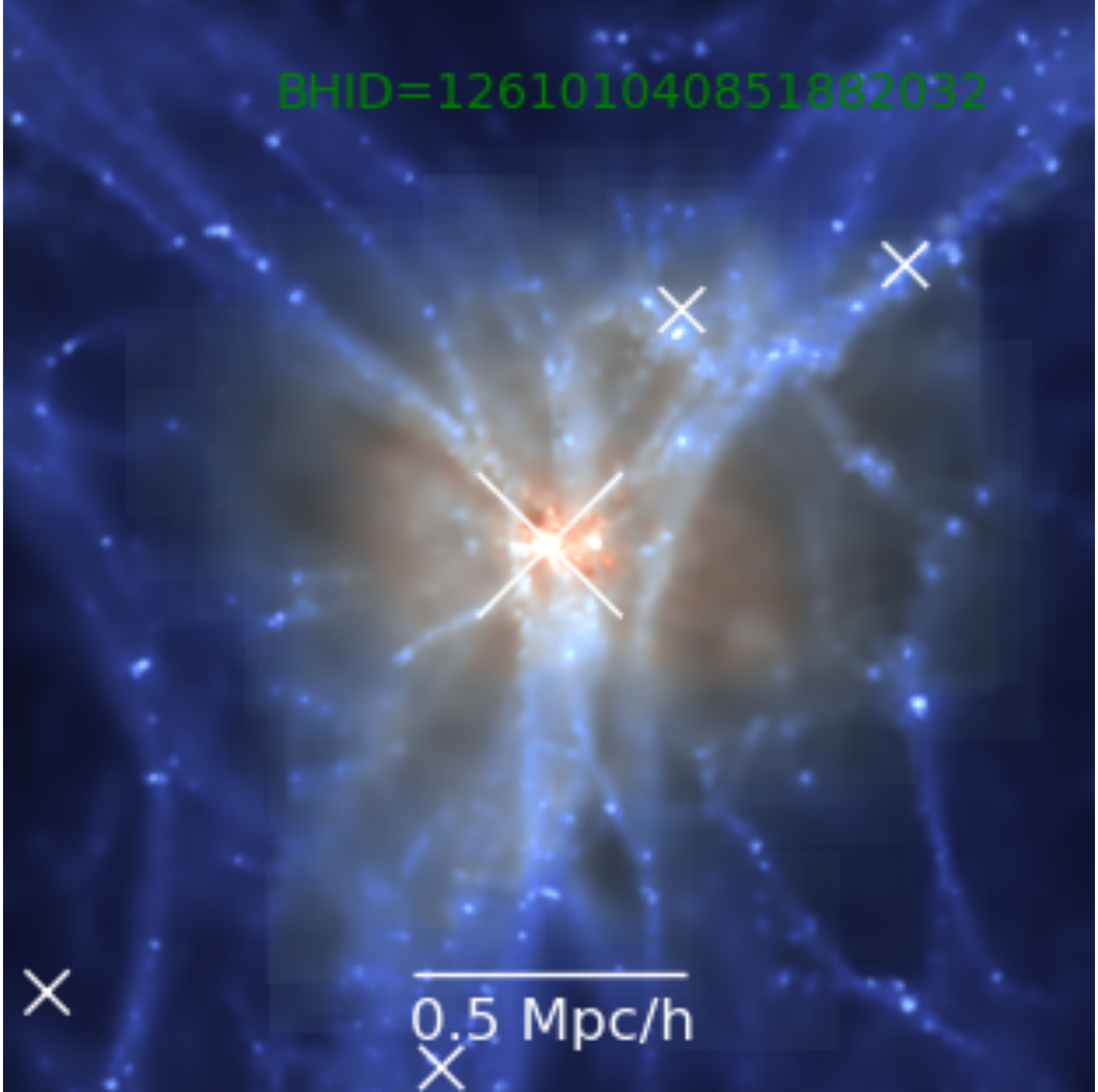


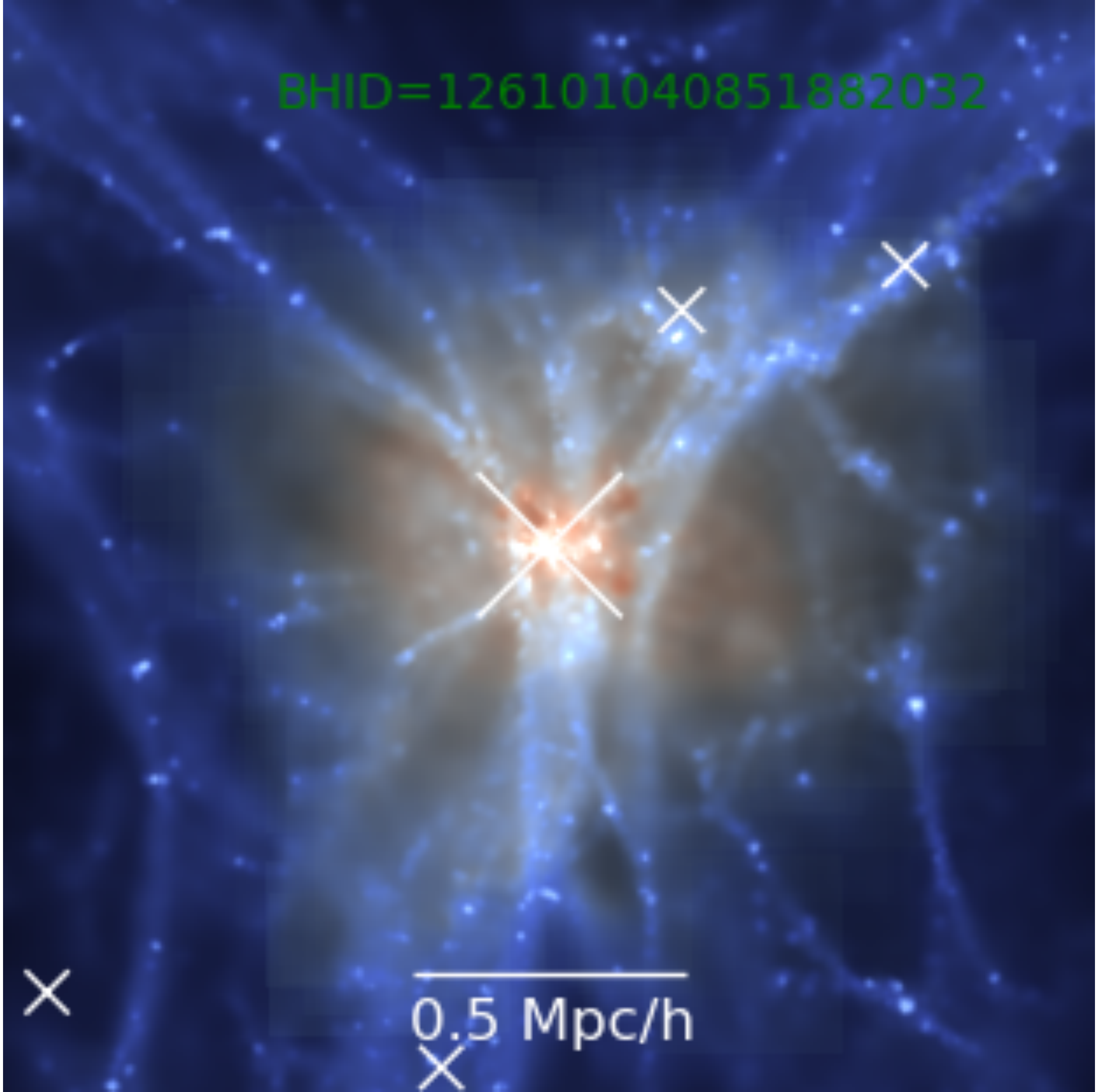
Primordial ‘Milky Way’ galaxies

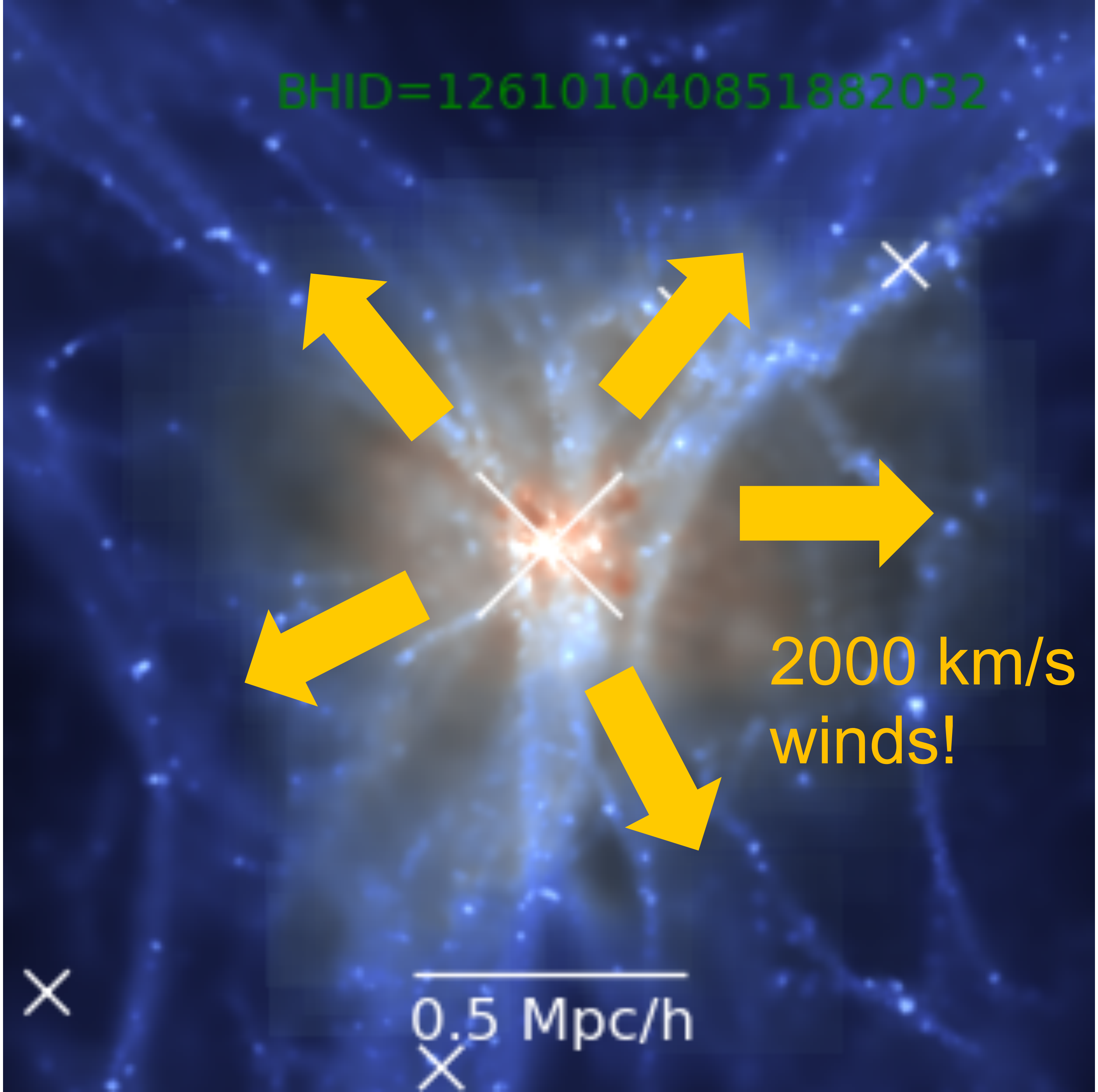
Does the BH ever stop growing?


BHID=54043446813954096
0.5 Mpc/h


BHID=1261010408518882032
0.5 Mpc/h


BHID=1261010408518820 32
0.5 Mpc/h

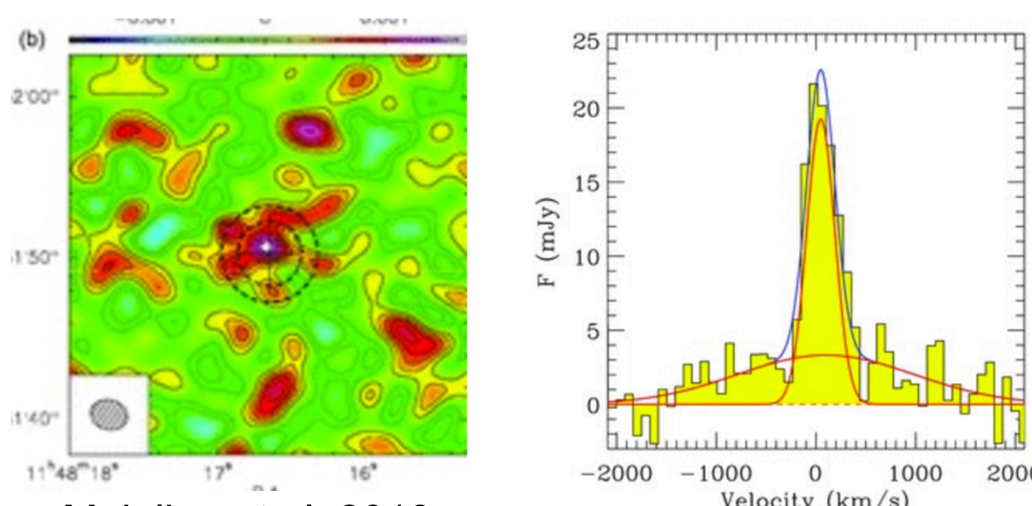

BHID=1261010408518820032
0.5 Mpc/h


BHID=126101040851882032
2000 km/s
winds!
0.5 Mpc/h

Does the BH ever stop growing?

YES

Evidence for BH feedback/winds in z=6 quasars



Maiolino et al. 2013

Where is the first supermassive BH today ?

How to find out ?

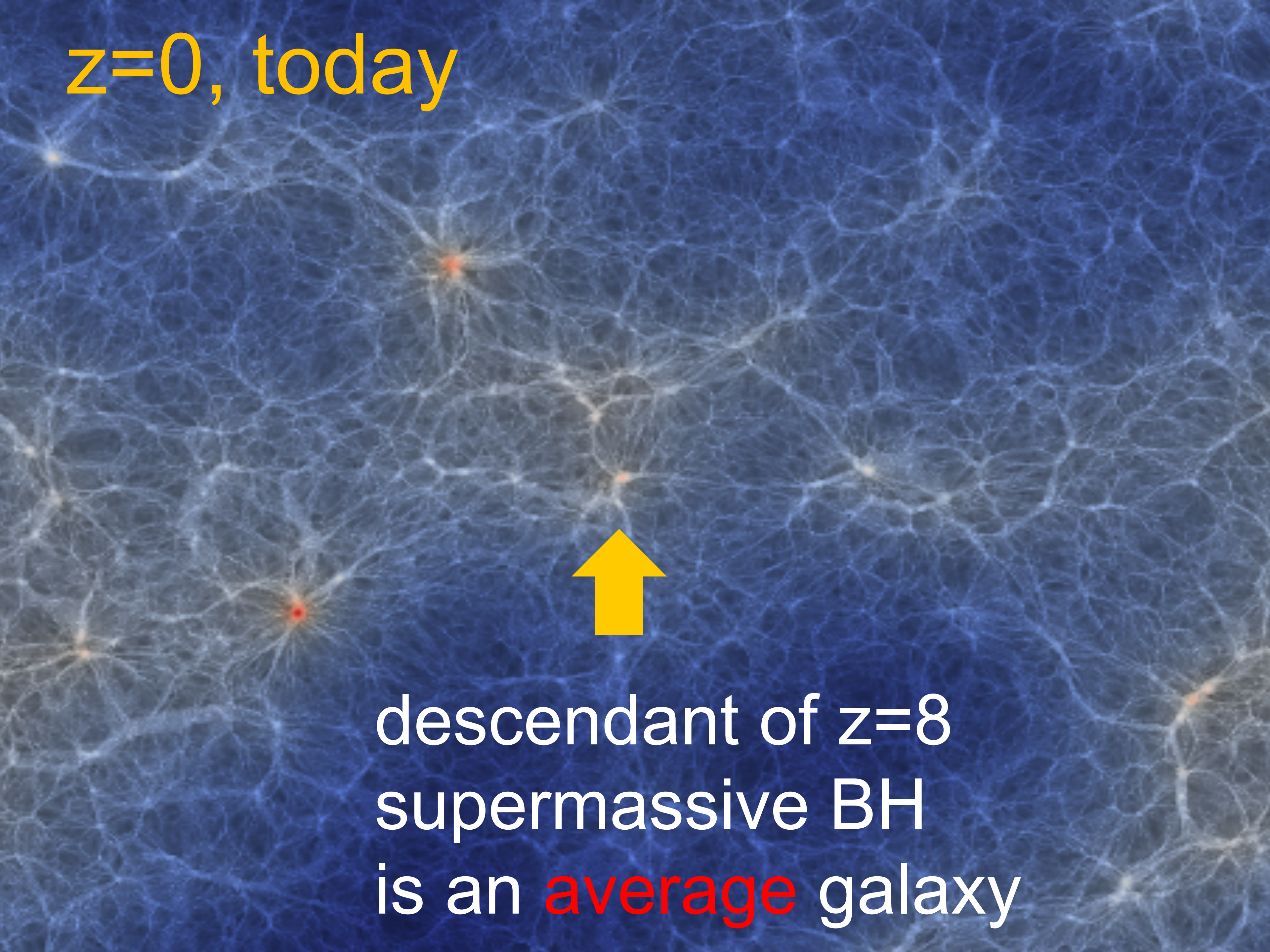
BTMassTracer

new simulation

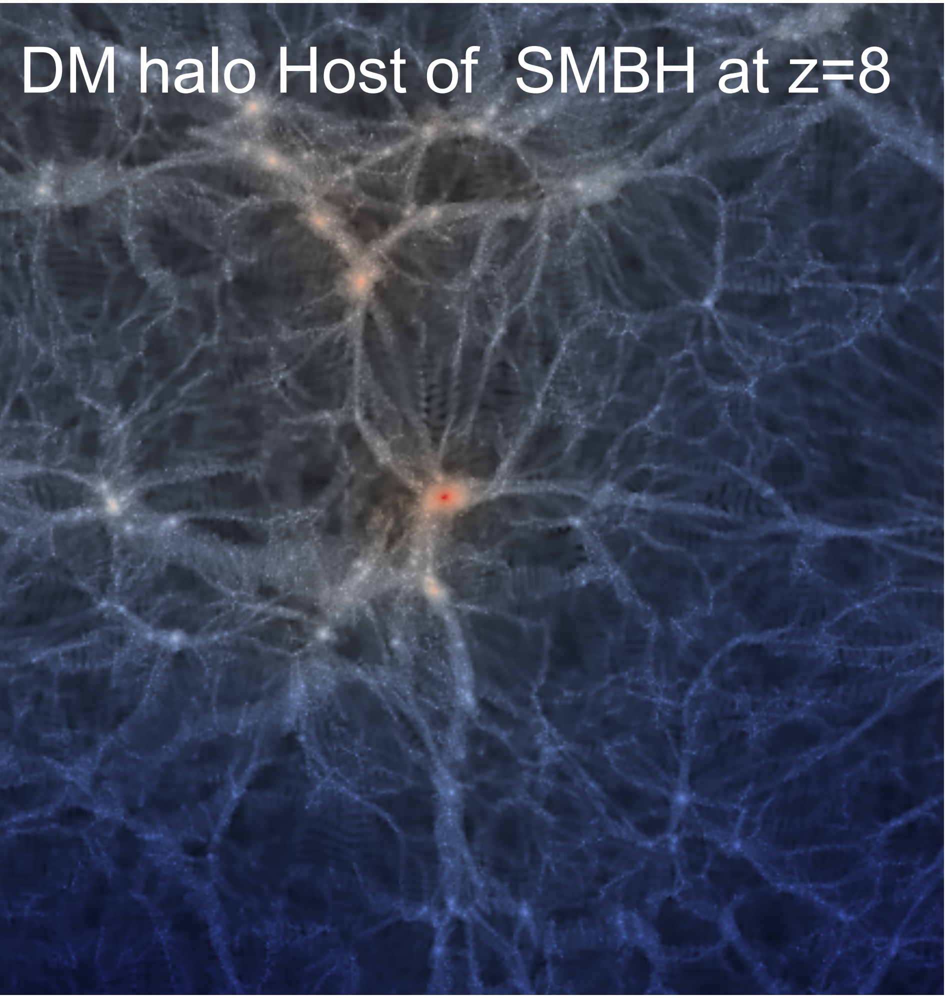
BlueTides

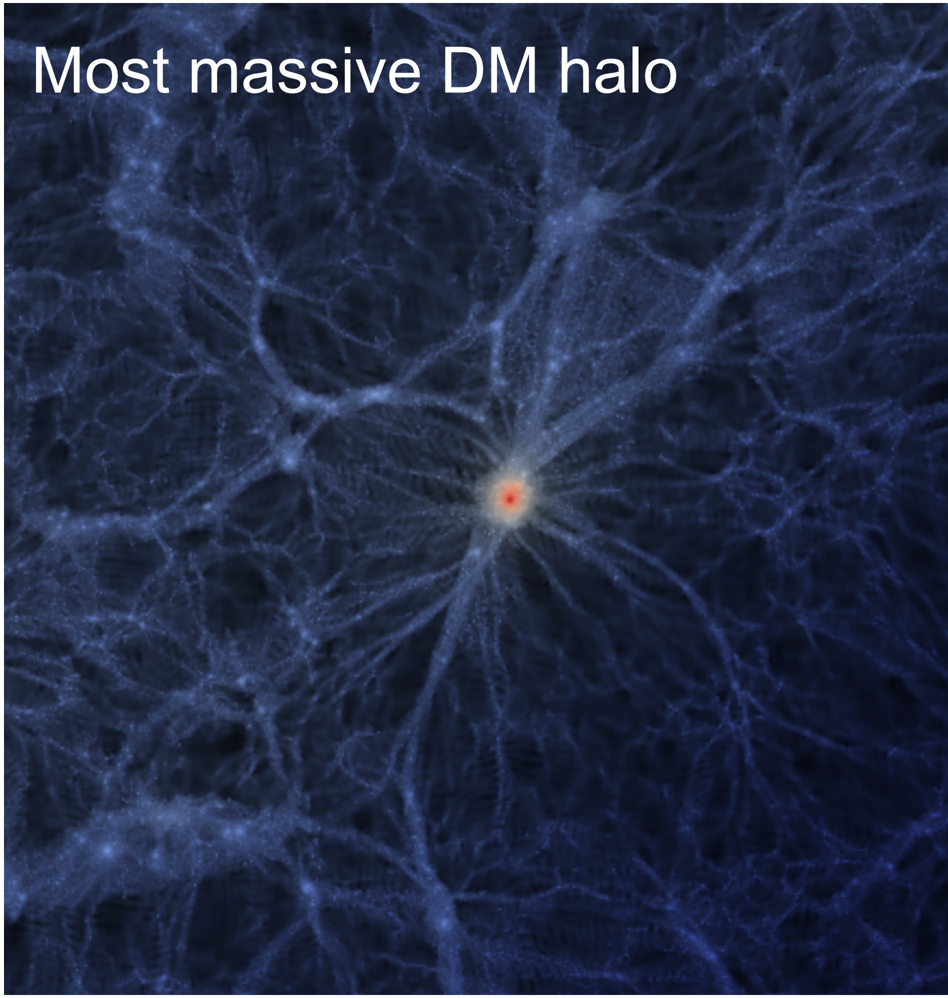
Universe

today


z=0, today
descendant of z=8
supermassive BH
is an average galaxy

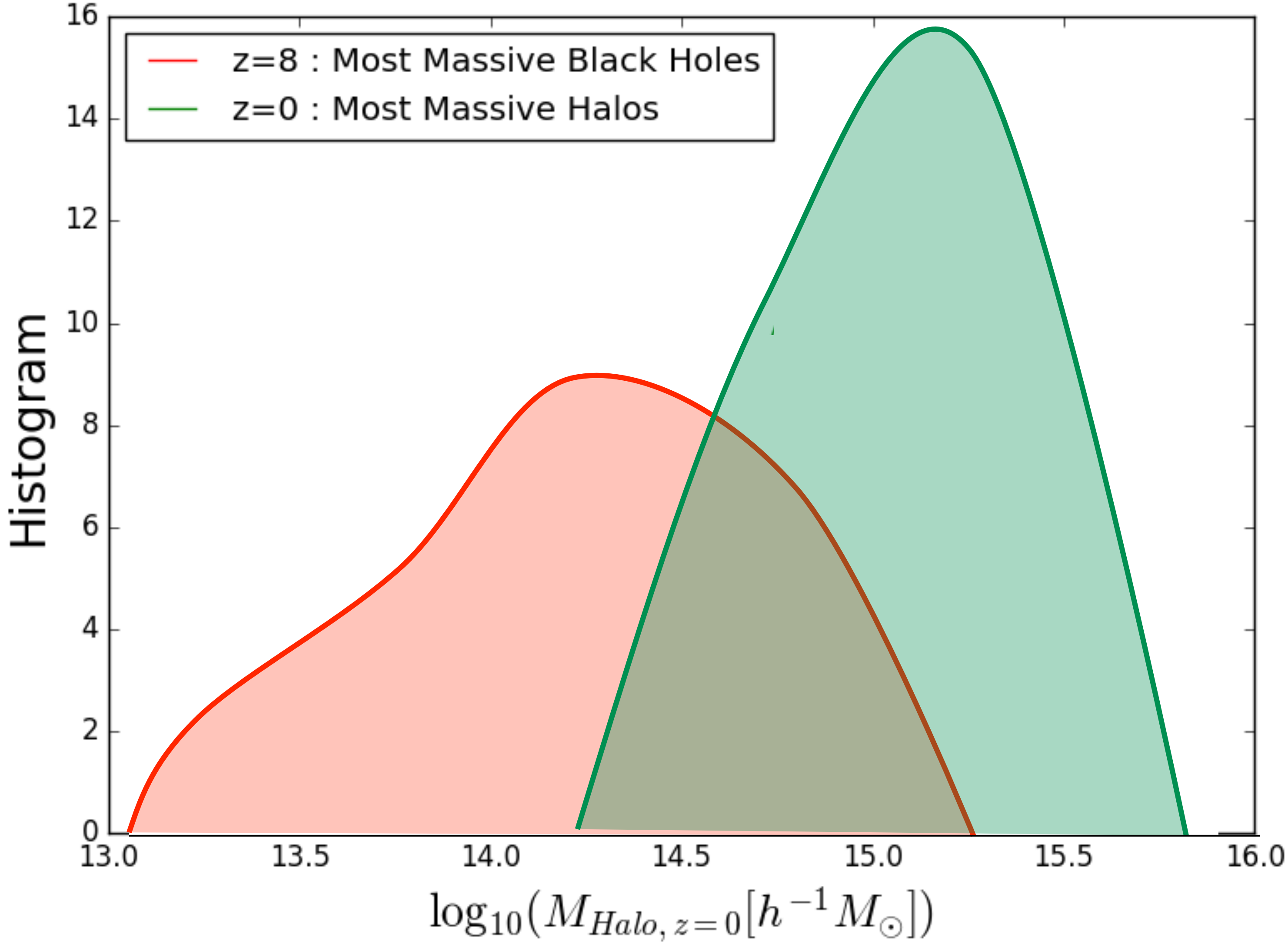
Today, environments at z=0



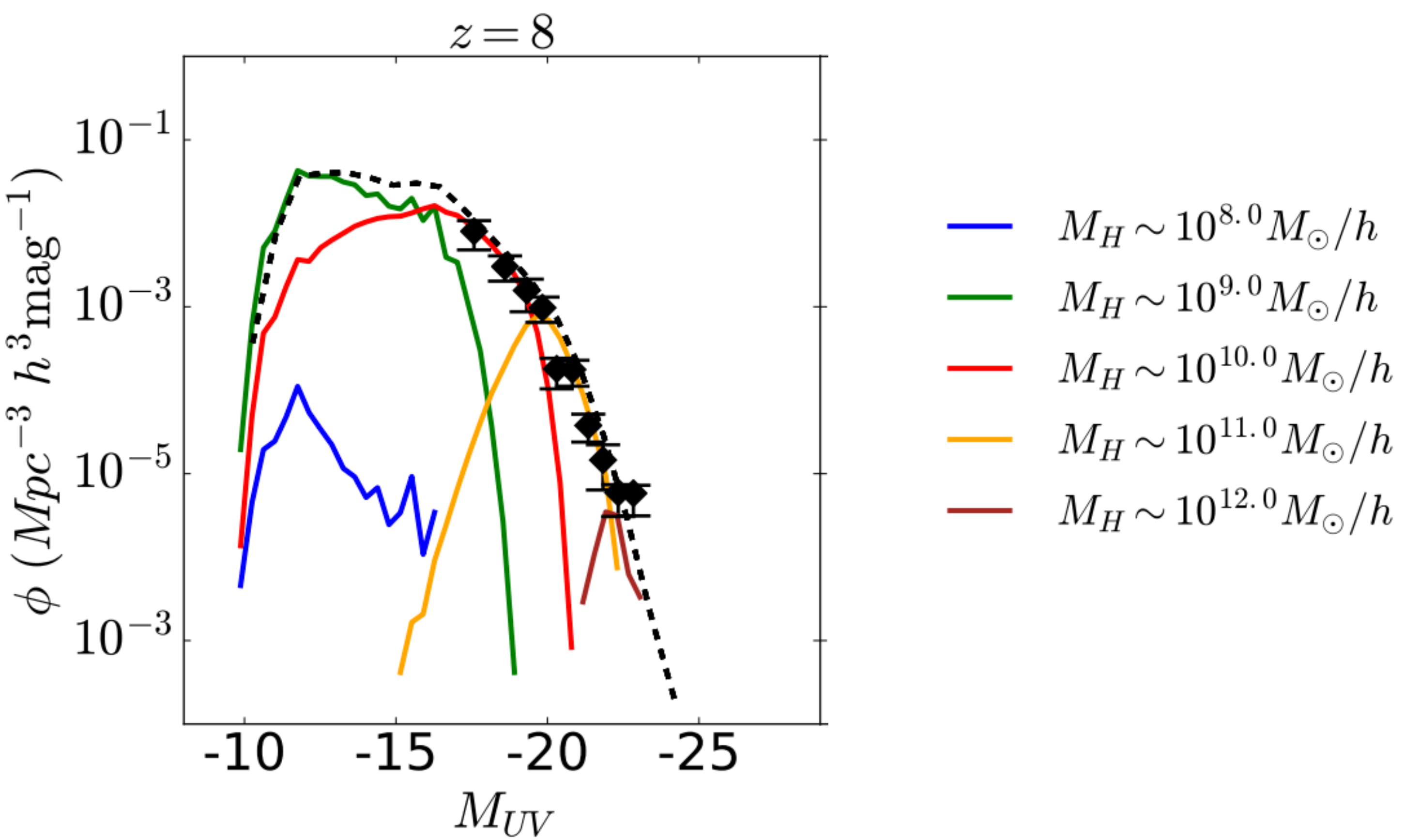


descendants of SMBHs
more isolated

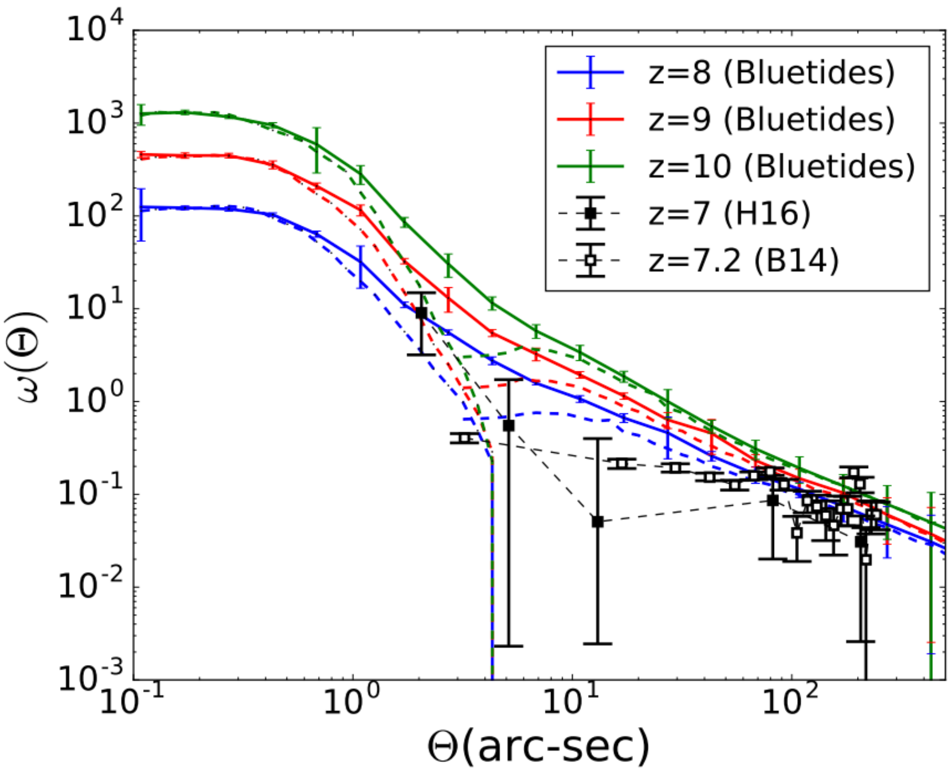
Top SMBHS end up in galaxy groups, not galaxy clusters

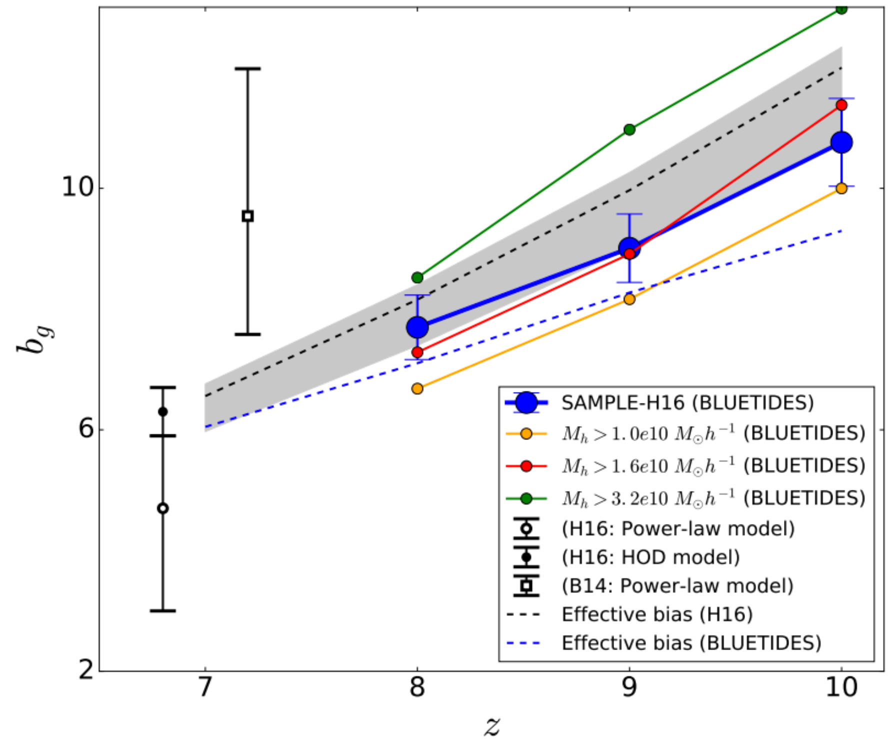


Cosmology with galaxies at z>7 ?



Clustering and bias of z=7 galaxies in HUDF

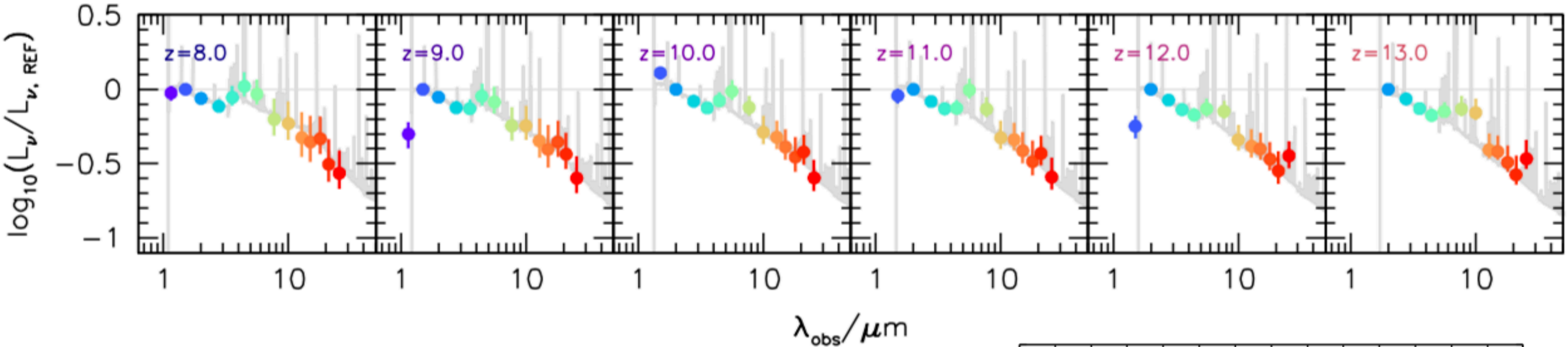




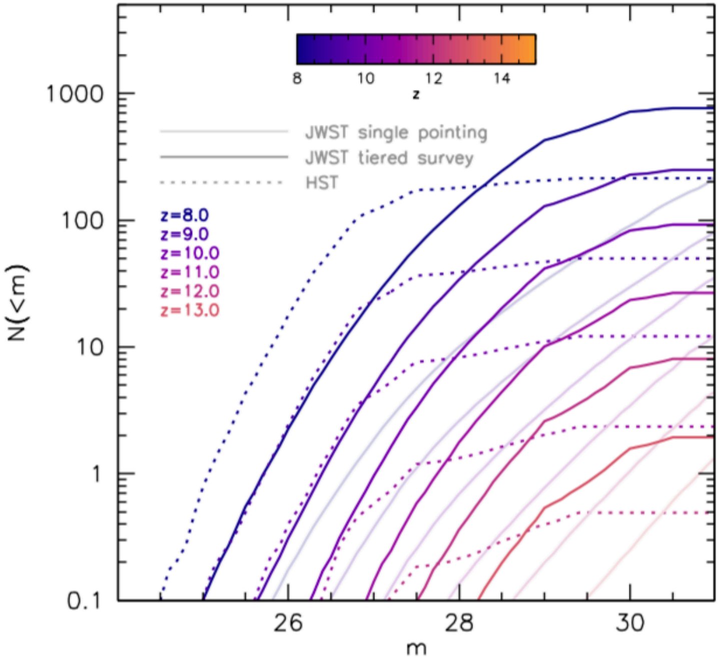
Bhowmick, DM et al. 17

The next frontier: HSC, JWST, WFIRST

Predictions for JWST

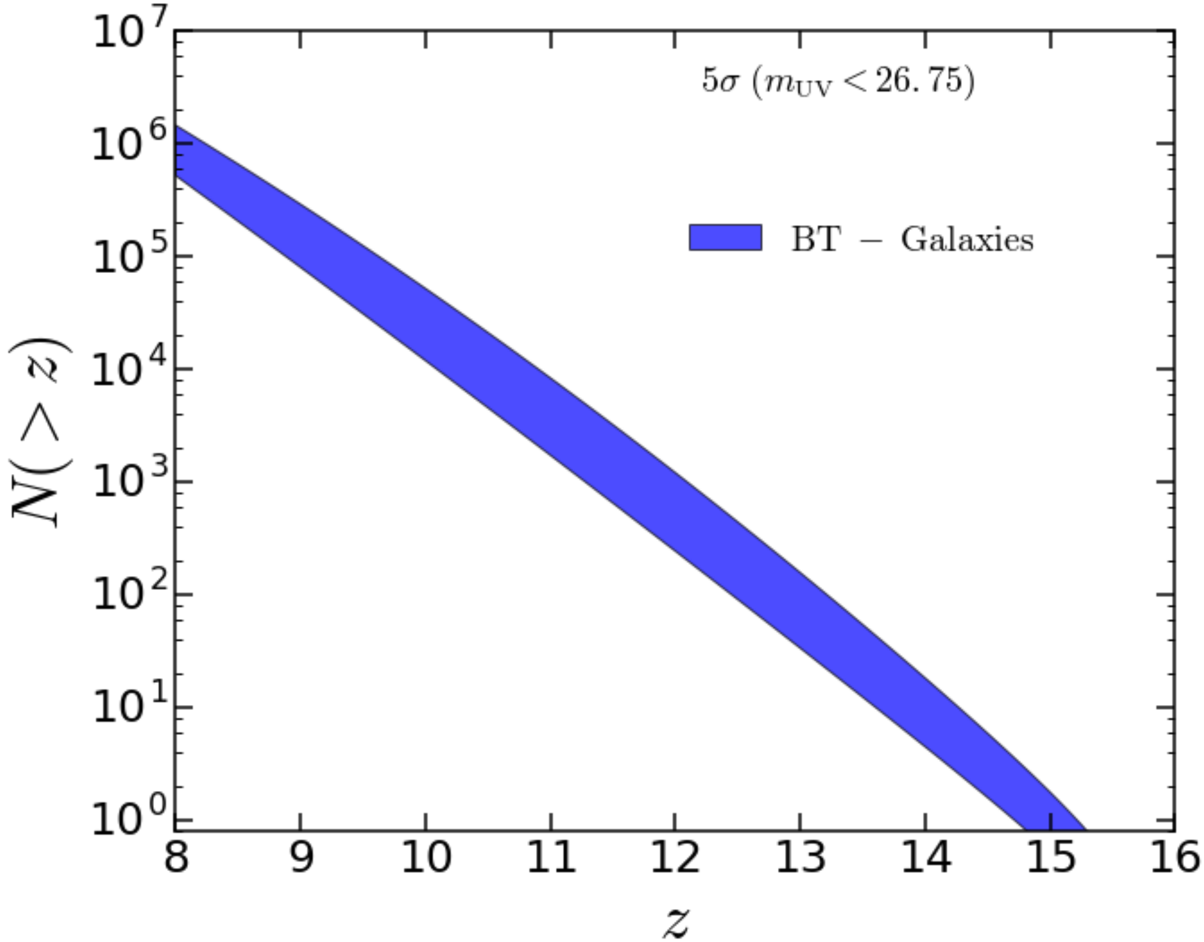


4 times as many galaxies as in current HST fields



The end of the dark ages is bright!

HLS 2200 sq degrees



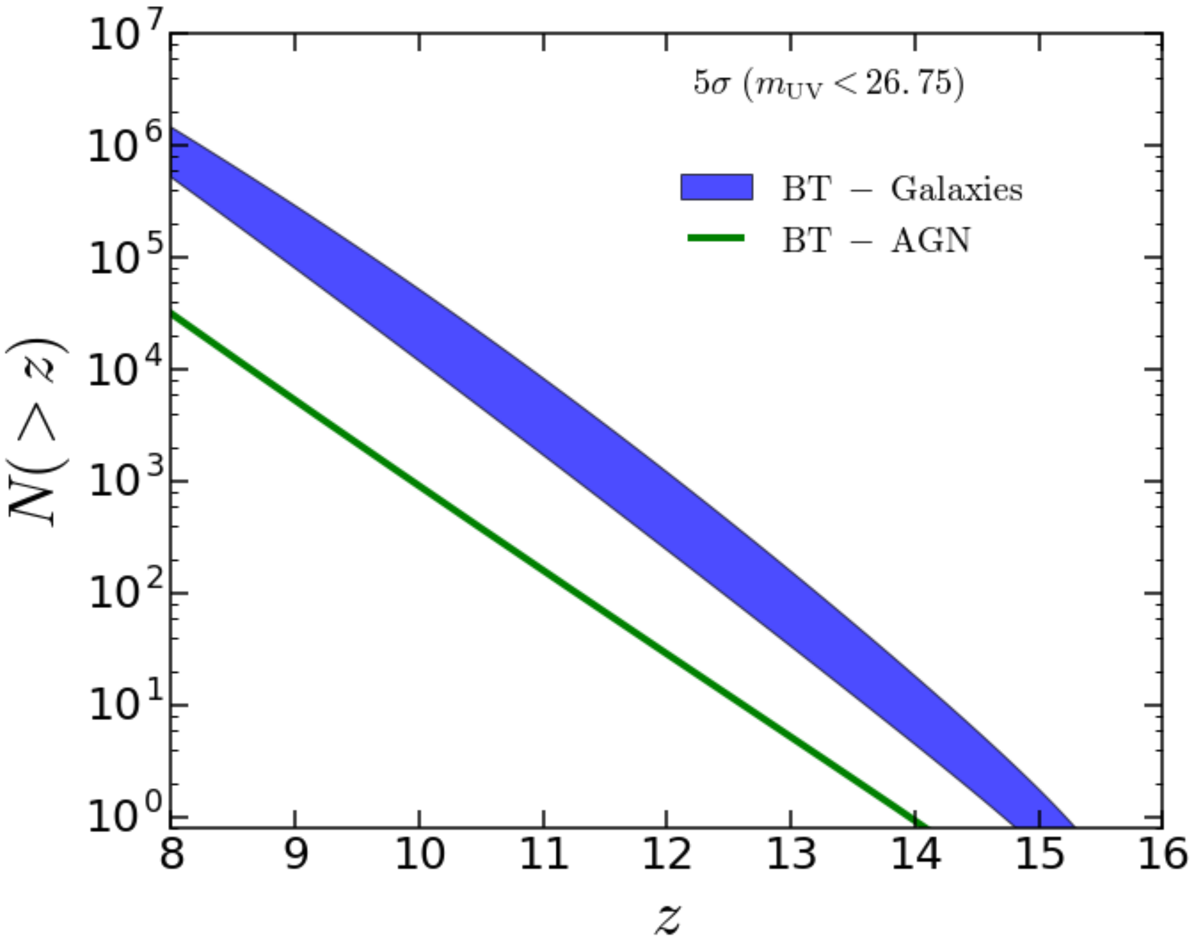
Waters, DM+, 17

Up to 1M galaxies,

First galaxies at z=15; t=300Myr

The end of the dark ages is bright!

HLS 2200 sq degrees



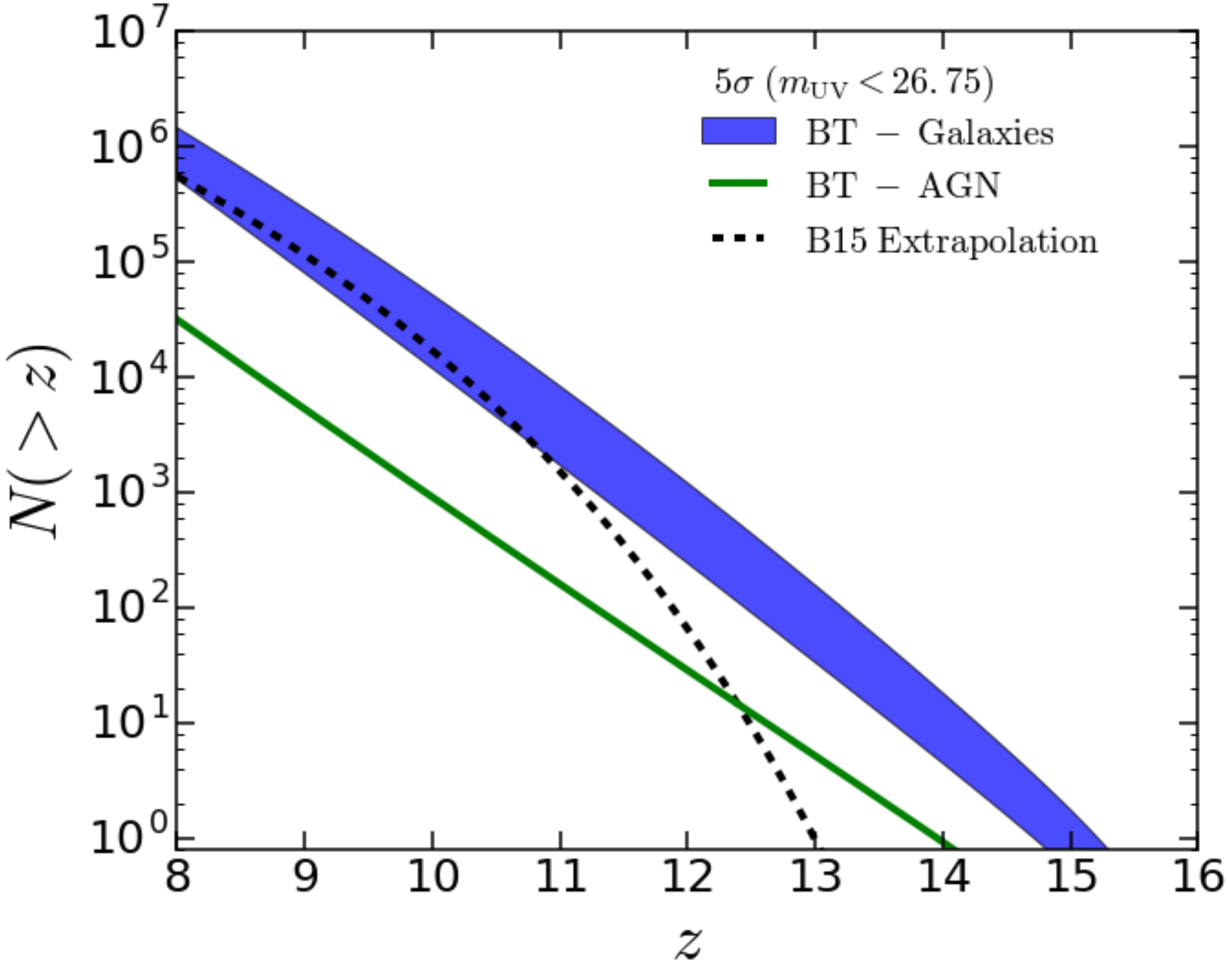
Waters, DM+, 16

Up to 1M galaxies, 10^4 AGN

First AGN at z=14

The end of the dark ages is **bright**!

HLS 2200 sq degrees

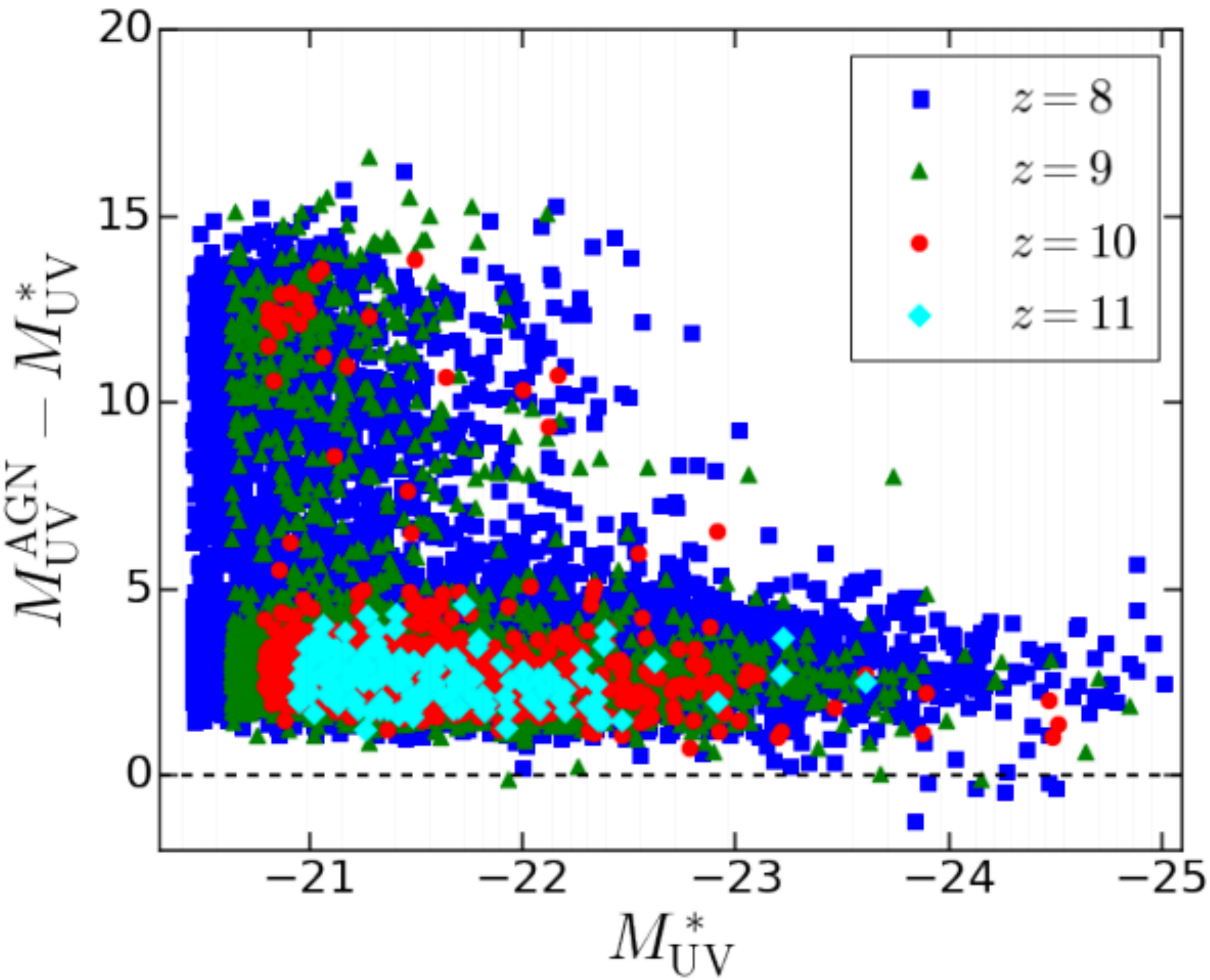


Waters, DM+, 16

Up to 1M galaxies, 10^4 AGN

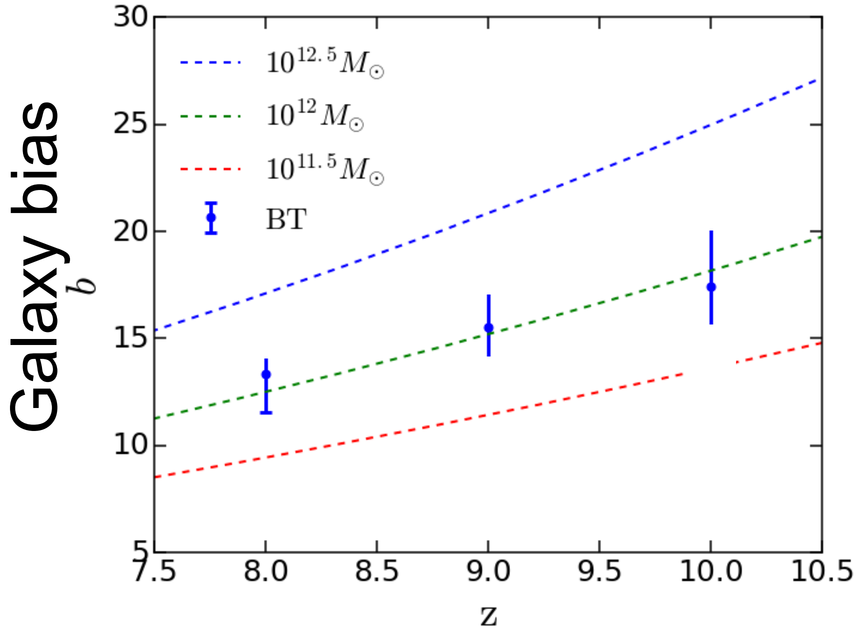
First galaxies at z=15, First AGN at z=14

Quasars, beyond z>7 are about
2 mag fainter than their hosts
apart from handful of very bright AGN



Cosmology with galaxies at z>7 ?

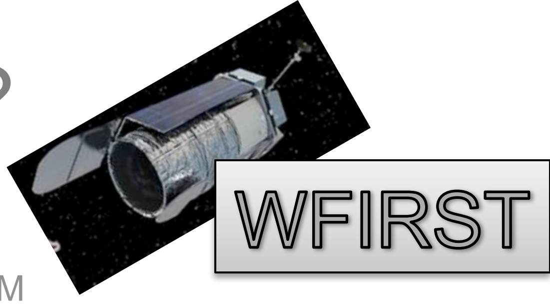
HLS 2200 sq degrees



Waters, DM+, 16

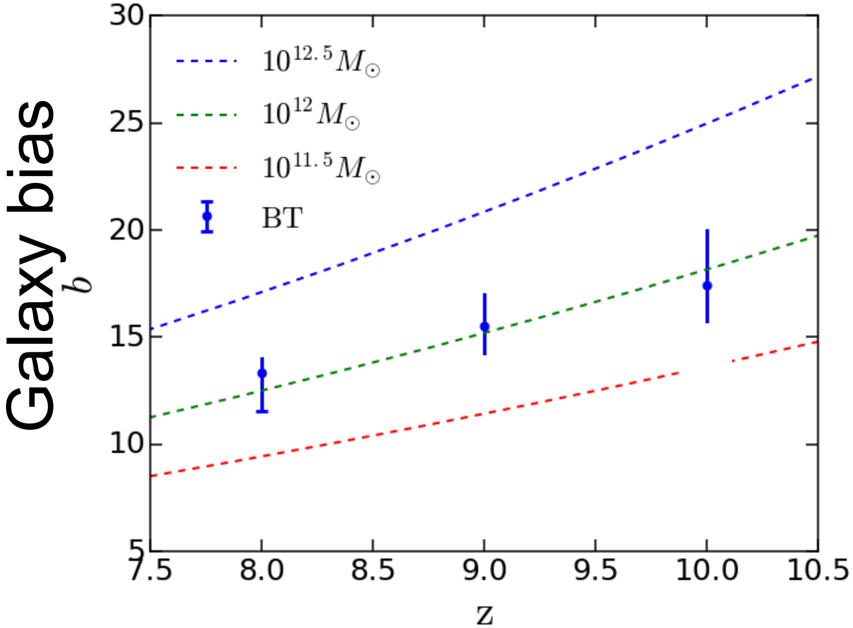
WFIRST galaxies, bias ~ 10-15

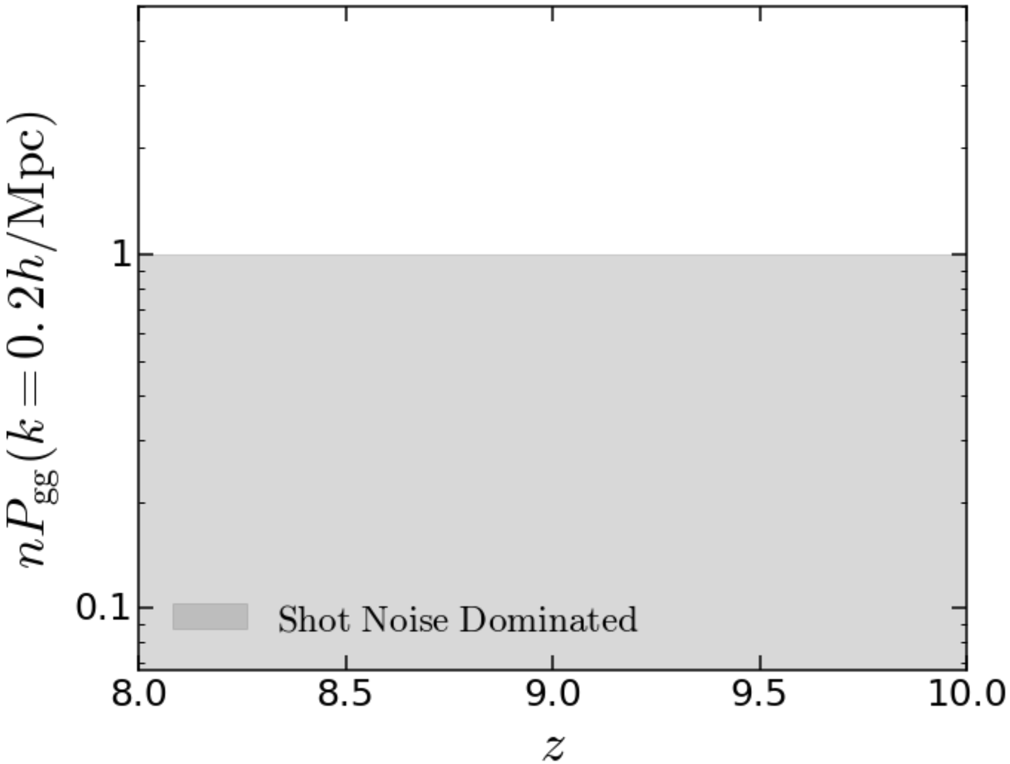
Cosmology with galaxies at z>7 ?



$n \sim 10^{-3}$

P_{gg}=bias x P_{DM}



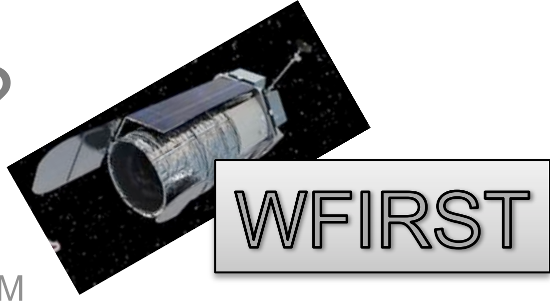


WFIRST galaxies, bias ~ 10-15

Waters, DM+, 16

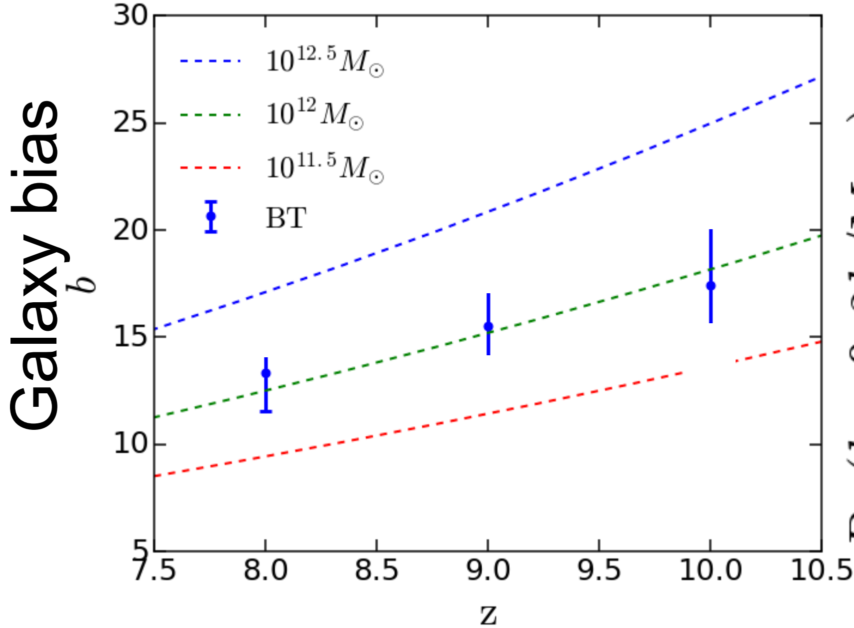
BAO detection feasible?

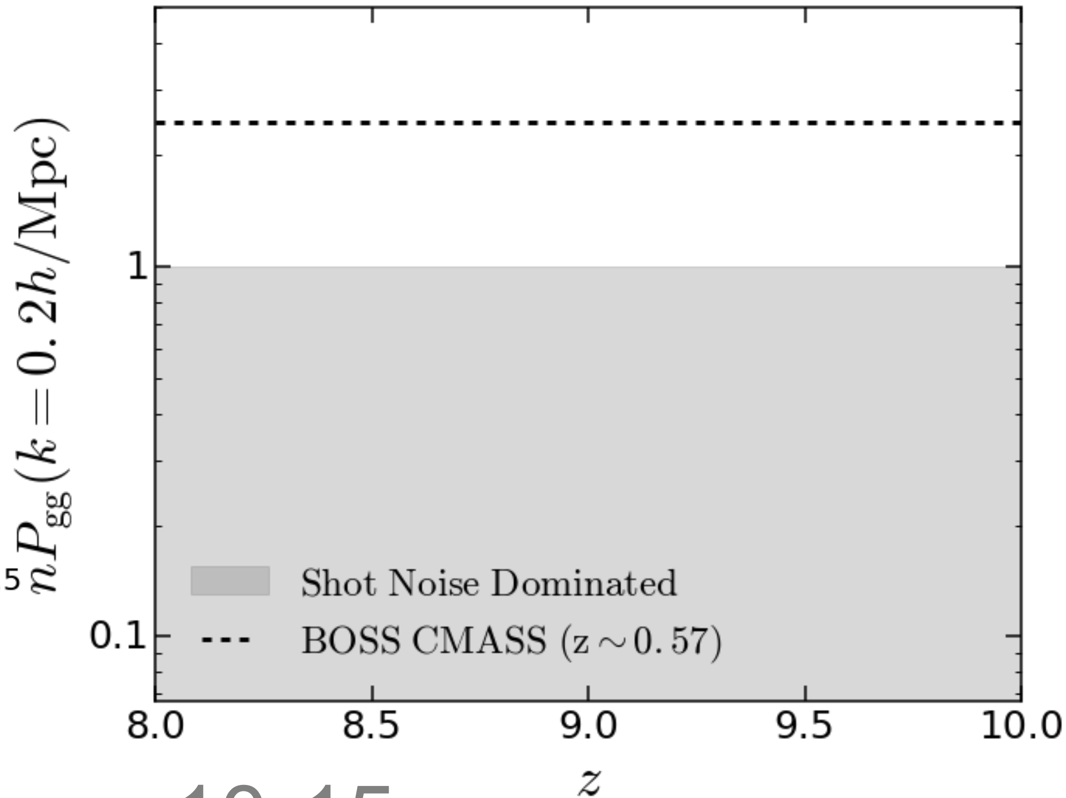
Cosmology with galaxies at z>7 ?



$n \sim 10^{-3}$

P_{gg}=bias x P_{DM}



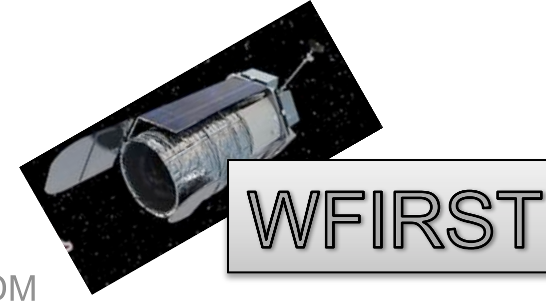


WFIRST galaxies, bias ~ 10-15

Waters, DM+, 16

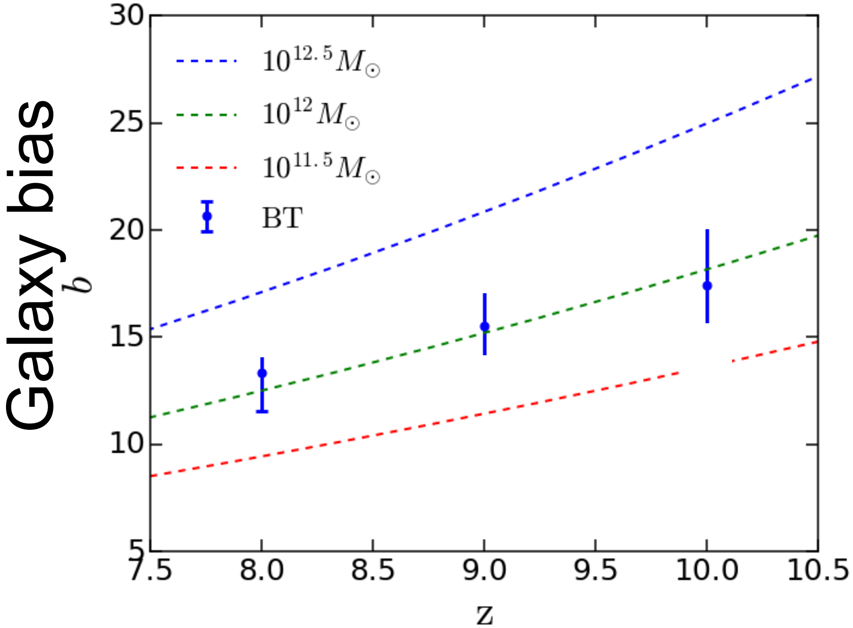
BAO detection feasible?

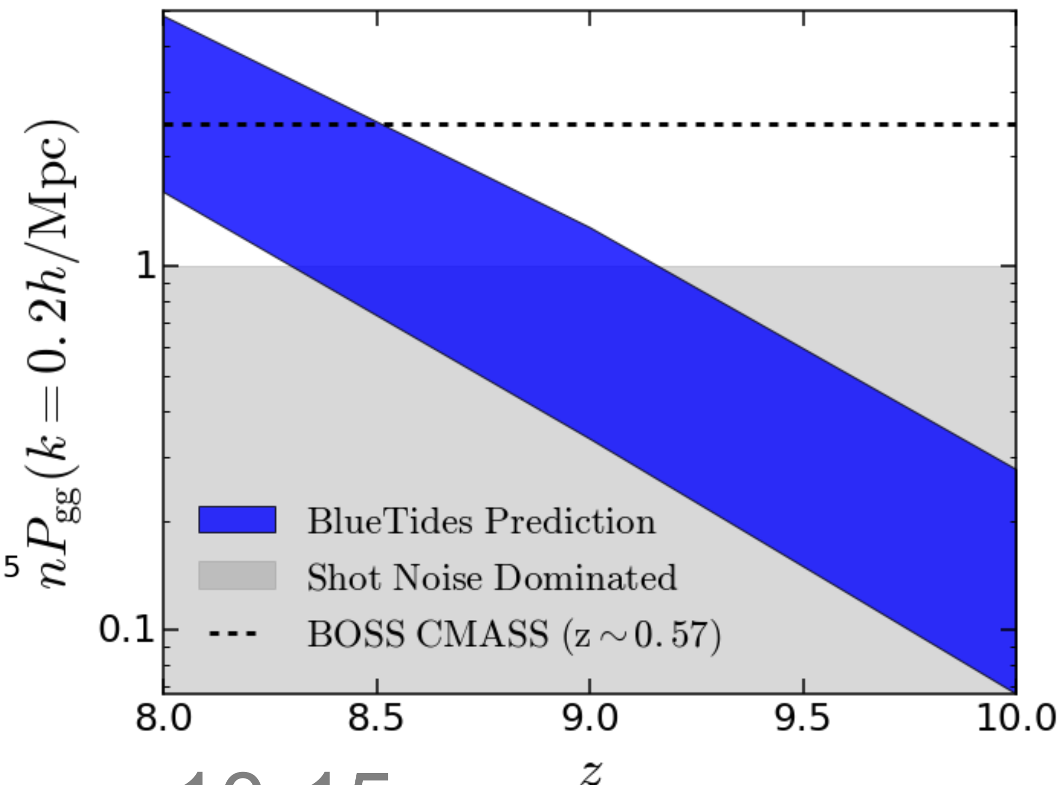
Cosmology with galaxies at z>7 !



$n \sim 10^{-3}$

P_{gg}=bias x P_{DM}



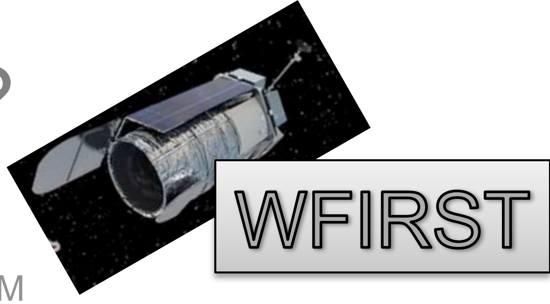


WFIRST galaxies, bias ~ 10-15

Waters, DM+, 16

BAO detection feasible up to z=8-9

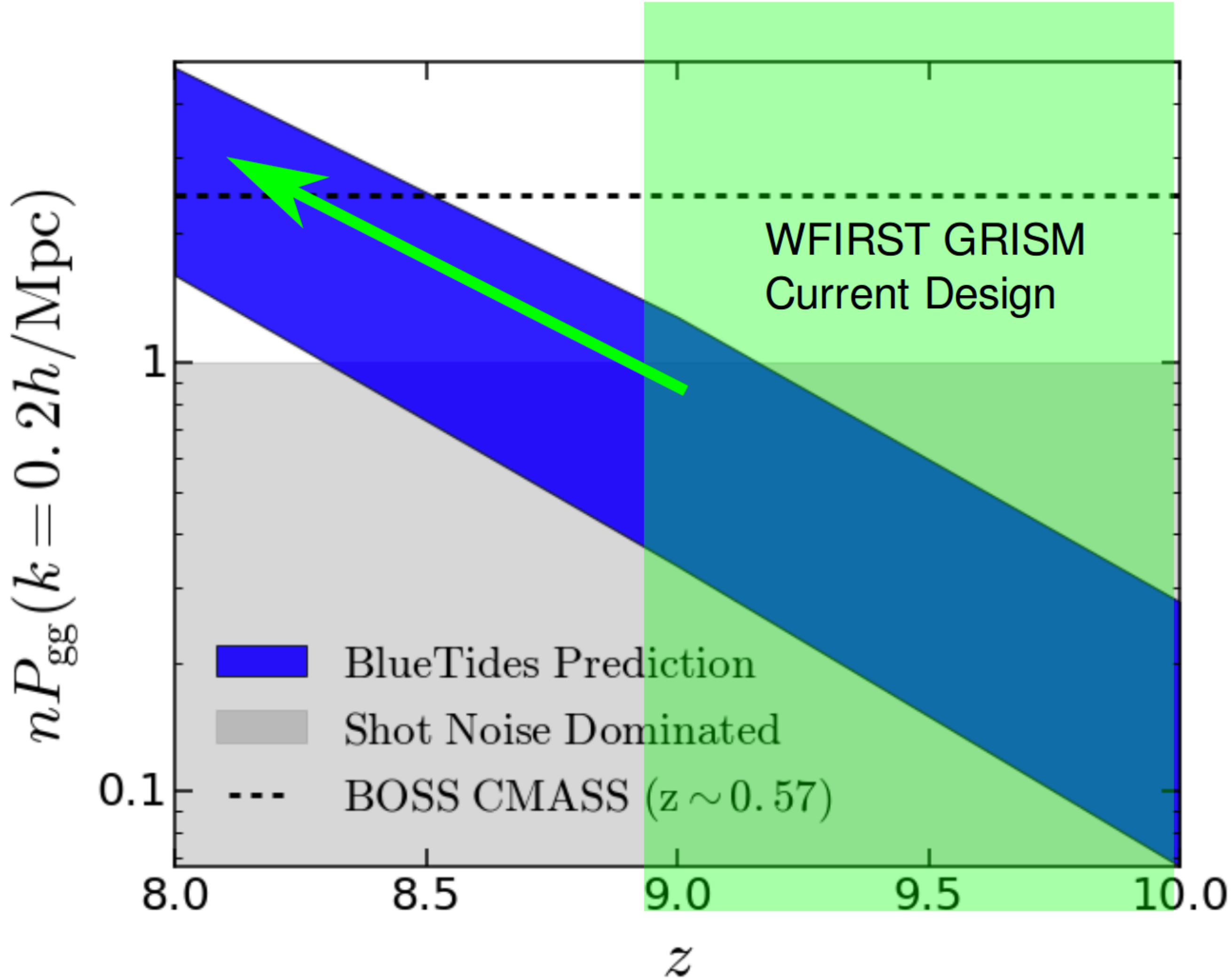
Cosmology with galaxies at z>7 ?



$n \sim 10^{-3}$

P_{gg}=bias x P_{DM}

First BAO detection in first half of Universe (at z=8-9)



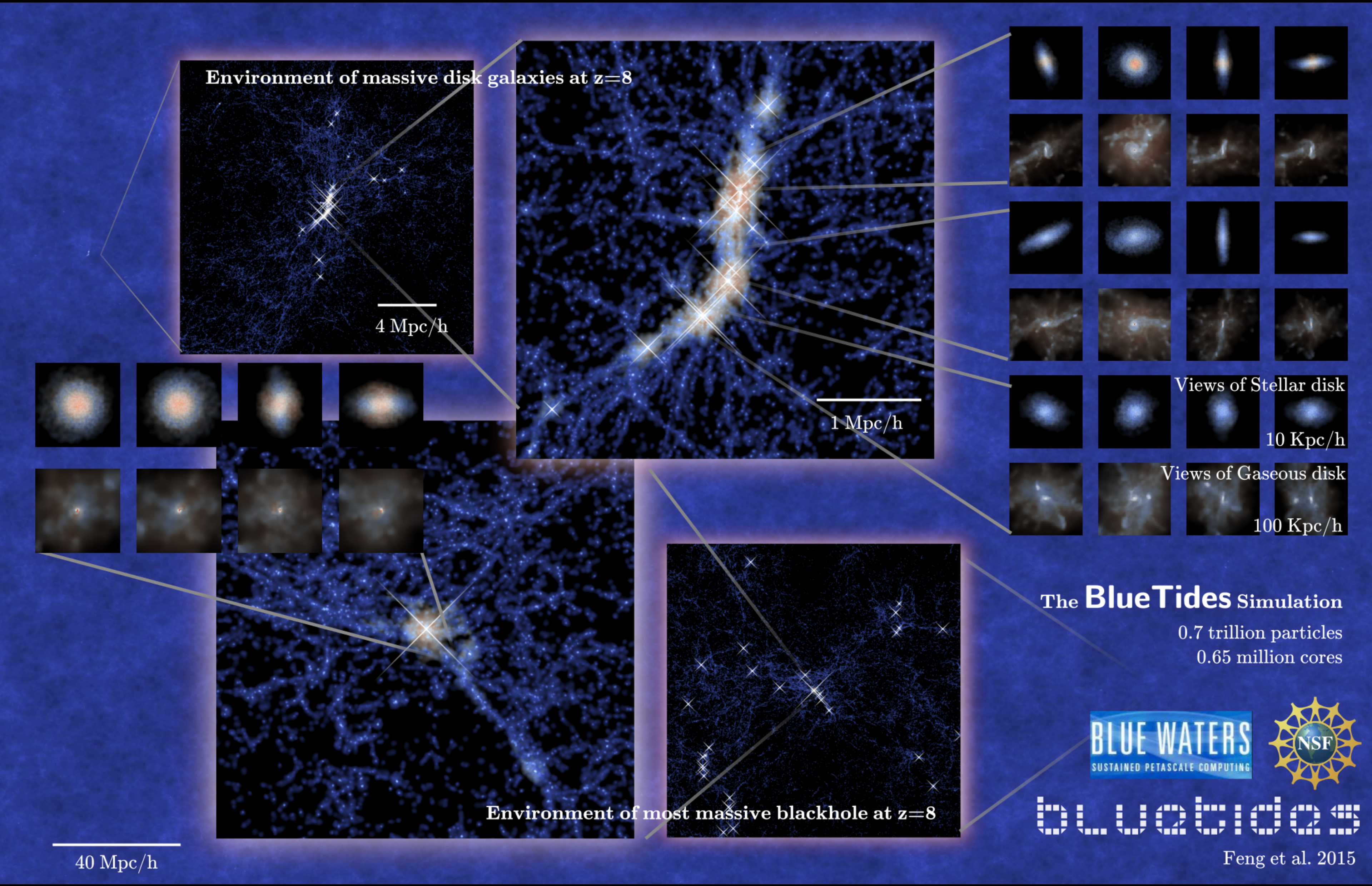
Summary:

New large volume high res BlueTides Simulation

predictions

for the next frontier of high-z surveys (WFIRST, JWST)

- statistical properties of BH and galaxy populations
- probe physics/origin of first black holes and galaxies


Environment of massive disk galaxies at z=8
4 Mpc/h
1 Mpc/h
Views of Stellar disk
10 Kpc/h
Views of Gaseous disk
100 Kpc/h
Environment of most massive blackhole at z=8
40 Mpc/h
The BlueTides Simulation
0.7 trillion particles
0.65 million cores
BLUE WATERS
SUSTAINED PETASCALE COMPUTING
NSF
bluetides
Feng et al. 2015