Superconducting antenna concept for gravitational waves

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LIGO: $h \sim 10^{-23} - 10^{-24}$
Crab pulsar: $h \sim 10^{-26}$
Summary on Novel Antenna:

- Concept exploits quadrupolar action of GW on bimetallc superconducting antenna.
- The antenna transforms part of the GW energy into the motion of superfluid electrons; the motion is detected electronically.
- This design avoids Coulomb blockade of the electronic motion.
- Technical realization of the antenna may require technology development, but there is no showstopper.
- These devices will be able to detect gravitational waves with amplitudes as low as $h_0 \sim 10^{-26}$: Crab Pulsar is within the reach.
- Such sensitivity could be obtained at spatial scales smaller than 10 meters.
Starting Point

\[ \Delta L = L h_0 \sin \omega t \]
Tidal action on a metallic wire

How to measure this?

R. Adler, 1976 : take two of them!
(Long conductors as antennae for gravitational radiation. *Nature* 259, 296-297.)
Quadrupolar tidal action on a wire:

\[ q = V C << e \]

Not the best design!

A bridge connecting two bars

Coulomb blockade: in the right design gravity should not fight against electromagnetism
Thinking continued:

\[ \Delta L = L h_0 \sin \omega t \]

Bimetallic bar, negative \( m_{\text{eff}} \)
Circular current, no charge accumulation

Seems like possibly right design. Bi-metalisity breaks the symmetry!
Why Superconductivity:
Motion of electrons in semiconductors and normal metals, though sometimes called “free”, is Aristotelian: it persists while the force is acting. Ohms law: \( j \sim v \sim eE \sim F \), \( v \sim F \), i.e., velocity in response to force
In superconductors \( \frac{dv}{dt} \sim E \), i.e., motion is Newtonian!

This difference has crucial consequences:
• S/C current response is greater by a factor \((\omega \tau)^{-1} \sim 10^{10+}\). Ten or more orders of magnitude more than justify SC.
• Price to pay: no negative masses for SC. Cooper pairs have a positive mass.
• Moreover, it looks like \( m_{CP} = 2m_0 \)!
Motion of electrons in gravity field: *Quo Vadis?*

**Frozen lattice**

**Unfrozen lattice**

\[ e \downarrow g \quad e \uparrow g \]
Frozen lattice \hspace{1cm} 1968 \hspace{1cm} Unfrozen lattice

\[ E = -\frac{mg}{e} \hspace{1cm} E = \alpha Mg/e \]


Some numbers

From Crab pulsar $\nu \sim 60\text{Hz}$, $h \sim 10^{-26}$, the energy flux density on Earth’s orbit $\sim 10^{-10}\text{ergs/(cm}^2\text{s)}$. $\Rightarrow$ Current for 10x10cm$^2$ cross section of conducting loop is $I \sim 10^{-13}\text{A}$. $E_{\text{kin}} \sim 10^{-39}\text{ergs}$. Efficiency is $10^{-31}$. 
“Spaghetti” Structure

layers with A and B swapped

- Currents move in opposite directions and cancel the magnetic field.
- The number of spaghetti depends on geometry; large but realistic.
At \( I = 1 \, fA \) and \( R = 5 \mu m \), \( B = \mu_0 I / (2R) \sim 10^{-16} T \).

SQUID noise floor \( 3fT/Hz^{1/2} : 10^{-17} T / \text{1 day of measurement} \).

Freedom to exploit, say, 10 SQUIDs for different groups of layers, and/or get to weaker GW source detection, and/or reduce the observation time.
Noise Floor of the Detector

• Real noise floor of this antenna is due to normal resistance

\[ \langle I_n^2 \rangle = 4 \left( \frac{k_B T}{R_n} \right) \delta \nu \]

• Two notes are important here:
  1) at low $T$ the normal fluid (and its influence) dies out exponentially;
  2) bandwidth $\delta \nu$ can be made narrow for periodic signals (large integration time).

Our estimates indicate that achievable noise floor is about $10 \text{ fA/Hz}^{1/2}$, which inspires optimism, since current is bigger: $\sim 10^{-13} \text{ A.}$
Thank you!
Conclusions

• We elaborated a novel concept of the GW antenna. We see no showstopper for this concept and would welcome experts opinion on its viability.

• Hopefully, in parallel to other large-scale efforts, such as the LIGO approach and LISA mission or NANO gravitational initiative, the suggested concept will become useful for one of the most challenging experiments – the detection of gravitational waves.