Carving through the Codes: Challenges in Computational Astrophysics
Davos 12-17.02.2017

Challenges in Simulating Cosmic Reionization

Benedetta Ciardi

Max Planck Institute for Astrophysics

Thanks to M. Eide, M. Glatzle, L. Graziani, K. Kakiichi et al.

Modelling of cosmic reionization

✧ Model of structure formation
(gas distribution & source type and location)

$$M\frac{dn}{dM} = \left(\frac{2}{\pi}\right)^{1/2} \frac{-d(\ln$$

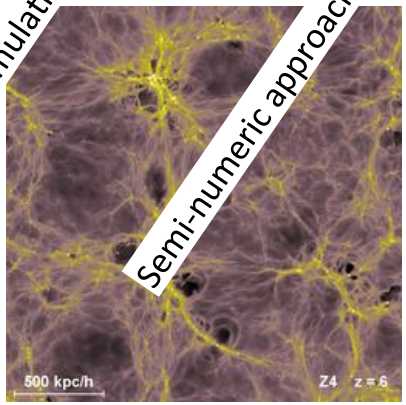
$$M_{\gamma} \dot{M}$$

$$< t_{dyn}$$

...

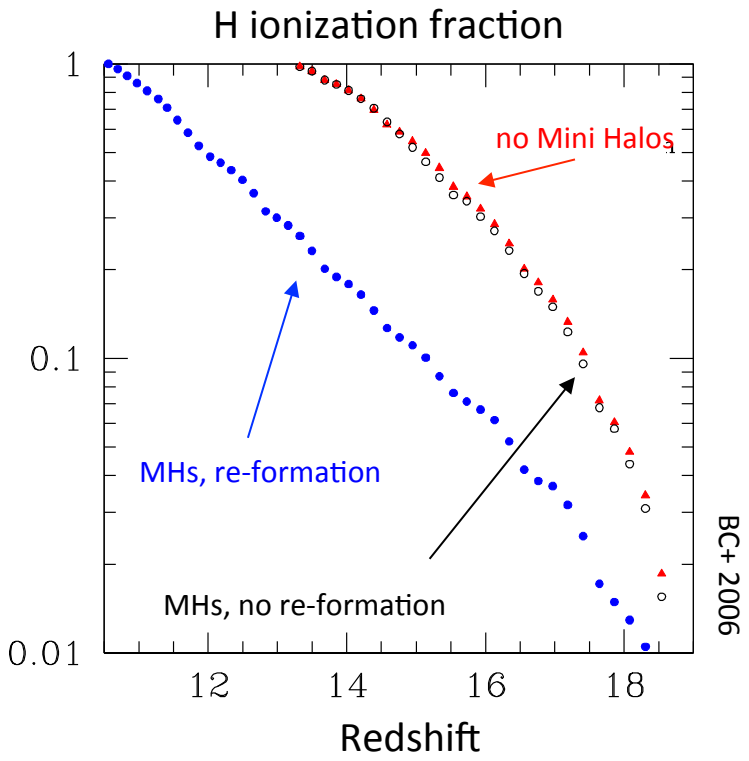
N-body + semi-analytic

Hydrodynamical simulations



Model of structure formation

box size (several 100 cMpc) vs. resolution ($10^{8\text{-}9}\ M_{\odot}$)



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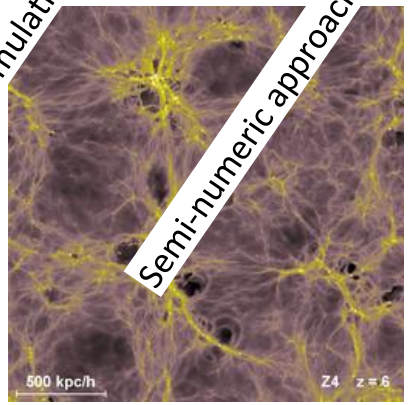
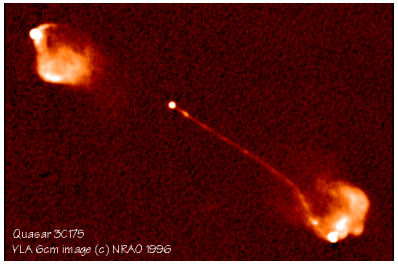


✧ Properties of the sources of ionizing radiation

Stellar type

Quasars



DM annihilation/decay

light dark matter

neutralinos

gravitinos

sterile neutrinos

...

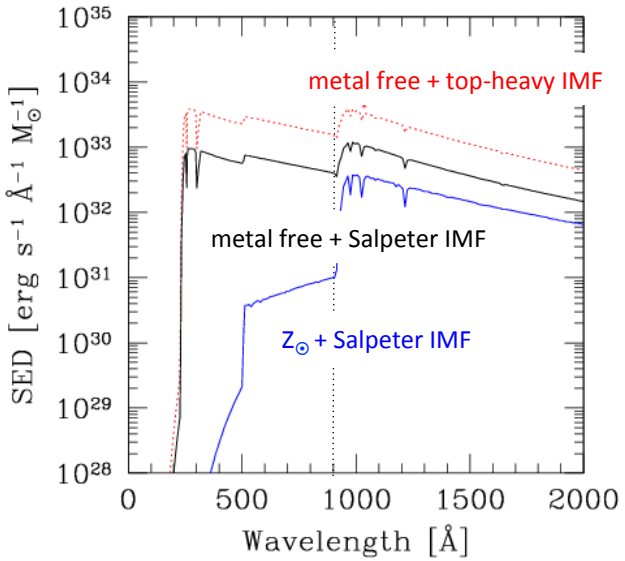
STELLAR TYPE SOURCES

✧ Initial Mass Function and spectrum

✧ Primordial (PopIII) → standard (PopII/I) star formation

✧ Escape fraction

Spectral Energy Distribution



Large uncertainties associated
to high-z stellar type sources

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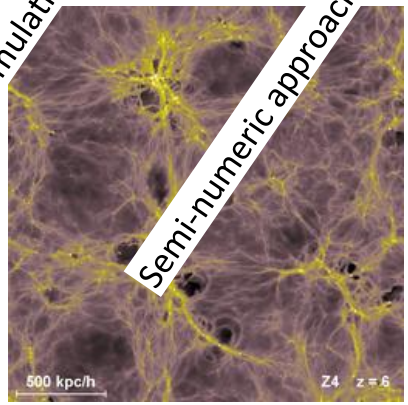

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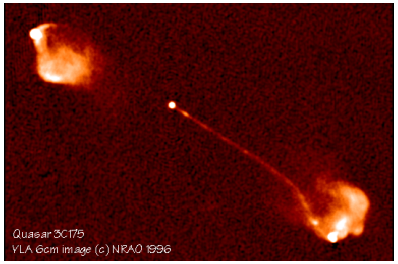

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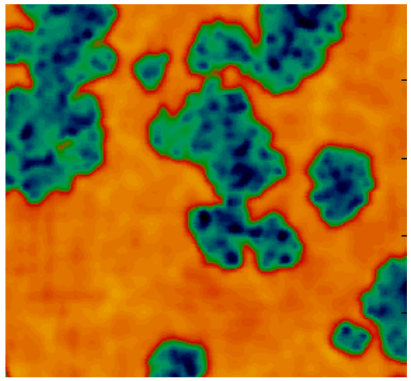
✧ Evolution of ionized regions



EVOLUTION OF IONIZED REGIONS

Cosmological radiative transfer codes comparison I

Code (Authors)	Grid	Gasdyn.	He	Rec. rad.
CRASH (Maselli, Ferrara, BC)	Fixed	No	Yes	Yes
C2-Ray (Mellema et al)	Fixed/AMR	Yes	No	No
OTVET (Gnedin, Abel)	Fixed	No	Yes	Yes
ART (Nakamoto et al)	Fixed	No	No	Yes
RSPH (Susa, Umemura)	Particle-based	Yes	No	No
FLASH-HC (Rijkhorst et al)	Fixed/AMR	Yes	No	No
SimpleX (Ritzerveld, Icke, Rijkhorst)	Unstructured	No	No	Yes
Zeus-MP (Whalen, Norman)	Fixed	Yes	No	No
IFT (Alvarez, Shapiro)	Fixed/AMR	No	No	No
Coral (Iliev et al)	AMR	Yes	Yes	No
FTTE (Razoumov)	Fixed/AMR	Yes	Yes	yes

Iliev+ (2006)

EVOLUTION OF IONIZED REGIONS

Cosmological radiative tra

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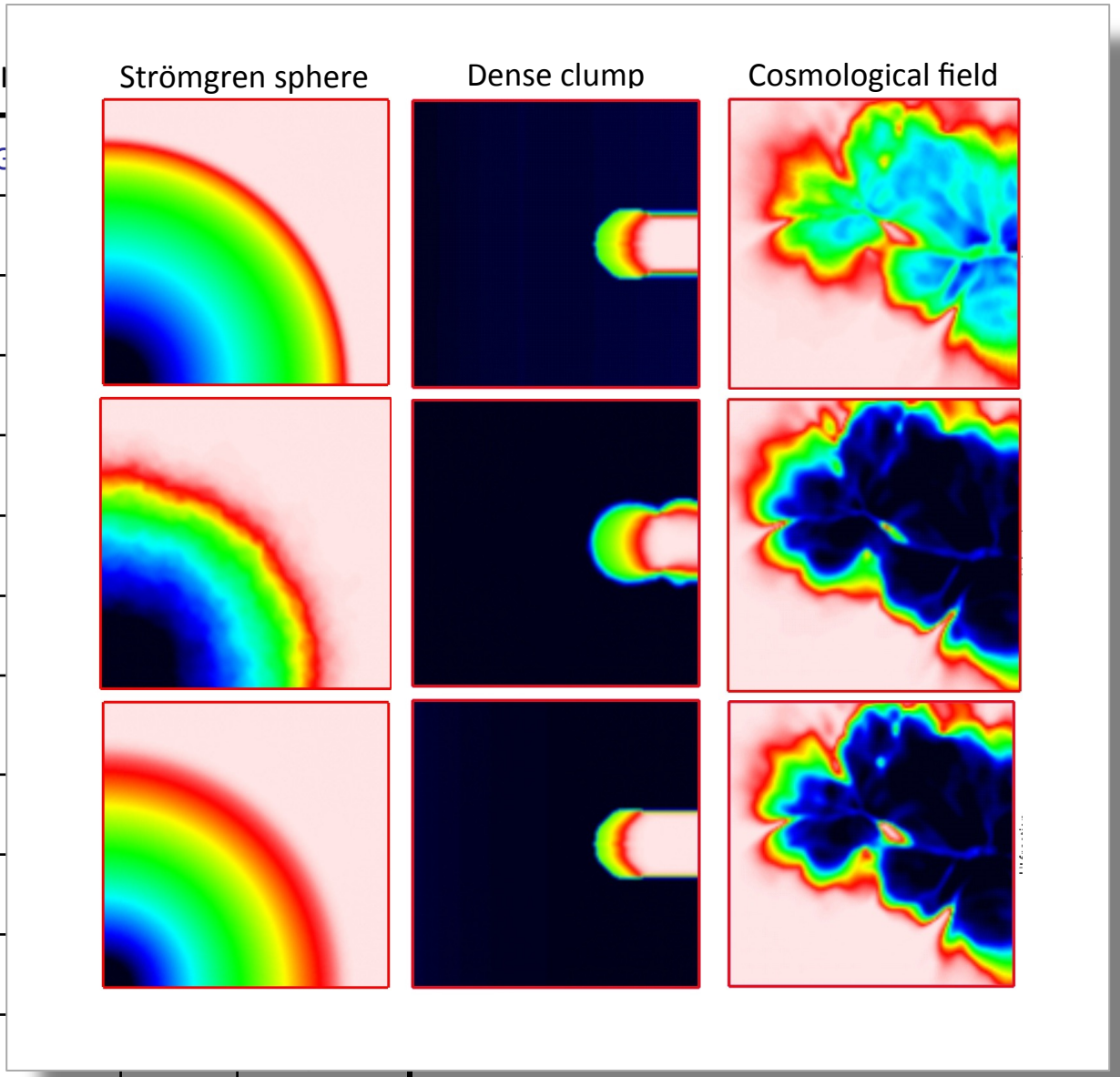

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1. Post-processing: He, high-energy photons
2. Coupled: properties of galaxies

STAY TUNED!

Iliev+ (2006)

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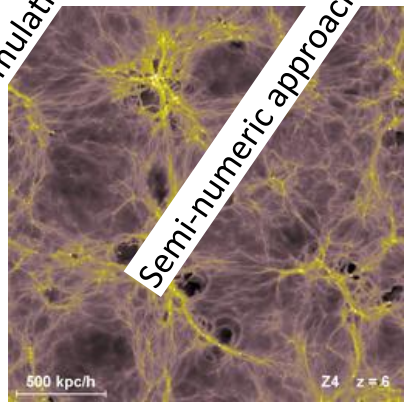

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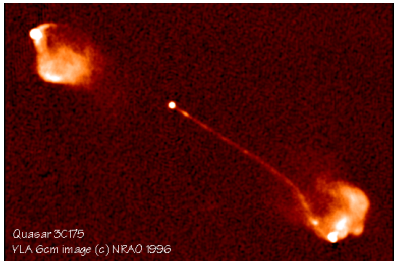

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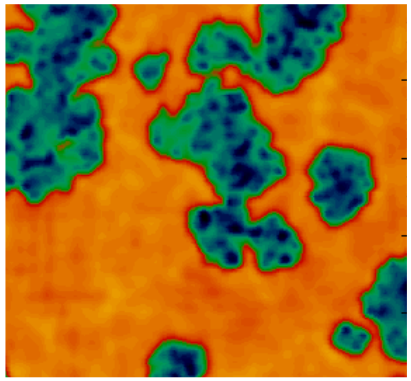

Simulations of H & He reionization

BC+ 2012; Eide+ in prep

Model of galaxy formation

MassiveBlack II (Khandai+ 2015)

L [Mpc/h com.]	Particles	Mgas [Msun/h]
533	2×3200^3	5.7×10^7
100	2×1792^3	2×10^6
35.12	2×512^3	4.15×10^6
8.78	2×256^3	6.48×10^4
4.39	2×256^3	8.11×10^3
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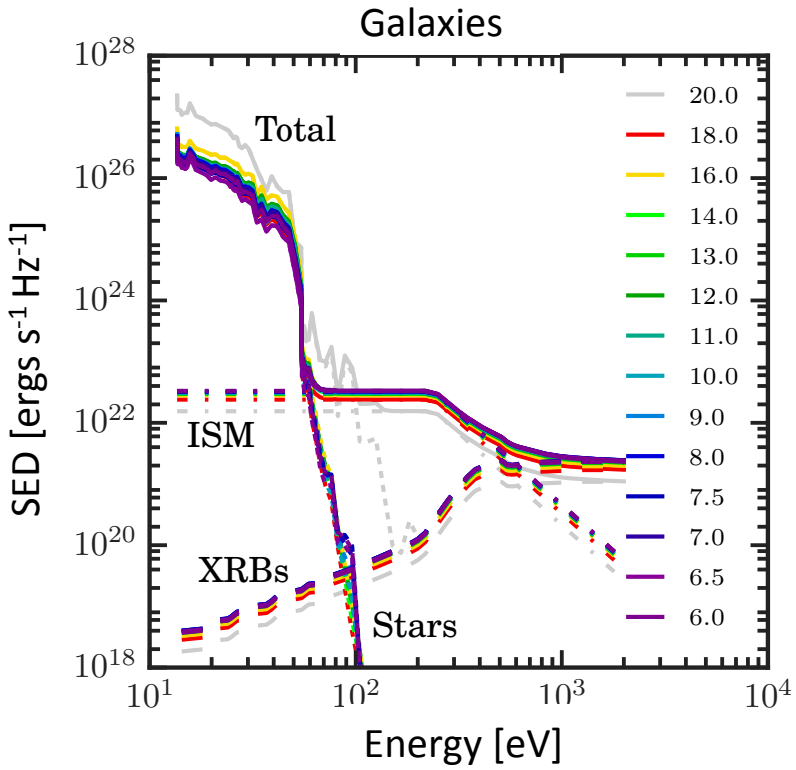
Properties of the sources of ionizing radiation

Stars, QSOs, XRBs, ISM



+ QSO

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Radiative transfer of ionizing photons

CRASH

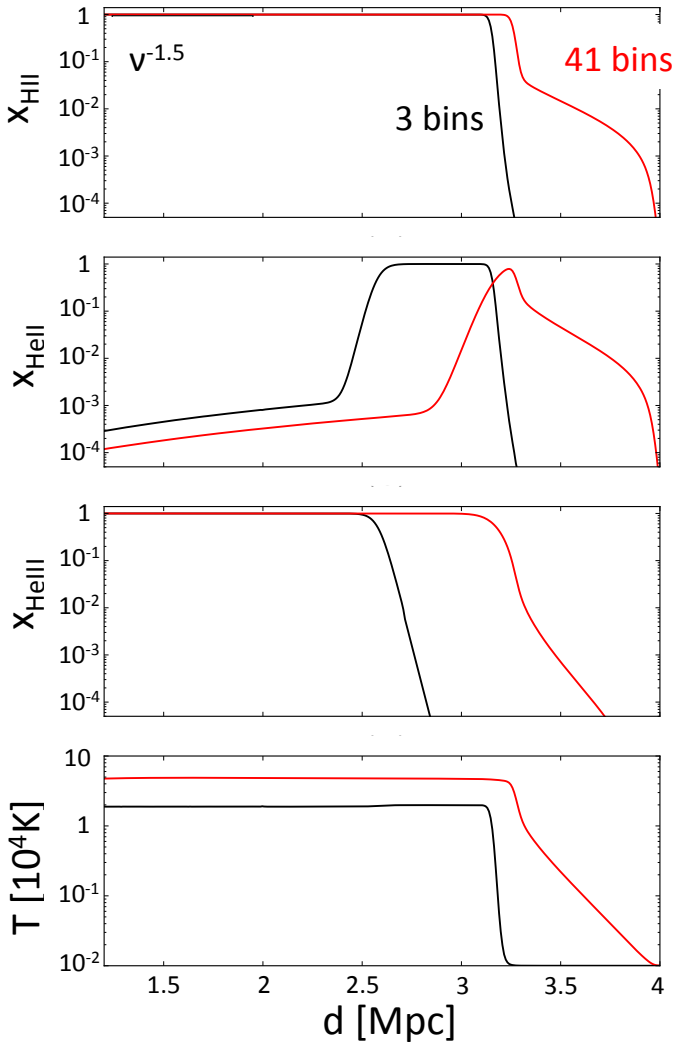
BC+ 2001; Maselli, Ferrara, BC 2003; Maselli, BC, Kanekar 2009; Pierleoni, Maselli, BC 2009; Partl+ 2011; Graziani, Maselli, BC 2013; Hariharan+ 2017; Graziani, BC, Ferrara in prep; Glatzle, Graziani, BC in prep

UV, x-rays, Lyα photons in H, He, metals, dust
radiation from recombination, background

RADIATIVE TRANSFER OF IONIZING PHOTONS

Eide+ in prep

- 127 frequency bins in 13.6eV-2keV



Frequency resolution is important!

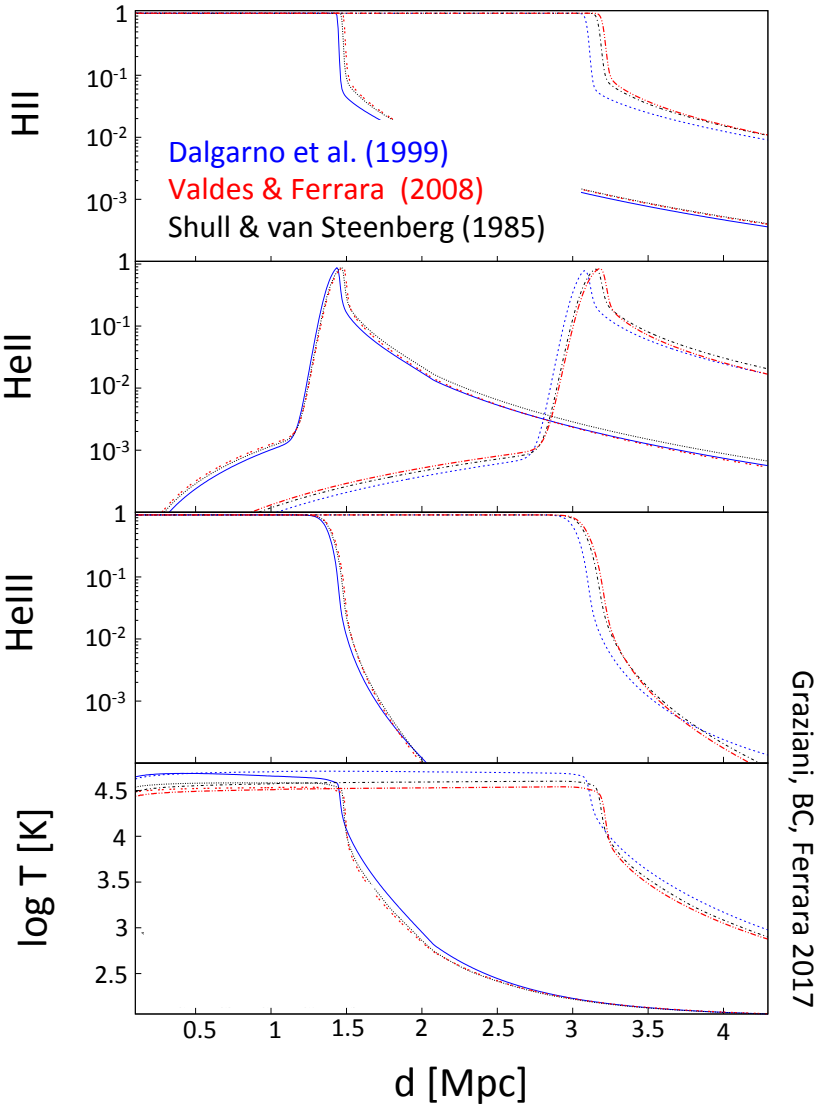
RADIATIVE TRANSFER OF IONIZING PHOTONS

- 127 frequency bins in 13.6eV-2keV

- Secondary ionization from Dalgarno+

Results mildly affected by secondary model

Eide+ in prep



RADIATIVE TRANSFER OF IONIZING PHOTONS

Eide+ in prep

- 127 frequency bins in 13.6eV-2keV

- Secondary ionization from Dalgarno+

- Escape fraction of UV photons 5%-20%

- Number of photon packets per source 1d3-1d6

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Eide+ in prep

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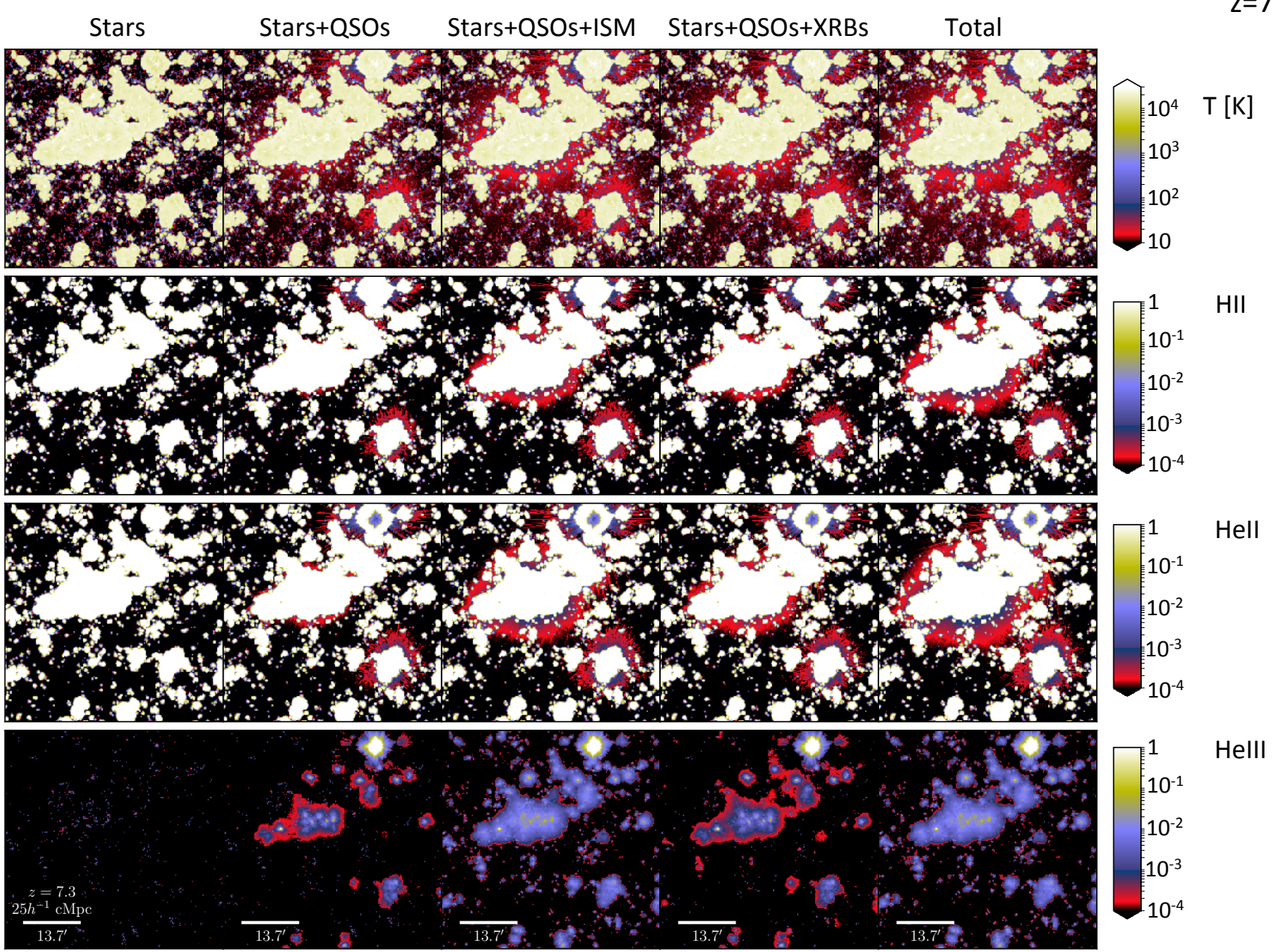
QUALITATIVE ESTIMATES



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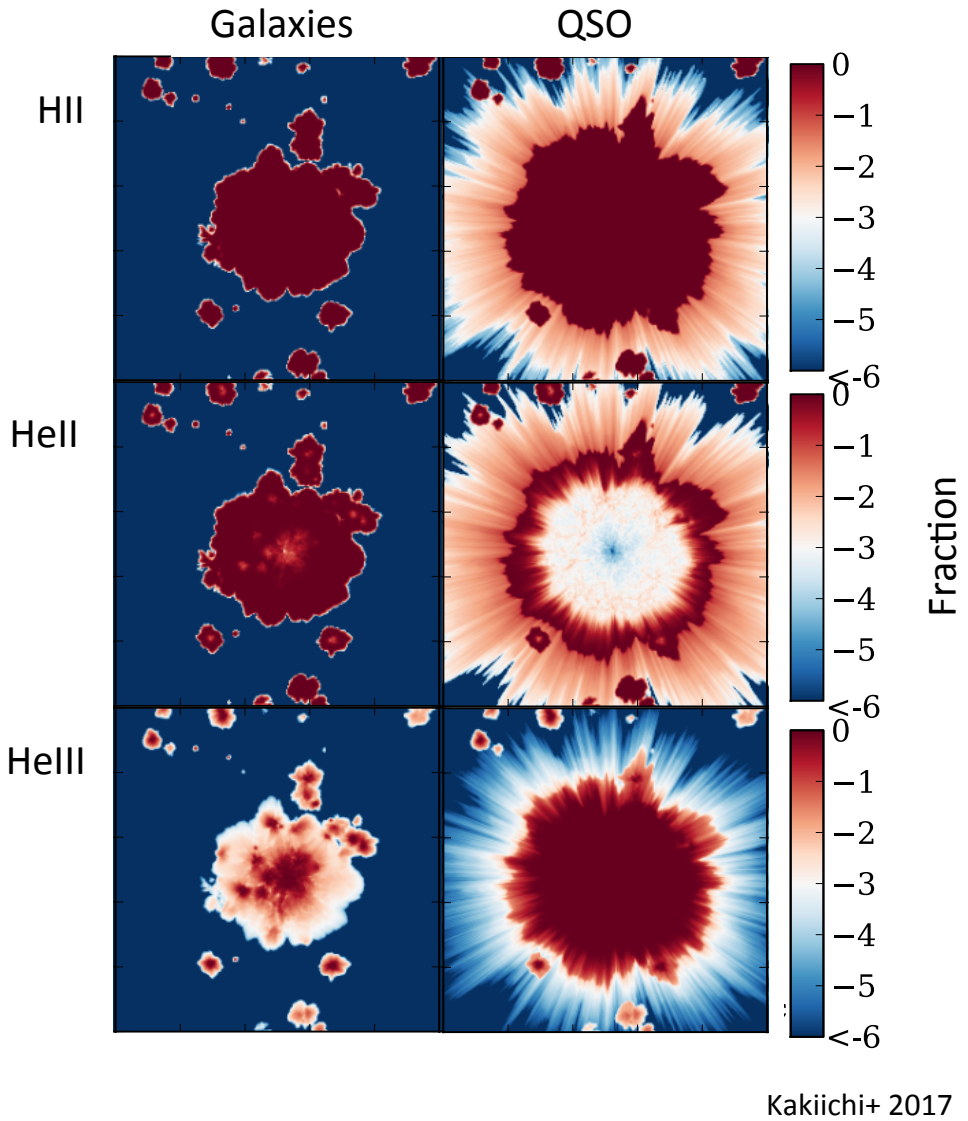
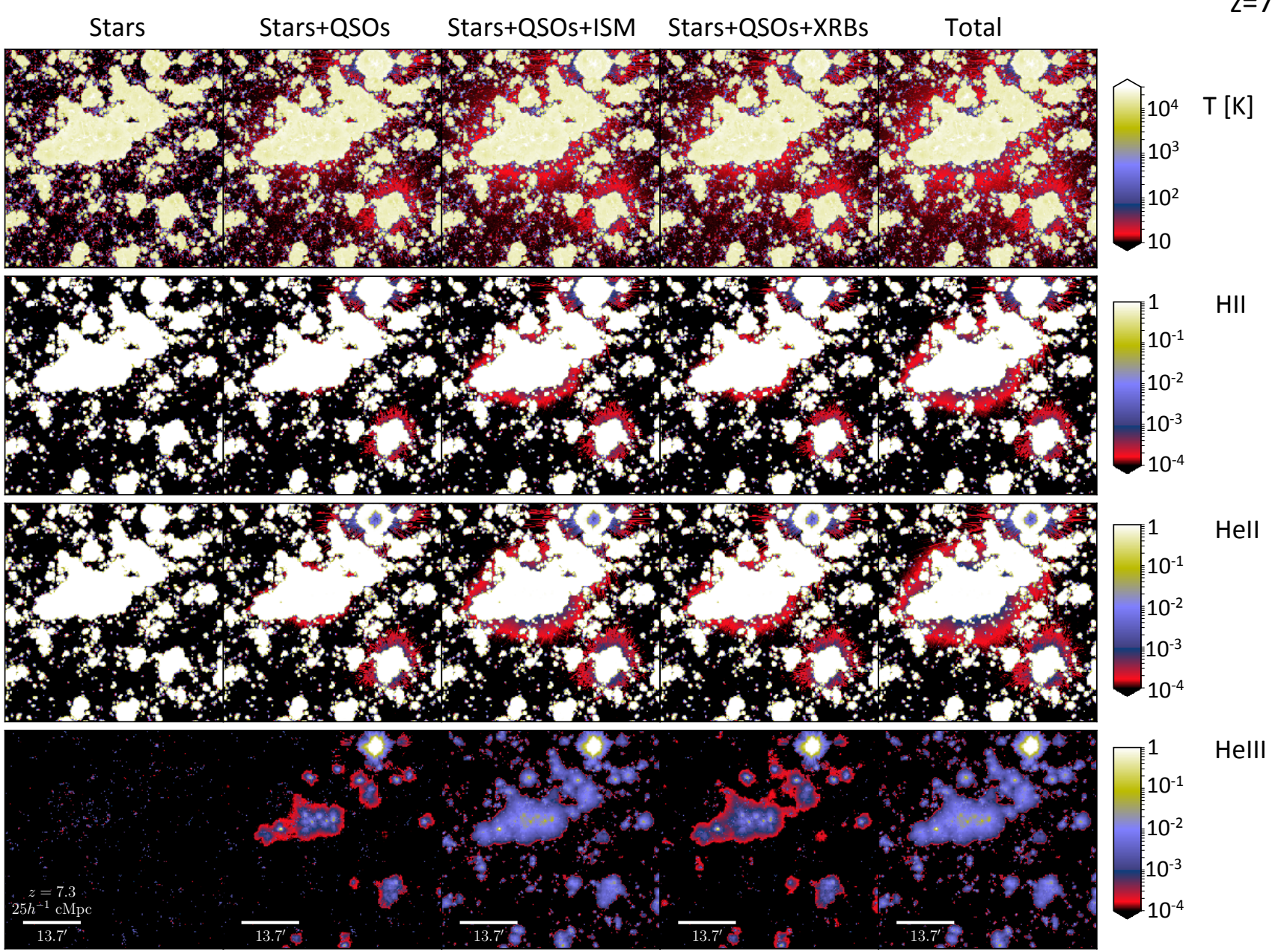


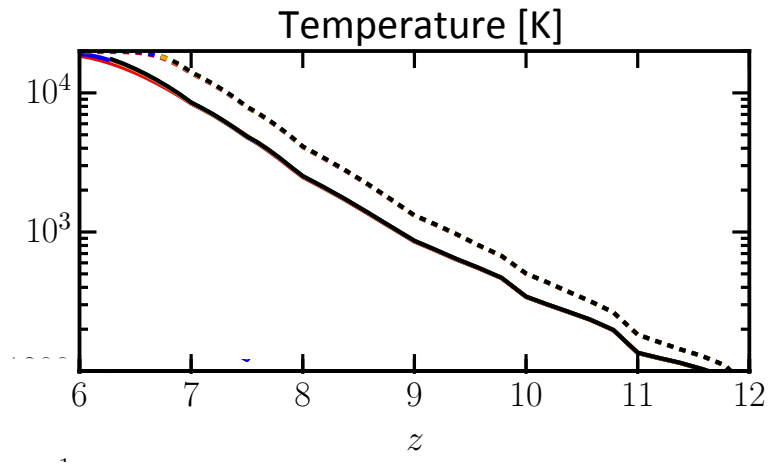
10^8 -10^9 photon packets

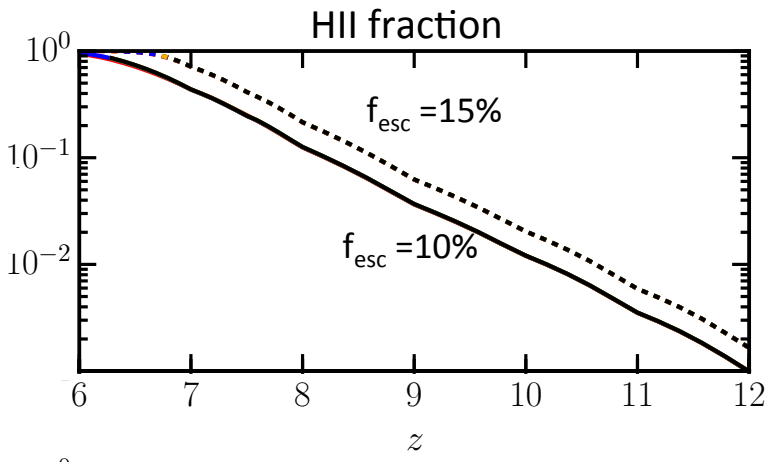
Kakiichi+ 2017

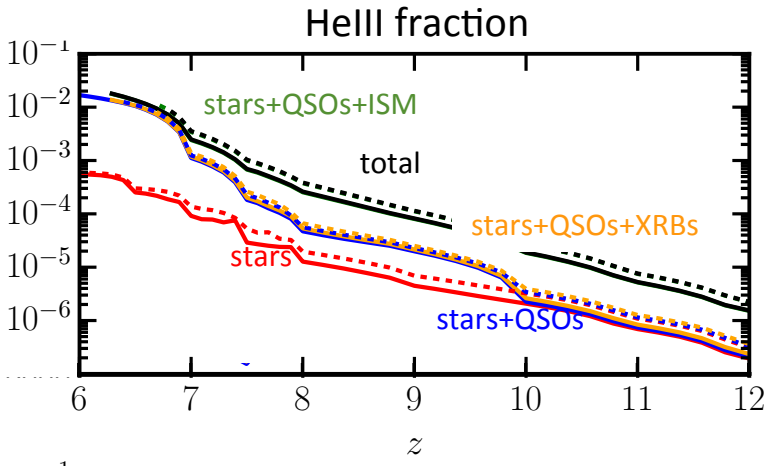
QUALITATIVE ESTIMATES

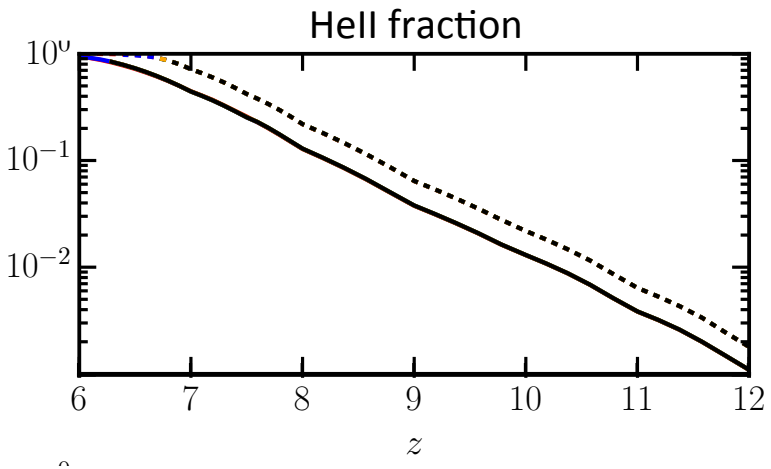


AVERAGE QUANTITIES









Conclusions

- ✧ Physics rich simulations of structure formation with large boxes and high resolution
- ✧ Better understanding of source properties
- ✧ Accurate radiative transfer