Title: Bungee jumping of black holes in AdS universe

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Abstract: C-metric describes uniformly accelerated black holes. We will review a global structure of these solutions especially in Lambda<0 context. It turns out that for an acceleration larger than the cosmological one the metric describes pairs of black holes "bungee jumping" into spacetime from AdS infinity.

Black hole bungee jumping in

(not only)

anti–de Sitter universe

Pavel Krtouš

Institute of Theoretical Physics,
Faculty of Mathematics and Physics,
Charles University, Prague

Perimeter Institute, Waterloo
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- C-metric – overture
- C-metric with negative Λ
  - Accelerated observers in Minkowski and AdS spacetimes
  - Schwarzschild black hole
- One accelerated black hole in anti-de Sitter universe
  - C-metric with vanishing Λ
  - Anti-de Sitter universe in accelerated coordinates
- Pairs of accelerated black holes in anti-de Sitter universe

C-metric

C-metric represents a black hole uniformly accelerated by a string

- two Killing vectors (boost-rotation symmetric solution)
- Petrov type D (two double degenerated PND)
- belongs to Plebański-Demiański family

Siblings in C-metric family:

- general cosmological constant Λ
- charged solutions
- extremal limits
- spinning black holes

C-metric relatives:

- Born solution
  field of uniformly accelerated charges
  widely discussed in the context of analysis of the radiation and of the radiation reaction force
  M. Born, Ann. Phys. (Leipzig) 30(1909)1; ... (infinite number of references)
  $\Lambda > 0$: J. Bičák, P. Krtouš: Phys. Rev. Lett. 88(2002)211101; J. Math. Phys. 46(2005)102504
- Black rings
  the metric of the 5-dimensional black ring is composed by
  4-dimensional euclidian C-metric-like piece "warped" with a time direction
  R. Emparan, H. Reall: Phys.Rev.Lett. 88(2002)101101
- Black funnels and droplets
  various degenerated cases and limits of the C-metric
  V. Hubeny, D. Marolf, M. Rangamani: Class.Quant.Grav. 27(2010)025001

C-metric – some applications:

- Numerical relativity
  boost-rotation symmetric solutions has been used as a test bed for numerical simulations
- Cosmological production of black hole pairs
  general Λ, topologically nontrivial identifications for $\Lambda < 0$
  R. Mann, S. Ross: Phys. Rev. D 52(1995)2254; R. Mann: Class. Quantum Grav. 14(1997)L109; etc.
  O. Dias: PhD thesis; O. Dias, J. Lemos: Phys. Rev. D 67(2003)084018; Phys. Rev. D 67(2003)064001
- Randall–Sundrum model in 3+1 dimensions
  3-dimensional brane in a special subcase of AdS C-metric
  R. Emparan, G. Horowitz, R. Myers: JHEP 0001(2000)007
- Ryu-Takayanagi formula for entanglement entropy in AdS/CFT correspondence
  a search for minimal surfaces in C-metric bulk spanned on spherical boundaries in AdS infinity
  P. Krtouš, A. Zelnikov: work in progress

C-metric with general Λ:

$$\boldsymbol{g} = \frac{1}{A^2(x+y)^2}\left(-F\,\mathbf{d}t^2 + \frac{1}{F}\,\mathbf{d}y^2 + \frac{1}{G}\,\mathbf{d}x^2 + G\,\mathbf{d}\varphi^2\right) \qquad \mathbf{F} = e\,\mathbf{d}y \wedge \mathbf{d}t$$

$$F = \ell^{-2}A^{-2} - 1 + y^2 - 2mA\,y^3 + e^2A^2\,y^4$$
$$G = \qquad\qquad 1 - x^2 - 2mA\,x^3 - e^2A^2\,x^4$$

m	mass parameter	
e	charge parameter	
A	acceleration parameter	
C	conicity parameter:	$\varphi \in (-C\pi, C\pi)$
ℓ	cosmological scale:	$\ell = \sqrt{-3/\Lambda}$

- Two Killing vectors $\boldsymbol{\partial}_t$, $\boldsymbol{\partial}_\varphi$
- Two double-degenerate principal null directions lying in surfaces $x =$ constant (Petrov type D)
- Conical singularity (cosmic string) on the axis

$\Lambda = 0$

T. Levi-Civita (1917)
H. Weyl (1918)
J. Ehlers, W. Kundt (1962)
W. Kinnersley, M. Walker (1970)
A. Ashtekar, T. Dray (1981)
W. B. Bonnor (1983)
...
J. B. Griffiths, P. Krtouš, J. Podolský (2006)

$\Lambda > 0$

J. Plebański, M. Demiański (1976)
...
J. Podolský, J. B. Griffiths (2001)
O. J. C. Dias, J. P. S. Lemos (2003)
P. Krtouš, J. Podolský (2003)

$\Lambda < 0$

J. Plebański, M. Demiański (1976)
...
O. J. C. Dias, J. P. S. Lemos (2003)
J. Podolský, M. Ortaggio, P. Krtouš (2003)
P. Krtouš (2005)

CAdSI: $A < 1/\ell$

$$\ell A = \sin\chi_o$$

$$\tau = \cot\chi_o\ t \qquad v = \tan\chi_o\ y \qquad \xi = -x$$

$$-\mathcal{F} = -1 - v^2 + 2\frac{m}{\ell}\cos\chi_o\, v^3 - \frac{e^2}{\ell^2}\cos^2\chi_o\, v^4$$

$$\mathcal{G} = 1 - \xi^2 + 2\frac{m}{\ell}\sin\chi_o\, \xi^3 - \frac{e^2}{\ell^2}\sin^2\chi_o\, \xi^4$$

$$\omega = v\cos\chi_o - \xi\sin\chi_o$$

CAdSII: $A > 1/\ell$

$$\ell A = \cosh\alpha_o$$

$$\tau = \tanh\alpha_o\ t \qquad v = \coth\alpha_o\ y \qquad \xi = -x$$

$$-\mathcal{F} = 1 - v^2 + 2\frac{m}{\ell}\,\mathrm{sh}\,\alpha_o\, v^3 - \frac{e^2}{\ell^2}\,\mathrm{sh}^2\,\alpha_o\, v^4$$

$$\mathcal{G} = 1 - \xi^2 + 2\frac{m}{\ell}\,\mathrm{ch}\,\alpha_o\, \xi^3 - \frac{e^2}{\ell^2}\,\mathrm{ch}^2\,\alpha_o\, \xi^4$$

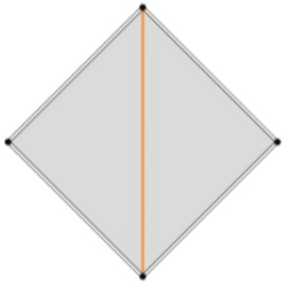
$$\omega = v\,\mathrm{sh}\,\alpha_o - \xi\,\mathrm{ch}\,\alpha_o$$

$$\boldsymbol{g} = \frac{\ell^2}{\omega^2}\left(-\mathcal{F}\,\mathbf{d}\tau^2 + \frac{1}{\mathcal{F}}\mathbf{d}v^2 + \frac{1}{\mathcal{G}}\mathbf{d}\xi^2 + \mathcal{G}\,\mathbf{d}\varphi^2\right)$$

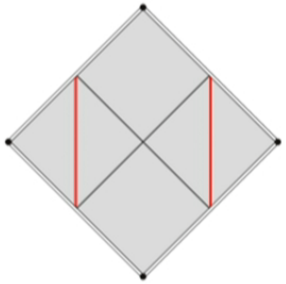
Accelerated observers in Minkowski and AdS spacetimes

Minkowski spacetime

$A = 0$



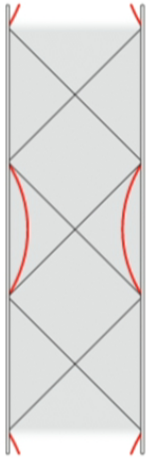
$A > 0$



Anti-de Sitter spacetime

$A < \frac{1}{\ell}$

$A > \frac{1}{\ell}$



Interpretation of coordinates τ, υ, ξ, φ:

$$\boldsymbol{g} = \frac{\ell^2}{\omega^2}\left(-\mathcal{F}\,\mathbf{d}\tau^2 + \frac{1}{\mathcal{F}}\,\mathbf{d}\upsilon^2 + \frac{1}{\mathcal{G}}\,\mathbf{d}\xi^2 + \mathcal{G}\,\mathbf{d}\varphi^2\right)$$

τ	time coordinate of 'accelerated' observers outside black hole	
υ	radial coordinate	$R = \ell/\upsilon$
ξ	angular coordinate measured from the axis of symmetry	$\Theta = \int \frac{1}{\sqrt{\mathcal{G}}}\, d\xi$
φ	angular coordinate around the axis of symmetry	

zeros of $\mathcal{G}$ — axes of φ symmetry

4 zeros, $\xi_b < \xi_f$ the smallest ones:

ξ_f axis in 'forward' direction
ξ_b axis in 'backward' direction

$$g = \frac{\ell^2}{\omega^2}\left(-\mathcal{F}\,\mathrm{d}\tau^2+\frac{1}{\mathcal{F}}\,\mathrm{d}v^2+\frac{1}{\mathcal{G}}\,\mathrm{d}\xi^2+\mathcal{G}\,\mathrm{d}\varphi^2\right)$$

zeros of $\mathcal{F}$ — horizons

CAdSI: 2 zeros $v_o < v_i$
CAdSII: 4 zeros $v_c < v_a < v_o < v_i$

v_c cosmological horizon
v_a acceleration horizon
v_o outer black hole horizon
v_i inner black hole horizon

assuming $m \neq 0$, $e \neq 0$

$$g = \frac{\ell^2}{\omega^2}\left(-\mathcal{F}\,\mathrm{d}\tau^2+\frac{1}{\mathcal{F}}\,\mathrm{d}v^2+\frac{1}{\mathcal{G}}\,\mathrm{d}\xi^2+\mathcal{G}\,\mathrm{d}\varphi^2\right)$$

zeros of ω — conformal infinity $\mathcal{I}$

CAdSI: $v = \tan\chi_o\ \xi$
CAdSII: $v = \coth\alpha_o\ \xi$

$$g = \frac{\ell^2}{\omega^2}\left(-\mathcal{F}\,\mathrm{d}\tau^2+\frac{1}{\mathcal{F}}\,\mathrm{d}v^2+\frac{1}{\mathcal{G}}\,\mathrm{d}\xi^2+\mathcal{G}\,\mathrm{d}\varphi^2\right)$$

Black hole in accelerated coordinates T, R, Θ, Φ:

$$T = \ell\tau \qquad R = \frac{\ell}{\upsilon} \qquad \mathbf{d}\Theta = \frac{1}{\sqrt{\mathcal{G}}}\,\mathbf{d}\xi \qquad \Phi = \varphi$$

$$\boldsymbol{g} = \frac{\ell^2}{\omega^2 R^2}\left(-\mathcal{H}\,\mathbf{d}T^2 + \frac{1}{\mathcal{H}}\,\mathbf{d}R^2 + R^2\left(\mathbf{d}\Theta^2 + \mathcal{G}\,\mathbf{d}\Phi^2\right)\right)$$

CAdSI: $A < 1/\ell$

$$\mathcal{H} = 1 + \frac{R^2}{\ell^2} - \cos\chi_{\rm o}\,\frac{2m}{R} + \cos^2\chi_{\rm o}\,\frac{e^2}{R^2}$$

$$\frac{\omega R}{\ell} = \cos\chi_{\rm o} - \frac{R}{\ell}\,\xi\,\sin\chi_{\rm o}$$

CAdSII: $A > 1/\ell$

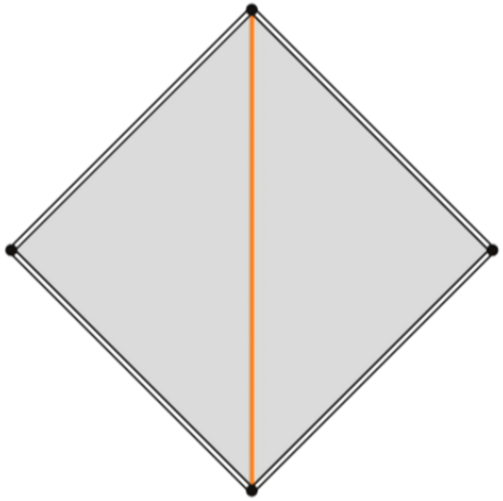
$$\mathcal{H} = 1 - \frac{R^2}{\ell^2} - \mathrm{sh}\,\alpha_{\rm o}\,\frac{2m}{R} + \mathrm{sh}^2\,\alpha_{\rm o}\,\frac{e^2}{R^2}$$

$$\frac{\omega R}{\ell} = \mathrm{sh}\,\alpha_{\rm o} - \frac{R}{\ell}\,\xi\,\mathrm{ch}\,\alpha_{\rm o}$$

$\chi_{\rm o} = 0 \quad \Rightarrow \quad \mathcal{H} = 1 + \frac{R^2}{\ell^2} - \frac{2m}{R} + \frac{e^2}{R^2} \qquad \mathcal{G} = \sin^2\Theta$

$\Rightarrow$ a black hole in anti-de Sitter universe

(Un)accelerated observer in Minkowski spacetimes



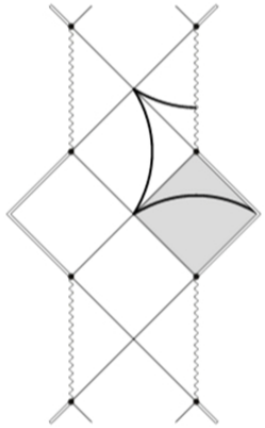
$A = 0$

Black hole in asymptotically flat spacetime, $\Lambda = 0$

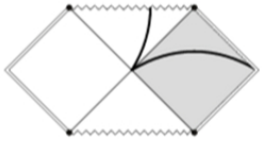
$$\boldsymbol{g} = -\mathcal{H}\,\mathbf{d}T^2 + \frac{1}{\mathcal{H}}\,\mathbf{d}R^2 + R^2\big(\mathbf{d}\Theta^2 + \sin^2\Theta\,\mathbf{d}\Phi^2\big)$$

$$\mathcal{H} = 1 - \frac{2m}{R} + \frac{e^2}{R^2}$$

T-R diagrams



$m \neq 0 \quad e \neq 0$



$m \neq 0 \quad e = 0$

$m = 0 \quad e = 0$

Minkowski spacetime – accelerated observers

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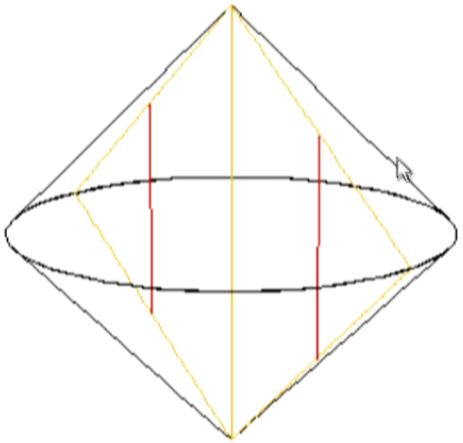

interactive view close horizon play θ=constant
section: 0 π

Minkowski spacetime – sections θ=constant

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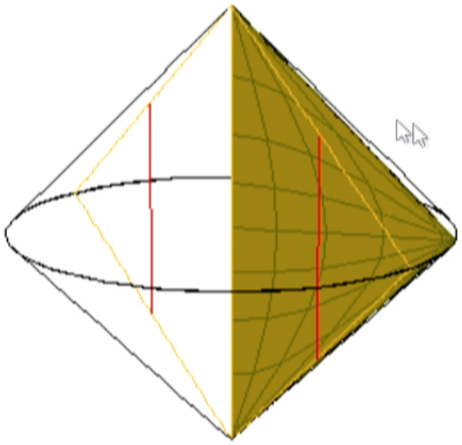

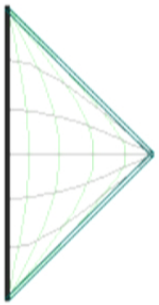

interactive view

close horizon
accelerated observers

stop θ=constant
section: 0 π

Minkowski spacetime – sections θ=constant

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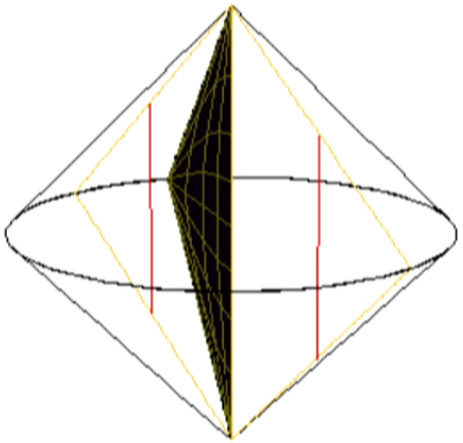

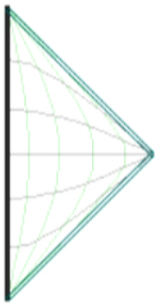

interactive view

close horizon
accelerated observers

stop θ=constant
section: 0 π

Minkowski spacetime – sections θ=constant

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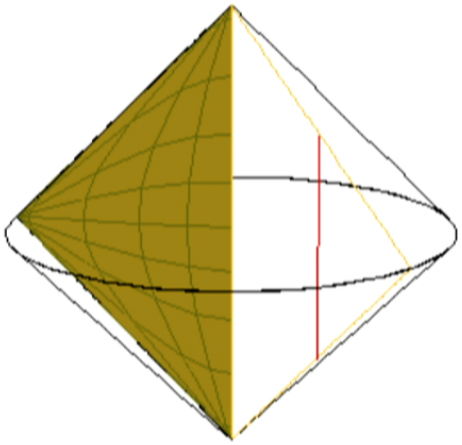

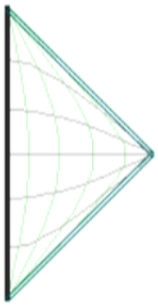

interactive view

close horizon
accelerated observers

stop θ=constant
section: 0 π

Minkowski spacetime – sections θ=constant

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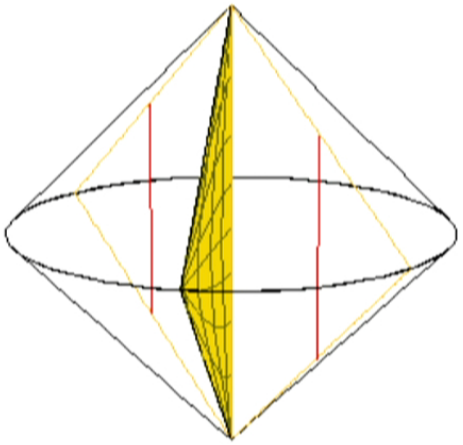

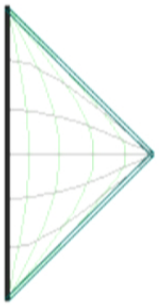

interactive view

close horizon
accelerated observers

stop θ=constant
section: 0 π

Minkowski spacetime – sections θ=constant

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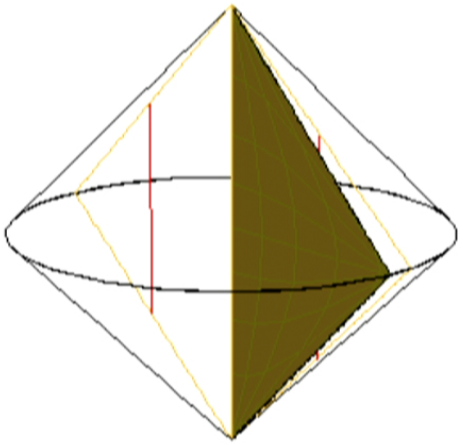

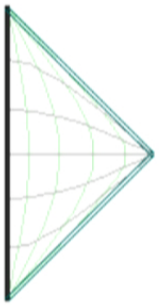

interactive view

close horizon
accelerated observers

stop θ=constant
section: 0 π

Black hole, Λ=0 – outer horizon

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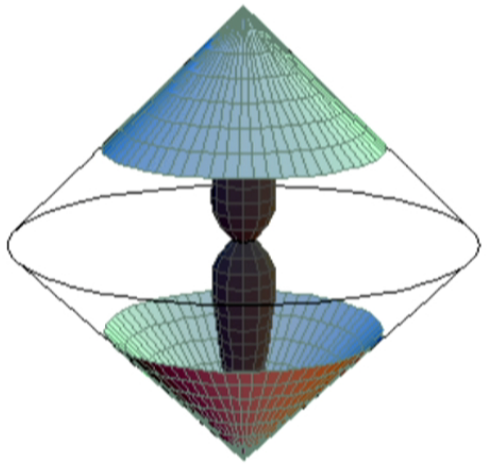

interactive view
expand black hole

close scri

play θ=constant

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Black hole, Λ=0 – outer horizon

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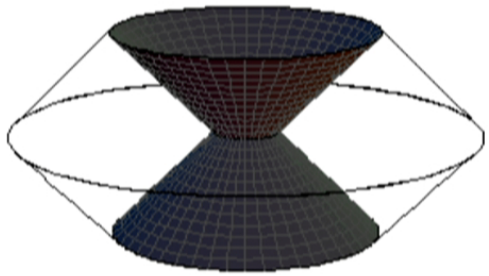

interactive view
squeeze black hole

close scri

play θ=constant
section: 0 π

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Black hole, Λ=0 – sections θ=constant

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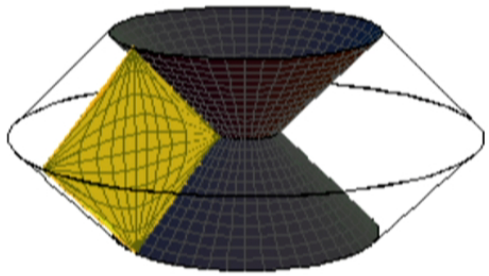
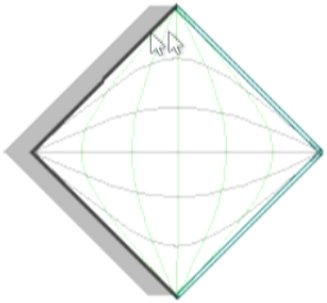


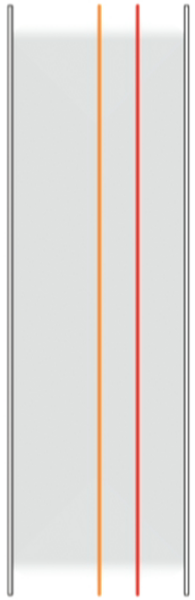


interactive view
squeeze black hole

close scri
outer horizon

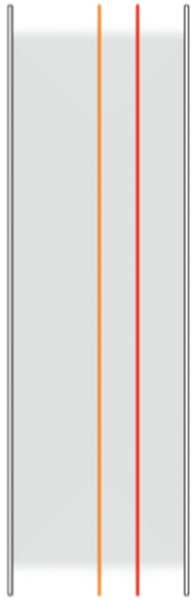
stop θ=constant
section: 0 π

Subcritically accelerated observer in AdS spacetimes



$$A < \frac{1}{\ell}$$

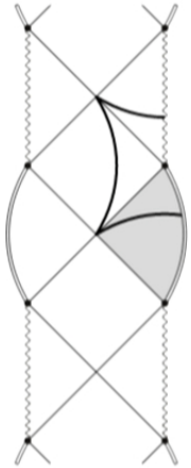
Subcritically accelerated observer in AdS spacetimes

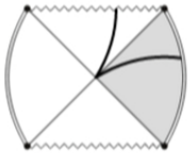


$$A < \frac{1}{\ell}$$

CAdSI: $A < 1/\ell$

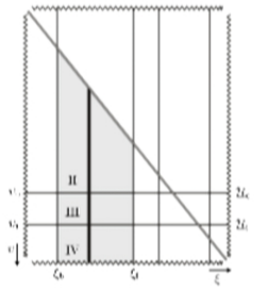
τ-v diagrams
$\xi, \varphi = \text{const.}$

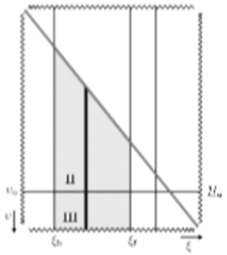


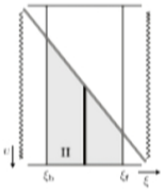


$m \neq 0 \quad e \neq 0$ $\quad m \neq 0 \quad e = 0$ $\quad m = 0 \quad e = 0$

ξ-v diagrams
$\tau, \varphi = \text{const.}$







C-metric, $\Lambda<0$, $a<1/l_\Lambda$ – conformal infinity (scri)

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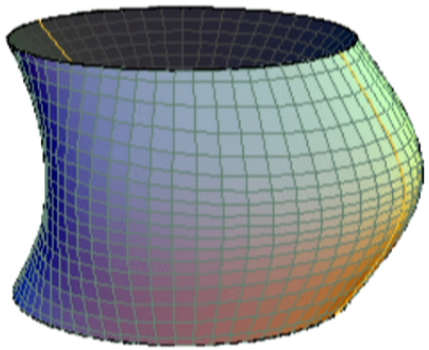

interactive view
squeeze black hole

open scri

C-metric, $\Lambda<0$, $a<1/l_\Lambda$ – sections θ=constant

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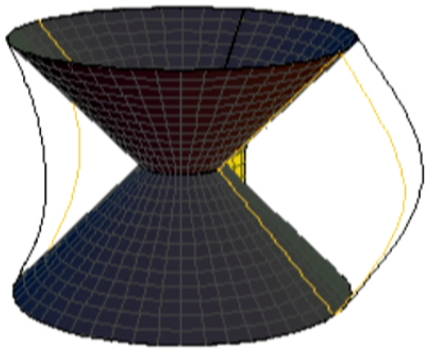

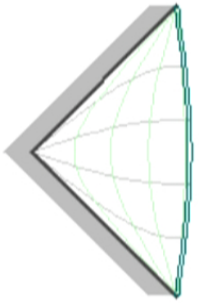

interactive view
squeeze black hole

close scri
outer horizon

stop θ=constant
section: 0 π

C-metric, $\Lambda<0$, $a<1/l_\Lambda$ – sections θ=constant

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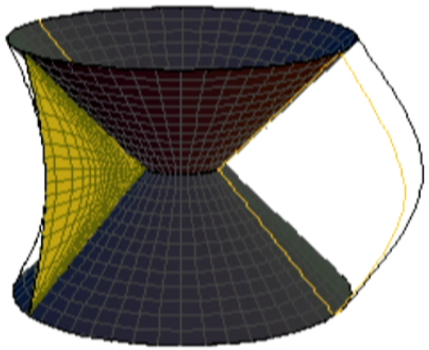
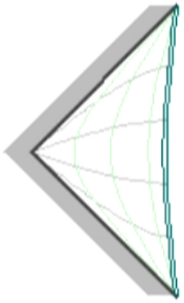
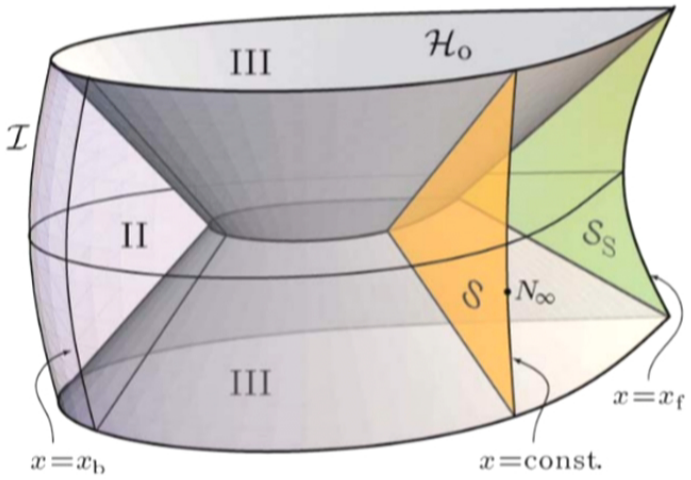


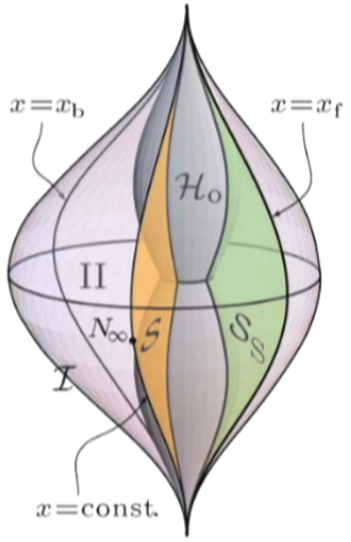


interactive view
squeeze black hole

close scri
outer horizon

stop θ=constant
section: 0 π

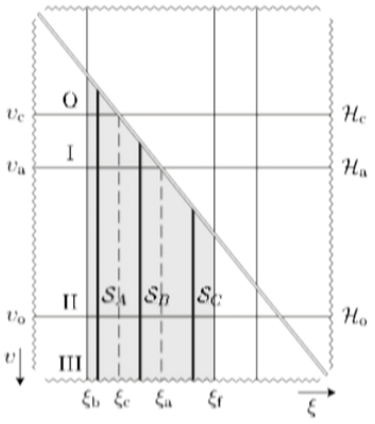

III
$\mathcal{H}_o$
$\mathcal{I}$
II
$\mathcal{S}_S$
$\mathcal{S}$
N_∞
III
$x=x_f$
$x=x_b$
$x=$const.


$x=x_b$
$x=x_f$
$\mathcal{H}_o$
II
N_∞
$\mathcal{S}$
$\mathcal{S}_S$
$\mathcal{I}$
$x=$const.

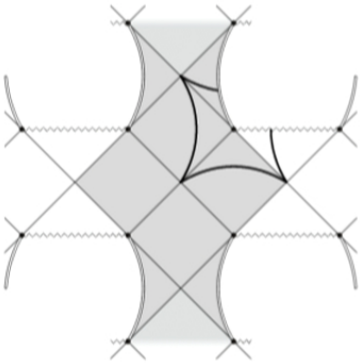
CAdSII: $A > 1/\ell$

$m \neq 0 \quad e = 0$

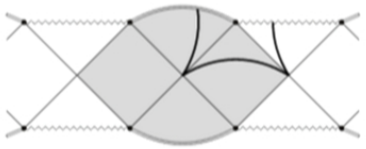
ξ-v diagram
$\tau, \varphi = \text{const.}$



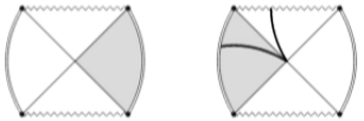
τ-v diagram $\xi, \varphi = \text{const.}$



$\mathcal{S}_A$: $\xi \in (\xi_b, \xi_c)$



$\mathcal{S}_B$: $\xi \in (\xi_c, \xi_a)$

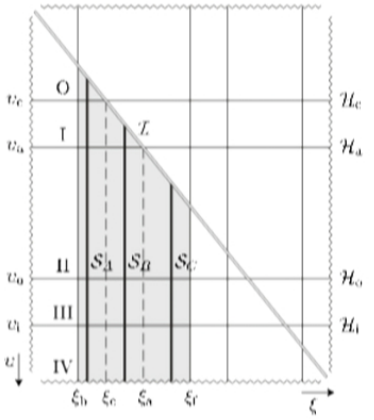


$\mathcal{S}_C$: $\xi \in (\xi_a, \xi_f)$

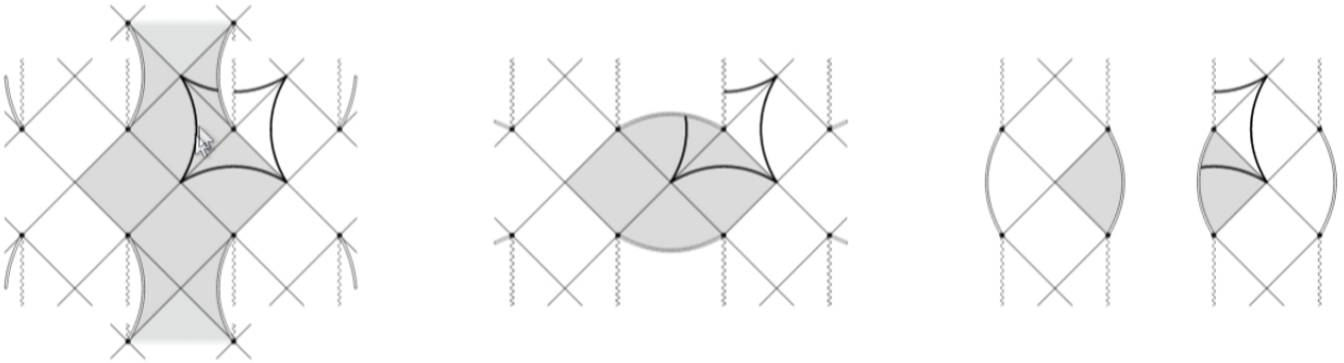
CAdSII: $A > 1/\ell$

$m \neq 0 \quad e \neq 0$

ξ-v diagram
$\tau, \varphi = \text{const.}$

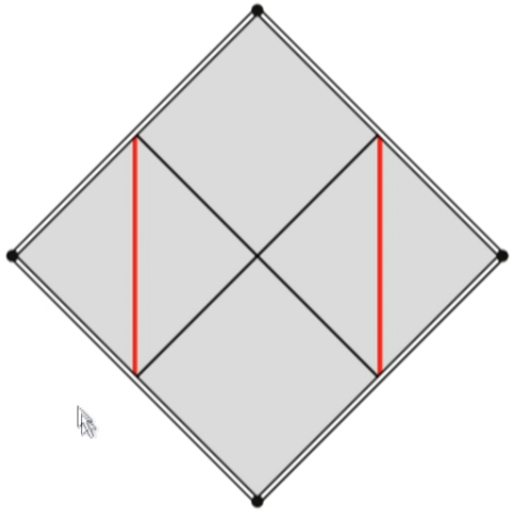


τ-v diagram $\xi, \varphi = \text{const.}$



$\mathcal{S}_A$: $\xi \in (\xi_b, \xi_c)$ $\mathcal{S}_B$: $\xi \in (\xi_c, \xi_a)$ $\mathcal{S}_C$: $\xi \in (\xi_a, \xi_f)$

Accelerated observers in Minkowski spacetime



$A > 0$

Minkowski spacetime – acceleration horizon

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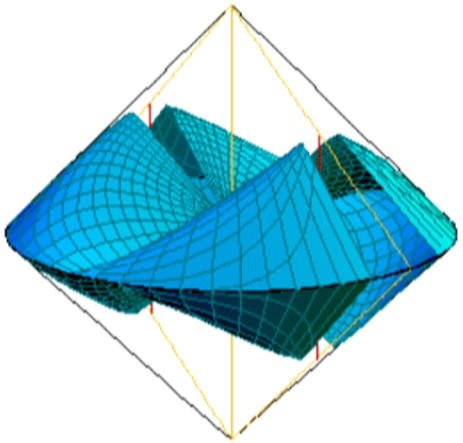

interactive view close scri open horizon

utf.mff.cuni.cz/~krtous/physics/CADS/show/Mink/data/eng/closescri.html

Minkowski spacetime – acceleration horizon

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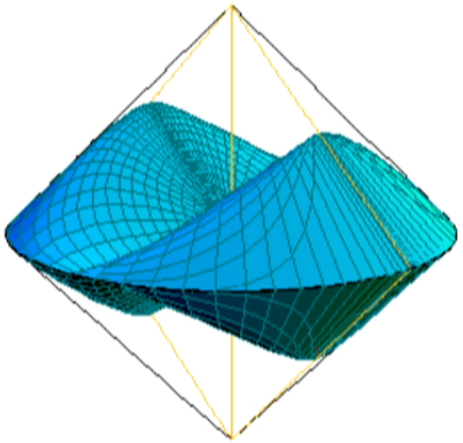
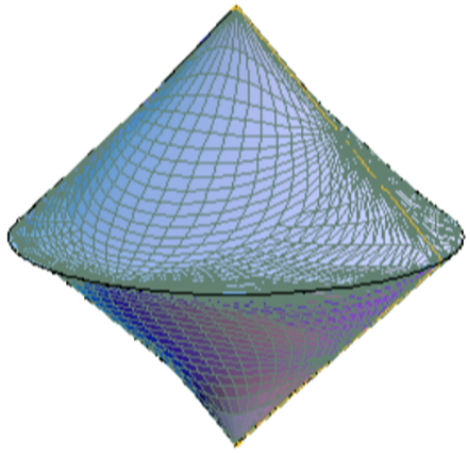


interactive view close scri open horizon

utf.mff.cuni.cz/~krtous/physics/CADS/show/Mink/data/eng/closescri.html

C-metric Λ=0 – conformal infinity (scri)

[back to top]

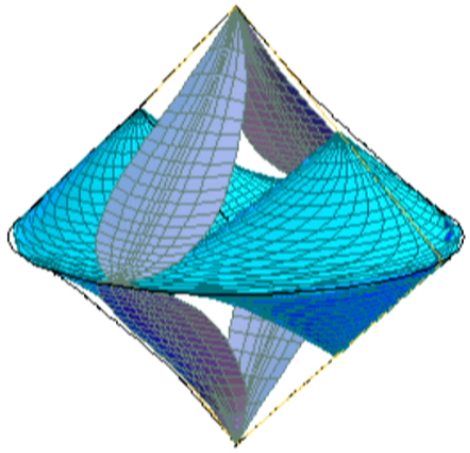


interactive view
expand black holes

open scri

C-metric Λ=0 – acceleration horizon

[back to top]



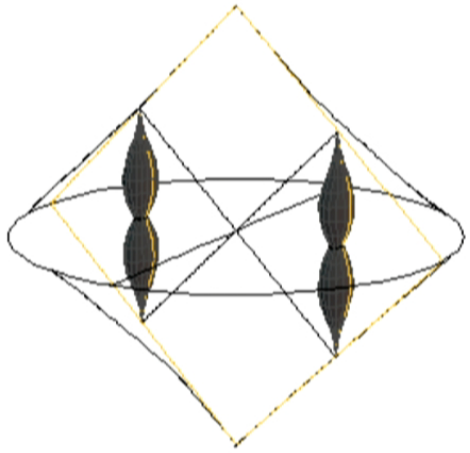
interactive view
expand black holes

close scri

open horizon

C-metric Λ=0 – outer horizons

[back to top]



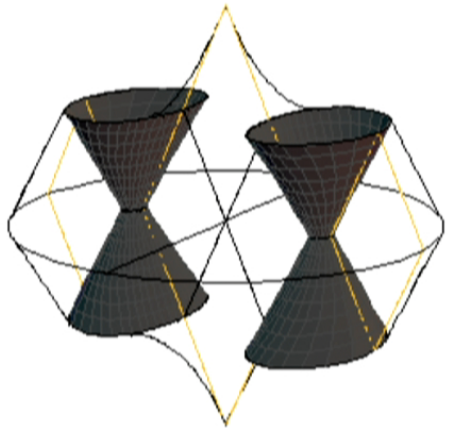
interactive view
expand black holes

close horizon

play ξ=constant
section: 0 π

C-metric Λ=0 – outer horizons

[back to top]



interactive view
squeeze black holes

close horizon

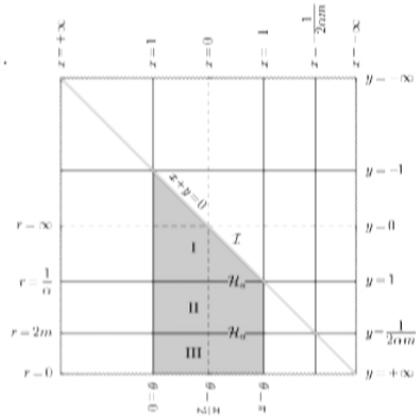
play ξ=constant
section: 0 π

utf.mff.cuni.cz/~krtous/physics/CADS/show/C0L/drop/eng/ohor.html

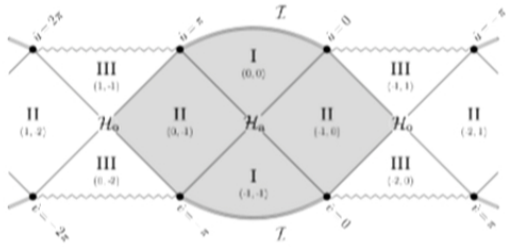
C-metric $\Lambda = 0$

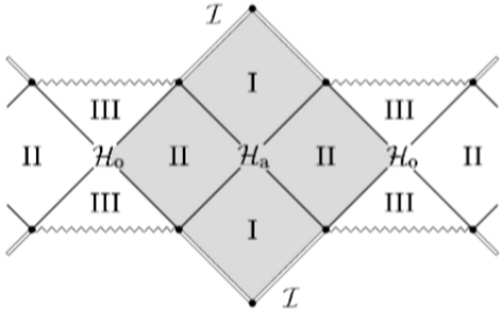
$m \neq 0 \quad e = 0$

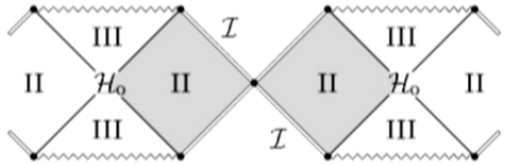
ξ-v diagram
$\tau, \varphi = \text{const.}$



τ-v diagram $\xi, \varphi = \text{const.}$

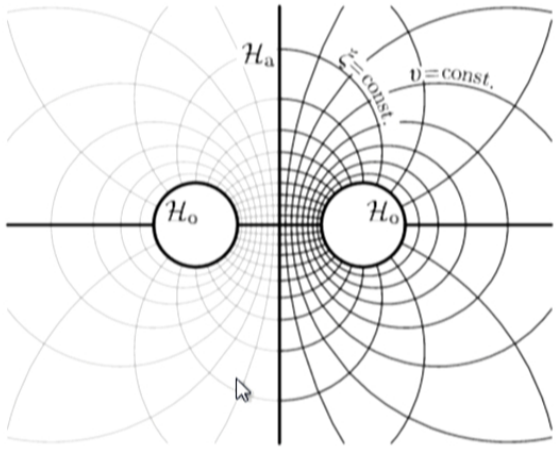






Bispherical coordinates

coordinates adjusted to two centers — two black holes



- υ is a 'radial' coordinate running between two holes
- ξ labels lines joining two holes

C-metric Λ=0 – sections ξ=constant

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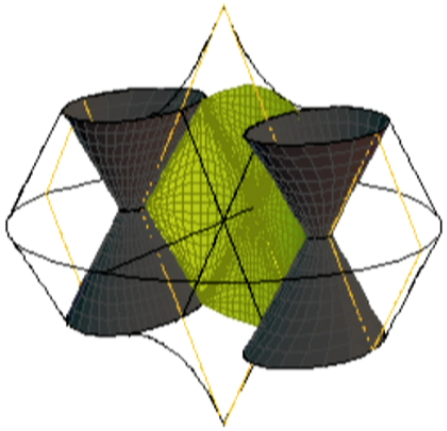
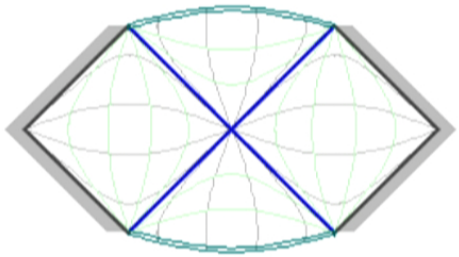




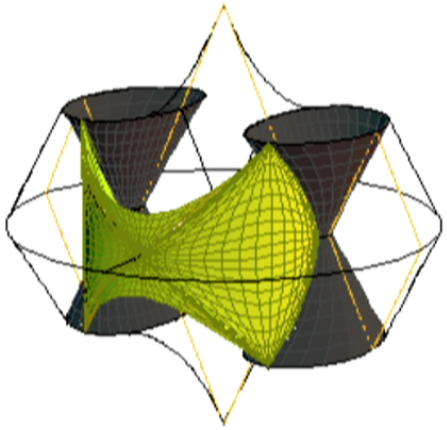
interactive view
squeeze black holes

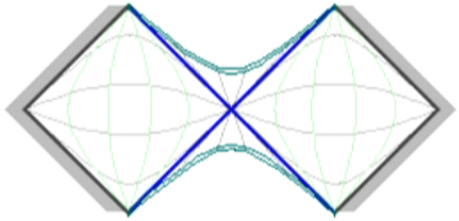
close horizon
outer horizons

stop ξ=constant
section: 0 π

C-metric Λ=0 – sections ξ=constant

[back to top]





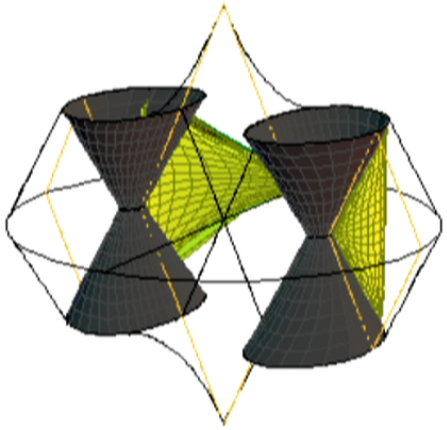
interactive view
squeeze black holes

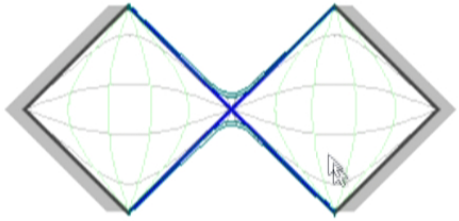
close horizon
outer horizons

stop ξ=constant
section: 0 π

C-metric Λ=0 – sections ξ=constant

[back to top]

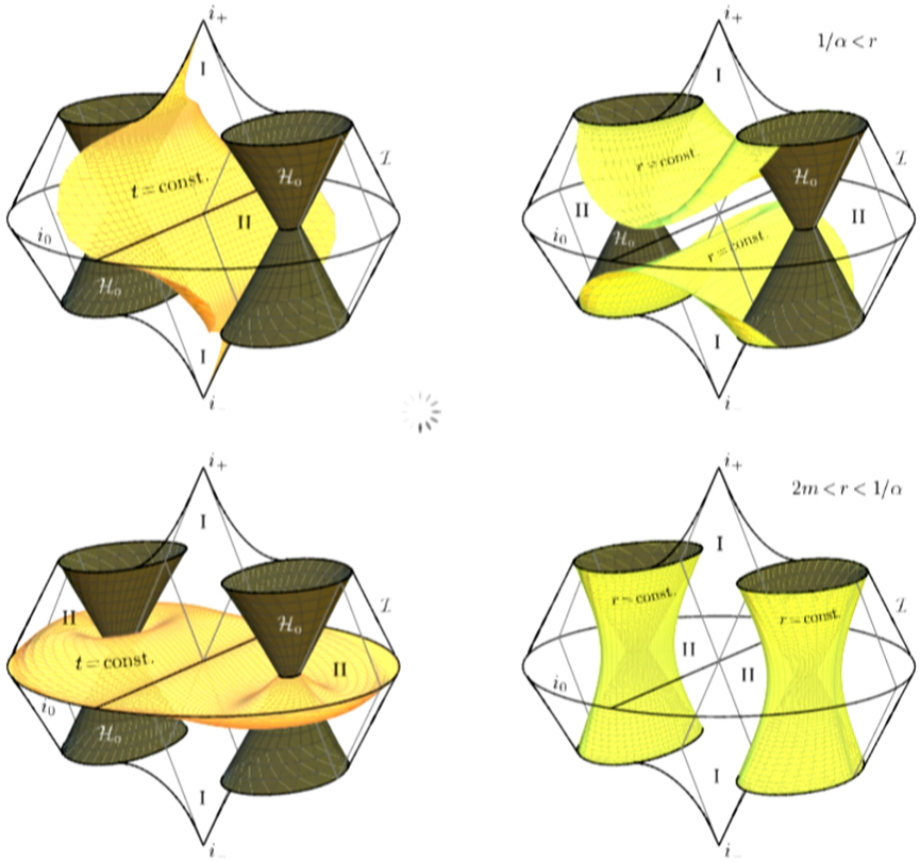




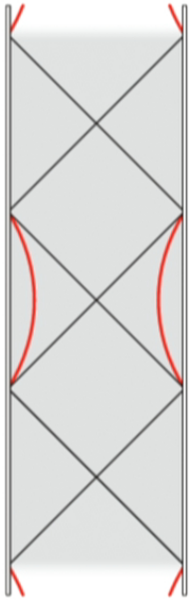
interactive view
squeeze black holes

close horizon
outer horizons

stop ξ=constant
section: 0 π


i_+
I
$\mathcal{I}$
$t = \text{const.}$
$\mathcal{H}_o$
II
i_0
$\mathcal{H}_o$
I
i_-
i_+
$1/\alpha < r$
I
$\mathcal{I}$
$r = \text{const.}$
$\mathcal{H}_o$
II
II
i_0
$\mathcal{H}_o$
$r = \text{const.}$
I
i_-
i_+
I
$\mathcal{I}$
II
$\mathcal{H}_o$
$t = \text{const.}$
II
i_0
$\mathcal{H}_o$
I
i_-
i_+
$2m < r < 1/\alpha$
I
$\mathcal{I}$
$r = \text{const.}$
$r = \text{const.}$
II
II
i_0
I
i_-

Supercritically accelerated observers in AdS spacetime



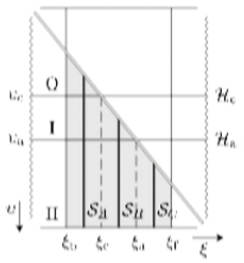
$$A > \frac{1}{\ell}$$

Anti-de Sitter in C-metric form

$m = 0 \quad e = 0 \quad A > 1/\ell$

$$\boldsymbol{g}_{\mathrm{AdS}} = \frac{\ell^2}{\omega^2}\left(-(v^2-1)\,\mathbf{d}\tau^2 + \frac{1}{v^2-1}\,\mathbf{d}v^2 + \frac{1}{\xi^2-1}\,\mathbf{d}\xi^2 + (1-\xi^2)\,\mathbf{d}\varphi^2\right)$$

$$= \frac{\ell^2}{\omega^2 R^2}\left(-\left(1-\frac{R^2}{\ell^2}\right)\mathbf{d}T^2 + \left(1-\frac{R^2}{\ell^2}\right)^{-1}\mathbf{d}R^2 + R^2\left(\mathbf{d}\Theta^2 + \sin^2\Theta\,\mathbf{d}\Phi^2\right)\right)$$



$$\omega = v\,\mathrm{sh}\,\alpha_0 - \xi\,\mathrm{ch}\,\alpha_0 \qquad \frac{\omega R}{\ell} = \mathrm{sh}\,\alpha_0 + \frac{R}{\ell}\,\mathrm{ch}\,\alpha_0\cos\Theta$$

$\mathcal{S}_A$: $\xi \in (\xi_b, \xi_c)$

$\mathcal{S}_B$: $\xi \in (\xi_c, \xi_a)$

$\mathcal{S}_C$: $\xi \in (\xi_a, \xi_f)$

Anti-de Sitter in cosmological and accelerated frame

$$\boldsymbol{g}_{\text{AdS}} = \frac{\ell^2}{\cos^2\tilde{r}}\Big(-\mathbf{d}\tilde{t}^2 + \mathbf{d}\tilde{r}^2 + \sin^2\tilde{r}\,\big(\mathbf{d}\vartheta^2 + \sin^2\vartheta\,\mathbf{d}\varphi^2\big)\Big) \qquad \text{cosmological coordinates}$$

$$= \frac{\ell^2}{\xi_{\text{II}}^2}\Big(-(v_{\text{II}}^2-1)\,\mathbf{d}\tau_{\text{II}}^2 + \frac{1}{v_{\text{II}}^2-1}\,\mathbf{d}v_{\text{II}}^2 + \frac{1}{\xi_{\text{II}}^2-1}\,\mathbf{d}\xi_{\text{II}}^2 + (1-\xi_{\text{II}}^2)\,\mathbf{d}\varphi^2\Big) \qquad \text{static type II coordinates}$$

$$= \frac{\xi^2}{\omega^2}\,\frac{\ell^2}{\xi^2}\Big(-(v^2-1)\,\mathbf{d}\tau^2 + \frac{1}{v^2-1}\,\mathbf{d}v^2 + \frac{1}{\xi^2-1}\,\mathbf{d}\xi^2 + (1-\xi^2)\,\mathbf{d}\varphi^2\Big) \qquad C\text{-metric coordinates}$$

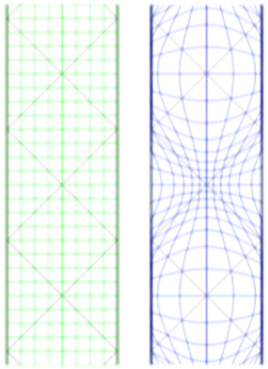
$$= \Omega^2\,\frac{\ell^2}{\cos^2\tilde{r}'}\Big(-\mathbf{d}\tilde{t}'^2 + \mathbf{d}\tilde{r}'^2 + \sin^2\tilde{r}'\,\big(\mathbf{d}\vartheta'^2 + \sin^2\vartheta'\,\mathbf{d}\varphi^2\big)\Big) \qquad \text{accelerated coordinates}$$

$$\Omega = \Big(\operatorname{ch}\alpha_0 + \operatorname{sh}\alpha_0\frac{\sin\tilde{t}'}{\cos\tilde{r}'}\Big) = \Big(\operatorname{ch}\alpha_0 - \operatorname{sh}\alpha_0\frac{\sin\tilde{t}}{\cos\tilde{r}}\Big)^{-1}$$

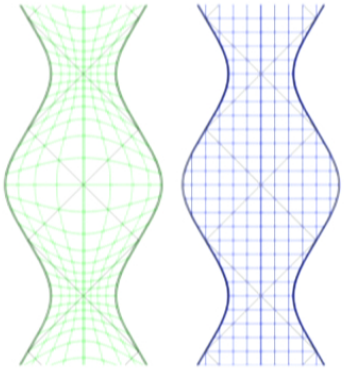
$$\tan\tilde{t}' = \frac{\operatorname{ch}\alpha_0\sin\tilde{t} - \operatorname{sh}\alpha_0\cos\tilde{r}}{\cos\tilde{t}}$$

$$\cot\tilde{r}' = \frac{-\operatorname{sh}\alpha_0\sin\tilde{t} + \operatorname{ch}\alpha_0\cos\tilde{r}}{\sin\tilde{r}}$$

$$\vartheta' = \vartheta$$



cosmological frame



accelerated frame

AdS: $A > 1/\ell$

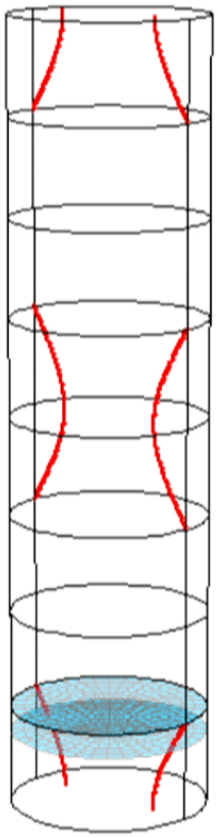
Accelerated coordinates in AdS

animation ...

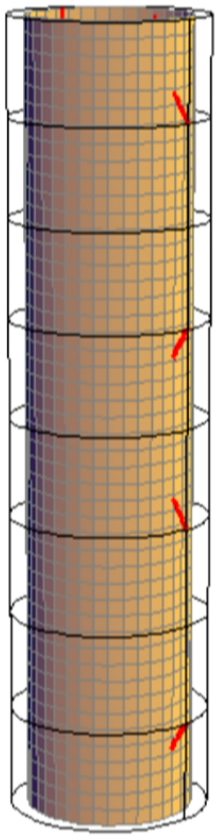
AdS - cosmological coordinates t, r, ϑ
cosmological frame

back to top

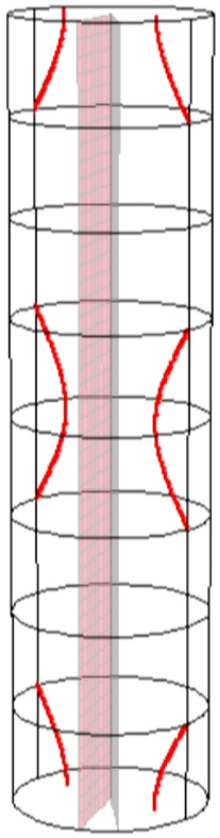
Surfaces t=constant, r=constant, ϑ=constant



deform to acc. frame



accelerated frame



τ, υ, ξ

AdS - cosmological coordinates t, r, ϑ
cosmological frame

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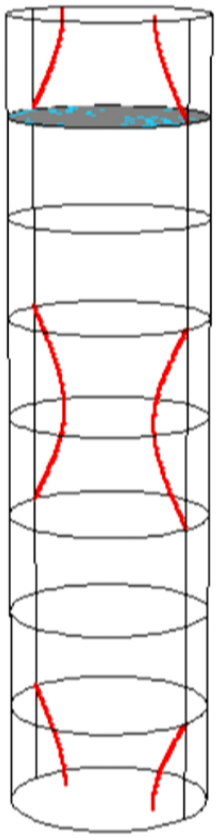
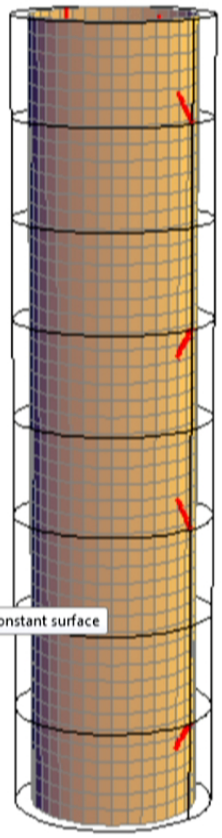
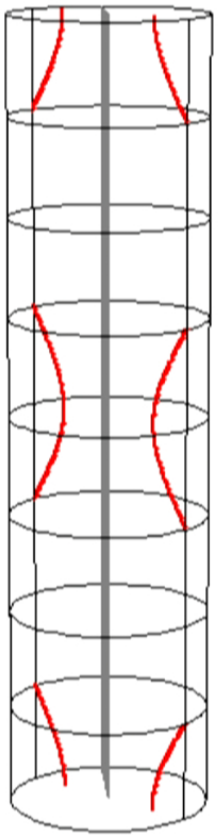
Surfaces t=constant, r=constant, ϑ=constant







deform to acc. frame

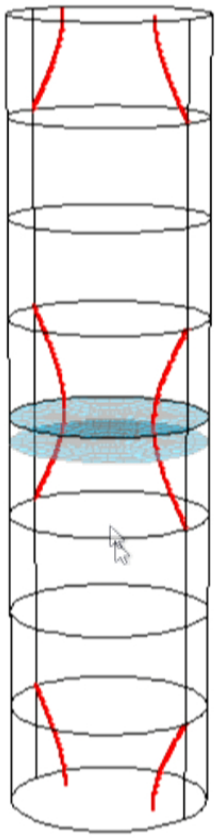
accelerated frame

τ, υ, ξ

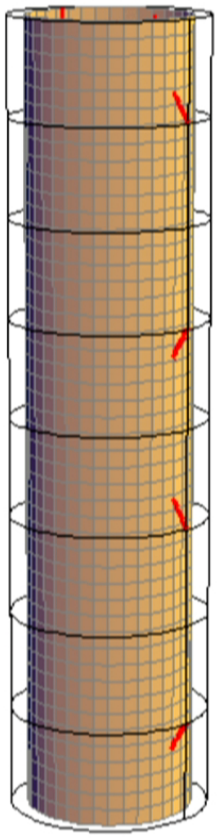
AdS - cosmological coordinates t, r, ϑ
cosmological frame

back to top

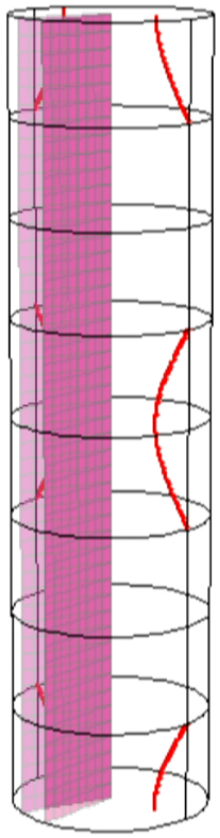
Surfaces t=constant, r=constant, ϑ=constant



deform to acc. frame



accelerated frame

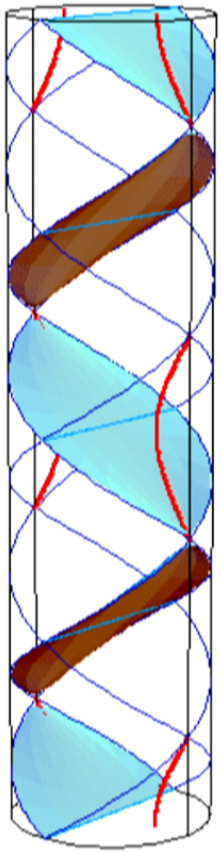


τ, υ, ξ

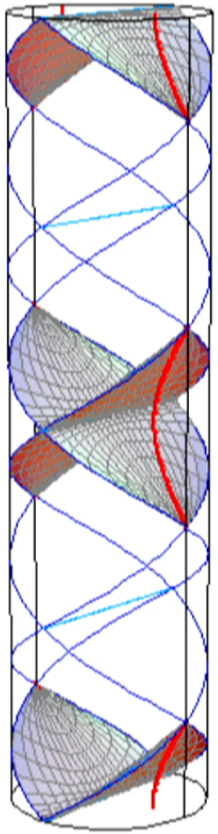
AdS - accelerated coordinates τ, υ, ξ
cosmological frame

back to top

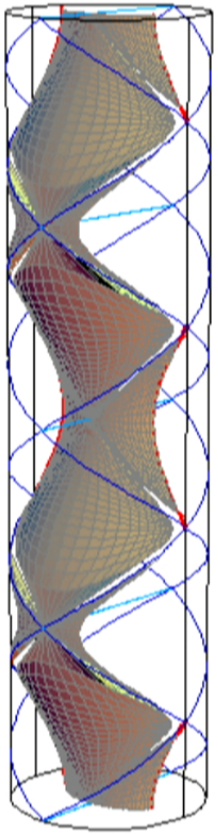
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



accelerated frame



t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
cosmological frame

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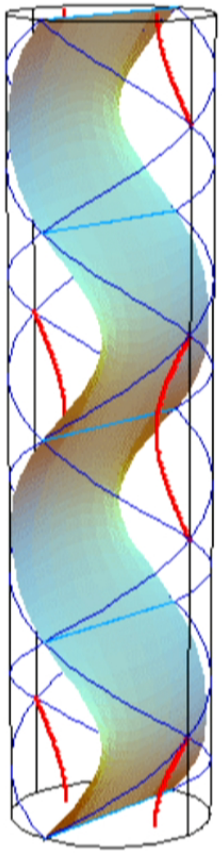
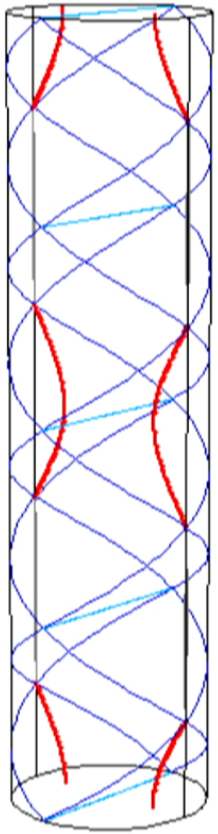
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



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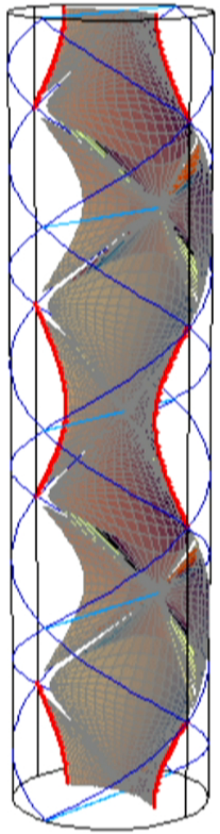

t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
cosmological frame

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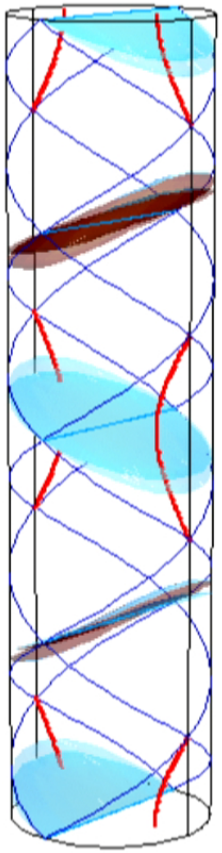
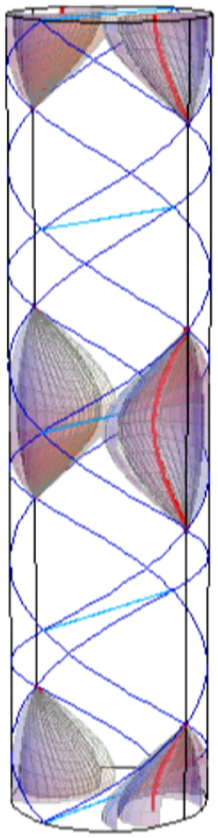
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



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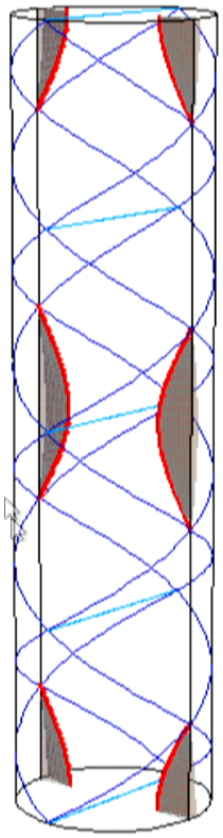

t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
cosmological frame

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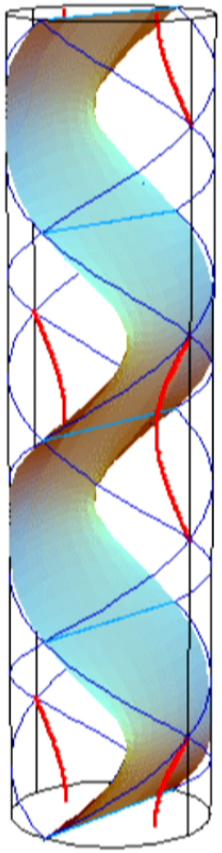
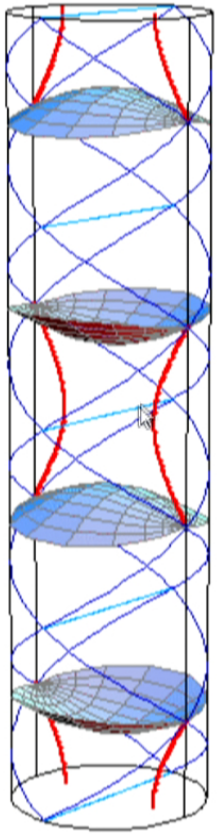
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



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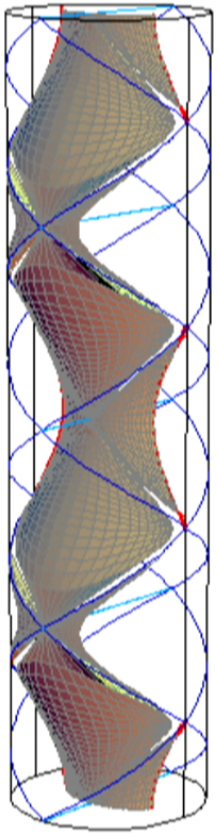

t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
cosmological frame

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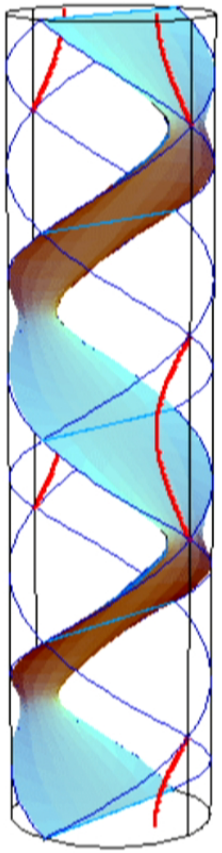
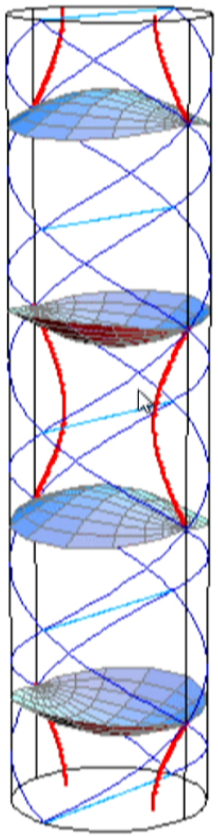
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



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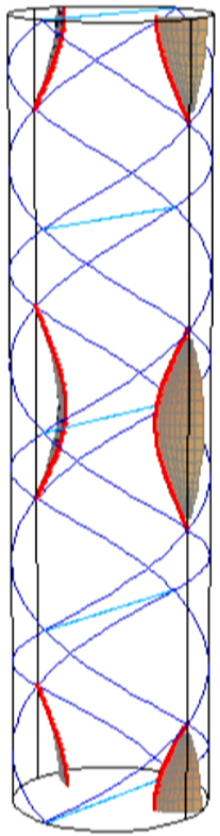

t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
cosmological frame

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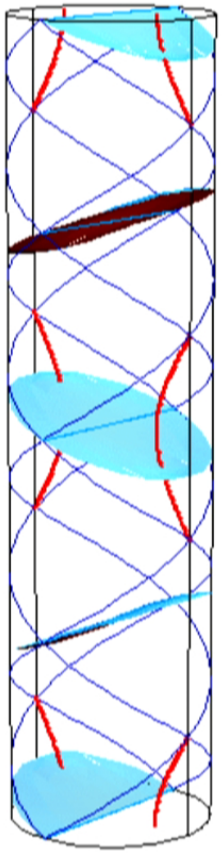
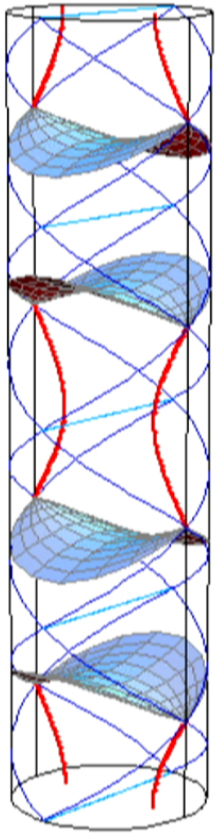
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



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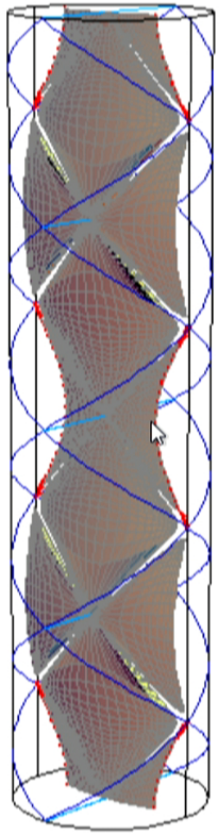

t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
cosmological frame

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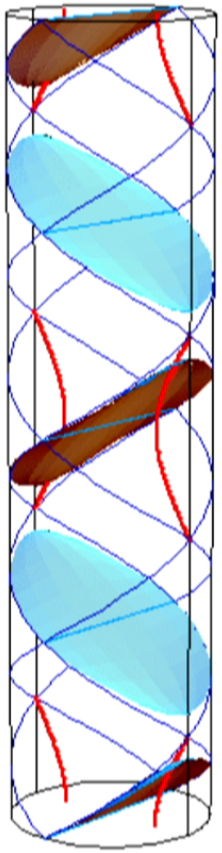
Surfaces τ=constant, υ=constant, ξ=constant



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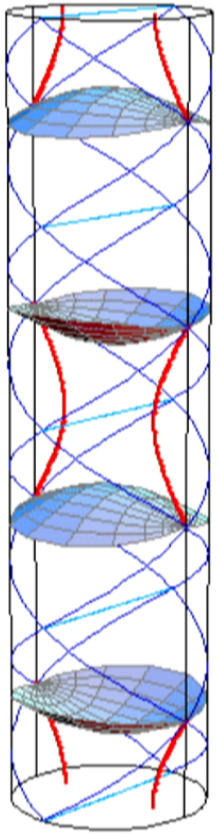

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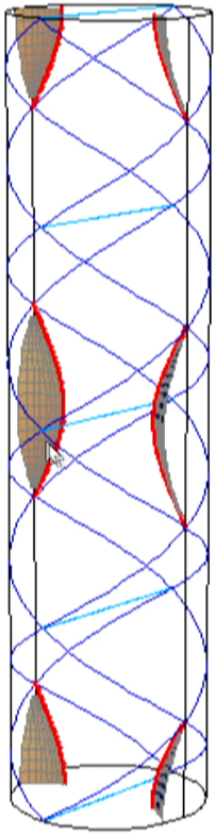

t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
cosmological frame

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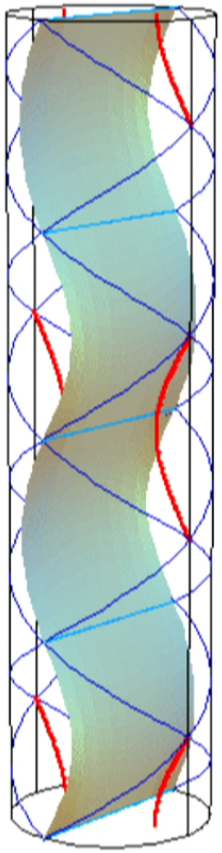
Surfaces τ=constant, υ=constant, ξ=constant



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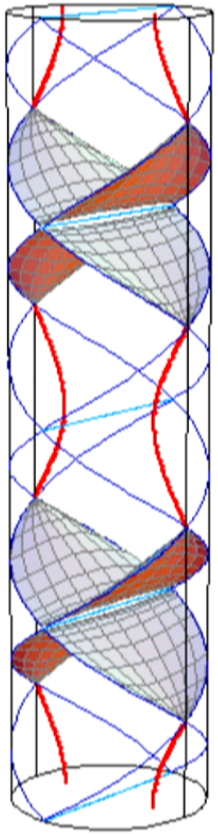

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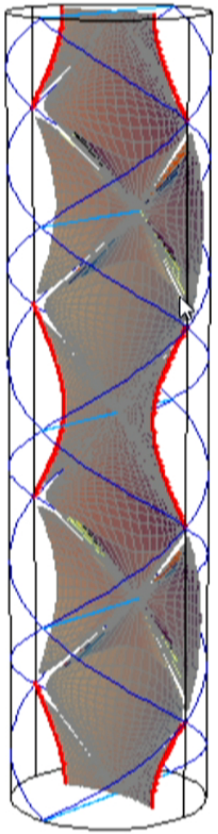

t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
accelerated frame

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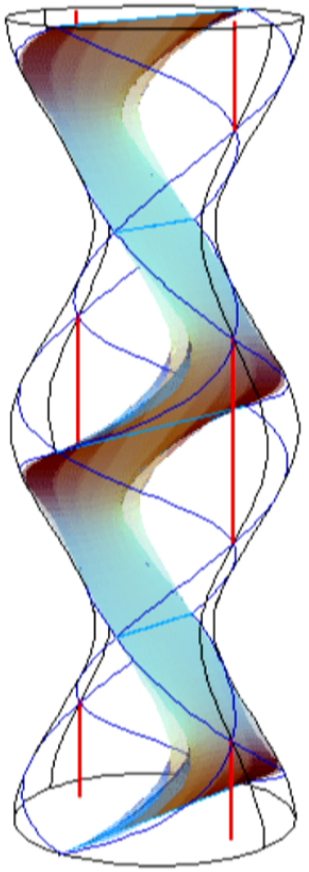
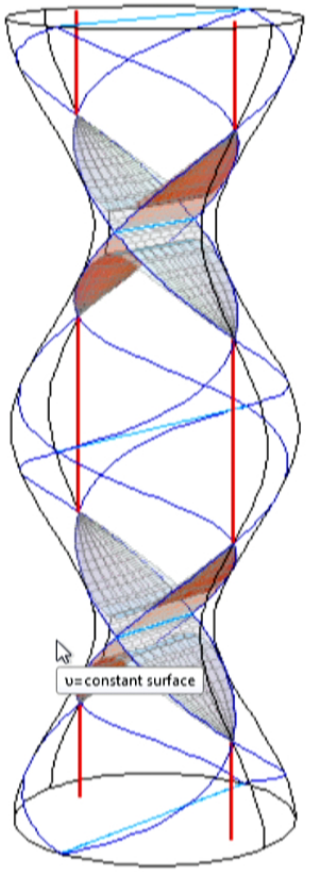
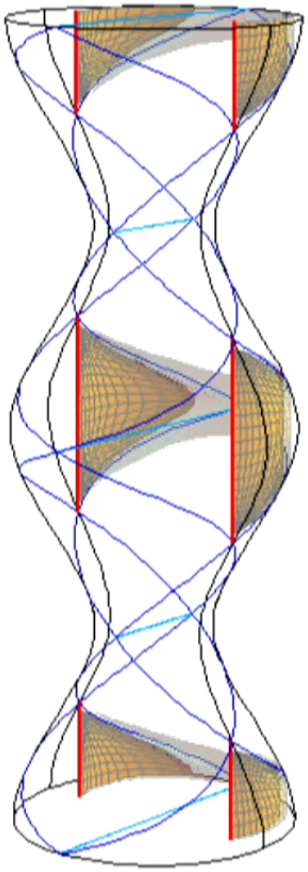
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



cosmological frame



t, r, ϑ

AdS - accelerated coordinates τ, υ, ξ
accelerated frame

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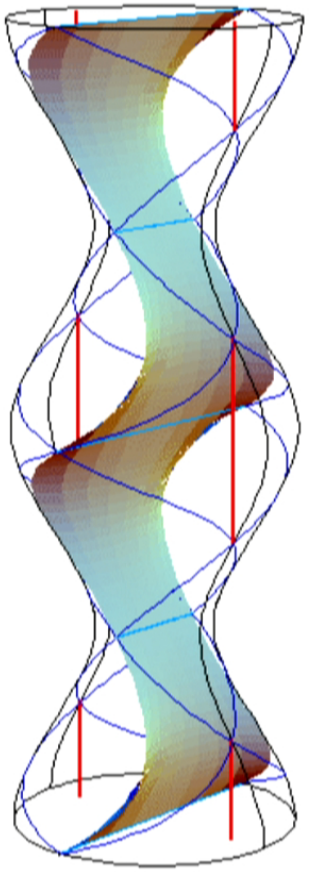
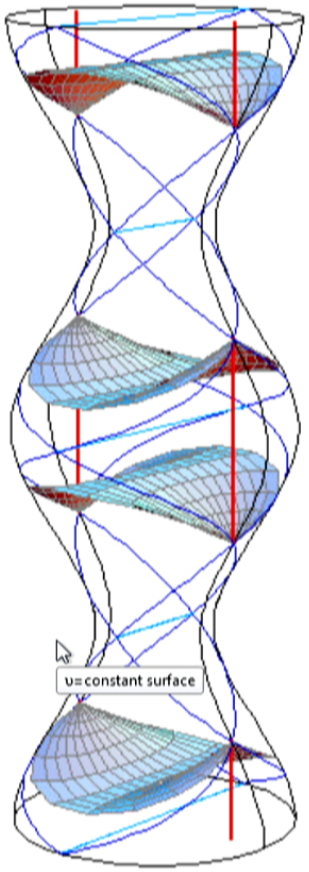
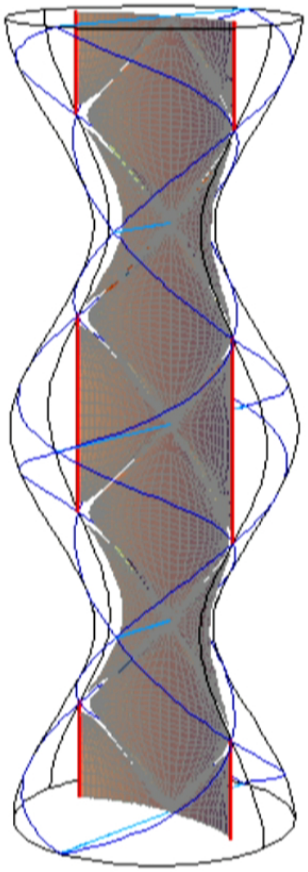
Surfaces τ=constant, υ=constant, ξ=constant



alternative view



cosmological frame



t, r, ϑ

AdS: $A > 1/\ell$

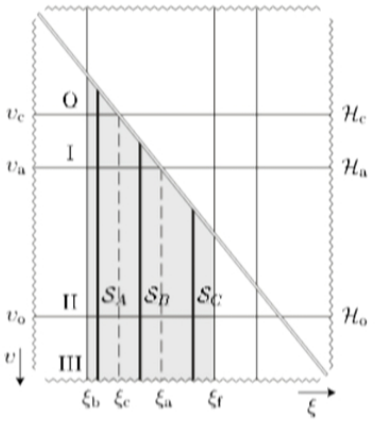
Accelerated coordinates in AdS

animation ...

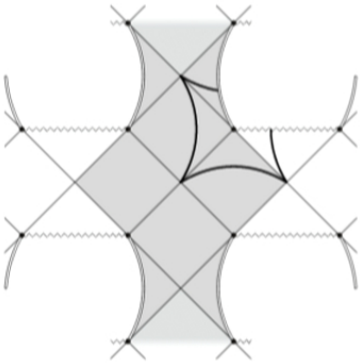
CAdSII: $A > 1/\ell$

$m \neq 0 \quad e = 0$

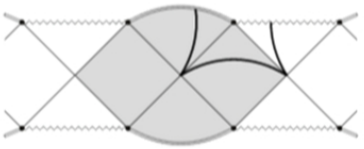
ξ-v diagram
$\tau, \varphi = \text{const.}$



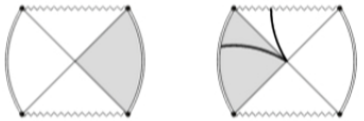
τ-v diagram $\xi, \varphi = \text{const.}$



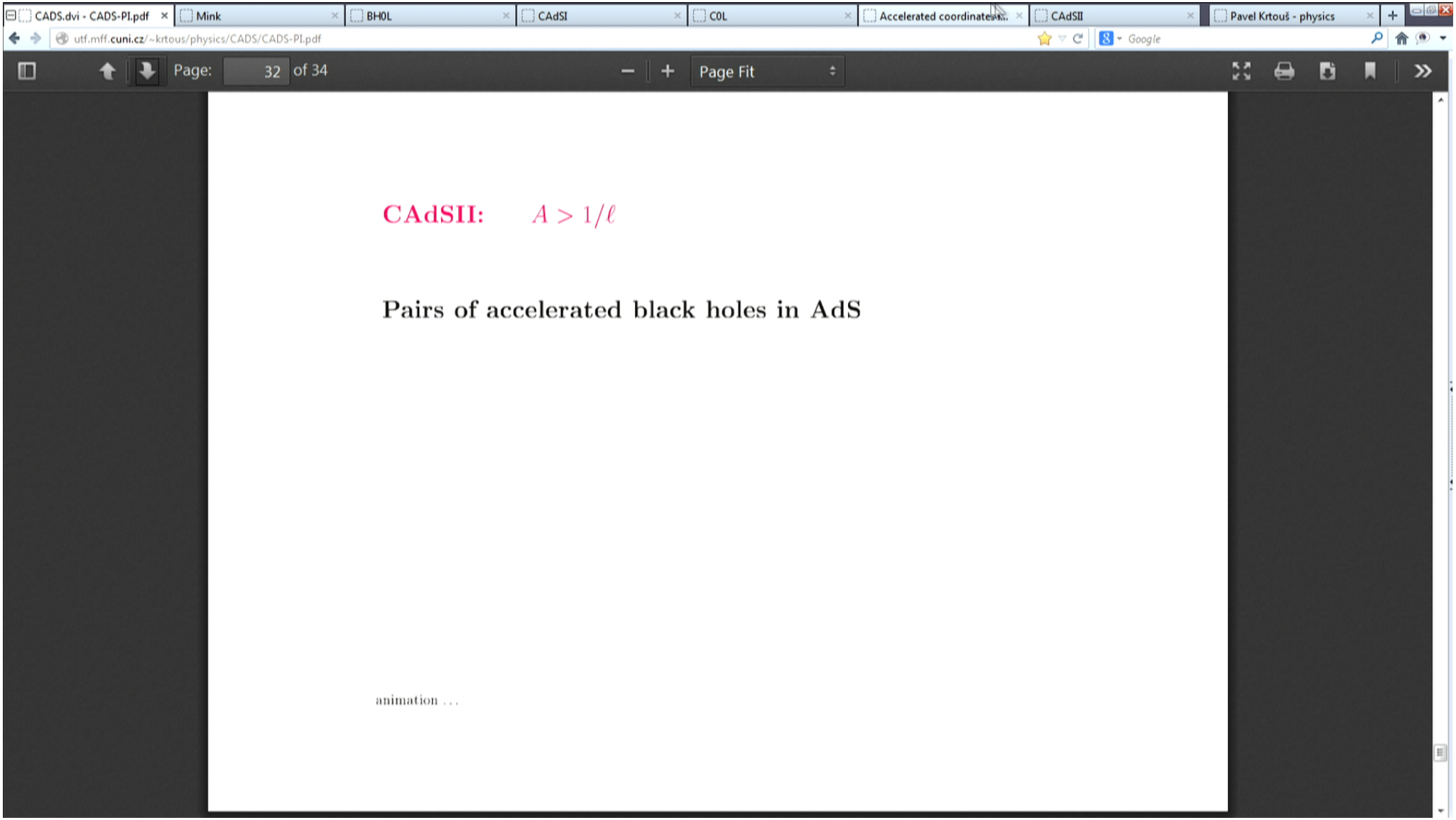
$\mathcal{S}_A$: $\xi \in (\xi_b, \xi_c)$



$\mathcal{S}_B$: $\xi \in (\xi_c, \xi_a)$



$\mathcal{S}_C$: $\xi \in (\xi_a, \xi_f)$


CADS.dvi - CADS-PI.pdf
Mink
BH0L
CAdSI
C0L
Accelerated coordinates...
CAdSII
Pavel Krtouš - physics
utf.mff.cuni.cz/~krtous/physics/CADS/CADS-PI.pdf
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Page Fit
CAdSII: $A > 1/\ell$
Pairs of accelerated black holes in AdS
animation ...

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – conformal infinity (scri)

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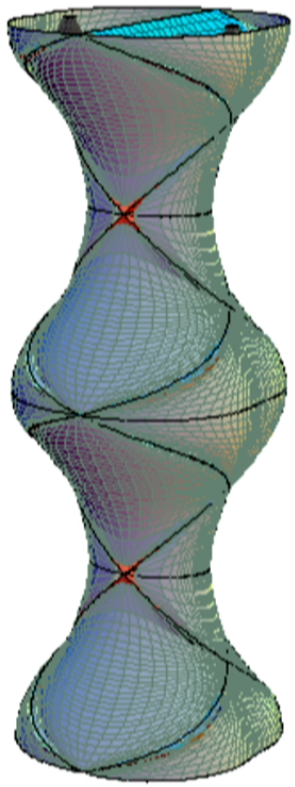

interactive view
expand black holes

open scri

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – horizons

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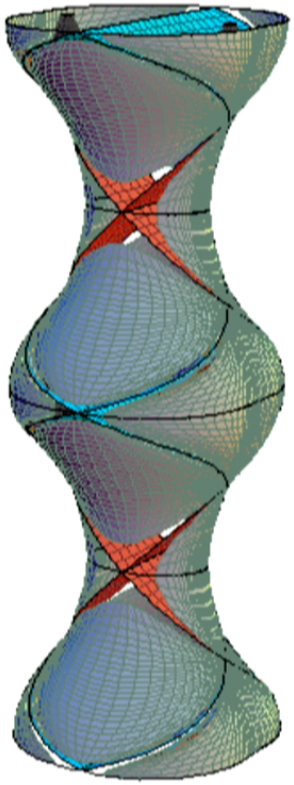


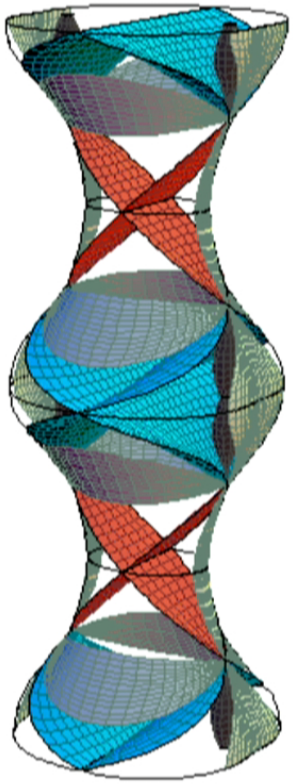
interactive view
expand black holes

close scri

play ξ=constant
section: A c B a C

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – conformal infinity (scri)

[back to top]



interactive view
expand black holes

open scri

utf.mff.cuni.cz/~krtous/physics/CADS/show/CAdSII/drop/eng/openscri.html

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – horizons

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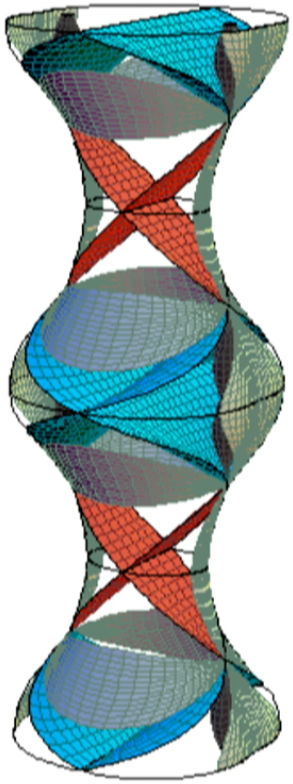

interactive view
expand black holes

close scri

play ξ=constant
section: A c B a C

utf.mff.cuni.cz/~krtous/physics/CADS/show/CAdSII/drop/eng/closescri.html

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – horizons

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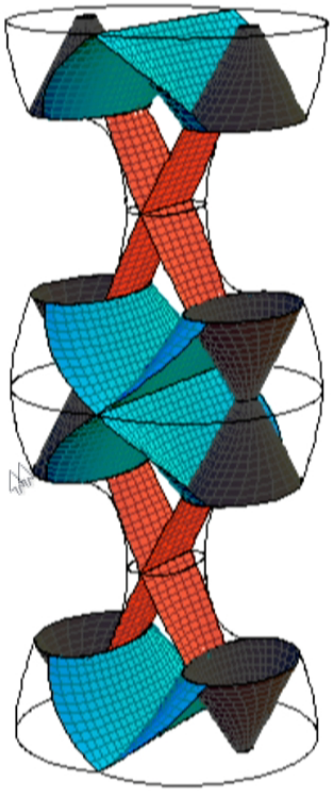

interactive view
squeeze black holes

close scri

play ξ=constant
section: A c B a C

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – sections ξ=constant

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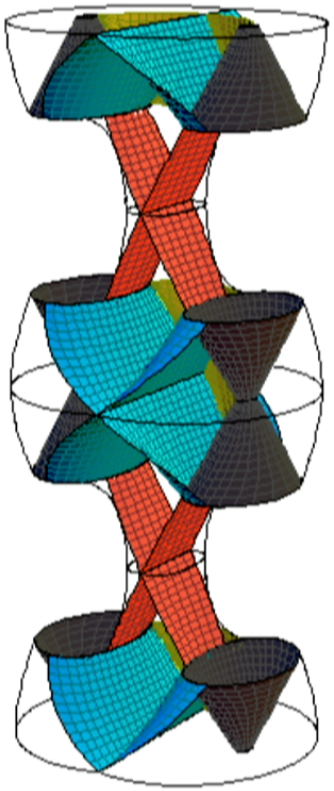

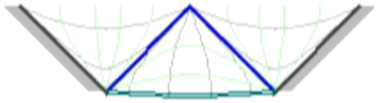

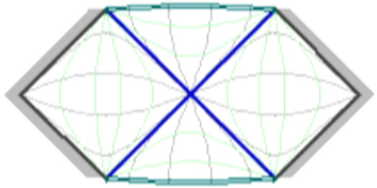

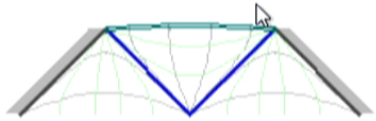

interactive view
squeeze black holes

close scri
horizons

stop ξ=constant
section: A c B a C

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – sections ξ=constant

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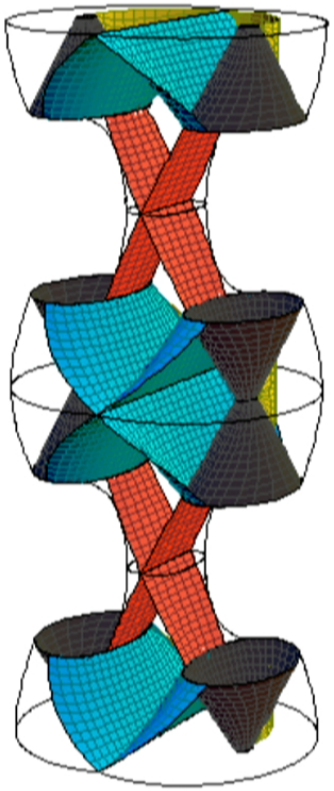

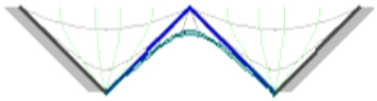

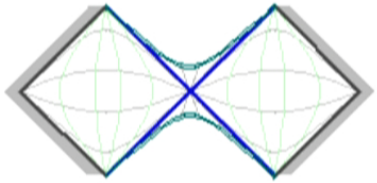

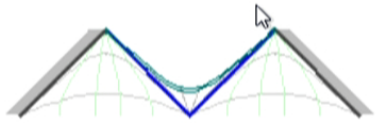

interactive view
squeeze black holes

close scri
horizons

stop ξ=constant
section: A c B a C

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – sections ξ=constant

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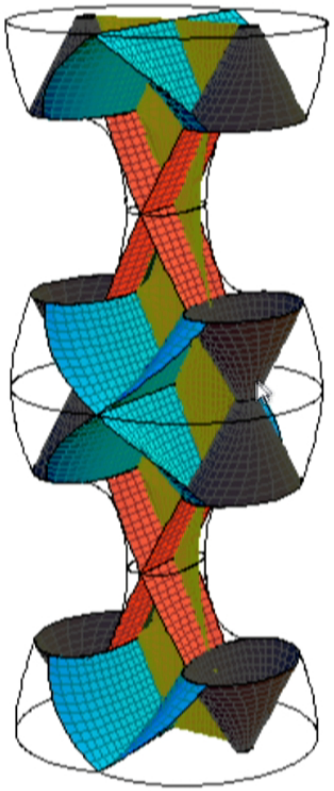

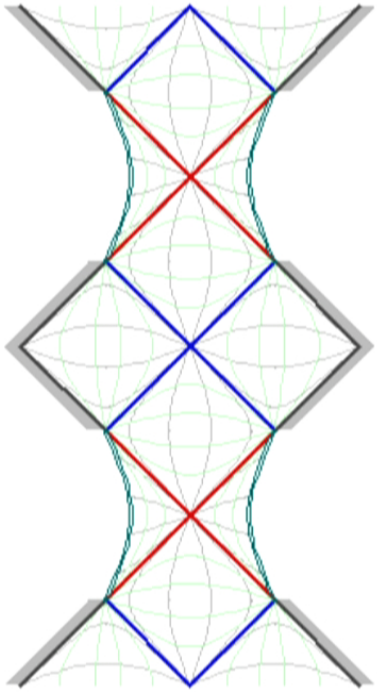

interactive view
squeeze black holes

close scri
horizons

stop ξ=constant
section: A c B a C

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – sections ξ=constant

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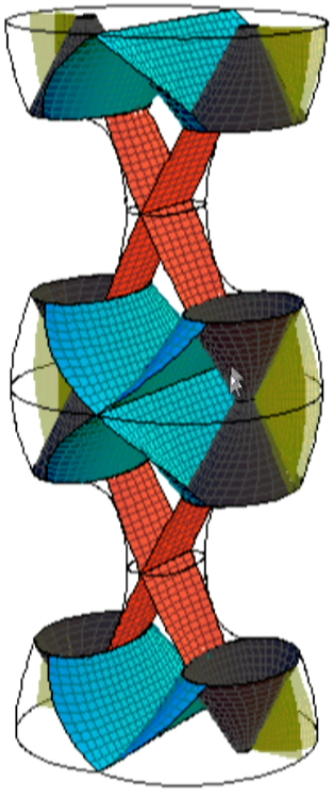
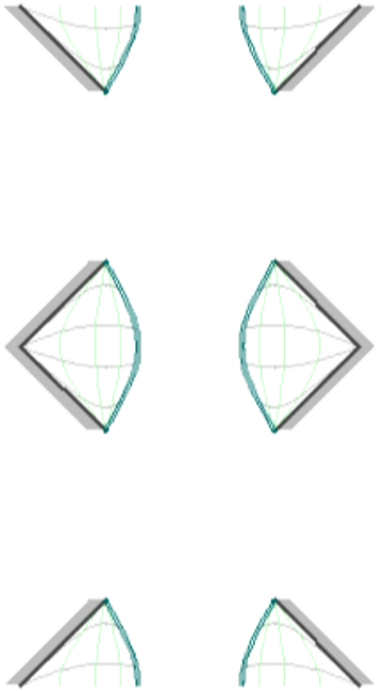




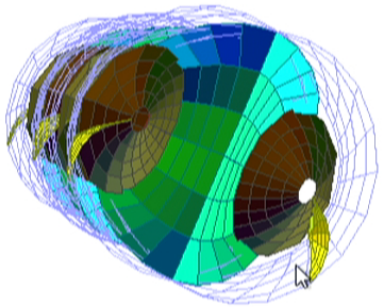
interactive view
squeeze black holes

close scri
horizons

stop ξ=constant
section: A c B a C

C-metric, $\Lambda>0$, $a>1/l_\Lambda$ – sections ξ=constant

[back to top]

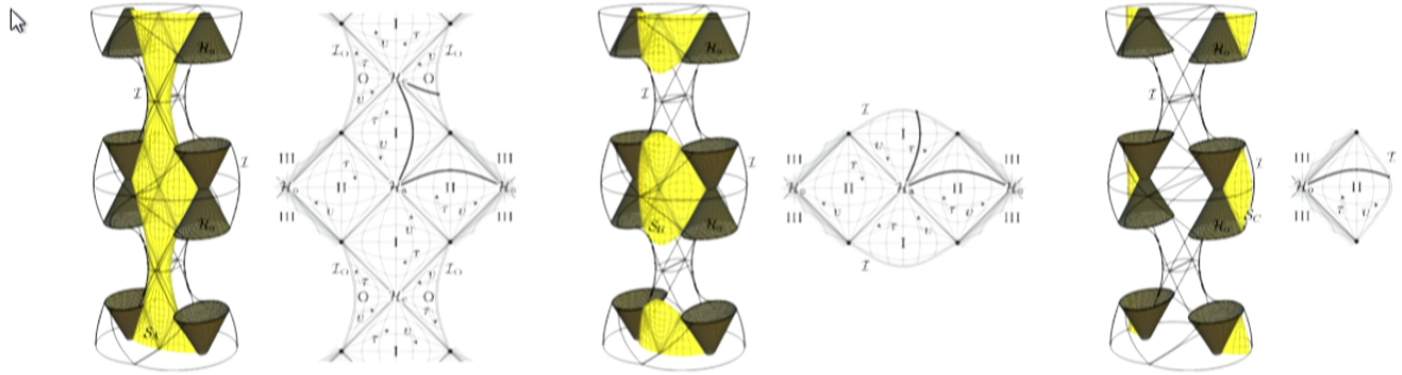


static view
squeeze black holes

close scri

stop ξ=constant

move mouse over the picture to start animation; double-click to stop/start animation; drag with right button to switch frames;
drag mouse to rotate the picture; release left button while dragging to spin; hold SHIFT while dragging to zoom and rotate; press HOME for default view



This presentation and the animations can be found at:
http://utf.mff.cuni.cz/~krtous/

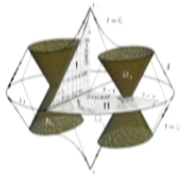
Related work

C-metric with non-vanishing Λ

Krtouš P.: Phys. Rev. D 72, 124019 (2005), gr-qc/0510101
Accelerated black holes in anti-de Sitter universe

Podolský J., Ortaggio M., Krtouš P.: Phys. Rev. D **68**, 124004 (2003)
Radiation from accelerated black holes in an anti-de Sitter universe

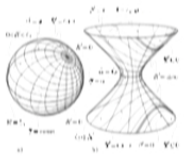
Krtouš P., Podolský J.: Phys. Rev. D **68**, 024005 (2003)
Radiation from accelerated black holes in a de Sitter universe



C-metric with vanishing Λ

Griffiths J. B., Krtouš P., Podolský J.: Class. Quantum Grav. 23, 6745 (2006), gr-qc/0609056
Interpreting the C-metric

Accelerated observers in (anti-)de Sitter universe



Bičák J., Krtous P.: Phys. Rev. D **63** (2001) 124020
Accelerated sources in de Sitter spacetime and the insufficiency of retarded fields

Bičák J., Krtouš P.: Phys. Rev. Lett. **88**, 211101 (2002)
The fields of uniformly accelerated charges in de Sitter spacetime

Bičák J., Krtouš P.: J. Math. Phys. **46**, J. Math. Phys. 46, 102504 (2005)
Fields of accelerated sources: Born in de Sitter