The Advanced LIGO Instrument, Its First Science Run and Gravitational Wave Detections

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1.3 billion years ago ... give or take few hundred million
The first observation run of Advanced LIGO - some stats

- 24/7 operators
- Data quality shifts
- Takes time to "lock" $\sim 1$hr
- Intricate procedures, (mostly) automated
- $V \sim r^3$
Why is it so hard to detect GWs?

Spacetime is hard!

- different methods: pulsar timing, CMB polarization, etc
- ground based: resonant masses (narrowband) interferometry (broadband)
- different sources for different methods
- some LIGO sources:
  - black hole coalescences (but not too heavy)
  - neutron star coalescences
  - supernovae (close by)
  - stochastic background
  - spinning pulsars

\[ \text{strain} = \frac{\Delta L}{L} \]

event of Sep 14, 2016, first GW detection

3 solar masses of energy
How does LIGO do it?

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LIGO is a Michelson interferometer with 4km long arms that are Fabry Perot cavities, with power recycling at the input port and signal extraction at the output port...
How does LIGO do it?

And a complex controls scheme to keep all cavities on resonance!
Fundamental Noise Sources

- seismic noise
- thermal noise
- quantum noise

Advanced LIGO Design

Performance: takes time to achieve perfection
How to beat quantum noise

More laser!

And, later, quantum squeezing, to shape the influence of shot noise versus radiation pressure.
How to beat seismic noise

- 2-stage active isolation platform to reduce motion above some 0.2 Hz (2 x 6 DOFs to control)
- quadruple pendula which isolate $\frac{1}{f^8}$ (4 x 6 DOFs to think about)
- if the ground moves some 1nm at 10 Hz, we can measure 9 orders of magnitude less motion!

- name of the game is give up super low frequency performance... so sources of noise at 0.2Hz and below can keep LIGO from running (e.g. ocean storms, earthquakes)
How to beat thermal noise

- big, expensive mirrors (40kg) with low losses and low absorption (few ppm)
- big laser beam (10 cm diameter)
- monolithic suspension with glass fibers, laser welded on the mirror
- low loss coatings (dominant term for LIGO)
At LIGO's sensitivity it’s easier to make a list of what doesn’t make noise...

- must carefully measure environmental couplings
- various ambient sensors (microphones, seismometers, magnetometers, etc)
- injection methods - make our own noise
- set data vetoes to cut polluted data
- over 100,000 auxiliary channels are checked to ensure the signal is of astrophysical origin!
Thank you for your attention! Questions?