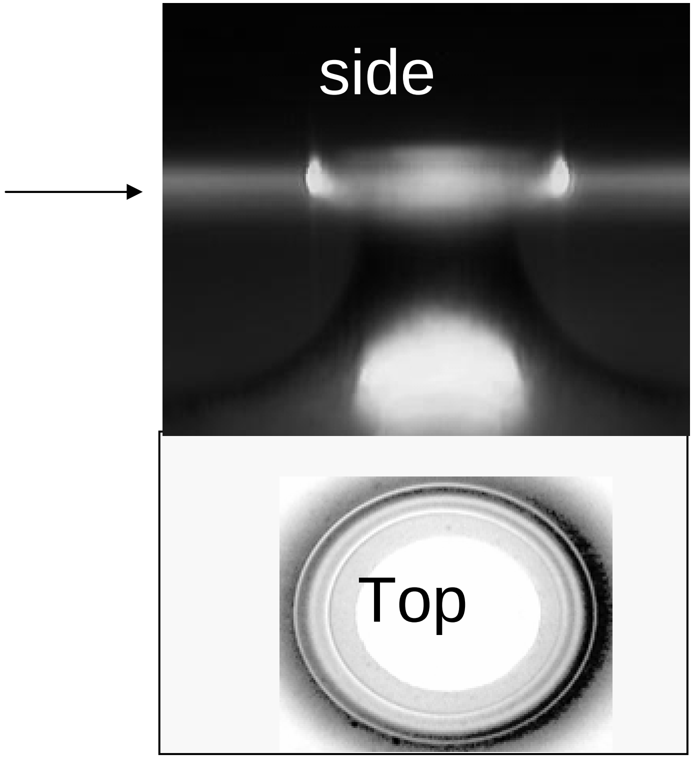
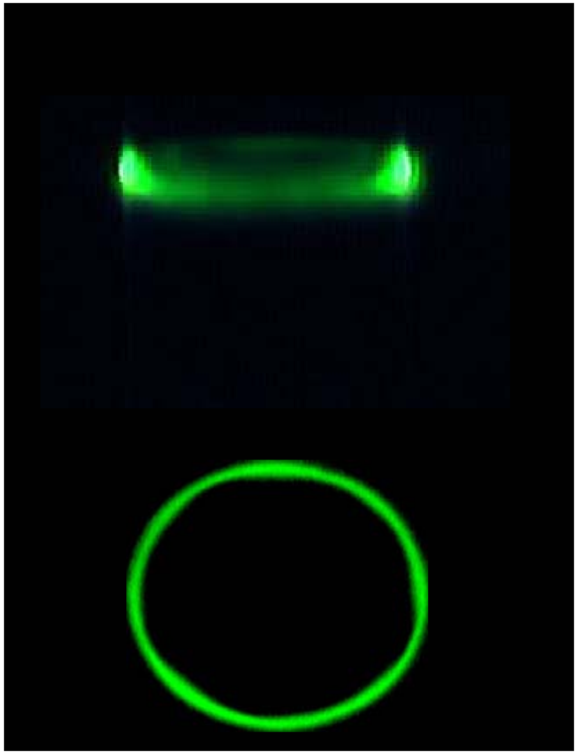
# Dynamical Thermal Behavior and Thermal Self-Stability of Microcavities .





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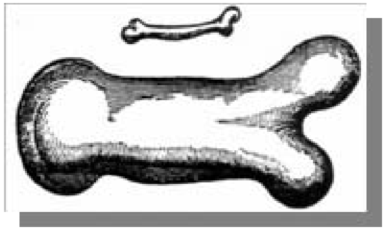
# Smaller objects in nature are not just scaled replicas of similar big objects[§]



⬇ Size

⬆ Cavity temperature ($10^0$C/mW)[ℵ]

⬇ Threshold for lasing (700nW) [限]

⬇ Thermal time constant ($<1\mu$s) [†]

⬇ Optical loss

⬇ Threshold for lasing

⬇ Cavity resonance bandwidth (<10 fm)

⬆ Thermal drift of resonance (400BW/mW) [ℵ]

## What is our playground

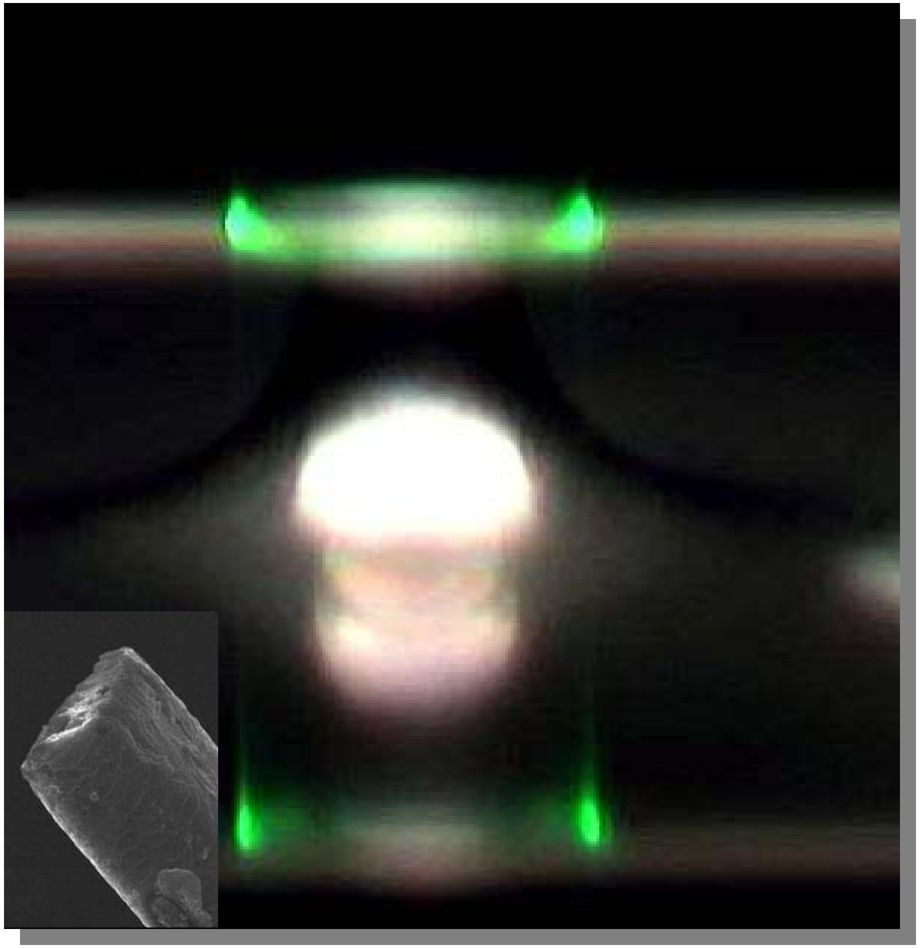
(§) *Galileo*, **Dialogue Concerning Two New Sciences**, (1638)

(ℵ) *T. Carmon, L. Yang, and K. J. Vahala* **"Dynamical thermal behavior and thermal self-stability of microcavities"** Optics Express, **12**, 4742 (2004).

(限) *L. Yang, T. Carmon, B. K. Min, S. M. Spillane, and K. J. Vahala* **"Erbium-doped and Raman microlasers on a silicon chip fabricated by the sol-gel process"** Appl. Phys. Lett, **86**, 091114, (2005)

(†) V. S. Ilchenko and M. L. Gorodetsky, **"Thermal nonlinear effects in optical whispering gallery microresonators,"** Laser. Phys. **2**, 1004 (1992).

# Playground – High Q microcavities



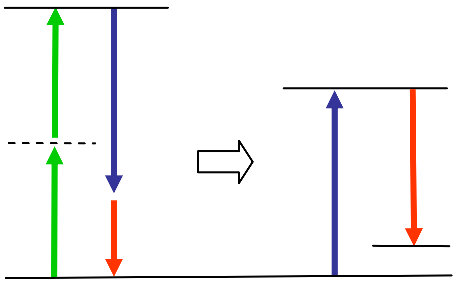
*D. Armani, T. Kippenberg, S. Spillane and K. Vahala* **"Ultra-high-Q toroid microcavity on a chip“** Nature, 421, 925 (2003)

Thermal effects:

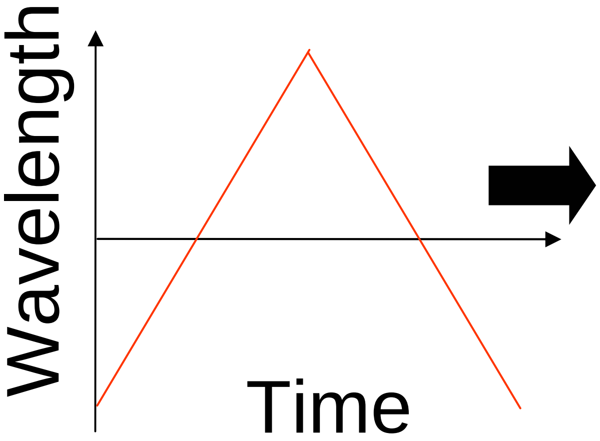
1. Hysteretic wavelength response.
2. Self stability.
3. Interplay with external stabilization system.

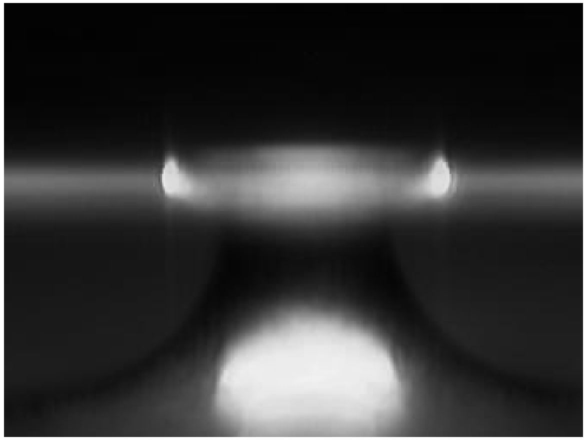
Other effects:

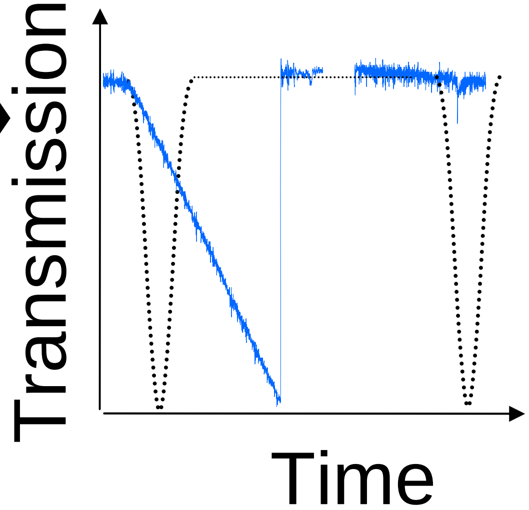
4. Cascaded NL, Pump -> idler+signal->Raman lasing



# (1) Thermal hysteretic response



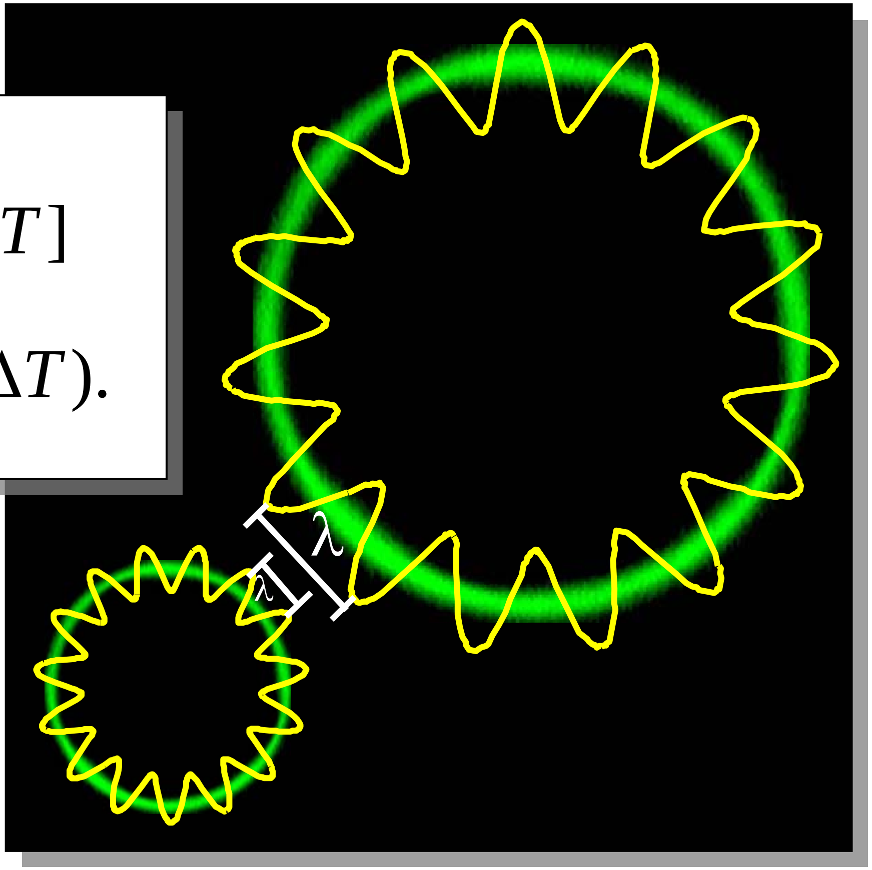




Reason: Thermal expansion of resonance wavelength

# Thermal expansion coefficient of resonance wavelength

$$\lambda_r(\Delta T) \cong \lambda_0\,[1 + (\varepsilon + \frac{dn}{dT}/n_0)\,\Delta T]$$
$$\equiv \lambda_0\,(1 + \qquad a \qquad \Delta T).$$



Dynamical equation?

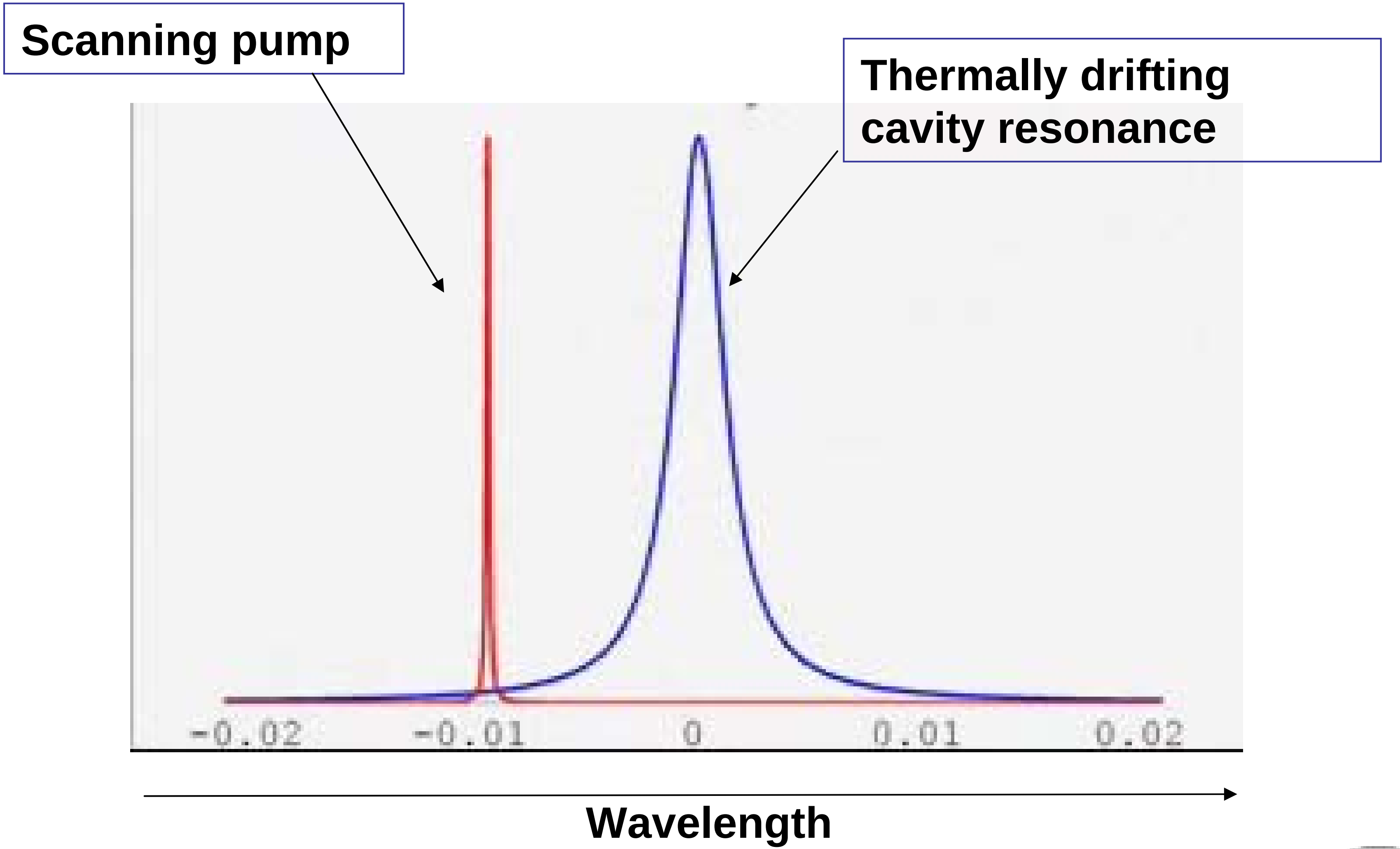
# Heat Eq. + Lorentzian absorption + Thermal expansion of resonance wavelength

$$Cp\,\Delta\dot{T}(t) = \dot{q}_{in} - \dot{q}_{out}$$

$$Cp\,\underline{\Delta\dot{T}(t)} = I_h \frac{1}{\left(\frac{\lambda_p(t)-\lambda_0\,(1+a\,\underline{\Delta T(t)})}{\Delta\lambda/2}\right)^2+1} - K\underline{\Delta T(t)}$$

See behavior

*T. Carmon, L. Yang, and K. J. Vahala* **"Dynamical thermal behavior and thermal self-stability of microcavities"** Optics Express, **12**, 4742 (2004).

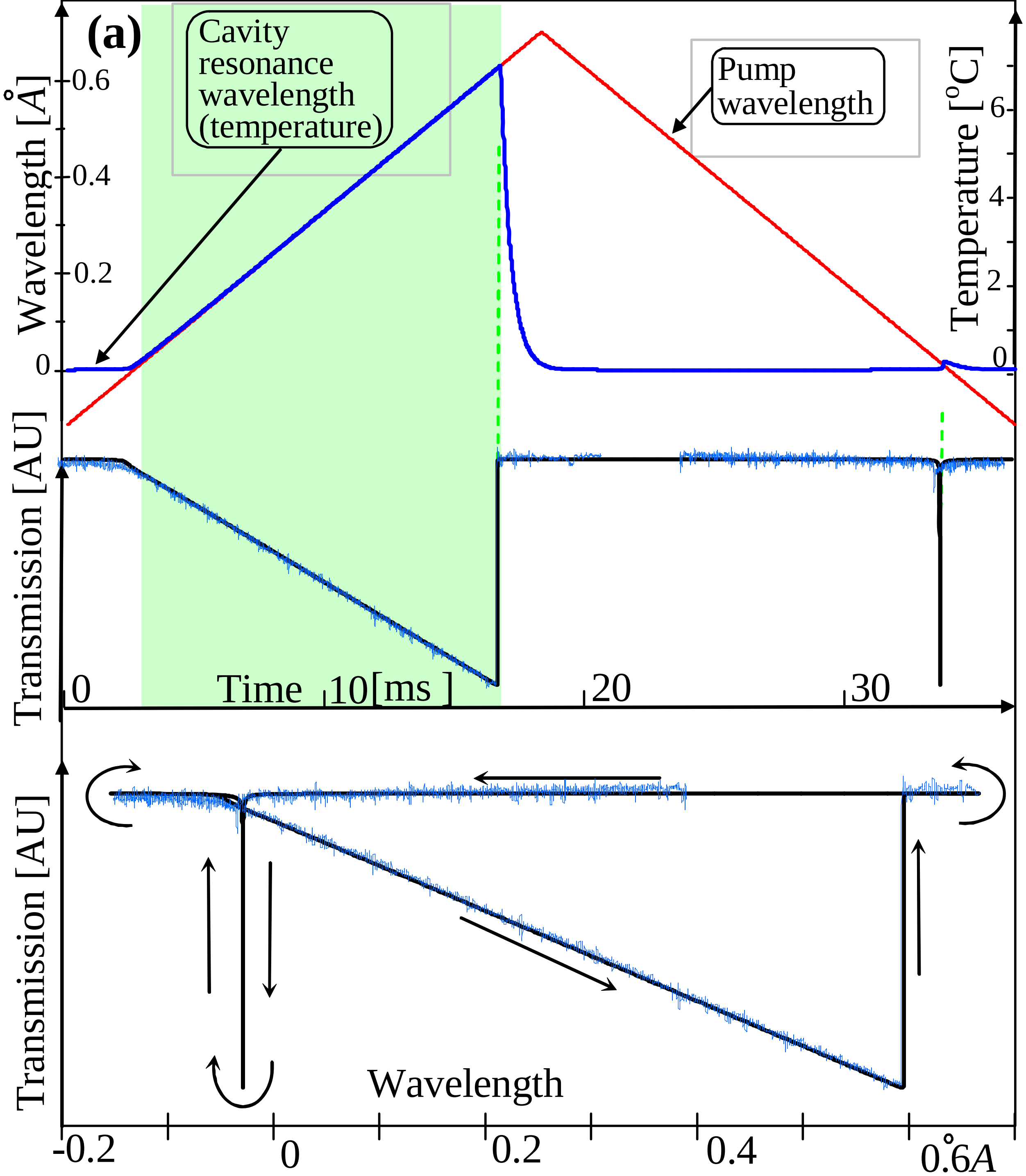


**Scanning pump**

**Thermally drifting cavity resonance**

**Wavelength**

# Compare experiment and theory



1) Change:
- Heat capacity
- Thermal conductivity

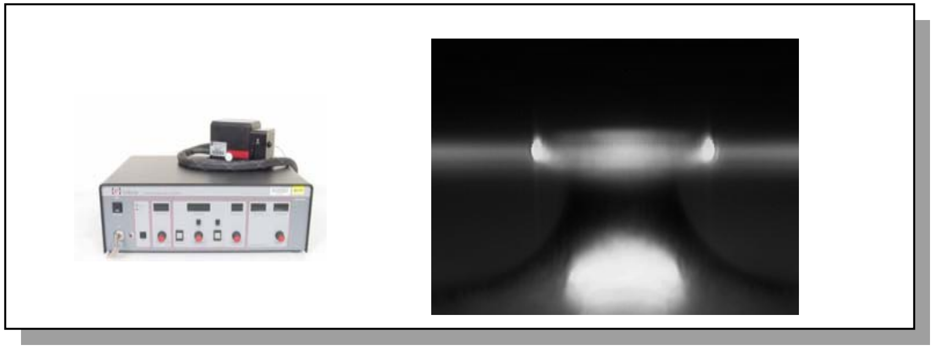
2) Fit between experimental and theoretical transmission

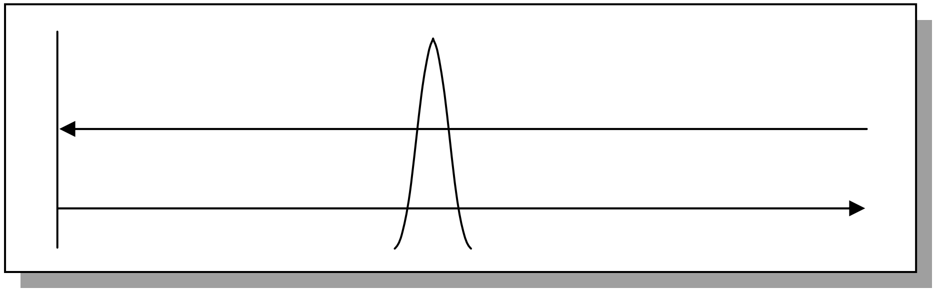
3) now:
- Temperature dynamics
- Dynamics of resonance

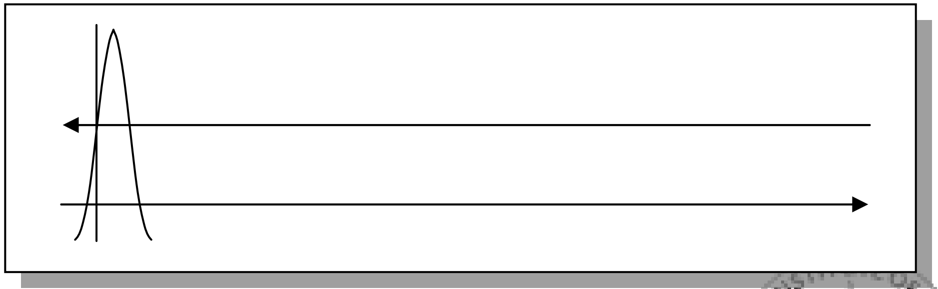
4) Can calculate cavity behavior for different scenario.

# (2) Self thermal Stabilization

- From pump spec: In 5 second pump drifts 10 cavity FWHMs.
- How a continuous operation is possible when cavity is loaded in 10% of time?
- Thermal nonlinearity cause resonance to follow the drifting pump. Resonance is maintained

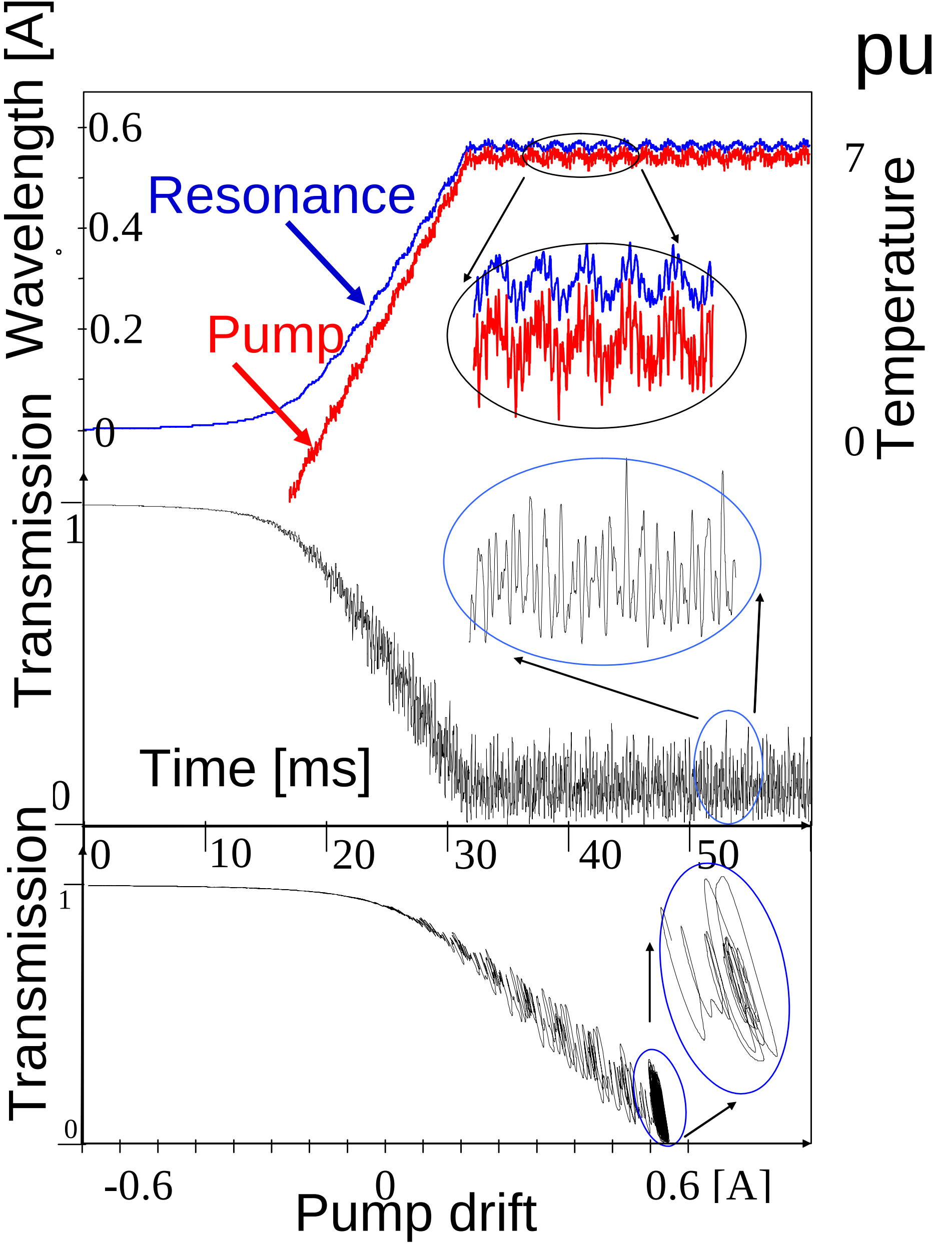






Calculation?

# Solution of dynamic thermal equation for a noisy pump

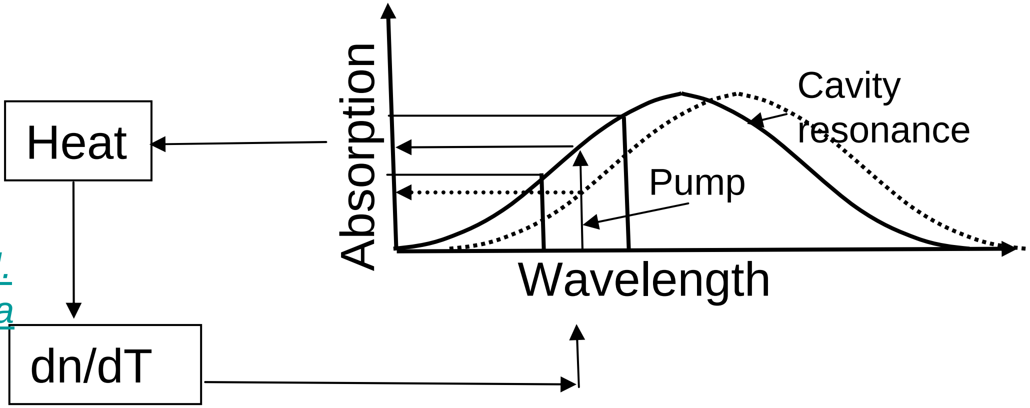


Resonance follows drifting pump to maintain resonance.

What do we do when pump is not strong enough for thermal self stabilization?

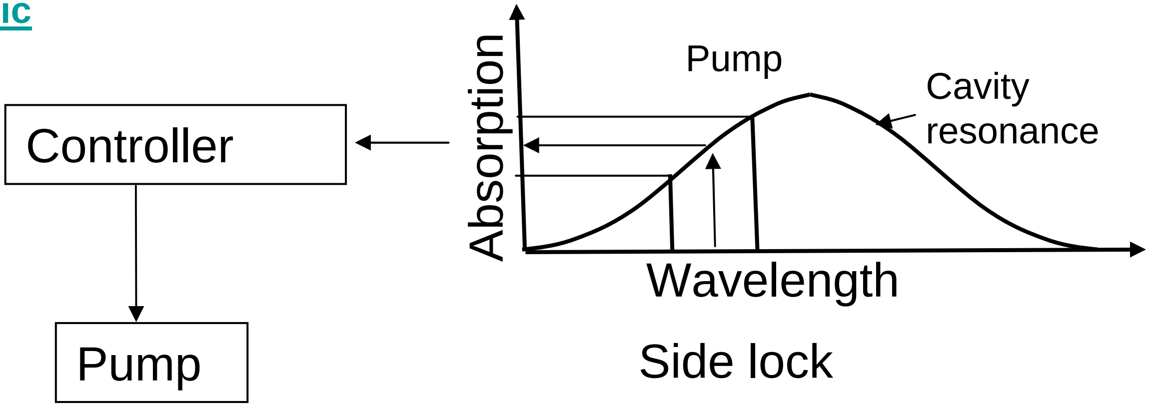
# Stabilization methods

Thermal Self Stabilization

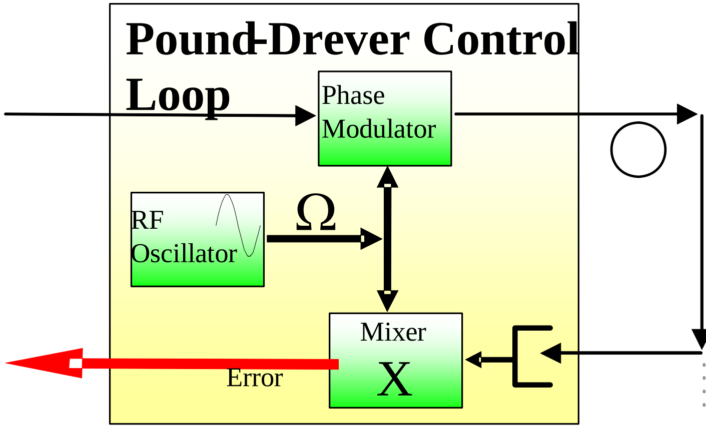


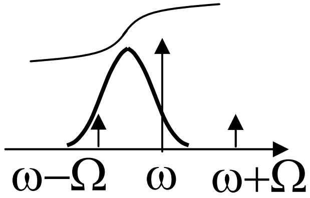
- *T. Carmon, T. J. Kippenberg, L. Yang, H. Rokhsari, S. M. Spillane, and K. J. Vahala* **“Feedback control of ultra-high-Q microcavities: application to micro-Raman lasers and microparametric oscillators”** Optics Express, 13, 2005.

Side lock



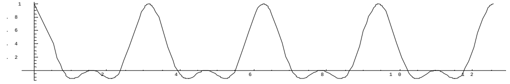
Side lock

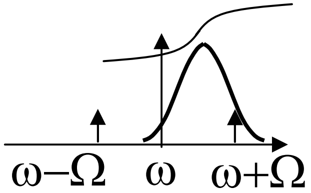




$\sin(\omega\tau)+\sin(\omega-\Omega)t=\sin(\Omega t/2)$

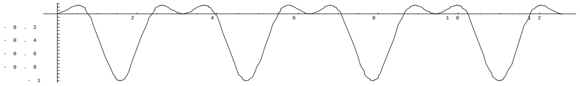
$\sin(\Omega t+\pi/2)\sin^2(\Omega t/2)$



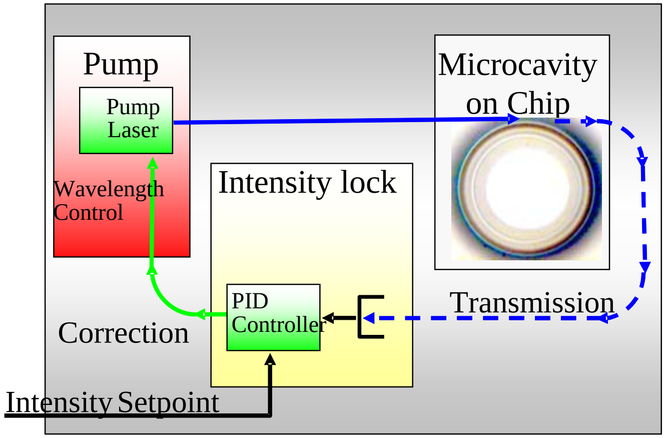


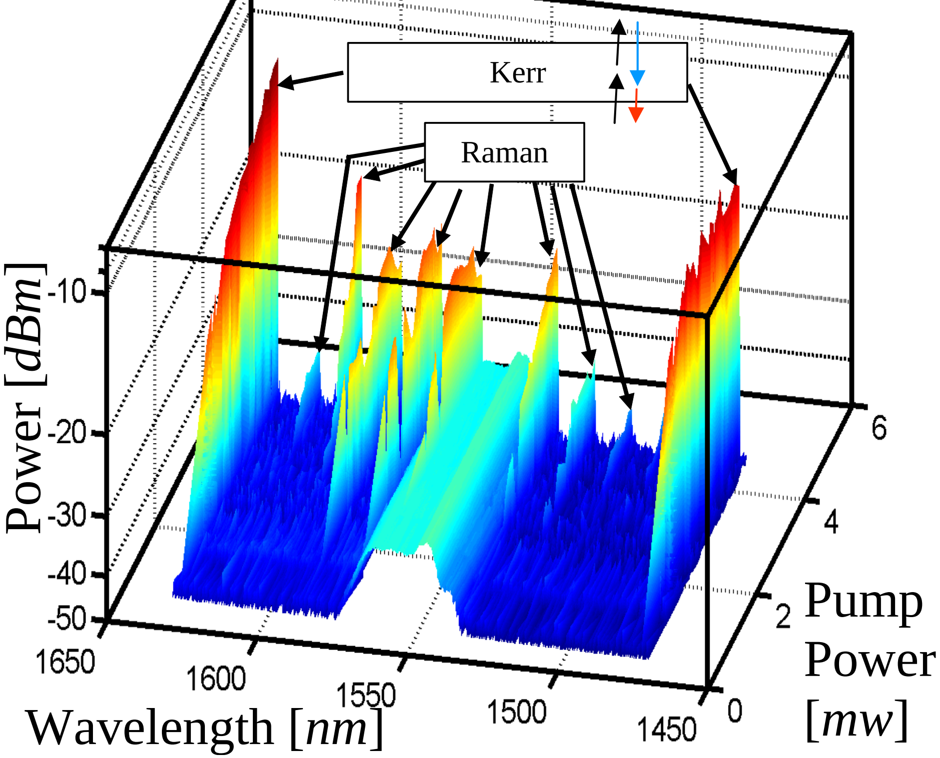
$-\sin(\omega\tau)-\sin(\omega+\Omega)t=\cos(\Omega t/2$

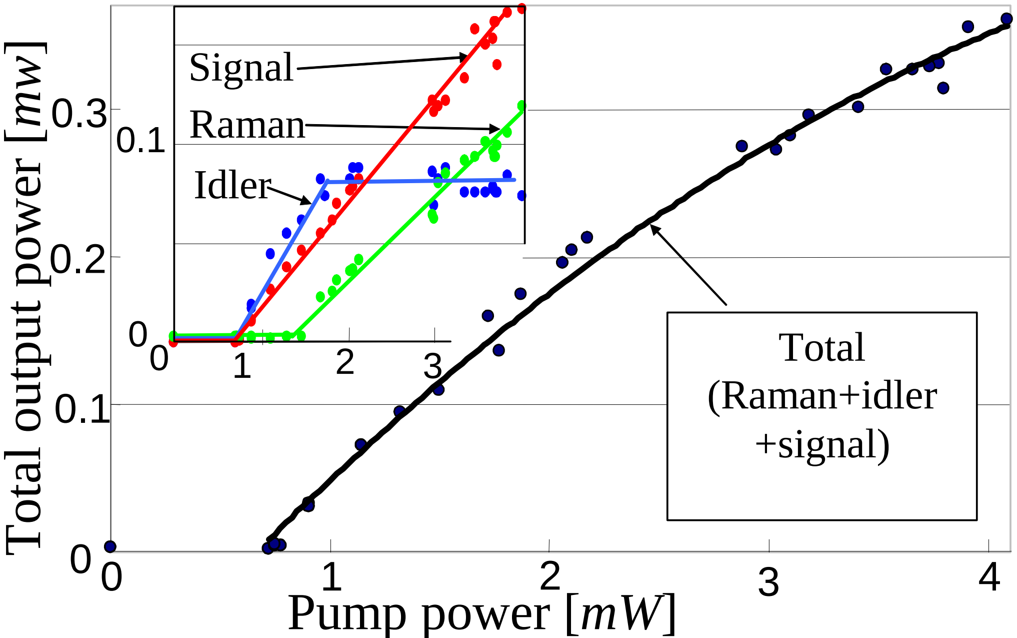
$\sin(\Omega t+p/2)\cos^2(\Omega t/2)$



# (3) Side lock stabilization
# Good for intensity scan







cascaded nonlinear process in which photons generated by optical parametric oscillations (OPO) function as a pump for Raman lasing

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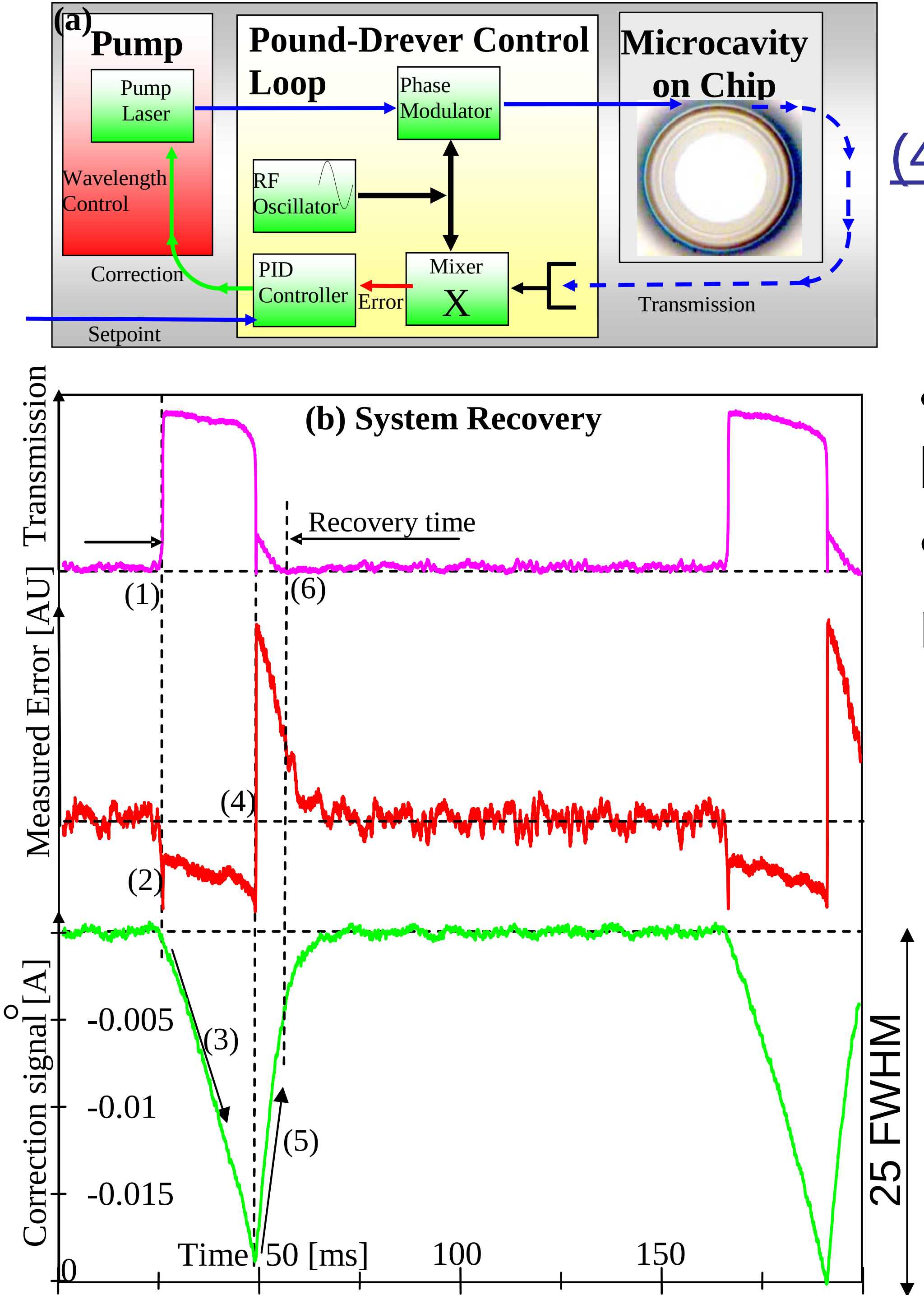
# (4) Pound Drever stabilization



- Recovery from resonance loss
- Interplay with thermal nonlinearity

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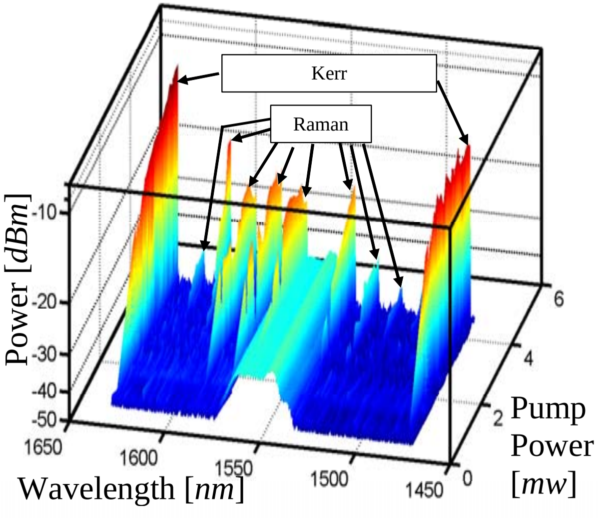
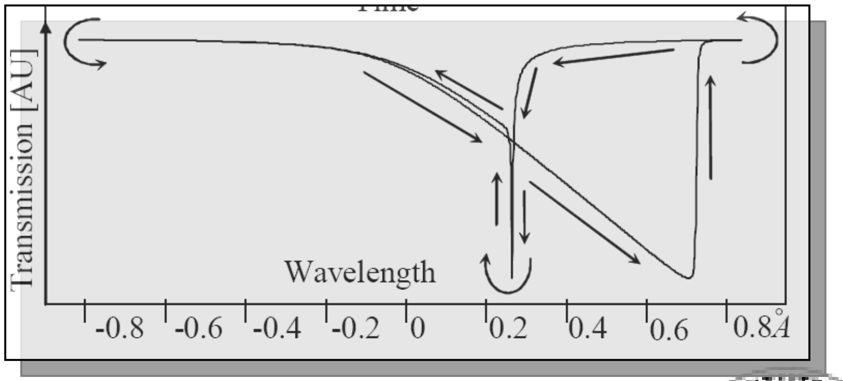
# Conclusion

- Cascaded nonlinear process in which photons generated by optical parametric oscillations (OPO) function as a pump for Raman lasing.
- CW operation, $SiO^2$ cavity. (no pulses, no depart).
- Model for thermal dynamical behavior.
- Explain thermal hysteretic wavelength response.
- Explain thermal self stability.
- Micro cavities are thermally self stable.





# http://www.vahala.caltech.edu

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  **"Feedback control of ultra-high-Q microcavities: application to micro-Raman lasers and microparametric oscillators"**
  Optics Express, 13, 2005.
- Talk.
- Code for cavity thermal dynamics.
- Movie.

Keywords: Cavity, microcavity, hysteretic wavelength response, hysteretic frequency response, Optical cavity, Optical microcavity, stabilizations of microcavities, stabilization of cavities, stabilization of optical cavities stabilization of optical microcavities. Thermal line broadening.