NEW LIGHT ON HYDROGEN AND HELIUM REIONIZATION IN A COSMOLOGICAL VOLUME

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OUTLINE

- Motivation:

  The role of galaxies, QSOs and X-ray binaries in H and He reioinization

- Method:

  The Massive-Crash simulations: 3D hydrodynamic + radiative transfer simulations

- Preliminary results:

  Galaxies and QSOs dominate on different scales

Motivation

for the

Massive-Crash simulations

MOTIVATION: IGM REIONIZATION BY GALAXIES, QSOS AND XRBS

1.

Reionization has happened

Fan et al. (2006) and Dijkstra (2014)

2.

Galaxies – QSOs – X-ray binaries – hot ISM X-rays
—their role and importance in H and He reionization?
Bright, faint, hard, soft and clustered sources

Eg. Haiman and Loeb 1998; Furlanetto 2006; Mineo et al. 2012a; Mineo et al. 2012b; Fragos et al. 2013; Fialkov et al. 2014; Pacucci et al. 2014; Giallongo et al. 2015; Madau and Haardt 2015; Bouwens et al. 2015

3.

Origin of sources and environment: MassiveBlack II simulation
—need to track ionising photons from them: CRASH

4.

Massive-Crash happens

Methods

of the

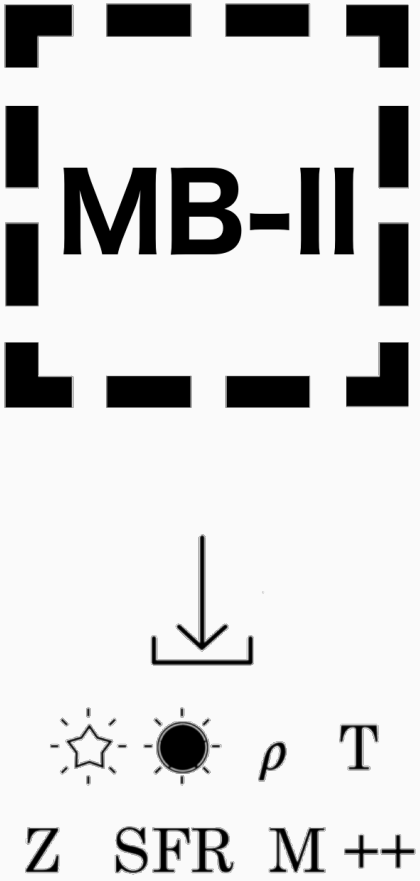
Massive-Crash simulations

METHOD: UNDERLYING COSMOLOGICAL SIMULATION

MassiveBlack II

Khandai et al. (2015)

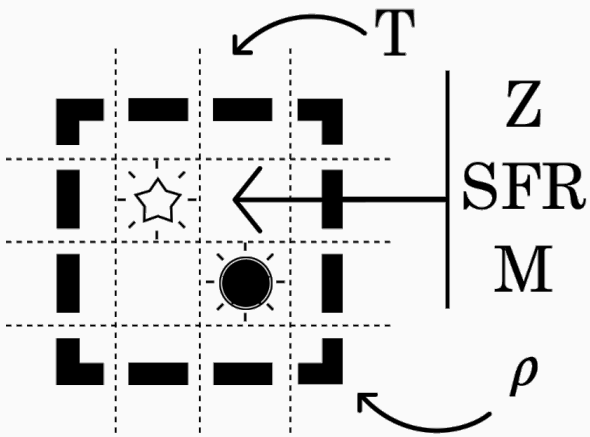
- Hydrodynamic simulation, baryonic physics
- Volume: $(100\ \mathrm{cMpc/h})^3$
- Mass resolution: $\sim 10^6\, M_\odot$
- Black hole growth and feedback from $5 \times 10^5 M_\odot$ seeds
- Subgrid models: star formation and supernova feedback



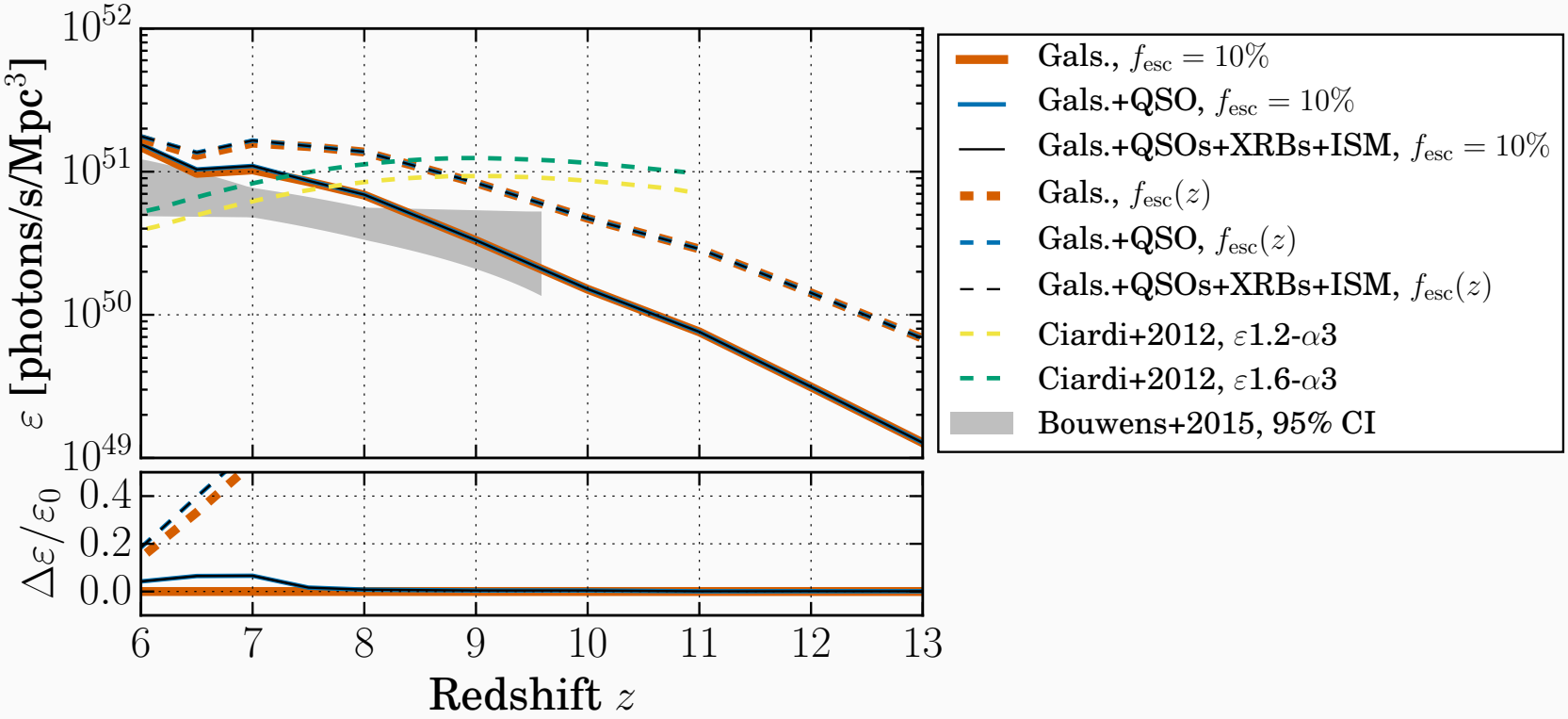
CRASH

Eg. Graziani et al. (2013)

- Using gridded input data from MassiveBlack II at 15 redshifts
- $z = 20$ to $z = 4.5$
- Tracking ionizing photon packets w/ 128 frequency bins 13.6 eV—2 keV
- Current runs: 256^3 grid, will upscale to 512^3: $\sim$ 200 kPc/h resoluton
- Different sources: different spectra



WHAT TO EXPECT – EMISSIVITIES



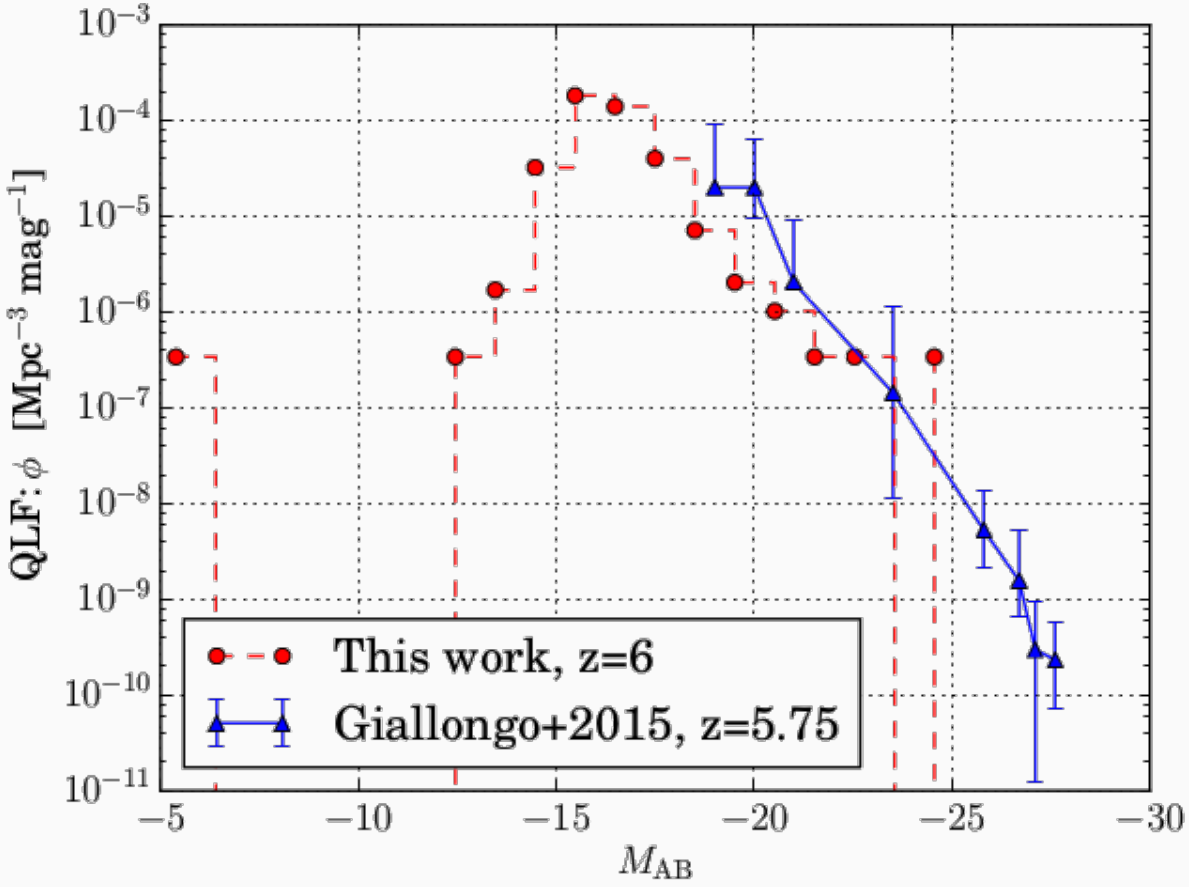
QSOs:

Not contributing significantly until $z \sim 7$

XRBs:

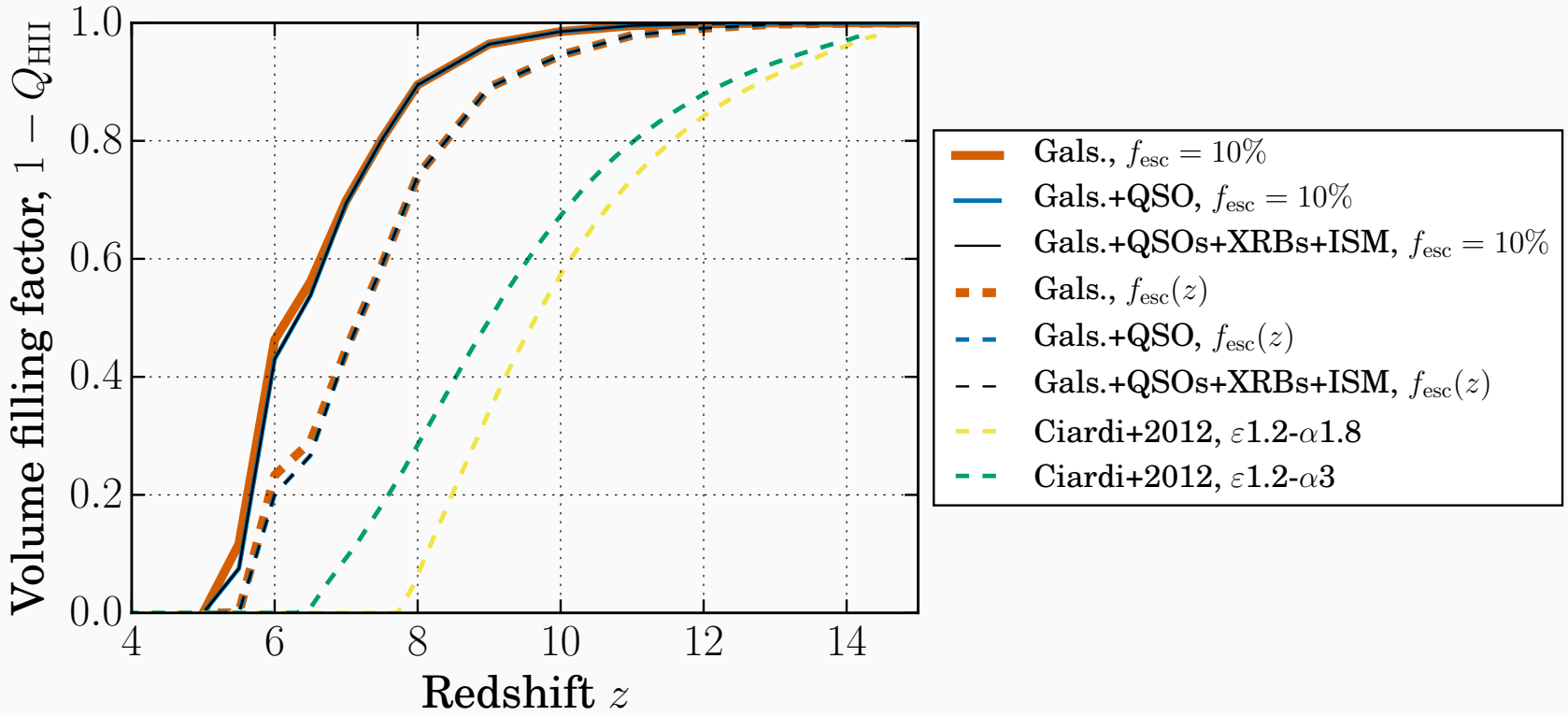
Orders of magnitude fewer photons – ubiquitous X-ray background?

QUASAR LUMINOSITY FUNCTION



QLF comparison at $z \sim 6$ against Giallongo et al. (2015)

WHAT TO EXPECT – FILLING FACTOR



QSOs:

Not contributing significantly until $z \sim 7$

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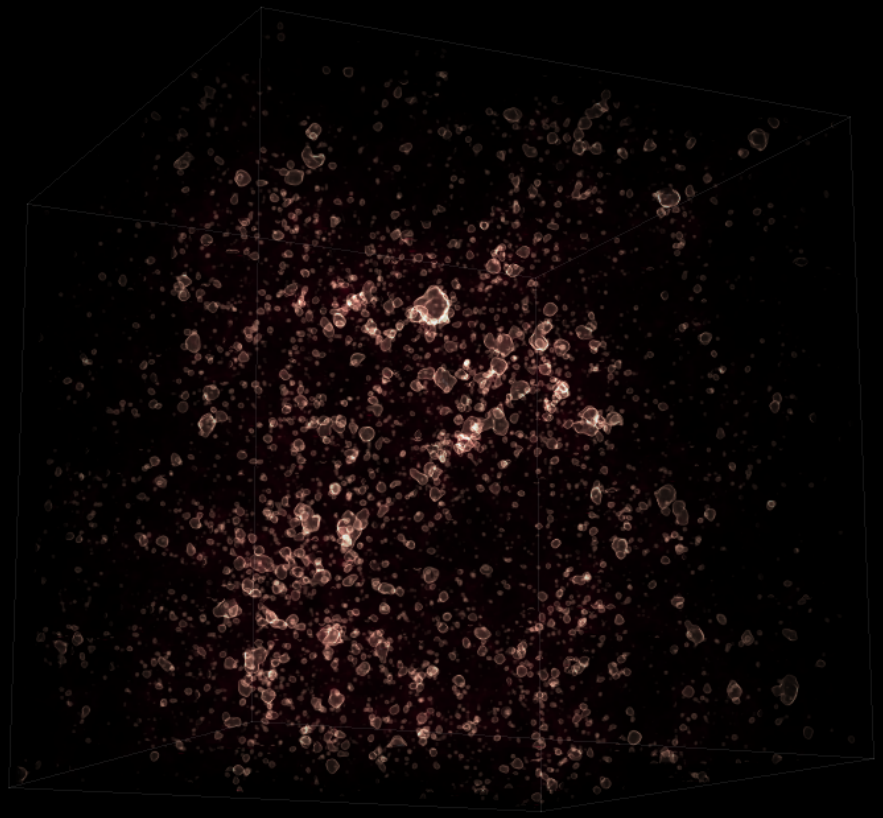
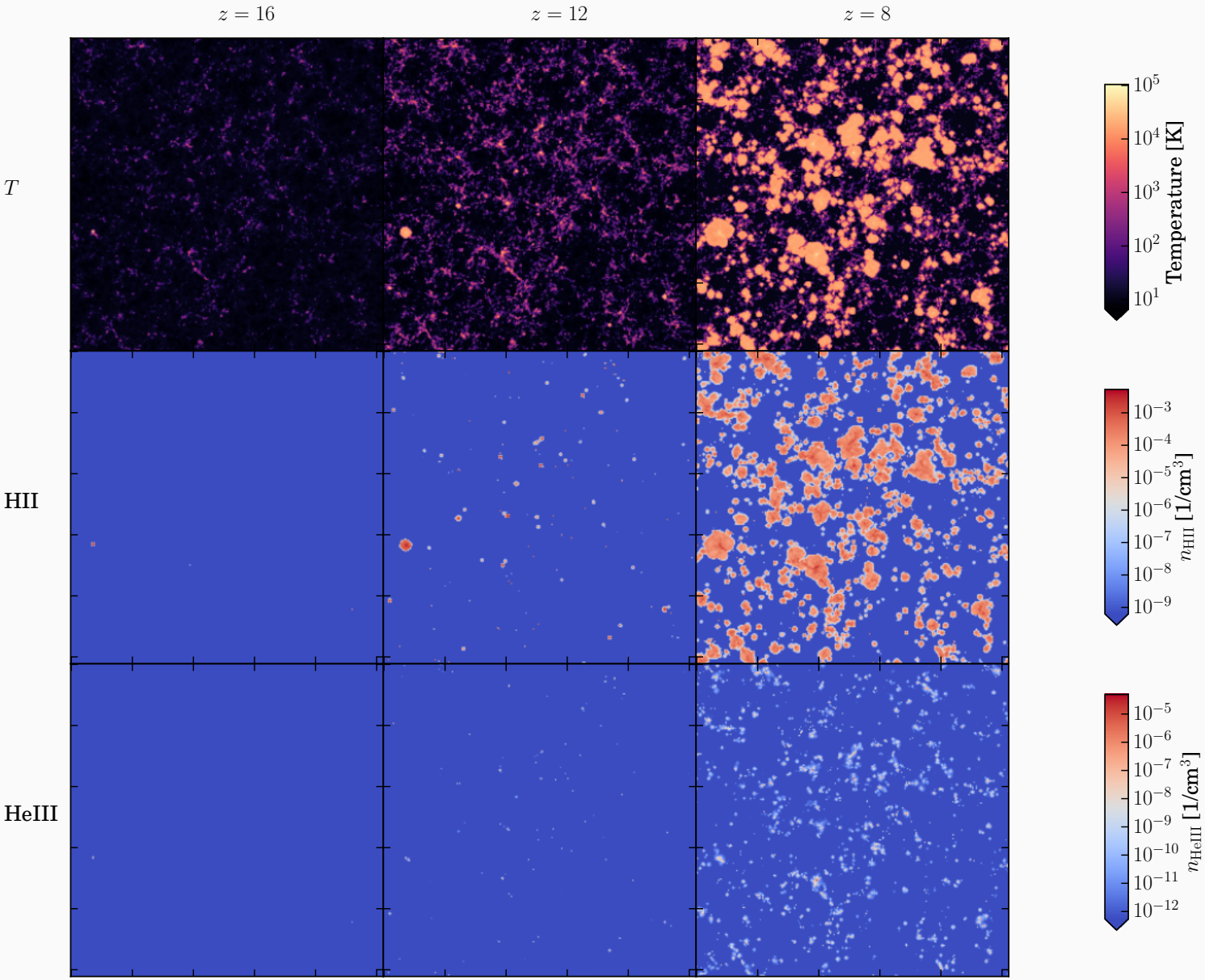
Preliminary results

from the

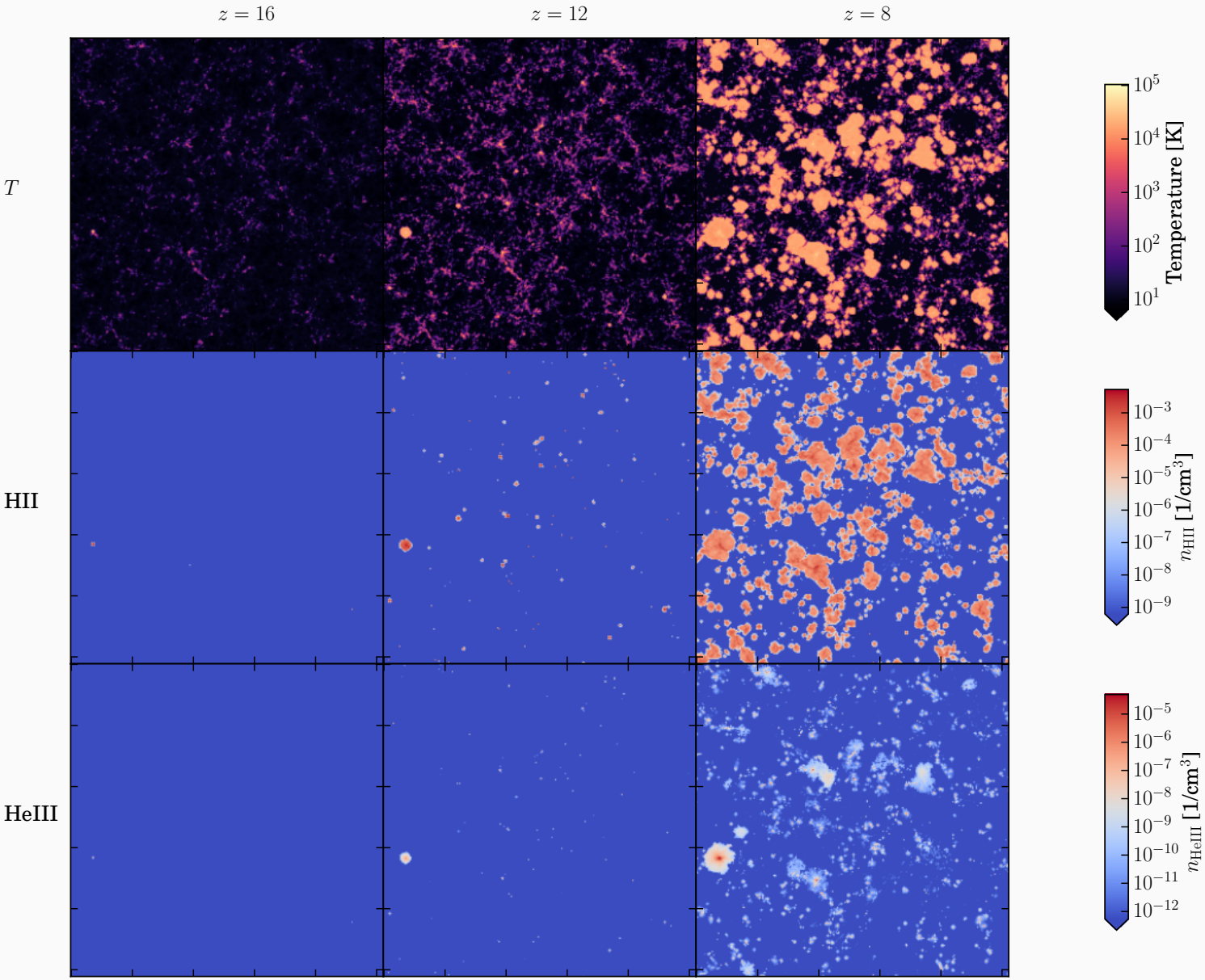
Massive-Crash simulations



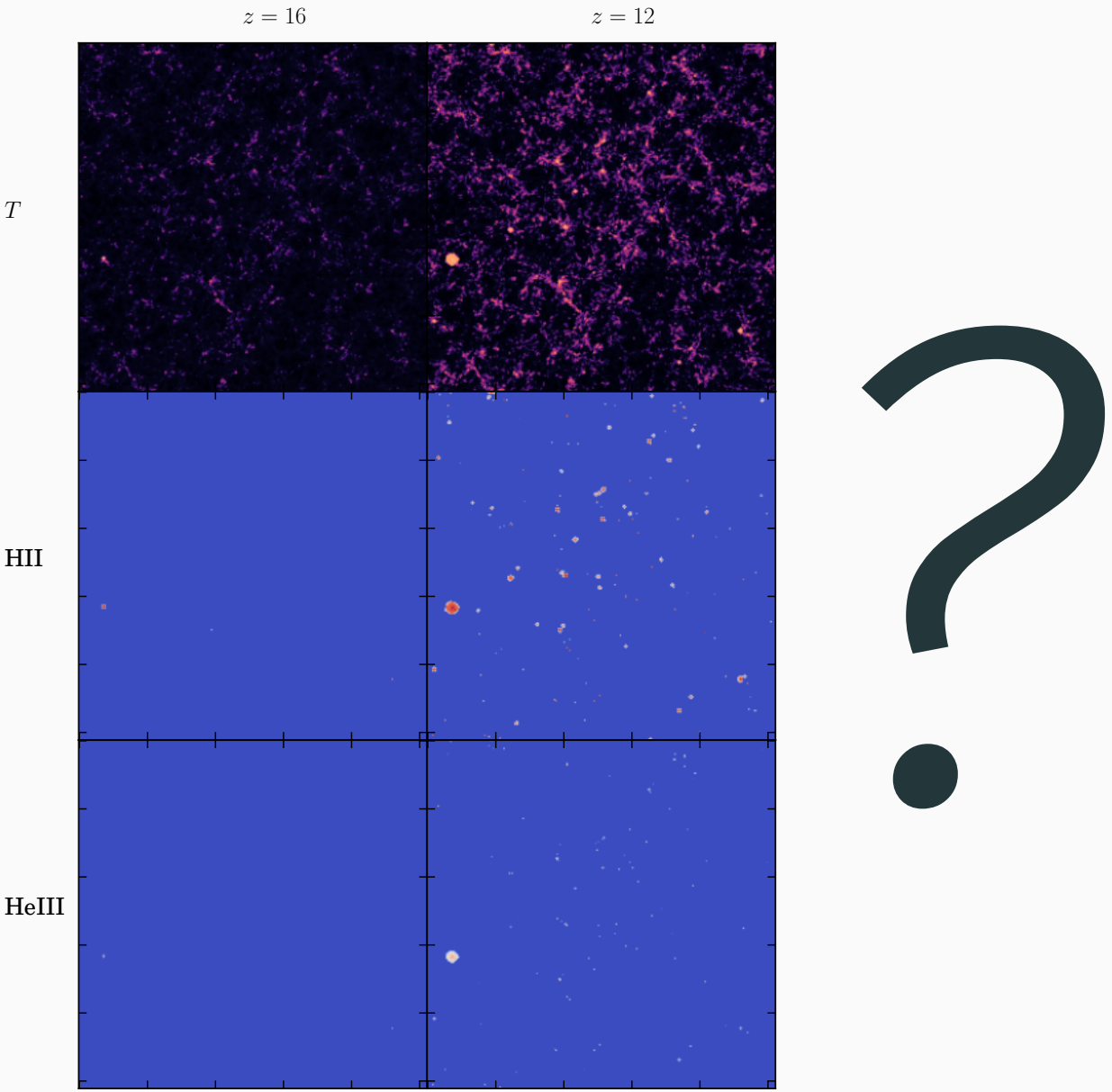
RESULTS: TRACKING THE STATE OF THE IGM - WITHOUT QSOS



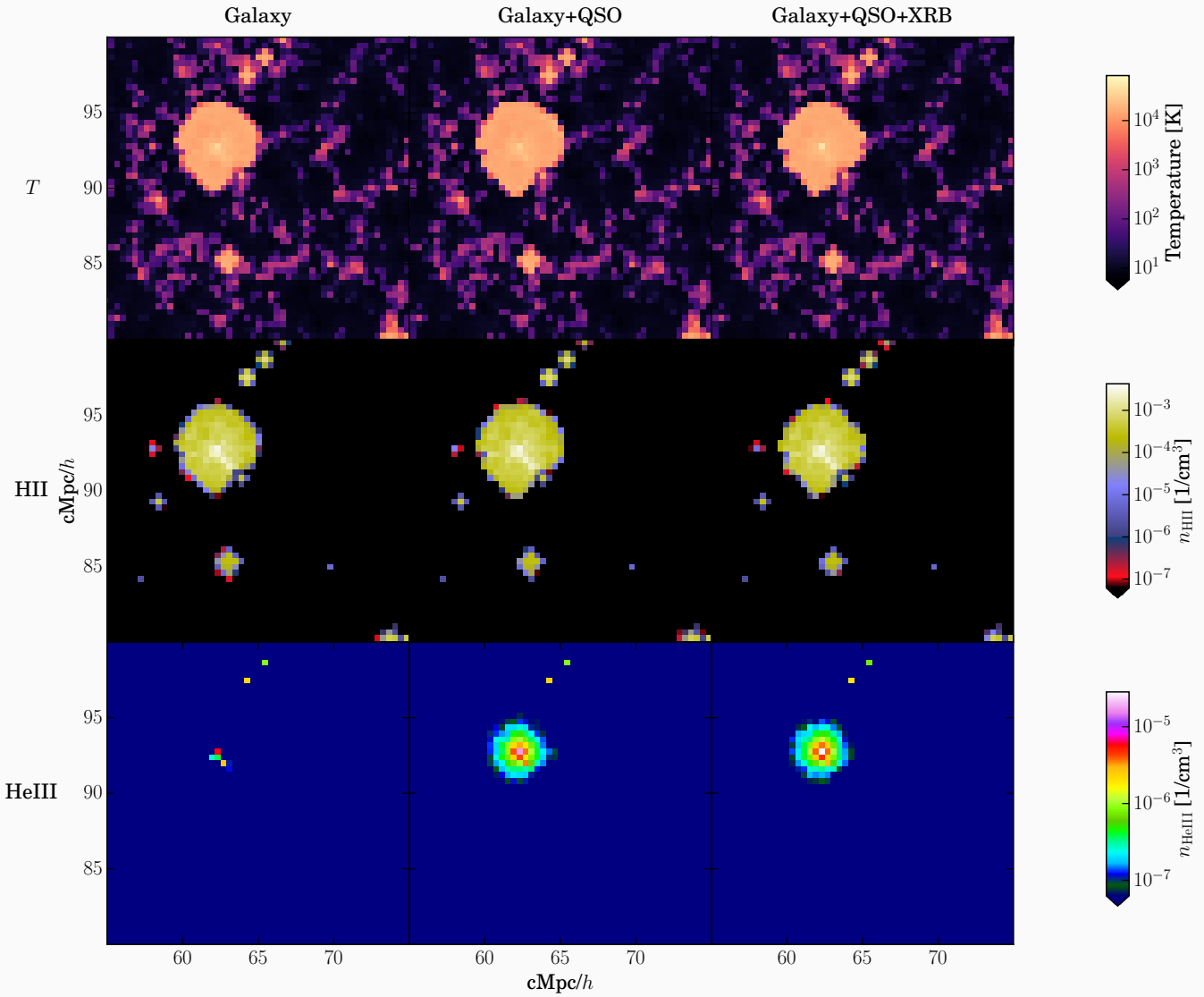
RESULTS: TRACKING THE STATE OF THE IGM - WITH QSOS



RESULTS: TRACKING THE STATE OF THE IGM - WITH QSOS AND XRBS



RESULTS: ZOOMING IN ON A $z = 10$ QSO

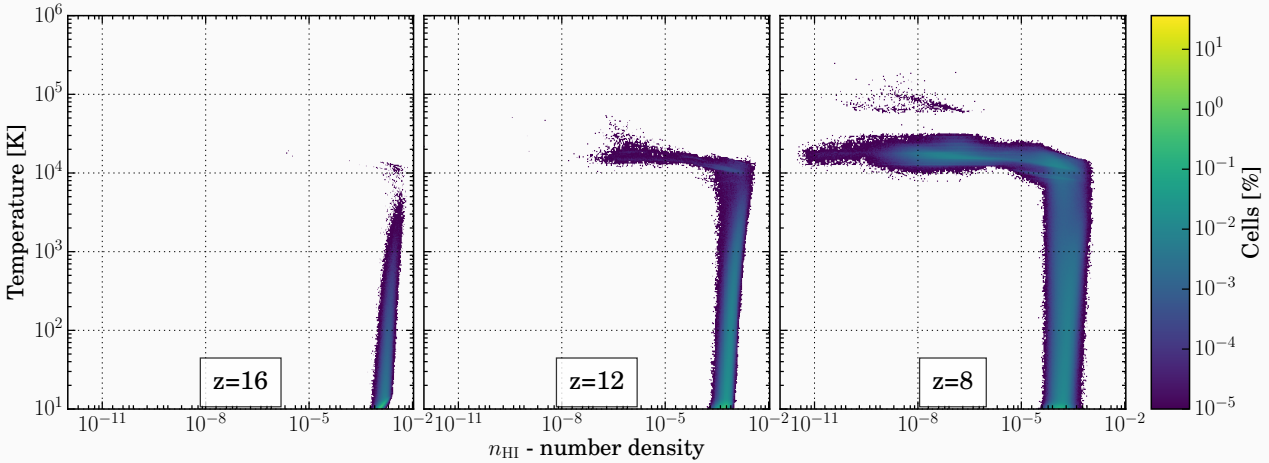


QSO: yields larger, smooth HeIII bubble,

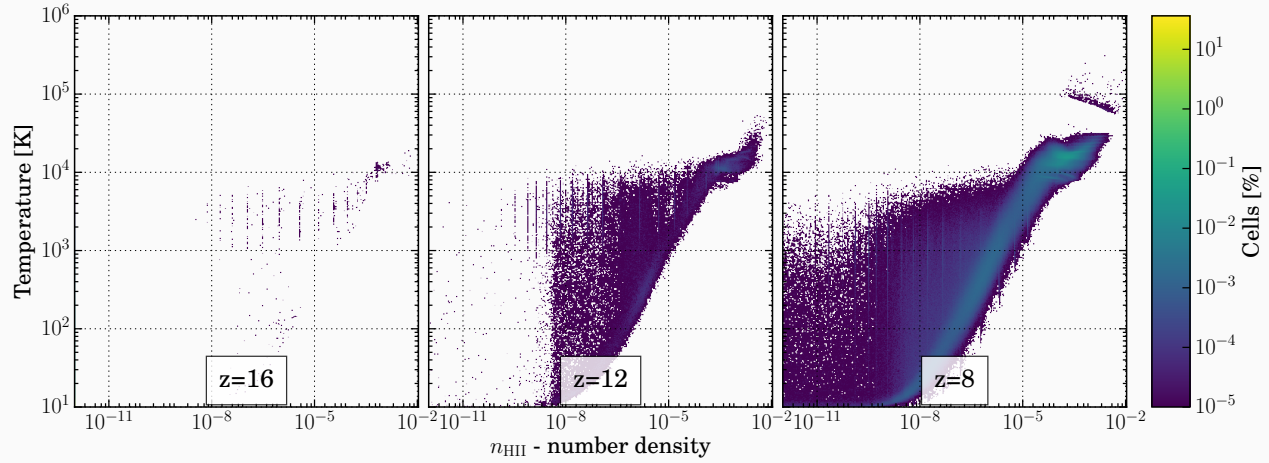
XRBs: increases temperature, n_{HeIII} slightly

RESULTS: IGM PHASE (NO QSOS) - HYDROGEN (1/3)

HI



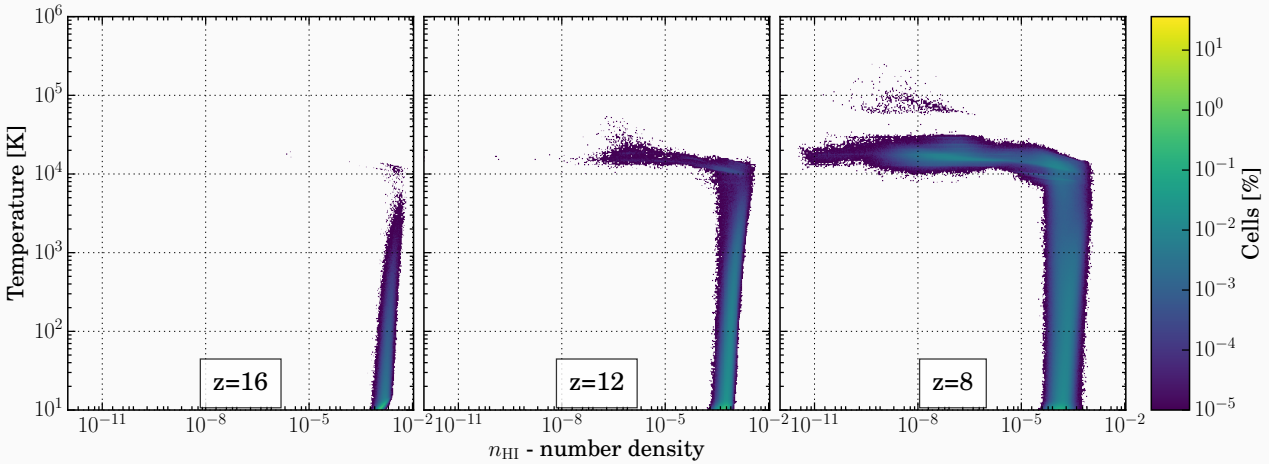
HII



VOLUME in different phases (*T* vs number dens.)

RESULTS: IGM PHASE (WITH QSOS) - HYDROGEN (1/3)

HI



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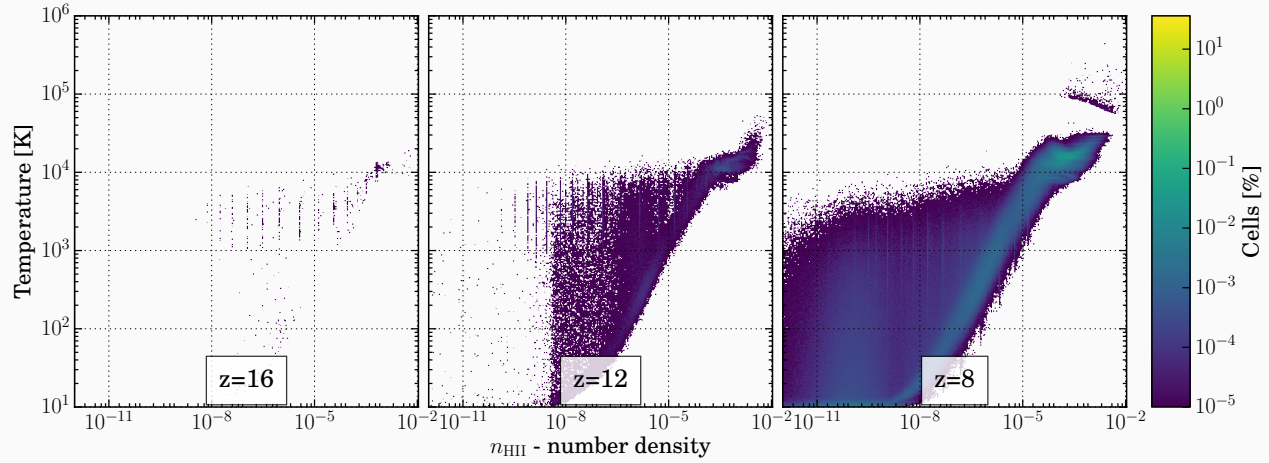

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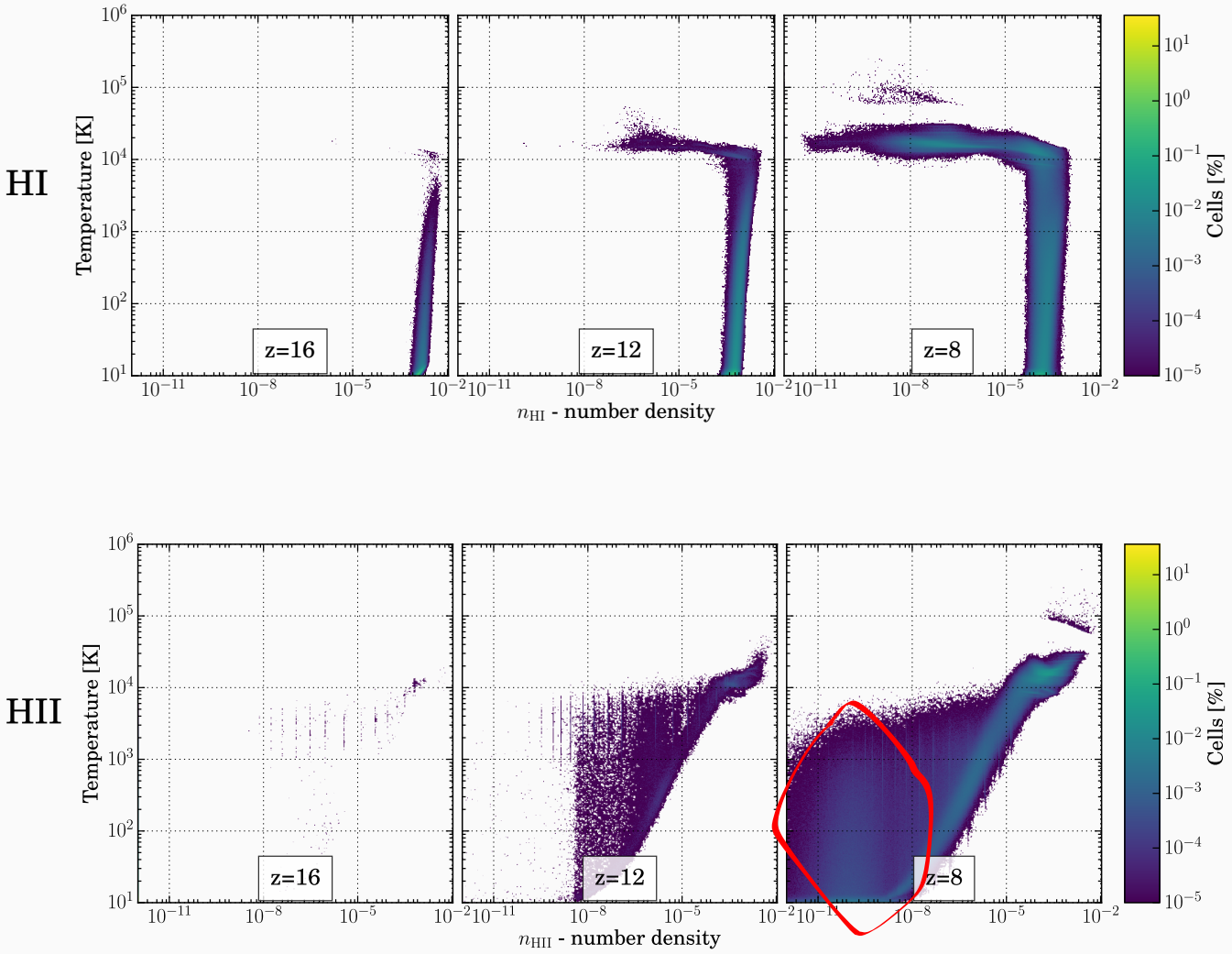
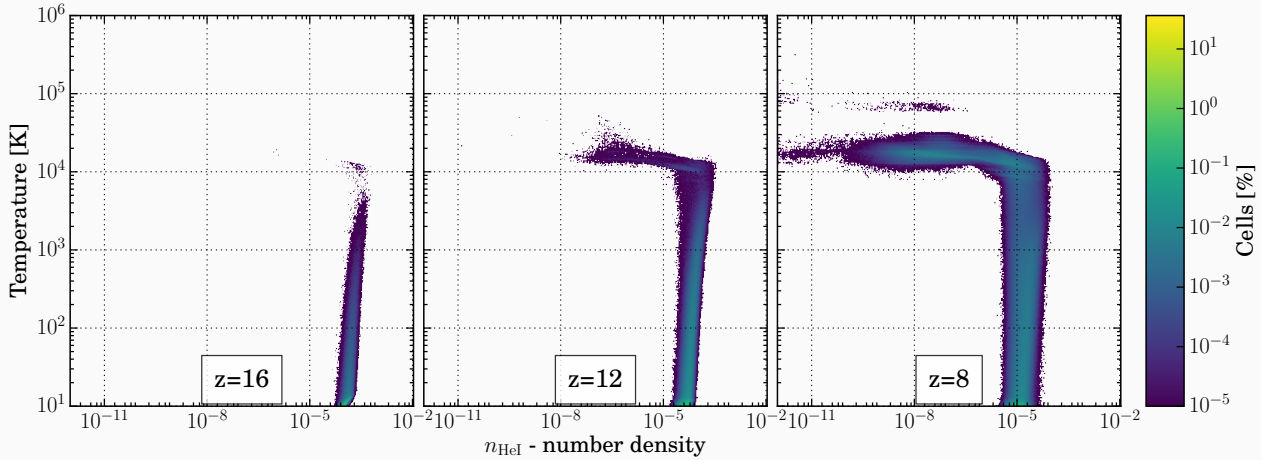
RESULTS: IGM PHASE (WITH QSOS) - HYDROGEN (1/3)



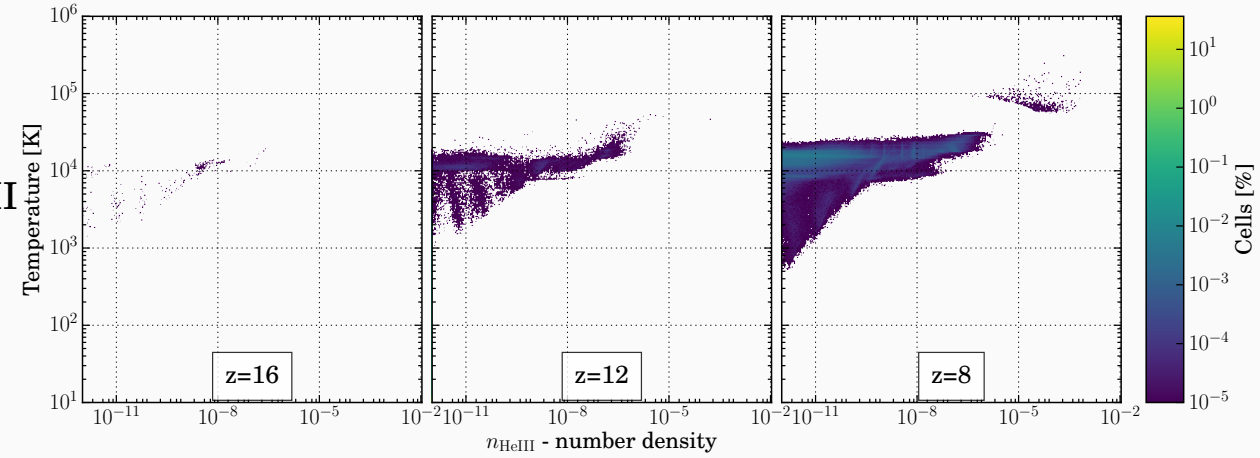
VOLUME in different phases (*T* vs number dens.)

RESULTS: IGM PHASE (NO QSOS) - HELIUM (2/3)

HeI



HeIII



VOLUME in different phases (*T* vs number dens.)

RESULTS: IGM PHASE (WITH QSOS) - HELIUM (2/3)

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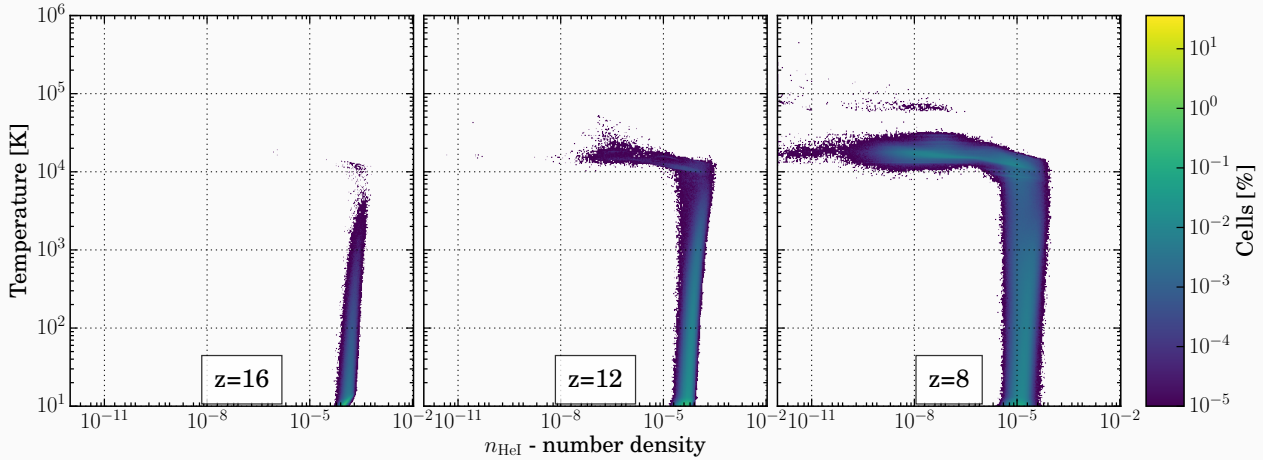
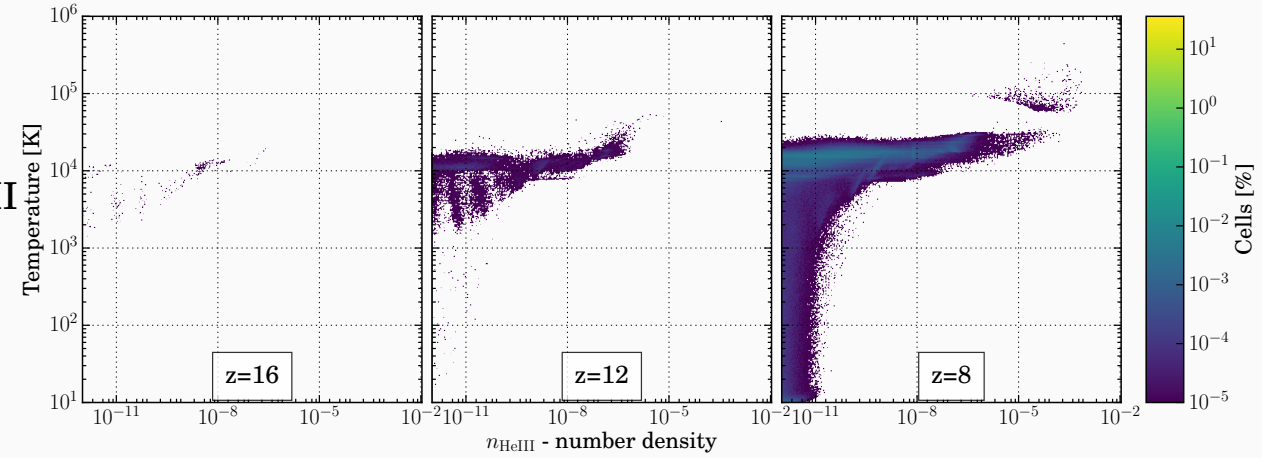
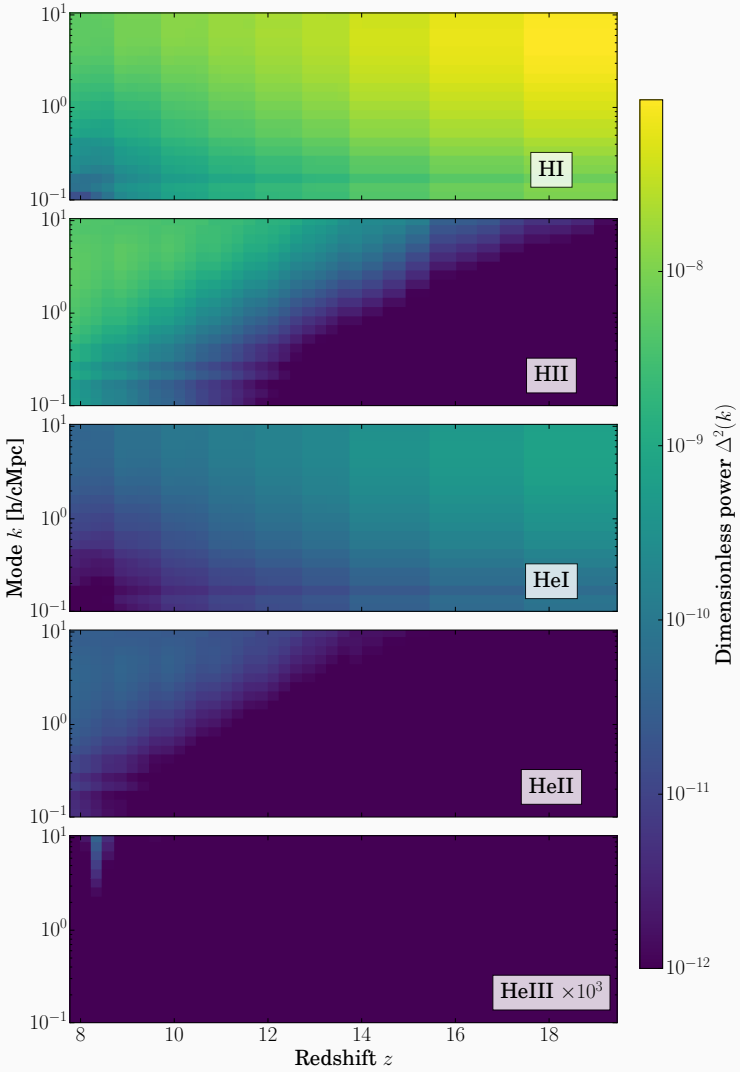


HeIII

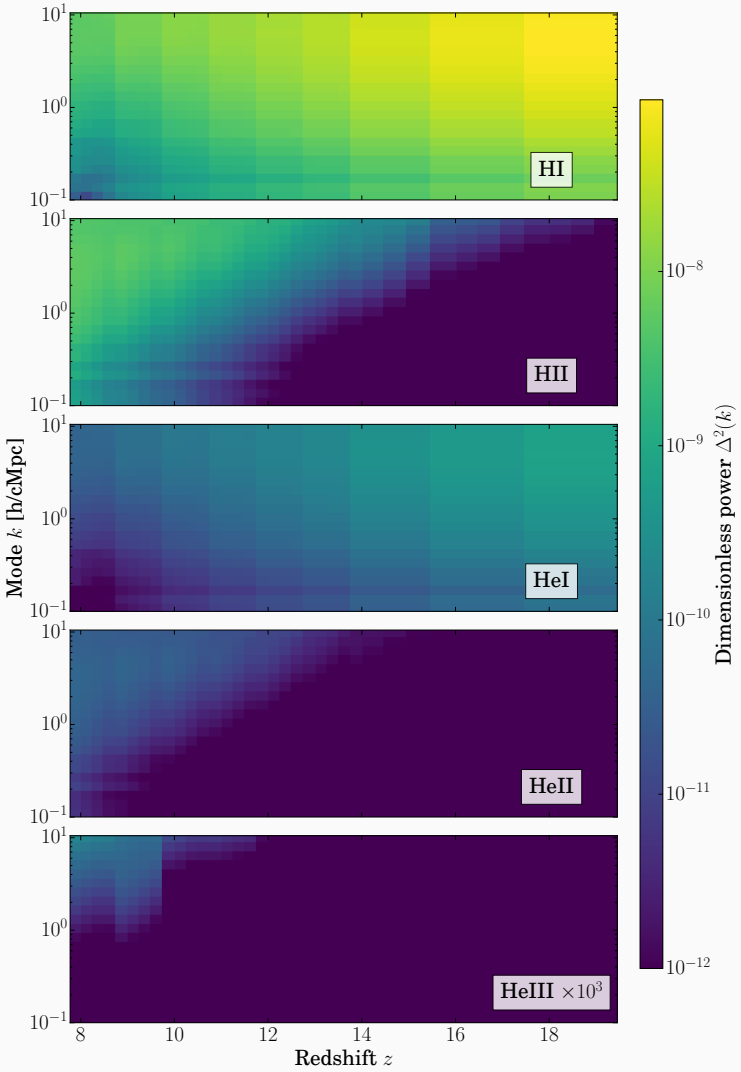


VOLUME in different phases (T vs number dens.)

RESULTS: SCALE OF STRUCTURES – STACKED POWER SPECTRA (3/3)



(a) Galaxies



(b) Galaxies+QSOS

CONCLUSIONS AND IMMEDIATE OUTLOOK

- Galaxies and QSOs leave their **imprint at different scales** – *globally larger differences at lower z?*
- HeIII (ion. erg. 54.4 eV) good indicator of X-ray activity
- Sources with different properties contribute **in concert** to the heating and ionization of the IGM – *K. Kakiichi*
- **But what about the XRBs?** Contribute to heating – *significant imprint on topology or only slight change in temperature?*
- *Impact on 21 cm signal? D. Vrbanec*
- QSOs wash out smaller structures of IGM – *IGM morphology and percolation: P. Busch*