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Workshop Towards Neutrino Technologies

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Applications of Hypersharp Neutrinos

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Hypersharp Neutrinos II
Applications to Topics at the Frontiers of Physics

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Applications of Hypersharp neutrinos from 2-body tritium decay

Novel Tools

- Low Energy (18.6 keV)
- Extreme Energy precision $(\Delta E/E \sim 5x10^{-29})$
- Very large resonance cross section $\sigma \sim 10^{-17}$ cm^2
- Long lifetime

Novel Problems---Bench top scale experiments

- Neutrino Oscillations
  - 1-3 mixing---"long" baseline→ 10m
  - Sterile-Active mixing—very short baseline →1-10 cm
- Time Energy Uncertainty
  - Quantum mechanics
  - Ultimate energy measurement—Fundamental Length
- Gravitational Wave Detection

Neutrino Oscillations

Theoretical Questions addressed by numerous papers

Compare Reactor baselines

E = 18.6 keV vs 1.8 MeV→ baseline 1km vs 10m

Reaction cross sections—10^{-43} cm^2 vs 10^{-20} cm^2

→Bench top baselines from km scale with

→ gm scale materials vs kiloton targetsen

→Sterile masses addressible in much extgended range with

→ higher sensitivity to oscillation amplitures

→→Much shorter baselines (tens of cms)

→Intial focus on <1m baselines

Quantum Mechanical Time -Energy uncertainty

$\Delta E\, \Delta t \sim h/2\pi$

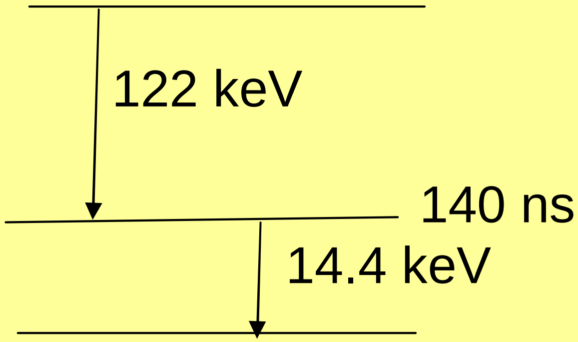
The energy of a decaying state has a width determined by the time of observation
If Δt is uncontrolled, Δt is the mean life time τ and the measurement yields an energy spread ΔE
The natural width of the decaying state $\Delta E \sim (h/2\pi)/\tau = \Delta E$ (nat)

If Δt is determined say as T, then the energy spread is more, given by
$\Delta E \sim (h/2\pi)/T \gg \Delta E$nat
→ Directly affects cross section $\propto (1/\Delta E)$

So, What is Δt in a resonance reaction? E.g. in Mossbauer experience?
in the tritium resonance reaction ?
According to QM Δt is counted from CREATION of the state

Question can be probed lifetimes of decaying states in both cases are long
Enough for external control of T

ME in 14.4 keV state of ^{57}Fe
Lifetime = 140 ns

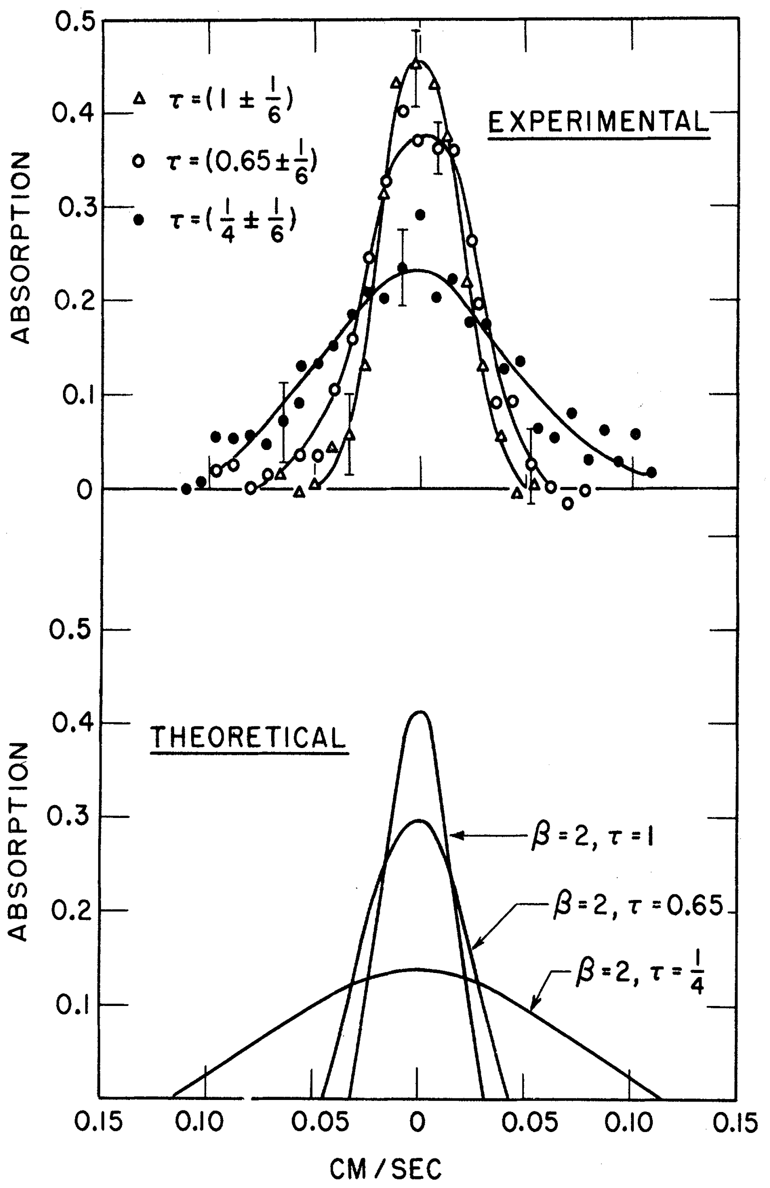


Δt can be controlled since the time of creation of the ME state can be tagged by the 122 keV Signal and the ME of the 14.4 keV γ can be observed After a delay T in coincidence.

→Time filtered resonance

Expts done in 50's by Wu et al and Lynch etal

TEU in Fe57 ME



In

Wu et al (1960)

Observed basically the cross section at resonance
Any broadening reduces this cross section relative to the geometrical value for natural linewidth.

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→TIME FILTERED RESONANCE

Observed width is QM limited width only if the nu is observed without limitation on the time of emission; i.e. the full lifetime is operational
If the time of emission is limited to times < τ the line is broadened, again because of QM, to a broadening a factor T / τ ➔ Time filtering effect –

Abs. at resonance max: ∝ $1-J_o^2$ (√(βT)
∝ t with T=t/τ <<1

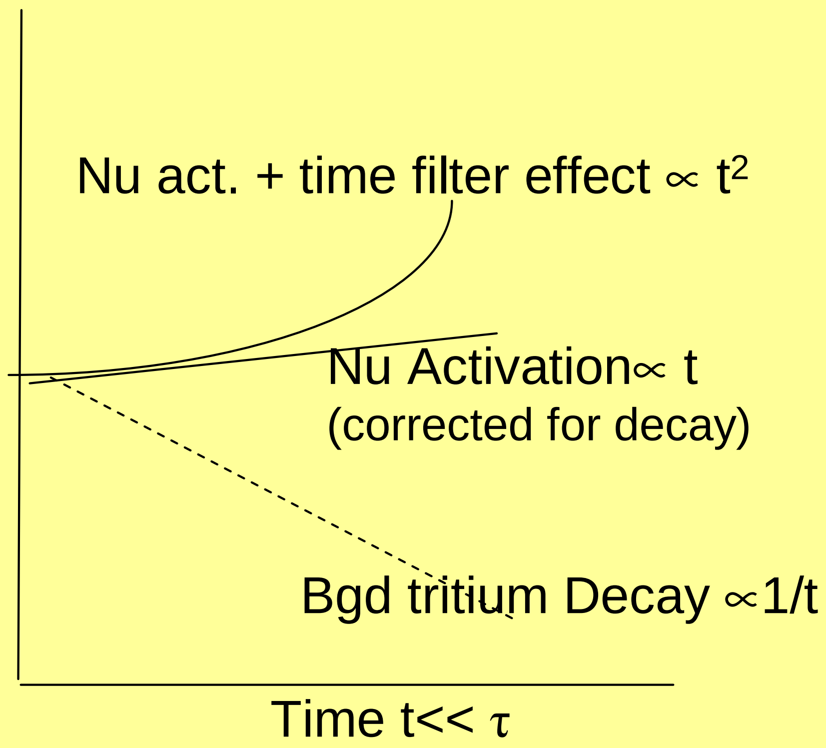
β = Nσ f = resonance thickness of absorber
In mfp units

me filtered Resonance Effect--Tritium

Abs. at resonance max: $\propto 1-J_o^2(\sqrt{(\beta T)})$

$\propto t$ with $T=t/\tau$

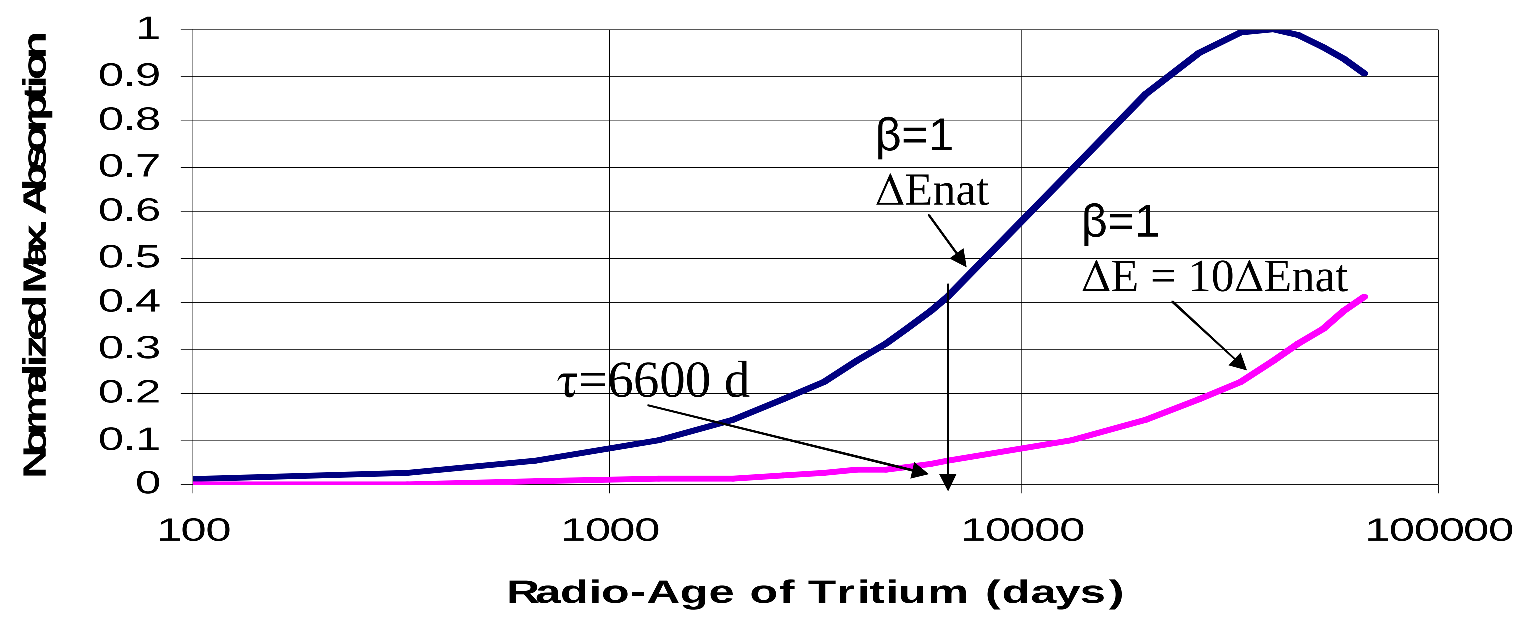
Signal Rate at Resonance vs time t



→Calibrates the prevailing width directly to signal rate controllable by the time window of emission.

- Easy for tritium –T is very long so that each day of measurement T increases naturally→ spontaneous signal growth with time predictable directly by the decay rate of tritium

- In- vivo rate increases as source ages;
- Activation and age dependence produce a **→ t^2 rate dependence**
- Two tools:
- Signal Rate ~t^2 measures E*nergy* width
- Rate decay ~1/t measures Time



The signal growth rate depends on β i.e the cross section at zero detuning== Thus the state width.

The two curves show that the growth rate can lead to the width of Tritium state.

The hypersharp basis presumes the resonance control of the tritium resonance
By the NATURAL width   ΔEnat

Deviation of growth rate of signal in time-filtered resonance Controlled
Prevailing width in experiment ΔE

If ΔE > ΔE nat   The experiment might be way to probe the TEU.

There may be reason for TEU could be violated because tiny widths
\at the level of 10^{-24} eV may be set by a
FUNDMENTAL length rather than by TEU

The Fundamental Length or Planck Length $\mathcal{L}$

said to indicate the limit on measurability of a physical dimension

Traceable to Max Planck himself

$$\mathcal{L} = (G\ \hbar/c^3)^{1/2} \sim 10^{-33}\ \mathrm{cm}$$

Minimum observable length

Connects explicitly the Universal Constants of Newton and Planck

Incredibly small--- smaller than physical experience so far

$\mathcal{L}$ ---Chimera or Physical Reality?

How to observe a very tiny length ? Two possible approaches
$\mathcal{L}$ implies a ”Grainy” space-time—look for effects on Cosmic scale
Or look for a locally measurable consequence–
-- such as limits on energy precision

Guidance from early work of Mead (1965)→
Tiny $\mathcal{L}$ implies a tiny limiting imprecision of the local potential $V(r)$
→Tiny energy imprecision or width of bound states
that overrides at some level the QM^{h} time-energy uncertainty width

Test by measuring the very small width ΔE of states with very long τ
$\mathcal{L}$ effect→ Planck broadened line width $\Delta E >$ QM width h/τ
Planck length or not, the test probes the keystone of QM
in the untested regime of extremely small energies

--Unprecedented precision needed: $\Delta E/E << 10^{-20}$!

Mead Theory of Fundamental Length

Ultimate widths of nuclear states i.e. $\Delta E/E$ depends on $\mathcal{L}$.

Range of predictions from simple arguments of Mead

$\Delta E/E \ (\mathcal{L}) = (\mathcal{L}/\mathcal{R})\ \lambda \ \sim 10^{-20}$ (for $\lambda = 1$)

$\Delta E/E \ (\mathcal{L}) \sim 10^{-40}$ (for $\lambda = \mathcal{L}/R$)

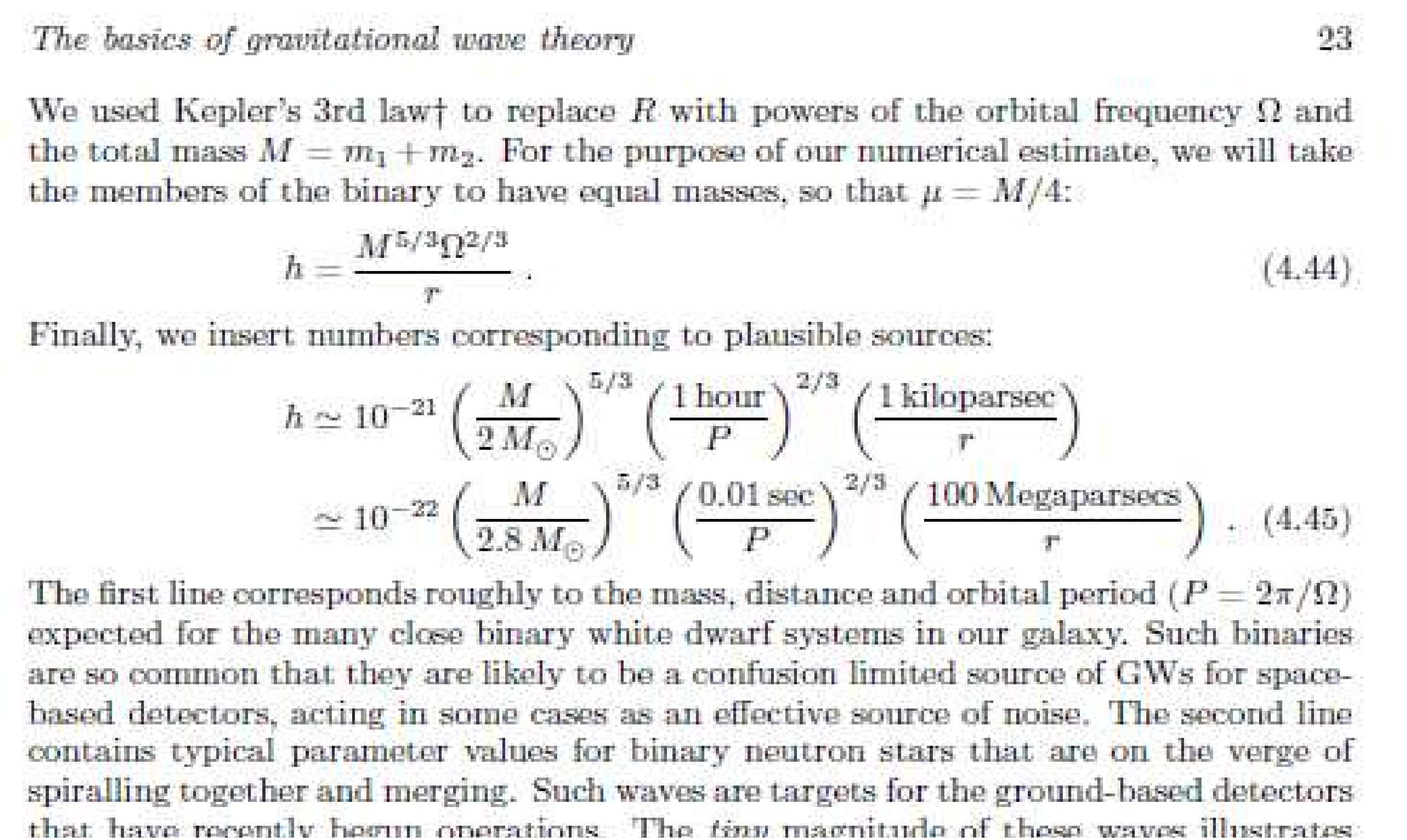
(R is the nuclear radius $\sim 10^{-13}$ cm) used as length scale.

Highest precision attainable—Best chance in T hypersharp resonance

$\Delta E/E = 10^{-29}$ situated strategically in the predicted range !!

Modern theory should be able to provide tighter predictions

Gravitational Waves



We used Kepler's 3rd law† to replace R with powers of the orbital frequency Ω and the total mass $M = m_1 + m_2$. For the purpose of our numerical estimate, we will take the members of the binary to have equal masses, so that $\mu = M/4$:

$$h = \frac{M^{5/3}\Omega^{2/3}}{r} \, . \tag{4.44}$$

Finally, we insert numbers corresponding to plausible sources:

$$\begin{aligned} h &\simeq 10^{-21} \left(\frac{M}{2\,M_\odot}\right)^{5/3} \left(\frac{1\text{ hour}}{P}\right)^{2/3} \left(\frac{1\text{ kiloparsec}}{r}\right) \\ &\simeq 10^{-22} \left(\frac{M}{2.8\,M_\odot}\right)^{5/3} \left(\frac{0.01\text{ sec}}{P}\right)^{2/3} \left(\frac{100\text{ Megaparsecs}}{r}\right) \, . \end{aligned} \tag{4.45}$$

The first line corresponds roughly to the mass, distance and orbital period ($P = 2\pi/\Omega$) expected for the many close binary white dwarf systems in our galaxy. Such binaries are so common that they are likely to be a confusion limited source of GWs for space-based detectors, acting in some cases as an effective source of noise. The second line contains typical parameter values for binary neutron stars that are on the verge of spiralling together and merging. Such waves are targets for the ground-based detectors that have recently begun operations. The *tiny* magnitude of these waves illustrates

Nuclear Resonance in Observation of Relativity Red Shifts

Red shift of photons at different Gravitational Potentials:

1. On the earth: $\Delta E/E = gh/c^2$

   $= 10^{-18}$ eV /cm vertical height diff.

   (g= acceleration due to earth gravity)

2. By Equivalence Principle red shift in lab Acceleration A

   : $\Delta E/E = A/c^2$

   $= 10^{-21}$ eV /cm/s^2

Both Effects due *only* to Special Relativity (time dilation)

Both effects observed (~1960)

Both effects used the sharp widths of Nuclear Gamma Rays
by the detuning by the red shifts in resonance absorption
in a resonator (absorber) tuned to the source emission

Effect of GR on nuclear resonance

So far unsuspected!

•GR creates space distortion→length *scale* is changed

→Typical Length Strain **$h = \Delta\ell/\ell \;\; 10^{-21}$**

→Detectable via Michelson-Morley→ LIGO, LISA

•GW also changes wavelength/ frequency / energy of photons/neutrinos since number of waves/unit length changes when length scale changes

→Detunes very sharp nuclear resonances

→Can be detected by a suitably sharp resonance

→New Approach to GW astronomy

Signatures & Sensitivity

GW effect→ Energy *modulation* of radiation
Modulation depends on Strain and Frequency of GW
Anisotropy of GW → Directional dependence of modulation
→ *locate source* of GW
→GW Astronomy

→Typical effect $\Delta E/E \sim 10^{-21}$→ need resonance sharpness of same order

→Best γ-resonances so far: $\Delta E/E \sim \mathbf{5\times10^{-13}}$; (^{57}Fe), $\mathbf{10^{-15}}$ (^{67}Zn)
→Need new "HYPERSHARP" nuclear Resonance for GW

→***Neutrino*** Resonance with

$\Delta E/E \sim 10^{-29}$ → HYPERSHARP !

GW Detection Strategy

Effect:

$\Delta E/E \sim h(L/\lambda)$ → 2×10^{-28}

where L is the baseline of the experiment

λ= wavelength of the GW

h = strain amplitude $\sim 10^{-20}$

L typically 100 cm << $\lambda \sim 5\times10^{9}$ cm for frequency f ~ 1 Hz

GW detction: Consider 2 absorbers for same source,
one absorber in the plane of GW, the other along axis
The absorber out of plane will see a line shifted out of resonance
The axial source-absorber path sees no differential strain→ zero shift→ in resonance
Detection by differential rates in the two absorbers.
The axis is continually changing by rotations of earth, solar system…galaxy---multiple **modulation**
→Differential rate is predictably time dependent→signature of GW
Also locate direction to GW source
→--practical design with *multiple detectors* at didfferent L and directions wrt the source

→ GW astronomy on the bench top

Conclusiions

Keep working on all fronts—
Good physics may be a hand !!