Interaction between bosonic dark matter and stars

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R.Brito, V. Cardoso & H. Okawa, Phys.Rev.Lett. 115 (2015) no.11, 111301 arXiv: 1508.04773
R. Brito, V. Cardoso, H. Okawa, C. Macedo & C.Palenzuela, Phys.Rev. D93 (2016) no.4, 044045, arXiv: 1512.00466

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

Gravity & fundamental (bosonic) fields

The never ending search for dark matter…

Signatures of dark matter in gravitating systems?

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

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

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

Bosonic stars

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

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

$$T^{\mu\nu}_{\rm vector} = F^{(\mu}_{\ \ \alpha} \bar{F}^{\nu)\alpha} - \frac{1}{4} \bar{F}^{\alpha\beta} F_{\alpha\beta} g^{\mu\nu} - \frac{1}{2} \mu_V^2 A_\alpha \bar{A}^\alpha g^{\mu\nu} + \mu_V^2 A^{(\mu} A^{\nu)}$$

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

Complex fields - Boson stars:

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

Real fields - Oscillatons:

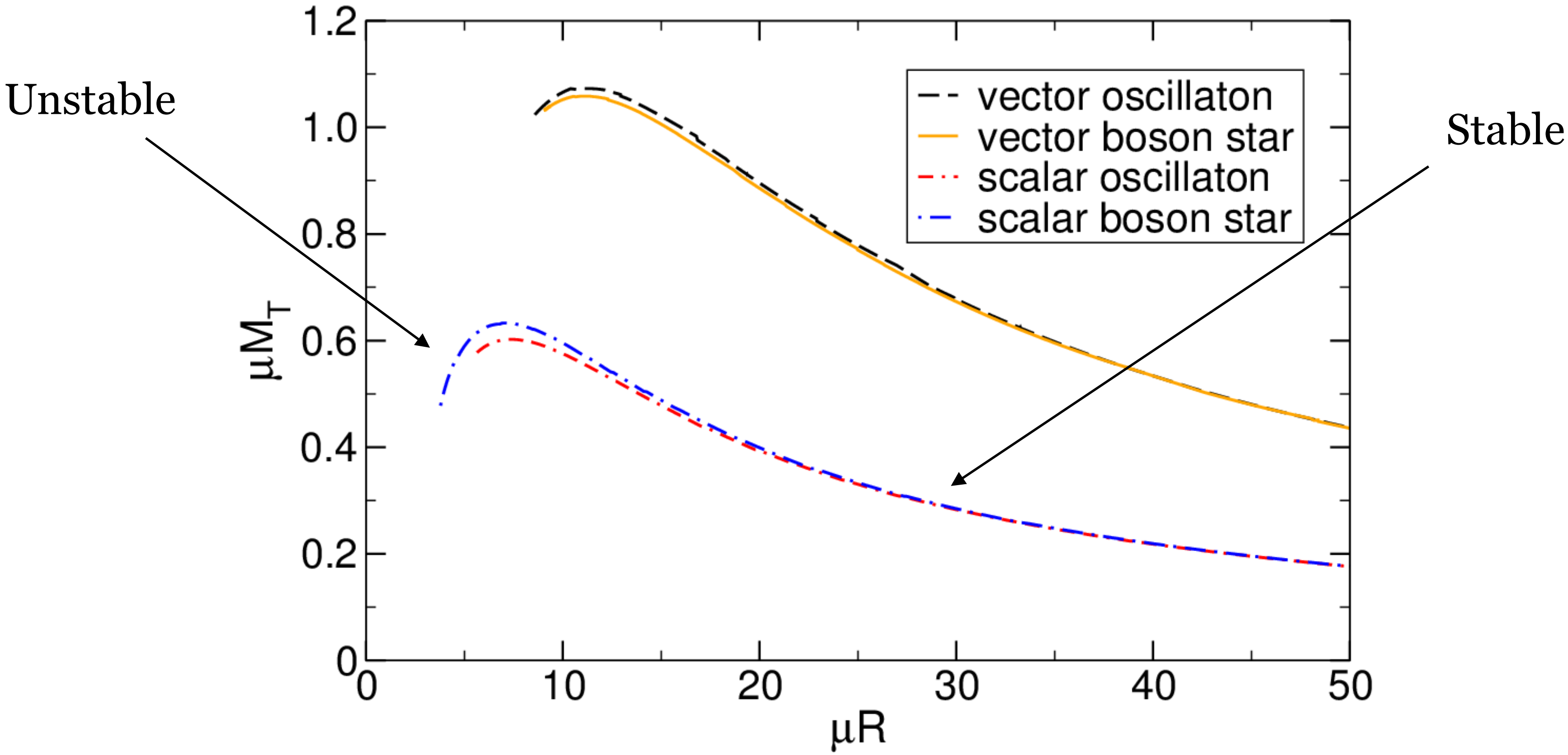
$$\begin{aligned} N^i(t,r) &= \sum_{j=0}^{\infty} N^i_{2j}(r) \cos(2j\omega t) \\ \Phi(t,r) &= \sum_{j=0}^{\infty} \phi_{2j+1}(r) \cos\left[(2j+1)\omega t\right] \end{aligned}$$

$$N^i = (B, F)$$

For rotating boson/Proca stars see:
Yoshida, Eriguchi '97; Schunck, Mielke '98
Brito, Cardoso, Herdeiro & Radu '15

Oscillatons and Boson stars

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



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

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

Accretion onto stars: boson-fluid stars

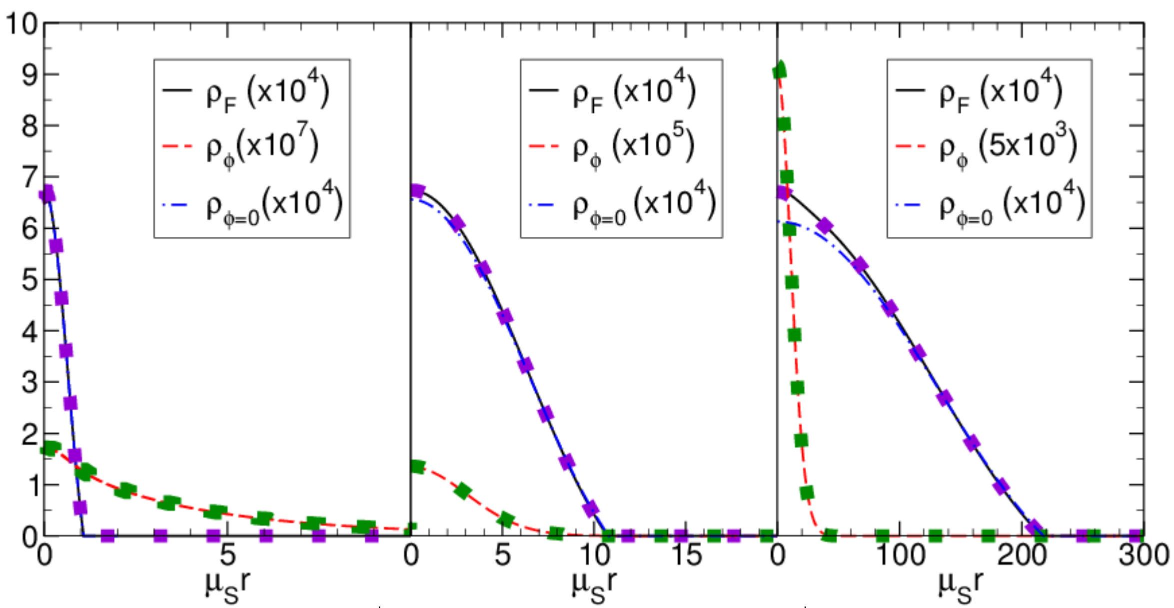
A. Henriques, A. R. Liddle & R. Moorhouse '89;
Brito, Cardoso & Okawa '15; Brito, Cardoso, Macedo, Okawa & Palenzuela, '16

Do Einstein's equations allow for stable solutions describing a star with a bosonic core?

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

For real bosonic fields, equations imply that the star's material must oscillate:

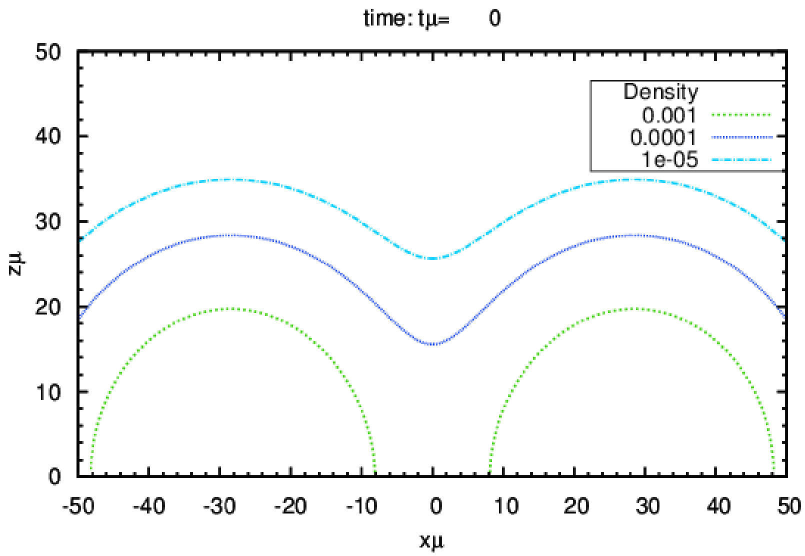
$$\rho_F = \sum_{j=0}^{\infty} \rho_{F\,2j}(r)\, \cos\left(2j\omega t\right)$$

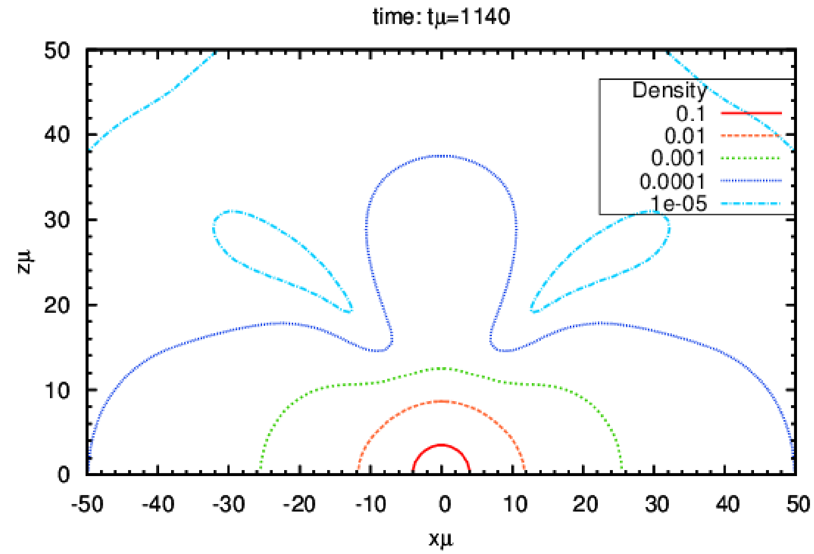


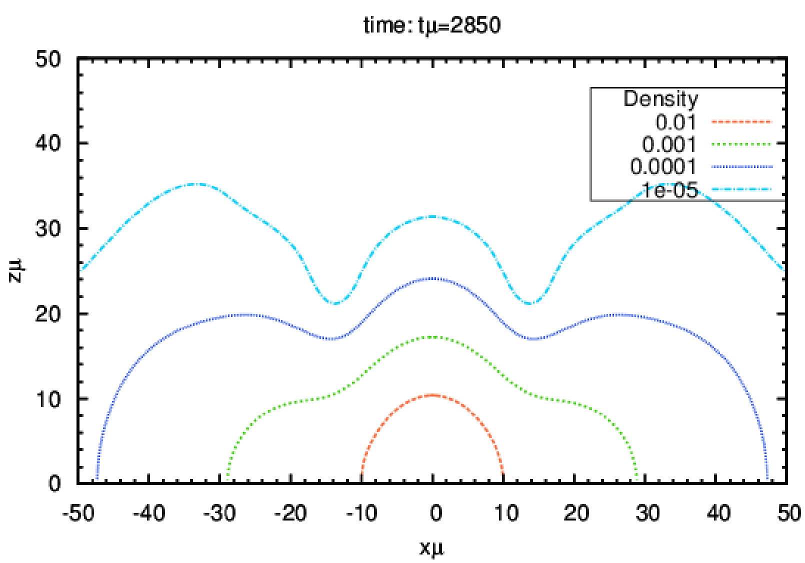
$M_T \mu_S = 0.1$ | $M_T \mu_S = 1$ | $M_T \mu_S = 20$

Growth of bosonic structures

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





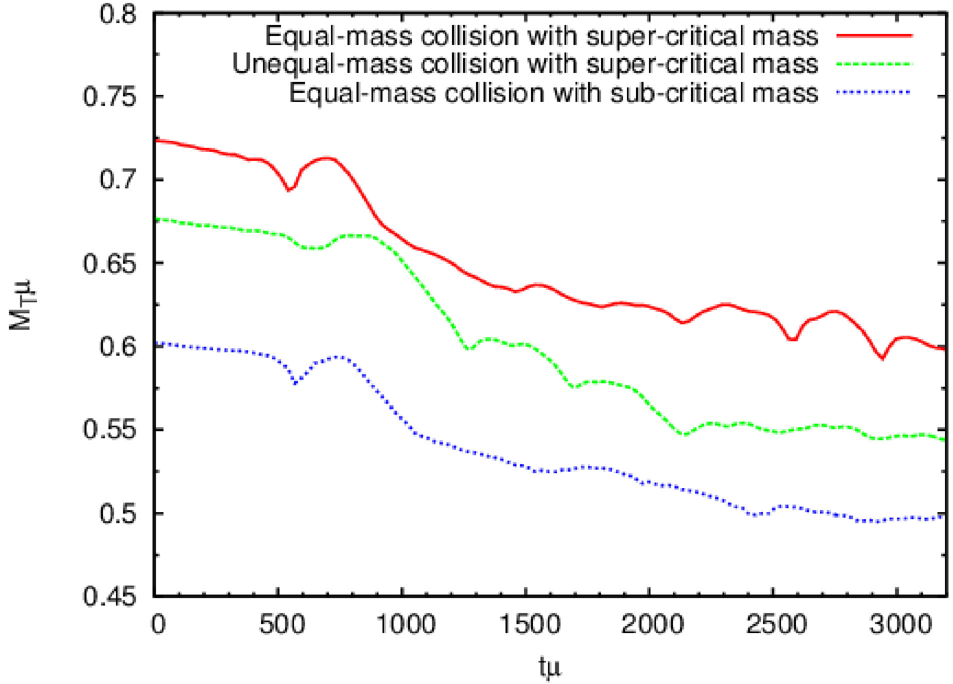


$$M_{\rm initial} \sim 0.3/\mu_S,\ R_{\rm initial} \sim 20/\mu_S$$

Mass of final object larger than initial mass of each oscillaton Mμ~0.5.

Collision of bosonic structures

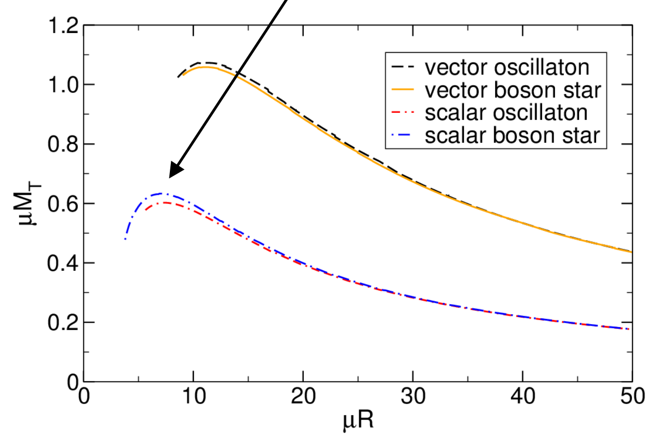
Brito, Cardoso & Okawa ‘15; Brito, Cardoso, Macedo, Okawa & Palenzuela, ‘16



Bosonic structures can grow through mergers.

Growth continues till the threshold mass Mμ~0.6.

Collapse to a black hole for Mμ>0.6 can be avoided due to a “gravitational cooling” mechanism.



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...

Thank you

Backup Slides

Accretion onto stars

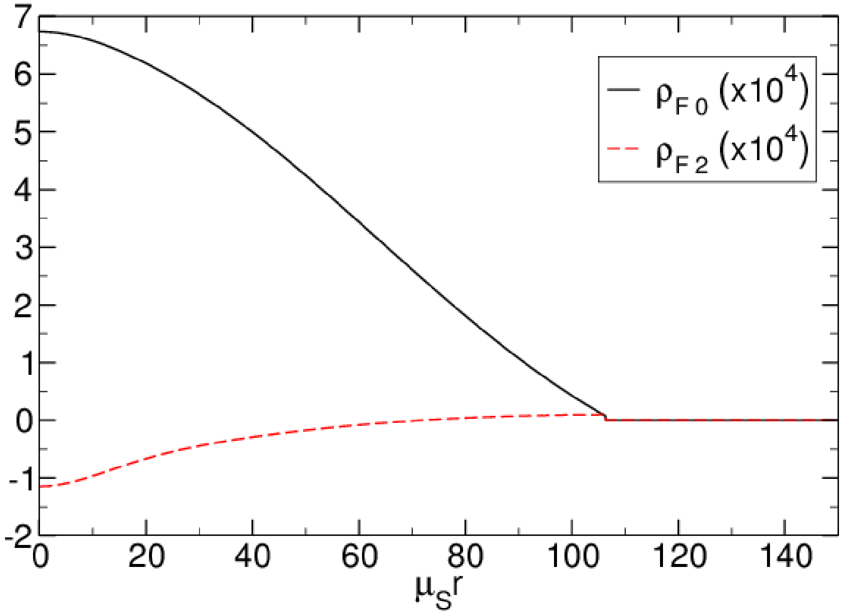
A. Henriques, A. R. Liddle & R. Moorhouse ‘89;
Brito, Cardoso & Okawa ‘15; Brito, Cardoso, Macedo, Okawa & Palenzuela, arXiv: 1512.00466

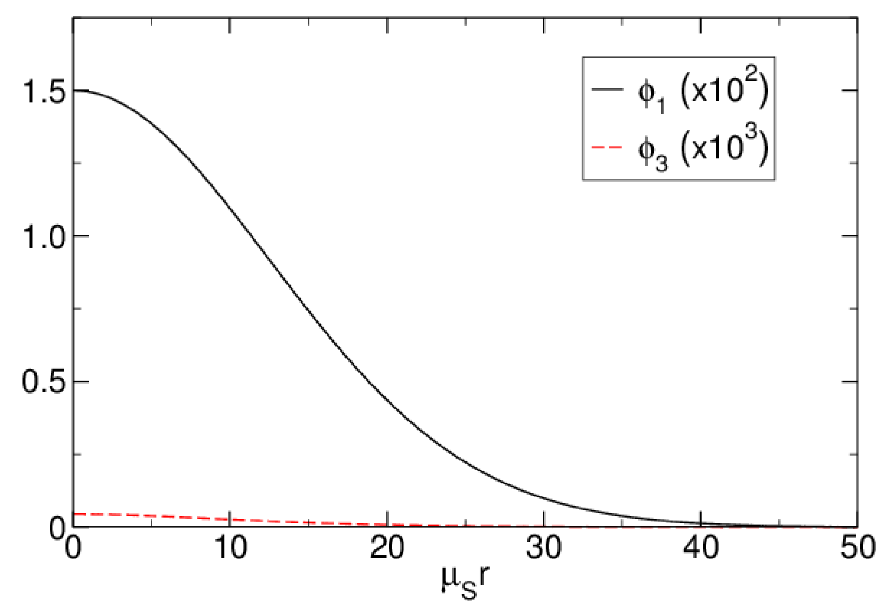
Perfect fluid star: $T^{\mu\nu}_{\rm fluid} = (\rho_F + P)\, u^\mu u^\nu + P g^{\mu\nu}$

$$u^\mu = \frac{\Gamma}{\sqrt{-g_{tt}}}\,(1, V(t,r), 0, 0)$$

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

$$N^i = (g_{tt}, g_{rr}, n_F, \rho_F, P, V)$$

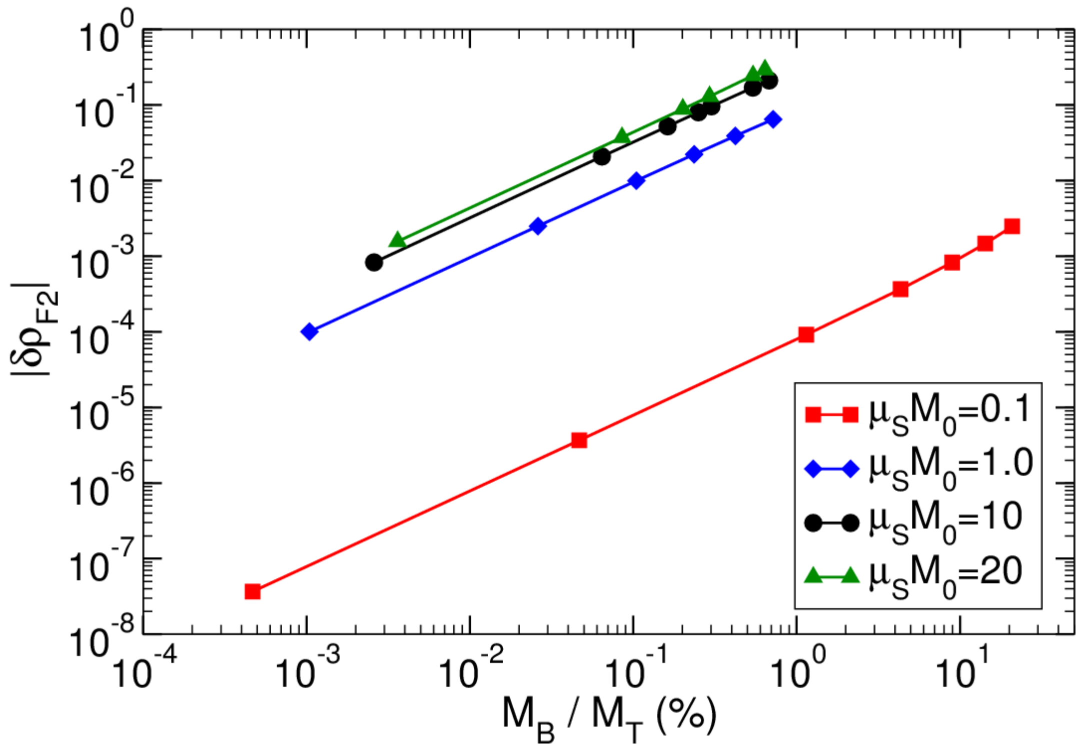




Fluid oscillations

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

Equations imply that the star material must oscillate: $\rho_F = \sum_{j=0}^{\infty} \rho_{F\,2j}(r)\ \cos(2j\omega t)$

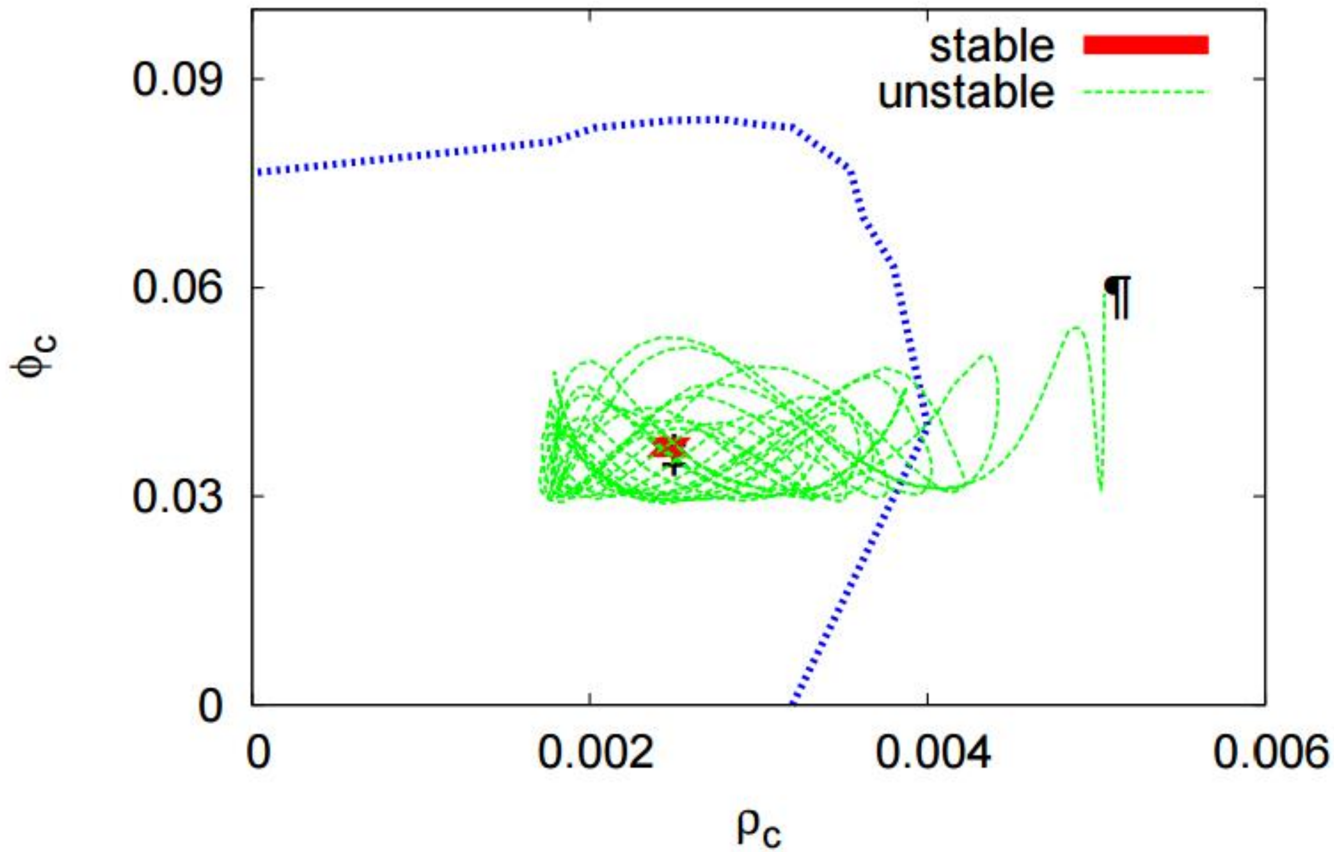


$$\omega \sim \mu_S \implies f = 2.5 \times 10^{14} \left(\frac{m_B c^2}{eV}\right) \text{Hz}$$

$$\mu_S^{-1} = \lambda_c \to \text{Compton wavelength}$$

Stability?

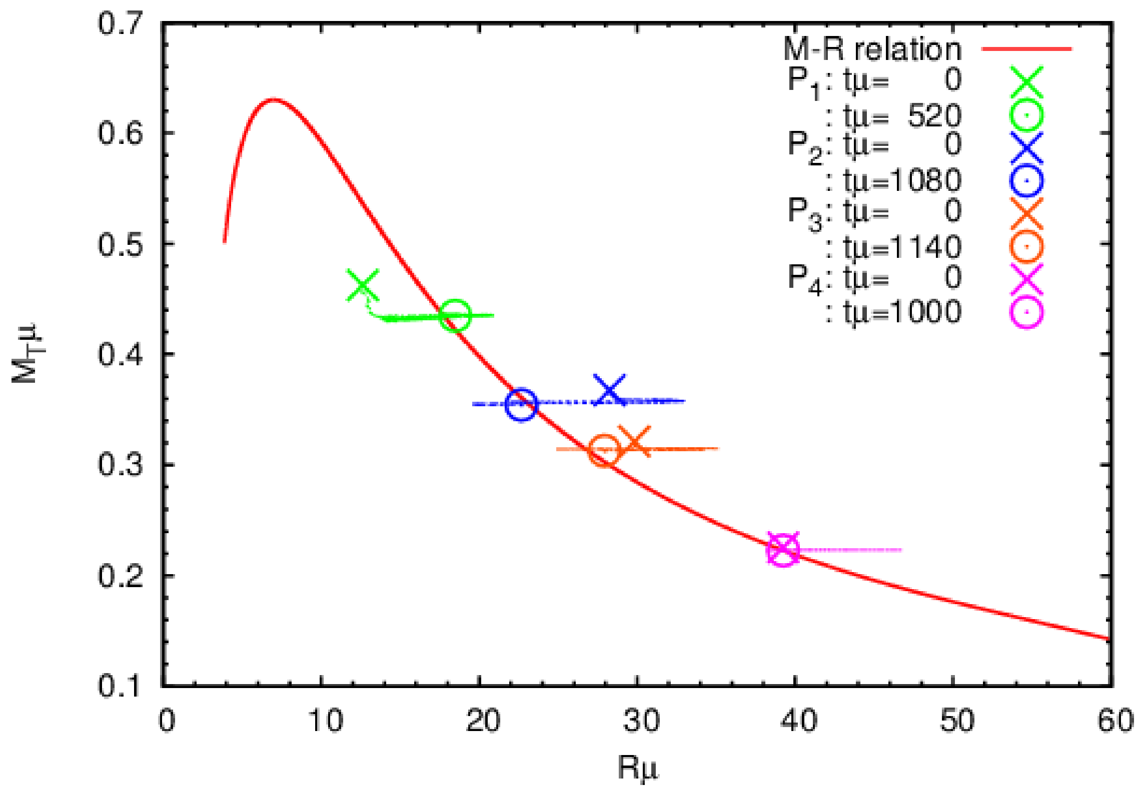
A. Henriques, A. R. Liddle & R. Moorhouse '90 ; Valdez-Alvarado, Palenzuela, Alic & Ureña-López '13; Brito, Cardoso, Macedo, Okawa & Palenzuela, '16



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. Collapse to a black hole?

Accretion onto stars

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

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

$$u^\mu = \frac{\Gamma}{\sqrt{-g_{tt}}}\,(1, V(t,r), 0, 0)$$

$$N^i = \sum_{j=0}^{\infty} N^i_{2j}(r)\,\cos(2j\omega t)$$

$$\Phi(t,r) = \sum_{j=0}^{\infty} \phi_{2j+1}(r)\,\cos\left[(2j+1)\,\omega t\right]$$

$$N^i = (g_{tt}, g_{rr}, n_F, \rho_F, P, V)$$