NEW LIGHT ON HYDROGEN AND HELIUM REIONIZATION IN A COSMOLOGICAL VOLUME

Marius B. Eide
Max Planck Institute for Astrophysics, Garching

With:
P. Busch (MPA), B. Ciardi (MPA), M. Glatzle (MPA), L. Graziani (INAF Rome), K. Kakiichi (MPA) and D. Vrbanec (MPA)

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• Motivation:

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

• 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
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
MassiveBlack II
Khandai et al. (2015)

- Hydrodynamic simulation, baryonic physics
- Volume: $(100 \, \text{cMpc}/h)^3$
- 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 resolution
- 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

Volume filling factor, $1 - Q_{\text{HII}}$

Redshift $z$

QSOs:
Not contributing significantly until $z \sim 7$

XRBs:
Orders of magnitude fewer photons – ubiquitous X-ray background?
PRELIMINARY RESULTS

FROM THE

MASSIVE-CRASH SIMULATIONS
RESULTS: TRACKING THE STATE OF THE IGM - WITHOUT QSOS

\[ z = 16 \]

\[ T \]

\[ T \]

\[ HII \]

\[ HII \]

\[ HeIII \]

\[ HeIII \]

Temperature [K]

\[ n_{HII} \text{ [1/cm}^3\text{]} \]

\[ n_{HeIII} \text{ [1/cm}^3\text{]} \]
RESULTS: TRACKING THE STATE OF THE IGM - WITH QSOS

Temperature [K]

$n_{\text{HII}}$ [1/cm$^3$]

$n_{\text{HeIII}}$ [1/cm$^3$]
RESULTS: ZOOMING IN ON A $z = 10$ QSO

QSO: yields larger, smooth HeIII bubble,
XRBs: increases temperature, $n_{\text{HeIII}}$ slightly
RESULTS: IGM PHASE (NO QSOS) - HYDROGEN

VOLUME in different phases ($T$ vs number dens.)
VOLUME in different phases (T vs number dens.)
RESULTS: IGM PHASE (WITH QSOS) - HYDROGEN

VOLUME in different phases ($T$ vs number dens.)
RESULTS: IGM PHASE (NO QSOS) - HELIUM

VOLUME in different phases ($T$ vs number dens.)
RESULTS: IGM PHASE (WITH QSOS) - HELIUM

VOLUME in different phases ($T$ vs number dens.)
RESULTS: SCALE OF STRUCTURES – STACKED POWER SPECTRA

(a) Galaxies

(b) Galaxies+QSOS
• 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*