Cosmological Impacts of the First Stars

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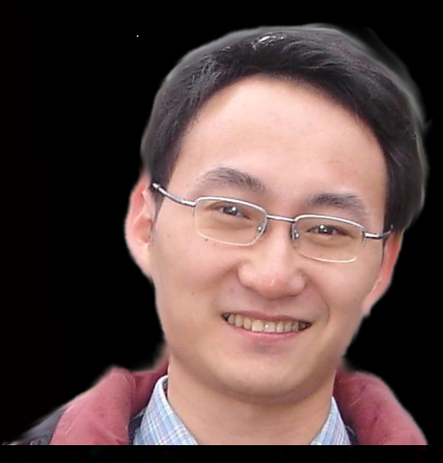
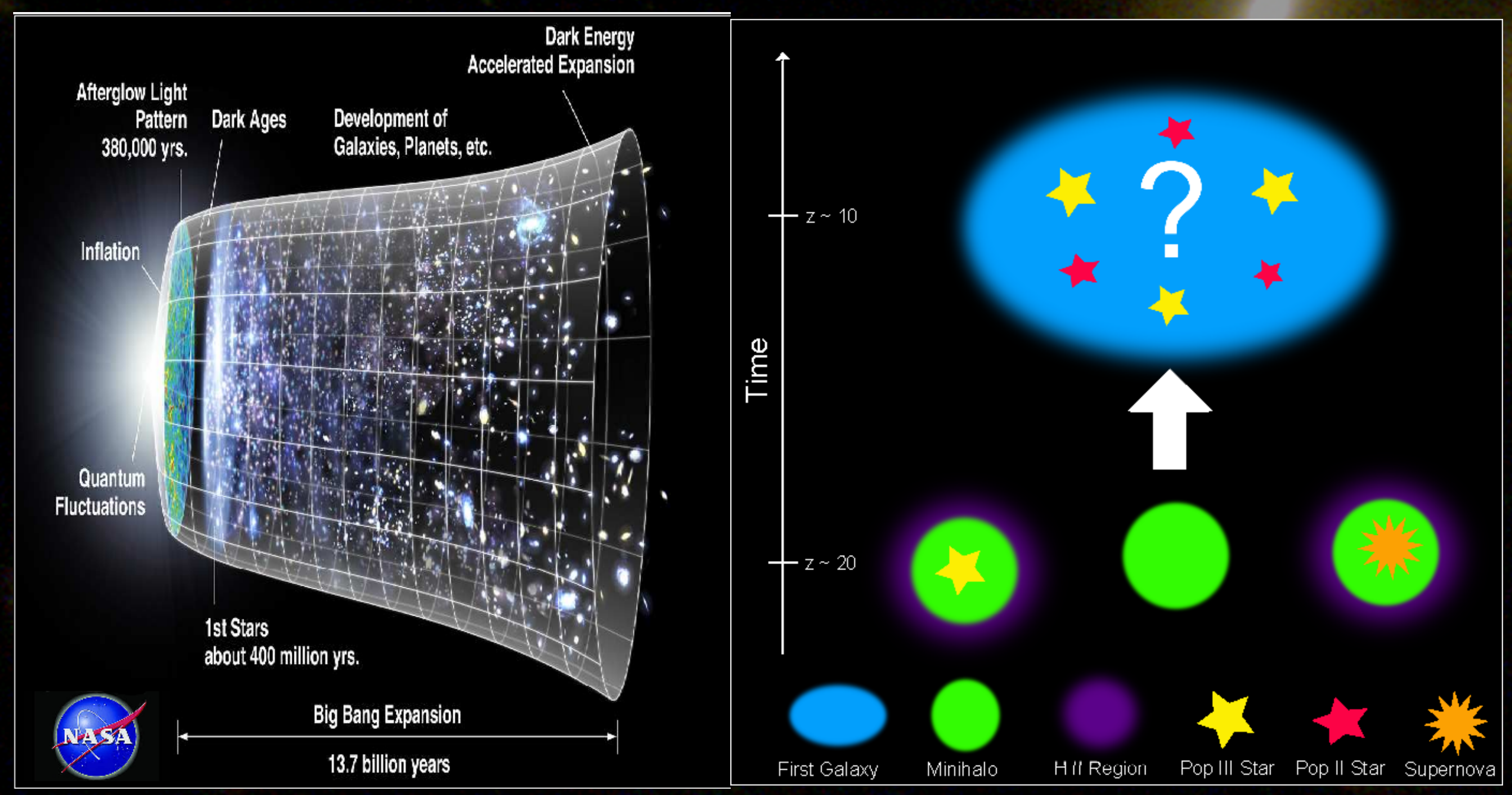


Abstract

We present the results from our cosmological simulations of the first galaxy formation. We use the well-tested, massively- parallel combined N-body and smoothed-particle hydrodynamics code Gadget-2, modified to include detailed cooling, chemistry, and radiative transfer of primordial gas to study the impacts of the first stars to the first galaxy formation. Different from previous work, we consider the realistic treatment of stellar feedback by using updated stellar models for the first stars. Our cosmological simulations are initialized at a redshift of $z \sim 99$ and evolve through the birth of the first stars, via their supernova explosions until the first galaxy starts to assemble. This poster discusses how stellar feedback from the first stars affects the primordial IGM, the major building block of the first galaxy.

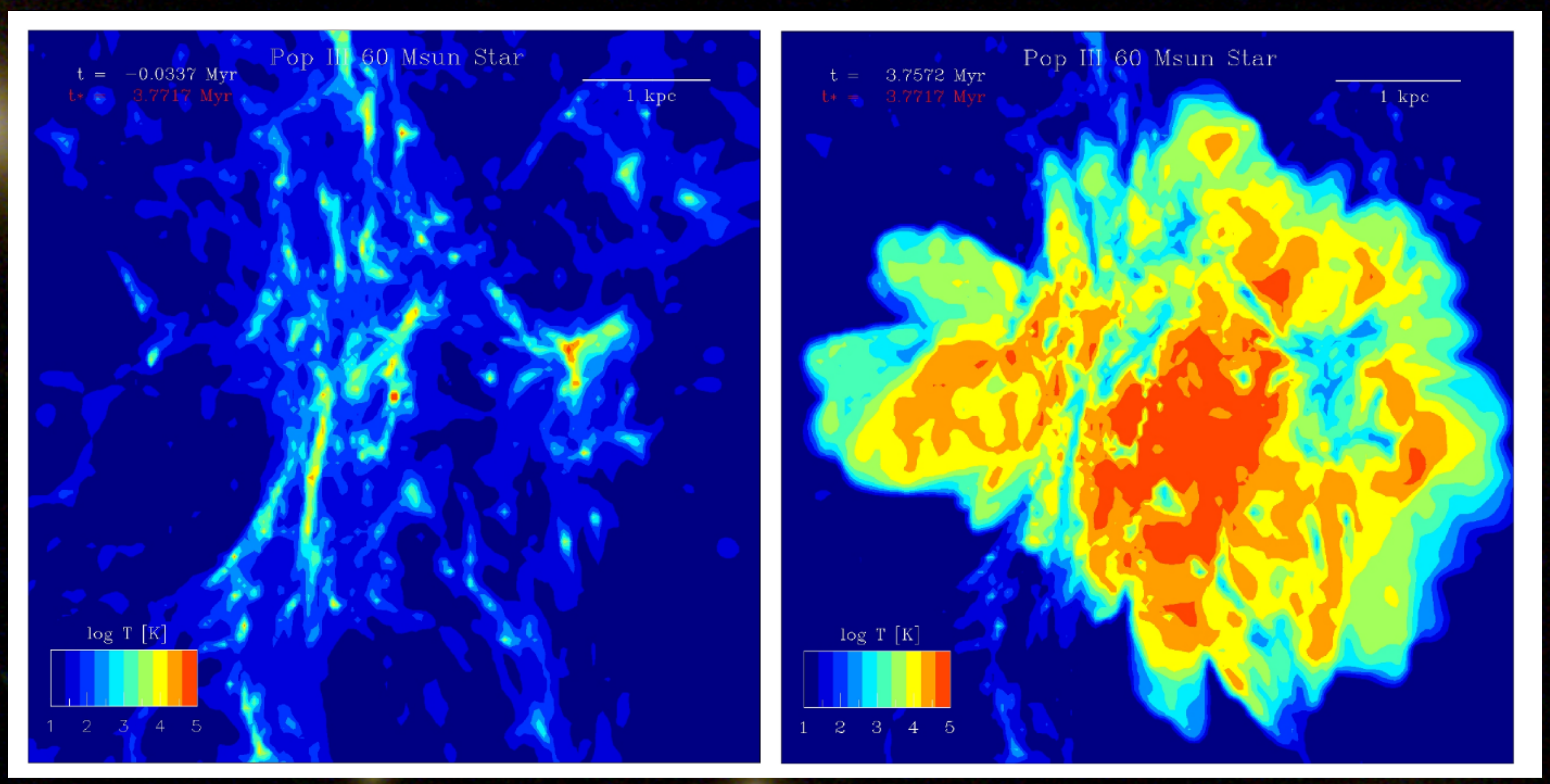
Introduction

One of the most fundamental questions in modern cosmology is understanding the end of the cosmic dark ages, when the first stars and galaxies transformed the simple early universe into states of ever-increasing complexity. The first galaxies comprised of the first systems of stars gravitationally bound in dark matter halos are naturally recognized as the building blocks of modern galaxies such as our Milky Way. But *how did the first galaxies form*? and *what is the relation between the first stars and the first galaxies*?



Assembly of the first galaxies: The first galaxies comprise a total mass of about 10^8 $M_\odot$ and typically collapse at $z \sim 10$. Their assembly is affected by feedback from the first (Pop III) stars formed earlier in the minihalo progenitor systems. The minihalos cannot be treated as galaxies, because strong feedback from the Pop III stars easily blows out all the gas of minihalos such that no stars can form in them.

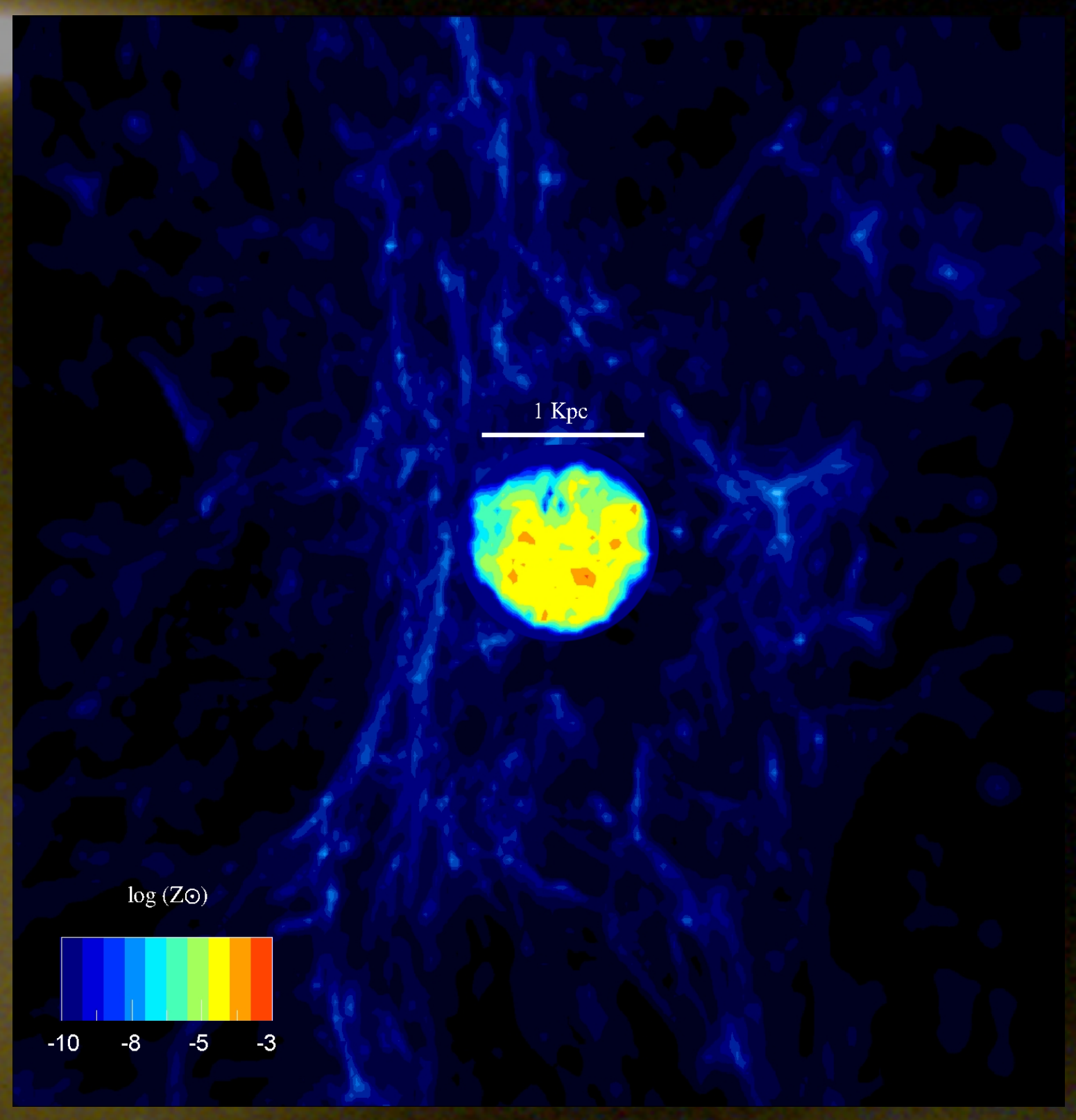
Birth of the First Stars

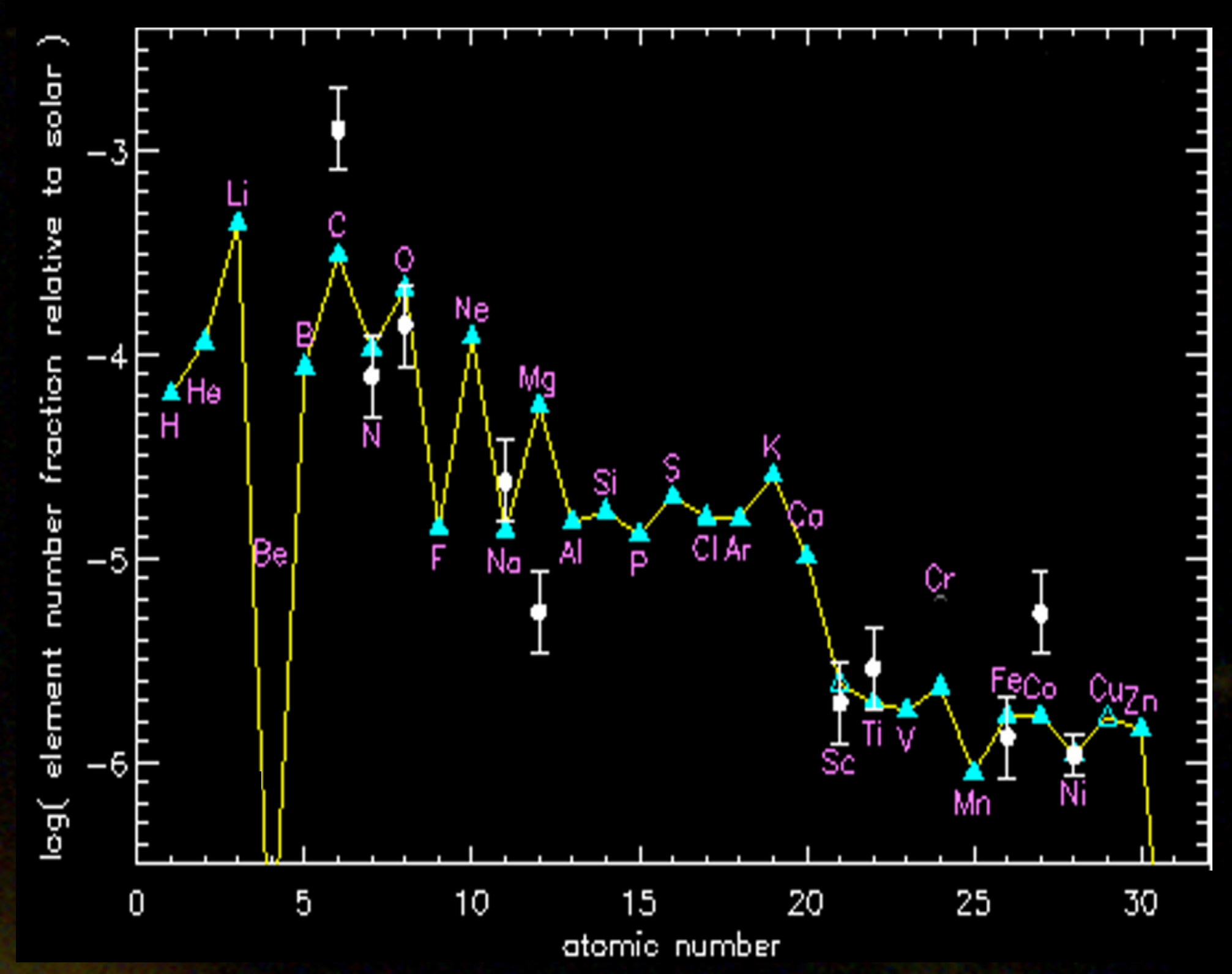


In our simulations, the first star with masses of 60 $M_\odot$ forms at a redshift of $z \sim 28$ inside a 5×10^5 $M_\odot$ dark matter halo. Once the star evolves to the main sequence when the stable hydrogen burning at core occurs, its surface temperature quickly rises to $T \sim 10^5$ K and begins to emit a large amount of ionizing photons for neutral hydrogen and helium. The gas inside the host halo is strongly photo-heated up temperatures, of $T \sim 2 \times 10^4$ K, which allows the gas to escape the gravitational well of the host halo forming an outflow. When the star dies, the I-front ultimately creates an extensive H II region of size ~ 4 kpc.

Backgroud image: Lensing Galaxy Cluster Abell 383 by NASA, ESA, J. Richard, and J.-P. Kneib

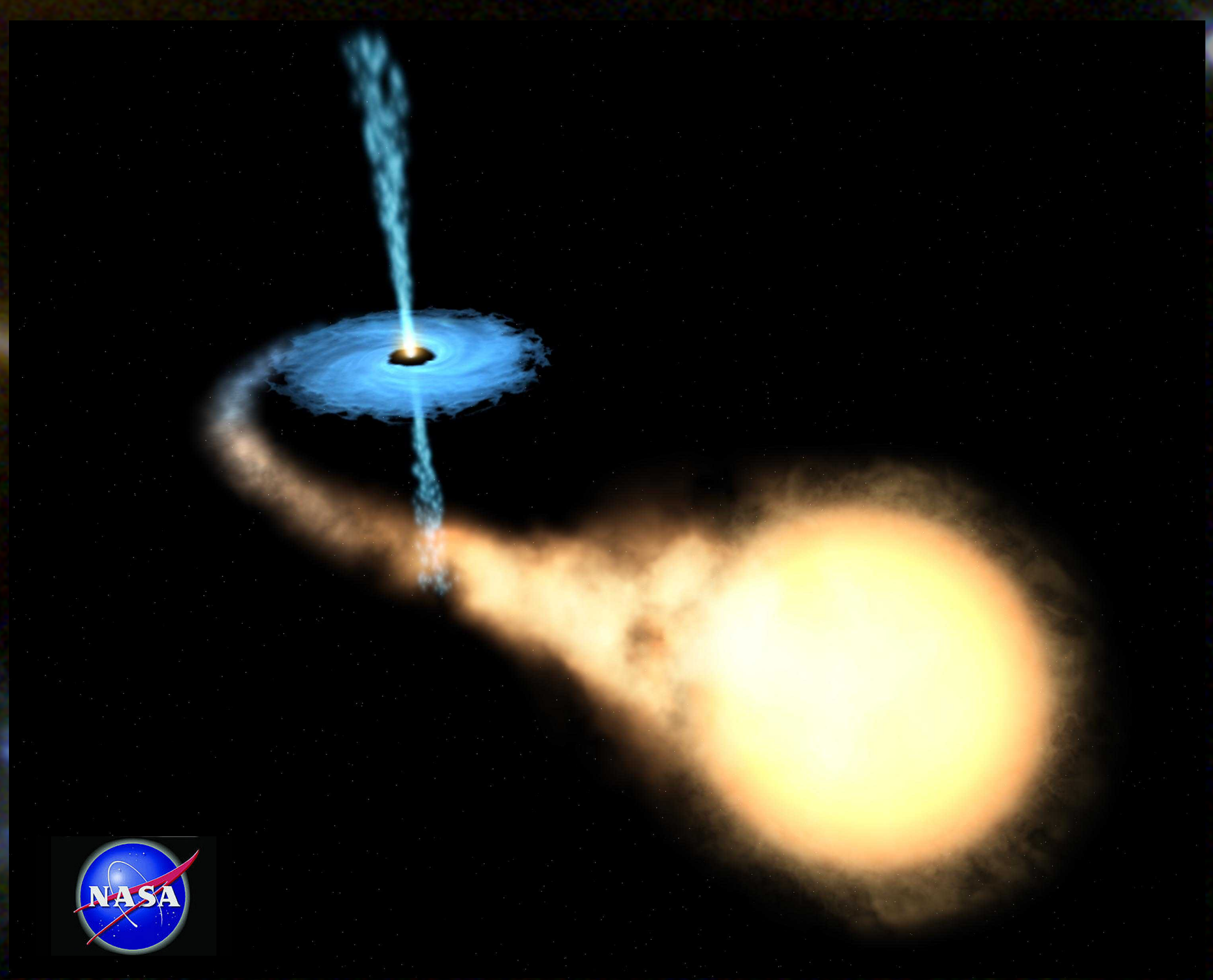
The First Supernovae

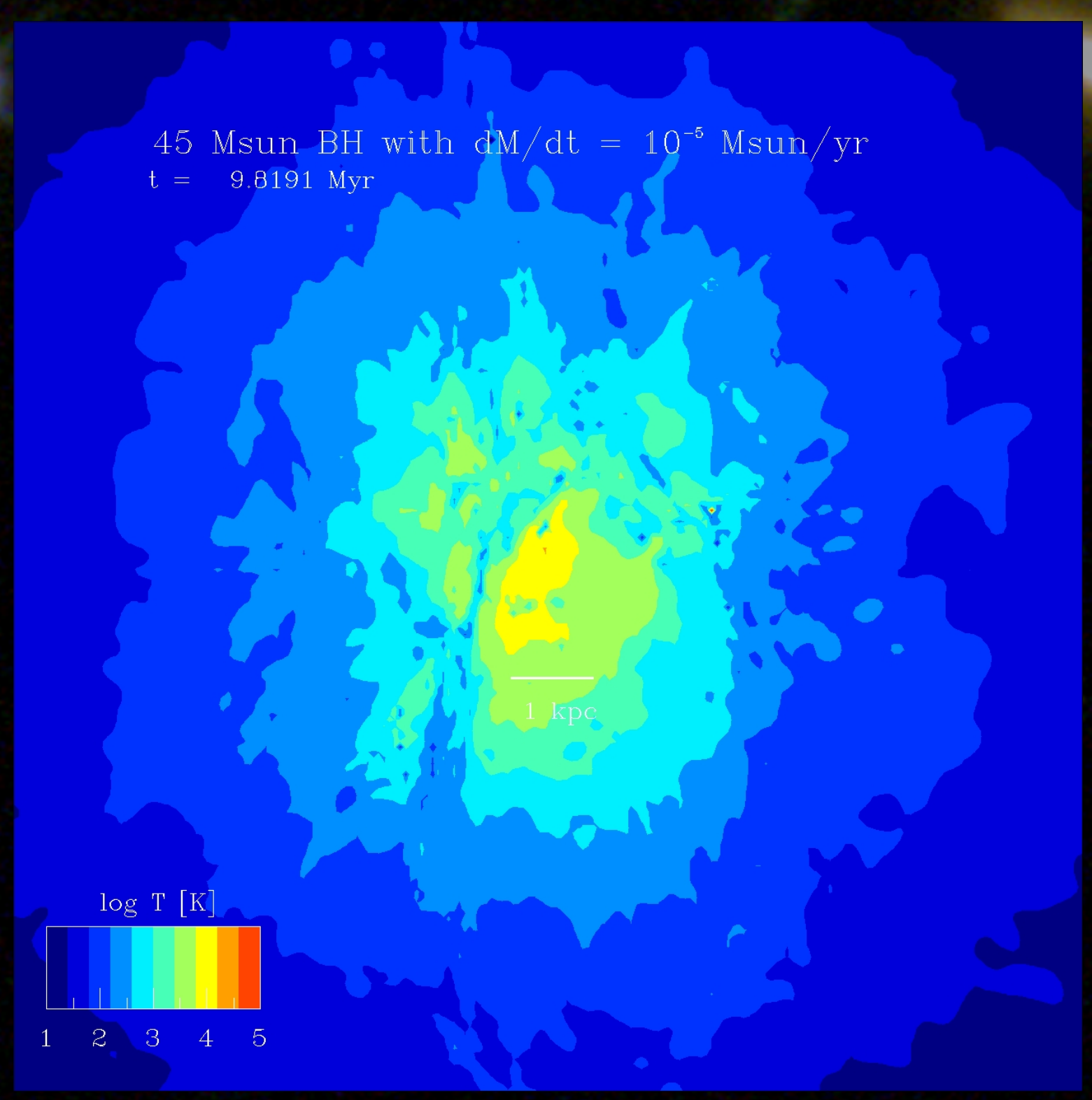




The first stars synthesized the first heavy chemical elements beyond hydrogen and helium during stellar evolution. Later, these metals were dispersed to the IGM when the stars died as supernovae. In our simulation, we assume the 60 $M_\odot$ star die as a core collapse supernova with explosion energy of 3×10^{51} erg. The explosion can efficiently spread the metals over 1 kpc in a few million years and enrich the metallicity of pristine gas inside IGM to 10^{-3} - 10^{-6} $Z_\odot$. The chemical enrichment can lead to the formation of the second generation of stars (Pop II stars) that reside in the first galaxies.

The First X-Ray Binaries





Recent simulations suggest the fragmentation of the first star-forming cloud may result in the formation of binaries or multi-stellar systems. In one of our scenarios, we assume the formation of a close binary with masses, of 15 $M_\odot$ and 45 $M_\odot$ stars instead of a single 60 $M_\odot$ Star. The 45 $M_\odot$ star first evolves into a black hole and starts to accrete the material from the 15 $M_\odot$ star. This accretion can effectively convert infalling masses into energy and release it in the form of X-ray emission. Compared with ionizing photons from stars, the IGM has a relative lower opacity to X-rays. This allows X-rays to propagate farther and heat the IGM through compton scattering.

Conclusions

We use sophisticated cosmological simulations to study the feedback from the first stars as well as the first binaries. The radiative feedback of the first stars can significantly ionize the gas of the IGM that changes the collapse mass scale for the first galaxies. The heavy elements dispersed through supernova explosions can easily enrich the IGM over a critical metallicity ($\sim 10^{-3}$ $Z_\odot$) resulting in the Pop II star formation. The impact of a single star can range from several kpc to a galactic scale. Hence, we conclude that the stellar feedback from the first stars is very critical in the assembly process of the first galaxies.

Acknowledgments & References

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