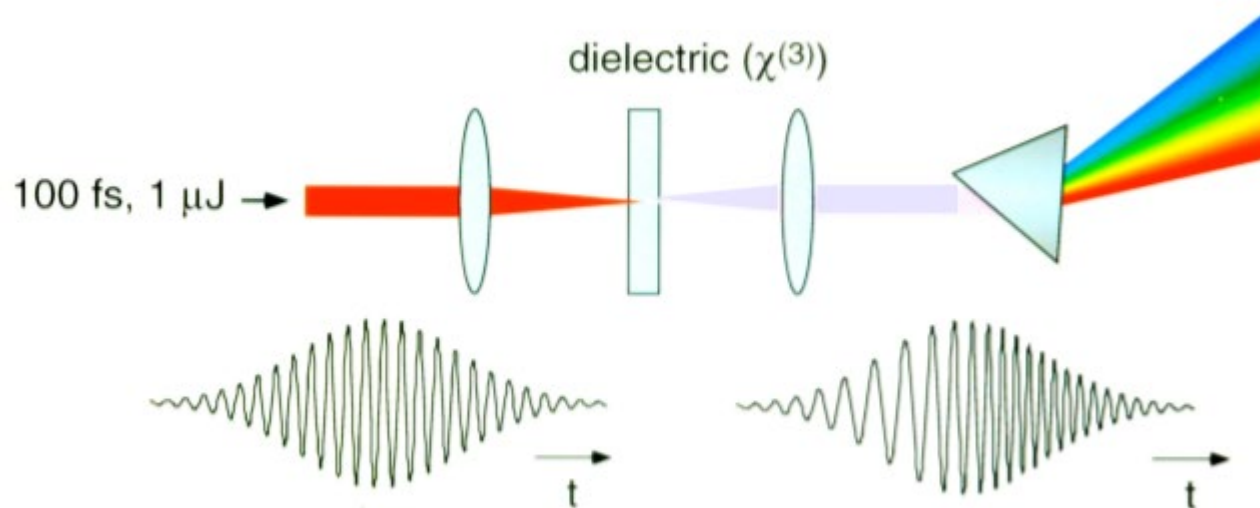


非线性光学



主讲：吴赛骏
助教：赵宇翔

saijunwu@fudan.edu.cn
yuxiangzhao21@fudan.edu.cn

选课须知

- 非线性光学：
 - 理解光影响光的现象
 - 运用光控制光的技术
 - 光学前沿技术的基础原理
- 准备课程：力学，光学、量子力学
- 拓展课程：电动力学+原子物理+固体物理
- 课程较短，积极参与讨论

Spring Semester

Feb. 18 – June 29, 2024

Week	SUN	MON	TUE	WED	THU	FRI	SAT	Notes
0	2/18	19	20	21	22	23	24	<p>9. Undergraduates: Online application for resits; Resits (Feb. 21 - 25); Registration (Feb. 25); Spring classes begin on Feb. 26.</p> <p>10. Graduates: Online application for resits; Resits (Feb. 21 - 25); Registration (Feb. 23); Spring classes begin on Feb. 26.</p> <p>11. Holiday breaks for Women's Day, Qing Ming Festival, Labor Day, Youth Day and Dragon Boat Festival are to be noticed by the University Office.</p> <p>12. May 17 - 18: Annual Sports Meeting. Classes do not meet on May 17.</p> <p>13. May 27: 119th Anniversary of the University (Academic Activities Week).</p> <p>14. Week 17: University Commencement.</p> <p>15. Week 16: Final examinations for General Education Courses; Weeks 17 - 18: Final Examinations.</p> <p>16. Spring semester (18 weeks, including final examination weeks) ends on June 29, 2024.</p> <p>17. Summer sessions (including various teaching activities for undergraduates, FIST courses and the Summer School) begin on June 30, 2024.</p> <p>18. Summer and winter vacations for graduates are to be arranged by the supervisors based on graduates' cultivation programs.</p> <p>19. Generally, summer and winter vacations for faculty and staff are to start one week later and end one week earlier than the schedules for students.</p>
1	25	26	27	28	29	3/1	2	
2	3	4	5	6	7	8	9	
3	10	11	12	13	14	15	16	
4	17	18	19	20	21	22	23	
5	24	25	26	27	28	29	30	
6	31	4/1	2	3	4	5	6	
7	7	8	9	10	11	12	13	
8	14	15	16	17	18	19	20	
9	21	22	23	24	25	26	27	
10	28	29	30	5/1	2	3	4	
11	5	6	7	8	9	10	11	
12	12	13	14	15	16	17	18	
13	19	20	21	22	23	24	25	
14	26	27	28	29	30	31	6/1	
15	2	3	4	5	6	7	8	
16	9	10	11	12	13	14	15	
17	16	17	18	19	20	21	22	
18	23	24	25	26	27	28	29	



课程

每周四上午3-5节: H2201



讨论/习题

隔周日下午3-5点: JWC213



期末考试 (半开卷)



学期论文

考核:

- 隔周作业: 30%, 提供一些答案提示, “认真、拓展”。
- 期末考试: 30%
- 期末论文及Pre: 40%

主讲: 吴赛骏 saijunwu@fudan助教: 赵宇翔 yuxiangzhao21@fudanOffice Hour: 每周日下午2-3点
(提前预约)

Elearning 资料

PHYS130029.01 非线性光学 > 文件

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- 原始讲义
- 参考书
- 项目资料

标题

创建时间

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修改人

大小



2024讲义

2024年2月
21日

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参考书

2024年2月
21日

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项目资料

2024年2月
21日

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原始讲义

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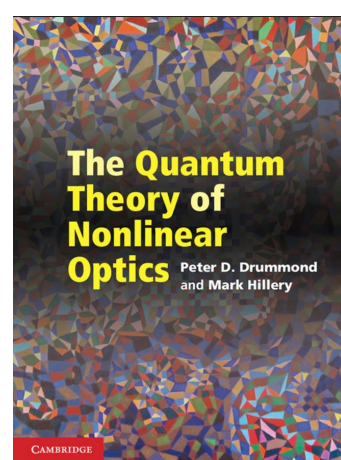
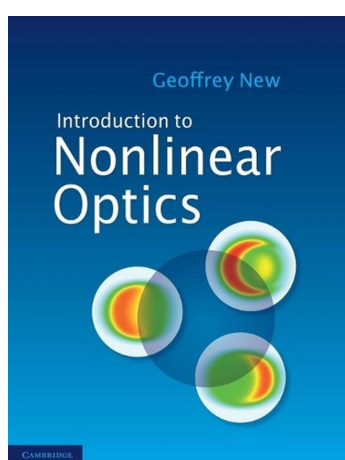
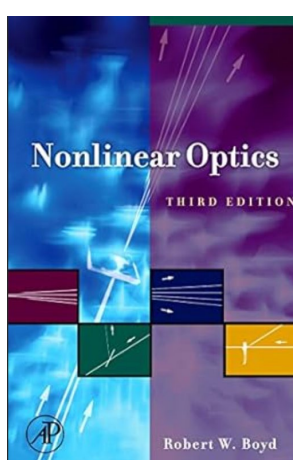
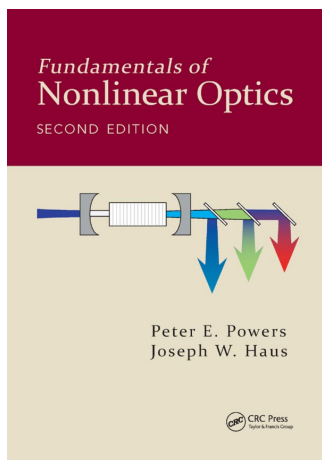
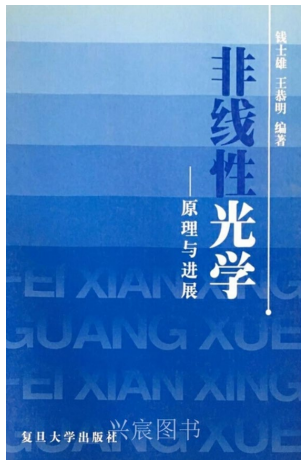
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2018讲义



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- PHYS130029.01 非线性光学 Nonlinear Optics
 - 2024讲义
 - 原始讲义
 - 参考书
 - Introduction to Nonlinear Optics
 - Nonlinear Optics
 - Quantum Theory of Nonlinear Optics
 - 项目资料

标题	创建时间	修改时间	修改人	大小	
非线性光学-原理与进展.pdf	15:57	15:57		36.6 MiB	✓
fundamentalsOfNL.pdf	2024年2月21日	2024年2月21日	吴赛骏	588.7 MiB	✓
Introduction to Nonlinear Optics	2024年2月21日			--	✓
Nonlinear Optics	14:29			--	✓
Quantum Theory of Nonlinear Optics	星期四			--	✓

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- 原始讲义
- 参考书
 - Introduction to Nonlinear Optics
 - Nonlinear Optics
 - Quantum Theory of Nonlinear Optics
- 项目资料
 - 光的Walk-off传播
 - 拉曼散射和激光冷却
 - 用Python探索光孤子
 - 相位匹配超级材料
 - 非线性极化张量和晶体点群
 - 高次谐波和阿秒激光

标题

创建时间

修改时间

修改人

大小



非线性极化张量和晶体点群

2024年2月21日

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高次谐波和阿秒激光

昨天

--



光的Walk-off传播

昨天

--



拉曼散射和激光冷却

星期一

--



相位匹配超级材料

2024年2月21日

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用Python探索光孤子

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--



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课程大纲

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1. 非线性光学：历史和前沿。原子(非)线性极化的经典图像，时域和频域分析，Kramer-Kronig 关系，超快和“超慢”的光学响应。从光和原子耦合到连续电介质的Maxwell波动方程。线性介质波动方程。非线性极化场的多频驱动产生和“前向辐射”，相位匹配条件,耦合波方程。
2. 线性波动光学要点回顾：原子气体线性极化张量的量子力学推导。磁光和二阶电光效应。极化率张量的对称性，吸收，相移，相速度，群速度，群速色散，线性双折射。极化率张量的局域场修正。
3. 非线性极化率张量：基本对称性，Neumann原理。晶体群分析初步，以晶体对称性约化极化率张量。
4. 和频过程：非线性耦合波方程的基本结构和解法。二阶和频过程的相位匹配：第一类和第二类。著名非线性晶体案例：LBO, BBO, KBBF。准相位匹配。脉冲光的自相关测量。深紫外辐射产生。
5. 差频过程：二阶差频过程基本解。参量下转换的光强关联。参量放大和参量振荡。THz辐射的产生和检测。啁啾脉冲放大技术。
6. 自相位调制：光强致折射率变化：光克尔效应。非线性薛定谔方程和光孤子。锁模激光，超连续产生，CEP稳定技术，光学频率梳。简并四波混频的光栅图像，动态全息及相位共轭成像技术。
7. 非线性光学响应的量子力学微扰计算方案：含时微扰理论。多光子吸收的费米黄金规则。极化率张量计算的图形规则。非线性极化的共振增强。混合态推广。
8. 原子气体中的 $(2n+1)$ 阶和频，真空紫外和极紫外辐射产生。
9. 拉曼和布里渊散射：分子的转动和振动激发：自发拉曼散射。激光冷却的概念。拉曼增益和受激拉曼散射。相干反Stokes拉曼散射技术。晶体声场激发：自发布里渊散射。声光效应和声光调制。
10. 超越微扰的非线性光学：二能级原子的Bloch方程和拉比振荡。Maxwell-Bloch耦合方程方法，自感应透明。强场物理：奇妙的高次谐波。阿秒光学简介。

线性和非线性

线性系统

$$\dot{x} = kx + f$$

解析求解，精确预测：通过傅里叶或者拉普拉斯变换，转化为线性代数方程

非线性系统

$$\dot{x} = kx + \beta xx + \gamma xxx + \dots + f$$

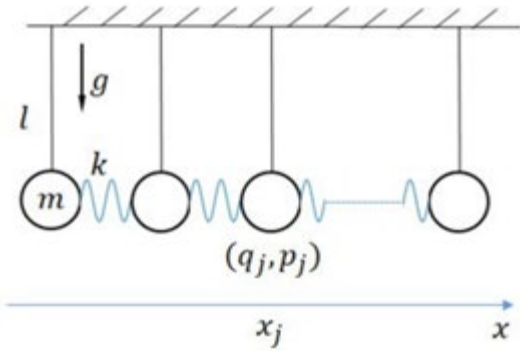
解析解法：找到特解，在特解附近做**微扰展开**

稳定解附近可以线性化

不稳定系统的动力学分叉，混沌，... 无法预测，例如三体问题

我们的世界是非线性的 (经典，量子)

耦合线性振子和波动方程



$$\dot{q}_j = p_j/m$$

$$\dot{p}_j = -m(\omega_0^2 q_j + \omega_c^2 (2q_j - q_{j-1} - q_{j+1})/2)$$



$$(\partial_t^2 - v_c^2 \partial_x^2)q(x, t) = -\omega_0^2 q(x, t).$$

非线性波

- 水波 (潮汐激流, 孤子波, ...)
- 声波 (冲击波, 快坏掉乐器的谐波产生)
- 微波电路信号处理 (脉冲控制脉冲)
- ...
- 光波? 似乎总是独立传播

电介质中的Maxwell方程

$$\left\{ \begin{array}{l} \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \cdot \mathbf{D} = \rho \end{array} \right. \quad \begin{array}{l} \mathbf{B} = \mu_0 \mathbf{H} \\ \mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P} \\ \rho = 0 \\ \mathbf{J} = 0 \end{array}$$

- 局域束缚电子，无自由电子
- 绝缘体，半导体
- 介质透明的必要条件

电极化矢量场

- $\mathbf{P}(\mathbf{r}, t) = \langle \sum_l \mathbf{d}^{(l)}(t) \delta^{(3)}(\mathbf{r} - \mathbf{r}_l) \rangle$
- $\mathbf{d}^{(l)}(t) = e\mathbf{q}^{(l)}(t)$ 是局域中性电荷体系的偶极矩, $\mathbf{q}^{(l)}(t)$ 是该处电荷相对运动坐标。
- $\langle \mathbf{d}^{(l)}(t) \rangle = \int_{-\infty}^t \boldsymbol{\alpha}(t - t') \mathbf{E}(\mathbf{r}_l, t')$,
因此 $\langle \mathbf{d}^{(l)}(t) \rangle = \boldsymbol{\alpha}(\omega) E(\mathbf{r}_l, \omega)$
- $\boldsymbol{\alpha}(\omega)$ 是局域电荷体系的线性响应系数, 用物质运动方程求解。

周期场的复表示

$$\mathbf{E}(\mathbf{r}, t) = \frac{1}{2} \int d\omega \mathbf{E}(\mathbf{r}, \omega) e^{-i\omega t} + c. c.$$

$$\mathbf{P}(\mathbf{r}, t) = \frac{1}{2} \int d\omega \mathbf{P}(\mathbf{r}, \omega) e^{-i\omega t} + c. c.$$

$$\mathbf{E}(\mathbf{r}, -\omega) = \mathbf{E}^*(\mathbf{r}, \omega)$$

$$\mathbf{P}(\mathbf{r}, -\omega) = \mathbf{P}^*(\mathbf{r}, \omega)$$

...

- 约定系数： $\frac{1}{2}$

电介质中的Maxwell方程

$$\left\{ \begin{array}{l} \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \cdot \mathbf{D} = \rho \end{array} \right. \quad \begin{array}{l} \mathbf{B} = \mu_0 \mathbf{H} \\ \mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P} \\ \rho = 0 \\ \mathbf{J} = 0 \end{array}$$

$$\mathbf{P}(\mathbf{r}, \omega) = \chi(\mathbf{r}, \omega) \mathbf{E}(\mathbf{r}, \omega)$$

电介质中的非线性Maxwell方程

$$\left\{ \begin{array}{l} \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \\ \nabla \cdot \mathbf{B} = 0 \\ \nabla \cdot \mathbf{D} = \rho \end{array} \right.$$

$$\mathbf{B} = \mu_0 \mathbf{H}$$

$$\mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P}$$

$$\rho = 0$$

$$\mathbf{J} = 0$$

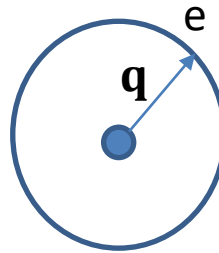
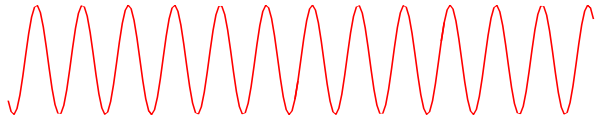
超极化率
(hyperpolarizability)

$$\langle \mathbf{d}(\omega) \rangle = \alpha(\omega) \mathbf{E}(\omega) + \beta(\omega; \omega_1, \omega_2) \mathbf{E}(\omega_1) \mathbf{E}(\omega_2) + \gamma(\omega; \omega_1, \omega_2, \omega_3) \mathbf{E}(\omega_1) \mathbf{E}(\omega_2) \mathbf{E}(\omega_3) + \dots$$

$$\mathbf{P} = \chi^{(1)} \mathbf{E} + \chi^{(2)} \mathbf{E} \mathbf{E} + \chi^{(3)} \mathbf{E} \mathbf{E} \mathbf{E} + \dots$$

如何实现非线性振荡？

$$\mathbf{H} = \frac{\mathbf{p}^2}{2m} + V(\mathbf{q}) + e\mathbf{E} \cdot \mathbf{q}$$



An oscillatory electric field drive the Displacement between electron and ion thereby generating $\mathbf{d} = -\langle e\mathbf{q} \rangle$

- Drive the displacement of the swing from equilibrium

如何实现非线性振荡？



- 方法一：强力， $F \sim \eta \times mg$
- 方法二：共振， $F = F_0 \sin(\omega t + \varphi), \omega \sim \omega_0$

$$F_0 \rightarrow F_0 Q, Q = \frac{\omega}{\Gamma}$$

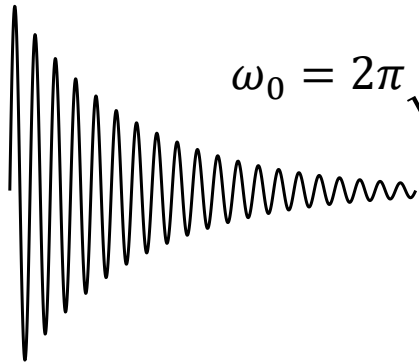


阻尼

ω
→

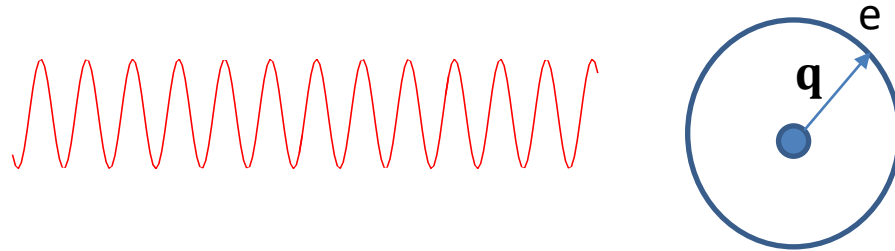
$$q(t) \approx q_0 \sin \omega_0 t e^{-\frac{\Gamma}{2}t}$$

$$\omega_0 = 2\pi \sqrt{\frac{g}{L}}$$



用自由振荡性质定义本征频率和阻尼

让原子成为一个非线性振子



- 氢原子模型: $E_a \sim 10^{10} V/m$

$$\mathbf{H} = \frac{\mathbf{p}^2}{2m} + V(\mathbf{q}) + e\mathbf{E} \cdot \mathbf{q}$$

- 光电场:

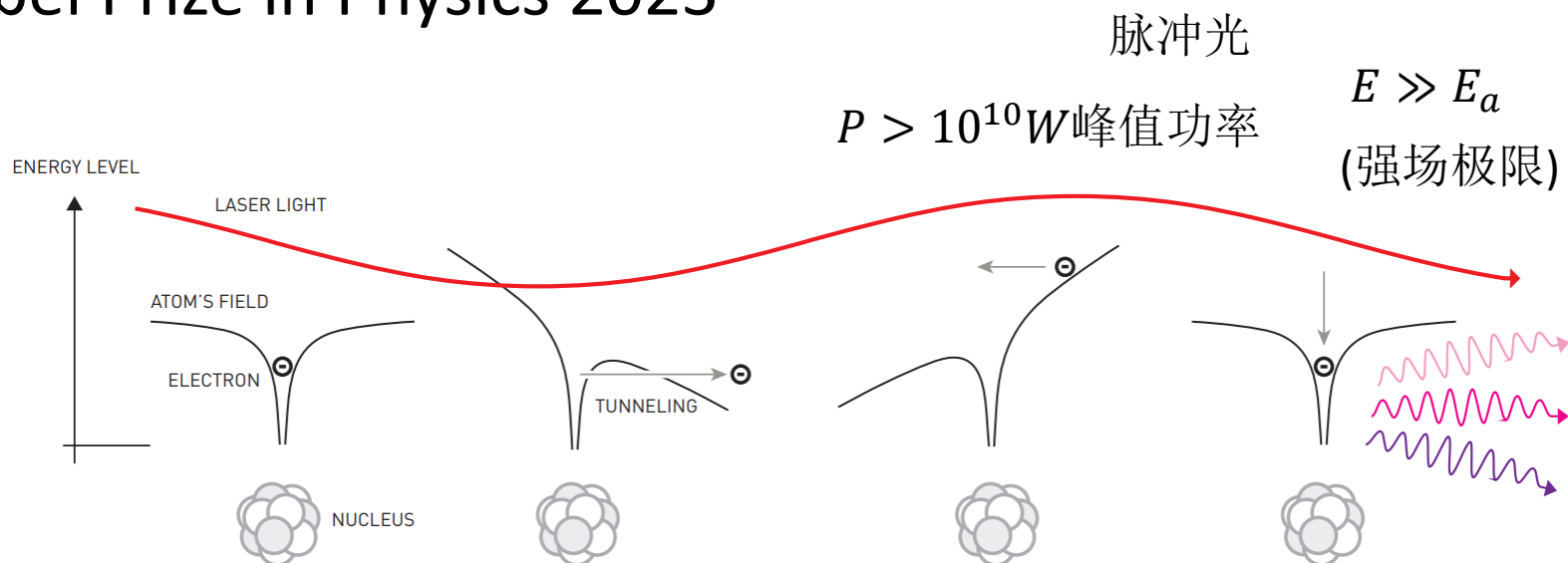
$$I = \frac{P}{A} = \varepsilon_0 |E|^2 c \rightarrow E \sim \sqrt{\frac{P}{\varepsilon_0 A c}} = \left(\frac{\mu_0}{\varepsilon_0}\right)^{1/4} \sqrt{\frac{P}{A}} = \sqrt{377 \Omega \times \frac{P}{A}}$$

$$P = 1W, A = (1\mu m)^2, E \approx 2 \times 10^7 V/m$$

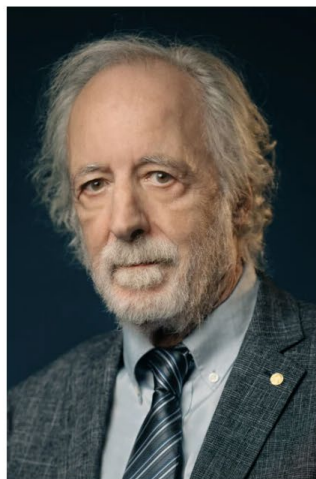
Z_0 Vacuum impedance

$P = 1W$, 是激光平均功率的合理值

Nobel Prize in Physics 2023



To Pierre Agostini, Ferenc Krausz and Anne L'Huillier "for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter"



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Pierre Agostini
Prize share: 1/3



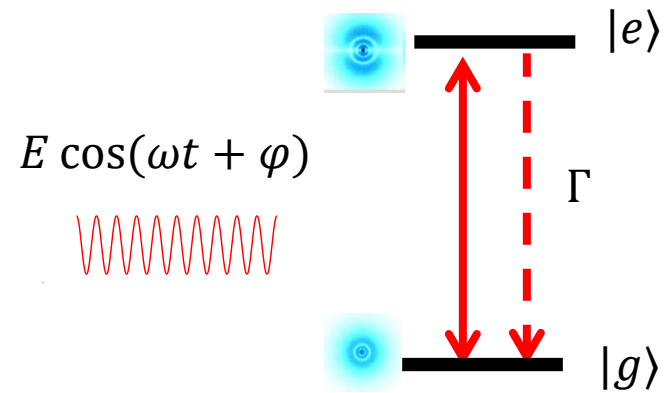
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Ferenc Krausz
Prize share: 1/3



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Anne L'Huillier
Prize share: 1/3

让原子成为一个非线性振子

- $Q = \frac{\omega_{eg}}{\Gamma} \sim 10^8$, 品质优越
- $E \sim E_a \rightarrow EQ \sim E_a, I_s \sim \frac{|E_a|^2}{Q^2 Z_0} \approx 10 \text{ mW/cm}^2$
↑
“饱和光强”



问题, $\langle d(t) \rangle$ for free atom:

$$|\psi\rangle = (|g\rangle + |e\rangle e^{-i\omega_{eg}t})/\sqrt{2}$$

n-阶超极化率的微扰计算基本方法 (复杂)

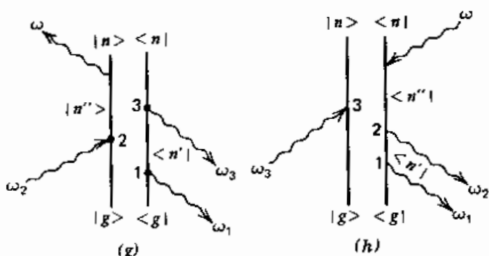
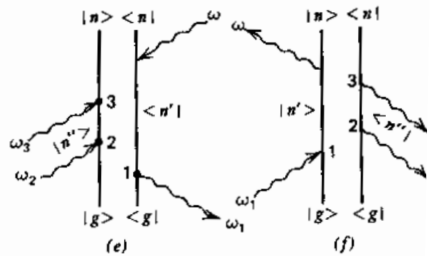
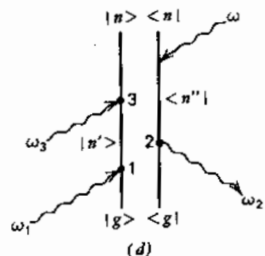
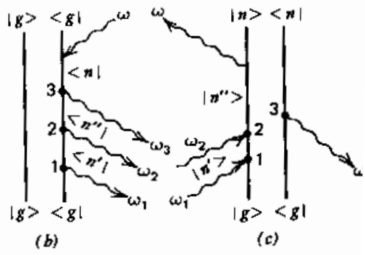
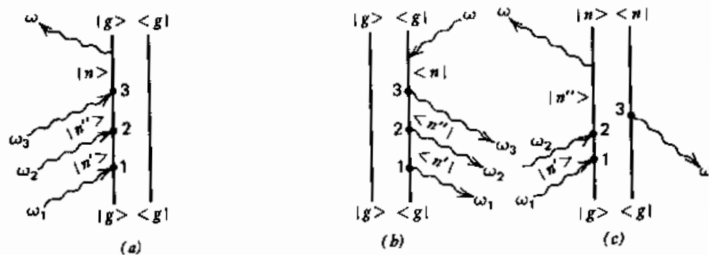


Fig. 2.3 The eight basic diagrams for $\rho^{(3)}(\omega = \omega_1 + \omega_2 + \omega_3)$.



沈元壤 先生

$\gamma^{(n)} \sim$

$$\sum_{g, a, \dots, n} \left\{ \frac{|n'\rangle \langle n'| \mathcal{H}(\omega_n) |m\rangle \cdots \langle b| \mathcal{H}(\omega_2) |a\rangle \langle a| \mathcal{H}(\omega_1) |g\rangle}{\hbar^n \left(\sum_{i=1}^n \omega_i - \omega_{n'n} + i\Gamma_{n'n} \right) \left(\sum_{i=1}^{n-1} \omega_i - \omega_{mn} + i\Gamma_{mn} \right) \cdots} \right. \\ \left. \times \frac{\rho_{gg}^{(0)} \langle g| \mathcal{H}(\omega_3) |c\rangle \cdots \langle | \mathcal{H}(\omega_{n-1}) |n\rangle \langle n|}{(\omega_1 + \omega_2 + \omega_3 - \omega_{bc} + i\Gamma_{bc})(\omega_1 + \omega_2 - \omega_{bg} + i\Gamma_{bg})(\omega_1 - \omega_{ag} + i\Gamma_{ag})} \right\} \quad (2.19)$$

$$\propto e^{-i(\omega_1 + \omega_2 + \cdots + \omega_n)t}$$

从超极化率到宏观极化率 (相当繁琐)

局域场修正因子

$$\chi^{(n)} \approx \eta^{(n)} \rho(\mathbf{r}) \gamma^{(n)}, \text{ n+1阶张量, } 3^{n+1} \text{ 个分量}$$

用法:

$$P_{\mu}(\omega) \sim \sum_{\omega = \sum \omega_n} \sum_{a_j = x, y, z} \chi_{\mu a_1 \dots a_n}^{(n)}(\omega; \omega_1, \dots, \omega_n) E_{a_1}(\omega_1) \dots E_{a_n}(\omega_n)$$

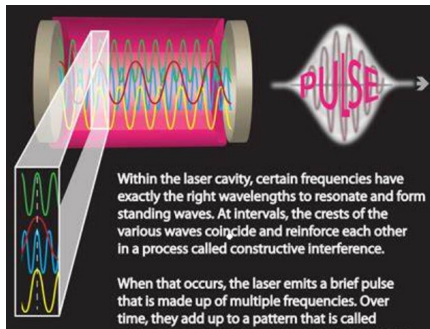
非线性波动方程, 耦合波方程...

$$\nabla^2 \mathbf{E} - \frac{1}{c^2} \partial_t^2 (\boldsymbol{\epsilon}_r * \mathbf{E}) \approx \mu_0 \partial_t^2 \mathbf{P}^{NL}, \quad \boldsymbol{\epsilon}_r = 1 + \chi^{(1)}$$

$$\mathbf{E}(\mathbf{r}, t) = \frac{1}{2} \sum A_j(\mathbf{r}, t) e^{i\mathbf{k}_j \cdot \mathbf{r} - \omega_j t} + c. c.$$

本课程目标

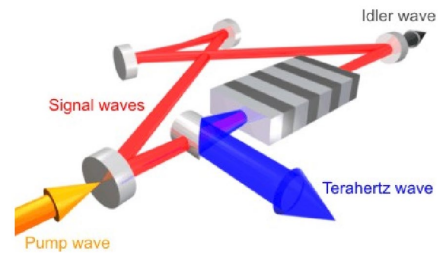
- 面向核心机制，精简讨论
- 适当勾画细节
- 面向前沿技术



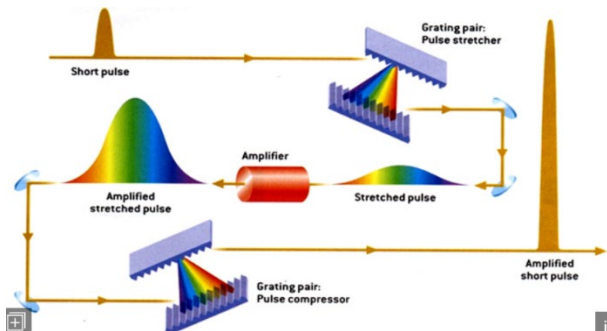
超快激光



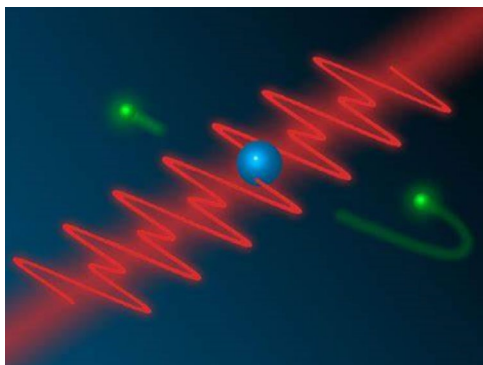
高效非线性频率转换



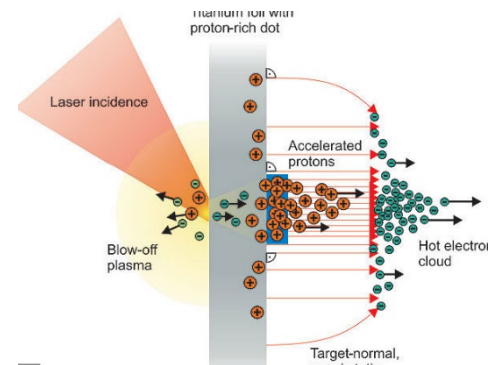
THz光源



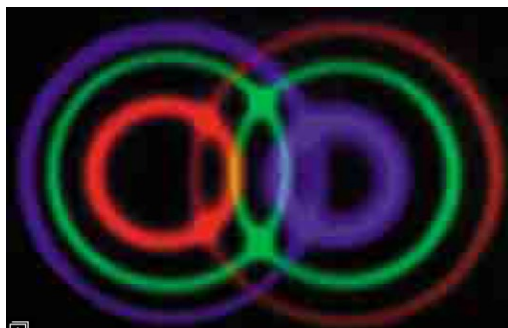
啁啾脉冲放大/强场物理



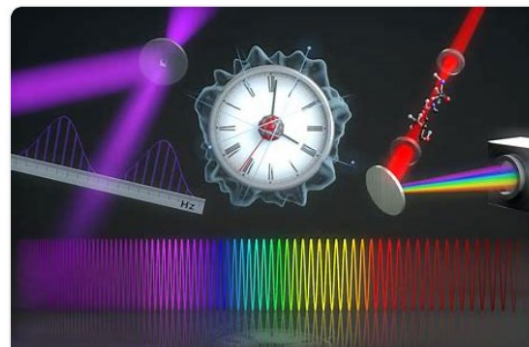
高次谐波/阿秒脉冲



激光加速



量子光源



光梳/光频标



History

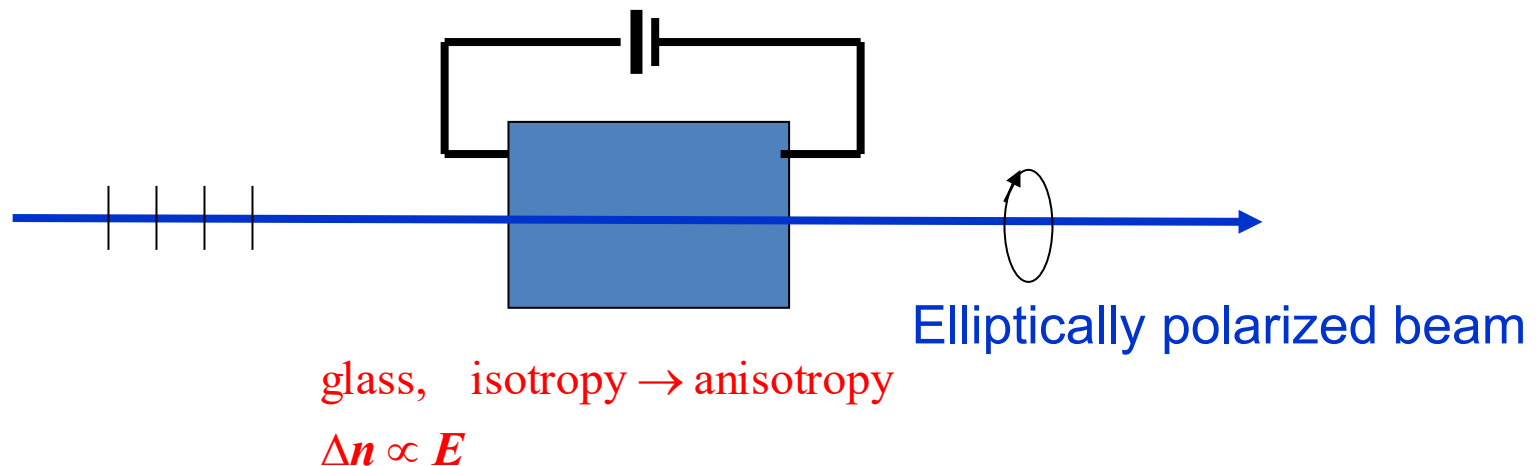
(Part of ppt from online material by
other professors)

电光效应

Pockels effect :

1893 by F. C. Pockels (Germany)

对晶体施加电场，可以产生双折射
应用：高速光开关



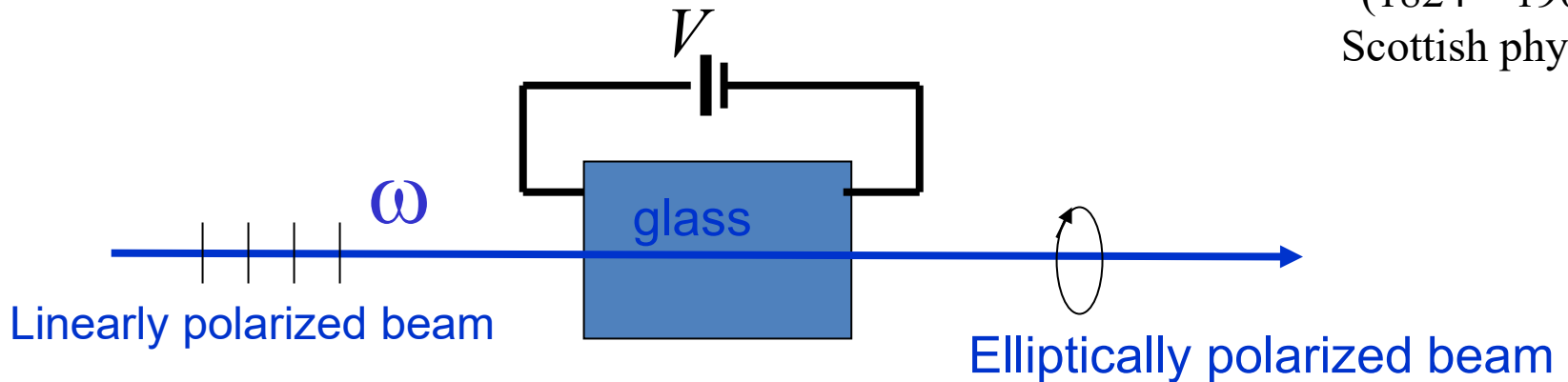
电光Kerr 效应:

1875 by John Kerr

双折射率的变化和场强平方成正比



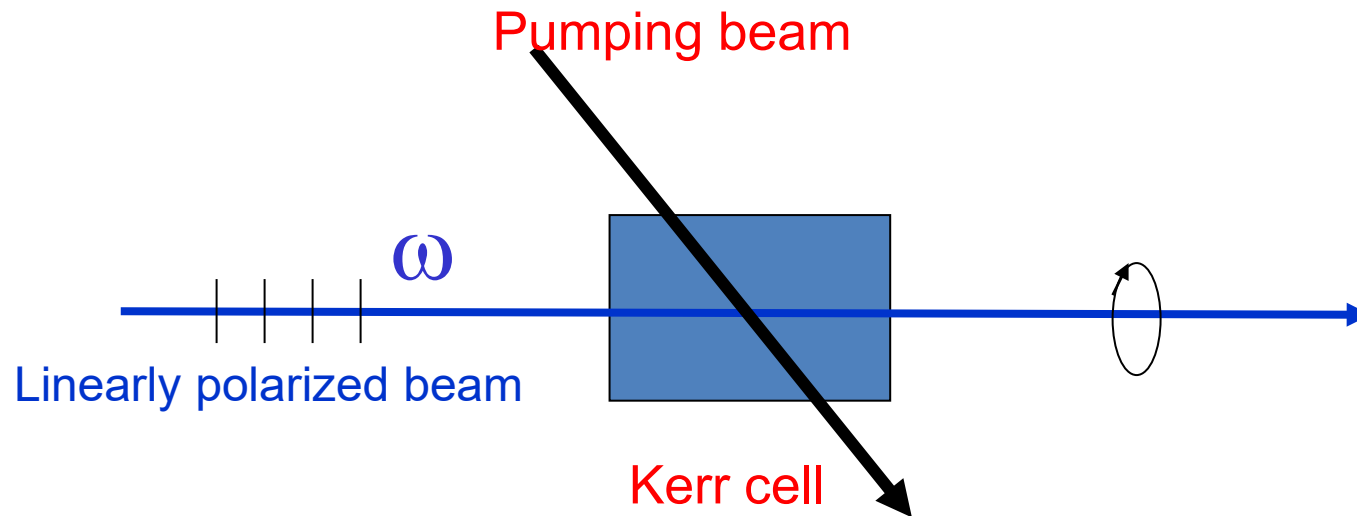
John Kerr FRS
(1824 – 1907),
Scottish physicist



glass, isotropy \rightarrow anisotropy

$$\Delta n \propto E^2$$

光Kerr效应



折射率: $n = n_0 + n_2 I$

拉曼效应

Nobel Prize in 1930

by C. V. Raman in 1928.

散射光频率出现分子振动频率边带



C. V. Raman
(1888-1970)
Indian physicist

布里渊散射

by Léon Nicolas Brillouin in 1922.

散射光出现晶格声场频率边带



Léon Nicolas Brillouin
(1889-1969)
French physicist

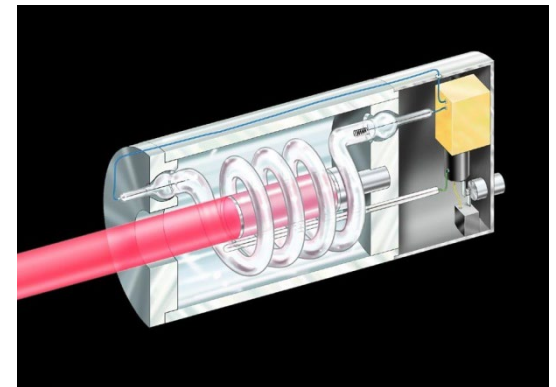
连续激光的发明

- (1951) **V. A. Fabrikant** "A method for the application of electromagnetic radiation (ultraviolet, visible, infrared, and radio waves)" patented in Soviet Union.
- (1958) **Townes and Arthur L. Schawlow**, "Infrared and Optical Masers," Physical Review
- (1958) **Gordon Gould** definition of "Laser" as "Light Amplification by Stimulated Emission of Radiation"
- (1960) **Schawlow and Townes**
U. S. Patent No. 2,929,922
- *****(1960) Theodore Maiman Invention of the first Ruby Laser**

- 增益介质
- 频率选择
- 受激振荡



Theodore Maiman
1927-2007
American engineer
and physicist



我国第一台激光器是中国科学院长春光学精密机械研究所王之江领导设计并和邓锡铭、汤星里、杜继禄等人共同实验研制成的，它的完成仅仅比梅曼发明激光器晚了一年，这与当时长春光机所的王之江、邓锡铭等年轻专家们及时提出这一前沿的科学研究课题有关。在1958年前后，中国科学院电子学研究所的黄武汉研究员通过阅读国外学术刊物，了解到国外微波量子放大器的研究信息，率先在国内开始了红宝石微波量子放大器的研制工作，并在1959年底做出了液氮温度下的10 cm 波段和3 cm波段的量子放大器。当时中科院长春光机所的研究人员受黄武汉工作的启发，开始构想做光量子放大器（当时还不叫激光器），这时梅曼的第一台红宝石激光器还没有诞生。

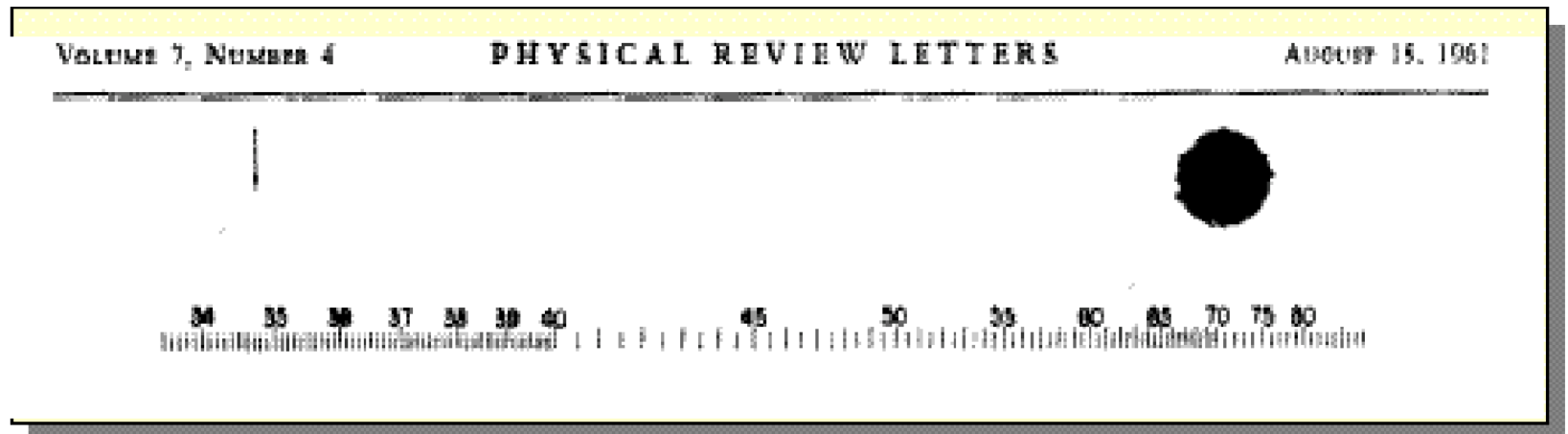
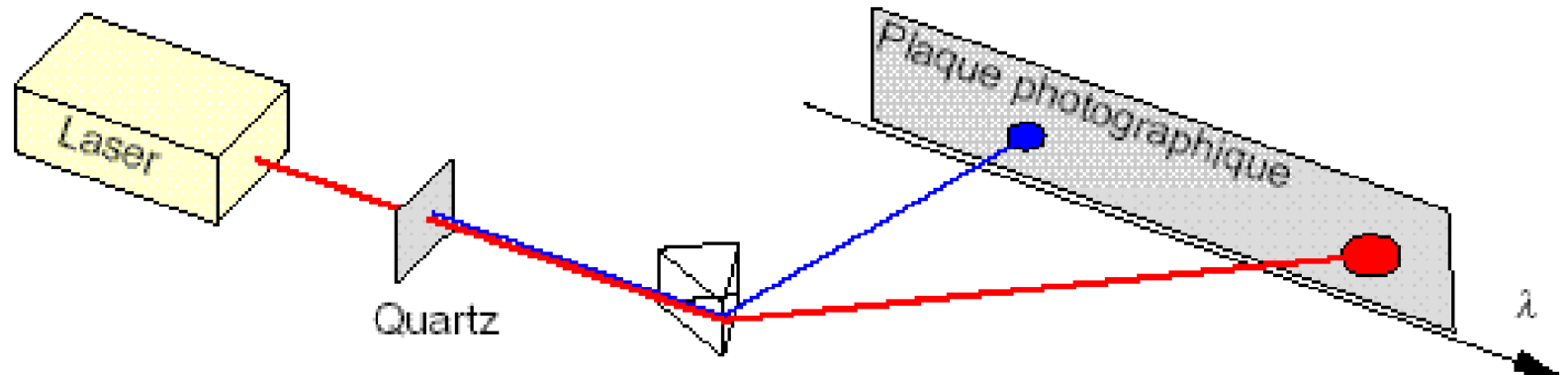


图2 中国第一台红宝石激光器研制者王之江院士及激光器

虽然我国研制的第一台红宝石激光器比国外晚了近一年，但是有许多特色直到今天仍被称道。

第一个非线性激光实验

Franken et al., Phys. Rev. Lett. 7, 118 (1961)



锁模脉冲激光

$$E(t) = E_0 \sum_j f(t - jT_{\text{rep}}) e^{-i\omega_0 t} \quad \longleftrightarrow \quad E(\omega) = E_0 F(\omega) \sum_j \delta(\omega - j\omega_{\text{rep}} - \omega_{\text{off}})$$

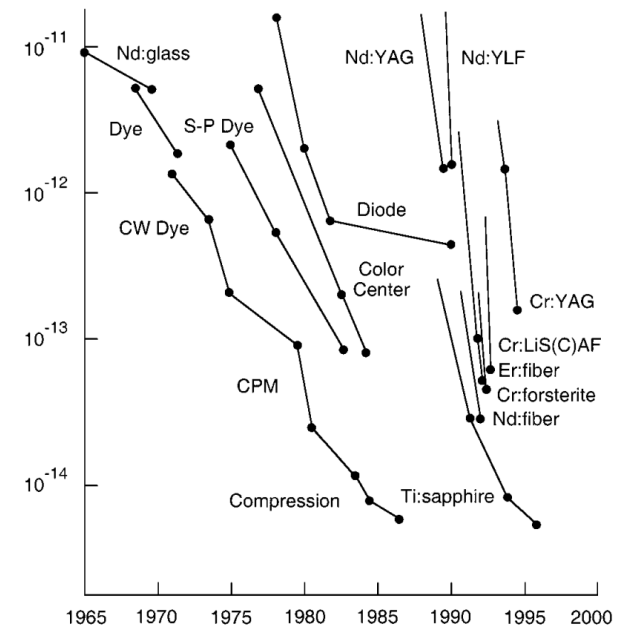
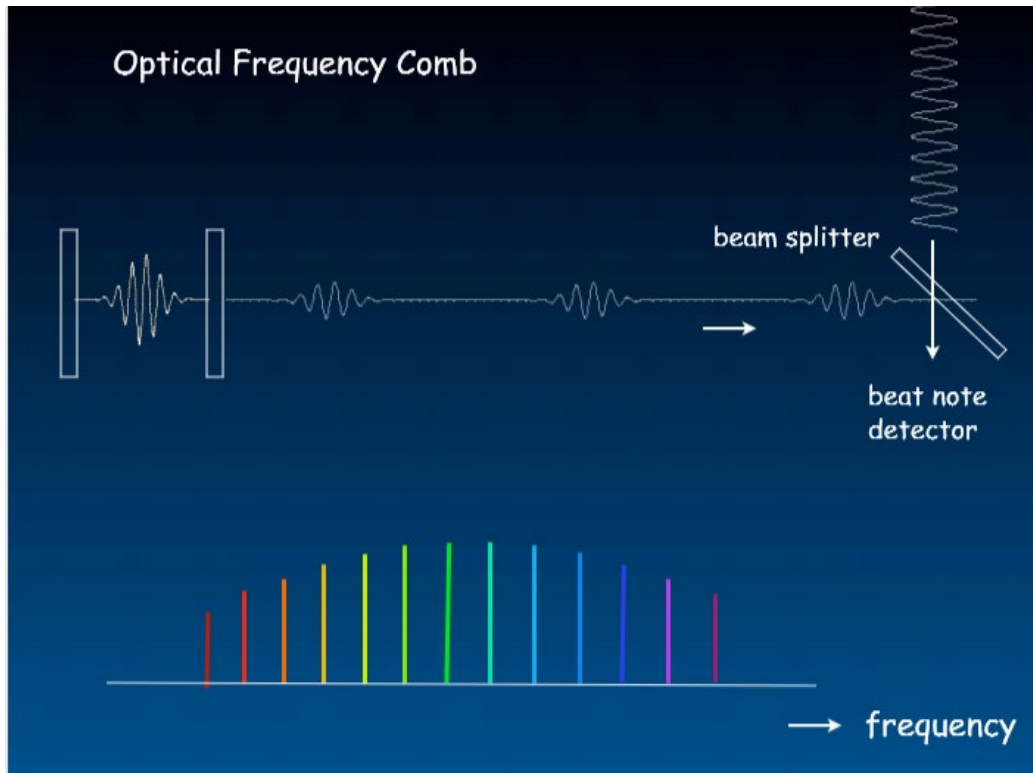
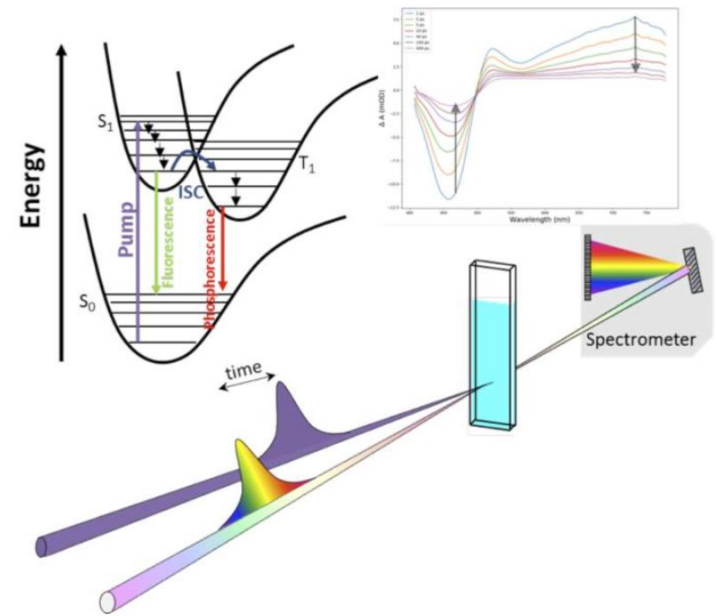
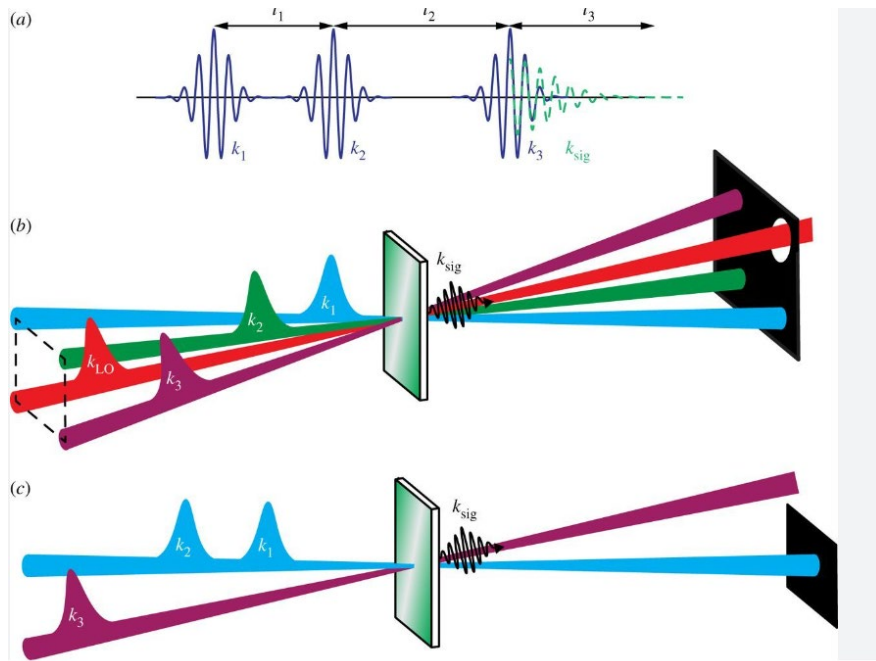


Fig. 1. Pulsewidths of different laser systems achieved year by year.

超快非线性光谱学： 以时间分辨光谱探究物质运动规律



Bloombergen, Shen, Weiner, Mukamel, ...

连续激光：（非线性）精密光谱

饱和吸收，光学泵浦，激光冷却，...

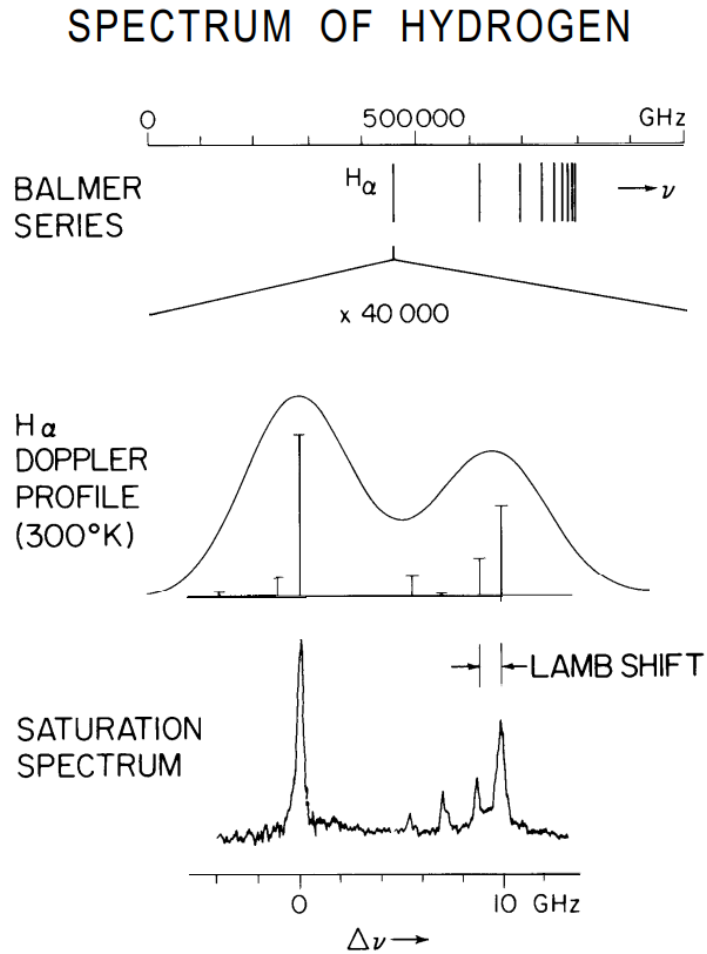
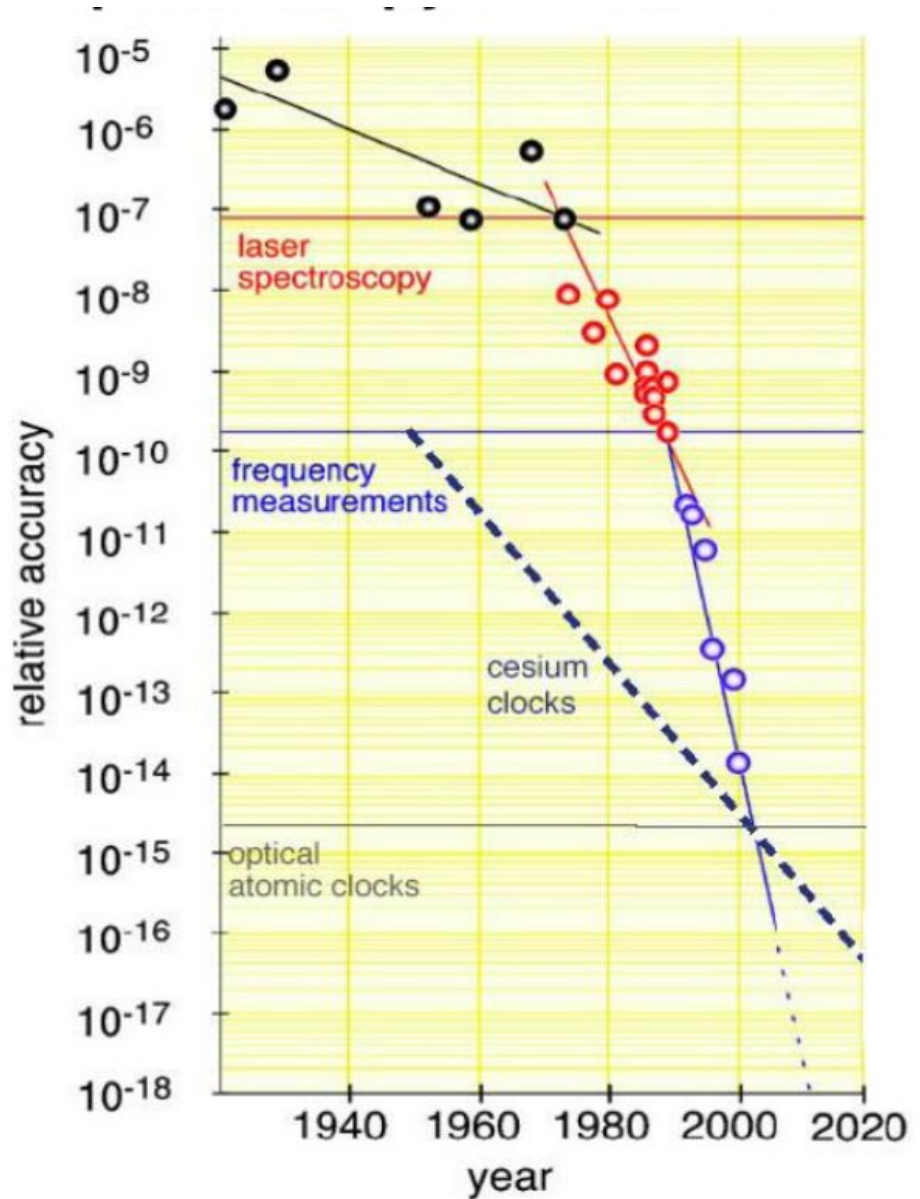


Fig. 7. Hydrogen Balmer series and fine structure of the red line H α , resolved by saturation spectroscopy.

Schawlow, Hansch, ...





The Nobel Prize in Physics 1981



Photo from the Nobel Foundation archive.

Nicolaas
Bloembergen

Prize share: 1/4



Photo from the Nobel Foundation archive.

Arthur Leonard
Schawlow

Prize share: 1/4

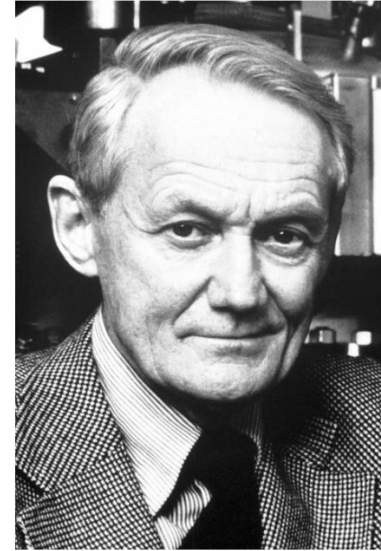


Photo from the Nobel Foundation archive.

Kai M. Siegbahn

Prize share: 1/2

The Nobel Prize in Physics 1981 was divided, one half jointly to Nicolaas Bloembergen and Arthur Leonard Schawlow "**for their contribution to the development of laser spectroscopy**" and the other half to Kai M. Siegbahn "for his contribution to the development of high-resolution electron spectroscopy"





飞秒化学

Nobel Prize in Chemistry 1999

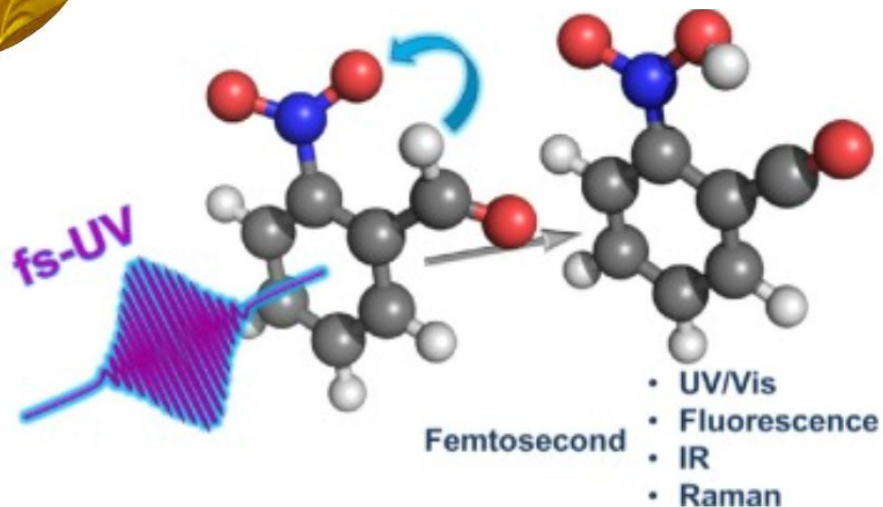
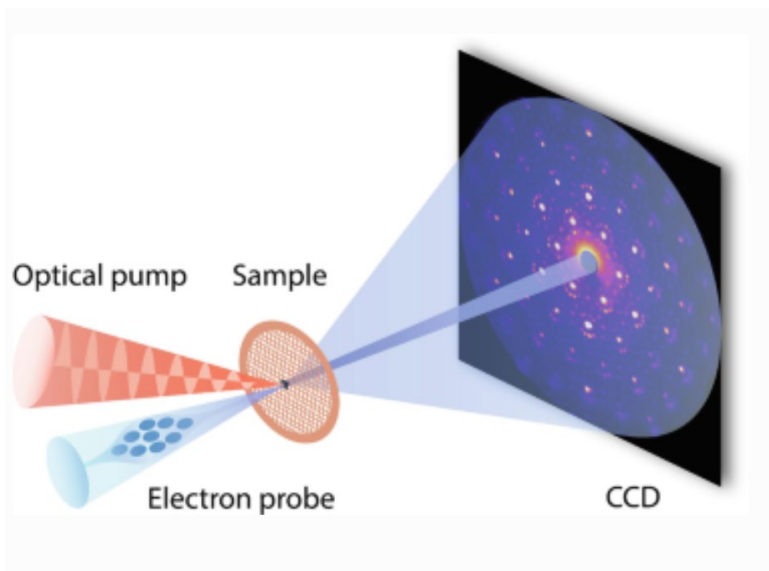


Photo from the Nobel Foundation archive.

Ahmed H. Zewail

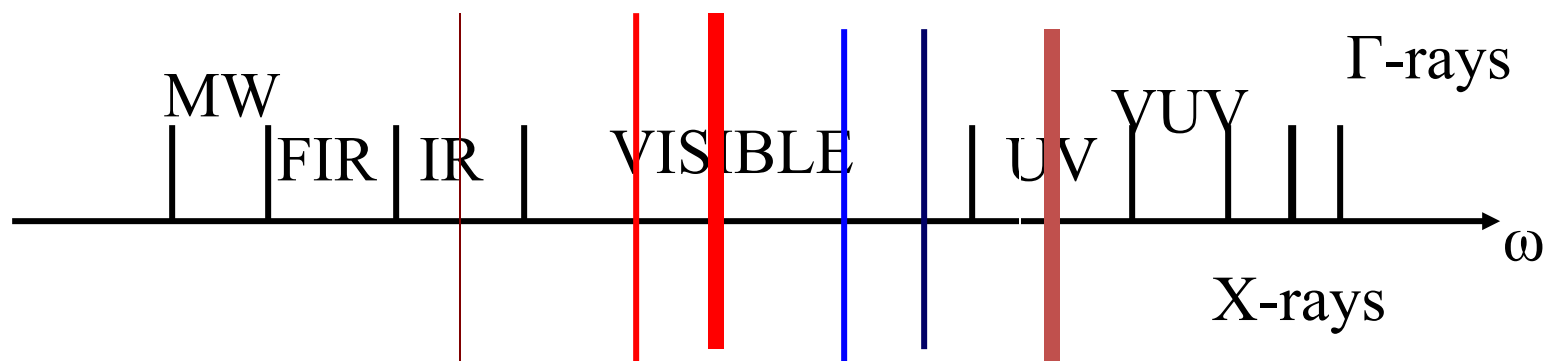
Prize share: 1/1



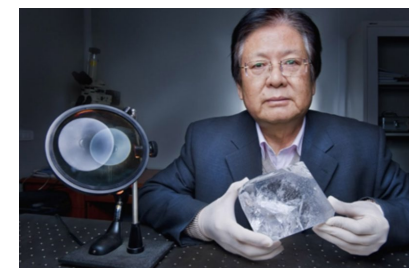
“For his studies of the transition states of chemical reactions using femtosecond spectroscopy”

激光频率合成, 功率放大

- 激光工作介质带宽有限
- 非线性频率变换极端重要



二阶非线性晶体极端重要：中国贡献 LBO, BBO, KBBF,...



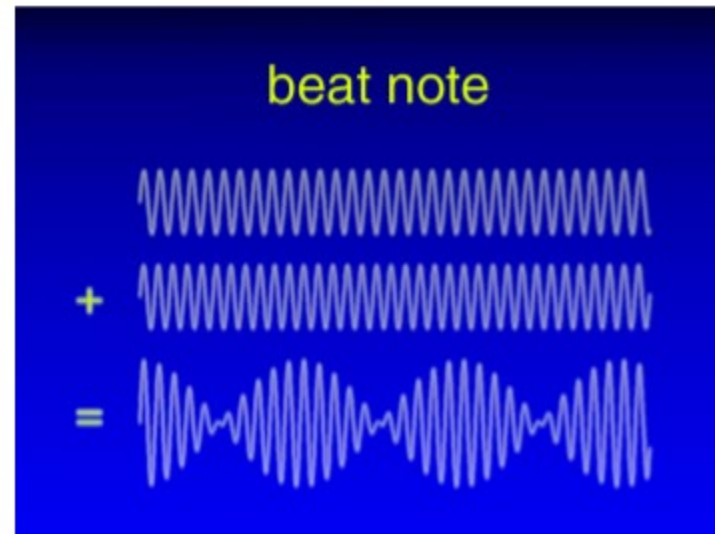
陈创天 教授
1937-2018

梦想：直接测量光学频率

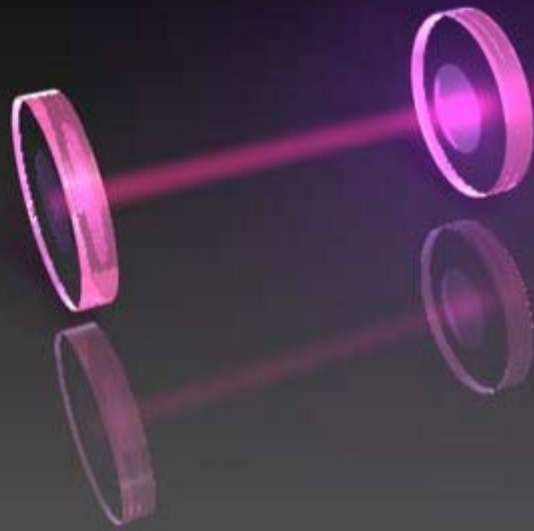
A dream... (Ali Javan, 1963)

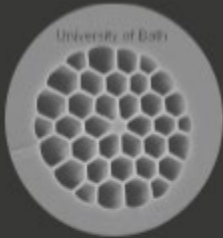


Extend microwave frequency counting techniques into the optical region.

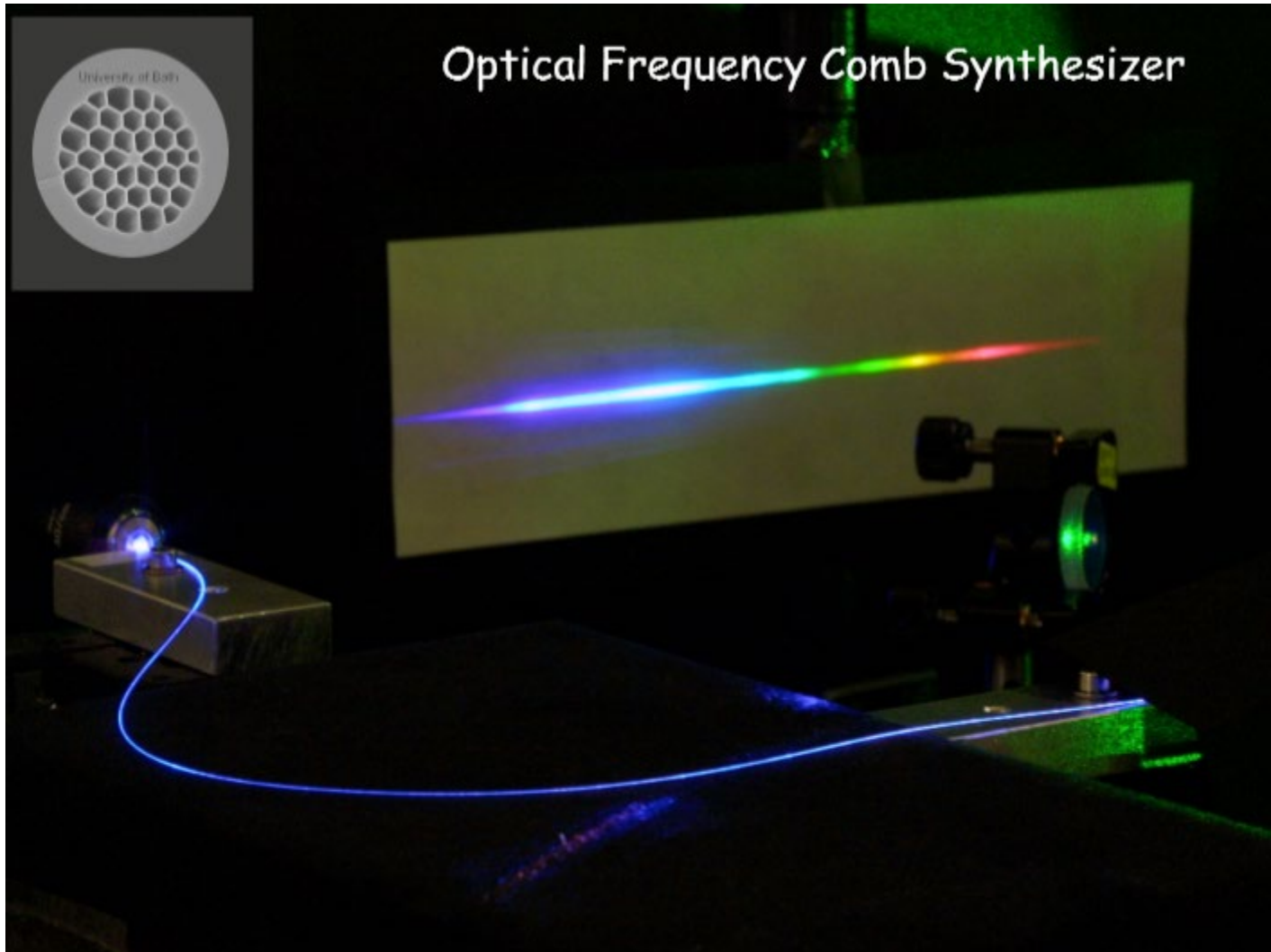


Optical frequency comb

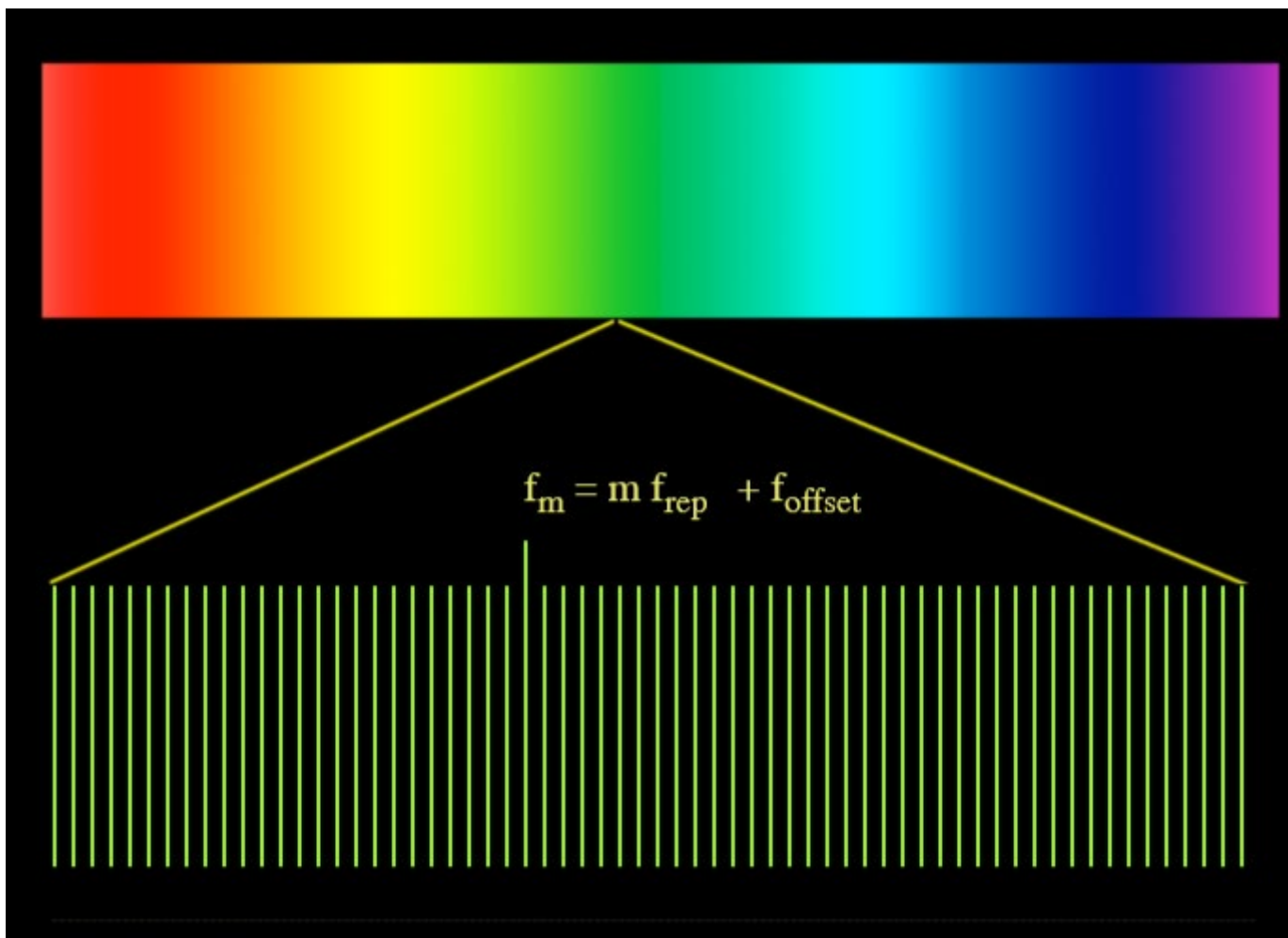




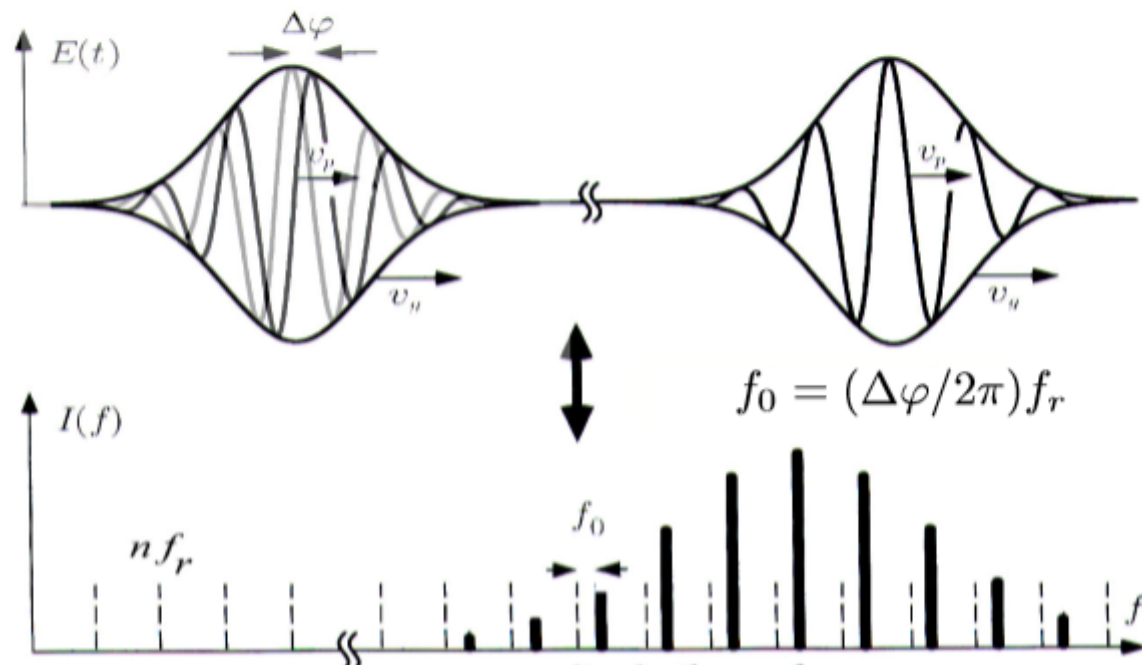
Optical Frequency Comb Synthesizer



通过将 f_{offset} 锁定到 f_{rep} , 并以原子标准稳定 f_{rep} , 光梳所有的梳齿频率就都完全确定了



carrier-envelope phase slips and offset frequency

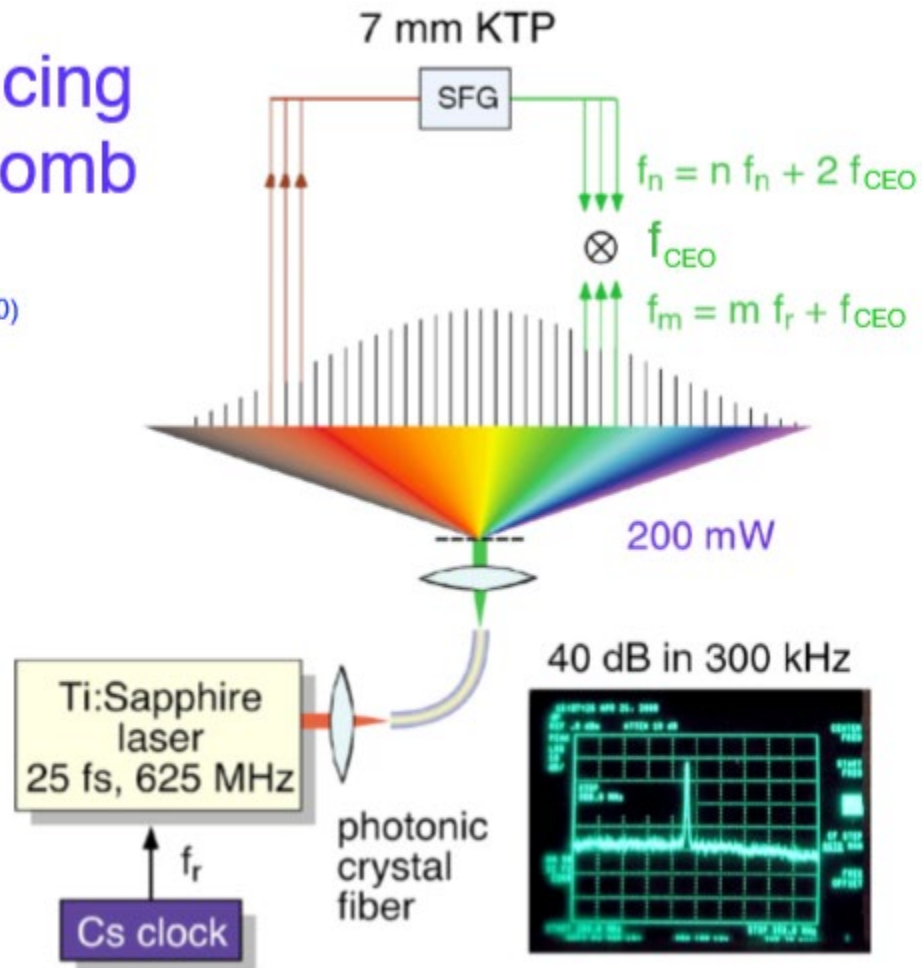


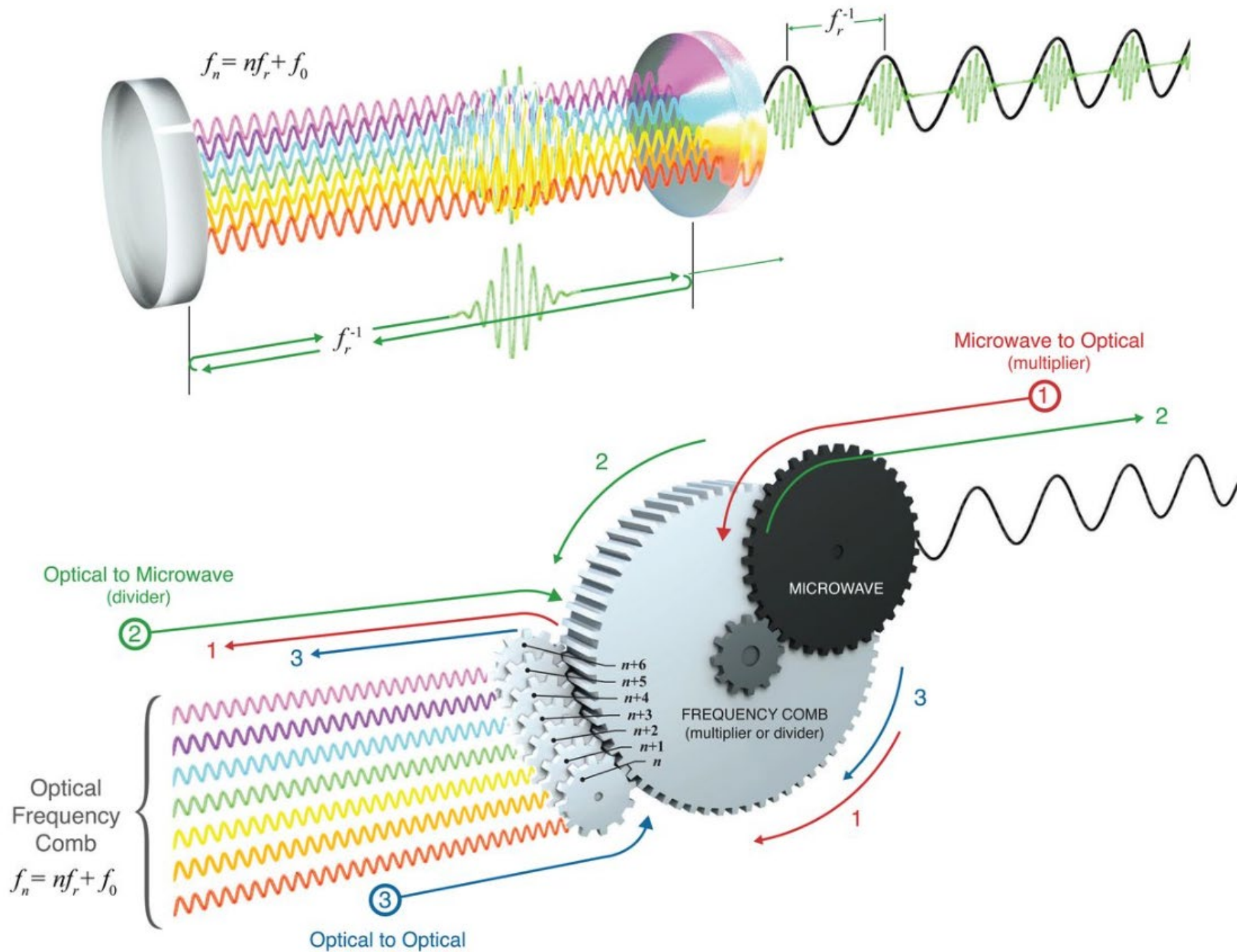
Self-referencing frequency comb

R. Holzwarth et al.,
Phys. Rev. Lett **85**, 2264 (2000)

D. Jones et al.,
Science **288**, 635 (2000)

T.W. Hänsch,
Witnessed disclosure
(March 30, 1997)







The Nobel Prize in Physics 2005

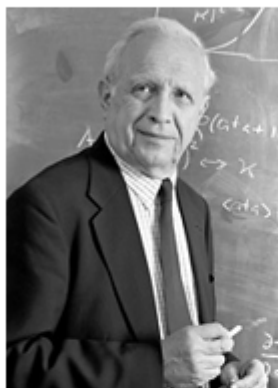


Photo: J.Reed
Roy J. Glauber
Prize share: 1/2



Photo: Sears.P.Studio
John L. Hall
Prize share: 1/4

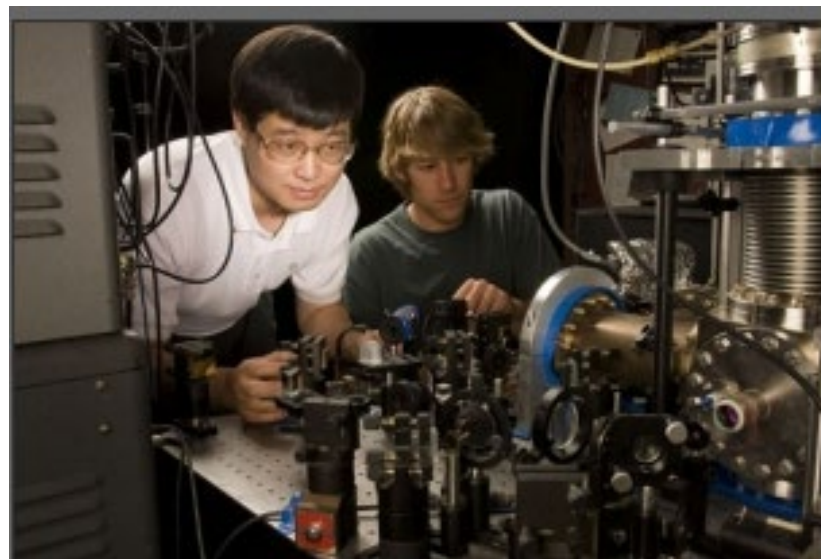


Photo: F.M. Schmidt
Theodor W. Hänsch
Prize share: 1/4

The Nobel Prize in Physics 2005 was divided, one half awarded to Roy J. Glauber *"for his contribution to the quantum theory of optical coherence"*, the other half jointly to John L. Hall and Theodor W. Hänsch *"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique"*.



华东师大 马龙生教授



科罗拉多大学 叶军教授

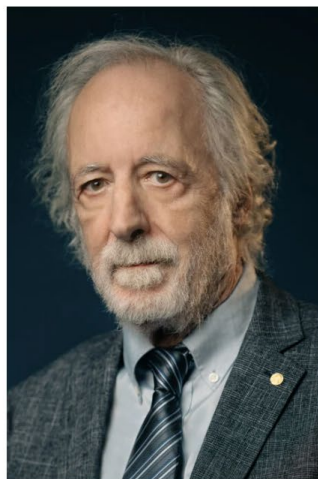
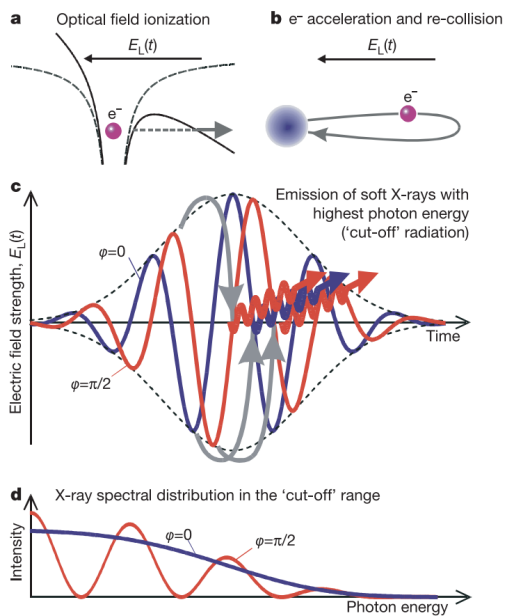
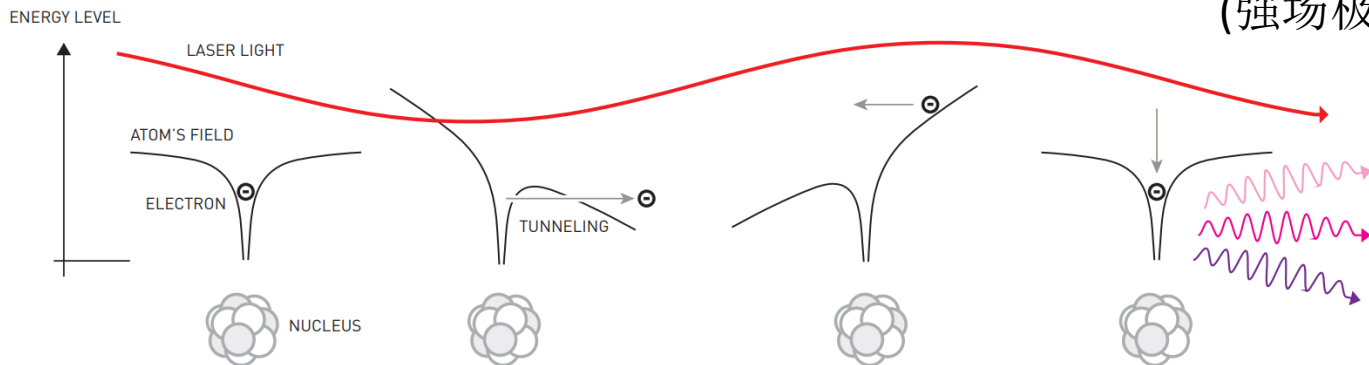
在光梳相关技术方面，马龙生老师和叶军老师做出了关键贡献

单个阿秒脉冲的产生

脉冲光

$P > 10^{10} W$ 峰值功率

$E \gg E_a$
(强场极限)



© Nobel Prize Outreach. Photo: Clément Morin
Pierre Agostini
Prize share: 1/3



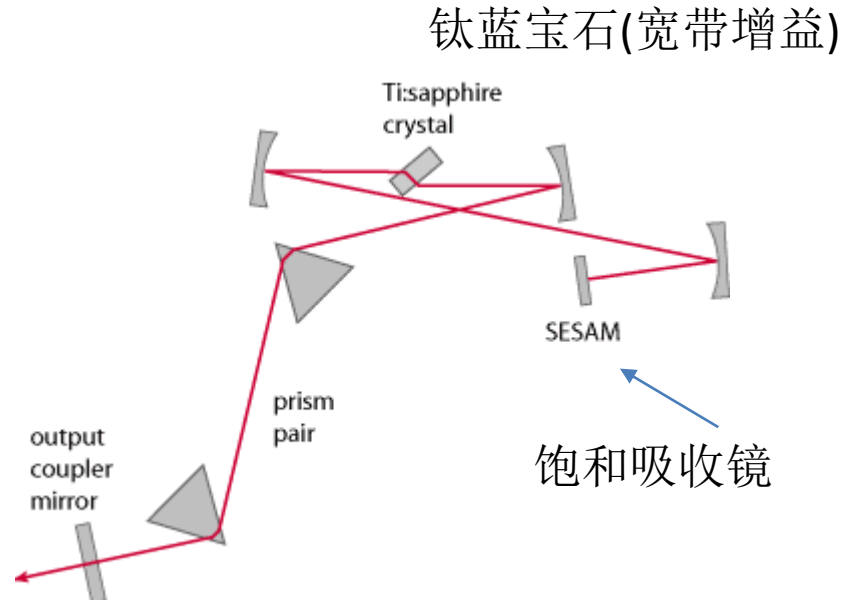
© Nobel Prize Outreach. Photo: Clément Morin
Ferenc Krausz
Prize share: 1/3



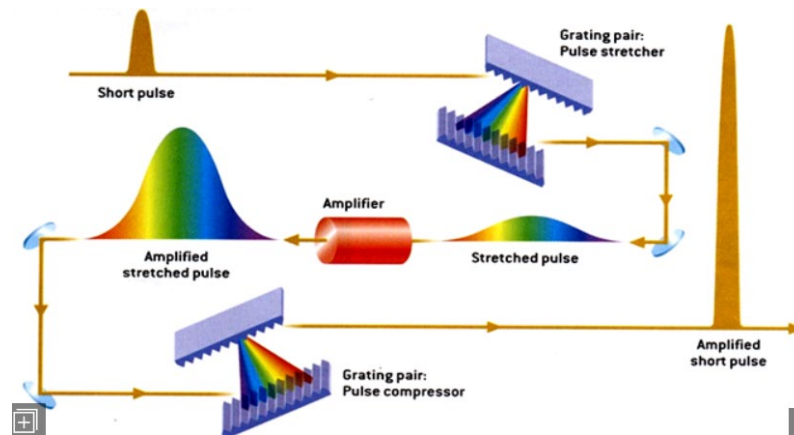
© Nobel Prize Outreach. Photo: Clément Morin
Anne L'Huillier
Prize share: 1/3

Lasers with shorter duration and larger peak power (10^{15}W !!!)

Ultrafast Laser
Mode lock basic



Chirped Amplification



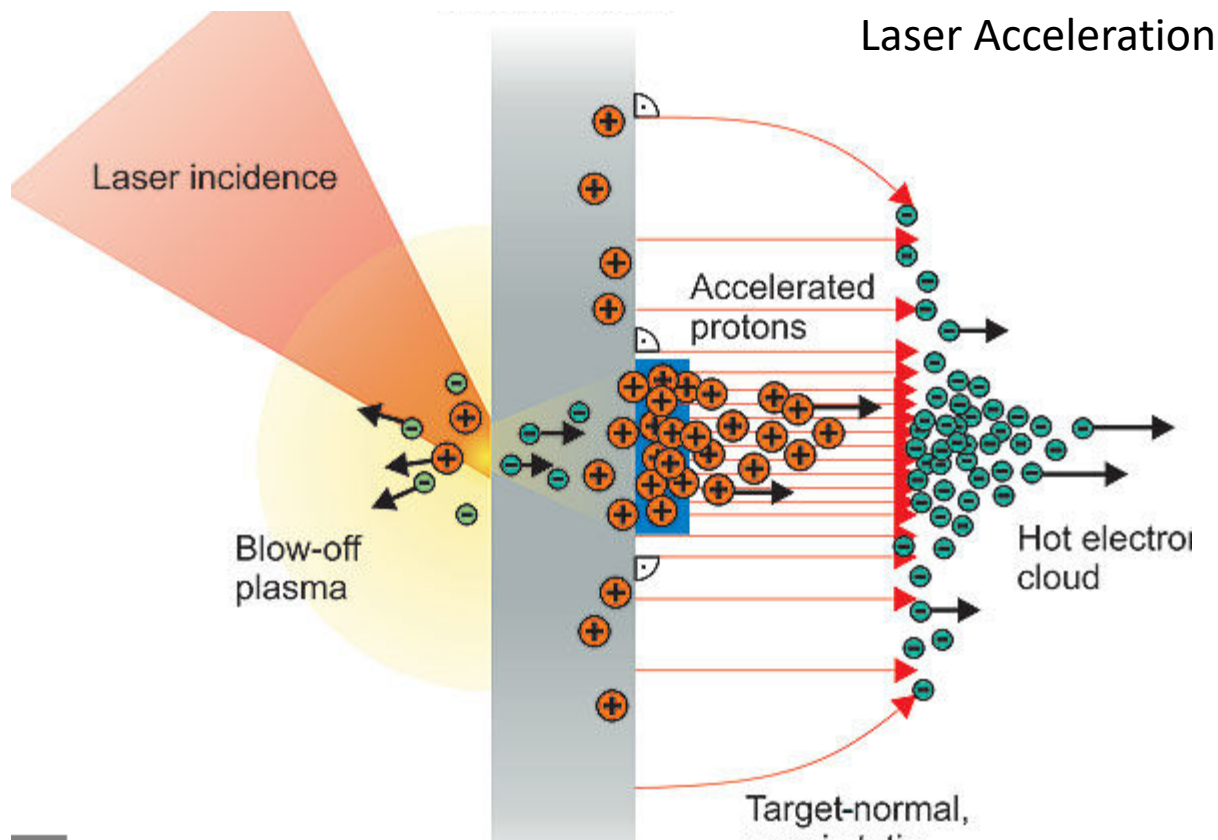


Nobel Prize in Physics, 2017



“For groundbreaking inventions in the field of laser physics”

激光加速： 桌面上的粒子加速器 (基础和应用)



量子光学和非线性光学

The Nobel Prize in Physics 2022



© Nobel Prize Outreach. Photo: Stefan Bladh

Alain Aspect

Prize share: 1/3



© Nobel Prize Outreach. Photo: Stefan Bladh

John F. Clauser

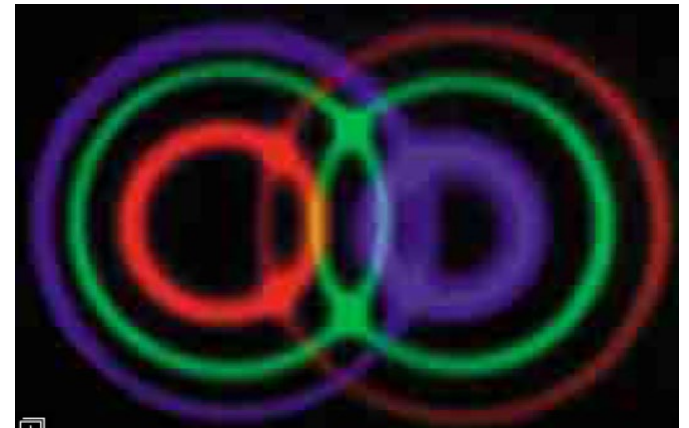
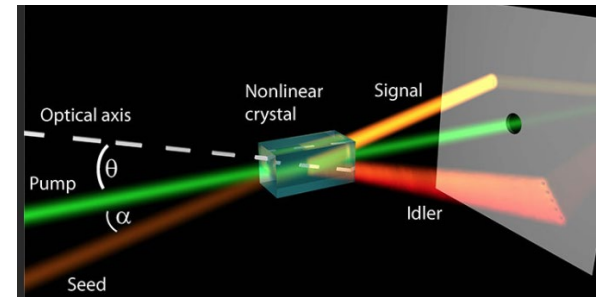
Prize share: 1/3



© Nobel Prize Outreach. Photo: Stefan Bladh

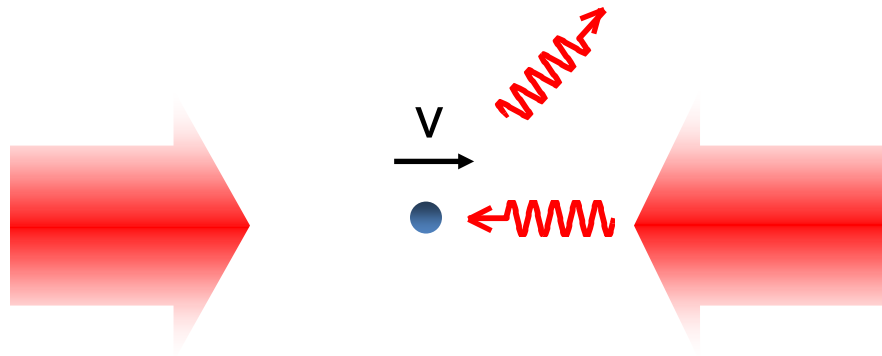
Anton Zeilinger

Prize share: 1/3



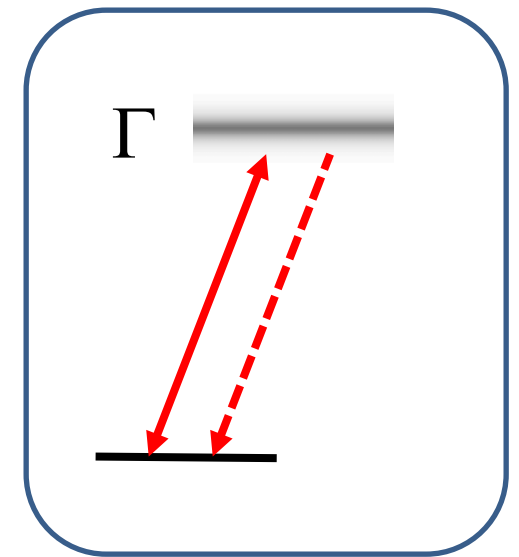
“For experiments with entangled photons,
establishing the violation of Bell inequalities
and pioneering quantum information science

激光冷却原理 (基本图像)



Hänsch and Schawlow 1975
Wineland and Dehmelt 1975

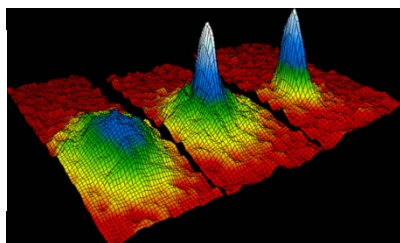
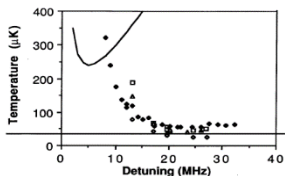
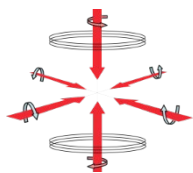
- 利用多普勒效应进行速度选择
- 基于反冲动量的减速
- 速度选择吸收 - 减速 - 自发辐射 循环
- 目前唯一一种把室温下物质冷却到微开量级的实验手段



$$k_B T \sim \hbar \Gamma$$

Typically sub-mK

激光冷却发展



1987
第一个MOT
Bell 实验室

1988
亚多普勒冷却发现
NIST

1995
玻色爱因斯坦凝聚
NIST/MIT

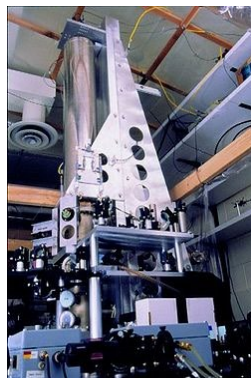
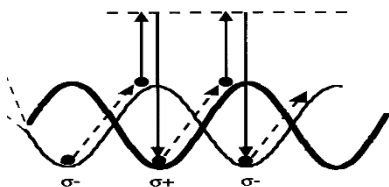
1997
诺贝尔奖
激光冷却



2016
铷原子钟
天宫二号

.....

1989
亚多普勒冷却理论解释
ENS



1999
原子喷泉钟
NIST

2001
诺贝尔奖
BEC



$T \sim nK, v \sim mm/s$
可极大地抑制多普勒效应，增加观测时间
提高光谱精度