Primordial Planck mass black holes (PPMBHs) as candidates for dark matter?

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Abstract. It is proposed here that due to rapid cooling at the end of the Planck-era a second order phase transition with Planck-size space-time-energy fluctuations may have led to a precipitation of Planck-dimension real objects with masses around \( m_P \) and hence a Schwarzschild radius \( \mathcal{R} = 2Gm_P/c^2 \). This equals twice their spatial dimension \( l_P \); hence they are black holes. They could have survived through inflation and expansion because of their extremely small cross section for the fluctuations that are supposed to cause the hypothetical Hawking decay. In the case of our galaxy they could thus be the missing WIMPS of the dark mass halo, consisting of \( \sim 10^{50} \) PPMBHs – in contrast to the \( \sim 10^{68} \) baryons in the stars – both bound together by gravitation with negligible other interaction between the two. They would constitute a storage of gravitational energy three orders of magnitude larger than the energy stock of \( H \rightarrow He \) fusion, an energy to be released somehow when they very slowly coalesce to form big black holes.

1. The birth of quantum theory and of Planck units

Six years after his epoch-making discovery of the quantization of radiation energy and a first remarkably accurate estimate of his constant \( h \), Max Planck devotes a chapter of his 1906 book Theory of Thermal Radiation to the construction of a system of basic natural units of length, time and mass, today called Planck units. They are constructed from the three fundamental constants of nature: \( c, G \) and \( h \) (or \( \hbar = h/2\pi \)); much of today’s cosmology uses these three alleged invariables to extrapolate the evolution of our universe back to a plausible model for the famous first three minutes, thus tacitly assuming these constants had their presently measured values throughout the evolution of our universe.

Planck units can be constructed because speed of light \( c \), gravitational constant \( G \) and Planck constant \( h \) all contain in their definition different arithmetic combinations of length \( L \), time \( T \) and mass \( M \): \( c [L/T] \), \( G [L^3/MT^2] \), \( h [ML^2/T] \).

Thus a seemingly trivial reshuffling leads to the desired new units: Planck length \( l_P \), Planck time \( t_P \), and Planck mass \( m_P \), given here with their numerical values [1] in our conventional SI units:

\[
\begin{align*}
l_P &= \sqrt{(hG/c^3)} = 1.62 \times 10^{-35} \text{ m} , \\
t_P &= l_P/c = 5.40 \times 10^{-44} \text{ s} , \\
m_P &= h/l_Pc = 2.17 \times 10^{-8} \text{ kg} .
\end{align*}
\]
The simple construction, though, implies a much deeper insight: if c, G and ℏ express universal relations within the dynamics of the universe, the Planck units should give us a universal natural metric for this universe, spanning the cosmological gap between microphysics and macrophysics, in contrast to our familiar SI units that – like foot, hour, and pound – are strictly incidental and geocentristic, based on an arbitrary choice of equally arbitrary fractions of spatio-temporal dimensions of our little home-planet.

In spite of this plausible argument for Planck units, the idea was not followed up and nearly forgotten in the next half-century: not only are the Planck dimensions rather impractical, more than 25 orders of magnitude smaller than any quantities considered in that period, there were (and are) also no physical effects for which a theory predicts results containing both ℏ and G. In other words: quantum gravity as a branch of the discipline did not exist. Only 50 years later, when astrophysics and cosmology had become respectable and promising fields, one came back to the attempt to bridge the gulf separating the two extremely successful theories involved - general relativity as the theory of the very large, ruled by G - and quantum theory as the theory of the very small, ruled by ℏ; for a thorough account of these efforts of the last 50 years see [2].

It may have been noticed before, but not much discussed, that if objects of Planck dimensions did exist, they would be black holes: not really surprisingly, since we only have c, G and ℏ to play around with: the Schwarzschild radius $\mathcal{R} = \frac{2Gm_P}{c^2}$ of a Planck mass object equals twice the Planck length:

$$2Gm_P/c^2 = 2\sqrt{G\hbar/c^3} = 2l_P.$$  \hspace{1cm} (4)

Such objects of semi-classical Planck dimension, from here on called Planck mass black holes – PMBHs – would then obviously be the materialization of the missing link between QT and GR: both ℏ and G determine their properties.

2. The Planck era and the putative birth of Planck mass primordial black holes

Within the widely accepted scenario of the very early universe it is assumed that in the first extremely hot stage, a few Planck times after the bang, the state is homogeneous up to space-time - energy fluctuations of Planck dimension ($l_P, t_P, m_Pc^2$); this stage hence has been called the Planck era.

The energy involved in the fluctuations – $m_Pc^2$ – is $\sim 10^{19}$ GeV, the corresponding Planck temperature is:

$$T_P = m_Pc^2/k_B \sim 10^{32} \text{ K}.$$  \hspace{1cm} (5)

Within quantum field theory this stage is understood as the high temperature phase of QCD; forty years ago George Gamow created the wonderful word YLEM for the substance of this primordial state [3].

Now one may imagine the following scenario of a second order phase transition brought about by the dominance of gravitation between masses of Planck order at distances of Planck length order: Above a critical temperature $T_c$ of the order $T_P$ the primordial soup Ylem is nearly homogeneous; as it cools down to approach $T_c$ one expects critical fluctuations on the Planck scale. At further cooling Ylem divides up into two phases: a precipitation of grains of the black hole phase immersed in what is to become the quark-gluon-plasma: this is where "God divided the light from the darkness" (Gen.1 verse 4) - Planck mass black holes floating around in the future ordinary matter ("light") with none but gravitational interaction between the two, except for the elusive quantum relativity effects that may or may not occur near the horizon of the PMBHs to couple them to all other fields.

The PMBH-grains need of course not be uniform in size; their size and mass distribution around $l_P$ and $m_P$ should be determined by factors like the compressibility of the high temperature phase and the speed of cooling. In the extremely rapid expansion and cooling
phase only some part of the grains may have had a chance to coagulate to become the seeds of macroscopic black holes, the others will have remained as an extremely rarified gas; see sec. 4.

3. Could Planck mass black holes be (meta)stable?
The answer is obviously connected to the general question of the coupling of black holes to all other, non-gravitational fields, more specifically to the possible effect of the Hawking process on Planck-size objects. To quote Kip Thorne, an important contributor to the Black Hole Physics development in the 1970ies, who expresses his doubts 20 years later: “Maybe we physicists understand the quantum fields in a curved space-time much less than we believe. Our assumption that black holes vaporize might turn out to be a complete error.” [4]

Both empirical and theoretical arguments nourish these doubts still now:

- The intensive gamma-radiation from Hawking decay could up to now not be extracted and identified within the total gamma spectrum obtained with ever more sensitive gamma telescopes.
- A fundamental theory to fully and correctly describe the process by which one photon of a pair is falling into the hole to deliver the escape energy for the other one: that is precisely the theory of Quantum Gravity which – in spite of half a century’s work of the physics elite – we still do not have.

There are, e.g., recent string theory considerations indicating the possibility of a very slow decay [5].

But even assuming the Hawking process does exist, one may argue that it is nearly forbidden for Planck size objects that can only interact with quantum fluctuations of wavelengths around $l_P$: the phase space segment of such fluctuations is vanishingly small and hence also the probability of PMBH vaporization. Accepting these arguments for the near stability of PMBHs and the evidence that galaxies are immersed in a halo of dark matter that may consist of WIMPs – massive particles slow enough to be bound gravitationally in this halo and with (nearly) vanishing other interactions – we arrive at the hypothesis that these mysterious WIMPs could be the primordial PMBHs.

4. Our galaxy’s dark matter halo
The proposition is that the dark matter halo in which our galaxy appears to be embedded is made up of black holes with undiminished masses of the order of Planck masses, i.e. some $10^{-8}$ kg each. With an estimated $2 \times 10^{41}$ kg of baryonic mass in the galaxy, roughly $10^{68}$ baryons, and apparently at least 5 times more dark mass, this amounts to an estimate of $10^{50}$ PMBHs within the halo of about $10^5$ light years diameter, in other words roughly one PMBH in $10^{13}$ m³.

Since they appear to be gravitationally bound to the galaxy, their velocities must be in the range up to the escape velocity from the galaxy’s outskirts, that is up to 500 km/s. In contrast to the nondescript WIMPs - after all nothing more than a nice word for something unknown - the proposed PMBHs would at least have a cosmological history, a plausible origin at the end of the Planck era. But how could any empirical evidence of their survival and their individual existence be obtained and a search for them organized, beyond the collective gravitational effect ascribed to them?

This question can convincingly only be answered once we have a valid concept of quantum gravitation, that is better understanding of the interaction of quantum fields with curved space-time.

In detail we would have to be able to answer questions like this:

What happens if the classical trajectory of a PMBH traverses a proton which - classically speaking - is twenty orders of magnitude larger than the hole’s Schwarzschild radius? (The
purely gravitational classical interaction of the two would lead to a transfer of a tiny fraction of kinetic energy of the order $m_p/m_P \sim 10^{-19}$, not much of a moderation.)

What happens in a rare close encounter of two PMBHs? In a fusion at least part of the gravitational potential energy of the Newtonian order $E_{pot} = Gm_P^2/l_P = m_Pc^2$, i.e. of the order of their rest energy, might be emitted as some kind of radiation.

What composition would this emission have – gravitons, ultrahard gamma rays, particle showers? How efficient would the different decay channels be?

One might announce a competition for a study: Potential graviton emission from the fusion of primordial Planck mass black holes.

To sum it up: if the speculations developed here find any attention, they might motivate some specialists for such investigations. In any case the gravitational fusion energy $E_{pot}$ stored in the PMBHs that make up all the dark matter in the galaxies would be three orders of magnitude larger than the $H \rightarrow He$-fusion energy of all protons. This gives rise to a further daring speculation: Might such energy, extremely slowly released as radiation over many billions of years since the formation of dense regions in galaxies, play a role as a source of dark energy?

References

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