Higgs Couplings 2018

Recent results of gravitational wave

Masaki Ando (Univ. of Tokyo / NAOJ)
on behalf of the DECIGO collaboration

Target of Physics

Fundamental Law of the Universe

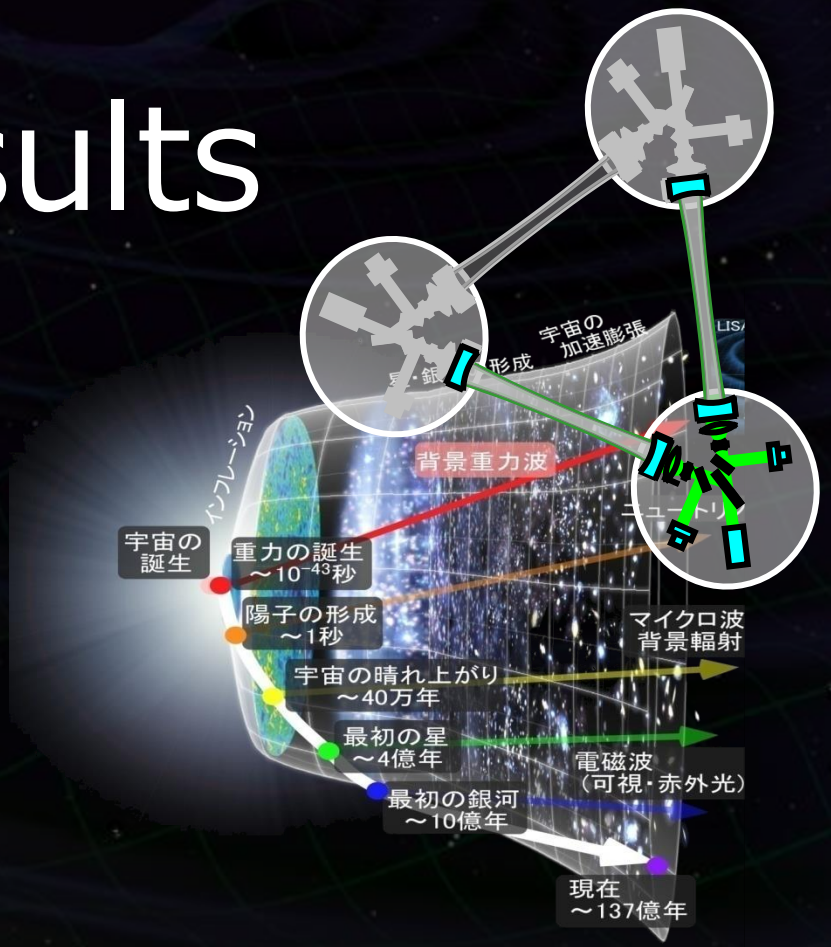
High-energy Physics

Astrophysics Cosmology

背景画:
佐藤 勝彦
「相対性理論における時間と宇宙の誕生」

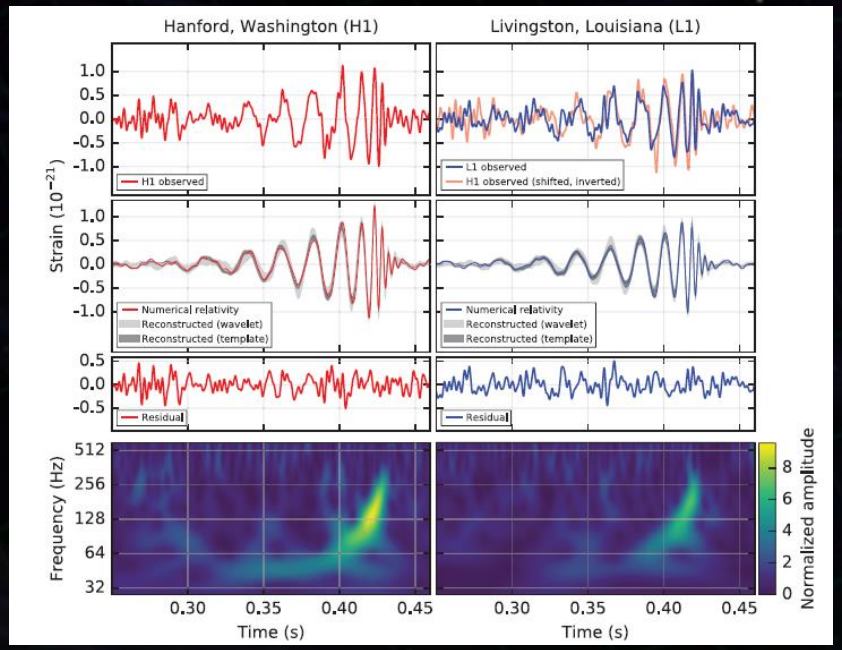
Outline

- Recent Results
- B-DECIGO
- DECIGO



First Detection of GW

- On Feb. 11th, 2016, LIGO announced first detection of gravitational wave. The signal was from inspiral and merger of binary black hole.
  - ⇨ Opens a new field of 'GW astronomy'.

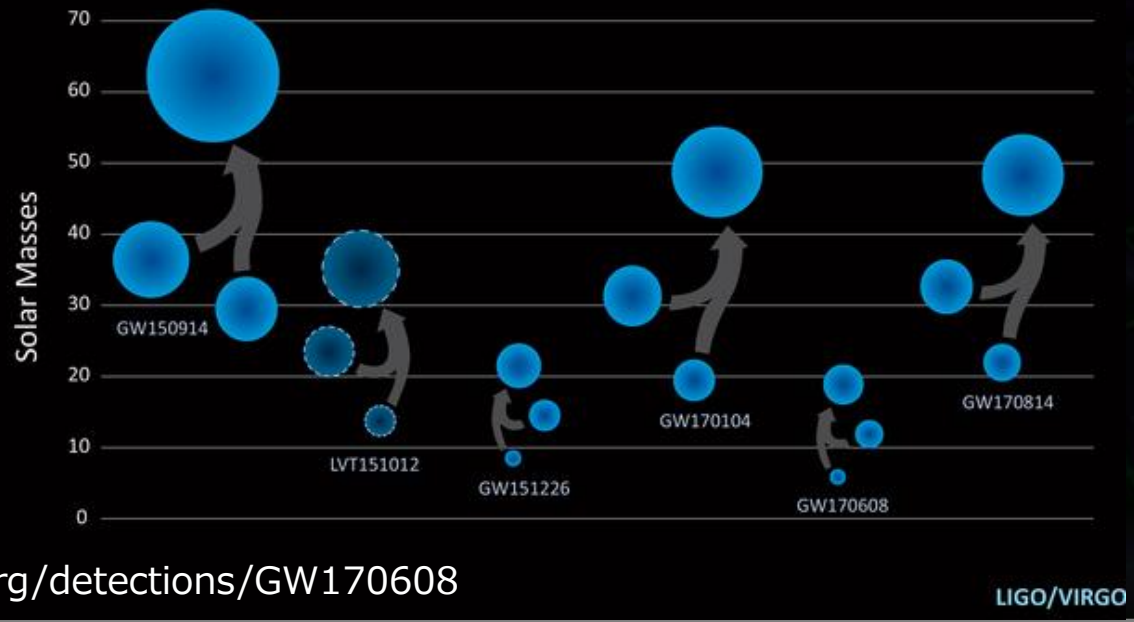


Courtesy Caltech/MIT/LIGO Laboratory

Mergers of Binary Black Hole

- 2nd: GW151226 (2016.6 announce)
- 3rd: GW170104 (2017.6.2 announce)
- 4th: GW170814 (2017.9.27 announce)
- 5th: GW170608 (2017.11.15 announce)

→ Mergers of binary black holes
would be common events in the universe.

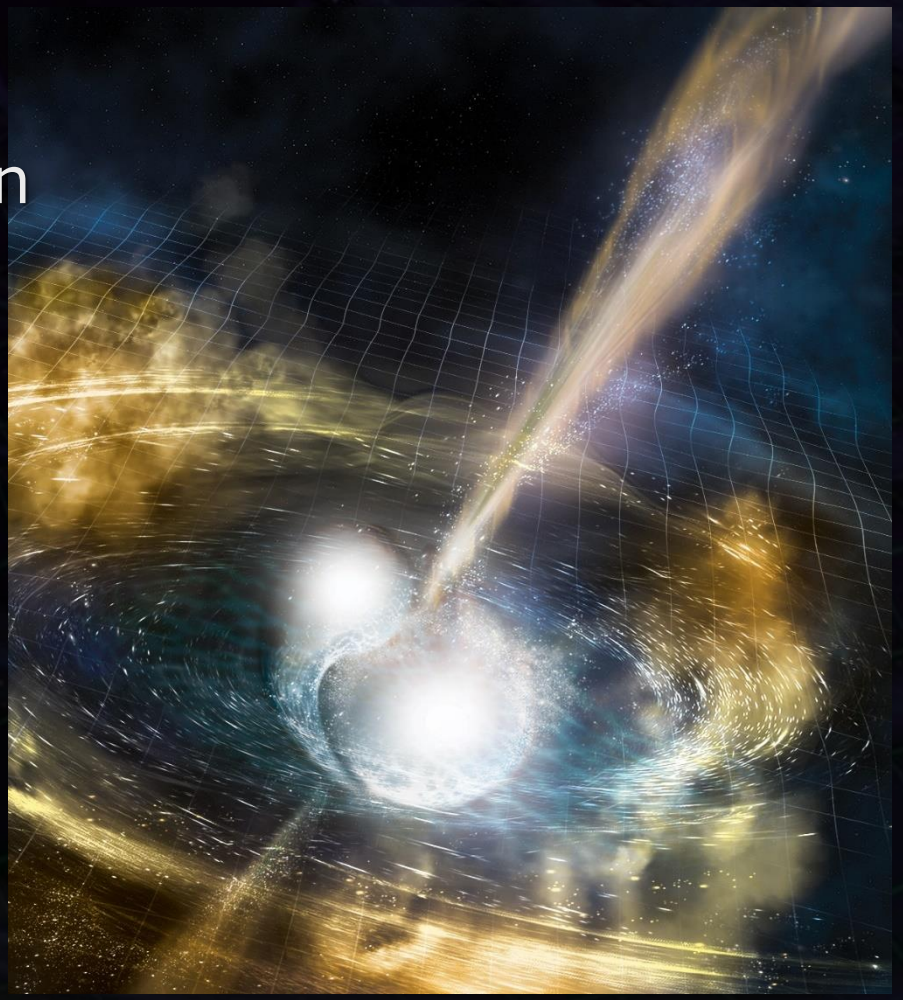


http://ligo.org/detections/GW170608

Merger of Binary Neutron Stars

- On Oct.16th, 2017, LIGO-VIRGO collaboration announced the first detection of gravitational-wave signal from merger of binary neutron stars

- The signal was detected on August 17th, 2017.
  → Named GW170817.
- Source Localization ~30deg^2



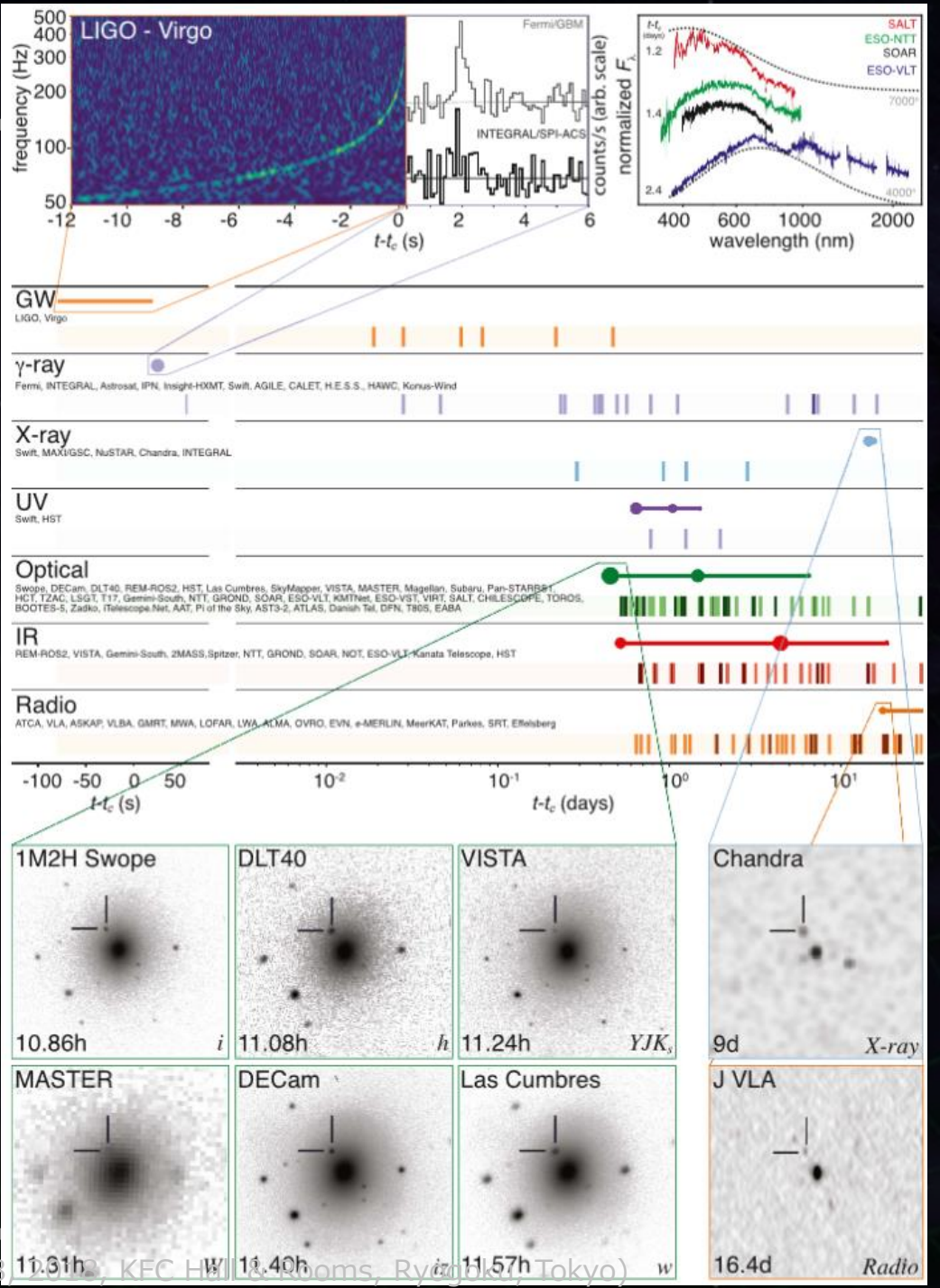
Courtesy Caltech/MIT/LIGO Laboratory

- EM counterpart was observed for the first time in GW170817.

⇩

- New knowledge
  - * Origin of SGRB.
  - * Origin of heavy elements in the universe.
  - * EoS of neutron star
  - * Fundamental physics and cosmology: speed of GW, Hubble's constant, ….

ApJL 848 L12 (2017)



Fundamental Physics

- Speed of GW
  - In GR prediction, GW propagates at the speed of light.
  - GW-EM arrival time difference was 1.7 sec.
  - Source distance 40Mpc (1.2×10^{24} m).

  → Upper limit $\frac{c_{\mathrm{GW}} - c_{\mathrm{EM}}}{c_{\mathrm{EM}}} < 3 \times 10^{-15}$.

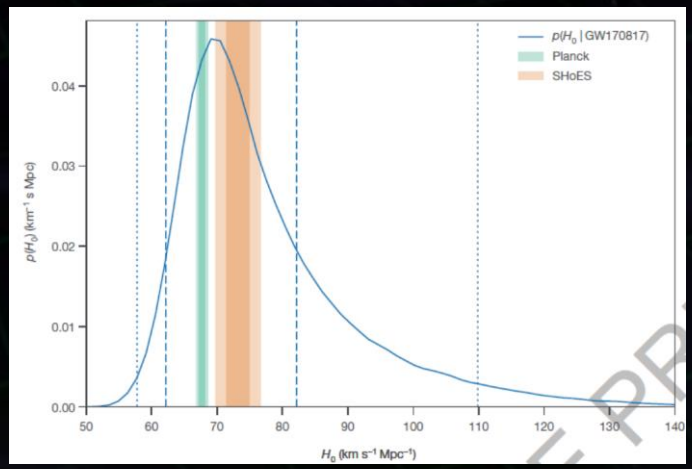
- Cosmological Parameter
  - GW amplitude → Source distance.
  - EM counter part → Redshift

  Hubble parameter:

  $H_0 = 70^{+12.0}_{-8.0}\ \mathrm{km/s/Mpc}$

  ⇨ Consistent with other results.
  Independent measurement.

Hubble parameter by CMB measurement (Planck):
$H_0 = 67.90 \pm 0.55\ \mathrm{km/s/Mpc}$



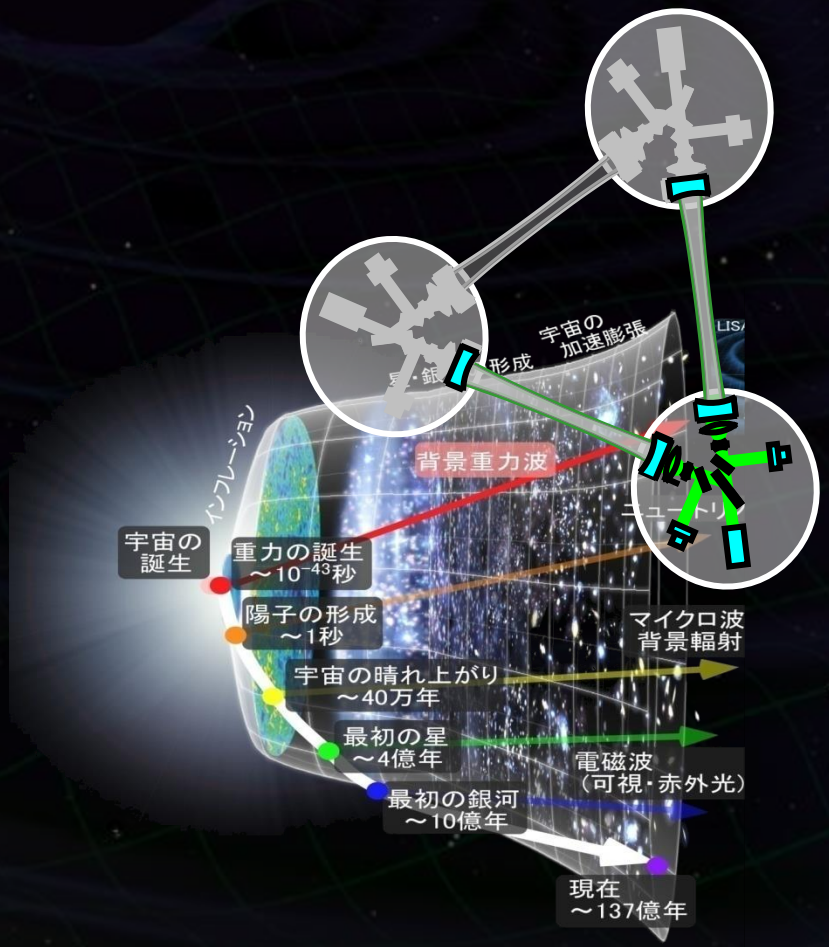
doi:10.1038/nature24471

After the First Detections ...

- The first GW (and EM counter part) detections demonstrated new possibilities by GW astronomy, and also showed new mysteries, such as the origin of heavier mass ($30M_{\odot}$) BBH, origins of heavy elements⋯.

- Network of 2nd-gen. GW antennae (aLIGO, AdVIRGO, KAGRA, LIGO-India) will be formed in several years.
- Two ways after that for Astronomy and Cosmology:
  - 3rd–gen. ground-based GW antennae (ET, CE).
  - Space GW antennae (LISA, B-DECIGO, DECIGO,⋯).

B-DECIGO


宇宙の
加速膨張
形成
インフレーション
背景重力波
宇宙の
誕生
重力の誕生
～10⁻⁴³秒
陽子の形成
～1秒
マイクロ波
背景輻射
宇宙の晴れ上がり
～40万年
最初の星
～4億年
電磁波
（可視・赤外光）
最初の銀河
～10億年
現在
～137億年

Space GW Observatory: B-DECIGO

※ We changed the name: Pre-DECIGO → B-DECIGO

- B-DECIGO
  - Space-borne GW antenna formed by three S/C
  - Target Sensitivity for GW : 2×10^{-23} $Hz^{-1/2}$ at 0.1Hz.

- Sciences of B-DECIGO
  (1) Compact binaries.
  (2) IMBH merger.
  (3) Info. of foregrounds for DECIGO.

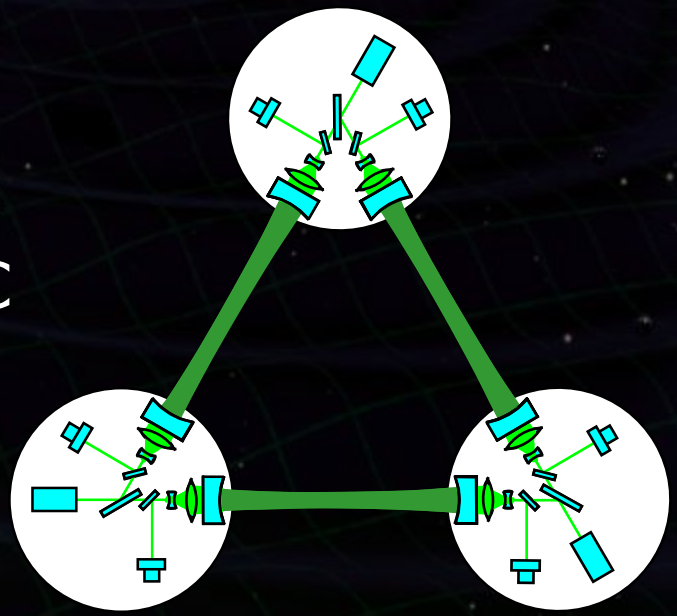
Fig. by S.Sato

Target: JAXA Strategic Medium-scale mission (2020s).

B-DECIGO Design (Preliminary)

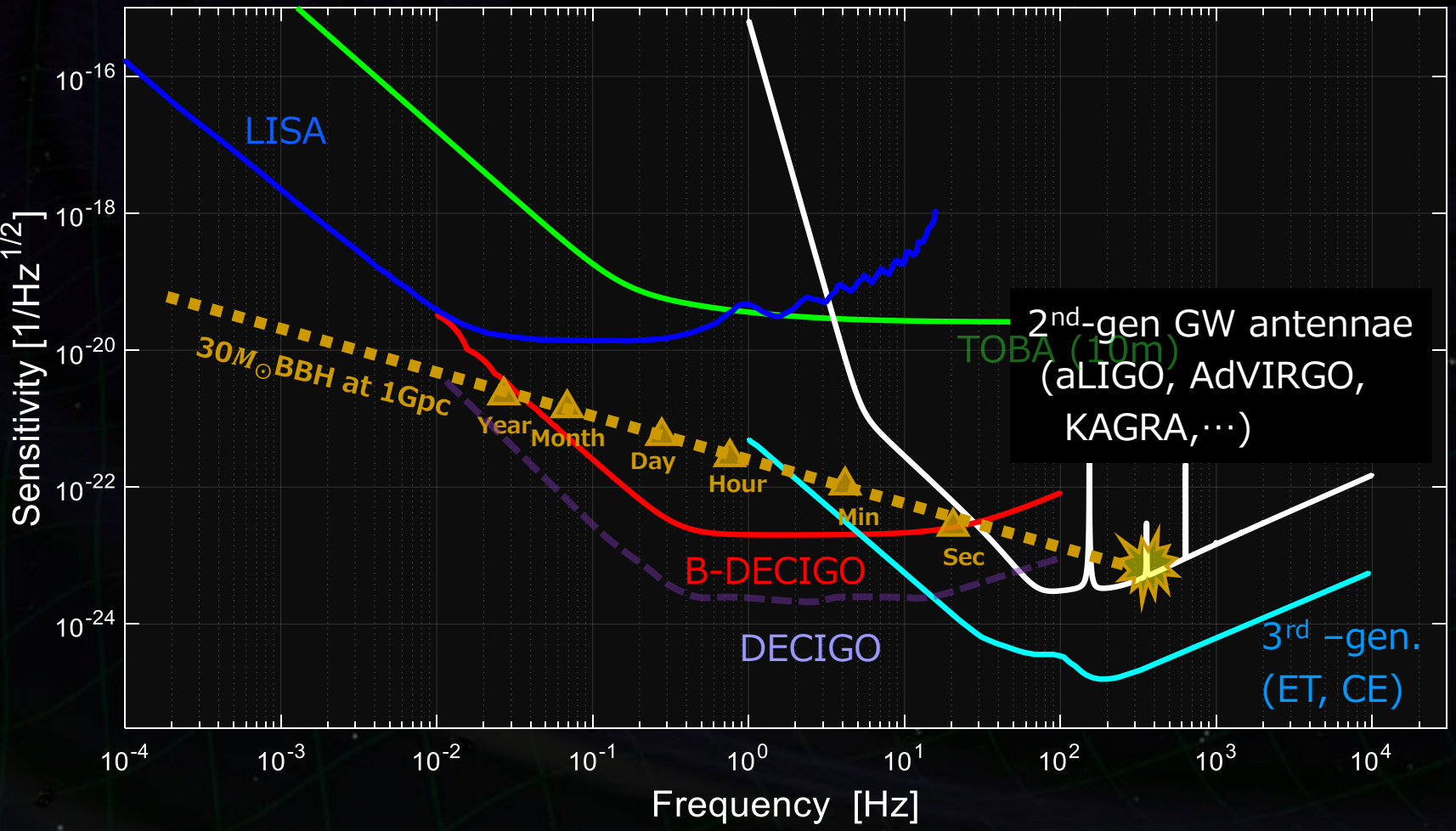
- Mission Requirement
  - Strain sensitivity of 2×10^{-23} $Hz^{-1/2}$ at 0.1Hz.
  - >3-years observation period.

- Conceptual Design
  - Laser interferometer by 3 S/C
  - Baseline : 100 km
    Laser source : 1W, 515nm
    Mirror : 300mm, 30kg
  - Drag-free and Formation flight.
  - Record-disk orbit around the earth:
    Altitude 2000km, Period ~120min (Preliminary).



Sensitivity Curves

T. Nakamura et al., Prog. Theor. Exp. Phys. 093E01 (2016)



Sciences by B-DECIGO

(1) Inspiral of Compact binaries ['Promised' target]

- High rate ~10^5 binaries/yr.
- Estimation of binary parameters and merger time.

→ Astronomy by GW only and GW-EM observations.

(2) Inspirals and mergers of IMBHs [Original science]

- Cover most of the universe.

→ Formation history of SMBH and galaxies.

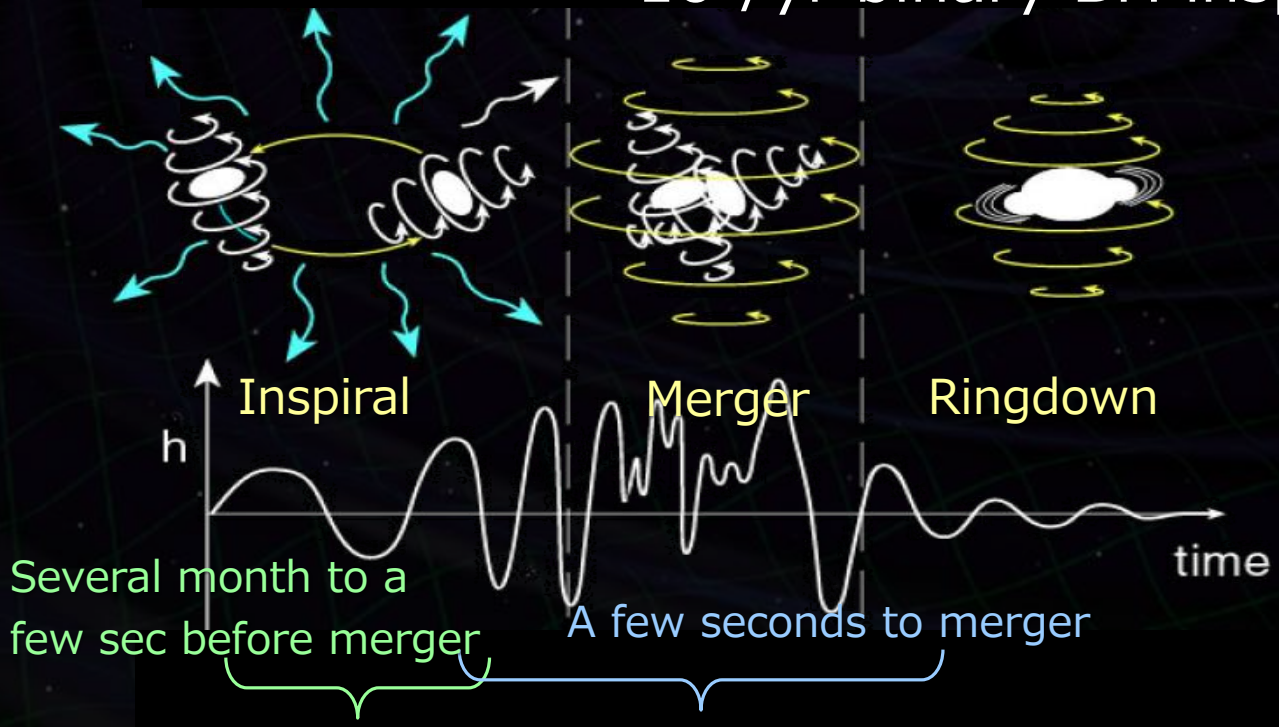
(3) Foreground understandings for DECIGO [Cosmology]

- Parameter estimation and subtraction of binaries.
- Characteristics of foreground.
- Is the any eccentric binaries?

Target (1) : Compact Binaries

B-DECIGO will observe >100/yr binary NS inspirals.

~10^5/yr binary BH inspirals.

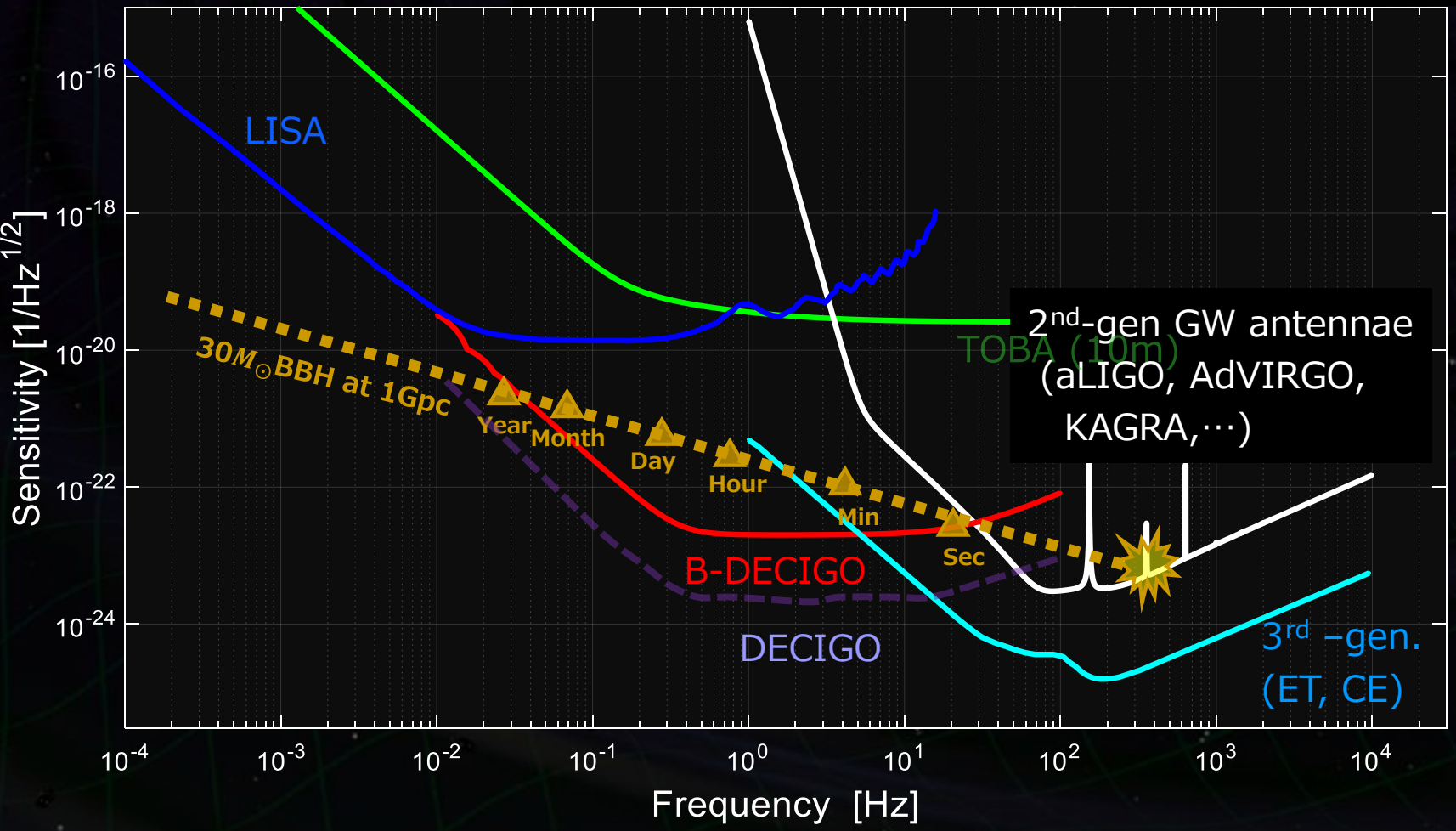


Low.-freq. → B-DECIGO
Mass, Position, Time,…

High-freq. → Ground based
Astrophysics, EoS of NS

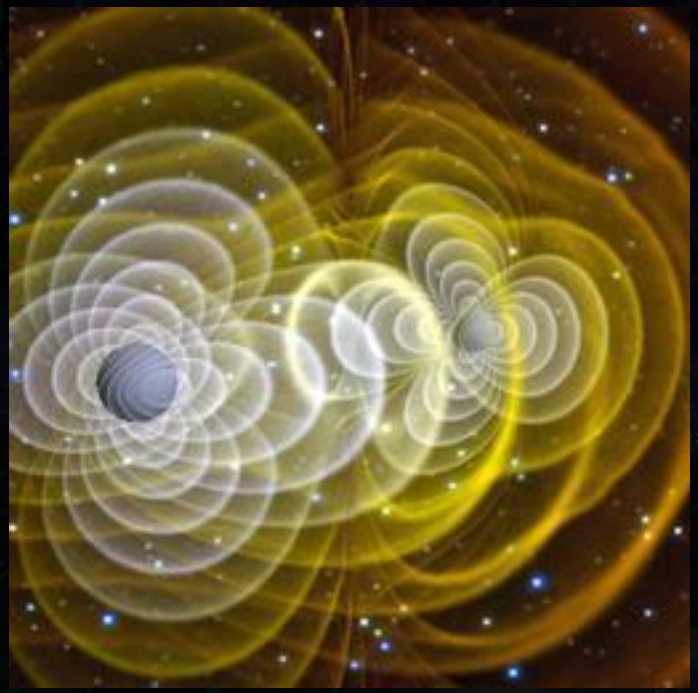
Sensitivity Curves

T. Nakamura et al., Prog. Theor. Exp. Phys. 093E01 (2016)



Target (2) : Intermediate-mass BH Merger

B-DECIGO will see almost the whole Universe.



The mystery on the history of SMBH at the centers of Galaxies:

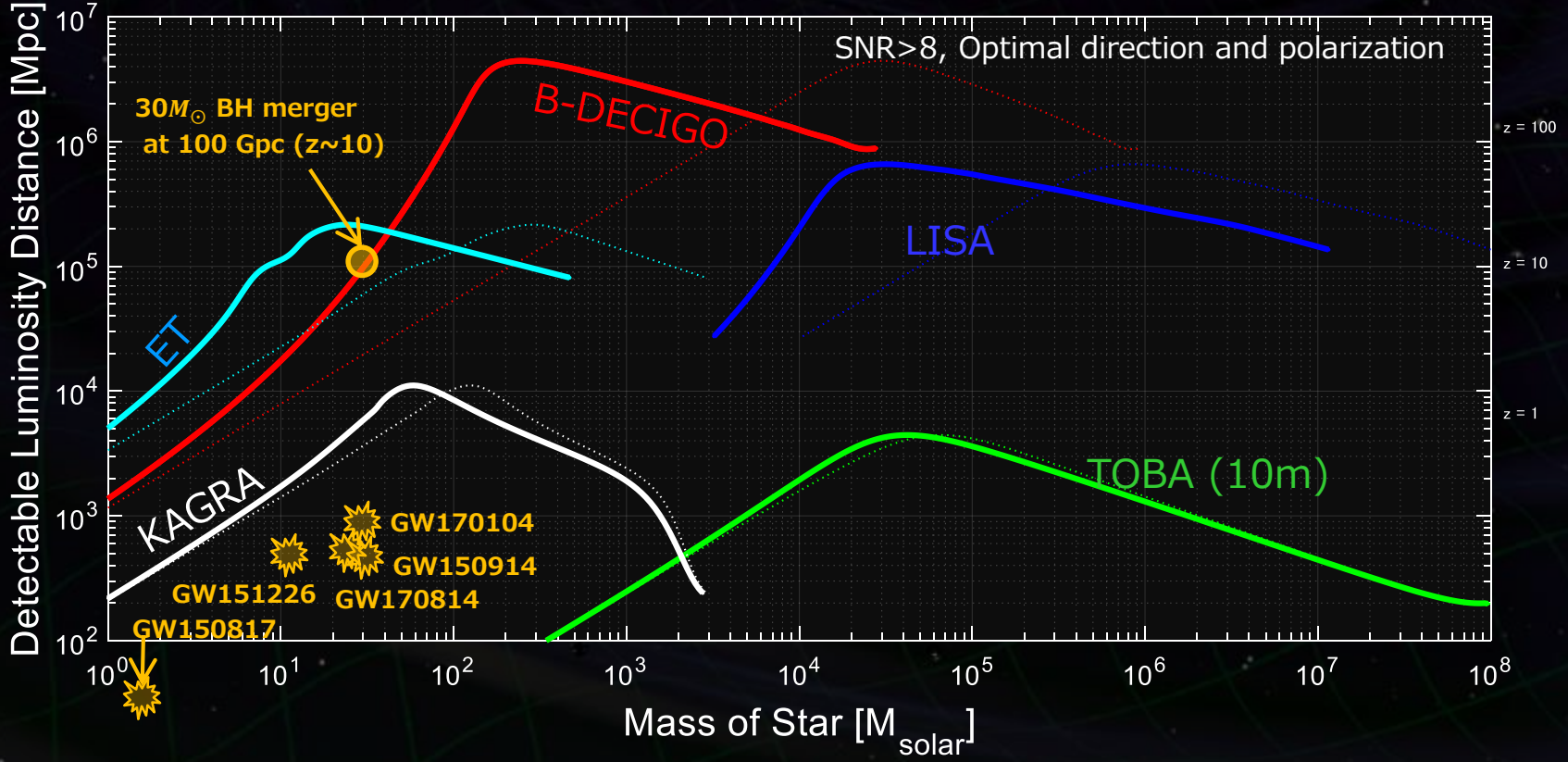
(A) Large BH + Accretion

(B) Hierarchical mergers

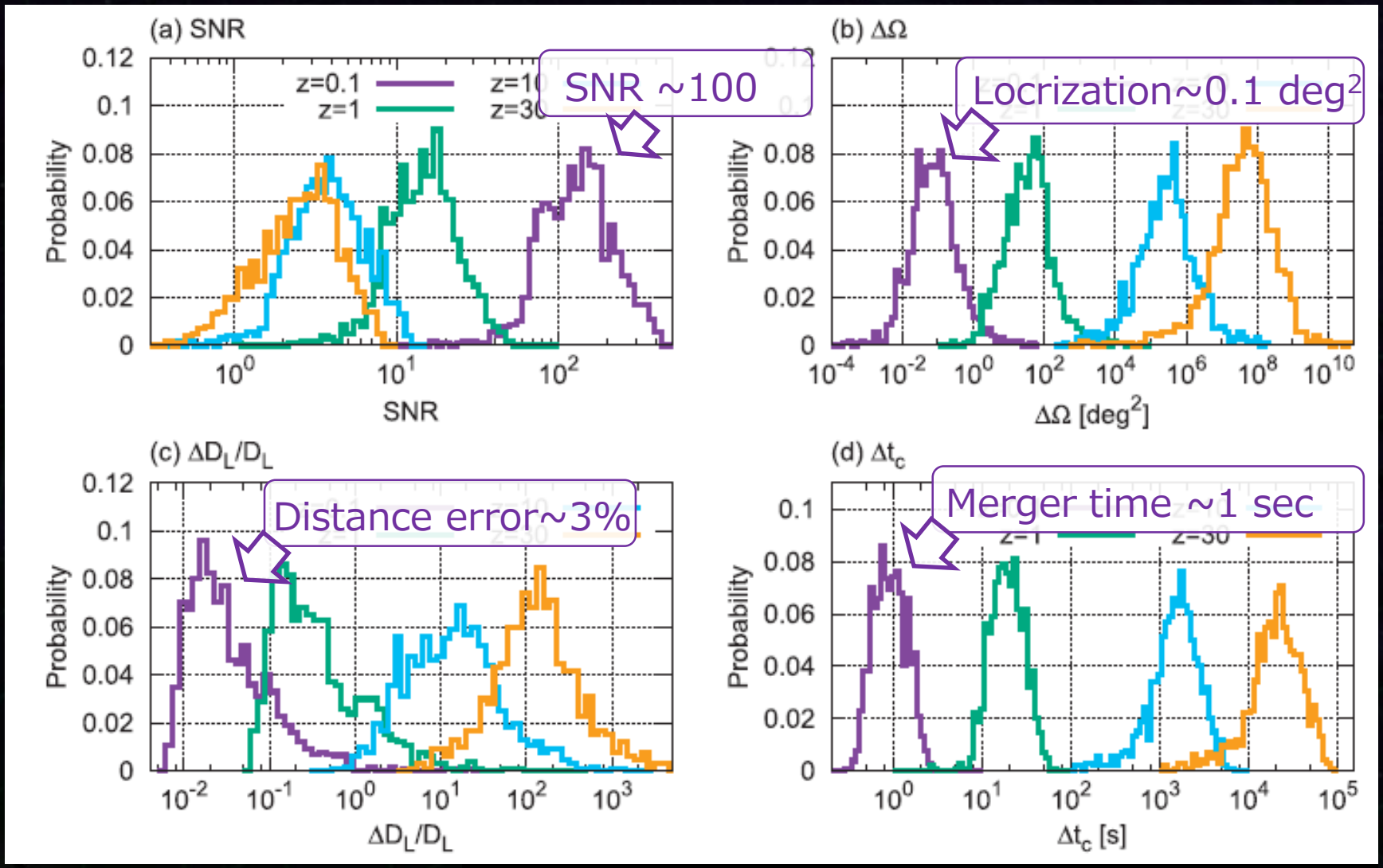
- B-DECIGO can pin-down the story.
- Original observation.

Observable Range

$30M_\odot$ BBH Merger : 100 Gpc (z>10) range
with SNR~8 (optimal direction/polarization).



Parameter Estimation Accuracy



T. Nakamura et al., Prog. Theor. Exp. Phys. 093E01 (2016)

B-DECIGO Sciences for CBC

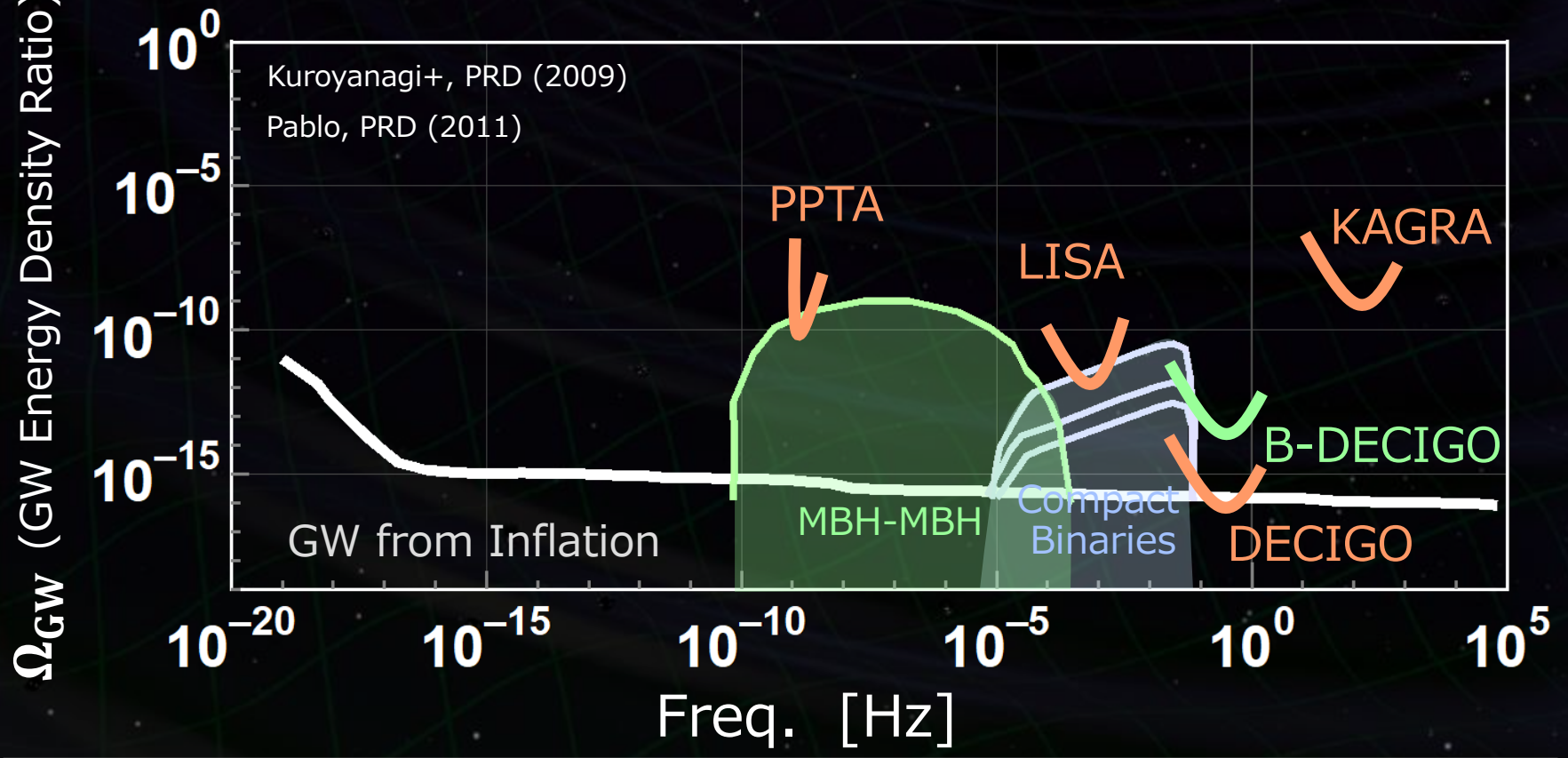
- With its BBH observable range, in B-DECIGO
  Detection Rate will be $\sim 4 \times 10^4 - 10^6$ events/yr .
  → Possible to identify the origin of BBH.
- Range for BNS is ~2Gpc → ~ 100 events/yr .
- With low-freq. GW observations, longer observation time is expected; in $30M_\odot$ BBH merger case, the signal is at 0.1Hz in 15days before merger.
  → Improved parameter estimation accuracy with lager cycle number (~10^5) :
  * Localization, Merger time → Alerts for GW-EM.
  * Mass, Distance, Spin → Origin and nature of BBH.

⇨ Fundamental physics, Cosmology

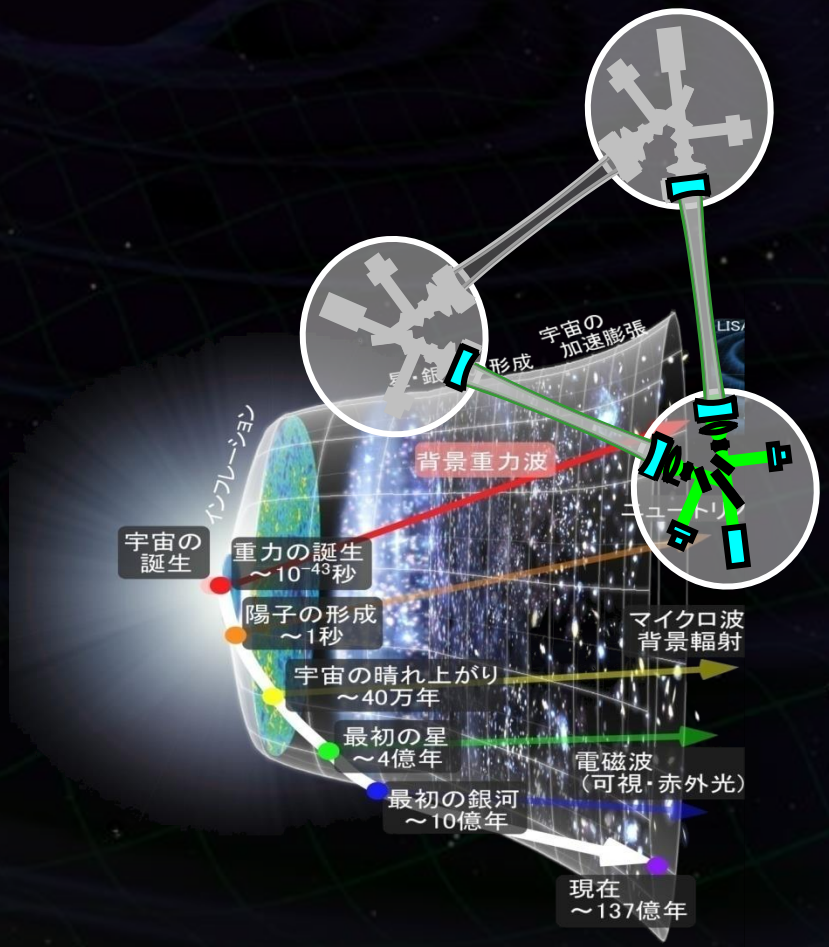
Target (3) : Foreground Understandings

In future DECIGO, unresolvable GWs by many binaries can be a foreground for primordial GW obs.

⇨ Gain understandings with >100 binaries.

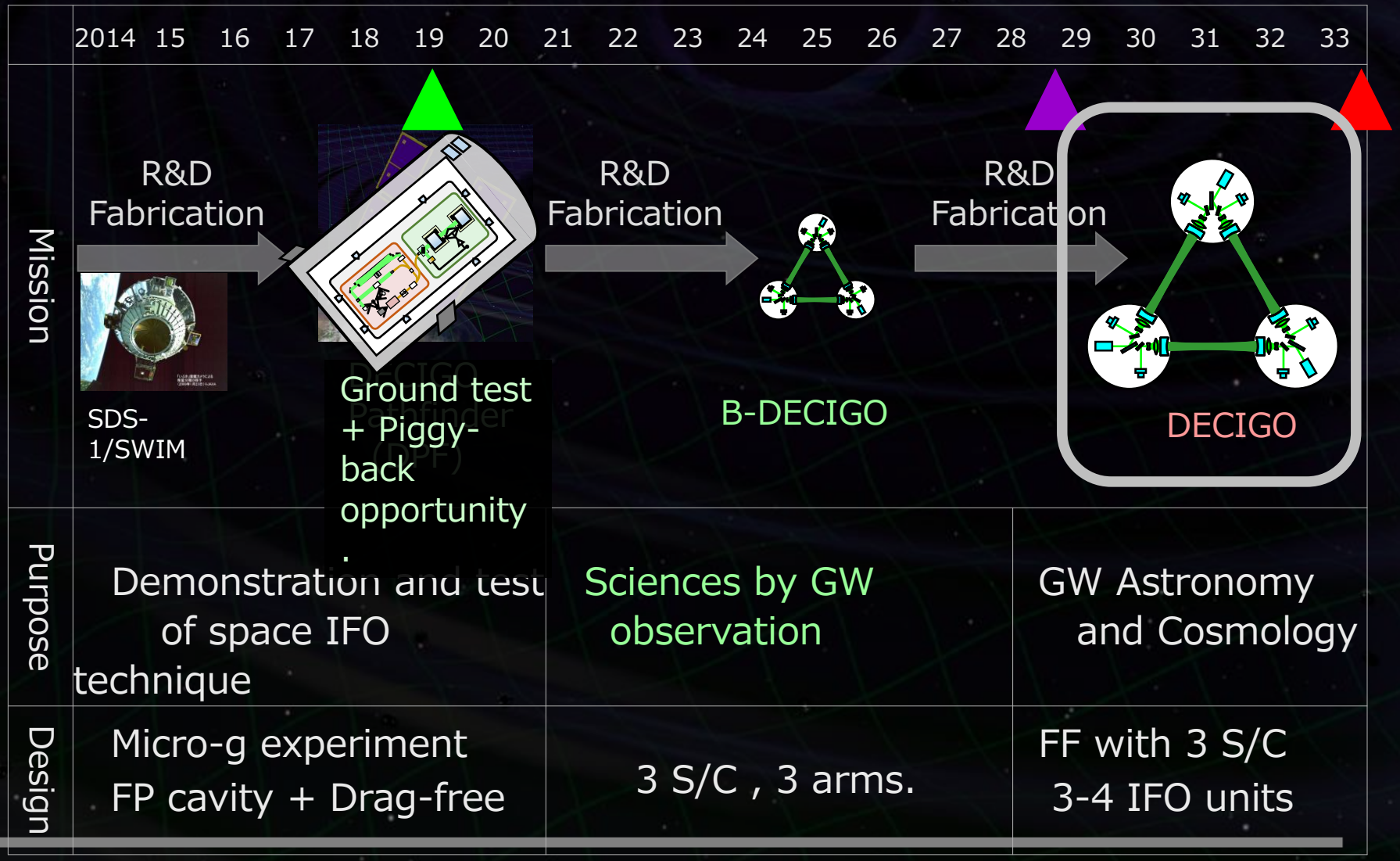


DECIGO


宇宙の
加速膨張
形成
インフレーション
背景重力波
宇宙の
誕生
重力の誕生
～10⁻⁴³秒
陽子の形成
～1秒
マイクロ波
背景輻射
宇宙の晴れ上がり
～40万年
最初の星
～4億年
電磁波
（可視・赤外光）
最初の銀河
～10億年
現在
～137億年

Updated Roadmap for DECIGO

Figure: S.Kawamura

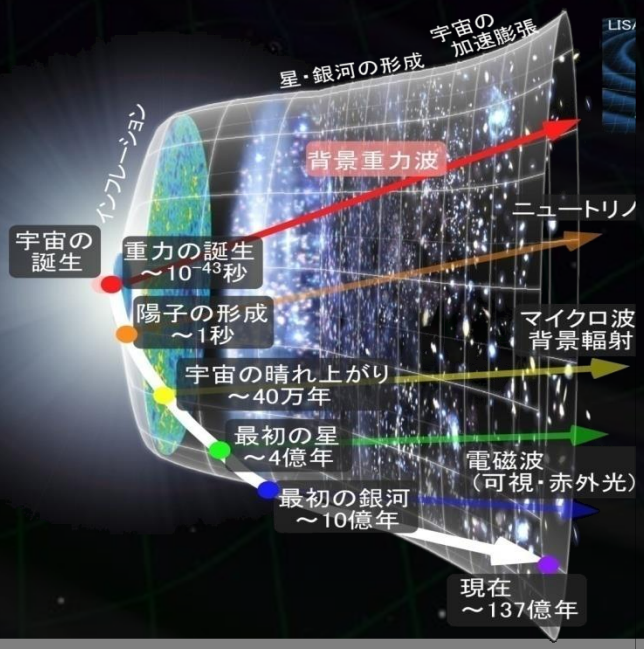


Space GW Antenna DECIGO

DECIGO (DECI-hertz interferometer Gravitational wave Observatory)

Purpose: To Obtain Cosmological Knowledge.

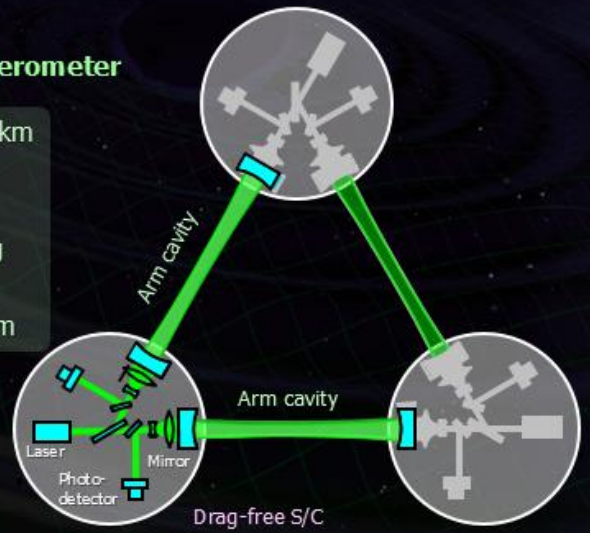
Direct observation of the origin of space-time and matter in Big-bang Universe.



Interferometer Unit:
Differential FP interferometer

Arm length:	1000 km
Finesse:	10
Mirror diameter:	1 m
Mirror mass:	100 kg
Laser power:	10 W
Laser wavelength:	532 nm

S/C: drag free
3 interferometers



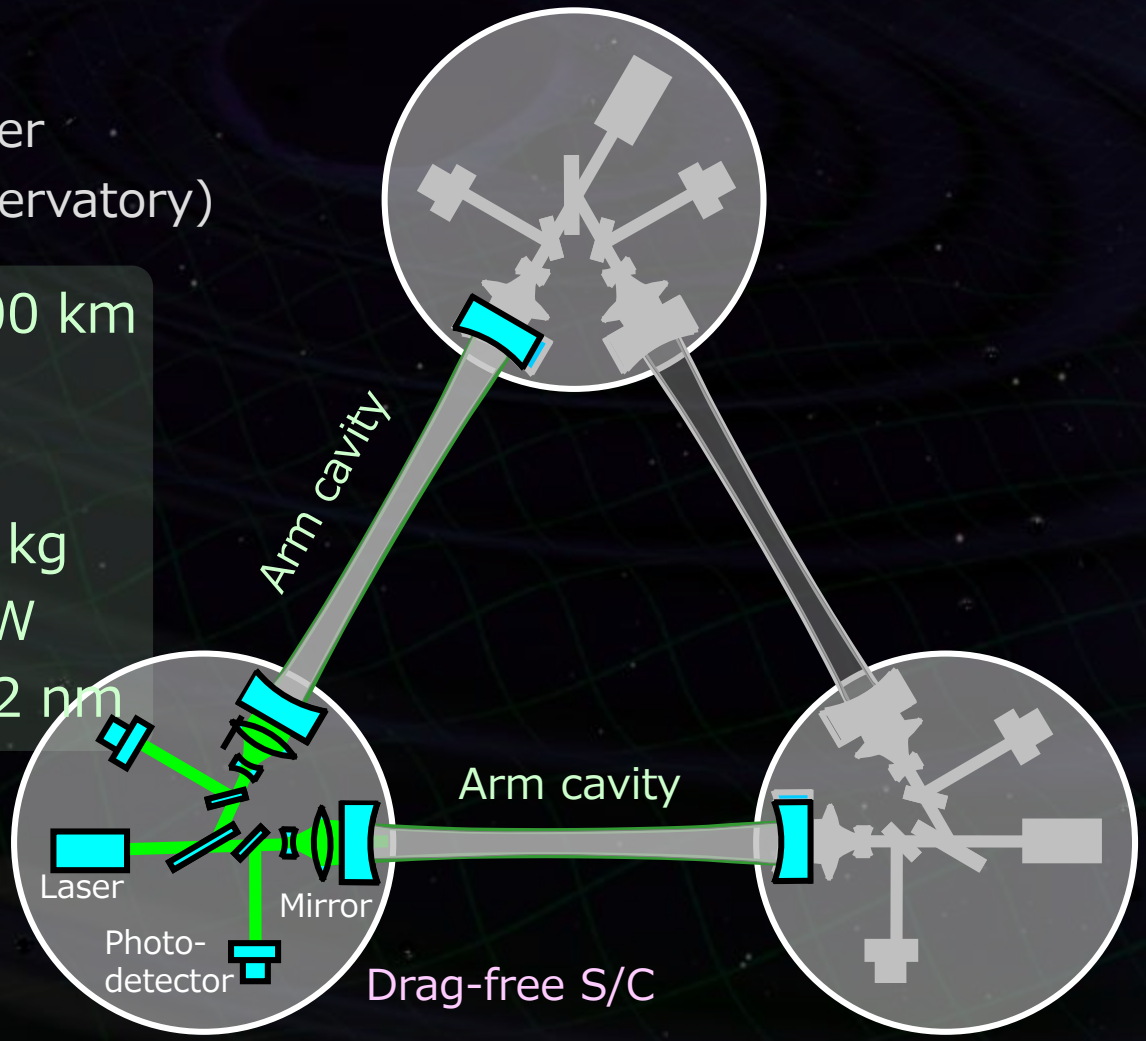
Conceptual Design

DECIGO

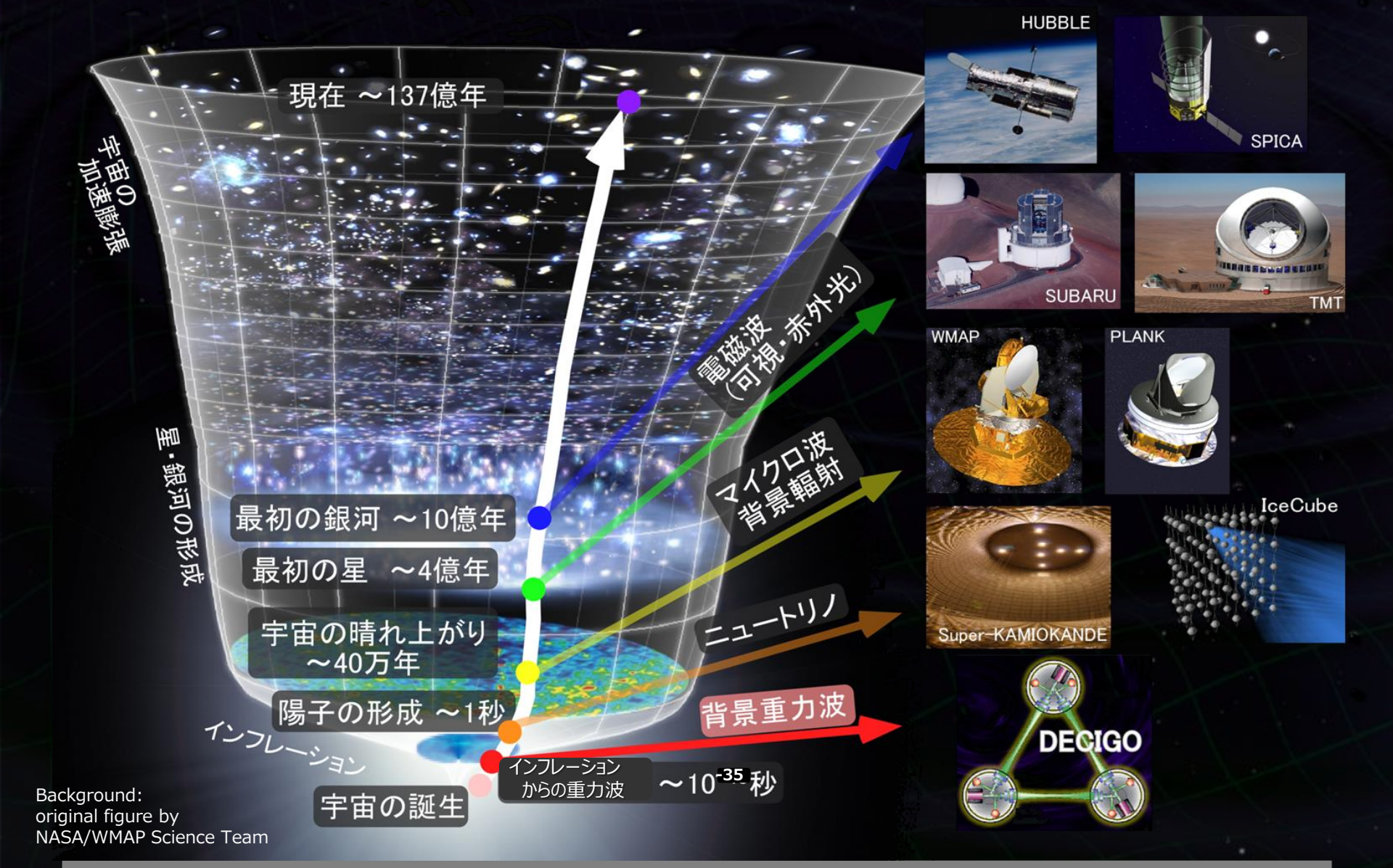
(DECI-hertz interferometer
Gravitational wave Observatory)

Arm length:	1000 km
Finesse:	10
Mirror diameter:	1 m
Mirror mass:	100 kg
Laser power:	10 W
Laser wavelength :	532 nm

S/C: drag free
3 interferometers



Observation of the Early Universe



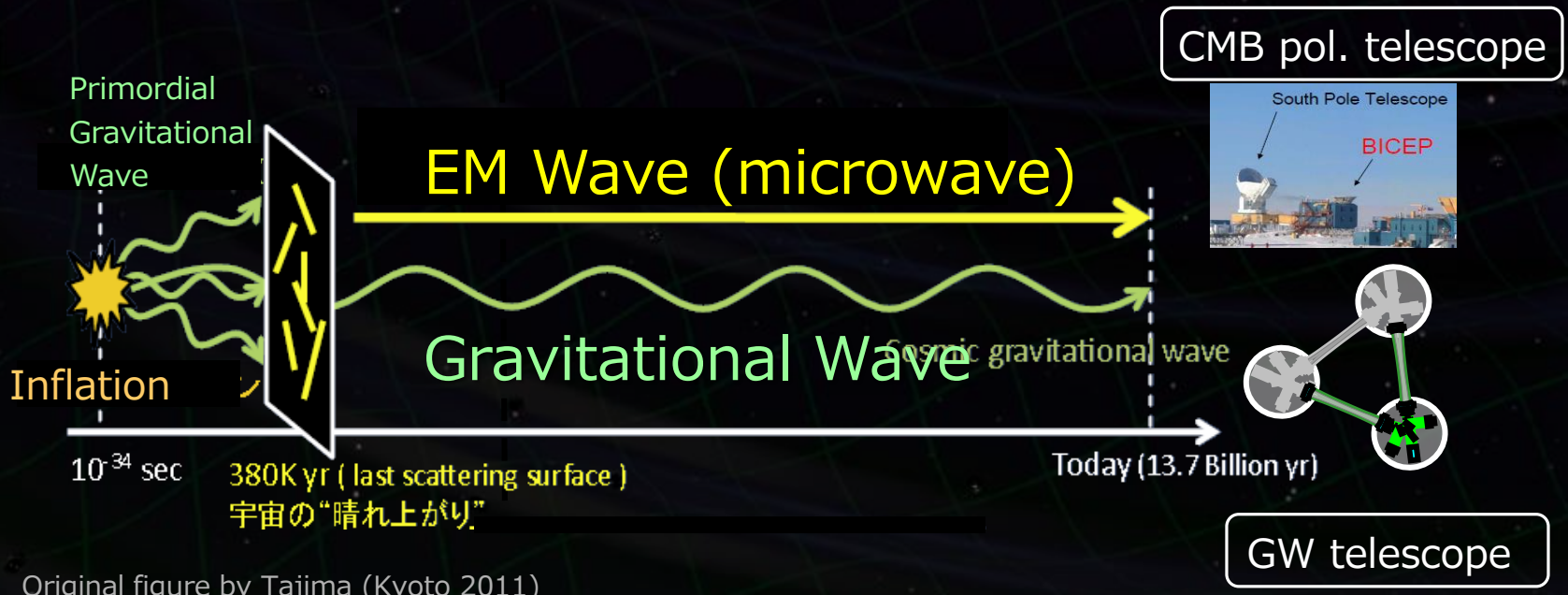
Observation of GW from Inflation

BICEP2 (LiteBIRD,…)

CMB B-mode polarization observation by micro-wave telescope.

DECIGO (KAGRA, aLIGO,…)

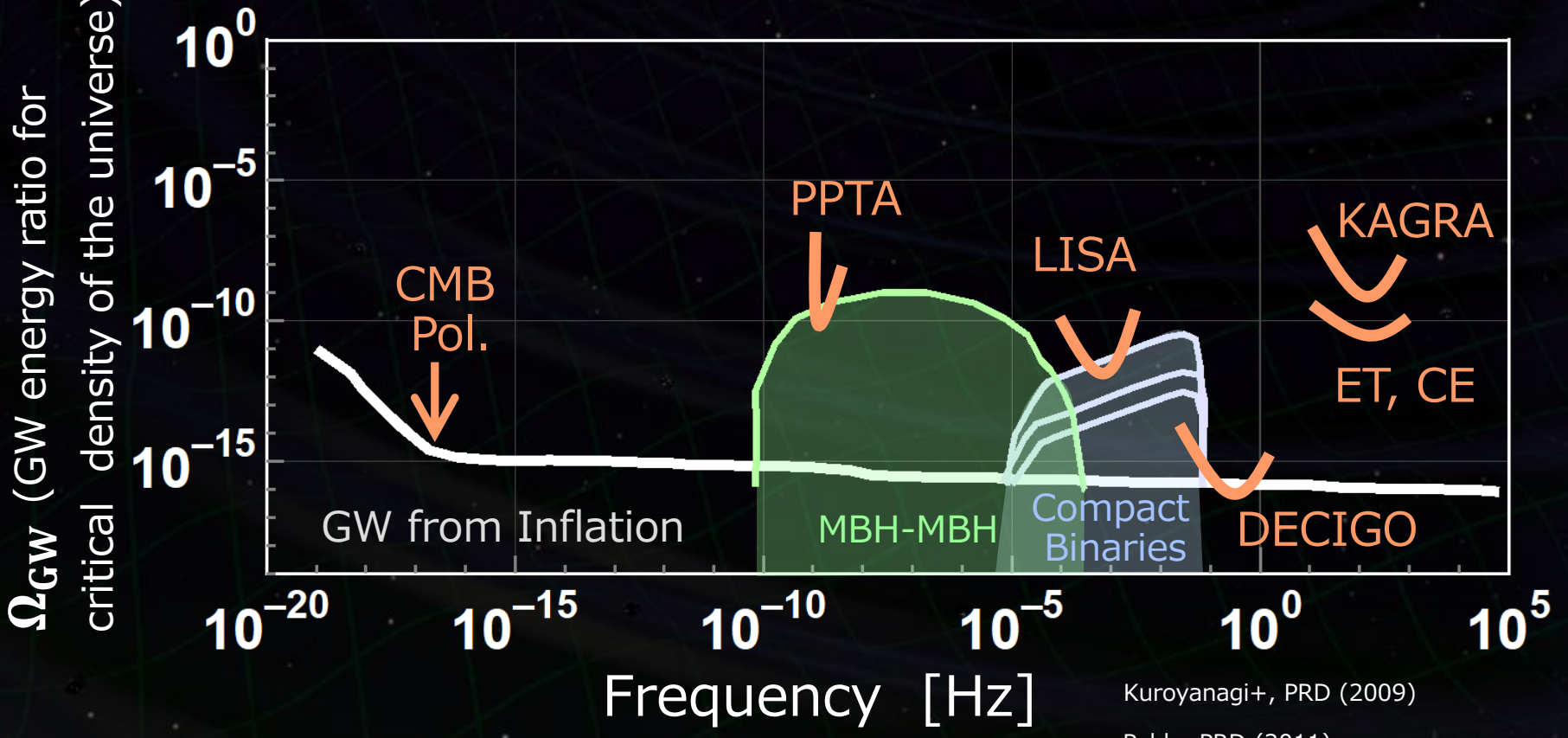
GWB observation by GW telescope.



Original figure by Tajima (Kyoto 2011)

‘Window’ for the Early Universe

DECIGO band is open window for direct observation of the early universe.



Kuroyanagi+, PRD (2009)

Pablo, PRD (2011)

Probing the Early Universe by GW

- GWs will carry direct information on the early universe.
- Spectrum : Initial fluctuation + Evolution history

Depends on r (tensor-to-scalar ratio), which may be also pinned-down by CMB B-mode polarization observation.

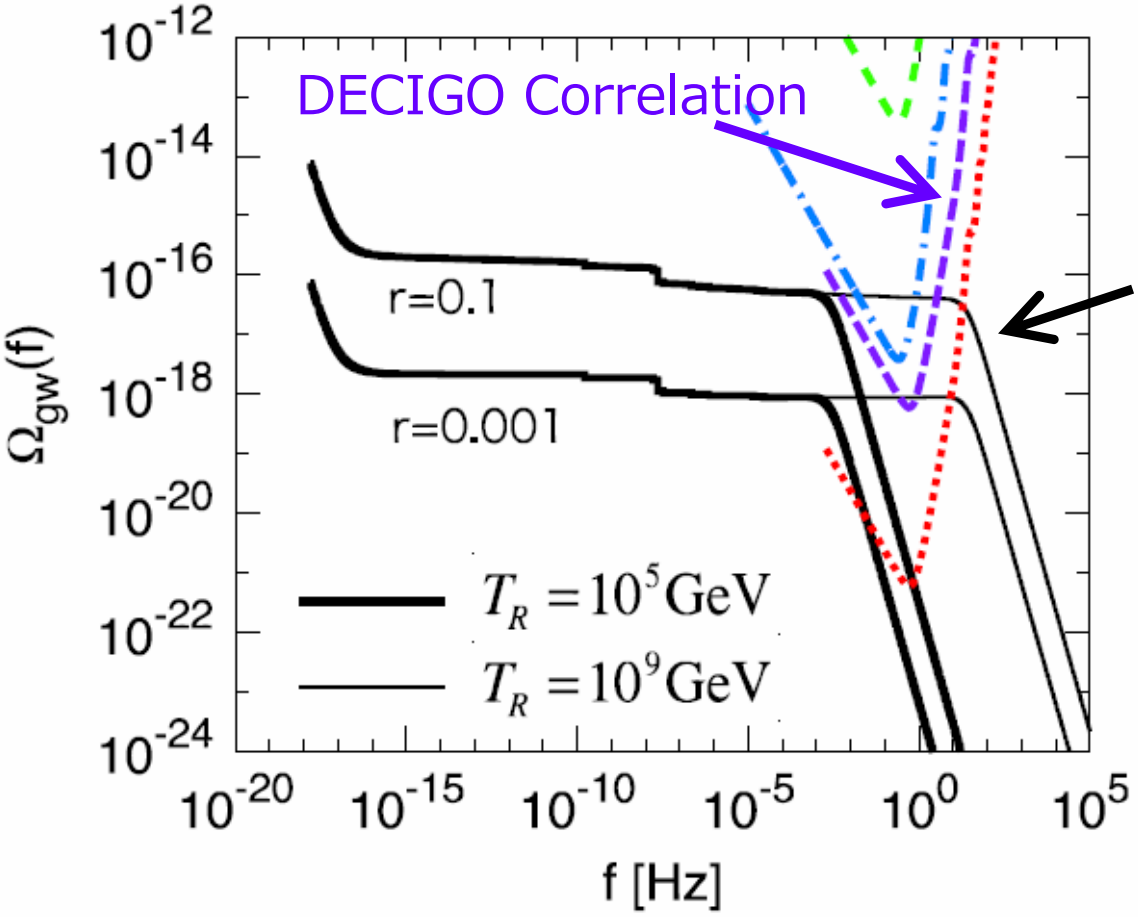
Different age in different freq.
Higher freq. → Earlier universe
- Reheating temperature
- Thermal history of the universe

….

GW from Inflation

Energy density ∝ Tensor-Scalar Ratio (r).

Power spectrum : Evolution history of the Universe.



- Spectrum Power.
  → Energy scale of inflation
- Cut-off freq.
  →Energy scale of Reheating

Nakayama+,
Journal of Cosmology and Astroparticle Physics 06 (2008) 020.

Summary

Summary

- First direct detection of GW was achieved by LIGO.
- GW from binary NS merger was detected. A lot of outcomes obtained together with EM follow-ups.
- New field of 'Gravitational-wave astrophysics' has started. We obtained a new prove to the universe.
- More range and more statistics are necessary.
  → Better sensitivity and different frequencies.
- Japanese KAGRA will improve the source parameter estimation accuracy. Best effort to join the network.
- B-DECIGO will provide fruitful sciences. Future DECIGO will be one of the dream of science; it will be able to observe the early universe directly.

End