Universitat Autònoma de Barcelona

Institut de Física d'Altes Energies

Exotic Stars

Cross-Collserola PhD Meeting, 6th of October 2023

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Overview

<u>Challenge</u>: proof new theories in particle physics

- Theorists should give unique signatures of their theories
- Usually: a unique (fundamental) particle
- However, what abound many-particle bound states
  - This is the regime of “Exotic Stars”

<u>Exotic Stars</u>: Bound Structures of many particles

- Described classically
- Extra signatures above the fundamental quant
- Many observational possibilities (other than lab experiments)

The model: a simple scalar

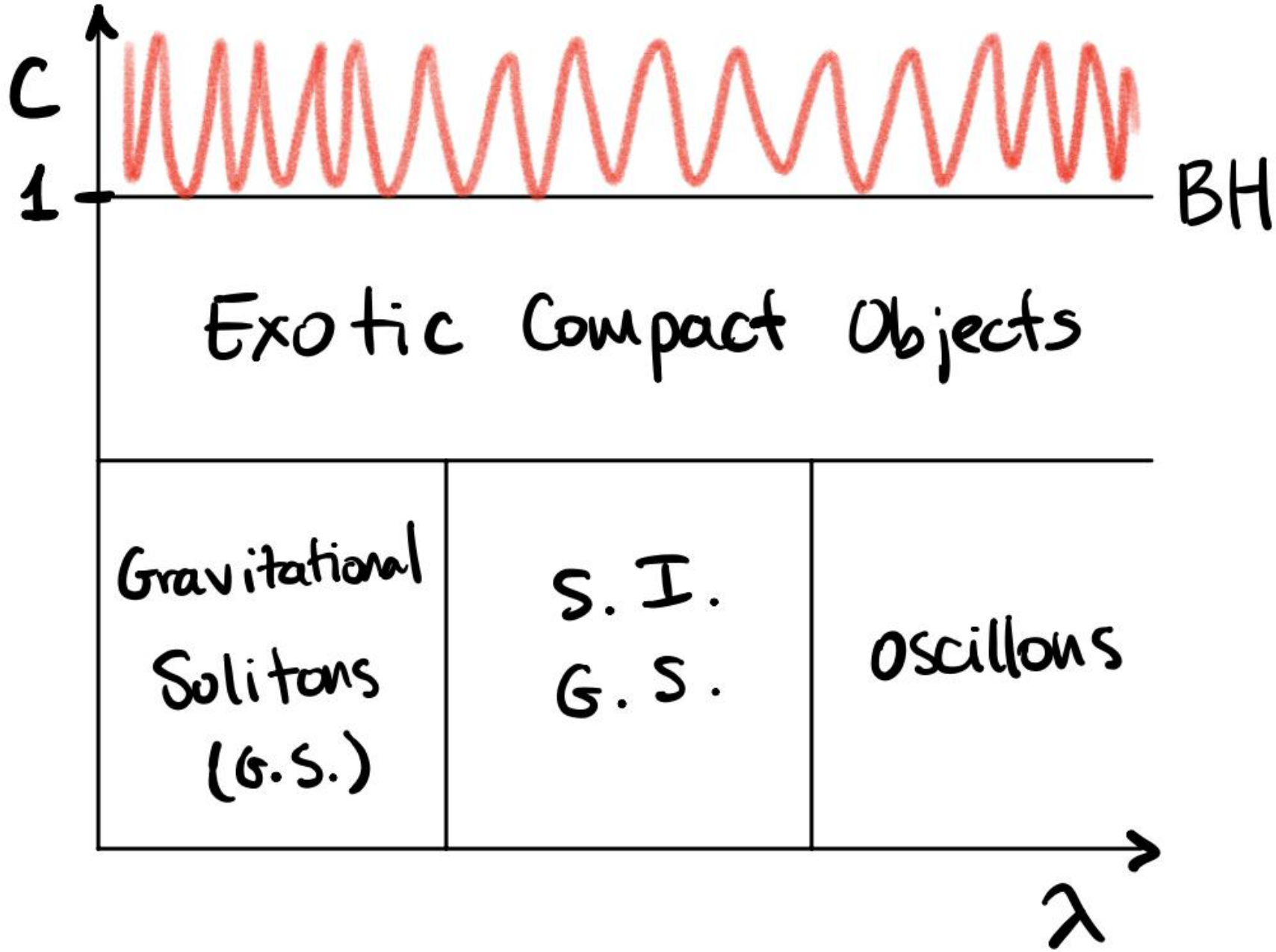
A scalar minimally coupled to gravity

$$\frac{L}{\sqrt{-g}} = \frac{R}{16\,\pi\,G} + \frac{1}{2}\,\partial_\mu\phi\,\partial^\mu\phi\; - \frac{1}{2}m^2\phi^2 + \frac{1}{4}\,\lambda\,\phi^4$$

Nomenclature very confusing: different limits have different names

The origin of boundedness can always be understood as an interplay between the dispersion of a free wave and attractive forces

OR particles in the bound structure lower their mass (binding energy)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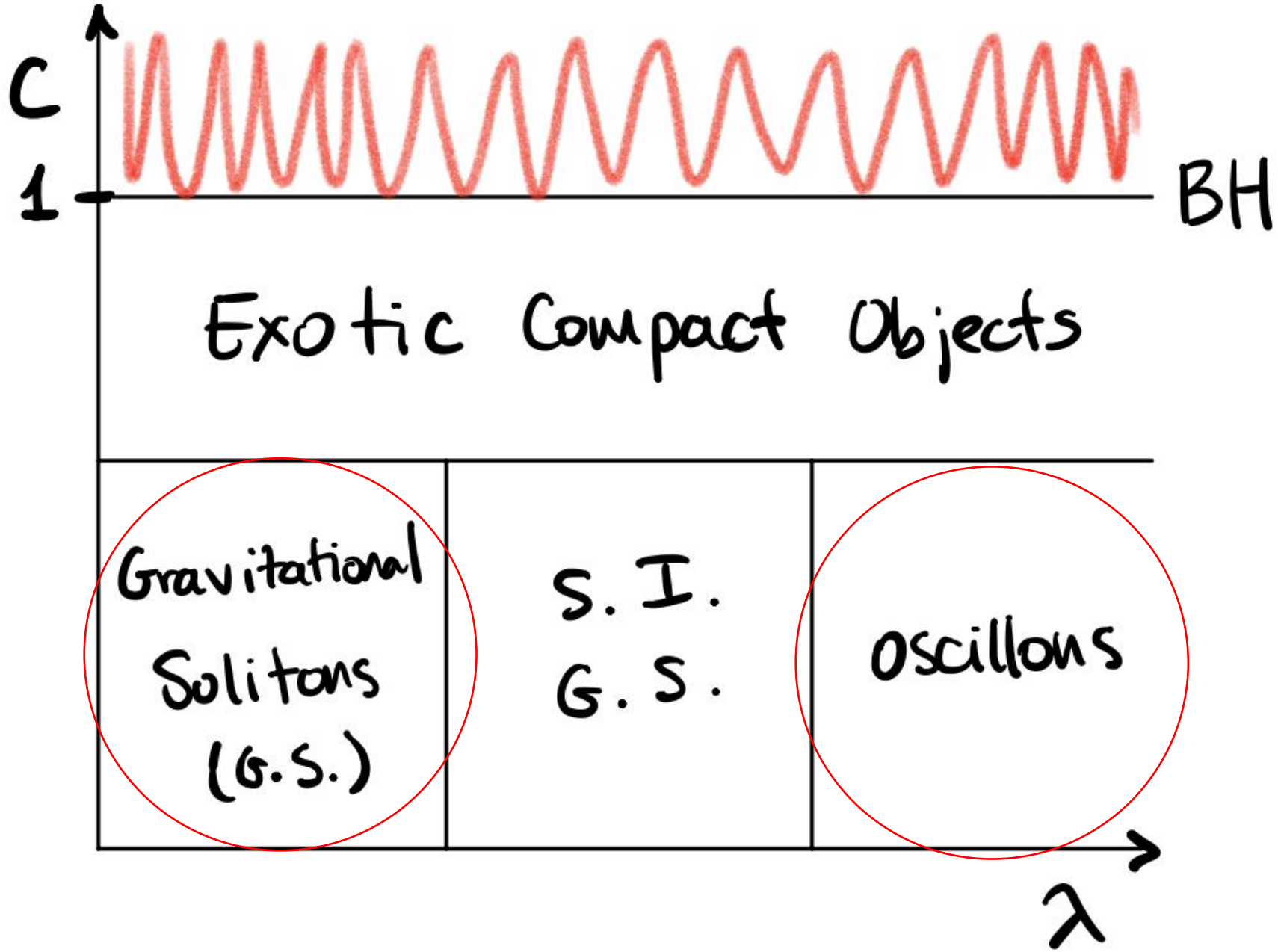
BH
Exotic Compact Objects
Gravitational Solitons (G.S.)
S.I. G.S.
Oscillons
λ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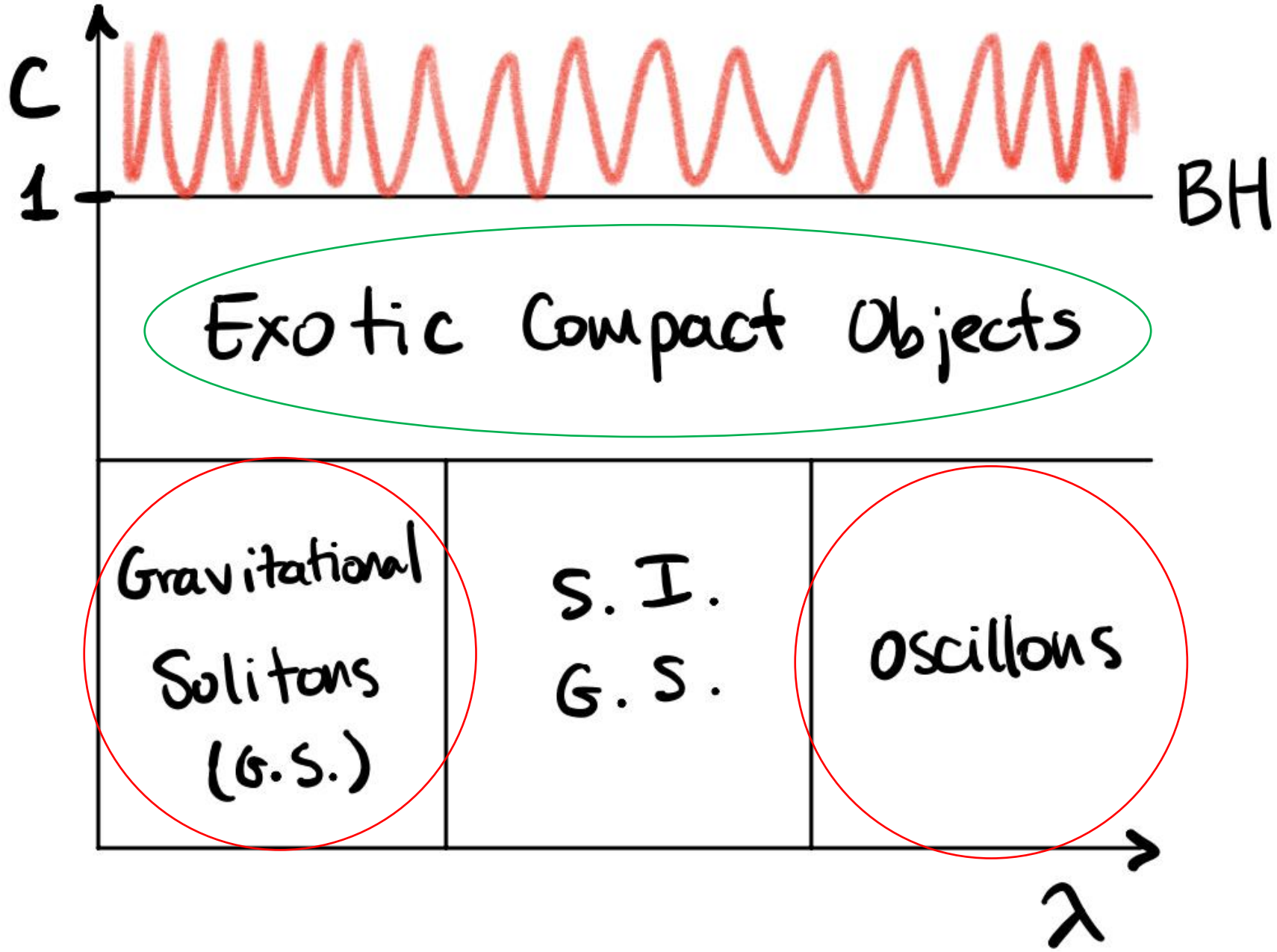
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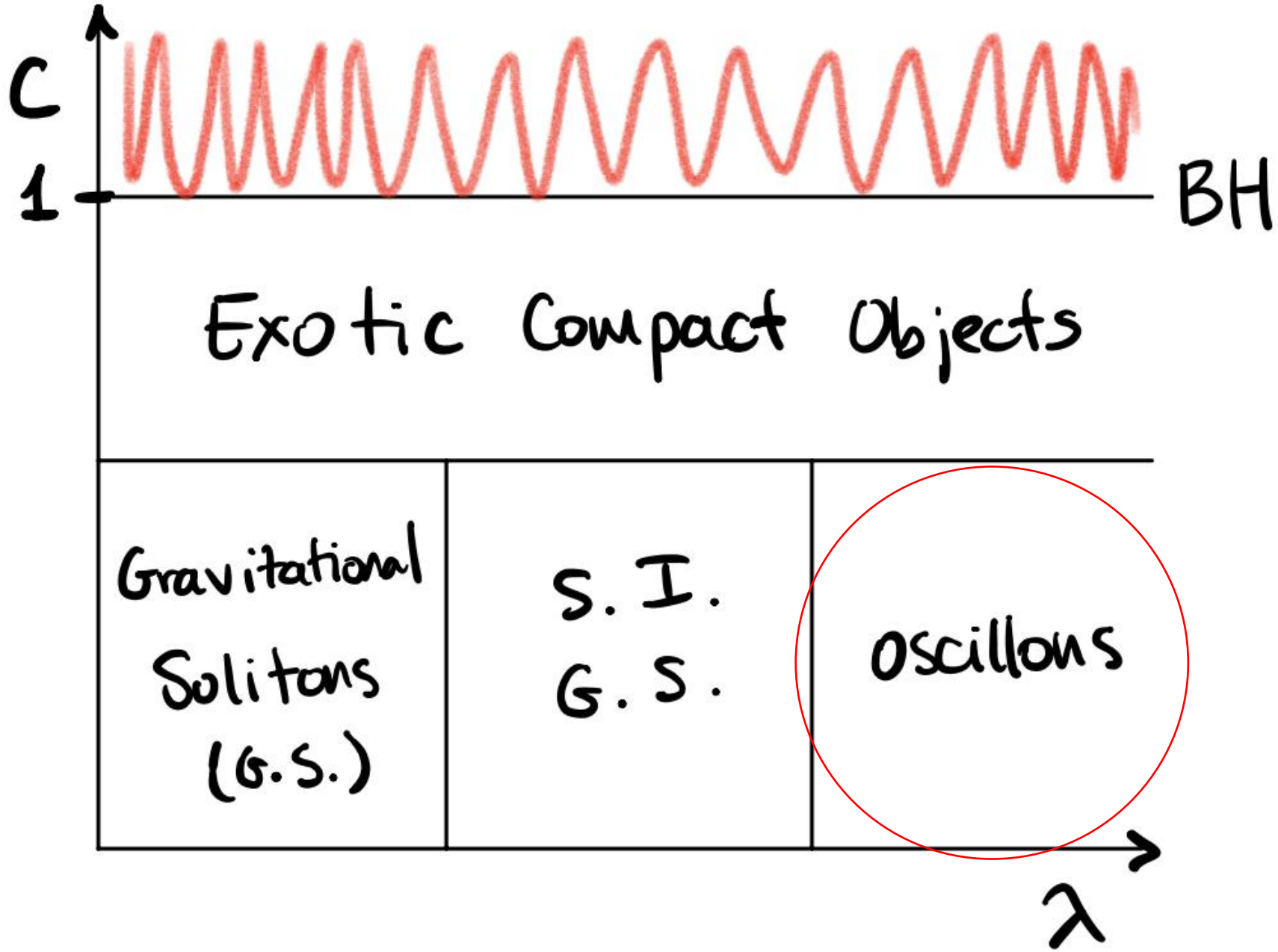
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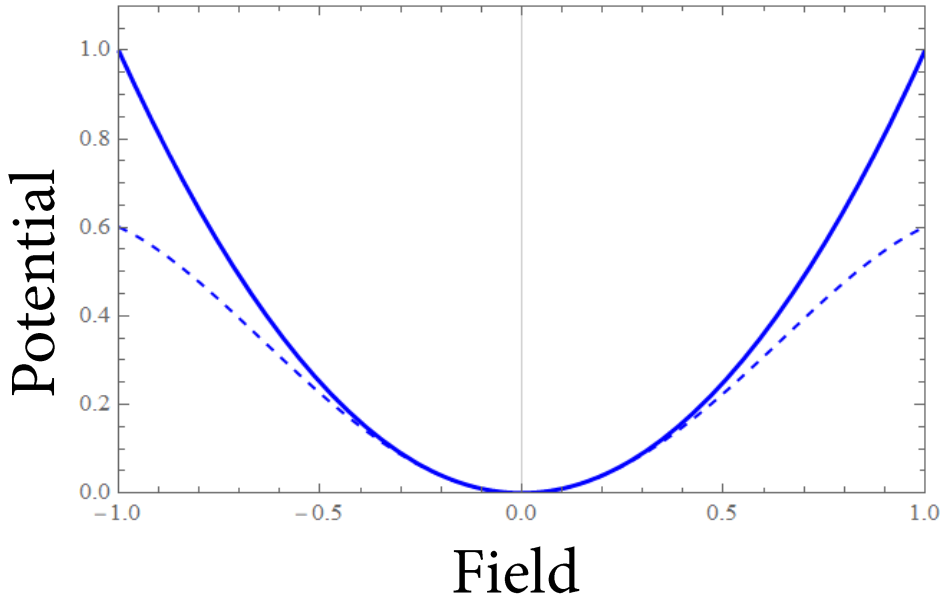
Oscillons

Characteristics:

1. Oscillating Field Configuration
2. Generally Attractors
3. Slowly Decaying (Unstable)

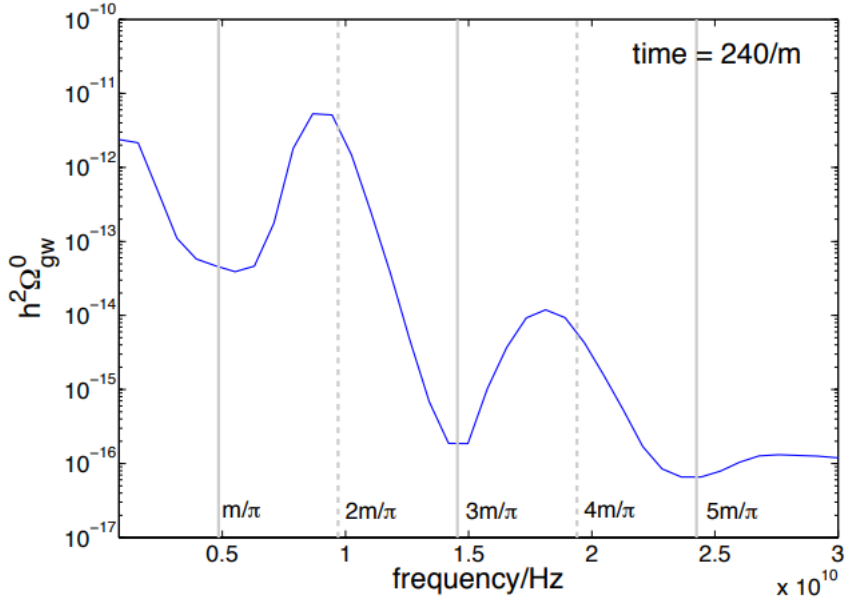


Requirements: Attractive Self-Interactions (“shallower than quadratic”)

Oscillons: applications

Cosmological

1. Generally form in any situation where parametric resonance occurs
2. Characteristic Signature in GW spectrum
3. Dark Matter?



1304.6094 (2013)

Oscillons: applications

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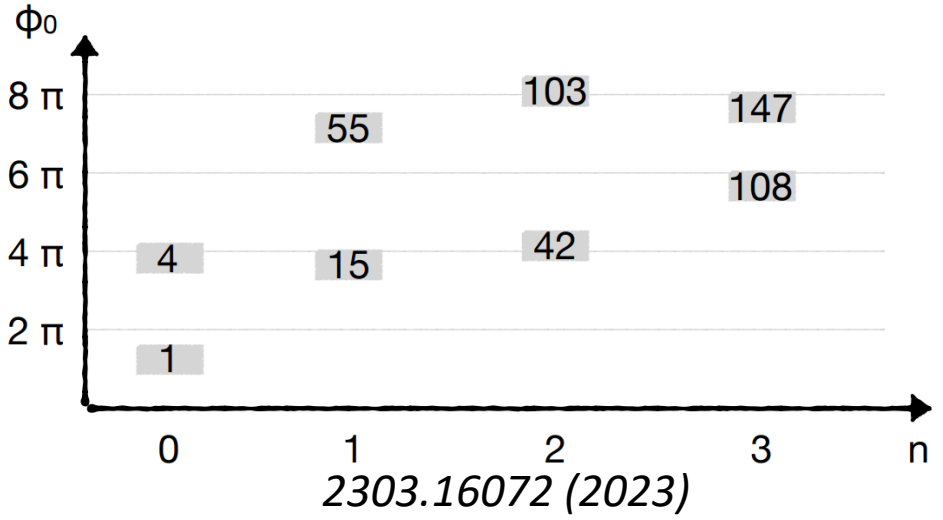
Particle Physics

1. May view them as resonances of many particles
2. Example: pions in the chiral lagrangian



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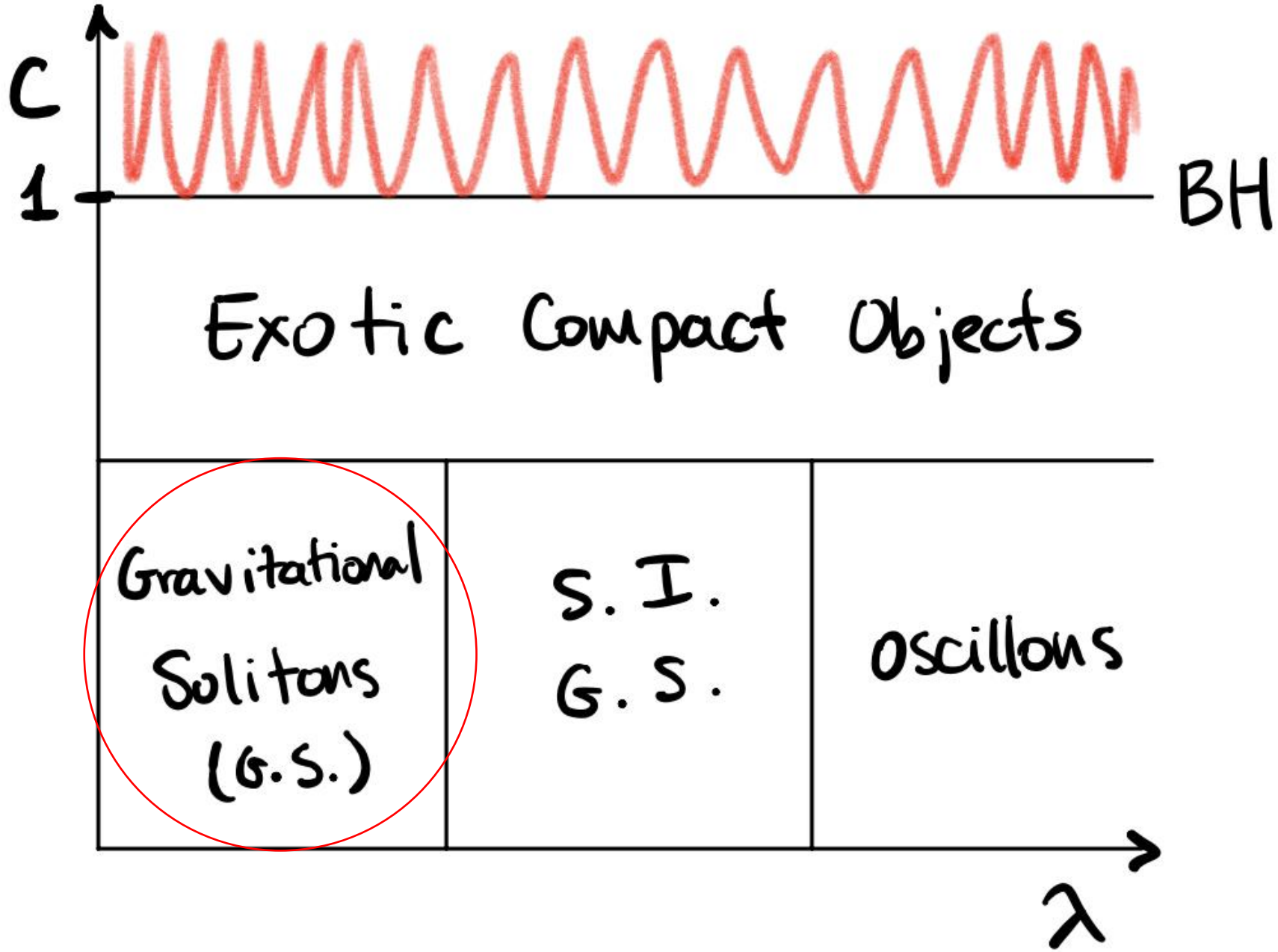
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Gravitational Solitons

<u>Relevance mainly in applications to DM</u>

- CDM has some problems on small scales
- In particular: lack of structure observed vs. Simulations
- Solution: Ultra-Light Dark Matter

$$\lambda_c \approx \frac{\hbar}{m\, v_{DM}}$$

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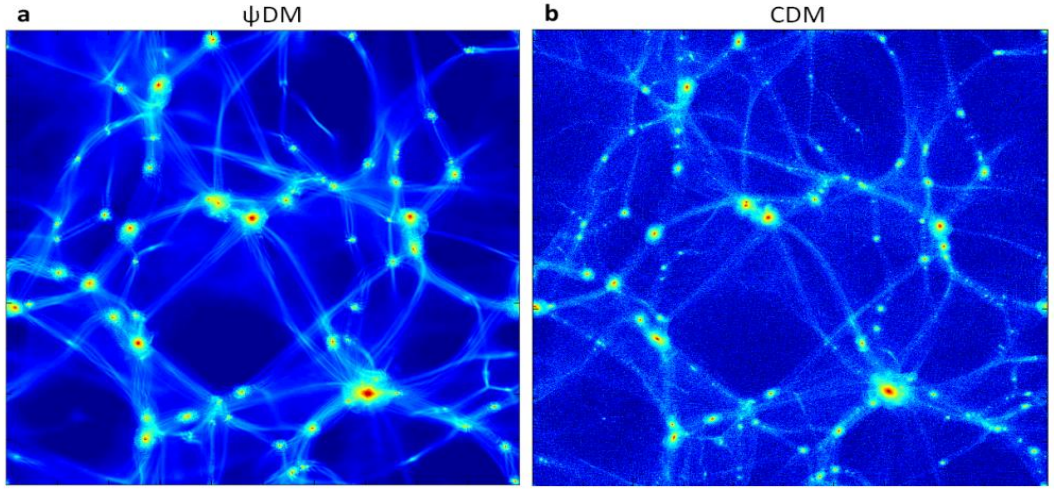

Schive et al. 2014 1406.6586

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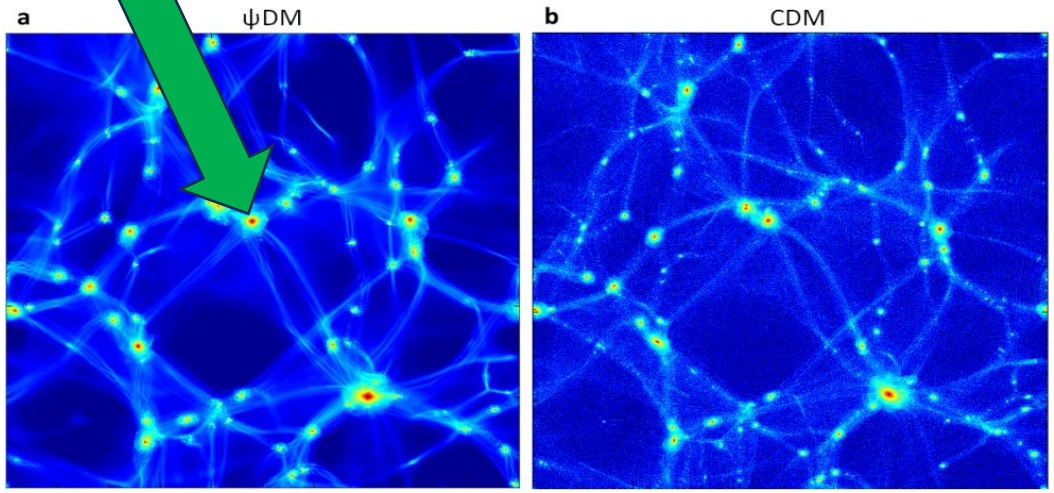

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Gravitational Solitons

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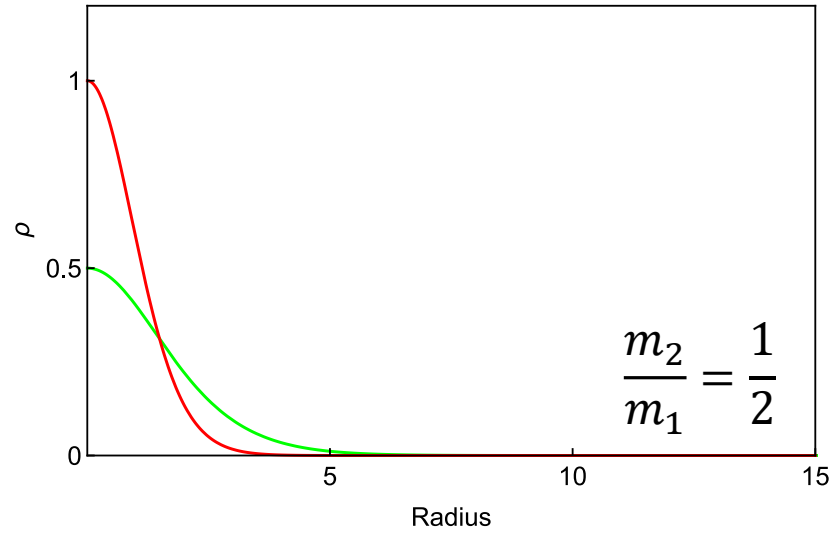
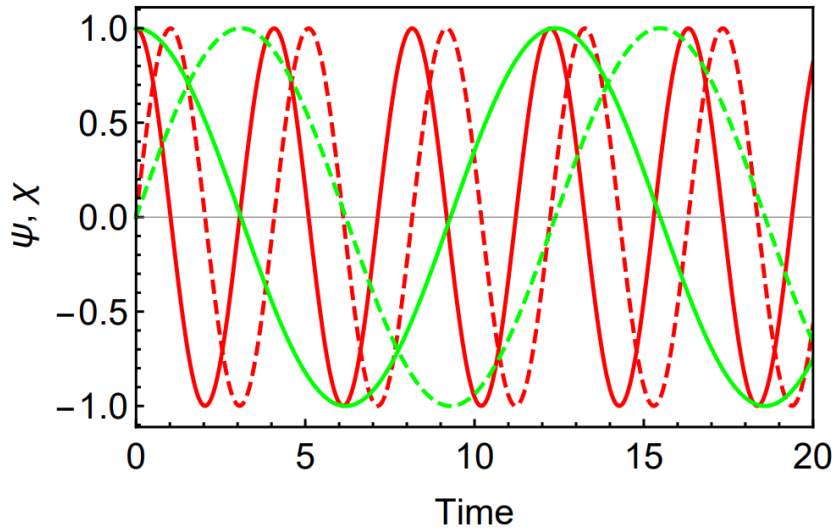
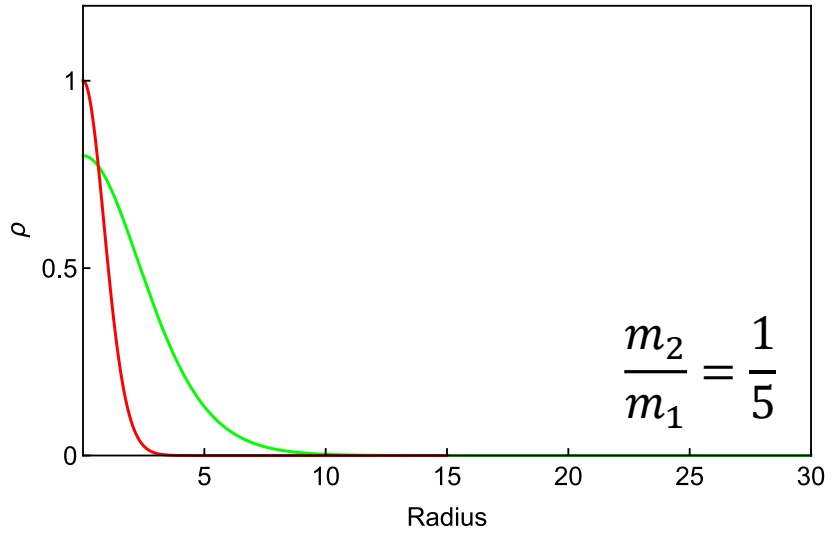
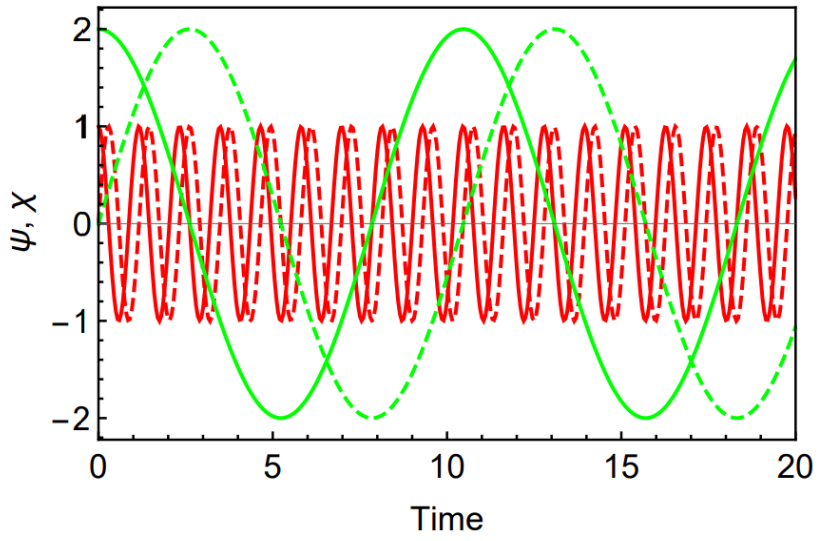
The Single Field Solitons don’t actually fit the rotation curve data on small scales!

Multi-Field Gravitational Solitons









Concluding remarks

Exotic Stars are bound structures made of many particles

- Described classically
- Obiquitous in theories with massive particles
- New probes of fundamental physics

Applications

- Gravitational Waves (both a stochastic background and inspirals)
- Resonances in colliders?
- Dark Matter