THE BLUETIDES SIMULATION

FIRST GALAXIES AND QUASARS AT THE COSMIC DAWN

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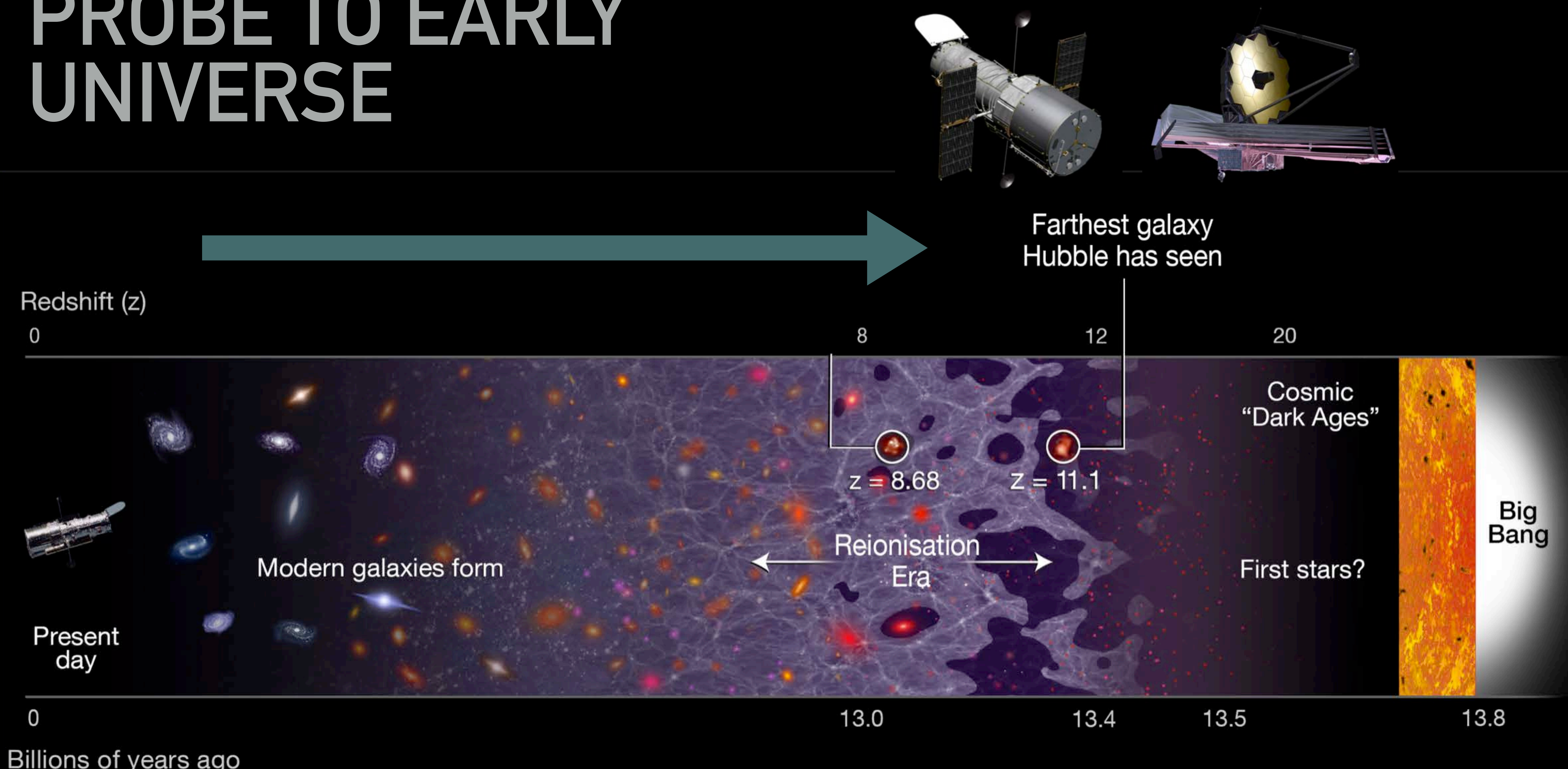
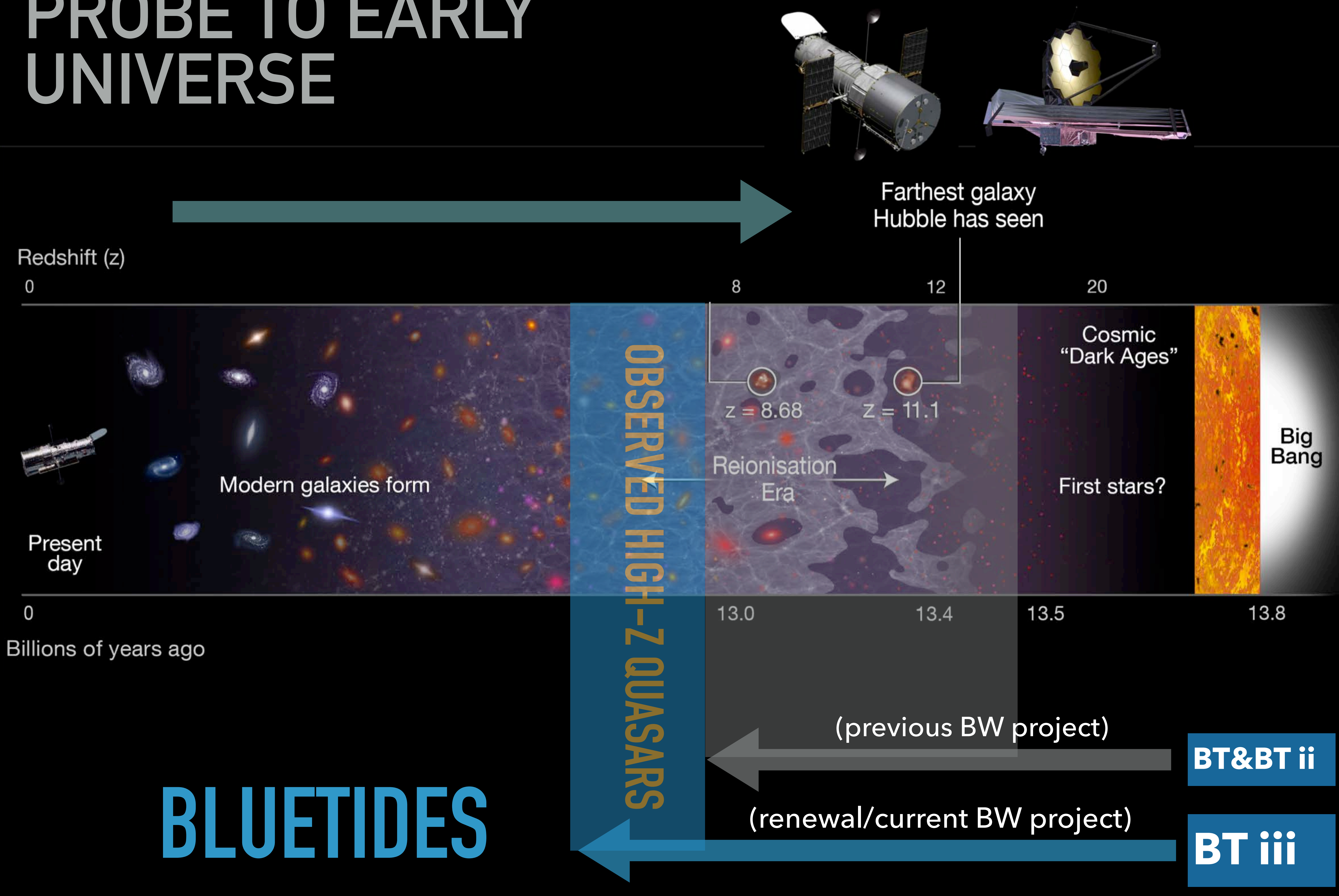
http://bluetides-project.org

PROBE TO EARLY UNIVERSE



PROBE TO EARLY UNIVERSE

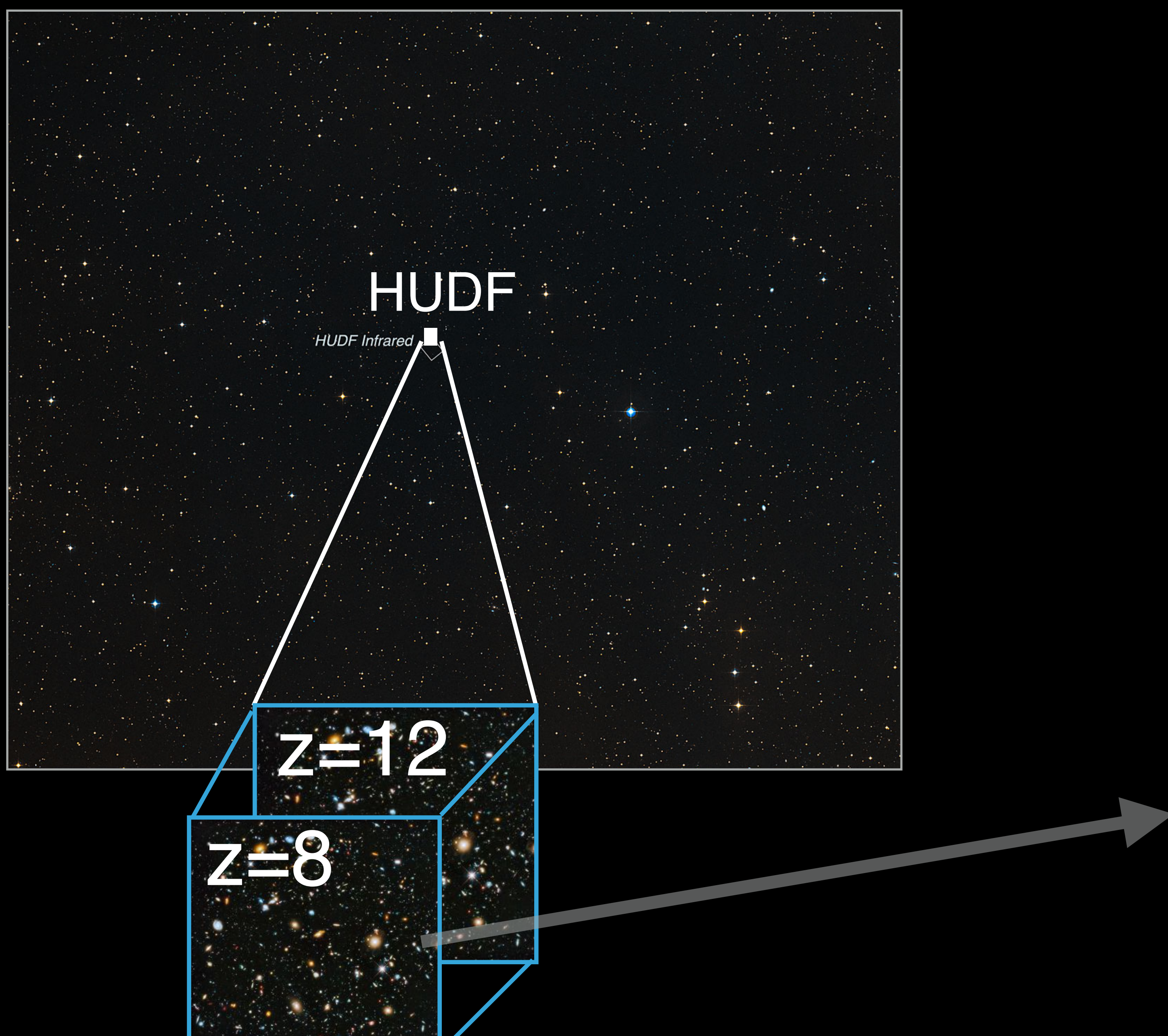


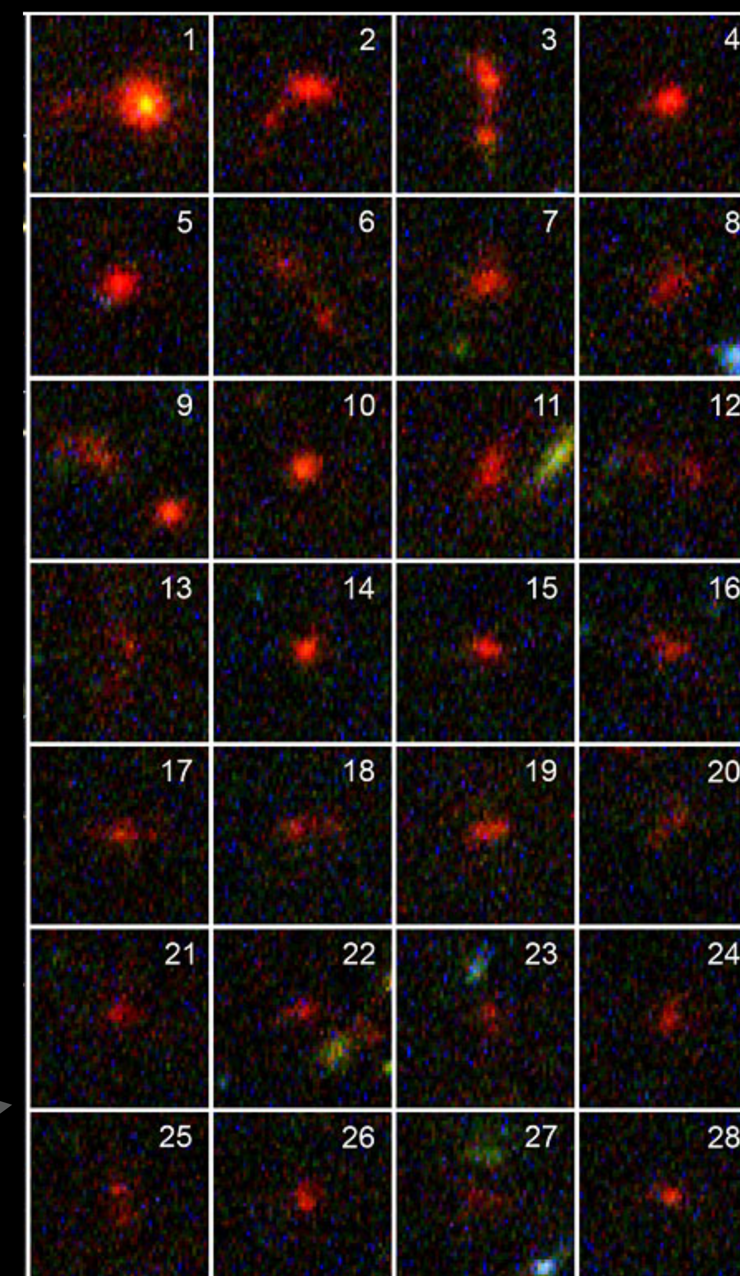
BLUETIDES

CURRENT HIGH-Z OBSERVATIONS OF GALAXIES

Hubble Ultra Deep Field:

1/12,000,000 of the entire sky

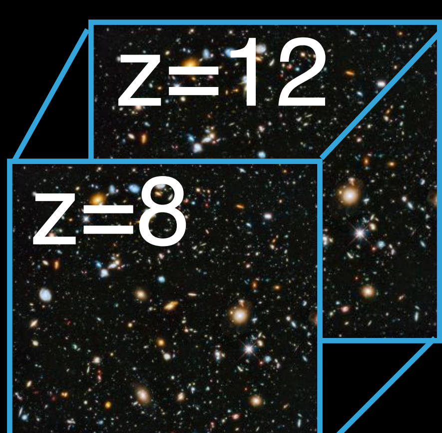




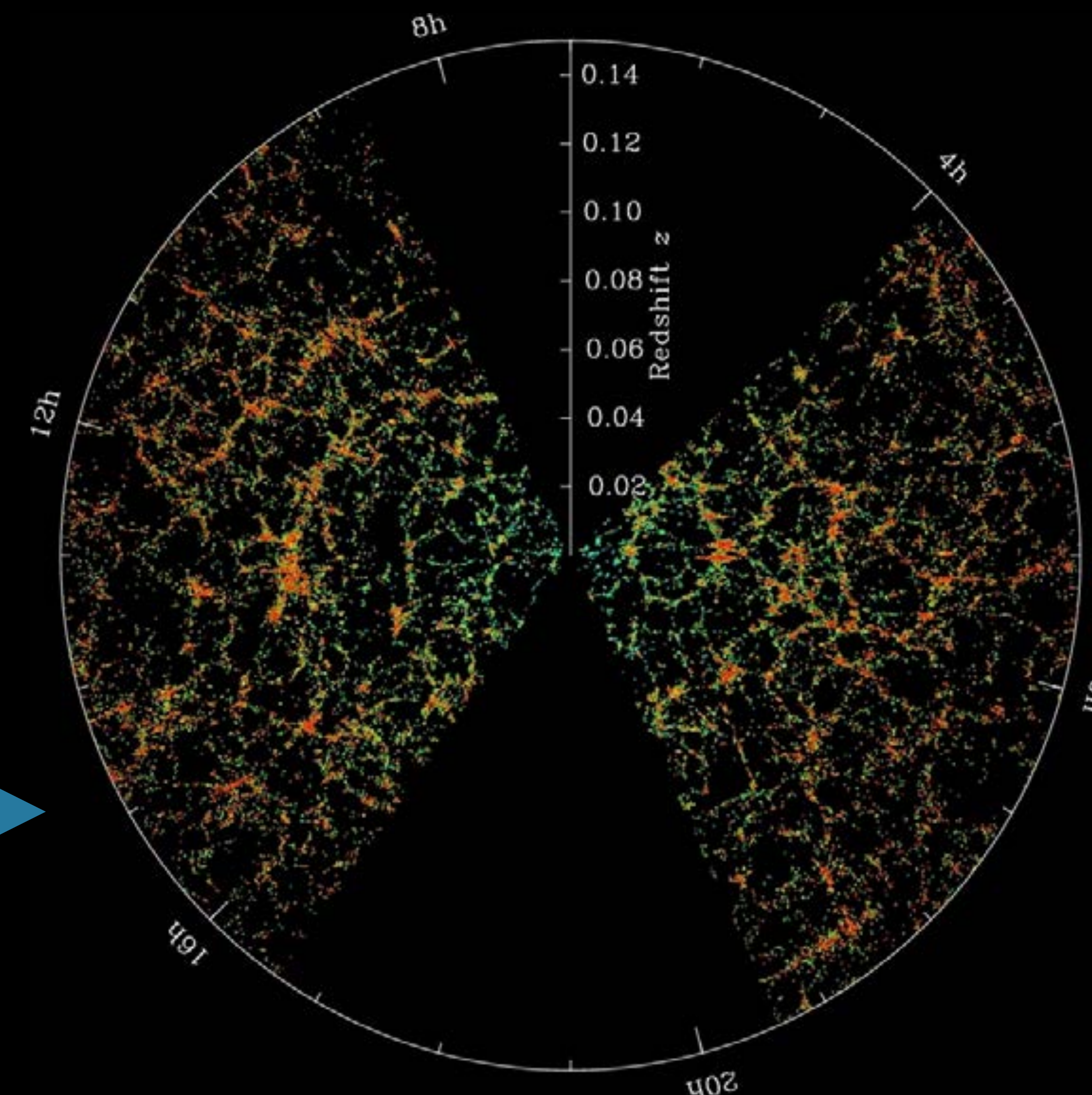
CURRENT HIGH-Z OBSERVATIONS OF GALAXIES

Hubble Ultra Deep Field:

1/200,000 times smaller than the survey volume of local galaxies



1/200,000



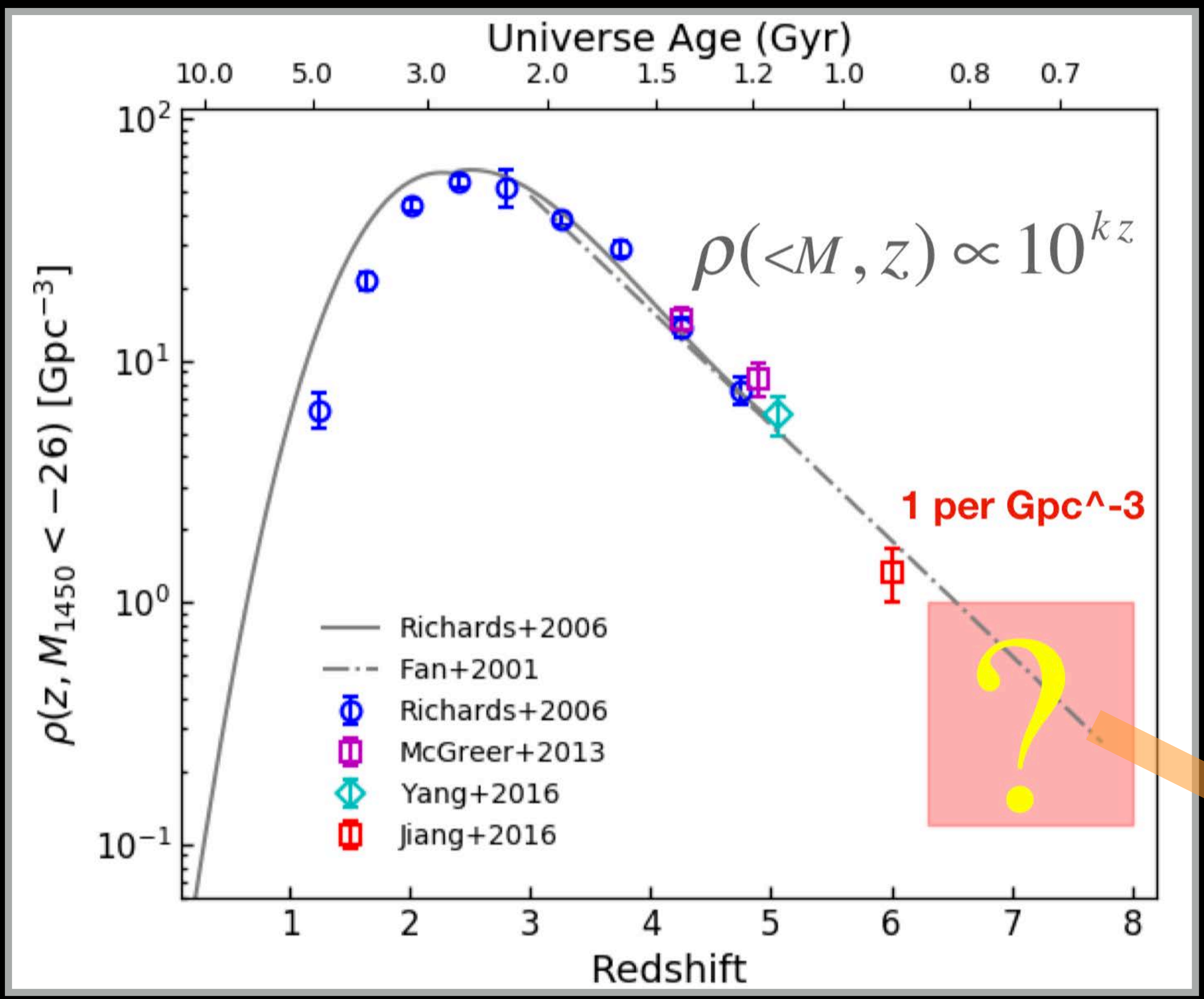
HUDF: ~ 23 Mpc/h cubic

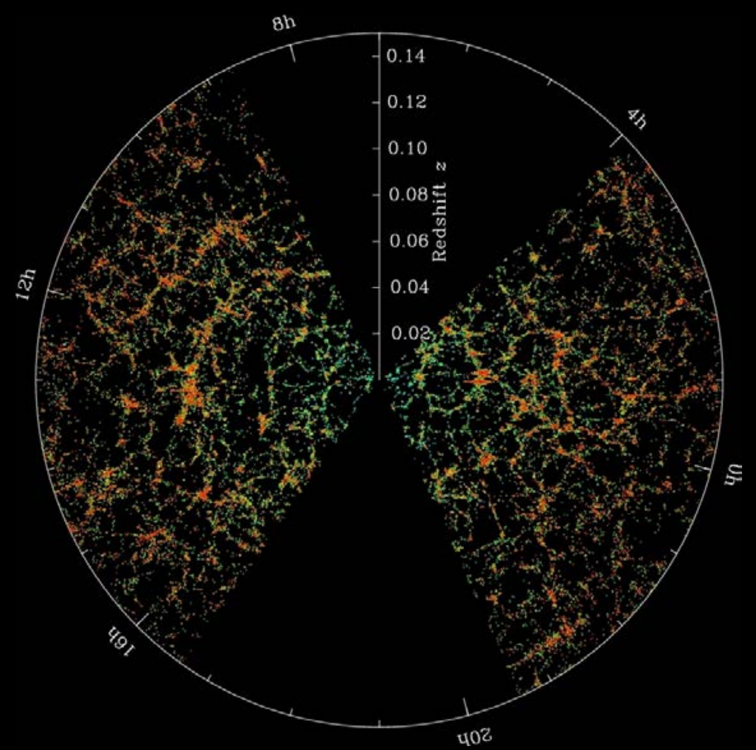
BOSS DR12: 2.2 Gpc/h cubic

CURRENT HIGH-Z OBSERVATIONS OF QUASARS

High-z luminous quasars are extremely rare

~ 1 quasar / Gpc cube at z > 6



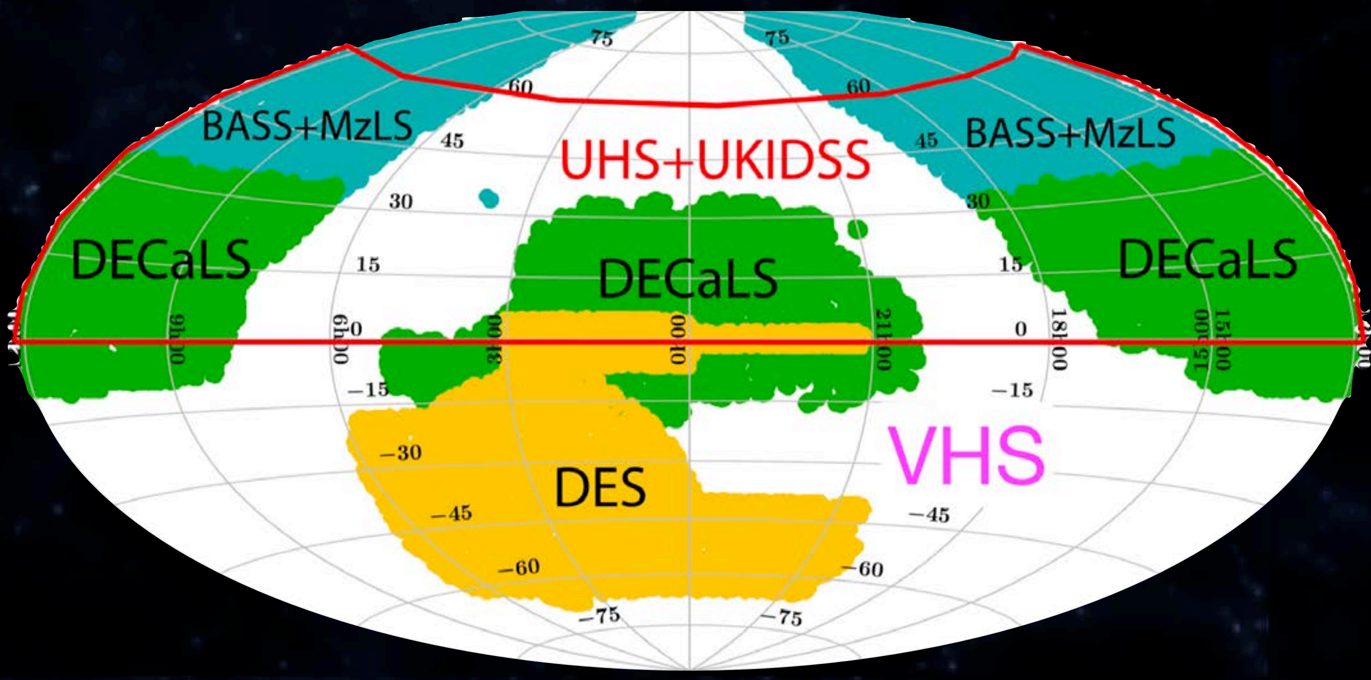


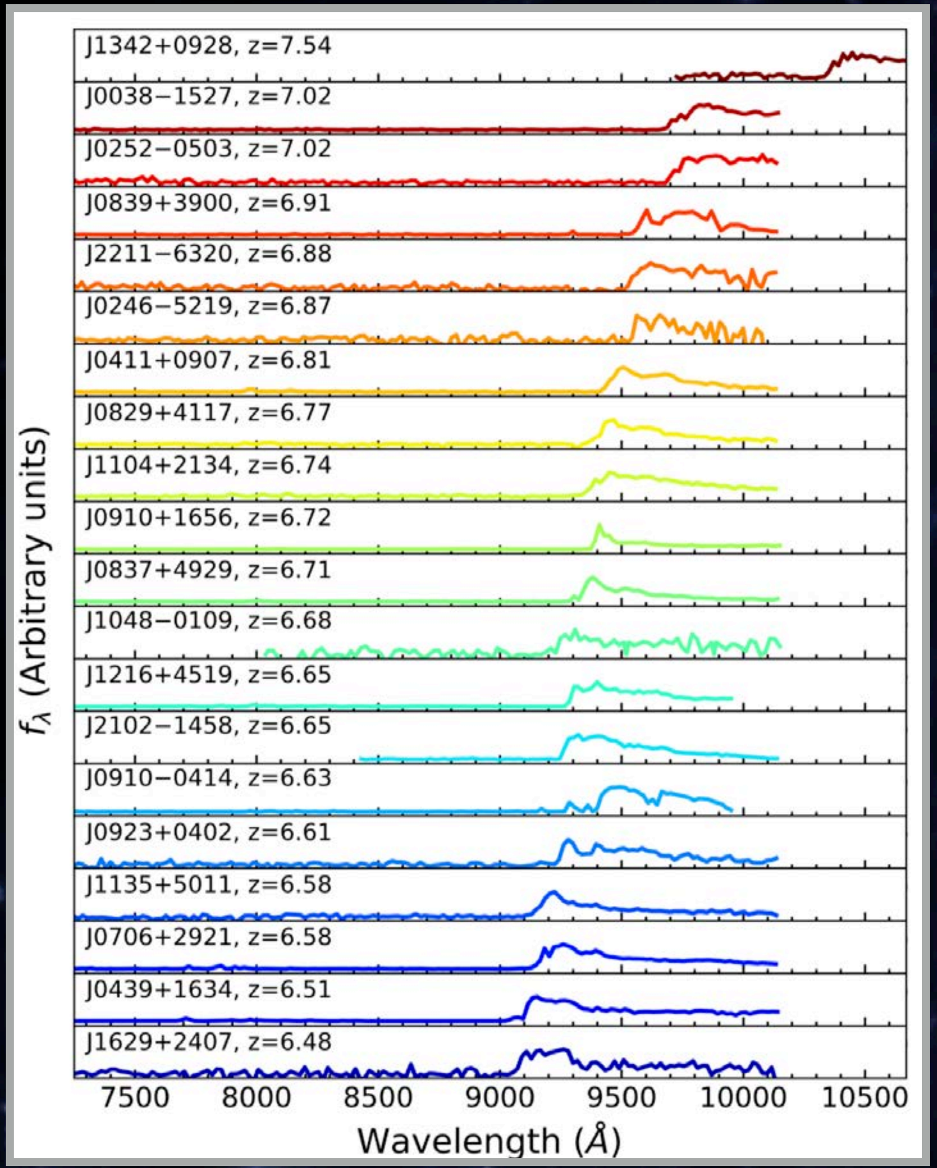
BOSS DR12: 2.2 Gpc/h cubic

only 2

CURRENT HIGH-Z OBSERVATIONS OF QUASARS

Searching for quasars ~ 20,000 deg^2 of the sky



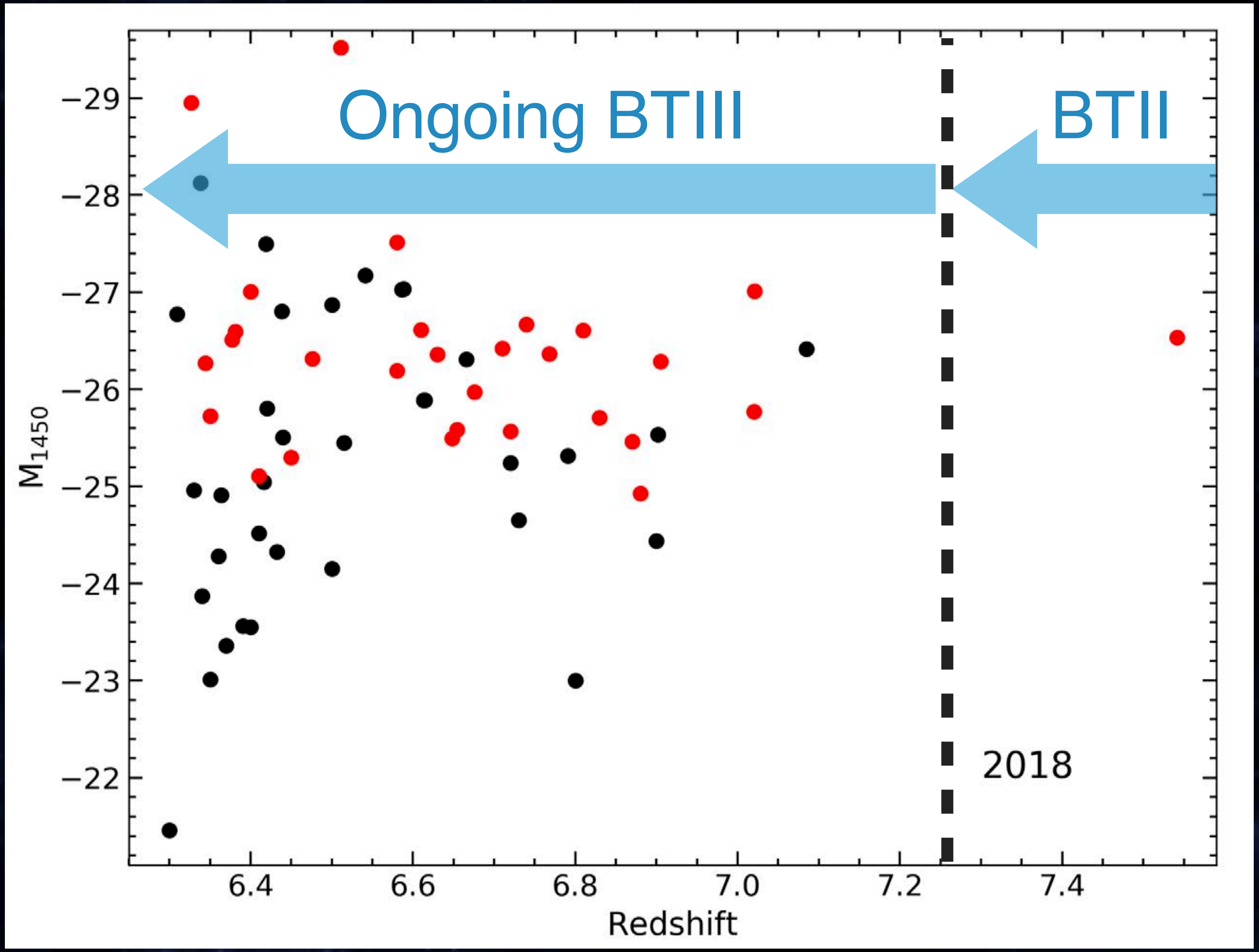


~ 30 New quasars at z>6.5
3 New quasars at z>7
discovered in the last year

Wang et al. 2018a,b
Yang et al. 2018
Fan et al. 2019
Banados et al. 2018

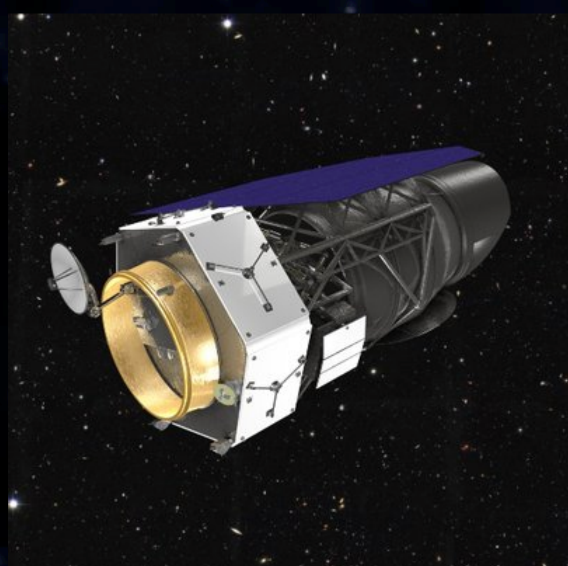
CURRENT HIGH-Z OBSERVATIONS OF QUASARS

30 new quasars at z>6.5 discovered in the last year

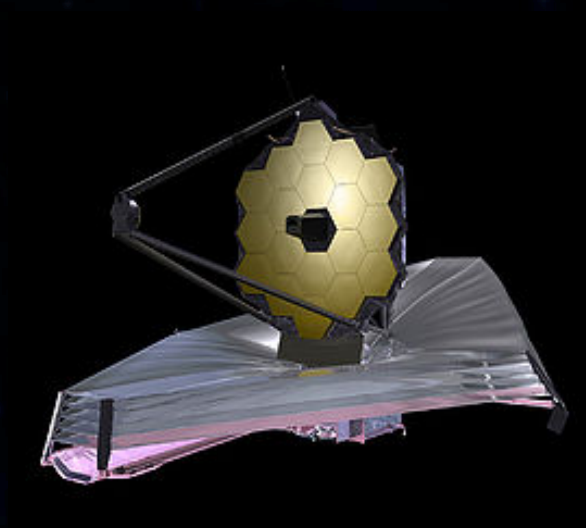


HIGH-Z OBSERVATIONS IN THE NEAR FUTURE

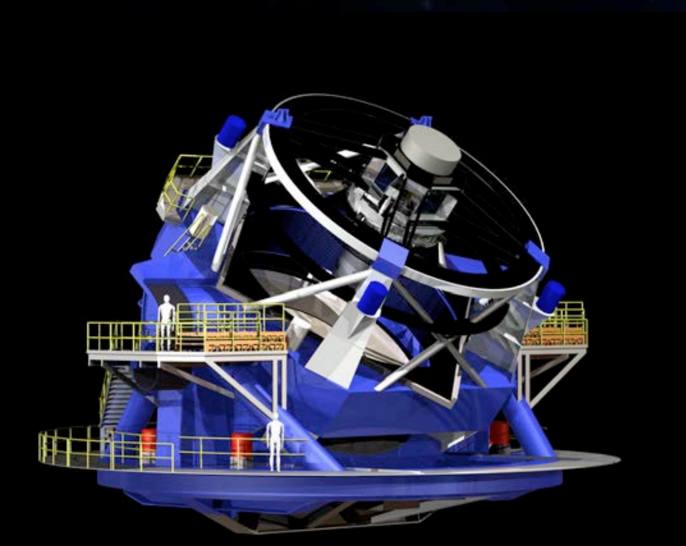
Next generation of telescopes will bring us 1000 times more data at $z > 7$



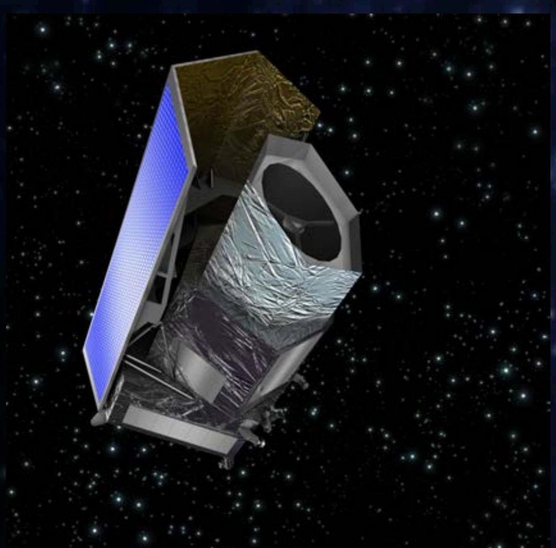
WFIRST



JWST

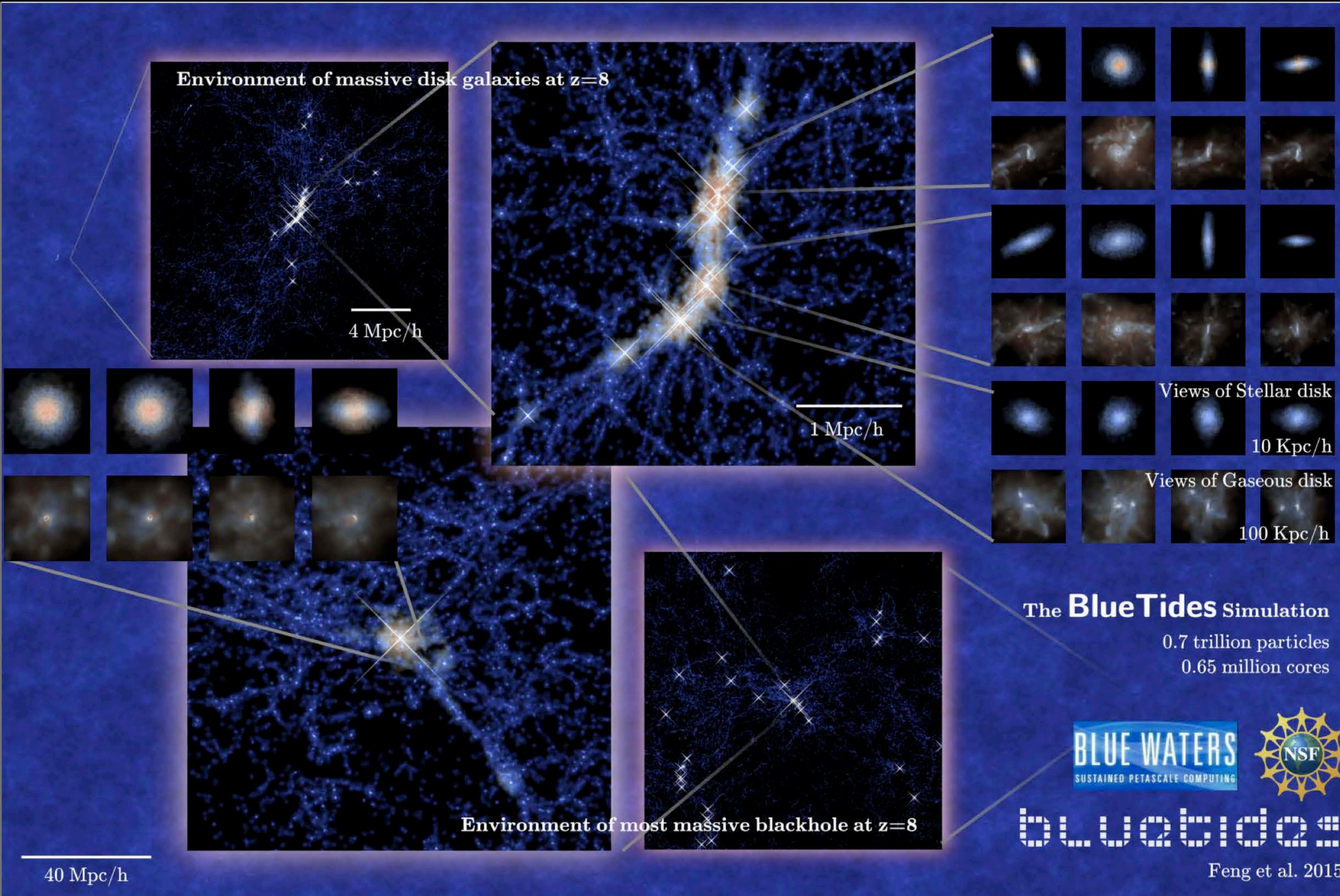


LSST



Euclid

BLUETIDES SIMULATION



CHALLENGE: HUGE DYNAMIC RANGE

Large Volume

$$P(M_{\mathrm{BH}} > 10^9 M_\odot) \sim 1/\mathrm{Gpc}^3$$

High resolution

DM halo / structure $R_{\mathrm{halo}} \sim \mathrm{Mpc}$

galaxy/star bulges $R_{\mathrm{galaxy}} \sim \mathrm{kpc}$

SMBH $R_{\mathrm{bondi}} \sim \mathrm{pc}$

WHY BLUEWATERS ?

NCSA BlueWaters

400 Mpc/h side box

0.7 trillion particles

0.7 million cpu cores

9 million node hours

Full hydrodynamics

BACKBONE OF MP-GADGET

Hybrid TreePM (gravity- dark matter)

Poisson

$$\nabla^2 \phi(\mathbf{x}) = 4\pi G \bar{\rho}(\mathbf{x}) a^2 \delta$$

$$\phi_k = \phi_k^{\text{long}} + \phi_k^{\text{short}}$$

SPH (Hydrodynamics – ideal fluid, baryons)

Continuity

$$\frac{\partial \rho}{\partial t} + \frac{3\dot{a}}{a}\rho + \frac{1}{a}\nabla \cdot (\rho \mathbf{v}) = 0$$

Euler

$$\frac{\partial \mathbf{v}}{\partial t} + \frac{1}{a}(\mathbf{v} \cdot \nabla)\mathbf{v} + \frac{\dot{a}}{a}\mathbf{v} = -\frac{1}{a\rho}\nabla P - \frac{1}{a}\nabla \Phi$$

Thermodynamic

$$\frac{\partial}{\partial t}(\rho u) + \frac{1}{a}\mathbf{v} \cdot \nabla(\rho u) = -(\rho u + P)(\frac{1}{a}\nabla \cdot \mathbf{v} + 3\frac{\dot{a}}{a})$$

Equation of state

$$p = (\gamma - 1)\rho\epsilon$$

BACKBONE OF MP-GADGET

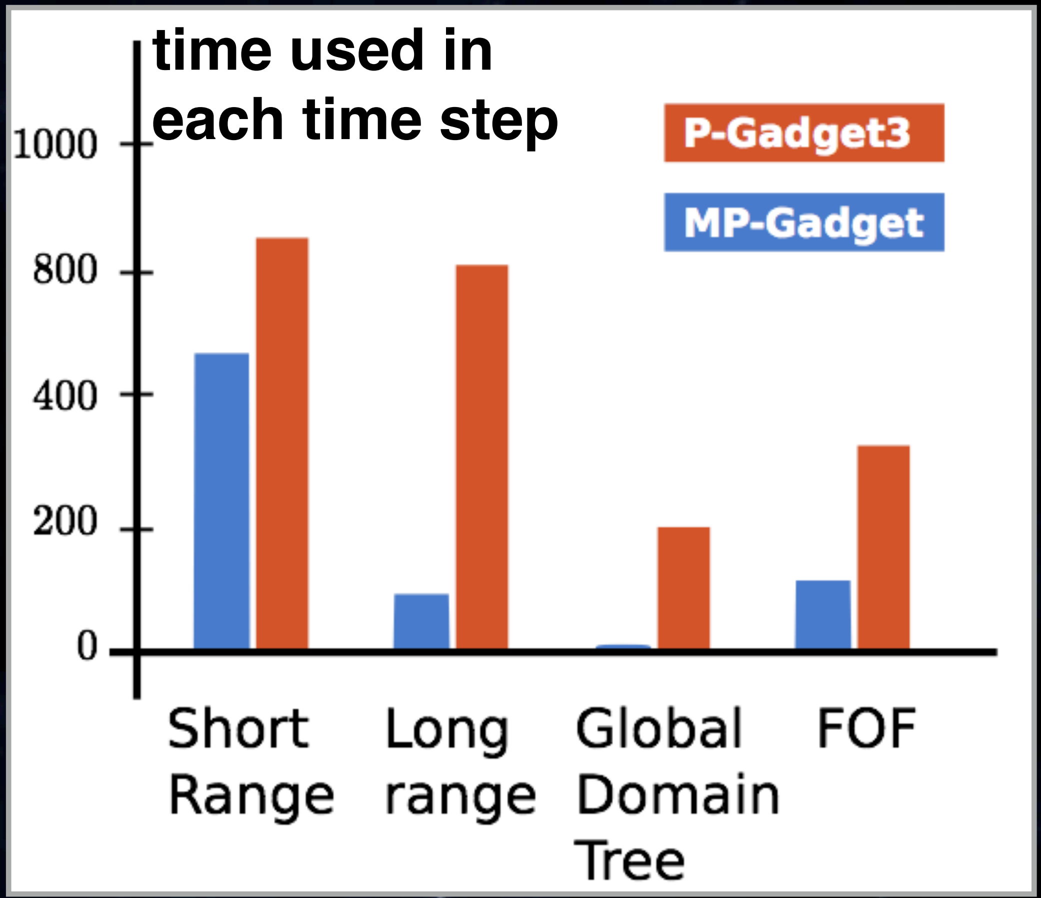
Hybrid TreePM (gravity- dark matter)

SPH (Hydrodynamics – ideal fluid, gas)

Sub-grid models

- Primodial cooling
- Multi-phase star formation
- H2 molecule fraction
- SN wind feedback
- AGN feedback
- Metal enrichment and cooling

MP-GADGET ARCHITECTURE



PetaPM: long range Solver

PFFT: Parallel FFT FFTW

PetaIO: IO interface

bigfile library POSIX IO

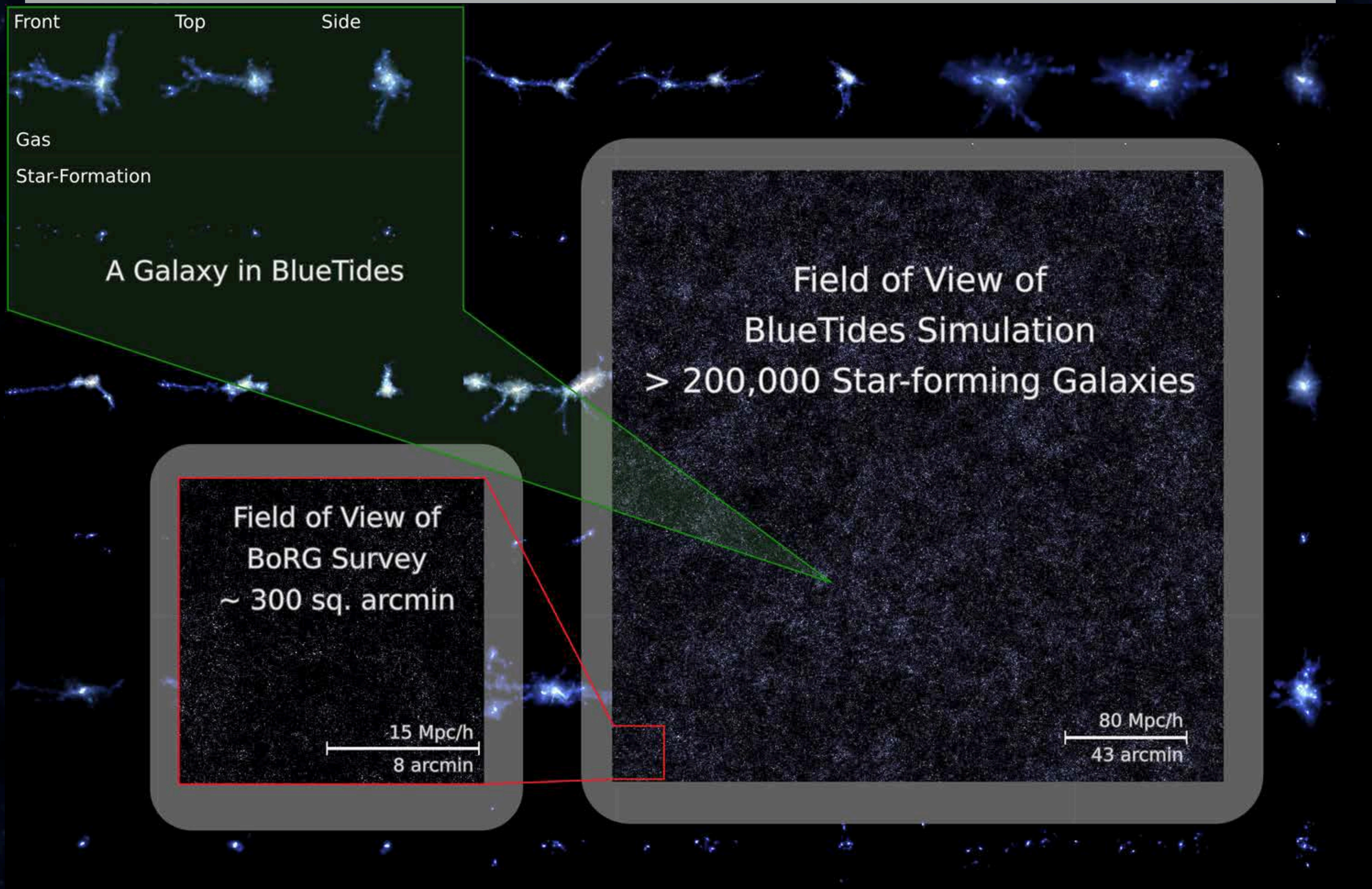
Short-range solver

improved multi-thread Gadget Tree code

Domain decomposition

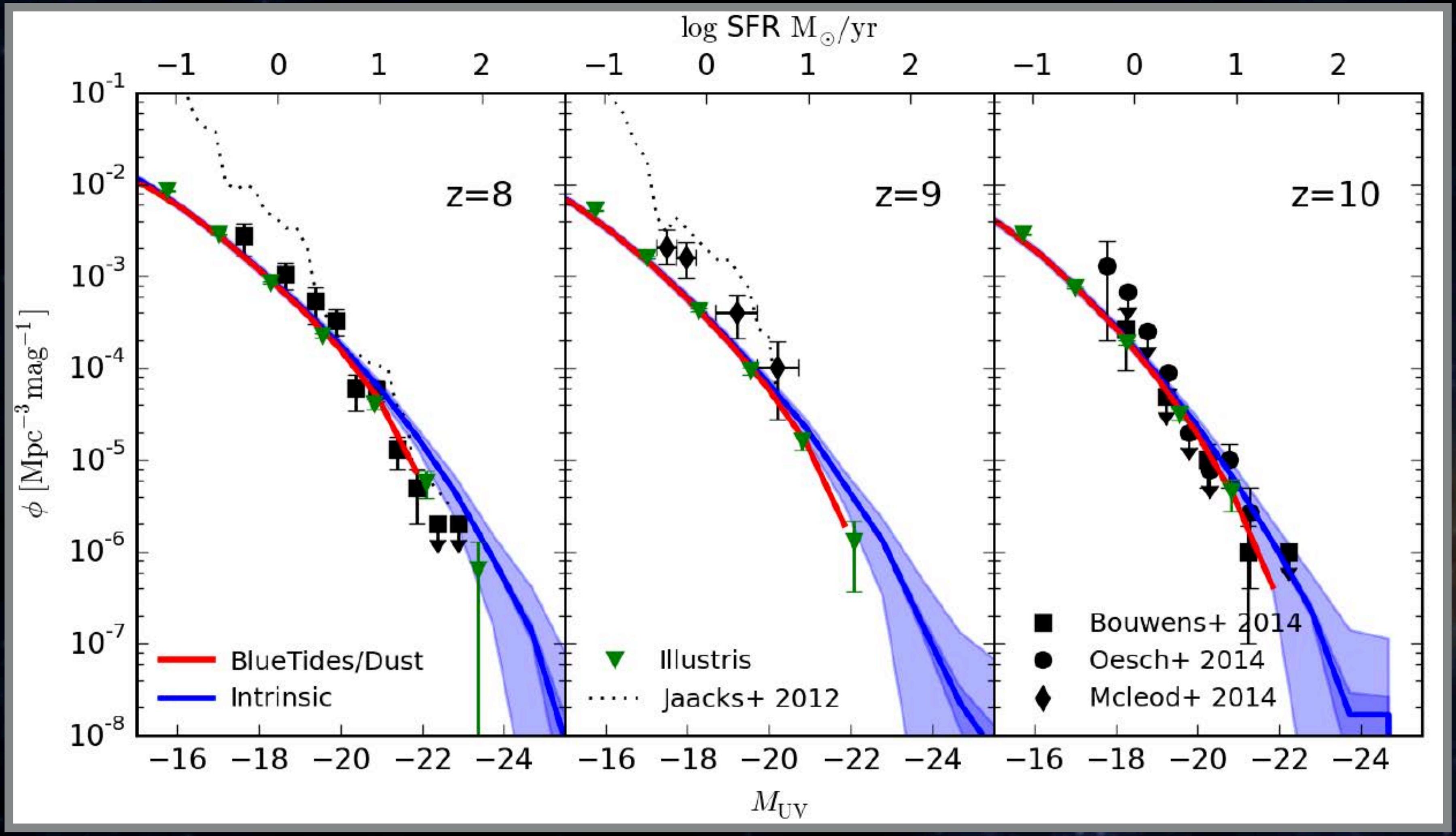
global index tree

BLUETIDES : 400 X VOLUME OF HUDF



RESULTS FROM BLUETIDES

The first validation: galaxy luminosity function is consistent with Hubble Legacy Fields



Galaxy luminosity ——> bright

Feng+2016

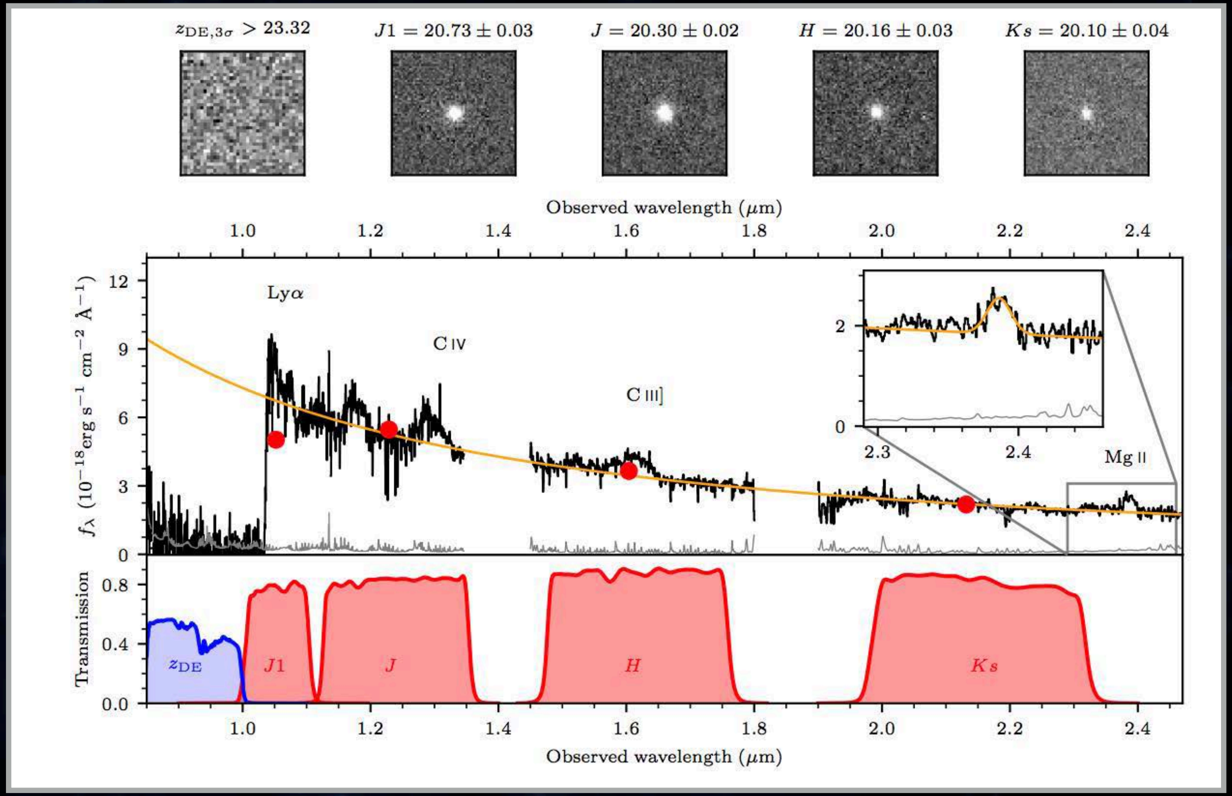
CURRENT RECORD HOLDER: Z = 7.54 QUASAR

Observation

$$M_{\rm BH} = 8 \times 10^8 M_\odot$$

J1342+0928

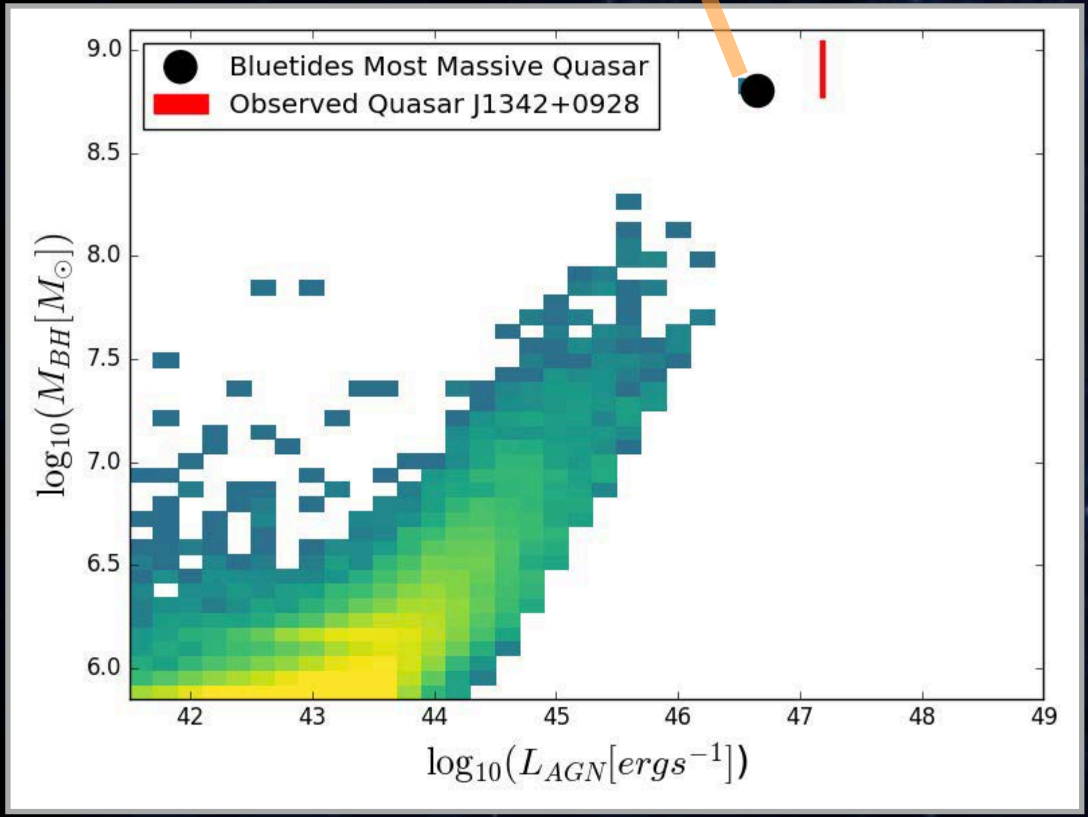
ALLWISE/Ukidss



Banados+17,

BLUETIDES

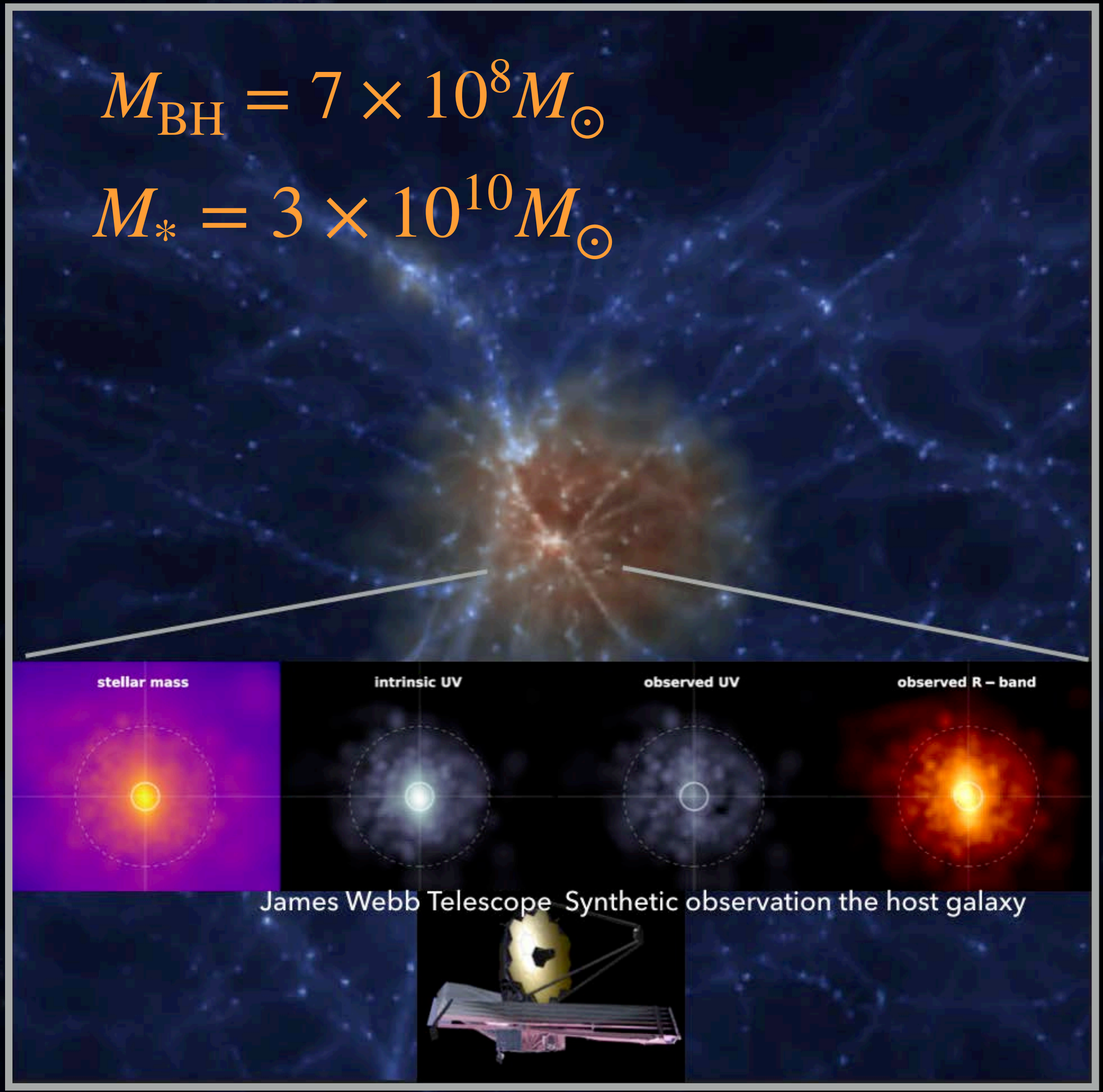
$$M_{\rm BH} = 7 \times 10^8 M_\odot$$

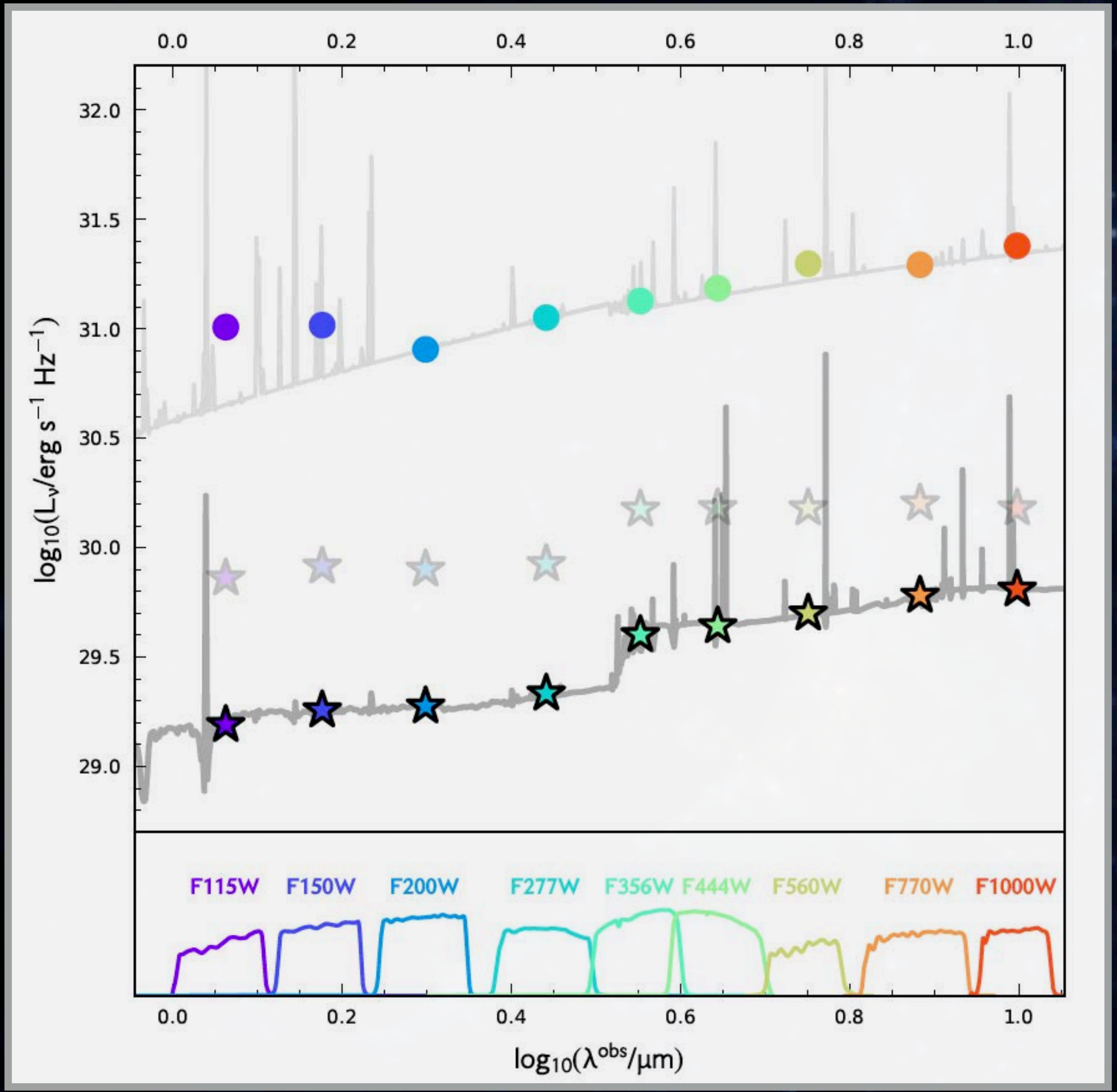


Tenneti, TDM+19

GALAXY HOSTS FOR THE FIRST QUASARS

JWST mock observations

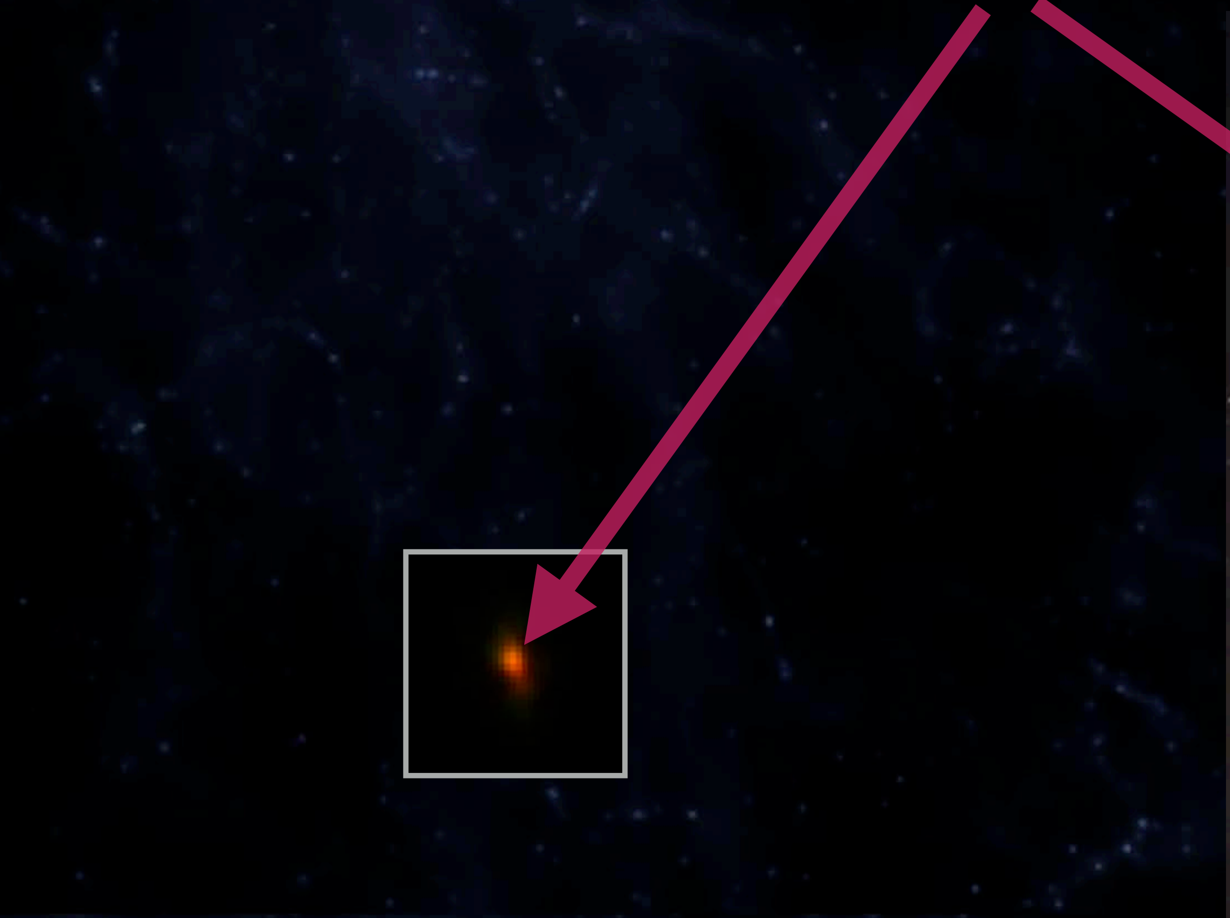




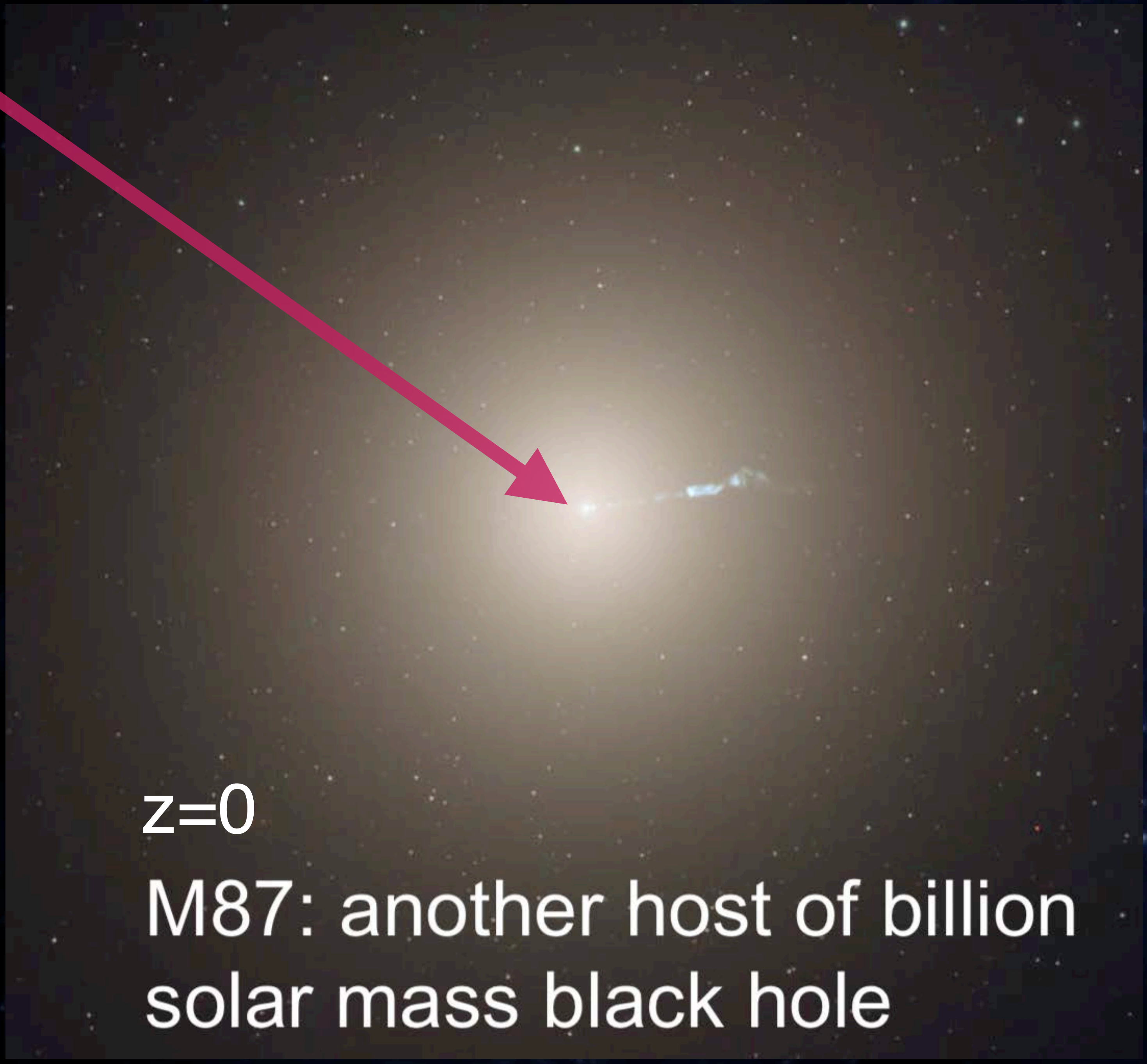
Tenneti, TDM+19

GALAXY HOSTS FOR THE FIRST QUASARS

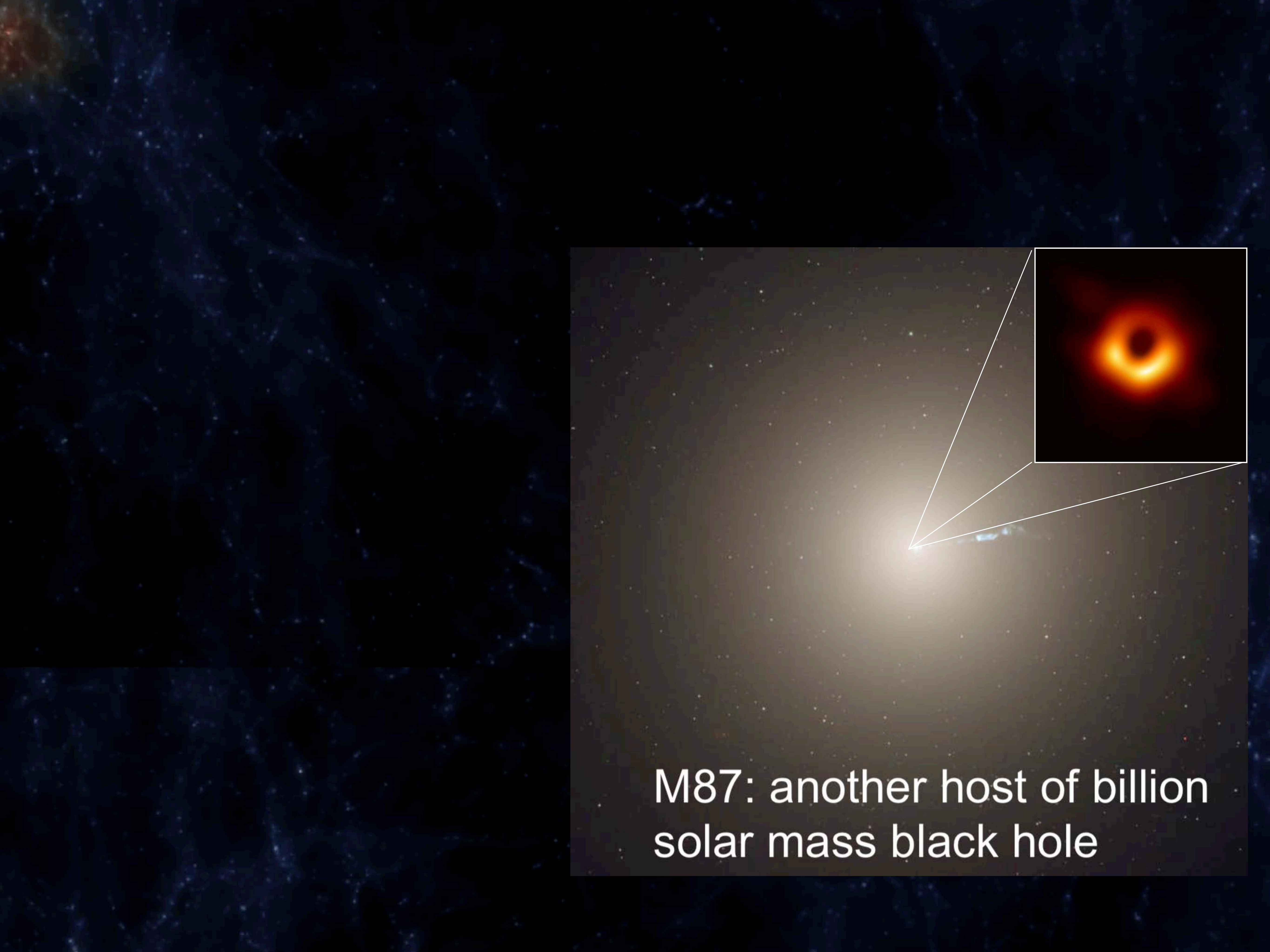
$$M_{\rm BH} \sim 10^9 M_\odot$$



z=7.54 quasar
host galaxy
BlueTides

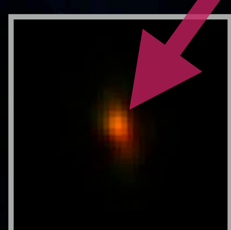


z=0
M87: another host of billion solar mass black hole

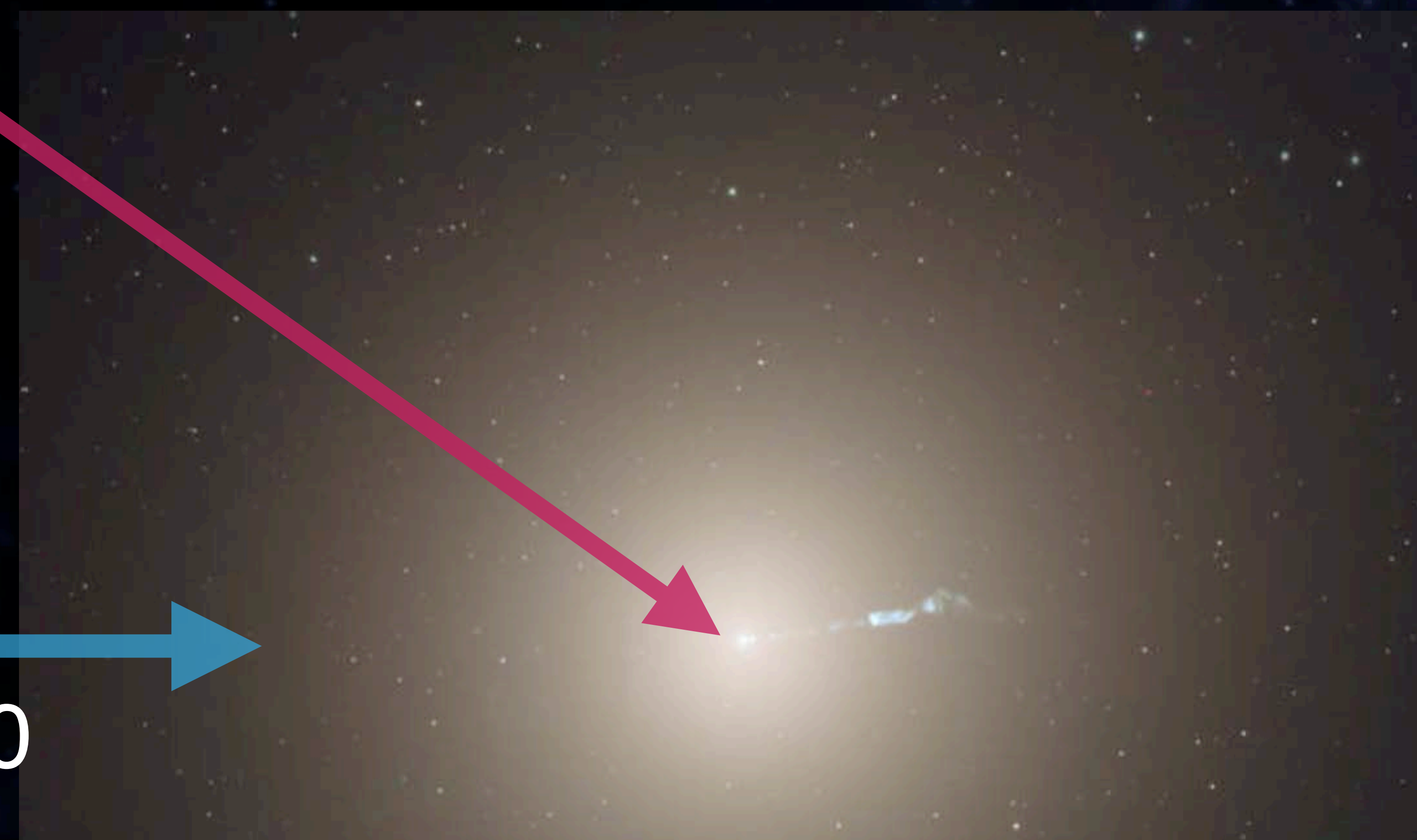

M87: another host of billion
solar mass black hole

GALAXY HOSTS FOR THE FIRST QUASARS

$M_{\mathrm{BH}} \sim 10^9 M_\odot$



1 : 200



$M_* = 3 \times 10^{10} M_\odot$

z=7.54 quasar

host galaxy

BlueTides

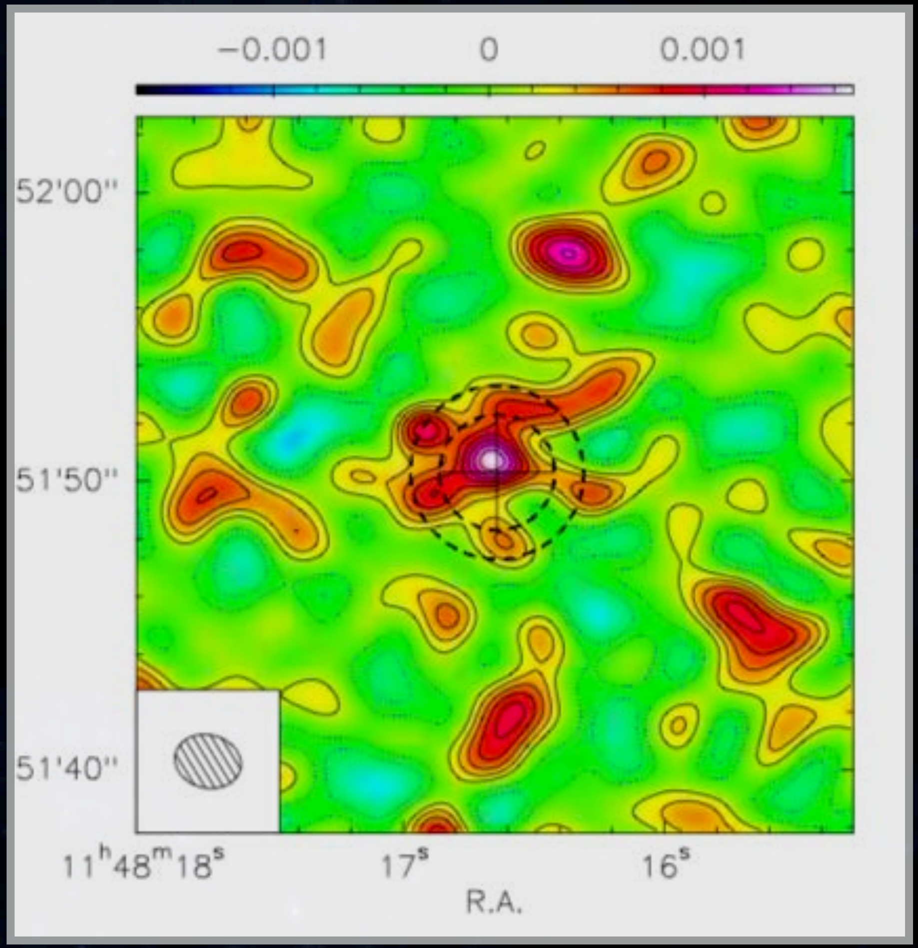
$M_* \sim 6 \times 10^{12} M_\odot$

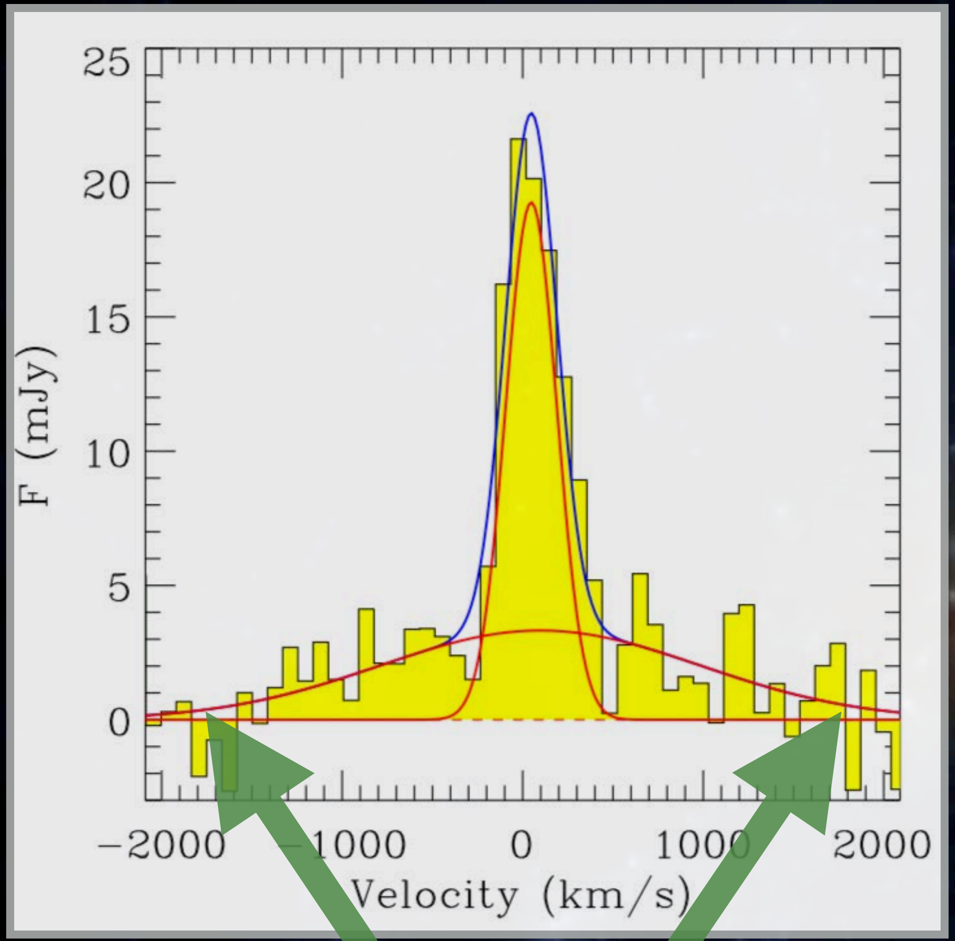
z=0

M87: another host of billion solar mass black hole

Does the BH ever stop growing?

Observational evidence for the BH feedback/winds in z=6 quasars



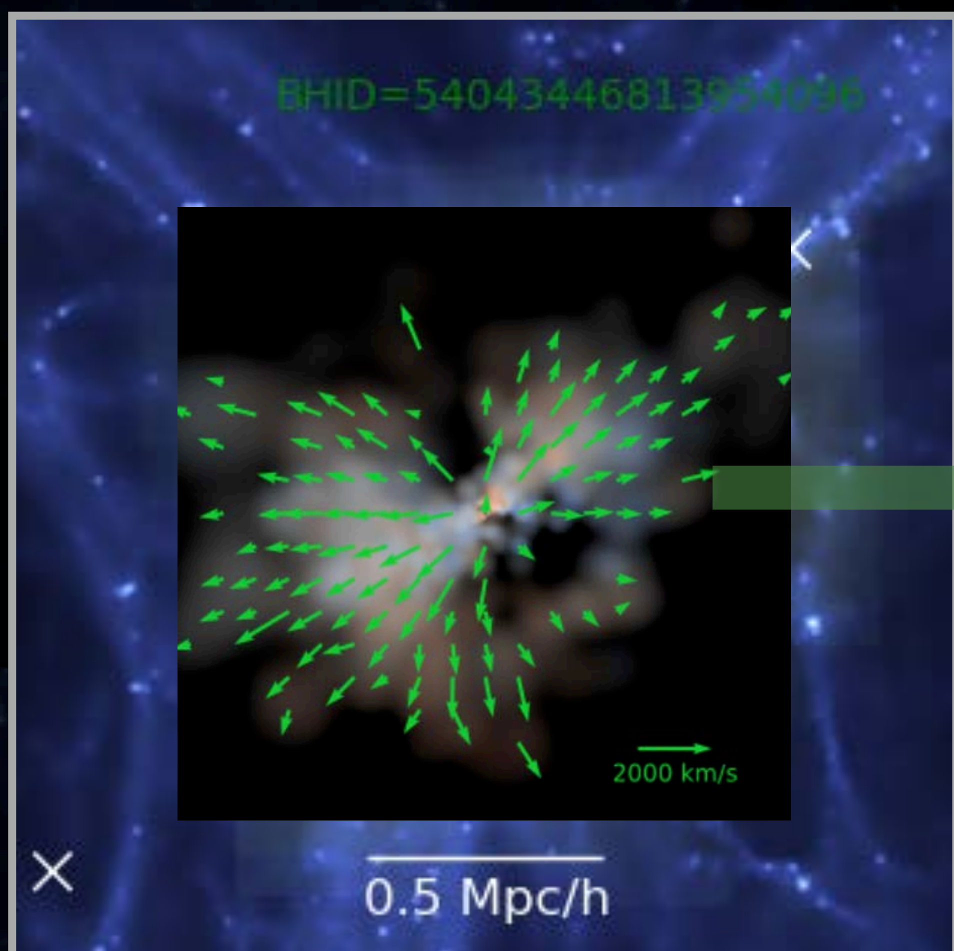


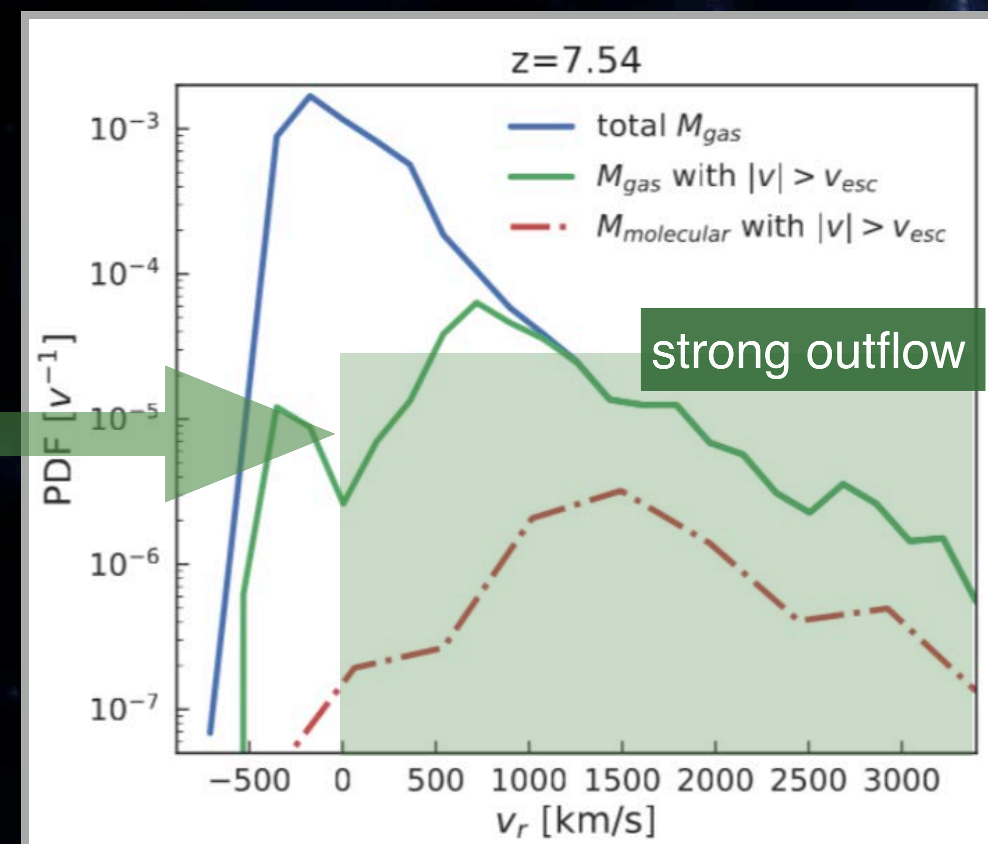
Maiolino et al. 2013

strong outflow

Does the BH ever stop growing?

In BlueTides simulation, we indeed find strong quasar-driven gas outflow





Ni+18

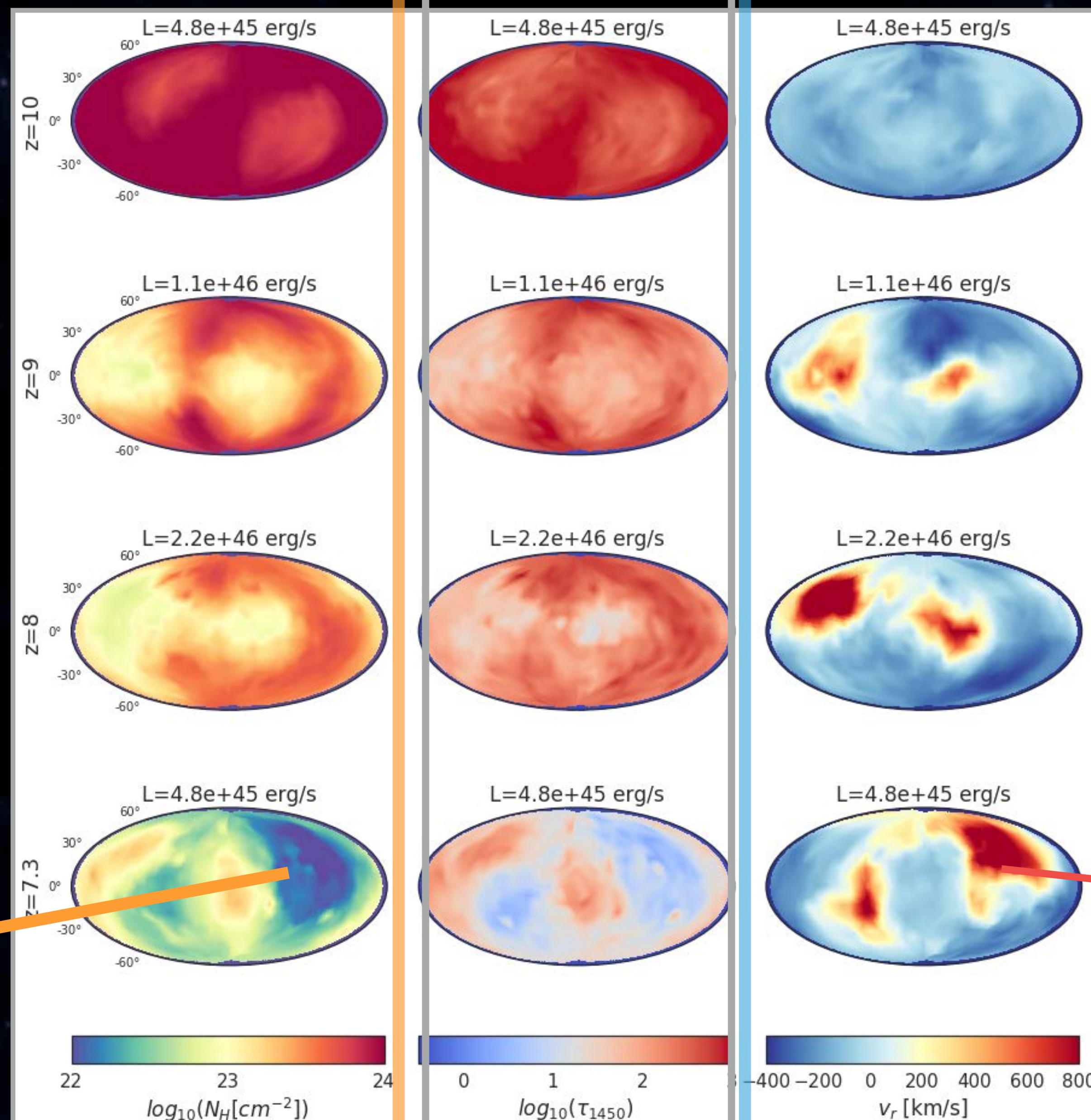
Are the first quasars obscured?

Column density NH

Radial velocity

z=10

z=7



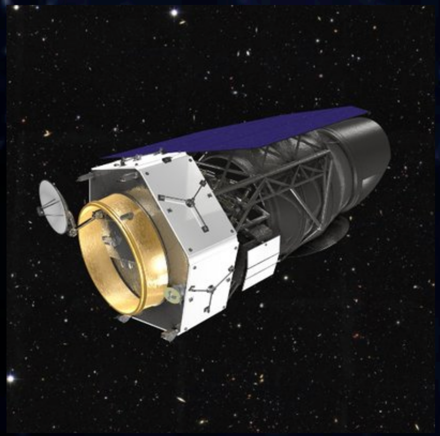
low NH,
less obscured

strong
outflow

dust extinction

Ni et al. in prep

THE BLUETIDES SIMULATION MAKES PREDICTIONS FOR FUTURE FACILITIES



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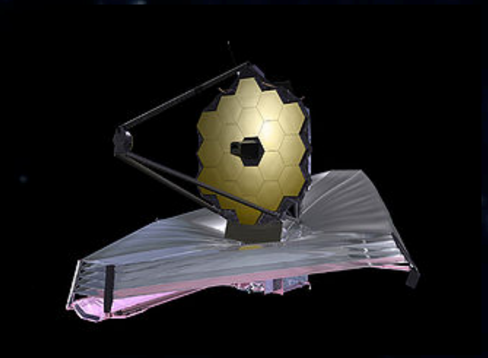
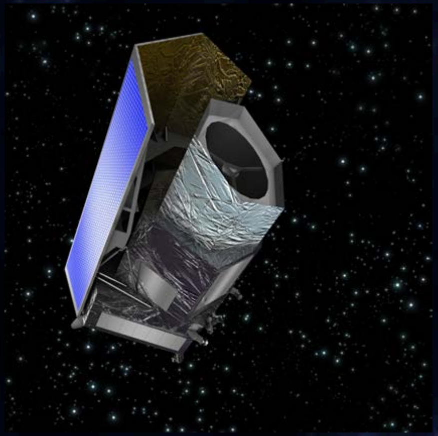
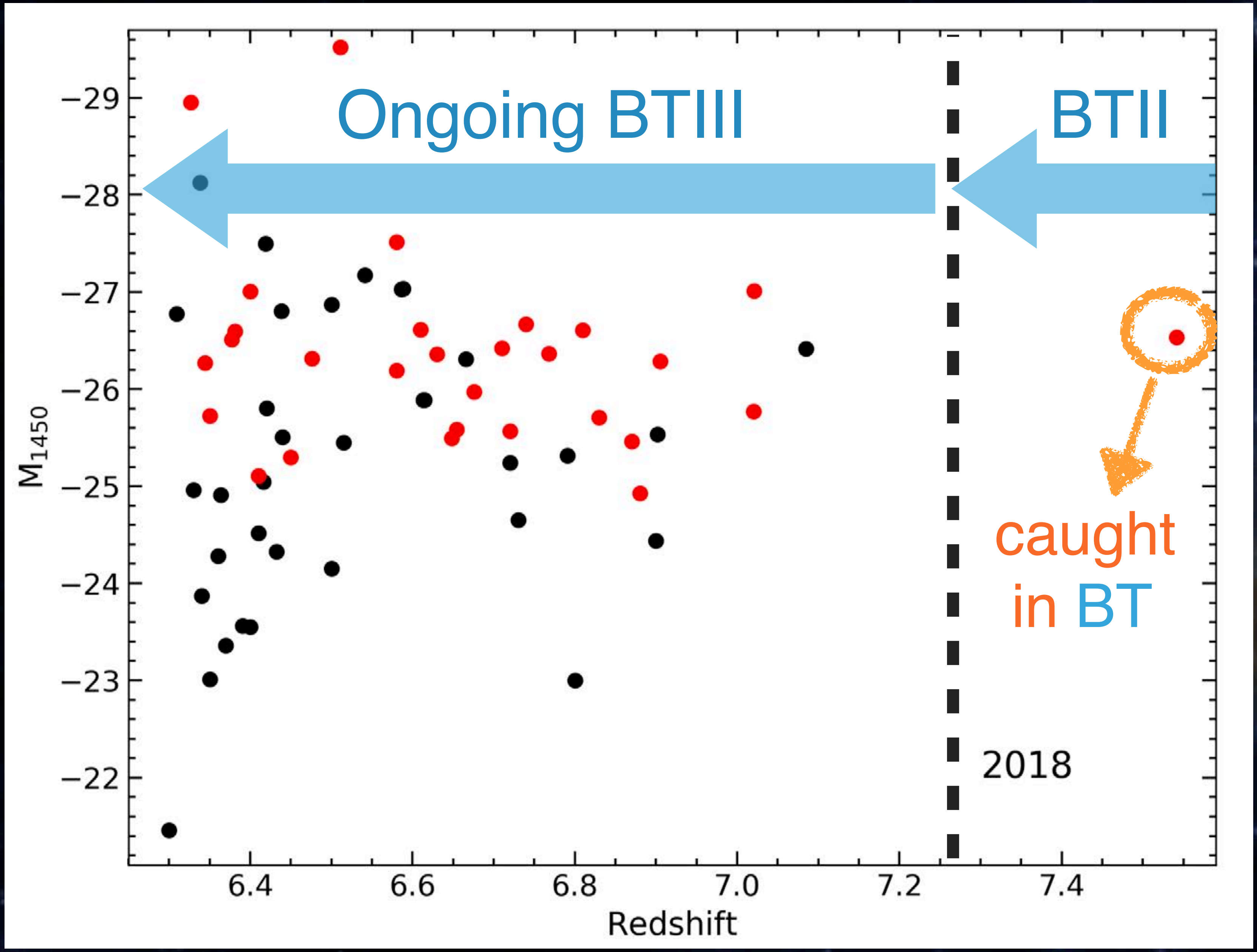


JWST



Euclid



Thank you