Black holes in D>4 dimensional space-times

R. A. Konoplya
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Why D>4

We know 4 fundamental interactions:

Interaction	Relative Strength	Theory
Gravitation	1	General Relativity
Weak	10^{25}	Electroweak theory
Electromagnetic	10^{36}	Quantum electrodynamics
Strong	10^{38}	Quantum chromodynamics

Weak:
The W^+ W Z gauge bosons mediate the weak interactions between particles of different flavors, called quarks and leptons.

Electromagnetic :
Photons mediate the electromagnetic force between electrically charged particles.

Strong :
Gluons mediate the strong interactions between color charged particles -the quarks.

- A few important facts:
- 1) Our usual matter consists of particles of half-integer spin called fermions, which are either quarks and or leptons.
- 2) In the same manner as electrons have electric charge, quarks and leptons have strong charge, called color.
- While there is one type of electric charge (or if you whish two: positive and negative), in strong interactions we observe 3 strong charges (colors) , usually called blue, green, and red (or if you wish 6, including anti-colors).
- Three of the four fundamental interactions can be well described by a single theory called the Standard Model.
- It is “so standard” by now that physicists use only two letters for it:

SM

And it seems everything is going very well, IF……………………..

- IF one does not wish to unify all interactions in a single theory
- IF one is not interested why gravitational energy scale is so small compared to the other three interactions energy scales.

- First IF is claimed to be answered in the future by an attempt to unify all interactions within a new paradigm called string theory
- Second IF could, hopefully be answered by the physical models implying existence of more than 4 space-time dimensions in nature: the brane-world models

- Both the string theory and the brane-world models imply that there are more than three spatial dimensions in our world! How one could imagine that!?
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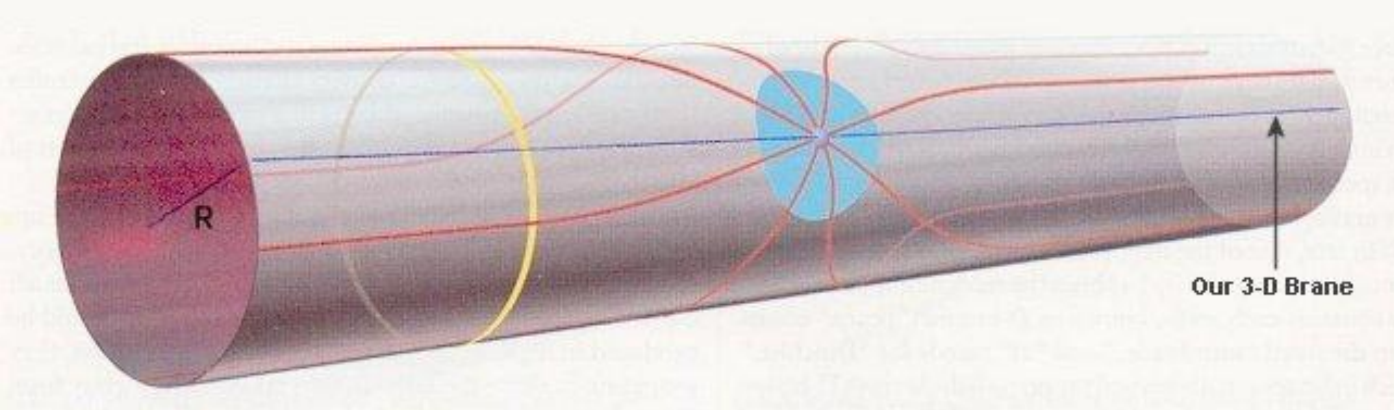
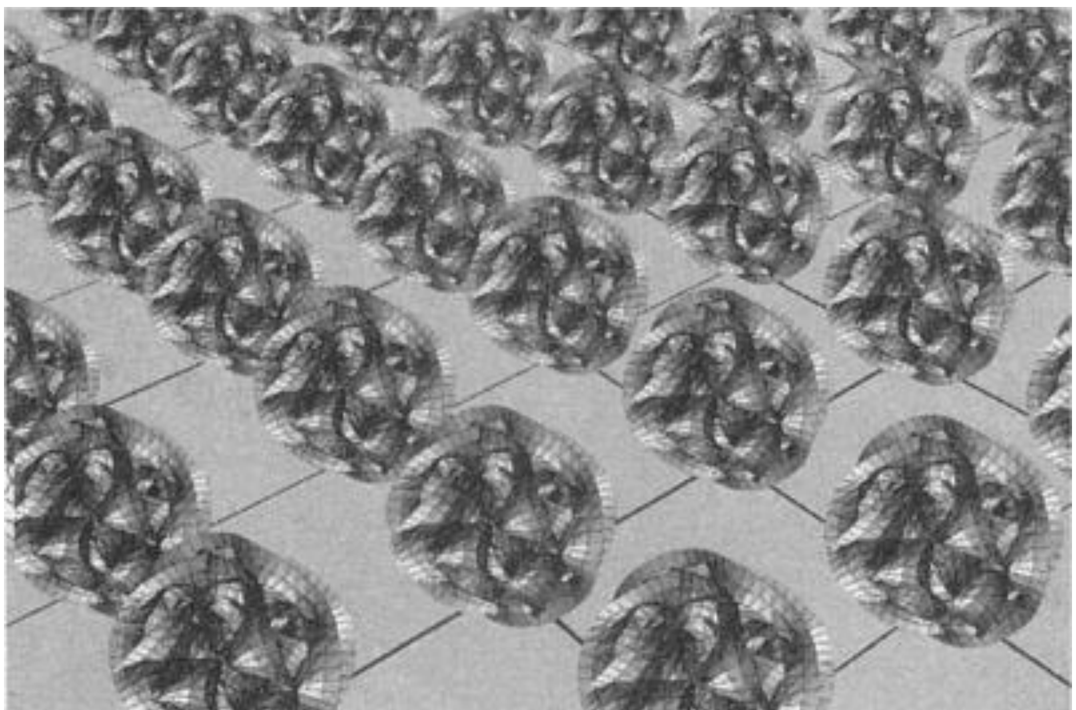
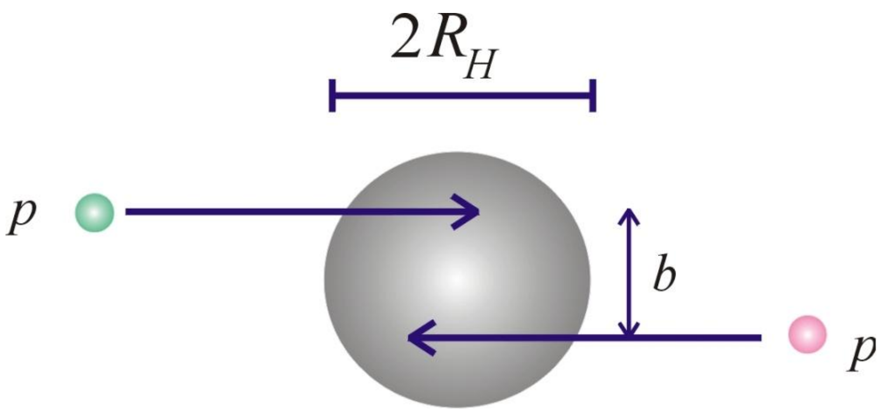


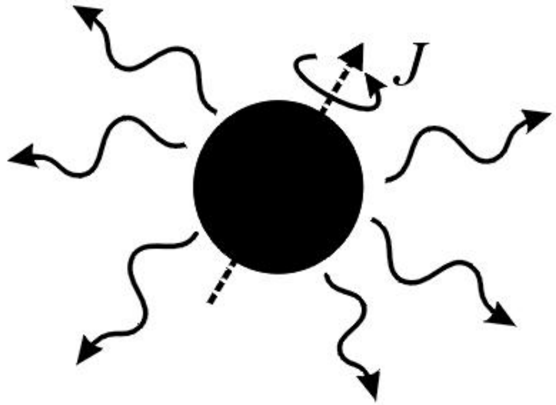
SMALL EXTRA DIMENSION wrapped in a circle (*circumference of tube*) modifies how gravity (*red lines*) spreads in space. At distances smaller than the circle radius (*blue patch*), the lines of force spread apart rapidly through all the dimensions. At much larger distances (*yellow circle*), the lines have filled the extra dimension, which has no further effect on the lines of force.



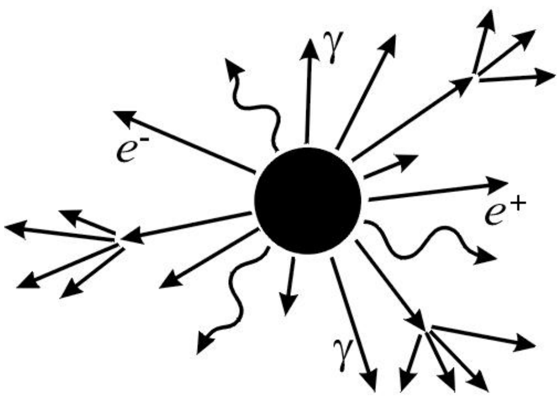
Higher dimensional models suggest an explanation why gravity is so weak in comparison with other interactions: electromagnetic , strong and weak interactions are supposed to be limited by our 3-dimensional world, called the brane, while gravity can live in the whole higher dimensional space. Being "smudged" over a number dimensions gravity is weak, while other interactions are "concentrated" in our 3-dimensional "brane".

In higher dimensions gravity becomes much stronger at small distances, so that the radius of the event horizon might be larger than expected from 4-dimensional theory, and possibly, even so large that a pair of particles colliding at Tev energies could enter under "a common horizon" , so that miniature black hole could be formed.



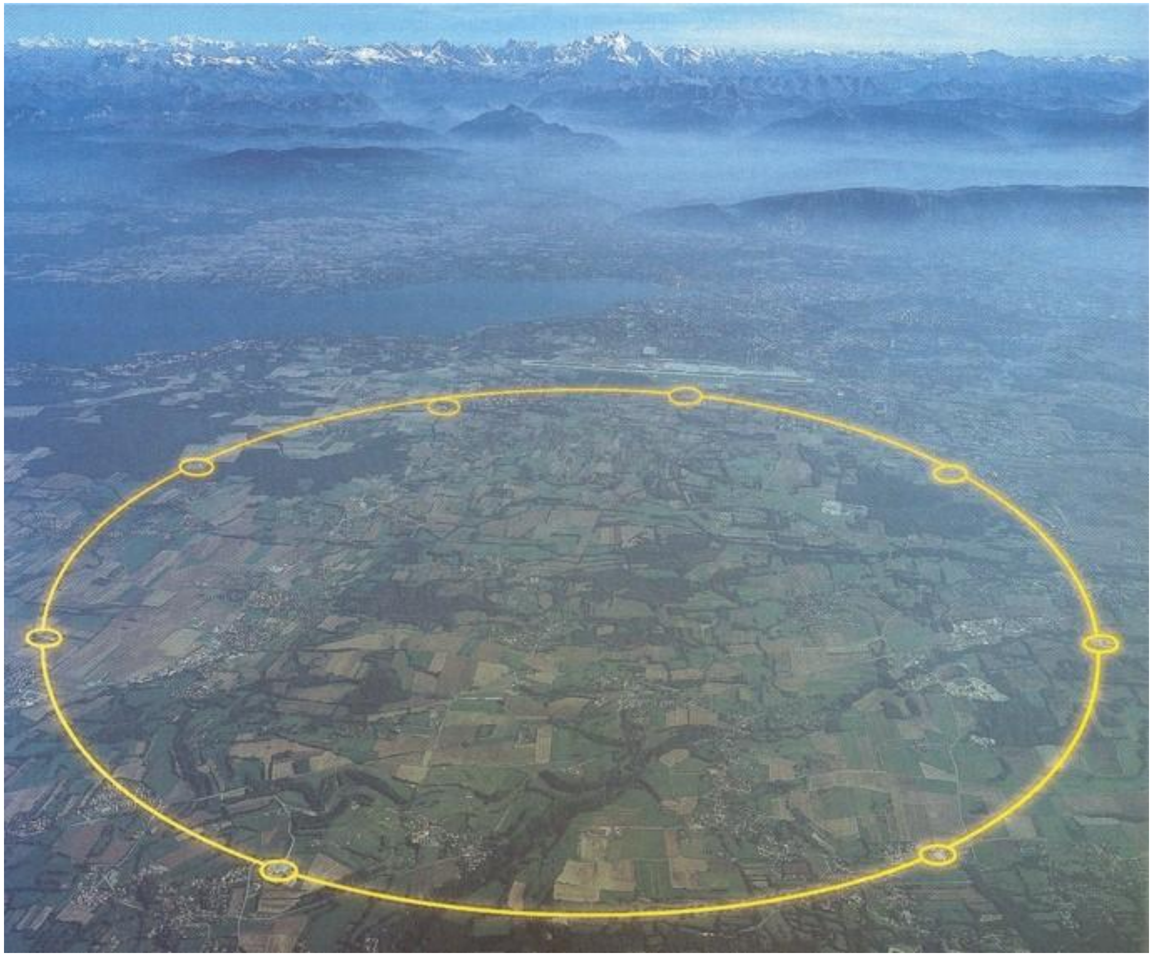


Balding phase



Evaporation phase

There is little hope that higher dimensional black holes might be observed in LHC



- There is a crucial difference between black holes in four and higher than four space-time dimensions:
- In four dimensions only black holes with the ball topology are possible (they are described by Schwrazschild or Kerr solutions of the Einstein equations)
- In D>4 dimensions there is a zoo of solutions which behavior like a black hole (i.e. they have an event horizon) but have different topology. For instance, there are black rings, which have a form of torus or the so-called black saturn, which is a black hole with a black ring around it.
- Which of these "black" solutions can exist?
- Stability may be the criterium of existence.
- In order to study stability of black holes we need to consider small gravitational perturbations of the black hole space-time and see the response of a black hole to the initial perturbation.

The response of the black hole to the initial perturbations consists of 1) initial outburst, 2) a number of damped oscillations called the quasi-normal modes , 3) the late time “tale”. The typical form of a response of the stable black hole is shown below:

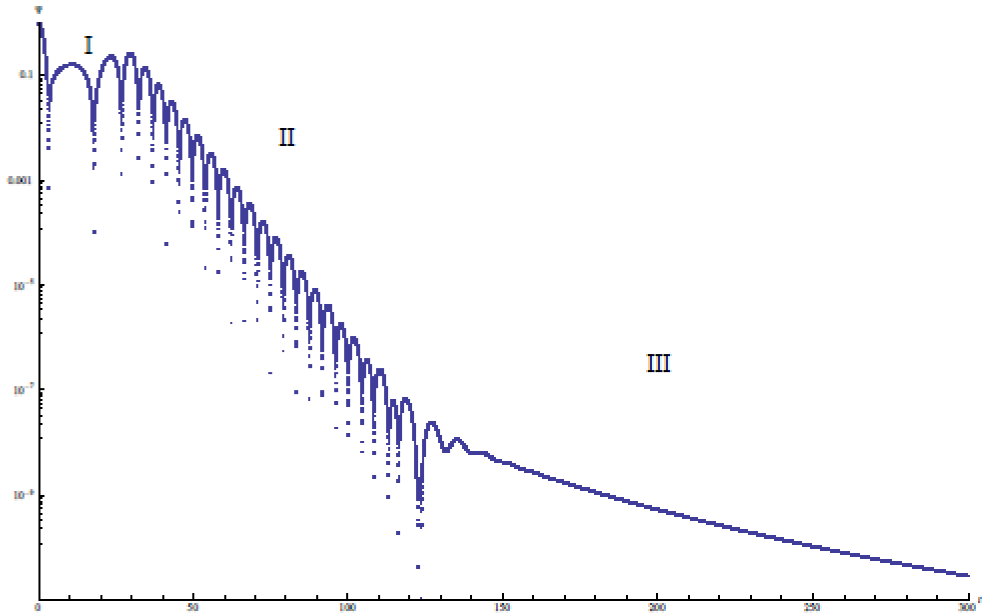


FIG. 3: An example of a time-domain profile for the Schwarzschild black hole gravitational perturbations ($l = 2$ vector type, in the point $r = 11r_+$).

Perturbations of higher dimensional black holes and string theory

- The key theoretical problem of the modern particle physics is search for the adequate description of interactions of quarks and gluons, quantum chromo-dynamics, that would be valid at all energies.
- An ordinary quantum chromo-dynamics is described by the symmetry which is called SU(3), where 3 is for the three colors of quarks (blue, green and red).
- String theory up to now can perform calculations in the theory called the conformal field theory SU(N), where N is infinite. Thus we have a theory with an infinite number of colors . The word "conformal" roughly means that the strength of particle interactions does not depend on the energy of the particles involved. This theory is certainly a robust approximation to the real situation.

There is a kind of calculation tool or duality, called

the correspondence between

the conformal field theory and the gravity

According to this duality the knowledge about characteristic spectrum of a perturbed black hole can give us description of the hydrodynamic regime of the conformal field theory at finite temperature T. This temperature is the Hawking temperature of the black hole on the side of the duality.

Though it sound as a science fiction rather than as science, this duality allowed to find a universal relation for quark-gluon plasma

$$\frac{\eta}{s} = \frac{1}{4\pi}. \qquad (205)$$

Thus, *for all field theories at finite temperature, which can be described by some dual gravitational background, the ratio of the shear viscosity η to the entropy density s is always $\hbar/4\pi k_b$*, where k_b is the Boltzmann constant.

Very close values of the shear viscosity/entropy density ratio is observed at the Relativistic Heavy Ion Collider.
This might be na experimental confirmation of string theory.