Report on Projects on CTCs and Black Holes

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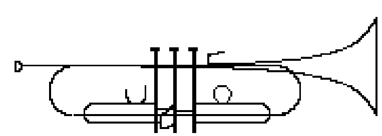
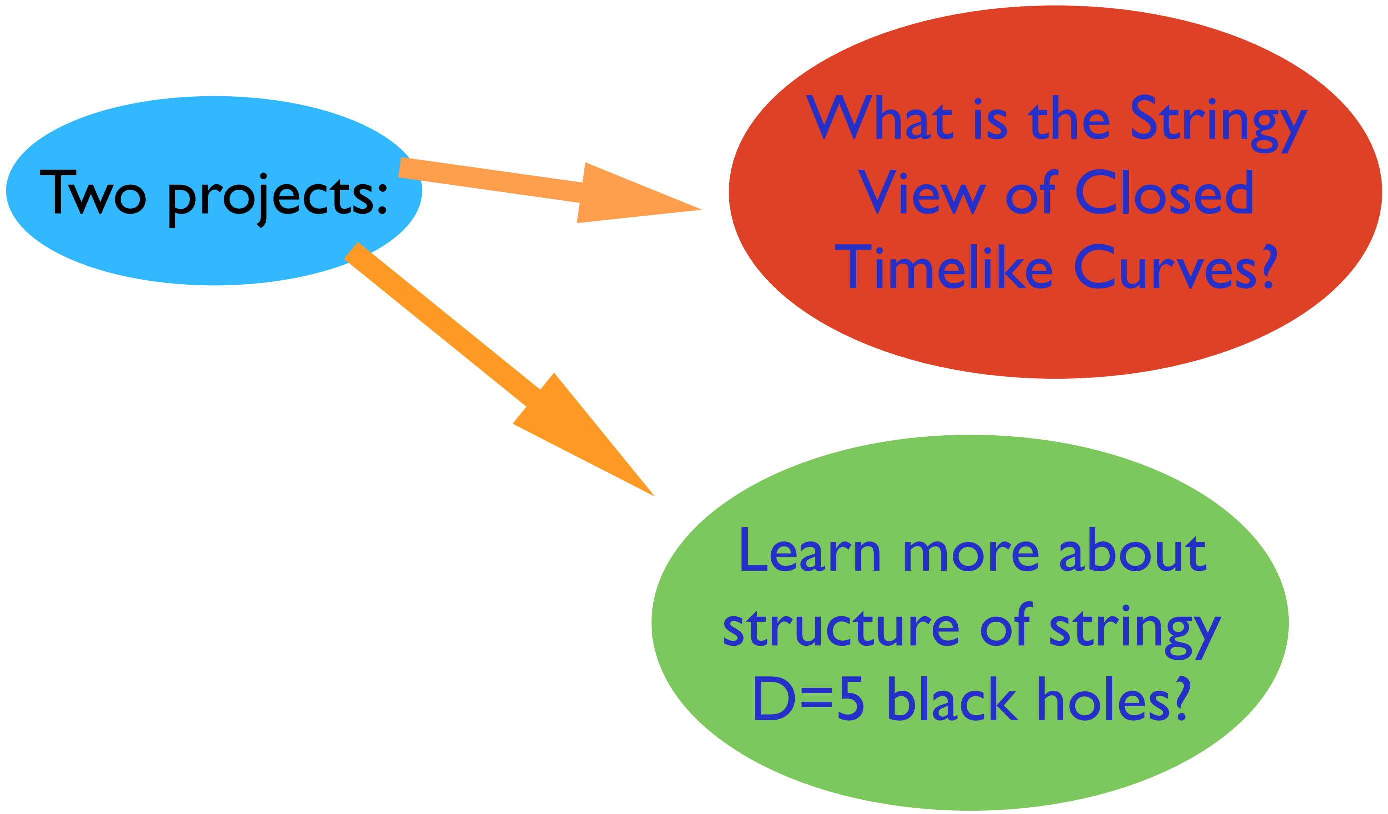


Overview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What is the Stringy View of Closed Timelike Curves?
Learn more about structure of stringy D=5 black holes?

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Project with H.G. Svendsen
hep-th/0405141

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Discover useful relation to recent proposal of S. Mathur?

Closed Timelike Curves

CTCs show up in GR a lot.
They're easy to make.
Classically pathological.

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Pick a Theory of QG and learn what it has to say

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Pick a Theory of QG and learn what it has to say

A traditional laboratory in GR has been Taub-NUT

Find a good laboratory in String Theory

Taub-NUT in GR

$$ds^2 = -f_1(dt - l\cos\theta d\phi)^2 + f_1^{-1}dr^2 + (r^2+l^2)(d\theta^2 + \sin^2\theta d\phi^2)$$

$$f_1 = 1 - 2\frac{Mr + l^2}{r^2 + l^2}$$

t has period $4\pi l$ (S^3 topology of constant r slices.)

$$f_1 < 0 \implies r \text{ is time}$$

$$f_1 > 0 \implies t \text{ is time}$$

NUT: region with CTCs

Taub:
Cosmological region
bounded by
Big Bang and Big Crunch

Taub-NUT in GR

Neighbourhood of Bang/Crunch is "Misner Spacetime":

$f_1(r) = 0$ is located at $r = r_\pm$ For small $\tau = r - r_-$:

$$ds^2 = -(c\tau)^{-1} d\tau^2 + c\tau d\xi^2$$

$$d\xi = dt - l\cos\theta d\phi$$

t fibred over S^2

Classic computation of stress tensor by Hiscock and Konkowski showed that it diverges there.

Suggests that (if one could do the QG computation), high energy effects destabilize the junction region.

Basis of e.g. Hawking's "Chronology Protection Conjecture"

Taub-NUT in String Theory

Wish:

Embed this problem into string theory and retain computational control over the relevant questions:

Is there a mechanism by which string theory removes CTCs, or makes them harmless?

Is the geometry modified by high energy effects, as suggested in GR?

Could there be other mechanisms that we can discover to achieve this?

And/or are there some contexts in which CTCs have a physical role?

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Luckily, there is a non-trivial embedding of Taub-NUT into string theory...
(C.V. Johnson, hep-th/9403192)

Furthermore... the full conformal field theory is known!

Taub-NUT in String Theory

$$ds^2 = k\left\{d\sigma^2 - \frac{\cosh^2\sigma - 1}{(\cosh\sigma + \delta)^2}(dt - \lambda\cos\theta d\phi)^2 + d\theta^2 + \sin^2\theta d\phi^2\right\}\ ,$$

$$\Phi - \Phi_0 = -\frac{1}{2}\ln(\cosh\sigma + \delta) \qquad B_{t\phi},\ A_\phi,\ A_t\ ,\ \text{also non-zero.}$$

Leading order in large $k \sim 1/\alpha'$
Heterotic string solution.

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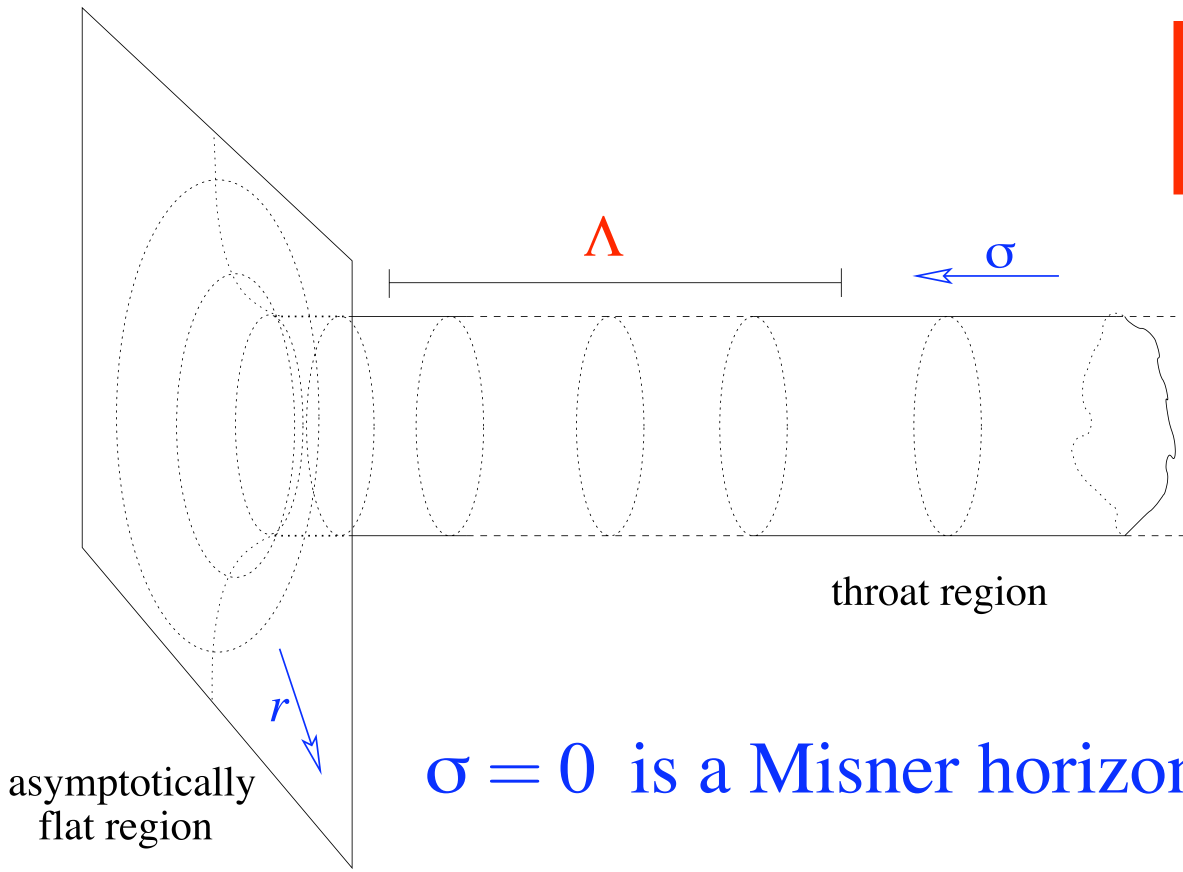

This is the near-horizon geometry of a larger solution

C.V. Johnson, hep-th/9403192
R.C. Myers and C.V. Johnson, hep-th/9406069
R.Kallosh et. al., hep-th/9406059.

$\sigma = 0$ is a Misner horizon.

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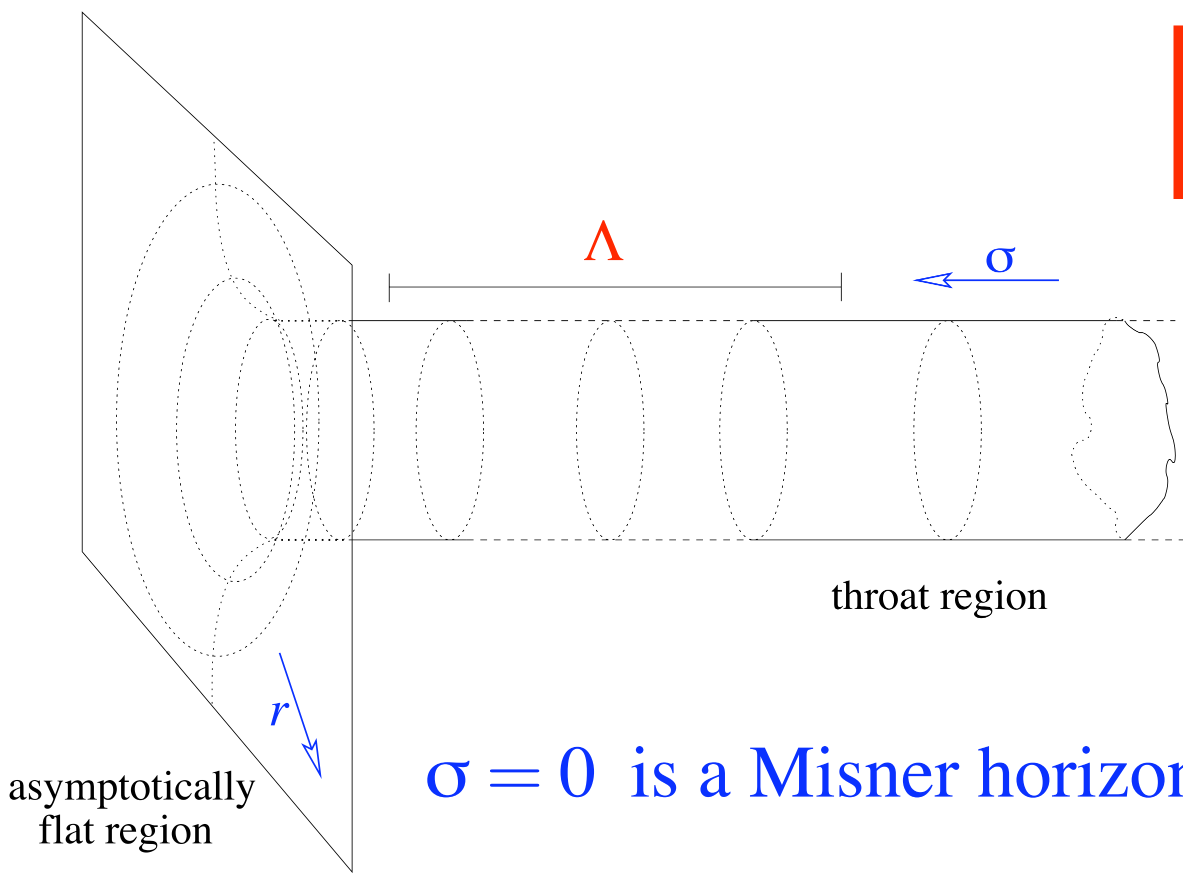

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Can we extend the geometry to get the full Taub-NUT?

Taub-NUT in String Theory

$$ds^2 = k\left(\frac{dx^2}{x^2-1} - \frac{x^2-1}{(x+\delta)^2}(dt - \lambda\cos\theta d\phi)^2 + d\theta^2 + \sin^2\theta d\phi^2\right) ,$$

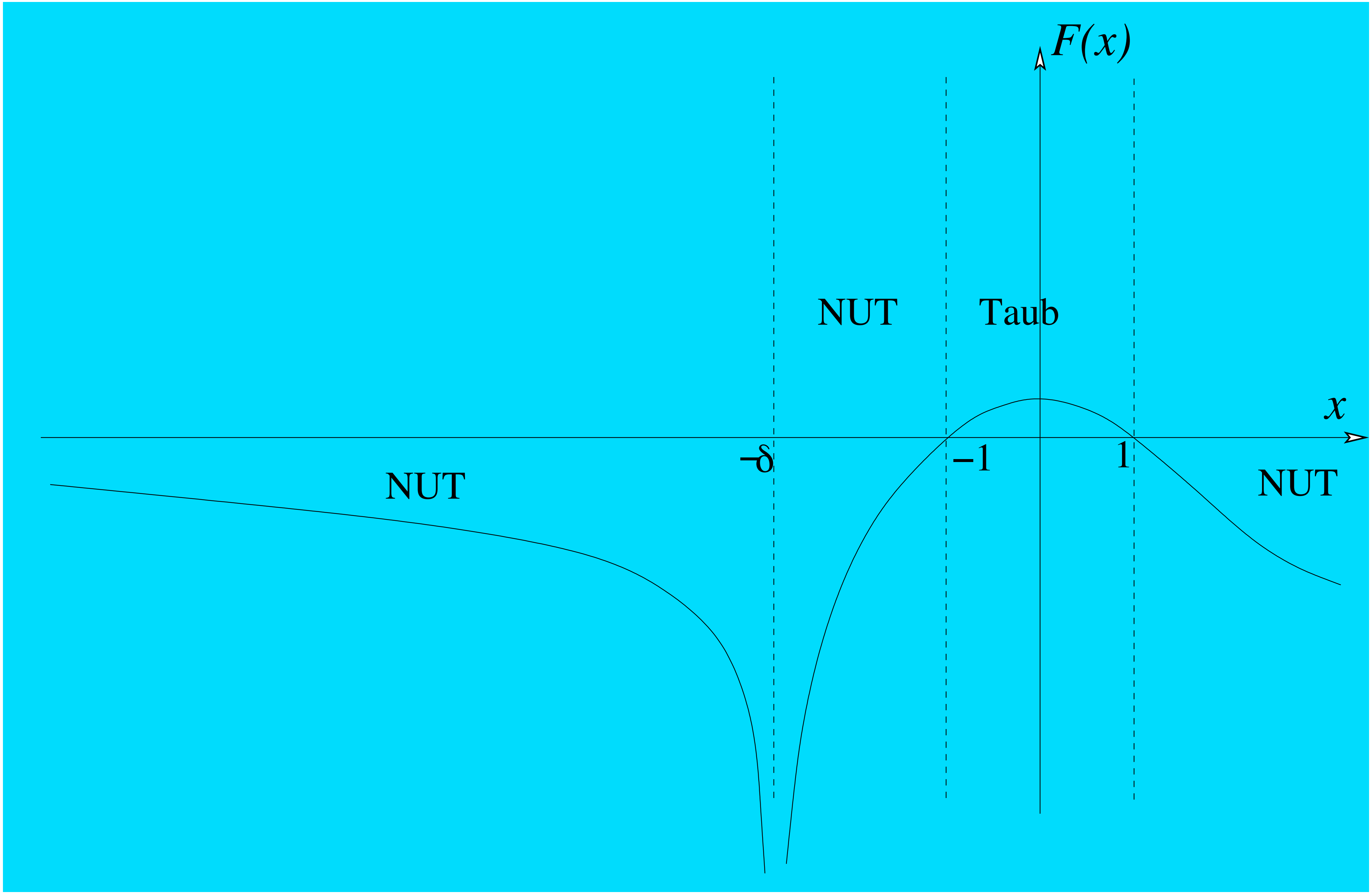
$$\Phi - \Phi_0 = -\frac{1}{2}\ln(x+\delta) .$$

$0 \leq x \leq +\infty$	$x = \cosh\sigma$
$-\infty \leq x \leq 0$	$-\infty \leq x \leq 0$
$-1 \leq x \leq +1$	$x = -\cos\tau$

Yes, can extend to the full three regions. The CFT naturally does this!

C.V. Johnson, and H.G. Svendsen, hep-th/0405141

Taub-NUT in String Theory



Taub-NUT in String Theory

$$\frac{SL(2,\mathbb{R})\times SU(2)}{U(1)\times U(1)}$$

CFT is "Heterotic coset model":

- o Asymmetric (anomalous) gauging of WZNW.
- o Anomalies cured by heterotic fermions.
- o Gives larger class of geometries than usual.
- o Series of techniques for extracting geometry.

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Can one capture the high energy corrections to this geometry?

High Energy Corrections

Possible to get *all* corrections!

o Adapt a technique of Tseytlin, and Bars and Sfetsos.
o Uses results for exact effective action of WZNW
o ....and gauged WZNW
o This allows for extraction of full geometry.

A. Tseytlin, hep-th/9301015,
I. Bars and K. Sfetsos, hep-th/9301047.

The Fully Corrected Geometry

$$ds^2 = (k-2)\left(\frac{dx^2}{x^2-1} + F(x)(dt - \lambda\cos\theta d\phi)^2 + d\theta^2 + \sin^2\theta d\phi^2\right) ,$$

$$\hat{\Phi} - \hat{\Phi}_0 = -\frac{1}{4}\ln D(x)$$

$$F(x) = -\frac{x^2-1}{D(x)} = -\left(\frac{(x+\delta)^2}{x^2-1} - \frac{4}{k+2}\right)^{-1}$$

C.V. Johnson, and H.G. Svendsen, hep-th/0405141

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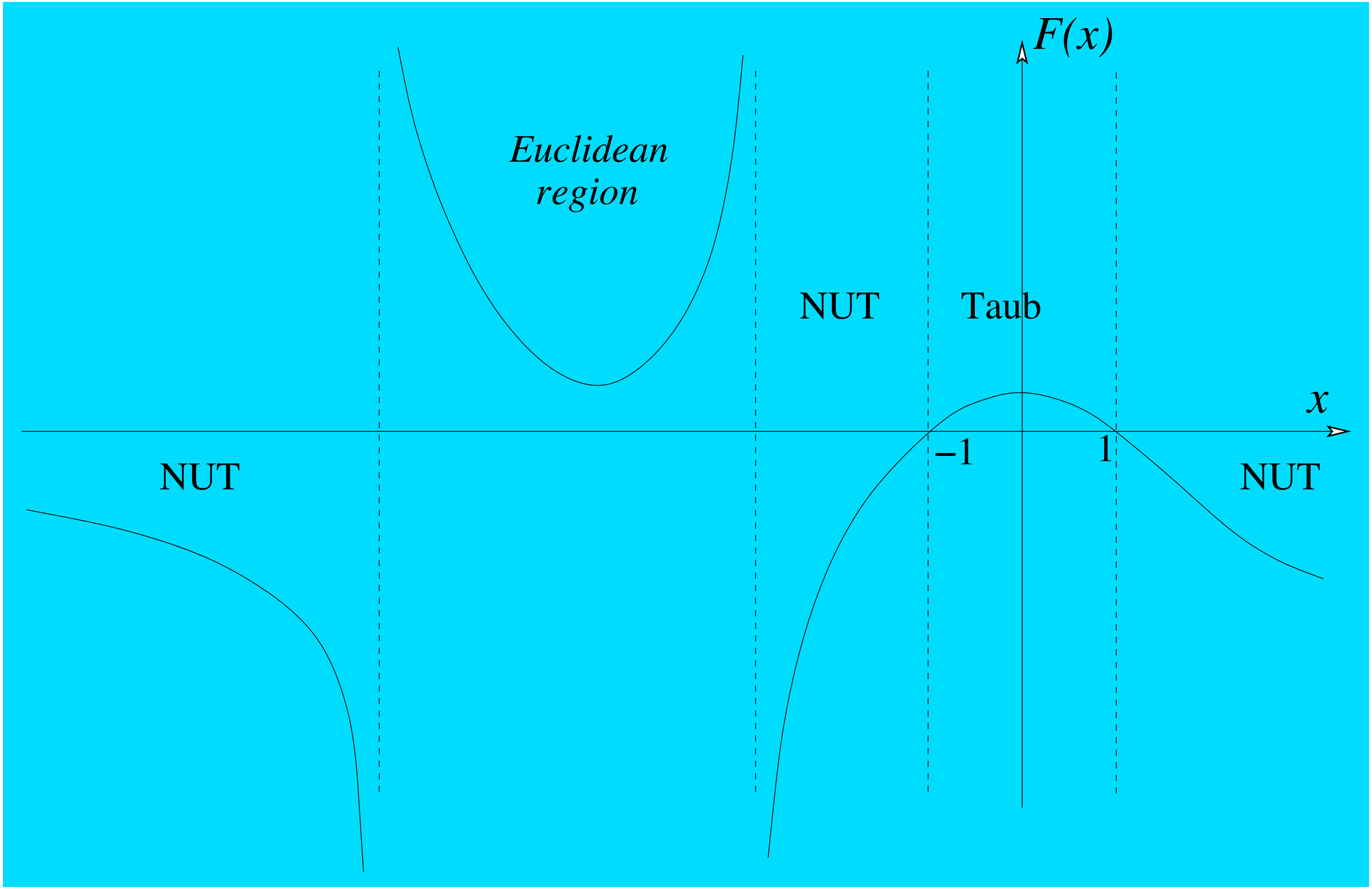

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Significant corrections, but the transition neighbourhoods, $x = \pm 1$, are unchanged!

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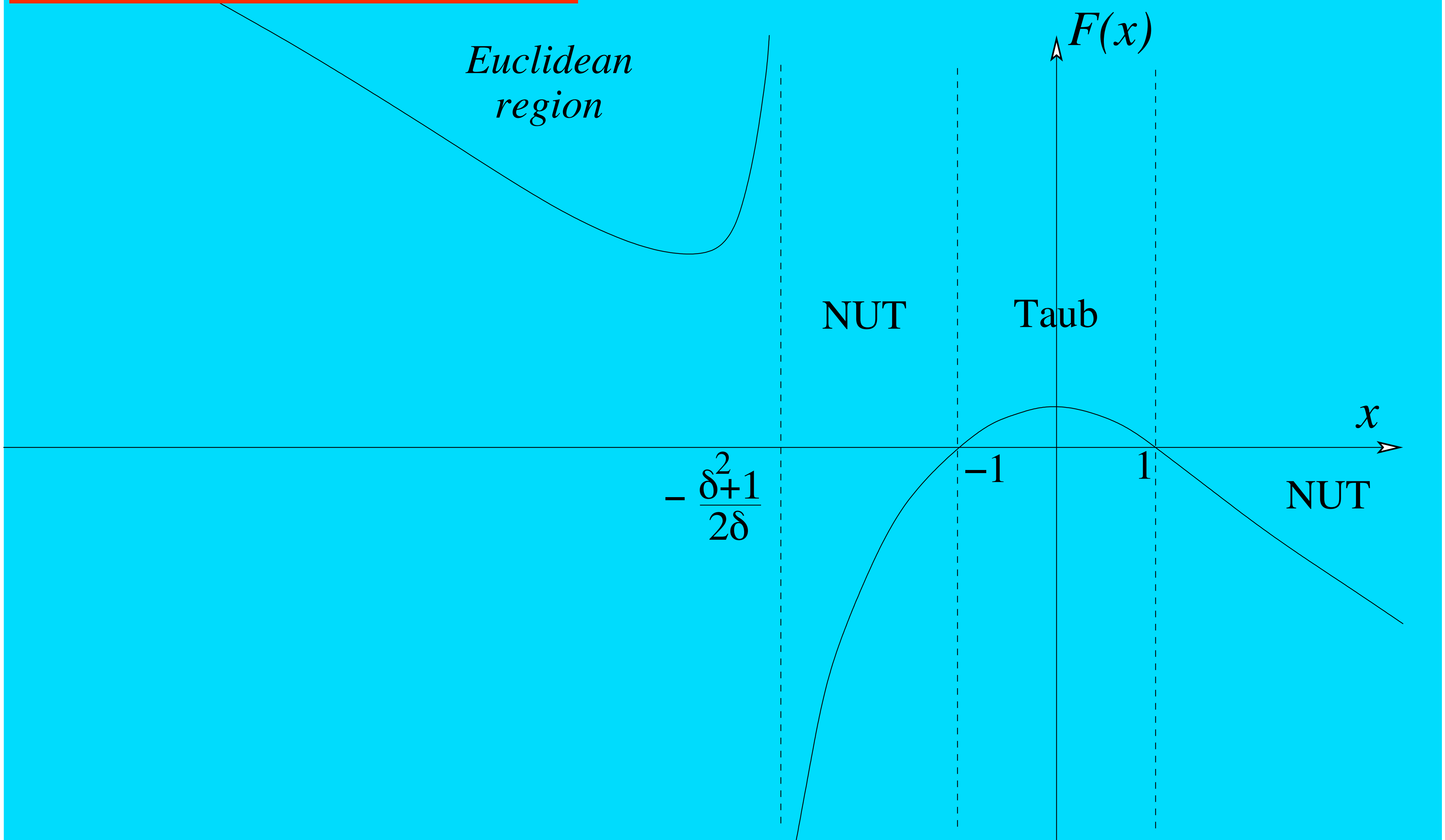
Maybe a sign that strings say that CTCs are ok? Tantalizing possibility. Especially in view of the adjoining cosmological region.

CTCs in “quantum geometric” description of pre-BB?

A Special Geometry

$k=2$ case is "most stringy".



To-do List

Not done yet.

Examine quantum effects?
String Loop corrections?

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Place to look is combined stringy and loop effects.

T-duality properties of geometry are potentially interesting. Winding strings condense at transition regions....

Study extended probes of geometry.

$k = 2$ CFT should be studied.

Stringy D=5 Black Holes

Consider the D1-D5-P black hole, made using K3

$$\mathbb{R}^{1,4} \times S^1 \times K3$$

$$\begin{array}{ccc} \swarrow & \downarrow & \searrow \\ x^0 - x^4 & x^5 & x^6 - x^9 \end{array}$$

	x^0	x^1	x^2	x^3	x^4	x^5	x^6	x^7	x^8	x^9
N_1 $D1$	—	·	·	·	·	—	·	·	·	·
N_5 $D5$	—	·	·	·	·	—	—	—	—	—

Q_P units of momentum in x^5

Stringy D=5 Black Holes

Supergravity solution:

$$ds^2 = f_1^{-3/4} f_5^{-1/4} \left(-dt^2 + dz^2 + k\,(dt - dz)^2\right) + f_1^{1/4} f_5^{-1/4} ds^2 + f_1^{1/4} f_5^{3/4} \left(dr^2 + r^2 d\Omega_3^2\right)$$

$$x^0 - x^4 \Rightarrow t, r, \theta, \phi, \chi\,. \qquad x^5 \equiv z \qquad d\Omega_3^2 = d\theta^2 + \sin^2\theta (d\phi^2 + \sin^2\phi\, d\chi^2)$$

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$$e^{2\Phi} = \frac{f_1}{f_5}\,, \qquad F^{(3)}_{rtz} = \partial_r f_1^{-1}\,, \qquad F^{(3)}_{\theta\phi\chi} = 2 r_5^2 \sin^2\theta \sin\phi\,.$$

$$f_1 = 1 + \frac{r_1^2}{r^2}\,, \qquad f_5 = 1 + \frac{r_5^2}{r^2}\,, \qquad k = \frac{r_P^2}{r^2}$$

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$$r_5^2 = g_s \ell_s^2 Q_5 \; , \qquad r_1^2 = g_s \ell_s^2 \frac{V^*}{V} Q_1 \; , \qquad r_P^2 = g_s^2 \ell_s^2 \frac{V^*}{V} \frac{\ell_s^2}{R_z^2} Q_P$$

$$r_H^2 = 0$$

Being Careful with Charge

The K3 induces negative D1 charge:

$$Q_5 = N_5$$

The number of D5-branes

$$Q_1 = N_1 - N_5$$

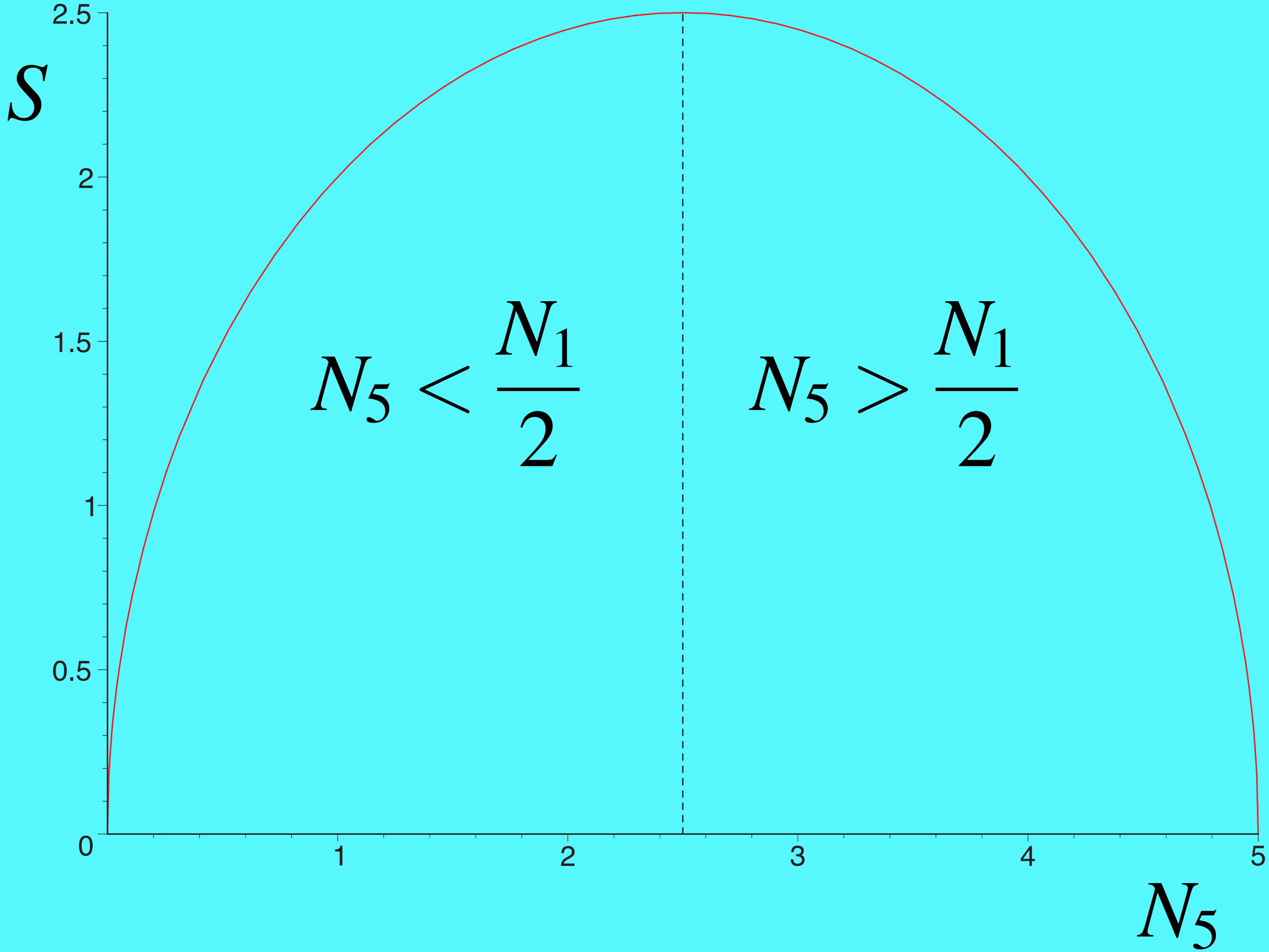
Correction due to induced charge.

Area and Entropy

$$S = \frac{A}{4G} = 2\pi\sqrt{Q_1 Q_5 Q_P} = 2\pi\sqrt{(N_1 - N_5)N_5 Q_P}$$

There is something disturbing about this formula.

Area and Entropy



You can reduce the entropy by adding more D-branes!!

Violation of Second Law?

Add brane with charges (n_1, n_5) :

$$\delta S^2 = 4\pi^2 Q_P \left(N_5 n_1 + (N_1 - 2N_5) n_5\right)$$

D1s and D5s preserve susy and so can reduce entropy adiabatically!

Saving the Second Law

Introduce a probe brane with charges (n_1, n_5).

Find that it is only physical for motion satisfying:

$$r^2 > r_e^2 \equiv g_s \ell_s^2 V^* \frac{(2N_5 - N_1)n_5 - N_5 n_1}{(V - V^*)n_5 + V^* n_1} \, .$$

This is the Enhançon Radius.

C.V. Johnson and R. C. Myers, hep-th/0105159

A Microscopic Filtering Mechanism

The bound state branes cannot approach the horizon *precisely* when they would decrease its area!

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$$r_H^2 = 0$$

$$\delta S^2 = 4\pi^2 Q_P \left(N_5 n_1 + (N_1 - 2N_5)n_5\right)$$

They *can* approach when there is no danger.

Where to go from here...?

D-branes are
the smallest
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The mechanism works as a *microscopic* filter to preserve a *macroscopic* law.

This is very rare (or possibly unique?) situation in physics.

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Clues in the context of Mathur's proposal?

Can the new proposal supply a natural description for D5 emission?