SRF for GW detection: MAGO

Sebastian A. R. Ellis

University of Geneva

Conclusion This Morning

Identify regime of GW by hierarchy with respect to size of detector:

- **Resonant regime:** $\omega_g \sim 1/L \gg c_s/L$ — **use PDF and account for current & boundary changes**

    e.g. axion cavity experiments — *Berlin, Blas, D'Agnolo, SARE, Harnik, Kahn, Schutte-Engel (2021)*

- **High-frequency regime:** $\omega_g \gg 1/L \gg c_s/L$ — **use TT gauge**

    e.g. MADMAX — *Domcke, Ellis, Kopp (2024)*

- **Low-frequency regime:** $1/L \gg \omega_g$ — **use PDF and account for current & boundary changes**

    e.g. Magneto-quasistatic experiments — *Domcke, Garcia-Cely, Rodd (2022)*; *Domcke, Garcia-Cely, Lee, Rodd (2023)*; *Domcke, Ellis, Rodd (2024)*

    e.g. Heterodyne experiments — *Berlin, Blas, D'Agnolo, SARE, Harnik, Kahn, Schutte-Engel, Wentzel (2023)*

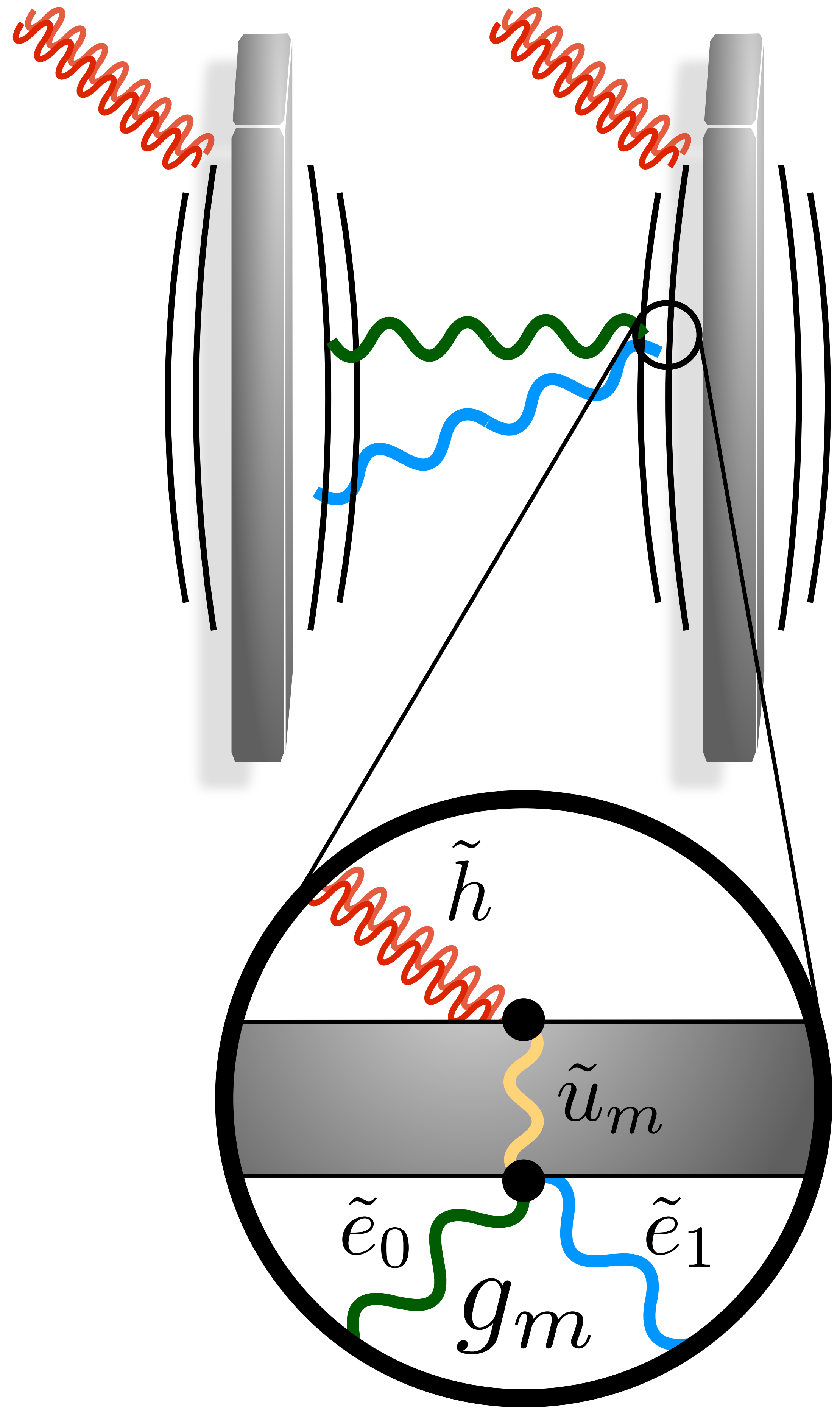
Transfer function for mechanical transduction

$$\left(\omega_m^2 - \omega^2 + i\frac{\omega\omega_m}{Q_m}\right)\tilde{u}_m(\omega) \simeq -\frac{\omega_g^2 L}{2}\tilde{h}^{\rm TT}(\omega)$$

$$\left(\omega_1^2 - \omega^2 + i\frac{\omega\omega_1}{Q}\right)\tilde{e}_1(\omega) \simeq \int d\omega'\tilde{e}_0(\omega-\omega')g_m\tilde{u}_m(\omega')$$

$$g_m \equiv -\frac{2\omega_1^2}{L}$$

$$\mathcal{T}^2_{\rm mech}(\omega) = \frac{\omega_g^4\omega_1^4}{\left((\omega_1^2-\omega^2)^2 + \frac{\omega^2\omega_1^2}{Q^2}\right)\left((\omega_m^2-\omega_g^2)^2 + \frac{\omega_g^2\omega_m^2}{Q_m^2}\right)}$$

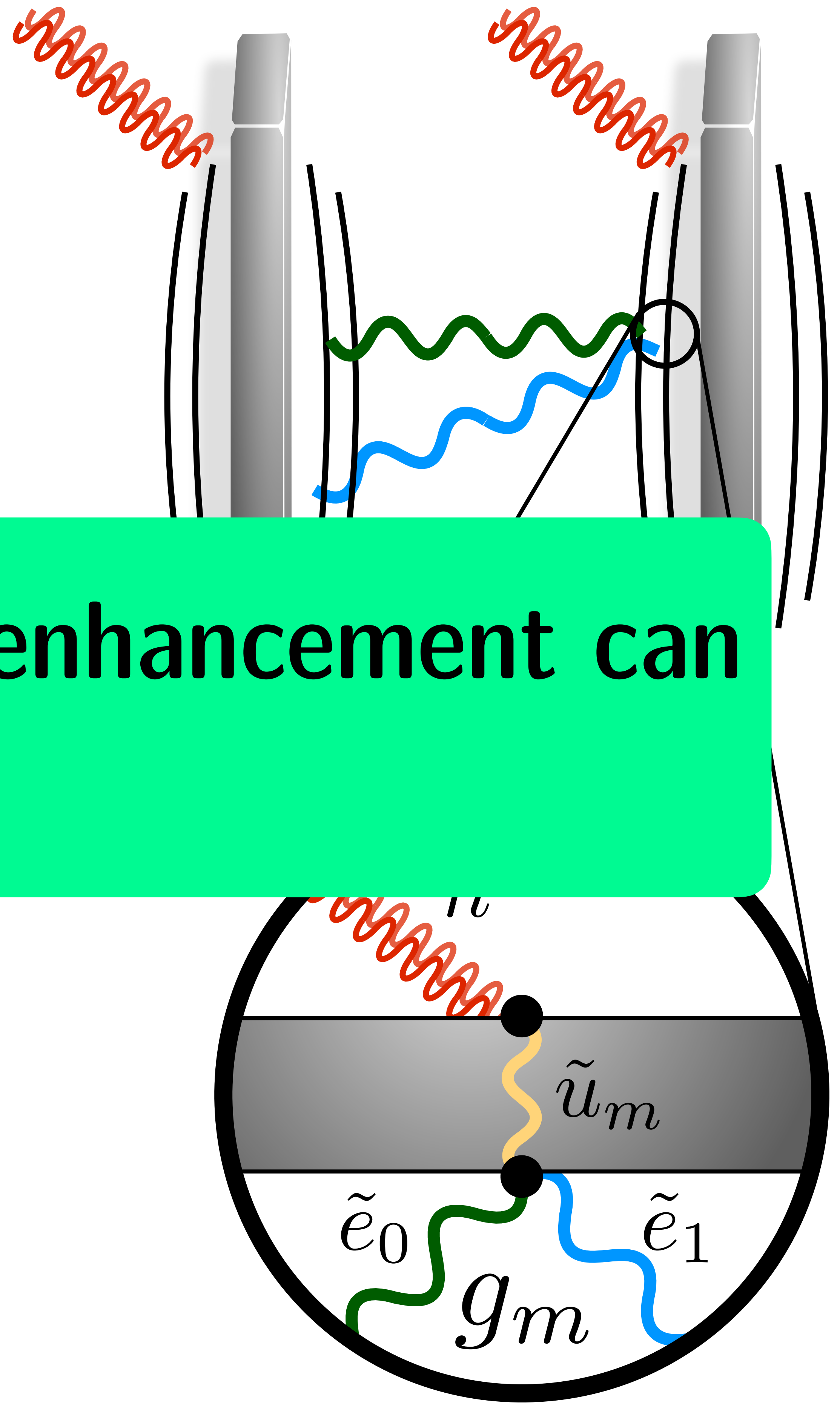


D'Agnolo, SARE (gr-qc/2412.17897)

Transfer function for mechanical transduction

$$\left(\omega_m^2 - \omega^2 + i\frac{\omega\omega_m}{Q_m}\right)\tilde{u}_m(\omega) \simeq -\frac{\omega_g^2 L}{2}\tilde{h}^{\rm TT}(\omega)$$

$$\left(\omega_1^2 - \omega^2 + i\frac{\omega\omega_1}{Q}\right)\tilde{e}_1(\omega) \simeq \int d\omega' \tilde{e}_0(\omega-\omega') g_m \tilde{u}_m(\omega')$$

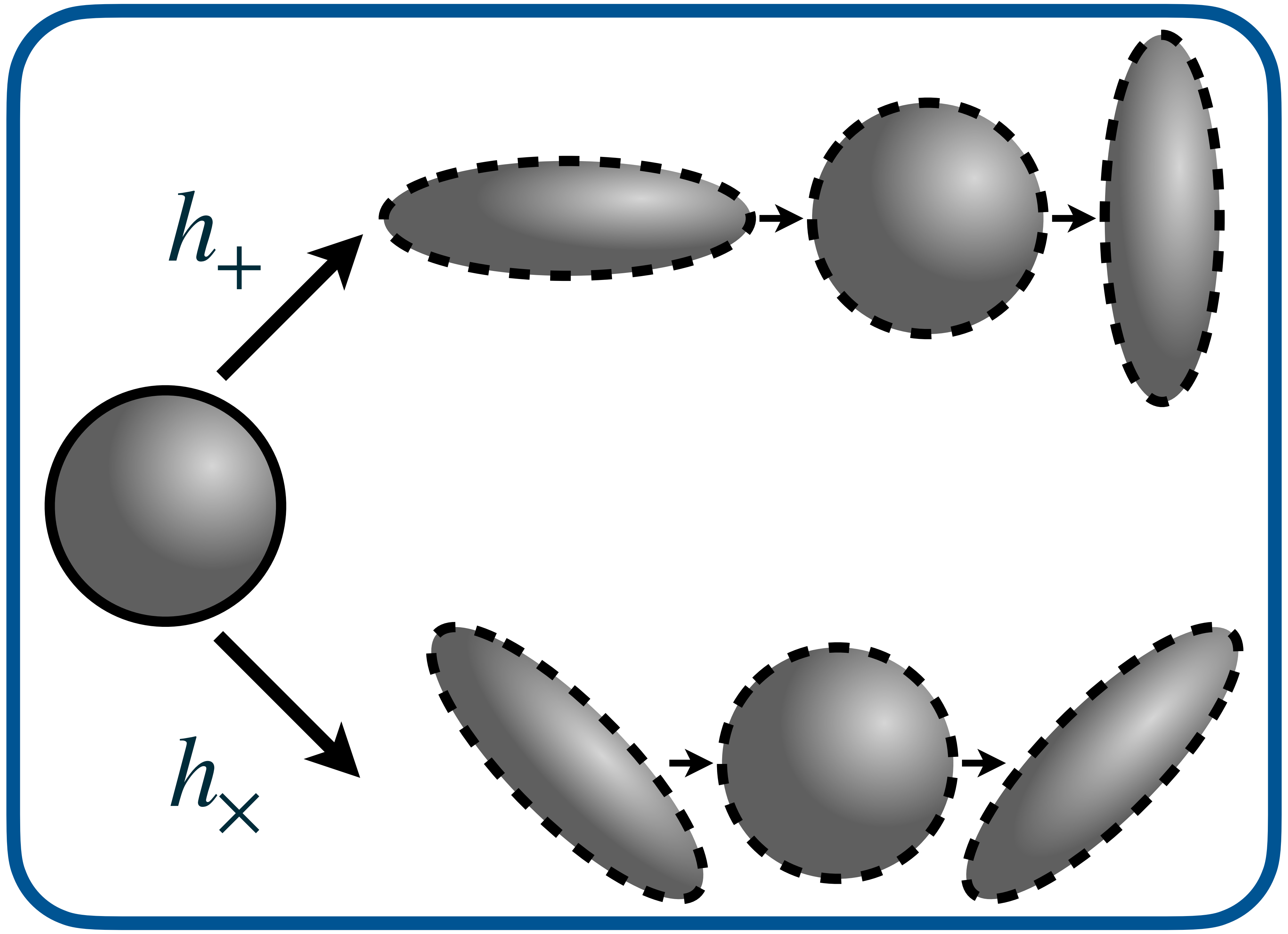


Is there a compact physical system where EM resonant enhancement can be realised?

$$\mathcal{T}^2_{\rm mech}(\omega) = \frac{\omega_g^4\omega_1^4}{\left((\omega_1^2-\omega^2)^2 + \frac{\omega^2\omega_1^2}{Q^2}\right)\left((\omega_m^2-\omega_g^2)^2 + \frac{\omega_g^2\omega_m^2}{Q_m^2}\right)}$$

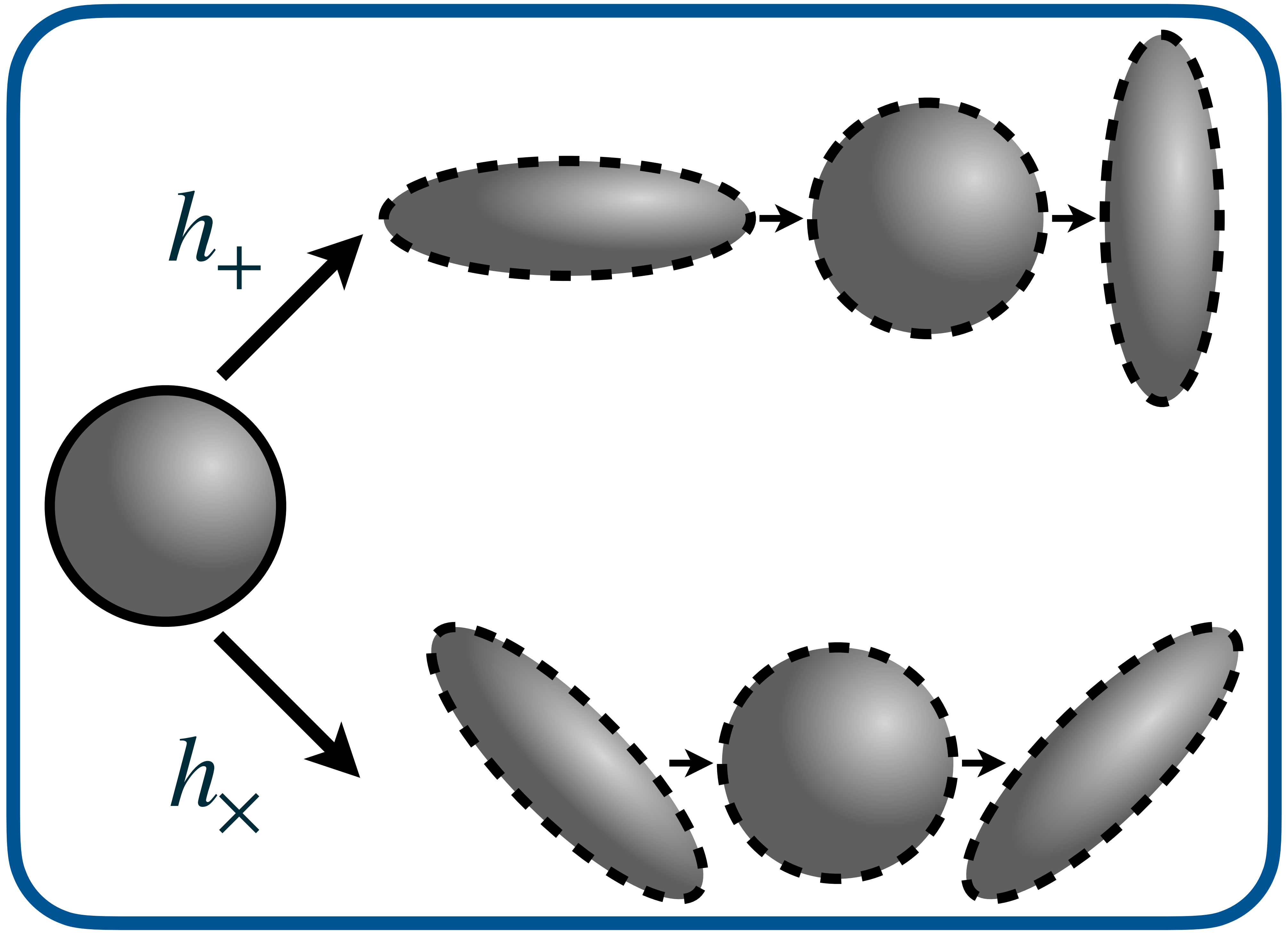
D'Agnolo, SARE (gr-qc/2412.17897)

Gravitational Wave and a Hollow Sphere



TT frame intuition

Gravitational Wave and a Hollow Sphere

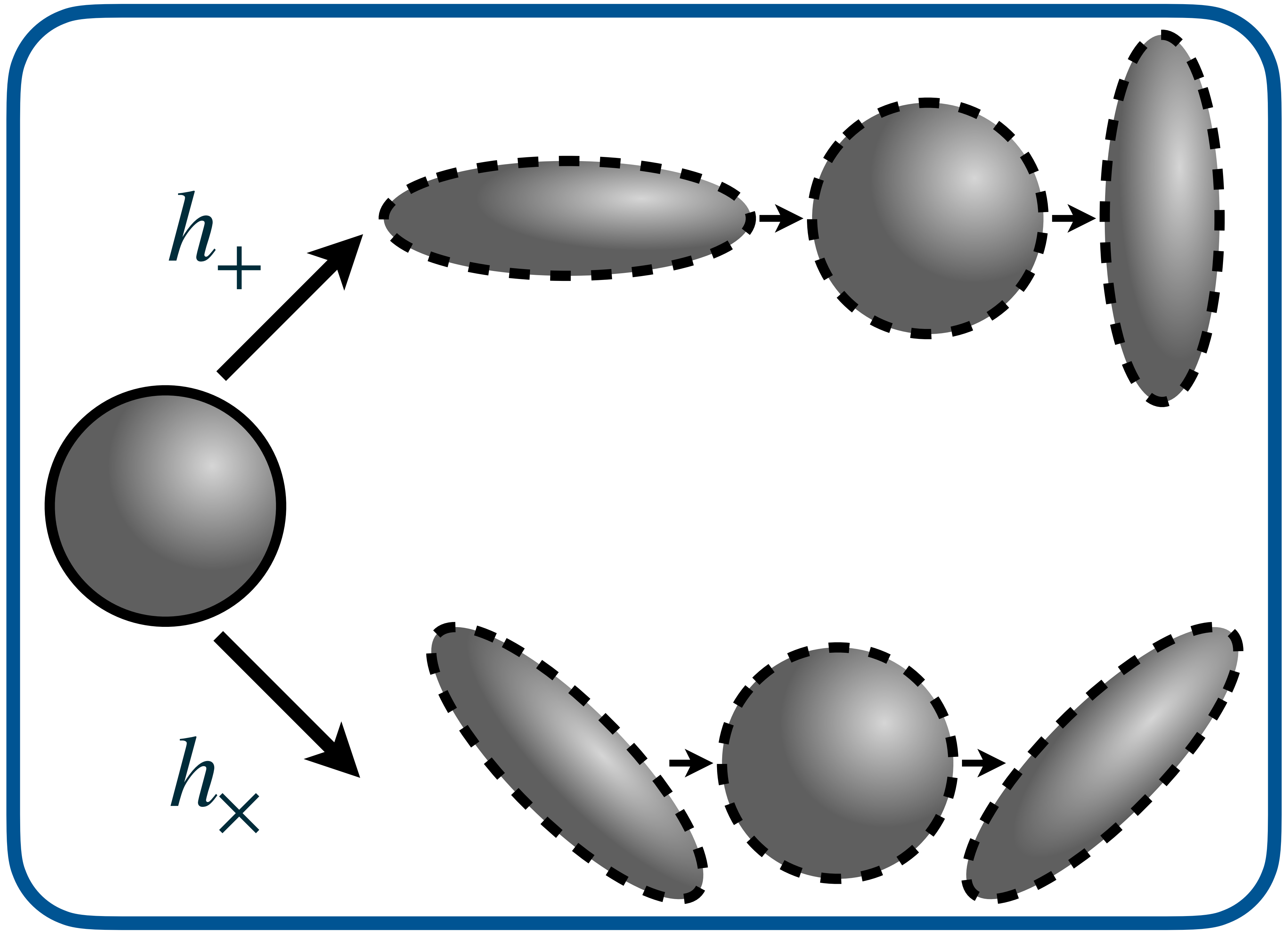


TT frame intuition

Mechanical modes of a sphere

$$\mathbf{U}_{lmn} = \nabla\phi_L + i\,\nabla\times\mathbf{L}\phi_{T_1} + i\,\mathbf{L}\phi_{T_2}\ .$$

Gravitational Wave and a Hollow Sphere

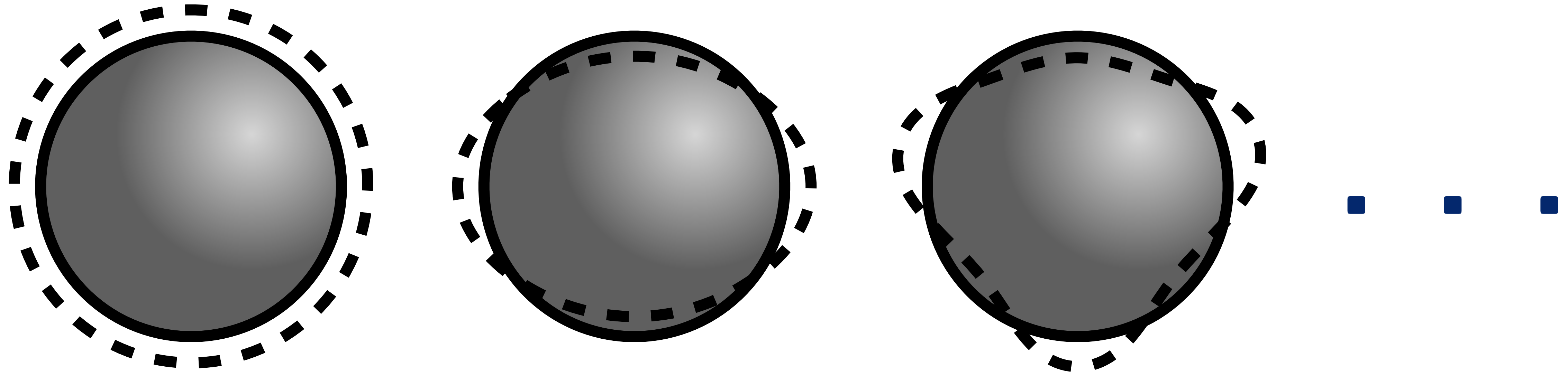


TT frame intuition

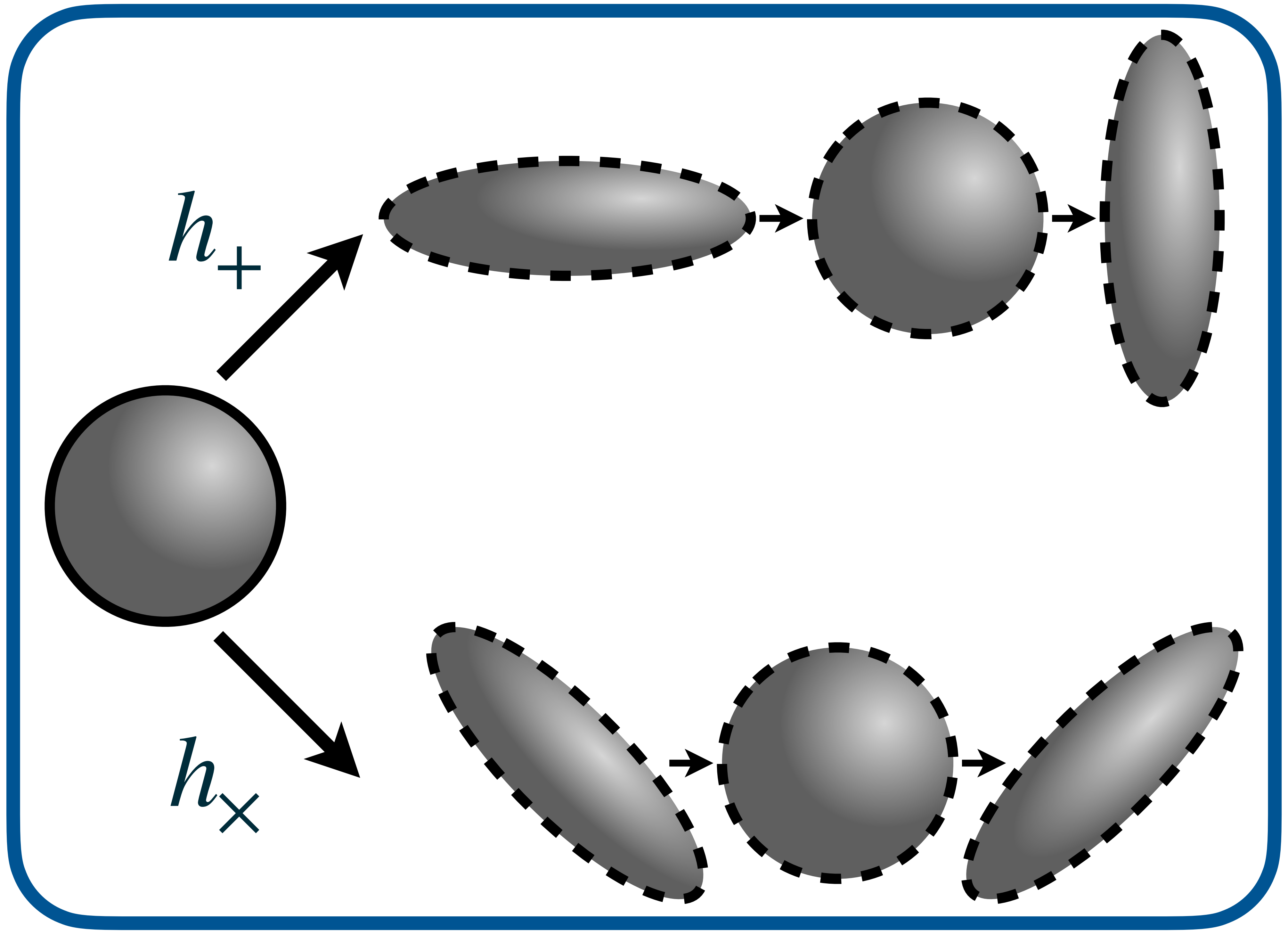
Mechanical modes of a sphere

$$\mathbf{U}_{lmn} = \nabla\phi_L + i\,\nabla \times \mathbf{L}\phi_{T_1} + i\,\mathbf{L}\phi_{T_2}\ .$$

Spheroidal



Gravitational Wave and a Hollow Sphere

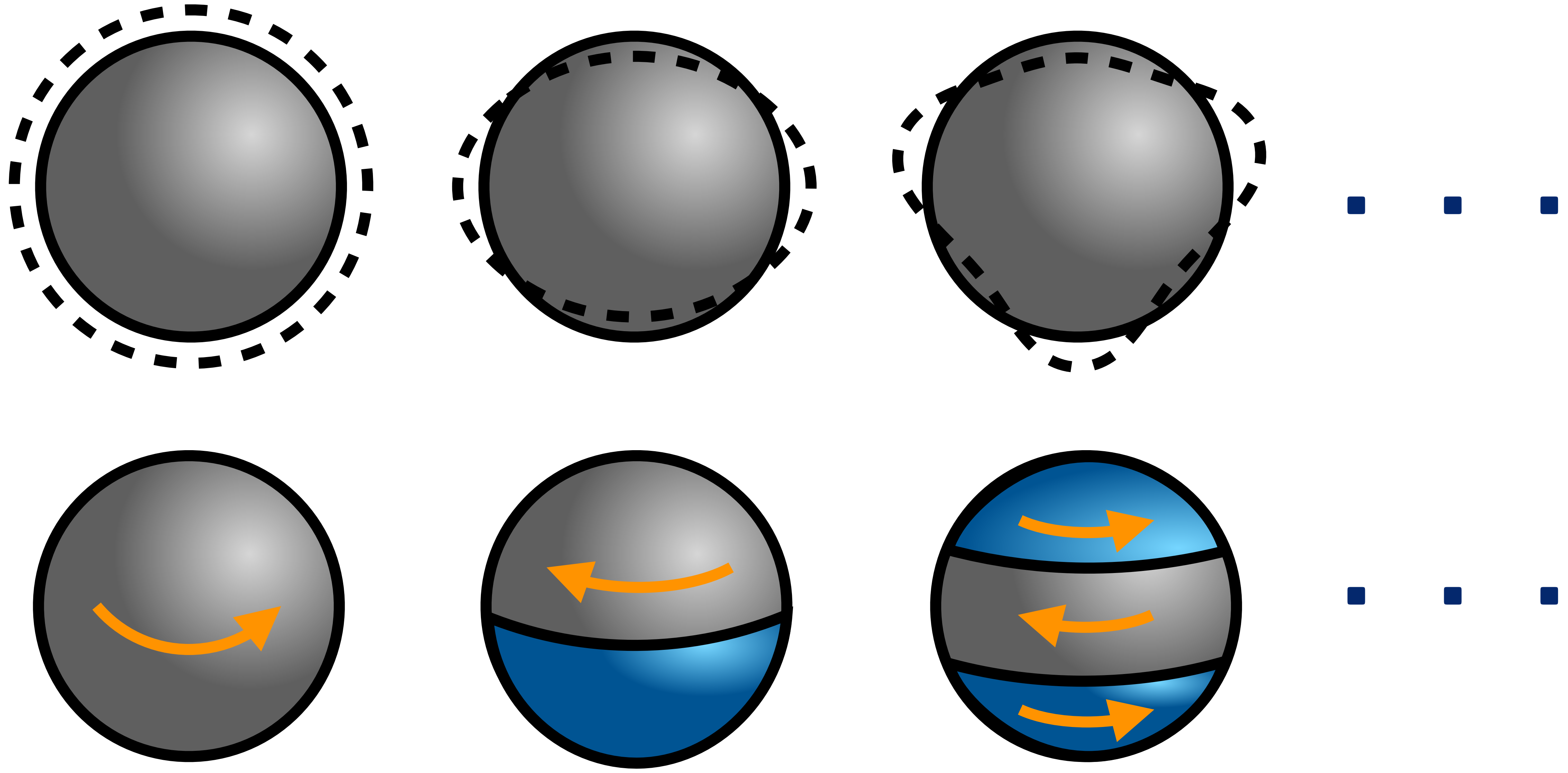


TT frame intuition

Mechanical modes of a sphere

$$\mathbf{U}_{lmn} = \nabla\phi_L + i\,\nabla \times \mathbf{L}\phi_{T_1} + i\,\mathbf{L}\phi_{T_2}\,.$$

Spheroidal — Toroidal



Gravitational Wave and a Hollow Sphere

Gravitational Wave and a Hollow Sphere

Mechanical modes of a sphere

$$\mathbf{U}_{lmn} = \nabla\phi_L + i\,\nabla\times\mathbf{L}\phi_{T_1} + i\,\mathbf{L}\phi_{T_2}\ .$$

$$\mathbf{U}(\mathbf{x},t) = u_p(t)\,\mathbf{U}_p(\mathbf{x})$$

Gravitational Wave and a Hollow Sphere

Mechanical modes of a sphere

$$\mathbf{U}_{lmn} = \nabla \phi_L + i\,\nabla \times \mathbf{L}\phi_{T_1} + i\,\mathbf{L}\phi_{T_2}\ .$$

$$\mathbf{U}(\mathbf{x}, t) = u_p(t)\,\mathbf{U}_p(\mathbf{x})$$

Equation of motion

$$\ddot{u}_p + \frac{\omega_p}{Q_p}\,\dot{u}_p + \omega_p^2\,u_p \simeq -\frac{1}{2}\,\omega_g^2\,V_{\rm cav}^{1/3}\,\eta^g_{\rm mech}\,h_0\,e^{i\omega_g t}$$

$$\eta^g_{\rm mech} = \frac{\hat{h}^{TT}_{ij}}{V_{\rm cav}^{1/3}\,V_{\rm shell}} \int_{V_{\rm shell}} d^3\mathbf{x}\,U_p^{*i}\,x^j$$

Gravitational Wave and a Hollow Sphere

Mechanical modes of a sphere

$$\mathbf{U}_{lmn} = \nabla\phi_L + i\,\nabla\times\mathbf{L}\phi_{T_1} + i\,\mathbf{L}\phi_{T_2}\ .$$

$$\mathbf{U}(\mathbf{x},t) = u_p(t)\,\mathbf{U}_p(\mathbf{x})$$

Equation of motion

$$\ddot{u}_p + \frac{\omega_p}{Q_p}\,\dot{u}_p + \omega_p^2\,u_p \simeq -\frac{1}{2}\,\omega_g^2\,V_{\rm cav}^{1/3}\,\eta^g_{\rm mech}\,h_0\,e^{i\omega_g t}$$

$$\eta^g_{\rm mech} = \frac{\hat{h}^{TT}_{ij}}{V_{\rm cav}^{1/3}\,V_{\rm shell}}\int_{V_{\rm shell}} d^3\mathbf{x}\,U_p^{*i}\,x^j$$

$$\langle\mathbf{U}_p\rangle \sim h_0\,V_{\rm cav}^{1/3}\,\eta^g_{\rm mech}\times\begin{cases}\frac{\omega_g^2}{\omega_g^2-\omega_p^2}\ , & |\omega_g-\omega_p| \gg \omega_p/Q_p\\ Q_p\ , & |\omega_g-\omega_p| \ll \omega_p/Q_p\end{cases}$$

Tiny displacement $\ll$ nm

MAGO 2.0: Mechanical and EM Signals

MAGO 2.0: Mechanical and EM Signals

On the operation of a tunable electromagnetic detector for gravitational waves

F Pegoraro†, E Picasso‡ and L A Radicati‡§

†Scuola Normale Superiore, Pisa, Italy
‡CERN, Geneva, Switzerland

Received 6 December 1977, in final form 20 April 1978

MAGO 2.0: Mechanical and EM Signals

On the operation of a tunable electromagnetic detector for gravitational waves

F Pegoraro†, E Picasso‡ and L A Radicati‡§
†Scuola Normale Superiore, Pisa, Italy
‡CERN, Geneva, Switzerland

Received 6 December 1977, in final form 20 April 1978

Microwave Apparatus for Gravitational Waves Observation

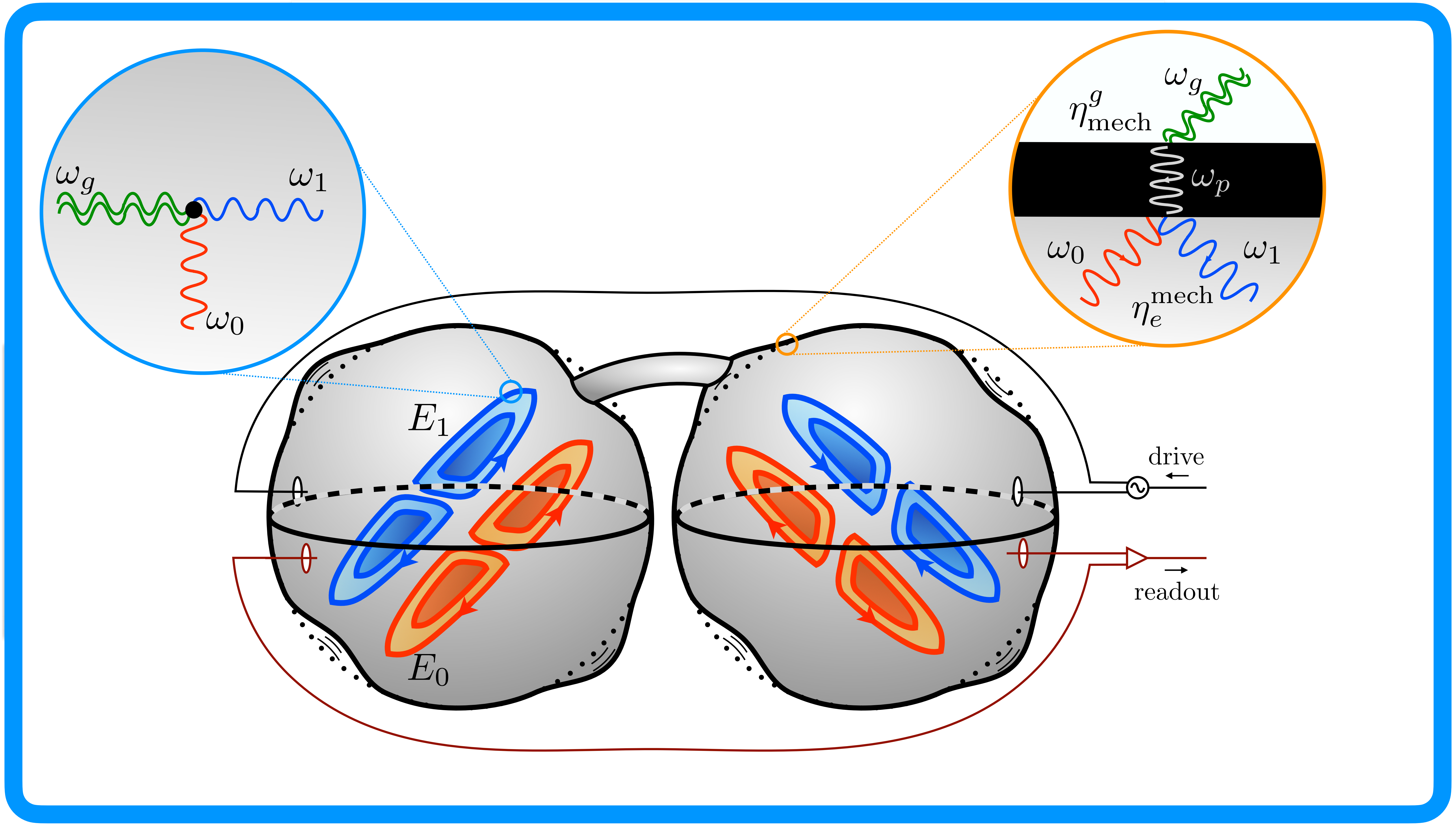
R. Ballantini, A. Chincarini, S. Cuneo, G. Gemme,* R. Parodi, A. Podestà, and R. Vaccarone
INFN and Università degli Studi di Genova, Genova, Italy

Ph. Bernard, S. Calatroni, E. Chiaveri, and R. Losito
CERN, Geneva, Switzerland

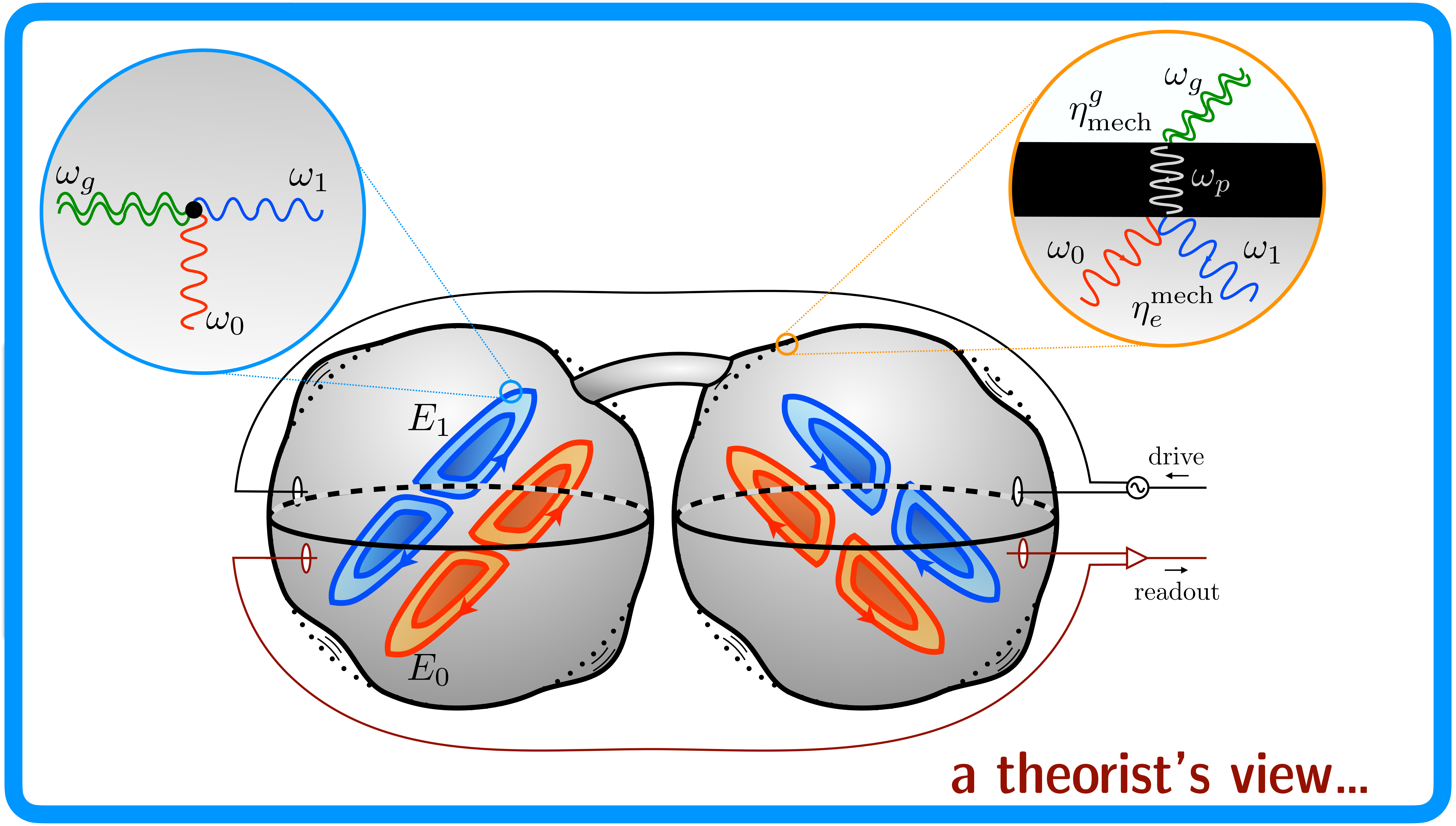
R.P. Croce, V. Galdi, V. Pierro, and I.M. Pinto
INFN, Napoli, and Università degli Studi del Sannio, Benevento, Italy

E. Picasso
INFN and Scuola Normale Superiore, Pisa, Italy and CERN, Geneva, Switzerland

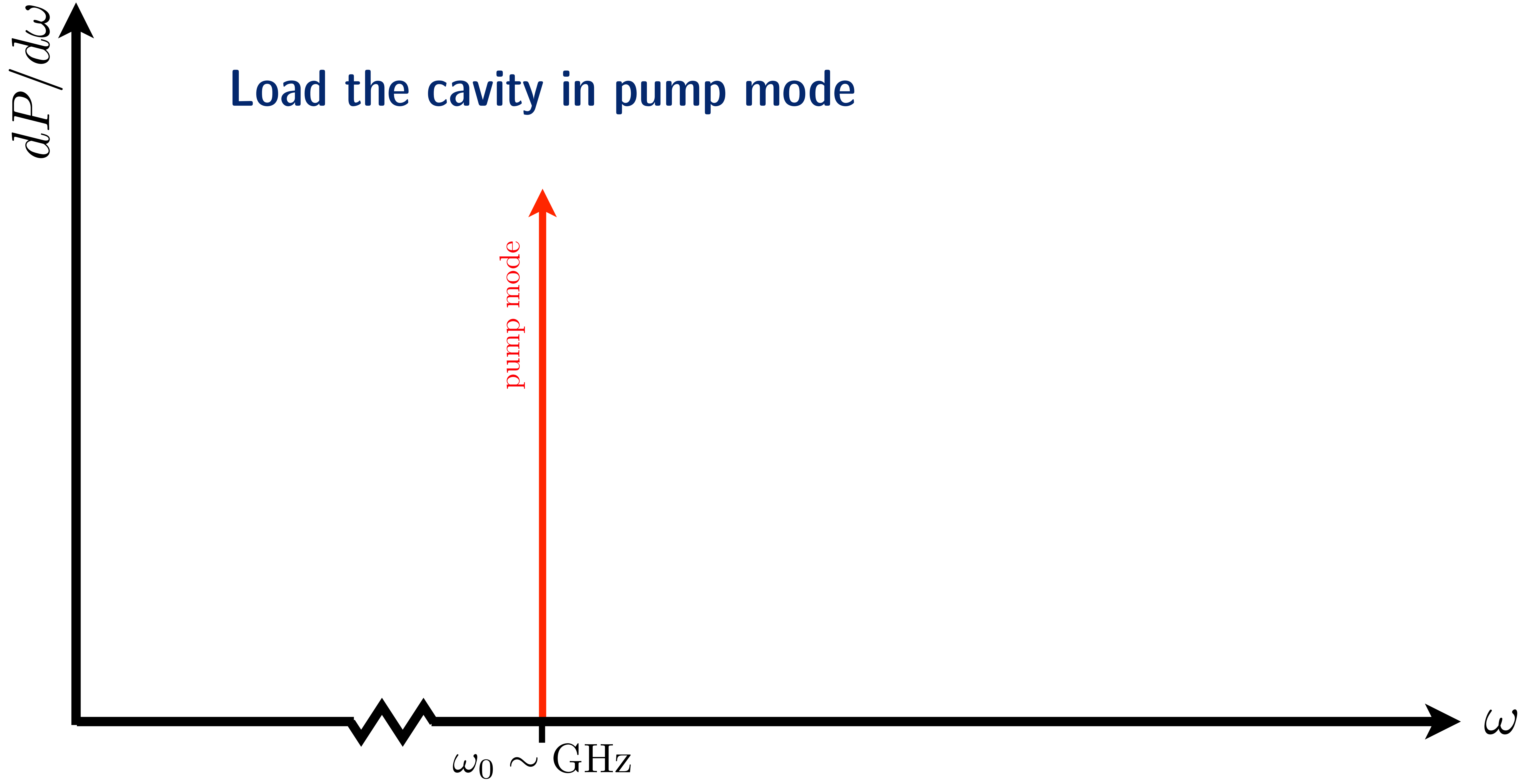
MAGO 2.0: Mechanical and EM Signals



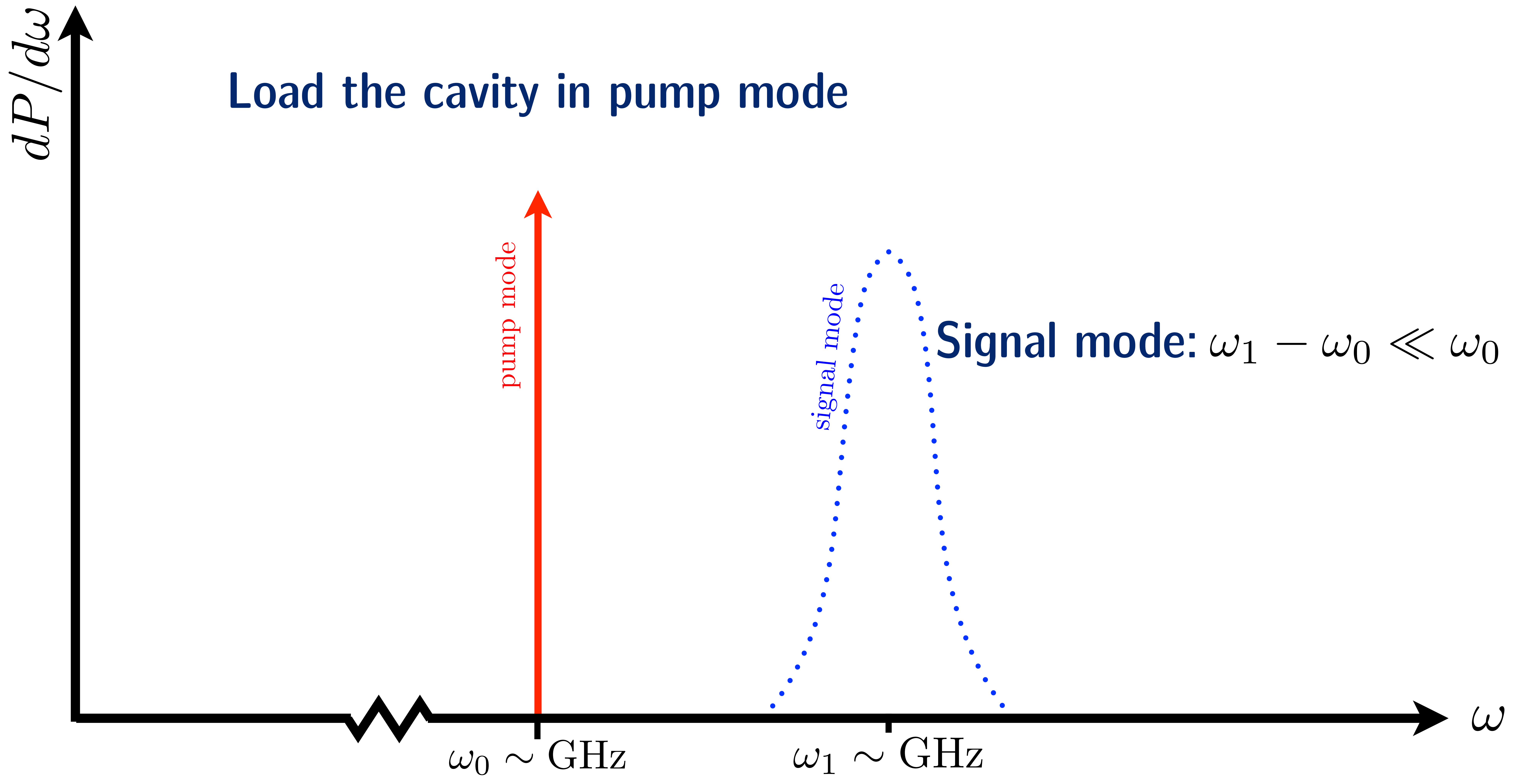
MAGO 2.0: Mechanical and EM Signals



MAGO 2.0

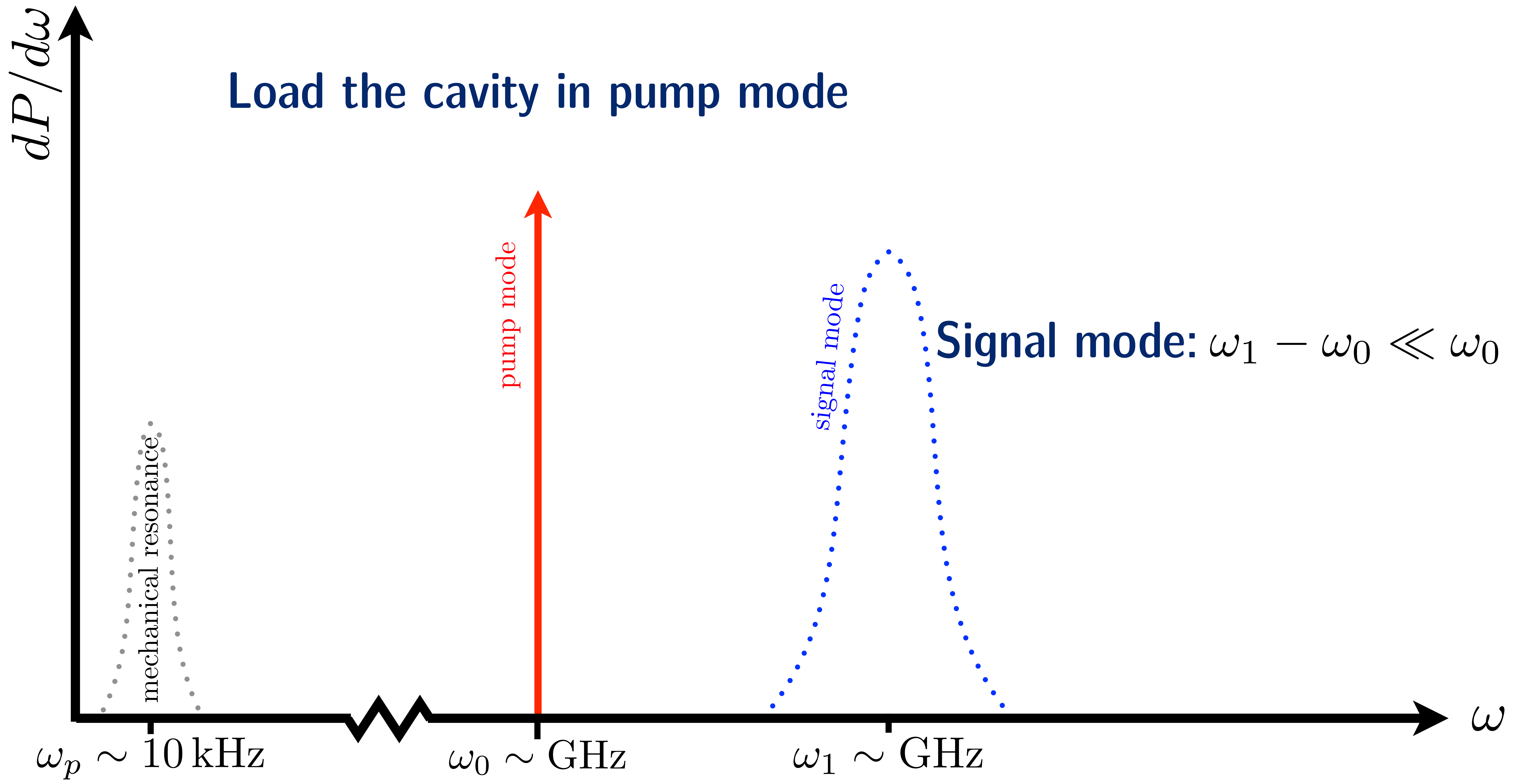

$dP/d\omega$
Load the cavity in pump mode
pump mode
$\omega_0 \sim \mathrm{GHz}$
ω

MAGO 2.0



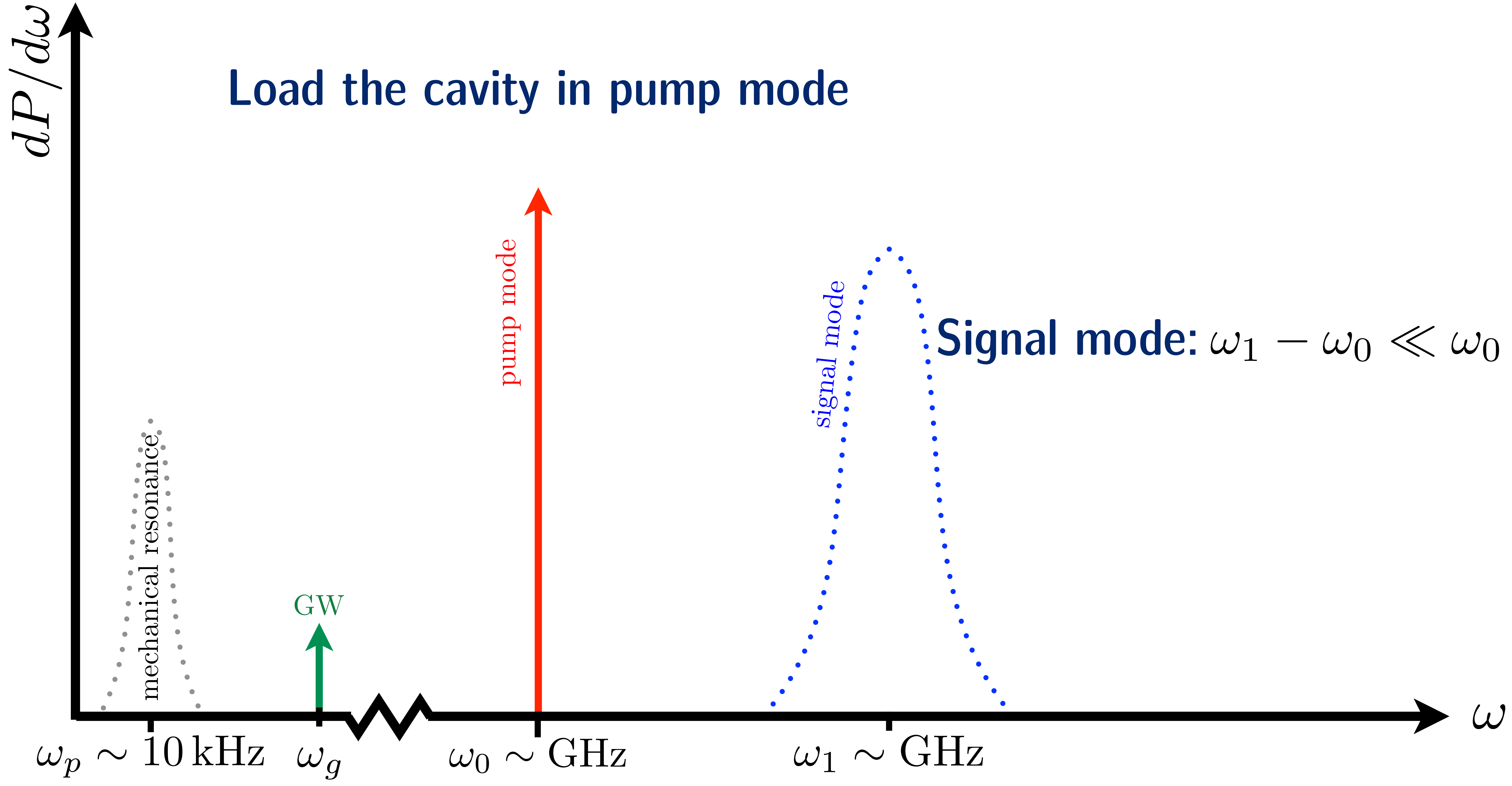
$dP/d\omega$
Load the cavity in pump mode
pump mode
signal mode
Signal mode: $\omega_1 - \omega_0 \ll \omega_0$
ω
$\omega_0 \sim \text{GHz}$
$\omega_1 \sim \text{GHz}$

MAGO 2.0

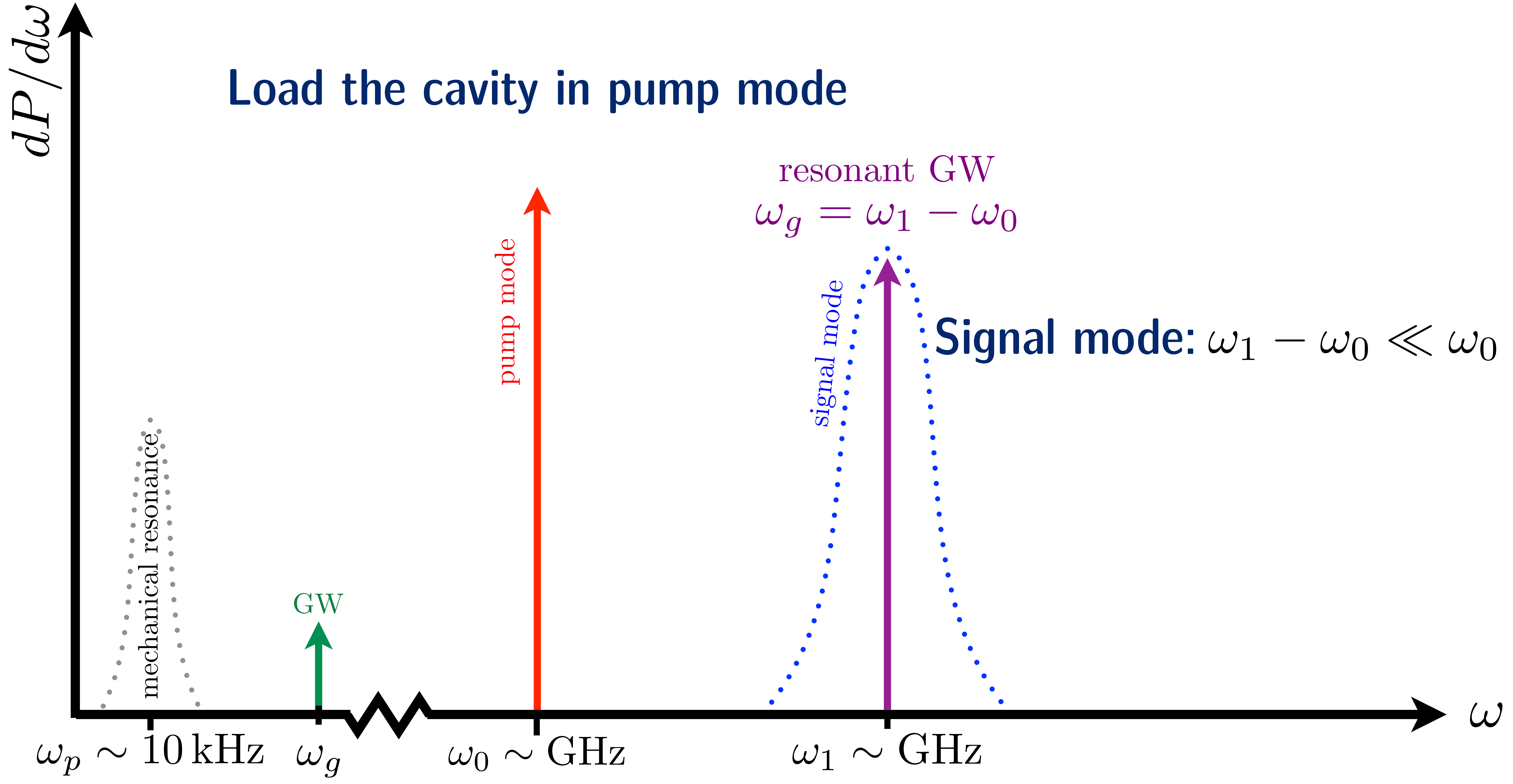


$dP/d\omega$
Load the cavity in pump mode
pump mode
signal mode
Signal mode: $\omega_1 - \omega_0 \ll \omega_0$
mechanical resonance
ω
$\omega_p \sim 10\,\mathrm{kHz}$
$\omega_0 \sim \mathrm{GHz}$
$\omega_1 \sim \mathrm{GHz}$

MAGO 2.0

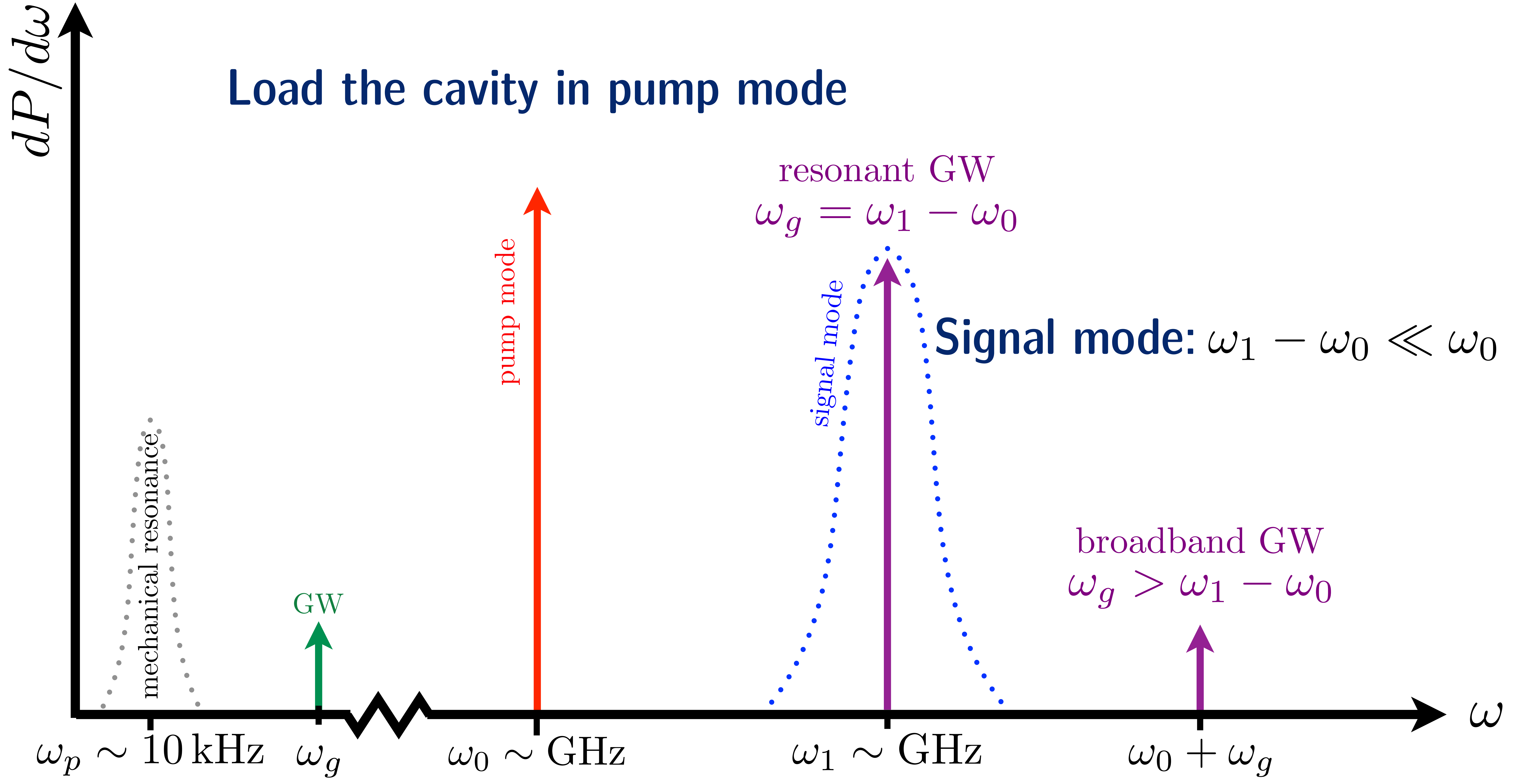

$dP/d\omega$
Load the cavity in pump mode
pump mode
signal mode
Signal mode: $\omega_1 - \omega_0 \ll \omega_0$
mechanical resonance
GW
ω
$\omega_p \sim 10\,\mathrm{kHz}$
ω_g
$\omega_0 \sim \mathrm{GHz}$
$\omega_1 \sim \mathrm{GHz}$

MAGO 2.0



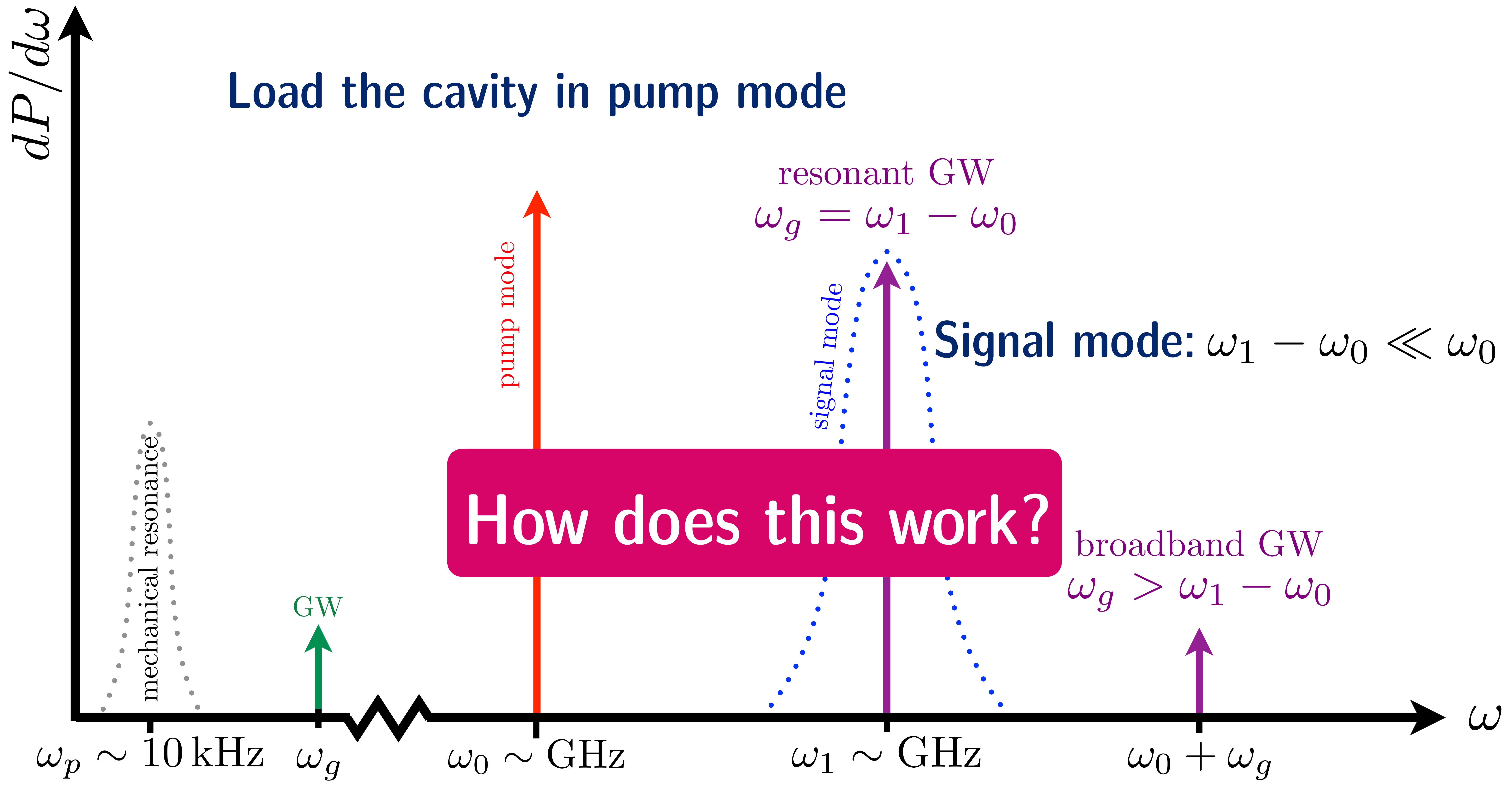
$dP/d\omega$
Load the cavity in pump mode
resonant GW
$\omega_g = \omega_1 - \omega_0$
pump mode
signal mode
Signal mode: $\omega_1 - \omega_0 \ll \omega_0$
mechanical resonance
GW
ω
$\omega_p \sim 10\,\text{kHz}$
ω_g
$\omega_0 \sim \text{GHz}$
$\omega_1 \sim \text{GHz}$

MAGO 2.0



$dP/d\omega$
Load the cavity in pump mode
resonant GW
$\omega_g = \omega_1 - \omega_0$
pump mode
signal mode
Signal mode: $\omega_1 - \omega_0 \ll \omega_0$
mechanical resonance
GW
broadband GW
$\omega_g > \omega_1 - \omega_0$
ω
$\omega_p \sim 10\,\mathrm{kHz}$
ω_g
$\omega_0 \sim \mathrm{GHz}$
$\omega_1 \sim \mathrm{GHz}$
$\omega_0 + \omega_g$

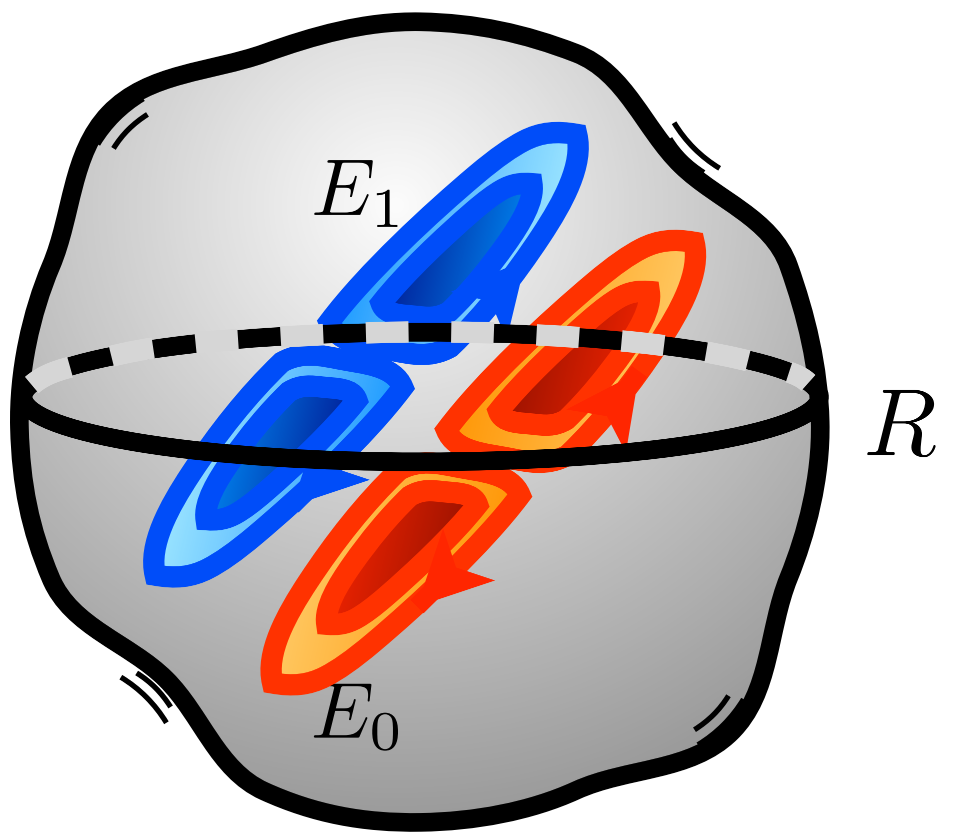
MAGO 2.0



$dP/d\omega$
Load the cavity in pump mode
resonant GW
$\omega_g = \omega_1 - \omega_0$
pump mode
signal mode
Signal mode: $\omega_1 - \omega_0 \ll \omega_0$
How does this work?
broadband GW
$\omega_g > \omega_1 - \omega_0$
mechanical resonance
GW
ω
$\omega_p \sim 10\,\mathrm{kHz}$
ω_g
$\omega_0 \sim \mathrm{GHz}$
$\omega_1 \sim \mathrm{GHz}$
$\omega_0 + \omega_g$

MAGO 2.0

$\omega \sim \mathrm{GHz}$



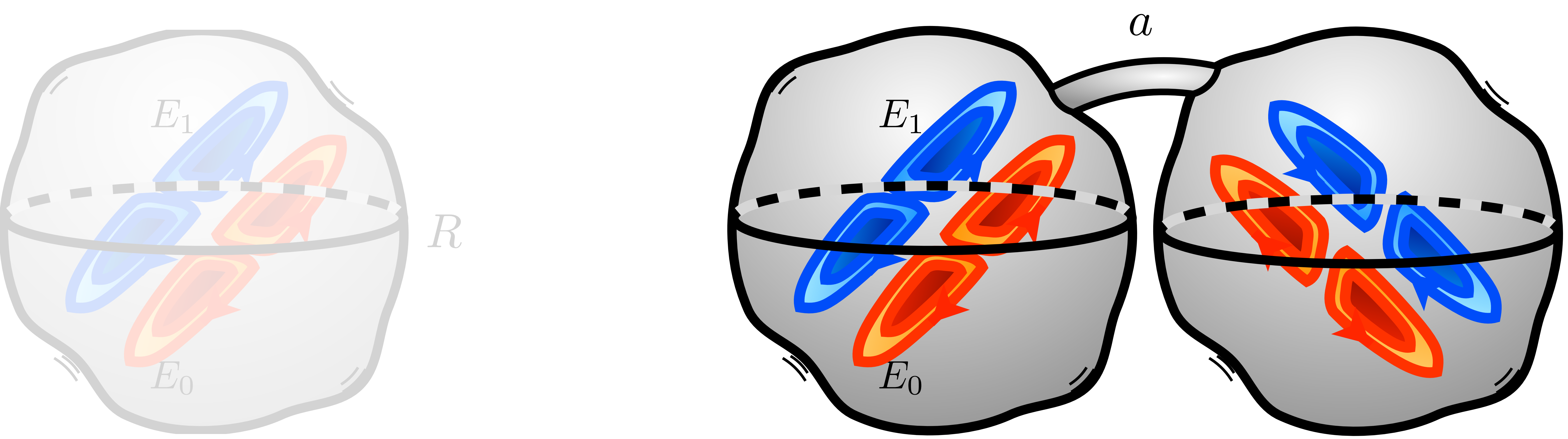
MAGO 2.0

$$\omega \sim \mathrm{GHz}$$

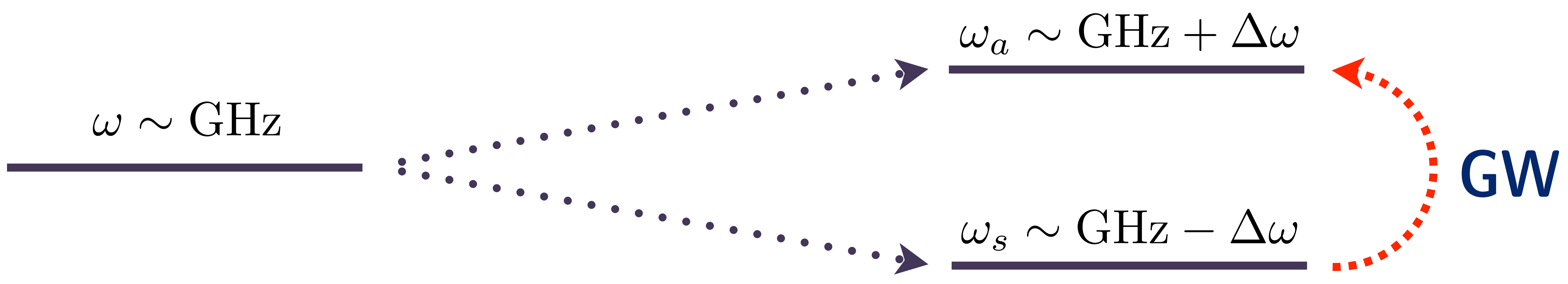
$$\omega_a \sim \mathrm{GHz} + \Delta\omega$$

$$\omega_s \sim \mathrm{GHz} - \Delta\omega$$

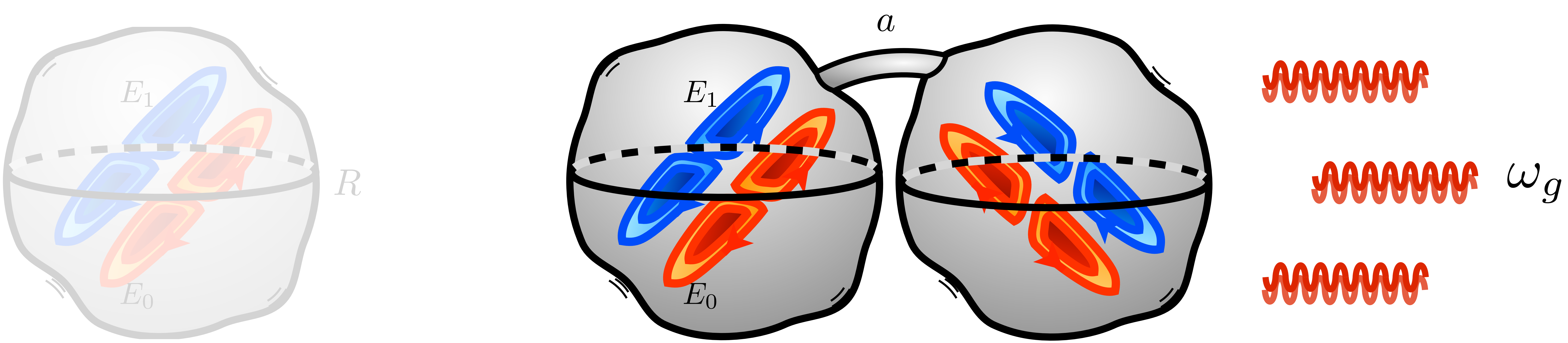
$$\Delta\omega \sim (a/R)^3$$



MAGO 2.0

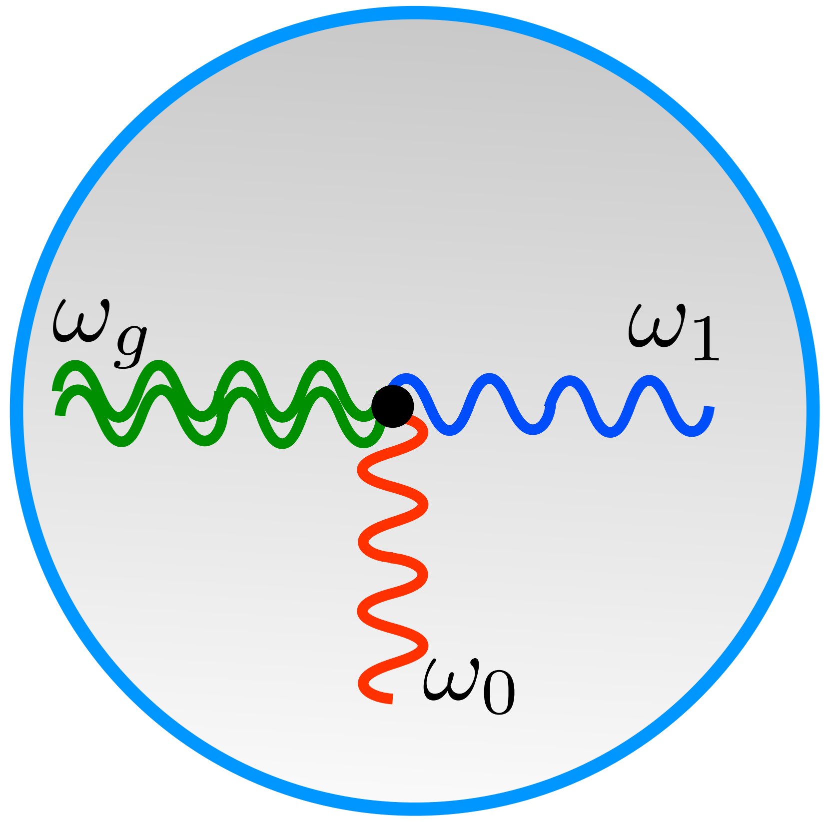


$\Delta\omega \sim (a/R)^3$



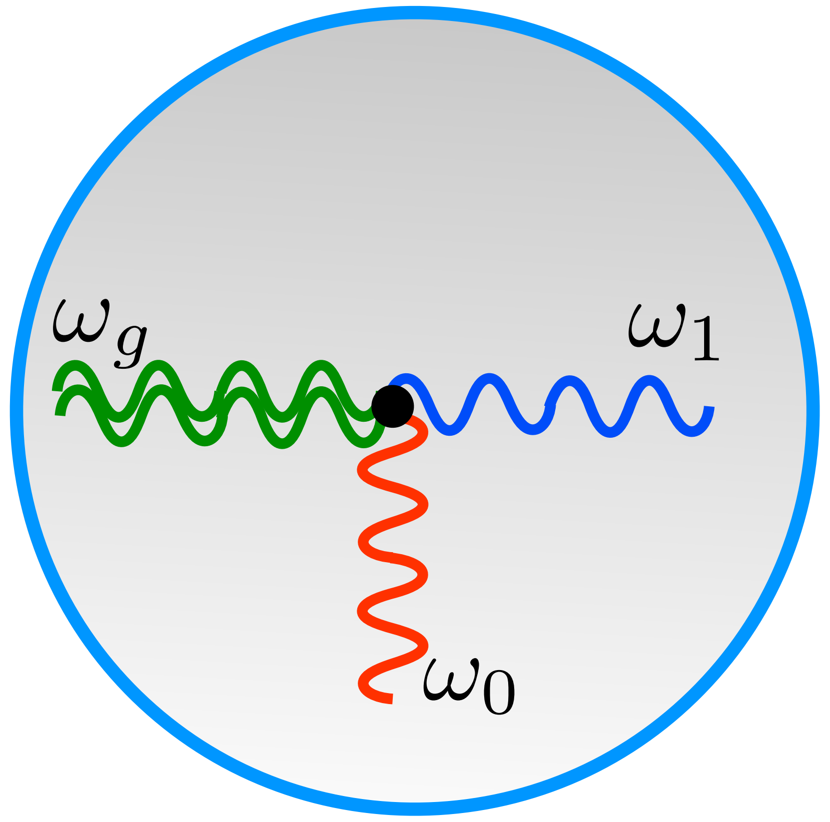
EM and Mechanical signals

EM and Mechanical signals



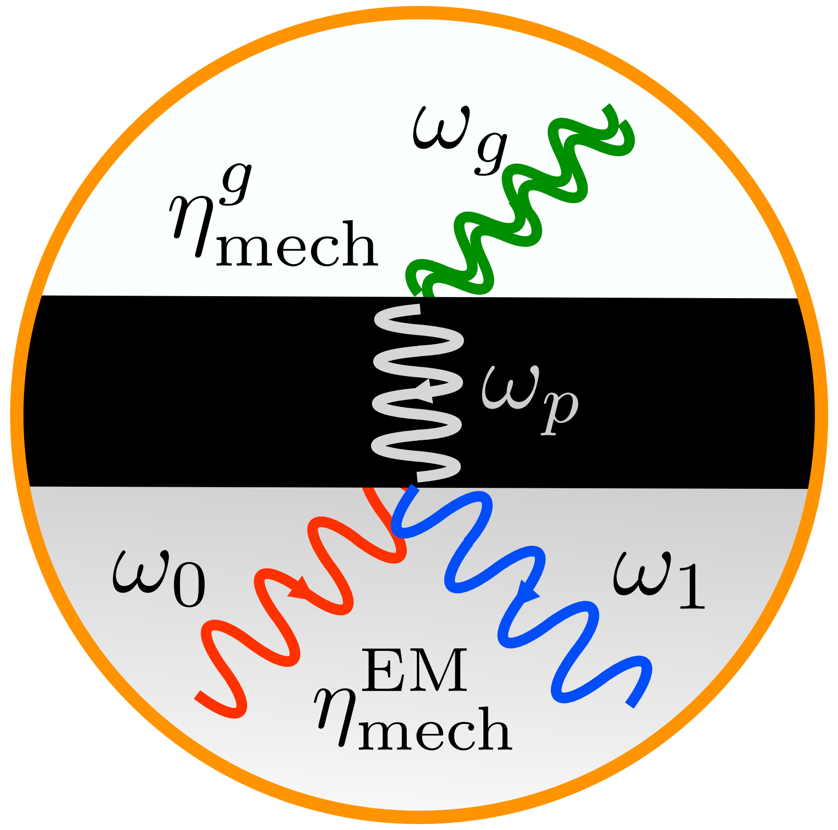
Parametrics of the EM signal: $E_{\rm sig}^{\rm (EM)} \sim Q_{\rm em}\,(\omega_g\,L_{\rm cav})^2\,h^{\rm TT}\,E_0$

EM and Mechanical signals

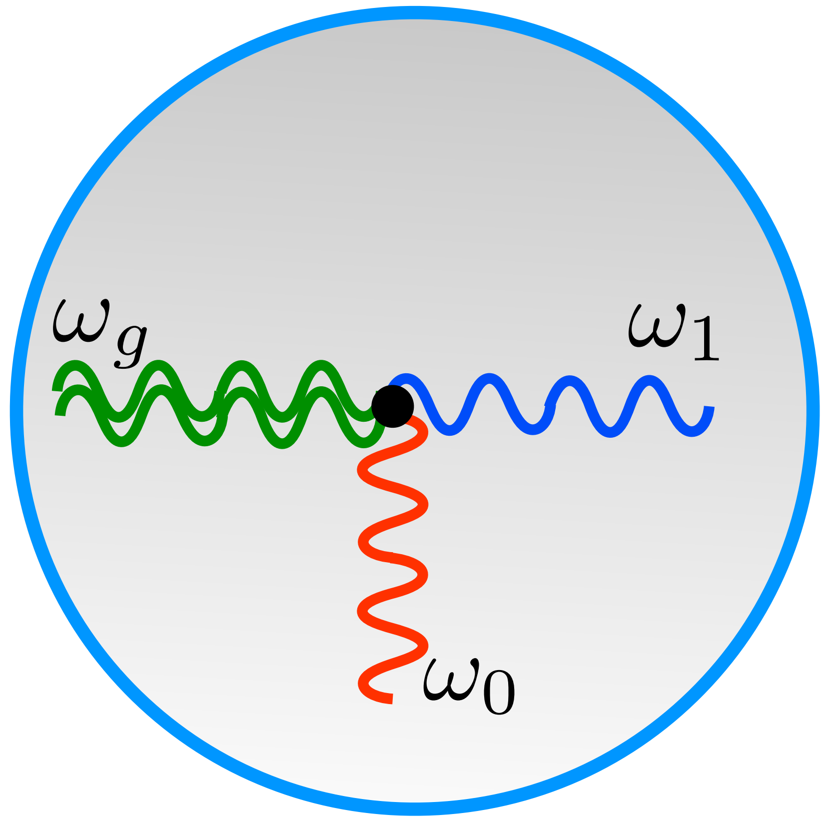


Parametrics of the EM signal: $E_{\rm sig}^{\rm (EM)} \sim Q_{\rm em}\,(\omega_g\,L_{\rm cav})^2\,h^{\rm TT}\,E_0$

Mechanical signal: $$E_{\rm sig}^{\rm (mech)} \sim Q_{\rm em}\,h^{\rm TT}\,E_0\,\min\left(1\,,\,\frac{\omega_g\,L_{\rm cav}}{c_s}\right)^2$$



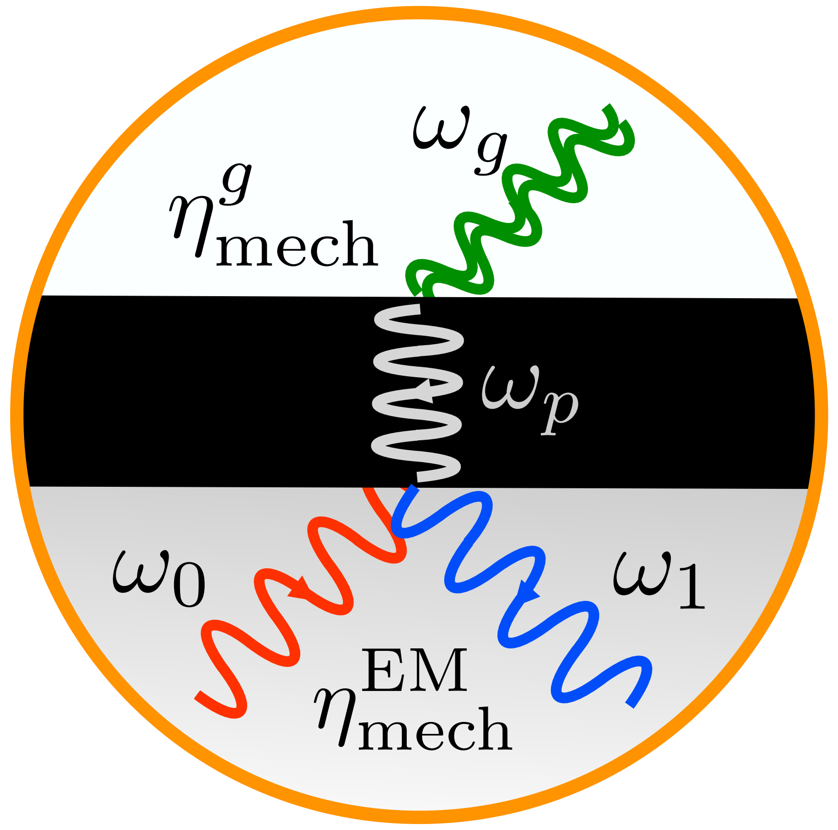
EM and Mechanical signals



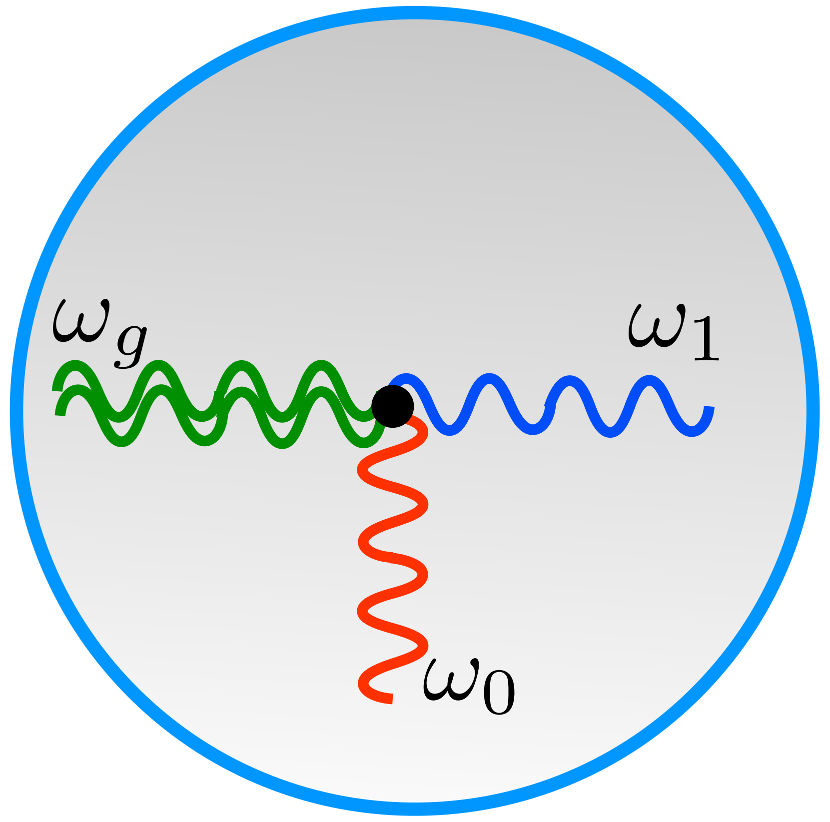
Parametrics of the EM signal: $E_{\rm sig}^{\rm (EM)} \sim Q_{\rm em}\,(\omega_g\,L_{\rm cav})^2\,h^{\rm TT}\,E_0$

Enhanced by up to $1/c_s^2 \gg 1$ *(!)*

Mechanical signal: $$E_{\rm sig}^{\rm (mech)} \sim Q_{\rm em}\,h^{\rm TT}\,E_0\,\min\left(1\,,\,\frac{\omega_g\,L_{\rm cav}}{c_s}\right)^2$$



EM and Mechanical signals

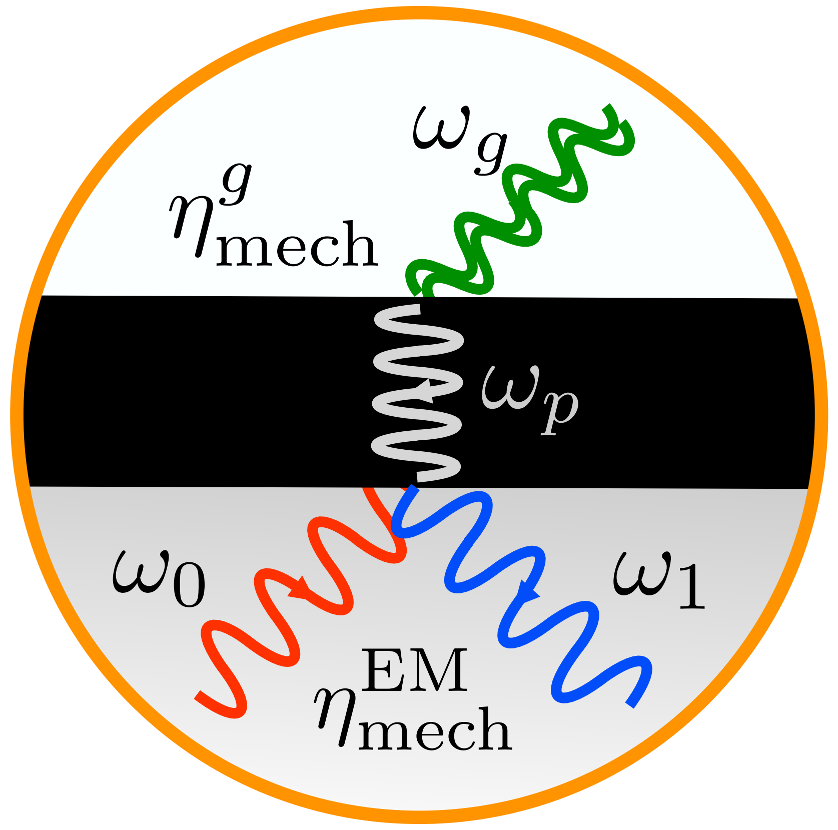


Parametrics of the EM signal: $E_{\rm sig}^{\rm (EM)} \sim Q_{\rm em}\,(\omega_g\,L_{\rm cav})^2\,h^{\rm TT}\,E_0$

Enhanced by up to $1/c_s^2 \gg 1$ *(!)*

Mechanical signal:

$$E_{\rm sig}^{\rm (mech)} \sim Q_{\rm em}\,h^{\rm TT}\,E_0\,\min\left(1\,,\,\frac{\omega_g\,L_{\rm cav}}{c_s}\right)^2$$

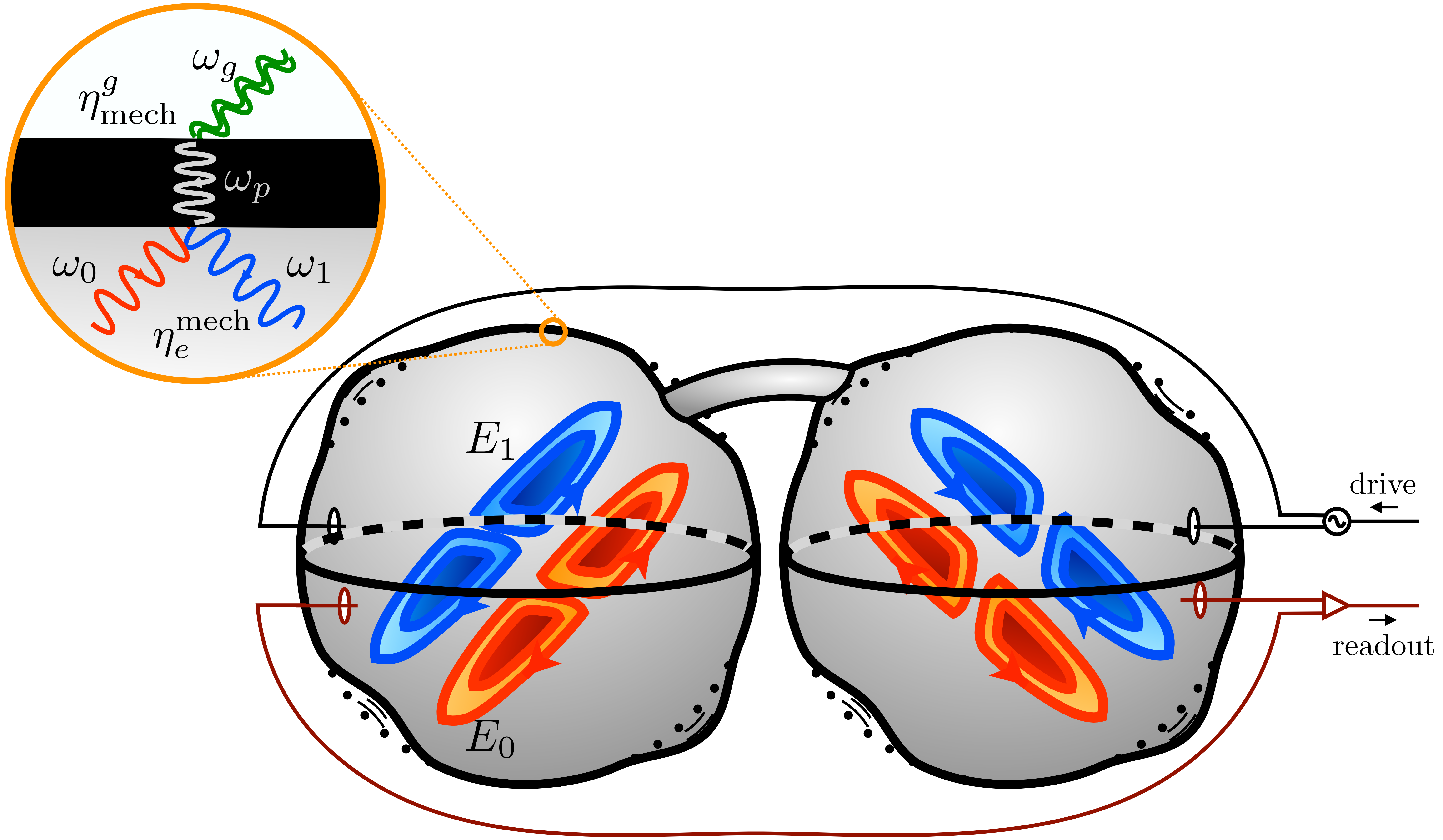


Mechanical modes less “rigid” than EM modes

Gravitational Wave Signal: *Mechanical*

Mechanical modes of a hollow sphere:

$$\mathbf{q}_{mnl} = q_{0,mn}\left[f_{mn}(r)Y_{ml}(\theta,\varphi)\hat{r} - i g_{mn}(r)\hat{r}\times \mathbf{L}Y_{ml}(\theta,\varphi)\right]$$



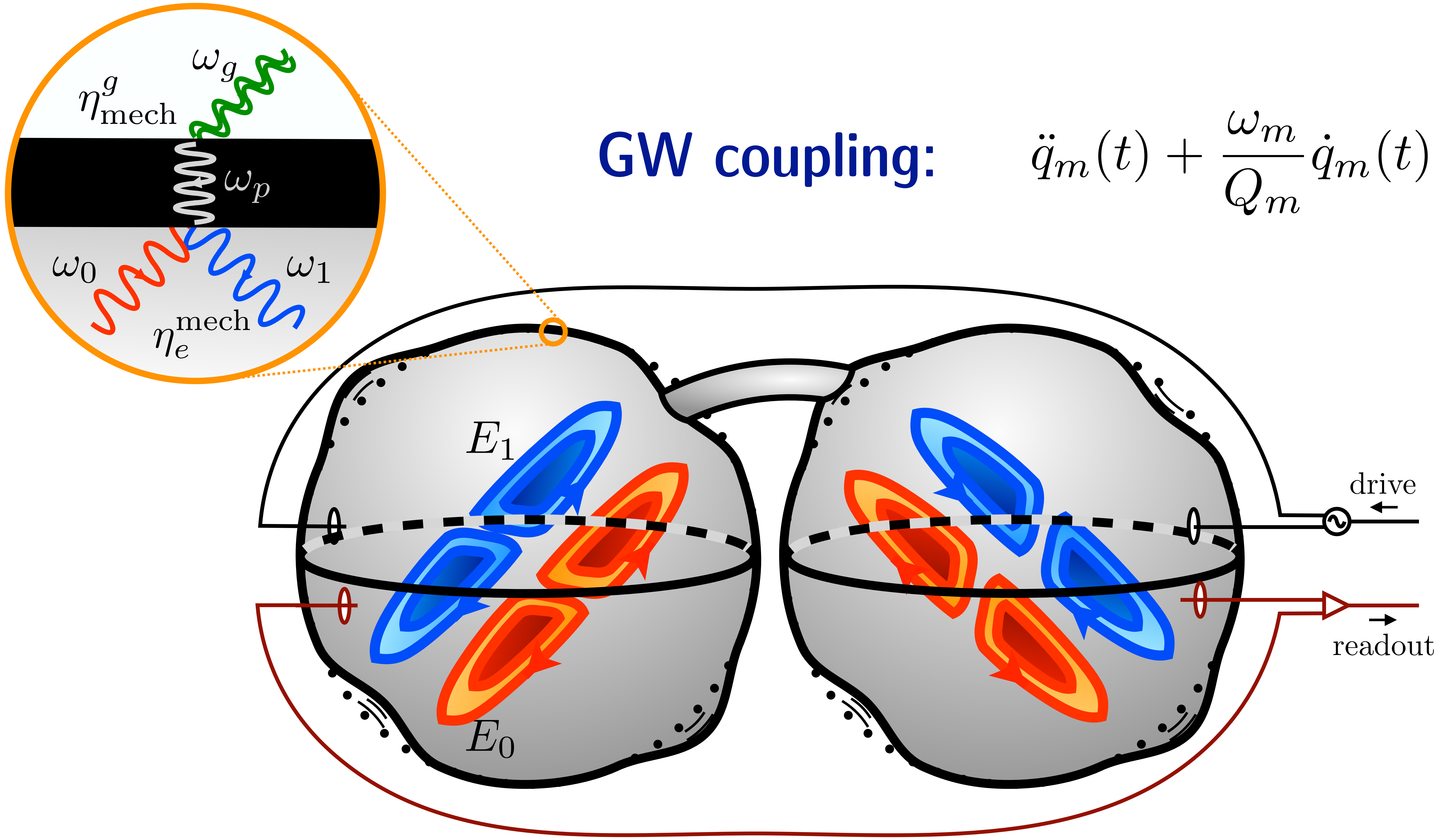
Gravitational Wave Signal: *Mechanical*

Mechanical modes of a hollow sphere:

$$\mathbf{q}_{mnl} = q_{0,mn}\left[f_{mn}(r)Y_{ml}(\theta,\varphi)\hat{r} - i g_{mn}(r)\hat{r}\times\mathbf{L}Y_{ml}(\theta,\varphi)\right]$$

GW coupling:

$$\ddot{q}_m(t) + \frac{\omega_m}{Q_m}\dot{q}_m(t) + \omega_m^2 q_m(t) = \frac{1}{2}\ddot{h}_{ij}^{\rm TT}\int_V d^3\mathbf{x}\, x_j (q_{mnl})_i$$



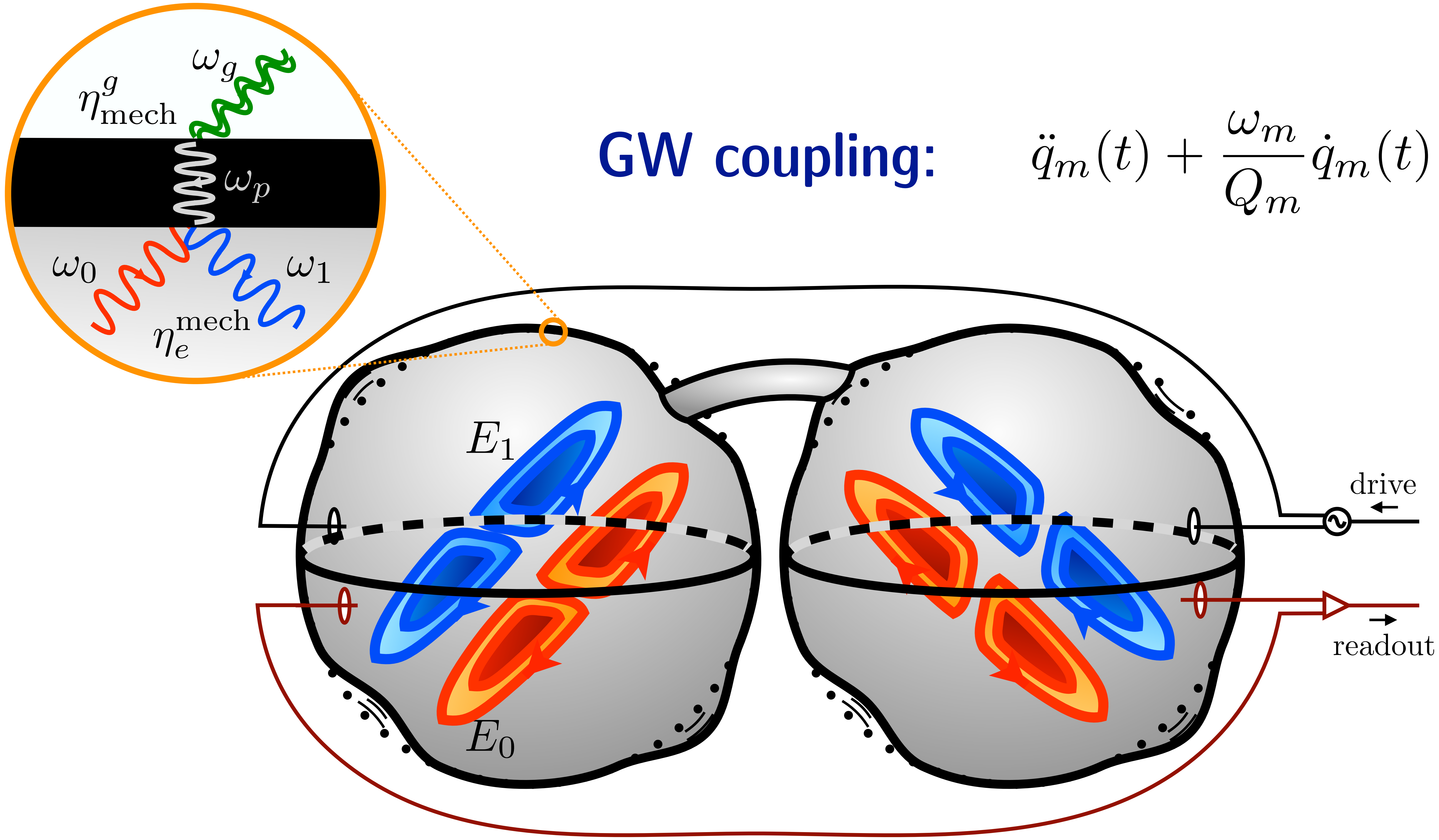
Gravitational Wave Signal: *Mechanical*

Mechanical modes of a hollow sphere:

$$\mathbf{q}_{mnl} = q_{0,mn}\left[f_{mn}(r)Y_{ml}(\theta,\varphi)\hat{r} - i g_{mn}(r)\hat{r}\times\mathbf{L}Y_{ml}(\theta,\varphi)\right]$$

GW coupling:

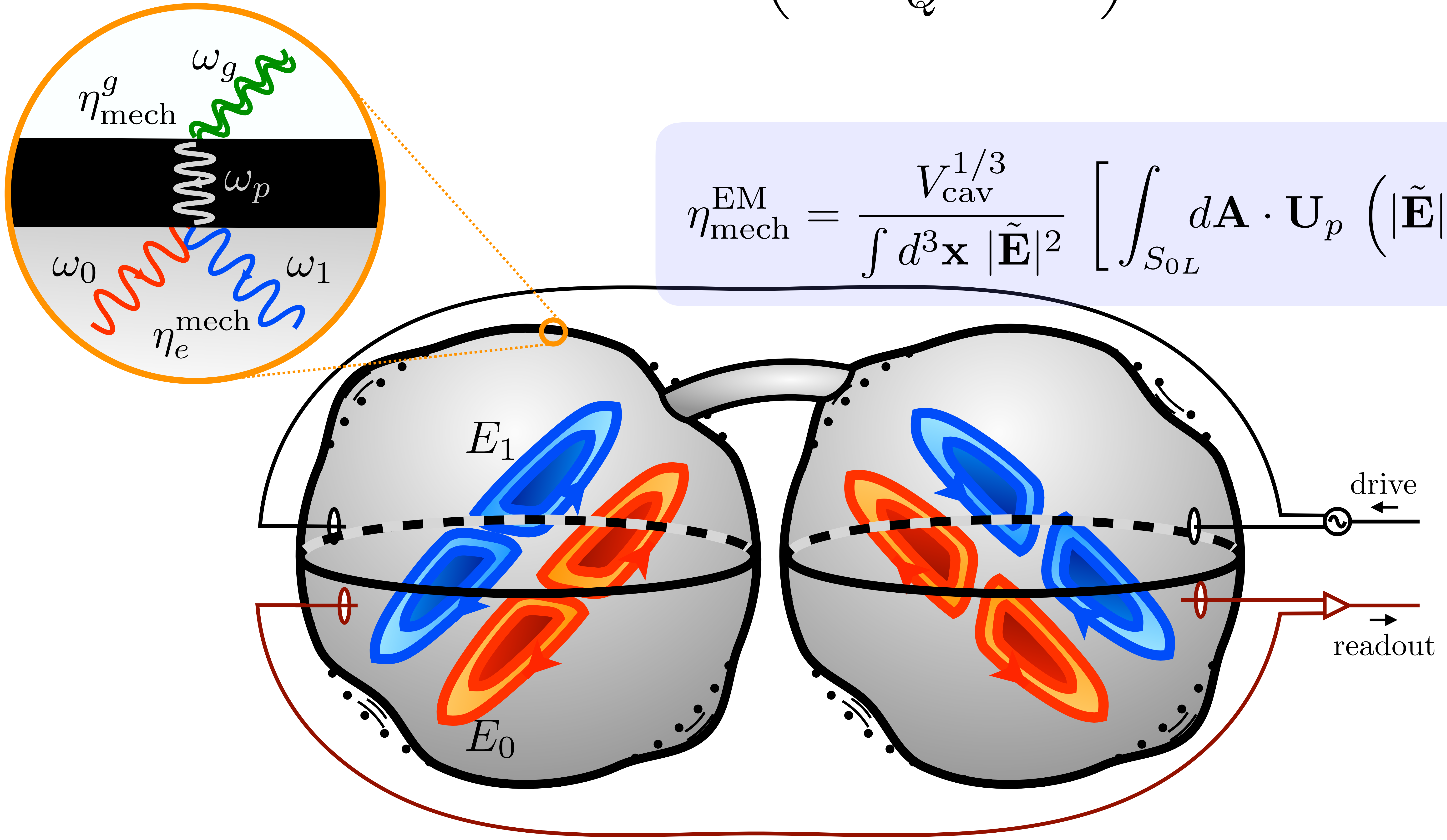
$$\ddot{q}_m(t) + \frac{\omega_m}{Q_m}\dot{q}_m(t) + \omega_m^2 q_m(t) = \underbrace{\frac{1}{2}\ddot{h}^{\mathrm{TT}}_{ij}\int_V d^3\mathbf{x}\, x_j (q_{mnl})_i}_{\eta_u^{\mathrm{mech}}}$$



Gravitational Wave Signal: *Mechanical*

Mechanical coupling to EM: $$\left(\partial_t^2 + \frac{\omega_1}{Q}\partial_t + \omega_1^2\right) e_1 = -\omega_1^2 e_0 \frac{\int_{\Delta V} d^3x \left(\mathbf{E}_0 \cdot \mathbf{E}_1^* - (\omega_0/\omega_1)\mathbf{B}_0 \cdot \mathbf{B}_1^*\right)}{\int_{V_0} d^3x |\mathbf{E}_1|^2} + \mathcal{O}(h^2)$$

$$\eta_{\rm mech}^{\rm EM} = \frac{V_{\rm cav}^{1/3}}{\int d^3\mathbf{x}\ |\tilde{\mathbf{E}}|^2} \left[\int_{S_{0L}} d\mathbf{A} \cdot \mathbf{U}_p \left(|\tilde{\mathbf{E}}|^2 - |\tilde{\mathbf{B}}|^2\right) - \int_{S_{0R}} d\mathbf{A} \cdot \mathbf{U}_p \left(|\mathcal{R}\tilde{\mathbf{E}}|^2 - |\mathcal{R}\tilde{\mathbf{B}}|^2\right) \right]$$

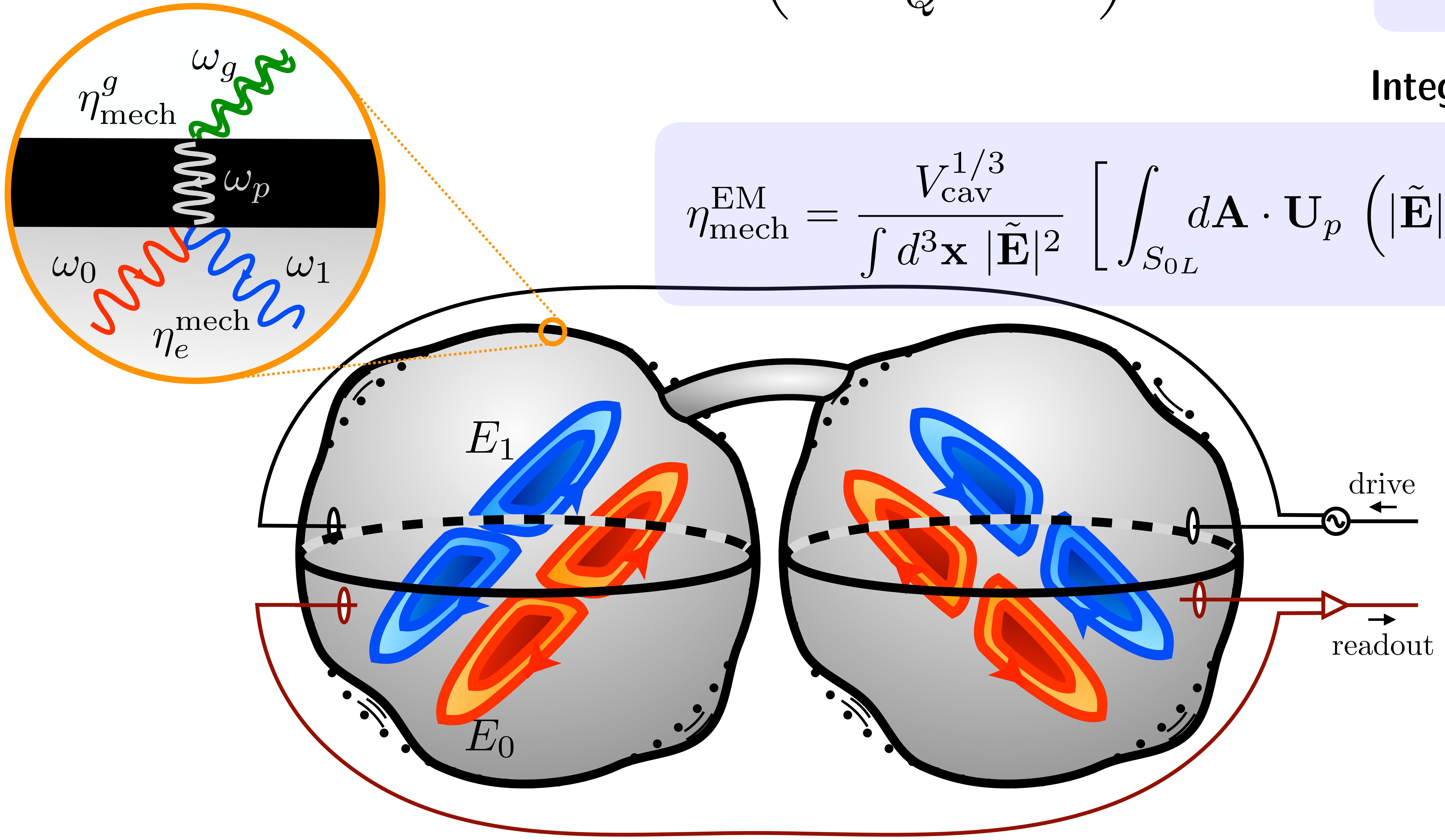


Gravitational Wave Signal: *Mechanical*

Mechanical coupling to EM: $$\left(\partial_t^2 + \frac{\omega_1}{Q}\partial_t + \omega_1^2\right) e_1 = -\omega_1^2 e_0 \frac{\int_{\Delta V} d^3x\,(\mathbf{E}_0\cdot\mathbf{E}_1^* - (\omega_0/\omega_1)\mathbf{B}_0\cdot\mathbf{B}_1^*)}{\int_{V_0} d^3x|\mathbf{E}_1|^2} + \mathcal{O}(h^2)$$

Integral over deformation to cavity volume

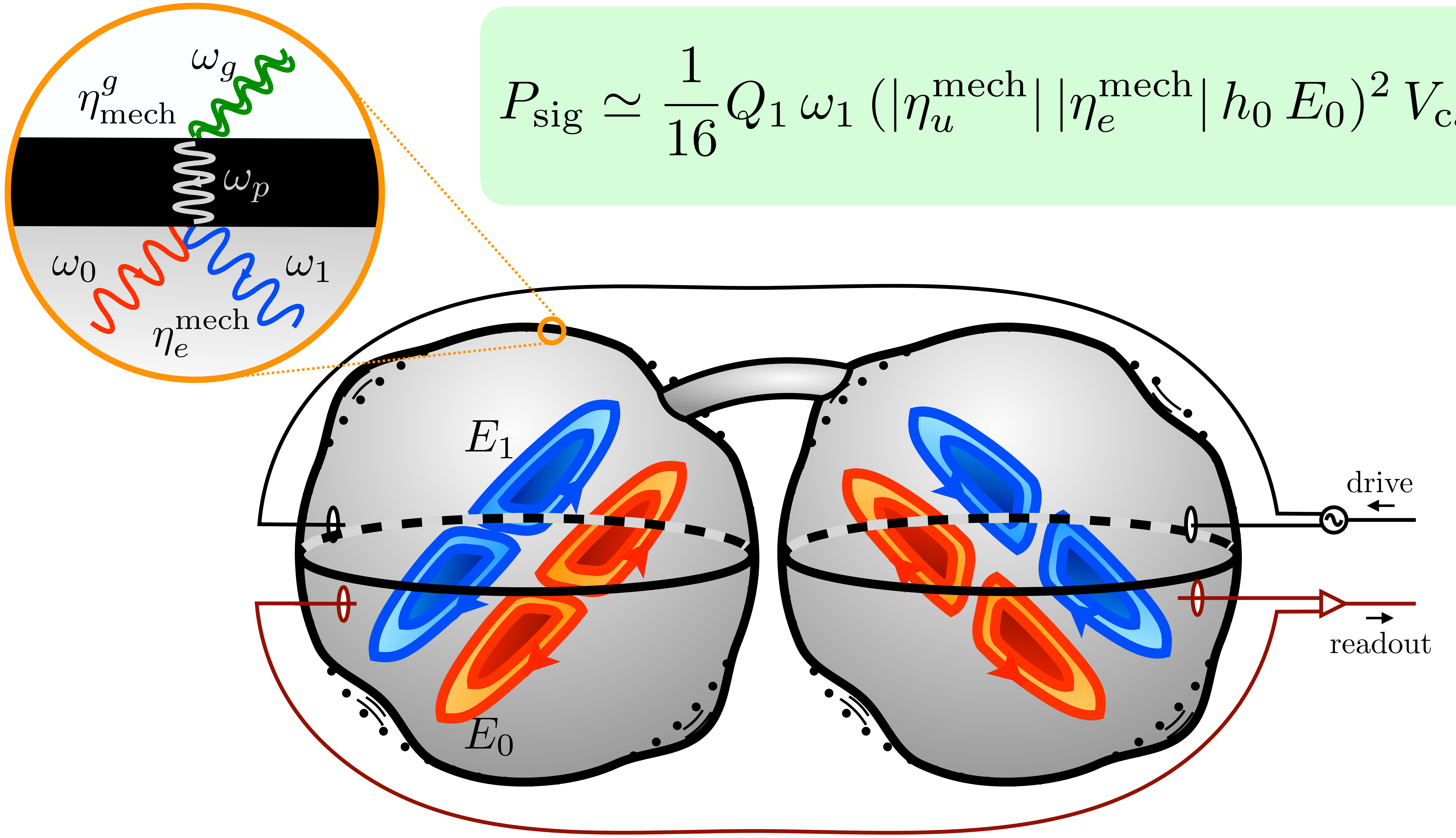
$$\eta_{\rm mech}^{\rm EM} = \frac{V_{\rm cav}^{1/3}}{\int d^3\mathbf{x}\,|\tilde{\mathbf{E}}|^2}\left[\int_{S_{0L}} d\mathbf{A}\cdot\mathbf{U}_p\left(|\tilde{\mathbf{E}}|^2 - |\tilde{\mathbf{B}}|^2\right) - \int_{S_{0R}} d\mathbf{A}\cdot\mathbf{U}_p\left(|\mathcal{R}\tilde{\mathbf{E}}|^2 - |\mathcal{R}\tilde{\mathbf{B}}|^2\right)\right]$$



Gravitational Wave Signal: *Mechanical*

Power in a heterodyne setup from monochromatic source

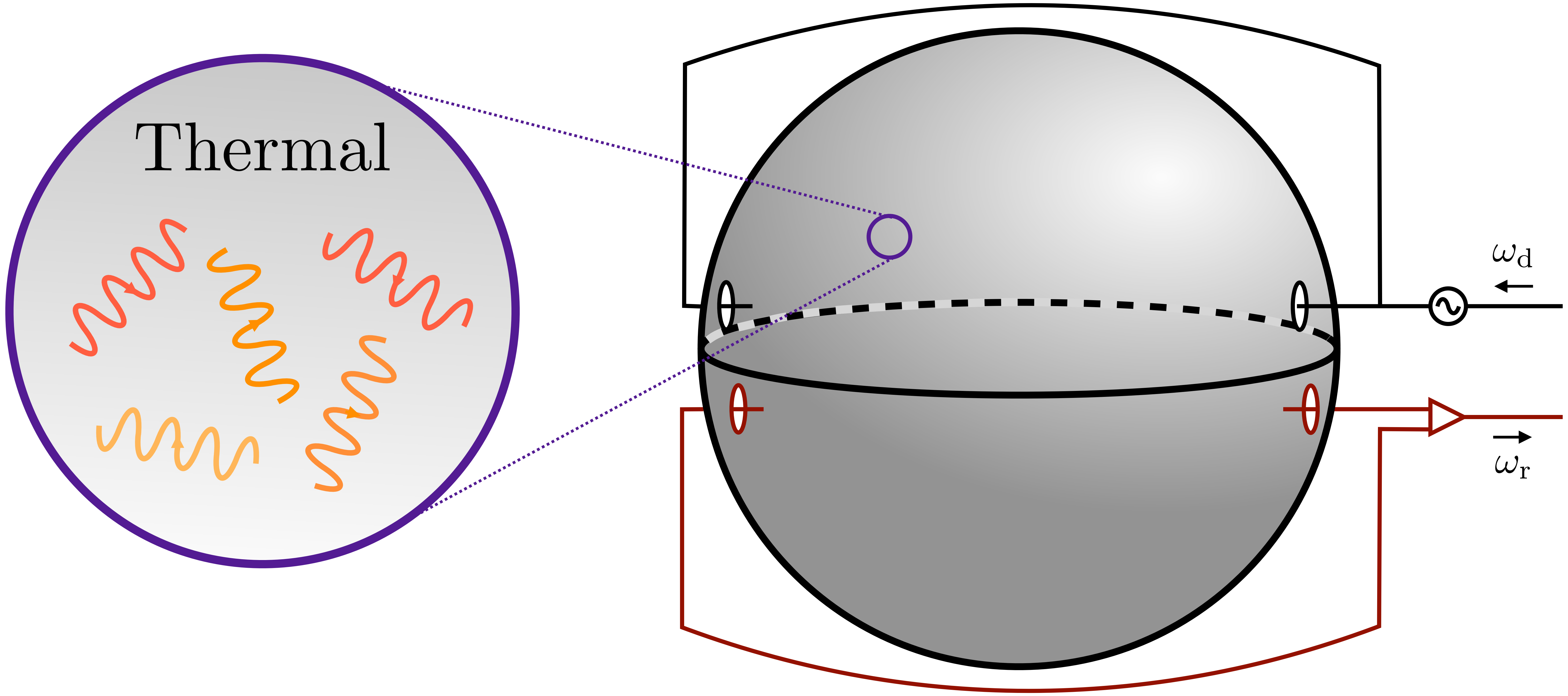
$$P_{\rm sig} \simeq \frac{1}{16} Q_1\, \omega_1 \left(|\eta_u^{\rm mech}|\, |\eta_e^{\rm mech}|\, h_0\, E_0 \right)^2 V_{\rm cav} \times \begin{cases} Q_m^2 & \omega_g^2 - \omega_m^2 \ll \frac{\omega_m \omega_g}{Q_m} \\ \frac{\omega_g^4}{(\omega_g^2 - \omega_m^2)^2} & \omega_g^2 - \omega_m^2 \gg \frac{\omega_m \omega_g}{Q_m} \end{cases}$$



Thermal Noise

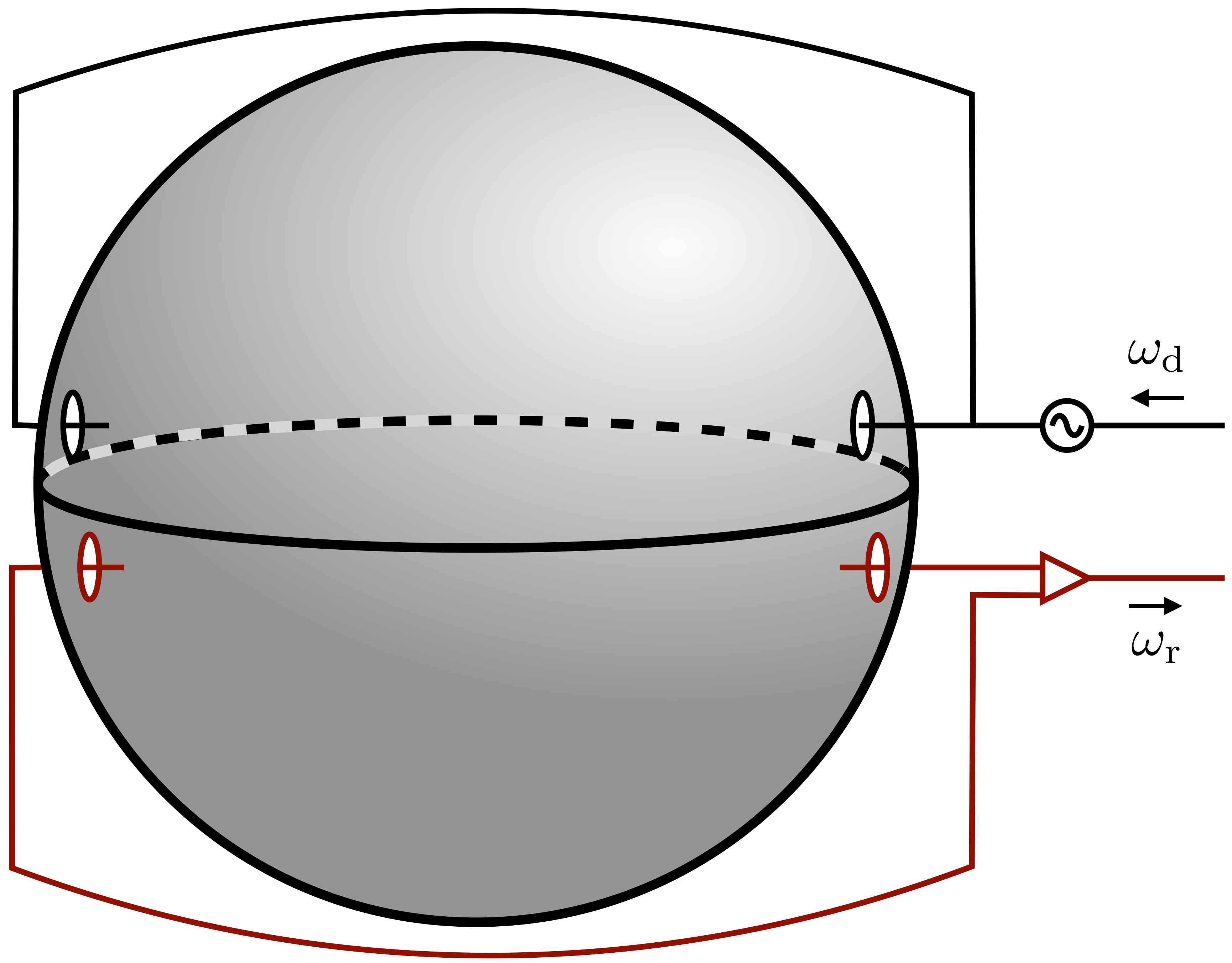
Power spectral density:

$$S_{\rm th}(\omega) = \frac{Q_1}{Q_{\rm int}} \frac{4\pi T\,(\omega\,\omega_1/Q_1)^2}{(\omega^2-\omega_1^2)^2+(\omega\,\omega_1/Q_1)^2}$$



Phase Noise

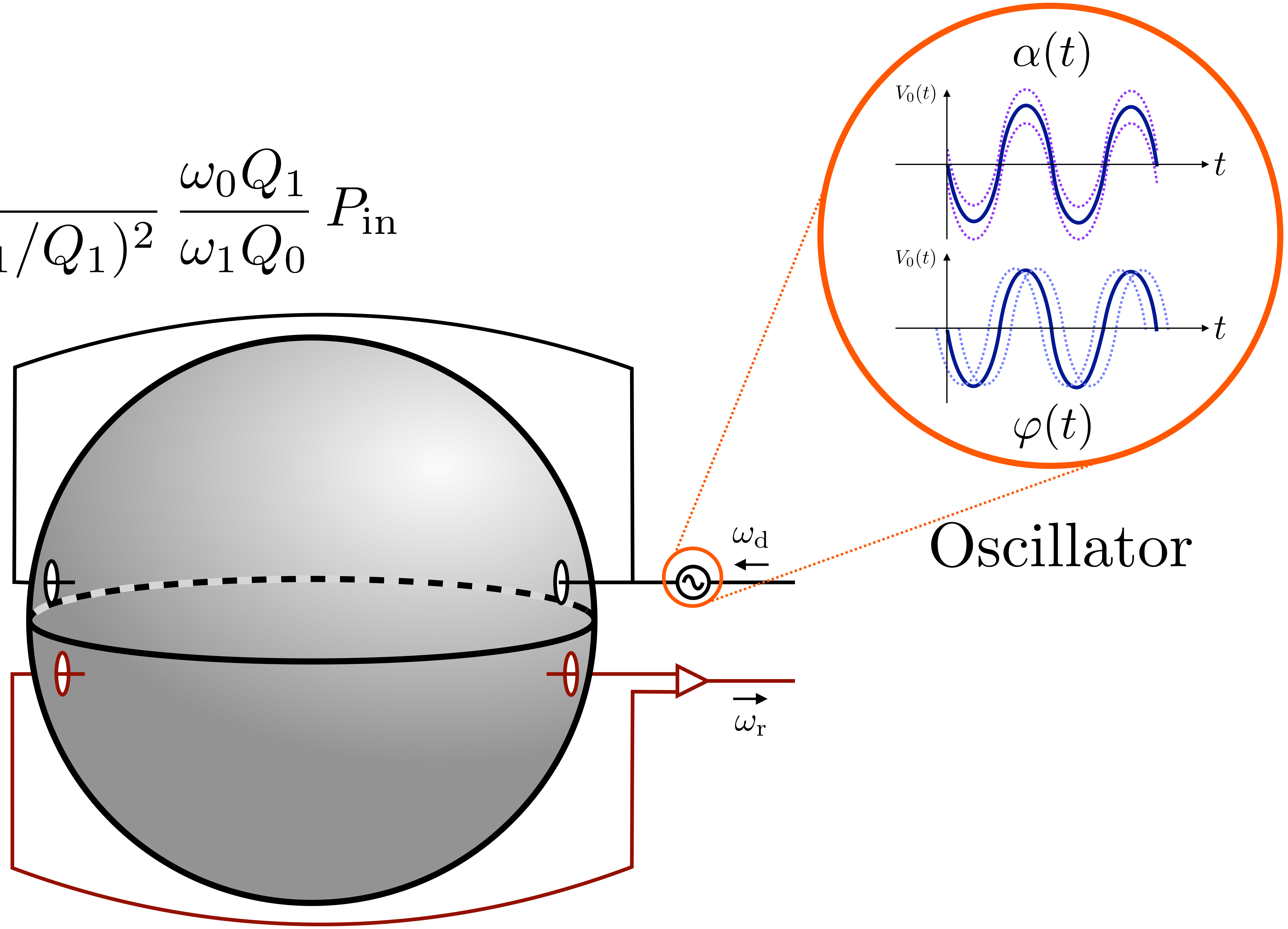
$$S_{\text{phase}}(\omega) \simeq \frac{1}{2}\,\epsilon_{1\text{d}}^2\, S_\varphi(\omega-\omega_0)$$
$$\times \frac{(\omega\,\omega_1/Q_1)^2}{(\omega^2-\omega_1^2)^2+(\omega\,\omega_1/Q_1)^2}\,\frac{\omega_0 Q_1}{\omega_1 Q_0}\,P_{\text{in}}$$



Phase Noise

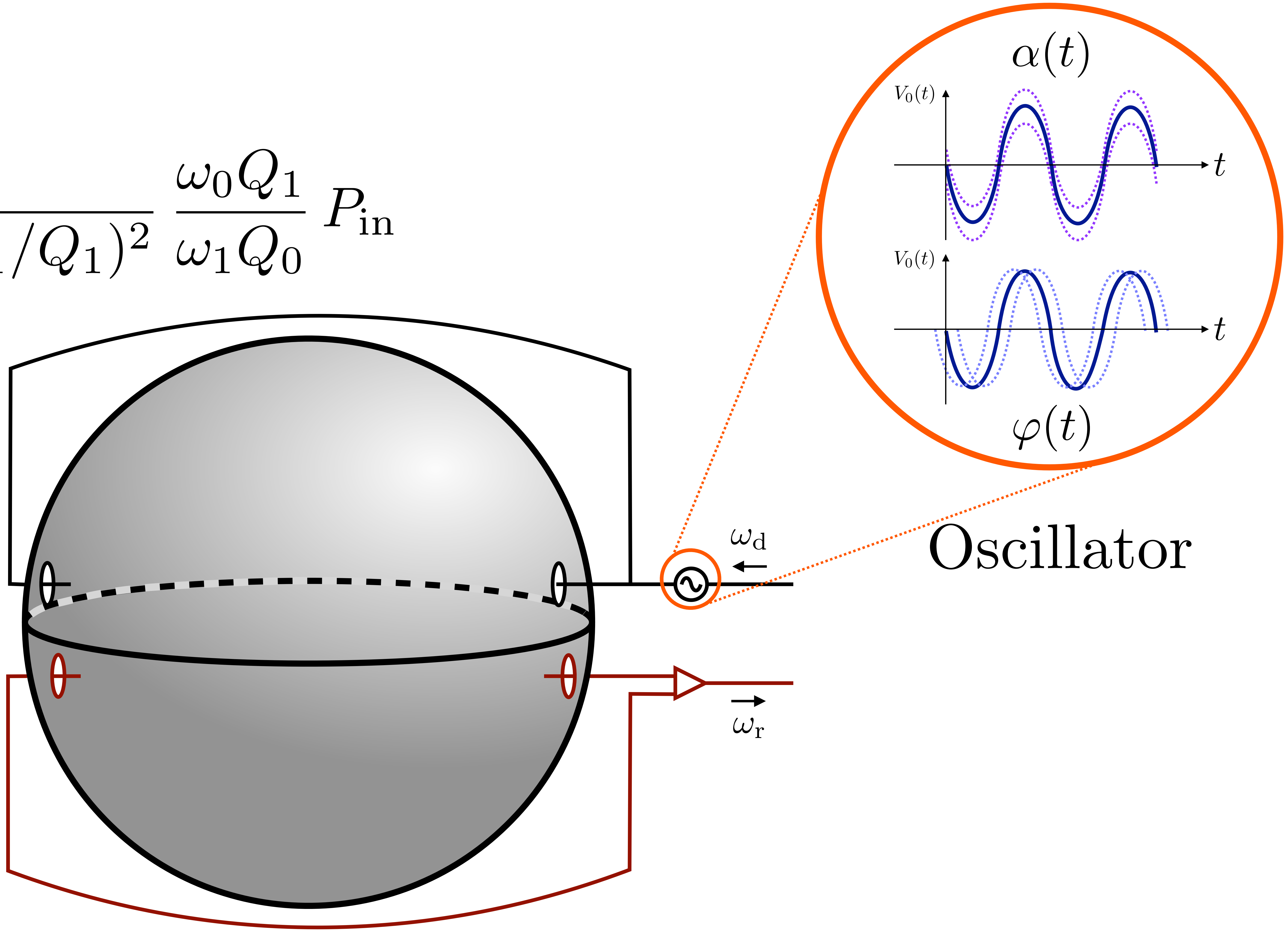
$$S_{\rm phase}(\omega) \simeq \frac{1}{2}\,\epsilon_{1\rm d}^2\, S_\varphi(\omega-\omega_0)$$

$$\times \frac{(\omega\,\omega_1/Q_1)^2}{(\omega^2-\omega_1^2)^2+(\omega\,\omega_1/Q_1)^2}\,\frac{\omega_0 Q_1}{\omega_1 Q_0}\,P_{\rm in}$$



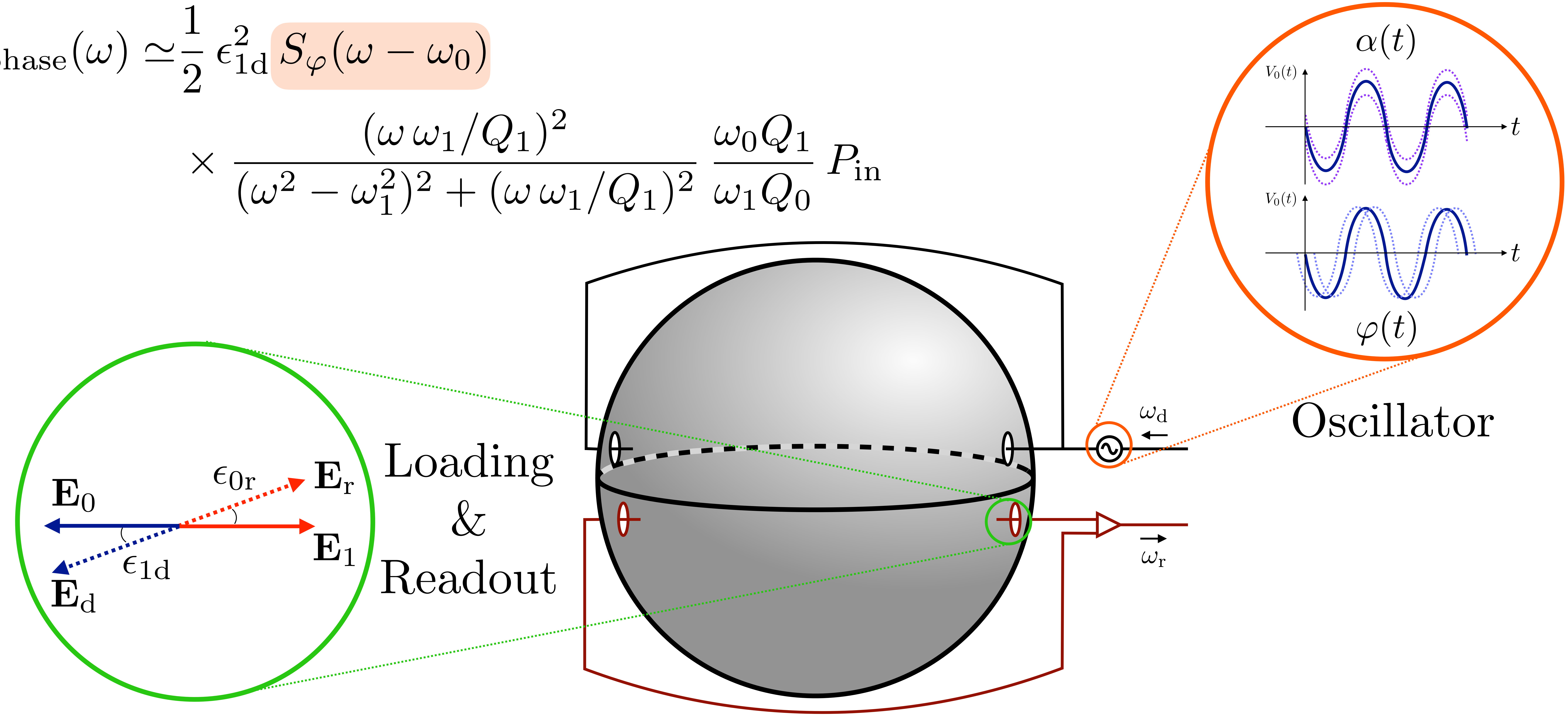
Phase Noise

$$S_{\text{phase}}(\omega) \simeq \frac{1}{2}\,\epsilon_{1\text{d}}^2\, S_\varphi(\omega-\omega_0)$$
$$\times \frac{(\omega\,\omega_1/Q_1)^2}{(\omega^2-\omega_1^2)^2+(\omega\,\omega_1/Q_1)^2}\,\frac{\omega_0 Q_1}{\omega_1 Q_0}\,P_{\text{in}}$$



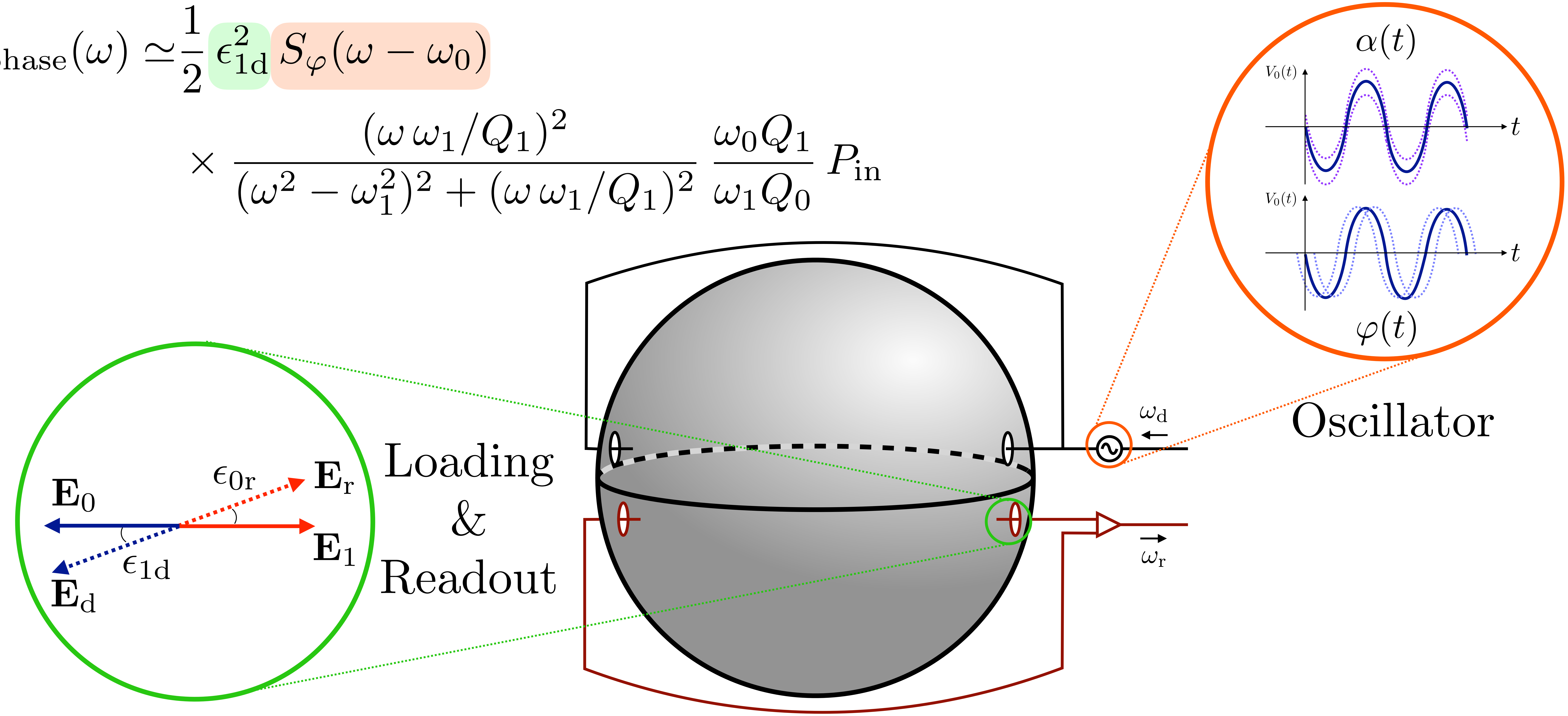
Phase Noise

$$S_{\text{phase}}(\omega) \simeq \frac{1}{2}\,\epsilon_{1\text{d}}^2\, S_\varphi(\omega-\omega_0)$$
$$\times \frac{(\omega\,\omega_1/Q_1)^2}{(\omega^2-\omega_1^2)^2+(\omega\,\omega_1/Q_1)^2}\,\frac{\omega_0 Q_1}{\omega_1 Q_0}\,P_{\text{in}}$$



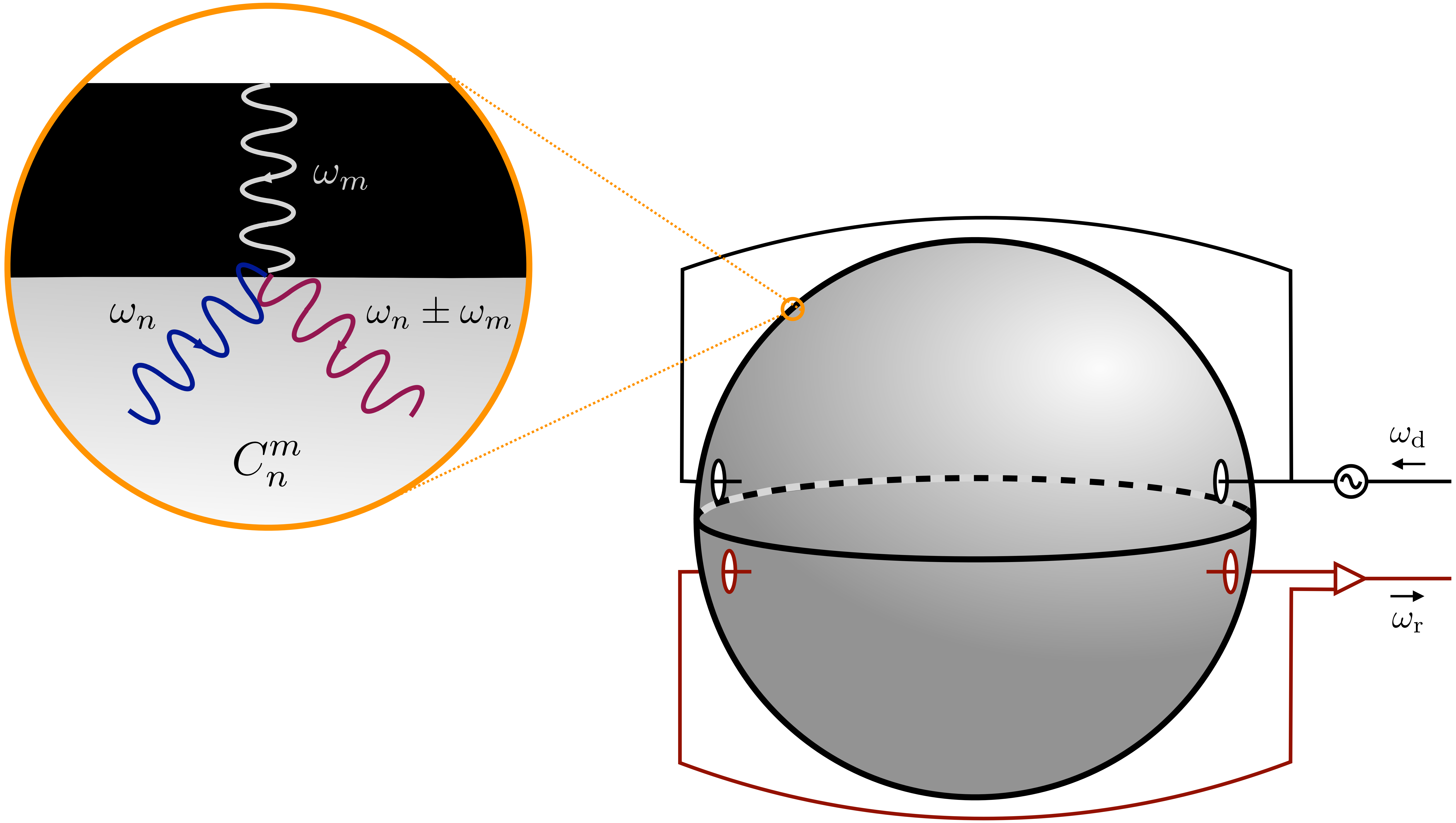
Phase Noise

$$S_{\text{phase}}(\omega) \simeq \frac{1}{2}\,\epsilon_{1\text{d}}^2\, S_\varphi(\omega-\omega_0) \times \frac{(\omega\,\omega_1/Q_1)^2}{(\omega^2-\omega_1^2)^2+(\omega\,\omega_1/Q_1)^2}\,\frac{\omega_0 Q_1}{\omega_1 Q_0}\,P_{\text{in}}$$



Mechanical Noise

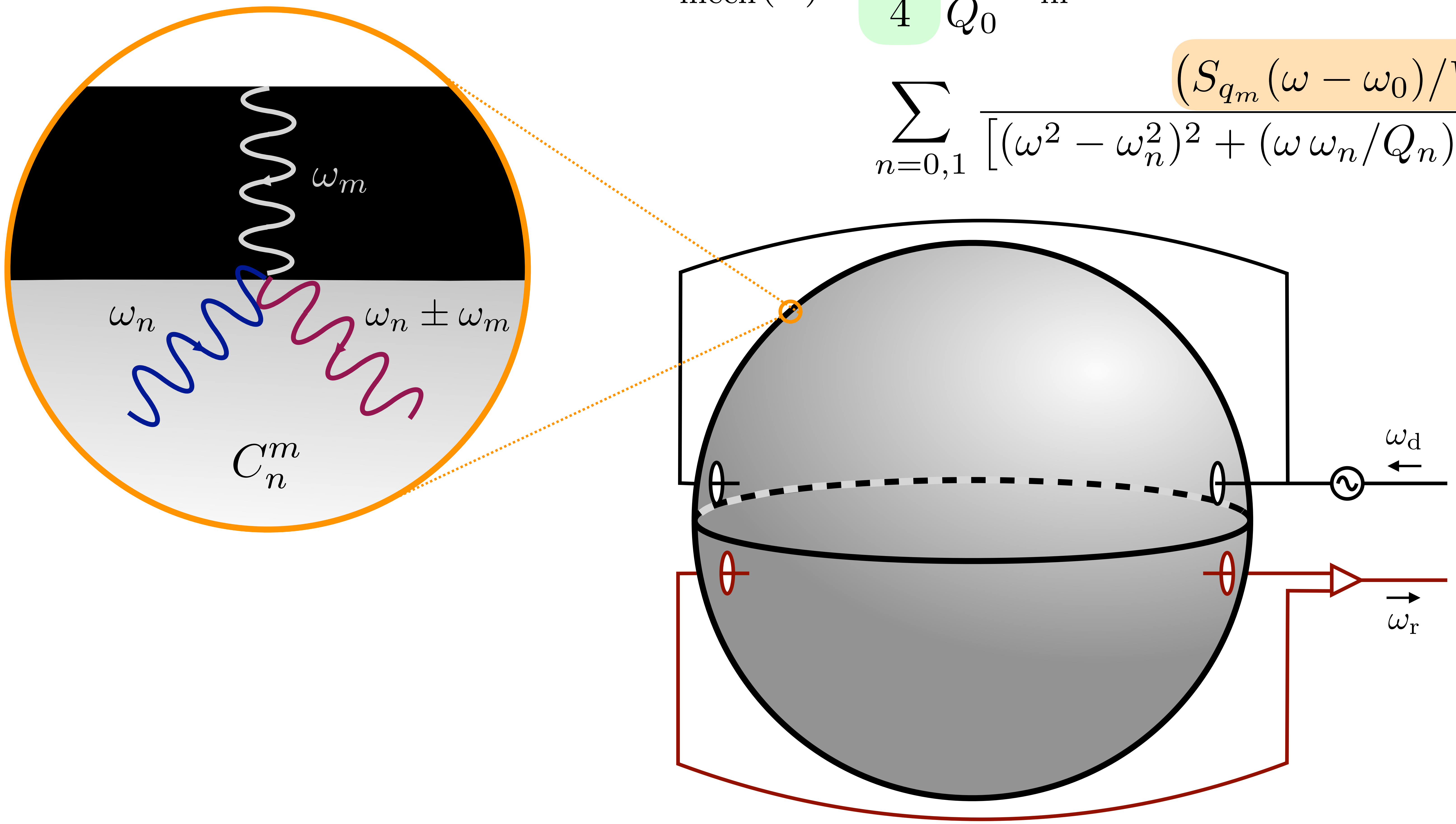
Vibrations



Mechanical Noise

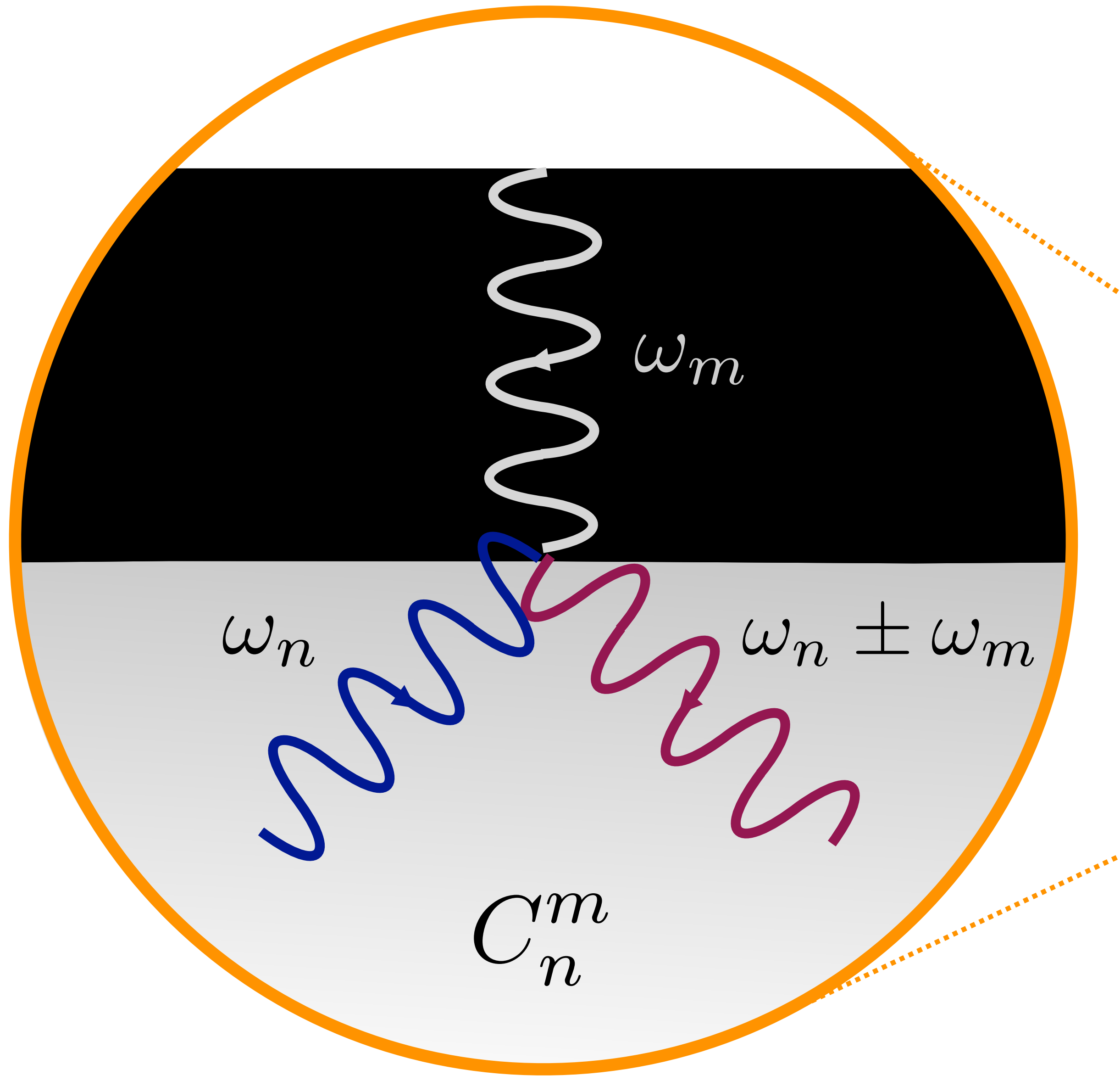
Vibrations

$$S_{\rm mech}(\omega) \simeq \frac{\epsilon_{1d}^2}{4}\frac{\omega_0}{Q_0}\,P_{\rm in}\times \sum_{n=0,1}\frac{\left(S_{q_m}(\omega-\omega_0)/V^{2/3}\right)(\omega_n/Q_n)\,\omega_n^4\,\omega^2}{\left[(\omega^2-\omega_n^2)^2+(\omega\,\omega_n/Q_n)^2\right]\left[(\omega_0^2-\omega_n^2)^2+(\omega_0\,\omega_n/Q_n)^2\right]}$$



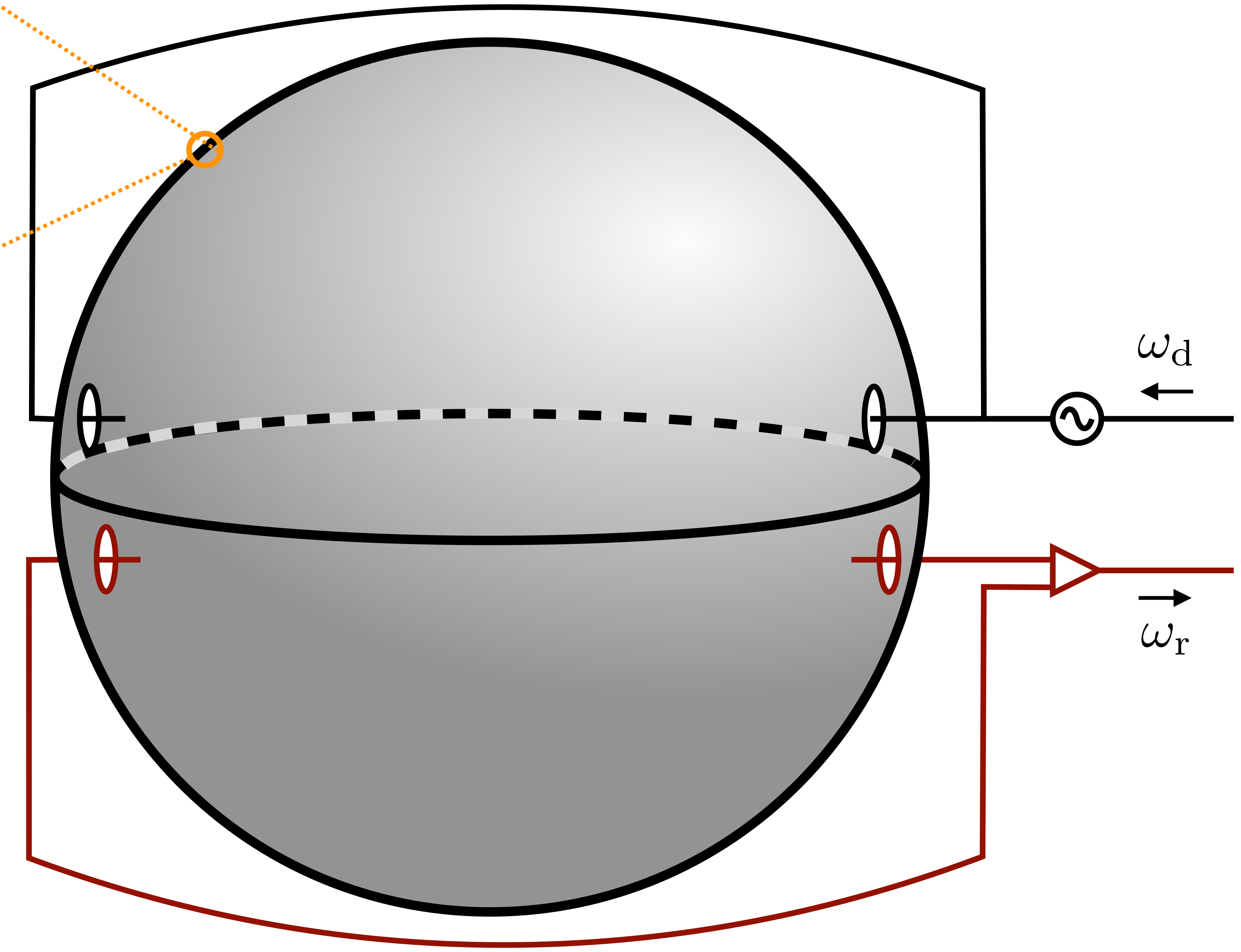
Mechanical Noise

Vibrations



$$S_{\rm mech}(\omega) \simeq \frac{\epsilon_{1d}^2}{4}\,\frac{\omega_0}{Q_0}\,P_{\rm in}\times$$

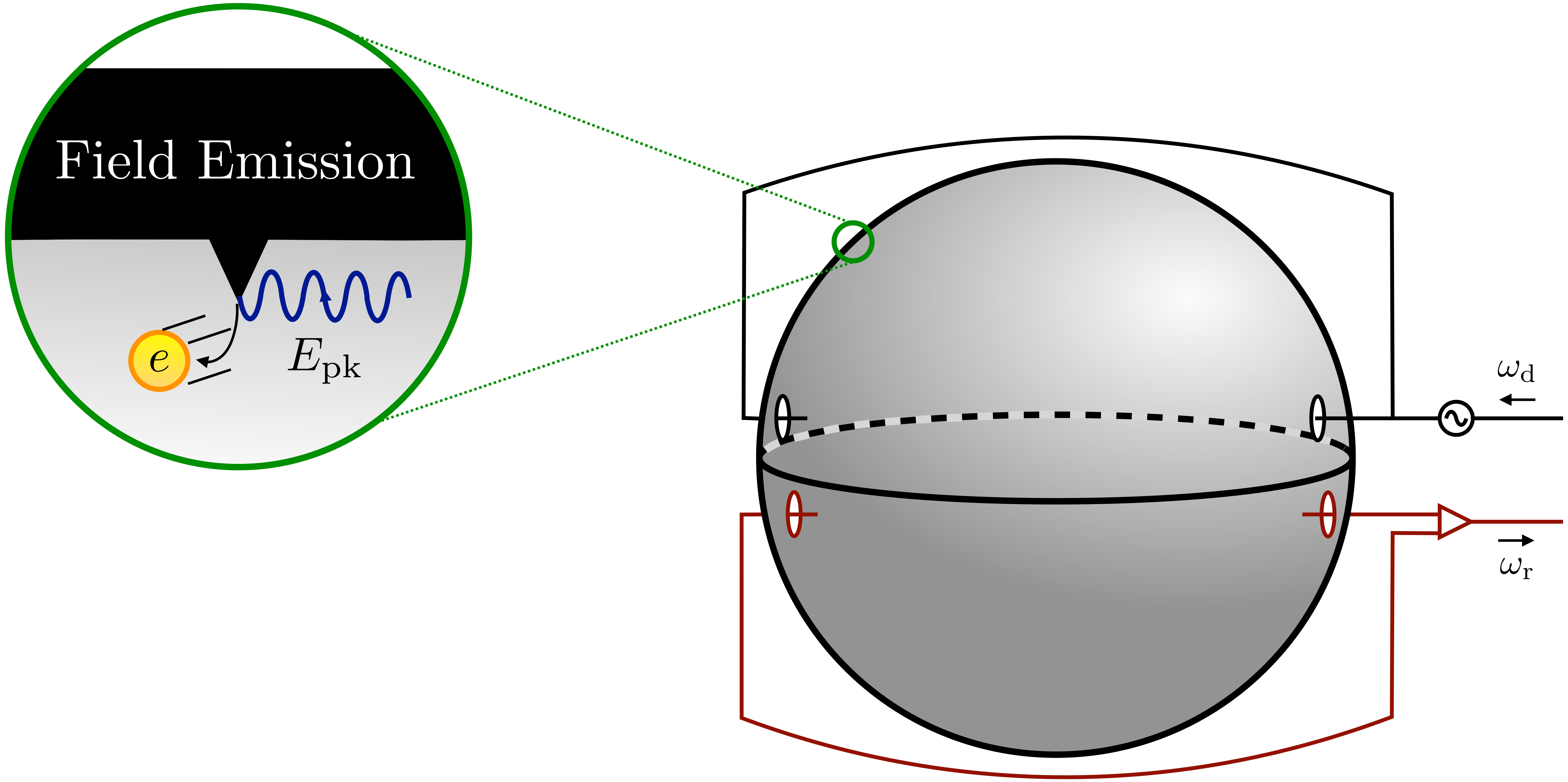
$$\sum_{n=0,1}\frac{\left(S_{q_m}(\omega-\omega_0)/V^{2/3}\right)(\omega_n/Q_n)\,\omega_n^4\,\omega^2}{\left[(\omega^2-\omega_n^2)^2+(\omega\,\omega_n/Q_n)^2\right]\left[(\omega_0^2-\omega_n^2)^2+(\omega_0\,\omega_n/Q_n)^2\right]}$$



Displacement PSD:

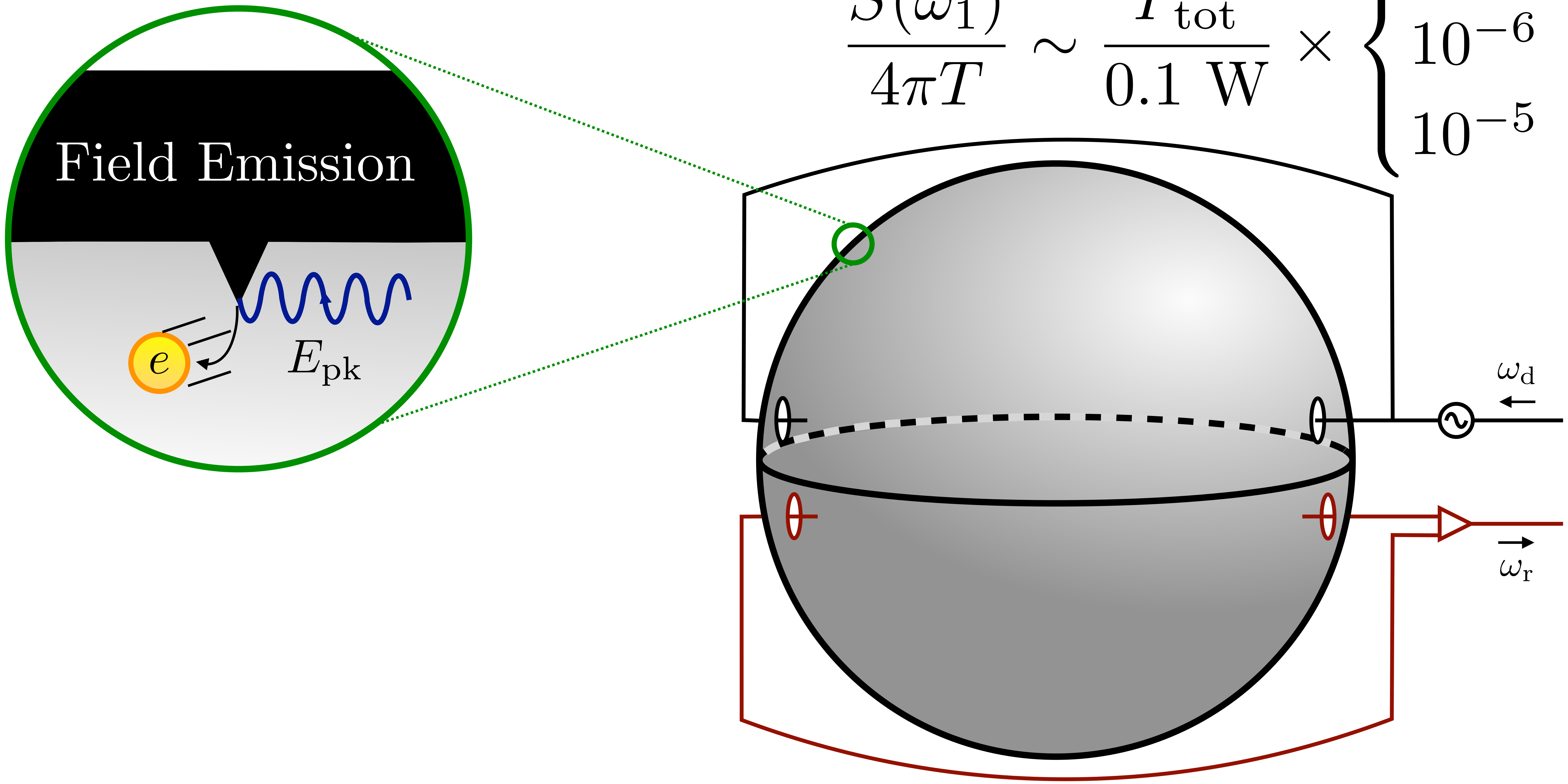
$$S_{q_m}(\omega) \simeq \frac{1}{M^2}\,\frac{S_{f_m}(\omega)}{(\omega^2-\omega_m^2)^2+(\omega_m\omega/Q_m)^2}$$

Non-standard Noise Sources: Field Emission



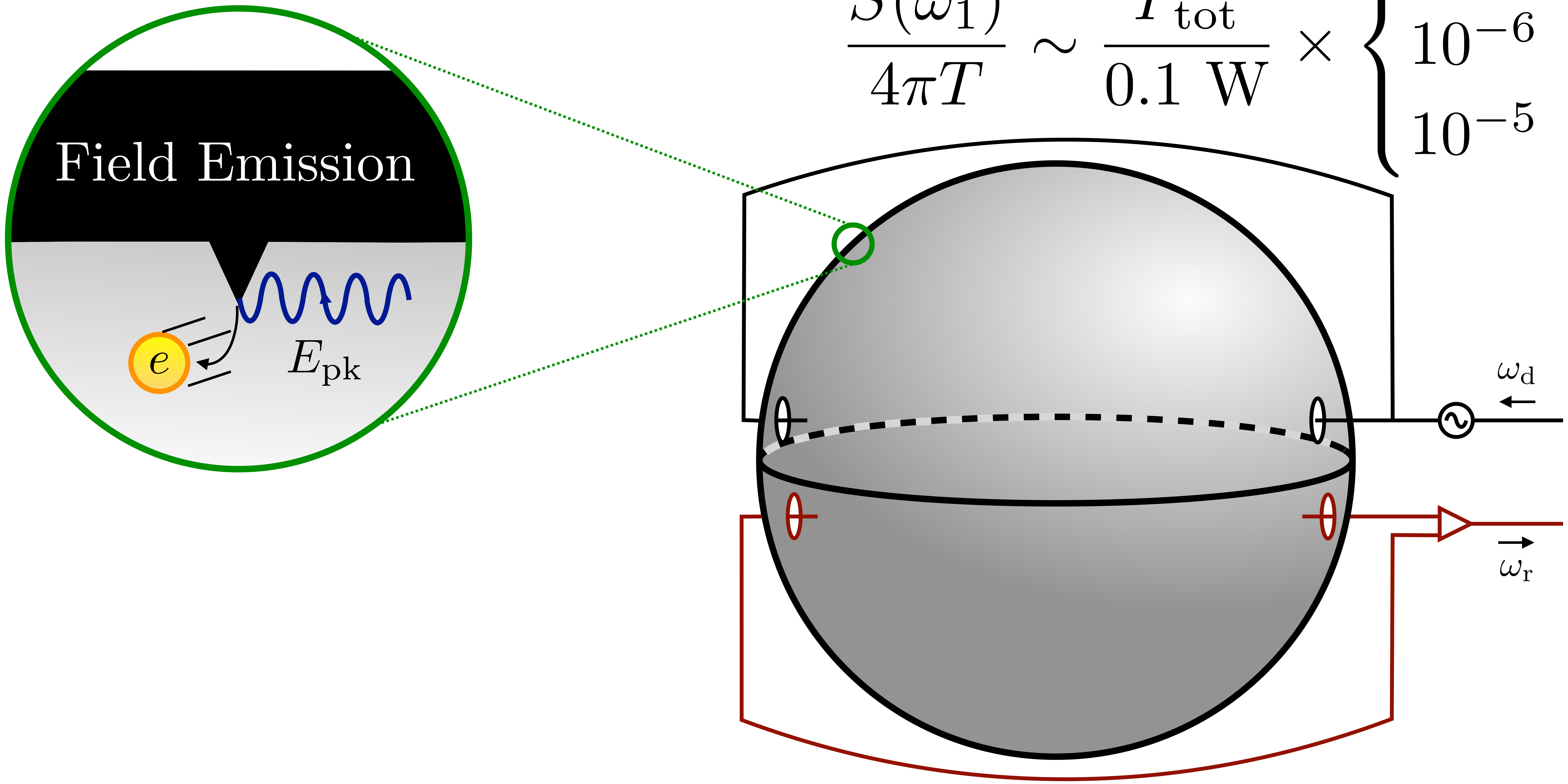
Non-standard Noise Sources: Field Emission

$$\frac{S(\omega_1)}{4\pi T} \sim \frac{P_{\text{tot}}}{0.1\ \text{W}} \times \begin{cases} 1 & \text{synchrotron} \\ 10^{-6} & \text{transition} \\ 10^{-5} & \text{Bremsstrahlung}, \end{cases}$$



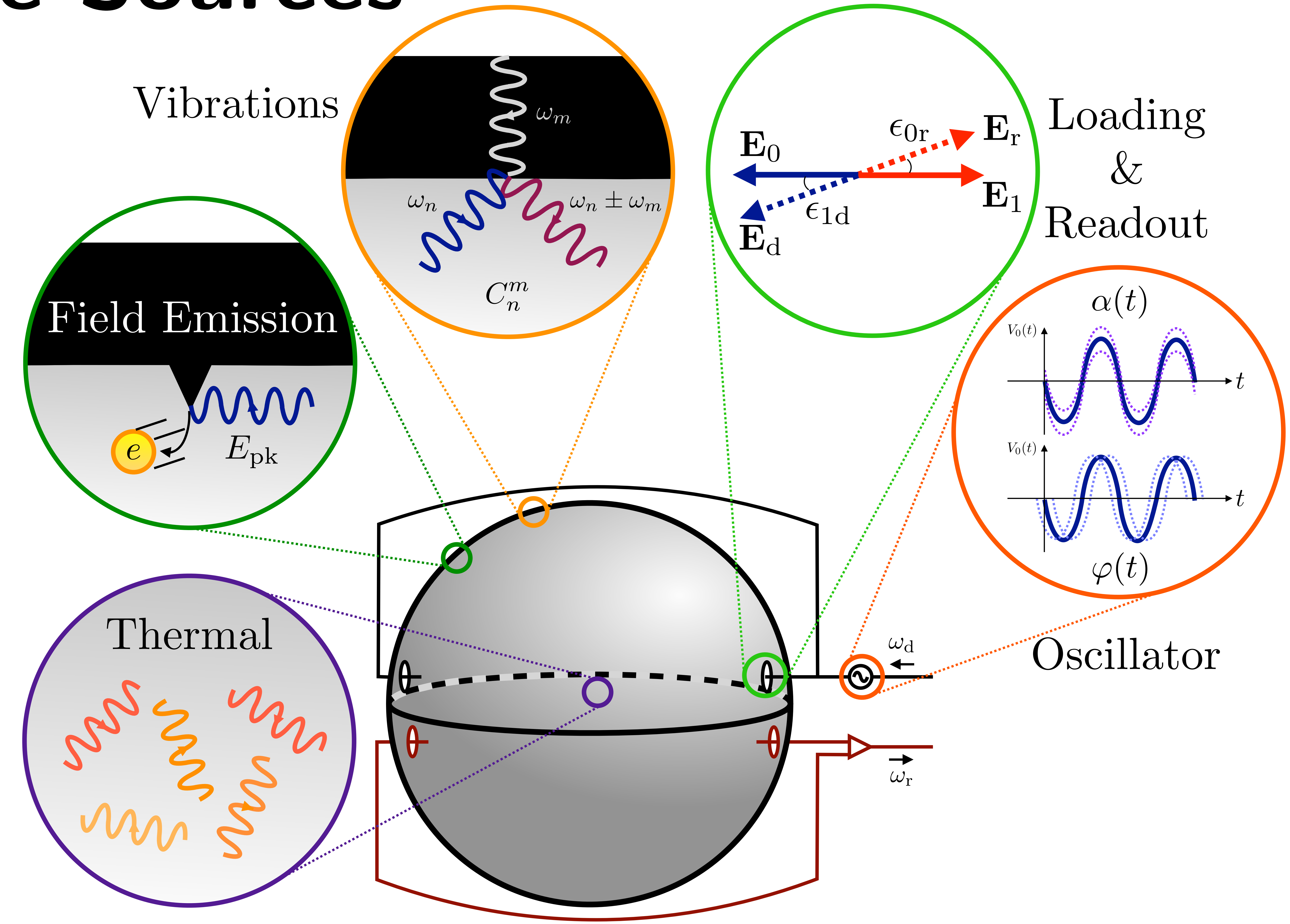
Non-standard Noise Sources: Field Emission

$$\frac{S(\omega_1)}{4\pi T} \sim \frac{P_{\text{tot}}}{0.1\ \text{W}} \times \begin{cases} 1 & \text{synchrotron} \\ 10^{-6} & \text{transition} \\ 10^{-5} & \text{Bremsstrahlung}\,, \end{cases}$$

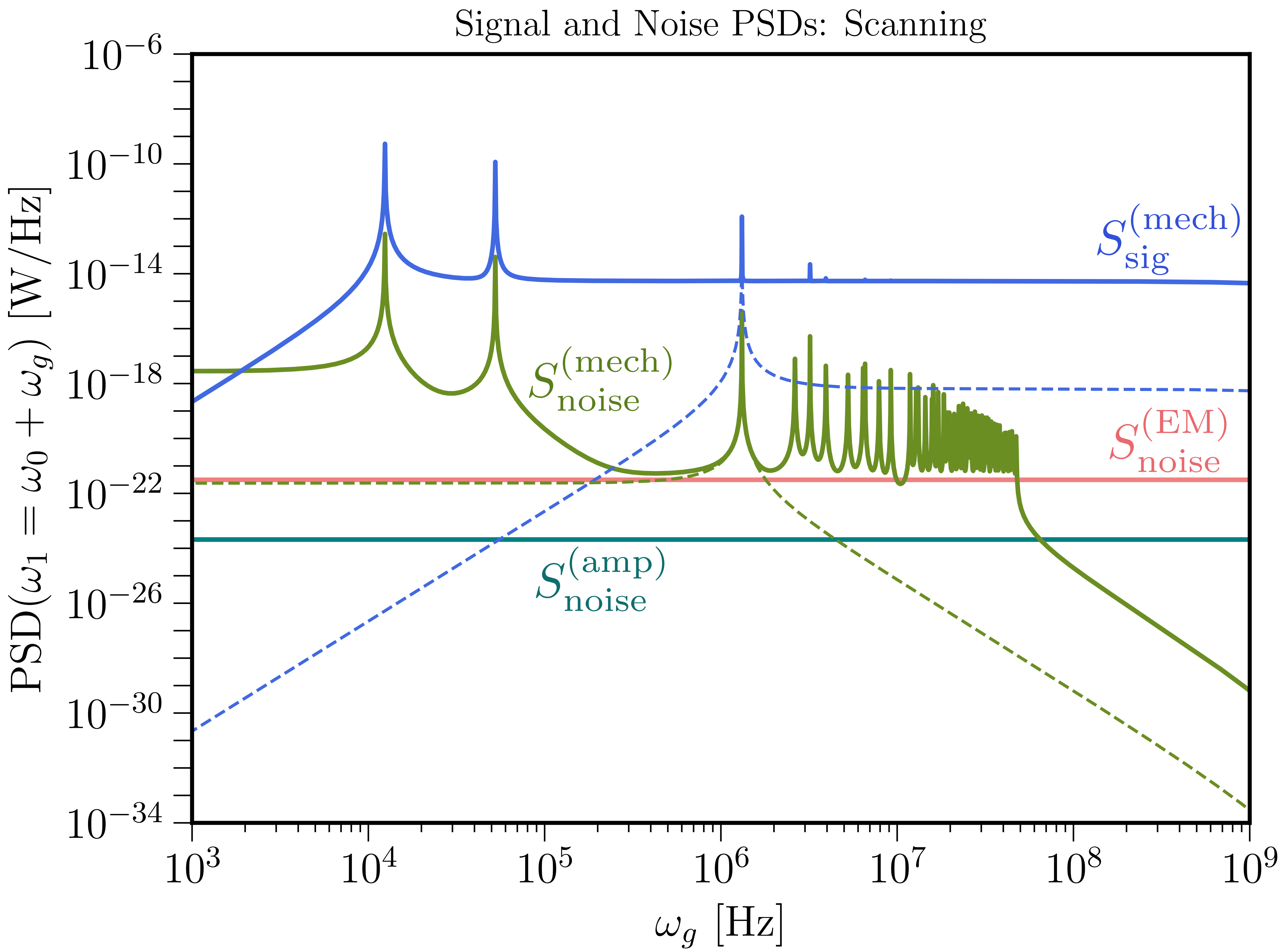


Limits max B-field $\sim$ 0.2T

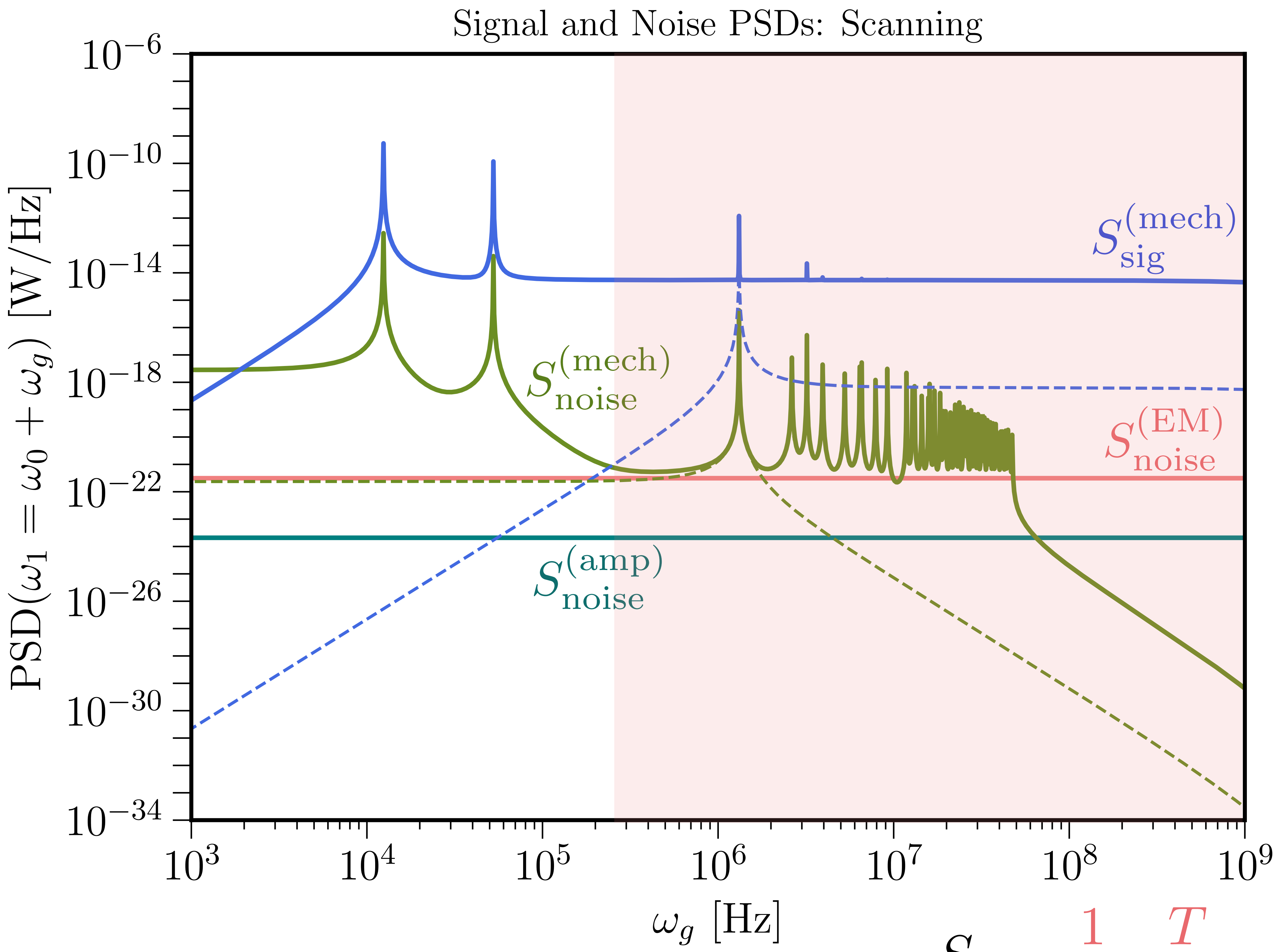
All Noise Sources



Noise in MAGO 2.0



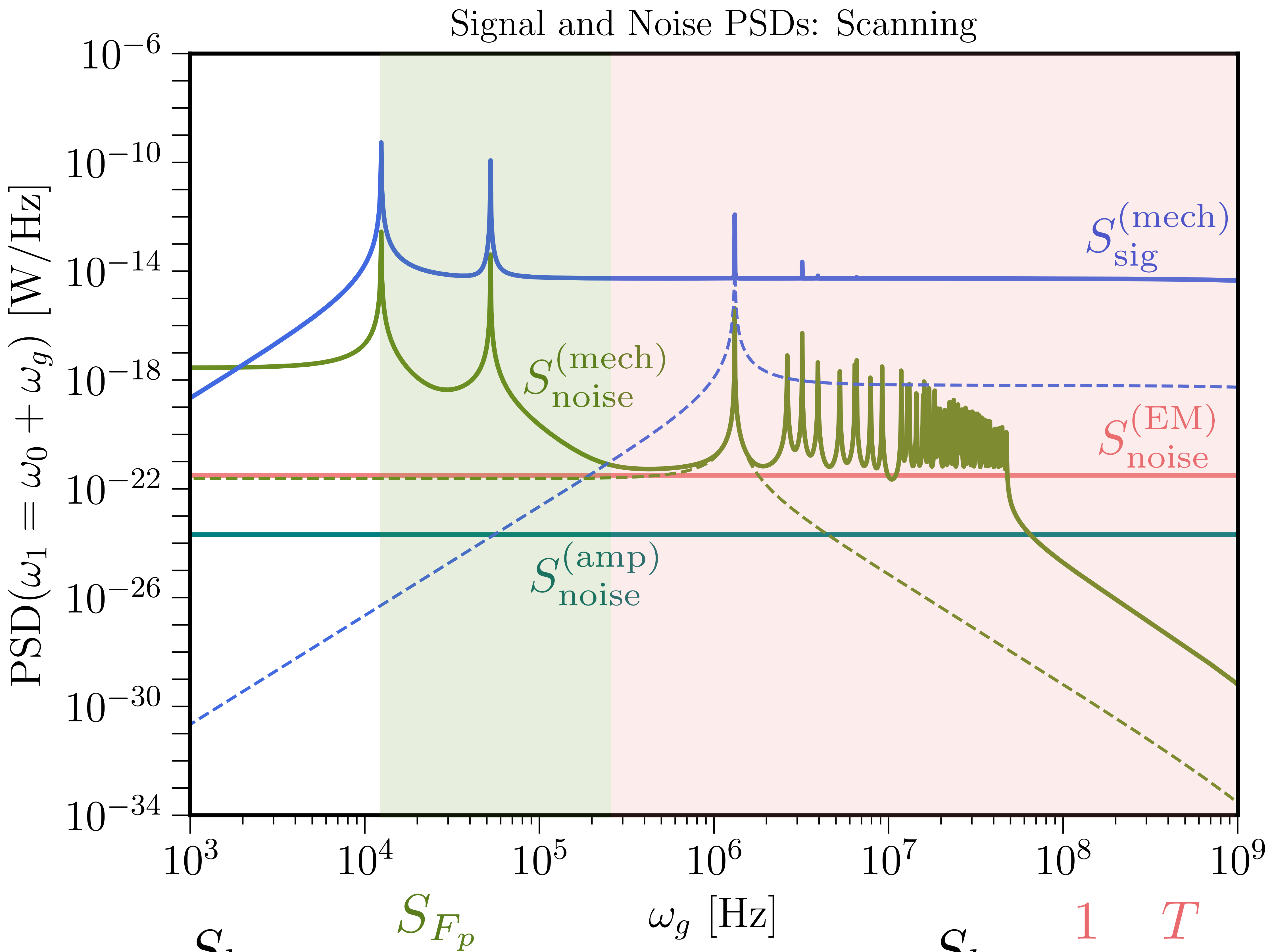
Noise in MAGO 2.0



$$S_h \sim \frac{1}{Q}\frac{T}{\omega_0 U_0}$$

EM Th. > MHz

Noise in MAGO 2.0



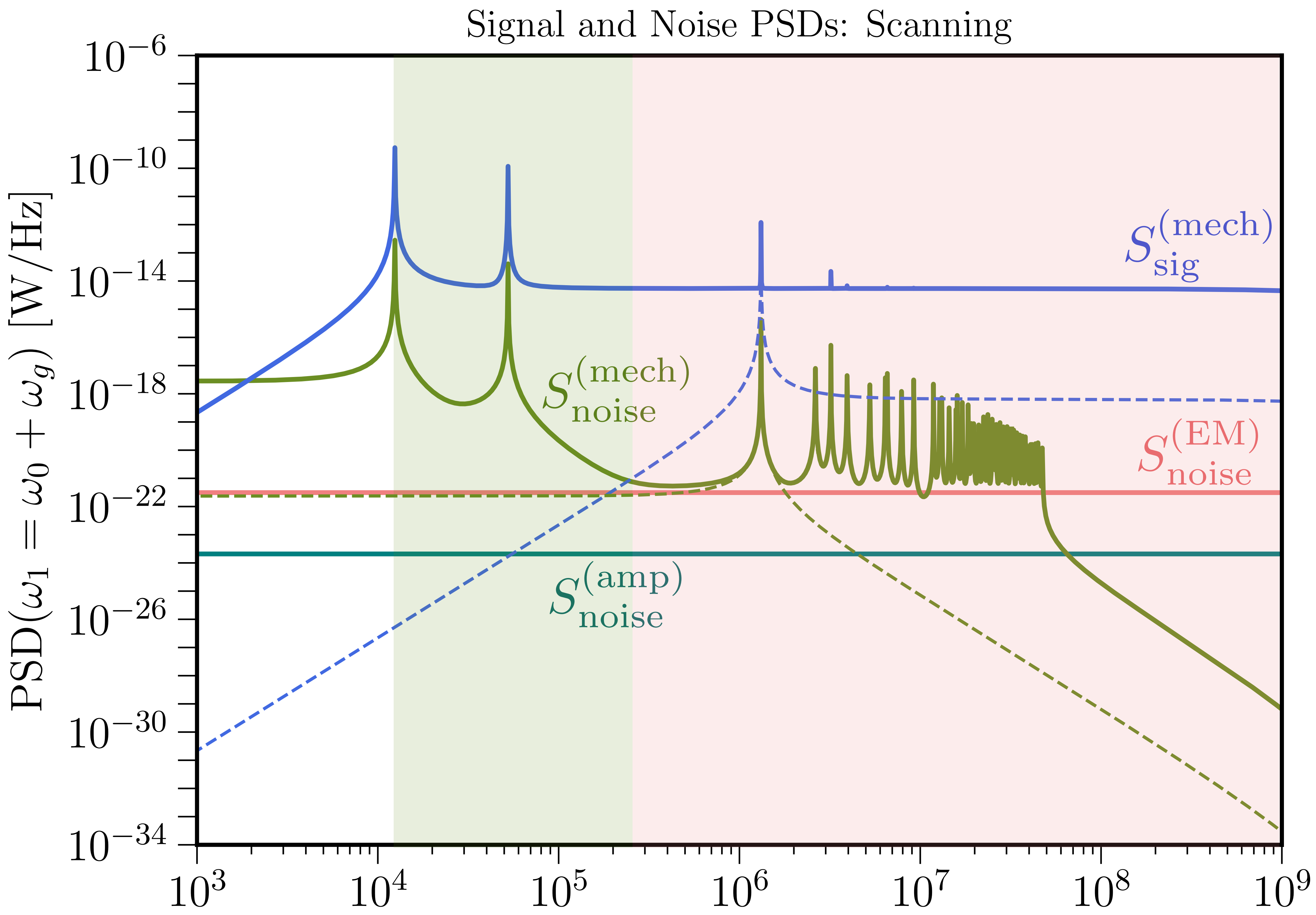
$$S_h \sim \frac{S_{F_p}}{\omega_g^4 \, (ML)^2}$$

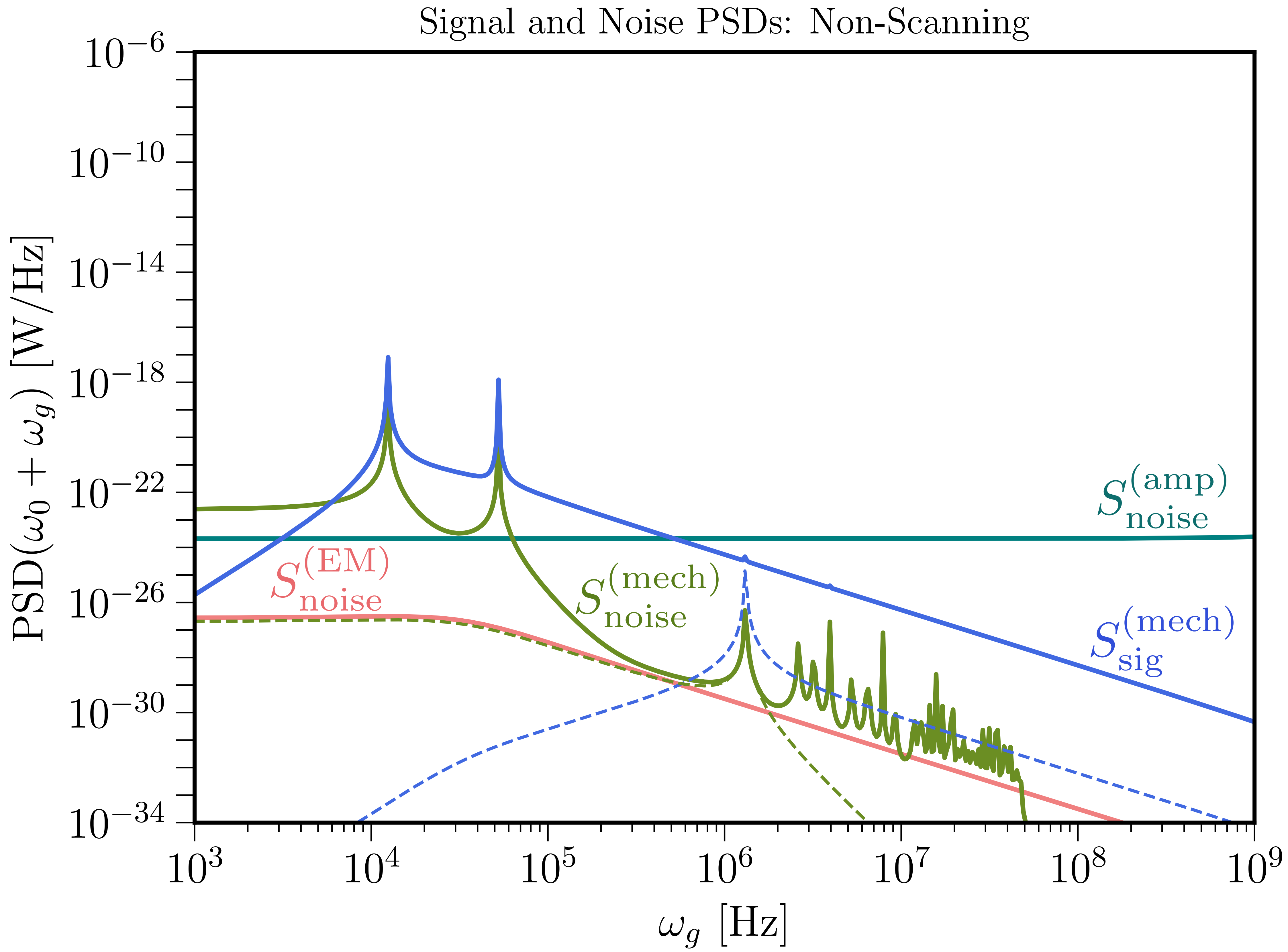
Mech < MHz

$$S_h \sim \frac{1}{Q} \frac{T}{\omega_0 U_0}$$

EM Th. > MHz

Noise in MAGO 2.0





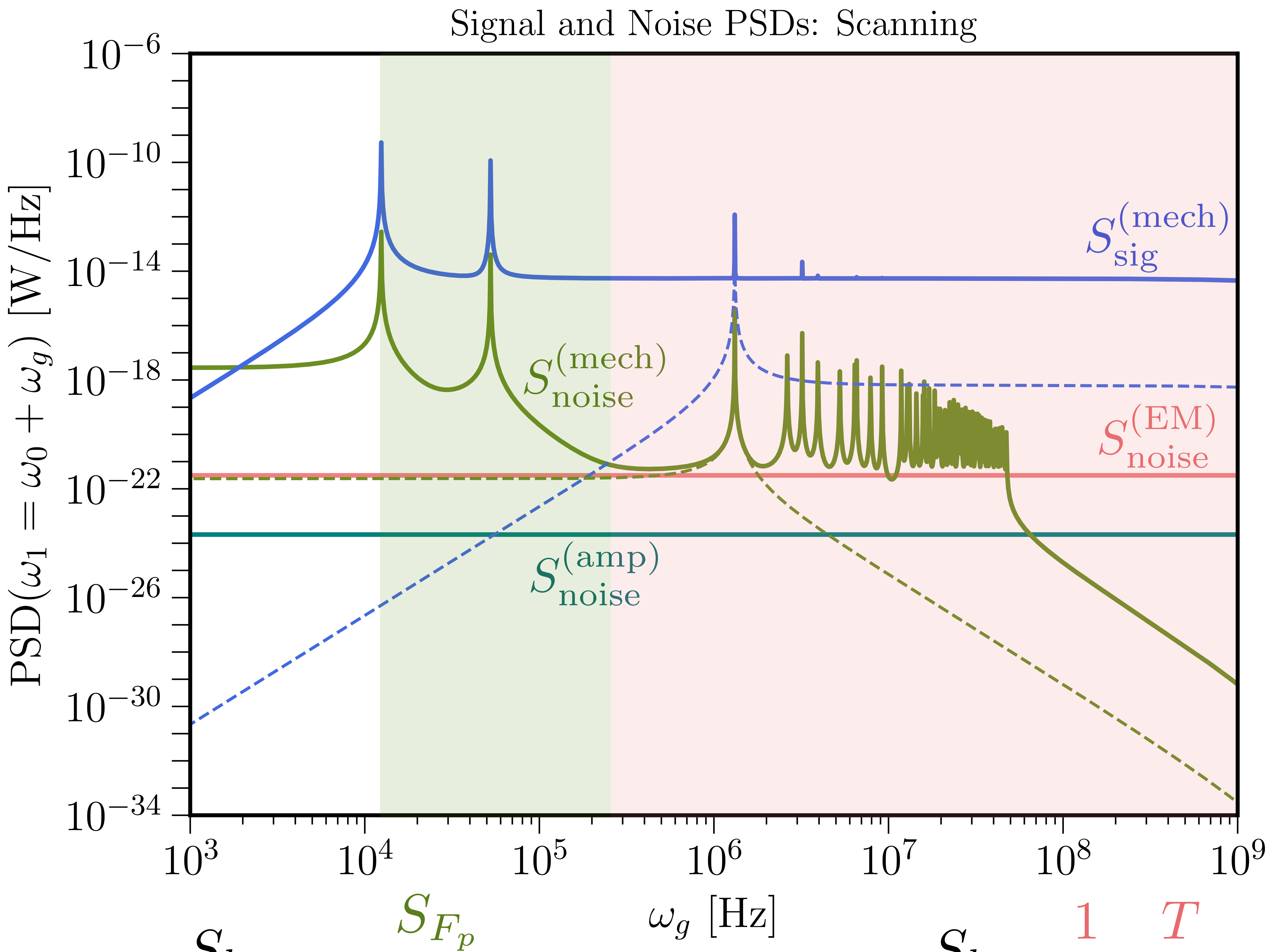
$$S_h \sim \frac{S_{F_p}}{\omega_g^4 \, (ML)^2}$$

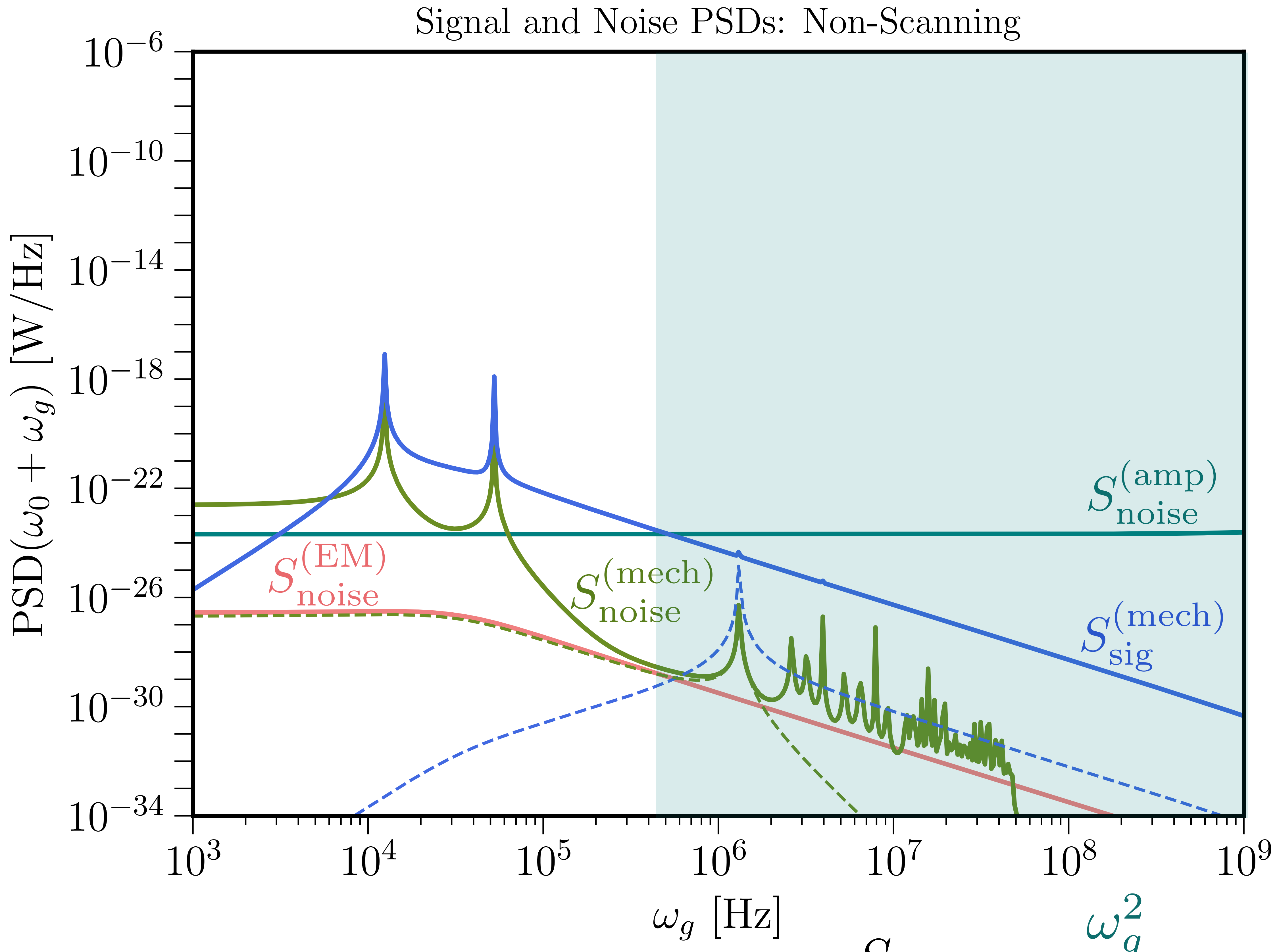
Mech $<$ MHz

$$S_h \sim \frac{1}{Q} \frac{T}{\omega_0 U_0}$$

EM Th. $>$ MHz

Noise in MAGO 2.0





$$S_h \sim \frac{S_{F_p}}{\omega_g^4 (ML)^2}$$

Mech < MHz

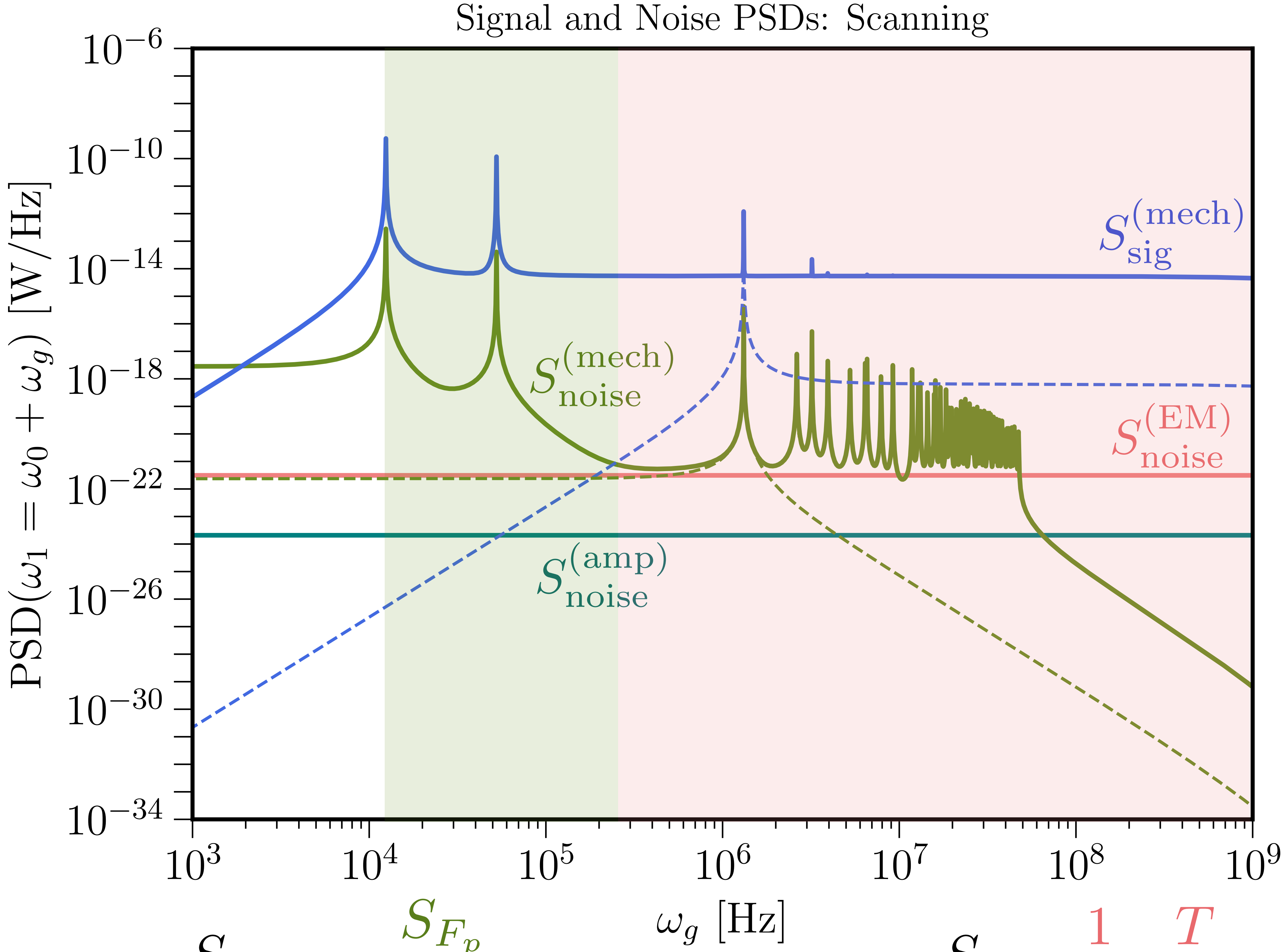
$$S_h \sim \frac{1}{Q} \frac{T}{\omega_0 U_0}$$

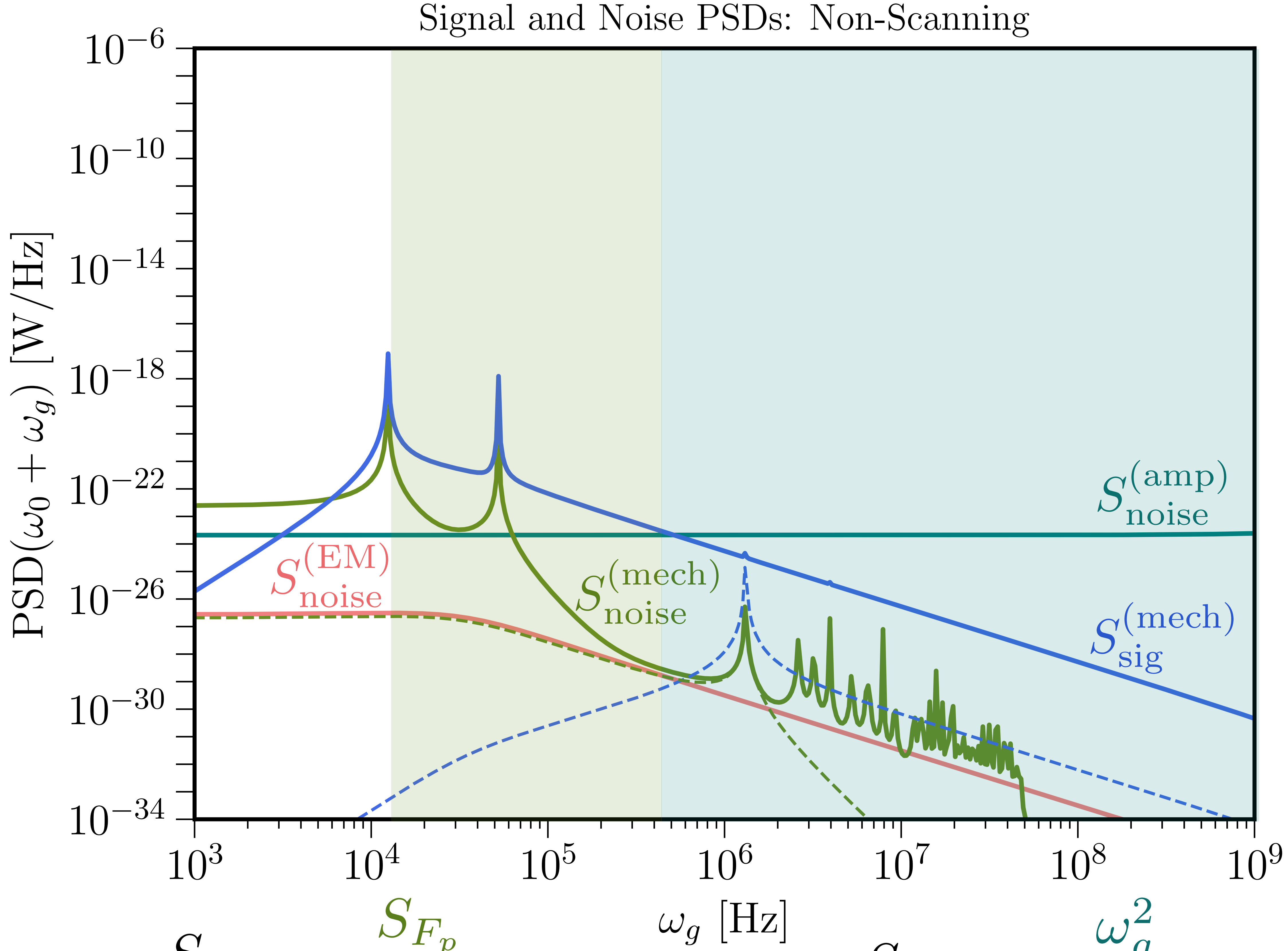
EM Th. > MHz

$$S_h \sim \frac{\omega_g^2}{\hbar \omega_0 (\omega_0 U_0)}$$

Amp > MHz

Noise in MAGO 2.0





$$S_h \sim \frac{S_{F_p}}{\omega_g^4 (ML)^2}$$

Mech < MHz

$$S_h \sim \frac{1}{Q}\frac{T}{\omega_0 U_0}$$

EM Th. > MHz

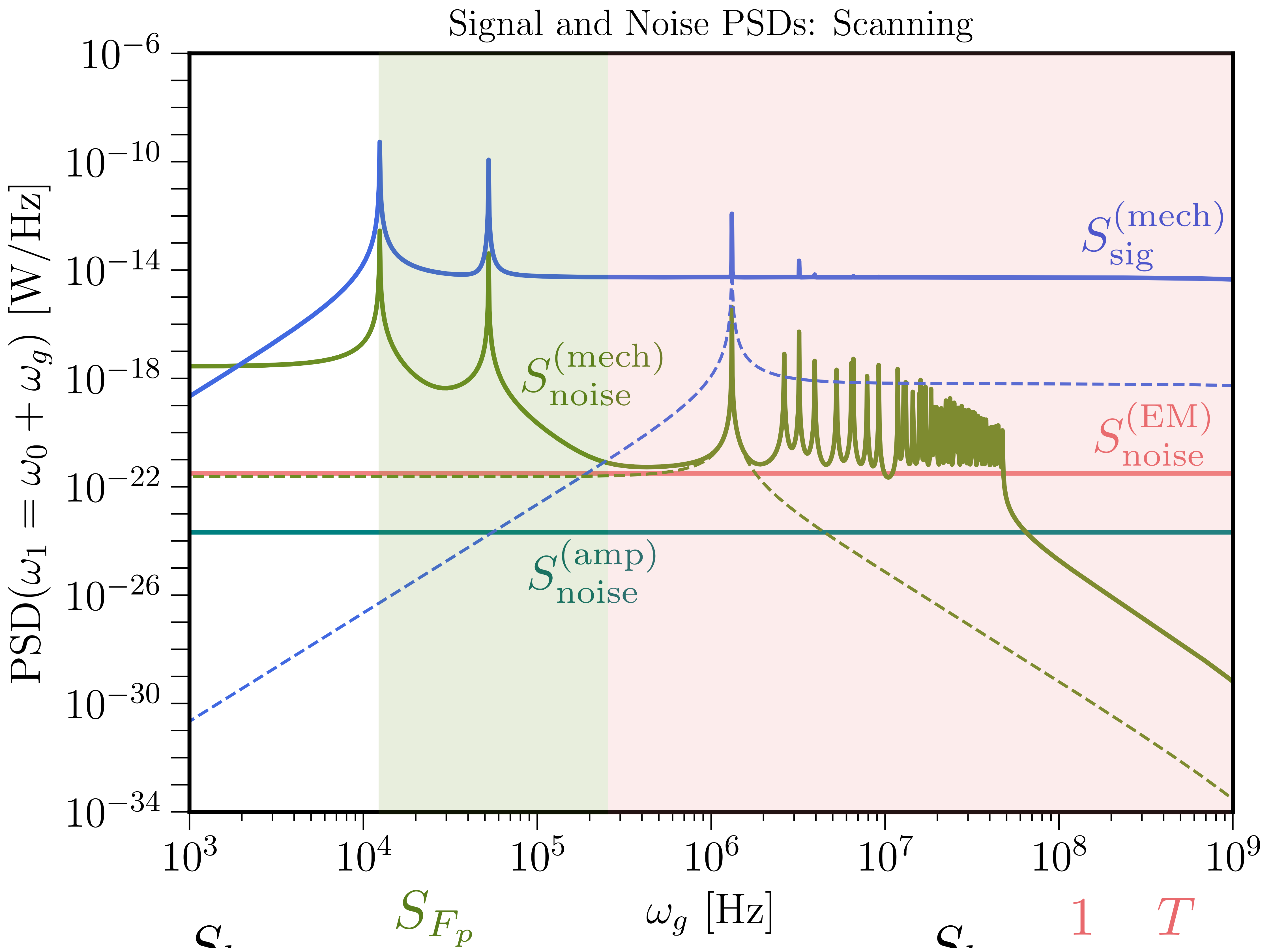
$$S_h \sim \frac{S_{F_p}}{\omega_g^4 (ML)^2}$$

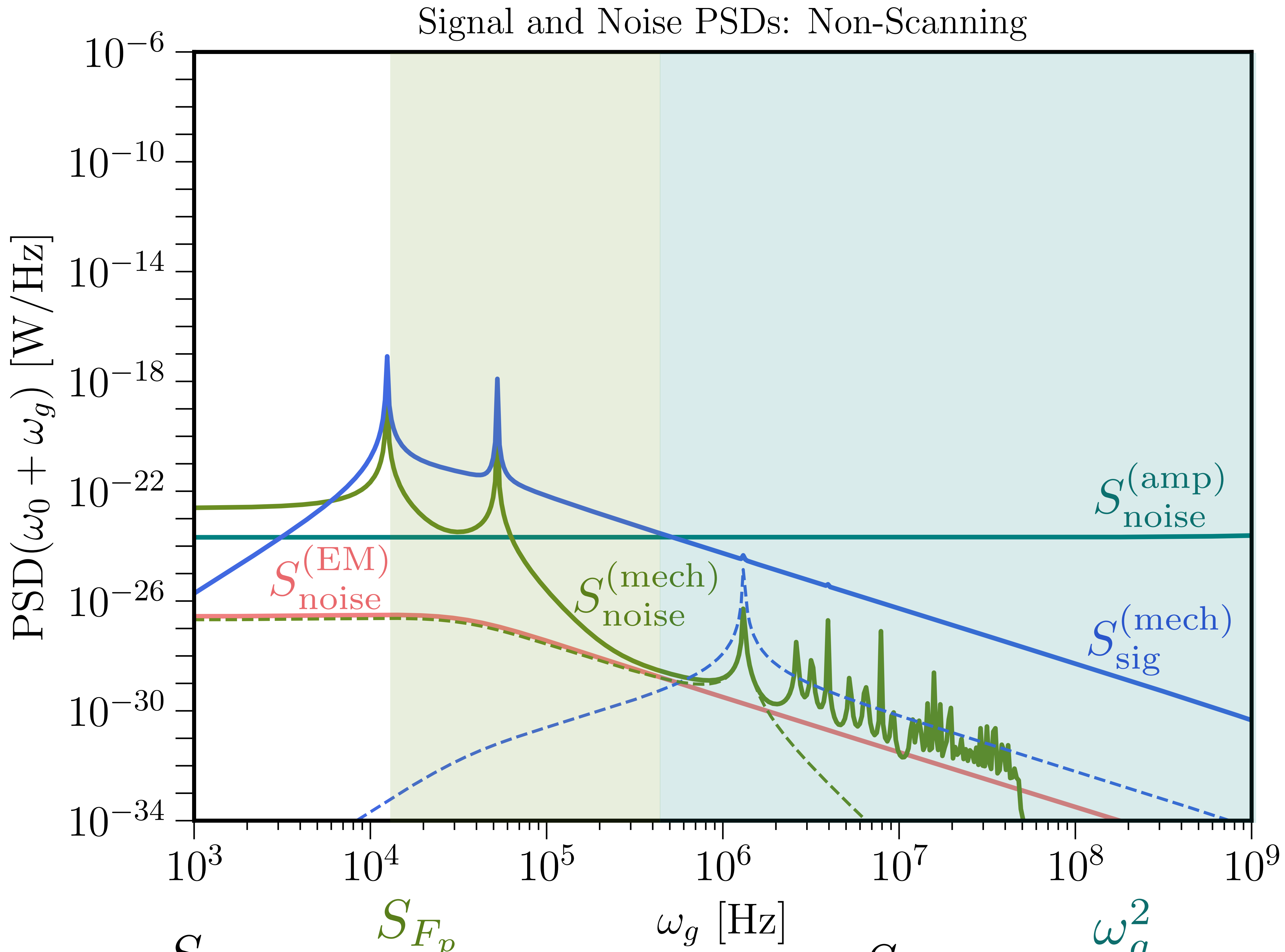
Mech < MHz

$$S_h \sim \frac{\omega_g^2}{\hbar\omega_0(\omega_0 U_0)}$$

Amp > MHz

Noise in MAGO 2.0





$$S_h \sim \frac{S_{F_p}}{\omega_g^4 (ML)^2}$$

Mech < MHz

$$S_h \sim \frac{1}{Q}\frac{T}{\omega_0 U_0}$$

EM Th. > MHz

$$S_h \sim \frac{S_{F_p}}{\omega_g^4 (ML)^2}$$

Mech < MHz

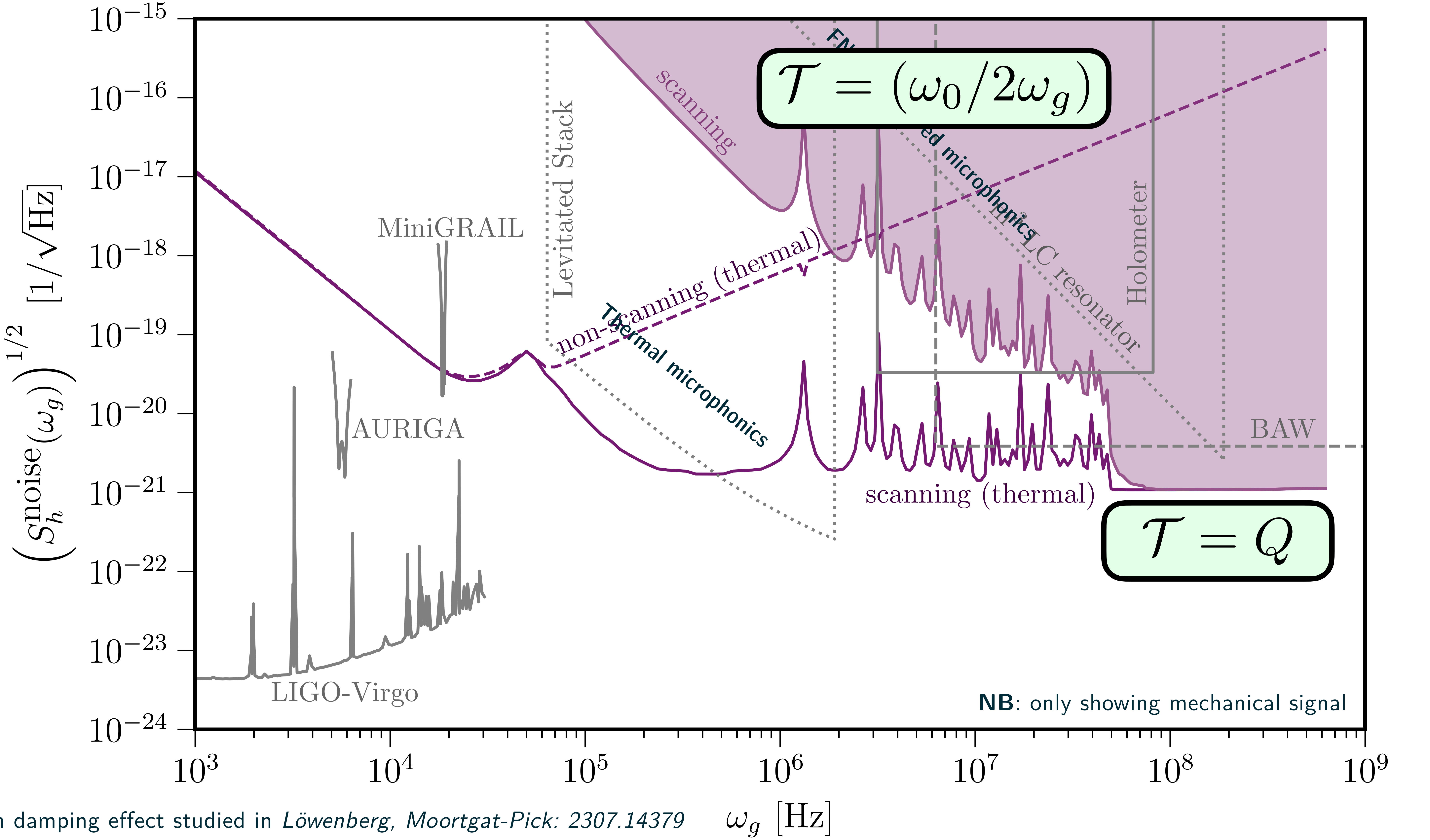
$$S_h \sim \frac{\omega_g^2}{\hbar\omega_0(\omega_0 U_0)}$$

Amp > MHz

NB: missing radiation damping effect studied in *Löwenberg, Moortgat-Pick: 2307.14379*

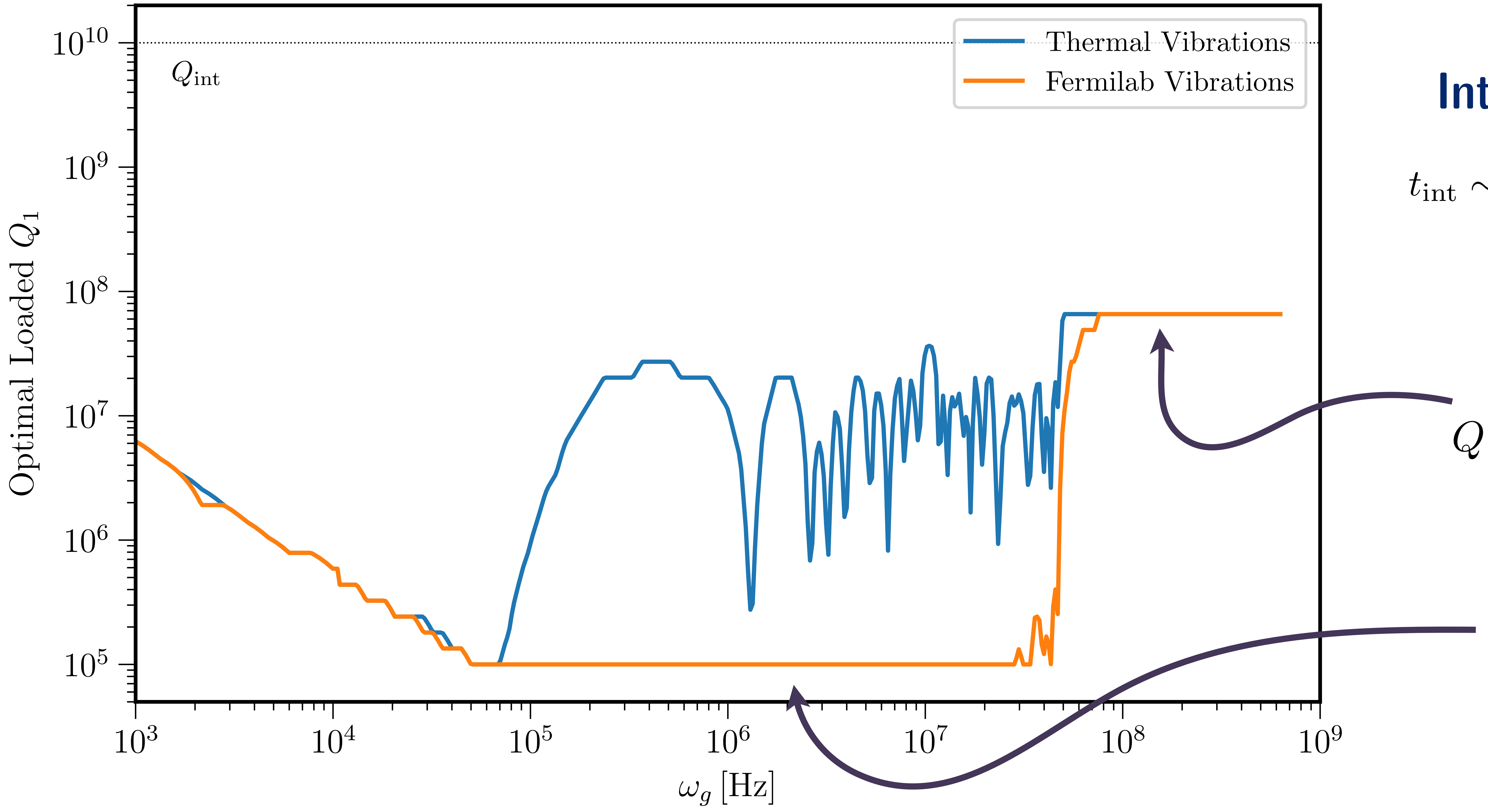
Noise-equivalent strain

Berlin, Blas, D'Agnolo, SARE, Harnik, Kahn, Schutte-Engel, Wentzel (PRD 2023)



NB: missing radiation damping effect studied in *Löwenberg, Moortgat-Pick: 2307.14379*

Optimal Scanning



Integration time:

$$t_{\rm int} \sim t_e \min\left(\frac{\omega_1}{Q_1\,\omega_g}\,,\,1\right)$$

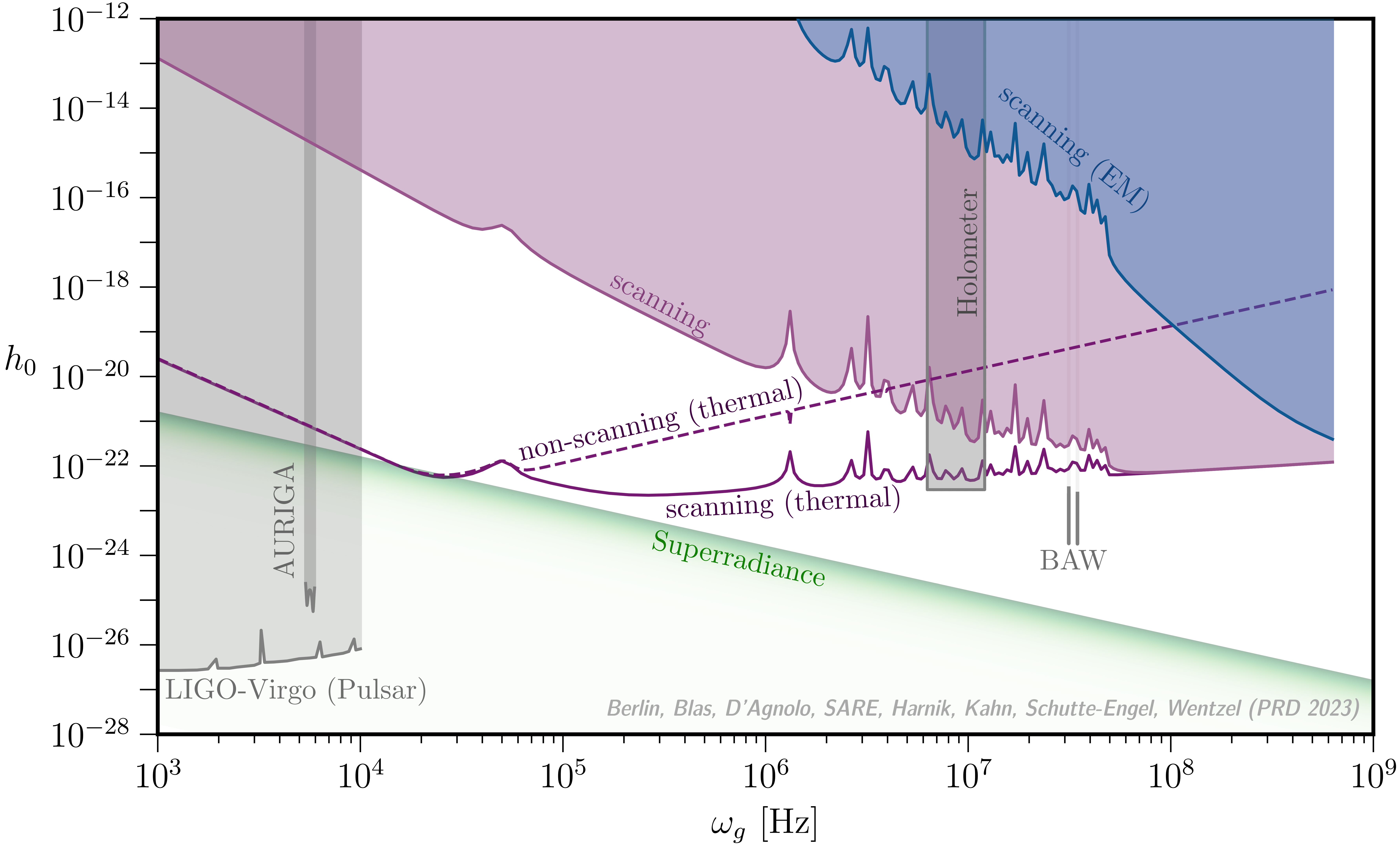
Thermal:

$$Q_1 \sim Q_{\rm int}(\omega_1/T)$$

Vibrations:

$$Q_1 \sim Q_1^{\rm min}$$

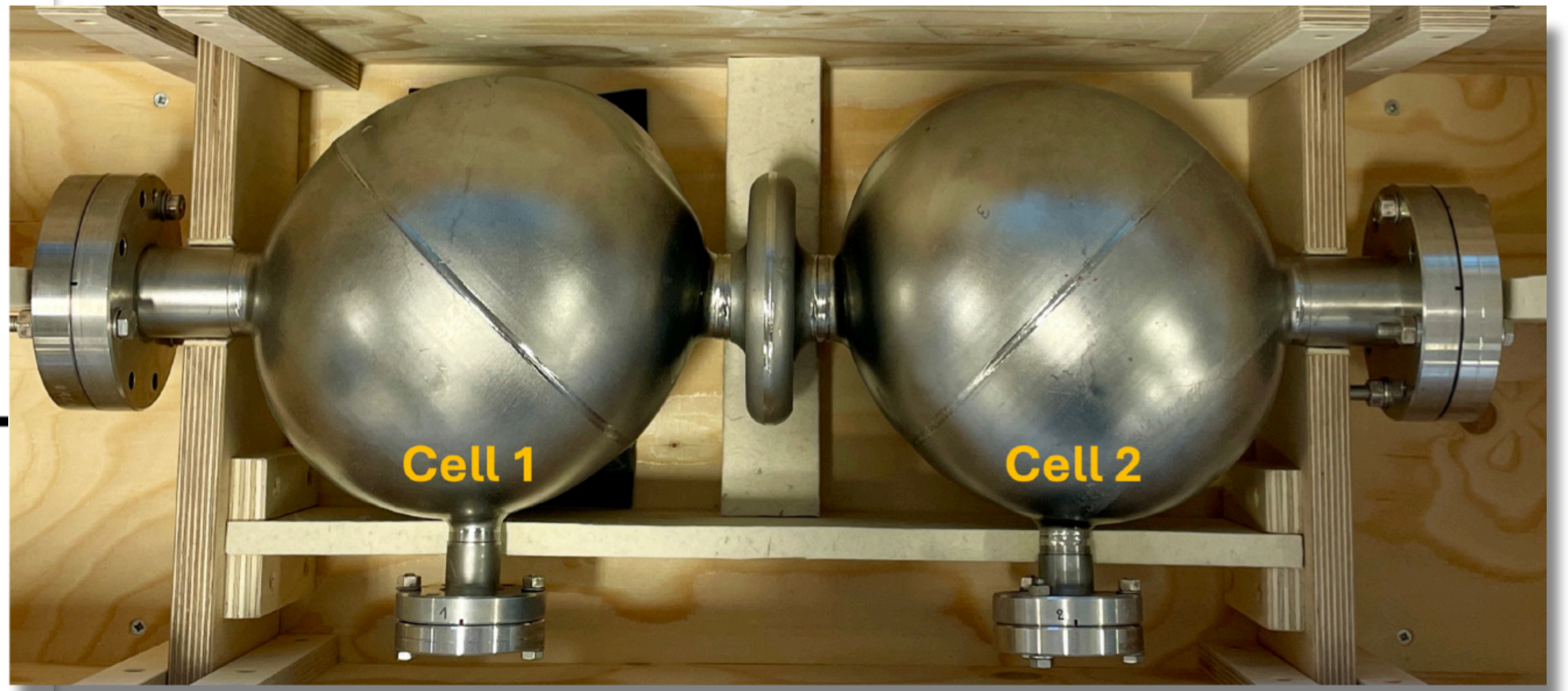
MAGO 2.0 sensitivity to coherent GWs



From Proposal to Practice

First characterisation of the MAGO cavity, a superconducting RF detector for kHz-MHz gravitational waves

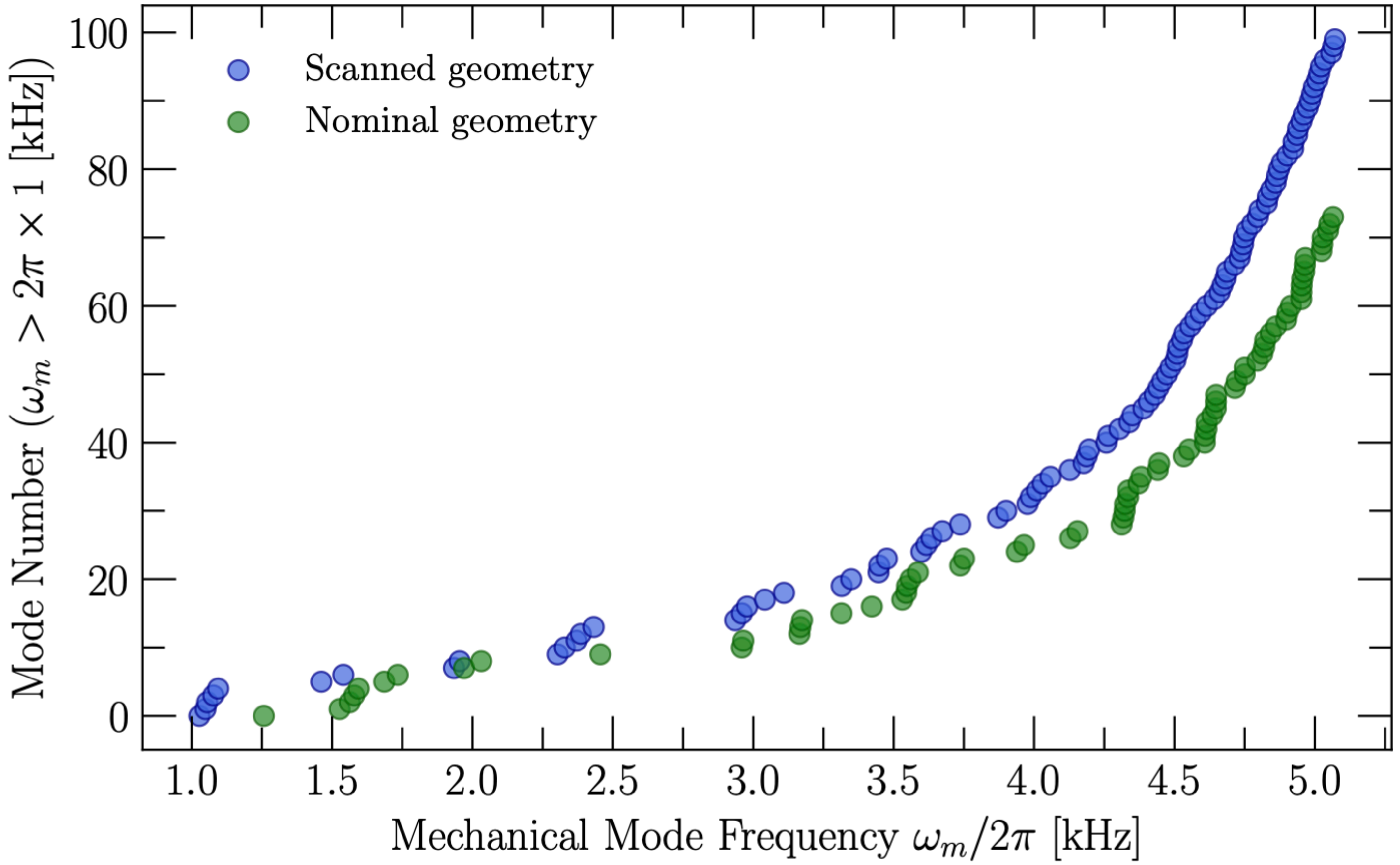
Lars Fischer[a] Bianca Giaccone[b] Ivan Gonin[b] Anna Grassellino[b] Wolfgang Hillert[a] Timergali Khabiboulline[b] Tom Krokotsch[a] Gudrid Moortgat-Pick[a,c] Andrea Muhs[c] Yuriy Orlov[b] Krisztian Peters[c] Sam Posen[b] Oleg Pronitchev[b] Marc Wenskat[a,c]



https://arxiv.org/abs/2411.18346

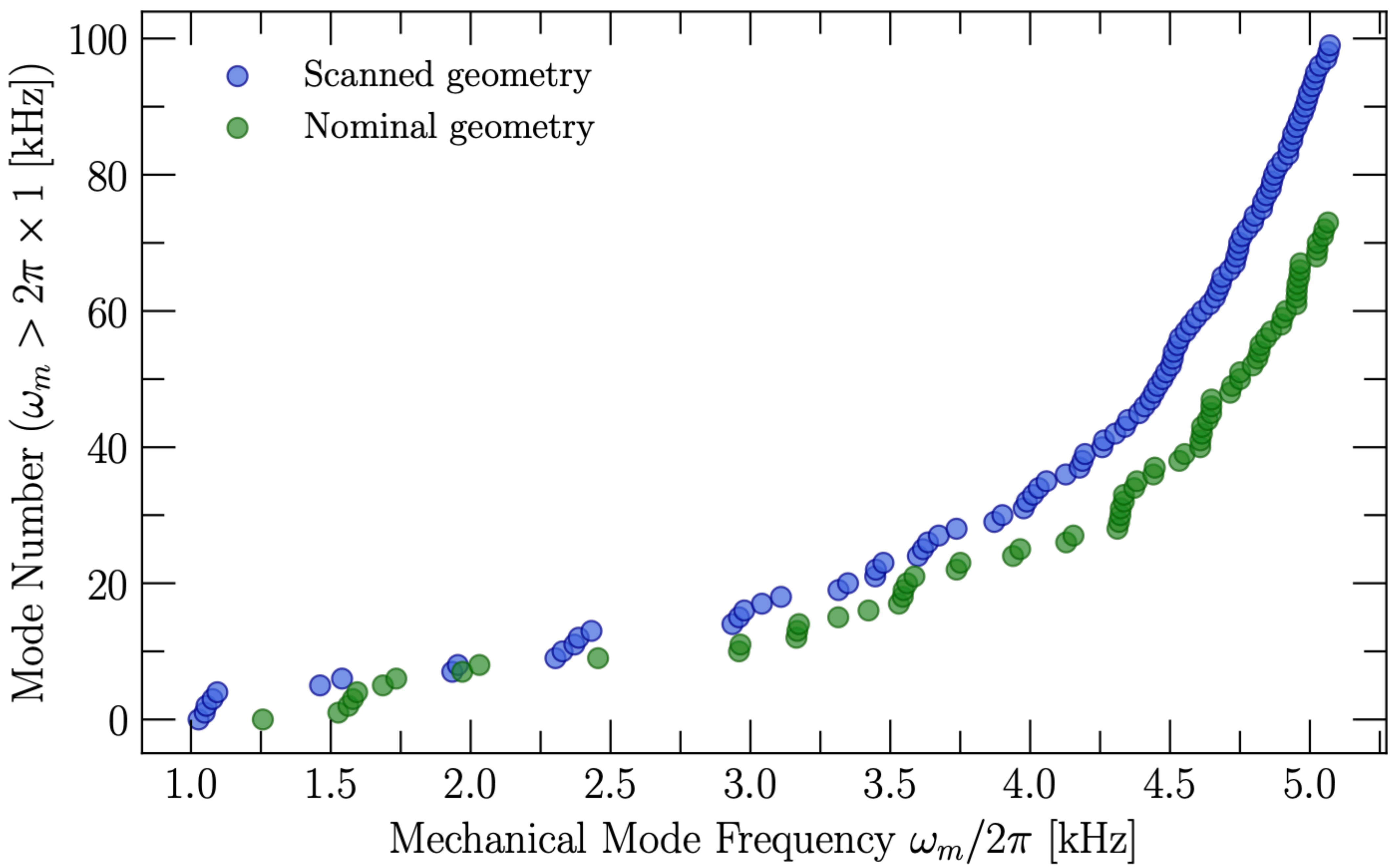
Ongoing collaboration between INFN/DESY/FNAL

Characterising the Prototype

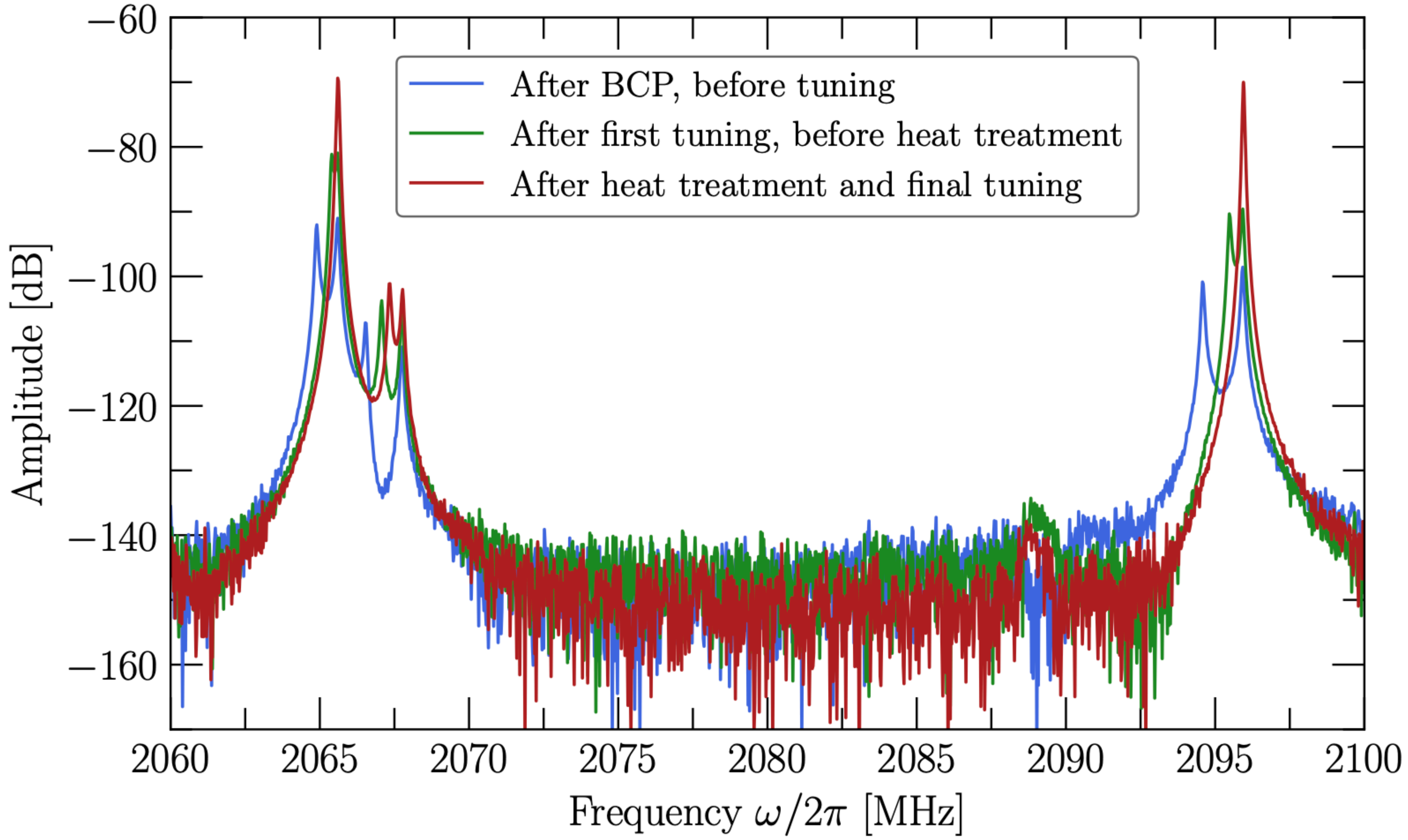


Mechanical modes

Characterising the Prototype



Mechanical modes



RF spectrum

Conclusion

MAGO operates in:

- Low-frequency regime: $1/L \gg \omega_g$ — use PDF and account for current & boundary changes

Renewed collaboration between INFN/DESY/FNAL

First data expected in 2025