Astrophys Space Sci (2013) 348:217–219
DOI 10.1007/s10509-013-1564-5

ORIGINAL ARTICLE

Holography, dark energy and entropy of large cosmic structures

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Received: 13 March 2013 / Accepted: 6 July 2013 / Published online: 1 August 2013

Abstract As is well known, black hole entropy is proportional to the area of the horizon suggesting a holographic principle wherein all degrees of freedom contributing to the entropy reside on the surface. In this note, we point out that large scale dark energy (such as a cosmological constant) constraining cosmic structures can imply a similar situation for the entropy of a hierarchy of such objects.

Keywords Black hole entropy · Holographic principle · Cosmological constant

The holographic principle (Susskind 1995; 't Hooft 1993) has been invoked in connection with the well known result that the entropy of black holes scales with the area of the horizon (rather than volume like other systems). Thus:

$$S = k_B \frac{c^3}{4G\hbar} A \tag{1}$$

where A is the black hole horizon given by:

$$A = 4\pi \left(\frac{2GM}{c^2}\right)^2 \tag{2}$$

M is the black hole mass.

This implies: $S \cong k_B \frac{A}{L_{Pl}^2}$ (3)

where, $L_{Pl} = (\frac{\hbar G}{c^3})^{1/2}$ is the Planck length.

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Now in recent papers (Sivaram 1994a, 2008; Sivaram and Arun 2012a) a new kind of cosmological paradigm was invoked wherein the requirement that for a hierarchy of large scale structures, like galaxies, galaxy clusters, superclusters, etc. their gravitational (binding) self energy density must at least equal or exceed the background repulsive dark energy density (a cosmological constant as current observations strongly suggests) implies a mass-radius relation of the type:

$$\frac{M}{R^2} = \frac{c^2}{G}\sqrt{\Lambda} \tag{4}$$

(The requirement that gravitational self energy density $= \frac{GM^2}{8\pi R^4}$ should be comparable to the background cosmic vacuum energy density of $\frac{\Lambda c^4}{8\pi G}$ for the object to be gravitationally bound (autonomous) structures, implies Eq. (4) above (Sivaram 1994a, 2007, 2008)). Λ here is the cosmological constant with an observed value of 10^{-56} cm^{-2}.

Thus: $M \propto R^2$ (5)

Equations (4) and (5) are seen to hold for a whole range of large scale structures, including the Hubble volume. Thus:

$$R_{gal} = 3 \times 10^{22}\ \text{cm} \quad \Rightarrow \quad M_{gal} = 10^{45}\ \text{g}$$

$$R_{clus} = 3 \times 10^{24}\ \text{cm} \quad \Rightarrow \quad M_{clus} = 10^{49}\ \text{g}$$

This relation holds right down to globular clusters (Sivaram 1994b).

Considering that these structures are constituted by N particles of mass m, then the entropy can be written as:

$$S = k_B N \tag{6}$$

(for identical particles).