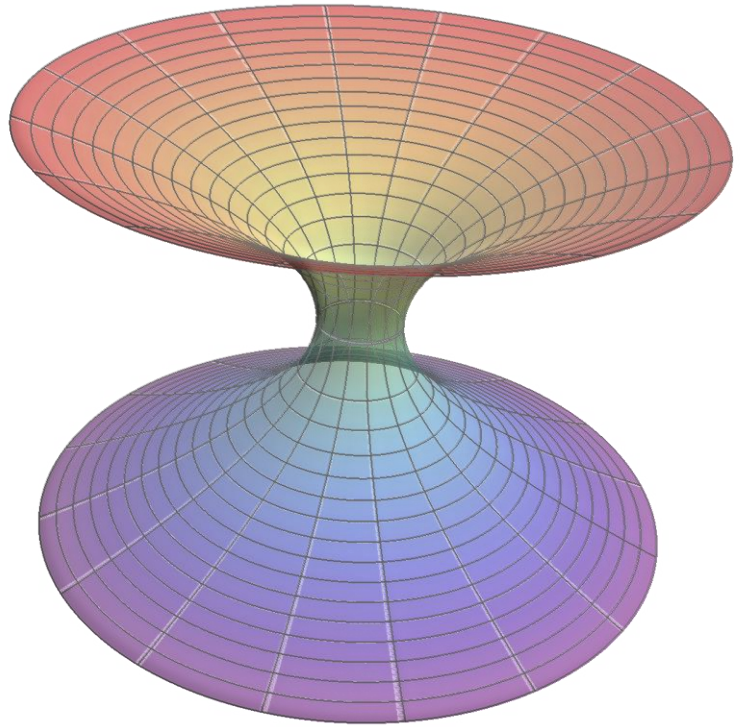

Light rings around exotic compact objects: Traversable wormholes

Sérgio Xavier, Carlos A. R. Herdeiro, Luís C. B. Crispino

Phys. Rev. D **109**, 124065 (2024)
arXiv:2404.02208

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GravEZon
Gravity @ Amazonia
Quantum Fields in
Curved Spacetimes

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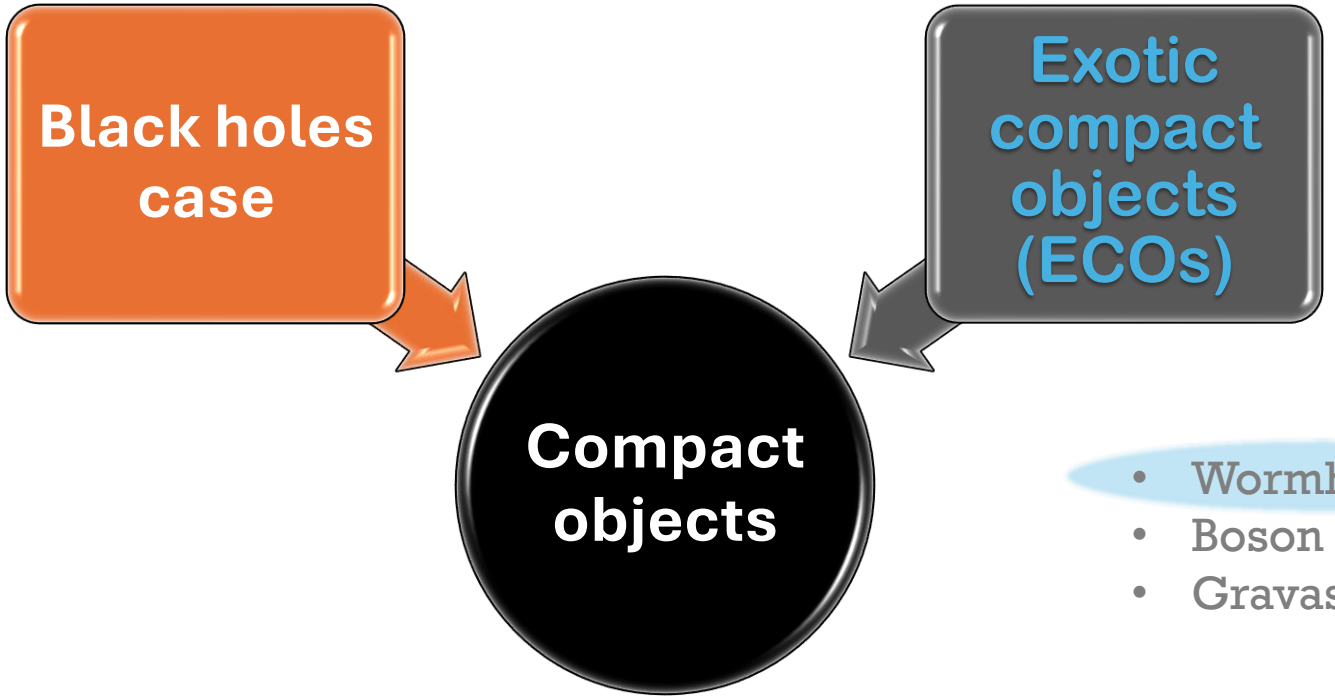
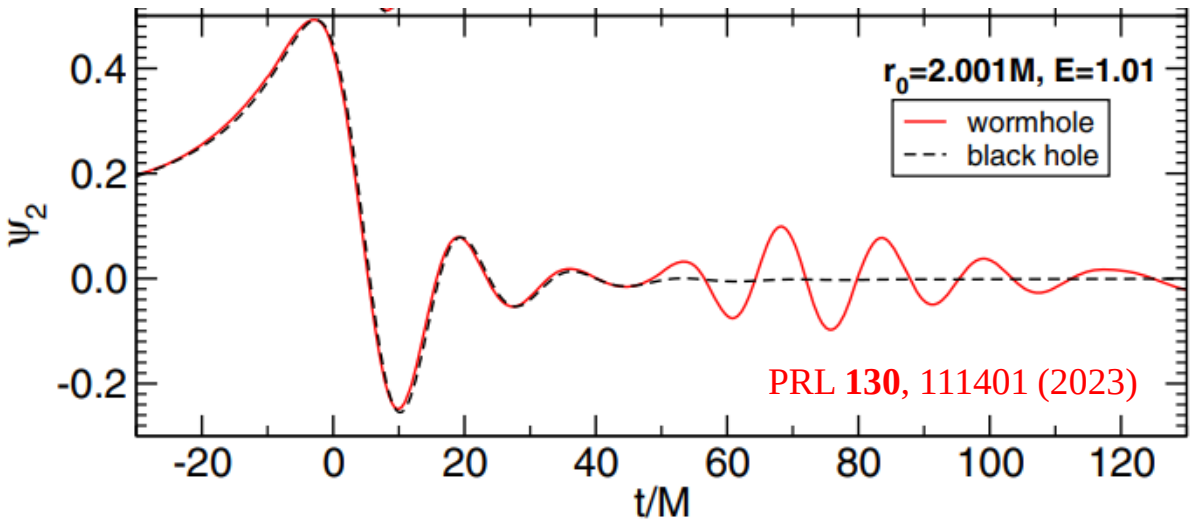
Kerr hypothesis and exotic compact objects

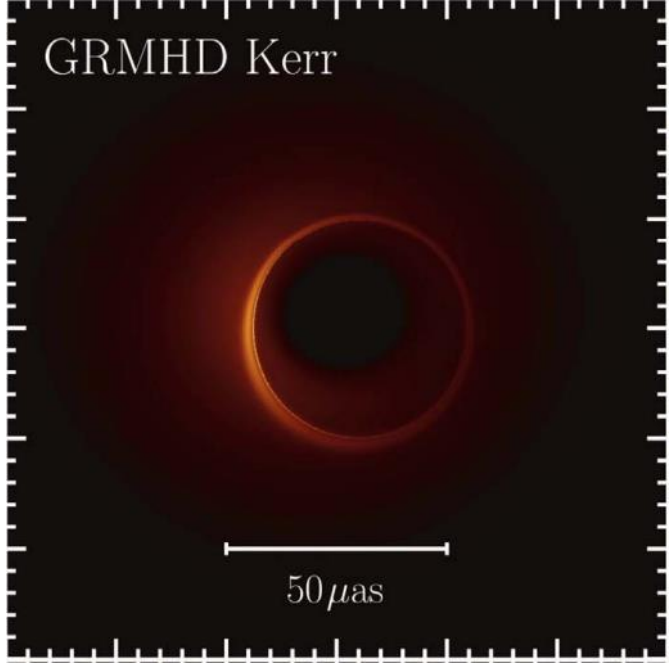


- Regular black holes
- Hairy black holes

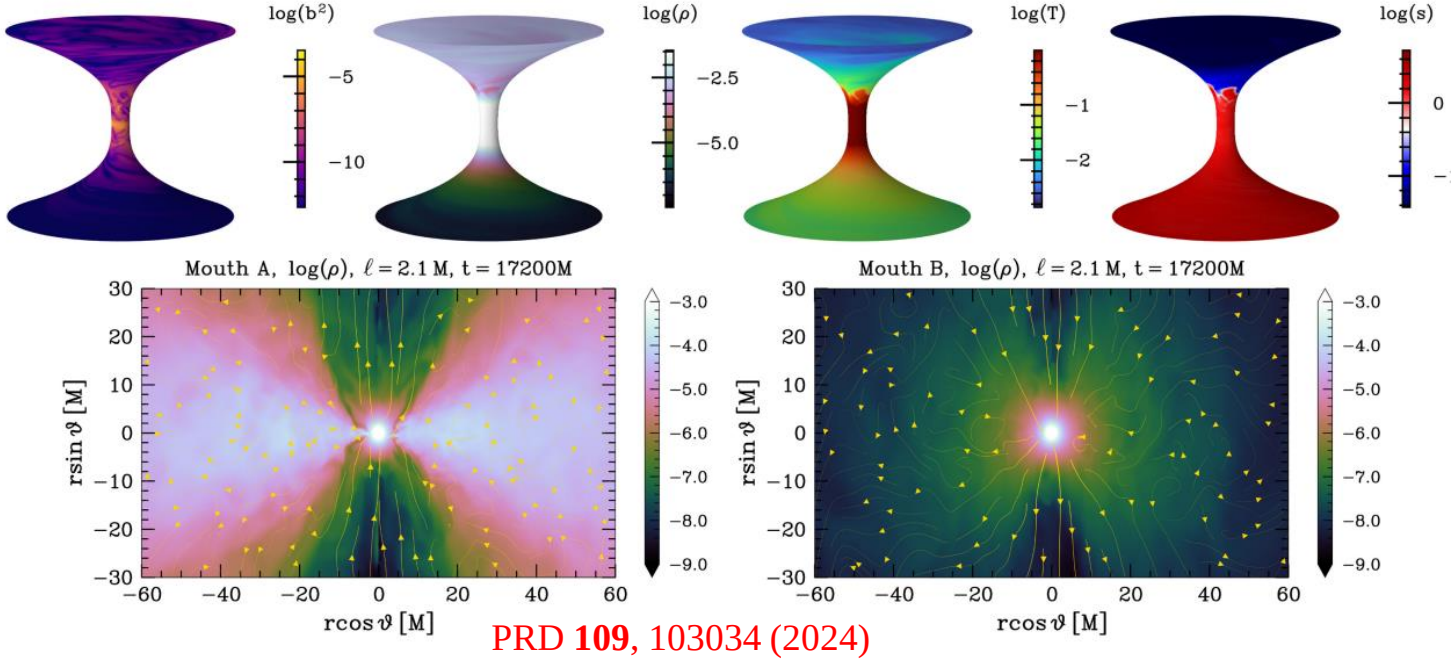
- Wormholes
- Boson stars
- Gravastars

Wormholes

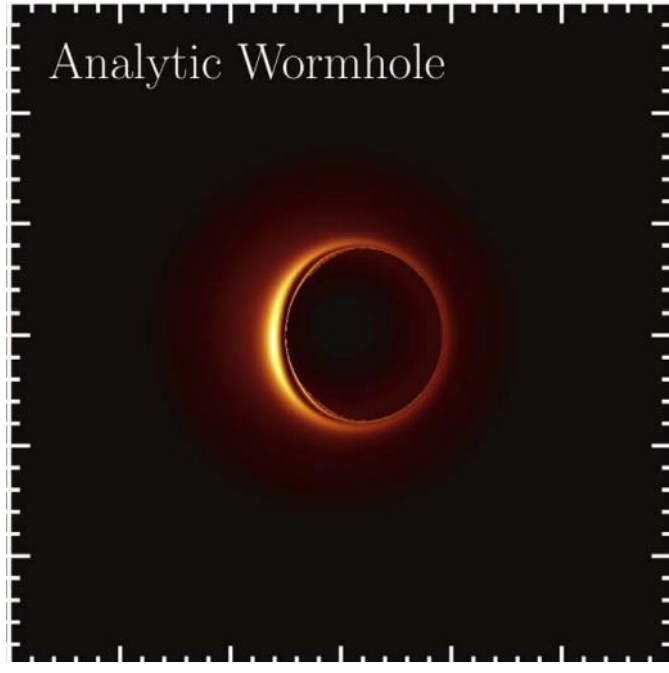




PRL **130**, 111401 (2023)



PRD **109**, 103034 (2024)



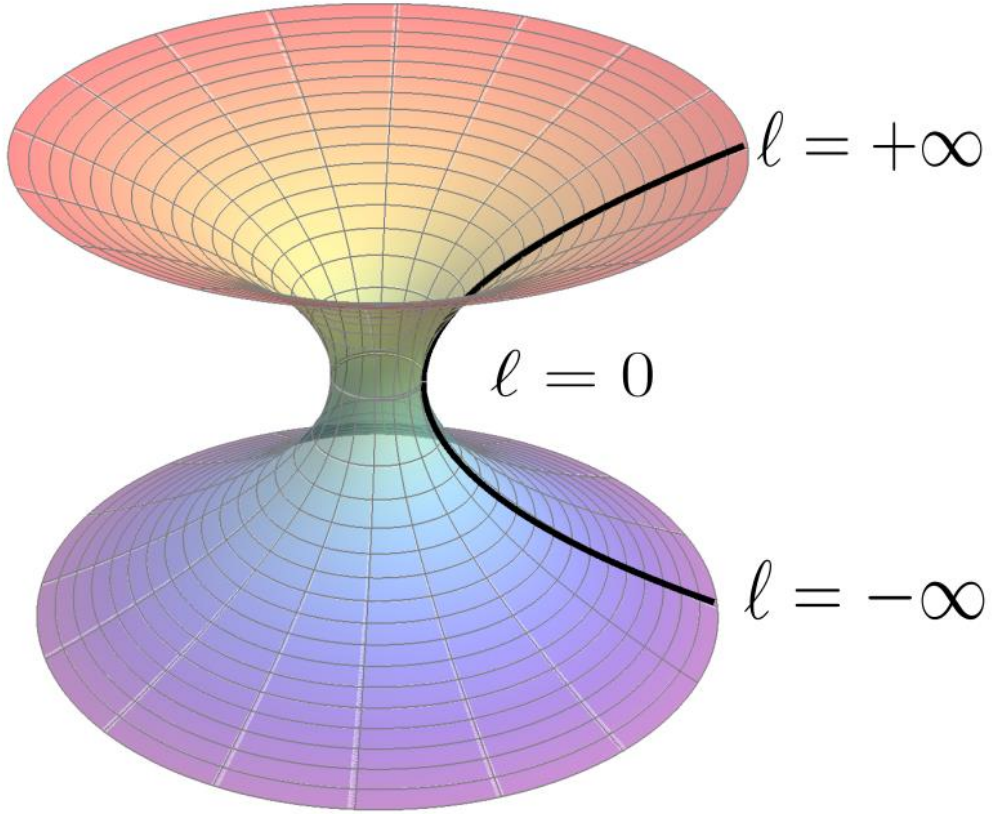
Do all wormholes have light rings?

Traversable wormholes

$\ell \in (-\infty, \infty)$

$$ds^2 = -\mathcal{N}(\ell,\theta)^2 dt^2 + d\ell^2 + \mathcal{R}(\ell,\theta)^2[d\theta^2 + \sin^2\theta(d\varphi - \omega(\ell,\theta)dt)^2]$$

Phys. Rev. D **105**, 024027 (2022)



Asymptotic flatness:

$$\mathcal{N} = 1 + \mathcal{O}(1/|\ell|),$$
$$\mathcal{R} = |\ell|(1 + \mathcal{O}(1/|\ell|)),$$
$$\omega = \mathcal{O}(1/|\ell|^2).$$

Light rings and black holes

PHYSICAL REVIEW LETTERS **124,** 181101 (2020)

Editors' Suggestion

$$w_{\mathrm{BH}} = -1$$

Stationary Black Holes and Light Rings

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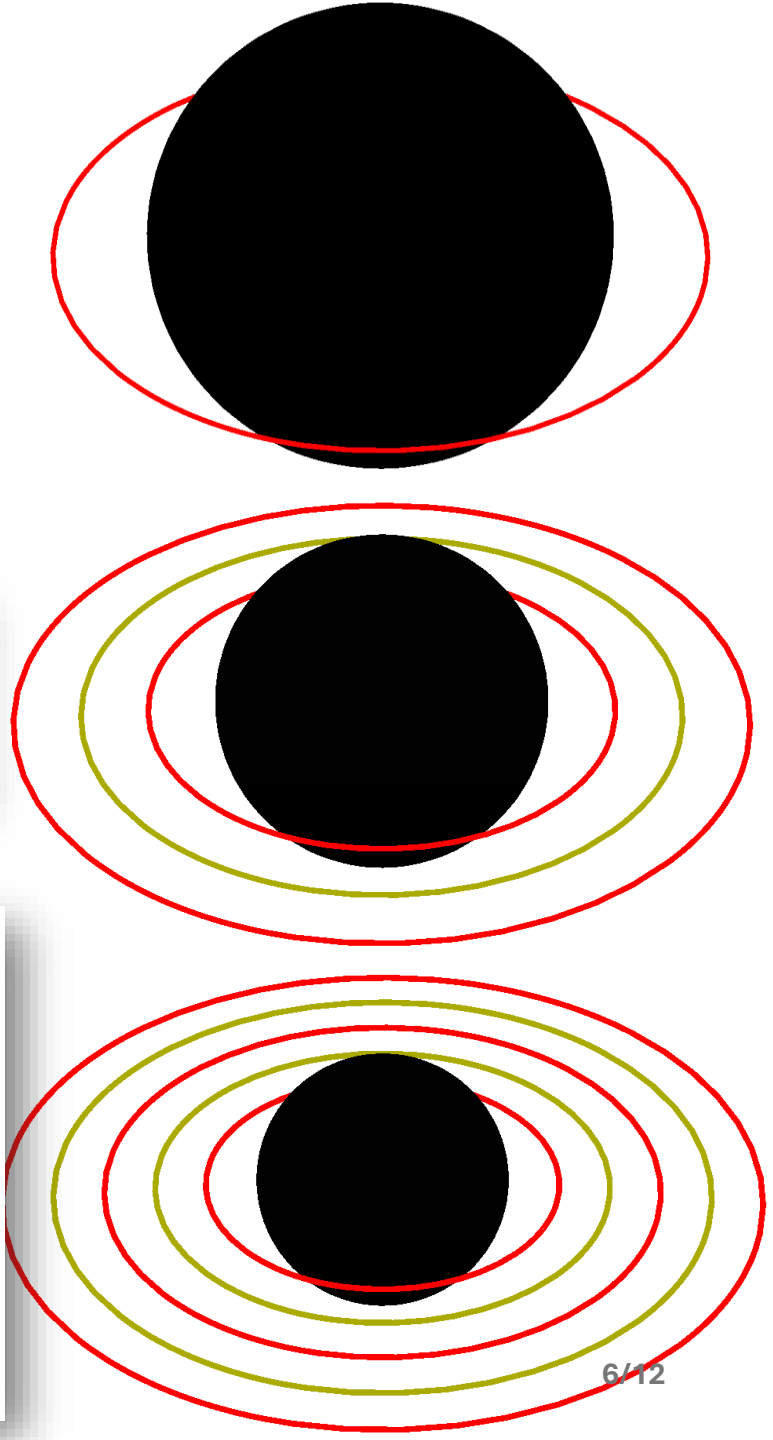
(Received 19 March 2020; accepted 15 April 2020; published 8 May 2020)

The ringdown and shadow of the astrophysically significant Kerr black hole (BH) are both intimately

equilibrium BH *must* possess such orbits? In this Letter we prove the following theorem. A stationary, axisymmetric, asymptotically flat black hole spacetime in $1+3$ dimensions, with a nonextremal, topologically spherical, Killing horizon admits, at least, one standard LR outside the horizon for each rotation sense. The proof relies on a topological argument and assumes C^2 smoothness and circularity, but

makes no use of the field equations. The argument is also adapted to recover a previous theorem establishing that a horizonless ultracompact object must admit an even number of nondegenerate LRs, one of which is stable.



PRL **119,** 251102 (2017) PHYSICAL REVIEW LETTERS week ending 22 DECEMBER 2017

$$w_{\mathrm{UCO}} = 0$$

Light-Ring Stability for Ultracompact Objects

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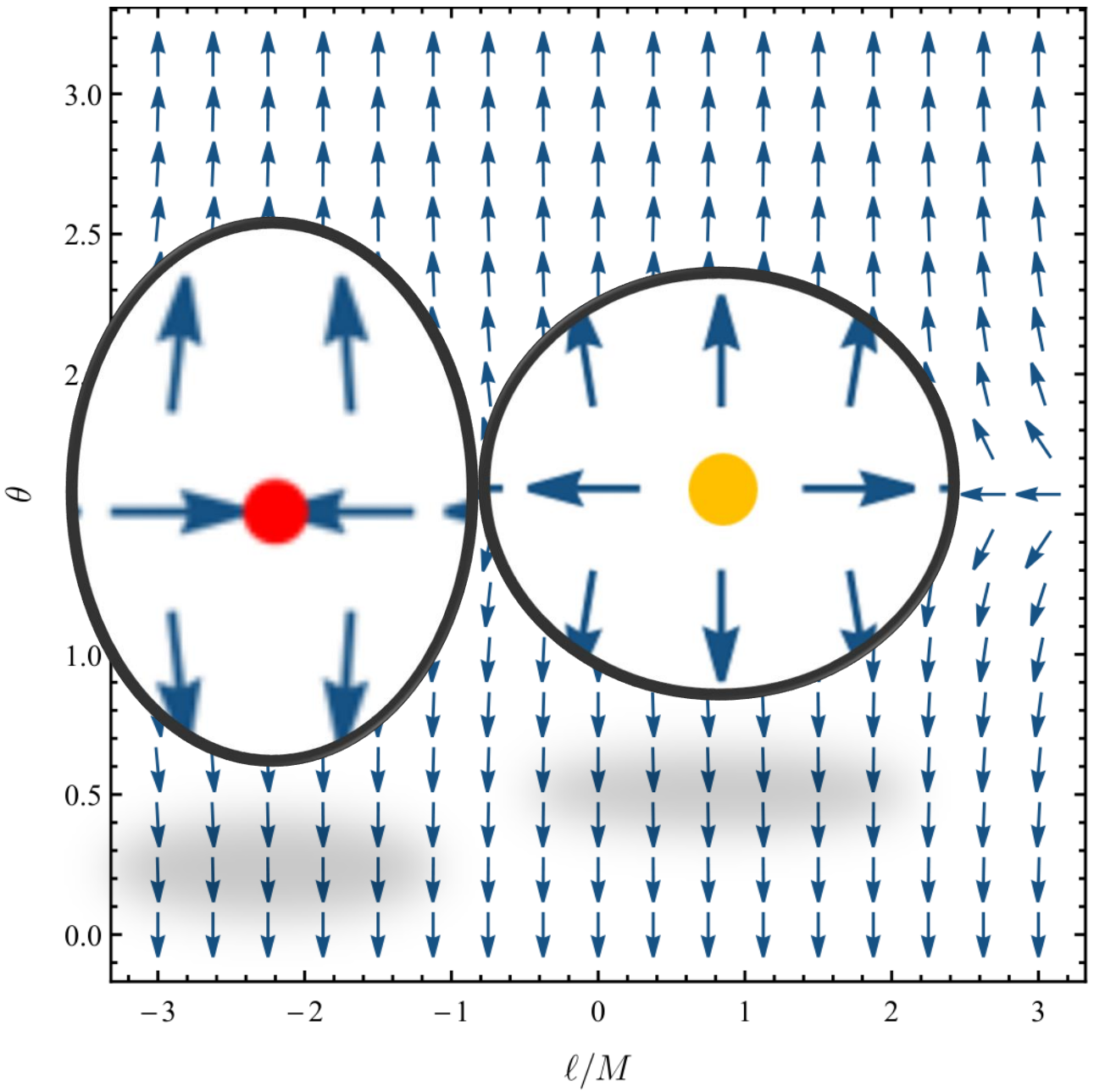
[2]*CENTRA, Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais 1, 1049 Lisboa, Portugal*
[3]*Department of Physics and Astronomy, The University of Mississippi, University, Mississippi 38677, USA*

(Received 3 August 2017; revised manuscript received 18 October 2017; published 18 December 2017)

Light rings



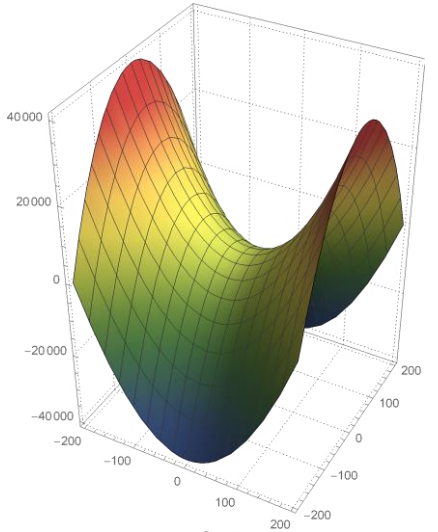
Standard LR: $w = -1$

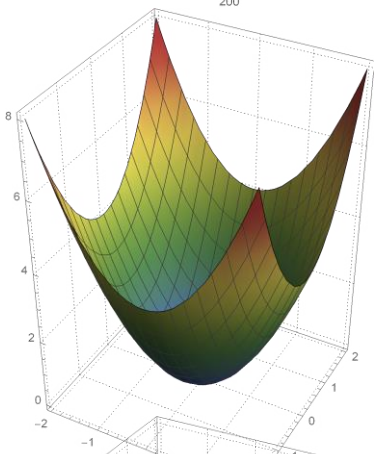
$$H(\ell,\theta)_{\pm} \equiv \frac{g_{t\varphi} \pm \sqrt{g_{t\varphi}^2 - g_{tt}g_{\varphi\varphi}}}{g_{\varphi\varphi}}$$

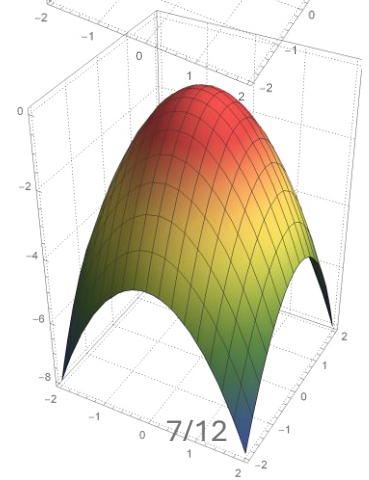
$$\nabla H_{\pm} = 0$$

$$\boldsymbol{v} = (v_\ell, v_\theta) = \left(\frac{\partial_\ell H_{\pm}}{\sqrt{g_{\ell\ell}}}, \frac{\partial_\theta H_{\pm}}{\sqrt{g_{\theta\theta}}}\right)$$

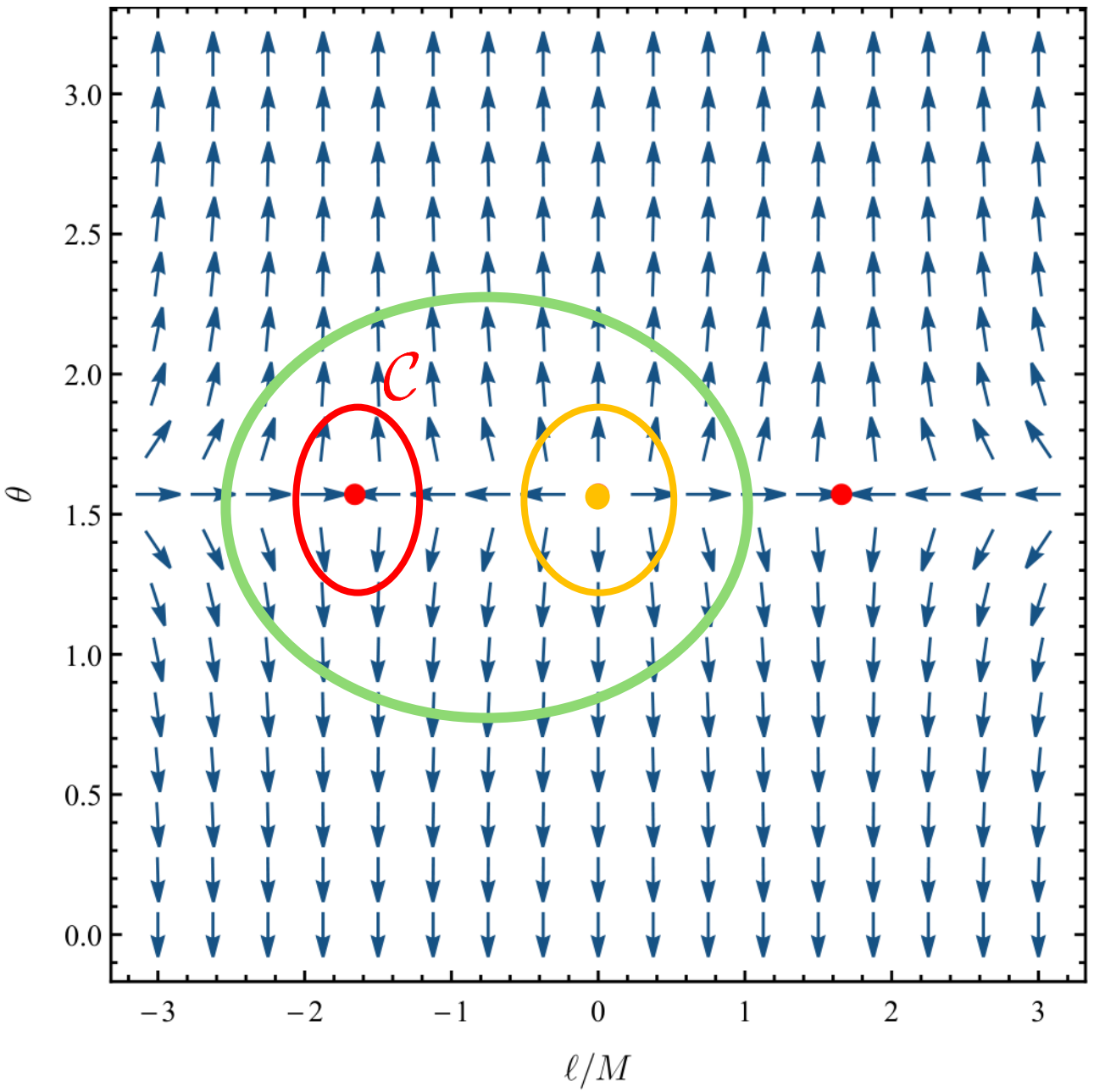
Exotic LR: $w = +1$







Light rings



$$H(\ell,\theta)_{\pm} \equiv \frac{g_{t\varphi} \pm \sqrt{g_{t\varphi}^2 - g_{tt}g_{\varphi\varphi}}}{g_{\varphi\varphi}}$$

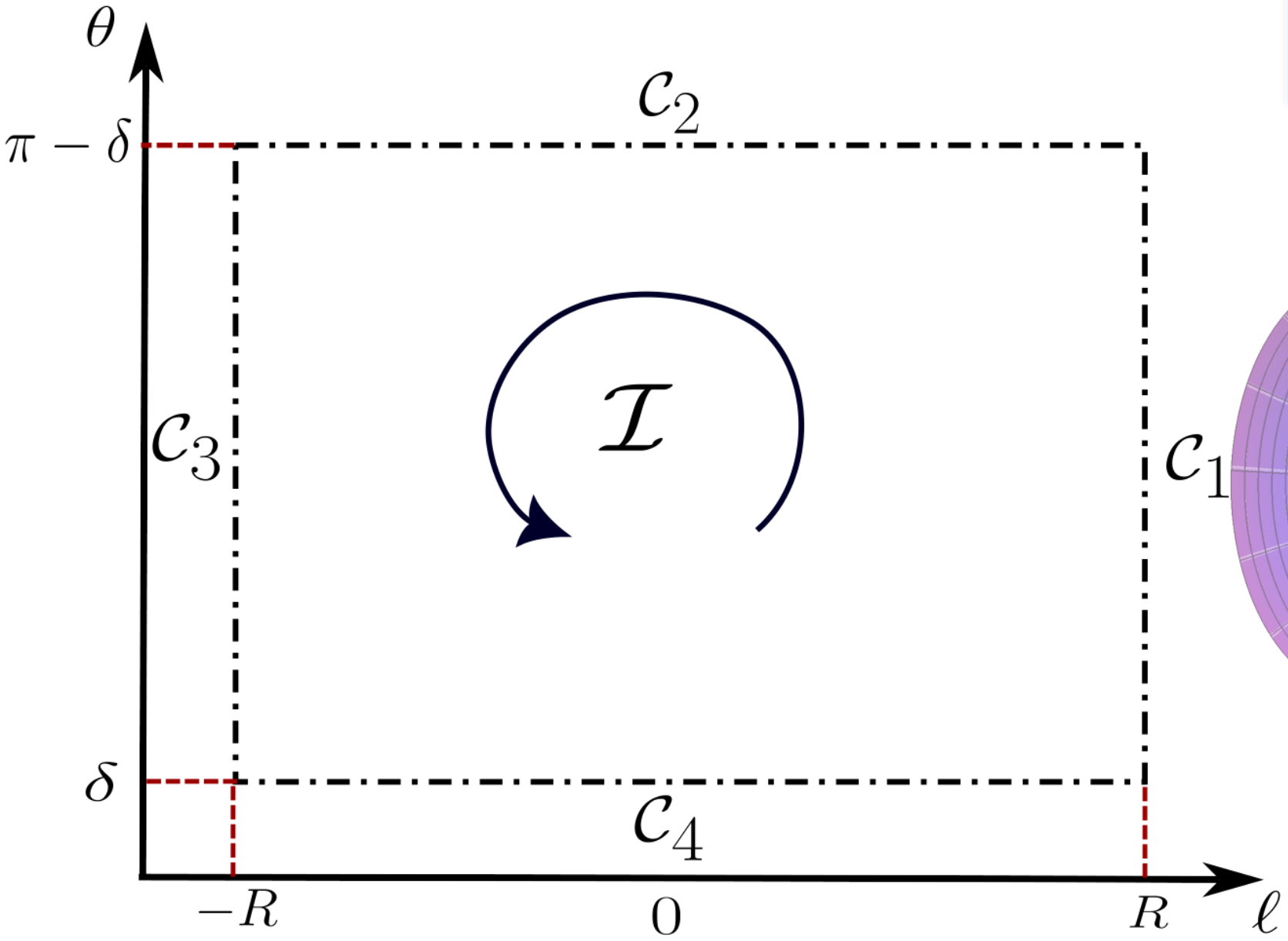
$$\boldsymbol{v} = (v_\ell, v_\theta) = \left(\frac{\partial_\ell H_\pm}{\sqrt{g_{\ell\ell}}}, \frac{\partial_\theta H_\pm}{\sqrt{g_{\theta\theta}}}\right)$$

$$w_{\mathcal{C}} = \frac{1}{2\pi}\oint_C d\Omega$$

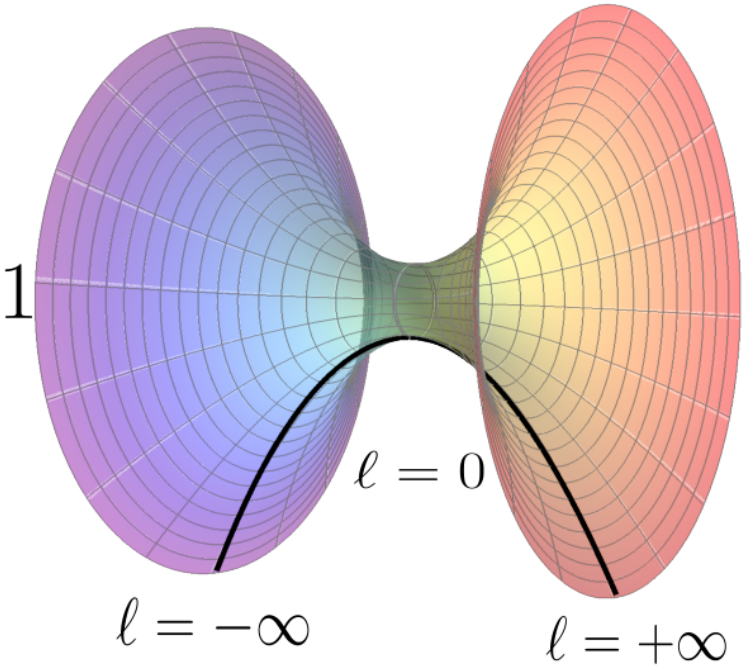
$$v_\ell = v\cos\Omega$$
$$v_\theta = v\sin\Omega$$

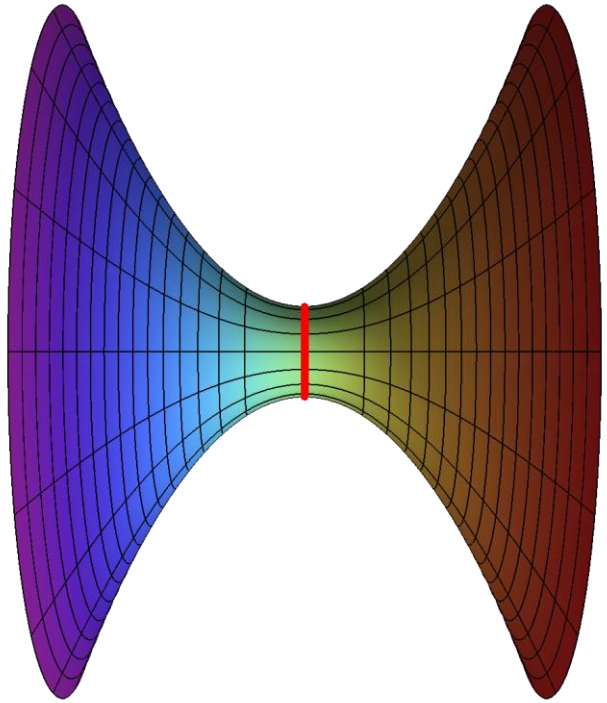
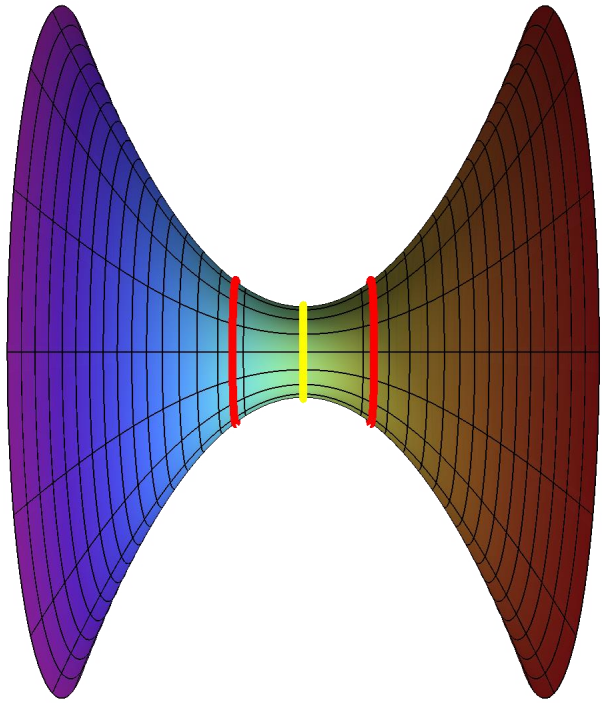
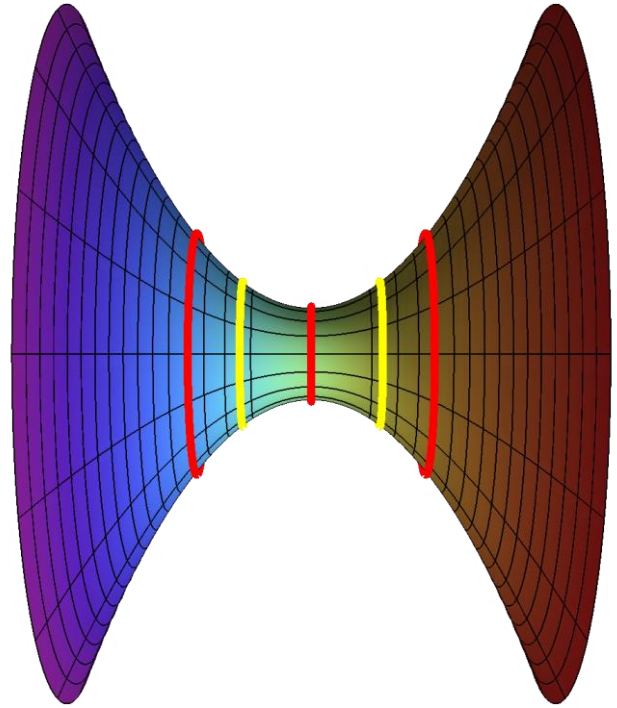
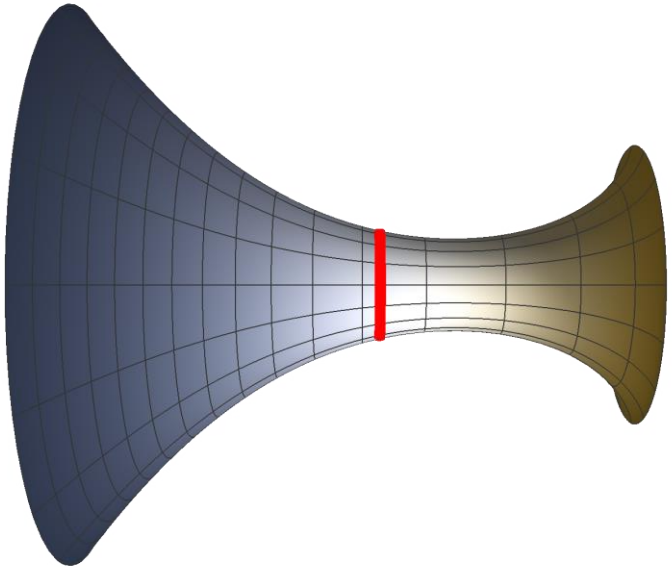
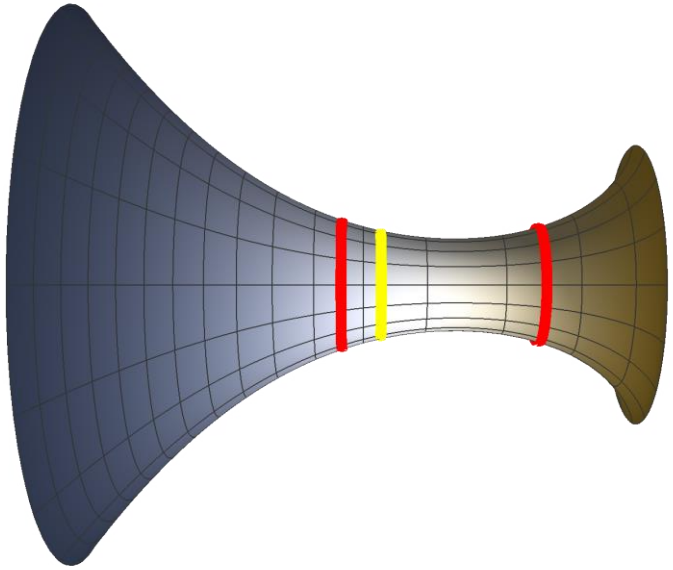
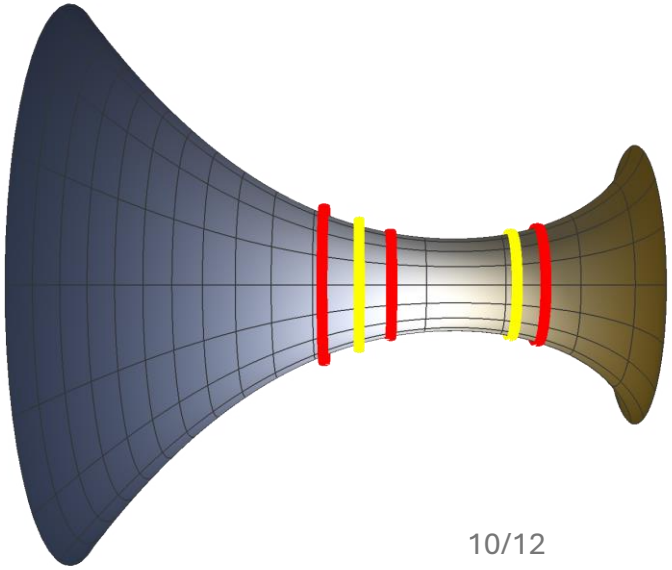
$w = -1$ $w = +1$ $w = 0$

Light rings and topological charge



$$w = -1$$

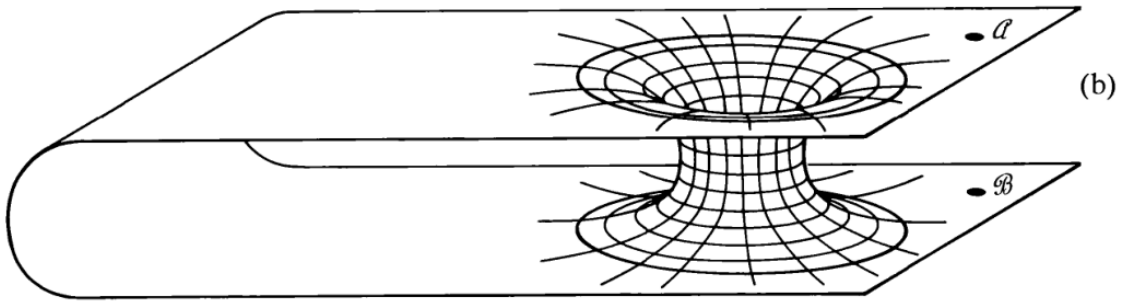


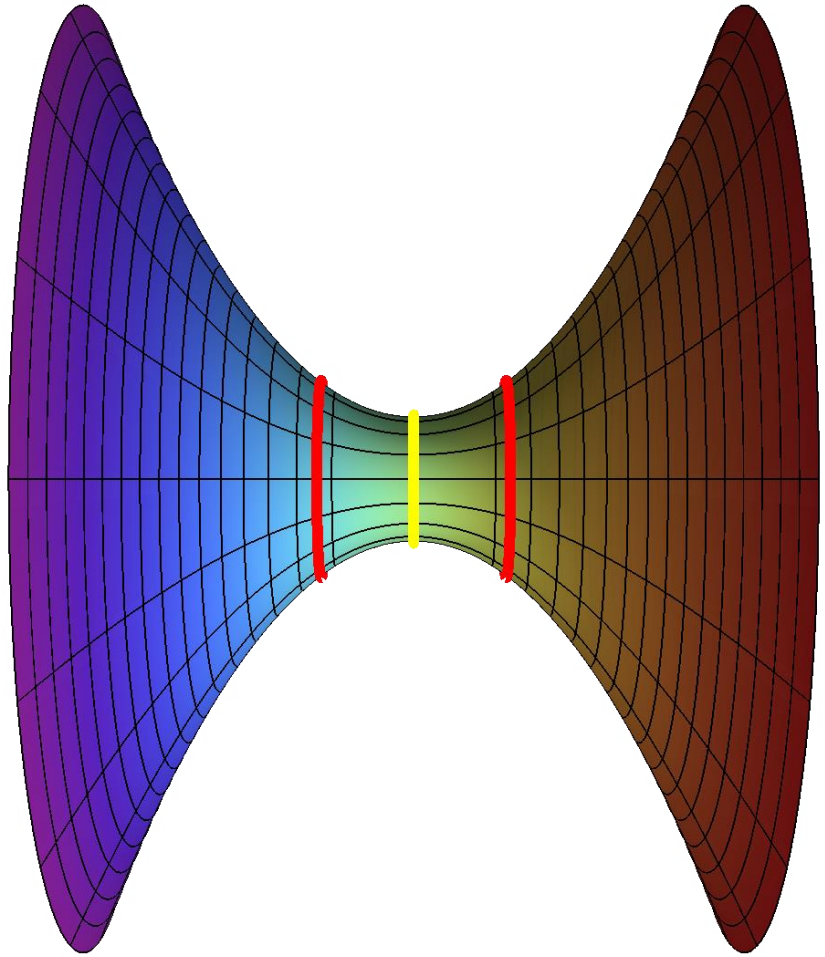







Final remarks

- We demonstrated that stationary, axisymmetric, asymptotic flat and traversable interuniverse wormhole must have at least one standard LR;

- We proved that if the wormhole is symmetric with respect to the throat. It will always have a LR in the throat.





Acknowledgements