Simulating the EOR with self-consistent growth of galaxies

Master's thesis presentation

ETH Zürich, University of Zürich

Simulating the Epoch of Reionization

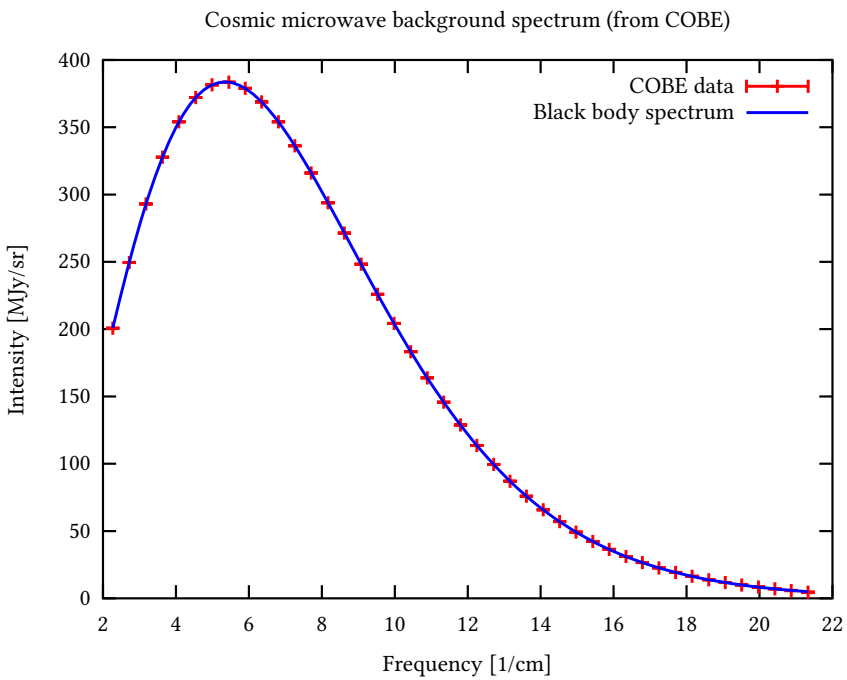
- The Epoch of Reionization
- The 21cm signal
- The halo model of reionization
- The current state of simulations
- `BEoRN`

The Epoch of Reionization

- Marks the universe's last major phase transition: from neutral to ionized hydrogen.
- Shapes the large-scale structure of the intergalactic medium (IGM).
- Is strongly linked to the formation and growth of the first galaxies and black holes.
- Sets the stage for many observables: CMB secondary anisotropies, 21-cm signal, high-z galaxy surveys.

The 21cm signal

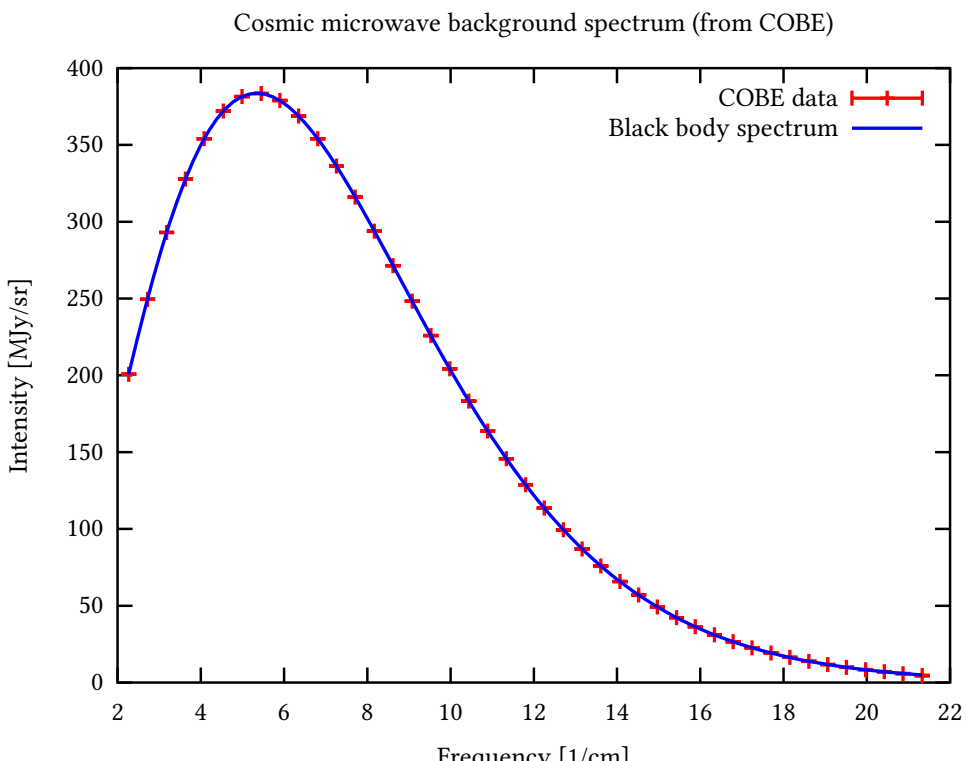
The brigthtness temperature describes the difference between the CMB temperature and the spin temperature of neutral hydrogen



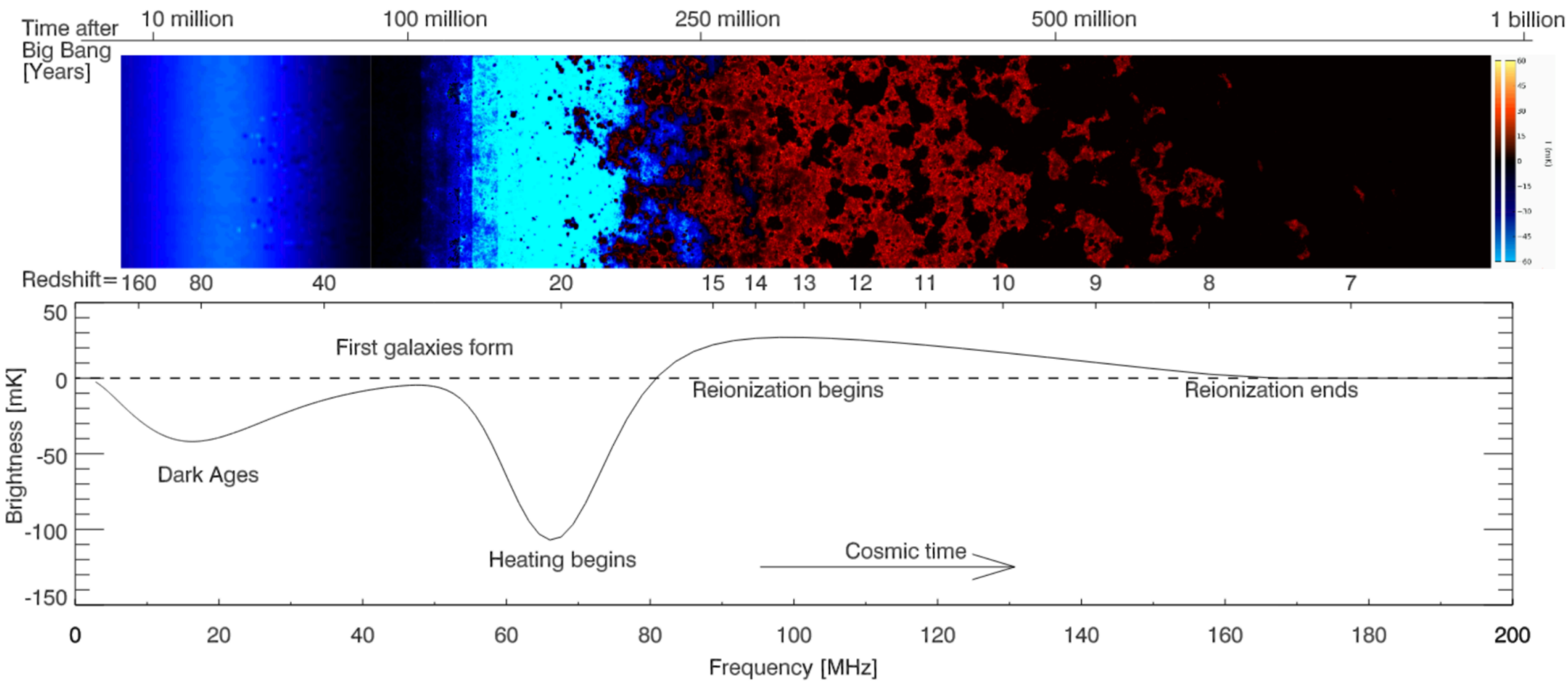
[1]

The 21cm signal

Removing the contribution from the black body spectrum of the CMB yields the explicit 21-cm signal:



The 21cm signal



The 21cm signal

[2]

The 21cm signal

$$dT_{\rm b}(\boldsymbol{x}, z) \simeq T_0(z) \cdot x_{\rm HI}(\boldsymbol{x}, z) \cdot (1 + \delta_b(\boldsymbol{x}, z)) \cdot \frac{x_\alpha(\boldsymbol{x}, z)}{1 + x_\alpha(\boldsymbol{x}, z)} \cdot \left(\frac{1 - T_{\rm CMB}(z)}{T_{\rm gas}(\boldsymbol{x}, z)} \right)$$

(e.g [2])

Following [3], [4]:

$$\rho_\alpha(r \mid M, z) = \frac{(1+z)^2}{4\pi r^2} \cdot \sum_{n=2}^{n_m} f_n \cdot \varepsilon_\alpha(\nu') \cdot f_\star \cdot \dot{M}(z' \mid M, z)$$

$$\frac{3}{2} \cdot \frac{\mathrm{d}\rho_h(r \mid M, z)}{\mathrm{d}z} = \frac{3\rho_h(r \mid M, z)}{1+z} - \frac{\rho_{\mathrm{xray}}(r \mid M, z)}{k_B(1+z)H(z)}$$

$$x_{\mathrm{HII}}(r \mid M, z) = \theta_{\mathrm{H}}\Big[R_b(M, z) - r\Big]$$

The current state of simulations

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- slow and big
- radiative transfer

$\Longrightarrow$ semi-numerical approaches such as `BEoRN` [5]

validation

Bibliography

[1] "CMB spectrum." [Online]. Available: https://commons.wikimedia.org/wiki/File:Cmbr.svg

[2] J. R. Pritchard and A. Loeb, "21 cm cosmology in the 21st century," *Reports on Progress in Physics*, vol. 75, no. 8, p. 86901, Aug. 2012, doi: 10.1088/0034-4885/75/8/086901.

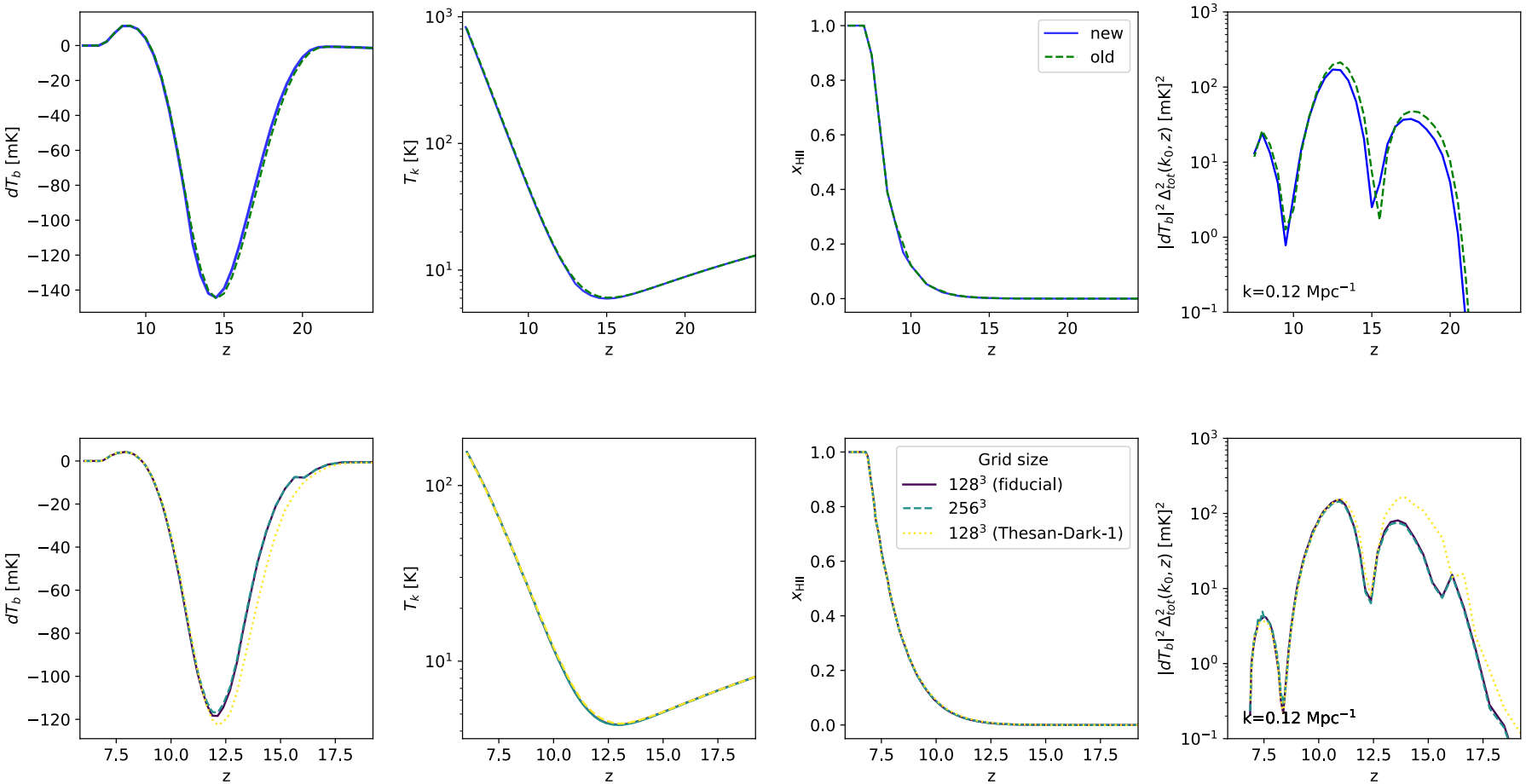
[3] A. Schneider, S. K. Giri, and J. Mirocha, "Halo model approach for the 21-cm power spectrum at cosmic dawn," *Physical Review D*, vol. 103, no. 8, Apr. 2021, doi: 10.1103/physrevd.103.083025.

[4] A. Schneider, T. Schaeffer, and S. K. Giri, "Cosmological forecast of the 21-cm power spectrum using the halo model of reionization." [Online]. Available: https://arxiv.org/abs/2302.06626

Bibliography

[5] T. Schaeffer, S. K. Giri, and A. Schneider, “<scp>beorn</scp>: a fast and flexible framework to simulate the epoch of reionization and cosmic dawn,” *Monthly Notices of the Royal Astronomical Society*, vol. 526, no. 2, pp. 2942–2959, Sep. 2023, doi: 10.1093/mnras/stad2937.

Validation


dT_b [mK]
T_k [K]
x_{HII}
$|dT_b|^2\,\Delta^2_{tot}(k_0, z)$ [mK]^2
z
new
old
k=0.12 Mpc^{-1}
Grid size
128^3 (fiducial)
256^3
128^3 (Thesan-Dark-1)

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Hello

— This works right

This works right

$$E = mc^2$$

This works right

$$E = mc^2$$

$$F = ma$$