Recall the formation of a black hole

All stars start their life in the same way. Basically, there is a cloud of dust and gas, called nebula. Then it gradually clusters together to form a protostar owing to gravitational interaction. This is considered as the first stage of a star's life and lasts 500,000 years for a small star, such as our sun. The next stage is main sequence star, in which nuclear fusion is ignited and provides with hot temperature and pressure to counterbalance its gravity. Next, depending on the mass of the star, a massive star can maintain its nuclear fusion while smaller stars have no choice but to end up being a red giant. Unfortunately, this is also the doom for massive stars. The only differences are that this stage comes later and they will be called red supergiant. Now I am only concerned about the red supergiant as they are the candidate for a black hole. After being red supergiant, they become a super nova, during the time they emit lots of hot gases out. However, they actually leave a dense core behind which then undergoes gravitational collapse. Depending on the mass, the core may become a black hole or a neutron star.

What's PBH?

PBH are hypothetical black holes that form soon after big bang. They formed after dense area underwent gravitational collapse. Owing to this, unlike other normal black holes formed from stars, primordial black holes could have masses ranging from 10-8 kg to more than thousands of solar masses.

History PBHs

The idea of primordial black hole can date back to 1966, precisely March 14^{th} 1966, and was proposed by two physicists from Russia and Soviet Union, Yakov Borisovich Zel'dovich and Igor Dmitriyevich Novikov. Later, in 1971, this hypothesis was first in depth studied by Stephen Hawking.

Why do Scientists Bring it back?

It's mainly because of LIGO, precisely the essay it published in 2016. Also, in 2017 Nobel Prize in Physics was awarded to three scientists who made decisive contributions to the LIGO detector and observation of gravitational waves. In the essay, LIGO considered the possibility that the detected binary black holes may be a signature of dark matter, and there remains a window for black holes whose masses range from 20M to 100M, where primordial black holes (PBHs) may constitute the dark matter.

This is an animation of two black holes merging. As you can see, they orbit each other at first. At this stage, they also give out gravitational waves, which cause them to lose energy. That's why they gradually spiral into each other. During the time, their potential energy is converted into kinetic energy. As you may notice, they spin faster when the distance between them is shorter. At the end, they begin to rip each other until they become a new black hole.

Current State

As mentioned before, due to Hawking radiation, black holes will gradually lose their masses over the time.

Here is the formula for Hawking Radiation, where P means the rate of giving energy out. This formula only links the energy with time, while it should be better if we can turn that into mass. Applying Einstein's mass energy equation and chain rule in calculus, we may write this new formula. You may still find it quite daunting, but no worries, we can give it a shorthand version because the first big chunk is nothing more than a constant! As you can see, the rate follows the inverse square law, indicating that the smaller a black hole is, the quicker it radiates energy out.

In order to show that clearly, I plot a graph showing the relation between mass of a black hole and time with the vertical axis being the mass and the horizontal axis being the time. As you can see, the graph becomes steeper when time goes by, showing that the rate of the loss of mass is getting larger.

And I made an animation showing the relation between mass and time with different initial masses. The vertical interception indicates the initial mass. As you may spot, with a bigger initial mass, the graph shifts to the right, showing more time is demanded for a black hole to vanish. (See PPT)

New Model, Supermassive Black Holes, Dark Matter

1. At present, our model does not allow the formation of black holes immediately after the Big Bang. Thanks for the fluctuation, galaxies and stars were then privileged enough to cluster owing to gravitational interaction. Afterwards, nuclear fusion is ignited, pushing hydrogen together and producing helium. When nuclear fusion terminates, stars collapse owing to gravitational interaction again. Then massive stars may end up

being a black hole. This model indicates that black holes did not form until the death of first generation of stars. But Hawking and Carr argued that PBHs could have formed as the result of the same density fluctuations in the early universe. In their model, regions of the universe with slightly more mass than average could have collapsed in on themselves to form these embryonic black holes. The European Space Agency argues that stars and galaxies could form around these primordial black holes, which enable them to exist longer than we expect. By contrast, a journal article published on Monthly Notices of the Royal Astronomical Society contended that black holes might also hinder the formation according to the simulations done by computers.

2. According to our model, the death of massive stars contributes to the formation of black holes. Therefore, the mass of a black hole therefore should be approximately the same or close to the mass of a star. However, we have already detected black holes in different scales, some of which are thousands of times as huge as our sun, whereas some of which are too tiny that cannot be formed from a star. Now, why is there a problem? Why having different scales of black holes doesn't sound quite right? Some may explain that as supermassive black holes grow by merging and tiny black holes stem from black holes experiencing Hawking Radiation. The explanation sounds brilliant except that the quantification does not sound right. Supermassive black holes are around millions or billions of the mass of a sun. How many black holes do they need to devour so that they can grow so big. Also, the theory of tiny black holes does not hold owing to the limited time. Hawking Radiation cannot reduce a black hole's mass so quickly. If we apply our primordial black hole model here, it fits into the reality. Supermassive black holes have already been there and are offered sufficient time to grow, while atom sized black holes are primordial black holes which haven't been merged yet. This time, the theory holds both qualitatively and quantitively.

3. Primordial black holes can also lead to another point, dark matter. scientists believe that around 23 percent of the universe is composed by dark matter, whereas nobody has observed it yet. For dark matter, the formation of primordial black holes might just use most of them. Even though they compose almost one fifth of the whole universe, they are concentrated at black holes. This means that it is harder to detect them. Is there any evidence to support this statement or is it just a fantasy I create? Well, there is research done by a group in Yale University. They propose that if a big fraction of PBHs were formed with a mass around 1.4 times that of the Sun, then they could account for all dark matter in the universe.

Planet Nine?

So everyone, you may start to panic now as it is suspected that there is a primordial black hole near our solar system. And the evidence is that the orbits of objects beyond Pluto are so organised. In theory, they should be random. Therefore, now scientists suspect there is another planet in the outer solar system and named it planet nine. Nevertheless, same as most things I mentioned above, it is still a hypothesis.

Impact

I guess you have heard about an asteroid hitting the earth, while I am pretty sure that you haven't heard about a black hole hitting the earth. You may find this idea ridiculous before coming here today. However, there is evidence supporting the statement.

Rahvar published an article on Monthly Notices of the Royal Astronomical Society. This is the same journal I showed to you just now. So according to the calculation, it is expected that the earth collides with a small PBH around every billion years. Right, now I want to do a simple calculation. What is the maximum number of times that a primordial black hole hits the earth? We know that the age of the earth is roughly 4 billion years. Therefore, the earth might be hit no more than 4 times. By the way, the calculation is constructed on the assumption that primordial black holes account for all dark matter in the Milky Way's galactic halo and dark disc, and a small primordial black holes here actually weighs 10^{12} kg.

And what happens afterward? Well, it is determined by the speed of a black hole.

We can imagine two potential outcomes from a black hole colliding with Earth. One possibility is that it would pass through and carry on out the other side with transferring some of its energy in the process. Alternatively, the black hole would be slowed down so much that it spirals down to the planet's core. At this point, it will be a disaster. "The accretion of matter into the black hole will heat the interior of the Earth and make the black hole grow – and finally, all the Earth will be swallowed by the black hole."

Fortunately, calculations indicate that if PBHs do make up the dark-matter structure of our galaxy, they would have such a high dispersion velocity and therefore make a short visit.

Conclusion

Well, you may realise that primordial black hole is just nice model as it combines dark matter and supermassive black holes together. In fact, it can also account for problems in other aspects. Personally speaking, it is such an elegant and neat model.

I need to reiterate that it has not been justified yet; it is still a hypothesis. However, maybe after a few years we may prove or rule out this hypothesis since a main goal of JWST is to detect the first galaxies and stars to form in the distant universe.