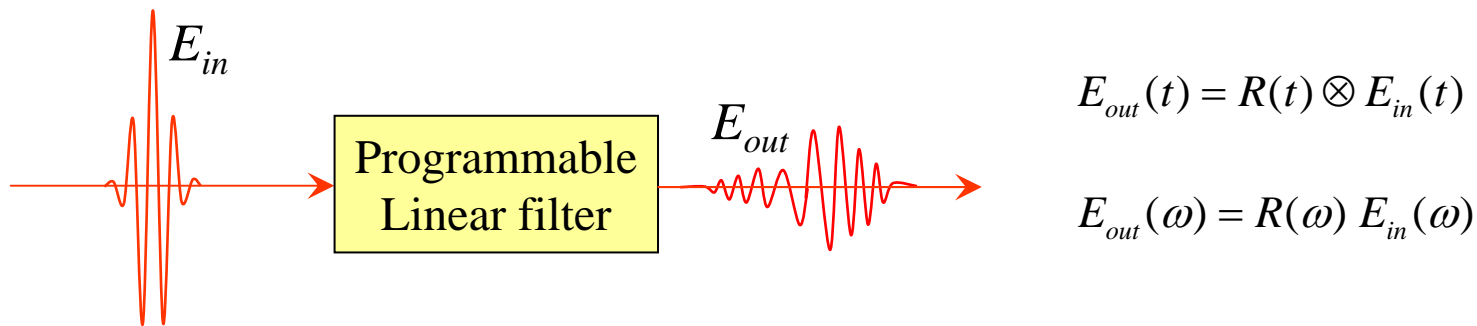


Façonnage d'impulsions et contrôle cohérent

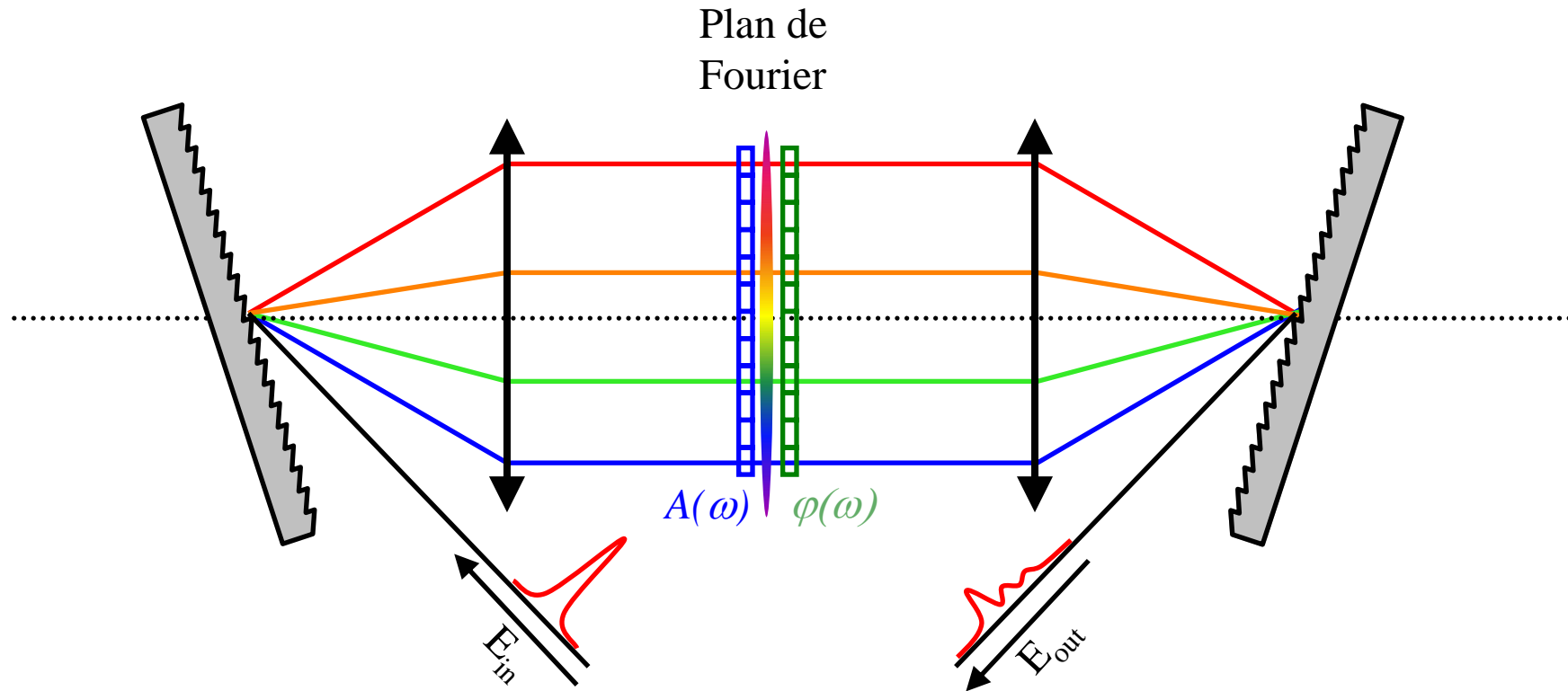
1. Façonnage d'impulsions
2. Contrôle cohérent
3. Contrôle optimal
4. Contrôle cohérent vibrationnel

Façonnage d'impulsions



- Transposition du domaine fréquentiel au domaine spatial
+ modulateur spatial de lumière
- Méthodes spécifiques dans le domaine des fréquences
 - Façonnage indirect par mélange non-linéaire
 - Filtre acousto-optique programmable (Dazzler)

Utilisation d'une ligne à dispersion nulle combinée à des modulateurs spatiaux de lumière



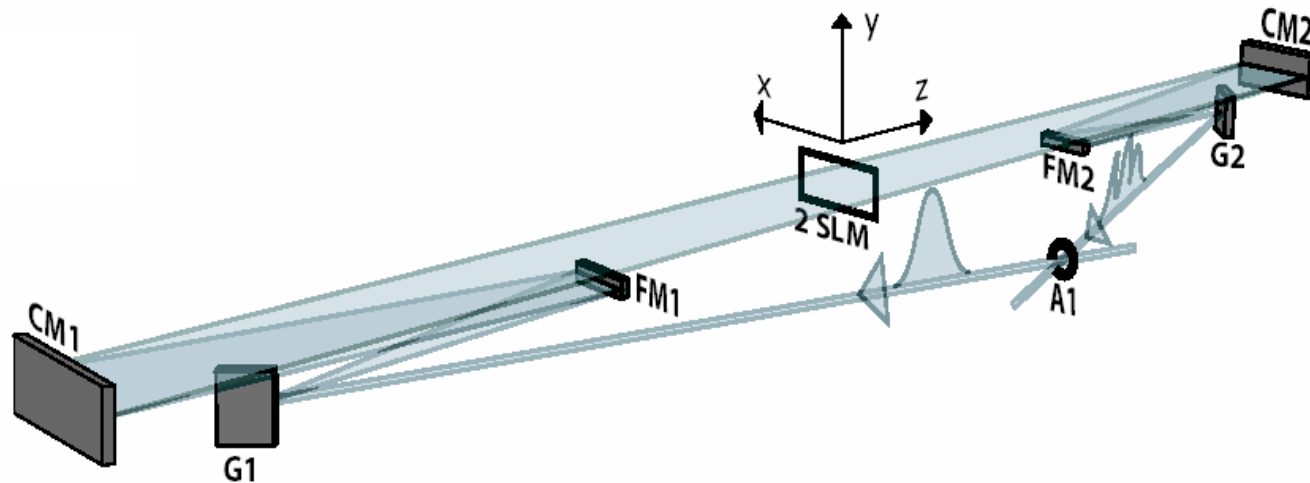
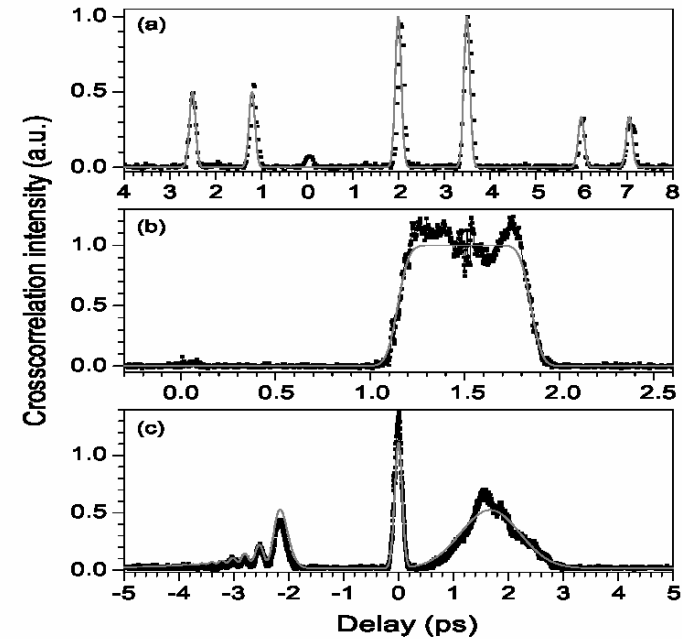
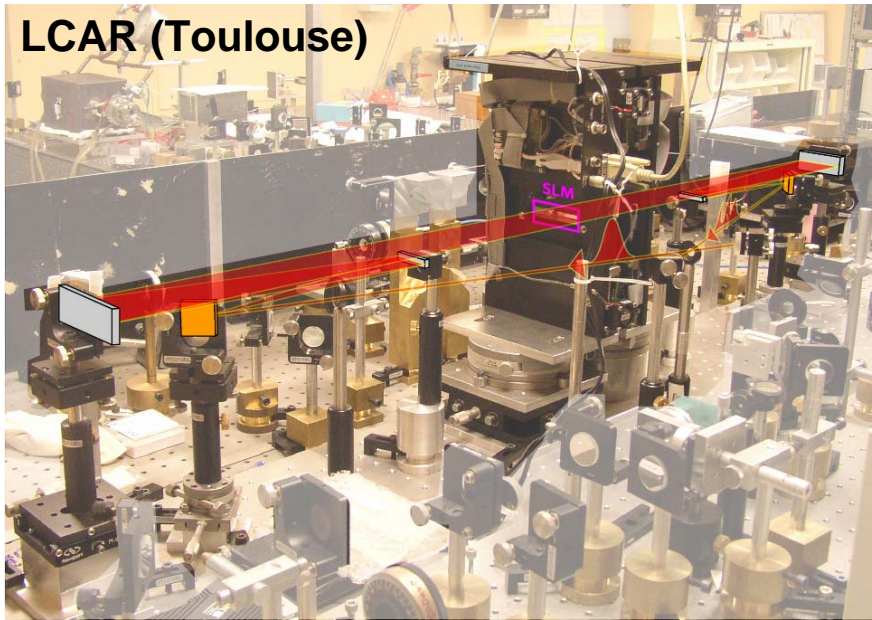
$$E_{out}(\omega) = E_{in}(\omega)A(\omega)\exp(i\varphi(\omega))$$

A.M. Weiner, Rev. Sci. Instr. **71**, 1929 (2000)

A. Monmayrant, B. Chatel, Rev. Sci. Instr. **75**, 2668 (2004)

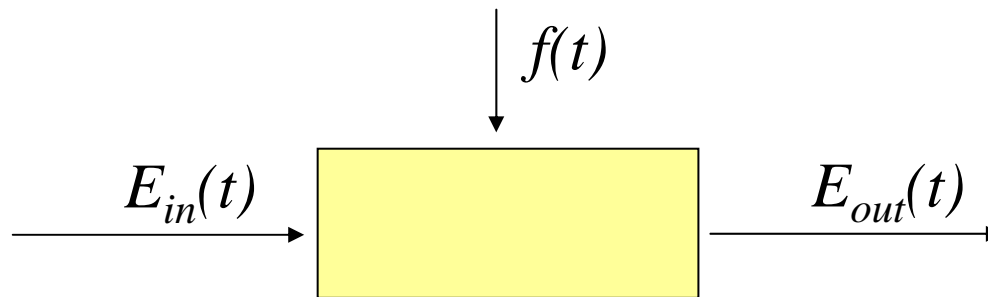
→ Filtre linéaire programmable

Utilisation d'une ligne à dispersion nulle combinée à des modulateurs spatiaux de lumière



Méthodes spécifiques du domaine fréquentiel

Exemple : Interaction bilinéaire entre un champ de contrôle et l'impulsion incidente

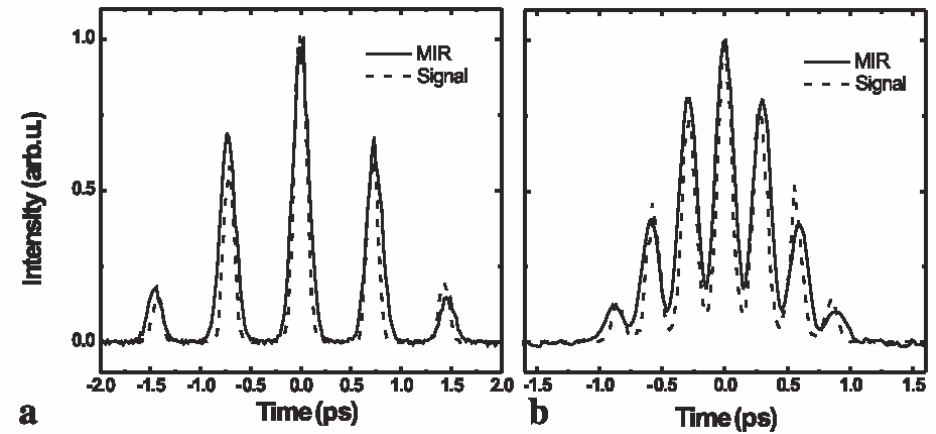
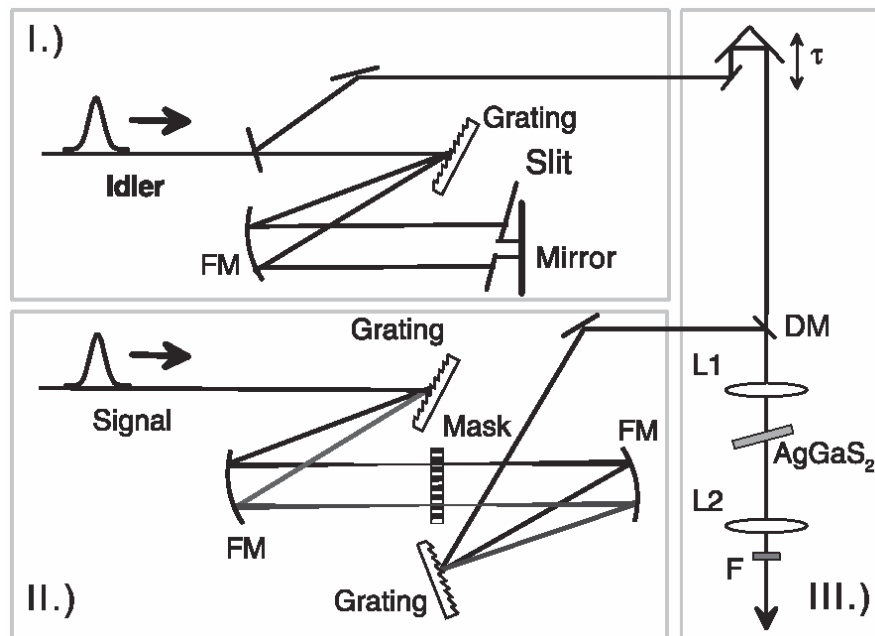


$$E_{out}(t) = \iint \Xi(\omega_1, \omega_2) f(\omega_1) E_{in}(\omega_2) \exp(-i(\omega_1 + \omega_2)t) \frac{d\omega_1}{2\pi} \frac{d\omega_2}{2\pi}$$

$$E_{out}(\omega) = \iint \Xi(\omega_1, \omega_2) f(\omega_1) E_{in}(\omega_2) \delta(\omega - \omega_1 - \omega_2) \frac{d\omega_1}{2\pi} \frac{d\omega_2}{2\pi}$$

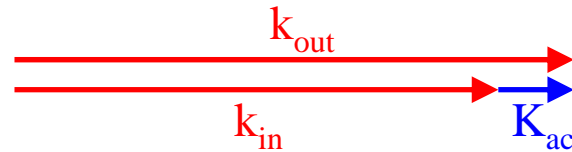
Façonnage indirect par mélange non-linéaire

$$E_{IR}(\omega) = \int \Xi(\omega_S, \omega_I) E_S(\omega_S) E_I^*(\omega_I) d\omega_S d\omega_I \delta(\omega_S - \omega_I - \omega_{IR}) \approx E_S(\omega + \omega_0) E_I^*(\omega_0)$$

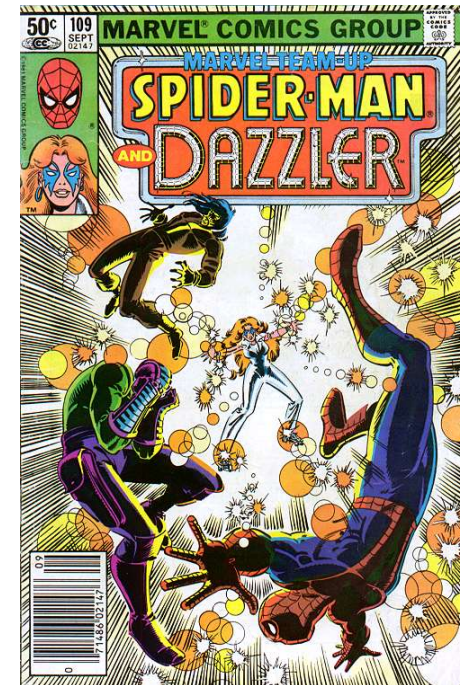
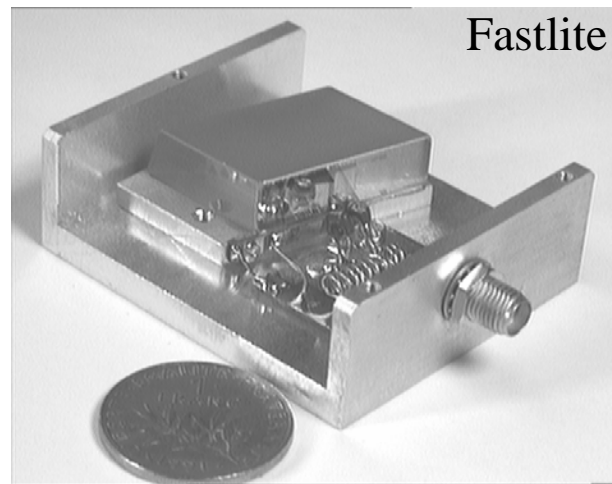


Filtre acousto-optique programmable (dazzler)

Interaction longitudinale dans un cristal acousto-optique entre une onde acoustique et une onde optique.

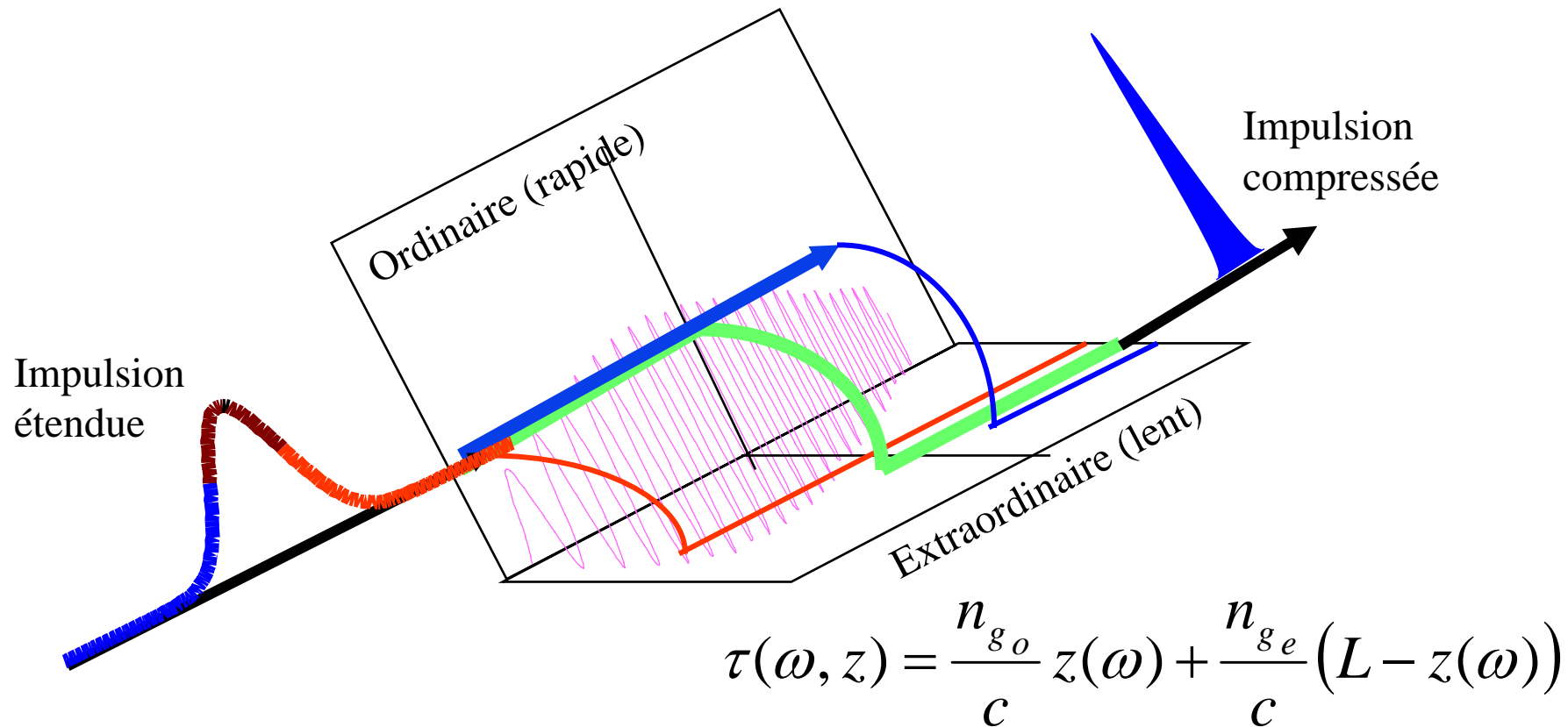


$$E_{out}(\omega) = \int \Xi(\omega_{ac}, \omega_{in}) f(\omega_{ac}) E_{in}(\omega_{in}) d\omega_{ac} d\omega_{in} \delta(\omega - \omega_{ac} - \omega_{in}) \approx f_{ac}(\Omega_{ac}(\omega)) E_{in}(\omega)$$

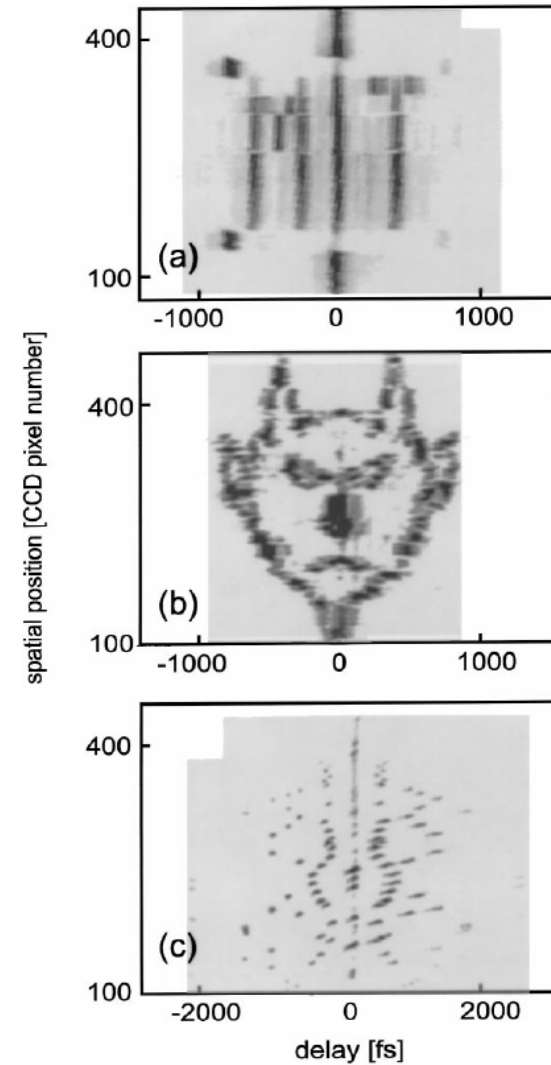
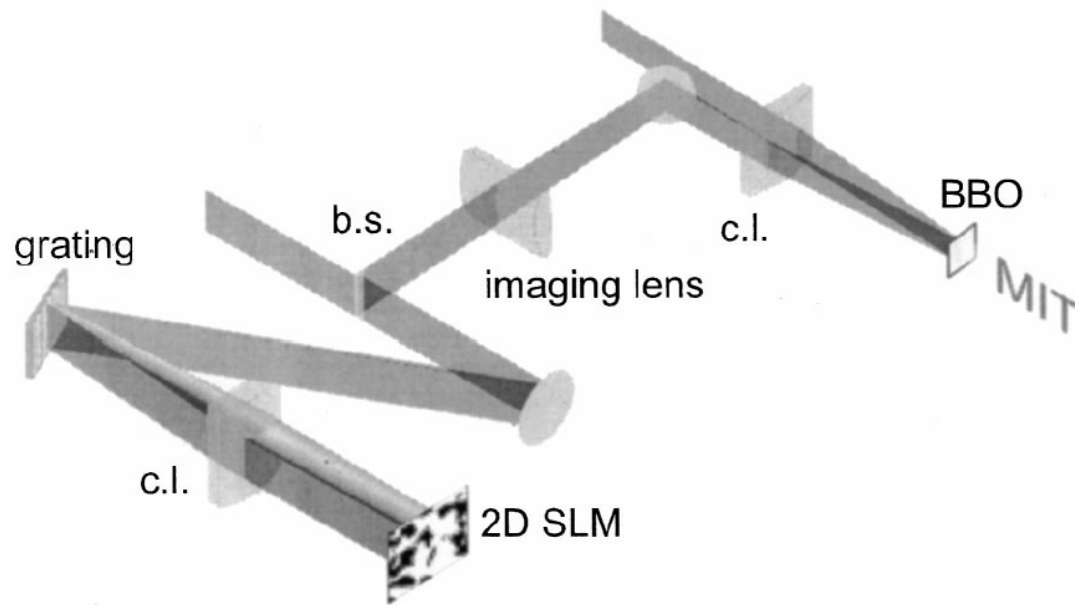


F. Verluise, V. Laude, Z. Cheng, Ch. Spielmann et P. Tournois, *Opt. Lett.* 25, 575 (2000).
D. Kaplan et P. Tournois, *J. Phys. IV France* 12, Pr5-69 (2002).

Dazzler : interprétation temporelle



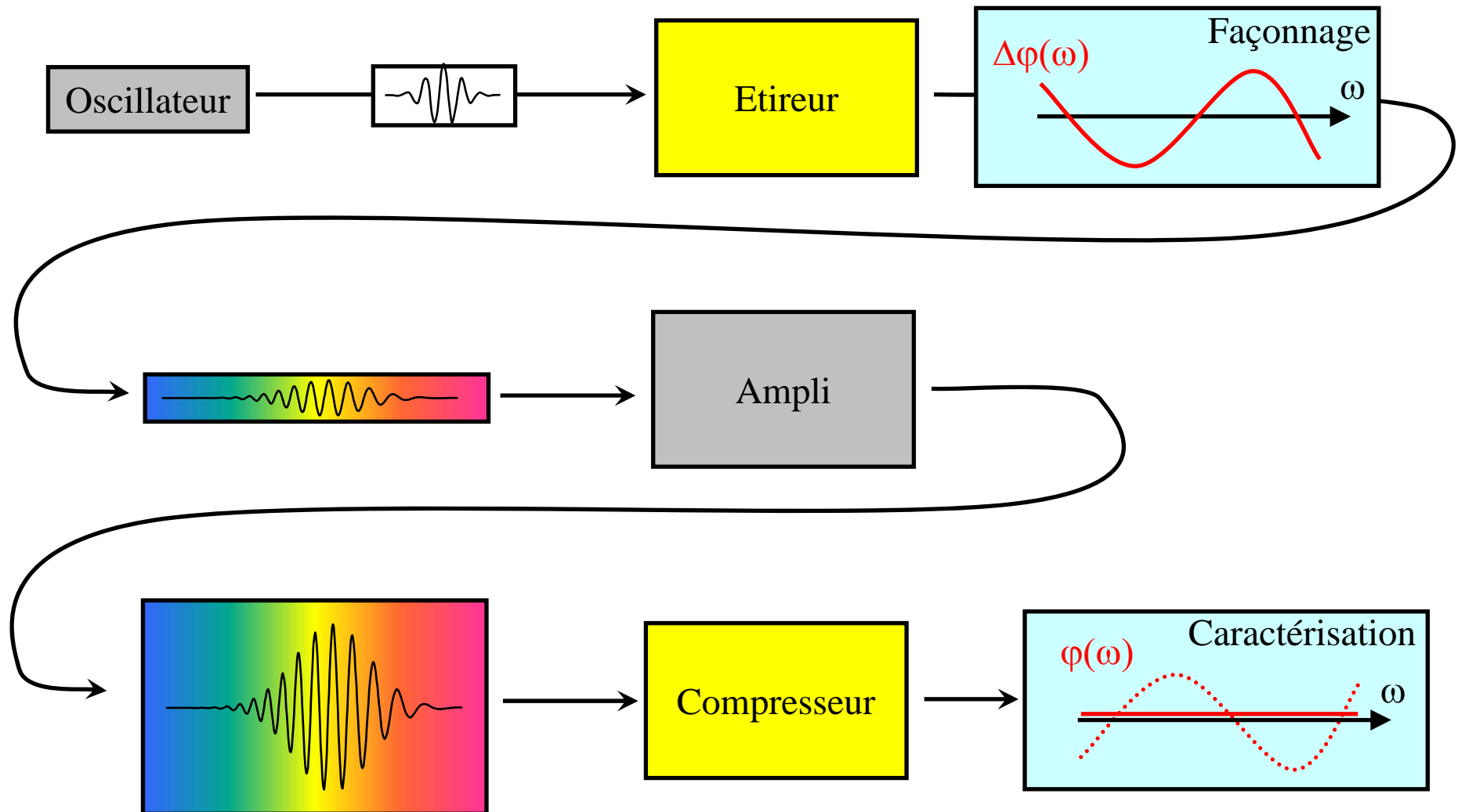
Façonnage spatio-temporel



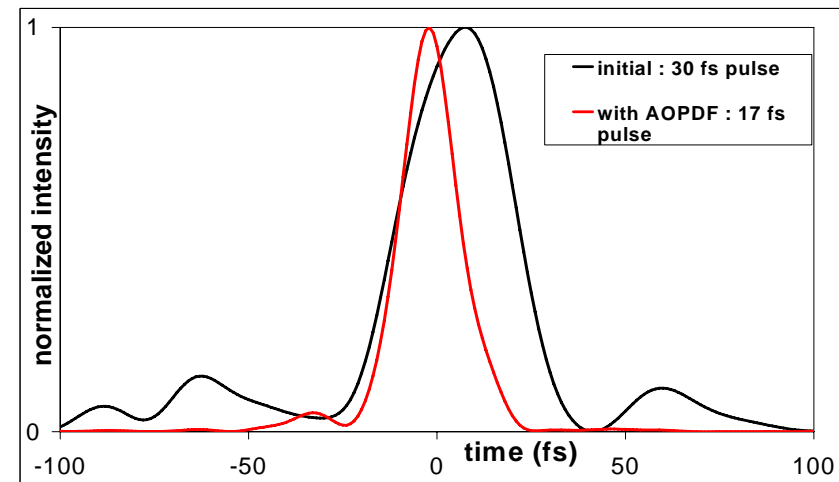
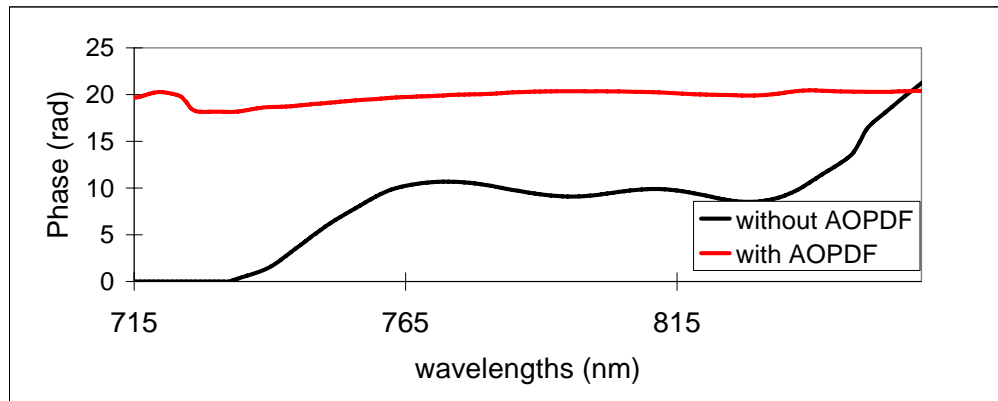
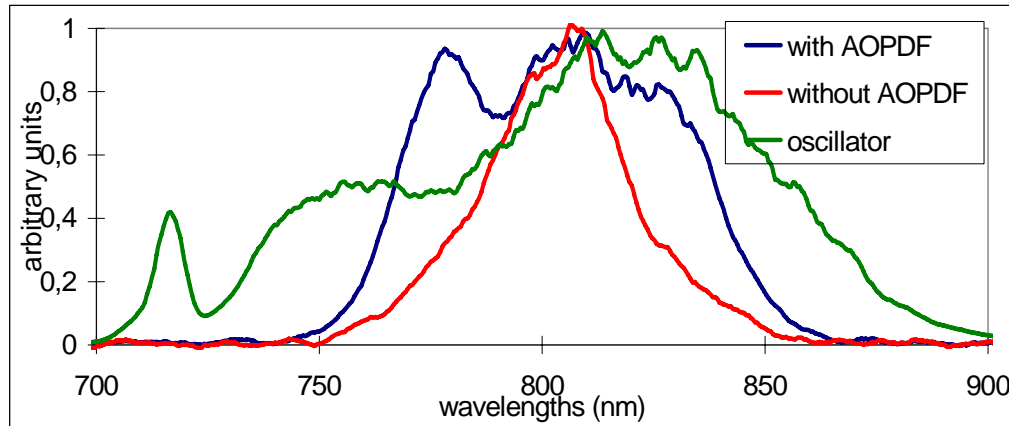
J. C. Vaughan, T. Feurer et K. A. Nelson, *JOSA B* **19**, 2489 (2002)

T. Hornung, J. C. Vaughan, T. Feurer et K. A. Nelson, *Opt. Lett.* **29**, 2052 (2004)

Correction adaptative de la phase spectrale

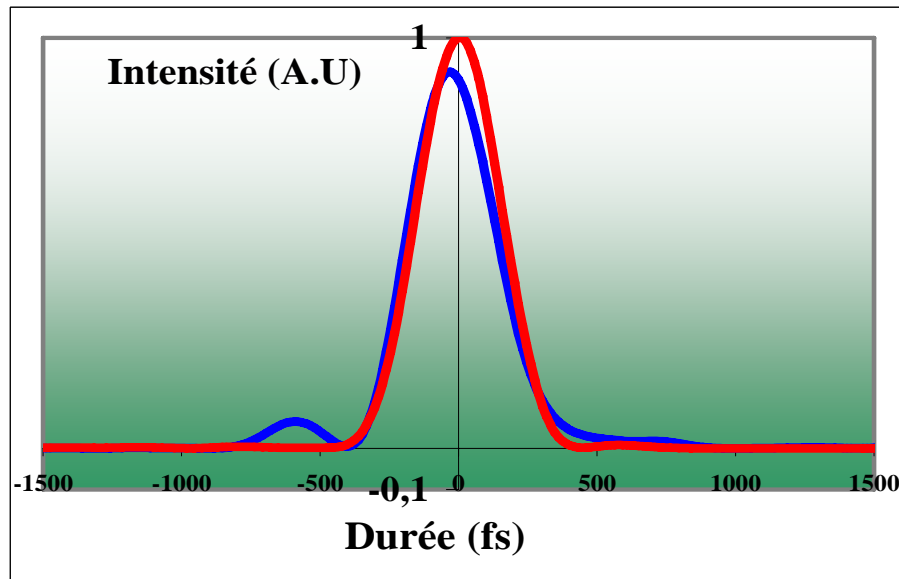


Correction adaptative de la phase spectrale



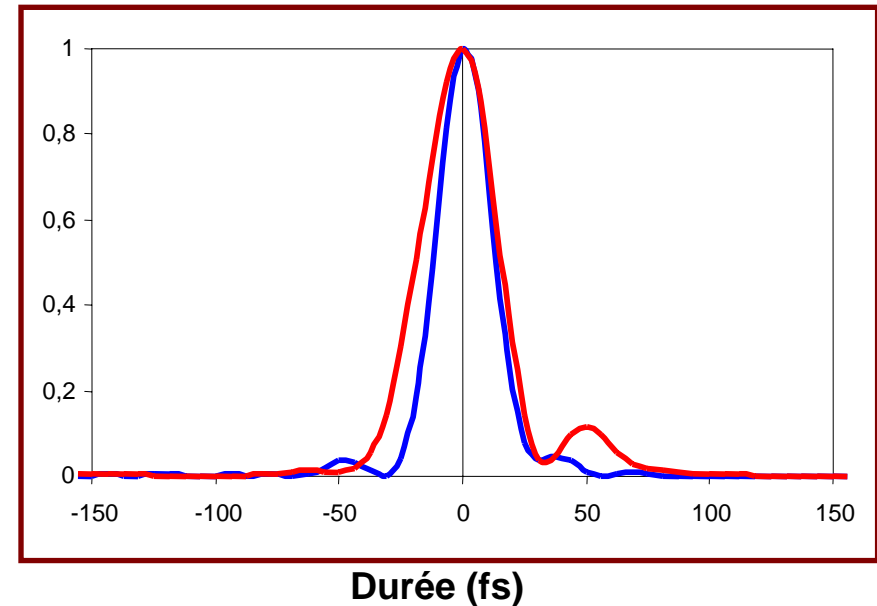
Correction adaptative de la phase spectrale

100 TW, 300 fs, 30 J



100 TW, 25 fs, 2.5 J

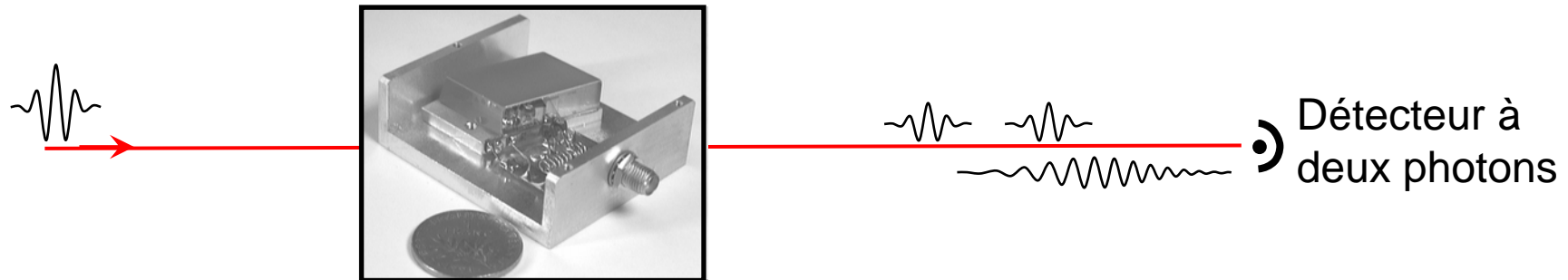
LOA



- C. Le Blanc, B. Wattelier, J.-P. Zou, A. Migus, C. Dorrer, I.A. Wamsley, F. Verluise, D. Kaplan et P.Tournois, *CLEO 2001*
- D. Reitze, F. Weihe, S. Kazamias, G. Mullot, D. Douillet, F. Augé, J.-P. Chambaret, D. Hulin et P.Balco, *Ultrafast 2002*

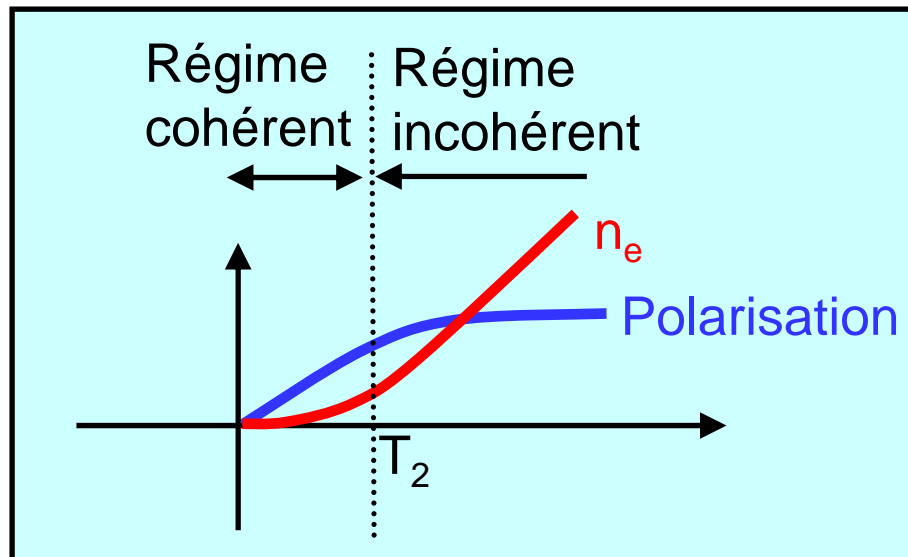
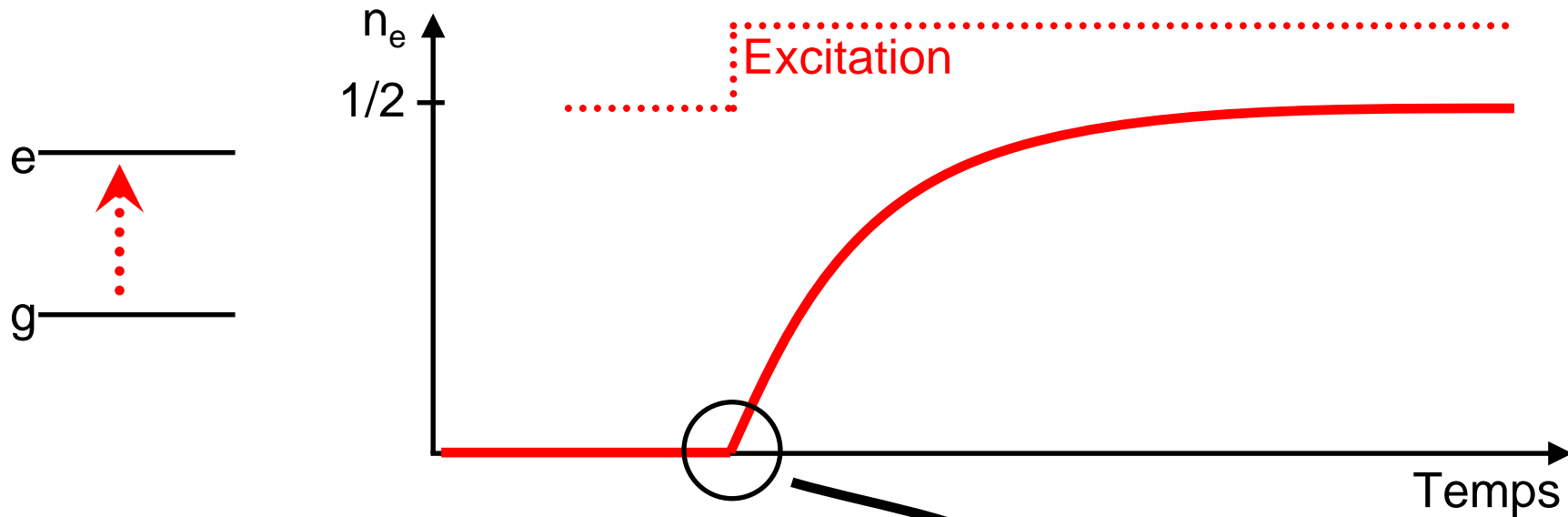
SPIDER temporel

Mise en œuvre à l'aide d'un dispositif de façonnage



2. Contrôle cohérent

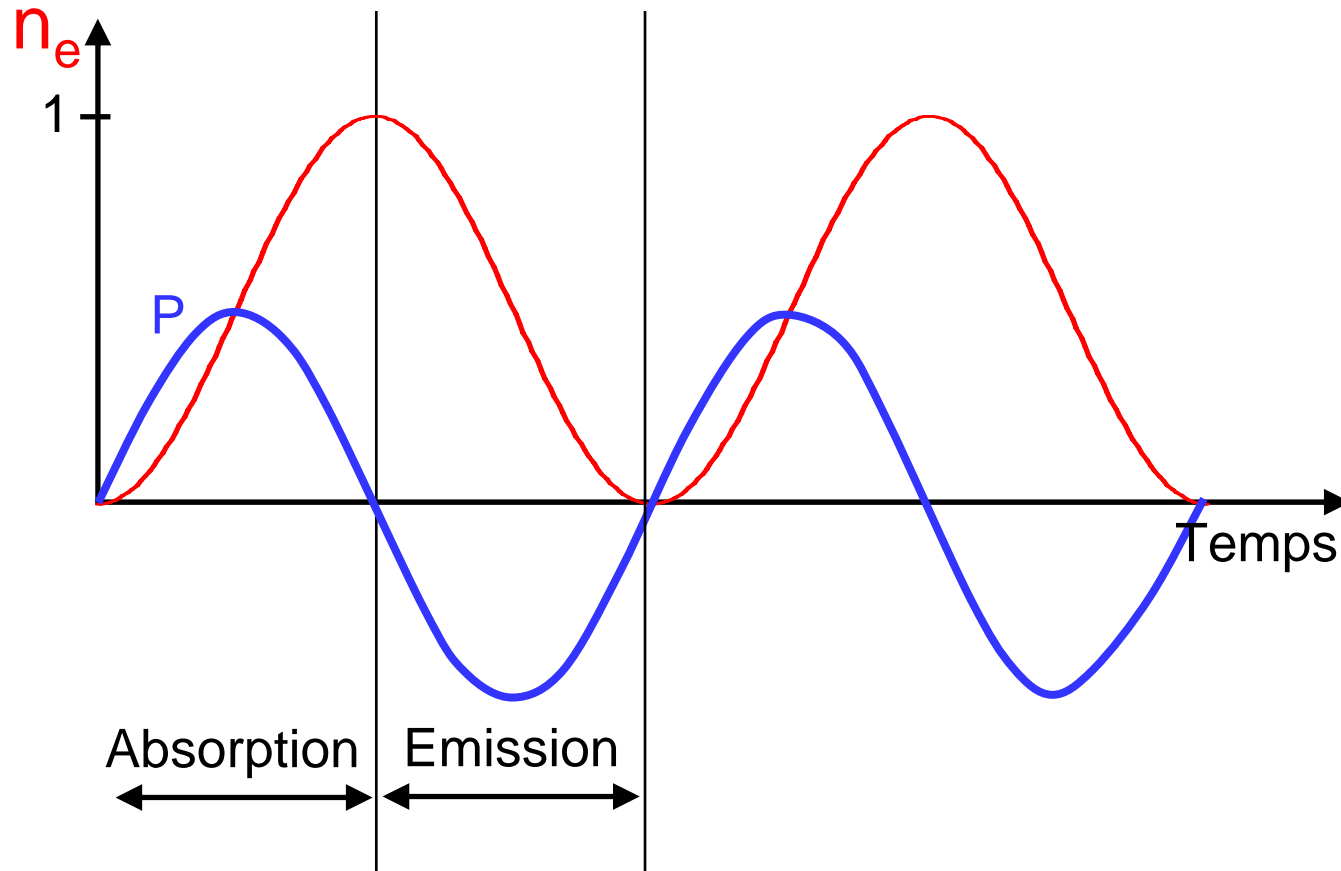
Régimes incohérent et cohérent



$$\frac{dn_e}{dt} \propto E \cdot (-iP)$$

$$\frac{dP}{dt} \propto iE(n_g - n_e) - \frac{P}{T_2}$$

Oscillations de Rabi

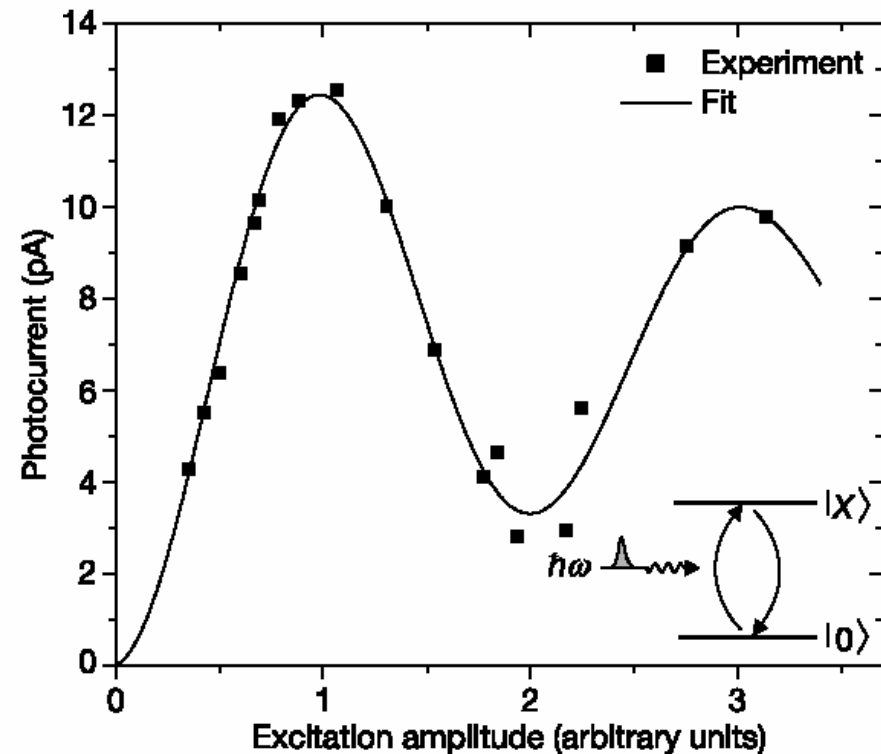
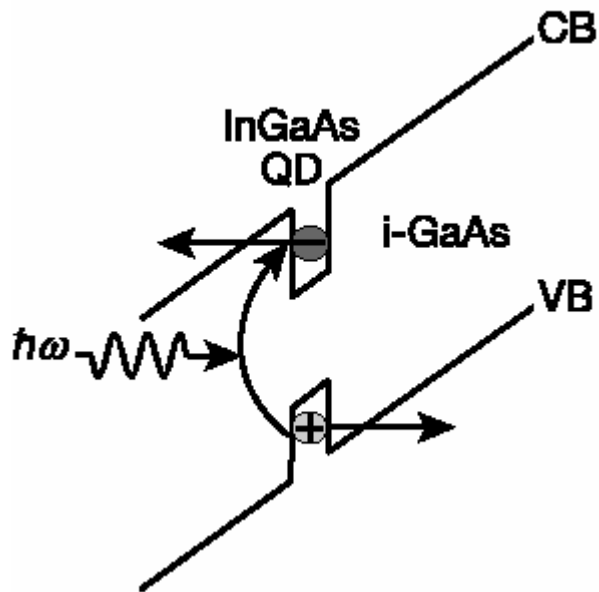


➤ Impulsion π (demi-oscillation de Rabi) $\rightarrow n_e = 1$.

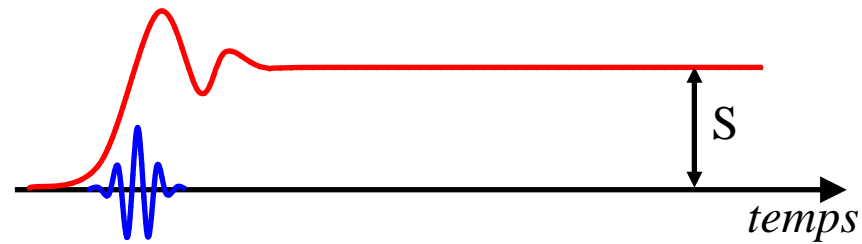
Coherent properties of a two-level system based on a quantum-dot photodiode

A. Zrenner*†, E. Beham*, S. Stufler*†, F. Findeis*, M. Bichler* & G. Abstreiter*

* Walter Schottky Institut, Technische Universität München, Am Coulombwall, D-85748 Garching, Germany



Processus à un photon



$$\text{Signal final} \propto \int_{-\infty}^{+\infty} g(\omega) |E(\omega)|^2 \frac{d\omega}{2\pi}$$

Resultat valable dès lors que le signal est stationnaire et bilinéaire par rapport au champ électrique.

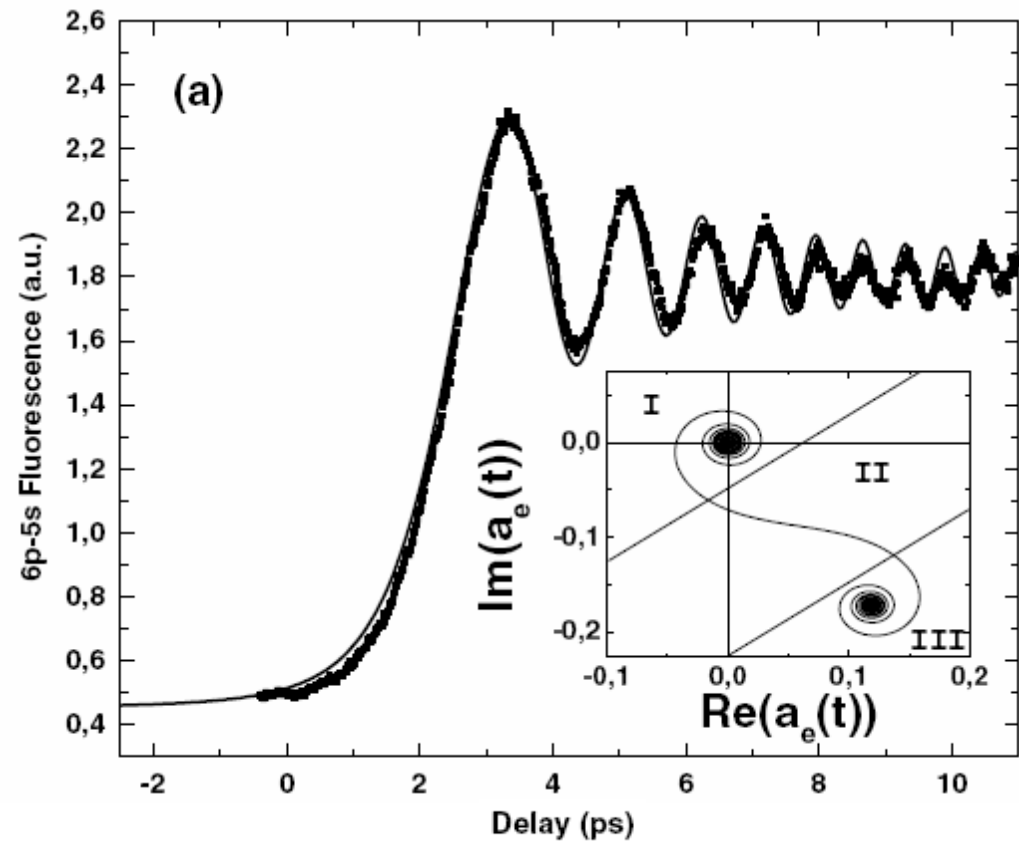
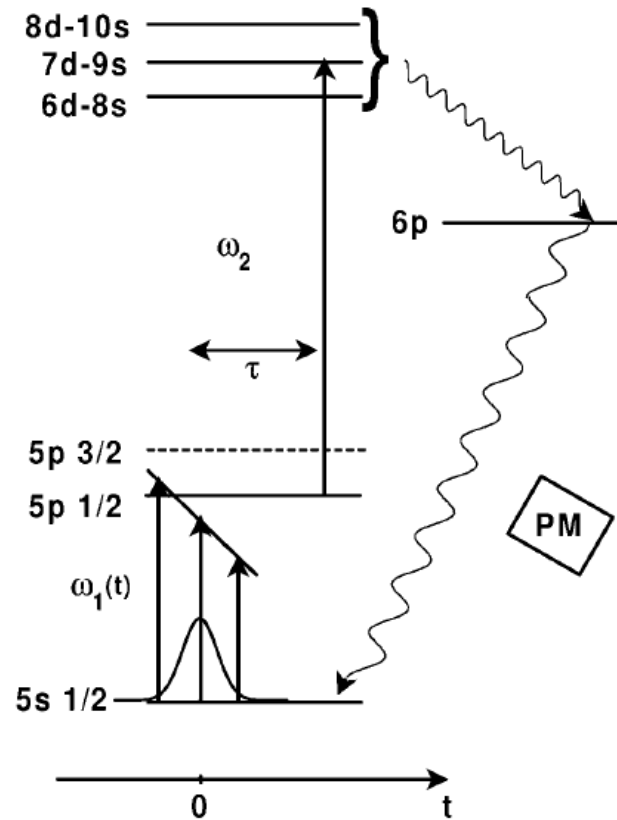
➤ Le signal final est indépendant de la phase spectrale de l'impulsion !

Paul Brumer, Moshe Shapiro

One photon mode selective control of reactions by rapid or shaped laser pulses : an emperor without clothes ?
Chem. Phys. 139, 221-228 (1989)

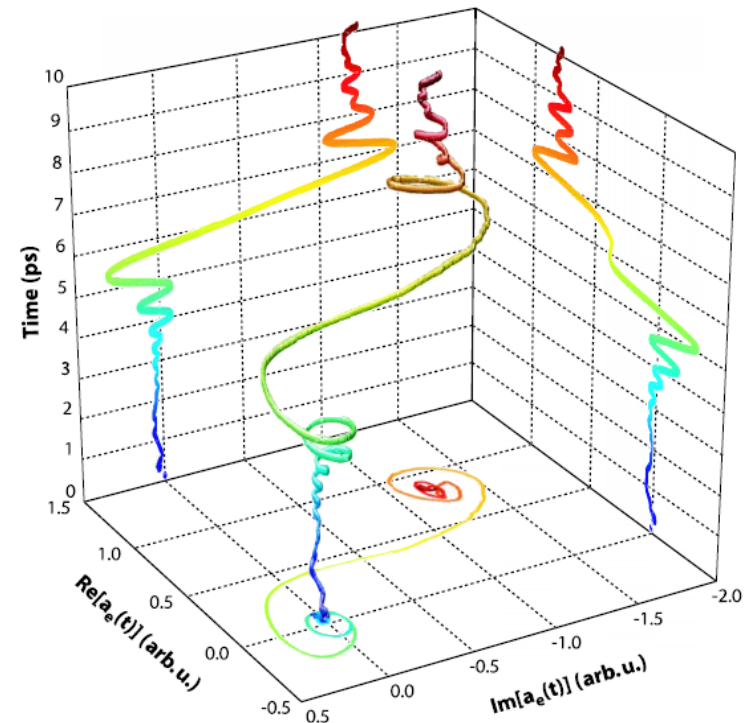
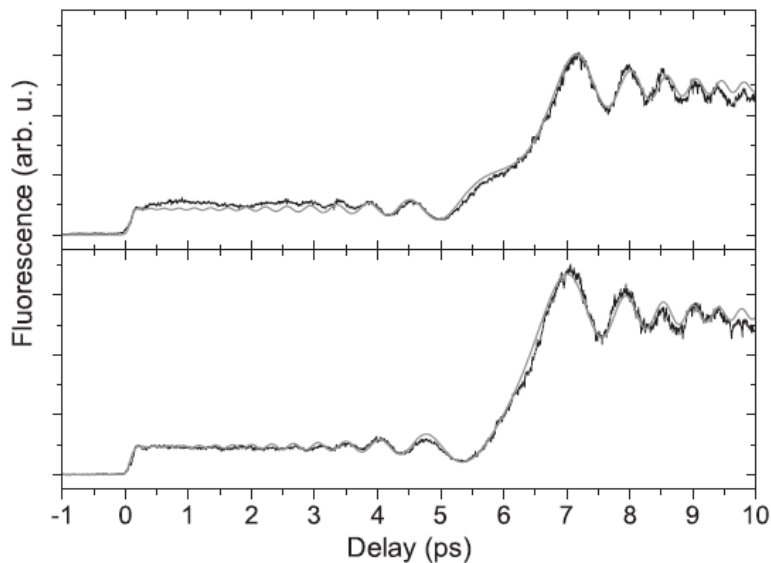
Transitoires cohérents

Excitation d'atomes de rubidium par une impulsion à dérive de fréquence.



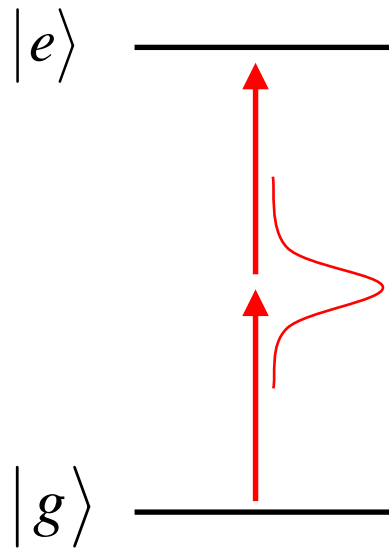
S. Zamith, J. Degert, S. Stock, B. de Beauvoir, V. Blanchet, M.A. Bouchene, B. Girard
Observation of coherent transients in ultrashort chirped excitation of an undamped two-level system
Phys. Rev. Lett. **87**, 033001 (2001)

Transitoires cohérents : application à la reconstruction holographique de l'état quantique



A. Monmayrant, B. Chatel, B. Girard
Quantum state measurement using coherent transients
Phys. Rev. Lett. **96**, 103002 (2006)

Processus à deux photons



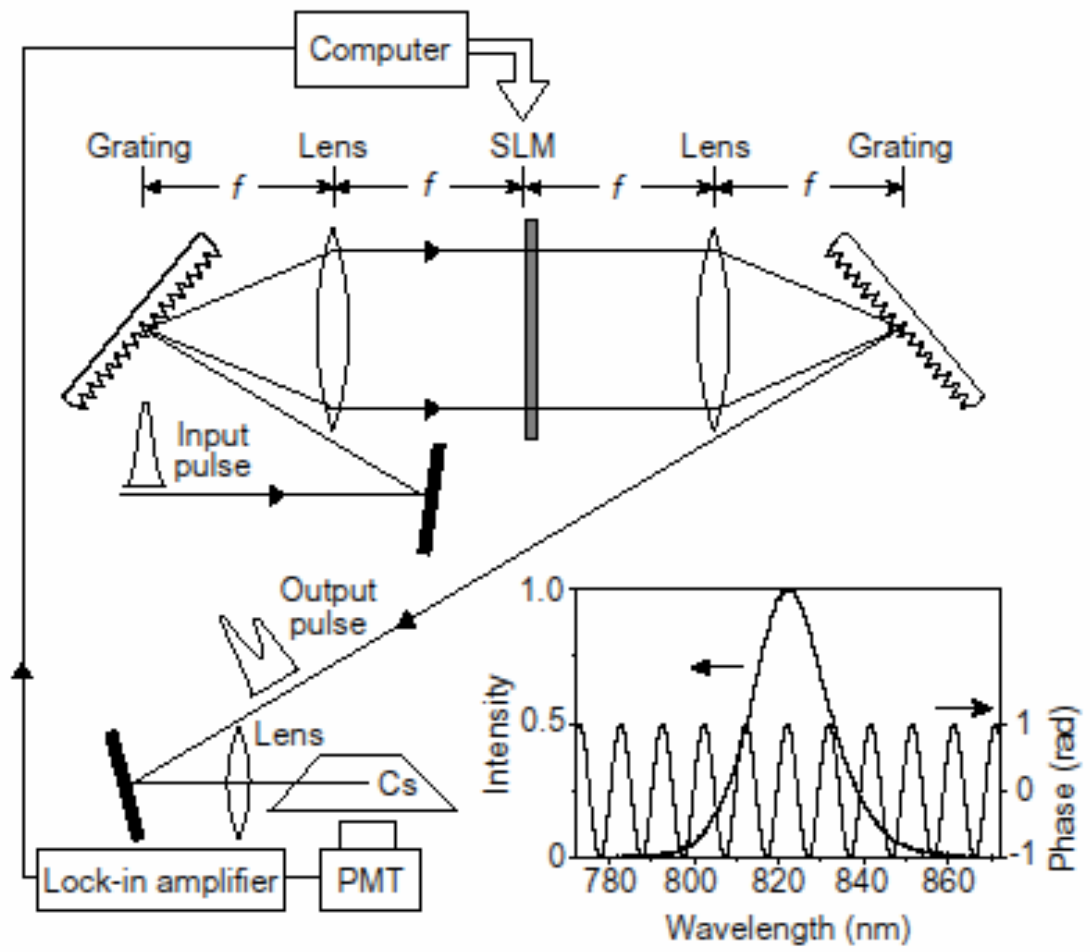
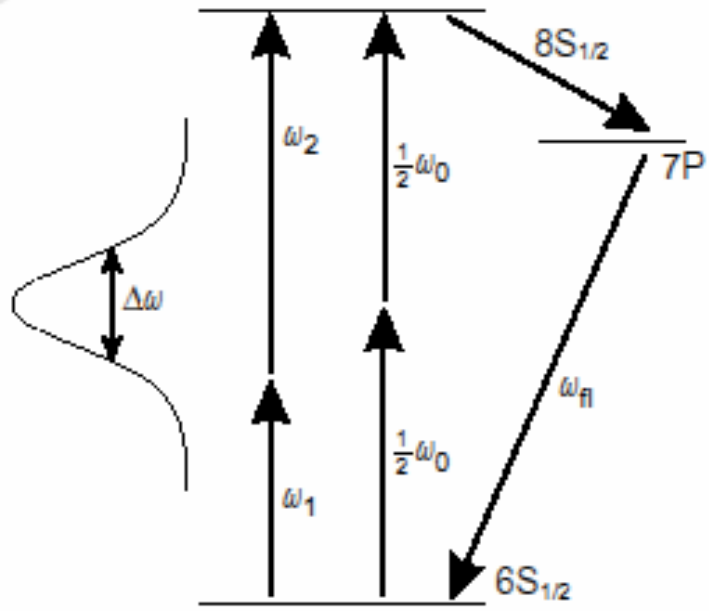
Absorption proportionnelle au carré de l'intensité, i.e. à E^4 .

$$\text{Signal} \propto \int g^{(2)}(\omega) |E^{(2)}(\omega)|^2 \frac{d\omega}{2\pi}$$

où $E^{(2)}(t) \equiv E(t)^2 = \int E^{(2)}(\omega) \exp(-i\omega t) \frac{d\omega}{2\pi}$ (champ doublé en fréquence)

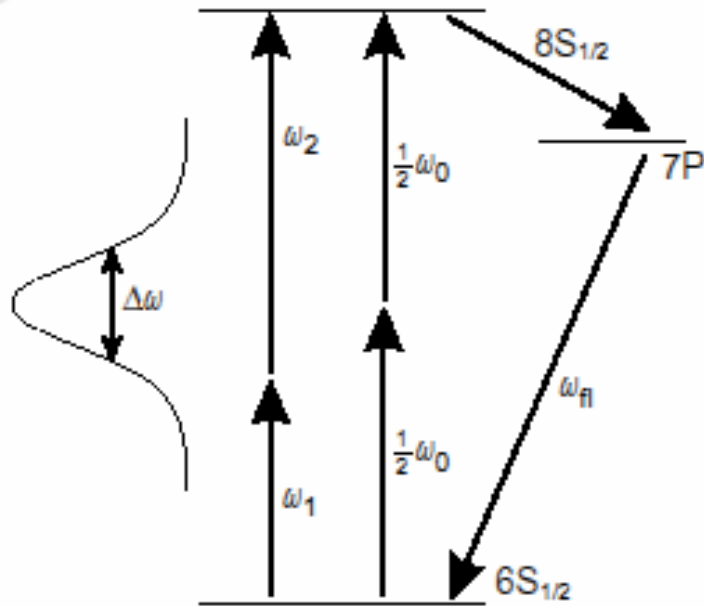
$$E^{(2)}(\omega) = \int E\left(\frac{\omega}{2} + \Omega\right) E\left(\frac{\omega}{2} - \Omega\right) \frac{d\Omega}{2\pi}$$

Contrôle cohérent de l'absorption à deux photons



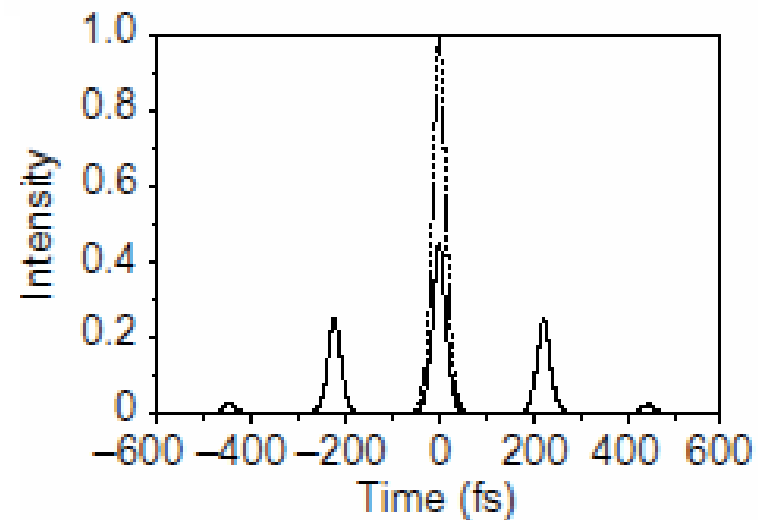
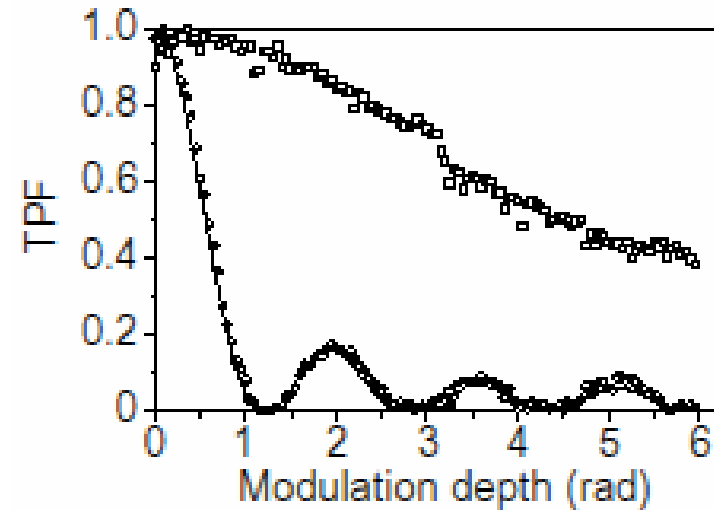
D. Meshulach et Y. Silberberg, Nature **396**, 239 (1998)

Contrôle cohérent de l'absorption à deux photons



$$S_2 = \left| \int E(\omega_0/2 + \Omega) E(\omega_0/2 - \Omega) d\Omega \right|^2$$

$$= \left| \int A(\omega_0/2 + \Omega) A(\omega_0/2 - \Omega) \exp \left\{ i[\Phi(\omega_0/2 + \Omega) + \Phi(\omega_0/2 - \Omega)] \right\} d\Omega \right|^2$$



D. Meshulach et Y. Silberberg, Nature **396**, 239 (1998)

Contrôle cohérent

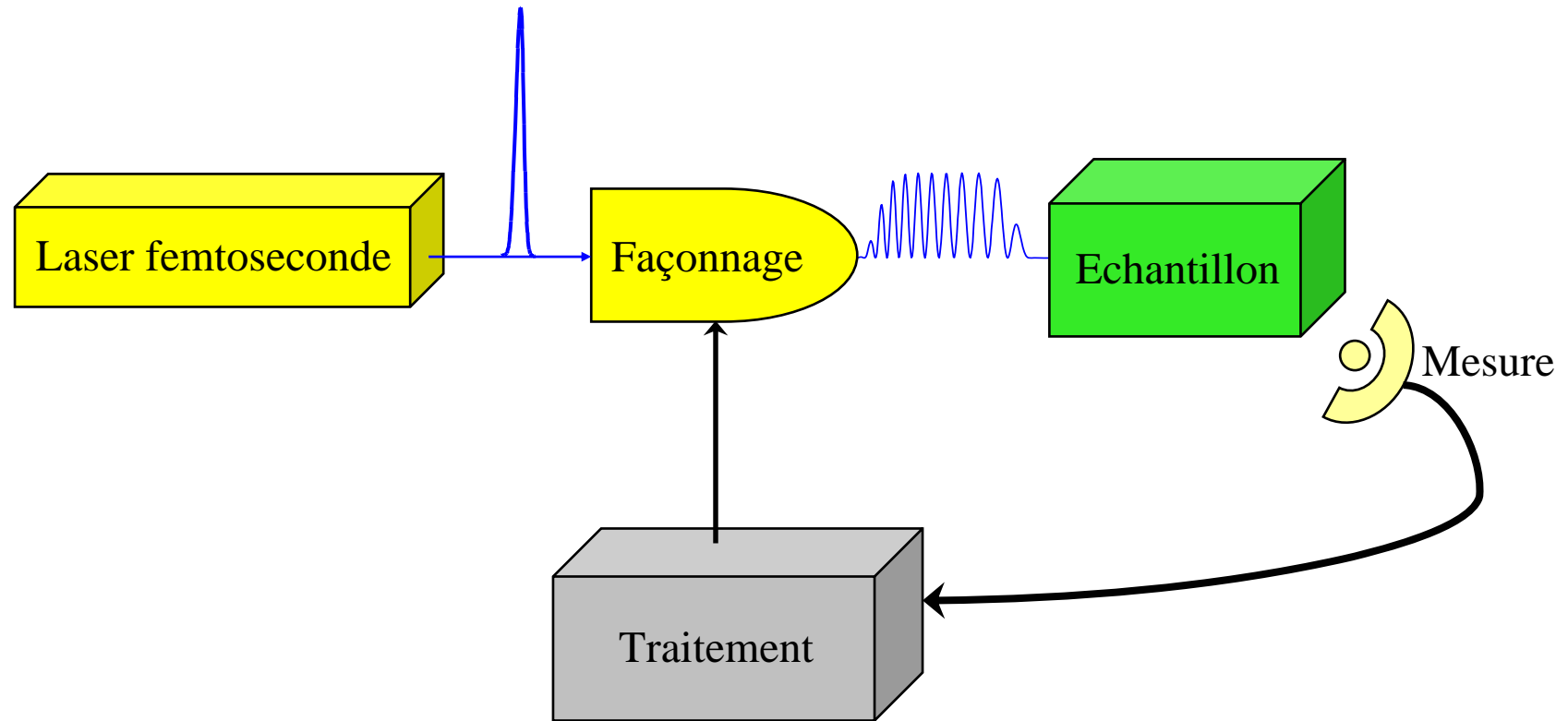
Manipuler directement l'état quantique d'un système sous l'action d'une impulsion brève de forme temporelle appropriée

Conditions :

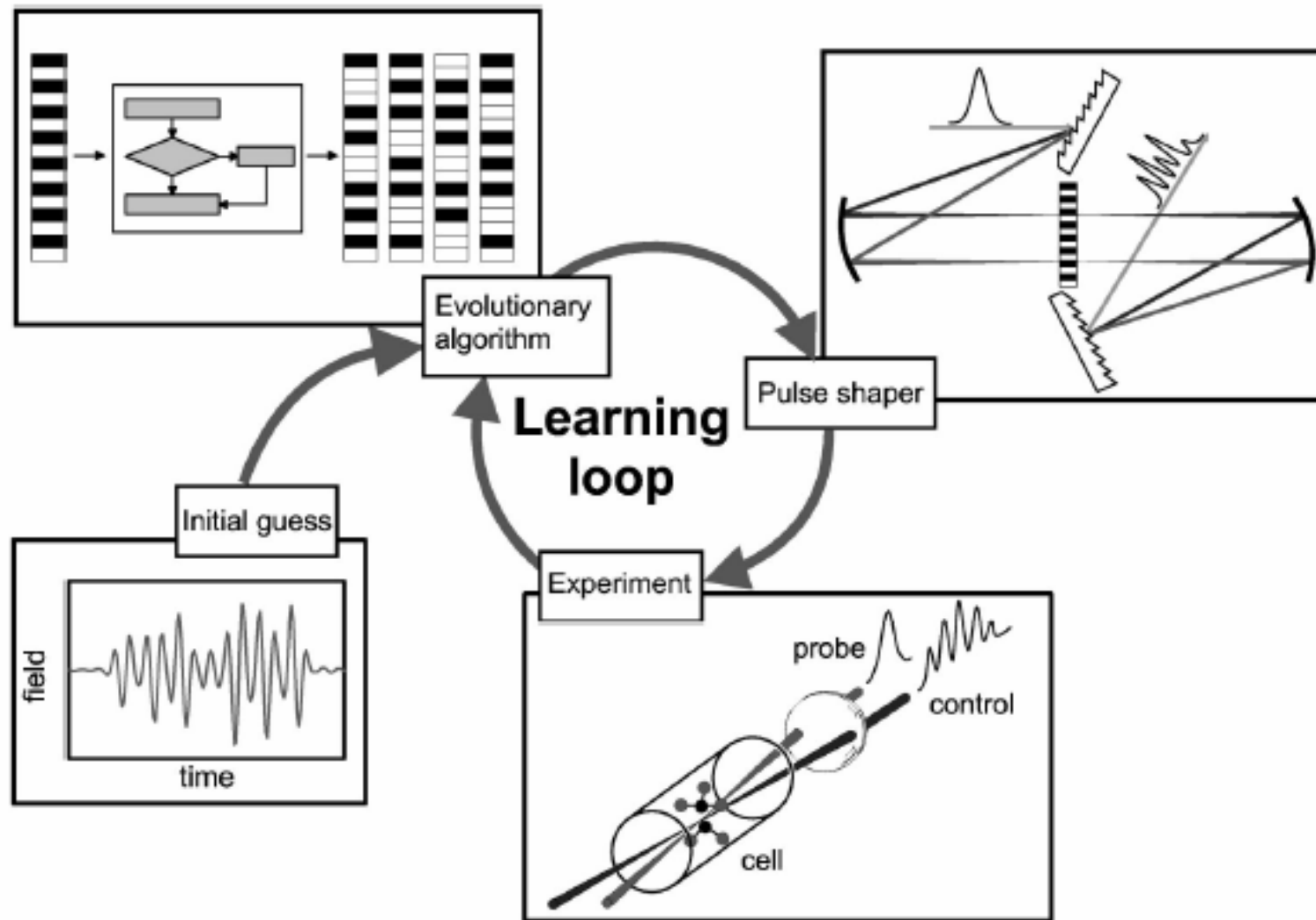
- ➡ Etre plus rapide que les processus de déphasage
- ➡ Disposer d'une énergie suffisante
- ➡ Façonner de façon arbitraire le profil temporel d'une impulsion

3. Contrôle optimal

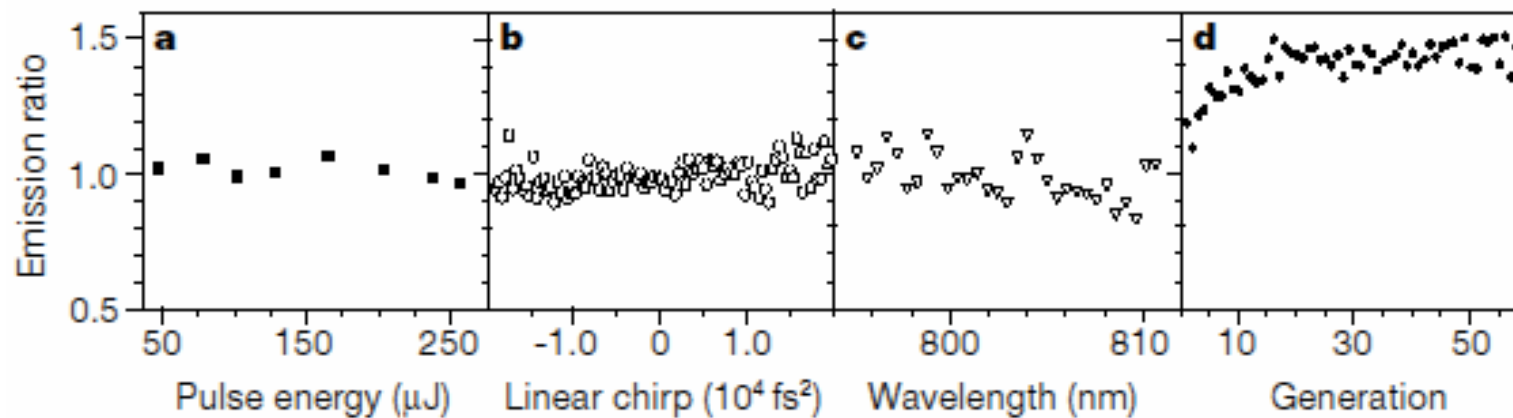
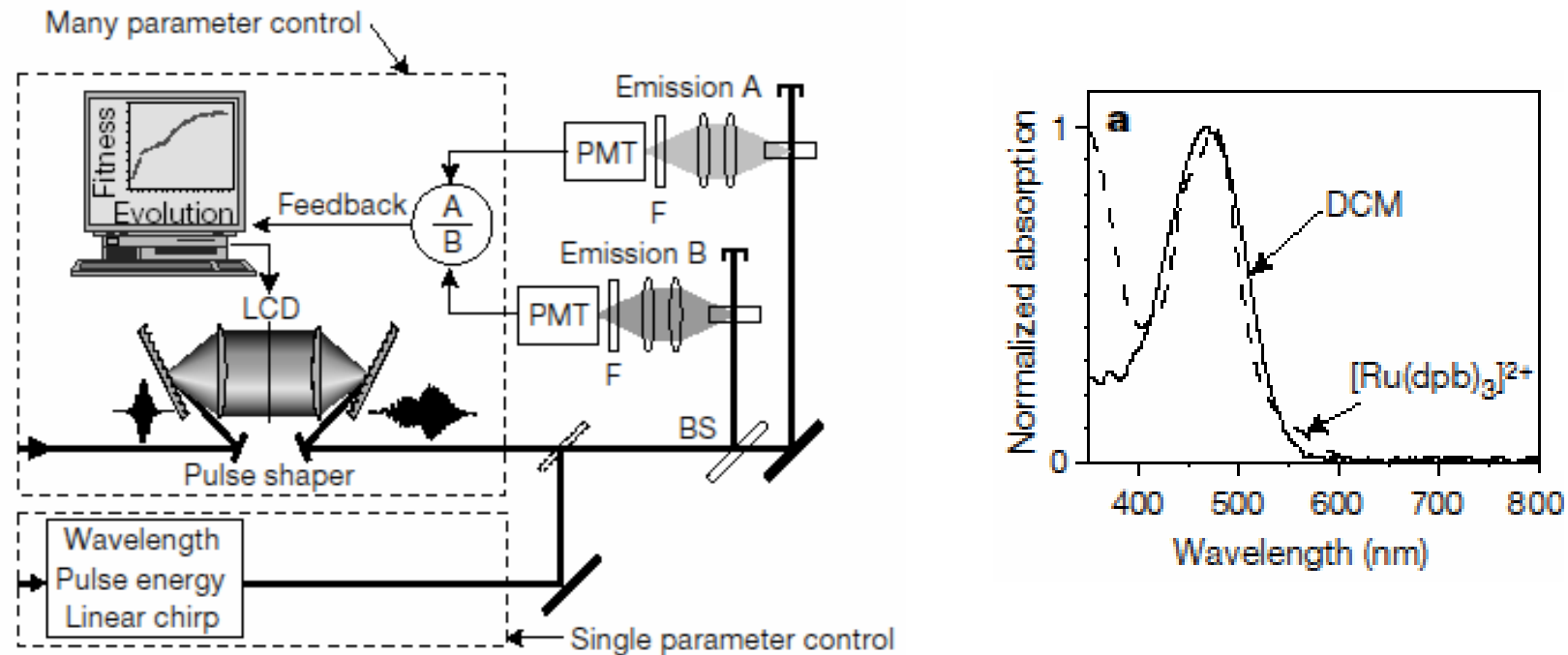
Contrôle optimal



Boucle d'apprentissage avec algorithme génétique

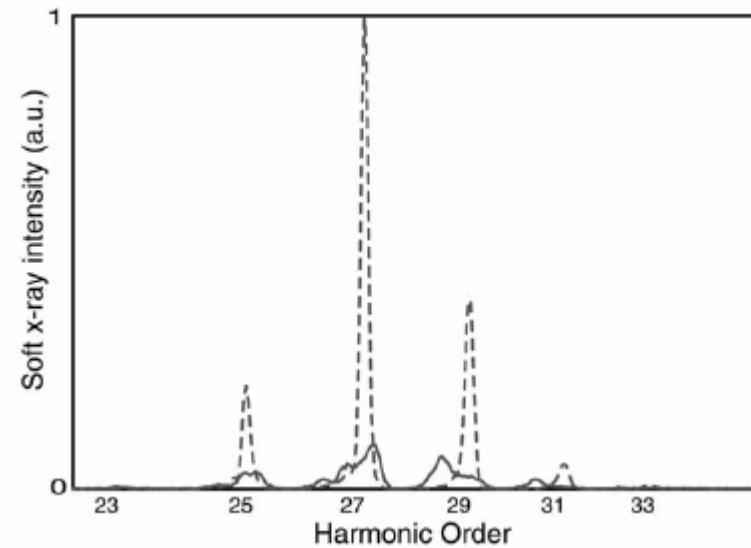
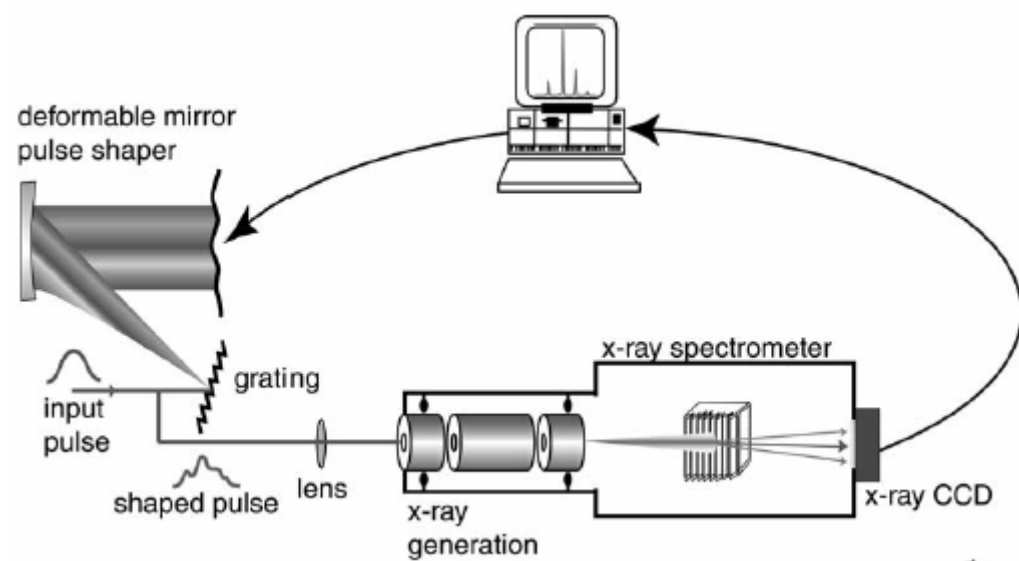


Contrôle optimal de l'excitation à deux photons



T. Brixner, N. H. Damrauer, P. Niklaus & G. Gerber, *Nature* **414**, 57 (2001)

Contrôle optimal de la génération d'harmoniques



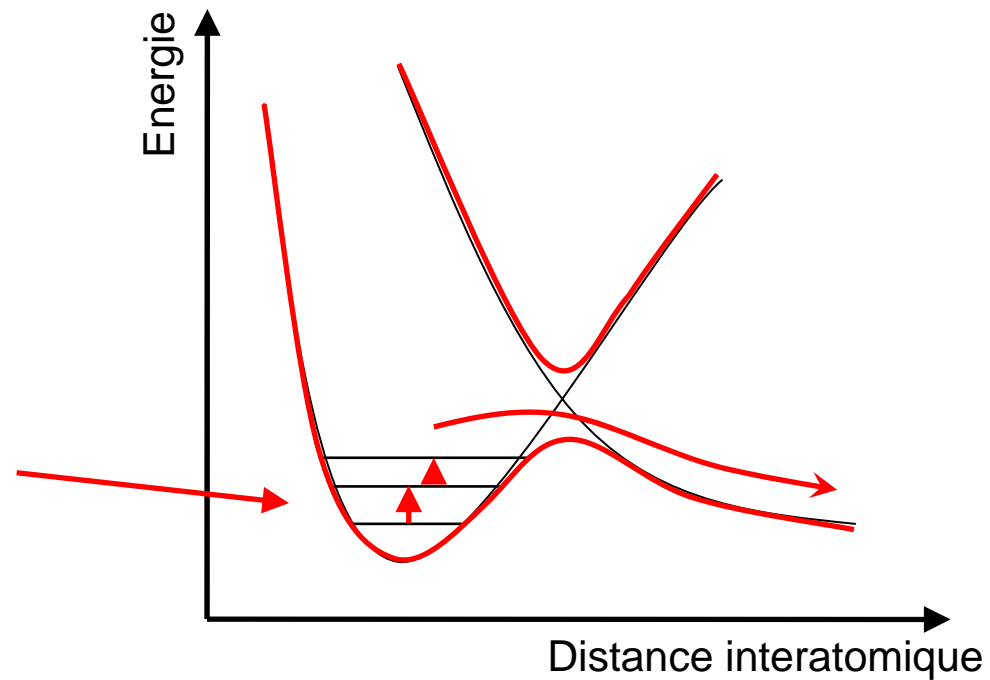
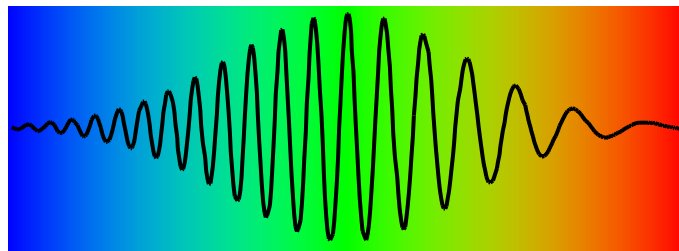
4. Contrôle cohérent vibrationnel

Contrôle cohérent vibrationnel

Efficient molecular dissociation by a chirped ultrashort infrared laser pulse

Szczepan Chelkowski, André D. Bandrauk et Paul B. Corkum

Phys. Rev. Lett. **65**, 2355 (1990)



S.M.Arrivo, T.P.Dougherty, W. Tandy Grubbs, E.J. Heilweil, Chem. Phys. Lett. 235, 247 (1995)

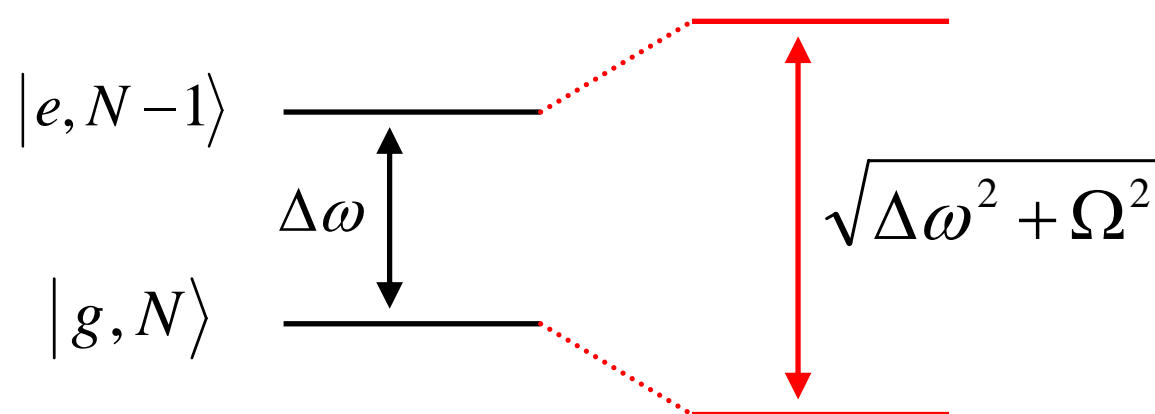
D.J.Maas, D.I.Duncan, R.B.Vrijen, W.J.vanderZande, L.D.Noordam, Chem. Phys. Lett. 290, 75 (1998)

T. Witte, T. Hornung, L. Windhorn, D. Proch, R. de Vivie-Riedle, M. Motzkus, and K. L. Kompa, J. Chem. Phys. 118, 2021 (2003)

T.L. Windhorn, J. S. Yeston, T. Witte, W.Fuß, M. Motzkus, D. Proch, K-L Kompa, J. Chem. Phys. 119, 641 (2003)

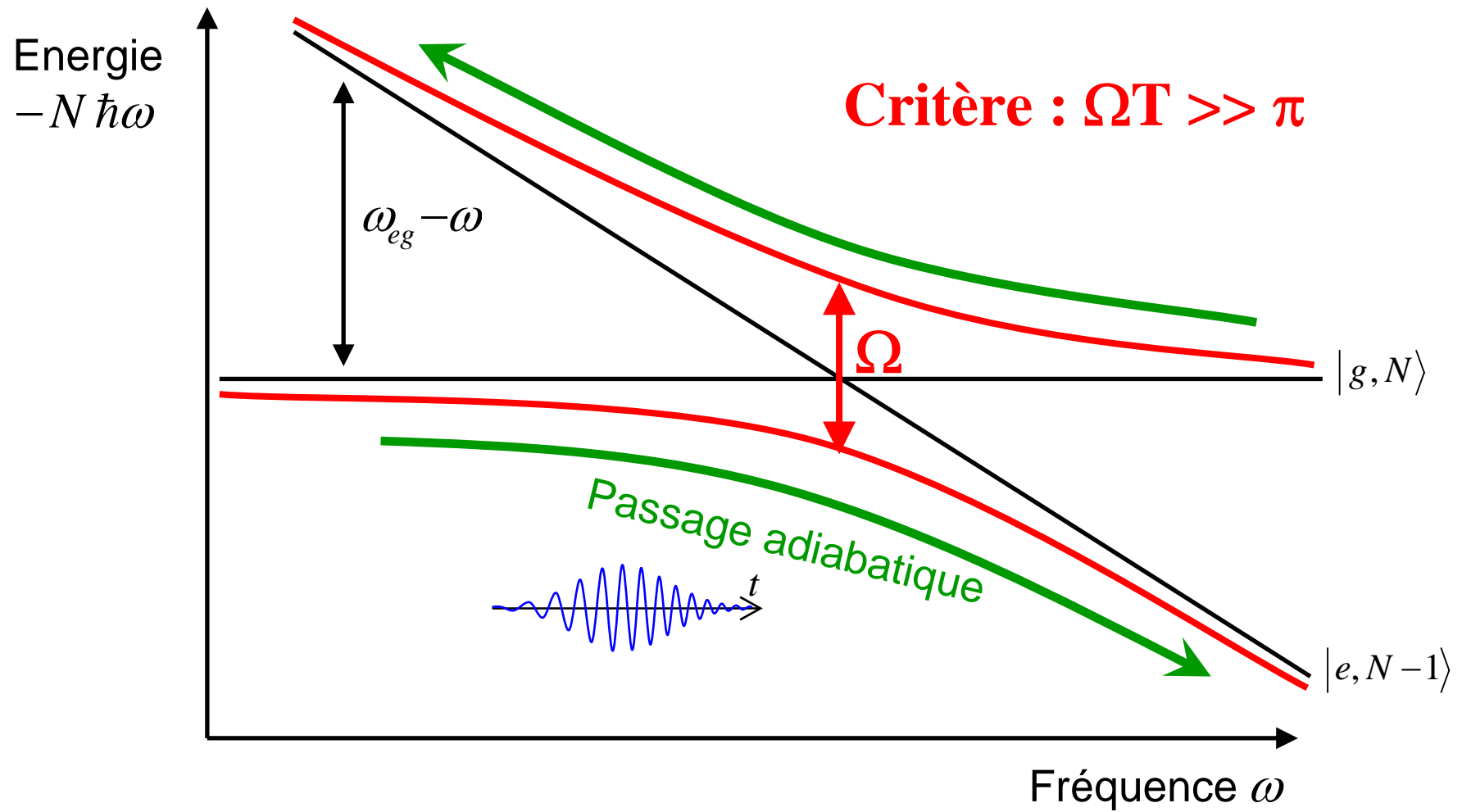
C. Ventalon, J.M. Fraser, M.H. Vos, A. Alexandrou, J.L. Martin, M. Joffre, Proc. Natl. Acad. Sci. USA 101, 13216 (2004)

Atome habillé



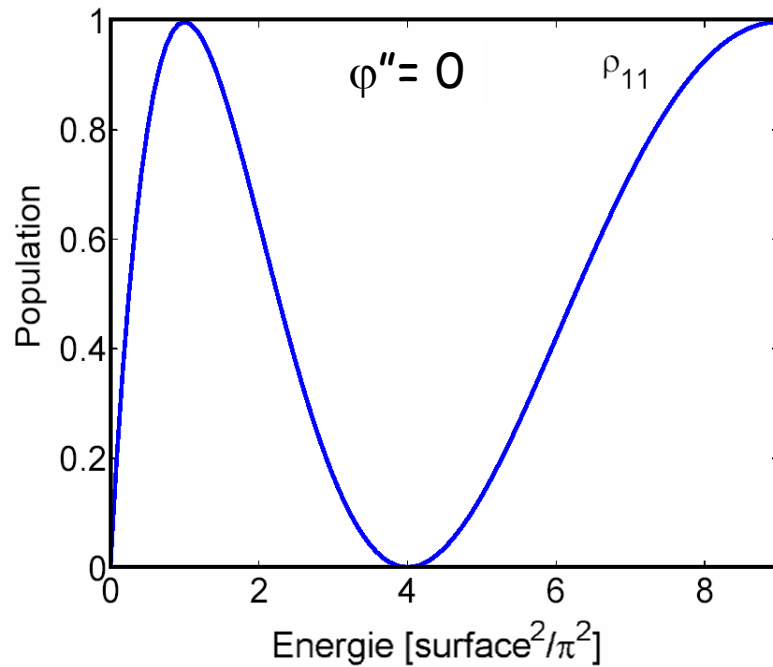
Fréquence de Rabi résonnante $\Omega = -\frac{\mu E}{\hbar}$

Passage adiabatique

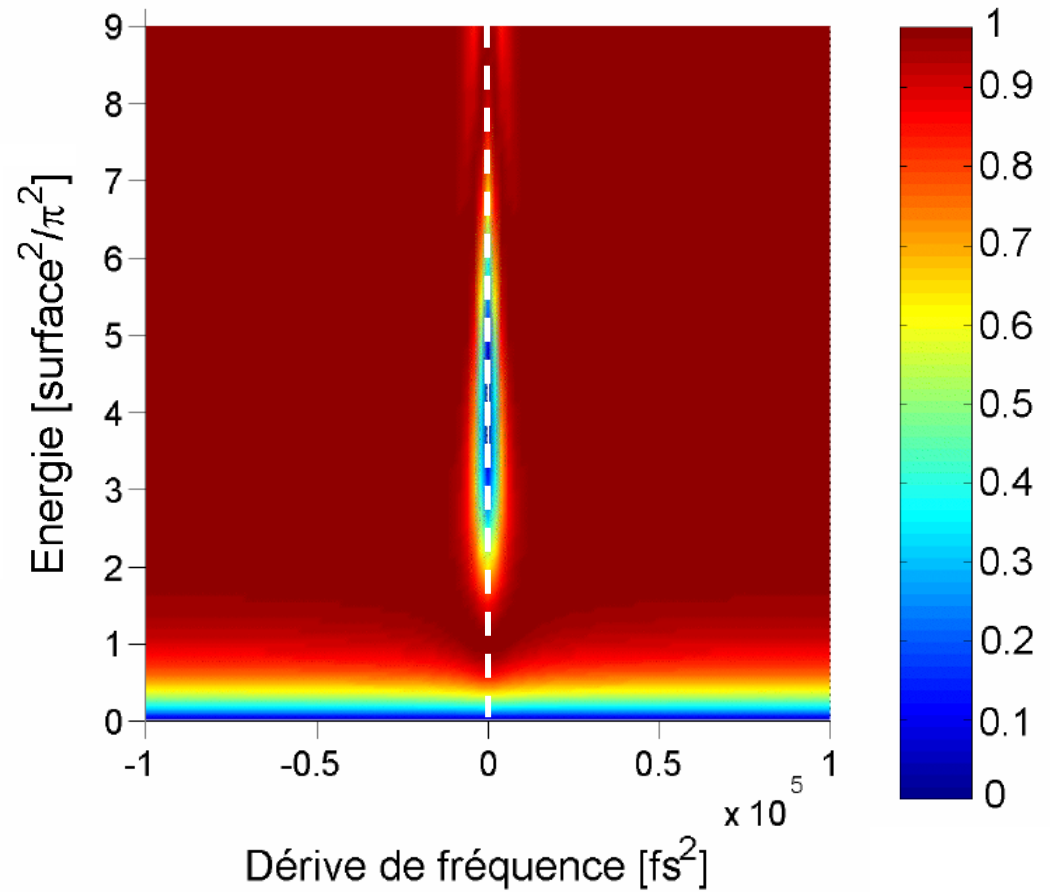


Passage adiabatique à l'aide d'une impulsion à dérive de fréquence

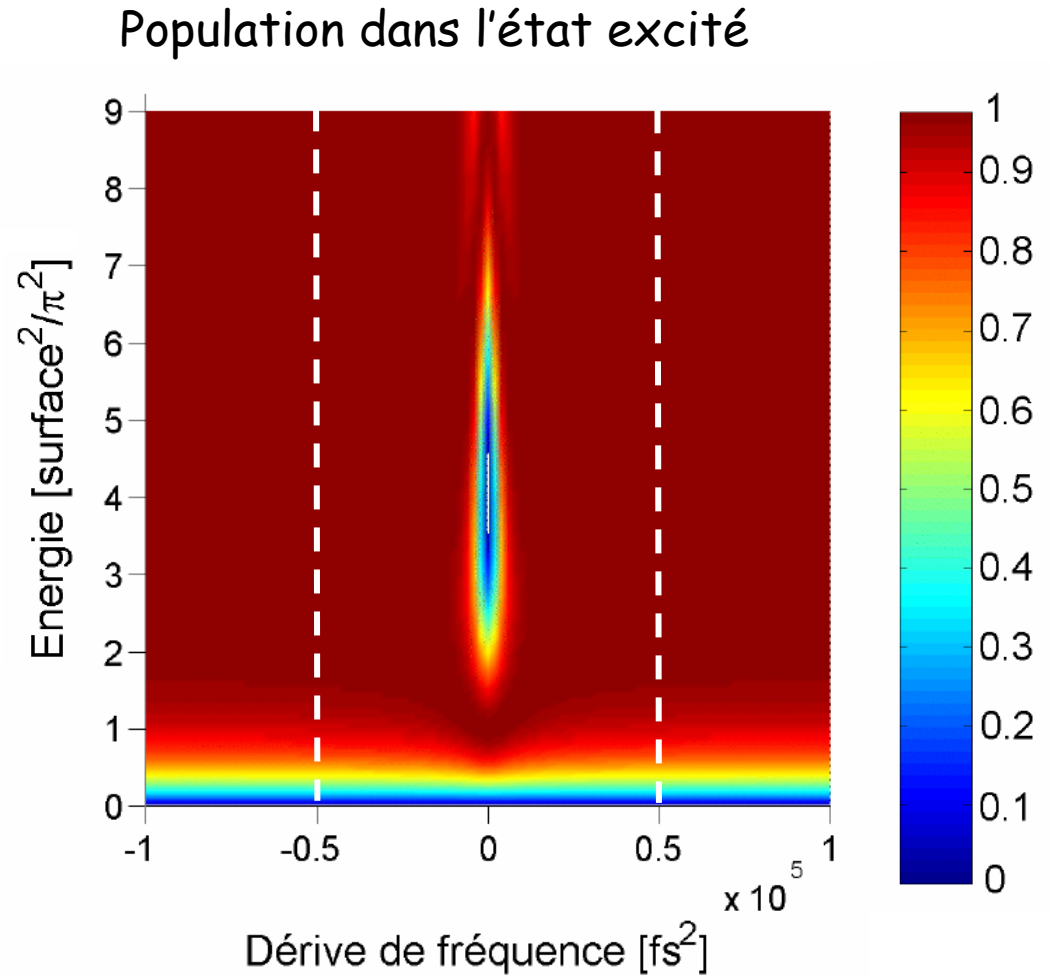
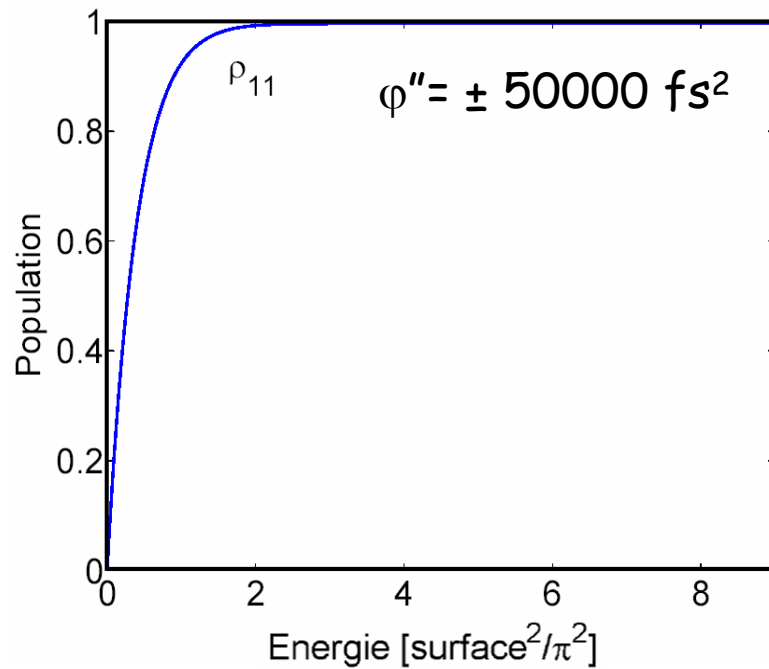
Oscillations de Rabi



Population dans l'état excité

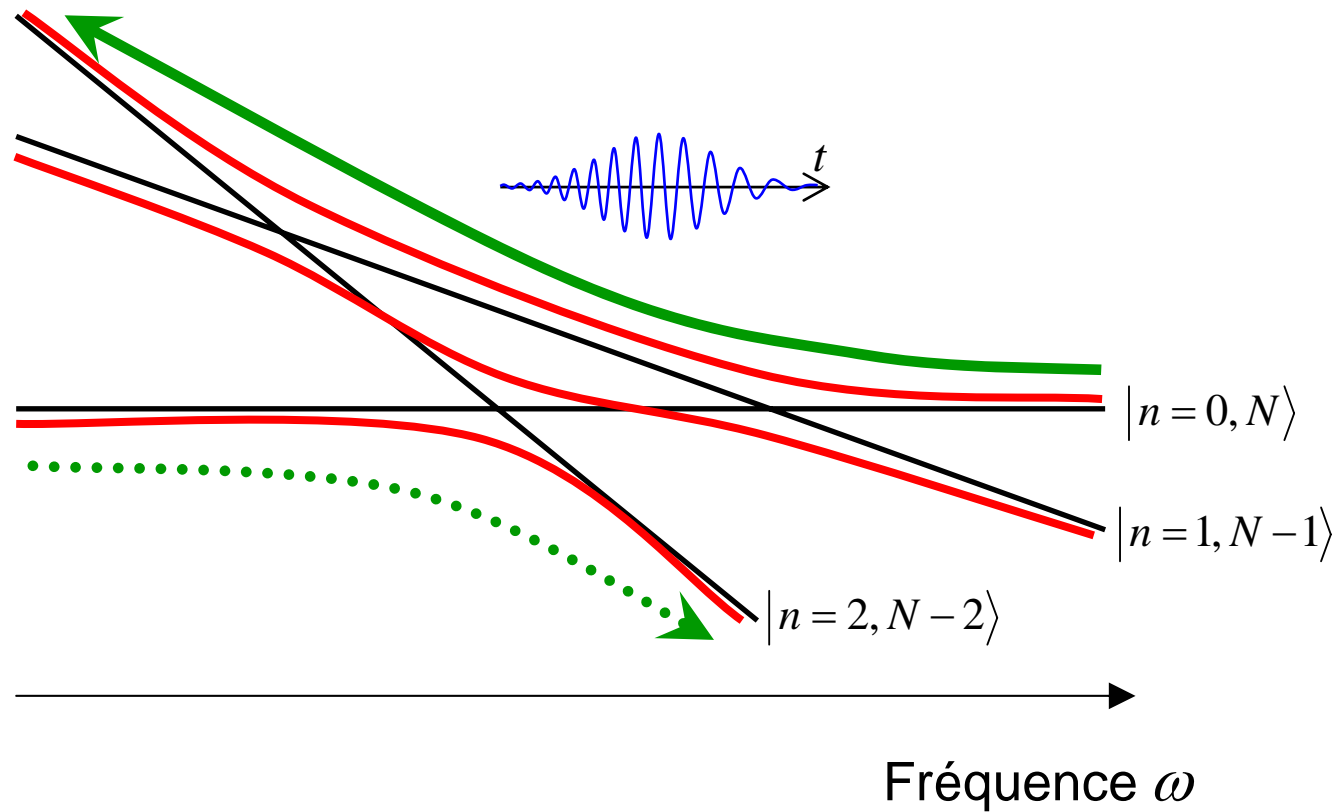
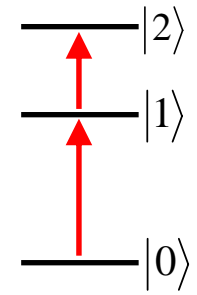


Passage adiabatique à l'aide d'une impulsion à dérive de fréquence

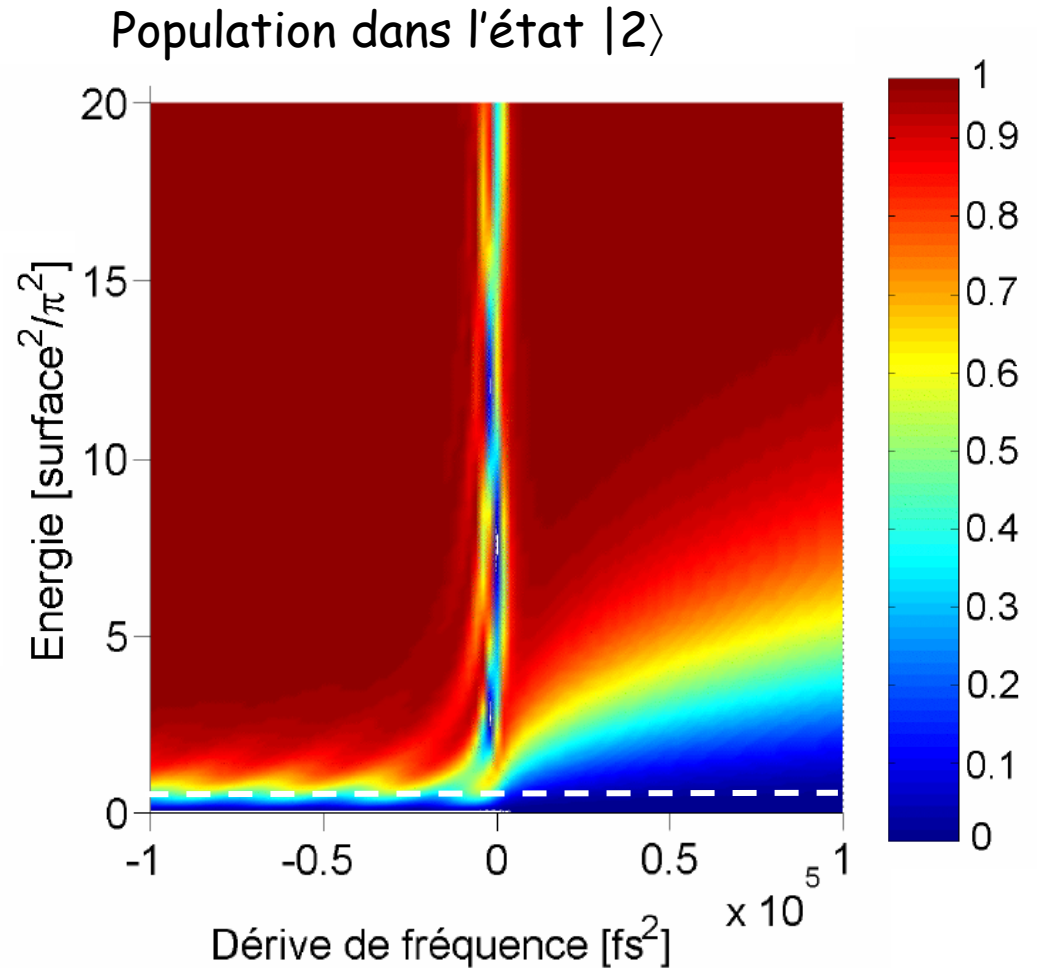
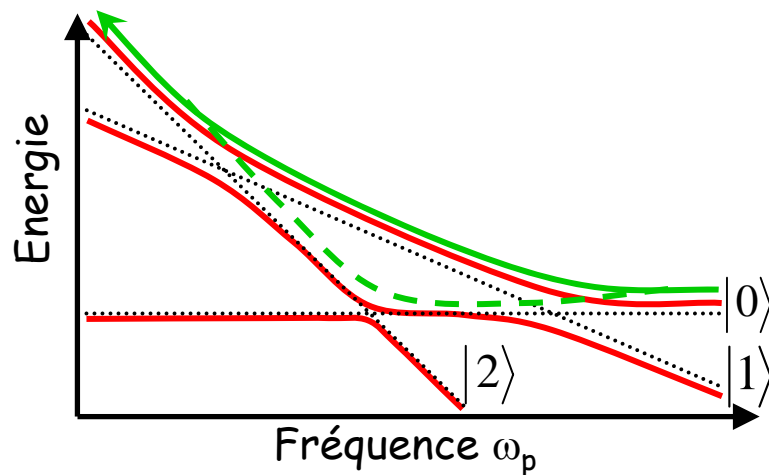
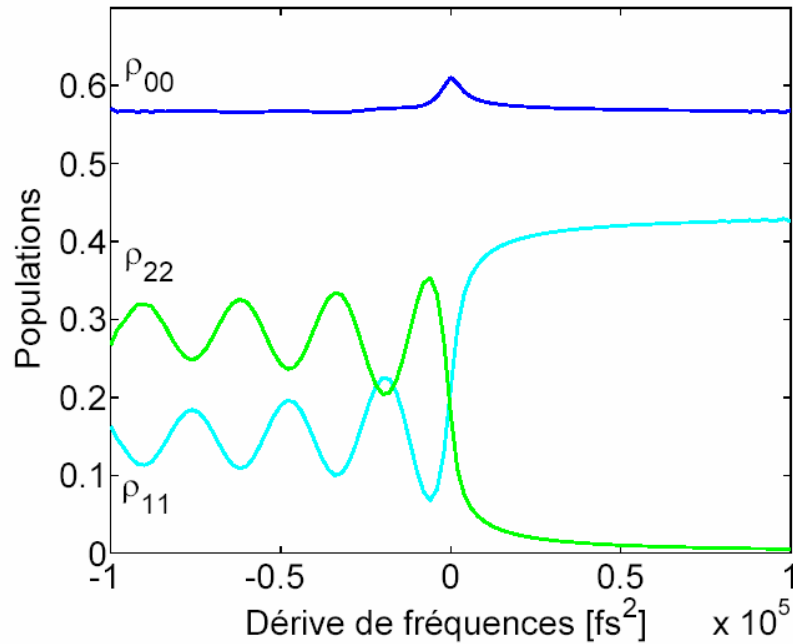


➤ Passage adiabatique plus robuste qu'une impulsion π

Passage adiabatique dans un système à trois niveaux



Passage adiabatique dans un système à trois niveaux

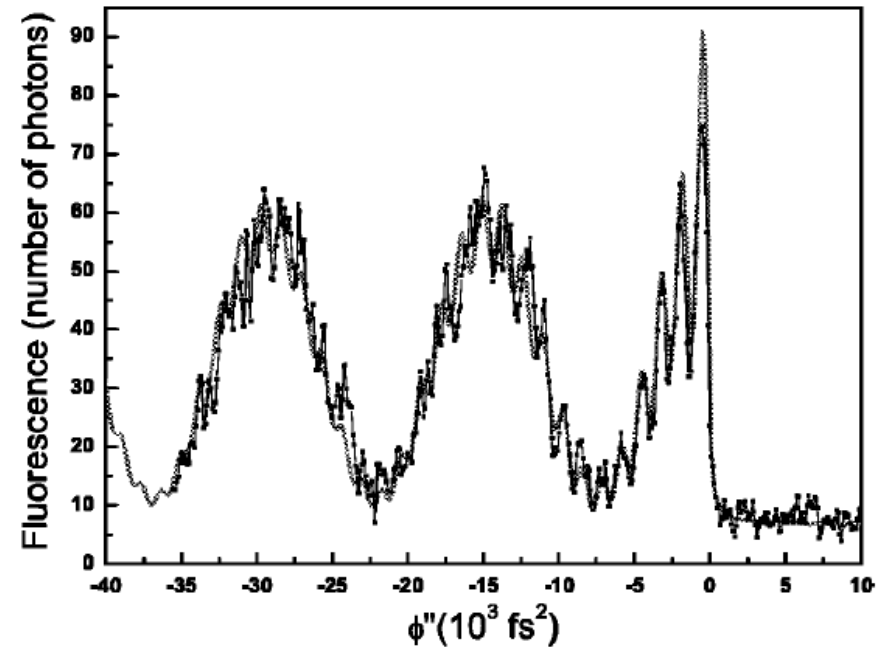
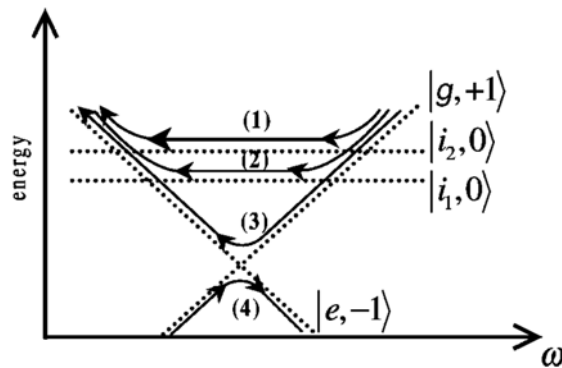
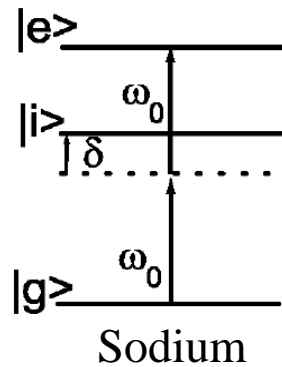


Noordam *et al.*, Phys. Rev. A **50**, 4276 (1994)

Noordam *et al.*, PRA **59**, 1374 (1999)

Chatel *et al.*, PRA **68**, 041402 (R) (2003)

Passage adiabatique dans un système à trois niveaux

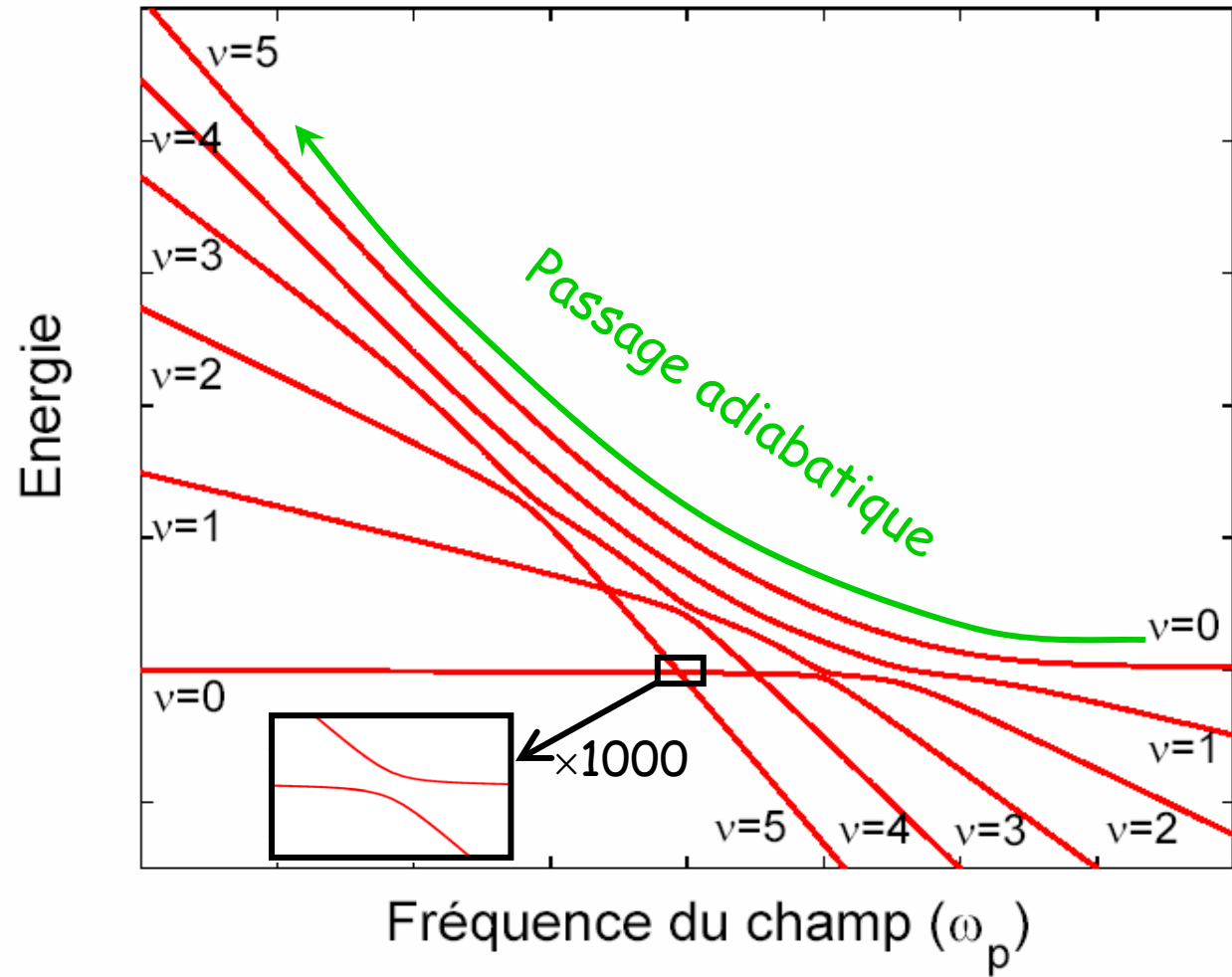
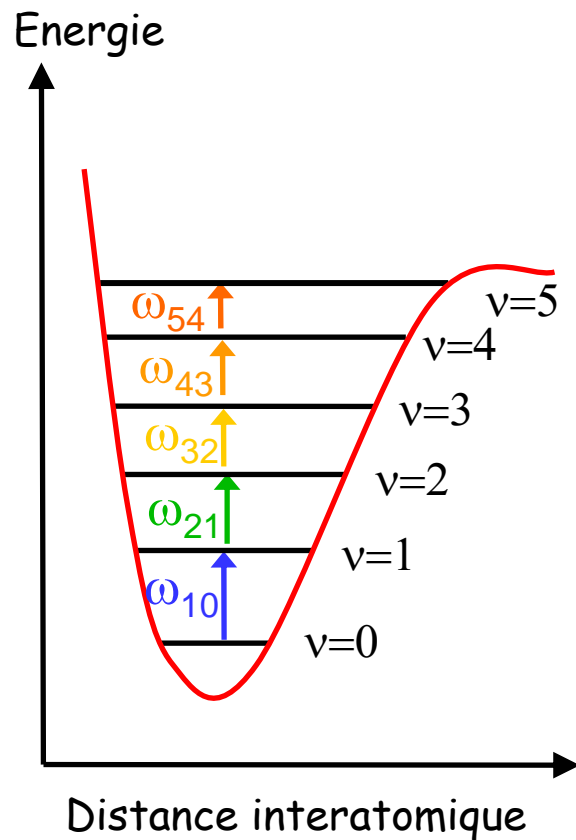


B. Chatel, J. Degert, S. Stock, B. Girard

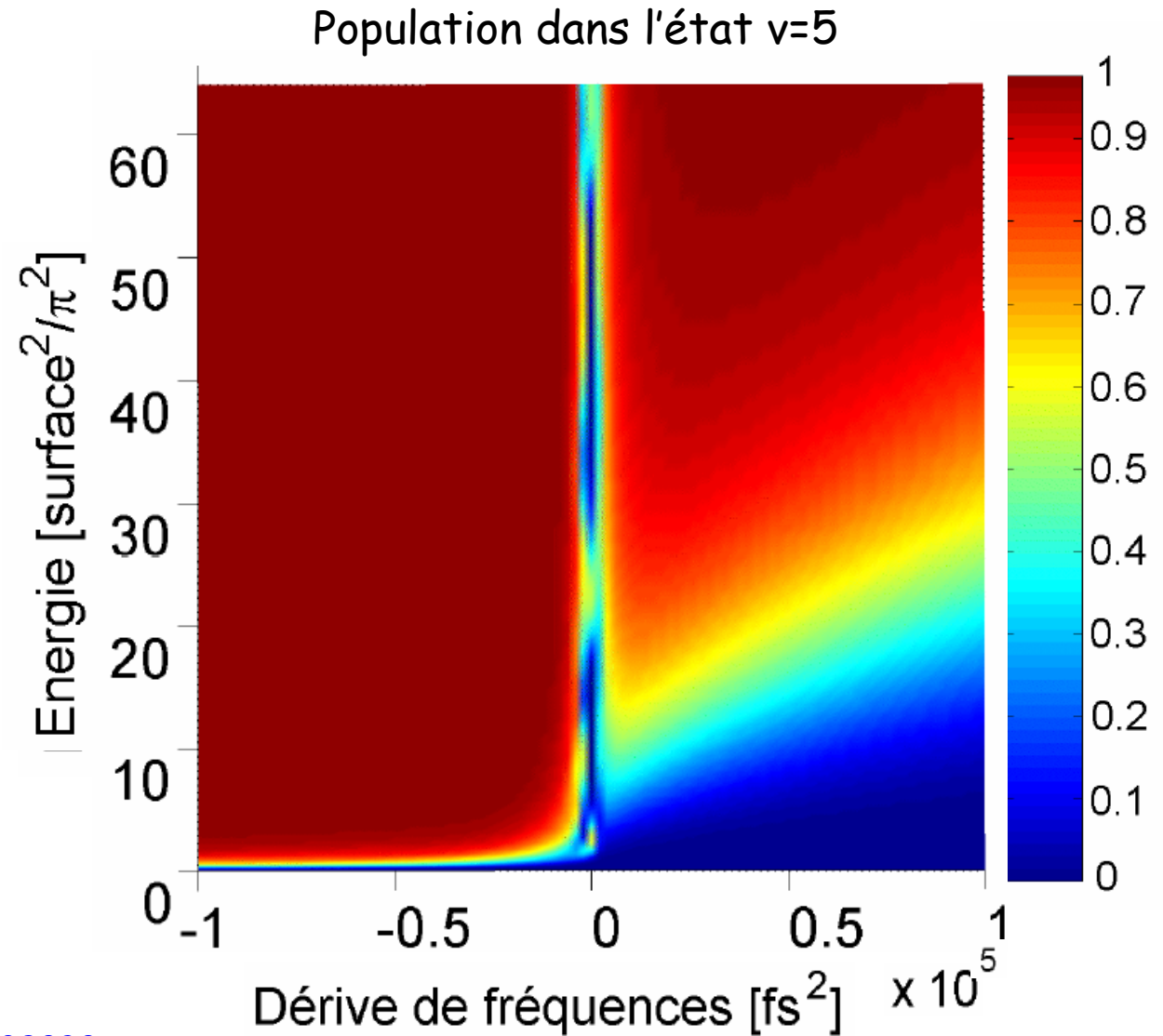
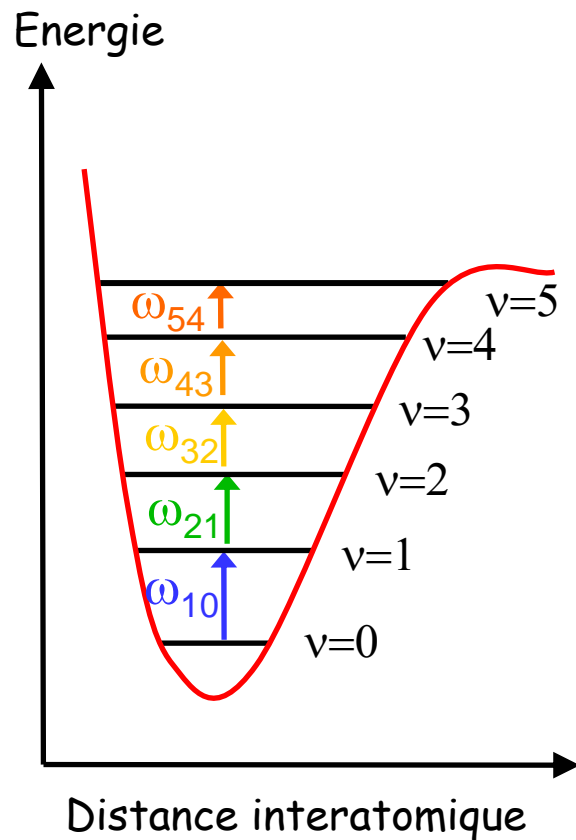
Competition between sequential and direct paths in a two-photon transition

Phys. Rev. A **68**, 041402 (2003)

Passage adiabatique dans un système à six niveaux



Passage adiabatique dans un système à six niveaux

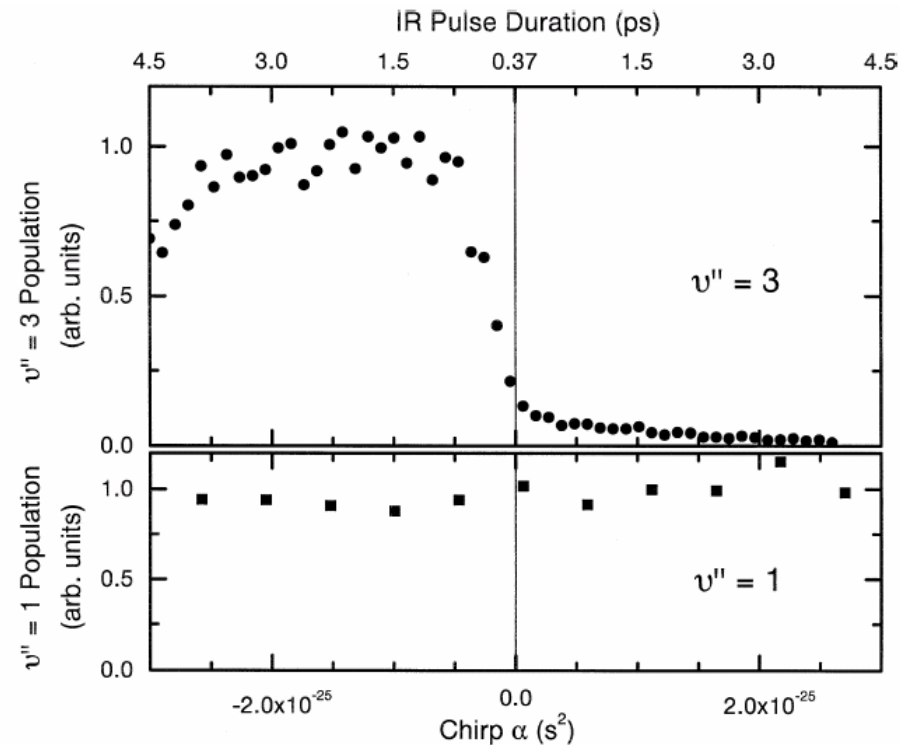


Vibrational ladder climbing in NO by (sub) picosecond frequency-chirped infrared laser pulses

D.J. Maas, D.I. Duncan, R.B. Vrijen, W.J. van der Zande, L.D. Noordam

FOM Institute for Atomic and Molecular Physics, Kruislaan 407, 1098 SJ Amsterdam, The Netherlands

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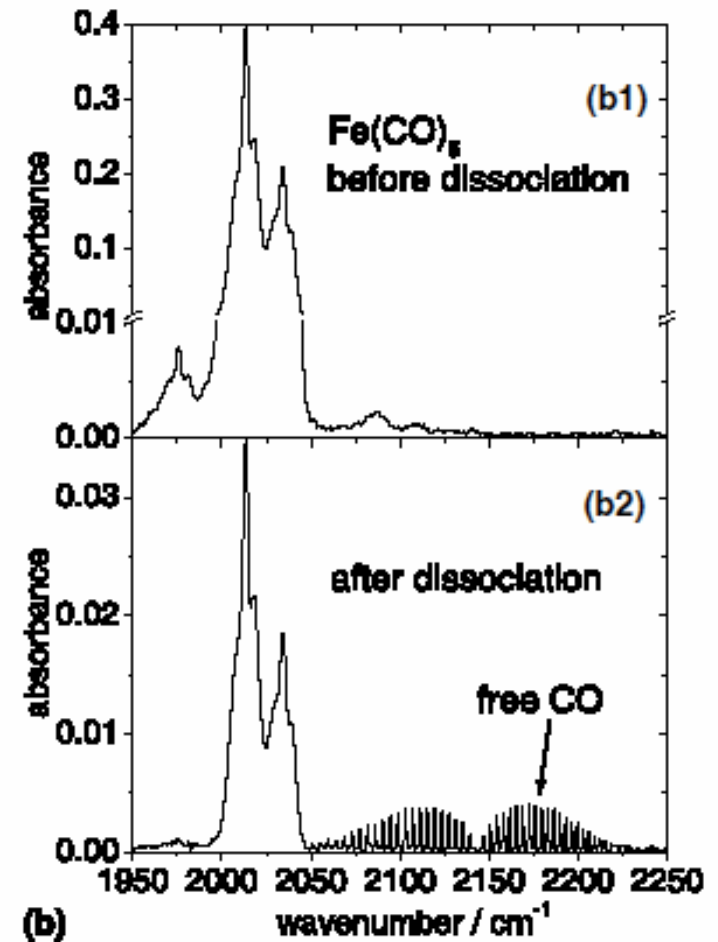
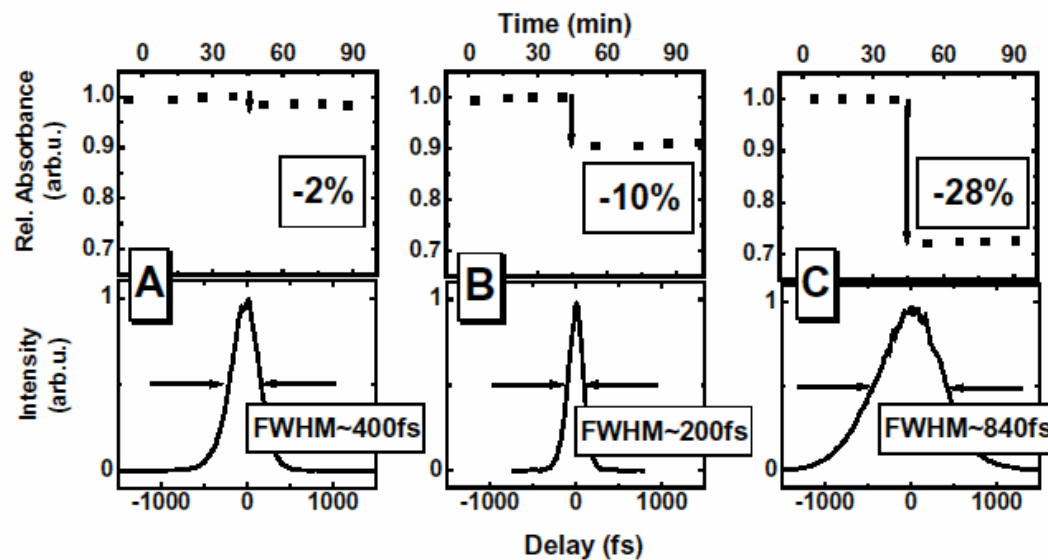
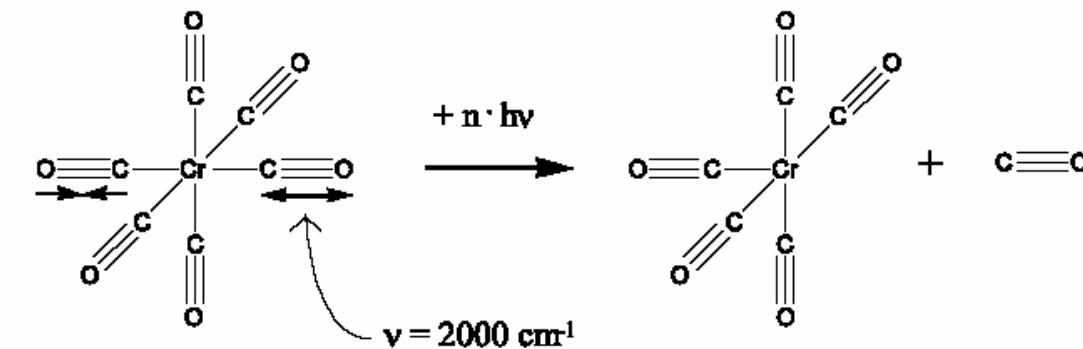
Laser à électrons libres (FELIX). 300 nJ
Chem. Phys. Lett. **290**, 75 (1998)

Molecular dissociation by mid-IR femtosecond pulses

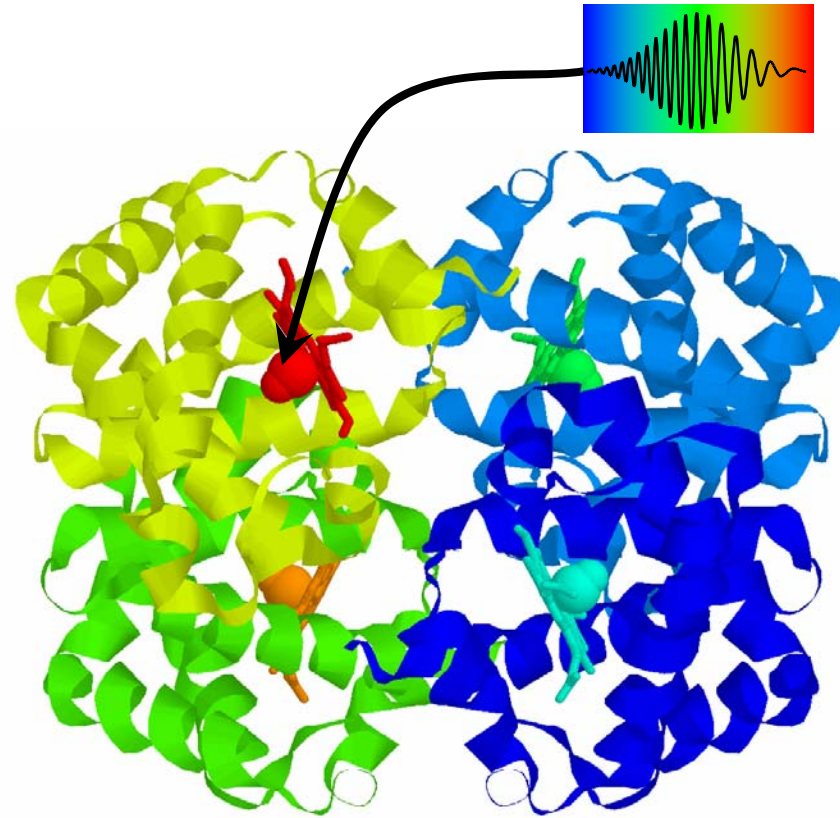
L. Windhorn, T. Witte, J.S. Yeston, D. Proch, M. Motzkus, K.L. Kompa,
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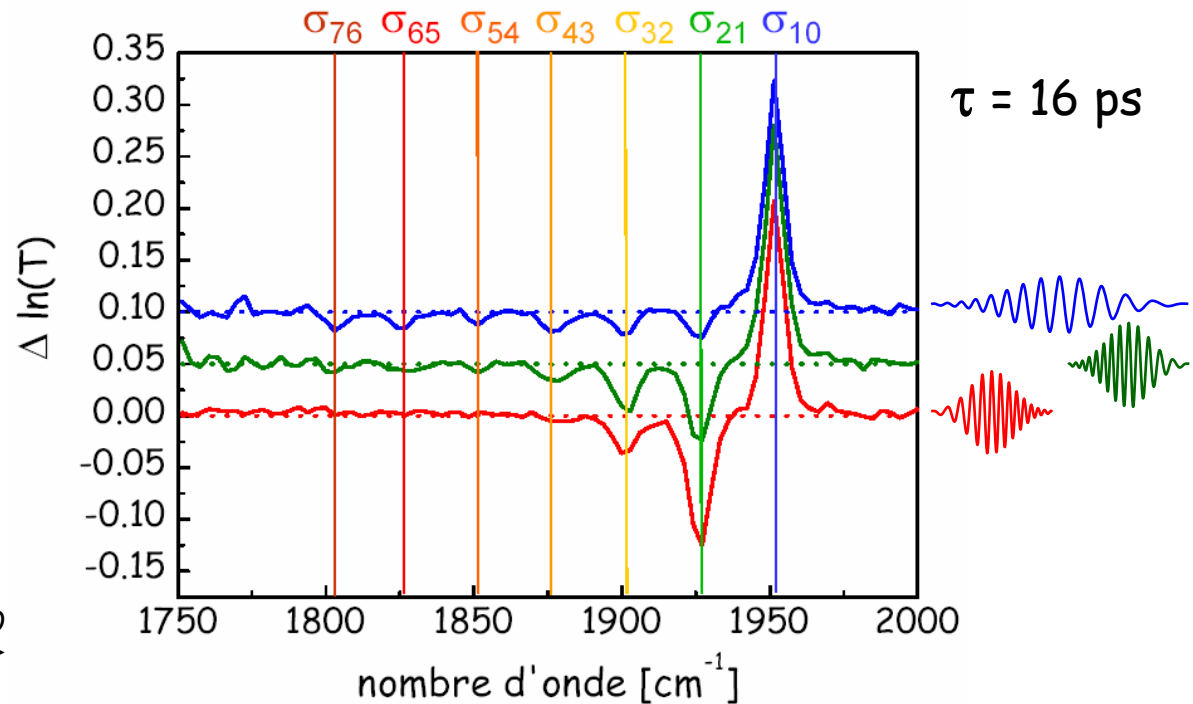
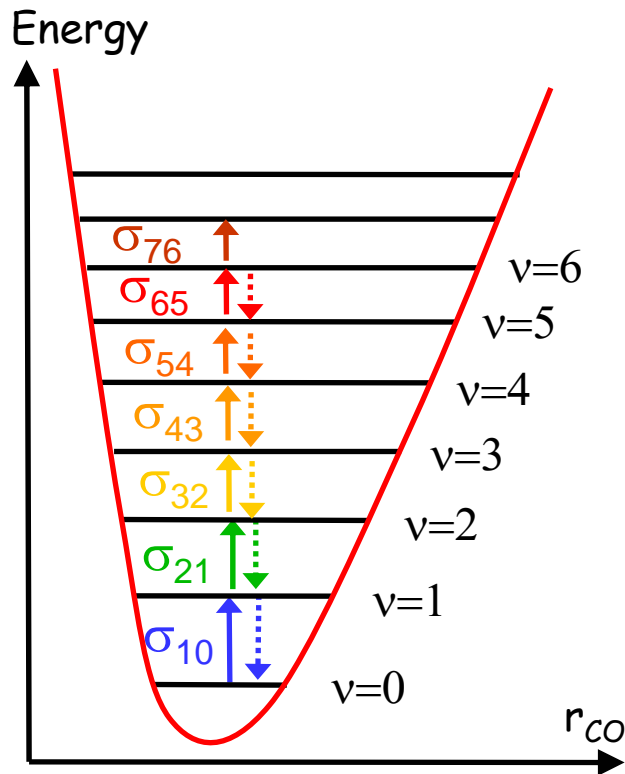
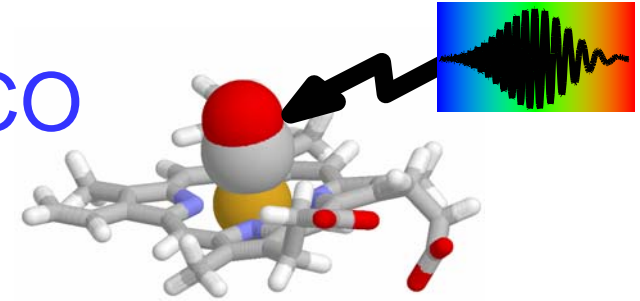
Received 6 December 2001



Contrôle cohérent dans les hémoprotéines

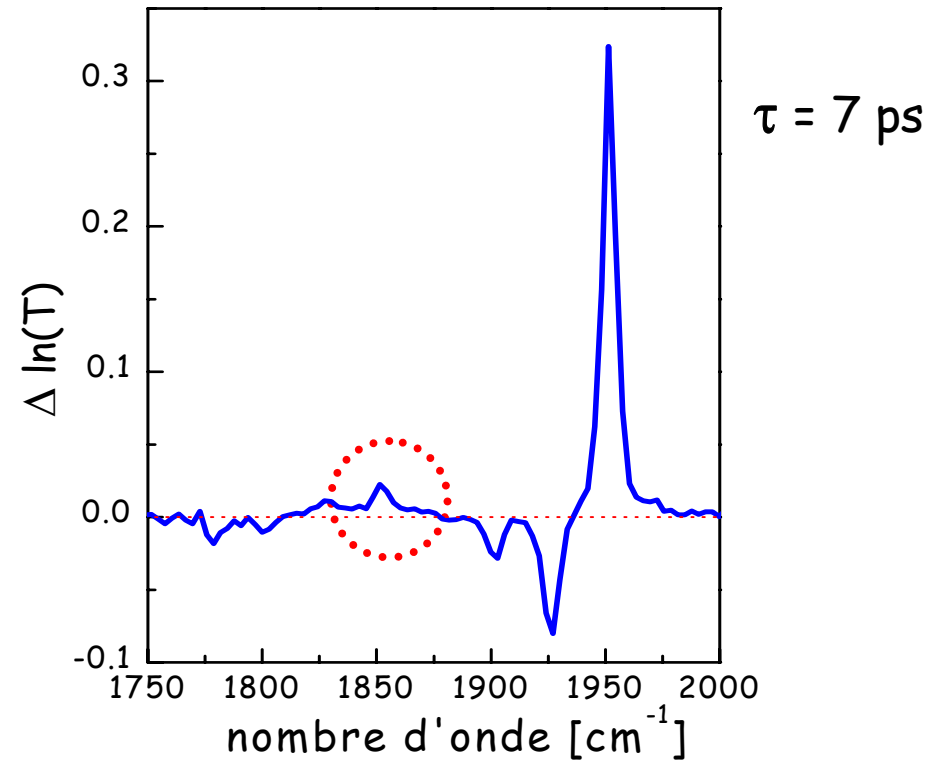
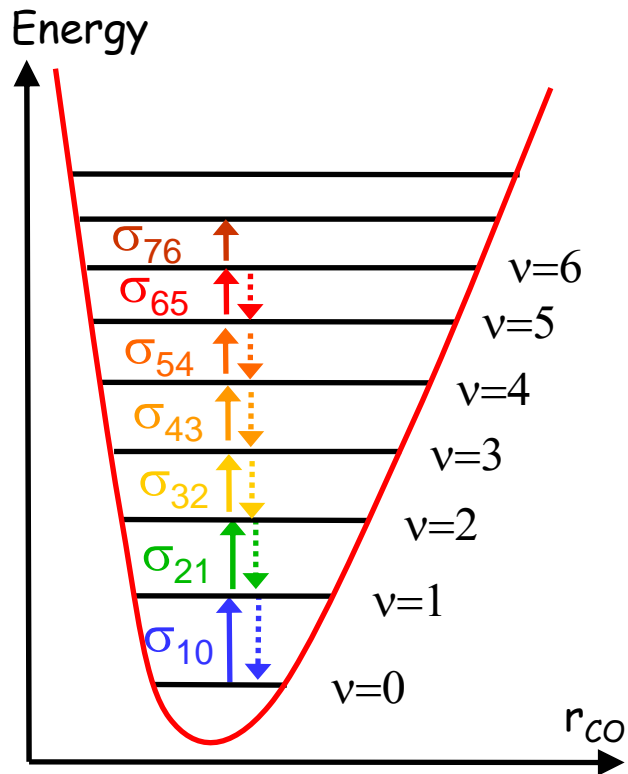
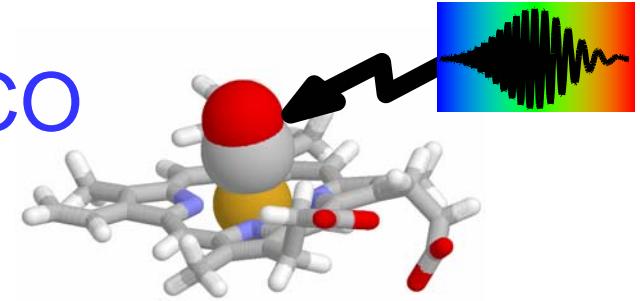


Ascension vibrationnelle dans HbCO



- ✓ Mise en évidence de l'effet de la dérive de fréquence
- ✓ Ascension jusqu'au niveau $\nu = 6$

Ascension vibrationnelle dans HbCO



✓ Inversion de population résultant de la nature cohérente de l'excitation