Exploring the Gravitational-Wave Universe: Science Cases for Taiji

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The International Conference on Fundamental Physics From Quanta to Cosmos

Outline

- **Introduction to Taiji**
- **Taiji sciences**
  - ✓ **Galactic compact binaries**
  - ✓ **Massive/Intermediate mass binary black holes**
  - ✓ **Extreme/intermediate mass ratio inspirals**
  - ✓ **Stellar binary black holes**
  - ✓ **Cosmic origin signals**
  - ✓ **Cosmology**
  - ✓ **Fundamental physics**
- **Summary**

Introduction: Multi-frequency GW Sources

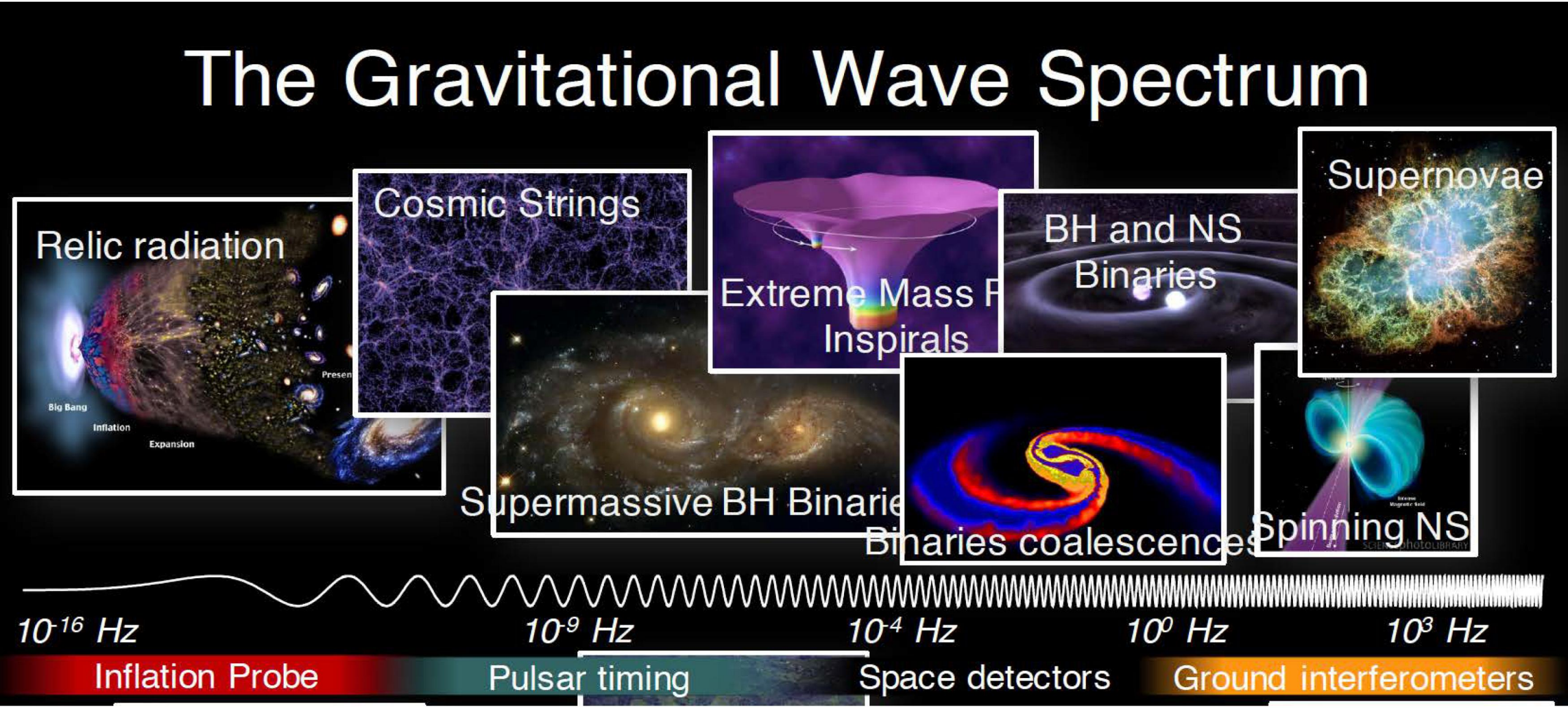
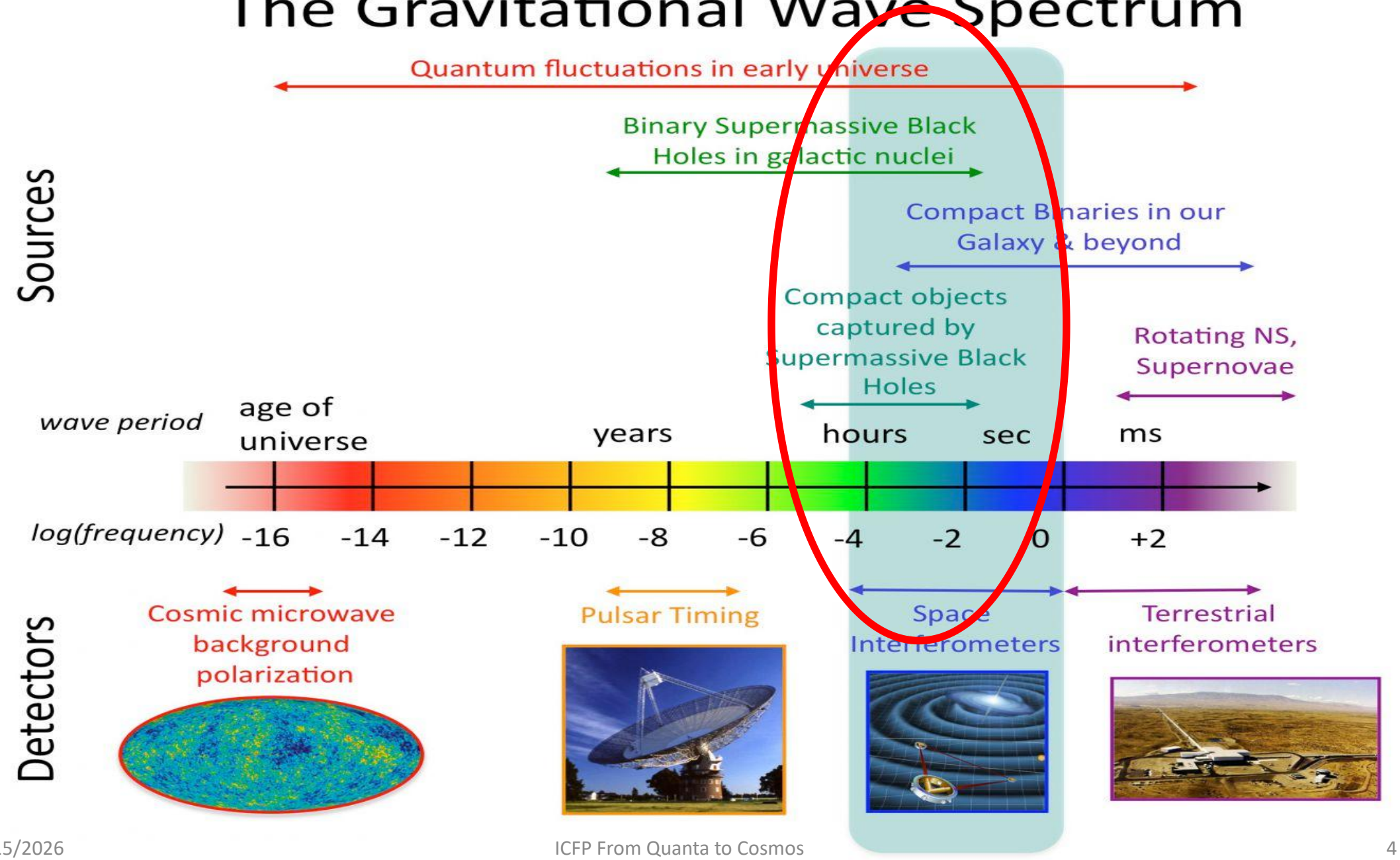


Figure: M Evans

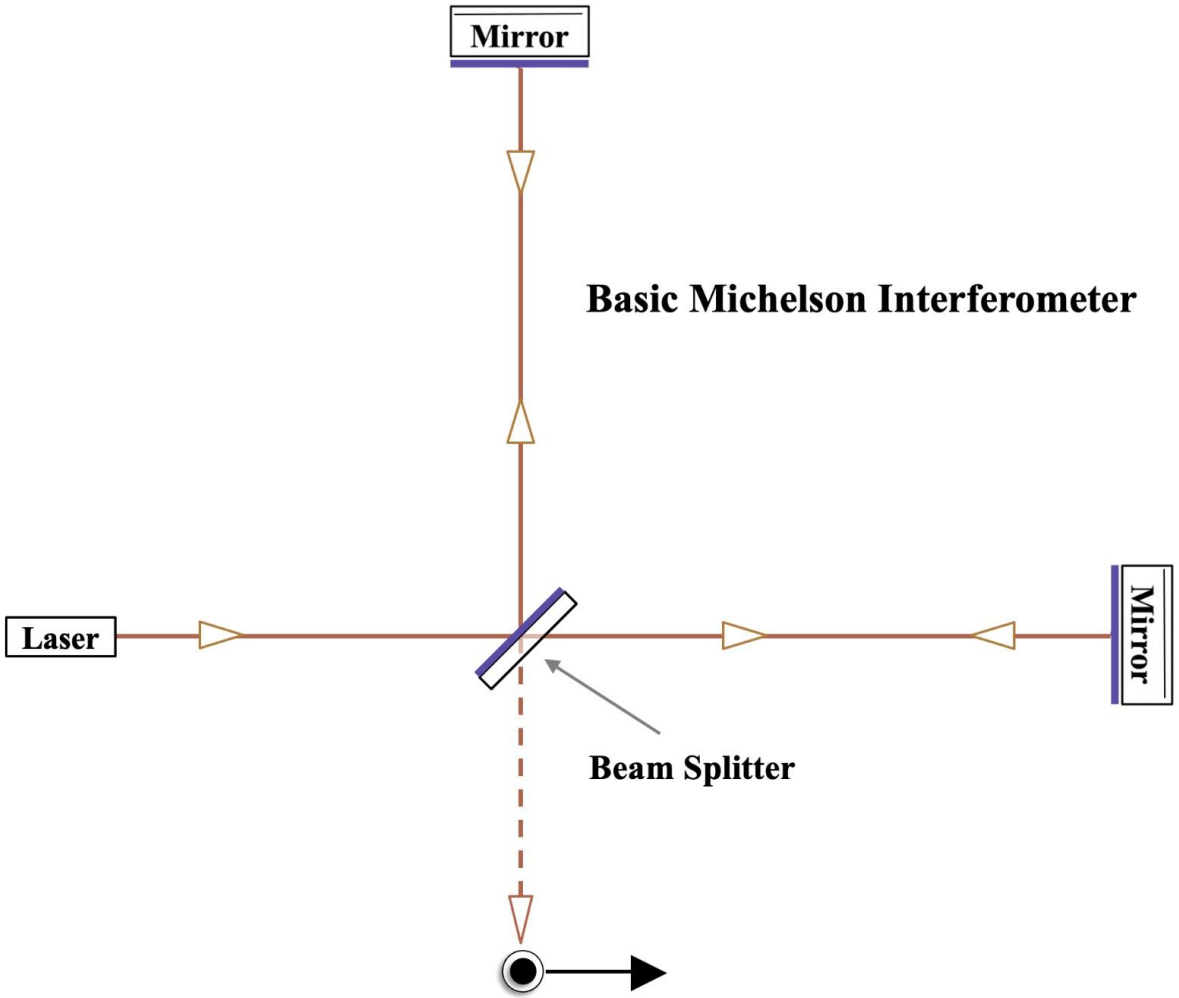
The Gravitational Wave Spectrum



Introduction: GW Sources in milihertz band

- **Mergers of SMBBH/IMBHs**
  - BBHs in galactic centers
  - Seed black holes (Pop III) at extremely high redshift
- **Extreme/intermediate mass ratio inspirals (EMRIs/IMRIs)**
- **Double white dwarfs in the Milky Way**
  - EM DWDs for verification
  - Individual DWD systems
  - GW foreground
- **Stellar binary black holes (+ ground-based detectors, multi-band GW)**
- **GW background from astrophysical sources**
- **Cosmological origin GW background**
  - GW relics from early universe
  - Primordial black hole binaries
- **Unknowns**

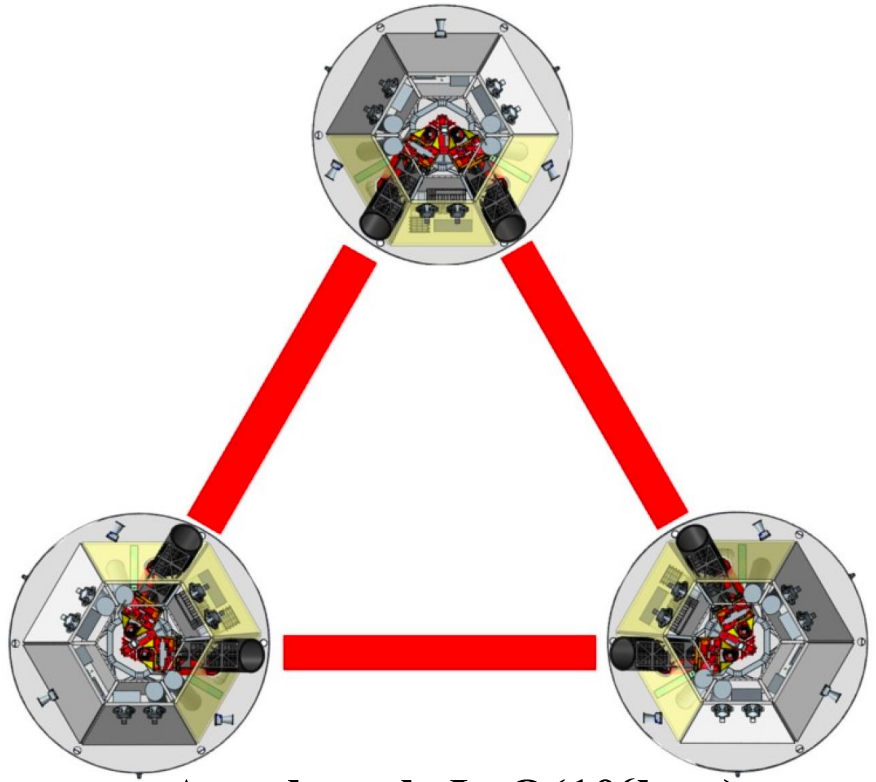
Laser Interferometer detection of GWs



Wavelength: ~10^6-10^8km; frequency: ~0.001-0.1Hz
GW strength: 10^{-21}-10^{-18}

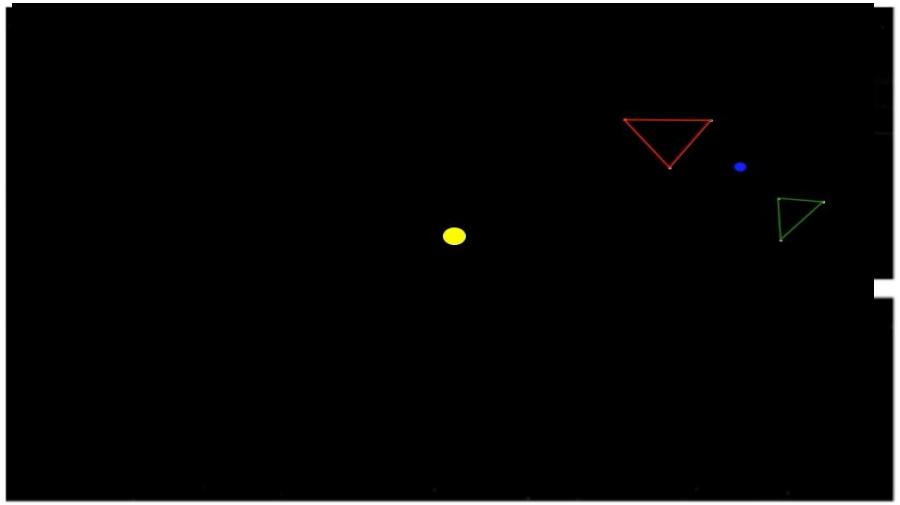


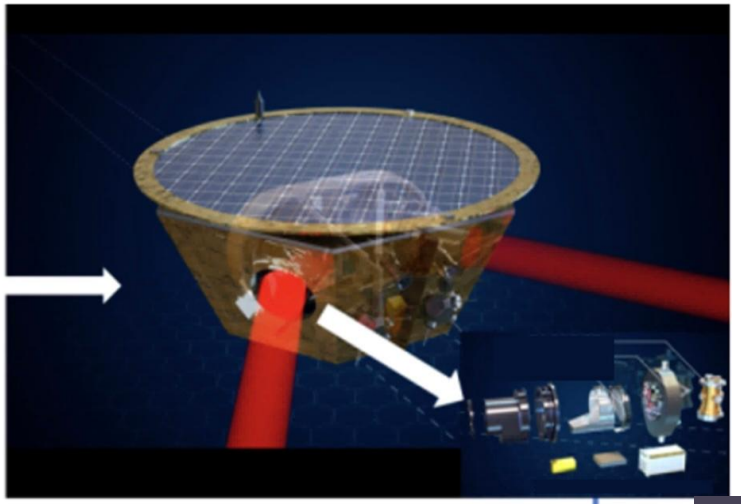
GW-induced displacement $\Delta l \propto L$



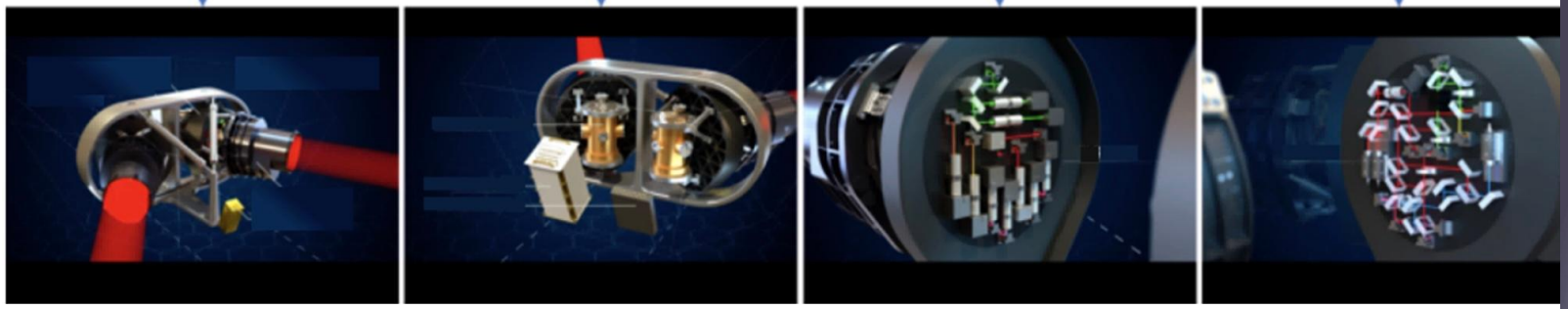
Arm length L: O(10^6km)

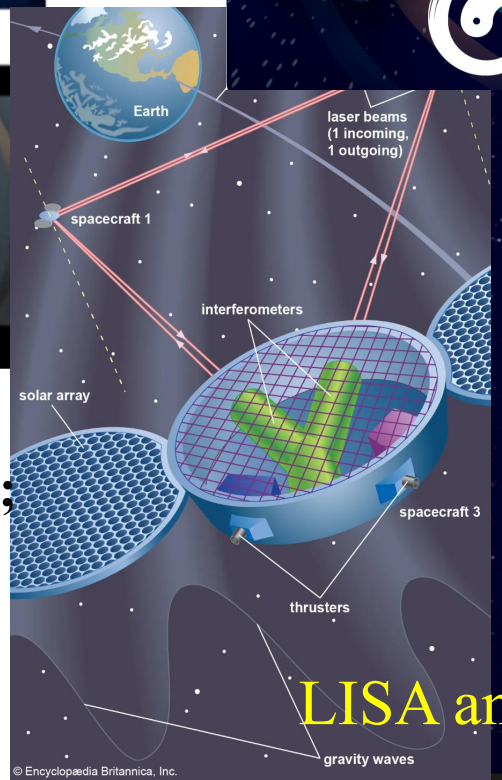
Taiji: Laser Interferometer detection of GWs

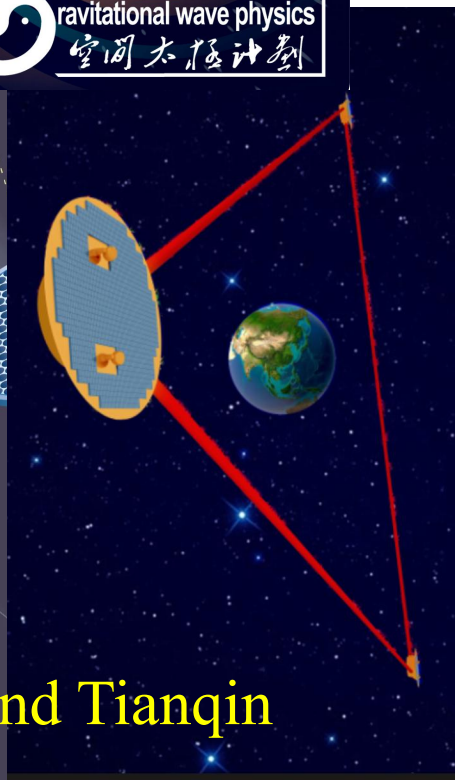








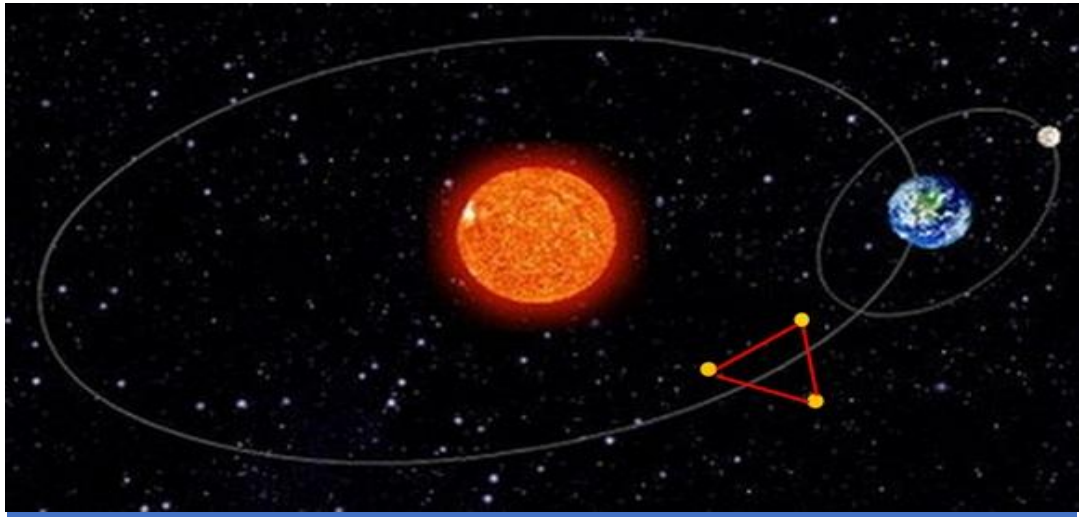




Three drag free satellites: an equilateral triangle, arm length 3Gm;
Helio-centric orbit: rotating around sun trailing/leading earth by 20°;
Displacement noise (TM-TM ranging)： 8pm/Hz$^{1/2}$
Acceleration noise (TM)： 3×10^{-15}ms^{-2}/Hz$^{1/2}$

LISA and Tianqin

Key technologies and challenges

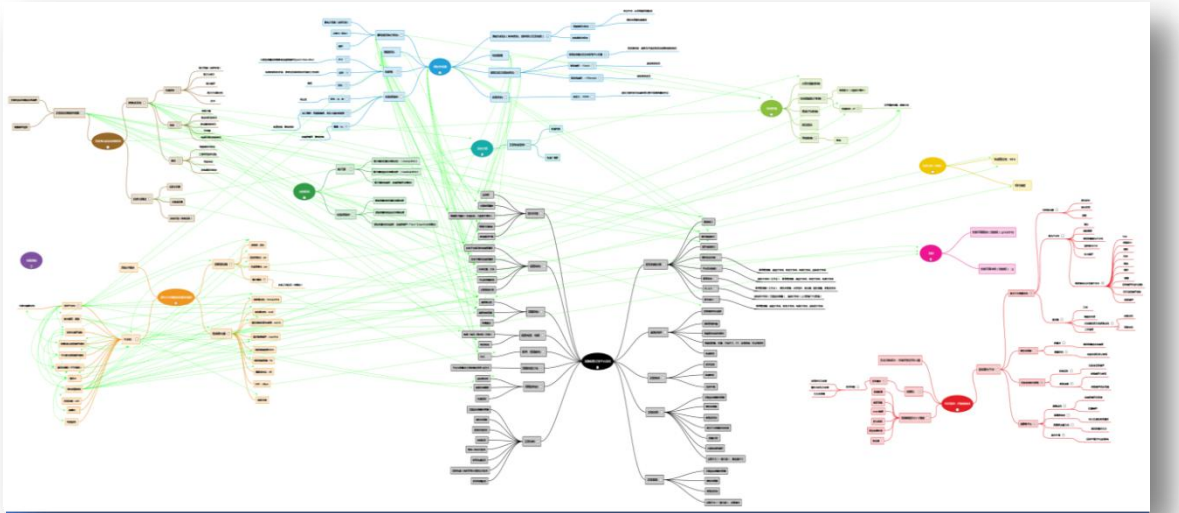


1. super-precision system

Interferometry 8 pm/Hz$^{1/2}$ precision

Free fall test mass 3×10^{-15}m s^{-2}/Hz$^{1/2}$

- **Optical metrology interferometry**
- **Free falling test masses and Gravitational reference systems**
- **Drag free control and micro-thrusters**
- **Constellation and Satellite**



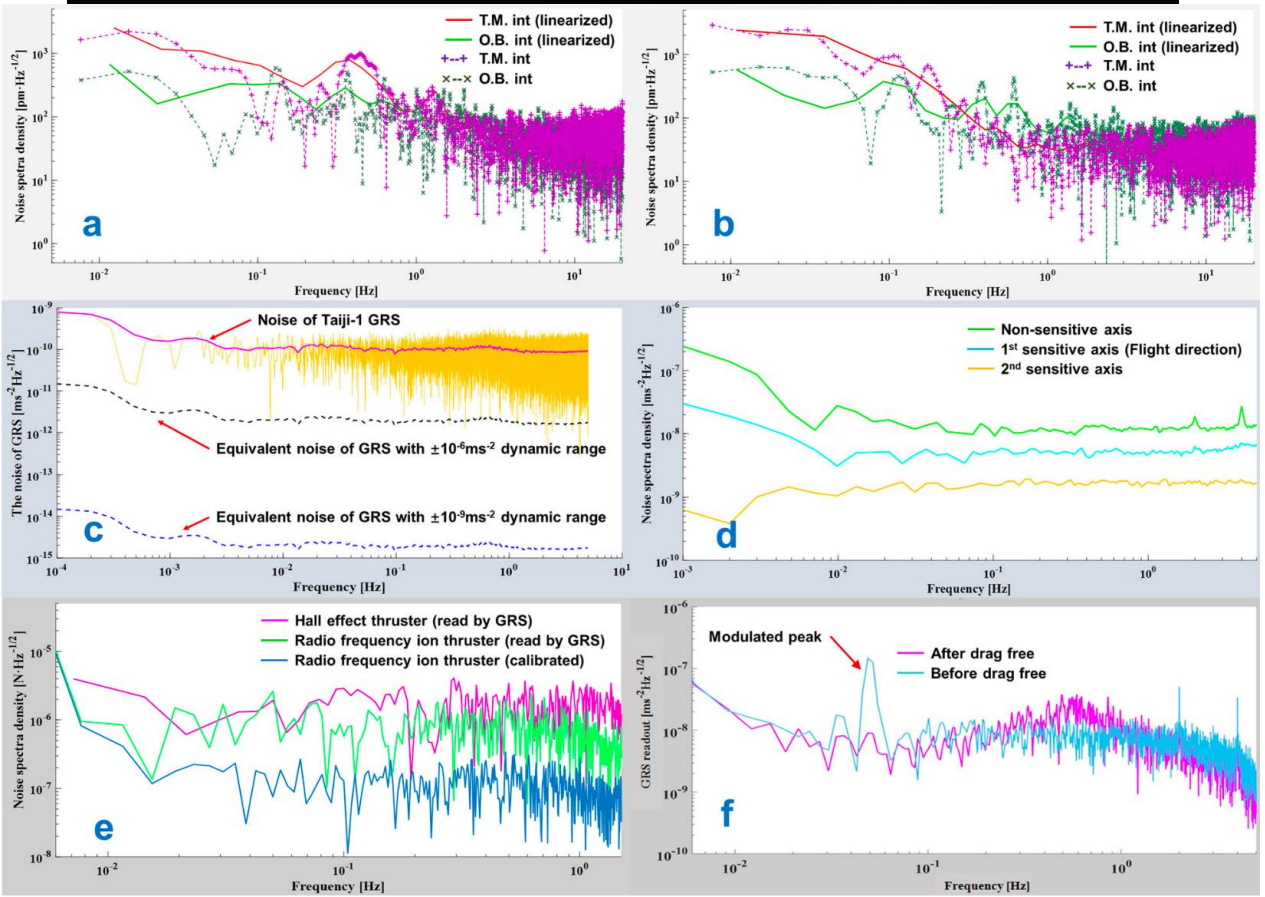
2. super-complex system

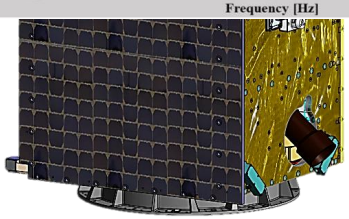
Mixed signals（millions sources）

Complicated coupling

- **GW sources and waveform template bank**
- **Constellation and sensitivity of detection**
- **Co-design of the spacecraft with payload, simulation of the couplings**
- **TDI and data analysis**

Pathfinder: Taiji-1



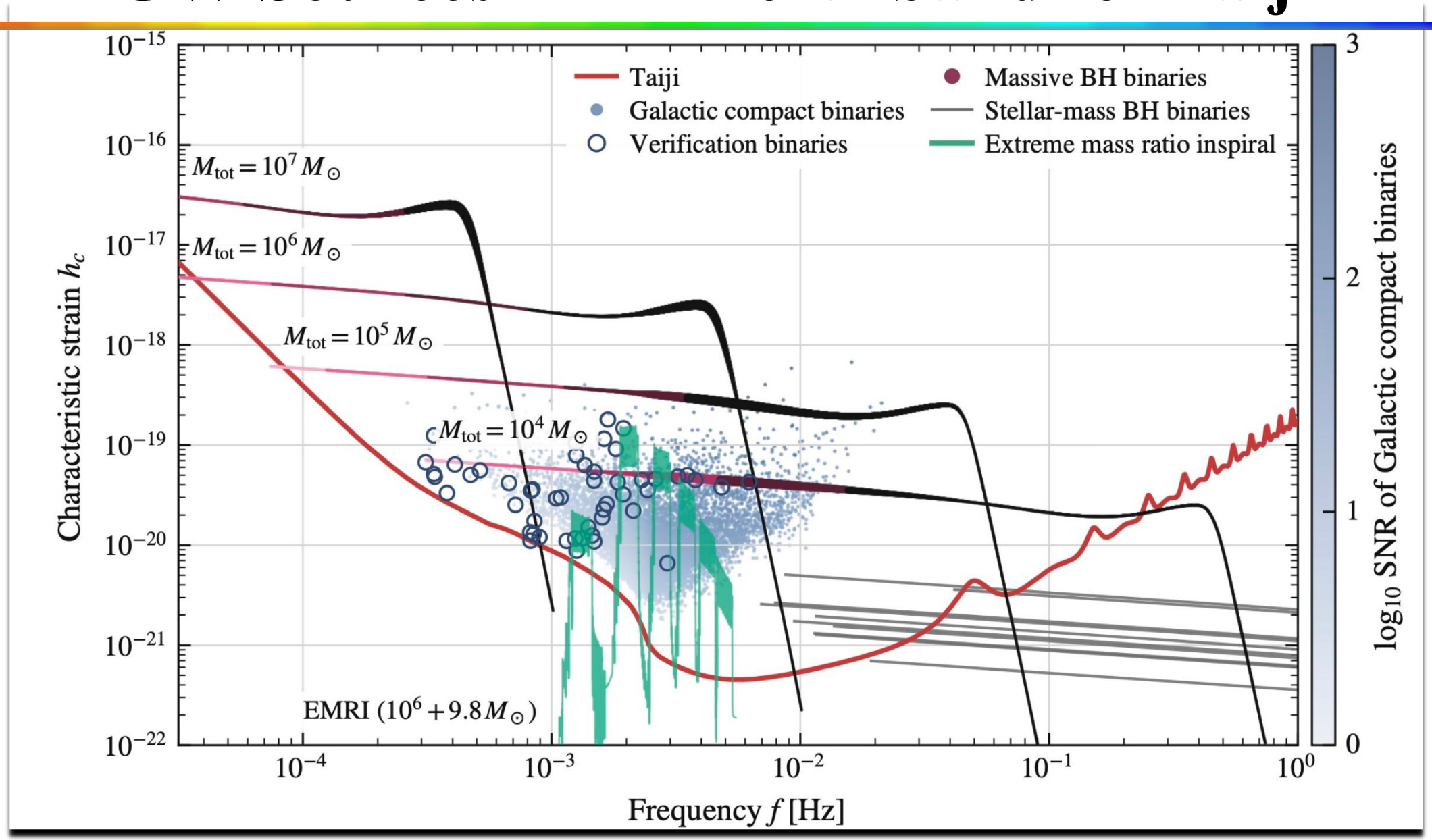




- **Laser interferometer precision: 10^2pm/$\sqrt{\text{Hz}}$, 25pm/$\sqrt{\text{Hz}}$**
- **Gravitational reference system precision: 10^{-10}m/s^2/$\sqrt{\text{Hz}}$**
- **Micro-thrusters: 1.5×10^{-7}N/$\sqrt{\text{Hz}}$**
- **Drag free test: 10^{-8}m/s^2/$\sqrt{\text{Hz}}$**
- **Temperature control: $\pm$2.6mk**

The Taiji Scientific Collaboration, COMMUNICATIONS PHYSICS, https://doi.org/10.1038/s42005-021-00529-z

GW Sources in milihertz band for Taiji



Waveform model for generic CBC SEOBNRE

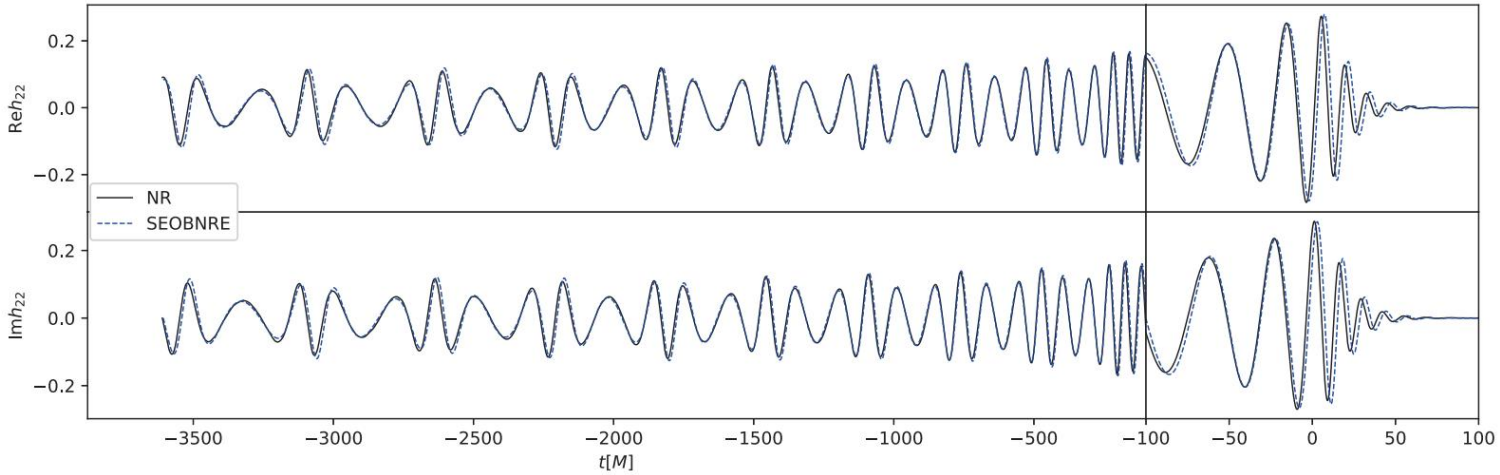
$$\frac{\mathrm{d}\boldsymbol{r}}{\mathrm{d}t} = \frac{\partial H_{\rm EOB}}{\partial \boldsymbol{p}},$$
$$\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t} = -\frac{\partial H_{\rm EOB}}{\partial \boldsymbol{r}} - \boldsymbol{F},$$
$$\frac{\mathrm{d}\boldsymbol{S}_{1,2}}{\mathrm{d}t} = \frac{\partial H_{\rm EOB}}{\partial \boldsymbol{S}_{1,2}} \times \boldsymbol{S}_{1,2} + \boldsymbol{F}^{s}_{1,2},$$

$$\mathbf{F}_1^s = \mathcal{F}^{\rm PS}\mathbf{p}\times\mathbf{S}_1 + \mathcal{F}^{\rm RS}\mathbf{r}\times\mathbf{S}_1 + \mathcal{F}^{\rm LS}\mathbf{L}\times\mathbf{S}_1 + \mathcal{F}^{\rm SS}\mathbf{S}_2\times\mathbf{S}_1$$

$$\boldsymbol{F} = \frac{\mathcal{F}}{\Omega L}(\mathcal{F}^e_p\boldsymbol{p} + \mathcal{F}^e_r\boldsymbol{r} + \mathcal{F}^e_L\boldsymbol{L} + \mathcal{F}^e_1\boldsymbol{S}_1 + \mathcal{F}^e_2\boldsymbol{S}_2)$$

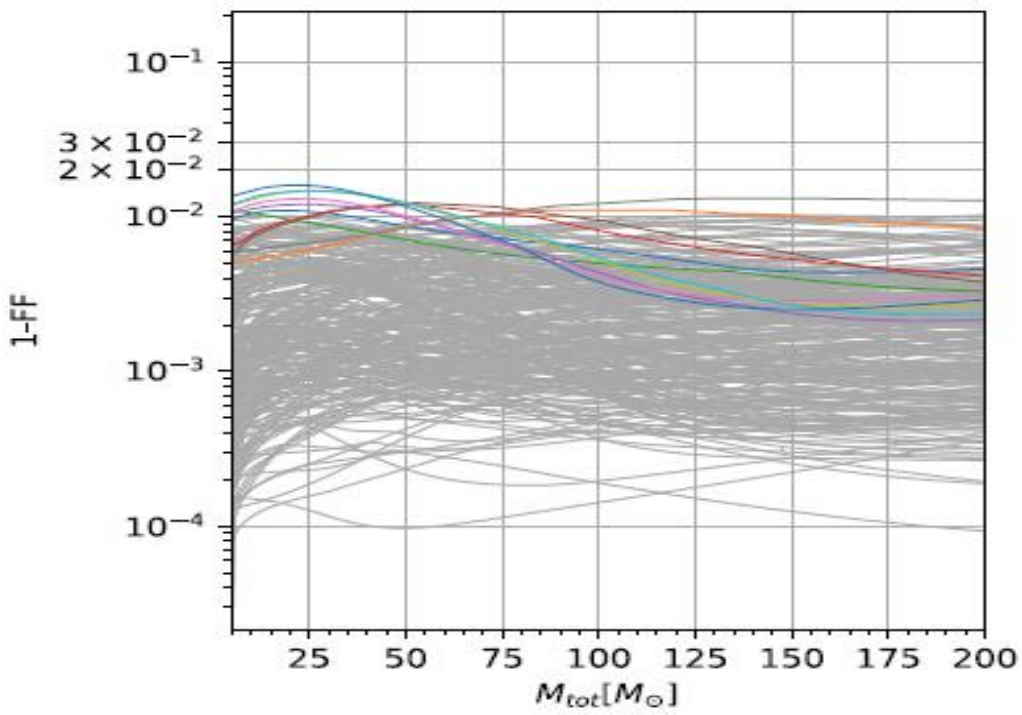
$$h^F_{\ell m} = h^N_{\ell m}\hat{S}_{\rm eff}T^{\rm qc}_{\ell m}e^{i\delta_{\ell m}}f_{\ell m}$$

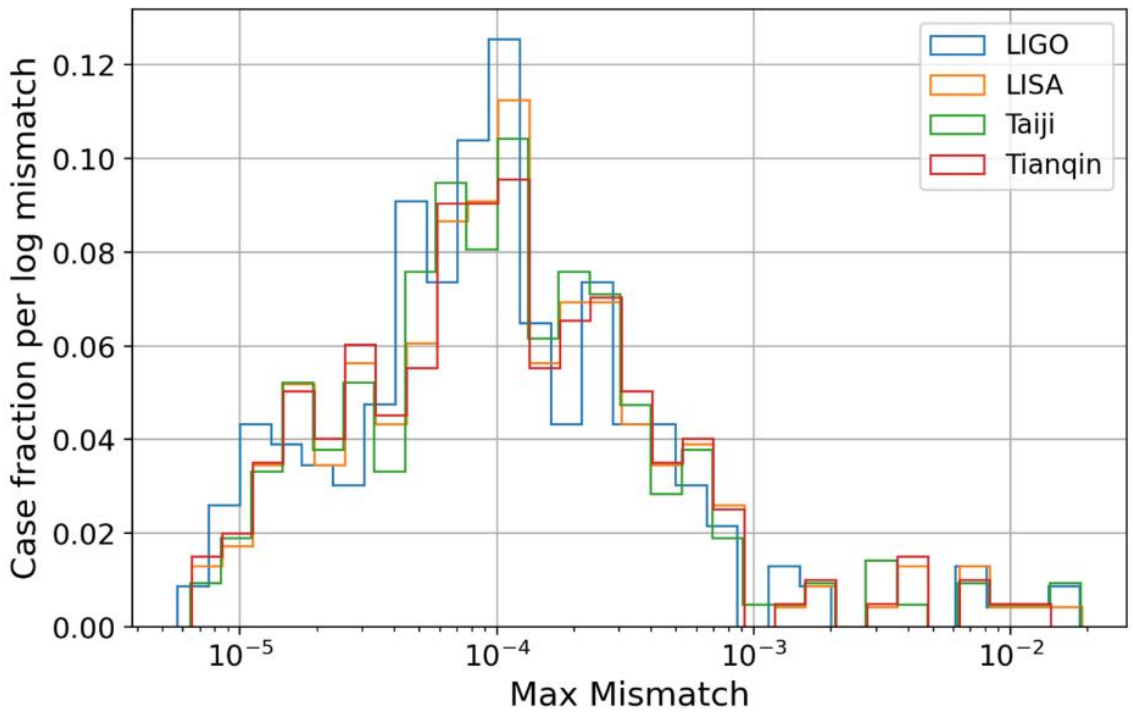
We have constructed waveform model SEOBNRE based on Effective-One-Body Numerical-Relativity technique for generic CBC, including orbit eccentricity, spin precession, higher modes than 22, and GR memory.



Credit: Zhoujian CAO

Waveform model for generic CBC SEOBNRE



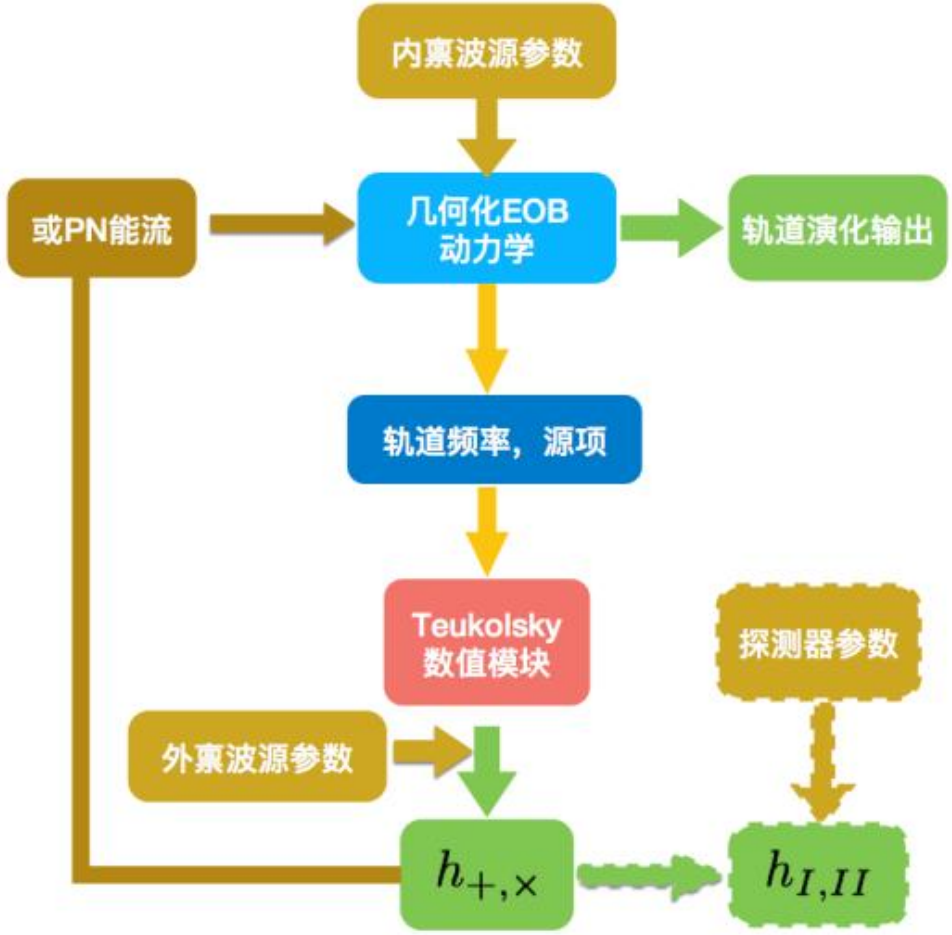


Tested against numerical-relativity results, SEOBNRE accuracy is better than 98% for current LIGO and designed Taiji.
SEOBNRE has been used by many groups and applied to LIGO data analysis.

Fast and accurate in generating waveform template bank

EMRI waveform EOB-Teukolsky (ET) codes

- **Geometrized Effective-One-Body (EOB) formalism (Zhang, Han+, 2021) to calculate the orbit (p, e, iota)**
- **EOB orbit sources the Teukolsky equation, calculate the energy fluxes and waveforms (Han, 2010; Han+, 2011 ……)**
- **Taking the energy fluxes as the EOB radiation reaction term, drive the compact object inspiraling SMBH, updating orbital parameters;**
- **With updated orbit, repeat the calculation from step 2, until the CO plunge into SMBH or a certain signal length.**



Han, 2010; Han & Cao 2011; Han 2014; Han 2016; Han+ 2017, Cao & Han 2017, Zhang&Han+ 2020,2021

“Dirty” EMRIs: Decoupling the Teukolsky equation

For real EMRI: CO is not a test particle but an extended body, in accretion disc or dark matter halo, extra radiation, scale field…

→The source term couples with space time

→Very complicated, or can not give explicit formalism

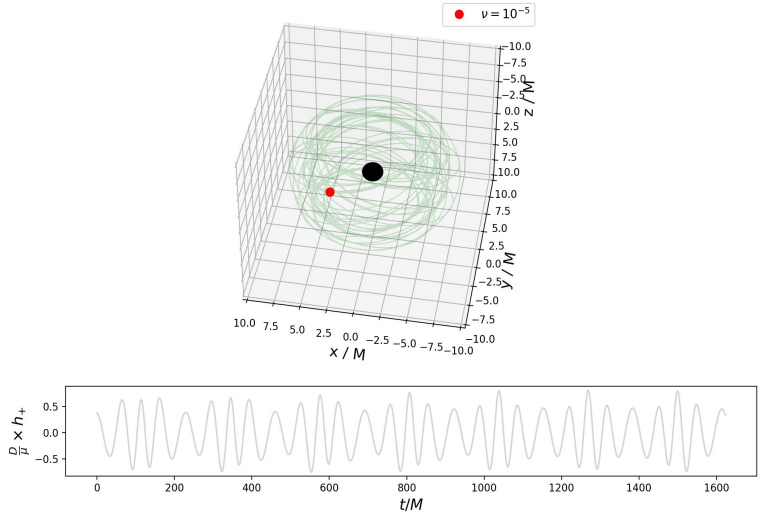
→We find a linear property in the master equation

→Then decoupling the solution, separate the source and spacetime

$$\mathcal{A}^{H,\infty}_{lm} = \sum_i x_i C^{in,up}_{ilm}(a,\omega,r)$$

Only related with the perturbation source

Only related with the background spacetime



Fluxes

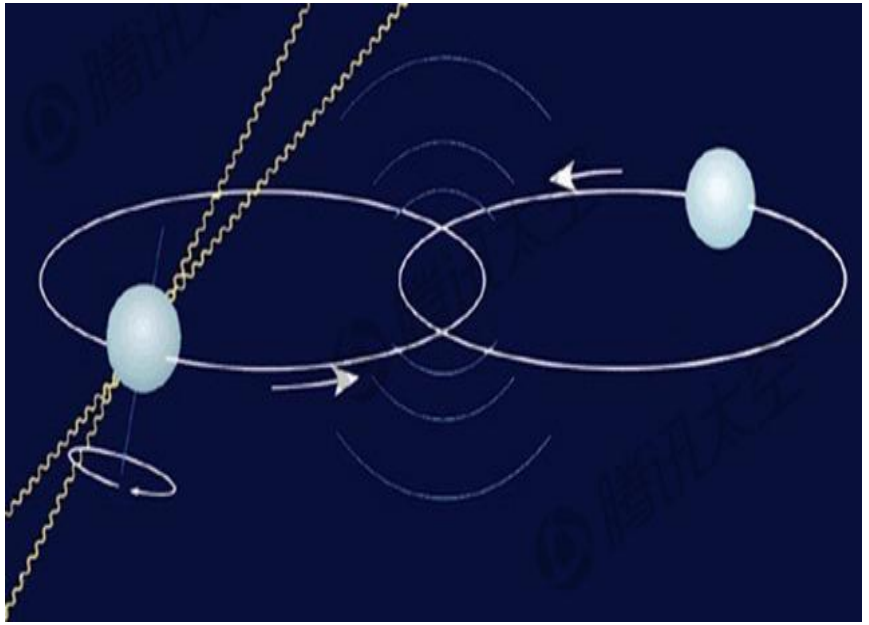
$$\mathcal{F}_{\rm GW} = \sum_{ij} x_i x_j f_{ij}(a,\Omega,r) \; f_{ij} = 2\pi \sum_{l=2}^{\infty} \sum_{m=1}^{l} ((C^{in}_{ilm} \diamond C^{in}_{jlm}) + \alpha_{lm}(C^{up}_{ilm} \diamond C^{up}_{jlm}))/\omega^2 \Big|_{\omega=m\Omega}$$

waveforms

$$h_+ - ih_\times = -\frac{2}{D} \sum_i x_i[r(t)] \sum_{l=2}^{\infty} \sum_{m=-l}^{l} \left\{ C^{\rm in}_{ilm}[a, m\Omega(t), r(t)] S_{lm}(\Theta) e^{im[\Phi - \phi(t)]} \right\}$$

Jiang & Han, SCPMA, 2024

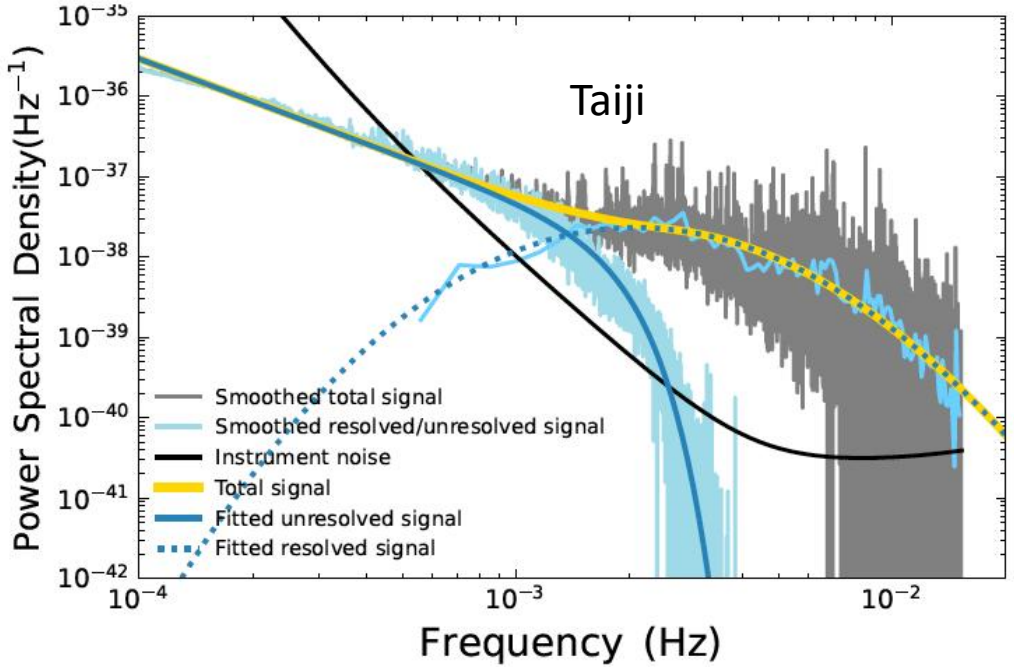
GCBs: Double White Dwarfs



- **Verification for Taiji by using known EM DWDs with precise parameter measurements: J0651+2844, J0935+4411**
- **Detecting tens of thousands Galactic DWDs, measuring their properties and distributions;**
- **Formation and evolution of compact binary stars;**
- **Merger rate of compact binaries, type Ia SNs;**
- **Detailed physics: mass transfer, tidal dissipation, electromagnetic signals; ……**

ZTFJ2243+5242	43.5	86.9	13.24	53.96	528.00	0.35	0.38	1760	81.88	[118]
SDSSJ0651+2844	28.4	56.7	101.33	5.81	765.50	0.25	0.49	960	86.90	[119, 120]
ZTFJ0538+1953	19.7	39.3	84.83	-3.46	866.40	0.45	0.32	1000	85.43	[77]
SDSSJ0935+4411	32.1	64.1	130.97	28.09	1188.00	0.31	0.75	400	59.80	[121, 122]
SDSSJ2322+0509	5.47	11.0	-6.57	8.46	1201.00	0.34	0.17	860	49.00	[123]
PTFJ0533+0209	4.19	8.37	82.91	-21.12	1233.97	0.65	0.17	1170	70.00	[77]
SDSSJ0634+3803	8.29	16.6	97.08	14.84	1591.00	0.45	0.21	433	37.00	[124]
J0526+5934	16.3	32.6	151.92	13.26	1230.37	0.38	0.89	845	57.00	[125]
J1239-2041	5.64	11.3	299.28	42.09	1350.43	0.29	0.68	972	71.00	[126]
ZTFJ0127+5258	15.3	31.5	128.47	-9.51	822.68	0.75	0.19	1283	82.50	[127]
ZTFJ0526+5934	11.05	22.08	81.54	59.58	1230.36	0.60	0.30	846	60.00	[92]
ZTFJ1611+6308	3.96	7.91	242.89	63.14	2982.48	0.60	0.30	257	60.00	[92]
ZTFJ2334+3921	4.14	8.29	353.51	39.36	4865.10	0.60	0.30	76	60.00	[92]
ZTFJ2007+1742	6.26	12.49	301.90	17.70	4897.86	0.60	0.30	45	60.00	[92]
UCXB										
4U1728-34	8.35	16.69	172.27	53.70	646.20	1.40	0.08	5700	60.00	[128]
4U1820-30	5.69	11.38	2.79	-7.91	685.00	1.40	0.07	7600	50.00	[129]

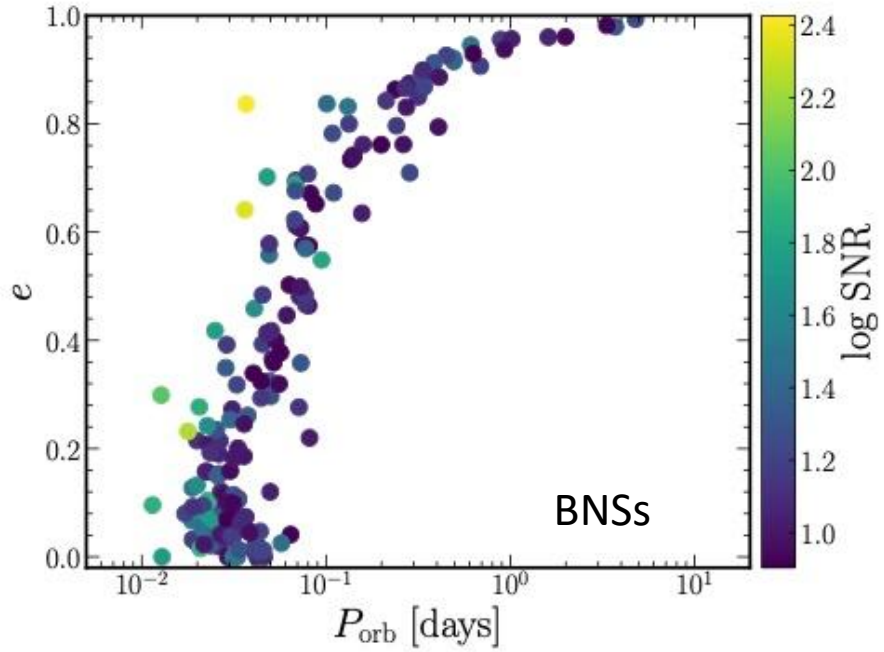
GCBs: Double White Dwarfs

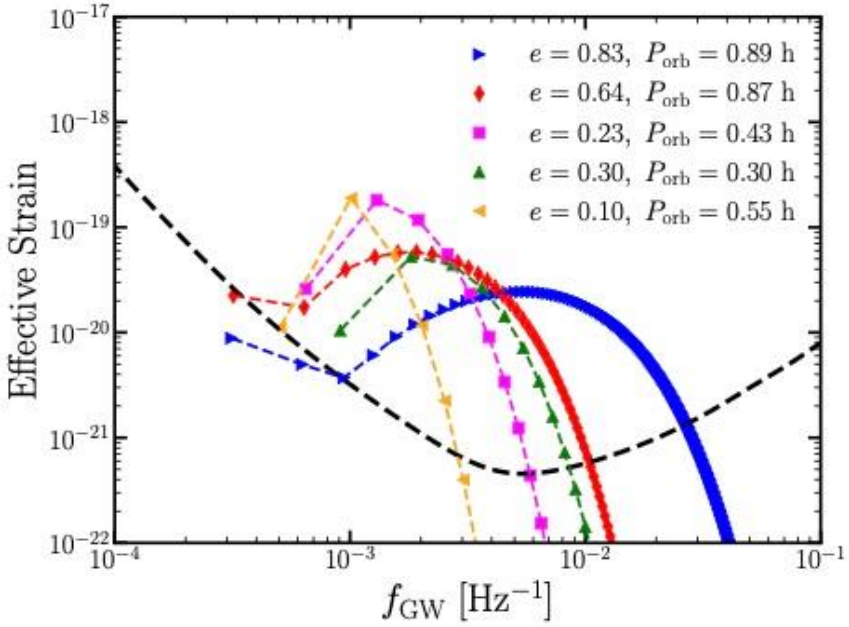


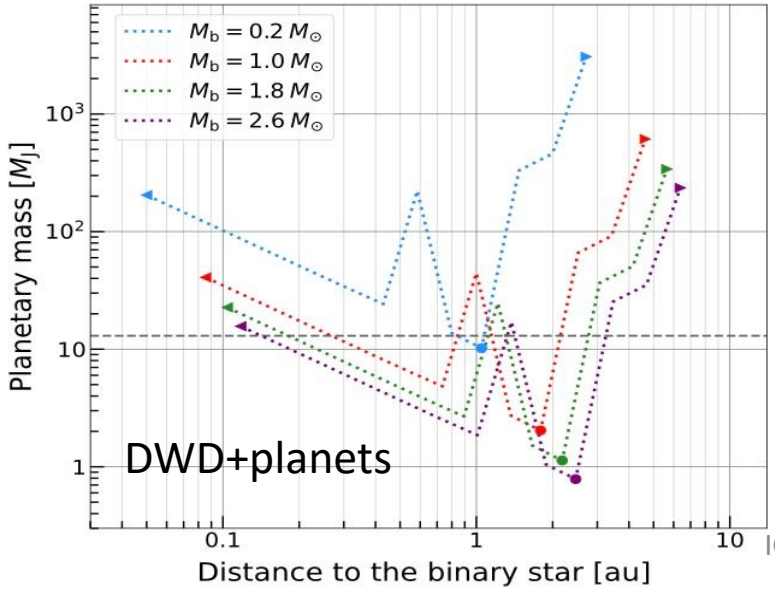
- **Detecting the WD-NS binaries in the Milky way;**
- **Revealing the physical processes that control the evolution of contact WD-NS binaries;**
- **Detecting the GW foreground by numerous GCBs;**
- **Constraining structure of WDs;**
- **Constraining Structure and mass distribution of the Milky Way.**

Yu et al. 2021, 2025, Zhang et al. 2025
Taiji white paper, in preparation

GCBs: BNSs and DWD+planets



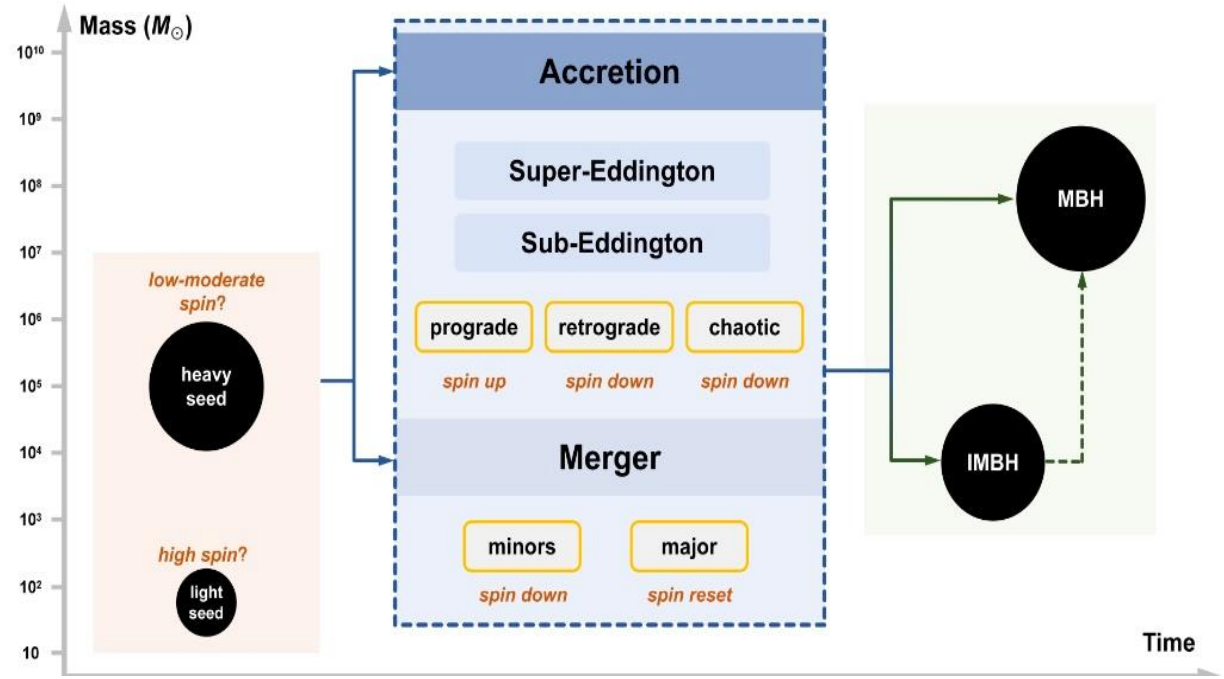




- **Detecting several tens BNSs with high eccentricities in the Milky way;**
- **Detecting planets rotating around DWDs.**

Chen et al. 2025, Kang et al. 2021
Taiji white paper, in preparation

MBBHs: seeds and growth

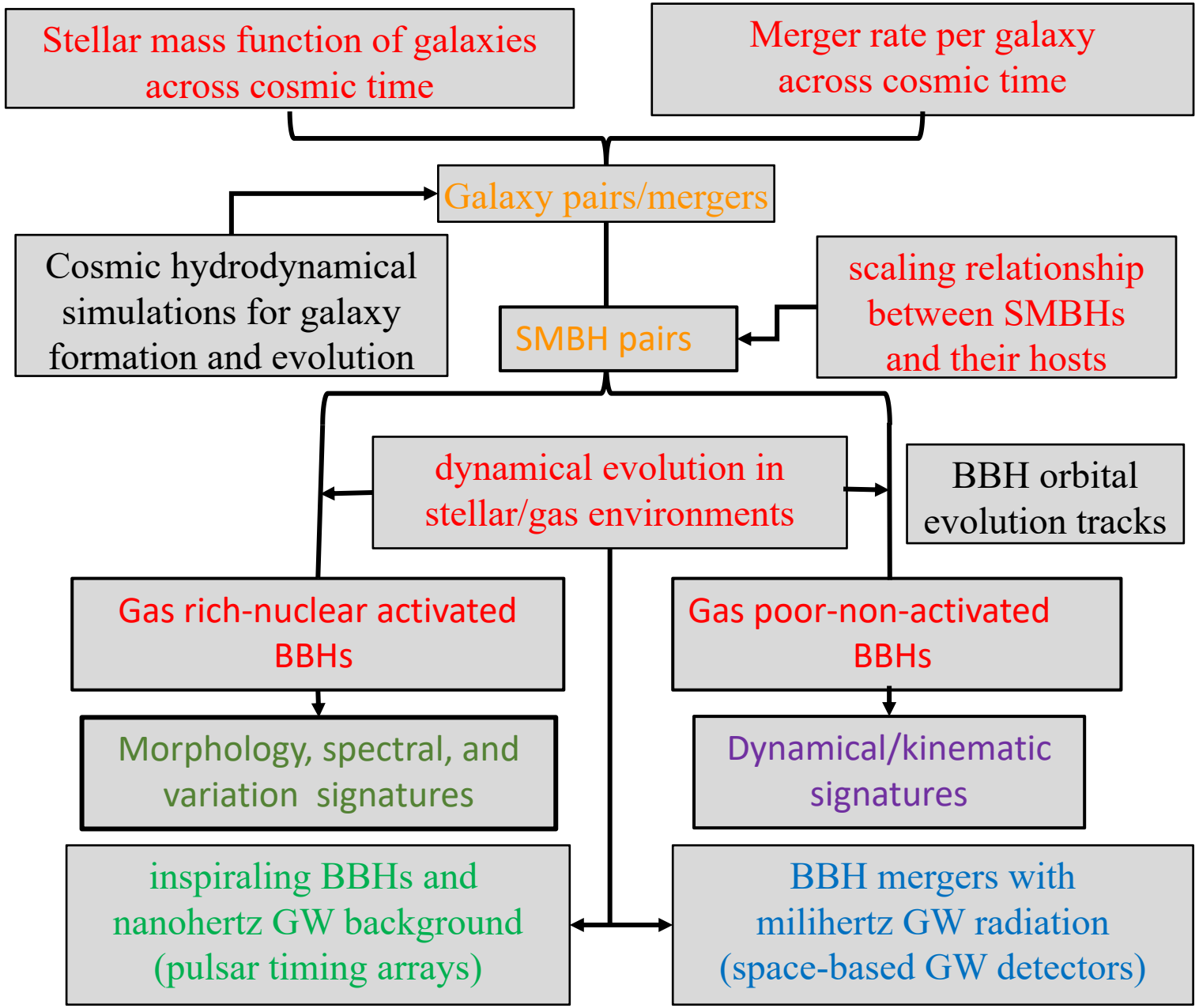


Formation of massive (binary) black holes (MBBHs):

- **Seed formation: heavy seeds (10^1 -10^2 $M_\odot$); light seeds (10^4 -10^6 $M_\odot$).**
- **Growth history: accretion and mergers, high and low spins.**

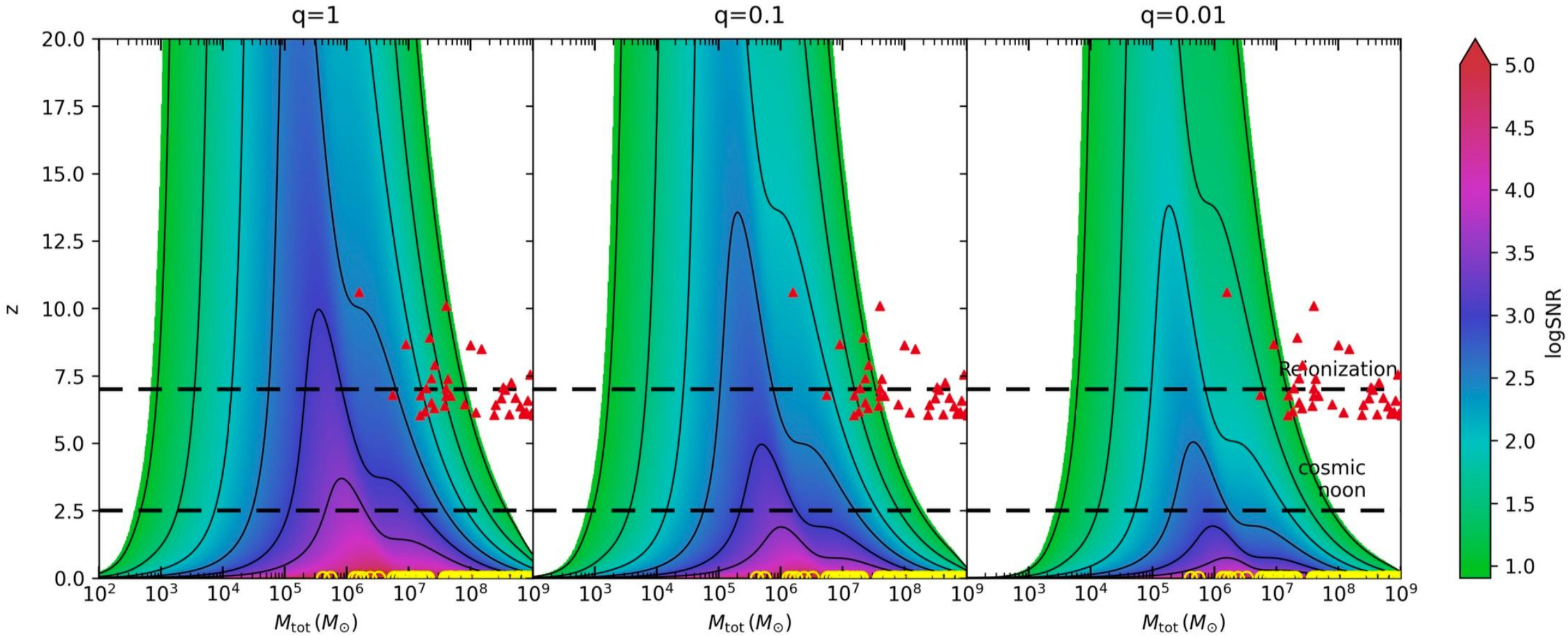
MBBHs: mergers

Population synthesis model:
Gas-poor and gas-rich mergers



Chen et al. 2020, 2023, 2024 ApJ; …
Li et al. 2026, MNRAS
Lu 2025 (CQG)

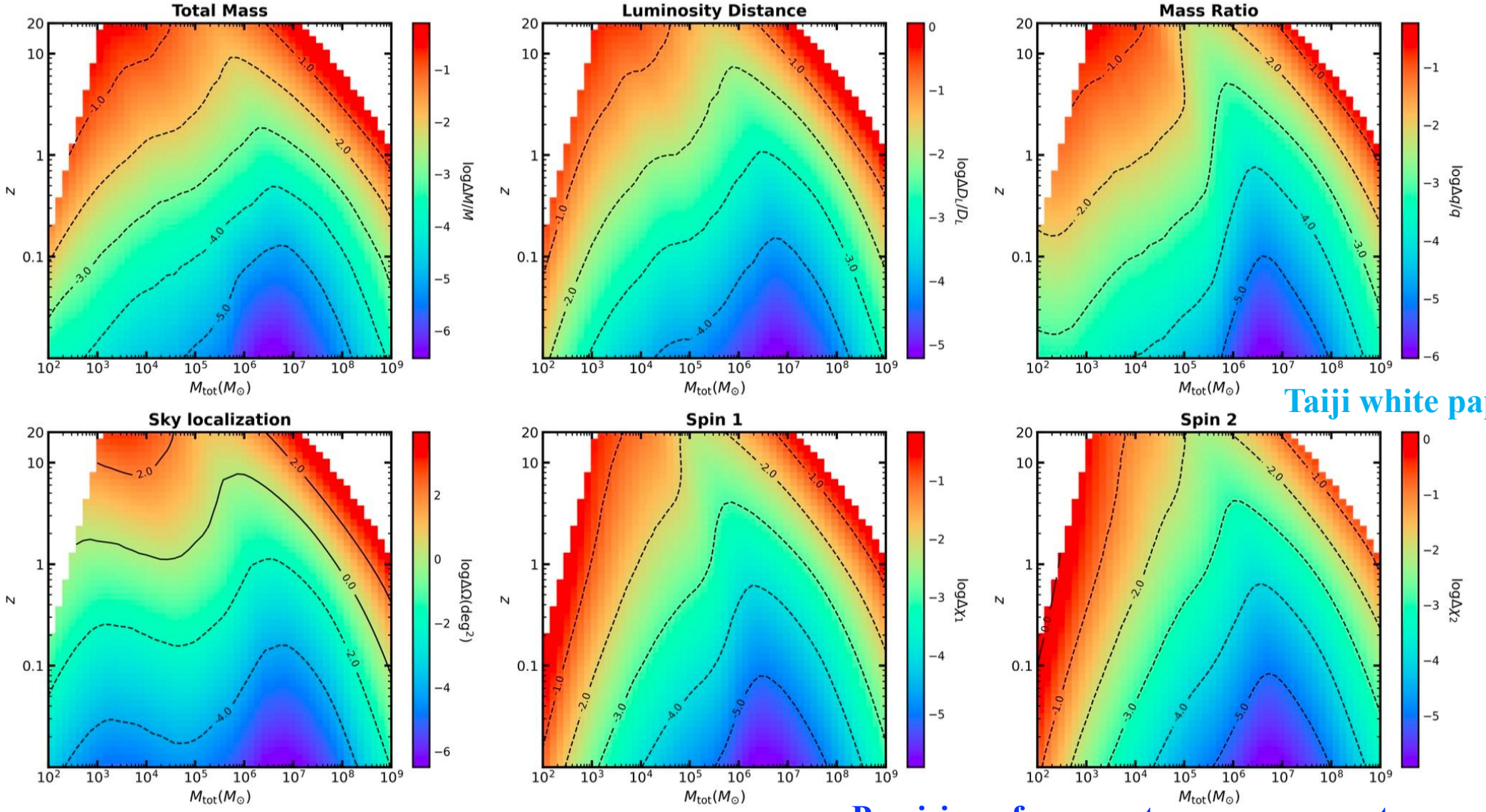
MBBHs: Taiji SNR



- detect mergers of BBHs with mass 10^4-$10^7\,M_\odot$ at z ~0-20;
- SNR up to several 10^3; BH seeds at z ~10-20.

Taiji white paper

MBBHs: parameter measurement uncertainty

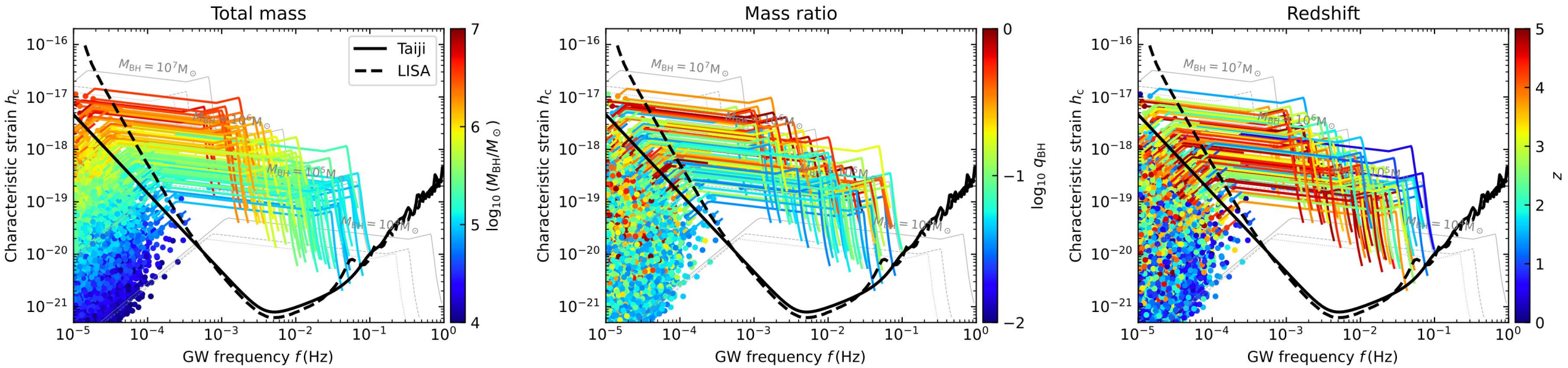


Taiji white paper

Fisher Matrix and Bayesian methods

Precision of parameter measurements

MBBHs: detection rate

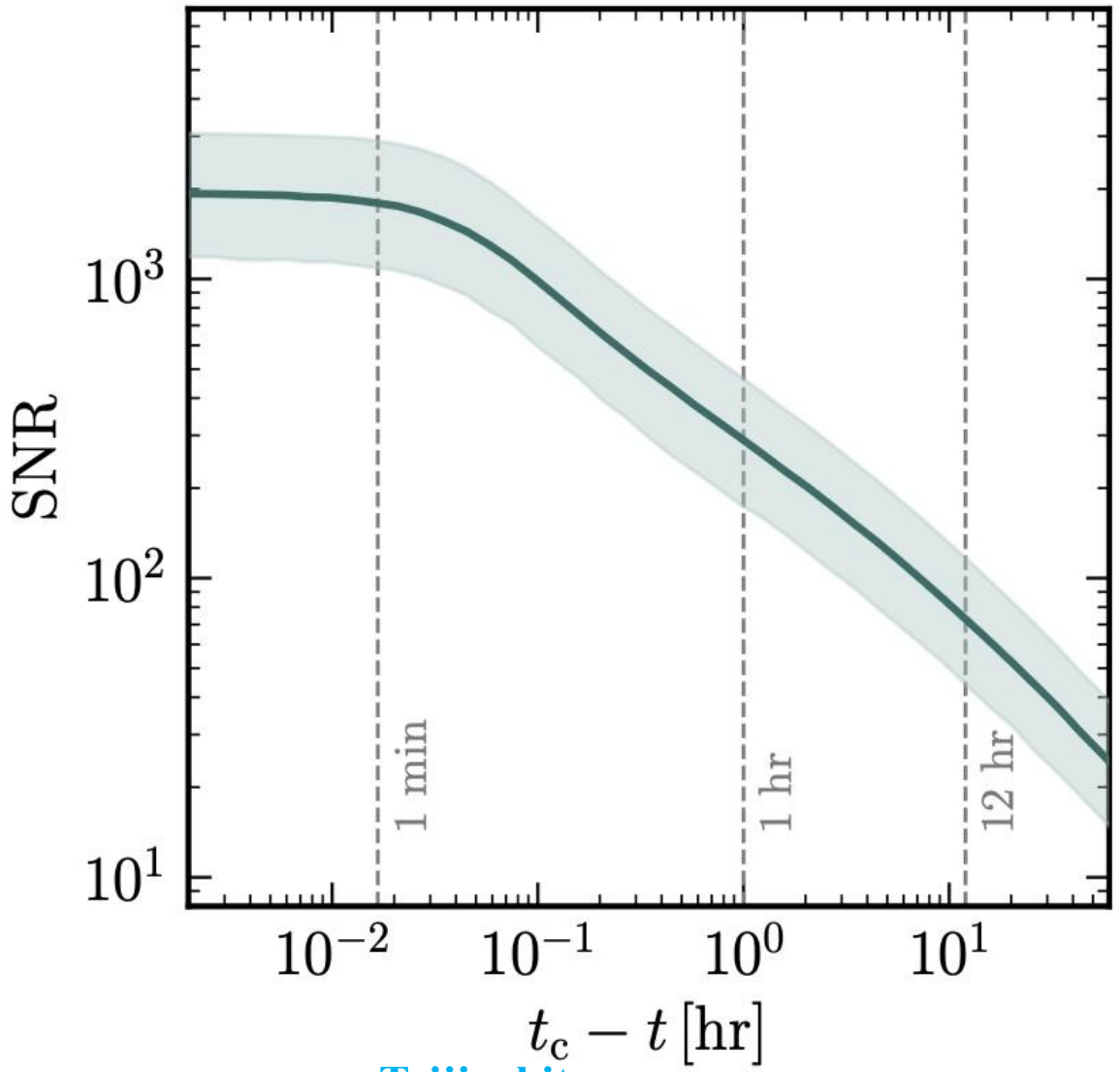


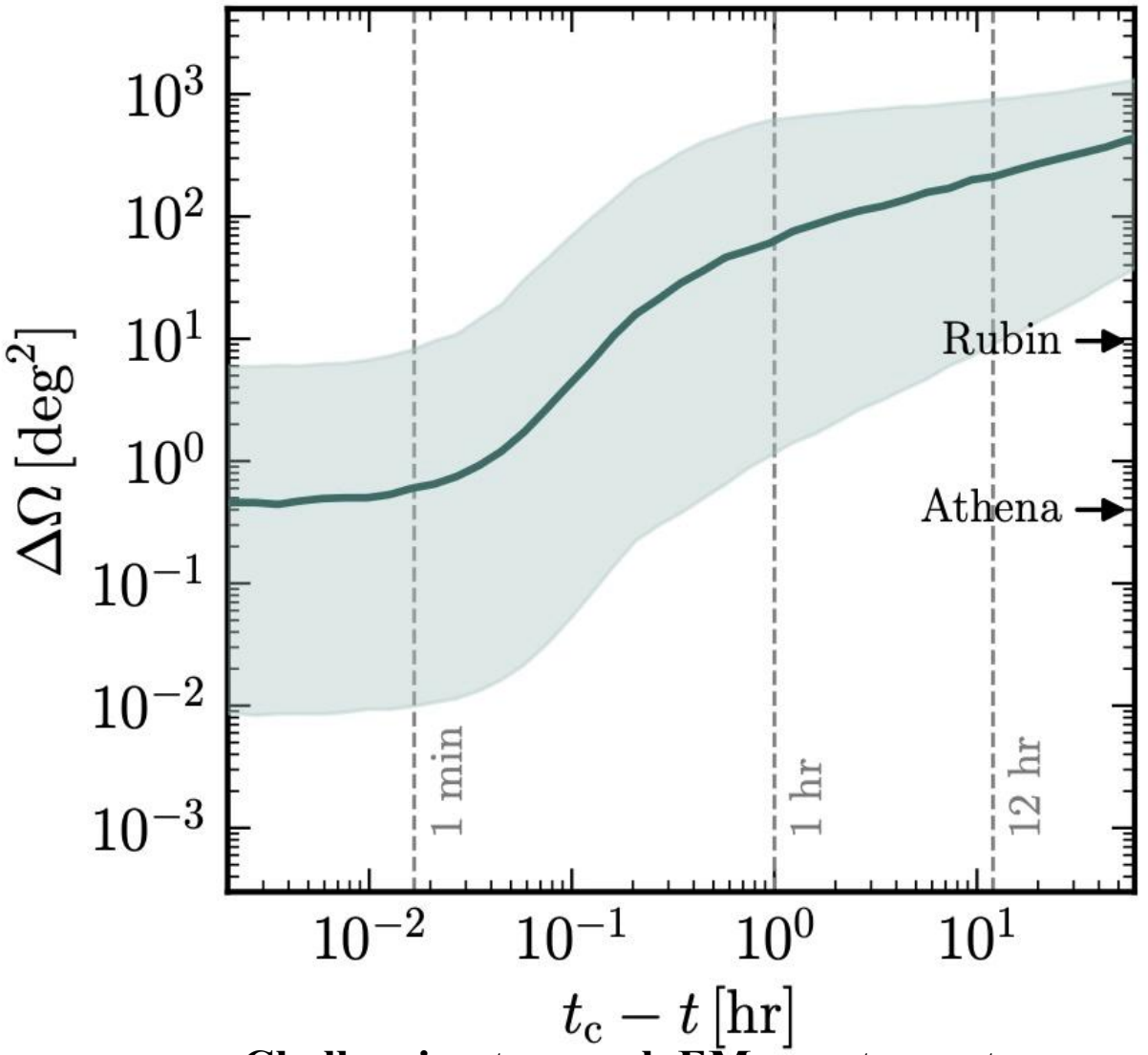
- **Assume the recent PTA detection of GWB is entirely due to cosmic BBHs, and the relatively high strain amplitude is due to the redshift evolution of the MBH-host relation.**
- **Optimistic about the Taiji detections.**

Mission time	Taiji SNR≥3/5/8	LISA SNR≥3/5/8
3 years	76/74/71	72/71/71
5 years	128/121/119	120/118/118
10 years	235/224/217	221/217/217

Chen et al. 2020, 2023, 2024, ApJ, …

MBBHs: EM counterparts





Taiji white paper
Xie et al. 2026

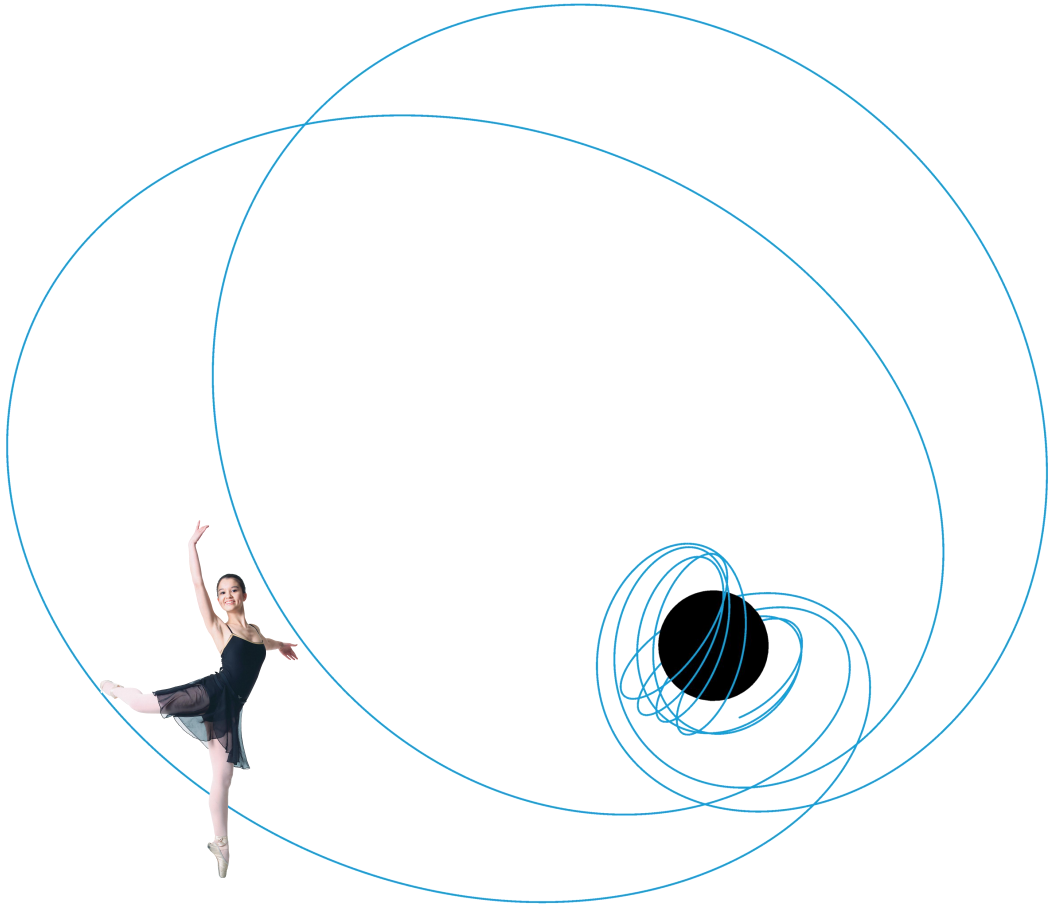
Challenging to search EM counterparts

MBBHs: Taiji objectives

- **Measuring physical parameters (mass and spin) of MBBH systems with high precision and obtaining their distributions;**
- **Detecting seed BHs and giving a definitive anwser to the existence of intermediate mass BHs;**
- **Constraining the evolution processes of SMBBHs;**
- **Revealing the formation and assembly history of SMBHs over cosmic time;**
- **Searching for EM counterparts of MBBH mergers and their host galaxies;**
- **Cosmolgical applications (measuring cosmological parameters);**
- **Testing gravity theory and black hole physics (extremely high SNR events);**
- **……**

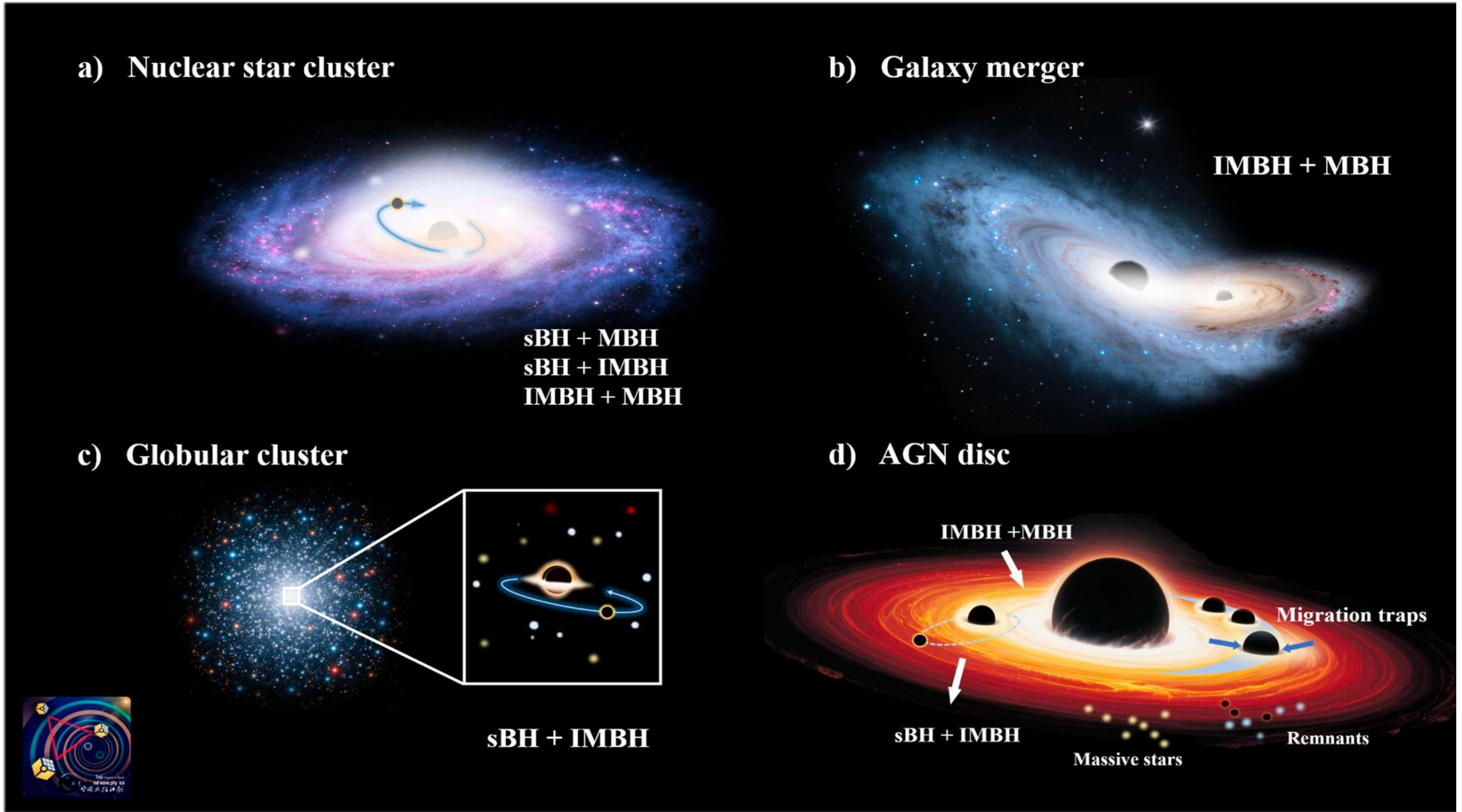
EMRI-Cosmic Ballet

- A compact object (CO) captured by a massive black hole (MBH)
- Orbit: large eccentricity and inclination→ strong precession; long duration
- CO "dances" around SMBH with complicated and elegant trajectory: "cosmic ballet"



→ Extreme/intermediate-mass-ratio inspirals: EMRI/IMRI

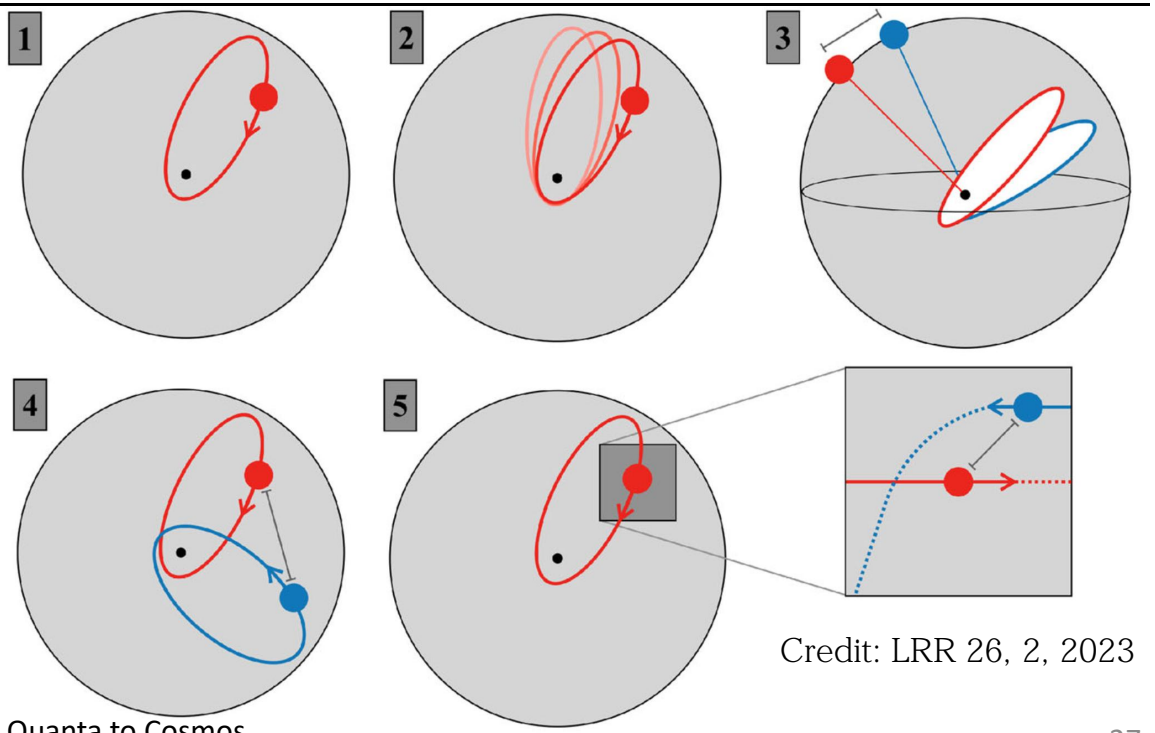
EMRIs: formation channels



Formation channels of EMRIs/IMRIs

- **Gas-poor: two-body relaxation; Formation and disruption of binaries around SMBH**
- **Heavy IMRIs from galaxy mergers or galactic nuclei assembly**
- **Light IMRIs in stellar clusters and dwarf nuclei**
- **AGN discs: Formation of EMRIs and IMRIs in gas-rich galactic nuclei**

Acronym	Meaning	Mass ratio	Constituents
light IMRI	Light intermediate mass-ratio inspiral	10^{-5}–10^{-2}	IMBH and stellar-mass compact object
heavy IMRI	Heavy intermediate mass-ratio inspiral	10^{-5}–10^{-2}	MBH and IMBH
EMRI	Extreme mass-ratio inspiral	10^{-8}–10^{-5}	MBH and stellar-mass compact object
b-EMRI	Binary-extreme mass-ratio inspiral	10^{-8}–10^{-5}	MBH and binary stellar-mass compact object
XMRI	Extremely large mass-ratio inspiral	$\lesssim 10^{-8}$	MBH and sub-stellar object

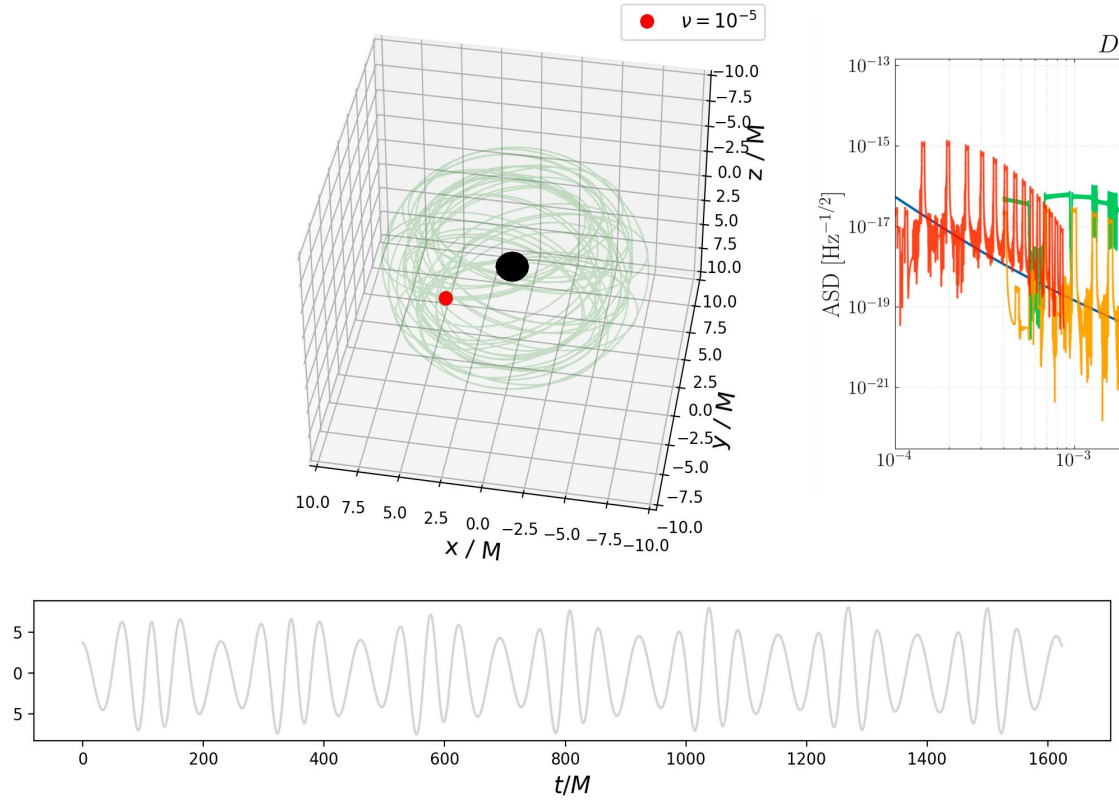


Credit: LRR 26, 2, 2023

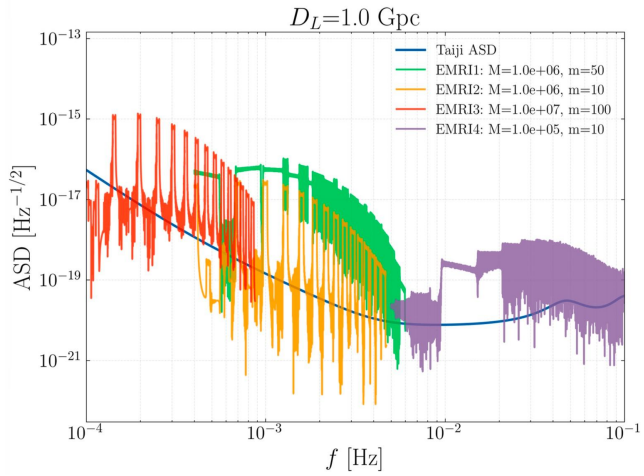
EMRI/IMRI properties

- **Event rate: O(10-100)/year**
- **Radiate low-frequency GWs for SMBH, high frequency for 10-100 solar mass BHs**
- **Long-weak-complex signals**
- **Localization: < 1 deg^2; Luminosity distance: 1%**
- **Intrinsic parameter (mass, spin) accuracy: 10^{-4}~10^{-5}**

EMRI orbits and waveform

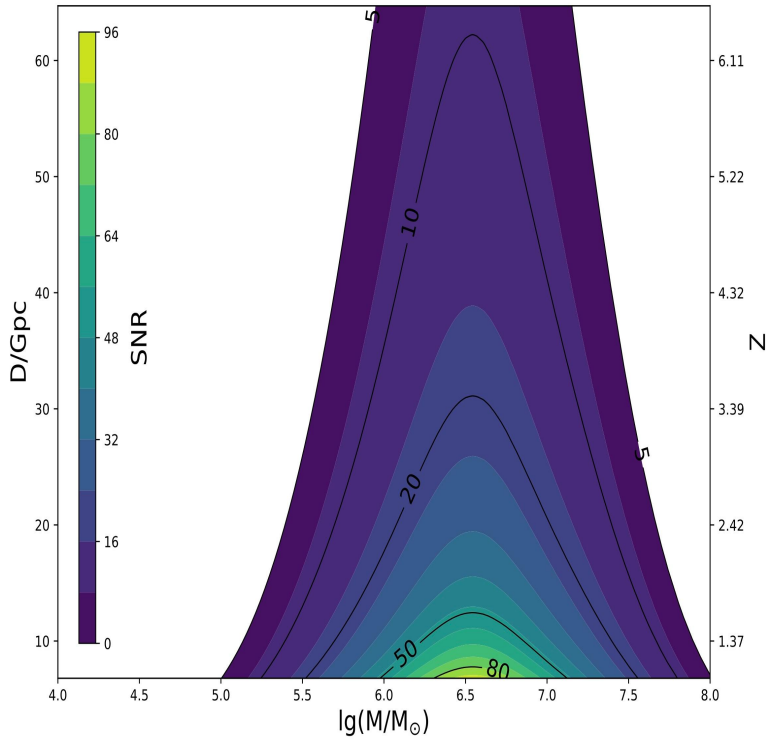


Example waveforms

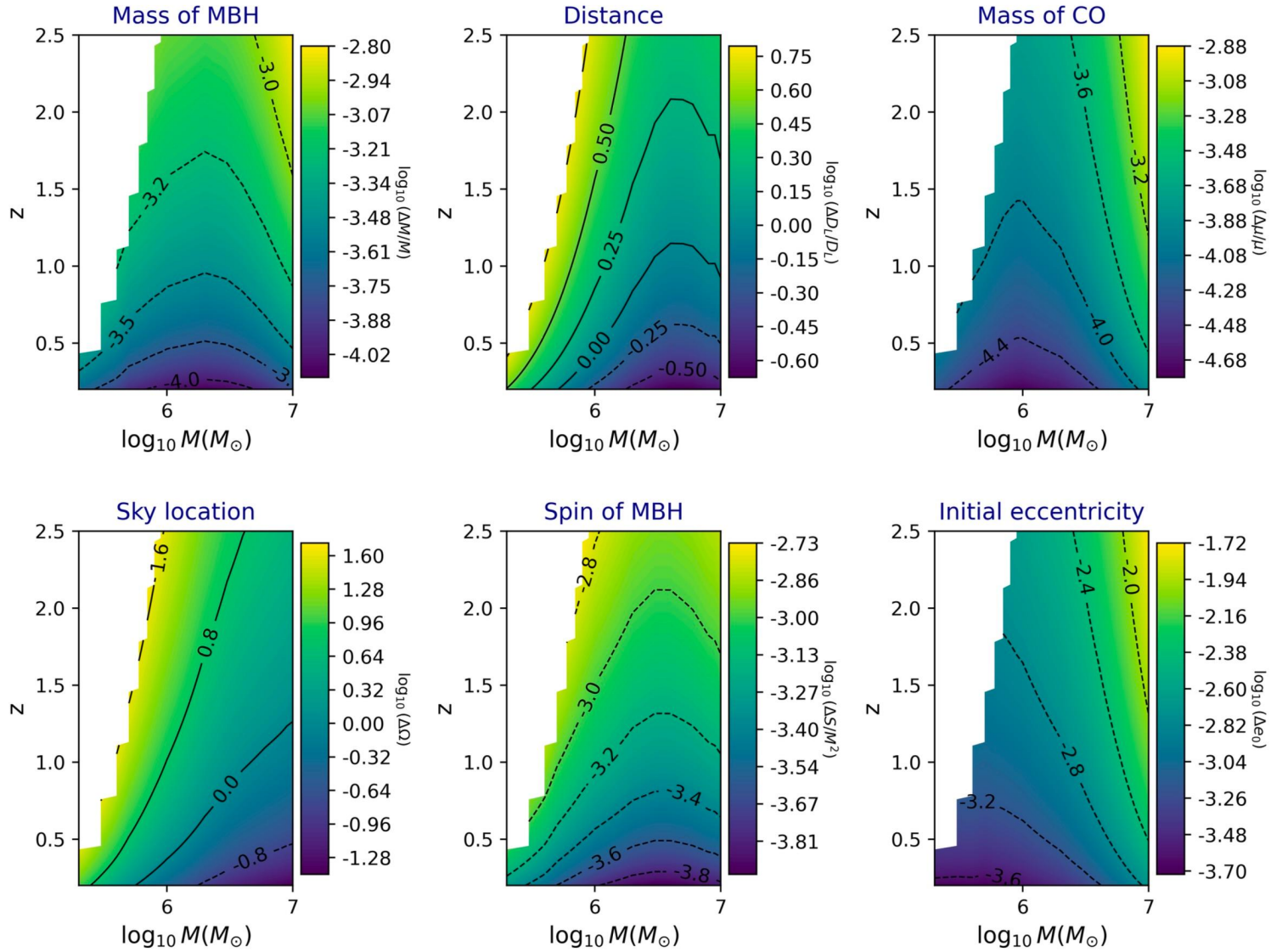


Credit: P. Shen & W. B. Han

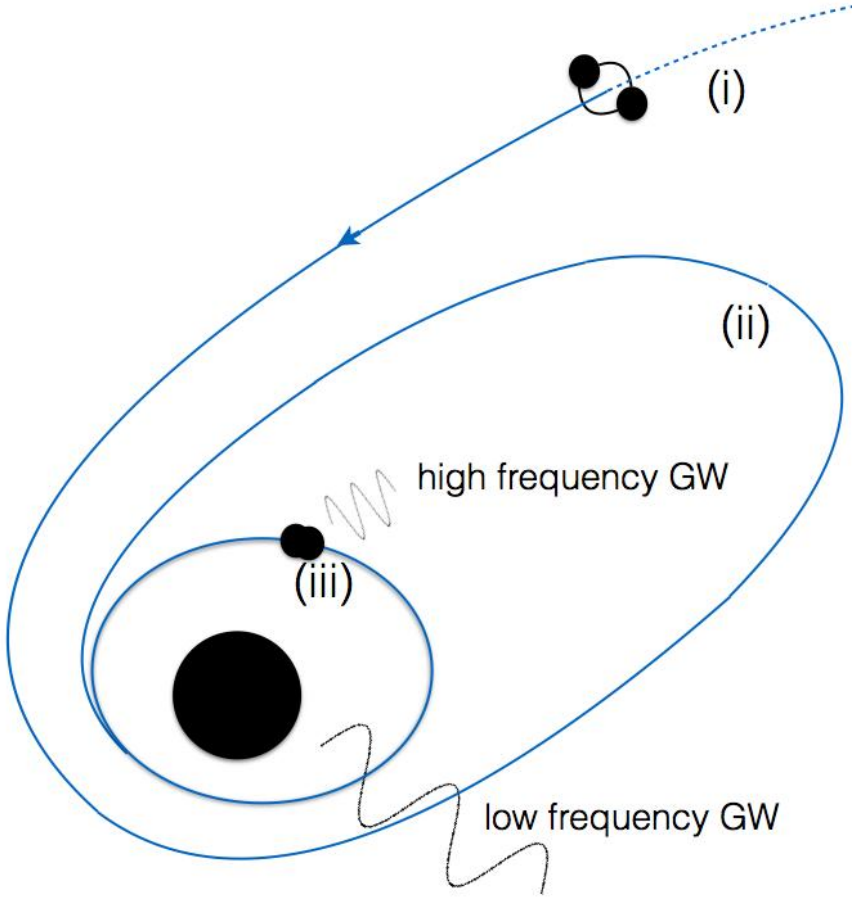
EMRIs: parameter uncertainties



EMRI horizon and SNRs by Taiji;
Parameter estimation uncertainties:
accurate determination of MBH spins and metric.



bEMRI-a multiband GW source



A bounded binary can be captured by a SMBH, form a b-EMRI: can be observed by LIGO and LISA at the same time.

Chen & Han, 2018
Han & Chen, 2019

Astrophysics with the Laser Interferometer Space Antenna

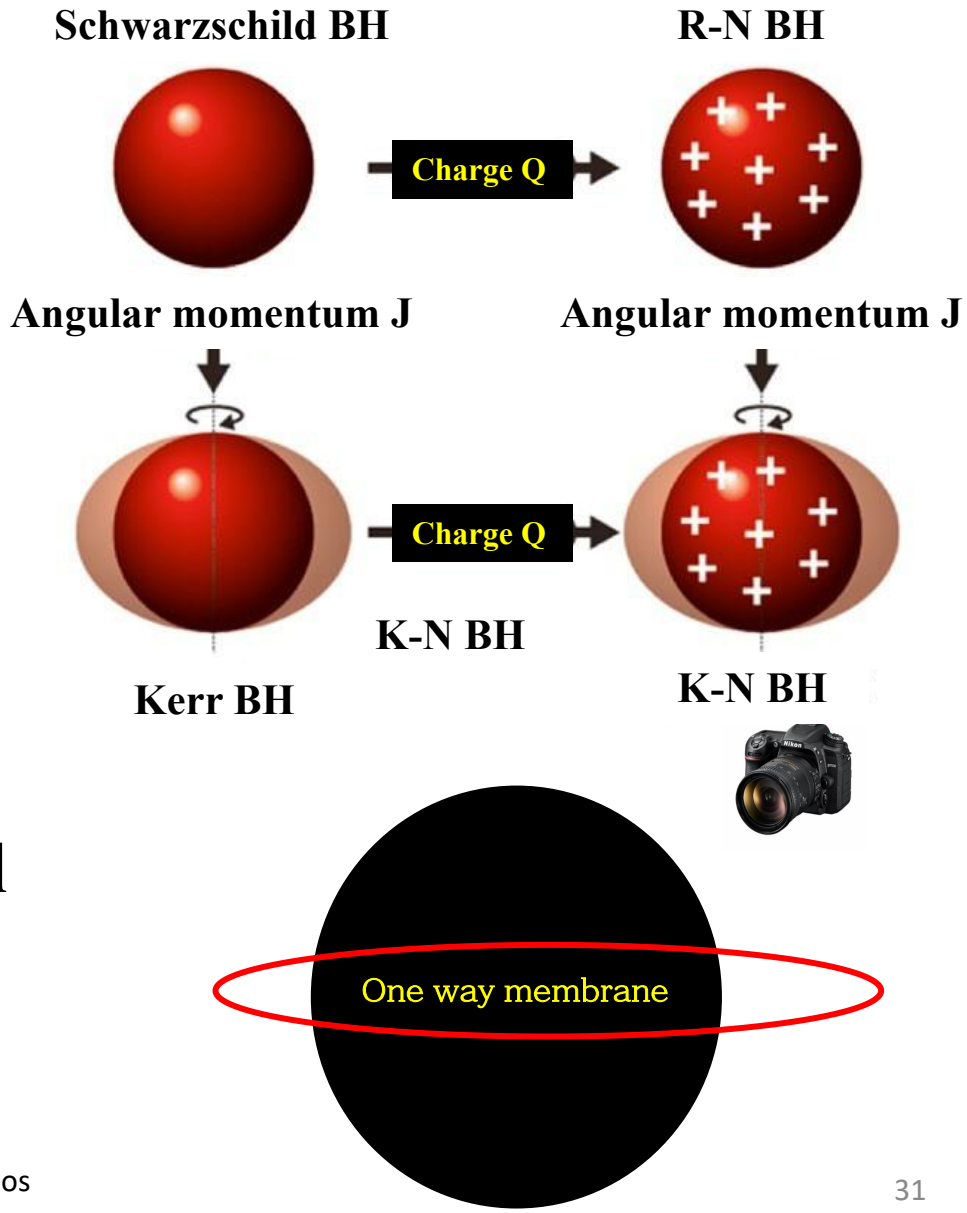
SSO	Substellar object
TDE	Tidal disruption event
UCB	Ultra-compact binary
UCXB	Ultra-compact X-ray binary
UV	Ultra-violet
WD	White dwarf (plural: WDs)
WD+WD	Double white dwarf (plural: WD+WDs)
XMRB	Extremely large mass-ratio burst
XMRI	Extremely large mass-ratio inspiral
ZKL	Von Zeipel–Kozai–Lidov
b-EMRI	Binary-extreme mass ratio inspiral

LISA white paper: LRR 26:2, 2023

Sciences of b-EMRI:
1 . weighting the remnant of BBH merger accurately;
2. measuring the kick velocity of BBH merger;
3. test GW dispersion ……

EMRI-Test BHs and GR with superb accuracy

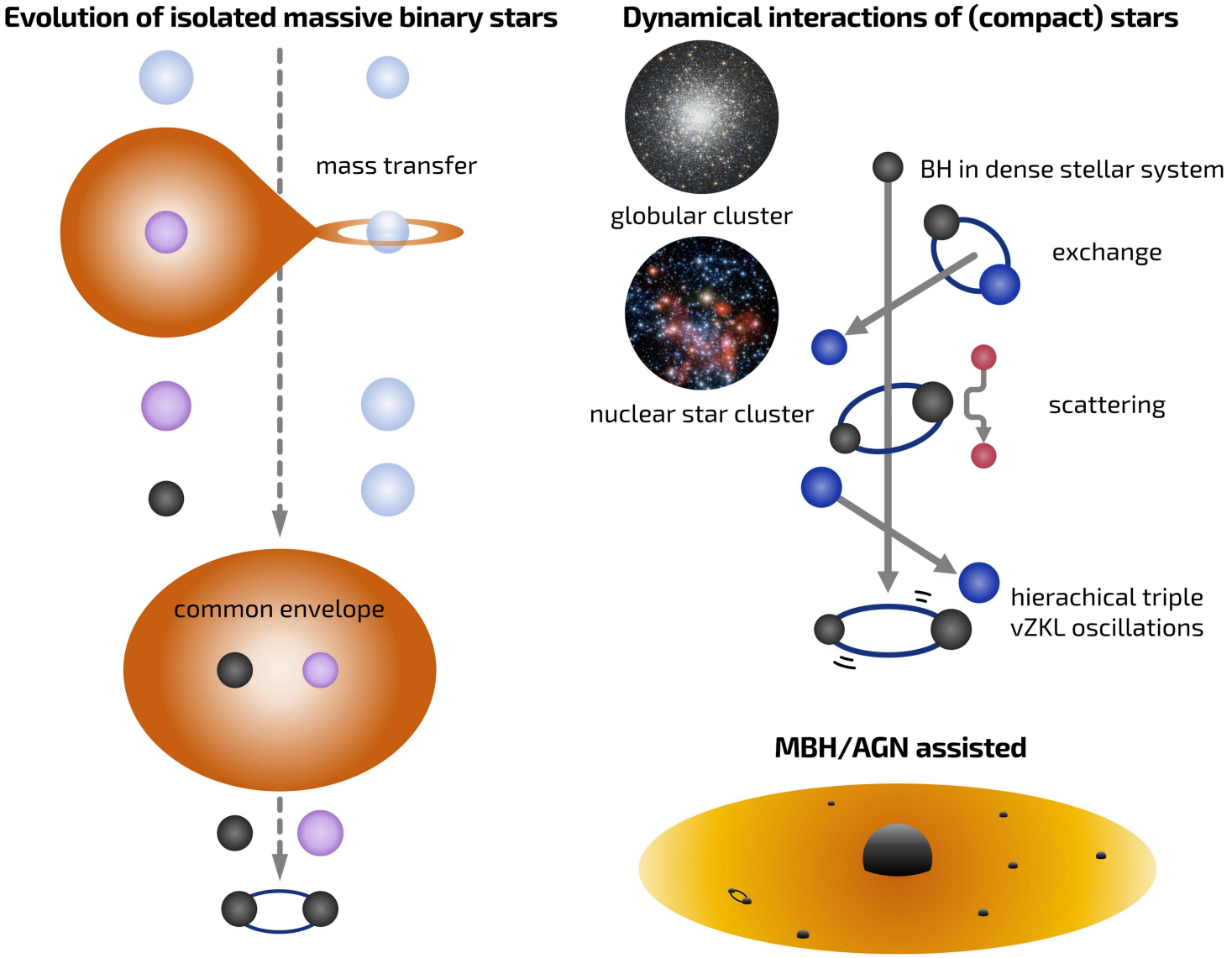
- The CO likes gravity satellite around MBH, maps space-time of MBH with superb accuracy: SNR > 20, mass and spin $10^{-4\sim-5}$, quadrupole $<10^{-3}\ M^3\ G^2/c^4$
- Test BH: no-hair theorem, only mass, spin and charge?
- Horizon exist? → BH or exotic compact object? $M_l + \mathrm{i}\, S_l = M\,(\mathrm{i}\, a)^l$
- Deviations from GR: reflect on inspiral



EMRIs/IMRIs: Taiji objectives

- **Detecting EMRIs with MBH mass at redshift up to a=4 with a broad peaking around z=1, and accurately measuring their extrinsic and intrinsic physical parameters;**
- **Detecting both light and heavy IMRIs and accurately measuring their physical parameters;;**
- **Detecting rare events, including XMRIs and unique b-EMRIs, constraining the spin of Sgr A* and precisely testing GR by using multiband GW observations;**
- **Confirming the existence of IMBHs and obtaining distribution of IMBHs and MBHs at the low-mass end;**
- **Inferring the demographics of EMRIs and IMRIs, revealing their formation mechanisms and constraining relevant relativistic processes;**
- **Testing the no-hair theorem and GR as well as modified gravity theories beyond GR;**
- **Searching for multi-messenger counterparts of wet EMRIs and constraining accretion-disk physics;**
- **Probing environments of MBHs/IMBHs through their effects on EMRI/IMRI signals.**

Stellar BBHs: formation channels

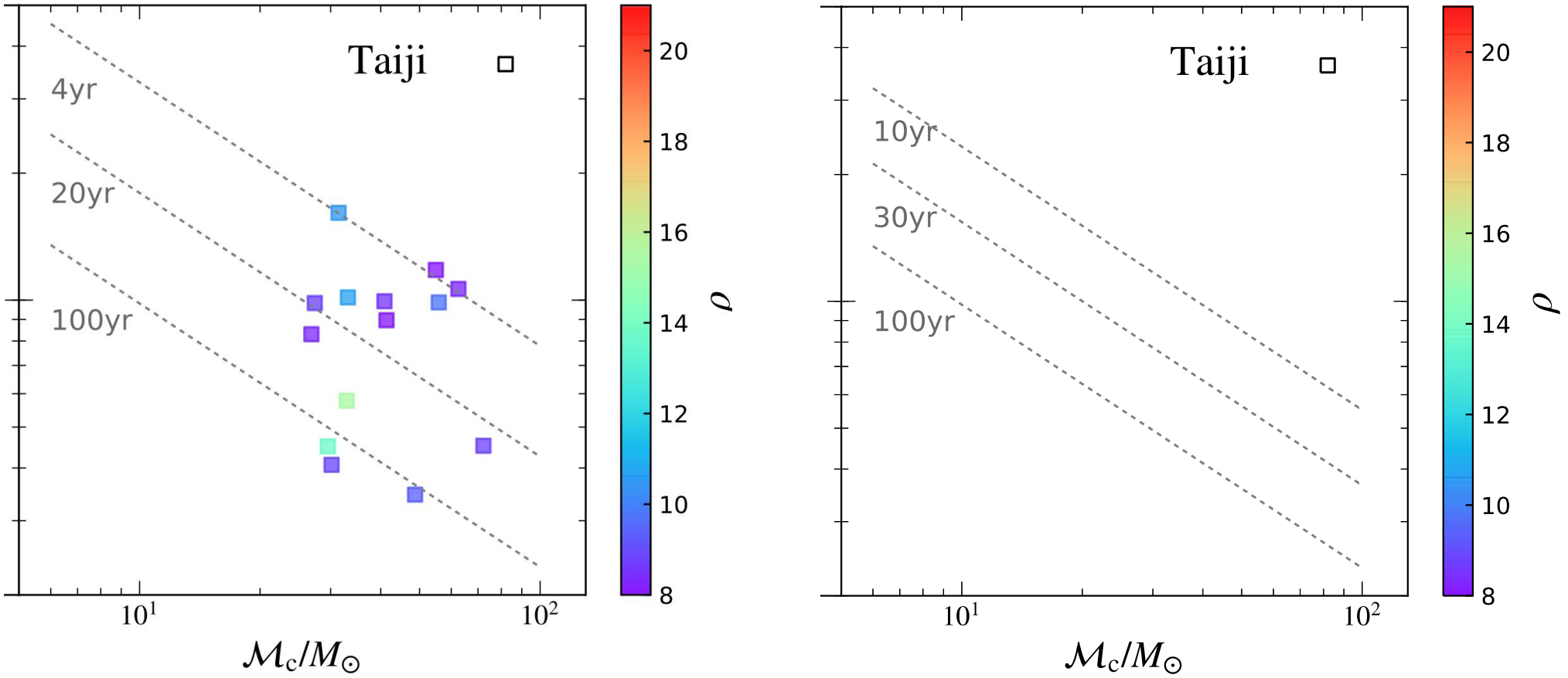


Formation mechanisms of sBBHs

- **Evolution of massive binary stars;**
- **Dynamical interactions in dense stellar clusters, including globular clusters, open clusters and nuclear clusters;**
- **Hierachical triples;**
- **AGN disks around supermassive black holes.**

Taiji white paper

Stellar BBHs/: Taiji detection



4 year operation: ~14 BBHs

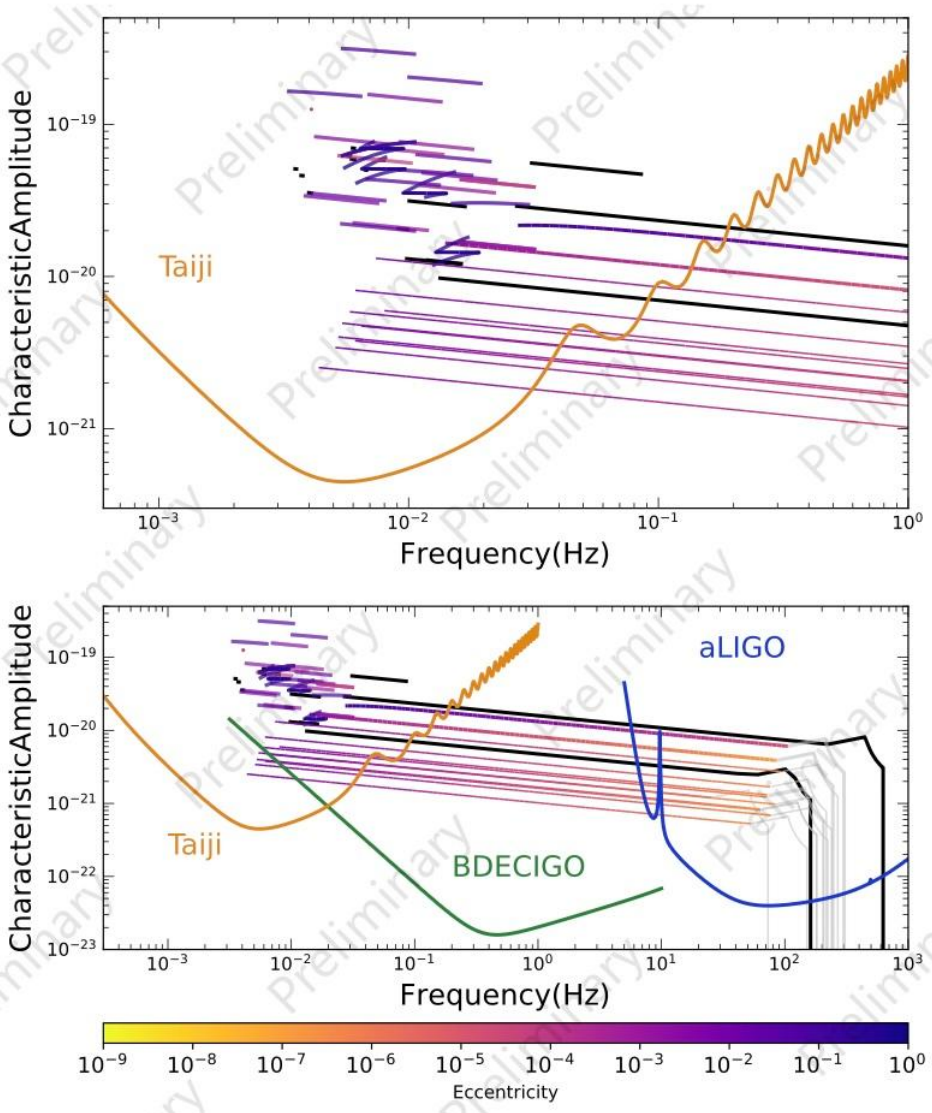
10 year operation: ~56 BBHs

Taiji white paper

Zhao et al. 2023, MNRAS

Cai et al. 2023, Fund. Res.

Stellar BBHs: Taiji detection

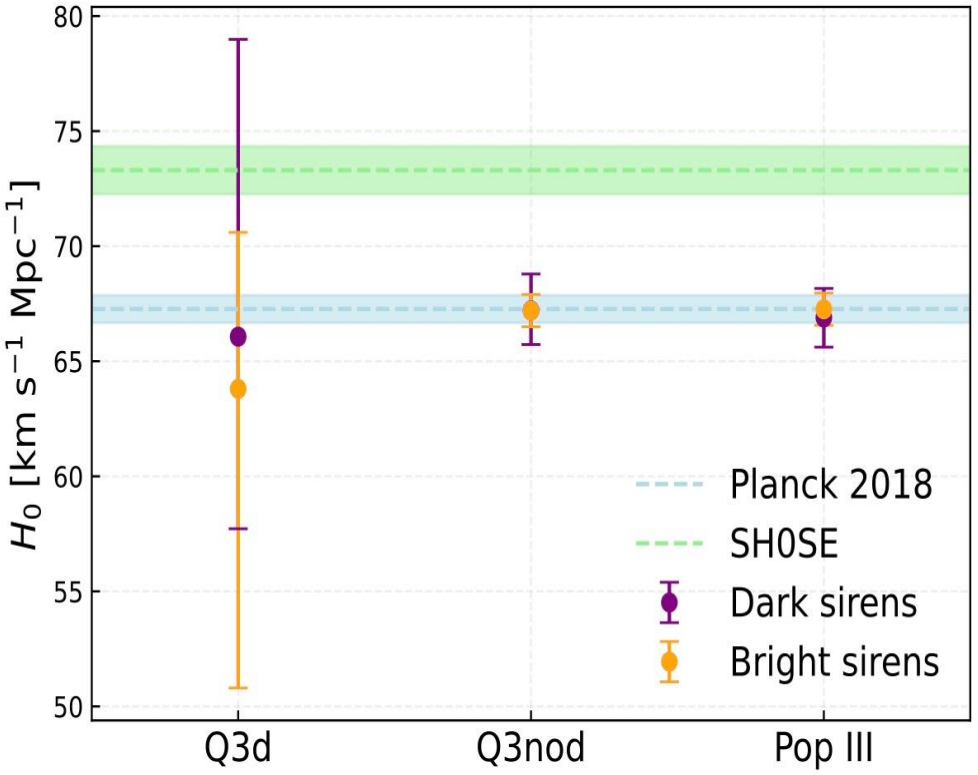


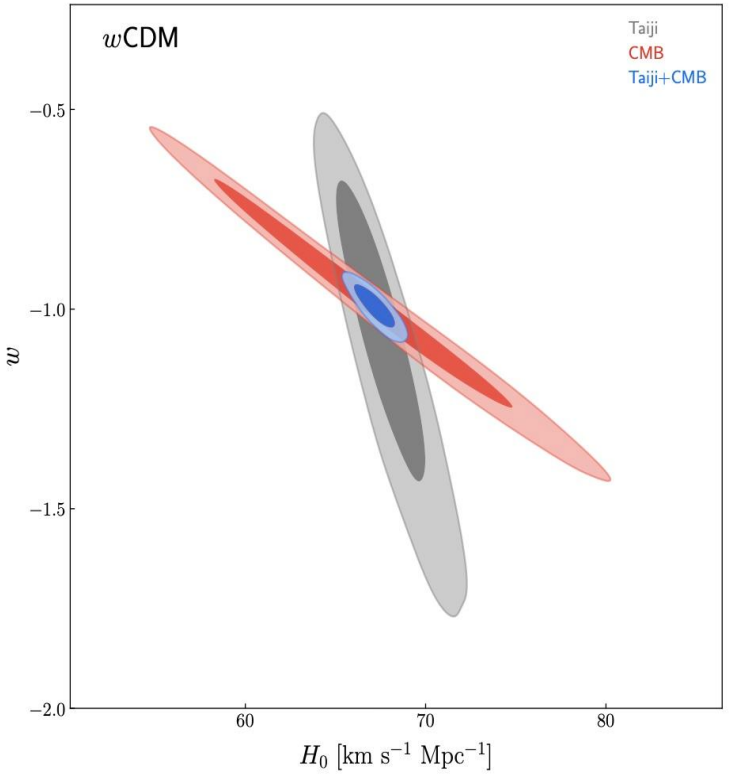
Detector	localization	Luminosity distance	Chirp mass	Mass ratio
Taiji	0.33-200 deg^2	0.053-0.1	8.6×10^{-7}-2.2×10^{-4}	0.0061-2.2

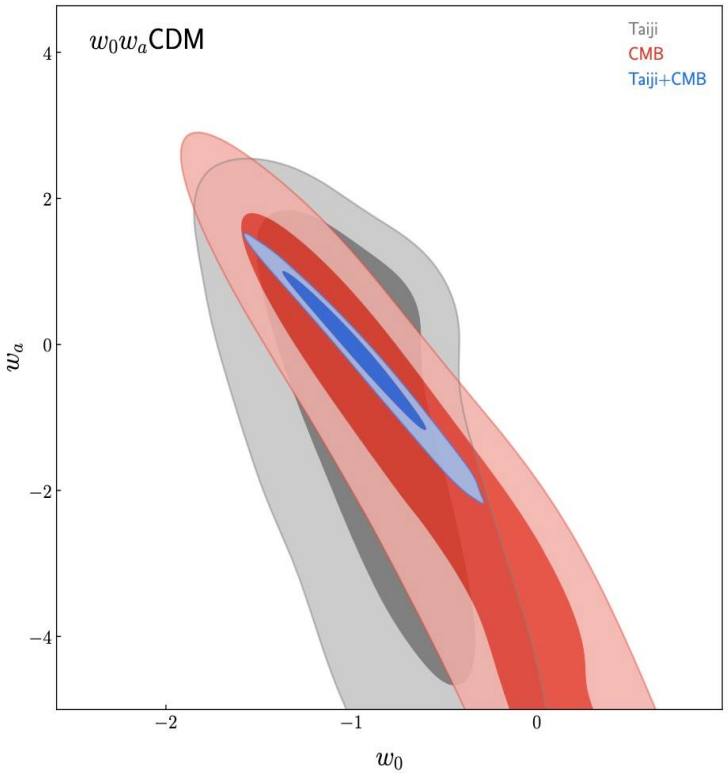
- **Identifying multiple formation channels**
- **Detecting high mass stellar BBHs and probing their environment**
- **Early warning for higher frequency (groundbased) GW detectors and enabling multiband and multimessenger observations**
- **Constraining the formation mechanisms of stellar black holes**

Zhao et al. 2023, MNRAS
Cai et al. 2023, Fund. Res.

Cosmology: standard sirens

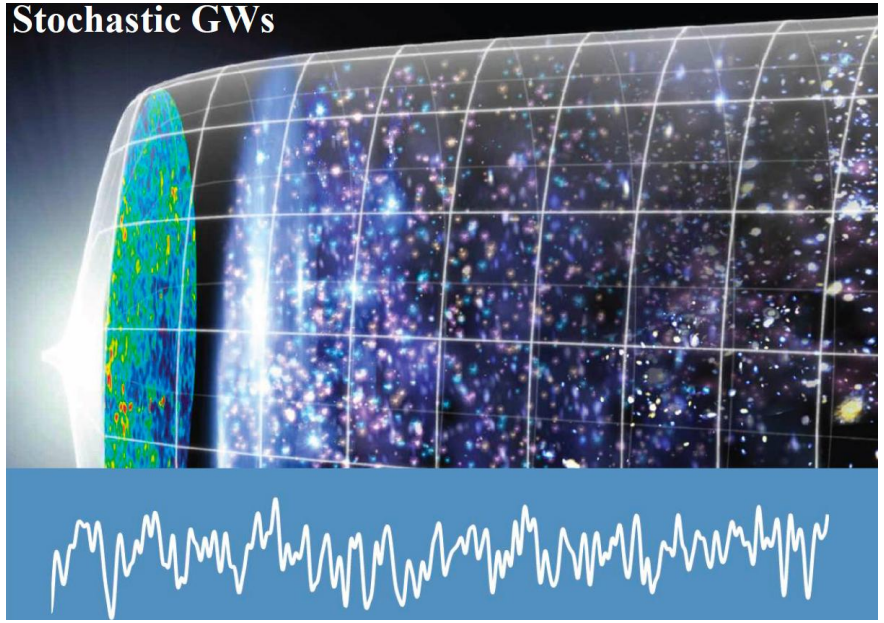


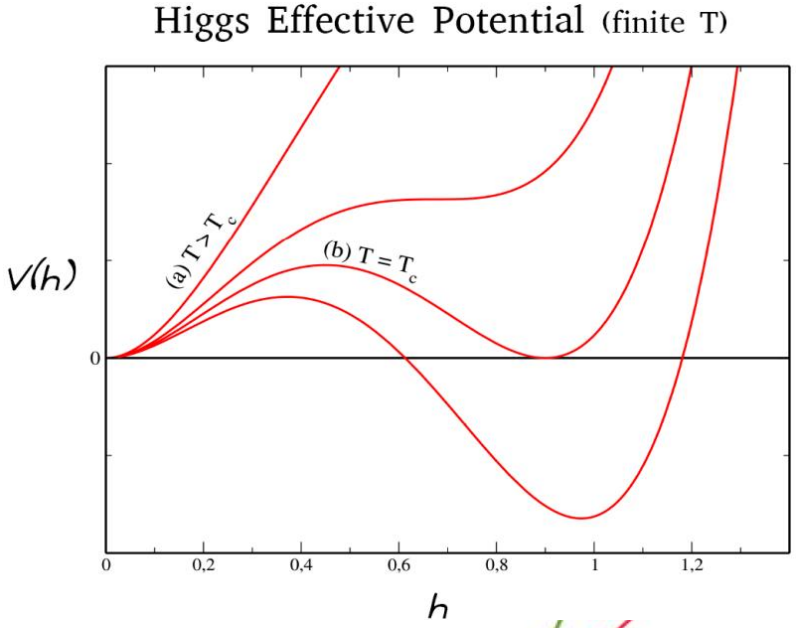




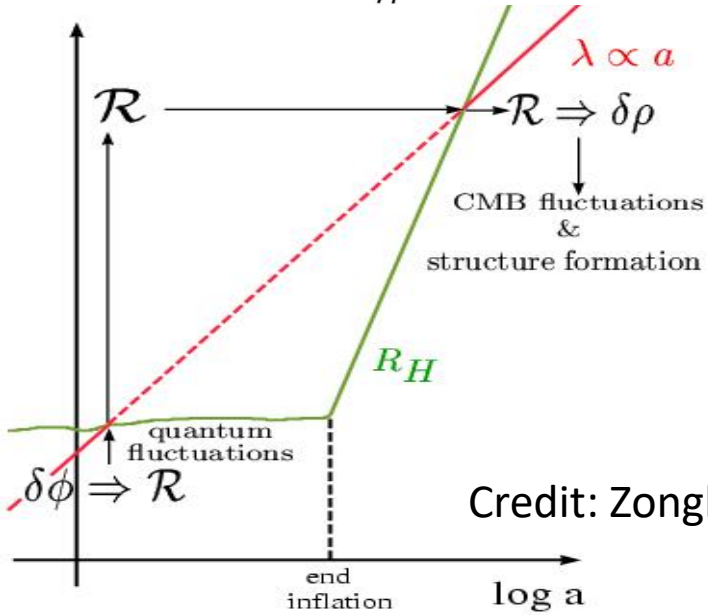
- **Bright and dark sirens: accurately measuring the Hubble constant, potentially solve the Hubble tension;**
- **Combination with other probes: tightly constraining other cosmological parameters and the evoluvtion of dark energy.**

Cosmology: processes in the early universe



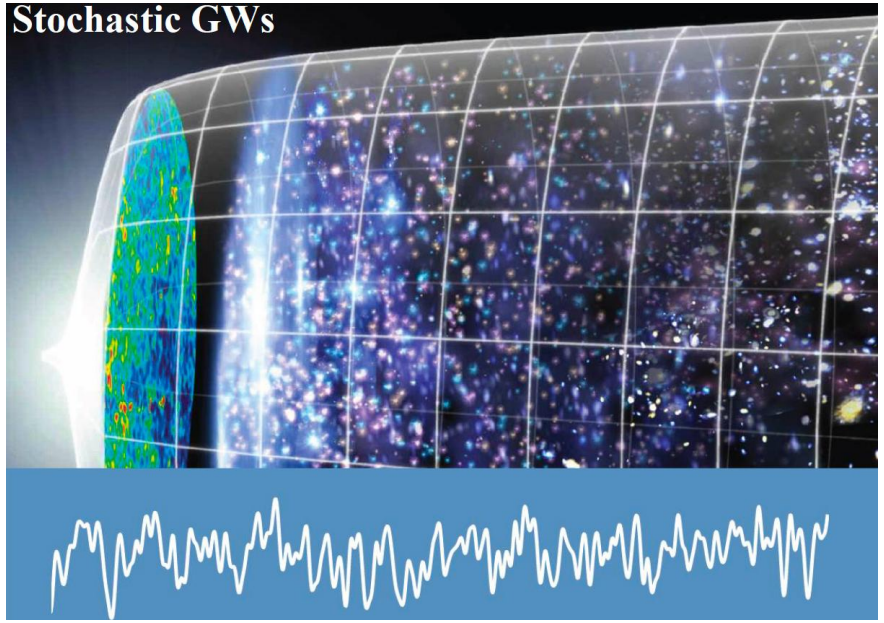


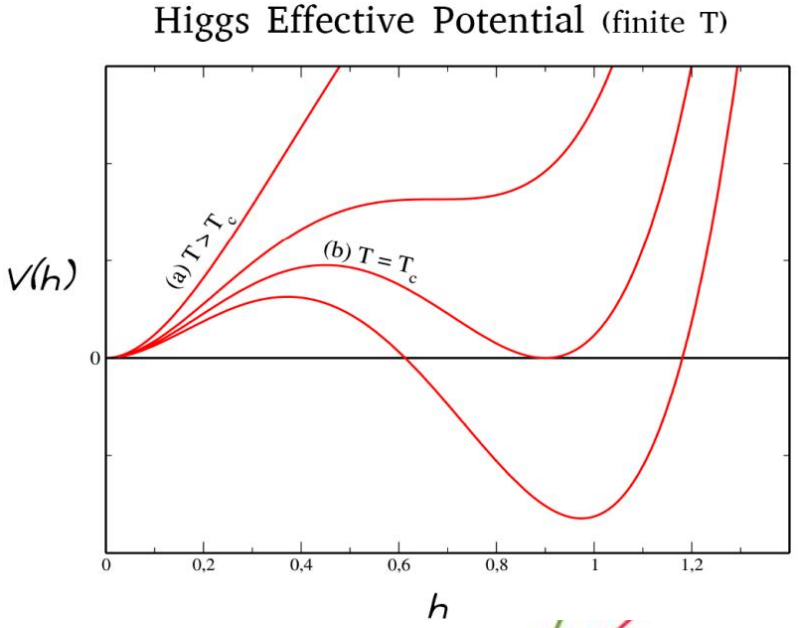
- (first order) phase transition in the early universe
- inflation
- reheating/preheating
- primordial perturbation induced GW
- cosmic domain wall
- cosmic string
- numerous beyond standard models…



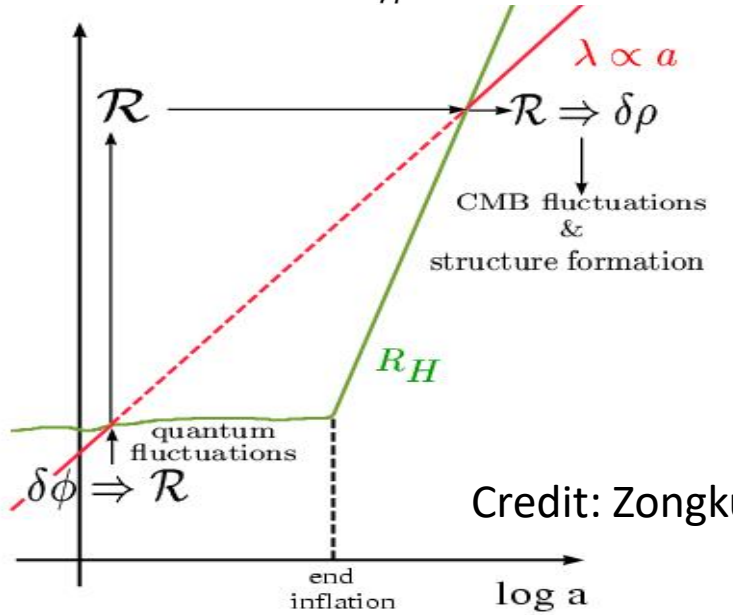
Credit: Zongkuan Guo

Cosmology: processes in the early universe





- probing or set upper limit on cosmic origin SGWB
- understanding the physical processes in the early universe
- electroweak phase transition and new physics
- revealing the nature of inflaton and determining the energy scale



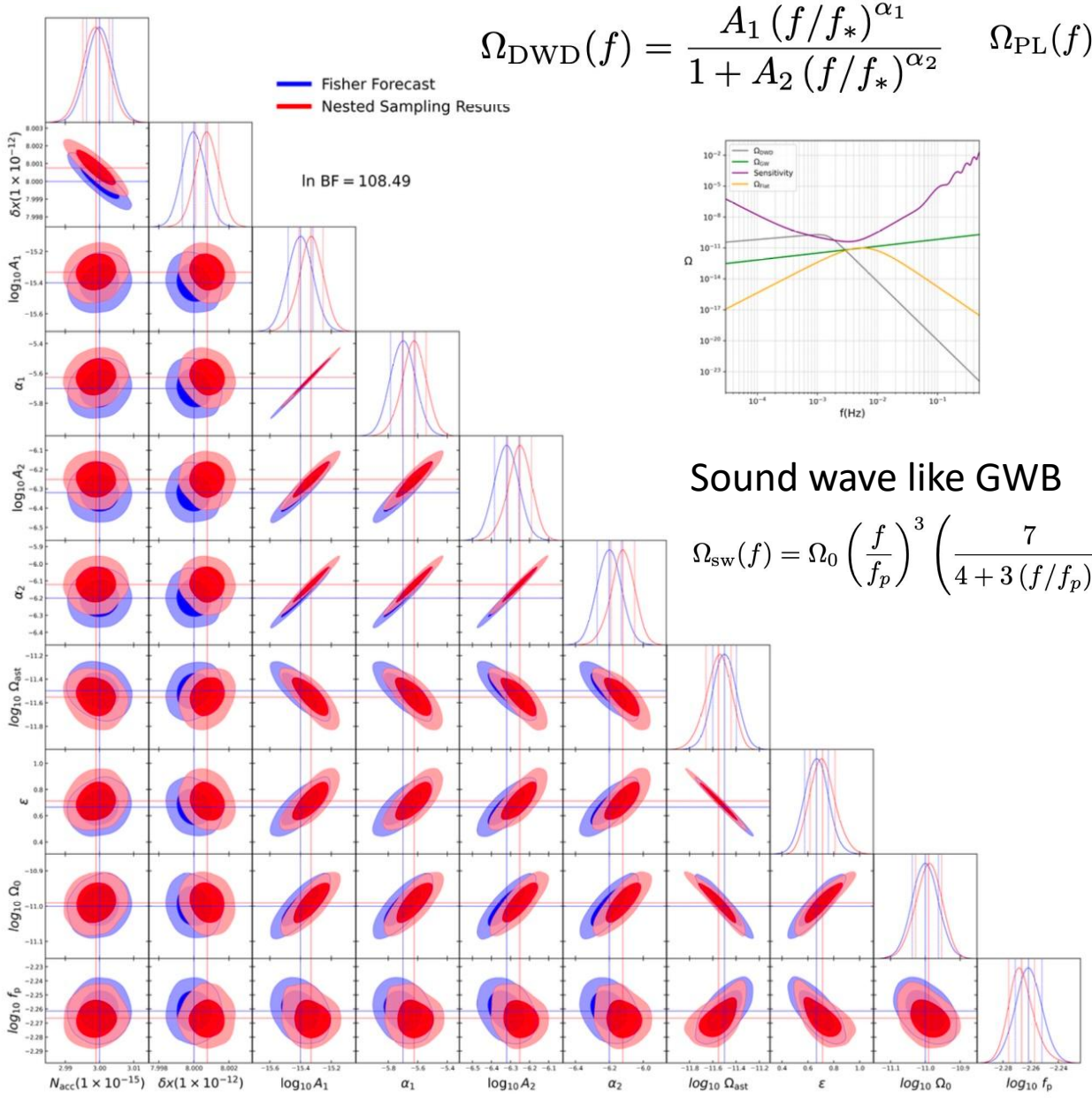
Credit: Zongkuan Guo

Cosmology: forecast examples

$$\Omega_{\rm DWD}(f) = \frac{A_1\,(f/f_*)^{\alpha_1}}{1 + A_2\,(f/f_*)^{\alpha_2}}$$

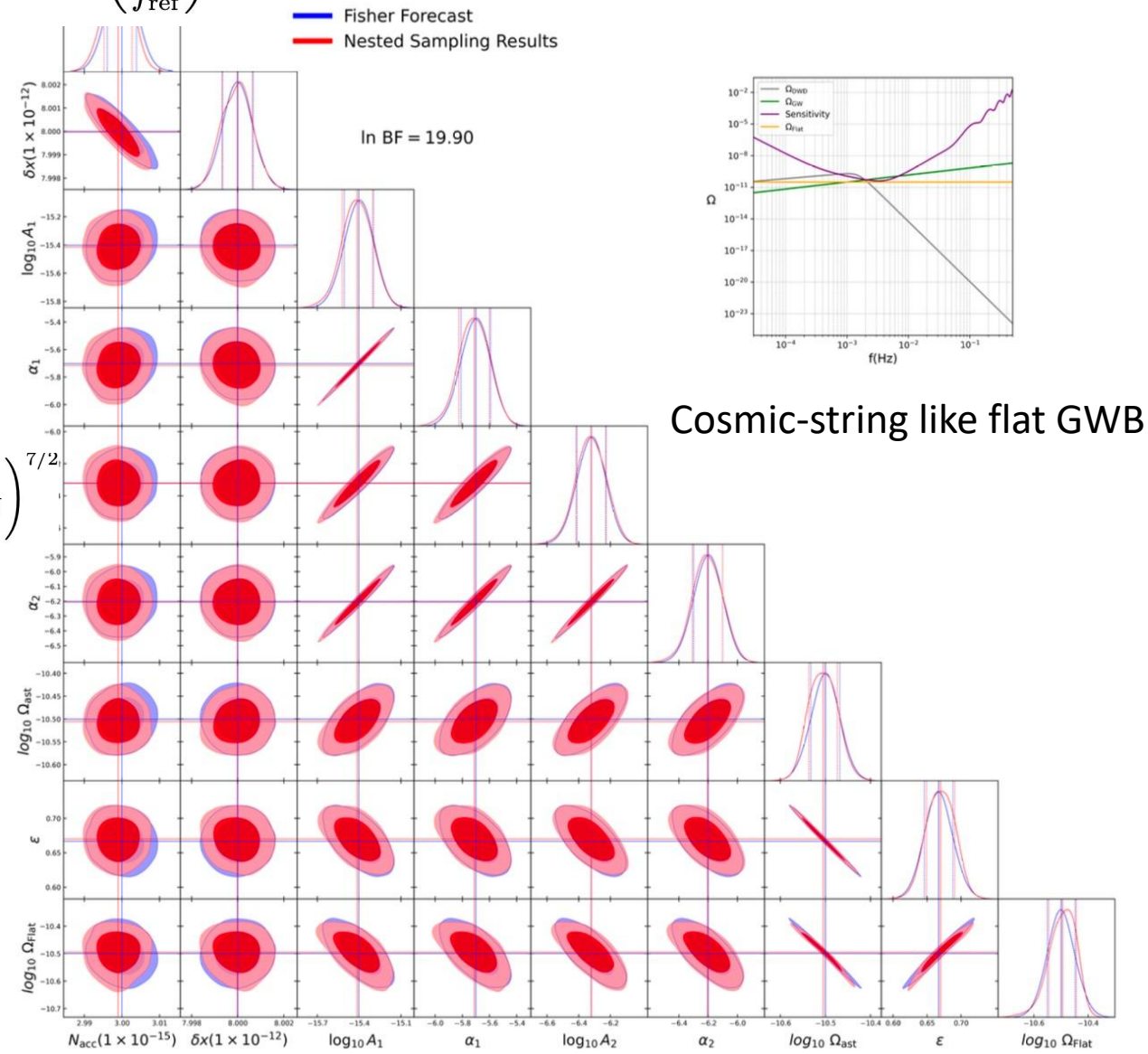
$$\Omega_{\rm PL}(f) = \Omega_{\rm ast}\left(\frac{f}{f_{\rm ref}}\right)^{\alpha_{\rm ast}}$$

Taiji white paper



Sound wave like GWB

$$\Omega_{\rm sw}(f) = \Omega_0\left(\frac{f}{f_p}\right)^3\left(\frac{7}{4+3\,(f/f_p)^2}\right)^{7/2}$$

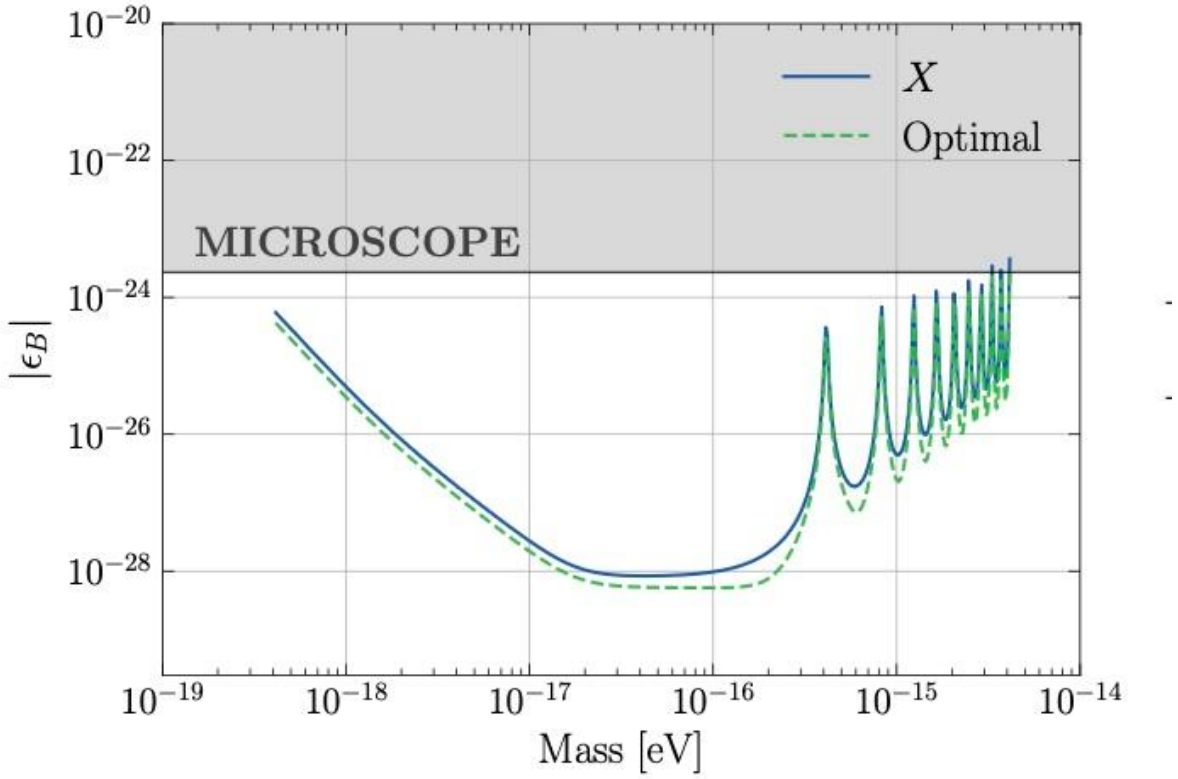


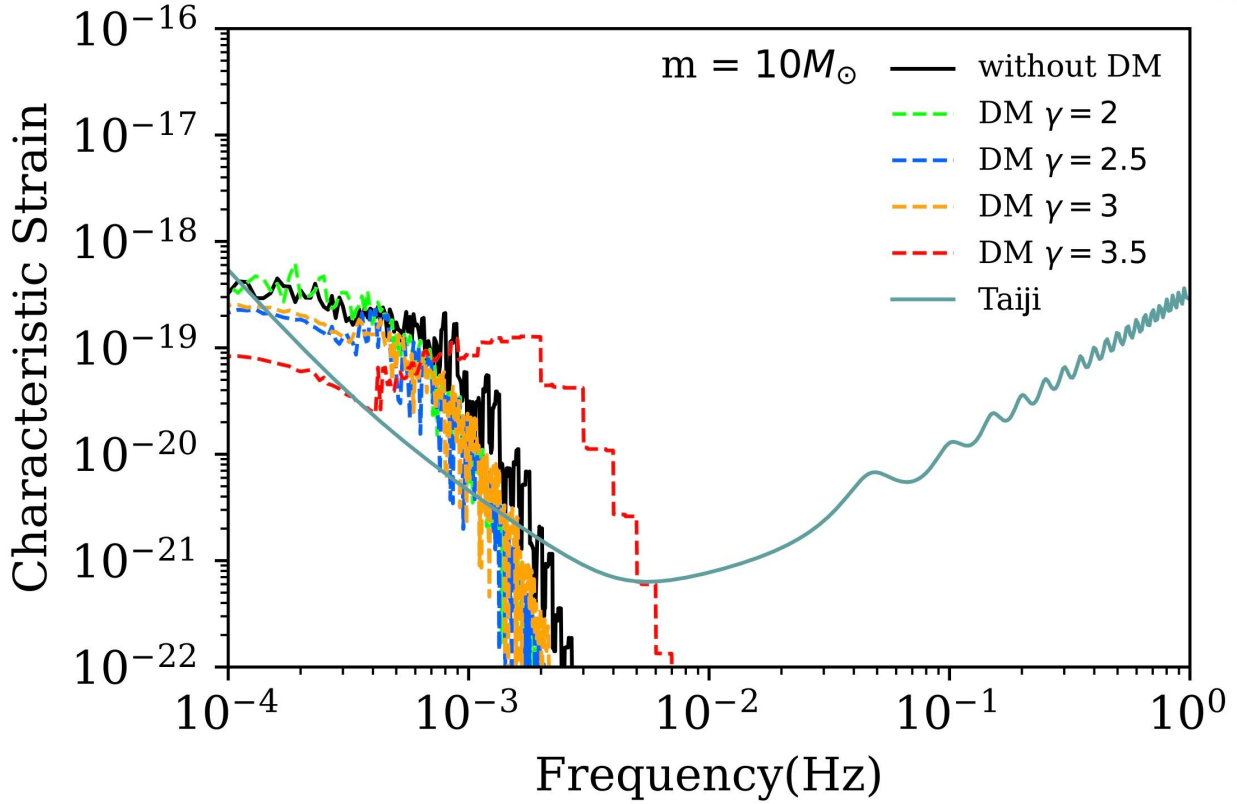
Cosmic-string like flat GWB

Cosmology: Taiji objectives

- **Measuring the Hubble constant with standard sirens;**
- **Probing inflation by measuring the SGWB due to quantum fluctuations;**
- **Probing the nature of the electroweak symmetry breaking;**
- **Probing the existence of cosmic strings due to high scale symmetry breakings;**
- **Detecting the SGWB of cosmological origins.**
- **…**

Fundamental physics: dark matter





Nature of dark matter:

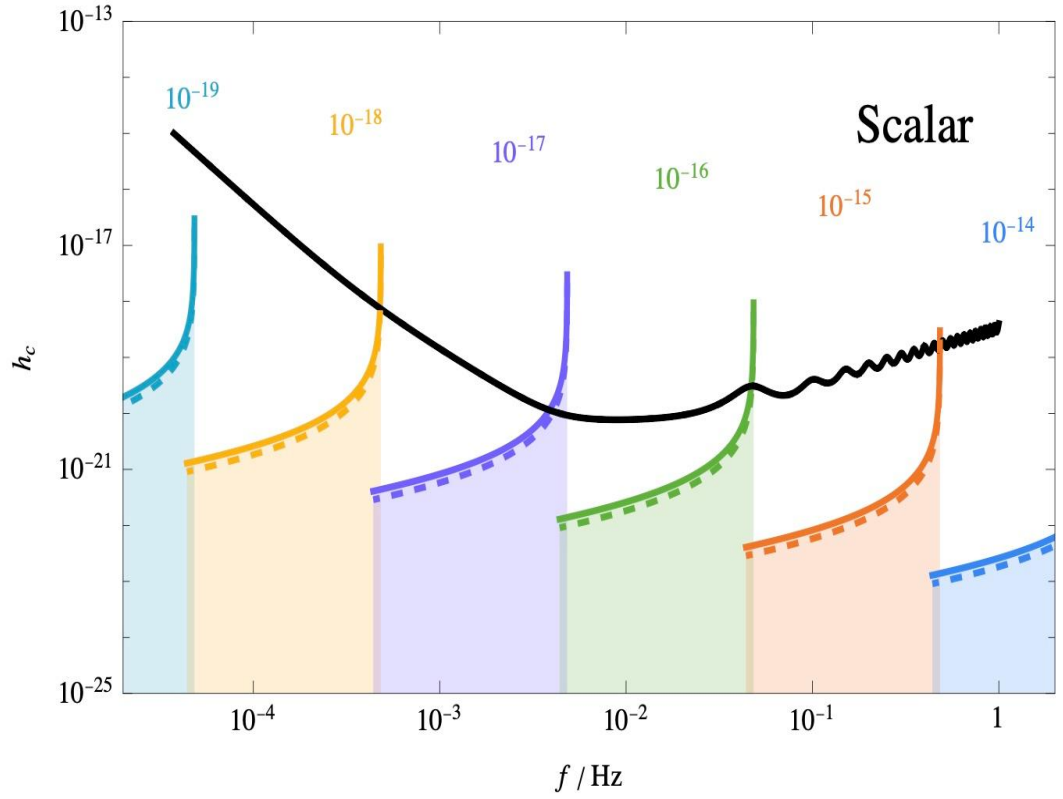
Direct test by ULDM (wave matter) effects on the detectors;

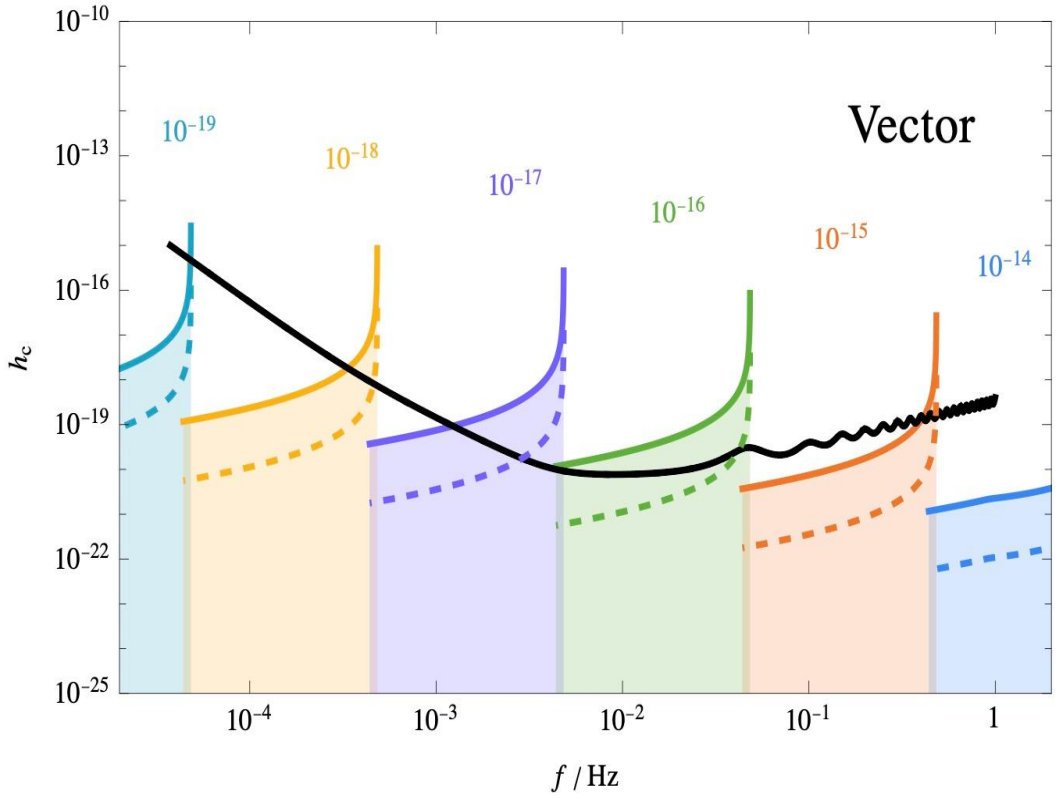
Indirect test by Dark matter effects on the density profile around MBHs.

Tang and others

Taiji white paper

Fundamental physics: dark matter



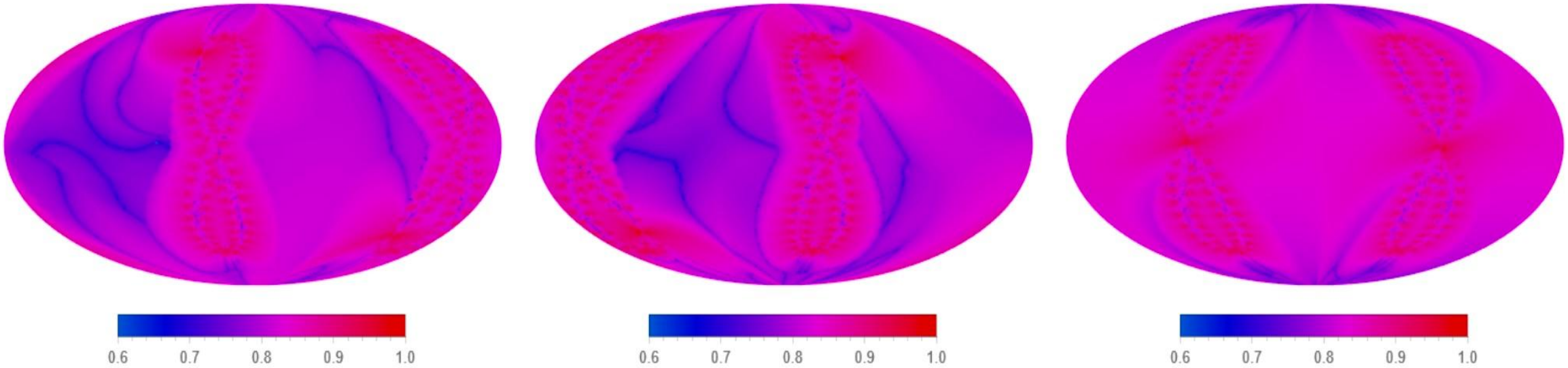


Nature of dark matter:

GW signals from scalar, vector, and axion clouds around MBHs

Fundamental physics: Gravitational Quantum field theory

Polarization map



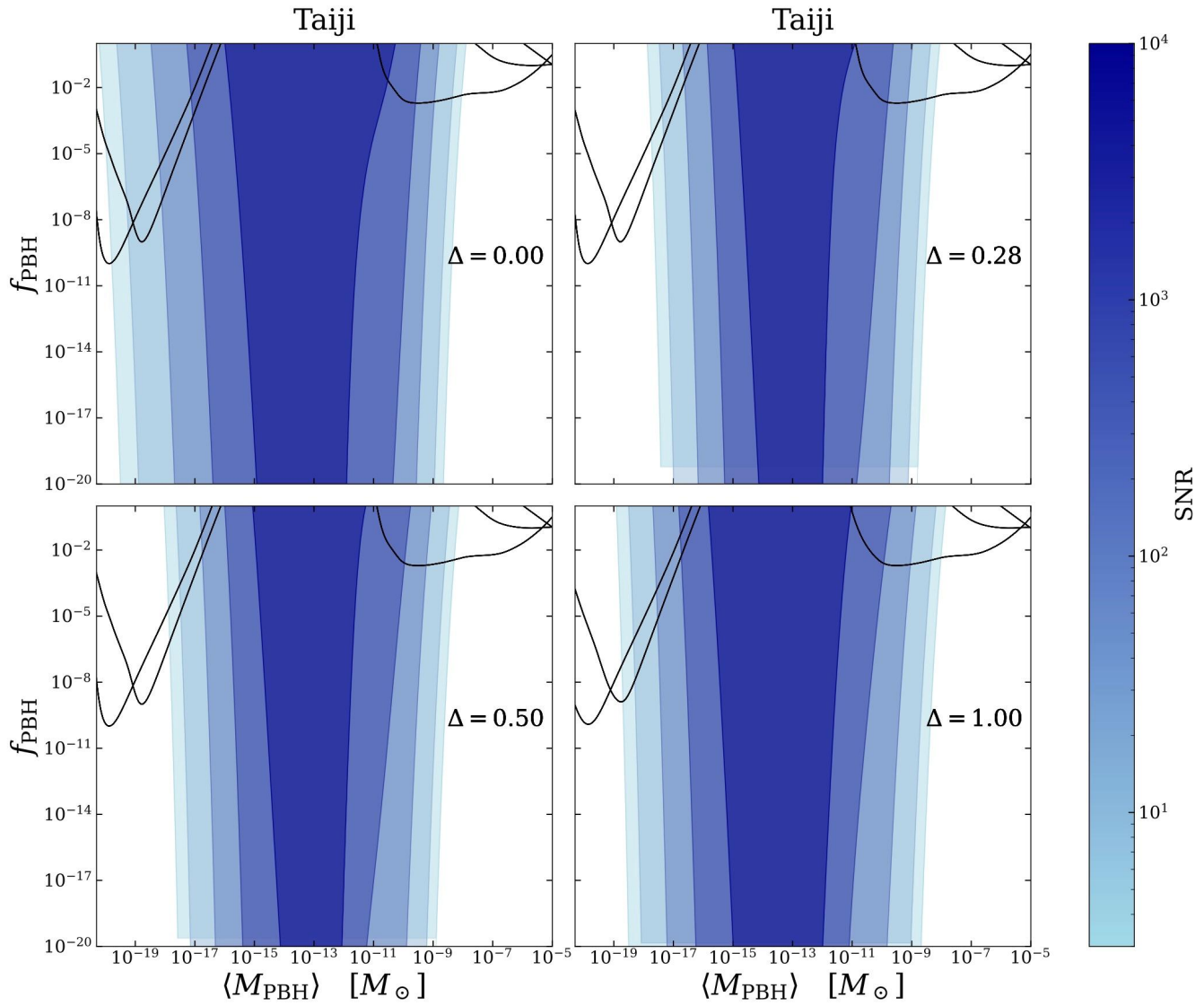
Predicted polarizations: two tensor modes, two vector modes, and one scalar mode
Taiji is only sensitive to the two tensor modes and one scalar mode (like a massless breathing scalar mode)

Fundamental physics: Primordial black holes

SNR contour maps by Taiji for induced GWs for different width of the power spectrum

$$f_{\rm IGW} \approx 0.03{\rm Hz}\left(\frac{M_{\rm PBH}}{10^{20}\ {\rm g}}\right)^{-1/2}$$

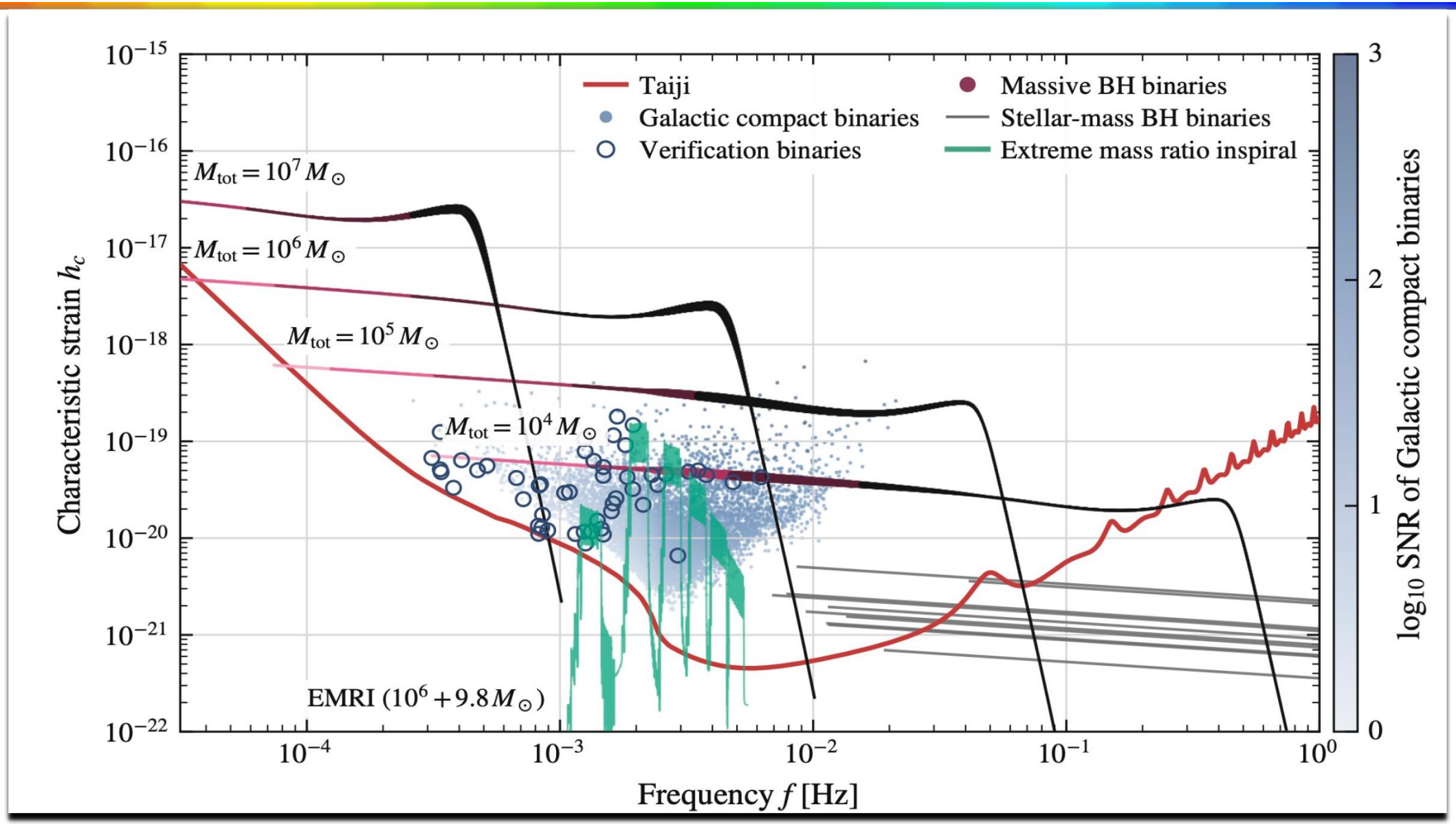
$$\mathcal{P}_\zeta = \frac{\mathcal{A}_\zeta}{\sqrt{2\pi\Delta^2}}\exp\left(-\frac{\ln^2(k/k_p)}{2\Delta^2}\right)$$



Fundamental physics: Taiji objectives

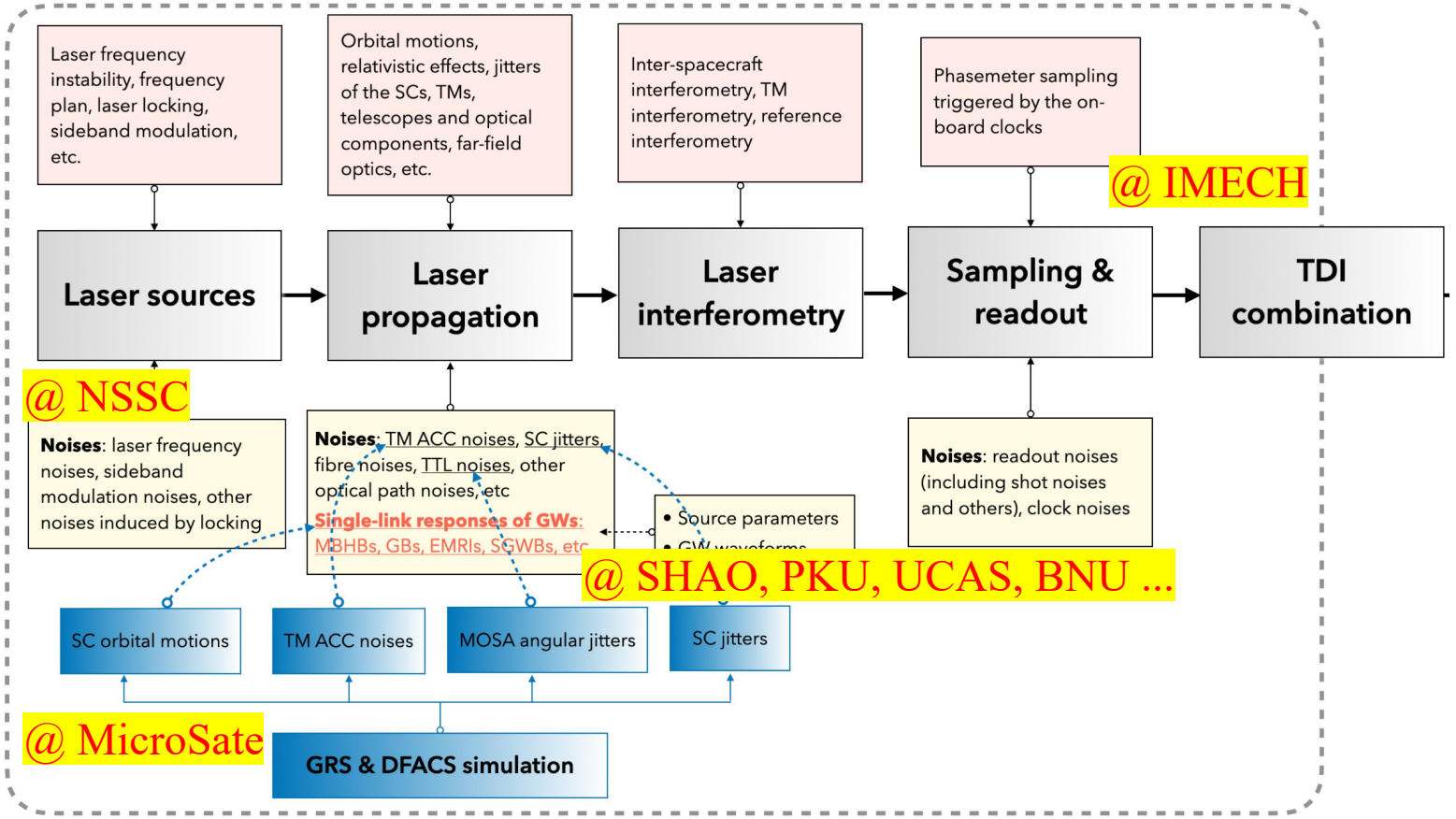
- **Testing gravity theories, including general relativity, modified gravity, theories with extra dimensions and polarizations;**
- **Testing the non-gravitational interaction between DM and ordinary matter;**
- **Testing the existence of ultralight bosons;**
- **Testing the formation mechanics of primordial black holes;**
- **…**

Mixed signals with background and foreground noises



Taiji Data Challenge

- **Taiji Data Challenge Simulation Platform**



Simulation framework [M. Du+, SCPMA (2025)]

KEY contributions:

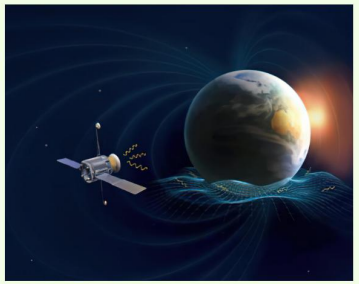
- **Integration of multiple sub-systems: laser interferometry, drag-free control, test-mass and gravitational reference sensor, etc;**
- **State-of-the-art signal waveform models;**
- **Complex and multi-source instrumental noises extracted from numerical simulations;**
- **Signal-noise-orbit couplings.**

Taiji Data Challenge

- **Taiji Data Challenge Mock Dataset**

Overview

Purposes MORE+



Taiji, a Chinese space-based gravitational wave detection project, aims to explore the millihertz gravitational wave universe with unprecedented sensitivity, targeting astrophysical and cosmological sources including Galactic binaries, massive black hole binaries, extreme mass-ratio inspirals, and stochastic gravitational wave backgrounds, etc. These observations are expected to provide transformative insights into astrophysics, cosmology, and fundamental physics. However, Taiji's da…

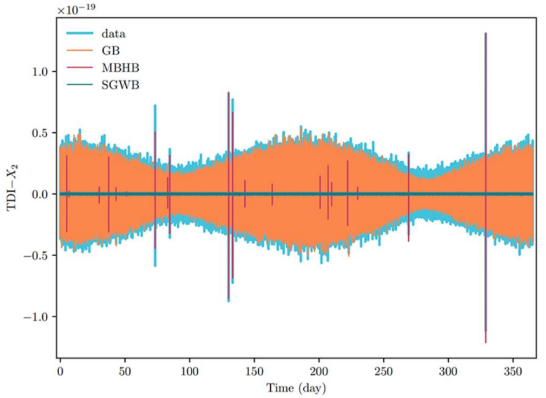
Highlights MORE+

Taiji Data Challenge II (TDC II) comprises 5 groups of datasets (**Challenge 0 - 4**), each targeting specific challenge topics. Except for **Challenge 0** designed as illustrative examples for the access and use of TDC II, most of the remaining datasets are blind (i.e. the source parameters are unknown).

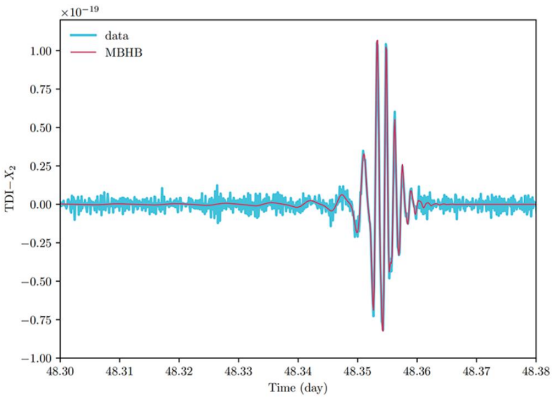
An outline for the challenges:

- **Challenge 0**: the "Verification" Datasets
- **Challenge 1**: the "Global Fit" Dataset
- **Challenge 2**: the "Single Source" Datasets
- **Challenge 3**: the "End-to-End" Dataset
- **Challenge 4**: the "Up-to-Date" Dataset

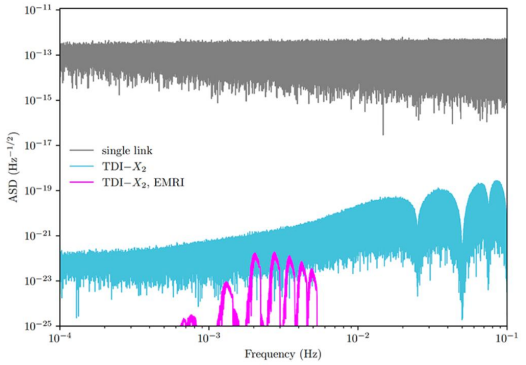
Each dataset is stored in a separate HDF5 (.h5) file. For the main challenges, a **"blind set"** version (parameters unknown) and a **"training set"** version (parameters known) are provided to establish a reasonable difficulty curve. Please visit the Challenges page to access the download links and diagrams of data. Detailed descriptions on the challenge topics and datasets, as well as how the datasets are created can be found in the Documents page (see the



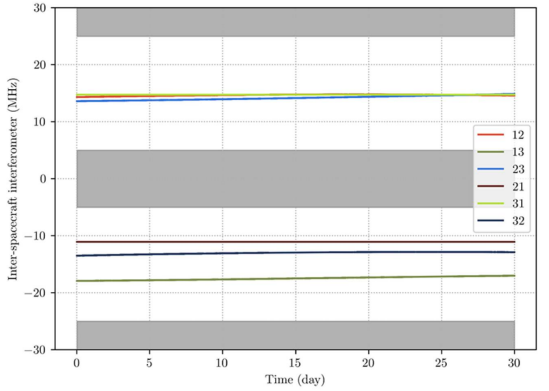
Global-fit data



Eccentric HM MBHB data



EMRI data



Level-0 raw data

Summary

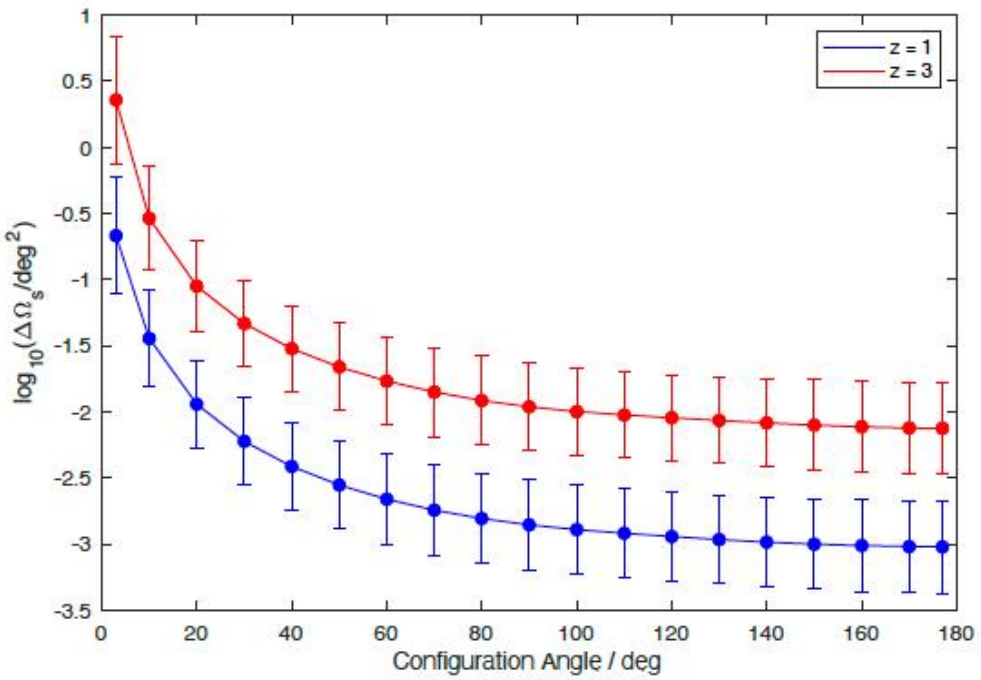
Taiji as a pivot facility for millihertz GW detection:

- **formation and evolution of compact objects, and their evolution with host galaxies;**
- **nature of black hole and gravity;**
- **expansion and evolution history of the universe, dark matter and dark energy;**
- **origin of the universe and fundamental physics in the early universe.**

Many breakthroughs in astrophysics, cosmology, and fundamental physics to come!

Thank you for your attention!

Space GW detectors： mergers of MBBHs



LISA+Taiji+Tianqin network：
Better localization and measurement precision

Ruan, Liu, Guo, Wu, & Cai 2020, NatAs
Gong, Luo, & Wang 2021, NatAs

Table 1 | The angular resolutions for monochromatic sources

f (Hz)	Angular resolution (deg²)				
	LISA	Taiji	TianQin	2 Network	3 Network
10^{-3}	2.0×10^{2}	1.4×10^{2}	1.2×10^{4}	1.3×10^{2}	69
10^{-2}	6.6	1.2	8.2	1.0	0.79
10^{-1}	7.6×10^{-2}	3.9×10^{-2}	6.9×10^{-3}	5.6×10^{-3}	4.9×10^{-3}

The mean angular resolutions for monochromatic sources are shown. 2 Network refers to the TianQin–Taiji network and 3 Network indicates the TianQin–Taiji–LISA network.

Table 2 | The angular resolutions for coalescence sources

Mass ($M_\odot$)	Angular resolution (deg²)				
	LISA	Taiji	TianQin	2 Network	3 Network
10^{3}	5.95	2.41	49.0	0.72	0.33
10^{4}	7.99	2.97	4.29×10^{2}	4.62×10^{-2}	1.65×10^{-2}
10^{5}	2.42	0.64	2.39×10^{3}	2.45×10^{-3}	6.19×10^{-4}

The mean angular resolutions for coalescence BBHs with equal mass at $z=1$.