

Squeeze and decoherence of vacuum fluctuations in relativistic stars

Daniel A. Turolla Vanzella



Workshop *Black holes and their analogues: 100 years of General Relativity*
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Outline

- Gravity and vacuum energy
- Awakening the vacuum in relativistic stars
- “Seed conjecture”
- Quantum fluctuations **x** classical perturbations
- Conclusions

Gravity and vacuum energy

- ▣ *Typical values of vacuum energy density*

$$\langle \rho \rangle \sim \frac{\hbar c}{L^{4-n} l_G^n} \approx \frac{3 \times 10^{-46} \text{ g/cm}^3}{(L/1 \text{ m})^4} \left(\frac{L}{l_G} \right)^n, \quad n = 0, \dots, 4$$

$$l_G \sim R^{-1/2}, \quad (R_{\mu\nu} R^{\mu\nu})^{-1/4}, \quad (R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma})^{-1/4} \sim \sqrt{\frac{c^2 L^3}{GM}}$$

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moreover...

- ▣ *Good behavior*

If a state has a renormalizable u.v.-behavior and no further singularities in its two-point function at some time (i.e., in a causal normal neighborhood of a Cauchy surface), then it will remain so throughout the (globally-hyperbolic) spacetime. [Fulling, Sweeny and Wald (1978); Kay and Wald (1991); Radzikowski (1996)]

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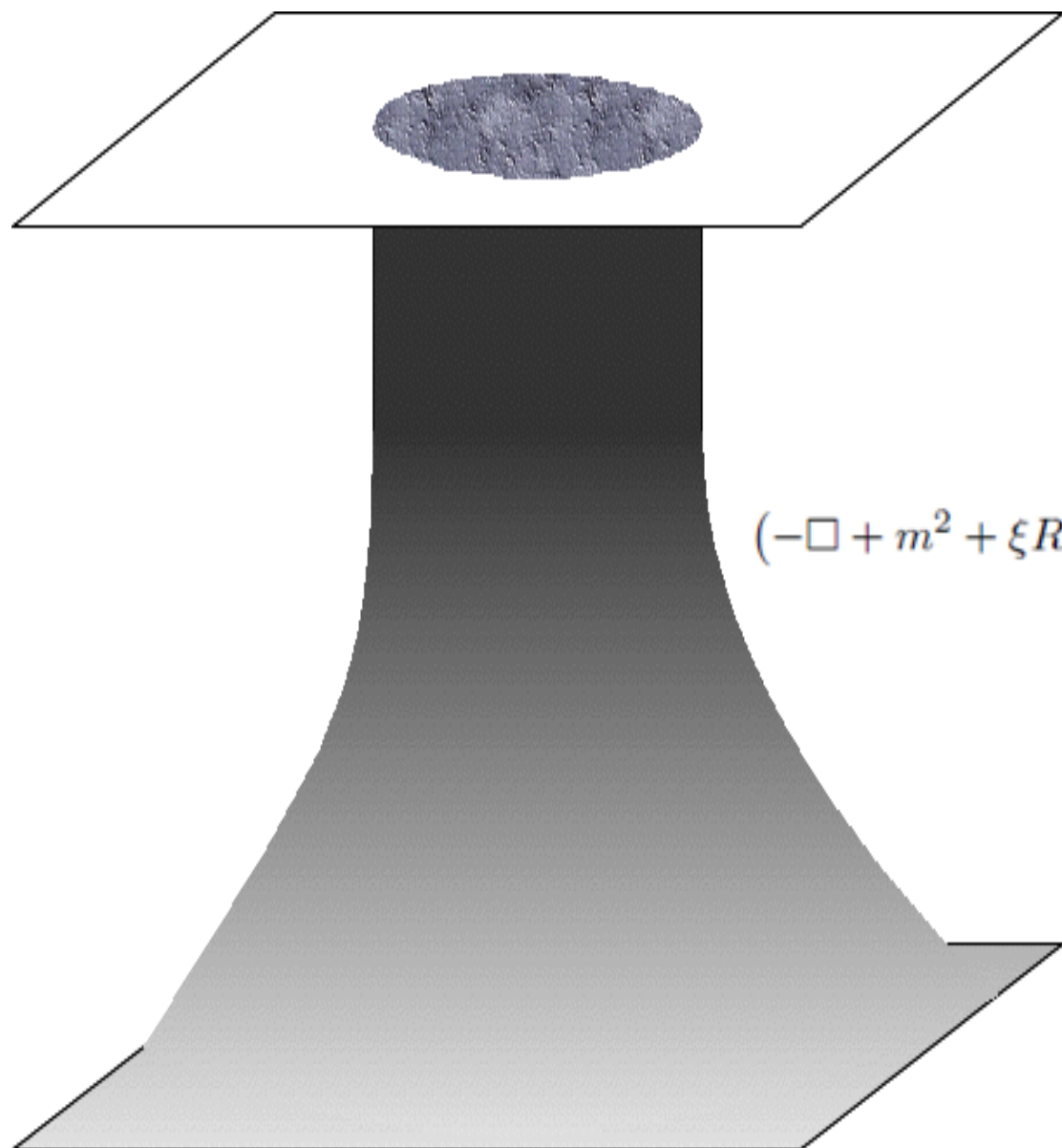
No divergences (ultraviolet or infrared) can appear dynamically in the course of a well-behaved background evolution.

Awaking the vacuum in relativistic stars

[W. Lima and D.V., PRL **104**, 161102 (2010); W. Lima, G. Matsas, and D.V., PRL **105**, 151102 (2010)]

▣ *The formation of a compact object*

$$ds^2 \sim f(\chi)(-dt^2 + d\chi^2) + r(\chi)^2(d\theta^2 + \sin^2\theta d\varphi^2)$$



$$(-\square + m^2 + \xi R)\Phi = 0$$

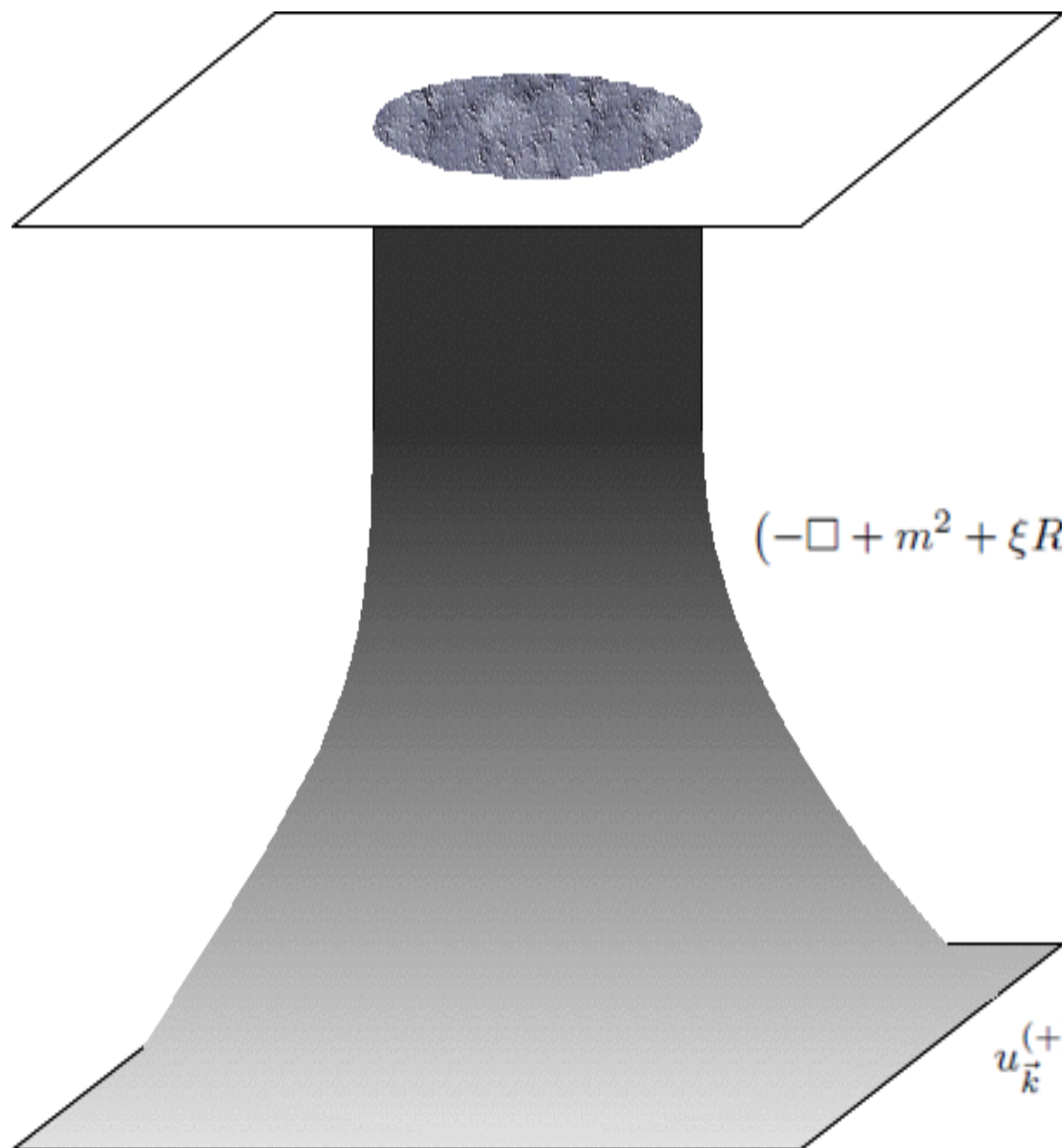
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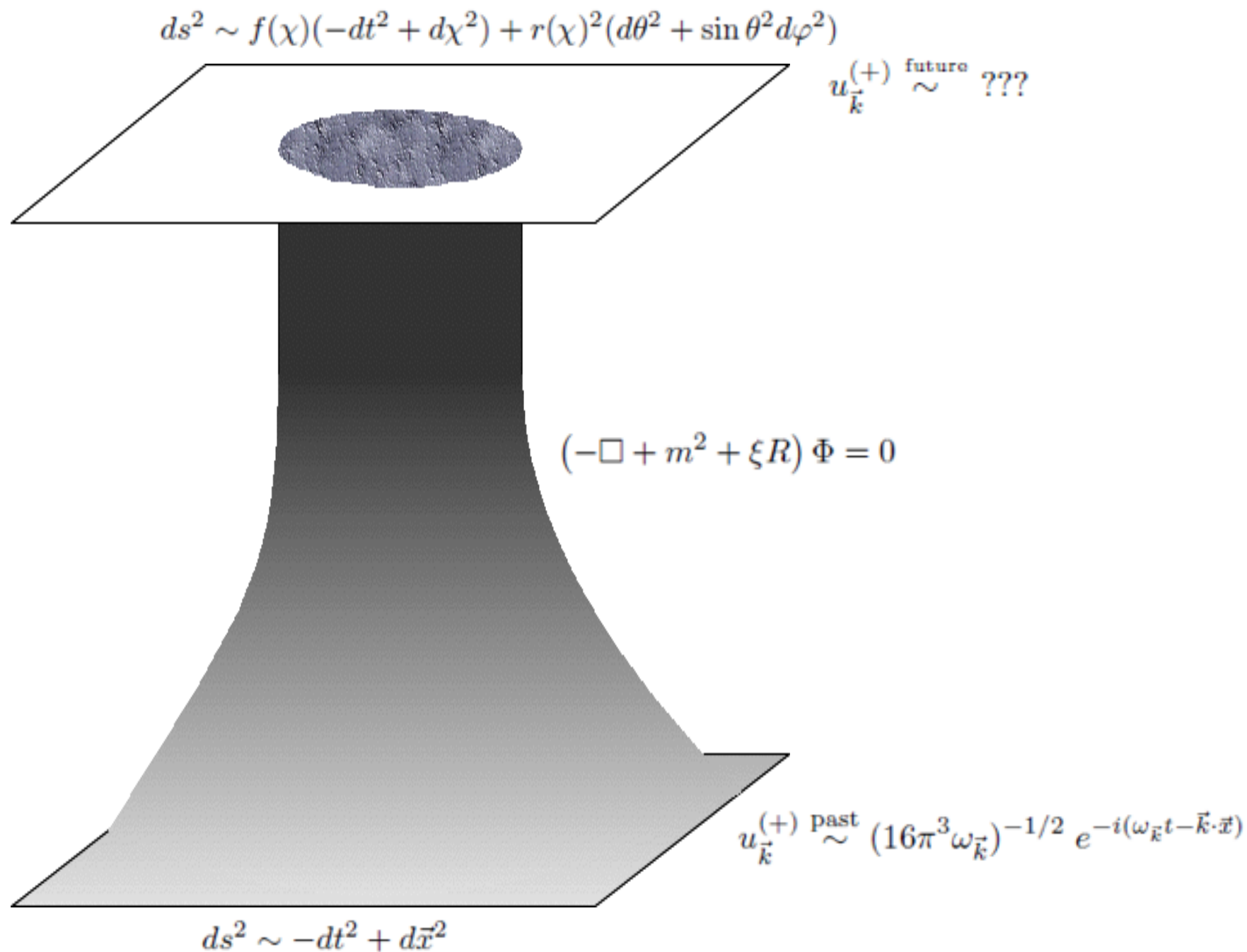
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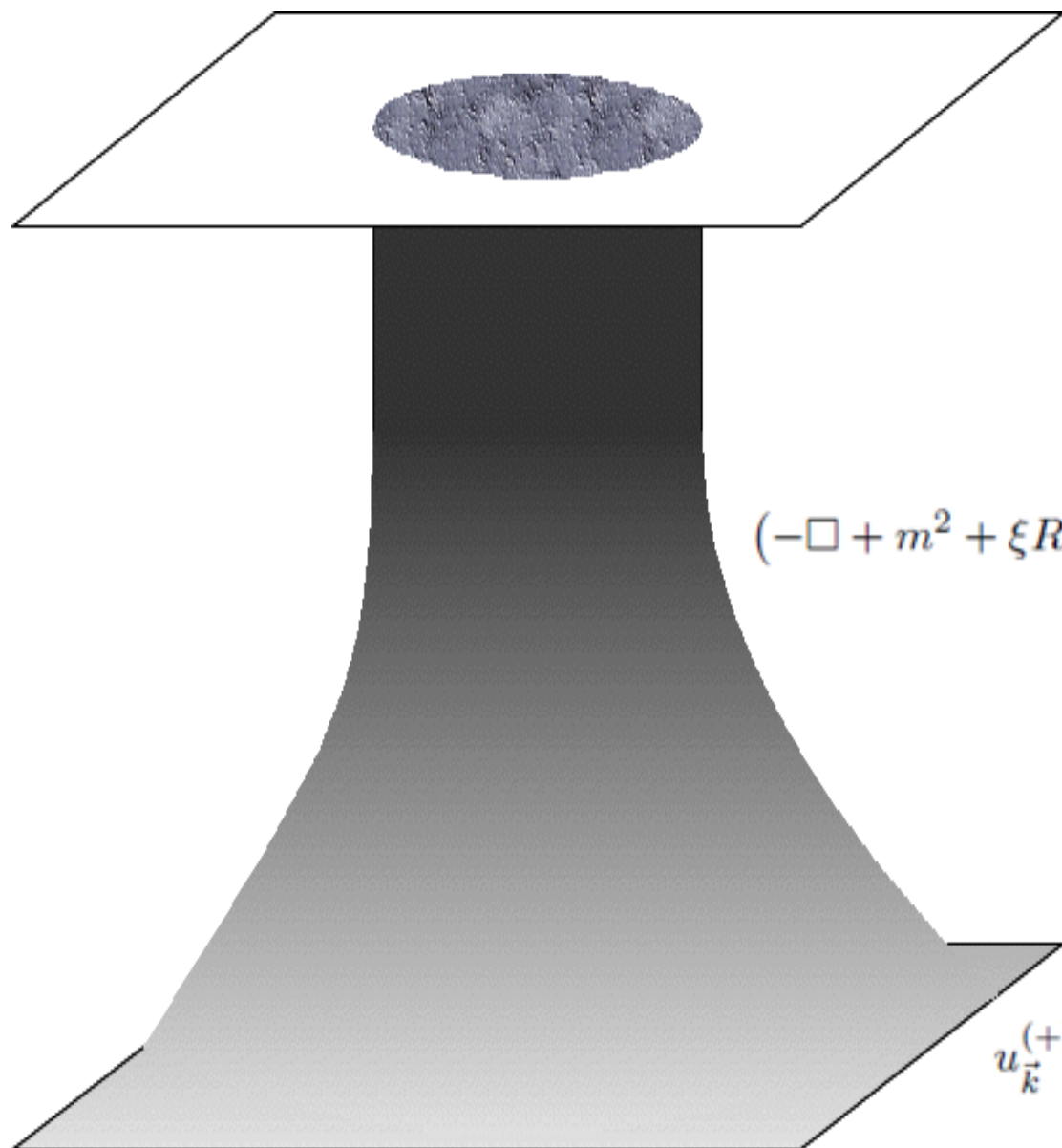


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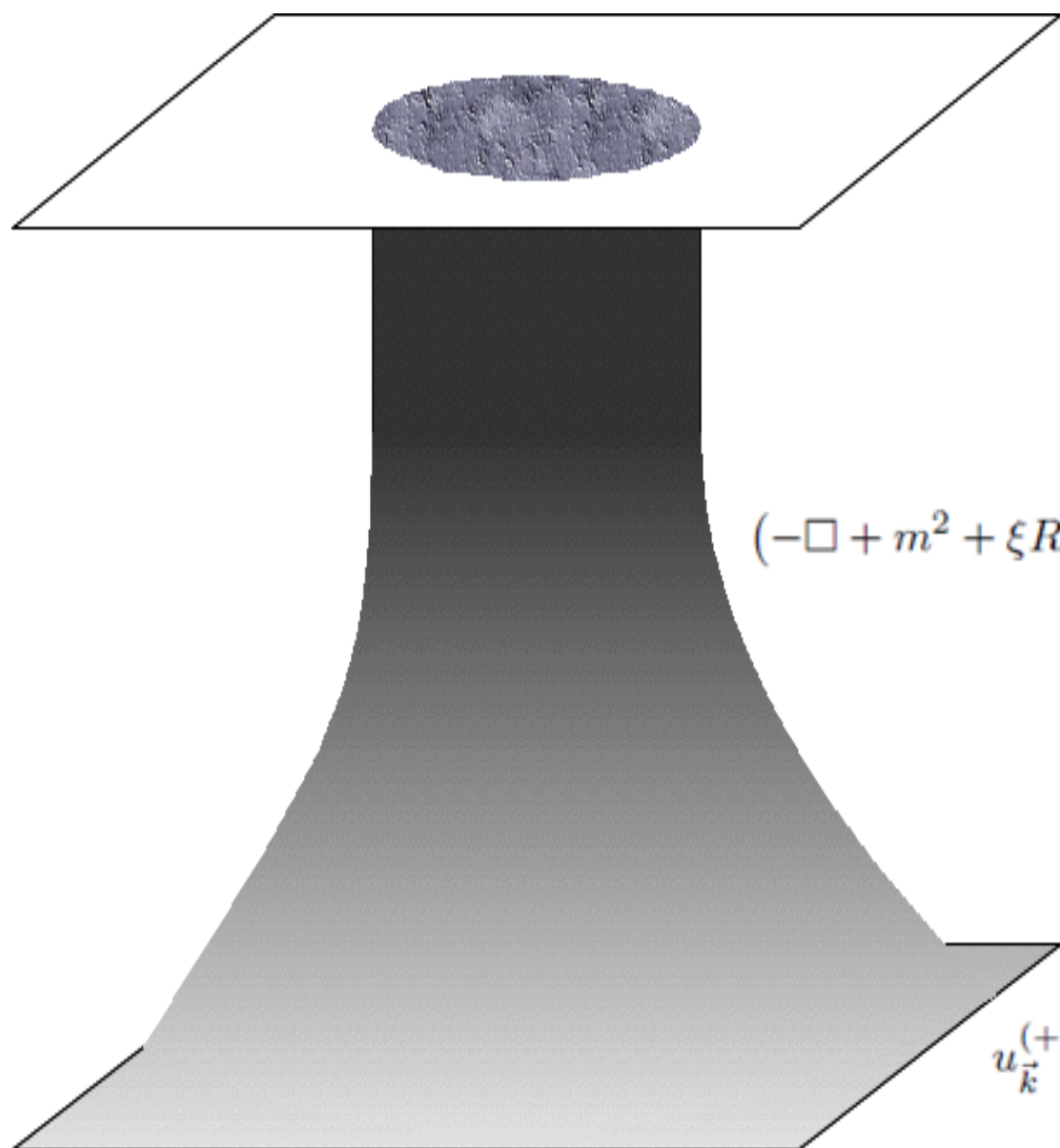
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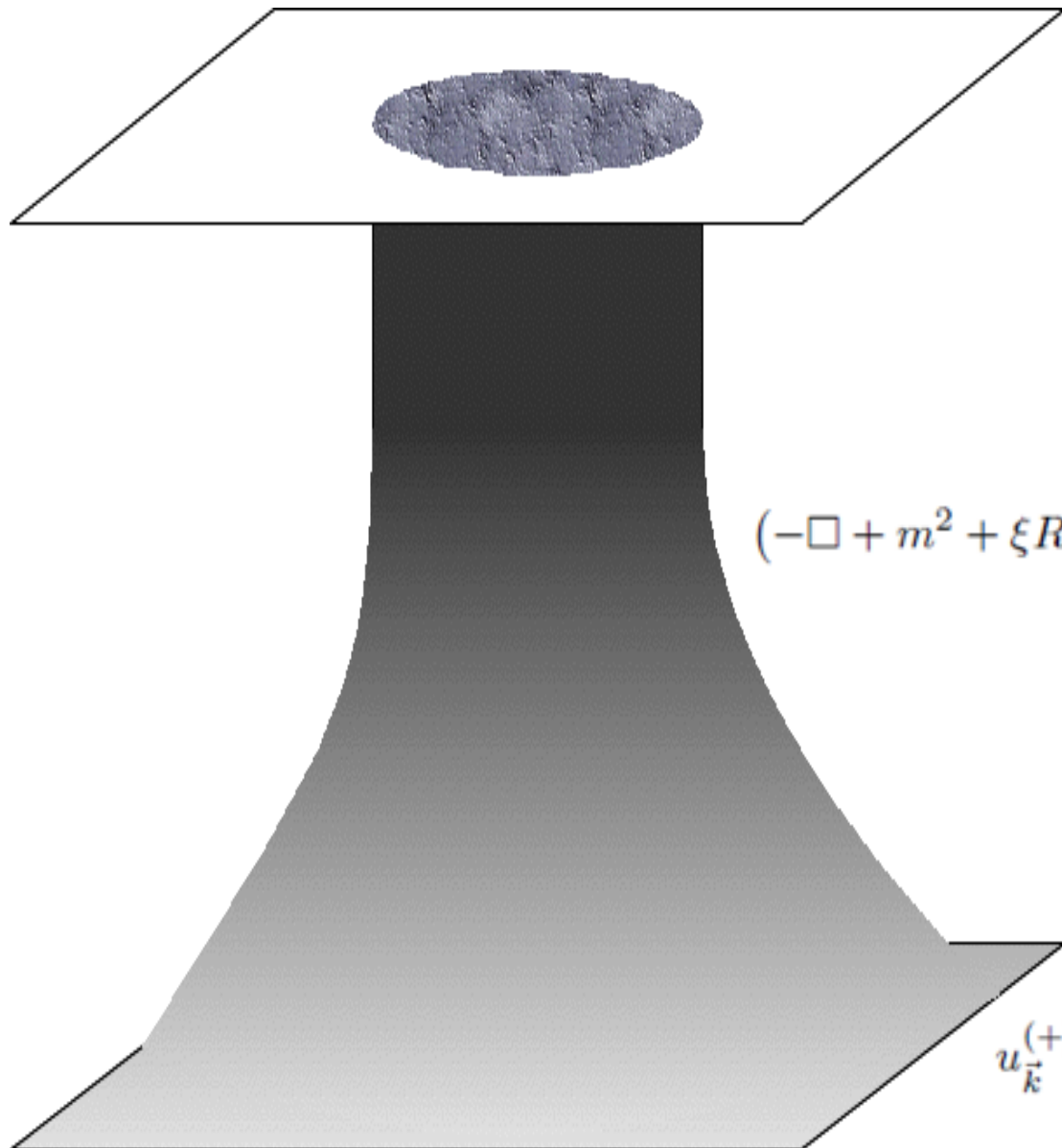
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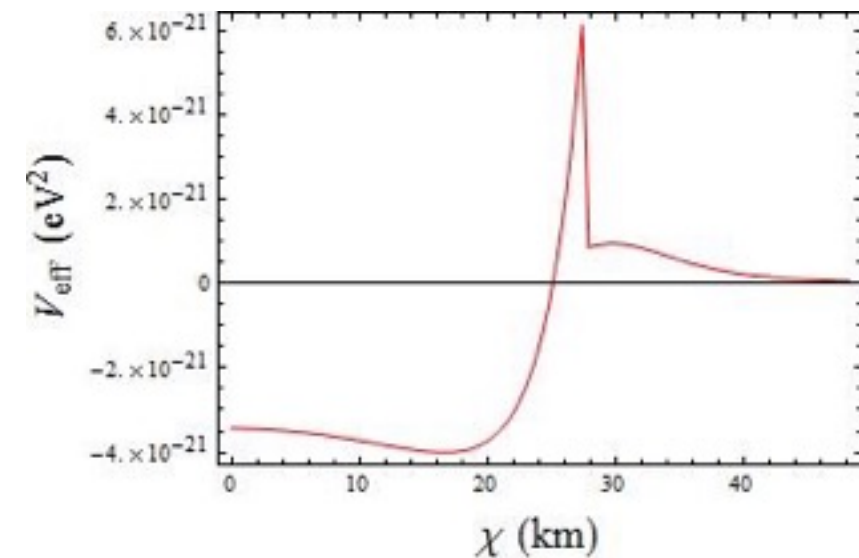


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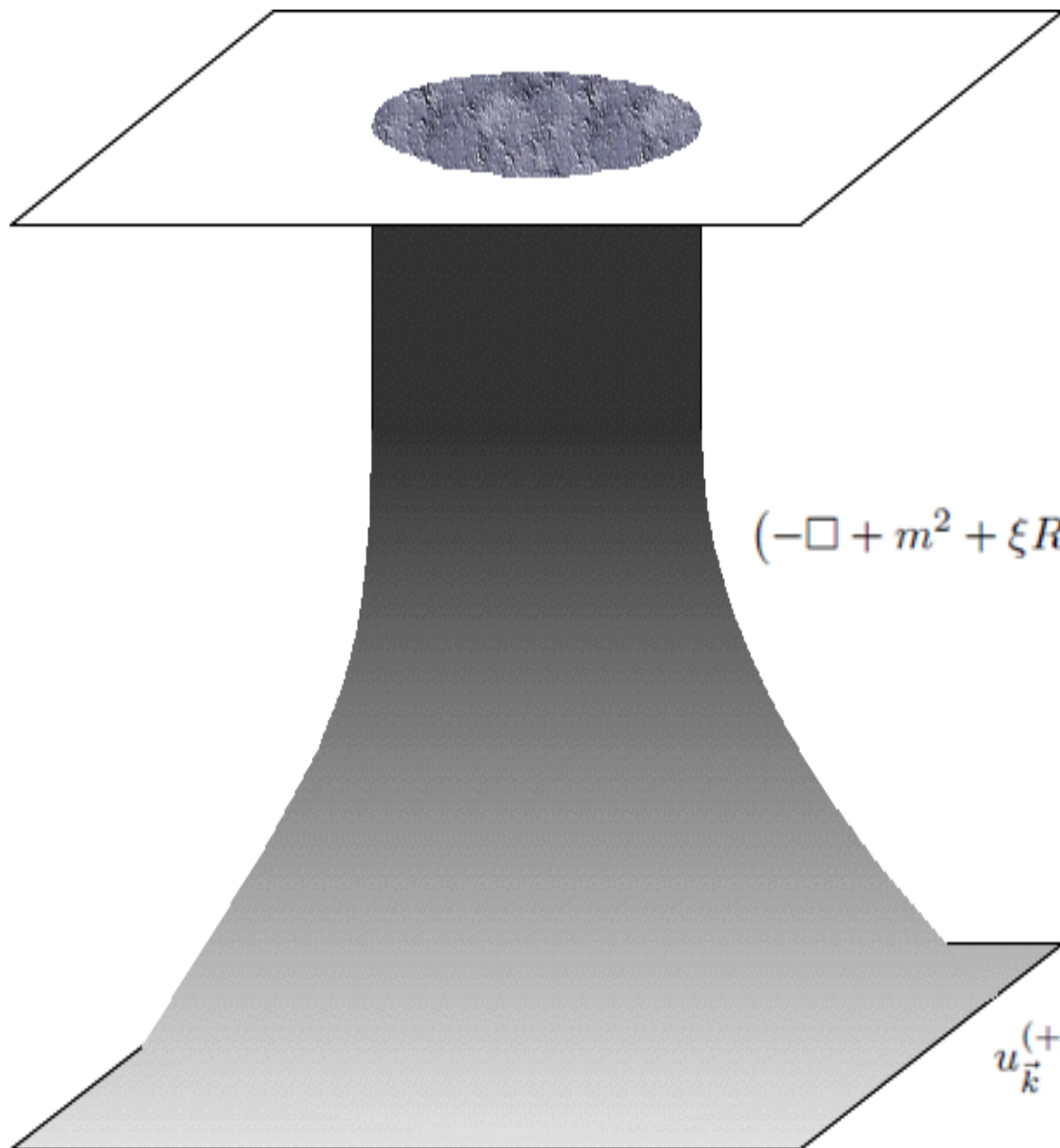
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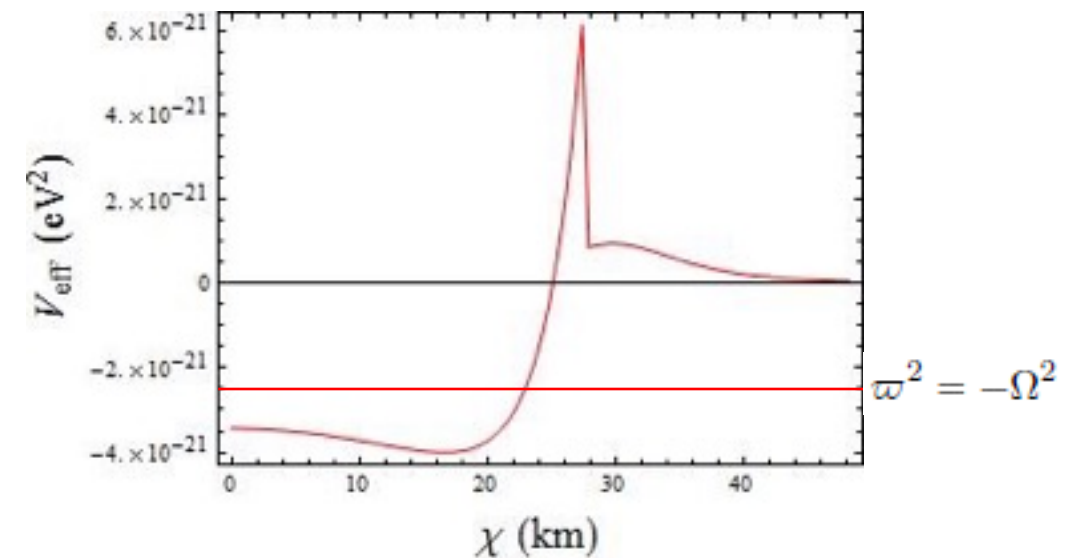


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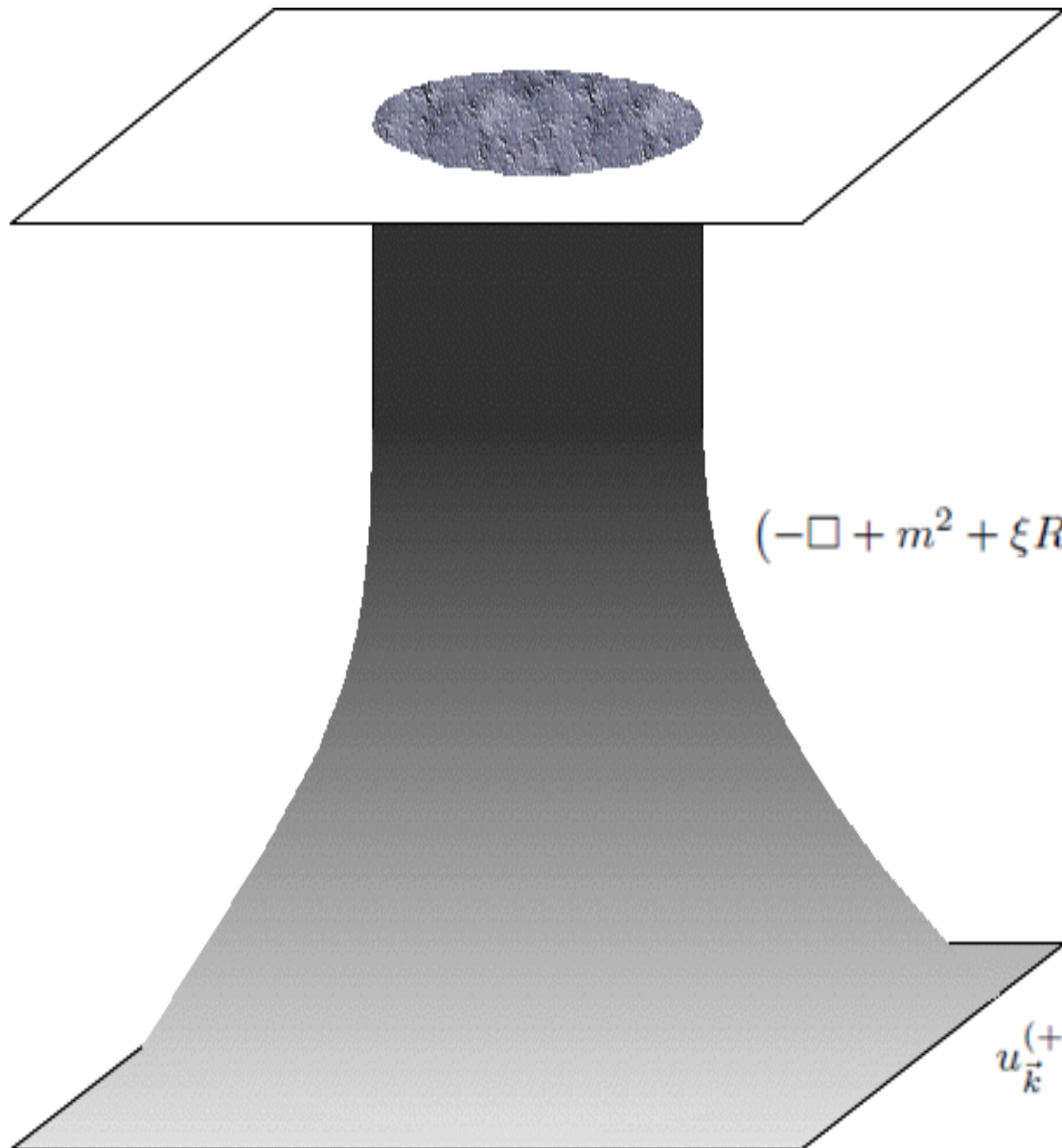
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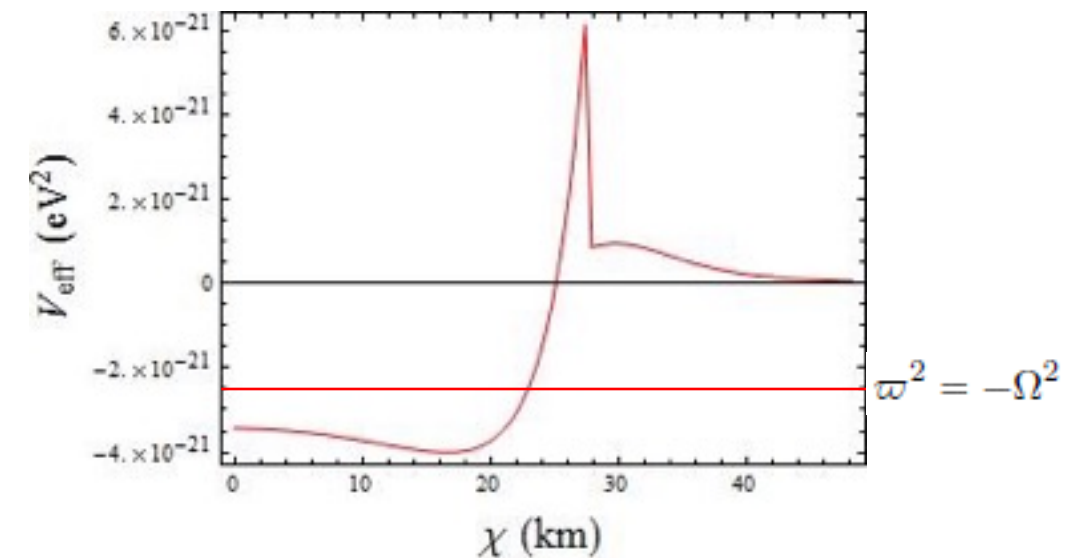
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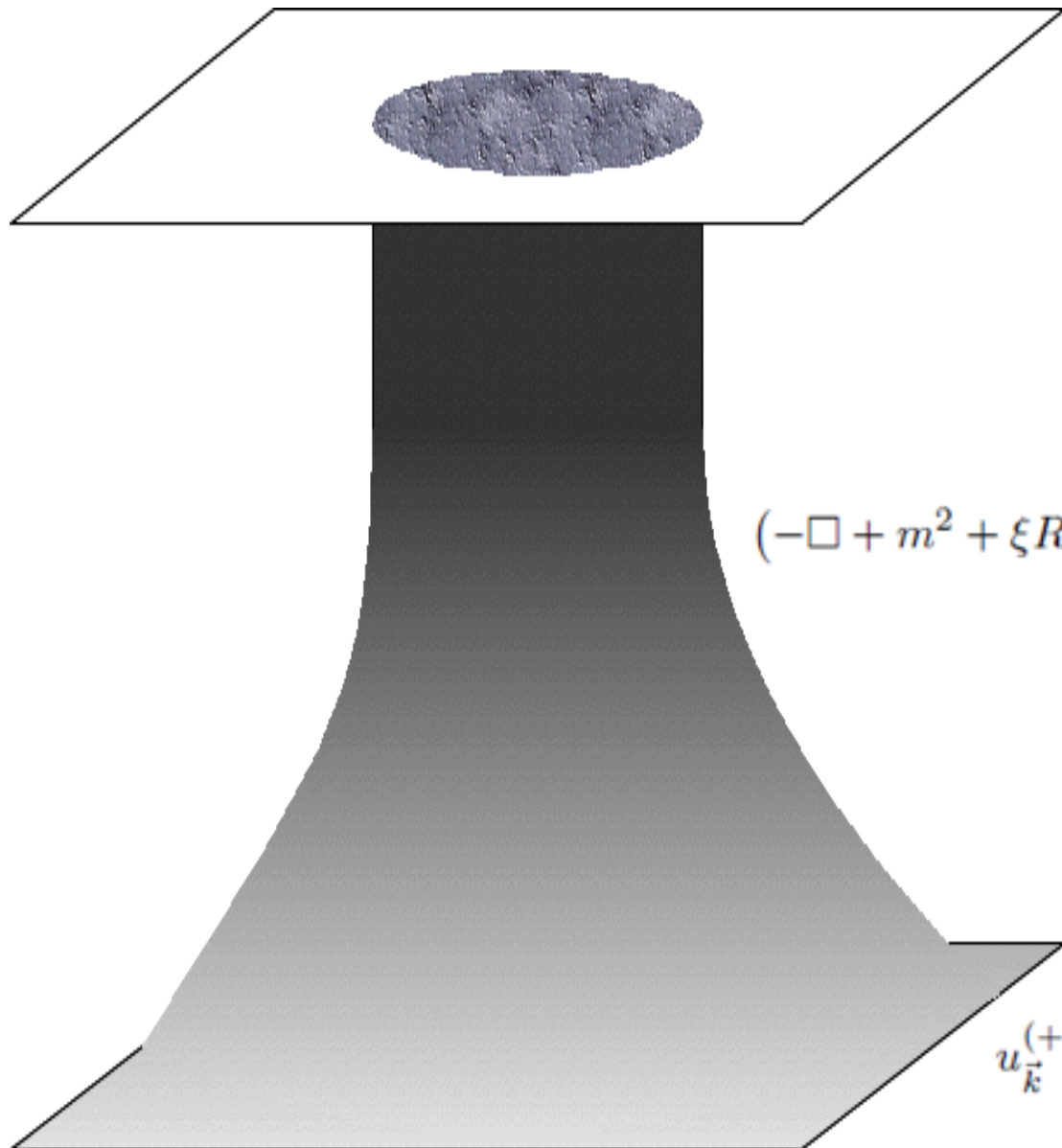
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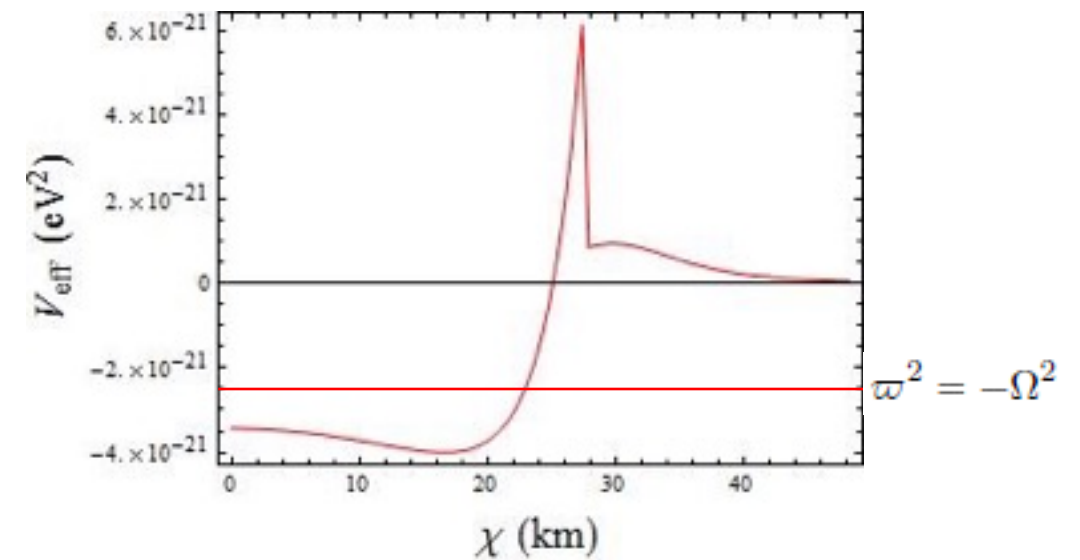


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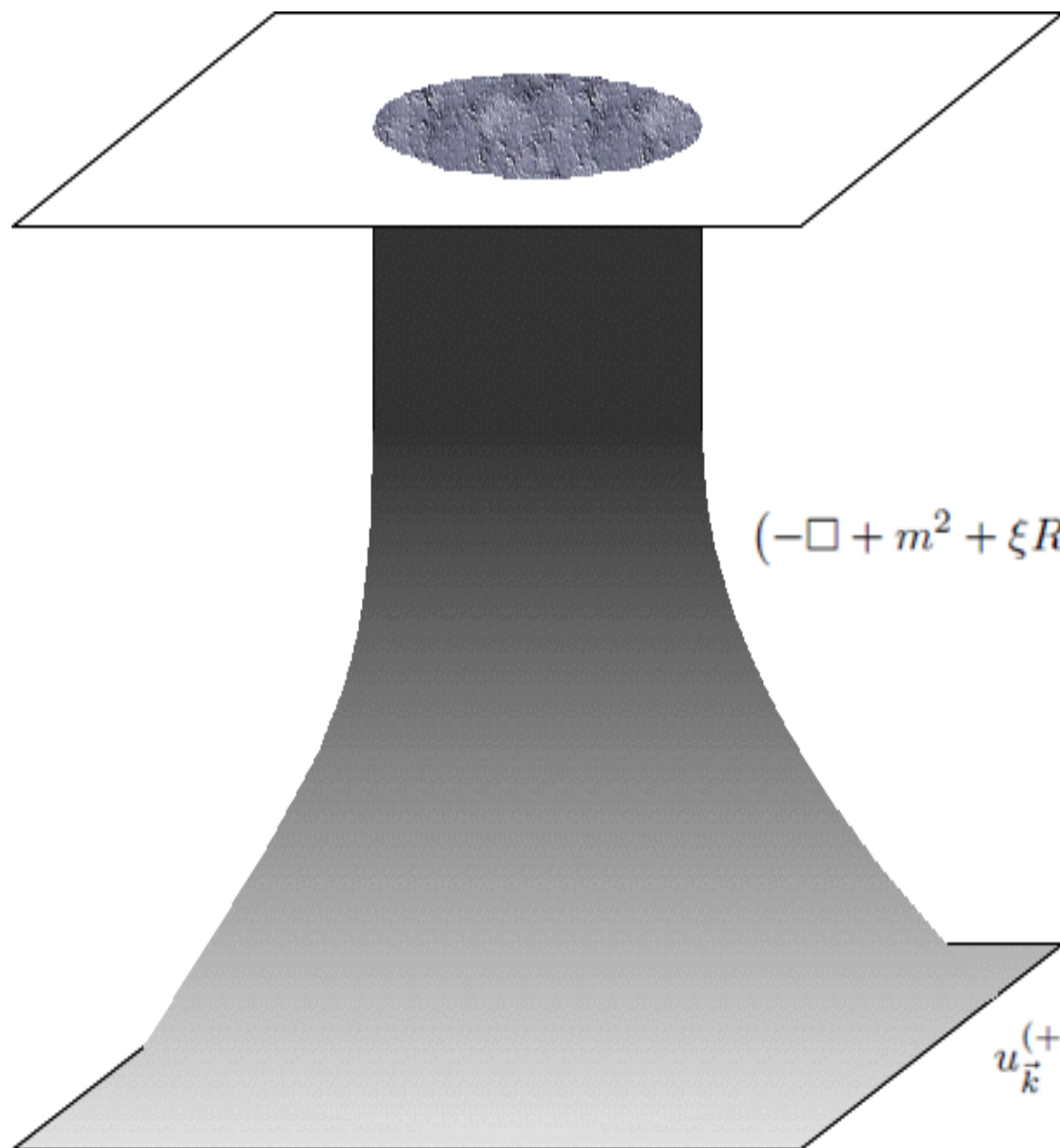
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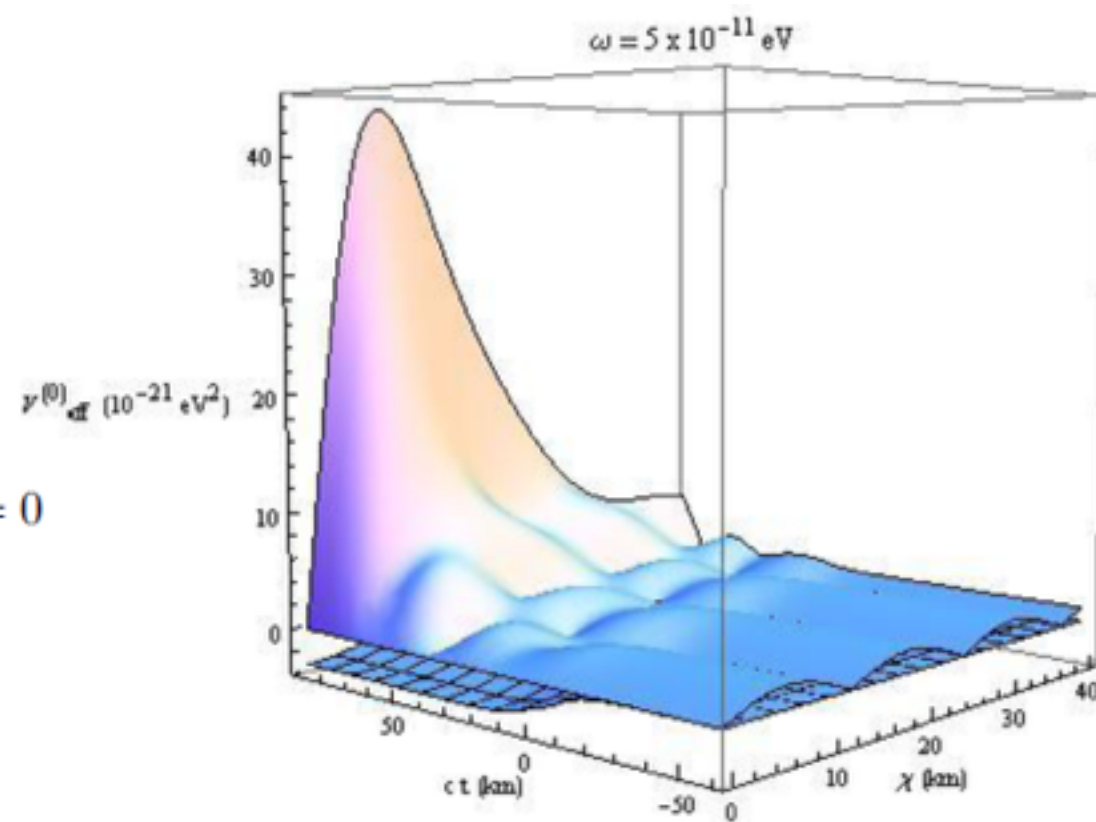
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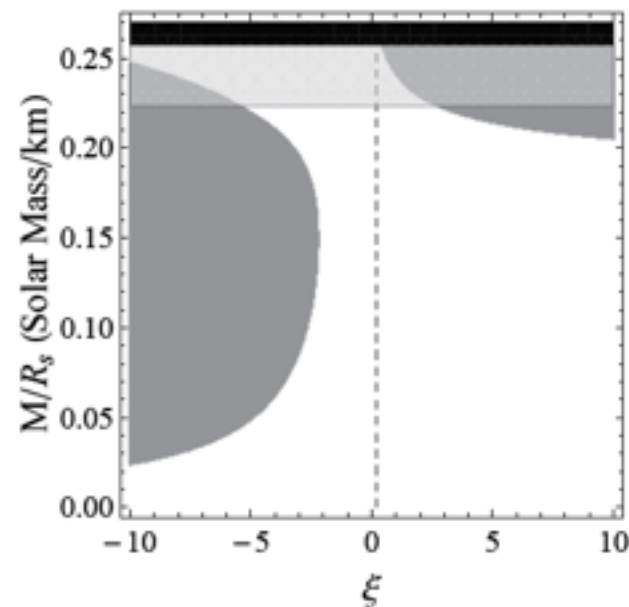
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- ✓ Numerical search for negative eigenvalues in the simplified case of a parabolic-density-profile compact object:



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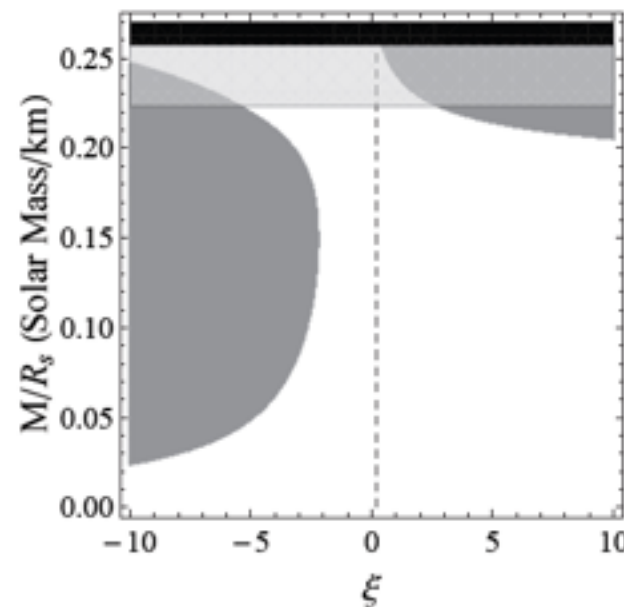
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- ✓ Numerical search for negative eigenvalues in the simplified case of a parabolic-density-profile compact object:



- ✓ In a few milliseconds the vacuum energy density would become comparable to the extremely dense matter constituting the compact object. And then what?

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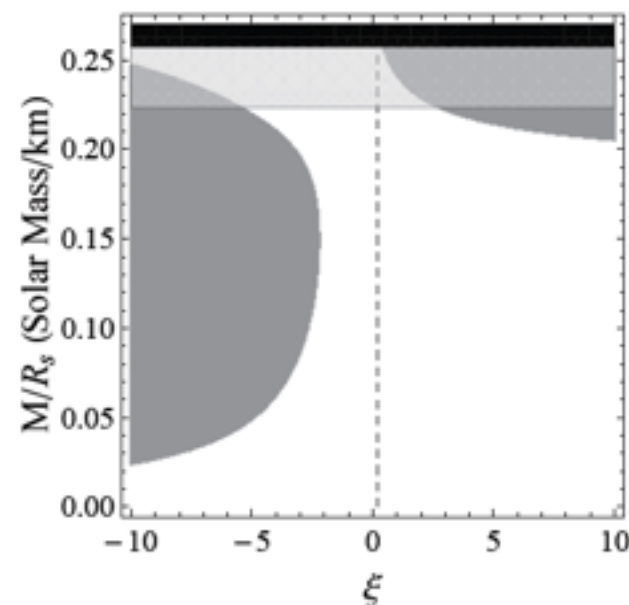
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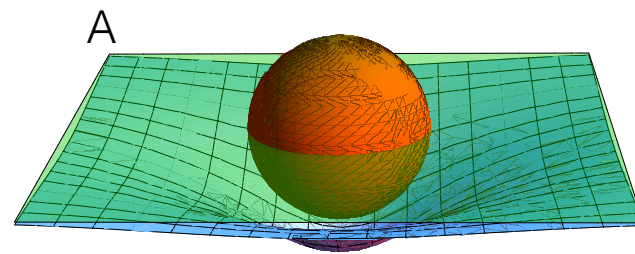
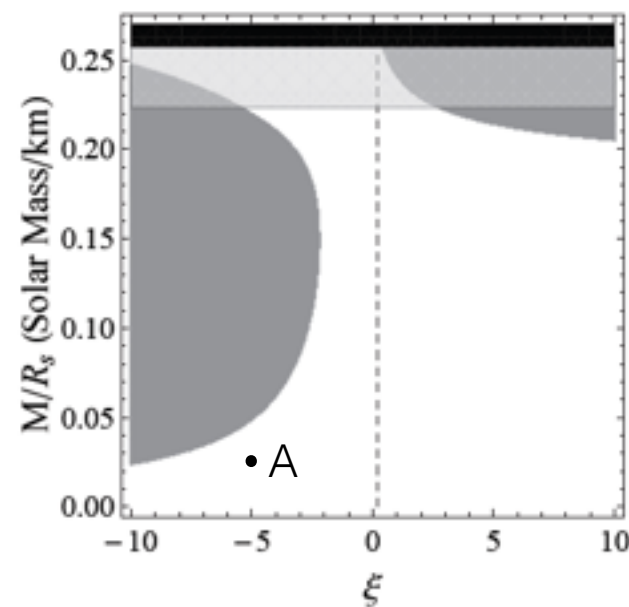
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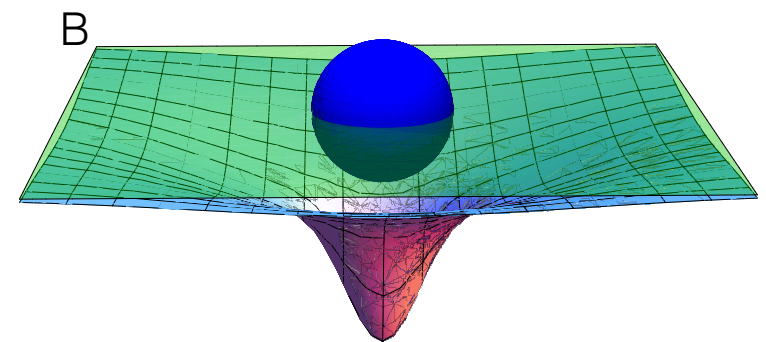
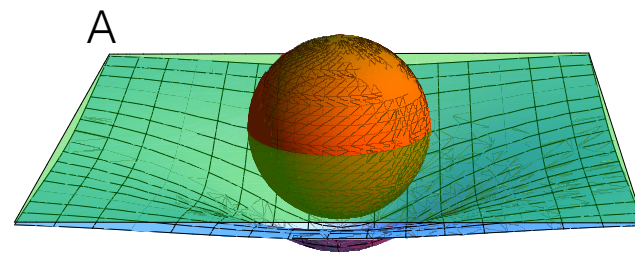
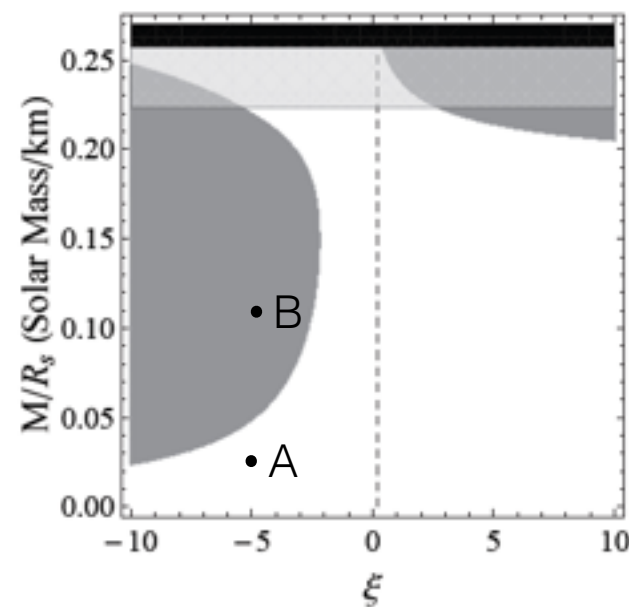
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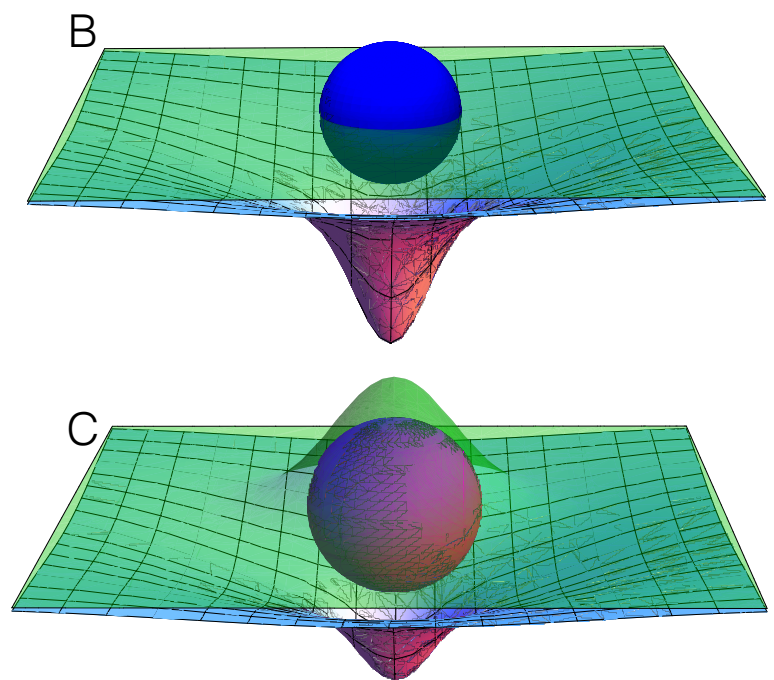
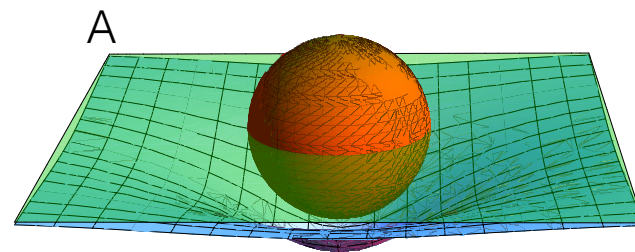
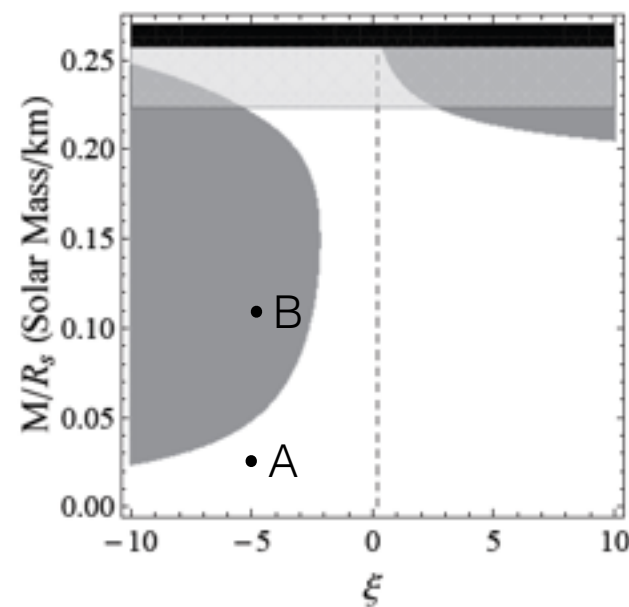
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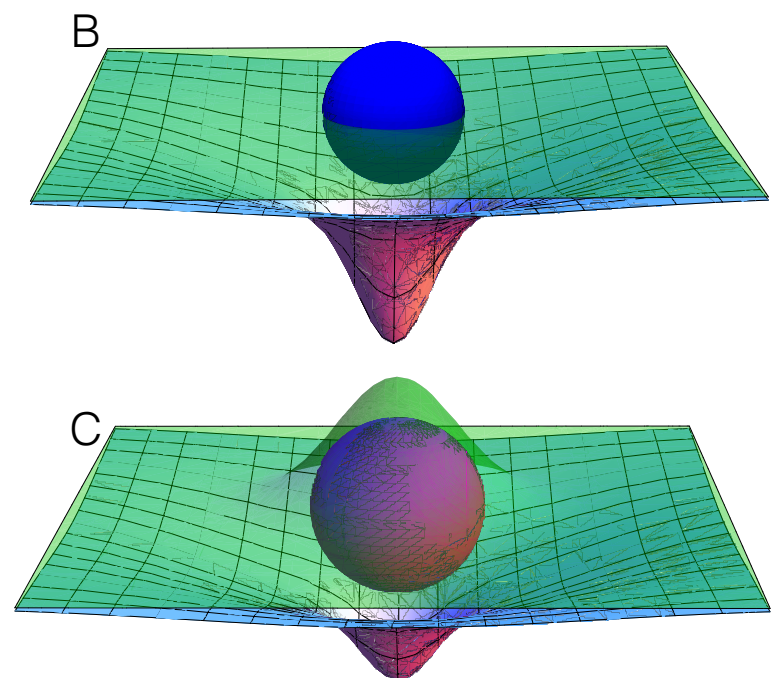
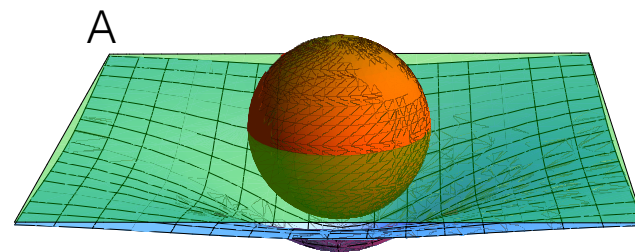
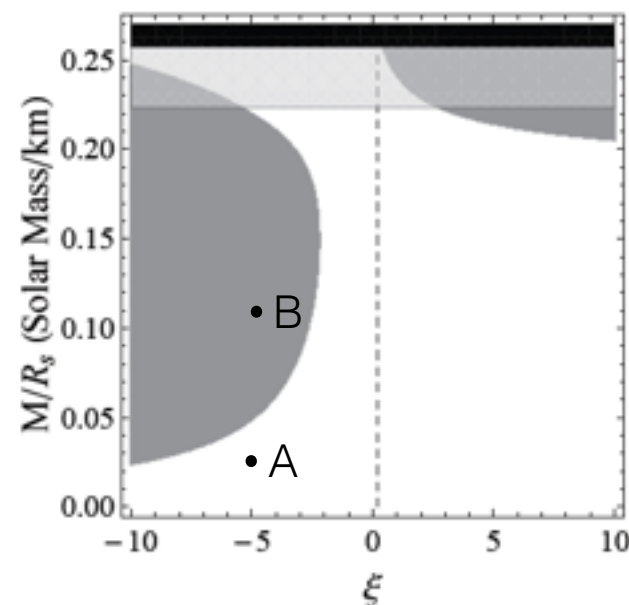
“Seed conjecture”

[P. Pani, V. Cardoso, E. Berti, J. Read, and M. Salgado, PRD **83**, 081501(R) (2011)]

▣ *Spontaneous scalarization*

[T. Damour and G. Esposito-Farèse, PRL **70**, 2220 (1993); PRD **54**, 1474 (1996). T. Harada, Prog. Theor. Phys. **98**, 359 (1997)]

- ✓ For some compact-object configurations, there are *static, nonzero, asymptotically vanishing* field profiles which are *energetically favored* (lower total gravitational mass for same baryonic mass) over the null field configuration;



- ✓ Supposedly, the amplified *vacuum fluctuations* would seed *classical perturbations* which would eventually evolve to the scalarized configuration;

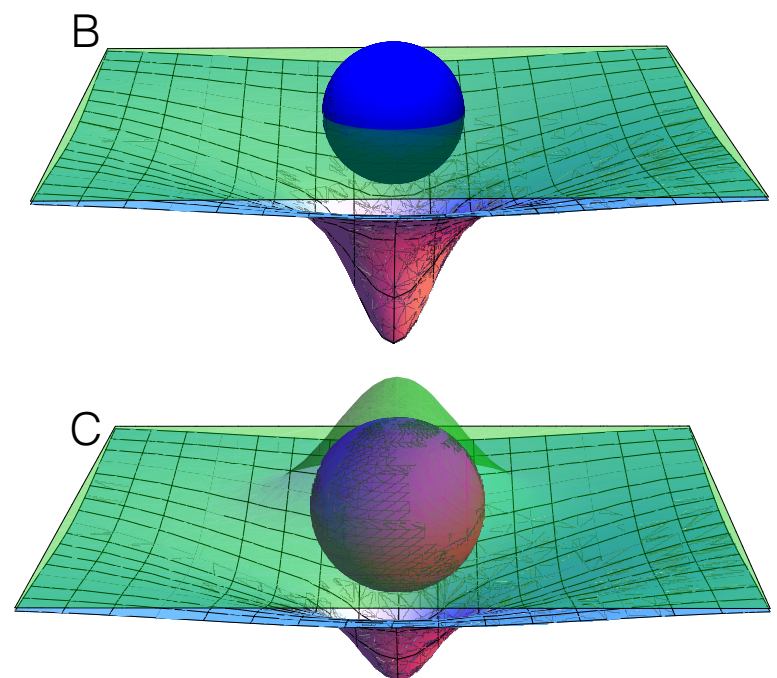
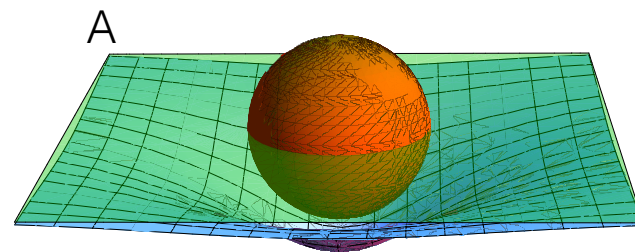
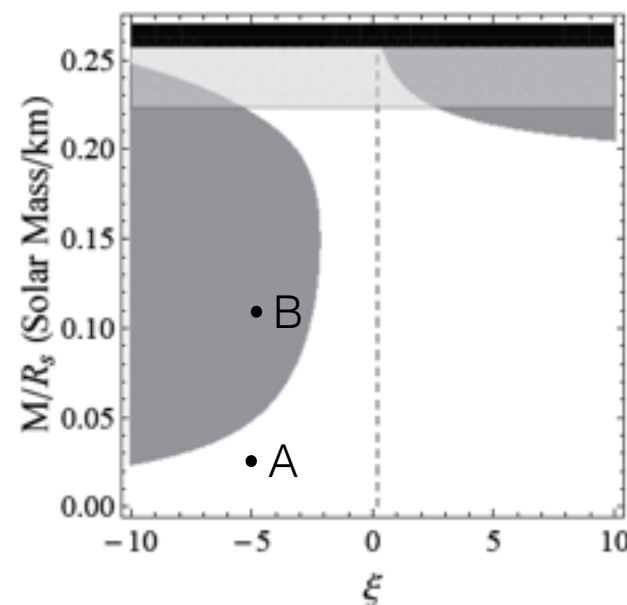
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- ✓ Supposedly, the amplified *vacuum fluctuations* would seed *classical perturbations* which would eventually evolve to the scalarized configuration;
- ✓ In the process, scalar particles/waves are emitted, carrying away (part of) the exceeding energy.

[A. Landulfo, W. Lima, G. Matsas, and D.V., PRD **86**, 104025 (2012); M. Ruiz, J. Degollado, M. Alcubierre, D. Núñez, and M. Salgado, PRD **86**, 104044 (2012)]

Quantum fluctuations **x** classical perturbations

[A. Landulfo, W. Lima, G. Matsas, and D.V., PRD **91**, 024011 (2015)]

- ▣ *“Classicalization” of vacuum fluctuations: two steps*

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▣ “*Classicalization*” of vacuum fluctuations: two steps

1. Appearance of “classical correlations”

Variables of a canonical pair (q,p) become strongly correlated: for some function $f(q,p)$,

$$\Delta_0 f(q,p) \xrightarrow{t \rightarrow \infty} 0 \iff W_0(q,p;t) \stackrel{t \rightarrow \infty}{\sim} \delta(f(q,p))$$

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2. Decoherence

Coherent quantum superposition becomes statistical mixture of “pointer” states (after tracing out the “environment” degrees of freedom E):

$$\rho_R(q, q'; t) := \int dE \langle q, E | \hat{U}(t) | 0, E_0 \rangle \langle 0, E_0 | \hat{U}^\dagger(t) | q', E \rangle \xrightarrow{t \rightarrow \infty} P(q) \delta(q - q')$$

Quantum fluctuations **x** classical perturbations

[A. Landulfo, W. Lima, G. Matsas, and D.V., PRD **91**, 024011 (2015)]

▣ *Classical correlations from squeezing dynamics*

Field: $\hat{\Phi} = \hat{a}_{\Omega} w_{\Omega}^{(+)} + \hat{a}_{\Omega}^{\dagger} w_{\Omega}^{(-)} + \sum_{l\mu} \int d\varpi (\hat{a}_{\varpi l\mu} v_{\varpi l\mu}^{(+)} + \hat{a}_{\varpi l\mu}^{\dagger} v_{\varpi l\mu}^{(-)})$

Hamiltonian: $\hat{H} = \hat{H}_{\text{u}} + \hat{H}_{\text{s}}, \quad \hat{H}_{\text{u}} = -\frac{\Omega}{2}(\hat{a}_{\Omega} \hat{a}_{\Omega} + \hat{a}_{\Omega}^{\dagger} \hat{a}_{\Omega}^{\dagger})$

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In the q -representation: $\eta(t, q) \equiv \langle q|\eta(t)\rangle = \left(\frac{a(t)}{\pi}\right)^{1/4} e^{i\alpha(t)q^2/2}$ (squeezed vacuum state)

Quantum fluctuations **x** classical perturbations

[A. Landulfo, W. Lima, G. Matsas, and D.V., PRD **91**, 024011 (2015)]

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Wigner function: $W(t, q, p) \equiv \frac{1}{2\pi} \int_{-\infty}^{+\infty} dy \varrho(t, q - y/2, q + y/2) e^{ipy}$, where $\varrho(t, q, q') \equiv \langle q | \hat{\varrho}(t) | q' \rangle$.

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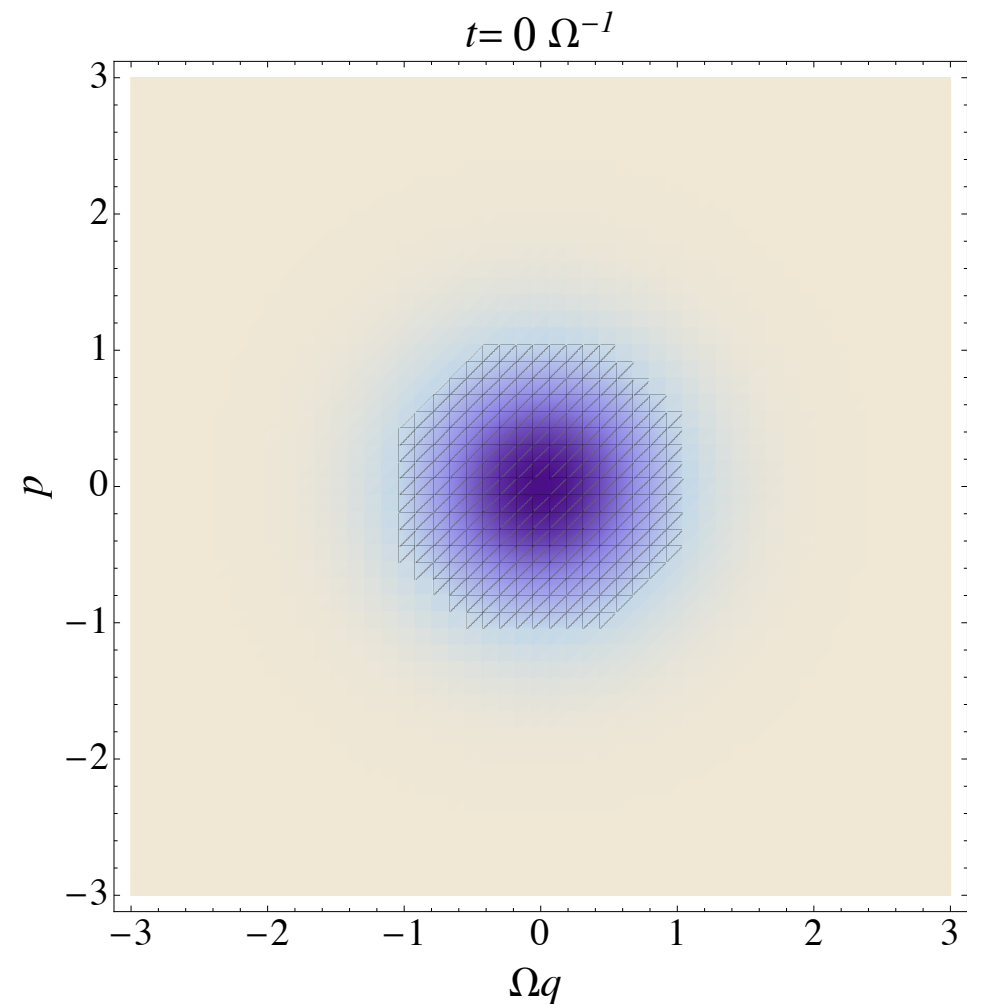
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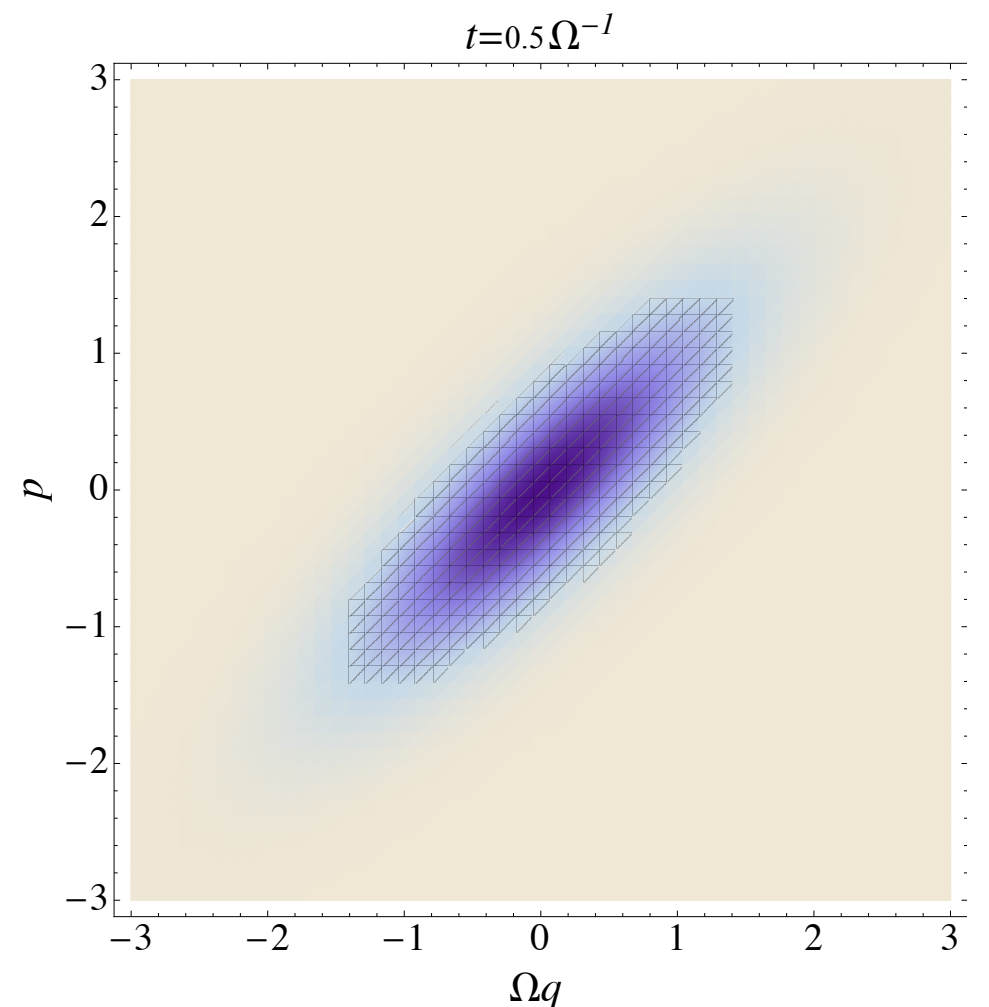
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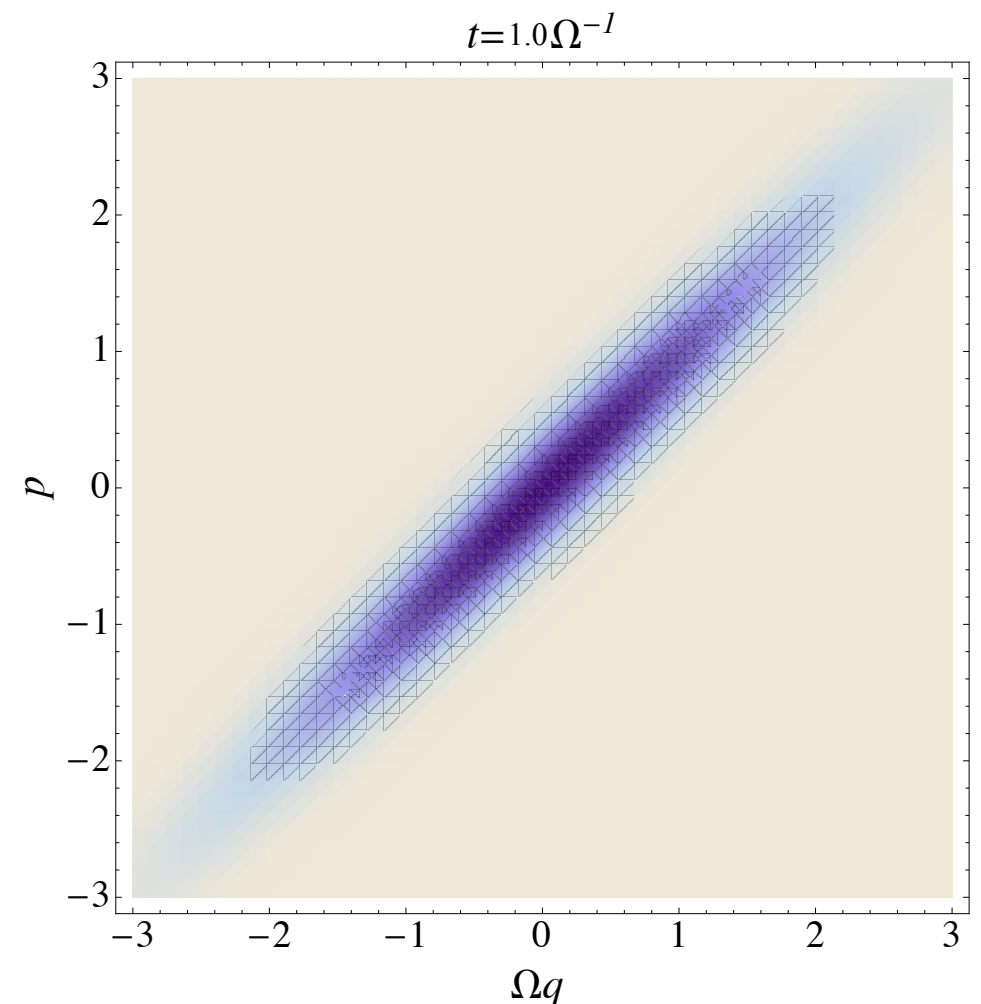
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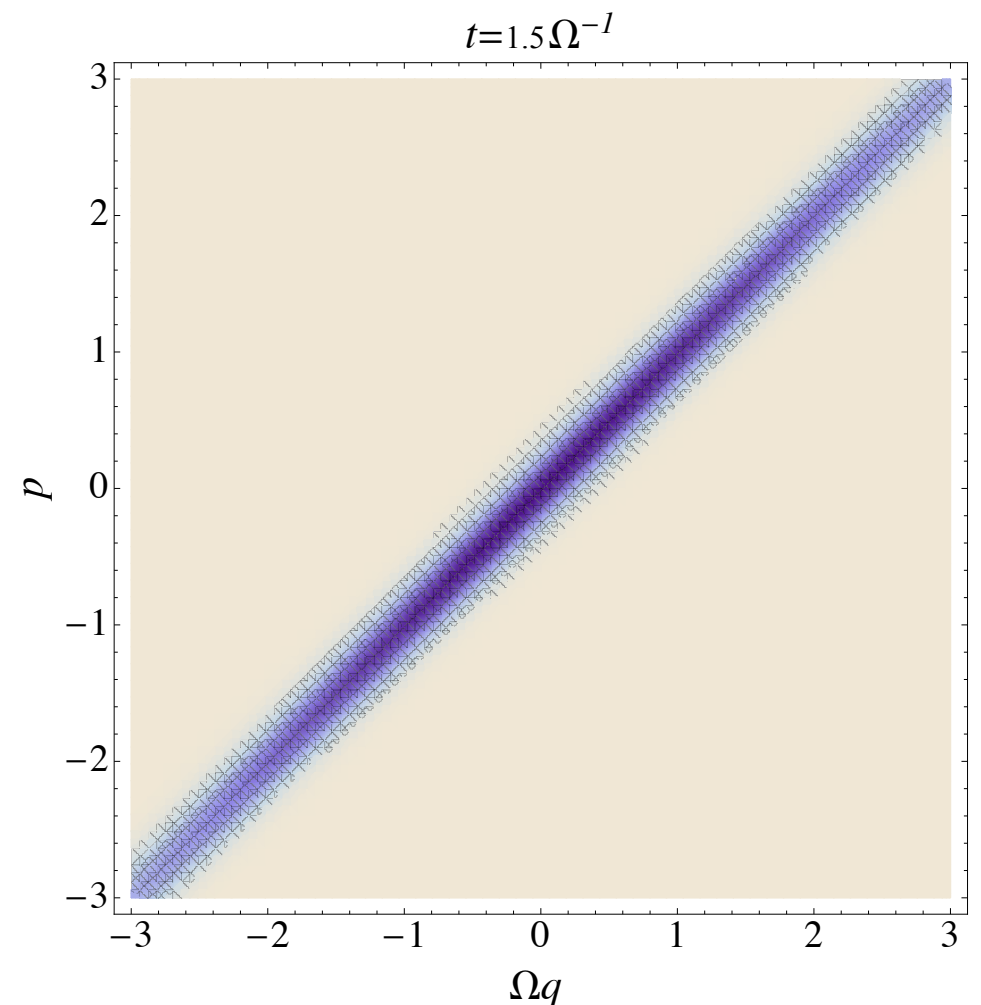
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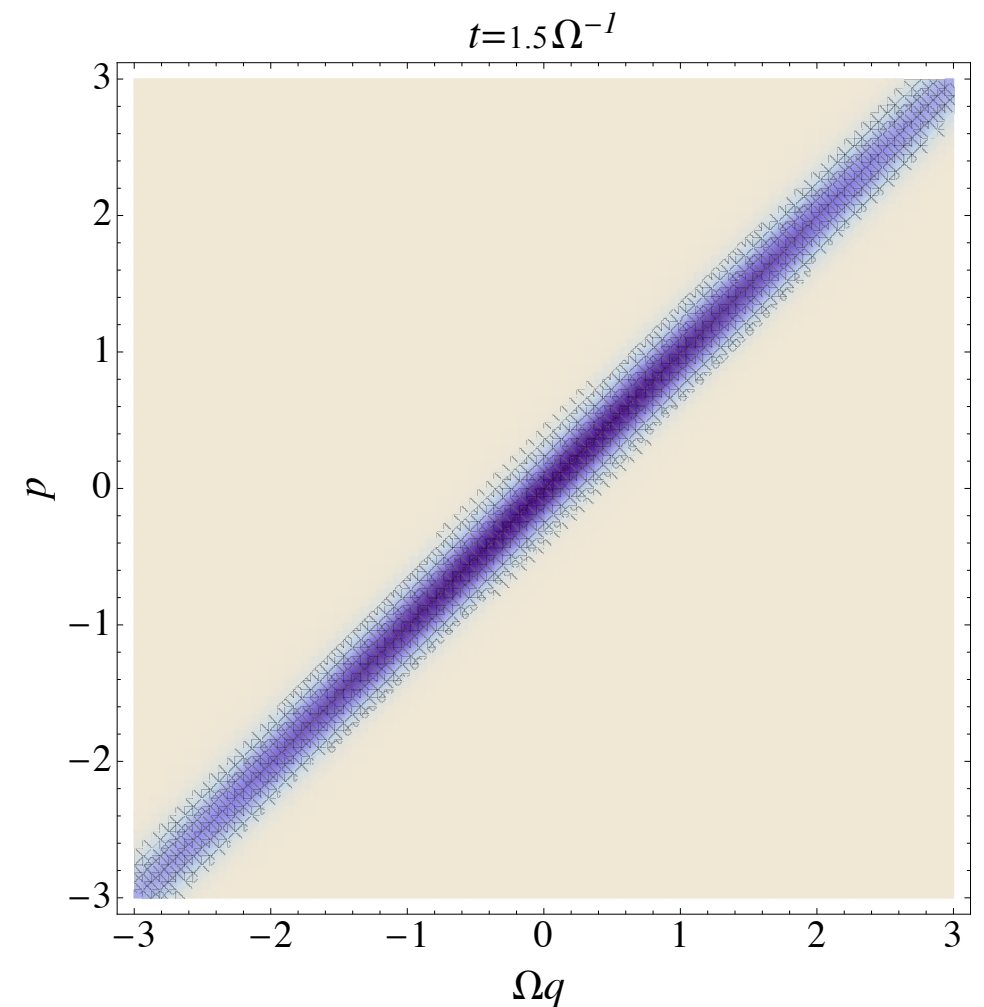
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Quantum fluctuations x classical perturbations

[A. Landulfo, W. Lima, G. Matsas, and D.V., PRD **91**, 024011 (2015)]

▣ *Decoherence*

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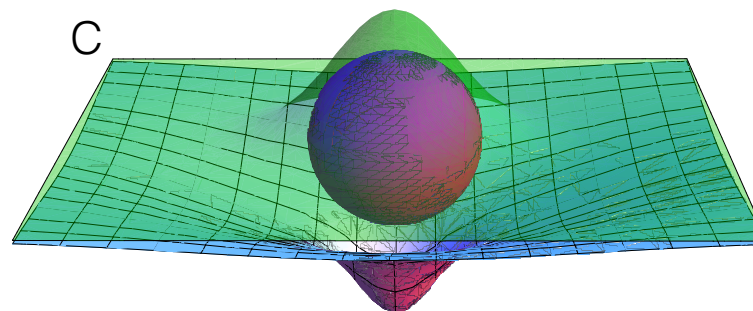
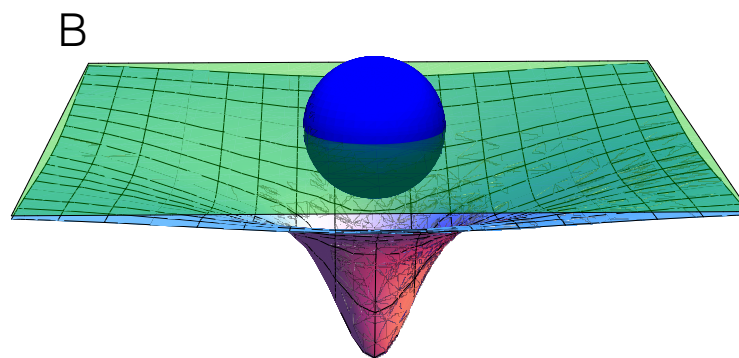
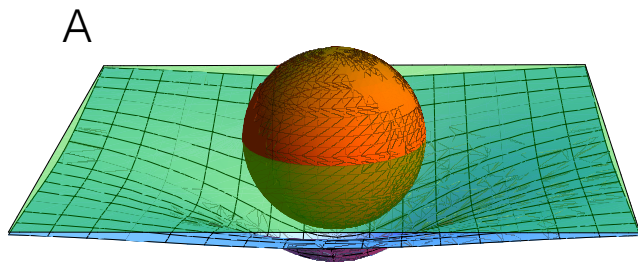
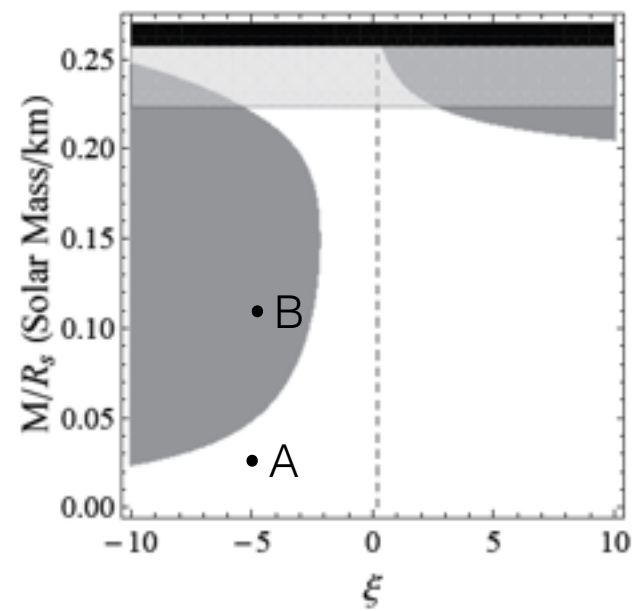
Conclusions

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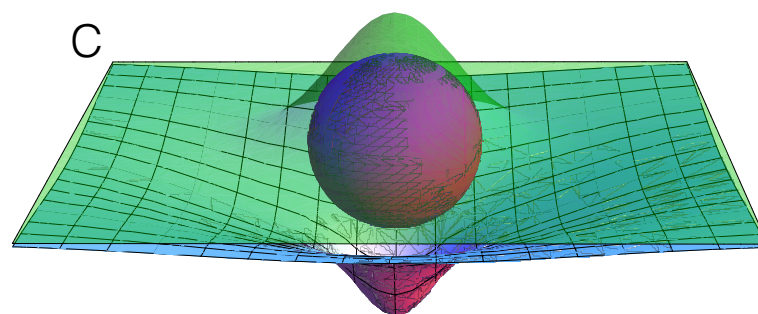
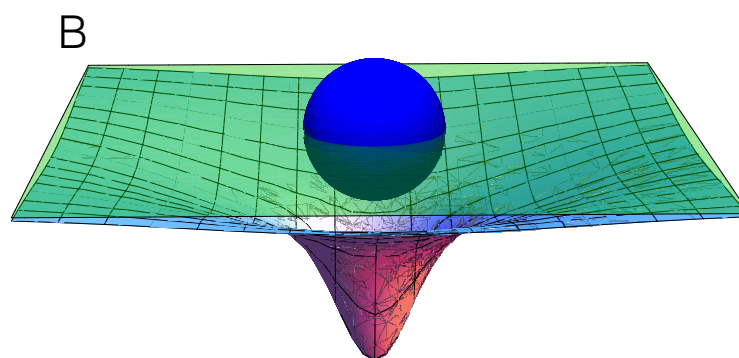
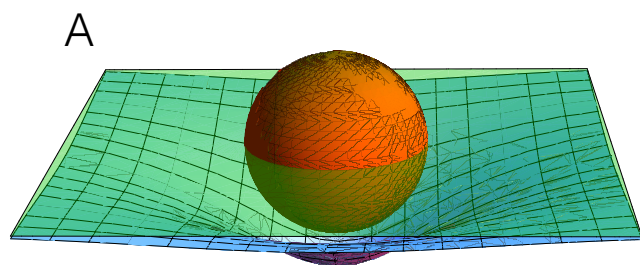
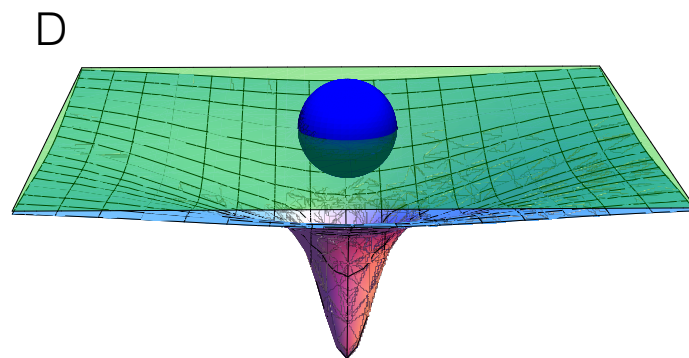
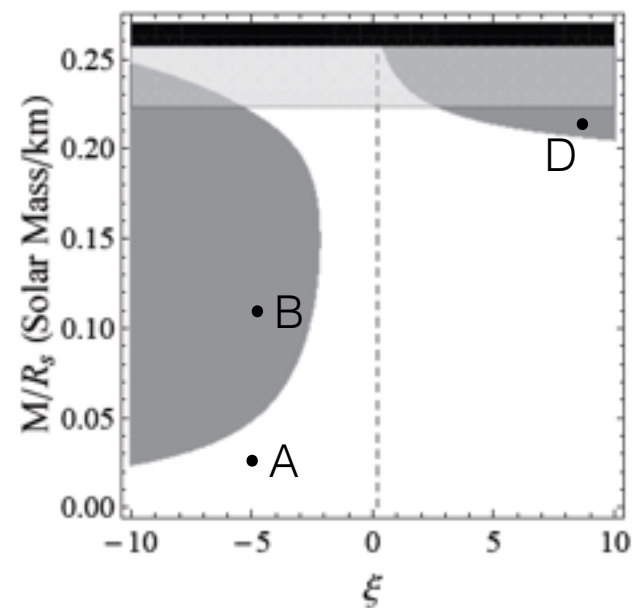
Conclusions

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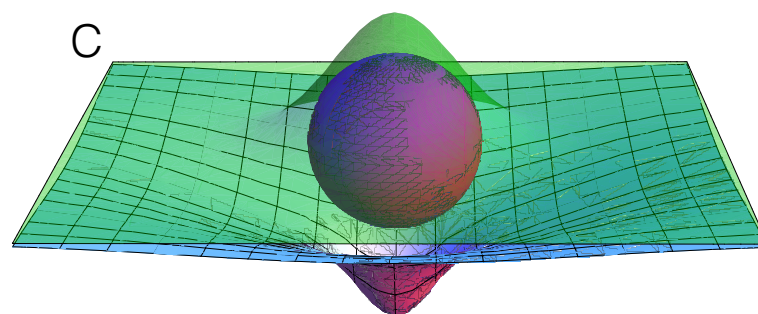
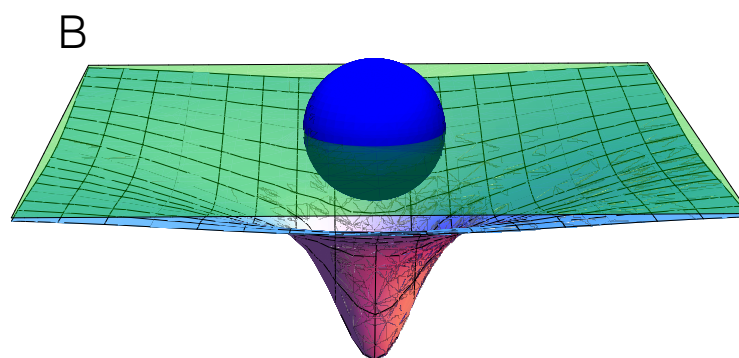
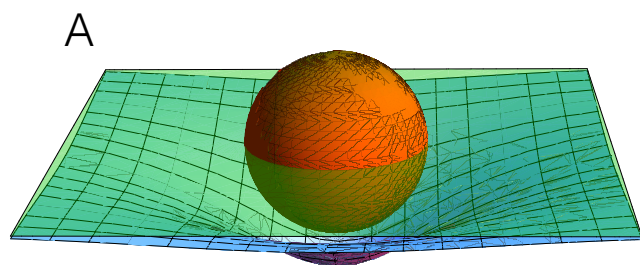
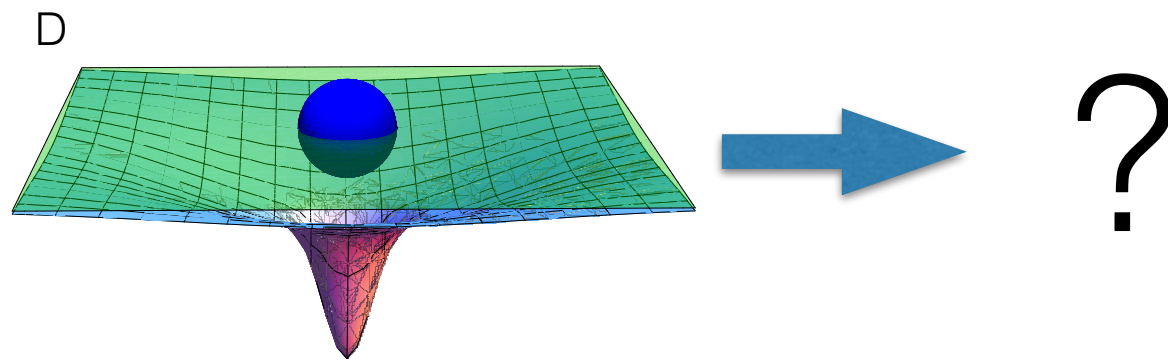
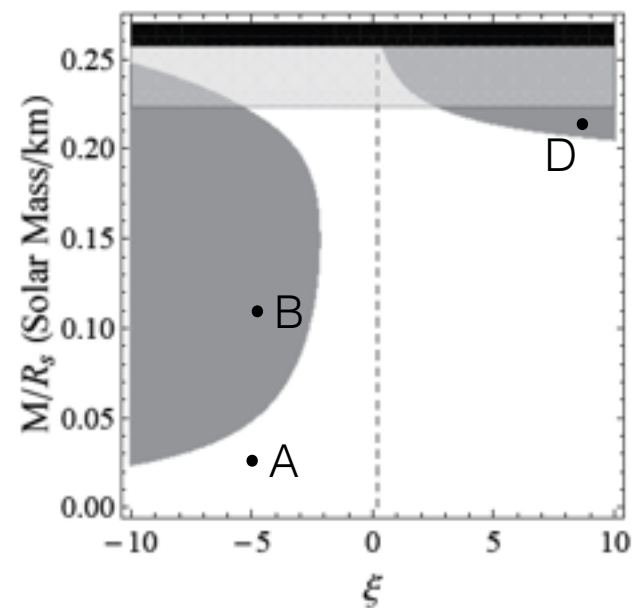
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