Science with the TianQin observatory: Preliminary results on stellar-mass binary black holes

Shuai Liu
TianQin Research Center for Gravitational Physics & School of Physics and Astronomy, Sun Yat-sen University

Collaborators: Yi-Ming Hu, Jian-dong Zhang, Jianwei Mei

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中山大學天琴中心
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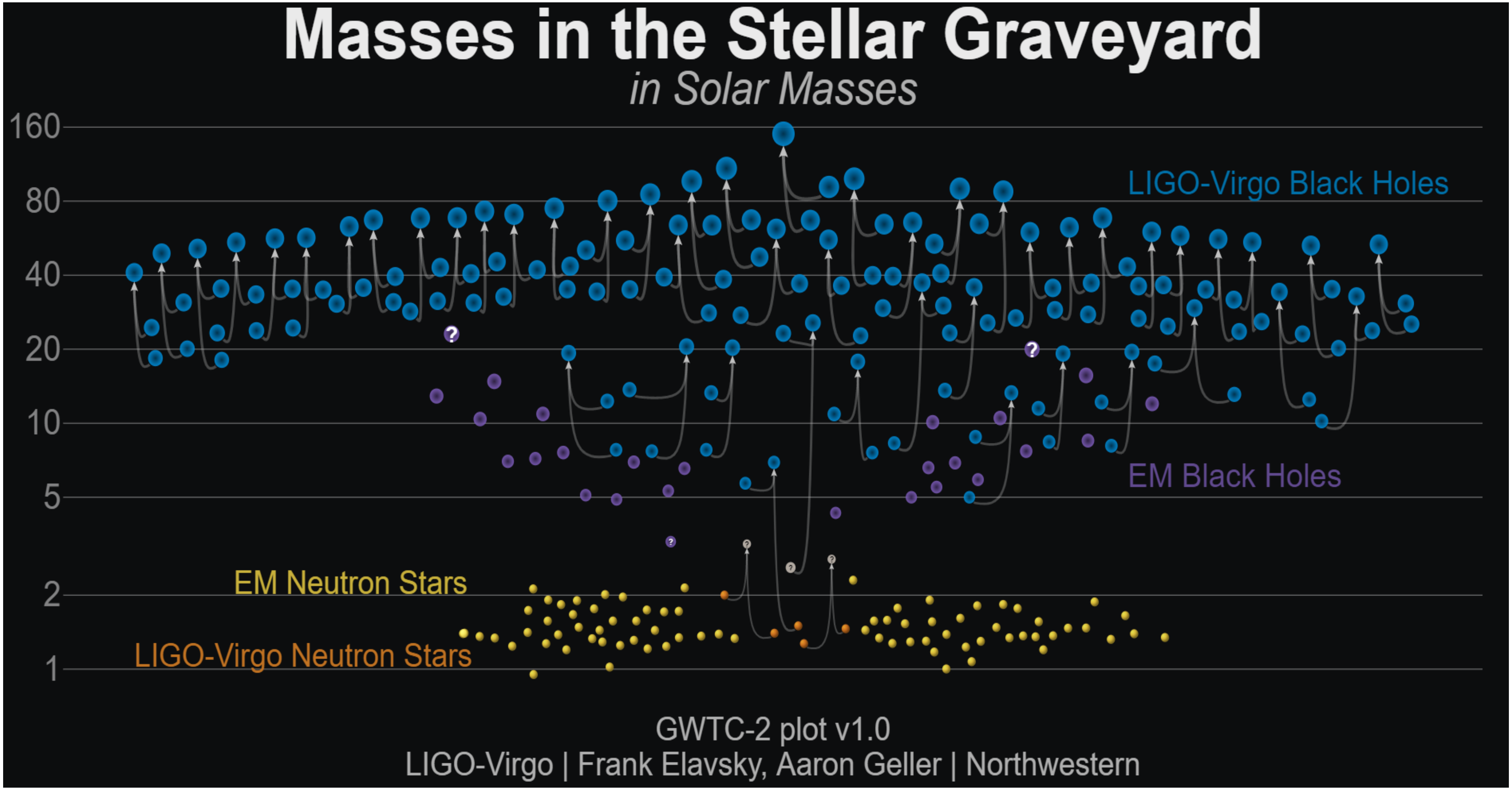
Outline

1. Background
2. Methods
3. Main results
4. Summary

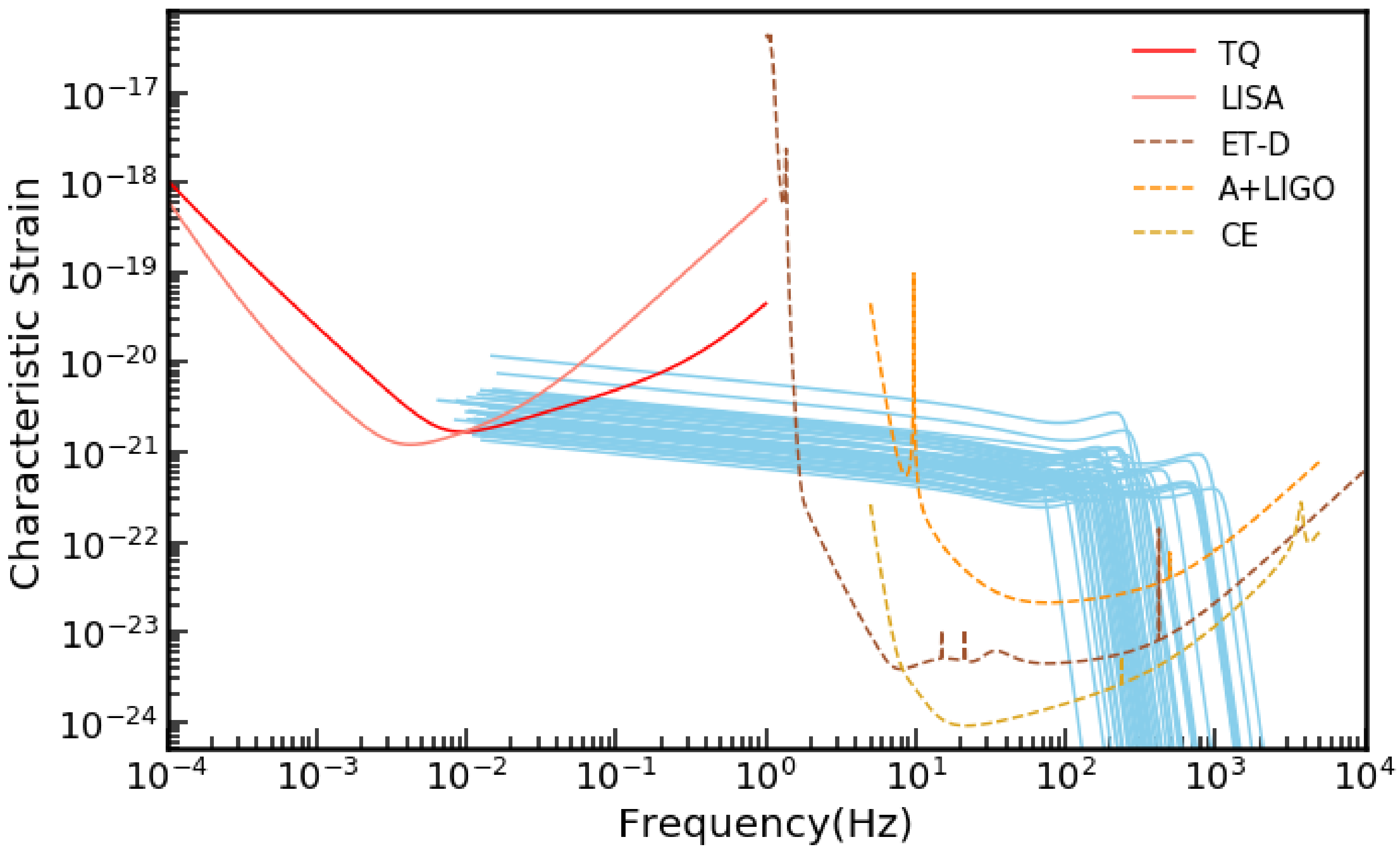
SBHs observed by aLIGO/Virgo are heavier



Credit LVC

The multiband observation for SBBHs

- Some massive SBBHs are in band of space-borne detectors



The work on SBBHs observed in space

☐ To study the capability of detection for SBBHs

- **eLISA/LISA**

  [1] Sesana, 2016, Phys. Rev. Lett., 116, 231102
  [2] Seto, MNRAS. 460(2016) no.1, L1-L4

- **Pre-DECIGO/DECIGO**

  [3] Nakamura, PTEP 2016 (2016) no.9, 093E01
  [4] Nair et al., PTEP 2016 (2016) 5, 053E01

☐ To distinguish the formation channel of SBBHs

- **Orbital eccentricity:**

  [5] Seto, MNRAS. 460(2016) no.1, L1-L4
  [6] Nishizawa et al., Phys. Rev. D 94, 064020 (2016)

- **Imprint of center of mass acceleration on GW signals**

  [7] Inayoshi et al., Phys. Rev. D 96, 063014 (2017)

☐ To constrain Hubble constant

- **Luminosity distance**

  [8] Del Pozzo et al. MNRAS, no. 3, 3485 (2018)

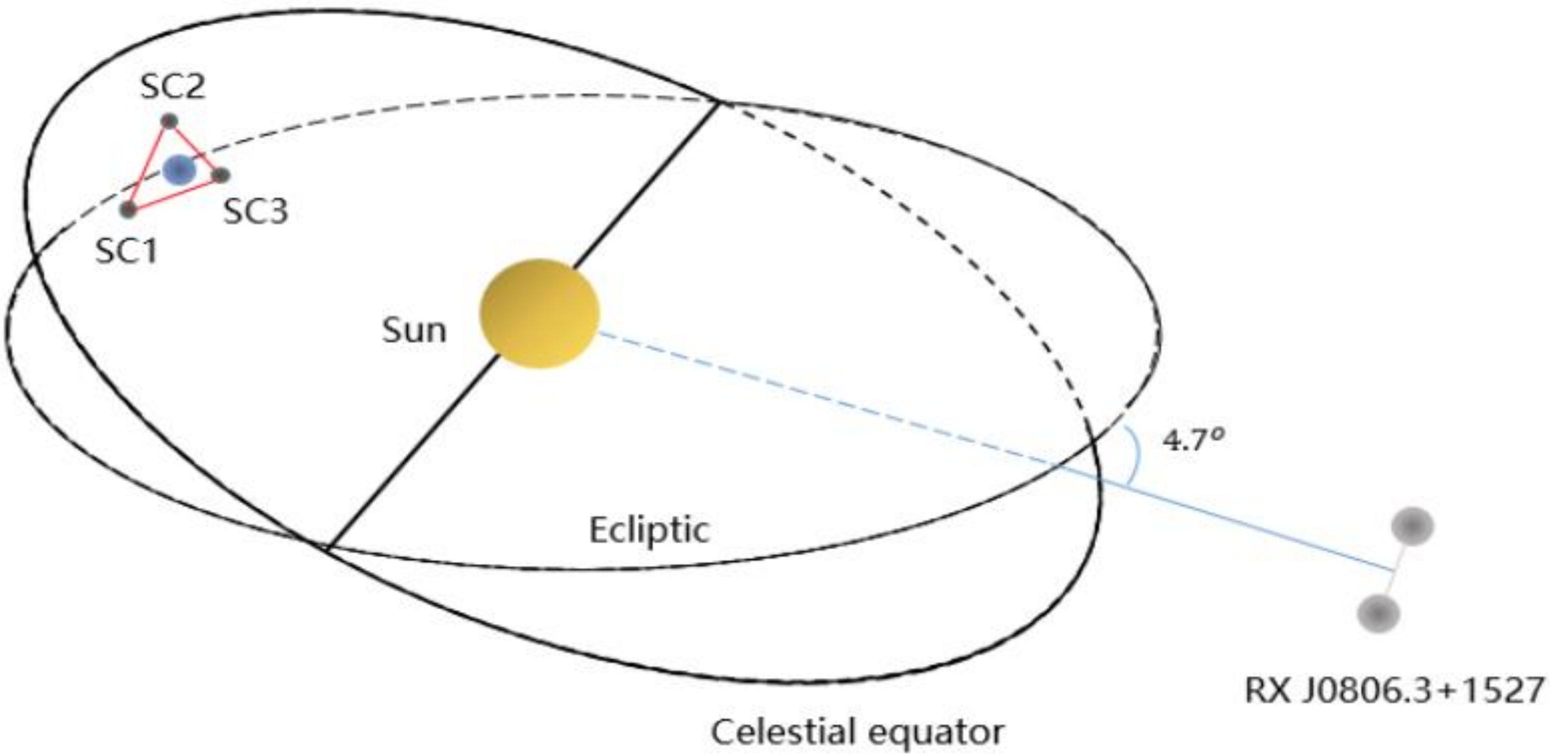
☐ To test GR

- **Dipole radiation parameter**

  [9] Barausse et al., Phys. Rev. Lett. 116, 241104 (2016)

TianQin (TQ)

- TQ is a space-borne GWs detector proposed by China [10]

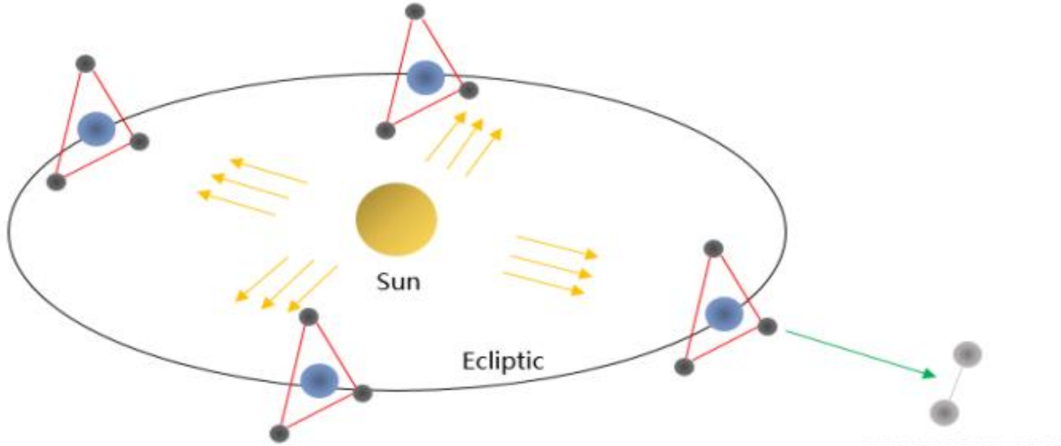


[10] Luo et al., Class. Quant. Grav. 33 (2016) 3, 035010

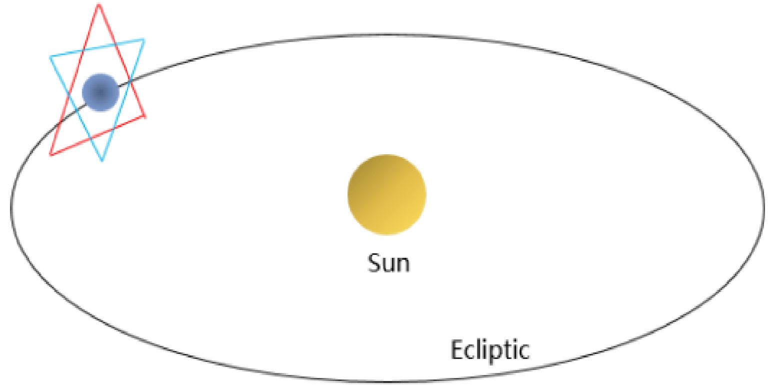
TianQin

☐ Observation scenario (Operation period is 5yr)

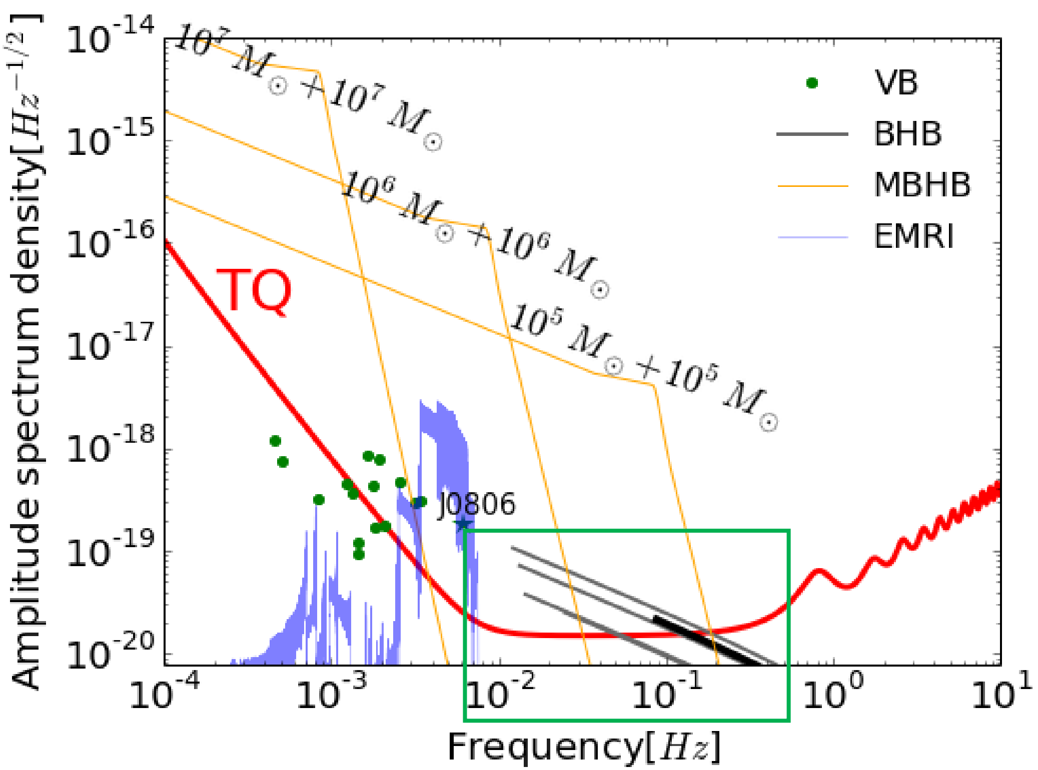
- **One constellation, TQ: 3 months on+3months off, the effective T_{obs} is 2.5yr**



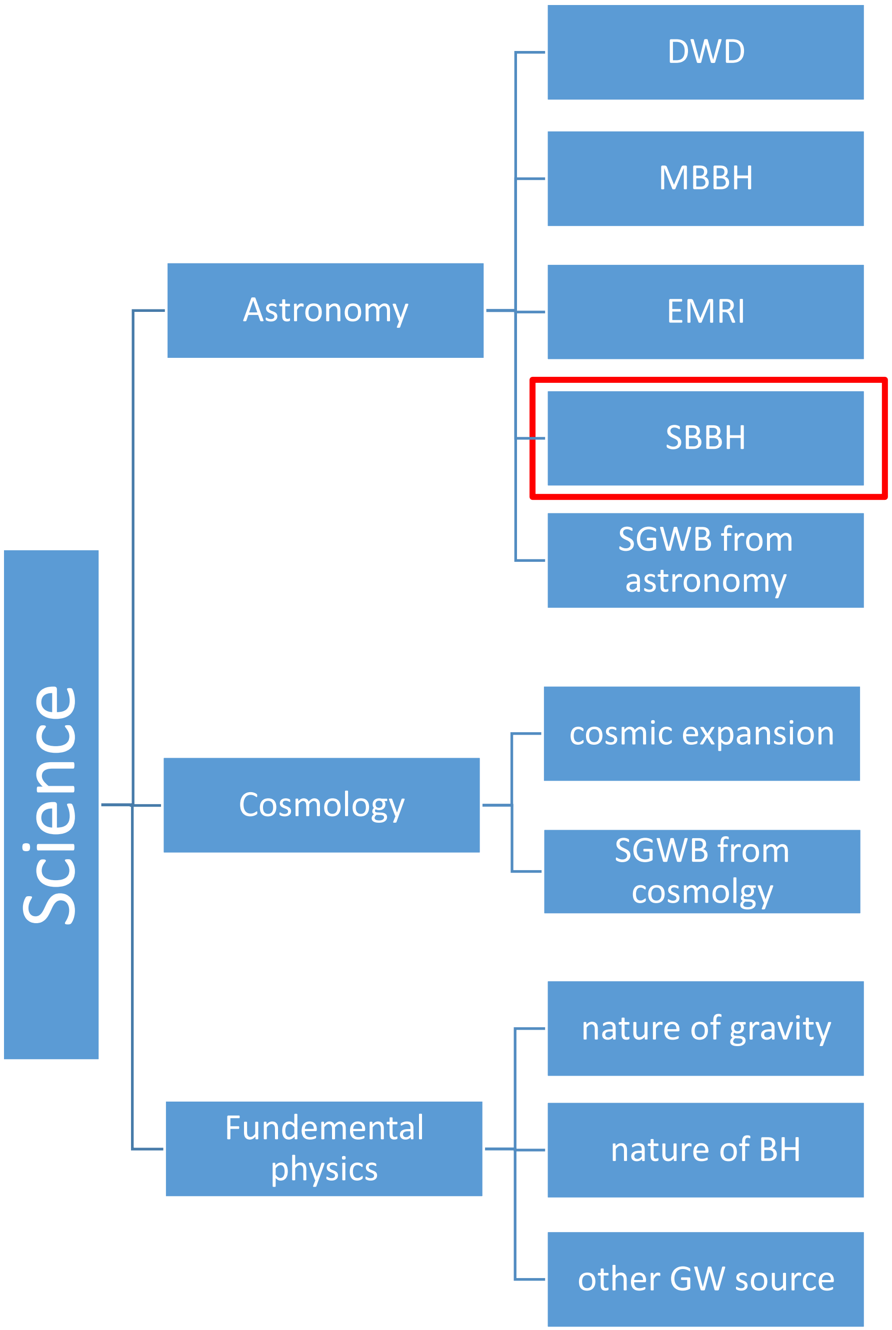
- **Two constellations, TQ I+II: observe alternately, the effective T_{obs} is 5yr**



Science with TianQin



[11]



[11] Hu et al., Natl. Sci. Rev. 4 (2017) no. 5, 683-684

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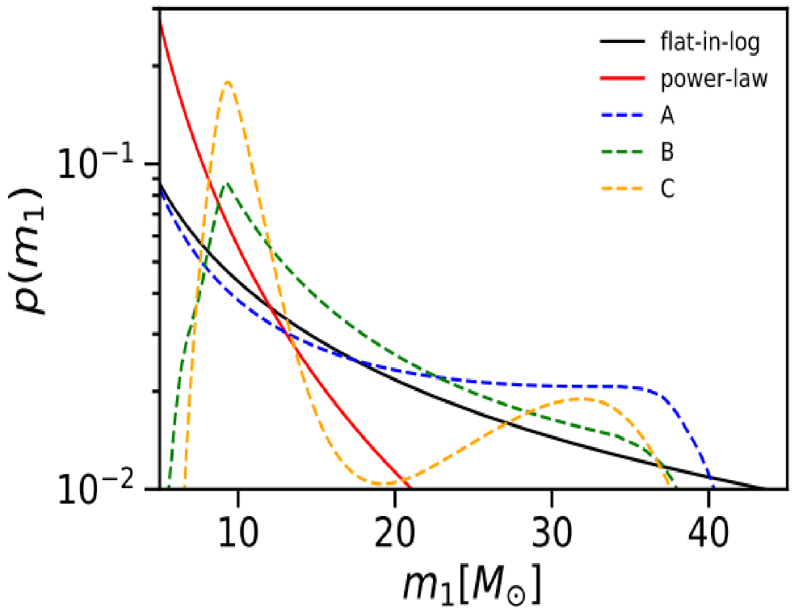
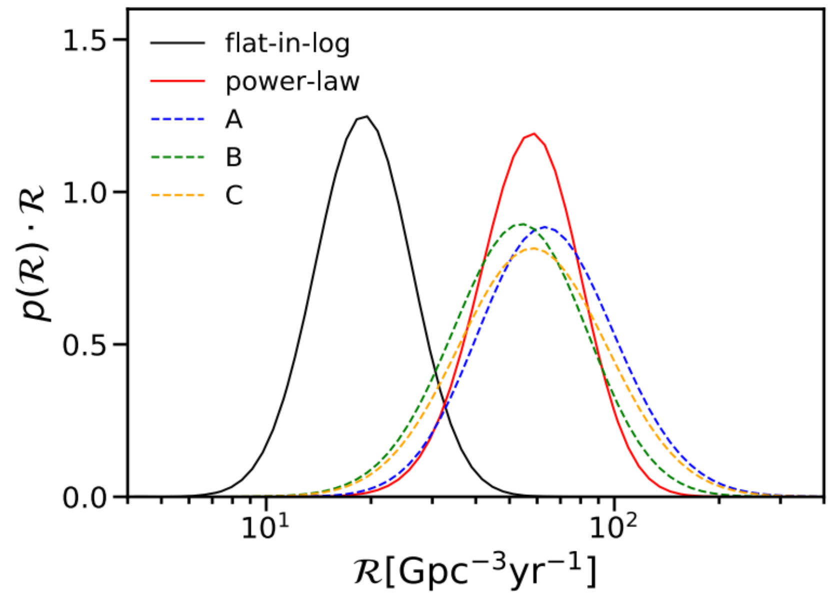
The mass distributions of SBBH

◻ We adopt five distributions [12]



m_1 **distribution [4]**



Merger rate distribution [4]

catalog of SBBHs

[12] LIGO Scientific and Virgo Collaborations, Astrophys. J. Lett. 882 (2019) 2, L24

The response signal

□ When GWs reach a detector, the detector will respond

- **The response signal in time domain [13]**

$$h(t) = \frac{\sqrt{3}}{2}\left[h_{+}(t)F^{+} + h_{\times}(t)F^{+}\right]$$

here, the factor $\frac{\sqrt{3}}{2}$ comes from the angle 60° between two arms

FFT

- **The response signal in frequency domain**

$$\tilde{h}(f) = \frac{\sqrt{3}}{2}\left[\tilde{h}_{+}(f) \star \tilde{F}^{+}(f) + \tilde{h}_{\times}(f) \star \tilde{F}^{\times}(f)\right]$$

here, $\tilde{h}_{+,\times}(f)$ and $\tilde{F}^{+,\times}(f)$ are the waveform and response function in frequency domain, respectively.

3PN waveform with eccentricity [14]. 3PN is sufficiently accurate for an unbiased recovery of the source parameters [15]

[13] Cutler, Phys. Rev. D57 (1998) 7089-7102
[14] Feng et al., Phys. Rev. D 99 (2019) 12, 123002
[15] Mangiagli et al., Phys. Rev. D 99 (2019) 6, 064056

The signal-to-noise ratio (SNR)

◻ The expression of SNR

- **For one detector [16]**

$$\rho = (h|h)^{1/2},$$

the definition of inner product is

$$(h|g) = 2\int_{f_i}^{f_f} \frac{\tilde{h}^*(f)\,\tilde{g}(f) + \tilde{g}^*(f)\,\tilde{h}(f)}{S_n(f)} df,$$

where h is the waveform, $S_n(f)$ is the power spectral density (PSD) of a detector.

- **For a detector network [17]**

$$\rho = \sqrt{\sum \rho_i^2},$$

where ρ_i is the SNR of ith detector.

[16] Cutler et al., Phys. Rev. D 49:2658-2697,1994
[17] Berti, et al., Phys. Rev. D 71 (2005) 084025

The Fisher information matrix (FIM)

☐ The expression of FIM

- In the case with high enough SNR, for one detector, the distribution of the error for parameters $\Delta\theta$ is [16]

$$p(\Delta\boldsymbol{\theta}) \propto exp\left(-\frac{1}{2}\Gamma_{ab}\Delta\theta^{a}\Delta\theta^{b}\right),$$

where Γ_{ab} is the FIM

$$\Gamma_{ab} = (\frac{\partial h}{\partial \theta^{a}} | \frac{\partial h}{\partial \theta^{b}}),$$

- For a detector network [17]

$$\Gamma_{ab} = \sum \Gamma_{ab}^{(i)},$$

where $\Gamma_{ab}^{(i)}$ is the FIM of ith detector.

- The precision of parameter θ^{a} is

$$(\Delta\theta^{a})_{rms} = \sqrt{(\Gamma^{-1})^{aa}}$$

where Γ^{-1} is the inverse matrix of FIM.

[16] Cutler et al., Phys. Rev. D 49:2658-2697,1994
[17] Berti, et al., Phys. Rev. D 71 (2005) 084025

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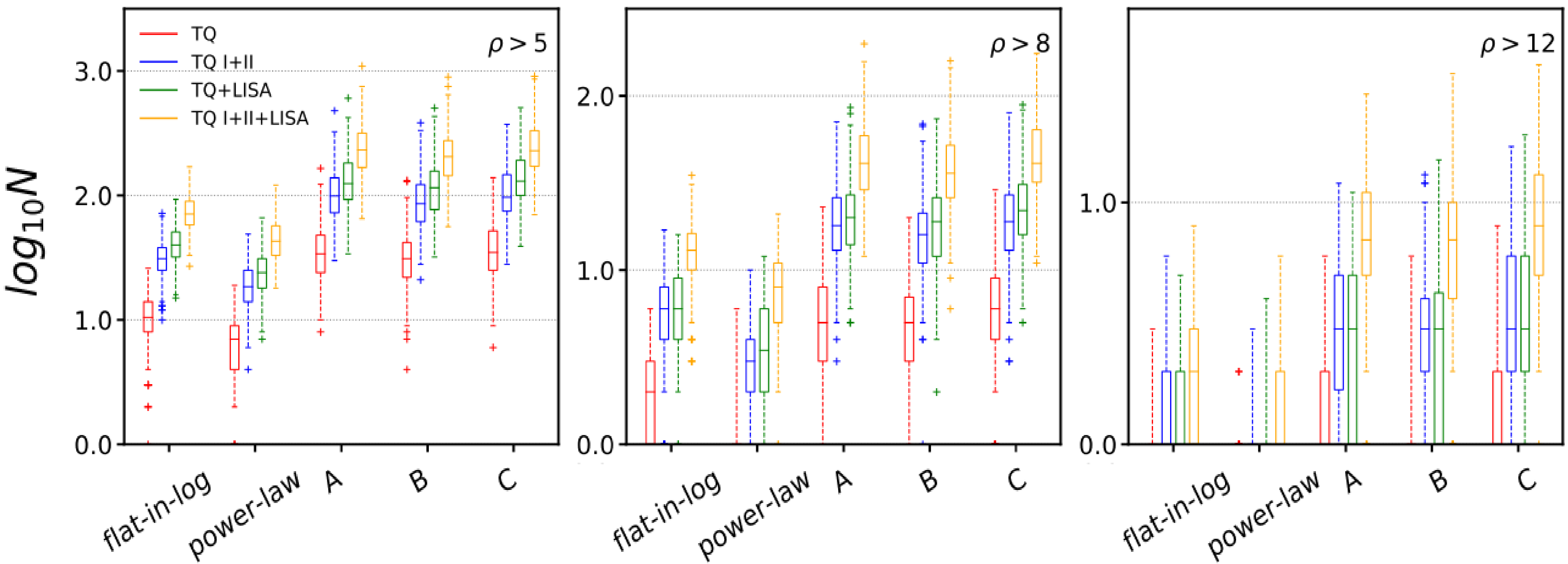
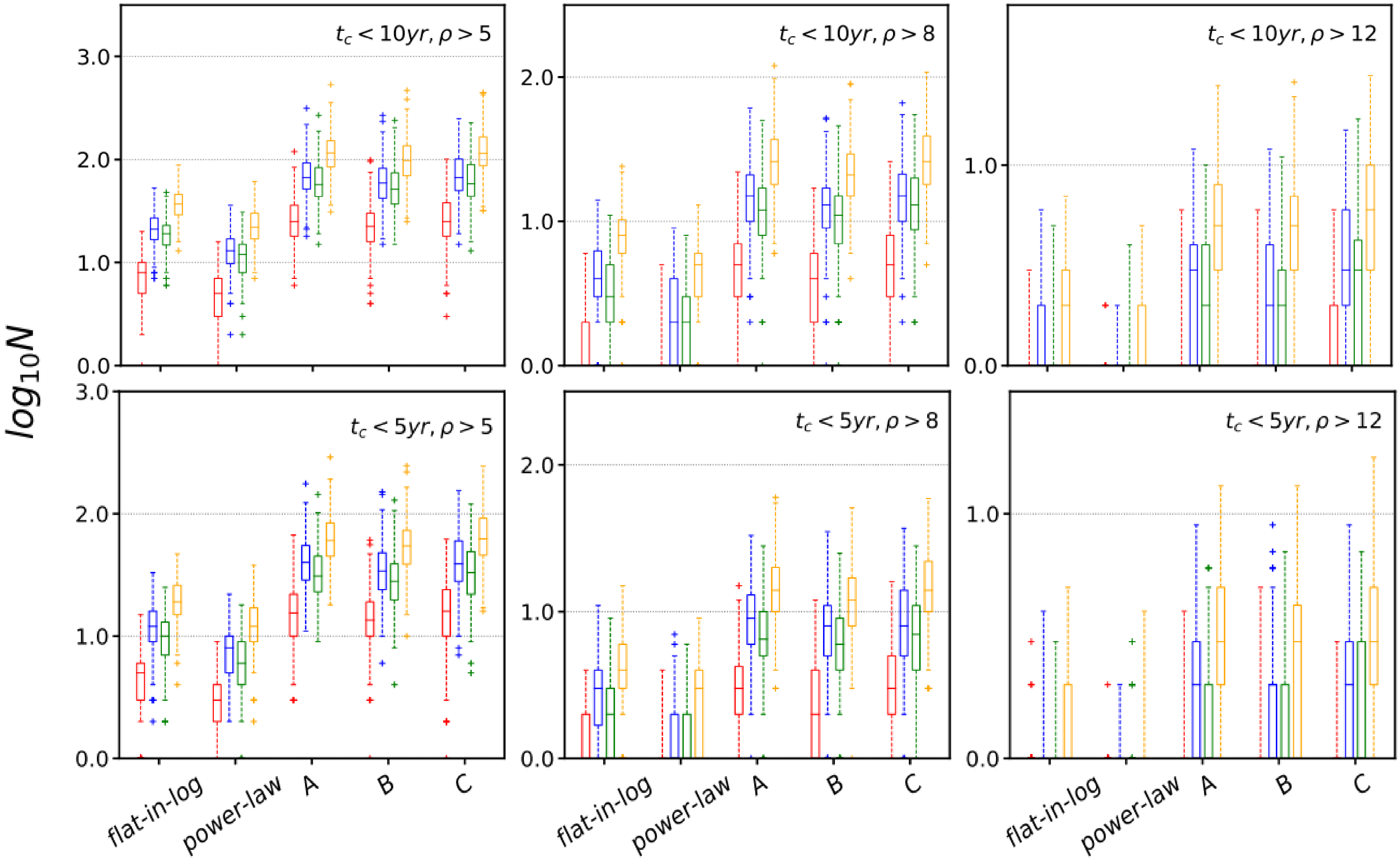
Detection number

◻ The total detection number



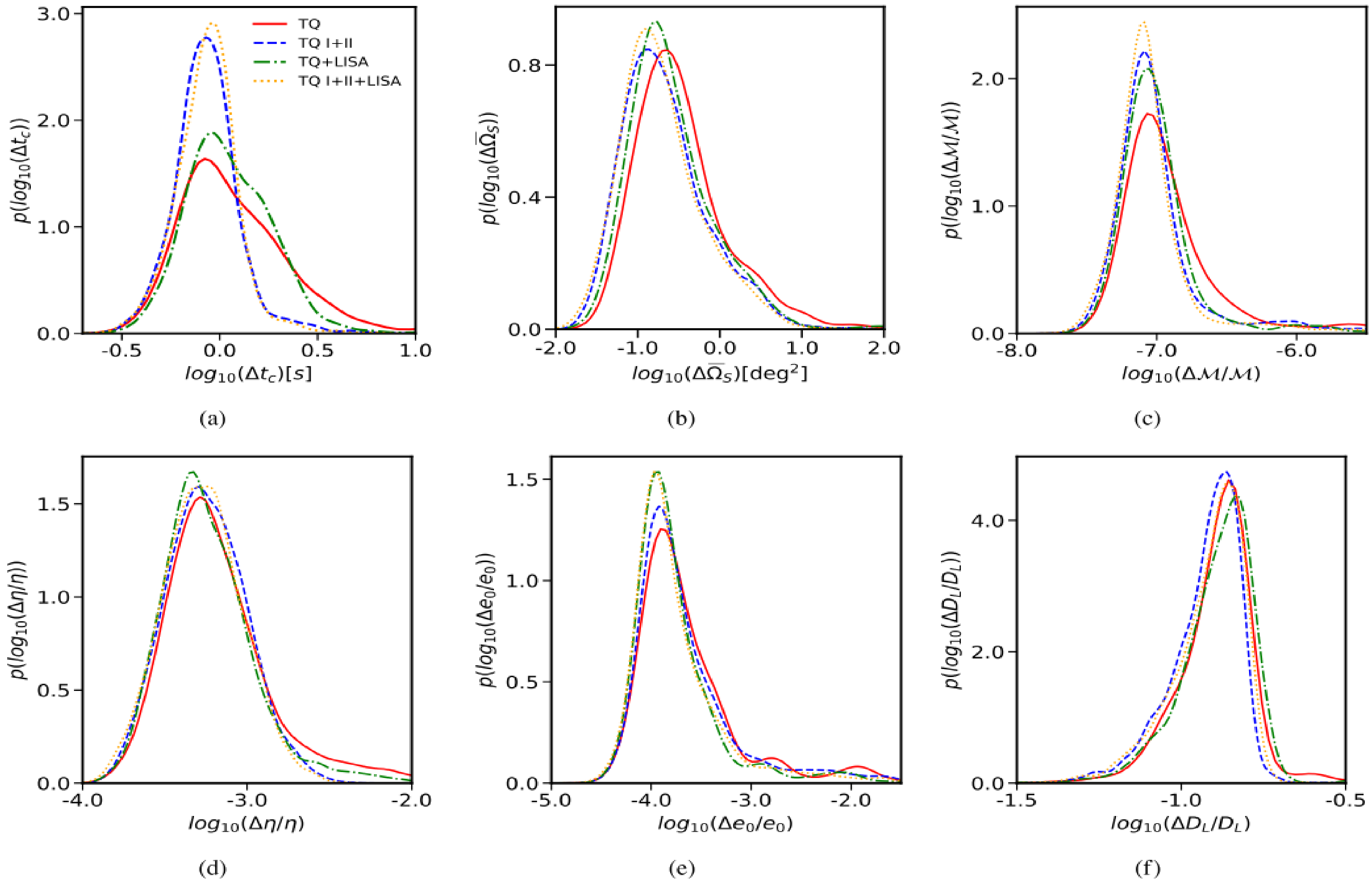
Detection number

◻ The detection number for SBBHs with t_c <10yr and 5yr



The parameters estimation precision

- SBBHs with $t_c < 5$ yr and $\rho > 8$ from model C



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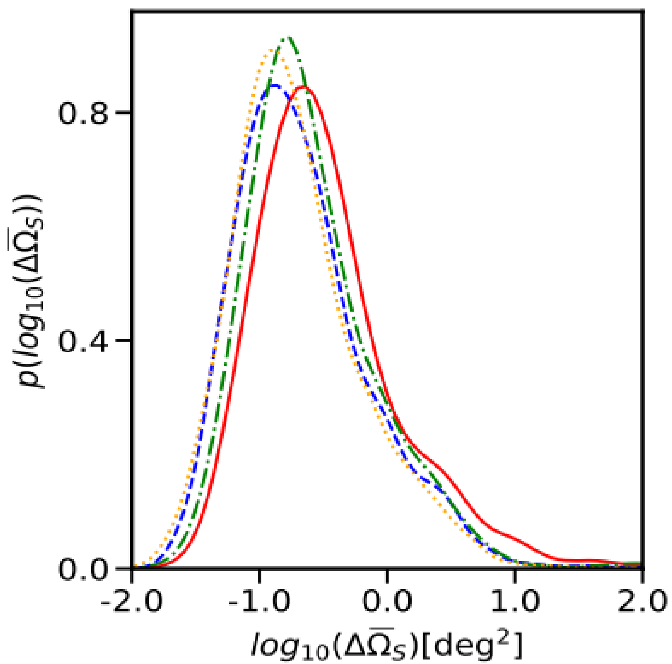
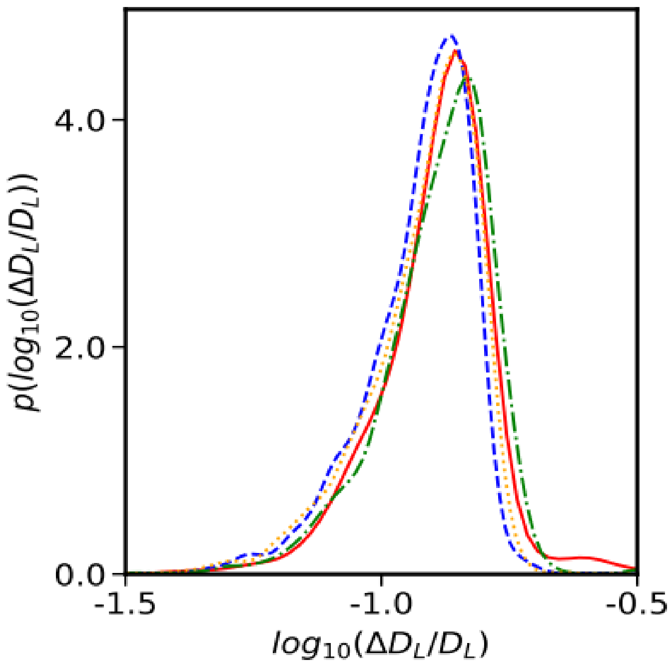




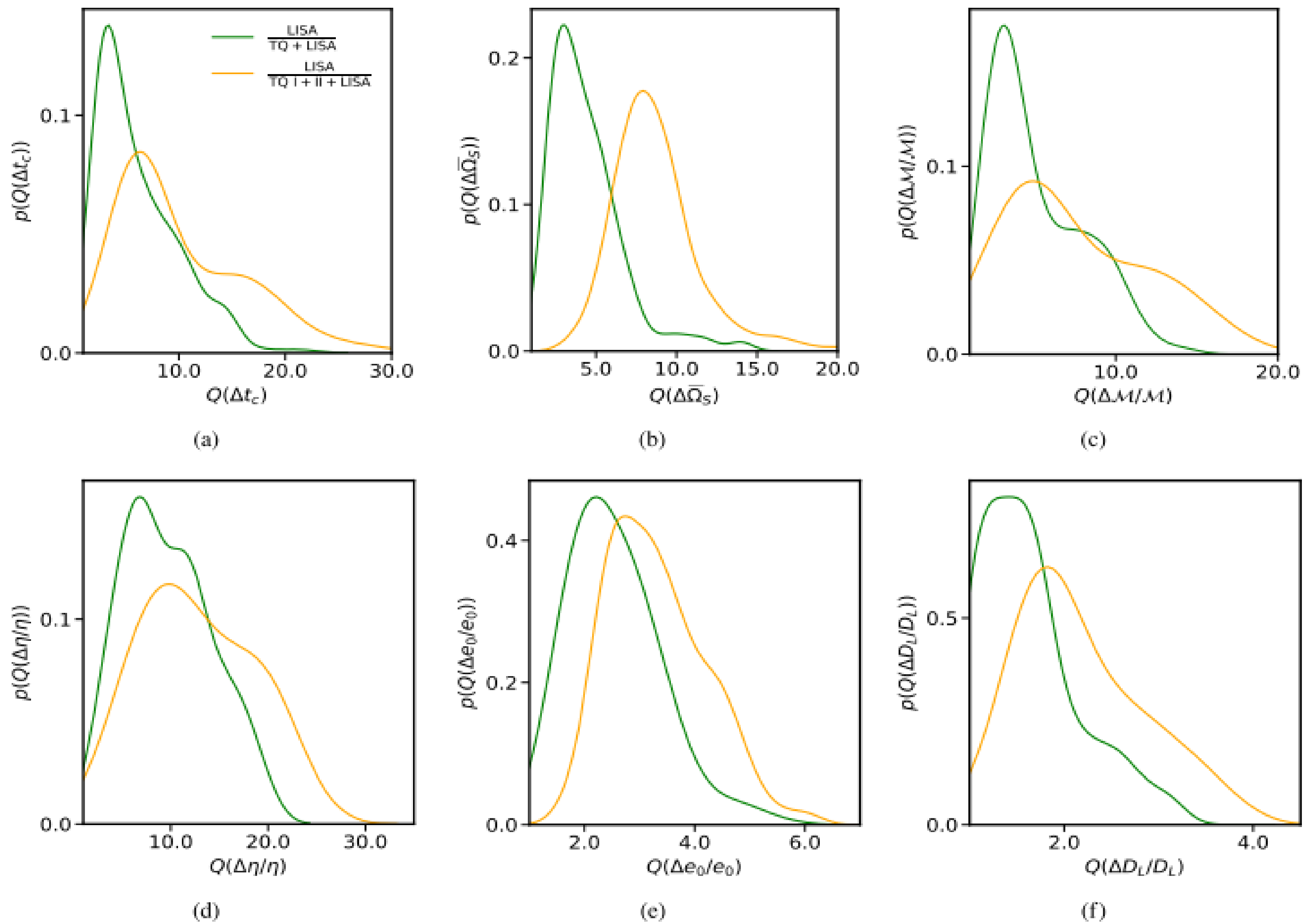
error volume $\Delta V \sim D_L^2 \Delta\bar{\Omega}_S \Delta D_L \sim 50 Mpc^3$
average density of galaxy $\sim 0.01 Mpc^{-3}$

⇓

TQ could identify the host galaxy which SBBHs reside in

The parameters estimation precision

☐ Precision improvement compared to LISA for same SBBHs



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The summary

□ The detection capability of TianQin for SBBHs

- **TQ could detect several to dozens of SBBHs**
- **TQ could provide early warning for ground GWs and EM observation**

  $\Delta t_c \sim 1s$， $\Delta\bar{\Omega}_s \sim 1deg^2$

- **TQ could distinguish formation channels of SBBHs by measuring eccentricity**

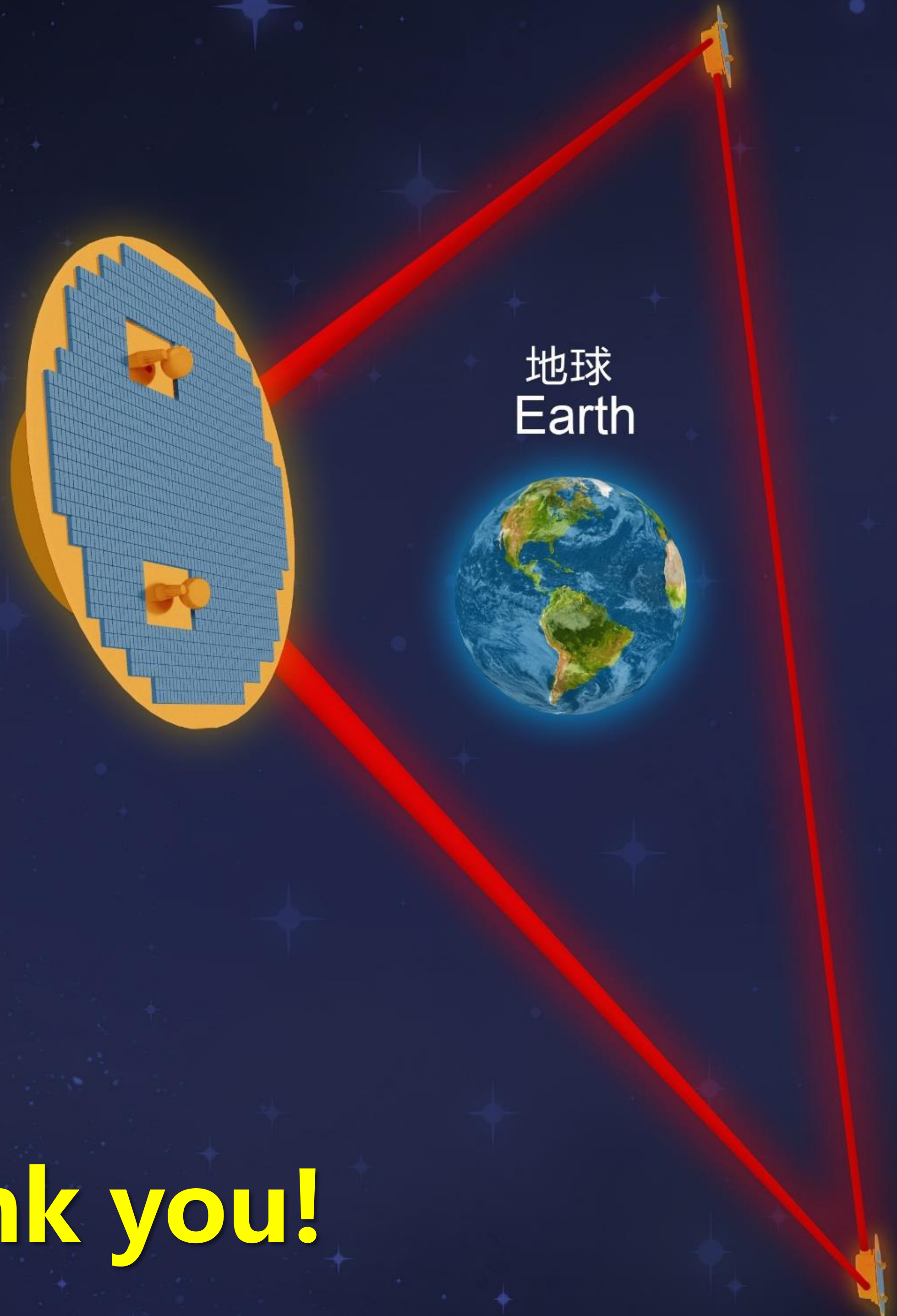
  $\Delta e_0/e_0 \sim 10^{-4}$

- **TQ has the potential to constrain the Hubble constant**

  $\Delta D_L/D_L \sim 0.1$

- **TQ could measure the SBHs mass**

  $\Delta M_c/M_c \sim 10^{-7}$， $\Delta\eta/\eta \sim 10^{-3}$



Thank you!