LIGO-G1200600

Sensitivity scenarios and calibration accuracy of future GW detectors

Stefan Hild

Burst workshop

Tobermory 2012

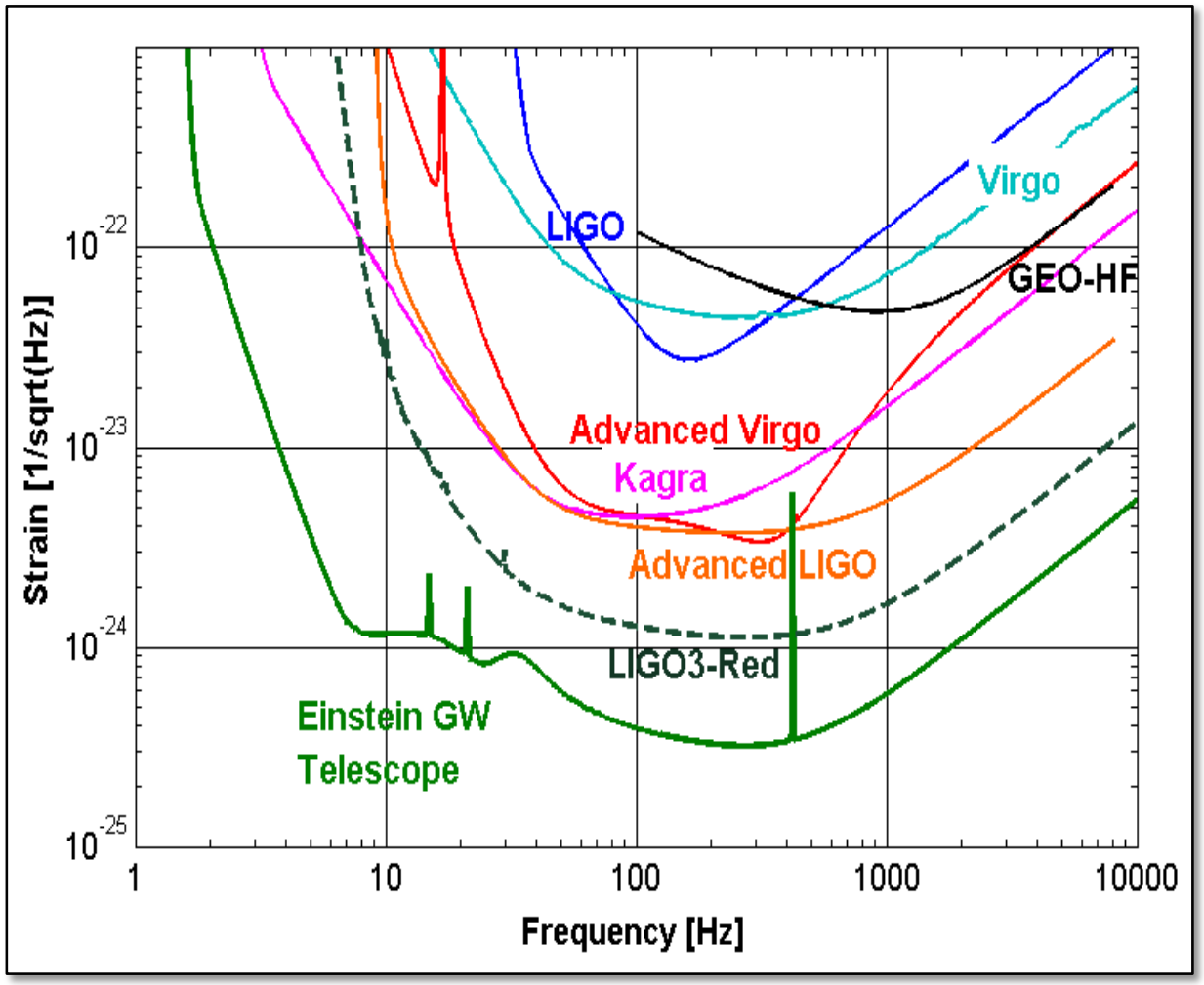
What sensitivity can future GW detectors achieve?

- With 2nd generation instruments under construction it is now time to look what comes afterwards.
- In Europe the design study for the third generation Einstein telescope (based on an underground xylophone with 10km armlength) has been completed.

https://tds.ego-gw.it/itf/tds/index.php?callContent=2&callCode=8709

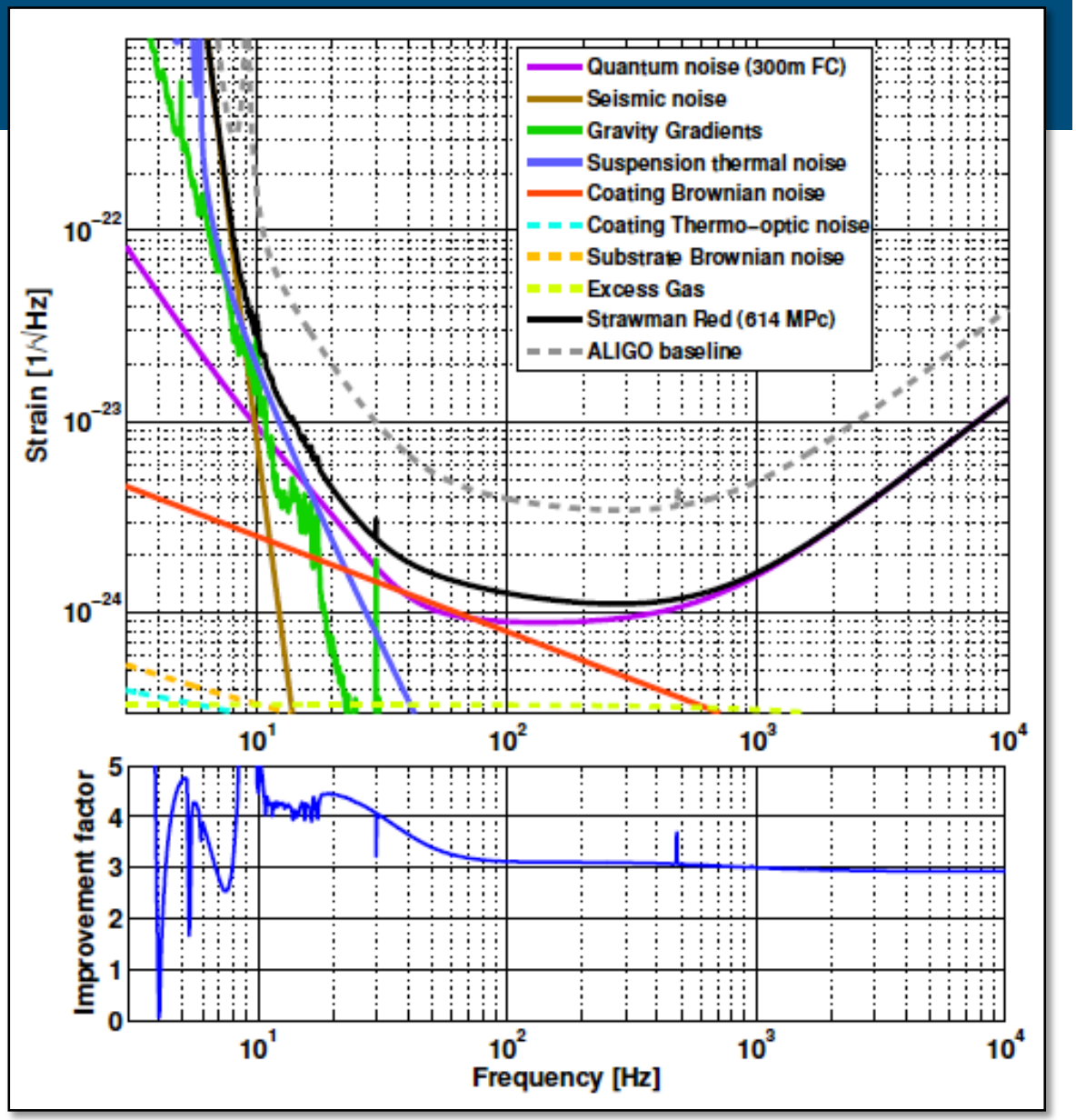
- **During the last year the LSC started to look at aLIGO upgrades**

LIGO-T1200031



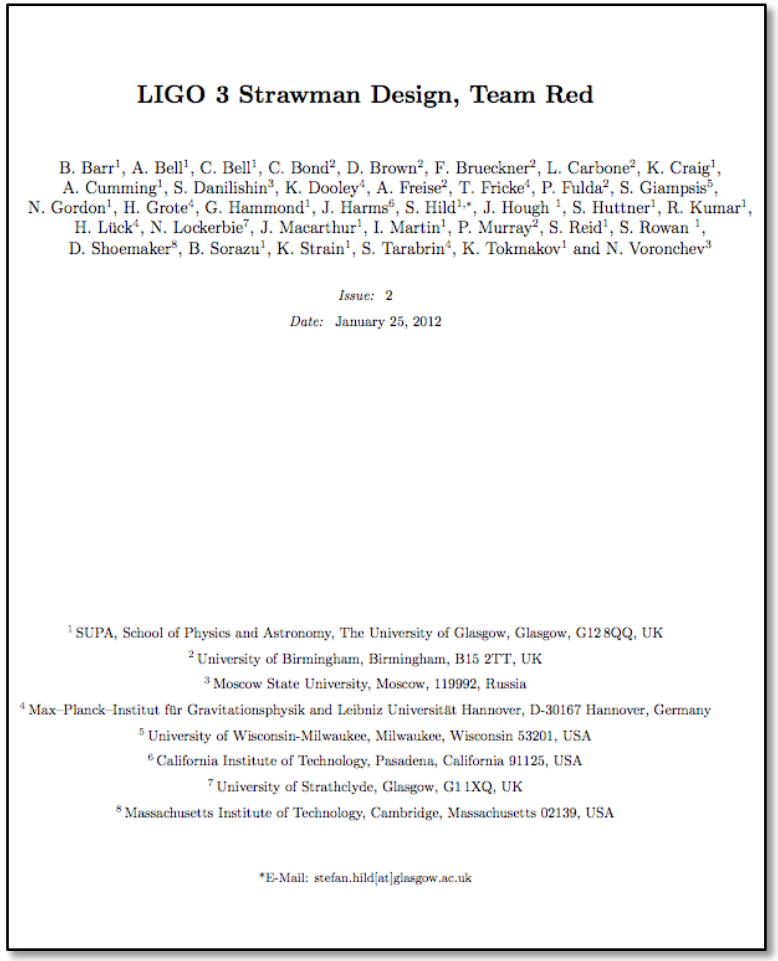
LIGO-3 Red Team design

- Only rather mature technologies considered
- Overall an improvement of a factor 3 at all frequencies above 100 Hz. And a factor 3-4 below 100Hz.
- The binary neutron star inspiral range would improve from about 200 Mpc to above **600 Mpc.**
- Rough hardware cost is 20 million $. So you can 'buy' sensitivity at a cost of **20Mpc/million $**.



More Details of the Team Red Design

- For details please see documents on the DCC:
- 50 page long description of the Team Red Design can be found at https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=78100
- The sensitivity data for the Team Red design are available at https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=86562



LIGO 3 Strawman Design, Team Red

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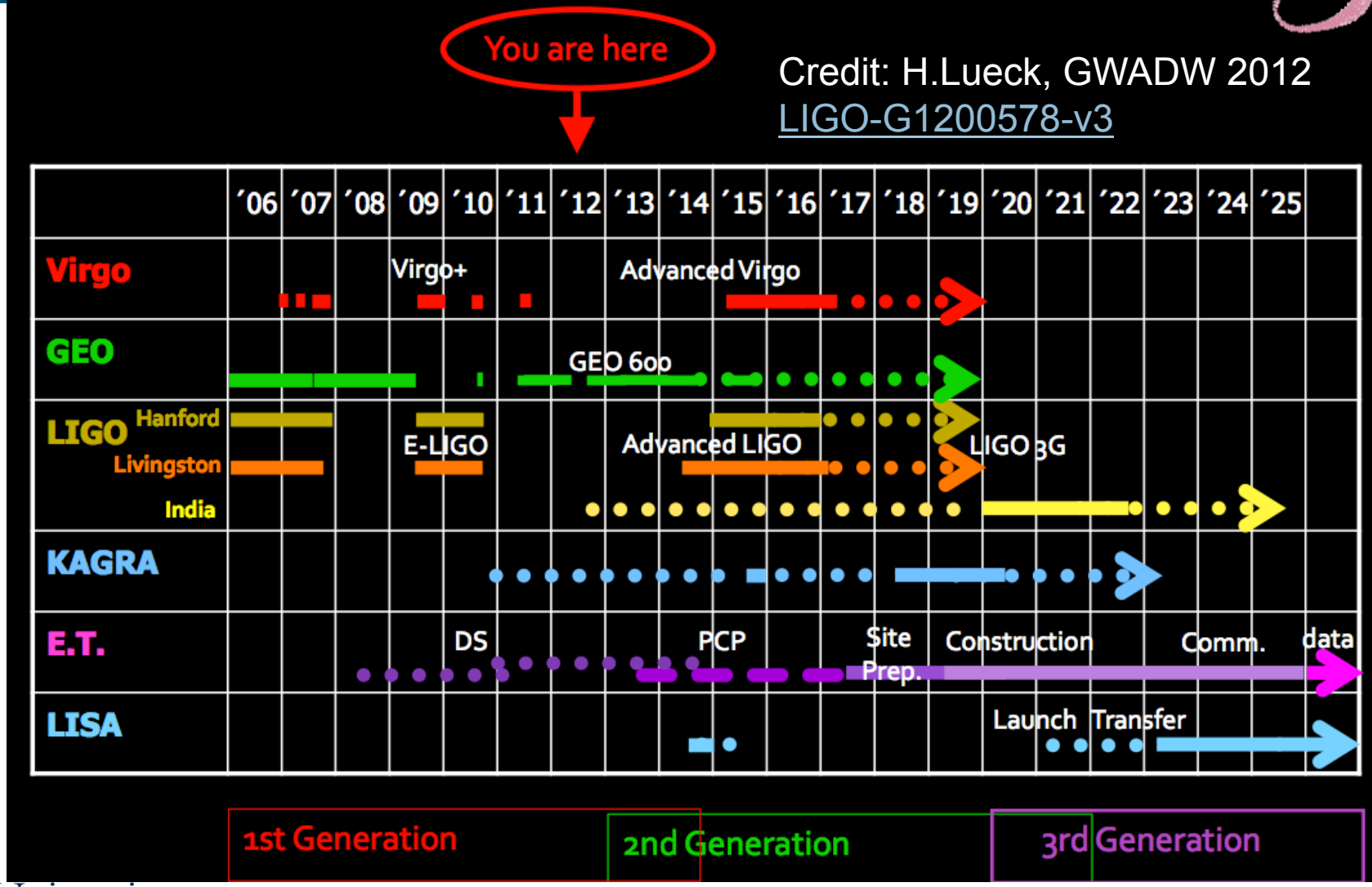
GW Timelines



Credit: H.Lueck, GWADW 2012
LIGO-G1200578-v3

Discussion Points

- **In what frequency range shall we push for improvement of the GW detectors?**
  - So far always focussed on broadband improvements.
  - However, technically there are ample of opportunities to emphasis a certain frequency range (which obviously comes at the cost of de-emphasising other frequency ranges).
  - Can you think of burst-specific figure of merit that can be used as quantitaive guidance for the configuration choice?
- **What calibration accuracy is required to do good science?**
  - Absolut calibration, frequency dependent error, sub-second time scale?
  - So far we have aimed for 10% and 10deg (and usually done a bit better in the end).
  - 'Insufficient' calibration might harm network analyses, null streams etc…
  - Would be good to have a quantitave motivation for the calibration requirement, rather than going for the 'as good as we can' approach.

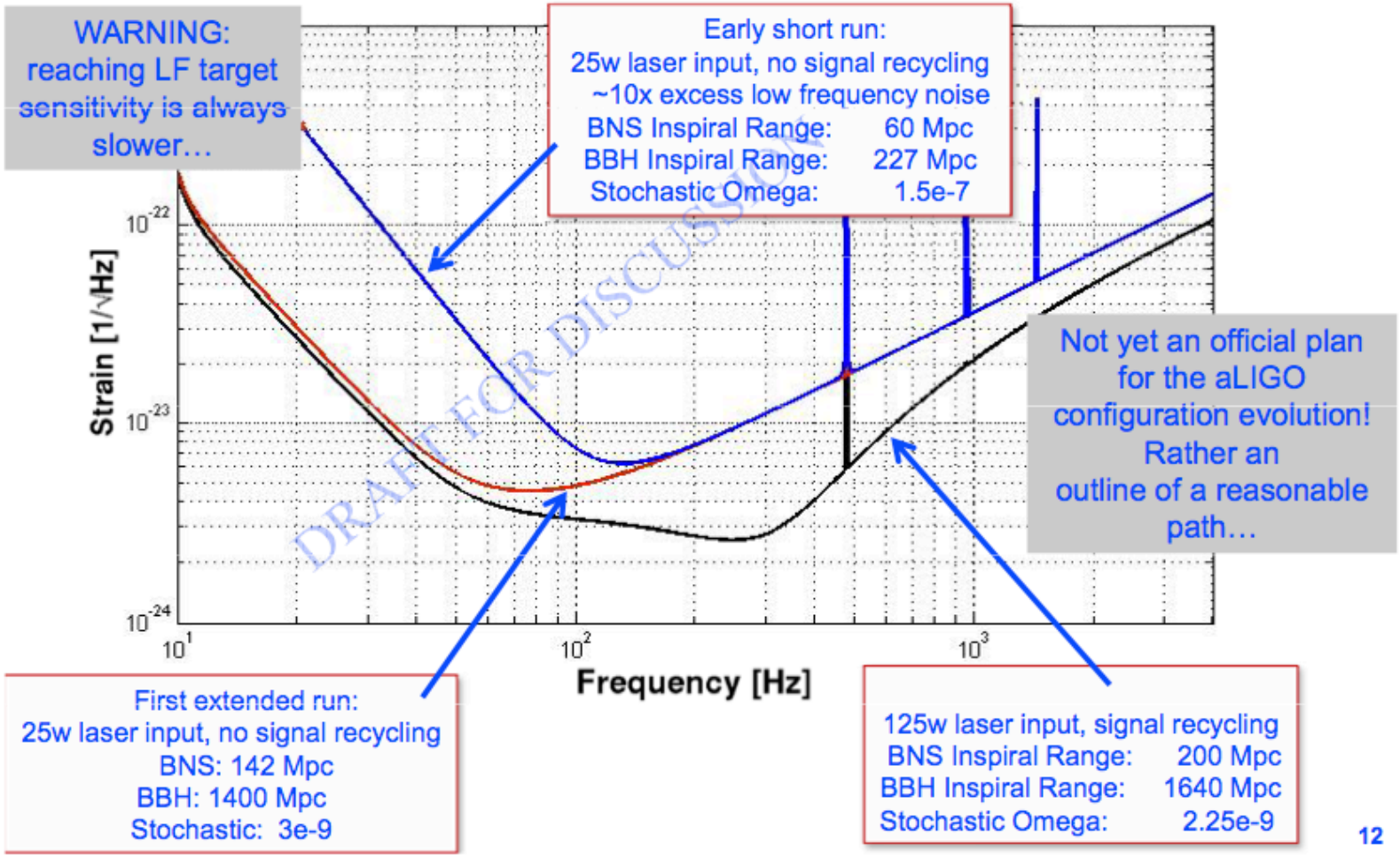
YOUR input required !

- For both (ET and LIGO3) input from your side is more than welcome!
- How shall we 'shape' the sensitivity for you to get the best science out of the data?
- What requirements do your searches have in terms of calibration?

- *Let me know and we will try to 'deliver' …*

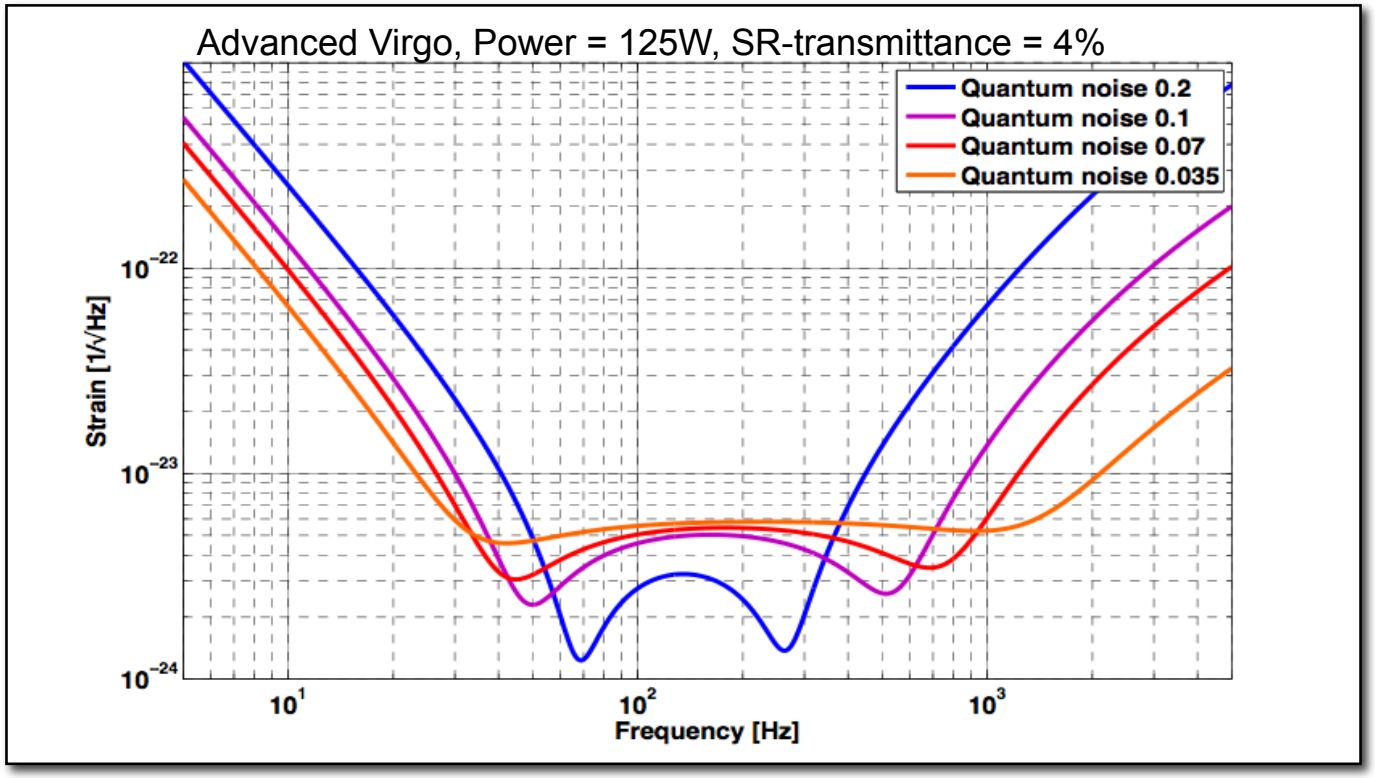
EXTRA SLIDES

Sketch of **possible** progression for Advanced **LIGO** sensitivity



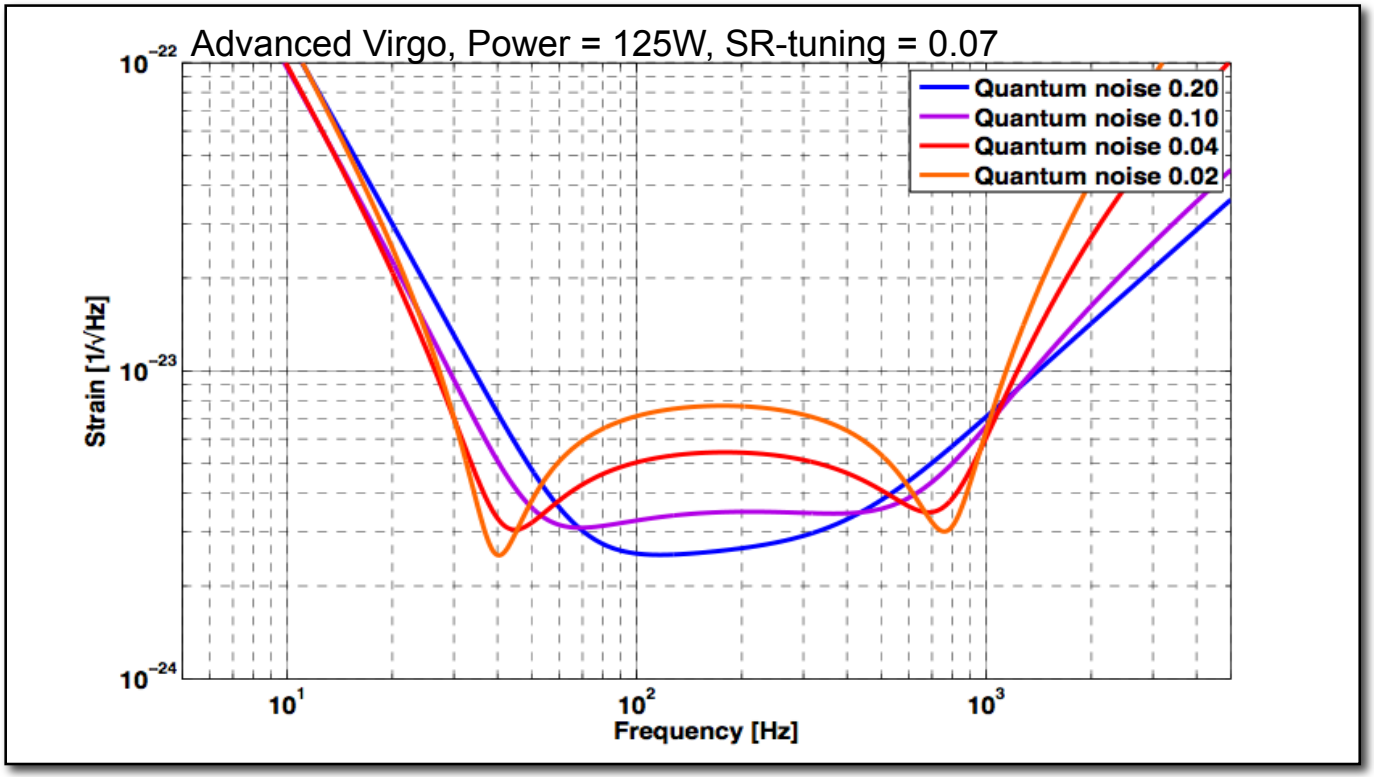
Credit: D.Shoemaker and G.Losurdo
LIGO-G1000176-v7

Signal-Recycling (de)tuning



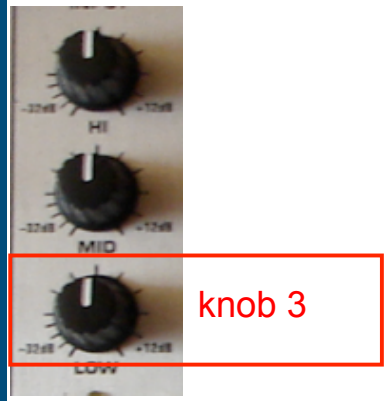
- Frequency of pure optical resonance goes down with SR-tuning.
- Frequency of opto-mechanical resonance goes up with SR-tuning

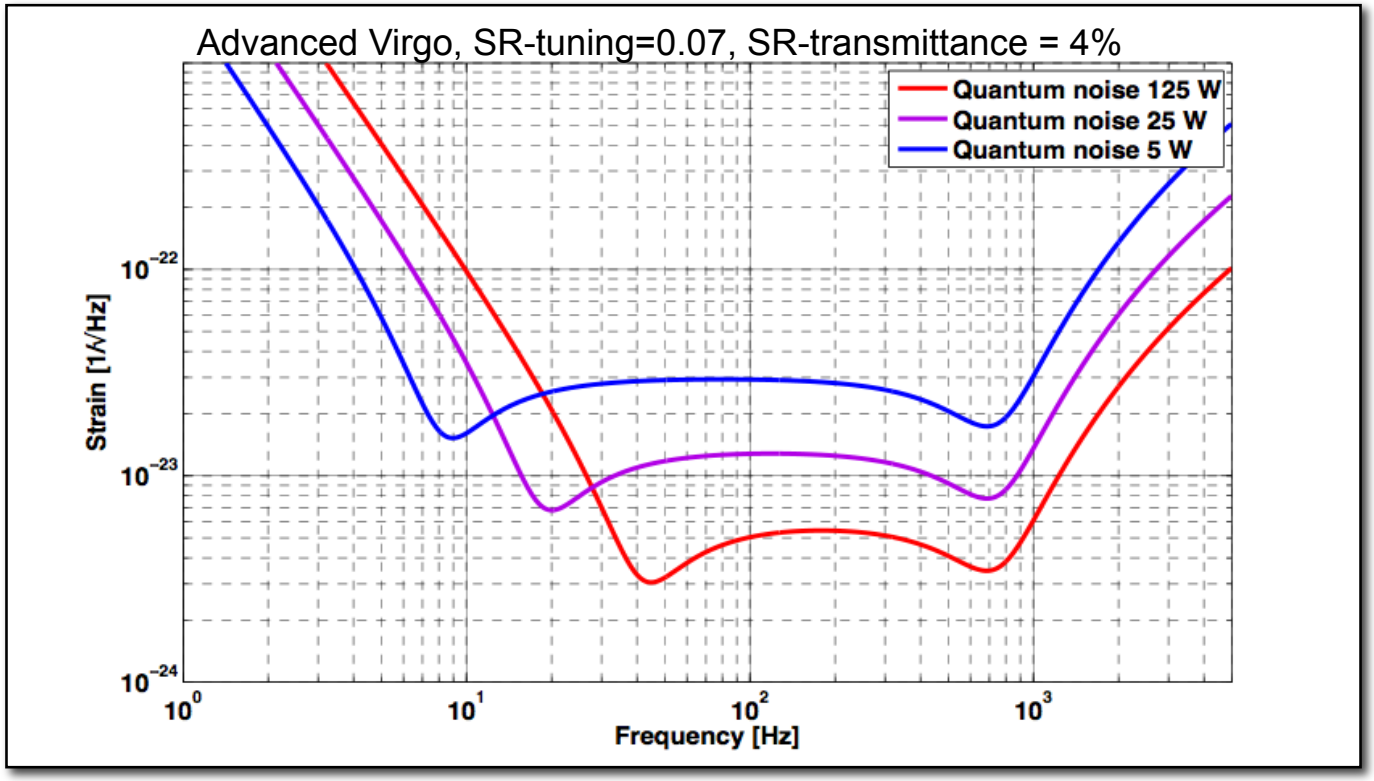
Signal-Recycling mirror transmittance



- Resonances are less developed for larger SR transmittance.

Knob 3: Optical Power





- High frequency sensitivity improves with higher power (Shotnoise)
- Low frequency sensitivity decreases with higher power (Radiation pressure noise)

Jun's Theorem

Laser wavelength

Peak sensitivity

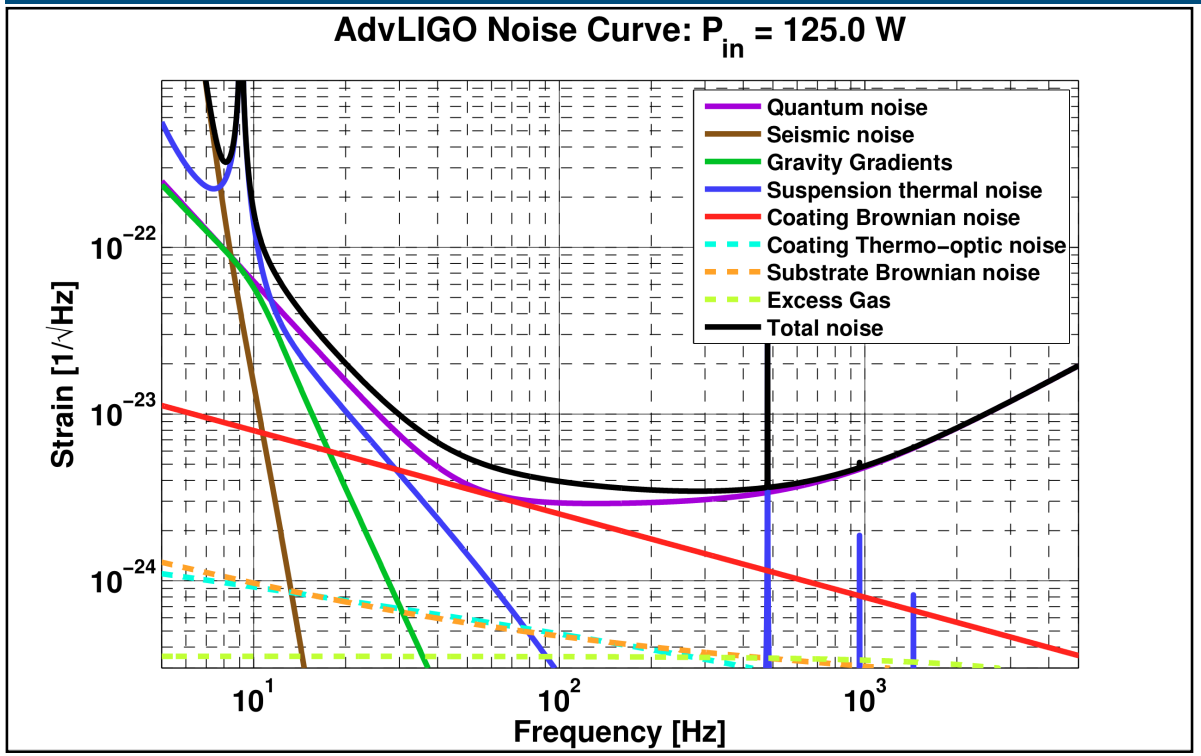
Bandwidth of
The 'bucket'

$$\tilde{h}_0 \gtrsim \sqrt{\frac{2\hbar\lambda}{\pi c}\frac{\Delta f_{\mathrm{BW}}}{\mathcal{E}}},$$

Energy stored
In the IFO

- Theorem from Jun Mizuno (PhD thesis 1995).
- "Any configuration storing the same amount of energy will have the same sensitivity when optimised for the same bandwidth."

Jun's Theorem: aLIGO as example



1064nm

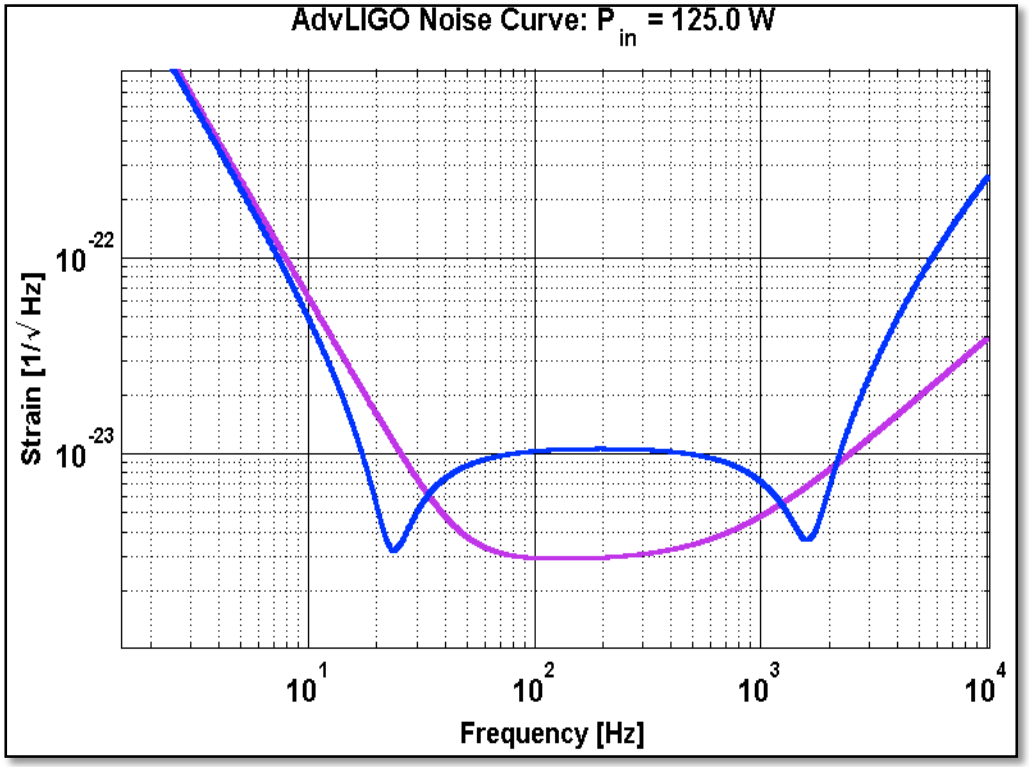
10J

~500 Hz

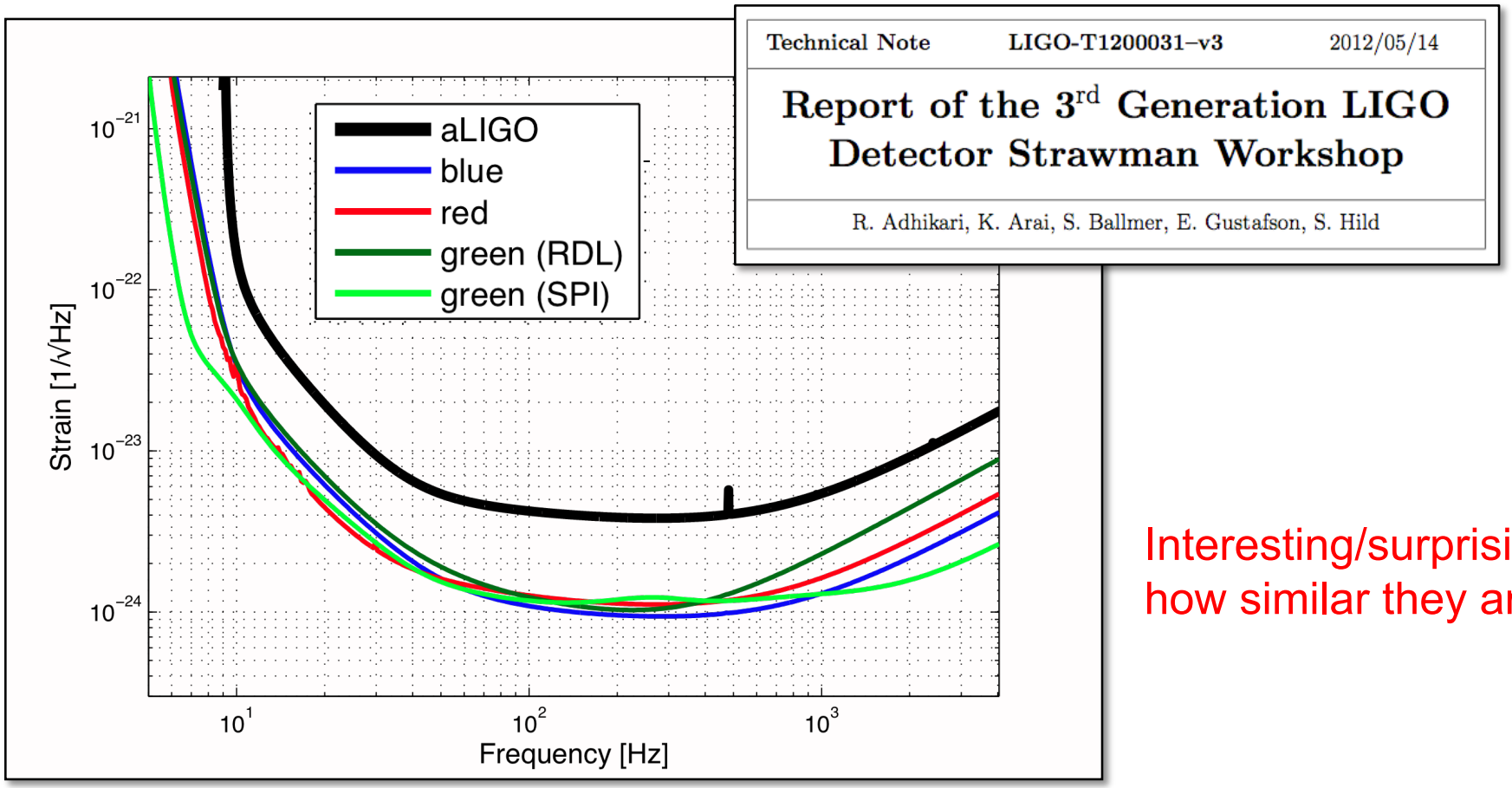
$$\tilde{h}_0 \gtrsim 3.3 \cdot 10^{-24}/\sqrt{\mathrm{Hz}} \times \left[\frac{\lambda}{1\,\mu\mathrm{m}}\right]^{\frac{1}{2}} \left[\frac{\mathcal{E}}{20\,\mathrm{J}}\right]^{-\frac{1}{2}} \left[\frac{\Delta f_{\mathrm{BW}}}{1\,\mathrm{kHz}}\right]^{\frac{1}{2}}.$$

Detuned RSE

- How about detuned RSE?
  - Can give improved HF sensitivity, **but on a hugely reduced LF sensitivity.**
  - Also losses will pose a limit on how narrow band you can do the RSE.
  - Perhaps for this better to use delay lines + signal recycling. Something like GEO style interferometer with 10km arm length.



How does the red design compare to blue and green?



Interesting/surprising how similar they are …