LCGT干渉計構成について

昨年の干渉計構成変更

Two nearby interferometers

As independent as possible
Center rooms: separated
3km vacuum tube: common

→

Single interferometer

New IFO layout

Main interferometer

Baseline Length : 3km
Broad band RSE
with power recycling
Arm cavity Finesse : 1550
Power Recycling Gain : 11
Signal band Gain : 15
Stored Power : 771kW
Signal band : 230Hz

→

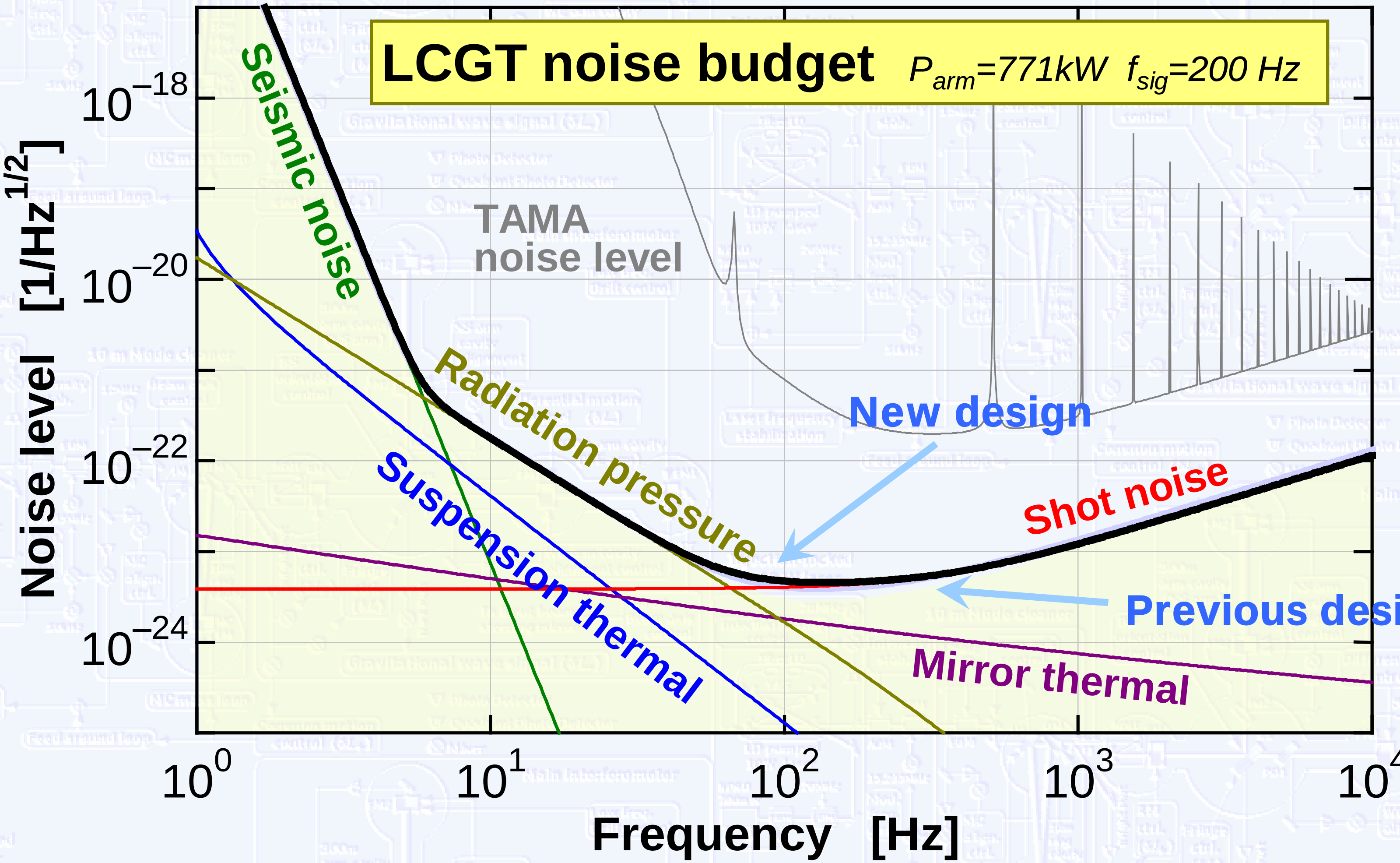
Baseline Length : 2.7km

Parameter optimization
Observable range

Sensitivity Curve

Dominant noise: optical-quantum noise

Floor level 4.58x10^{-24} Hz$^{-1/2}$



感度向上の可能性

	Obs. range [Mpc]	Range gain	Rate ratio
Previous design Baseline 3km	185 (103)	10%	1.33
Current design Baseline 2.7km	167 (93)	---	1
High Laser Power Power in arm x2	179 (100)	7%	1.23
Narrow band Detuned RSE	200 (112)	20%	1.72
Squeezing Shot noise -10dB	284 (159)	70%	4.92
Heavy mirror 30kg → 42kg	190 (106)	13%	1.47
Adv. LIGO	320 (180)	92%	7.03
Adv. VIRGO	215 (120)	29%	2.13

感度向上の可能性

ハイパワー化

レーザー光源 (出力 150W)
入出射光学系 (透過率 50%)
鏡の品質 (光損失 10ppm)
パワーリサイクリング (ゲイン 11)
→ パワー 2倍

7%程度のレンジ向上
(ただし鏡冷却 →FM透過 3kWが限界
現状 0.39kW)
実現度：△

狭帯域化

Detuned RSE

20%程度のレンジ向上
(70-80%程度のイベントレート向上)
実現度：○

スクイージング

ダークポートからの入射 ~10dB?

70%程度のレンジ向上
(5倍程度のイベントレート向上)
実現度：×

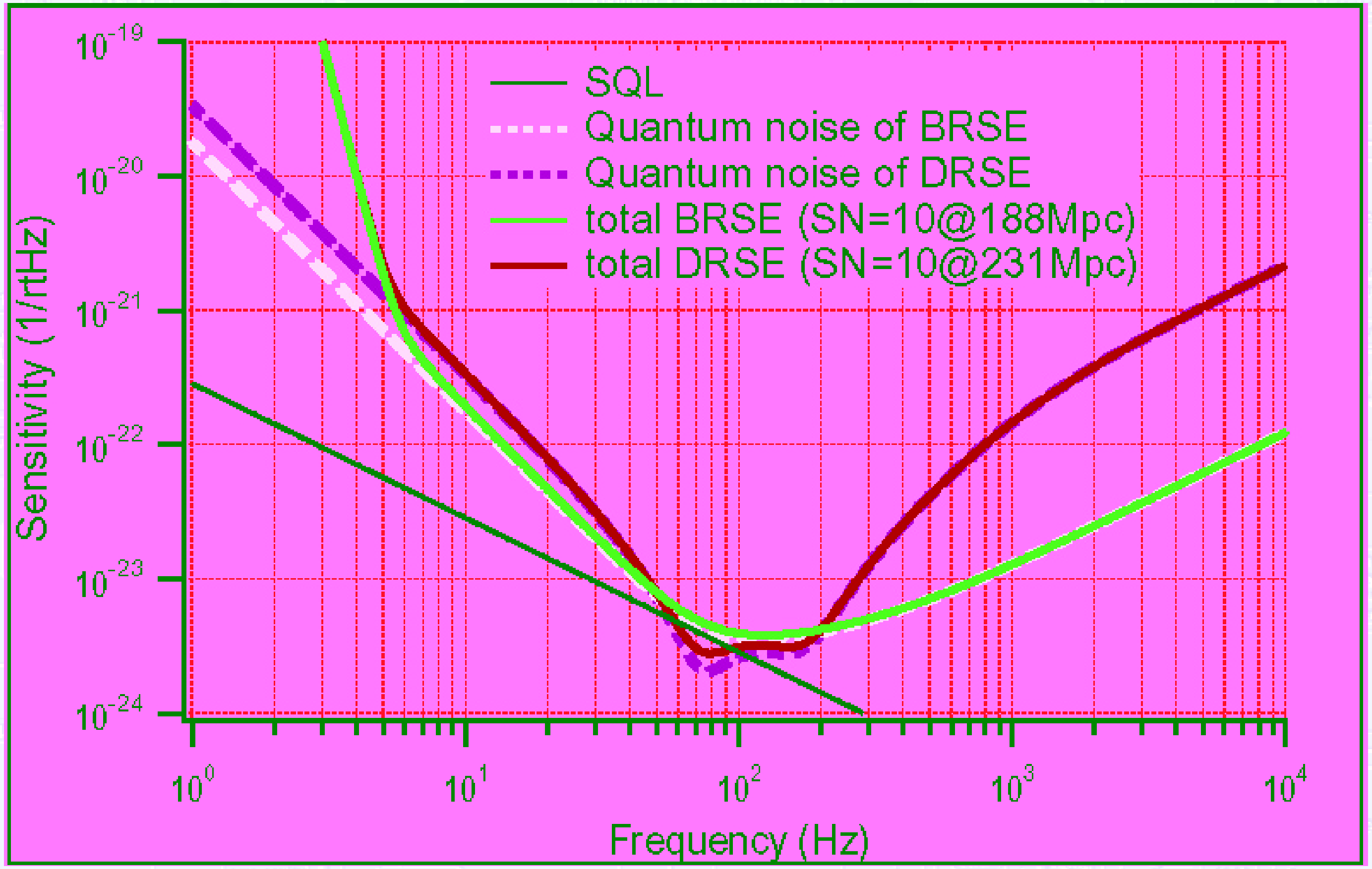
鏡の大型化

現状: 直径 25cm, 厚さ 15cm, 30kg
→ 直径 30cm, 42kg

13%程度のレンジ向上
(40%程度のイベントレート向上)
実現度：○

Broadband - Narrowband

Detuned RSE configuration
→ SNR increase 23 %
Event rate increase 86 %



まとめ

基線長が 3km → 2.7kmに短縮されたことにより
観測レンジは 184Mpc → 167Mpc に低下する
イベント数は　約3 / 4になる

提言：　LCGT もしくは Ad. LCGT として、
感度向上の方策を持っているべき

ブロードバンドRSEかDetuned RSEかは
干渉計や感度だけからは決められない

判断材料をまとめる
- 真空槽・入射光学系等に大きな変更なく
  両者を切り替えられるか？
- 実現可能性まで配慮したDRSE構成
- 詳細で具体的な構成まで詰める

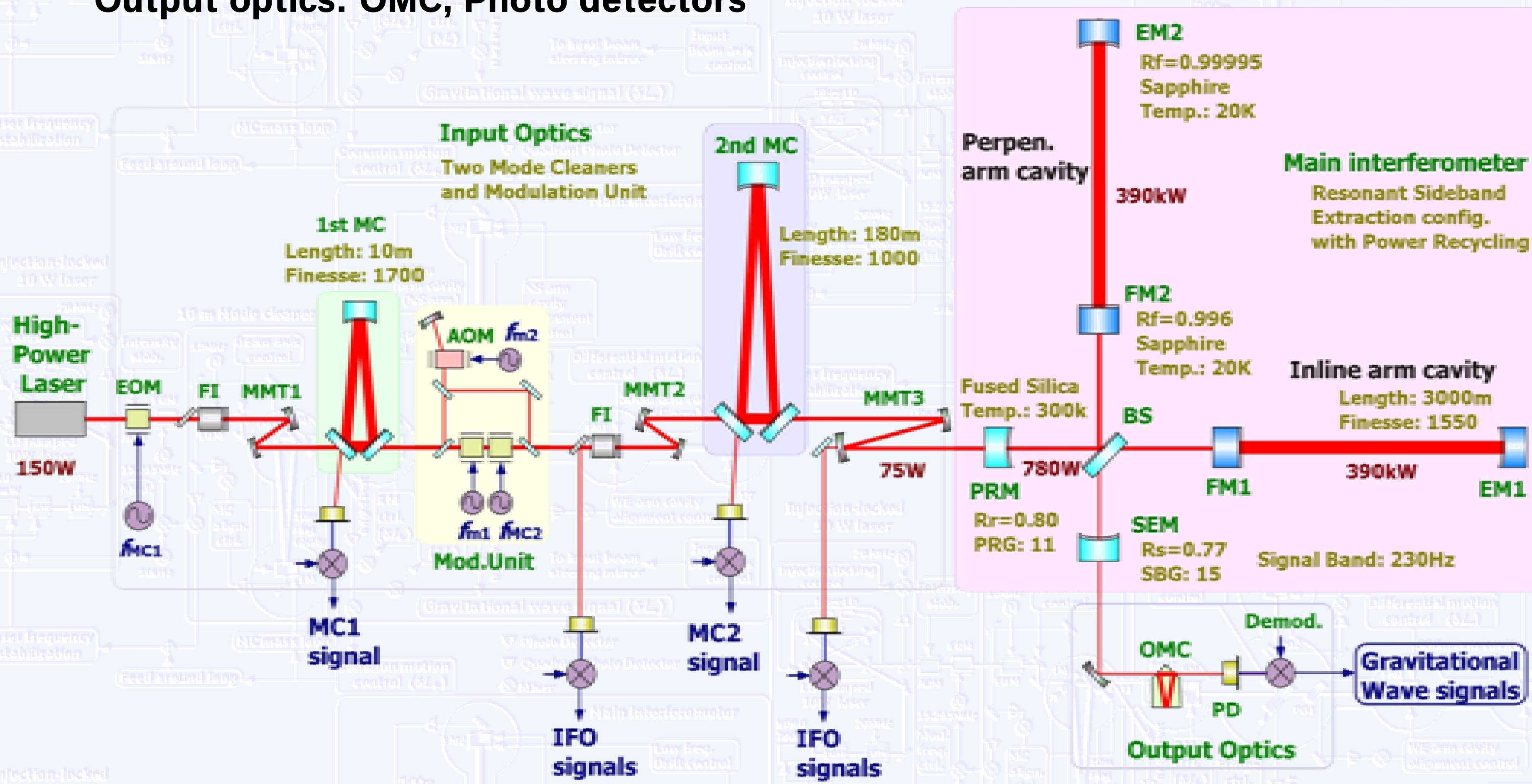
LCGT commissioning 手順
Ad. LCGTの具体像

End

Overview (2)

- **LCGT interferometer**

Main IFO : 2.7-3km IFO
Input optics : Two MCs, Modulators, MMT
Output optics: OMC, Photo detectors



Optical readout noise

LCGT sensitivity : Mostly limited by quantum noises (Radiation pressure noise and Shot noise)

Shot noise

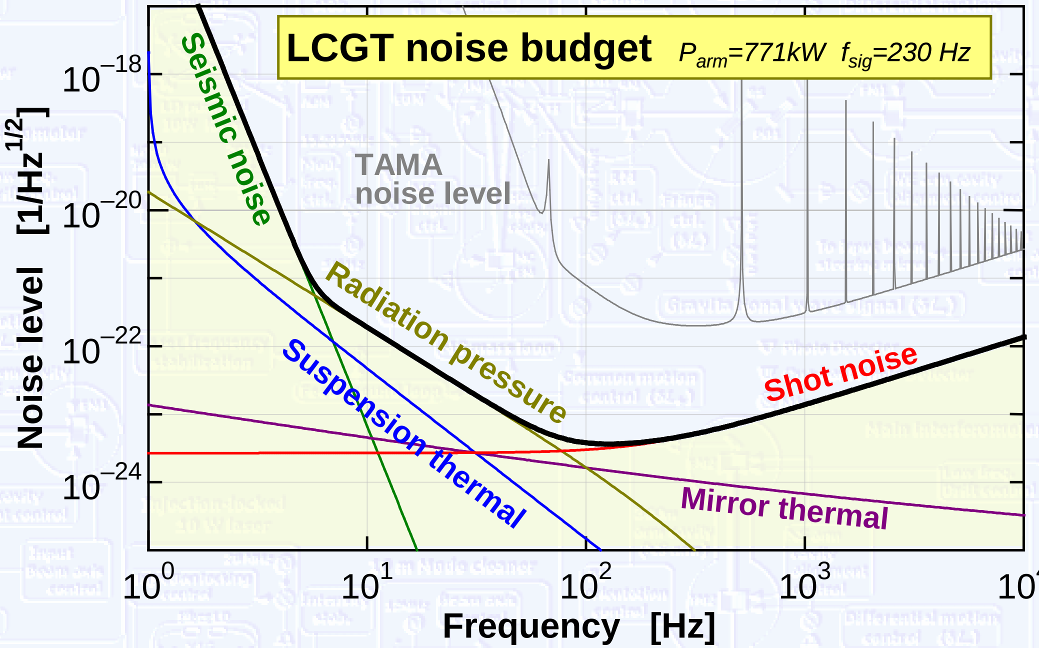
- Phase fluctuation of light
- Proportional to $P^{-1/2}$

Radiation pressure noise

- Amplitude fluctuation of light
- Proportional to $P^{1/2}$

Noise level depends on

- Laser power in IFO
- Signal band of IFO



Design the interferometer optical parameters

Comparison of detectors

- **Comparison of next generation GW detectors**

LCGT (JPN)		Advanced LIGO (USA)
2 detectors (3km) (2 nearby detectors)	Scale	3 detectors (4km) (2 nearby, 1 separated)
Long baseline Better seismic attenuation system Underground site	Seismic noise reduction	Long baseline Better seismic attenuation system Suburban site
Low-mechanical-loss mirrors and suspensions Cryogenic (20k)	Thermal noise reduction	Low-mechanical-loss mirrors and suspensions Flat-top beam
High-power laser source Low-loss optics Broad-band RSE config.	Quantum noise reduction	High-power laser source Low-loss optics Detuned RSE config.

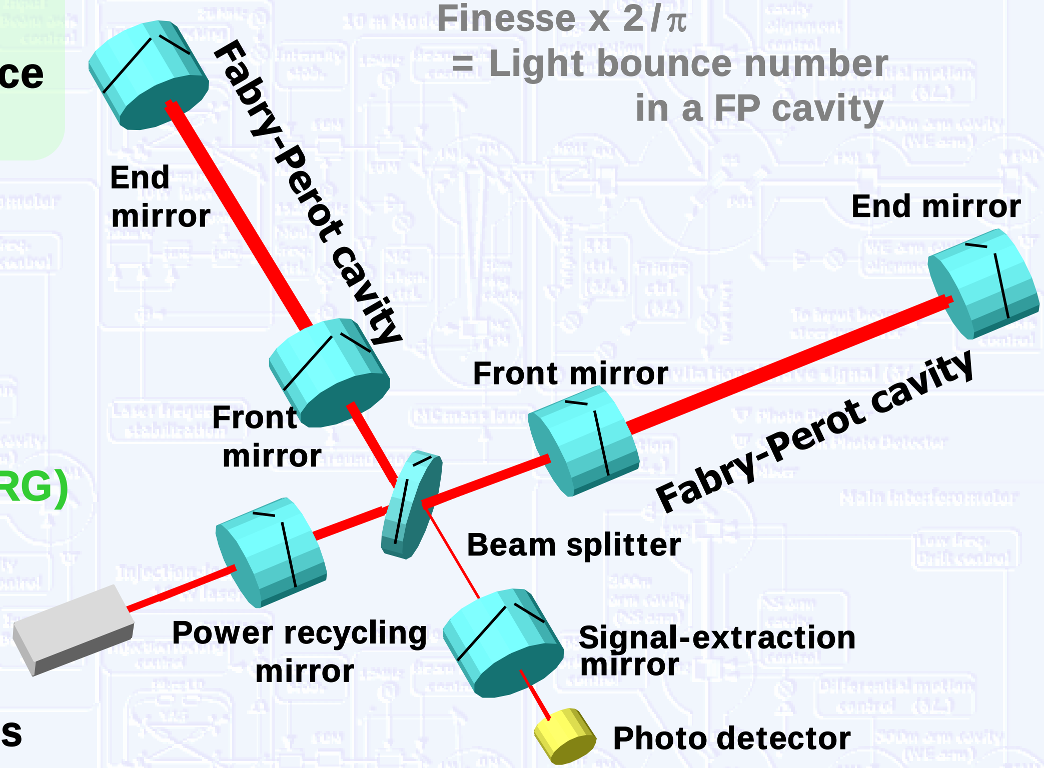
Main interferometer (3)

- **LCGT optical configuration**

Resonant-sideband extraction with power recycling

High-finesse arm cavities
PRM between BS and laser source
SEM at the detection port

Finesse x $2/\pi$ = Light bounce number in a FP cavity



Power recycling
PRM+FM
→ Increase effective finesse
→ Increase power in cavities
by **Power-recycling gain (PRG)**

Resonant-sideband extraction
SEM+FM
→ Decrease effective finesse for signals
→ Increase signal band
by **Signal-band gain (SBG)**

LCGT optical configuration

Resonant-sideband extraction with power recycling

High-finesse arm cavities
PRM between BS and laser source
SEM at the detection port

Power recycling
PRM+FM
→ Increase effective finesse
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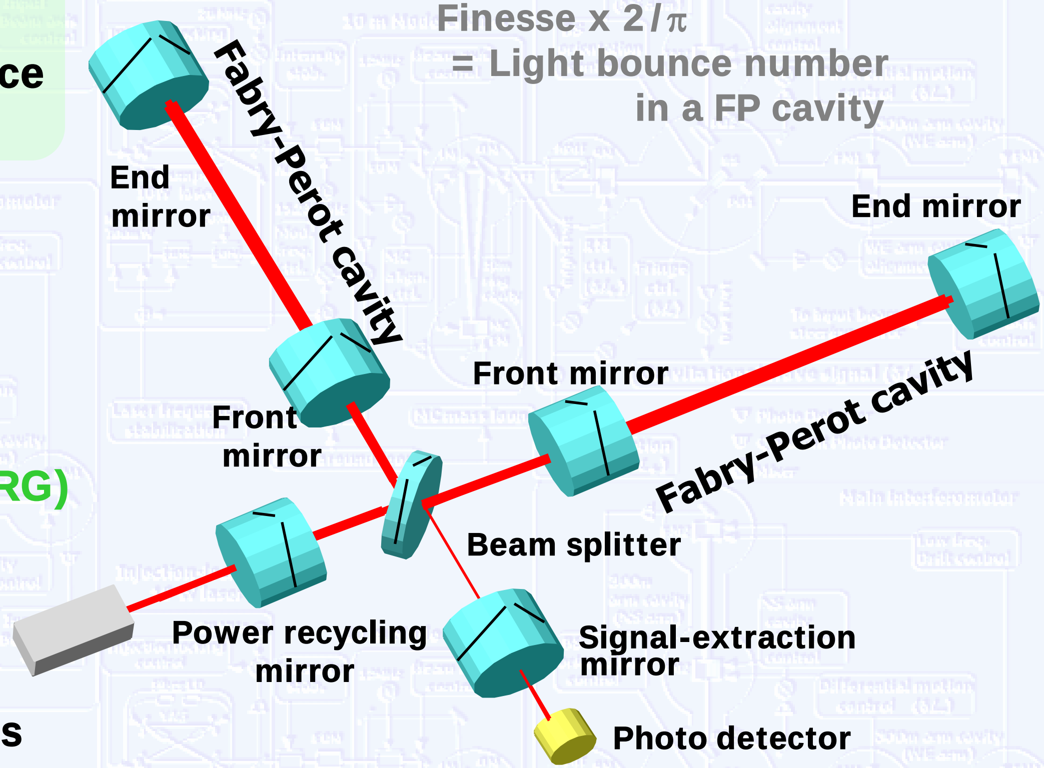


Overview (1)

- **Interferometer overview**

Underground interferometer

>100m from ground-level
2.7km baseline length
Suspension-point interferometer

Main interferometer

Broad band RSE
with power recycling
Arm cavity Finesse : 1550
Power Recycling Gain : 11
Signal band Gain : 11
Stored Power : 771kW
Signal band : 195Hz

Input optics

Two mode cleaners
Baseline lengths : 10m and TBD m
Modulators for IFO control
Laser stabilization

Output optics

Output mode cleaner
Round trip length : 70mm
Multiple InGaAs photo diodes

Observation system

Monitor and organize
the whole detector system
Automatic lock-acquisition
Automatic interferometer adjustment
Monitor and diagnosis

Main interferometer (2)

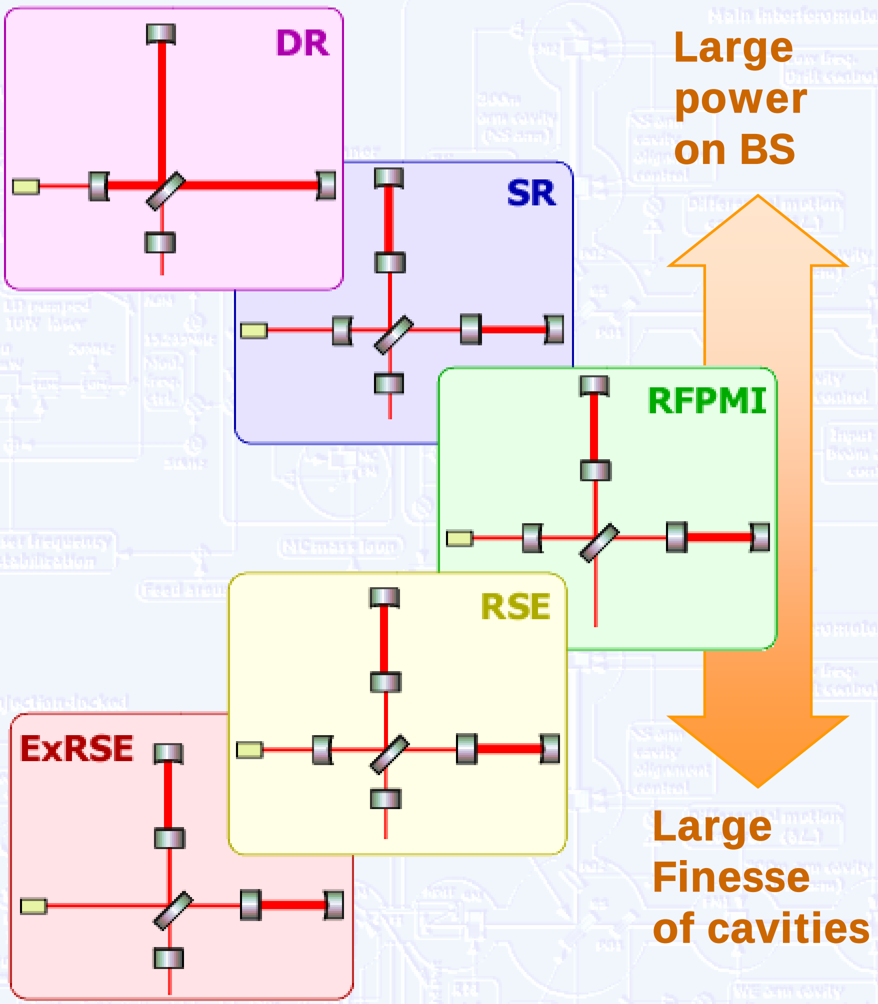
- **Interferometer optical configuration**

Ideally, possible to realize same power and signal BW with any config.

Power : cavity finesse, PRM
Signal BW : cavity finesse, SRM

Realistic constraint

Loss in optics and interference
Simplicity of control system
Thermal problem in optics



Main interferometer (4)

- **Merit of RSE**

High-finesse cavity and moderate PRG

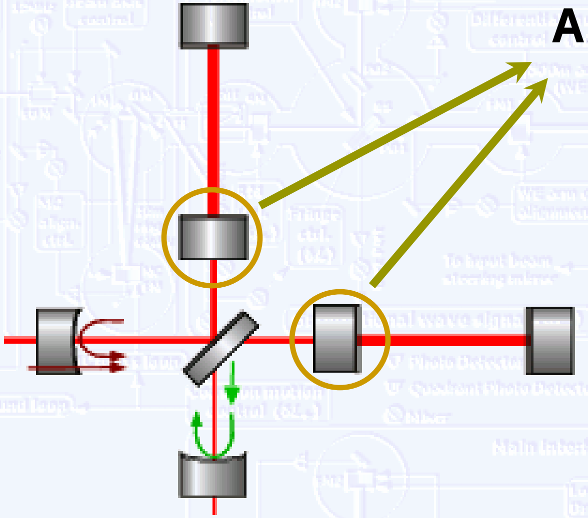
Easier to realize high power in cavities

Smaller transmission light in optics ⇐ **Main reason for LCGT**

Flexible optimization for GW sources

Independent adjustment of power in cavities and signal band

Narrow-band observation (optional)



Absorption in sapphire substrates

Heat absorption : 20ppm/cm x 15 cm = 300 ppm

Cooling power : 1W for each mirror

⇓

Laser power on BS should be less than ~1kW (safety factor 3)

Main parameters

- Detector parameters

Laser
Nd:YAG laser (1064nm)
Injection lock + MOPA
Power : 150 W

Main Interferometer
Broad band RSE configuration
Baseline length : 3km
Beam Radius : 3-5cm
Arm cavity Finesse : 1550
Power Recycling Gain : 11
Signal Band Gain : 15
Stored Power : 771kW
Signal band : 230Hz

Vacuum system
Beam duct diameter : 100cm
Pressure : 10^{-9} Torr

Mirror
Sapphire substrate
+ mirror coating
Diameter : 25cm
Thickness : 15cm
Mass : 30 kg
Absorption Loss : 20ppm/cm
Temperature : 20 K
$Q = 10^8$
Loss of coating : 10^{-4}

Final Suspension
Suspension + heat link
with 4 Sapphire fibers
Suspension length : 40cm
Fiber diameter : 1.5mm
Temperature : 16K
Q of final suspension : 10^8

Optical parameter selection

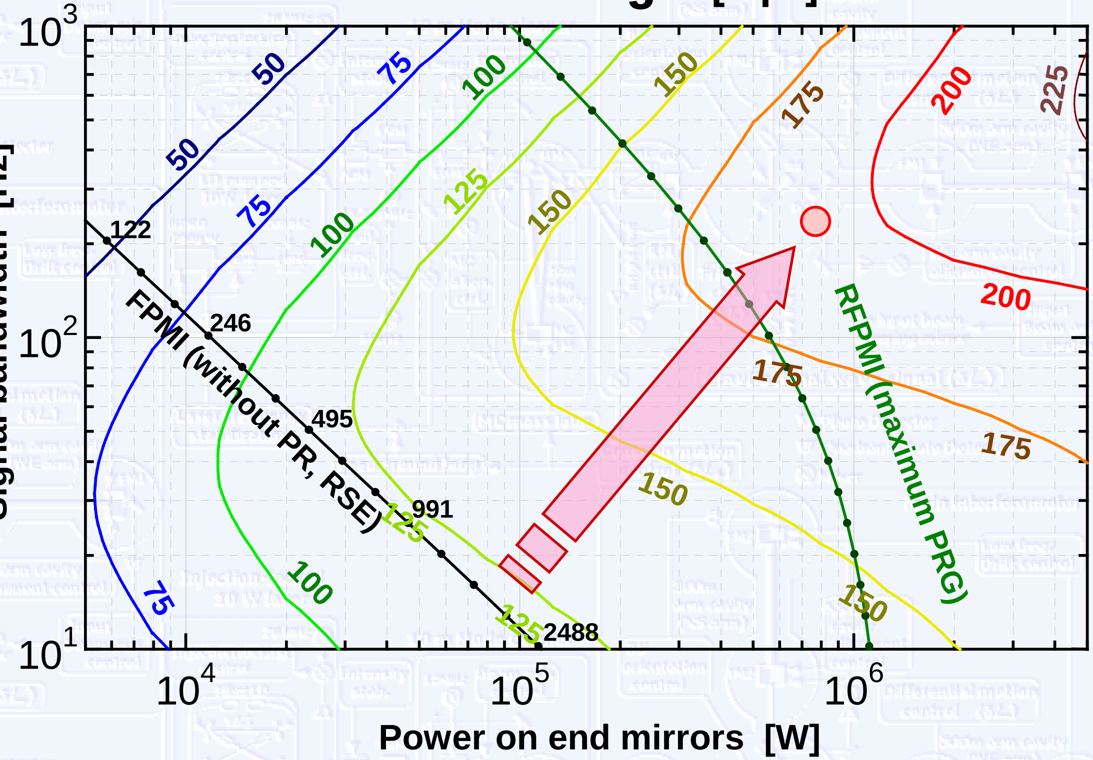
(Previous design)

Optimize for 1.4M_{solar} NS inspiral
Realistic parameters

Calculate observable range
as a function of
Light power in cavities
Signal bandwidth

Arm cavity Finesse :	1550
Power Recycling Gain :	11
Signal Band Gain :	15
Stored Power :	771kW
Signal band :	230Hz

Observable range : 185Mpc



SNR = 10
Single interferometer
Optimal direction and polarization

Optical parameter selection

Baseline length → 2.7km

Optimize for 1.4M_{solar} NS inspiral
Realistic parameters

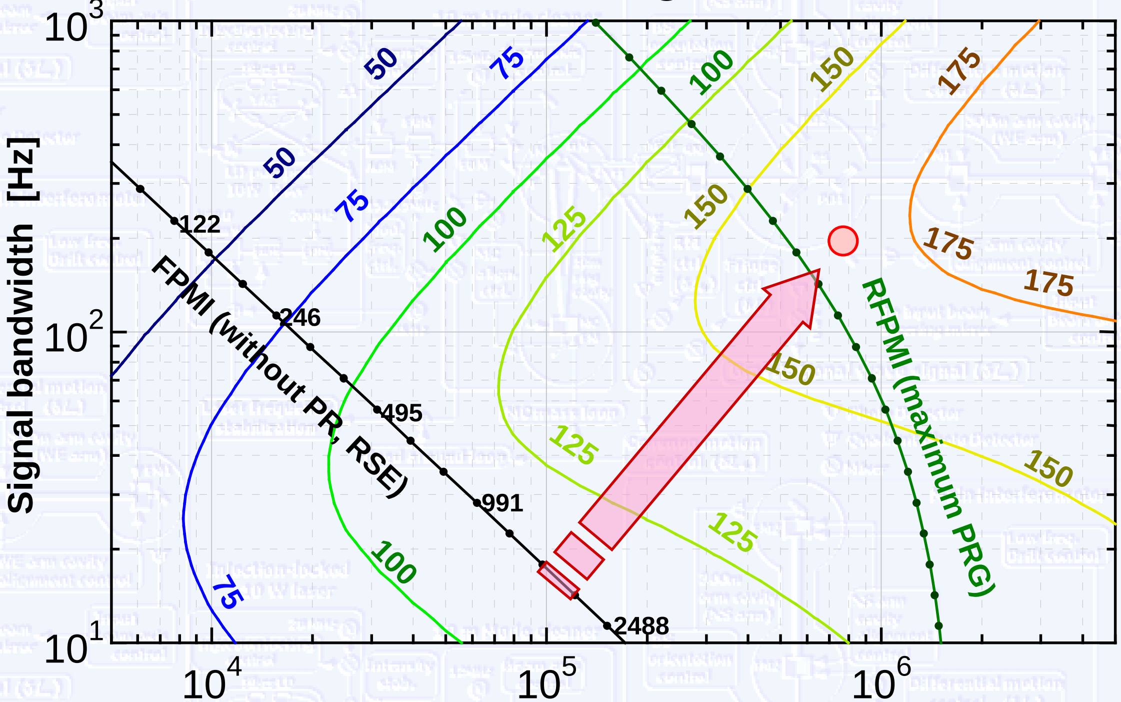
Calculate observable range as a function of
- **Light power in cavities**
- **Signal bandwidth**

Arm cavity Finesse :	1550
Power Recycling Gain :	11
Signal Band Gain :	11
Stored Power :	771kW
Signal band :	195Hz

Observable range : 167Mpc

(10% reduction, → event rate ~25% reduction)

Observable range [Mpc]



SNR = 10
Single interferometer
Optimal direction and polarization