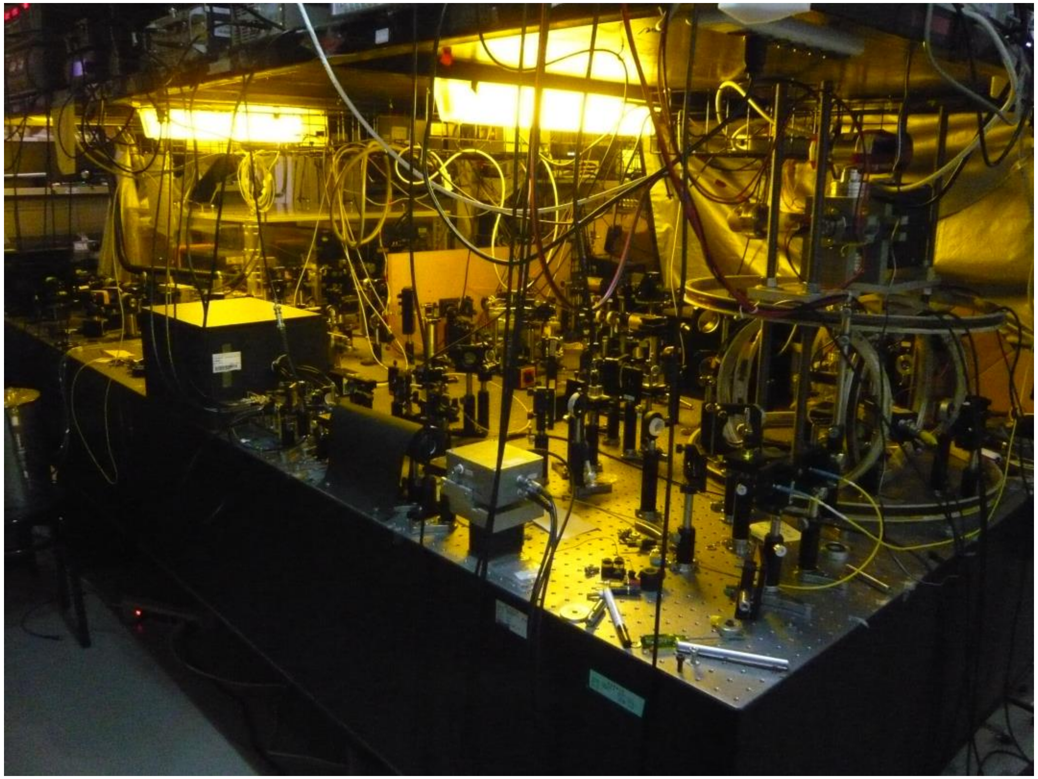
實驗室導覽

中央物理

光梳雷射光譜實驗室



實驗室導覽內容

- 我們是哪一行
  - 我們的領域叫AMO
  - 我們的專長：光梳雷射物理、量子控制(雷射穩頻與物質波控制)
- 學生在這一行會學到什麼
- 我們過去做了什麼
- 我們未來會做什麼
- 我們對科學界及社會有什麼貢獻

我們是哪一行

什麼是AMO?

美國物理協會有一個分支：

Damop: Division of atomic, molecular, and optical physics

光與原子分子的交互作用，以用途而言，分兩類

用光來控制原子分子的量子狀態

用原子分子來控制光的量子狀態

1997~2005，AMO這個小族群，有九個人拿諾貝爾獎

1997: Laser cooling (Since 1986) (用光來製造冷原子)

S. Chu, B. Philips and C. Tonugui

2001: Bose-Einstein Condensation (since 1995) (用光使原子凝結)

C. Wiman, E. Cornell, W. Kettler

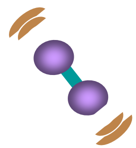
2005: High precision measurement and Comb laser (since 1999) (用原子控制光)

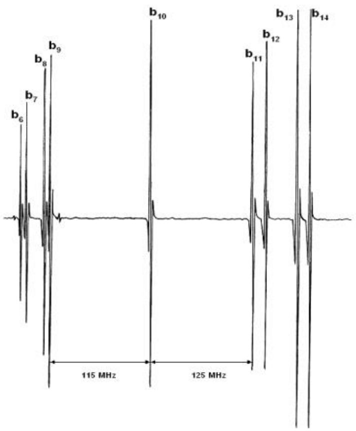
R. Clauber, T. Hansch, J. Hall

他們的雷射都需要穩頻！！！

穩頻雷射拿來做光鐘

Iodine standard





Linewidth : 23 kHz

strontium clock

Linewidth : mHz

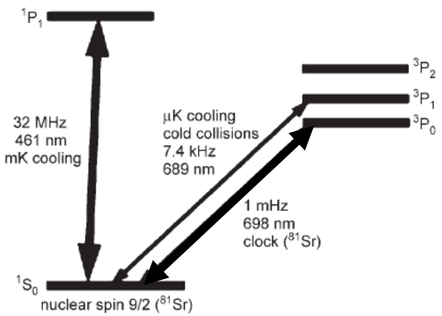
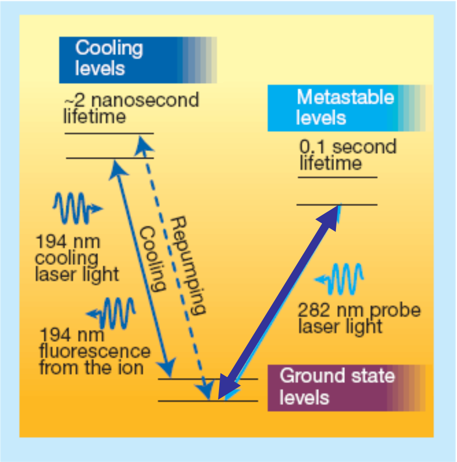


Figure 3. The lowest energy levels of strontium.



Hg^+ clock

Linewidth : 6.7 Hz

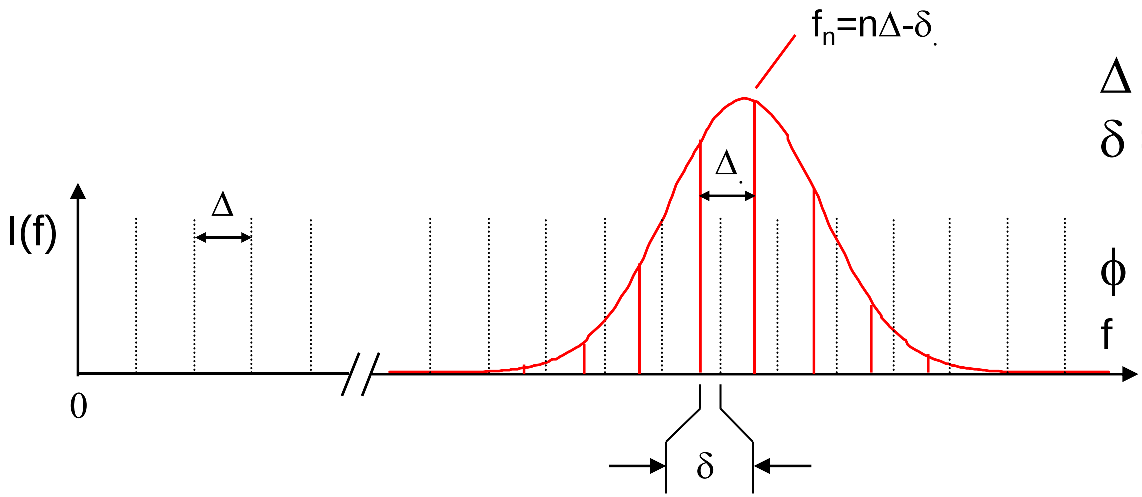
我們在AMO這行的專長

– 光梳雷射物理
– 量子控制 (雷射穩頻與物質波控制)
– 原子分子光譜

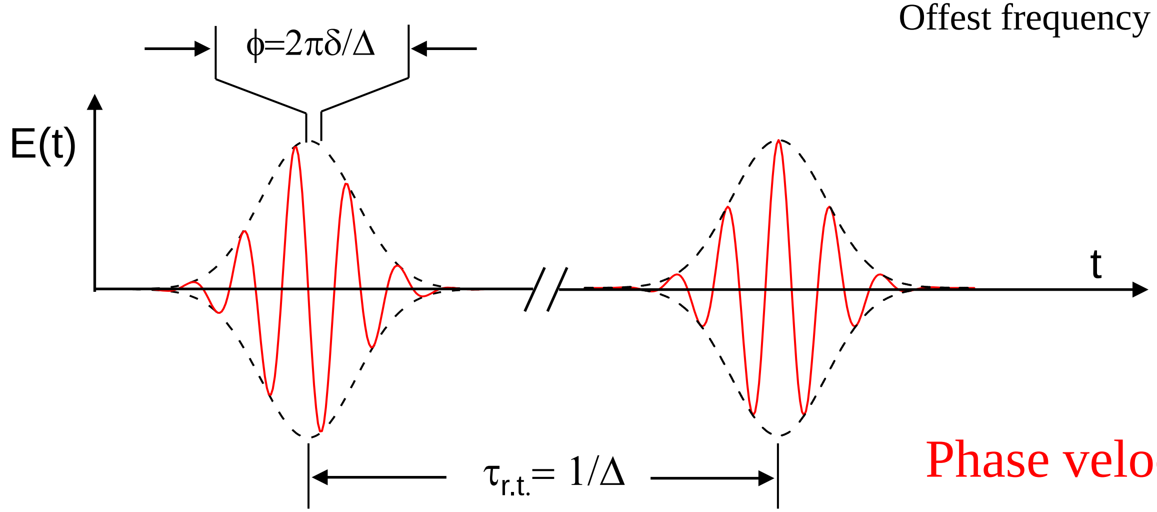
我們在AMO這行的專長

–光梳雷射物理

飛秒(10^{-15} sec)光梳雷射 time domain與 frequency domain 性質



Δ = repetition rate=1/T
δ = Comb offset from
harmonics of Δ
ϕ = Phase slip b/t carrier &
f envelope each round trip



Offest frequency δ

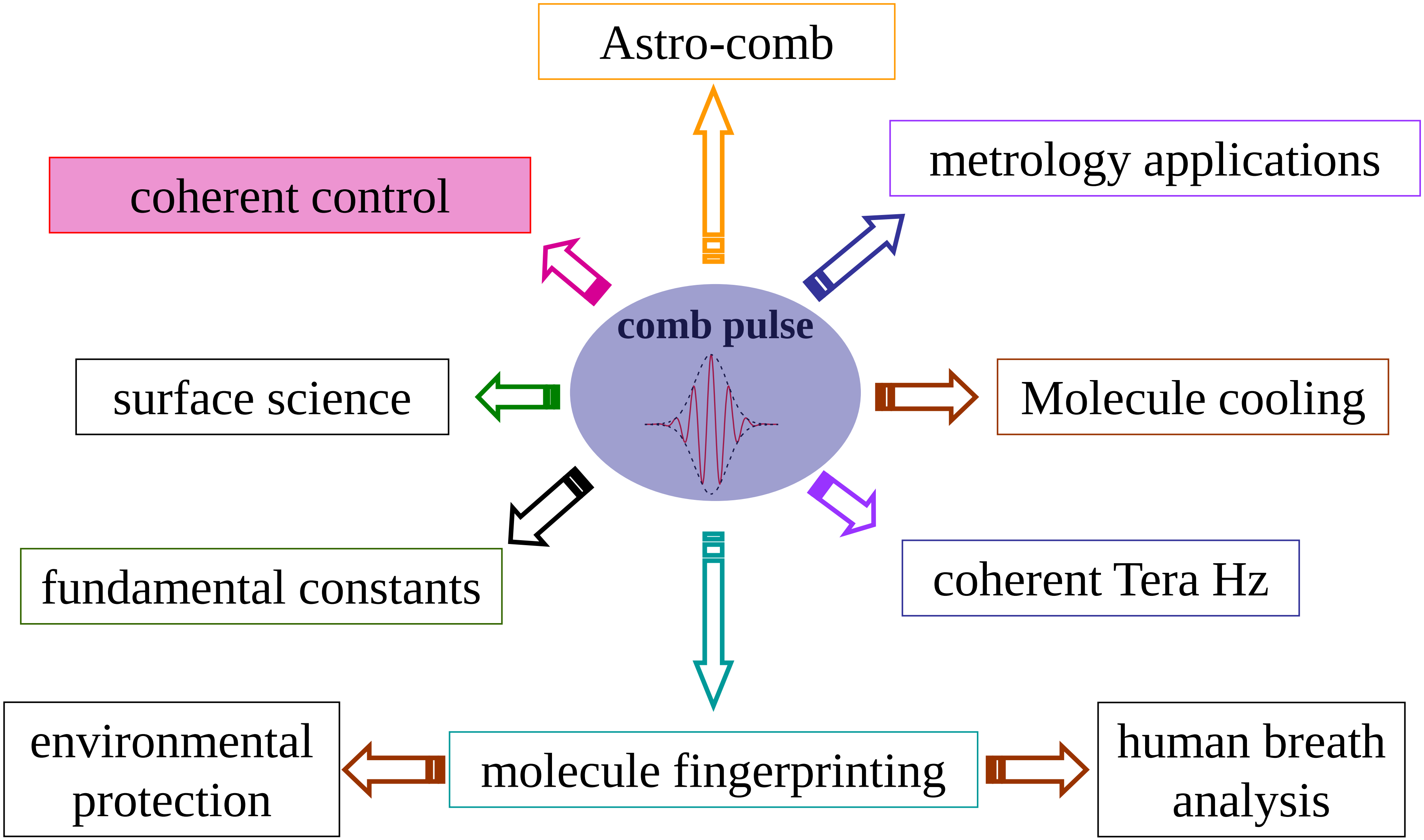
$$\equiv \frac{d\phi}{dt} = \frac{1}{2\pi}\frac{\phi / pulse}{T}$$

Phase velocity ≠ Group velocity

D. J. Jones, S. A. Diddams, J. K. Ranka, A. Stentz, R. S. Windeler, J. L. Hall, S. T. Cundiff, Science **288**, 635 (2000).

光梳雷射如何為科學界打開一扇窗

(jobs down and proposed since 2005)



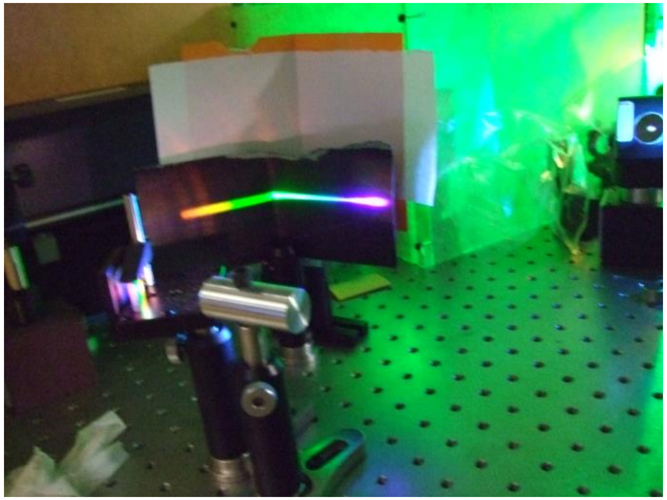
光梳雷射 time domain的 特色:

High peak power (compared to CW laser)

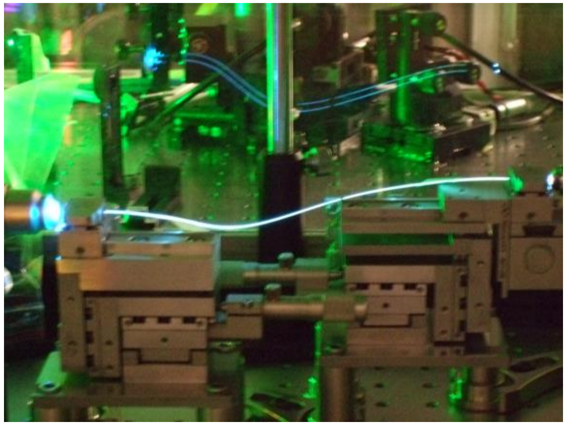
Fixed carrier-envelope phase

(good for selective or delicate pumping)

Femtosecond time scale



圖片來自我們實驗室



圖片來自我們實驗室

Examples:

Science ***307,*** *400 (2005)*

→ *Kr atom ionization rate control*

Nature ***436,*** *234 (2005)*

→ *XUV comb*

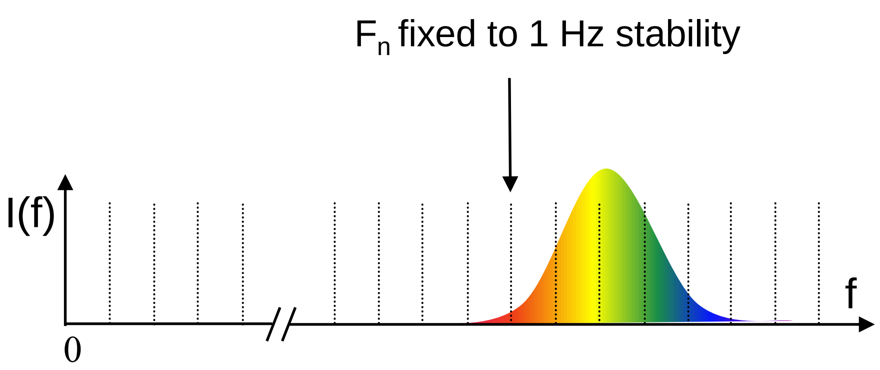
Nature physics ***2,*** *327 (2006)*

→ *Terahertz comb*

光梳雷射 frequency domain的 特色:

Wide-band

High-resolution



Rapid-wideband measurement

Examples:

Nature ***445,*** *627 (2007)*

→ *molecular fingerprinting,* I_2 *, span: 16,00,000 MHz (9 nm), resolution: 1 MHz*

Science ***311,*** *1595 (2006)*

→ *comb laser cavity ring down,* C_2H_2*,* H_2O*,* O_2*,* NH_3*, 210,00 GHz (130 nm), resolution: 25 GHz*

我們在AMO這行的專長

—雷射穩頻

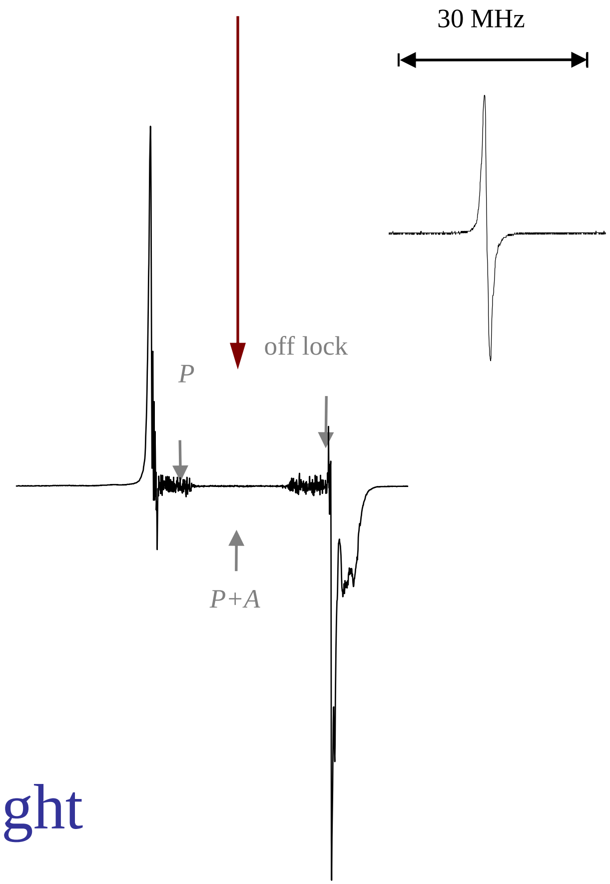
我們的實驗為例

藉此得知原子分子特性

*Optical frequency 4.5*10^{14}*
*~**150** Hz frequency uncertainty*

cesium 6S-8S
dipole not allowed transition

Opt. lett. **32**, 563 (2007)



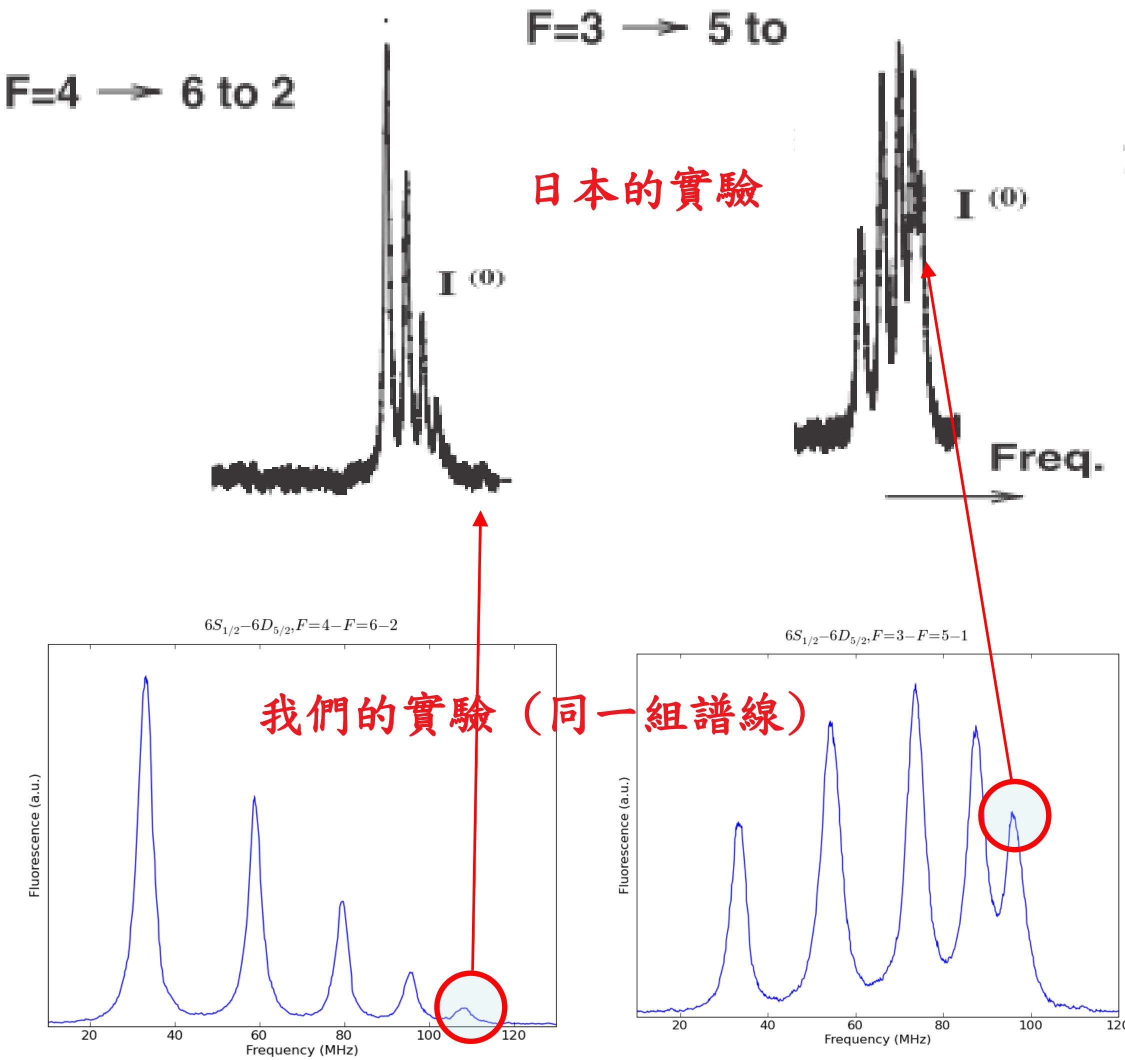
electronics for feedback control

Ultra-high Coherence light

我們在AMO這行的專長

超高解析光譜

穩頻雷射的好處：



Journal of the Physical Society of Japan
Vol. 74, No. 9, September, 2005, pp. 2487–2491

雷射功率: 32 W
鈦藍寶石雷射:~300萬台幣
雷射頻率穩定度:
1 MHz
(未穩頻)

Opt. lett. **36**, 76 (2011)

雷射功率: 0.03 W
半導體雷射:~3萬台幣
雷射頻率穩定度:
0.0003 MHz
(穩頻於光學共振腔)

2005年諾貝爾物理獎得主 John Hall 看到我們工作後的感觸

From: JHall @JILA
To: <wycheng@gate.sinica.edu.tw>
Sent: Wednesday, January 12, 2011 5:22 AM
Hi Wang-Yau
I like you first day of the New Year article in Opt Lett. Looks like some good results from intensity measurements. It would really be neat to have the lasers frequency-locked to a cavity when looking at the dispersion of the two-photon transitions. I think that it should be a good S/N highway, but only if one is at shot noise stability level. ... Anyway, it's certainly fun to play in the labs!
J

把劍磨利，有時勝過千軍萬馬

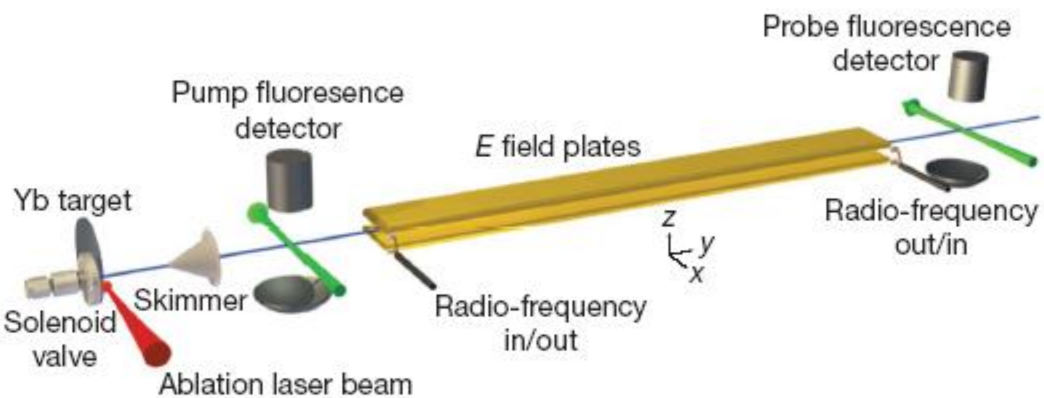
一個很好的註腳

Improved measurement of the shape of the electron

J. J. Hudson[1], D. M. Kara[1], I. J. Smallman[1], B. E. Sauer[1], M. R. Tarbutt[1] & E. A. Hinds[1]

26 MAY 2011 | VOL 473 | NATURE | 493

with 90 per cent confidence. This result, consistent with zero, indicates that the electron is spherical at this improved level of precision. Our measurement of atto-electronvolt energy shifts in a molecule probes new physics at the tera-electronvolt energy scale[2].



穩頻雷射在基礎科學之貢獻 (小錢做大實驗)

電子形狀之檢測

(Nature **473**, 10104(2011))

質子大小之檢測

(Nature **466**, 09250(2010))

標準模型之檢測

(Science **275**, 1759 (1997))

實驗室重力紅移

(Nature **463**, 08776 (2010))

夸克質量變化之檢測

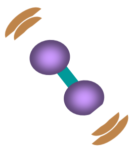
proposed, Phys. Rev. A 79, 054102 (2009)；

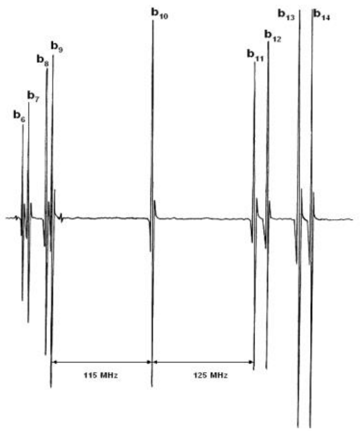
弦論之檢測

proposed, Phys. Rev. A 59, 230 (1999)

穩頻雷射拿來做光鐘

Iodine standard





Linewidth : 23 kHz

strontium clock

Linewidth : mHz

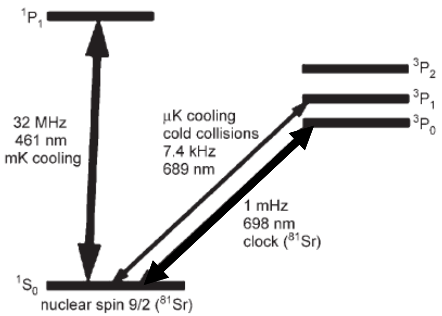
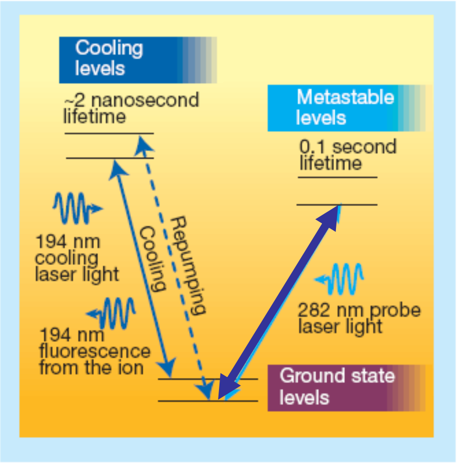


Figure 3. The lowest energy levels of strontium.



Hg^+ clock

Linewidth : 6.7 Hz

認真的學生可以學到什麼？

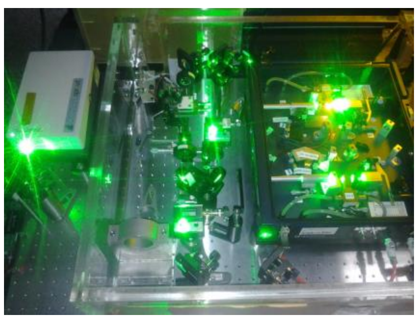
- 進階的電子電路
  - 回授電路　　　　鎖相迴路　　　　Lockin
  - 各式電路設計(電流供應器、頻率產生器、PCB lay out技術等)
- 光電元件的使用
- 雷射物理(大部分雷射我們自組)
- 原子分子光譜與量子力學的更加認識
- 量子光學計算(我們非常歡迎單純想做計算的人)
  - 量子干涉的發生條件　　　連立微分方程的解
  - 光梳雷射與物質交互作用的模型建立

我們之前的成果(2005~2015)

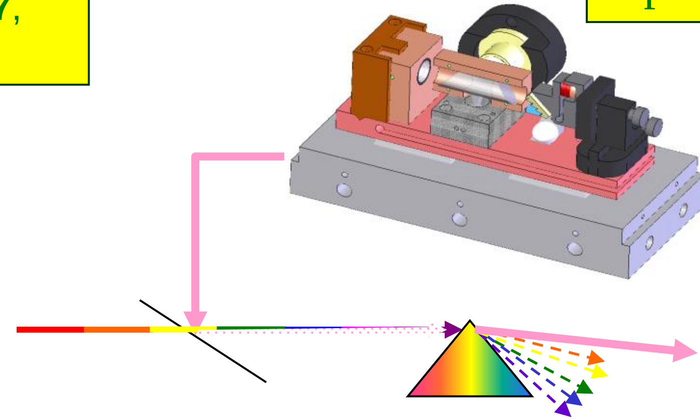
–二級光鐘與電子電路設計(Review of Scientific Instrument, 2005)
–新光頻標準(Optics Letters, 2007)
–新穎光梳雷射 (Applied Phys. B, 2014,2008)
–超高解析光譜(Optics Letters, 2011)
–原子躍遷雷射絕對頻率量測(Optics Letters, 2013)
–雙光子量子干涉理論與實驗(Physical Review A, 2015)
–超冷原子(建構中)

精密光頻量測，有助於原子分子躍遷理論之檢驗

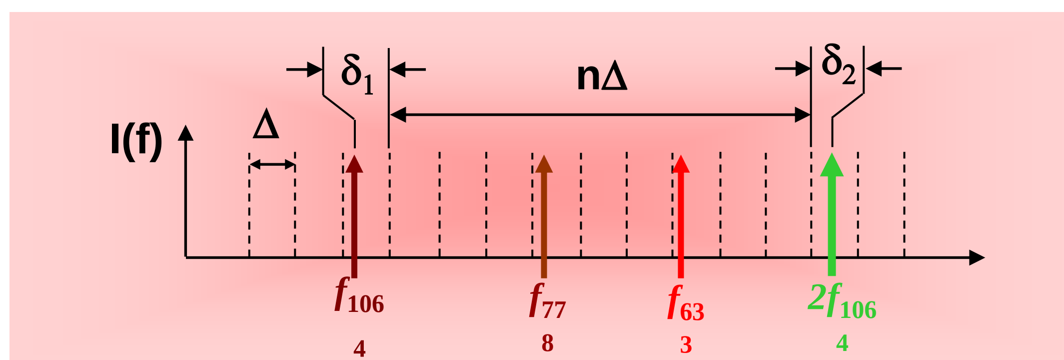
光梳雷射
Apply Physics **B 92**, 13 (2008);**117**, 699 (2014)



銫原子6S→8S雙光子躍遷
Optics Letters, **36**, 76 (2011)

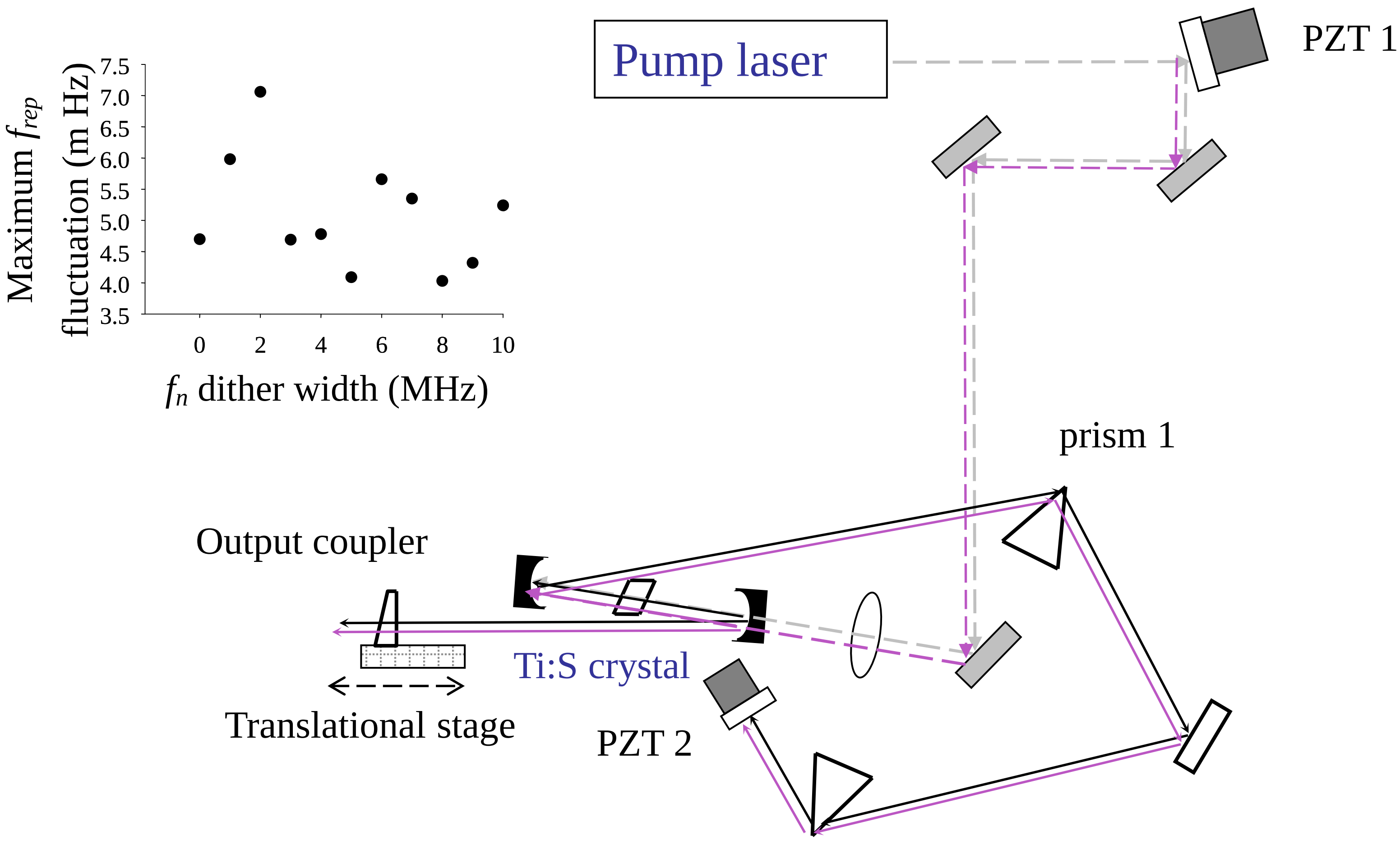


未知雷射與光梳雷射比頻率

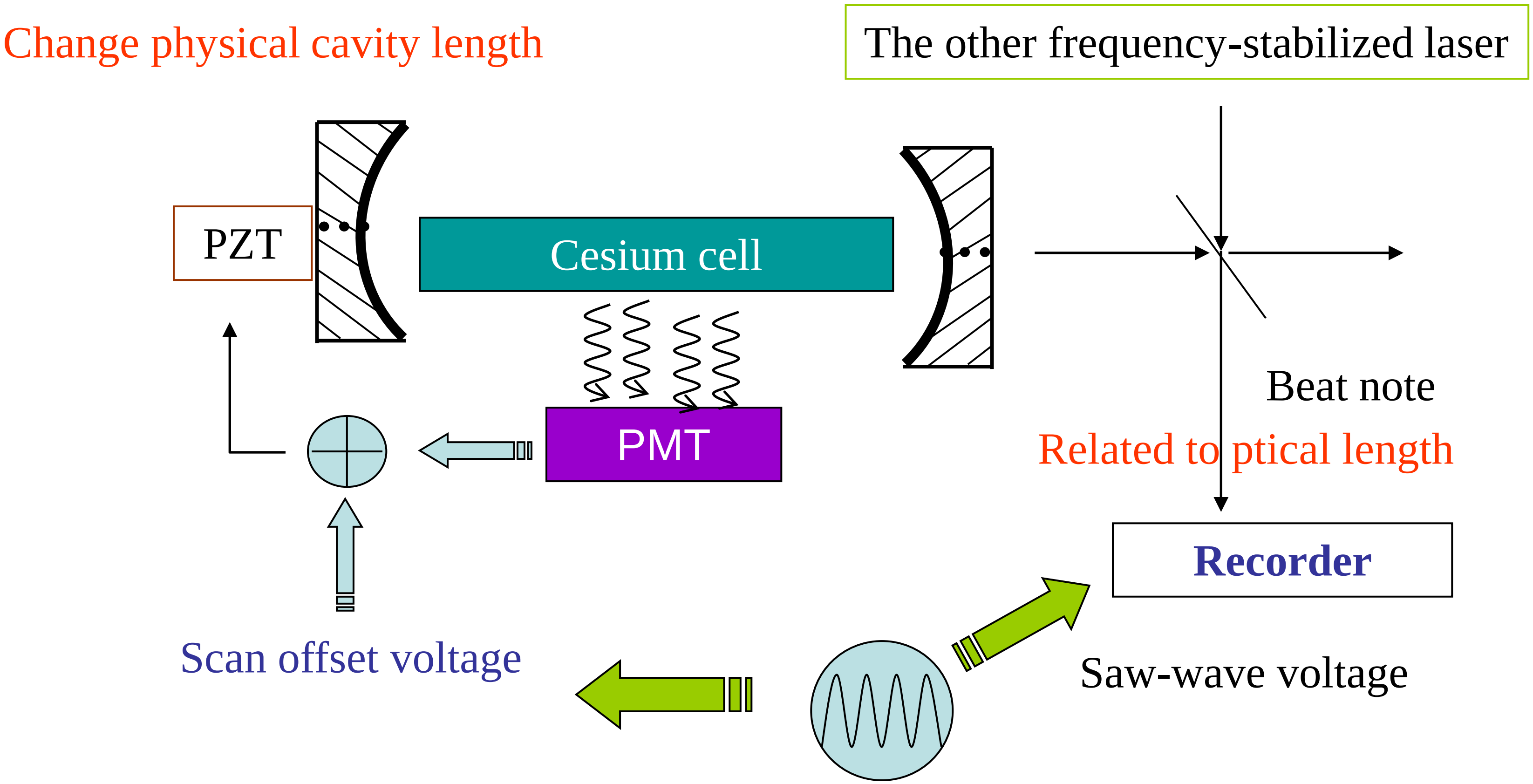


新的單獨控制雷射相位的方法

Apply Physics **B** 92, 13-18 (2008)

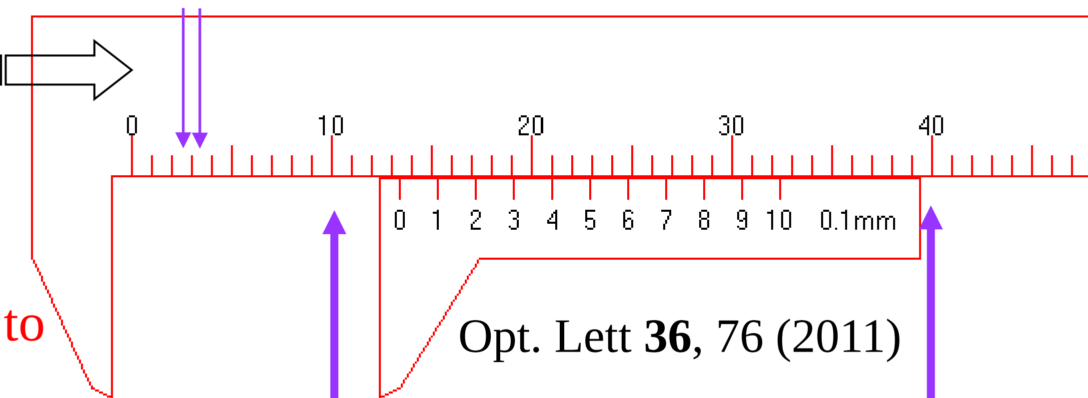


銫原子放到雷射中之新雙光子吸收光譜



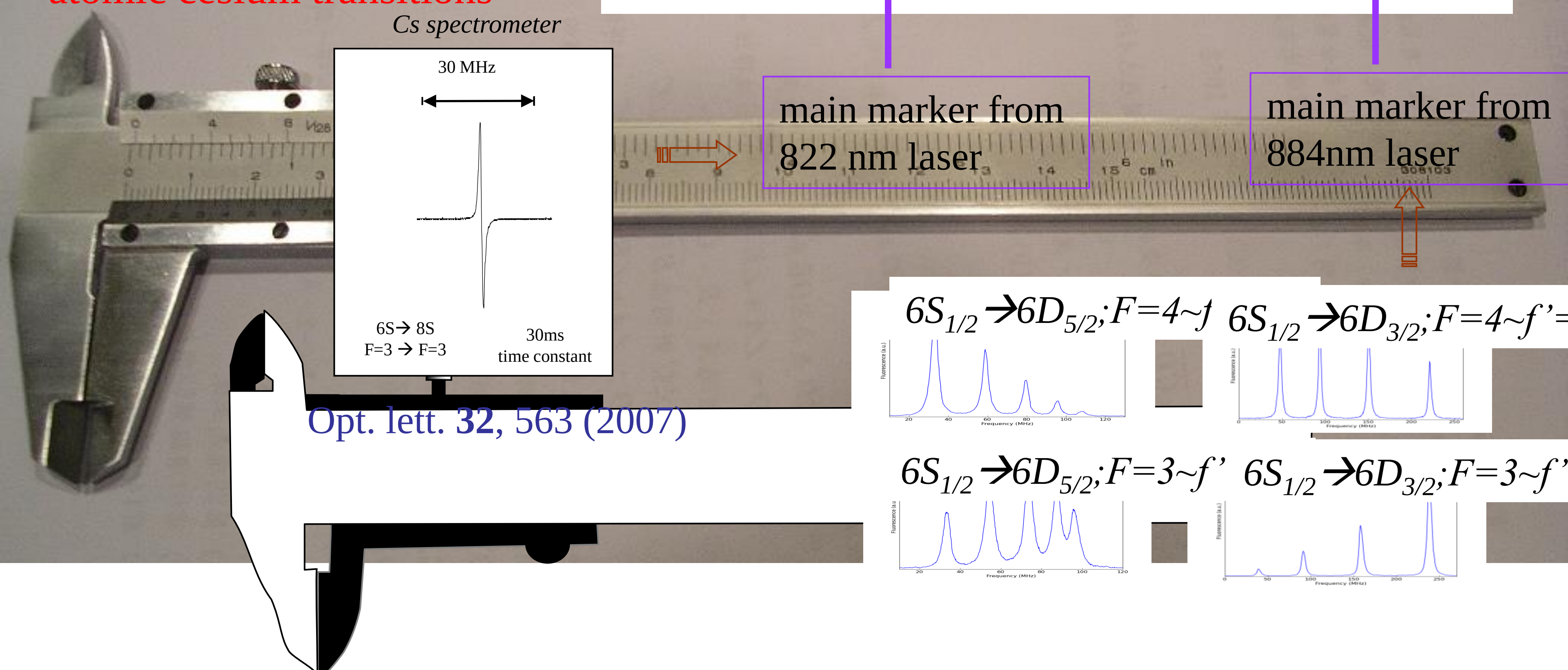
做了高精密光學游標尺

scale: Cmob-CPT clock



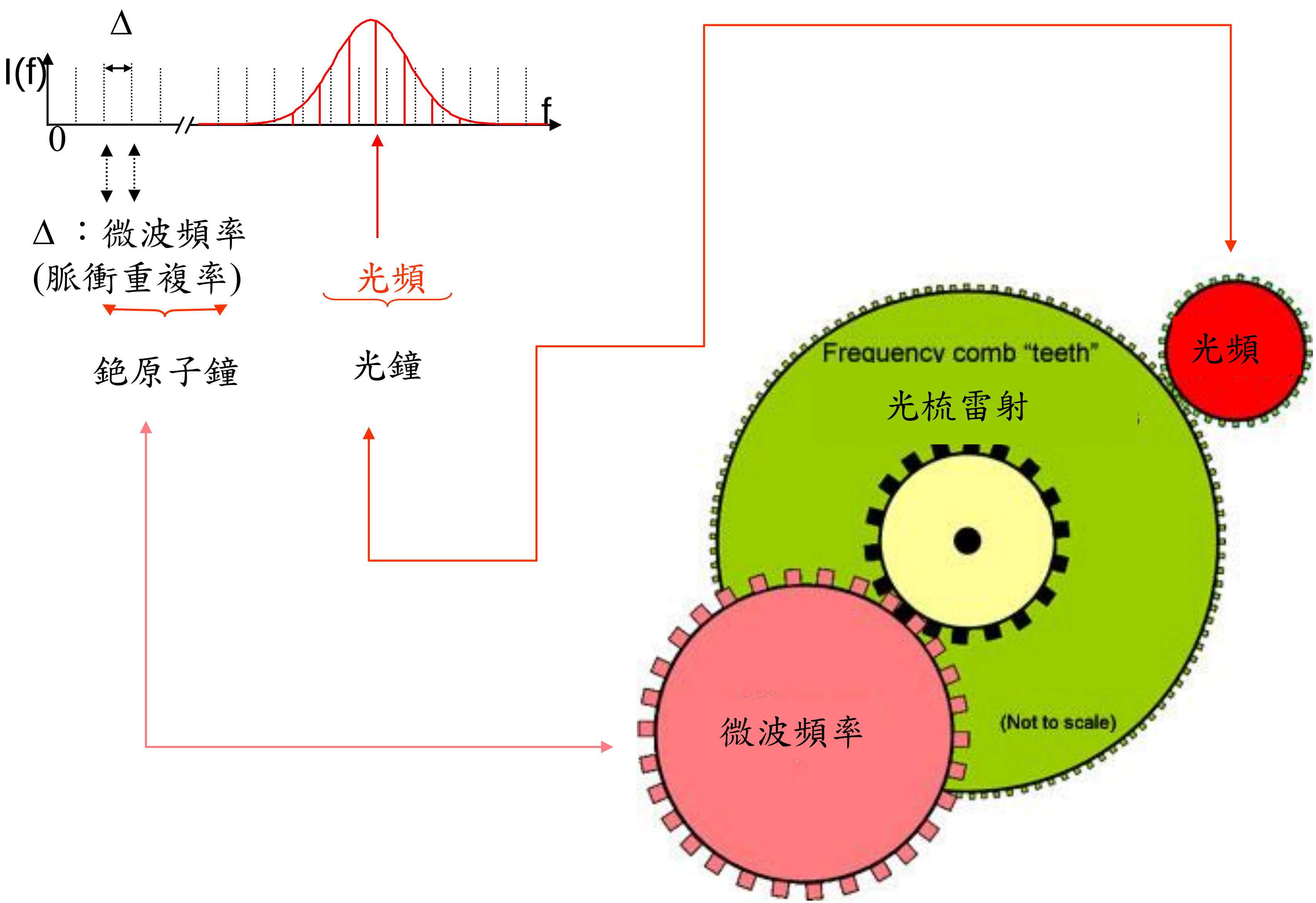
Opt. Lett **36**, 76 (2011)

1. no 1f-2f scheme
2. all comb parameters referring to atomic cesium transitions

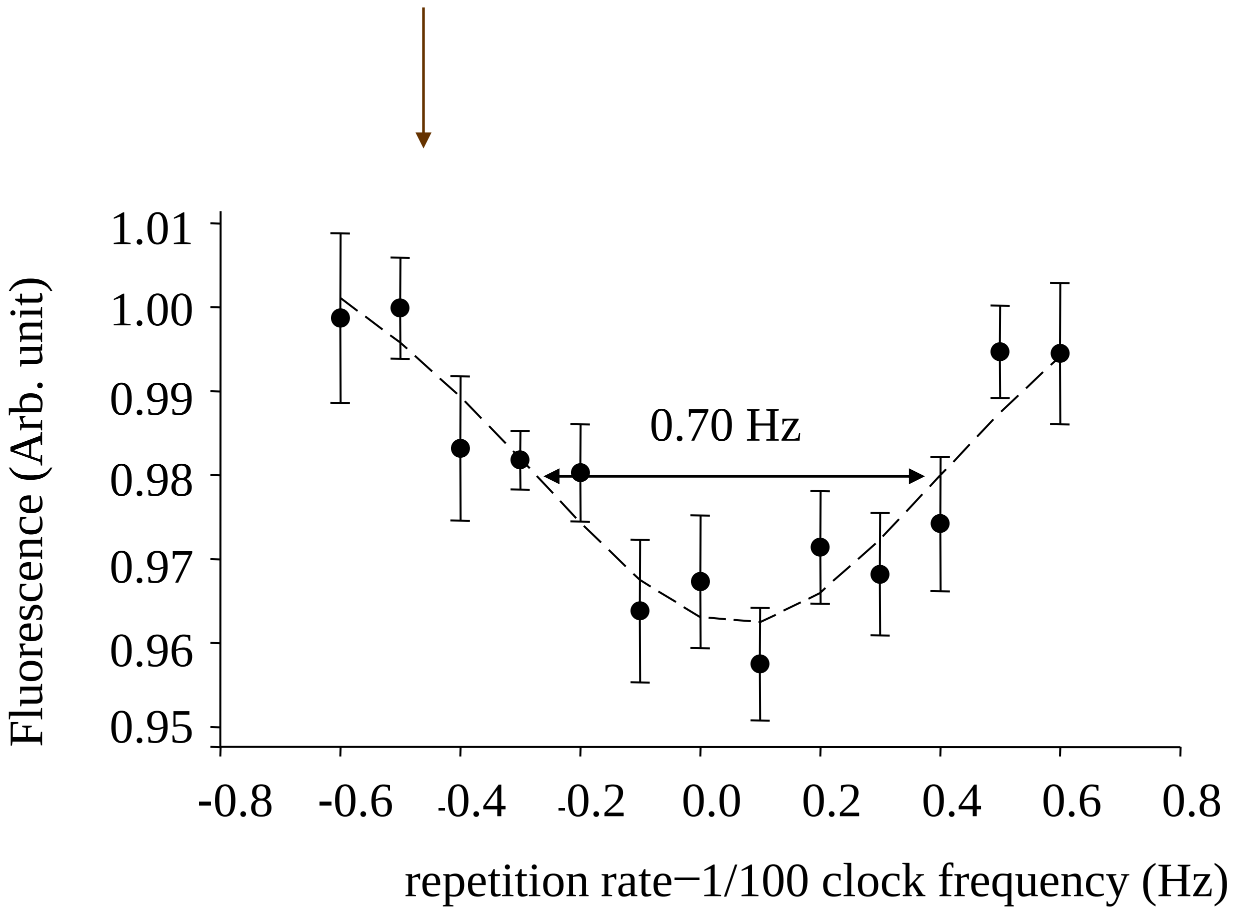


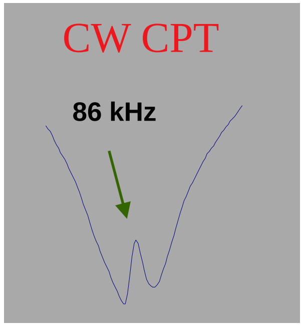
Opt. lett. **32**, 563 (2007)

光梳雷射在"鐘"之間，扮演什麼角色？

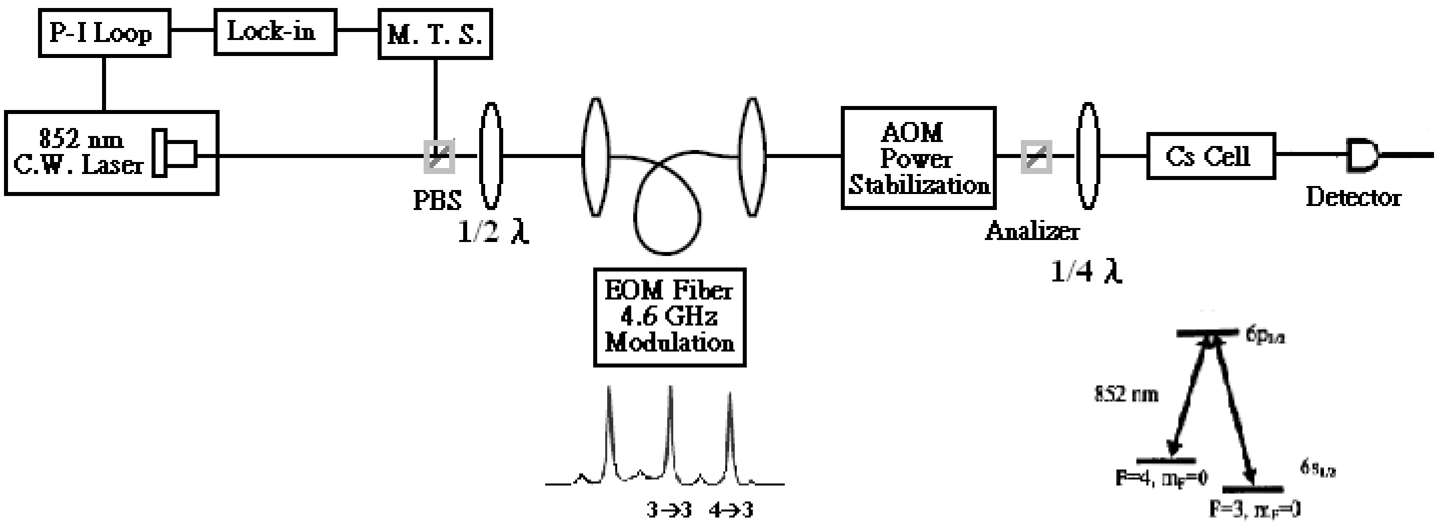


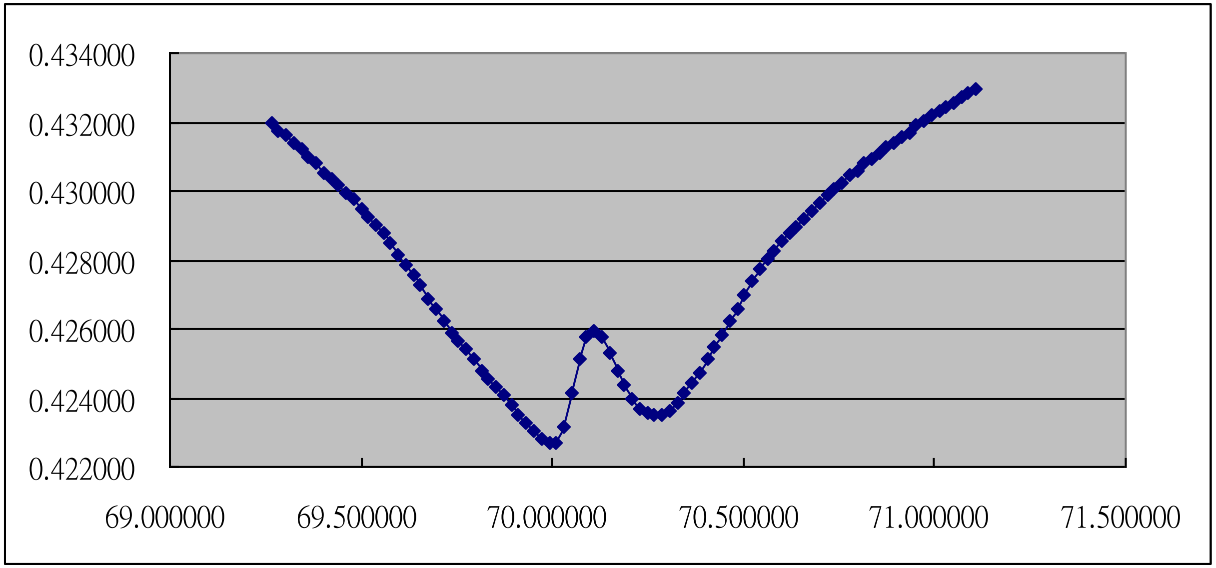
光梳雷射誘發透明→利用光梳雷射做量子干涉實驗



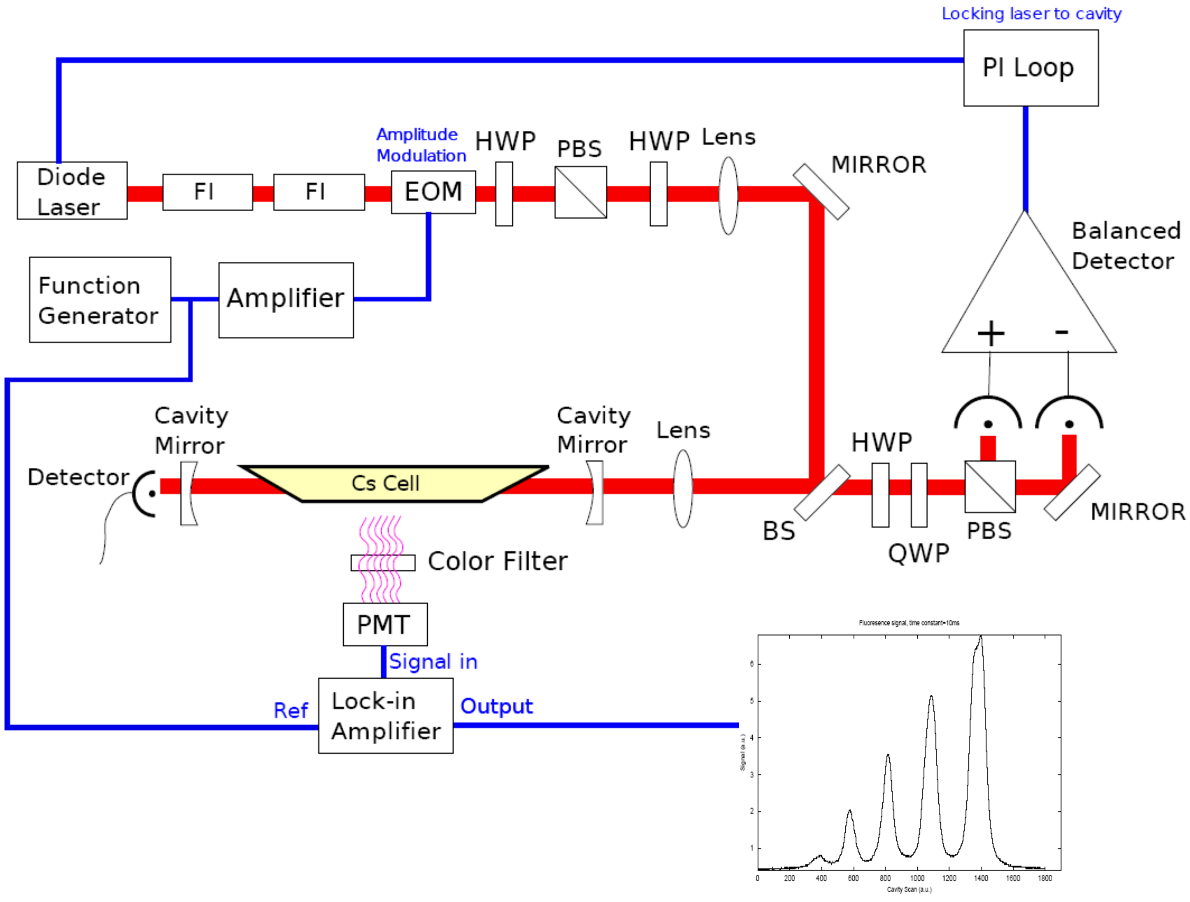


Probe CPT signal by CW laser





Cesium atom 6S→6D two-photon transition as a frequency reference on 884-885 nm wavelength regime



Cesium atom $6S_{1/2}$, F=4→$6D_{5/2}$, F'=6, 5, 4, 3, 2
Sampling time: 10 mS

Significance:

1. Reliable frequency reference of Ti:sapphire comb laser
2. Provide precise data for cesium atom hyperfine structure
3. Frequency reference of UV heterodyne spectroscopy project
4. Resolving the nuclear magnetic octupole

超冷銫原子

Cs MOT (under construction)

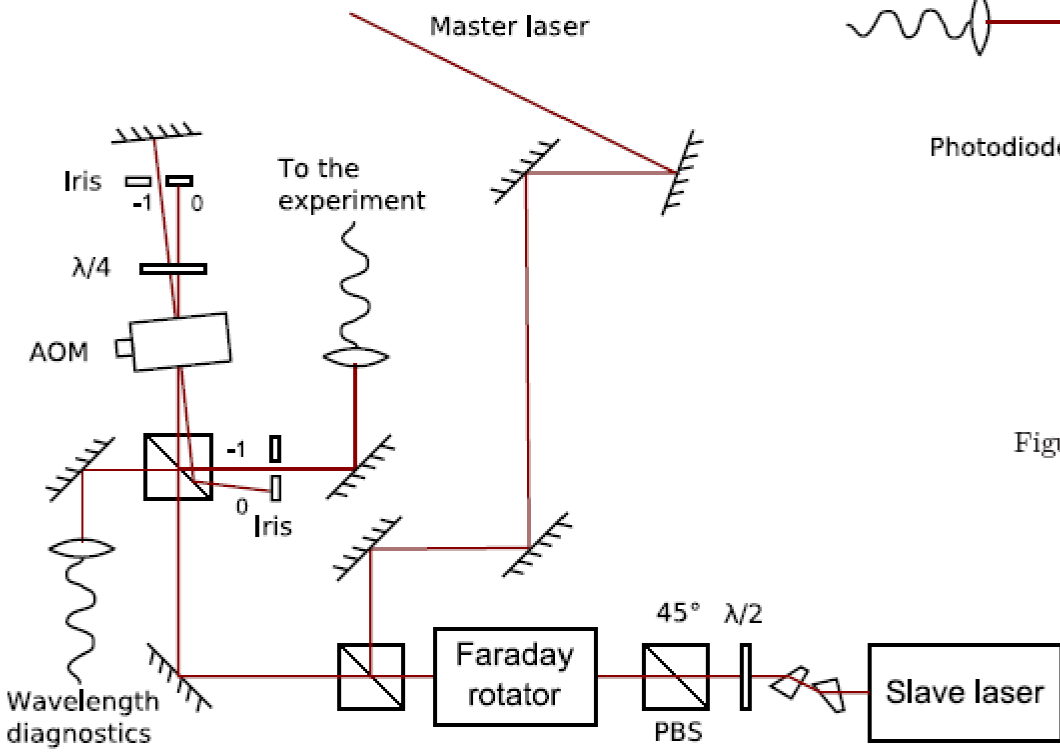


Figure 1: Trapping laser system optical setup.

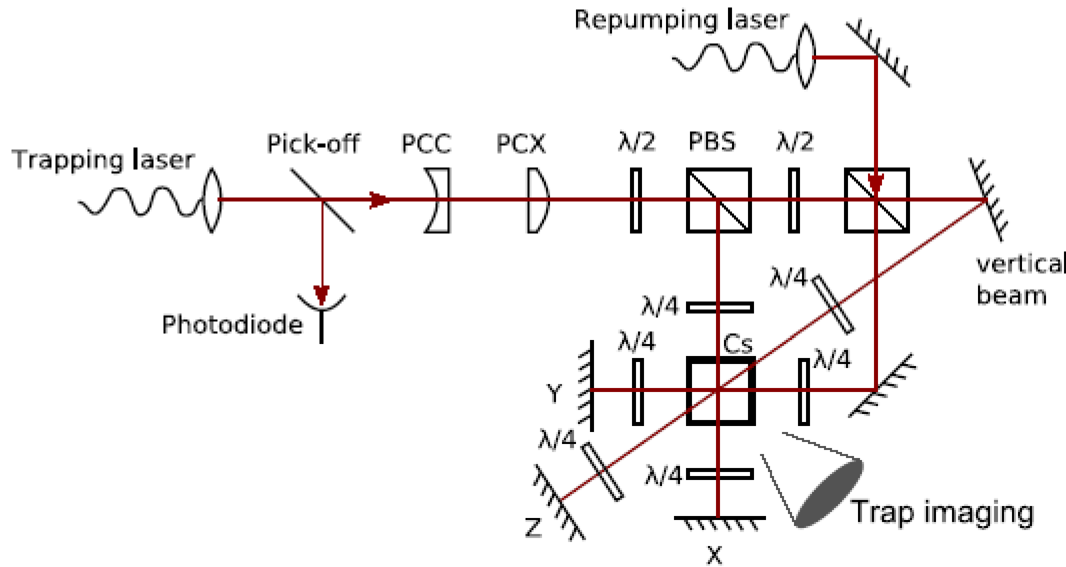
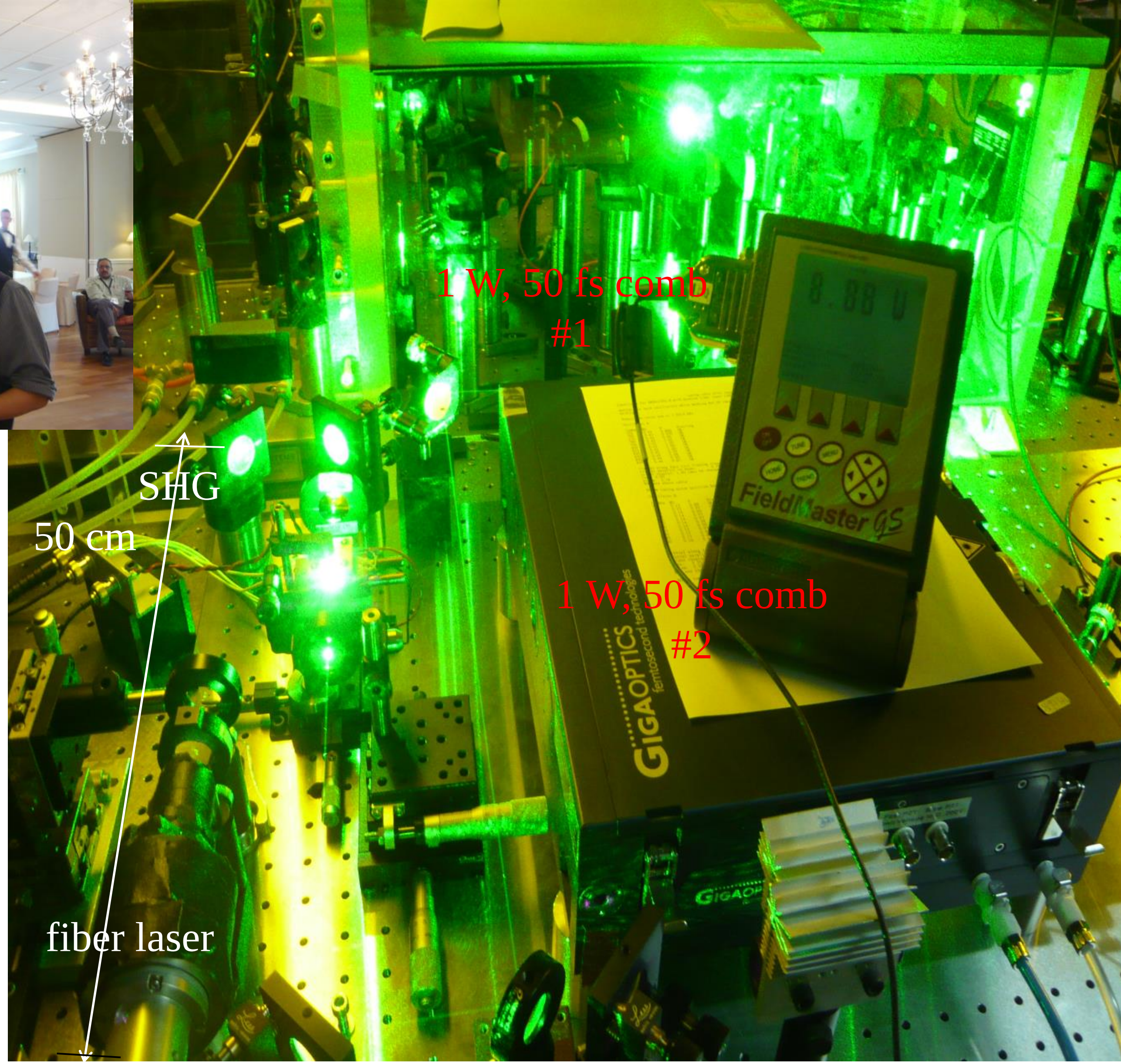


Figure 2: Trapping laser system optical setup.

fiber laser based two Ti:sapphire lasers which were presented in the conference of ICOLS



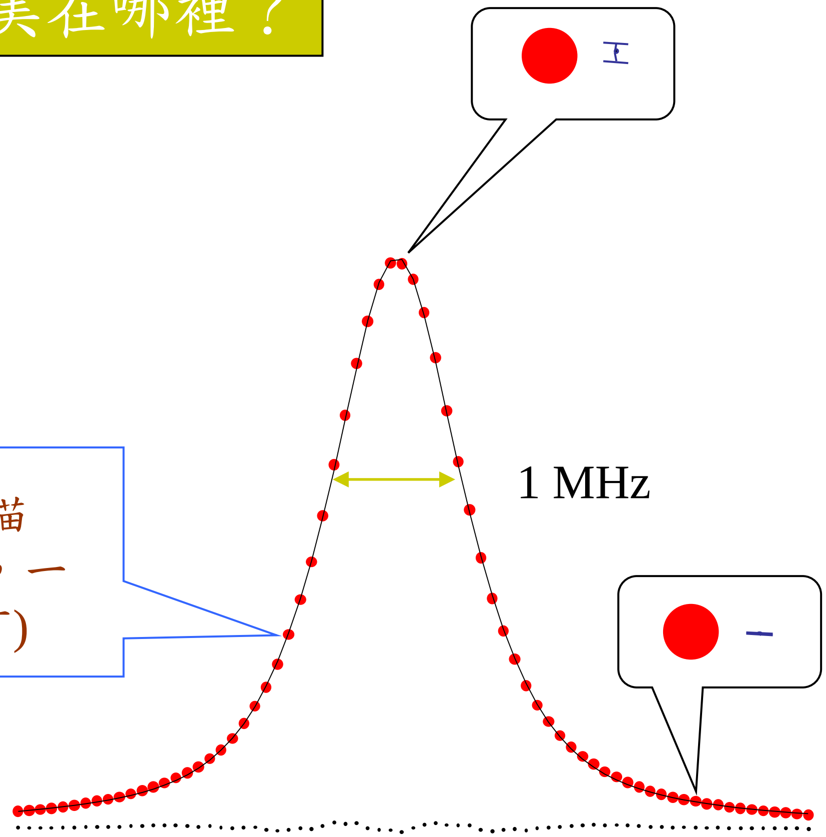
55 cm

green power: 8.88 W

精研高解析光譜就像是在畫一幅畫

中心頻率不準度: 900 Hz

吳建明博士作品美在哪裡？

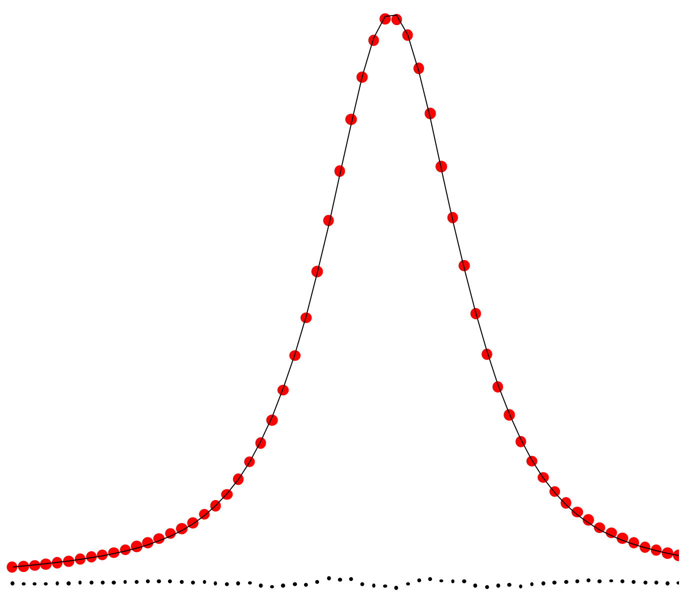


一小點一小點的描
(目前每步100 kHz，一
步 30 Hz亦無不可)

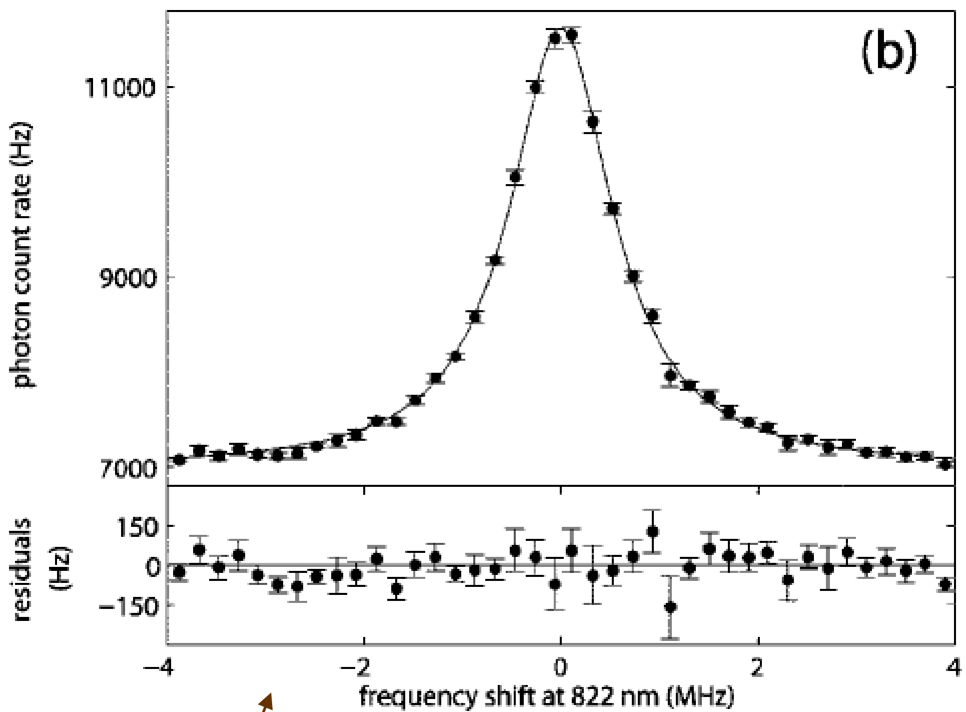
高度對稱的fitting殘餘

10^{-2}的fitting殘餘

我們與另外一份畫作的比較(同一條譜線)

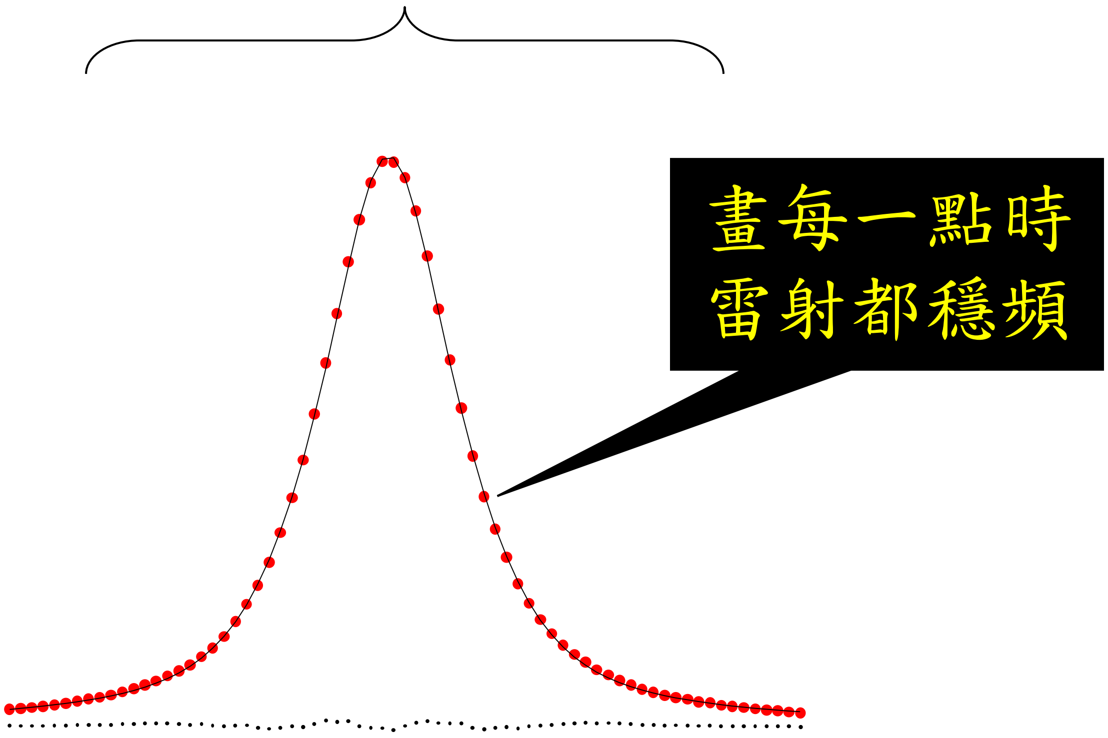


我們的作品



2005諾貝爾獎得主實驗室作品

最後得到高解析光譜



AMO的新發展來自於各個極限

極高能量(Peta Watt 例： 強場物理）

極冷（nano Kelvin 例：分子冷卻）

極瞬間（atto second 例：電子軌跡，化學反應）

極精密量測（mHz, 例：光鐘）

這些AMO成果如果有跨領域的應用，必發光發亮！！！