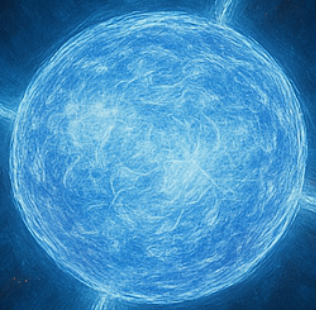
Φ-Dwarfs:
White Dwarfs Probe Quadratically Coupled Scalars



Kai (χ) Bartnick

Interested in BSM and Astroparticle Physics

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Technical University of Munich

BSM Odyssey 2025, Cargèse 29/07/25

My supervisor

with K. Springmann, S. Stelzl, A. Weiler, D. Koester, R. Kudritzki

2508.xxxxx, 2508.xxxxx

ORIGINS Excellence Cluster | SFB 1258 Neutrinos Dark Matter Messengers | TUM

Motivation and setup

- Light scalars are very common in BSM theories:
  - (QCD) axions
  - ULDM
  - …

- Consider generic scalar coupling to electrons

$$\mathcal{L} = \bar{\psi}_e \left(\gamma^\mu \partial_\mu - m_e\right) \psi_e + \frac{1}{2}\partial_\mu \phi \partial^\mu \phi - \frac{1}{2} m_\phi^2 \phi^2 - \frac{d_{m_e}^{(2)}}{2M_{pl}^2} \phi^2 m_e \bar{\psi}_e \psi_e$$

$\frac{\phi^2}{\Lambda^2}\mathcal{O}_{\rm SM}$

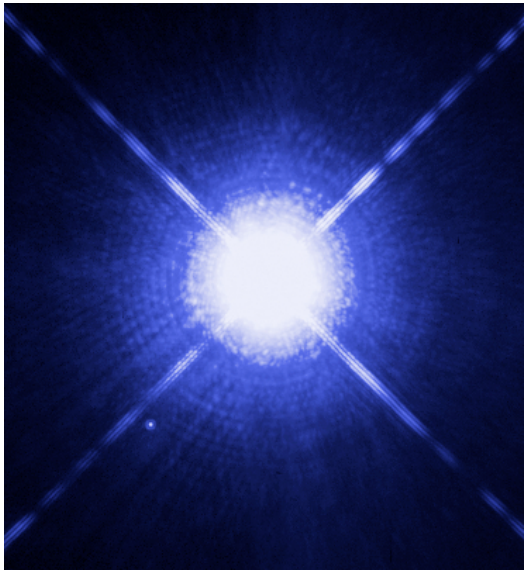
- linear couplings are tightly constrained $\Longrightarrow$ impose $\mathbb{Z}_2$ symmetry

- scattering, production are strongly suppressed: $\sim \frac{1}{\Lambda^4}$

White Dwarfs

Willhelm Bessel, 1841:

Sirius has a companion



By NASA, ESA, H. Bond (STScI), and M. Barstow (University of Leicester) - http://www.spacetelescope.org/images/heic0516a/

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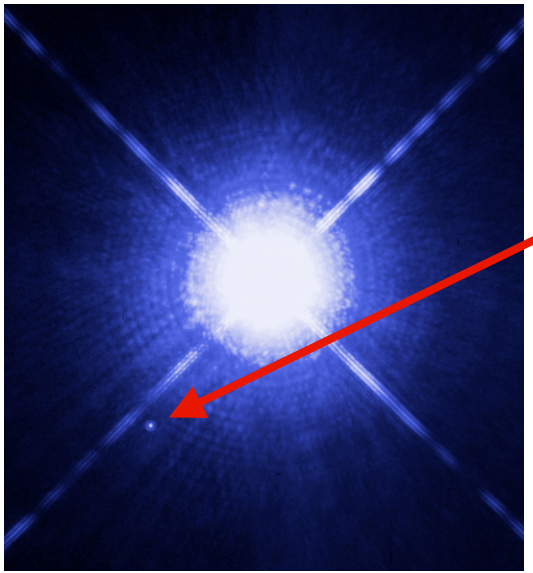

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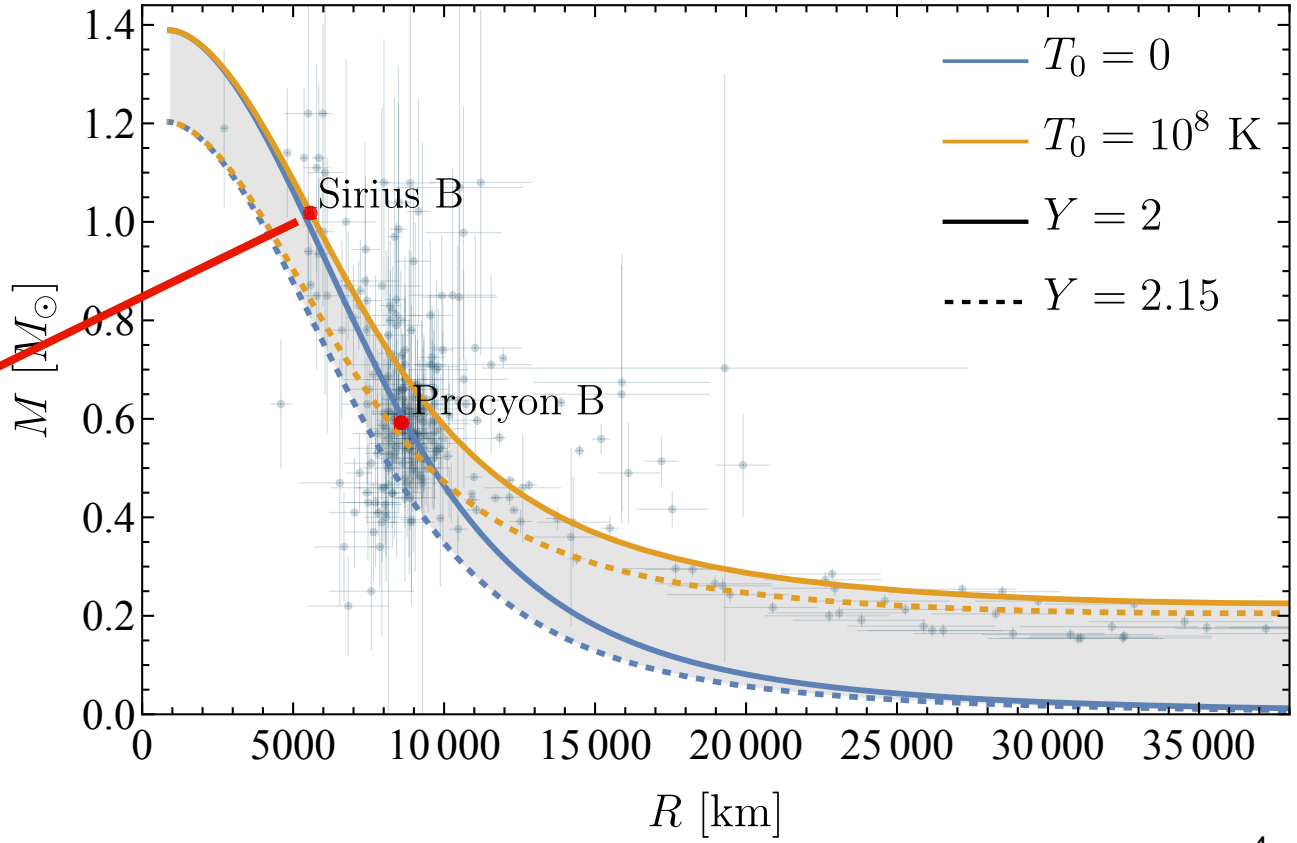


Scalar sourcing

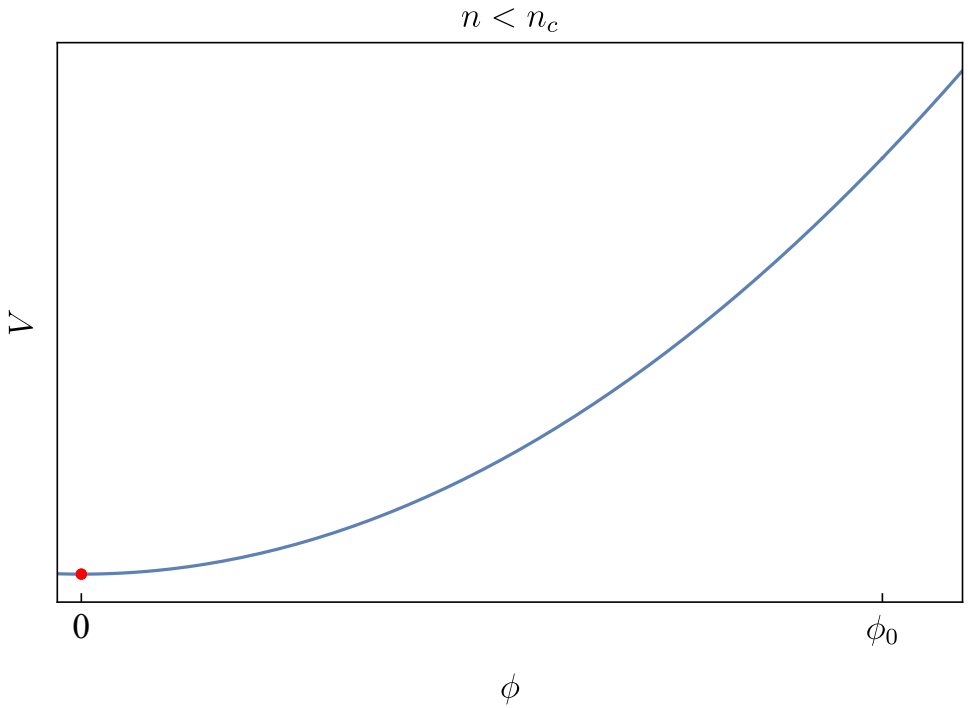
[Hook, Huang, 1708.08464]
[Balkin, Serra, Springmann, Stelzl, Weiler, 2211.02661 & 2307.14418]
[KB, Springmann, Stelzl, Weiler: 2508.xxxxx]

$$\mathcal{L} \supset -\frac{1}{2} m_\phi^2 \phi^2 - \frac{d_{m_e}^{(2)}}{2M_{pl}^2} \phi^2 m_e \bar{\psi}_e \psi_e$$

$$< \bar{\psi}_e \psi_e > \approx n_e$$

$$\mathcal{L} \supset -\frac{1}{2} m_\phi^2 \phi^2 - \frac{d_{m_e}^{(2)}}{2M_{pl}^2} \phi^2 m_e n_e$$

$$\Longrightarrow \quad \left(m_\phi^{\text{eff}}\right)^2 = m_\phi^2 - \frac{\left(-d_{m_e}^{(2)}\right)}{M_{\text{pl}}^2} m_e n_e$$



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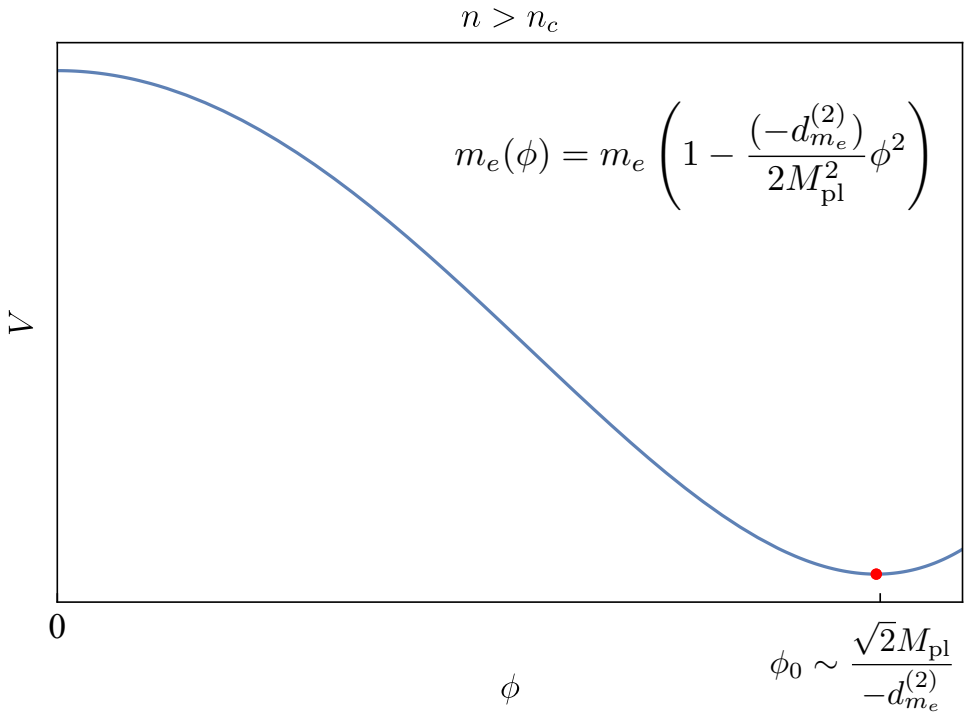
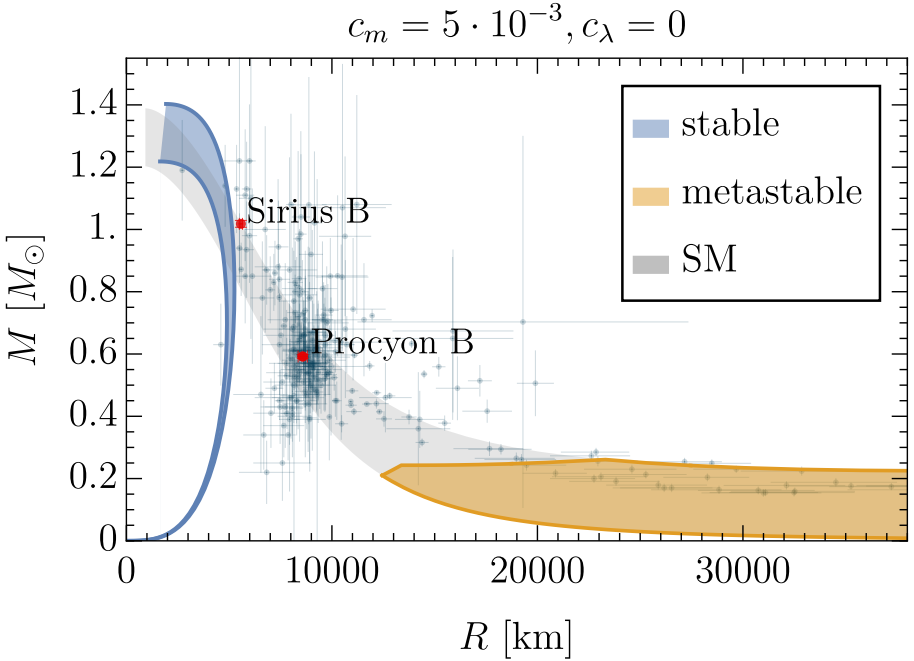
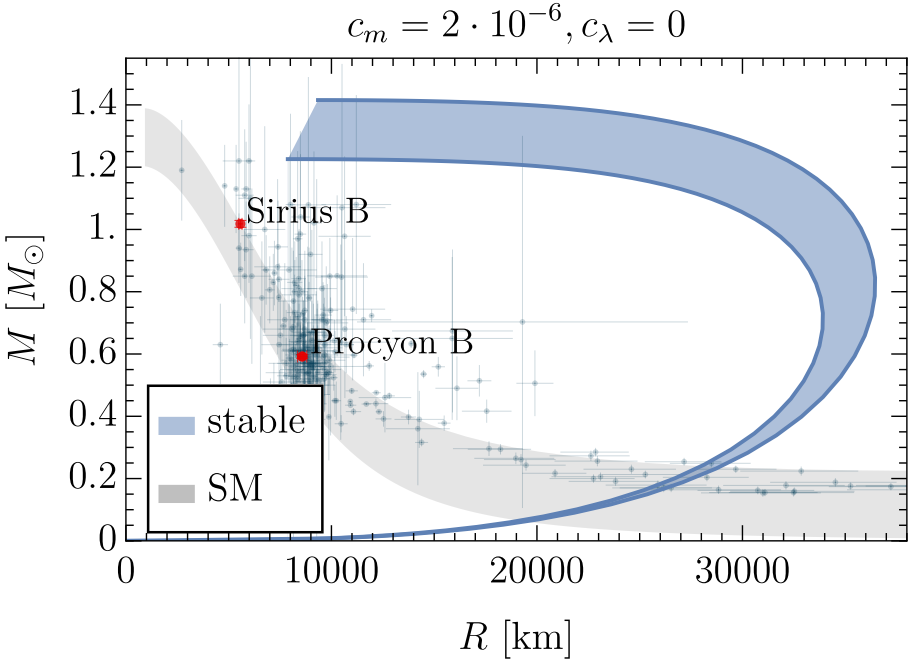
mass can become tachyonic



Φ-Dwarfs

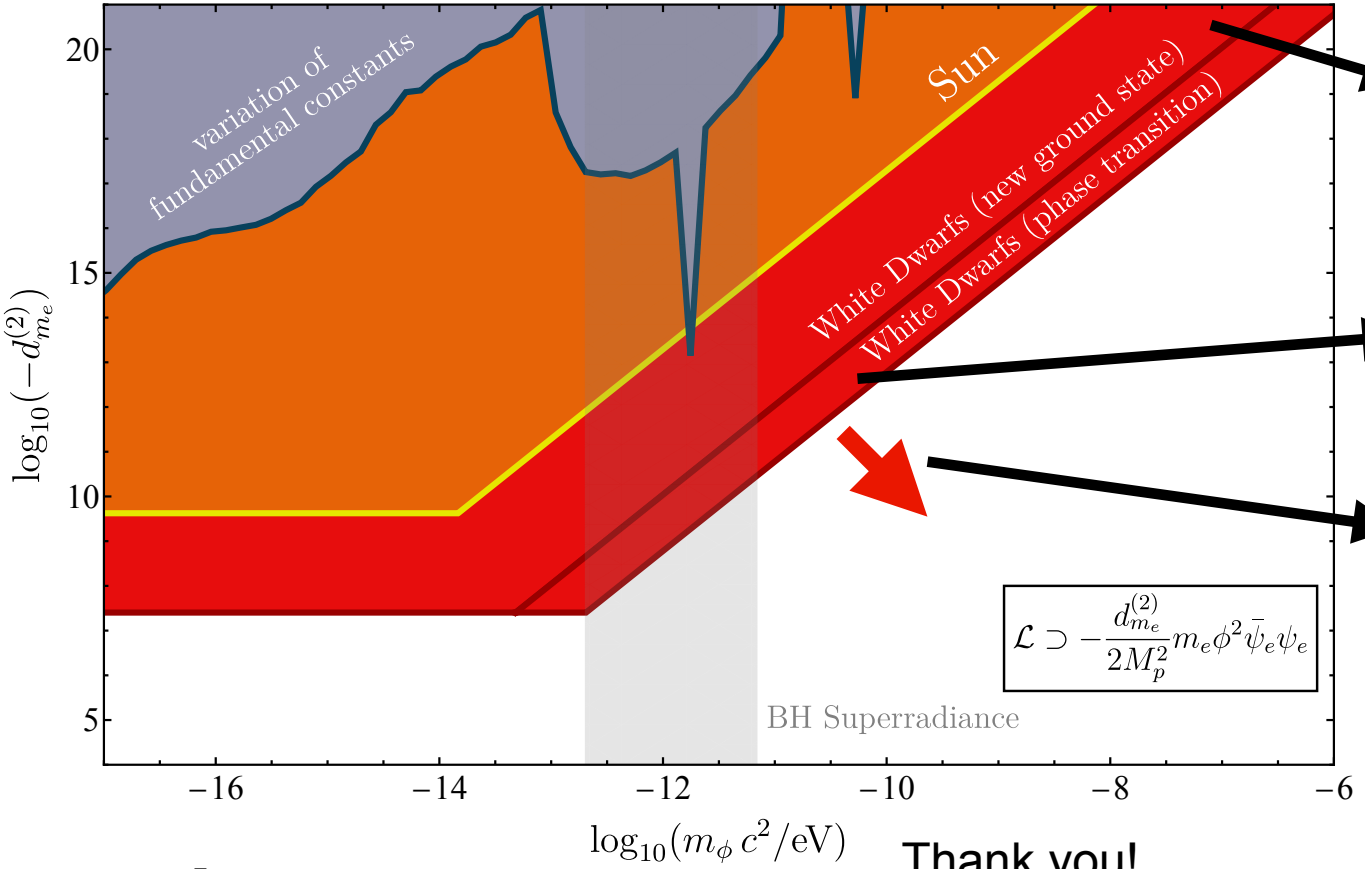




with $c_m = \dfrac{m_\phi^2 M_{\rm pl}^2}{d^{(2)}_{m_e} m_e^4}$ $c_\lambda = \dfrac{2M_{\rm pl}^2}{d^{(2)}_{m_e} f_\phi^2} c_m$

[KB, Springmann, Stelzl, Weiler: 2508.xxxxx]

Parameter Space



[KB, Springmann, Stelzl, Weiler: 2508.xxxxx]
QCD axions: [Balkin, Serra, Springmann, Stelzl, Weiler, 2211.02661]

[KB, Koester, Kudritzki, Springmann, Stelzl, Weiler: 2508.xxxxx]

Need to consider neutron stars (coupling to nucleons):
[Gómez-Bañón, KB, Springmann, Pons, 2408.07740]
see also [Kumamoto, Huang, Drischler, Baryakhtar, Reddy, 2410.21590]

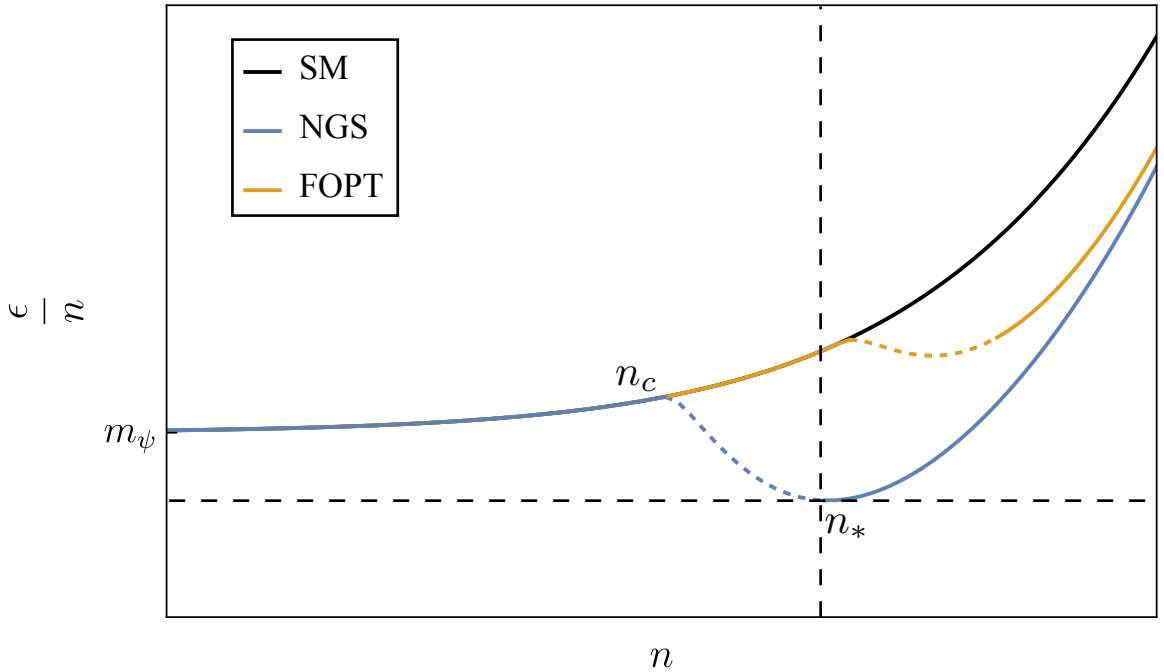
Thank you!

Backup

Scalar Induced Phase Transition

[Balkin, Serra, Springmann, Stelzl, Weiler, 2211.02661]
[Balkin, Serra, Springmann, Stelzl, Weiler, 2307.14418]

Phase structure best understood by looking at energy per particle $\frac{\varepsilon}{n}$



New Ground State (NGS):

lowest $\frac{\varepsilon}{n}$ at n_*

$\Longrightarrow$ ground state of matter

$n < n_c$: metastable