Lumina:
The first self-consistent simulation of hydrogen and helium reionization

Oliver Zier (CfA)

CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

MAX-PLANCK-INSTITUT
FÜR ASTROPHYSIK

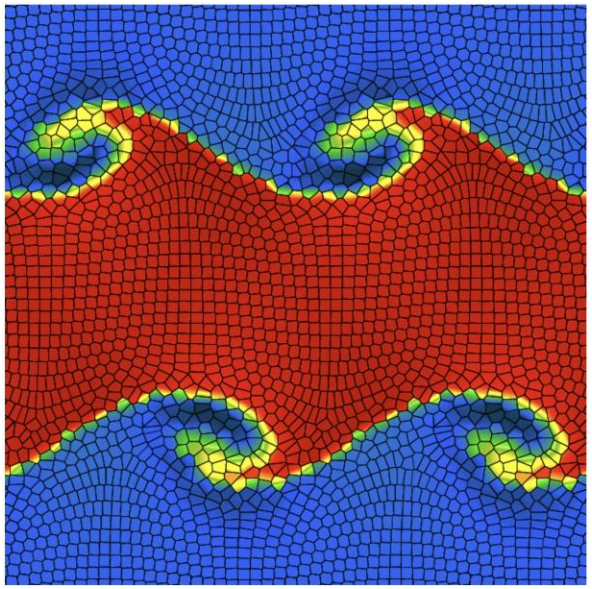
Massachusetts Institute of Technology

OAK RIDGE National Laboratory | LEADERSHIP COMPUTING FACILITY

THE UNIVERSITY OF TEXAS AT DALLAS

YORK UNIVERSITÉ UNIVERSITY

The Lumina model



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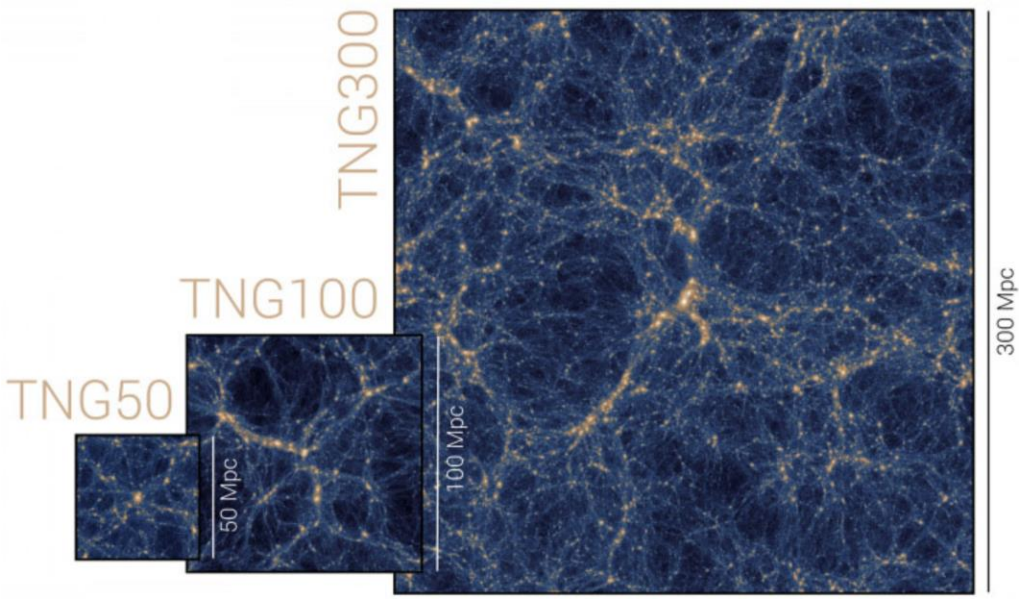

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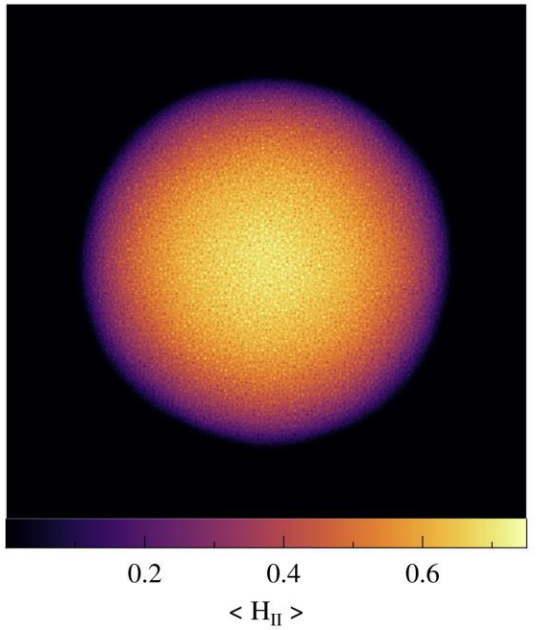


AREPO code
(Springel 2009)

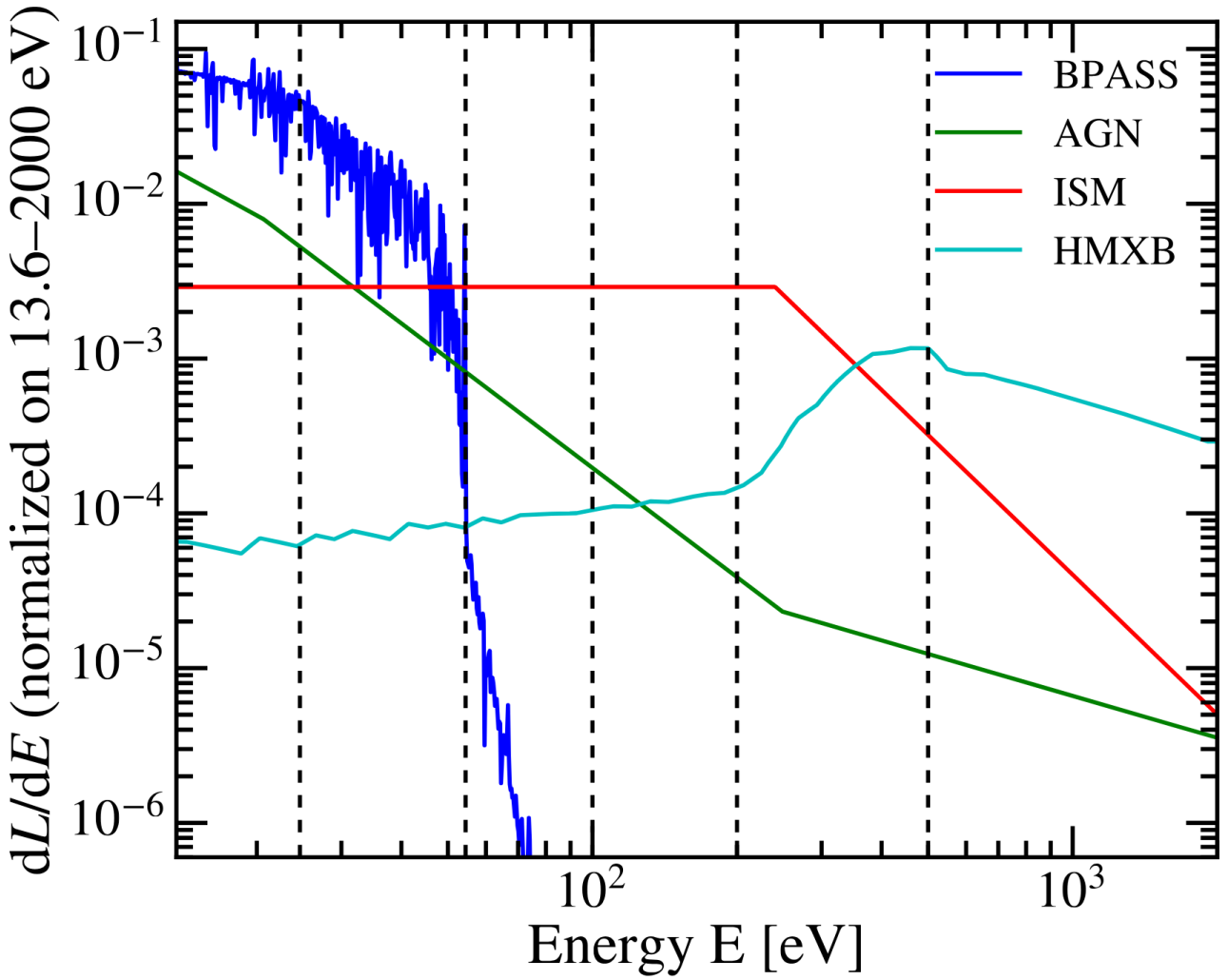
Illustris TNG model
(Pillepich et al. 2018,
Weinberger et al. 2016)

GPU accelerated RT
(Kannan et al. 2018,
Zier et al. 2024)

Radiation sources

Stars
BPASS v2.2.1
f_{esc} = 18%

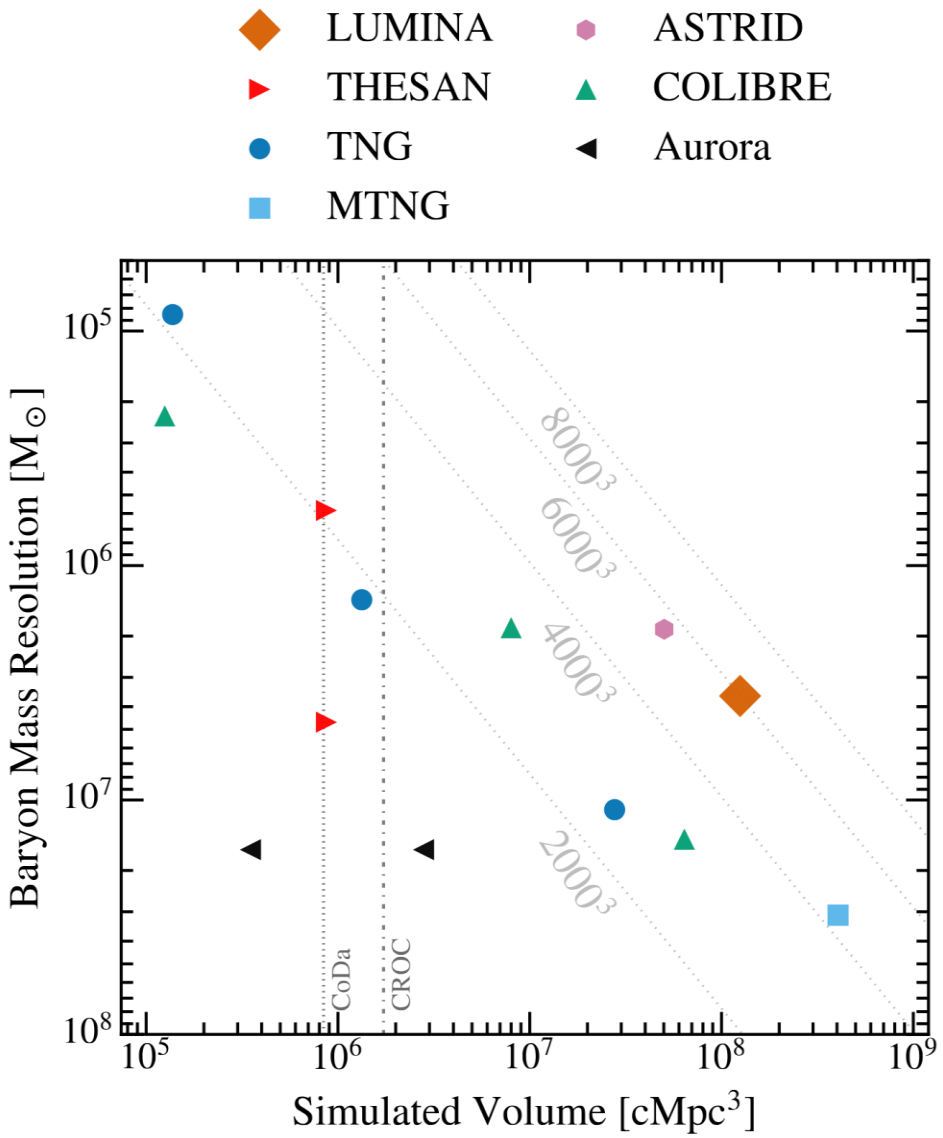
Shock heated ISM
T = 240eV



Black holes
Shen et al. (2020)
ε_{rad} = 20%

HMXB
Fragos et al. (2013)

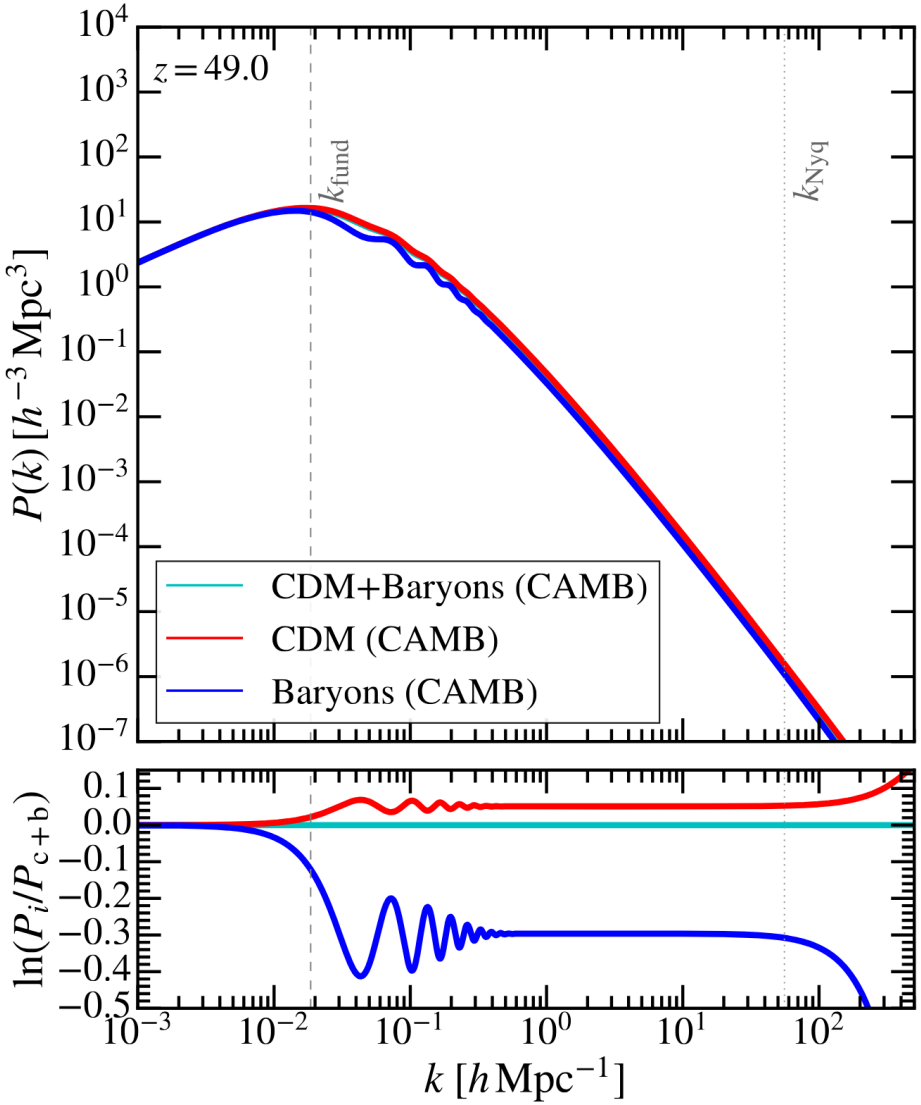
The Lumina simulation



Run	Boxsize		N_{gas}	N_{dm}	m_b	m_{dm}	ϵ	$\epsilon_{gas,min}$	z_{final}
	(h^{-1} cMpc)	(cMpc)			($M_\odot$)	($M_\odot$)	[ckpc]	[ckpc]	
LUMINA	338.3	500	6000^3	6000^3	3.6×10^6	1.9×10^7	1.77	0.44	3
DM-3000	338.3	500	0	3000^3	–	1.8×10^8	1.77	–	0
DM-1500	338.3	500	0	1500^3	–	1.4×10^9	1.77	–	0
Reference simulations									
THESAN-1	64.7	95.5	2100^3	2100^3	5.8×10^5	3.1×10^6	2.2	2.2	5.5
THESAN-2	64.7	95.5	1050^3	1050^3	4.7×10^6	2.5×10^7	4.4	4.4	5.5
TNG100	75	110	1820^3	1820^3	1.4×10^6	7.5×10^6	0.74	0.19	0
MTNG	500	740	4320^3	4320^3	3.1×10^7	1.7×10^8	3.7	0.37	0

Largest galaxy formation simulation (and RT)

Self-consistent initial conditions

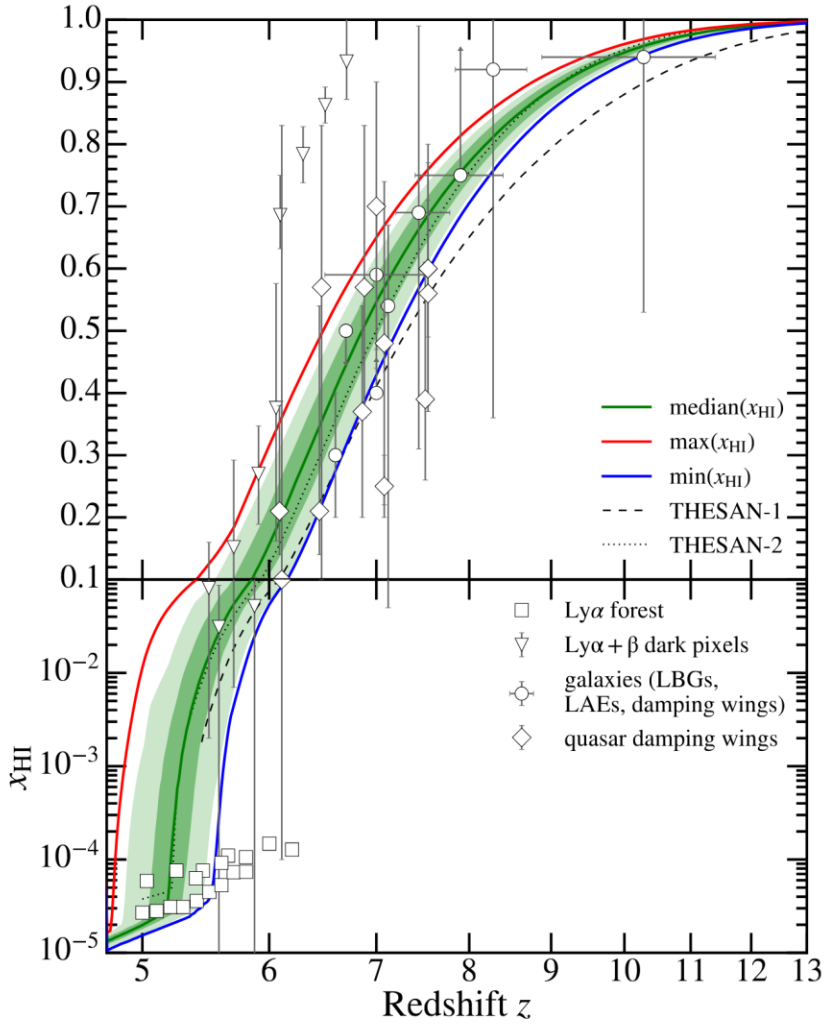


2nd order LPT for both transfer functions
2nd order LPT for relative streaming velocity
Including neutrino/radiation background in Hubble rate

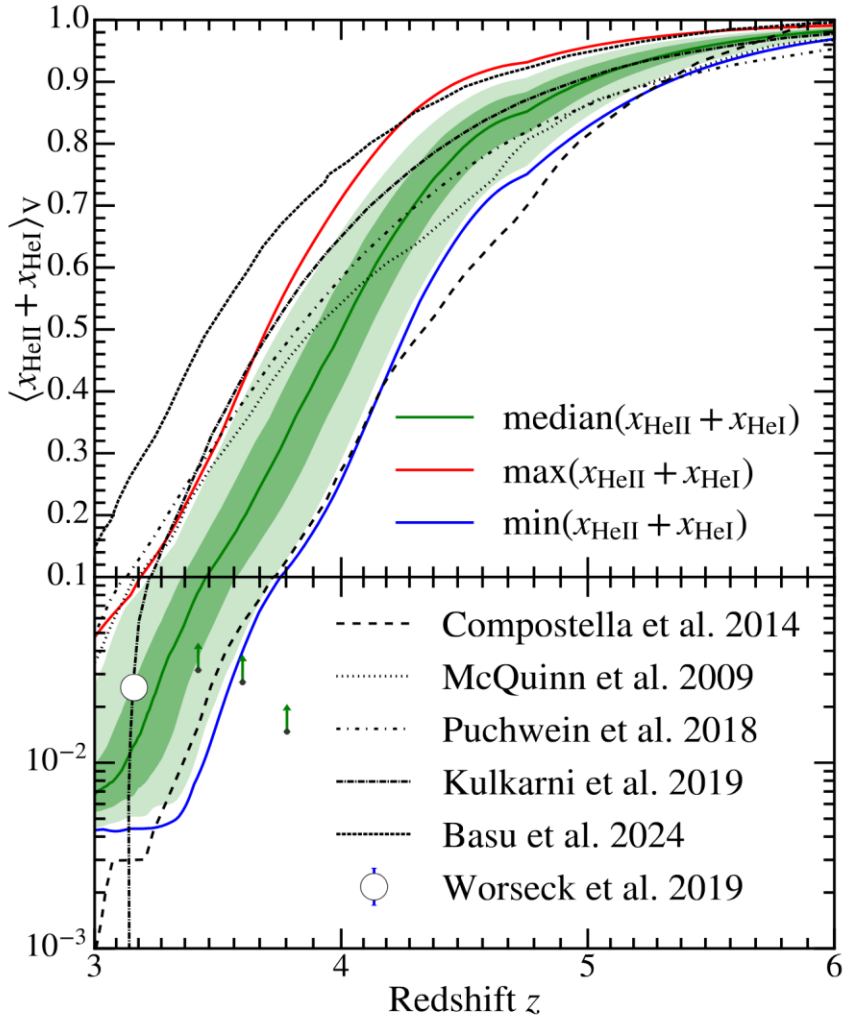
Essential for early galaxy formation

Zier et al. (2026, in prep.)

Reionisation history



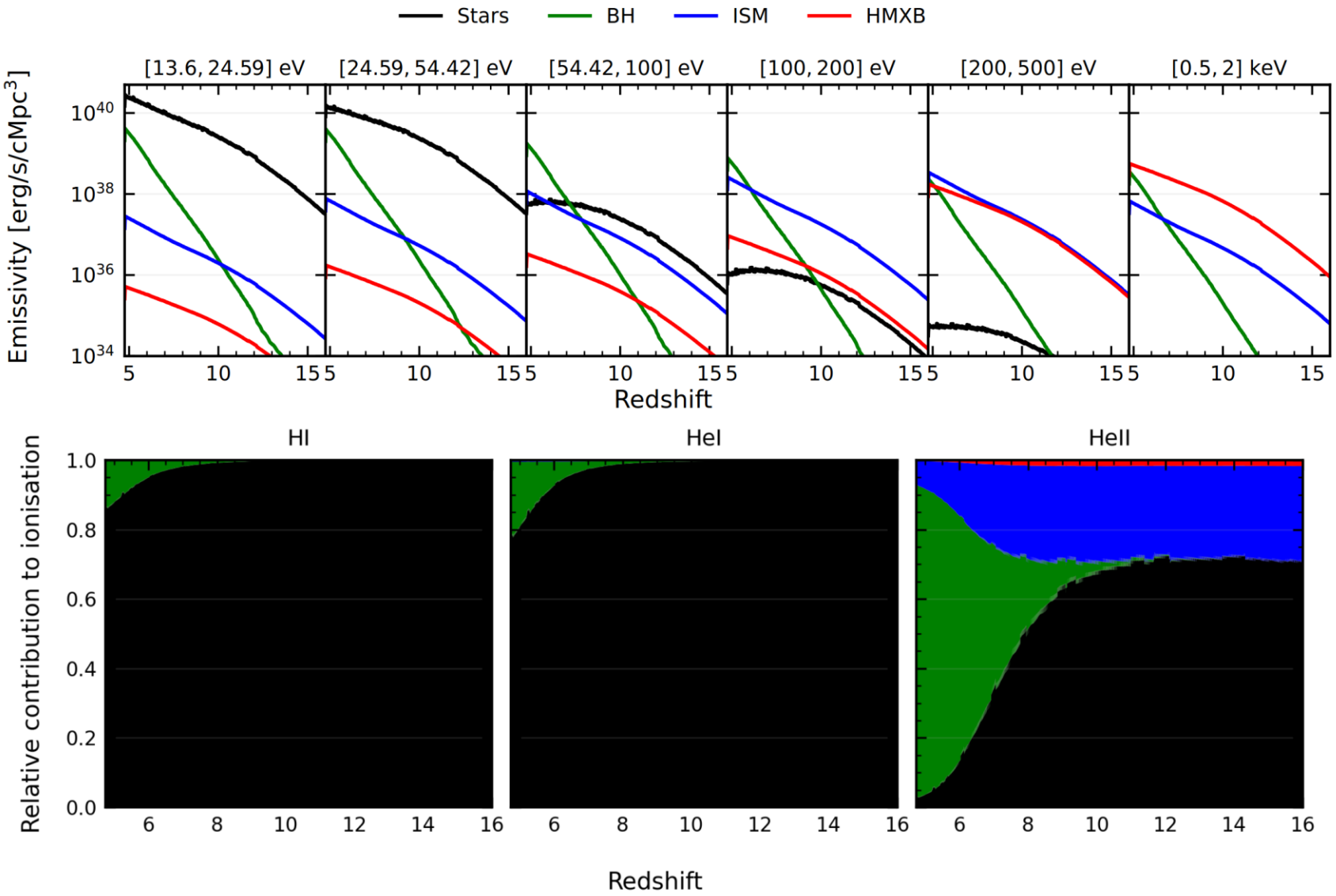
Split into 125 subboxes with L = 100cMpc



Calibrated with f_{esc}

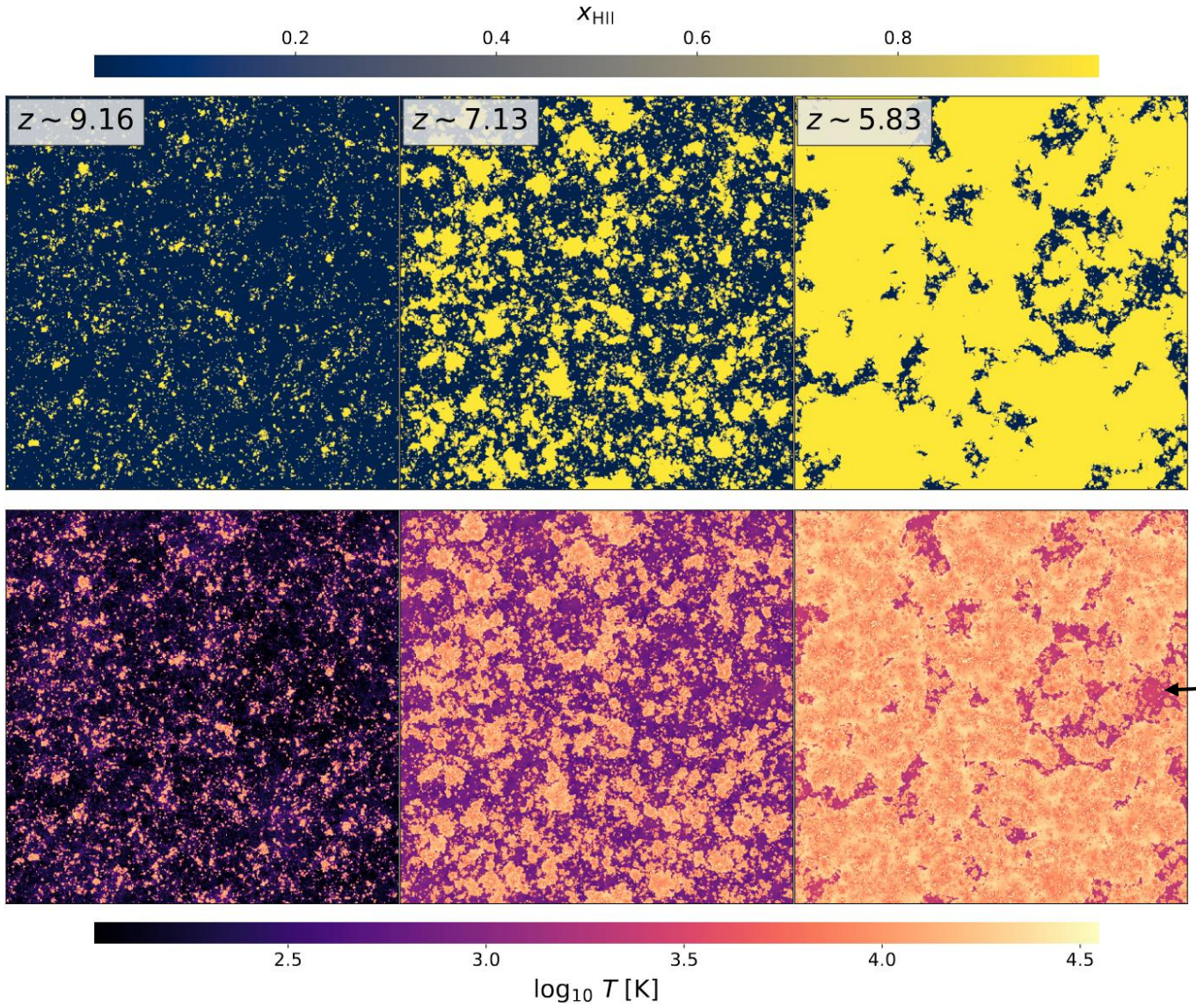
No calibration!

Driver of HI reionisation



Stars drive HI + HeI reionisation
AGN drive HeII reionisation ($z < 7$)
ISM + HMXB dominate Xrays

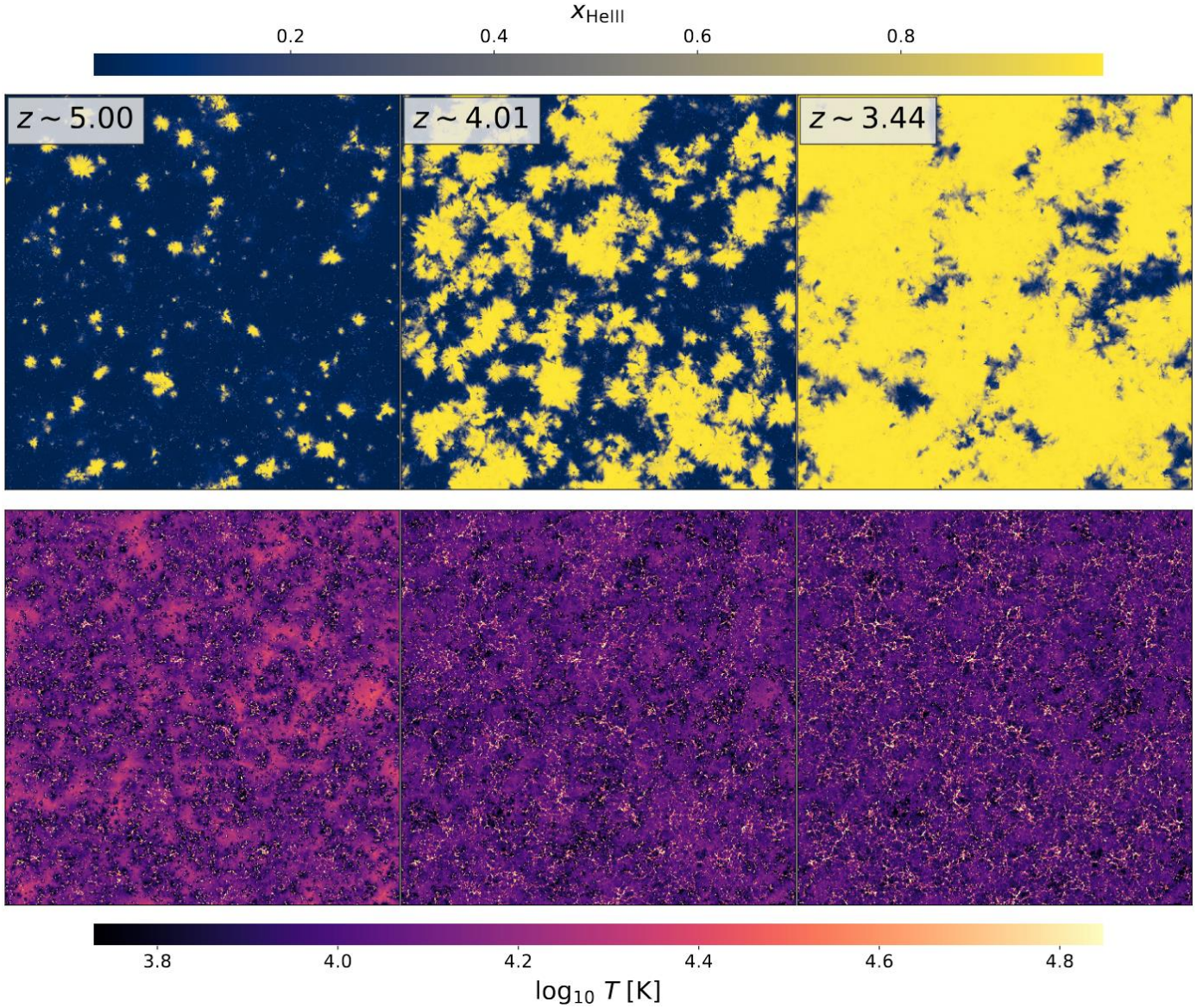
Hydrogen reionisation



Driven by small, overlapping bubbles

Preheating of IGM by X-rays

HeII reionisation

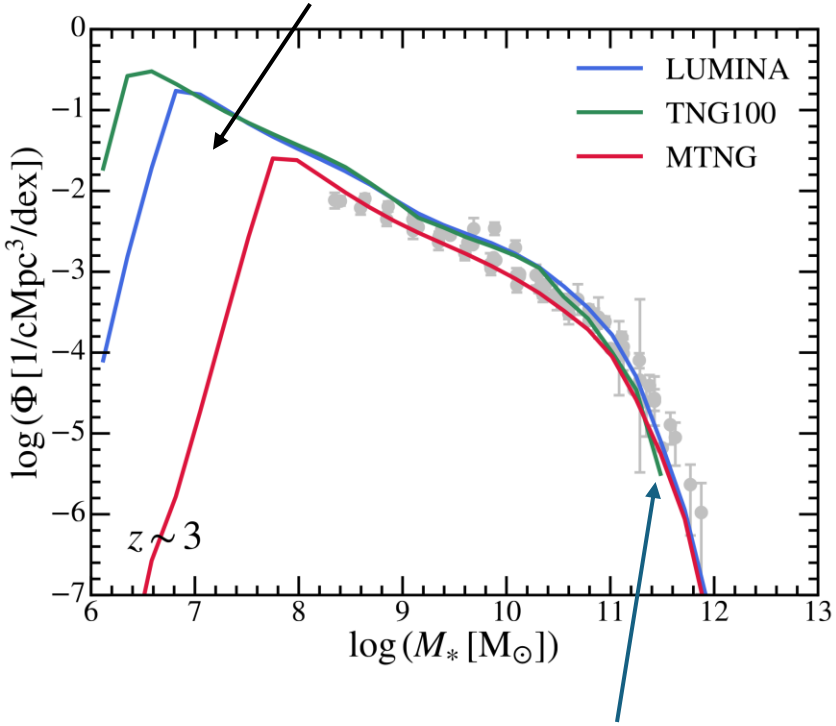


Driven by large bubbles

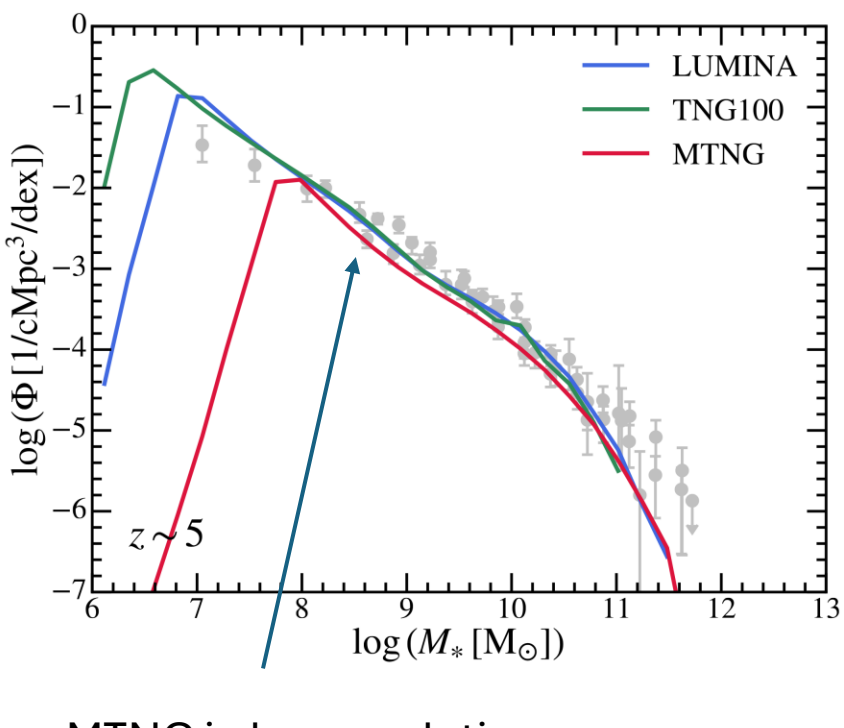
Competition: adiabatic cooling + HeII photoheating

Stellar mass function

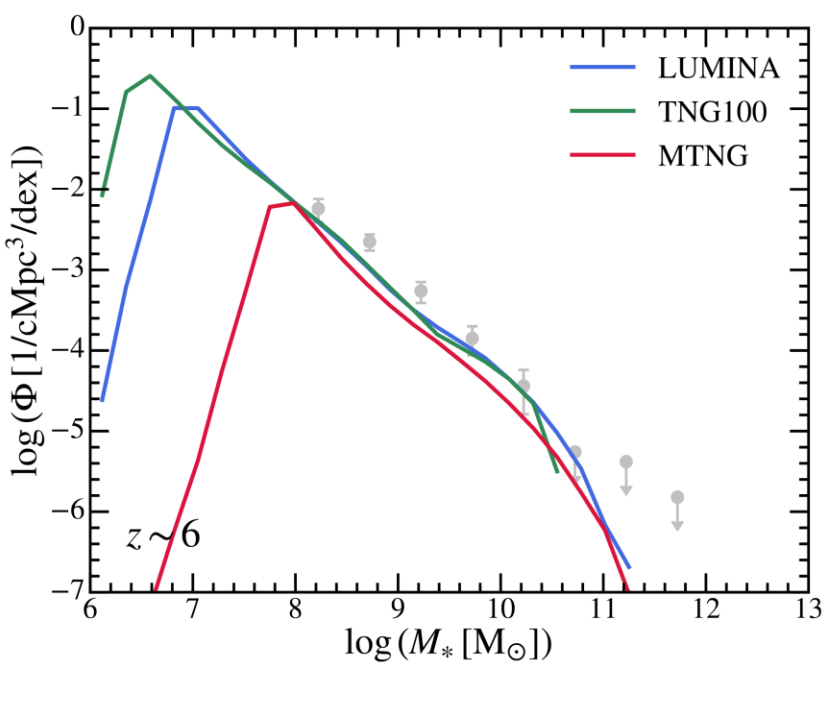
Resolution effect



Box size dependent

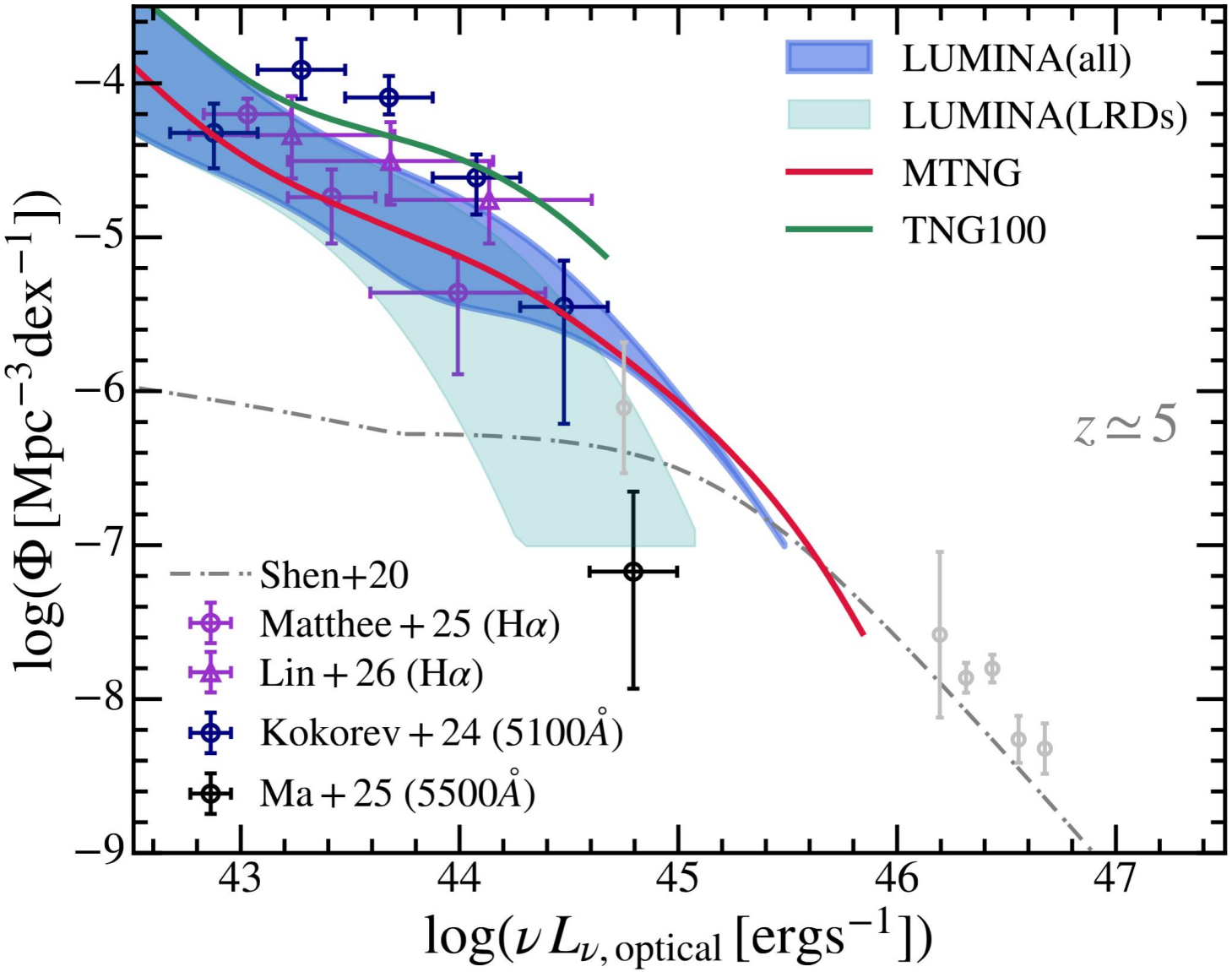


MTNG is low resolution



Perfect agreement with
TNG galaxies

AGN luminosity function



Realistic sources for HeII reionisation

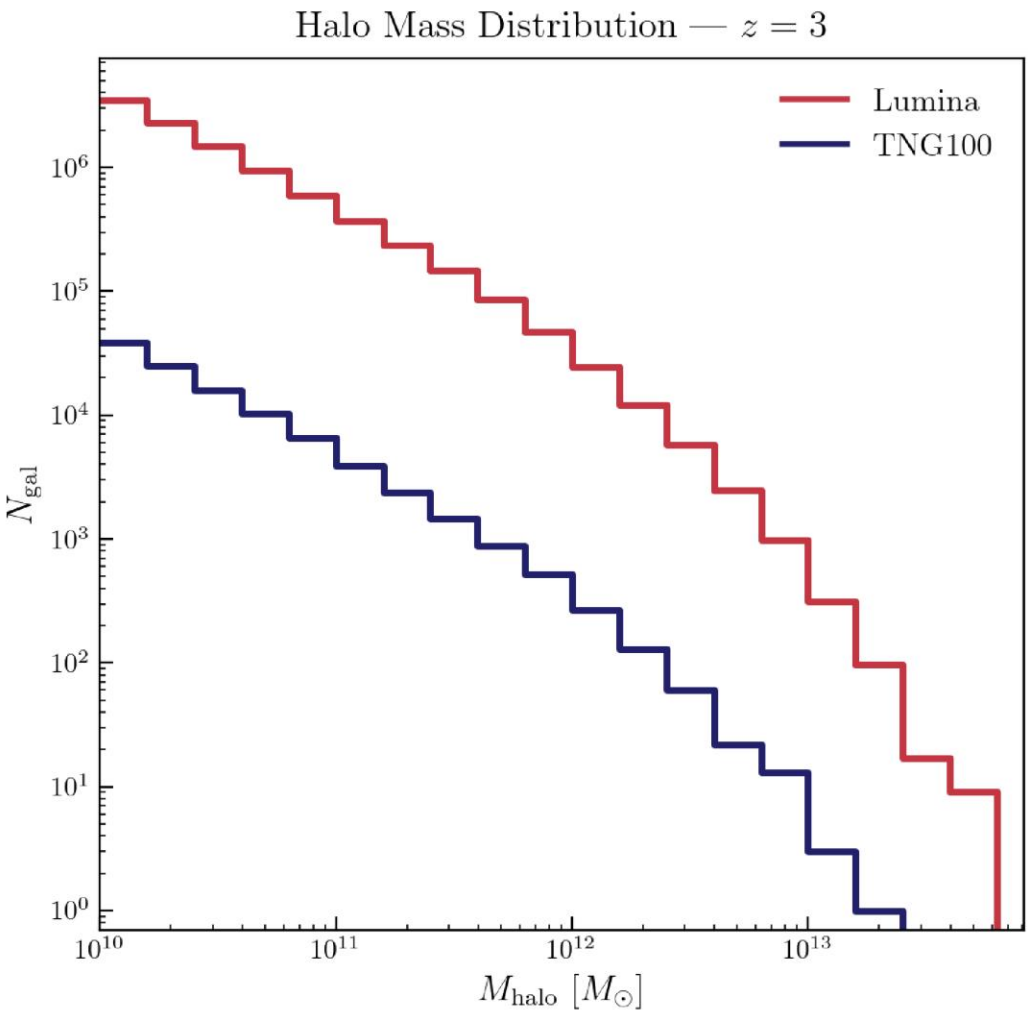
2,000,000 SMBH at z = 3

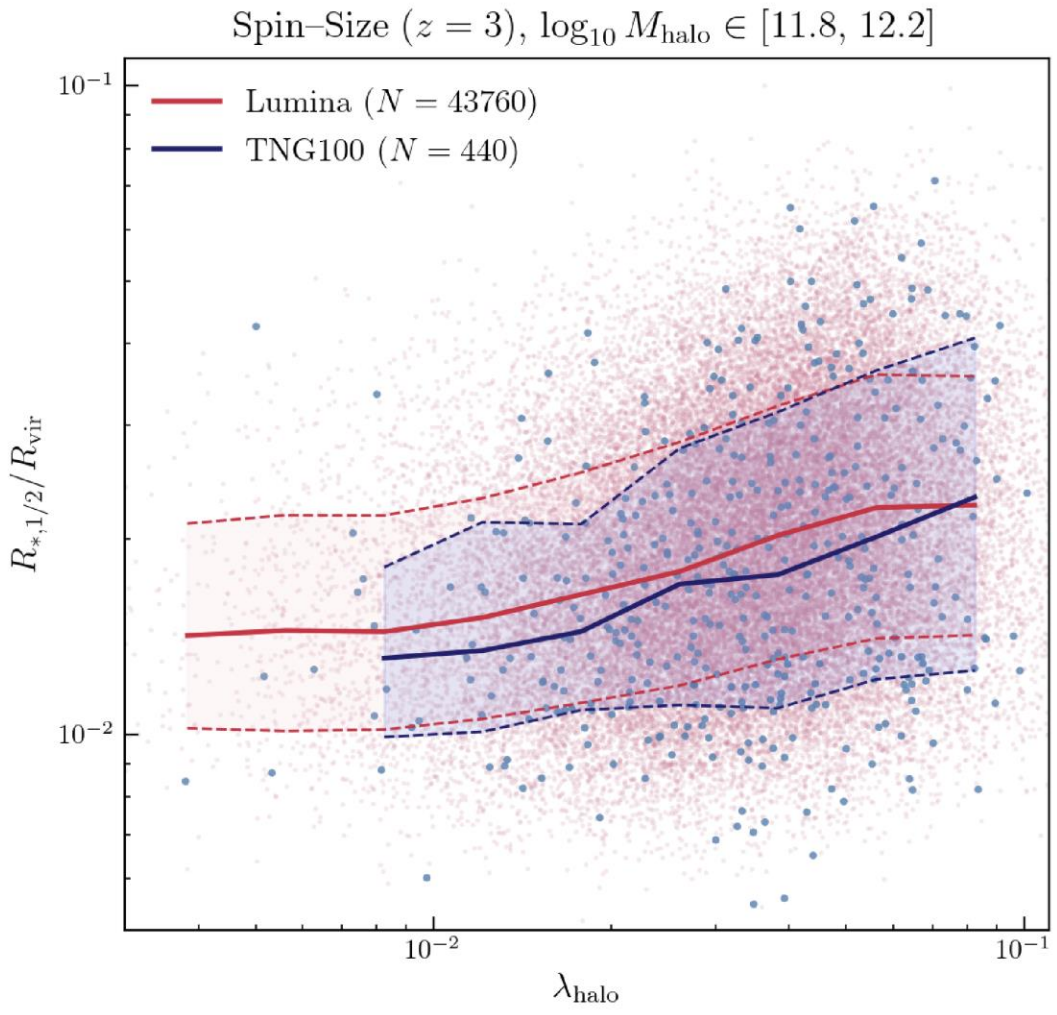
Different bands:



Jacob Shen (MIT)

Galaxy morphology

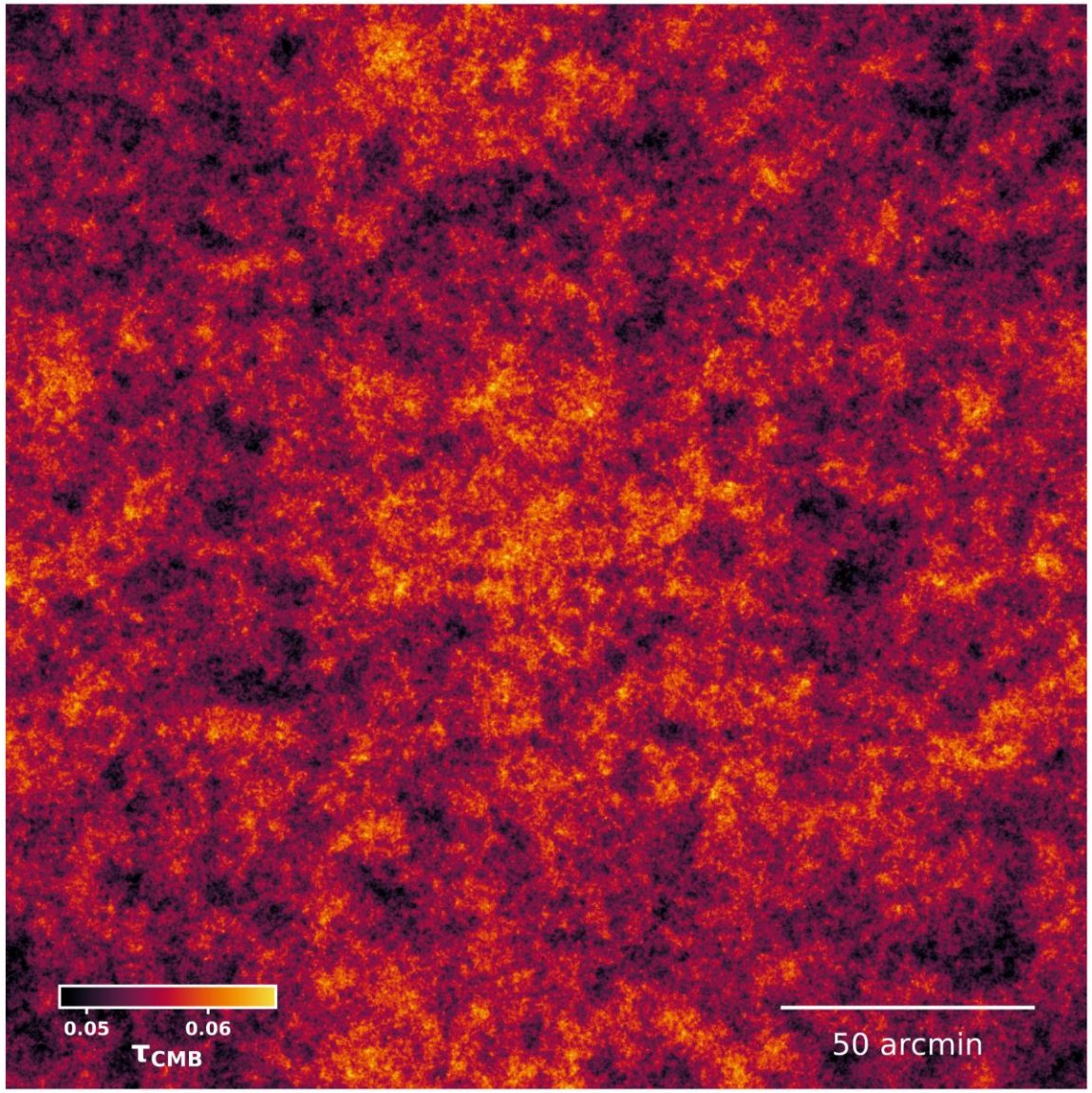


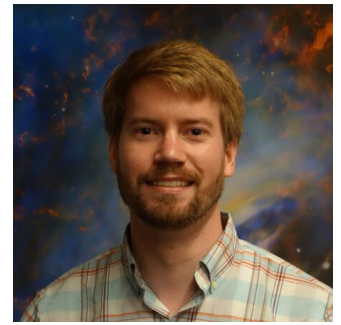




Rongrong Liu
(CfA)

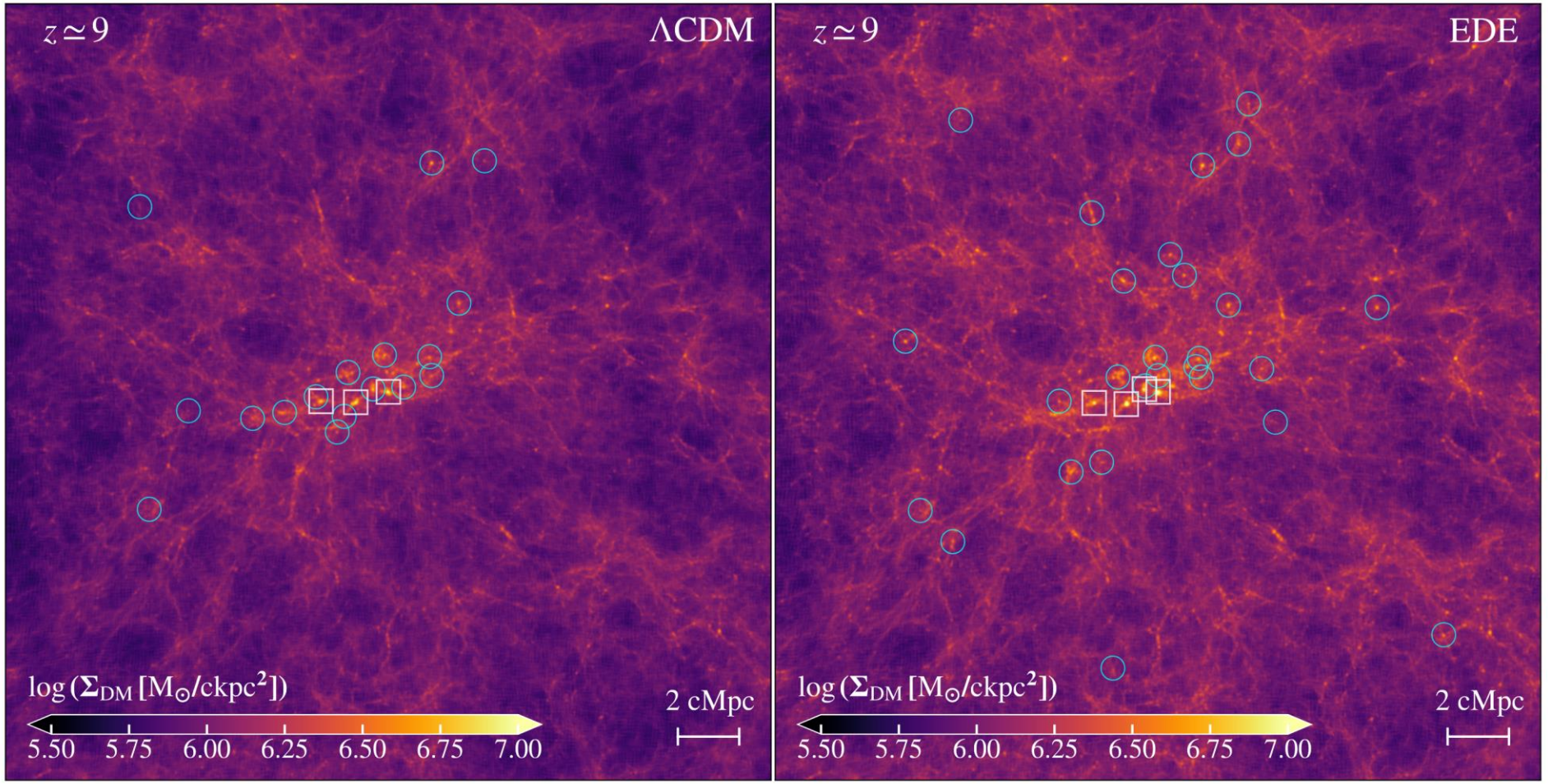
Variance of optical depth





Aaron Smith
(UT Dallas)

Outlook: Lumina-EDE



Lumina with EDE, Goals:

- Galaxy clustering
- Quasar clustering
- Topology of reionisation

INCITE 2026 award

Start March 2026

Summary

- Lumina model: TNG + GPU accelerated RT
- Self consistent HI + HeII reionisation
- Improved initial conditions
- To z = 3
- Equivalent early dark energy run available

