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Fifth Force and Vainshtein Mechanism in two-body systems

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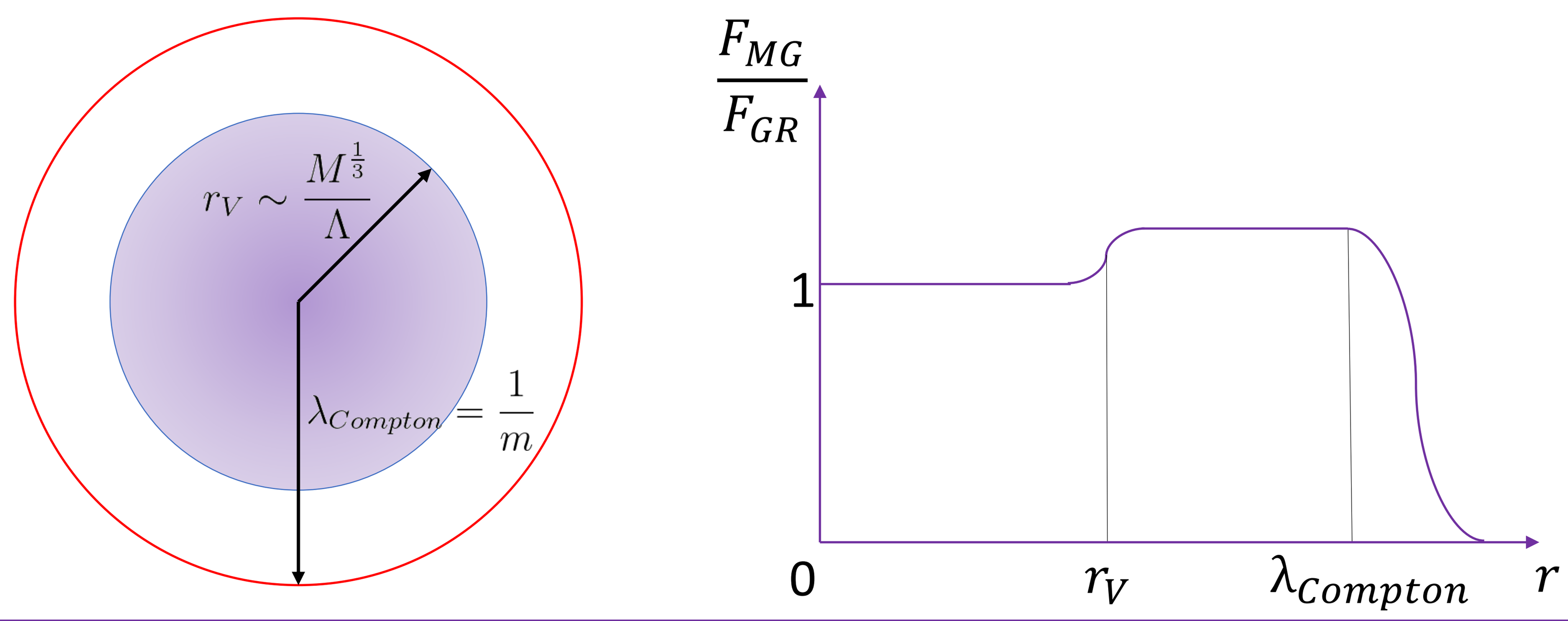
ABSTRACT

We propose the first analytic insight on how the Vainshtein screening mechanism occurs in two-body systems. We apply the variational approximation method to study the behaviour of the fifth force by considering the helicity-0 mode of the field in the DGP model of massive gravity for a two-body system. The analytical result is numerically applied to various two-body systems to show that the fifth force can sustain stable procession orbits under appropriate initial conditions.

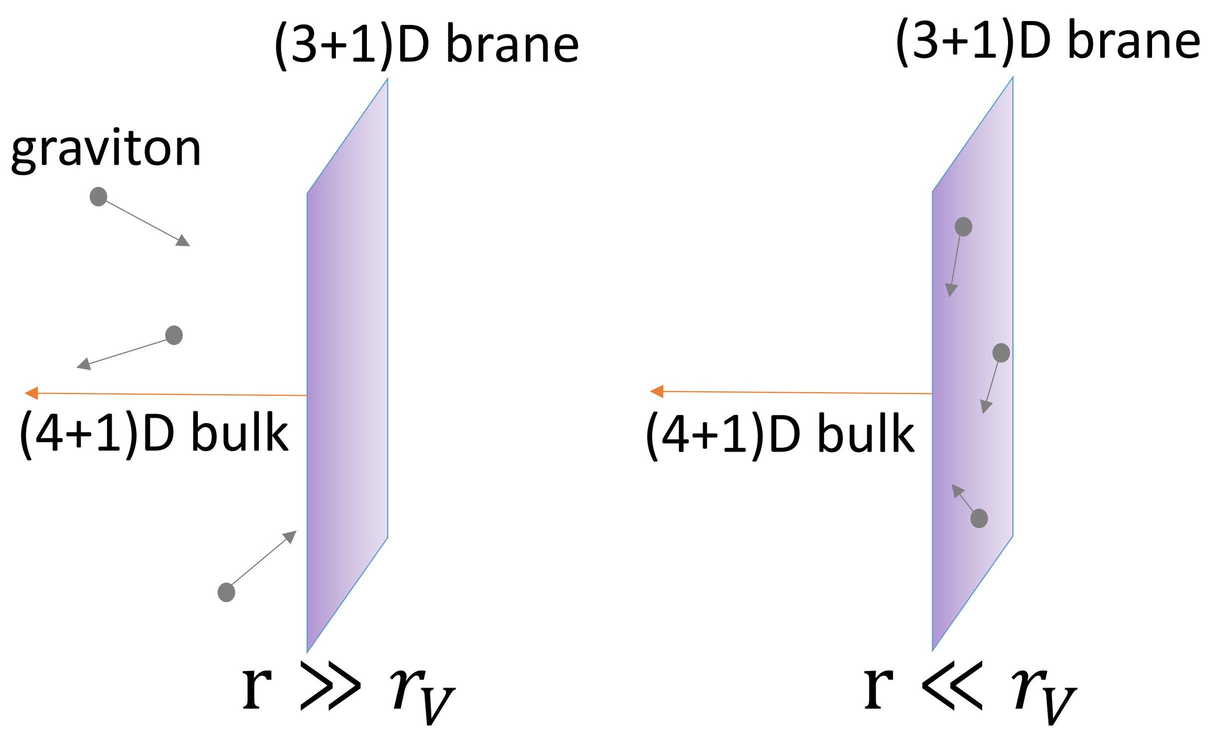
MASSIVE GRAVITY

- A *modified gravity theory* with m ≠ 0 graviton.
- Exists self-accelerating solution, i.e., no need for dark energy
- Extra gravitational force contributions, the 'Fifth Force' F_{fifth}.
- F_{fifth} causes discrepancy with observation (light bending).
  → *Vainshtein Mechanism*: F_{fifth} is screened within the so called Vainshtein radius r_v if having non-linear interaction.



DGP MODEL

- The first model of massive gravity to explicitly demonstrate the Vainshtein mechanism.
- D = (3 + 1) brane embedded in a D = (4 + 1) bulk.
- Gravitons can propagate in the extra spatial dimension.
- Gravitons tend to propagate along the brane within r_v (GR).



- Fifth force carried by a decoupled scalar field π.
- The Lagrangian density considered.

$$\mathcal{L}_\pi = \frac{1}{2}(\nabla\pi)^2 - \frac{1}{\Lambda^3}(\nabla\pi)^2(\nabla^2\pi) + \pi\rho$$

- A Galileon theory with cubic interaction.
- Solvable for one-body problem $\rho = \delta(r)$:

$$F_\pi = -\frac{\partial\pi}{\partial r} = -\frac{r\Lambda^3}{8}\left(-1 + \sqrt{1 + \frac{16M}{M_{Pl}r^3\Lambda^3}}\right)$$

- Two-body systems? Difficult due to non-linearity!

VARIATIONAL APPROXIMATION METHOD

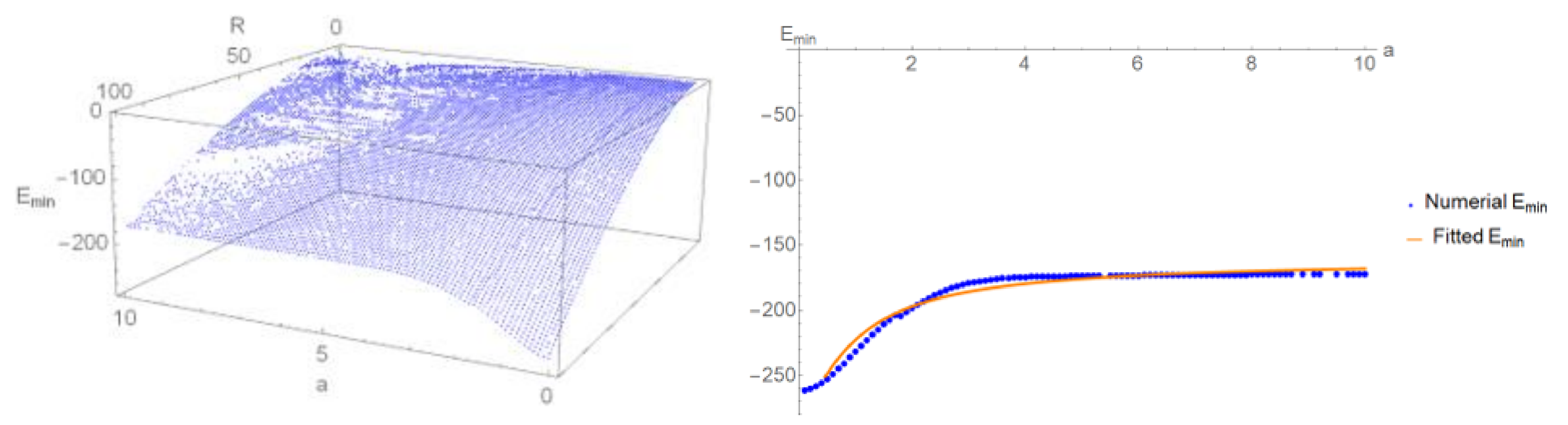
- Usually used in quantum mechanics: pick an ansatz for the wavefunction ψ and minimise $\langle\psi|H|\psi\rangle$.
- Here, we pick an ansatz for π based on the one-body solution and minimise.

$$E = \int d^3x \left[\frac{1}{2}(\nabla\pi)^2 + \frac{1}{\Lambda^3}(\nabla\pi)^2(\nabla^2\pi) + \pi\rho\right]$$

- First try gaussian! $\pi(\vec{r}_1, \vec{r}_2) = C_1 e^{-\frac{|\vec{r}_1 + \frac{a\hat{z}}{2}|^2}{L_1^2}} + C_2 e^{-\frac{|\vec{r}_2 - \frac{a\hat{z}}{2}|^2}{L_2^2}}$

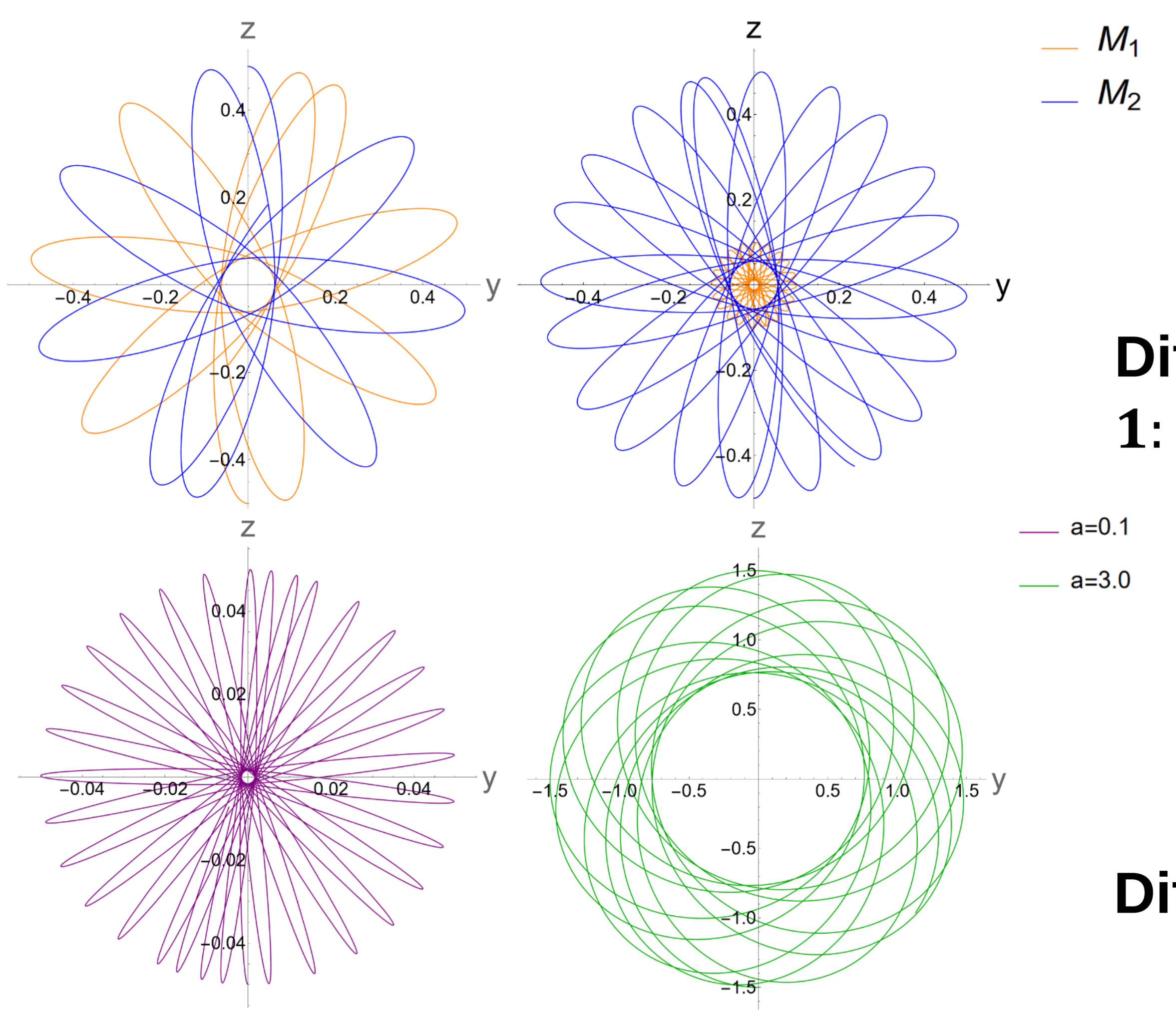
RESULTS AND APPLICATIONS

- Transform so that energy only depends on separation, $\boldsymbol{a}$, and the mass ratio, $\boldsymbol{R}$.
- Minimise the energy for each value of $(\boldsymbol{a}, \boldsymbol{R})$ using the ansatz.



- Fit E_{min} for a fixed R's: $E(a) = A + B \arctan a$

- Consider two masses that start moving in opposite directions in the yz-plane, numerically we found by solving the Lagrangian: $L = \frac{1}{2}M_1\dot{\vec{r}}_1^2 + \frac{1}{2}M_2\dot{\vec{r}}_2^2 - E(|\vec{r}_1 - \vec{r}_2|)$

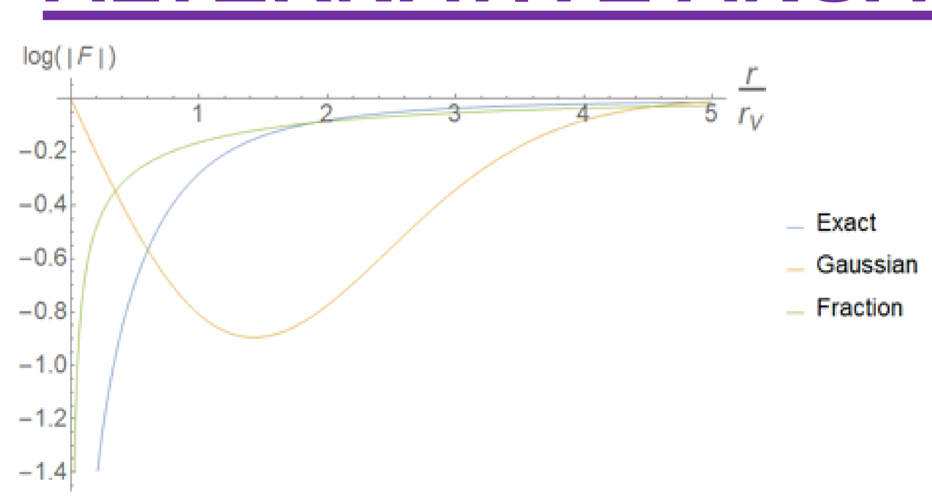


Different mass ratio $1:1$ and $1:10^6$

Different separations

Stable procession orbits under the fifth force

ALTERNATIVE ANSATZE



Sophisticated ansatze typically pose challenges for analytical integration -- tested only in one-body problem , e.g.

$$\pi(r) = \frac{A_1 - A_2 e^{-\sqrt{\frac{r}{L}}}}{B + (\frac{r}{L})}$$

Contributions to π with $\pi(0) = 0$ vanish → limitation of using point mass

SUMMARY & OUTLOOK

- Analytically solved the two-body problem using VAM with gaussian ansatz, and tested the validity of the latter
  → incorporate key physics properties
- Found stable procession orbits for binary system only by fifth force
- Will do: Apply the method to more body problem and/or using better ansatz (finite-size source? Compactify the space?) + combine with the GR force