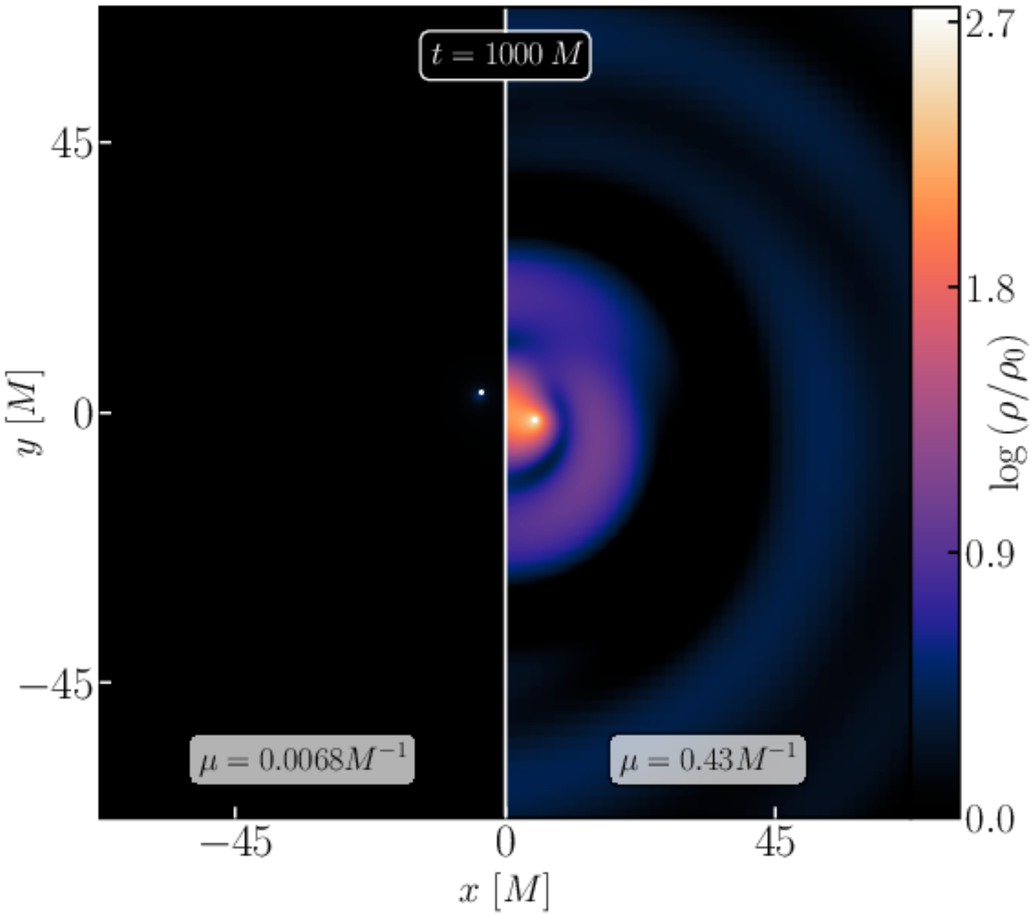
Impact of self interactions in wave dark matter environments

Katy Clough
In work with Josu Aurrekoextea, Jamie Bamber, James Marsden and Pedro Ferreira



J. Aurrekoetxea, KC, J Bamber, P Ferreira 2023
Phys.Rev.Lett. 132 (2024) 21, 211401

J. Marsden, J. Aurrekoetxea, KC, P Ferreira 2024
e-Print: 2403.17595 [gr-qc]

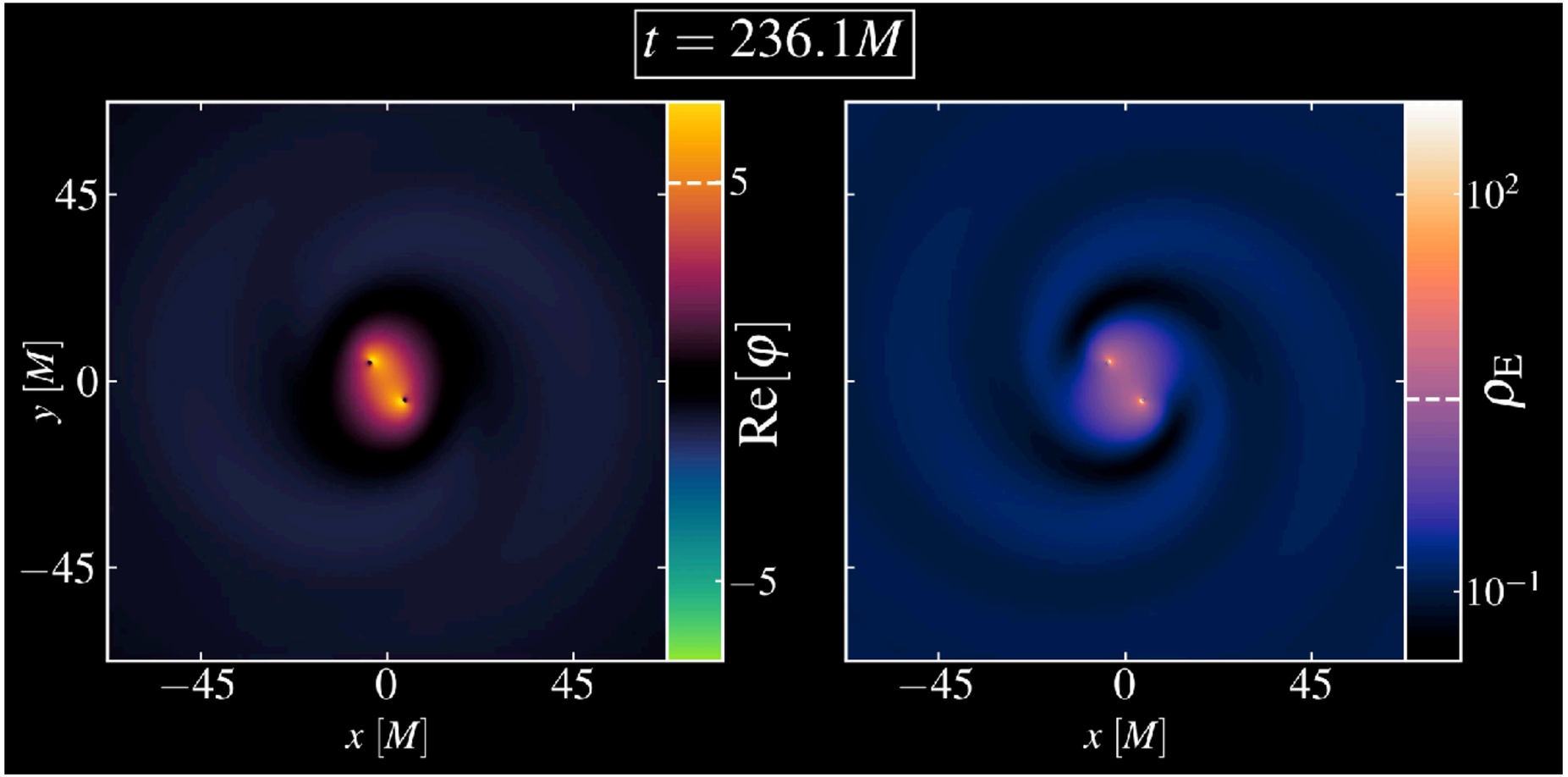
J. Aurrekoetxea, J. Marsden, KC, P Ferreira 2024
e-Print: 2409.01937 [gr-qc]

Science & Technology Facilities Council

Queen Mary University of London

The story so far…

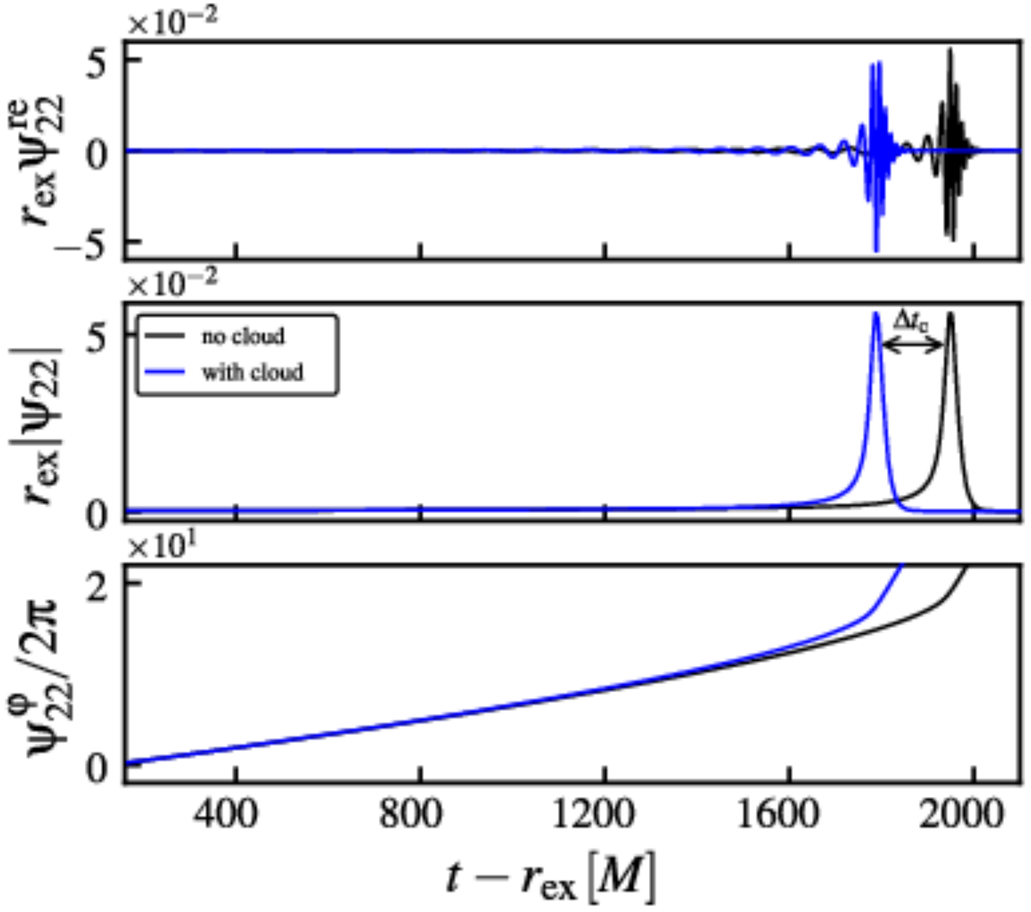
Field



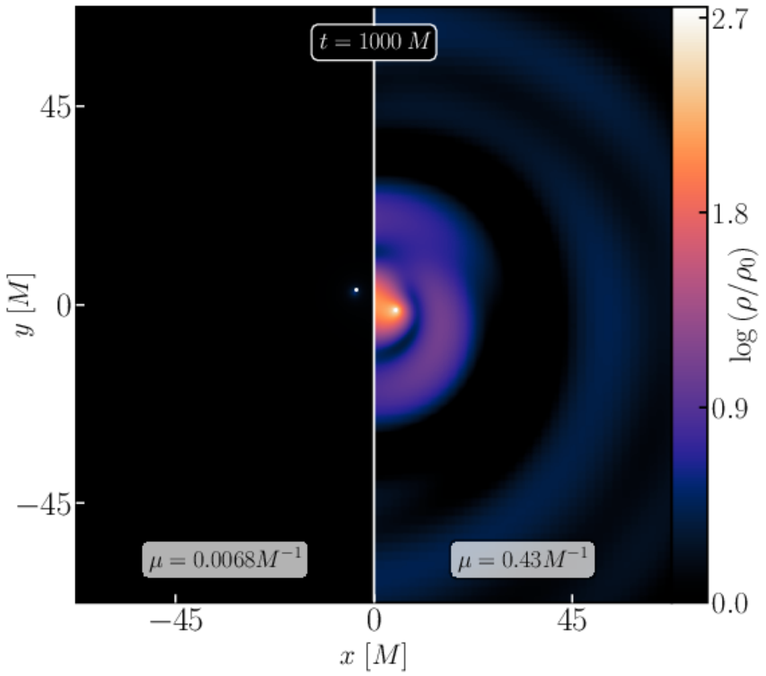
energy density

J. Bamber, J. Aurrekoetxea, KC, P. Ferreira 2023
Phys Rev D 107 2, 024035

The story so far…



density



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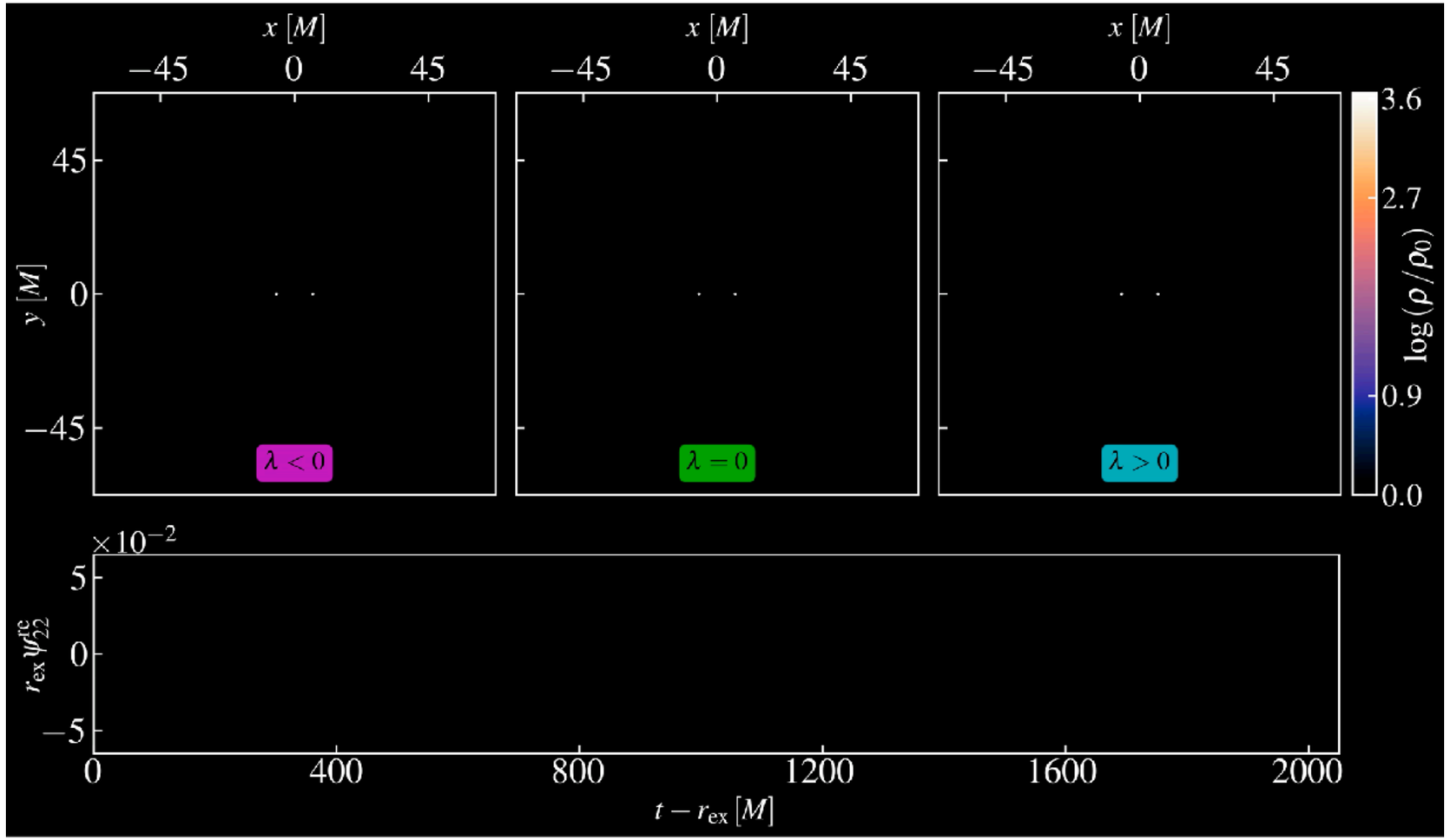
How do self interactions change things?

More attractive interactions



More repulsive interactions

J. Aurrekoetxea, J. Marsden, KC, P Ferreira 2024
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Preliminaries

Does dark matter give signatures in strong gravity environments?

$$\rho \sim 1\ \mathrm{GeV/cm^3}\ \textbf{or}\ 1\ \mathrm{M_\odot/pc^3}$$

(Particle physicist) (Astrophysicist)

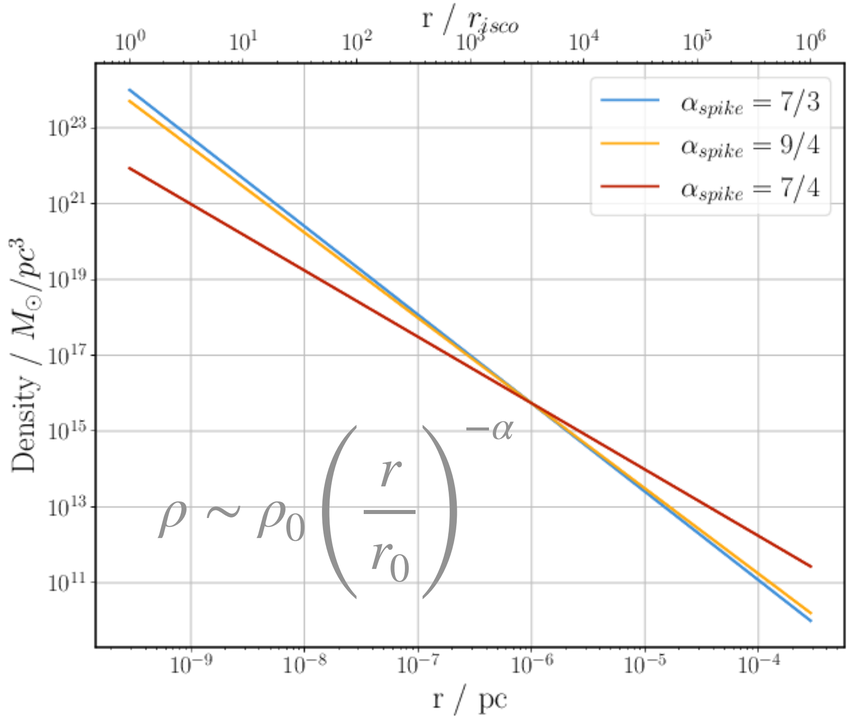
Does dark matter give signatures in strong gravity environments?

Tiny effect at average galactic densities

$$\frac{\rho}{1/R_s^2} \sim 10^{-30} \left(\frac{M_{BH}}{10^6 M_\odot} \right)^2$$

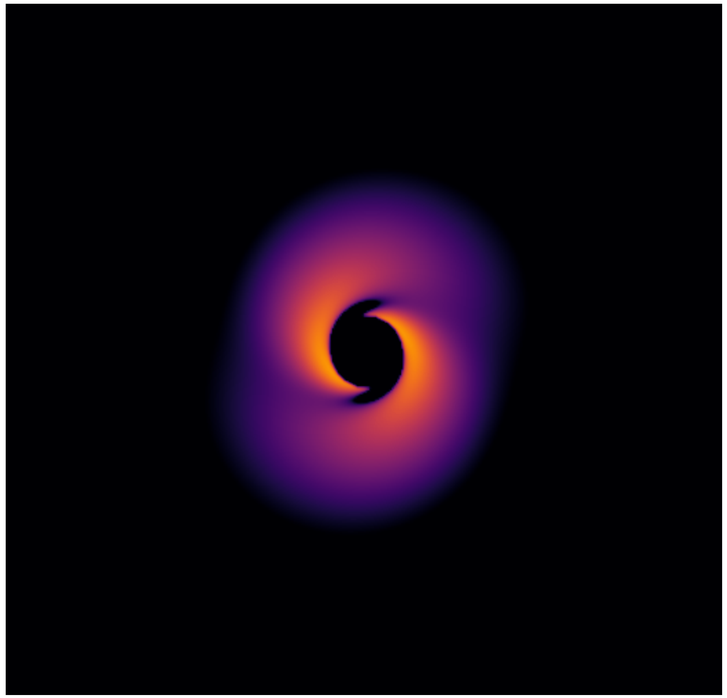
(Numerical relativist)

However, potential for significant enhancements around BHs



Accretion

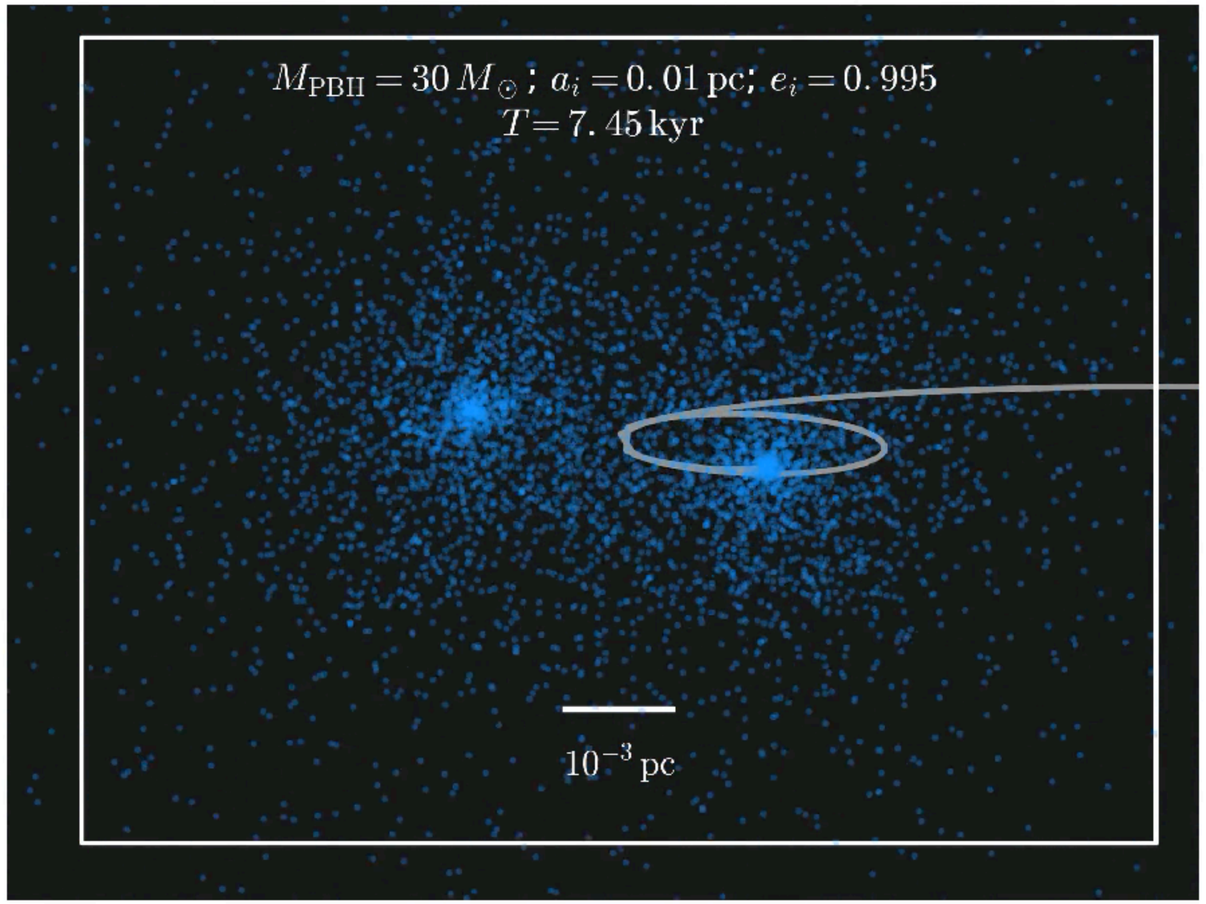
Becker et.al. 2021
Circularization vs. Eccentrification in Intermediate Mass Ratio Inspirals inside Dark Matter Spikes



Superradiance

Review by Brito et. al. (updated 2020)
Superradiance: New Frontiers in Black Hole Physics

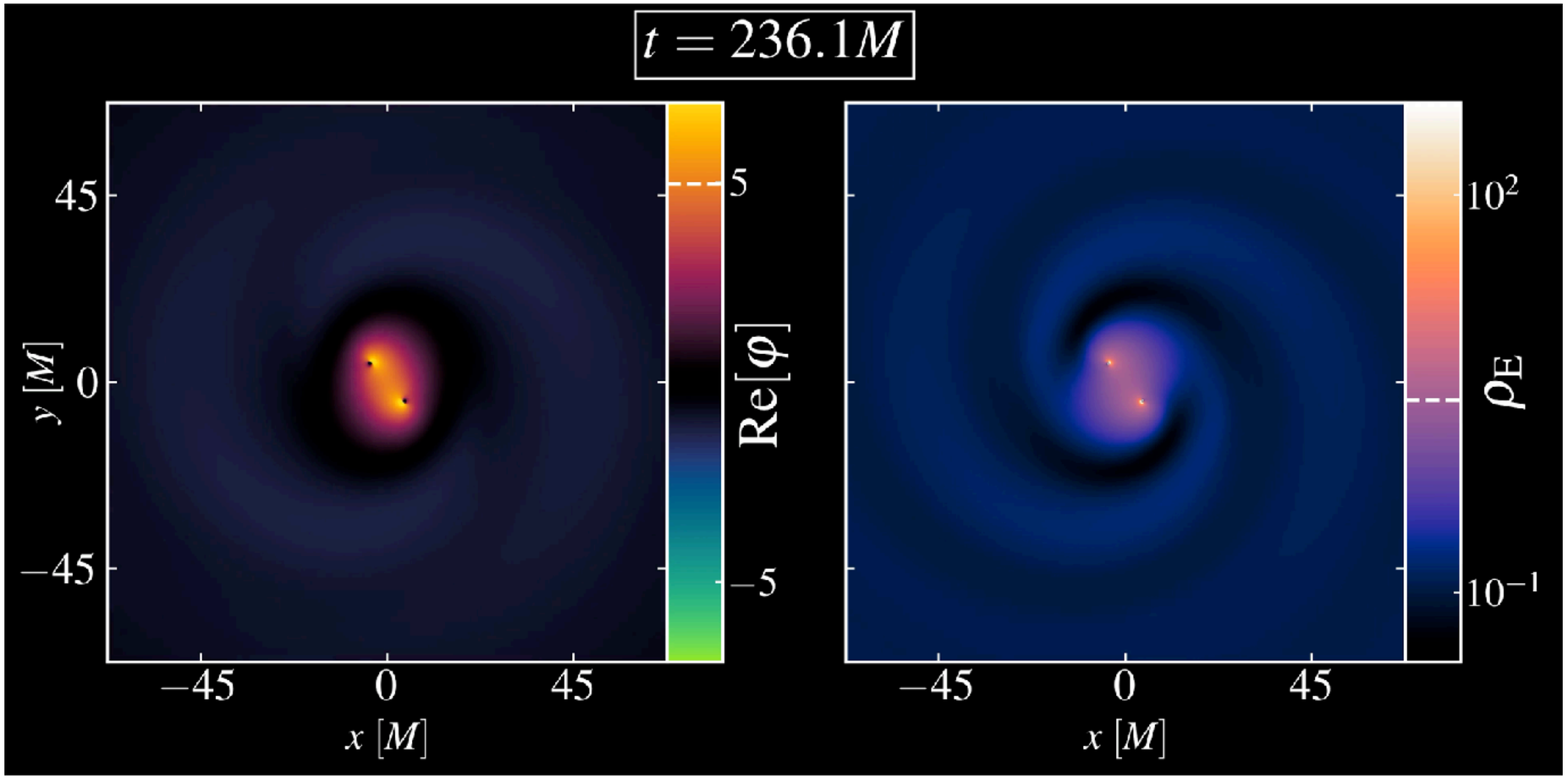
Equal mass binaries have been thought to be an unlikely candidate due to DM dispersal



Bertone et. al. 2020
Gravitational wave probes of dark matter: challenges and opportunities

However, wave like case seems to resist dispersal, and forms a central overdensity

Field



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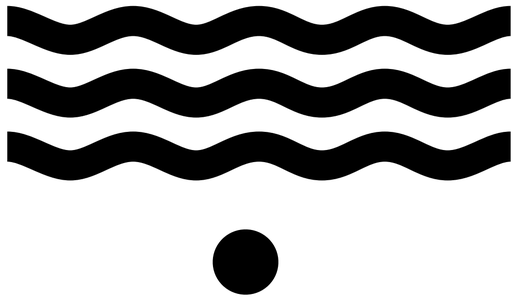
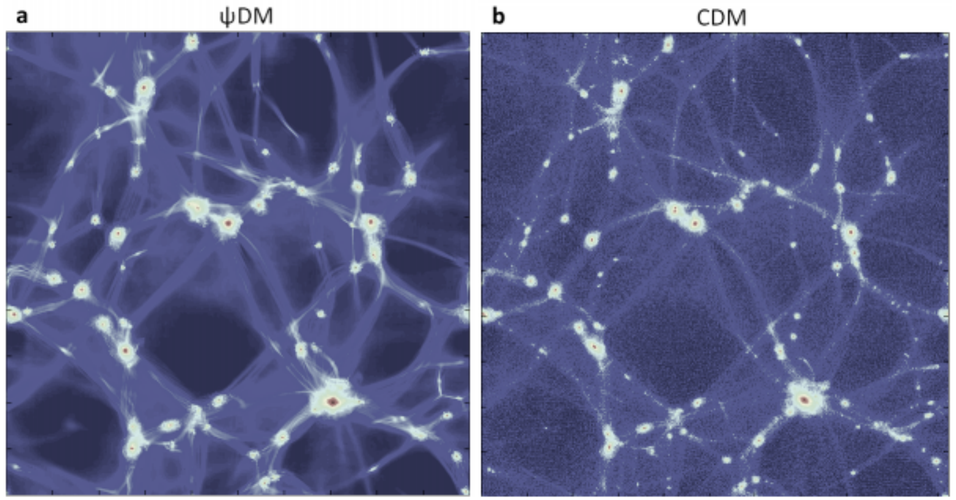
Wave versus particle: the strong gravity perspective

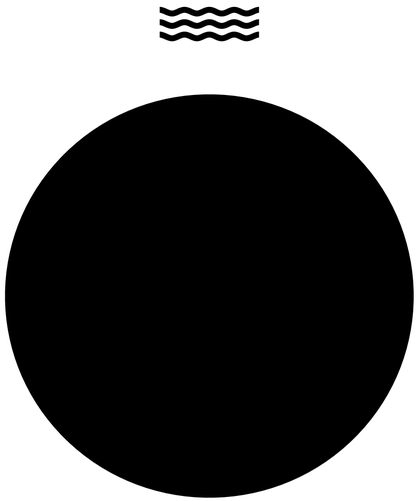


Wave



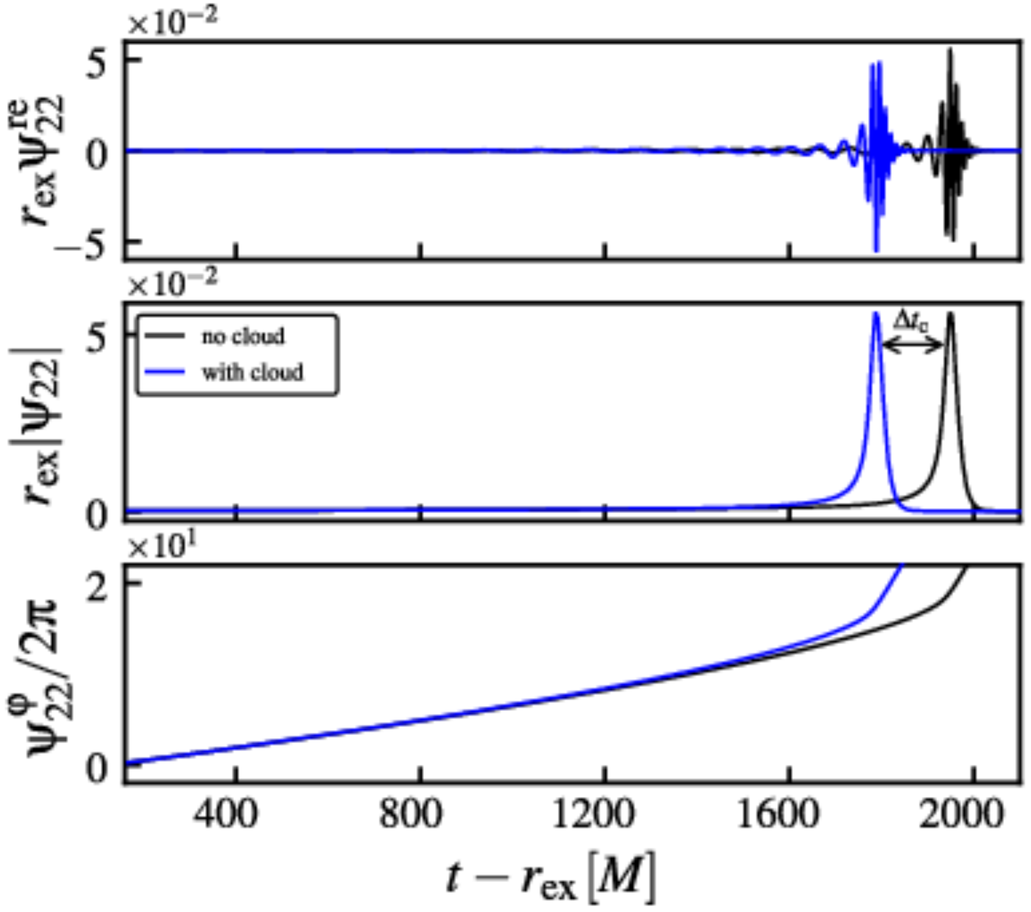
Schive et al. 2014
Cosmic structure as the quantum interference of a coherent dark wave

See also Wave Dark Matter review by Lam Hui
Ann.Rev.Astron.Astrophys. 59 (2021) 247-289

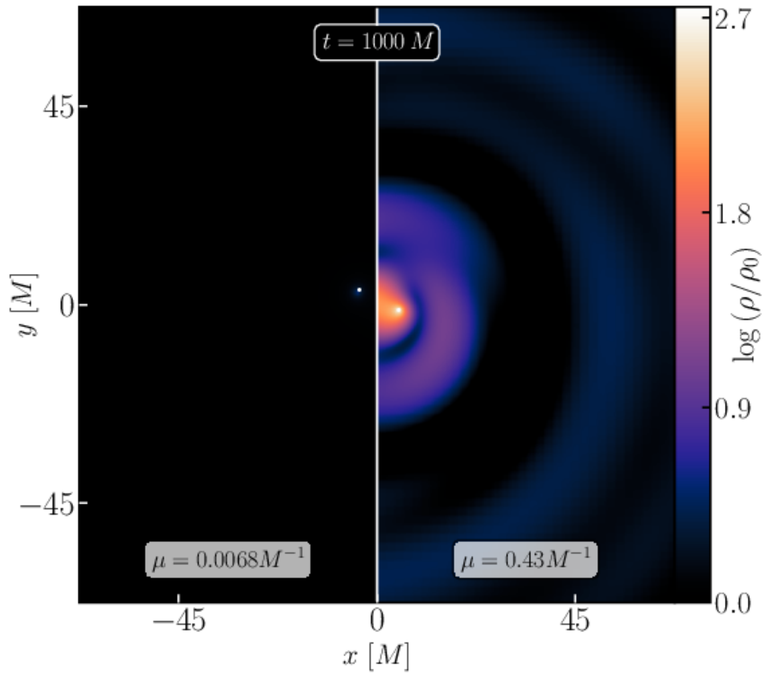


Particle

Potentially significant dephasing



density



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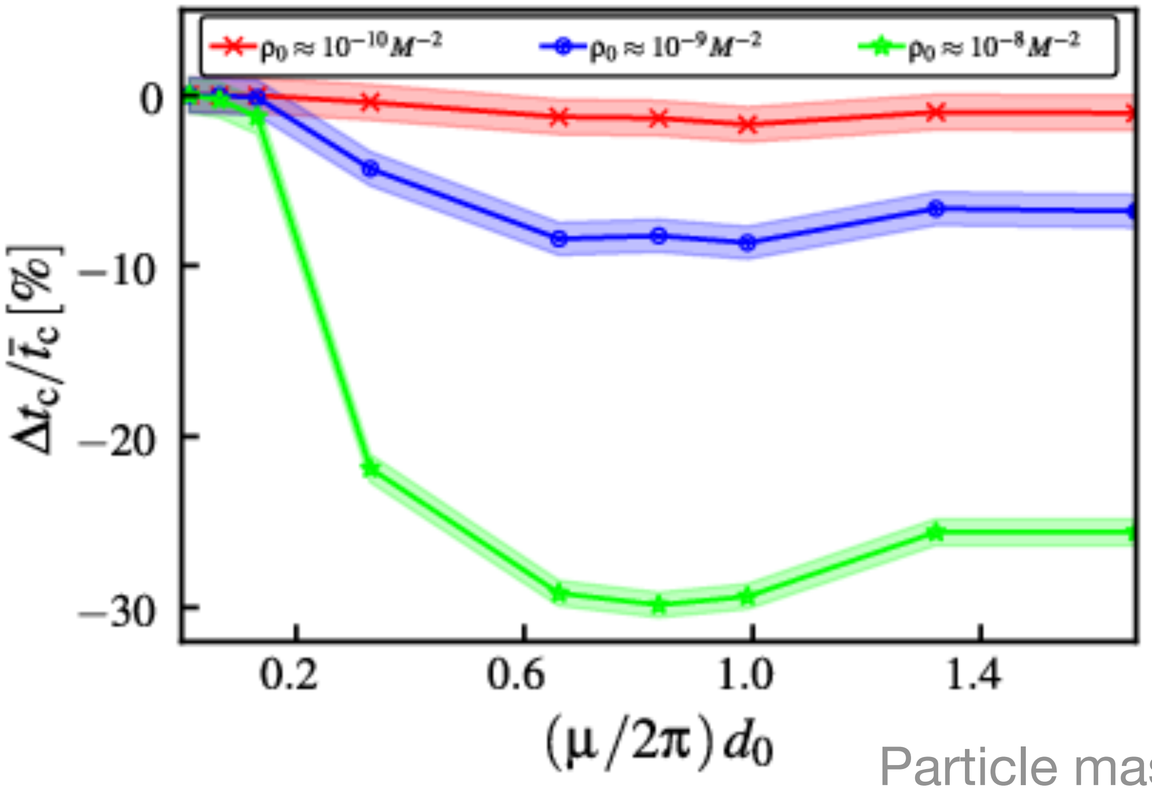
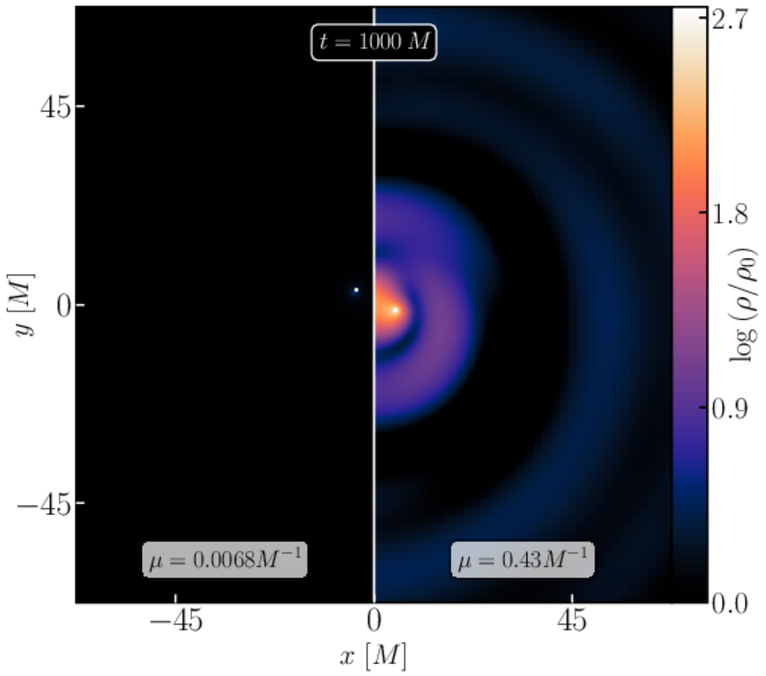
Surprisingly persistent effect at higher masses

dephasing



Particle mass

density



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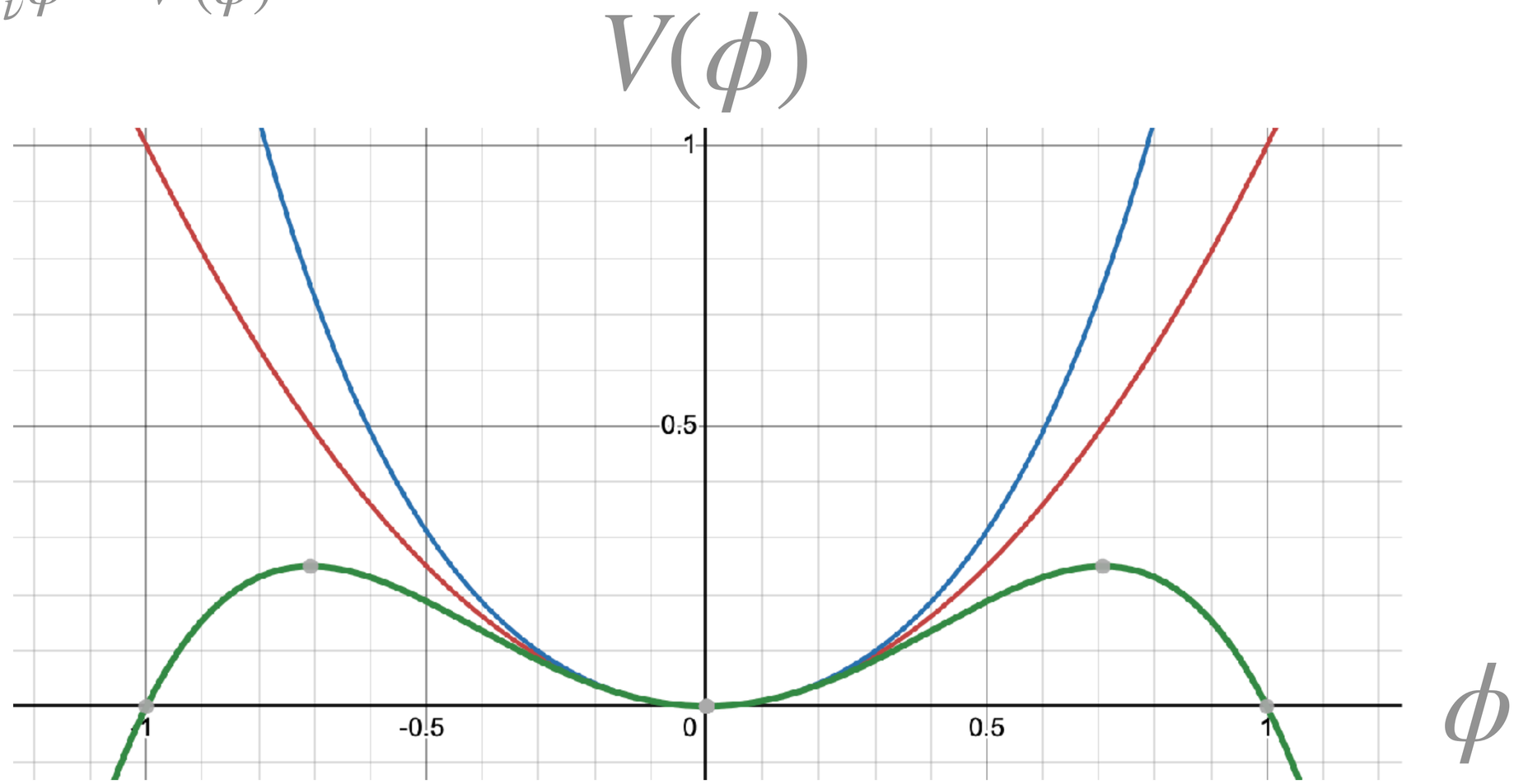
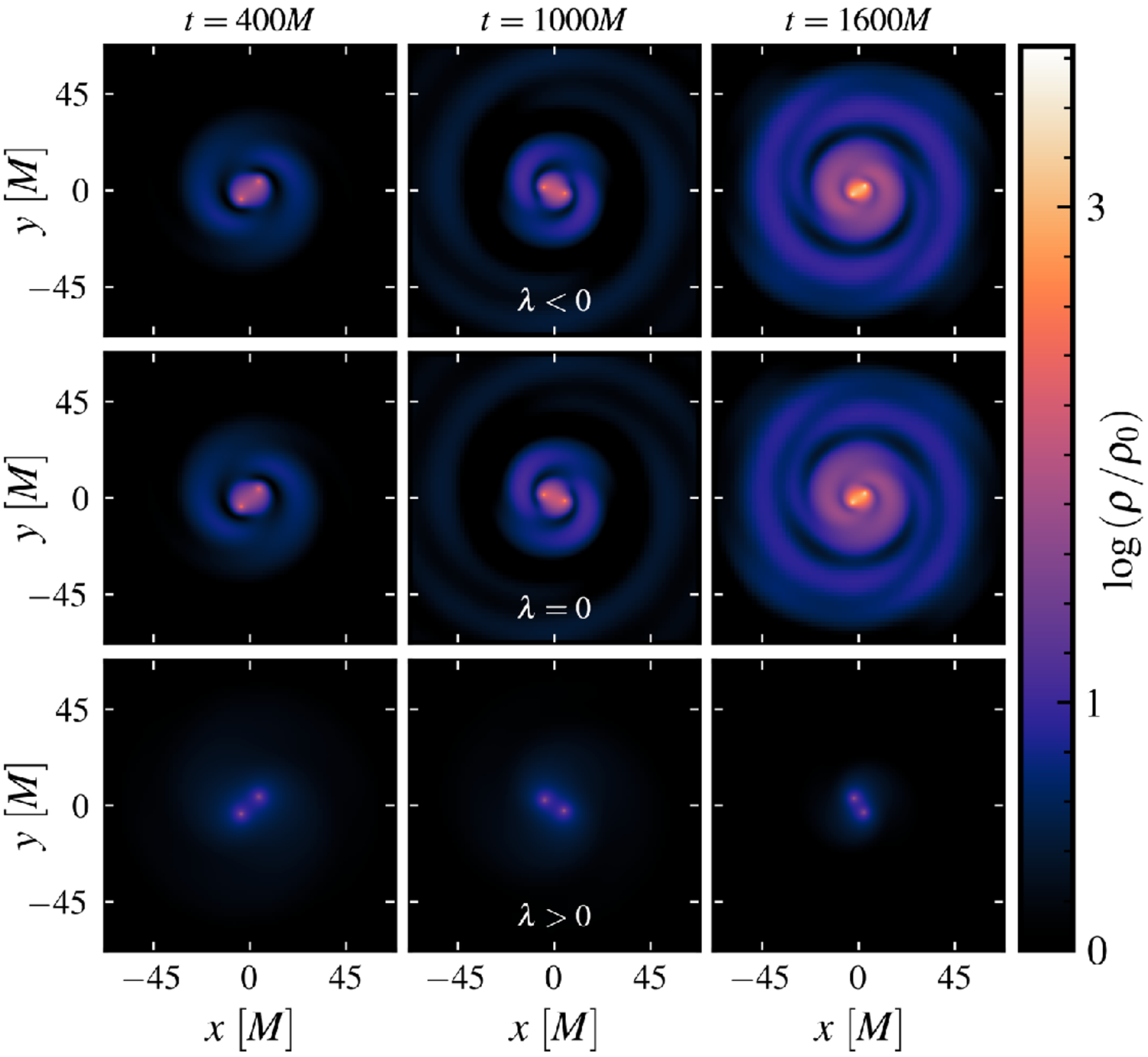
Self interactions

How do we add the self interaction?

$$g^{\mu\nu}\nabla_\mu\nabla_\nu\phi = V'(\phi)$$



Cloud suppressed by repulsive self interactions, so dephasing reduced



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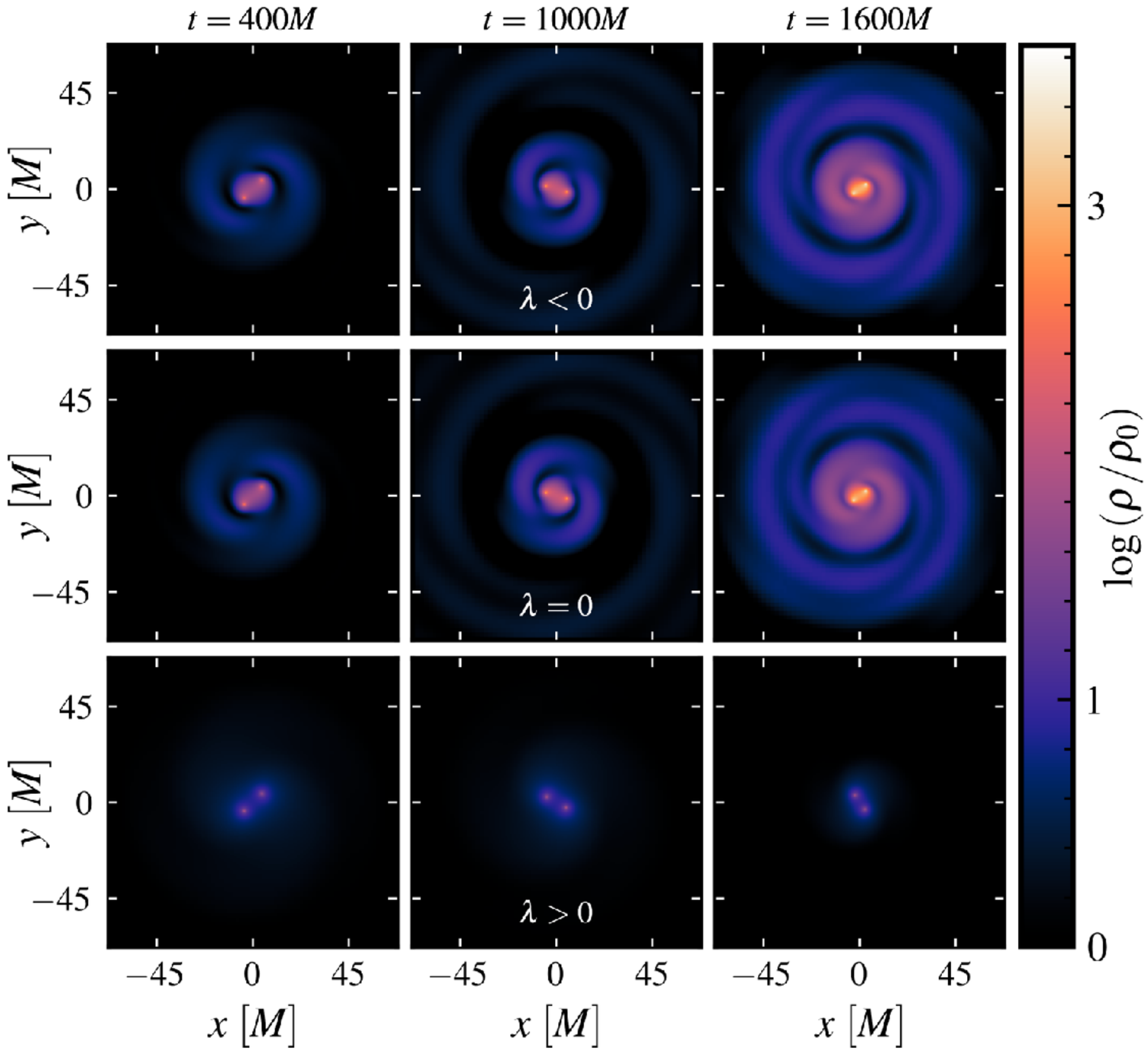
Cloud (slightly) enhanced by attractive self interactions, so dephasing increased



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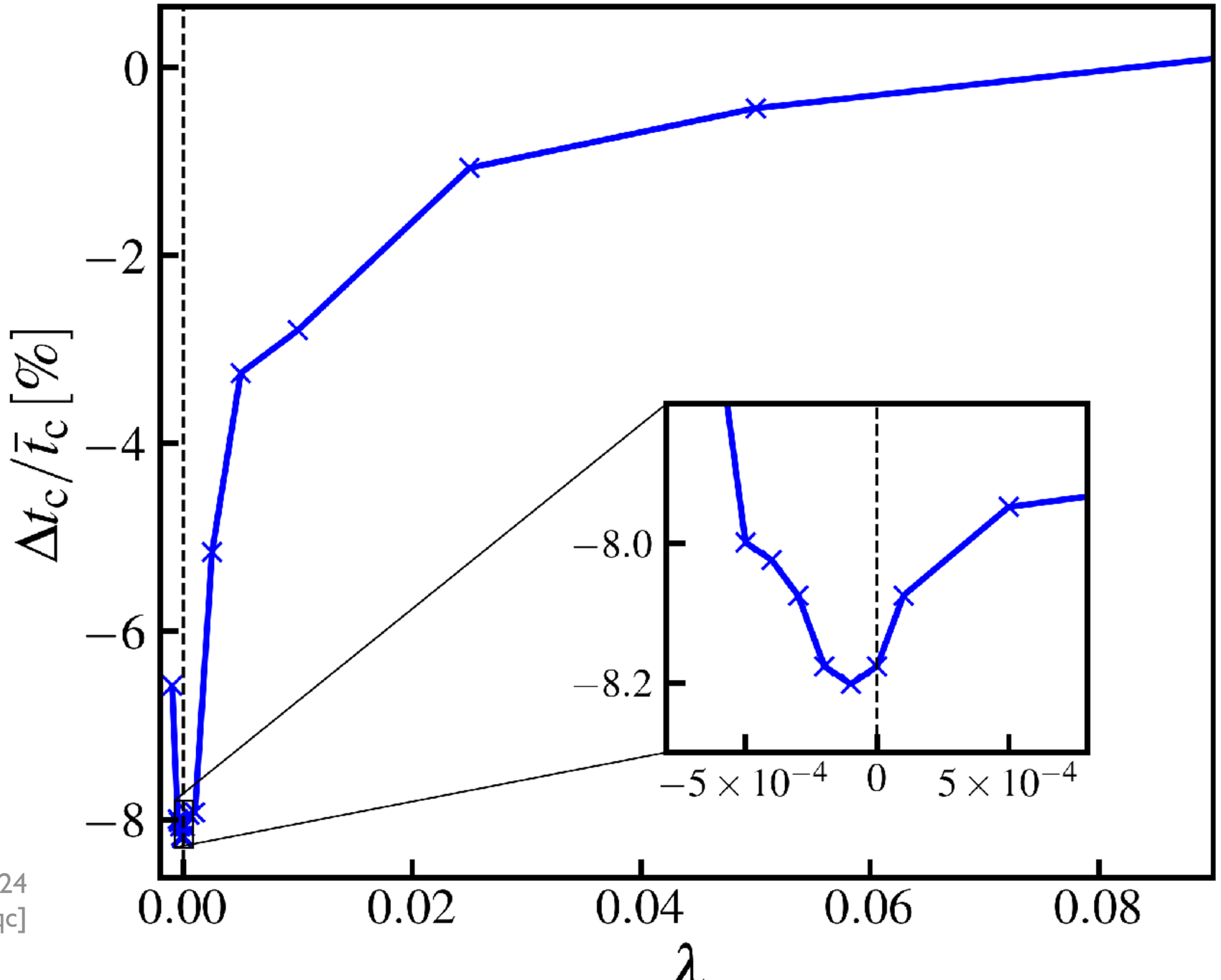
Attractive self interaction increases dephasing, up to a point



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Above this the field exhibits “bosenova” like bursts

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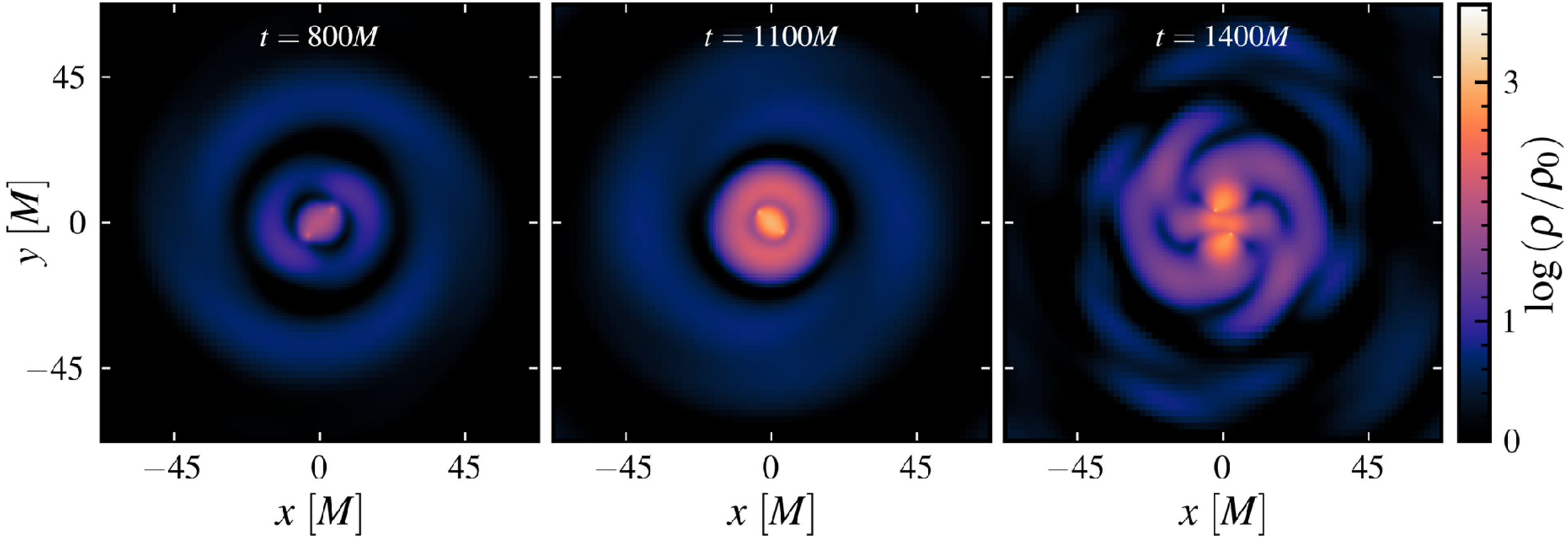
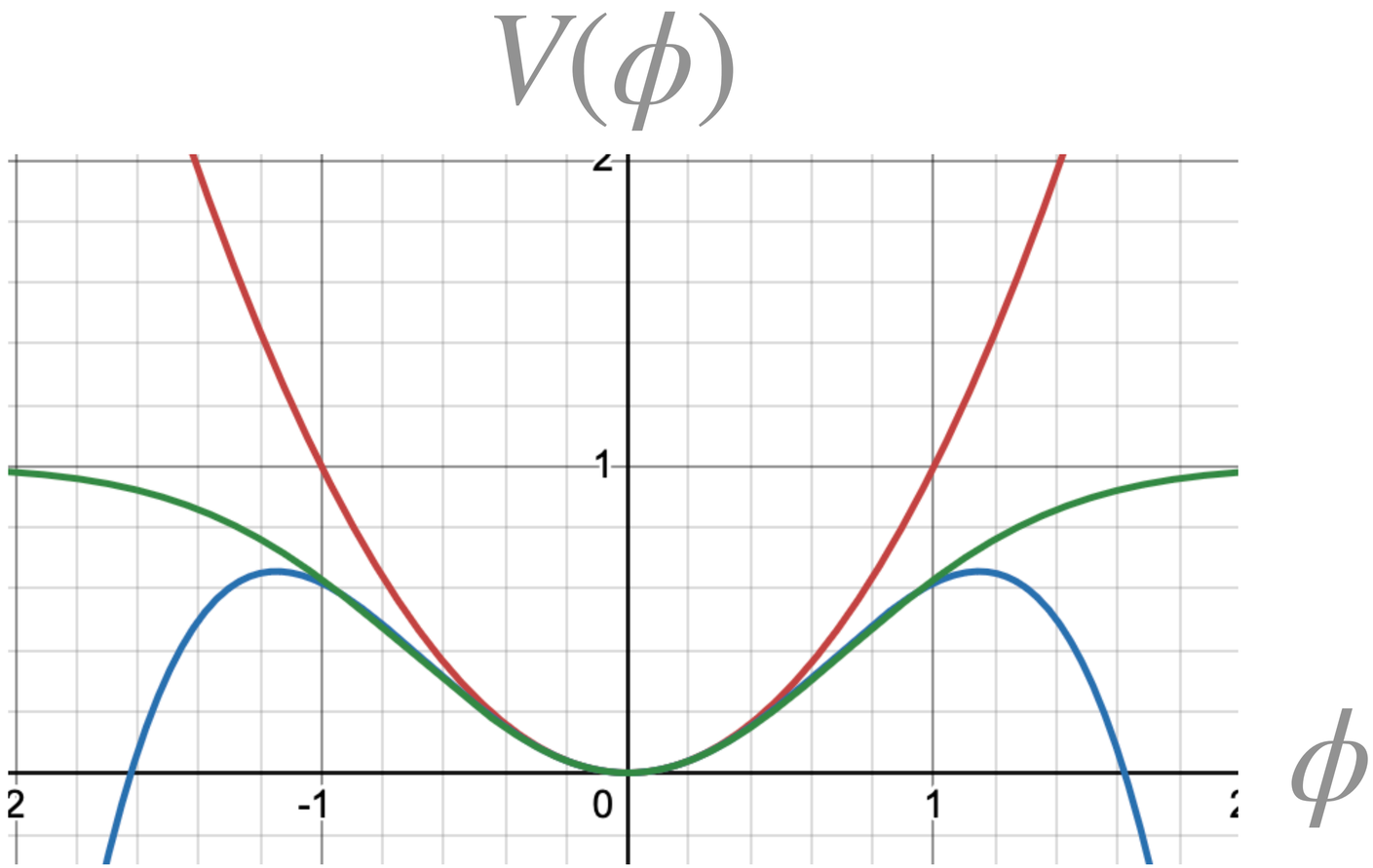
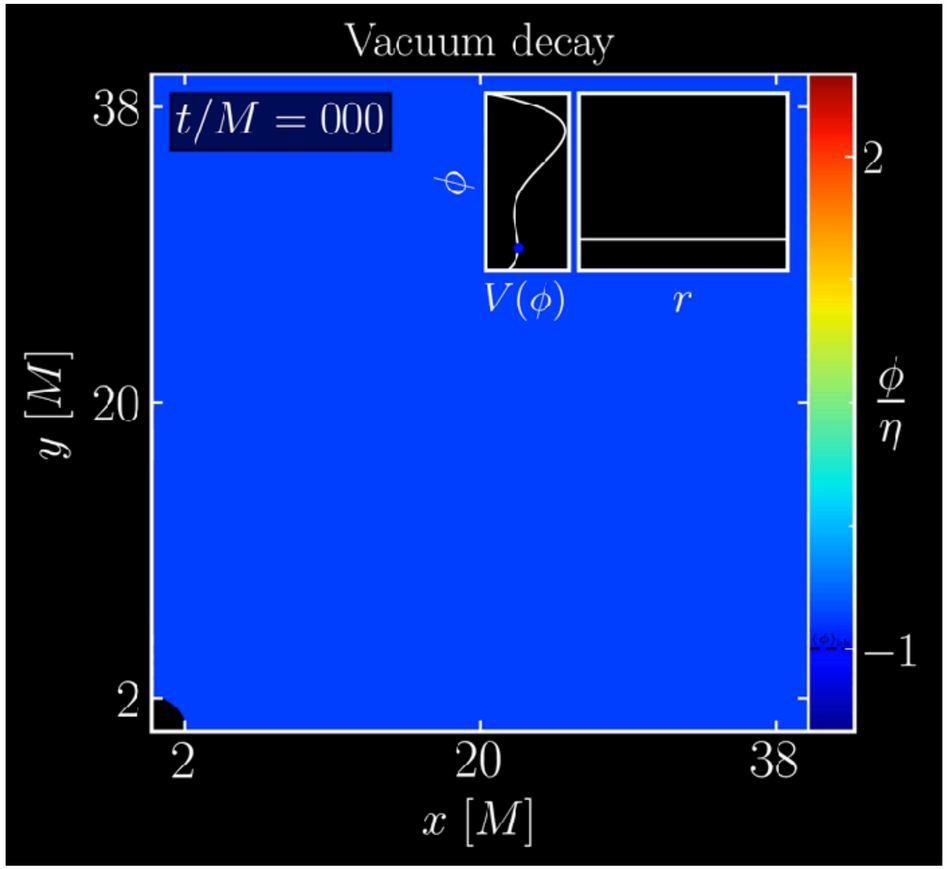


End state will depend on the form of the potential beyond the lambda phi^4 term



Overdensities from accretion around black holes may lead to phase transitions



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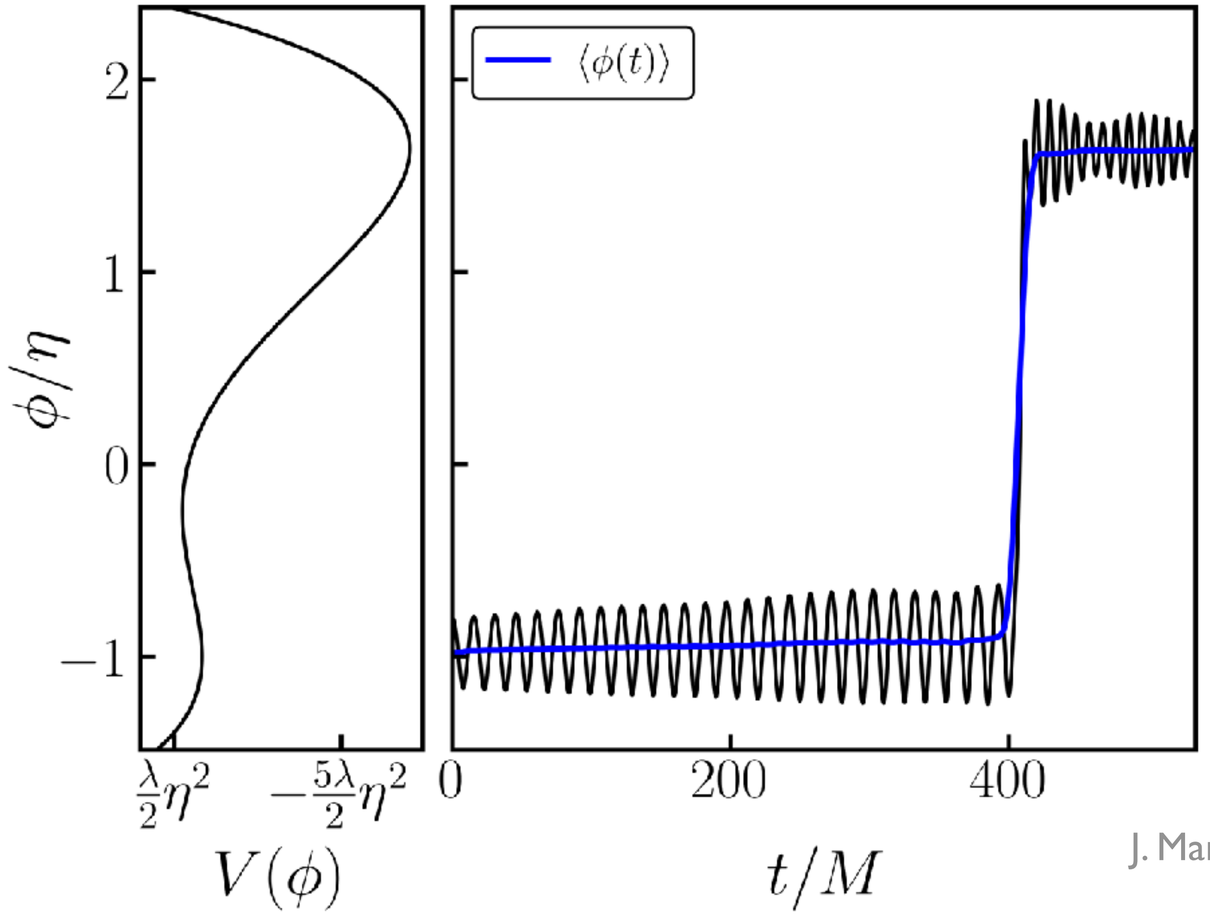

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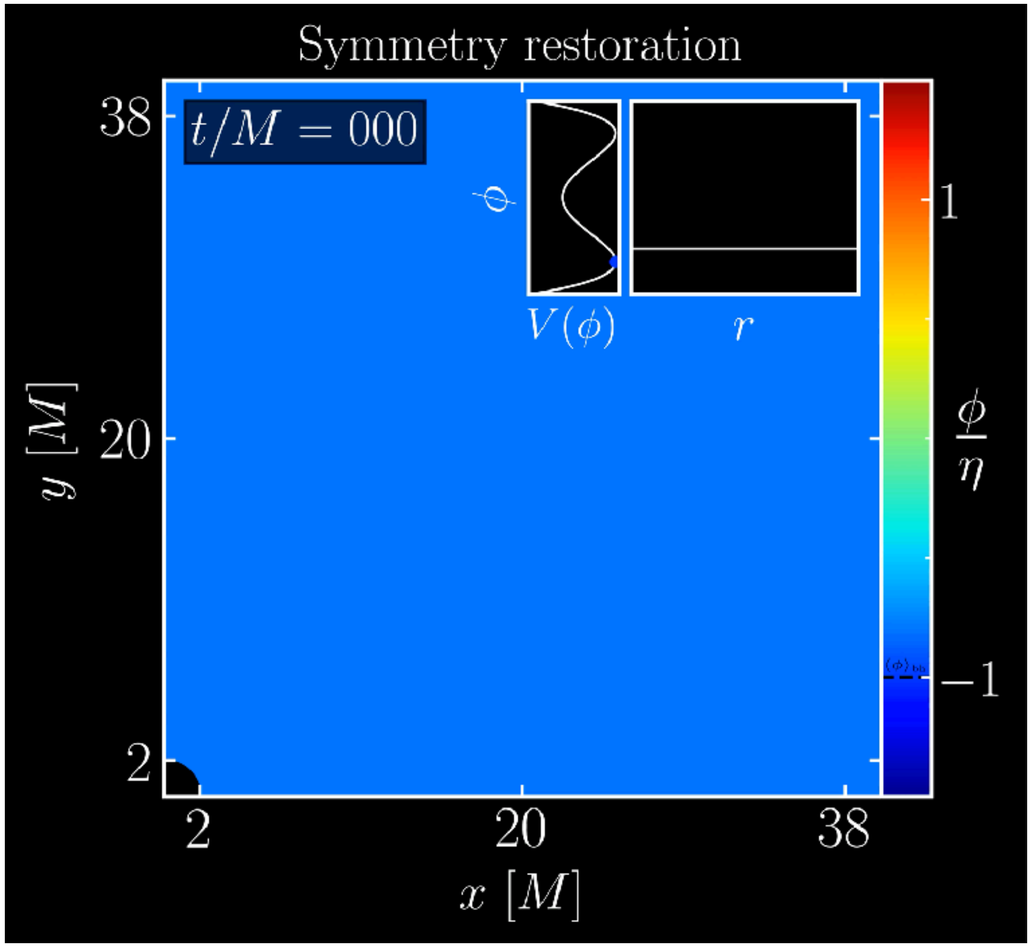
Overdensities from accretion around black holes may lead to symmetry restoration



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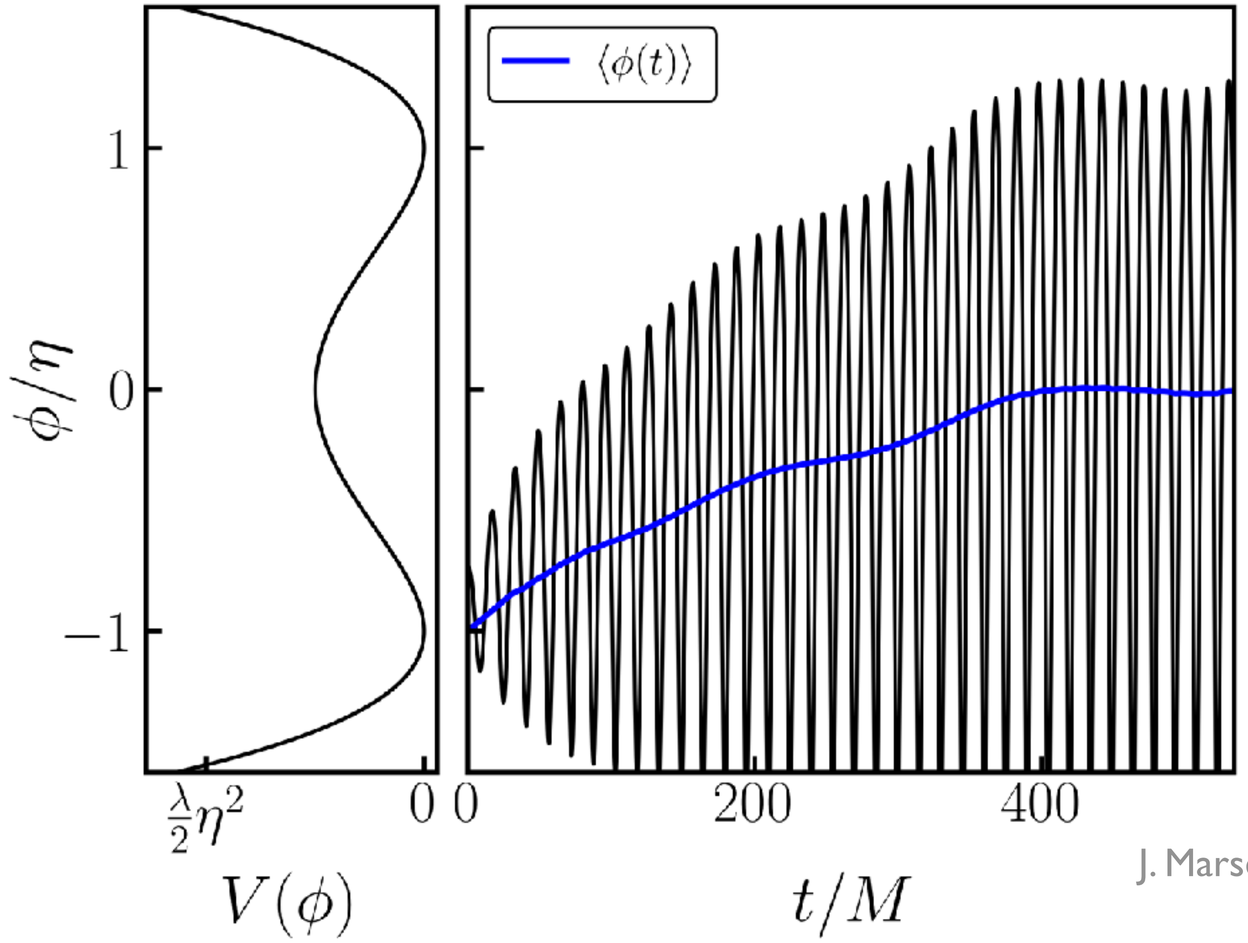

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How big are we talking about for these self interactions?

$$V(\phi) \sim m^2\phi^2\left(1 \pm \frac{\phi^2}{f^2}\right)$$

For most of our simulations

$$f \sim M_{pl} \quad \mu M \sim 1 \quad \rho \sim 10^{-9}M^{-2}$$

S2 star constraints on DM around Sag A are* $\rho \sim 10^{-15}M^{-2}$

Next steps

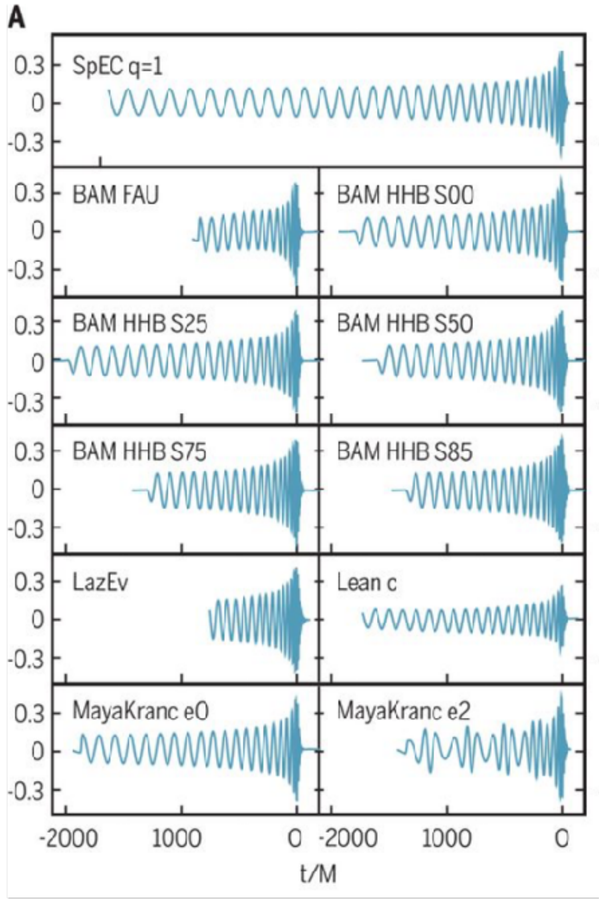
- **How to model this?**

  With help from Rodrigo Vicente

- **Study cases with precession / unequal masses**

  With help from Shrobana Ghosh

- **Study environments with angular momentum e.g. arising from superradiance**



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