Coherent quantum states in resonant-mass gravitational wave detectors

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IWARA
From Quarks to Cosmos

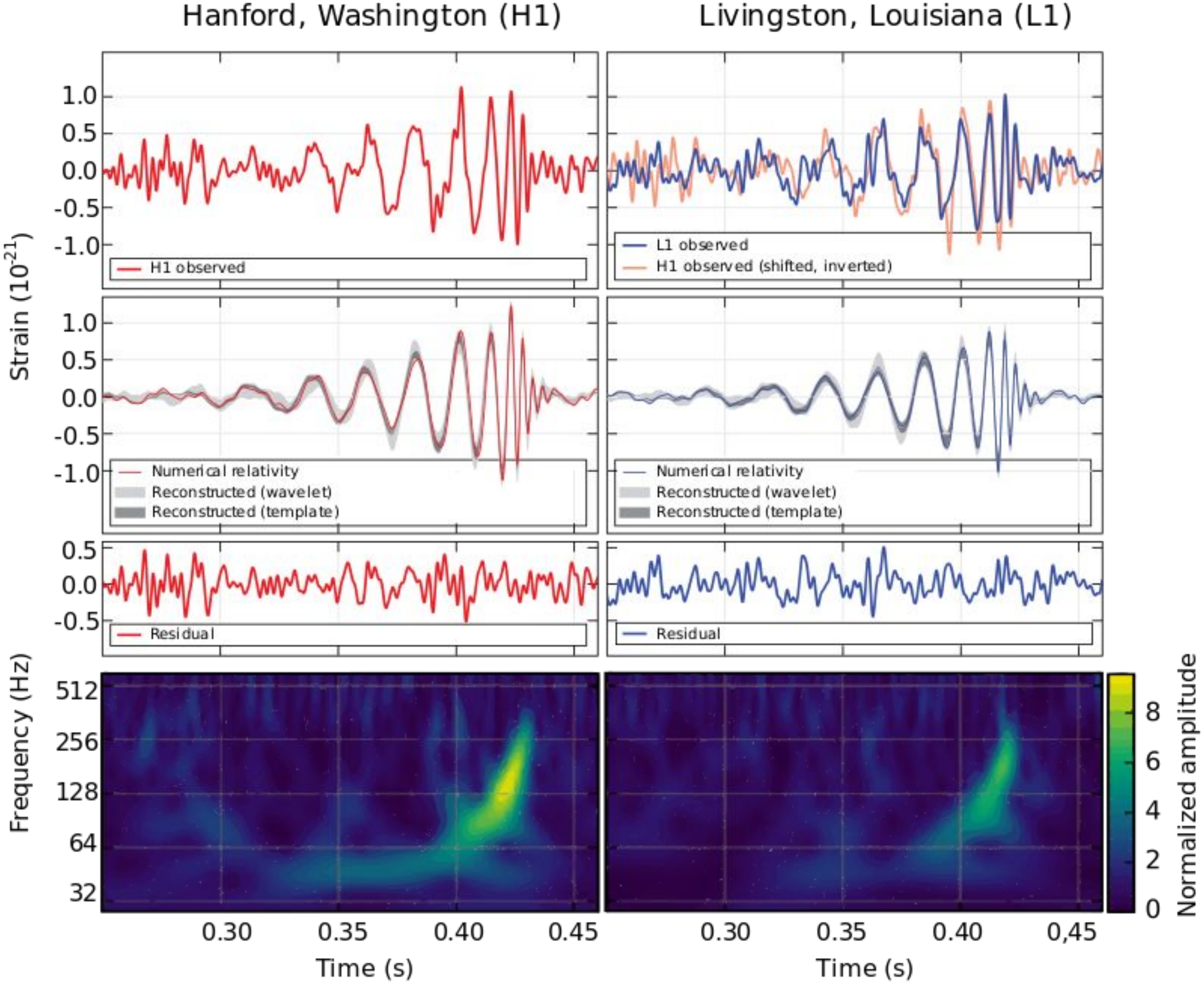
Abstract

Quantum coherent states is a new features in quantum mechanics. Resonant-mass gravitational waves detectors didn´t succeed in detecting gravitational waves probably because of the operational frequency range chosen when the design of such detectors. But such detectors can be important in the future. This work describe the importance of quantum coherent states when the a resonant mass gravitational detects a energy from the gravitational wave very very close to the quantum limit. At this point quantum coherent states of vibration and quantum non-demolition measurements becomes essential.

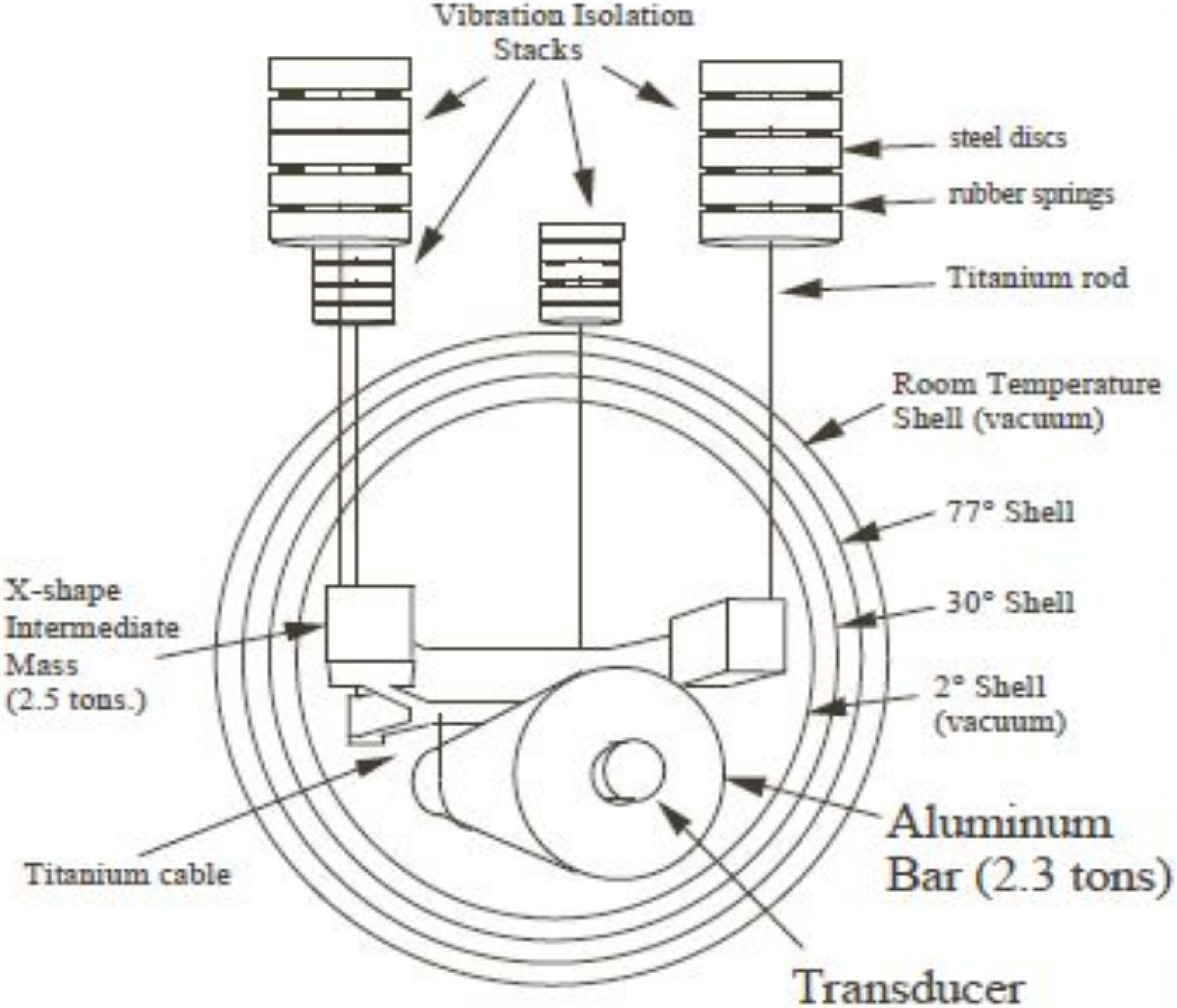
Outline

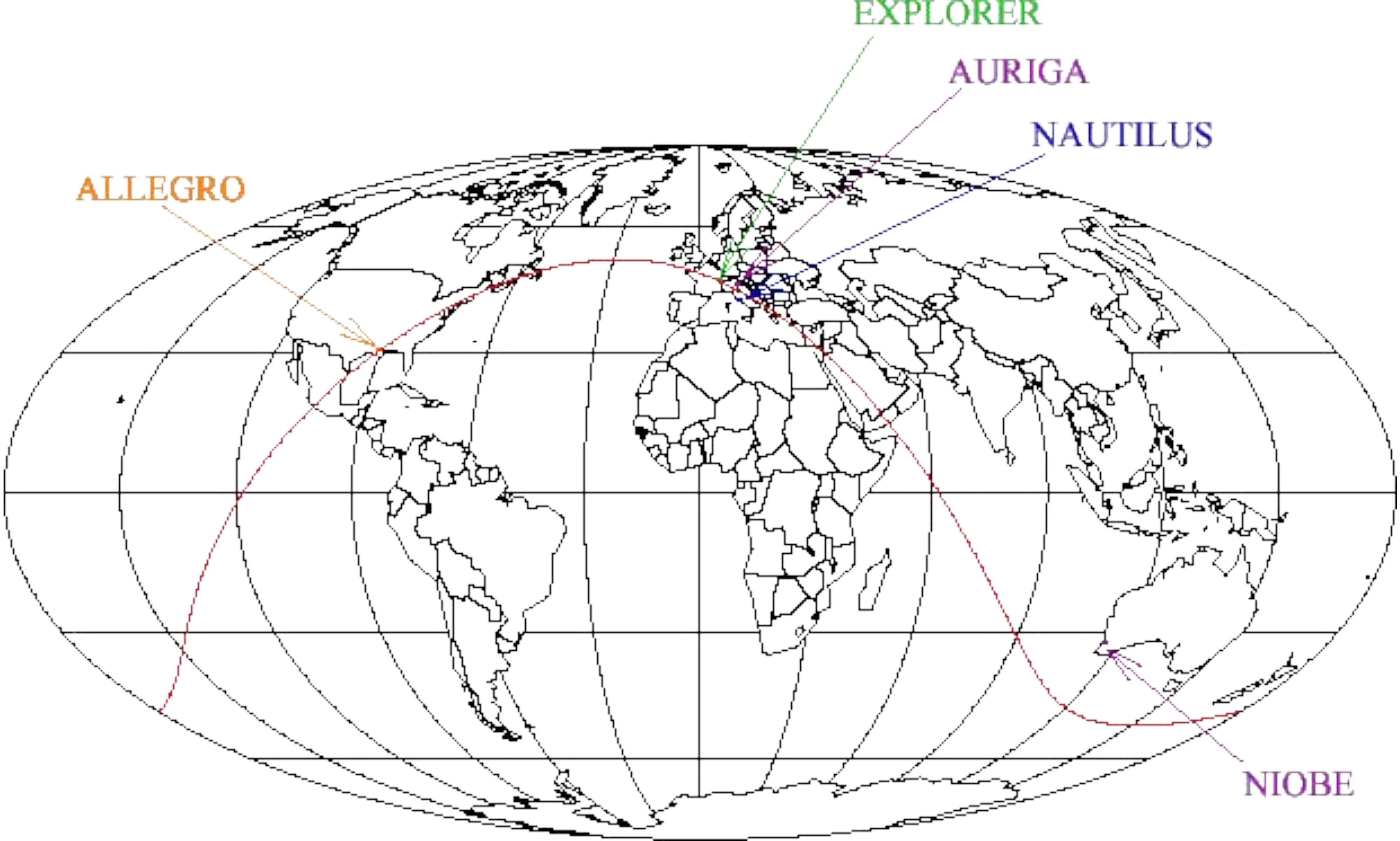
- Resonant mass gravitational wave detectors
- The GW detection frequency range
- IWARA 2020 presentation: quantum limit
- The classical solution
- Coherent quantum states
- The quantum solution

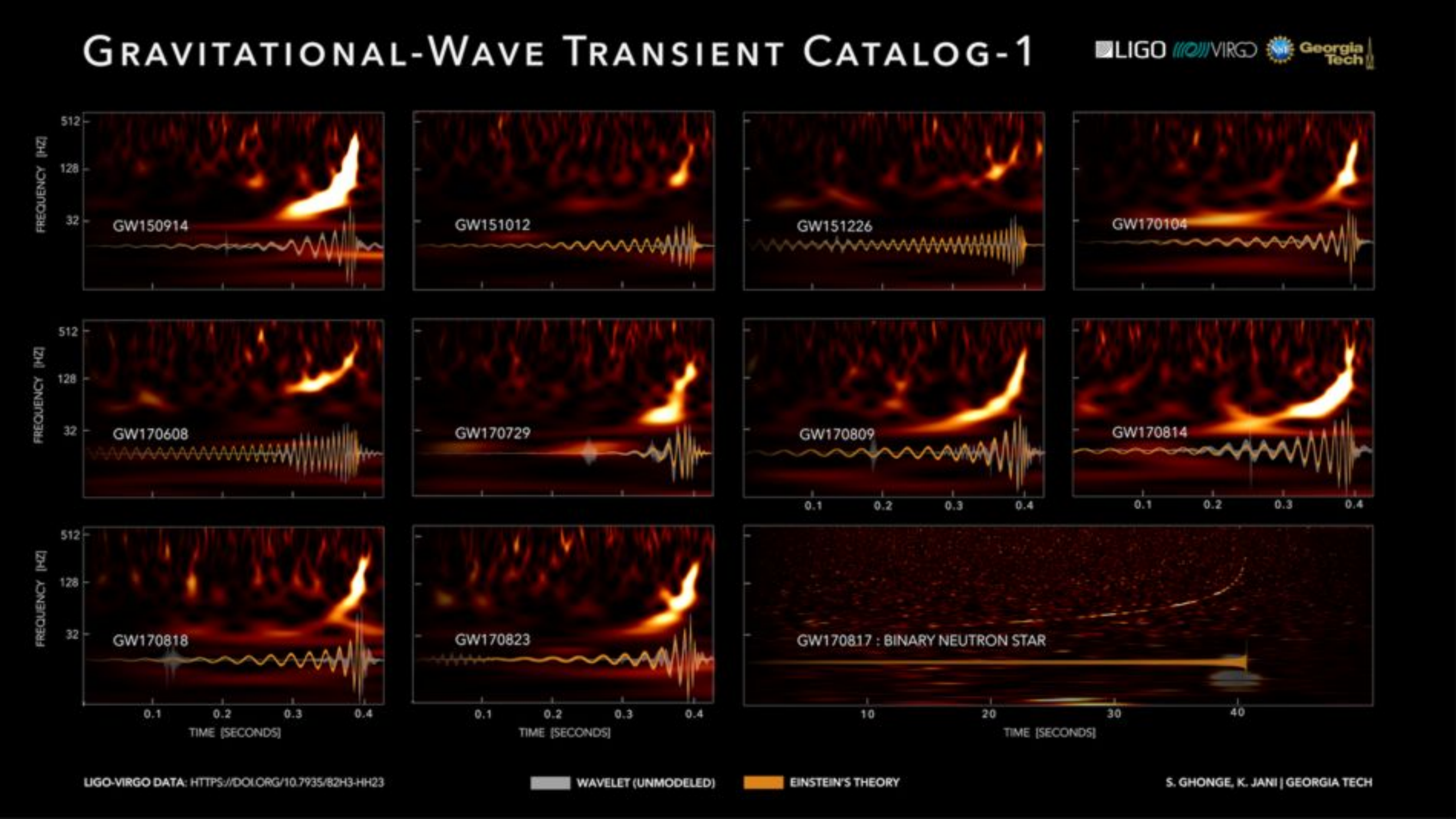
First Gravitational Wave Detection

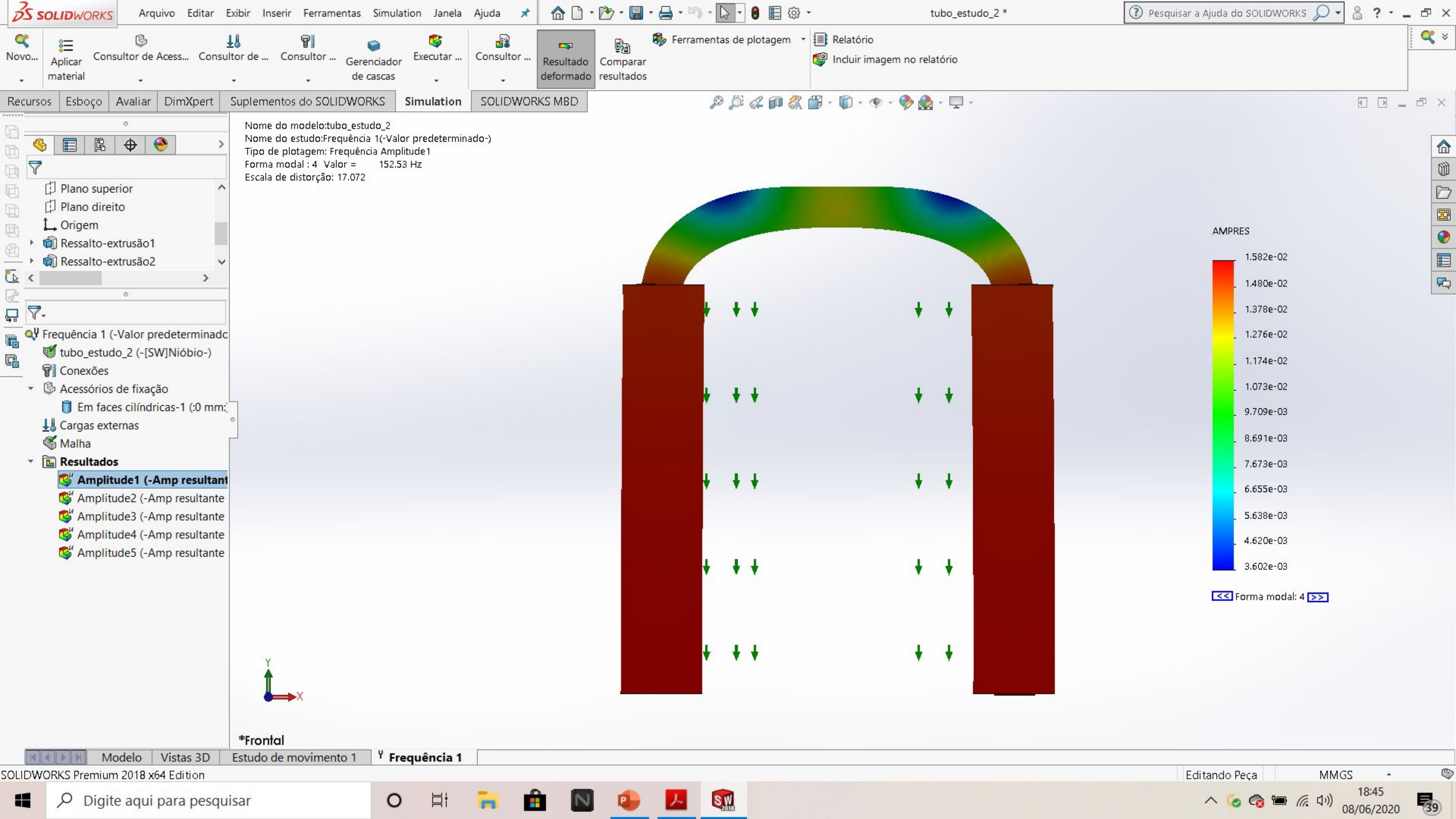


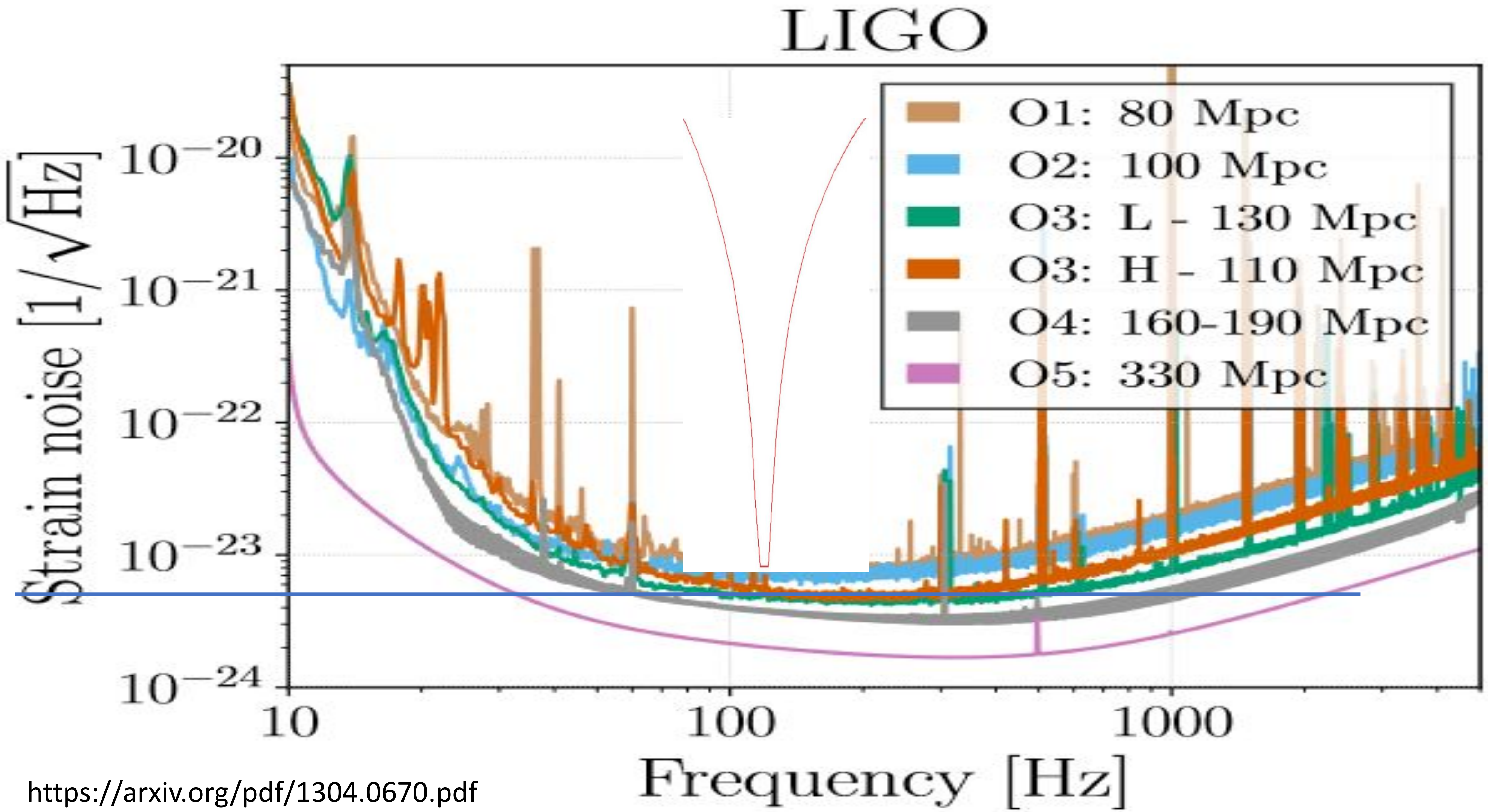
Resonant-mass GWD
Easily calibrated.





EXPLORER
AURIGA
NAUTILUS
ALLEGRO
NIOBE


GRAVITATIONAL-WAVE TRANSIENT CATALOG-1
LIGO
VIRGO
Georgia Tech
FREQUENCY [HZ]
512
128
32
GW150914
GW151012
GW151226
GW170104
GW170608
GW170729
GW170809
GW170814
GW170818
GW170823
GW170817 : BINARY NEUTRON STAR
0.1
0.2
0.3
0.4
10
20
30
40
TIME [SECONDS]
LIGO-VIRGO DATA: HTTPS://DOI.ORG/10.7935/82H3-HH23
WAVELET (UNMODELED)
EINSTEIN'S THEORY
S. GHONGE, K. JANI | GEORGIA TECH


Arquivo Editar Exibir Inserir Ferramentas Simulation Janela Ajuda
tubo_estudo_2 *
Pesquisar a Ajuda do SOLIDWORKS
Novo...
Aplicar material
Consultor de Acess...
Consultor de ...
Consultor ...
Gerenciador de cascas
Executar ...
Consultor ...
Resultado deformado
Comparar resultados
Ferramentas de plotagem
Relatório
Incluir imagem no relatório
Recursos Esboço Avaliar DimXpert Suplementos do SOLIDWORKS Simulation SOLIDWORKS MBD
Plano superior
Plano direito
Origem
Ressalto-extrusão1
Ressalto-extrusão2
Frequência 1 (-Valor predeterminadc
tubo_estudo_2 (-[SW]Nióbio-)
Conexões
Acessórios de fixação
Em faces cilíndricas-1 (:0 mm:
Cargas externas
Malha
Resultados
Amplitude1 (-Amp resultant
Amplitude2 (-Amp resultante
Amplitude3 (-Amp resultante
Amplitude4 (-Amp resultante
Amplitude5 (-Amp resultante
Nome do modelo:tubo_estudo_2
Nome do estudo:Frequência 1(-Valor predeterminado-)
Tipo de plotagem: Frequência Amplitude1
Forma modal : 4 Valor = 152.53 Hz
Escala de distorção: 17.072
AMPRES
1.582e-02
1.480e-02
1.378e-02
1.276e-02
1.174e-02
1.073e-02
9.709e-03
8.691e-03
7.673e-03
6.655e-03
5.638e-03
4.620e-03
3.602e-03
Forma modal: 4
Y
X
*Frontal
Modelo Vistas 3D Estudo de movimento 1 Frequência 1
SOLIDWORKS Premium 2018 x64 Edition
Editando Peça
MMGS
Digite aqui para pesquisar
18:45
08/06/2020

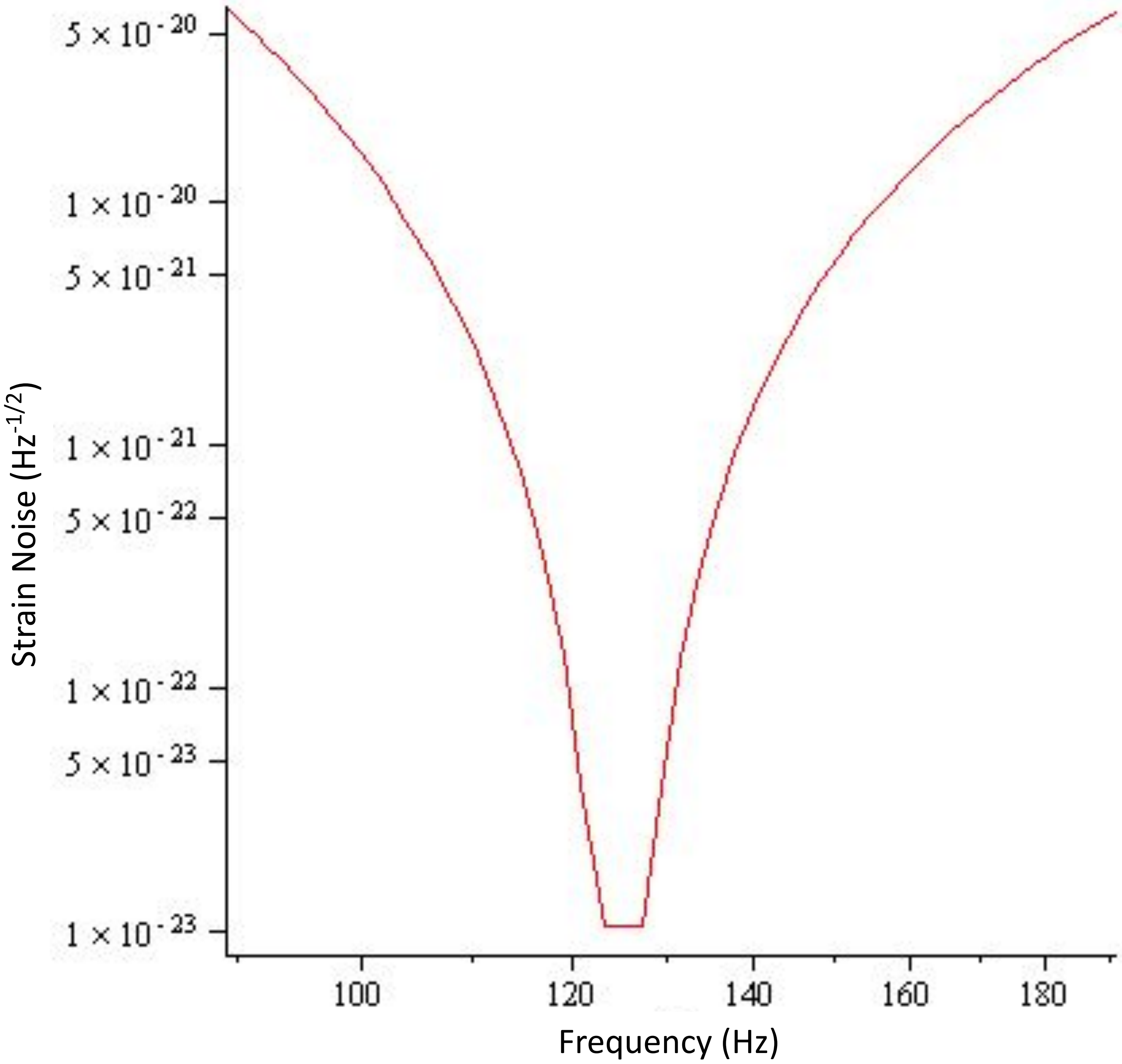


https://arxiv.org/pdf/1304.0670.pdf

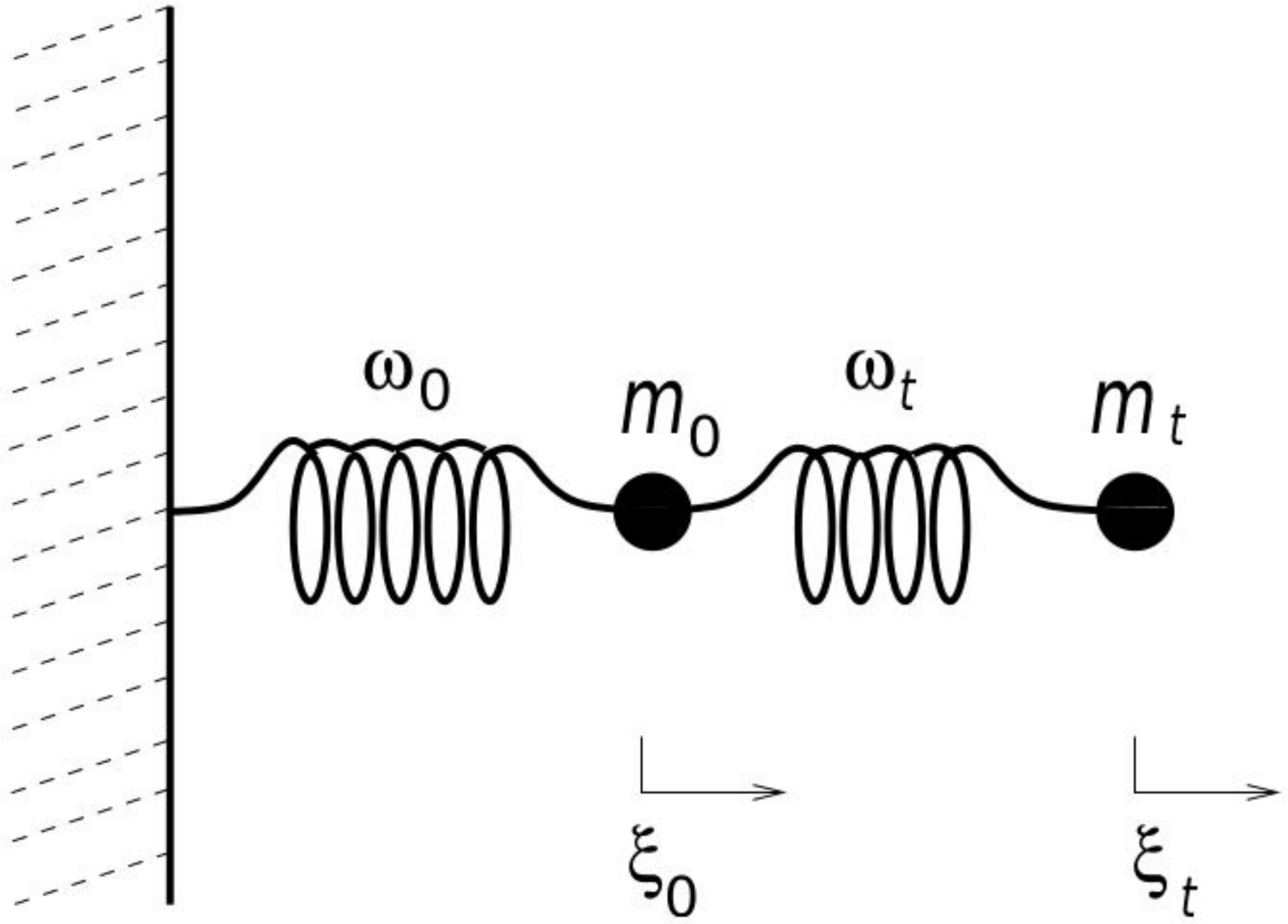
Strain Sensitivity = 1.31 10^{-21}

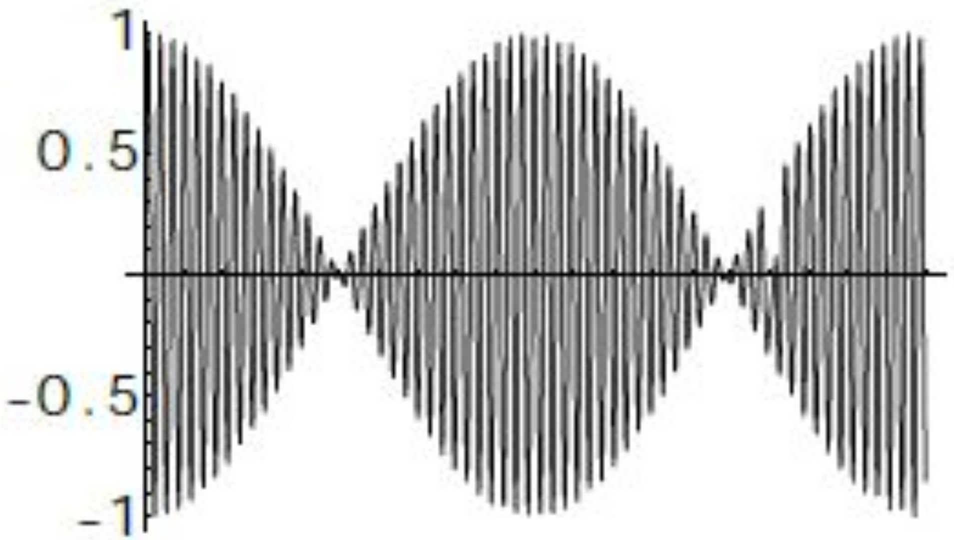
Quantum Limit = 1.29 10^{-21}

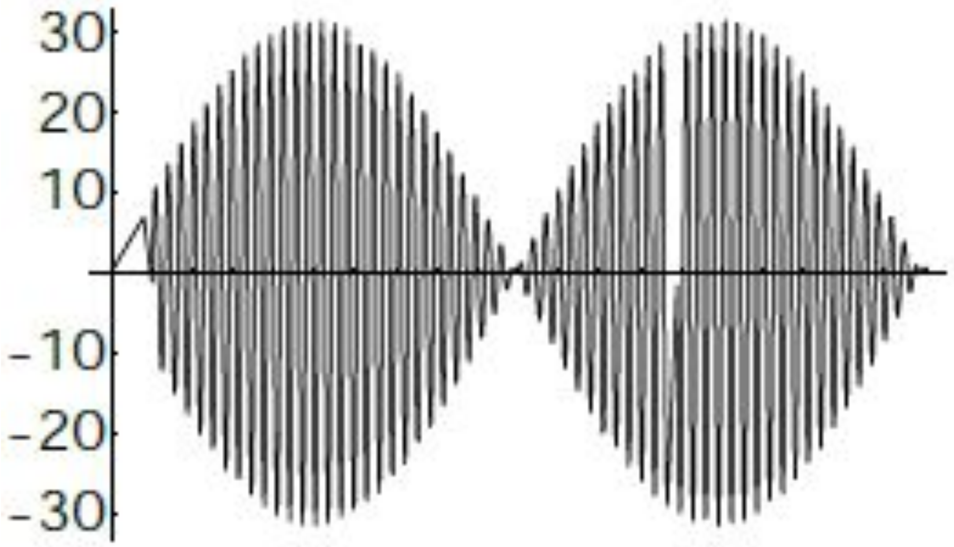
Noise temperature = 6.14 10^{-9} K



The force actuating in the mass is classical.




1
0.5
-0.5
-1


30
20
10
-10
-20
-30

$$H = \frac{p_0^2}{2m_0} + \frac{p_t^2}{2m_t} + \frac{1}{2}k_0\xi_0^2 + \frac{1}{2}\kappa(\xi_t - \xi_0)^2$$

$$\Xi_0 = \left(\frac{m_0}{m_t}\right)^{1/4}\xi_0; \quad \Xi_t = \left(\frac{m_t}{m_0}\right)^{1/4}\xi_t$$

$$P_0 = \left(\frac{m_t}{m_0}\right)^{1/4}p_0; \quad P_t = \left(\frac{m_0}{m_t}\right)^{1/4}p_t$$

$$\mu \equiv (m_0 m_t)^{1/2}$$

$$H = \frac{P_0^2}{2\mu} + \frac{P_t^2}{2\mu} + \frac{1}{2}\mu\omega^2\Xi_0^2 + $$

$$+\frac{1}{2}\left[\left(\frac{m_0}{m_t}\right)^{1/4}\Xi_t - \left(\frac{m_t}{m_0}\right)^{1/4}\Xi_0\right]$$

$$\begin{pmatrix}\xi_+\\ \xi_-\end{pmatrix} = \begin{pmatrix}\cos\alpha & \sin\alpha\\ -\sin\alpha & \cos\alpha\end{pmatrix}\begin{pmatrix}\Xi_0\\ \Xi_t\end{pmatrix}$$

$$\begin{pmatrix}p_+\\ p_-\end{pmatrix} = \begin{pmatrix}\cos\alpha & \sin\alpha\\ -\sin\alpha & \cos\alpha\end{pmatrix}\begin{pmatrix}P_0\\ P_t\end{pmatrix}$$

$$H = \frac{p_+^2}{2\mu} + \frac{1}{2}\mu\omega_+^2\xi_+^2 + \frac{p_-^2}{2\mu} + \frac{1}{2}\mu\omega_-^2\xi_-^2$$

$$\omega_+ = \left\{ \omega_0^2 \cos^2 \alpha + \omega_t^2 \sin^2 \alpha + \right.$$

$$\left. + \frac{\kappa}{\mu} \left[\left(\frac{m_0}{m_t} \right)^{1/4} \sin \alpha - \left(\frac{m_t}{m_0} \right)^{1/4} \cos \alpha \right]^2 \right\}^{1/2}$$

And

$$\omega_- = \left\{ \omega_0^2 \sin^2 \alpha + \omega_t^2 \cos^2 \alpha + \right.$$

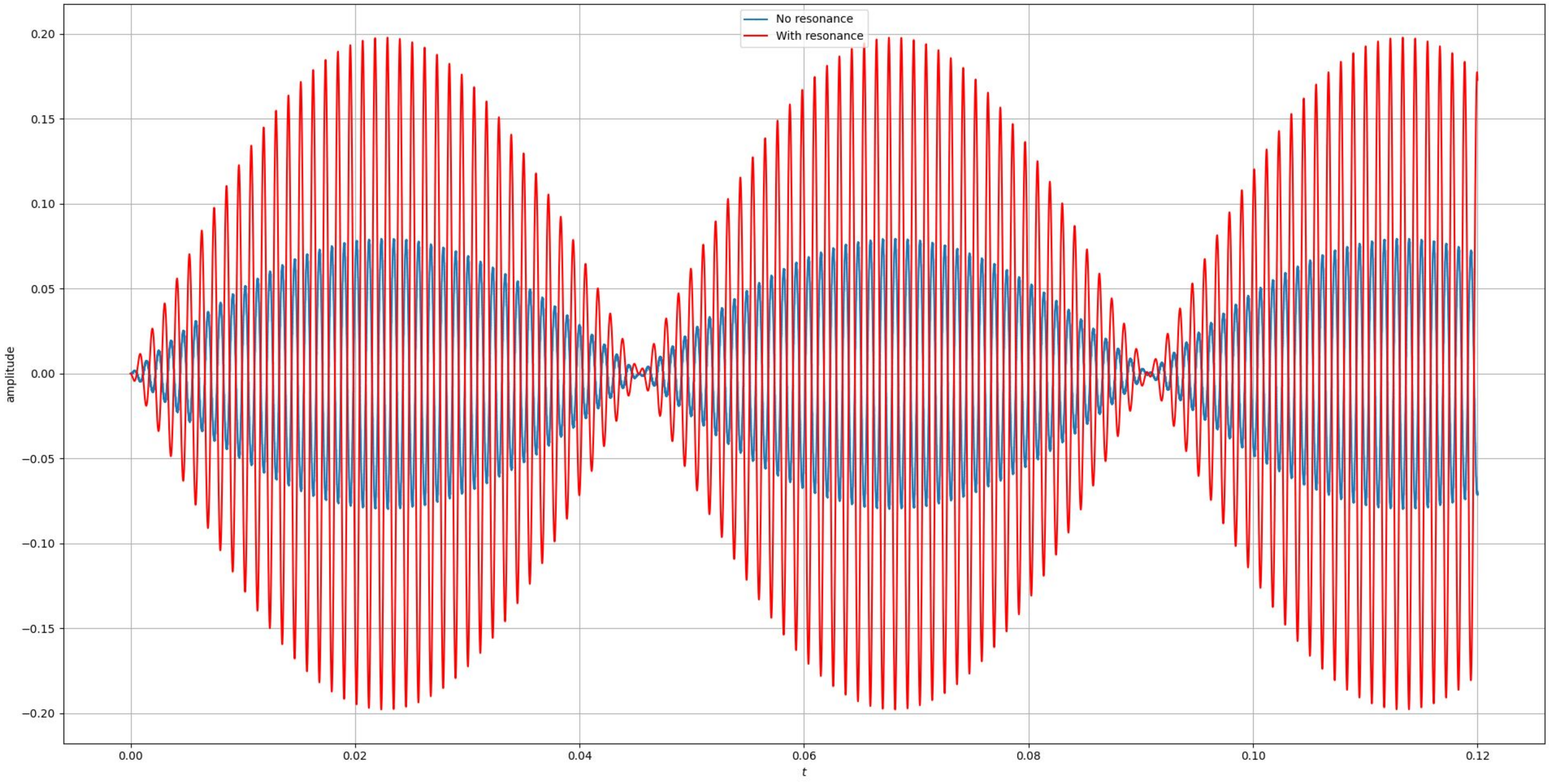
$$\left. + \frac{\kappa}{\mu} \left[\left(\frac{m_0}{m_t} \right)^{1/4} \cos \alpha - \left(\frac{m_t}{m_0} \right)^{1/4} \sin \alpha \right]^2 \right\}^{1/2}$$

$$\hat{H} = \hat{a}_+^\dagger \hat{a}_+ + \hat{a}_-^\dagger \hat{a}_-$$

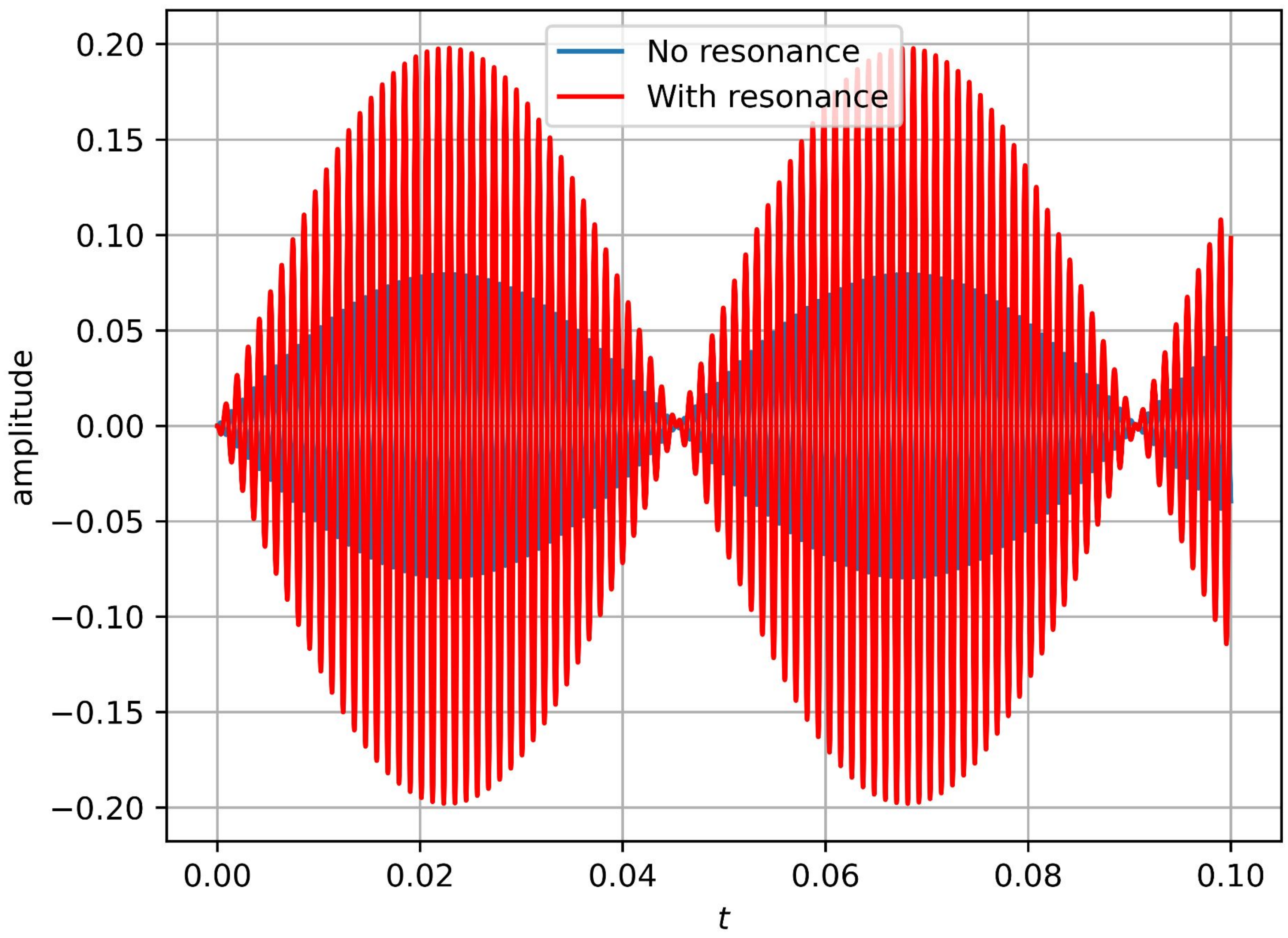
$$\hat{H} = \hat{N}_+ + \hat{N}_-$$

$$\Psi(\xi_0,\xi_t,0)=\left(\frac{m_0 m_t \omega_0 \omega_t}{\pi^2\hbar^2}\right)^{1/4} exp\left(-\frac{m_0\omega_0\xi_0^2+m_t\omega_t(\xi_t-A)^2}{2\hbar}\right)$$

$$\langle y_0\rangle=\left(\frac{m_t}{m_0}\right)^{\frac{1}{2}} A\sin\alpha\cos\alpha[\cos\omega_+t-\cos\omega\_t]$$



No resonance
With resonance
amplitude
t
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0.00
0.02
0.04
0.06
0.08
0.10
0.12



No resonance
With resonance
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
amplitude
0.00
0.02
0.04
0.06
0.08
0.10
t

Main conclusion

The solution for the averaged position is the same as the classical one.

Next step is to study the measurement process during the detection.

On Thursday poster with a complementary work will be presented.

Thank you for your kind attention.