

LIGO SCIENCE

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GRAVITATIONAL WAVES CONTRASTED WITH ELECTROMAGNETIC WAVES

ELECTROMAGNETIC

Oscillations of EM field, propagating through spacetime

Incoherent superposition of waves from molecules, atoms, and particles

Easily absorbed and scattered

GRAVITATIONAL

Oscillations of the “fabric” of spacetime itself

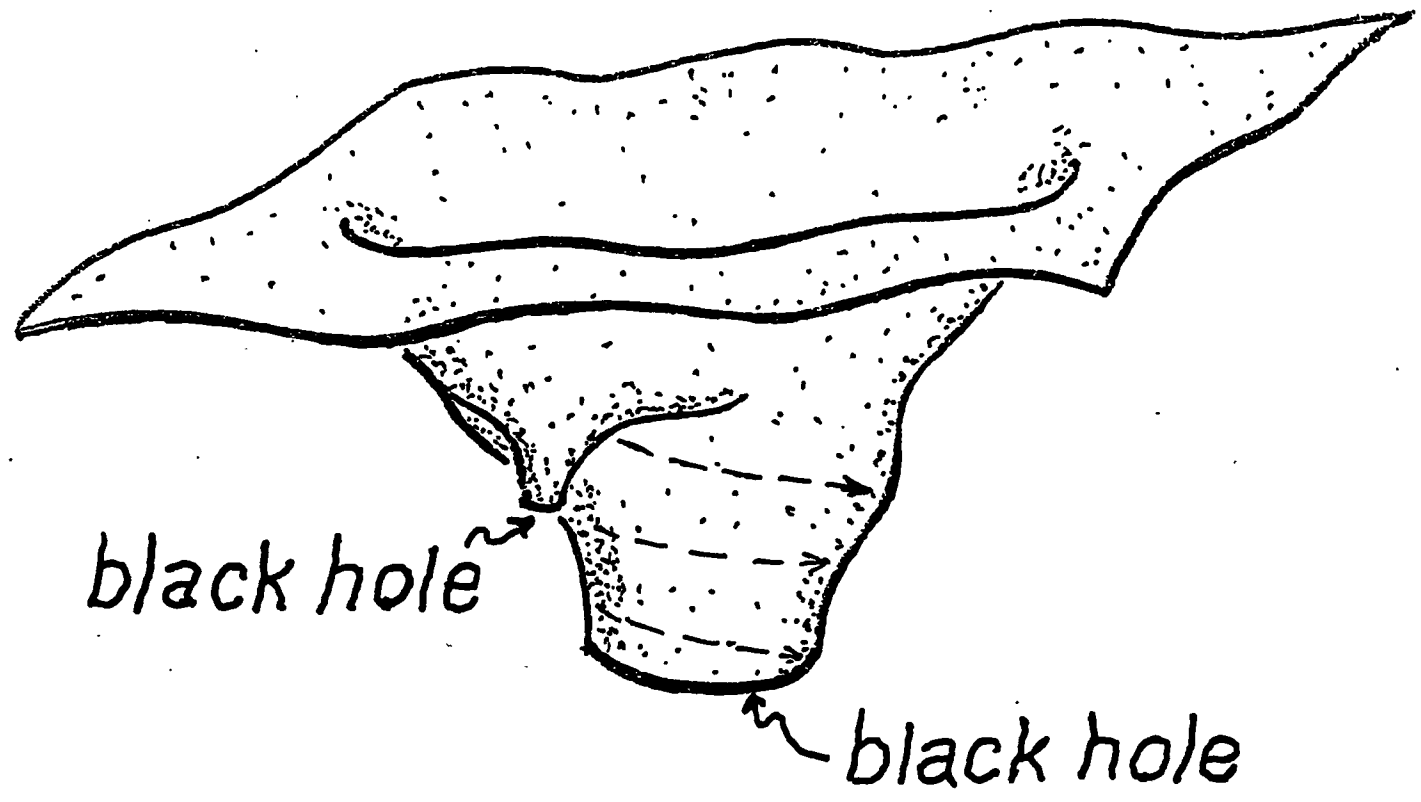
Coherent emission by bulk motion of matter and energy

Never significantly absorbed or scattered

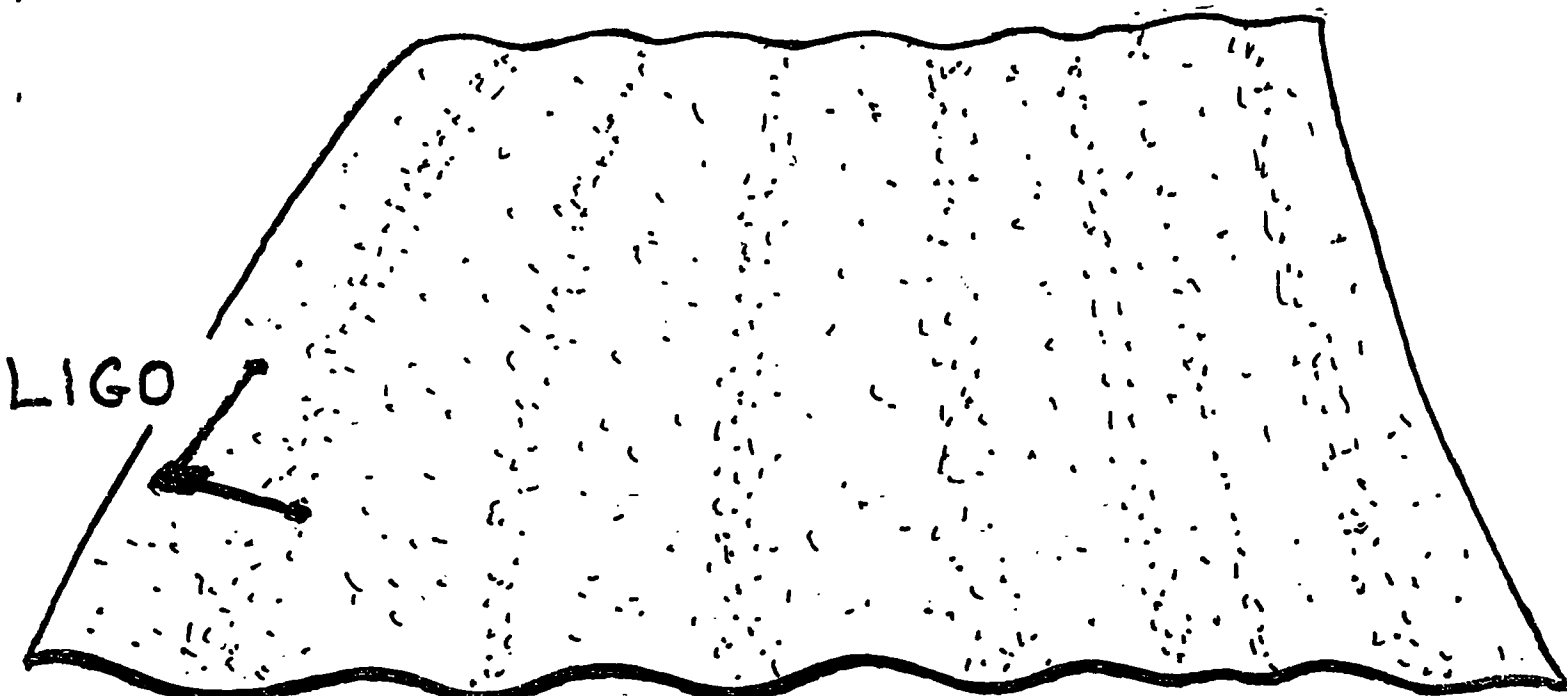
Implications:

- *Most grav’l sources not seen em’ly*
- *Potential for great surprises --- a “revolution” in our understanding of the universe*
- *Uncertainty in strengths of grav’l waves*

EXAMPLE: BLACK-HOLE BINARY



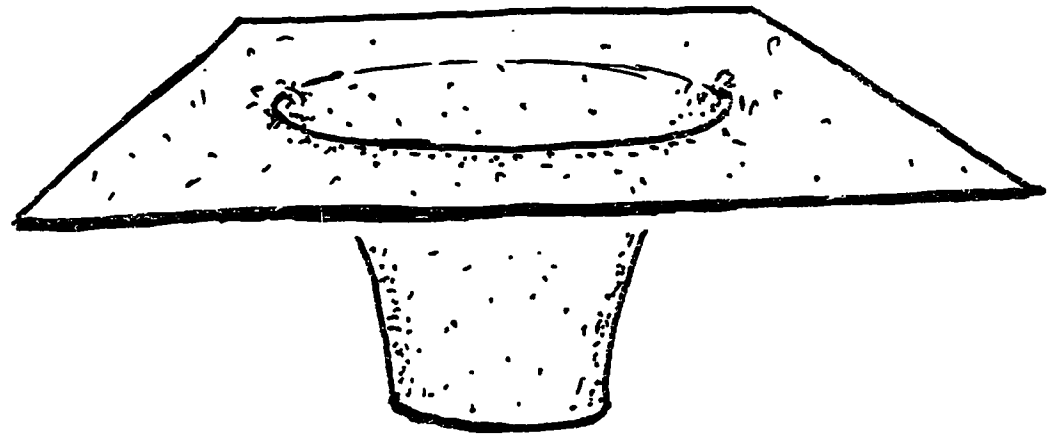
gravitational waves ↷



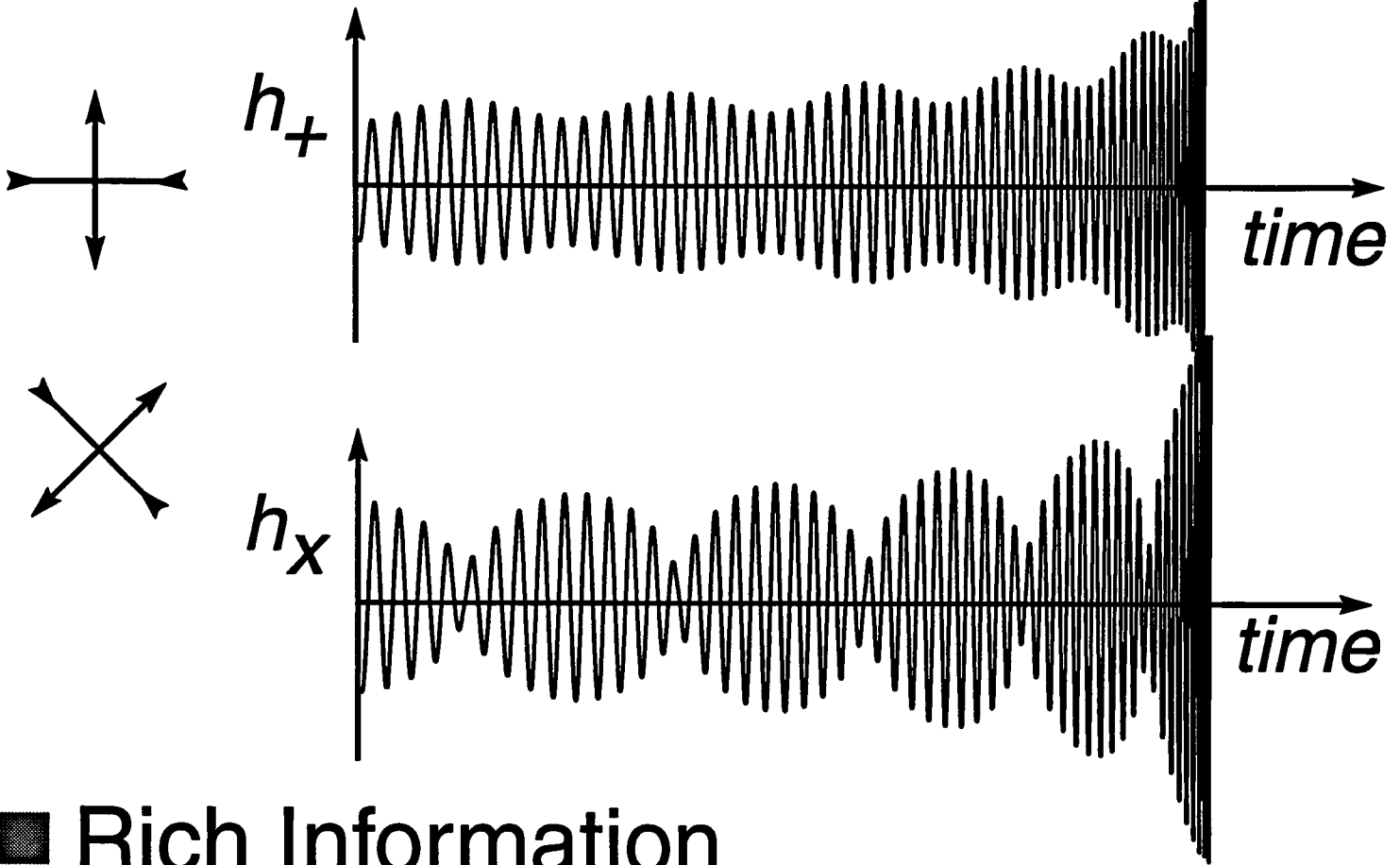
LIGO



MAP OF BLACK HOLE



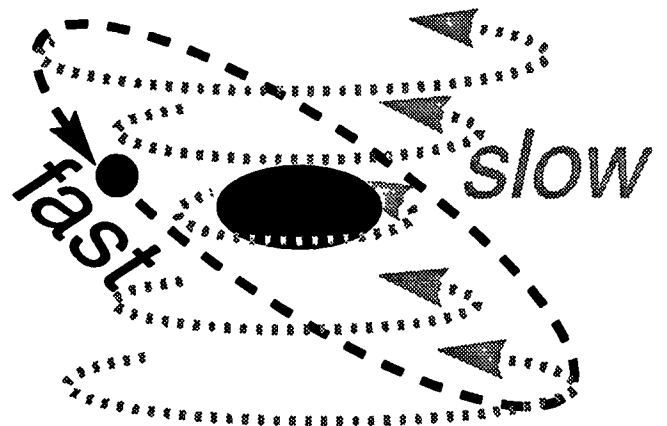
TWO WAVEFORMS [*Stereophonic*]



■ Rich Information

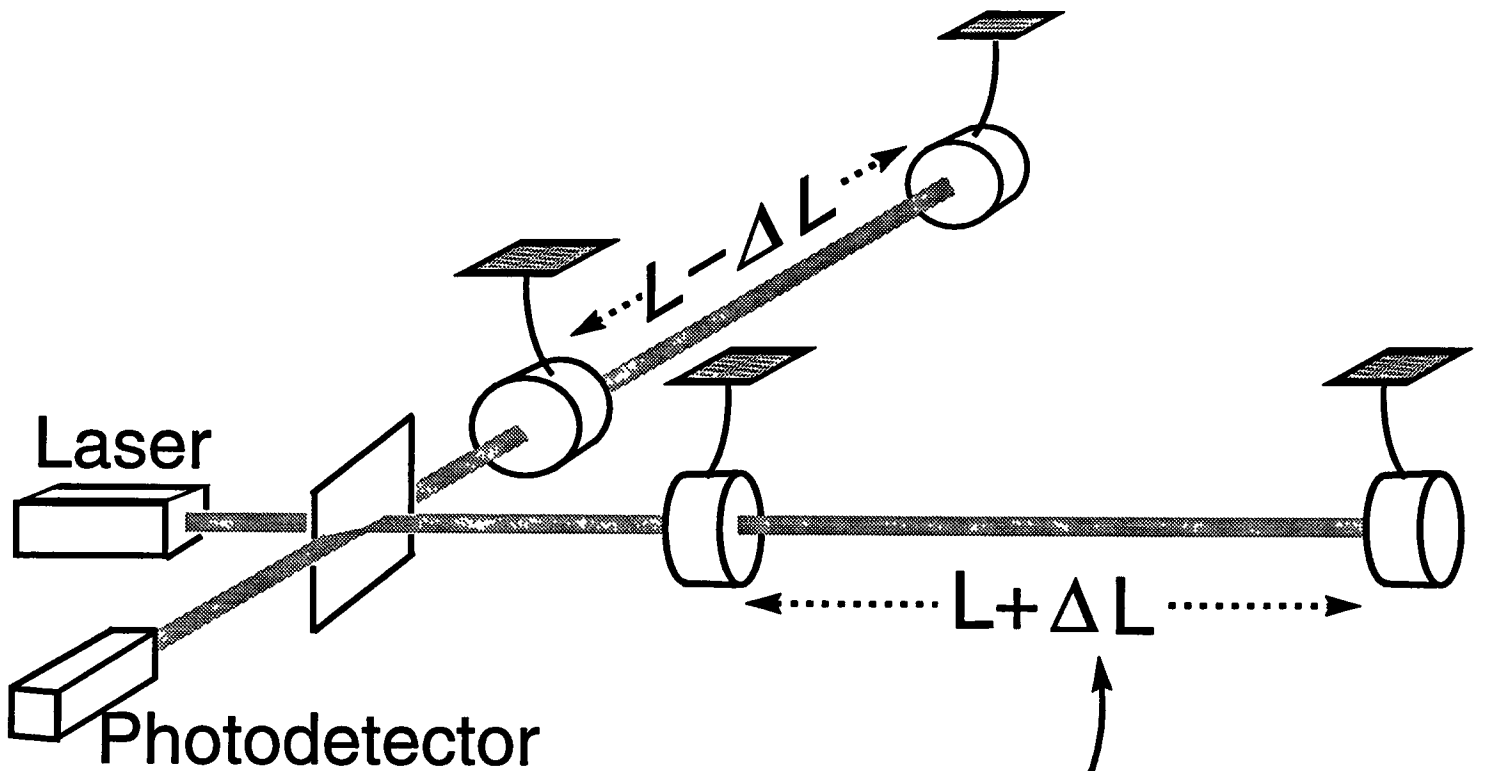
- *Map of spacetime warpage*

- *Tornado-like swirl of space around big hole*



- *Nonlinear vibrations of spacetime*
[Compare with Grand Challenge Supercomputer Simulations]

LIGO INTERFEROMETERS



- To make ΔL large enough for detection requires $L \gtrsim 4 \text{ km}$

$$\Delta L = hL = 4 \times 10^{-16} \text{ cm}$$

10^{-21} 4 km

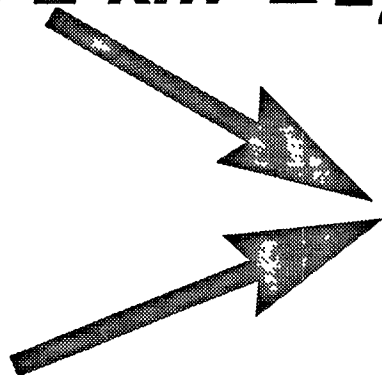
- Measured waveform, $h(\text{time}) = \Delta L/L$, is a linear combination of h_+ and h_x , which depends on interferometer's orientation

NOISE AND ITS CONSEQUENCES

- Noise in an interferometer can mimic a gravitational wave signal
- Prototype interferometers have about 5 to 50 spurious signals per hour
- Spurious signals eliminated by comparing outputs of **3 interferometers at 2 widely separated sites** with (nearly) independent noise:

● *Hanford, WA*

one 4 km $\frac{\Delta L_4}{\Delta L_2} = 2$ Spurious signals
one 2 km ΔL_2 reduced to 1/day

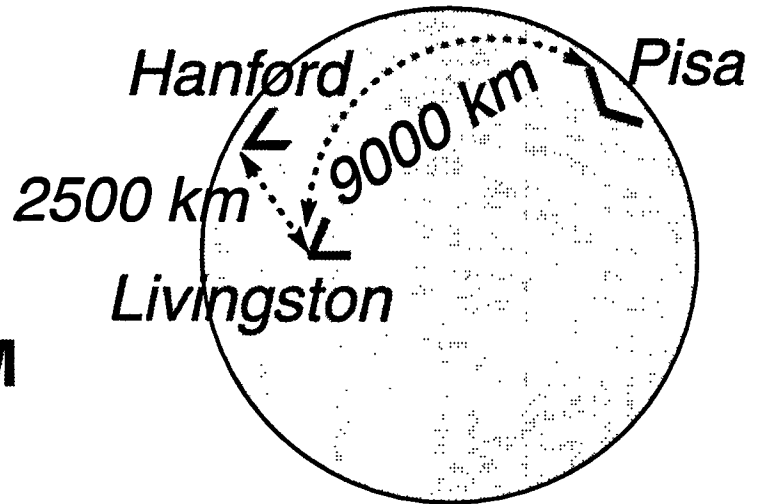


**Spurious signals
reduced to 1/10 yrs**

● *Livingston, LA* *one 4 km*

THE LIGO/VIRGO NETWORK

- Hanford & Livingston:
close enough together
to be nearly in same
plane; same orientation.
SEE SAME WAVEFORM



- Hanford/Livingston plane is approximately
perpendicular to Pisa plane; so orientations are
very different. Thus, **DIFFERENT WAVEFORMS**

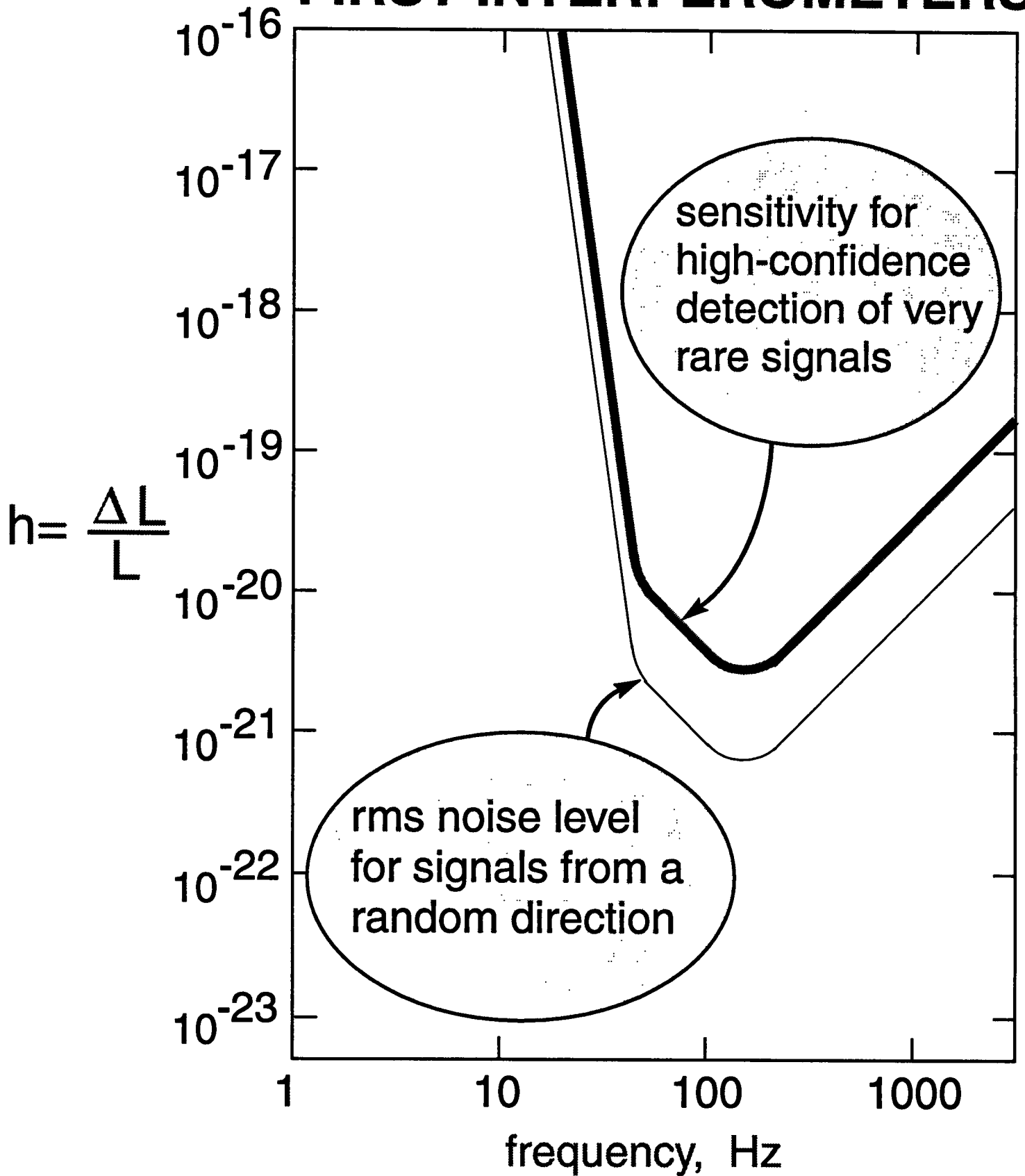
- Consequences:

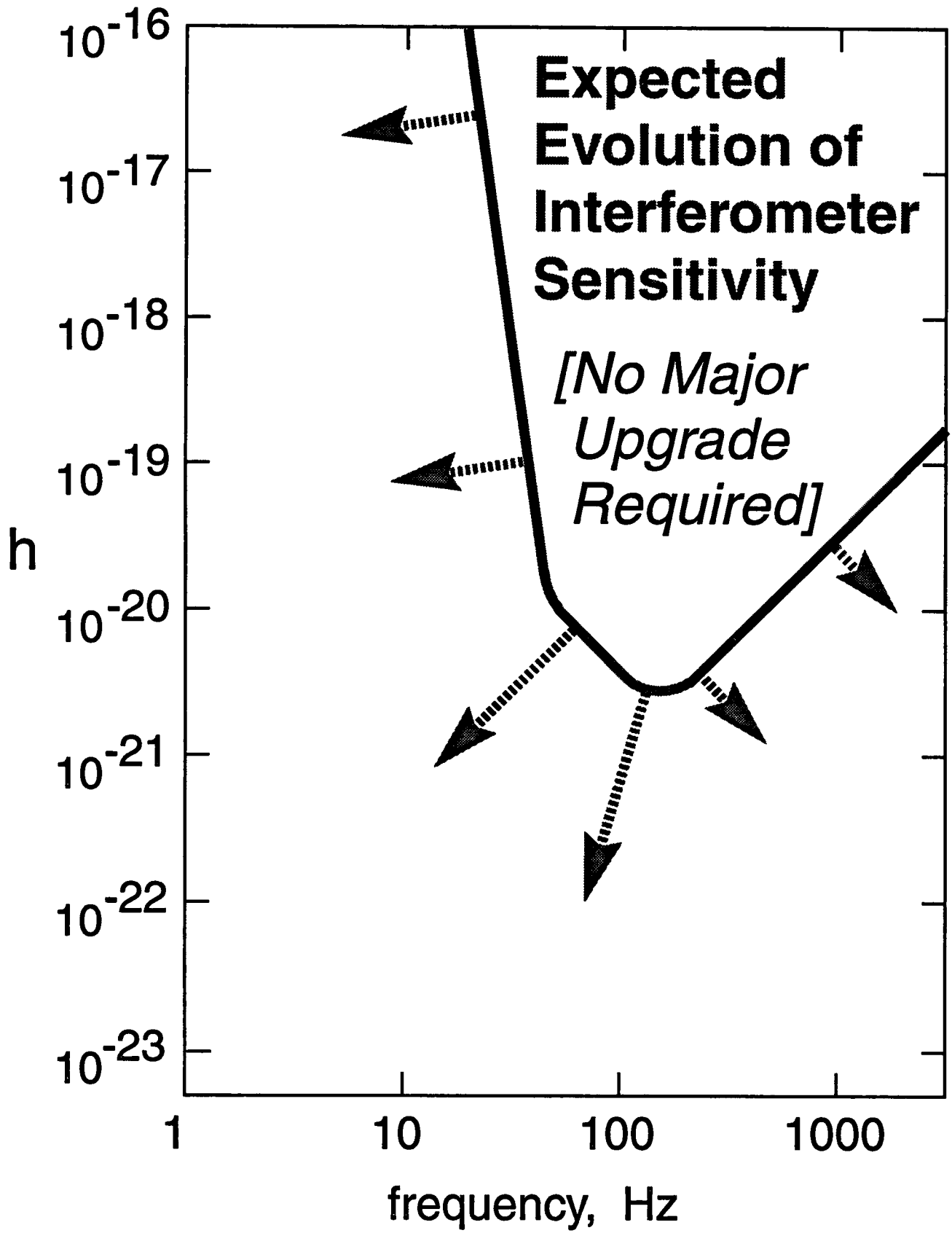
Pisa **CANNOT** be used,
together with Hanford or Livingston,
to search for waves

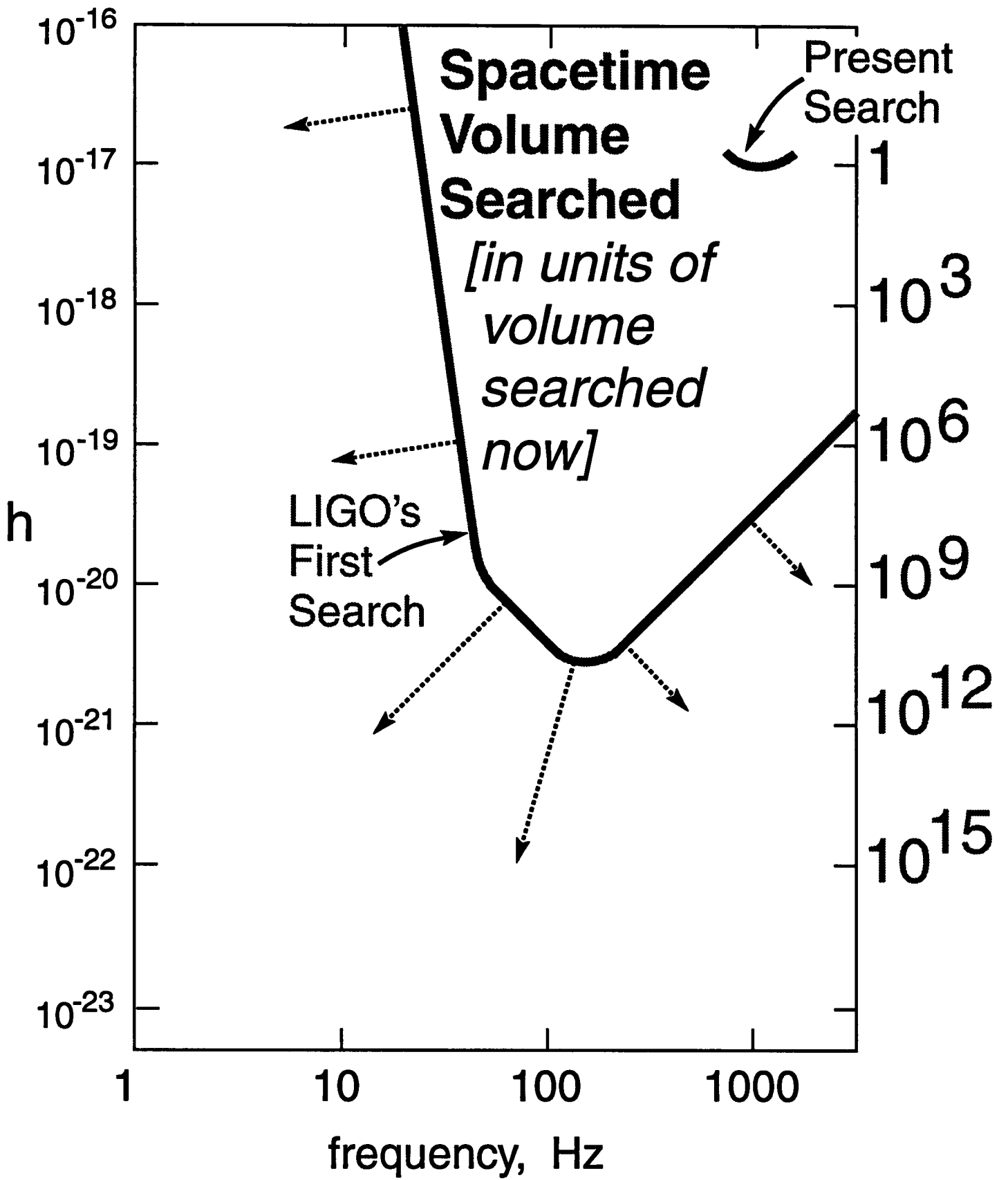
Pisa must be added to the Network,
in order to extract full information
from the waves:

Both Waveforms: h_+ , h_x
Direction to Source

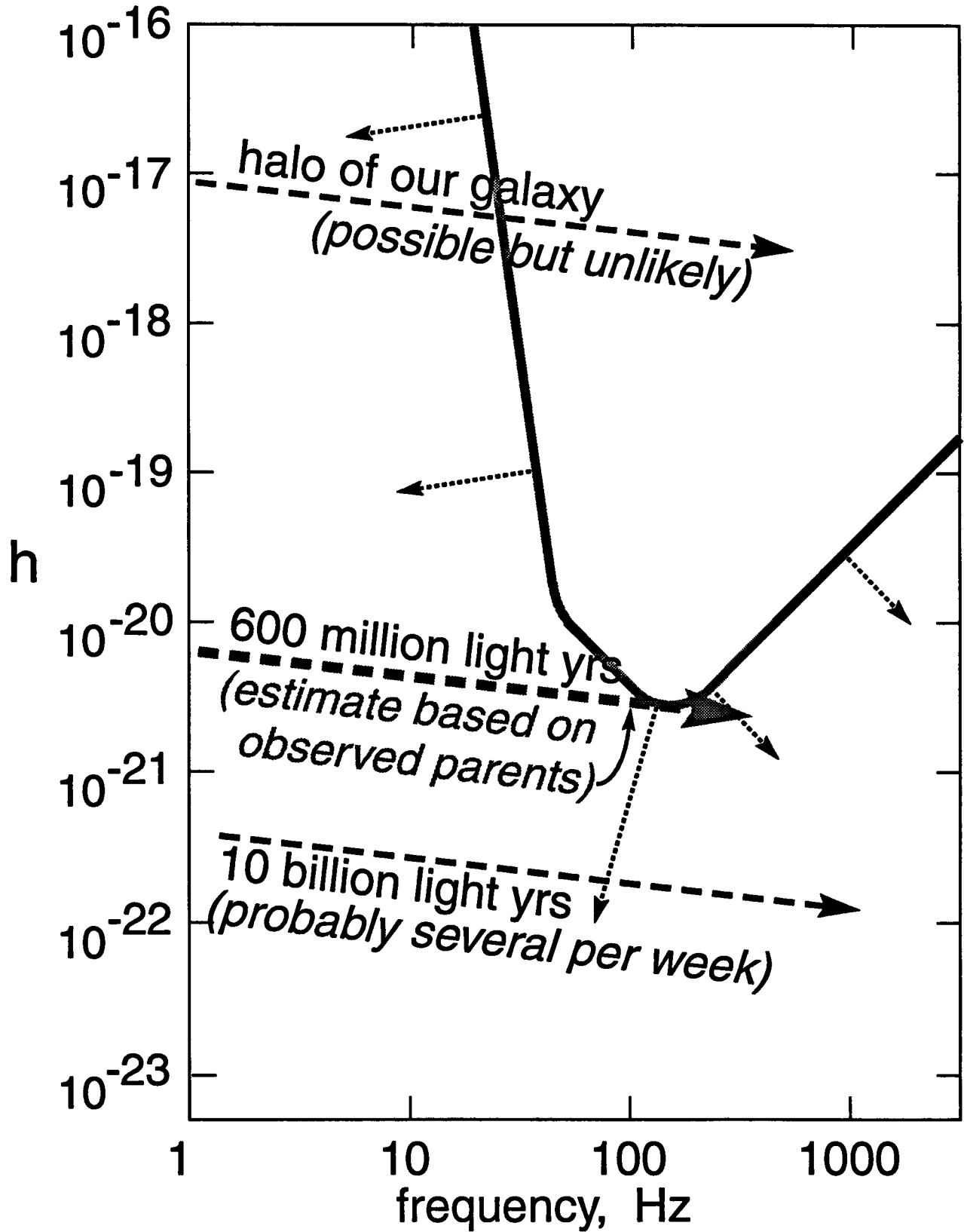
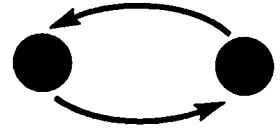
SENSITIVITY OF LIGO'S FIRST INTERFEROMETERS







BLACK HOLE BINARIES



SOURCES FOR WHICH EM WAVES GIVE LITTLE OR NO GUIDANCE

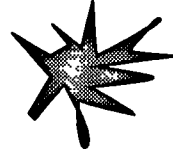
■ *Examples: (made from spacetime warpage)*

● *The Big Bang Singularity*

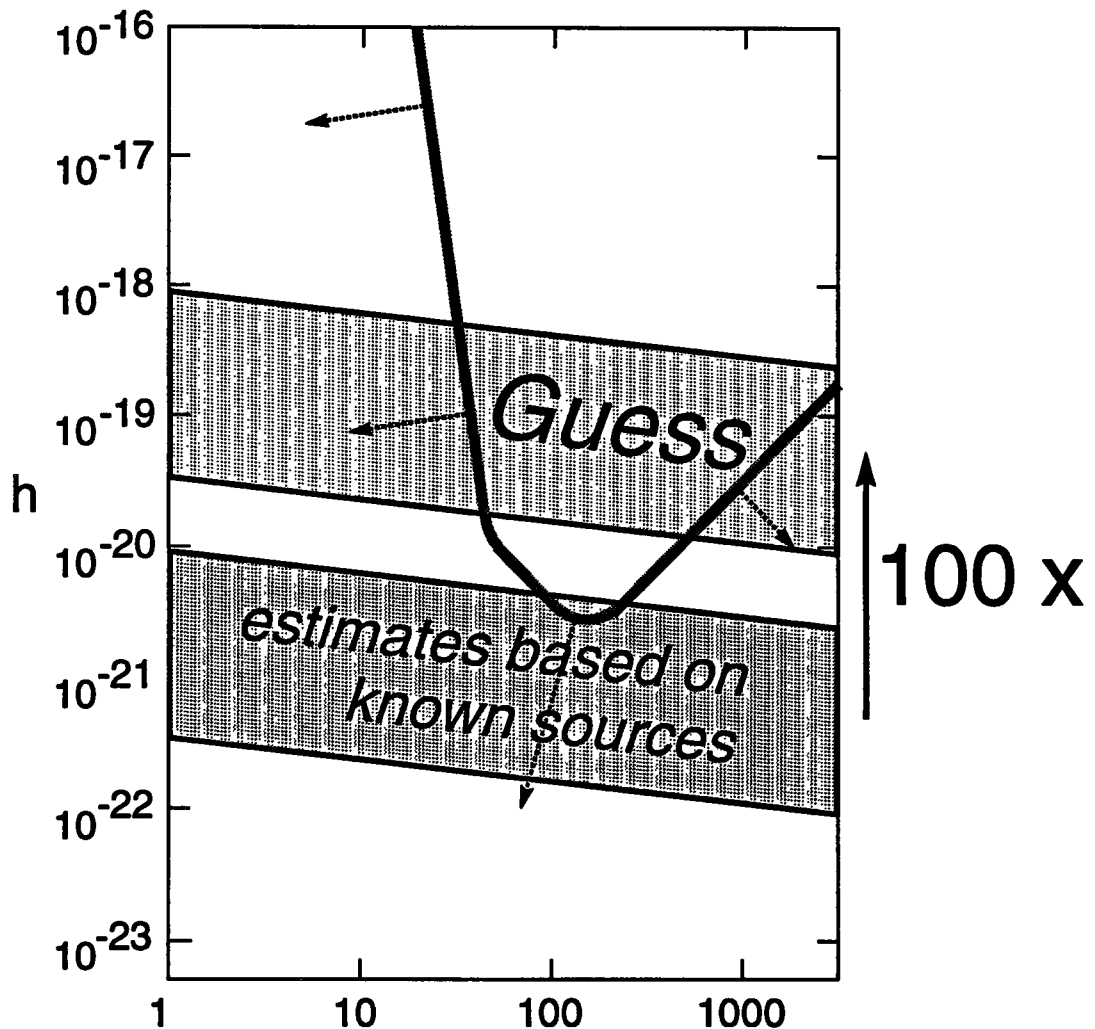
● *Naked Singularities*

● *Vibrating Cosmic Strings*

● *Colliding Bubbles of False Vacuum*



■ **Wave Strengths ... Based on Other New “Windows”:** Radio, X-Ray -- 100 x known



NEUTRON STAR BINARIES

[our best understood source] 

■ *Hulse/Taylor (1993 Nobel Prize):*

- *Observed slight inspiral of PSR1913+16, due to energy lost to grav'l waves*
- *Thereby proved (indirectly) that gravitational waves exist*

■ *LIGO's Goals:*

To detect the waves directly, and by extracting the rich information they carry, use them to study:

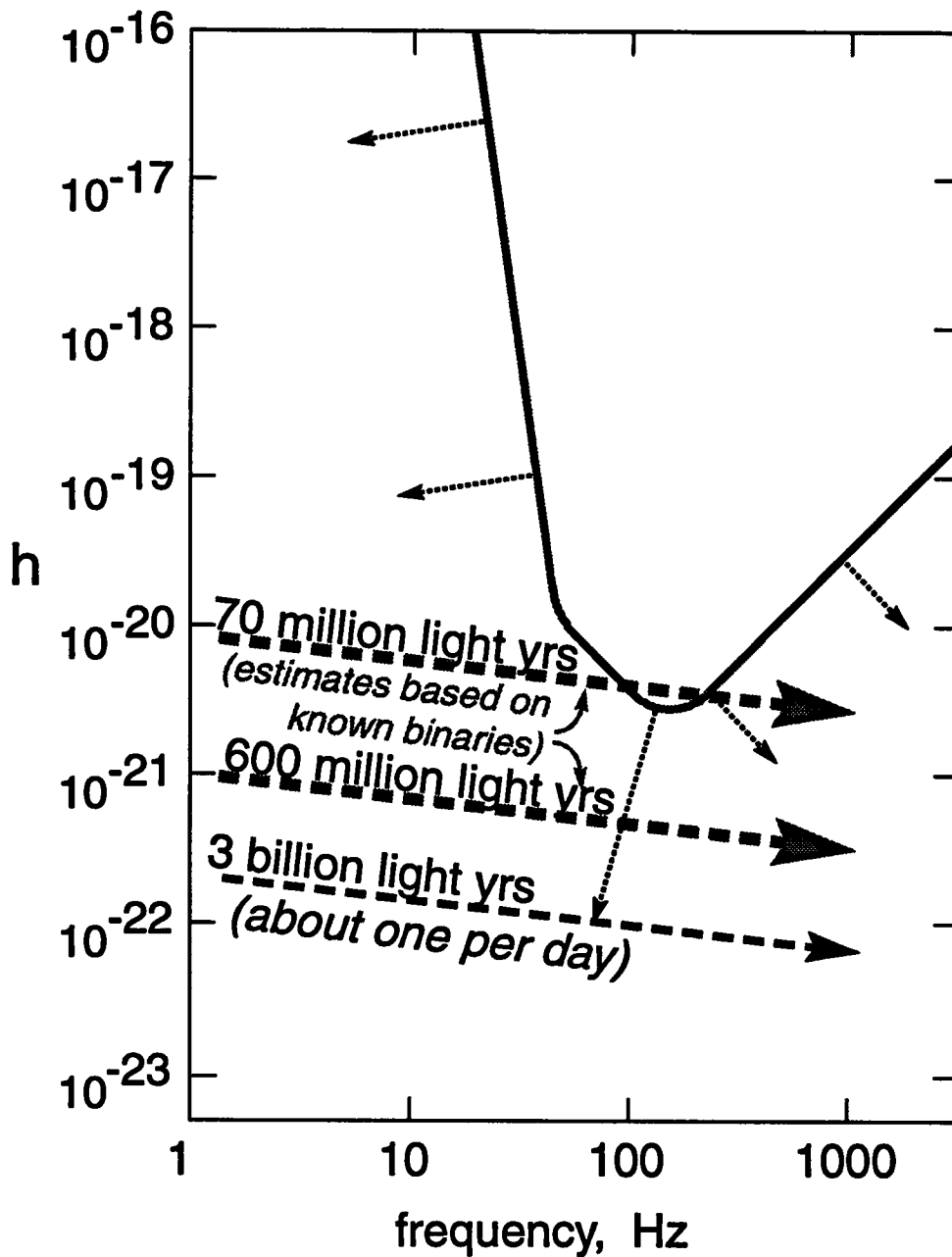
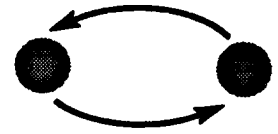
- *The nature and dynamics of gravity (spacetime warpage)*
- *The "dark side" of the universe*

■ *The trouble with PSR1913+16:*

- *It's wave frequency is 0.0001 Hz*
- *LIGO's band is 10 to 1000 Hz*
- *We must wait 100 million yrs for PSR1913+16 to reach LIGO's band*

NEUTRON STAR BINARIES

["Guaranteed" source]



■ *15 minutes & 10,000 orbits in LIGO band*

■ *Rich information in waveforms:
masses, spins, distance, direction,
nuclear equation of state*