

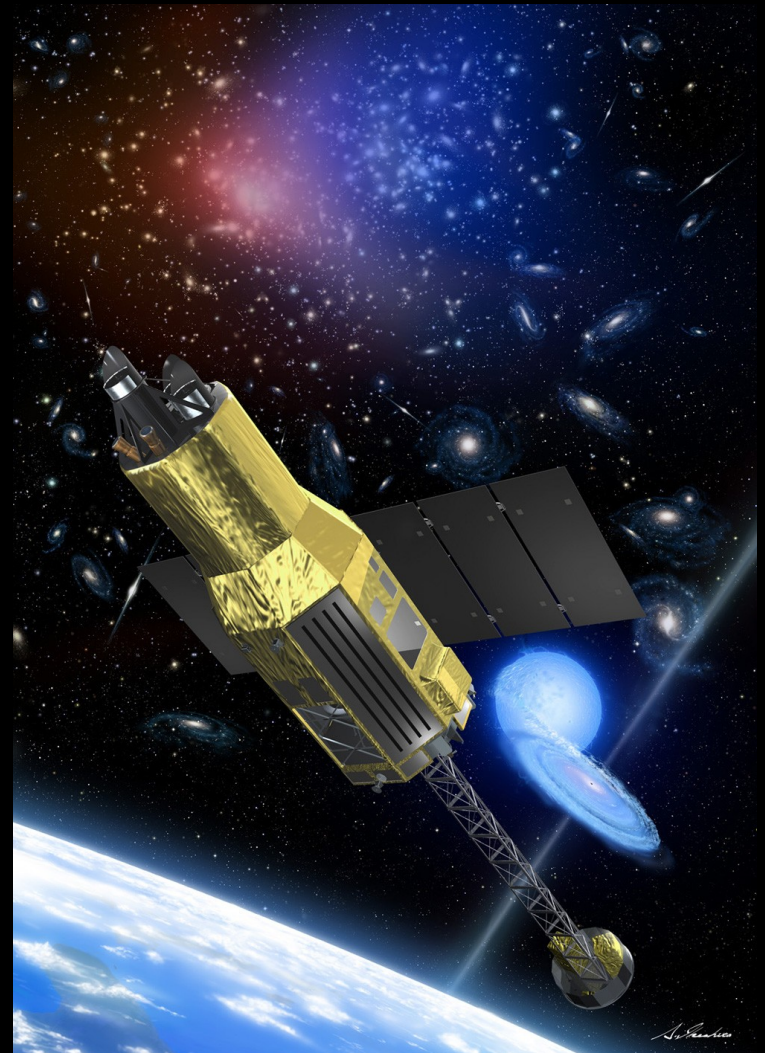
重力波検出器

KAGRAで拓く新しい天文学

国立天文台 重力波プロジェクト推進室
麻生洋一

2015/6/3 NINS機構長プレス懇談会

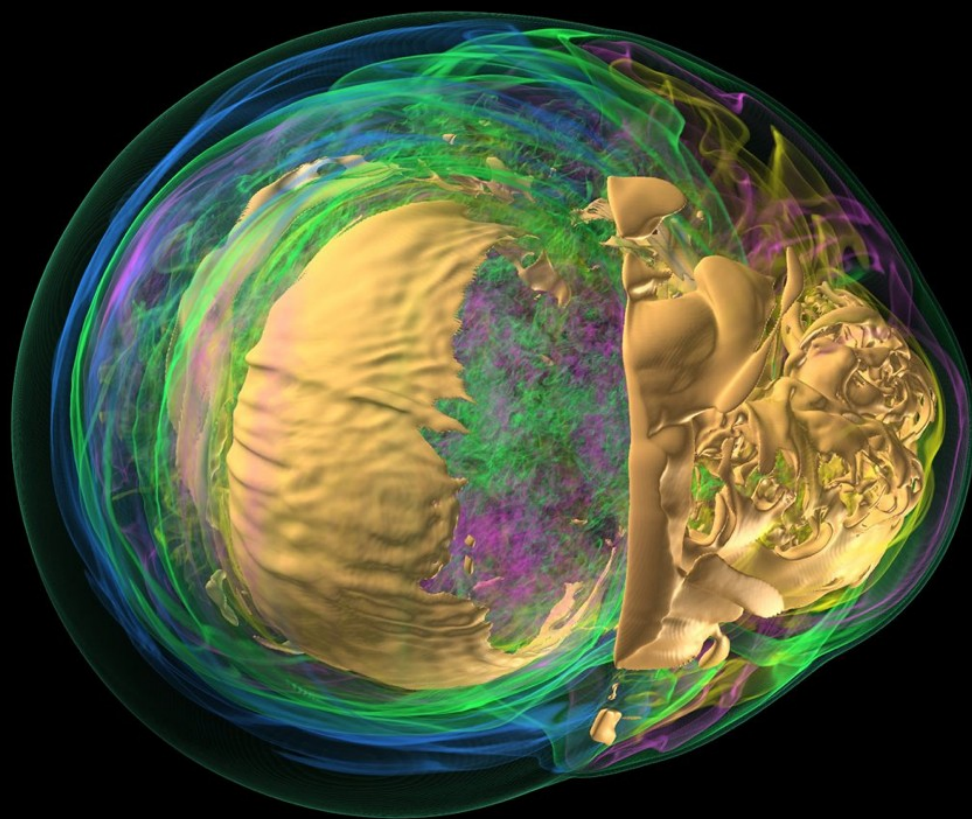
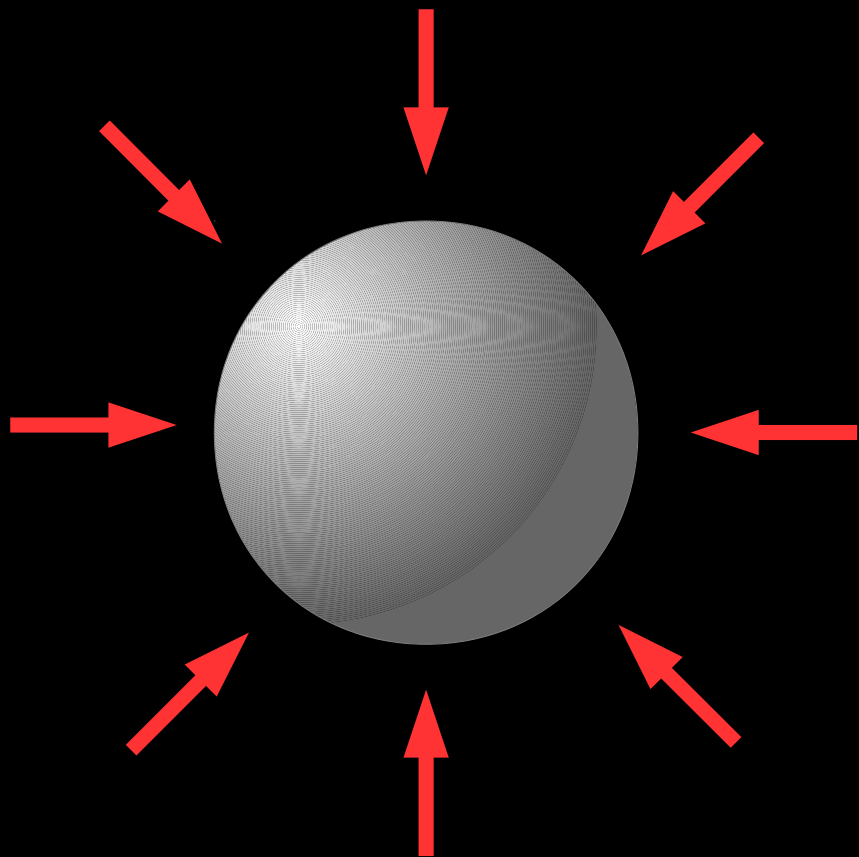
電磁波による観測

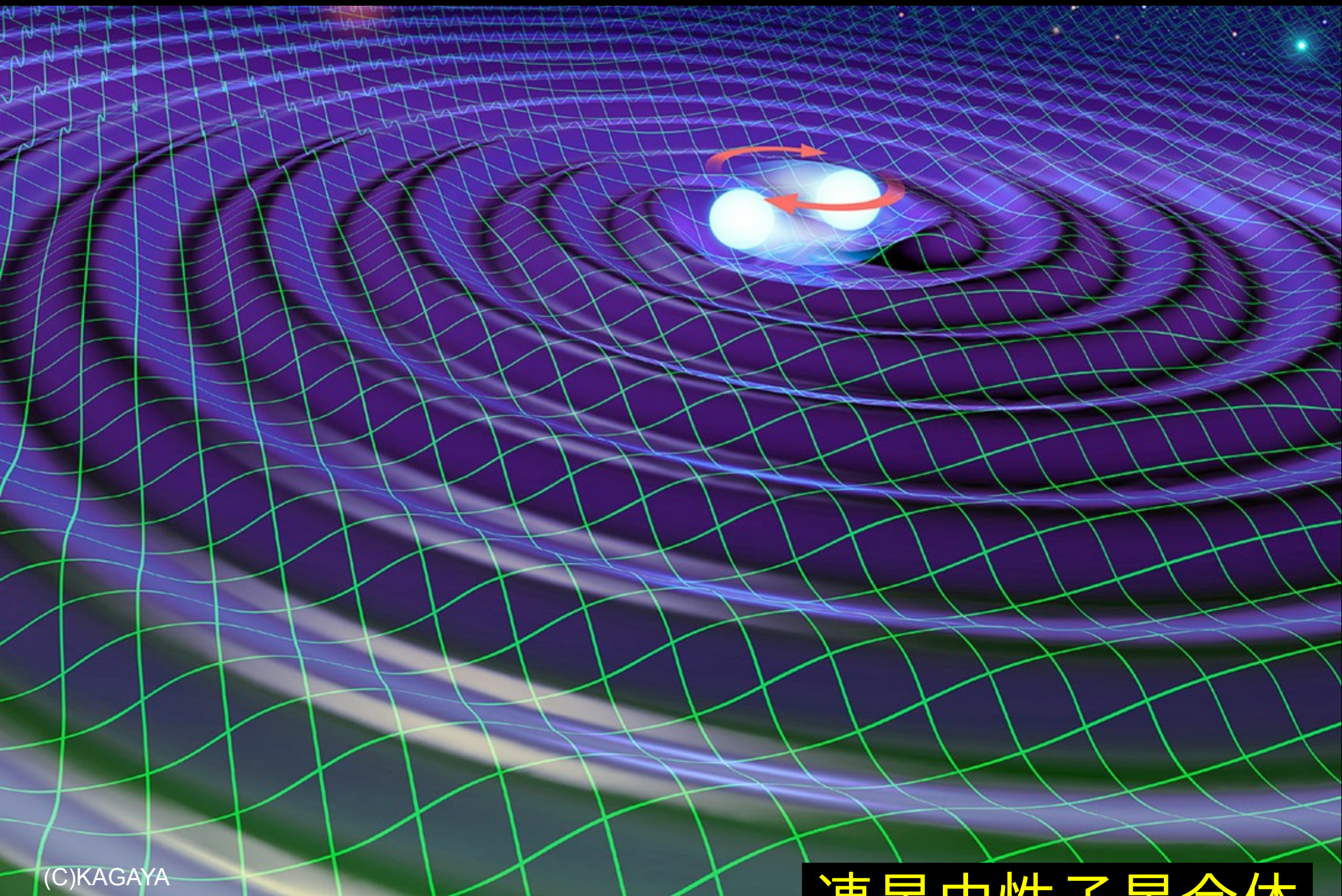




ガンマ線バースト

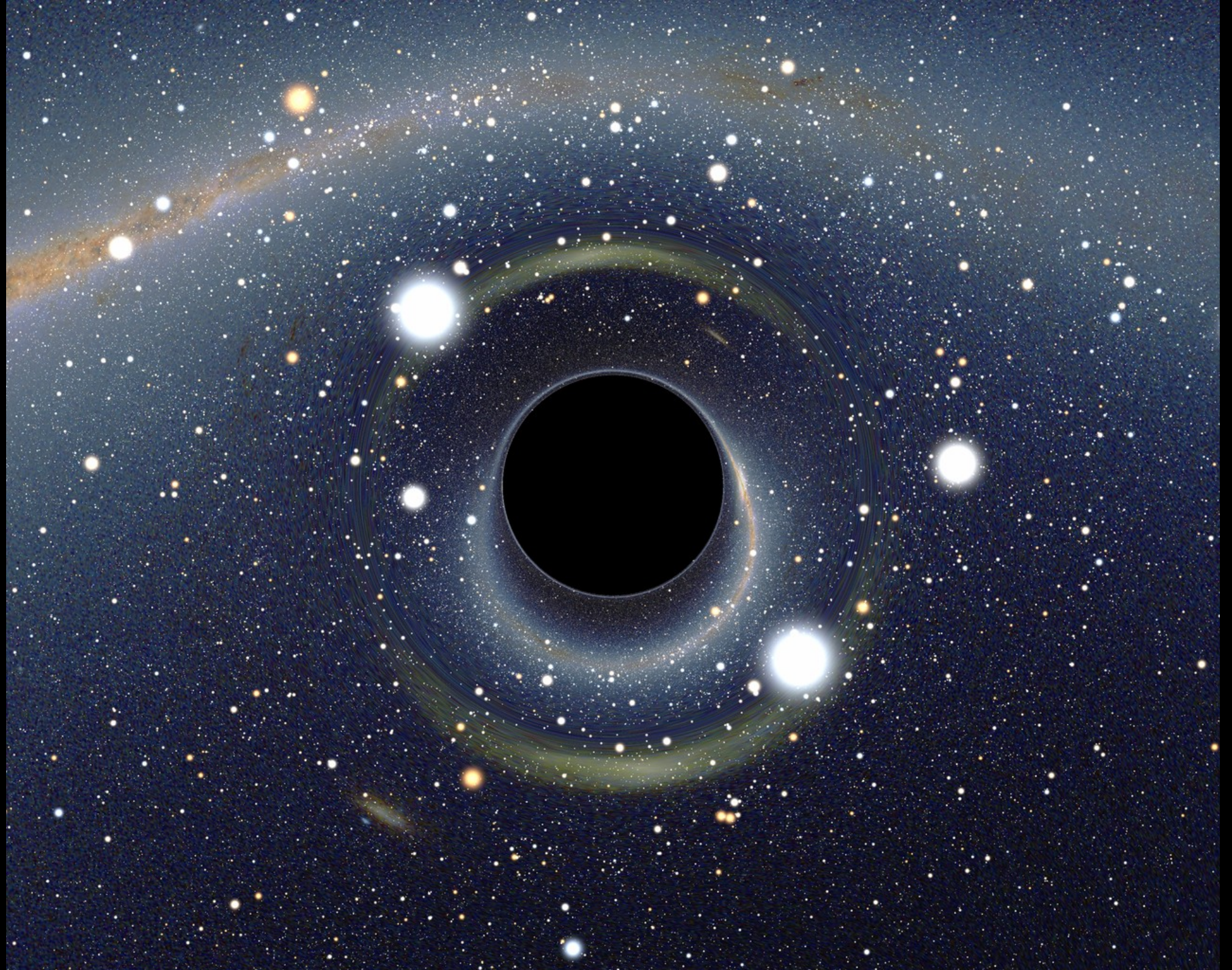
星コアの重力崩壊

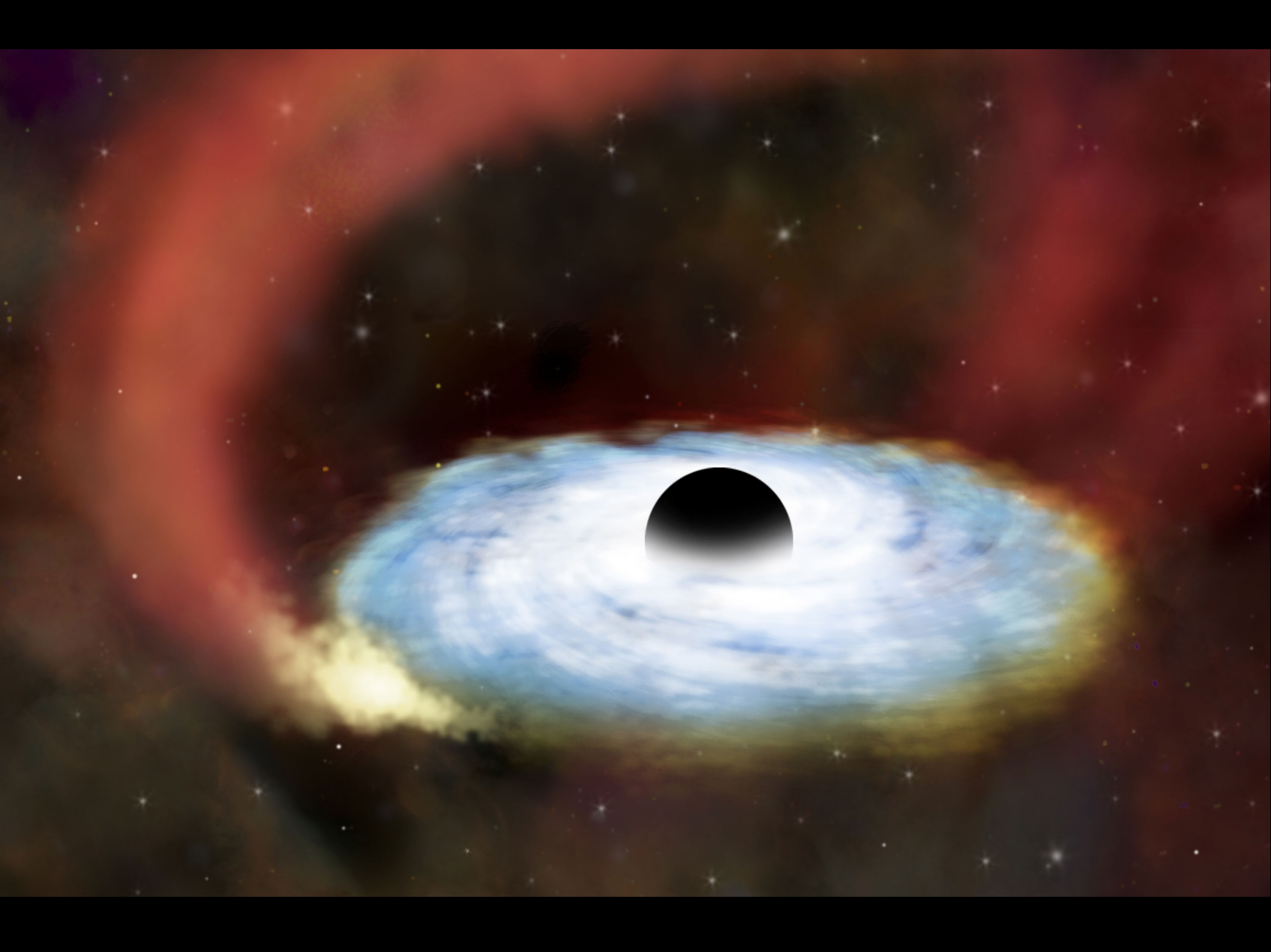


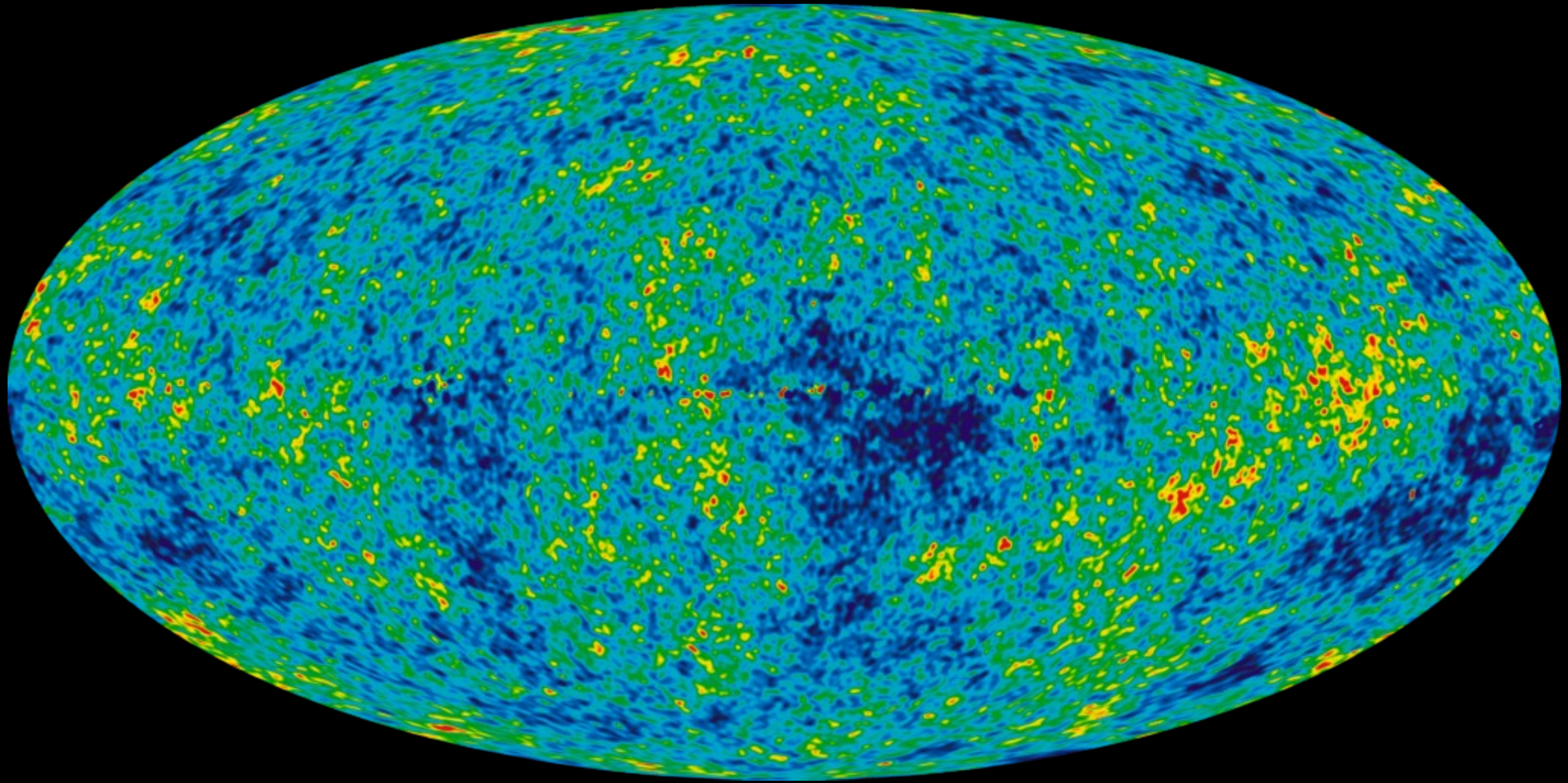


(C)KAGAYA

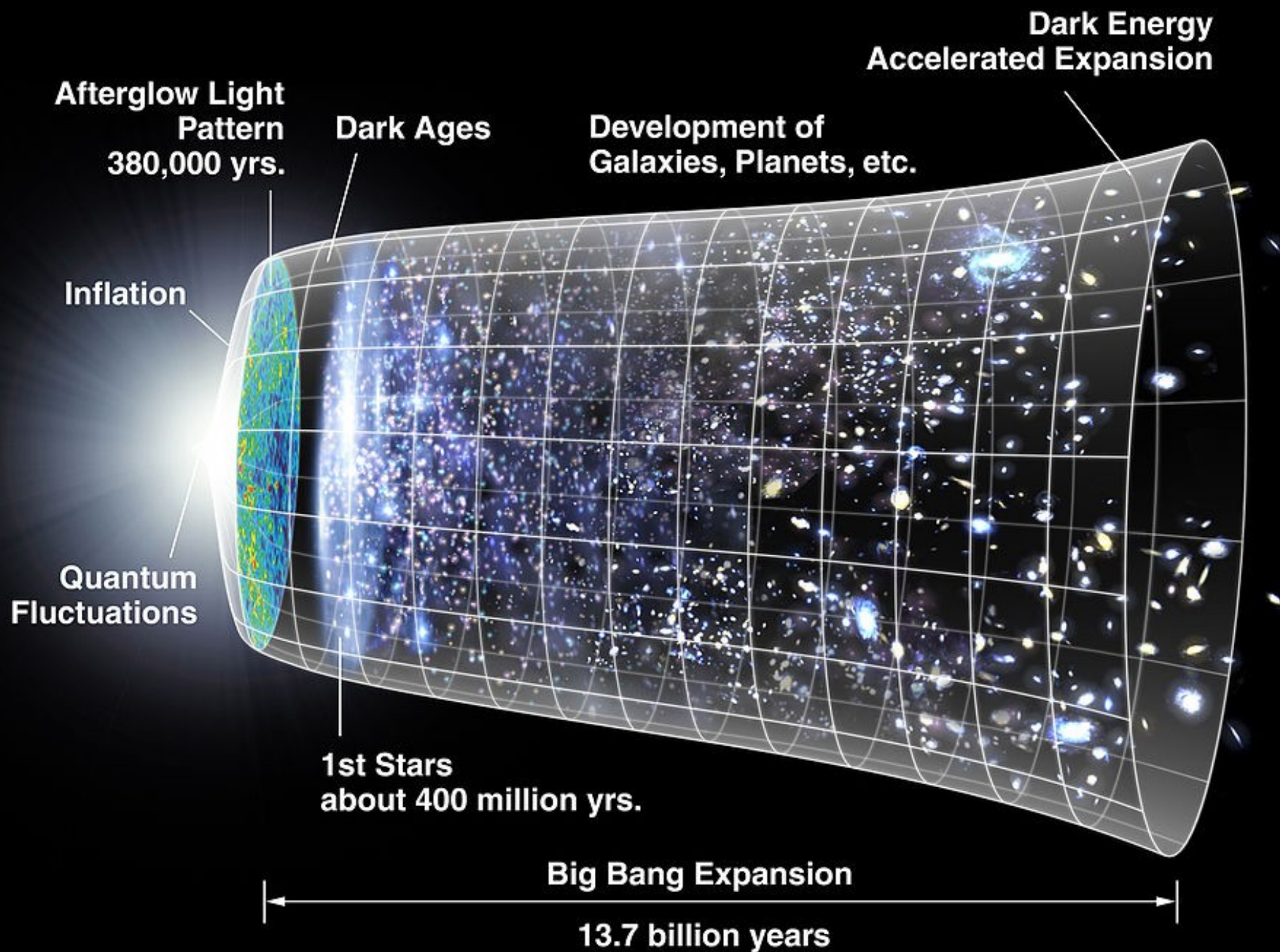
連星中性子星合体



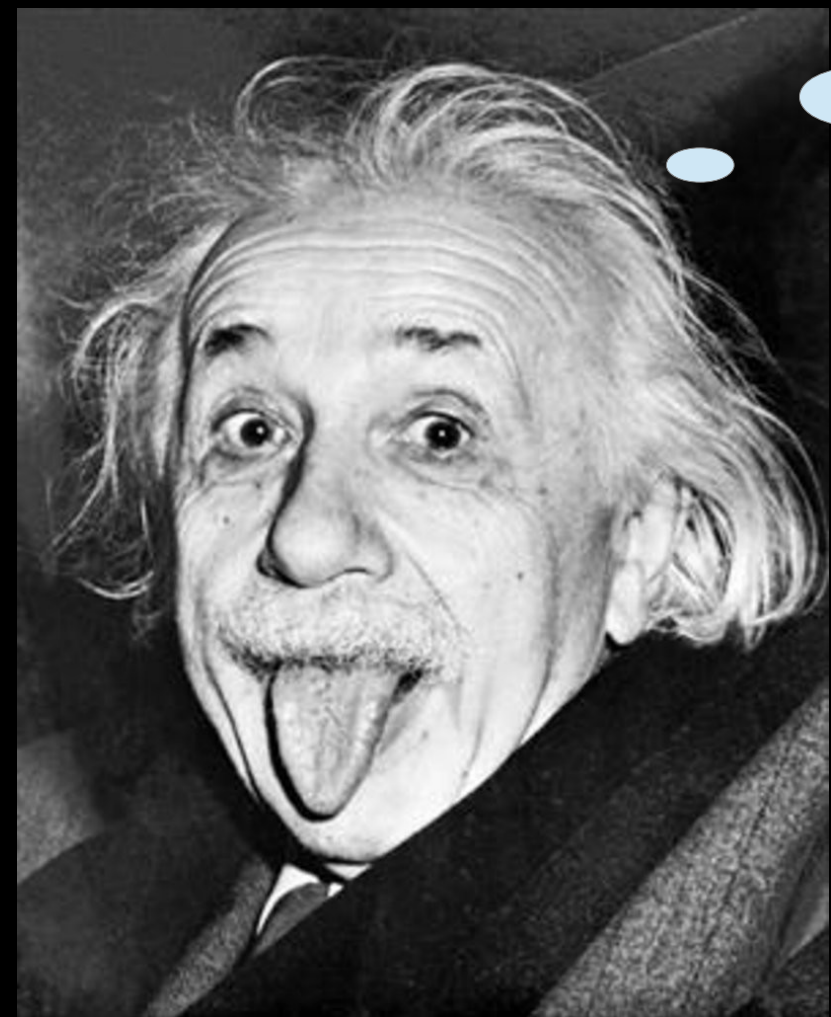


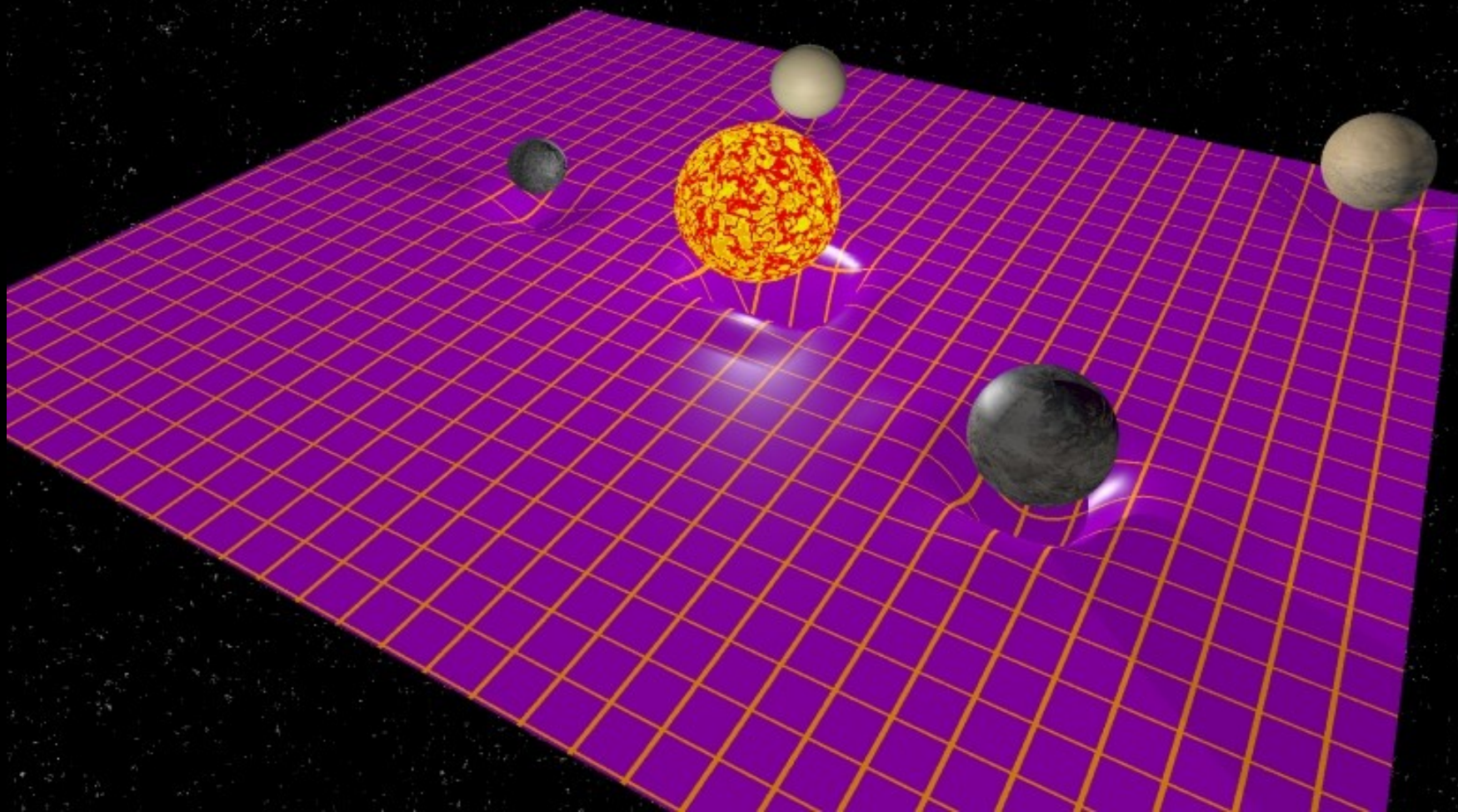


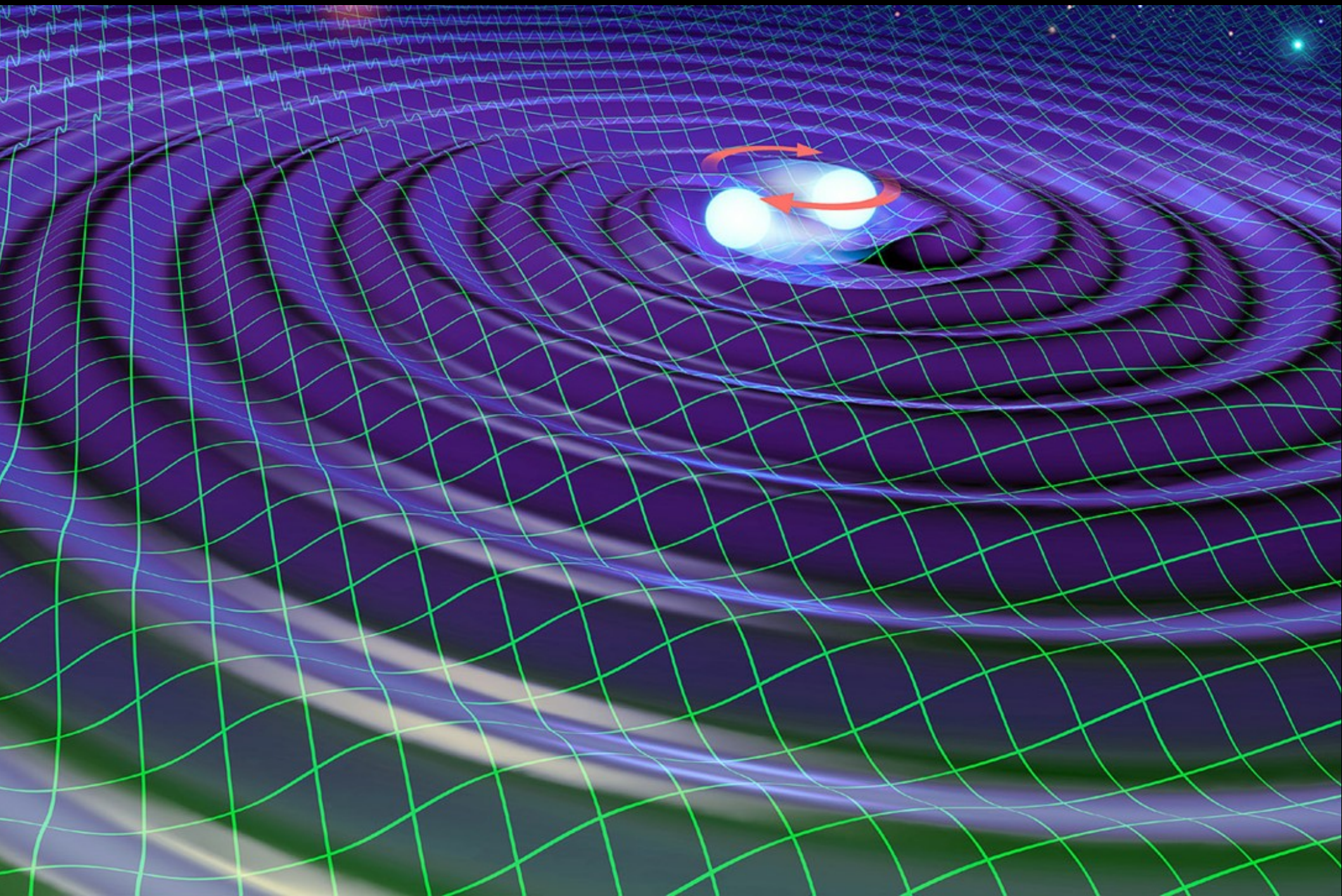
Cosmic Microwave Background



$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$







重力波

電磁波

生成機構

巨視的な質量
の運動

荷電粒子の運動

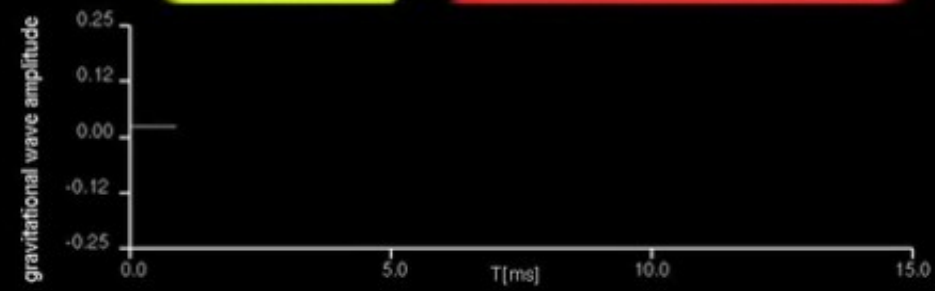
物質との相互作用

極めて弱い

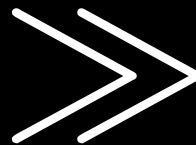
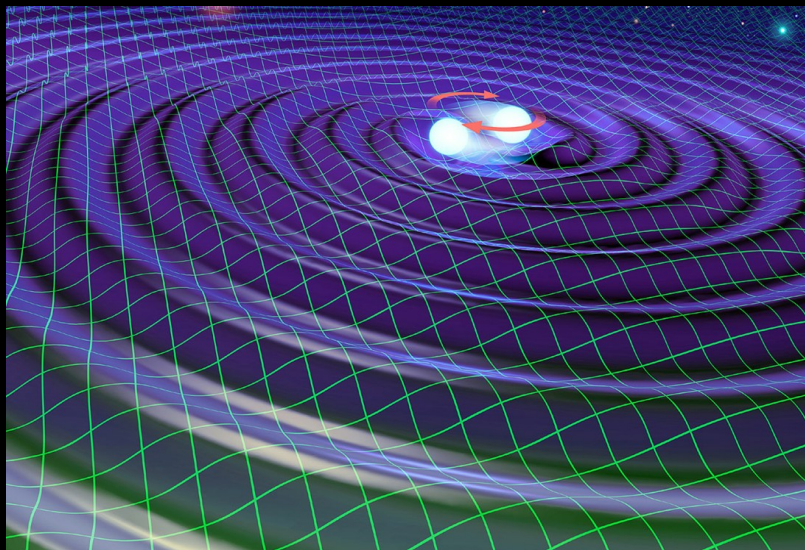
強い



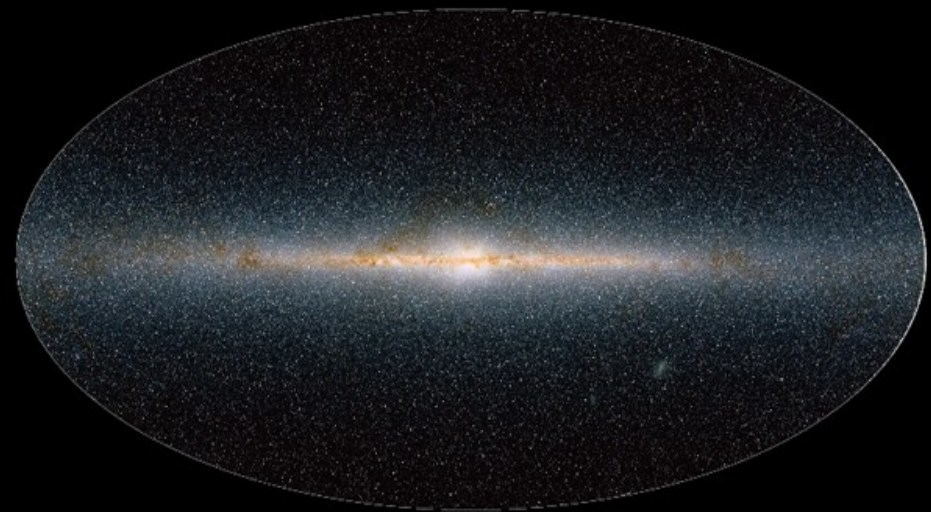
$T[\text{ms}] = 0.88$
 $T[\text{M}] = 93.64$



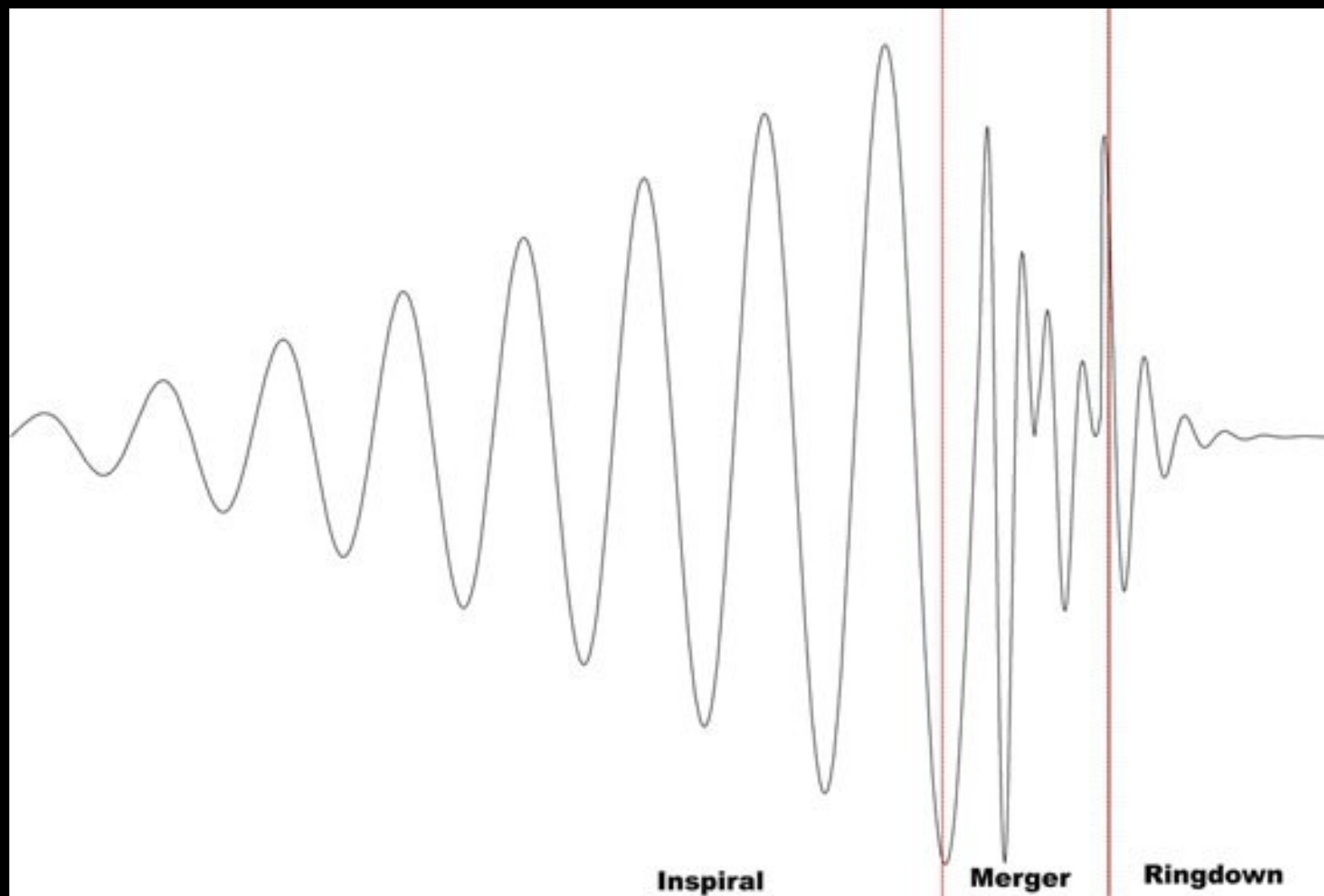
重力波の
エネルギー放出率

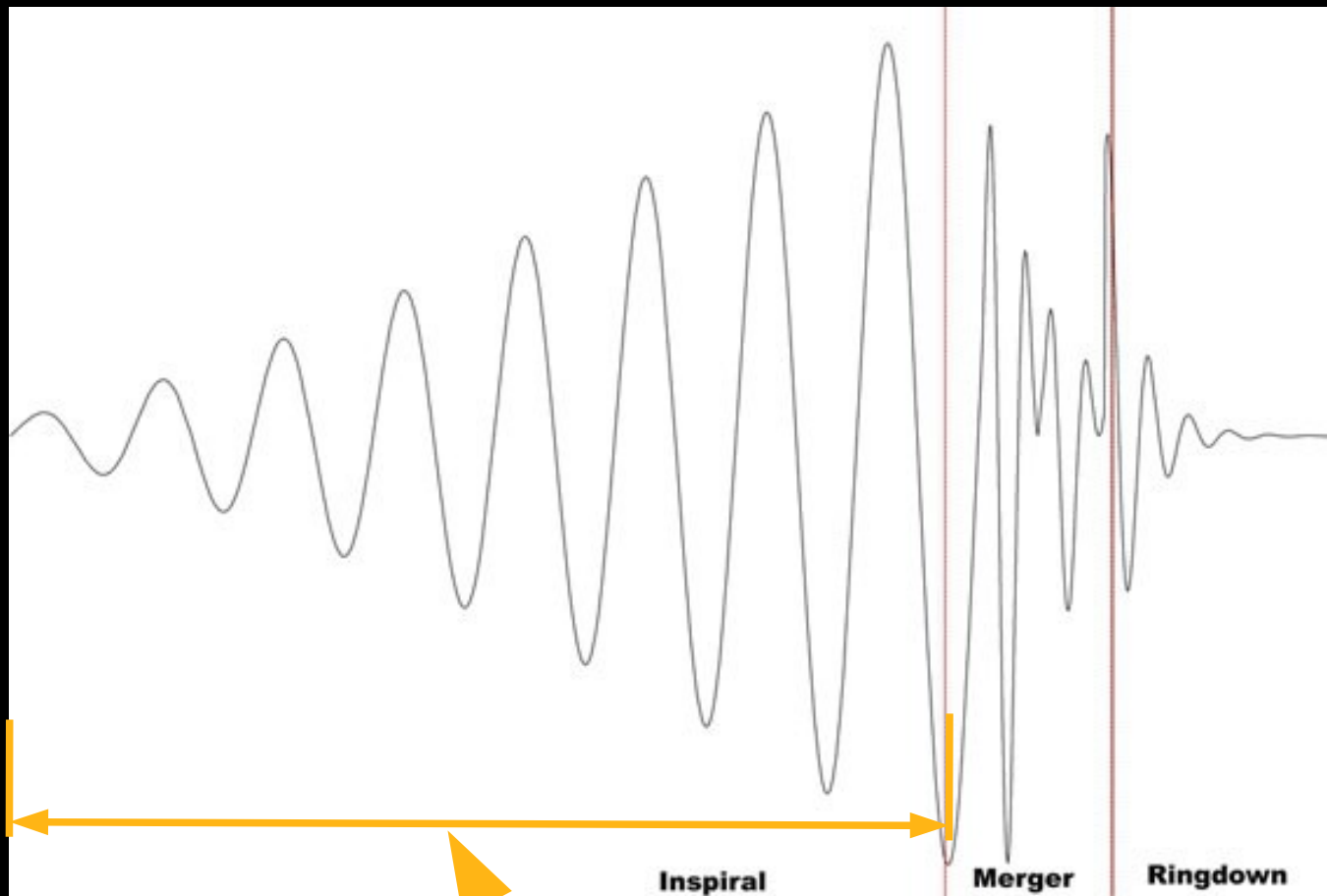


全宇宙可視光
のエネルギー放出率

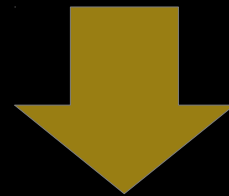


連星中性子星合体: 重力波の波形



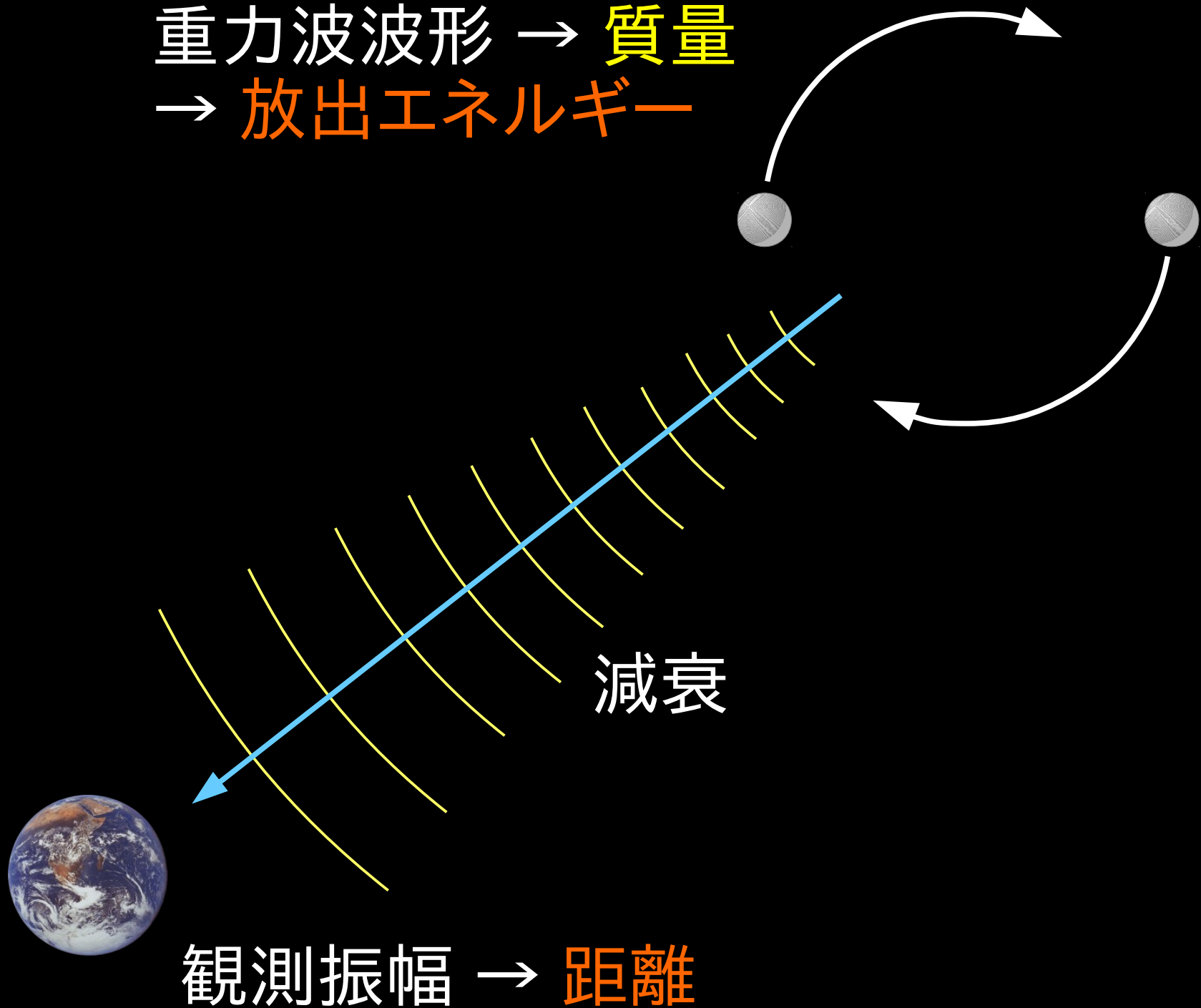


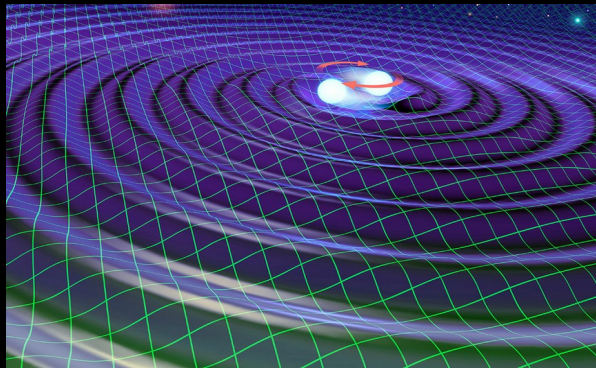
振幅・周波数・周波数変化・位相発展



連星系の質量情報

重力波波形 → 質量
→ 放出エネルギー





重力波観測



- 距離
- 大まかな位置



ガンマ線バースト
残光観測



- 母天体特定



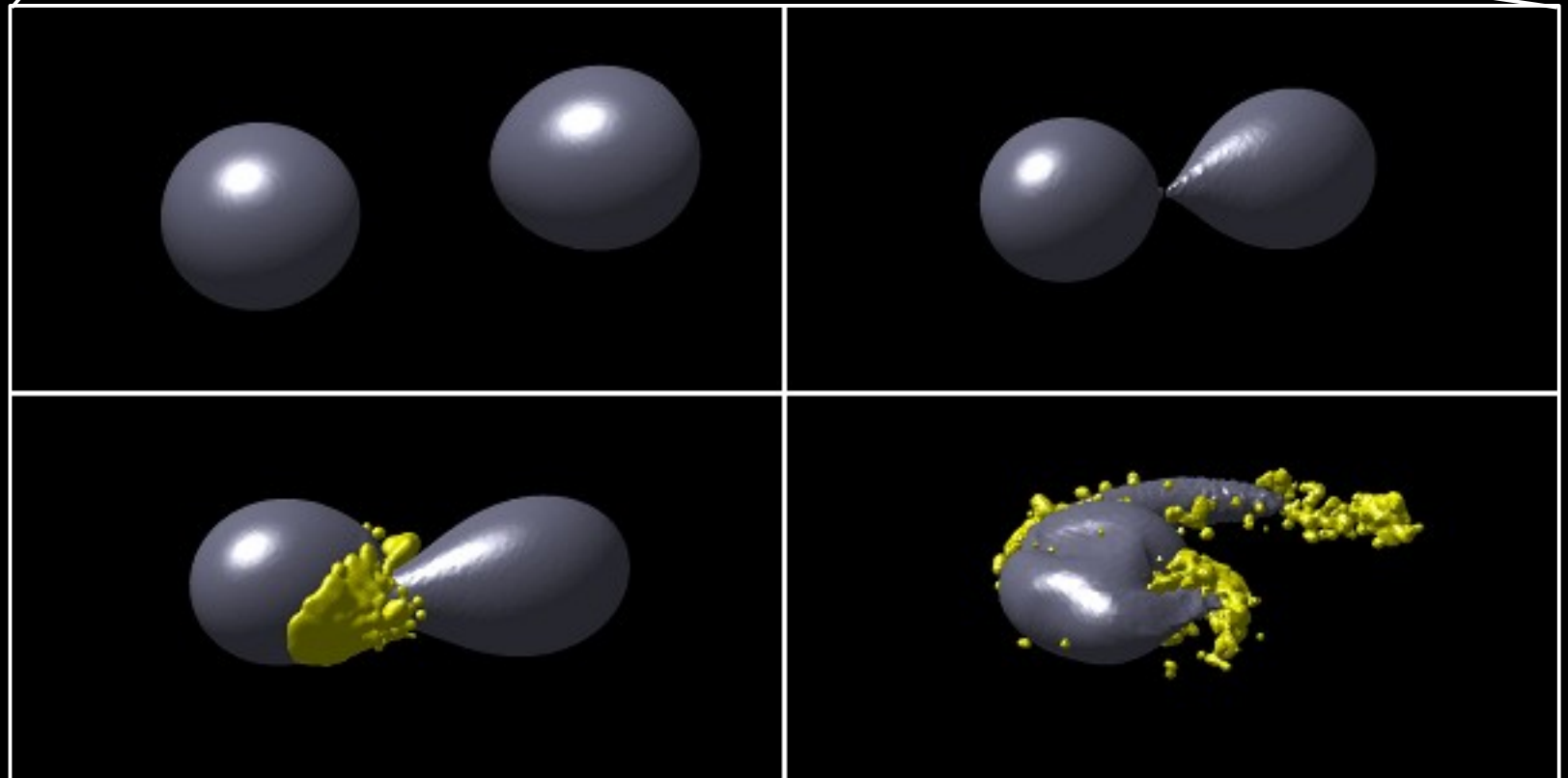
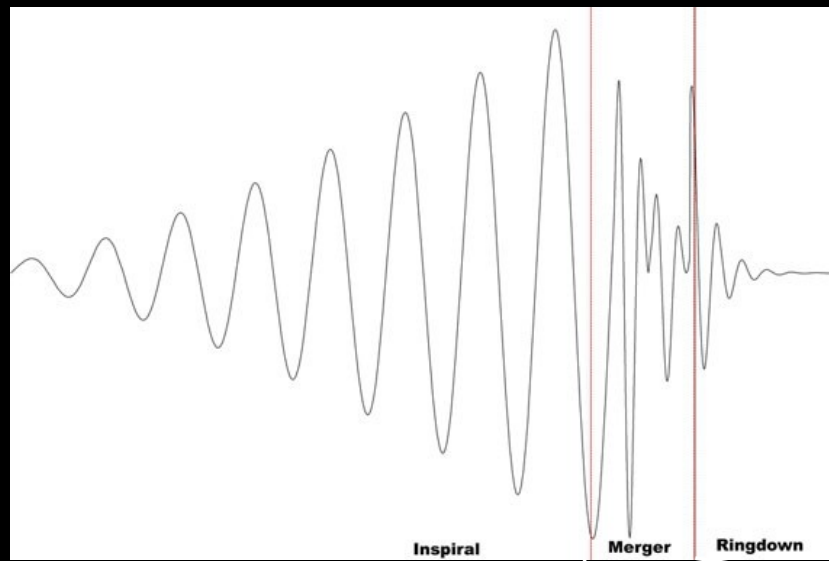
分光観測

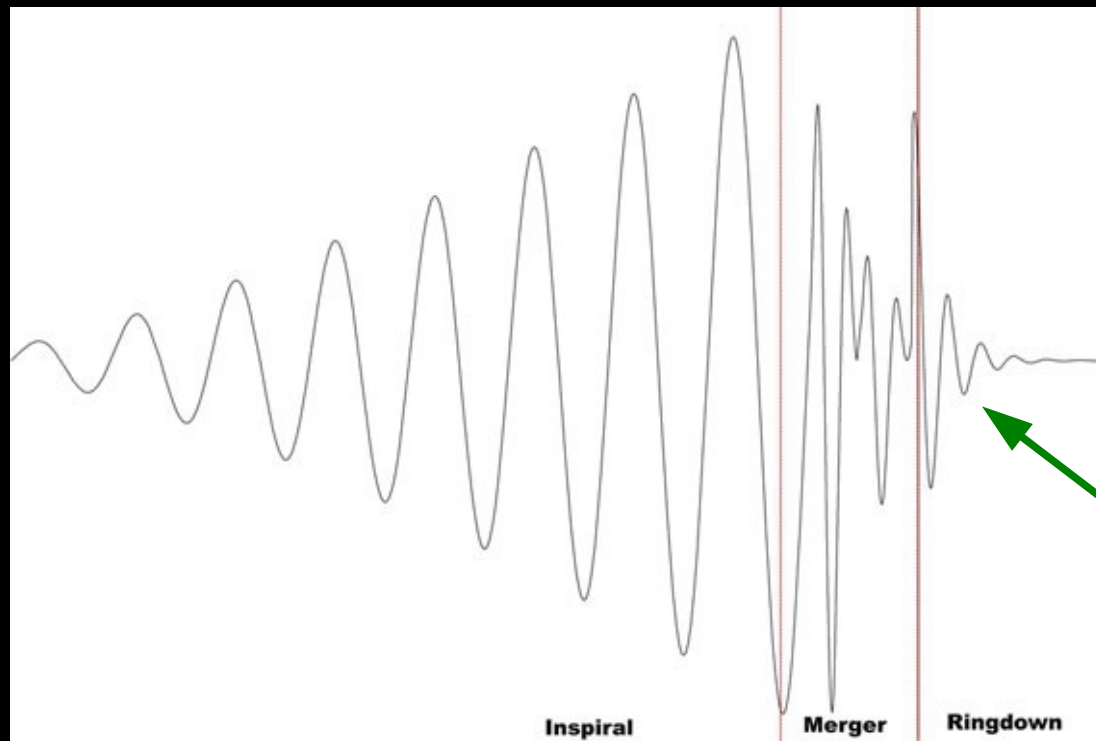


- 赤方偏移

宇宙膨張率の(独立な)測定

中性子星の状態方程式

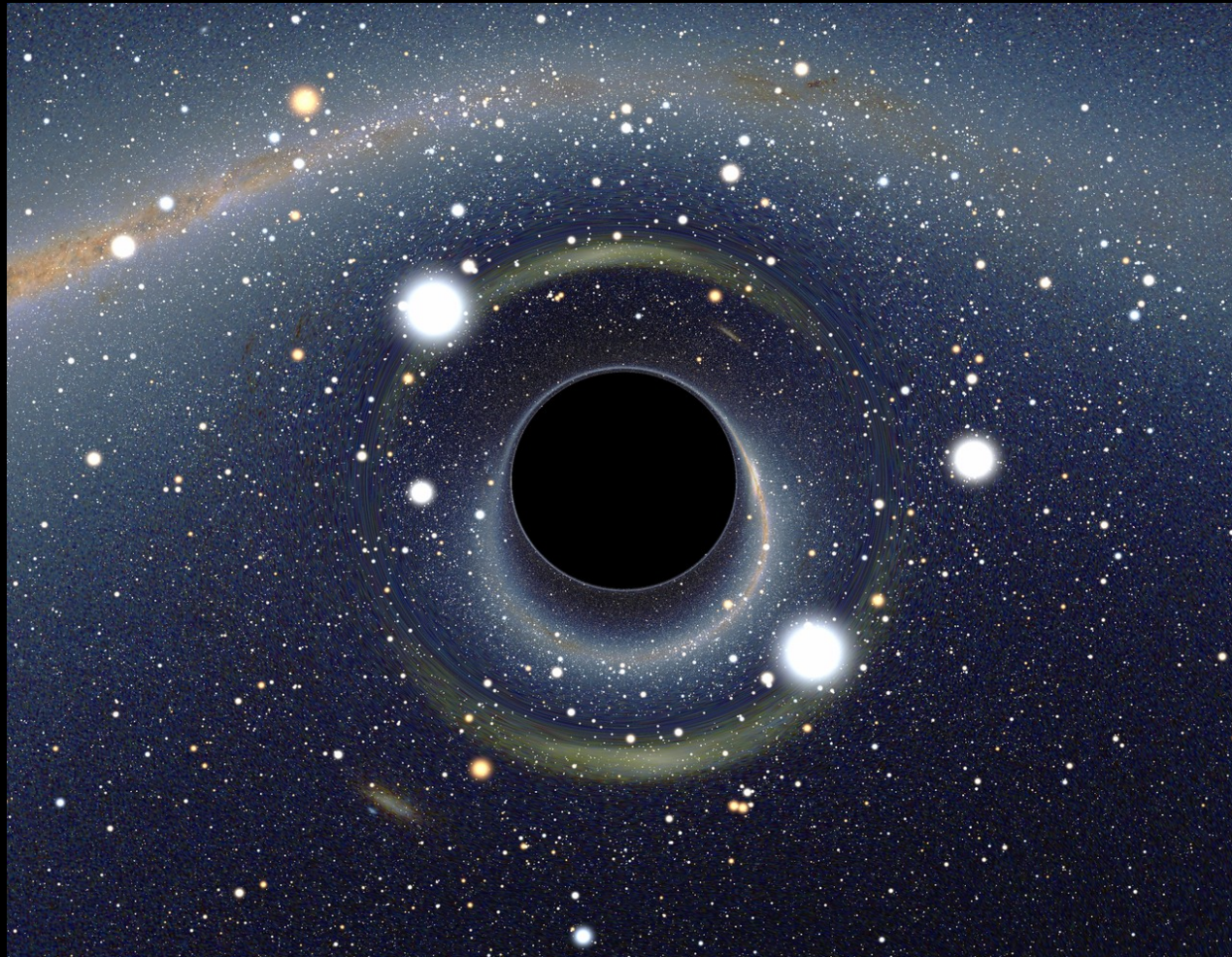




周波数・減衰率

ブラックホールの質量・スピン

ブラックホールの無毛定理

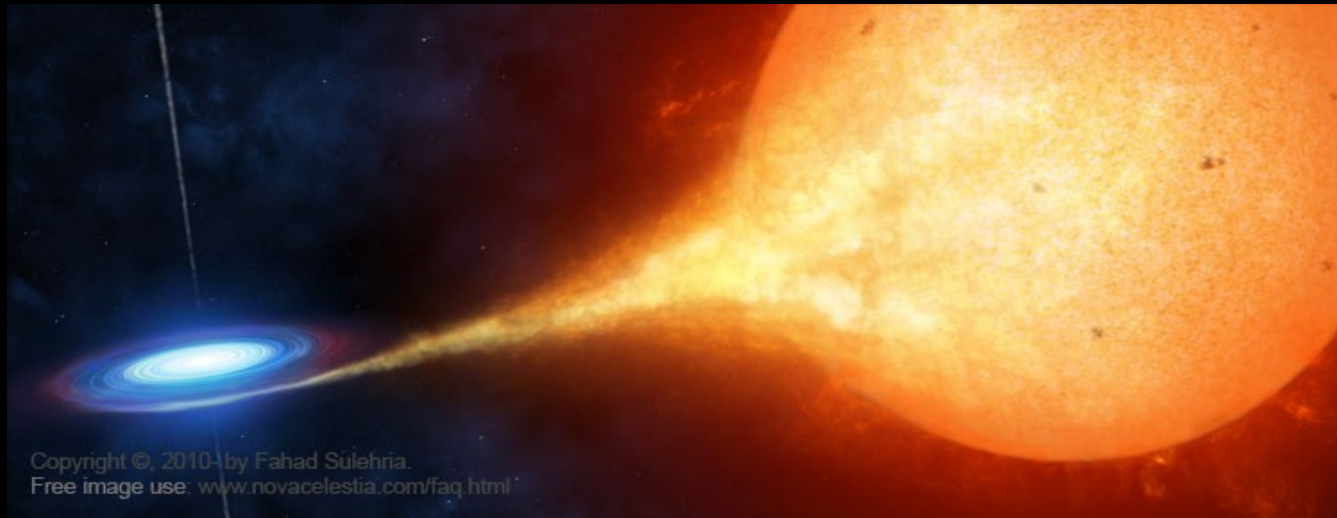
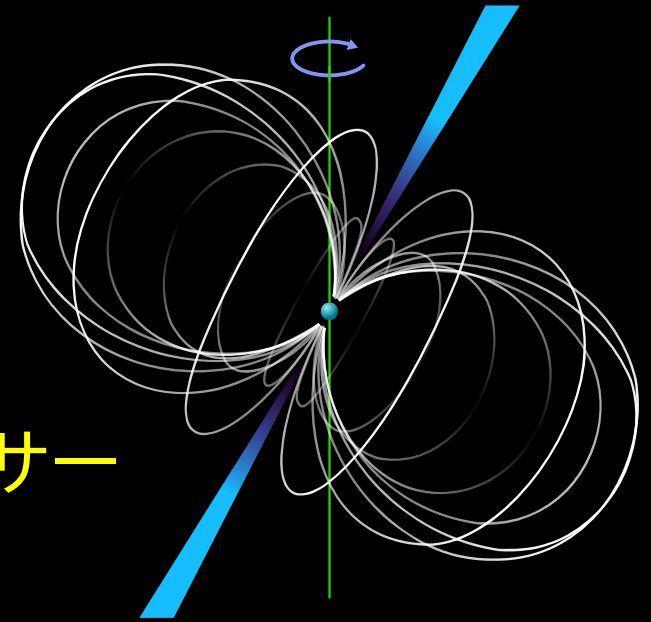


質量・スピン・電荷

超新星爆発

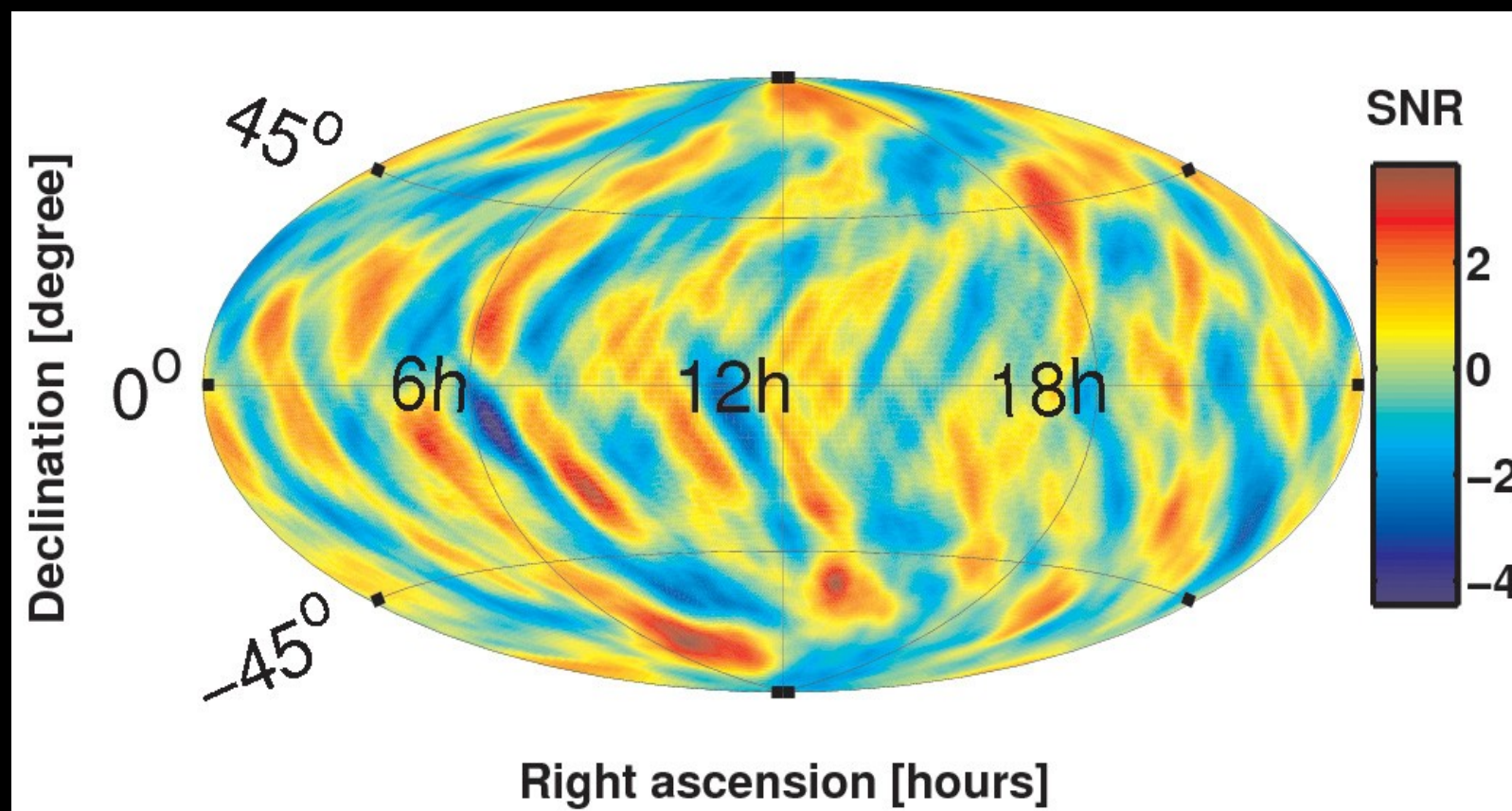


パルサー



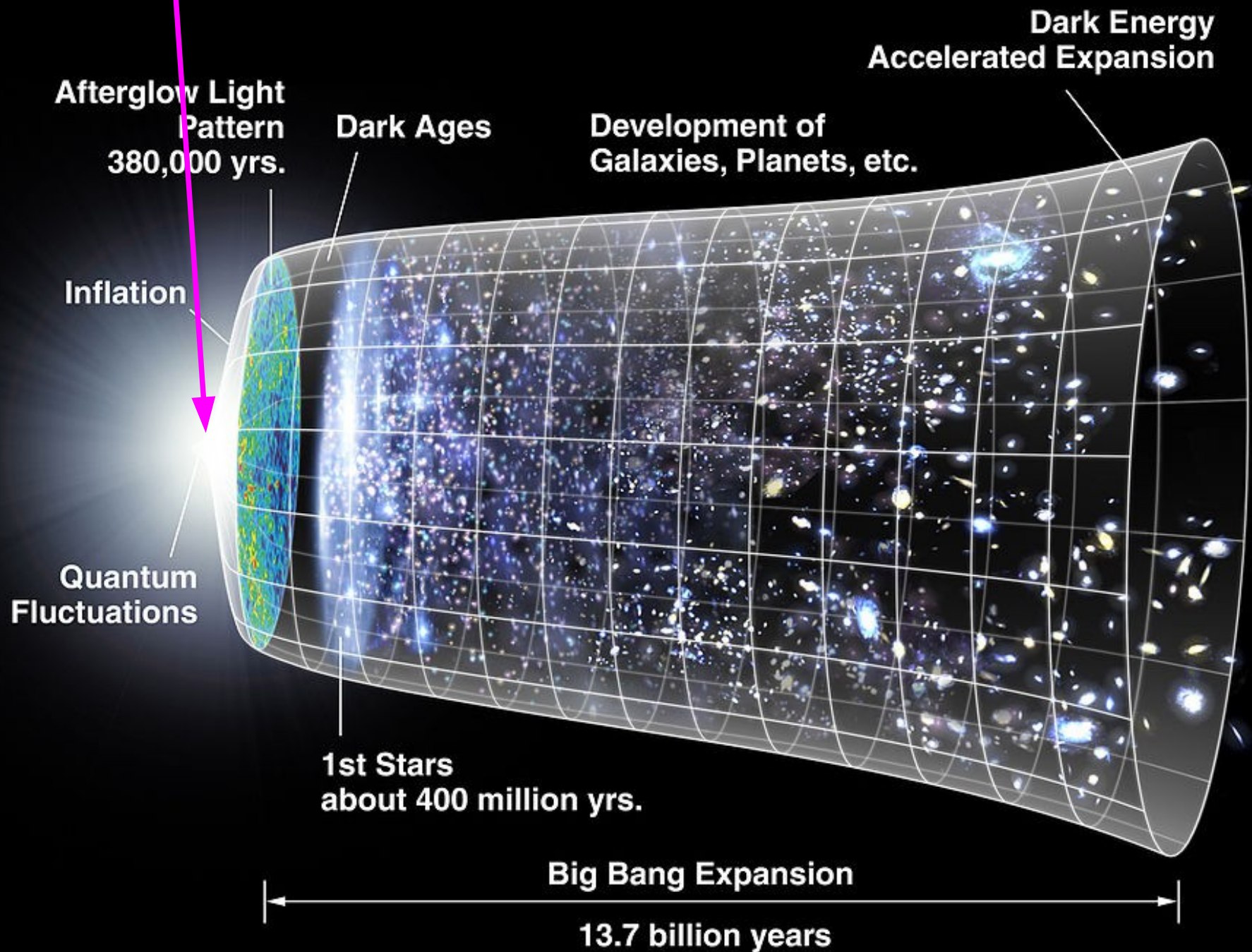
低質量X線連星(LMXB)

宇宙背景重力波

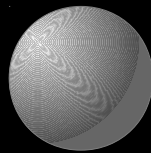
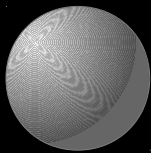


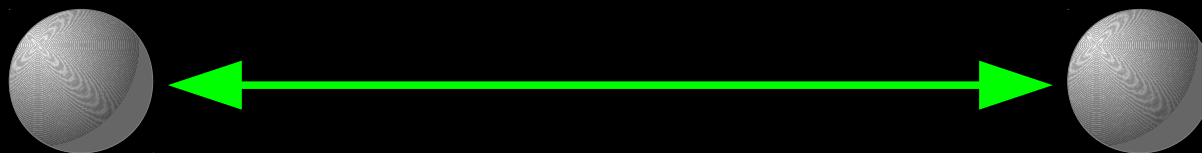
S. Ballmer, CQG (2006)

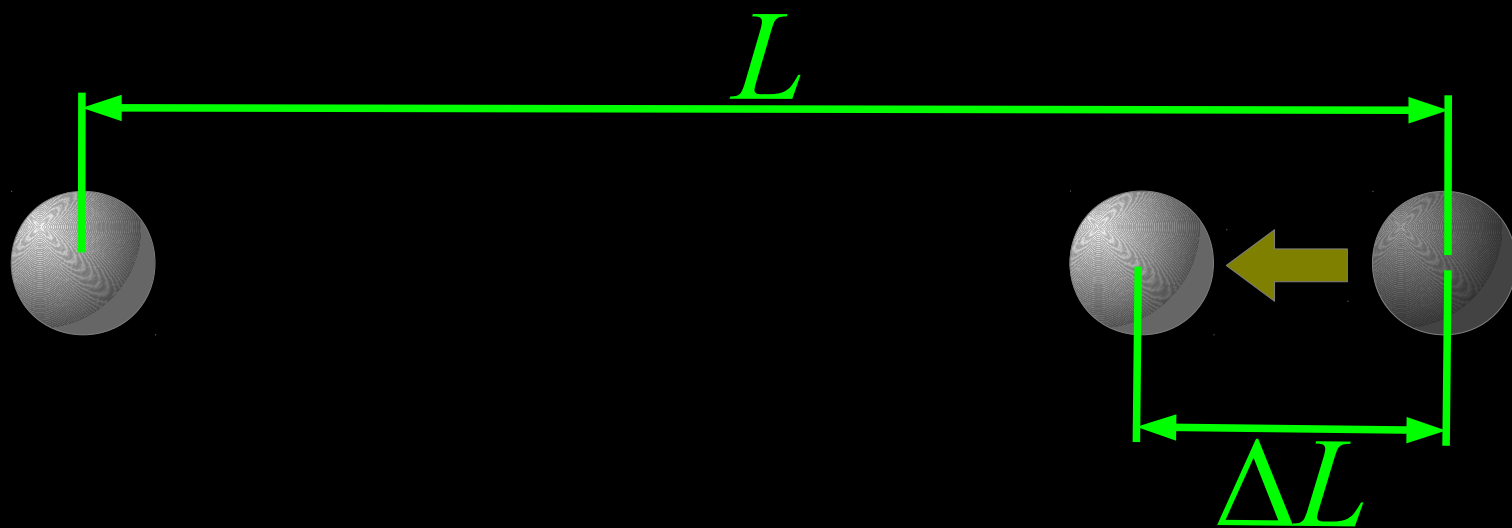
10⁻³⁰秒後



ではどうやって検出するか？





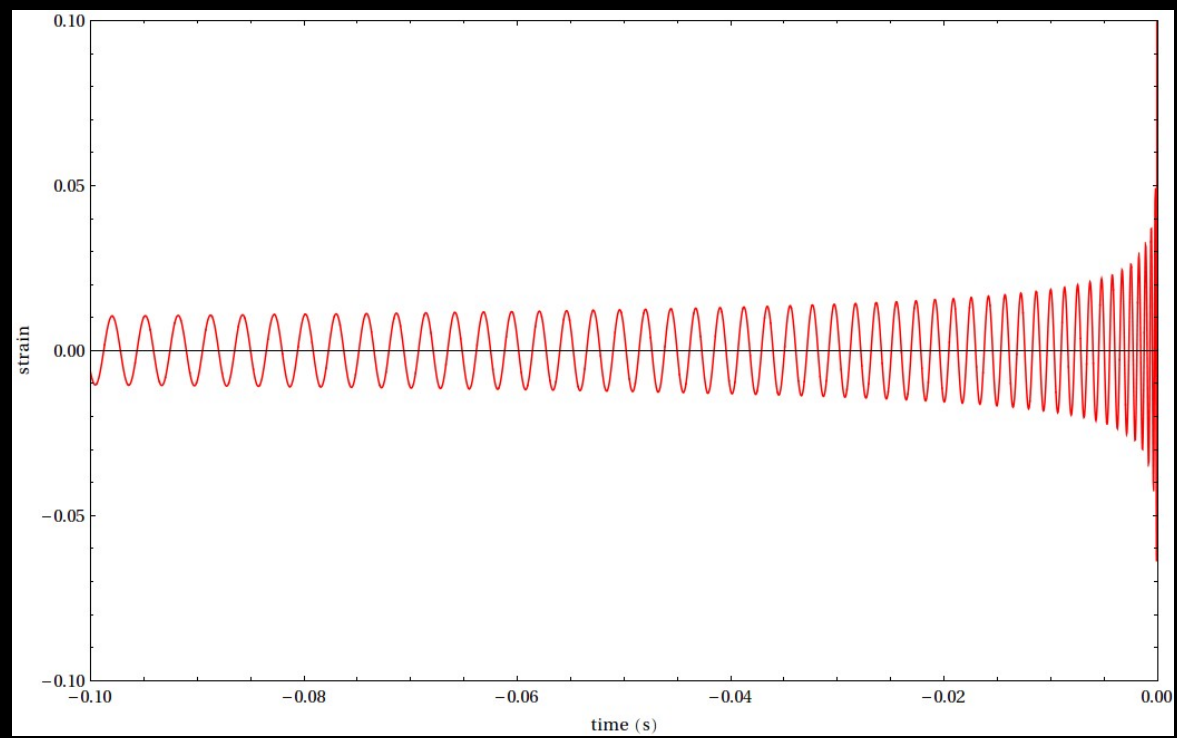
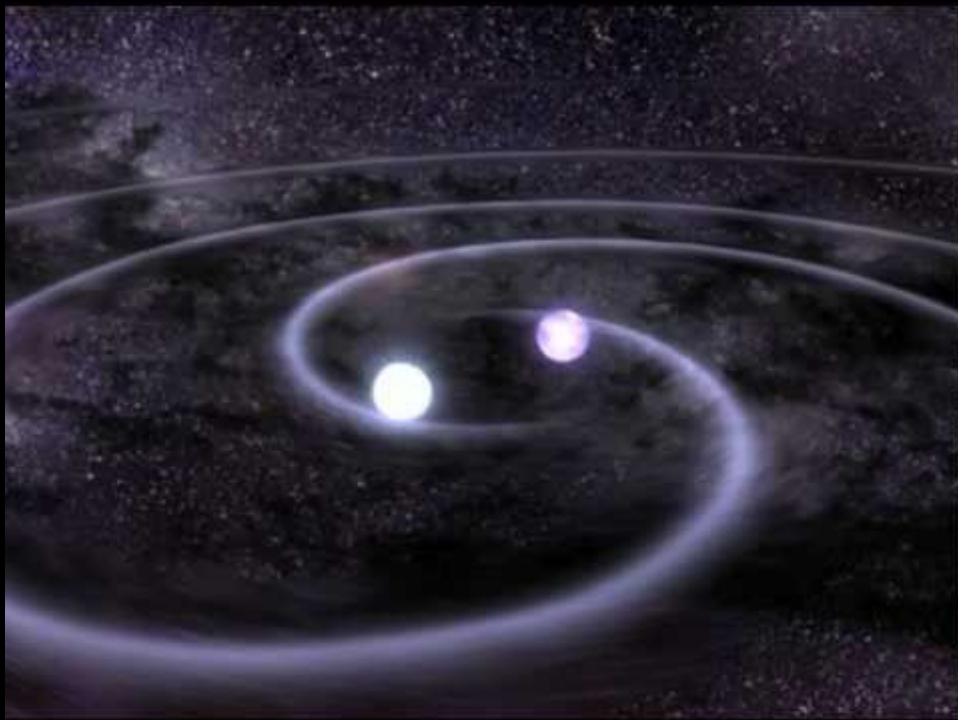


$$h = \frac{\Delta L}{L}$$

重力波振幅

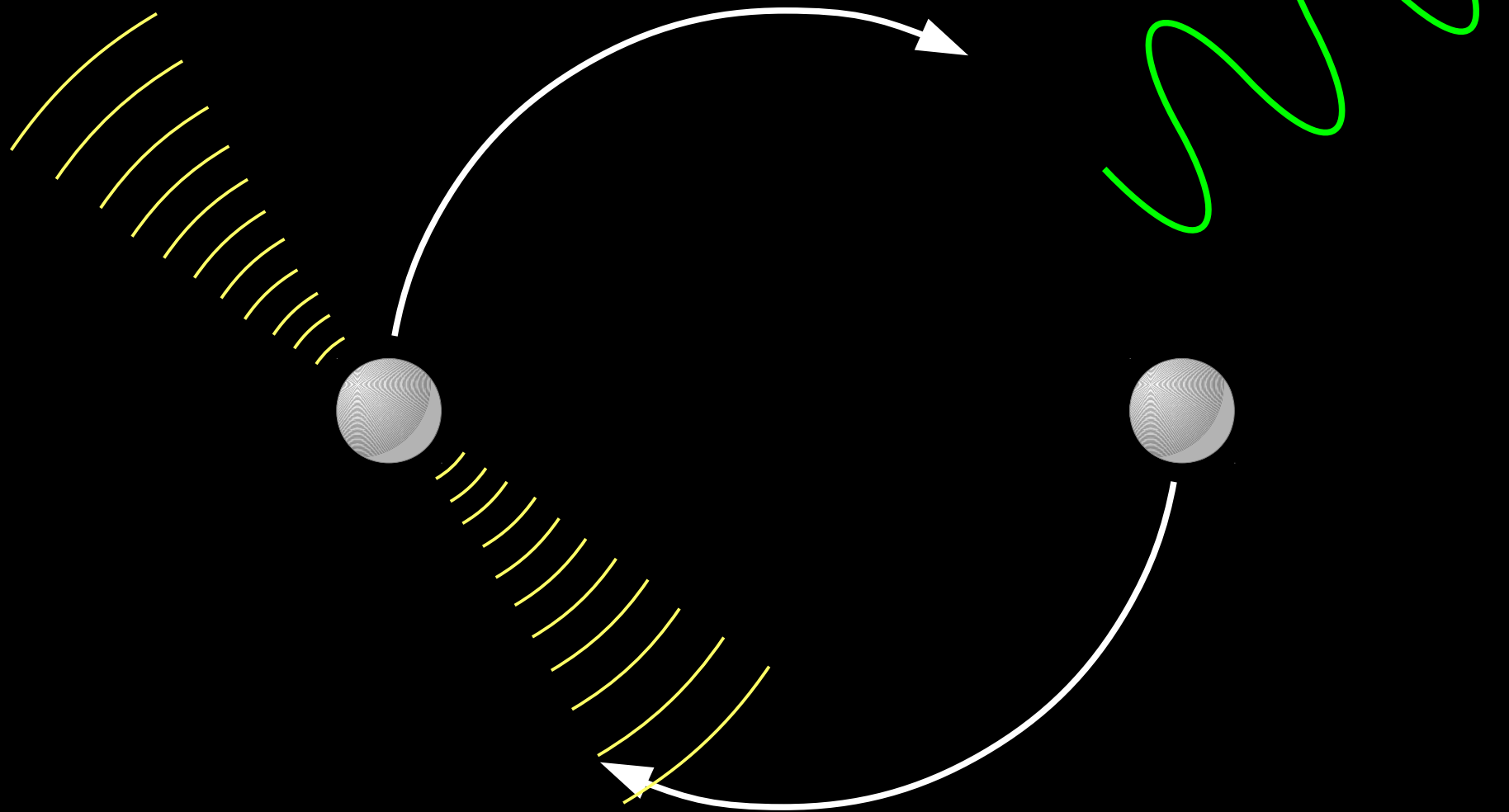
検出すべき h の大きさは？

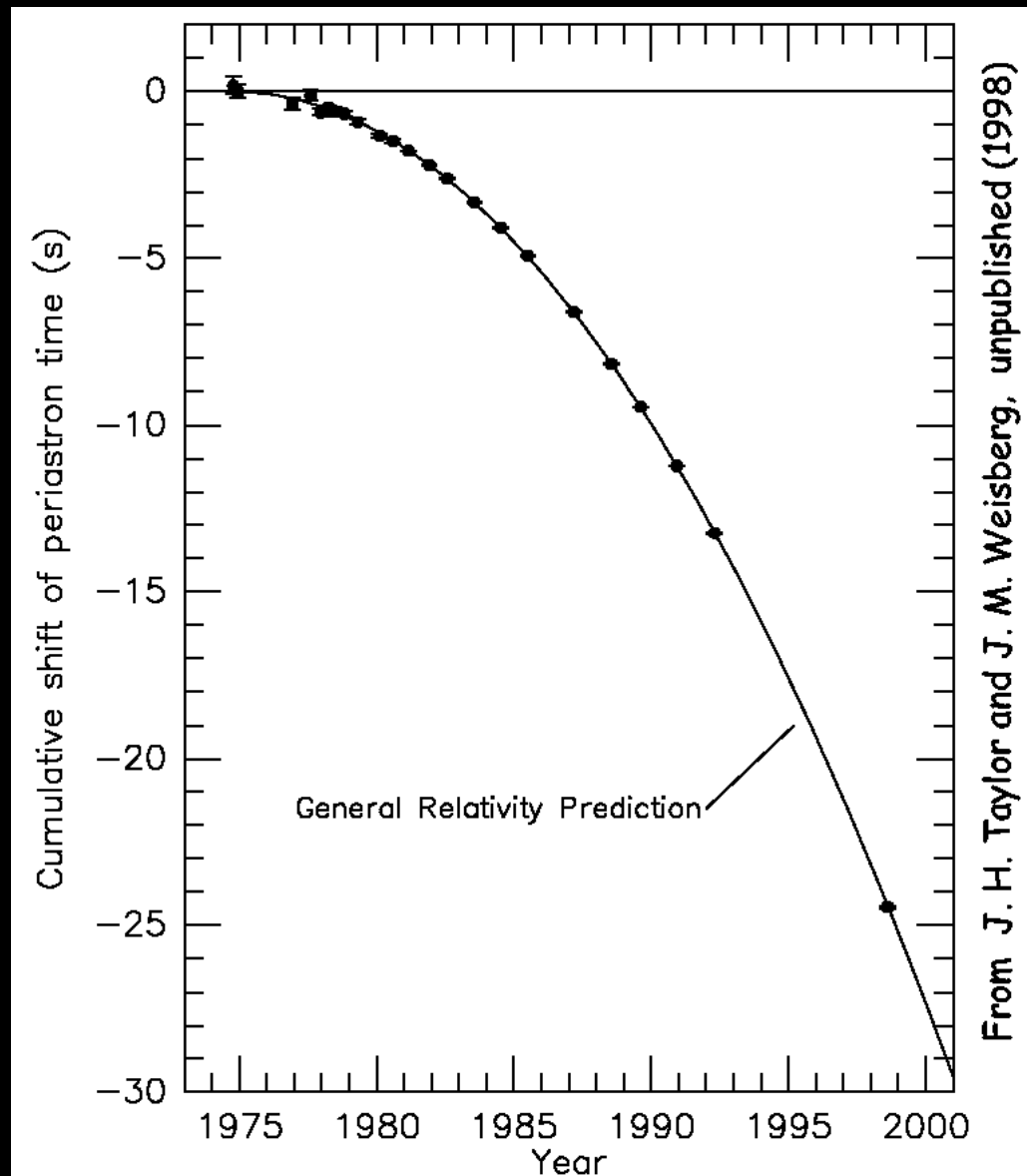
1年に1回以上観測したい



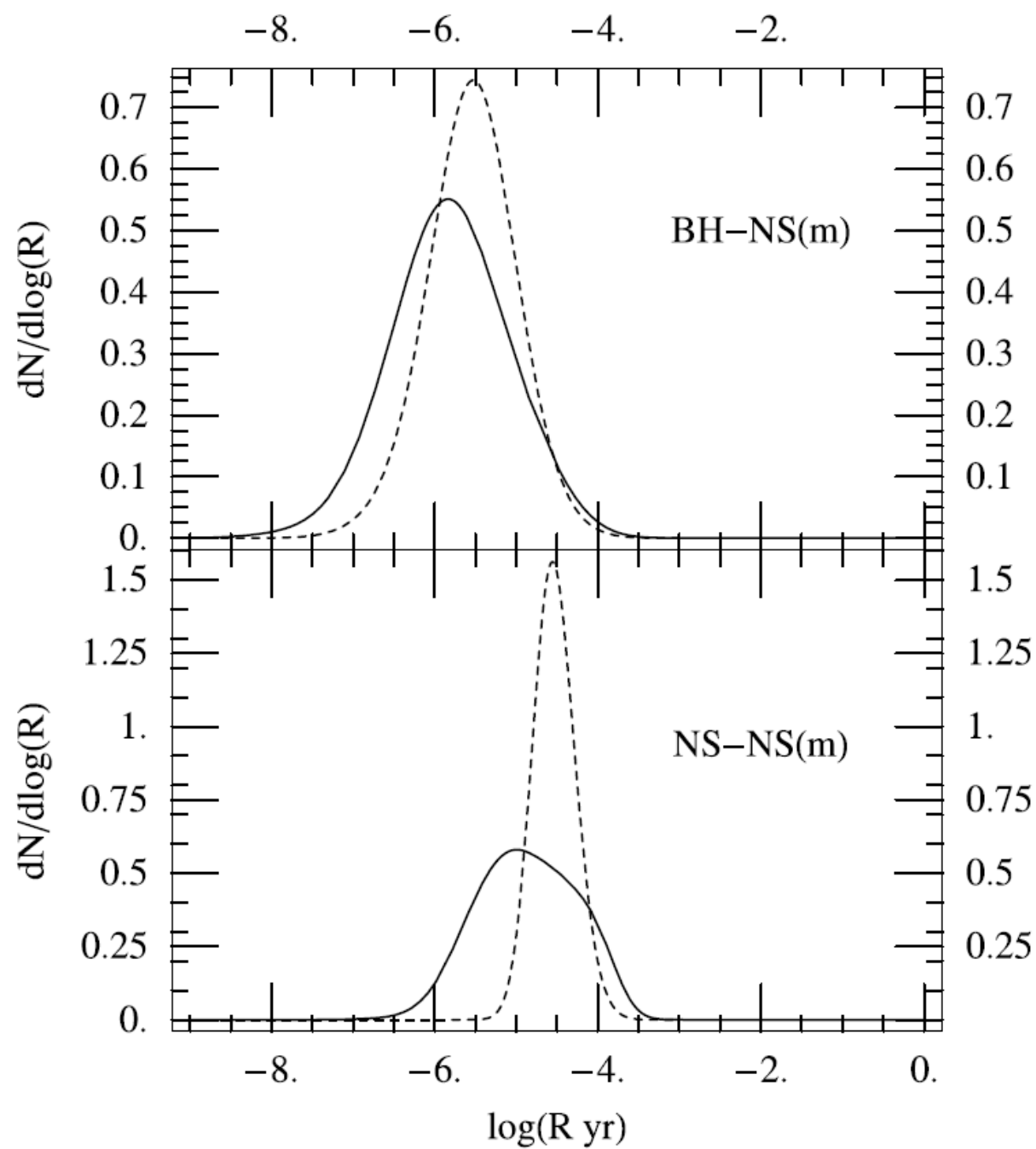


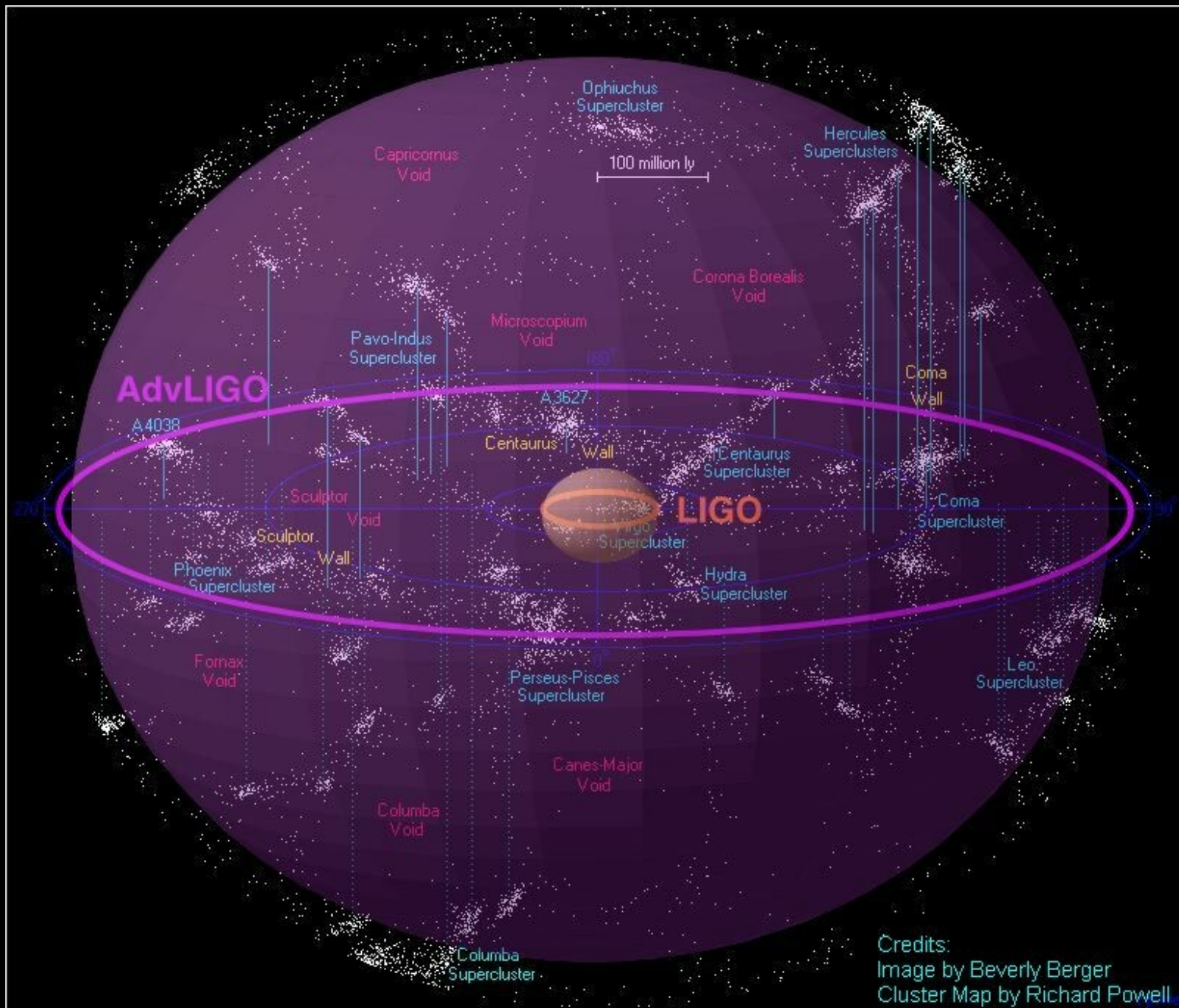
重力波





銀河系内: 1万から10万年に一回

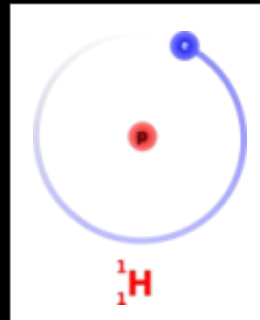
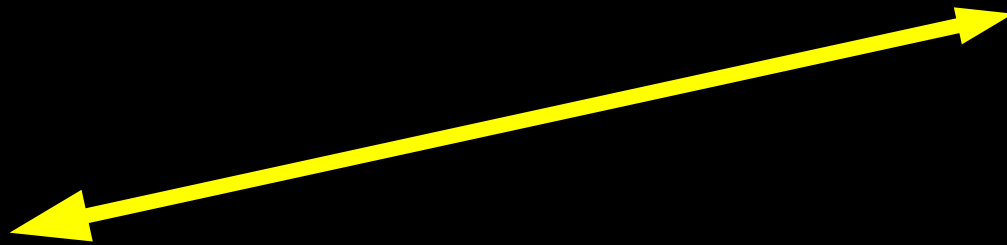




200Mpc = 6億5千万光年

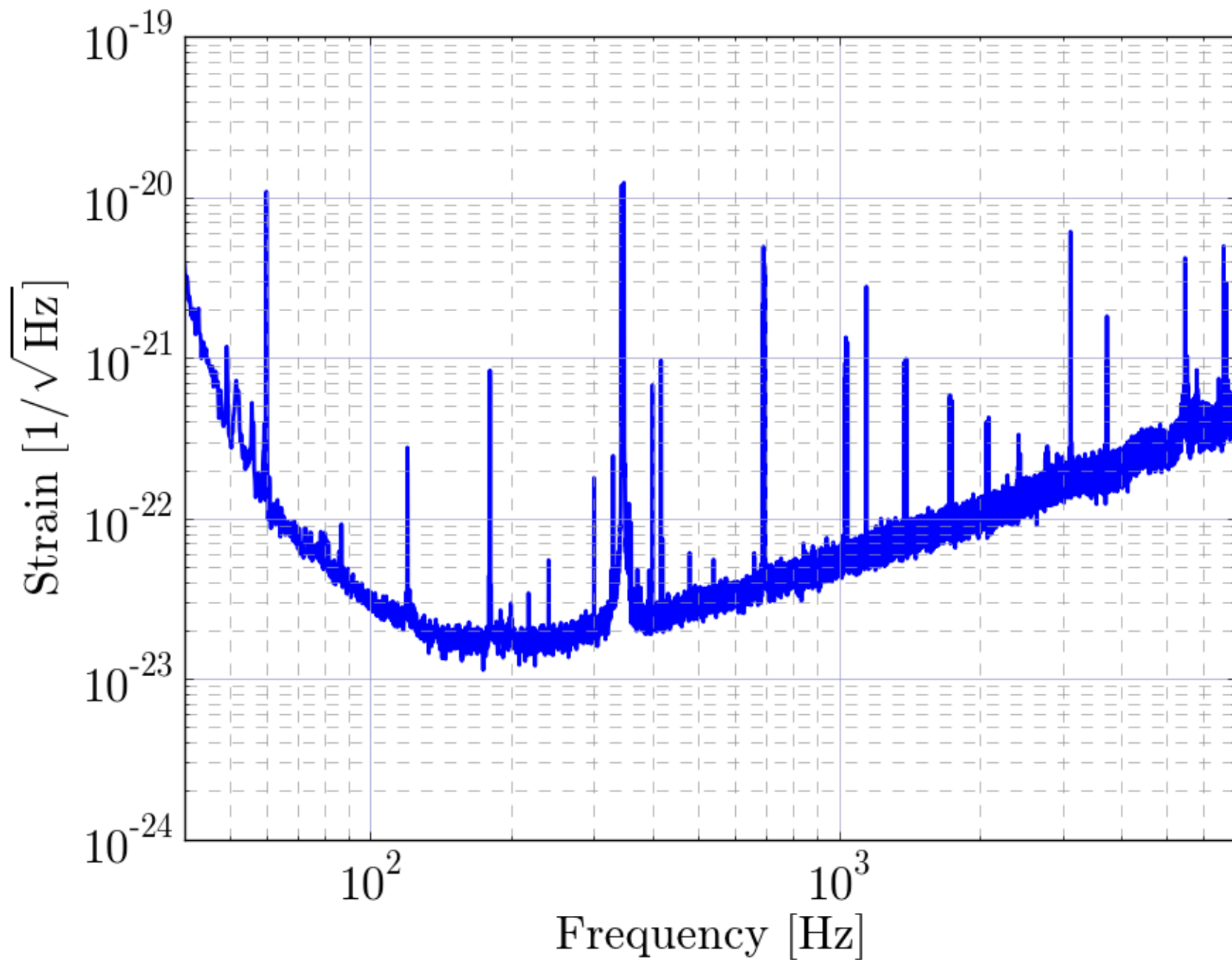
$$h = 10^{-23} \sim 10^{-24}$$

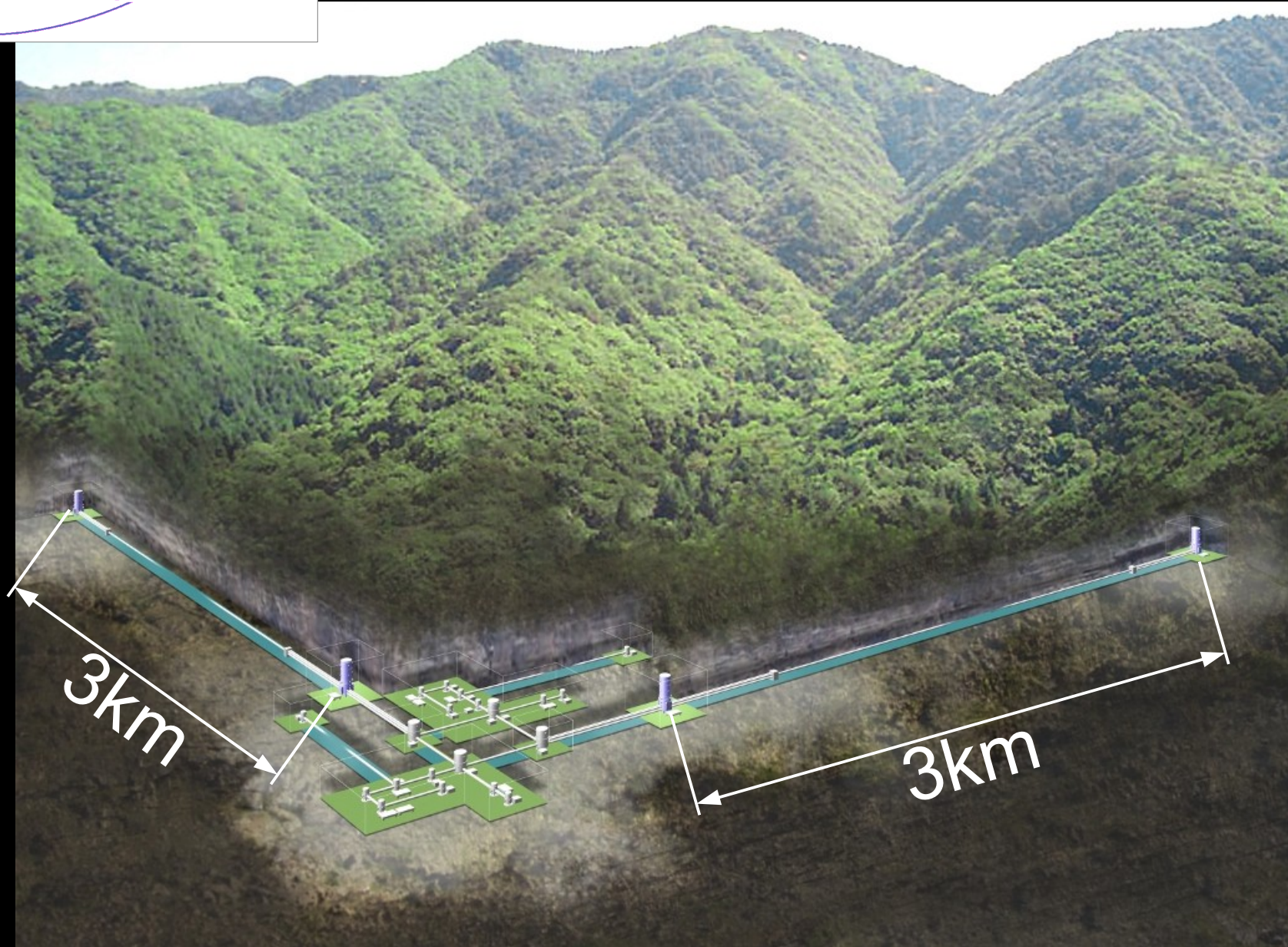
$$h = 10^{-24}$$



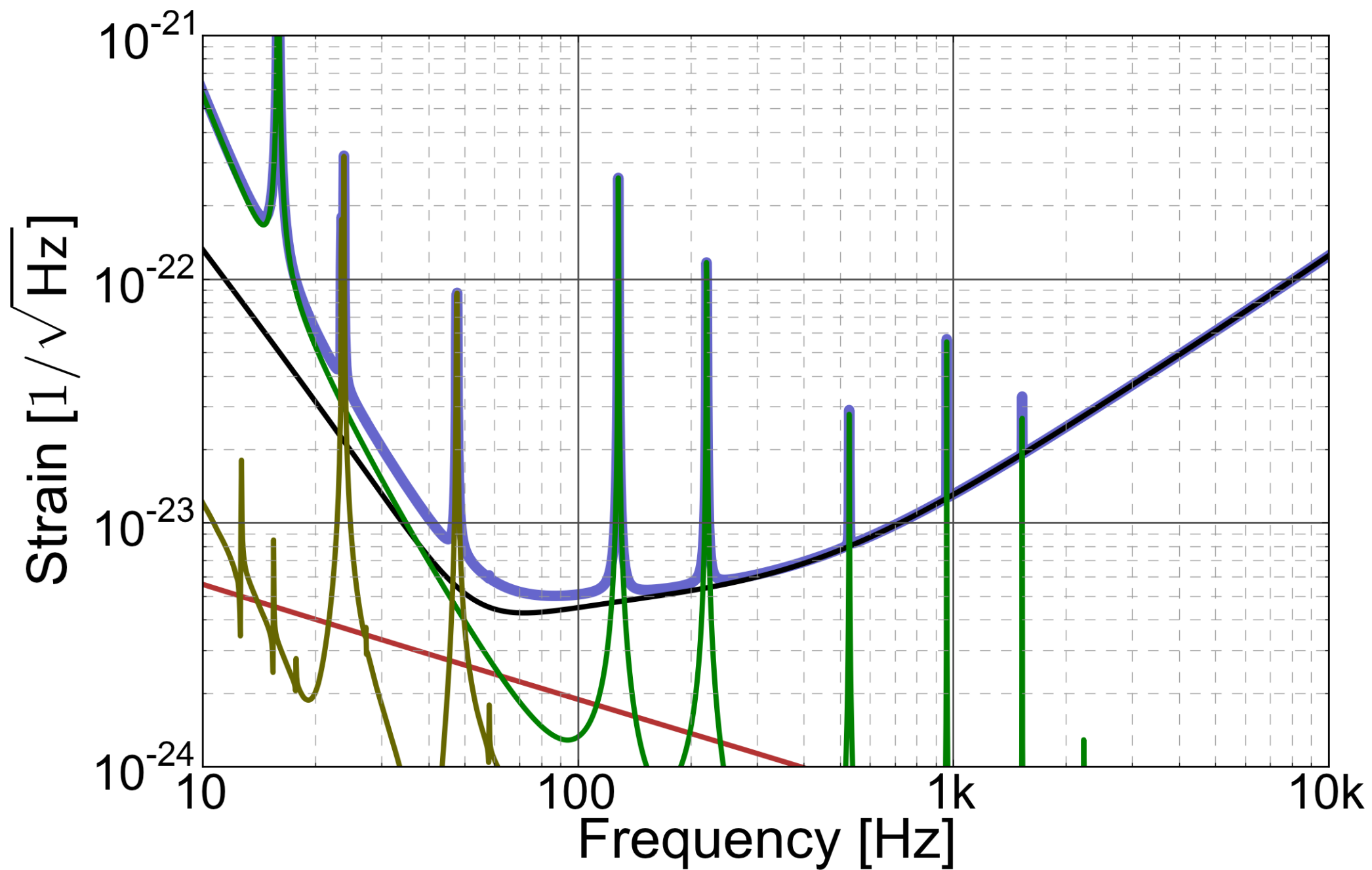
$$\times 1/1000$$

LIGO S6 Sensitivity

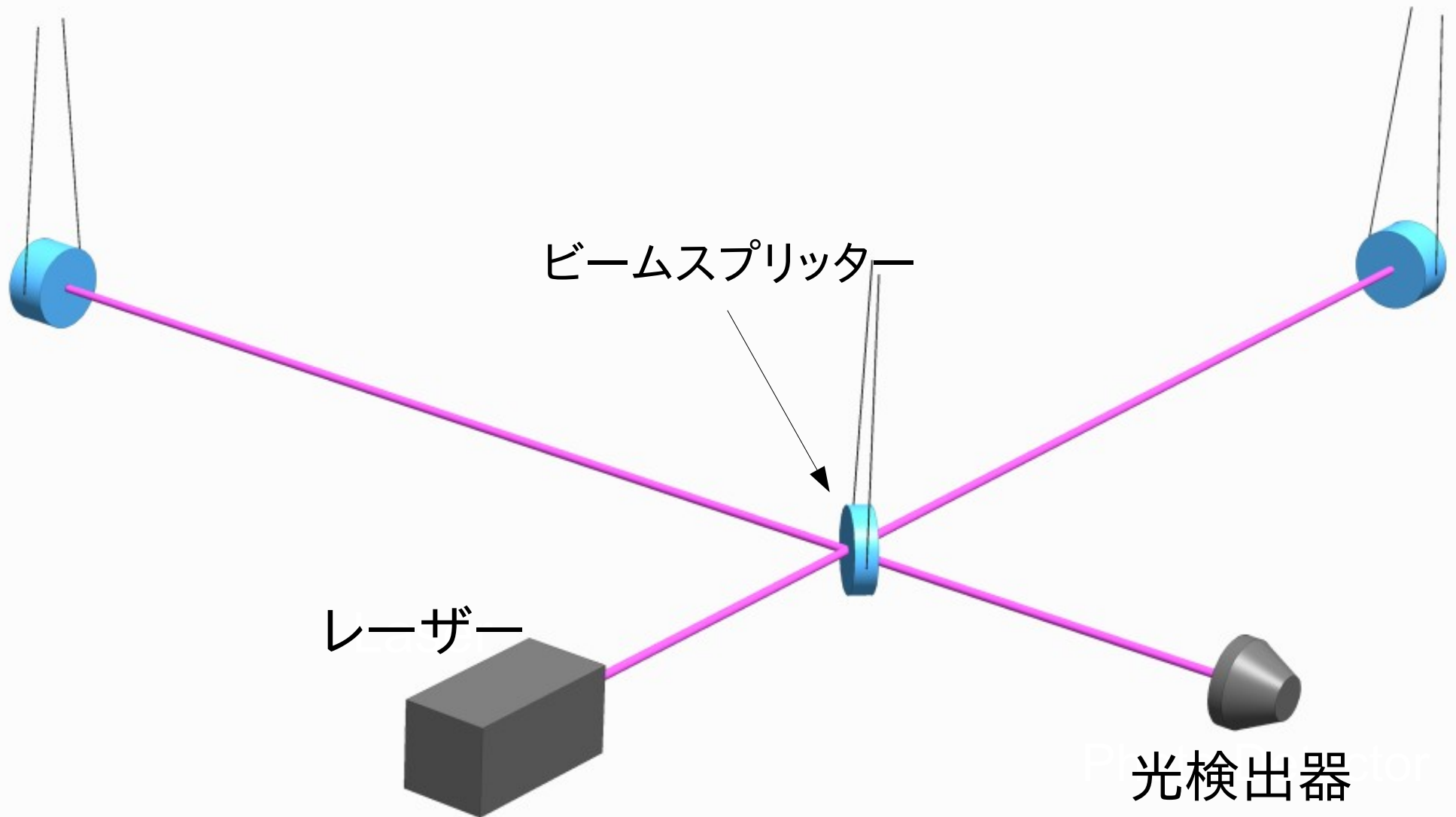


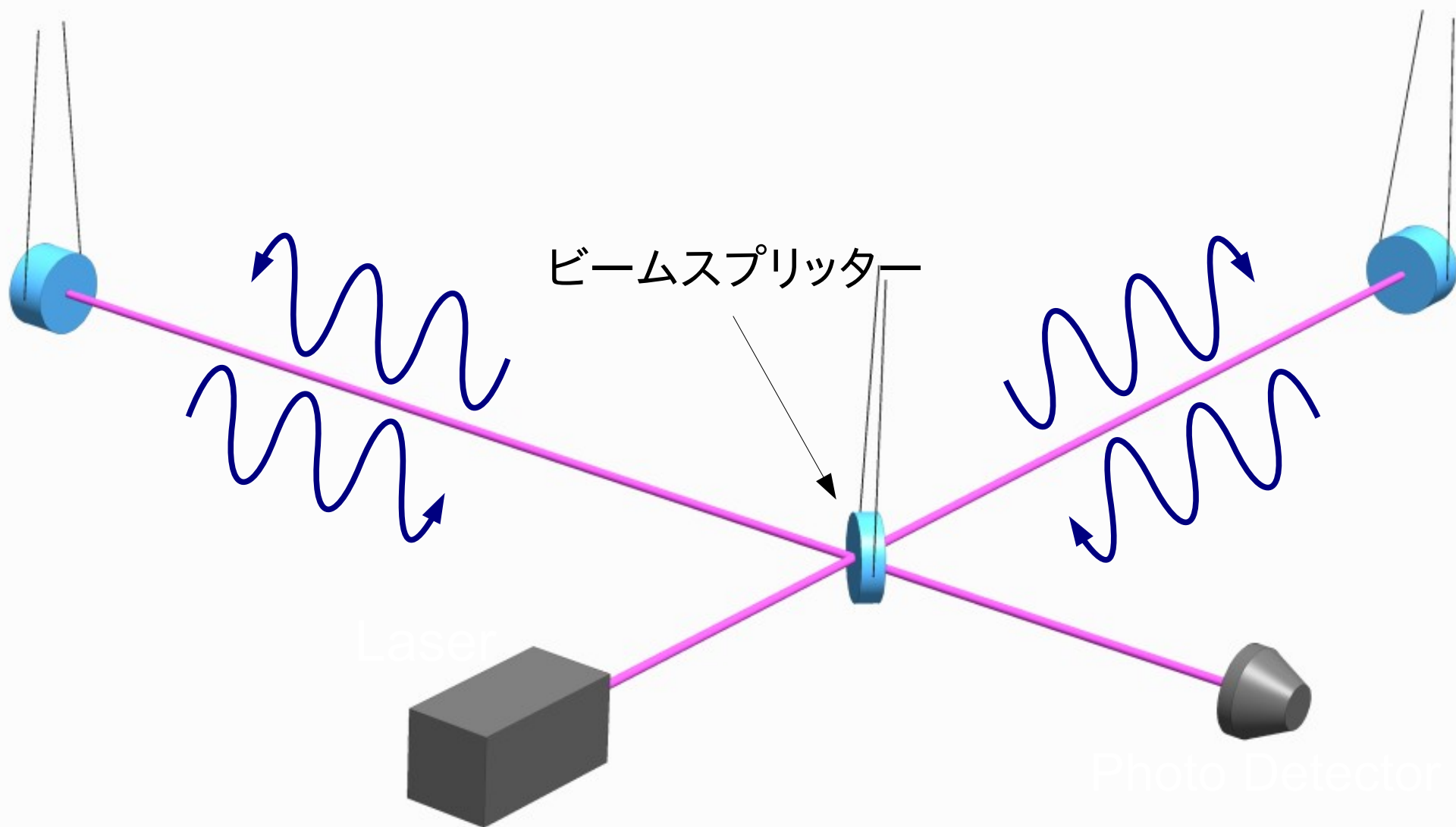


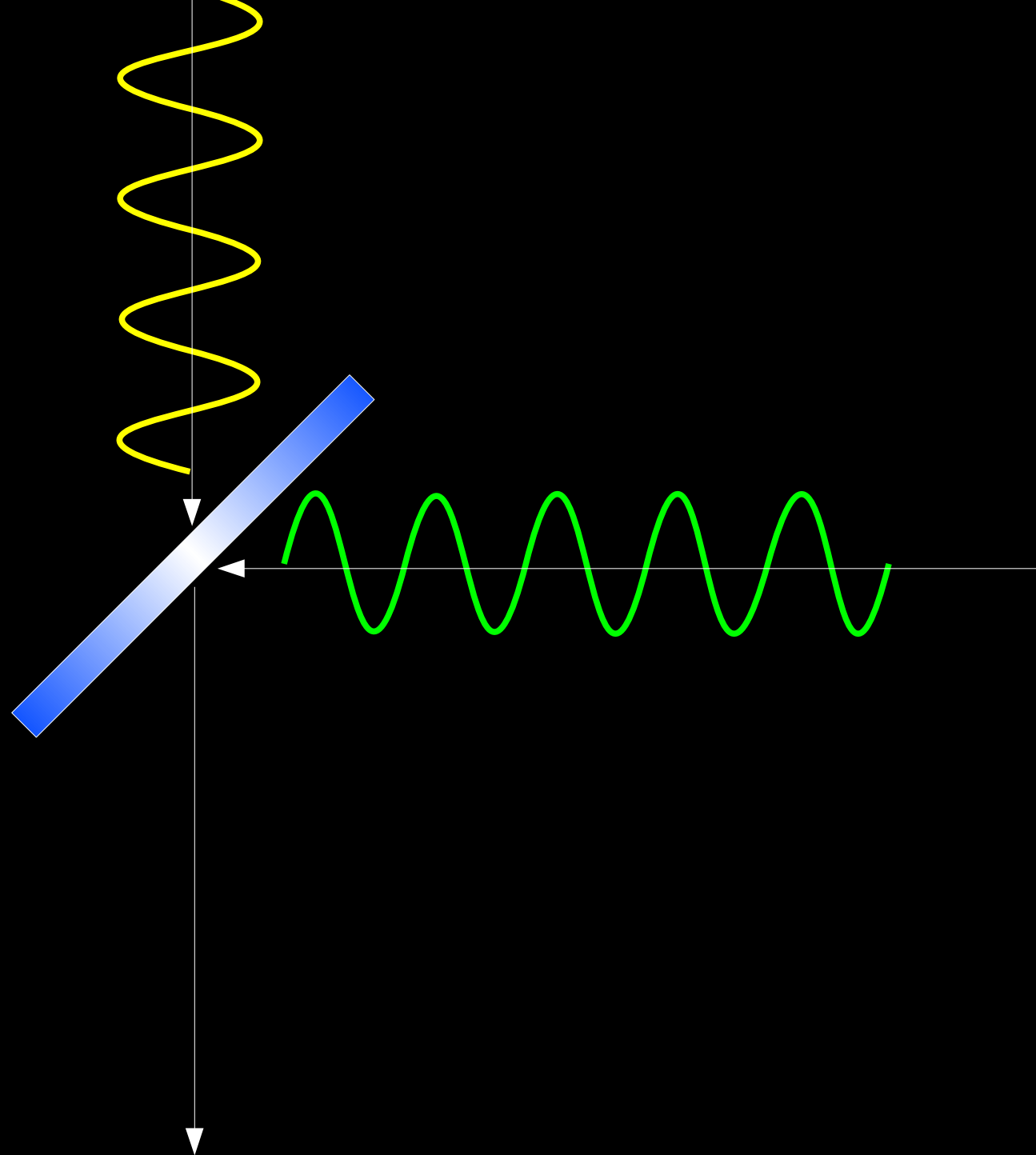
KAGRAの目標感度

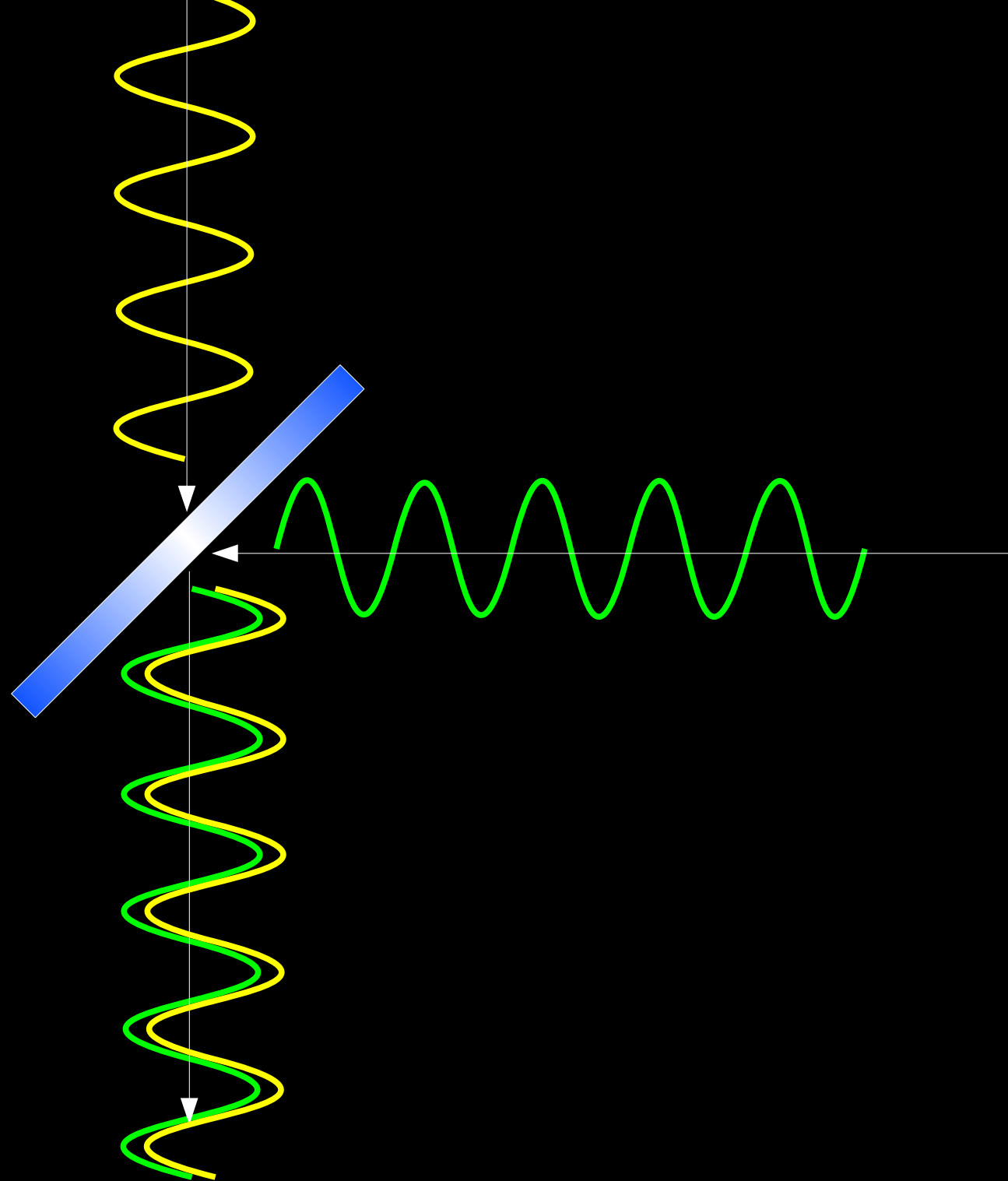


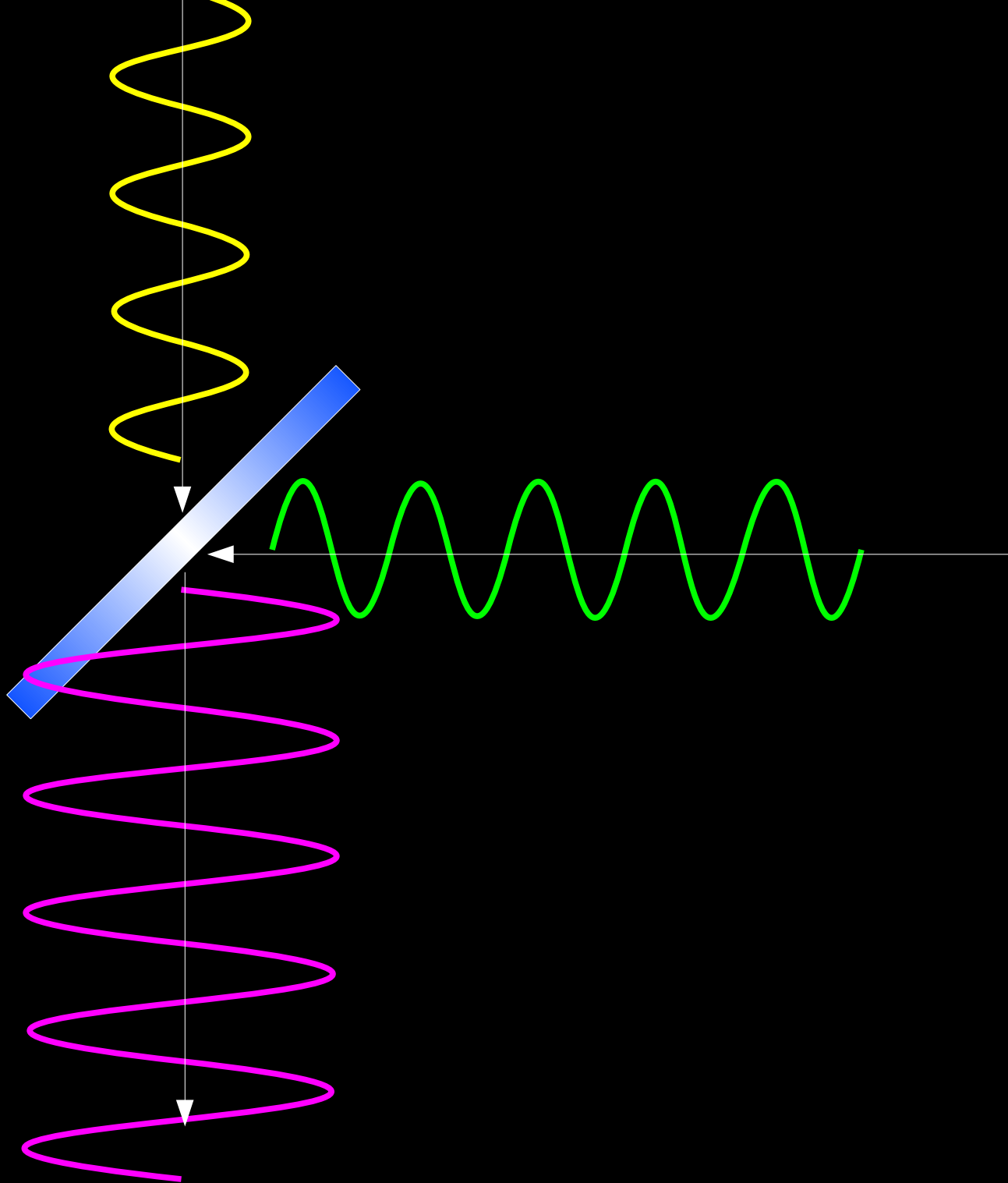
マイケルソン干渉計

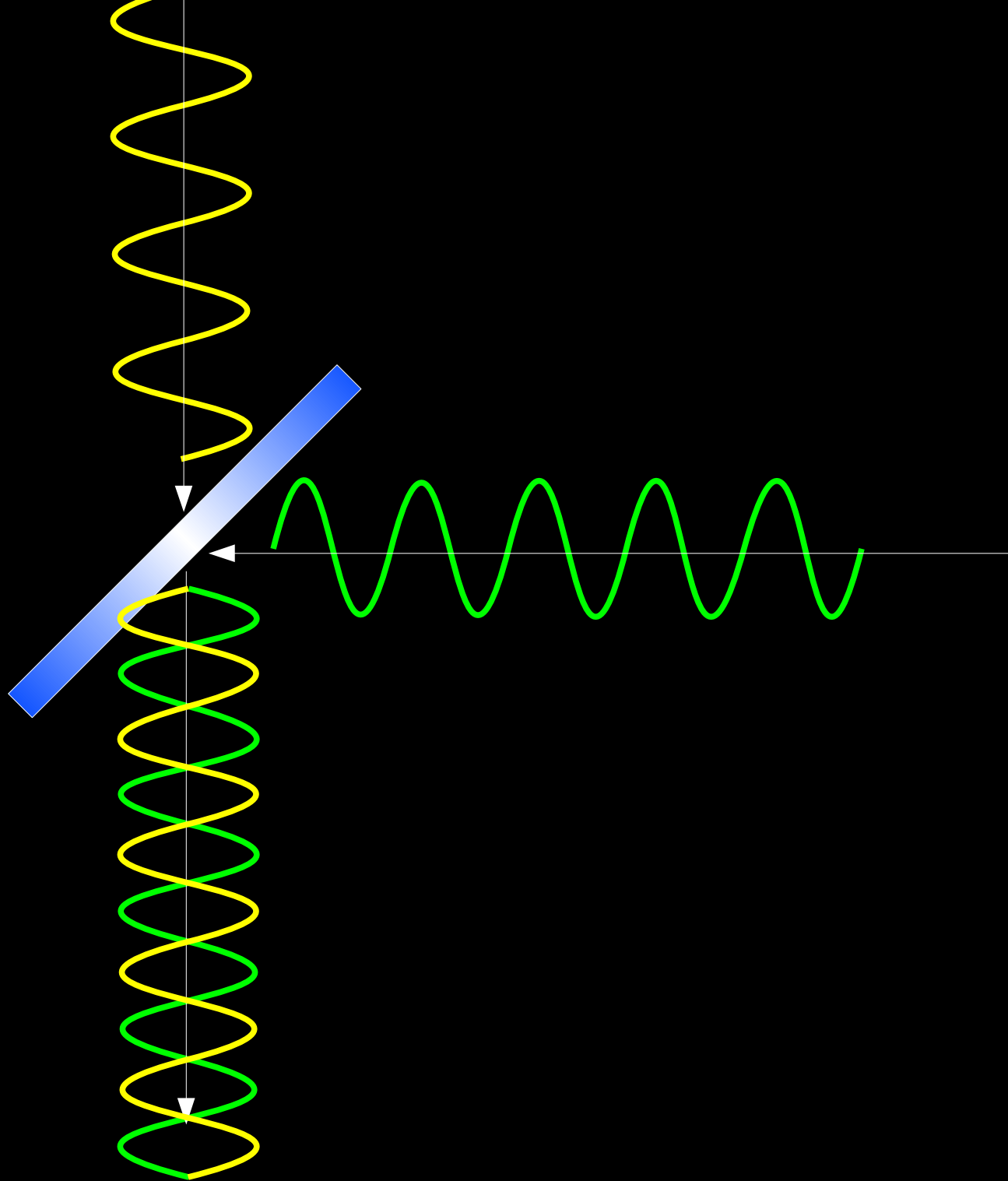


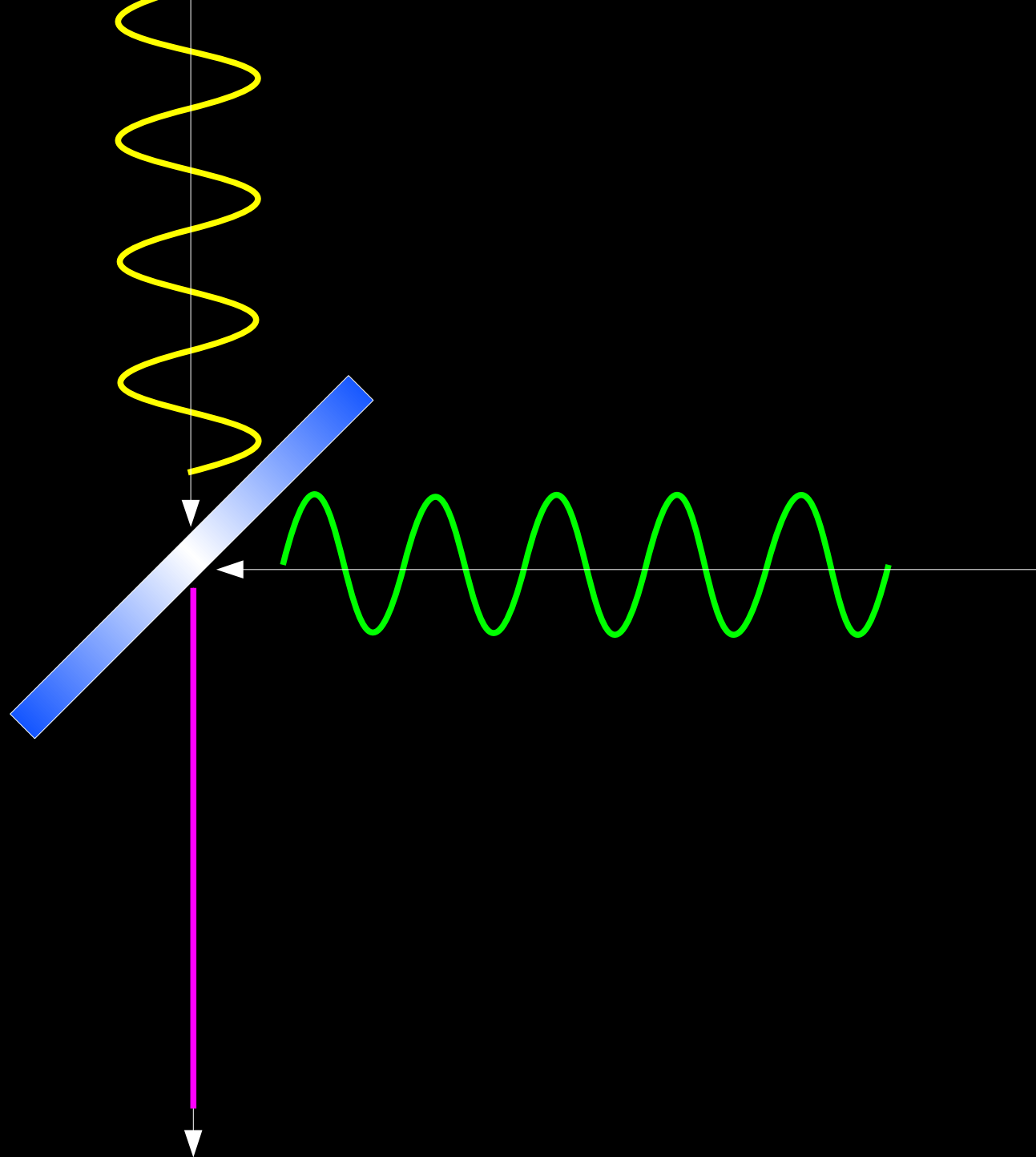


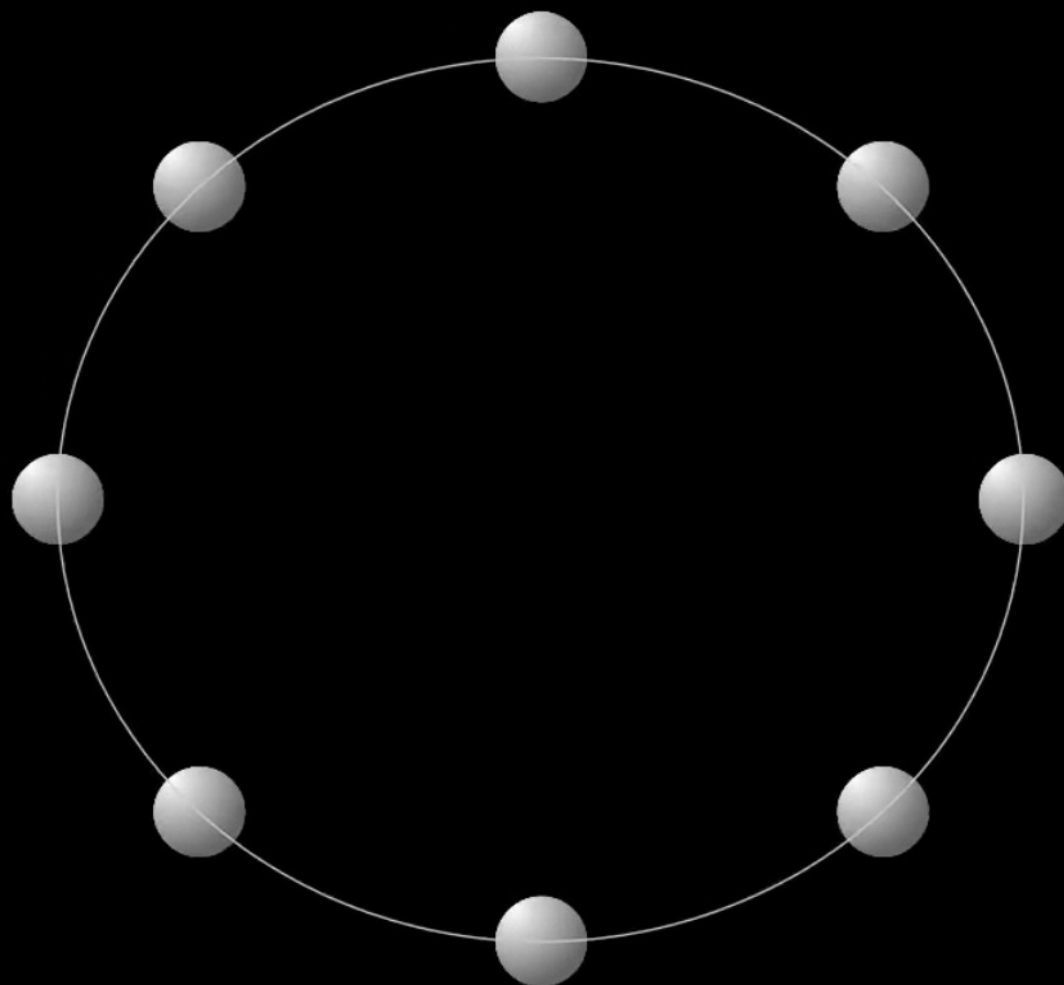


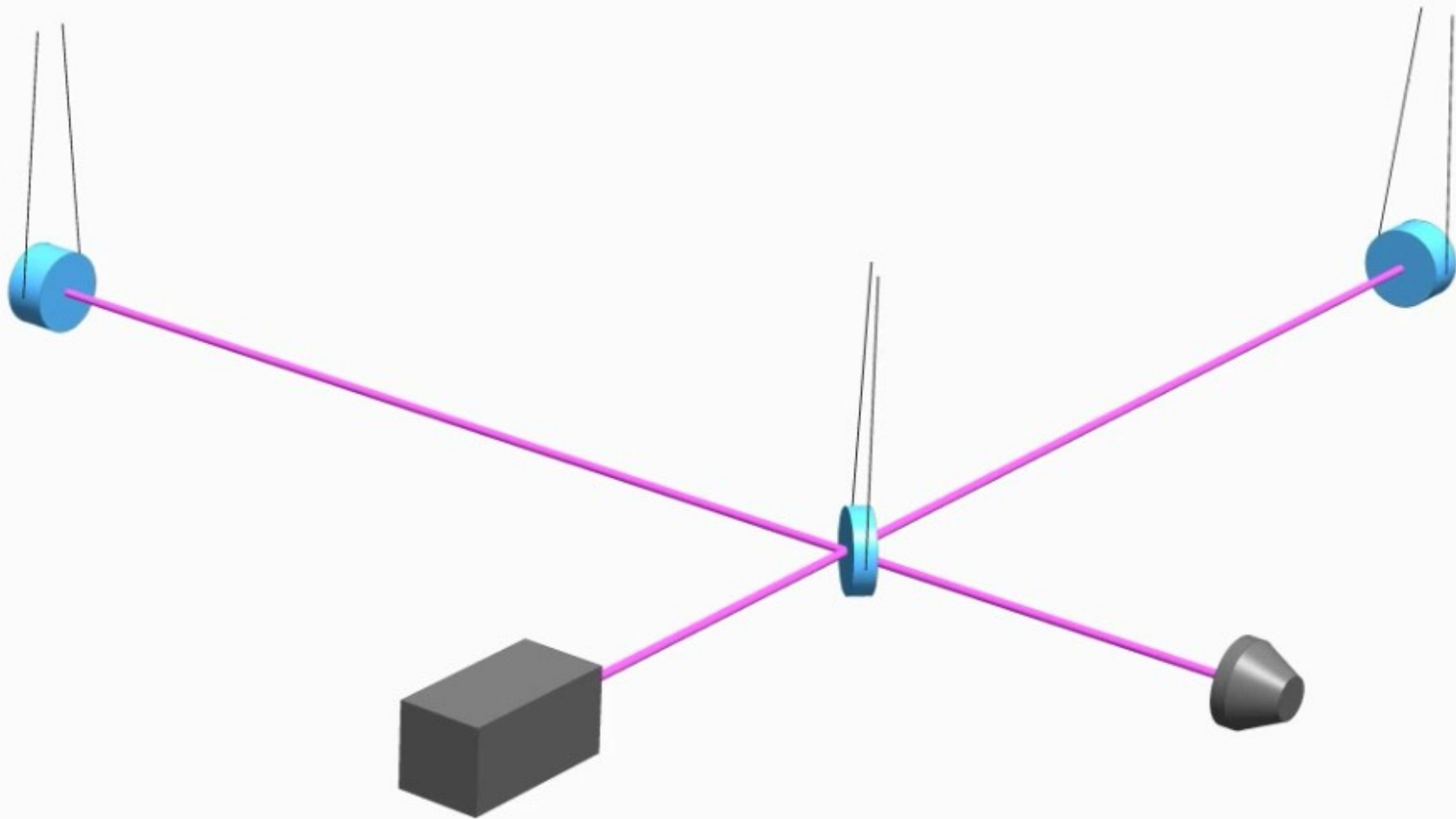


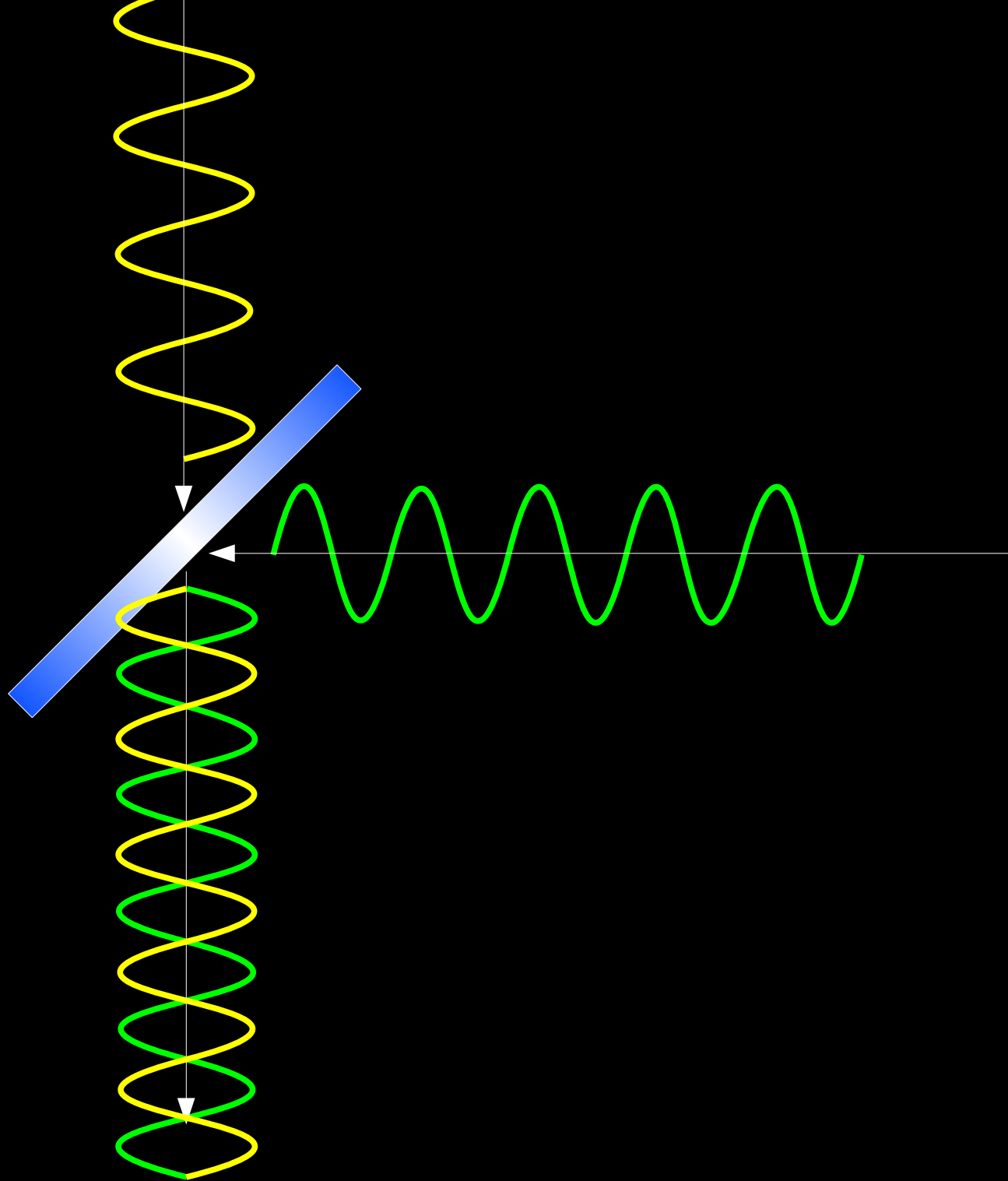


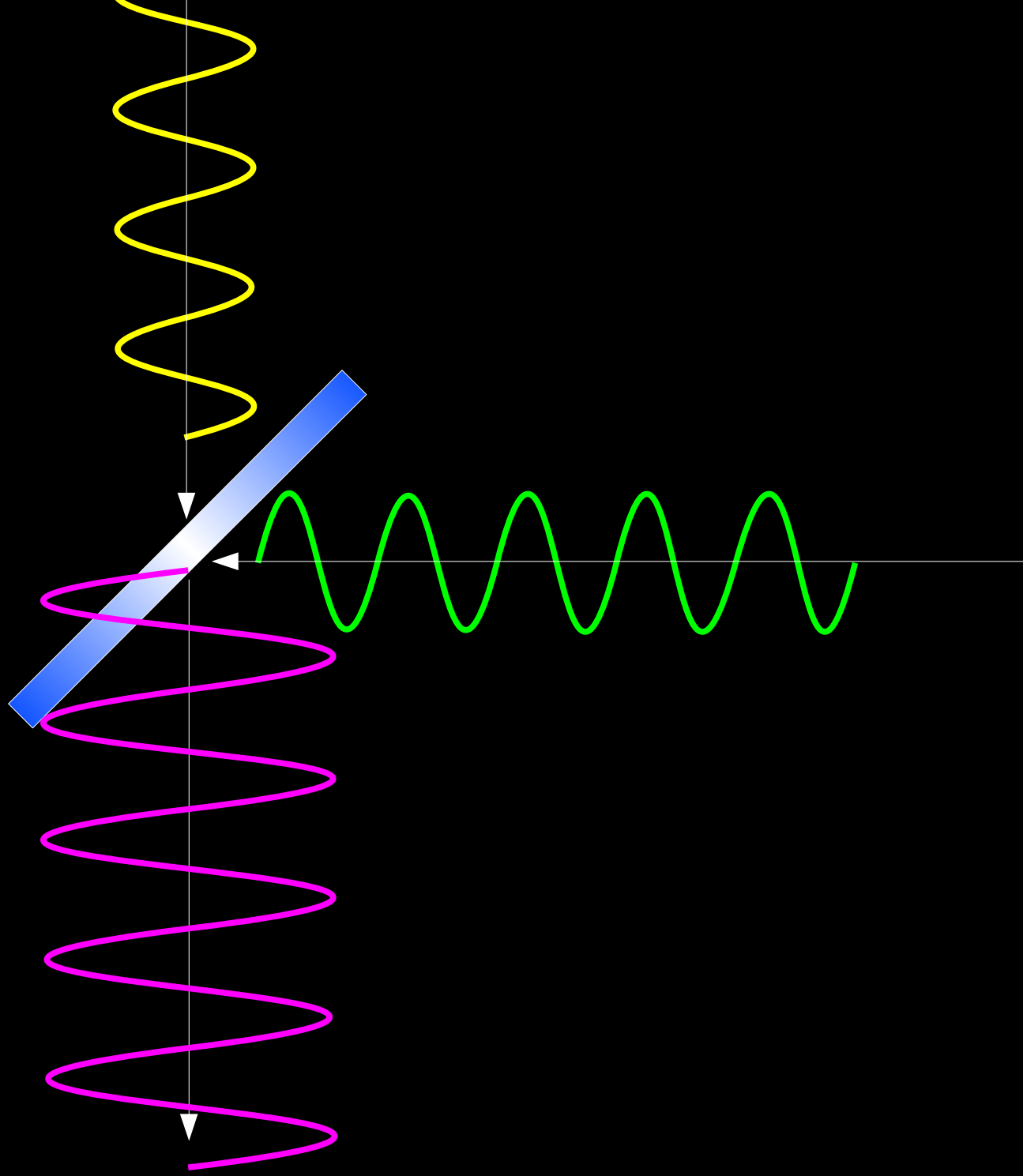




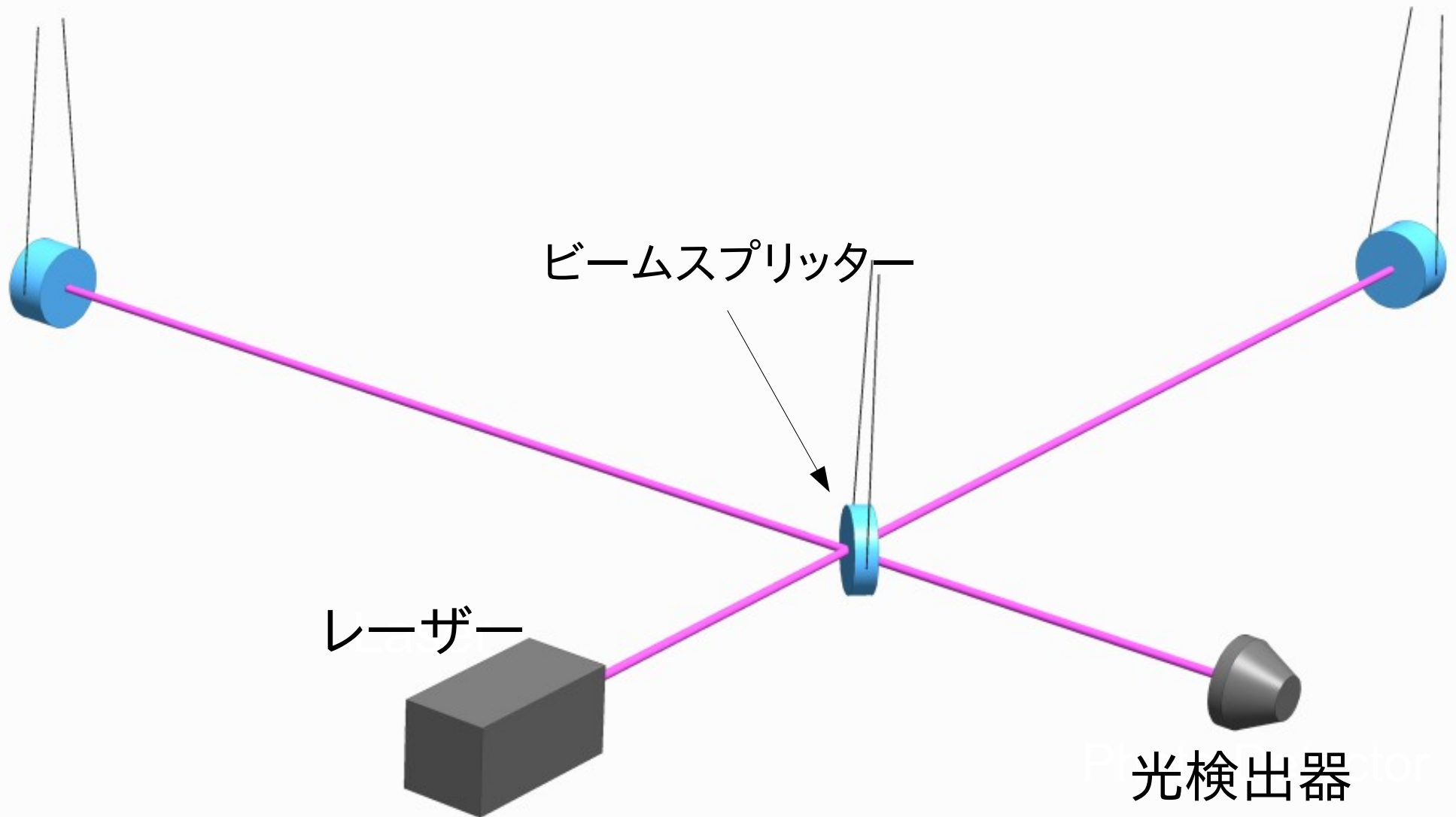








マイケルソン干渉計



どこまで見えるのか？

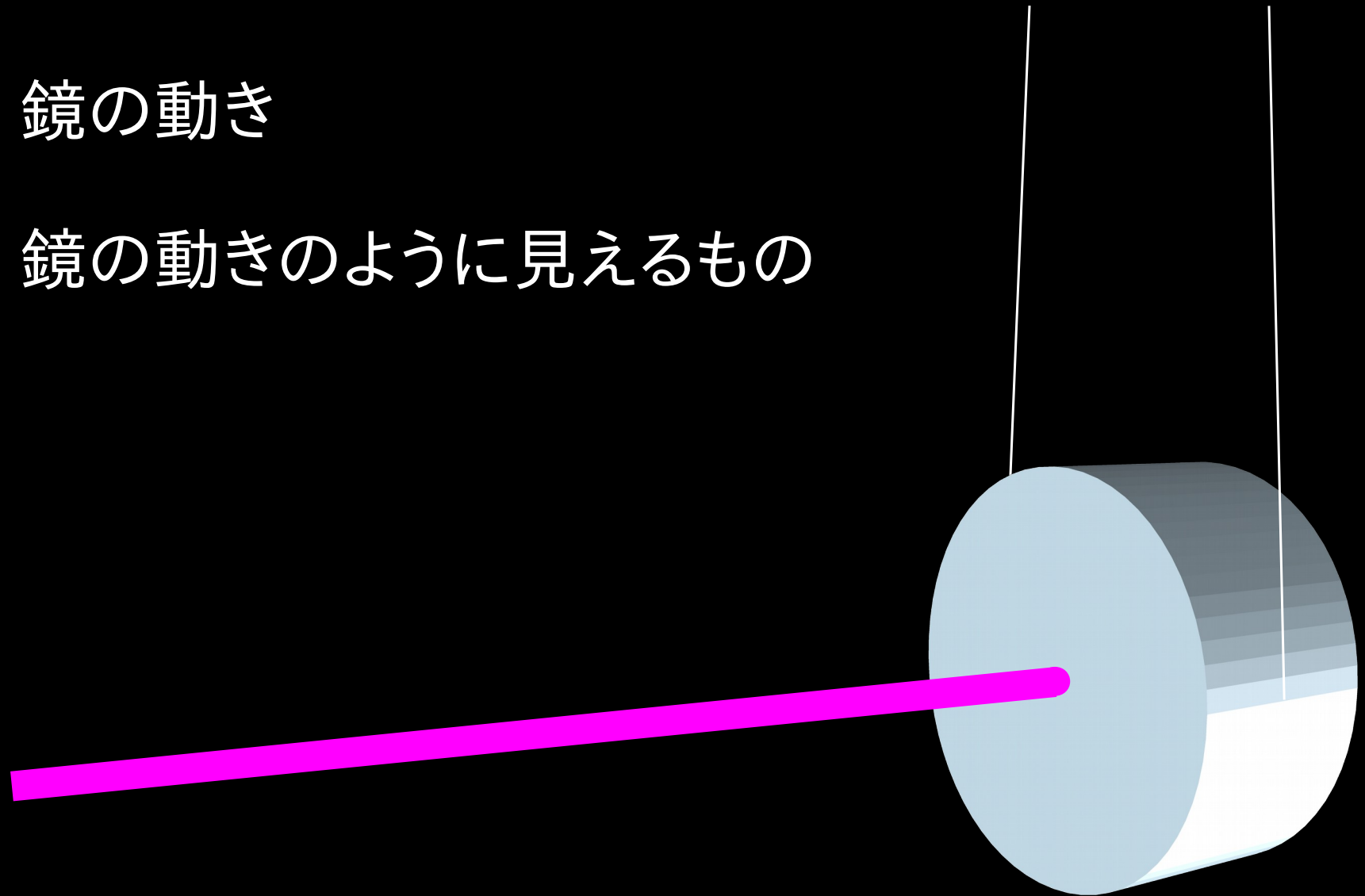


信号 > 雑音

雑音とは？

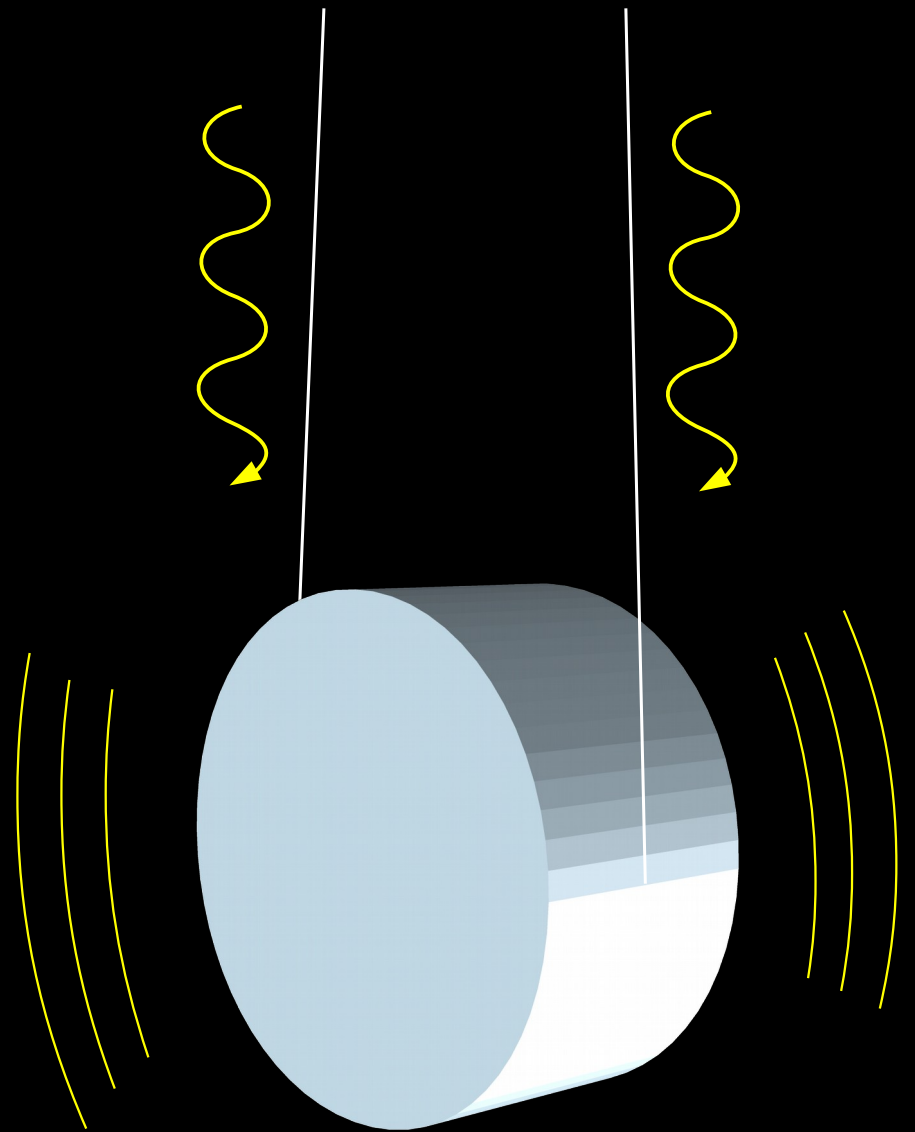
(1) 鏡の動き

(2) 鏡の動きのように見えるもの





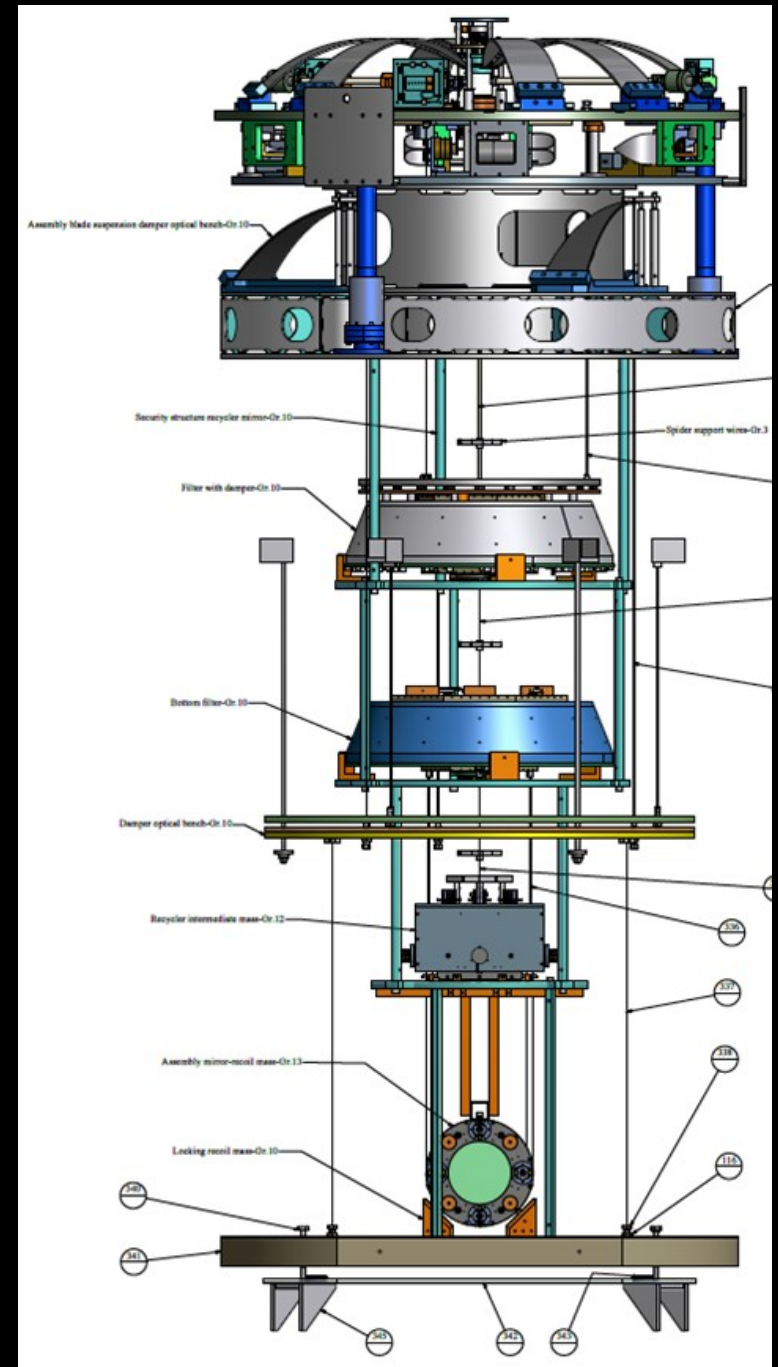
地面振動

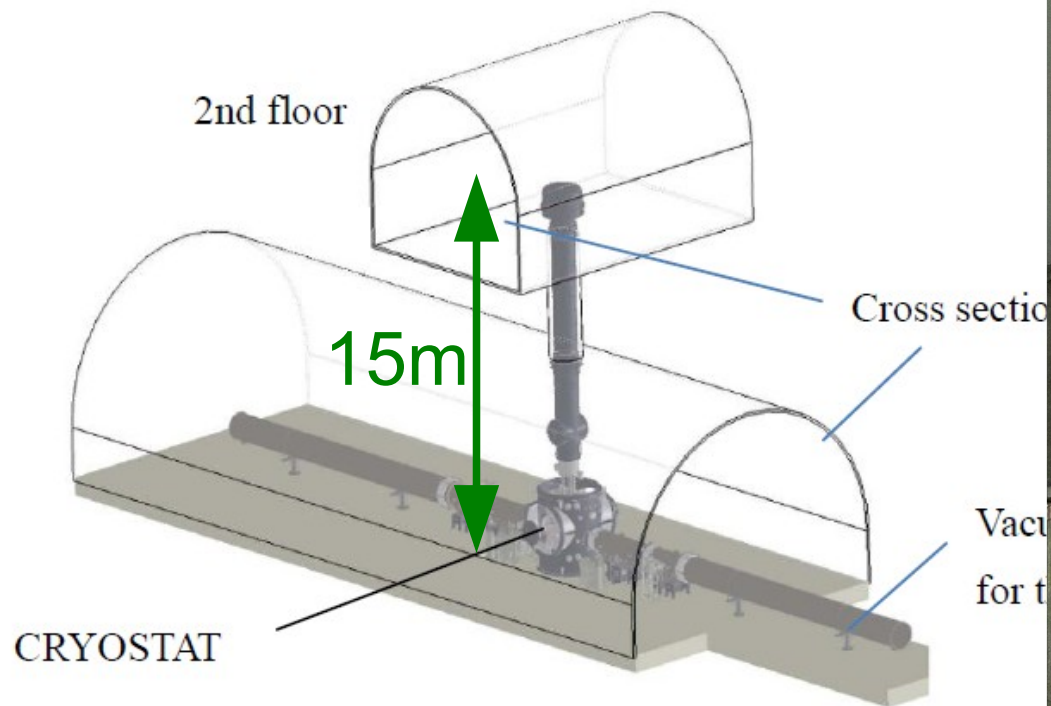
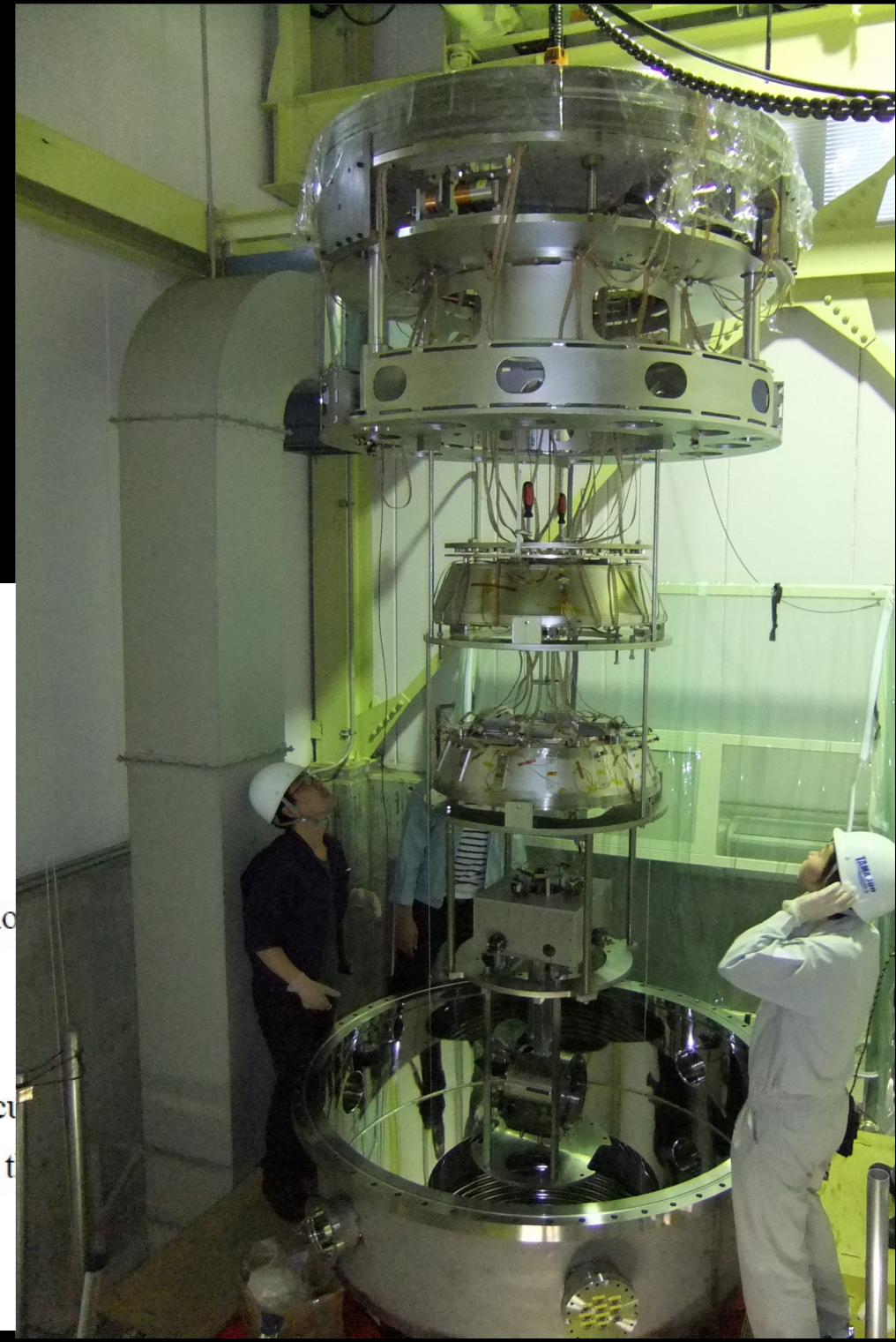
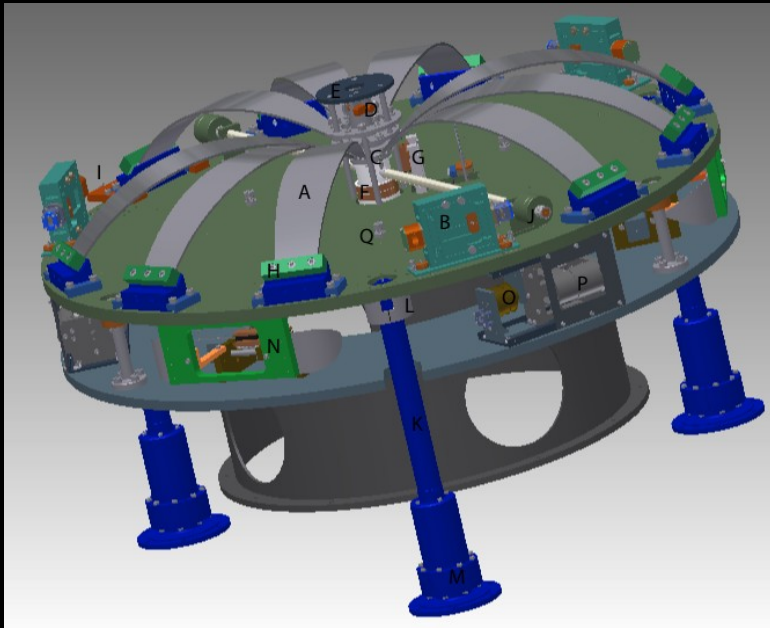


多段防振システム

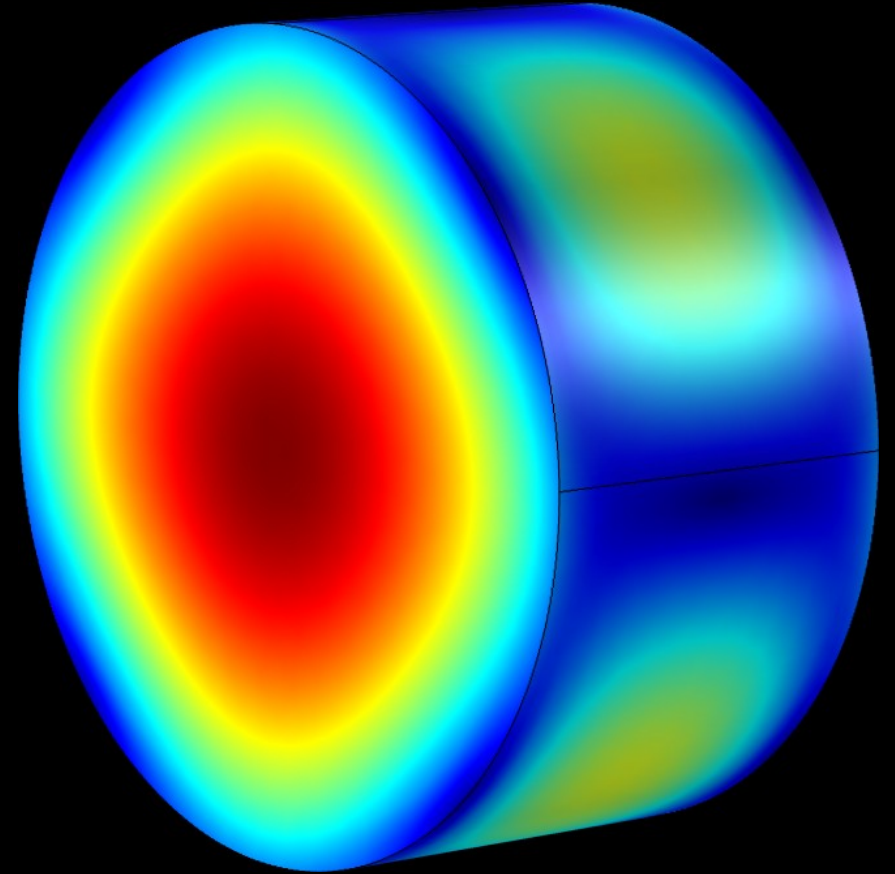
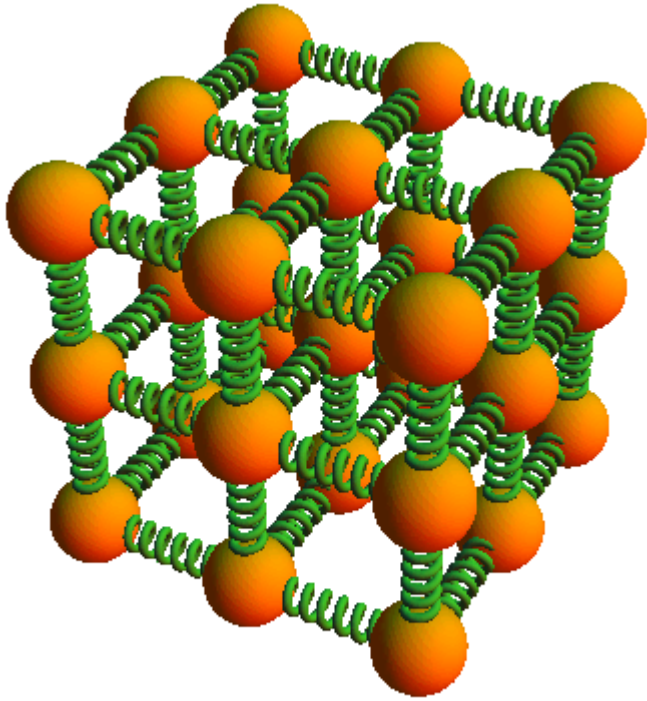
1

100000000000

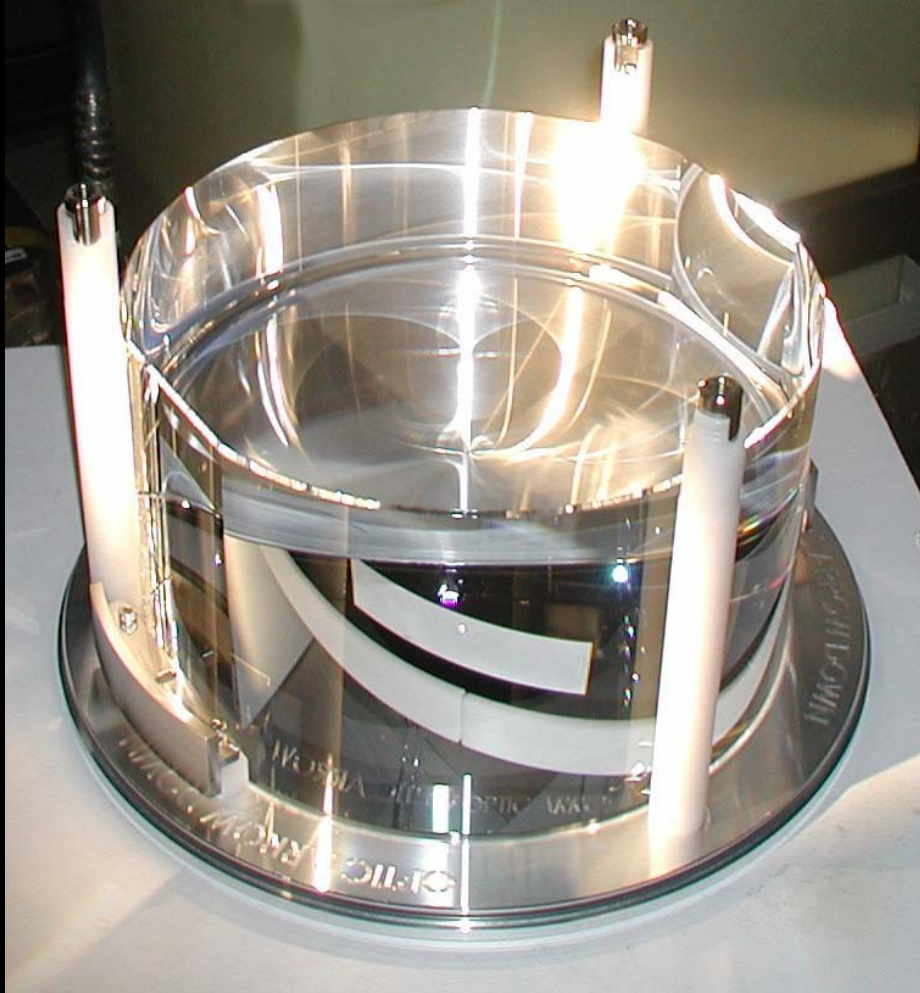




熱雑音

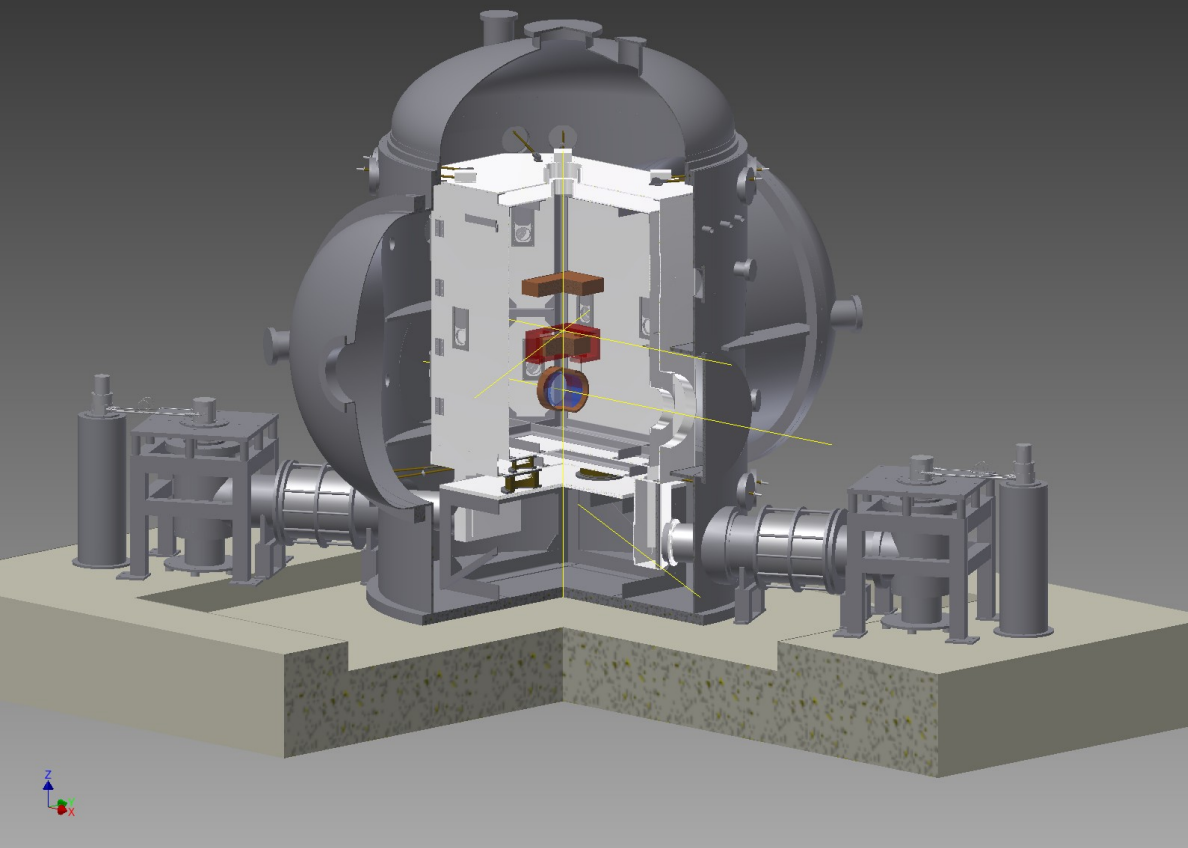


Fused Silica



Sapphire

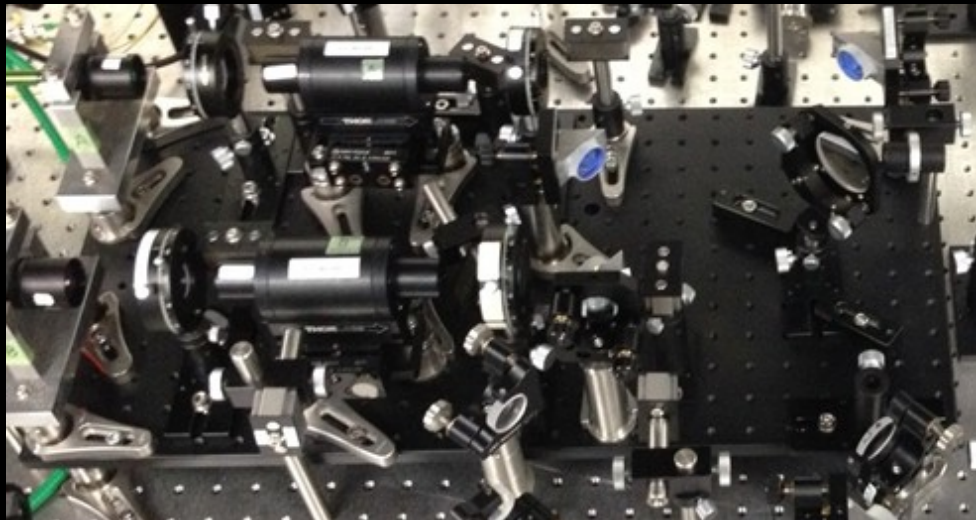




低温サファイア鏡

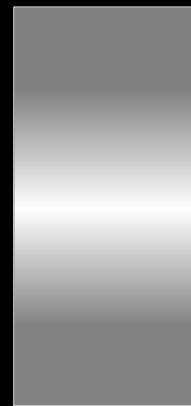
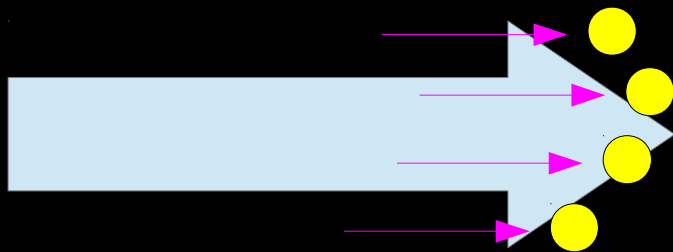
20Kまで冷却



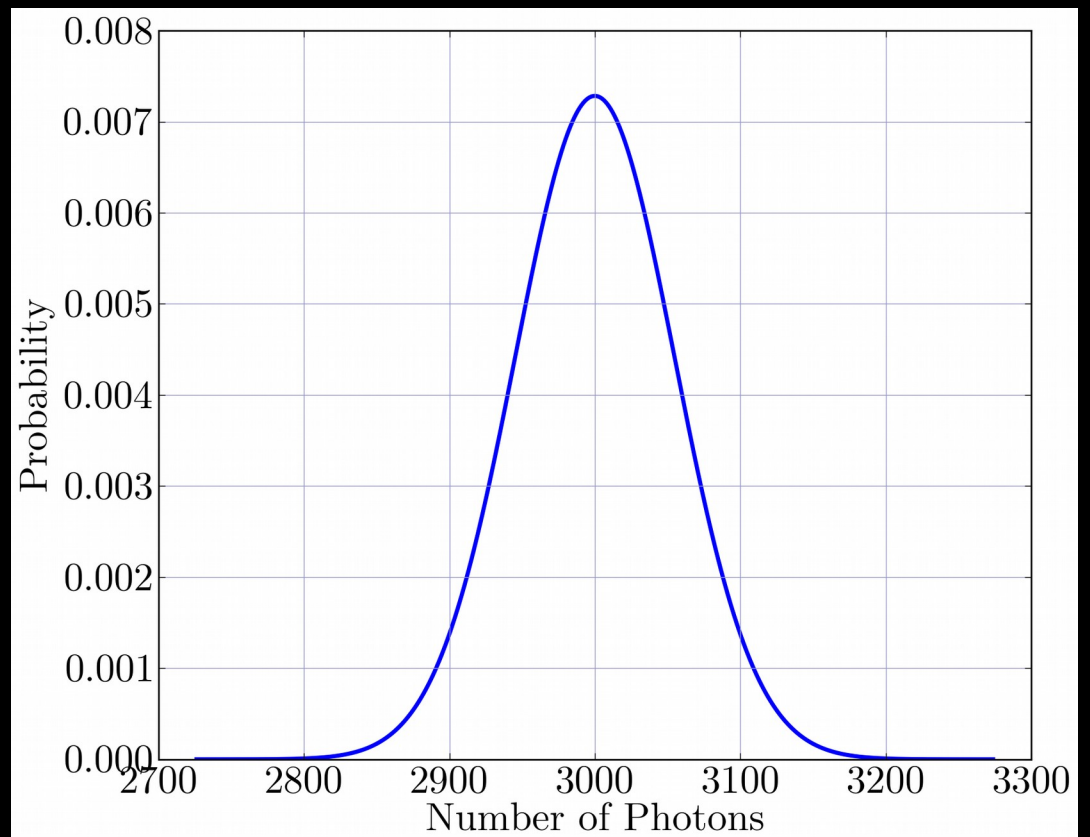


量子力学的不确定性原理

ショットノイズ



光検出器



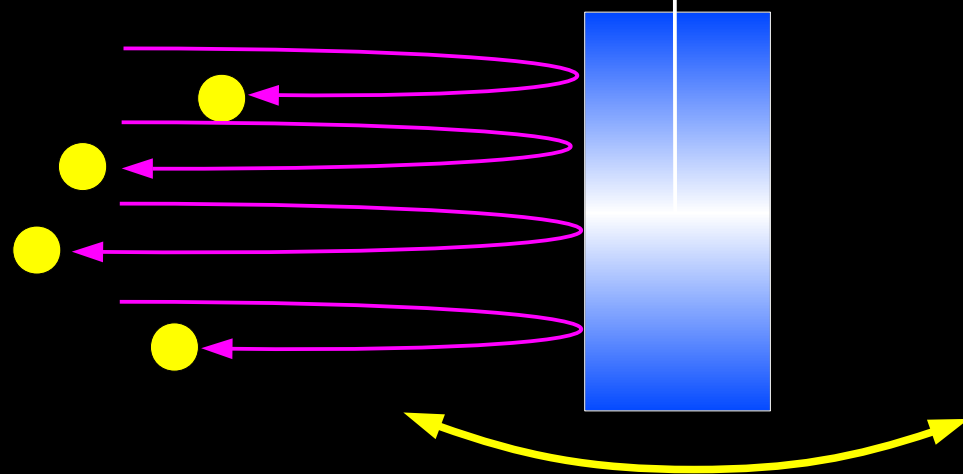
$$\text{信号} \propto P$$

$$\text{雑音} \propto \sqrt{P}$$



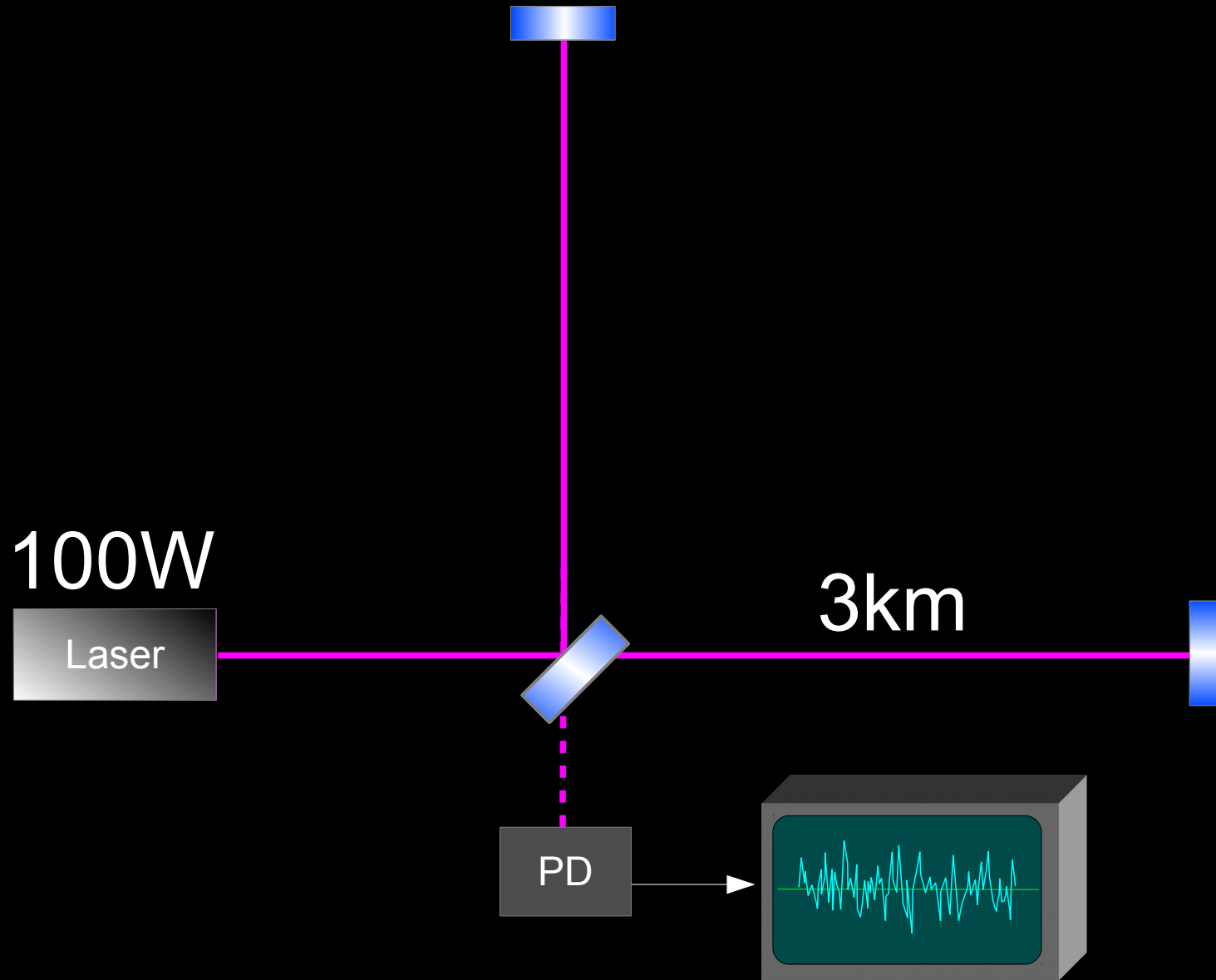
$$\frac{\text{信号}}{\text{雑音}} \propto \sqrt{P}$$

量子輻射压雑音



$$\frac{\text{信号}}{\text{雑音}} \propto 1/\sqrt{P}$$

マイケルソン干渉計



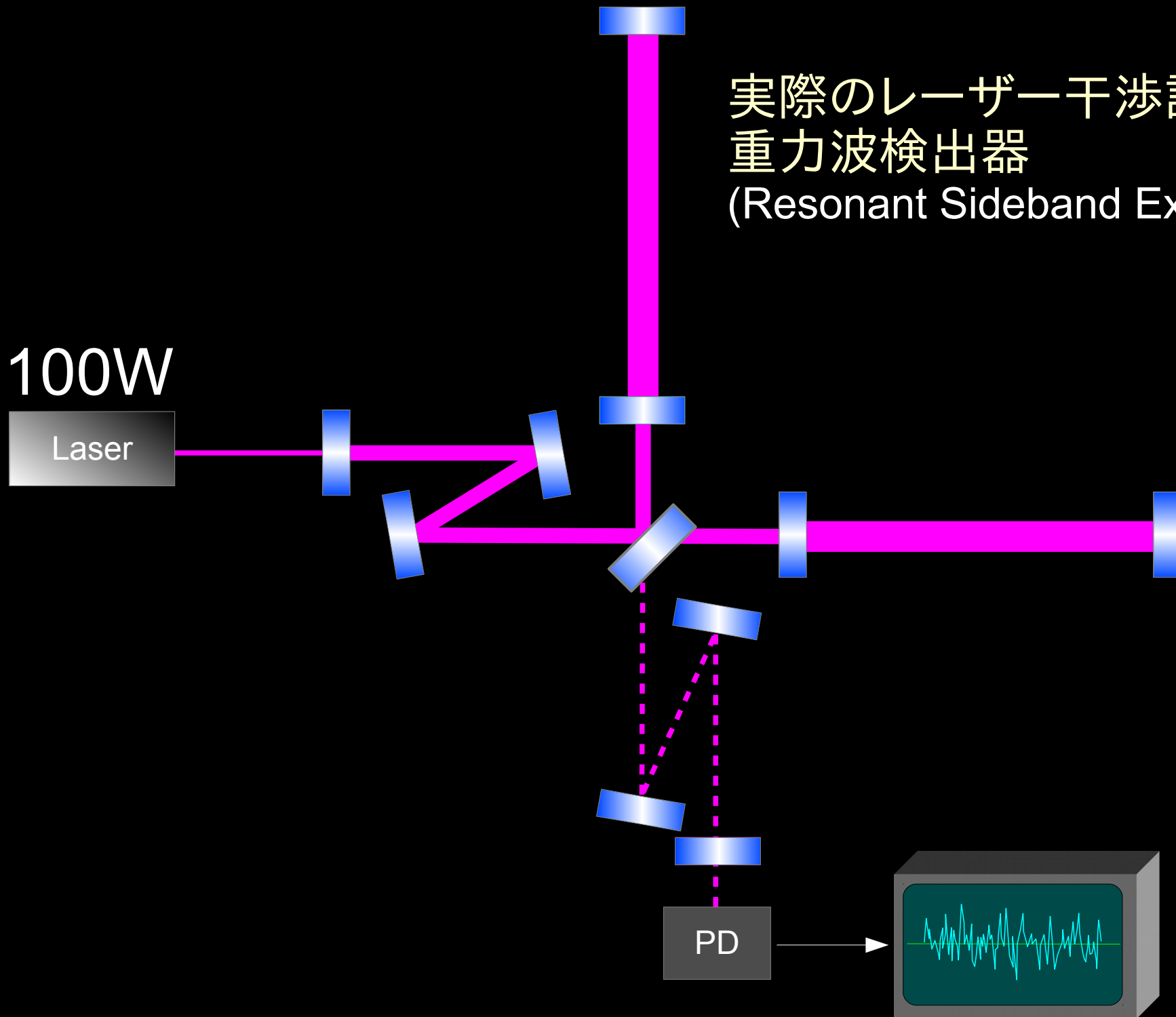
$$h = 2 \times 10^{-21}$$

実際のレーザー干渉計型
重力波検出器
(Resonant Sideband Extraction型)

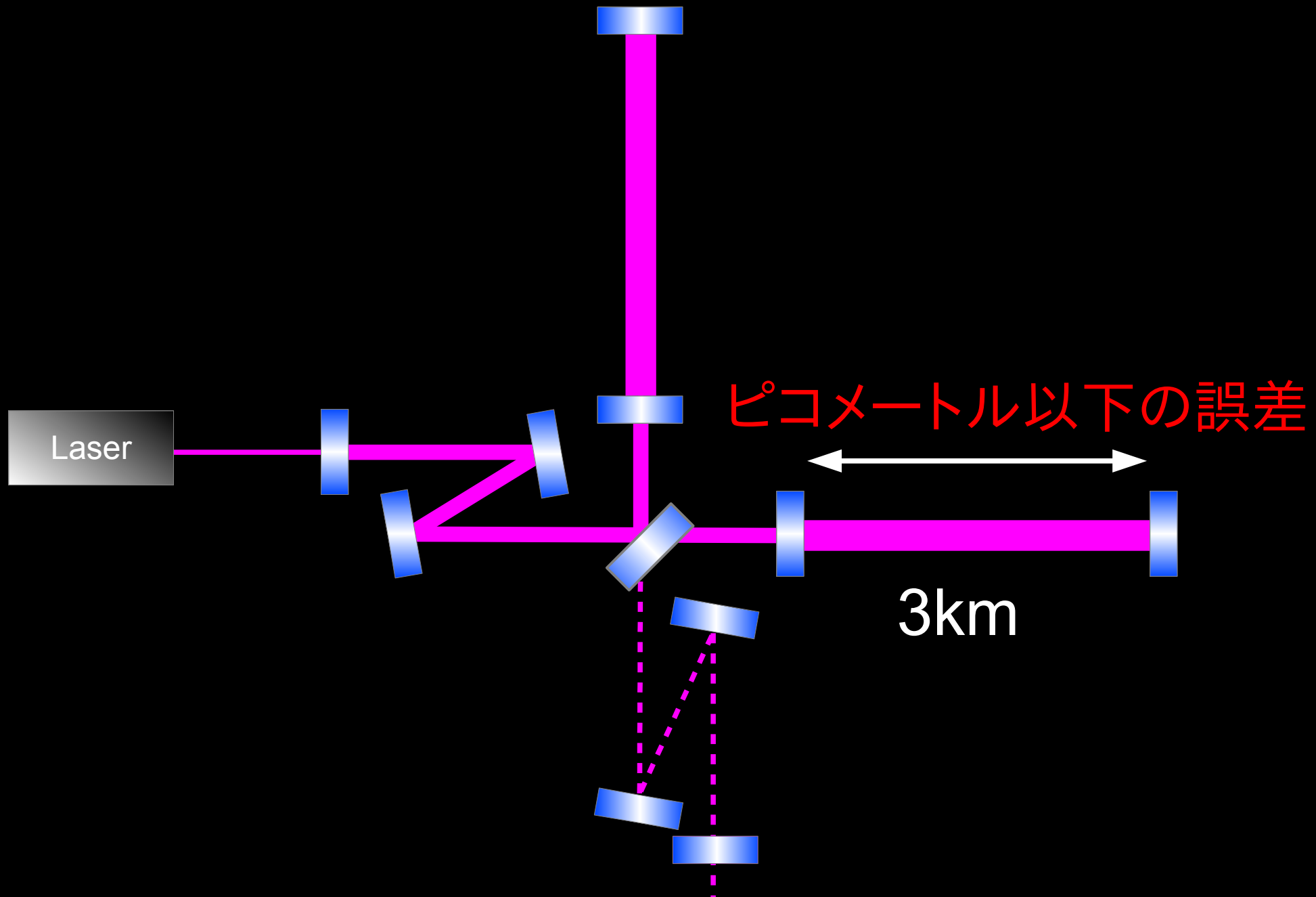
100W

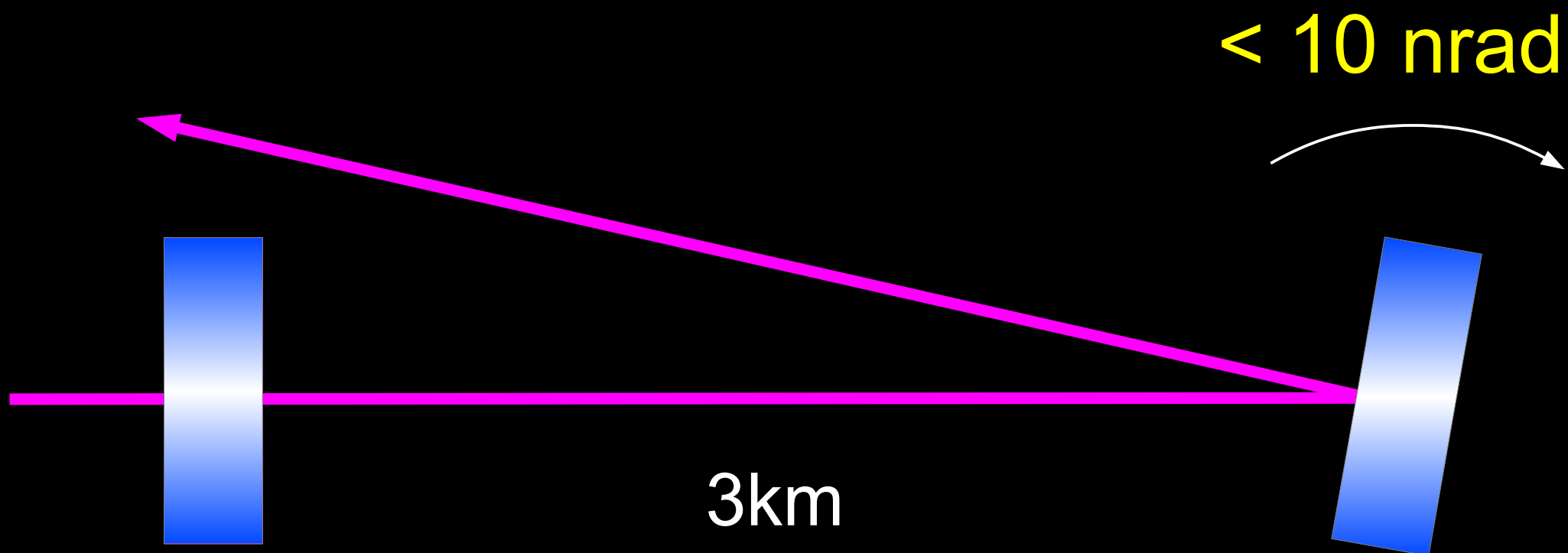
Laser

PD

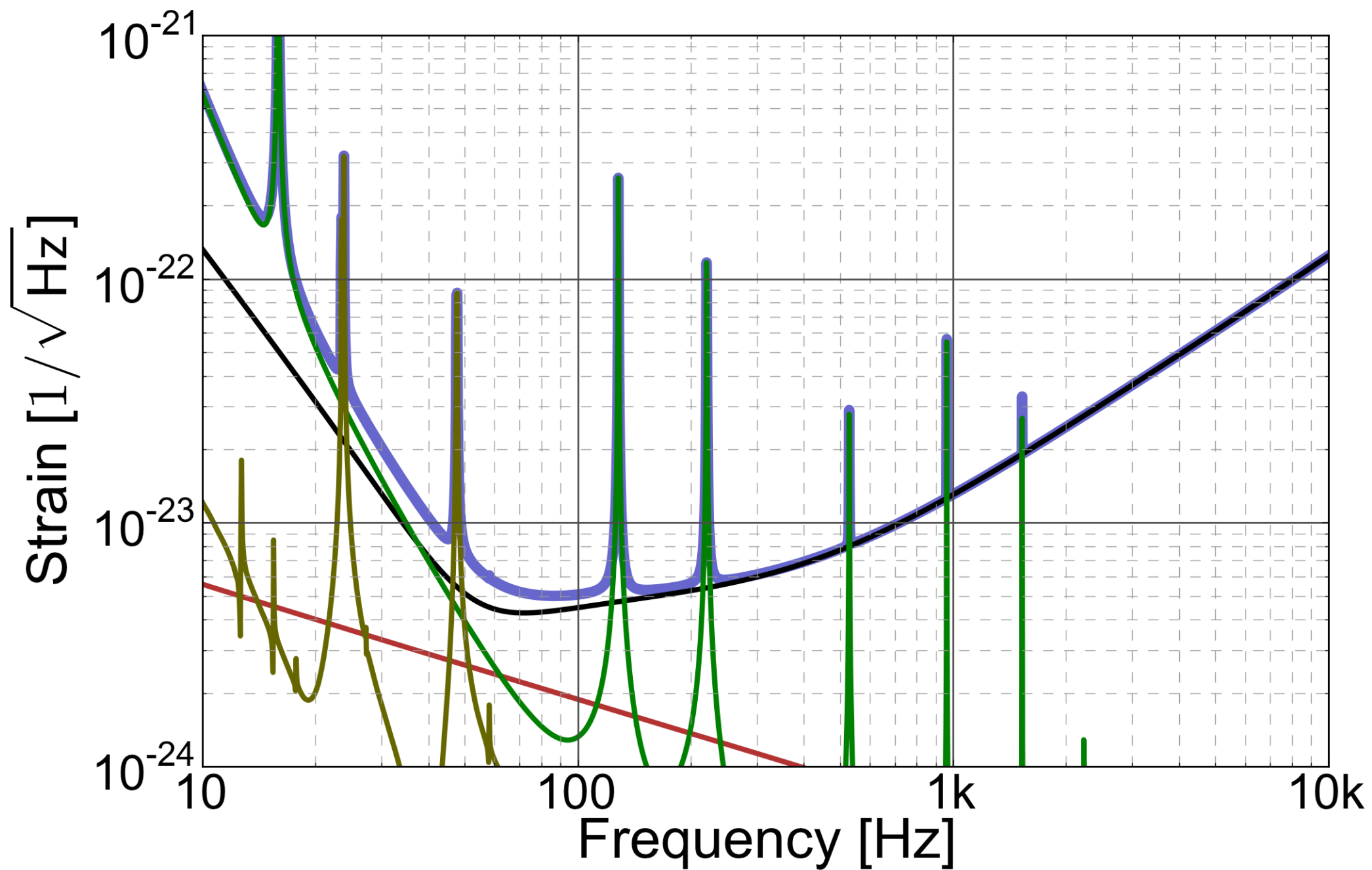


干渉計を最適動作点に保持する





KAGRAの目標感度

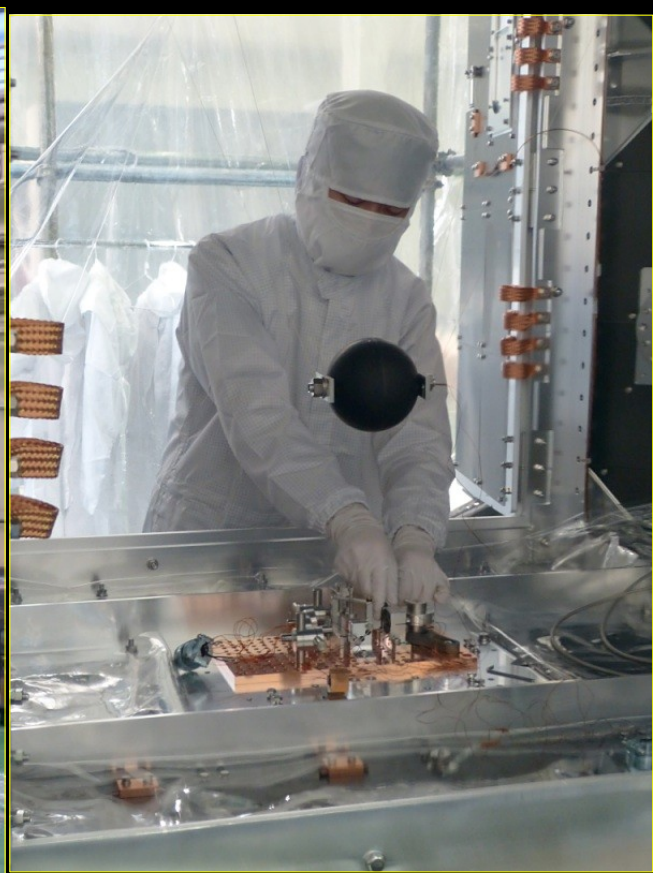
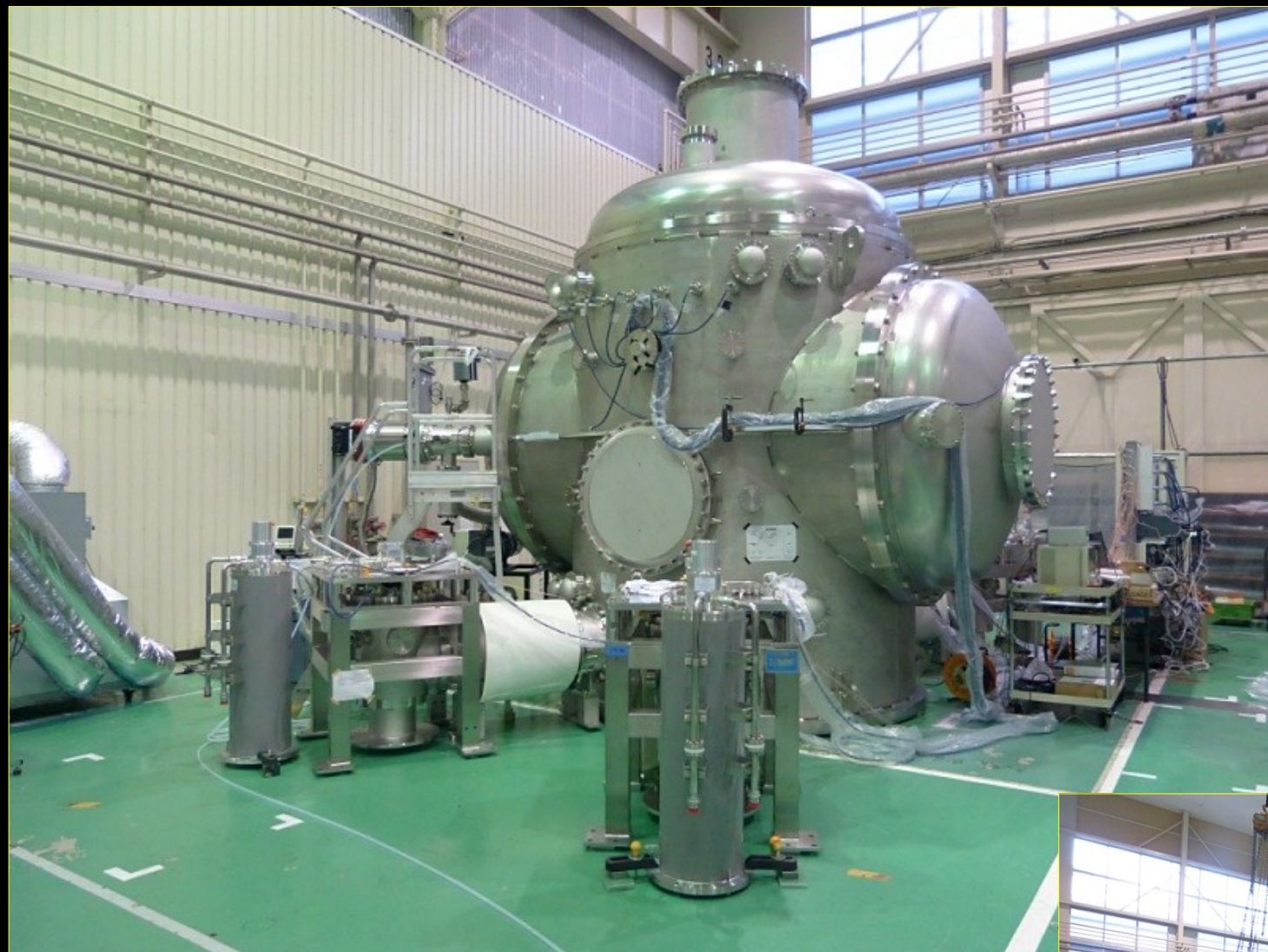




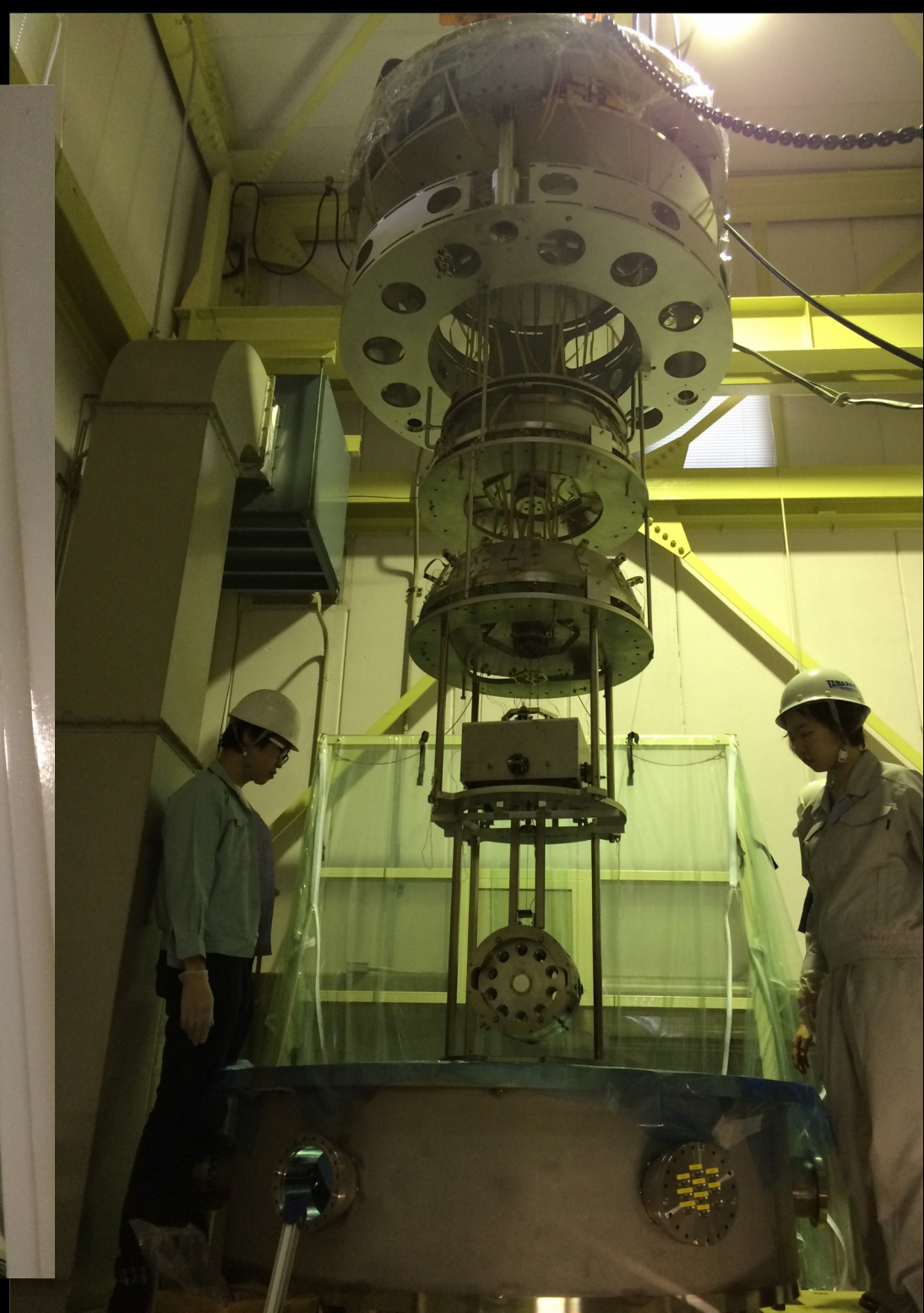
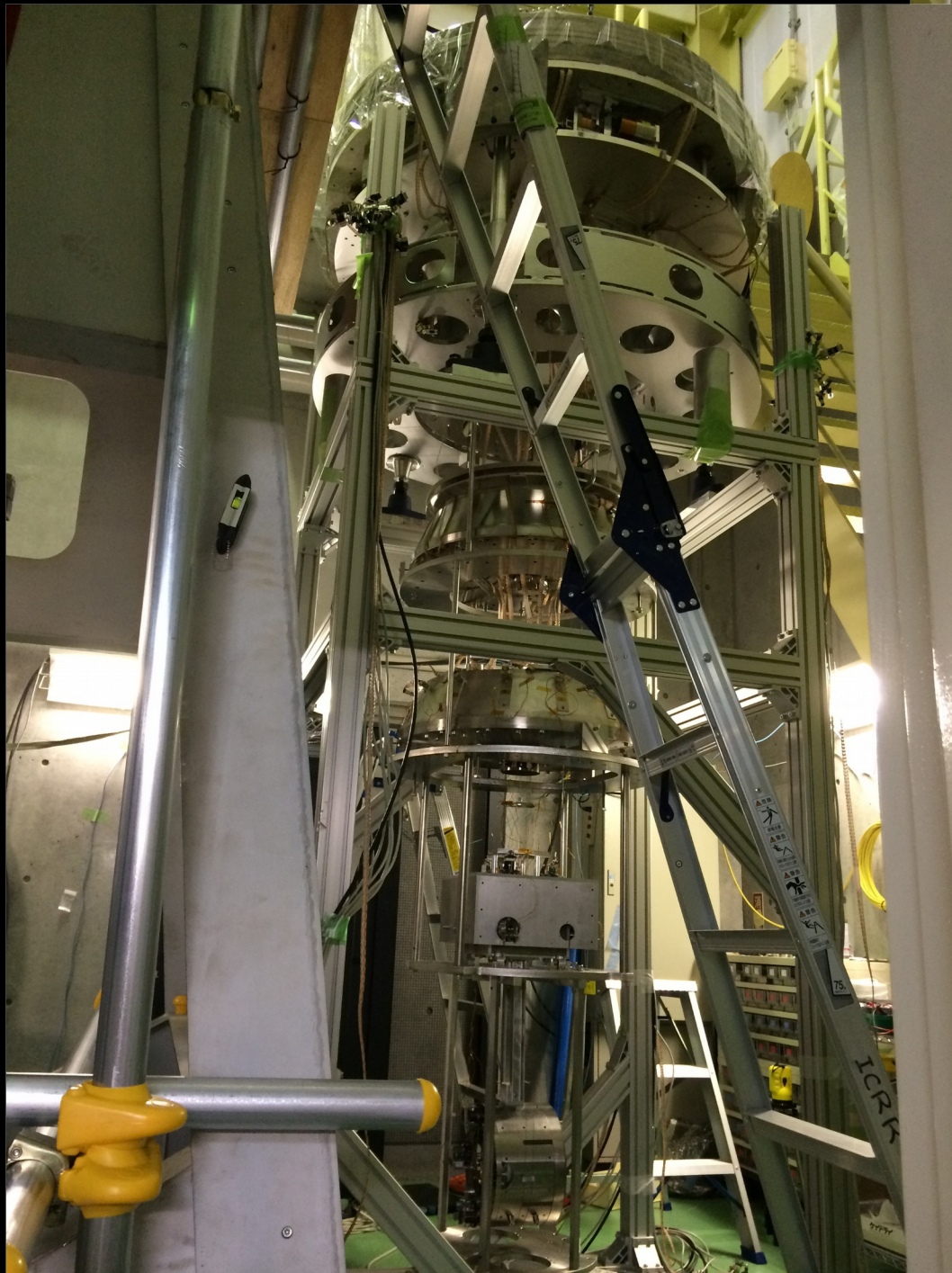
Location of Center (BS)

- latitude: 36.41°N , longitude: 137.31° .
- Y arm direction: 28.31° deg. from the North.
- Height from the sea level : about 372m.
- **2 entrances for the experiment room.**
- Center, Xend, Yend are inside more than 200m from the surface of the mountain.
- Tunnel floor is tilted by 1/300 for natural water drainage.
- Height of the Xend: 382.095m.
- Height of the Yend: 362.928m.





クライオスタット試験@東芝





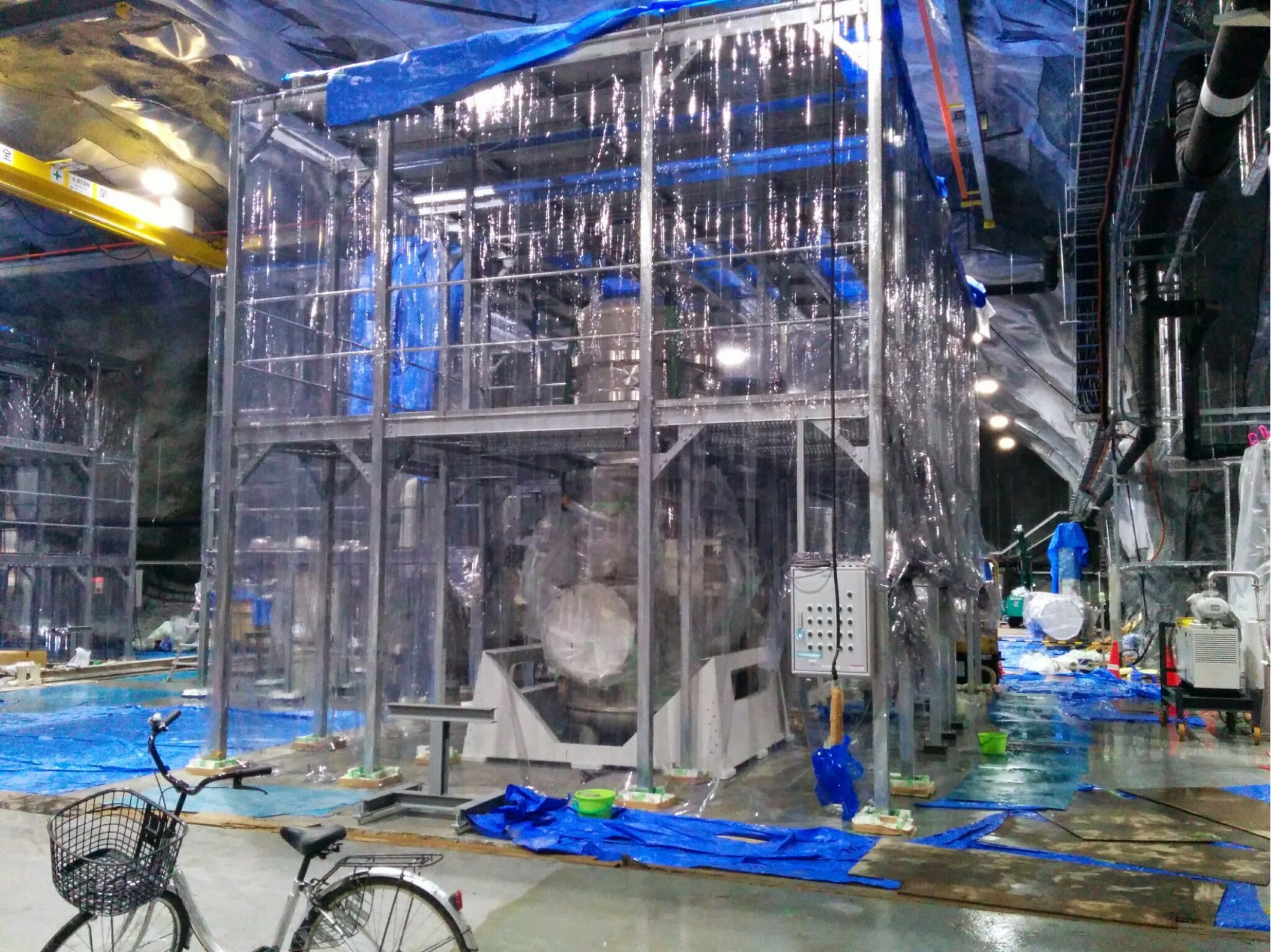
2012年末



掘削完了直後



2015年4月

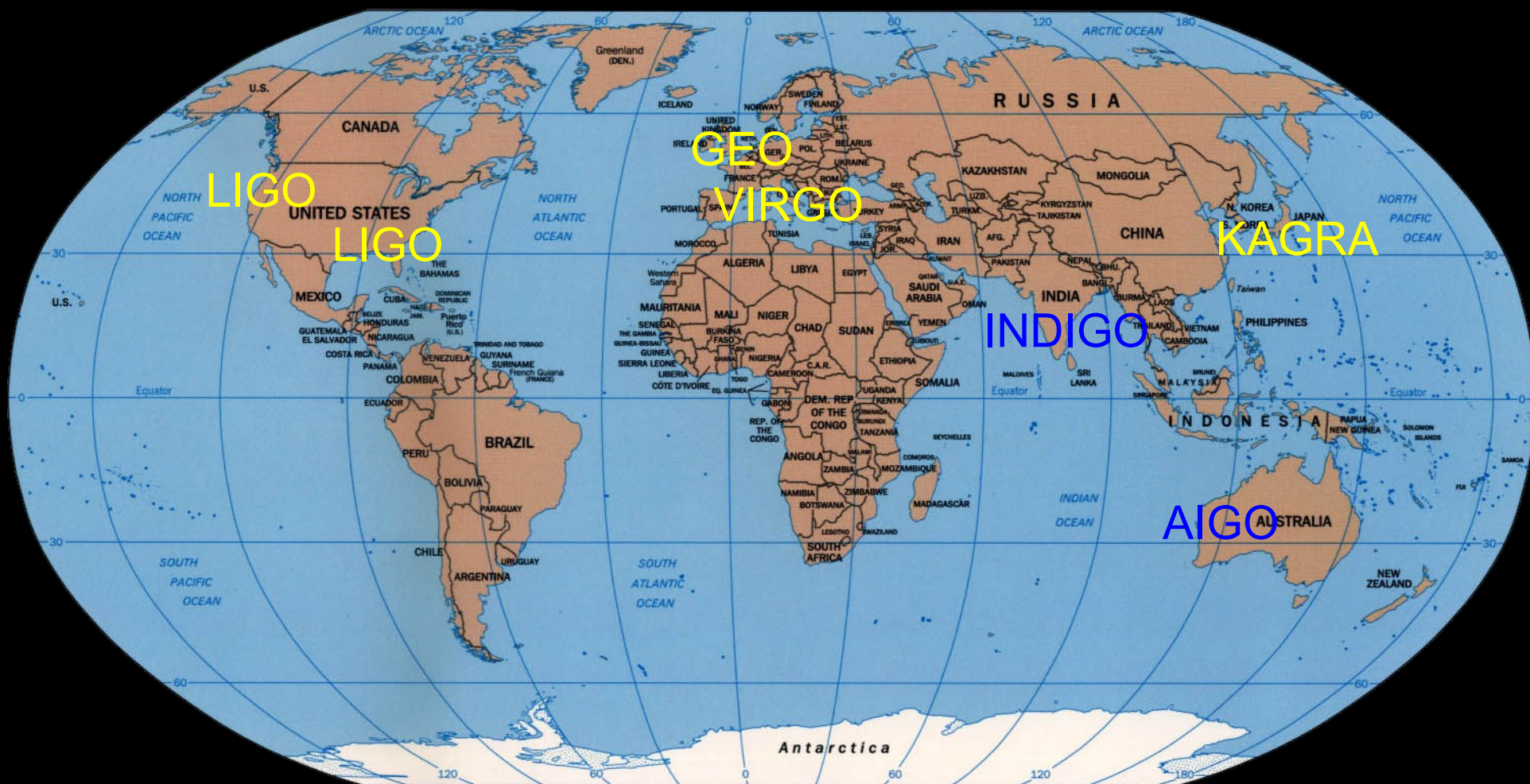






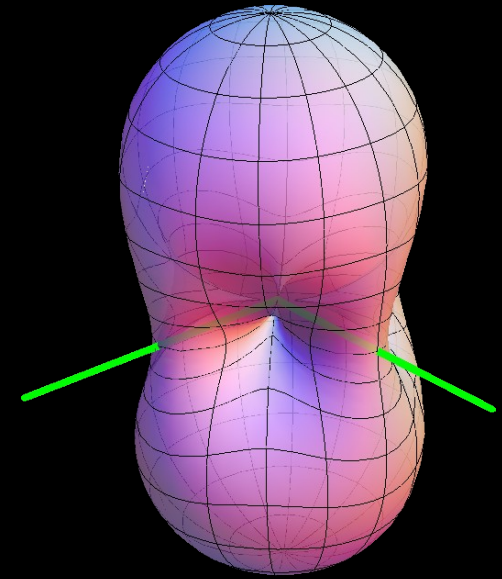


世界の重力波検出器ネットワーク



観測開始: ~ 2017-2018

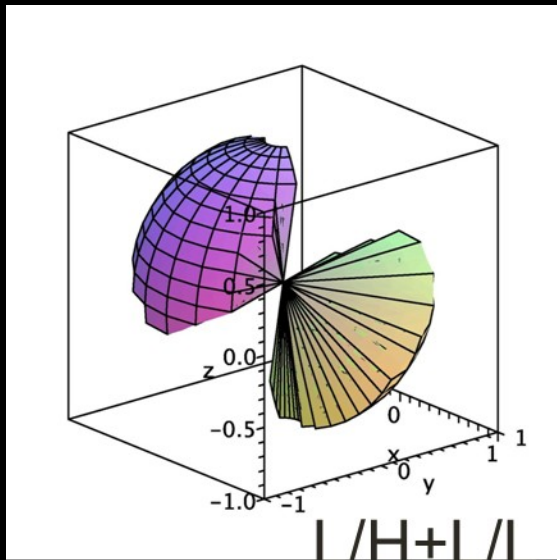
天球カバー率



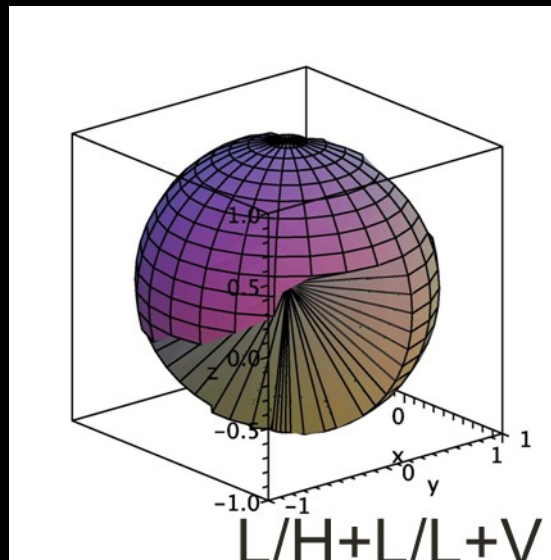
LIGO Only

LIGO+VIRGO

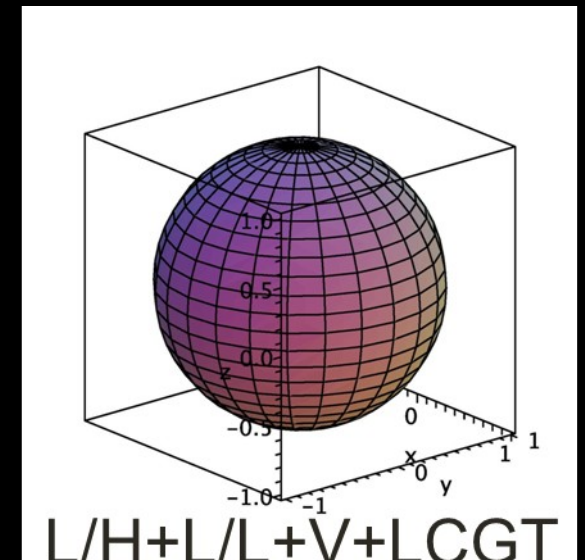
LIGO+VIRGO+KAGRA



33%



72%



100%

重力波源の位置決定精度

