Advanced LIGO in brief
What we’ll be covering

• Sensitivity Curve(s) of the Advanced LIGO design

• Optical layout
  • How is Advanced LIGO different to a simple Michelson?

• Timeline and highlights so far
Design Sensitivity of Advanced LIGO

What are we aiming for? What are the limiting noise sources we expected to see?
So far: quantum noise-limited sensitivity

- Set by the optical topology of the detector: layout, power, mirror masses, and squeezing

**Low freqs:**
Quantum **Radiation Pressure** Noise
\[ S_{rp} \propto \frac{P}{m^2} \]
- Photons hitting mirrors
- Depends on beam power & mirror mass

**High freqs:**
**Shot** Noise
\[ S_{sh} \propto \frac{1}{P} \]
- Photon counting at detector
- Depends on beam power
Many other noise sources, including:

**Seismic Noise**

- Motion of the test masses due to ground motion
- Not just earthquakes! E.g. trucks passing, waves crashing, people dancing in the control room,…
- $1/f^2$ suppression from each pendulum stage; 4 stages.
Many other noise sources, including:

**Coating Brownian**
- Brownian motion of the atoms in the coatings of the mirrors
- Depends on material choices and temperature
Many other noise sources, including:

**Controls noises**
- Noise introduced when we try to control the interferometer
- Generally affect low frequencies more
- Many, many different types and sources, some understood more than others (we’ll come back to this...)

![](image)
Optical Layout of Advanced LIGO

How does Advanced LIGO differ from a simple Michelson?
So far: simple Michelson

- Michelson you saw yesterday required **1MW** input power to achieve sensitivity of $10^{-23}$ h/sqrt(Hz)...unfortunately not very practical.

- Advanced LIGO design specifies **125W** input power

![LIGO Diagram](image-url)
Optical Layout of Advanced LIGO

Goal: high signal strength, low quantum noise

- Core Principal: Michelson
Optical Layout of Advanced LIGO

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- Core Principal: Michelson
- Arm Cavities
  - Amplify signal
How does the sensitivity change?
Optical Layout of Advanced LIGO

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- Power Recycling
  - Increases arm power (lower quantum shot noise)
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Optical Layout of Advanced LIGO

Goal: high signal strength, low quantum noise

- Core Principal: Michelson
- Arm Cavities
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- Power Recycling
  - Increases arm power (lower quantum shot noise)
- Signal Recycling (actually Resonant Sideband Extraction)
  - Transmit signal efficiently to detector
How does the sensitivity change?
Detector layout in Finesse

- DRFPMi + input and output optics
  - Mode cleaners, modulators, isolators, squeezer, ...
- Still not the full set of optics that make LIGO happen!
Current Status – some highlights

Observing runs, sensitivity, and detections
aLIGO timeline

- 2000-2008: iLIGO, eLIGO
- 2008-2015: commissioning aLIGO
- 14th September 2015: aLIGO turns on, first detection
- Observing runs:

<table>
<thead>
<tr>
<th>Run</th>
<th>Dates</th>
<th>LIGO BNS characteristic inspiral range</th>
<th>Detections</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1</td>
<td>Sept 2015 - Jan 2016</td>
<td>~80Mpc</td>
<td>3 (all BBH)</td>
</tr>
<tr>
<td>O2</td>
<td>Nov 2016 - Aug 2017</td>
<td>~100Mpc</td>
<td>8 (1 BNS)</td>
</tr>
<tr>
<td>O3a</td>
<td>Apr - Oct 2019</td>
<td>~110Mpc</td>
<td>~40 candidates so far, many types</td>
</tr>
<tr>
<td>O3b</td>
<td>Nov 2019 -</td>
<td>~130Mpc +</td>
<td></td>
</tr>
</tbody>
</table>
Observing runs

LIGO
- O1: 80 Mpc
- O2: 100 Mpc

Virgo
- O3: 105-130 Mpc

KAGRA
- O4: 160-190 Mpc
- O5: Target 330 Mpc

LIGO-India
- O2: 50 Mpc
- O3: 90-120 Mpc
- O5: 150-260 Mpc
- Target 330 Mpc
Change in sensitivity through the observing runs

Detector noise expressed as equivalent GW strain

Source: DCC LIGO-G1900897
O3a LLO detector sensitivity

Many controls noises!

Source: DCC LIGO-G1901761
O3a: frequency-independent squeezing introduced
Effect of squeezing on the sensitivity curve

- Frequency independent
- Looks like changing the input power
- Currently use to boost high-frequency sensitivity
- Future: frequency dependent – choose angle to suit each frequency. Aim: use in O4 (~2022)
Keep up with detector alerts

- [gracedb.ligo.org](http://gracedb.ligo.org)
- Chirp