Large-scale Cryogenic Gravitational-wave Telescope in Japan

APPC11@Shanghai

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Waseda Inst of Advanced Study

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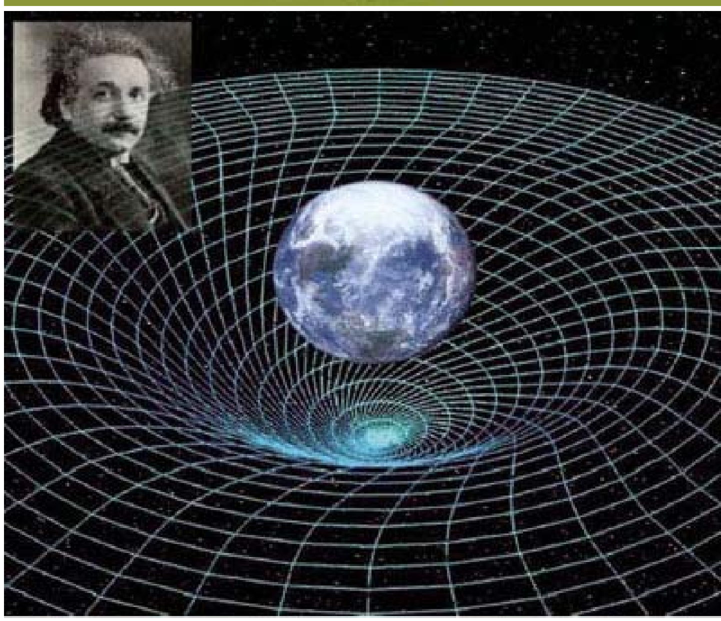
Gravity, GR, Gravitational waves



Newton's Gravity
"Attracting force of Earth & Moon"

Einstein's Gravity
"Nonflatness of spacetime"

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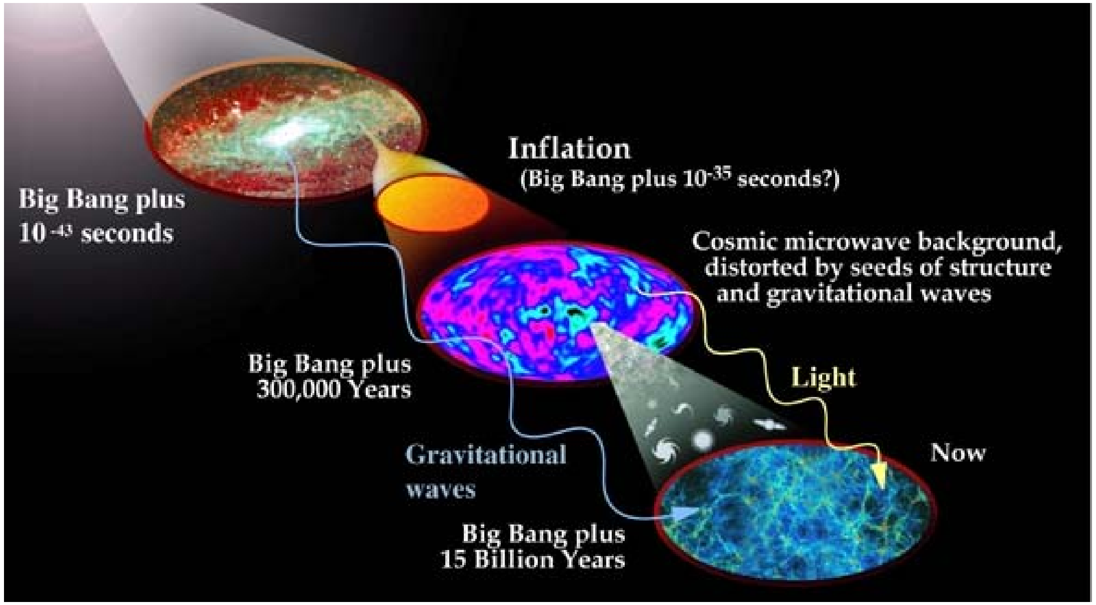
Dynamic change of spacetime will propagate as a wave.

Einstein's prediction of gravitational waves

(1917)

What if we observe GW?

[image:NASA]



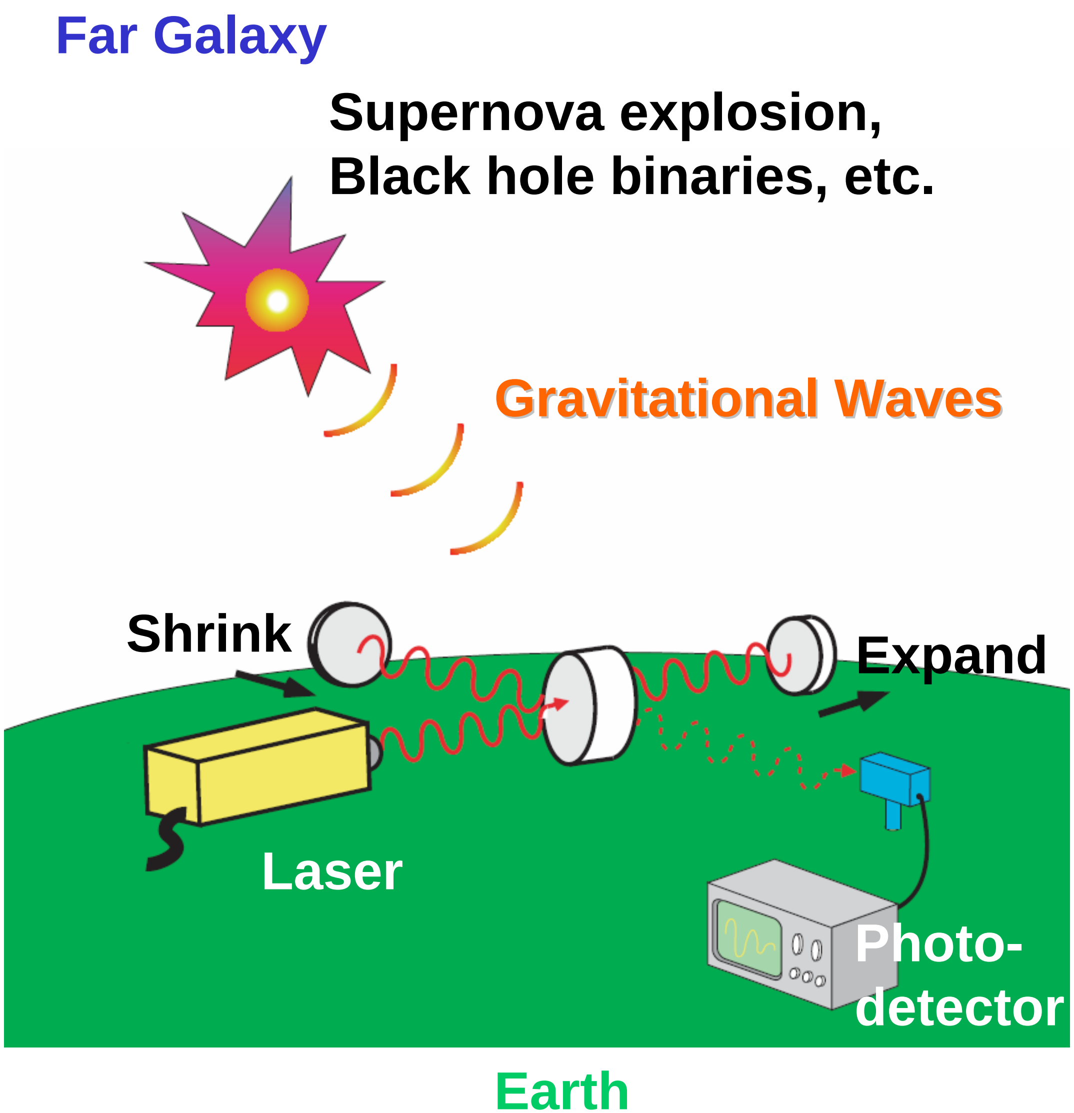
GW penetrates the matters

↓

Info different from EM waves

- Last proof of Einstein's predictions ⇒ GR
- Understanding the early universe ⇒ Cosmology
- Observation of Black Holes, etc. ⇒ Astronomy
- Deep core of neutron stars ⇒ Nuclear Physics

Ground-based GW detector



Massive Astronomical events.

⇩

Distance of two objects changes.

⇩

Observe the change with big high-power interferometers

- LIGO in US [4km]
- Virgo in Italy [3km]
- GEO in Germany [600m]
- LCGT in Japan [3km] (just funded!!)

~$120M

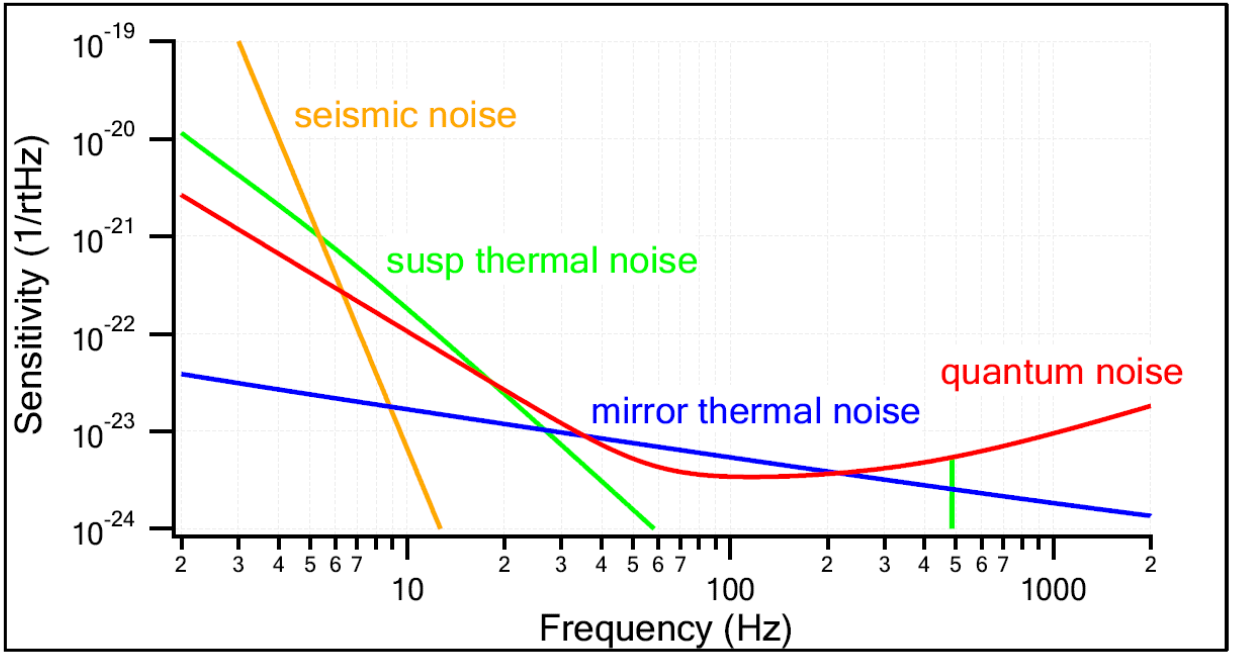
GW detectors in the world

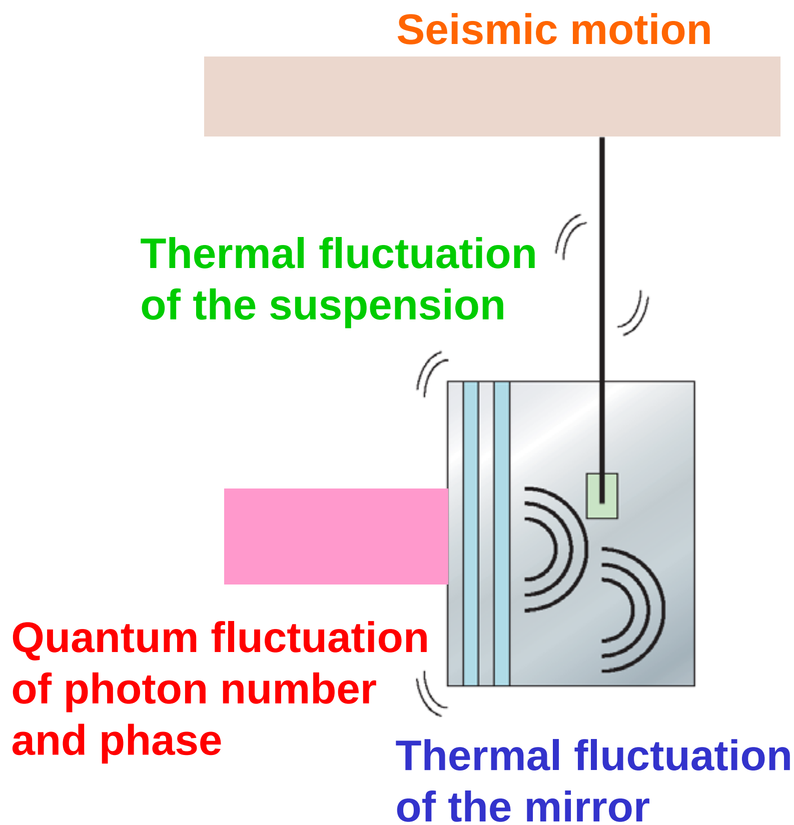
~ 2nd generation detectors ~

The more detectors, the more information.

Sensitivity of the detector

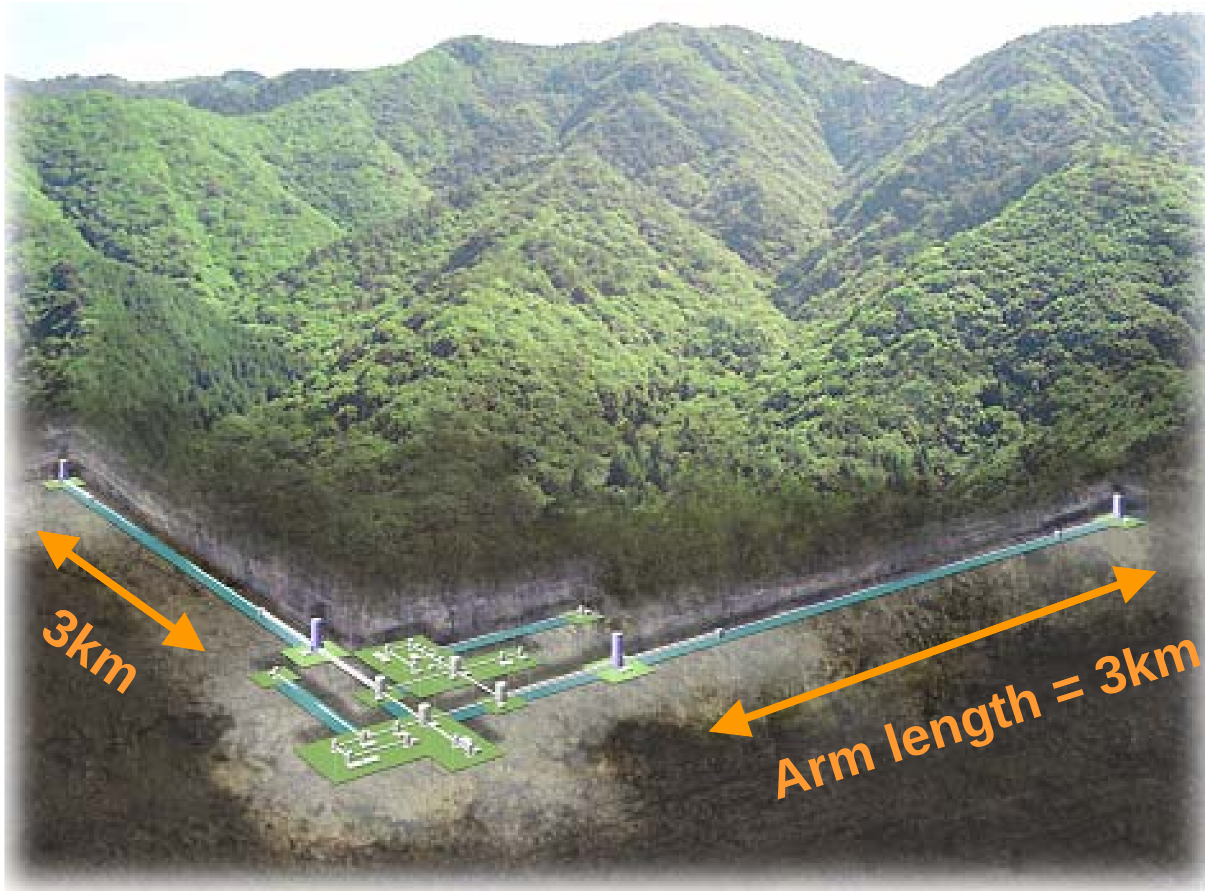
Typical sensitivity spectrum of a 2G detector (300K)





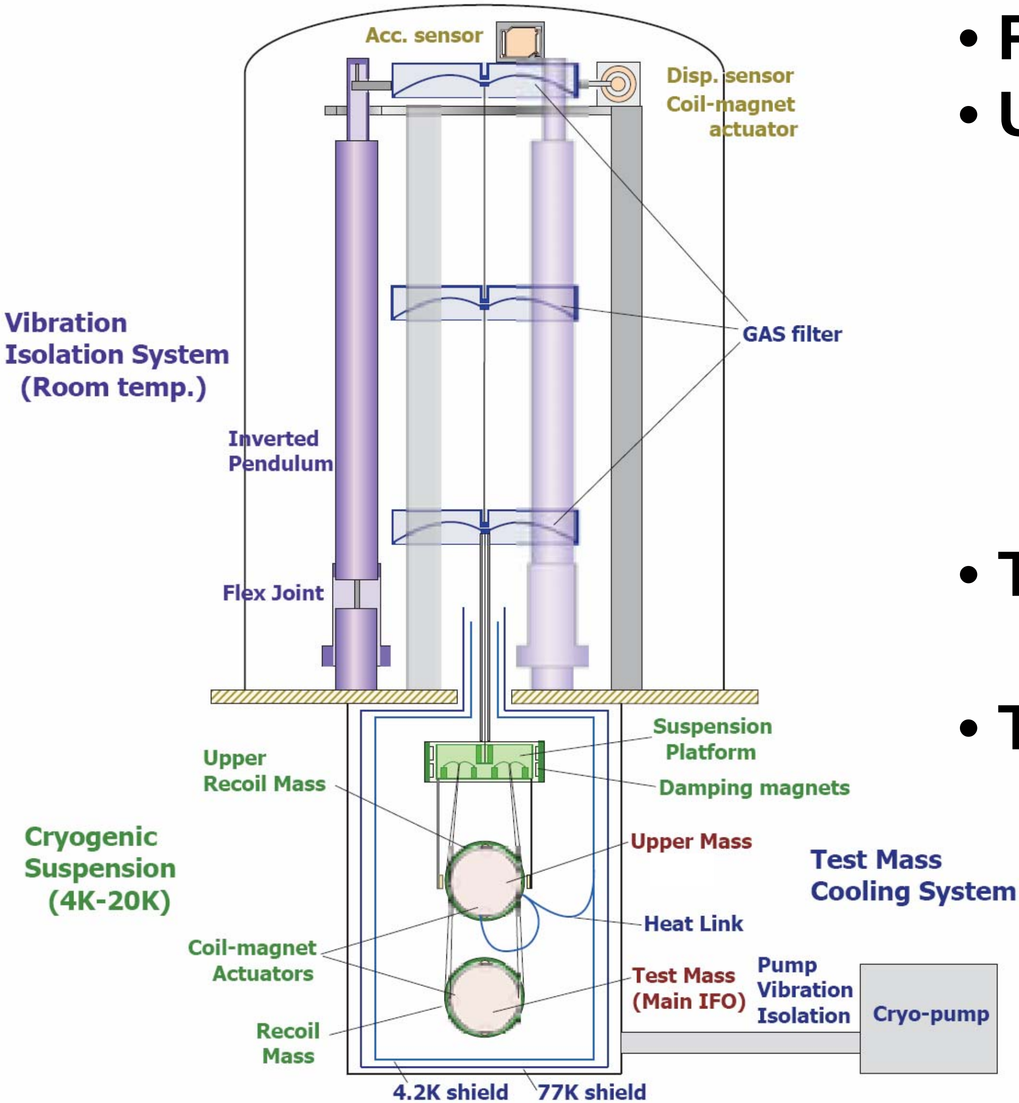
- **Seismic noise at low frequencies**
- **Thermal noise at middle frequencies**
- **Quantum noise at middle-high frequencies**

LCGT techniques to improve sensitivity



- **Underground** detector to lower seismic noise
- **Cryogenic mirrors** to lower thermal noise
- **RSE** and **optical spring** to lower quantum noise

Low thermal noise with cryogenics



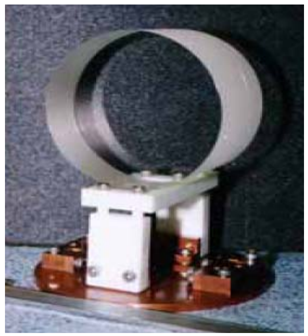
- **Radiation shield**
- **Upper mass cooled via heat link**

~ pure Aluminum
(99.999%)
ϕ=0.15 mm

- **Test mass cooled via suspension**

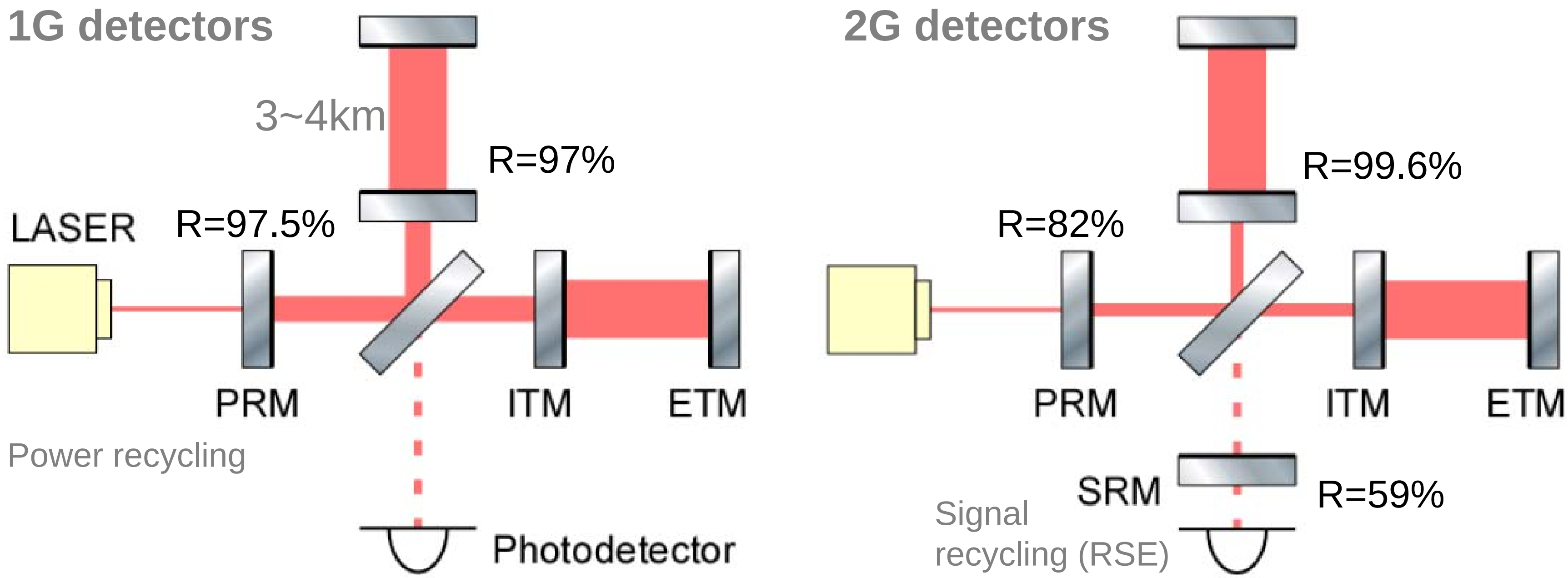
~ crystallized Sapphire ϕ=1.8mm

- **Test mass temperature 20K**



~ Sapphire crystal
30kg, Q=1e8

RSE is suitable with cryogenics



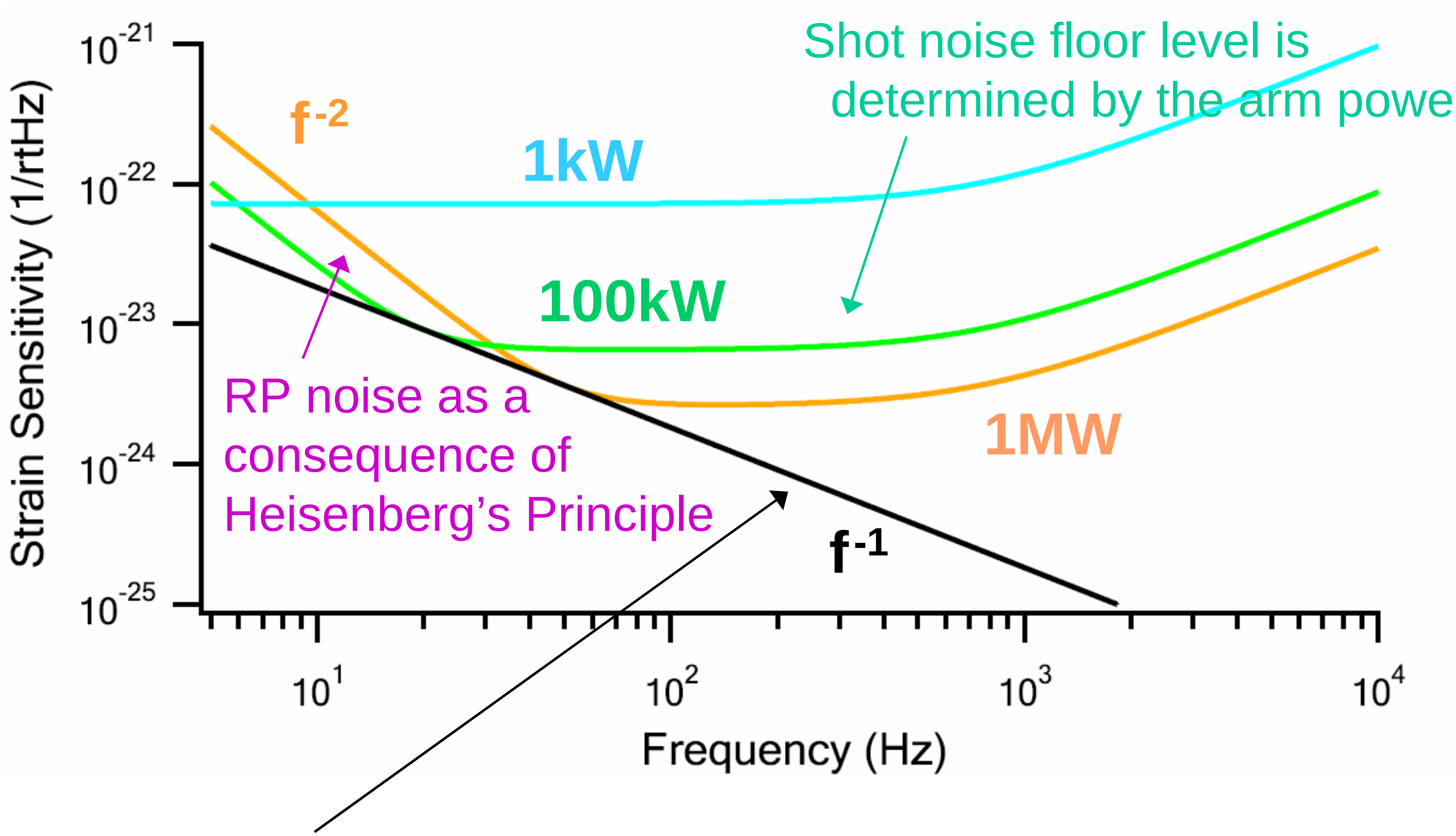
The shot-noise level of these two interferometers is same but the power transmitting ITM is less in 2G (RSE)

Resonant Sideband Extraction

Low heat absorption is essential to cool the mirror.

⇨ LCGT employs the RSE configuration.

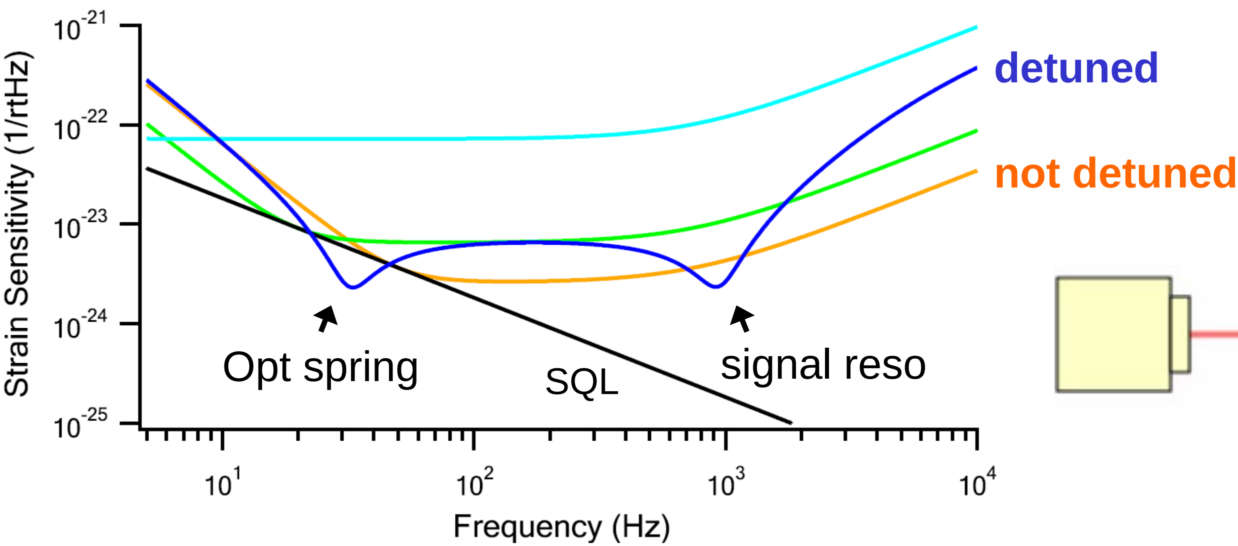
Quantum noise spectrum

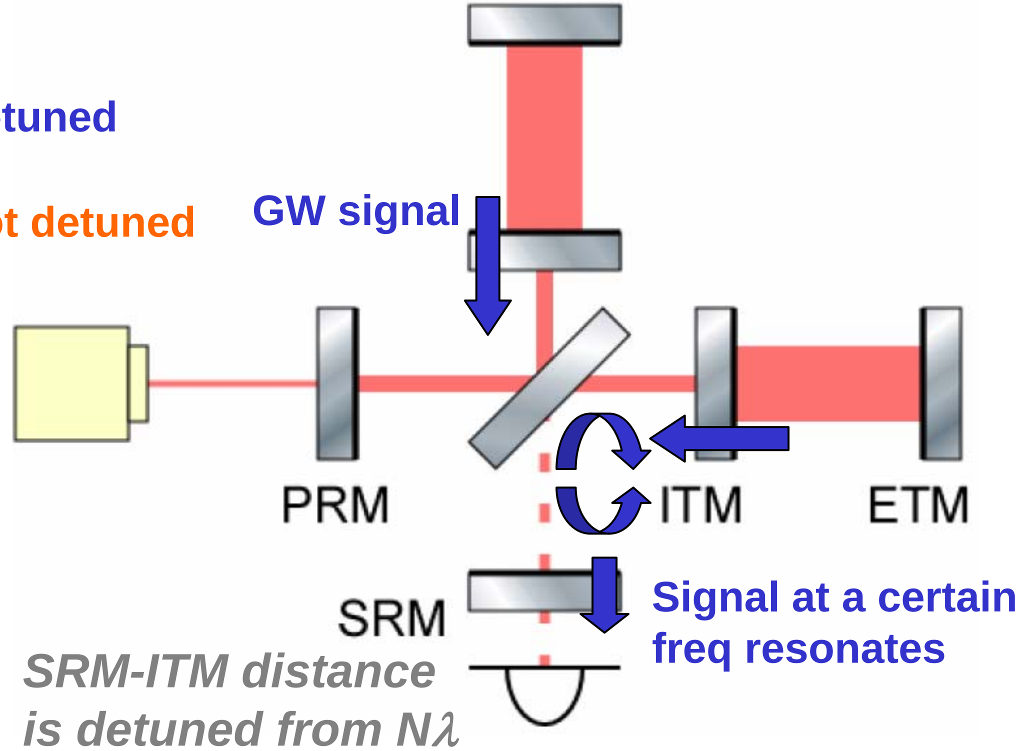


This limit cannot be overcome by changing the power.

→ **Standard Quantum Limit (SQL)**

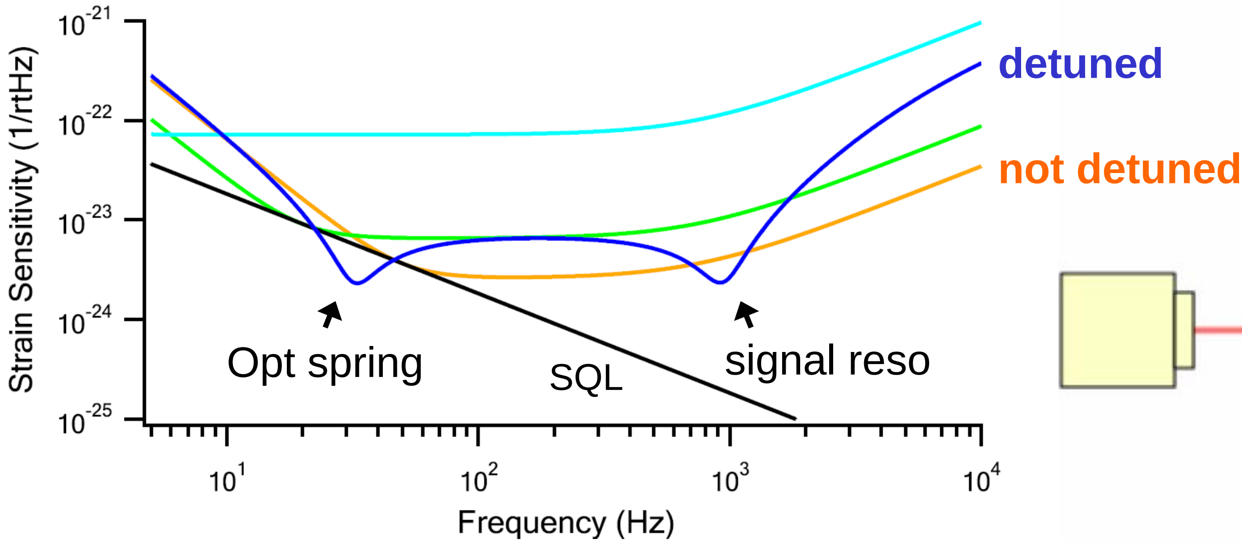
Optical spring to overcome SQL

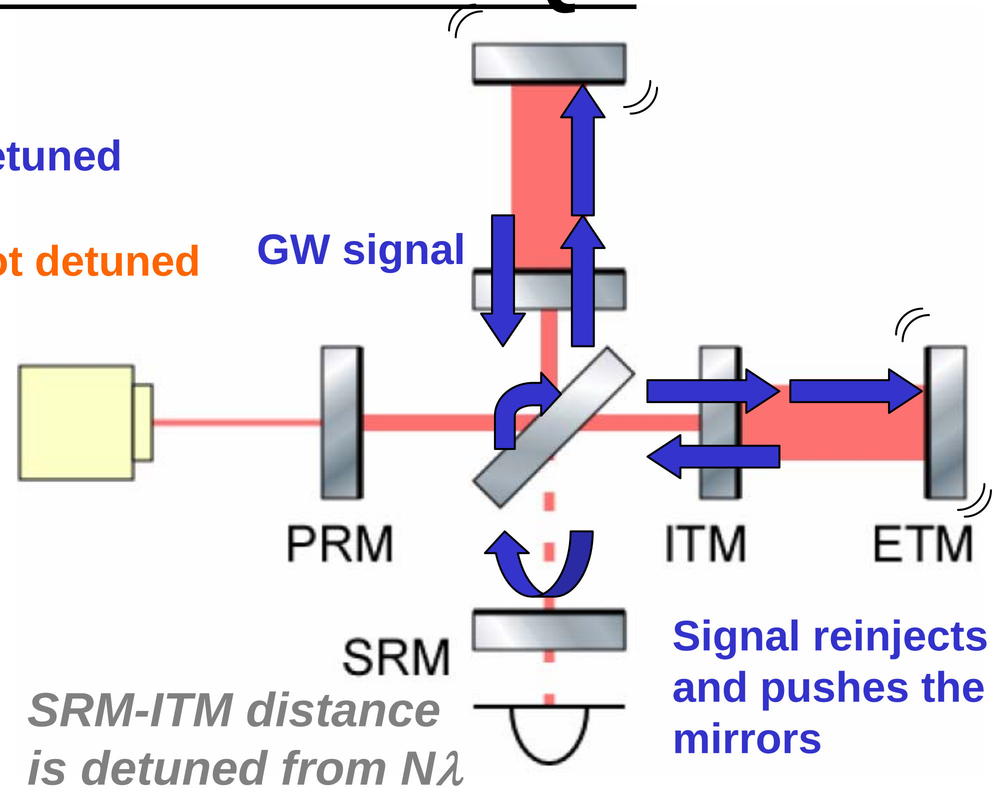




- High-freq peak : signal resonance

Optical spring to overcome SQL

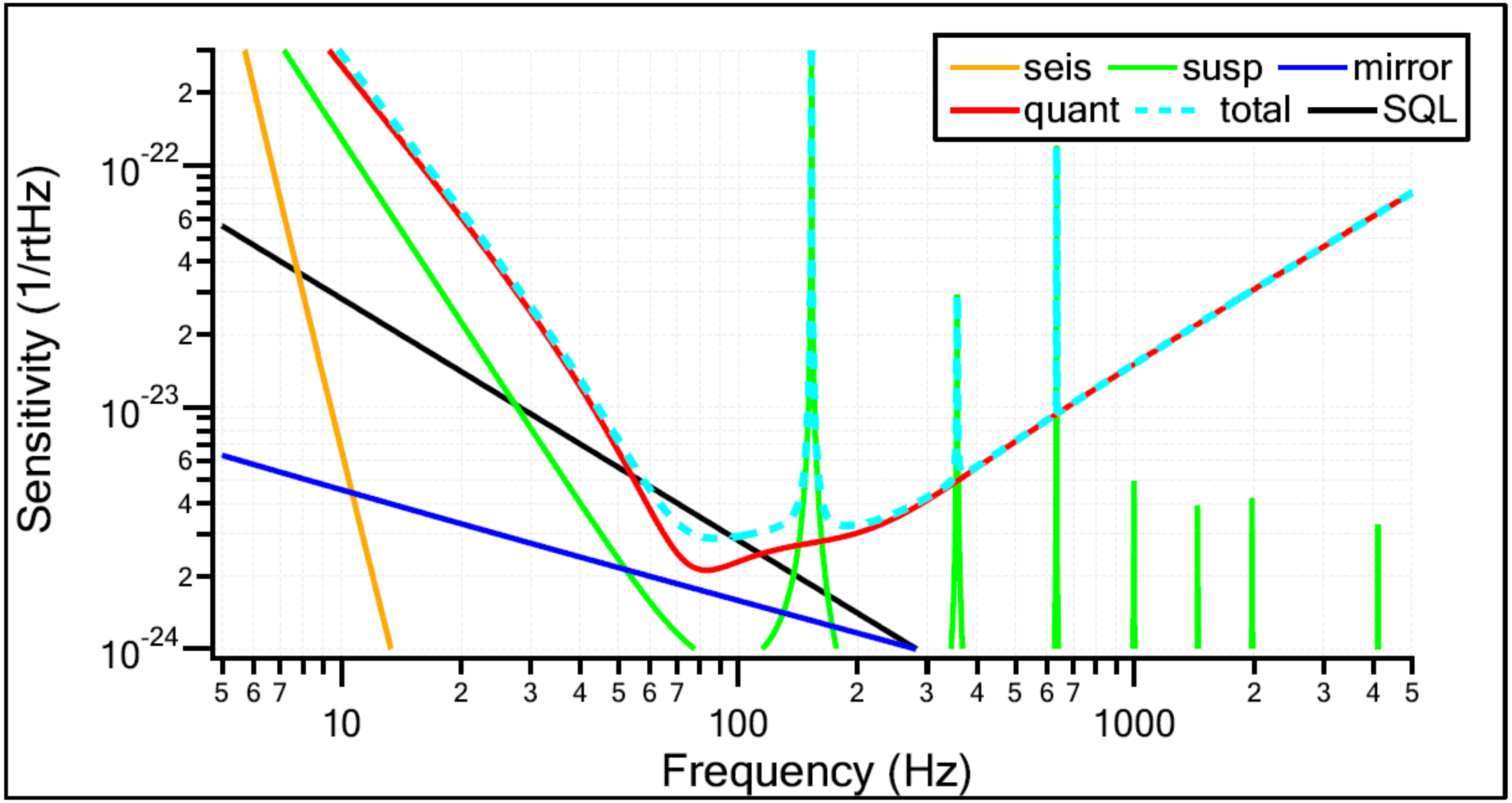




- High-freq peak : signal resonance
- Low-freq peak : signal loop via radiation pressure (opt spring)

Response from GW to mirror motion increases so that we can overcome the SQL defined for free mass.

LCGT design sensitivity



- R_{ITM}=99.6%, R_{SRM}=85%, R_{PRM}=77%, I=90W
- NS-NS inspiral at 291Mpc can be observed by SN=8

(neutron star; M=1.4Ms) (for optimal orientation)

Summary and prospect

• LCGT is finally funded and the construction has started

• Advanced techniques to realize extremely high sensitivity
- Underground
- Cryogenics with Sapphire mirrors/fibers
- Detuned RSE configuration with optical spring

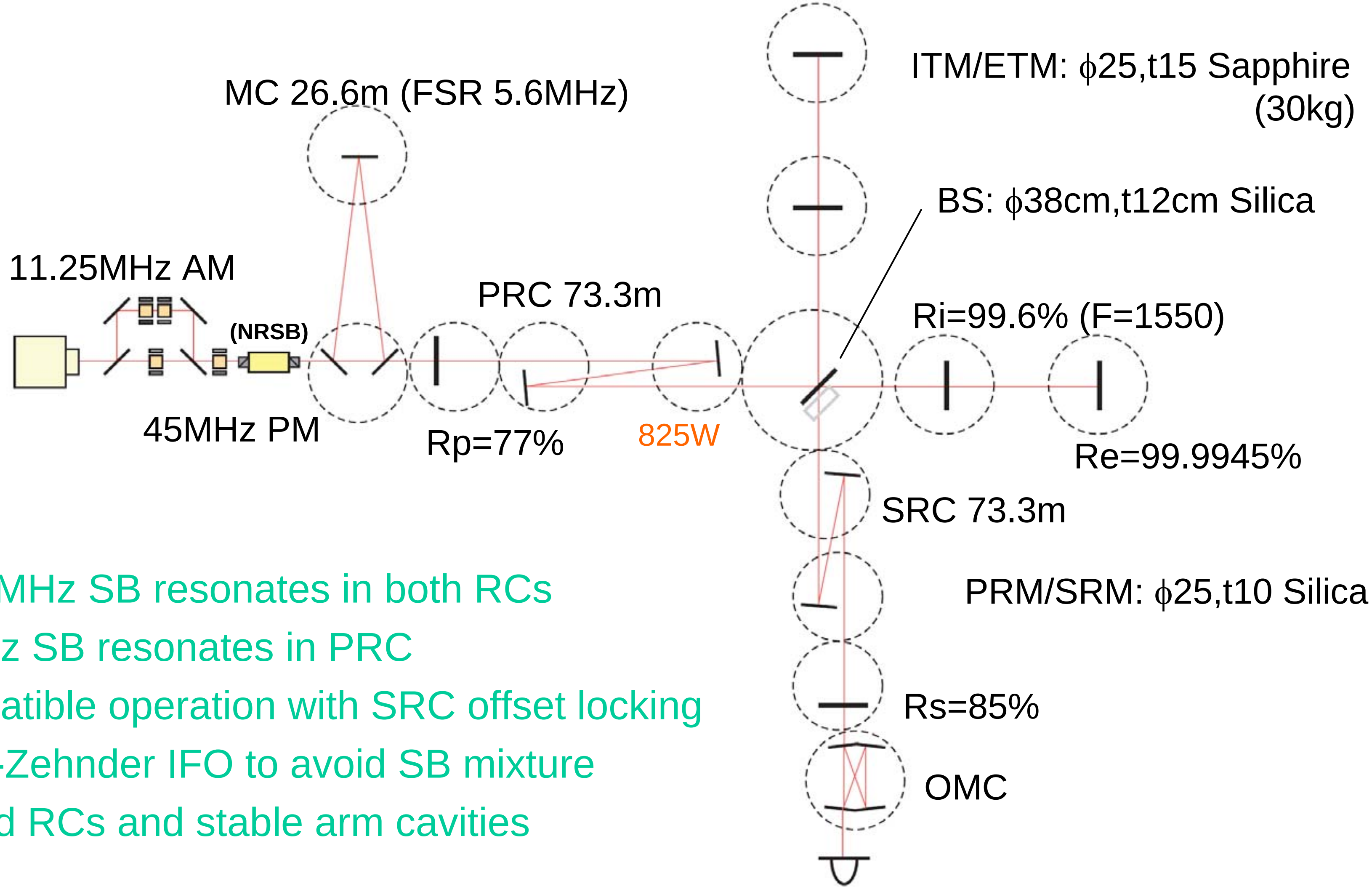
• Broadband sensitivity (20Hz - a few kHz)

• Inspiral range of 291Mpc for NS-NS binaries

• First observation run in a few years; full configuration in 2016

End

Baseline-design IFO setup



- 11.25MHz SB resonates in both RCs
- 45MHz SB resonates in PRC
- Compatible operation with SRC offset locking
- Mach-Zehnder IFO to avoid SB mixture
- Folded RCs and stable arm cavities
- SAS
- DC readout