Gravitational Wave Detection – “TianQin” Mission

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How Hadrons relate to GW?

Cool Quark Matter

A. Kurkela & A. Vuorinen, PRL 117 042501 (2016)

Kurkela and Vuorinen developed an improved method of analyzing the "quark matter" that is thought to exist in the cores of neutron stars. This theory could be tested by gravitational waves generated from mergers of two neutron stars or a neutron star and a black hole.

The spinning neutron star (pulsar), known as PSR J0357+3205.
Image credit: X-ray: NASA/CXC/IUSS/A.De Luca et al; Optical: DSS

Outlines

1. **TianQin mission concept**
2. **Key technologies**
3. **Development strategy**

What is gravitational waves ?

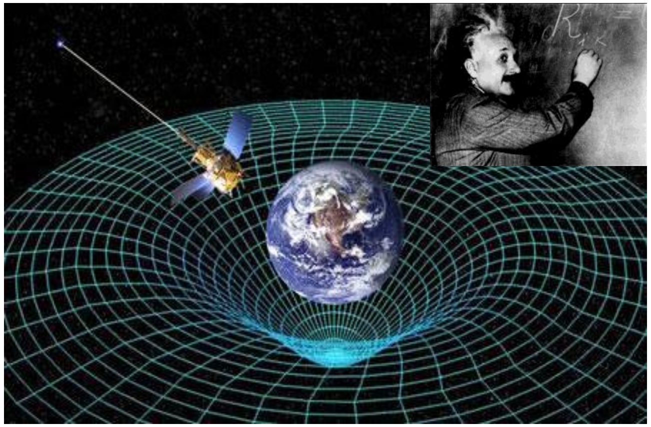
Basic concepts of GR and GW

Matter determines structure of spacetime;
Spacetime determines motion of matter.

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

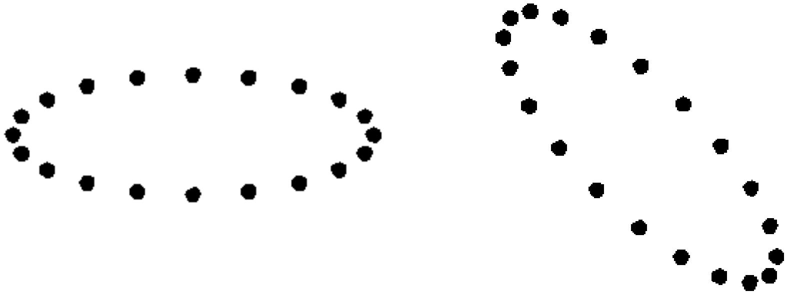
$$h^{\mu\nu} = \eta^{\mu\nu} - g^{\mu\nu}\sqrt{|g|}$$

$$g^{\mu\nu}\partial_\mu \partial_\nu h^{\mu\nu} = 0$$



Characteristics of GW:

- ripples of spacetime
- change in distance
- speed of light
- two polarizations



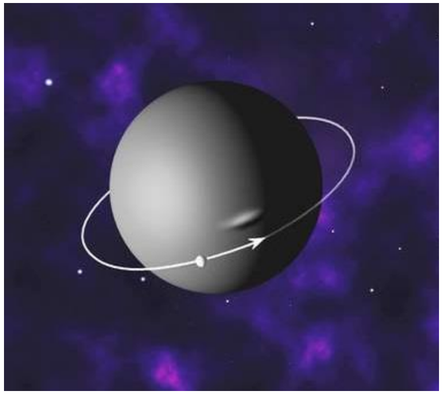
Significances of GW detection

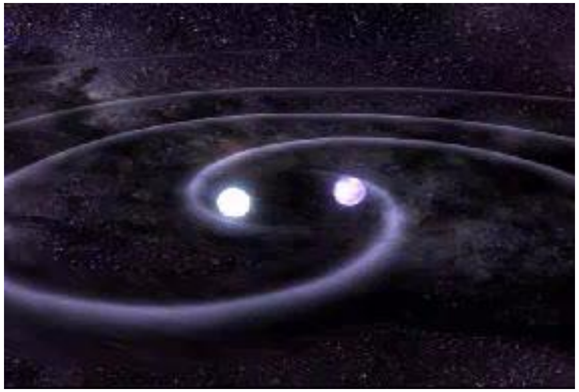
Fundamental physics：

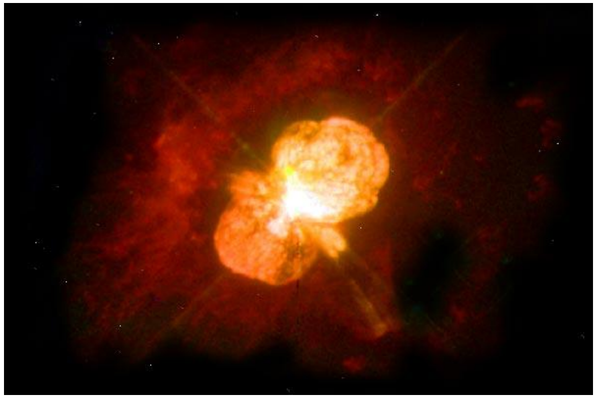
Test theories of gravity in the strong field regime.

Gravitational-wave astronomy：

Provide a new tool to explore black holes, dark matters, early universe and evolution of universe.





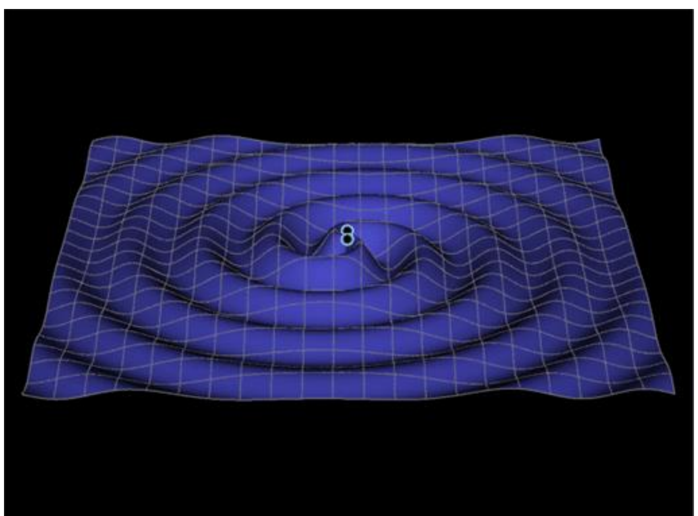


Why is GW detection so tough ?

- **Two 1-solar-mass stars with inter-distance of 1AU, detecting far from 1 light-year**

$$h \sim \frac{10^3 m * 10^3 m}{10^{16} m * 10^{11} m} \sim 10^{-21}$$

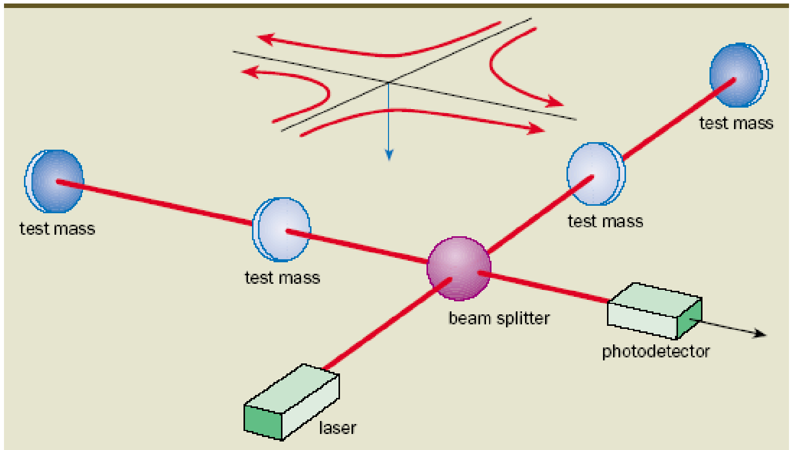
Distance change of 1Å over 1AU !

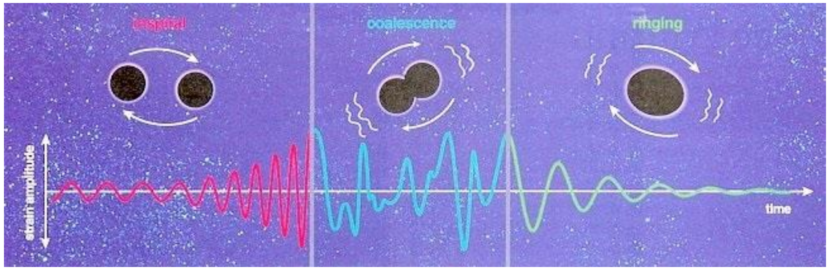


Difficulties :

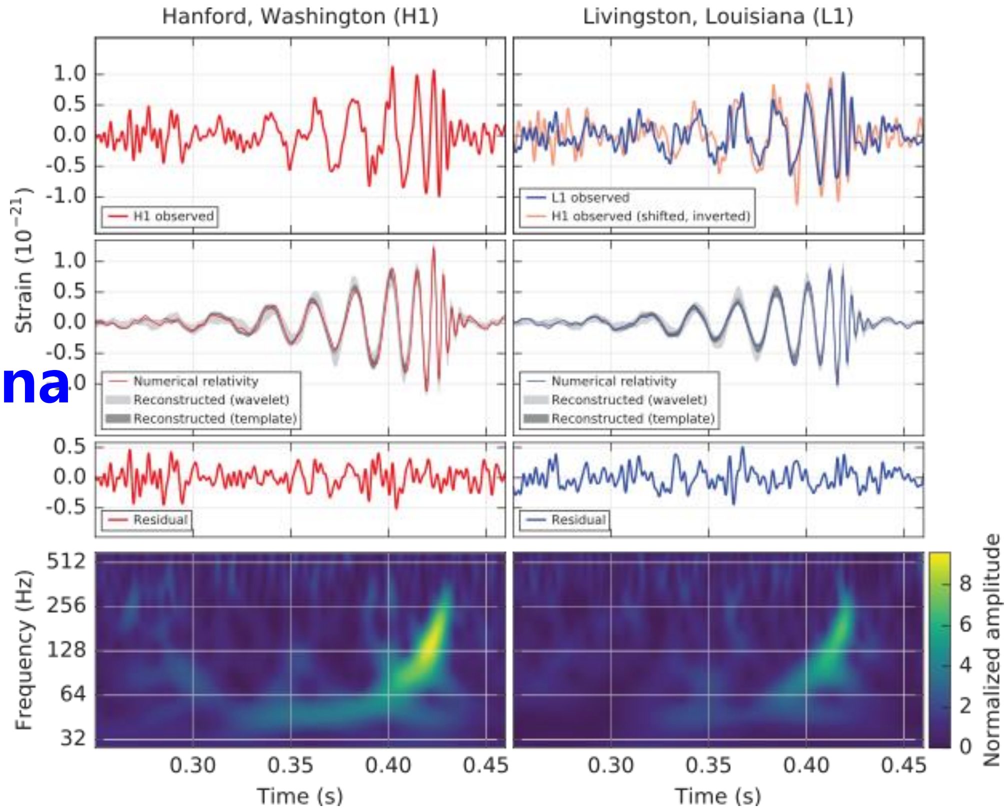
- **direction ?**
- **distance ?**
- **polarization ?**
- **wave shape ?**
- **large intrinsic noise!**
- **overlapping signals!**

LIGO GW Antenna





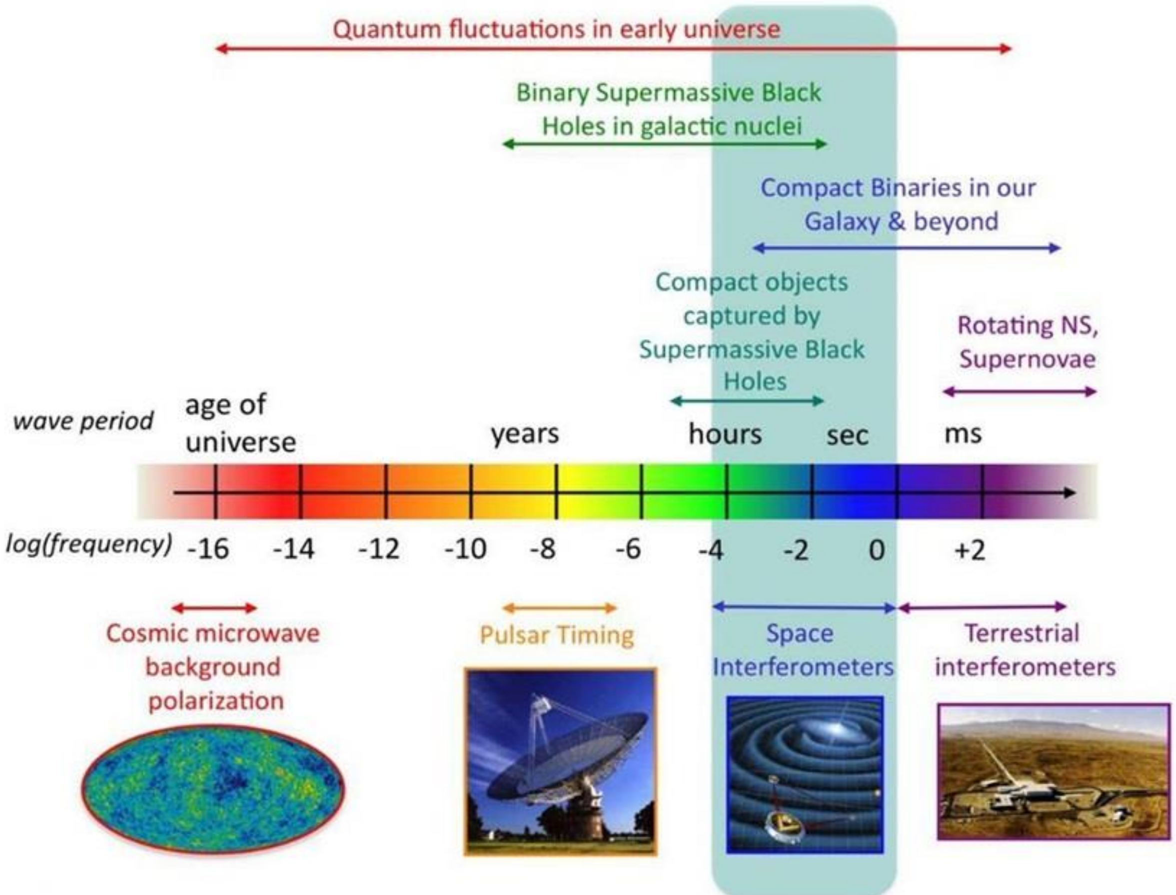
Merging of 2 black holes



1915 : General Relativity
1916 : prediction of GW
1962 : interferometer antenna
1984 : initiating LIGO
2002 : LIGO started exp.
2010 : upgrade aLIGO
2016 : GW detected

Why needs space GW detections?

GW spectrum and detectors



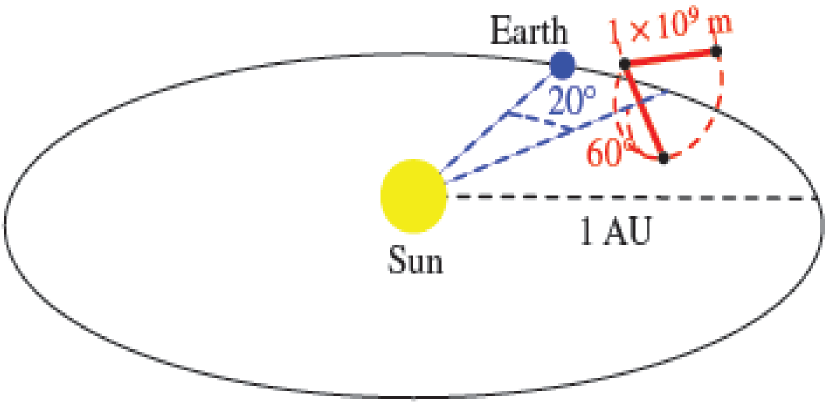
http://www.ast.cam.ac.uk/sites/default/files/assets/images/research/cosmology/gravitational_waves/GWspec.jpg

Significances：

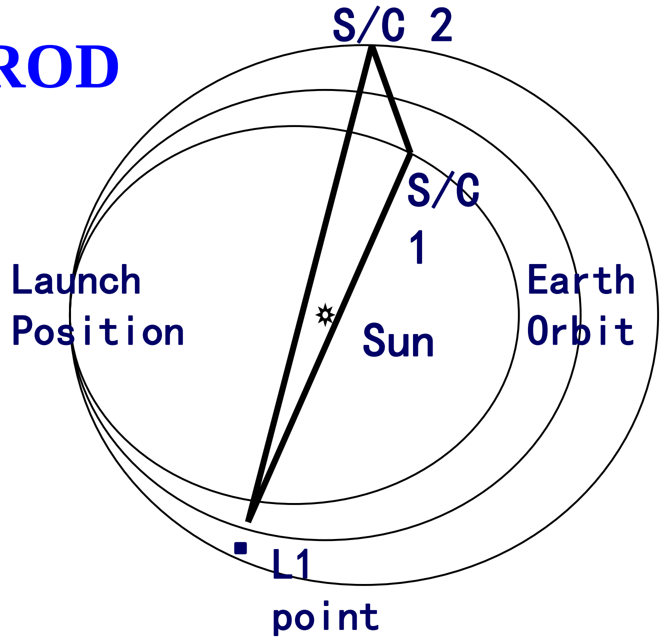
- **various types of sources**
  Binary systems（white dwarfs、neutron stars、black holes）、merging of massive black holes、primordial GW
- **stable sources**
  Compact binaries
- **strongest sources**
  Binary super-massive black holes

Space GW mission concepts

eLISA/NGO



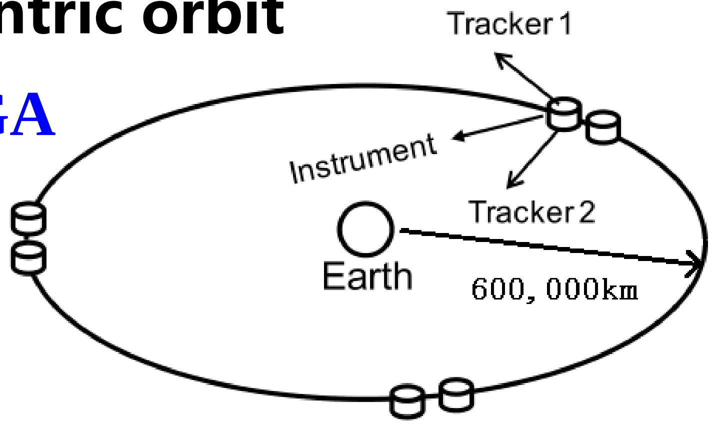
ASTROD



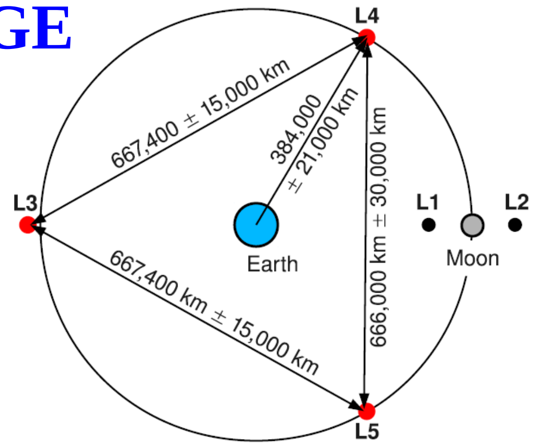
Solar orbit

Geocentric orbit

OMEGA



LAGRANGE



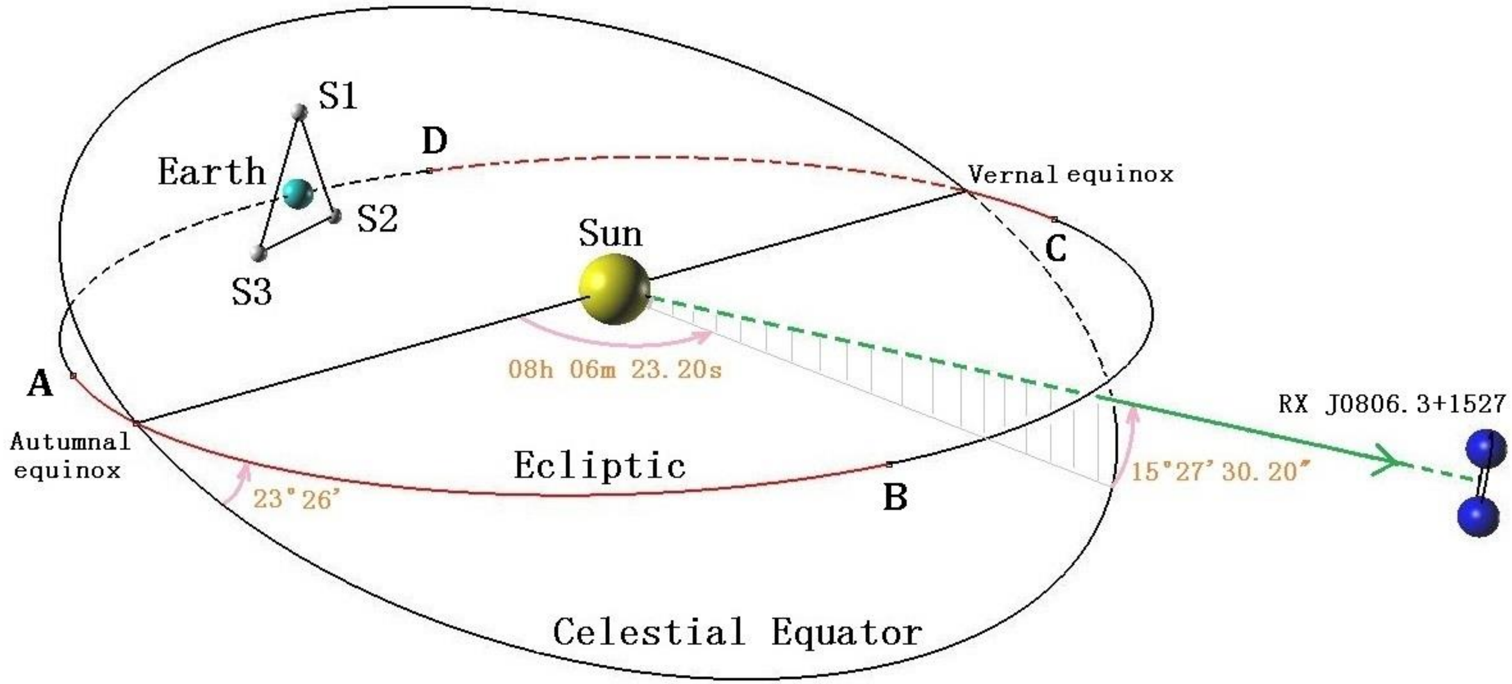
TianQin Mission Concept

Guidelines :

- Develop key technologies by ourselves;
- Target specific source, identified by telescopes;
- Geocentric orbit, shorter arm-length, higher feasibility;

TianQin GW Antenna

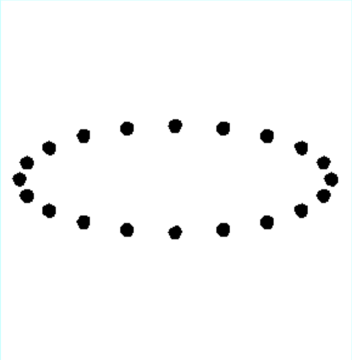
- **Orbit:** geocentric orbit with altitude of 100,000km;
- **Configuration:** 3-satellite triangular constellation, nearly vertical to the Ecliptic;
- **"Calibrated" source:** J0806.3+1527, close to the ecliptic;
- **Detection time window**: 3 months;



Outlines

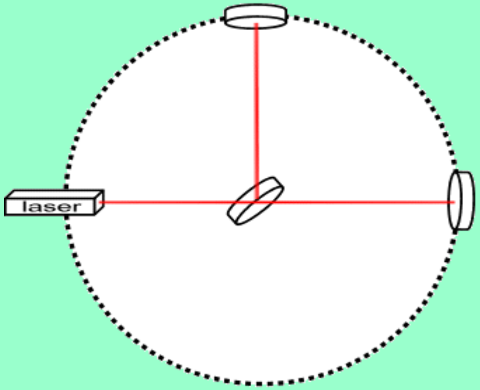
1. TianQin mission concept
2. Key technologies
3. Development strategy

Principle of GW Antenna



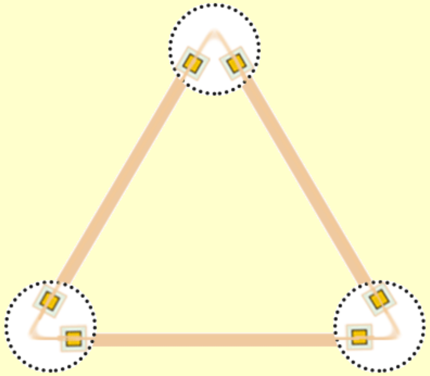
Two polarizations:

Shortening in one direction, enlarging in perpendicular direction, and vice versa.



Michelson's interferometer:

Detecting OPL difference between two perpendicular arms.

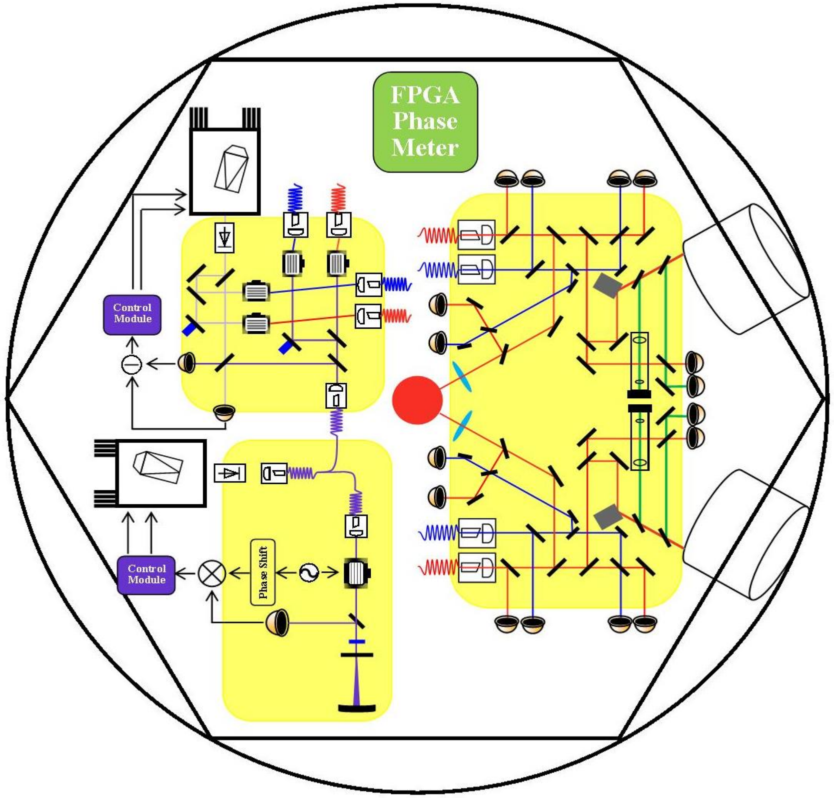


Space GW antenna:

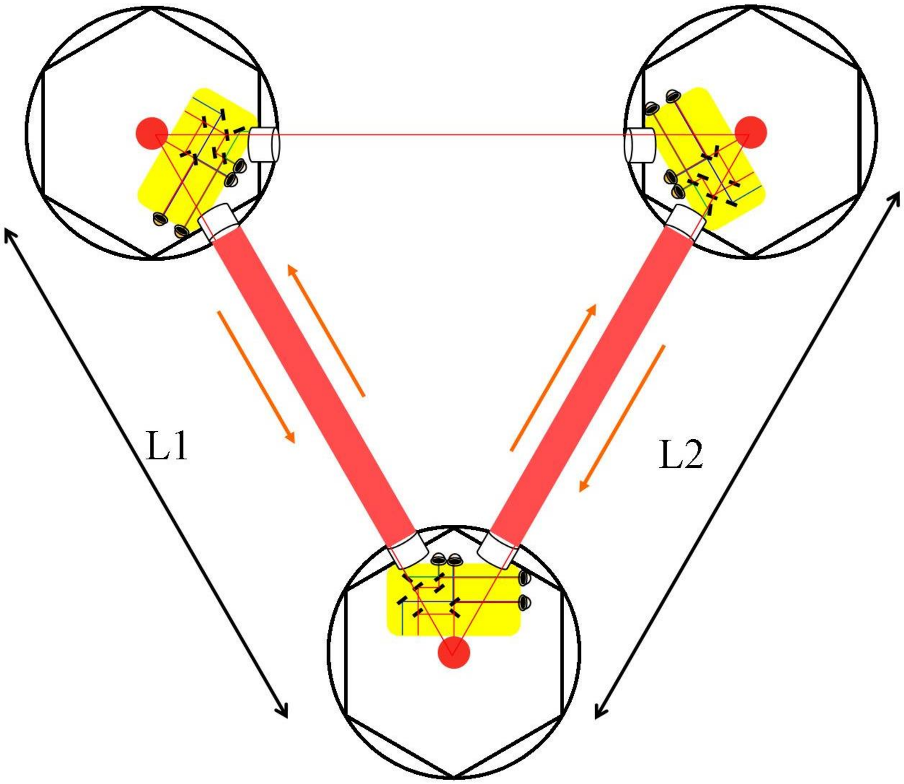
Detecting OPL difference between two adjacent arms.

Configuration of Space GW Antenna

Single Satellite



Triangular constellation



Requirements

Key Technologies		Specifications
Inertial sensing & Drag-free control 10^{-15} m/s^2/Hz$^{1/2}$	**Proof mass**	magnetic susceptibility 10^{-5} Residual charge $1.7*10^{-13}$C Contact potential 100uV/Hz$^{1/2}$ @ 10mV
	Cap. Sensor	$1.7*10^{-6}$pF/Hz$^{1/2}$（3nm/Hz$^{1/2}$） @ 5mm
	Temp. stability	5uK/Hz$^{1/2}$
	Residual magnetic field	$2*10^{-7}$T/Hz$^{1/2}$ Satellite remanence 1Am^2@0.8m
	uN-thruster	100 uN (max); 0.1 uN/Hz$^{1/2}$
Space Interferometry 1pm/Hz$^{1/2}$	**Nd:YAG Laser**	Power 4 W, Freq. noise 0.1 mHz/Hz$^{1/2}$
	Telescope	Diameter 20 cm
	Phasemeter	Resolution 10^{-6} rad
	Pointing control	Offset & jitter 10^{-8} rad/Hz$^{1/2}$
	Wavefront distortion	$\lambda/10$
	thermal drift of OB	5nm/K

Precision Inertial Sensing

1996-2000: develop flexure-type ACC

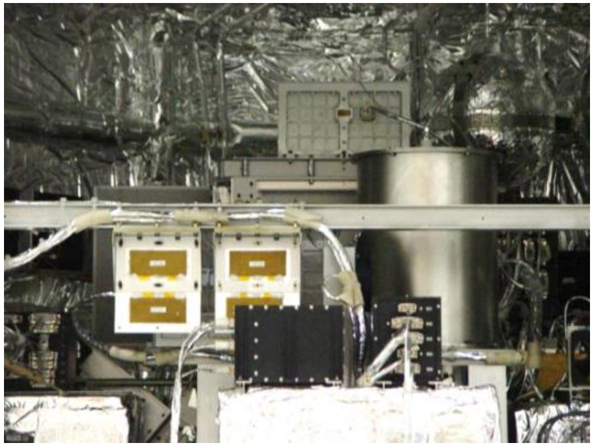
2001-2005: space test of flexure-type ACC

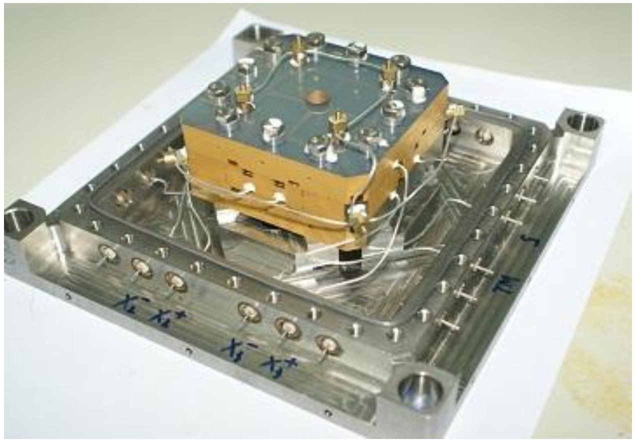
— launched in 2006

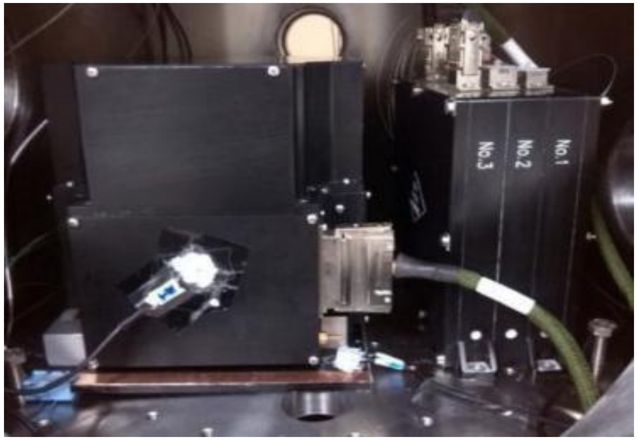
2006-2010: develop electrostatic ACC

2011-2015: space test of electrostatic ACC

— launched in 2013



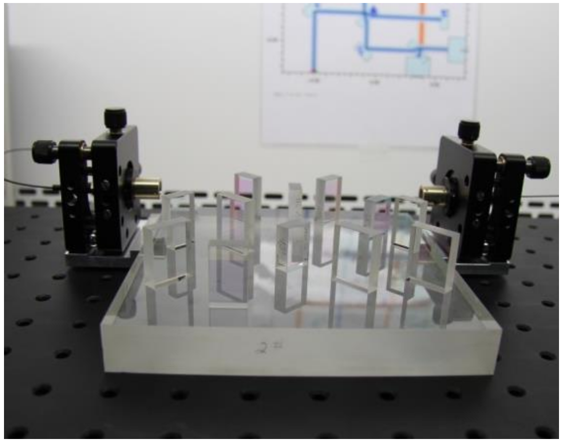


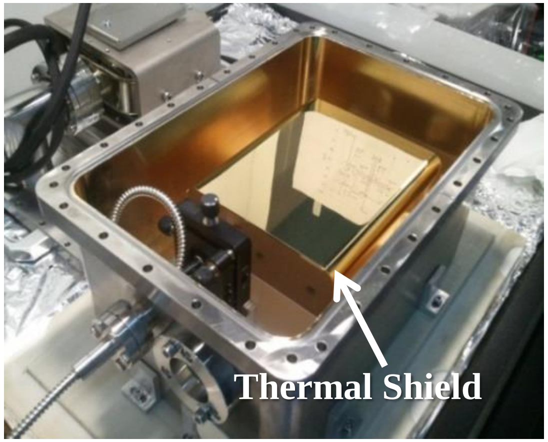


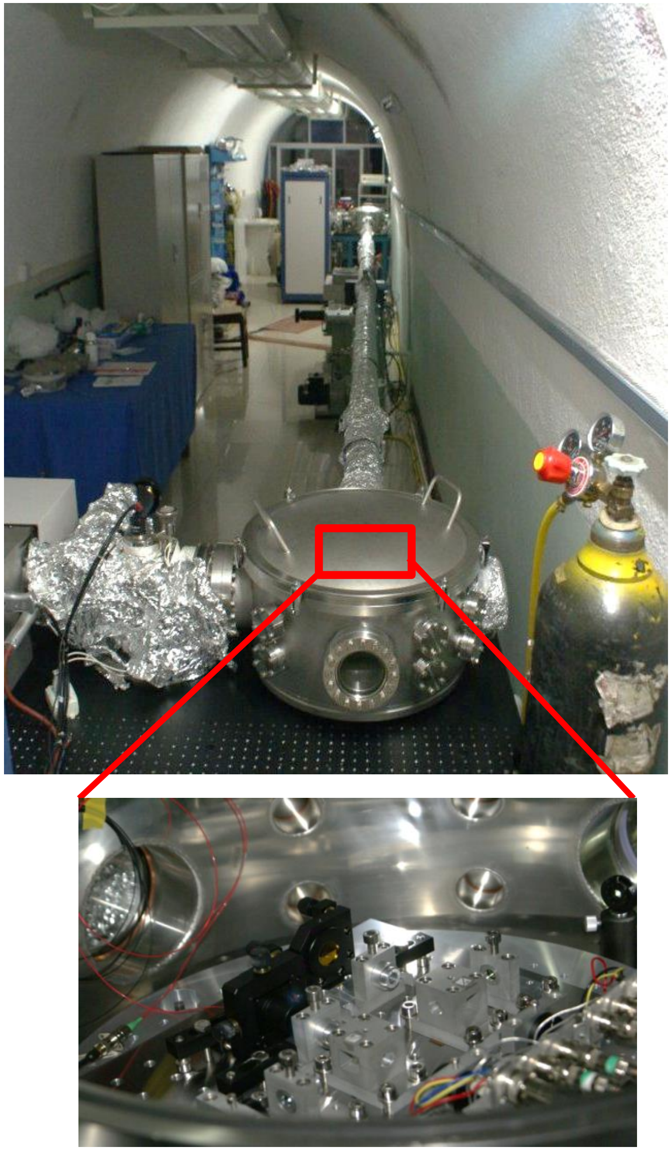
Space Laser Interferometry

2001-2005: nm laser interferometer
2006-2010: (10m) nm laser interferometer
2011-2015: (200km) inter-satellite laser ranging system

- **Picometer laser interferometer**
- **nW weak light OPLL**
- **nrad pointing angle measurement**
- **10Hz space-qualified laser freq. stab.**







Key Technologies

- **Femto-g Drag-free control:**
  - Ultraprecision inertial sensing: ACC, proof mass
  - uN-thruster: continuously adjustable, 5-year lifetime
  - Charge management (UV discharge)
- **Picometer laser interferometry:**
  - Laser freq. stab.: PDH scheme + TDI
  - Ultra-stable OB: thermal drift 1nm/K
  - Phase meas. & weal-light OPLL: 10^{-6}rad , 1nW
  - Pointing control: 10^{-8}rad@10^{6}km
- **Ultrastable satellite platform:**
  - Stable constellation: min. velocity and breathing angle
  - Environment control: temperature, magnetic field, gravity and gravity gradient
  - Satellite orbiting: position(100m), velocity(0.1mm/s) （VLBI+SLR）

Outlines

1. **TianQin mission concept**
2. **Key technologies**
3. **Development strategy**

Development Strategy

- Technology verification for every 5 years;
- One mission for each step with concrete science objectives.

Roadmap

0

E.P., $1/r^2$, $\dot{G}$, …

- LLR
- High-altitude satellite positioning

2016-2020

1

Test of E.P.

- Inertial sensing
- Drag-free control
- Laser interferometer

2

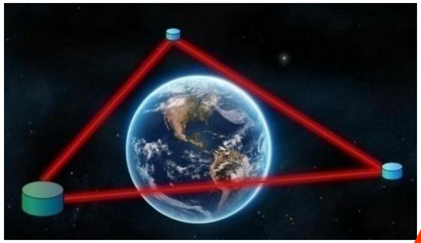
Global Gravity

- Intersatellite laser ranging
- Precision accelerometer

2021-2030

3

GW detection



- Precision satellite formation fly
- Picometer space interferometry
- Femto-g drag-free control

2031-2035

Summary

1. Space GW missions are compulsory to research in the frontiers of physics.
2. TianQin includes a series of scientific space missions, and its final goal is to establish a space-based GW observatory.
3. International cooperation is always welcome.

Thanks for your attentions!