3-20-2009

Hearing Voices in the Dark: Probing the gravitational wave Cosmos with LISA

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Probing the gravitational wave Cosmos with LISA

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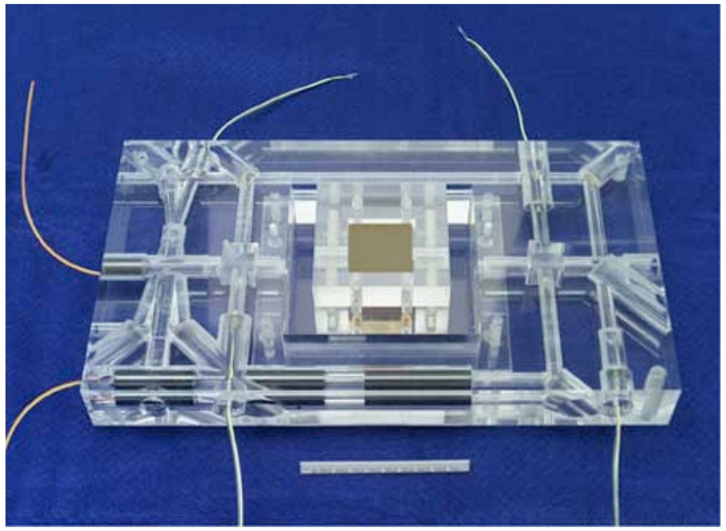
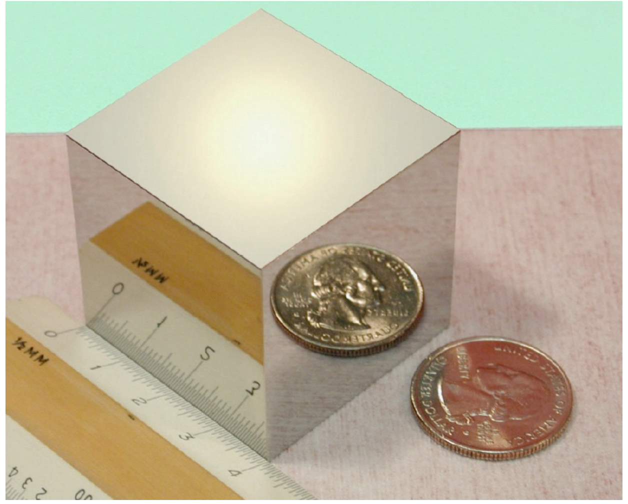
Logan, UT
20 March 2009

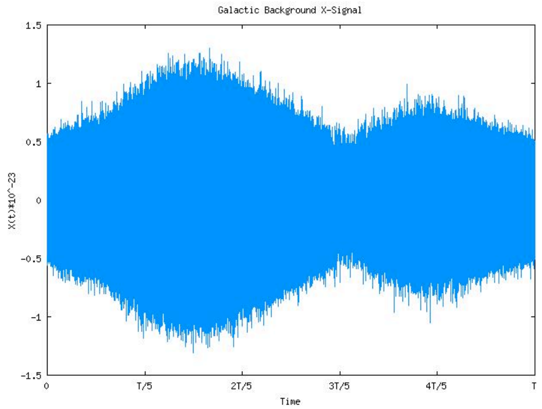
Facets of LISA

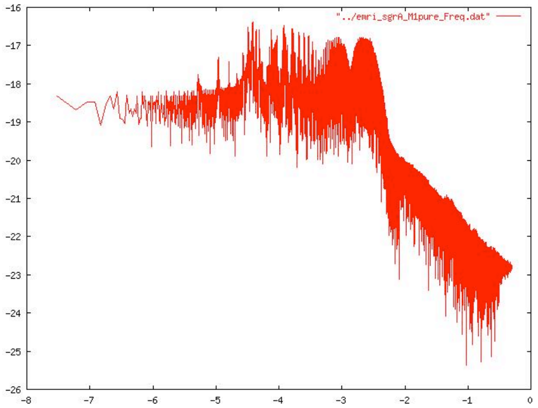
Technology

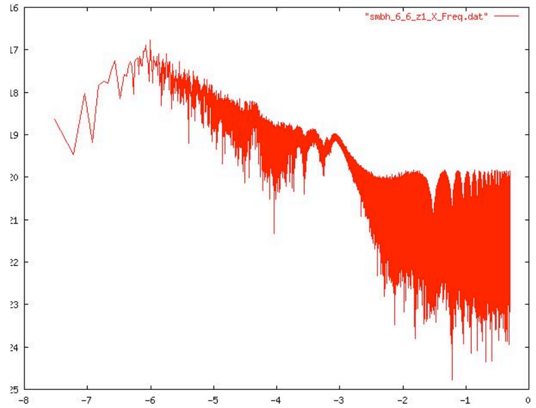




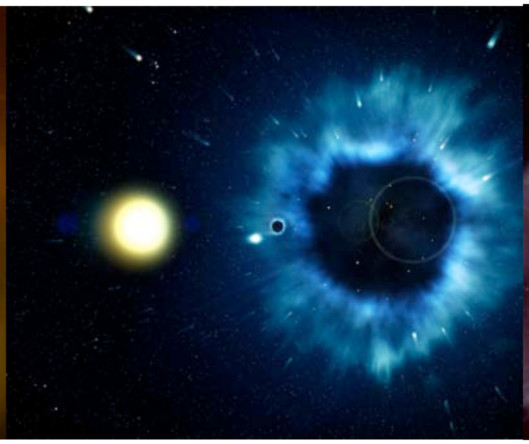
Science Analysis





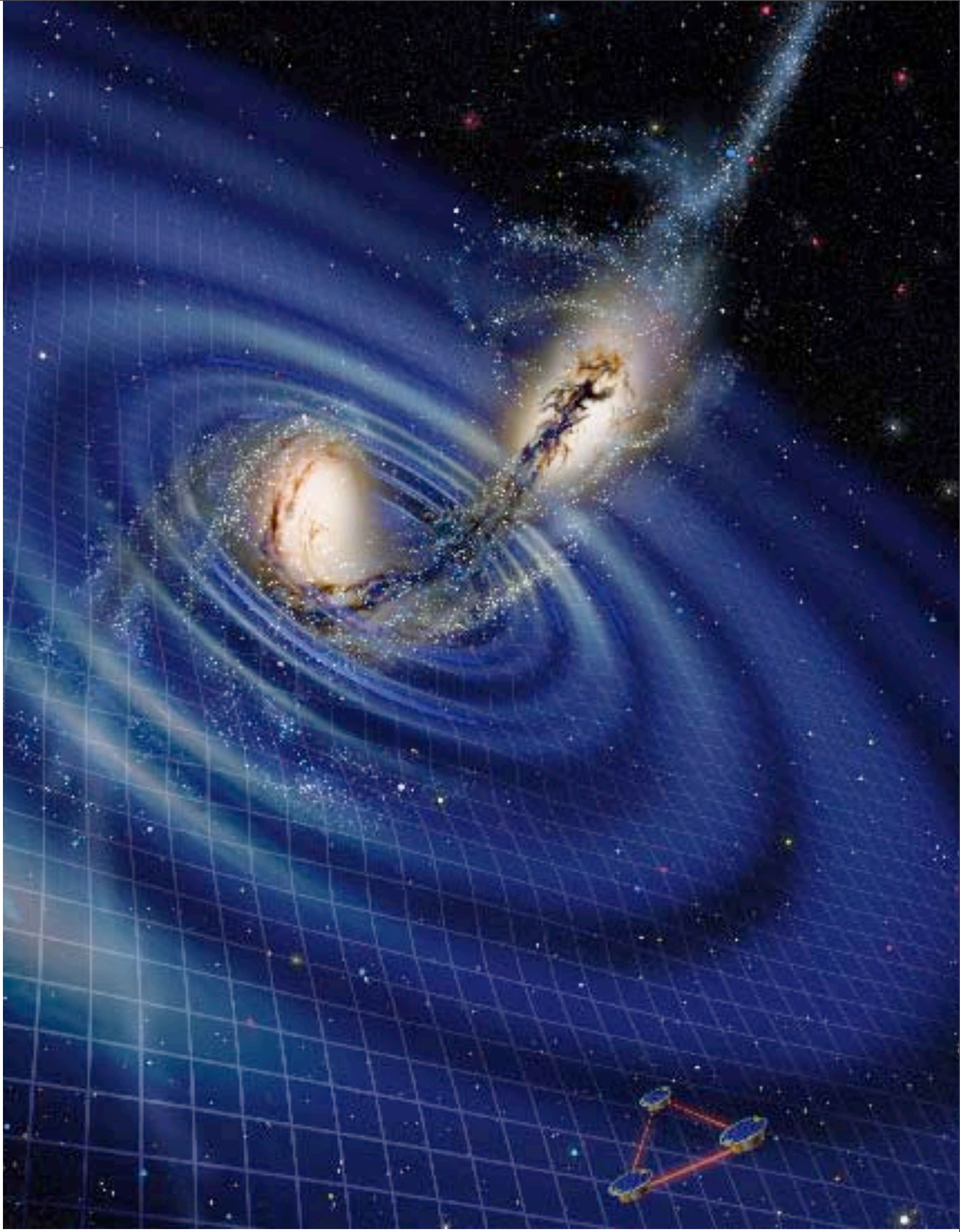


Astrophysics & Gravitational Science

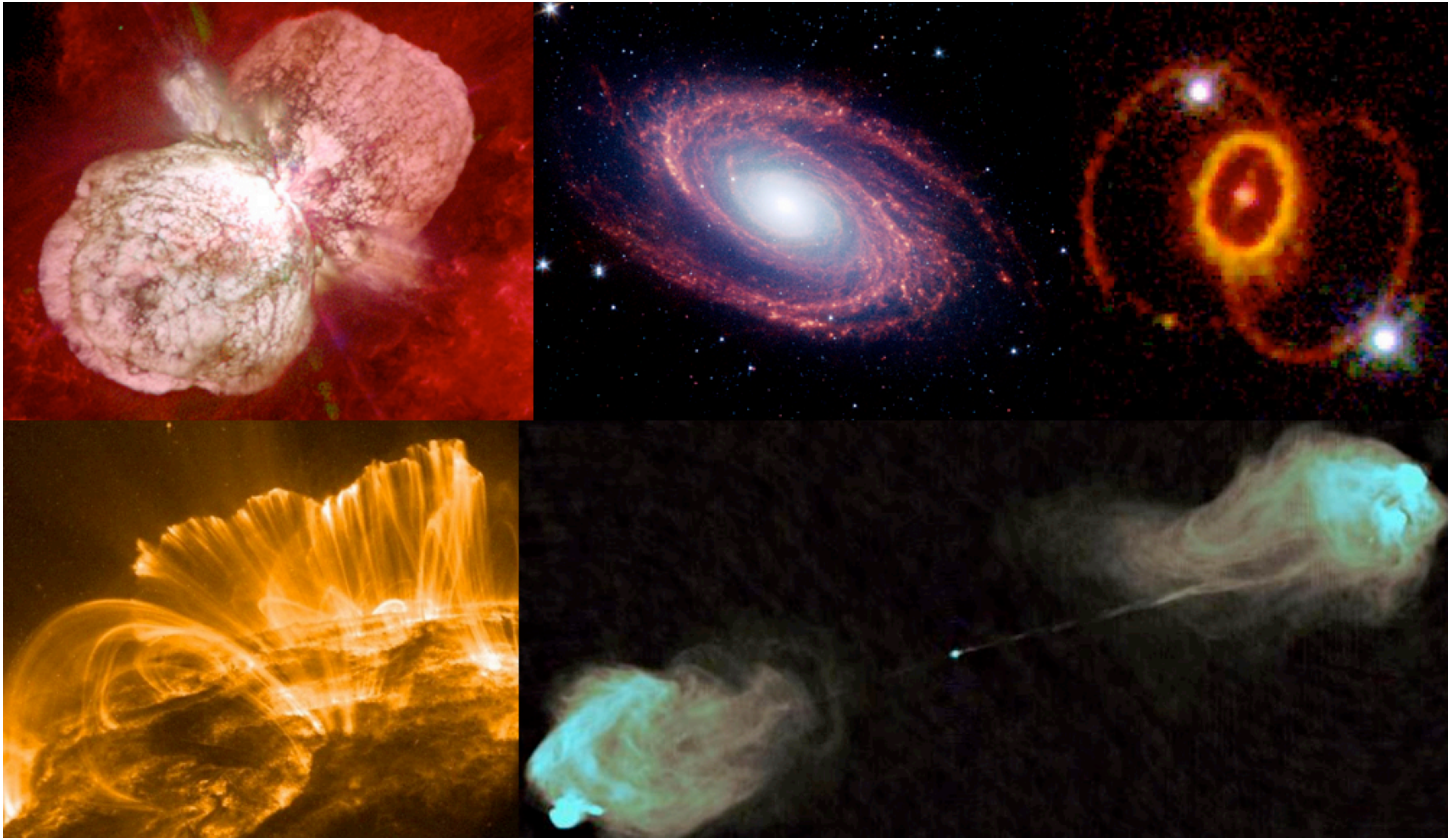


Storyline

- The Gravitational Wave Spectrum
- LISA mission
- Sources in LISA's Cosmos (with audio!)
- LISA Status

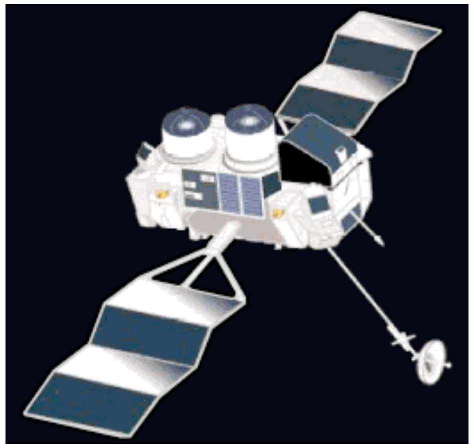


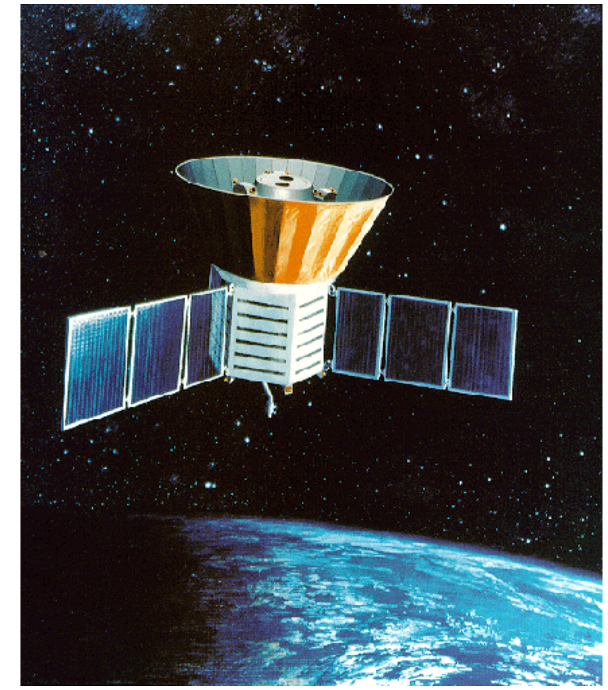
The Cosmos as we know it



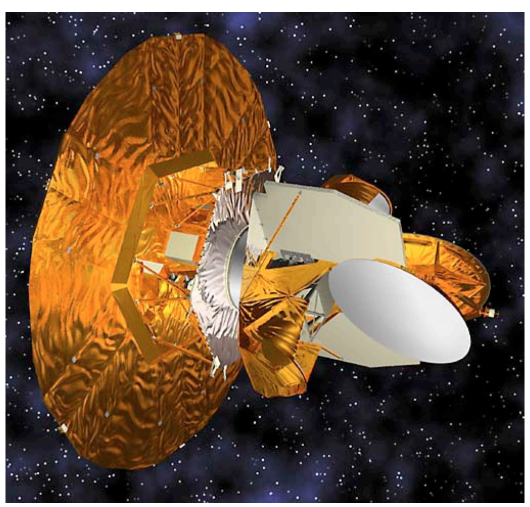
- **Light** has traditionally been our messenger from the Universe

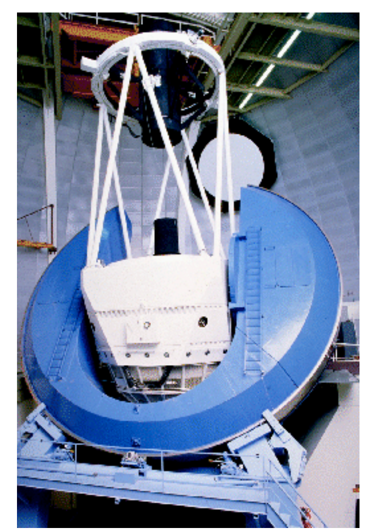
Photon eyes





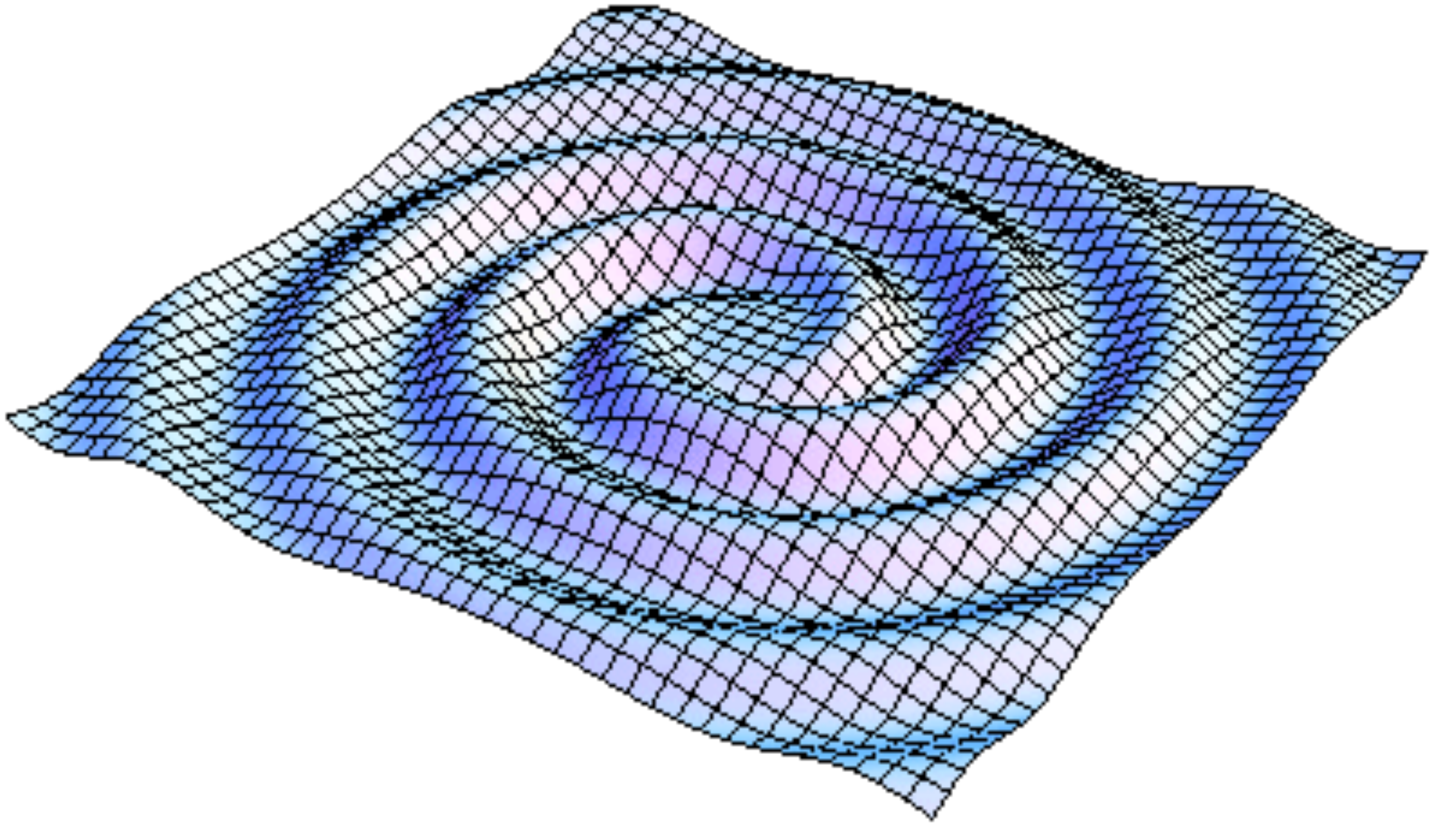





- A myriad of instruments exist to detect photons, but photons are limited by the fact that they interact readily with matter.

Gravitational waves

- All information is bound by the **Ultimate Speed Limit**, then information about changes in the gravitational field must propagate
- Gravitational waves are ripples in the fabric of spacetime, produced by **dynamical motions of mass**
- Their physical effect is to **change the proper distance** between particles



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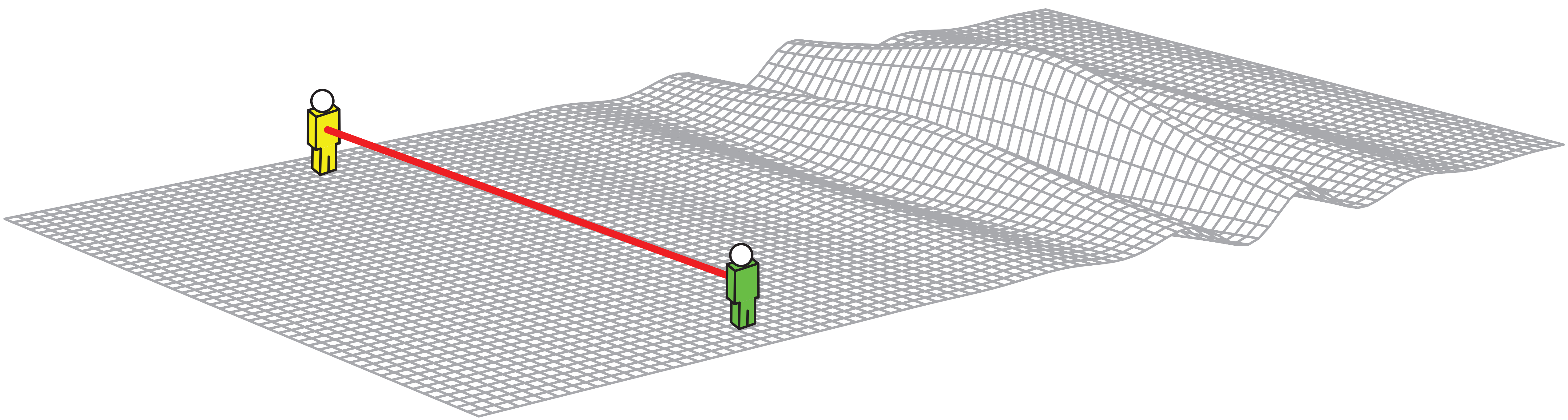

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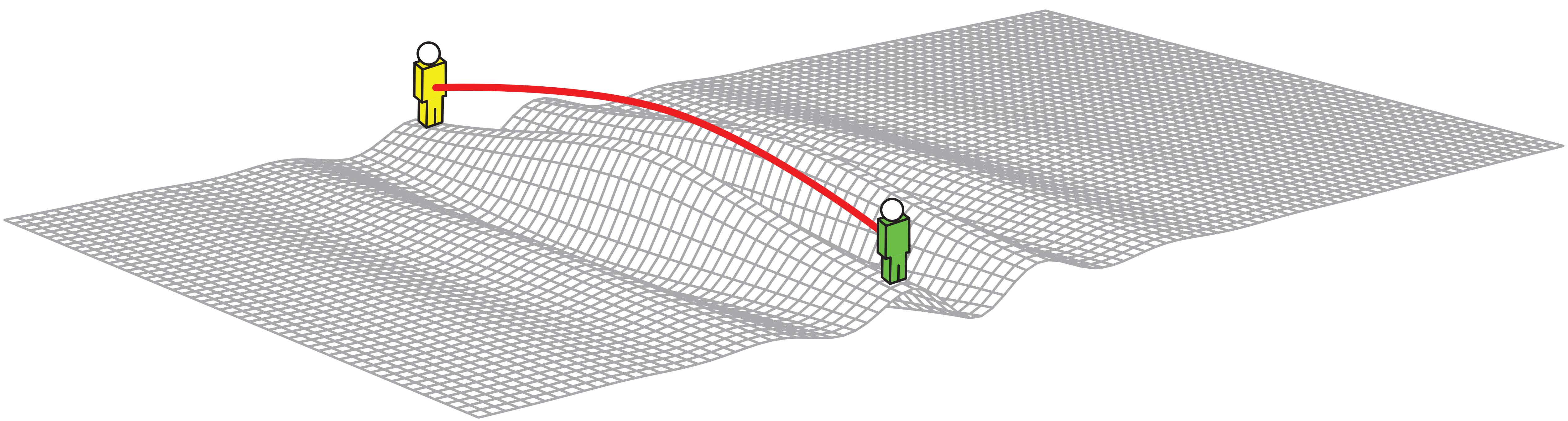
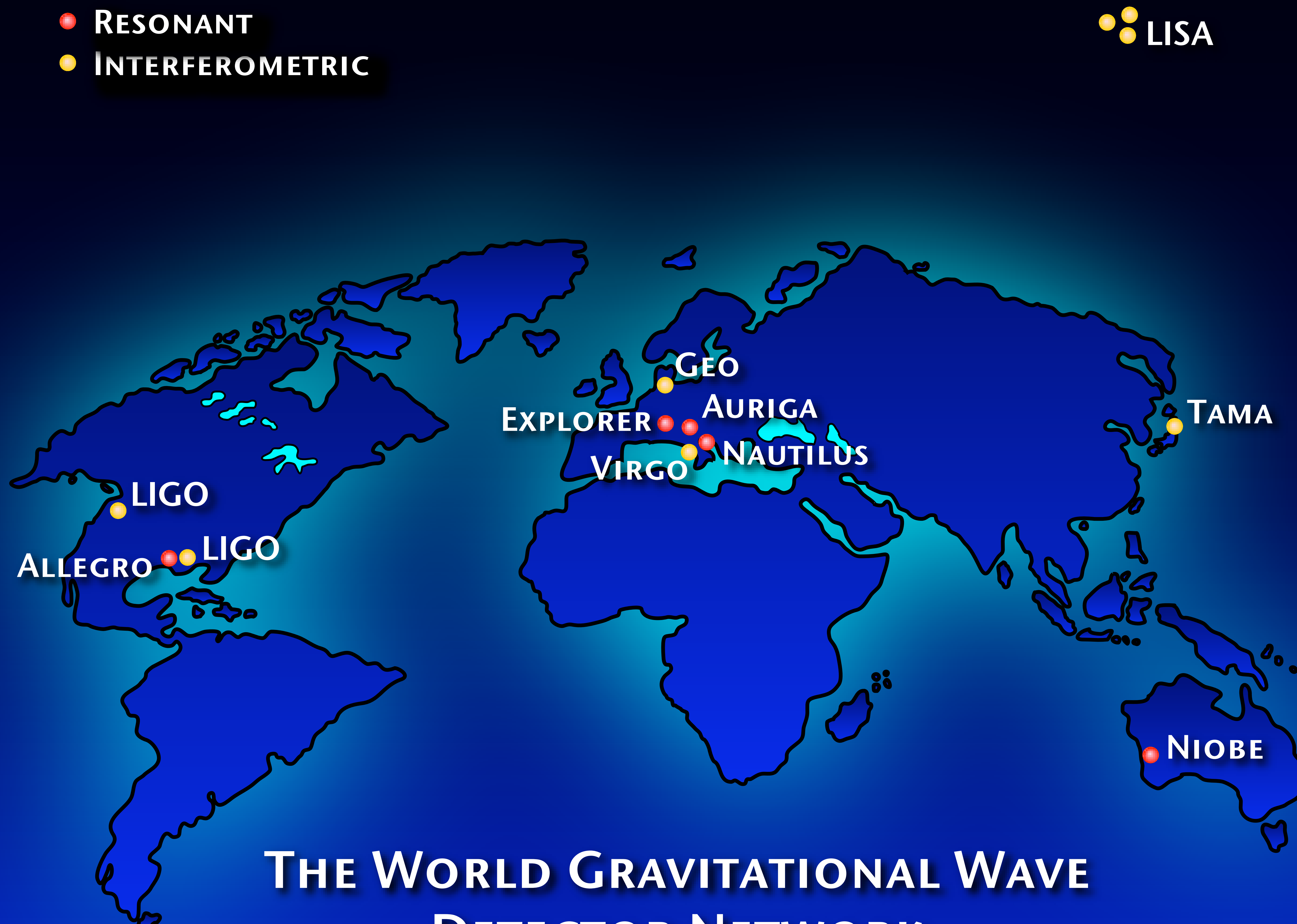


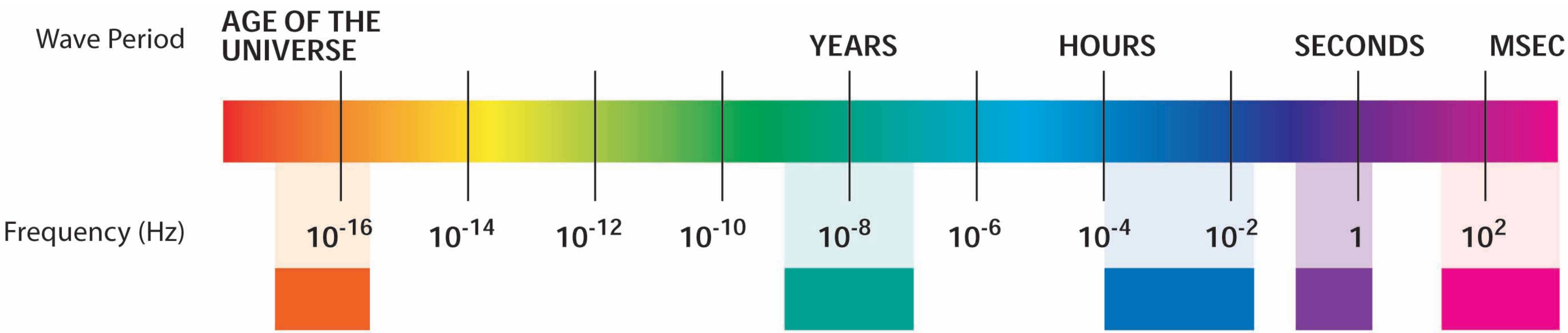


The World Gravitational Wave Detector Network

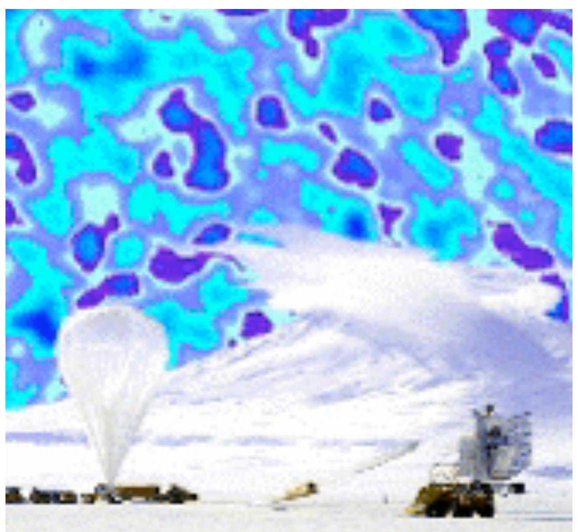
Gravitational wave astronomy

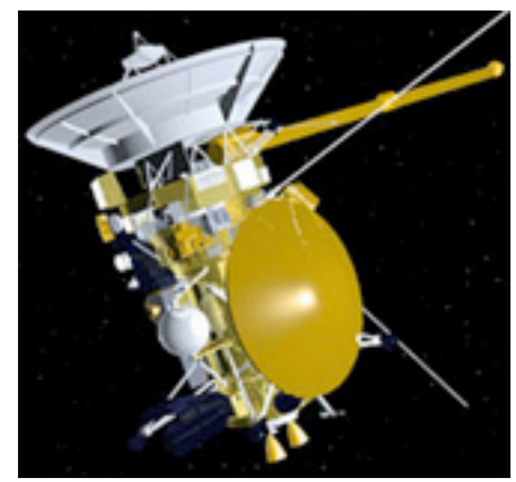
- Ground-based gravitational wave astronomy is well underway, with interferometric detectors ranging from 300m to 4000m armlengths
- LIGO, VIRGO, GEO, TAMA

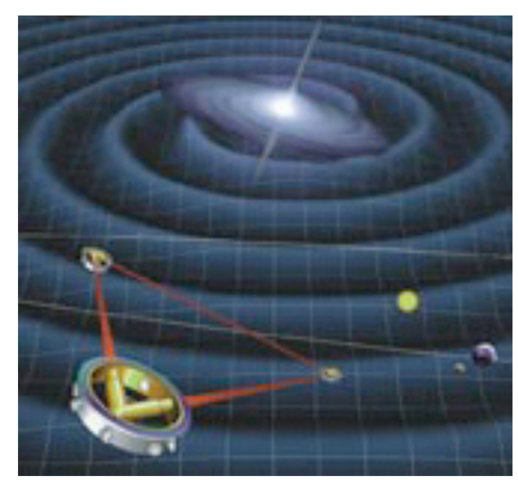
Gravitational wave spectrum



Space







CMB Polarization

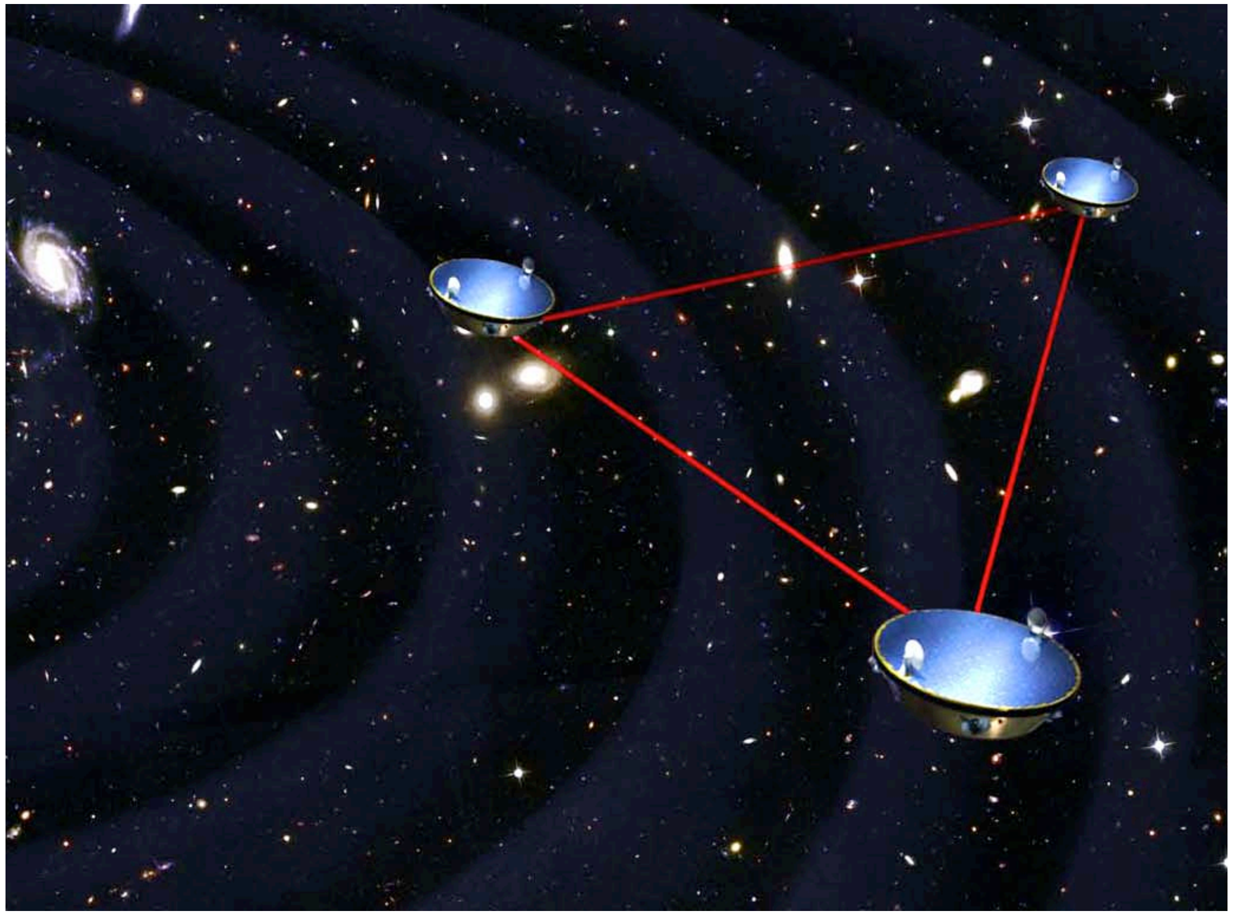
Pulsar Timing

Ground

Why gravitational waves rock

- **Gravitational waves are excellent astrophysical probes**
  - **GW are not attenuated** (Universe became transparent at about 10^{-34} sec)
  - **GW sources are "clean and simple"** (BH have mass and spin, and they radiate coherently)
  - **GW sources are strong** (high signal to noise allows precision measurements)
  - **GW sources are standard candles** (luminosity distances are measured with ~1% accuracy). *Luminosity distance from gravitational physics only*

LISA (Laser Interferometer Space Antenna)



- Joint **NASA/ESA mission**, expected to launch in the late-2010s
- Covers low frequency band, from ~ 10^{-5} Hz and 1 Hz
- 3 sciencecraft, freely flying in a 5 million km equilateral triangle

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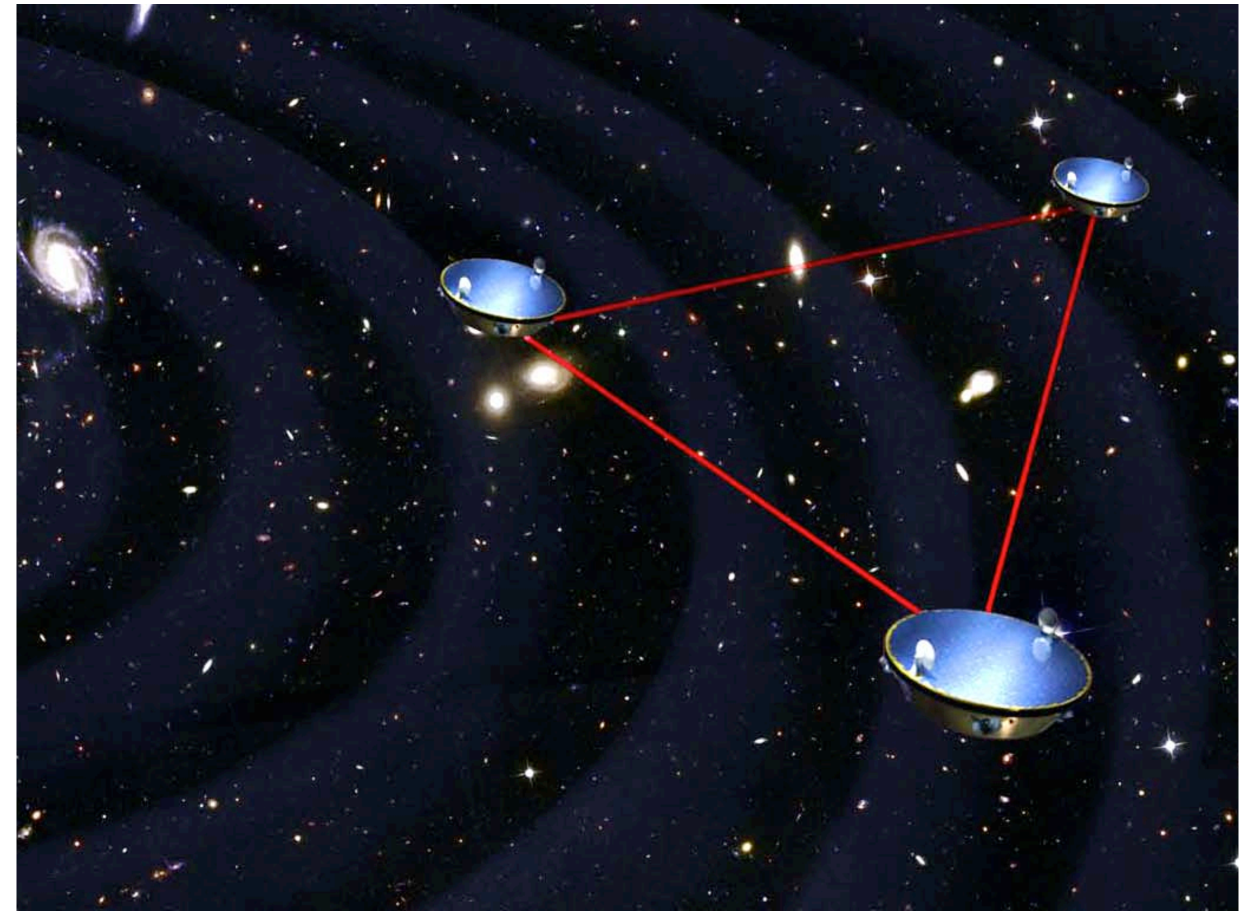

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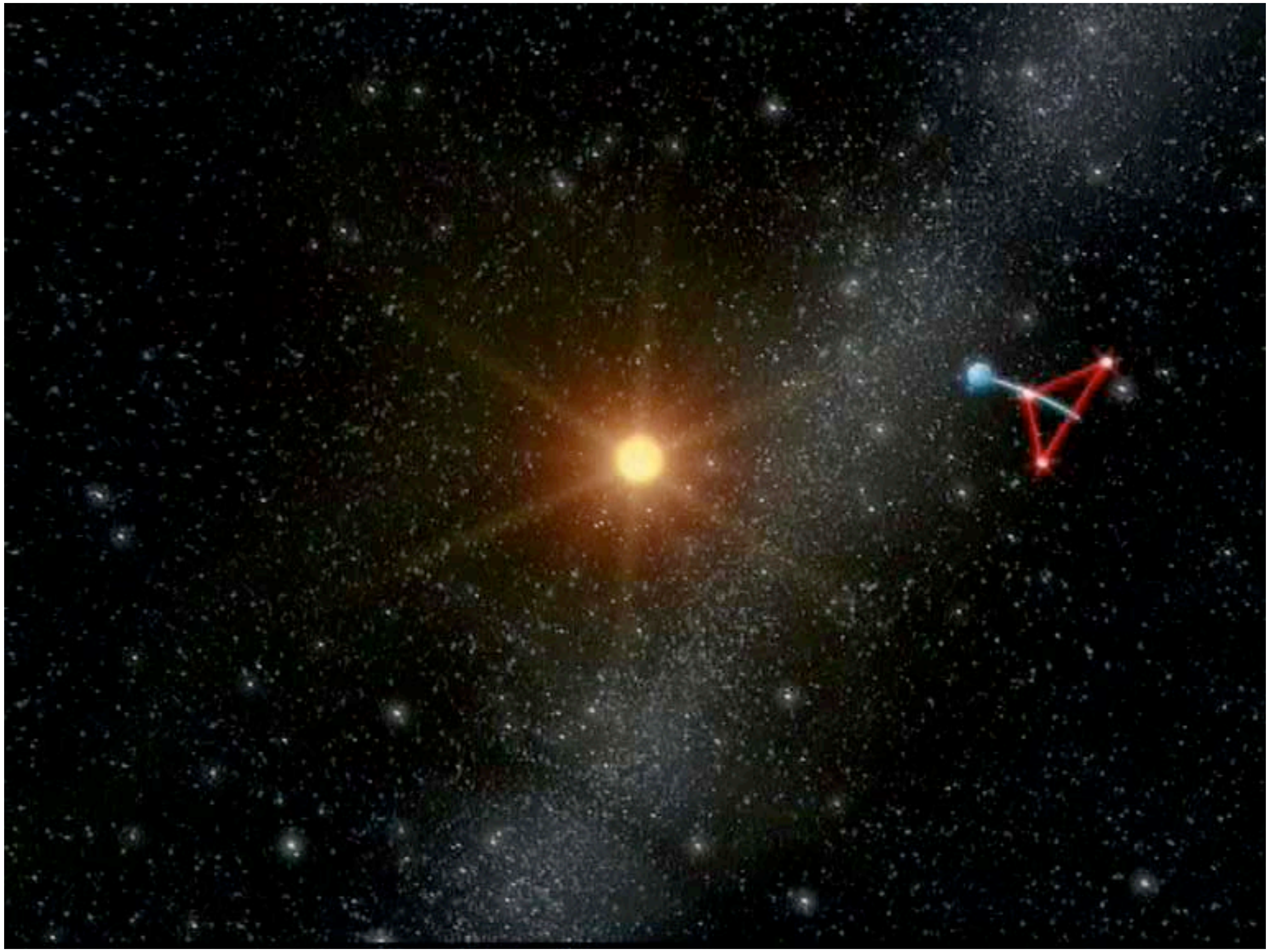
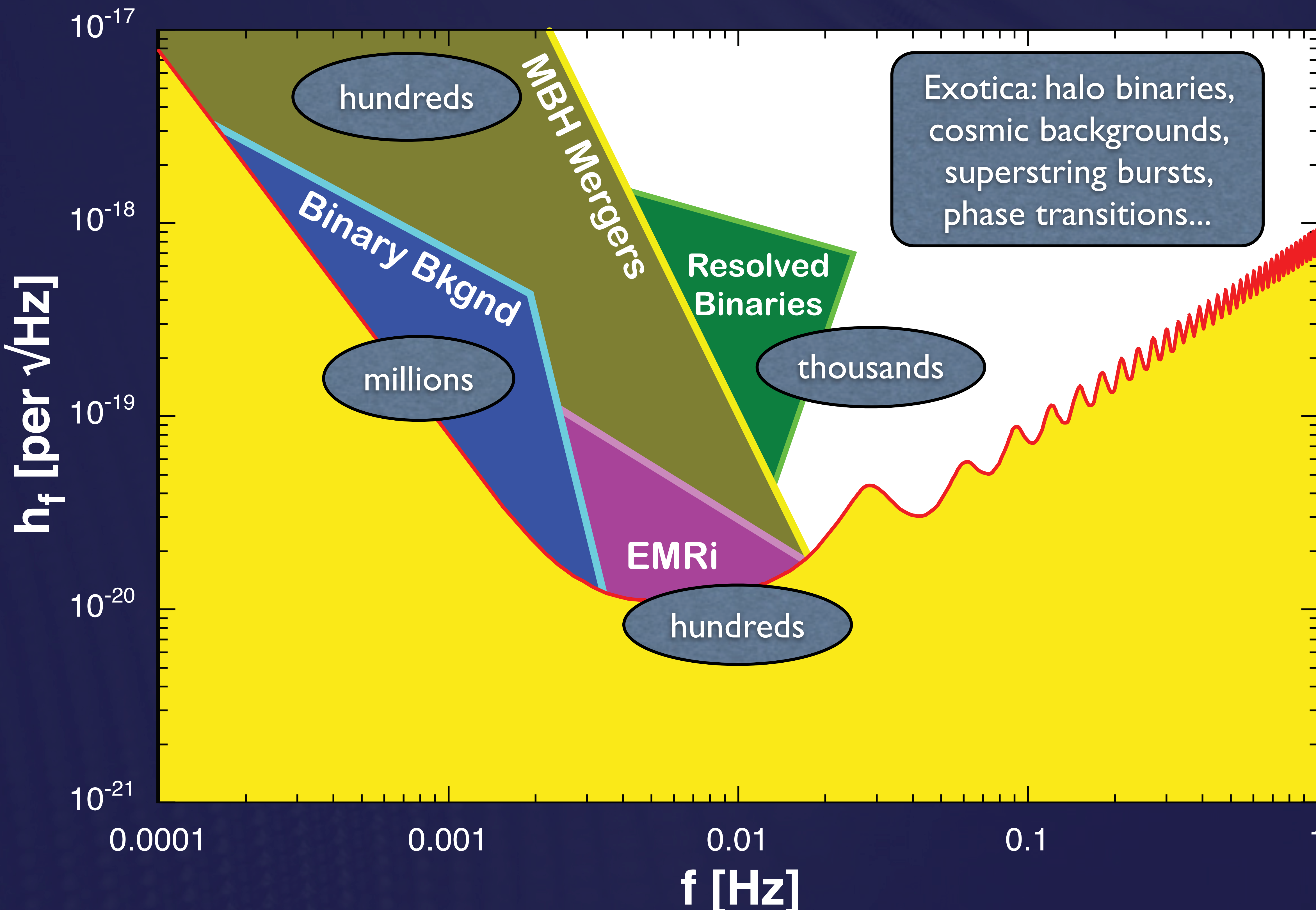
LISA Orbit



- LISA is in an Earth-trailing or Earth-leading orbit, 20° away from the Earth, inclined to the ecliptic by 60°
- The constellation motion modulates signals, giving pointing capability. Other pointing ability comes from interferometry (Tinto & Larson 2004)

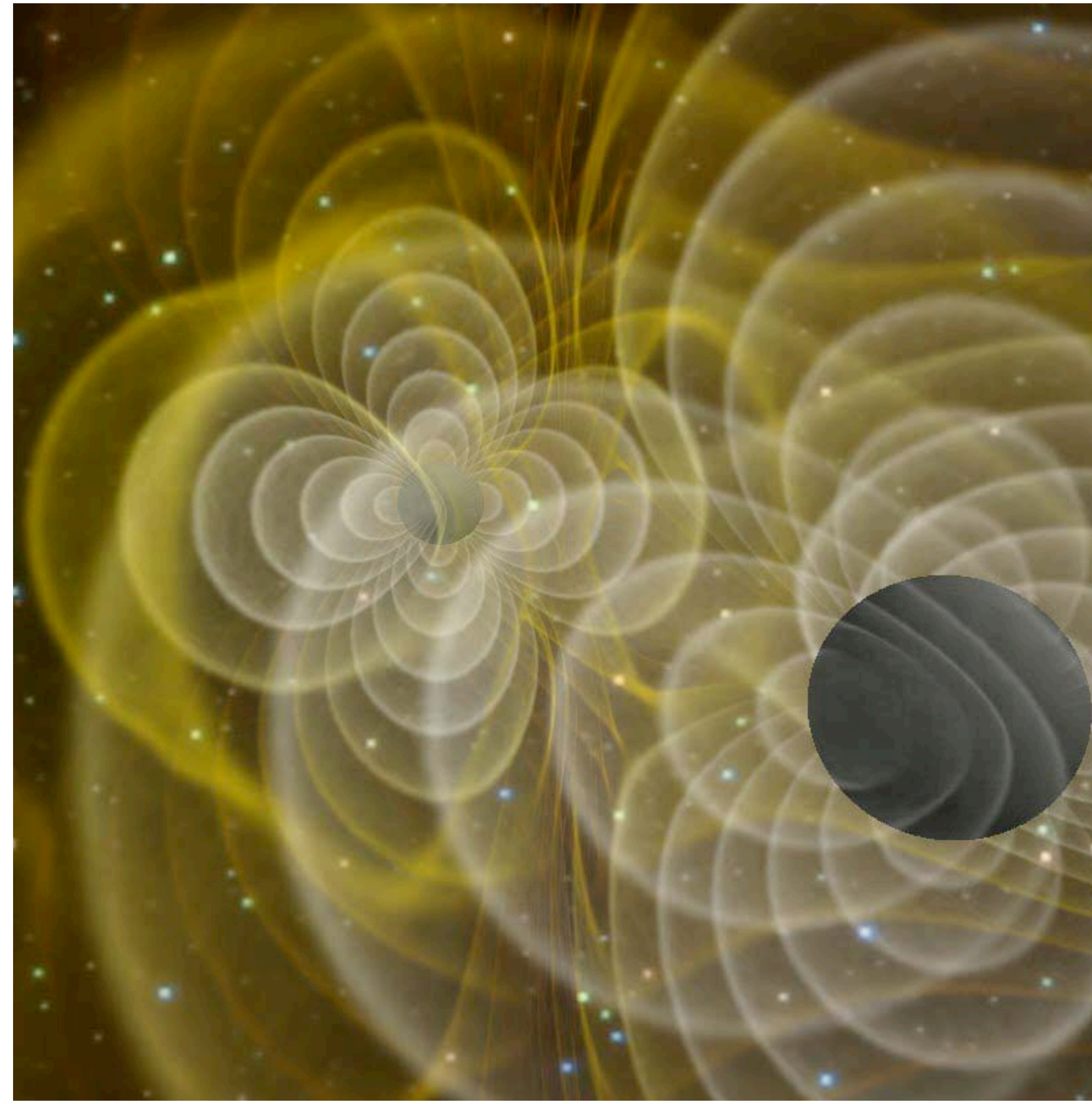
LISA Discovery Space



Larson, Hiscock & Hellings (2000)

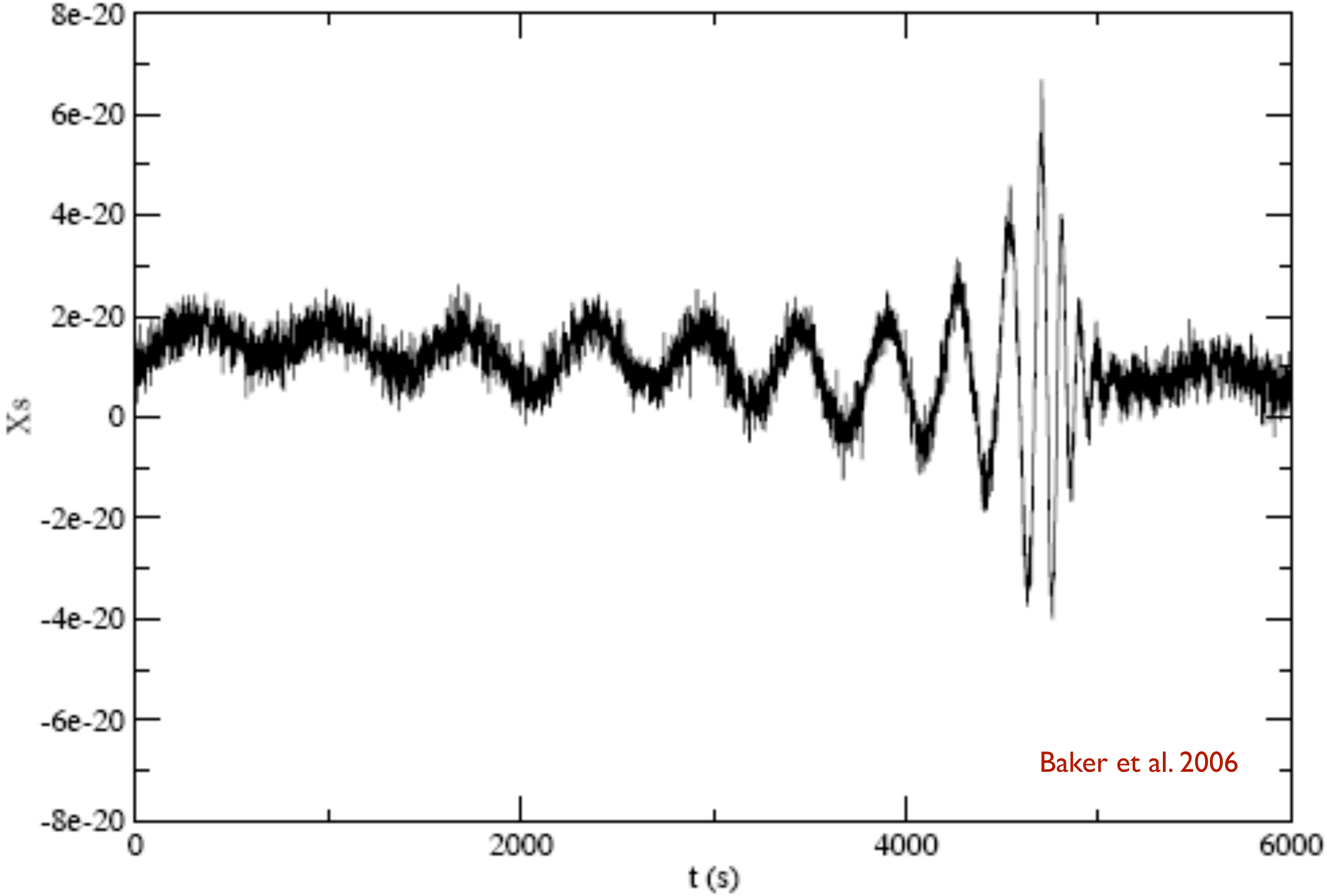
Massive Black Hole Binaries

- By far the strongest sources LISA will see (out to high z)
- Will detect mergers of 10^4 – 10^7 $M_\odot$ binaries out to z = 20
- High precision measurements!
- These signals are **easy to detect**!



Visualization by GSFC

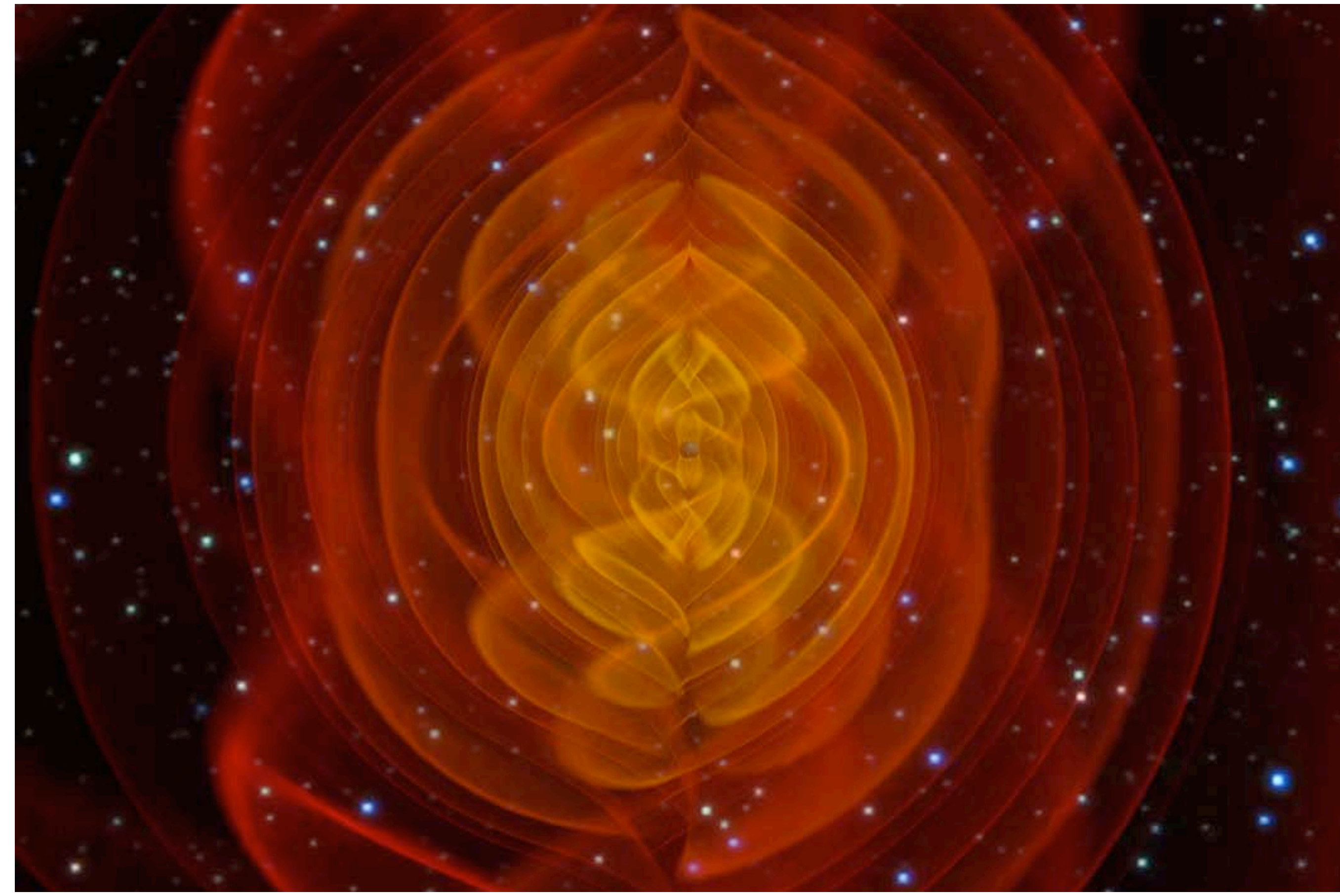
Massive Black Hole Binaries

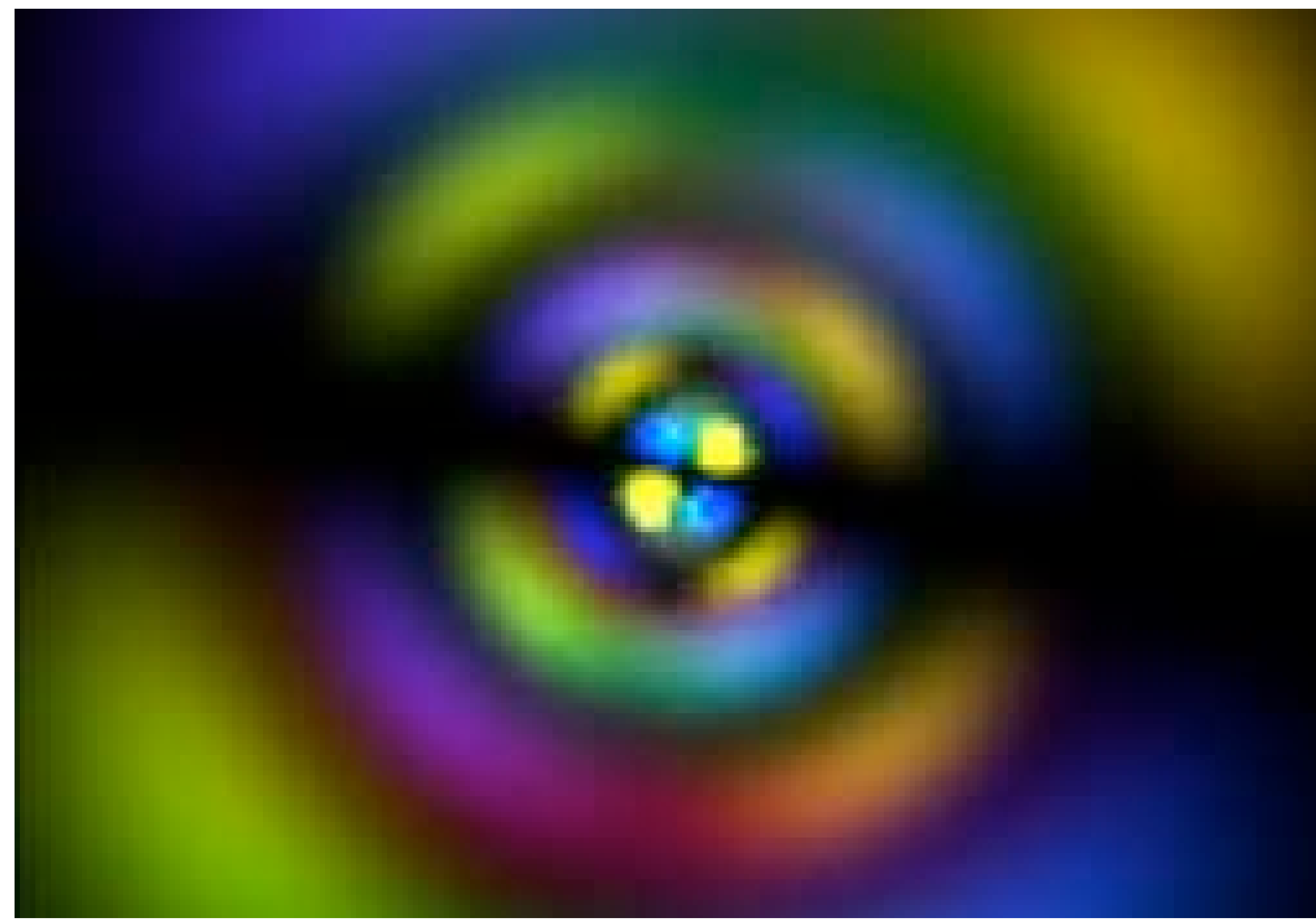


- Simulated merger, with instrumental noise, of $10^5\ M_\odot$ binary at $z = 15$

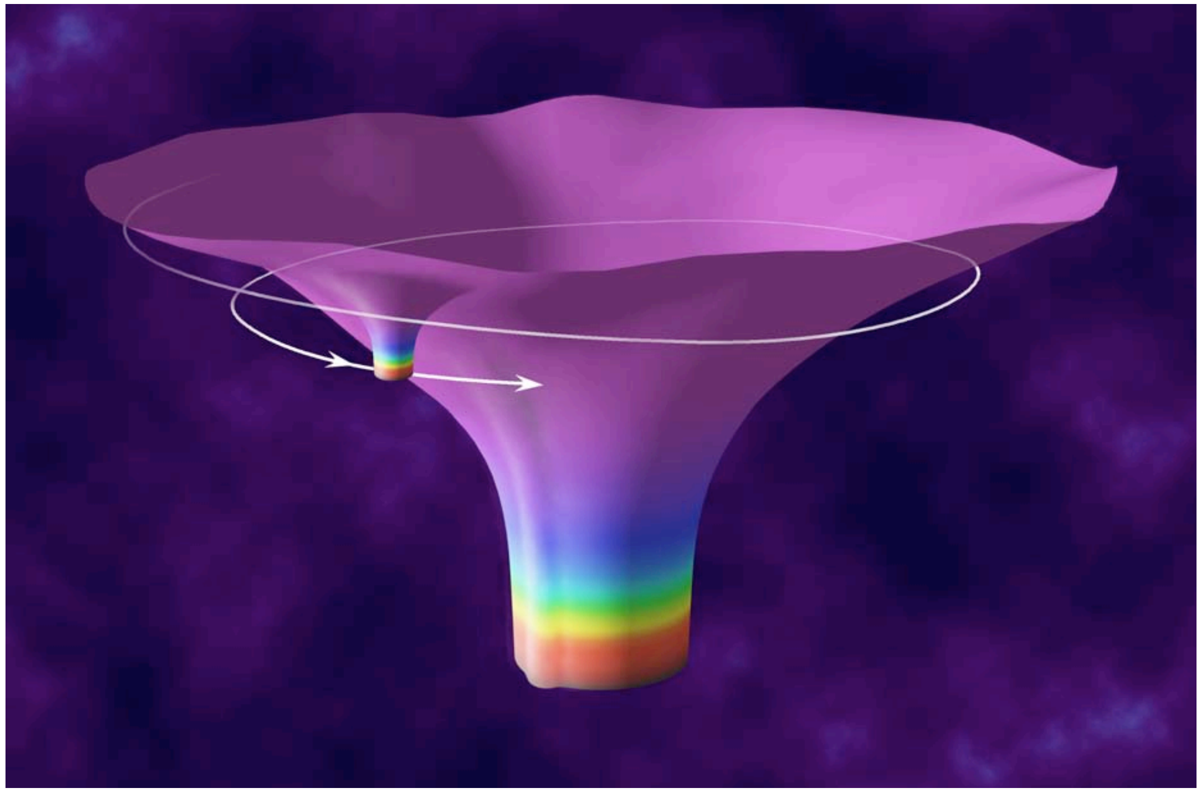
MBH Science

- With a population of LISA mergers and their parameters:
  - How did black holes spin up? How do spins evolve over time?
  - How did black holes form? What was the initial mass function? Black hole mergers relation to galaxy merger history? (Plowman et al. 2009; arxiv: 0903.2059)
- Fundamental physics of black holes
  - Comparison with GR simulations
  - Tests of black holes mechanics (e.g. area theorem)

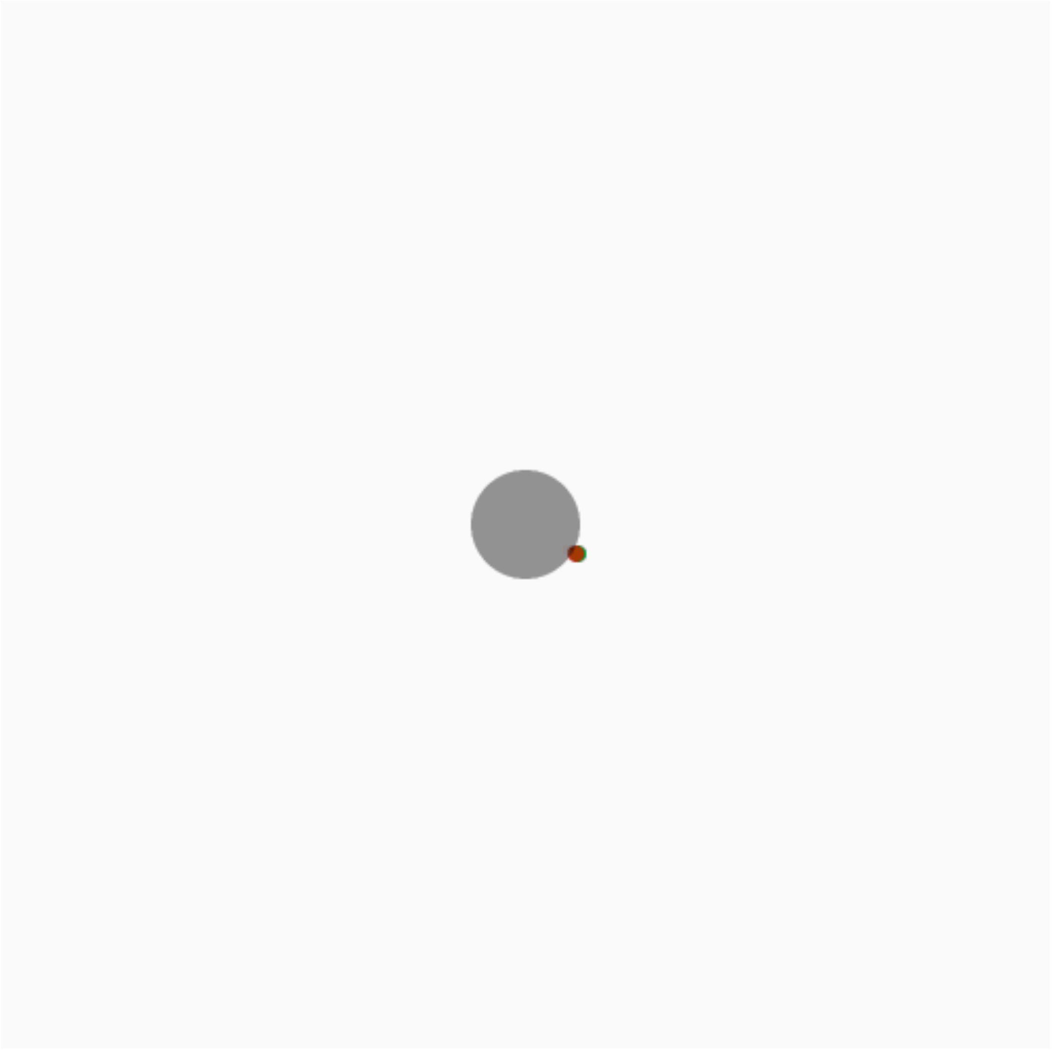




Extreme Mass Ratio Inspirals

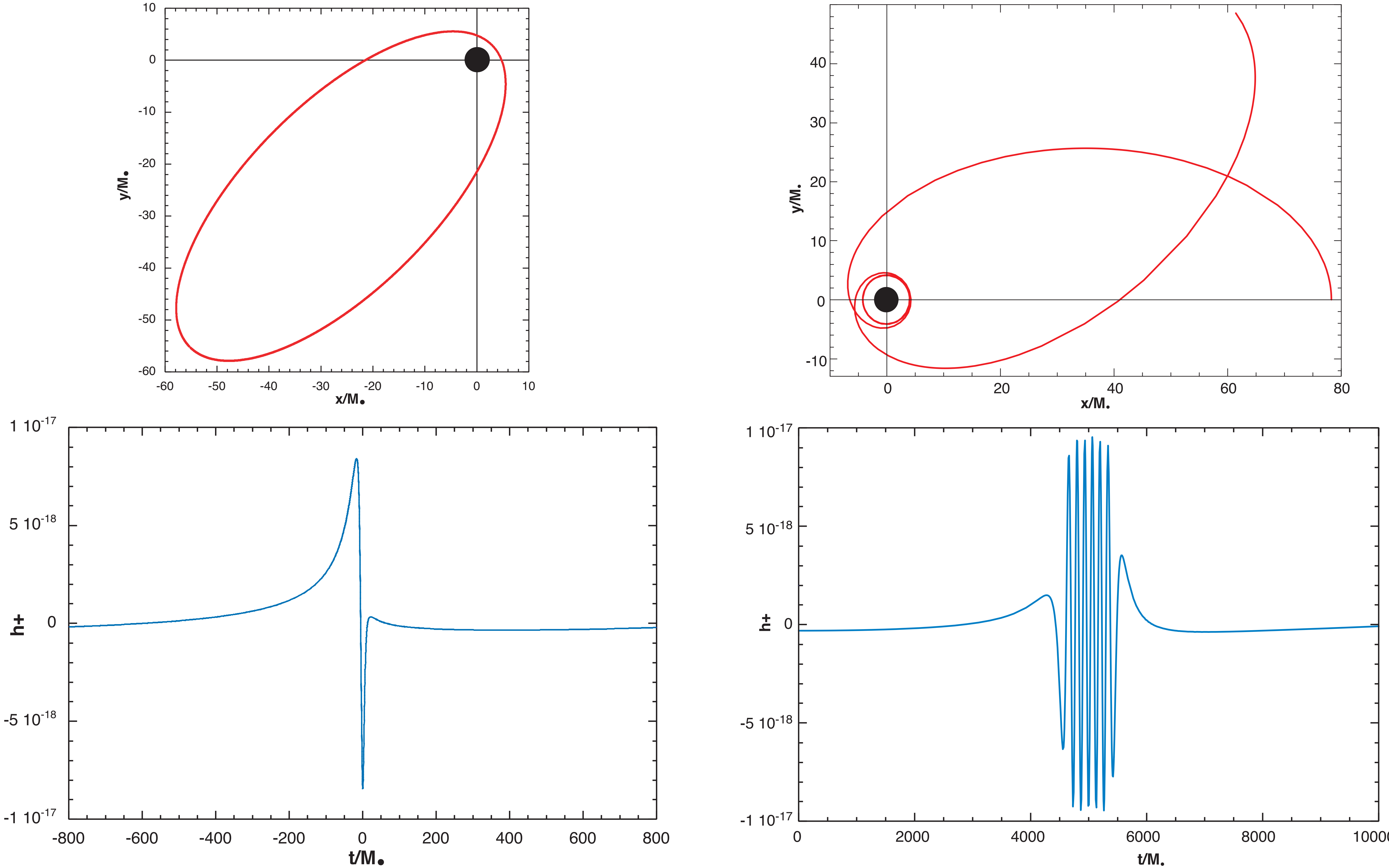


- **EMRIs**: little stars & big black holes, (m*/m•) ~ 10^{-5} to 10^{-8}
- **CAPTURE CONTENT**: what are the constituents of nuclear star clusters? What is the growth history of galactic black holes?
- **HOLIODESEY**: the mapping of black hole spacetimes
- Testing the "**Kerr-iness**" of black holes



Zoom-Whirl Orbits

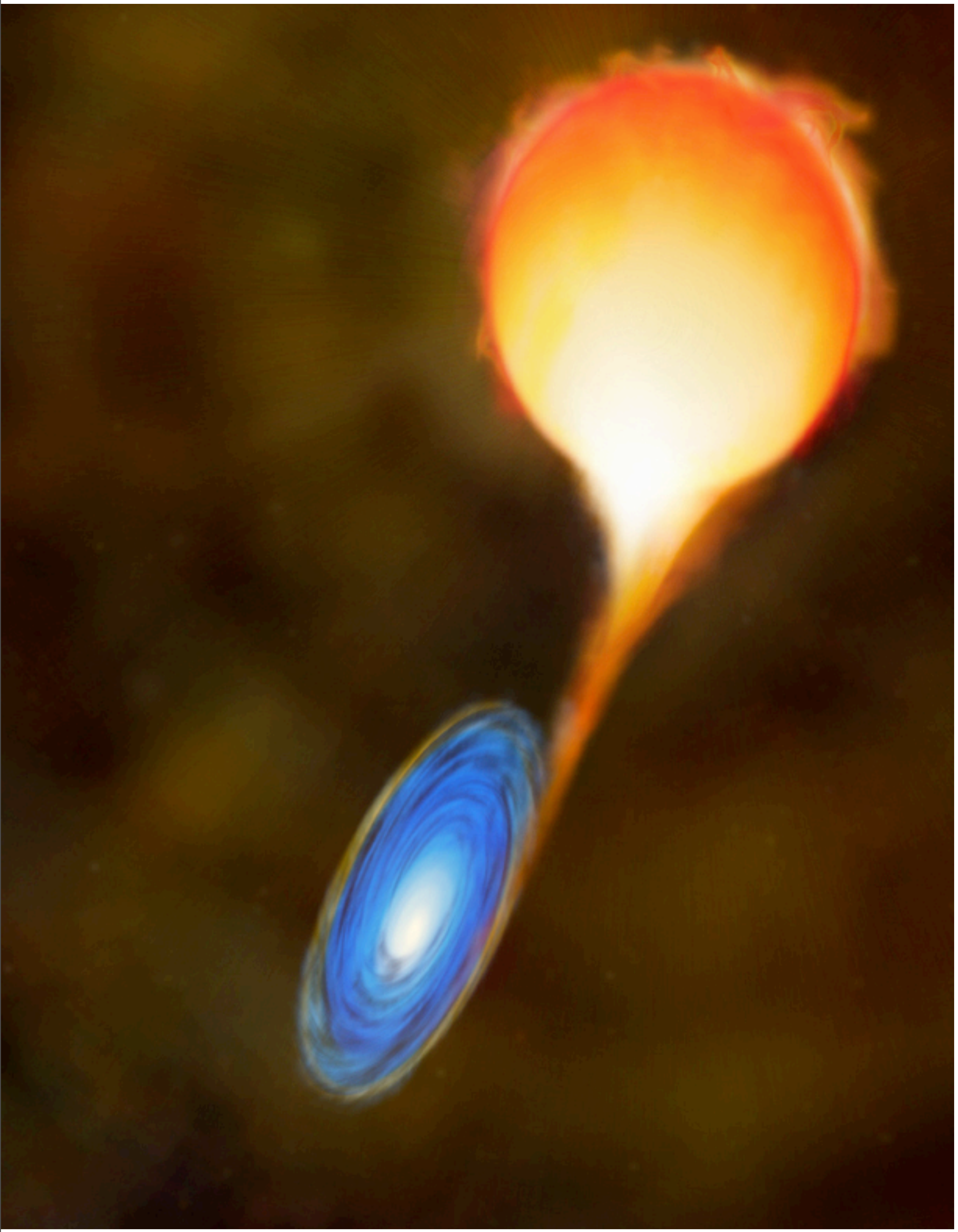
Gair, Kennefick & Larson (PRD, 2005)



Black Holes – The Greatest Hits

- The waveforms encode information about the black hole system, which I can demonstrate by converting into sound
- Consider black hole + black hole with ~10^{-5} mass ratio
  - **Sound 1**: Non-spinning big black hole, circular orbits
  - **Sound 2**: Spinning big black hole, circular orbits
  - **Sound 3**: Spinning big black hole, eccentric orbits

Sounds by
Scott Hughes, MIT

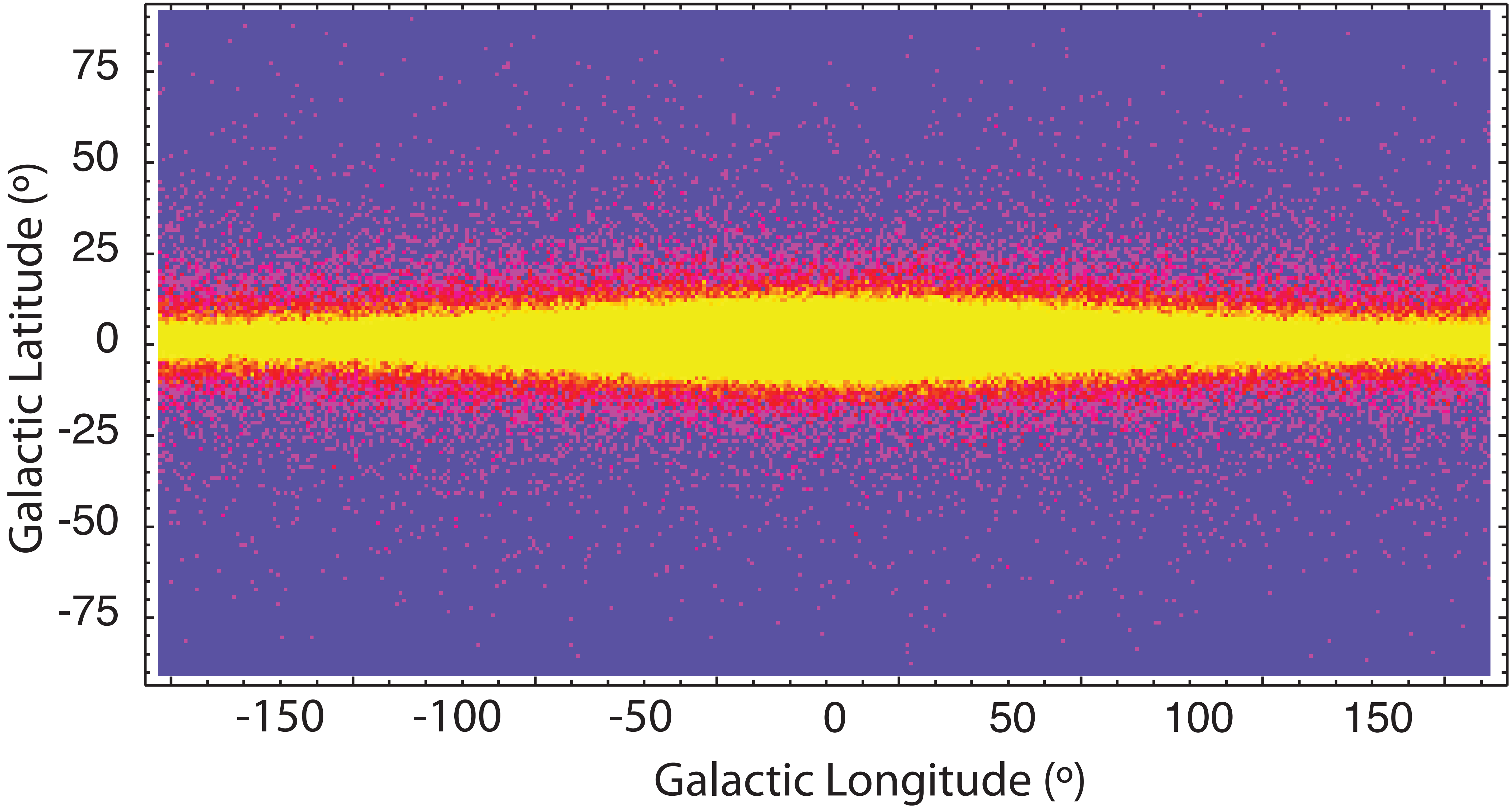


Ultra-compact Binaries

- The galaxy is alive with some **10 million+** compact binaries
- There are so many binaries, their signals overlap, and it is difficult to tell them apart
- This is called the "**confusion limit**", and is analogous to a party
- You can hear people **nearby**
- You can hear **loud people**
- All else is a **dull noise**

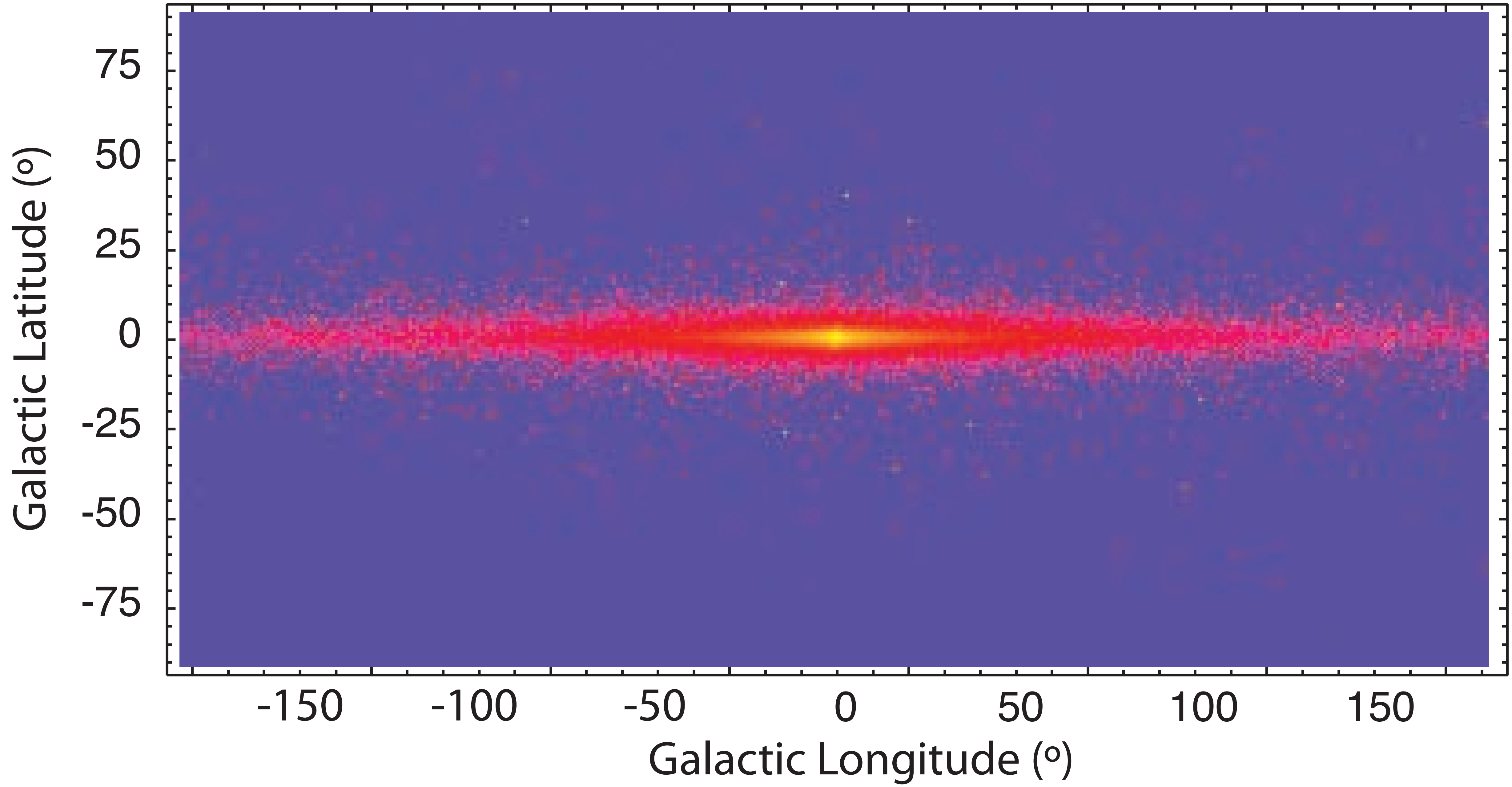
The Galaxy in Gravitational Waves

- LISA will see all 30 million compact binaries together
- The signal encodes the physical structure of the Milky Way



The Galaxy in Gravitational Waves

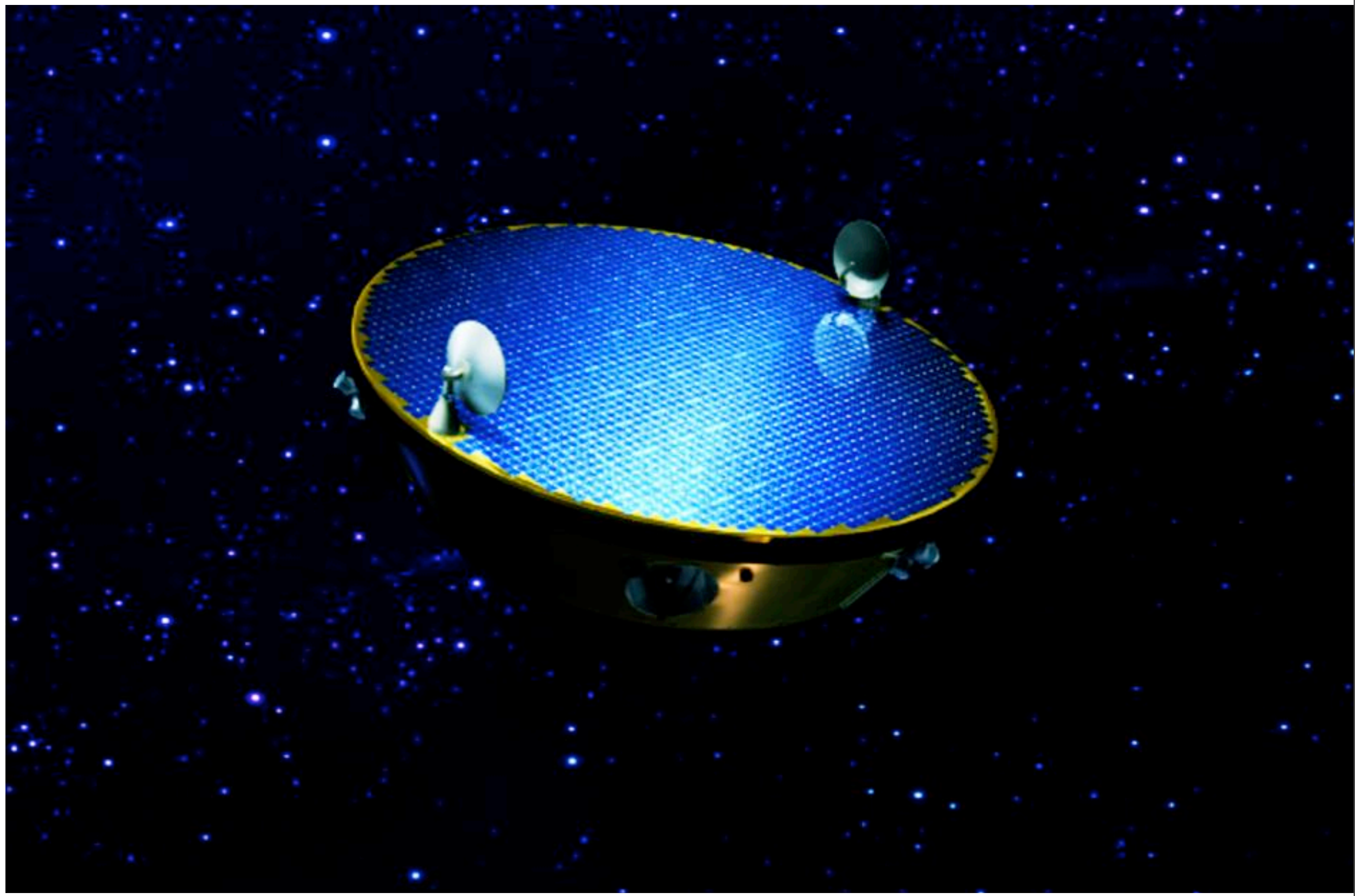
- ~10,000 binaries will be separable from the confusion
- You can still recover the structure of the galaxy!

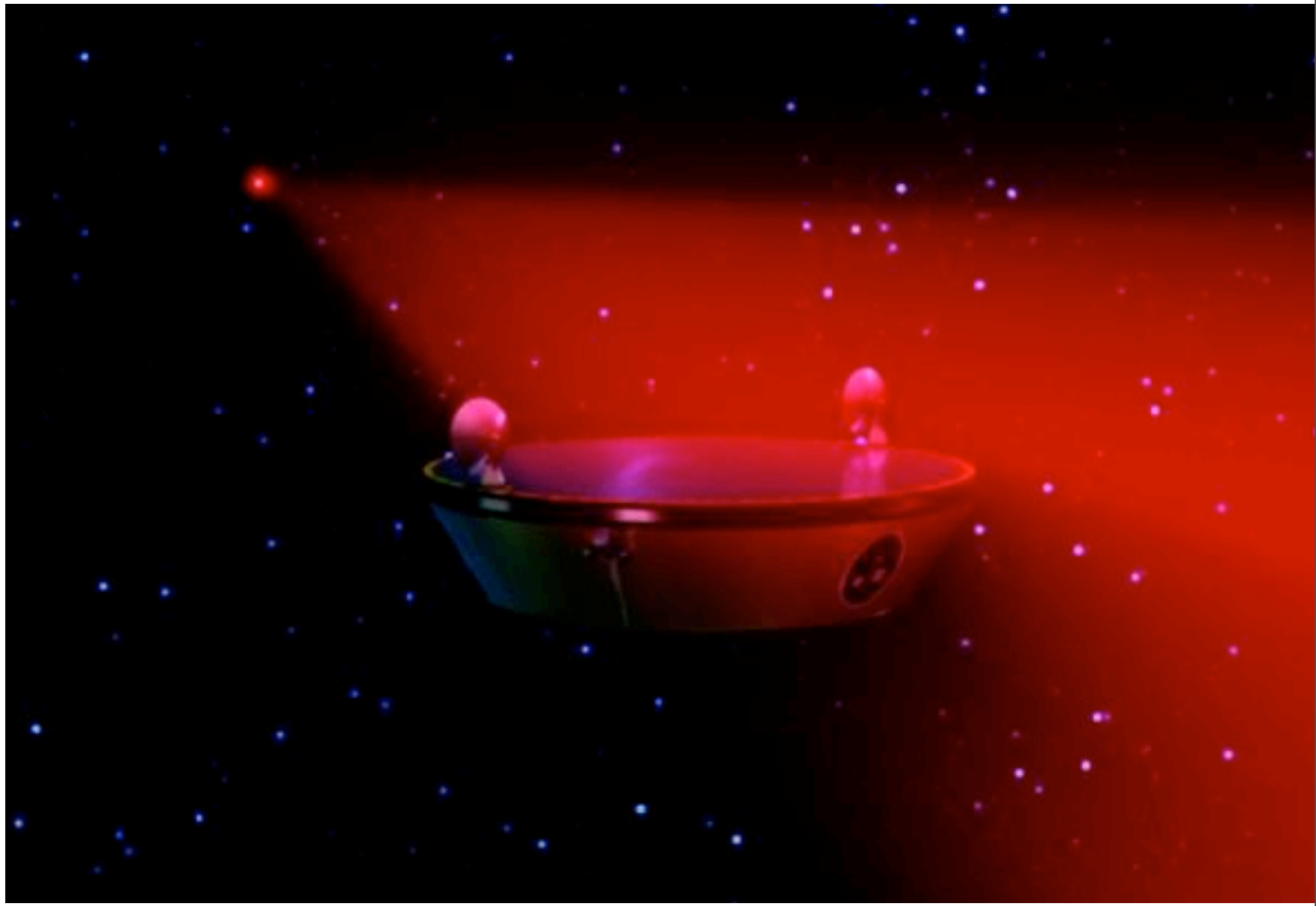


Larson, Benacquista & Taylor (in prep)

Status

- LISA is in formulation/pre-phase A.
- LISA, like most major missions, is currently part of the Astro2010 Decadal Survey
- LISA has been highly ranked during every recent review, notably the NRC BEPAC (Kennel 2007) Report:
- "On purely scientific grounds LISA is the (Beyond Einstein) mission that is most promising and least scientifically risky ... **Thus, the committee gave LISA its highest scientific ranking**."





LISA Pathfinder

- LISA Pathfinder is our technology development mission
- Spacecraft has been built and is in pre-flight preparations before ~2010 launch
- Payload is the LISA Technology Package
- LTP is the basic LISA sensing instruments connected to the Disturbance Reduction System
- Micro-Newton thrusters control the spacecraft position

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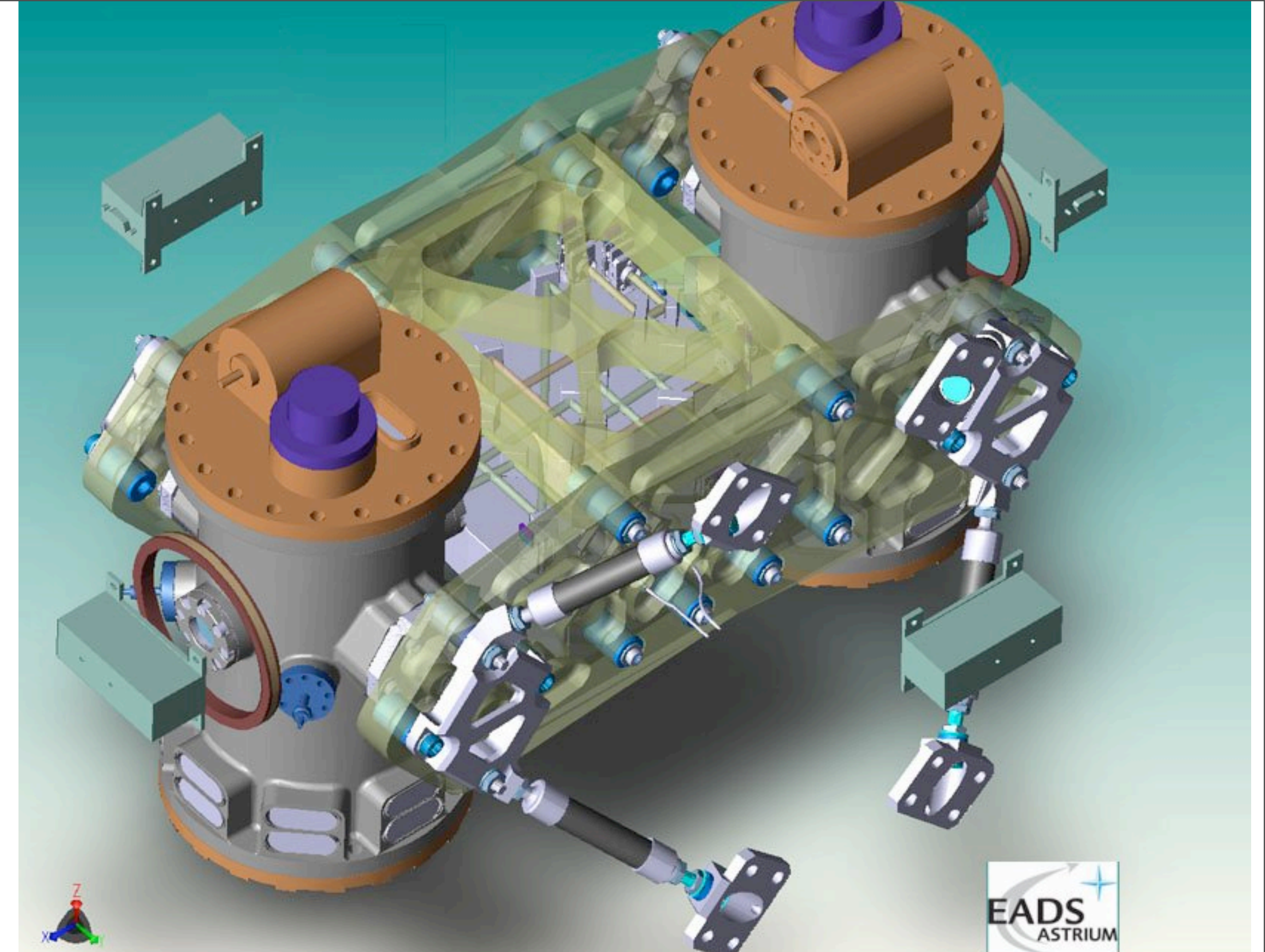

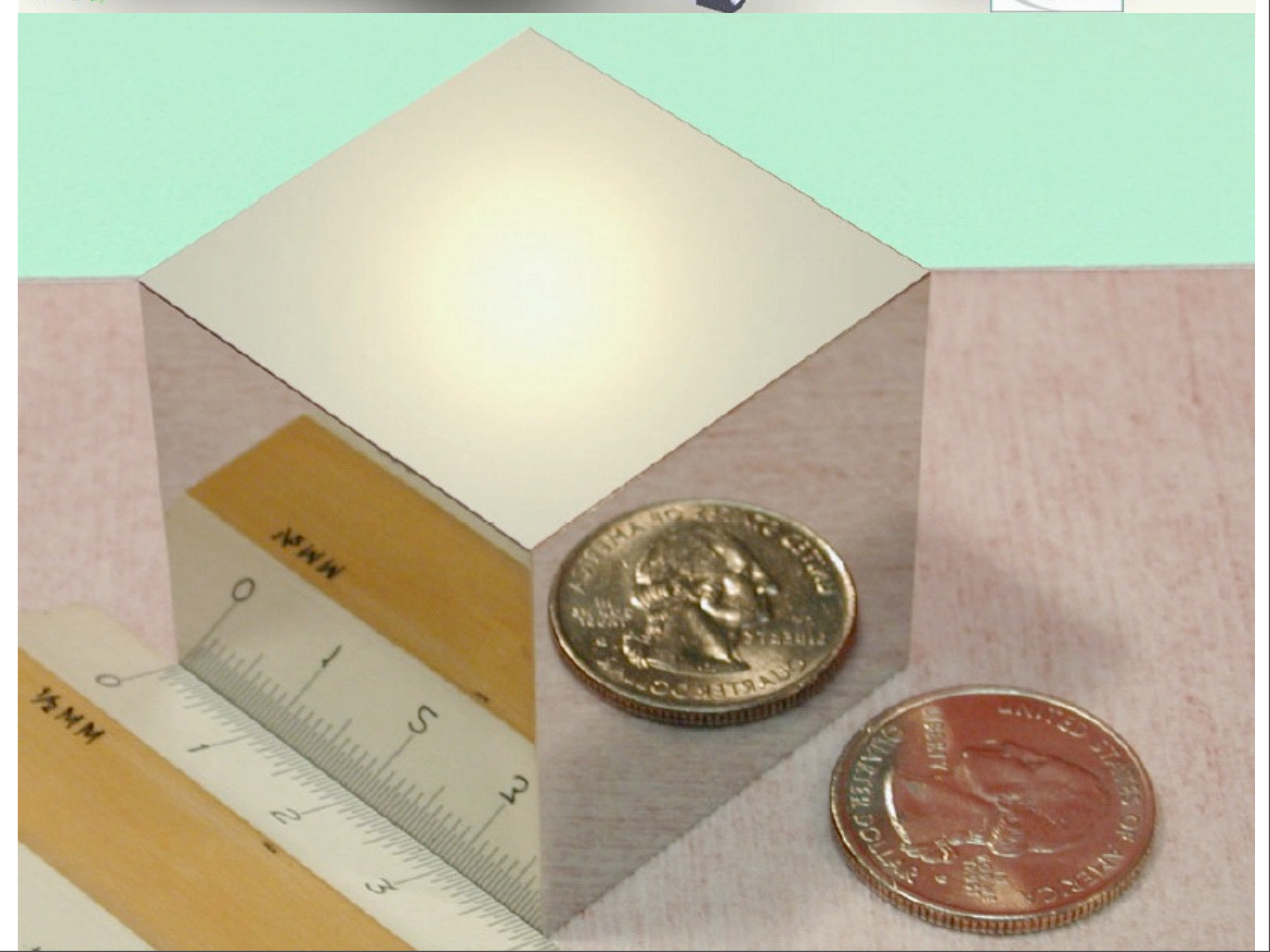

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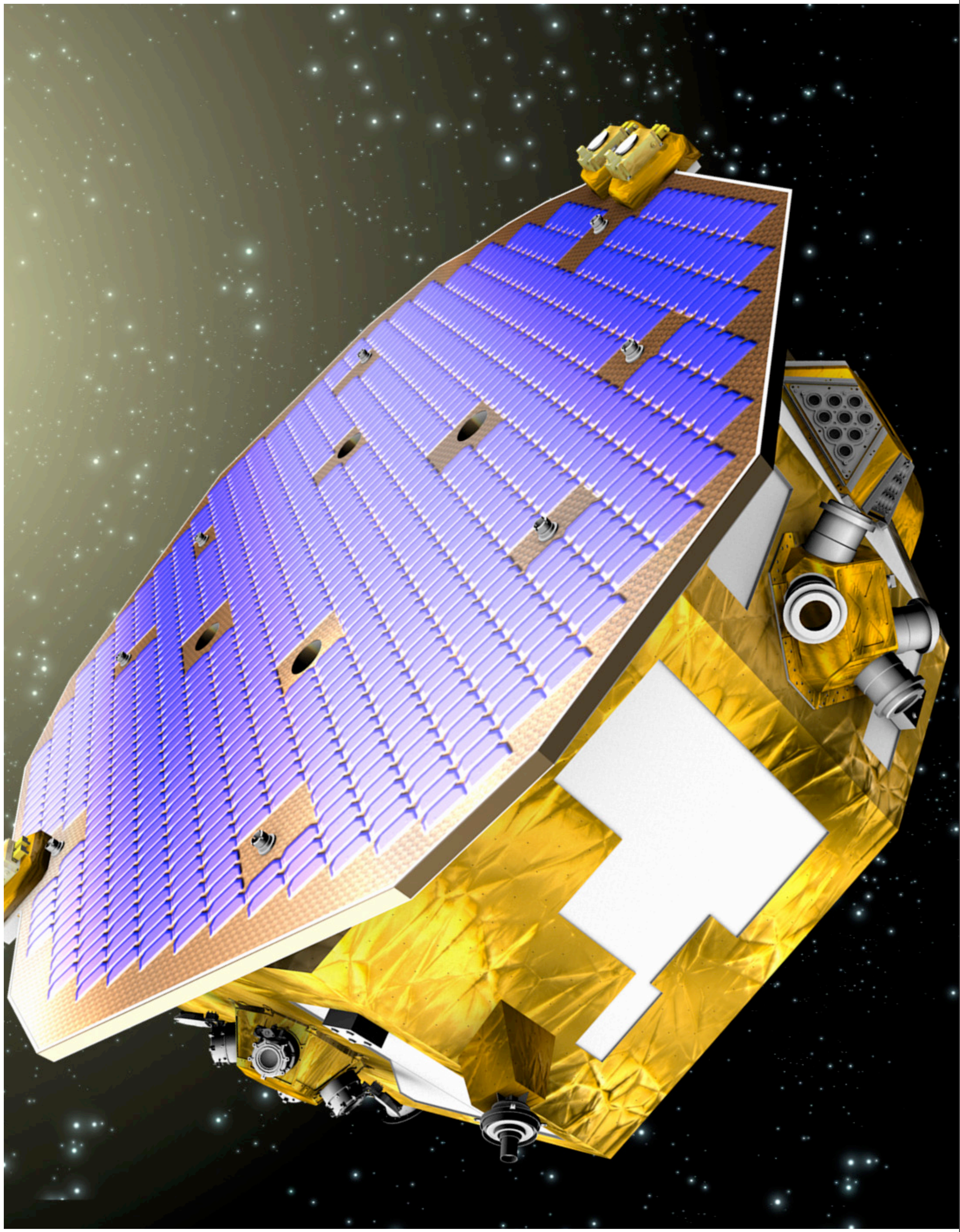
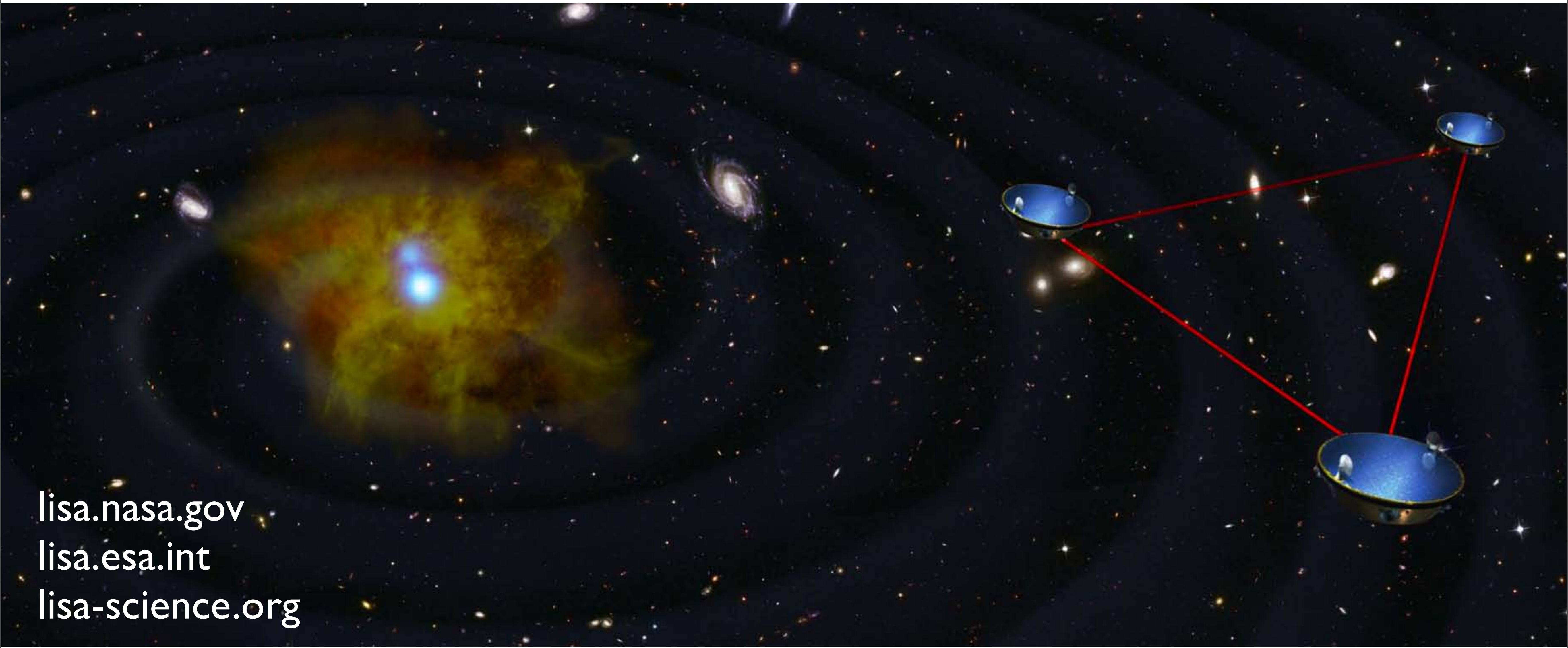


Summary



- LISA will be a superb astrophysical probe for many sources
- LISA complements other astronomical tools and enhances our science capabilities
- Technology development is well underway. Launch 2018+ (?)

Thanks!

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