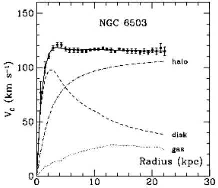
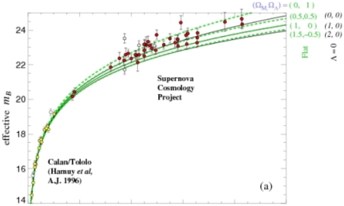
Is Anti-Gravity Possible ?

Why Large Scale Modification Of General Relativity ?

- Confrontation between different theories is nedded in order to understand what does and what does not depend on the particular gravitational model chosen to described the observations,
- General Relativity has only been confirmed in its weak field limits, and on Solar System scales,
- Dark Matter & Dark Energy paradigms





Massive Gravity Model

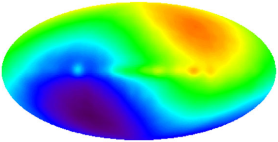
General Relativity + four scalar fields ϕ^0, ϕ^1, ϕ^2 and ϕ^3

$$\mathcal{S} = \mathrm{M}_{\mathrm{pl}}^2 \int \mathrm{d}^4x\sqrt{-g}\left[-\mathcal{R} + m^2\mathcal{F}\left(X, W^{ii}\right)\right] \quad , \quad \left\{ \begin{array}{l} X = g^{\mu\nu}\partial_\mu\phi^0\partial_\nu\phi^0, \\ W^{ij} = \left(g^{\mu\nu} - \dfrac{g^{\mu\alpha}g^{\nu\beta}\partial_\alpha\phi^0\partial_\beta\phi^0}{X}\right)\partial_\mu\phi^i\partial_\nu\phi^j. \end{array}\right.$$

- Minkowski space-time is the vacuum solution if $\phi^0 = t$ and $\phi^i = x^i$,
- This vacuum is stable against small perturbations,
- The background spontaneously breaks Lorentz invariance (Higgs mechanism for gravity),
- Gravitons are massive :

$$\omega^2 = k^2 + m^2.$$

- General relativity is recovered when $m \rightarrow 0$,
- The vacuum is invariant under translations of the coordinates along with a shift of the scalar fields .



The CMB seen by WMAP

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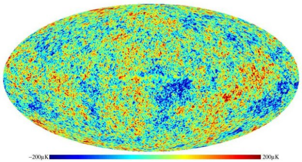


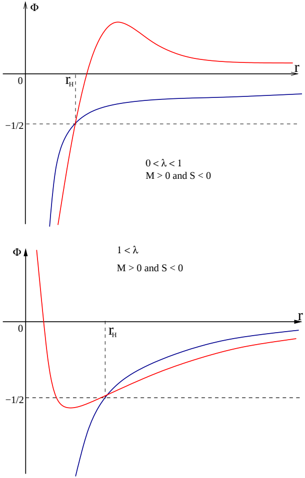
The CMB seen by WMAP

Exact static spherically symmetric solutions (ArXiv 0902.3899)

- The exact static spherically symmetric solutions of the Einstein equations have been found in massive gravity :

$$\begin{aligned} ds^2 &= (1+2\Phi)\,dt^2 - \frac{dr^2}{1+2\Phi} - r^2 d\Omega^2, \\ \Phi &= -\frac{M}{r} - \frac{S}{r^\lambda}, \end{aligned}$$

  where λ is a free parameter of the action.
- These solutions depend on two integration constants M and S instead of one in General Relativity
  $\rightarrow$ richier phenomenology
- For $S = 0$, this solution reduce to the usual Schwarzschild solution of General Relativity,
- The force acting on a particle of mass m is $F = -m\nabla\Phi$.



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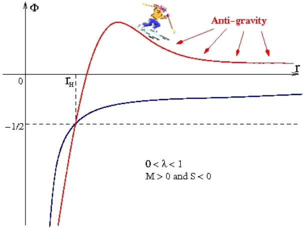

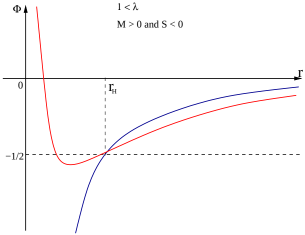

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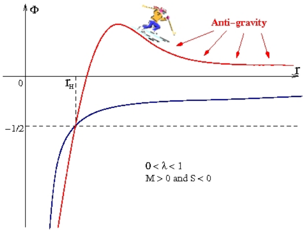

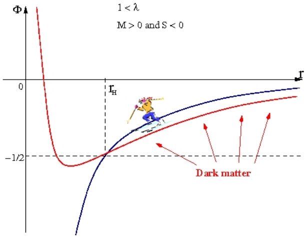

Conclusion

- Massive gravity theories are well defined and are consistant with the actual test of gravity
- If General Relativity is modified in the infrared, we should expect a more rich phenomenology than the one predicted by Einstein's theory.