Institute of Cosmos Sciences

EXCELENCIA MARÍA DE MAEZTU

Primordial Black Holes: Interactions with Main Sequence Stars

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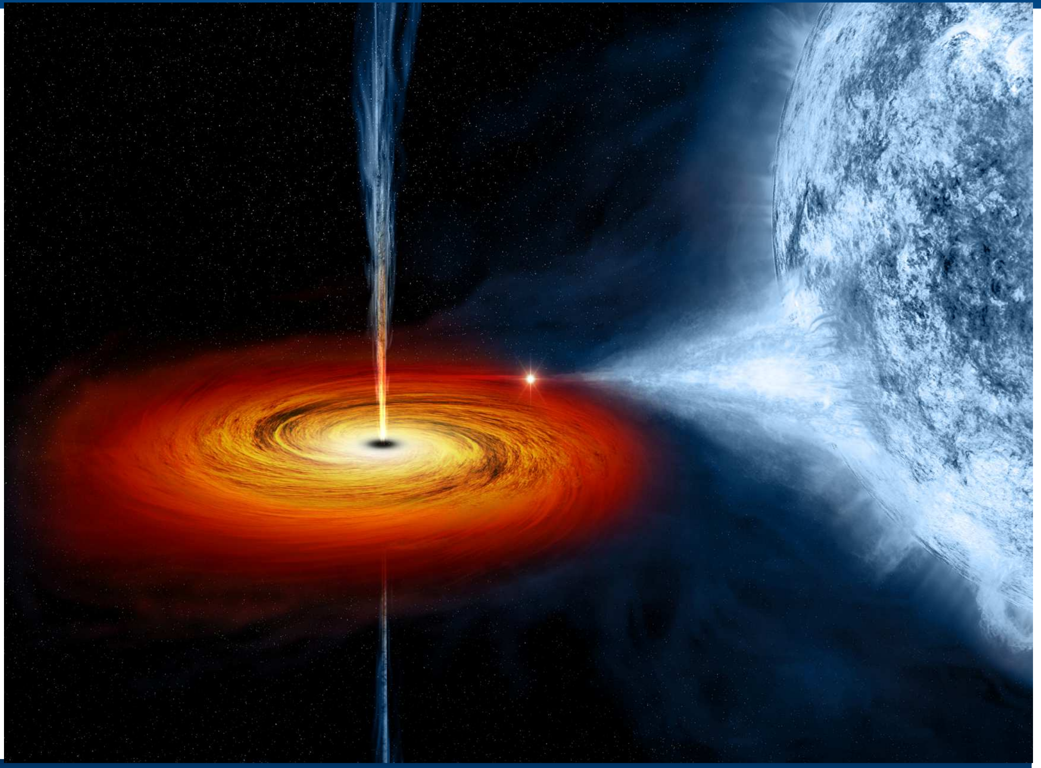

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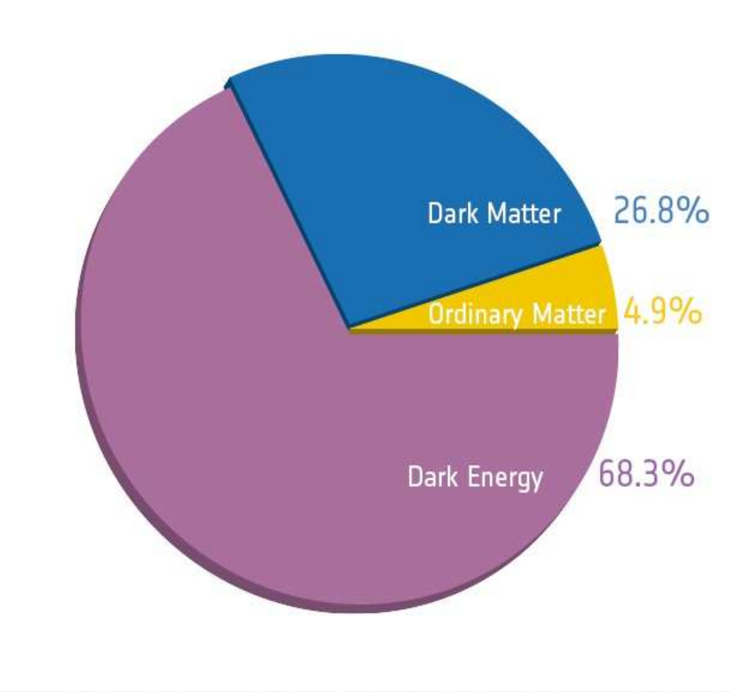
Primordial Black Holes and Dark Matter

- PBHs are Black Holes that don't have a stellar origin, and thus might be as old as the fluctuations they arise from.

- Dark Matter is an unknown component of the universe that contributes the majority of its matter and can only be detected by its gravity.

- PBHs stand as one of the very few explanations of Dark Matter that don't require any new particles or modifications of General Relativity.

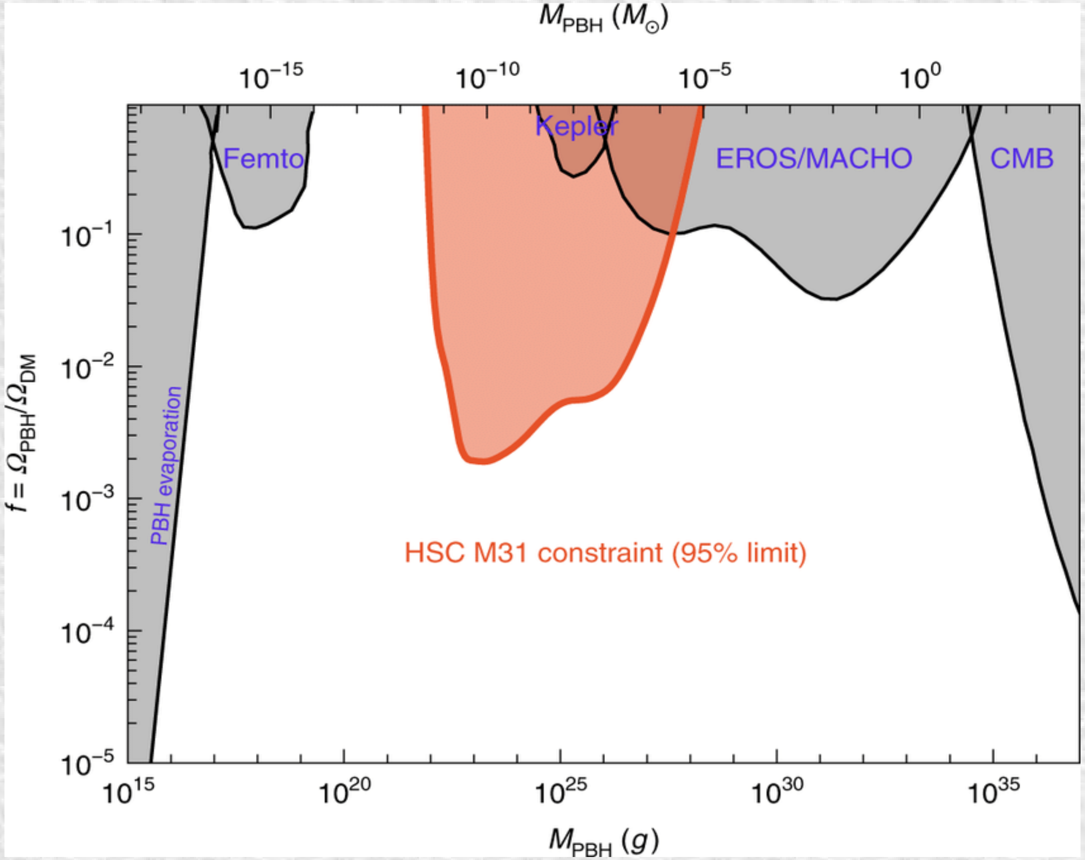
- But even in the case they aren't the main component of DM, PBHs remain interesting, being able to explain the Gravitational Waves detected by the LIGO collaboration for example.



Detection?

- Lensing
- Dynamical effects
- Gravitational waves
- Effects on the CMB
- Capture by stars

Small PBHs ($m<10^{-10}M_{\odot}$) might be captured by stars of any type. PBHs that fall to the core of a star can accrete it, leaving a clear signal of their presence.



From Niikura et al. (2017) A clear window at 10^{-12} $M_{\odot}$ can be appreciated.

Collision and capture with stars

At our current redshift, ρ_{DM} is too small and collisions or captures would be very rare. However, the first stars form around z~20, in very dense Dark Matter haloes with low velocity dispersions:

$$\rho_{vir}(z\sim 20)\approx 0.1 M_{\Theta}/pc^3 \qquad \sigma(z\sim 20)\approx 10\,km/s$$

As pre-stellar cores start forming, some of the DM (PBHs) will be bounded to them or the original gas cloud. These PBHs will contract adiabatically together with the baryons as the later collapse into a star. Without any other interaction necessary, DM will take the following distribution around the star:

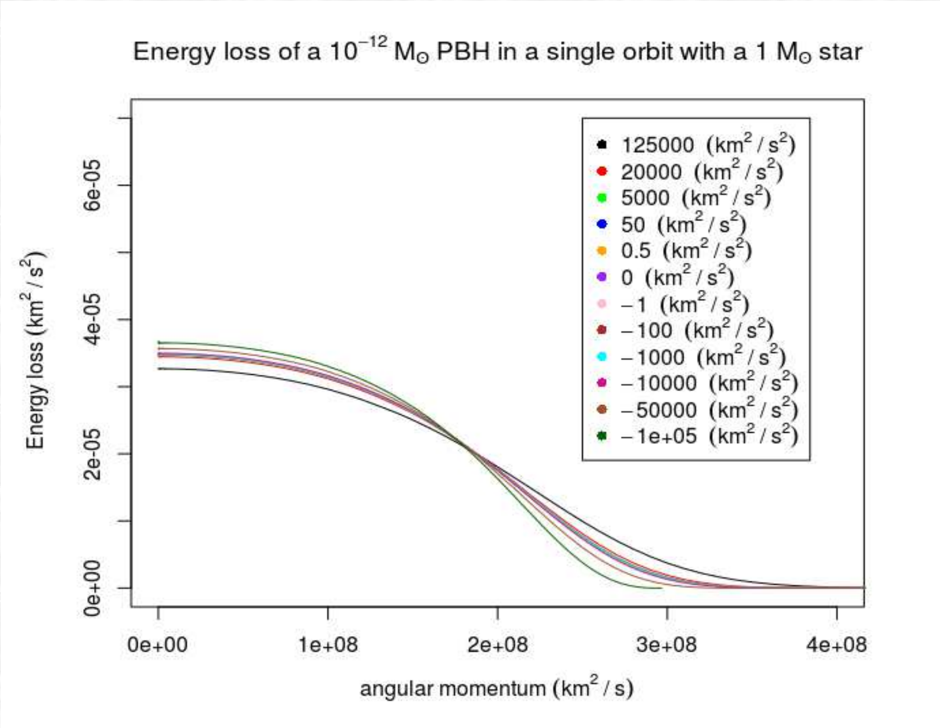
$$\rho_{DM} = \left(\frac{GM_*}{r\sigma^2}\right)^{3/2} \bar{\rho}_{DM}$$

The above distribution of PBHs have been gravitationally bounded and will orbit around the main sequence star. The ones closest to the star, or with very eccentric orbits may even cross the surface, meaning there will be dynamical friction affecting the PBH's orbit.

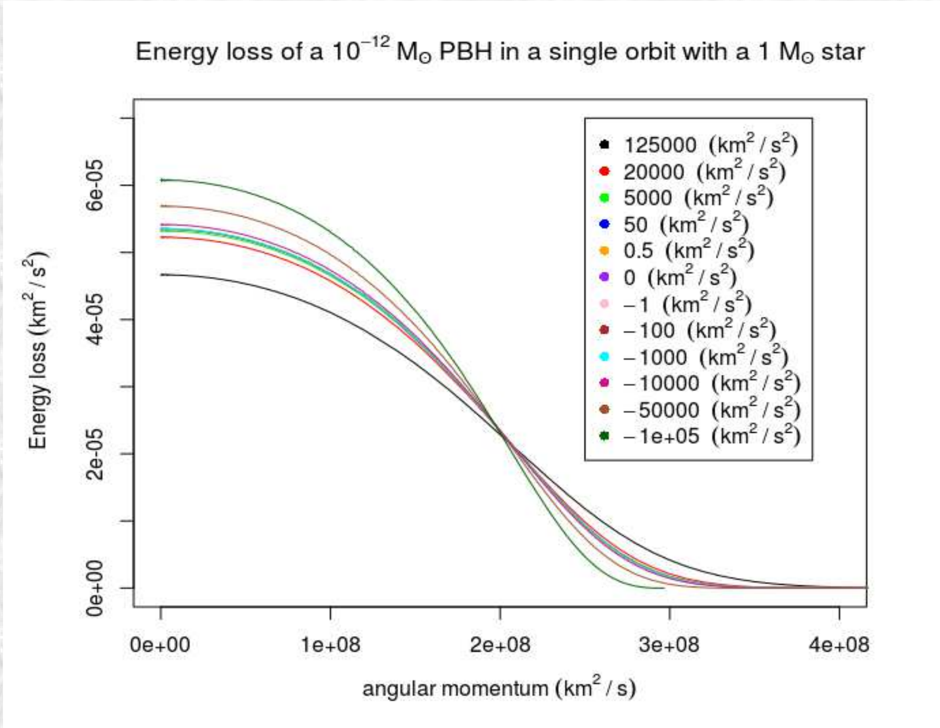
If the PBH ends up falling to the core of the star (“captured”), the accretion time ranges from 10^7 to 10^9 yrs for 10^{-12} $M_\odot$ PBHs. So as long as the PBH finished this process in $t<10^{10}$ yrs, the end result is a BH that could still be below the Chandrasekhar mass but would be much easier to observe than the extremely small initial ones.

Dynamical Friction

- If the PBH partially orbits inside the star the dynamical friction will affect their orbital energy, slowly changing the orbit until they settle in the core.



Colliosionless friction by Chandrasekhar (1949).



Friction in a gaseous medium by Thun et al. (2016), based on Ostriker (1999).

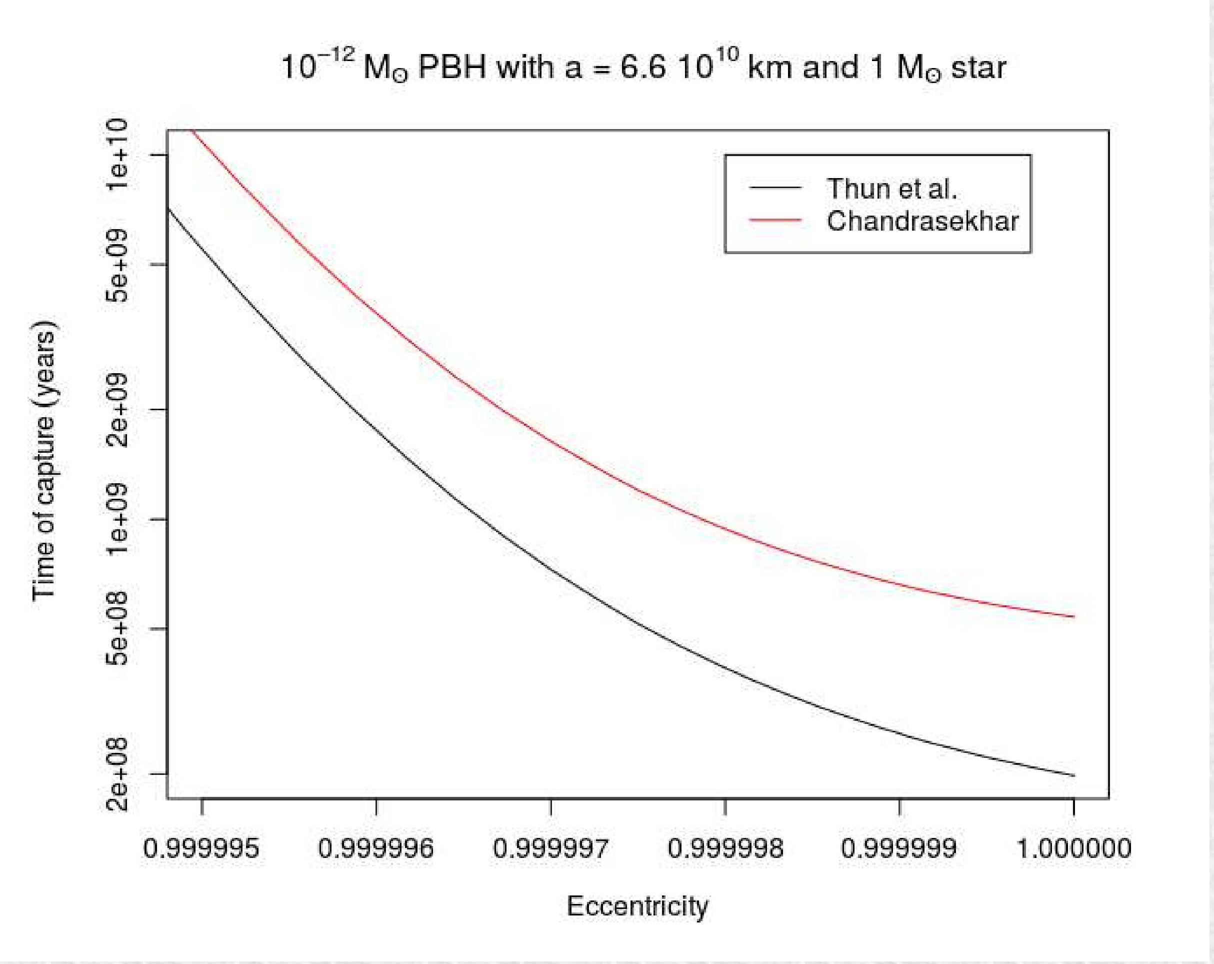
The loss of energy per orbit increases the deeper it reaches into the star and the slower the PBH goes but at some point it reaches a maximum, around $5 \cdot 10^{-5}$ km^2/s^2 for this particular case. This means if a PBH is captured in time or not depends heavily on the period of the orbit.

Capture Rate

- We start a test case, a $10^{-12}\ M_{\odot}$ PBH orbiting a $1M_{\odot}$ star at around $7\cdot 10^{10}$ km, and evolve the orbit at various eccentricities.

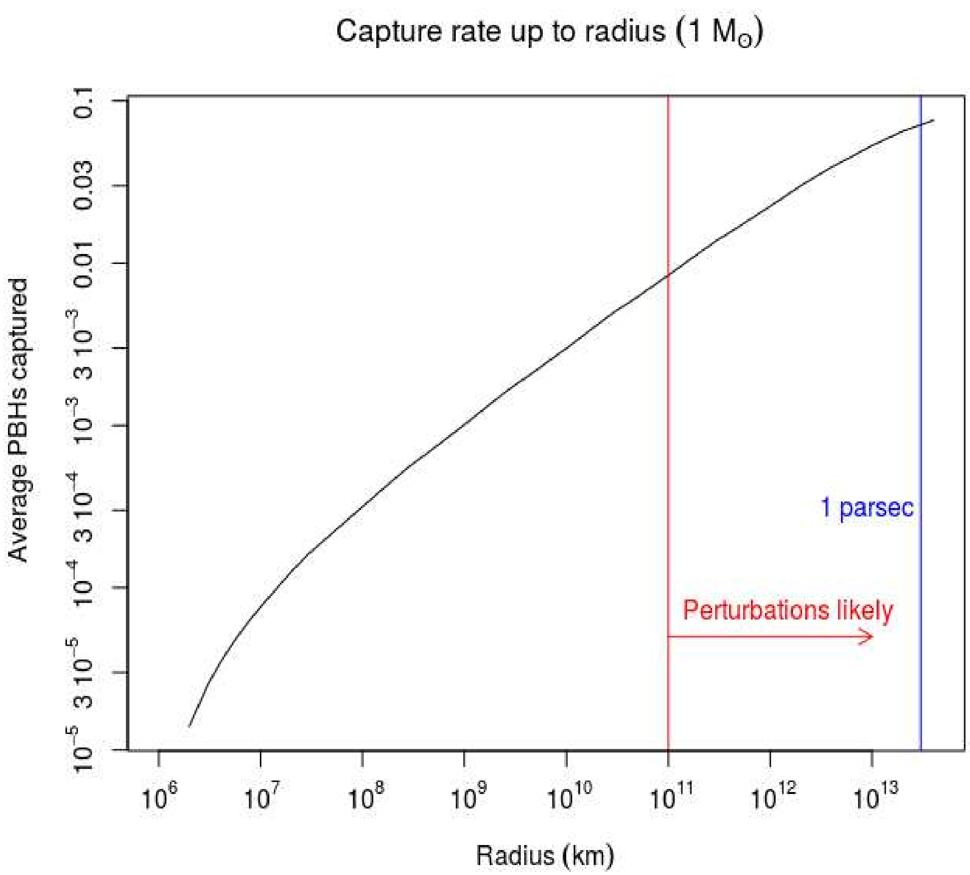
- We found that while it requires high eccentricity, capture is still possible even at such distances.

- As expected, higher eccentricities result in smaller times of capture. This allows us to define a critical eccentricity, above which the PBHs at that distance/energy will be captured within 10^{10} years.

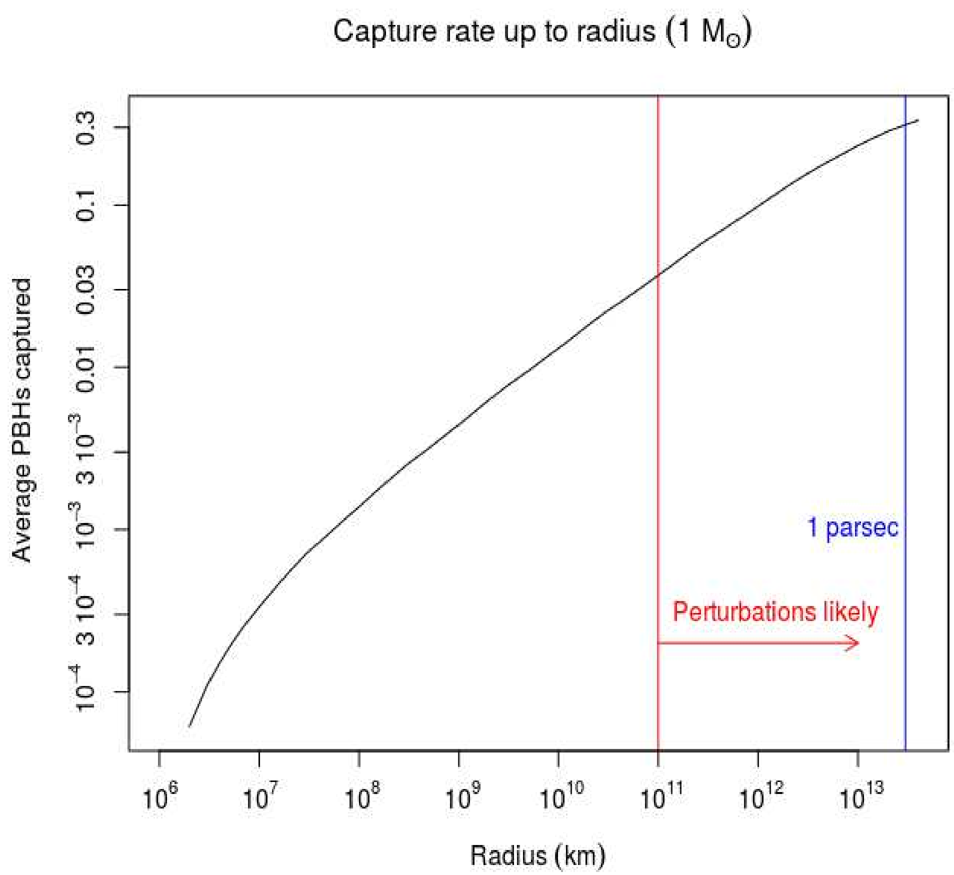


Results

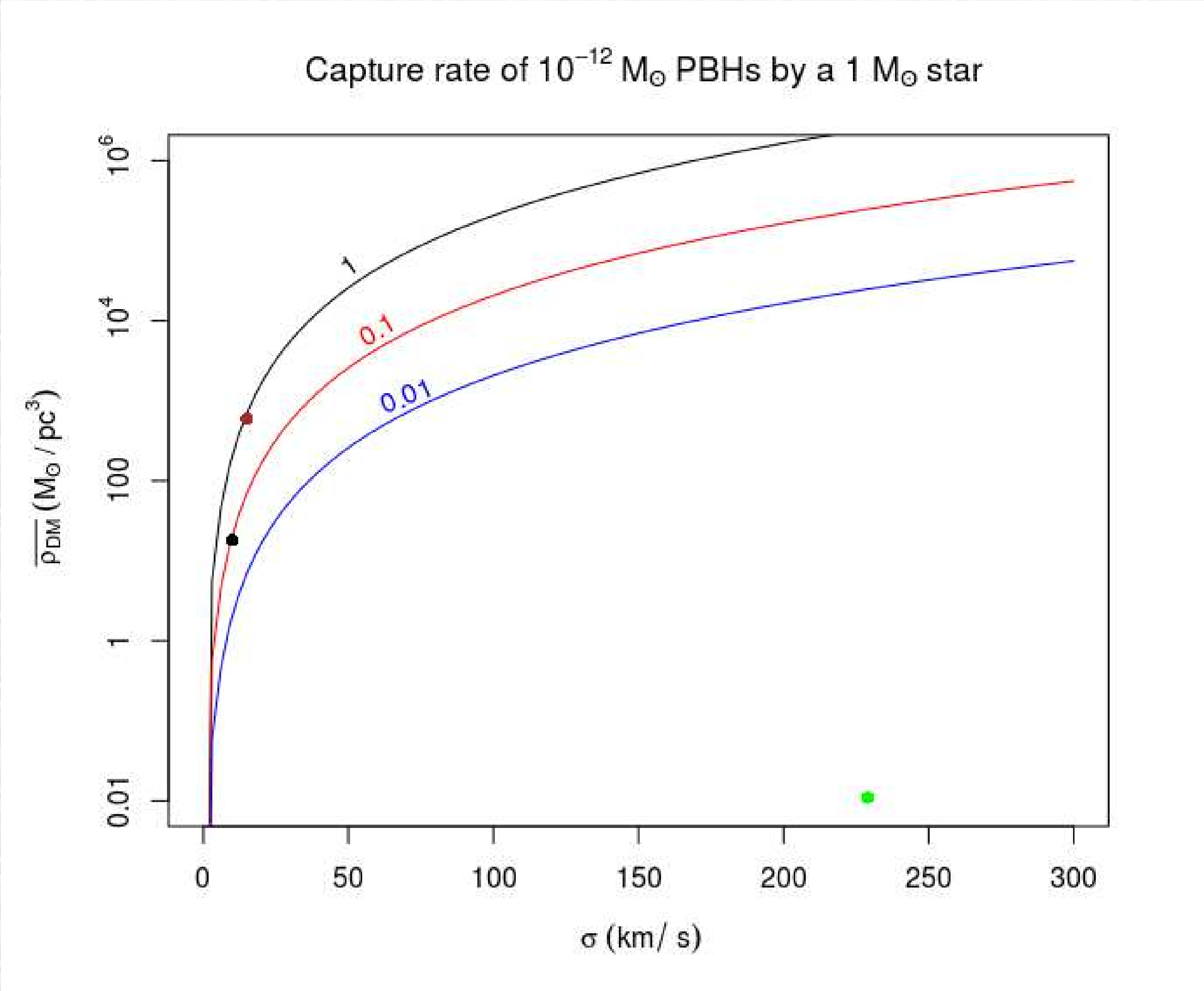
DM density determines the chances a PBH is at a certain radius and we assume a flat thermal eccentricity distribution ($F(e) = e^2$). This allows us to compute the average PBHs within that radius that are captured in 10^{10} years, assuming they have a mass of $10^{-12}\ M_\odot$.



Capture rate of a star at 0.1 R_{vir} .



Capture rate of a star in the same relative position as the Sun.



Capture rate contours (1, 0.1 and 0.01 average PBHs captured in 10^{10} years) at various densities and dispersion velocities. Black point is our test case, the star at z~20 and $0.1R_{vir}$. The brown point is the globular clusters argued by Capela et al. 2017, while the green point is the local solar environment.

Conclusions

- PBHs still have a window in which they can comprise all of the Dark Matter between 10^{-15} and 10^{-12} $M_{\odot}$. This window is hard to constrain, but one way to do it is by studying the possible capture of PBH by stars.
- While it's a lengthy process, dynamical friction can amount to a high enough energy loss that the PBH ends up settling at the core of the star. At the core of main sequence stars, accretion is relatively fast and the process would be finished in 1 Gyr.
- In particular, in the high density and low velocity dispersion of the early universe it should be a surprisingly common process.
- This should result in Black Holes massive enough to be observable, but with a significant fraction below the Chandrasekhar mass. The PBH would also take the star's position, mass and velocity. An observable result of this would be a sub-Chandrasekhar mass BH-star binary.