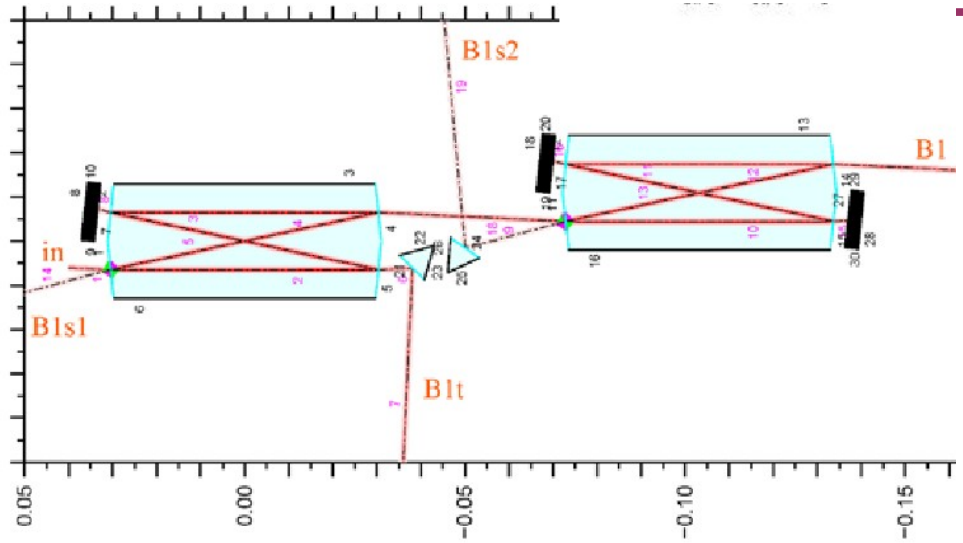
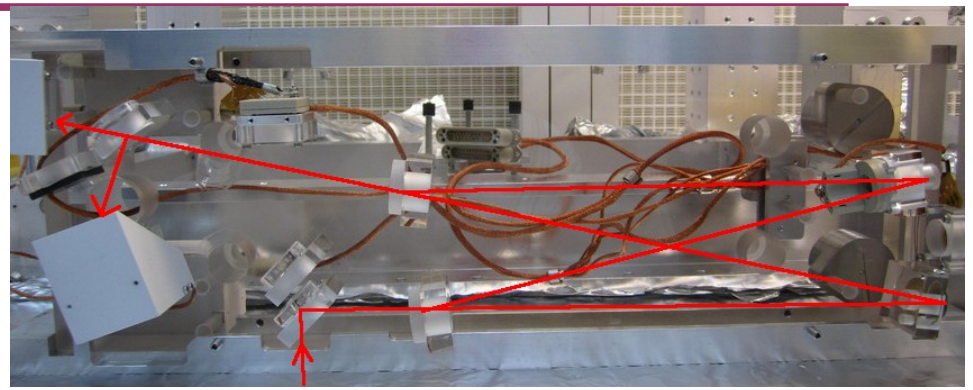
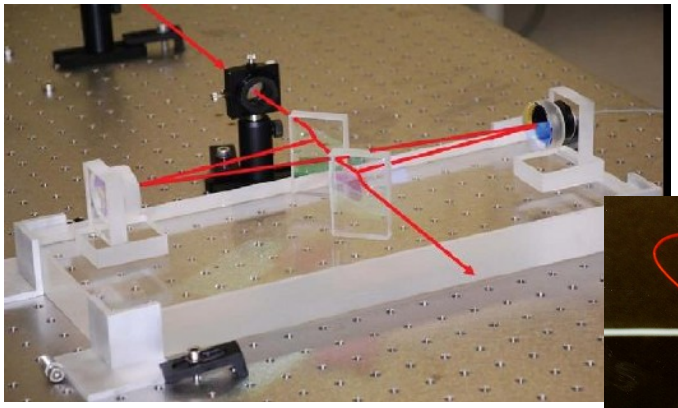
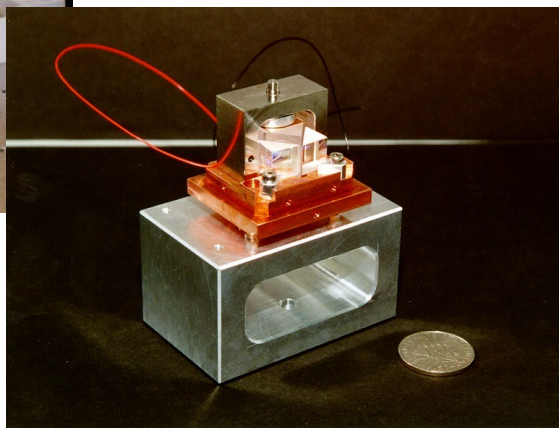
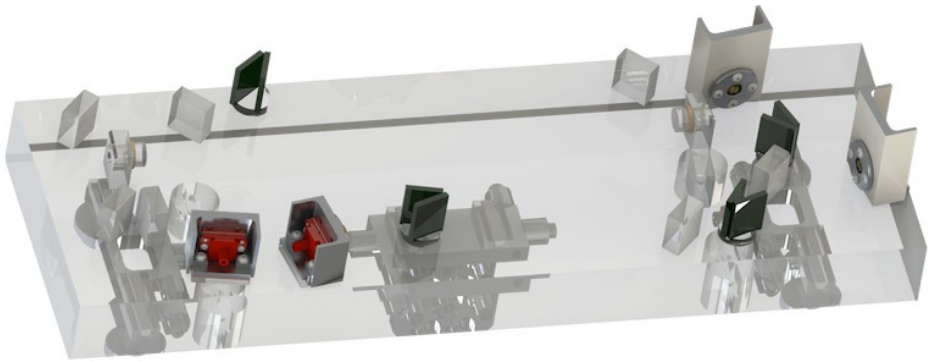
Output Mode Cleaners: Introduction for non-experts











Koji Arai, **Keita Kawabe (speaker)**, Mirko Prijatelj, Nic Smith, Kentaro Somiya, Gabriele Vajente

Prerequisite

- Qualitative understanding of interferometry.
- Vague memory of what you've learned about TEM modes (TEM00 etc.).

Will be covered

- What GW IFOs do.
- Why OMCs are cool.
  - What do they do?
  - How do they look?
- Only one type of OMC (for DC detection)
- In a totally simplified, qualitative way.

Not covered

- Details
- Use of OMC for RF detection
- Advanced topics (will be left for Nic)

Look at our wiki page.

- “Transmit signal sidebands and local oscillator beam to DCPD(s)”
- “Reject higher-order carrier and any-order RF sidebands such that they do not disturb DC signal detection.”
- https://nodus.ligo.caltech.edu:30889/wiki/doku.php?id=jan._2013_commissioning_workshop:omc

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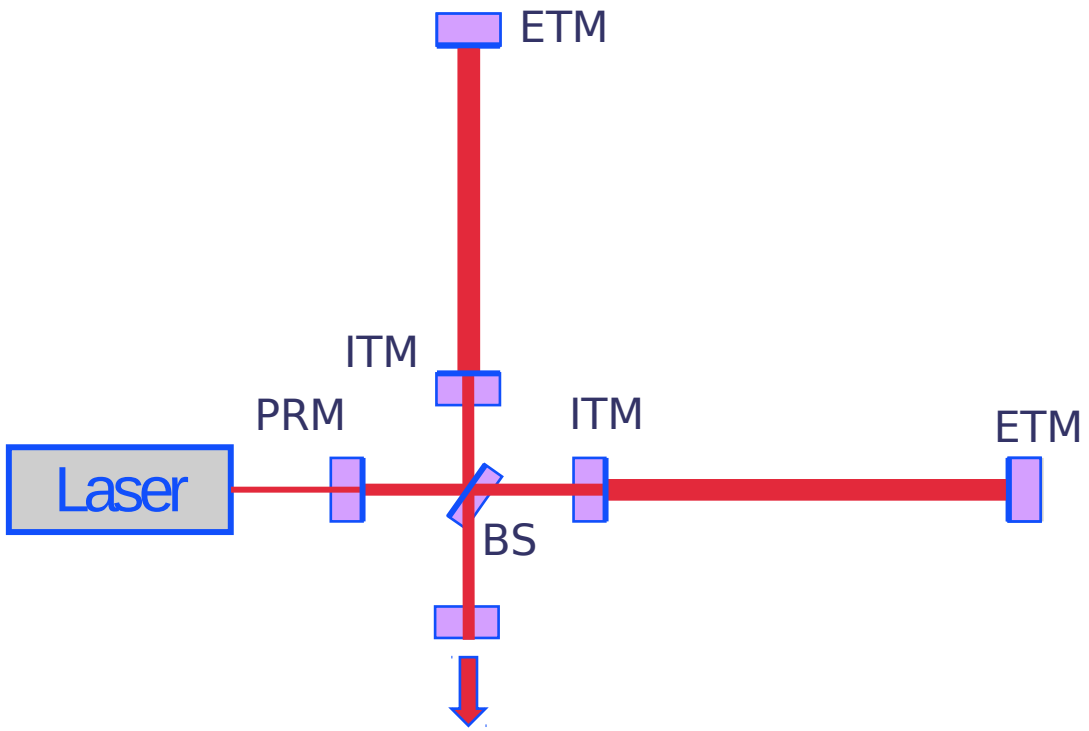
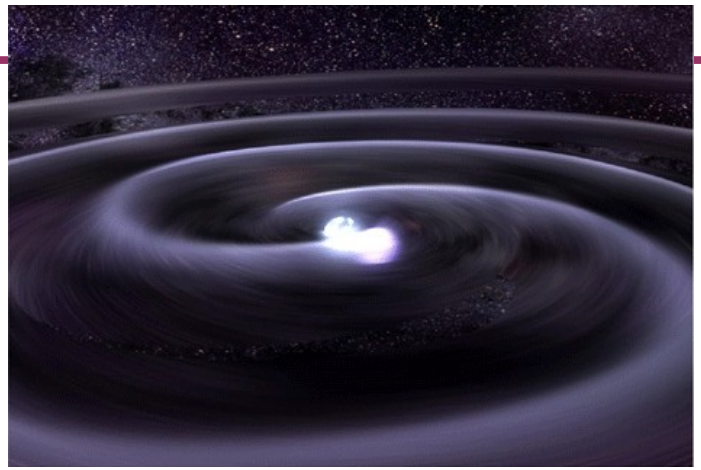
- Cool, but what does that mean? To know the answer, we need to know
  - what IFOs do, and
  - who the bad guys are.

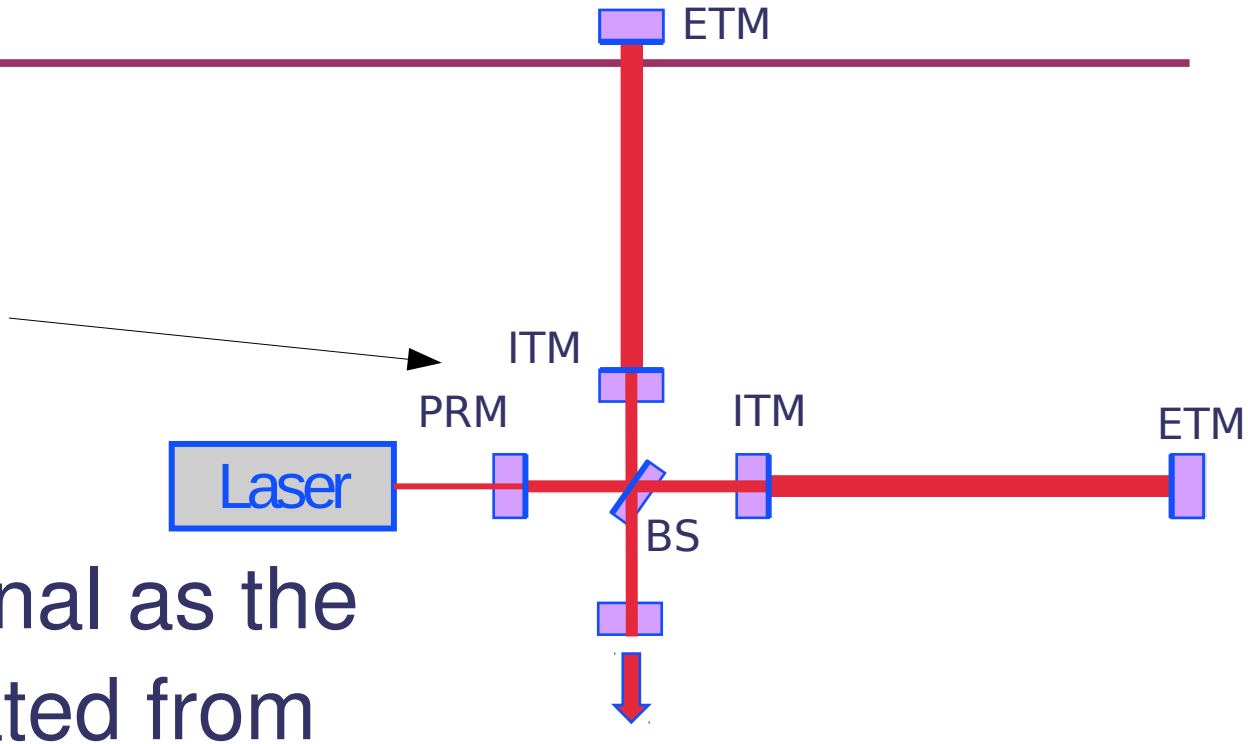
What does an IFO do for you?



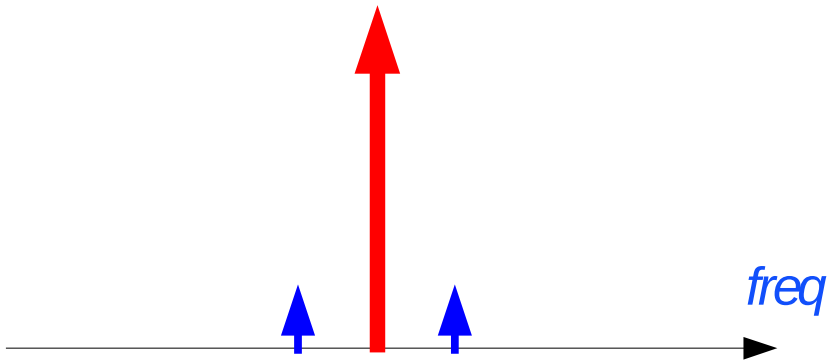
Simple answer

Image by NASA





- Encodes GW signal as the signal SB generated from the carrier (i.e. local oscillator) light field,



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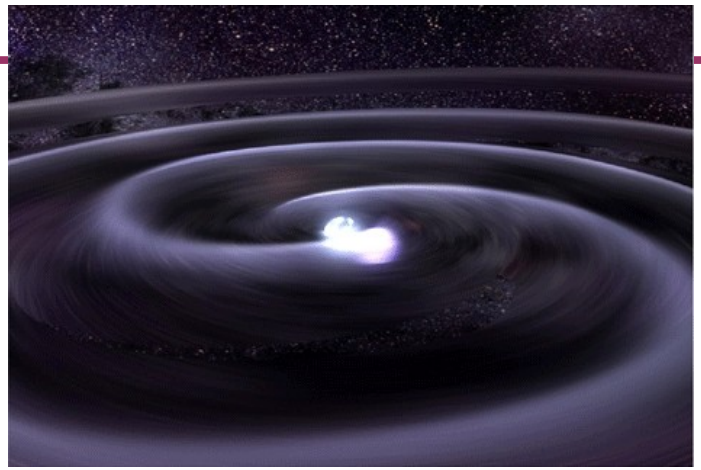

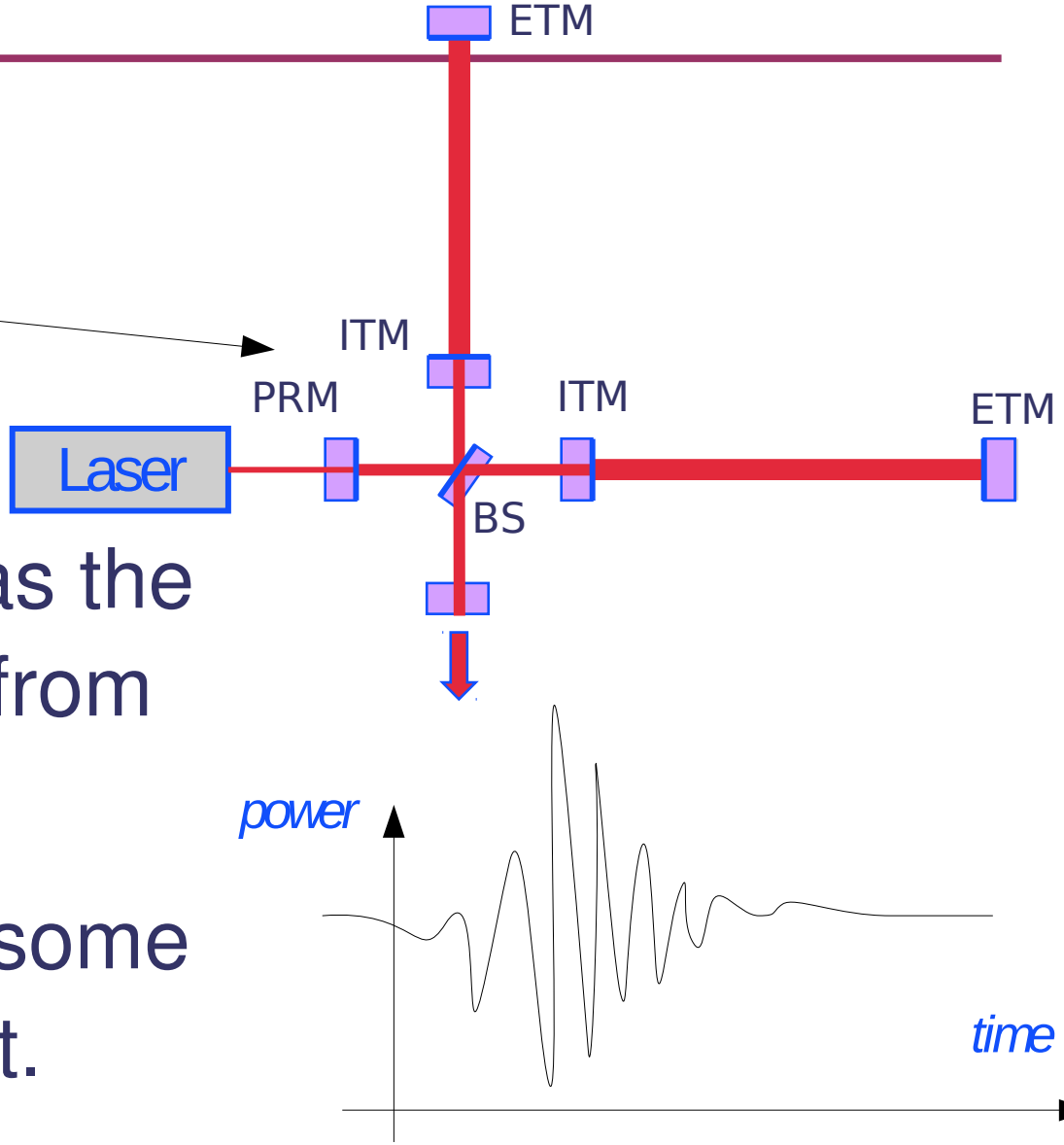

- Encodes GW signal as the signal SB generated from the carrier light field,
- i.e. power change of some kind at the output port.

Villain 1: Necessary Evil but Useless in the Detection Port: Modulation SBs

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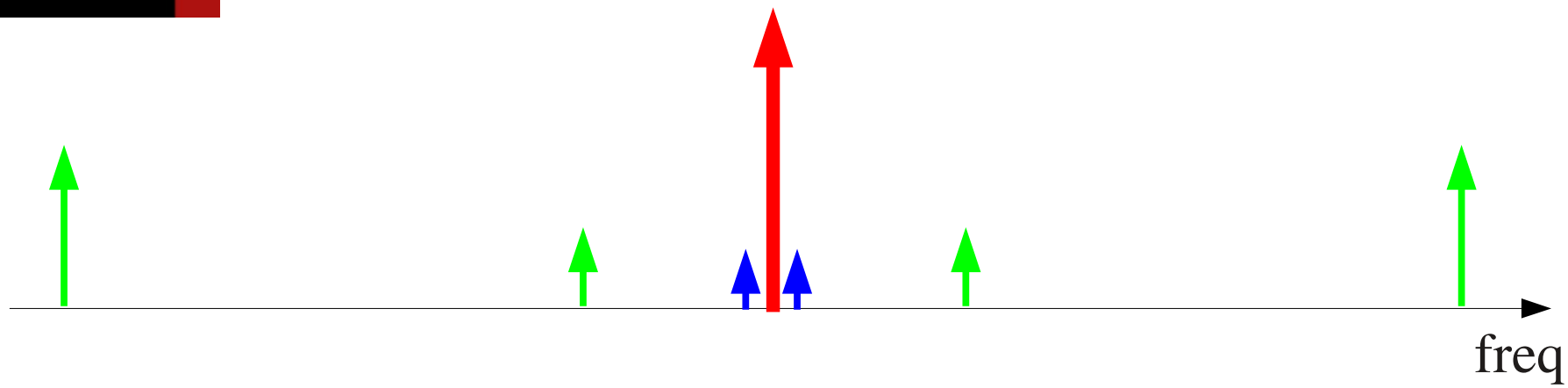
- Intentionally generated/injected to sense/control aux. DOFs (PRC, SRC, MICH, ASC).
- Large frequency offset from the carrier and the signal SB
  - ex. +-9M and +-45MHz for aLIGO



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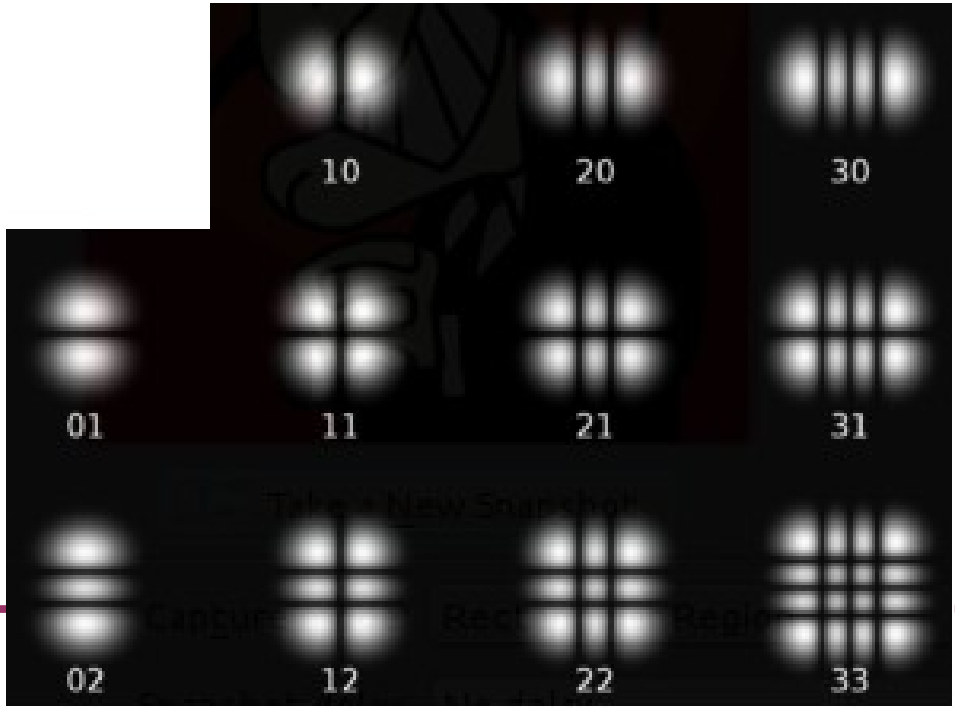
Mod SBs are bad because

- they increase the shot noise without increasing the signal.
- No decent squeezing (squeezed vacuum for DC plus multiple MHz bands).

Villain 2: Genuinely Useless and Harmful: Higher Order Modes (HOMs)

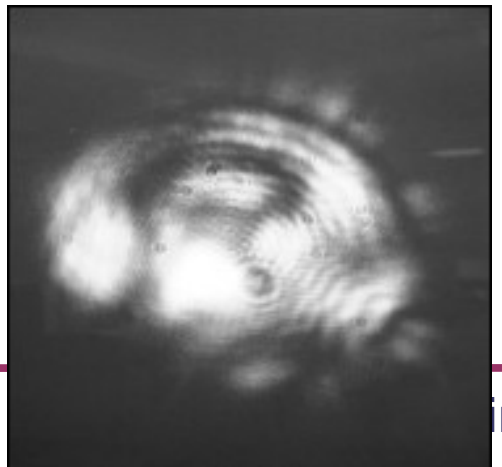
- IFO is meant to operate with a specific spatial mode (usually TEM00)
- HOMs are generated by IFO asymmetry (mirror surface figure, heating, misalignment etc.)
- As a result, ...

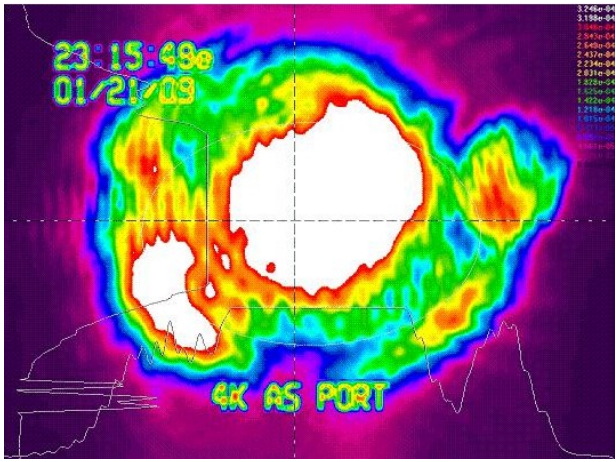


Villain 2: Genuinely Useless and Harmful: Higher Order Modes (HOMs)

- IFO beam becomes ugly.
- Carrier as well as modulation SBs could have HOMs.
- HOMs have additional phase shift (Gouy phase shift) relative to TEM00.

GEO





eLIGO

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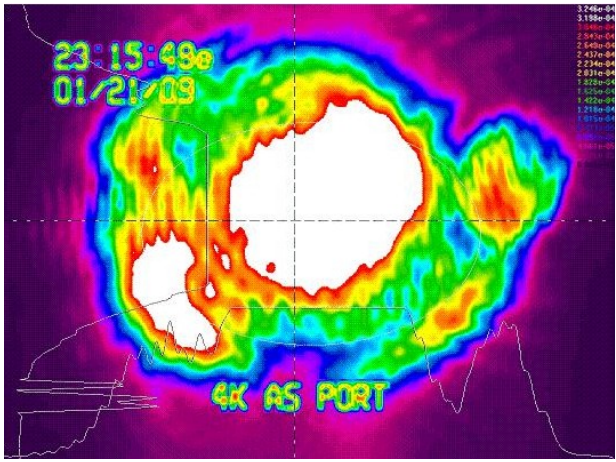
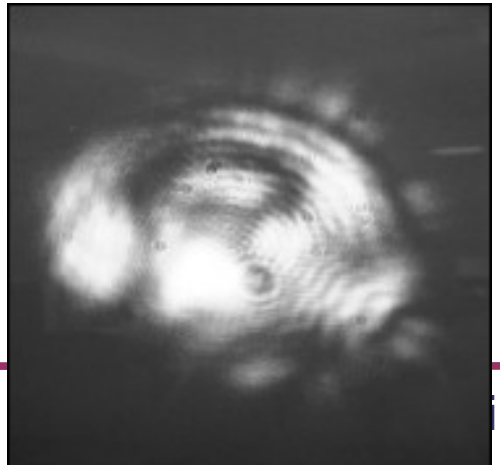
Vabo-chan



eLIGO

GEO

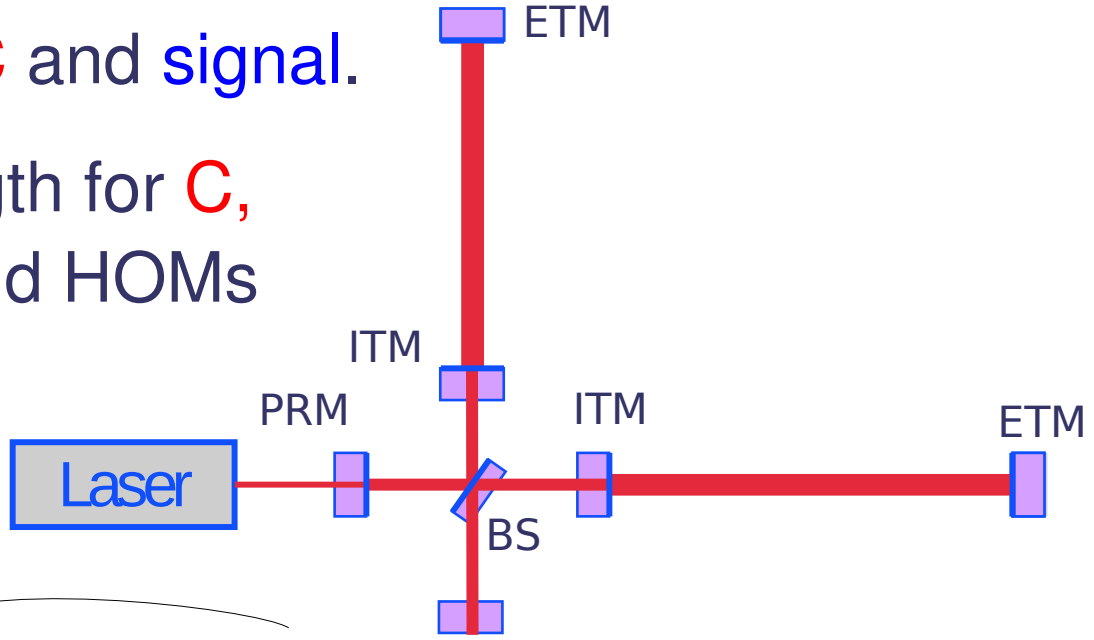


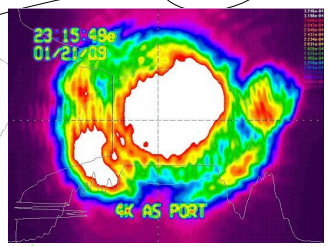
HOMs are bad because:

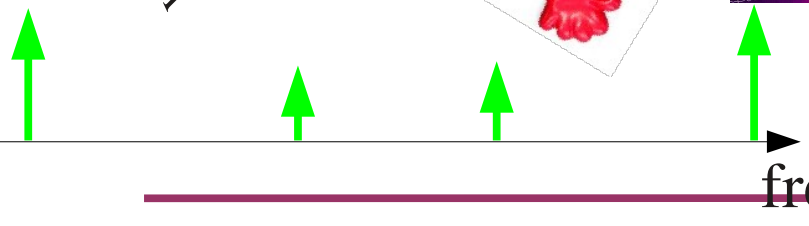
- They increase the shot noise without increasing the signal.
- Might be more harmful than just shot noise: We don't like a mess that wobbles.
  - http://www.youtube.com/watch?v=6ROILGVXOFM
  - http://www.youtube.com/watch?feature=player_embedded&v=eG_CkxoNfeA
- No decent squeezing (what spatial mode to match?).

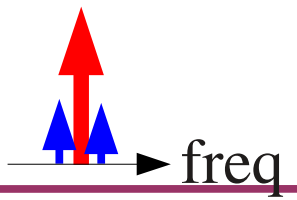
Here comes the OMC.

- Rejects everything but C and signal.
- Different resonance length for C, Mod SBs (freq offset) and HOMs (Gouy phase shift).

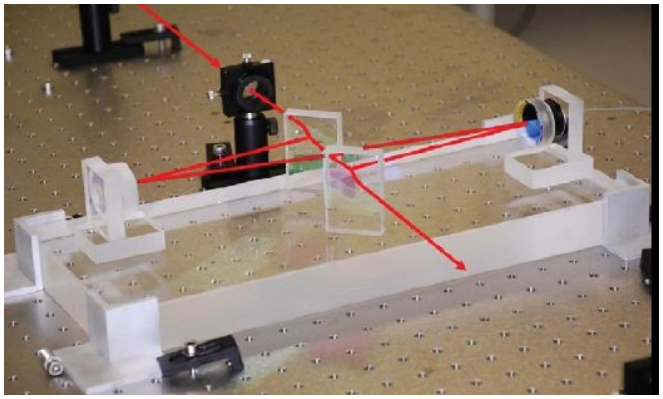


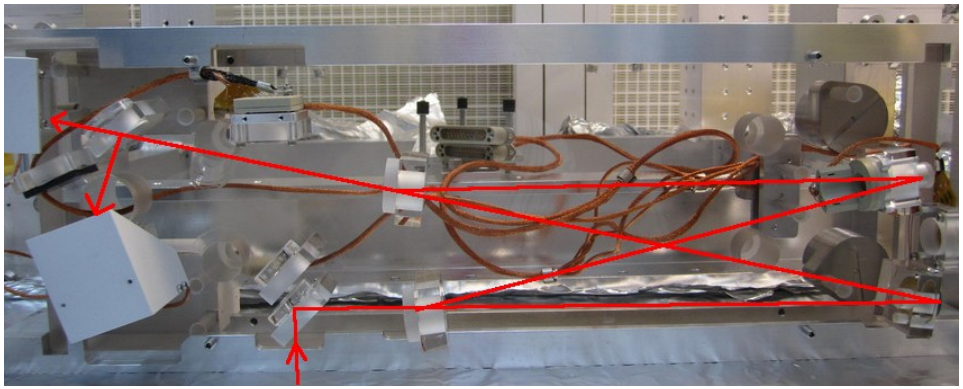


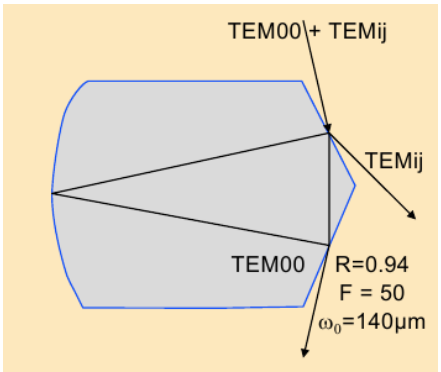


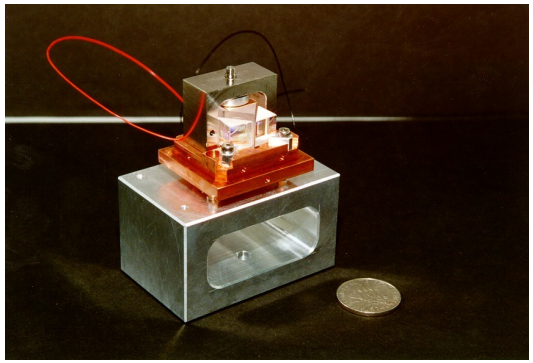


OMCs of various design already exist (and work) in large IFOs.





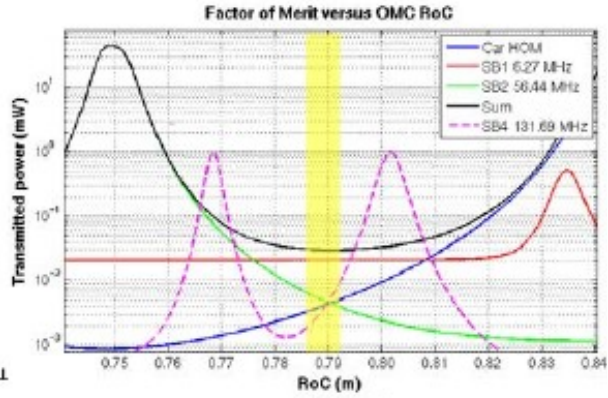


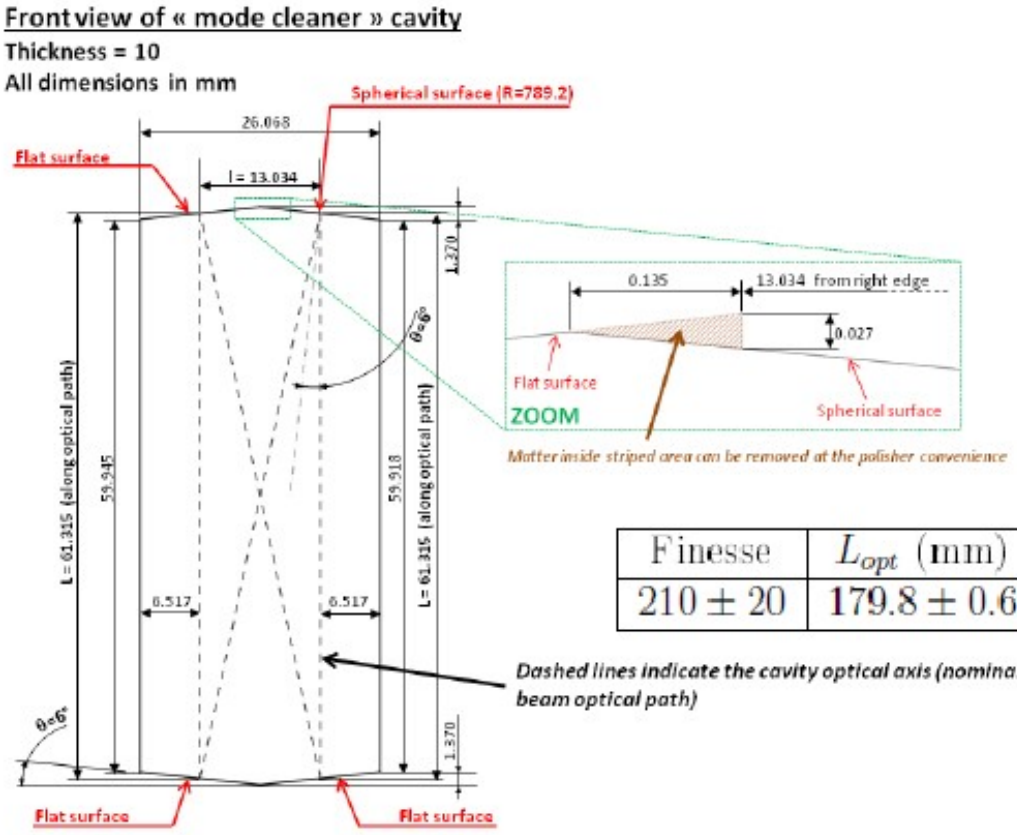


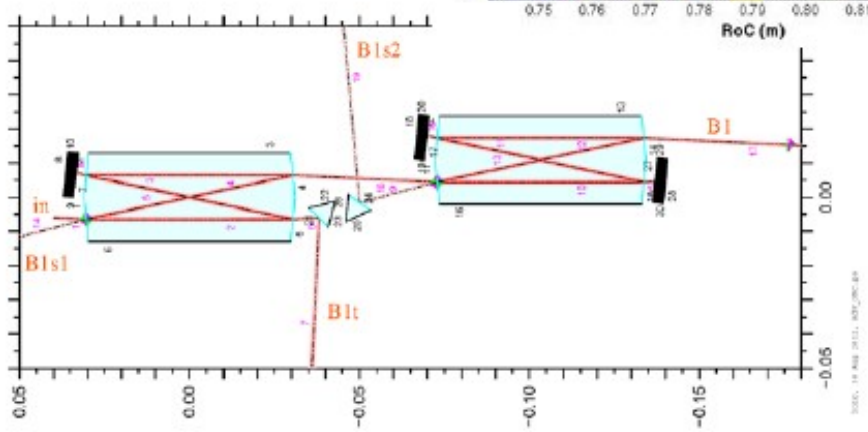
- GEO (bow-tie-ish, DC, SQZ, breadboard & tombstone, PZT control)
- eLIGO (bow-tie, DC, SQZ, breadboard & tombstone, PZT and thermal control)
- VIRGO (triangle, RF, monolithic, thermal control

Near Future: Advanced VIRGO

- Tiny monolithic bow-tie, two in series
- Length dither, thermal control
- Picomotor alignment(??)

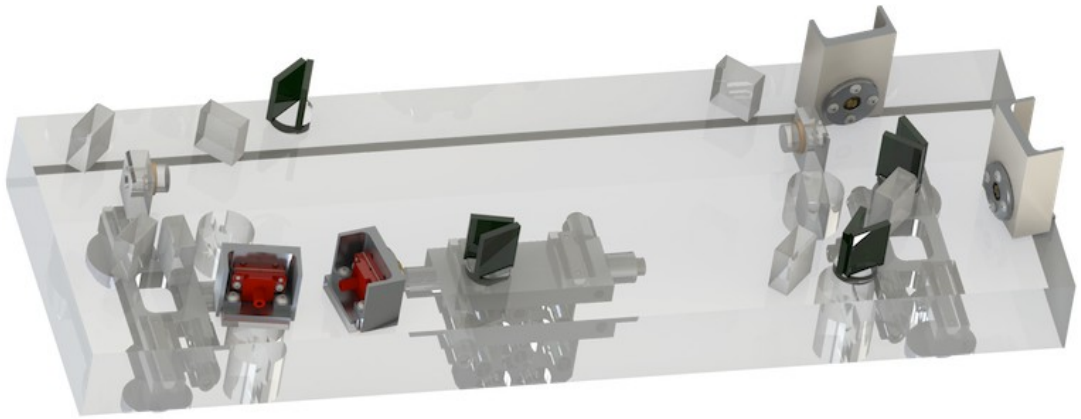


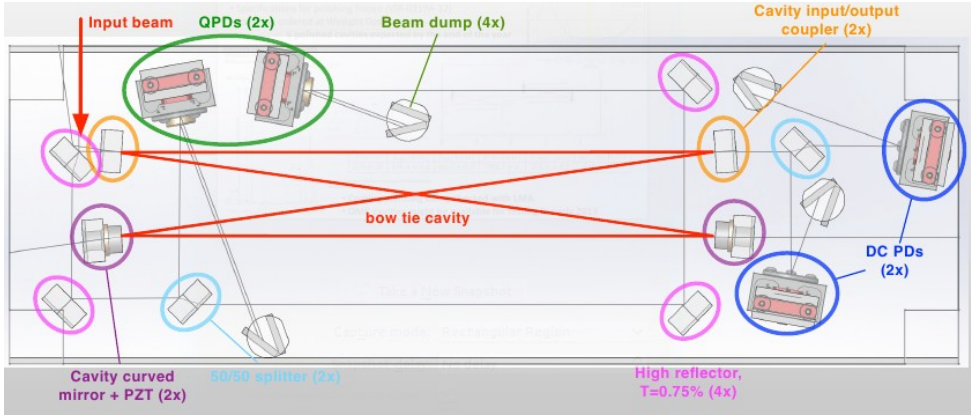




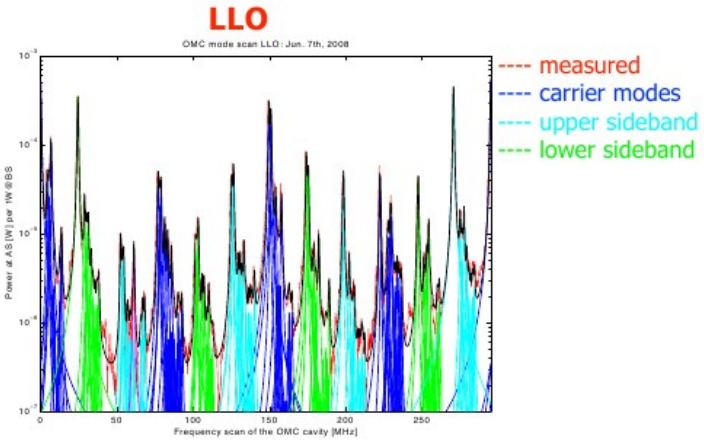
Finesse	L_{opt} (mm)	L_{geo} (mm)	RoC (mm)	Waist (μm)	Inc. angle (°)
210 ± 20	179.8 ± 0.6	62.0 ± 0.2	789.2 ± 3	259.0 ± 0.2	6.00 ± 0.03

Near Future: aLIGO





- Bowtie, tombstone
- Length dither, 2 identical PZTs for different use (large/slow and small/fast)
- TT angle dither and control



Near Future: KAGRA

- 4-mirrors, L=1.74m, g=0.88
- Details TBD

That's the end of the real easy part.

- But how do we design these?
- Don't they introduce some noise?
  - Yes, via alignment fluctuation, length fluctuation etc.
- Nic will talk about some of the details.

What do we want to know in this workshop? My personal view.

- How does everybody tackle various OMC problems?
  - Design parameters (length, ROC, finesse).
  - Noise caused by OMCs.
  - Mode matching. (what else?)
- Are some approaches better than the others?
  - Hopefully, we as a group can come to some FOM that help answering these questions.
- What is an awesome OMC? How awesome is enough, for what? Are some OMCs more awesome than the others?
  - Again, FOM.