Thermal feedback from reionization

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Huub Röttgering

Outline

- Introduction
- Thermal feedback (positive / negative)
- TRAPHIC - radiative transfer for SPH

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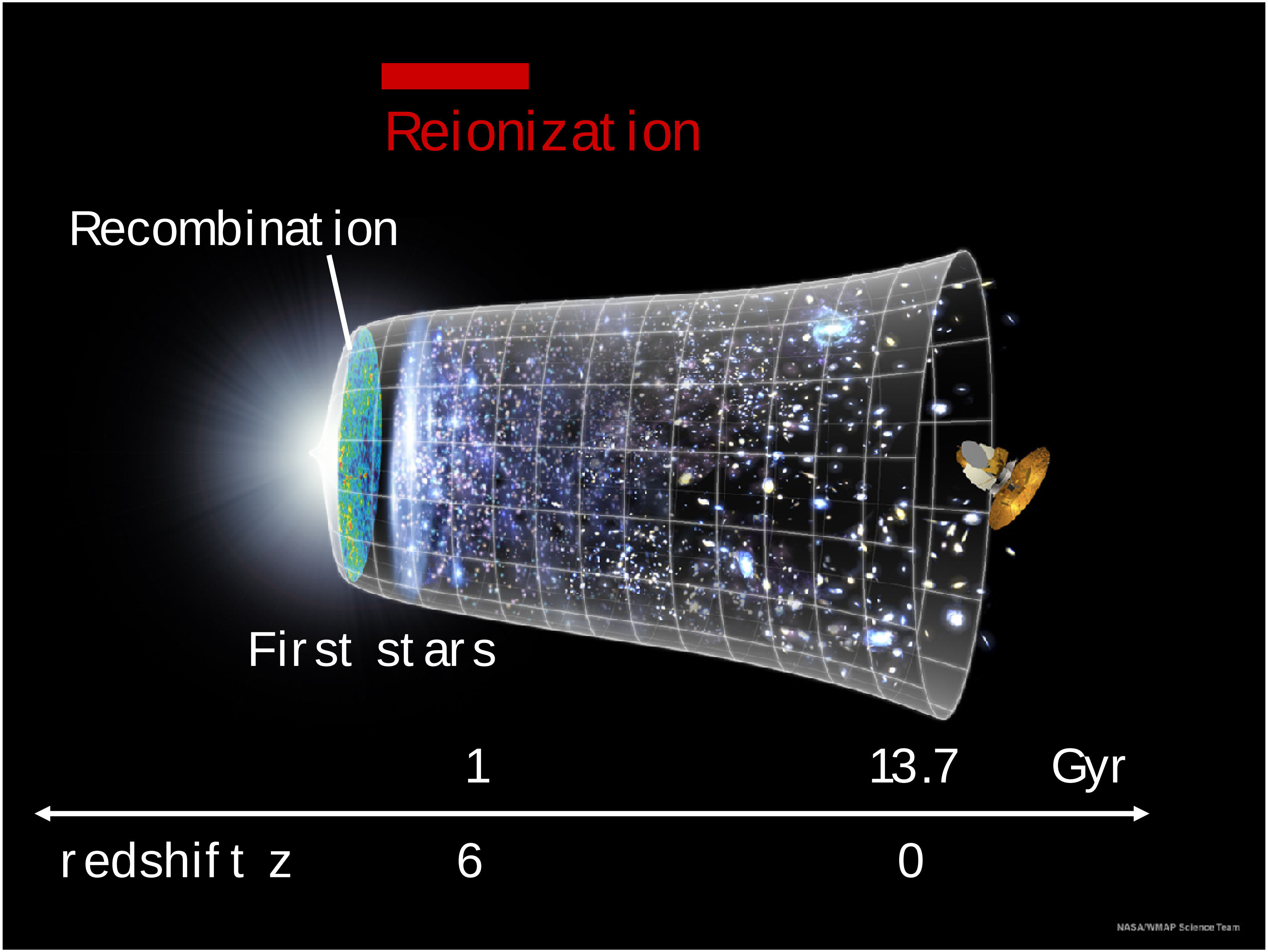
Reionization
Recombination
First stars
1
13.7
Gyr
redshift z
6
0
NASA/WMAP Science Team

Effect of reheating - simulations

- Gadget-2
  (Springel '05)
- Default runs:
  $L = 6.25$ Mpc/h, $N = 2 \times 256^3$
- Star formation (Schaye & Dalla Vecchia '07)
- UV background ($z < 9$)
  (Haardt & Madau '01; cooling tables: Wiersma et al. '08)

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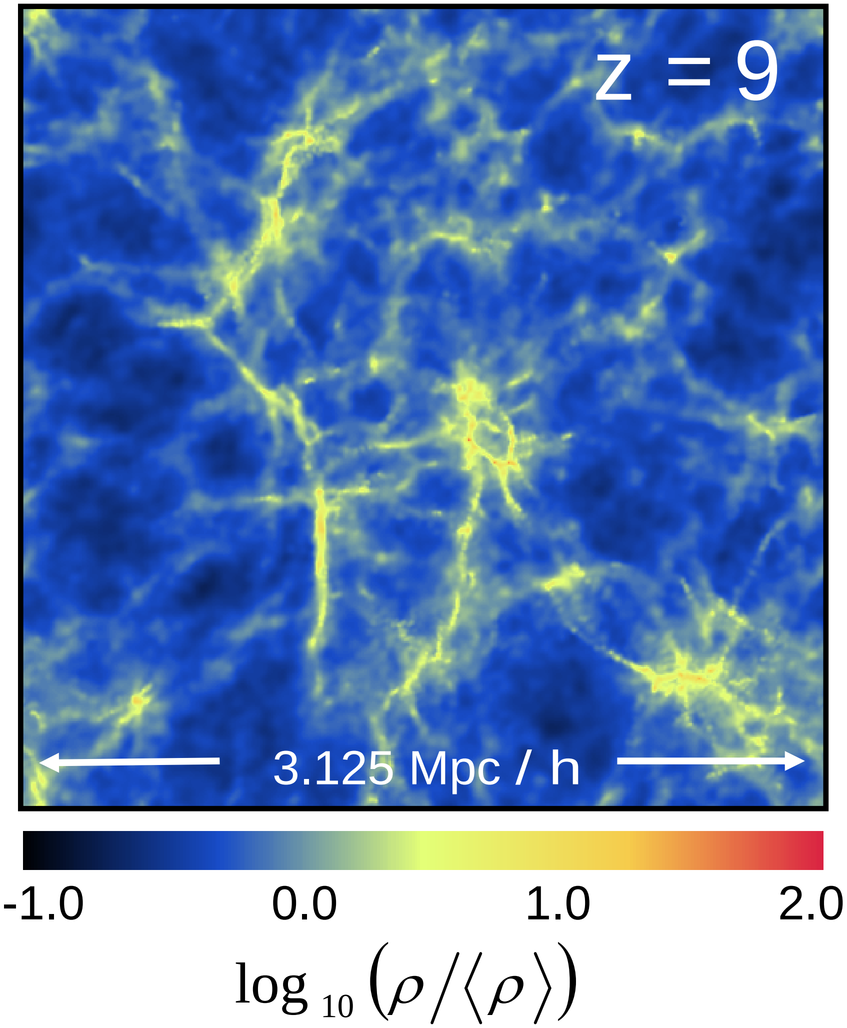
Gas density



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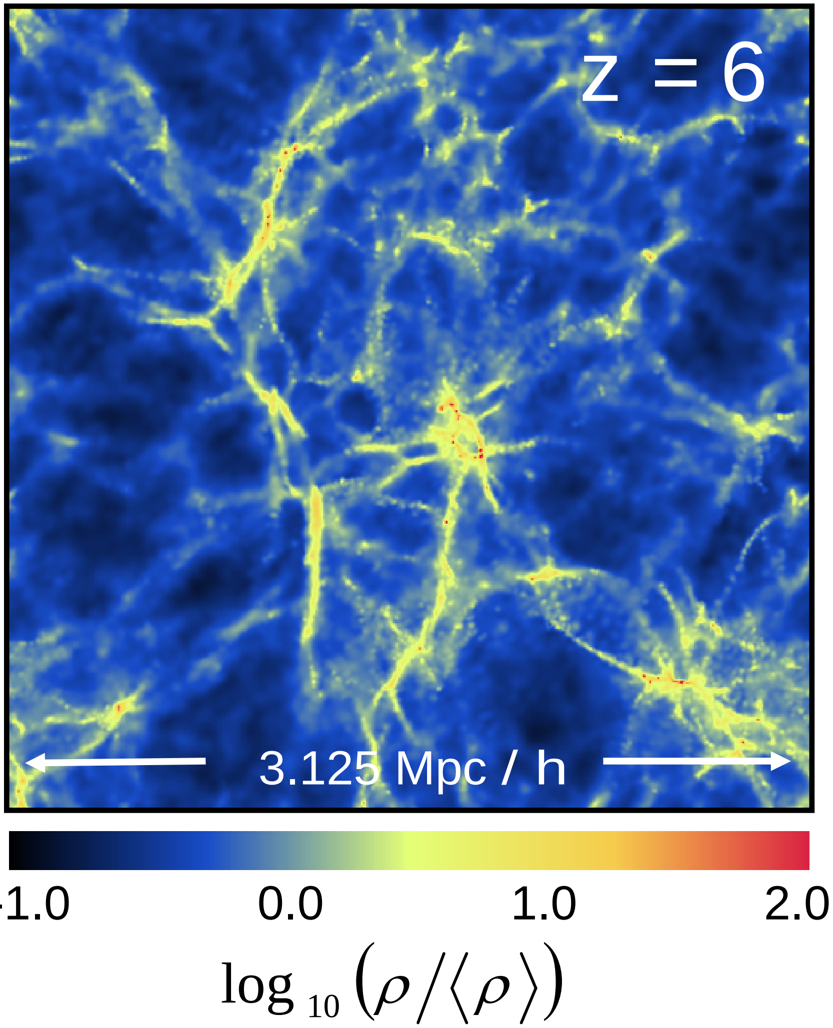
Gas density



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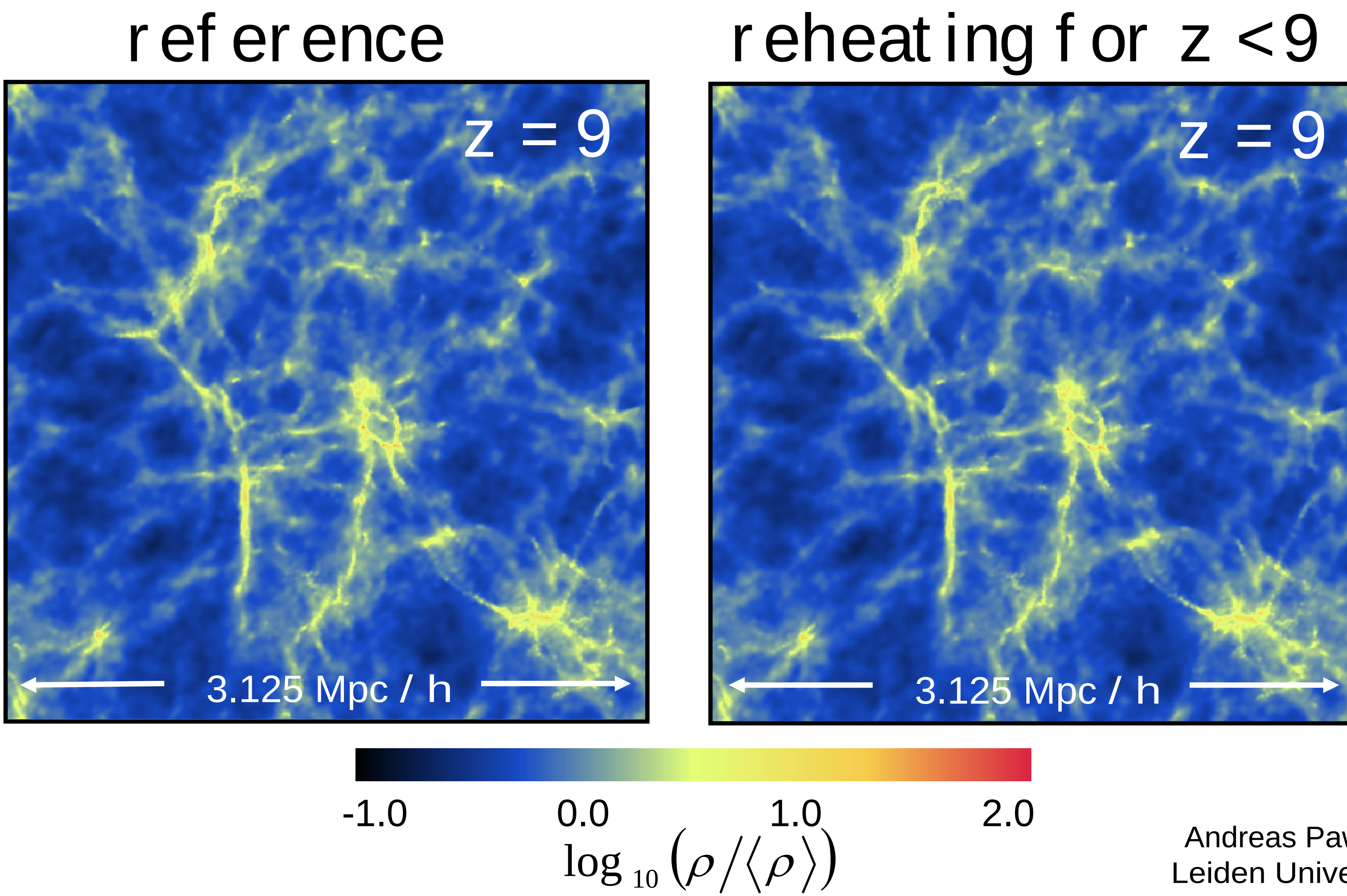
Effect of reheating



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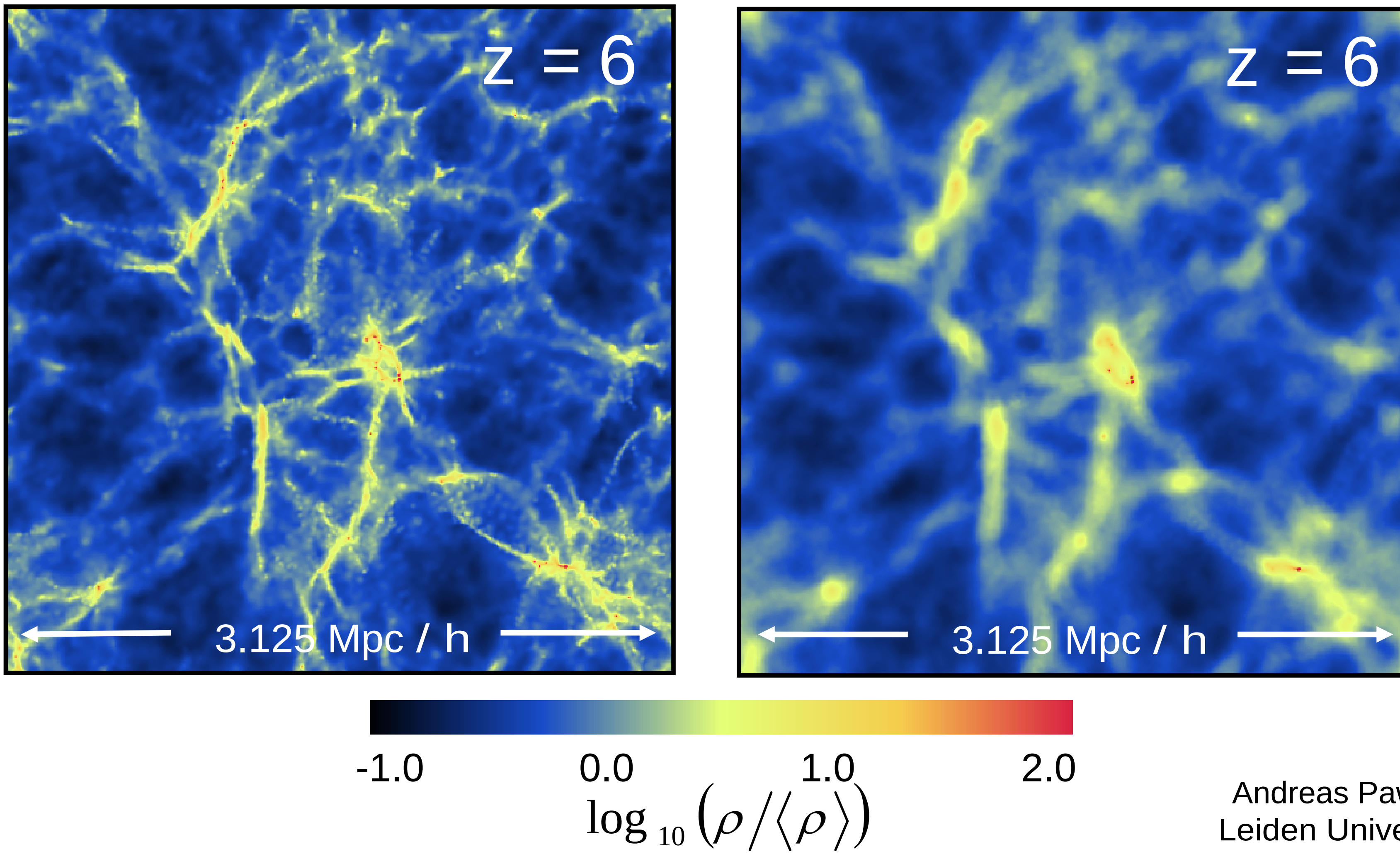
Effect of reheating

reference

reheating for z < 9



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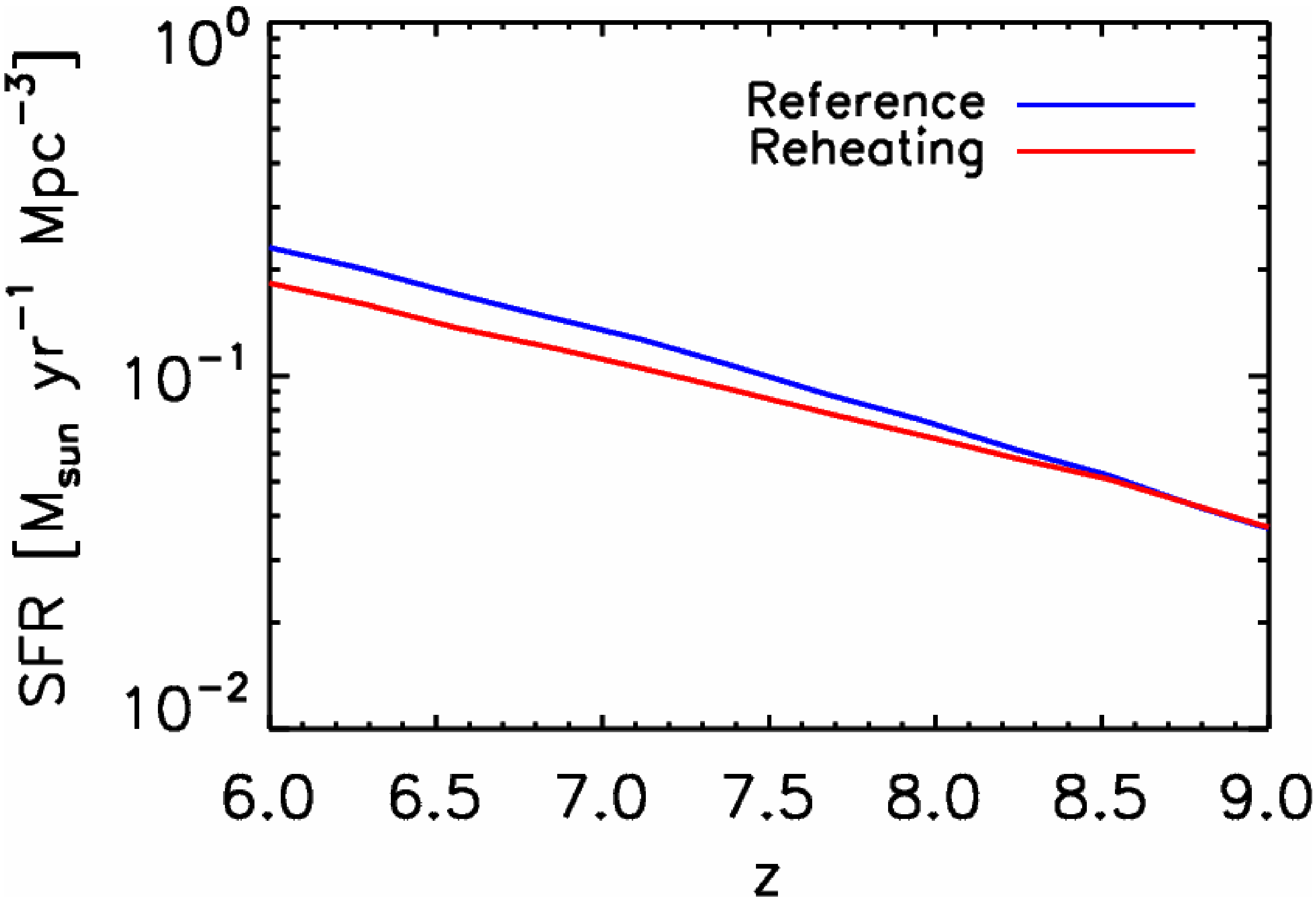
Thermal feedback

- Smoothing of fluctuations
  ->lowering of recombination rate
  ->reduces required star formation rate
  ->positive feedback

AP, J. Schaye & E. van Scherpenzeel (arXiv:0807.3963)

- Photo-evaporation of low-mass halos
  ->reduces star formation rate
  ->negative feedback

Suppression of star formation: reheating



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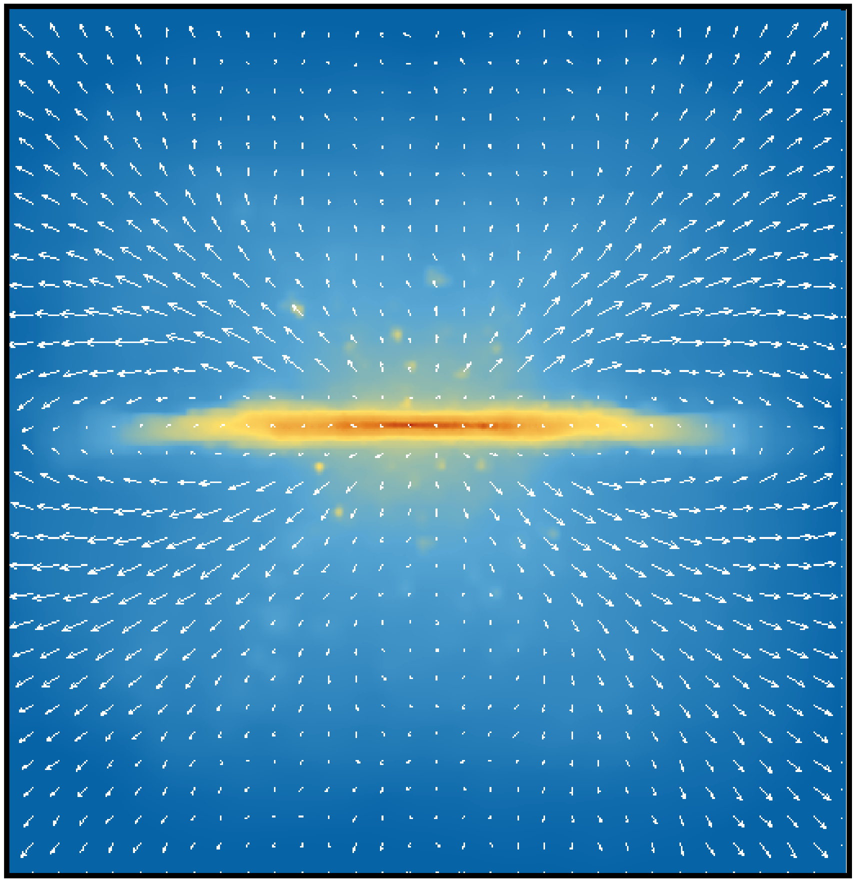
Suppression of star formation: supernova winds



Isolated galaxy, 10^{12} M_{sun}/ h
Dalla Vecchia & Schaye (2008)

- Dalla Vecchia & Schaye (2008)

  (Springel & Hernquist '03)

- v = 600 km s^{-1}
- Mass loading = 2

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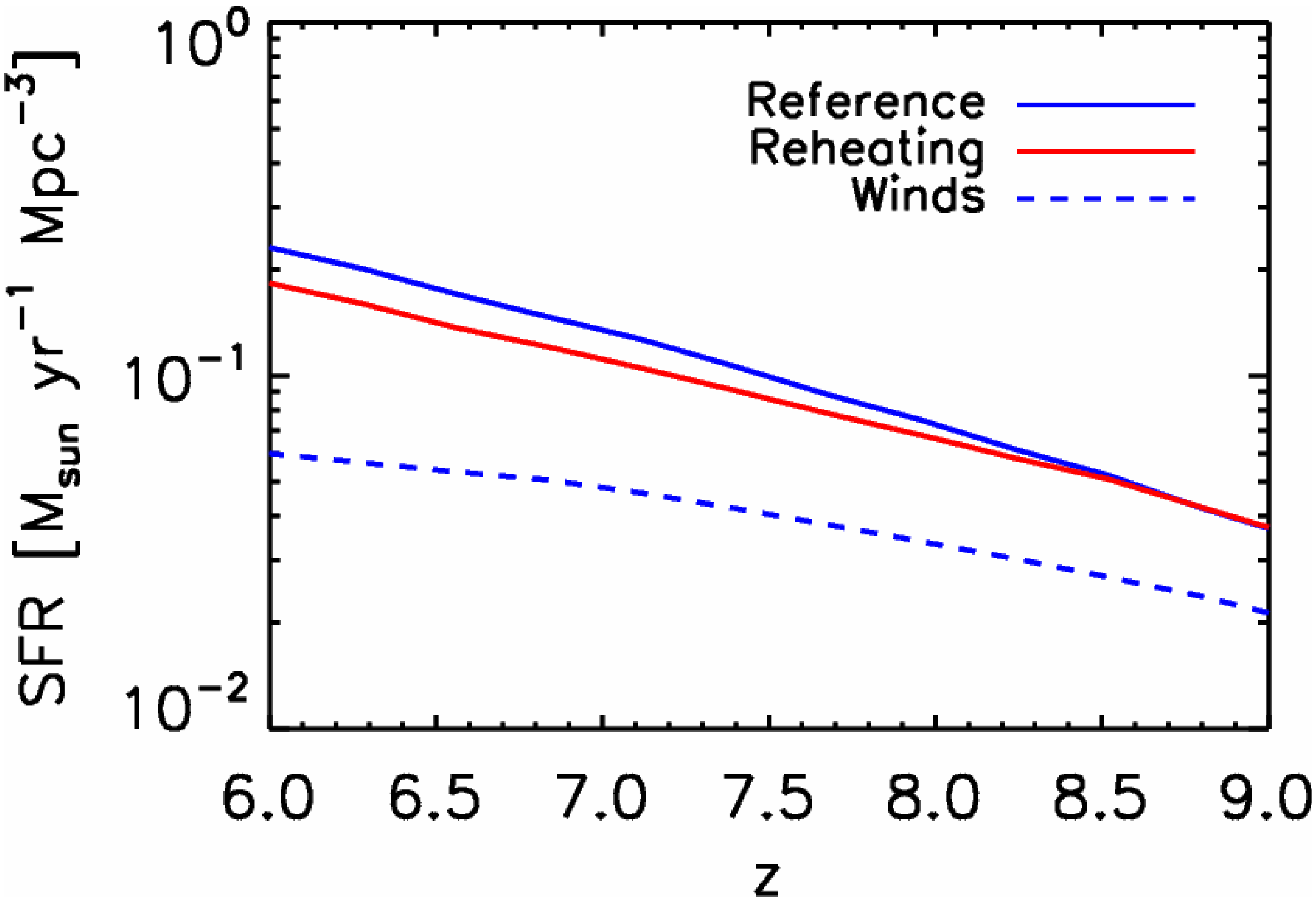
Suppression of star formation: supernova winds



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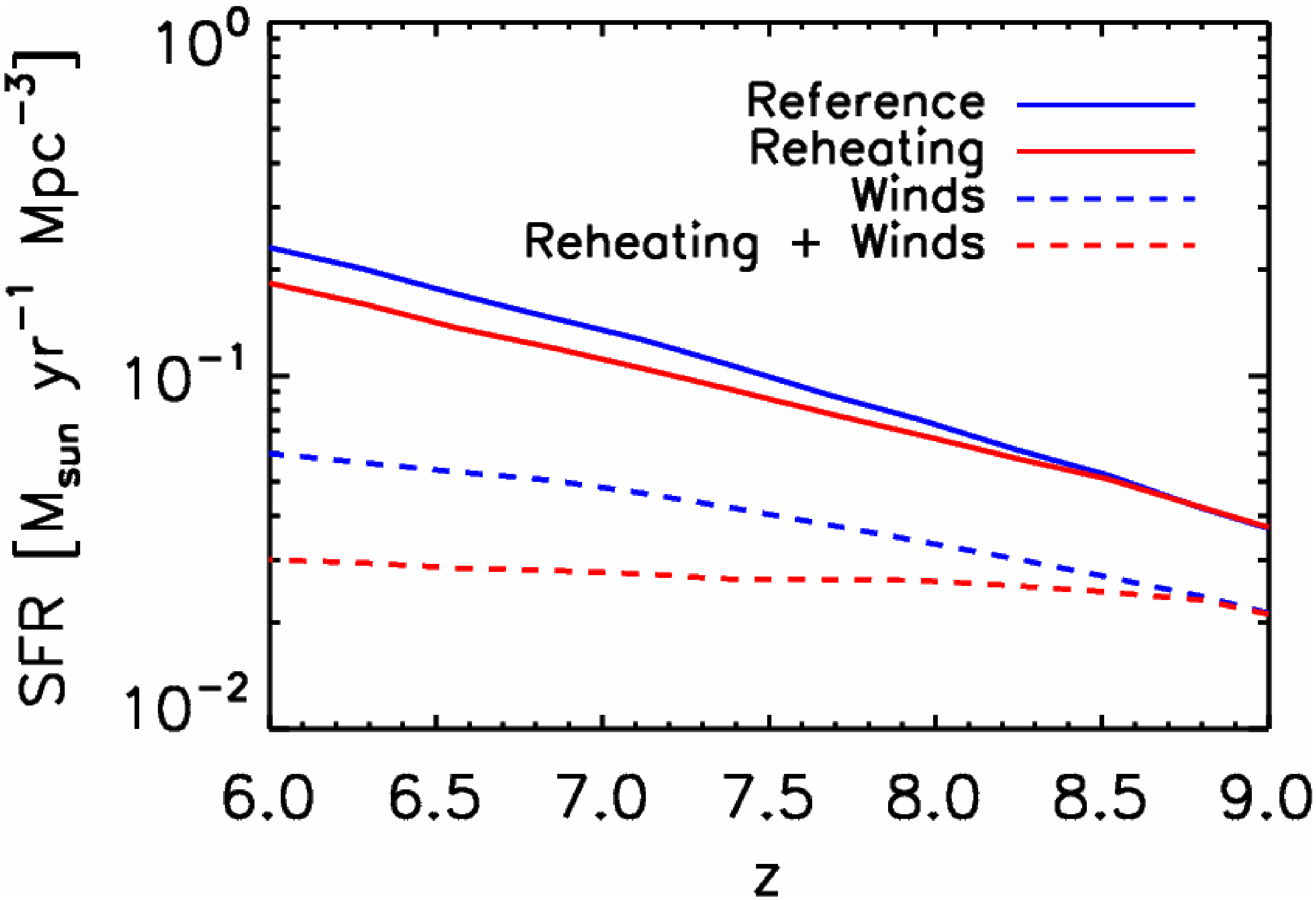
Suppression of star formation: reheating + supernova winds



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Feedback amplification

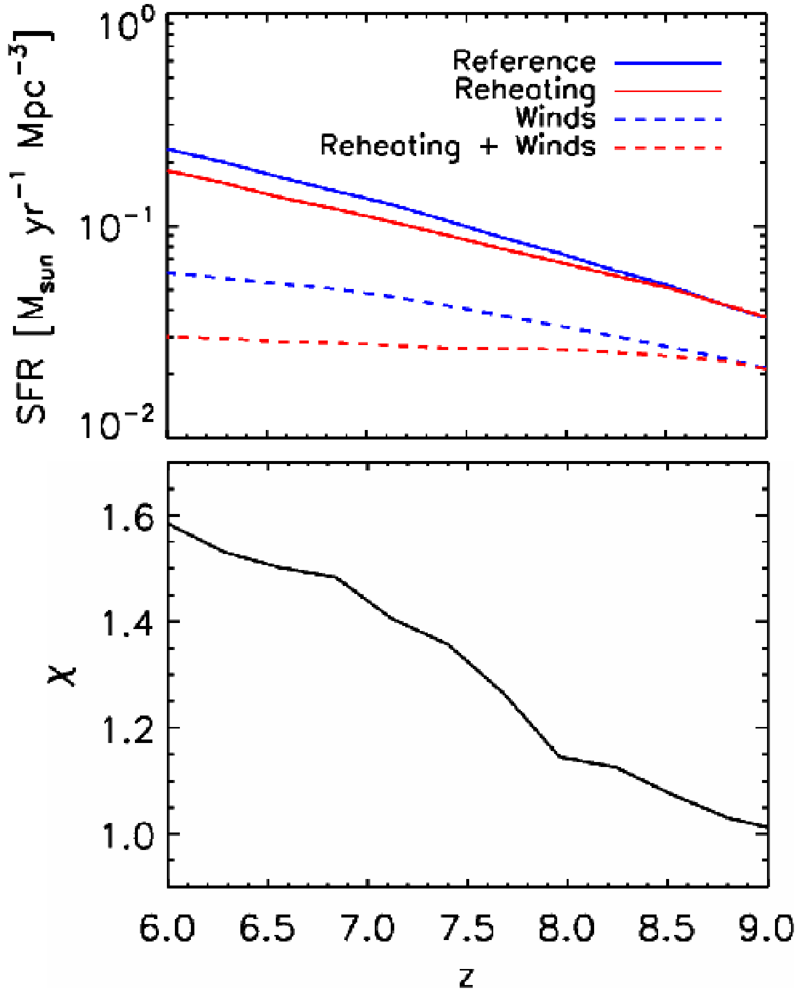
$$S_h \equiv \frac{\dot{\rho}_*}{\dot{\rho}_{*,h}}$$

$$S_w \equiv \frac{\dot{\rho}_*}{\dot{\rho}_{*,w}}$$

$$S_{wh} \equiv \frac{\dot{\rho}_*}{\dot{\rho}_{*,wh}}$$

$$S_{wh} \stackrel{?}{=} S_w \times S_h$$

$$\chi \equiv S_{wh} / (S_w \times S_h)$$



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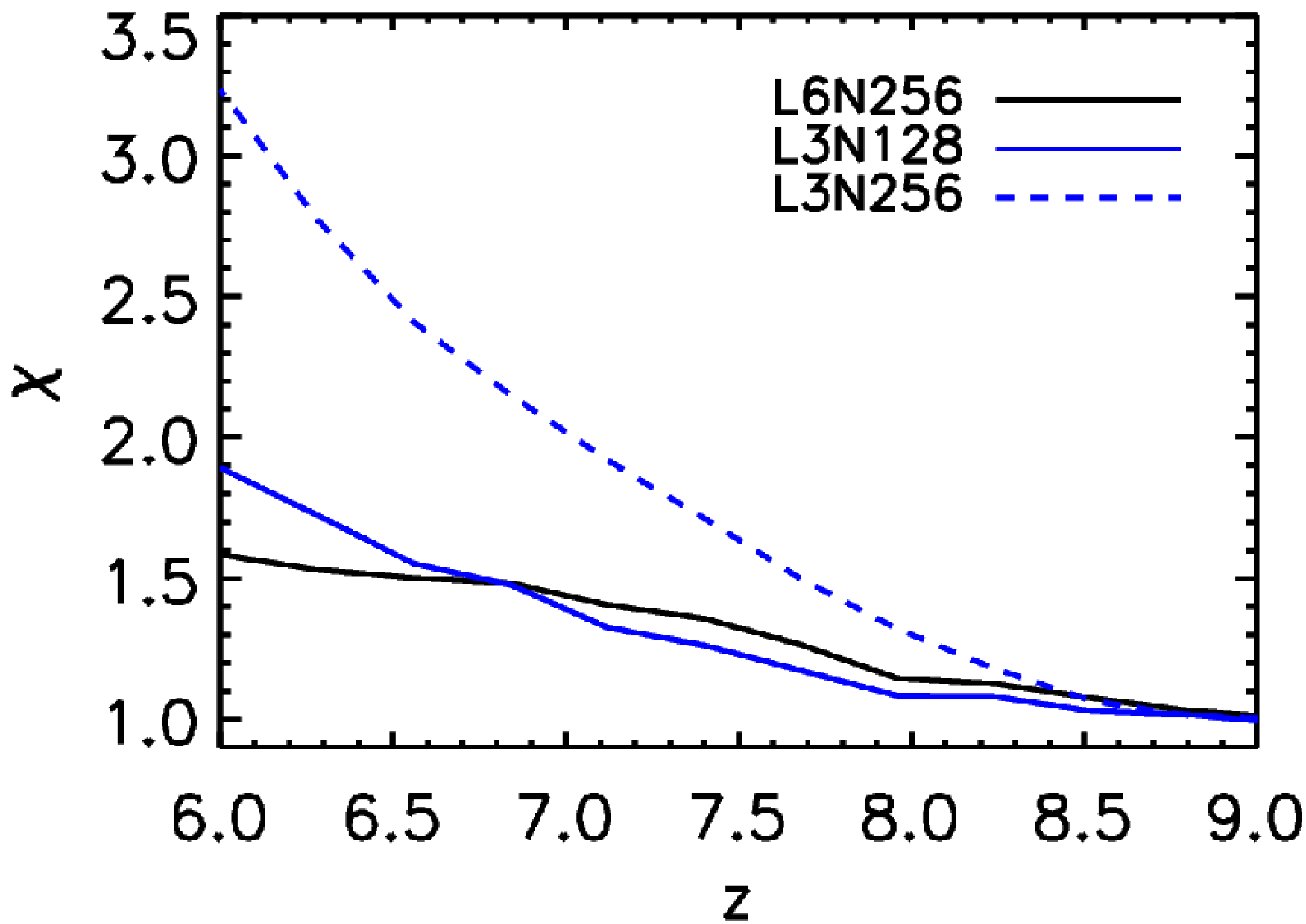
Feedback amplification: dependence on box & resolution



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Conclusion (1/2)

- Both reheating and supernova feedback reduce the SFR -> negative feedback

- Reheating and supernova feedback mutually strengthen each other

- Effect increases with resolution

AP & J. Schaye (in preparation)

Reionization simulations - challenges

- Large representative volumes
  (cosmic variance, long wavelengths)
- High resolution
  (first galaxies, atomic coolers ~10^8 M_{sun})
- Accurate gas distribution
  (recombination rate)
- Many sources
  (stellar and recombination radiation)

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Radiative transfer - what you want

- Radiative transfer on hydrodynamics
  (vs. N-body/semi-analytics)
- Spatially adaptive
  (vs. uniform mesh)
- Parallel on distributed memory
  (vs. serial; parallel on shared memory)
- Avoid scaling with # sources
  (vs. linear scaling)

TRAPHIC – radiative transfer for SPH

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TRAPHIC

TRAnsport of PHotons In Cones

- Adaptive: Directly on SPH particles

- Parallel: Transport employs the SPH particle-neighbor scheme

- Efficient: Computation time independent of # sources

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Controlling TRAPHIC

- Spatial resolution: # SPH neighbors
- Angular resolution: # Cones
- Temporal resolution: Clocks
- Computation time: Photon packet merging

AP & J. Schaye (2008), MNRAS 389, 651

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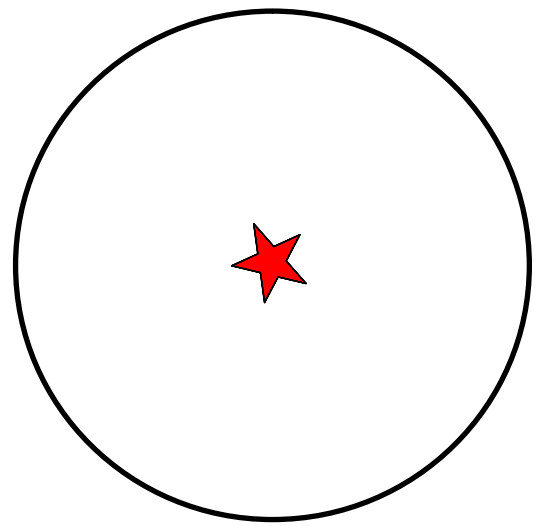
Conclusion (2/2)

- Reionization simulations require tailored approaches for solving the radiative transfer problem
- TRAPHIC – radiative transfer for SPH adaptive, parallel, efficient

AP & J. Schaye (2008), MNRAS 389, 651

Outlook: thermal coupling

- Thermal coupling requires multi-frequency treatment
- Example: Star with blackbody spectrum $T = 10^5$ K in homogeneous hydrogen-only medium initially neutral and at 100 K



neutral & cold

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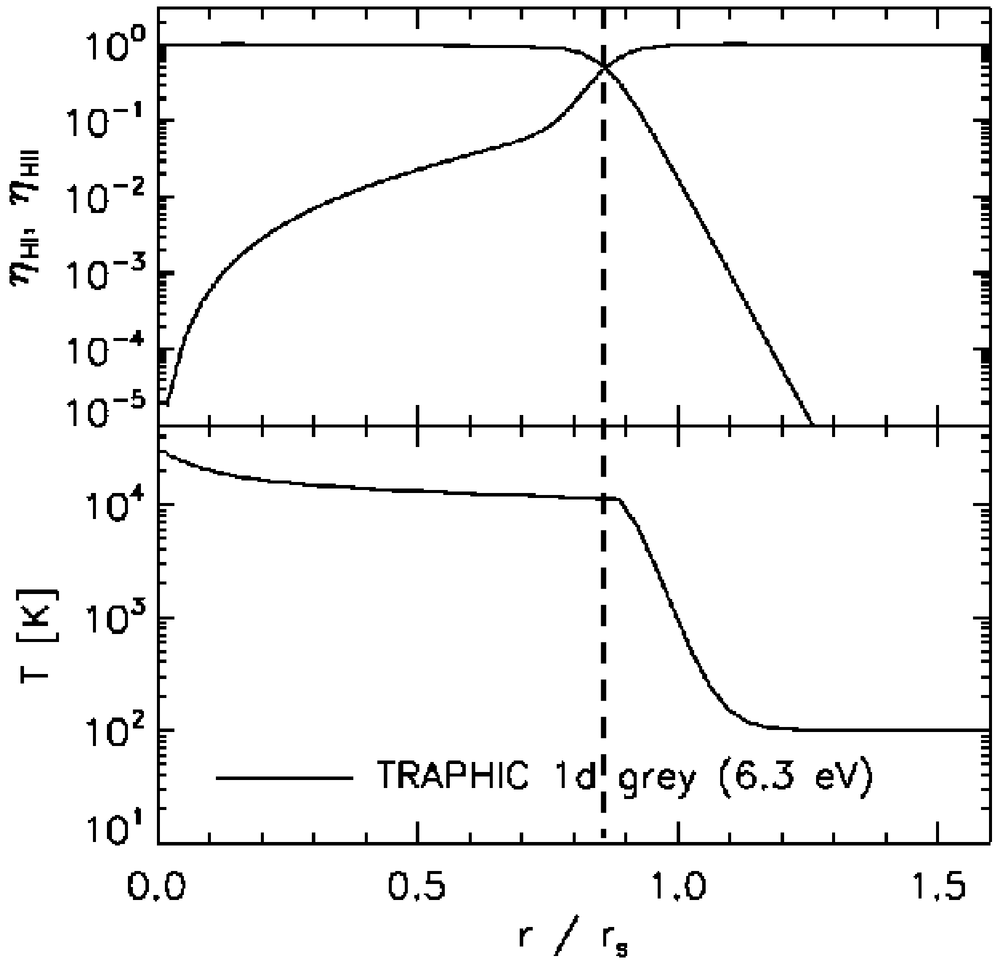
Mono-chromatic approximation

neutral / ionized fraction

Temp.



Normalized distance to star

blackbody

$T_{bb} = 10^5$ K

$t = t_{rec}$

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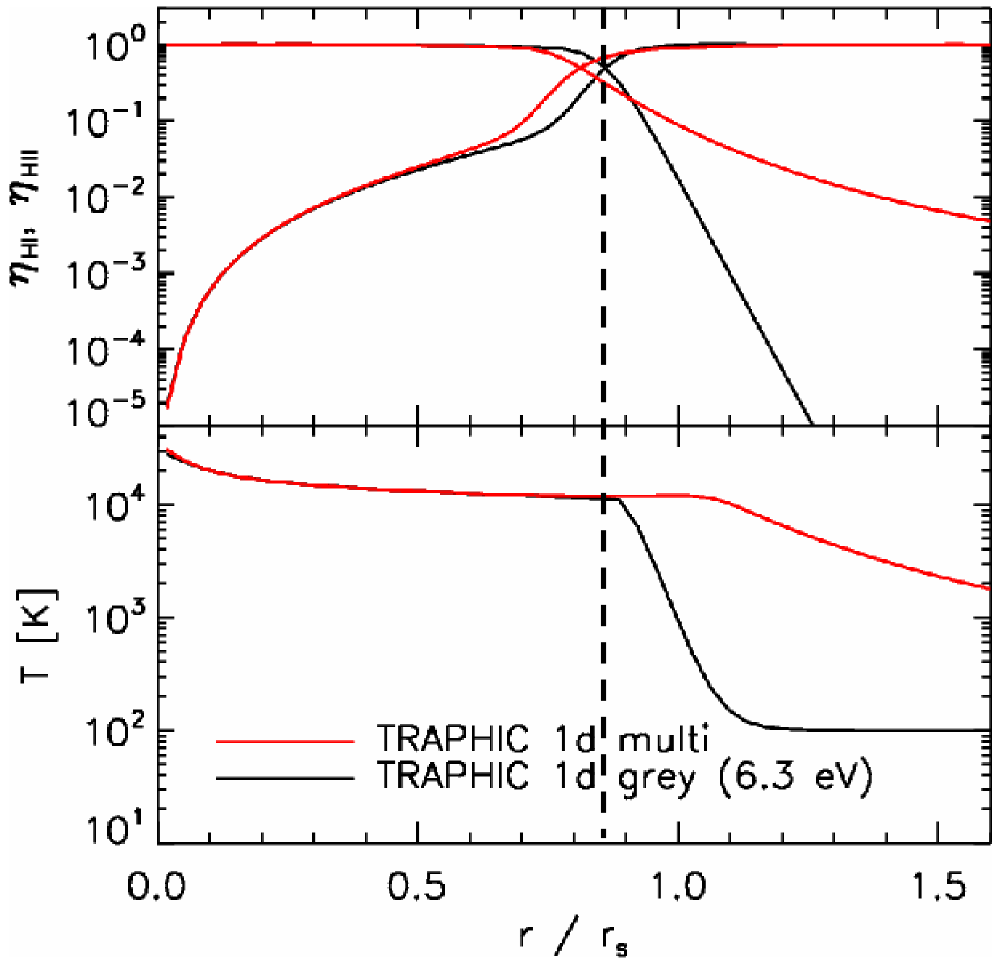
Exact multi-frequency

neutral / ionized fraction

Temp.



Normalized distance to star

blackbody

$T_{bb} = 10^5$ K

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