Science Frontiers of the World-Wide Gravitational Wave Network

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Topics

1. How gravitational waves are different
2. Operating detectors and upgrade plans
3. Networking of detectors
4. Science goals through 2015
5. Science goals in the longer term, and how to reach them

How Gravitational Waves are Different

Gravitational Wave Detection

"Gravitational wave detection is about seeing the biggest things that ever happen – the collisions, explosions, and quakings of stars and black holes – by measuring the smallest changes that have ever been measured…"

Harry Collins

Gravity's Shadow: The Search for Gravitational Waves

(University of Chicago Press 2004)

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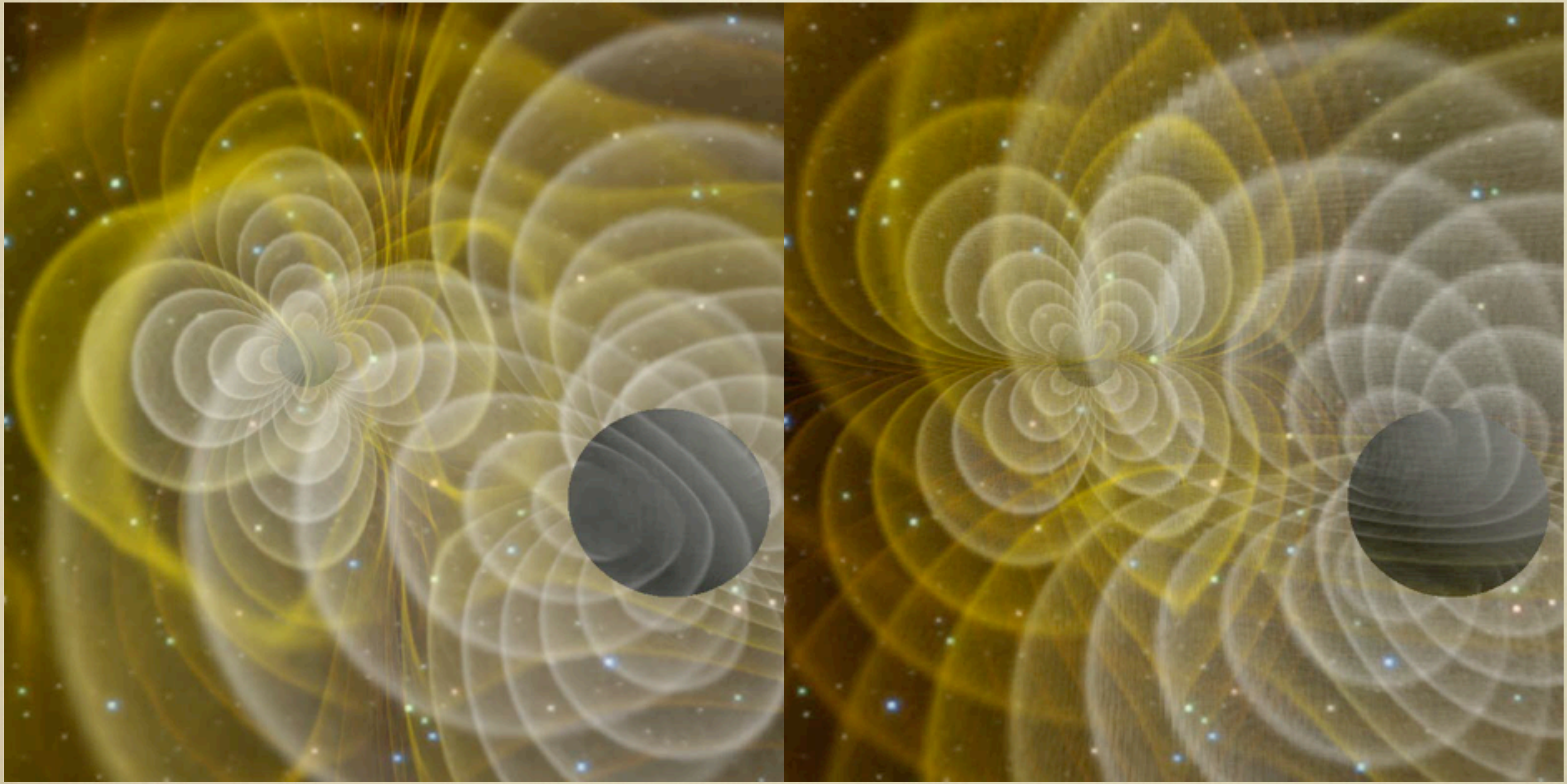

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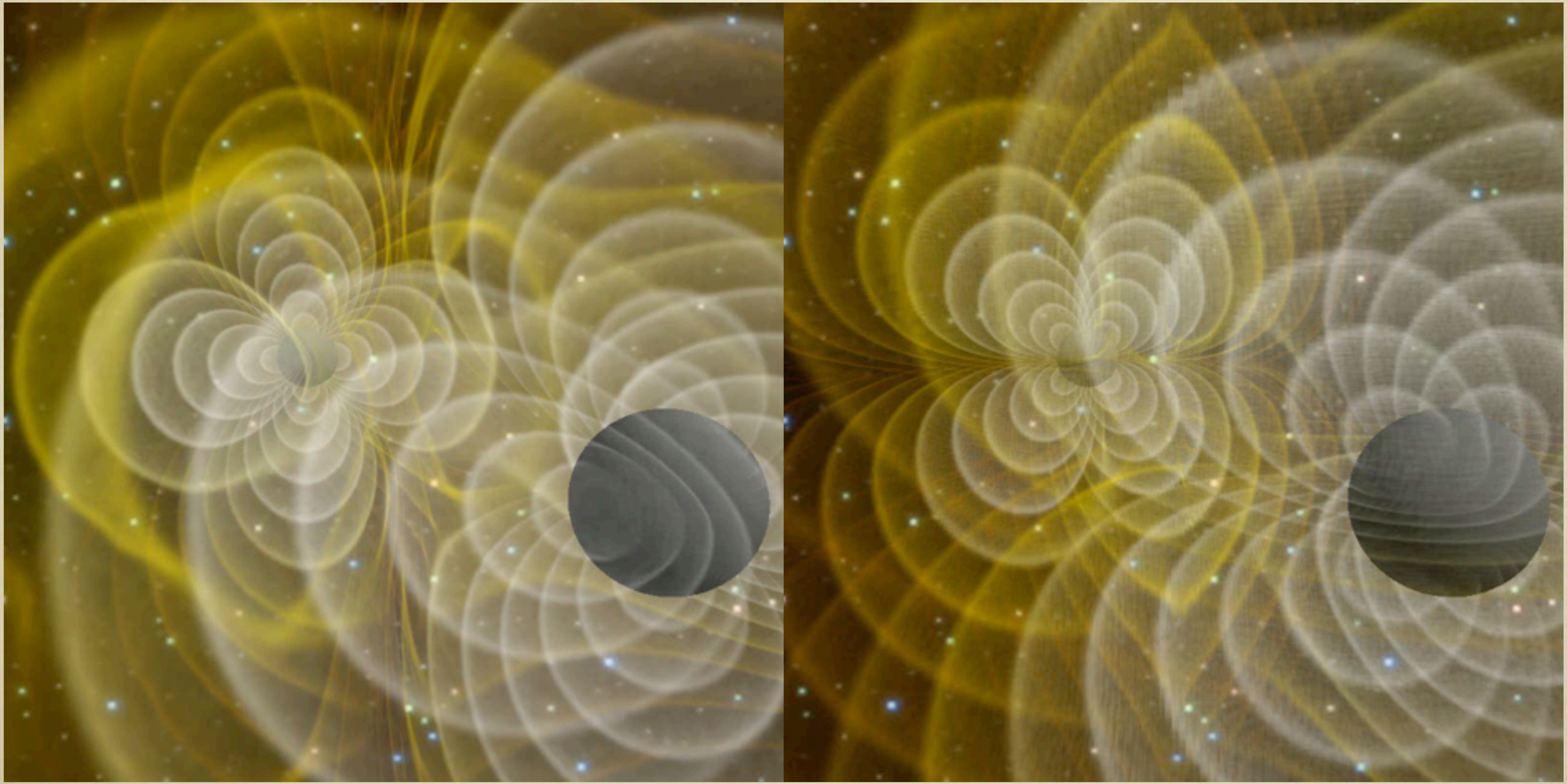

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- *Review published recently: B Sathyaprakash, B F Schutz, "Physics, Astrophysics and Cosmology with Gravitational Waves" Living Reviews in Relativity* ***12*** *(2009), 2. (http://www.livingreviews.org/lrr-2009-2)*

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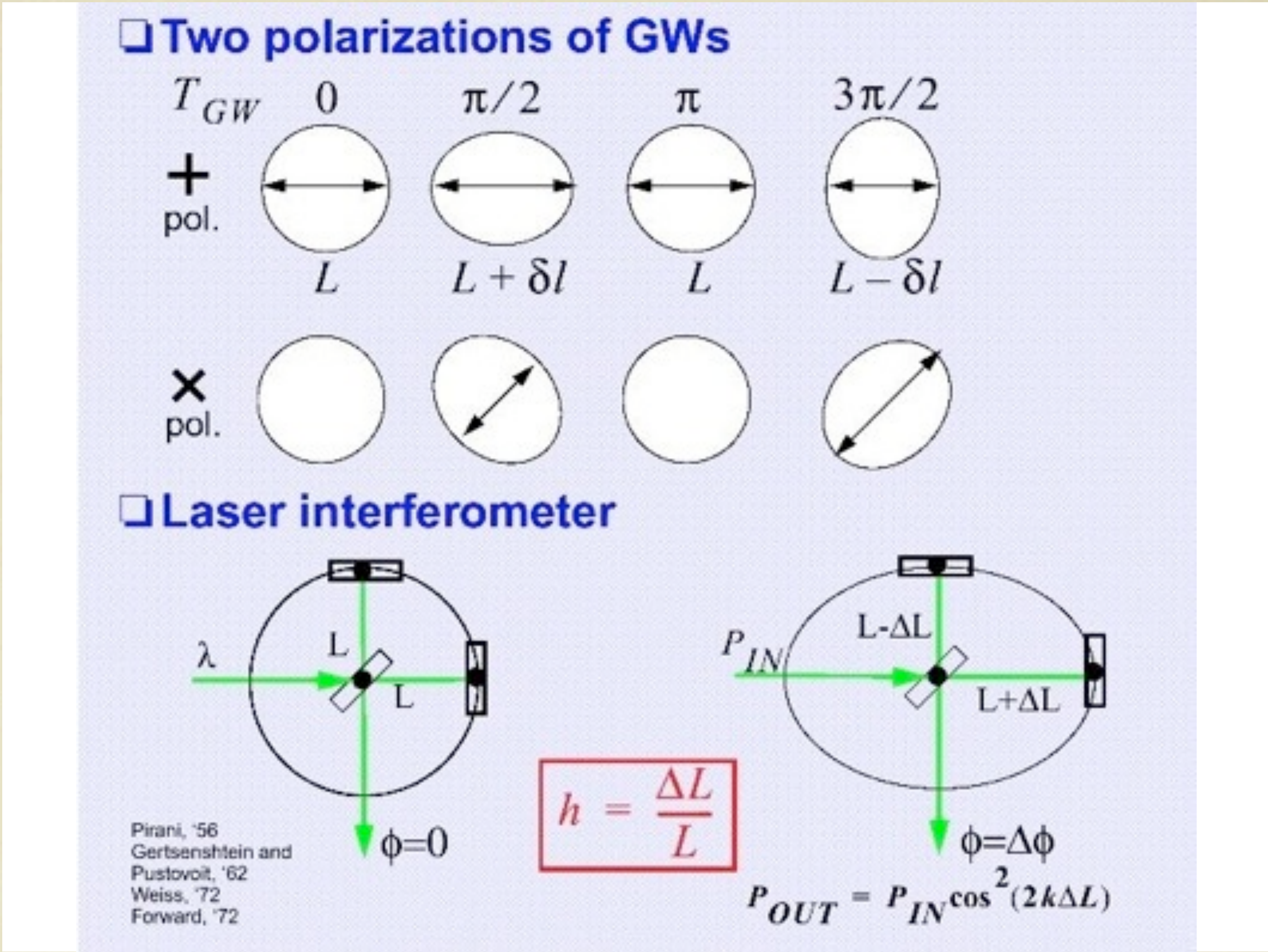

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- Detection is **coherent**, following phase and amplitude.
  - Sensitivity given in terms of amplitudes
  - Look for signals in noise by convolving with expected **templates**
  - Signals emitted coherently by entire masses

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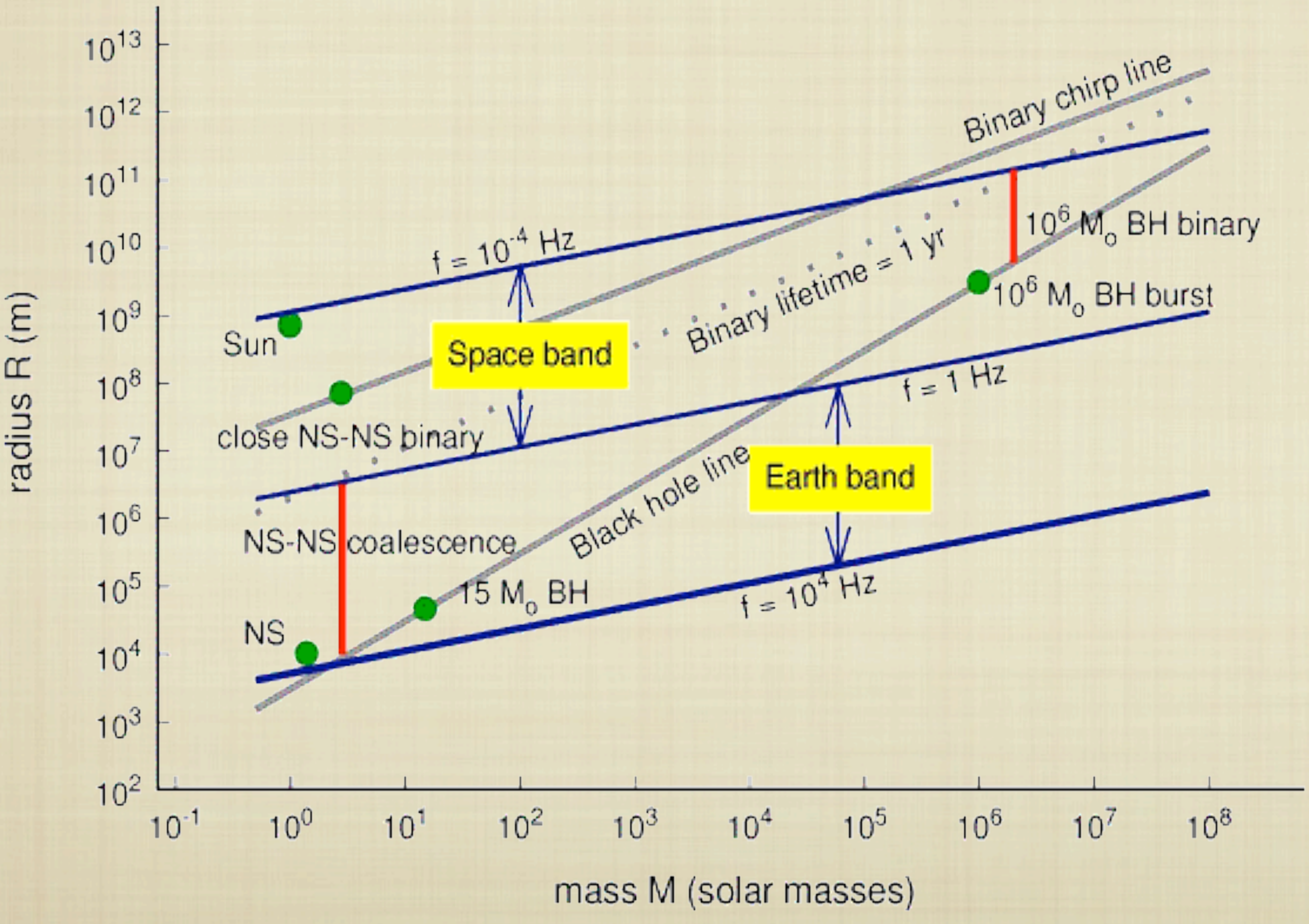

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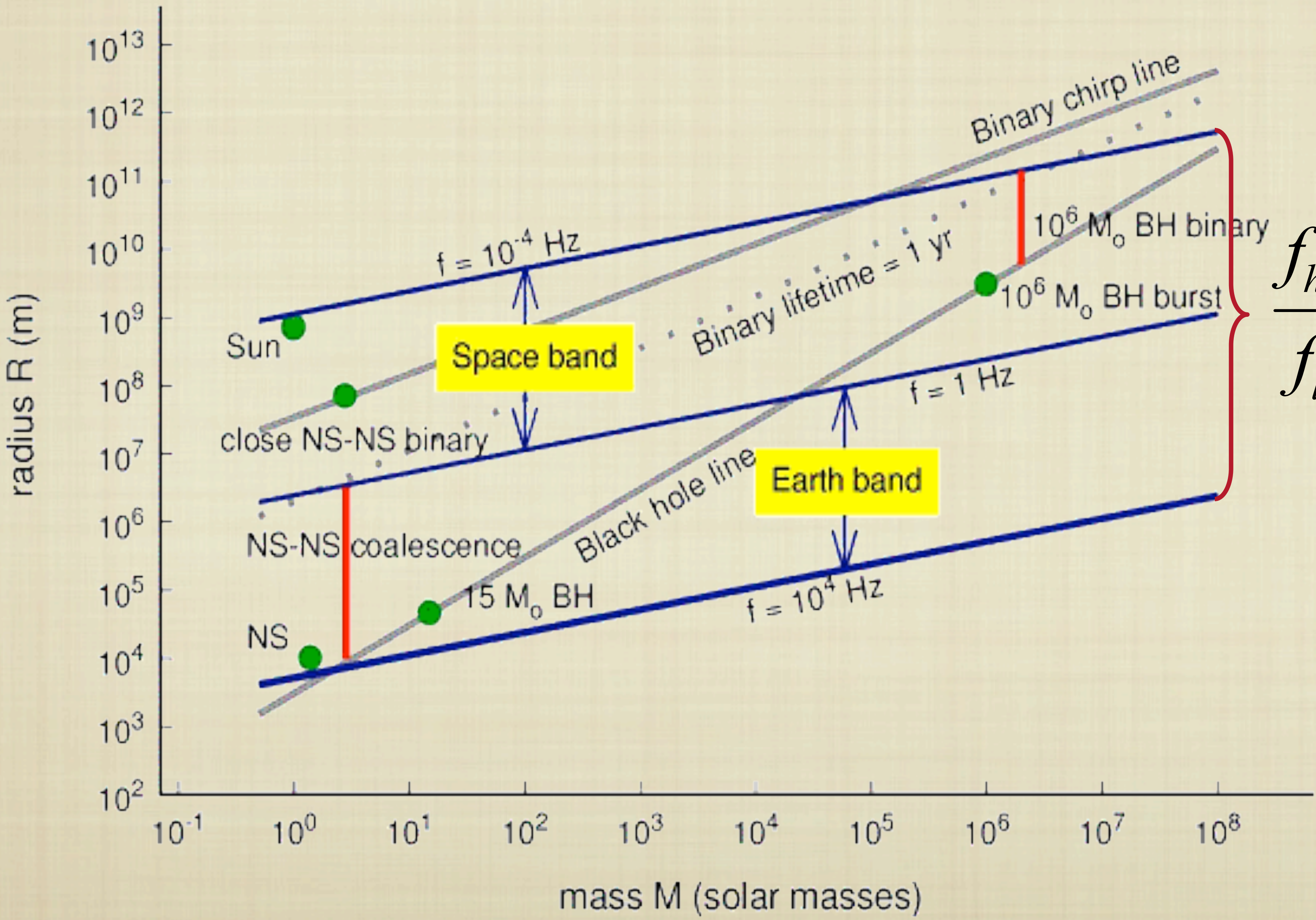

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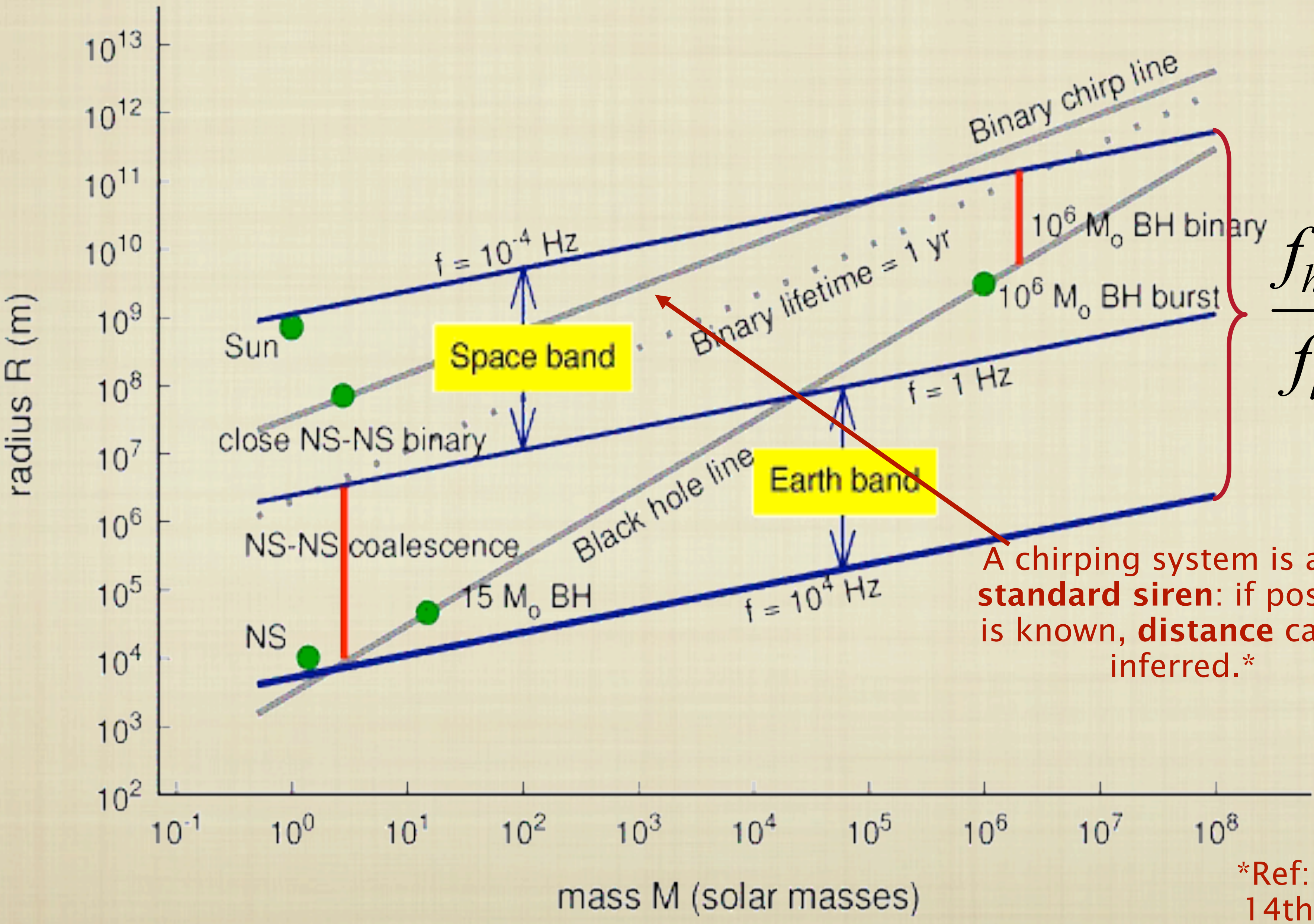

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A chirping system is a GW **standard siren**: if position is known, **distance** can be inferred.*

*Ref: Schutz in Sato & Nakamura, 14th Yamada Conference (1986)

Operating Detectors and Upgrades

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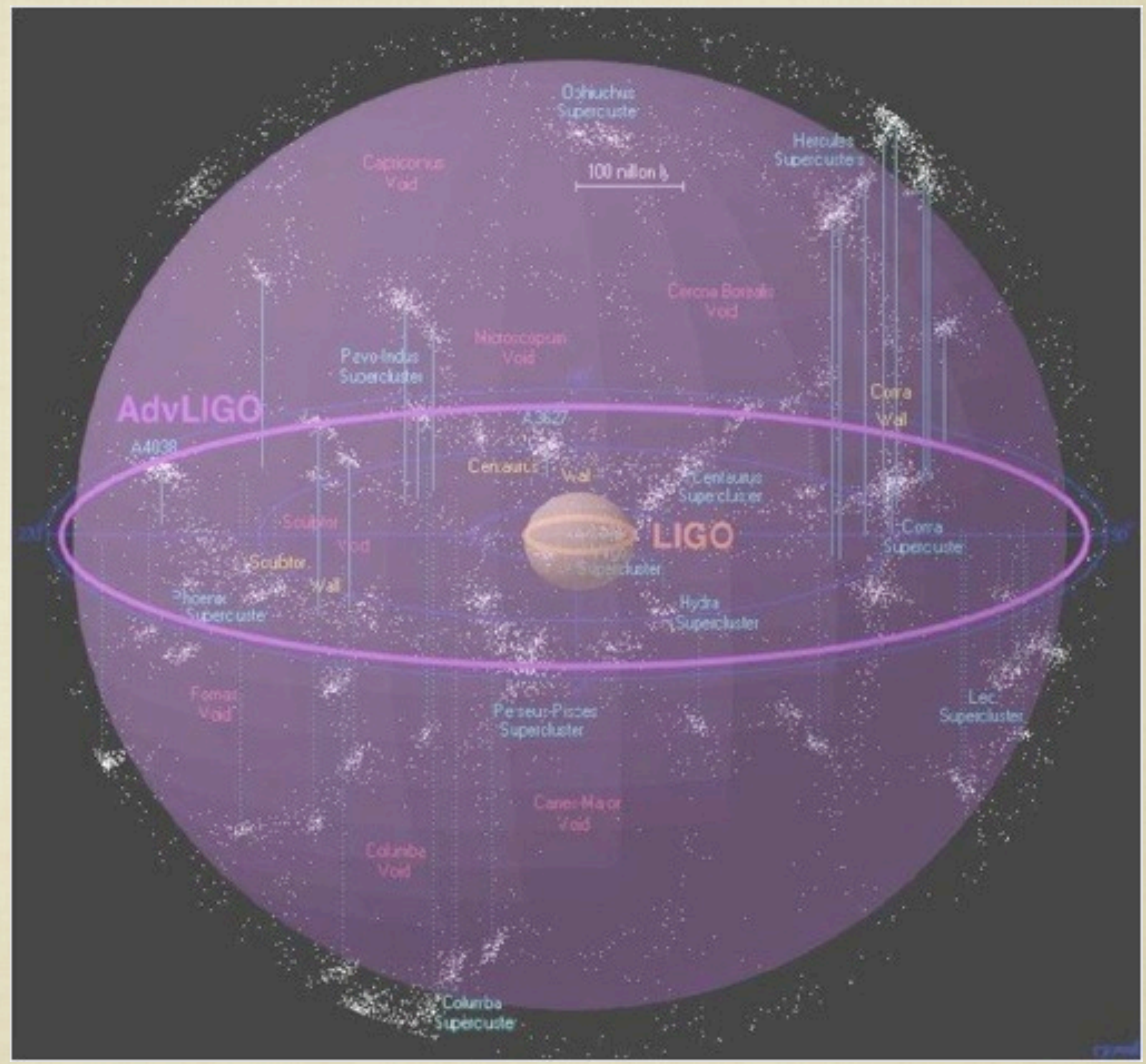

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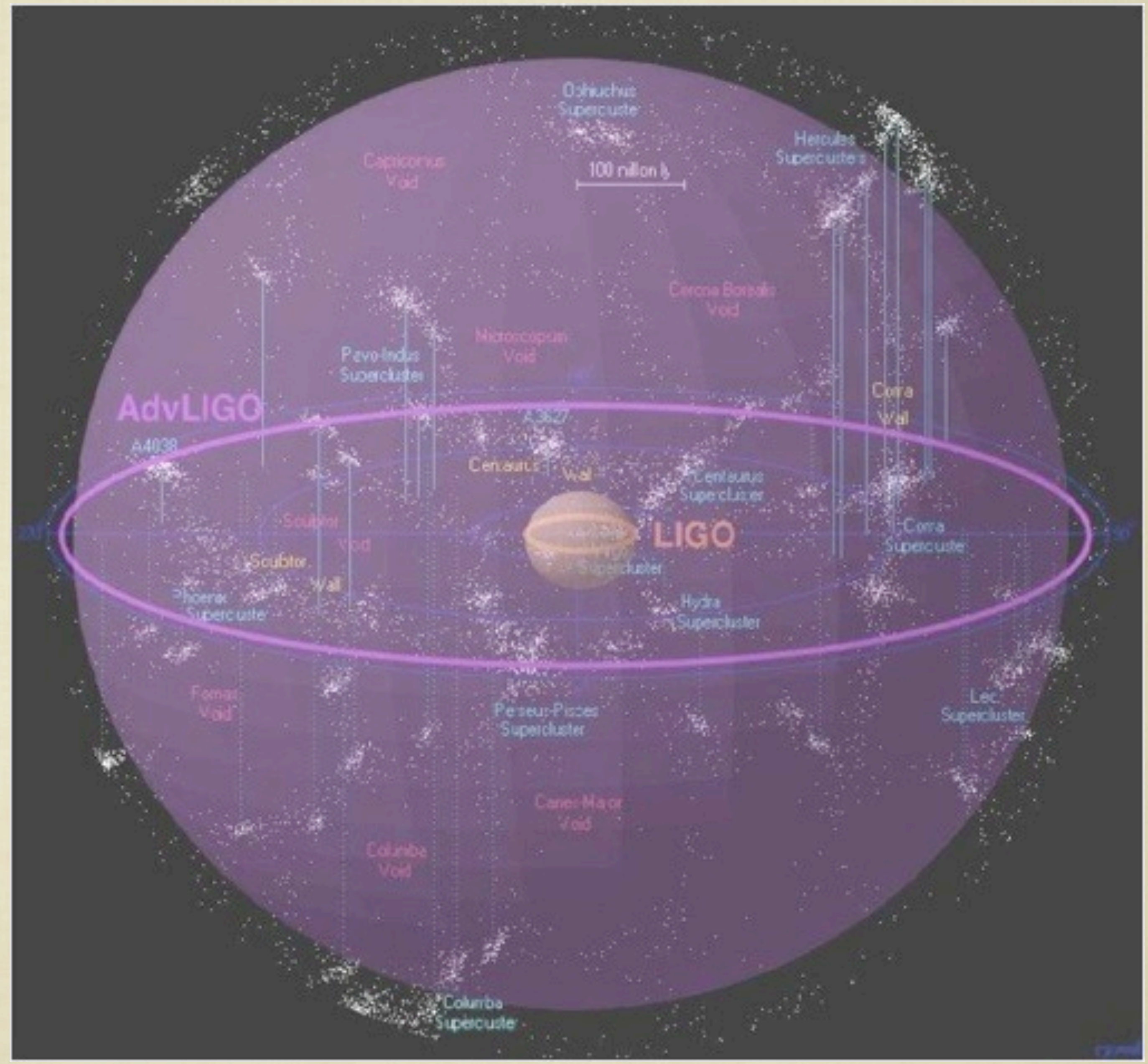

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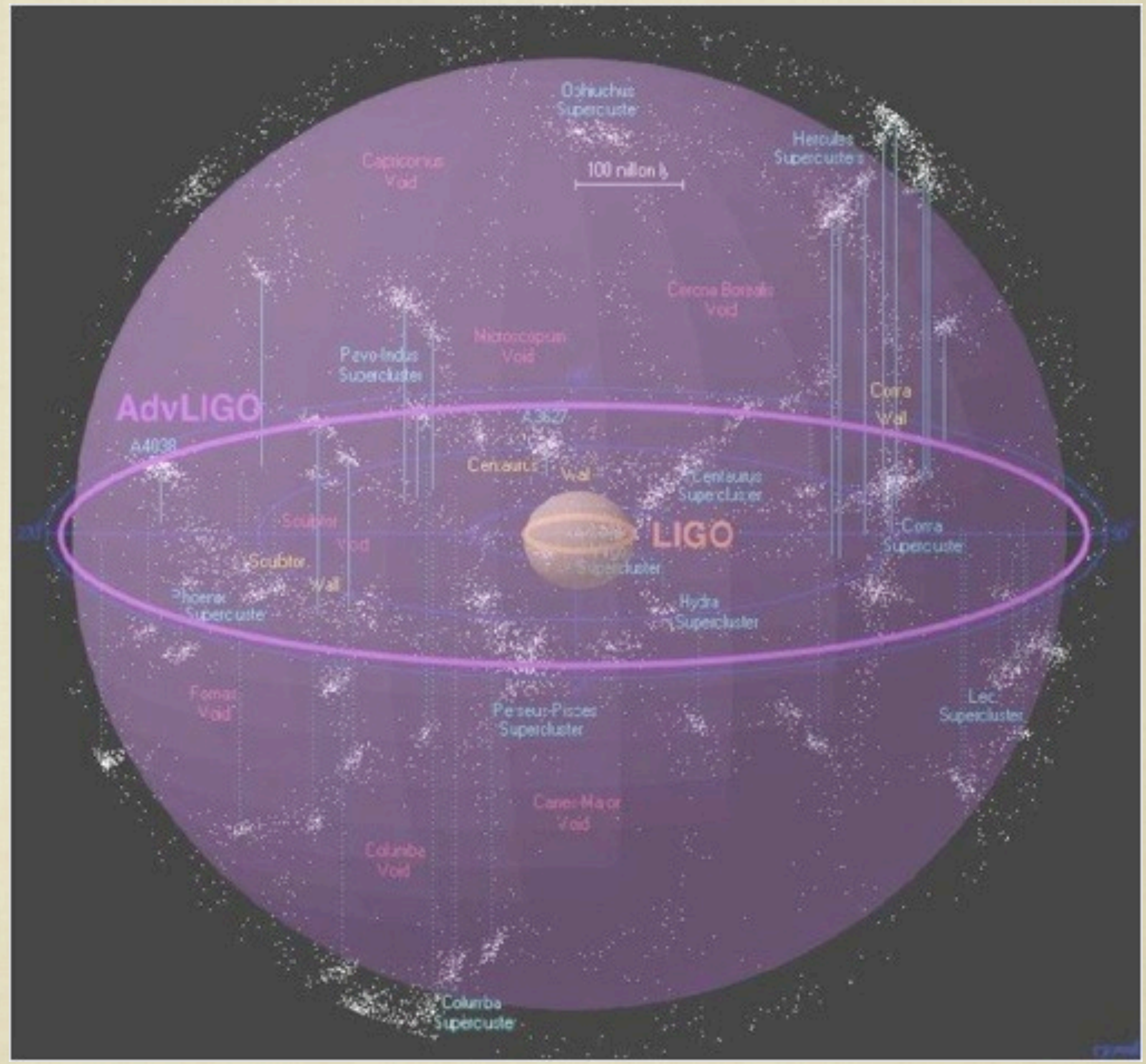

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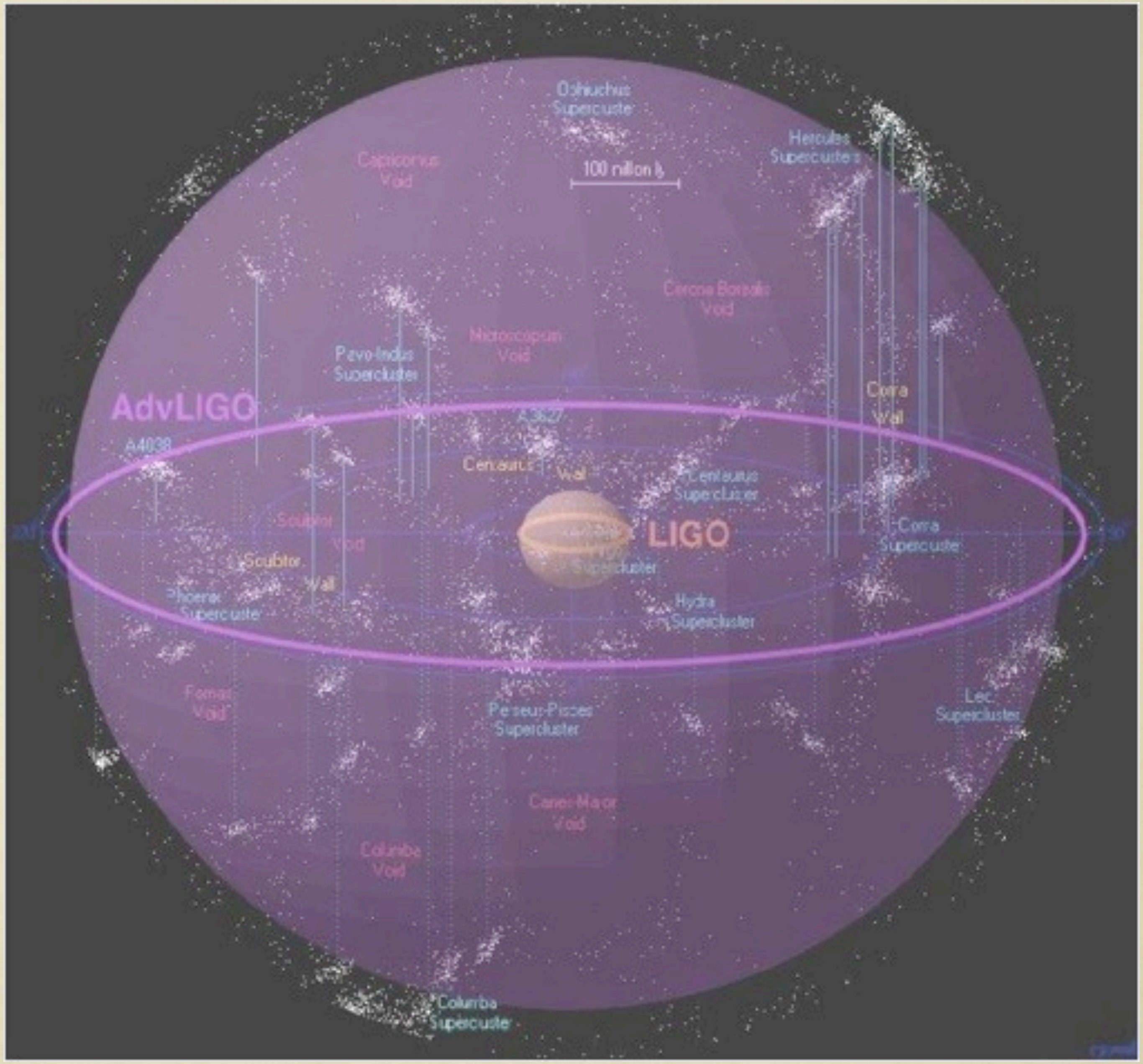

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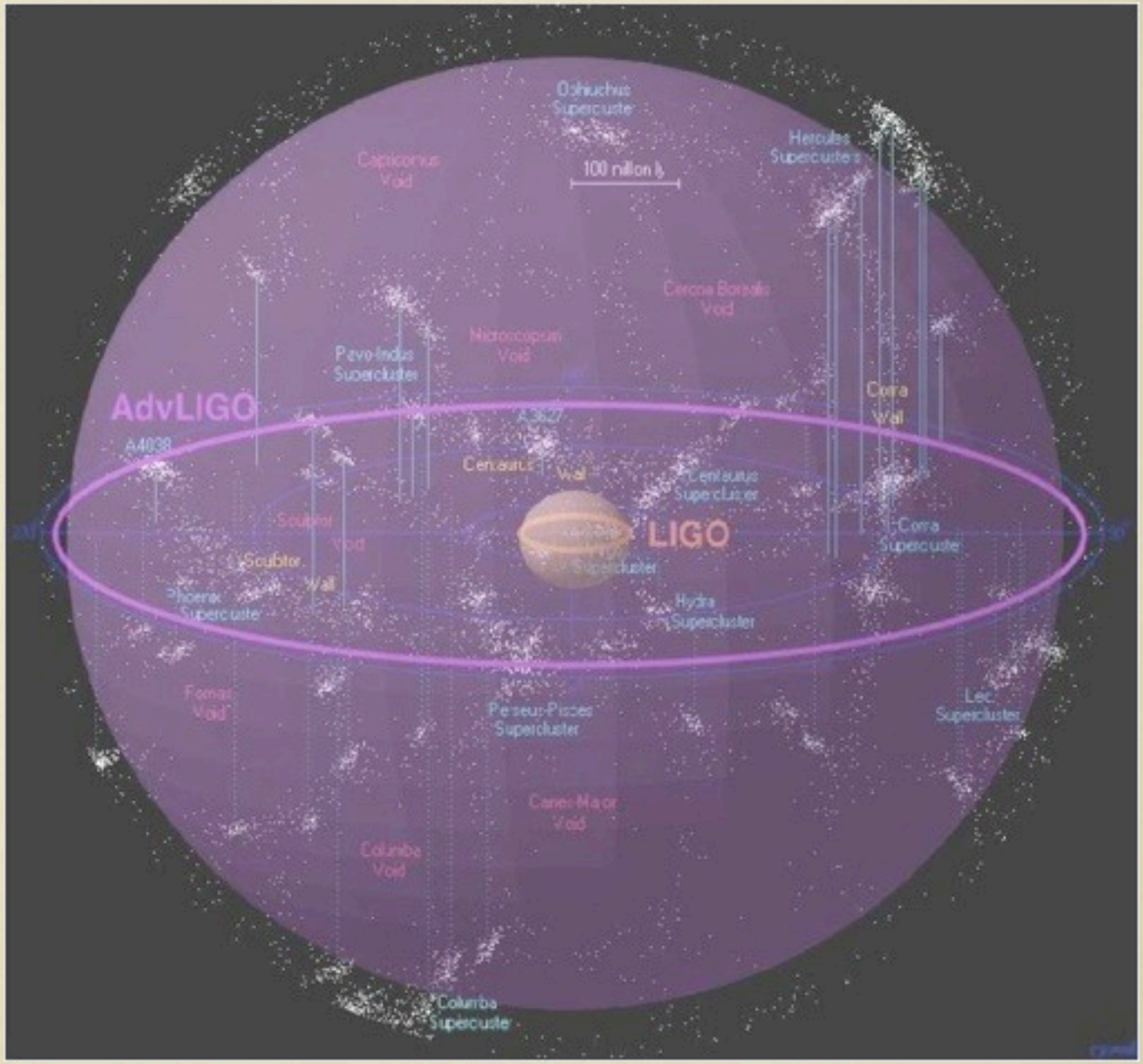

Networking of Detectors

Global Network of Interferometers

- Detection confidence
- Source polarization
- Sky location
- Duty cycle
- Waveform extraction

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  - Polarization: need non-aligned detectors. Two LIGO sites very closely aligned. VIRGO breaks degeneracy. Strong covariance between polarization errors and position errors for some sources.

Science Goals Through 2015

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4. Measure distances to binaries (standard sirens) and obtain a calibration-free value of the local Hubble constant. Compare to astronomers' cosmic distance ladder, test for anomalous local velocity fields.

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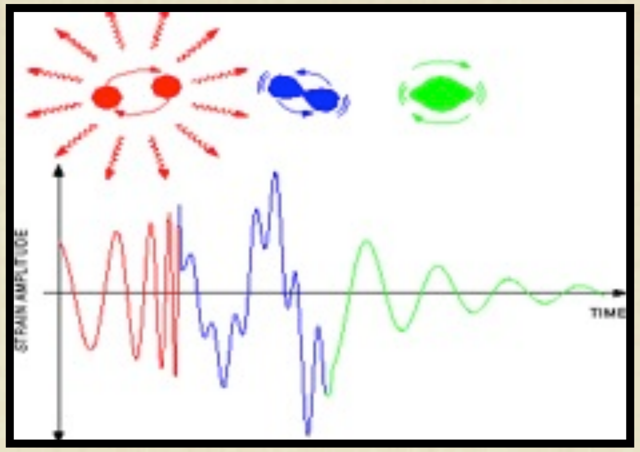

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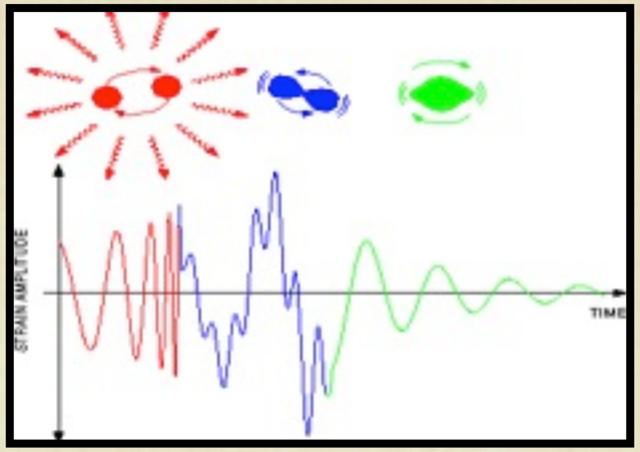

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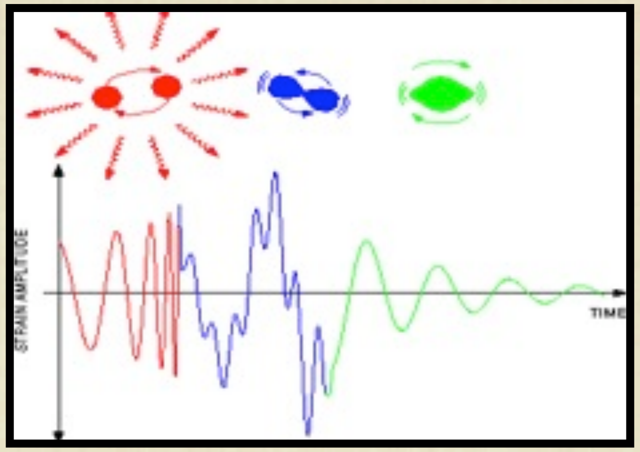

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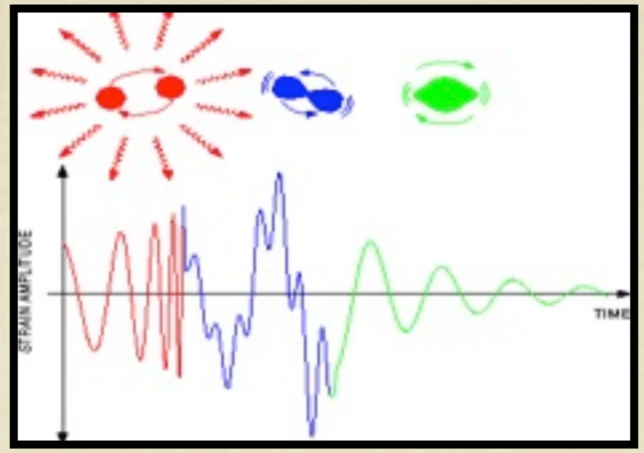

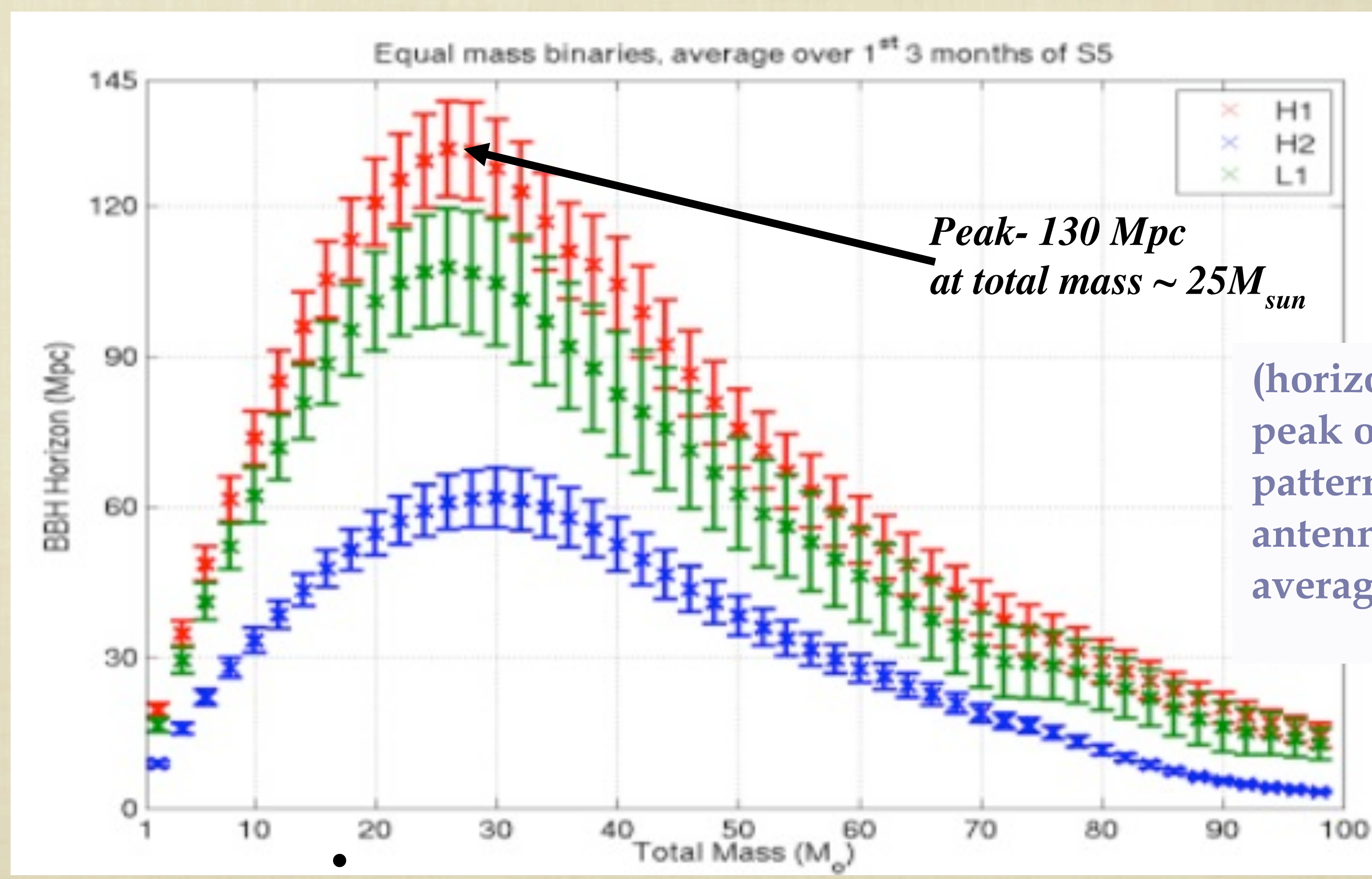

(horizon=range at peak of antenna pattern; ~2.3 x antenna pattern average)

COMPACT COALESCING BINARY SYSTEMS

Compact Coalescing Binary Systems

Merger of two NS's (Rezzolla et al, AEI)

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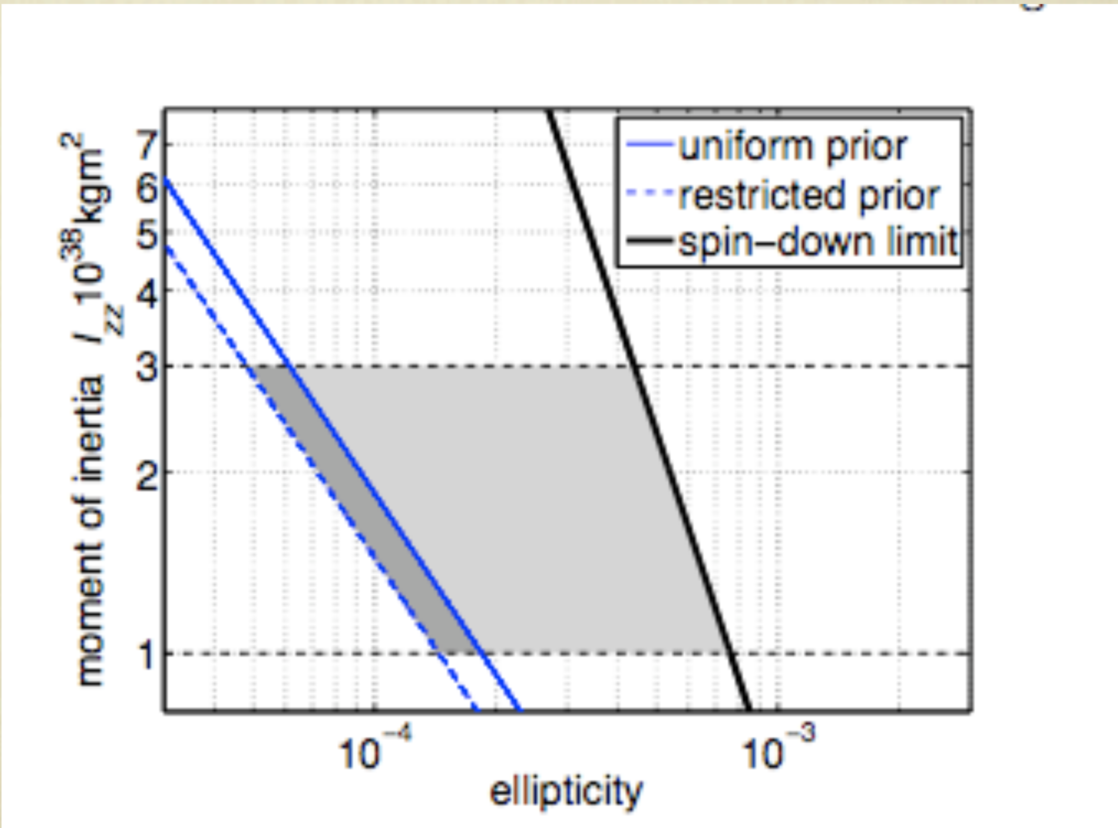

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- GEO-HF could observe normal-mode ringdown from glitching and bursting neutron stars. This would open NS asteroseismology, strongly constraining EoS.

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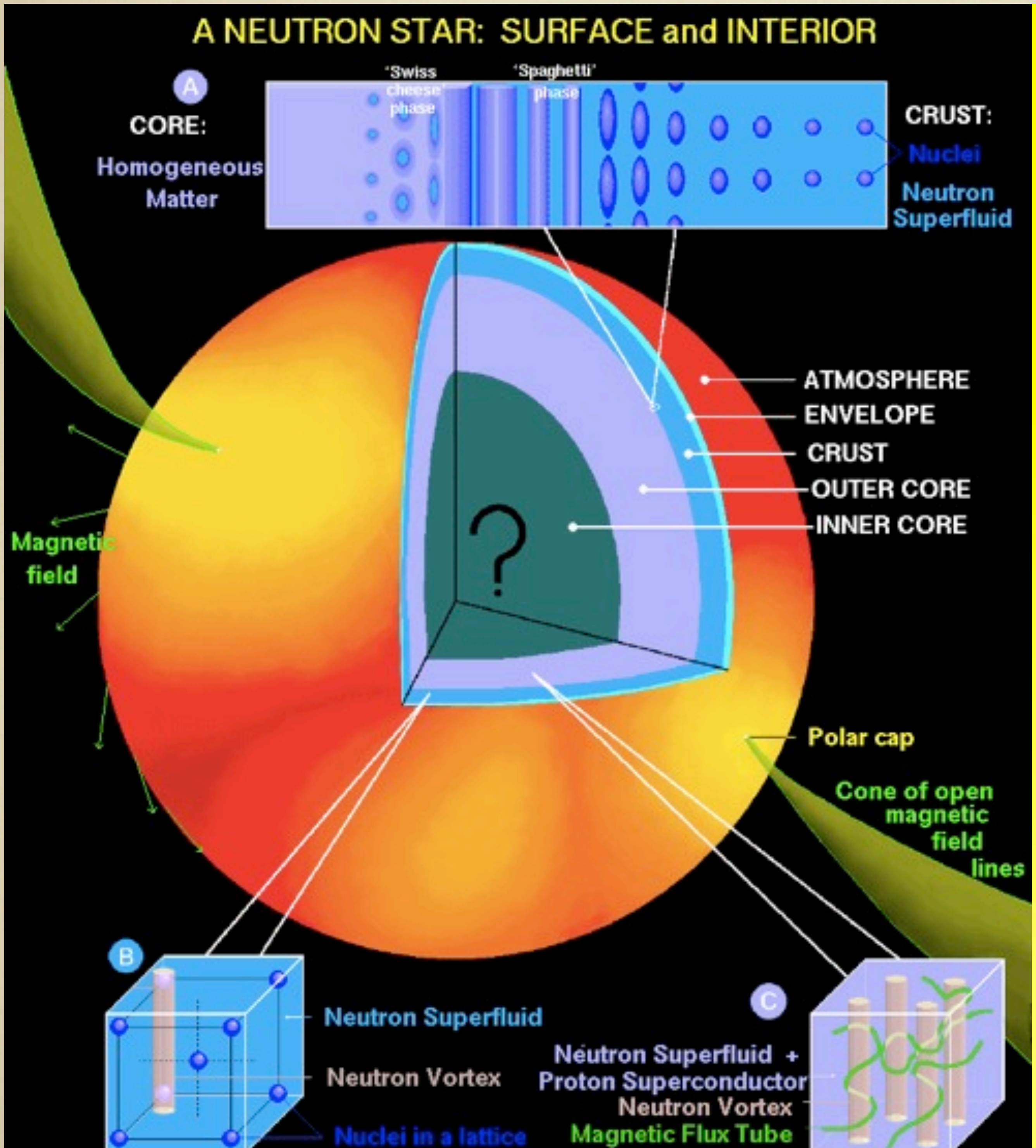

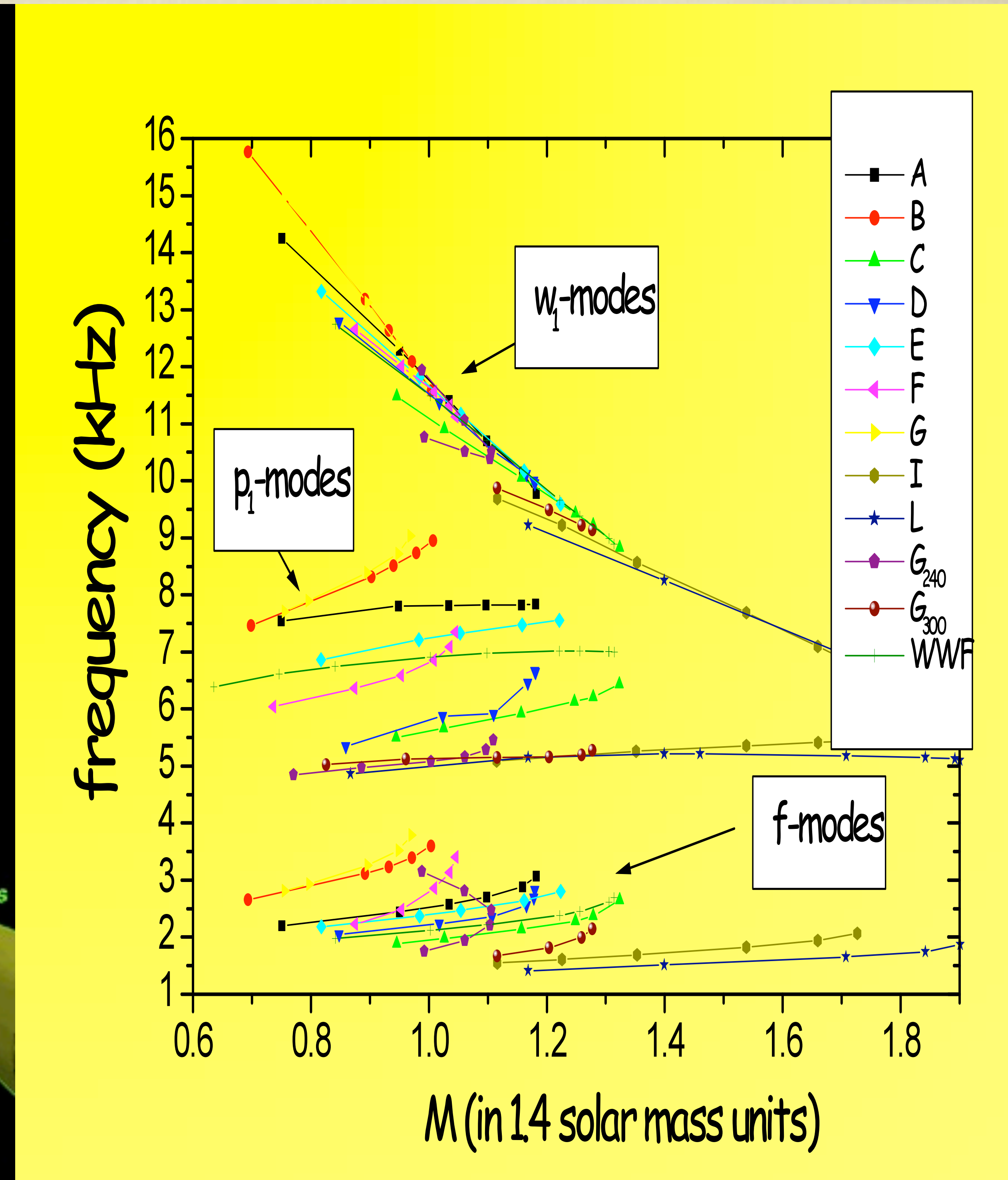

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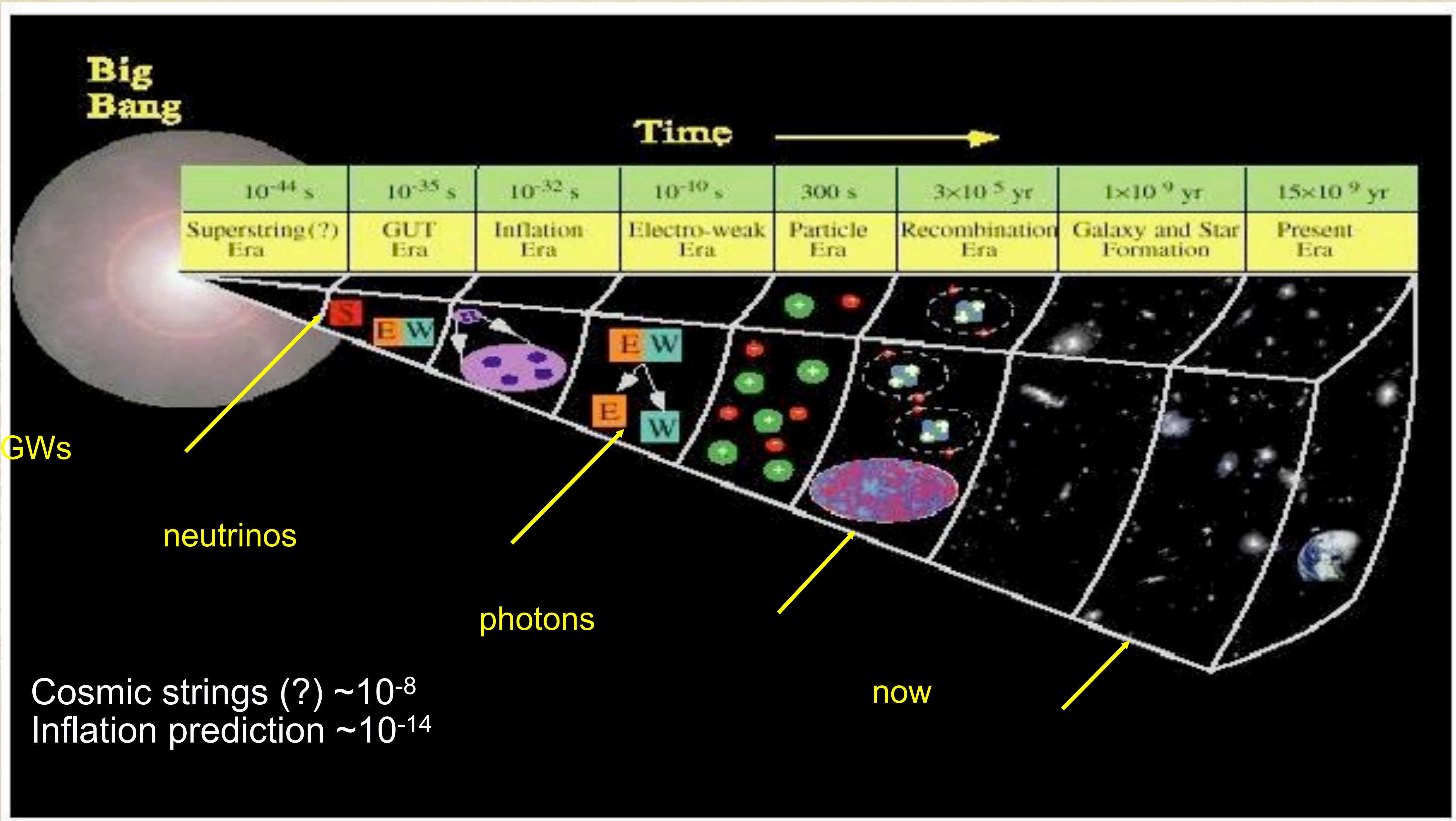

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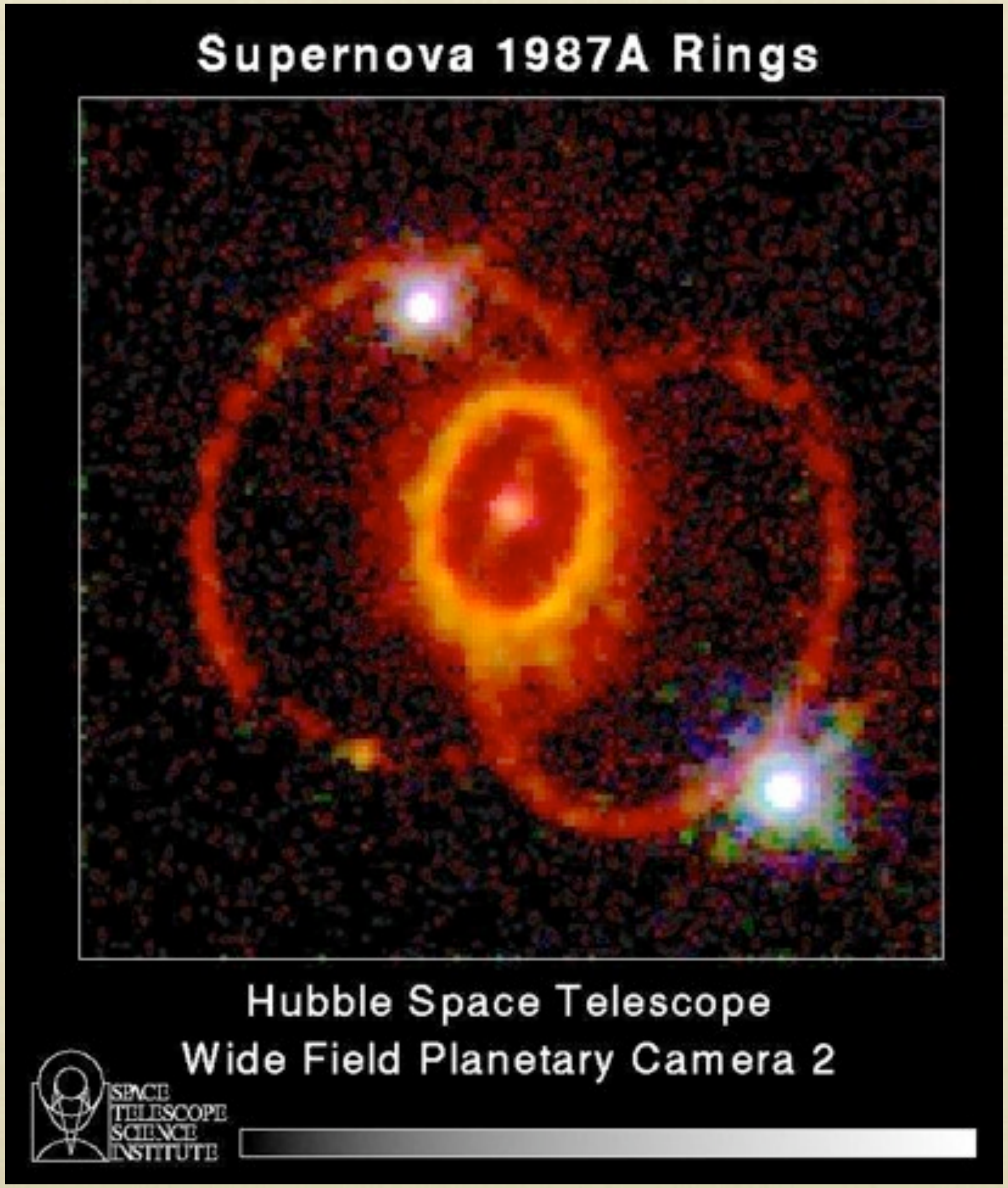

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- Explosion mechanism still uncertain, so there is room for surprise with this source. Coordinated observations with large telescopes also important. Any GW observation will be informative about the mechanism.

Science Goals in the Longer Term
... and How to Reach Them

Discovery Space

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- Exploring the universe to higher redshifts, z ~ 0.5: population evolution for NS and BH; calibration-free measurement of not only H_0 but also w (dark energy parameter); understanding gamma-ray bursts; finding intermediate-mass BHs; measuring GWs from supernovae in the Virgo Cluster.

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- The most interesting sources may be ones we have not thought about! GW detection explores the dark sector, which makes up 96% of the energy in the universe. If there are structures in this sector (shadow matter, mirror matter, nearby branes, ...) then the only way to discover them is to study their GWs.

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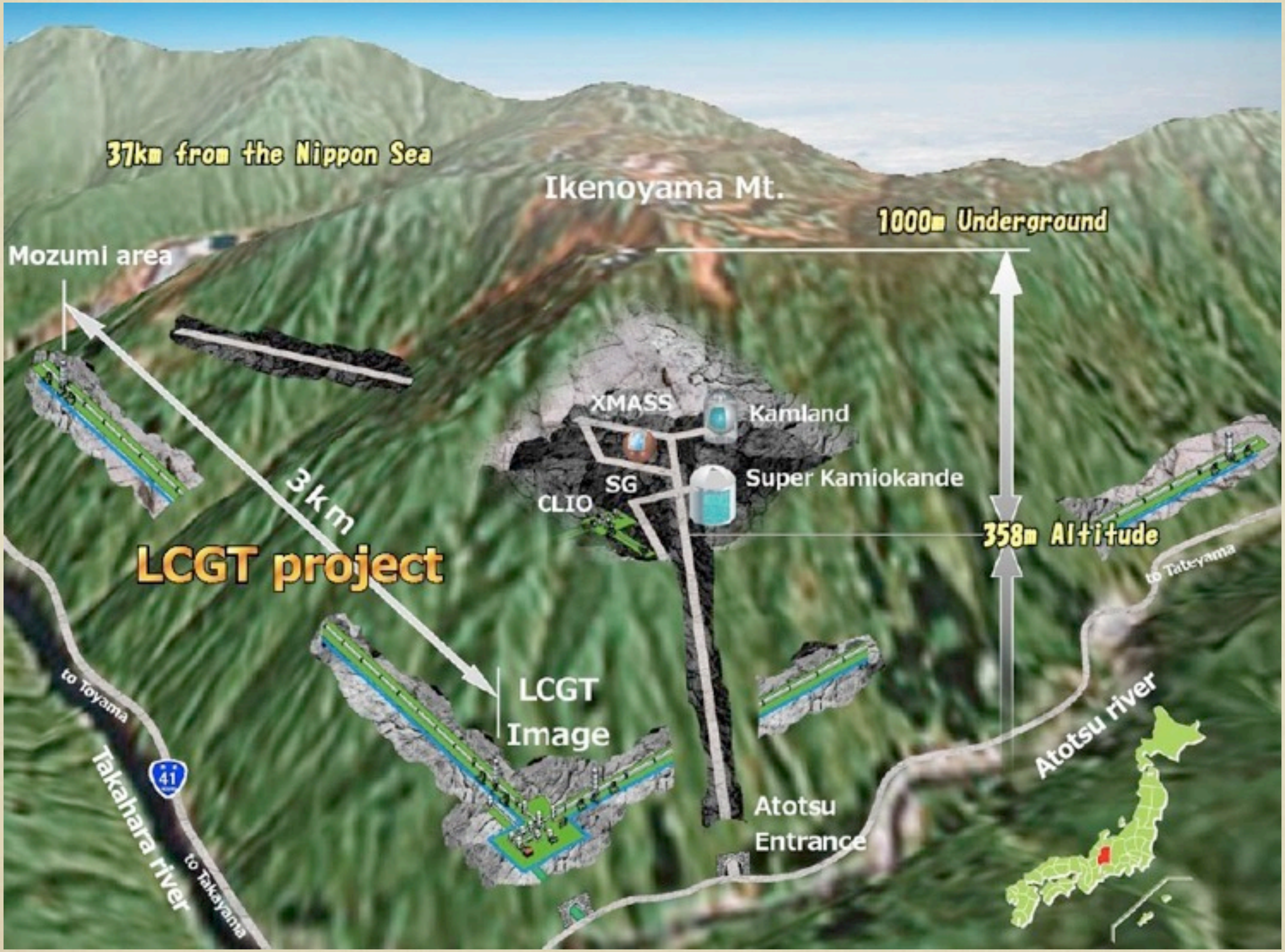
- For these and other objectives, more sensitivity is crucial. There are two ways to improve sensitivity beyond the existing planned Advanced Detectors: more detectors, and new technology. LCGT is seen by the international community a key to both.

More Detectors at the Advanced Level



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- LCGT would improve the detection network in many ways:
  - Improved confidence: a 4-way detection rejects hugely more "glitches" than a 3-way event search. Network range extends by factors of ~1.5, volume by > 3!
  - Antenna pattern fills in existing weak spots, improving 3-way event rate.
  - Resolving power of network doubles due to multiple long baselines: error boxes much smaller, optical and X-ray identifications much easier.
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- Only LCGT could do this in time for the early observations and possibly the first detection. Other proposals are much further in the future. The international GW network is hoping for LCGT approval!

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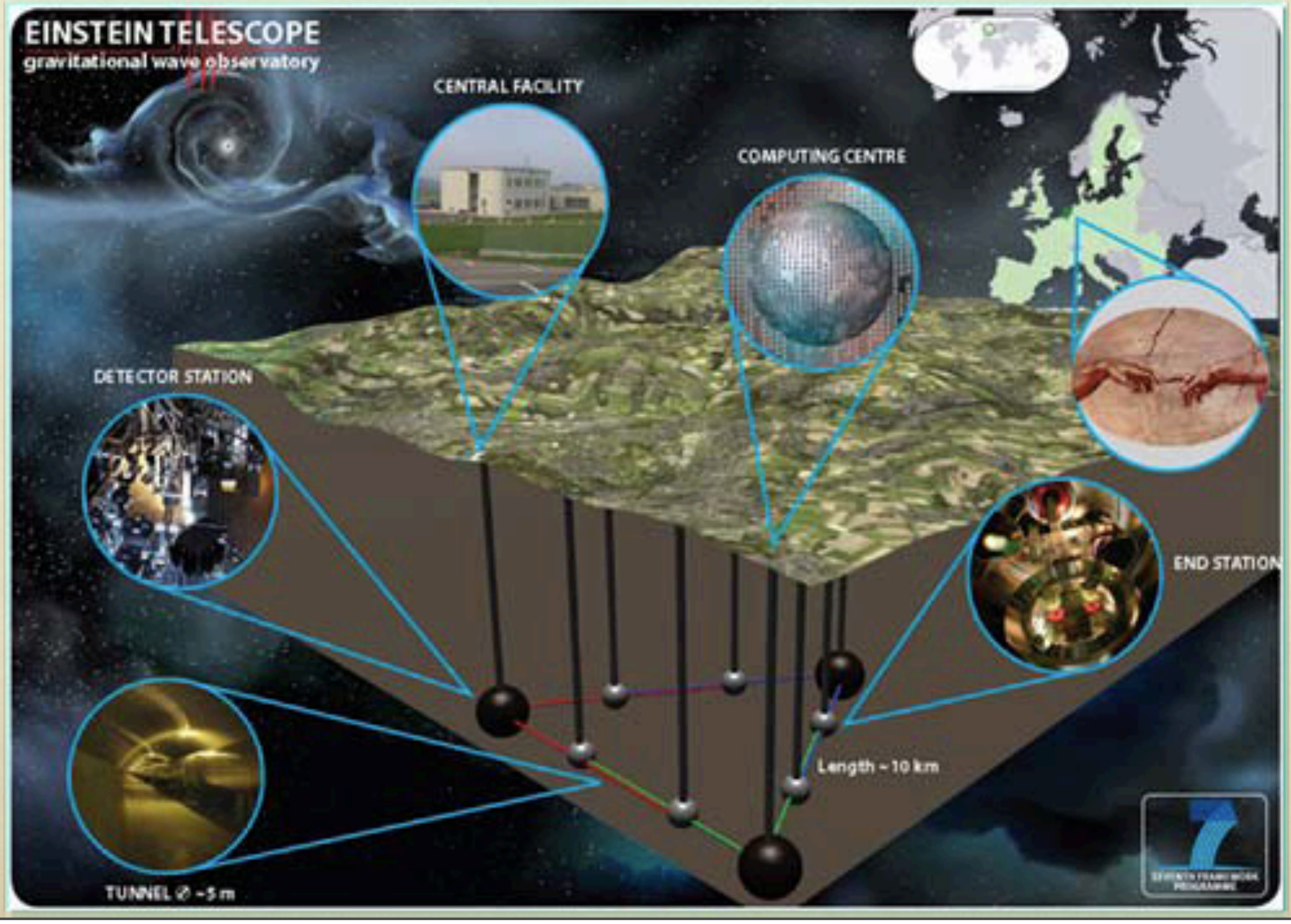

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- But LCGT is more: If ET is funded at all, then between 2020-2030 perhaps only one ET-like instrument would start operating in Europe and one in the USA. ET-style upgrades (more massive mirrors, squeezed light, suspensions) might enable LCGT to be competitive with ET-class instruments. The other Advanced Detectors would be used to provide high-frequency sensitivity, or be dismantled.

Thank You!