Kerr combs in whispering-gallery-mode resonators

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Laboratoire FEMTO-ST, Besançon

November 12, 2012

Outline

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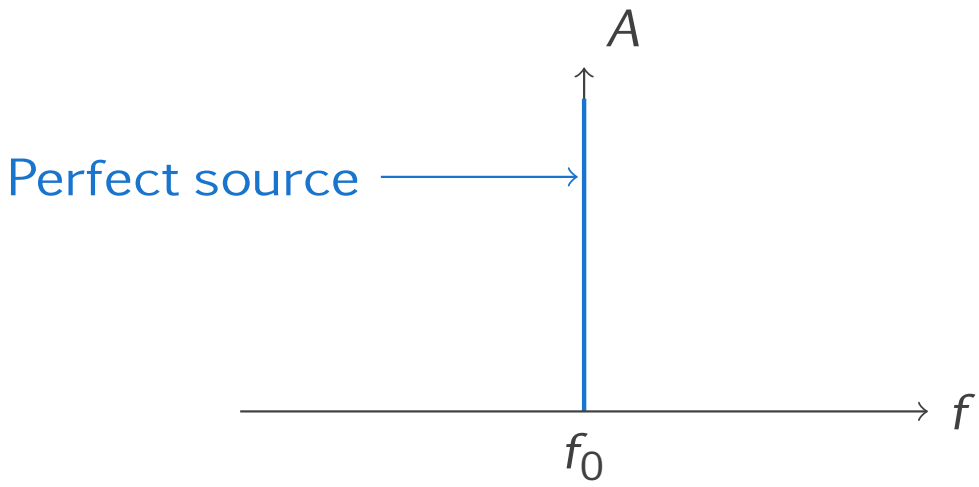
Introduction

Microwave radar: GHz source



$$A(t) = A\cos(2\pi f_0 t + \varphi_0 \qquad)$$

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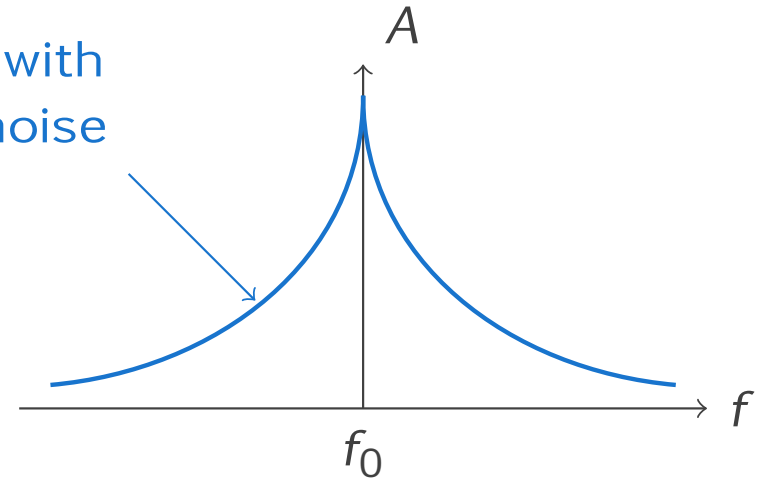
Introduction

Microwave radar: GHz source

Source with phase noise



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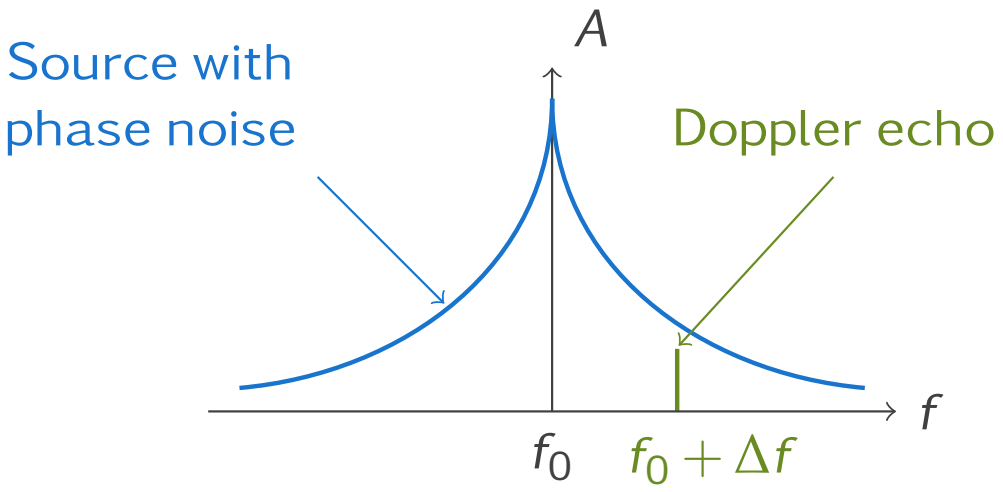

$$A(t) = A\cos(2\pi f_0 t + \varphi_0 + \varphi(t))$$

- Aerospace needs ultra-stable GHz Microwaves

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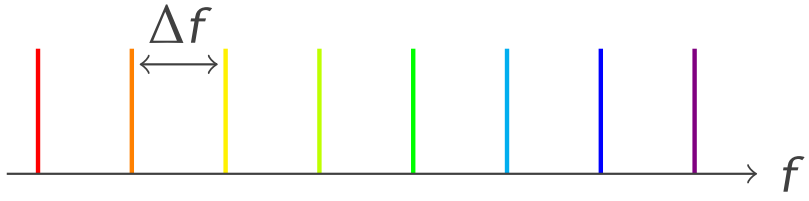
Introduction

- Most existing technologies reach their top performances
- Need for alternative paradigm, technological leap
- A possible solution:

  microwave photonics and Kerr combs

Optical frequency combs

Equally spaced spectral lines:



- High-precision frequency "ruler stick"
- Nobel prize for John L. Hall and Theodor W. Hänsch
- Generated with mode-locked femtosecond lasers

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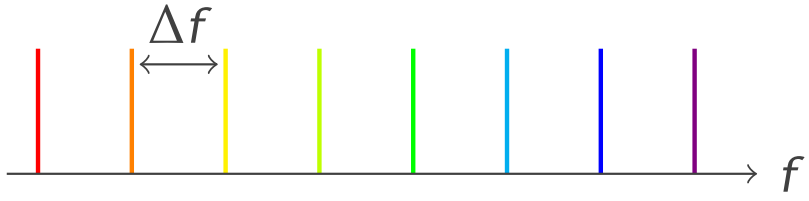

- High-precision frequency "ruler stick"
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- Generated with mode-locked femtosecond lasers
- New method: four-wave mixing in high-Q resonators
  → Kerr combs

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Kerr combs

- Kerr effect and four-wave mixing:

$$hf_\alpha + hf_\beta \rightarrow hf_\gamma + hf_\delta$$

- Nonlinear effect
- Energy and momentum conservation

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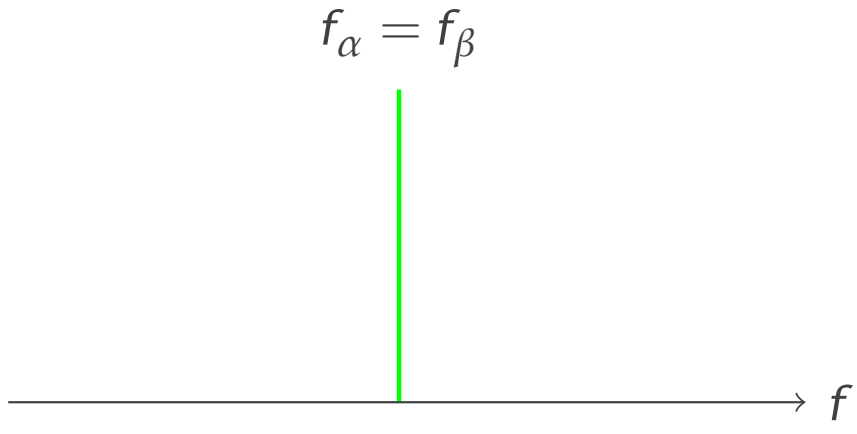

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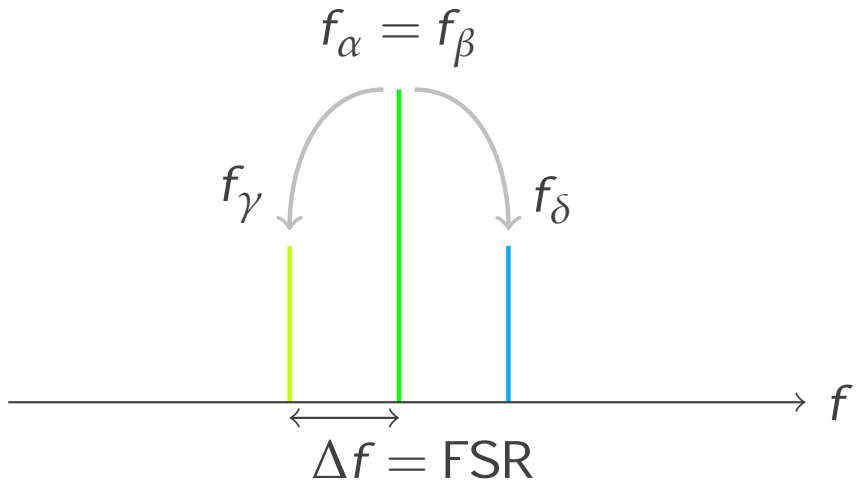

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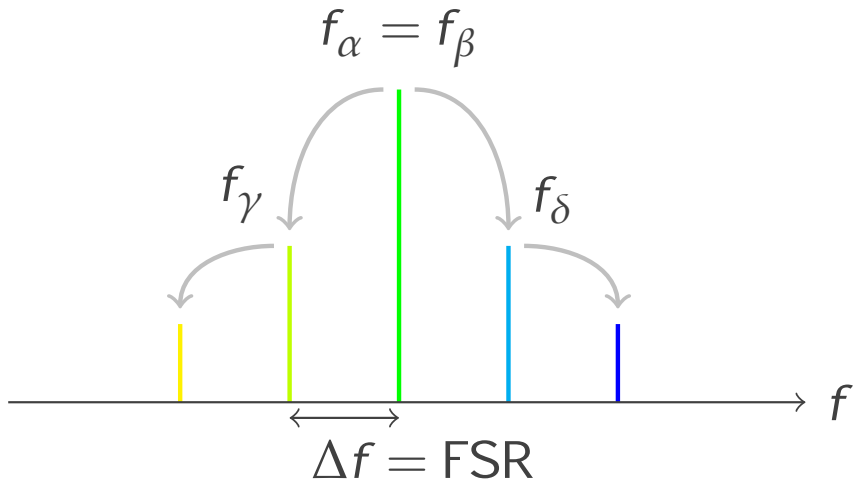

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Kerr combs

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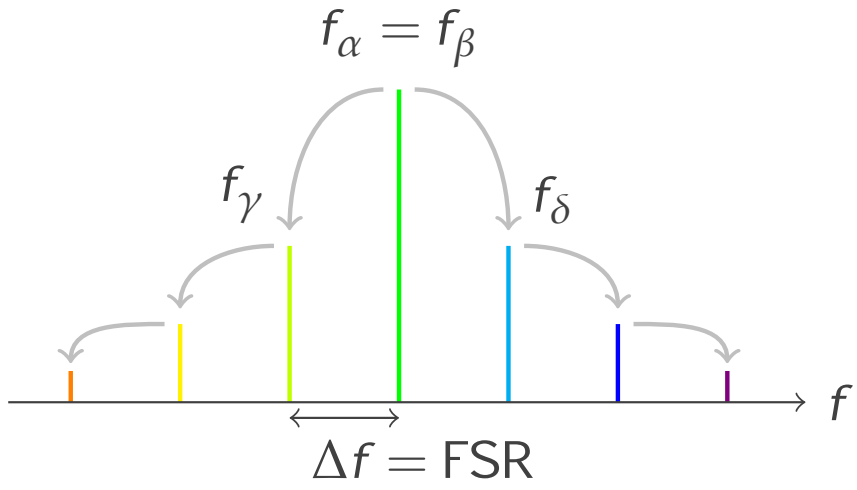
- Cascaded FWM $\rightarrow$ Kerr combs



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Whispering-gallery modes

- Nonlinear effect require high intensity
  $\rightarrow$ ultra-high $Q \sim 10^9$

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- Crystalline whispering-gallery mode resonator:
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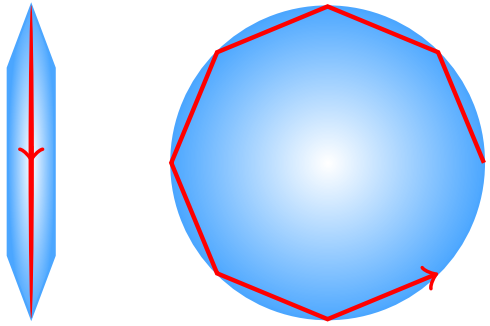

Ray optics:
total internal reflections

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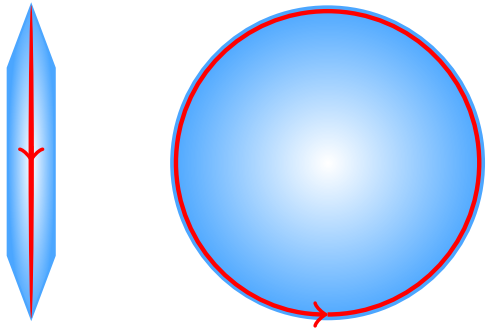

Wave optics:
modes confined at the surface

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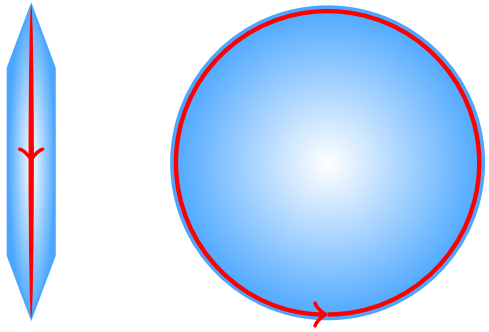

Wave optics:
modes confined at the surface

- Quality factor limited by the intrinsic material absorption

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Theoretical model[1]

- Envelop approximation
- Modal description
- Dispersion and Kerr nonlinearity

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[1] Y. K. Chembo & N. Yu, *Physical Review A* **82,** 033801 (2010)

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$$\dot{A}_\eta = -\frac{1}{2}\Delta\omega_\eta A_\eta$$

Resonator & dispersion

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I. Balakireva, Tuesday 10 am

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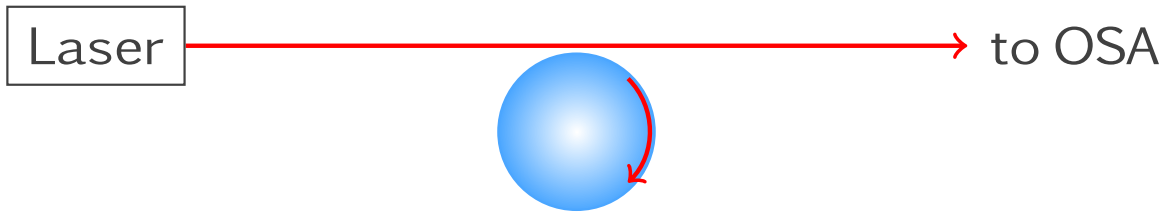
Experimental setup

- Simple setup:



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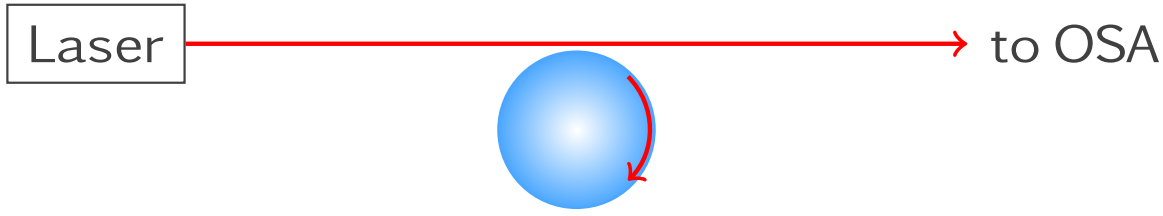

- Technical challenges:

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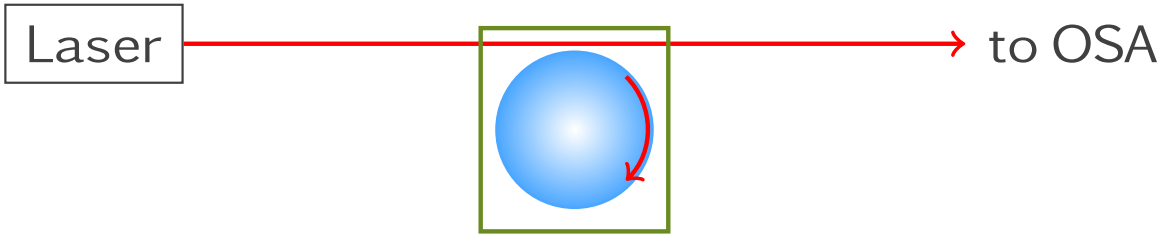

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  - High-Q WGM resonator
    R. Henriet, Tuesday 3:15 pm

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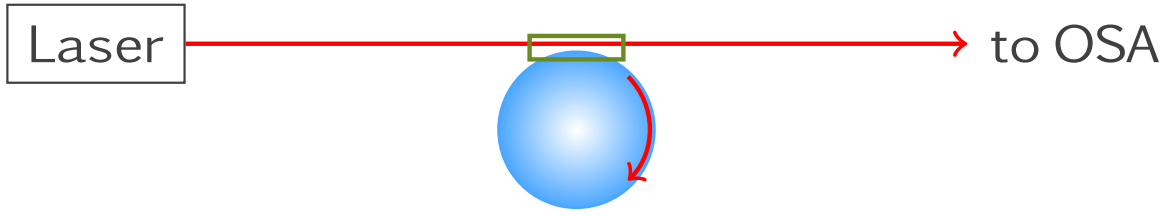

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  - Coupling

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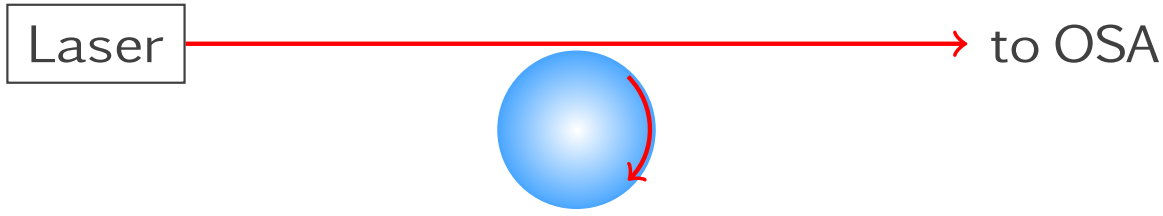

- Technical challenges:
  - High-Q WGM resonator
    R. Henriet, Tuesday 3:15 pm
  - Coupling
  - Stabilization

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Coupling

- Launch light in the resonator
- Evanescent field & phase-matching

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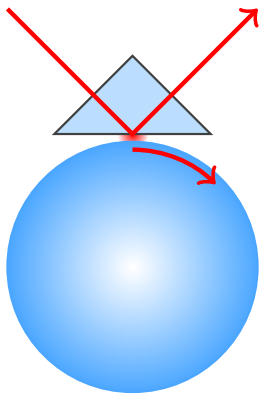
Coupling

- Launch light in the resonator
- Evanescent field & phase-matching
- 3 technics:
  - Prism coupling



- Stable
- Difficult alignment
- Poor efficiency

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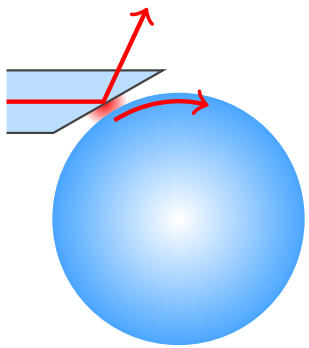
Coupling

- Launch light in the resonator
- Evanescent field & phase-matching
- 3 technics:
  - Angle-polished fibre



- Stable
- Difficult fabrication
- Difficult alignment
- Poor efficiency

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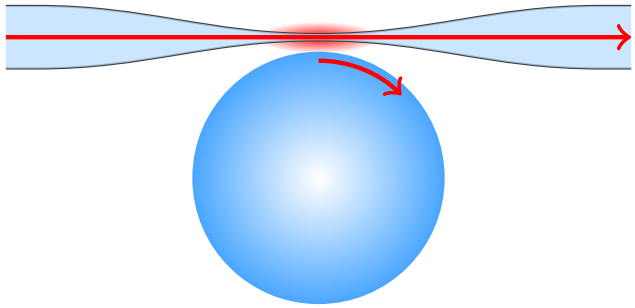
Coupling

- Launch light in the resonator
- Evanescent field & phase-matching
- 3 technics:
  - Tapered fibre



- Needs stabilization
- Easy alignment
- Efficiency up to 99.9%

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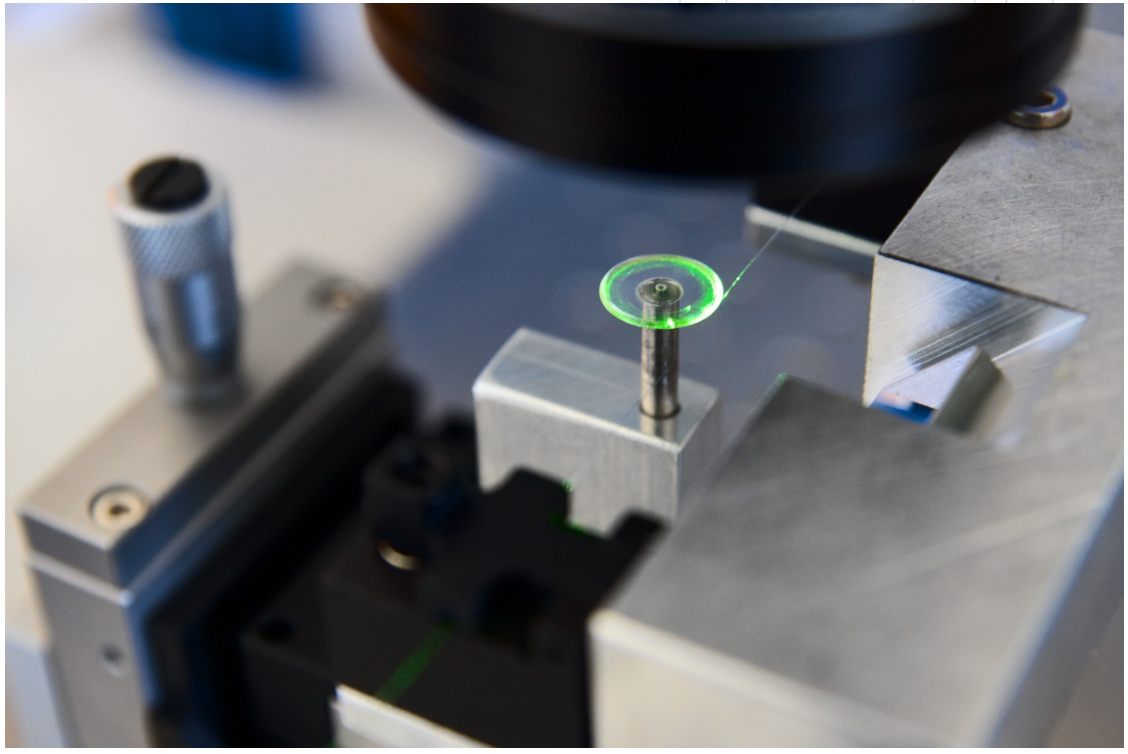
Coupling



Green light coupling

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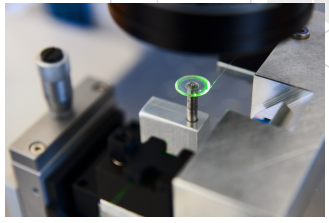
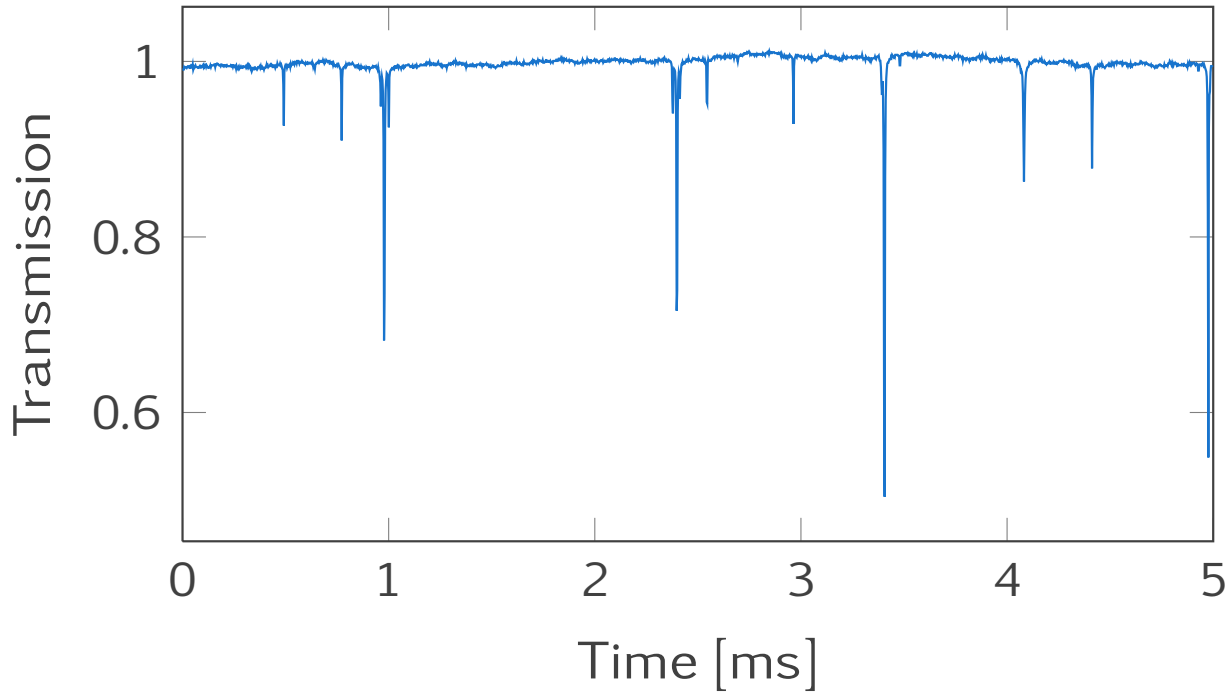
Coupling





Resonance spectrum

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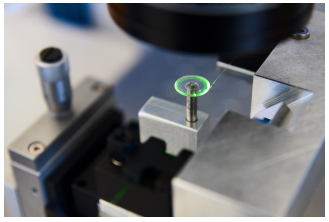
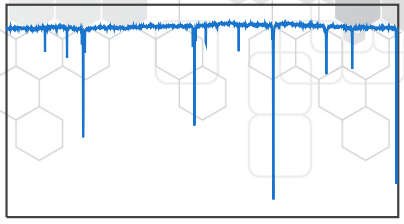
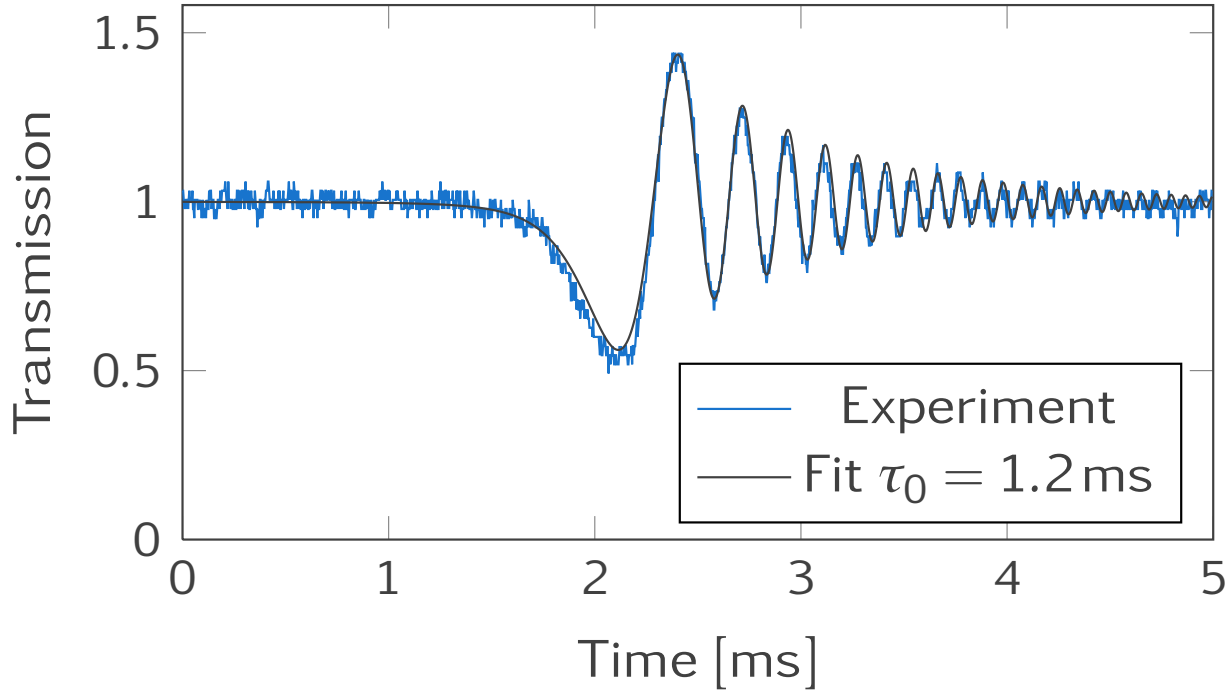
Coupling







Cavity ring-down measurement: $Q = 7.3 \times 10^8$

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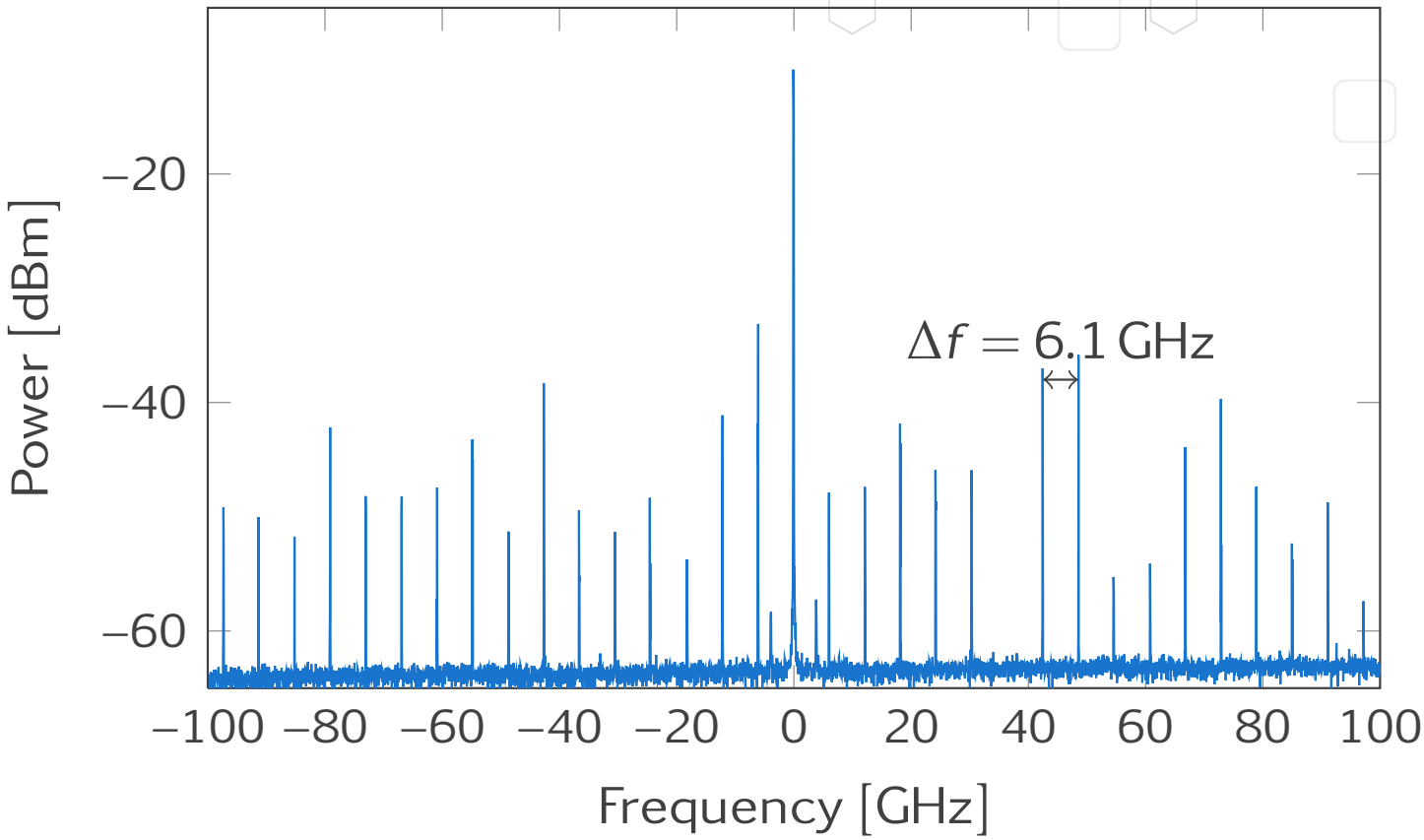
Results



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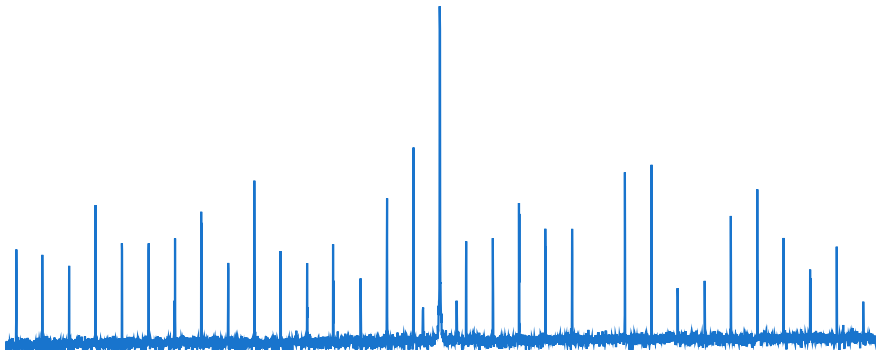
Conclusion

- 1 year old ERC starting grant project
- Next steps:
  - Study the dynamics
  - Stabilize the combs
  - Extract the microwave signal



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Thanks for your attention!

cnrs erc nextphase