Exotic Compact Objects

(Frontiers in Particle Physics 2024, CHEP, IISc. Bangalore)

Arun Thalapillil, IISER-Pune

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- Unusual astrophysical objects

Dark stars powered by self-interacting dark matter

Youjia Wu, Sebastian Baum, Katherine Freese, Luca Visinelli, and Hai-Bo Yu
Phys. Rev. D **106**, 043028 – Published 29 August 2022

Physics Reports
Volume 1052, 12 February 2024, Pages 1-48

Dark matter in compact stars

Joseph Bramante [a b c], Nirmal Raj [d]

Supermassive Dark Star candidates seen by JWST

Cosmin Ilie, Jillian Paulin, and Katherine Freese   Authors Info & Affiliations

Contributed by Katherine Freese; received April 10, 2023; accepted June 2, 2023; reviewed by Marc P. Kamionkowski and Laura Baudis

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July 11, 2023 | 120 (30) e2305762120 | https://doi.org/10.1073/pnas.2305762120

Fundamental Physics Opportunities with the Next-Generation Event Horizon Telescope

D. Ayzenberg (U. Tubingen), Lindy Blackburn (Harvard-Smithsonian Ctr. Astrophys. and Harvard U. (main)), R. Brito (Lisbon, CENTRA), S. Britzen (Bonn, Max Planck Inst., Radioastron.), A. Broderick (Perimeter Inst. Theor. Phys. and Waterloo U. and Waterloo U., IQC) Show All(48)
Dec 4, 2023

- Topological solitonic objects

Q-monopole-ball: a topological and nontopological soliton

Yang Bai,[a] Sida Lu[b] and Nicholas Orlofsky[c]

Comments on magnetic black holes

Juan Maldacena
Institute for Advanced Study, Princeton, NJ 08540, U.S.A.

Tidal Love numbers and approximate universal relations for fermion soliton stars

Emanuele Berti, Valerio De Luca, Loris Del Grosso, and Paolo Pani
Phys. Rev. D **109**, 124008 – Published 4 June 2024

- Non-topological solitonic objects

Solitonic boson stars: Numerical solutions beyond the thin-wall approximation

Lucas G. Collodel and Daniela D. Doneva
Phys. Rev. D **106**, 084057 – Published 28 October 2022

Living Reviews in Relativity (2019) 22:4
https://doi.org/10.1007/s41114-019-0020-4

REVIEW ARTICLE

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Testing the nature of dark compact objects: a status report

Vitor Cardoso[1,2] · Paolo Pani[3]

Characteristic sizes and masses of Boson stars

$$mv \sim \frac{1}{2R} \Rightarrow K \sim \frac{1}{8mR^2} \qquad V_{total} \sim -\frac{3G_N M^2}{5R} \qquad N \sim M/m$$

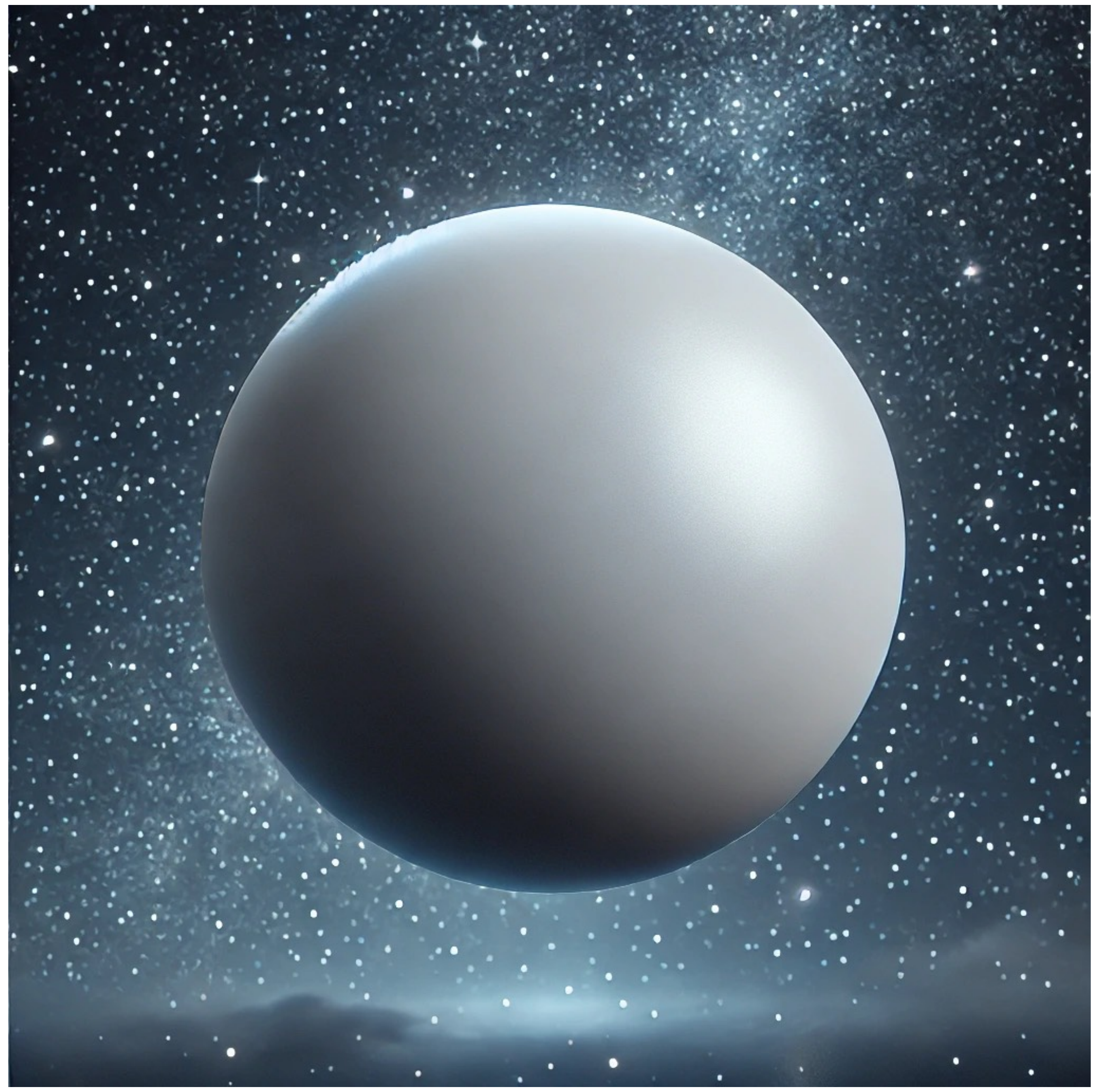
$$E_{total} = K_{total} + V_{total} \sim \frac{N}{8mR^2} - \frac{3G_N M^2}{5R}$$

$$\frac{\partial E_{total}}{\partial R} = 0 \quad \rightarrow \boxed{R_* \sim \frac{5}{12 G_N m^2 M}}$$

$$2M < R_*$$

$$\boxed{M_{max.} \sim \sqrt{\frac{5}{24}}\,\frac{1}{G_N m}}$$

(Kaup mass limit)



[Dall-E]

How different?

$$ds^2 = -e^{2\alpha(r)}\,\mathrm{d}t^2 + e^{2\beta(r)}\,\mathrm{d}r^2 + r^2\,d\Omega^2.$$

$$T_{\mu\nu} = (\rho + p)U_\mu U_\nu + p g_{\mu\nu}. \qquad T_{\mu\nu} = \begin{pmatrix} e^{2\alpha}\rho & & & \\ & e^{2\beta}p & & \\ & & r^2 p & \\ & & & r^2(\sin^2\theta)p \end{pmatrix}.$$

$$\frac{dp}{dr} = -\frac{(\rho + p)[Gm(r) + 4\pi G r^3 p]}{r[r - 2Gm(r)]}.$$

(Tolman-Oppenheimer-Volkoff equation)

$$T_{\phi}^{\mu\nu} = \frac{2}{\sqrt{-g}} \frac{\partial\left(\sqrt{-g}\mathscr{L}_{\phi}\right)}{\partial g_{\mu\nu}} \longrightarrow T_{\mu\nu} = \nabla_{\mu}\phi^{*}\nabla_{\nu}\phi + \nabla_{\mu}\phi\nabla_{\nu}\phi^{*} - g_{\mu\nu}\left(g^{\alpha\beta}\nabla_{\alpha}\phi^{*}\nabla_{\beta}\phi + V(\phi^{*}\phi)\right)$$

$$\downarrow$$

$$p_r^{\phi} \neq p_T^{\phi}$$

$$\frac{1}{\sqrt{-g}}\partial_{\mu}\left(\sqrt{-g}g^{\mu\nu}\partial_{\nu}\phi\right) - m^2\phi = -\frac{dV}{d\phi}.$$

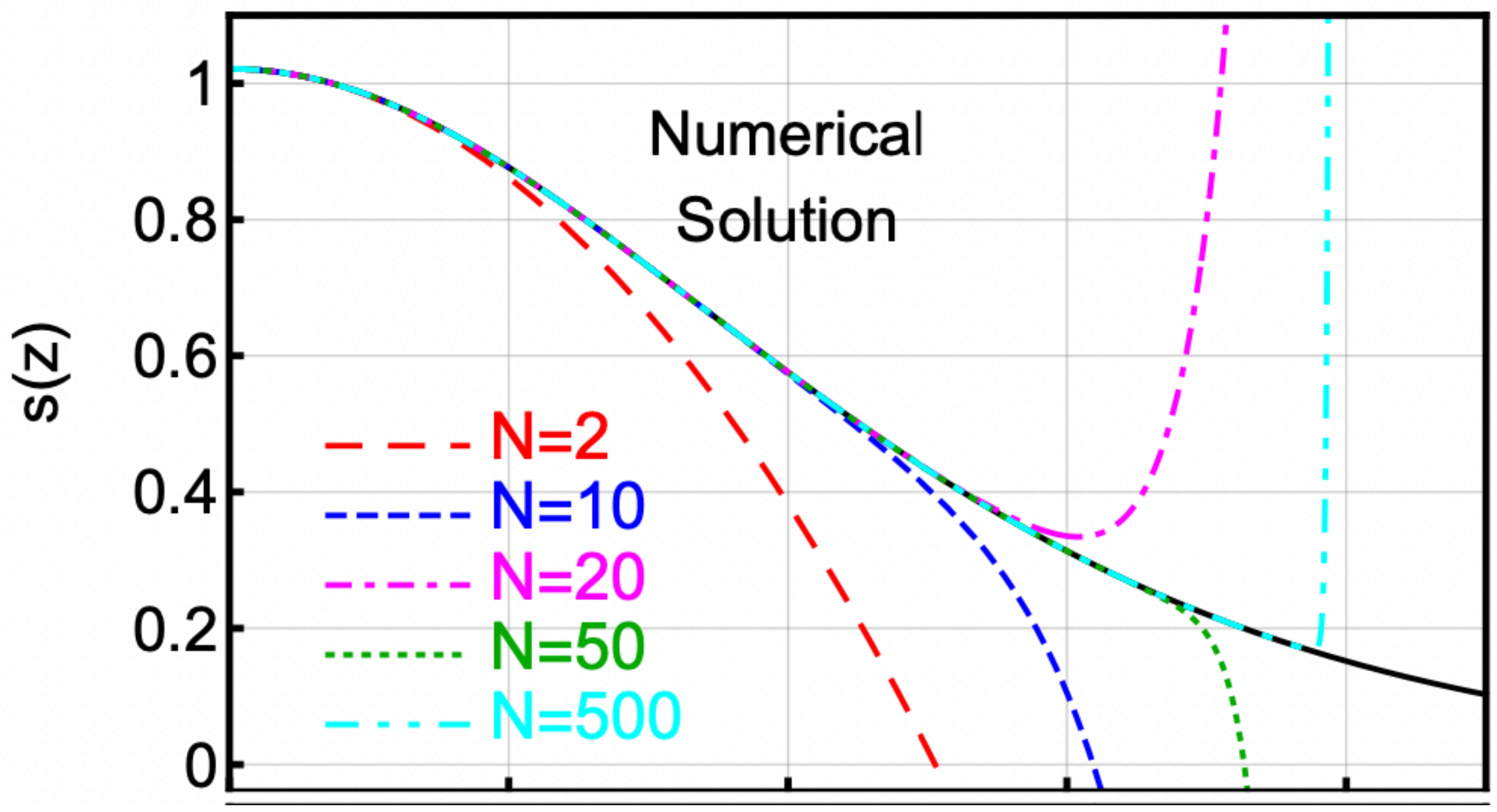
$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = 8\pi G T_{\mu\nu}.$$

Need to usually solve the full Einstein Klein-Gordon system of equations

$$e\psi = -\frac{1}{2m}\nabla^2\psi + m\Phi\psi + \frac{N\lambda}{4m^2}\psi^3.$$

$$\nabla^2\Phi = 4\pi G N m \psi^2$$

$$\longrightarrow \quad \nabla^2 V = -S^2 \quad \text{and} \quad \nabla^2 S = -VS + \Lambda S^3.$$



Towards an analytic construction of the wavefunction of boson stars

Felix Kling and Arvind Rajaraman
Phys. Rev. D **96**, 044039 – Published 28 August 2017

Profiles of boson stars with self-interactions

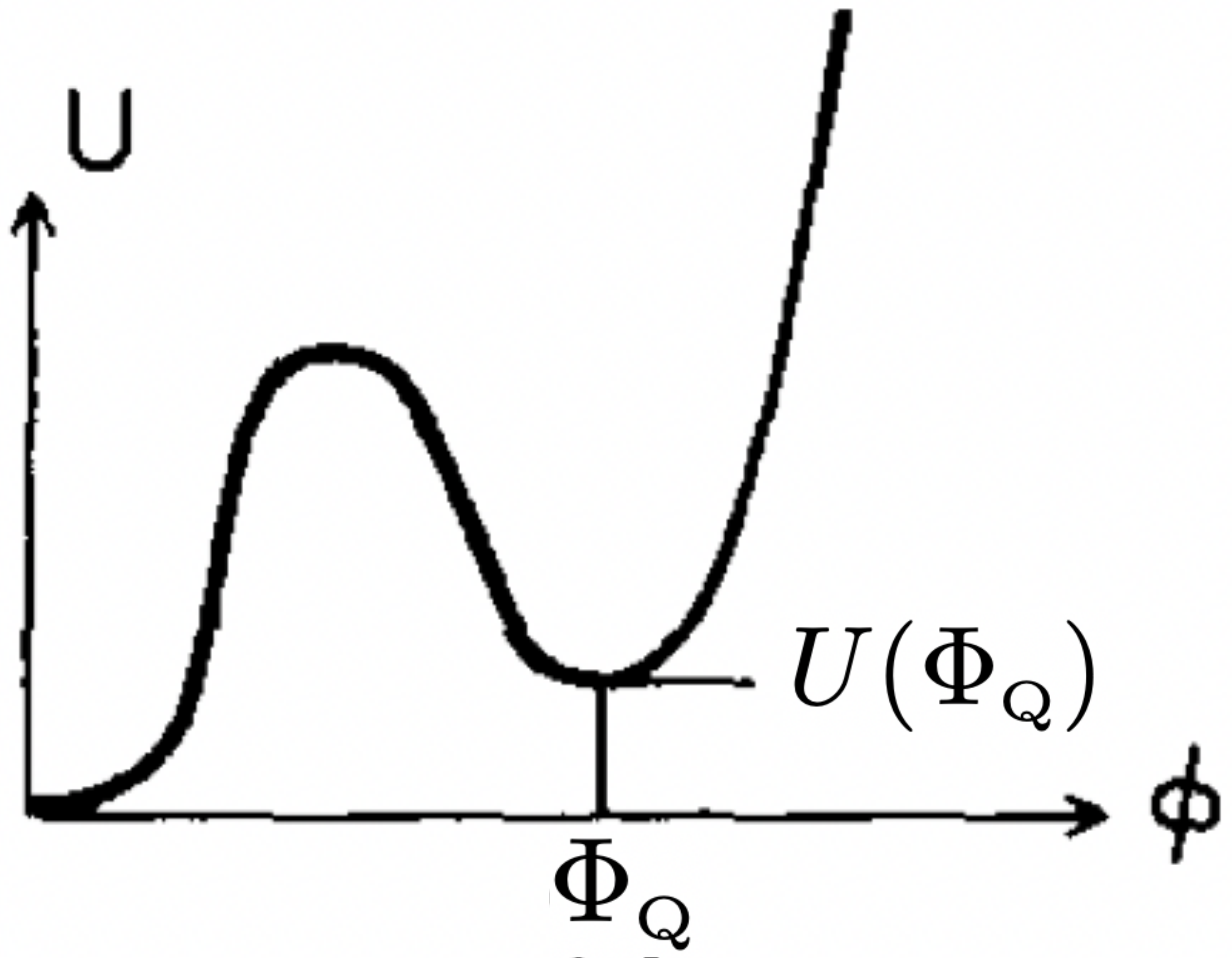
Felix Kling and Arvind Rajaraman
Phys. Rev. D **97**, 063012 – Published 20 March 2018

Q-balls

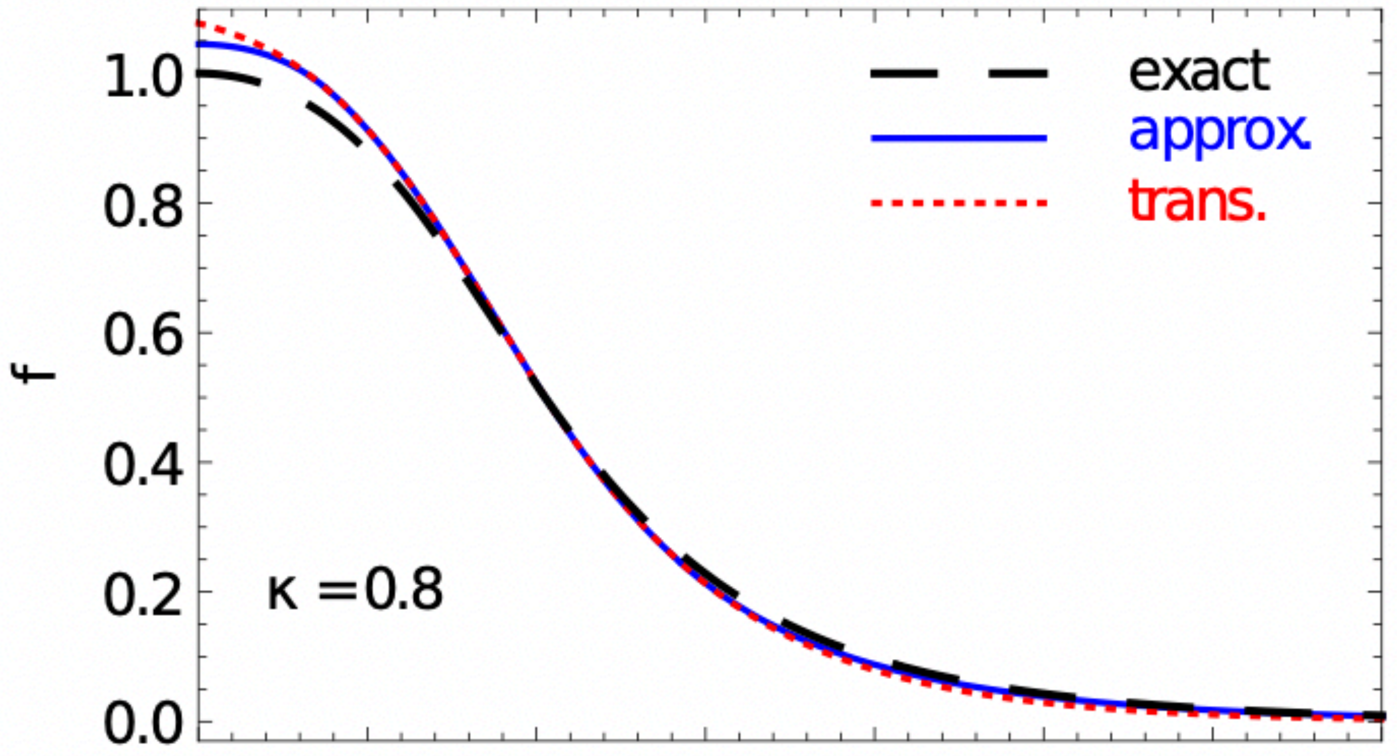
$$\mathcal{L} = \partial_\mu \Phi \partial^\mu \Phi^\dagger - U(\Phi^\dagger \Phi) \, .$$

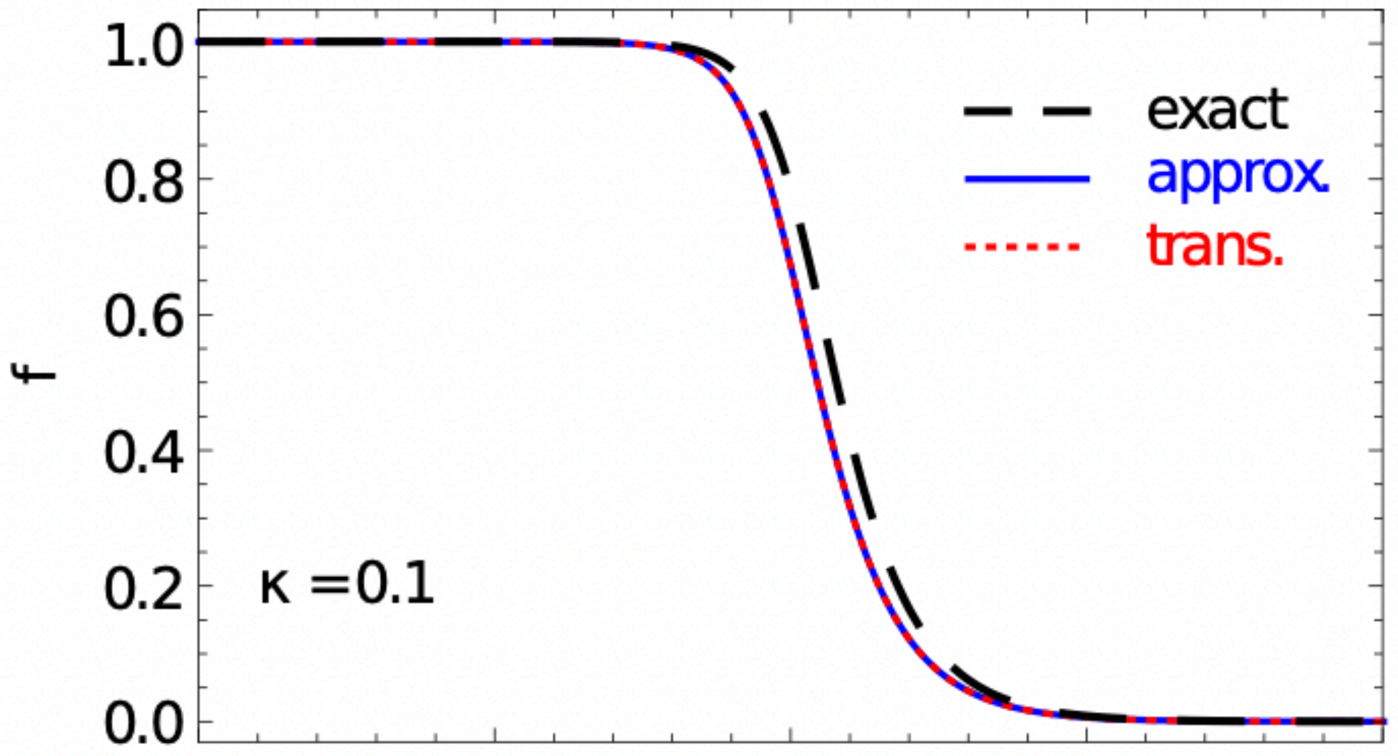
$$0 \leqslant \frac{U(\Phi_Q)}{\Phi_Q^2} \equiv \omega_Q^2 < m^2 \, .$$

$$E \; = \; \omega Q + \frac{8\pi}{3} \int dr r^2 \phi'^2 \, .$$



$$U(\phi) = m^2\phi^2 + \lambda\phi^4 + \zeta\phi^6 \, .$$





Q-BALLS*

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Understanding Q-balls beyond the thin-wall limit

Julian Heeck, Arvind Rajaraman, Rebecca Riley, and Christopher B. Verhaaren

Phys. Rev. D **103**, 045008 – Published 9 February 2021

Eur. Phys. J. C (2024) 84:364
https://doi.org/10.1140/epjc/s10052-024-12712-x

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Theoretical Physics

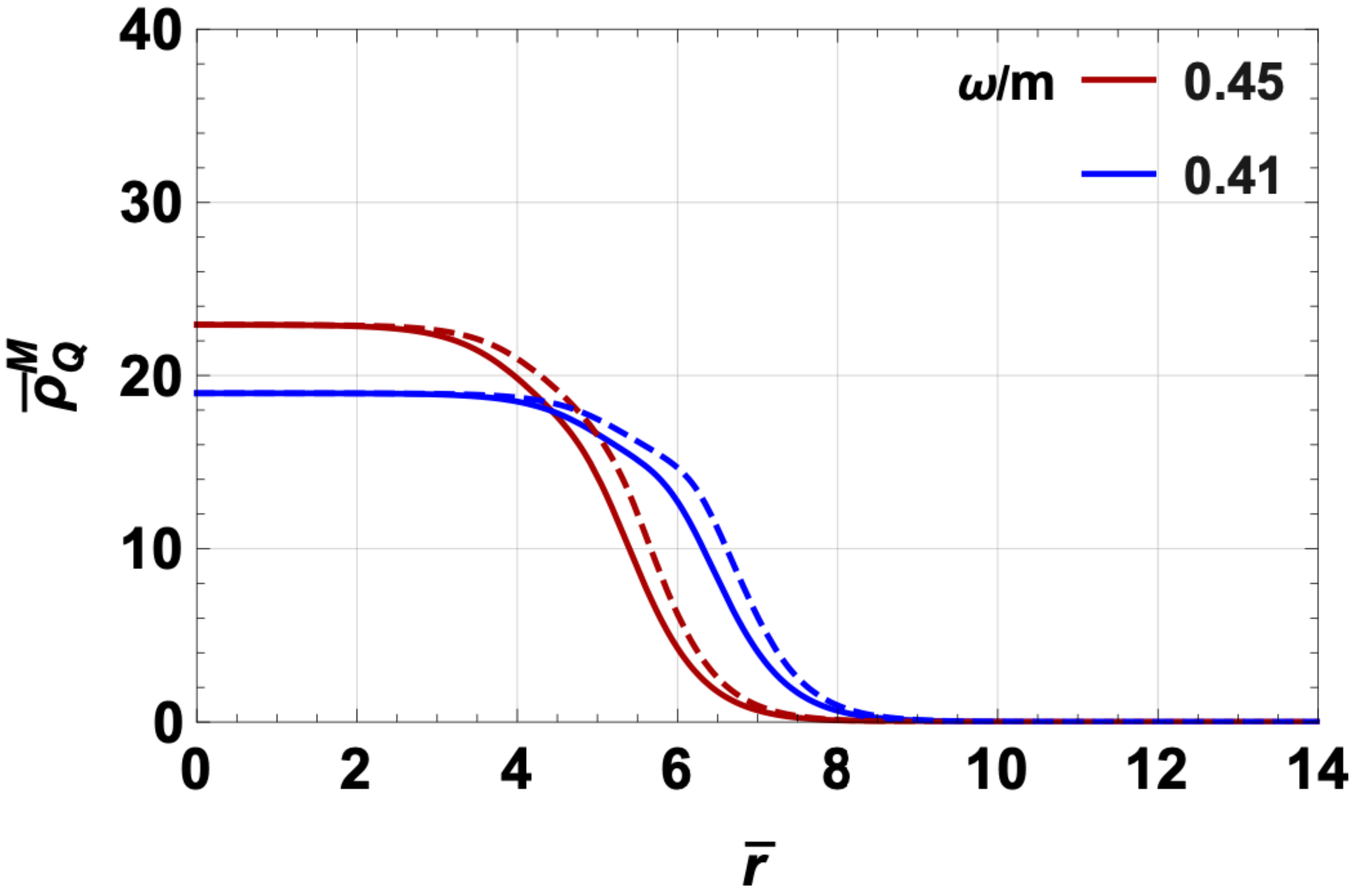
Slowly rotating Q-balls

Yahya Almumin[1,2,a], Julian Heeck[3,b], Arvind Rajaraman[1,c], Christopher B. Verhaaren[4,d]

Energy Extraction from Q-balls and Other Fundamental Solitons

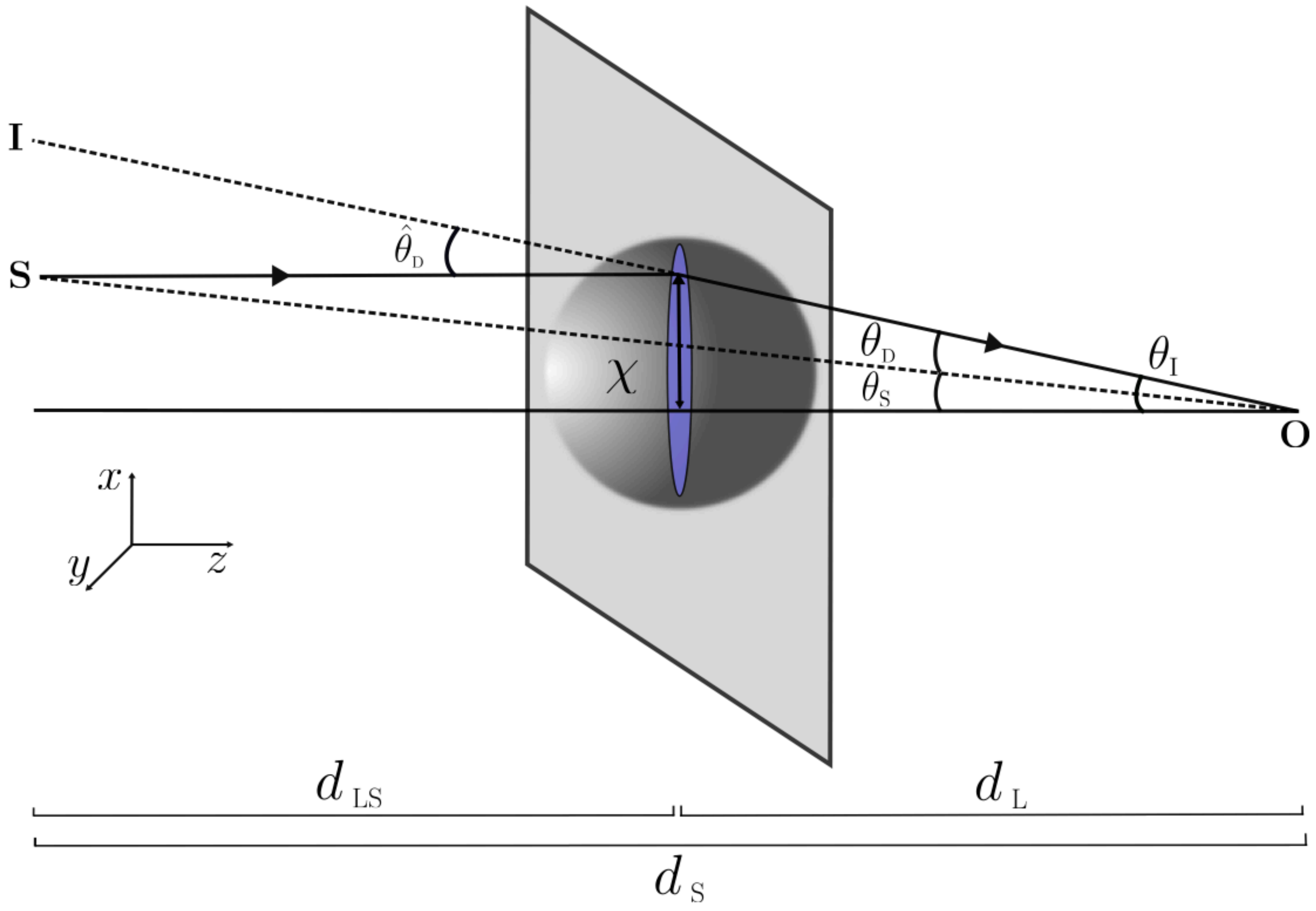
Vitor Cardoso, Rodrigo Vicente, and Zhen Zhong

Phys. Rev. Lett. **131**, 111602 – Published 11 September 2023



$$\phi(r) = \frac{\phi_*}{\sqrt{1 + 2\exp\left[2\sqrt{m^2-\omega_{\mathrm{Q}}^2}\,(r - R_{\mathrm{Q}})\right]}}\,,$$

$$\phi_*^2 = \frac{\phi_{\mathrm{Q}}^2}{3}\left[2 + \sqrt{1 + 3\left(\frac{\omega^2-\omega_{\mathrm{Q}}^2}{m^2-\omega_{\mathrm{Q}}^2}\right)}\,\right]$$



Thank you