Gravity Group, UC Davis

Faculty:

Steven Carlip

Graduate Students:

Damien Martin

Rajesh Kommu

At least three others interested. . .

Visitors:

Alberto García, CINVESTAV, Mexico

Recent personnel changes:

Sachindeo Vaidya (postdoc) $\Rightarrow$ tenure track faculty position,
Indian Institute of Science, Bangalore

David Mattingly (postdoc) $\Rightarrow$ computer start-up company

Jim Van Meter (student) $\Rightarrow$ NRC postdoc, NASA Goddard

Eric Minassian (student) $\Rightarrow$ postdoc, ITP, Bern

Yujun Chen (student) $\Rightarrow$ postdoc, Perimeter Institute

Sayandeb Basu (student) $\Rightarrow$ visiting faculty, University of the Pacific
(postdoc and potential permanent position waiting for him in India)

Peter Salzman (student) $\Rightarrow$ Wall Street

Some recent accomplishments:

Carlip served on Visiting Committee to NSF Physics Division

Carlip elected Fellow of the Institute of Physics

Carlip became a Divisional Associate Editor of PRL,
and joined editorial board of Proc. R. Soc. London A

General strategy

Look for “windows” into quantum gravity

- Black hole thermodynamics/statistical mechanics:
  collective properties of microscopic states
- Very early Universe cosmology: theory and possible observation
- Semiclassical Newtonian gravity and experiment
- Lattice approximations (“Lorentzian dynamical triangulation”)
- Lower dimensional models and other simplified models

No premature commitment to any one particular approach;
search for general implications of attempts to quantize gravity

Black hole statistical mechanics and the problem of universality

Black holes are thermodynamic objects

$$T = \frac{\hbar\kappa}{2\pi c}, \qquad S_{BH} = \frac{A}{4\hbar G}$$

Quantum ($\hbar$) and gravitational (G)

Does this thermodynamic behavior have a microscopic "statistical mechanical" explanation?

Black hole entropy counts:

- Weakly coupled string and D-brane states
- Horizonless “fuzzball” geometries
- States in a dual conformal field theory “at infinity”
- Spin network states crossing the horizon
- Spin networks *inside* the horizon
- “Heavy” degrees of freedom in induced gravity
- Points in a causal set crossing the horizon
- No local states – it’s inherently global
- Nothing – it comes from quantum field theory in a fixed background, and doesn’t know about quantum gravity

Answer: apparently, all of the above

Is there an underlying structure that can explain why these approaches all agree?

Program:

1. Near the horizon, black holes have an approximate two-dimensional conformal symmetry
2. The presence of the horizon (weakly) breaks this symmetry
3. Symmetry-breaking leads to Goldstone modes
4. Techniques from conformal field theory (Cardy formula) can be used to count these states – answer is universal, independent of details of underlying theory

Current Status:

1. Symmetry-breaking and state-counting successfully understood in two formalisms: “horizon as a boundary” and “horizon as a constraint”
2. Correct Bekenstein-Hawking entropy obtained for a very large class of black holes
   - any dimension
   - charged and rotating
   - with higher order curvature terms in action
3. Goldstone modes can be understood explicitly in 2+1 dimensions
4. “Horizon constraint” method can reproduce some detailed properties of string theoretical black holes

Next steps:

1. Extend results to light cone quantization
2. Work out explicit relationship to other approaches
   - path integral/instanton calculations
   - “membrane paradigm”
   - “isolated horizons” and loop quantum gravity
3. Couple Goldstone modes to matter: reproduce Hawking radiation

Semiclassical gravity and experiment

"If quantum gravity is so hard, then maybe you shouldn't quantize gravity."

Møller, Rosenberg: "semiclassical gravity"

$$G_{ab} = 8\pi G \langle T_{ab} \rangle$$

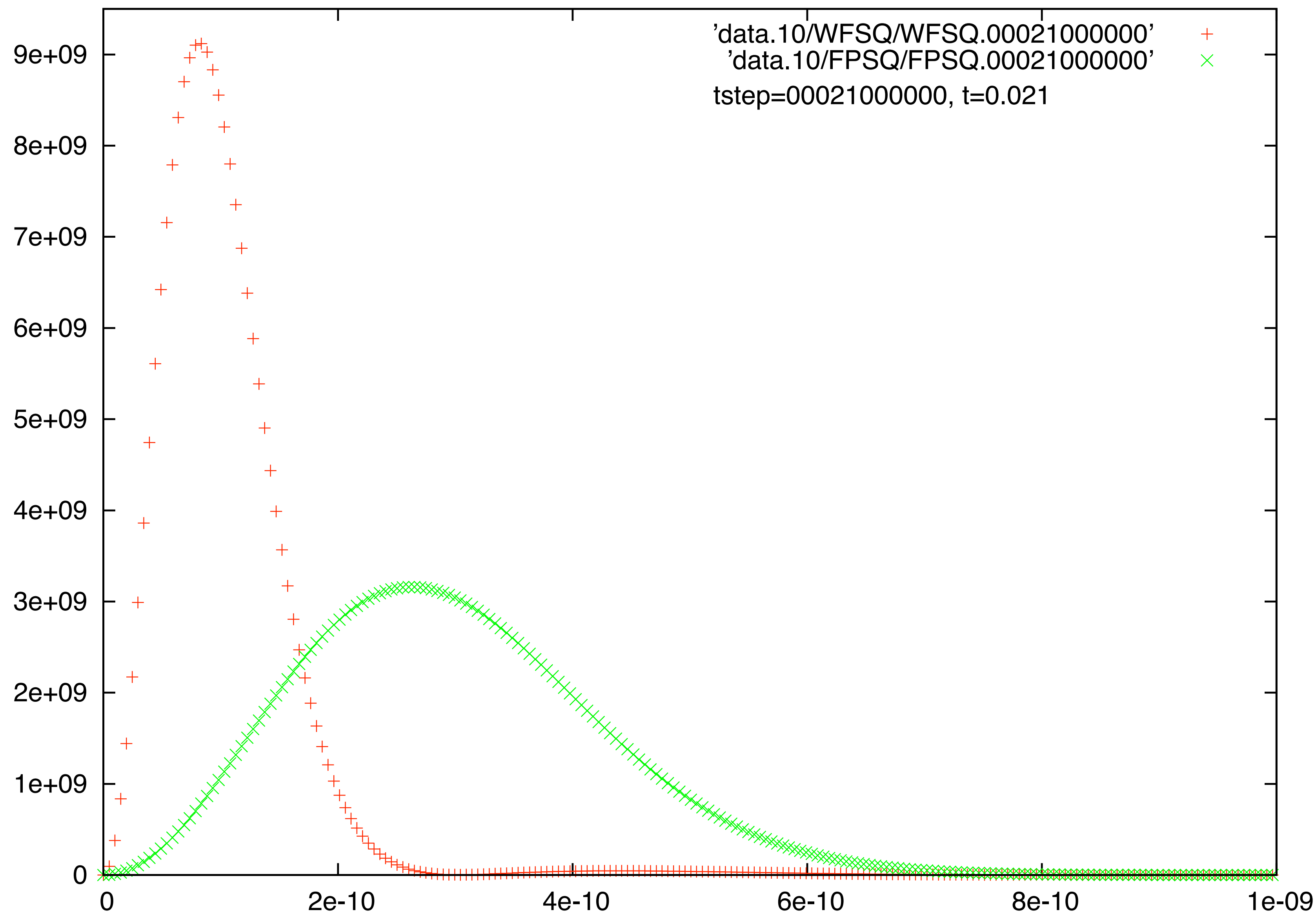
Newtonian version:

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m} \nabla^2 \Psi(\tilde{\mathrm{x}}, t) + V(\tilde{\mathrm{x}}, t)\Psi(\tilde{\mathrm{x}}, t)$$

$$V(\tilde{\mathrm{x}}, t) = -Gm^2 \int \frac{|\Psi(\tilde{\mathrm{x}}', t)|^2}{|\tilde{\mathrm{x}} - \tilde{\mathrm{x}}'|} d^3x'$$

Nonlinear Schrödinger equation: V depends on Ψ

For small distances/large masses, self-interaction leads to wave function “collapse”



Comparison of Schrödinger-Newton and free particle wave functions. For large masses, the wave packet “collapses” under its self-gravitation.

Preliminary results:

- Present molecular interferometry experiments miss "collapse" by about two orders of magnitude
- Model should be testable in next generation experiments

Semiclassical gravity may be experimentally excluded!

Further directions:

Even if semiclassical gravity is wrong, Schrödinger-Newton equation should be a good Hartree-like approximation for many-body systems

May be able to test TeV-scale gravity at distances $\sim .1\mu$m

Some other projects

Causal dynamical triangulations: New approach to discretizing quantum gravity while preserving causal structure (Ambjørn, Loll)

- Try to understand observables
- Compare to other quantizations in 2+1 dimensions

Quantum fluctuations of spacetime topology: For negative cosmological constant, we have shown that a "sum over topologies" leads to a high probability for a homogeneous universe; can this be generalized to $\Lambda > 0$?

Black hole "information loss": In string theory AdS/CFT correspondence, local operators at boundary $\Leftrightarrow$ bulk operators that are nonlocal in time; is this important for questions of unitary evolution?

Quantum gravity phenomenology: Can we find new astrophysical tests of Planck-scale physics?

Tests of gravitational theories: Work on "speed of gravity," equivalence principle tests, tests of brane world models