Summary of the previous study

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In an attempt to unify fundamental forces including gravity, the possibility that the space-time dimensions of our universe is higher than four has been much discussed. Such higher dimensional theories need a mechanism to reduce the space-time dimensions down to four. The brane world scenario is an attractive idea of the dimensional reduction. In this scenario, the standard model particles are confined to the boundary of higher-dimensional space-time and only gravity can propagate in the extra dimensions.

Some model of the brane world scenario suggest that small black holes are produced in high energy cosmic ray events or in accelerators, such as the CERN Large Hadron Collider. In order to understand physical phenomena caused by strong gravitational fields, the criterion for black hole formation is very crucial.

Recently, two of the collaborators, Daisuke Ida and Ken-ici Nakao, proposed such a criterion (*the hyperhoop conjecture*) ; *"Black holes with horizons form when and only when a mass M gets compacted into a region whose $(D-3)$-dimensional area V_{D-3} in every direction is*

$$V_{D-3} \lesssim G_D M.\text{"}, \tag{1}$$

where G_D is the gravitational constant in D-dimensional theory of gravity, and the $(D-3)$-dimensional area means a volume of $(D-3)$-dimensional closed submanifold (*the hyperhoop*) of a spacelike hypersurface.

Then we studied both the necessity and sufficiency of the inequality (1) in the five-dimensional space-time $D = 5$. We considered four-dimensional initial hypersurfaces in which a four-dimensional homogeneous spheroid is put as a gravitational source, and we obtained consistent results with hyperhoop conjecture. The other important result is obtained from infinitely thin limit of the spheroid. In this case, we found the space-time singularity which is not covered by an apparent horizon. Our results suggest a possibility of naked singularity formation by spindle gravitational collapses in five-dimensional space-time, where naked sigularity is the singularity which do not covered by the event horizon.