Superluminality and EFT

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With Kurt Hinterbichler (in progress)

Outline

- Massive GR, DGP and galileons are three related modifications of gravity.
- Rich phenomenology from a simple Effective Field Theory (EFT).
- But also troubling *superluminality*.
- Would like to compare to another system.

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- Massive GR, DGP and galileons are three related modifications of gravity.
- Rich phenomenology from a simple Effective Field Theory (EFT).
- But also troubling *superluminality*.
- Would like to compare to another system.
- **QED**! Surprisingly, also exhibits "superluminality."
- Qualitative differences exist.
- Study sheds light on *both* modified gravity *and* QED.

Modified Gravity

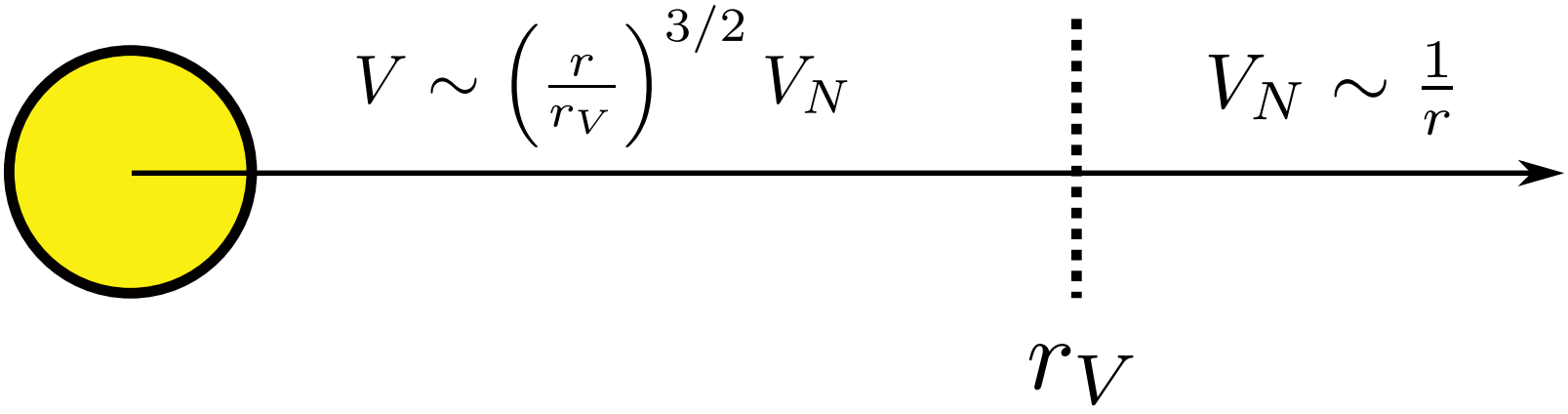
- Late time acceleration very exciting (and confusing).
- Long distance effect $\longrightarrow$ long distance modification?
- Two common ideas:
  1. Self acceleration (no Λ).
  2. Degravitation (screened Λ).
- Generically, new *light* DOF are needed, but must be hidden.
- Massive GR (mGR), DGP and galileons each hide in the same way.

Example: dRGT Massive GR

- Adding a mass to GR is a natural step to take.
- New long distance scale $m^{-1} \sim H_0^{-1}$.
- Surprisingly hard to make consistent, even classically (dRGT, 2010)
- New DOF hidden via non-linearities.
- *Same* non-linearities: superluminality. Generic to Vainshtein.

Cubic Galileon: The Bright Side

$$\mathcal{L} = -\tfrac{1}{2}(\partial\pi)^2 - \tfrac{1}{\Lambda^3}(\partial\pi)^2\Box\pi + \tfrac{\pi}{M_{pl}}T^{\mu}{}_{\mu}$$



- Physics captured by *galileon* EFT. $\pi \leftrightarrow$ longitudinal mode.
- Fifth force shuts off below $r_V = \Lambda^{-1}\left(M/M_{pl}\right)^{1/3}$. "Vainshtein."
- For us, $\Lambda^{-1} \sim 10^3$km, $r_V^{\odot} \sim 200$pc ($\gg 10^{-4}$pc).

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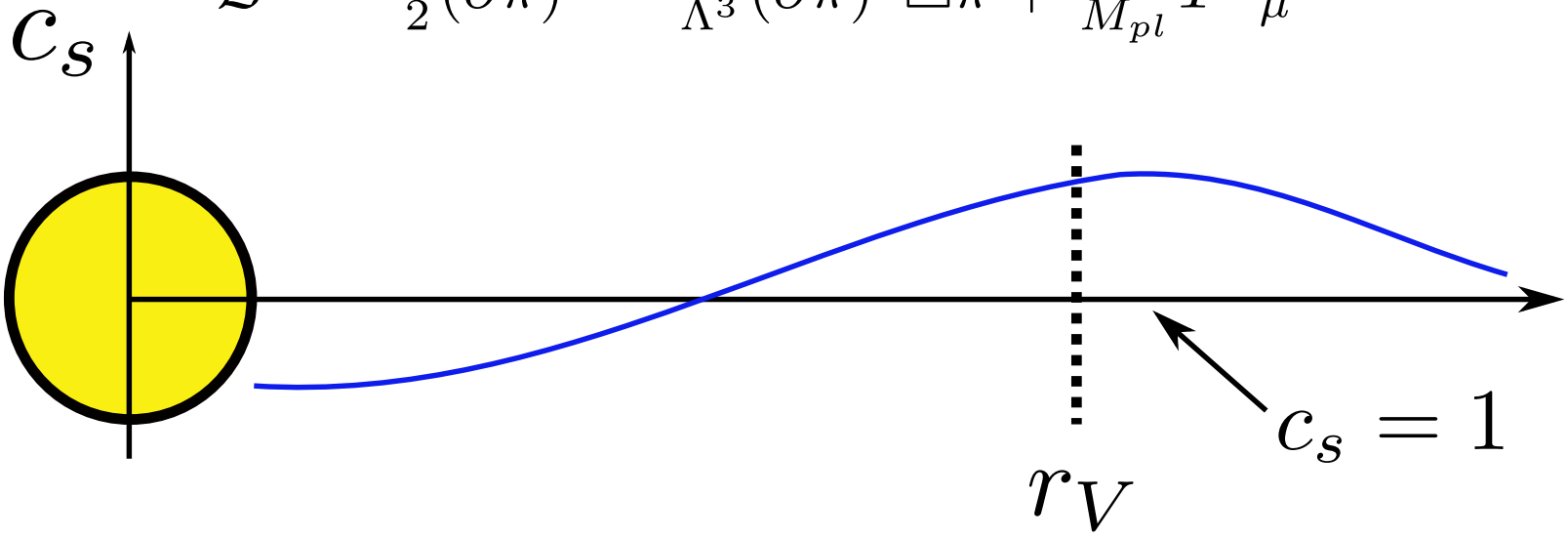
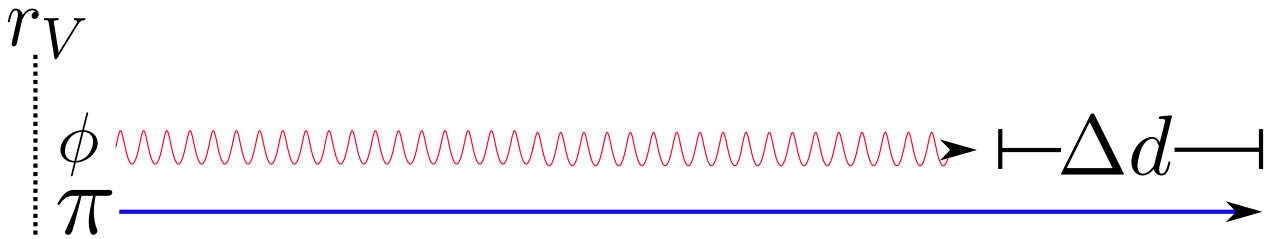


- Radial superluminality unavoidable. Immediately present.



- In a race, $\Delta d \sim r_V \gg \Lambda^{-1}$. "Macroscopic" superluminality.

Comparisons

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- Would like to compare to another EFT theory we trust.
- **QED!** (Drummond and Hathrell, 1980)
- Similar effect occurs for *photon* propagation in QED near black holes.
- Due to e^- induced non-minimal photon-gravity couplings.

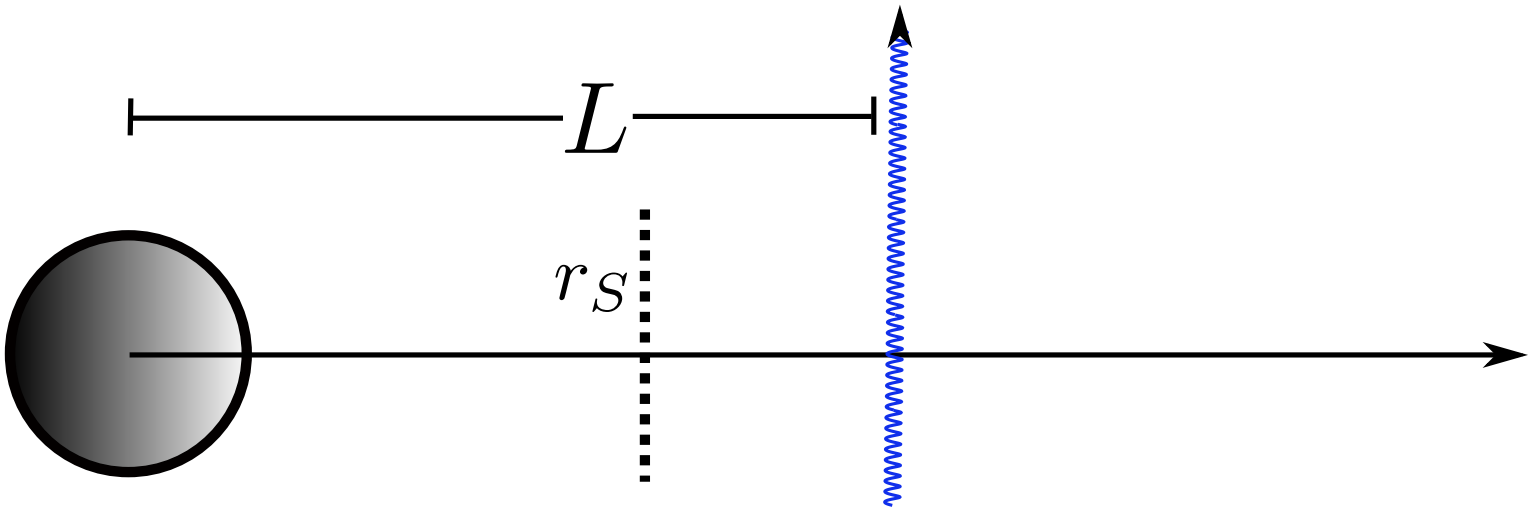
The Drummond-Hathrell EFT

$$\mathcal{L} = M_{pl}^2 R - \frac{1}{4e^2} F_{\mu\nu}^2 + \bar{\psi}\left(i\not{D} - m\right)\psi$$

$$\mathcal{L} = M_{pl}^2 R - \frac{1}{4e^2} F_{\mu\nu}^2 + \frac{c_1}{m^4} F_{\mu\nu}^4 + \frac{c_2}{m^2} R_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma} + \ldots$$

- If e^-'s aren't important, work with the EFT above.
- Any term with $F_{\mu\nu}$ can alter photon propagation.
- Last term gives the biggest effect on BH backgrounds.

The Drummond-Hathrell Effect

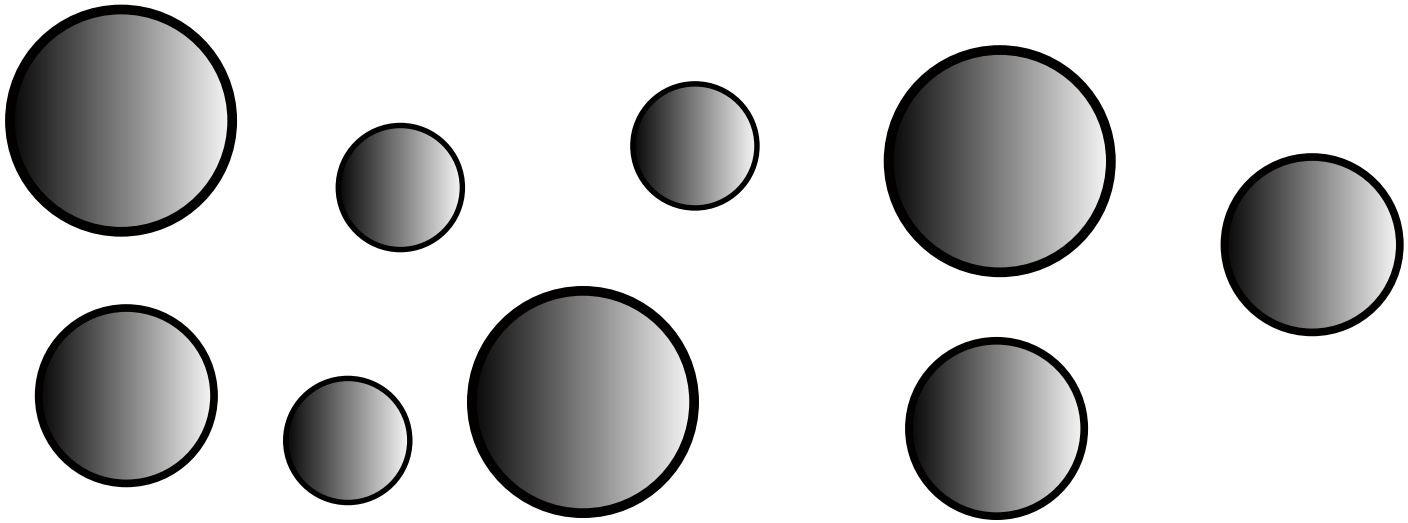


$$\mathcal{L} = M_{pl}^2 R - \frac{1}{4e^2} F_{\mu\nu}^2 + \frac{c_2}{m^2} R_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma} + \dots$$

- Similar to mGR/DGP/galileons, but qualitative differences.
- Photons can be "superluminal" in the *angular* direction.
- In a race, $\Delta d \sim m^{-1} e^2 \frac{r_S^2}{L^2} \ll m^{-1}$.
- Is this superluminality even real?

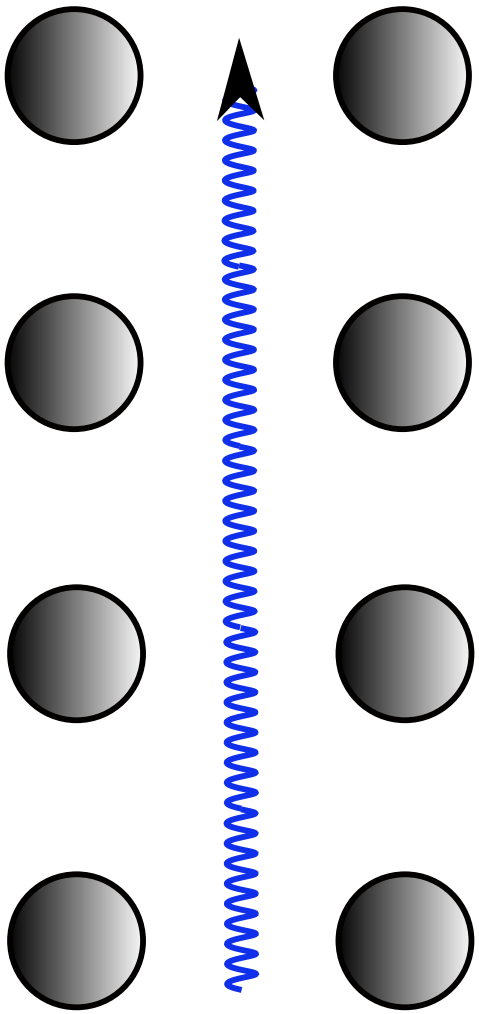
The Majumdar-Papapetrou Solutions

- We try to build "macroscopic" superluminality in QED, $\Delta d \gg m^{-1}$
- Simple setup: Add many extremal Reissner-Nordstrom black holes.



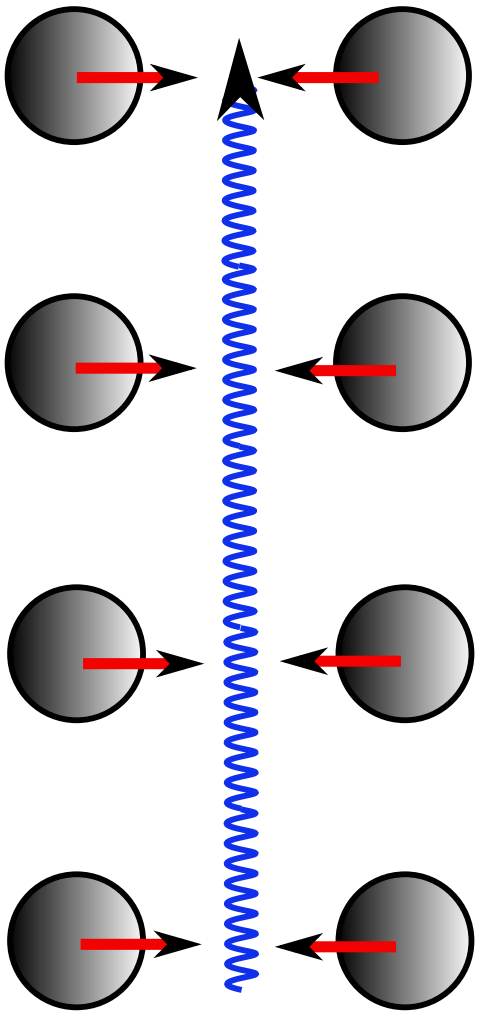
- An **exact** solution of *pure* Einstein-Maxwell (no e^-'s!).
- GR attraction and EM repulsion perfectly balanced.
- What stops superluminality here? Is QED $\cong$ mGR/DGP/Galileons?

Our Setup: A Tunnel of BHs



- Easiest to consider pairs of BH's.
- Now, Δd scales with number of pairs.
- Does QED protect itself?

Our Setup: Destabilization



- No longer an exact solution with e^-'s.
- Find perturbative corrections using
$$\mathcal{L} = M_{pl}^2 R - \frac{1}{4e^2} F_{\mu\nu}^2 + \frac{c_2}{m^2} R_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma} + \dots$$
- New force destabilizes the setup: $\delta F \sim \frac{1}{r^5}$.
- At maximum, $\Delta d \approx e \times m^{-1}$.
- *Qualitatively* differs from mGR/DGP/galileons.
- Indication that the DH effect is an artifact.

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- Main difference: easy to achieve $\Delta d \gg \Lambda^{-1}$.
- Indicative of r_V as the true cutoff? Hard to get $\Delta d \gg r_V$.
- Otherwise, closed timelike curves may simply never form.
- Study furnishes a neat demonstration of how a real world EFT protects itself from apparent superluminality.

Single BH Pair