

# Polarized solitons in higher-spin dark matter

*Mudit Jain*

Based on

[arXiv:2109.04892](#), w/ Amin

[arXiv:2111.08700](#), w/ Amin, Zhang

[arXiv:2203.11935](#), w/ Amin, Karur, and Mocz

[arXiv:2205.03418](#) fresh from the oven



PHENO 2022



# dark matter mass ?

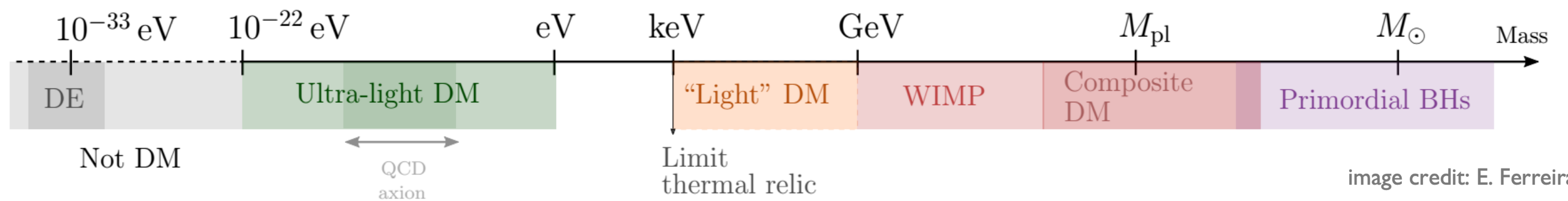
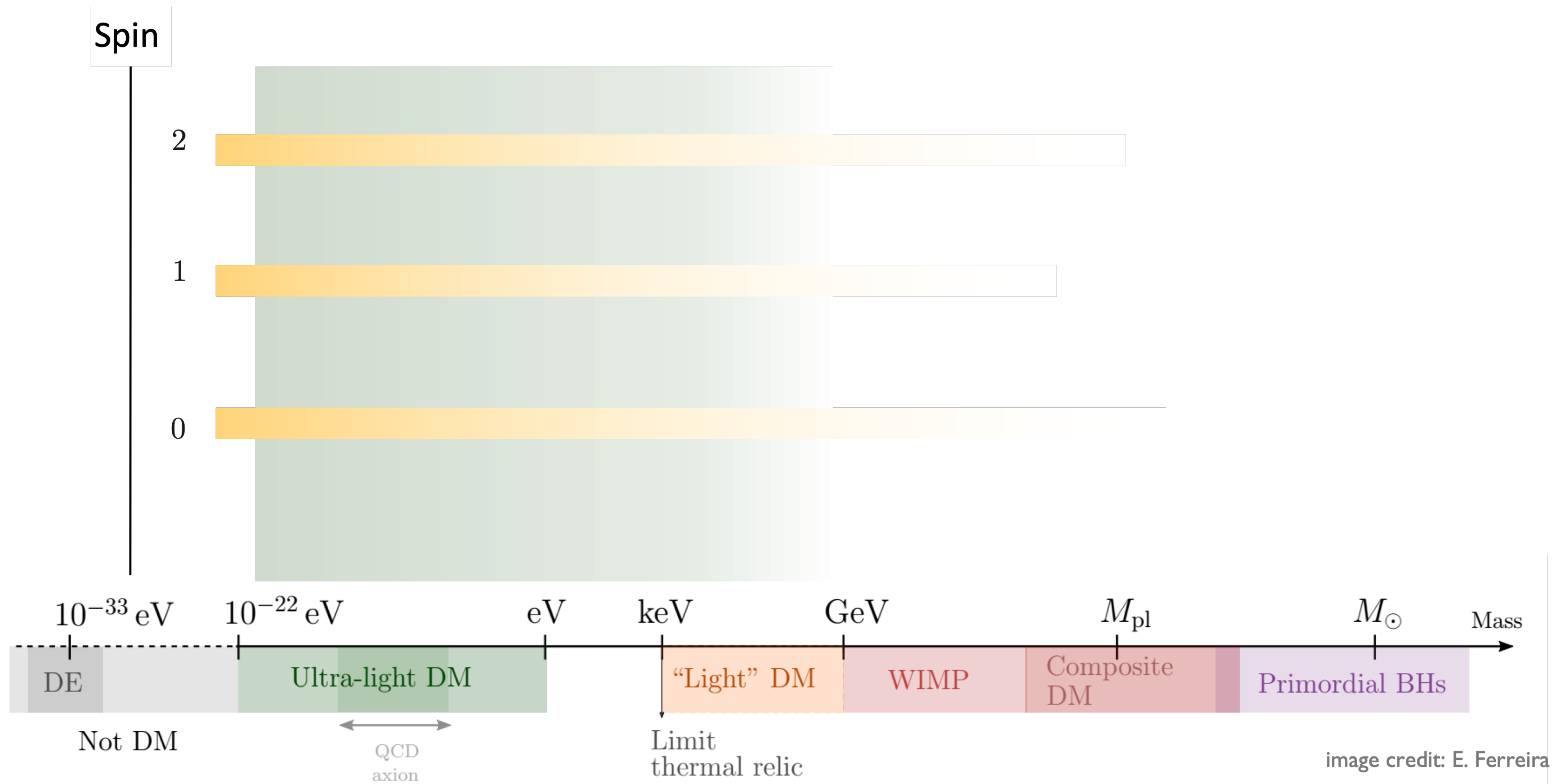


image credit: E. Ferreira

dark matter mass ?

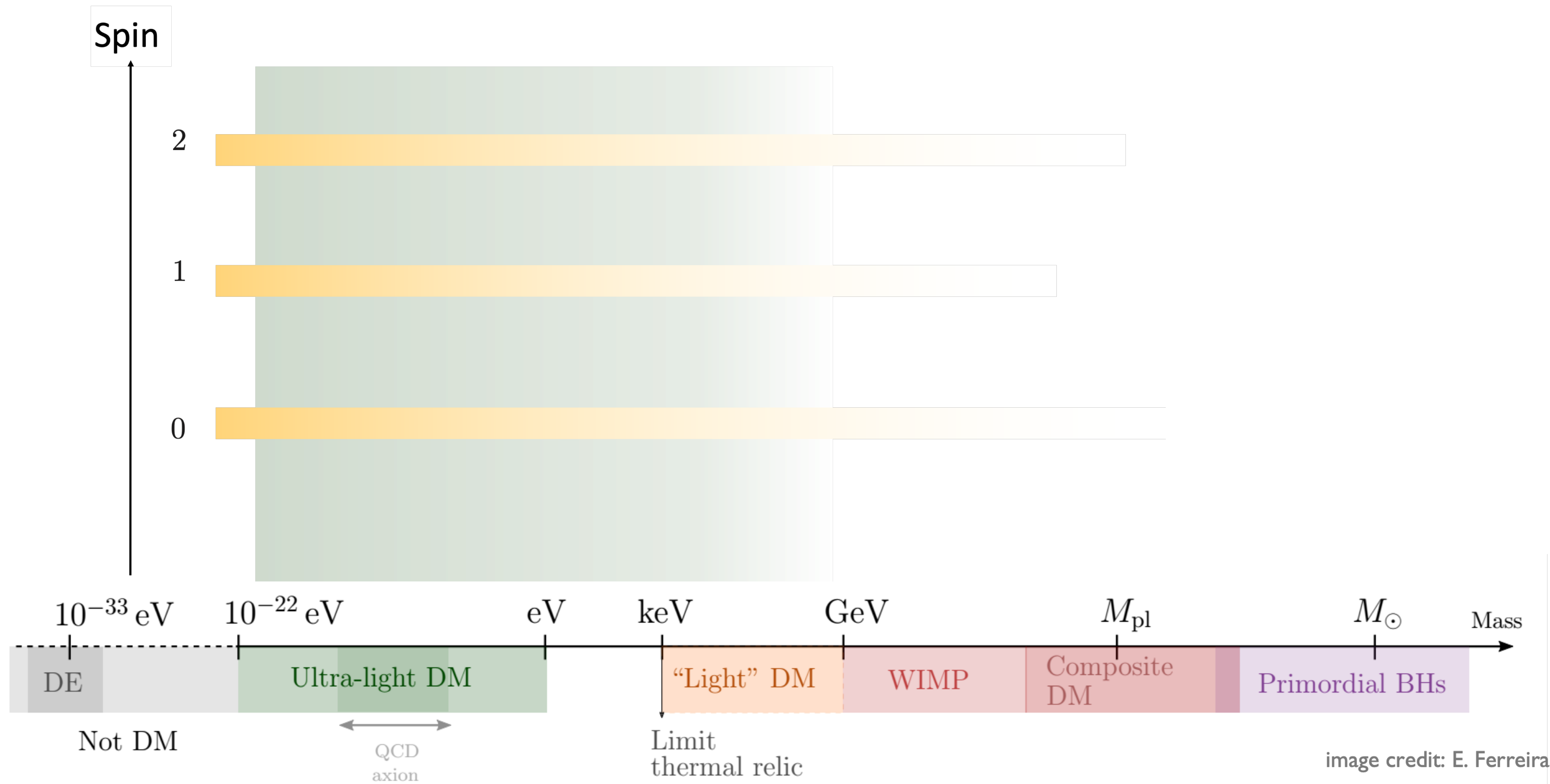
spin ?



dark matter mass ?

spin ?

self-interactions ?



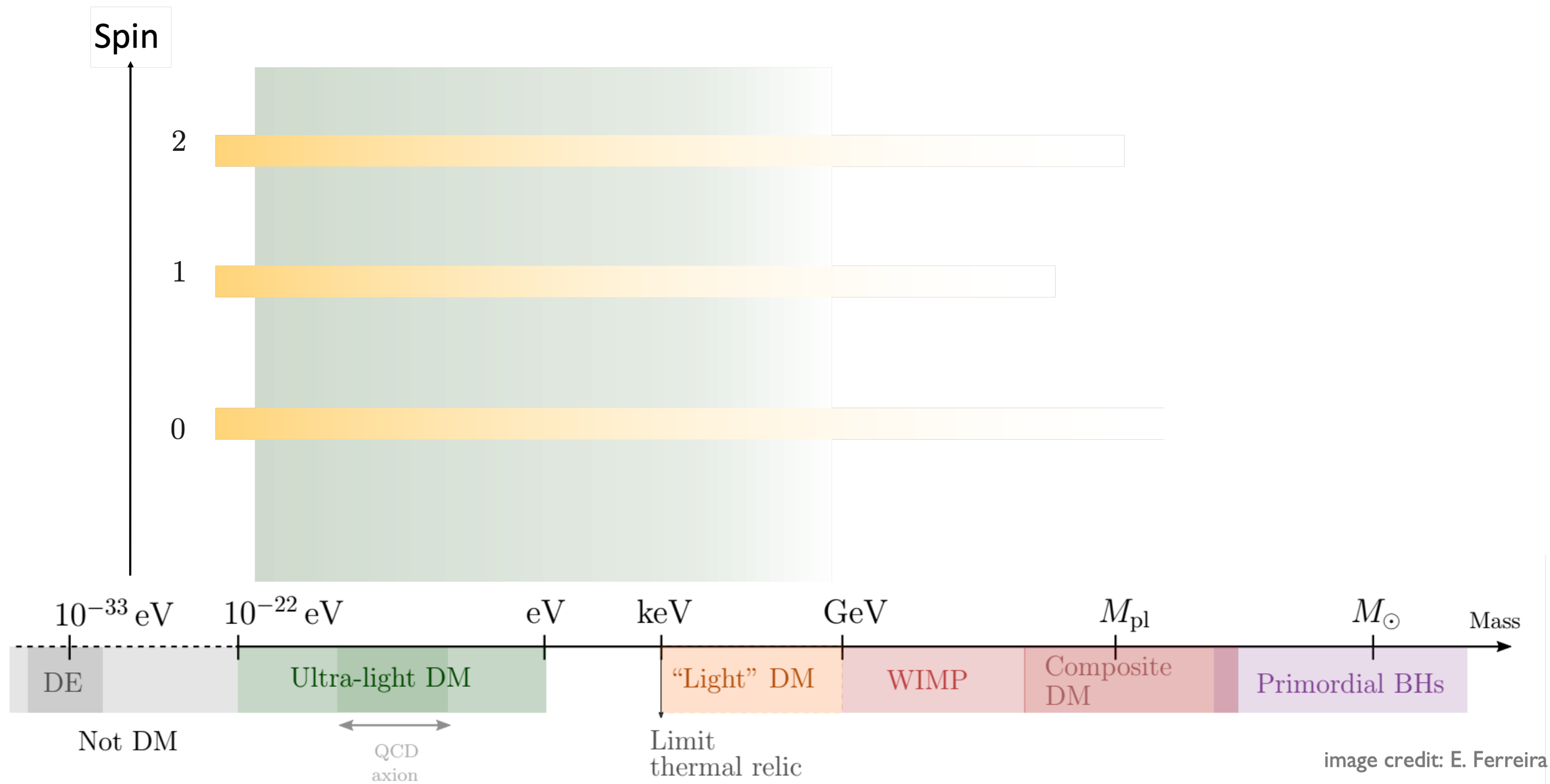


dark matter mass ?

spin ?

self-interactions ?

huge dark sector ?

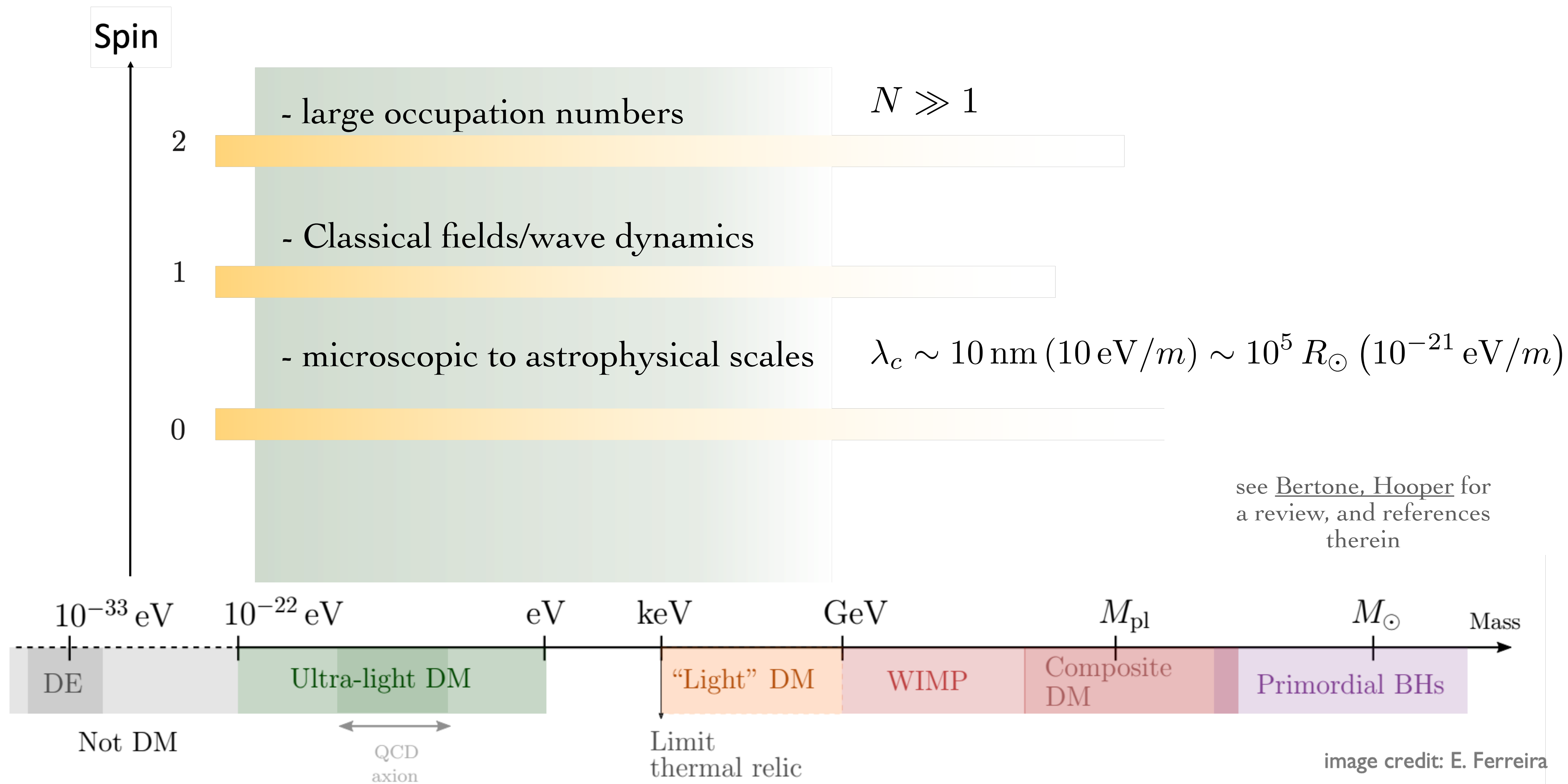


dark matter mass ?

spin ?

self-interactions ?

huge dark sector ?



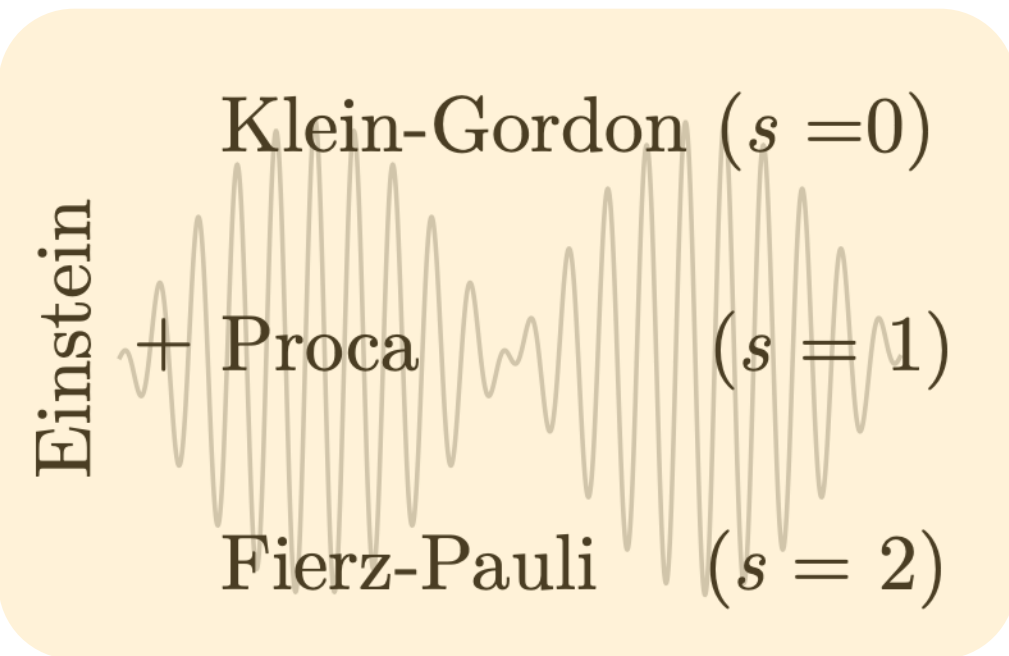
# (non-topological) soliton

long lived, coherent states of a field, formed due to a balance between nonlinearities and/or dispersion



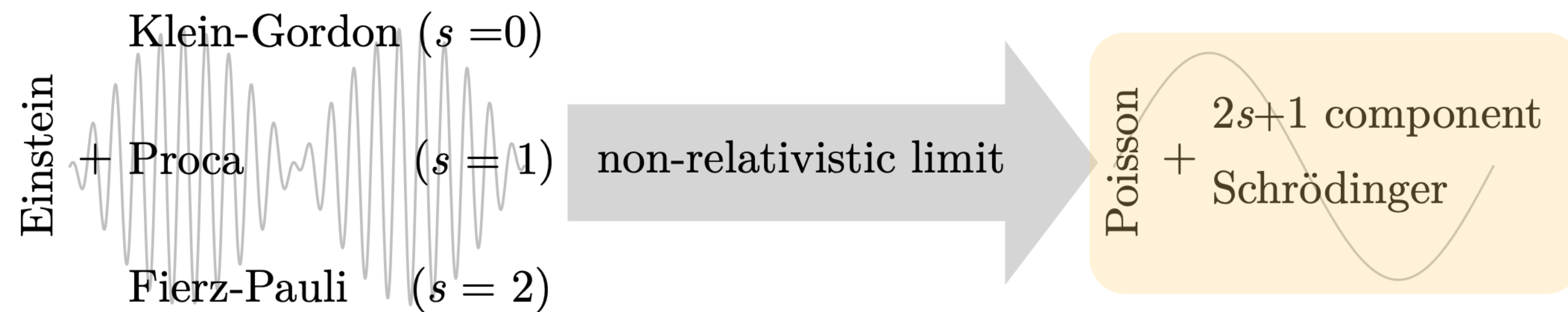
- discovered in nonlinear waves in water in canals (John Scott Russell, 1834)
- optics, hydrodynamics, BECs, high energy physics, and cosmology

# spin- $s$ field as dark matter



# non-relativistic limit = multicomponent Schrödinger-Poisson

spin- $s$  fields as dark matter



scale separation  
- phenomenology/numerical simulations

# extremally polarized solitons

(focus on lowest energy states, no orbital angular momentum)

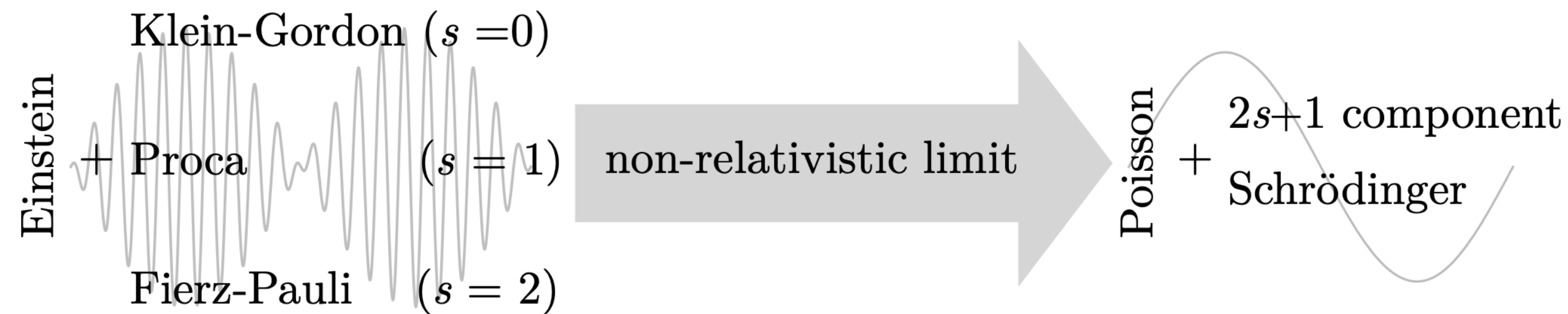
2109.04892

$$i \frac{\partial}{\partial t} \Psi = -\frac{1}{2m} \nabla^2 \Psi + m \Phi \Psi$$

$$\nabla^2 \Phi = \frac{m}{2m_{\text{pl}}^2} \text{Tr}[\Psi^\dagger \Psi].$$

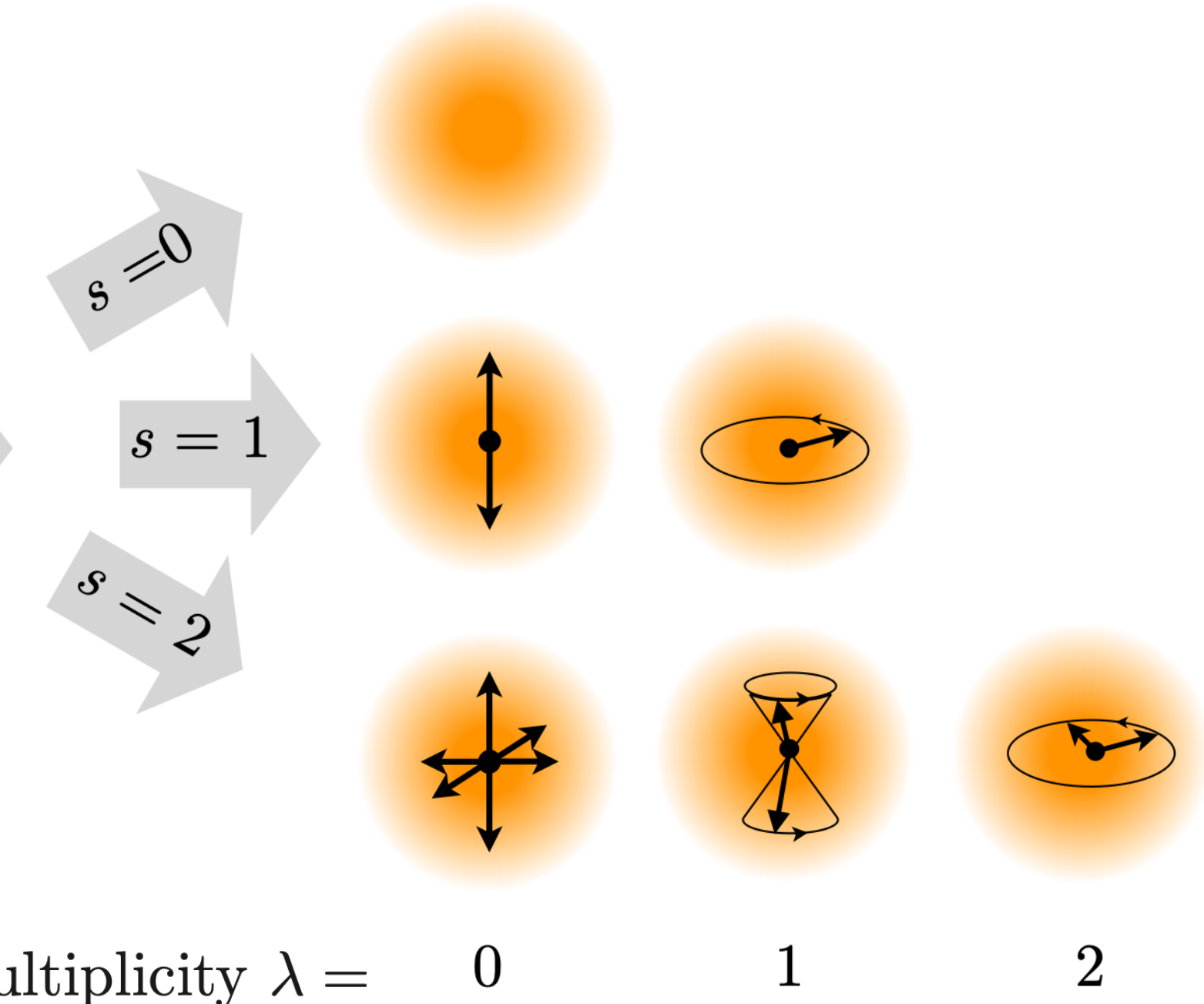
extension to FRW:  $\partial_t \rightarrow \partial_t + 3H/2, \nabla \rightarrow \nabla/a$

spin-s fields as dark matter



## Macroscopic/Astrophysical intrinsic spin

Degenerate; can form infinitely many partially polarized solitons



scale separation  
- phenomenology/numerical simulations

macroscopic spin  $\mathbf{S}_{\text{tot}}/\hbar = \lambda N \hat{z}$   
N = # of particles in soliton



# extremally polarized solitons

(focus on lowest energy states, no orbital angular momentum)

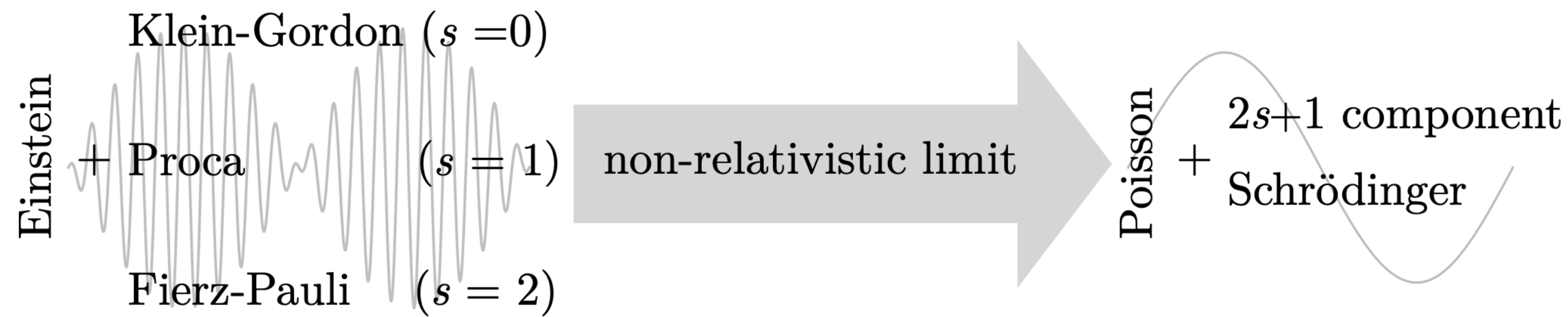
2111.08700    2205.03418

$$i \frac{\partial}{\partial t} \Psi = -\frac{1}{2m} \nabla^2 \Psi + m \Phi \Psi + \partial_{\Psi^\dagger} V_{\text{self}}$$

$$\nabla^2 \Phi = \frac{m}{2m_{\text{pl}}^2} \text{Tr}[\Psi^\dagger \Psi].$$

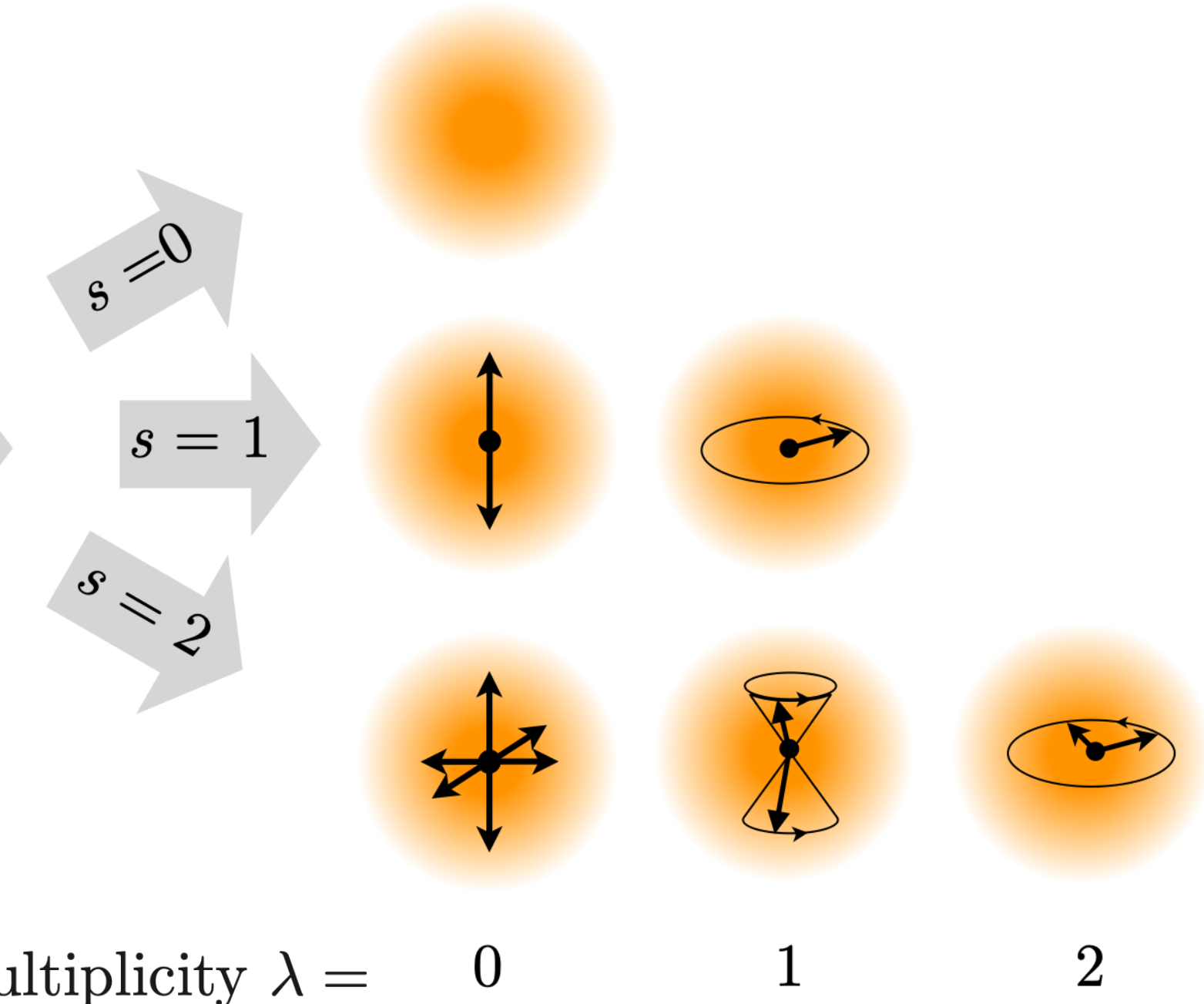
extension to FRW:  $\partial_t \rightarrow \partial_t + 3H/2$ ,  $\nabla \rightarrow \nabla/a$

spin-s fields as dark matter



Macroscopic/Astrophysical intrinsic spin

~~Degenerate; can form infinitely many partially polarized solitons~~

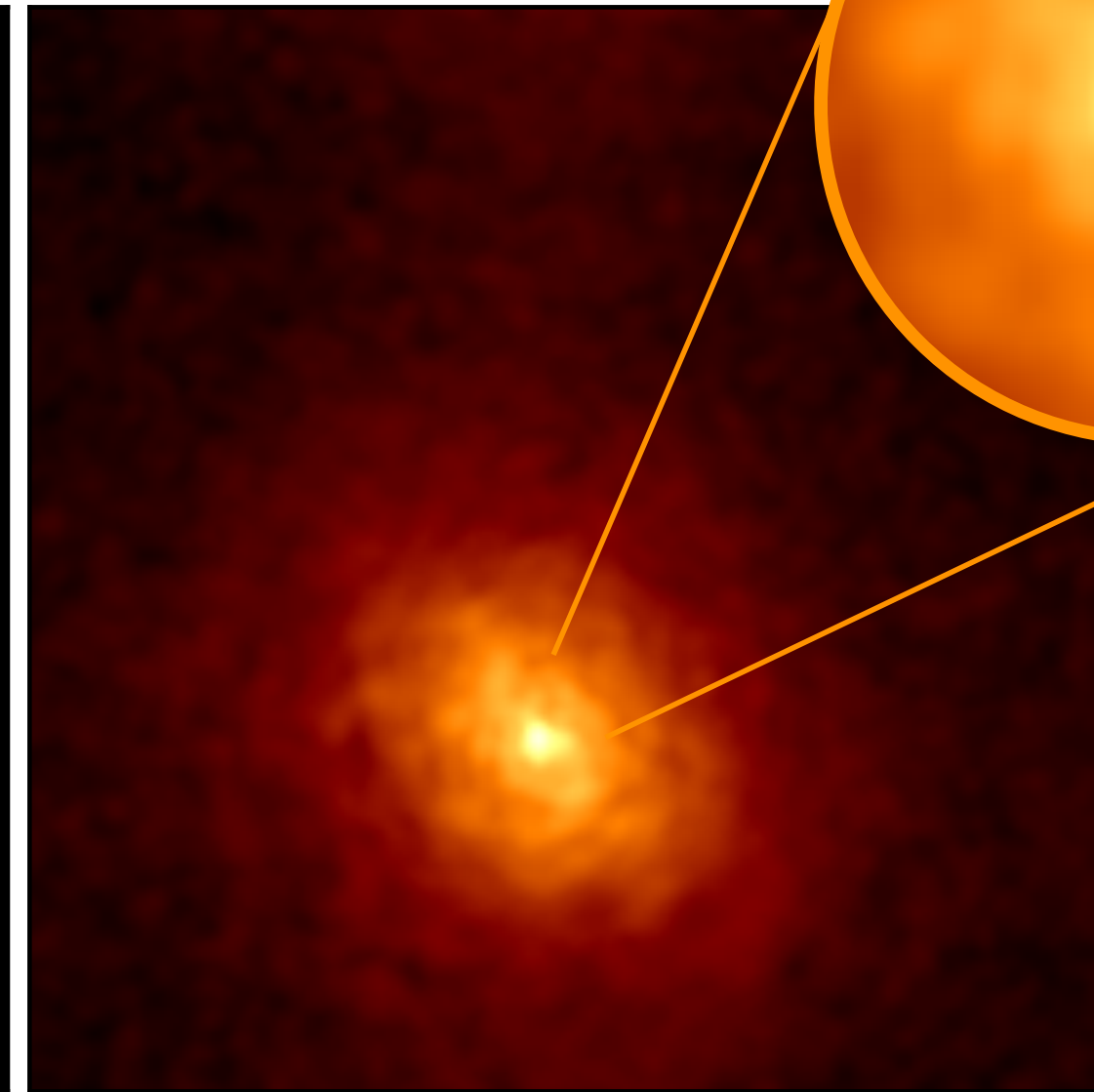
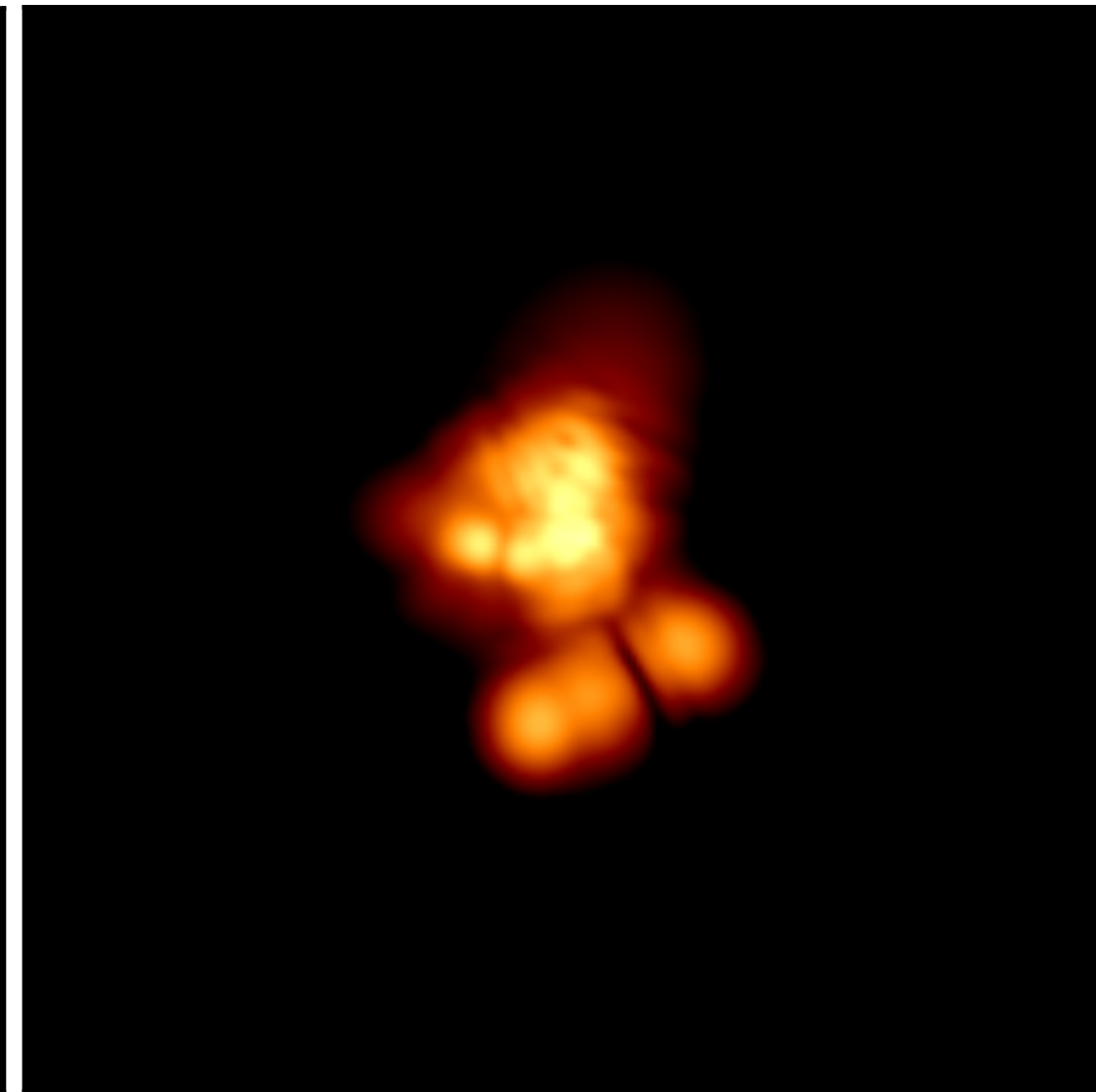
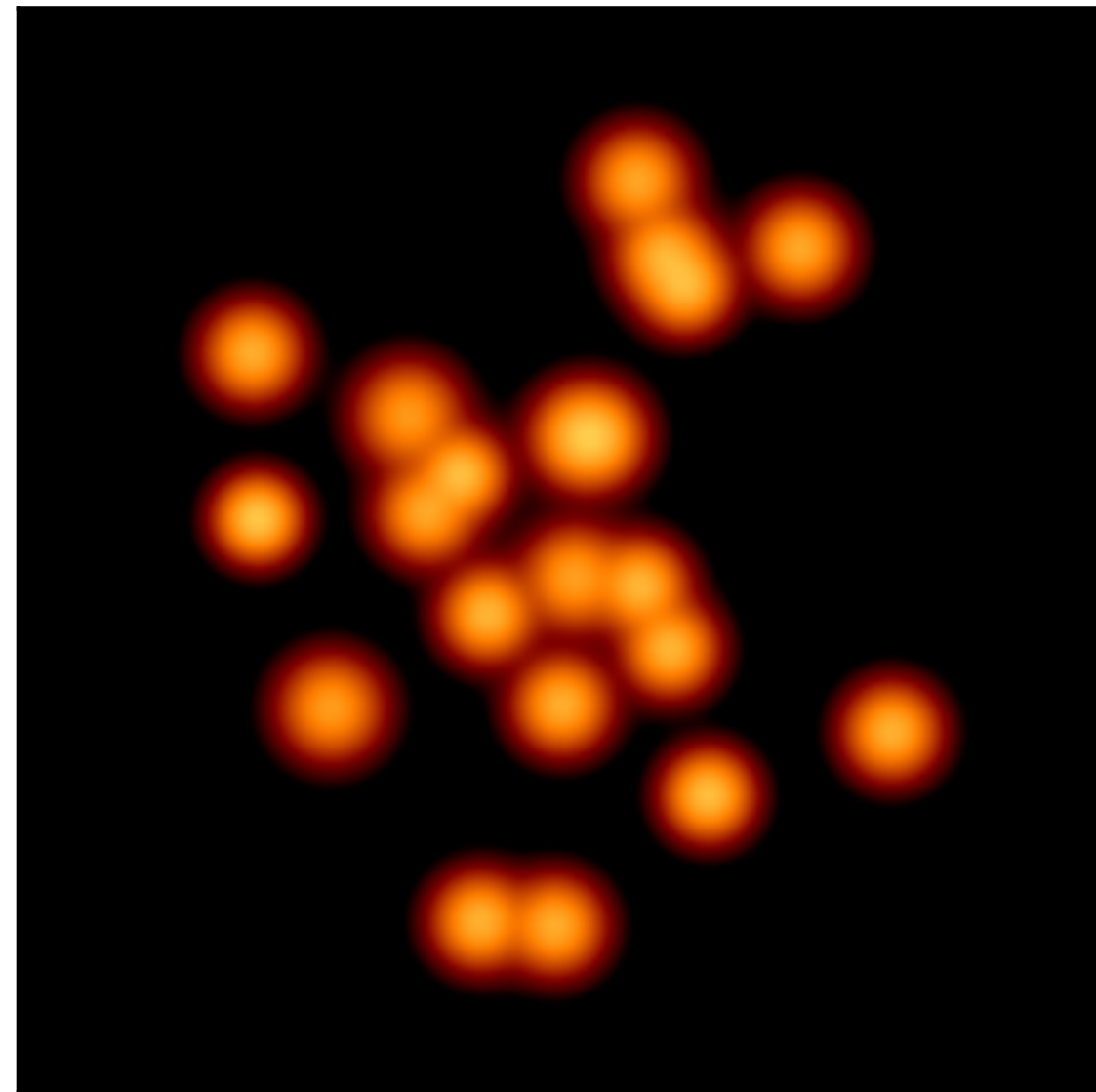


scale separation  
- phenomenology/numerical simulations

macroscopic spin  $S_{\text{tot}}/\hbar = \lambda N \hat{z}$   
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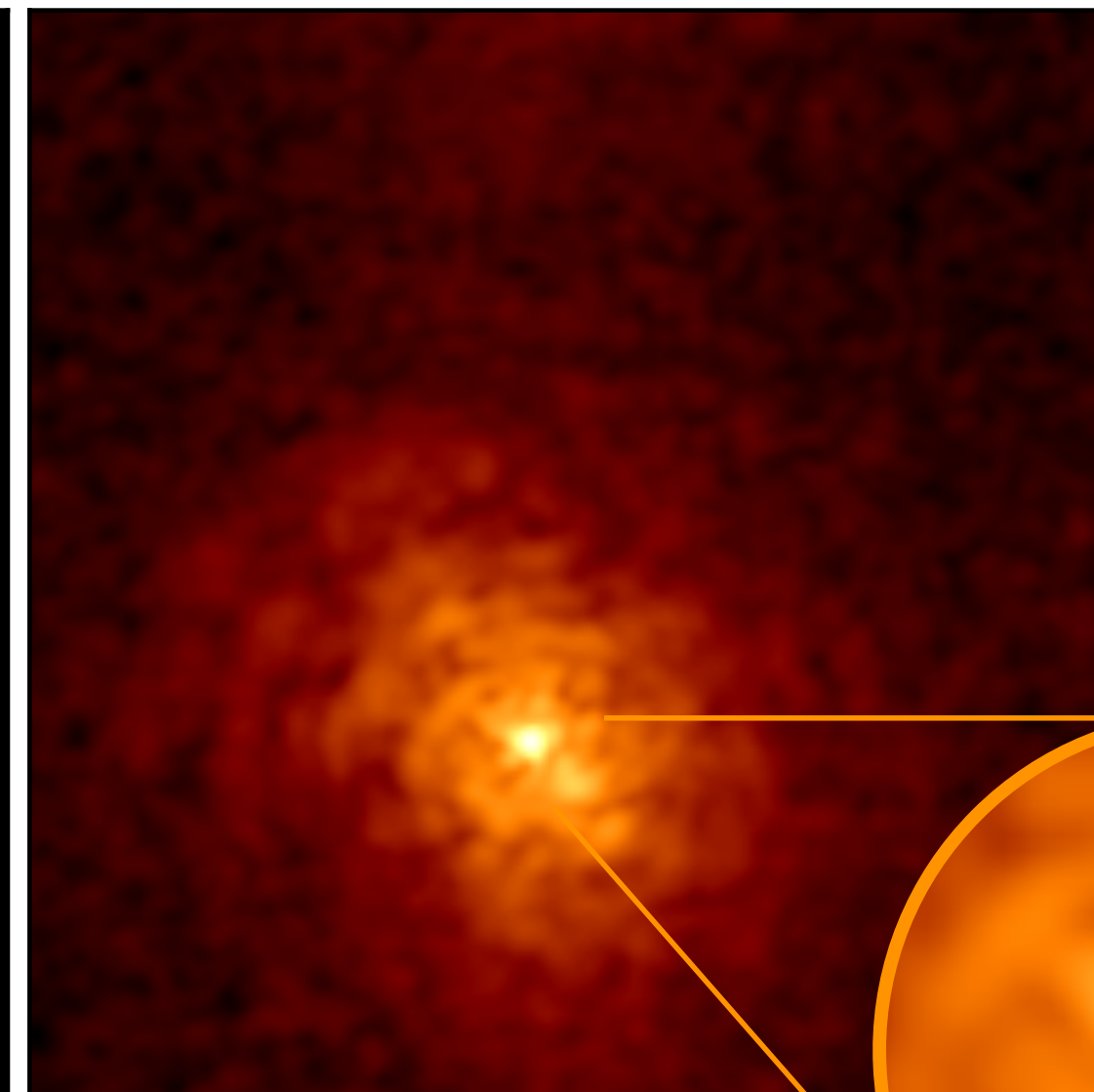
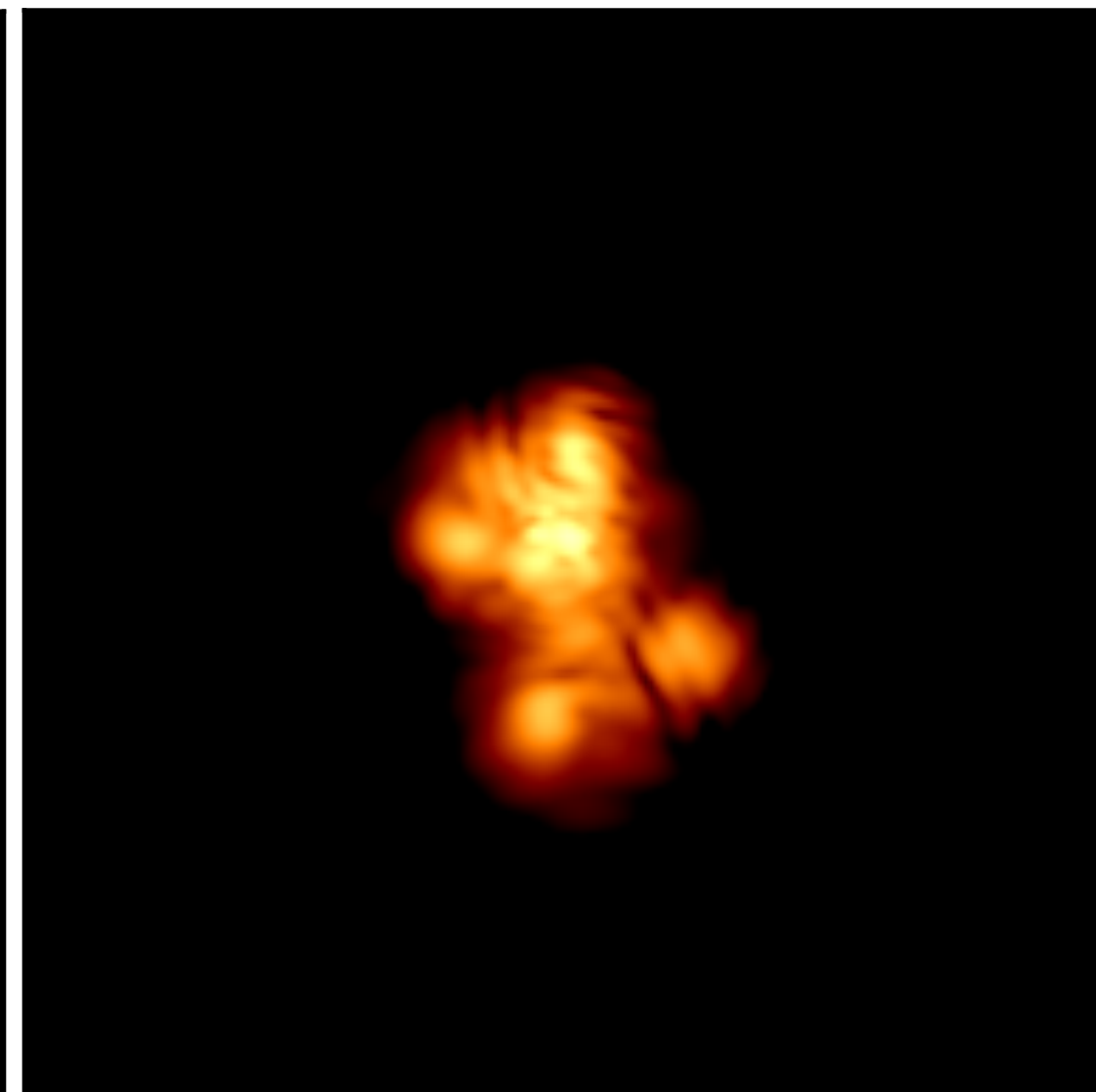
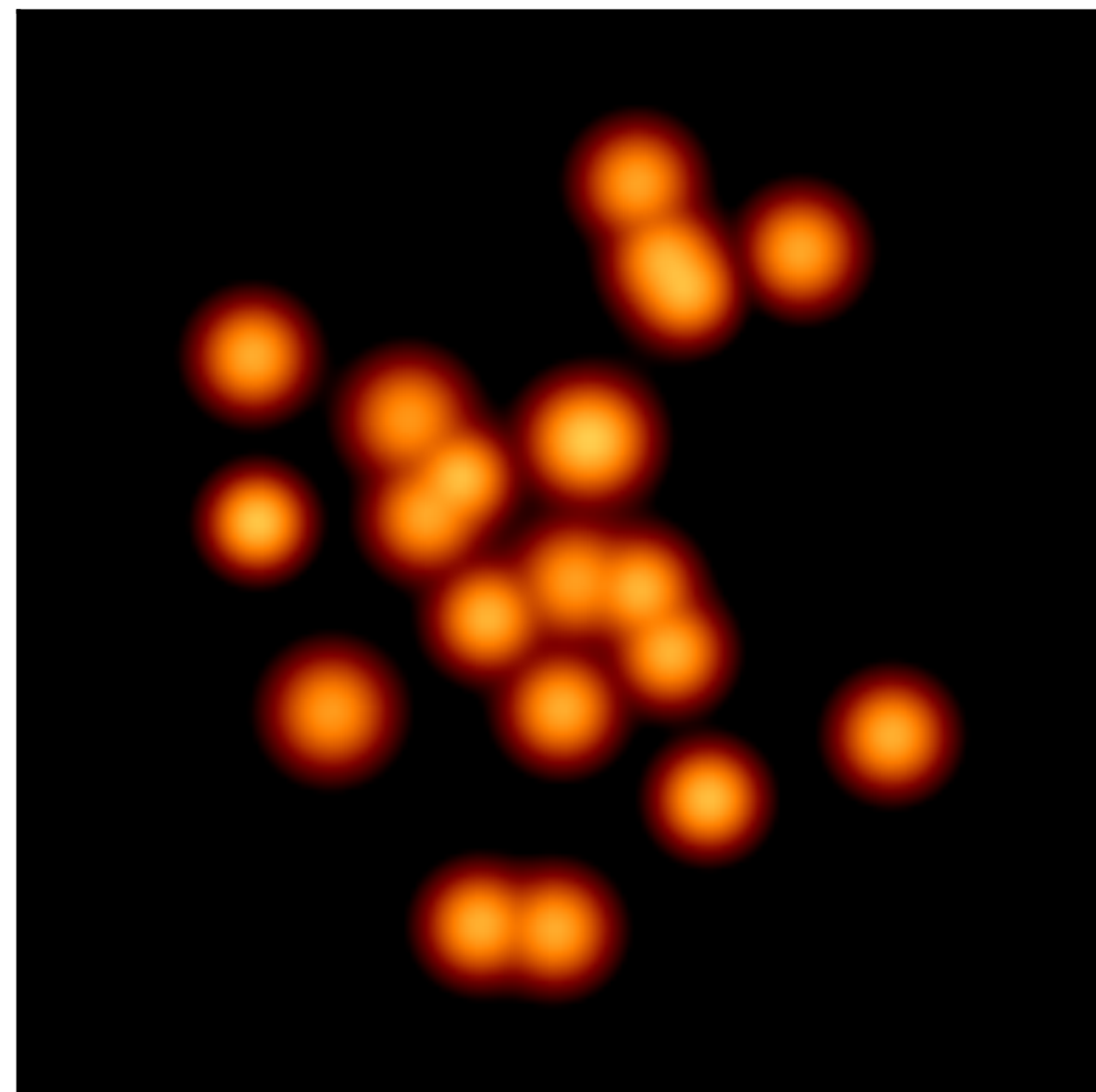


VDM



- less interference in VDM
- less dense granules in VDM
- VDM Halo cores can have huge spin

SDM



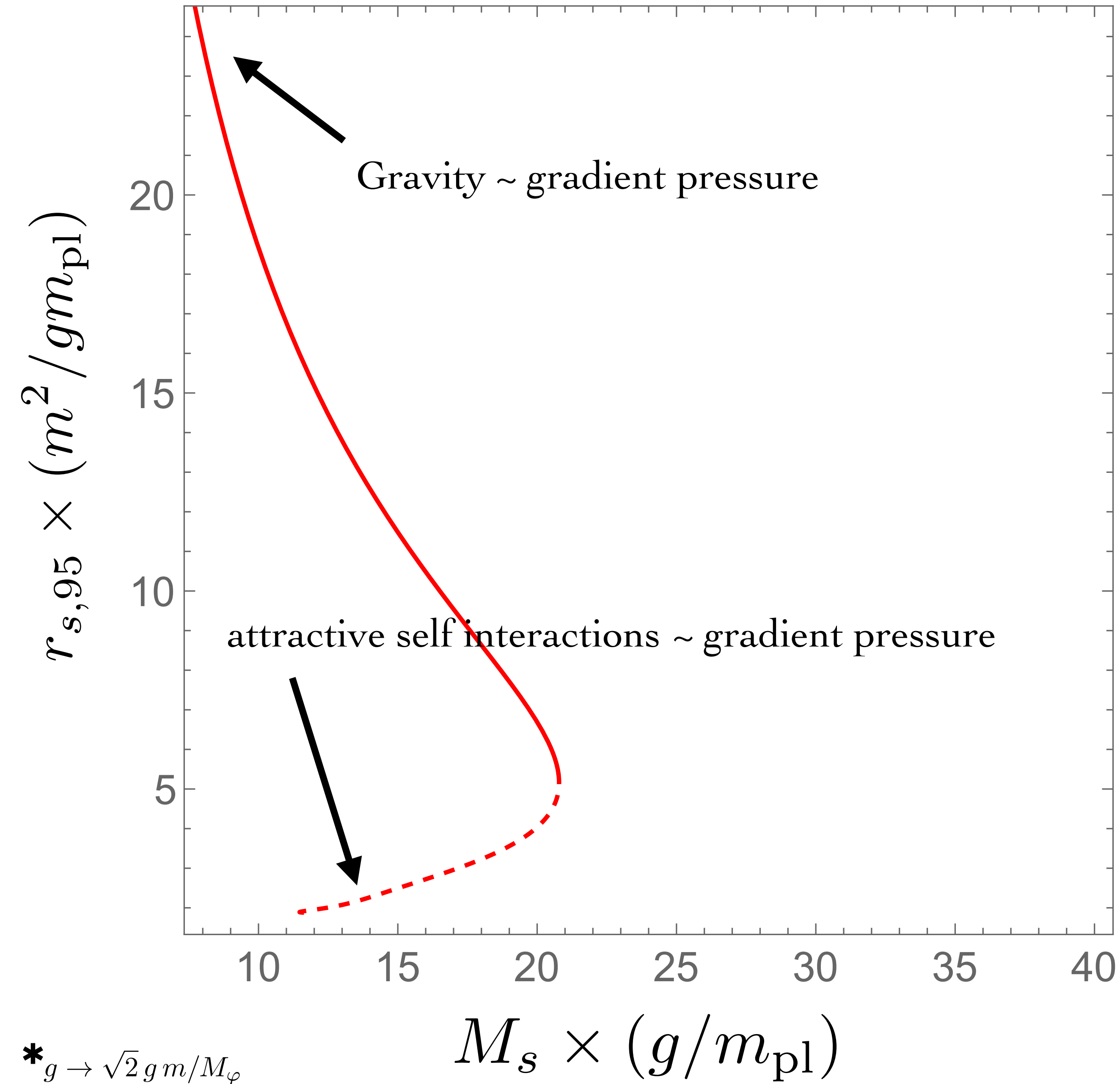
0

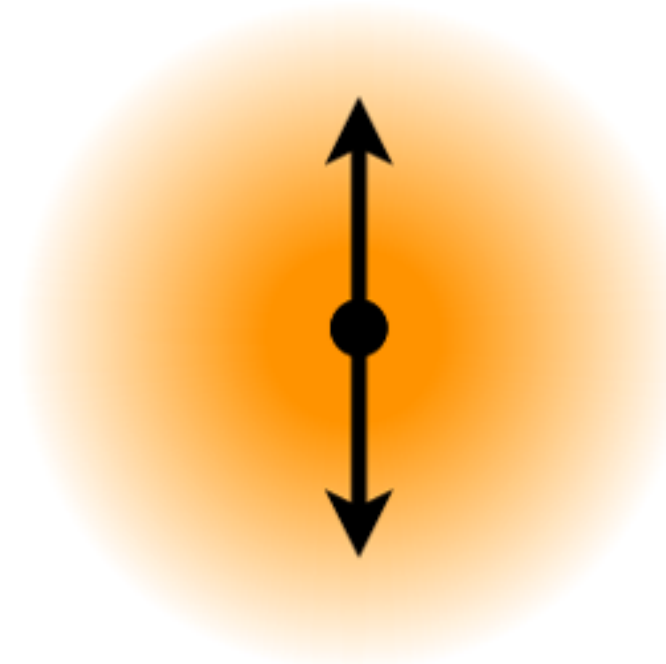
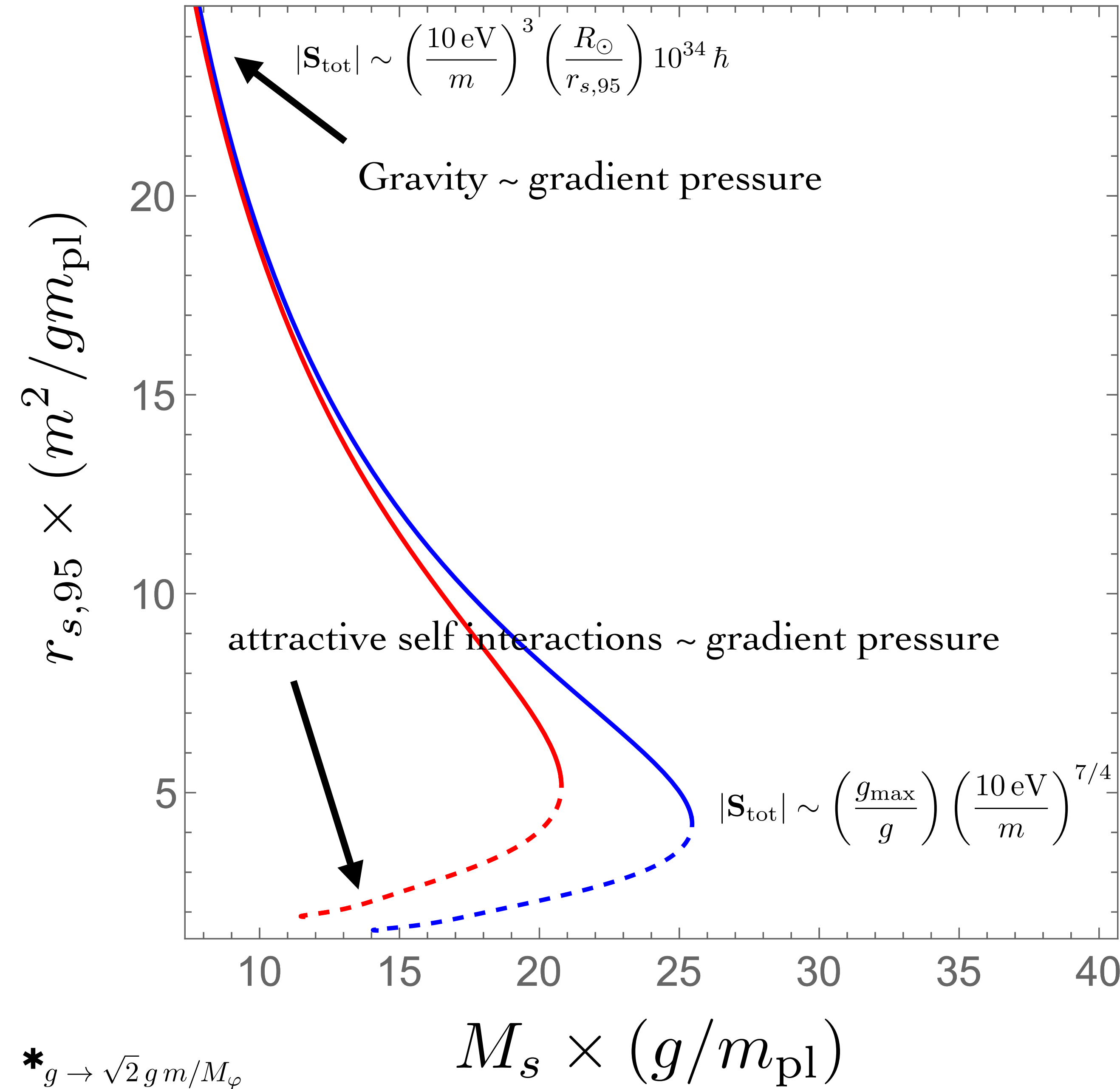
0.34

1.36

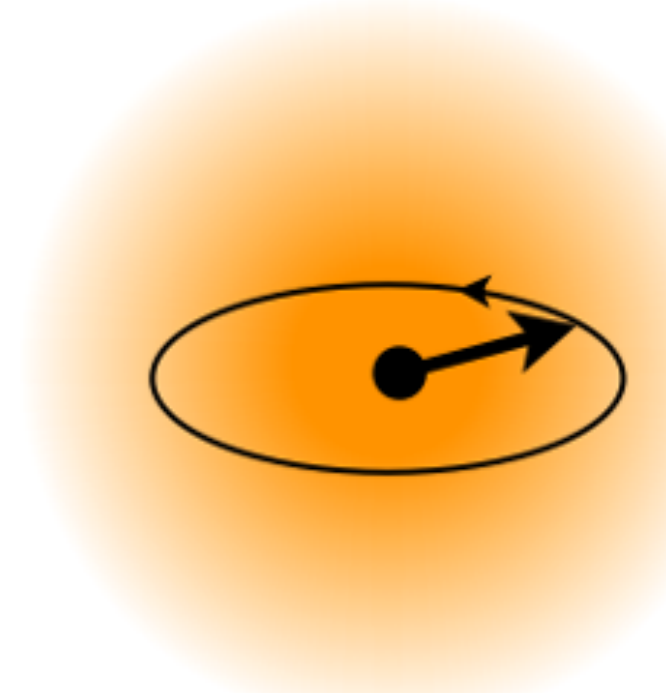
$t/t_{\text{dyn}} \longrightarrow$

- also see [Gorghetto et al](#)





Linearly polarized

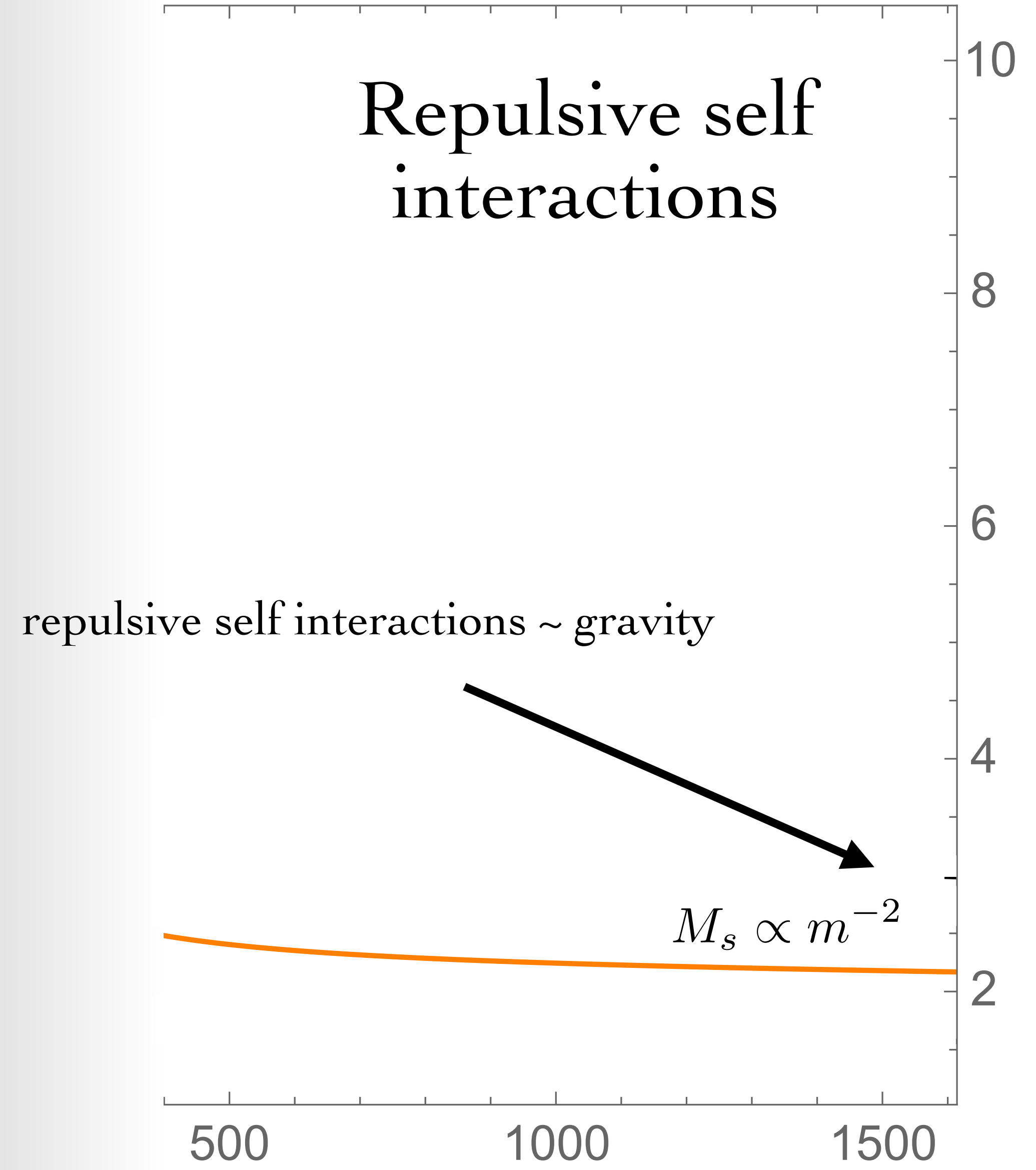
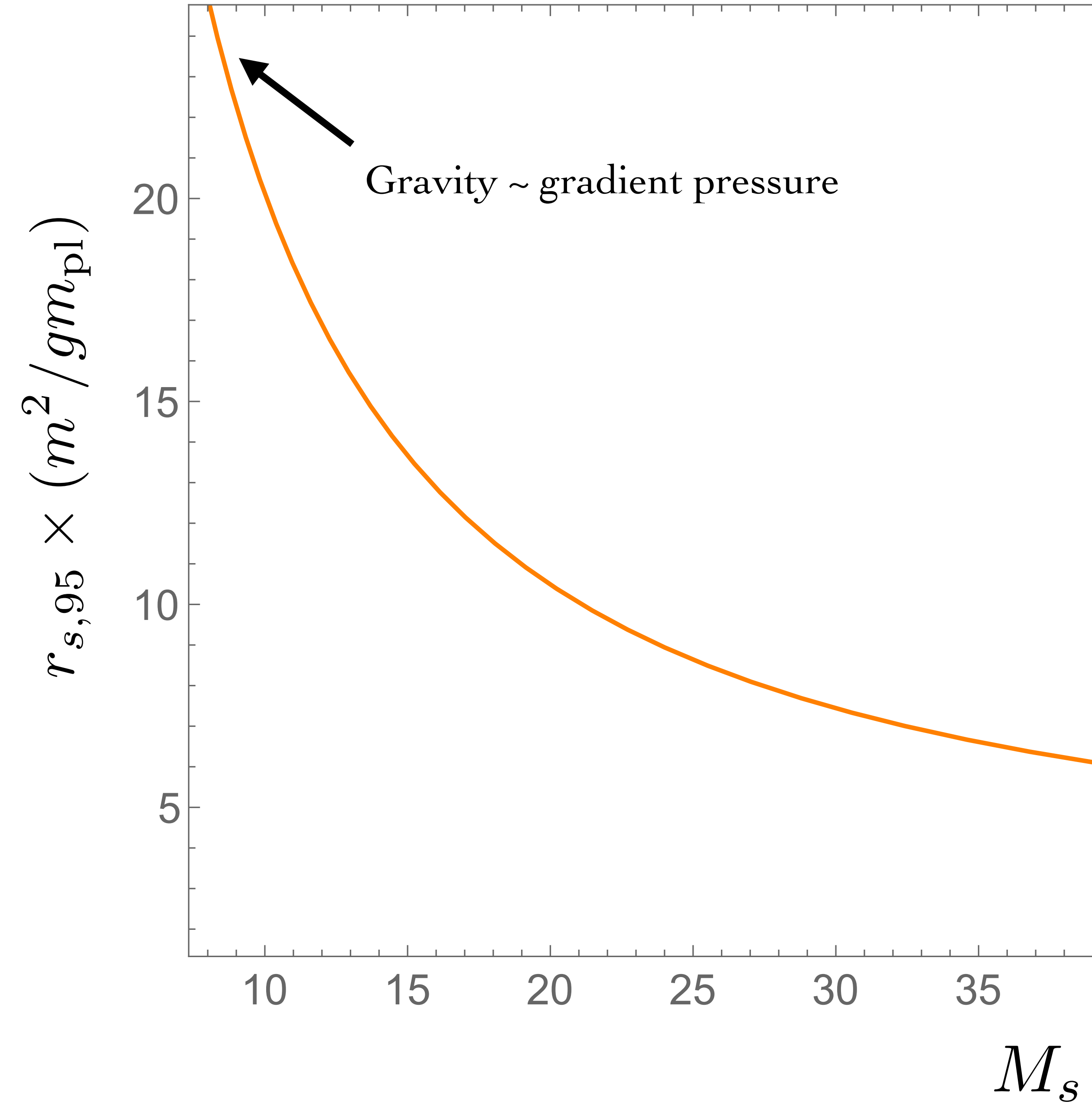


Circularly polarized

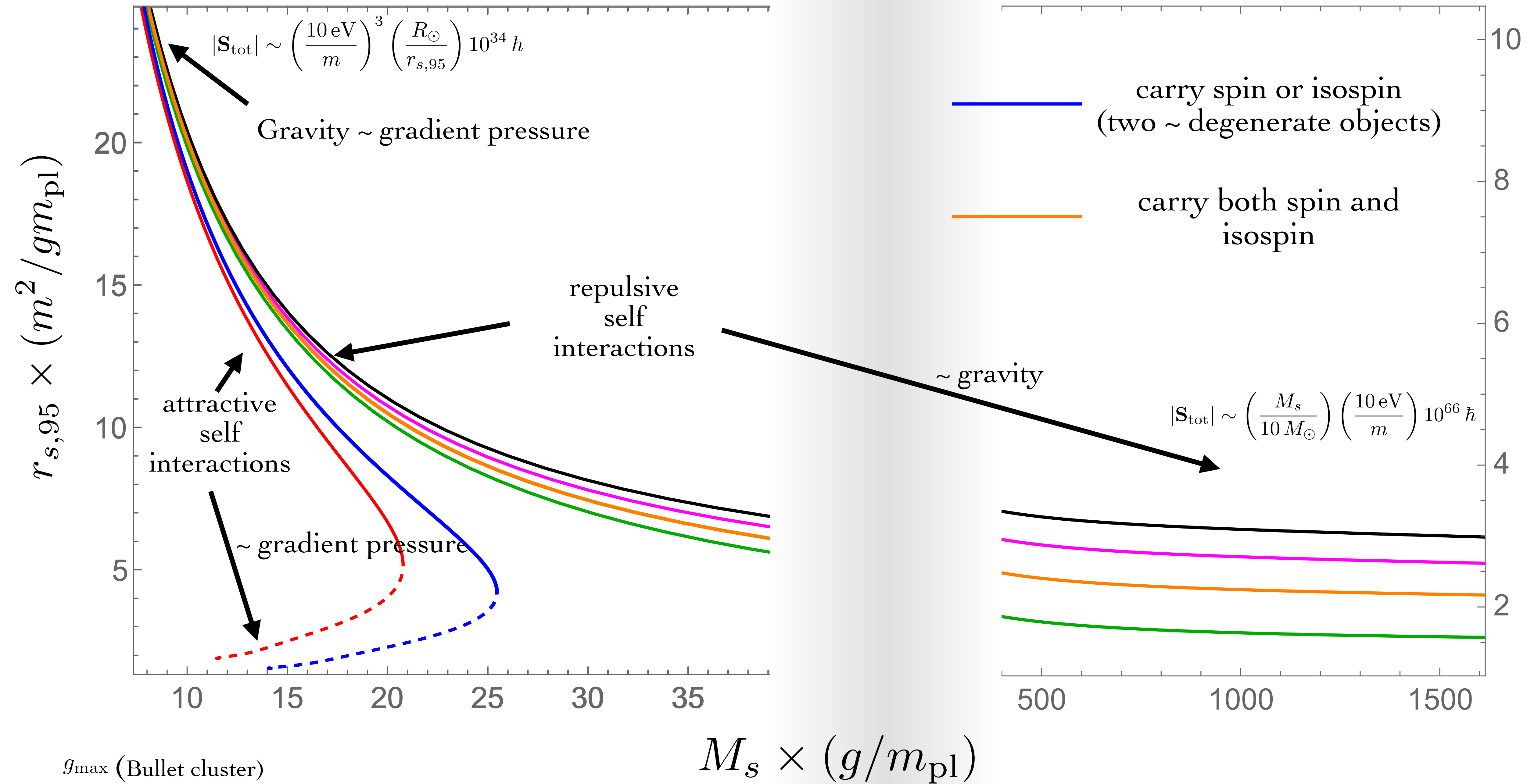
$g_{\text{max}}$  (Bullet cluster)

\* $g \rightarrow \sqrt{2} g m / M_{\phi}$

see [2111.08700](#) for vector Oscillons (w/o gravity)



# Higgsed SU(2) Yang-Mills, heavy Higgs



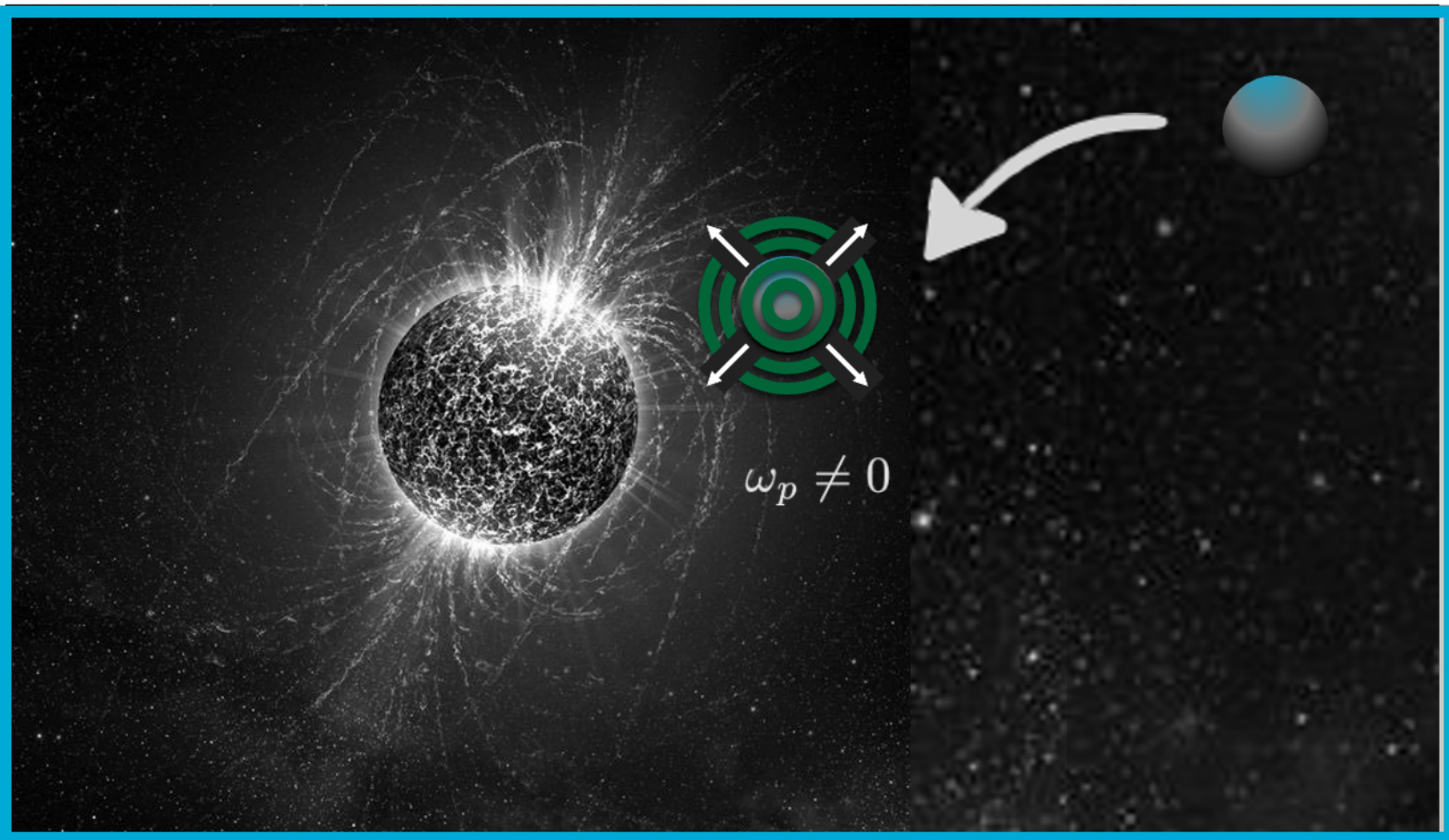
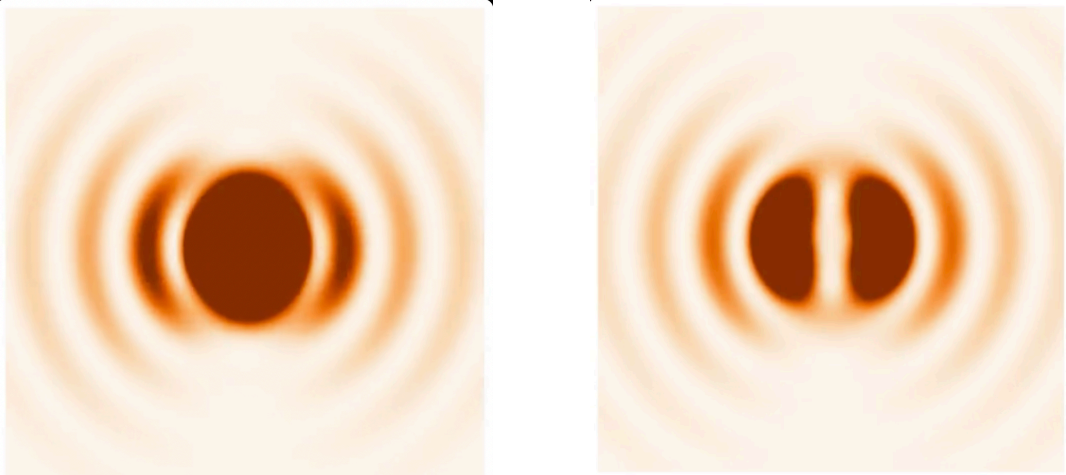


# SM coupling and radiation

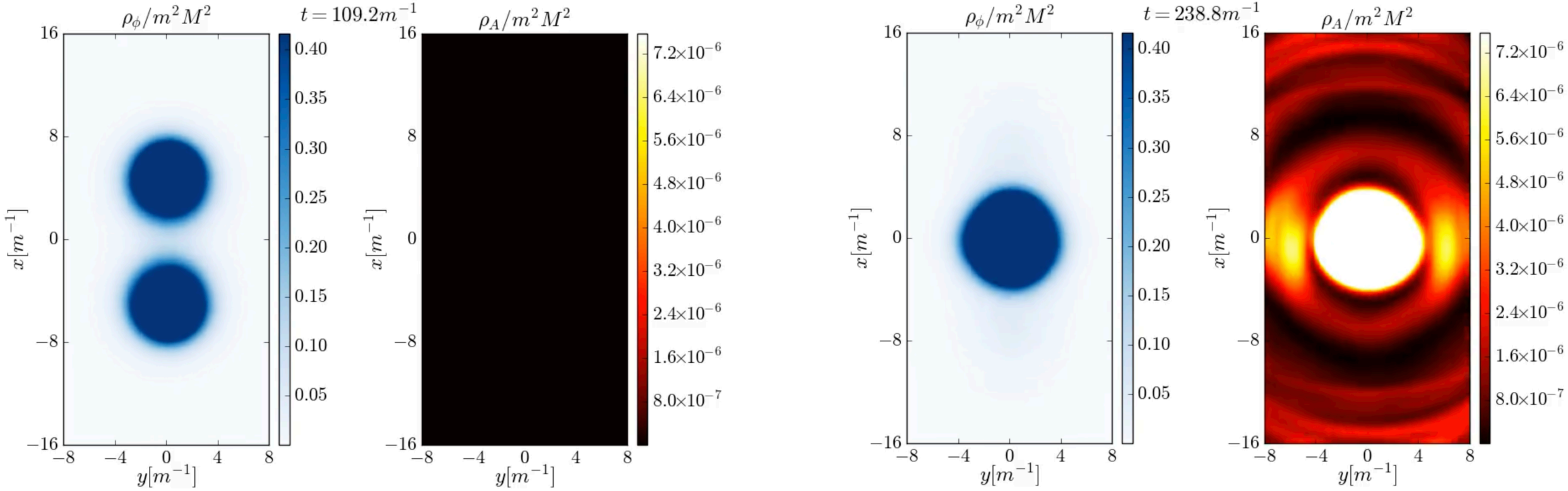
electromagnetic coupling and radiation ( axion + photons )

$$\mathcal{L}_{int} \sim g_{\phi\gamma}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

“Searching for axions at Magnetic White Dwarfs”  
(yesterday) - [Dessert et al](#)



- [Amin et al](#)



- [Amin et al](#)



# SM coupling and radiation

electromagnetic coupling and radiation

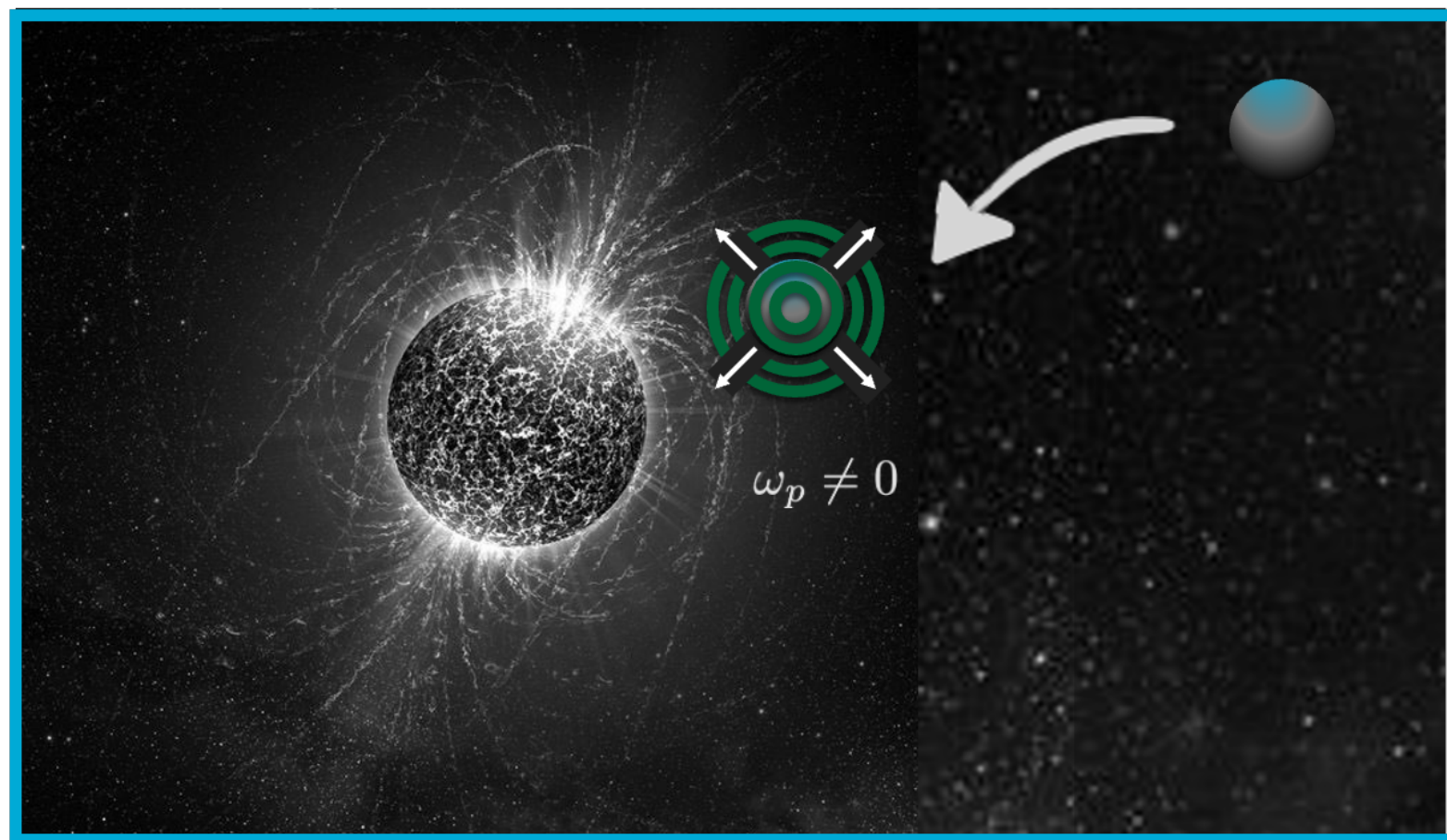
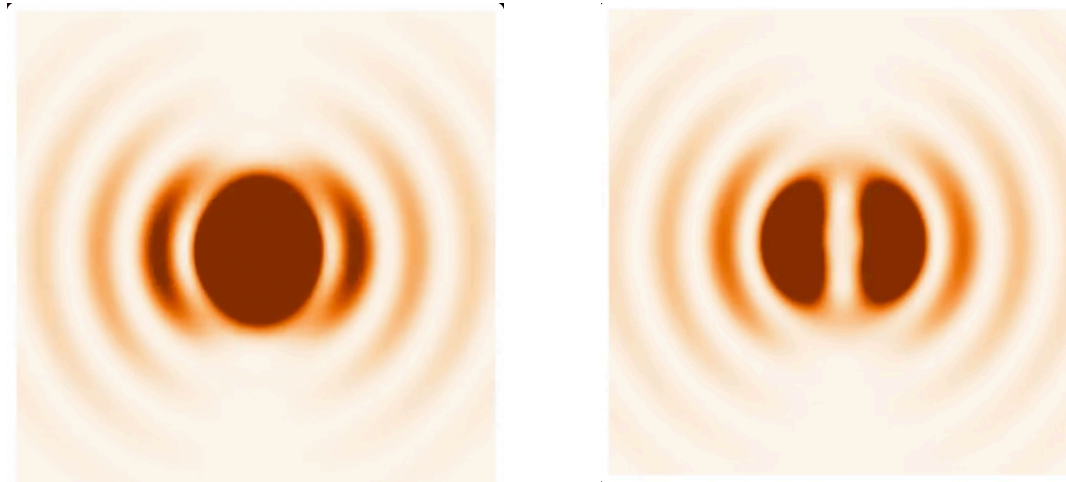
$$\mathcal{L}_{int} \sim g_{\phi\gamma} \phi F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$\mathcal{L}_{int} \sim \begin{cases} g_{W\gamma}^2 W_\mu W^\mu F_{\alpha\beta} \tilde{F}^{\alpha\beta} & \text{spin-1} \\ g_{H\gamma}^2 (H_{\mu\nu} H^{\mu\nu} - H^2) F_{\alpha\beta} \tilde{F}^{\alpha\beta} & \text{spin-2} \end{cases}$$

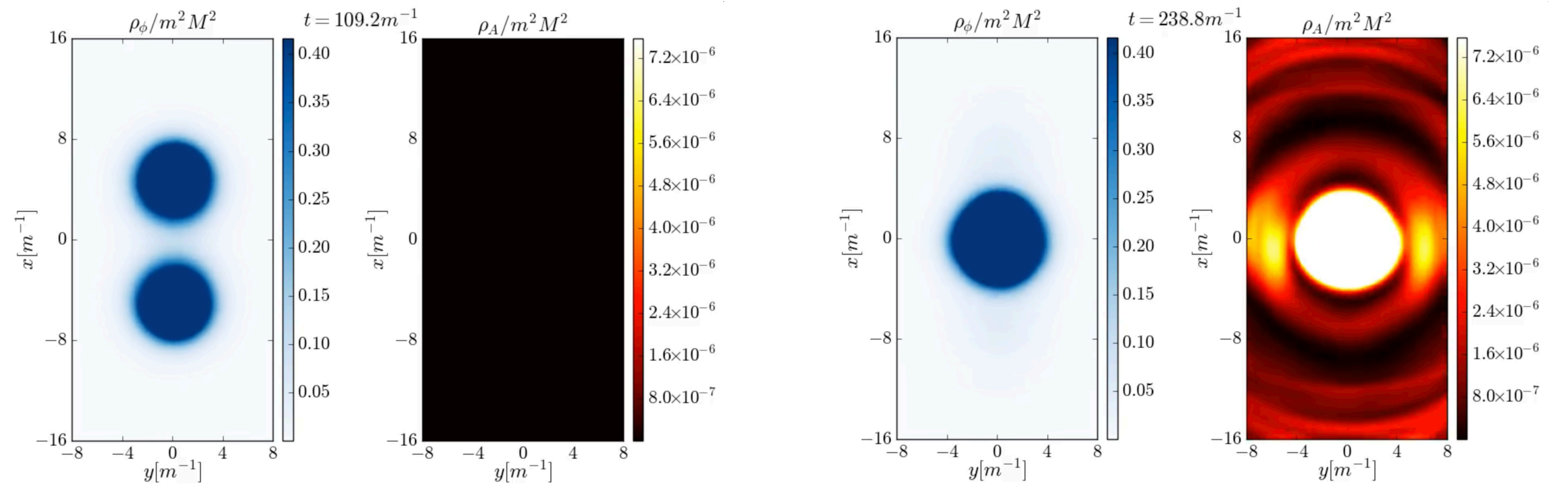
$$\sim g_{\mathcal{F}\gamma}^2 \text{Tr}[\mathcal{F}\mathcal{F}] F_{\alpha\beta} \tilde{F}^{\alpha\beta} \quad \text{NR limit}$$

$$\mathcal{L}_{int} \sim \lambda_{\varphi h} H^\dagger H \Phi^\dagger \Phi$$

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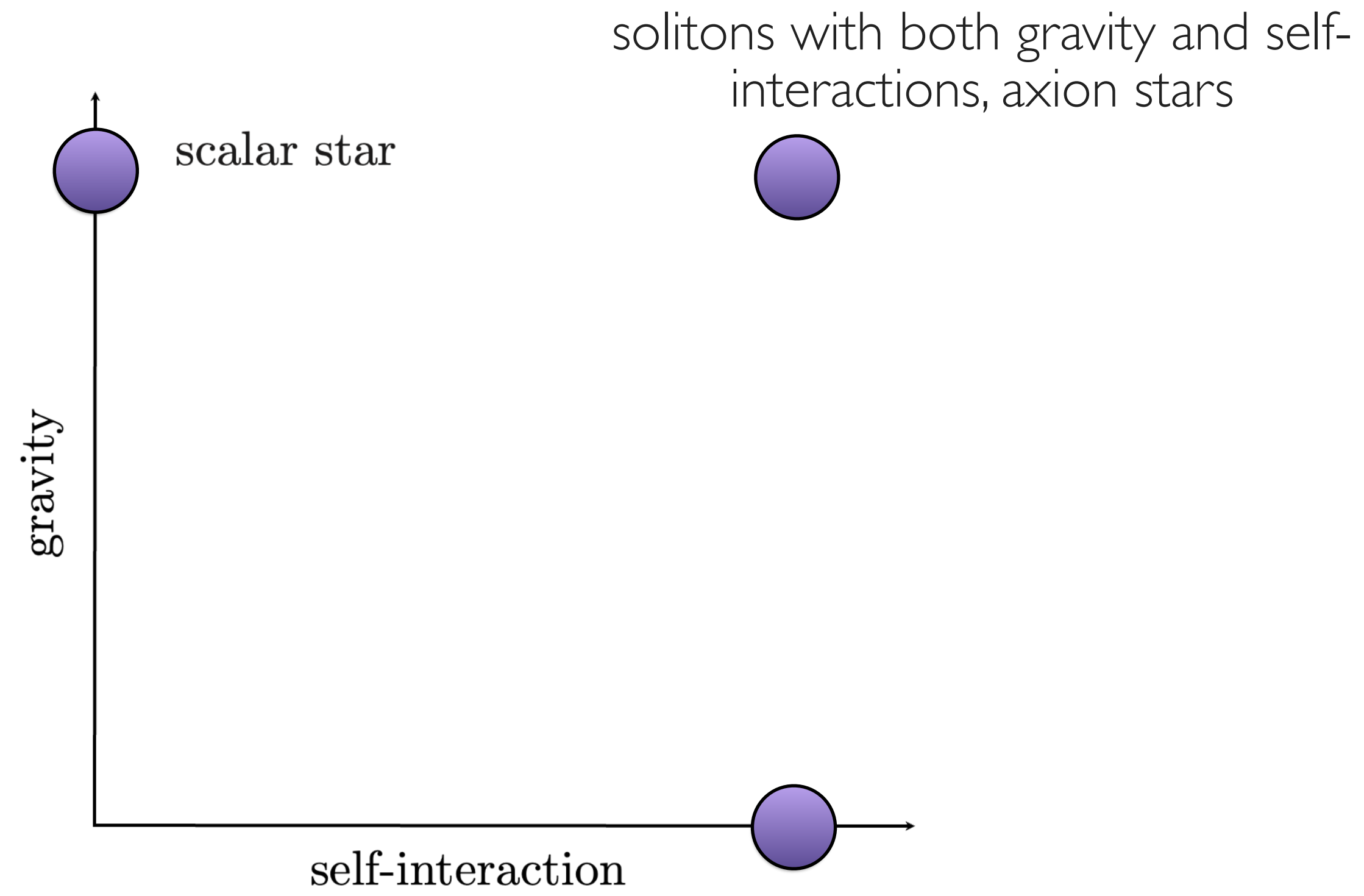


- [Amin et al](#)



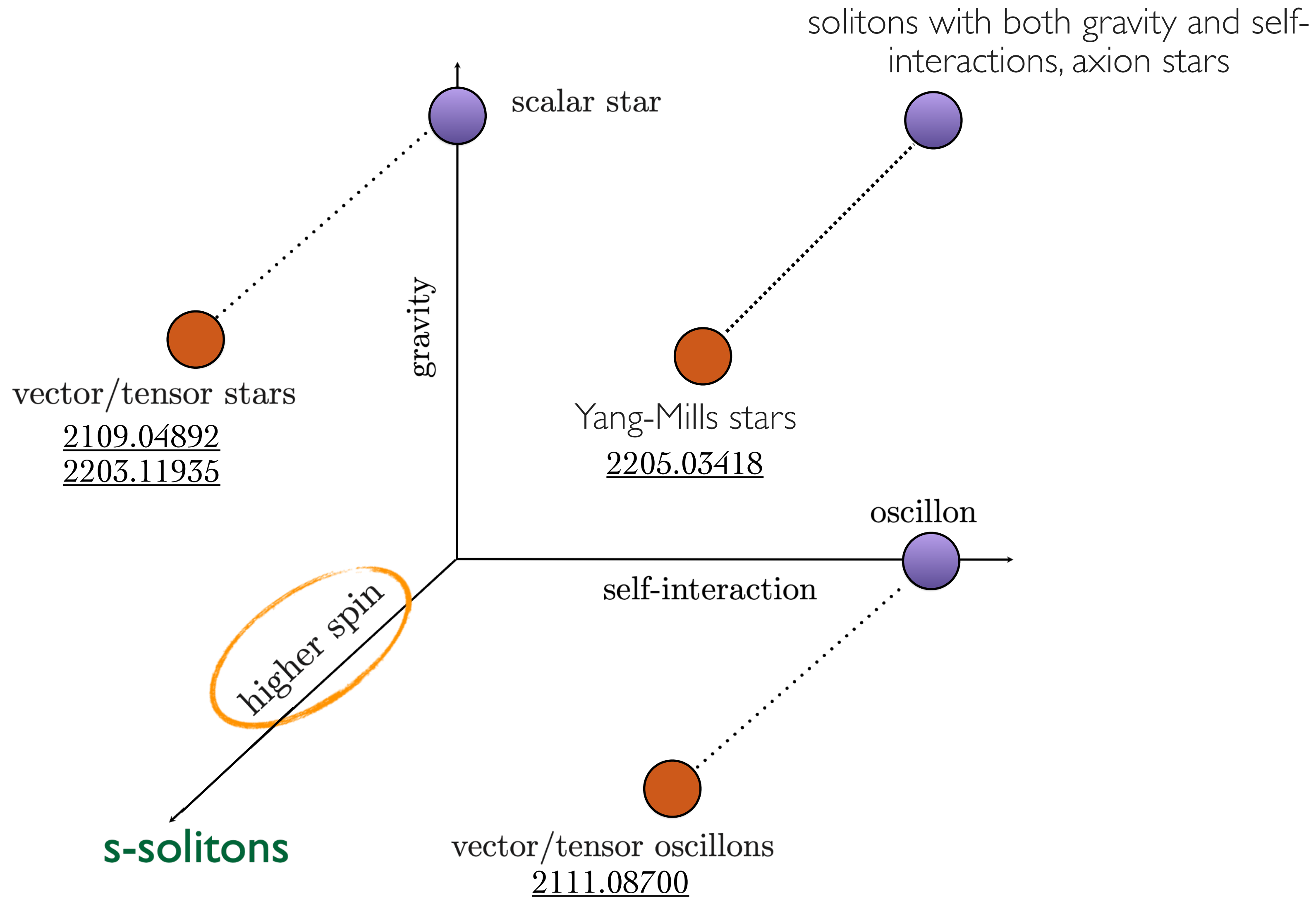
# non-topological solitons

spatially localized, coherently oscillating, long-lived



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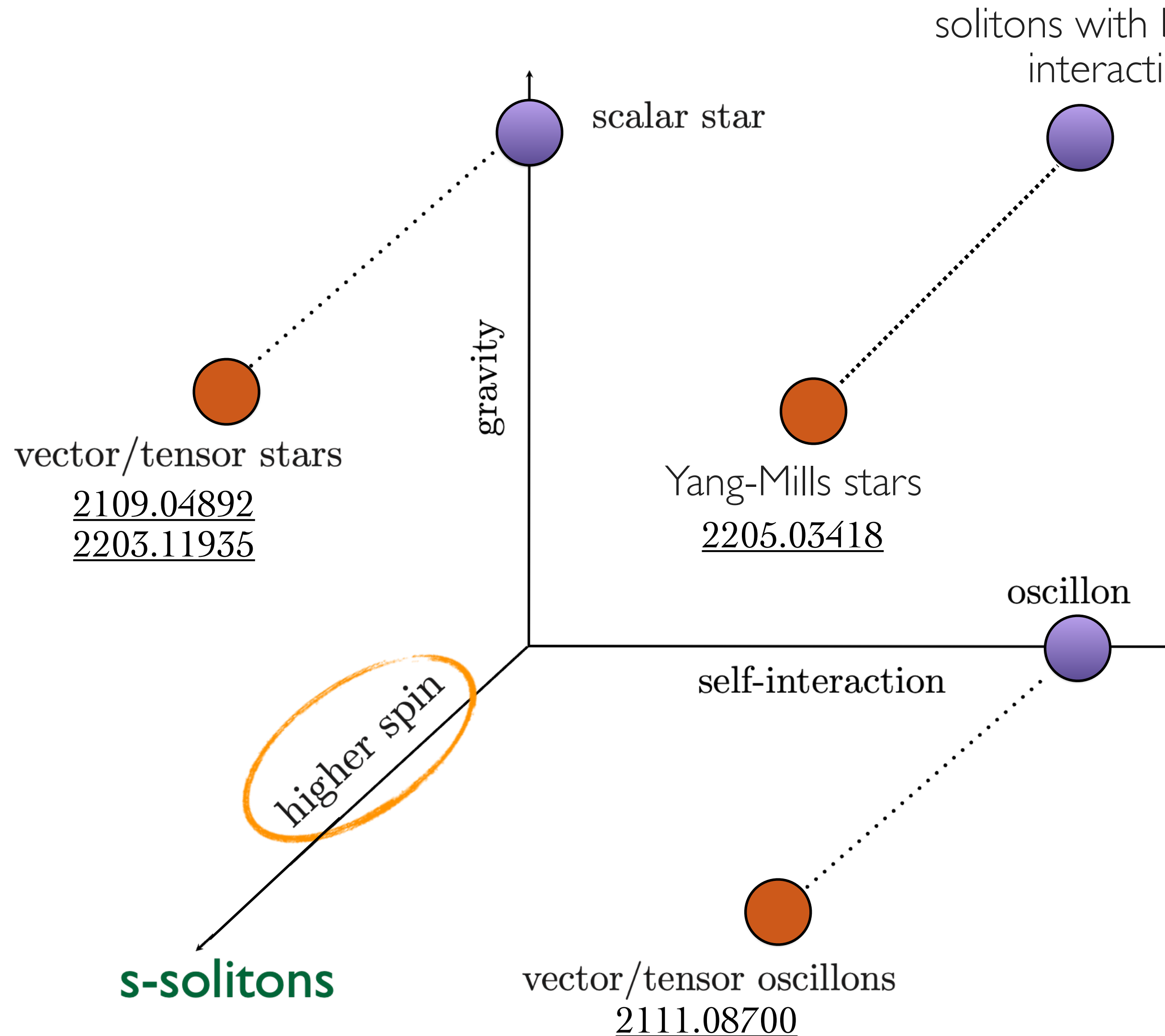
spatially localized, coherently oscillating, long-lived



# non-topological solitons

spatially localized, coherently oscillating, long-lived

Many **PHENO**menological implications



- Relativistic corrections (also see 2111.08700); Post Newtonian corrections  $\leftrightarrow$  sourcing gravitational waves
- Couplings with the Standard Model, signatures due to intrinsic spin polarization;
- Dwarf galaxies core radius vs density relationship
- so much more

Thanks!