Measuring Optical Clock Transitions in Neutral Mercury Vapor

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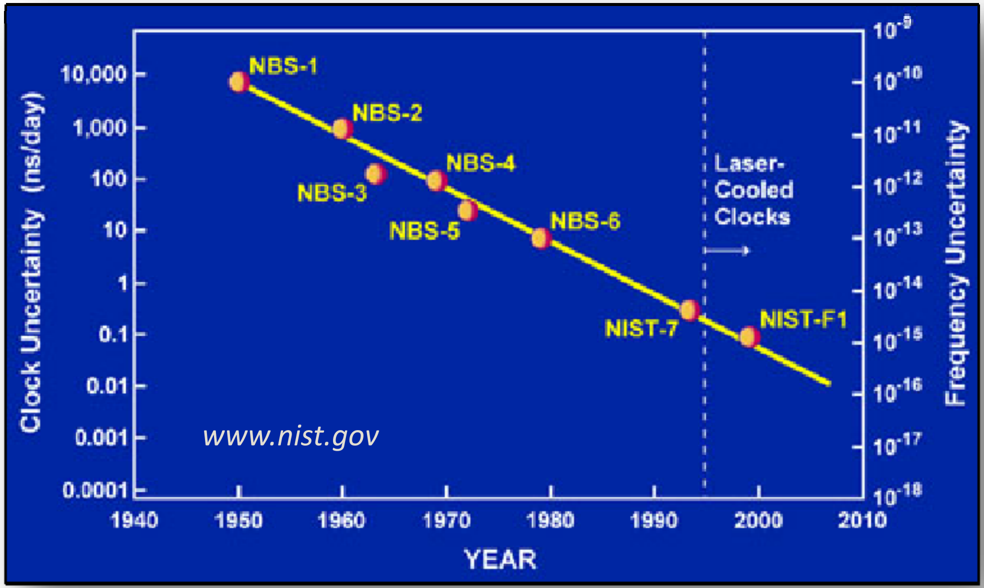
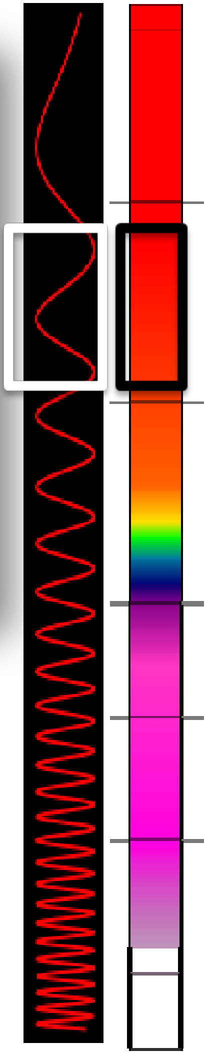
REU Talk

07/28/2010

Microwave Atomic Clocks

Applications:
- Time and frequency **standards** for the scientific community, U.S., and world
- Control of broadcast frequencies
- Global Positioning System





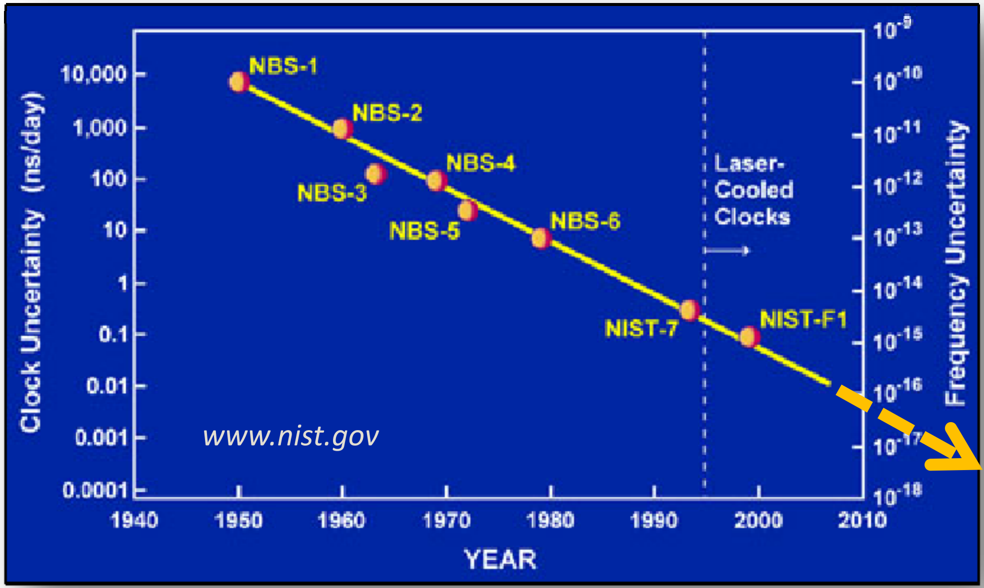
1 second = 9,192,631,770 periods
of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the **Caesium-133** atom [NIST]

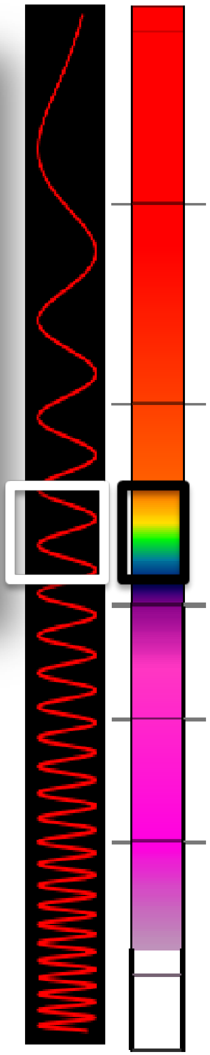
Optical Atomic Clocks

Applications:

•Ability to measure time and frequency **more precisely**

•Can test fundamental interactions to high levels of precision, i.e. gravity sensors (LIGO) or time variation of the fine-structure constant

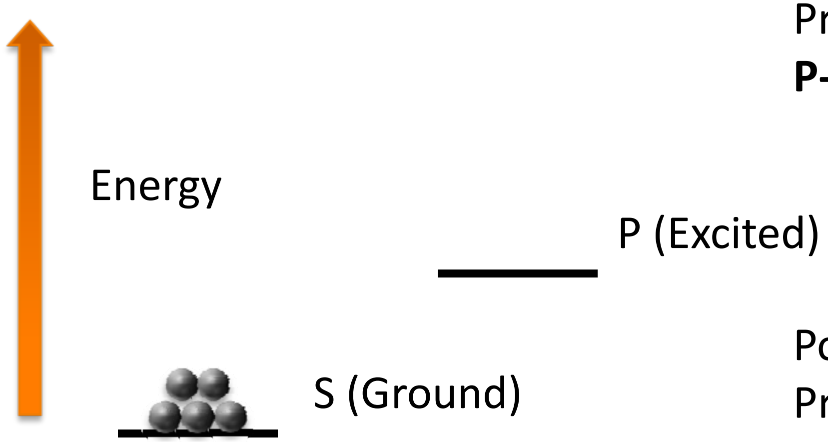


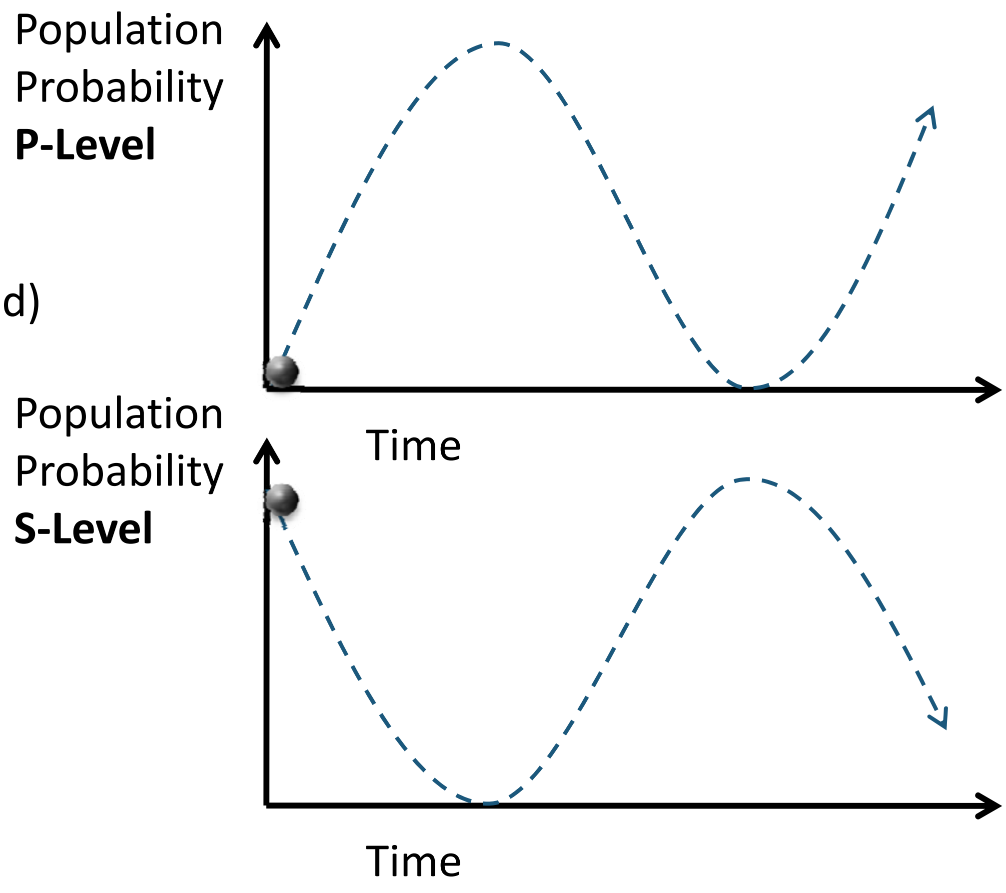


1 second ≈ 10^{15} periods of radiation emitted from an atom

Rabi Oscillations

Q: How do we drive these regular, flip-flopping oscillations in an atomic system?

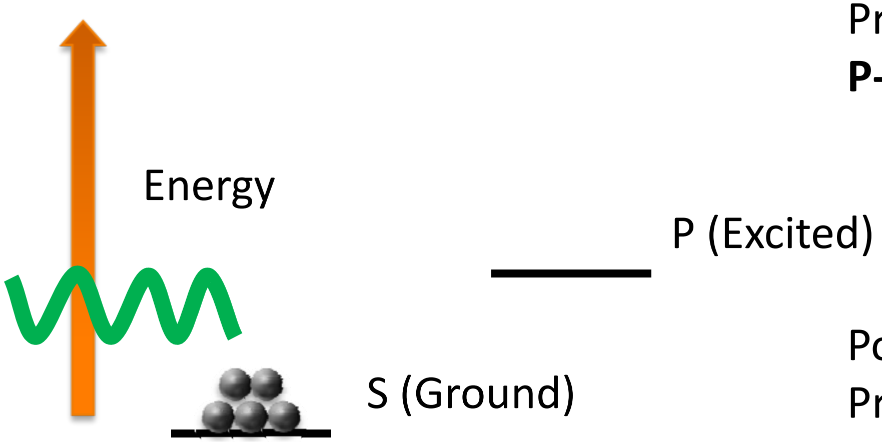


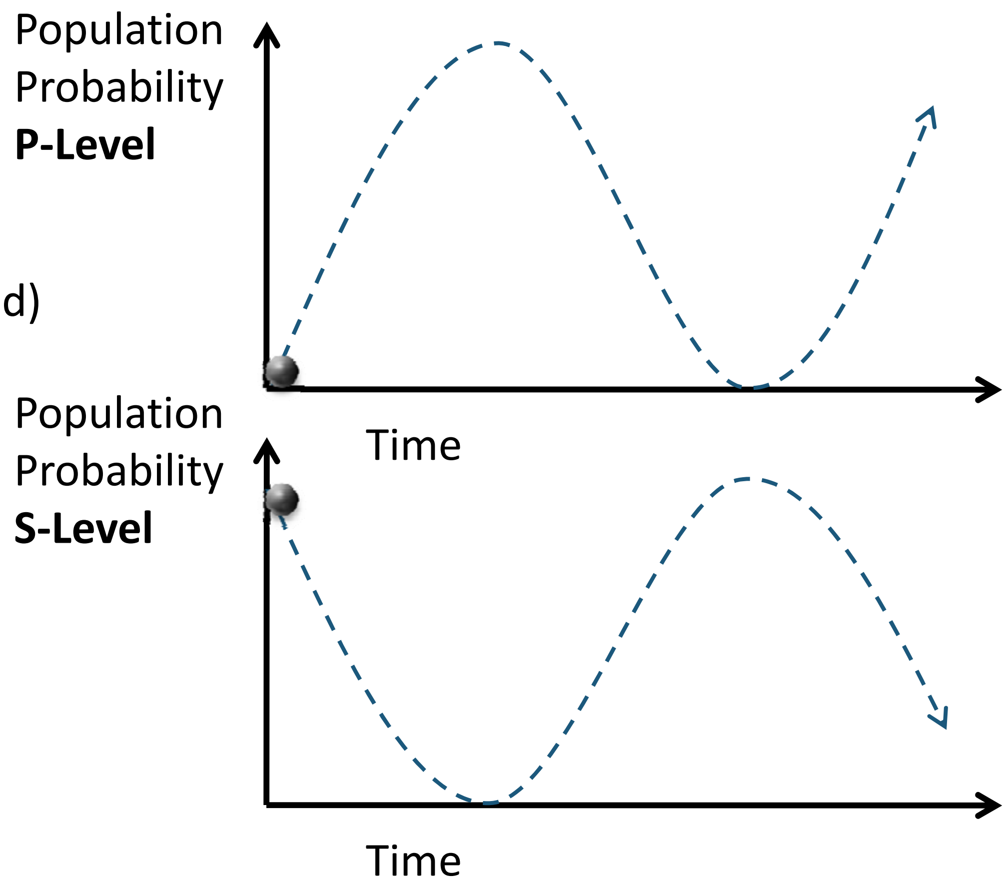


Rabi Oscillations

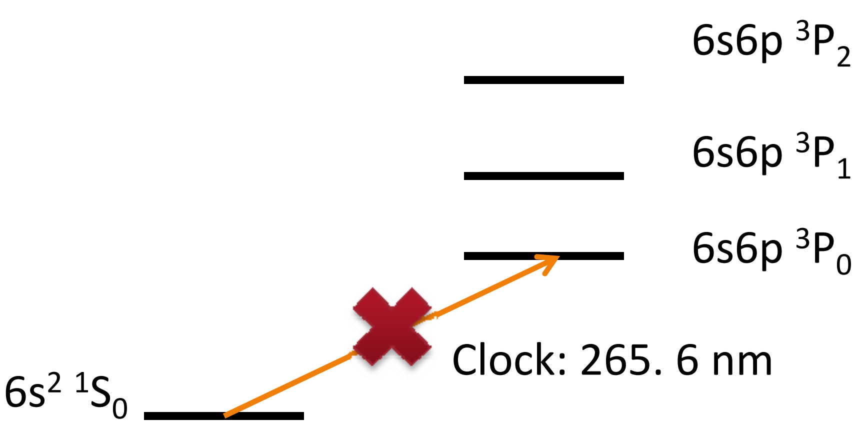
Q: How do we drive these regular, flip-flopping oscillations in an atomic system?

A: Use a laser tuned to the resonance frequency $\mathbf{v_0}$ of the system.



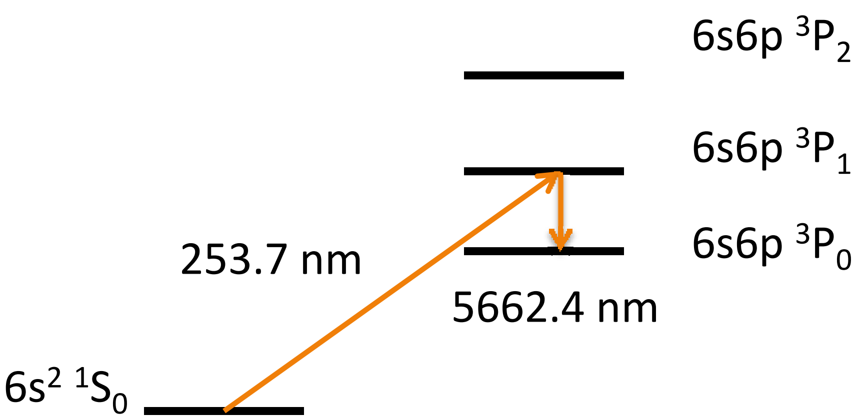


Atomic Mercury



Due to various selection rules, as well as an important experimental concern, we are actually using a **two-photon** transition between the $^1S_0$ and $^3P_0$ levels. This is essentially an "E1-M1" transition.

Atomic Mercury



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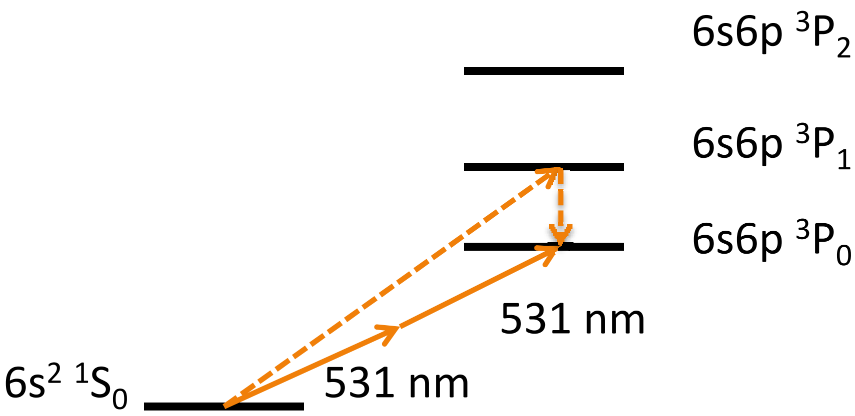

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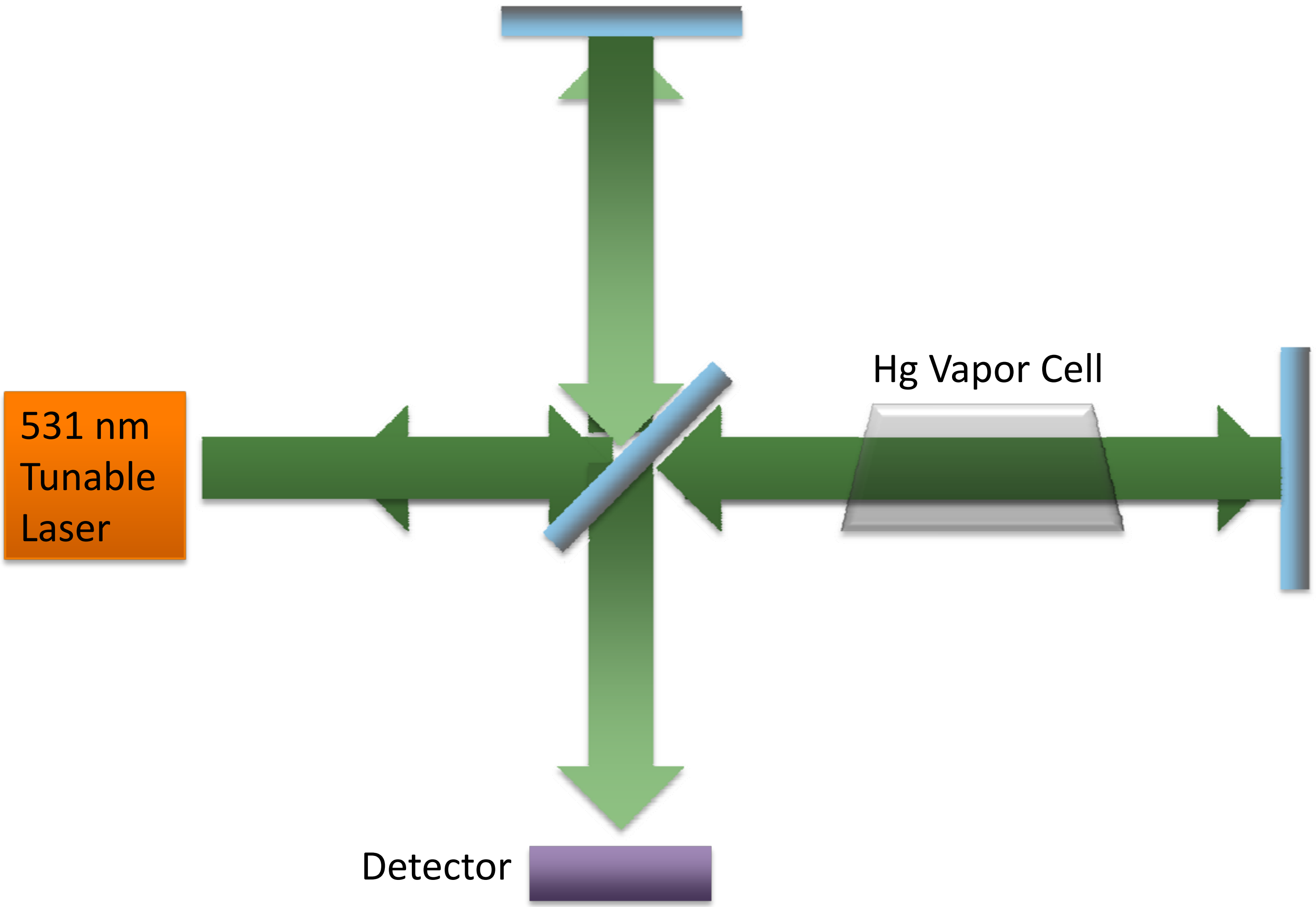
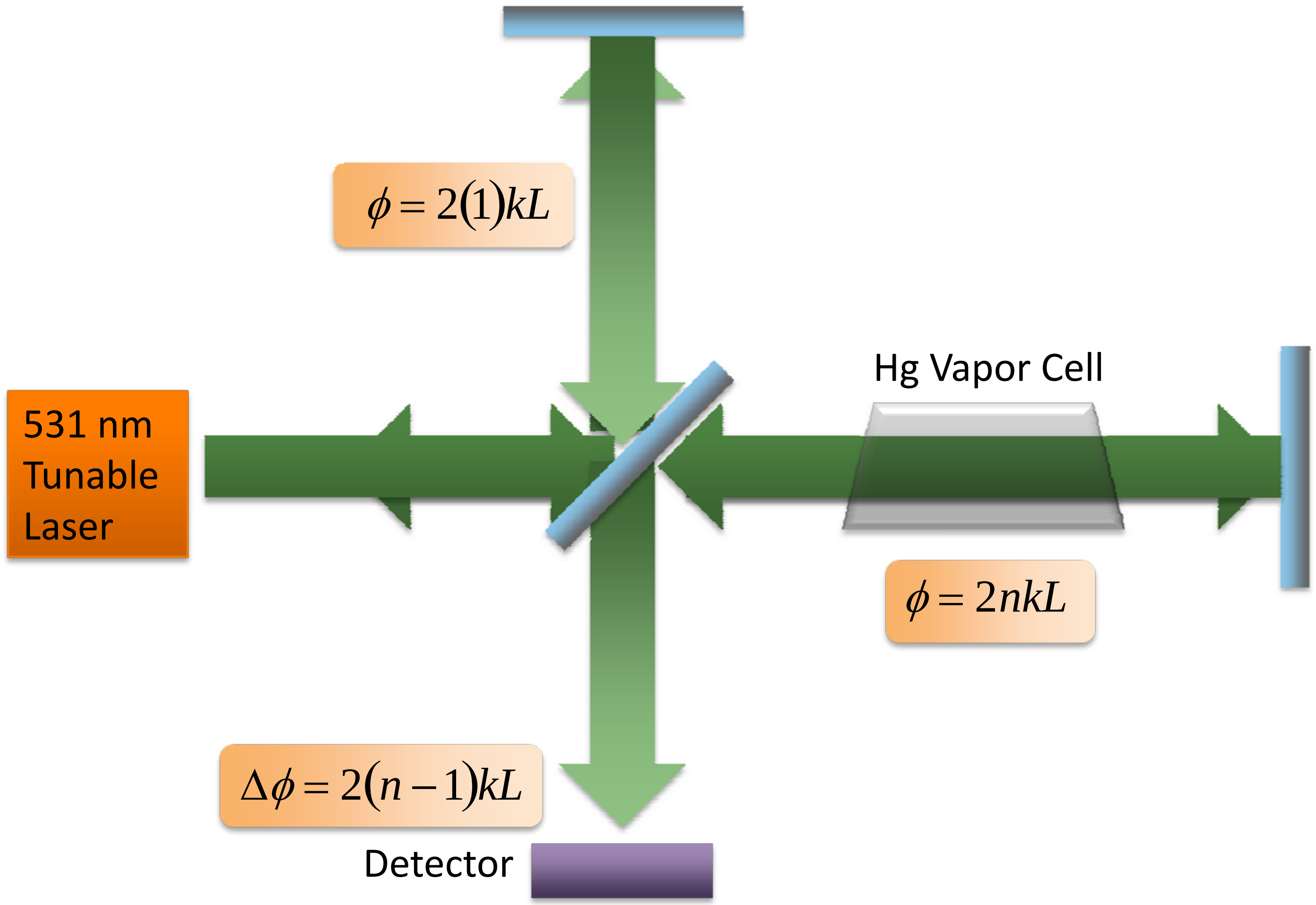
Michelson Interferometer



Michelson Interferometer



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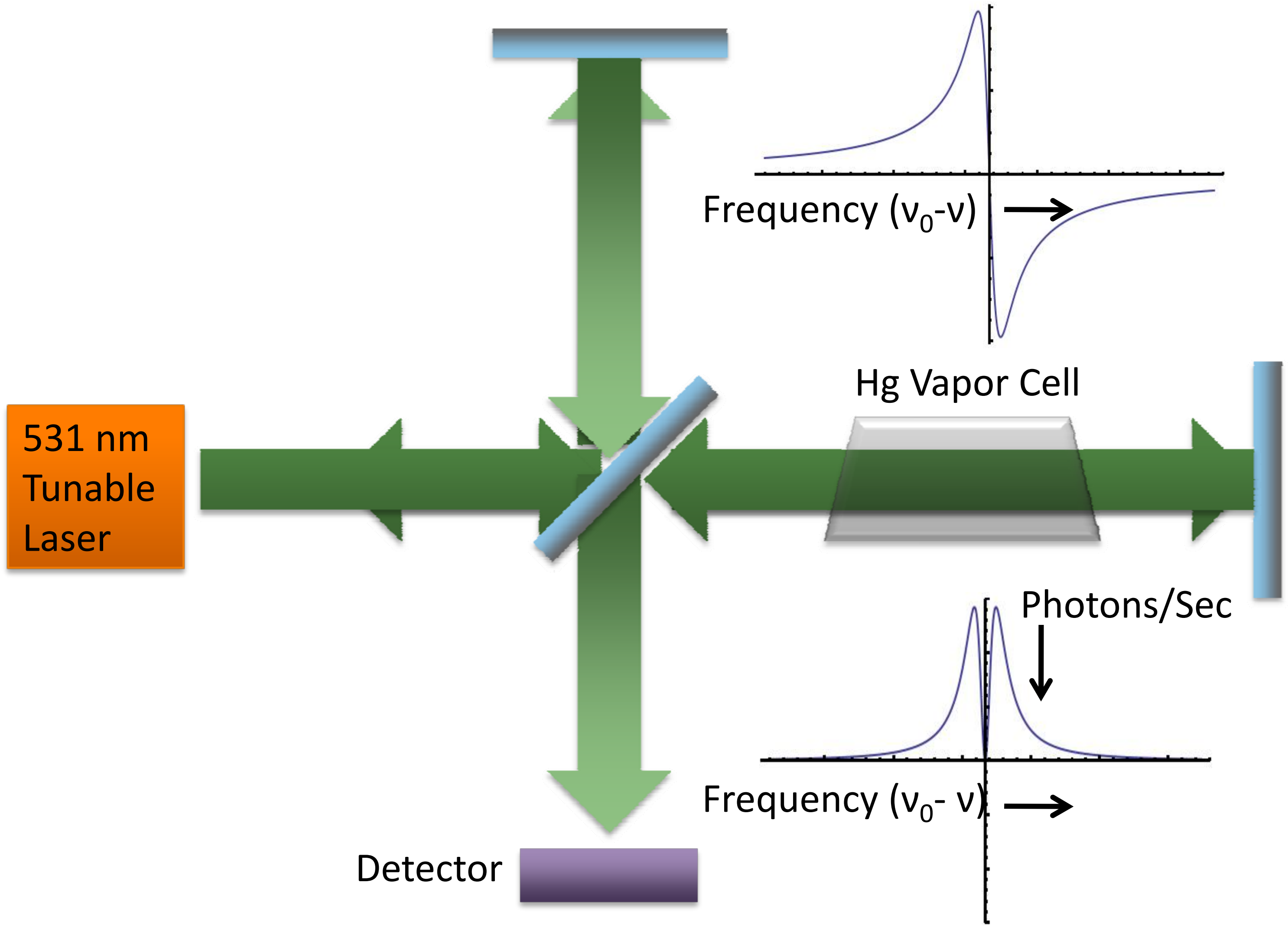

Building a Model

Schrödinger Equation of Motion:

$$\dot{\rho}(t) = -\frac{i}{\hbar}[H, \rho]$$

$$\rho(t) = |\Psi\rangle\langle\Psi|$$

Density Matrix

$$H|\Psi\rangle = i\hbar\frac{\partial}{\partial t}|\Psi\rangle$$

Hamiltonian

Building a Model

Schrödinger Equation of Motion:

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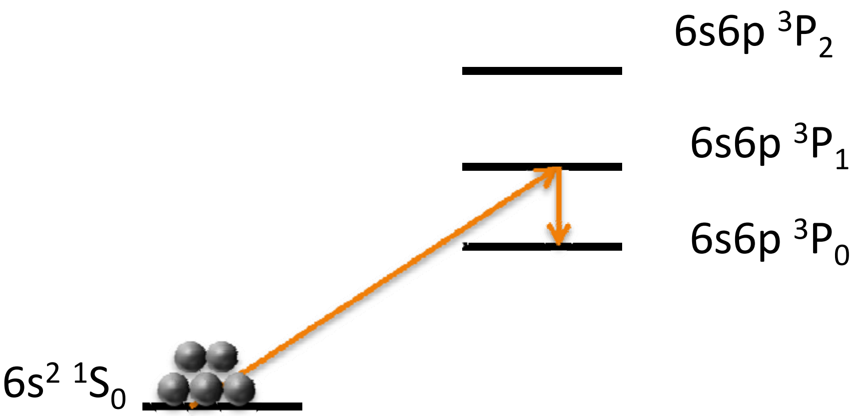
Evolution of density matrix **ρ(t)**:



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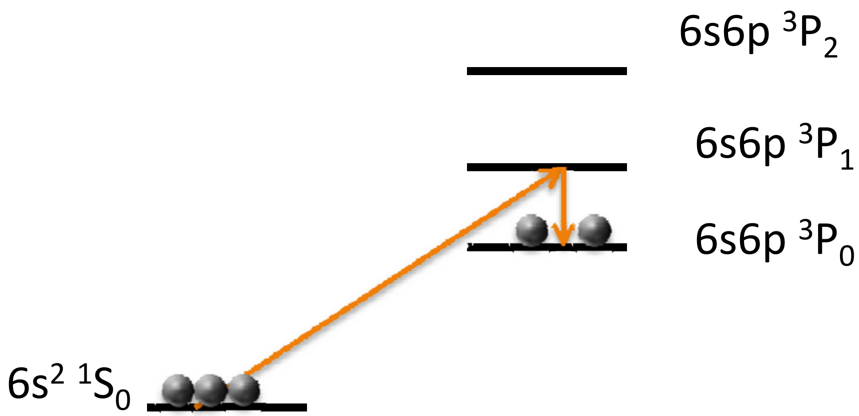

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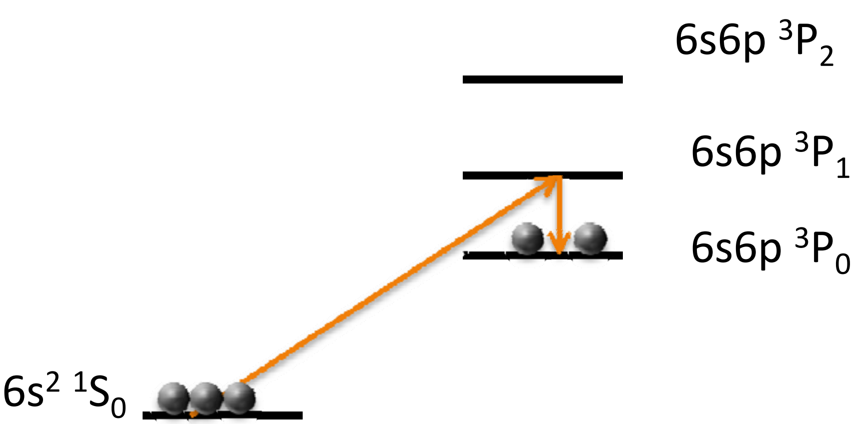
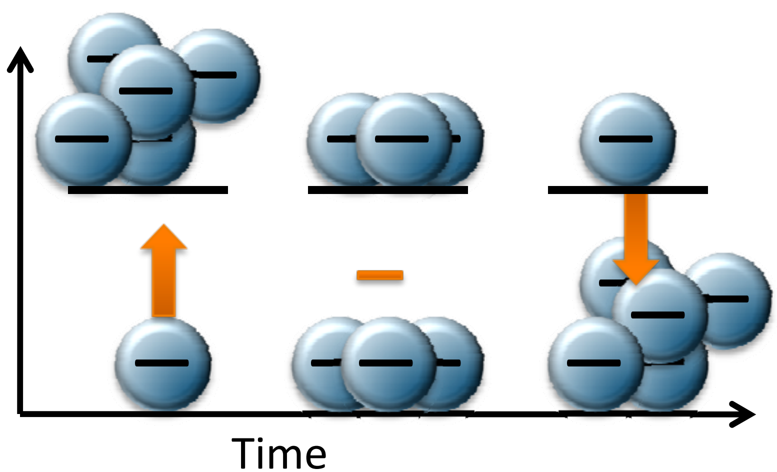
Evolution of density matrix **ρ(t)**:

Polarization/Magnetization behavior of transitions between levels:





Building a Model

Schrödinger Equation of Motion:

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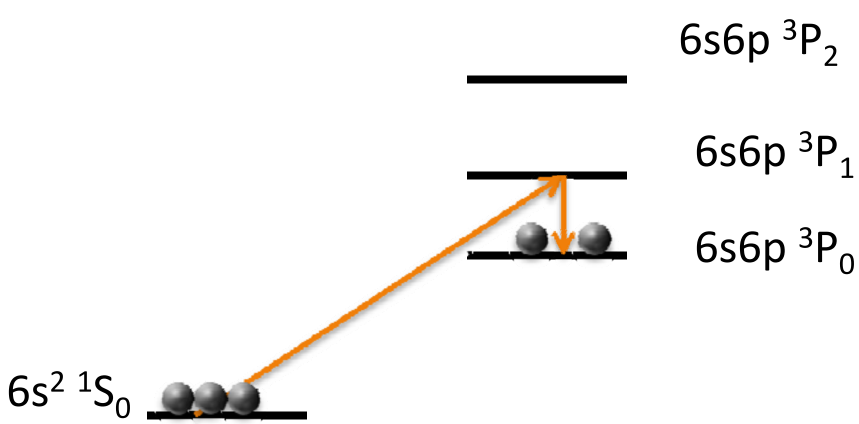
Susceptibility to various frequencies:

$$\chi_E = \frac{P}{\varepsilon_0 E} \qquad \chi_M = \frac{M\mu_0}{B}$$

Evolution of density matrix **ρ(t)**:



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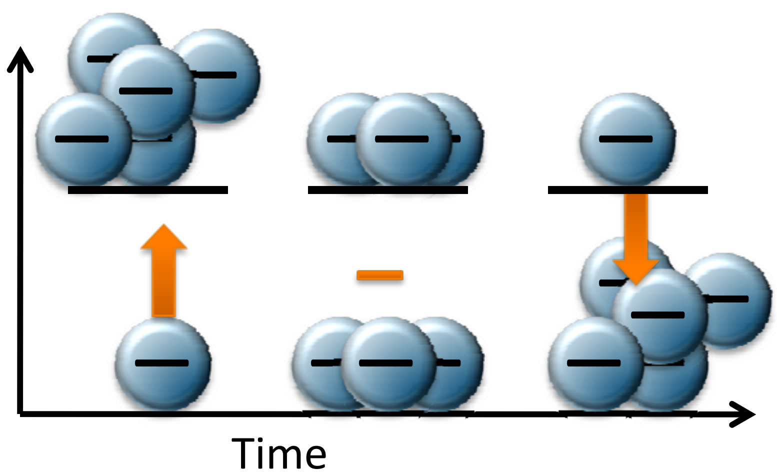
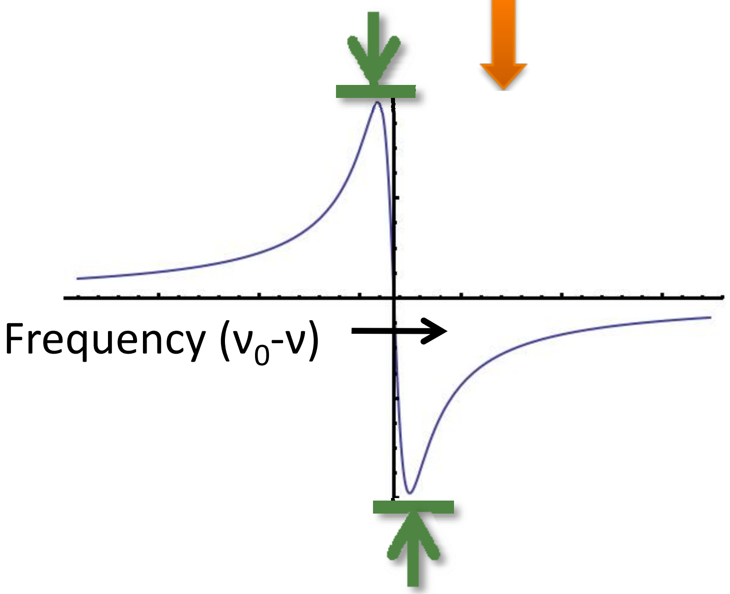


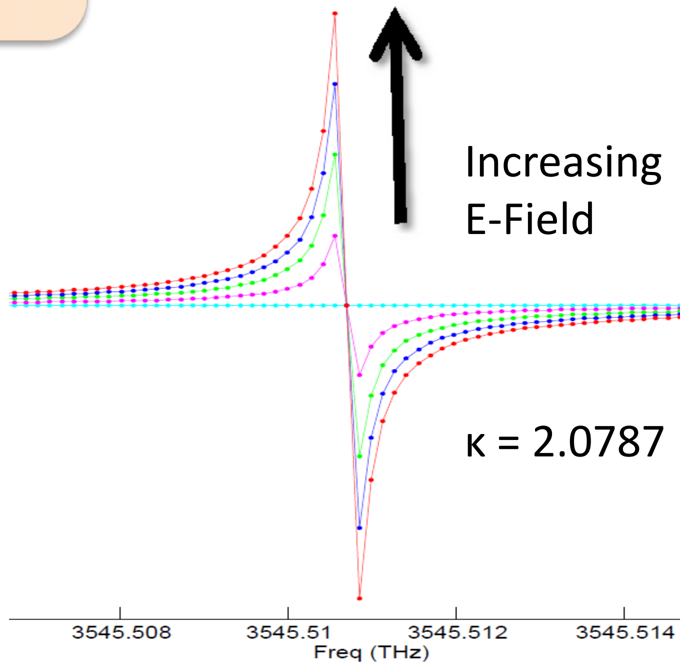
Model Results

Goal: Obtain as narrow a dispersion pattern as possible in order to measure the resonance frequency ω_0 precisely

$$\chi_{EM}'(\nu) \cong \frac{N}{\hbar\varepsilon_0 c^2} \frac{\mu_{E1}^2 \mu_{M1}^2}{\left|\hbar\left(\nu - \nu_{H_0}\right)\right|^2} \frac{E^2}{\Gamma_2} \frac{\Delta_2/\Gamma_2}{1+\left(\Delta_2/\Gamma_2\right)^2}$$

$$\Delta_2 \equiv \nu_0 - 2\nu$$





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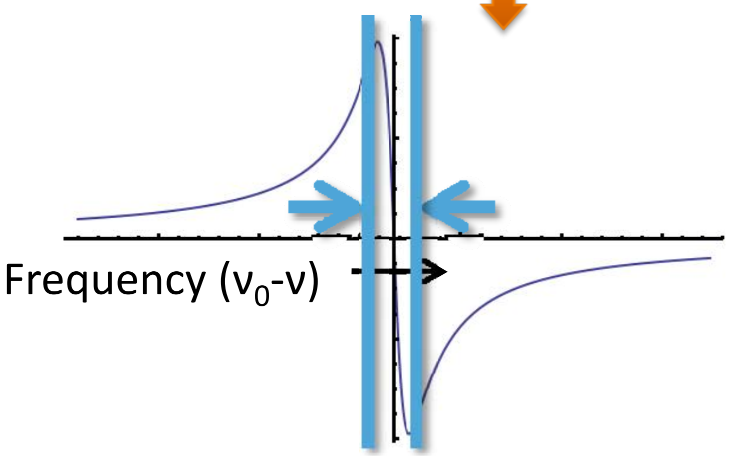

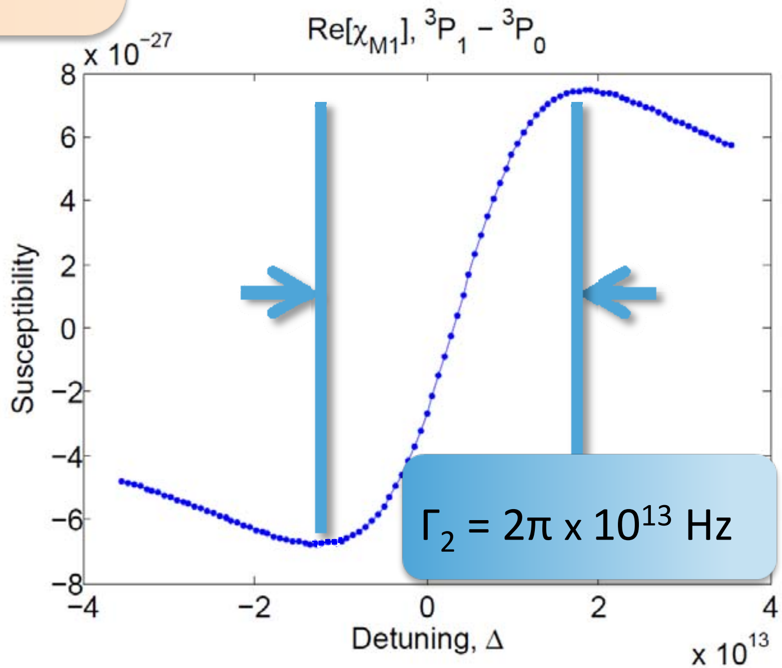

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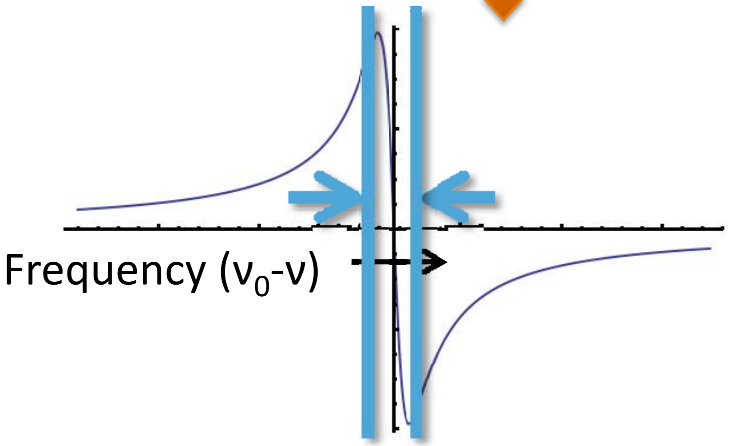

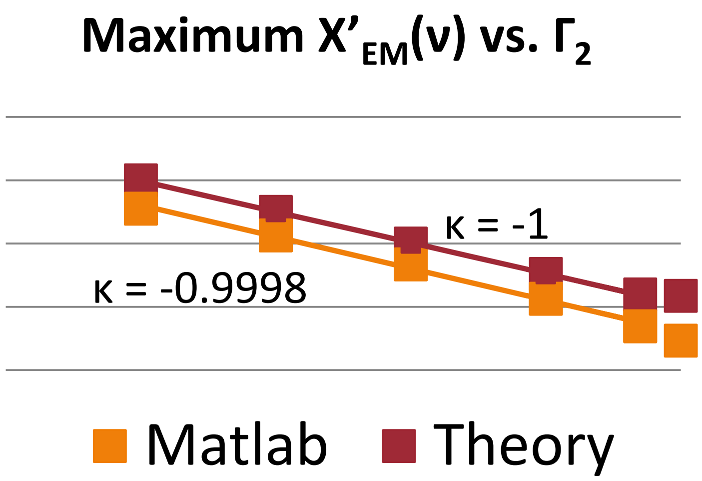

Summary

•**Goal**: Obtain as narrow a dispersion pattern as possible in order to measure the resonance frequency ω_0 precisely

•**Method**: Model with the computer to determine expectations and experimental parameters

•**Future work**: Set up experiment using Michelson-Morley interferometer

Thank you for your attention!

Acknowledgement

The Leanhardt Atomic, Molecular and Optical (AMO) physics group

Left to Right:

Emily Alden (grad), Jinhai Chen (postdoc), Chris Lee (grad), Kaitlin Moore (postbac), Yisa Rumala (grad), Aaron Leanhardt (PI)

Not in picture: Chuck Siedlecki (undergrad), Peter Tarle (undergrad), Charlie Steiner (undergrad)