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String Condensation and Gravitational Collapse - or why AdS may be closer than you think!

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Introduction

This talk in structured as a progress report on work done since Discrete 2016 (MH 2016). The main new features of the current version are:

- An improved understanding of the relationship between the thermalon and acceleration.
- Torsion/contorsion is generated by the accelerated thermalon.
- The resulting geometry is AdS4 with torsion and a boundary with monotonic surface gravity.
- Extreme gravitational polarization at the boundary is no longer present.

cont...

- The thermal solution represents a modified vacuum with a different geometry.
- Matter in the interior is converted to excitations of this modified vacuum during collapse.
- The vacuum solution is an accurate approximation for astrophysical applications.
- The conversion to the string phase is now adiabatic - the conversion is ”frictionless”and does not generate entropy
- In the AdS bulk the torsion breaks the maximal symmetry, but not T, SO(3) rotations (if applicable) or D (dilatations)
- The final state would be T reversible if surrounded by a mirrored surface. A small window could be opened to allow arbitrarily slow decay.

- The analogue of the AdS/CFT correspondence applicable here implies that there should exist a scale invariant field theory on S2 x R1 equivalent to the strongly coupled bulk phase.
- This would describe the excitations produced by the ”swallowed”matter.
- The history of a collapsing object would have 3 stages

1. Initial ringdown
2. Adiabatic conversion
3. Decay, producing Hawking-like radiation

Background

- The programme here originated with (MH 1993). This was an attempt to address issues with the string theory of gravity in $D = 4$ rather than the black hole information problem. However, it suggests a scenario in which this problem does not arise.
- In $D = 4$ most string states would be hidden by horizons, leading to problems with unitarity for high energy scattering amplitudes.
- It was shown (MH 1993) that $< R^2 >\sim M$ using a generating function method.

This implies that for $D = 4$ strings and black holes cannot be distinct (if possibly) equivalent entities - they should be merged into some hybrid object, to avoid a conflict with unitarity for the hidden states.

Note: In (MH 1993) the divergent ground state contribution to $< R^2 >$ was discarded. This represents the logarithmically divergent length of a quantum string at short distances. This is similar to a fractal coastline, but with Hausdorff dimension less than $1 + \epsilon$ for any $\epsilon > 0$. Even if $< R^2 > \sim (M + \alpha \mathrm{log} M)$ this does not alter the conclusion.

Further, the average values of $< J^2 >$ and $< Q^2 >$ grow too slowly with the level $< n >$ to prevent horizons for most states.(Unlike for elementary particles.)

Another distinctive feature of $< D = 4 >$ is the role of a dimensionless coupling $< g >$.

The maximal value of $< Q^2 >$ for free heterotic strings agrees with that for an extremal Reissner-Nordstrom BH for any $< g >$, while the maximal $< J^2 >$agrees with an extremal Kerr BH for $g = 1$.

In the following we will consider the strong coupling limit $< g1 >$ where there would be no visible long strings in the normal vacuum.

Merging strings and BHs

Comparing the density of states for free strings and BHs, it can be seen that these can be reconciled using gravitational redshift at a fixed distance from the would be horizon, independent of M (MH 1993, Susskind 1993).

Here the surface gravity has a string scale value, which is also independent of M. Thus the Unruh temperature has a string scale value, suggesting a connection to the Hagedorn transition.

For this proposed merger to work, we need to LIMIT the gravitational redshift to $z \sim O(M)$. This requires that in some sense gravitational fields must be expelled once they reach a critical value related to the string scale. This would give a constant temperature in the interior.

The phenomenon of thermal duality (Atick, Witten) could provide such a stable temperature (MH 2015). Analysis of the free energy showed that screening could occur in GR with gravitational polarization giving positive energy at the outer boundary and negative energy at the inner boundary of a shell region of the string phase.

However, this extreme polarization seems an unattractive feature of this model.

Thermalon acceleration and (con-)torsion

- The Unruh temperature experienced by an accelerated observer in Minkowski spacetime can be understood via the observation that the Rindler coordinate system can be extended to complex time, and that along the imaginary time axis the hyperbolas generated by static time translation become circles. Applying this to the neighbourhood of a BH horizon gives the Hawking temperature when redshifted for a distant observer.
- Extending the thermal equilibrium solution of MH(2013) to complex time allows us to picture the thermalon as a string wrapped around the imaginary time direction.

- Our new model is based on extending Einstein gravity to the Einstein-Cartan framework with torsion. The surface gravity will level off from where the Unruh temperature reaches the Hagedorn point, stabilizes at the dual point and at the inner boundary increases to the dual Hagedorn temperature, where the condensate ends. In effect the constant temperature in the bulk is maintained by a Newton-Cartan anti-gravity compensating Einstein gravity to give a buoyancy effect. This gives an interior AdS with torsion geometry. Our claim is that the necessary torsion is provided by the accelerated thermalon condensate. How does this work?

As in the previous version the interior of the shell is under pressure from the boundaries giving a hyperbolic spatial curvature. As shown below the thermalon condensate generates torsion. At the dual point the system stabilizes, so the Einstein and Newton-Cartan components of gravity must cancel. The constant radial Einstein gravity will then)give the overall AdS4 geometry.

At each point of the interior AdS4 geometry the static time coordinate can be complexified giving a complex direction which closes as a circle with the dual point circumference. The complex spacetime is thus an S^1 bundle over the real spacetime. The complex time direction is spacelike, making a KK type manifold with constant S^1 circumference.

The heterotic thermalon is now the equivalent of a gauge boson for displacement along the imaginary static time direction. The wrapping round S^1 gives the left moving excitation of the thermalon string and an imaginary time coordinate fermion gives the right moving excitation. Note that both are imaginary, so their product gives a minus sign. Now an imaginary static time displacement is equivalent to an imaginary boost (as in the Rindler case) so the overall effect is to give a timelike gauge boson for boosts. This is a contorsion C^1_{00} in the Einstein-Cartan framework, giving a mapping or interpretation $\phi \rightarrow C^1_{00}$.

The negative sign means that the contorsion cancels the curvature of lines generated by static time displacement (hyperbolas) in the final geometry. Static time displacement thus generates parallel transport in addition to Lie transport, consistent with thermal equilibrium. The presence of two 0 indices respects T reversal as claimed.

ϕ as it generates C^1_{00} breaks the full symmetry of AdS4, but the property of scaling as the boundary is approached is preserved. There should exist a model with dilation symmetry on $S^2 \times R^1$ which captures the excitations of the strongly coupled system in the bulk.

The entropy density of the bulk vacuum is in some sense a mirage, as it represents the entanglement entropy of small volumes, whereas the whole is in a coherent state just as the Minkowski vacuum is in a coherent state despite the entanglement entropy of an accelerated observer.

Conversion process - some points

- The nucleation condition for conversion to the string phase to begin (MH 2015) is based on a generalisation of the local condition for forming a Penrose trapped surface. This is related to the concept of an apparent horizon, and is defined locally on time slices (Cauchy surfaces). Although in a collapse these surfaces would be found by a kind of quantum computation, a quantum computer is not needed for a simulation. Simulations similar in principle to those used in numerical GR would be needed to find how the model behaves beyond the simplest and most symmetrical cases.

- In particular, the nucleation condition is not related directly to event horizons which are a global property of spacetime. There is no relevance to cosmological event horizons, as a concentration of mass is needed to feed the conversion process.
- From GR there is a universal force of 1/2 in Planck units acting on a spherical shell of matter falling onto an existing collapsed core causing further nucleation. Similarly the shell experiences the equivalent of a Newtonian attraction of 1/4, and the net effect is to reverse the inward acceleration due to gravity.
- Because this braking force is distributed across solid angle, a more localised body will initiate nucleation further out. For a body of mass m distributed across a cross section a falling onto a collapsed core of mass M the nucleation distance for $a >> Mm$ is approximately

$$s = 16M^{3/2}\sqrt{\frac{\pi m}{a}}$$

- For a proton localized on an atomic scale falling onto a 10 solar mass collapsed core the nucleation distance is about 10^{-10} metres.
- For a supermassive 10^9 solar mass core, the corresponding distance might extend to 10 metres.
- It is doubtful whether this could have observable consequences.
- The conversion time is $O(M^2)$ so that for astrophysical applications this would still be ongoing, but most of the original mass would have been redshifted away already from our point of view.
- In the previous version the conversion process was interpreted as thermodynamically irreversible and made probable by the increase of entropy. In this version the conversion occurs as the string vacuum responds to the infalling matter, and simply represents a saddle point of the action.

Conclusions

- An updated model of the thermalon vacuum has an AdS4 geometry with torsion.
- This has surface gravity of the same order of magnitude through the boundary layers and avoids the extreme gravitational polarization of the original model.
- The modified vacuum would be a good approximation for astrophysical applications.
- The matter swallowed by the collapse would translate into excitations of this modified vacuum.
- These excitations should be described by an equivalent scale invariant boundary model (a version of AdS-CFT).
- Due to the absence of horizons there would be no information problem.
- Time reversal invariance is respected in the modified vacuum.
- Numerical simulation is probably required for all but the simplest cases.

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