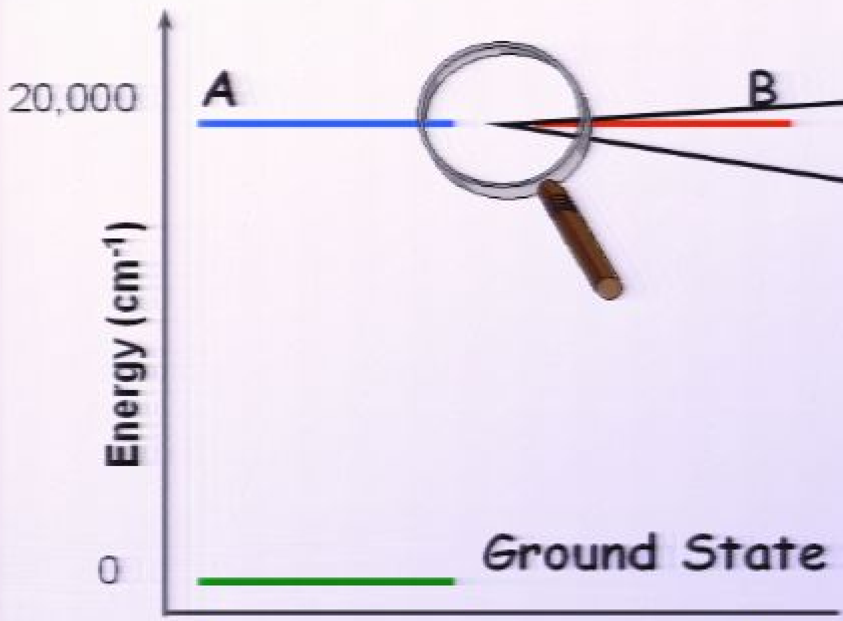
Title: Search for temporal variation of alpha in radio-frequency transitions of atomic dysprosium.

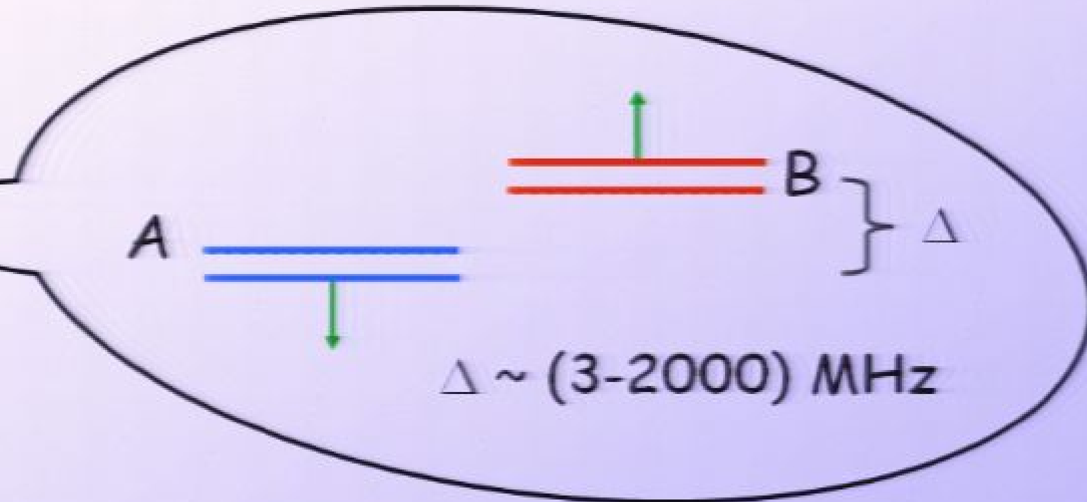
Date: Jul 17, 2008 10:40 AM

URL: http://pirsa.org/08070019

Abstract:

Search for temporal variation of the fine-structure "constant" in radio-frequency transitions of Dy





$d\Delta/dt \sim 2\times10^{15}$ Hz $\dot{\alpha}/\alpha$

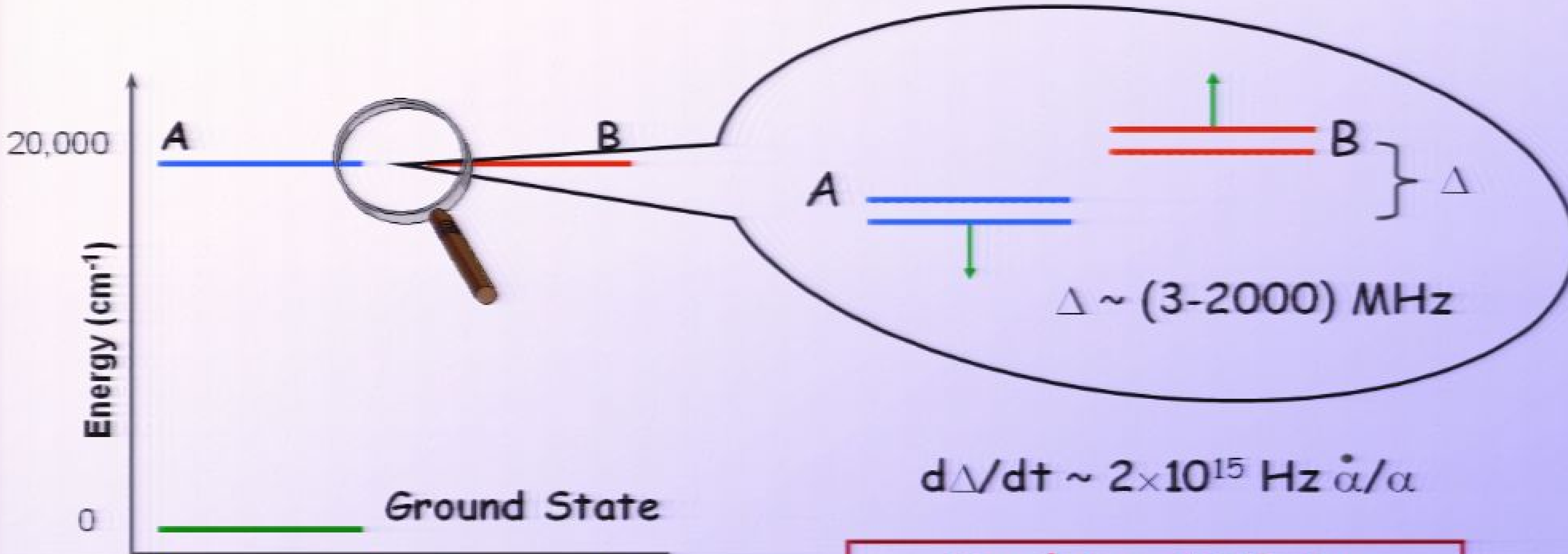
For $\dot{\alpha}/\alpha \sim 10^{-15}$ /yr

$\Rightarrow$ $d\Delta/dt \sim 2$ Hz/yr !!

Dzuba, Flambaum, Kozlov, et al

$\dot{\alpha}$

Search for temporal variation of the fine-structure "constant" in radio-frequency transitions of Dy



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Result: Phys. Rev. Lett. **98**, 040801 (2007)

Limit on the Temporal Variation of the Fine-Structure Constant Using Atomic Dysprosium

A. Cingöz,[1] A. Lapierre,[1] A.-T. Nguyen,[2] N. Leefer,[1] D. Budker,[1,3] S. K. Lamoreaux,[2,*] and J. R. Torgerson[2]

[1]*Department of Physics, University of California at Berkeley, Berkeley, California 94720-7300, USA*
[2]*Los Alamos National Laboratory, Physics Division, P-23, MS-H803, Los Alamos, New Mexico 87545, USA*
[3]*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

(Dated: August 30, 2006)

$$\dot{\alpha}/\alpha = (-2.7 \pm 2.6_{\text{mostly syst}}) \times 10^{-15}\ \text{yr}^{-1}$$

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Independent of other fundamental constants

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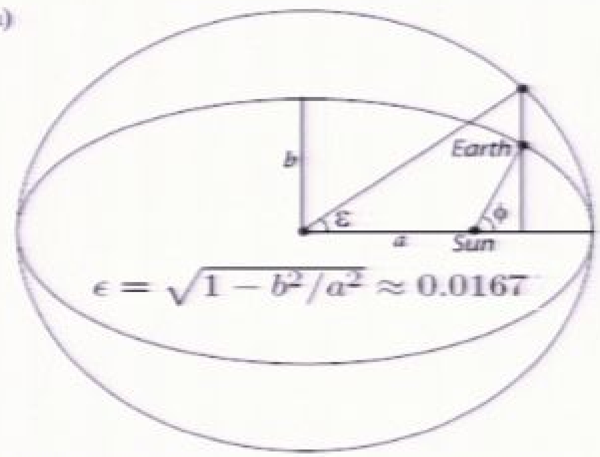
PHYSICAL REVIEW A 76, 062104 (2007)

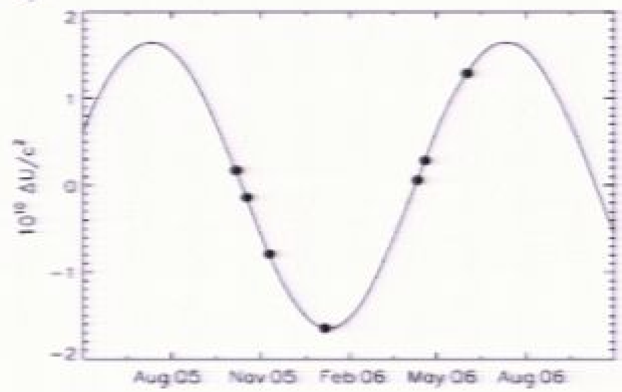
Investigation of the gravitational-potential dependence of the fine-structure constant using atomic dysprosium

S. J. Ferrell,[1] A. Cingöz,[1] A. Lapierre,[2] A.-T. Nguyen,[3] N. Leefer,[1] D. Budker,[1,4] V. V. Flambaum,[5,6] S. K. Lamoreaux,[7] and J. R. Torgerson[3]

a)



b)



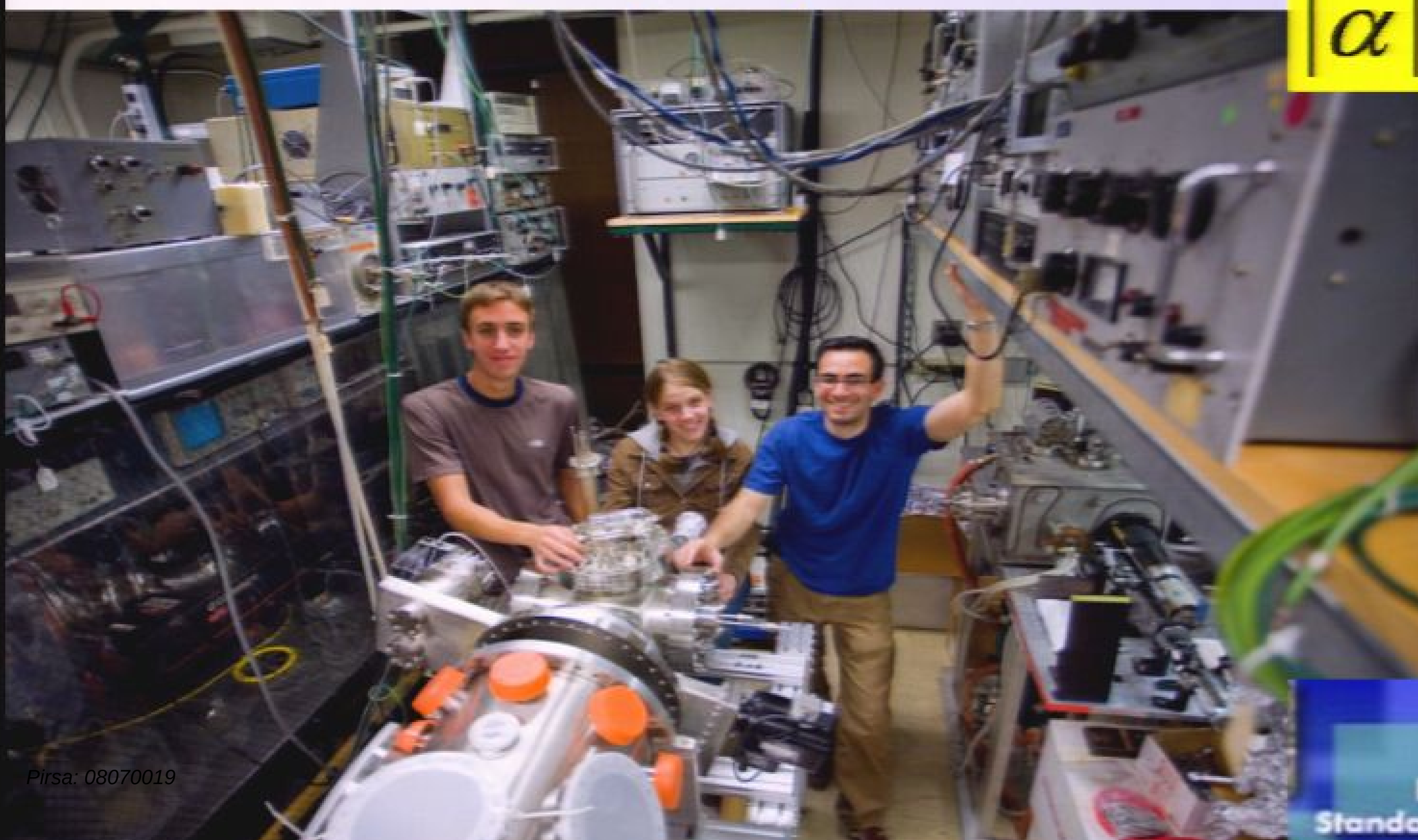
Parameter	Constraint	Experimental Ref.
$k_\alpha + 0.17k_e$	$(-3.5 \pm 6) \times 10^{-7}$	[15]
$\lvert k_\alpha + 0.13k_q \rvert$	$< 2.5 \times 10^{-5}$	[22]
$k_\alpha + 0.13k_q$	$(-1 \pm 17) \times 10^{-7}$	[23]
k_α	$(-8.7 \pm 6.6) \times 10^{-6}$	this work
k_e	$(4.9 \pm 3.9) \times 10^{-5}$	this work
k_q	$(6.6 \pm 5.2) \times 10^{-5}$	this work

NIST Trapped-Ion/ Frequency-Comb work

Future...

- Explore laser cooling of atomic beam
- Operate new apparatus optimized for the α-dot experiment
- Measure frequency to ~1 mHz

$$\left|\frac{\dot{\alpha}}{\alpha}\right| \sim 10^{-18} / yr$$



Support:

Los Alamo
NATIONAL LABORATO
EST. 1943

NIST
National Institute of Standards and Technology

Fine-Structure Constant α

- Dimensionless fundamental constant

- Characterizes the strength of all electromagnetic interactions

- Energy of atomic levels $\propto m_e c^2 \cdot \alpha^2 \cdot (1 + k\alpha^2 + \ldots)$

$$\alpha = \frac{e^2}{\hbar c} = \frac{1}{137.035\,999\,084\,(96)} \quad [0.37 \text{ ppb}]$$

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D. Hanneke, S. Fogwell, and G. Gabrielse, Phys. Rev. Lett. **100**, 120801 (2008)

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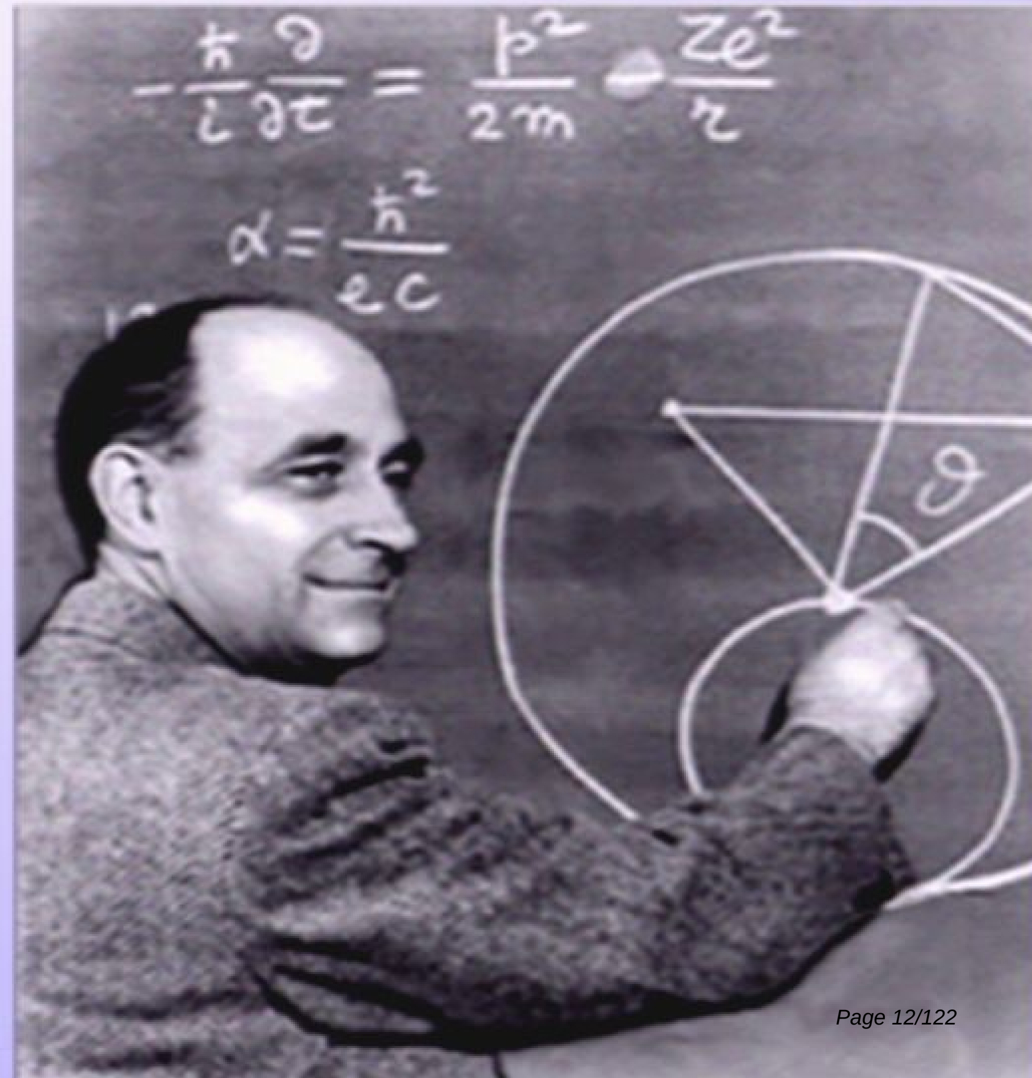
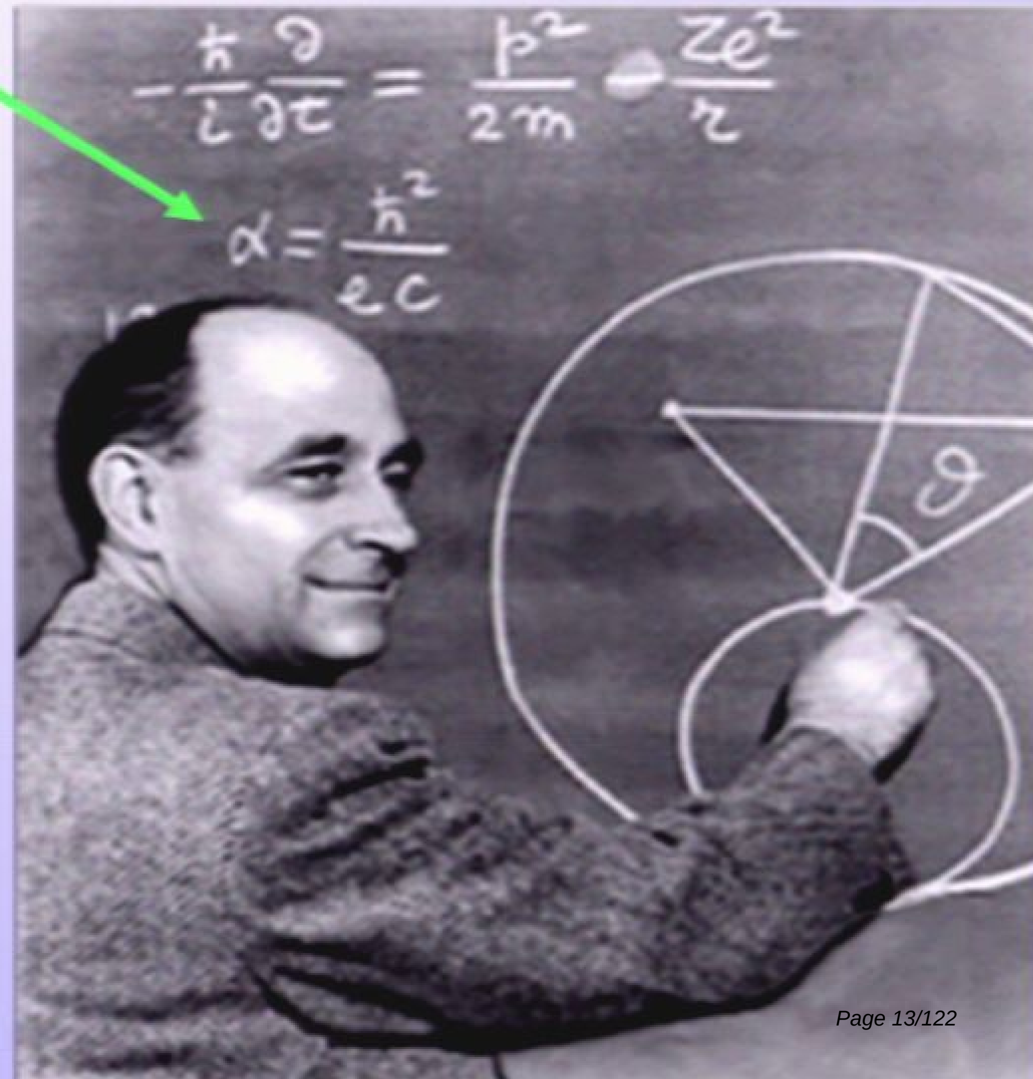


Professor Enrico Fermi

A ***gross*** variation



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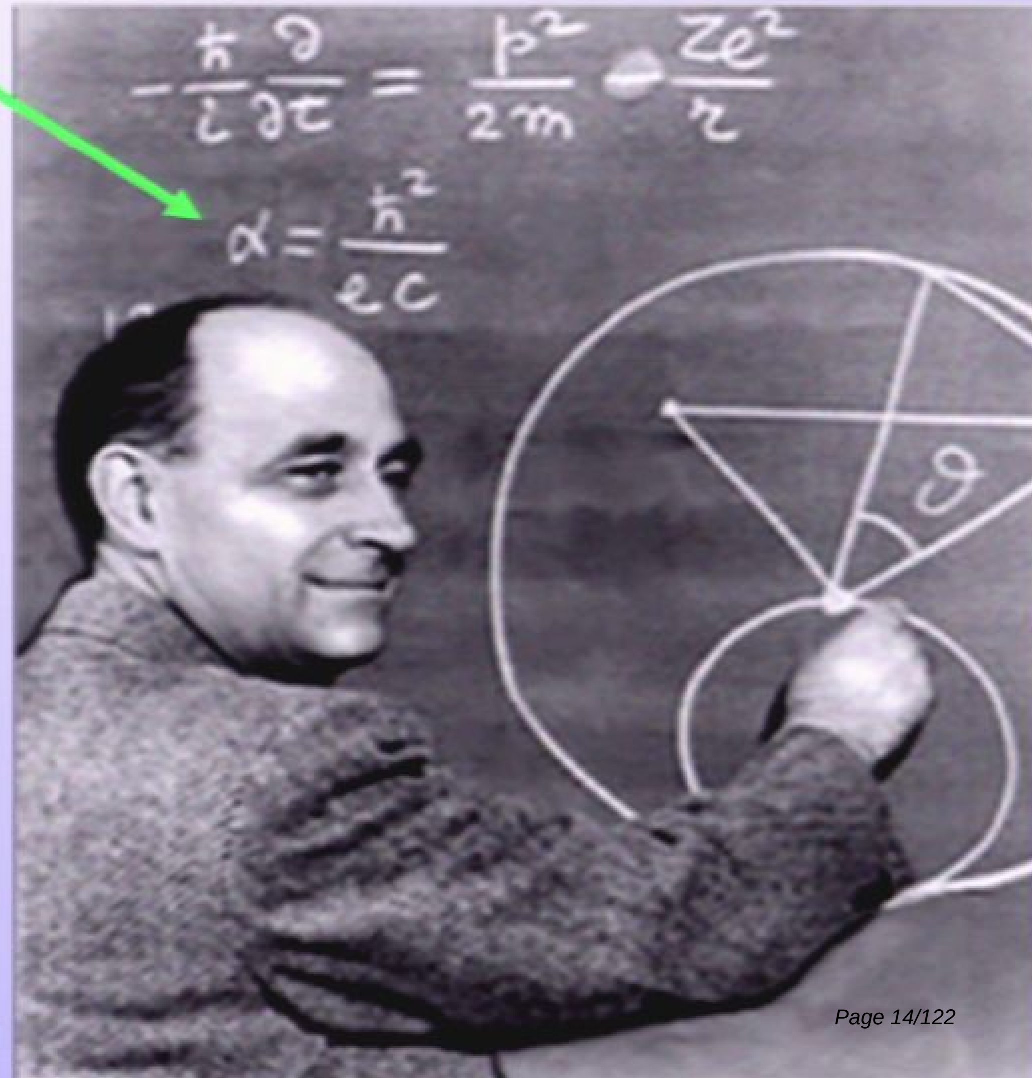

We search for *small* temporal variation of α

Professor Enrico Fermi

Laboratory Searches

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- Looking for *present-day* variation [e.g., $\dot{\alpha}(t = now)$]

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- Which is $1/10^{15}$ per year (assuming linear variation)
- This is about where **best atomic clocks** are today
- Clock laboratories search for variation of constants
- (We do not rely on fancy clock, but still would like to have one)

Laboratory limits (1σ):

Year	$\dot{\alpha}/\alpha$ ($\times 10^{-15}$/yr)	Method	Reference
1995	≤ 37	H-maser vs. Hg^+ hyperfine††	J. D. Prestage *et al.*, PRL, **74**, 3511 (1995)
2003	-0.4 ± 1.6	Rb fountain vs. Cs fountain††	H. Marion *et al.*, PRL, **90**, 150801 (2003)
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Combined result with other optical clock vs. Cs fountain comparisons to date of publication
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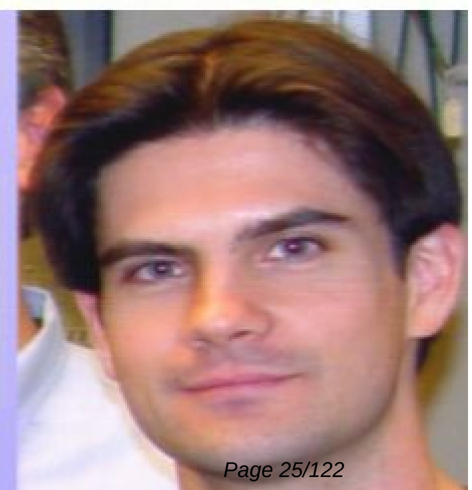
Sensitive to other fundamental constants

Rapid progress with trapped single ions and femtosecond frequency combs !



Jason F. Stalnaker

PRL 98, 070801 (2007) PHYSICAL REVIEW LETTERS week ending 16 FEBRUARY 2007

Precision Atomic Spectroscopy for Improved Limits on Variation of the Fine Structure Constant and Local Position Invariance

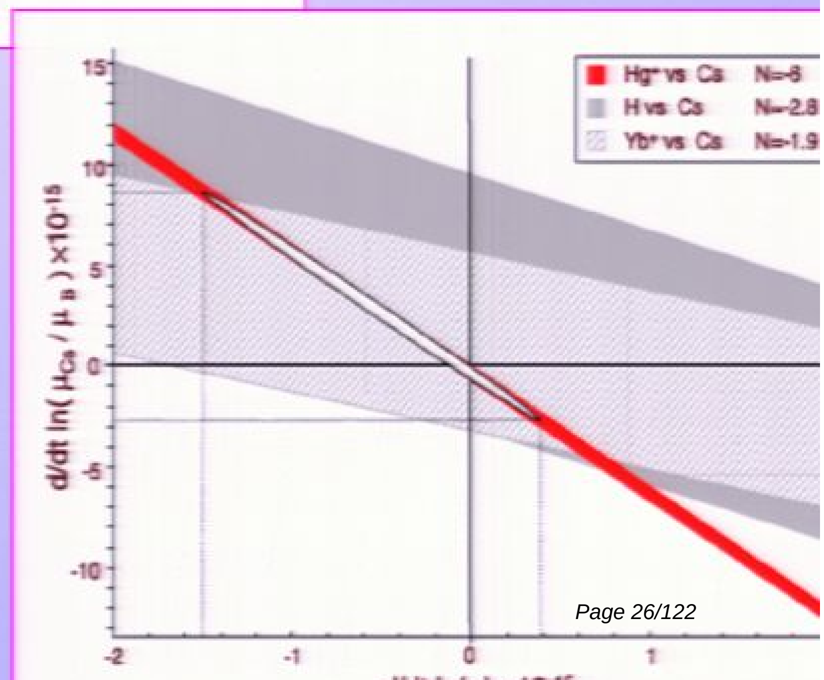
T. M. Fortier,[1,2] N. Ashby,[2] J. C. Bergquist,[2] M. J. Delaney,[2,*] S. A. Diddams,[2,†] T. P. Heavner,[2] L. Hollberg,[2] W. M. Itano,[2] S. R. Jefferts,[2] K. Kim,[2,‡] F. Levi,[2,§] L. Lorini,[2] W. H. Oskay,[2] T. E. Parker,[2] J. Shirley,[2] and J. E. Stalnaker[2]

[1]*P-23 Physics Division MS H803, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

[2]*Time and Frequency Division MS 847, National Institute of Standards and Technology, Boulder, Colorado 80305, USA*

(Received 5 September 2006; published 16 February 2007)

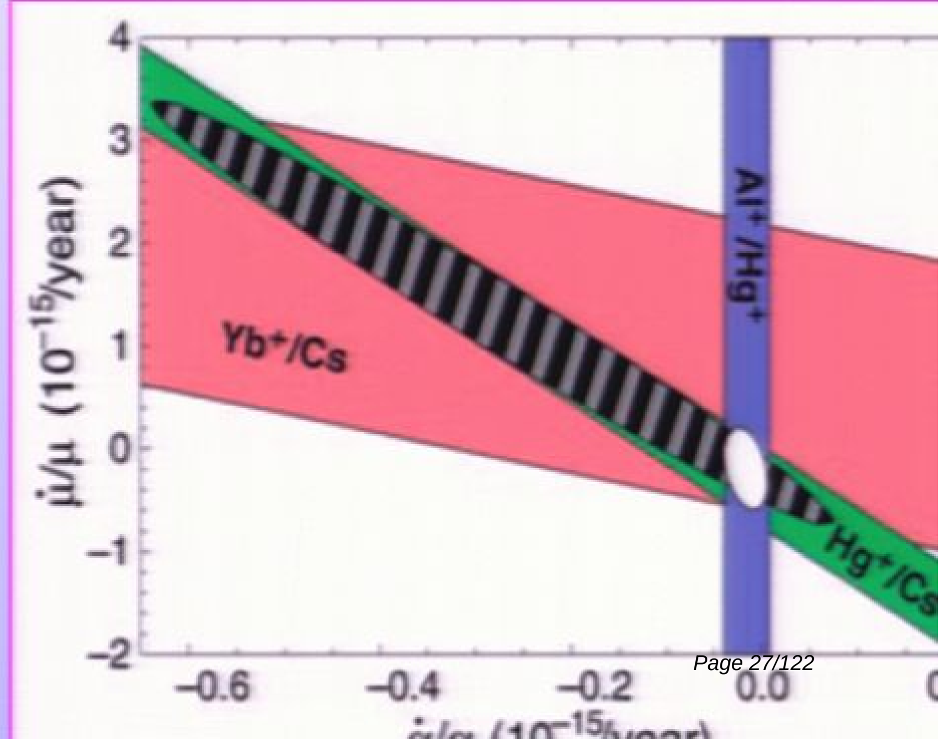
We report tests of local position invariance and the variation of fundamental constants from measurements of the frequency ratio of the 282-nm $^{199}Hg^+$ optical clock transition to the ground state hyperfine splitting in ^{133}Cs. Analysis of the frequency ratio of the two clocks, extending over 6 yr at NIST, is used to place a limit on its fractional variation of $<5.8 \times 10^{-6}$ per change in normalized solar gravitational potential. The same frequency ratio is also used to obtain 20-fold improvement over previous limits on the fractional variation of the fine structure constant of $|\frac{\dot{\alpha}}{\alpha}| < 1.3 \times 10^{-16}$ yr^{-1}, assuming invariance of other fundamental constants. Comparisons of our results with those previously reported for the absolute optical frequency measurements in H and $^{171}Yb^+$ vs other ^{133}Cs standards yield a coupled constraint of $-1.5 \times 10^{-15} < \dot{\alpha}/\alpha < 0.4 \times 10^{-15}$ yr^{-1} and $-2.7 \times 10^{-15} < \frac{d}{dt} \ln\frac{\mu_{Cs}}{\mu_B} < 8.6 \times 10^{-15}$ yr^{-1}.



Frequency Ratio of Al^+ and Hg^+ Single-Ion Optical Clocks; Metrology at the 17th Decimal Place

. Rosenband,* D. B. Hume, P. O. Schmidt,† C. W. Chou, A. Brusch, L. Lorini,‡ W. H. Oskay,§
. E. Drullinger, T. M. Fortier, J. E. Stalnaker,‖ S. A. Diddams, W. C. Swann,
. R. Newbury, W. M. Itano, D. J. Wineland, J. C. Bergquist

Science **319**, 1808 (2008)



PHYSICAL REVIEW A **69**, 022105 (2004)

Towards a sensitive search for variation of the fine-structure constant using radio-frequency $E1$ transitions in atomic dysprosium

A. T. Nguyen*
Department of Physics, University of California at Berkeley, Berkeley, California 94720-7300, USA

D. Budker†
Department of Physics, University of California at Berkeley, Berkeley, California 94720-7300, USA
and Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA

S. K. Lamoreaux‡ and J. R. Torgerson§
University of California, Los Alamos National Laboratory, Physics Division, P-23, MS-H803, Los Alamos, New Mexico 87545, USA
(Received 28 August 2003; published 12 February 2004)

It has been proposed that the radio-frequency electric-dipole ($E1$) transition between two nearly degenerate opposite-parity states in atomic dysprosium should be highly sensitive to possible temporal variation of the fine-structure constant (α) [V. A. Dzuba, V. V. Flambaum, and J. K. Webb, Phys. Rev. A **59**, 230 (1999)]. We analyze here an experimental realization of the proposed search in progress in our laboratory, which involves monitoring the $E1$ transition frequency over a period of time using direct frequency counting techniques. We estimate that a statistical sensitivity of $|\dot{\alpha}/\alpha| \sim 10^{-18}$/yr may be achieved and discuss possible systematic effects that may limit such a measurement.

DOI: 10.1103/PhysRevA.69.022105 PACS number(s): 06.20.Jr, 32.30.Bv

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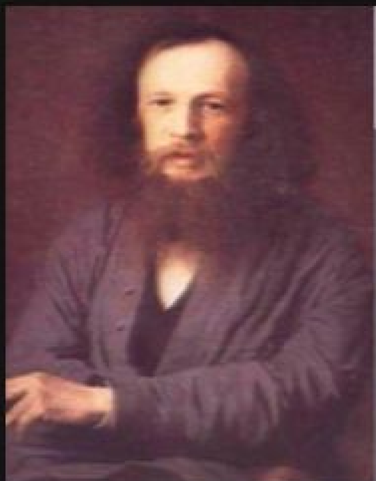


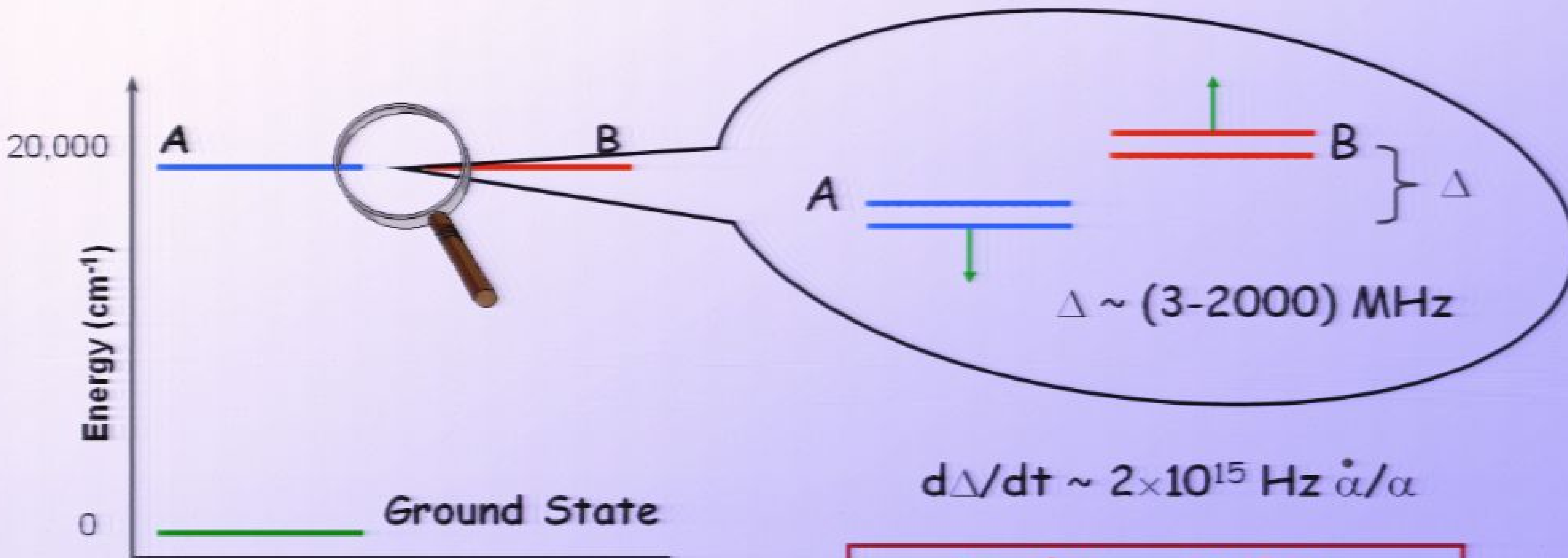
The periodic table of the elements

	1A	2A	3A	4A	5A	6A	7A	8			1B	2B	3B	4B	5B	6B	7B	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	L	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	A															
		L	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		A	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

- Metals
- Metalloids
- Non-metals
- Transition Metals
- Gases

α-Variation in Atomic Dysprosium

- Two nearly degenerate states in dysprosium (Dy, Z=66) are highly sensitive to α-variation:



$d\Delta/dt \sim 2\times10^{15}$ Hz $\dot{\alpha}/\alpha$

For $\dot{\alpha}/\alpha \sim 10^{-15}$ /yr

$\Rightarrow$ $d\Delta/dt \sim 2$ Hz/yr !!

Dzuba, Flambaum, Kozlov, et al.

A and B States

- Opposite parity
- $\Delta E \sim$ 3-2000 MHz

$\Rightarrow$ E1 transition connecting the states can be driven with rf electric field

$\Rightarrow$ small enough to allow accurate direct counting of transition frequency

$\Rightarrow$ relaxed requirements on reference clock ($\Delta\upsilon/\upsilon$)

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$$\frac{1\text{ Hz}}{1\text{ GHz}} = 10^{-9}$$

Statistical Sensitivity

- Transition linewidth ~ 20 kHz

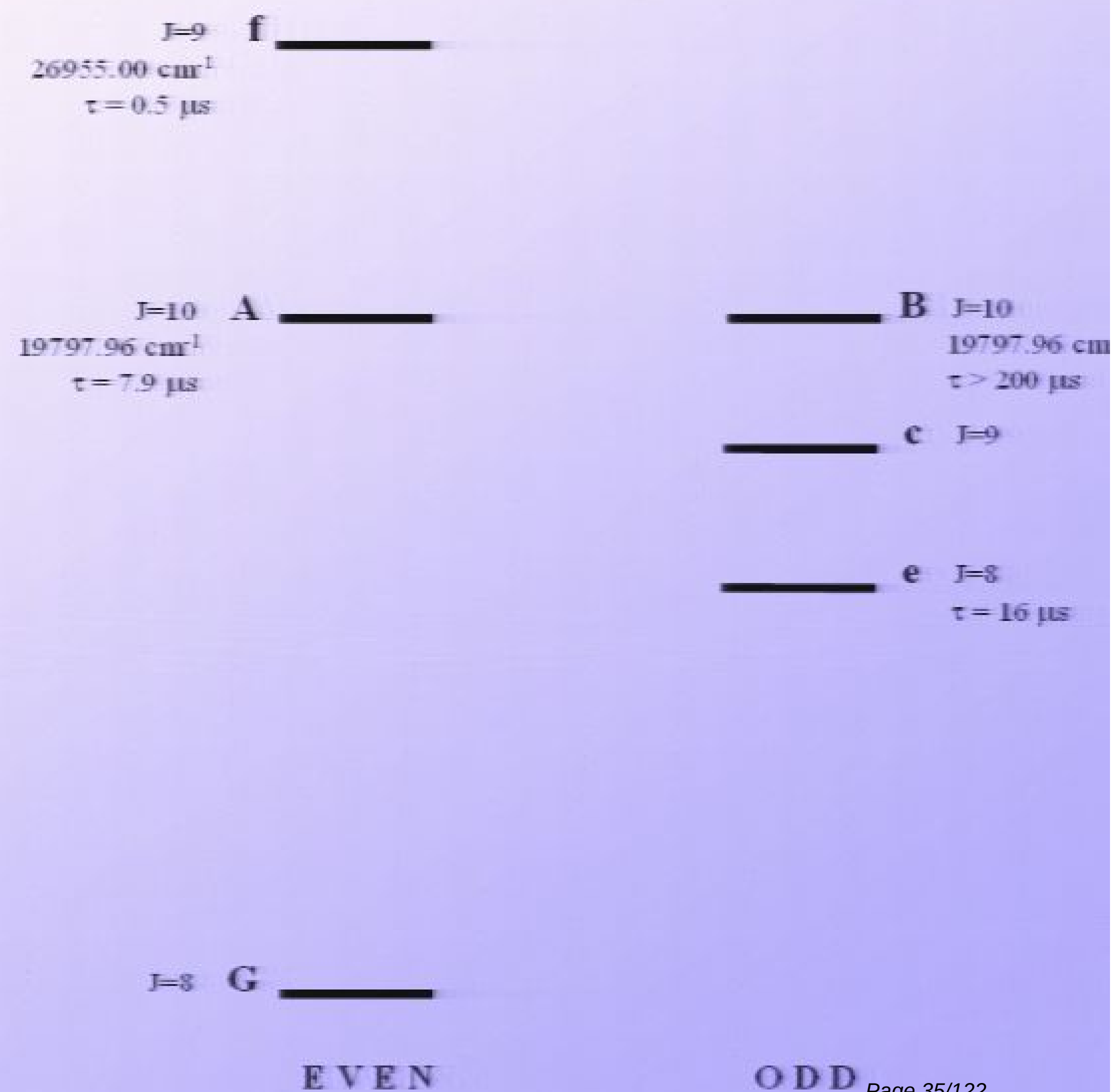
- Counting rate ~ $10^9\ s^{-1}$

$\Rightarrow$ Sensitivity: $\delta\nu \sim \frac{0.6}{T^{1/2}}\ \text{Hz s}^{1/2}$

After an hour of data taking, $\delta\nu$ ~ 10 mHz which allows for a sensitivity of

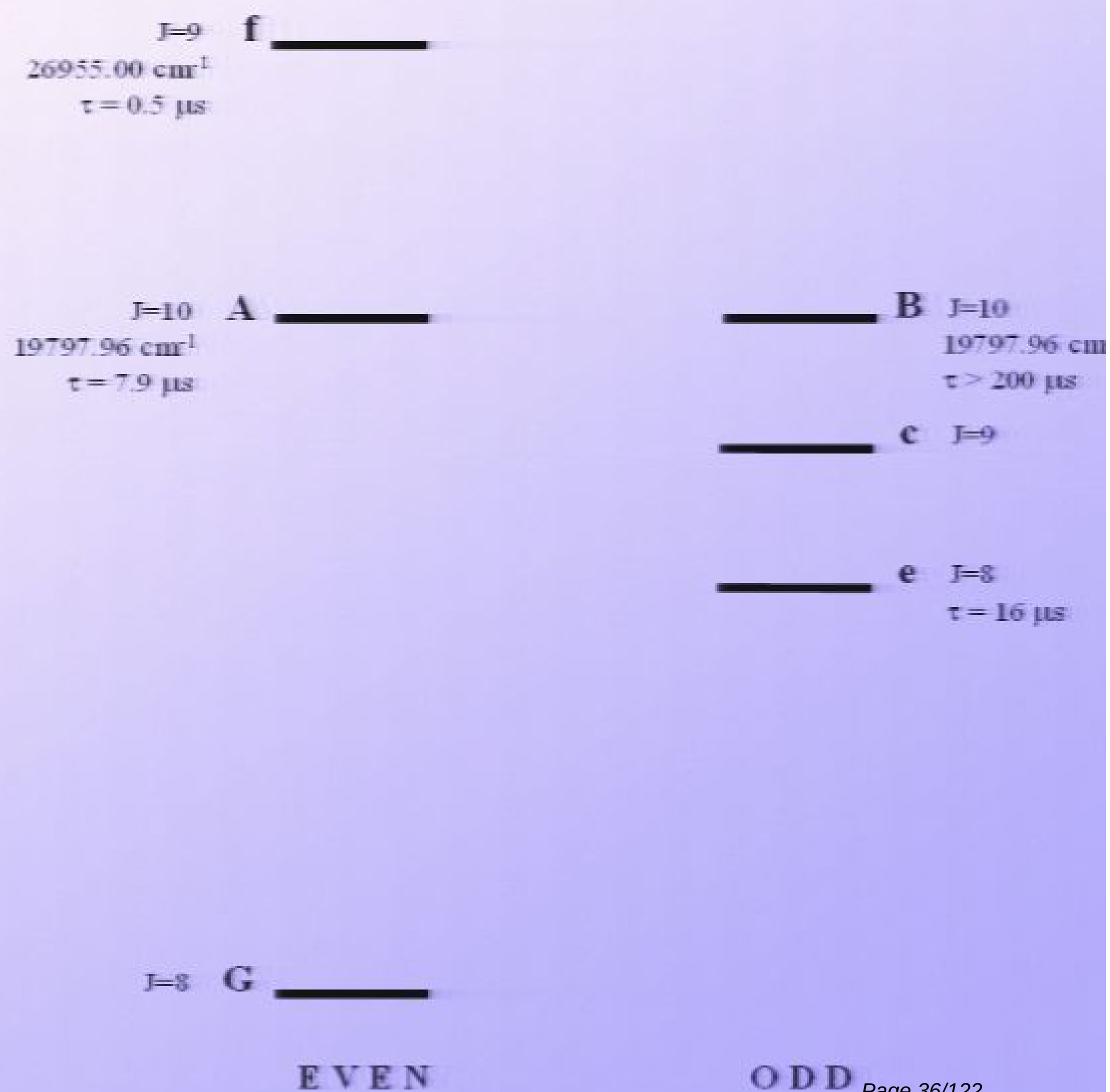
$$\left|\frac{\dot{\alpha}}{\alpha}\right| \sim \frac{10^{-18}}{T_{(yr)}^{3/2}}$$

Population


J=9
f
26955.00 cm-1
τ = 0.5 μs
J=10
A
19797.96 cm-1
τ = 7.9 μs
B
J=10
19797.96 cm
τ > 200 μs
c
J=9
e
J=8
τ = 16 μs
J=8
G
EVEN
ODD

Population

- Three-step scheme:



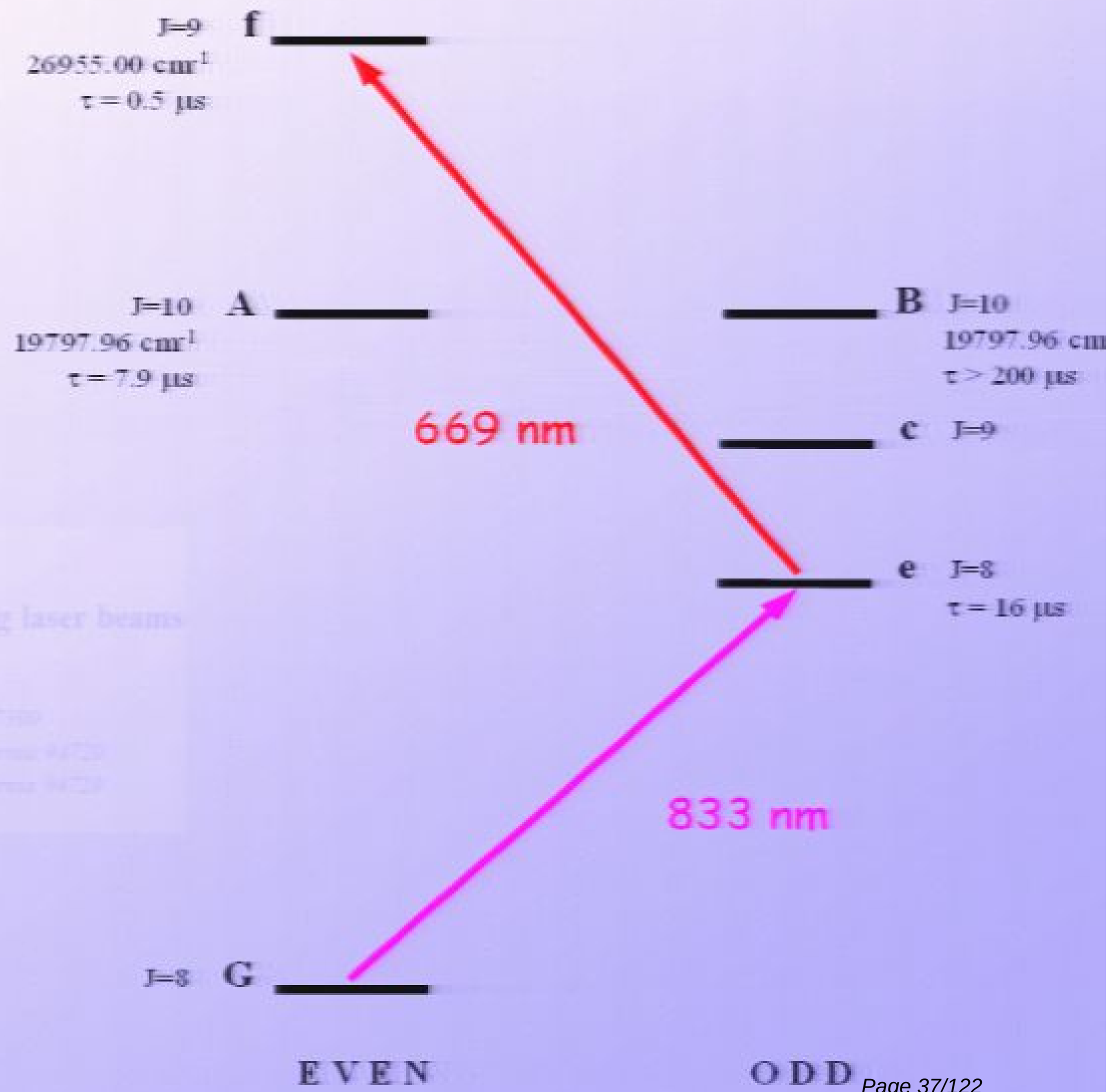
Population

- Three-step scheme:

1st & 2nd - cw laser excitation

PHYSICAL REVIEW A, VOLUME 63, 013406

Efficient population transfer in a multilevel system using diverging laser beams



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PHYSICAL REVIEW A, VOLUME 63, 013406

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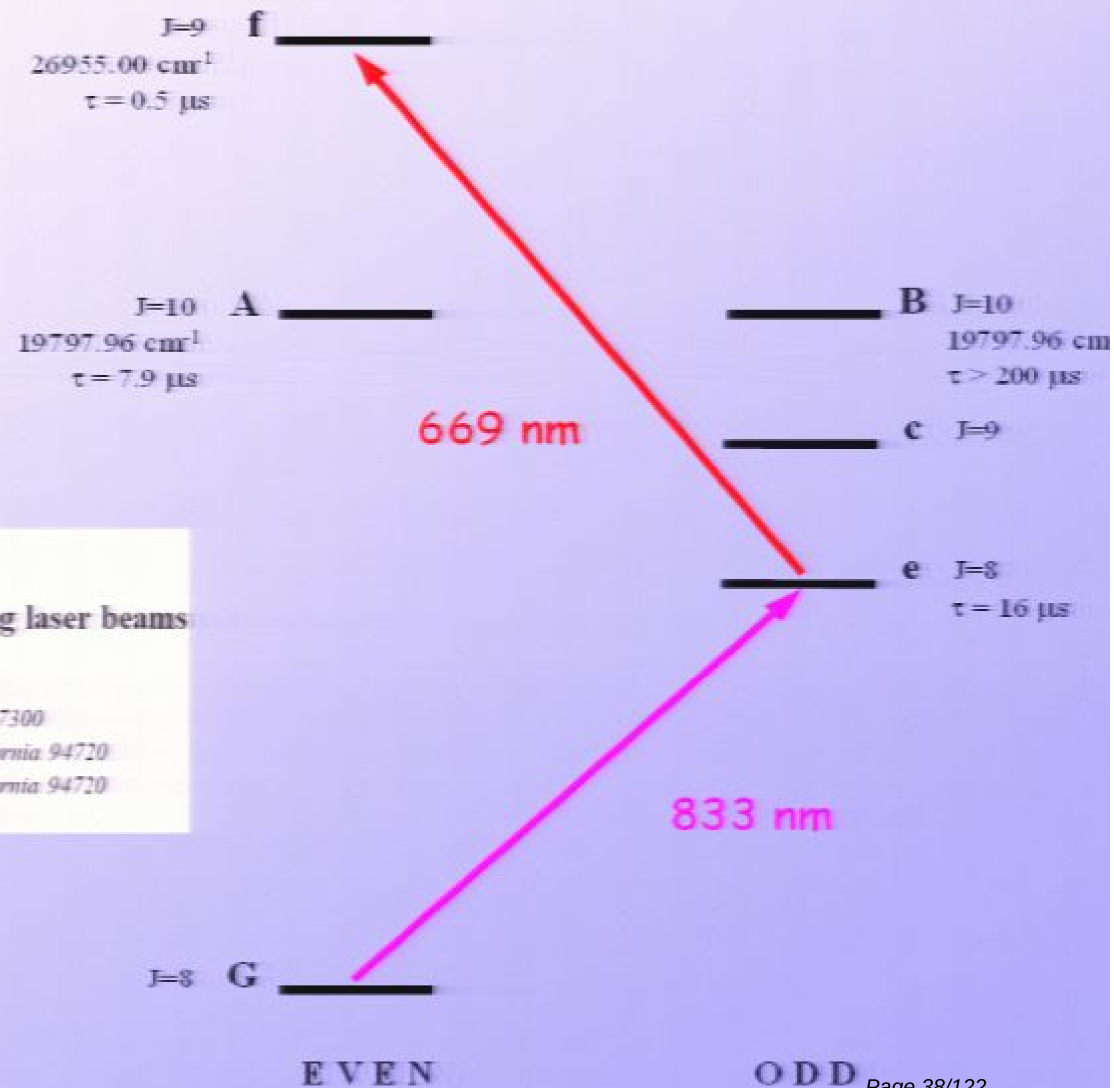
A. T. Nguyen,[1,*] G. D. Chern,[1] D. Budker,[1,2] and M. Zolotorev[3]
[1]Department of Physics, University of California, Berkeley, California 94720-7300
[2]Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720
[3]Center for Beam Physics, Lawrence Berkeley National Laboratory, Berkeley, California 94720
(Received 23 July 2000; published 5 December 2000)



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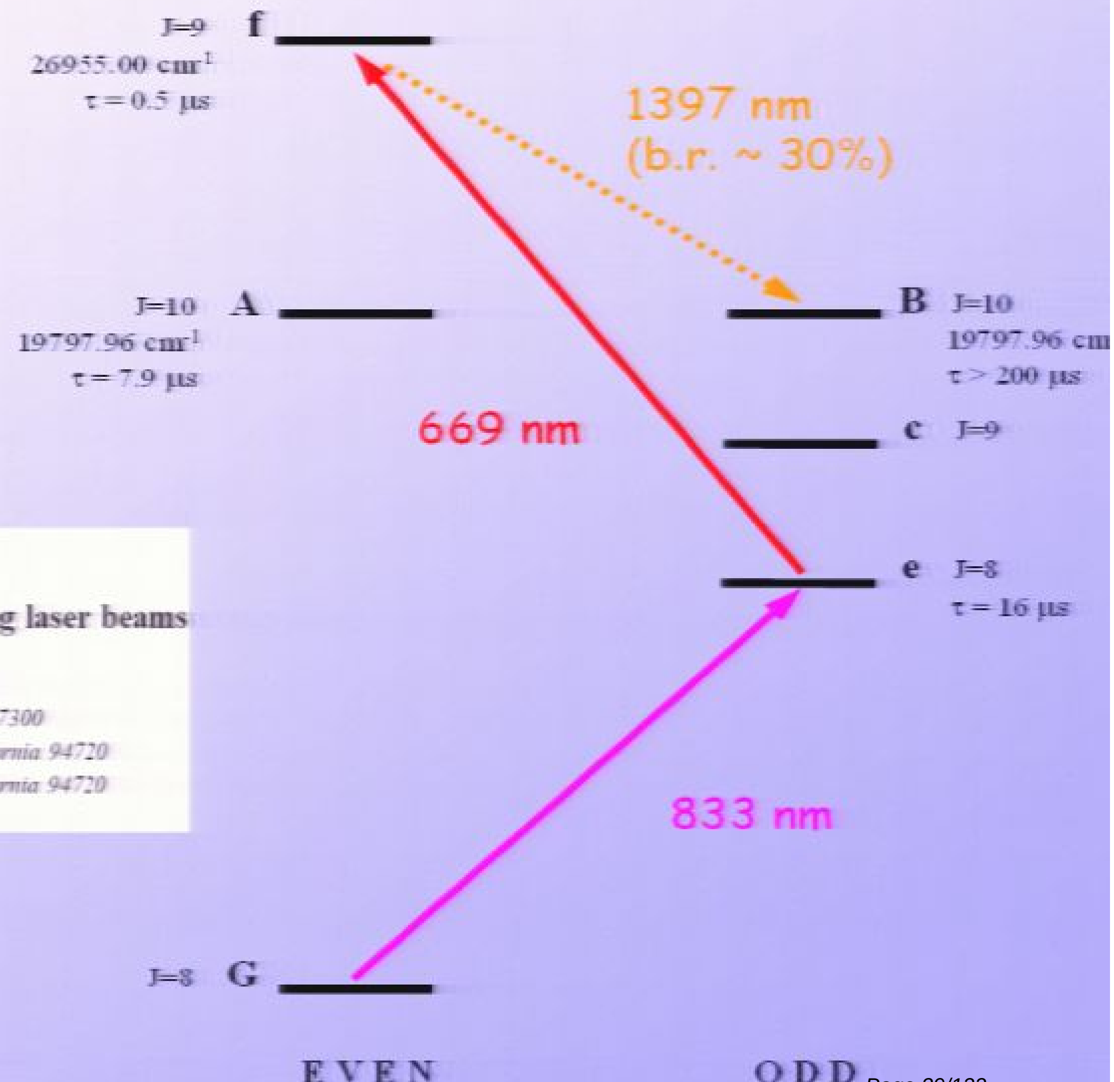
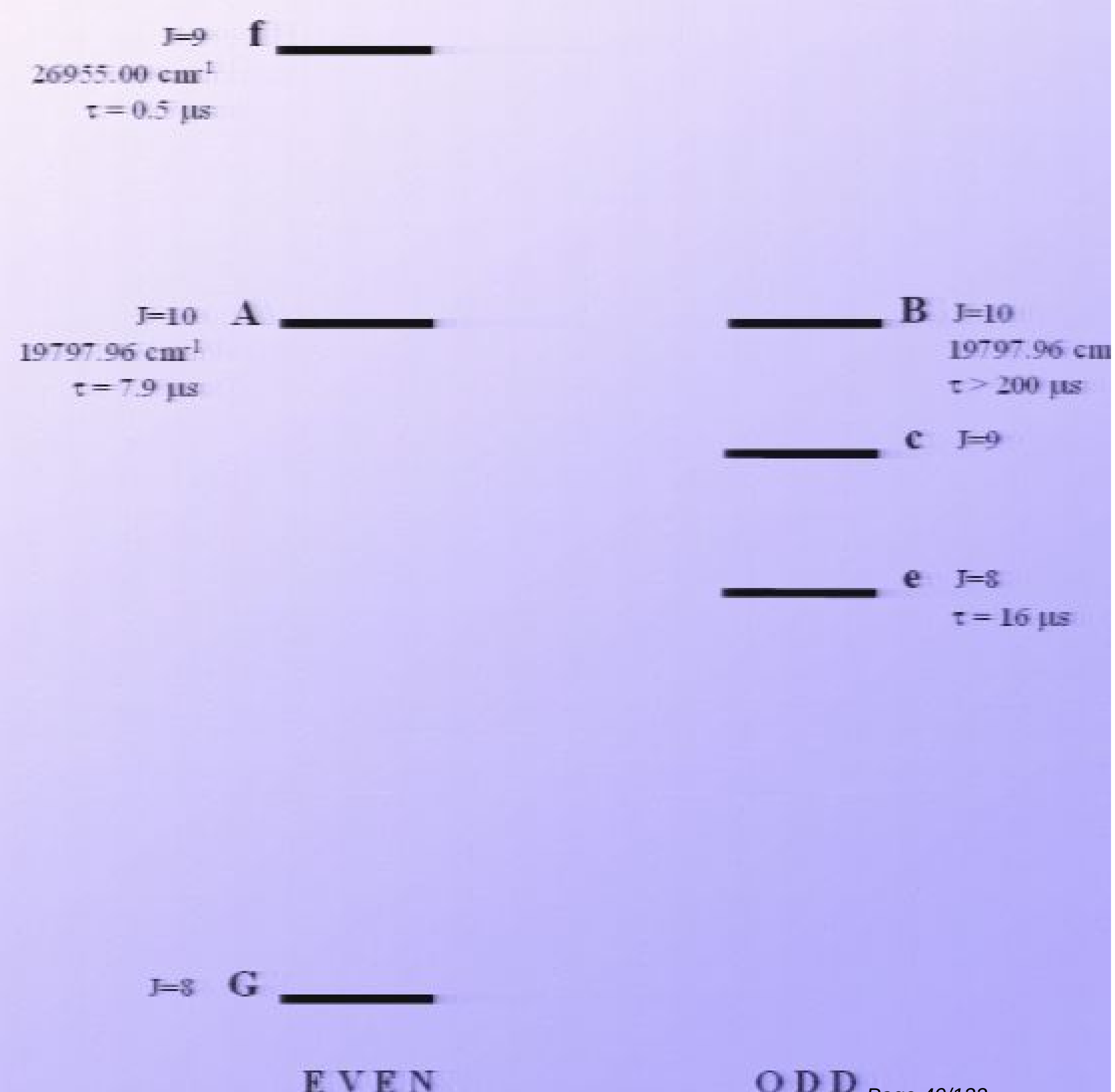
3rd - spontaneous emission

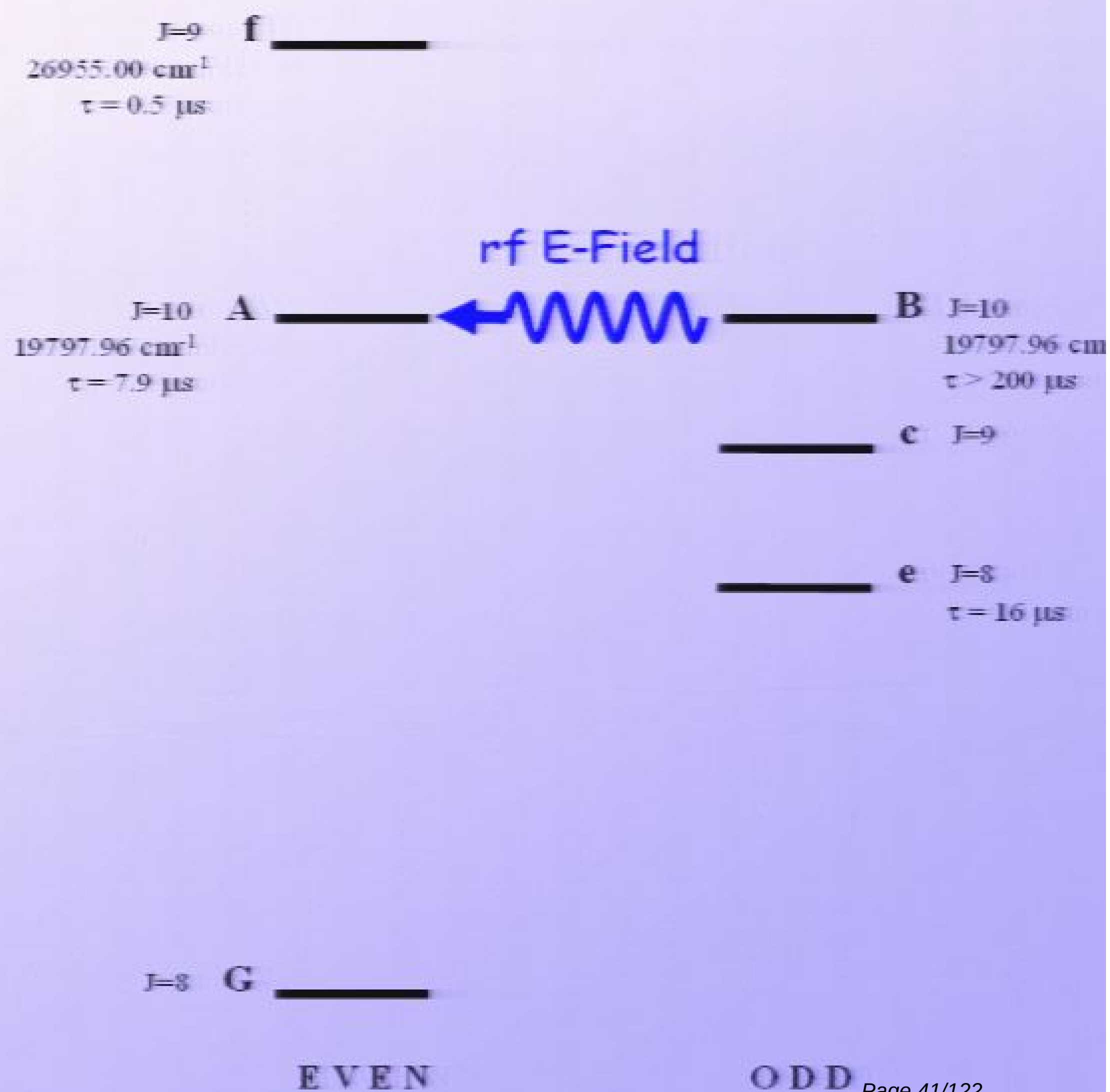


rf Transition and Detection



rf Transition and Detection

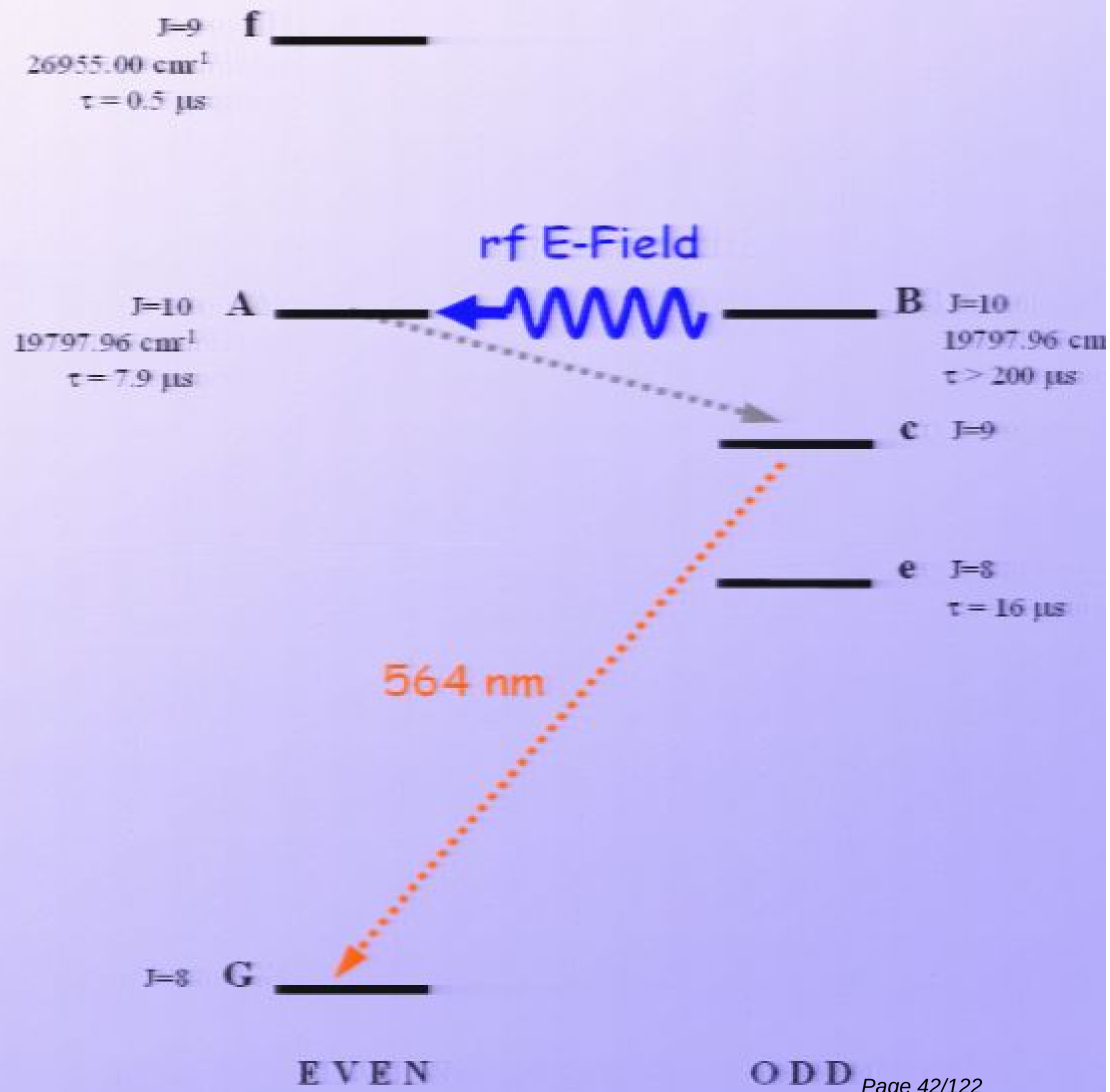
- rf E-field excites atoms to state A



rf Transition and Detection

- rf E-field excites atoms to state A

- State A decays and 564-nm light is detected



The experiment evolved from a **parity nonconservation** search in Dy

PHYSICAL REVIEW A VOLUME 56, NUMBER 5 NOVEMBER 199

Search for parity nonconservation in atomic dysprosium

A. T. Nguyen,[1] D. Budker,[1,2] D. DeMille,[1,*] and M. Zolotorev[3]

[1]*Physics Department, University of California, Berkeley, California 94720-7300*

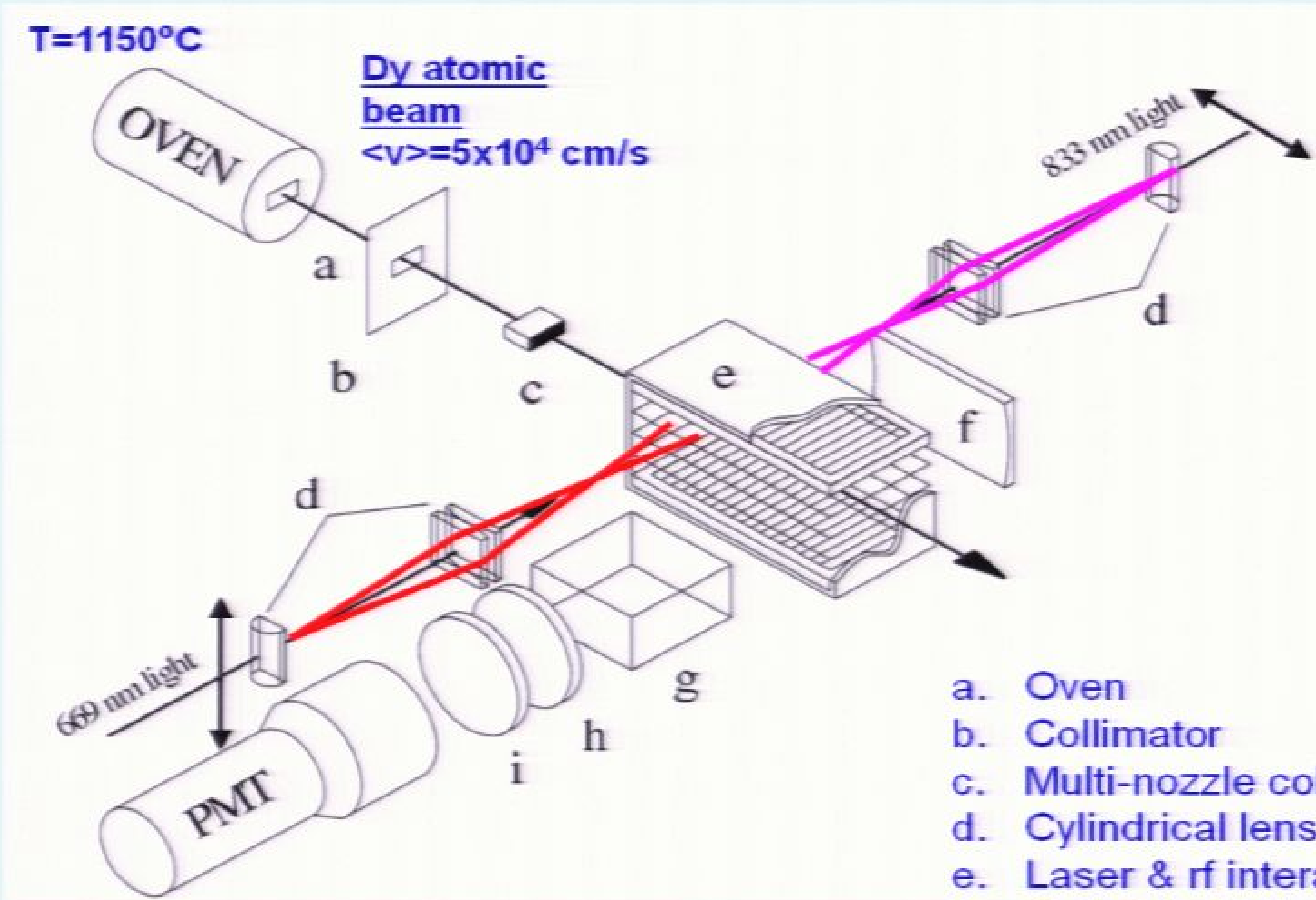
[2]*Nuclear Science Division, E. O. Lawrence Berkeley National Laboratory, Berkeley, California 94720*

[3]*Center for Beam Physics, E. O. Lawrence Berkeley National Laboratory, Berkeley, California 94720*

(Received 2 June 1997)

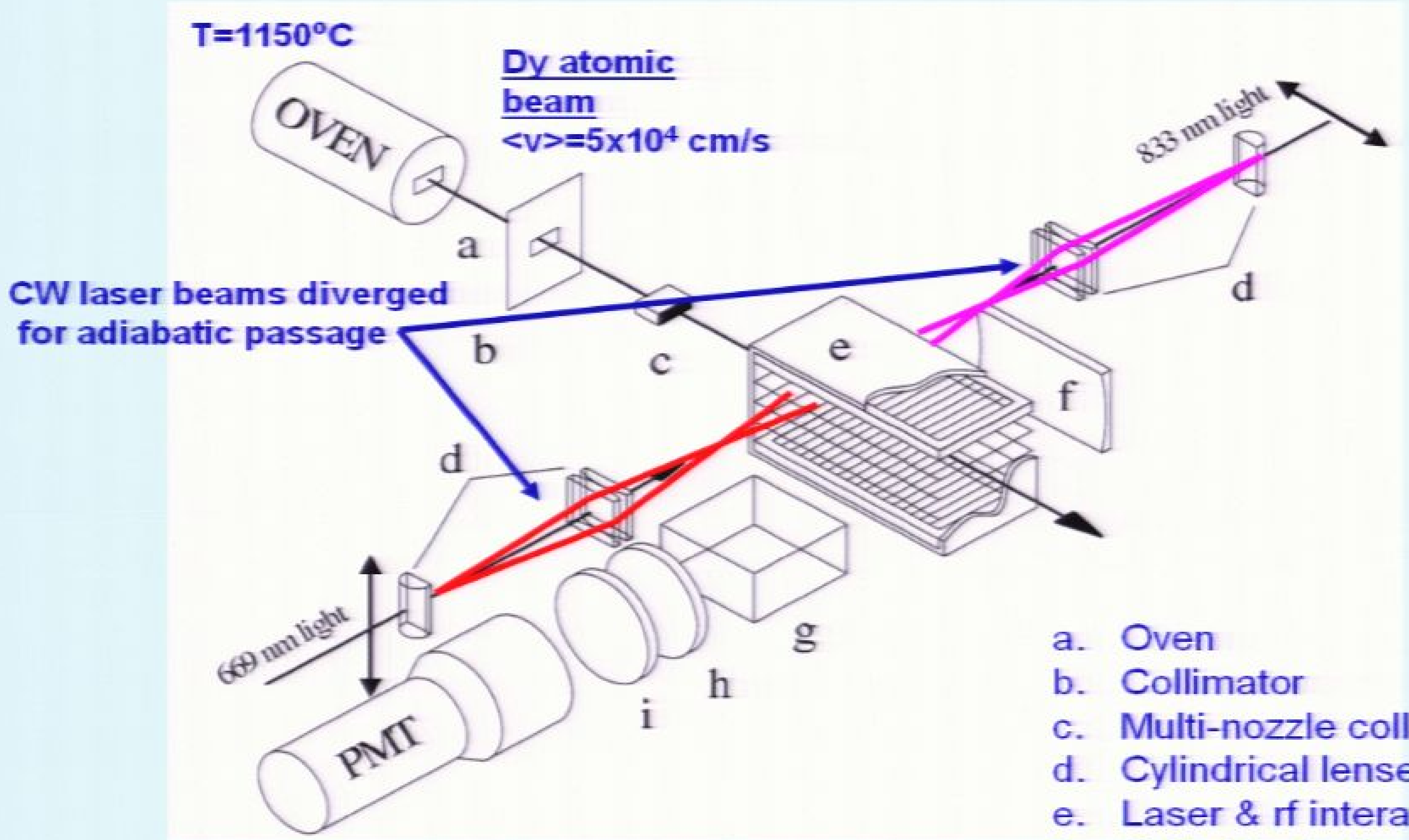
Results of a search for parity nonconservation (PNC) in a pair of nearly degenerate opposite-parity states in atomic dysprosium are reported. The sensitivity to PNC mixing is enhanced in this system by the small energy separation between these levels, which can be crossed by applying an external magnetic field. The metastable odd-parity sublevel of the nearly crossed pair is first populated. A rapidly oscillating electric field is applied to mix this level with its even-parity partner. By observing time-resolved quantum beats between these sublevels, we look for interference between the Stark-induced mixing and the much smaller PNC mixing. To guard against possible systematic effects, reversals of the signs of the electric field, the magnetic field, and the decrossing of the sublevels are employed. We report a value of $|H_w| = |2.3 \pm 2.9\ \text{(statistical)} \pm 0.7\ \text{(systematic)}|$ Hz for the magnitude of the weak-interaction matrix element. A detailed discussion is given of the apparatus, data analysis, and systematic effects. [S1050-2947(97)02111-2]

Apparatus



a. Oven
b. Collimator
c. Multi-nozzle collimator array
d. Cylindrical lenses
e. Laser & rf interaction region
f. Cylindrical mirror
g. Lucite light pipe
h. & i. Filters

Apparatus



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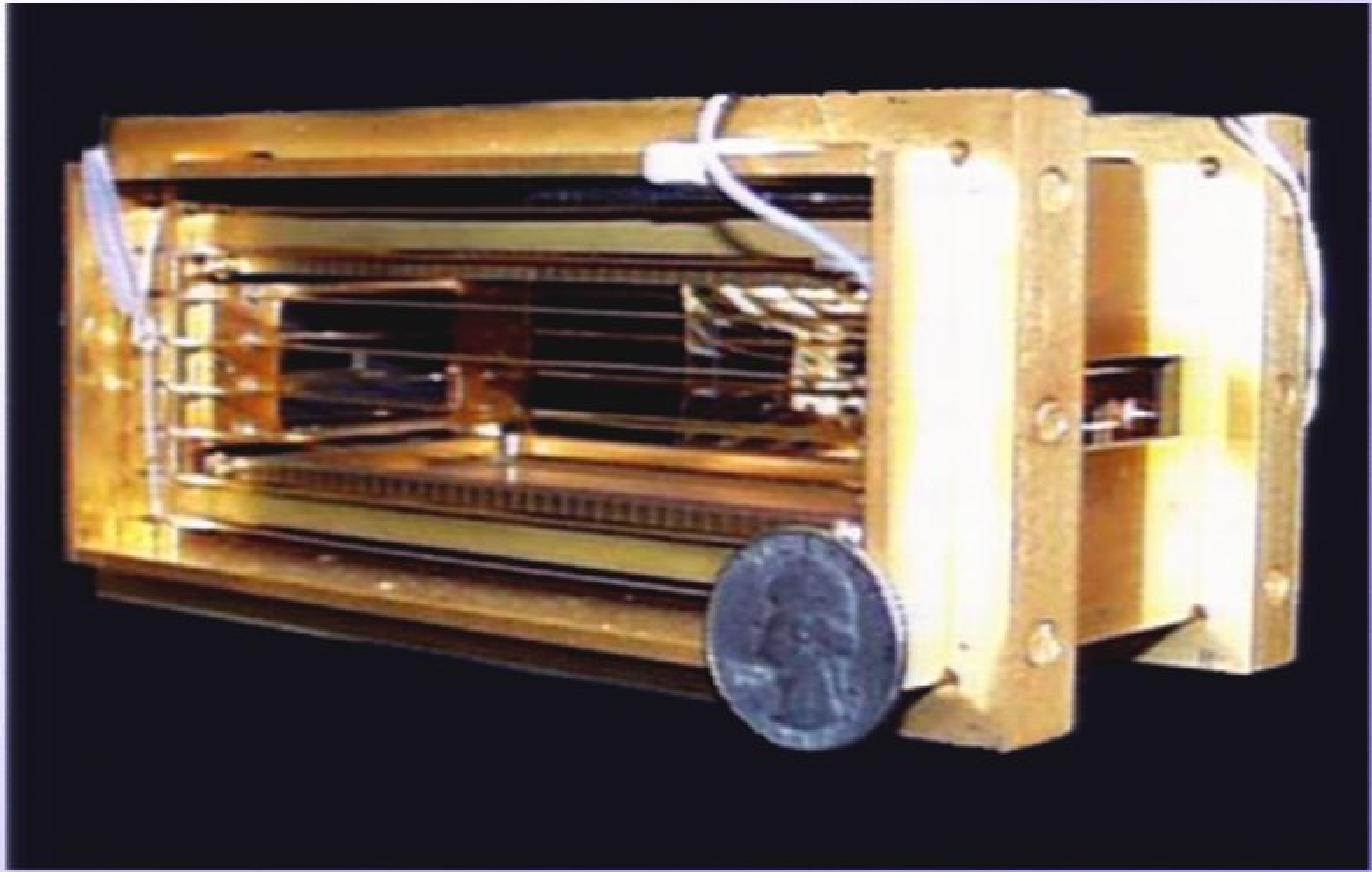
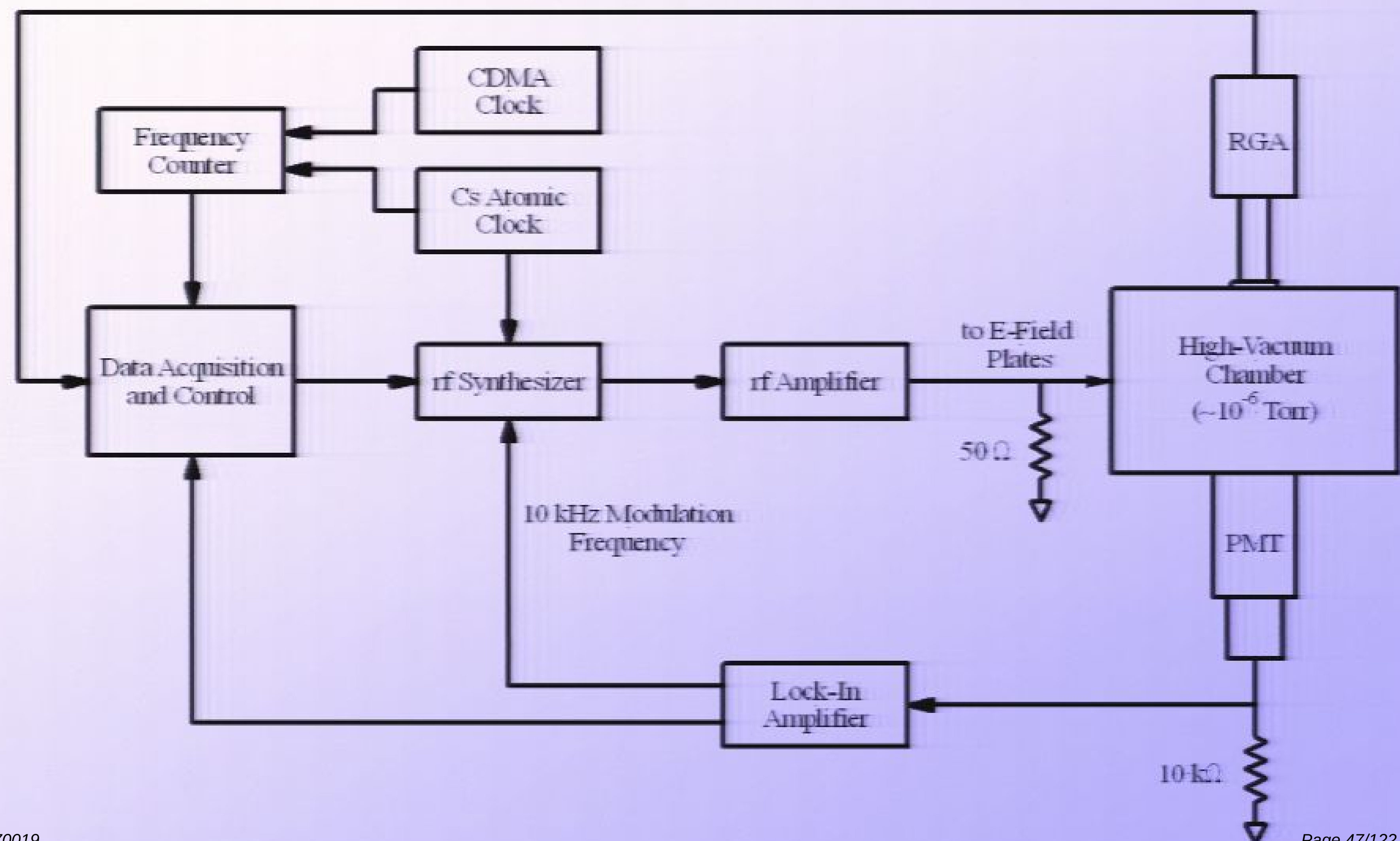
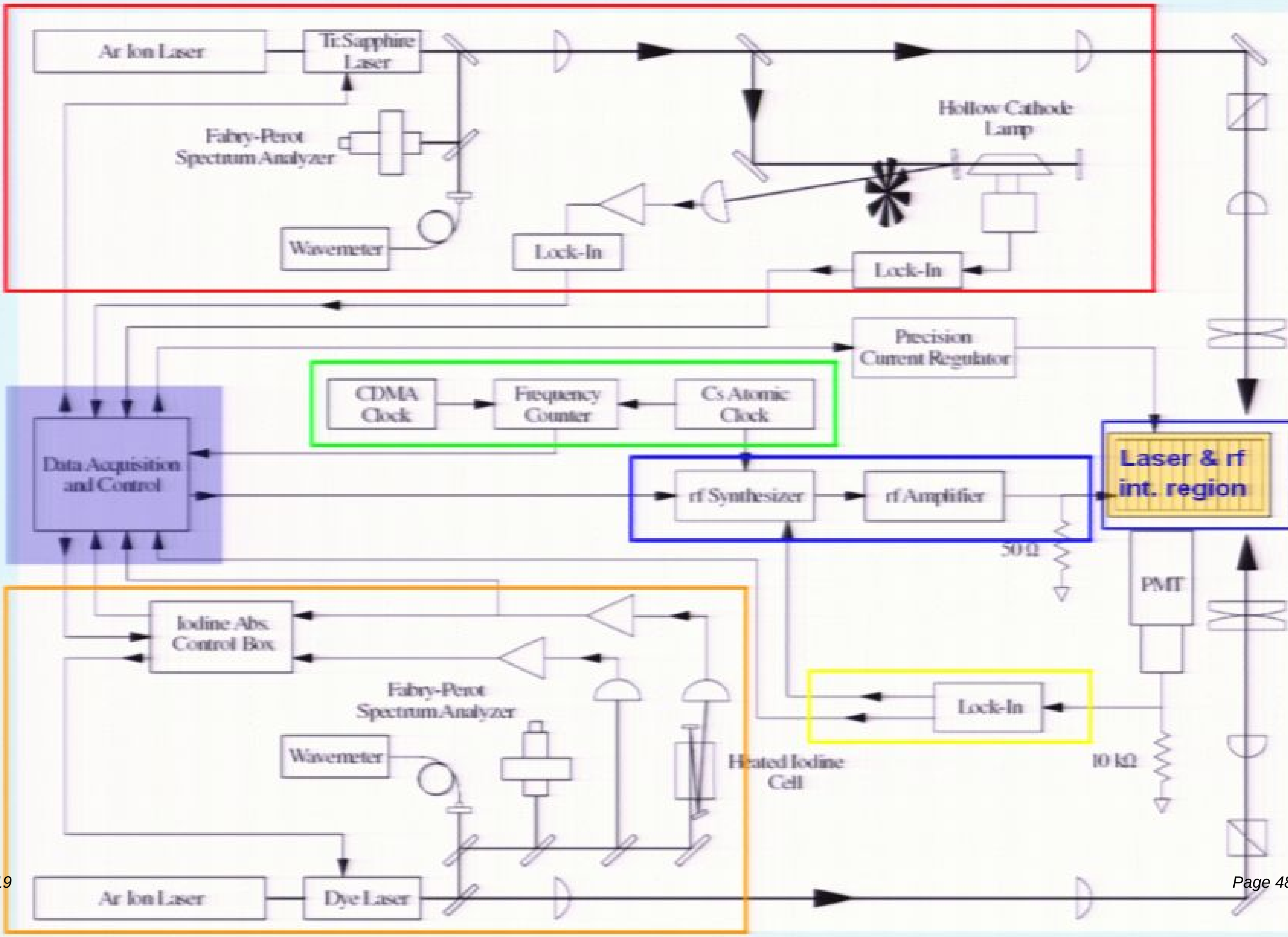
Interaction Region



Experimental Setup



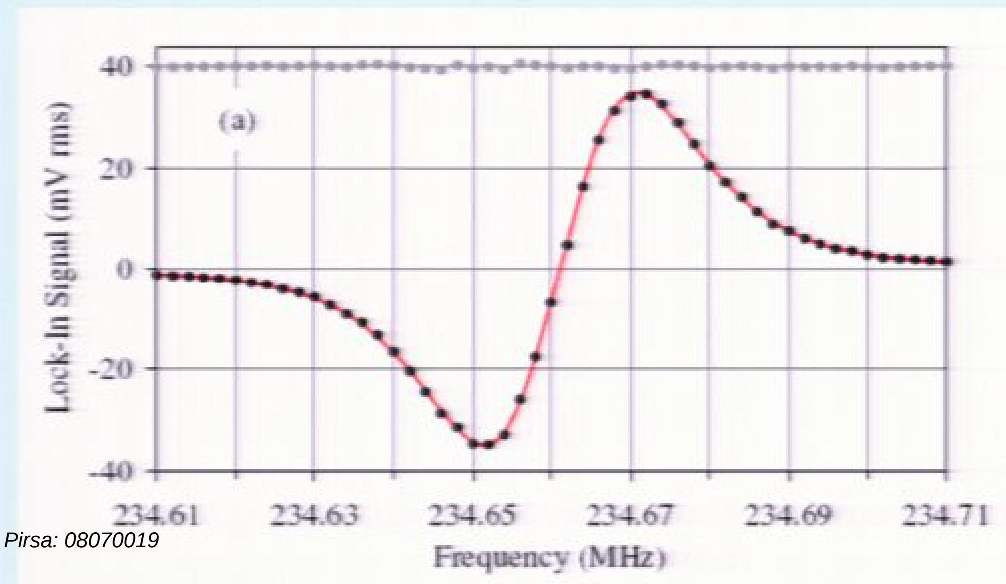
Experimental Setup (with lasers)



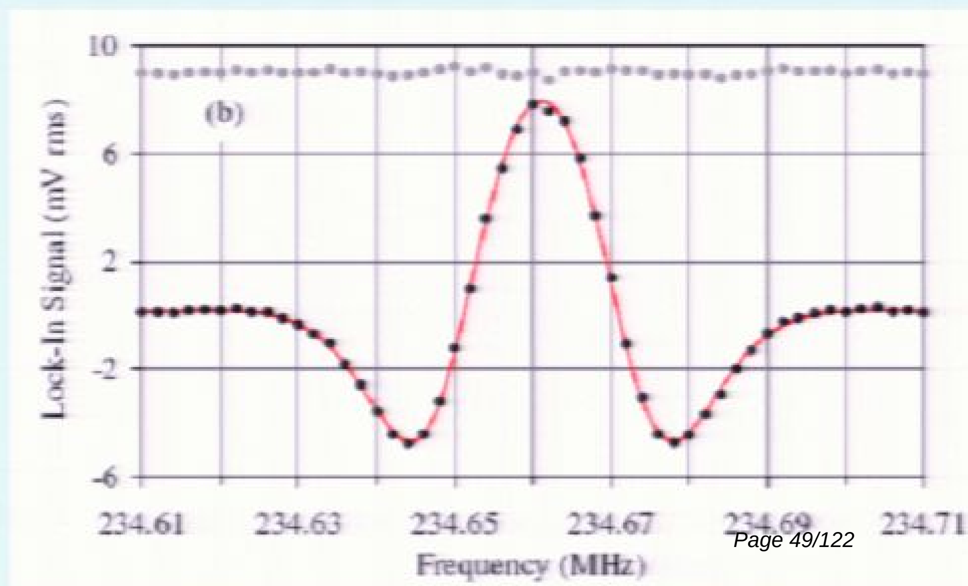
Lock-in Detection Technique

- rf field is frequency modulated at 10 kHz with a modulation index of 1
- Reduces asymmetries in the line shape caused by drifts (laser and atomic beam fluctuations)

First Harmonic



Second Harmonic



Two-step Measurement Process

- Use ratio of 1st to 2nd Harmonic to reduce drifts

- First step: Calibration between ratio, R, and frequency, ν.

$$R=C(\nu-\nu_o)$$

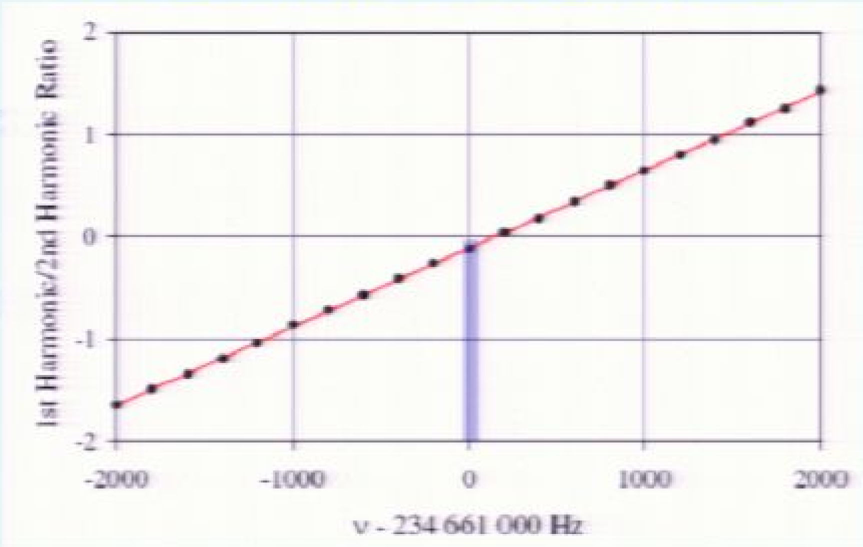
Referenced to Cs frequency standard

- Second Step: Take ratio at fixed carrier frequency.

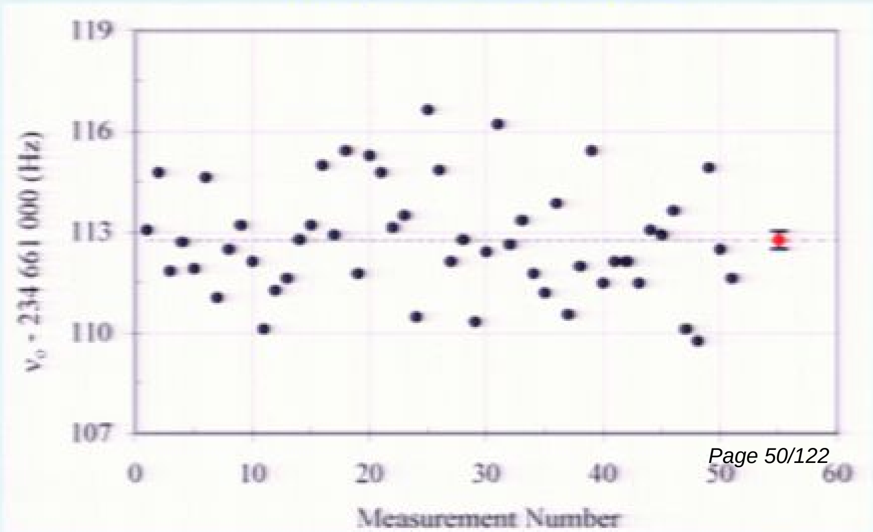
$$\nu_o-\nu_c=-\langle R\rangle/C$$

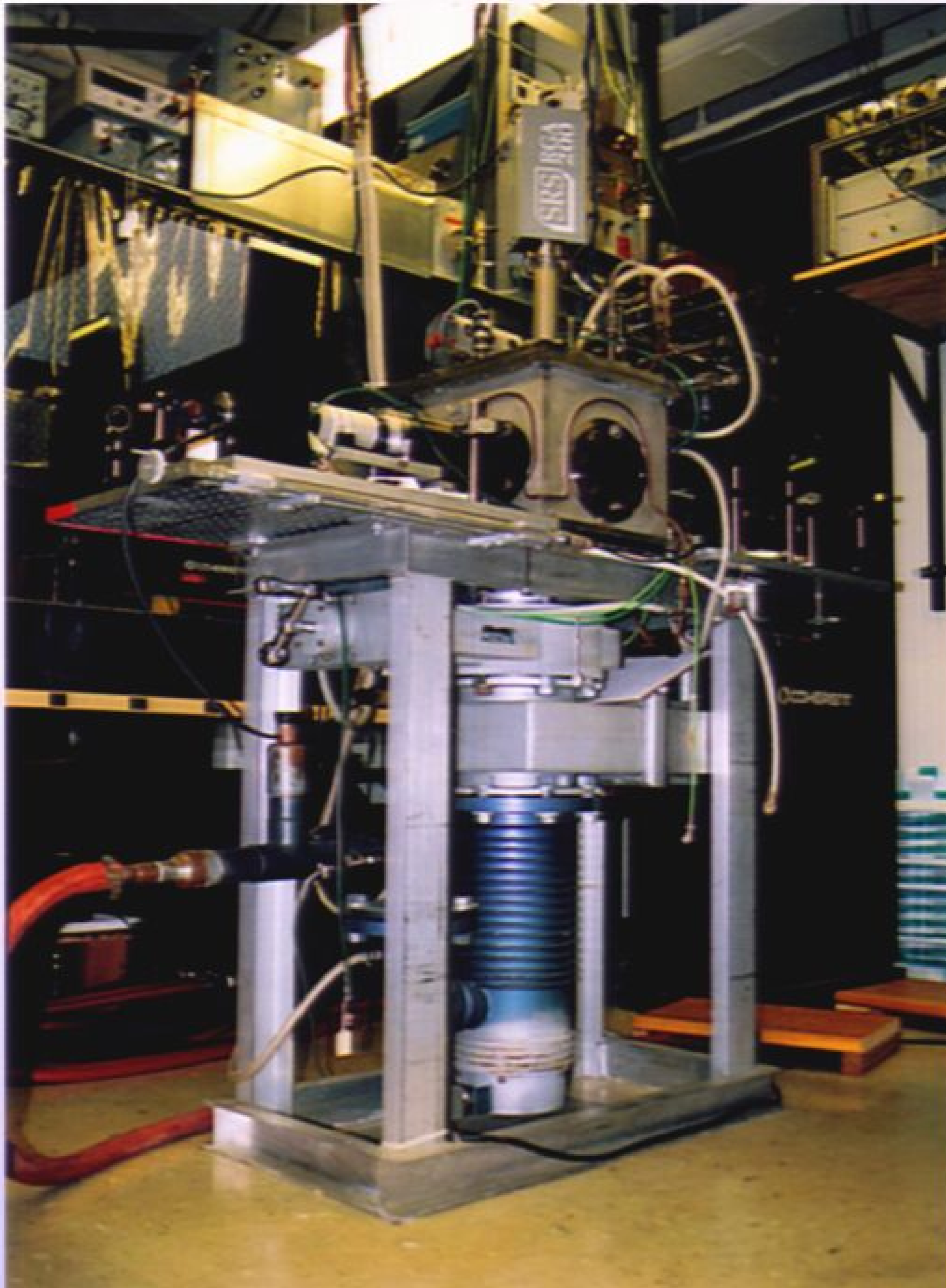
Fixed carrier frequency

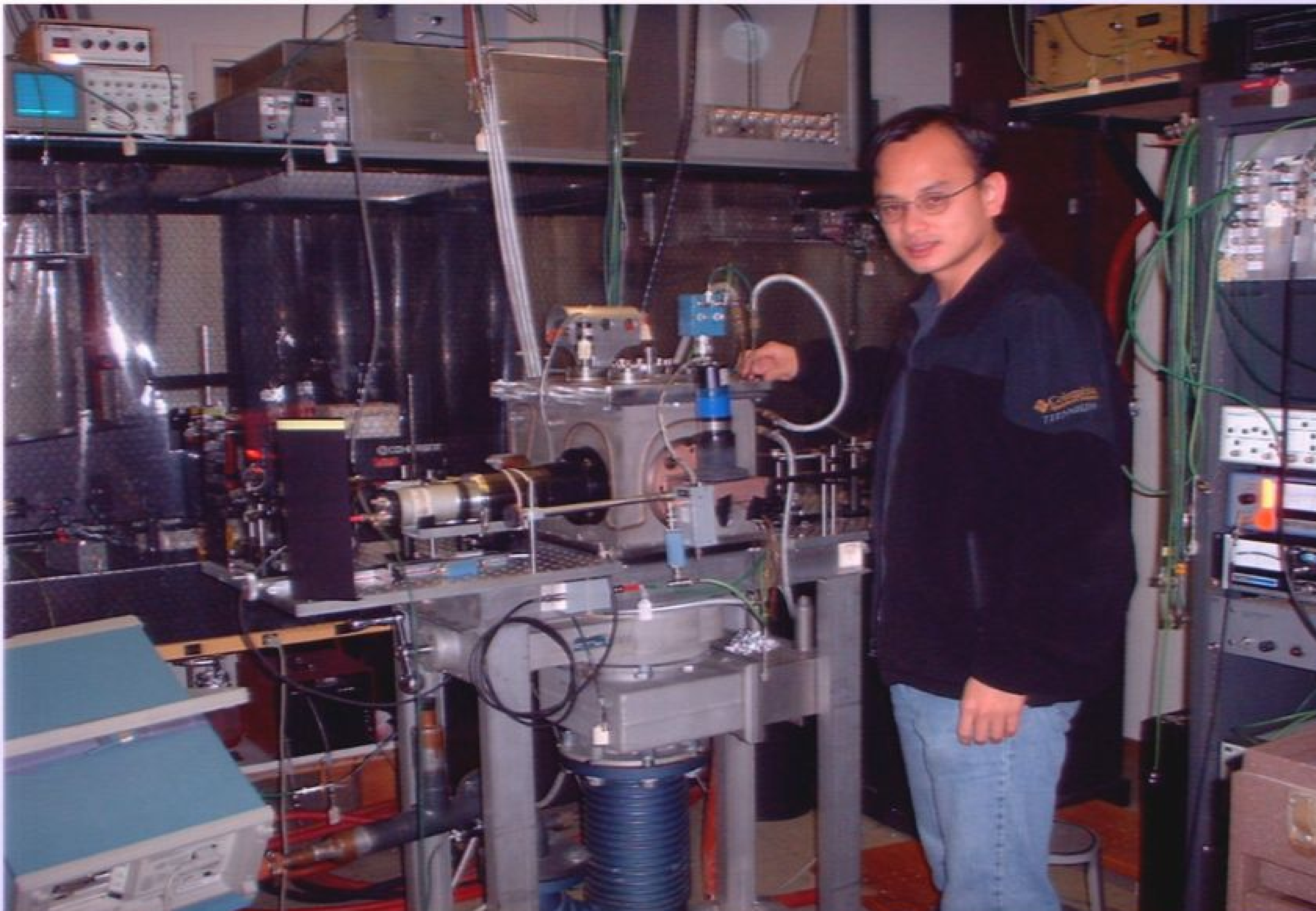
First/Second Harmonic Ratio



Fixed frequency







Dr. A.-T. Nguyen

UCB⟶LANL(trapped ions) ⟶Biophysics

Arman Cingöz

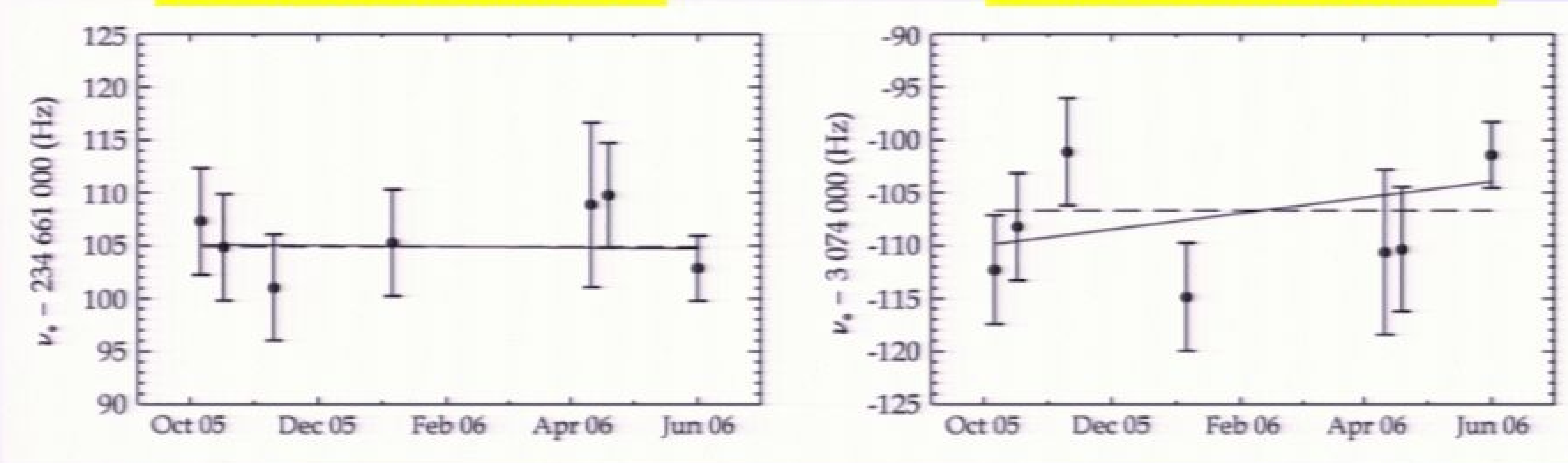
Discussion of systematics

Discussion of systematics

Results

235-MHz transition

3.1-MHz transition



-0.6 ± 6.5 Hz/yr

9.0 ± 6.7 Hz/yr

$\dot{\alpha}/\alpha =$ (-0.3 ± 3.6) x 10^{-15} yr^{-1}

(-5.0 ± 3.7) x 10^{-15} yr^{-}

Result: Phys. Rev. Lett. **98**, 040801 (2007)

Limit on the Temporal Variation of the Fine-Structure Constant Using Atomic Dysprosium

A. Cingöz,[1] A. Lapierre,[1] A.-T. Nguyen,[2] N. Leefer,[1] D. Budker,[1,3] S. K. Lamoreaux,[2,*] and J. R. Torgerson[2]

[1]*Department of Physics, University of California at Berkeley, Berkeley, California 94720-7300, USA*
[2]*Los Alamos National Laboratory, Physics Division, P-23, MS-H803, Los Alamos, New Mexico 87545, USA*
[3]*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

(Dated: August 30, 2006)

$$\dot{\alpha}/\alpha = (-2.7 \pm 2.6_{\text{mostly syst}}) \times 10^{-15}\ \text{yr}^{-1}$$

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Independent of other fundamental constants

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Independent of other fundamental constants






Summary of Laboratory Tests

Year	$\dot{\alpha}/\alpha$ ($\times 10^{-15}$/yr)	Method	Reference
1995	≤ 37	H-maser vs. Hg^{+} hyperfine[††]	J. D. Prestage *et al.*, PRL, 74, 3511 (1995)
2003	-0.4 ± 1.6	Rb fountain vs. Cs fountain[††]	H. Marion *et al.*, PRL, 90, 150801 (2003)
2003	< 1.2	Hg^{+} optical vs. Cs fountain[††]	S. Bize *et al.*, PRL, 90, 150802 (2003)
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Combined result with other optical clock vs. Cs fountain comparisons to date of publication

[†]Sensitive to other fundamental constants

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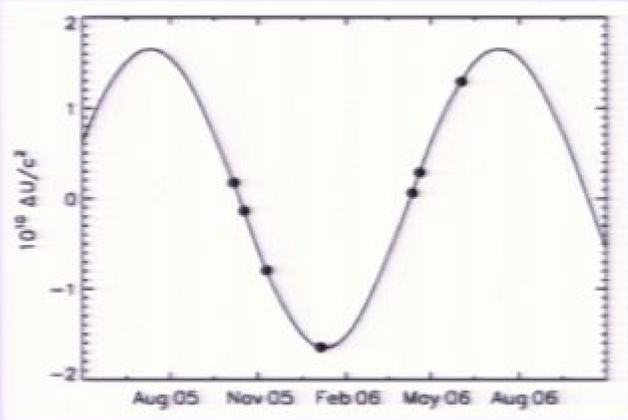
Results: Gravitational Variation

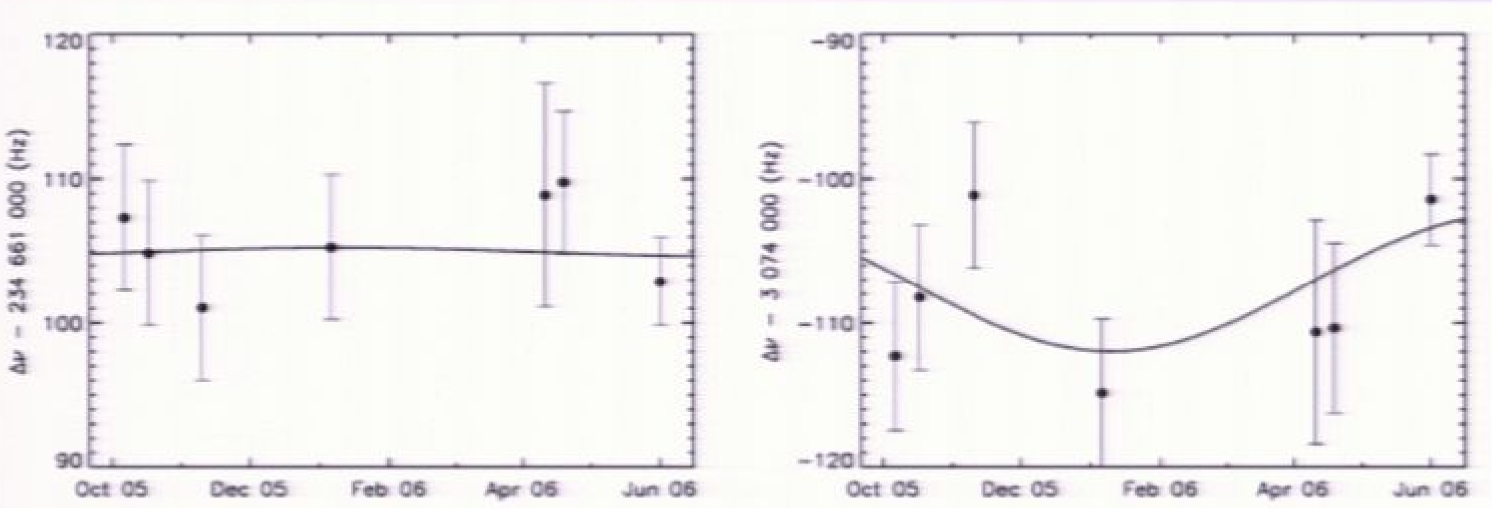
- Can analyze for Gravitational Potential Dependence of α due to the eccentricity of Earth's orbit around the Sun (~0.02).



- Parameterize as:

$$\frac{\delta\alpha}{\alpha} = k_\alpha \frac{\Delta U(t)}{c^2} \Rightarrow \delta(\Delta\nu) = -1.8 \times 10^{15}\, k_\alpha \frac{\Delta U(t)}{c^2}\ \mathrm{Hz}$$

Results: Gravitational Variation



$k_\alpha = (-1.1 \pm 9.2) \times 10^{-6}$ $k_\alpha = (-16.9 \pm 9.4) \times 10^{-6}$

$$k_\alpha = (-8.7 \pm 6.6) \times 10^{-6}$$

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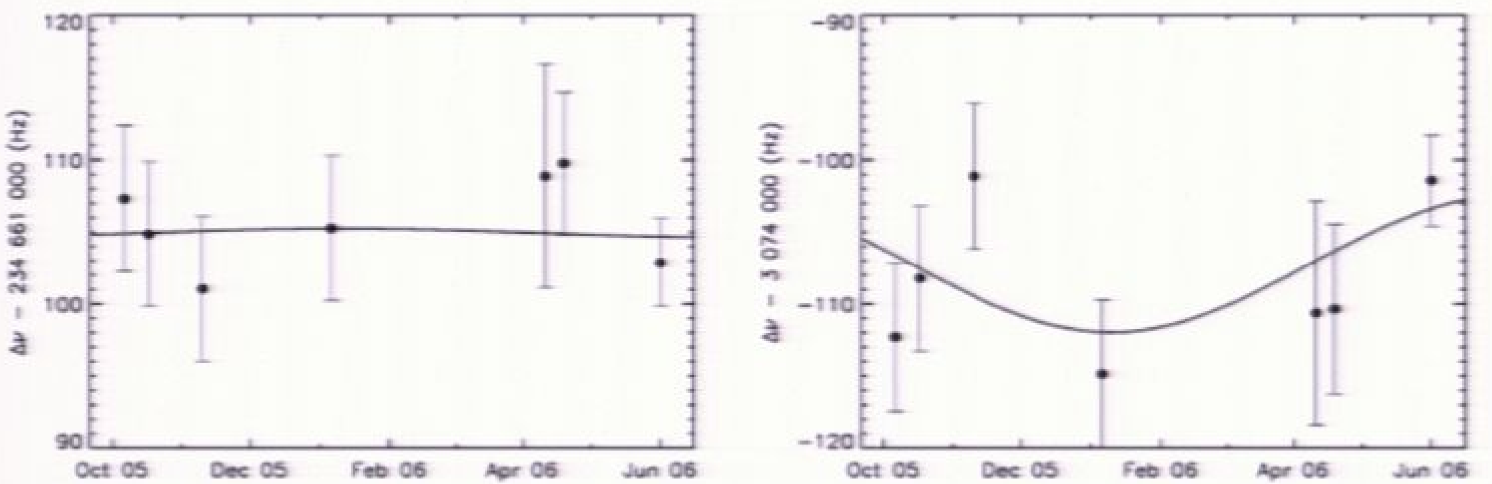

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Results: Gravitational Variation

Comparison	Parameter	Constraint ($\times 10^{-6}$)	Exp. Ref.
Hg^+ vs Cs	$k_\alpha + 0.17 k_e$	$0.35 \pm 0.6^\dagger$	[1]
H maser vs Cs	$k_\alpha + 0.13 k_q$	$0.1 \pm 1.7^\dagger$	[2]
Dy	k_α	-8.7 ± 6.6	[3]
Sr vs Cs	$k_\alpha + 0.36 k_e$	-2.1 ± 3.2	[4]
Combination of Dy with other comparisons			
	k_e	$29 \pm 44^\dagger$	[3]
	k_q	$68 \pm 52^\dagger$	[3]
Combination of optical clock vs Cs comparisons			
	k_α	2.5 ± 3.1	[4]
	k_e	-13 ± 17	[4]
	k_q	-19 ± 27	[4]

† After sign correction in Hg^+ and H maser comparisons

[1] T. Fortier *et al.*, PRL, **98**, 070801 (2007).
[2] N. Ashby *et al.*, PRL, **98**, 070802 (2007).
[3] S. Ferrell *et al.*, PRA, **76**, 062104 (2007).
[4] S. Blatt *et al.*, PRL, **100**, 140801 (2008).

Systematic Effects

- 1st generation apparatus not optimized for this experiment

1st Generation Apparatus Systematic Effects

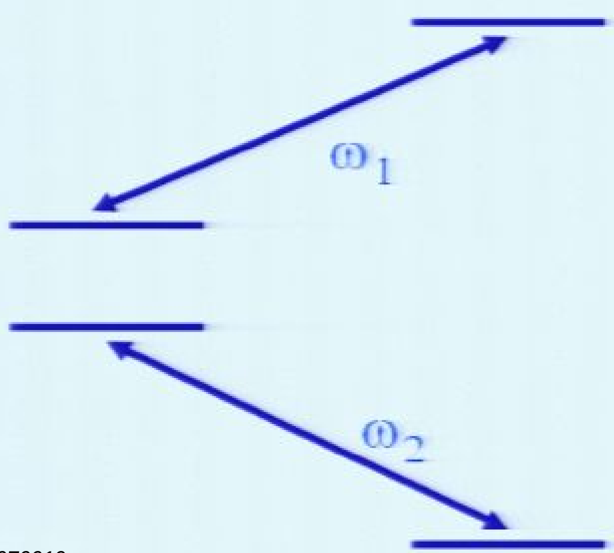
Shift	**Estimated/Measured Size (Hz)**
Stray B-field/ Laser light polarization	2 – 5
Collisional	1 – 2
Detuning effect	<0.4
ac Stark†	~ $(10^{-3} - 1)$
Doppler	< 0.2
Room temp. black-body radiation	$\lesssim$ 0.1
Oven temp. black-body radiation	$\lesssim$ 0.02
dc Stark†	~ $(10^{-4} - 10^{-2})$

†transition dependent

Powerful Check for Systematics

Since Dy has many isotopes (some with hfs), more than one rf transition frequency can be measured

For example, two transition frequencies can be simultaneously measured:



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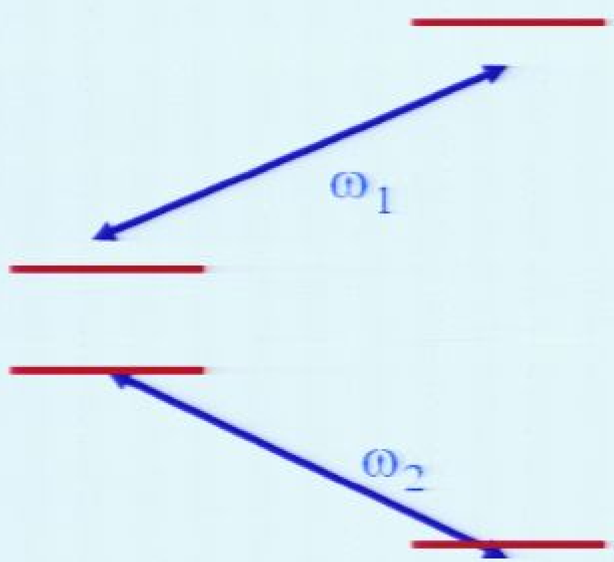

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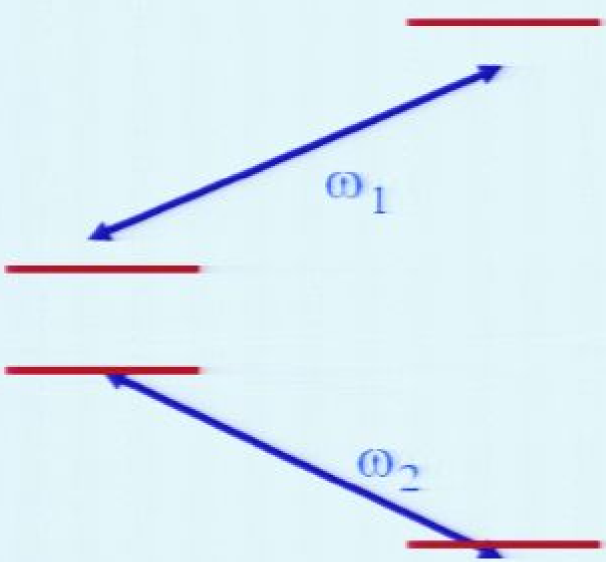

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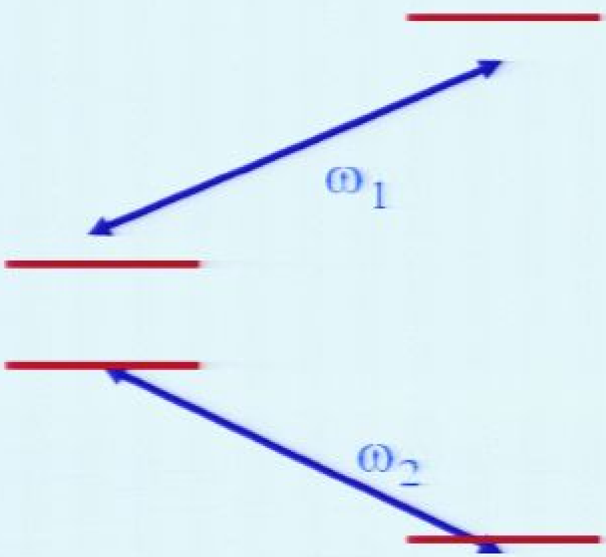

$\omega_1 + \omega_2 \Rightarrow$ insensitive to α variation

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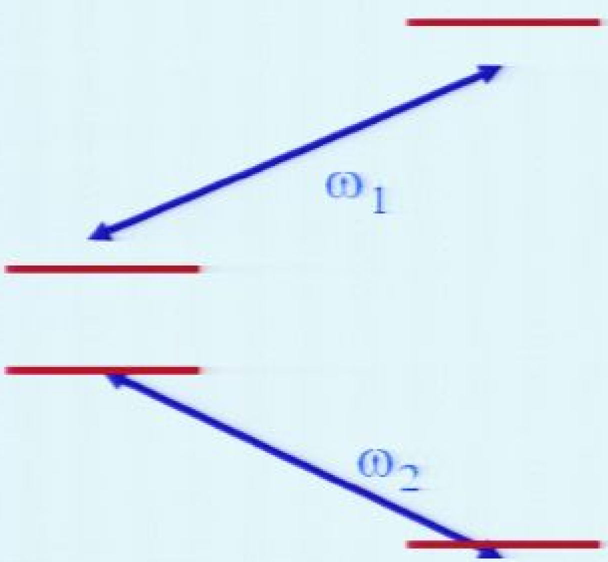

$\omega_1 + \omega_2 \Rightarrow$ insensitive to α variation

$\omega_1 - \omega_2 \Rightarrow \alpha$ variation is twice as large

Stray B-fields

- If unresolved Zeeman sublevels are:

  sym. populated ⇒ leads to broadening , but no shifts

  asym. populated ⇒ leads to broadening and shifts

  $\Delta\nu/B = \Delta g_{AB}\mu_o m_{Fmax} \sim 2$ kHz/mG

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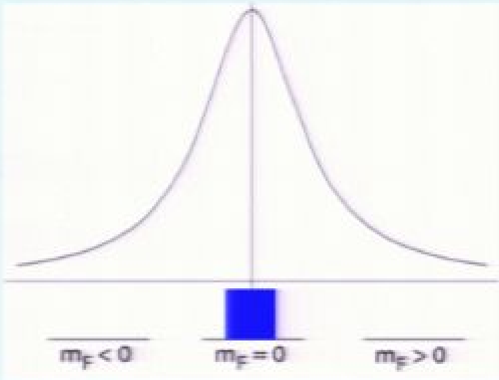

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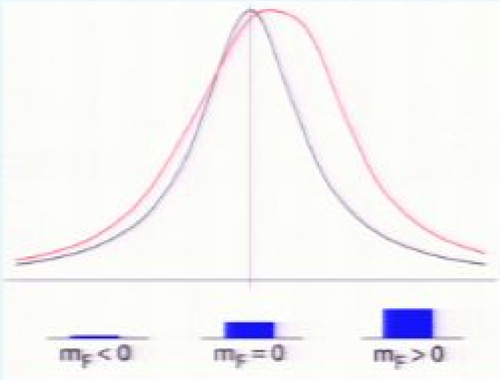

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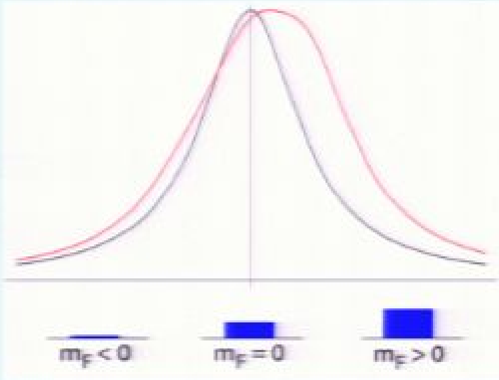
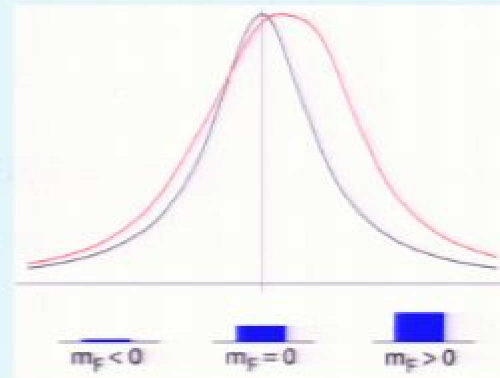


- Nominal config.: ***linearly polarized pop. beams*** $\Rightarrow$ aligned state; no shifts

Stray B-fields



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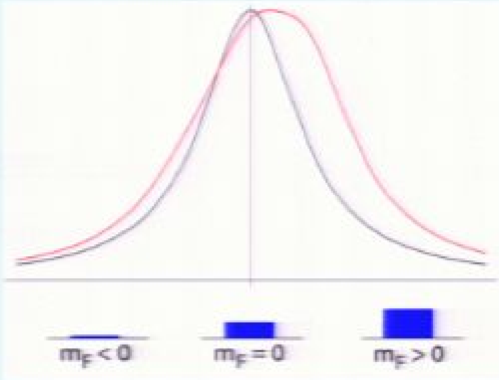
- Nominal config.: ***linearly polarized pop. beams*** ⇒ aligned state; no shifts

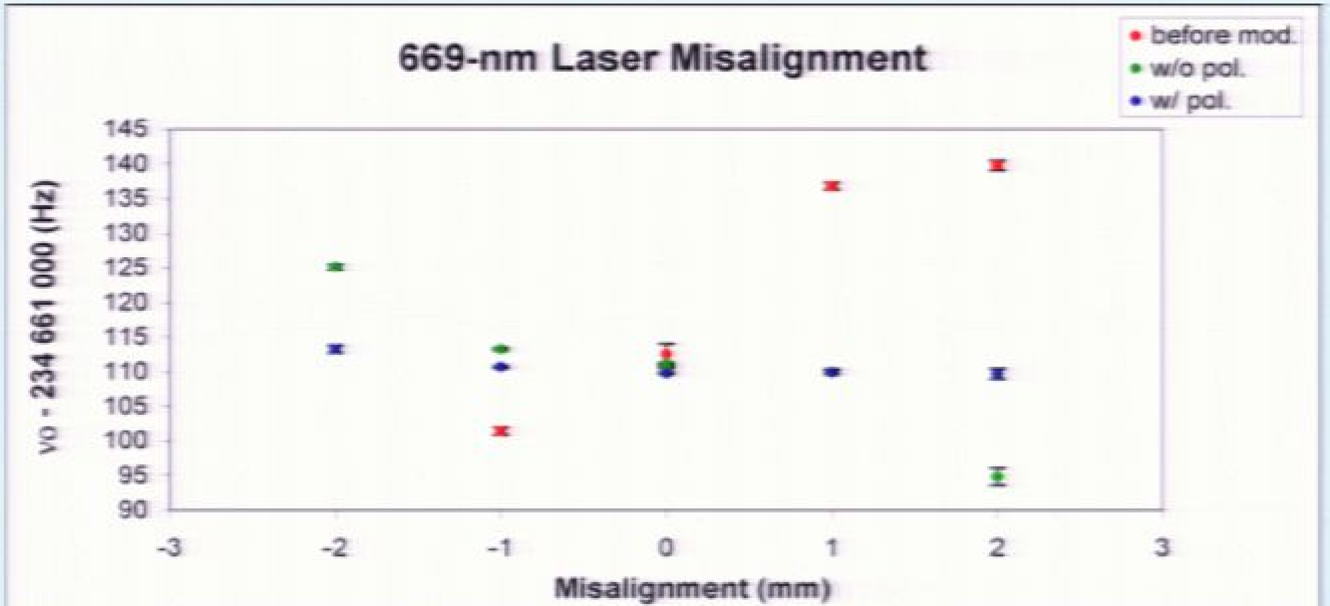
- Systematic due to: spatially varying stress-induced birefringence on optics

  ⇒ run-to-run variations due to laser pointing variations

Stray B-fields



- If unresolved Zeeman sublevels are:
  sym. populated ⇒ leads to broadening , but no shifts
  asym. populated ⇒ leads to broadening and shifts
  $\Delta\nu/B = \Delta g_{AB}\mu_o m_{Fmax} \sim 2$ kHz/mG
- Nominal config.: *linearly polarized pop. beams* ⇒ aligned state; no shifts
- Systematic due to: spatially varying stress-induced birefringence on optics
  ⇒ run-to-run variations due to laser pointing variations



Collisional Effects

- Collisions with residual background atoms perturbs a Dy atom undergoing rf transition

$\Rightarrow$ lineshape broadening and shift

- Collisional effects in high-vacuum (10^{-6} Torr) have rarely been measured

- Simple estimate:

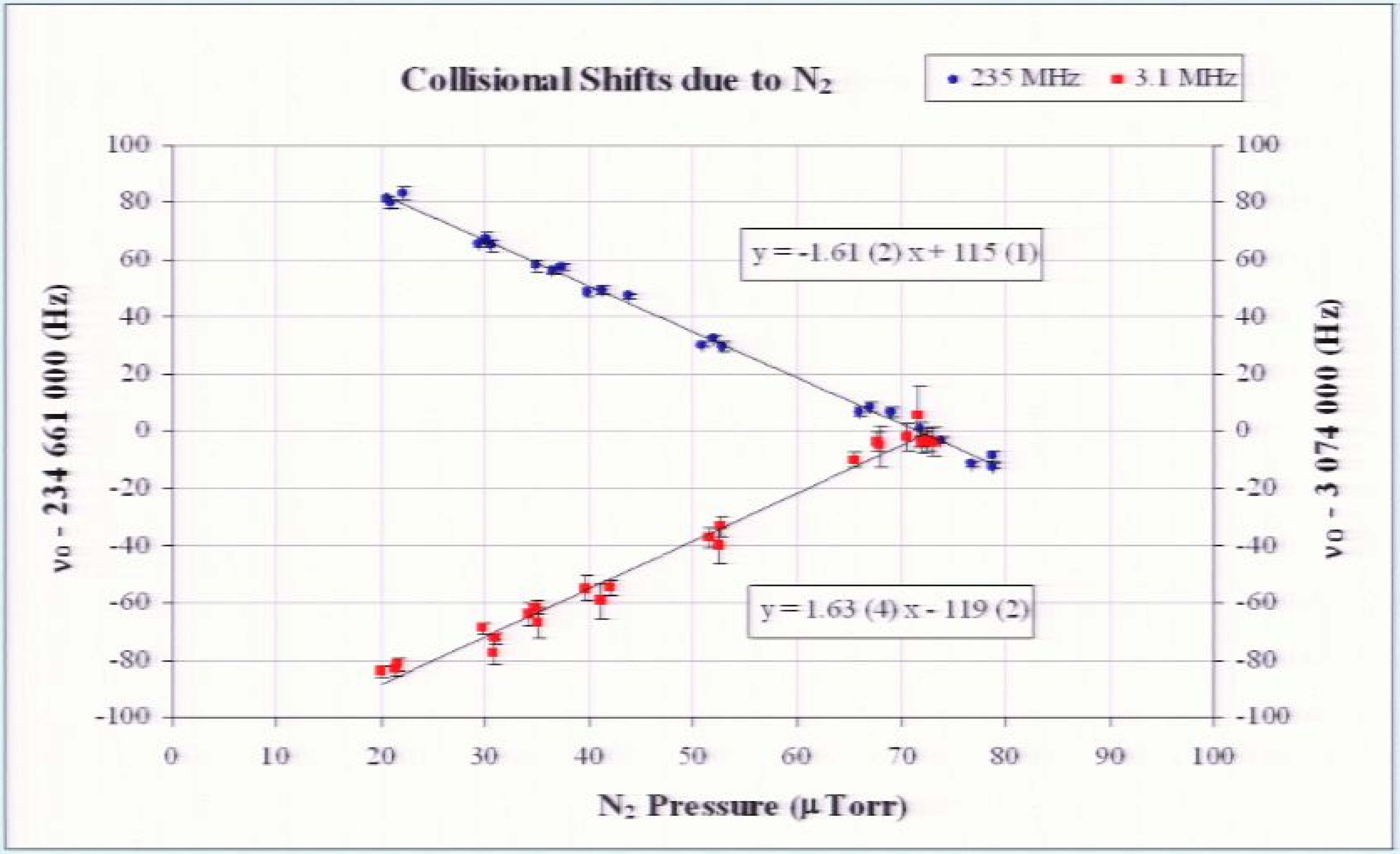
$$\sigma \sim 10^{-14}\ \text{cm}^2$$

$$n \simeq 3\times10^{10}\ \text{molecules/cm}^3 \text{ at } 1\mu\text{Torr}$$

$$v \simeq 4\times10^{4}\ \text{cm/s}$$

$$\Rightarrow \delta\nu \sim (2\pi)^{-1}\, n\, \sigma\, v = 2\ \text{Hz}$$

Collisional Data: N_2



Collisional Shifts

Gas	Shift Coefficients (Hz/μTorr)	
	3.1-MHz	235-MHz
H_2	-0.09 (8)	-0.02 (4)
He	-1.27 (6)	+1.25 (3)
Ne	-0.02 (6)	-0.01 (3)
N_2	+1.72 (7)	-1.71 (5)
O_2	< 5	-1.97 (30)
Ar	+2.14 (11)	-2.21 (7)
Kr	+2.78 (9)	-2.78 (7)
Xe	+2.75 (10)	-2.74 (7)

- collisional effects are consistent with those found in 1-Torr measurements

PHYSICAL REVIEW A 72, 063409 (2005)

Collisional perturbation of radio-frequency $E1$ transitions in an atomic beam of dysprosiu

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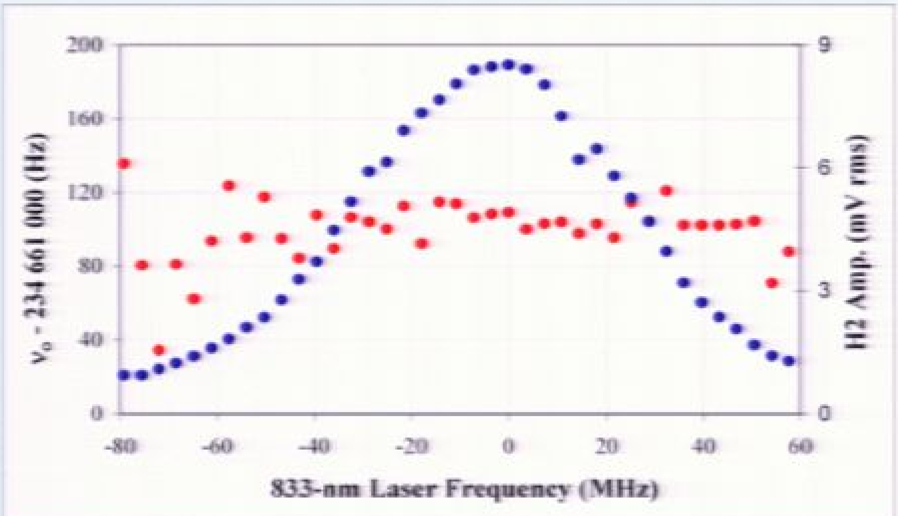

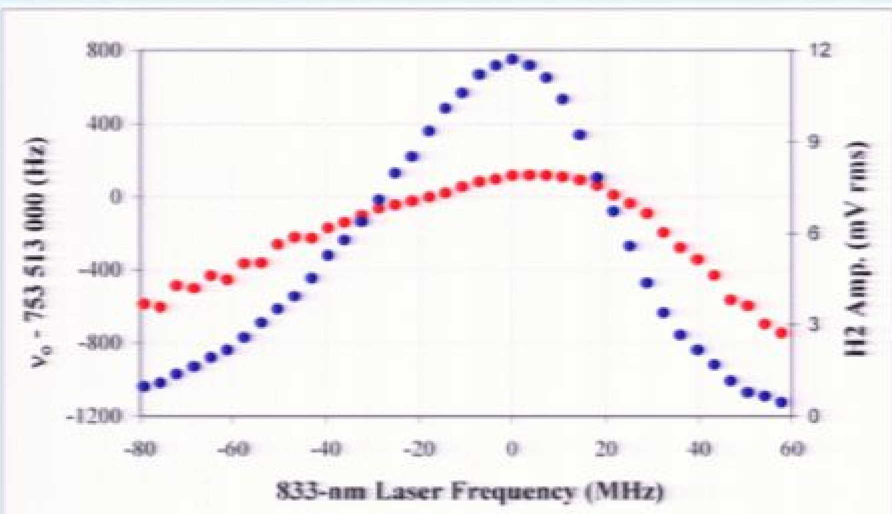

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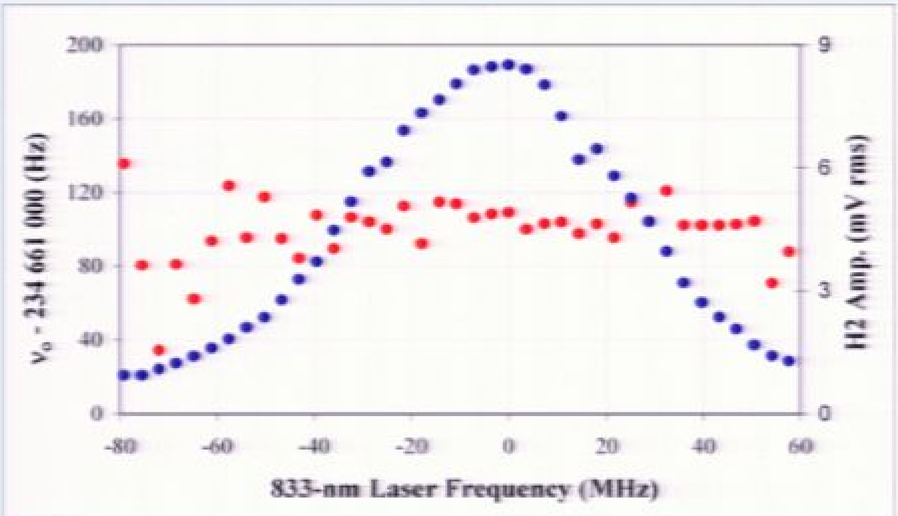

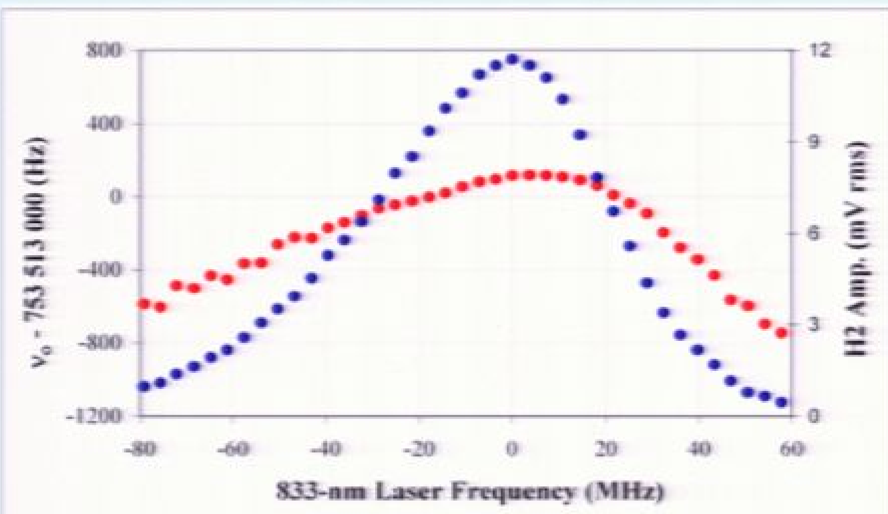

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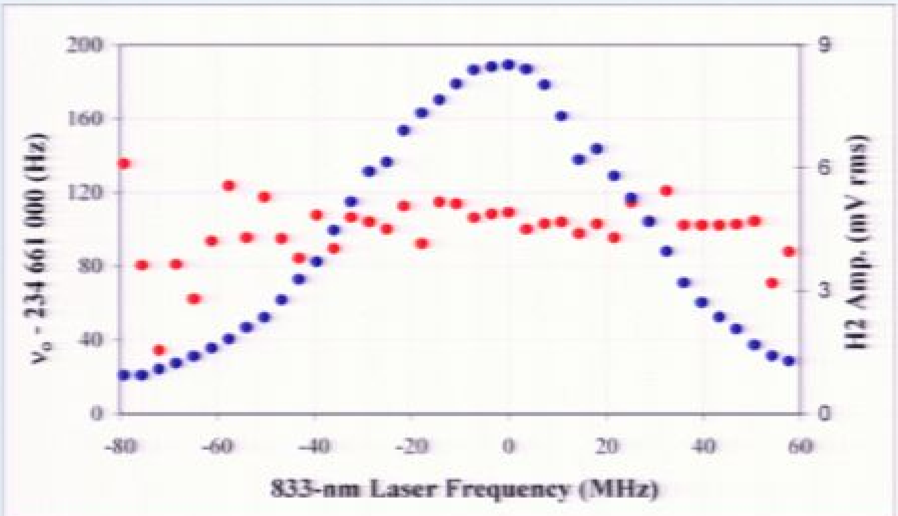
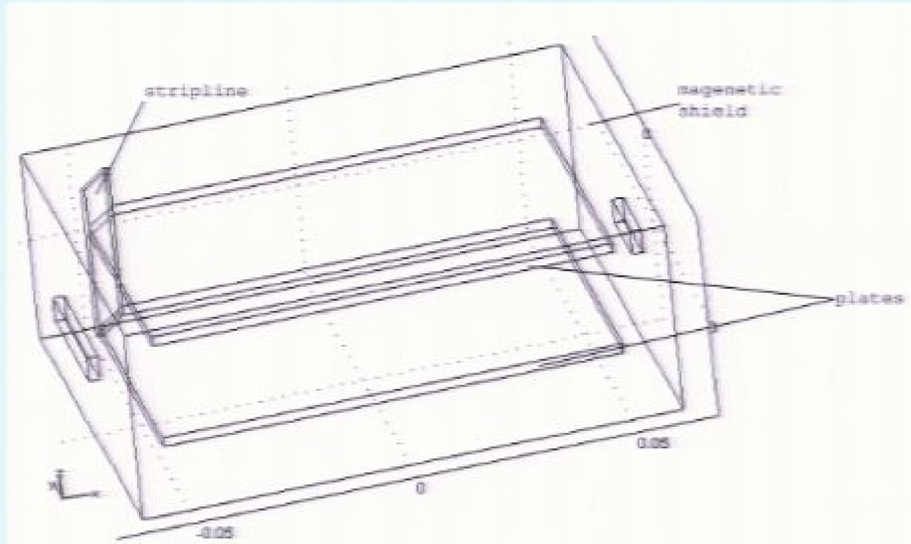
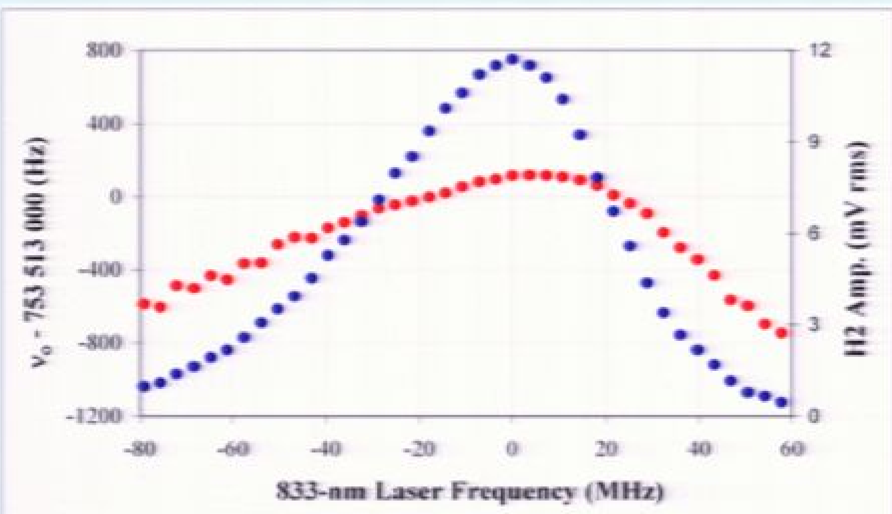
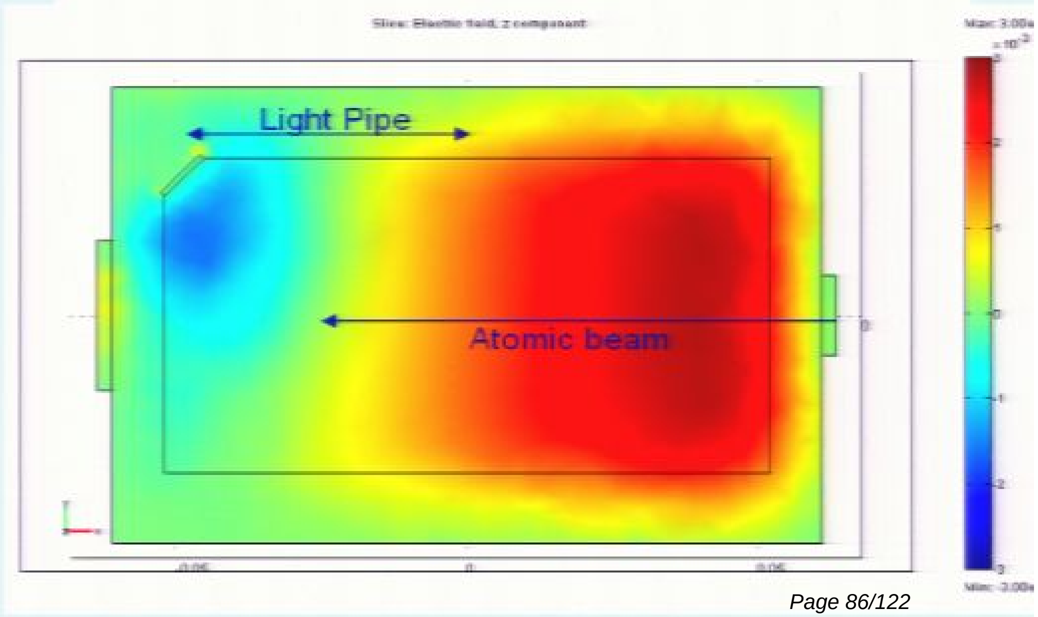








2^{nd} Generation Apparatus

• Ultra high vacuum system: ~10^{-10} Torr

$\Rightarrow$ collsional shifts ~0.2 mHz

• New rf-electrode design

$\Rightarrow$ suppress effects associated with rf inhomogeneities

• Better magnetic shielding to control stray B-fields, better laser light polarization control and 3-axis B-field coils

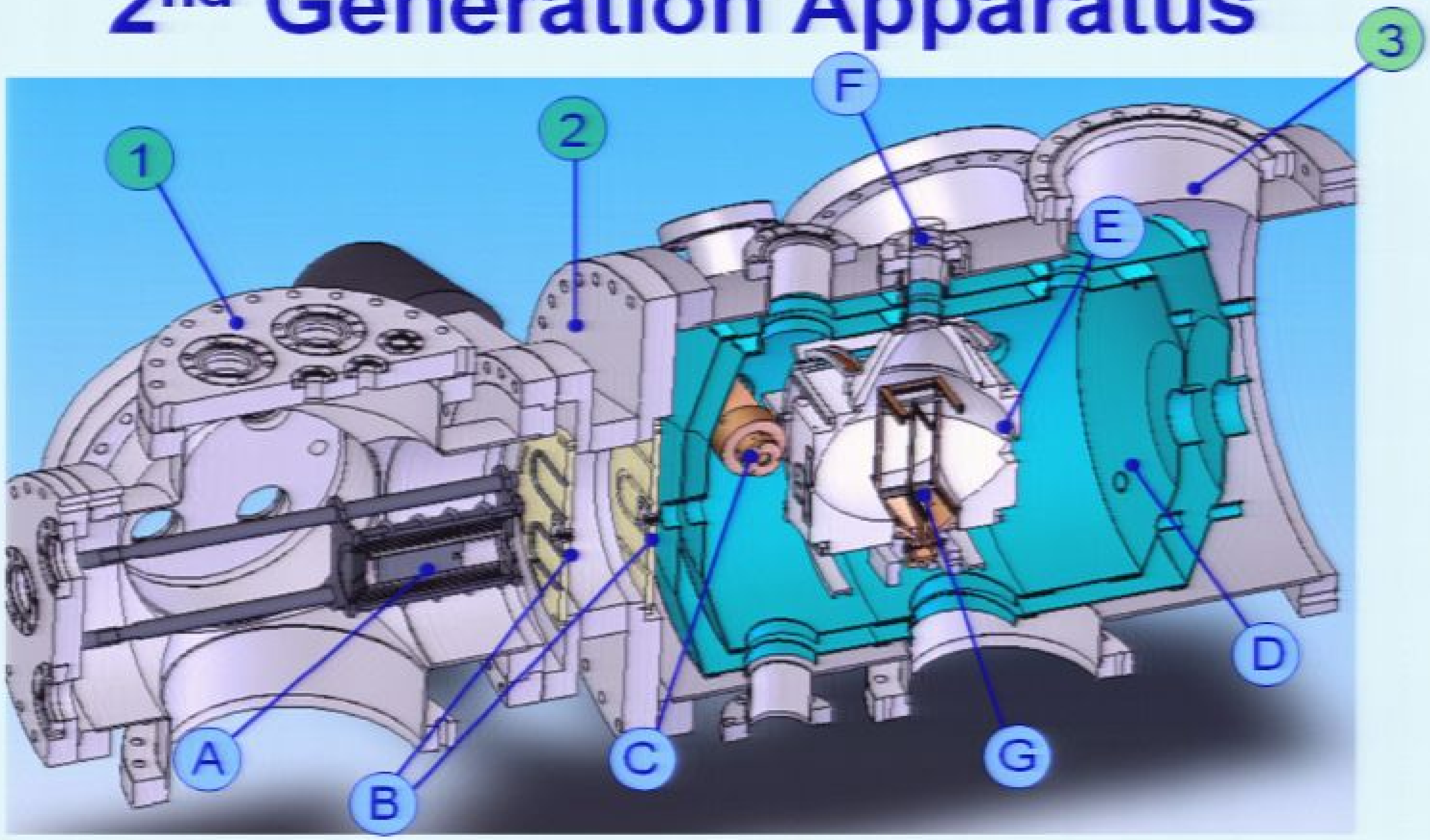
$\Rightarrow$ supress B-field associated effects to 1mHz

• Temperature control of the interaction region and ovens

$\Rightarrow$ reduce and control Black-Body shifts

~10 mHz sensitivity possible $\Rightarrow |\dot{\alpha}/\alpha| \sim 5 \times 10^{-18}\ \mathrm{yr}^{-1}$

2nd Generation Apparatus

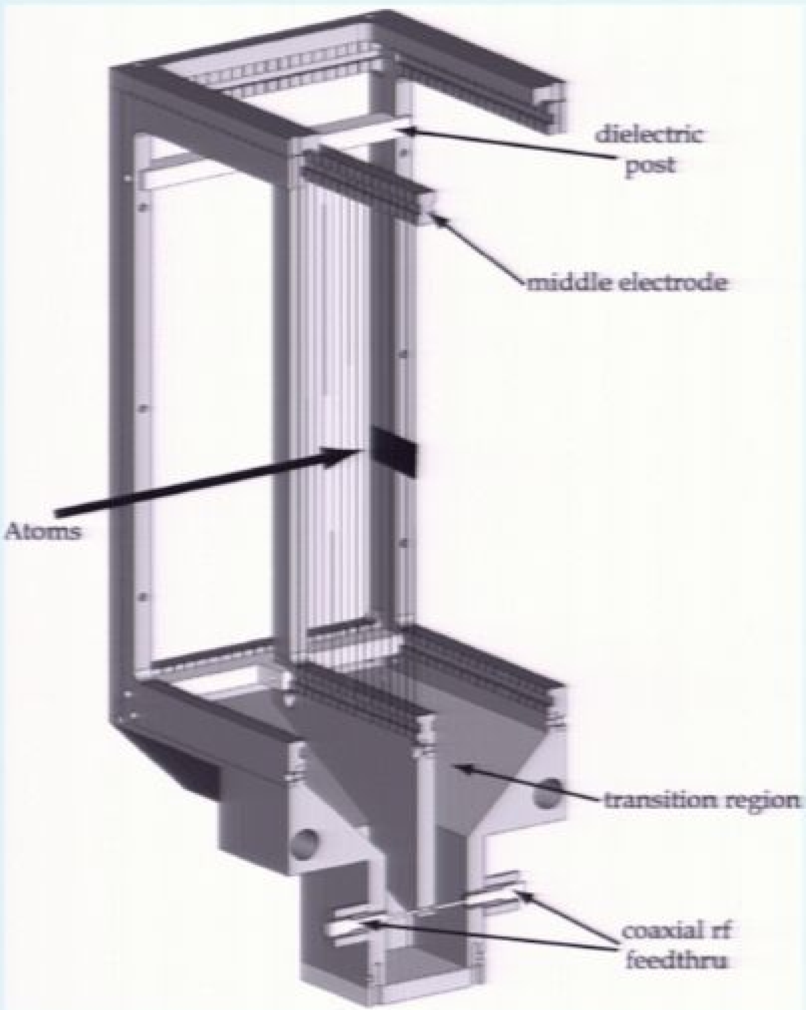


Differentially pumped chambers

1. **Oven chamber**
2. **Gate valve**
3. **Interaction chamber**

A. Dy effusive oven
B. Collimator
C. Laser access port
D. Two-layer magnetic shield
E. 4π Optical collection system
F. PMT viewport
G. RF electrodes

RF Interaction Region



- Terminated rectangular coax. transmission line ⇒ no cutoff for TEM mode: Broadband
- Impedance matched coax. rf feedthru joined to main region by a conical transition
- Wire grid electrodes with 50μm Be-Cu wires ⇒ transparent to atoms and light
- Two rf feedthrus for systematics

Status and Future

- Has been operational for several months
- Differential pumping works: int. region pressure down to 10^{-9} torr dominated by H_2 (limited by baking)
- Laser detuning improved
- B-field effects: in progress
    - Improve shielding with cryogenic
    - Building some additional coils

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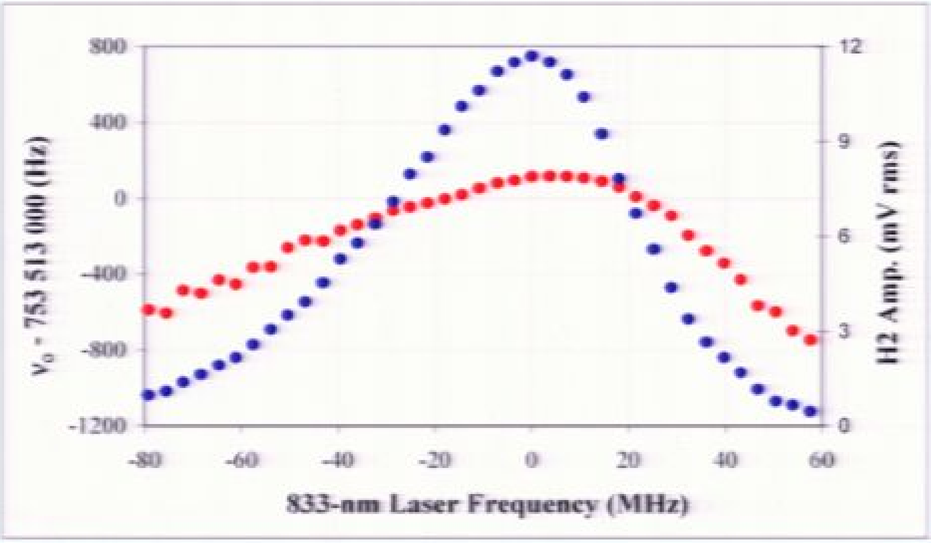

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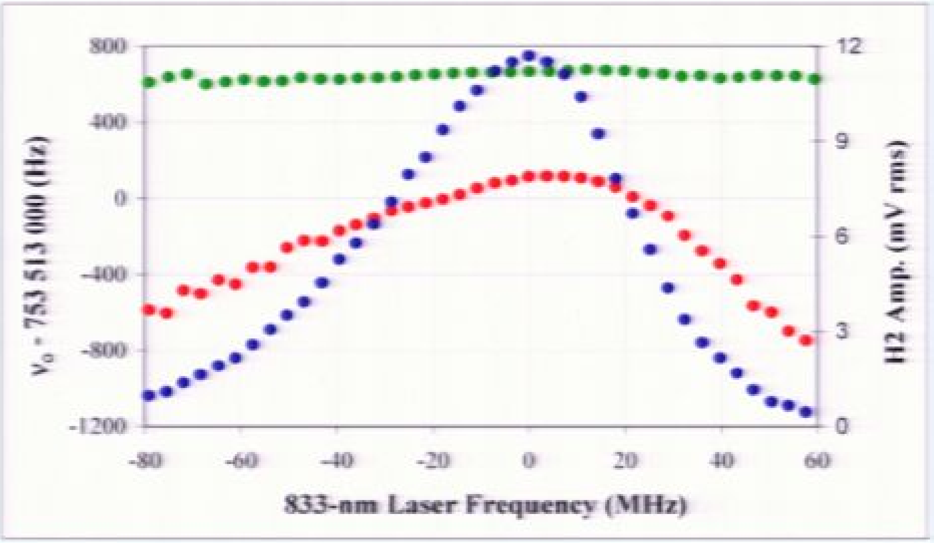
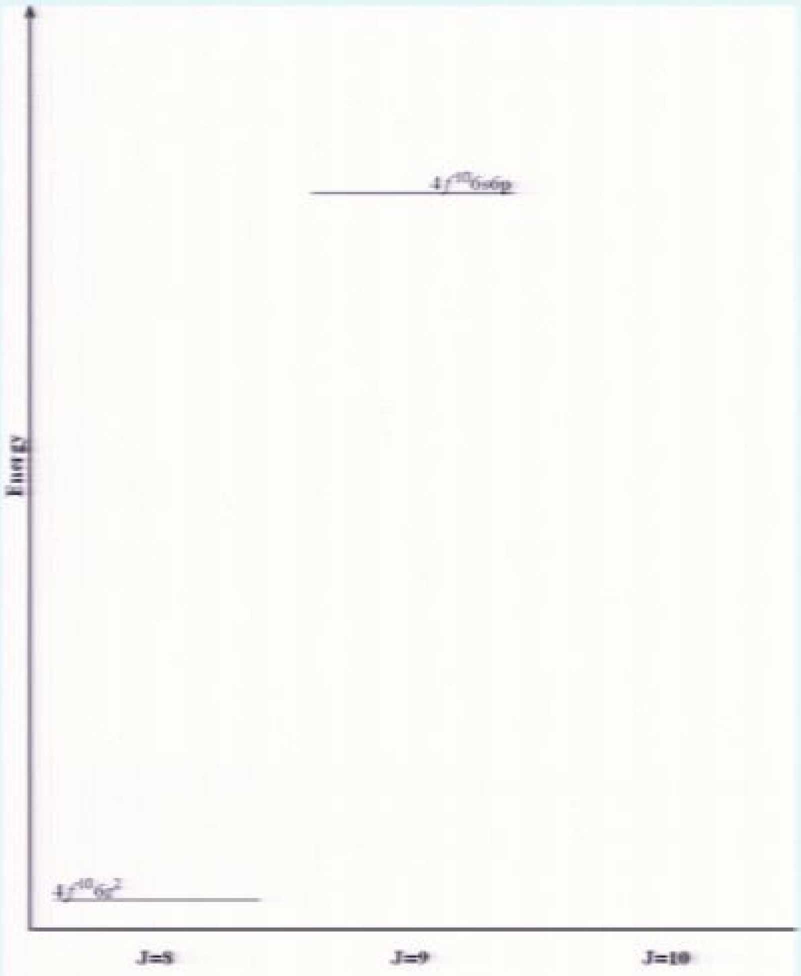


Investigation of Dy Laser Cooling

Dy Laser Cooling



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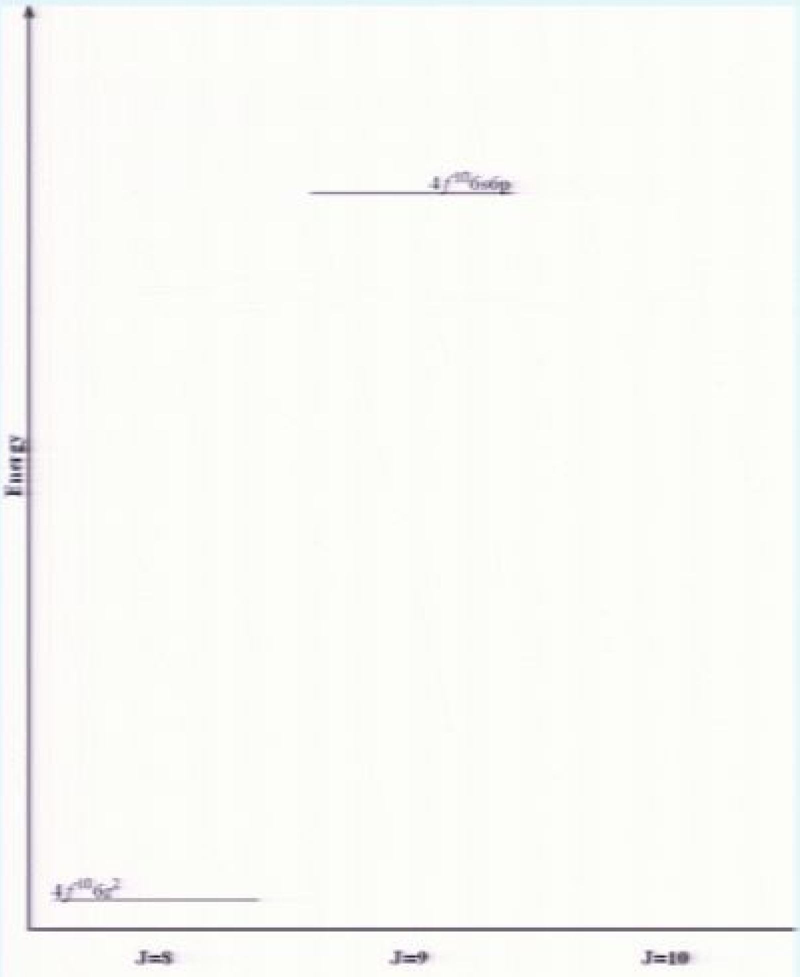

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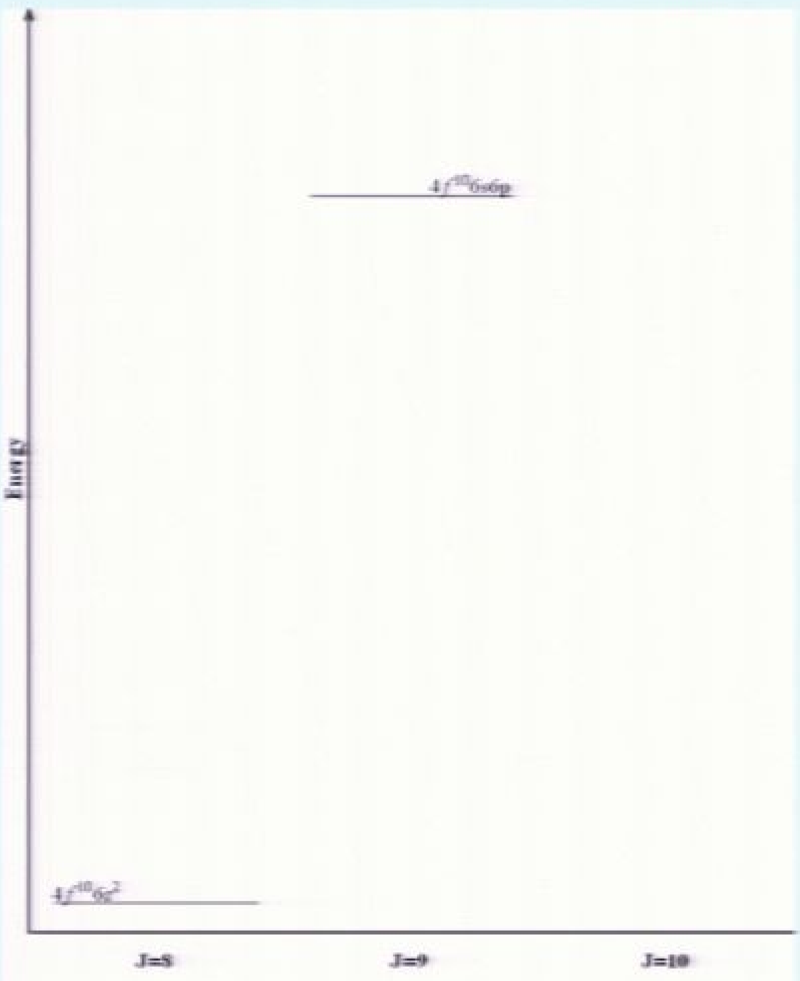

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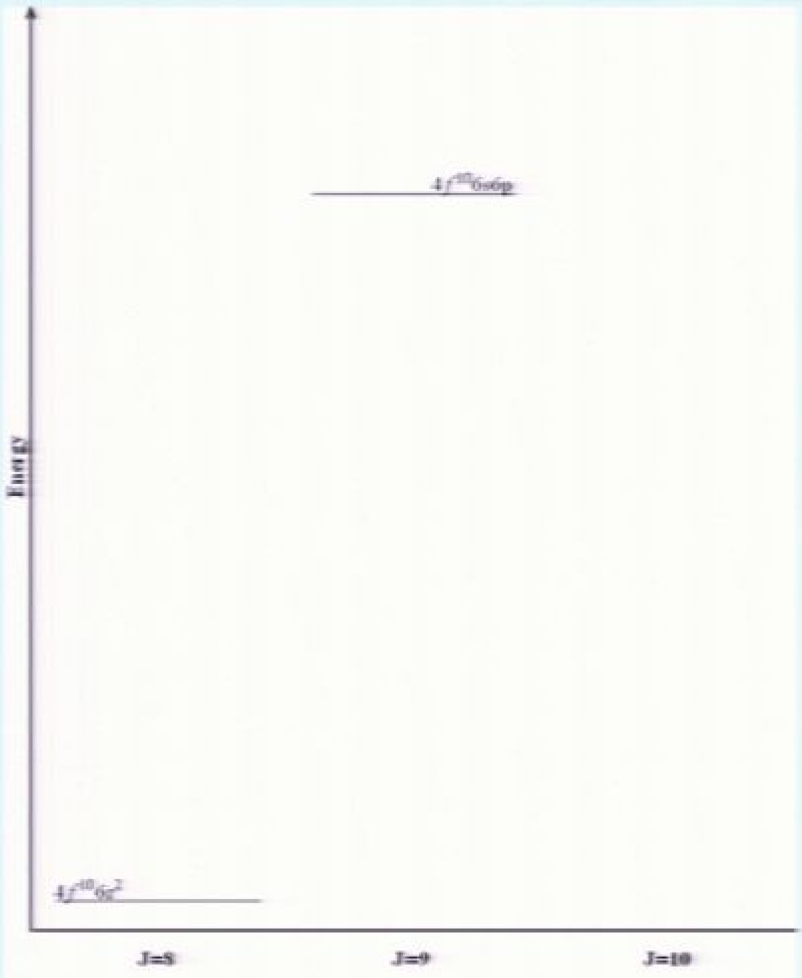

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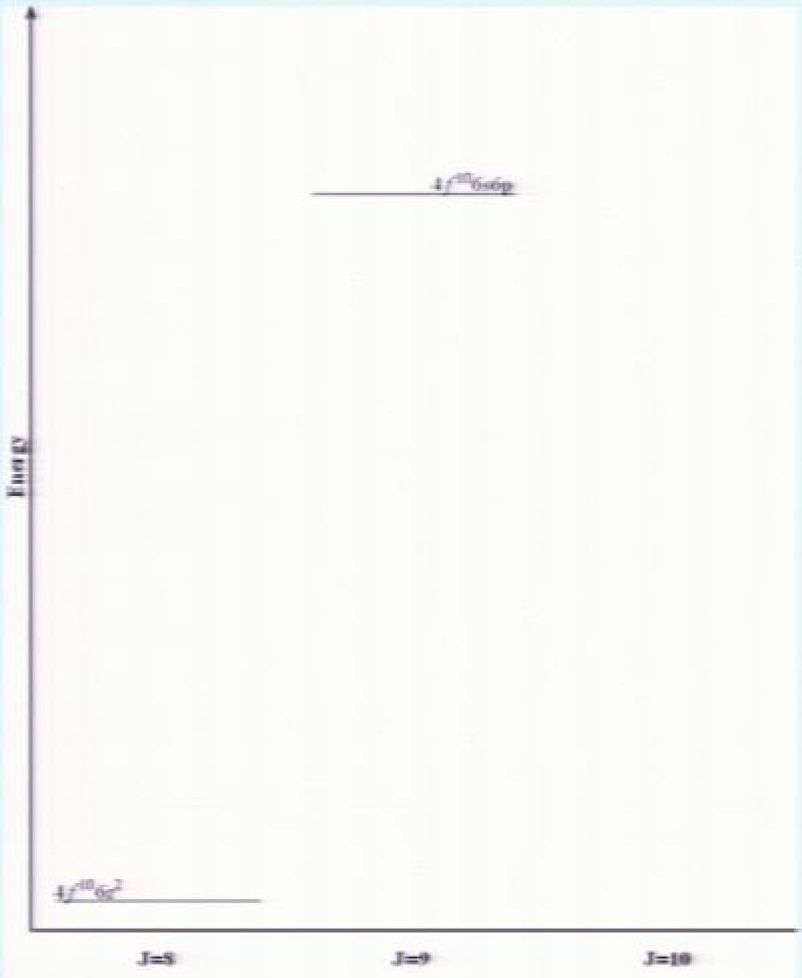
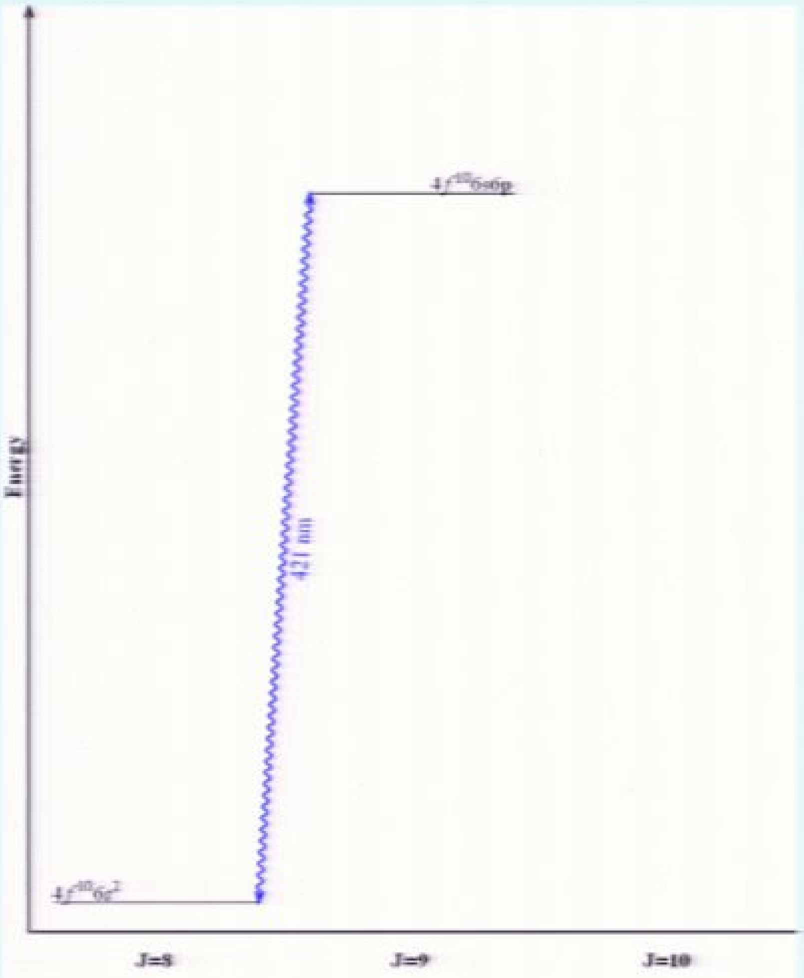
- Increase Beam Brightness

Dy Laser Cooling



- Dy has never been laser cooled
- Increase Beam Brightness
- Additional handle on systematics

Dy Laser Cooling



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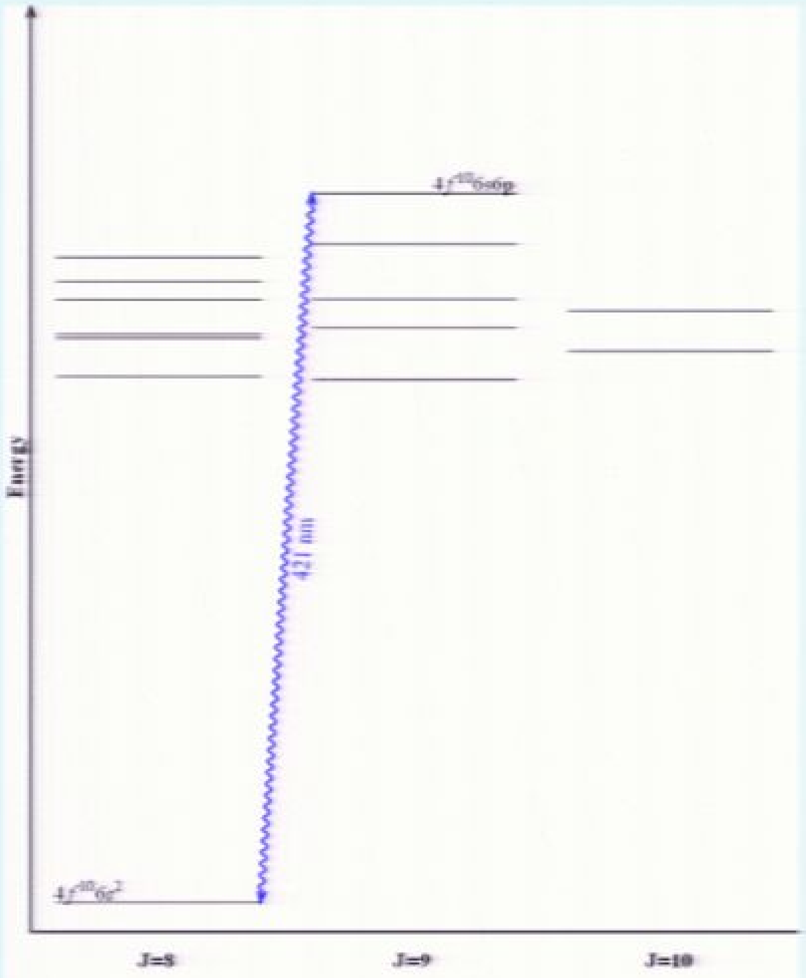
Dy Laser Cooling



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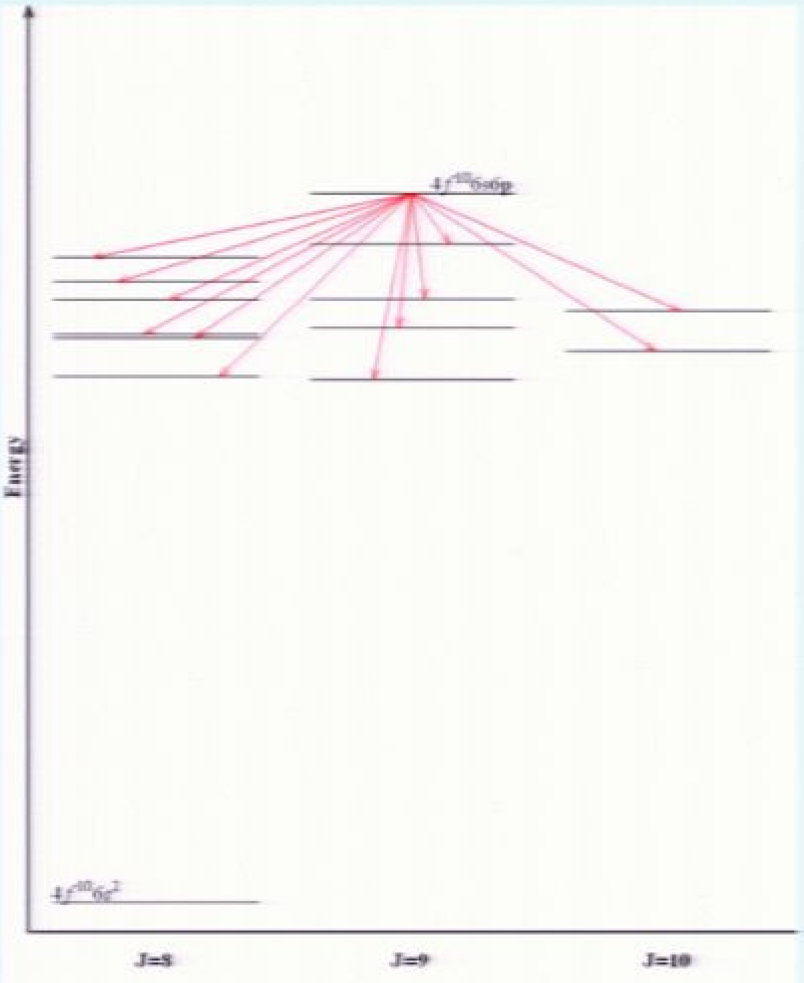
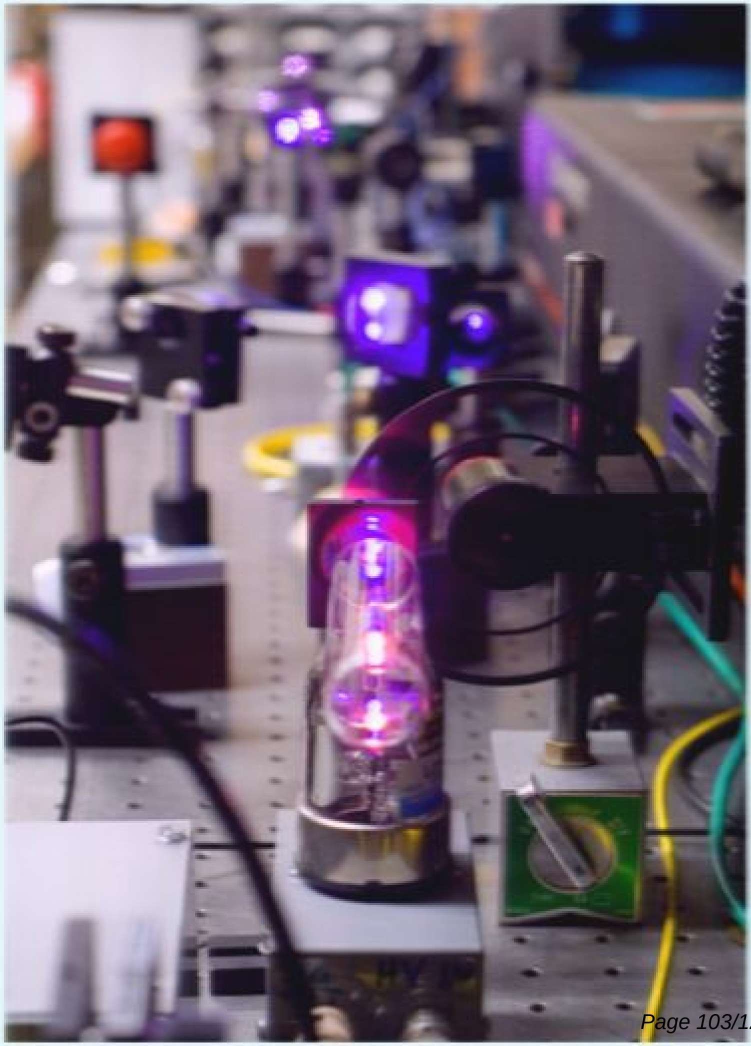


- Strong cycling transition at 421 nm but…
- Many possible trap states exist
- Branching ratios are not known, but expected $<10^{-4}$

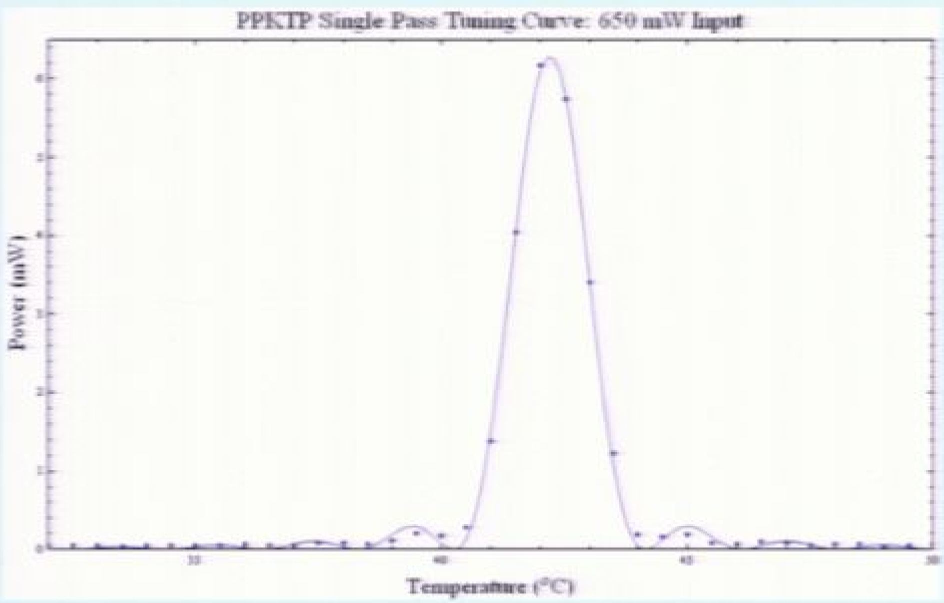
SHG Generation of 421 nm

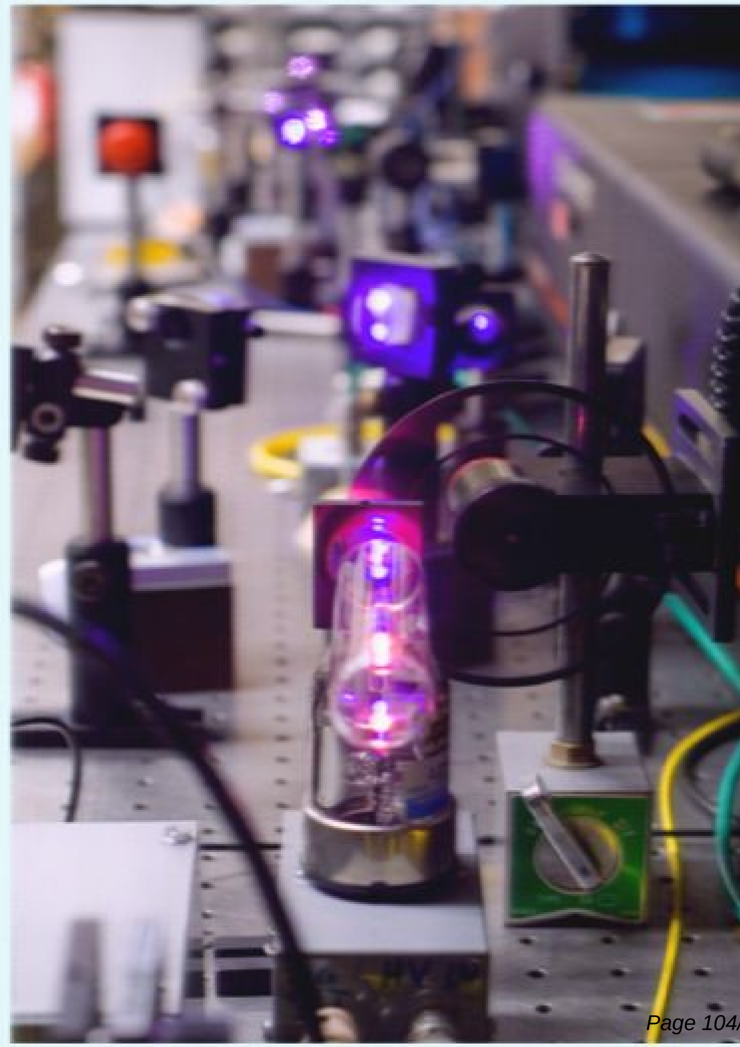
- Use 1 cm PPKTP crystal with Ti:Saph pump at 842 nm



SHG Generation of 421 nm

- Use 1 cm PPKTP crystal with Ti:Saph pump at 842 nm
- Single Pass Conversion Efficiency about 1% at 650 mW pump power





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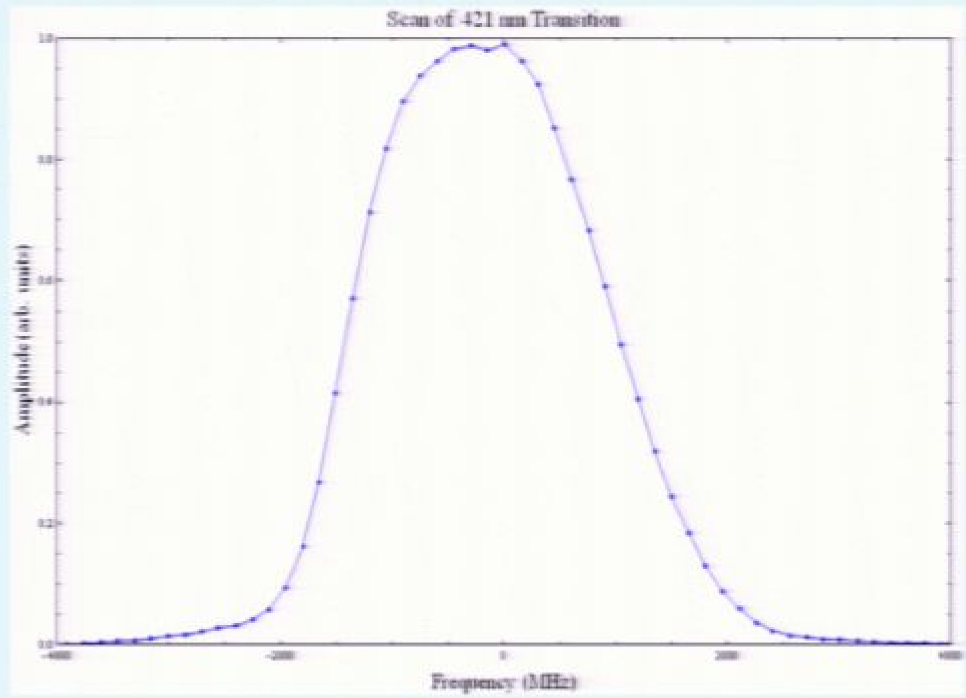
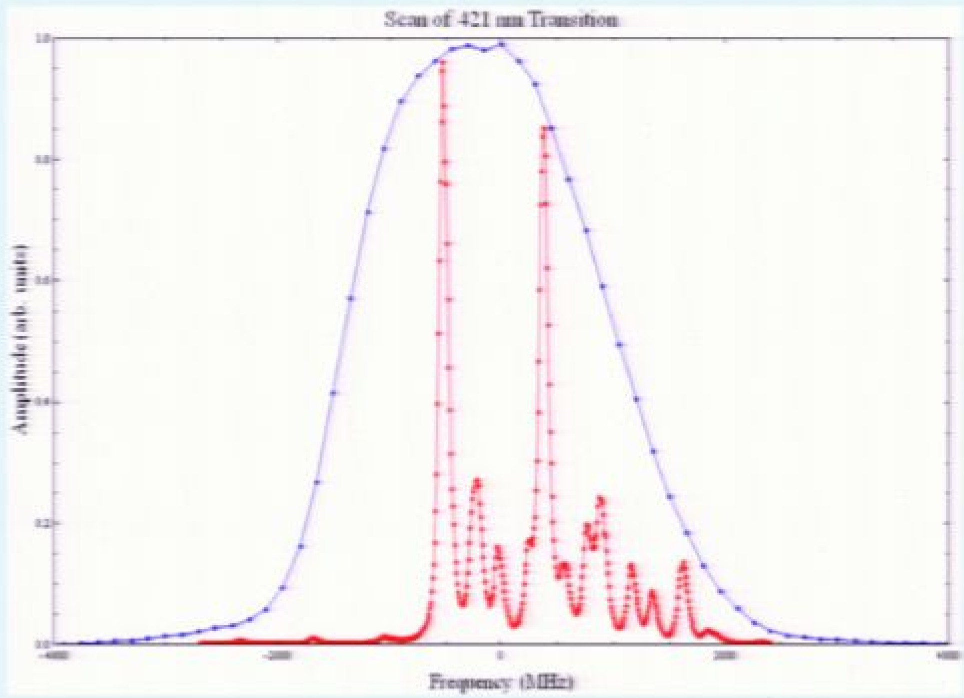
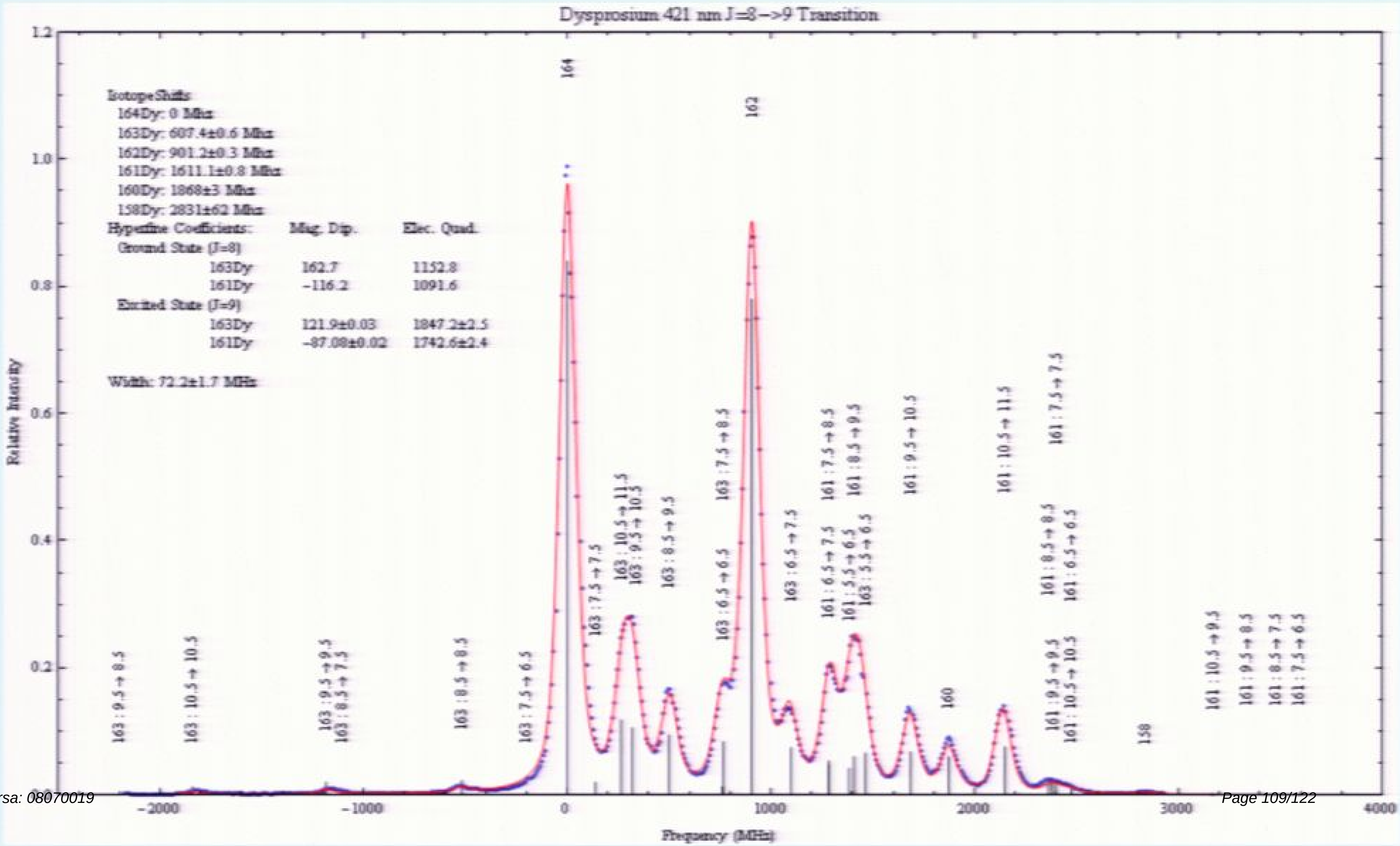


Identification of Transition

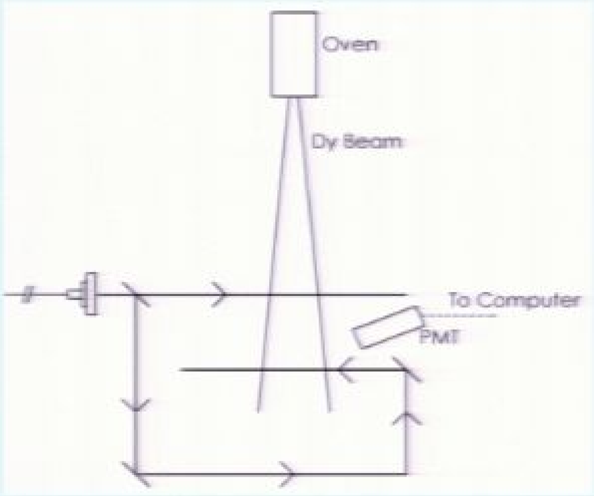
- Used hollow cathode lamp to find transition
- Five even and two odd isotopes with I=5/2 should make for rich structure
- Try again with atomic beam

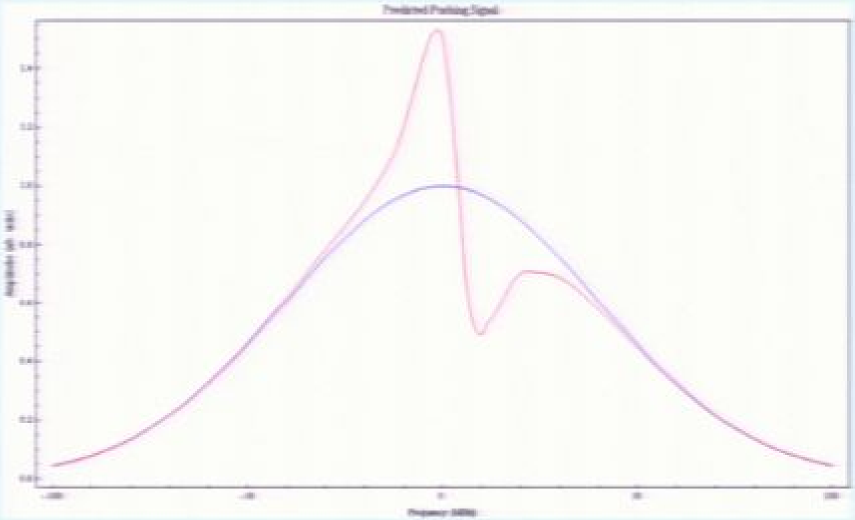


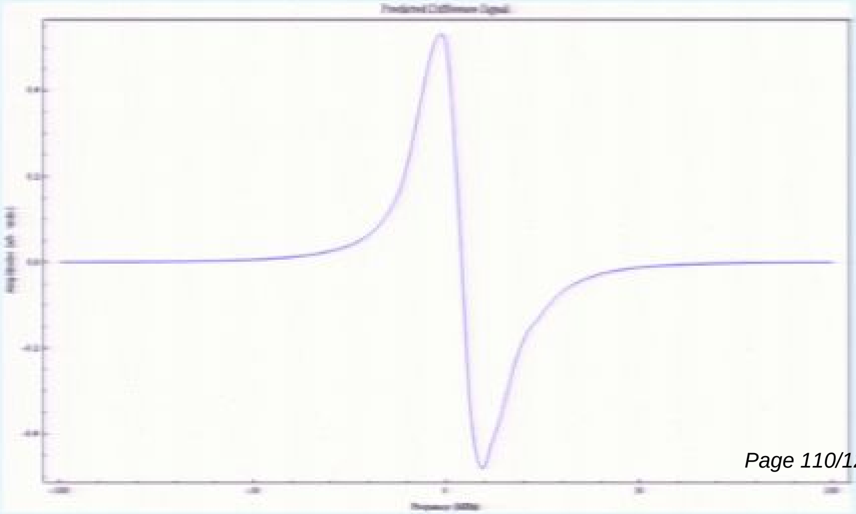
Identify Isotope Shifts and Hyperfine Coefficients for Odd Isotopes



Attempt to Push Atomic Beam







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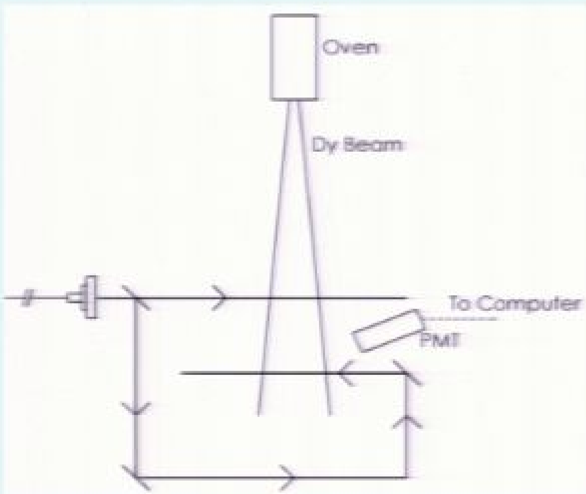
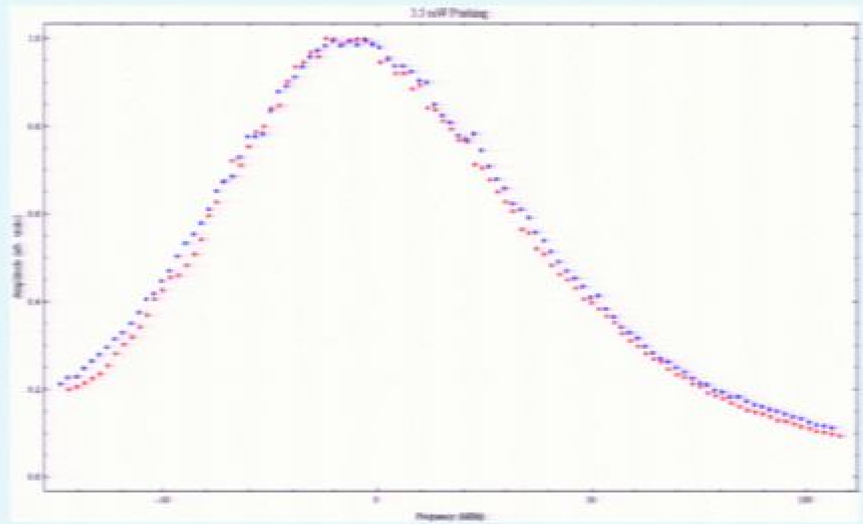
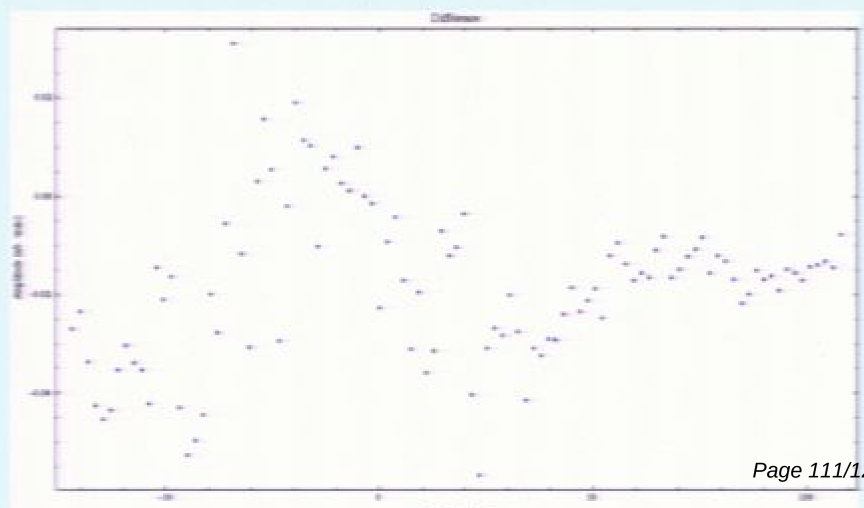


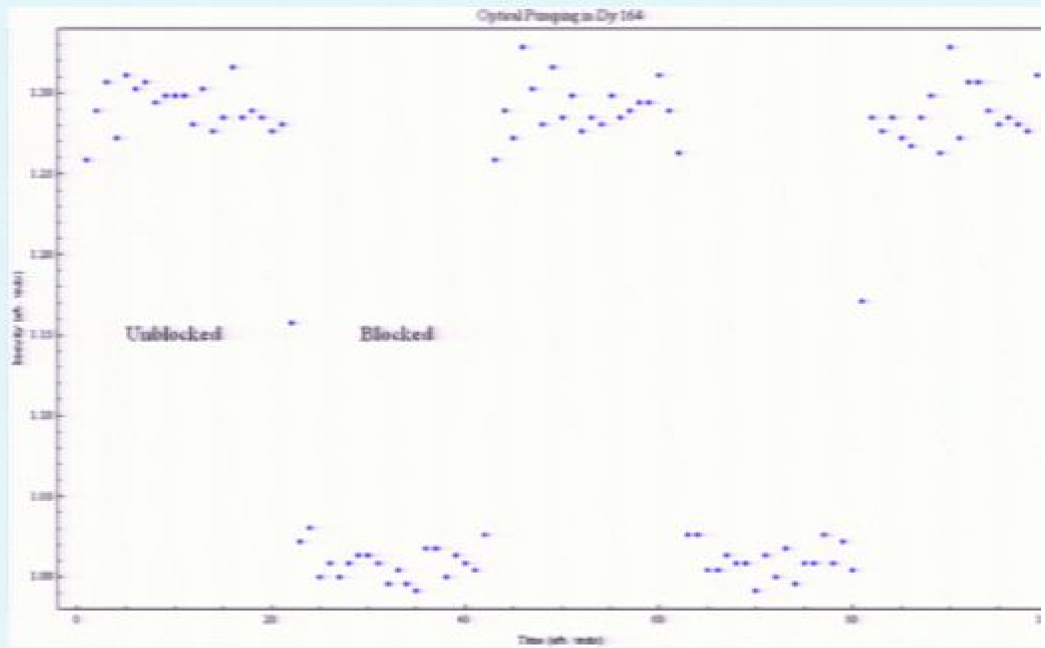




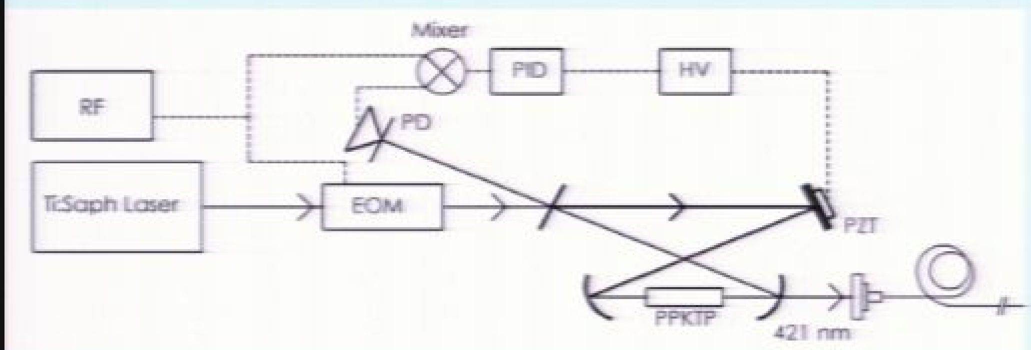
- Use strong pump beam with weak counter-propagating probe atoms down stream
- With 3.5 mW no significant pushing

Still Have Optical Pumping

- By blocking and unblocking pump beam we see ~30% **gain** in probe fluorescence



Cavity-Assisted Doubling



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- Promising results, but temperature stability of crystal is an issue
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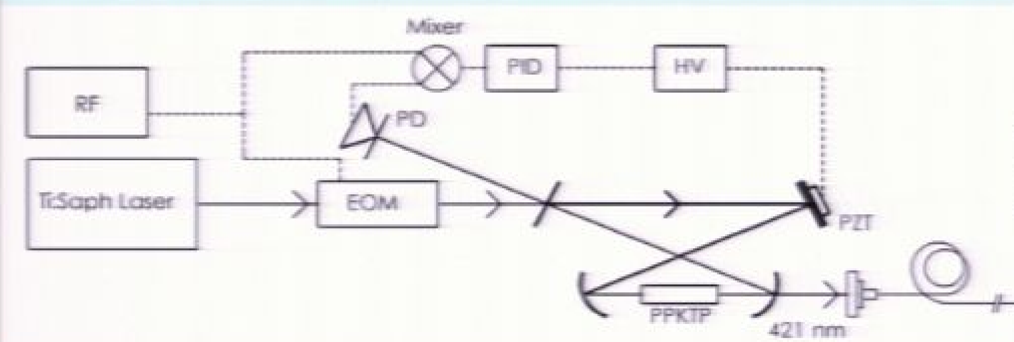

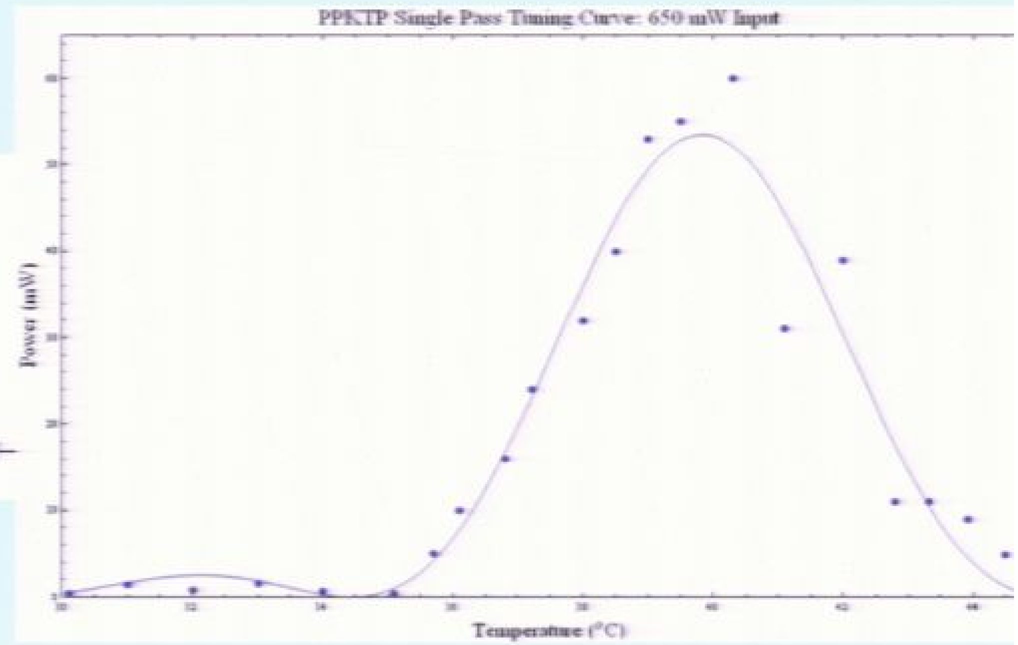

- Cavity-enhanced second harmonic generation
- Promising results, but temperature stability of crystal is an issue
- Best conversion efficiency achieved: 90 mW @ 335 mw Pump, 27%
- About to try again with pushing/cooling

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PHYSICAL REVIEW A VOLUME 56, NUMBER 5 NOVEMBER 1

Search for parity nonconservation in atomic dysprosium

A. T. Nguyen,[1] D. Budker,[1,2] D. DeMille,[1,*] and M. Zolotorev[3]
[1]Physics Department, University of California, Berkeley, California 94720-7300
[2]Nuclear Science Division, E. O. Lawrence Berkeley National Laboratory, Berkeley, California 94720
[3]Center for Beam Physics, E. O. Lawrence Berkeley National Laboratory, Berkeley, California 94720
(Received 2 June 1997)

Results of a search for parity nonconservation (PNC) in a pair of nearly degenerate opposite-parity states in atomic dysprosium are reported. The sensitivity to PNC mixing is enhanced in this system by the small energy separation between these levels, which can be crossed by applying an external magnetic field. The metastable odd-parity sublevel of the nearly crossed pair is first populated. A rapidly oscillating electric field is applied to mix this level with its even-parity partner. By observing time-resolved quantum beats between these sublevels, we look for interference between the Stark-induced mixing and the much smaller PNC mixing. To guard against possible systematic effects, reversals of the signs of the electric field, the magnetic field, and the decrossing of the sublevels are employed. We report a value of $|H_w| = |2.3 \pm 2.9$ (statistical) ± 0.7 (systematic)$|$ Hz for the magnitude of the weak-interaction matrix element. A detailed discussion is given of the apparatus, data analysis, and systematic effects. [S1050-2947(97)02111-2]

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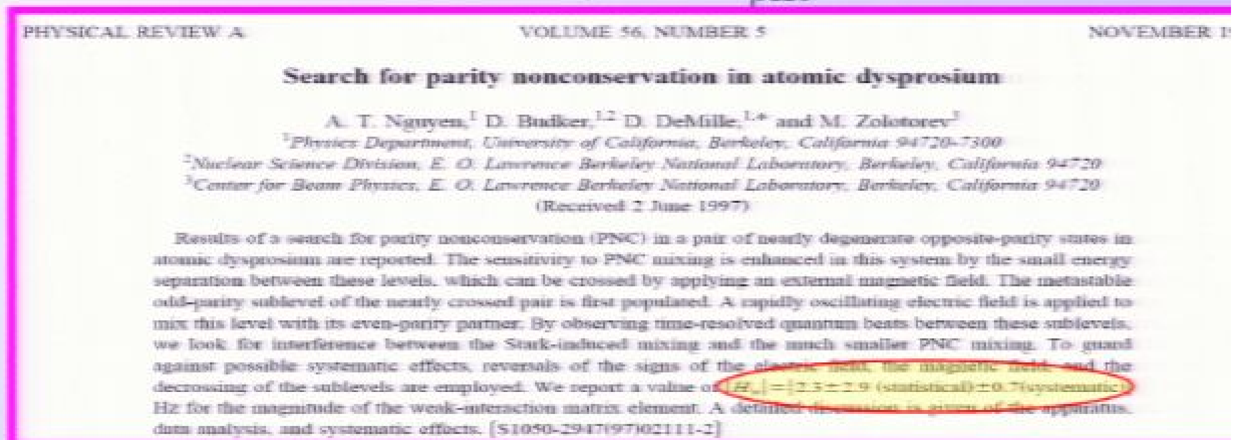

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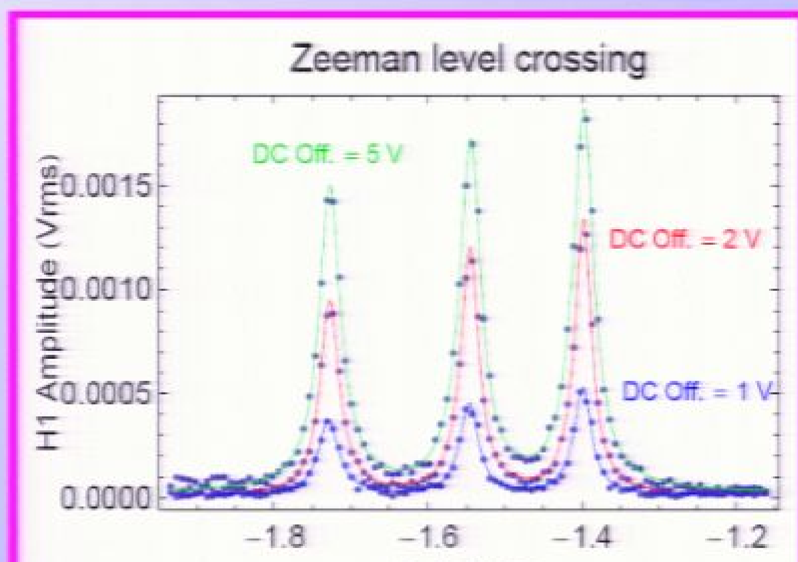
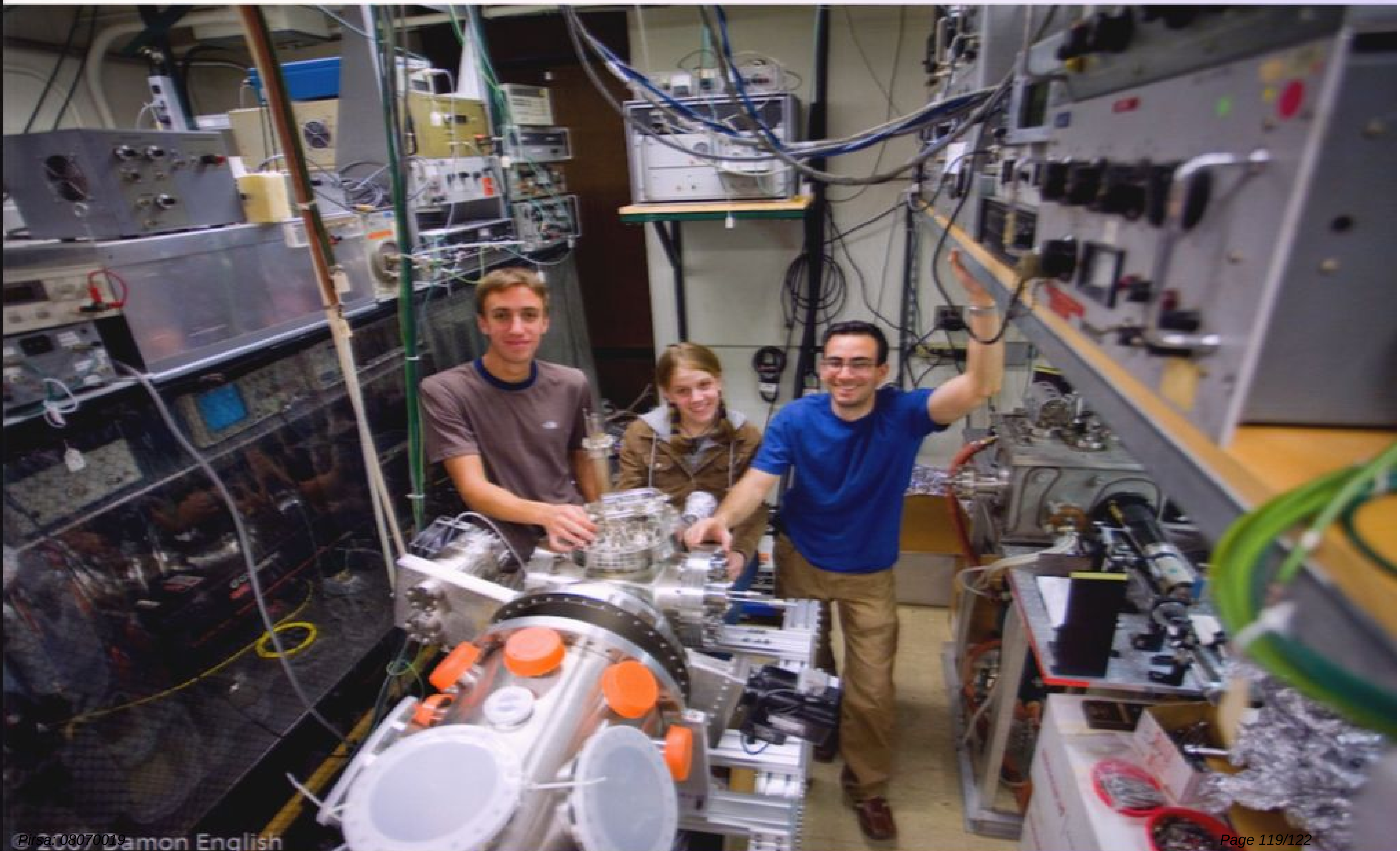
- We are working on it!



The Future



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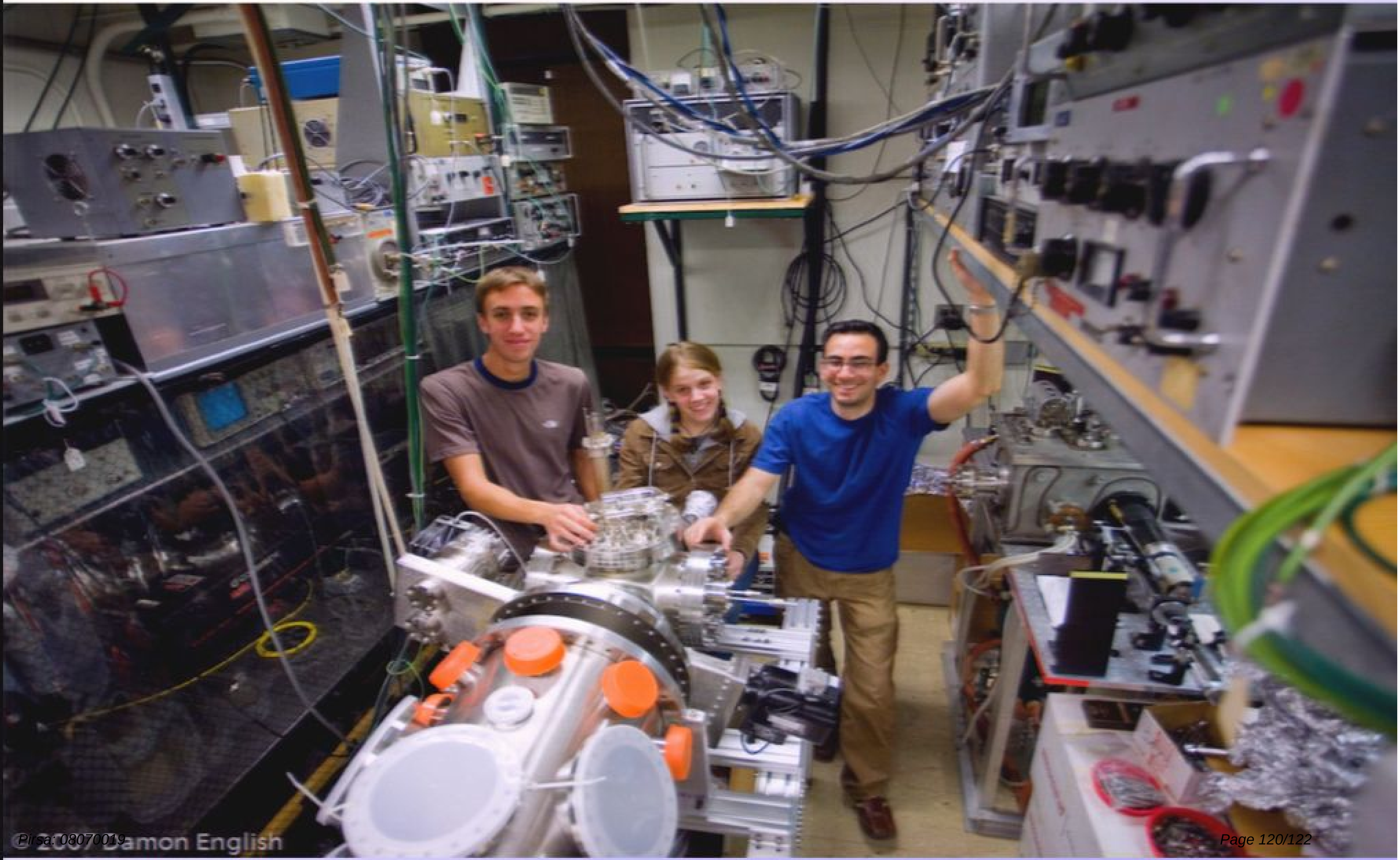
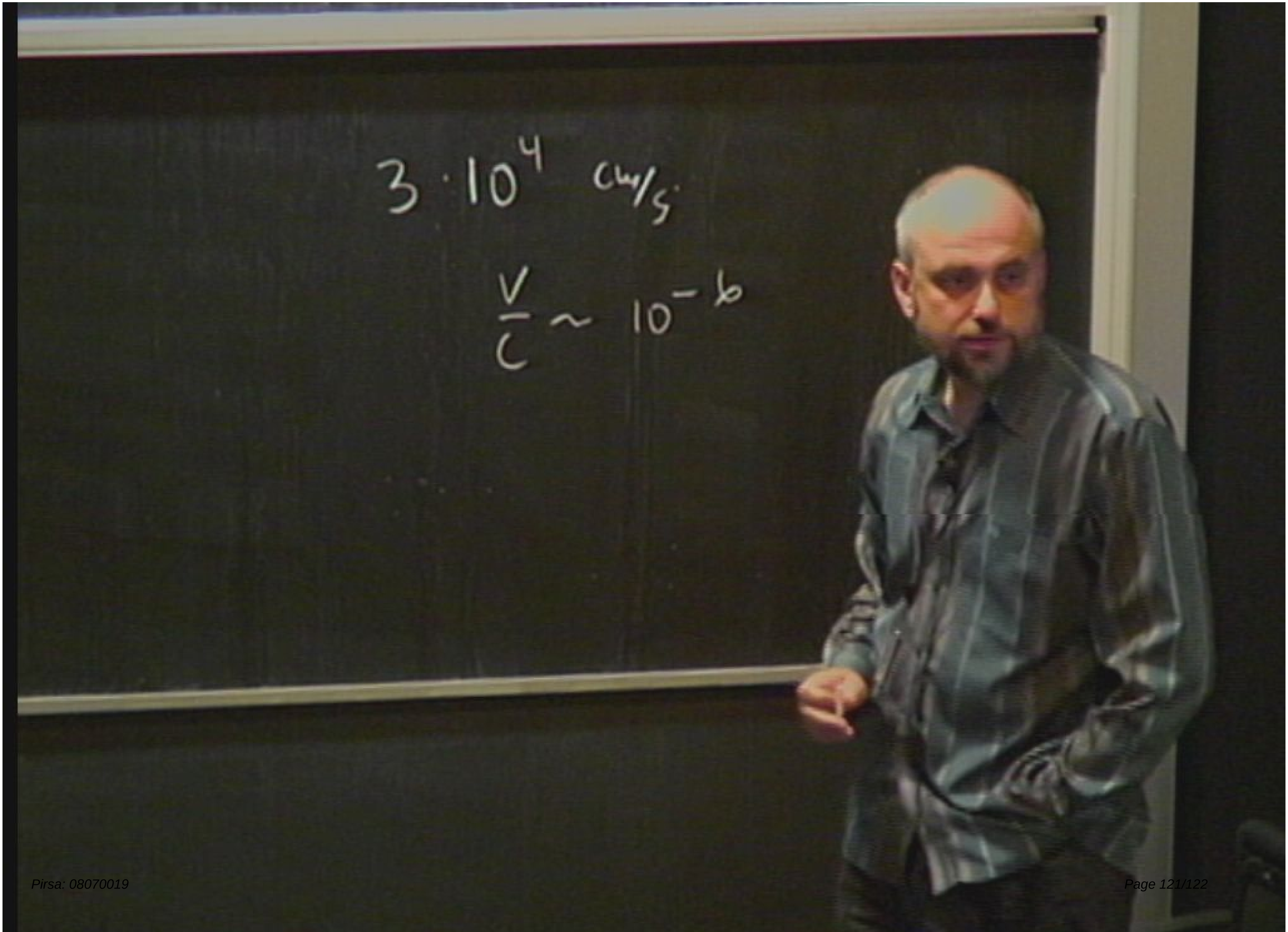
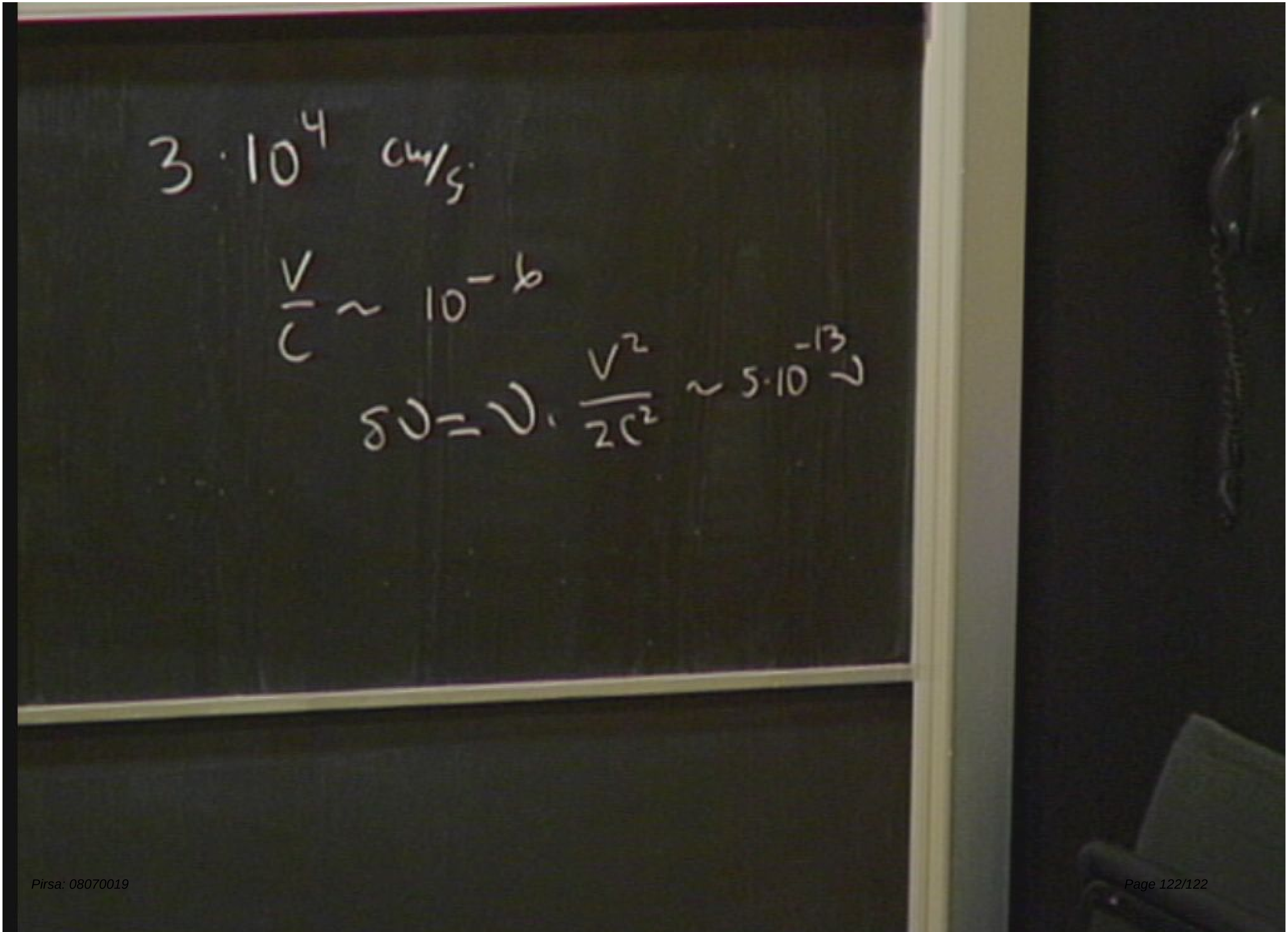



3 · 10^4 cm/s
v/c ~ 10^-6


$3 \cdot 10^4$ cm/s
$\frac{v}{c} \sim 10^{-6}$
$\delta\nu = \nu \cdot \frac{v^2}{2c^2} \sim 5 \cdot 10^{-13}\,\nu$