Quantum Sensing for Fundamental Physics

Peter Graham

Stanford

Topics for all 3 lectures

- 1. Gravitational wave detection with new quantum sensors
- 2. Open questions in particle physics and new detectors

Part I: Gravitational Waves

Topics for gravitational waves

- 1. Why study them?
- 2. New ways to detect with quantum sensors (atomic interferometry)
- 3. New science available from quantum sensing

Gravitational Wave Observations





On Sept 14, 2015 LIGO saw the first gravitational wave!

Since then already many exciting observations:

Gravitational Wave Observations





On Sept 14, 2015 LIGO saw the first gravitational wave!

Since then already many exciting observations:

- many black hole binaries discovered, wide range of masses has implications for generation mechanism, observed very close to horizon, strong-field gravity, spins being measured...
- neutron star observations tell us about origin of heavy elements (kilonova), internal state of neutron stars, limit on modified gravity theories (speed of GWs), standard sirens for measuring cosmological distances...

Why are GW's so useful?

gravitational waves open a new window to the universe

Two key properties:

- 1. Sourced by mass, not charge
 - compact objects (BH's, NS's, WD's) bright GW sources, hard to detect in EM
 - unique information on physics of these objects, high density environment, strong gravity...
- 2. Very weakly interacting
 - may be only way to directly observe the universe before formation of CMB (signals from inflation, reheating, early universe phase transitions, etc)

Every EM band had unexpected discoveries, gravitational waves give a new spectrum



Gravitational Spectrum

Gravitational waves will be major part of future of astronomy, astrophysics and cosmology

Crucial to observe as many bands as possible!

many observatories operating or planned from ~ nHz to kHz



Important to consider all possible detection techniques to cover the entire spectrum

LIGO Noise Sources

New ways to detect GW's with quantum sensors

Quantum Technologies?

e.g. atomic clocks have improved sensitivity rapidly

