UNIVERSITY OF BIRMINGHAM

EGO

# Arm Cavity Finesse of Advanced Virgo

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# Executive summary: Arm Cavity Finesse

- Current value for the Advanced Virgo arm cavity finesse is 880.
  - Advanced LIGO will use about 450 (original aimed at 1250)
  - LGCT plans to use 1600.

- At the moment there is no strong argument to change this value.
- However, in case new or updated information appears, we can perform a new trade-off decision.

- The main arguments considered in such trade-off process are:
  - Signal loss inside the signal recycling cavity
  - Suppression of noise from the central interferometer
  - Thermal load of the central interferometer
  - Lock acquisition *(currently not)*

# And now the details …

# How to compare different arm cavity finesse values?

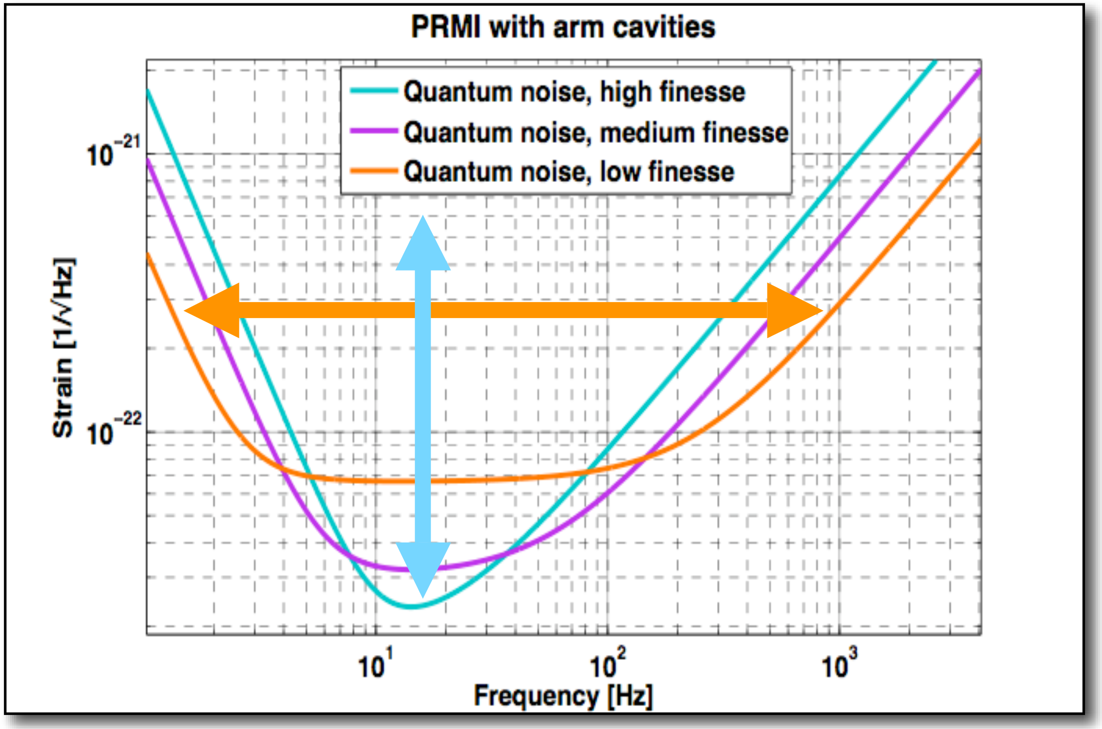
- A change of arm cavity finesse goes hand in hand with a change of the optical power inside the arm cavities.
- If we decrease the arm cavity finesse, the stored optical power will go down as well. => stronger shot noise contribution. => not a fair comparison.
- One can compensate for the lower finesse by increasing the power recycling gain.
- Our approach for a fair comparison: If we change the arm cavity finesse we will always restore the intra cavity power by increasing the power recycling gain, thus we always compare configurations with ~750kW per arm.

# Potential reasons for lowering the finesse?

- Sensitivity ???
- Mirror losses ???
- Coupling of diff losses to dark port power ???
- Noise couplings from small Michelson ???
- Thermal load of BS, ITM and CPs?
- Lock acquisition ???
- Losses inside the recycling cavities ???
- Coating Brownian from ITMs ???
- … anything else ???

# Michelson sensitivity versus arm cavity finesse

- In the initial detectors the arm cavity finesse determines the detector bandwidth:
  - Low finesse = large bandwidth
  - High finesse = best peak sensitivity




- Is this also true for Advanced Virgo?

# Sensitivity for finesse 888 and 444

➲ Let's see how the ADV sensitivity changes if we lower the arm cavity finesse by a factor of 2.

**Step 1:**
- double ITM transmission
- double PR factor

| | |
|---|---|
| ITM transmission: | 0.0070 |
| PRM transmission: | 0.0464 |
| Finesse: | 888.08 |
| Power Recycling Factor: | 21.53 |
| Arm power: | 760.78 kW |

↓

| | |
|---|---|
| ITM transmission: | 0.0141 |
| PRM transmission: | 0.0240 |
| Finesse: | 444.04 |
| Power Recycling Factor: | 41.19 |
| Arm power: | 727.69 kW |

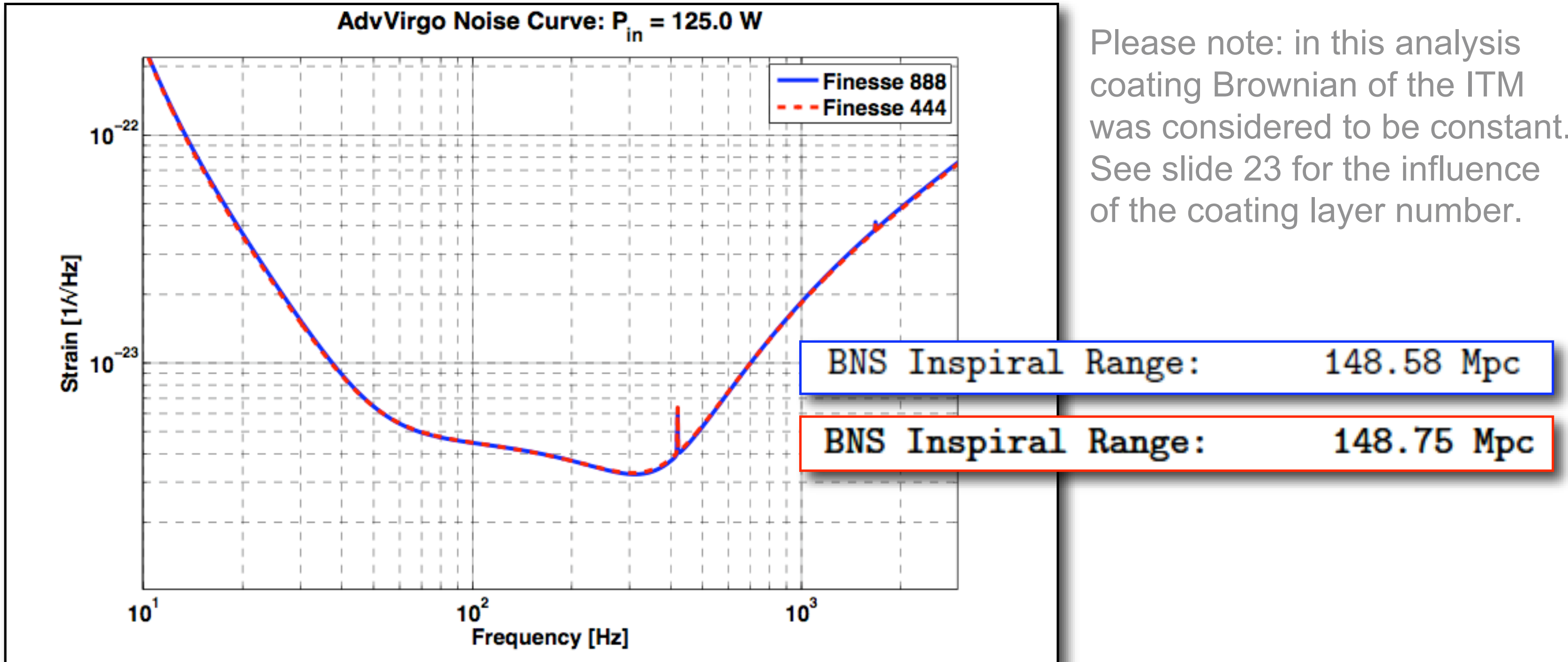
**Step 2:**
If we half the arm cavity finesse we also have to compensate the Signal Recycling parameters:
- double Signal Recycling detuning
- double SRM transmittance

| | |
|---|---|
| SRM Detuning: | 8.59 degree |
| SRM transmission: | 0.1100 |

↓

| | |
|---|---|
| SRM Detuning: | 17.19 degree |
| SRM transmission: | 0.2200 |

# Sensitivity for finesse 888 and 444




Please note: in this analysis coating Brownian of the ITM was considered to be constant. See slide 23 for the influence of the coating layer number.

- The Advanced Virgo sensitivity is (within a certain) range independent of the arm cavity finesse !!

# Potential reasons for lowering the finesse?

- Sensitivity ………………………………………………..*independent*
- Mirror losses ???
- Coupling of diff losses to dark port power ???
- Noise couplings from small Michelson ???
- Thermal load of BS, ITM and CPs?
- Lock acquisition ???
- Losses inside the recycling cavities ???
- Coating Brownian from ITMs ???
- … anything else ???

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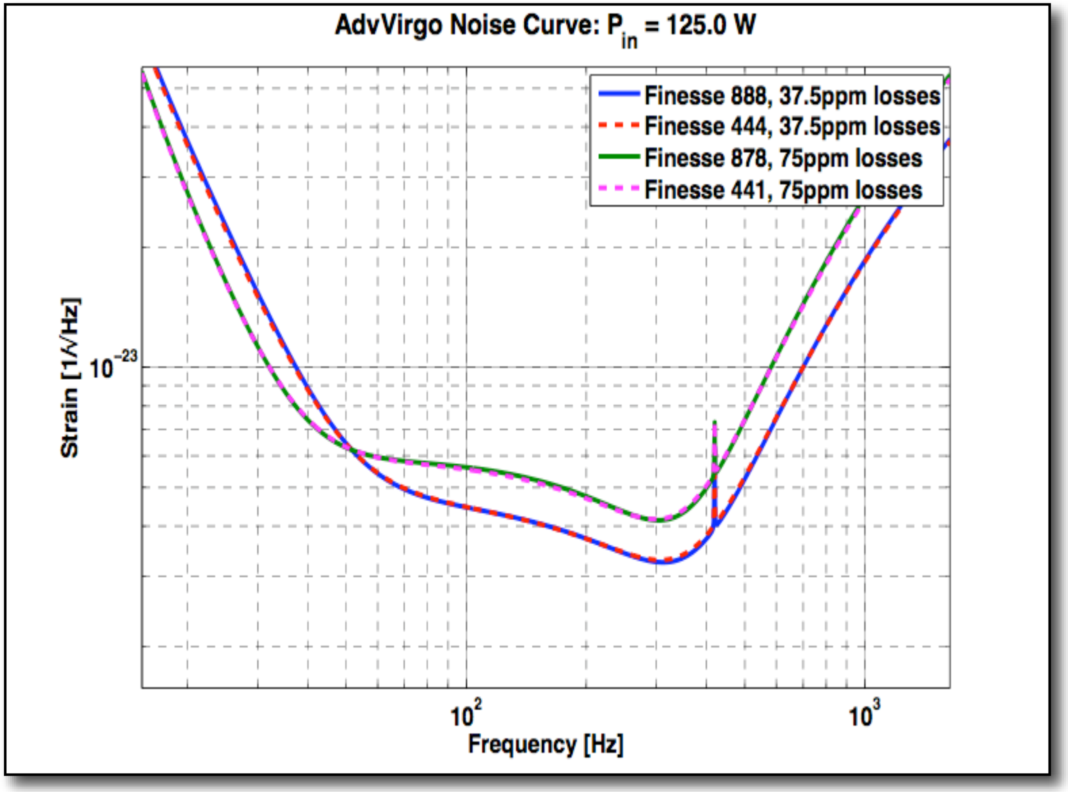
# Finesse and mirror losses

- Advanced Virgo preliminary design assumes 37.5ppm loss per surface.
- This is an ambitious goal. What happens if the losses turn out to be twice as much (75ppm)? Any influence of arm cavity finesse?

- The sensitivity changes with the actual mirror losses, BUT is independent of the arm cavity finesse.



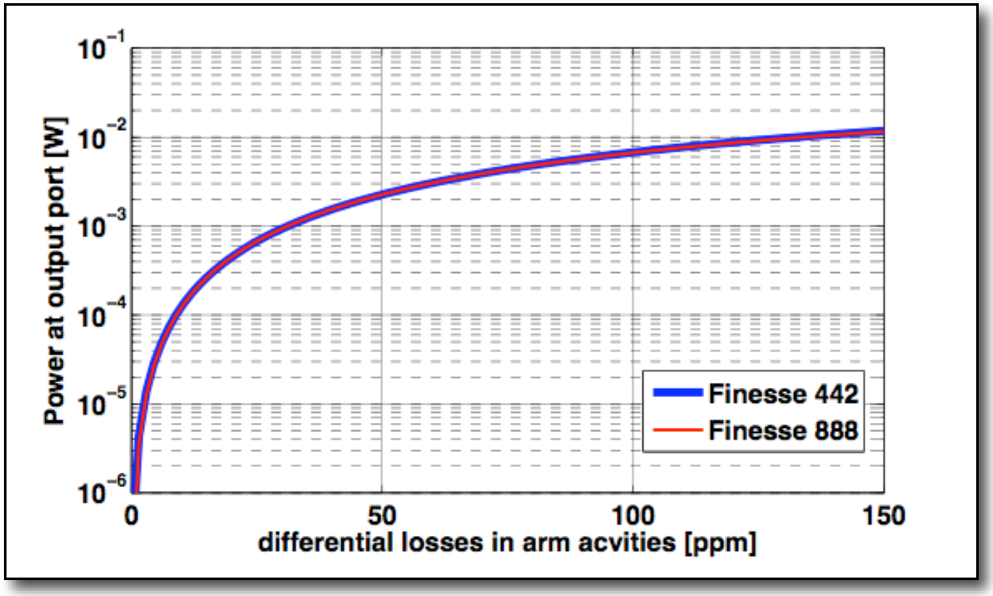
# Potential reasons for lowering the finesse?

- Sensitivity .................................................*independent*
- Mirror losses .........................................*independent*
- Coupling of diff losses to dark port power ???
- Noise couplings from small Michelson ???
- Thermal load of BS, ITM and CPs?
- Lock acquisition ???
- Losses inside the recycling cavities ???
- Coating Brownian from ITMs ???
- … anything else ???

# Dark fringe offset and arm cavity finesse

- Consider imbalanced  losses in the two arm cavities. => Does the coupling of differential losses to dark port power depend on the arm cavity Finesse?
- Performed a simple numerical simulation using Finesse software:

- The coupling of differential losses to the dark port power is independent of the arm cavity finesse.



# Potential reasons for lowering the finesse?

- Sensitivity ………………………………………………..*independent*
- Mirror losses ………………………………………….*independent*
- Coupling of diff losses to dark port power ………*independent*
- Noise couplings from small Michelson ???
- Thermal load of BS, ITM and CPs?
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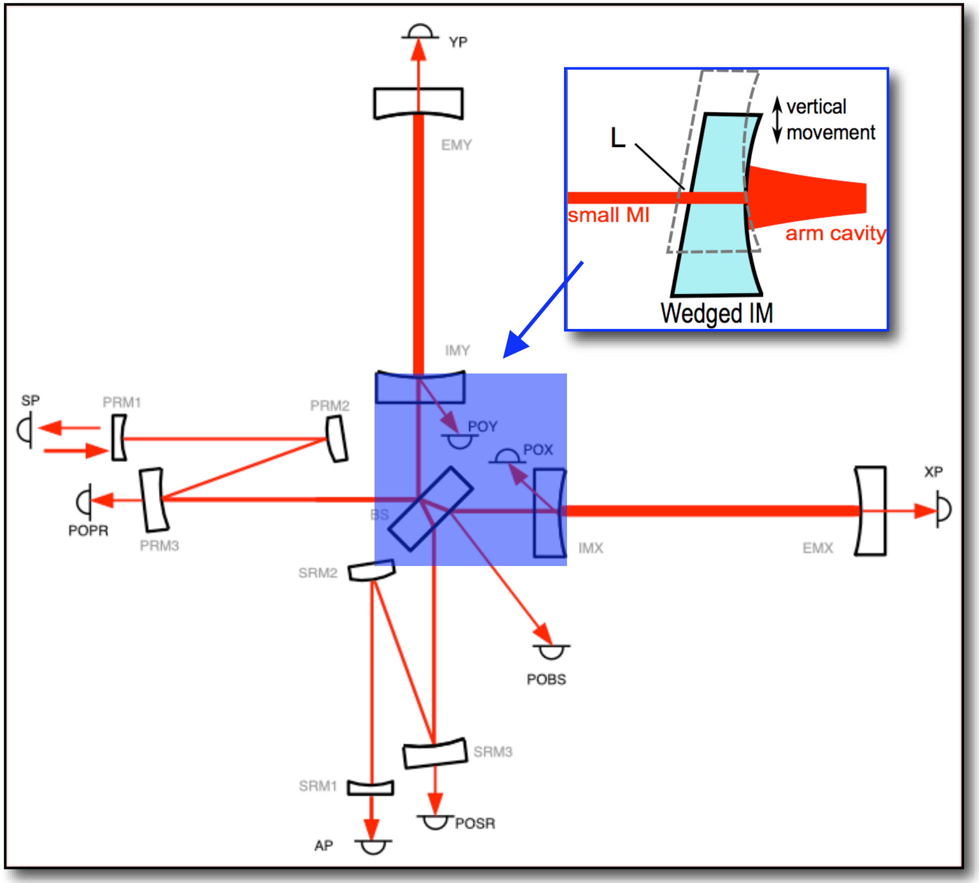
- Losses inside the recycling cavities ???
- Coating Brownian from ITMs ???
- … anything else ???

# Noise coupling from the small Michelson

- All differential arm length noise inside the small Michel-son (MICH) gets suppressed by the arm cavity finesse.
- Lower finesse => stricter requirements for:
  - Thermo refractive noise inside ITMs, CPs, BS.
  - Quietness of wedged optics (CPs? ITMs? BS?)
  - … etc …



# Potential reasons for lowering the finesse?

- Sensitivity ..........................................................*independent*
- Mirror losses .....................................................*independent*
- Coupling of diff losses to dark port power .........*independent*
- Noise couplings from small Michelson ..................**NO**
- Thermal load of BS, ITM and CPs?
- Lock acquisition ???
- Losses inside the recycling cavities ???
- Coating Brownian from ITMs ???
- … anything else ???

# Thermal load of BS, CP and ITM substrates

- Optical power inside the power recycling cavity is proportional to inverse of the arm cavity finesse.
- Lowering the arm cavity finesse from 888 to 444 increases optical power in BS, CP and ITM substrates from 2.7kW to 5.1kW.
- Any problem from thermal lensing?

| | |
|---|---|
| ITM transmission: | 0.0070 |
| PRM transmission: | 0.0464 |
| Finesse: | 888.08 |
| Power Recycling Factor: | 21.53 |
| Arm power: | 760.78 kW |
| Power on beam splitter: | 2691.27 W |

| | |
|---|---|
| ITM transmission: | 0.0141 |
| PRM transmission: | 0.0240 |
| Finesse: | 444.04 |
| Power Recycling Factor: | 41.19 |
| Arm power: | 727.69 kW |
| Power on beam splitter: | 5148.41 W |

*...need to check with TCS ...*

*... work in progress...*

# Potential reasons for lowering the finesse?

- Sensitivity ……………………………………………….*independent*
- Mirror losses ………………………………………………*independent*
- Coupling of diff losses to dark port power ………*independent*
- Noise couplings from small Michelson ……………..**NO**
- Thermal load of BS, ITM and CPs ……………..……..**NO**
- Lock acquisition ???
- Losses inside the recycling cavities ???
- Coating Brownian from ITMs ???
- … anything else ???

# Lock-acquisition and finesse

- The capture range of arm cavities inverse proportional to the Finesse.
- Would lowering the arm cavity finesse make lock acquisition easier?
- Input from ISC: *In AdV, even with a finesse of 444, we are in a regime where "ringings" dominate (storage time > time through resonance), so that linearization technique does not work. Then we have to have the "auxiliary laser" technique => finesse at 1064 nm does not matter for lock acquisition.* (Email Bondu: 8/1/2009)

# Potential reasons for lowering the finesse?

- Sensitivity ..........................................................*independent*
- Mirror losses .......................................................*independent*
- Coupling of diff losses to dark port power .........*independent*
- Noise couplings from small Michelson ..................**NO**
- Thermal load of BS, ITM and CPs .........................**NO**
- Lock acquisition ................................................ *independent*
- Losses inside the recycling cavities ???
- Coating Brownian from ITMs ???
- … anything else ???

# Losses inside PRC and SRC

- If there are unexpectedly high losses inside the PRC, then a high arm cavity finesse would be better.
- If there are unexpectedly high losses inside the SRC, then a low arm cavity finesse would be better.
- PRC losses can be compensated for by higher laser power or different PRM reflectivity.
- SRC losses can not be compensated !! => favors low arm cavity finesse.

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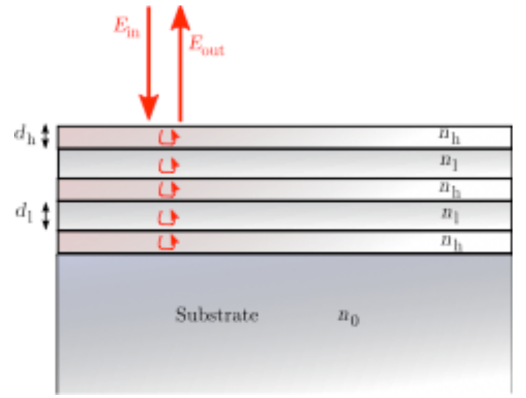
- To evaluate this effect we need to know the expected signal loss inside the signal recycling cavity. This strongly depends on the choice between MSRC and NDRC. *...work in progress...*

# Potential reasons for lowering the finesse?

- Sensitivity ...................................................................*independent*
- Mirror losses .................................................................*independent*
- Coupling of diff losses to dark port power ........*independent*
- Noise couplings from small Michelson .................**NO**
- Thermal load of BS, ITM and CPs ........................**NO**
- Lock acquisition ............................................. *independent*
- Losses inside the recycling cavities ....................**YES**
- Coating Brownian from ITMs ???
- … anything else ???

# Coating Brownian and finesse (I)

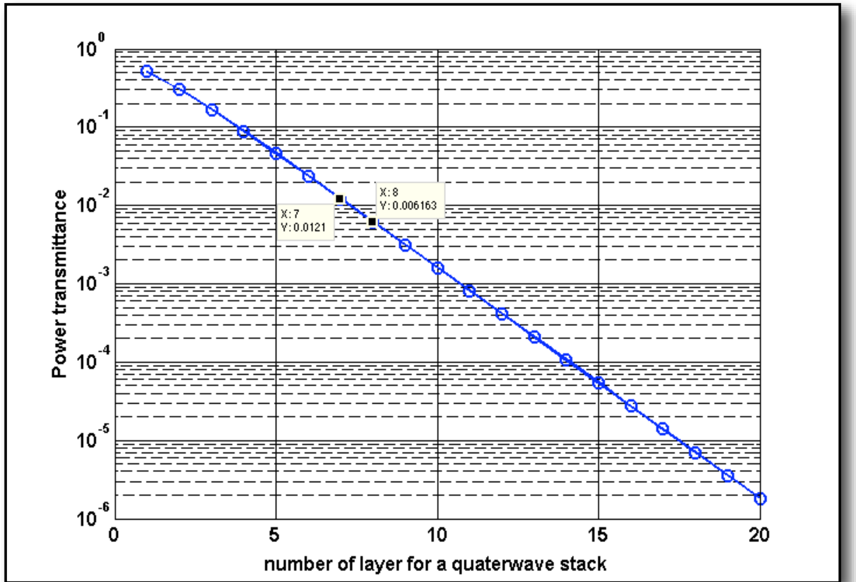
- Lower finesse => higher transmittance of the ITM HR coating.
- Lowering arm cavity finesse from 888 to 444:
  - increasing ITM transmittance from 0.007 to 0.014
  - might be able to get rid of one coating layer on ITM
  - Reduce coating Brownian of ITM

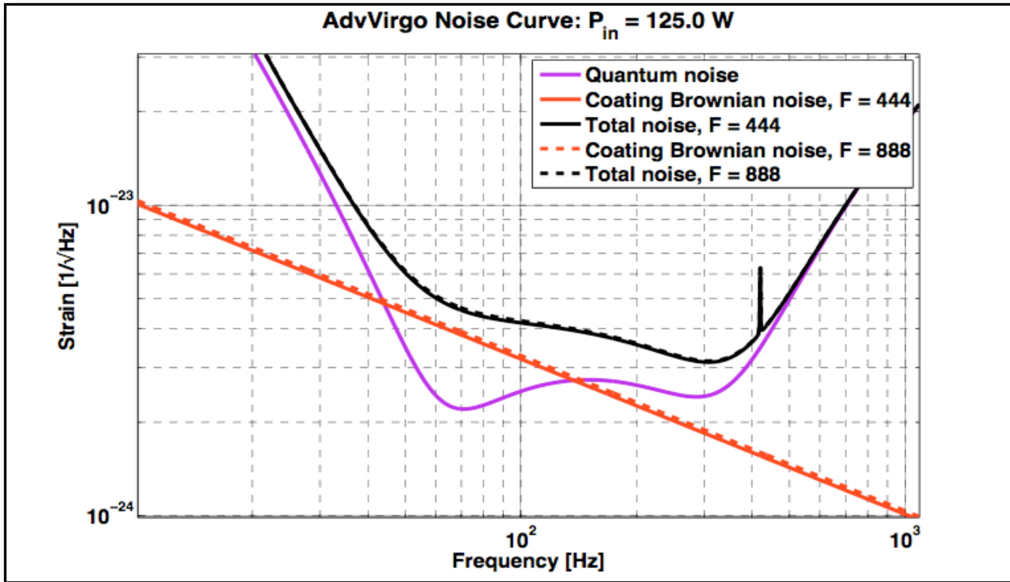



Coating Brownian noise of one mirror:

$$S_x(f) = \frac{4k_BT}{\pi^2 fY}\frac{d}{r_0^2}\left(\frac{Y'}{Y}\phi_{||} + \frac{Y}{Y'}\phi_{\perp}\right)$$

# Coating Brownian and finesse (II)




| Optic | Number of HLL | Thickness of low index material [m] | Thickness of high index material [m] |
|---|---|---|---|
| ITM, Fin = 888 | 8 | 1.83e-6 | 1.05e-6 |
| ITM, Fin = 444 | 7 | 1.65e-6 | 0.92e-6 |
| ETM | 16 | 3.30e-6 | 2.09e-6 |

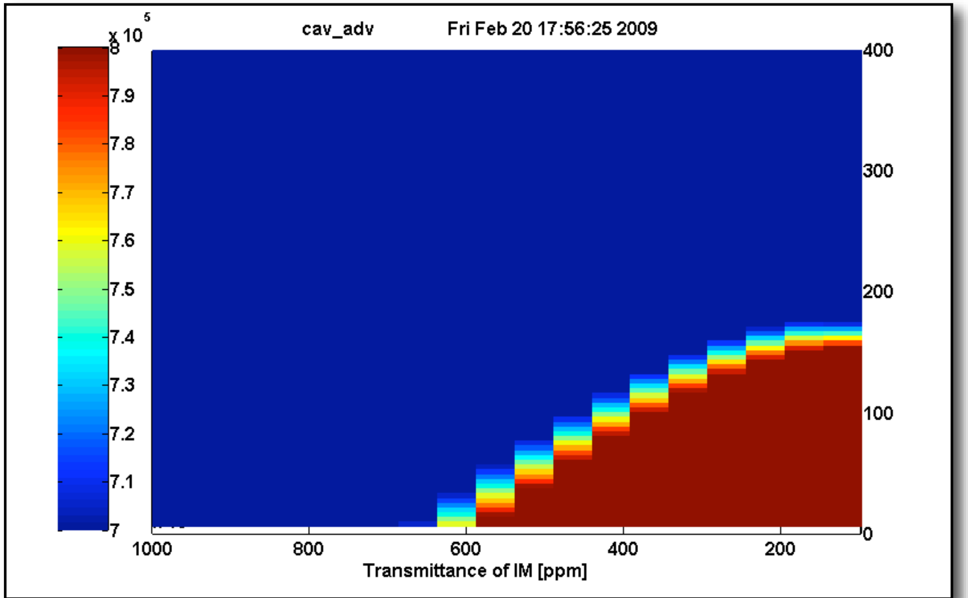
- When going from 888 to 444 in arm cavity Finesse the BNS inspiral increases by only 1.3%.
- We do not consider this small influence as significant.

# Potential reasons for lowering the finesse?

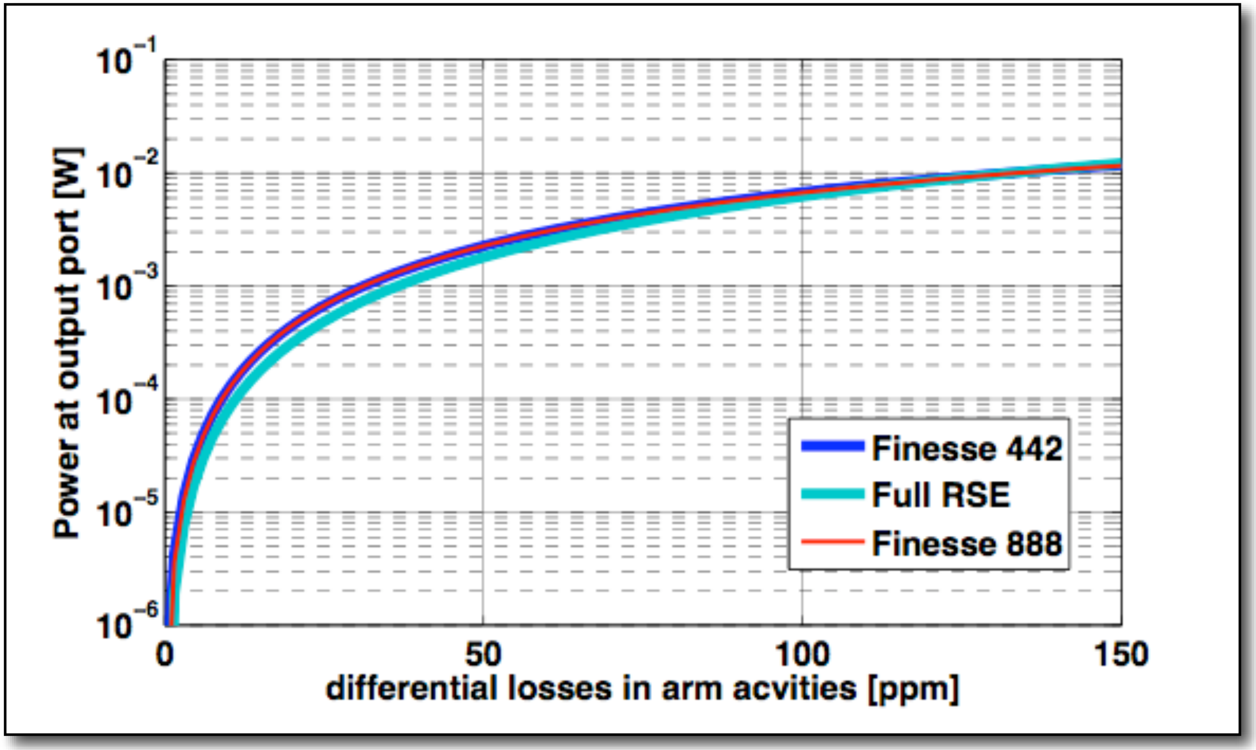
- Sensitivity ...................................................*independent*
- Mirror losses ...............................................*independent*
- Coupling of diff losses to dark port power .........*independent*
- Noise couplings from small Michelson ..................**NO**
- Thermal load of BS, ITM and CPs ........................**NO**
- Lock acquisition ...............................................*independent*
- Losses inside the recycling cavities ....................**YES**
- Coating Brownian from ITMs ............................ *independent*
- ... anything else ???

# Full RSE (I)

- Recently the question rose, why not to use full RSE? This would mean:
  - Get rid of power recycling
  - Increase arm cavity finesse to restore high optical power.
  - Increase SRM reflectivity.
- To get 750 kW:
  - ITM transmittance = 300ppm
  - Arm cavity Finesse = 19333
- Adjusting RSE again:
  - SRM transmittance = 0.005

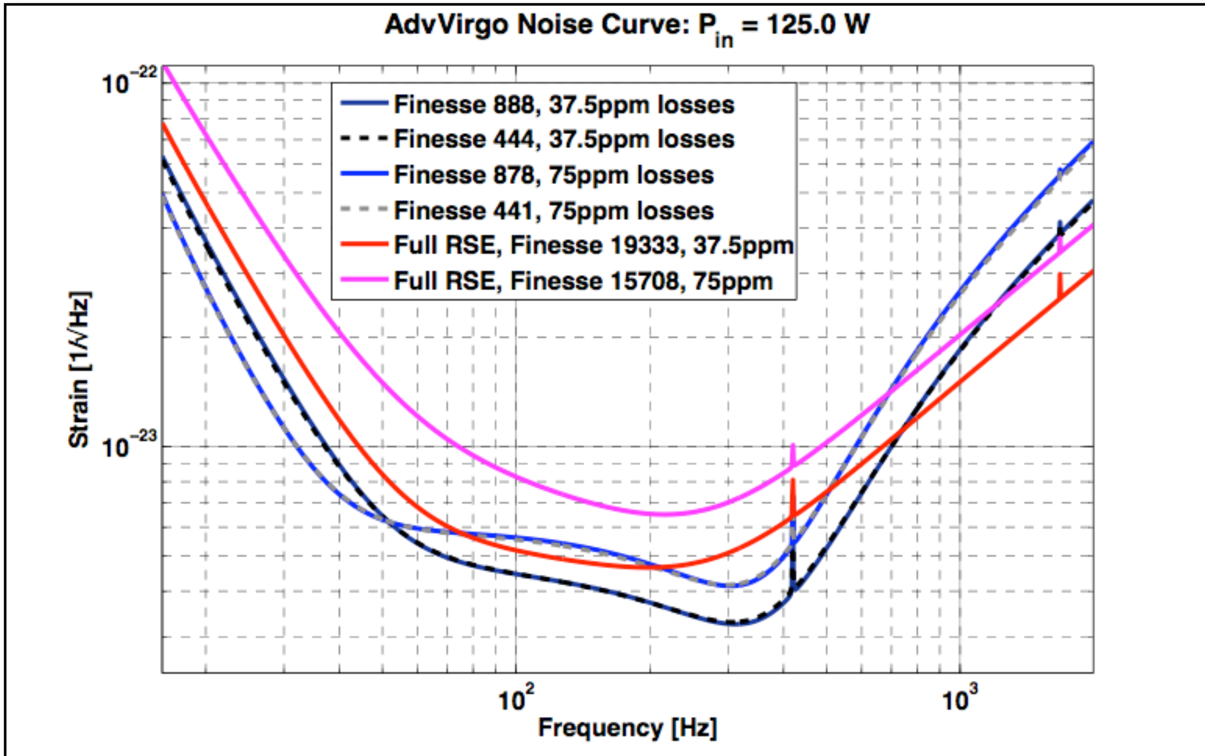


# Full RSE (II)




- Analysis of full RSE confirms that coupling of differential losses to the dark port is independent of the arm cavity finesse.

# Full RSE (III)




- High Finesse 'amplifies' the influence of losses inside the signal recycling cavity. With 37.5ppm loss per surface Full RSE cannot achieve a sensitivity compatible with dual-recyling.

# Executive summary: Arm Cavity Finesse

- Current value for the Advanced Virgo arm cavity finesse is 880.
  - Advanced LIGO will use about 450 (original aimed at 1250)
  - LGCT plans to use 1600.
- At the moment there is no strong argument to change this value.
- However, in case new or updated information appears, we can perform a new trade-off decision.
- The main arguments considered in such trade-off process are:
  - Signal loss inside the signal recycling cavity
  - Suppression of noise from the central interferometer
  - Thermal load of the central interferometer
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# E N D