Cryogenic Detectors

Amaldi-NRDA at Cardiff
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Would cryogenics improve the sensitivity of future GW detectors?

~ by a factor of 4 for going down to 20K?

~ maybe more for a higher Q at low T?

Yes…

- Mirror thermal noise decreases
- Thermoelastic noise decreases

No…

- Coating loss increases at low T
- Thick suspension fiber increases TN
- Power limitation by cooling capability

Complex detector design is necessary to make the most use of cryogenics

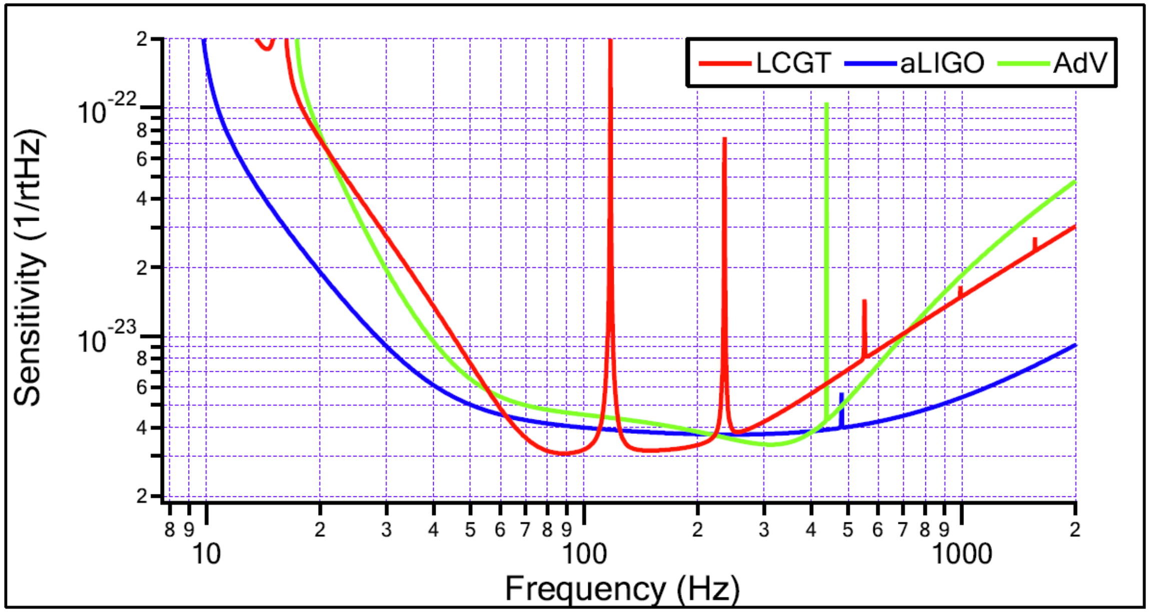
Advanced detectors

	Mirror	m	T	λ (nm)
2G (aLIGO, AdV, GEO-HF)	Silica	40kg	290K	1064
2.5G (LCGT)	Sapphire	30kg	20K	1064
3G (ET, LCGT+?, LIGO3?)	Silicon	200kg	10K	1550

- LCGT uses Sapphire as it transmits 1064nm
- Prototype tests at CLIO using Sapphire mirrors

- 1550nm is almost ready at LZH
- Silicon is expected to be larger than Sapphire

Comparison of 2G and 2.5G



Inspiral range for NS binaries (optimal direction)

LCGT (3km): 273Mpc

aLIGO (4km): 309Mpc

AdV (3km): 242Mpc

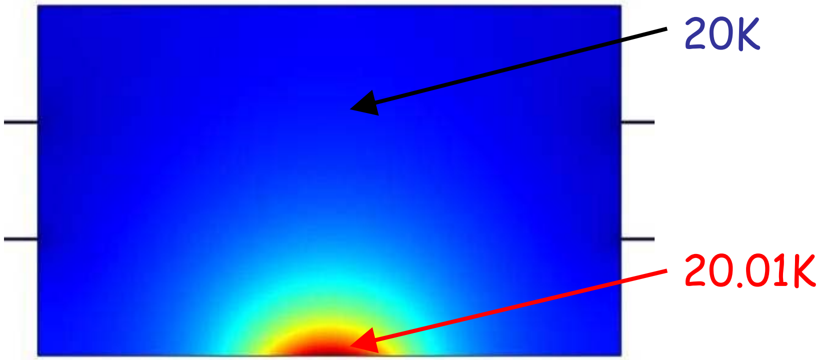
- LCGT can go deeper for low mirror TN
- LCGT bandwidth is a bit narrow for detuning
- 12% better IR compared with AdVirgo

(18% better than aLIGO x 3km/4km)

Only 12%? Is that the only benefit of cryogenics?

Benefits of cryogenics

(1) No thermal lensing problem



Temperature profile of LCGT ITM
(courtesy calculation by M.Arain)

High thermal conductivity
- Sapphire (20K) 15700 W/m/K
- Silica (290K) 1.38 W/m/K

(2) Less parametric instability problem

- LCGT's elastic mode density is 5-times smaller than aLIGO as Sapphire is harder than Silica
- LCGT's optical mode density is 2-times smaller than aLIGO as the beam radii are smaller

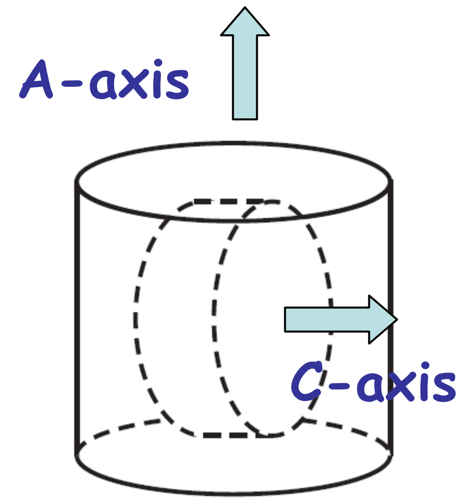
In total, LCGT's PI problem is 10-times easier than aLIGO

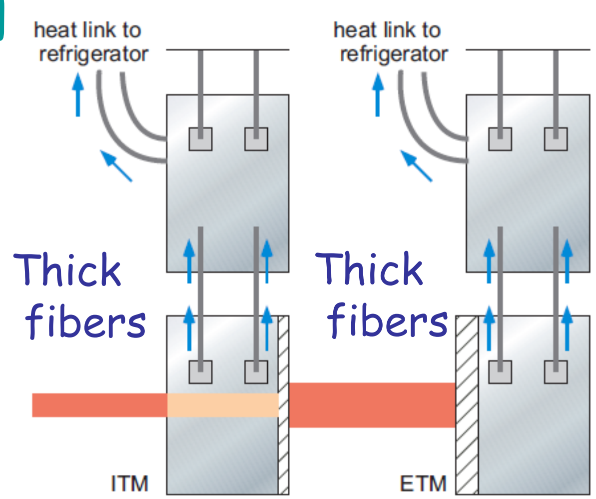
[Yamamoto, JPCS 2008]

Issues in LCGT

- The largest C-axis Sapphire is 30kg
- Substrate absorption is high: 20ppm/cm
- Incident laser power is limited
- Thick fiber increases suspension TN

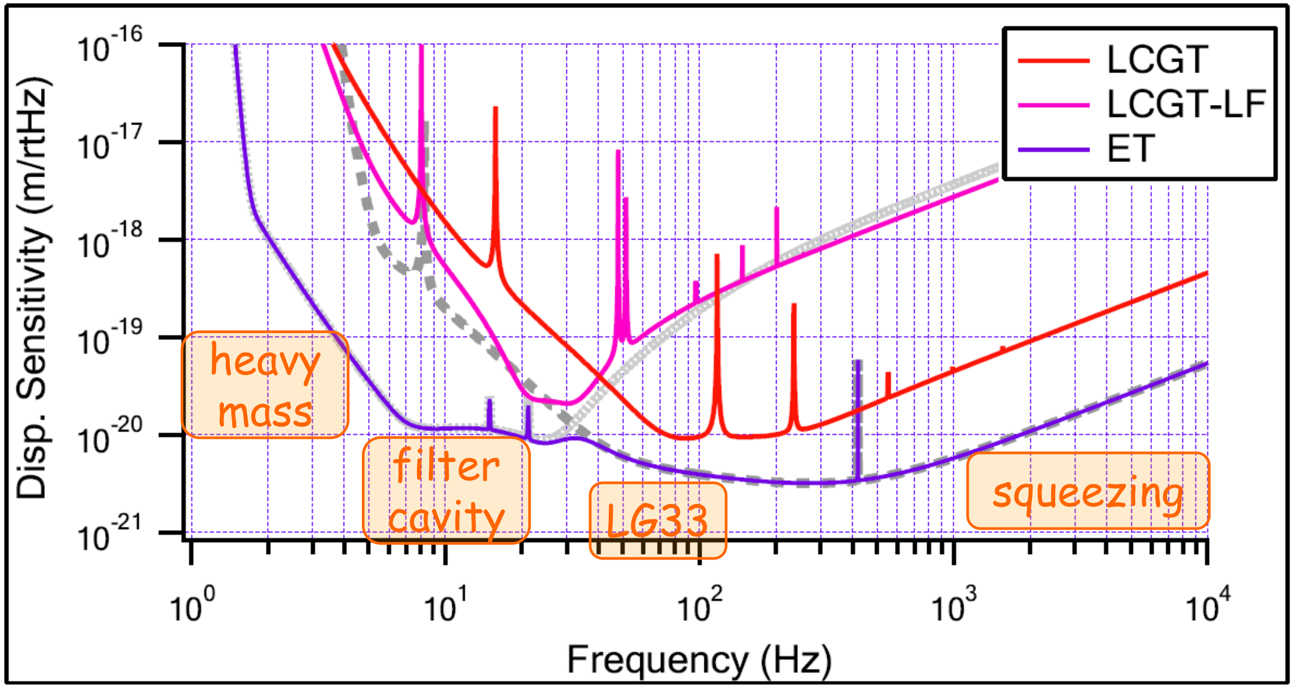
… etc.





These issues will be solved in ET…

Comparison of 2.5G and 3G (ET)



ET-HF:
3MW in arm
290K, m=200kg

ET-LF:
18kW in arm
10K, m=211kg
fiber d=3mm, l=2m

LCGT:
0.4MW in arm
20K, m=30kg
fiber d=1.6mm, l=0.3m

*LCGT-LF (hypothetical):
1.5kW in arm, 20K

- Silicon can be bigger than Sapphire
- Silicon absorption is almost zero for 1550nm
- Xylophone strategy; only 18kW in ET-LF

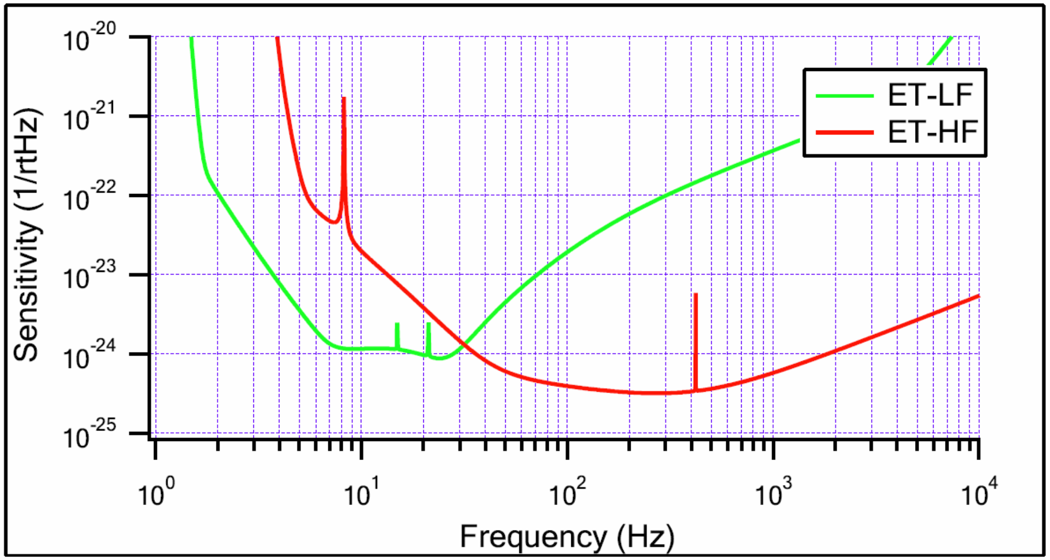
⇨ Suspension TN is low, RP noise is low, High-freq part is covered by ET-HF

Comparison of Sapphire and Silicon

	Sapphire	Silicon	difference
Max size available	30kg	**60kg+**	~2+
Subst. Absorption	20ppm/cm	**0**	N/A
Laser wavelength	**1064nm**	1550nm	~1.2 in coat TN
			~1.2 in shot noise
Young's modulus	**400GPa**	132GPa	~1.4 in coat TN
			~2.3 in el. mode density for PI
Fiber bonding	weak	**strong**	??
Coating material	Ta_2O_5-SiO_2	**Silicon**-SiO_2	~2.5+ in coat TN

Sapphire is not so bad but Silicon would be good in the future.

Possible heat problem in ET-HF

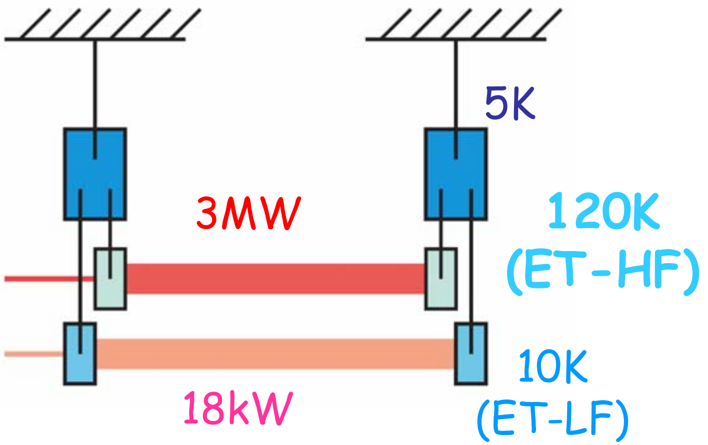


ET-HF:
290K Interferometer
3MW in each arm
10dB squeezing

4-times higher power in the arm without cooling

One good advantage of cryogenic detector is missing...

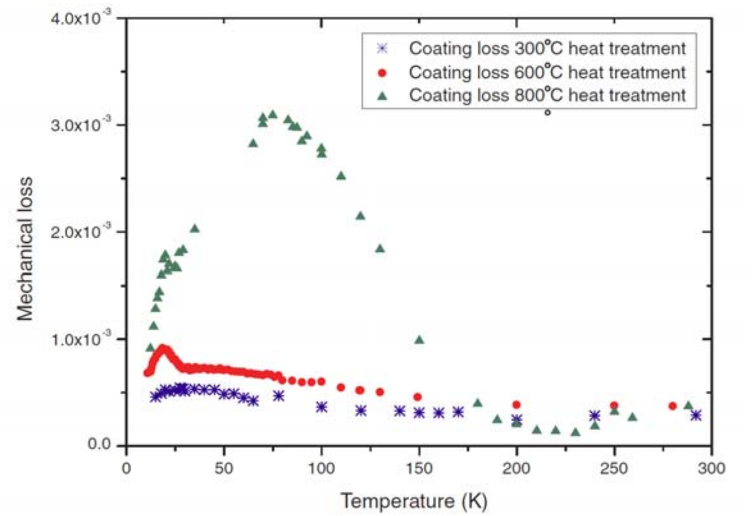
A possible solution is to use 120K Silicon;
- thermoelastic noise is zero (α=0)
- no thermal lensing
- much heat can be transferred at 120K



Other issues of cryogenic detectors

- Coating mechanical losses peak at around 20K (Tantala/Silica)

  ~ I.Martin's talk yesterday, AT session

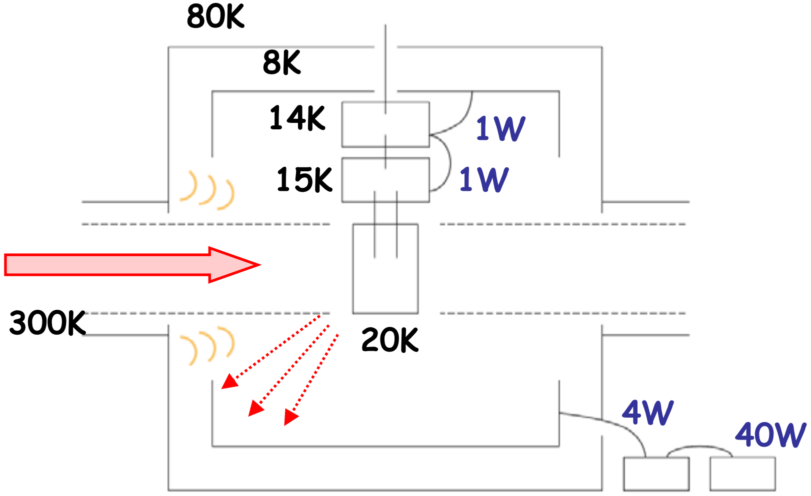


- Point scattering heats up the radiation shield

  - 10ppm of 400kW is 4W

- Heat-link vibration noise

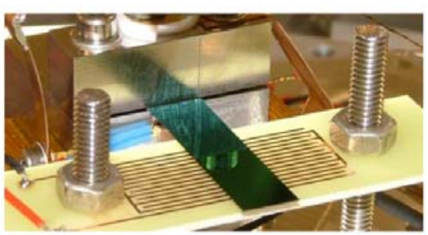
  - SPI would be a possible solution

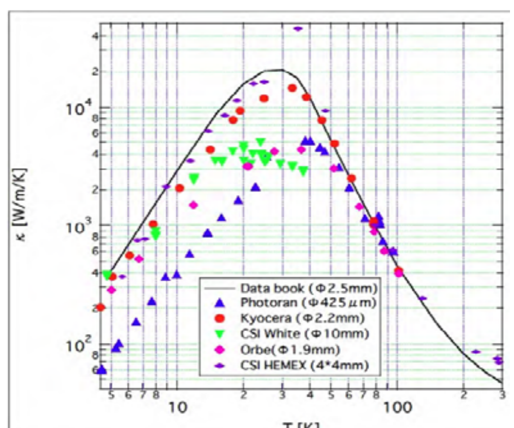


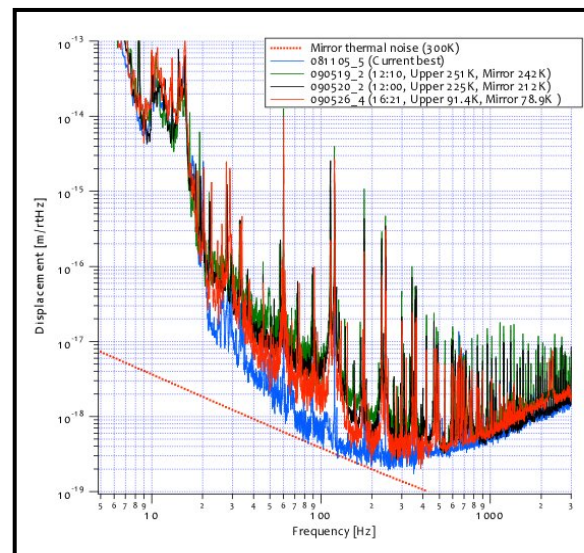
R&Ds

- Cryogenic interferometer operation (CLIO)
- Sapphire testing (NAOJ)
- Silicon testing, LT coatings (Glasgow/Jena)
- Evanescent-wave cooling (UFL)

… etc.







Roadmap of cryogenic detectors

2010 CLIO demonstrated TN reduction by cryogenics

2010 LCGT was funded

2011 ET study report completed

⋮

2016 LCGT starts to be cooled down

⋮

2020 ET may start?

LIGO3 may start?

Find good Sapphire

1st GW?

Find better coatings

FD 10dB squeezing