# Interaction between bosonic dark matter and stars

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More info at http://blackholes.ist.utl.pt

# Gravity &
# fundamental (bosonic) fields

**The never ending search for dark matter…**

Explore the rich phenomenology of fundamentals fields within full General Relativity.

Signatures of dark matter in strongly gravitating systems?

Can we use it to constrain (or even detect) dark matter candidates?

$$\begin{aligned} S &= \int d^4x\sqrt{-g}\left(\frac{R}{\kappa} - \frac{1}{4}F^{\mu\nu}\bar{F}_{\mu\nu} - \frac{\mu_V^2}{2}A_\nu\bar{A}^\nu\right. \\ &- \left.\frac{1}{2}g^{\mu\nu}\Phi^*_{,\mu}\Phi_{,\nu} - \frac{\mu_S^2|\Phi|^2}{2} + \mathcal{L}_{\rm matter}\right) \end{aligned}$$

# Solitonic stars

D.J. Kaup '68; Ruffini & Bonazzola '69; Seidel & Suen '91;
Brito, Cardoso, Herdeiro & Radu '15; Brito, Cardoso & Okawa '15

Geometry ← $G^{\mu\nu} = 8\pi T^{\mu\nu}$ → Matter

$$\nabla_\mu \nabla^\mu \Phi = \mu_S^2 \Phi \qquad (\mu_S^{-1} = \lambda_c \to \text{Compton wavelength})$$

$$T^{\mu\nu}_{\text{scalar}} = -\frac{1}{4} g^{\mu\nu}\left(\Phi^*_{,\alpha}\Phi^{,\alpha} + \mu_S^2 \Phi^*\Phi\right) + \frac{1}{4}\left(\Phi^{*,\mu}\Phi^{,\nu} + \Phi^{,\mu}\Phi^{*,\nu}\right)$$

**Spherical symmetry:** $ds^2 = -F(t,r)dt^2 + B(t,r)dr^2 + r^2 d\Omega^2$

**Complex fields - Boson stars:**

$N^i = (B, F)$

$$\begin{aligned} N^i(t,r) &= N(r) \\ \Phi(t,r) &= \phi(r)e^{-i\omega t} \end{aligned}$$

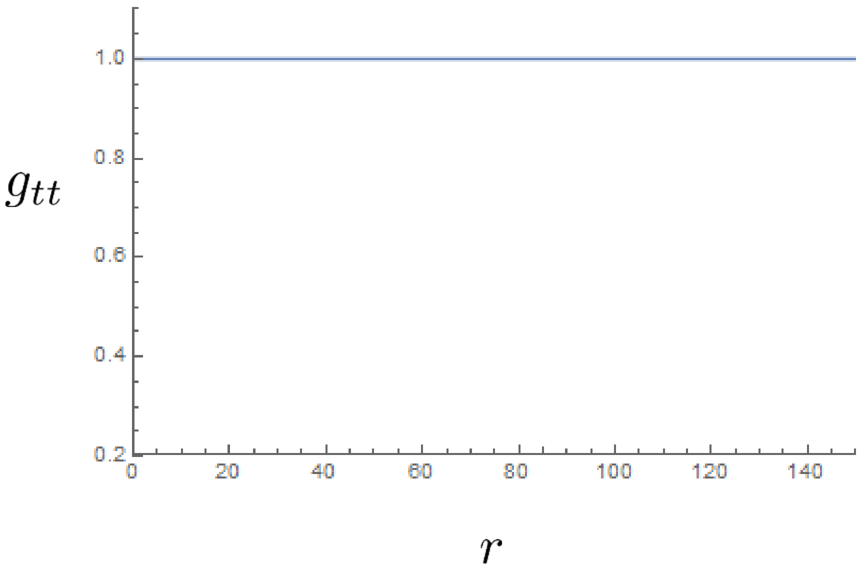
**Real fields - Oscillatons:**

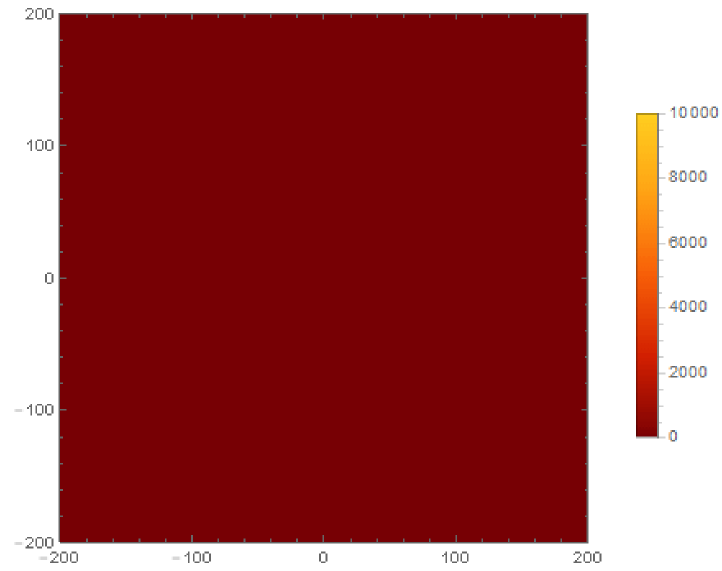
$N^i = (B, F)$

$$\begin{aligned} N^i(t,r) &= \sum_{j=0}^{\infty} N^i_{2j}(r)\,\cos(2j\omega t) \\ \Phi(t,r) &= \sum_{j=0}^{\infty} \phi_{2j+1}(r)\,\cos\left[(2j+1)\,\omega t\right] \end{aligned}$$

# Massive Scalar field

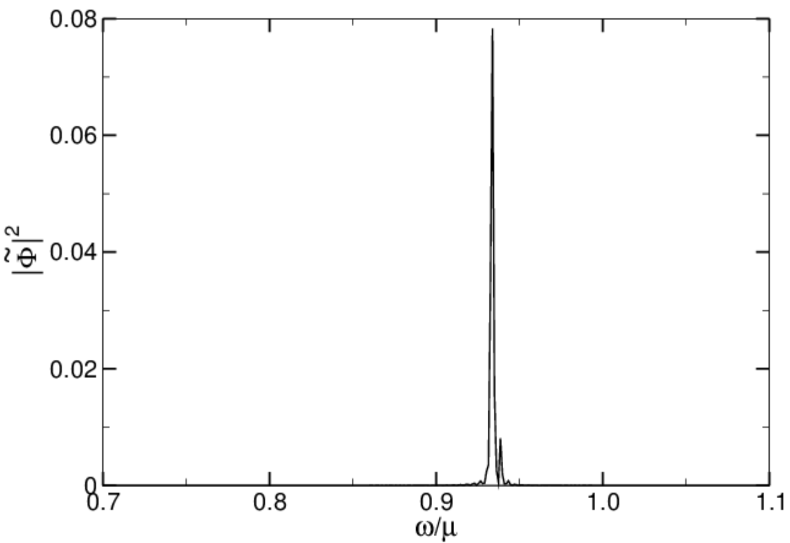
$$\mu_S \neq 0$$



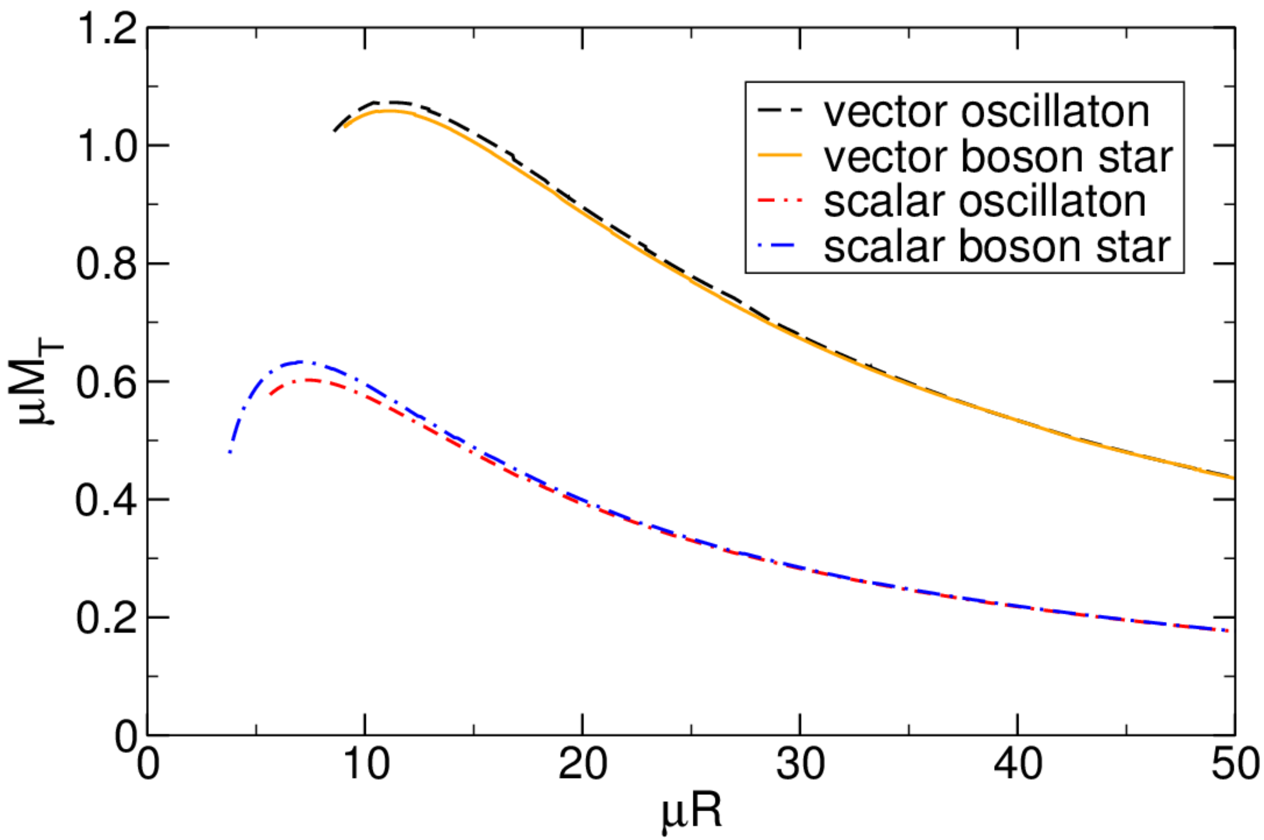

$$ds^2 = -g_{tt}dt^2 + g_{rr}dr^2 + r^2 d\Omega^2$$

$$\phi(r \to \infty) \propto e^{-r\sqrt{\mu^2 - \omega^2}}$$



# Oscillatons and Boson stars

D.J. Kaup ‘68; Ruffini & Bonazzola ’69; Seidel & Suen ’91;
Brito, Cardoso, Herdeiro & Radu ’15; Brito, Cardoso & Okawa ‘15




$$\frac{M_{\rm max}}{M_\odot} = 8 \times 10^{-11} \left( \frac{\rm eV}{m_B c^2} \right)$$

$$\omega \sim \mu \implies f = 2.5 \times 10^{14} \left( \frac{m_B c^2}{eV} \right) \text{ Hz}$$

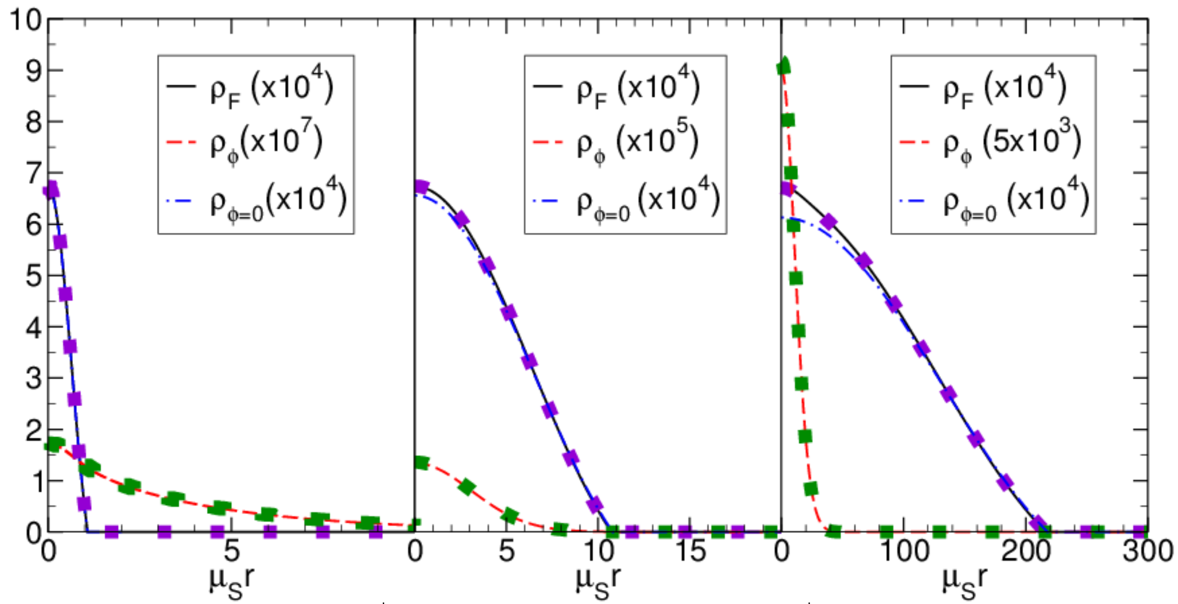
# Accretion onto stars

Brito, Cardoso & Okawa '15

Do Einstein's equations allow for stable solutions describing a star (e.g. neutron star, white dwarf or any other kind of star) with a bosonic core?

**Perfect fluid star:** $T^{\mu\nu}_{\text{fluid}} = (\rho_F + P)\, u^\mu u^\nu + P g^{\mu\nu}$

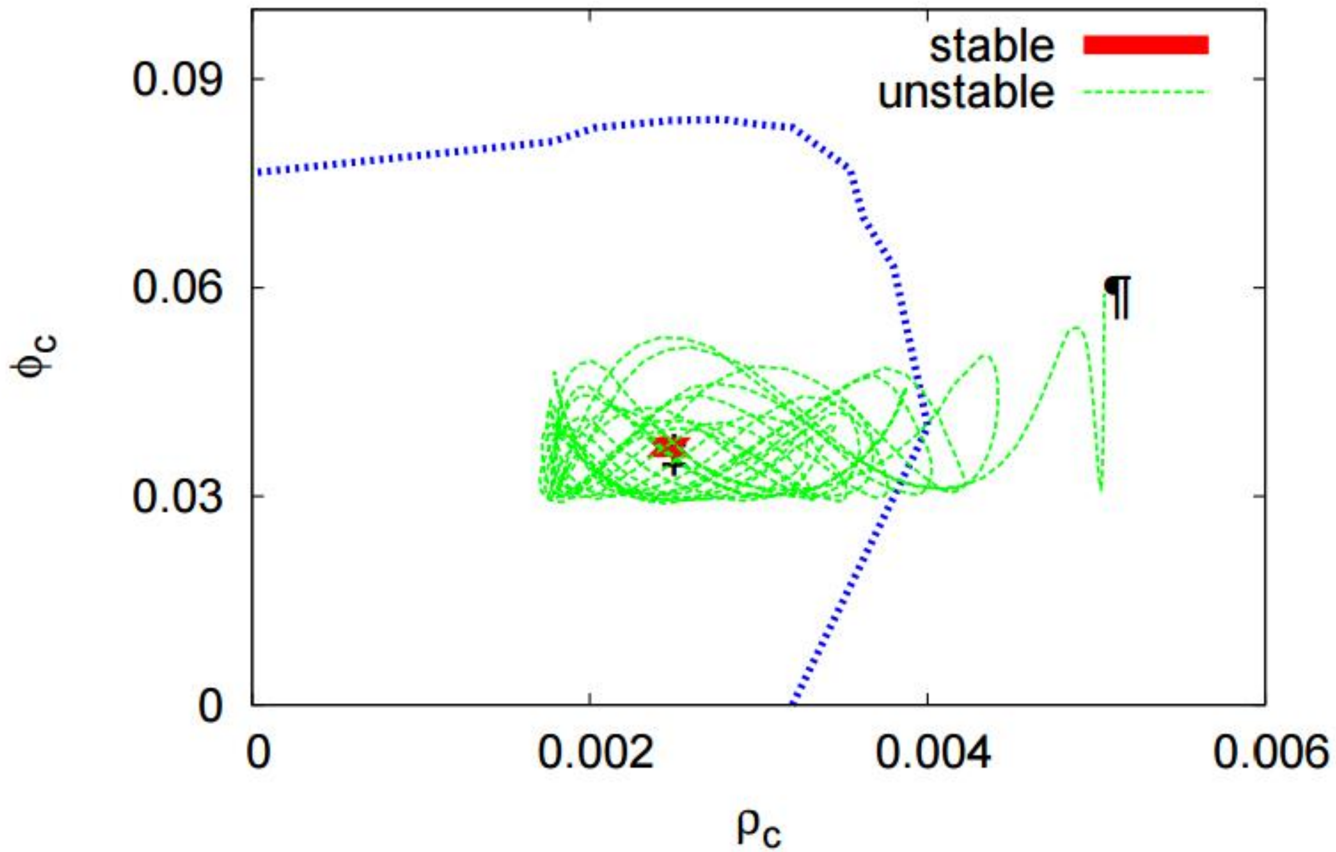
Equations imply that the star's material must oscillate: $\rho_F = \sum_{j=0}^{\infty} \rho_{F\,2j}(r)\, \cos(2j\omega t)$




$M_T\mu_S = 0.1$ | $M_T\mu_S = 1$ | $M_T\mu_S = 20$

# Stability?

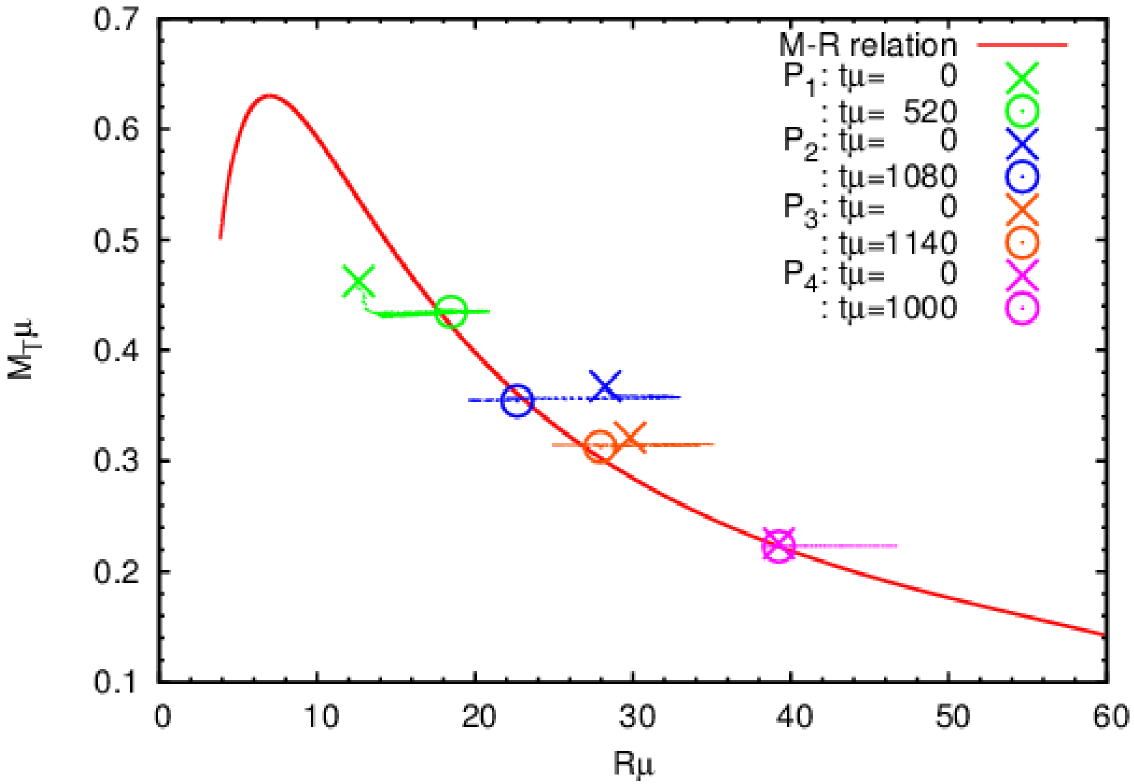
A. Henriques, A. R. Liddle & R. Moorhouse ‘90 ; Valdez-Alvarado, Palenzuela, Alic & Ureña-López ’13; Brito, Cardoso, Macedo, Okawa & Palenzuela, ‘16




From: Valdez-Alvarado, Palenzuela, Alic & Ureña-López, Phys.Rev. D87 (2013) 8, 084040

**Stability?** For sufficiently small scalar composites (or vice-versa) stability analysis of the host star is still valid. (A. Henriques, A. R. Liddle & R. Moorhouse PLB B251, 511 (1990))

# Do they ever form?

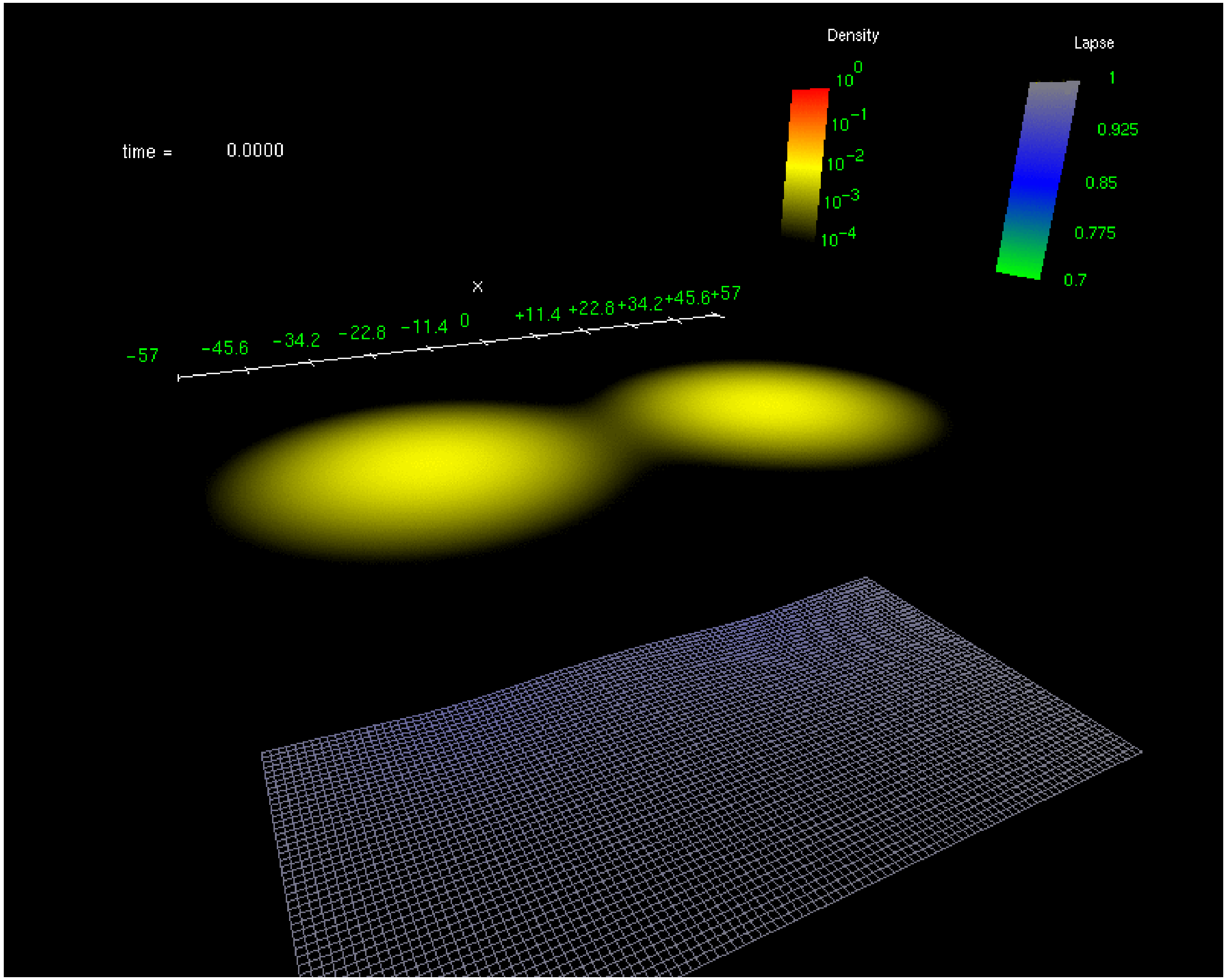



Purely bosonic states do.

Two channels for composite fluid-boson stars:

- Gravitational collapse in a bosonic environment;
- Capture and accretion of DM into the core of compact stars.

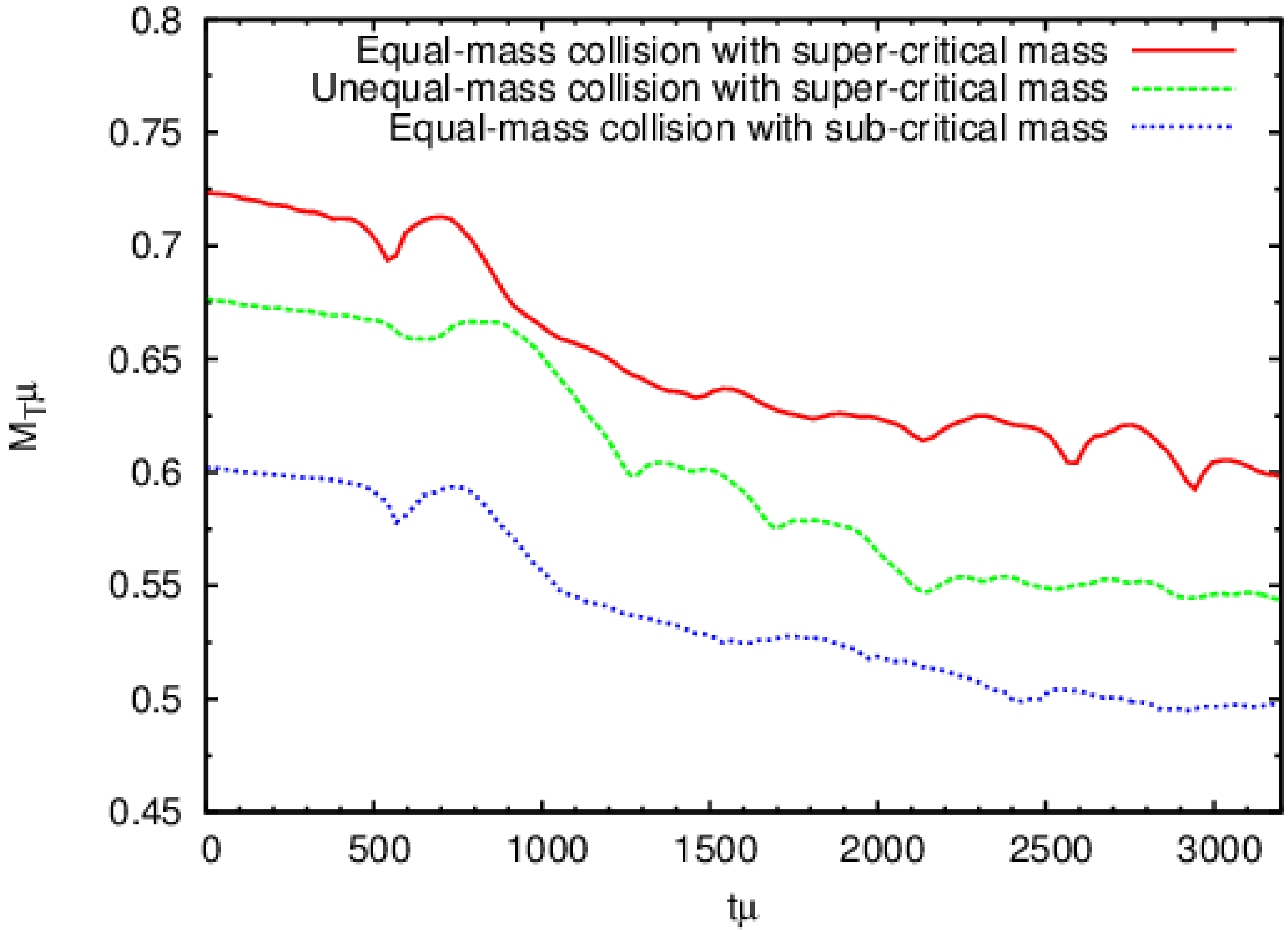
# Growth of bosonic structures




Equal-mass collision Mμ~0.3. Total mass below the maximum mass.
Final mass larger than initial mass of each oscillaton Mμ~0.5.

# Collision of bosonic structures

Brito, Cardoso & Okawa '15;
Brito, Cardoso, Macedo, Okawa & Palenzuela, '16



# Accretion onto stars

Standard picture

- Accumulation stage and thermalization.
- DM core collapses, after becoming self-gravitating or when the DM core reaches the thresold $M\mu \sim 0.6$.

(Goldman and Nussinov PRD40, 3221 (1989); Bertone and Fairbairn PRD77, 043515 (2008); Bramante, PRL115, 141301 (2015); Kurita and Nakano, arXiv:1510.00893...etc)

- Lack of rigorous support for this picture.
- For Compton wavelengths smaller than size of star, bosonic core behaves as isolated oscillaton.
- We just showed cases where the core does *not* collapse to a black hole when $M\mu > 0.6$.
- Stable configurations with self-gravitating DM cores can be constructed...

# Conclusions

- Fundamental fields when coupled to gravity have a very rich and unexplored phenomenology.
- Accretion onto stars might in principle lead to stable periodically oscillating configurations and possible observable effects through a very definite oscillation frequency in the star's material.
- Collapse to a black hole can be avoided by an efficient gravitational cooling mechanism.

# Thank you