THE BLUETIDES SIMULATION

FIRST GALAXIES AND QUASARS AT THE COSMIC DAWN

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http://bluetides-project.org
PROBE TO EARLY UNIVERSE

Redshift (z)

0

8

12

20

Farthest galaxy Hubble has seen

Cosmic “Dark Ages”

First stars?

Present day

Modern galaxies form

Reionisation Era

z = 8.68

z = 11.1

Billions of years ago

Big Bang

13.4

13.5

13.8
PROBE TO EARLY UNIVERSE

OBSERVED HIGH-Z QUASARS

BLUETIDES

PROBE TO EARLY UNIVERSE

Redshift (z)
0

Present day

Billions of years ago

Modern galaxies form

Reionisation Era

Cosmic "Dark Ages"

First stars?

Big Bang

z = 8.68

z = 11.1

Farthest galaxy Hubble has seen

BT iii

BT&BT ii

(provisional BW project)

(renewal/current BW project)
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

HUDF: ~ 23 Mpc/h cubic

BOSS DR12: 2.2 Gpc/h cubic
High-z luminous quasars are extremely rare
~ 1 quasar / Gpc cube at $z > 6$

$\rho(<M,z) \propto 10^{kz}$

BOSS DR12: 2.2 Gpc/h cubic

only 2
CURRENT HIGH-Z OBSERVATIONS OF QUASARS

Searching for quasars \(\sim 20,000 \text{ deg}^2\) of the sky

\(\sim 30\) 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
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

Environment of massive disk galaxies at $z=8$

Environment of most massive blackhole at $z=8$

Views of Stellar disk
Views of Gaseous disk

The BlueTides Simulation
0.7 trillion particles
0.65 million cores

Feng et al. 2015
Large Volume

\[ P(M_{\text{BH}} > 10^9 M_\odot) \sim 1/\text{Gpc}^3 \]

High resolution

DM halo / structure \[ R_{\text{halo}} \sim \text{Mpc} \]
galaxy/star bulges \[ R_{\text{galaxy}} \sim \text{kpc} \]
SMBH \[ R_{\text{bondi}} \sim \text{pc} \]
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
\[
\nabla^2 \phi(x) = 4\pi G \bar{\rho}(x)a^2 \delta
\]
\[
\phi_k = \phi_k^{\text{long}} + \phi_k^{\text{short}}
\]

SPH (Hydrodynamics – ideal fluid, baryons)

Continuity
\[
\frac{\partial \rho}{\partial t} + \frac{3}{a} \frac{\partial}{\partial x} (\rho a v) = 0
\]

Euler
\[
\frac{\partial v}{\partial t} + \frac{1}{a} (v \cdot \nabla) v + \frac{\partial}{\partial x} (a \dot{v}) = -\frac{1}{a} \rho \nabla P - \frac{1}{a} \nabla \Phi
\]

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

Equation of state
\[
p = (\gamma - 1) \rho \epsilon
\]
SPH (Hydrodynamics – ideal fluid, gas)

Hybrid TreePM (gravity- dark matter)

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

[Graph: time used in each time step]

- Short Range
- Long range
- Global Domain Tree
- FOF
BLUETIDES: 400 X VOLUME OF HUDF

A Galaxy in BlueTides

Field of View of BlueTides Simulation
> 200,000 Star-forming Galaxies

Field of View of BoRG Survey
~ 300 sq. arcmin

15 Mpc/h
8 arcmin

80 Mpc/h
43 arcmin
RESULTS FROM BLUETIDES

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

![Graph showing galaxy luminosity function](image)

Galaxy luminosity $\rightarrow$ bright
CURRENT RECORD HOLDER: \( Z = 7.54 \text{ QUASAR} \)

**Observation**

\[ M_{BH} = 8 \times 10^8 M_\odot \]

**BLUETIDES**

\[ M_{BH} = 7 \times 10^8 M_\odot \]

J1342+0928
ALLWISE/Ukidss

Banados+17,

J1342+0928
ALLWISE/Ukidss

Tenneti, TDM+19
GALAXY HOSTS FOR THE FIRST QUASARS

JWST mock observations

\[ M_{\text{BH}} = 7 \times 10^8 M_\odot \]
\[ M_\star = 3 \times 10^{10} M_\odot \]
GALAXY HOSTS FOR THE FIRST QUASARS

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

$z=7.54$ quasar
host galaxy
BlueTides

$z=0$
M87: another host of billion solar mass black hole
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GALAXY HOSTS FOR THE FIRST QUASARS

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

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

$z=7.54$ 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.
Are the first quasars obscured?

Column density NH

Radial velocity

low NH, less obscured

strong outflow

Ni et al. in prep
THE BLUETIDES SIMULATION MAKES PREDICTIONS FOR FUTURE FACILITIES

Ongoing BTIII

BTII

cought in BT

WFIRST

JWST

Euclid
Thank you