Massive Black Hole Formation

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ABSTRACT

In recent years, there have been many observations of supermassive quasars illuminating the cores of early universe black holes. Many seeding mechanisms for such supermassive black holes (SMBH) have been proposed, and as of yet the direct collapse black hole (DCBH) formation seems the most likely for producing the size and mass of what we observe in the early universe. However, there is not currently a framework for the detection of halos likely to form a DCBH. This poster and the research presented in it aims to understand the physical quantities and environments that contribute to the formation of a black hole through direct collapse. Using current physics-rich simulations and a selection process based on prior works in this field we analyze halos selected for DCBH candidacy and use statistical analysis to understand and compare the halo properties. In future, we plan to use this research and machine learning methods to formulate such a framework that will determine if a halo is a candidate for direct collapse for application in simulation and extension to real world data.

SEEDING MECHANISMS

Light Seeds:

- Black holes formed from remnants of Population III stars – primordial metal free stars that are typically more massive than other stars
  - Generally do not form supermassive black holes ~10 M_{sun}

Medium Seeds:

- Black holes seeded from remnants of dense stellar clusters formed by stellar collisions
  - ~10^3 M_{sun}

(Regan et al. 2020)

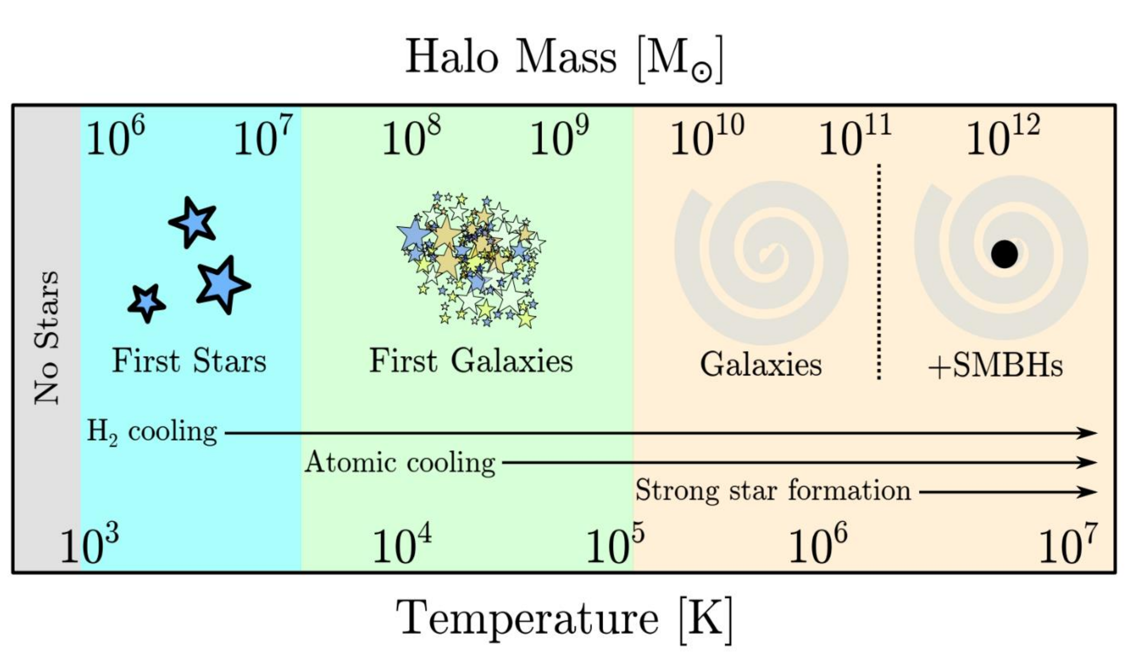


Figure 1: From *Cosmic Reionization* by John Wise showing the evolution of galaxies

Heavy seeds or direct collapse black holes:

- Seeded from remnants of supermassive stars that directly collapse into a black hole ~10^5 M_{sun}
  - Formed in atomic cooling halos – when a halo reaches ~8000K and ~10^8 M_{sun} – hot enough to ionize hydrogen (form HII) and suppress the formation of H_2
- In metal-free halos molecular hydrogen (H_2) is the strongest coolant this leads to low temperatures and causes fragmentation into stars, preventing the gas in the cloud from isothermally collapsing
  - Population III stars are formed in halos with high amounts of H_2 and when they die they chemically enrich the environment
  - Metal enriched halos negate the effects of dynamical heating – which occurs in rapidly growing halos at high temperatures and can suppress the formation of H_2

(Wise et al. 2019)

RENAISSANCE SIMULATIONS

- Use Enzo (Bryan et al. 2014) an adaptive mesh refinement code to track ray tracing and photodissociation of H_2
  - Analyze the RarePeak region (high halo density) with a total of 76 DCBH candidates – we analyze 61 of these
- Simulation does not track black hole formation, halos are selected for candidacy to be metal free and starless atomic cooling halos

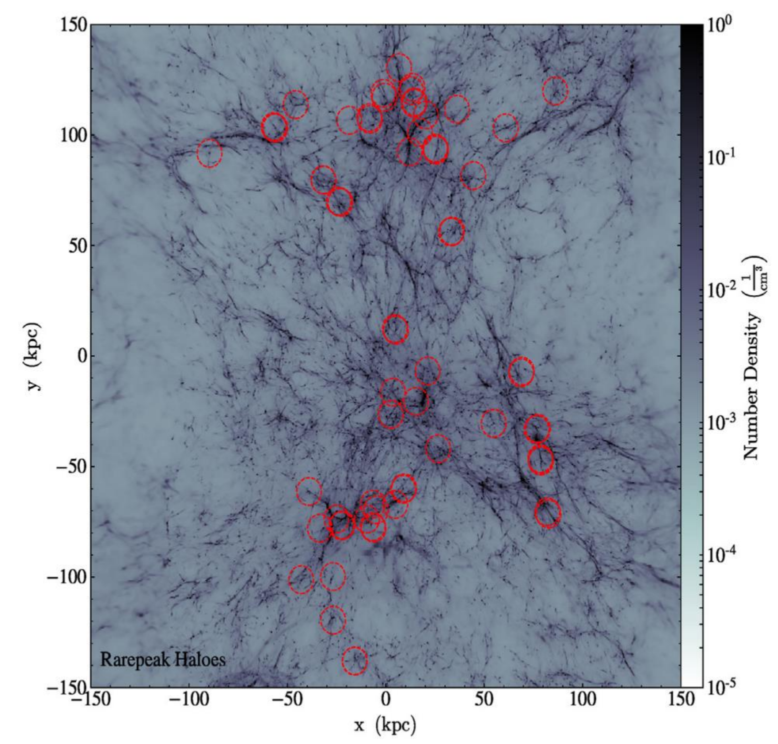


Figure 2: From Regan et al. 2020 depicting the RarePeak region of the renaissance simulations and the DCBH candidates circled in red

PRIOR WORKS

"Formation of Massive Black Holes in Rapidly Growing Pre-Galactic Gas Clouds" (Wise et al. 2019):

- Initial look into supermassive star formation in atomic cooling halos at z=15 from galaxy simulations
- Findings: Halos are in region 10-25 kpc from large galaxy formations outside the 5 kpc radius of enrichment
  - Halos experience fast growth

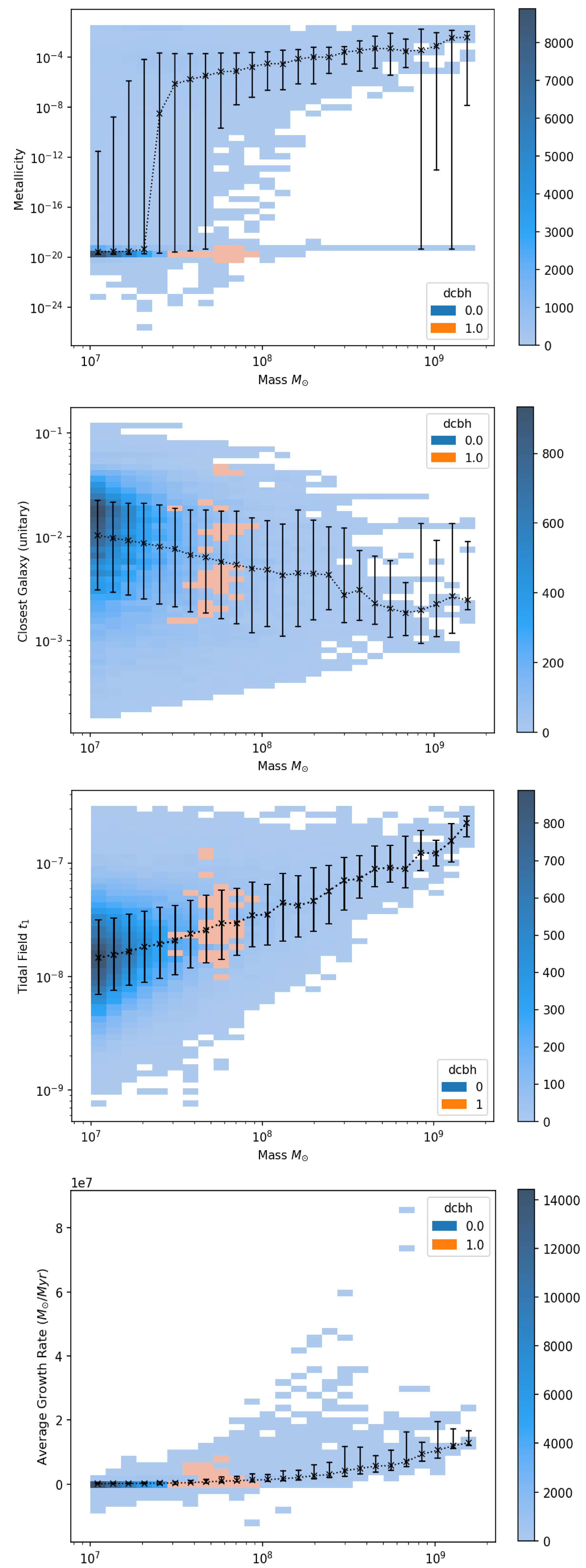
"The Emergence of the First Star-Free Atomic Cooling Halos in the Universe" (Regan et al. 2020):

- Analysis on the same DCBH candidate halos we use
- Findings: Halos were found to experience lower LW flux than needed to suppress H_2 formation
  - High growth rates however this is not necessarily unique
- Ideal distance from galaxy is 10-100 kpc to have higher than average
  - LW flux but not chemically enriched by galaxy
- Dynamical heating – growth rate and temperature – also important in suppression of H_2 formation

METHODS

- Using the DCBH halos presented in Regan et al. (2020) we use ytree to select the halos and yt (Turk et al. 2011) to perform calculations
  - We find the halos central properties such as metallicity, density, temperature, H_2 fraction, Lyman Werner Flux (radiation from stars), radial mass flux, large-scale overdensity, and velocity
  - Additionally, we calculate a few halo properties such as the spin parameter, growth rate, tidal field, and distance to nearest galaxy.
- The tidal field is calculated following Dalal et al. (2008) and Di Matteo et al. (2016) to calculate the direction of greatest "stretch" on the halo which is expected to be low

GRAPHS



Figures 3-6: 2D histograms of halo mass and metallicity (figure 3), distance to nearest galaxy (figure 4), tidal field (figure 5), and halo mass growth rate (figure 6) along with medians marked with an x and 1-sigma deviation error bars. DCBH candidates shown in orange non-candidates in blue

RESULTS

Figures 3-6 represent only a small fraction of the current results, these graphs were chosen as they are all values that have been previously studied or selected. We expected the metallicity to be low which is accurately represented in figure 3. As shown in figure 6 growth rate is not significantly higher for DCBH candidates partially agreeing with Regan et al. (2020) as candidates are not uniquely fast growing and suggesting other mechanisms are more important. However, tidal field is not lower for candidates which disagrees with Di Matteo et al. (2016) for SMBH formation.

FUTURE WORK

Graphs are only a representation of data. In order to better understand the results, we will perform a robust statistical analysis including using the KS-test, Bhattacharyya test, Mahalanobis distance, and KL-divergence to quantify the differences or lack thereof between candidates and non-candidates. We will also perform analysis on zoom-in regions of the halo mass and get a better understanding of anomalous data

In the future will create a machine learning algorithm using support vector classification. We will take the different calculations and data for DCBH and non-DCBH candidates and train an algorithm to detect a DCBH candidate based on its properties and environment. We can also use this classification to find what parameters are most important for a halo to host a DCBH

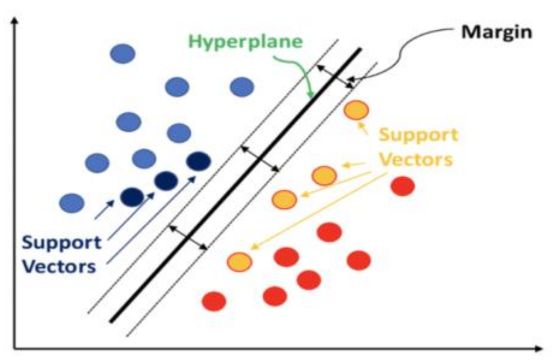


Figure 7: From datatron.com "What is a Support Vector Machine" depicting a basic graph of the use of a support vector machine

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