Post Amaldi7 Meeting
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Parametric Instability of LCGT Interferometer

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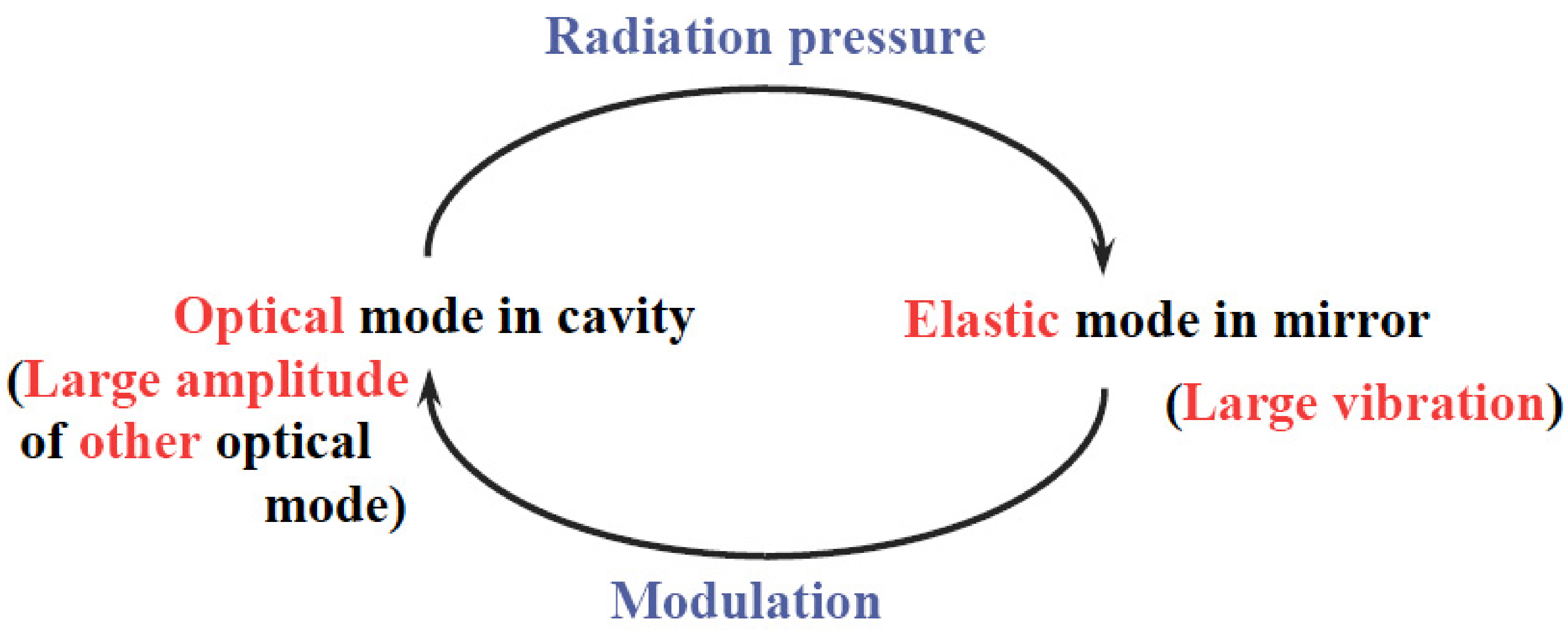
LCGT and Adv. LIGO

- LCGT is a cryogenic 3km base line Fabry-Perot Michelson interferometer with RSE scheme.
- Adv. LIGO is a room temperature operated 4km base line interferometer with RSE scheme.

Physics of optical parametric instability

Optical parametric Instability is given in the paper:
Phys. Lett. A 287 (2001) 331 and several theoretical calculations have been published and a few experiments have been disclosed.



Condition of instability growth

$$R \sim \sum \frac{2PQ_mQ_o}{McL\omega_m^2}\,\frac{\Lambda_o}{1+\Delta\omega^2/\delta_o^2} < 4000$$

- **Power** — P
- **Q of mirror** — Q_m
- **Spatial overlap between optical and elastic modes** — Λ_o
- **Frequency of elastic mode** — ω_m
- **Frequency difference between optical and elastic modes** — $\Delta\omega$
- **Width of optical mode** — δ_o

$$\delta_o^2 = \omega_o/2Q_o$$

The formula is deduced in an interferometer without power recycling, RSE, anti-Stokes modes.

Parameters of calculation

Curvature radius
LCGT: 7114m
aLIGO: 2076m

Cavity Length
LCGT: 3000m
aLIGO: 4000m

Cavity Power
LCGT: 0.81MW
aLIGO: 0.83MW

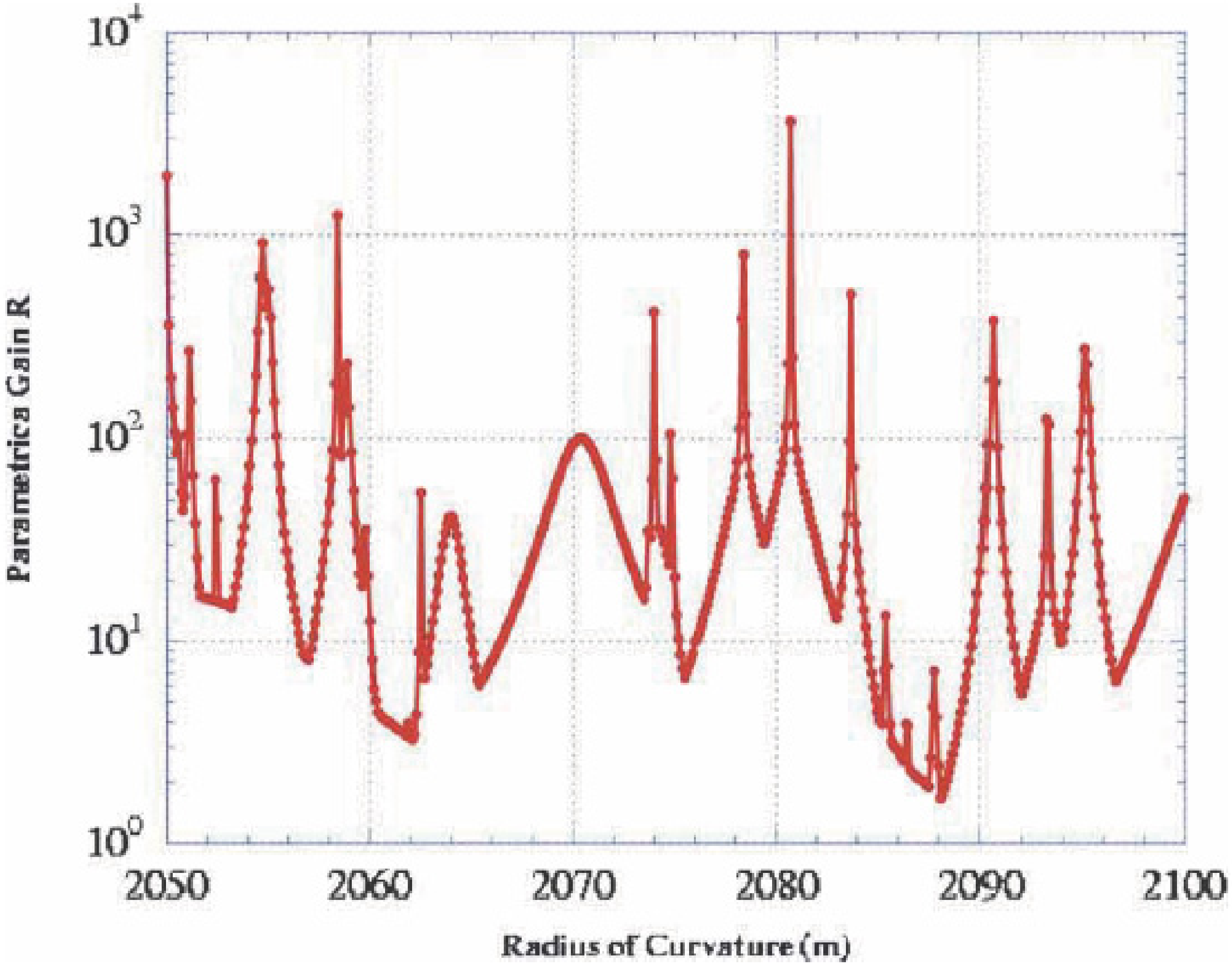
Mirror substrate
LCGT: Sapphire, 20K
aLIGO: Fused silica
300K

Gaussian Beam
Wvelength: 1064nm

a-LIGO

Estimated maximum of R by UWA

[Phys. Lett. A 354 (2006) 360]



Number of unstable modes

[Phys. Lett. A 355 (2006) 419.]

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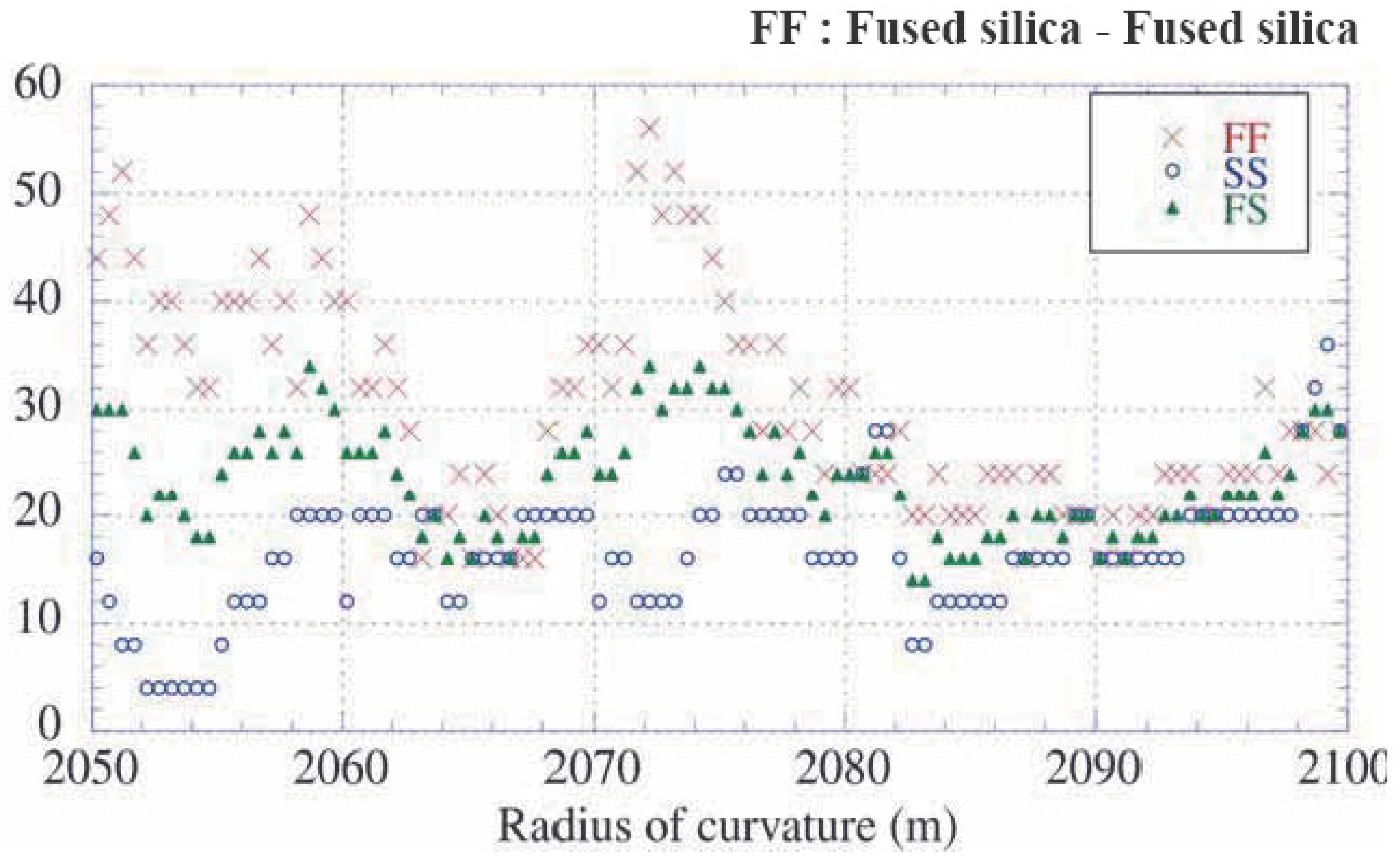


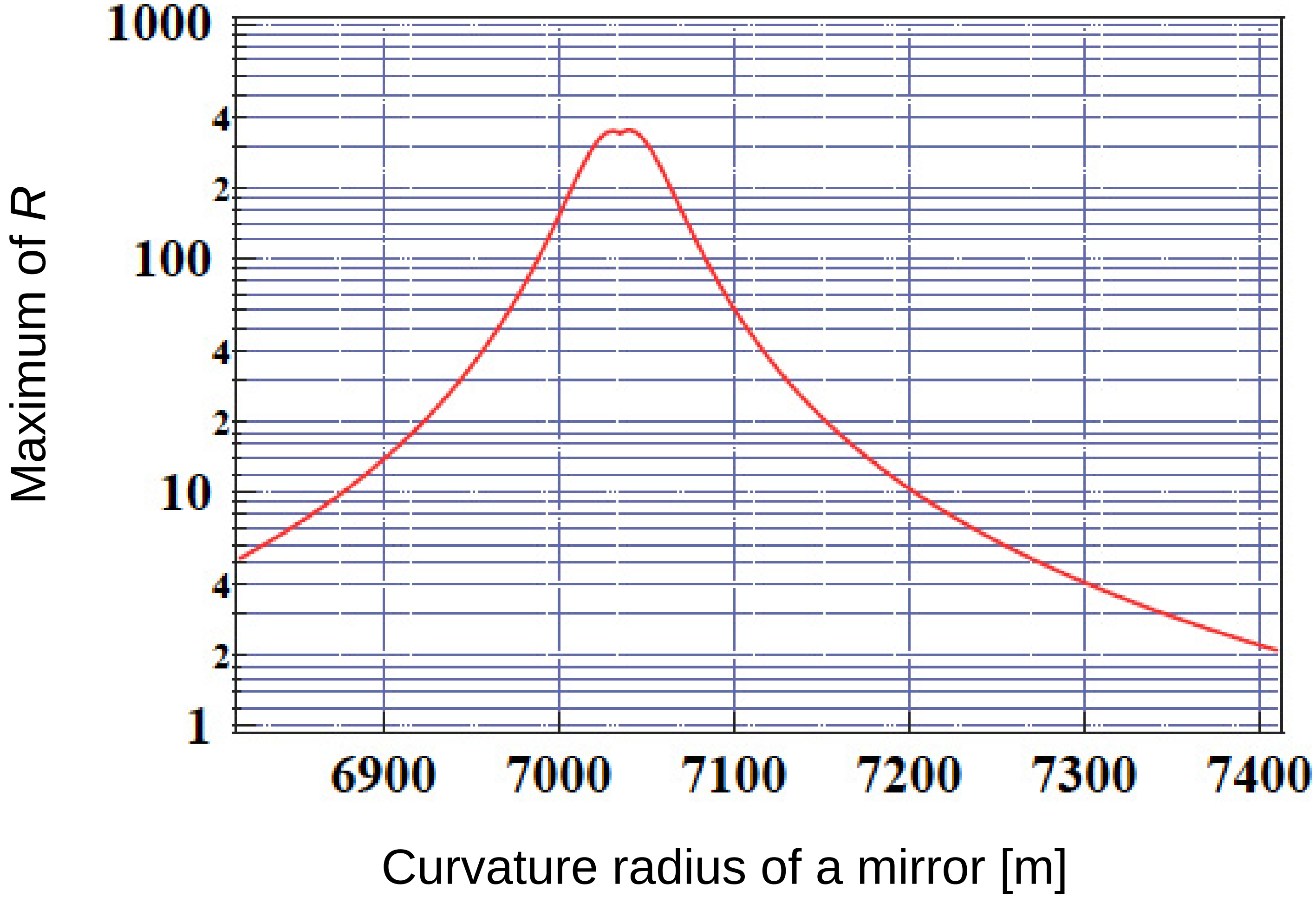
Case of a-LIGO

- Typical maximum of R : 10~1000
- Typical number of unstable modes: 20~60
- R strongly depends on mirror curvature

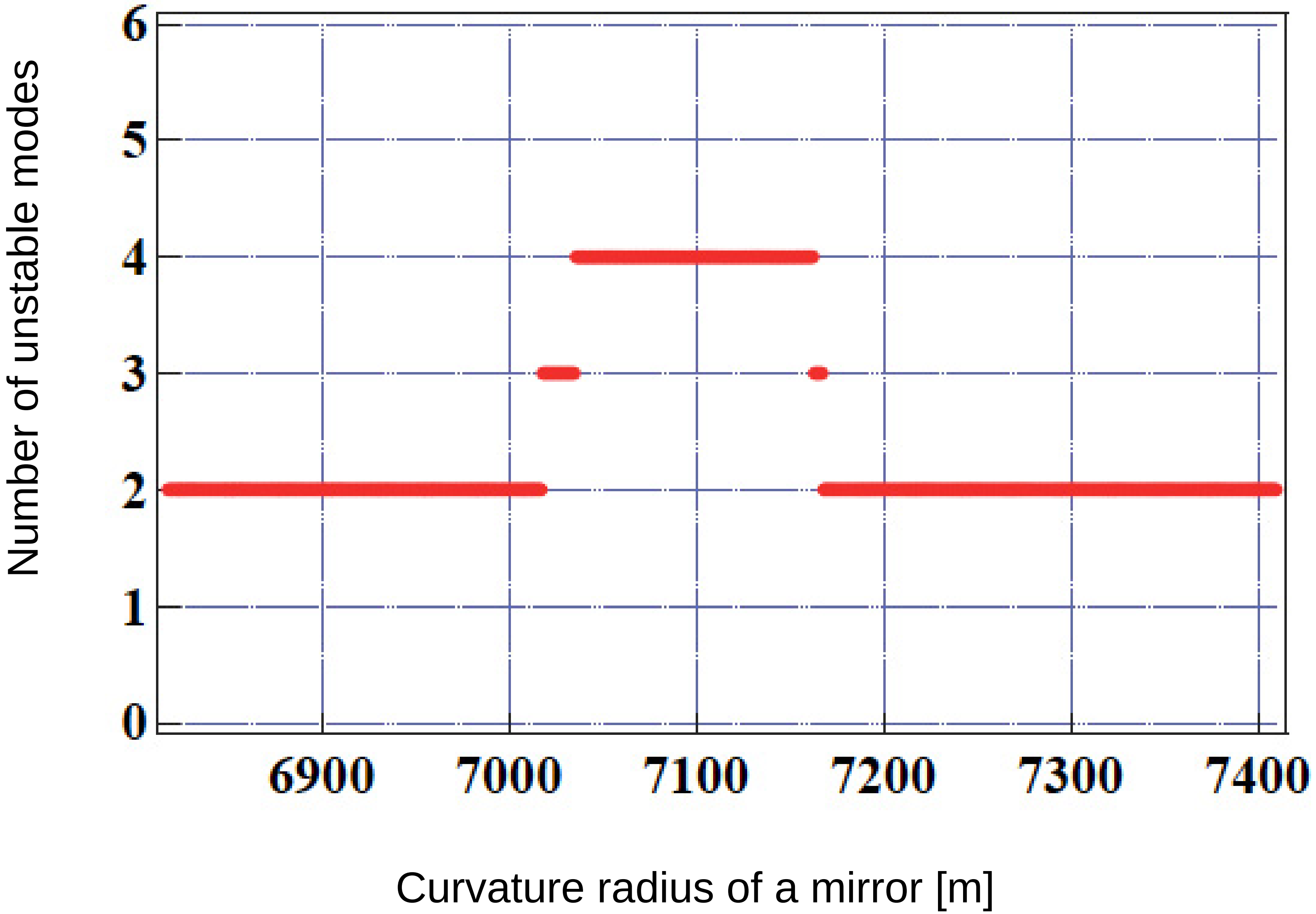
Accurate determination of R is not easy

LCGT

Maximum of *R*



Number of unstable modes of LCGT



Case of LCGT

- Typical maxmum of R : 3~300
- Typical n umber of unstable modes : 2~4
- R weakly depends on mirror curvatire.

Discussion

1. Number of unstable mode

LCGT : 2~4
aLIGO : 20~60

Elastic mode density ~ (sound velocity) $^{-3}$

LCGT(sapphire): 10km/s
aLIGO(silica) : 6km/s

Number of unstable modes of LCGT are less by 5 times than that of aLIGO.

2. Optical mode density

LCGT : 3 modes / FSR
aLIGO : 7 modes / FSR

Mode density of LCGT is smaller by 2 times than that of a-LIGO. This is because a-LIGO adopts larger beam size for thermal noise reduction.

3. Product of elastic mode and optical mode density of LCGT is smaller by 10 times than a-LIGO.

Mirror curvature

- *R* is a function of optical mode frequency
- *R* strongly depends on mirror curvature in a-LIGO
- Whereas, *R* weakly depends on mirror curvature in LCGT
- Mirror curvature dependences of interval of transverse optical mode are 0.58Hz/m in LCGT and 15Hz/m in a-LIGO.
- LCGT has wider spacing of critical curvatures in terms of mode frequencies (10 times better).

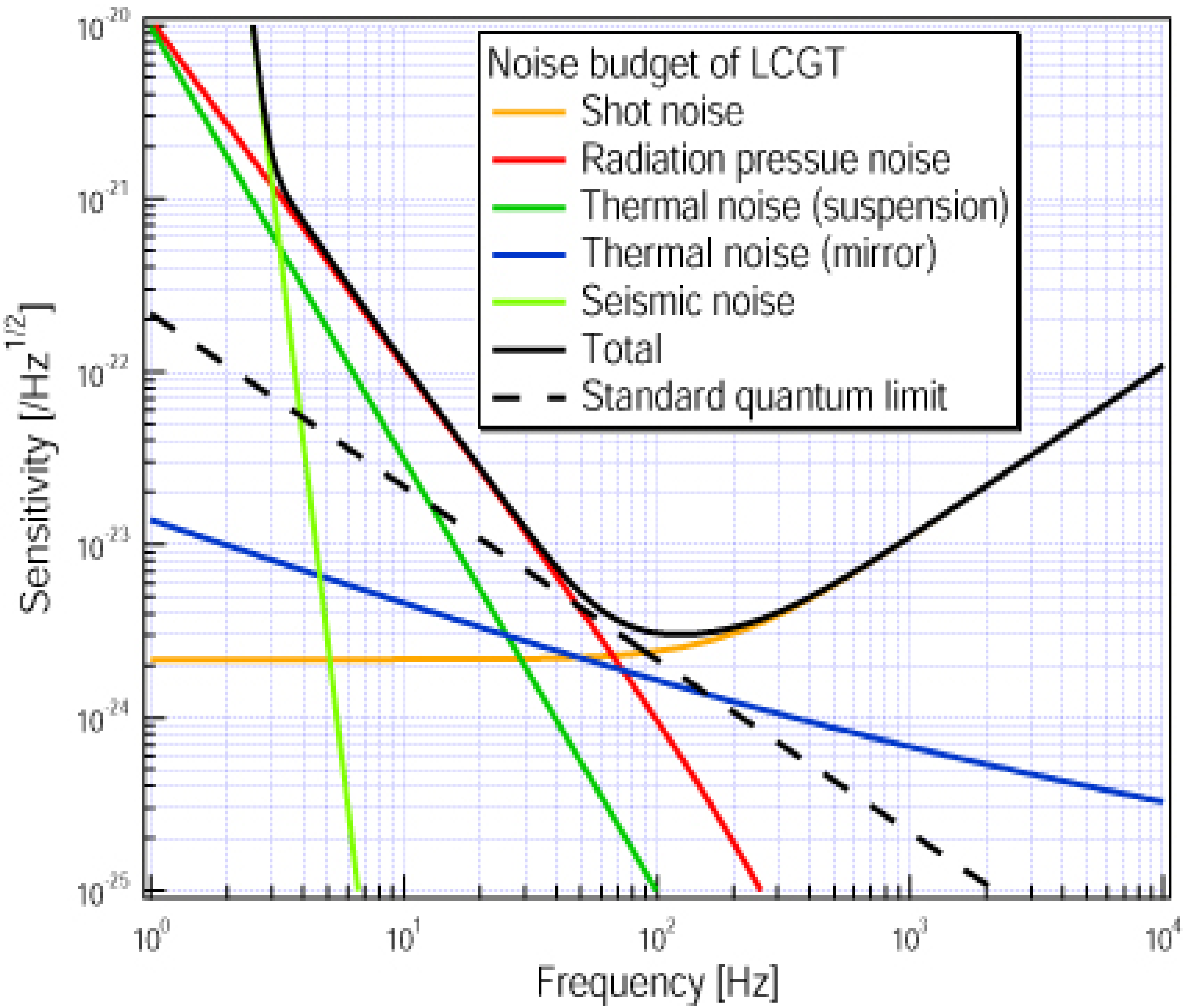
How to suppress instability?

- Parametric instability of LCGT is not more serious than a-LIGO. However, maximum of R is usually larger than unity, which has to be considered.
- There are some proposals presented by UWA (Phys. Lett. A 355 (2006) 419, J. Phys. Conf. Ser. 32 (2006) 251.
  - Thermal tuning

    useless for LCGT due to cold mirror and the weakness of the dependence to *R*
  - Q reduction

    10^8->10^6 *R* 0.03~3 (3~300)
  - Feedback control

    not easy



Noise budget of LCGT
Shot noise
Radiation pressue noise
Thermal noise (suspension)
Thermal noise (mirror)
Seismic noise
Total
Standard quantum limit
Sensitivity [/Hz^1/2]
Frequency [Hz]
10^-20
10^-21
10^-22
10^-23
10^-24
10^-25
10^0
10^1
10^2
10^3
10^4

Conclusion