A proposal for additional Low Frequency Gravitational Wave Interferometric Detectors at LIGO

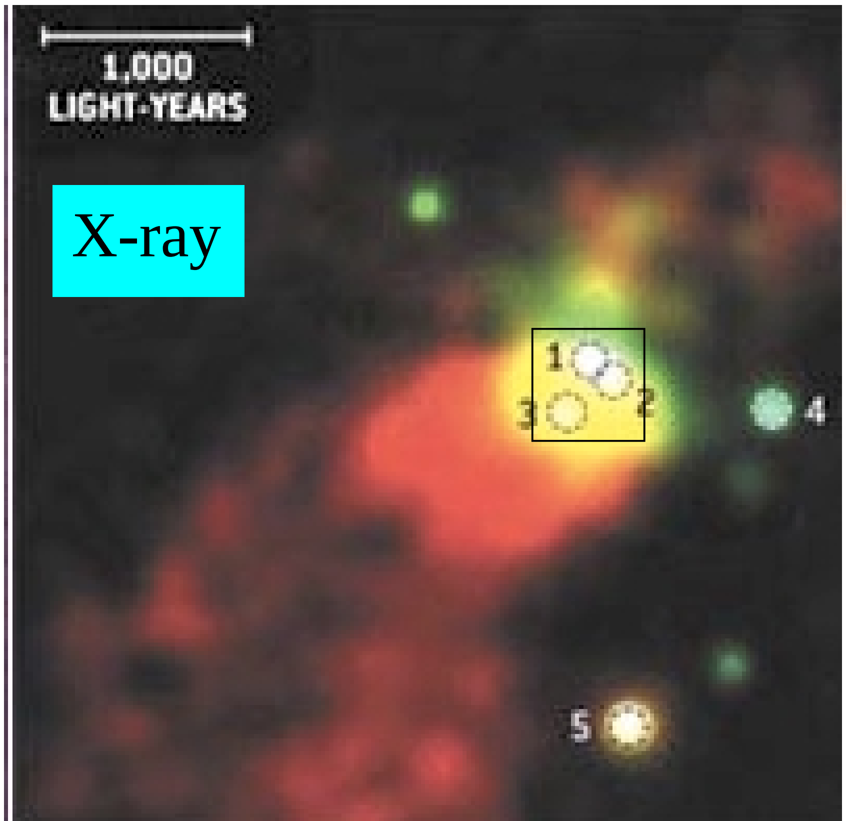
Riccardo DeSalvo

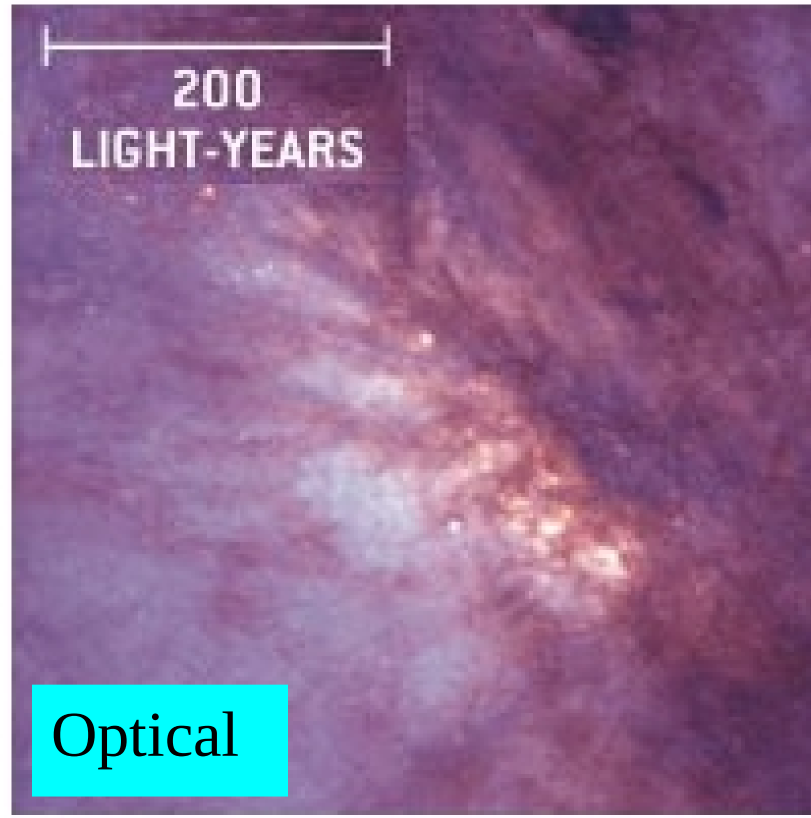
California Institute of Technology

Amaldi 5 11th July 2003

LIGO-G030332-00-R

NGC 253
just 3Mpc away





NASA/SAO/CXC

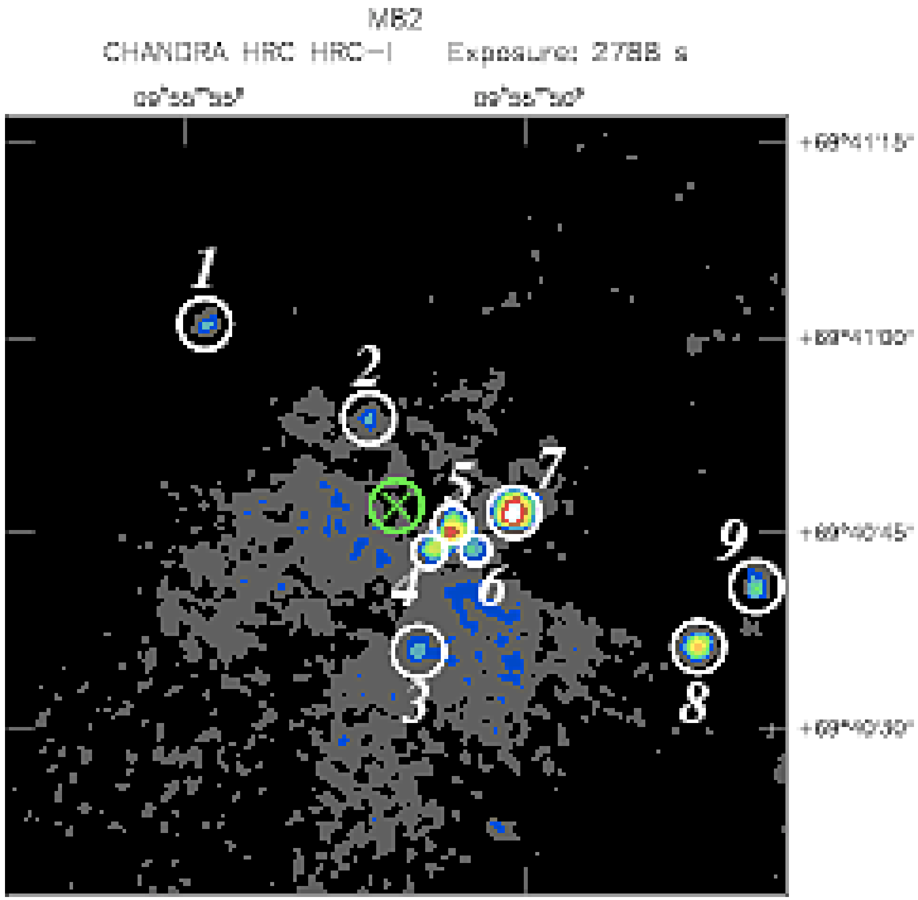
EUROPEAN SOUTHERN OBSERVATORY

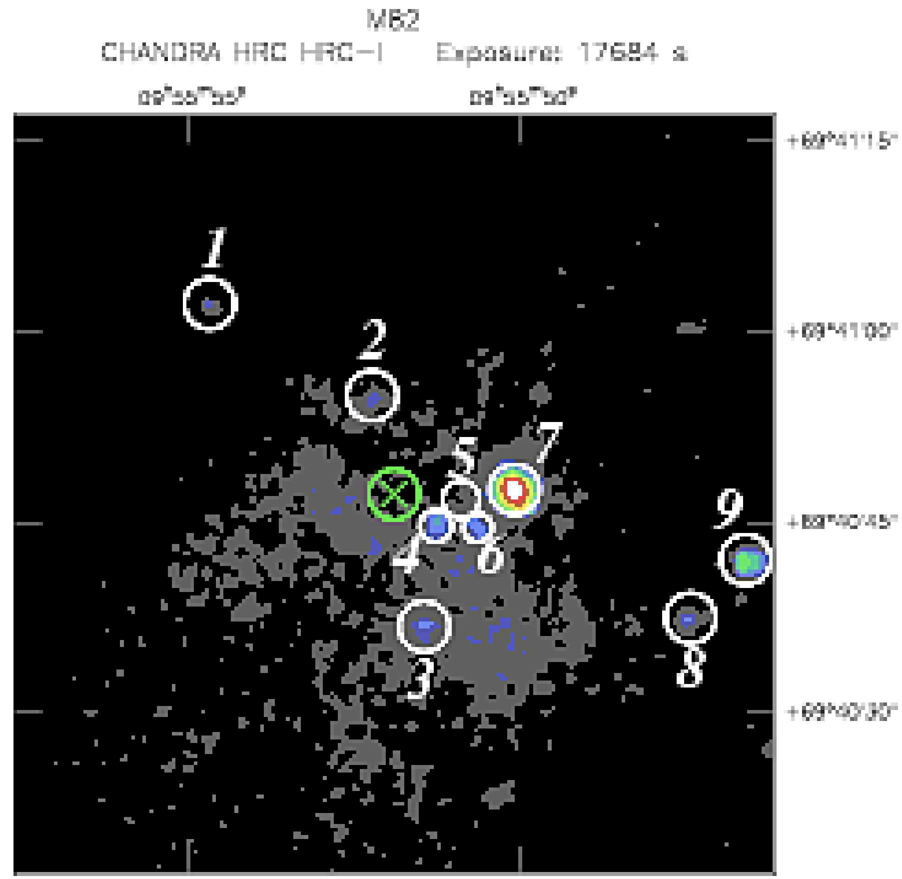
K. Weaver Astro-ph0108481/Sci. Am. July 2003

The numbered point sources all have luminosities at least 10 times larger than expected for the Eddington Limit of a ~ 1 $M_{\odot}$ accreting compact object.

Star # 1 ~ 100 M_{sun} will chirp < 50 Hz

X-ray observations of M82

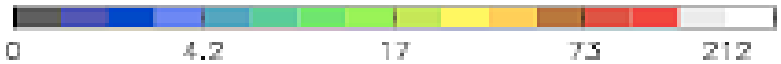




28 October 1999

Matsumoto et al.

20 January 2000



Catalyzed inspirals

- X-ray and optical observations indicate the presence of Intermediate Mass Black Holes (IMBH) or other hidden dense mass in globular clusters and elsewhere

- Optical observations show densities of 10^6 stars / pc^3

- At these densities dynamical braking (grand scale thermalization) **expected to induce catalyzed inspiral** of the heaviest objects available (in time scales of My instead of Gy)

- Mass segregation and BH growth by **hierarchical mergers** are expected

Cole Miller

Optical observations:
Swirl in globular clusters

- **Swirl** is observed in the core stars around central hidden mass

  But

- Dynamical braking would rapidly eliminate the observed swirl!

  Explanation (controversial but growing evidence)

- Core stars soak angular momentum from central BH binary (or cluster) thus hardening their orbit

- **Is swirl a catalyzed inspiral Smoking gun?**

Astronomical observations conclusions

- IMBHs may provide copious sources of GWs
  - Linqing Wen, this conference
- Tens of BH-BH detectable inspiral events per year may be expected
  - Coleman Miller. Astrophysics Journal 581: 438-450, Dec 2002 and Pr.Comm.

- GW are emitted mainly at frequencies at the lower end of Adv-LIGO range

- LIGO-P030039-00-D http://www.ligo.caltech.edu/~desalvo/DESALVO_ELBA_manuscript.doc
- And references therein and http://www.ligo.caltech.edu/~desalvo/desalvo-elba.ppt

BH chirp and ringdown frequencies

- final chirp frequency can be approximated by:
- f ~ 4.4/ M [kHz]
  - 100 M_{sun} systems at 44 Hz,

- Kerr BH ringdown frequency after merger for mass M:

  f ~ 32/M [kHz]

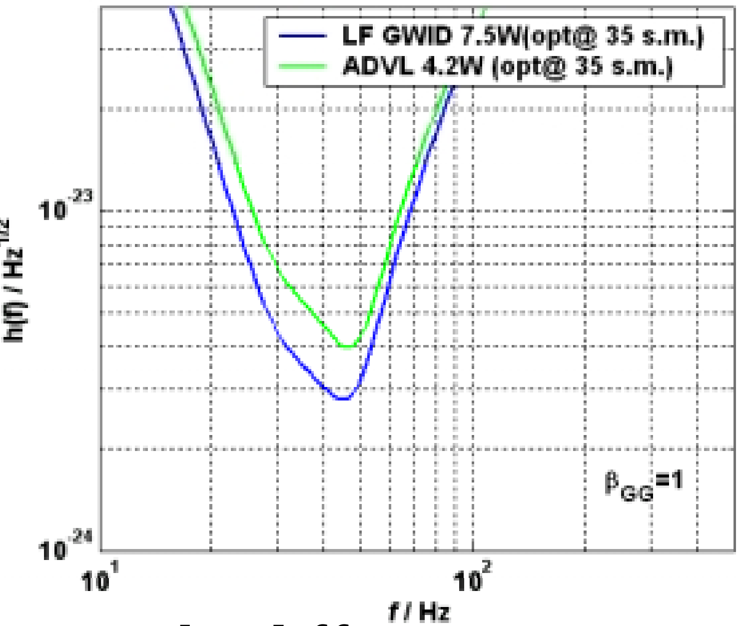
  » (J. Creighton, gr-qc/9712044 or F. Echeverria, PRD 40, 3194 (1989))
- ringdown for a 1000 M_{sun} BH at ~ 32 Hz.

Matthew Benacquista

Why LF-GWIDs?

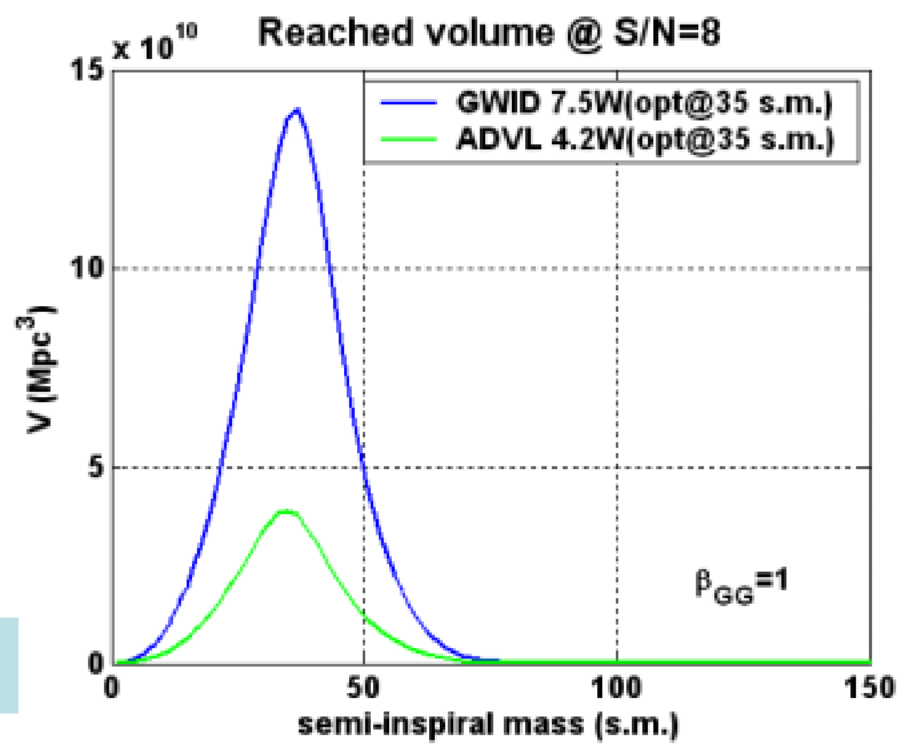
- Adv-LIGO covers the detection of NS-NS and low-mass BH inspirals, the coalescence phase, pulsars, and other GW physics with its best sensitivity around100 Hz
- The new observations give strong reasons to desire ground based GWIDs capable to monitor even lower frequencies
  - Also (old reasons):
  - Every chirp starts at LF
  - The GW signals have more statistical power at LF ($f^{-7/3}$)
  - The lower frequency templates are easier to calculate => can detect fainter objects with matched filters
  - … … .et c.

Advantages of a Low Frequency optimized design



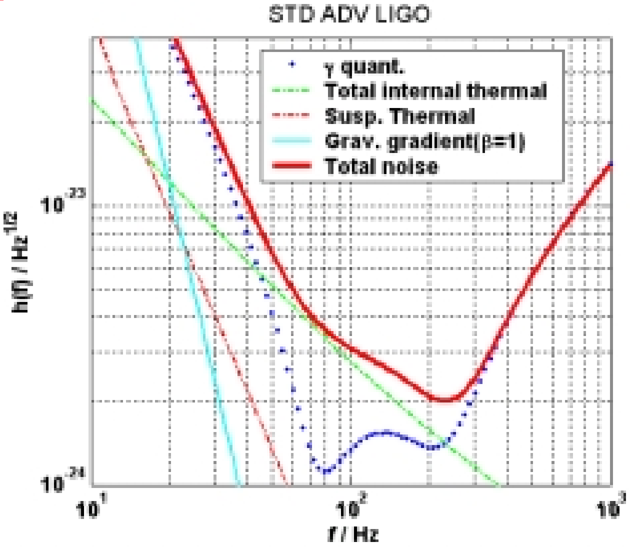
Comparison between LF-tuned AdL and a fully optimized LF interferometer, both for 35+35 s.m. insp.

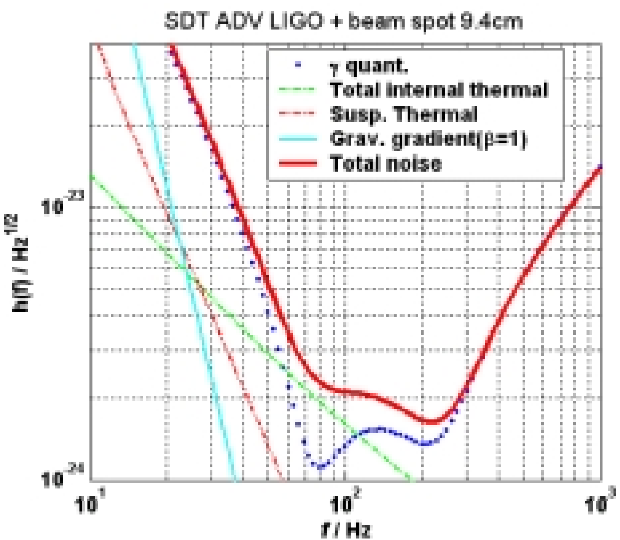
The difference comes from longer suspensions and larger test masses (Fused Silica)

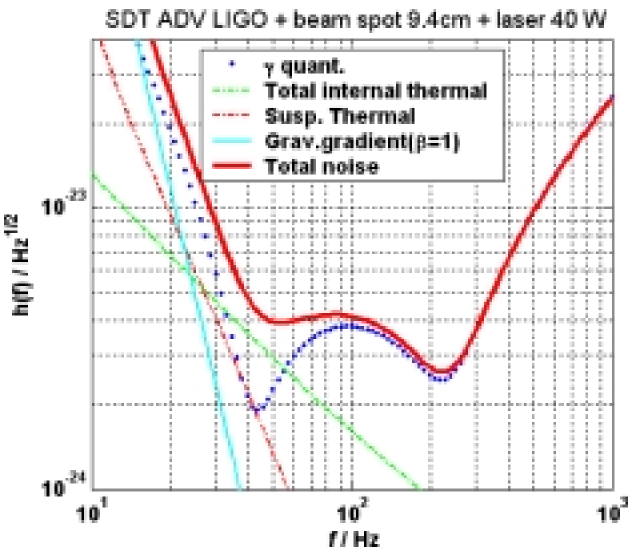


Bench studies and graphs from E.Campagna

What limits the LF optimization of AdL?





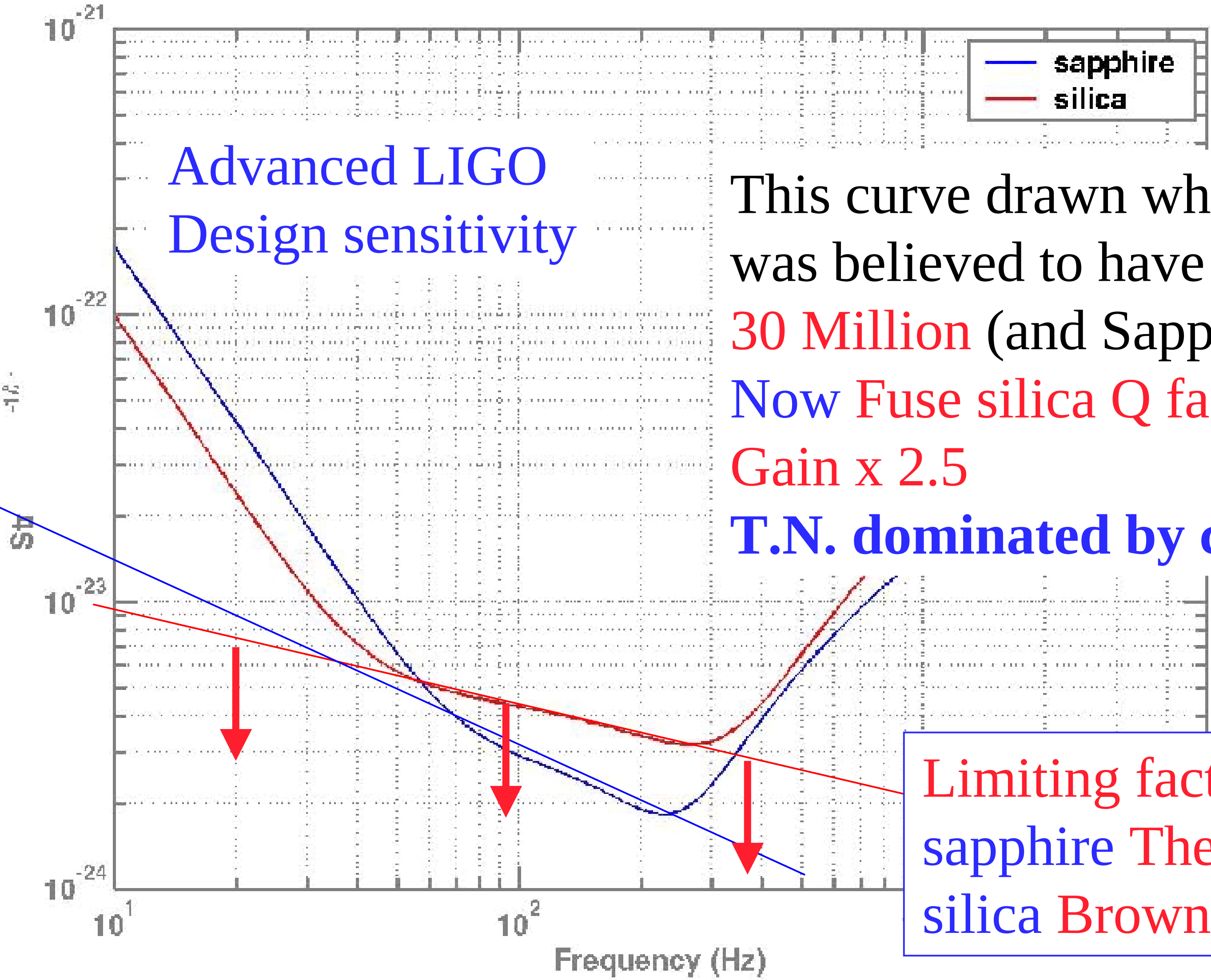


What are the requirements?

- **GW Interferometers can be optimized for LF with the following changes**
  - Reduce beam power and different finesse (rad. Pressure)
  - Use longer suspensions (susp. TN)
  - Use Supersized, double weight, mirrors (coating TN, rad. Pr)
  - Use Fused Silica instead of Sapphire mirrors (bulk TN)
  - (And wide beams Erika D'Ambrosio, this conference)
- And LF-tuning would divert them from their original mission!

- Need operation of separate Low and High Frequency complementary interferometers

Effect of different substrate choice



Advanced LIGO
Design sensitivity

This curve drawn when Fused Silica was believed to have a Q-factor of 30 Million (and Sapphire T-E limited)

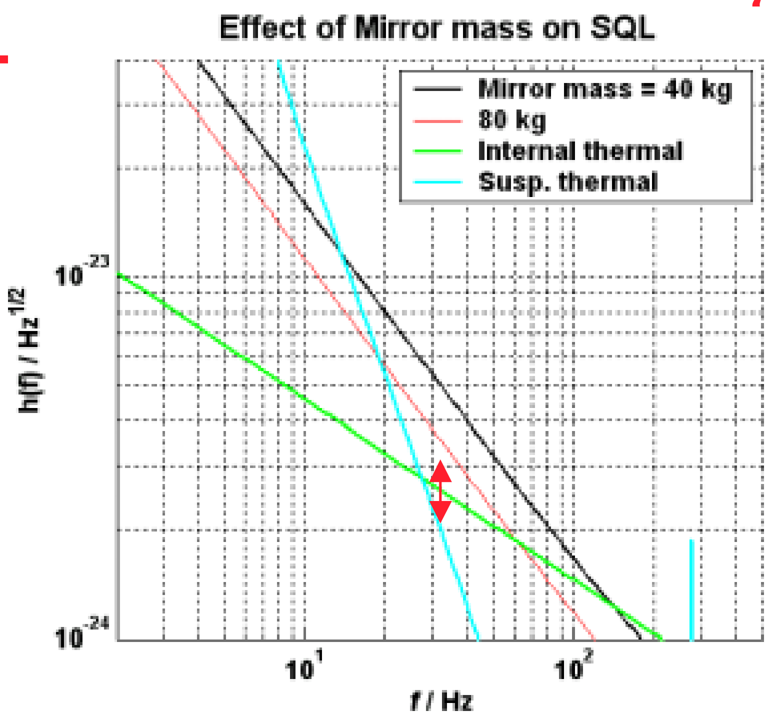
Now Fuse silica Q factor >200 Million

Gain x 2.5

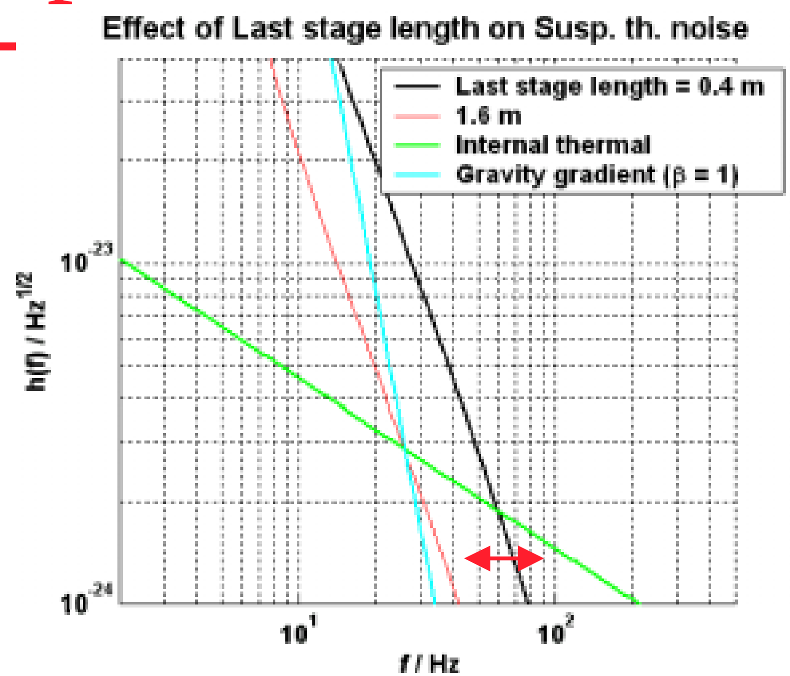
T.N. dominated by coating noise

Limiting factors:
sapphire Thermoelastic noise
silica Brownian Thermal noise

Effects of increased mass and longer suspensions



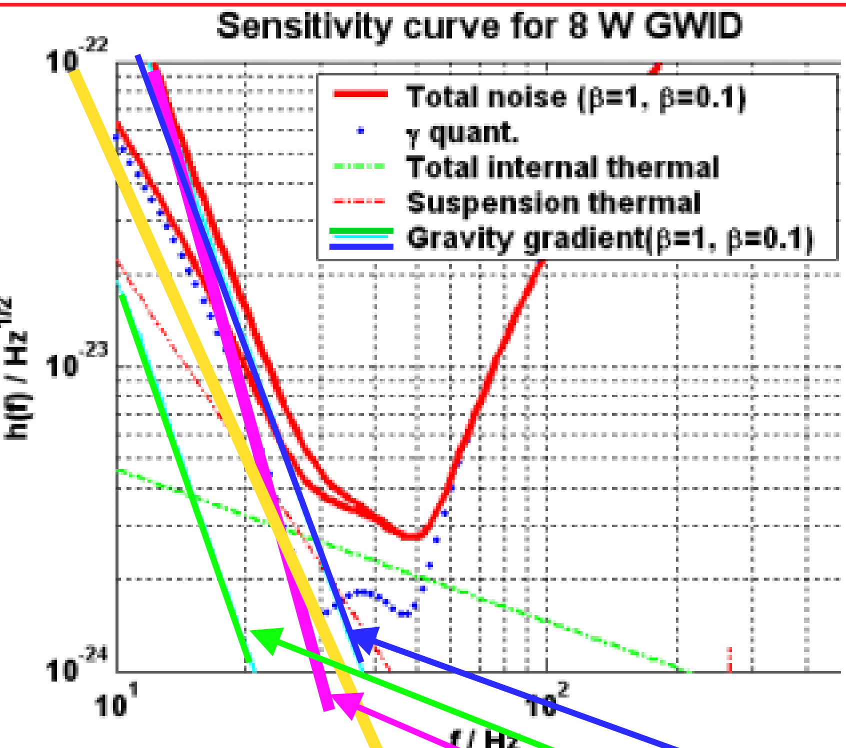
Indicative only:
Limit exceeded
with signal
recycling

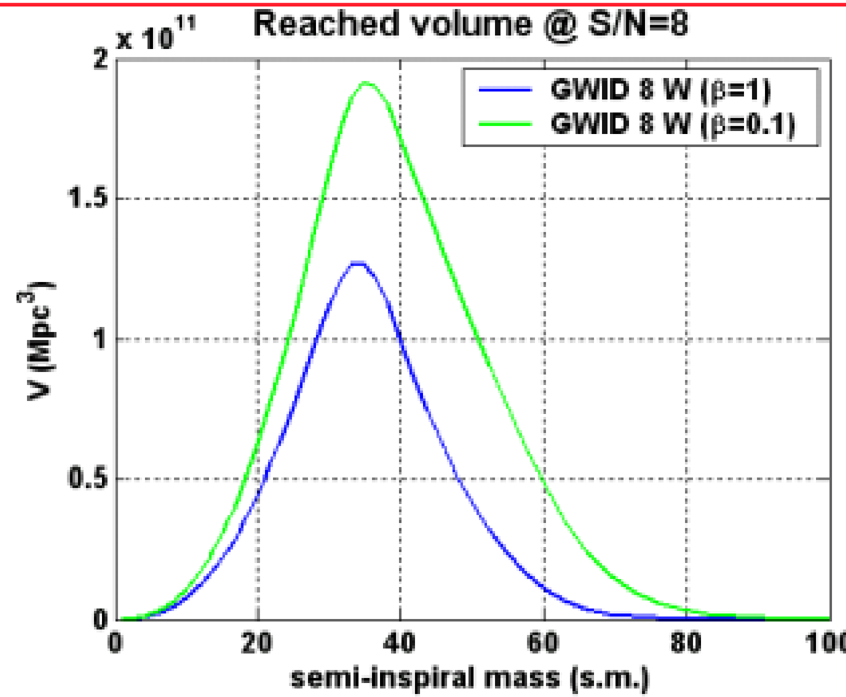


0.4 vs 1.6 m suspensions

Fused silica suspensions
Fused silica mirror
Substrate Q 200M
Coating Q 50K
Spot 12 cm

Is Gravity Gradient a big problem?



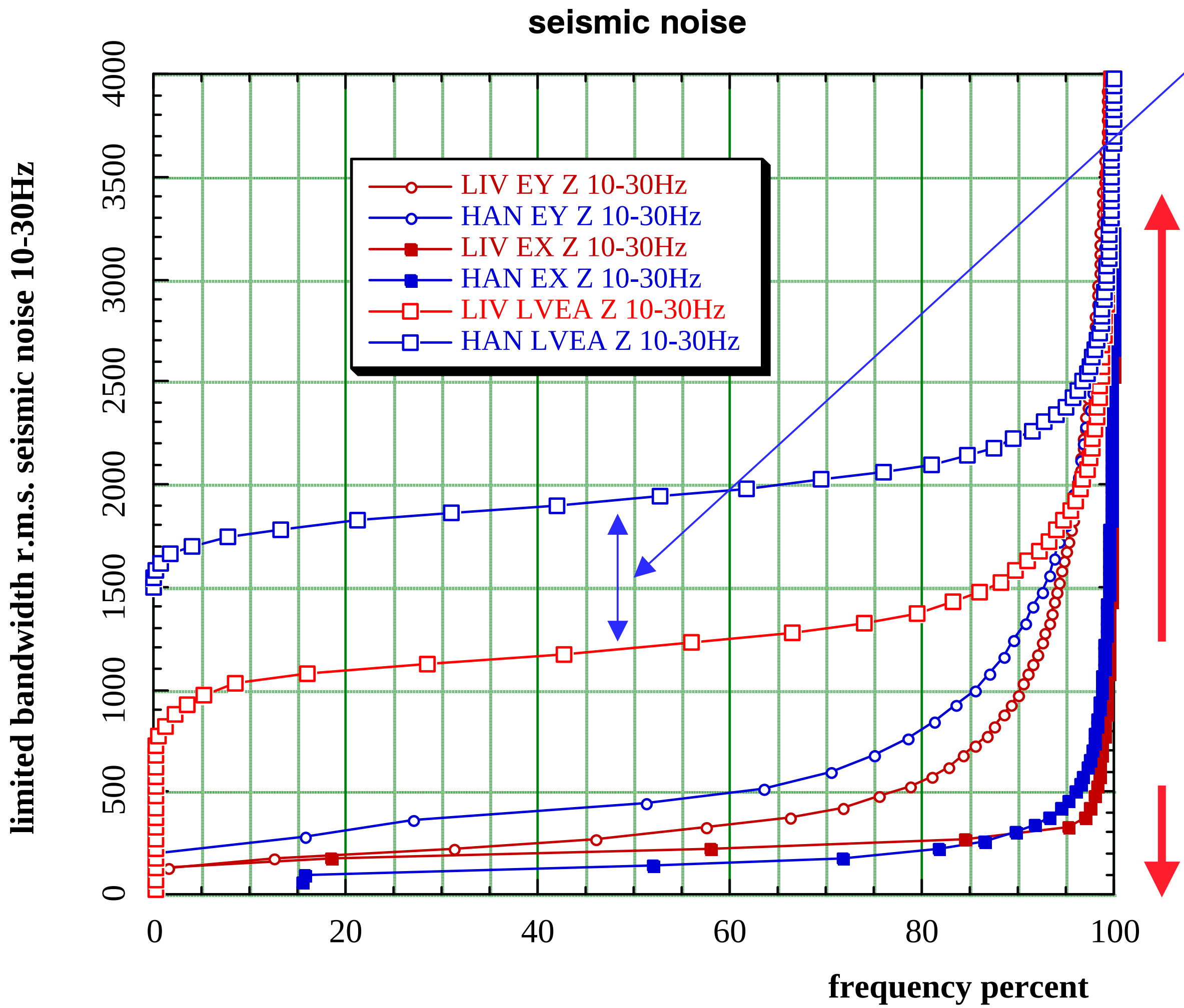


Added bonus if β = 0.1

Gravity Gradient:
Kip's β = 1.0 for bad times
Kip's β = 0.1 for good times
Schofield estimation (AdL)
Cella's estimation

How often it is a bad day?

Minute trends. Bandwidth limited r.m.s.



Excess of ambient noise in the corner stations
(Real or acoustic noise on the seismometers?
How much is lines that can be shifted/gated?
……)

Bad times

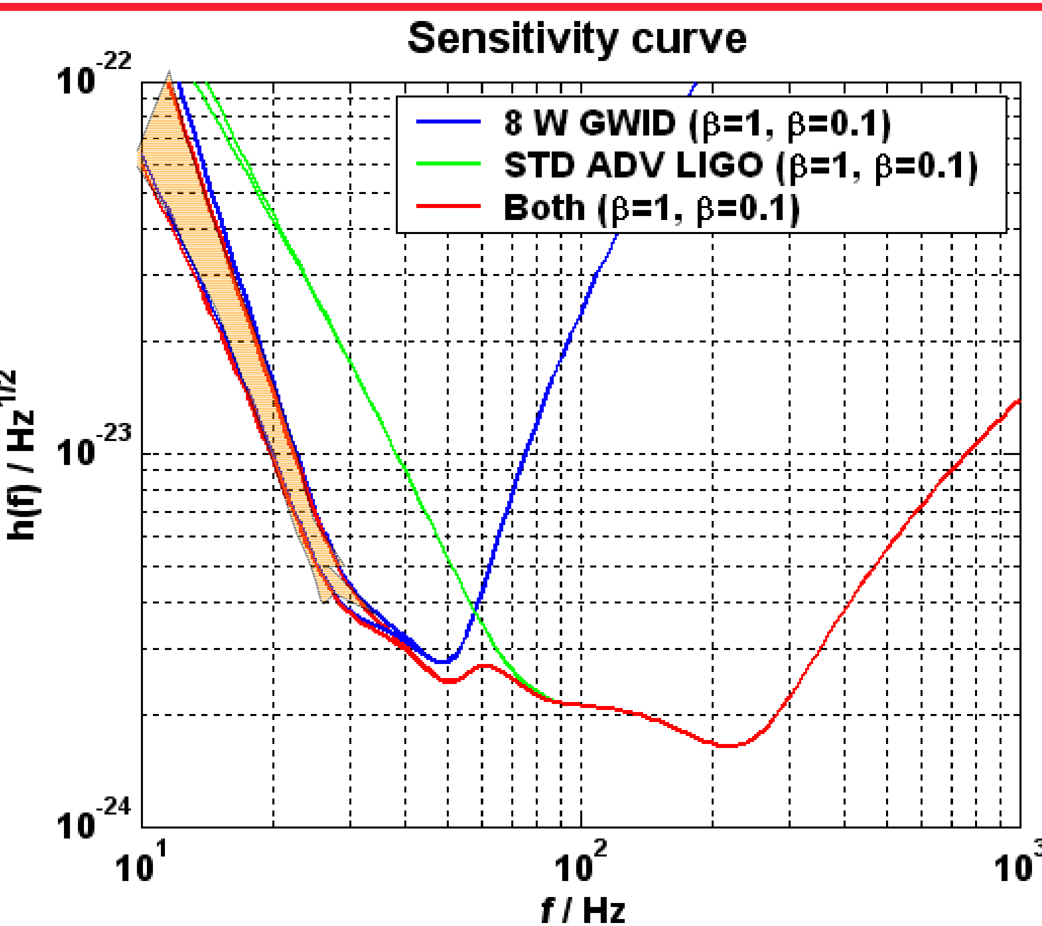
Good times

Comments on Gravity Gradient

- Bad times could be gated off
- Most of the time natural GG may not be such a big problem
- But human ambient noise (fans, hums) will be a continuous problem
- Bonus only if solve the human pollution problem

LIGO

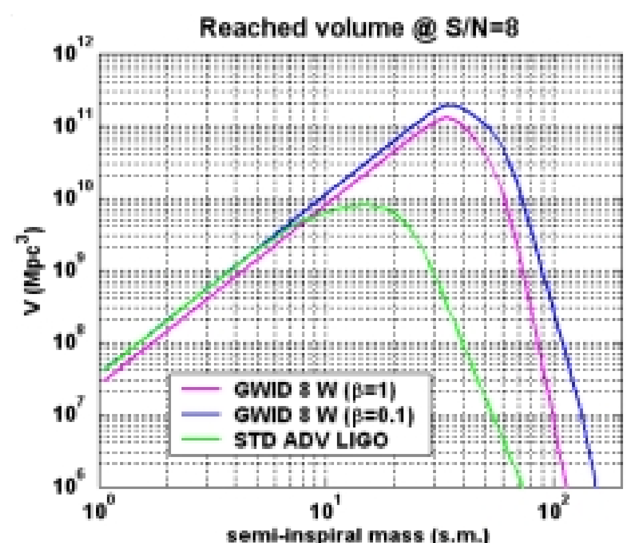
AdL LF-GWID complementarity



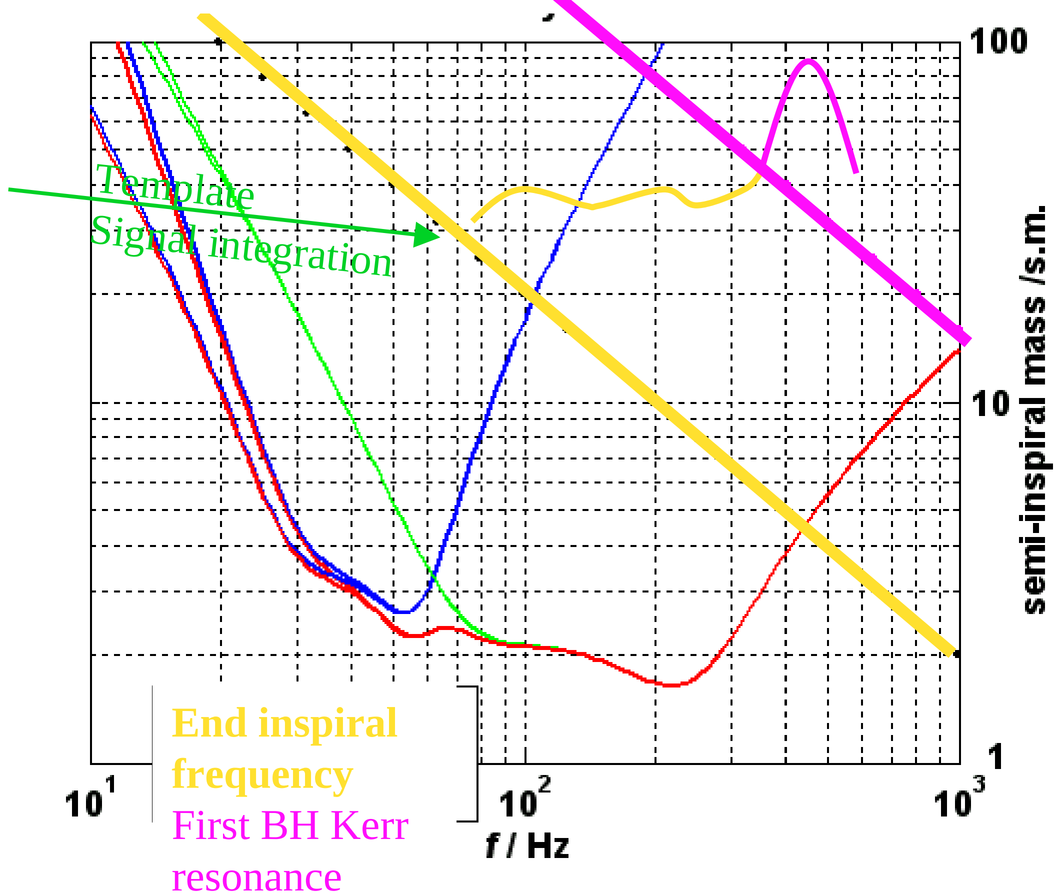
(both simul with wide beams)

The better HF sensitivity of AdL is better suited to follow the fully relativistic plunge and ringdown (no even counting narrow banding).

LF-GWID is better suited for early detection, determination of orbital parameters, and triggering.



AdL LF-GWID complementarity

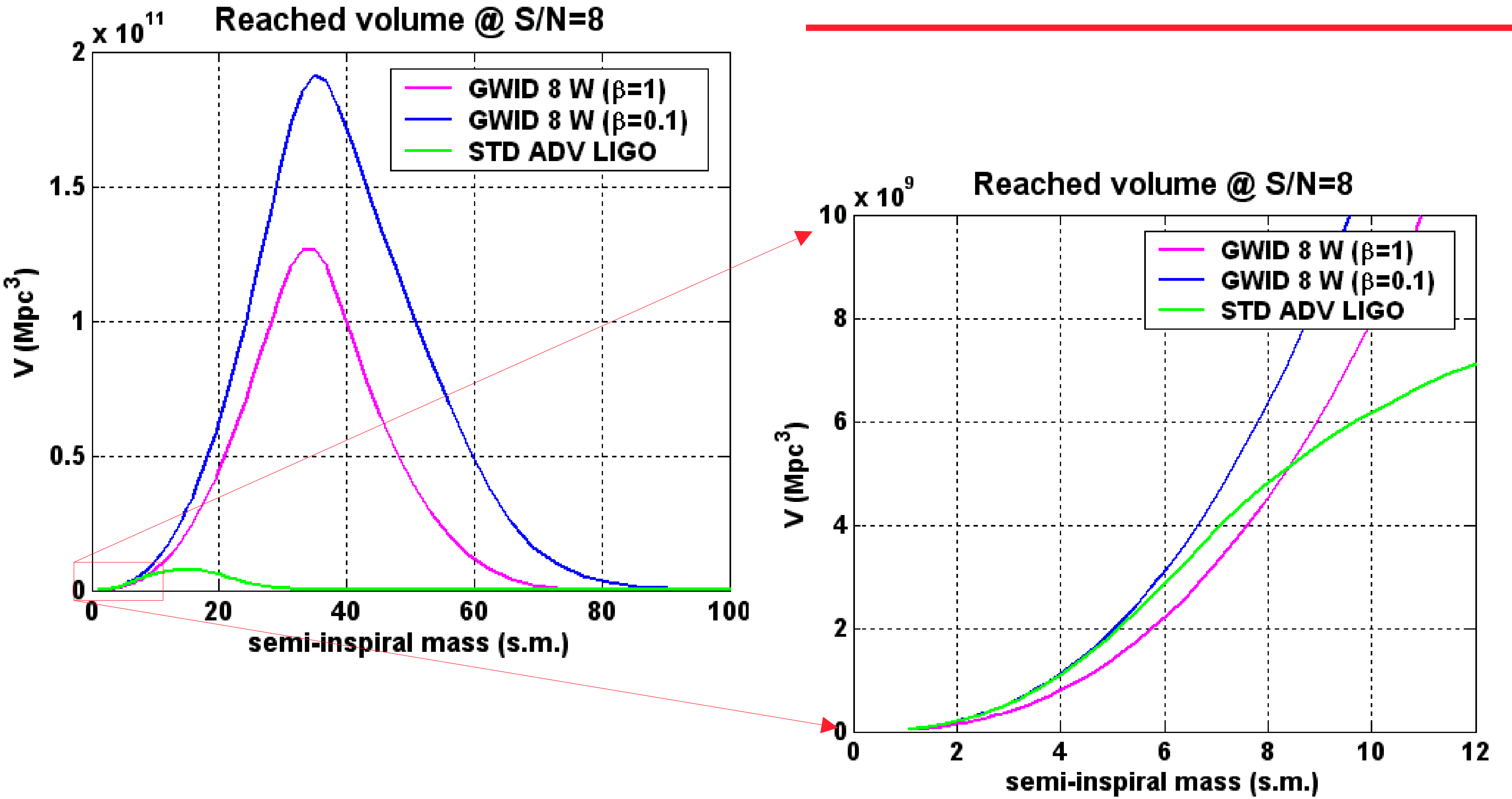


Triggered searches
LF trigger
HF signal exploration

BH ring down in the frequency mass area above the purple line

Merger phase follow-up in the frequency mass area above the yellow line

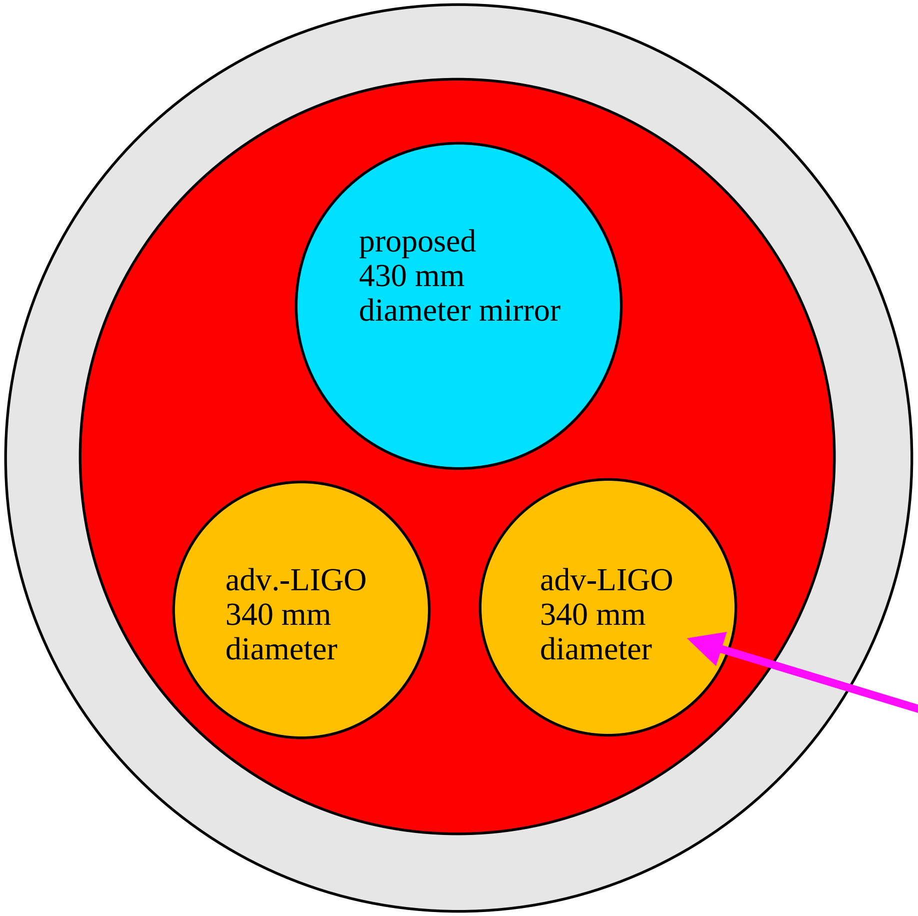
AdL LF-GWID complementarity



The idea: Additional LF interferometers at LIGO

- Is there sufficient interest in LF-GWID physics?
- Is the gain sufficient to justify the effort and expense in running time and money?
- Can we get the additional funding?
- The interest and feasibility of this idea should be evaluated by the community

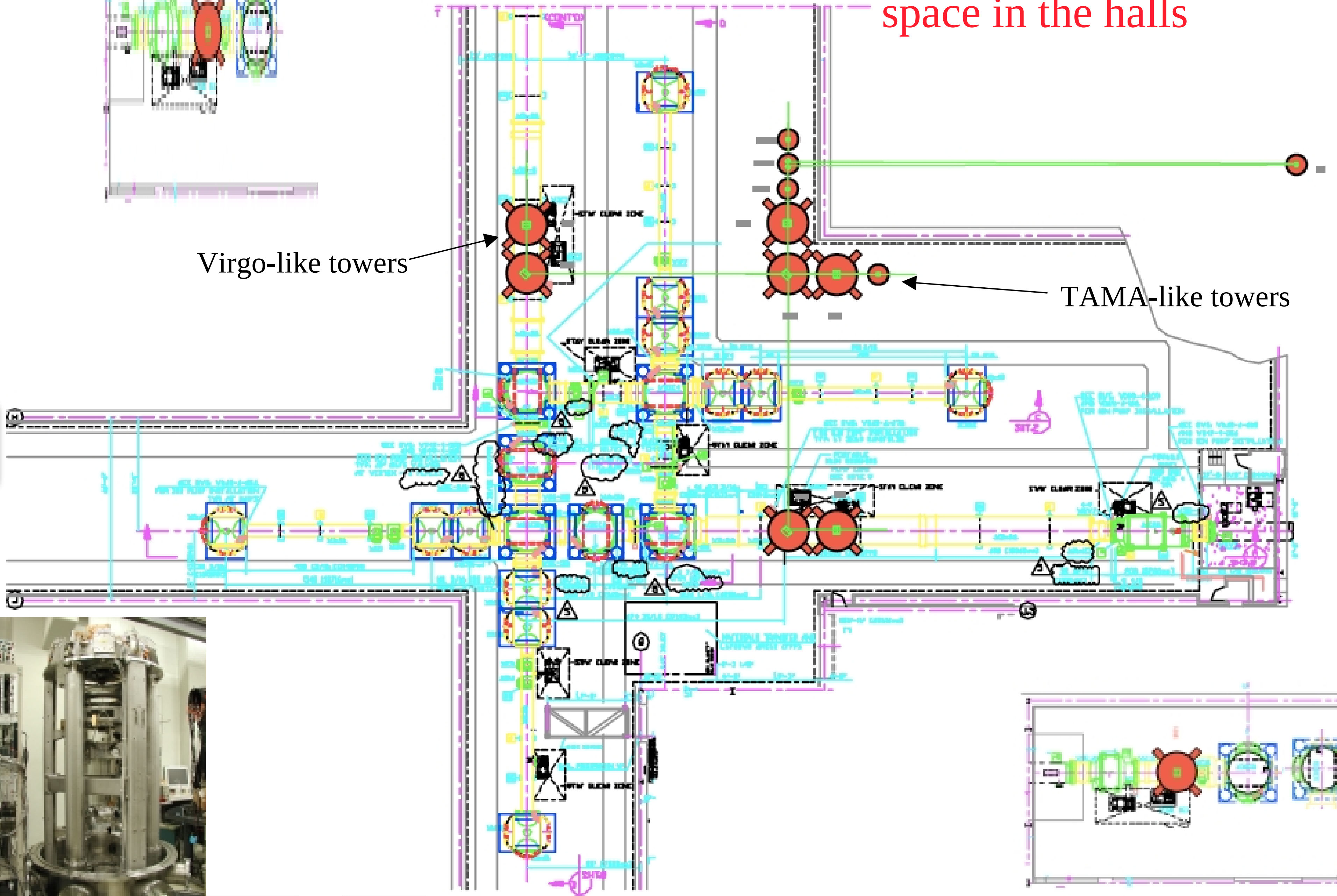
Can we accommodate a LF interferometer next to Adv-LIGO?



- There seems to be space in the LIGO beam pipe just above and forwards of the Adv-LIGO mirrors

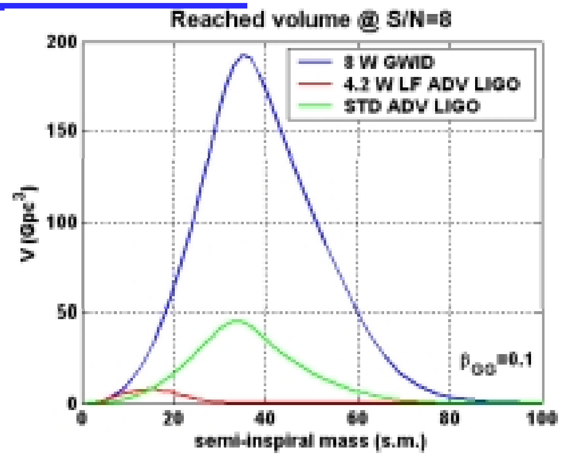
Advanced LIGO nominal beam positions

And there appears to be space in the halls



Conclusions

- **<u>IMBH are important and compelling potential GW sources for a LF interferometer</u>**



- Optimized LF sensitivity would allow:
  - Increase quite significantly the explored volume in the Universe for heavier mass objects
    (3.6 Gpc, real cosmology reach).
  - Study of the genesis of the large galactic BH
    (believed to be central to the dynamics of galaxies)
  - Mapping the globular clusters in our neighborhood
  - Enhancement of the performance of both Virgo and LIGO
    - They would be "triggered" by the LF detection and follow up studying final inspiral and merge signals
    - Advanced LIGOs are freer to be narrow banded
    - Splitting up the frequency range between two different interferometers eases lots of design constraints and allows better performance from both