Testing Gravity

Vancouver 2015

Lam Hui
Columbia University


IT TAKES SKILL
TO TRIP OVER
FLAT SURFACES

Fantastic experiments

Laboratory tests: $\text{acc.} < 10^{-13} g$

Astrophysical tests: $\beta, \gamma, \text{etc.} < 10^{-4}$

Cosmological tests: $\text{dev.} < 0.01 - 0.1$

How about the state of theory?

Minimalist

$$S = \int d^4x \sqrt{-g}\,(M_P^2 R + c_1 R^2 + \ldots) + S_{\rm matter}$$

expand $g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$

$$\sqrt{-g}R \sim \partial^2 h + \partial^2 h^2 + \partial^2 h^3 + \ldots$$

$$\sqrt{-g}R^2 \sim \partial^4 h^3 + \ldots$$

$$\text{e.o.m.}\;:\; \partial^2 h + h\partial^2 h + \ldots + \frac{c_1}{M_P^2}(\partial^2 h)^2 + \ldots \sim G T_{\rm matter} \sim \frac{GM}{r^3}$$

$$h \sim \frac{GM}{r} + \left(\frac{GM}{r}\right)^2 + \ldots + c_1 \frac{M_P^{-2}}{r^2}\left(\frac{GM}{r}\right)^2 + \ldots$$

testing gravity = checking coeff.

strong field

$$\frac{M_P^{-2}}{r^2} \sim 10^{-66}\ \frac{\rm cm^2}{r^2}$$

Quantum correction

Donoghue (1994) showed:

$$h \sim \frac{GM}{r} + \left(\frac{GM}{r}\right)^2 + \ldots + c_1 \frac{M_P^{-2}}{r^2}\left(\frac{GM}{r}\right)^2 + \ldots + \left(\frac{GM}{r}\right)\frac{M_P^{-2}}{r^2}$$

precise calculable coeff.
from one-loop correction to grav. propagator.

larger than this
but still very small.

e.g. for earth-moon system, this is larger by 10^{76}

Non-minimalist

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But why haven't we seen it in the solar system?

Scalar is very weakly coupled to baryons.
(But O(1) coupling to DM is possible.)
Note: scalar needs not be universally coupled.

Scalar is screened in the solar system.

?

Scalar is unscreened in compact objects (scalarization).

Scalar is unscreened on cosmological scales (chameleon, galileon, k-mouflage)

Screening mechanisms

Chameleon: *screening in Milky Way constrains* $m_\phi^{-1} < \mathrm{a\ few\ Mpc}$
$V(\phi)$ *thus, negligible effects on large/linear scales.*

(Should stop doing linear-scale forecast for f(R); nonlinear scales still interesting though.)

Galileon: *good features are symmetries, presence of self-acceleration,*
$(\partial\phi)^2\Box\phi$ *and unsuppressed effects on linear scales.*

A problematic feature is superluminal excitations around reasonable backgrounds. Can it be saved by duality? Another issue is the low (energy) cut-off.

Massive gravity, which is closely related, has the additional issue of strong coupling around those backgrounds.

K-mouflage?

$[(\partial\phi)^2]^2$

Parametrizing our ignorance

In the absence of compelling alternatives to GR, the pragmatic approach is to parametrize deviations from it.

PPN has played a very useful role in small scale tests.

On cosmological/linear scales, natural parametrizations exist.
A systematic approach is EFT.

But there is no single parametrization that covers both small and large scales. We can of course do this on a model by model basis.
But is a generic parametrization possible ?

Lorentz violations

Recall Weinberg/Deser theorem: at low energies (long distances), a Lorentz invariant theory of a massless spin-2 particle must be GR.

The Lorentz violation must be confined to the gravitational sector. Any LV coupling to SM is very small. Why ?

Massive gravity in condensed matter system (of the LV variety).

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Spectral Sum Rules and Magneto-Roton as Emergent Graviton in Fractional Quantum Hall Effect

Siavash Golkar, Dung X. Nguyen, and Dam T. Son

Enrico Fermi Institute, James Franck Institute and Department of Physics, University of Chicago, Chicago, Illinois 60637, USA

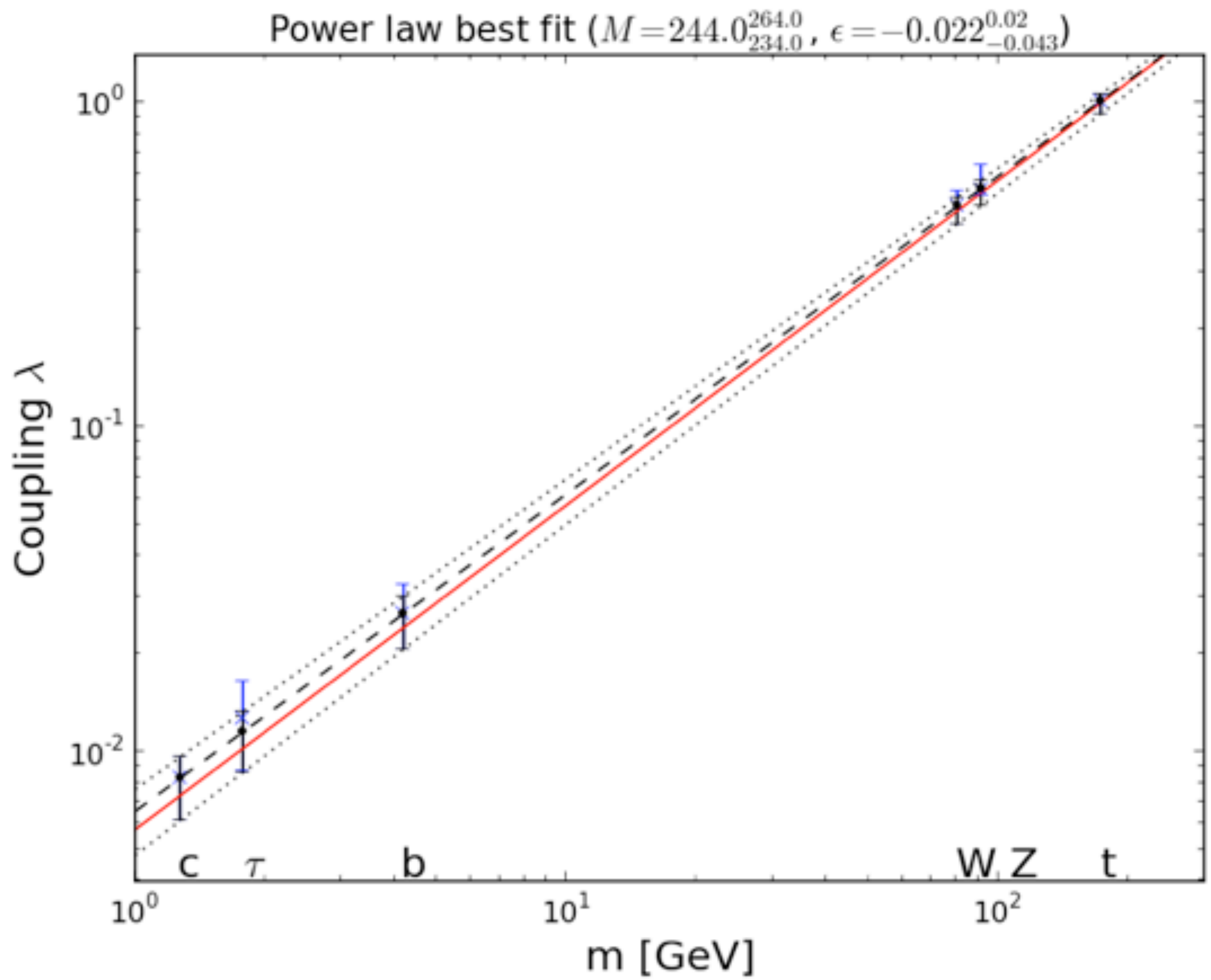
Abstract

We consider gapped fractional quantum Hall states on the lowest Landau level when the Coulomb energy is much smaller than the cyclotron energy. We introduce two spectral densities, $\rho_T(\omega)$ and $\bar{\rho}_T(\omega)$, which are proportional to the probabilities of absorption of circularly polarized gravitons by the quantum Hall system. We prove three sum rules relating these spectral densities with the shift $\mathcal{S}$, the q^4 coefficient of the static structure factor S_4, and the high-frequency shear modulus of the ground state μ_∞, which is precisely defined. We confirm an inequality, first suggested by Haldane, that S_4 is bounded from below by $|\mathcal{S}-1|/8$. The Laughlin wavefunction saturates this bound, which we argue to imply that systems with ground state wavefunctions close to Laughlin's absorb gravitons of predominantly one circular polarization. We consider a nonlinear model where the sum rules are saturated by a single magneto-roton mode. In this model, the magneto-roton arises from the mixing between oscillations of an internal metric and the hydrodynamic motion. Implications for experiments are briefly discussed.

PACS numbers: 73.43.-f

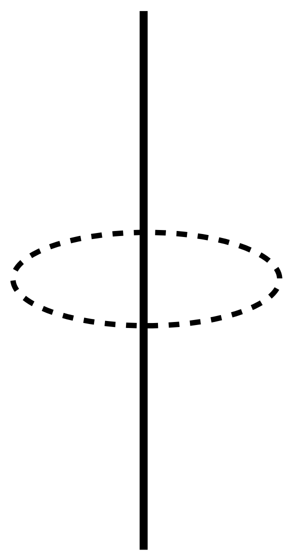
Higgs

$$\mathcal{L}_{\text{Yukawa}} = \lambda_e \phi \bar{\psi}_e \psi_e + \lambda_\mu \phi \bar{\psi}_\mu \psi_\mu + \ldots$$



Electron and muon interacts by Higgs exchange in a way that is proportional to their masses. (But Higgs is massive.)

And of course, there is the cosmological constant problem.



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Levon's proposal:

A three day workshop on various ways of testing gravity - cosmological, astrophysical and terrestrial. ....

We would like to bring together people with different perspectives on testing gravity. Perhaps people who would not normally attend the same conference. The scientific objective is to give theorists, working on modified gravity theorist, a realistic view on what they can expect to be technologically possible. On the other hand, the experimentalists and observers will welcome the chance to search for new kinds of questions that their measurements can answer.

Let's thank our organizers!