Space gravitational wave antenna DECIGO

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Gravitational Wave Probes of Physics Beyond Standard Model
Noise curves of GW detectors

What kind of detector?
Scientific targets
Primordial GW backgrounds
Cosmological binaries
Basic design of DECIGO

Why FP cavity?

Transponder type

Shorten arm length

Implement FP cavity

More photons available (high-f)

(cf) Kawamura et al. CGQ 2011

$$\delta h \sim \frac{\int dt \int dt \delta a}{L} \quad \text{(low-f)}$$

More stringent acceleration noise requirement

Better shot-noise-limited sensitivity
Pre-conceptual design

Differential FP interferometer

Arm length: 1000 km (LISA 2.5Mkm)
Mirror diameter: 1 m
Laser wavelength: 0.515 µm
Finesse: 10
Laser power: 10 W
Mirror mass: 100 kg
S/C: drag free
3 interferometers

from Kawamura
Roadmap updated

~2030?

<table>
<thead>
<tr>
<th>Mission</th>
<th>R&amp;D Fabrication</th>
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<th>R&amp;D Fabrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWIM</td>
<td>DICIGO Pathfinder</td>
<td>B-DECIGO</td>
<td>DECIGO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Test of key technologies</th>
<th>Detection of GW w/ minimum spec. Test FP cavity between S/C</th>
<th>Full GW astronomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope</td>
<td>1 S/C, 1 arm</td>
<td>3 S/C, 3 interferometer</td>
<td>3 S/C, 3 interferometers, 4 clusters</td>
</tr>
</tbody>
</table>

from Kawamura
>10 better sensitivity
Orbit and constellation (preliminary)

4 units would be used

from Kawamura
Science targets of DECIGO -outline-

• Stochastic GW backgrounds
  – primordial backgrounds
  – Correlation analysis

• Cosmological binaries (s-BH, NS)
  – Foreground subtraction problem
  – Use them as powerful science tools

• GWs from Intermediate mass BHs (IMBHs)
Stochastic GWs from Early Universe

Gravitational interaction: weak
GWs: extremely high permeability

Directly catch wave oscillation
Probes the generation and history

Important fossil

Strong candidate: GWs generated during Inflation (next slide)
Expected present-day spectrum

\[ T_{RH} = 10^9 \text{GeV} \]

Energy density \( \rho_{gw} / \rho_{cr} \) vs. frequency in \( \log_{10} f [\text{Hz}] \) for different probes and models:

- DECIGO
- Upgraded DECIGO
- BBO
- Ultimate DECIGO

Models:
- Model (i): \( m^2 \phi^2 / 2 \)
- Model (ii): \( \phi = 7M_{pl} \)
- \( \lambda \phi^4, \xi = 0 \)
- \( \lambda \phi^4, \xi = -0.005 \)

\( \text{CMB} \approx 10^{-17} \text{Hz} \)

Probes:
- Probe A
- Probe A, B

Complementary probes:
- 0.1 Hz

A. Generation: potential shape

×

Transfer function

B. Cosmic history
Correlation analysis for GWB

Correlate two (noise) independent detectors

\[ S_1 = h + n_1 \]
\[ S_2 = h + n_2 \]

Separation << wavelength

\[ S_1 S_2 = hh + n_1 n_2 + h(n_1 + n_2) \]
\[ \int dt \propto T \]
\[ \propto T^{1/2} \]

Sensitivity to \( \Omega_{GW} \propto T^{-1/2} \)

No correlation only with a single triangular unit

No overlap (cancel!)
Correlation analysis with DECIGO

Long-term signal integration

$\Omega_{GW} \propto h^2 f^3 \propto T^{-1/2}$

DECIGO
Designed to detect

$\Omega_{GW} \sim 10^{-16}$

Improve sensitivity goal?
Outline

• Stochastic GW background from Early Universe
  – GW background generated during inflation
  – Correlation analysis

• GWs from cosmological compact binaries (s-BH, NS)
  – Foreground subtraction problem
  – Use them as powerful science tools

• GWs from IMBHs
Forefront cleaning around 0.1-1Hz

Pioneering work by Cutler & Harms 06 for NS-NSs (DNSs)

Many merger events after GW150914
1. Higher NS-NS (DNS) rate $100\text{Gpc}^{-3}\text{yr}^{-1} \rightarrow \sim 300\text{Gpc}^{-3}\text{yr}^{-1}$
2. Existence of BBH $\sim 30+30\text{M}_{\odot} \rightarrow \sim 30\text{Gpc}^{-3}\text{yr}^{-1}$

$$\Omega_{GW} \propto h^2 \propto \text{rate} \times \text{mass}^{5/3}$$

Foreground noise amplitudes become much stronger
Binary Subtraction

- Sufficient data amount
  - # of fitting parameters: $10 \times 10^5 \text{/yr}$
  - # of data amount: $1 \times (3 \times 10^7) \text{/yr}$

- Redshift dependence
  - $\text{SNR} \propto (1+z)^{-1/6}$
  - Rotation cycles: smaller at high-$z$

- Nearly sufficient sensitivity

- Complicated/weak signals?
Individual DNSs (BBHs)

- **New tools for physics, cosmology and astronomy**
  - large number, DNS: $\sim O(10^5/\text{yr})$
    - Must be identified for detecting primordial GWs
  - Large cycles with $\sim 10$ fitting parameters
    - Examine theory of gravity
  - Good sky localization + distance measurement
    - Dark energy
  - Merger time: predictable
    - GRB,…

Results for BBO (Cutler & Holz 09)
Summary

• **DECIGO: FP-type**
  - Shorter arm length
    - Larger photon number (suppress shot noise)
    - Stringent requirement on acceleration noise

• **Scientific targets**
  - Primordial GWB ($\Omega_{GW} \sim 10^{-16}$)
    - Strong candidate: inflation background
    - Correlation analysis
  - Individual compact binaries
    - Foreground cleaning is essential ($\Omega_{GW} \sim 10^{-10}$)
    - Powerful tools for cosmology/astronomy (Dark energy..)
      - Sky localization for Host galaxy identification, reliable distance,..