Supermassive Black Holes: Seeds and Evolution

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1 Note To Students

• Following the spirit of past winter camp projects, the following questions are, as of this writing, still completely open for active research and ongoing debates. Students are welcomed to challenge themselves to push their limits, and see how far down the list they can go.

• While the items (1) to (4) examine ideas that are rather well-established, students are highly encouraged to explore the items (5) to (7) and even beyond.

• Good luck!

2 Seed Black Holes and Baryonic Accretion Onto A Black Hole

• Black holes are known to have wildly different masses, ranging from stellar-mass black holes of $1-10\,\mathrm{M}_\odot$ to so-called "supermassive" black holes of up to $\sim 10^{10}\,\mathrm{M}_\odot$.

(1) How many black holes are known to mankind with their masses at least approximately estimated? How can we classify them? Do all of them have the same origin story?

(2) To investigate the growth of supermassive black holes, the masses of their "seeds" turn out to be very crucial. Explain why — especially in regard with the item (4) below. What are the "seeding" mechanisms being proposed by contemporary researchers?

(3) The recent discovery of a $\sim 70\,\mathrm{M}_\odot$ black hole claimed by Liu et al. (2019) may trigger interesting discussions about the seeds of very massive black holes. Think about why. But also study the debates about this "discovery" and explain why the paper is being challenged by other researchers.

• Now imagine a seed black hole of mass $10^6\,\mathrm{M}_\odot$ sitting at the center of a large spiral galaxy like our own Milky Way. For simplicity, assume hereafter that there is a sufficiently large reservoir of baryons and dark matter in the vicinity of the black hole; that is, the black hole's growth is limited *not* by the amount of materials available for accretion, *but* only by the fundamental physical processes you consider.

(4) Let us first assume that the black hole is growing by devouring only baryons in its neighborhood. There is a fundamental limit to the rate of this baryonic accretion, called the Eddington limit. Explain what it is. What are the assumptions that need to be made for the Eddington limit argument? Explain how fast our seed black hole could double its mass assuming the Eddington-limited accretion. Is the rate fast enough to resolve the puzzle of supermassive black holes at redshift $z > 7$ in our Universe (e.g., Mortlock et al. 2011; Banados et al. 2018)?

3 Dark Matter Accretion Onto A Black Hole

• Now let us consider more exotic processes. A black hole can be a great portal that connects the baryonic sector and the dark matter sector. That is to say that a black hole might have grown by devouring only dark matter and yet, to us, a baryonic black hole and a dark matter black hole would be largely indistinguishable.

(5) Estimate how fast our seed black hole could grow if we assume that its growth is by only "cold" dark matter accretion. What are the assumptions you made about the accretion process? What are the assumptions other researchers made in previous estimates (e.g., Peirani & Pacheco 2008)?

• Now consider alternative models of dark matter.

(6) For example, what if we assume a "warm" or "self-interacting" dark matter model? Explain the specific dark matter model you considered, and estimate how fast the black hole could grow by devouring only your particular type of dark matter particles. What are the other assumptions you made about the accretion process? What are the models and assumptions other researchers considered in previous studies (e.g., Pollack et al. 2015)?

(7) How about yet another, alternative model of dark matter, so-called "dissipative dark sector" model. Explain the specific dark matter model you considered, and estimate how fast the black hole could grow. What are the other assumptions you made about the accretion process? What are the models and assumptions other researchers considered in previous studies (e.g., D'Amico et al. 2018, Outmazgine et al. 2018)?