# Effects of hyperfine structure on atomic frequency comb formation and pulse storage in Pr:YSO

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## 1. Atomic Frequency Comb quantum memory

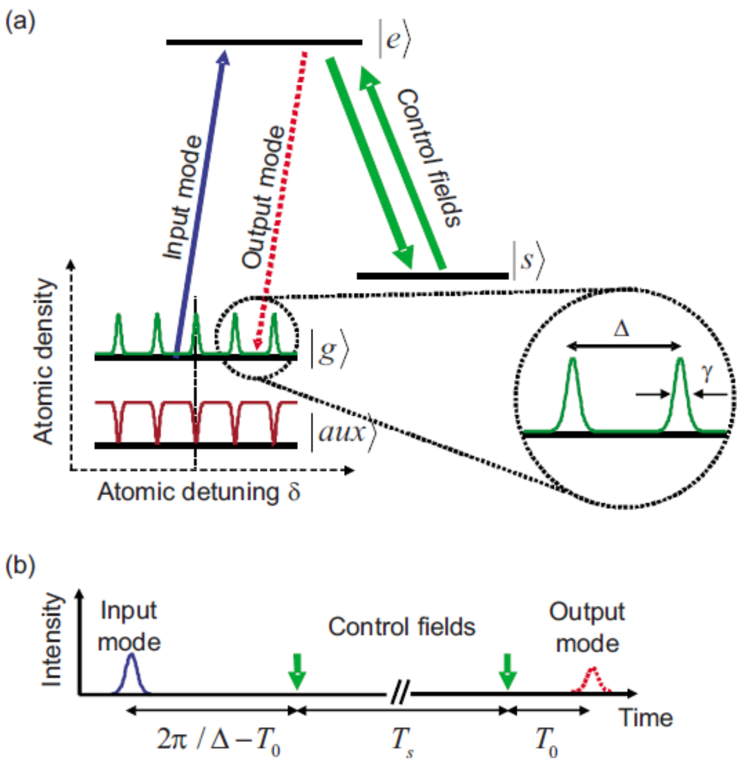
**Future quantum networks will require quantum memory.**

**The AFC protocol is one approach to quantum memory.**

- Crystal with frequency comb absorption spectrum.
- Photon stored as collective excitation.
- Rephasing → emission after $t = 1/\Delta$.
- Control pulses for on-demand memory.

- Broad-bandwidth comb → more modes.
- Add storage and control pulses → on-demand memory.

**This work deals with efficiency of the echo process.**




[Afzelius et al., PRA **79**, 052329 (2009)].

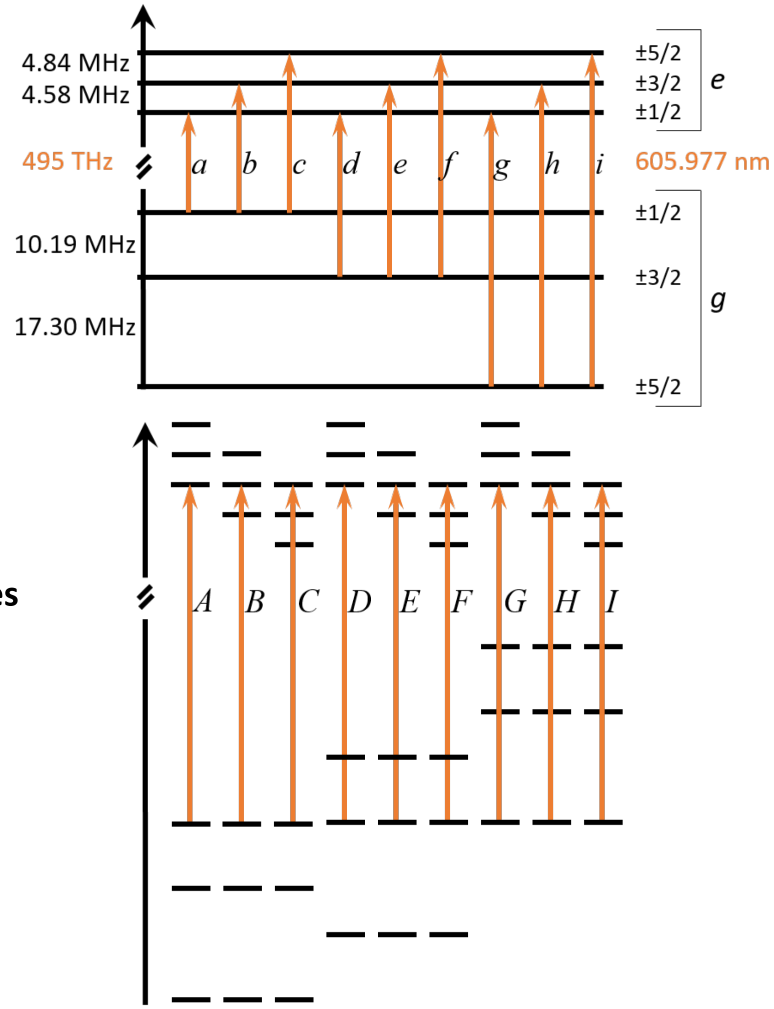
## 2. Hyperfine structure and spectral-hole burning in Pr:YSO

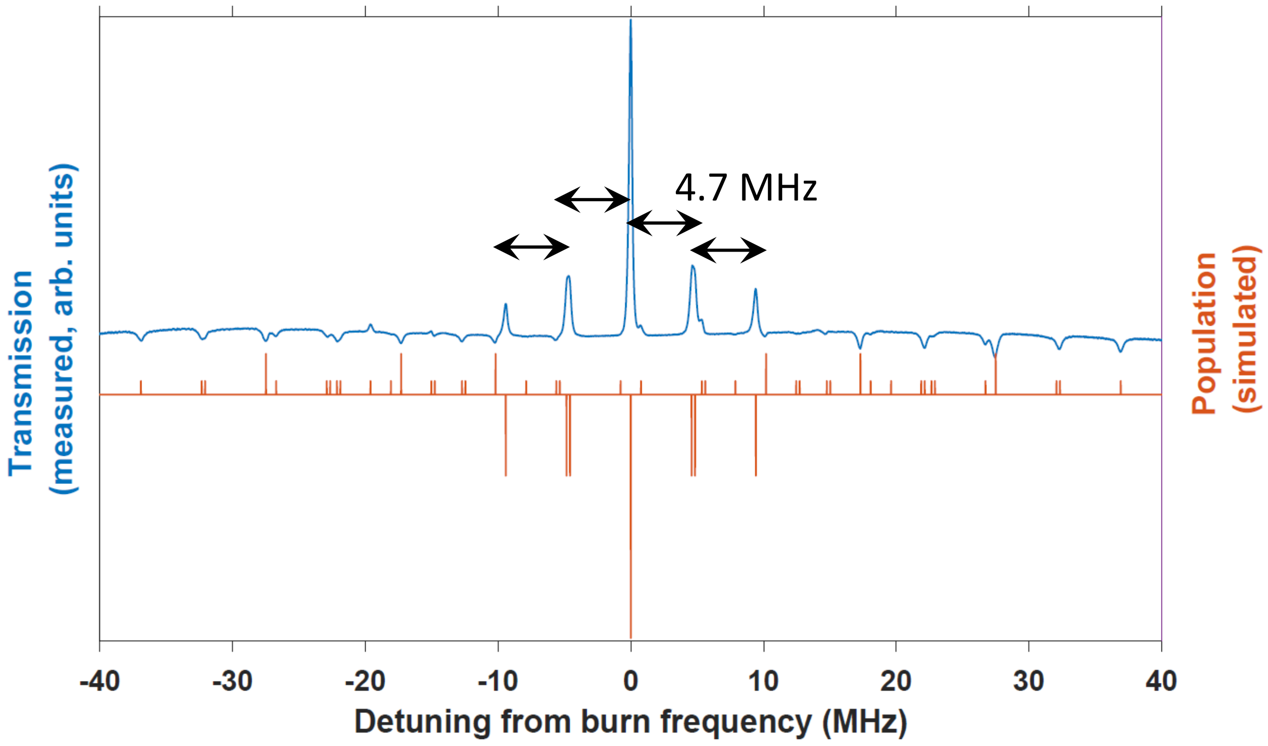
**Pr:YSO has hyperfine transitions at 605.977 nm:**

- **1 kHz homogeneous linewidths → can burn narrow spectral holes.**
- **5 GHz inhomogeneous linewidths → can make broadband AFCs.**

**Each atom has 9 transitions.**

**Each freq. addresses 9 atom classes**




***Comb-like structure emerges when burning with even a single frequency.***

## 3. Experimental setup and procedure

**Beam #1: optical frequency comb.**
**Burns crystal to prepare AFC.**

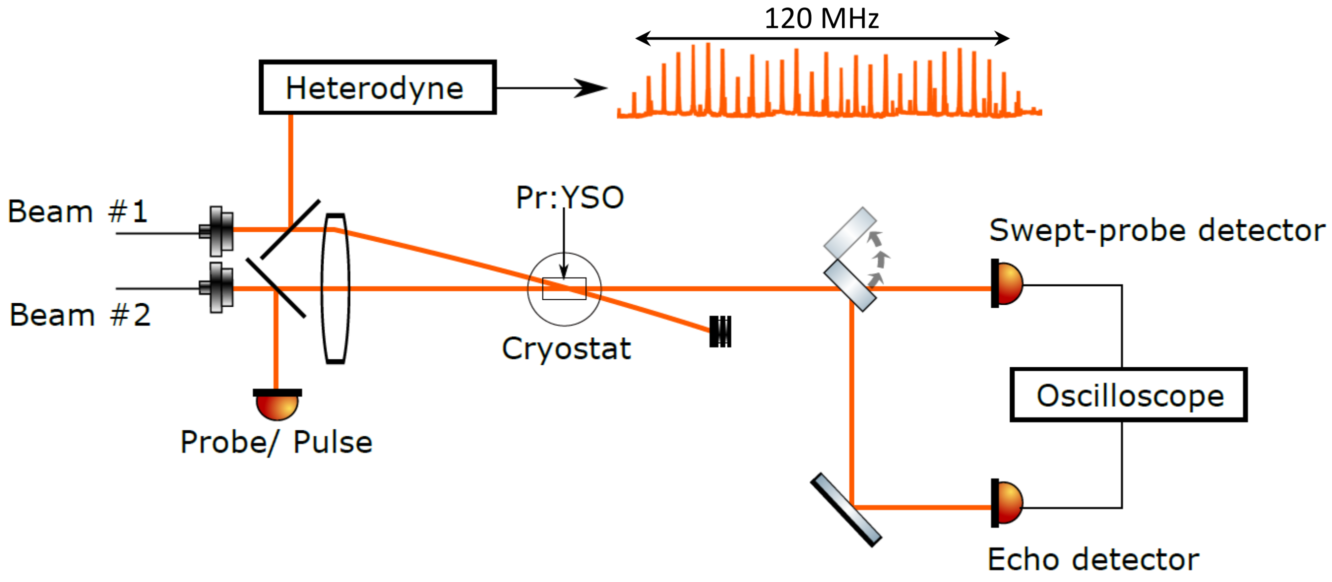
- 120 MHz bandwidth
- Tooth spacing ranging from 0.1 – 20 MHz.

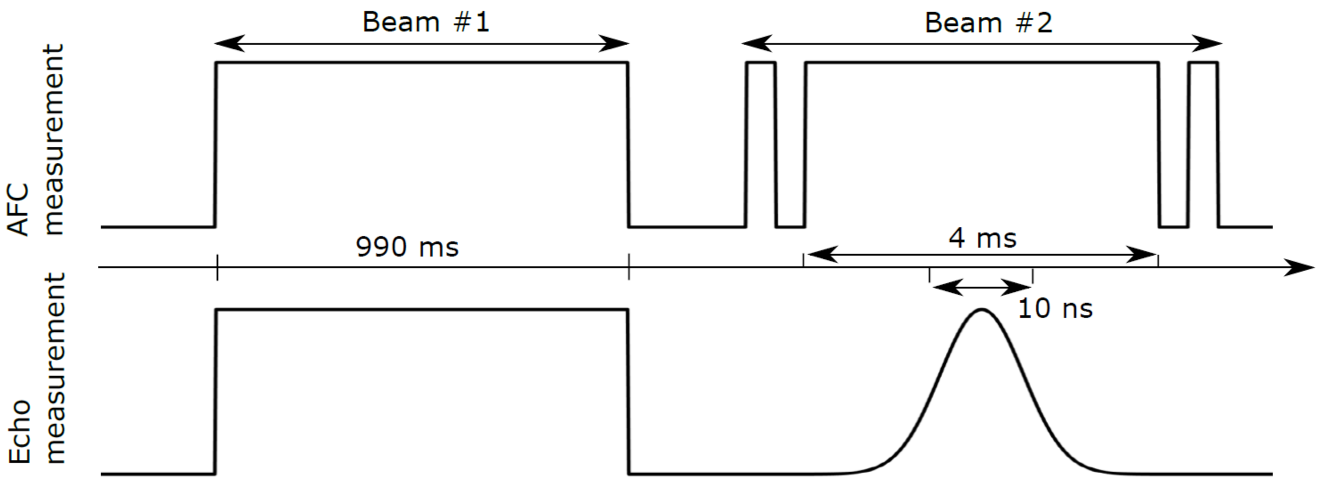
Two different measurements:

(a) AFC measurement:
**Beam #2: slow freq. sweep across bandwidth;**
**Detect transmitted light to infer spectrum.**

(b) Echo measurement:
**Beam #2: 10 ns pulse;**
**Detect echo pulses.**

Measurement cycle synched to cryostat cycle.
Measurements are averaged over 30 cycles.



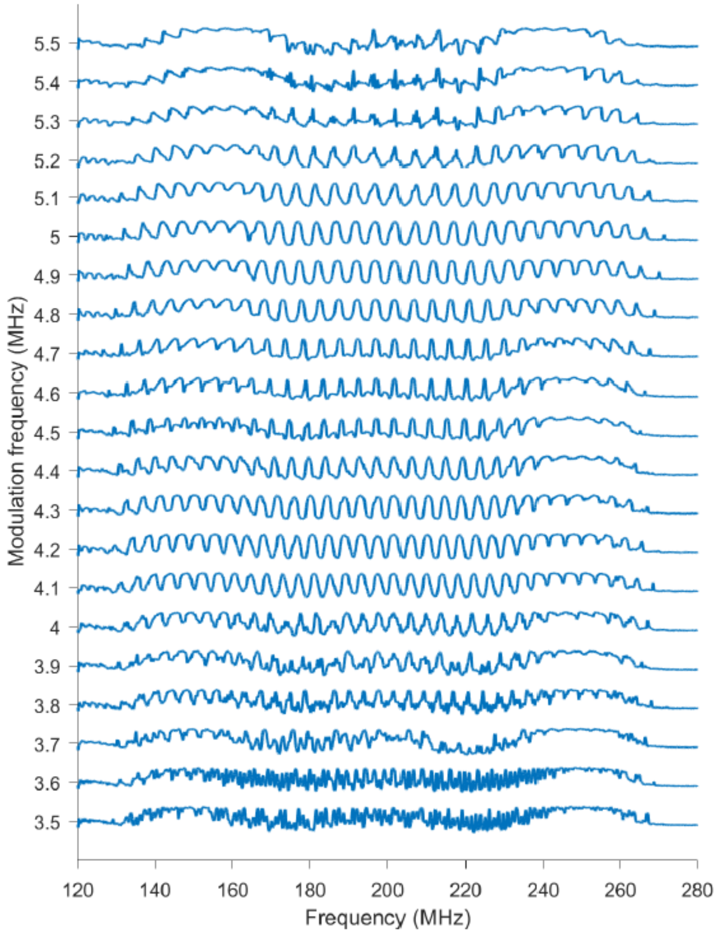



## 4. AFC and echo measurements

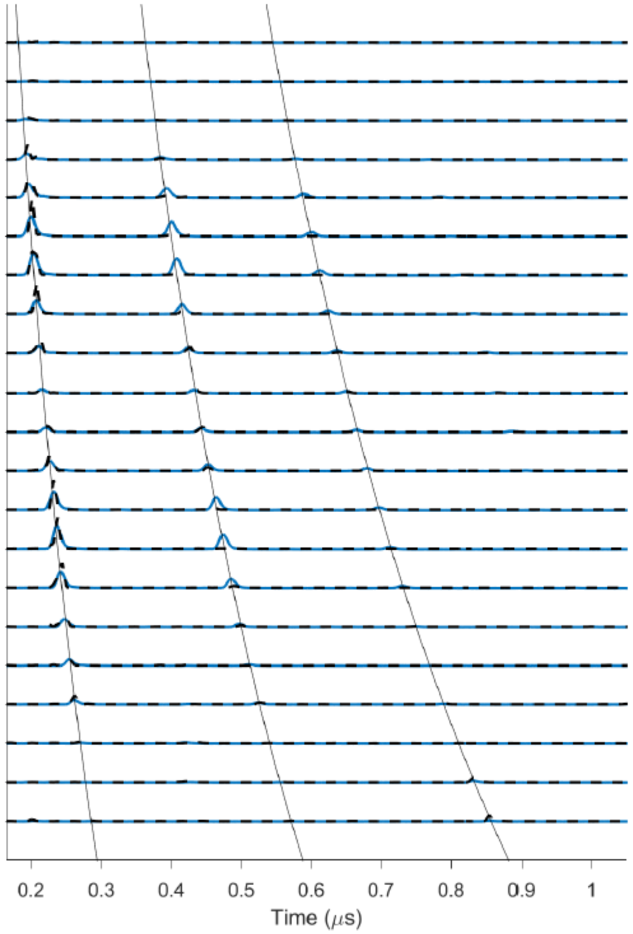
High-quality AFCs occur for tooth spacing ~ 4.7 MHz.

Large echo pulses for these combs (dotted curves show AFC Fourier transforms.

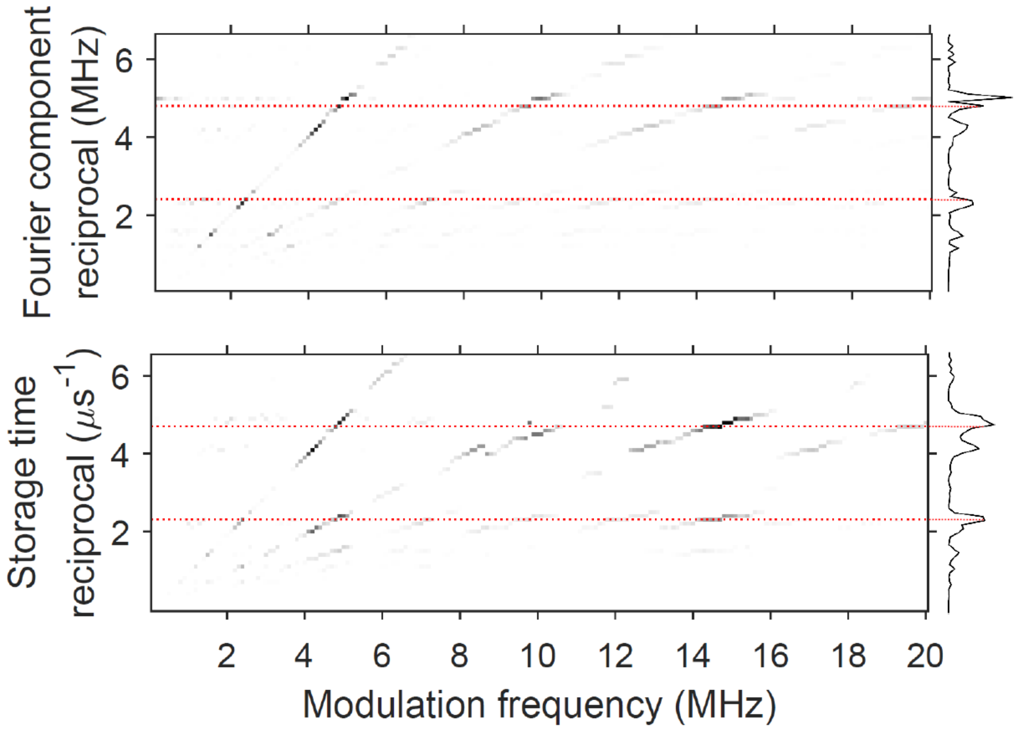
**Crystal transmission spectrum**




**Echo signal from 10 ns pulse**




**Overall, large FT components of the AFC and large echoes tend to occur for tooth spacings near (2.4 MHz)$^{-1}$ and (4.7 MHz)$^{-1}$.**



## 5. Conclusions

- Pr:YSO transmission spectra are naturally periodic since the excited-state spacings happen to be similar.
- AFC preparation works best when the tooth spacing matches this natural periodicity (or a harmonic).
- AFC quality is directly tied to pulse retrieval efficiency.
- **Practical AFC quantum memory in Pr:YSO needs to use tooth spacings compatible with the hyperfine level spacings.**

Current work: apply an external ***B*** field to better control response to the optical frequency comb and to produce better AFCs.