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Letter

Where is the Entropy in DSSYK–De Sitter? Correction to a Wrong Claim

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Abstract. In this paper I explain the relation between the need for observers in de Sitter space and the spontaneous breakdown of time-reversal symmetry. In this paper I explain the relation between the need for observers in de Sitter space and the spontaneous breakdown of time-reversal symmetry.

Keywords: Holography; De Sitter Space; Time-Reversal Symmetry.

Contents

1 Notational Issues and Scales

Before discussing main point of this note I'll address some notational issues. I will use the notations of my Stoney Brook lectures with one exception[1]

Coupling Constants

In earlier papers [1,2] and in my lectures I identified the DSSYK$_\infty$ parameter λ with g_{string} by which I meant the closed-string coupling constant. This may be confusing because the 't Hooft model [3] does not have closed strings; it is a pure open string theory. What I should have said is that

$$\lambda = g_{string}^2,$$

where g_{string} is the open-string coupling. But it's too late for that now. Instead I will write,

$$\lambda = g_{open}^2. \tag{1.1}$$

As I said, there are no closed strings in the 't Hooft model so that

$$g_{closed} = g_{open}^2, \tag{1.2}$$

is merely a definition, but in string theory with both open and closed strings (1.2) correctly relates closed and open string couplings.

Review of Scales

In figure 1 the relation between the various scales that appeared in my lectures is shown on a logarithmic plot [4]. The relations between the scales are,

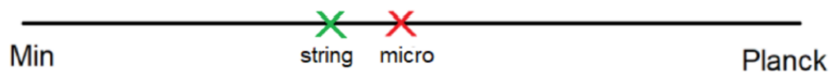

Figure 1: Energy scales shown from the lowest M_{min},
i,e,. the Gibbons Hawking temperature, to the maximum mass—the scale at which the conical deficit is equal to 2π. The micro scale is the geometric mean of M_{max} and M_{min}.

$$\begin{aligned} M_{micro} &= \sqrt{M_{planck} M_{min}} = M_{Planck}/\sqrt{N}, \\ \frac{M_{planck}}{M_{min}} &= N, \\ M_{string} &= \sqrt{\lambda} M_{micro} = \sqrt{\frac{\lambda}{N}} M_{Planck}. \end{aligned} \tag{1.3}$$

[1] Here is the URL to access the lectures. https://scgp.stonybrook.edu/video_portal/results.php?profile_id=2366

2 The Phase Boundary

In this note I want to correct a serious error that I made in a number of papers [1][2] as well as lectures at the Simons Center in Stoney Brook. The error has to do with the nature of the stretched horizon in the DSSYK_∞/ JT-de Sitter correspondence. It relates to a puzzle that bothered me, having to do with the role of the Planck scale in the DSSYK_∞/ JT-de Sitter correspondence. In my lectures the string scale played a very prominent role but the Planck length ℓ_{planck} played almost none. This was based on a misconception that I will explain shortly.

Let me summarize what I said at the end of Lecture 2 (and then repeated at the end of Lecture 4) where I was explaining the flat-space limit, in which the static patch becomes the Rindler patch. I began by dividing the Rindler patch into two regions, a cold region $T < \Lambda$ and a hot region $T > \Lambda$ (see figure 2). Λ is the QCD scale[2] defined by the string tension $\tau = \Lambda^2$. It also corresponds to the string-mass M_{string} in equations (1.3).

The mistake was to conflate Λ with the confinement-deconfinement transition temperature T_c which would be correct in four-dimensional QCD but not in two-dimensional QCD. I also mistakenly identified the blue curve, at a distance ℓ_{string} from the horizon, as the phase boundary separating the confined and deconfined phases.

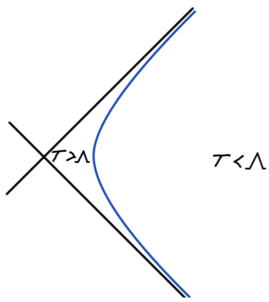

Figure 2: Rindler space divided into hot and cold regions by a curve along which the temperature is the QCD-scale. The distance of the dividing curve from the horizon is the string length. The mistake was to identify the curve with the phase boundary separating the cold confined region from the hot plasma deconfined region.

My conclusion was that in the region $\rho < \ell_{string}$ (ρ is the proper distance from the horizon) quarks are unconfined and propagate freely, and that the entropy stored in this stringy region is order N, while the entropy in the cold region is order 1.

The argument is correct except for the fact that the confinement-deconfinement transition in QCD_2 is not at the string-scale temperature Λ, but at the parametrically higher temperature[3] [5],

$$\begin{aligned} T_c &= \Lambda\sqrt{N} \\ &= M_{string}\sqrt{N} \end{aligned} \tag{2.1}$$

Using the relations (1.3)

$$M_{string} = \sqrt{\lambda} M_{micro}$$

[2]The QCD scale Λ should not be confused with the DSSYK parameter λ.

[3]I thank Steve Shenker and Sumit Das for pointing this out to me.

$$= \sqrt{\frac{\lambda}{N}} M_{planck} \tag{2.2}$$

and $\lambda = g^2_{open}$ we find,

$$T_c = g_{open} M_{planck}, \tag{2.3}$$

rather than the parametrically lower scale M_{string}. Correspondingly, the distance of the stretched horizon from the mathematical horizon is,

$$\rho_{sh} = T_c^{-1} = g^{-1}_{open} \ \ell_{planck}. \tag{2.4}$$

Assuming $g_{open} \sim 1$ the Plank scale emerges as the scale at which the horizon entropy is stored. Perhaps this is not unexpected in retrospect, but it is interesting the way it follows from the the statistical mechanics of the 't Hooft model as calculated by McLerran and Sen.

3 Comparison with String Theory

Let us compare (2.3) with closed string theory in higher dimensions where there really is a transition at $T_c = M_{string}$, namely the Hagedorn transition. However, it is also true that the string and Planck scales are parametrically the same,

$$M_{string} = g_{closed} M_{planck}. \tag{3.1}$$

Thus it follows in string theory that,

$$T_c = g_{closed} M_{planck}. \tag{3.2}$$

Equations (2.3) and (3.2) are remarkably similar with the exception that g_{open} is replaced by g_{closed}. That is not at all surprising since the 't Hooft model is a pure open string theory with no closed strings in its spectrum.

4 Summary and Conclusion

It was in error on my part when I assumed that the confinement-deconfinement temperature was Λ, or equivalently the string scale, in the 't Hooft model. In fact the transition temperature was shown by McLerran and Sen to be much higher at

$$T_c = \Lambda\sqrt{N}.$$

That translates to a temperature near the Planck scale,

$$T_c = g_{open} M_{planck}.$$

This parallels closed string theory where the corresponding formula is

$$T_c = g_{closed} M_{planck}.$$

One lesson is that the huge horizon entropy in both cases is a Planck-scale phenomenon. In higher dimensional string theory there is not much difference between the string and Planck scales but in the two-dimensional case the difference is very large: the Planck and string scales differ by a factor of order $\sqrt{N}$.

In both cases the transition temperature has the form

$$T_c = gM_{planck}$$

with g being the open string coupling for the 't Hooft model, and the closed string coupling for closed string theory. This reflects the fact that the 't Hooft model is a theory of open strings.

Data Availability

The manuscript has no associated data or the data will not be deposited.

Conflicts of Interest

The author declares that there is no conflict of interest.

Ethical Considerations

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

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