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Arnaud Garnache, David Holleville

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Single-frequency diode-pumped semiconductor laser tuned on a Cs transition

B. Cocquelin, Gaëlle Lucas-Leclin and P. Georges

Laboratoire Charles Fabry de l'Institut d'Optique,
Palaiseau, France

I. Sagnes

Laboratoire de Photonique et de Nanostructures,
Marcoussis, France

A. Garnache

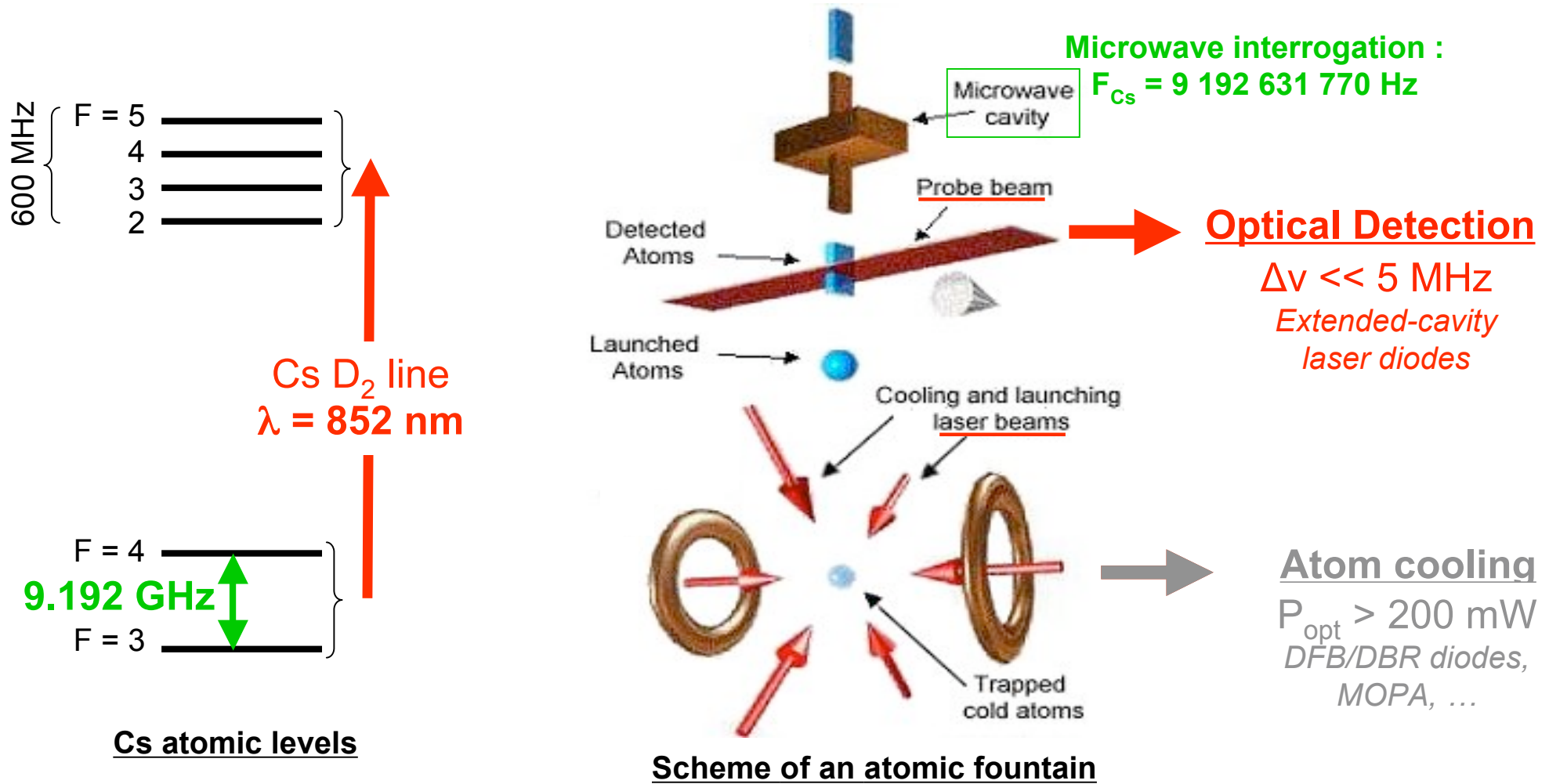
Institut d'Électronique du Sud,
Montpellier, France

D. Holleville

LNE/SYRTE - Observatoire de Paris ,
Paris, France

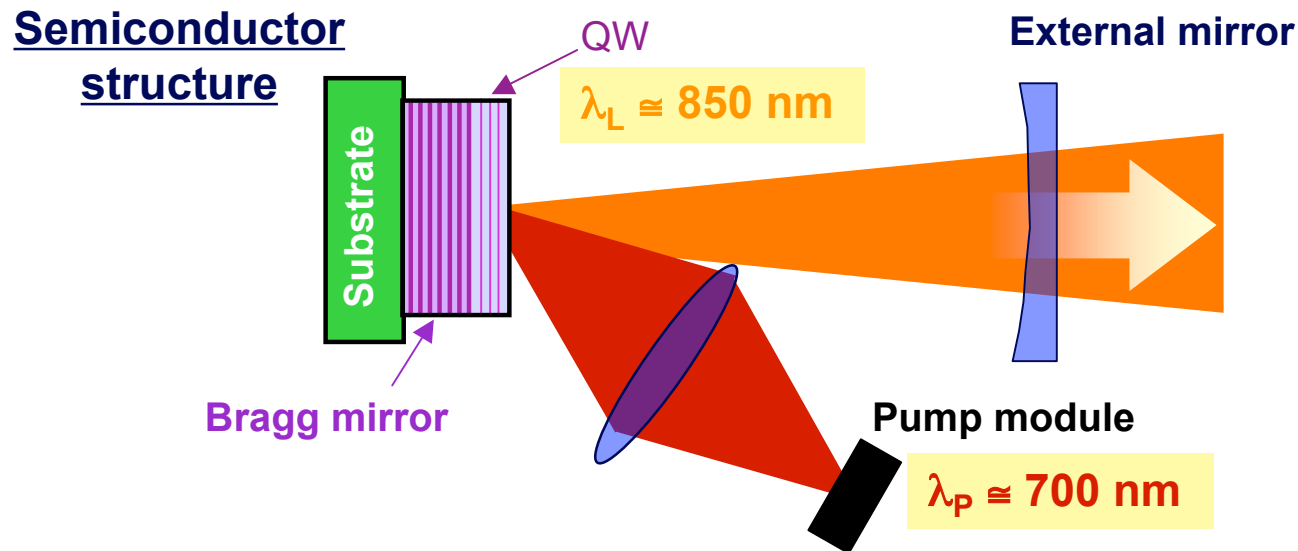
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Need for **high-power** and **narrow-linewidth** sources emitting at the Cesium D₂ line (852 nm)

⇒ a single OP-VECSEL ?



- **High power** in Optically Pumped-VECSEL

30 W @ 980 nm, $M^2 = 3$ (Coherent - Photonics West '04)

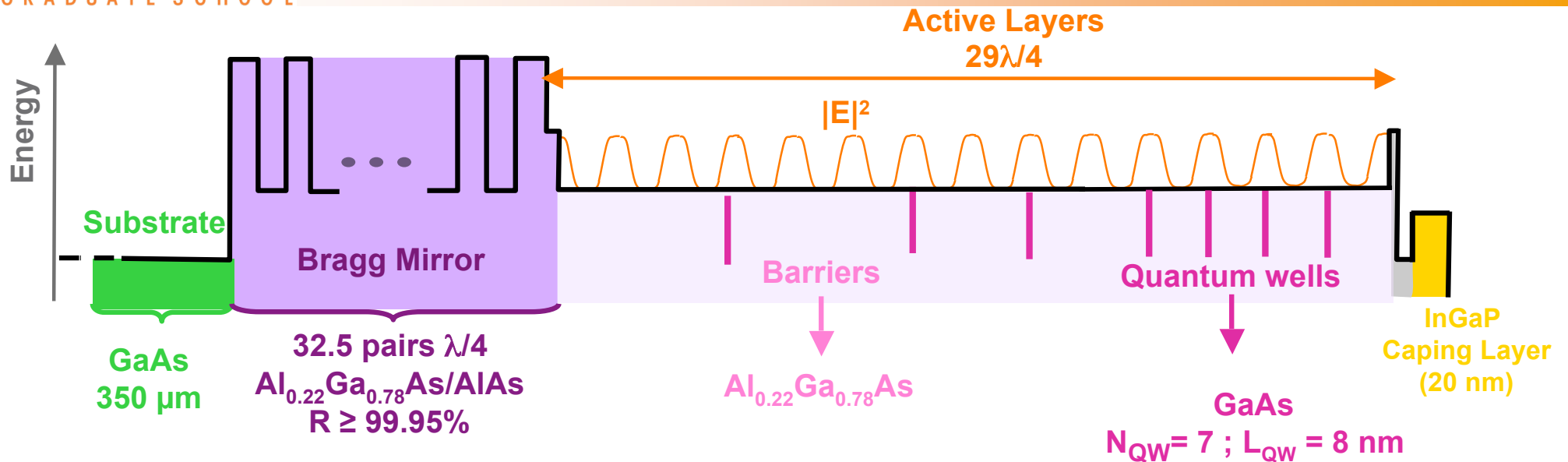
1.0 W in-well pump / 0.7 W @ 850 nm, $M^2 = 5$ (University of Strathclyde)

- No spatial hole-burning : **single-frequency** in simple linear cavity

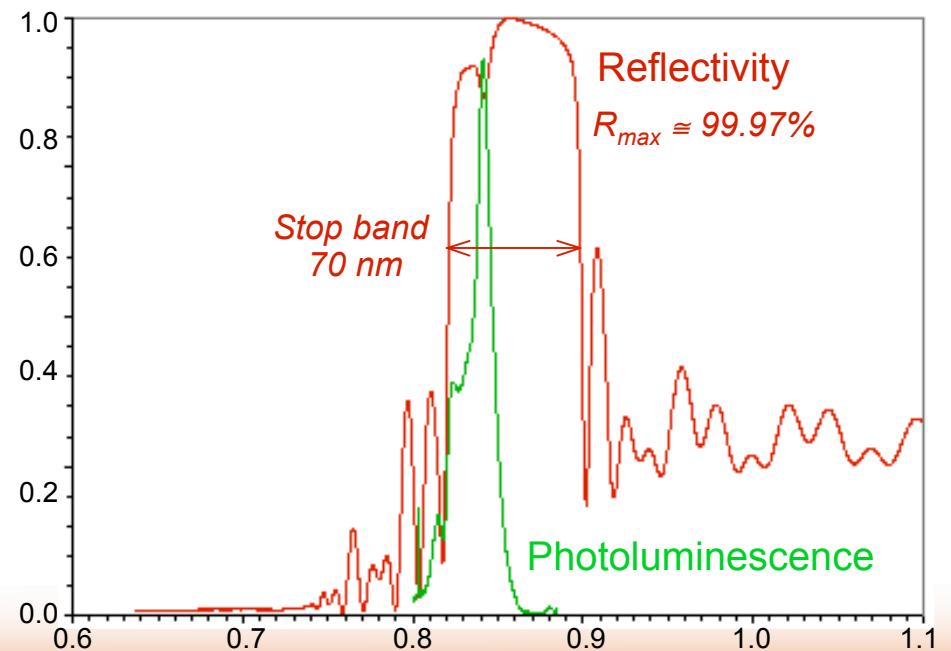
500 mW @ 1003 nm (Jacquemet et al, *App.Phys. B* 86, 503 (2007))

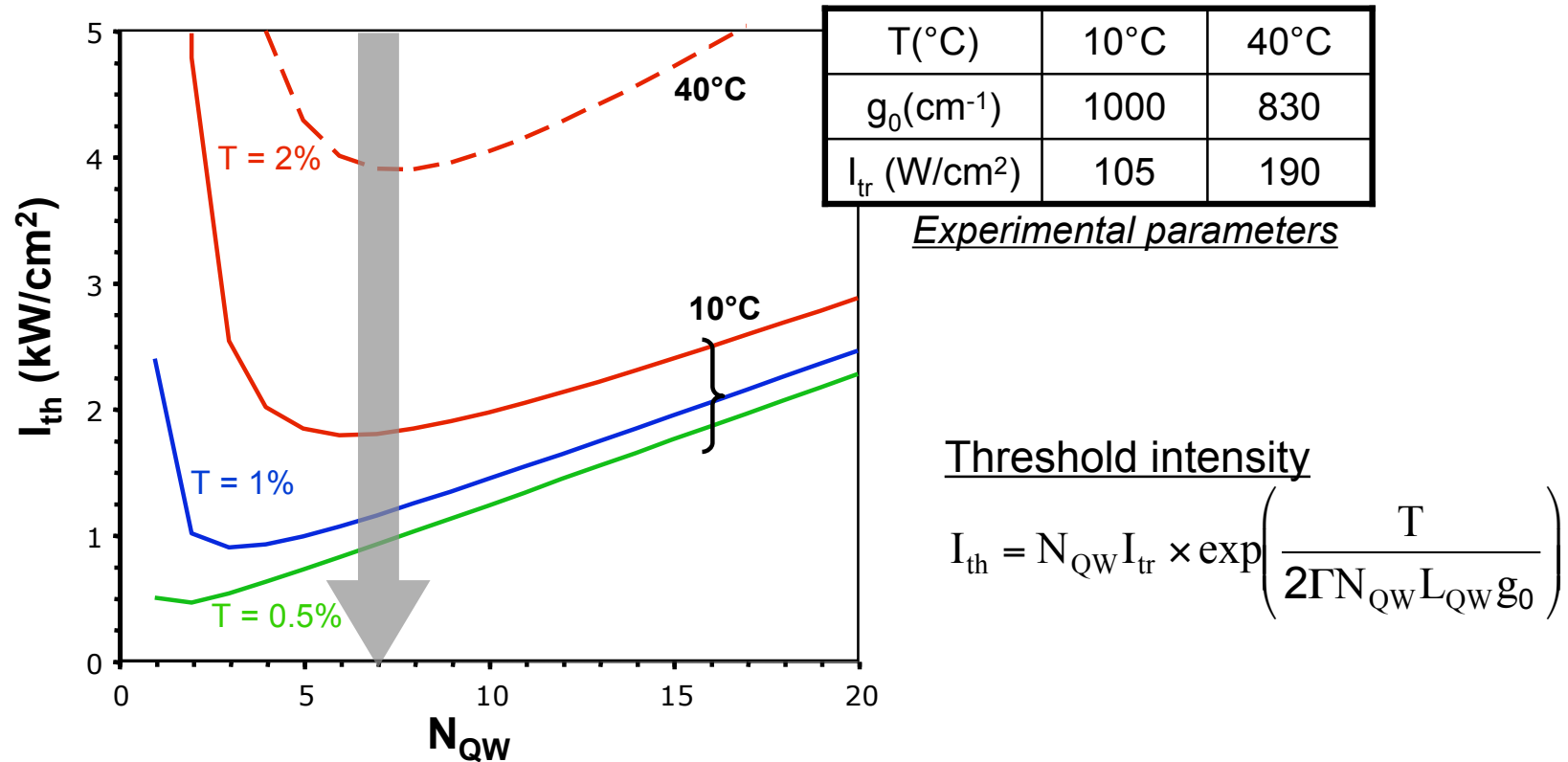
42 mW @ 870 nm, $\Delta\nu_L \approx 3 \text{ kHz}$ (Holm et al, *IEEE PTL* 11, 1551 (1999))

- Linearly polarized, circular TEM₀₀ beam

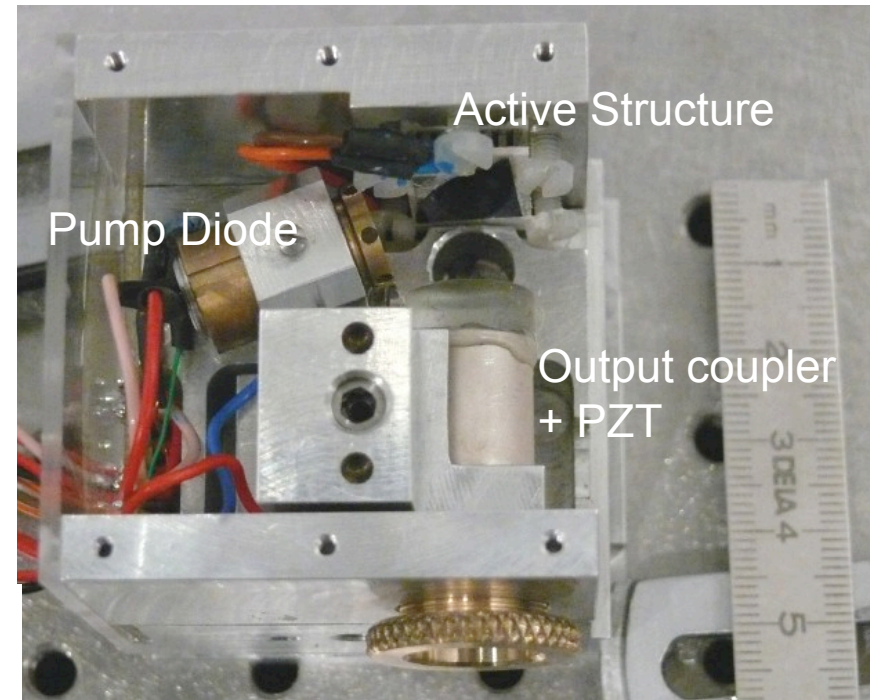
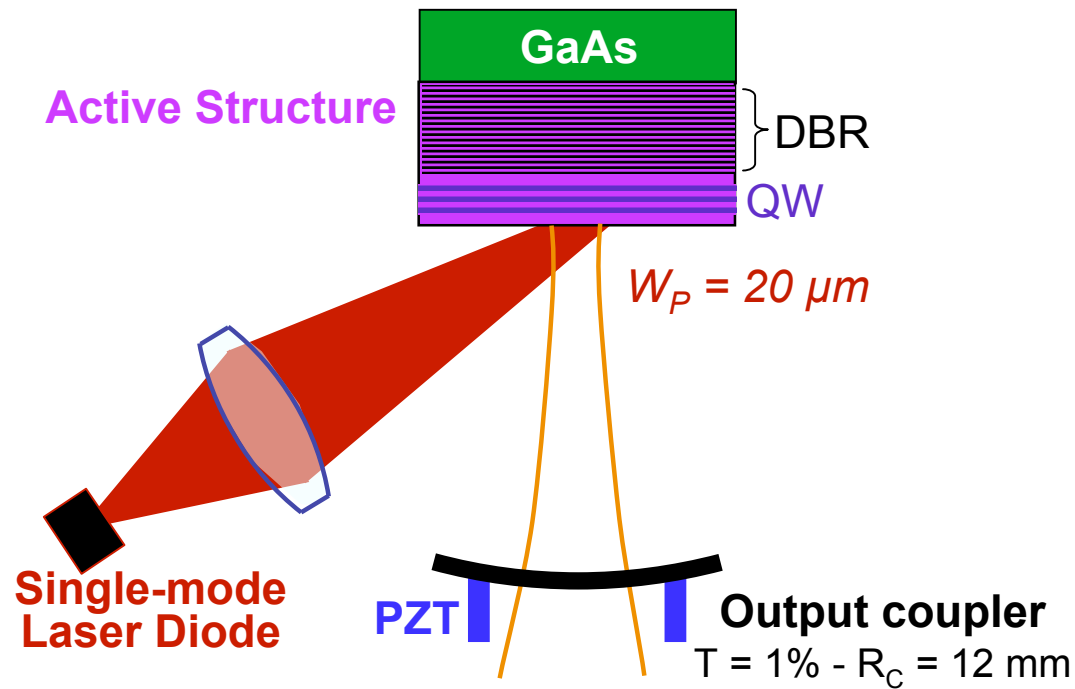


- $\lambda_L = 852 \text{ nm}$
- Barriers absorption at $\lambda_p \leq 720 \text{ nm}$
 $e_b \cong 2 \mu\text{m} \Rightarrow \eta_p = 85\%$
- AR coating (Si_3N_4) at air/SC surface for :
 maximum pump transmission
 + reduction of microcavity etalon effect
- Structure grown by MOCVD

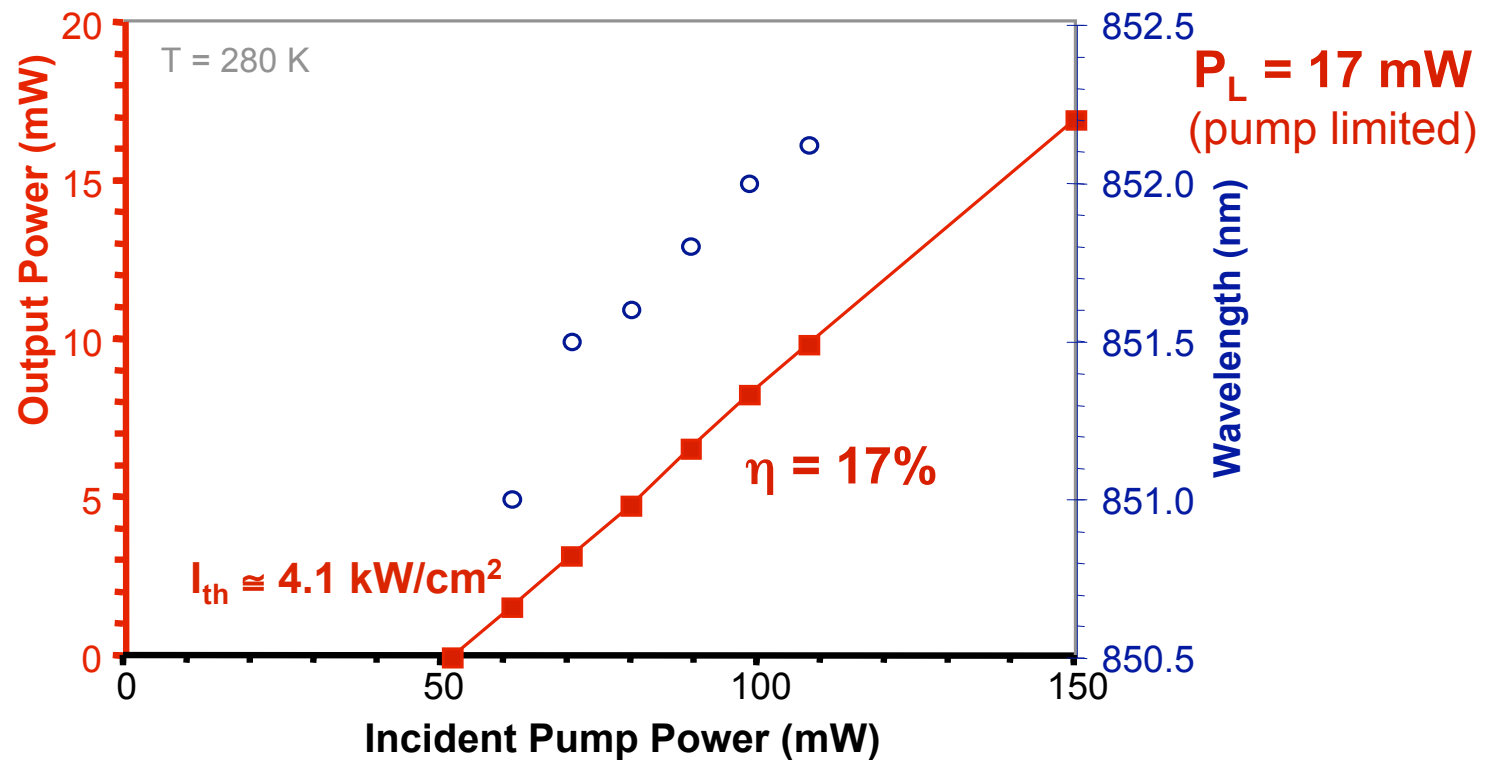
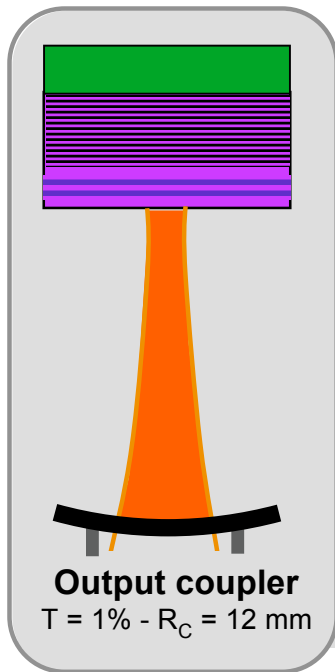




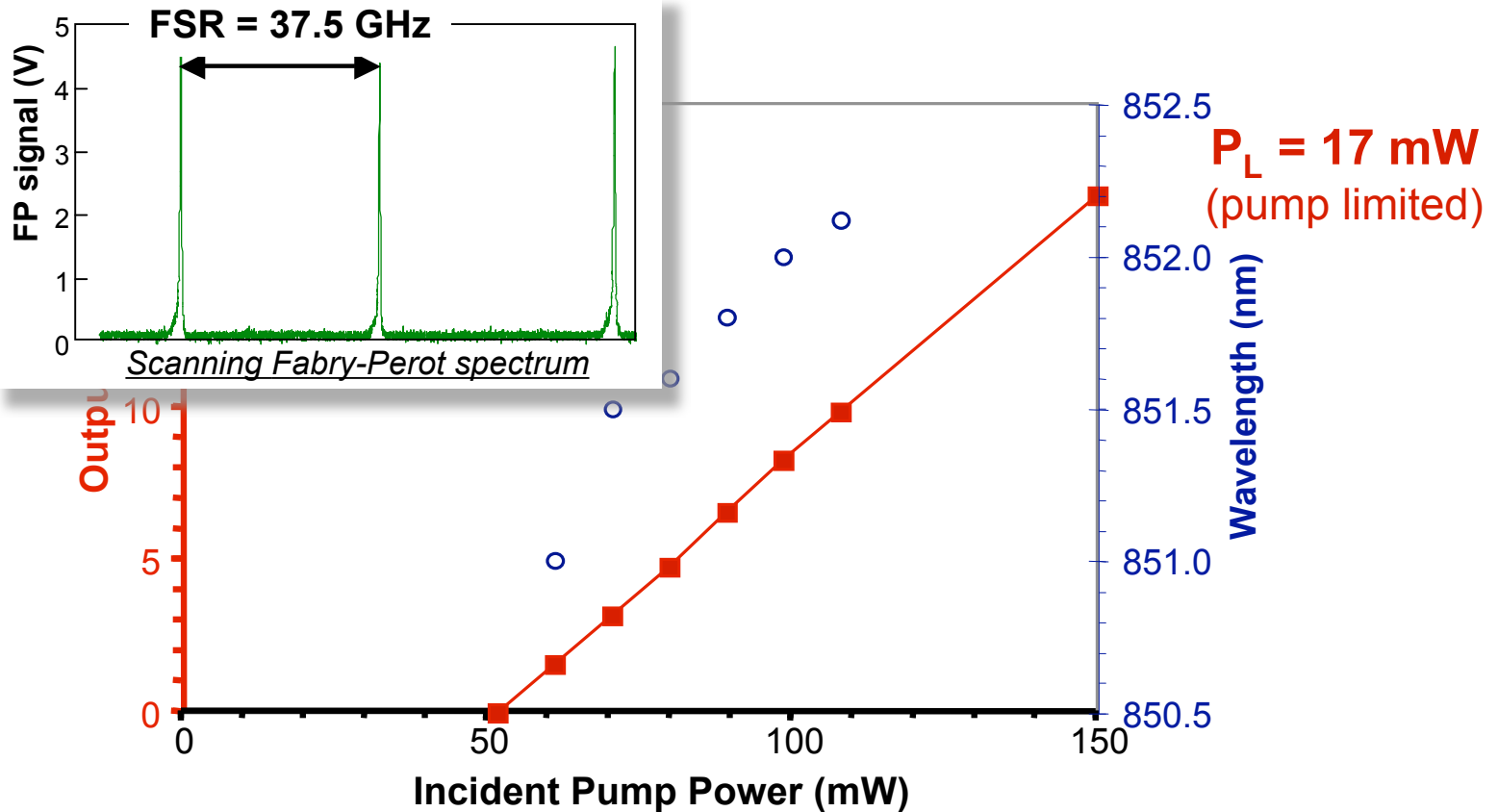
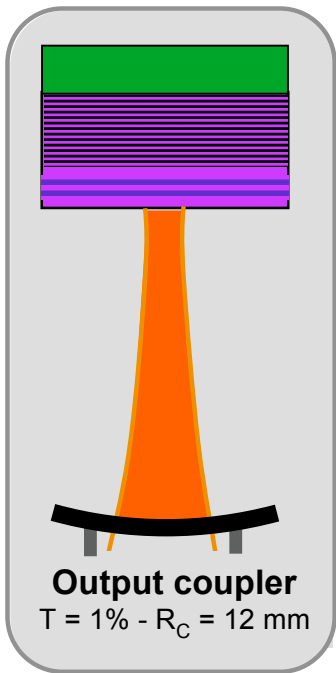
- Low threshold pump intensity I_{th} for high opt-opt efficiency
 $\Rightarrow N_{QW} = 7$ is optimal for ~ 2% losses



- Compact plane-concave cavity : $L_{\text{ext}} \cong 10 \text{ mm}$
- Single-transverse mode pump laser diode :
 $P_{\text{max}} = 120 \text{ mW (245 mA) at } \lambda_p = 658 \text{ nm}$
- $52 \times 52 \times 58 \text{ mm}^3$ integrated setup for improved mechanical stability



- Low threshold: 4.1 kW/cm²
- Good beam quality : $M^2 < 1.2$ and linear polarization



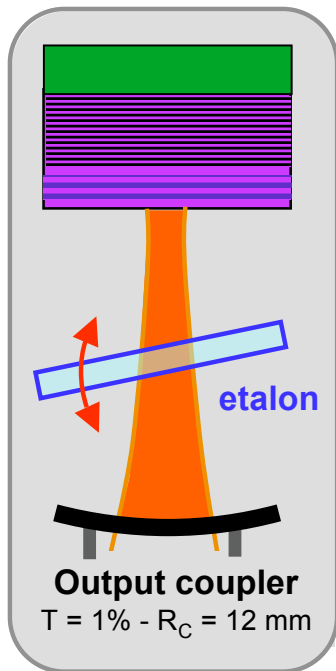
- Single frequency operation **without intracavity λ -selective element** :
checked with a high Finesse ($F = 130$) 37.5-GHz-FSR scanning Fabry-Perot
SMSR > 25 dB

$$\text{Single-mode spectrum in } t_{\text{SM}} \cong T_C \left(\frac{\Gamma}{\text{FSR}} \right)^2 \cong 1 \text{ ms for } L_{\text{ext}} = 10 \text{ mm} \begin{cases} T_C = \text{photon lifetime } (\sim 10 \text{ ns}) \\ \Gamma = \text{gain bandwidth } (\sim 10 \text{ nm}) \end{cases}$$

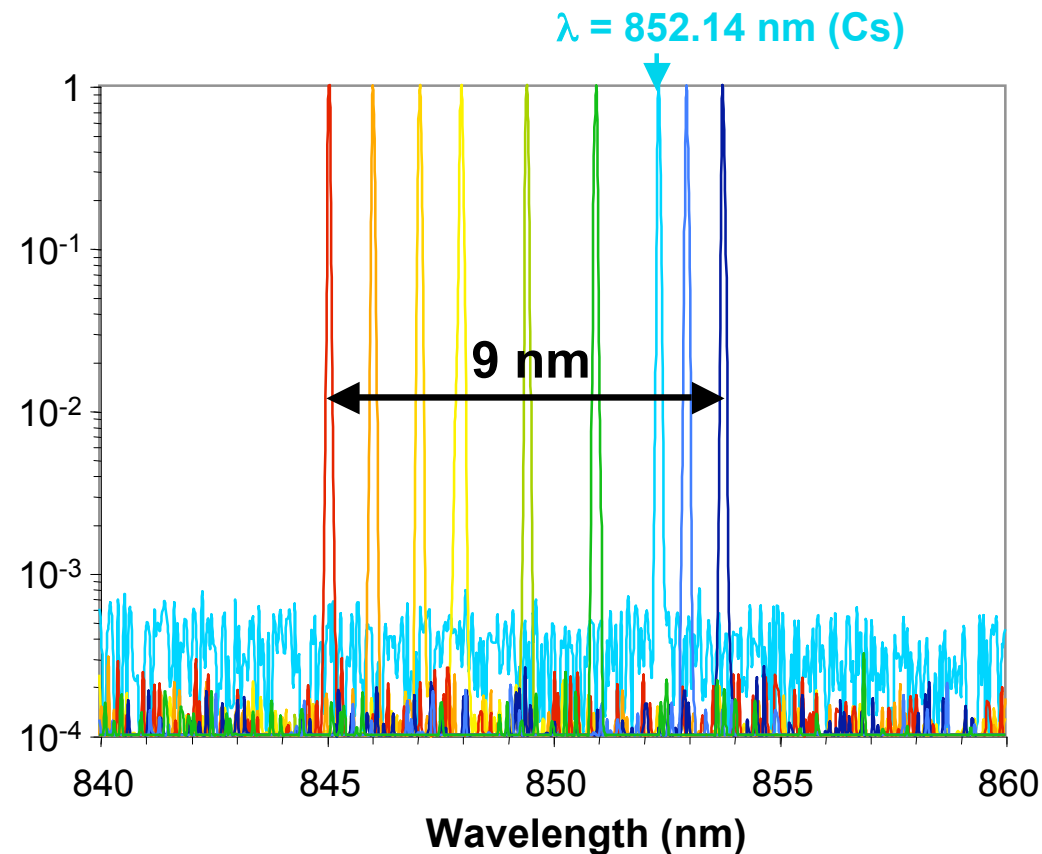
Jacquemet et al, *App.Phys. B* (2006)

Single-frequency diode-pumped semiconductor laser at the Cs line

With an intracavity etalon

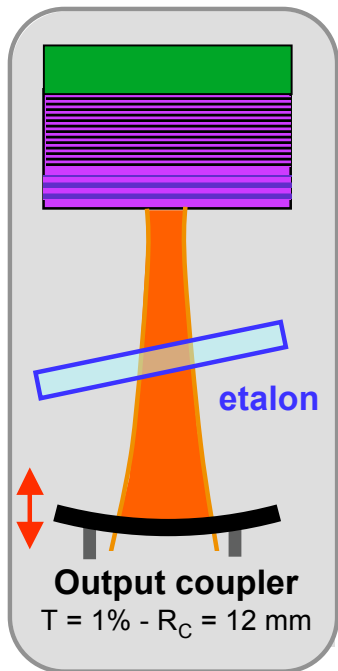


25- μm thick (\cong 9 nm FSR) silica etalon
 \Rightarrow λ independent of operating conditions (T° , P_P)
 + improved long-term stability

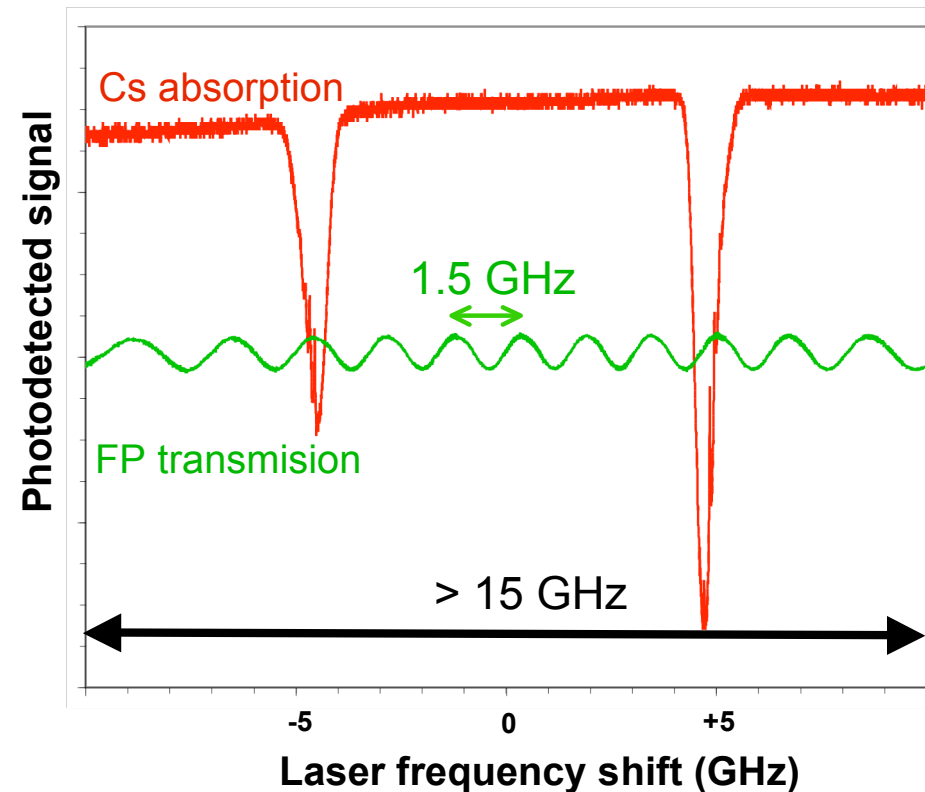


• Increased losses at $\theta \neq 0^\circ \Rightarrow \searrow$ laser power : $P_L = 7 \text{ mW @ } 852.14 \text{ nm}$

Single-frequency tunability

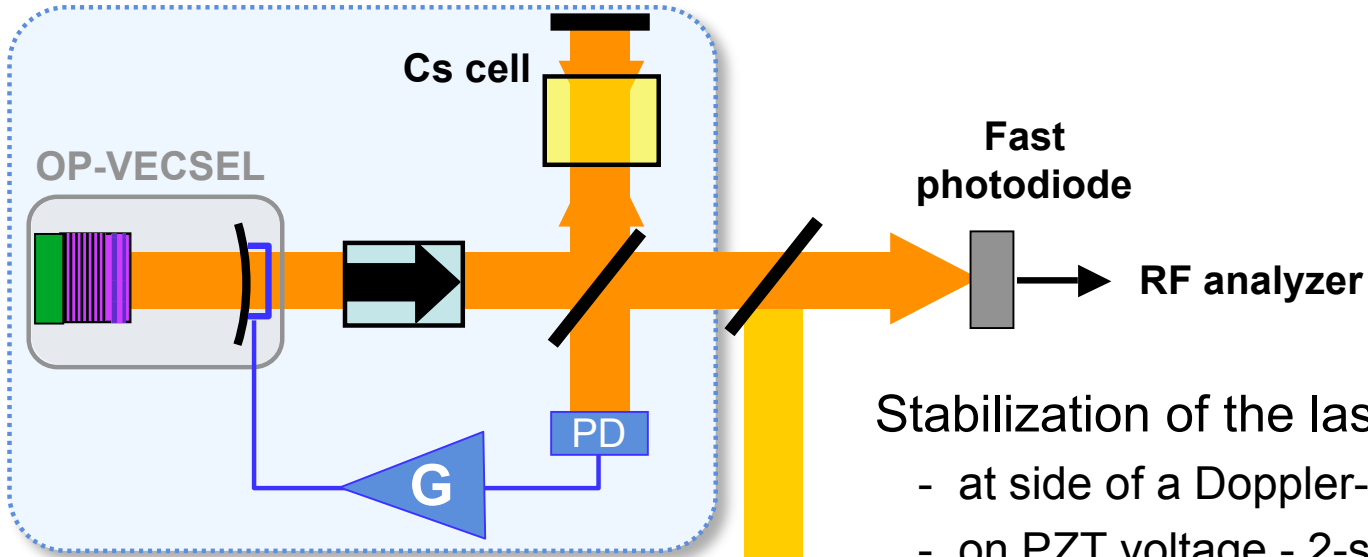


- more than 15 GHz continuous tunability (without mode-hops) by translating the external cavity mirror with PZT



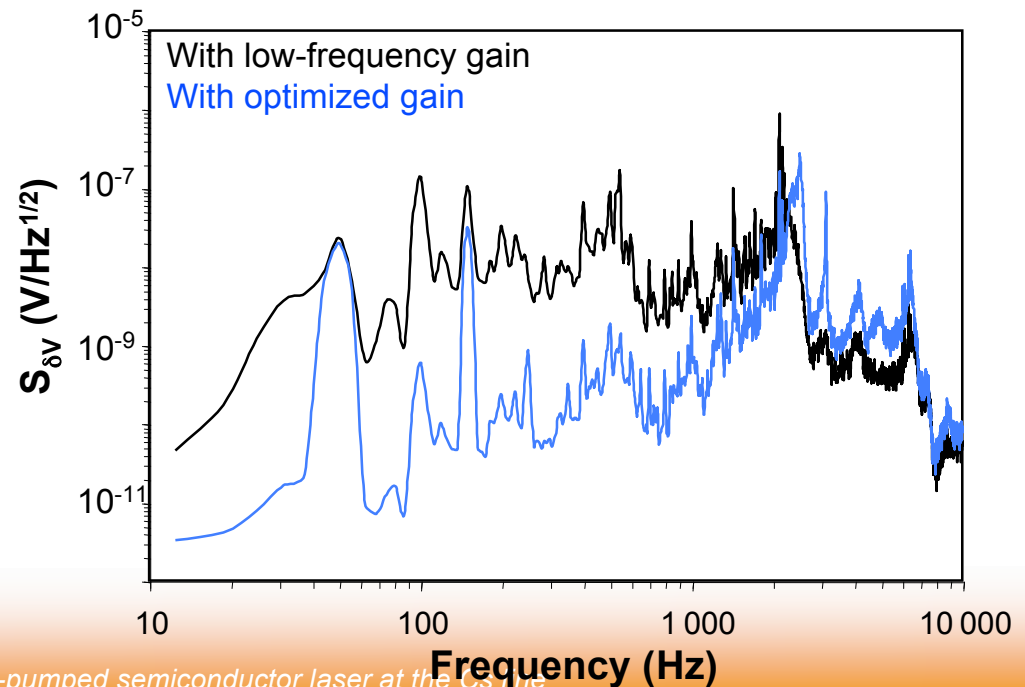
Frequency-shift measurement with a low-finesse static 1.5-GHz-FSR Fabry-Perot

⇒ Tuning over the Cs-absorption spectrum (9 GHz)



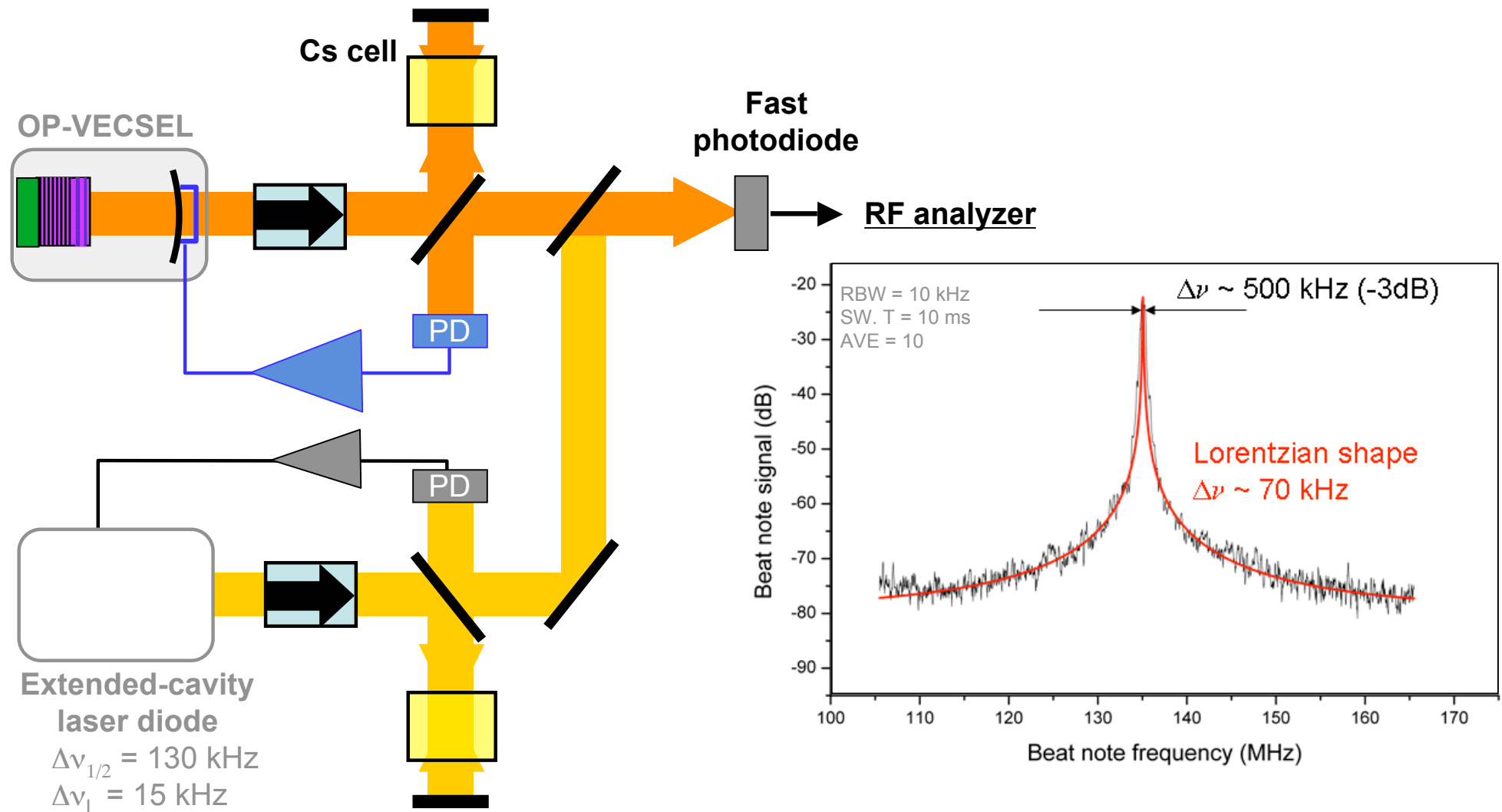
Stabilization of the laser frequency

- at side of a Doppler-free Cesium line (5 MHz FWHM)
- on PZT voltage - 2-stage integration electronics
- low-frequency servo loop ($F < 2$ kHz)



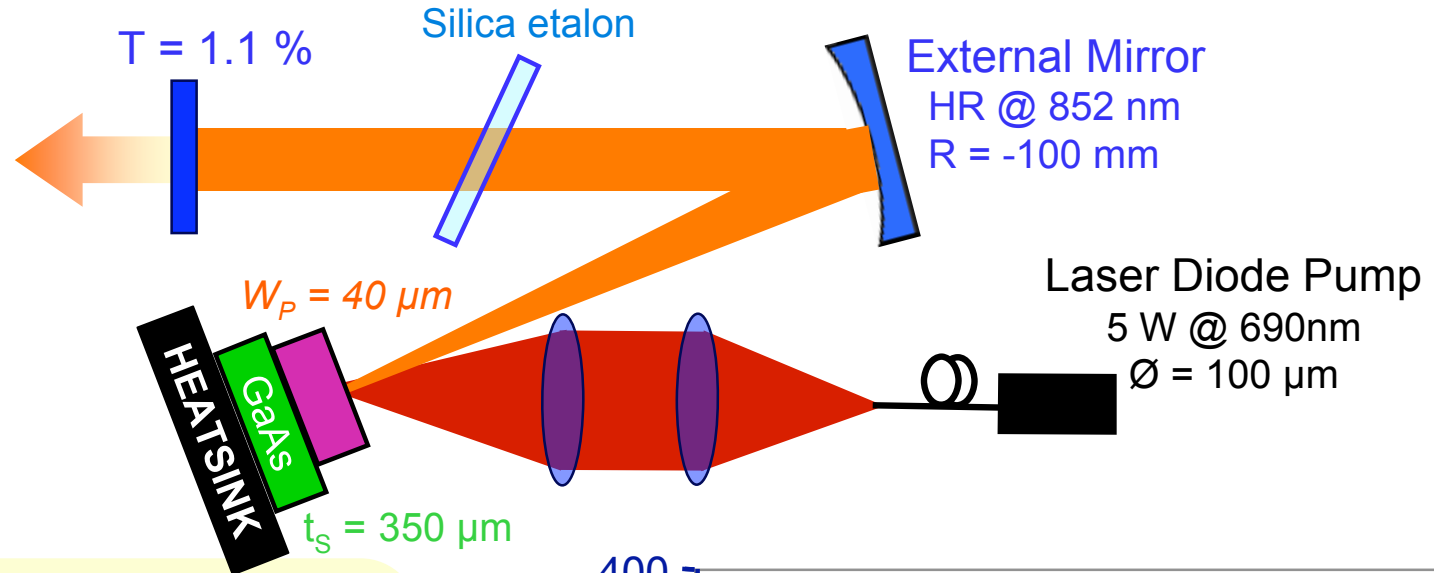
Extended-cavity
laser diode
 $\Delta\nu = 130$ kHz

Baillard et al, *Opt Comm* (2006)



- FWHM linewidth $\cong 500$ kHz : low-frequency noise contribution
- Lorentzian linewidth $\cong 70$ kHz related to white noise floor

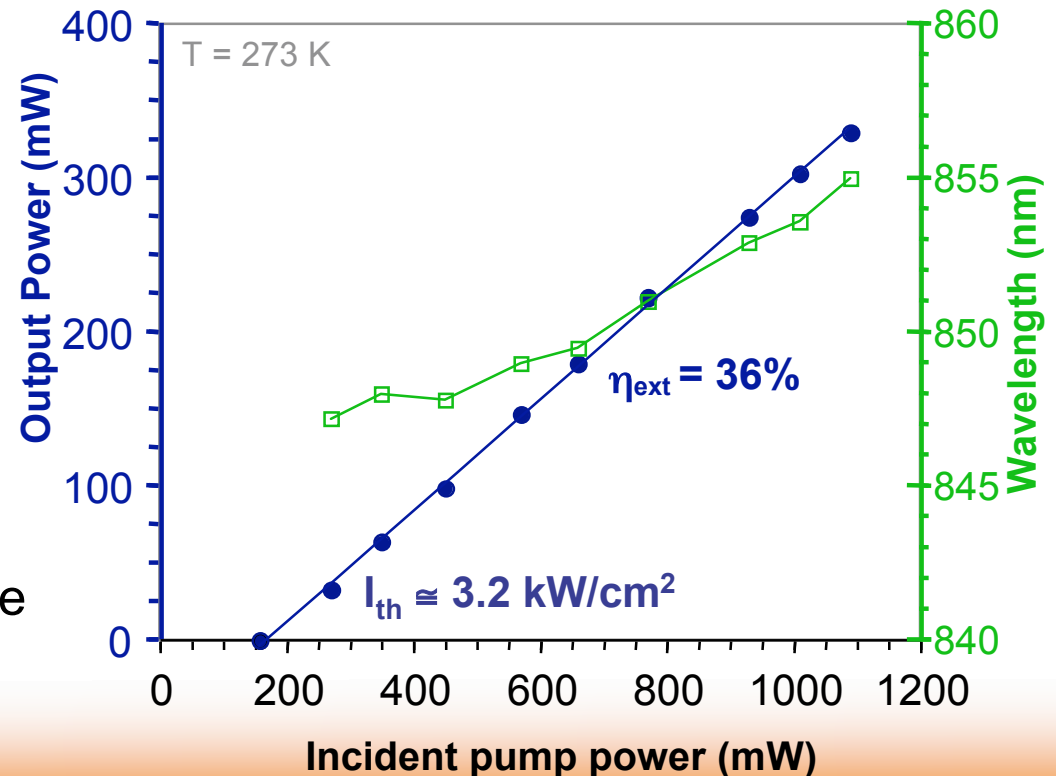
Towards higher power...



- 330 mW at $P_p = 1.1$ W
 $\lambda = 855$ nm ($\Delta\lambda \cong 1$ nm)
- 450 mW under QCW pumping
- Single transverse mode

• 120 mW single-frequency

- ⇒ Thermal-limited output power
- ⇒ High output power on a GaAs substrate
- ⇒ Low threshold & high opt-opt efficiency



- Design & fabrication of a AlGaAs/GaAs structure at $\lambda = 852 \text{ nm}$ optimized for low power/high efficiency operation
 - 7 QWs
 - low threshold $I_{\text{th}} \leq 4 \text{ kW/cm}^2$
 - Single-frequency operation in a simple linear cavity
 - without λ -selective element : 17 mW
 - with a 25- μm thick etalon : 7 mW
 - Validation on a Cs atomic line
 - >15 GHz continuous tunability
 - frequency lock-in on an absolute reference (*atomic line*)
 - comparison with an independent laser source :
 $\Delta\nu_L = 500 \text{ kHz}$ (-3dB / 10 ms *sweep time*)
 - Increase of the single-frequency power under high power pumping
 - 120 mW without specific thermal management
(*GaAs substrate, no intracavity heatspreader*)
- ⇒ evaluation of the spectral properties
+ thermal management for power scaling

} at 852.14 nm

Specifications already adequate for optical detection in atomic clocks