IDPASC PhD Students Workshop

Rotating clumps of scalar field dark matter

Phys. Rev. D 99, 103008
(arXiv:1904.10777)

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We have **strong evidence** in favor of the **existence** of a scalar field (Higgs boson);

Scalar fields appear as **fundamental elements** of a number of theories, from **extensions of well known setups**, as the Standard Models of Particles and Cosmology, or as part of **String Theory**; [Hu+,2000] [Peccei&Quinn,1977] [Svrcek&Witten,2006]

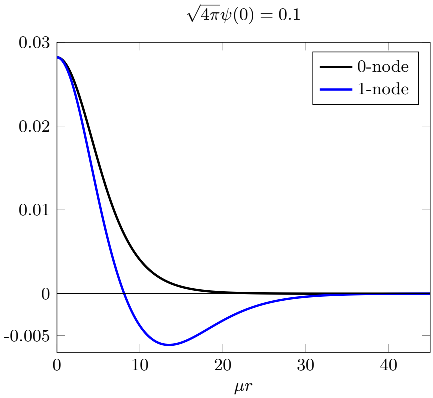
Some of these scalar fields are predicted to be **ultra light** - $[10^{-33}, 10^{-10}]$ eV - and to interact very weakly with the SM; [Arvanitaki+,2010] [Hui+,2017]

Boson stars

$$R_{\alpha\beta} - \frac{1}{2}Rg_{\alpha\beta} = 8\pi G T_{\alpha\beta}^{\text{scalar field}}$$

$$\frac{1}{\sqrt{-g}}\left(\sqrt{-g}g^{\alpha\beta}\Phi_{,\alpha}\right)_{,\beta} - \mu^2\Phi = 0$$

$$\Phi = \exp(-\mathrm{i}\omega t)\psi(r)$$



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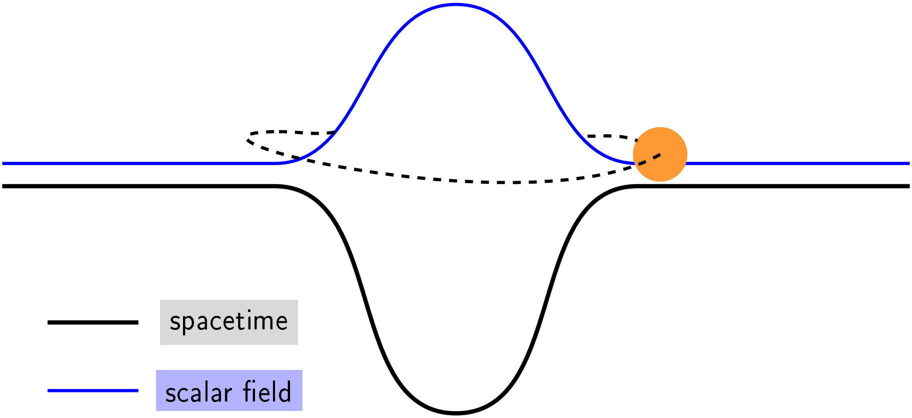
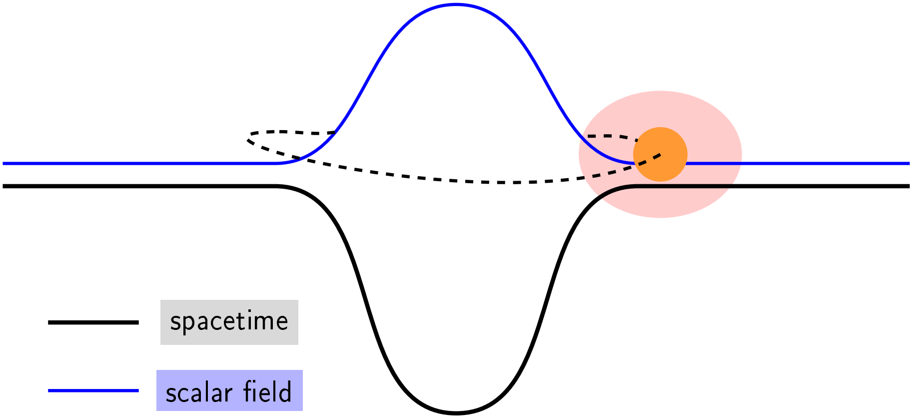
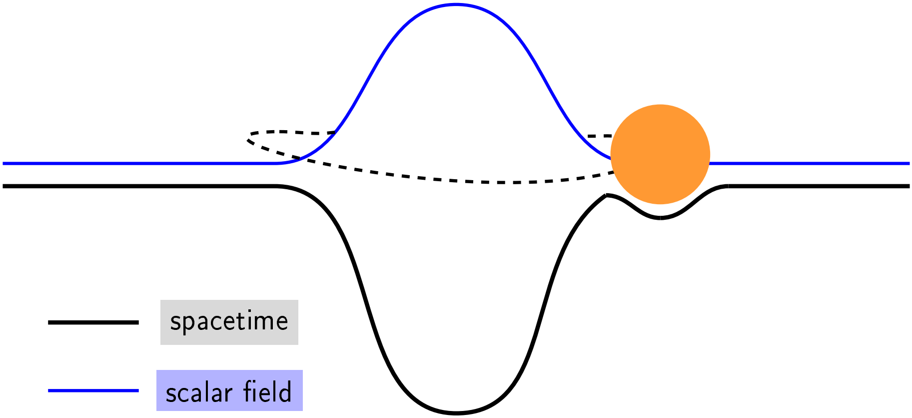
Backreaction of the field



Backreaction of the field



Backreaction of the field



The Newtonian limit: Schrodinger-Poisson equations

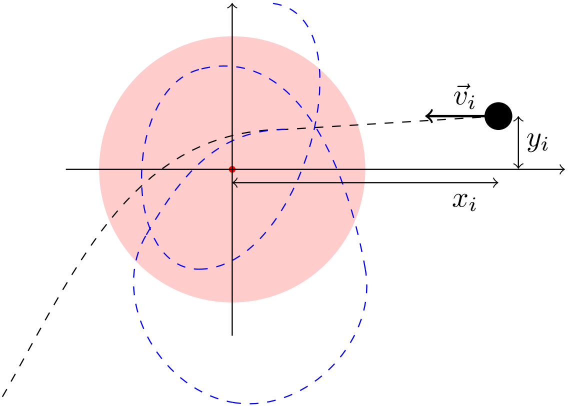
$$R_{\alpha\beta} - \frac{1}{2} R g_{\alpha\beta} = 8\pi G \left(T^S_{\alpha\beta} + T^P_{\alpha\beta} \right)$$

$$\frac{1}{\sqrt{-g}} \left(\sqrt{-g} g^{\alpha\beta} \Phi_{,\alpha} \right)_{,\beta} - m_s^2 \Phi = 0,$$

$$\Phi = \exp(-\mathrm{i} m_S t) \psi(t, \vec{x}), \quad \begin{cases} g_{00} \sim -1 + 2U \\ g_{0j} \sim 0 \\ g_{jk} \sim (1 + 2U) \delta_{jk} \end{cases}$$

$$\begin{cases} \mathrm{i}\partial_t \psi + \frac{1}{2m_S} \nabla^2 \psi + \frac{m_S}{\hbar} U \psi = 0 \\ \nabla^2 U = -4\pi \left(m_P \delta^{(3)}(x - x_P) + m_S^2 |\Phi|^2 \right) \end{cases}$$

Penetrating a weak-field boson star



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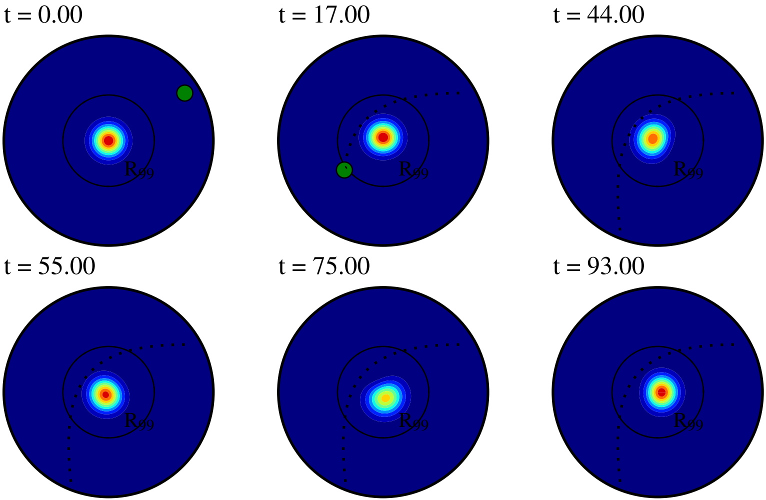

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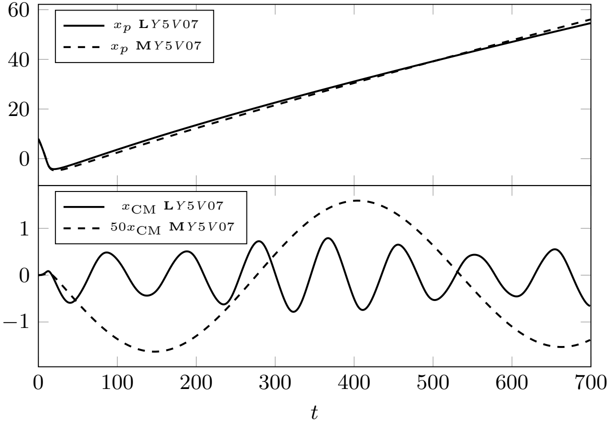
Rotating clumps of scalar field – center-of-mass

$$\vec{r}_{CM} = \frac{\int \rho_f(\vec{r})\vec{r}\mathrm{d}^3r}{\int \rho_f(\vec{r})\mathrm{d}^3r},$$



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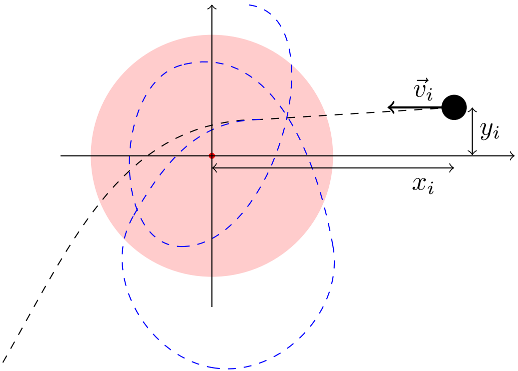
Gravitational friction



$$\vec{F}_{\mathsf{f}} = \vec{F}_{\mathsf{with}} - \vec{F}_{\mathsf{without}}$$

Gravitational friction

$$\vec{F}_{\mathsf{f}} = \vec{F}_{\mathsf{with}} - \vec{F}_{\mathsf{without}}$$

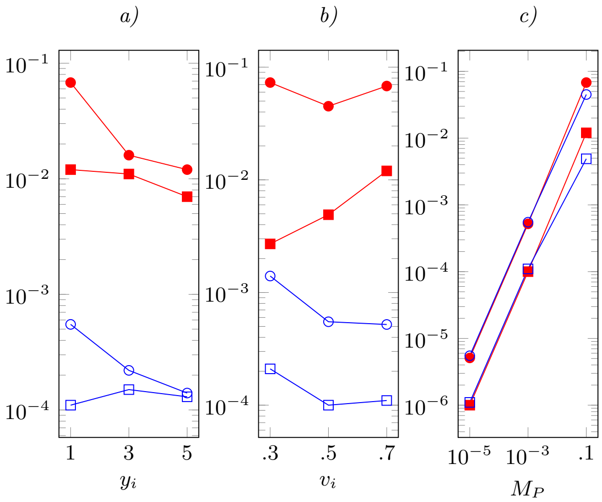
$$\frac{\vec{F}_{\mathsf{f}}}{m_P} \equiv \vec{f}_{\mathsf{f}}$$

$$\vec{f}_{\mathsf{f}} = \vec{a}_{\mathsf{with}} - \vec{a}_{\mathsf{without}}$$

$$\vec{a} = \left[\frac{d^2 r}{dt^2} - r\left(\frac{d\phi}{dt}\right)^2\right]\hat{r} + \left[r\frac{d^2\phi}{dt^2} + 2\frac{dr}{dt}\frac{d\phi}{dt}\right]\hat{\phi}v$$

Gravitational friction

$$-\langle f_{\mathsf{f}}^{r} \rangle \sim \alpha_r m_P, \quad -\left\langle f_{\mathsf{f}}^{\phi} \right\rangle \sim \alpha_\phi m_P,$$



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Final notes

1. Scalar field may be responsible for the development of structures of astrophysical relevance;
2. The scalar field structures react to the presence of the orbiting stars, developing long-lived rotating clumps;
3. The reaction of the scalar field to the presence of orbiting bodies gives rise to a friction force that is proportional to the square of the body's mass.

Thanks for the attention!