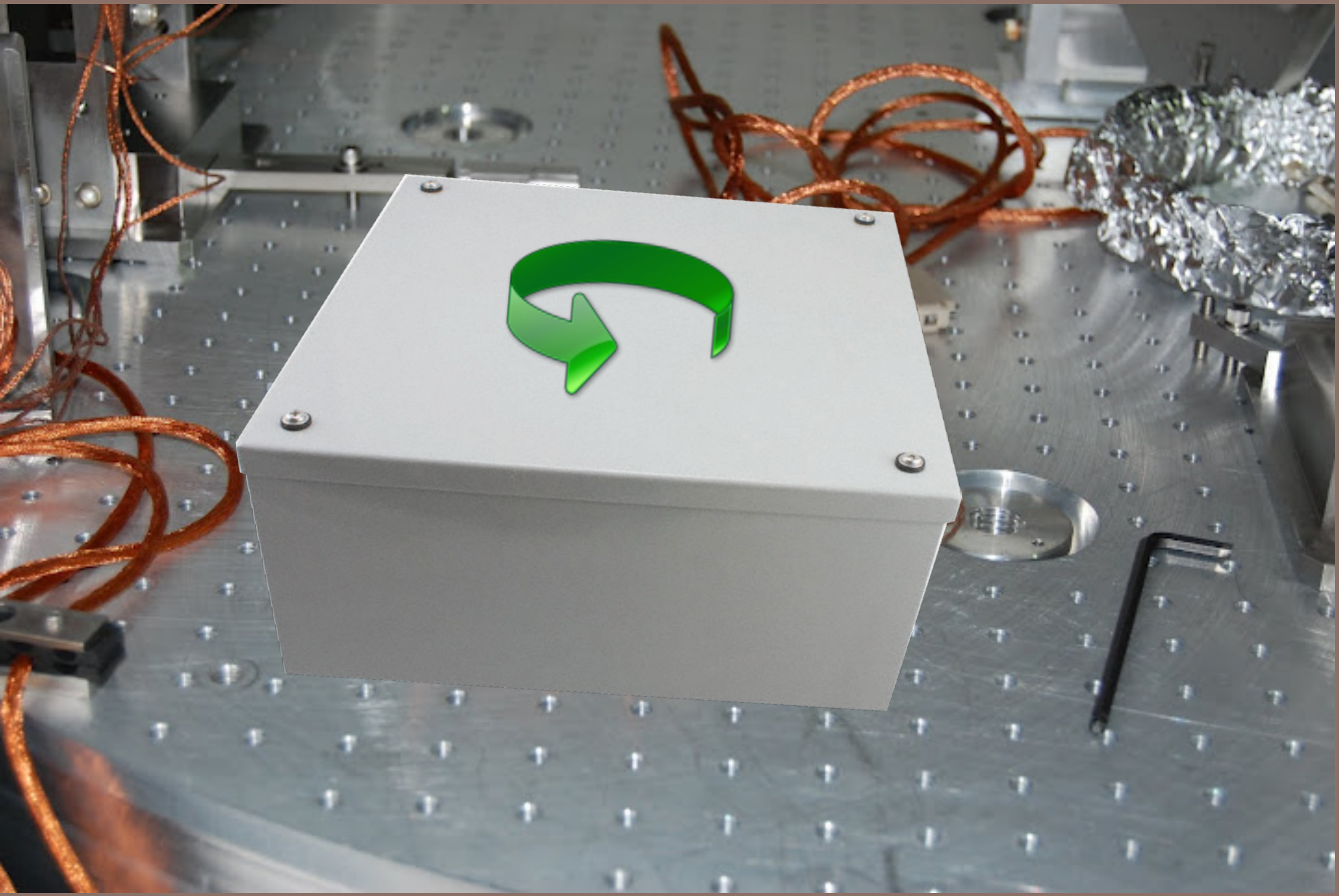
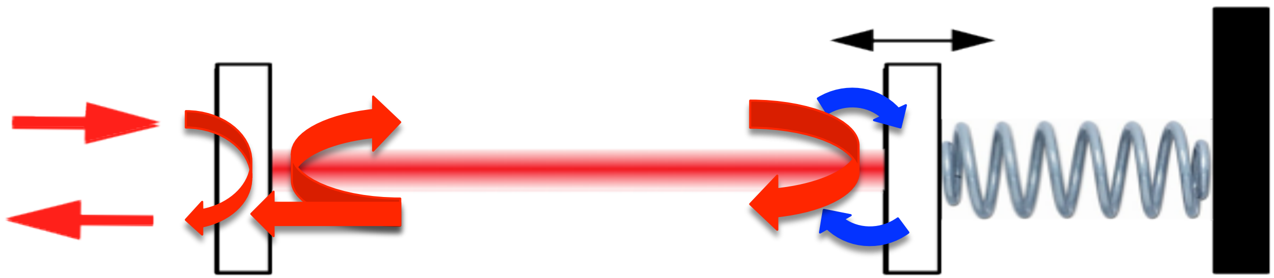


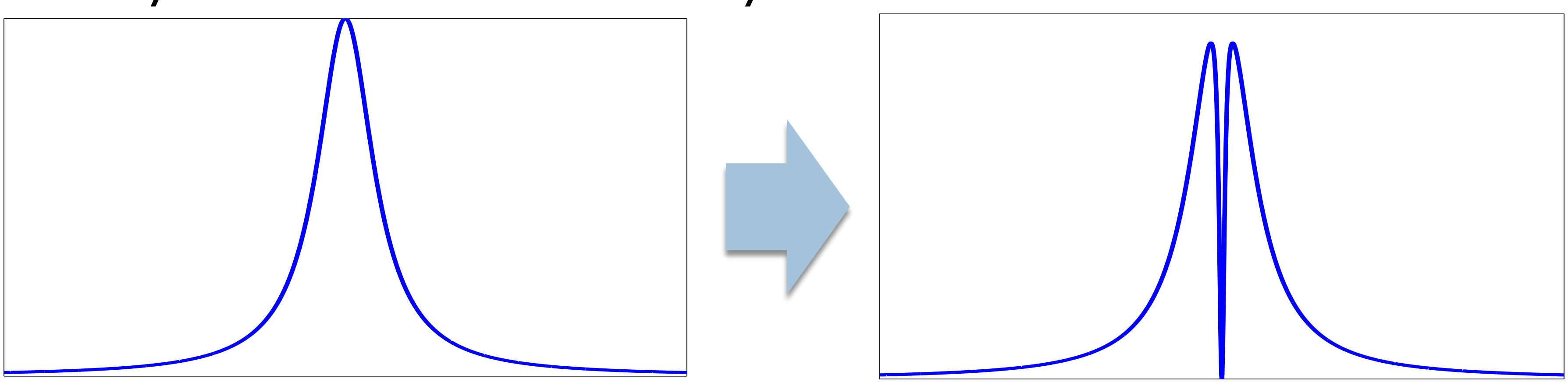
PONDEROMOTIVE ROTATOR: REQUIREMENTS

Zach Korth (Caltech) – GWADW '12 – Waikoloa, HI

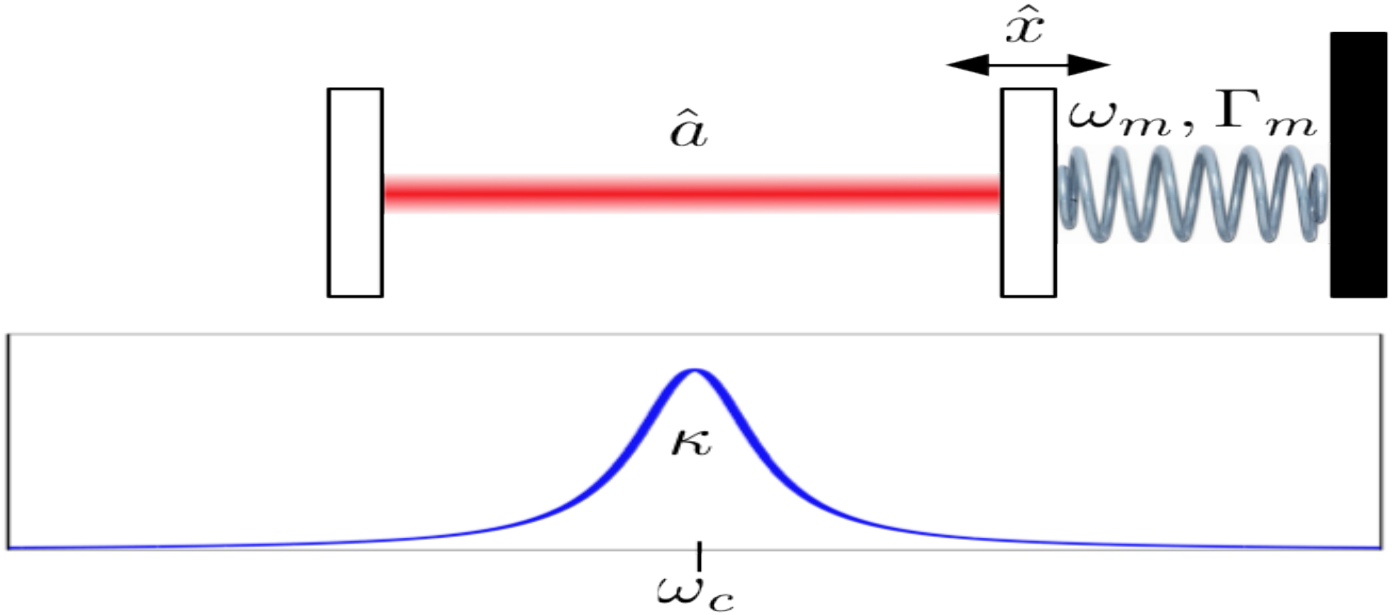
The optomechanical advantage



- Simple cavity: interference between optical pathways produces amplitude/phase shifts
- Optomechanical cavity: Added pathway through mechanical system → modification of dynamics



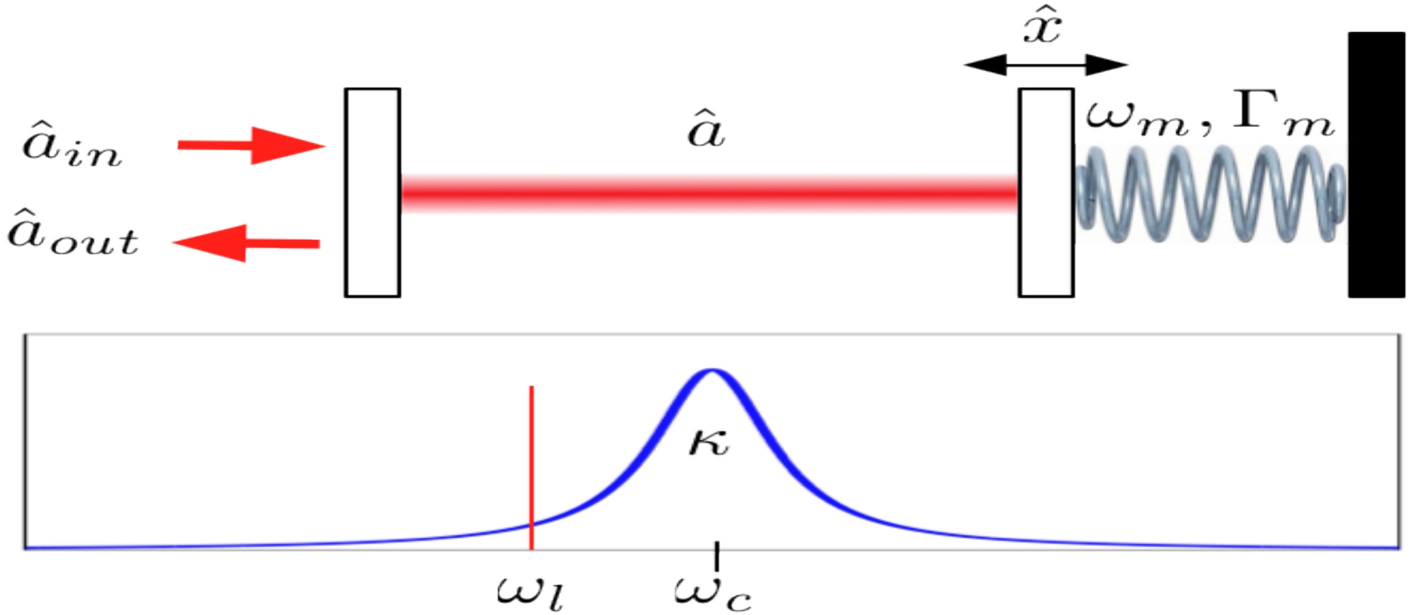
Optomechanical dynamics



$$\hat{\mathcal{H}} = \hbar\omega_c \hat{a}^\dagger \hat{a} + \frac{\hat{p}^2}{2m} + \frac{1}{2} m\omega_m^2 \hat{x}^2 + \hbar G_0 \hat{x} \hat{a}^\dagger \hat{a}$$

$$G_0 = \frac{\omega_c}{L}$$

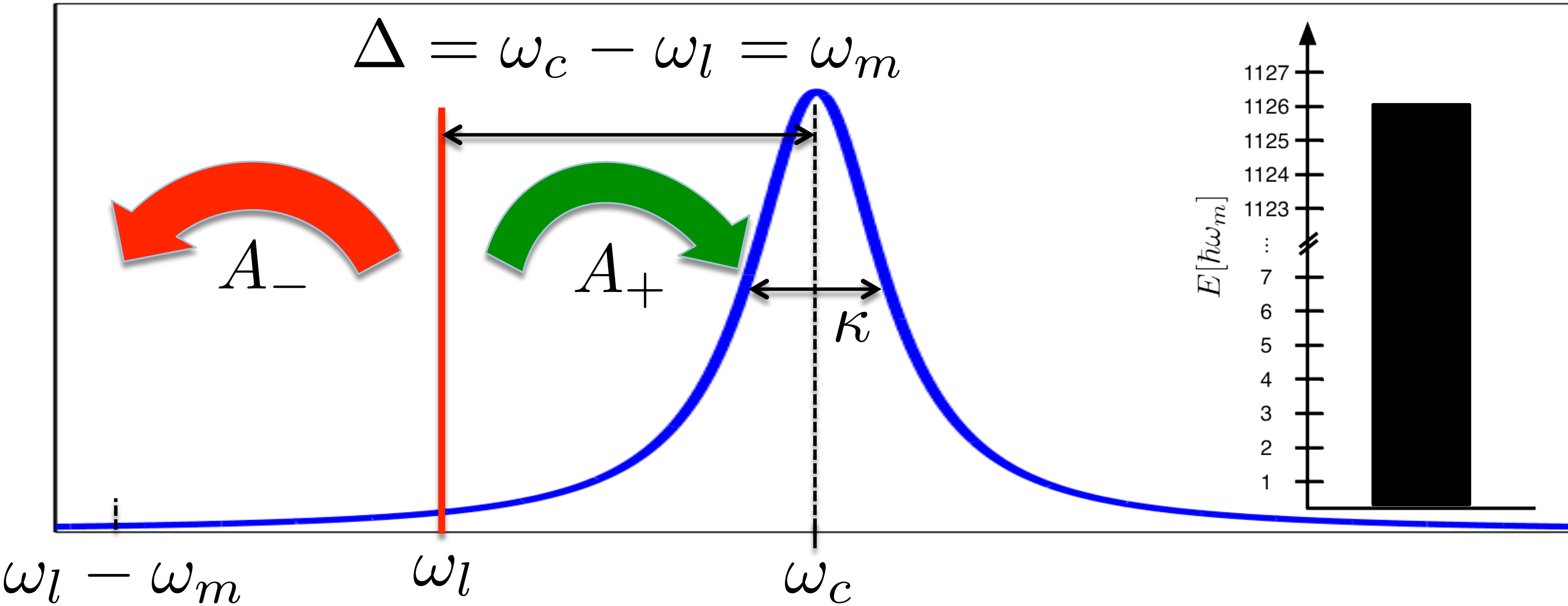
Optomechanical dynamics



$$\hat{\mathcal{H}} = \hbar\omega_c \hat{a}^\dagger \hat{a} + \frac{\hat{p}^2}{2m} + \frac{1}{2} m\omega_m^2 \hat{x}^2 + \hbar G_0 \hat{x}\hat{a}^\dagger \hat{a}$$

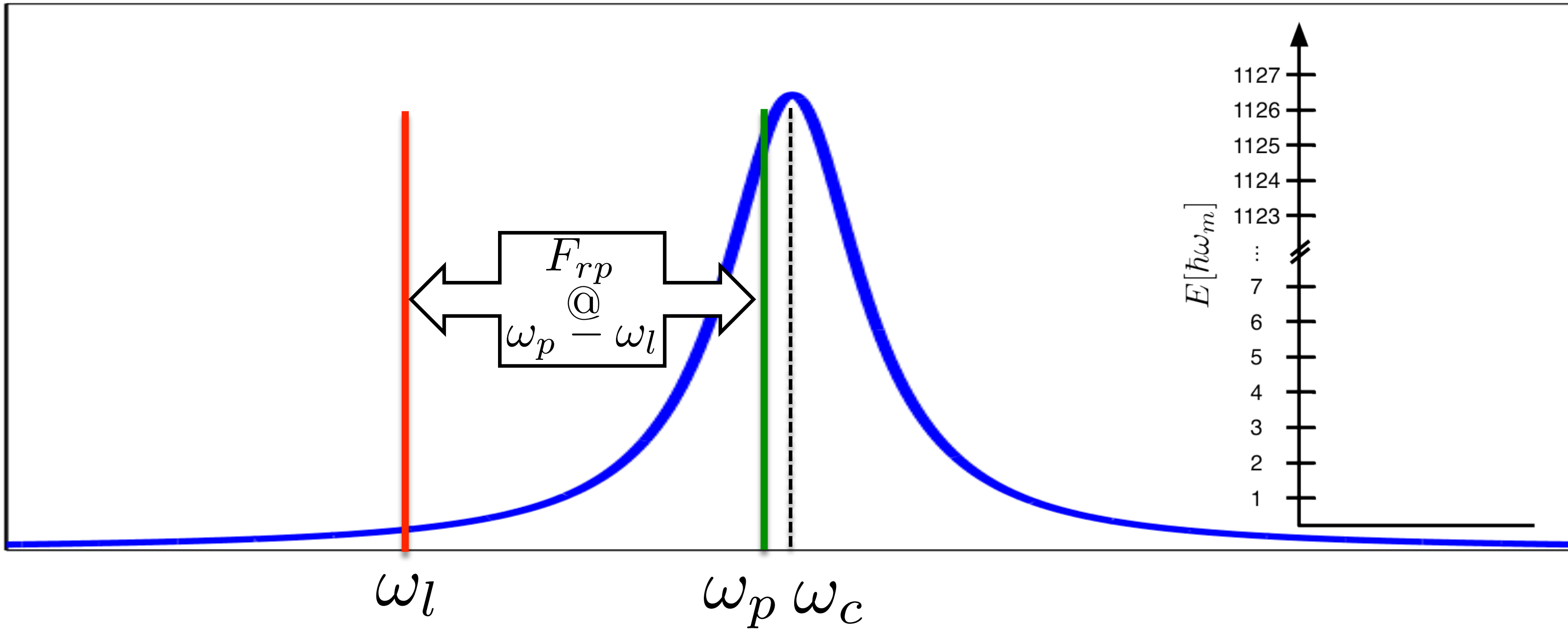
$$+ i\hbar\sqrt{\kappa}\left(\hat{a}^\dagger \hat{a}_{in} e^{-i\omega_l t} + \hat{a}\hat{a}_{in}^\dagger e^{i\omega_l t}\right)$$

Sideband cooling



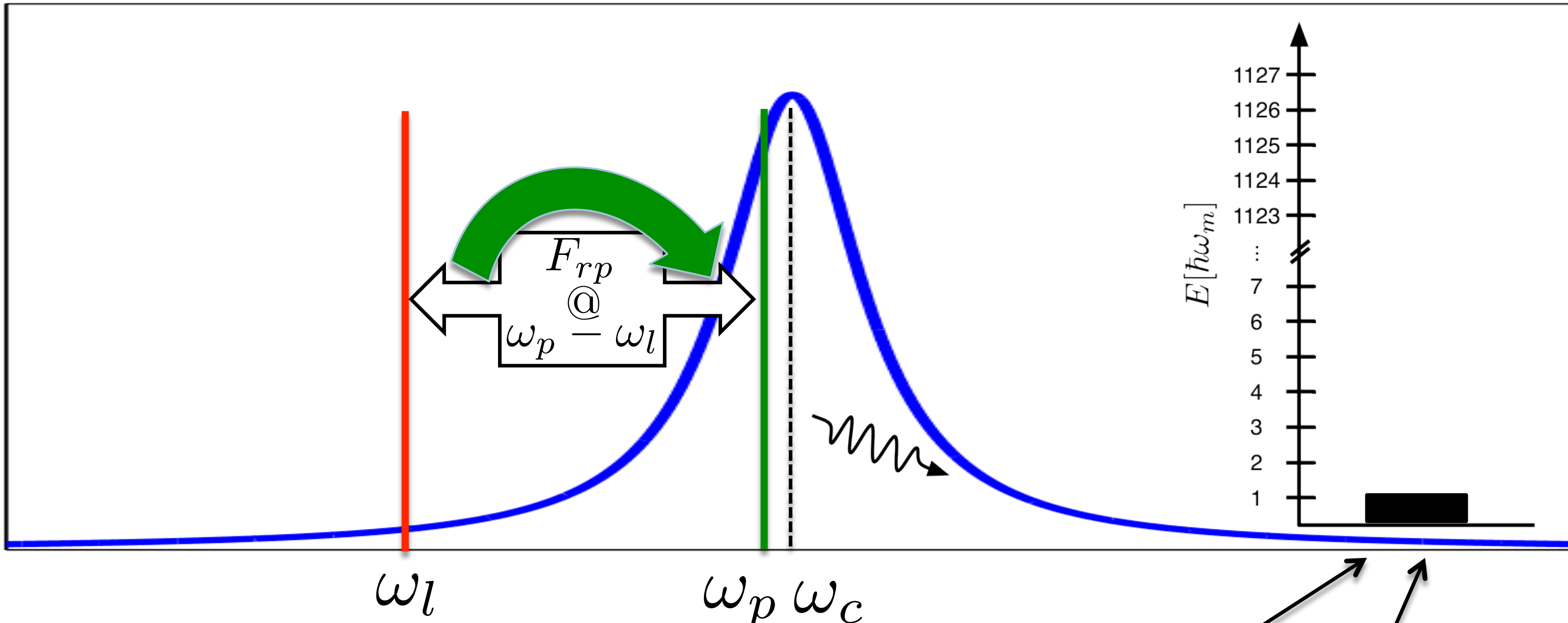
- Upshifted SB is resonant → $A_+ \gg A_-$
- Cooling limit: $\bar{n}_{min} = \left(\frac{\kappa}{4\omega_m}\right)^2$ → want $\omega_m \gg \kappa$

OMIT



- Introduce second, "probe" beam at ω_p
- Produces radiation pressure force at laser beat frequency, $\omega_p - \omega_l$

OMIT



- RP force excites mechanical oscillator
- As it cools, it scatters a photon up by $\Delta E = \hbar\omega_m$

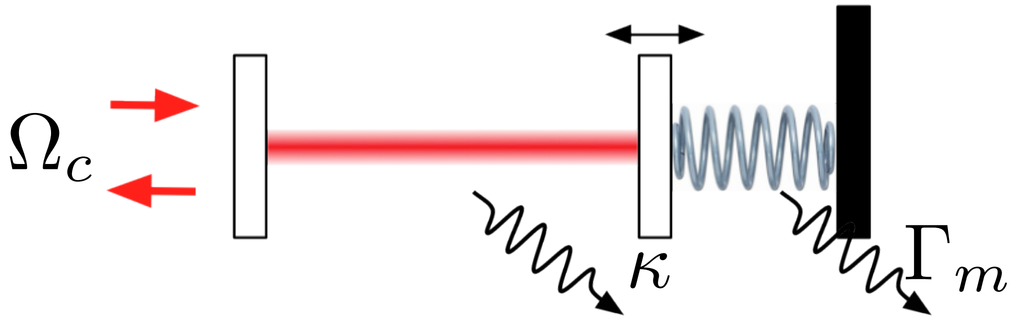
OMIT

- Optomechanical coupling rate:

$$\Omega_c \equiv \bar{a} G_0 \sqrt{\frac{2\hbar}{m\omega_m}}$$

- To preserve quantum state, must have

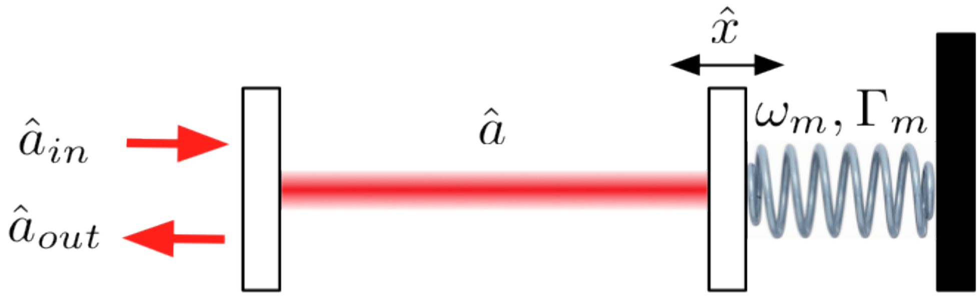
$$\Omega_c \gg \kappa, \Gamma_m$$



OMIT as a rotator

FI squeezing →

FD squeezing ←

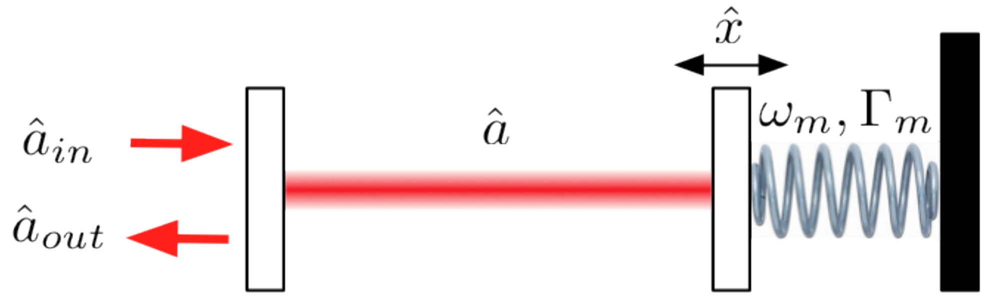


$$\hat{a}_{out}(\omega) = -\hat{a}_{in}(\omega) + \sqrt{\kappa}\hat{a}(\omega)$$

$$\hat{a}(\omega) \approx \sqrt{\frac{4}{\kappa}}\hat{a}_{in}(\omega) + \frac{2\bar{a}G_0}{i\kappa}\hat{x}(\omega)$$

$$\hat{x}(\omega) = \chi_{eff}^{-1}(\omega)[\hat{F}_{rp}(\omega) + \hat{F}_{th}(\omega)]$$

Thermal noise



SIGNAL　　　　NOISE

$$\hat{a}_{out}(\omega) \approx \frac{\omega - \delta - i\Gamma_{opt}}{\omega - \delta + i\Gamma_{opt}} \hat{a}_{in}(\omega) + \frac{iG_0}{\sqrt{\kappa} m\omega_m(\omega - \delta + i\Gamma_m + i\Gamma_{opt})} \hat{F}_{th}(\omega)$$

$$\delta \equiv \Delta - \omega_m \qquad \Gamma_{opt} \equiv \frac{\hbar \bar{a}^2 G_0^2}{m\omega_m \kappa} \qquad S_{FF}^{th}(\omega) = 4m\Gamma_m k_B T$$

Pump detuning　　**→ Rotation frequency ←**　　Thermal force spectrum

Thermal noise

Need

$$\frac{G_0^2 S_{FF}^{th}}{\kappa m^2 \omega_m^2 [(\omega - \delta)^2 + \Gamma_{opt}^2]} \approx \frac{2 k_B T}{\hbar Q \Gamma_{opt}} \ll 1$$

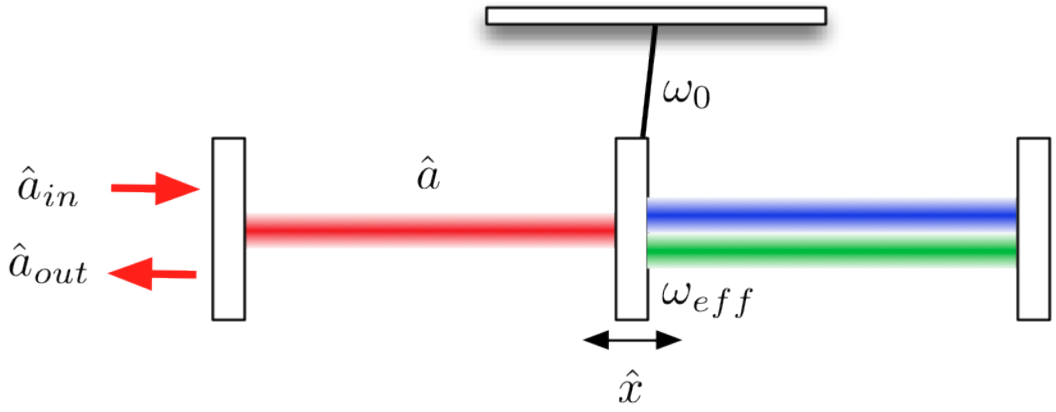
Or,

$$\boxed{T \ll \frac{\hbar Q \Gamma_{opt}}{k_B}}$$

$$\Gamma_{opt}/2\pi \sim 50\ \text{Hz},\ Q \sim 10^6 \longrightarrow T \ll \underline{2.4\ \text{mK}\ (!)}$$

Solutions?

- One idea: optical dilution



$$\omega_{eff} \gg \omega_0$$

$$\omega_0 \text{ lower, } \Gamma_0 \text{ lower} \longrightarrow S_{FF}^{th} \text{ lower}$$

The End

- ANYONE HAVE ANY IDEAS? LET US KNOW!

- Acknowledgements
  - Haixing Miao
  - Thomas Corbitt
  - Amir Safavi-Naeini (O. Painter group, CIT)

- References:

  - Weis, et al., “Optomechanically induced transparency,” *Science* **330** (6010), 2010
  - Safavi-Naeini, et al., “Electromagnetically induced transparency and slow light with optomechanics,” *Nature* **472**, 2011
  - Corbitt, et al., “Optical Dilution and Feedback Cooling of a Gram-Scale Oscillator to 6.9 mK,” *Phys. Rev. Lett.* **99** 160801 (2007)