Mon. Not. R. Astron. Soc. **000**, 1–2 (2015) Printed July 25, 2015 (MN LaTeX style file v2.2)

The Dynamics of Seed Black Holes in the First Galaxies

Chao Shi[1⋆], John H. Wise[1], Other authors
[1] *Center for Relativistic Astrophysics, Georgia Institute of Technology, 837 State Street, Atlanta, GA 30332, USA*

July 25, 2015

ABSTRACT

Copied from AAS. Should be updated before submission with main results. The discovery of bright quasars at redshift $z \geqslant 6$ in the Sloan Digital Sky Survey implies that black holes (BHs) as massive as $10^9 M_\odot$ were already assembled within 1 Gyr. Generically, these SMBHs are thought to have assembled by mergers with other BHs and by gas accretion onto less massive seed BHs. One candidate of such seed BHs are Population III (Pop III) stellar remnants. In order to map out plausible scenarios such massive objects form from Pop III remnants, we run a cosmological adaptive refinement mesh simulation of an overdense region of about 300 Mpc^3, which forms a few $10^9 M_\odot$ dark matter halos and over 13000 Pop III stars by redshift 15. Then we focus on one of these massive halos, containing 20 Pop III stellar remnants, to study the dynamical behavior of these BH seed candidates. Here we report on the evolution of the orbital properties of stellar-mass seed BHs in one of the first galaxies. They are distributed throughout the halo, creating a swarm of BHs, gradually falling toward the halo center through dynamical friction. From these characteristics, we estimate the BH merger rate in this particular galaxy, which is an important quantity to assess during the early buildup of massive BHs.

Key words: galaxies: formation – galaxies: dwarf – galaxies: high-redshift – methods: numerical

1 MOTIVATION

* mention Haiman's paper, which is semi-analytical.

* we did a full numerical study.

2 METHODS

2.1 Simulation Setup

Our analysis starts from the "Rarepeak" simulation conducted by Xu et al. (2013) that focuses on the frist stars and galaxies in an overdense region with $\langle\delta\rangle \equiv \langle\rho\rangle/(\Omega_M \rho_c) - 1 \simeq 0.65$ at $z = 15$ in the volume of 135 comoving Mpc^3, where Ω_M is the density of matter in units of critical density $\rho_c = 3H_0^2/8\pi G$. The simulation is performed with the adaptive mesh refinement(AMR) cosmological hydrodynamics code *Enzo* (Bryan et al. 2014). Radiation transport of ionizing photons are tracked by the adaptive ray tracing module *Moray*, which is coupled to the hydrodynamics, energy and chemistry solvers in *Enzo*. We have studied the number of Pop III remnants in the first galaxies(Xu et al. 2013), their contribution to the X-ray background(Xu et al. 2014). In this paper, we focus on the evolution of seed black holes(BHs) formed from these Pop III remnants. Here we give an overview of the simulation setup and numerical methods. A more detailed description of the star formation and feedback models are given in Wise et al. (2012a, 2012b) and Xu et al.(2013).

MUSIC(Hahn&Abel 2011) is used to generate the initial condition for the simulation at $z = 99$. The cosmological parameters are adopted from the 7-year *Wilkinson Microwave Anisotropy Probe*(WMAP) ΛCDM+SZ+LENS best fit (Komatsu et al. 2011):$\Omega_M = 0.266$, $\Omega_\Lambda = 0.734$, $\Omega_b = 0.0449$, $h = 0.71$, $\sigma_8 = 0.81$, and $n = 0.963$, where the variables have the usual definitions. We use a comoving simulation volume of (40Mpc)^3 that has a 512^2 root grid resolution and three initial nested grids each with mass resolution of $2.9 \times 10^4 \mathrm{M}_\odot$. The finest nested grid has a comoving voulme of $5.2 \times 7.0 \times 8.3$ Mpc^3(302 Mpc^3). Further refinement in the Lagrangian volume of the finest nested grid is allowed up to a maximum AMR level $l = 12$, giving a maximal spatial resolution of 19 comoving pc. Refinement occurred when either a baryon or DM overdensity of $4 \times \Omega_{\{\mathrm{b,DM}\}} \rho_c N^{l(1+\phi)}$, where $N = 2$ is the refinement factor , and $\phi = -0.1$ allows more aggressive refinement at higher densities, i.e., super-Lagrangian behavior.

⋆ e-mail: cshi31@gatech.edu

*Further zoom-in simulation description
John's simulation on Bluewater(for more representative massive halos)

2.2 Orbital Elements

*approximation: key orbital properties of seed BHs: semi-major axes and eccentricities
calculation of semi-major axis and eccentricities
Angular momentum and estimation of merger rate by the evolution.

3 RESULTS

3.1 Stacked Analysis

Radial distribution of seed BHs at different stages:
Orbital properties:

3.2 Case Study: High Temporal Analysis of a Single Galaxy

Seed BHs position: Angular momentum evolution:

ACKNOWLEDGMENTS

This work is supported by NSF grants AST-1211626 and AST-1333360. This research has made use of NASA's Astrophysics Data System Bibliographic Services. The majority of the analysis and plots were done with YT(Turk et al. 2011).

References

Turk M. J., Smith B. D., Oishi J. S., Skory S., Skillman S. W., Abel T., Norman M. L., 2011, ApJS, 192, 9

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