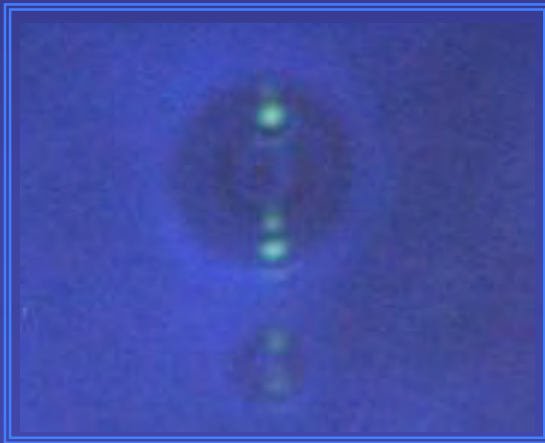


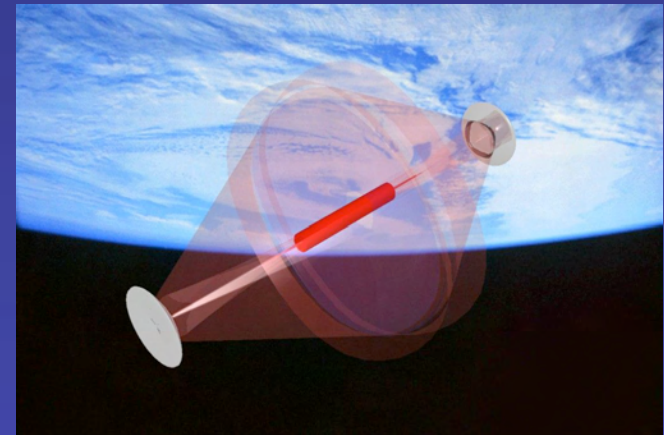


Laboratoire d'Interférométrie Stellaire et Exoplanétaire  
Collège de France  
Observatoire de Haute Provence  
04870 Saint Michel l'Observatoire, France

# Pression de radiation et forces de cohésion optiques: Application au « Laser Trapped Mirror »

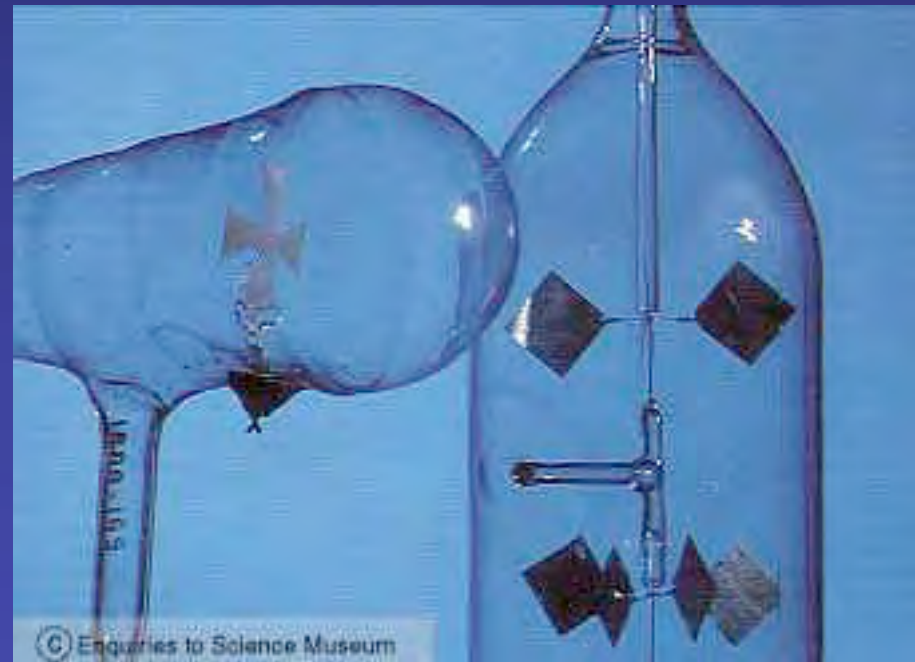
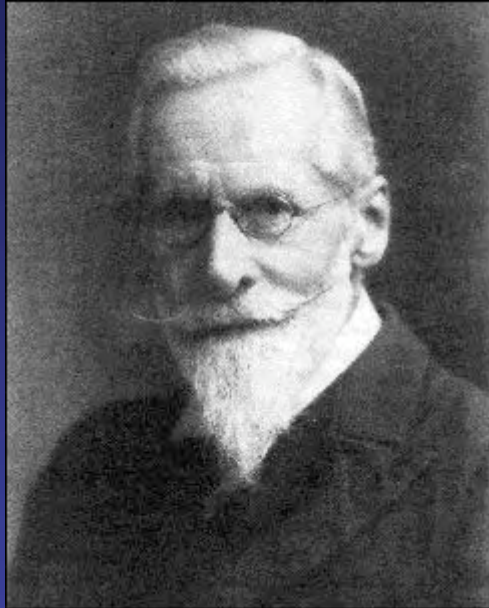


**Marc Guillon**

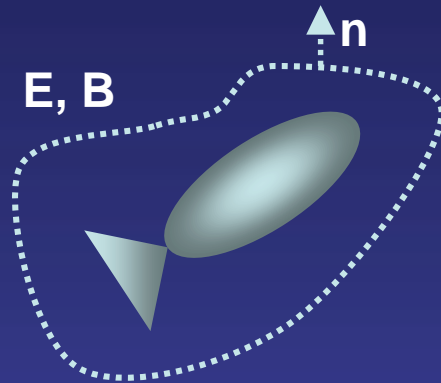


Séminaire présenté au collège de France le 6 février 2007

# Le radiomètre de Crookes (1875)



# Forces Optiques



$$\frac{\partial P_{meca}}{\partial t} + \iiint \frac{\partial g_\alpha}{\partial t} d\tau = \oint T_{\alpha\beta} n_\beta da$$

conservation  
de l'impulsion

$$\frac{\mathbf{r}}{g} = \frac{\mathbf{E}\mathbf{H}}{c^2}$$

Impulsion EM

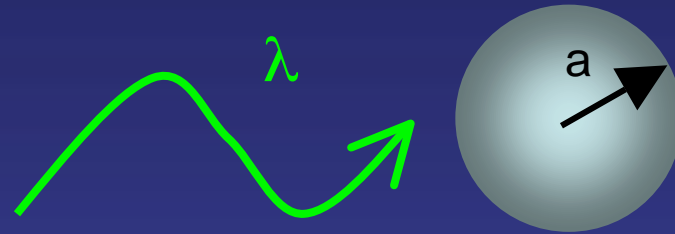
$$T_{\alpha\beta} = \epsilon_0 \left( E_\alpha E_\beta + c^2 B_\alpha B_\beta - \frac{\delta_{\alpha\beta}}{2} (E^2 + c^2 B^2) \right)$$

Tenseur de Maxwell

$$\mathbf{E}_{tot} = \mathbf{E}_{inc} + \mathbf{E}_{scat}$$

Champ total

# Billes sphériques: trois régimes



$$a \ll \lambda$$

Régime dipolaire

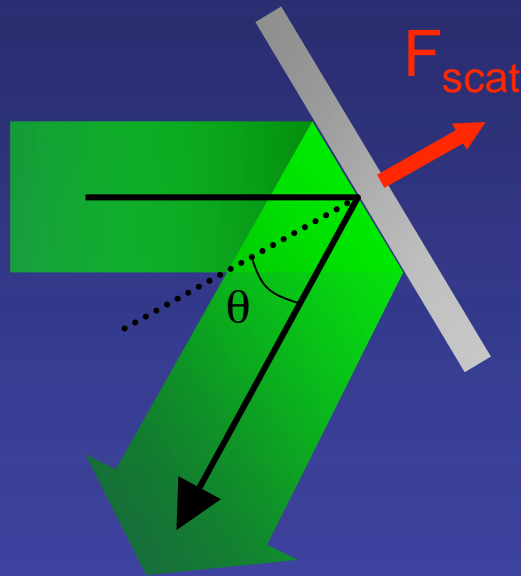
$$a \sim \lambda$$

Régime de Mie  
(résonant)

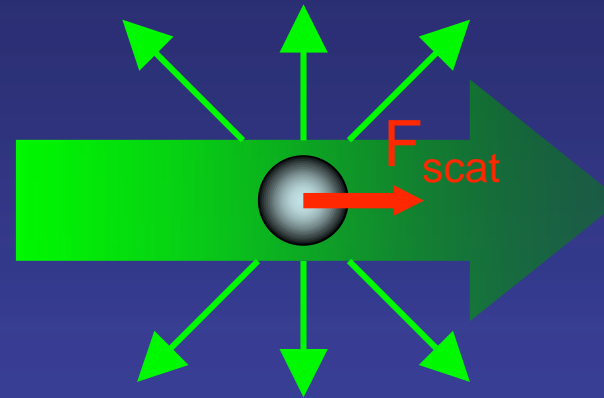
$$a \gg \lambda$$

Régime classique

# Forces Optiques: La pression de radiation.



$$F = \frac{I.S.\cos^2\theta}{c} \frac{\vec{k}}{k}$$



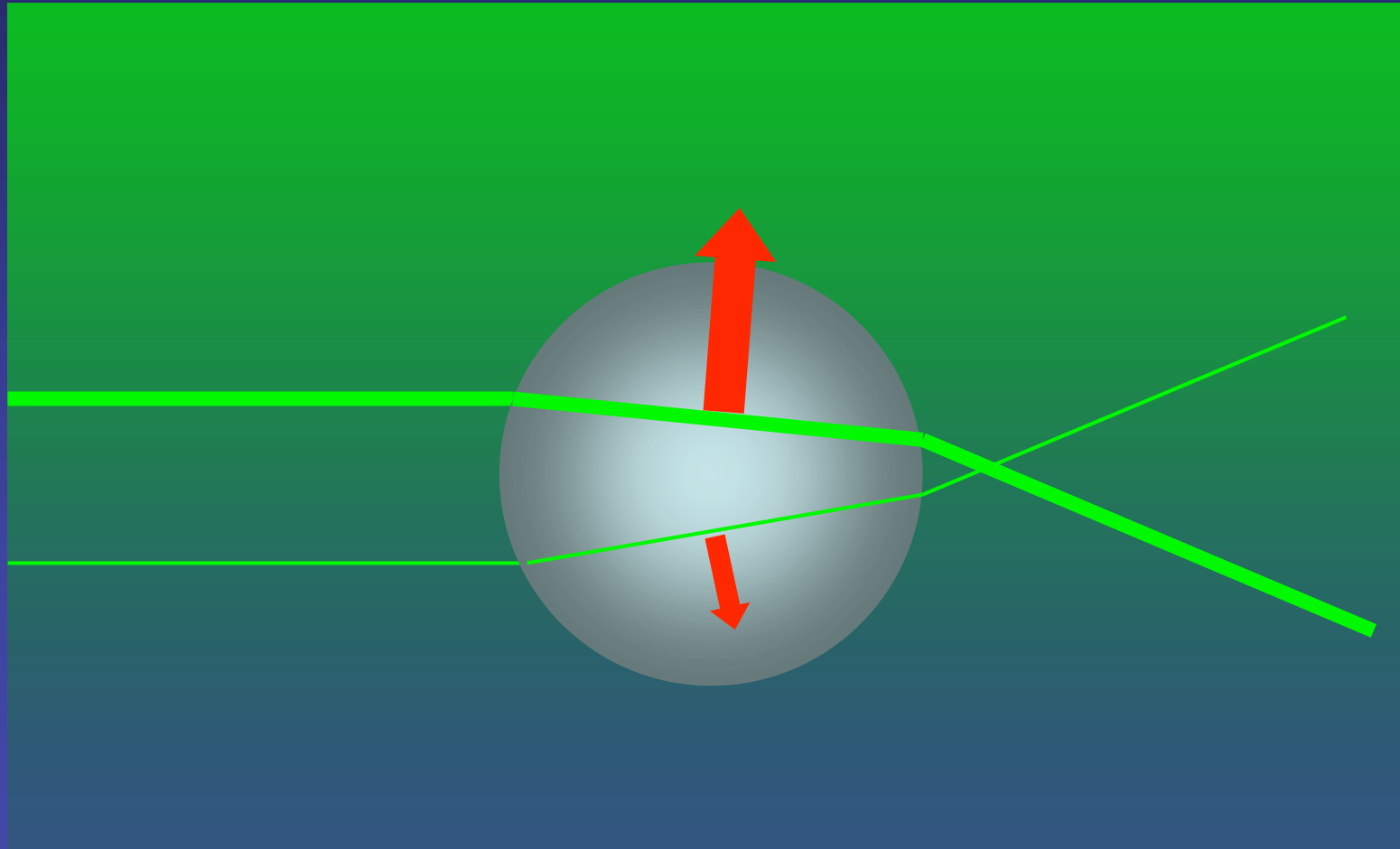
$$F = \frac{I.\sigma}{c} \frac{\vec{k}}{k}$$

A. Ashkin, Phys. Rev. Lett. **24**, 156-159 (1969)

# Pression de radiation

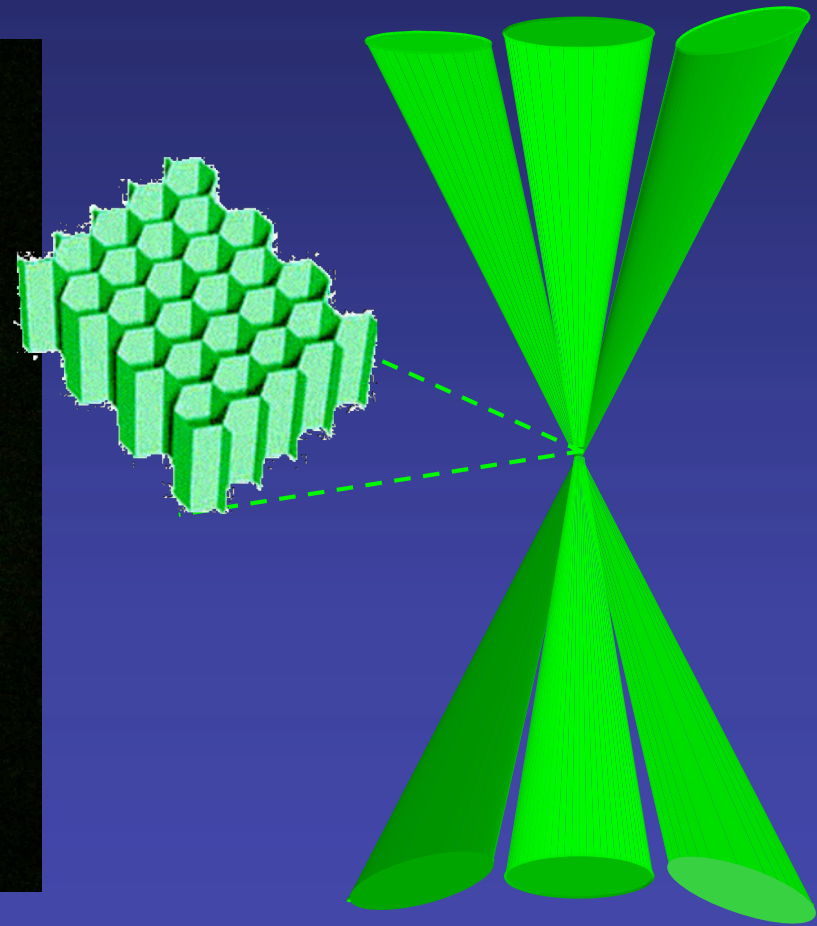
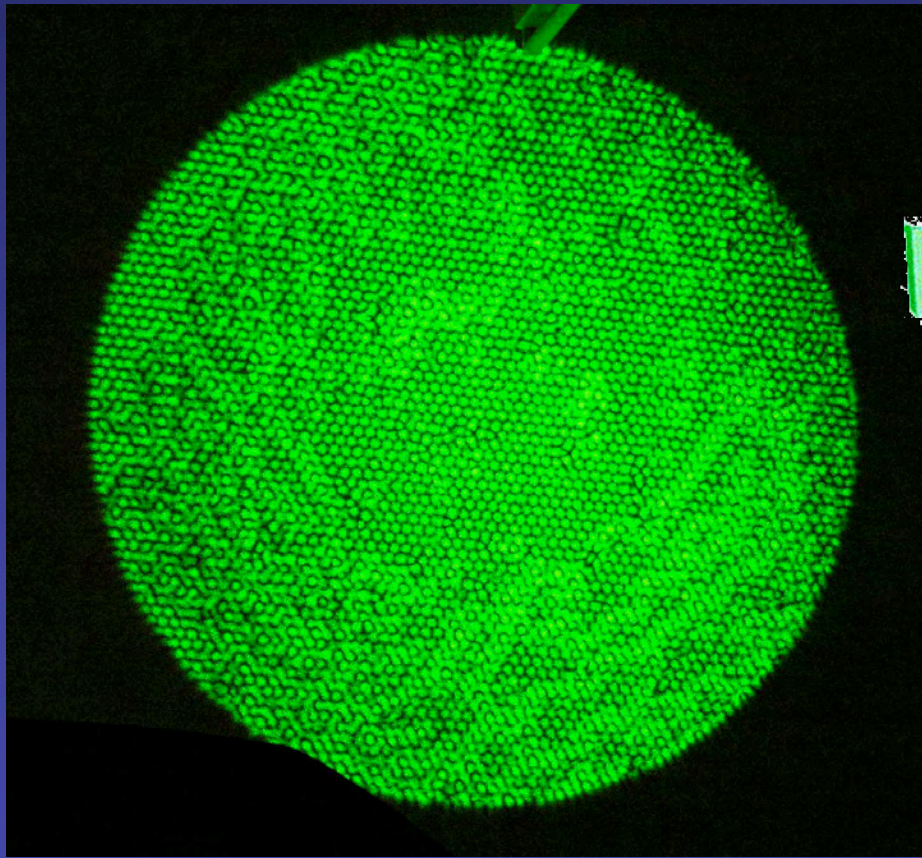


Forces Optiques:  
La force de gradient.  
(cas  $a \gg \lambda$ )



A. Ashkin, Phys. Rev. Lett. **24**, 156-159 (1969)

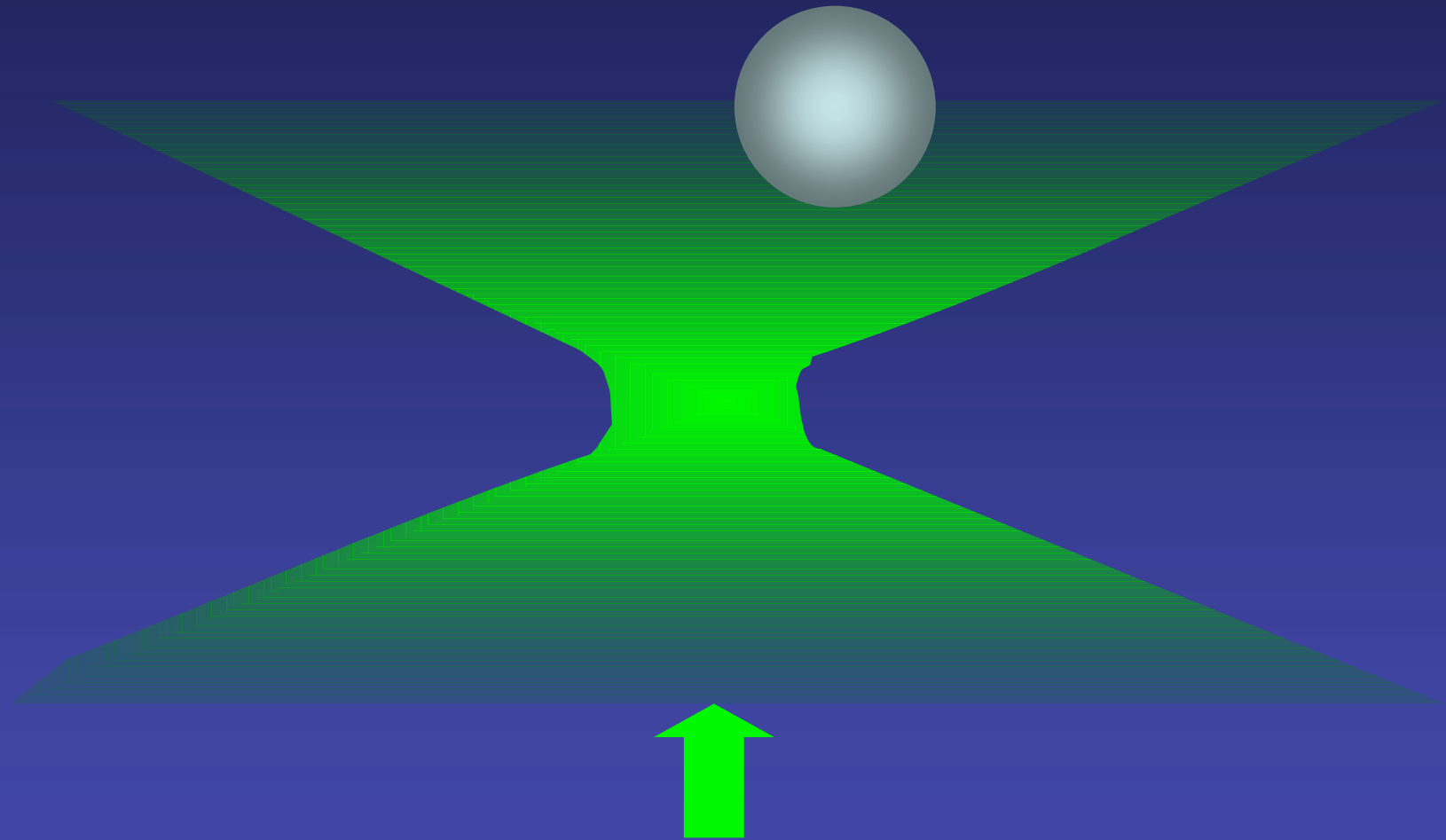
# Réseau de pièges en nid d'abeille



M.M. Burns, J.-M. Fournier, J.A. Golovchenko, Science 249, 749-754 (1990)

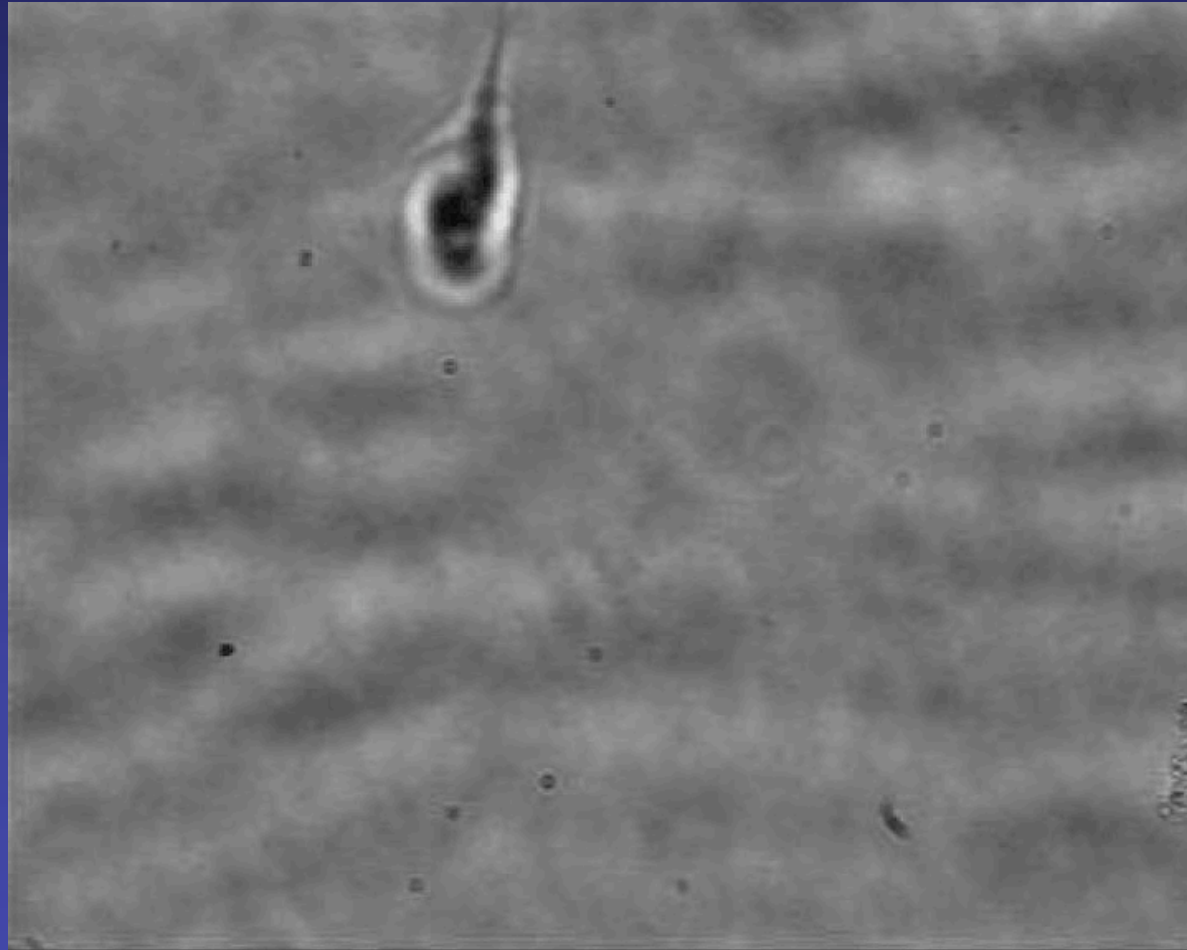


# Principe de la pincette optique

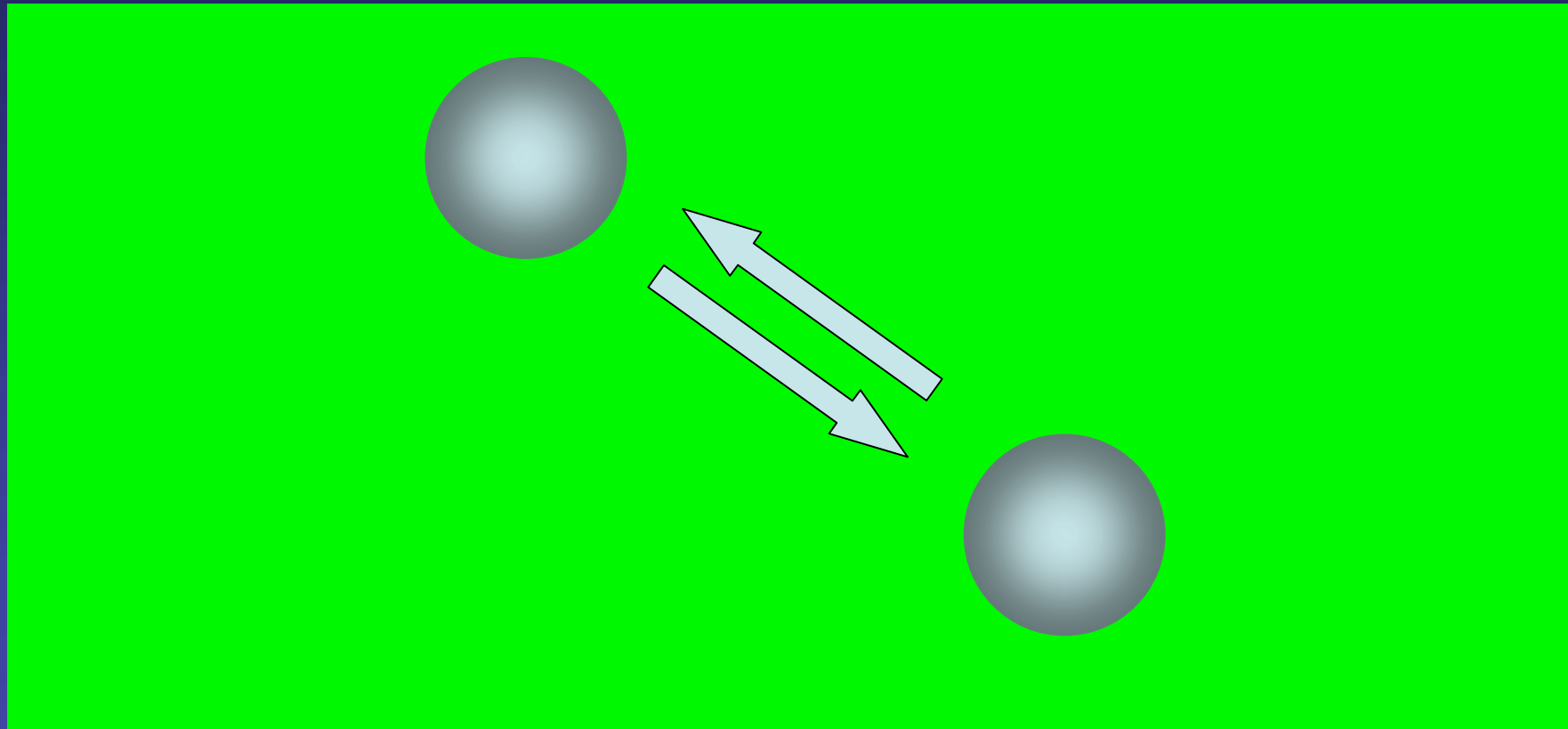


A. Ashkin, J.M. Dziedzic, J.E. Bjorkholm, S. Chu, Opt. Lett. **11**, 288-290 (1986)

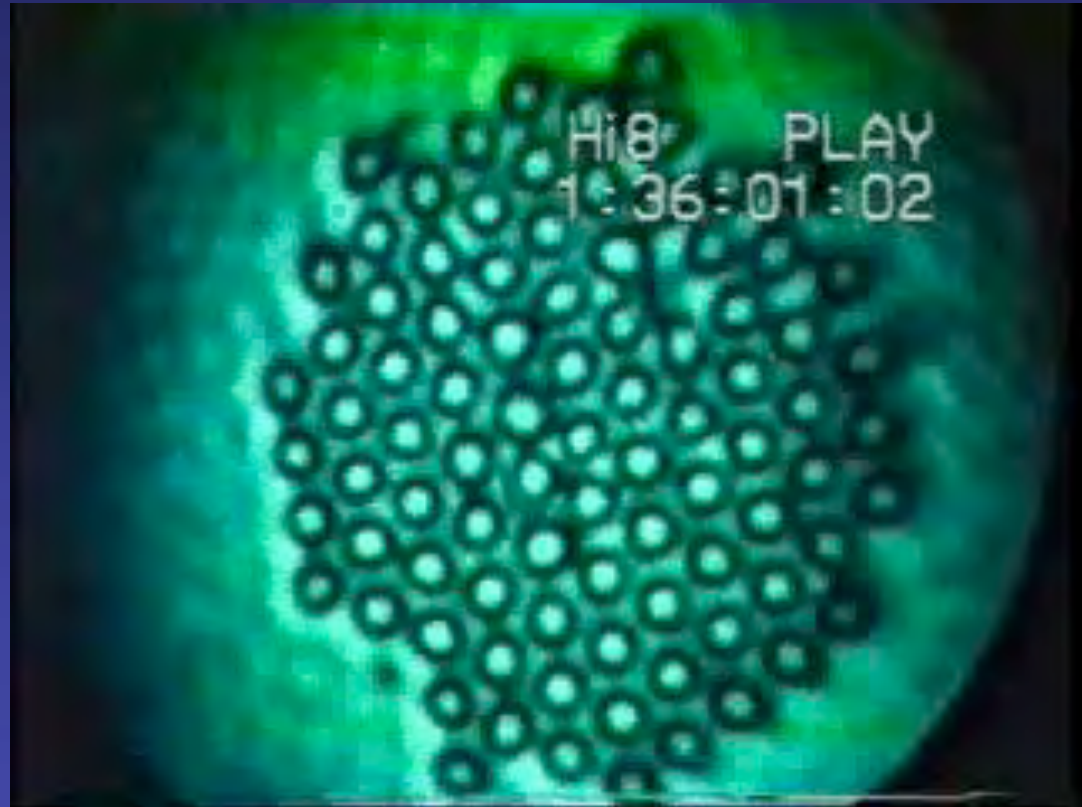
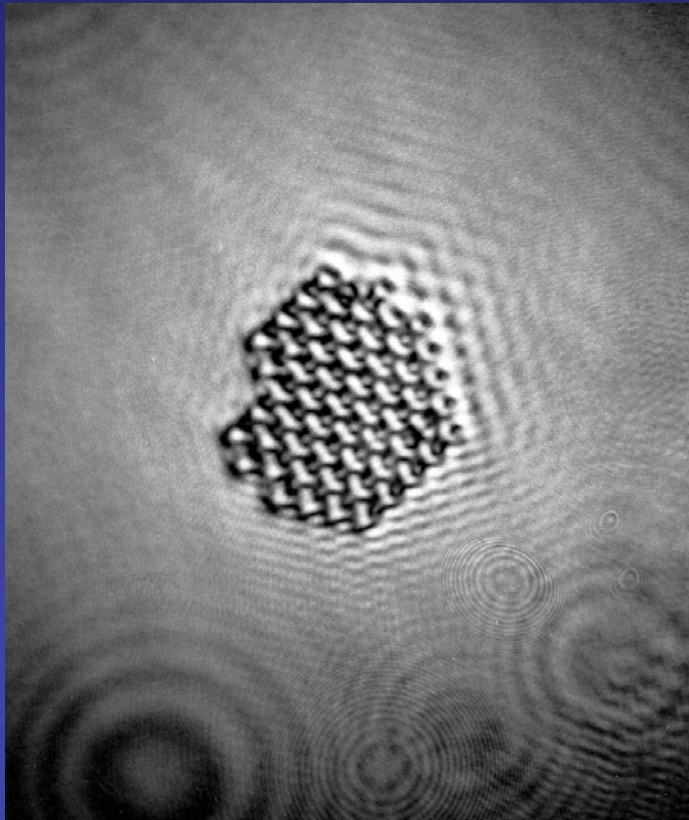
# Pincette Optique



# Forces de cohésion

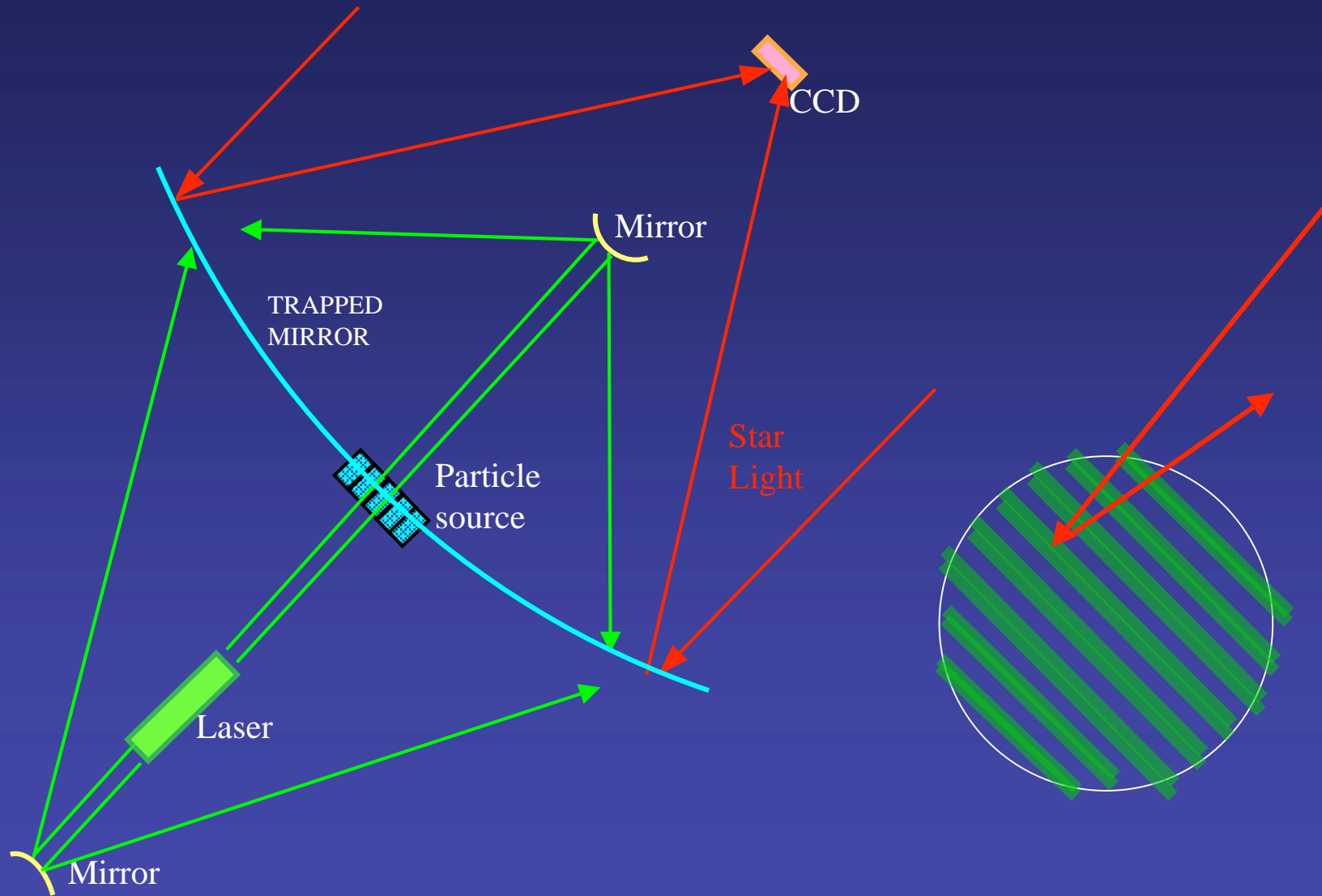


# Cristallisation



J.-M. Fournier, M.M. Burns, J.A. Golovchenko, Proc. SPIE Cambridge (MA) 2406,  
101-111 (1995).

# Principe du "Laser Trapped Mirror" (LTM)

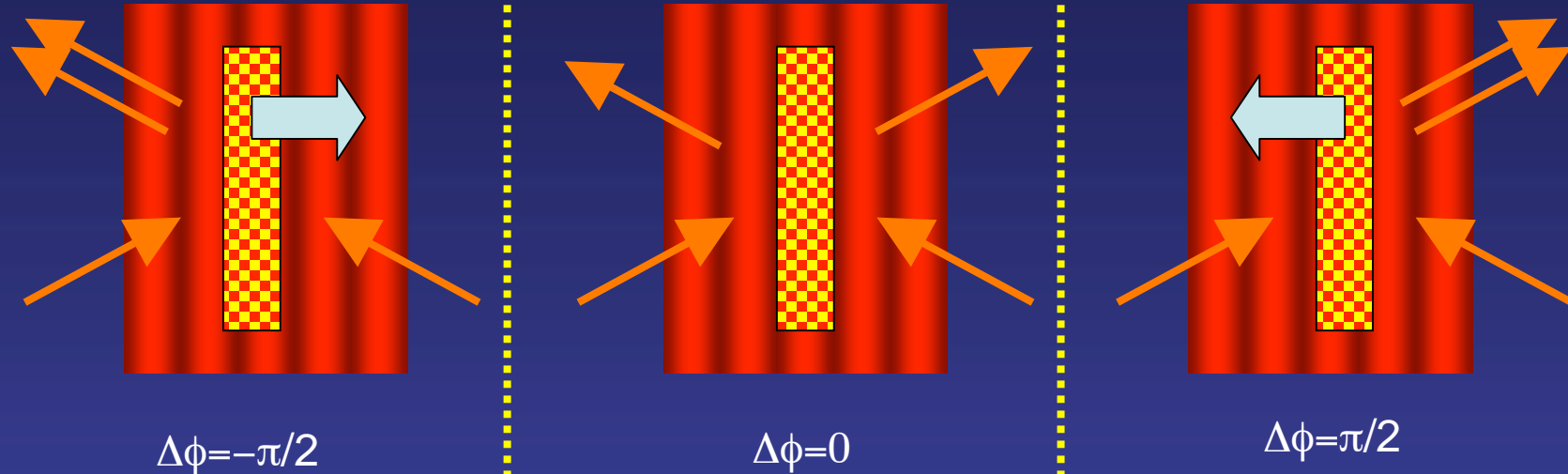


# Position possible dans l'espace

- Dans l'ombre d'une planète ou d'un astéroïde
- Photopiles éclairées par le soleil

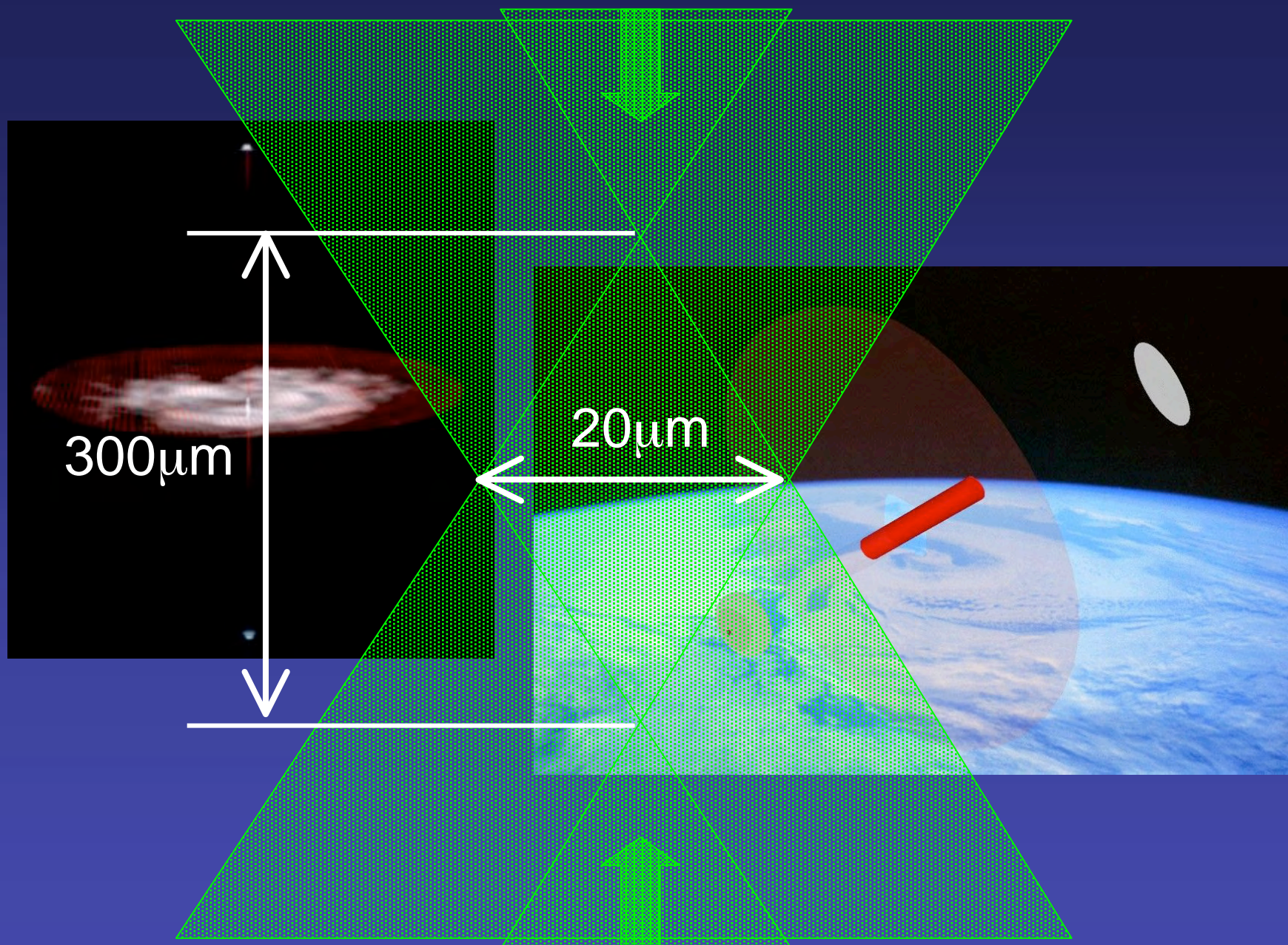


# Principe & Objectifs



- Coefficient de reflexion à la longueur d'onde de piégeage=50%
- Structure auto-organisée
- Coefficient de réflexion / pas de structure
- Mirroir  $\varnothing > 100\text{m}$
- Intensité de piégeage  $< 1\text{W.m}^{-2}$

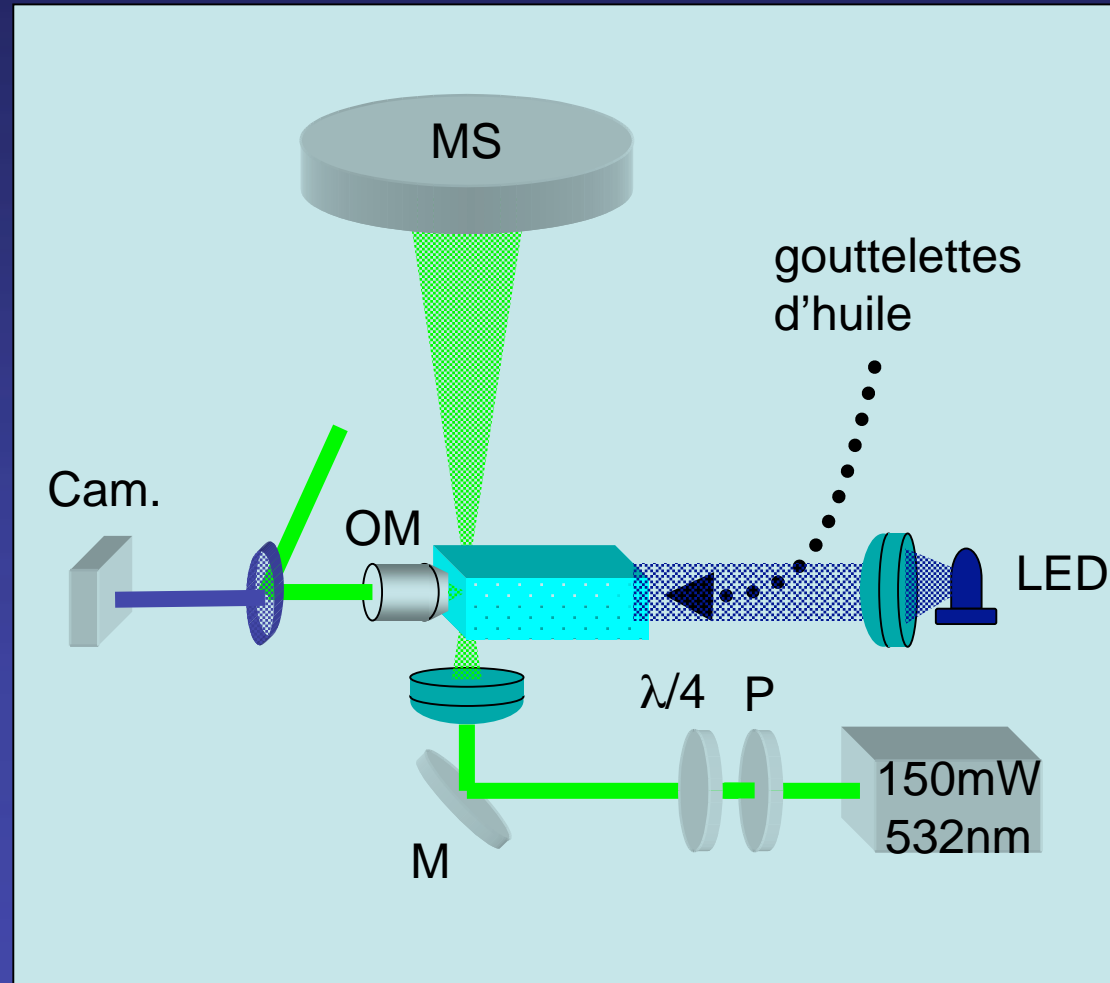
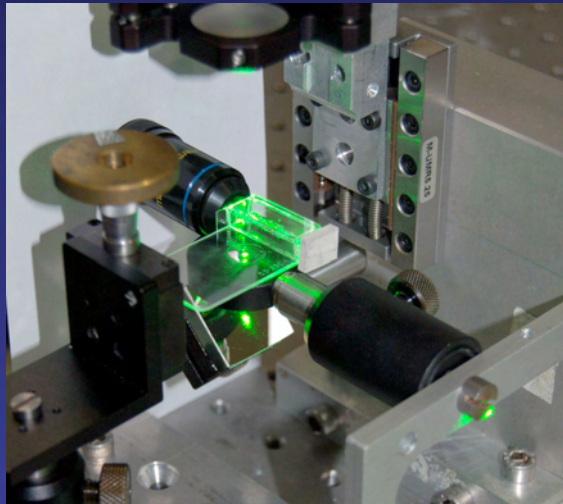
A. Labeyrie, M. Guillon, J.-M. Fournier, Proc. SPIE 5899-0V (Aug. 2005)



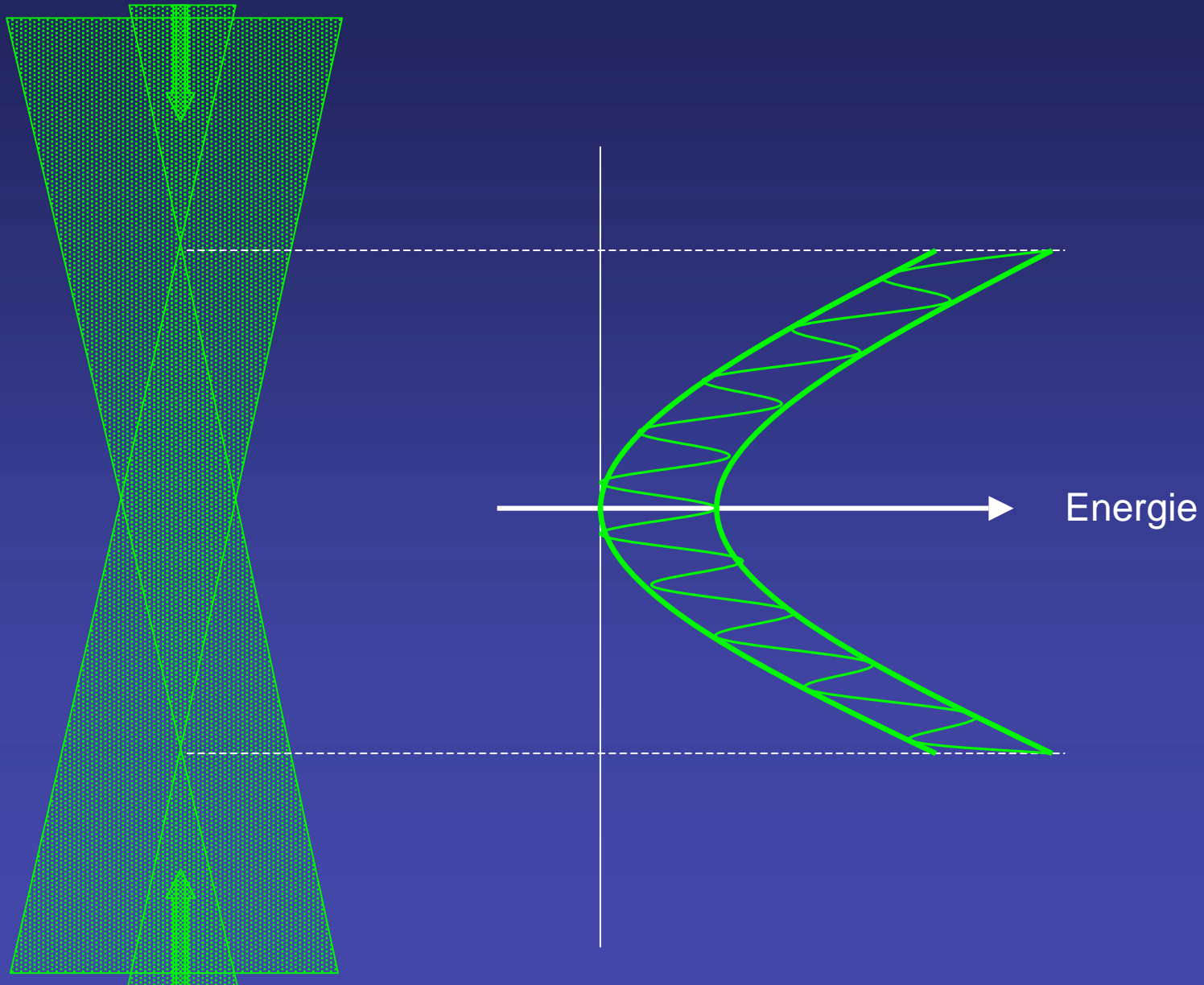


# Piège optique utilisé

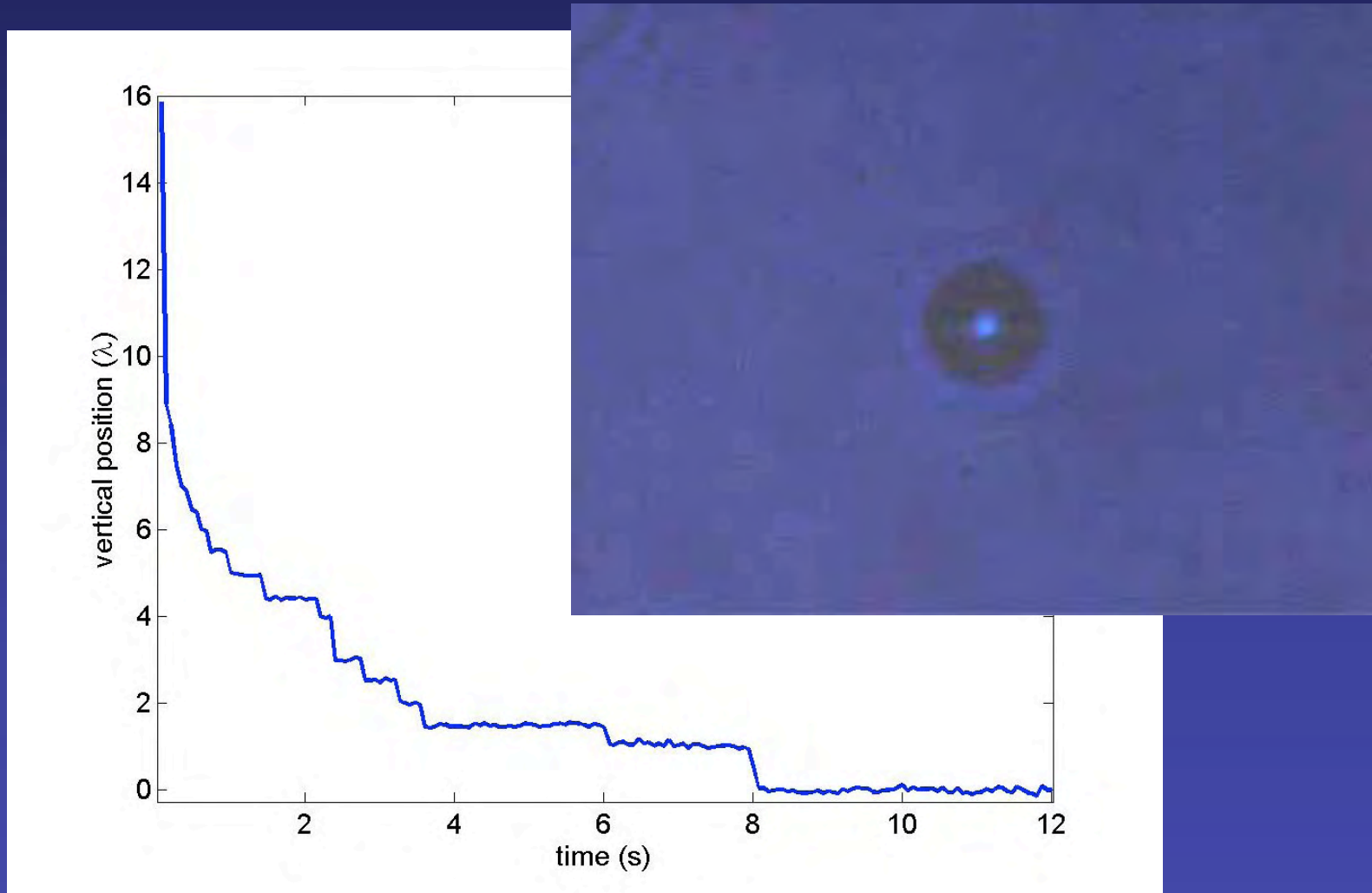
Expérience montée au LISE (Obs. de Haute Prov.)



# Géométrie du piège optique



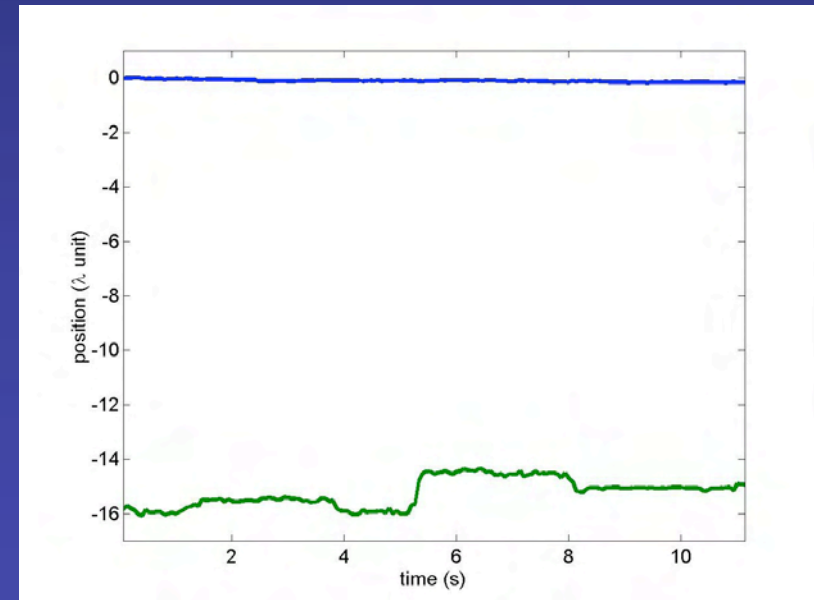
# Piégeage dans les franges.



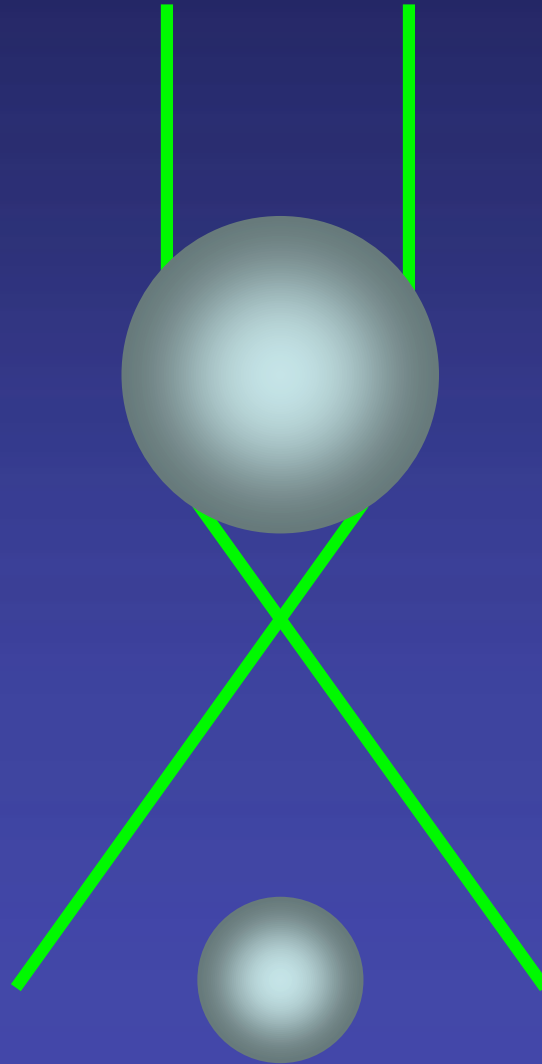
M. Guillon, O. Moine, B. Stout, Phys. Rev. Lett. **96**, 143902 (2006).

# Forces de cohésion entre grosse gouttelettes

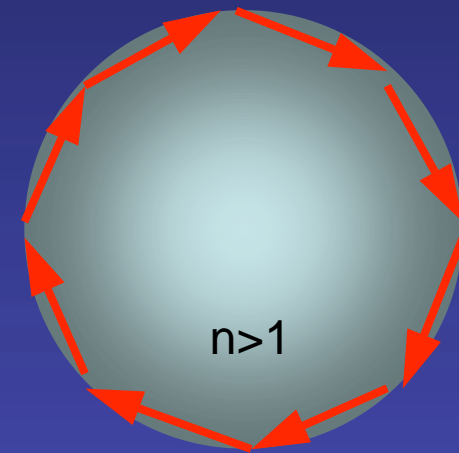
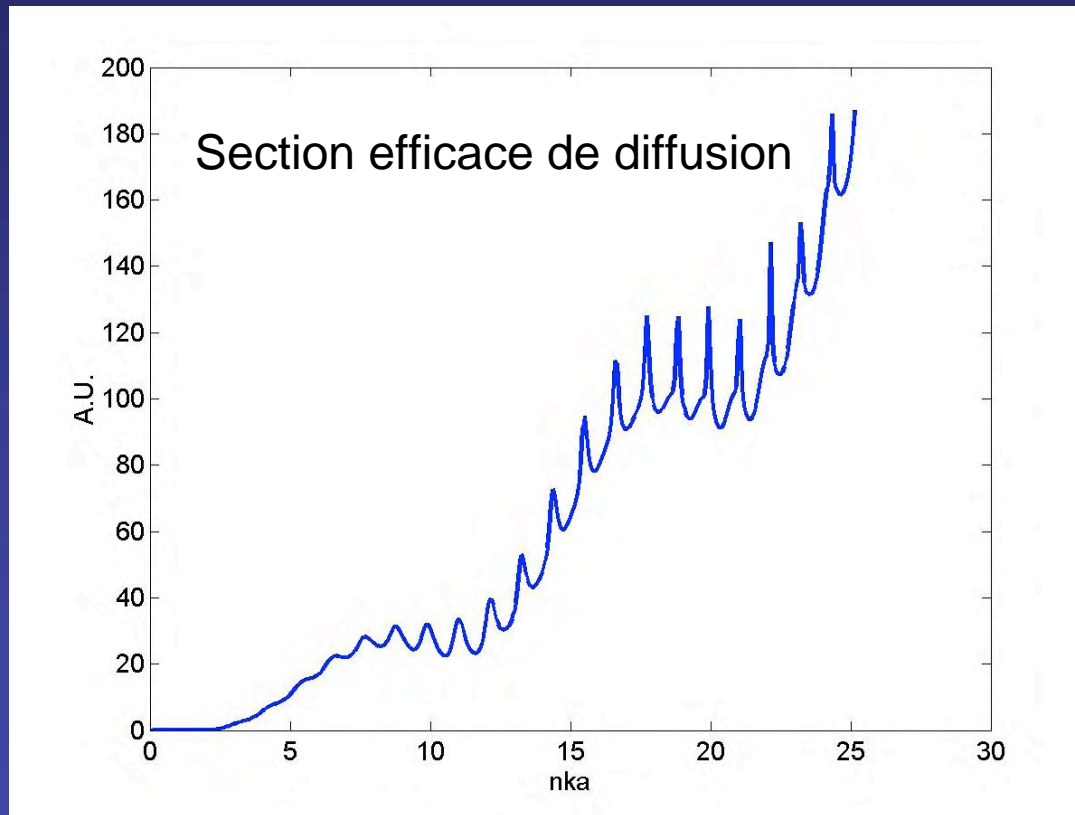
3 $\mu$ m [



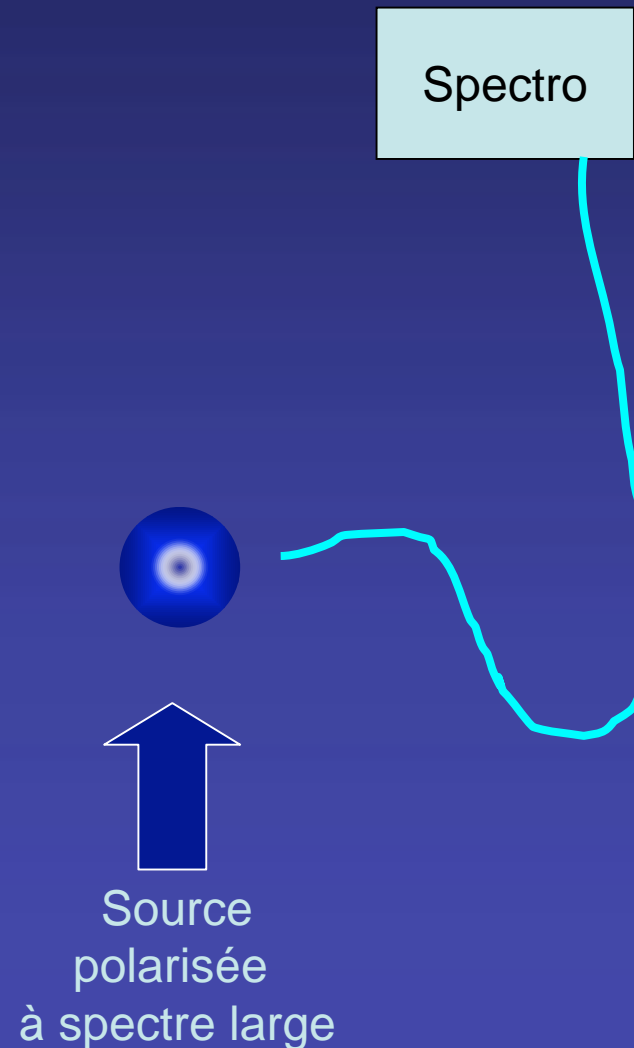
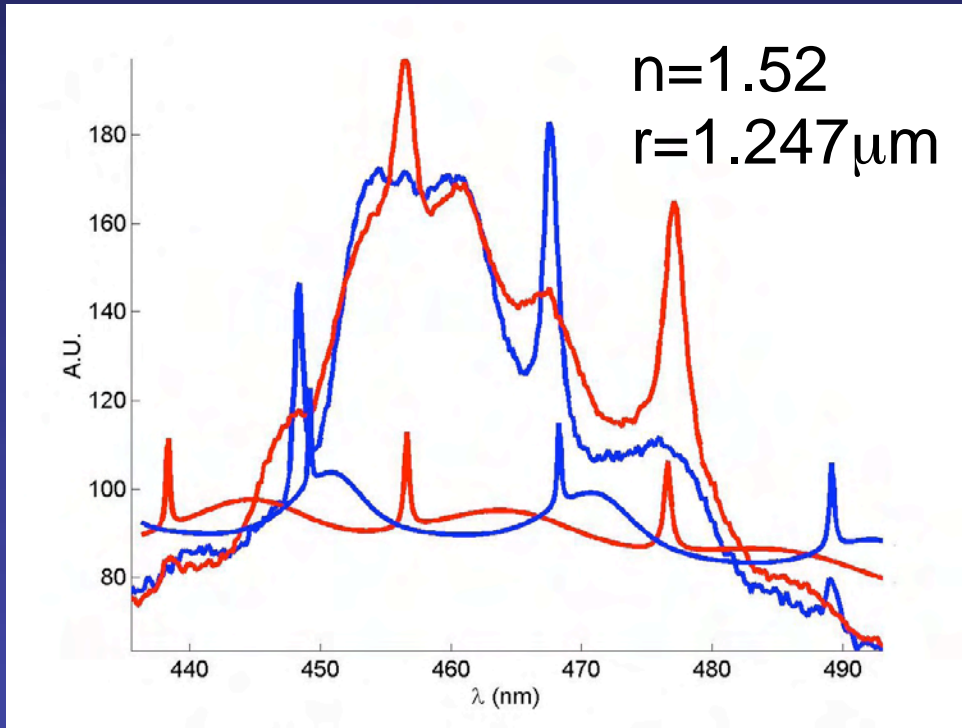
# Modelisation dans l'approximation des rayons lumineux



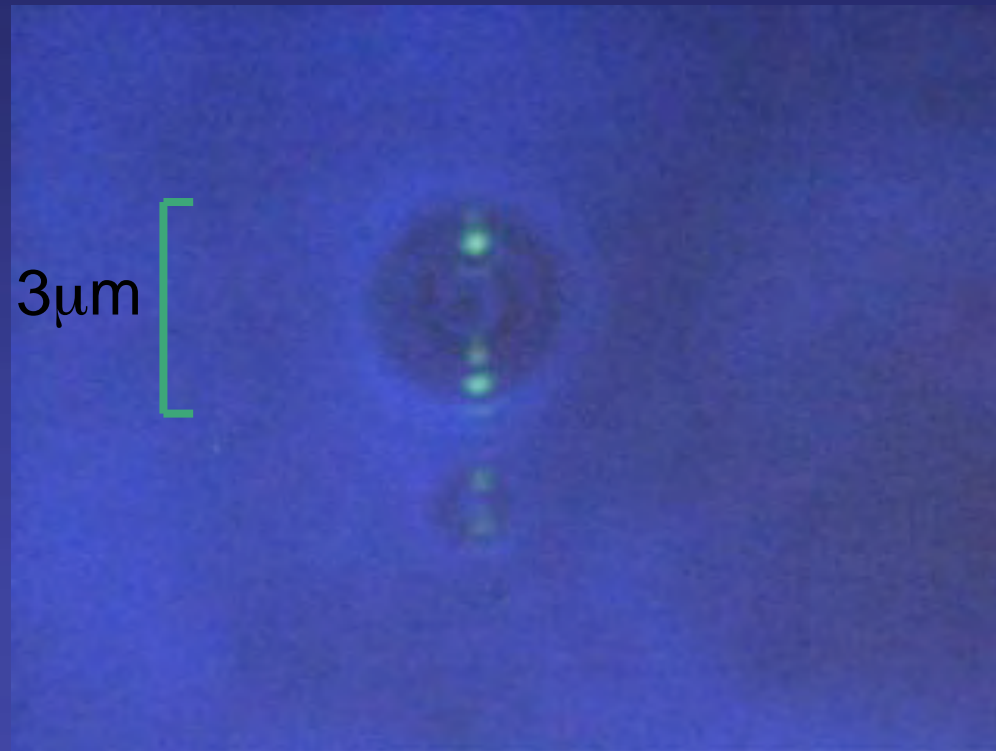
# Résonances de galerie



# Spectre diffusé: principe de la mesure

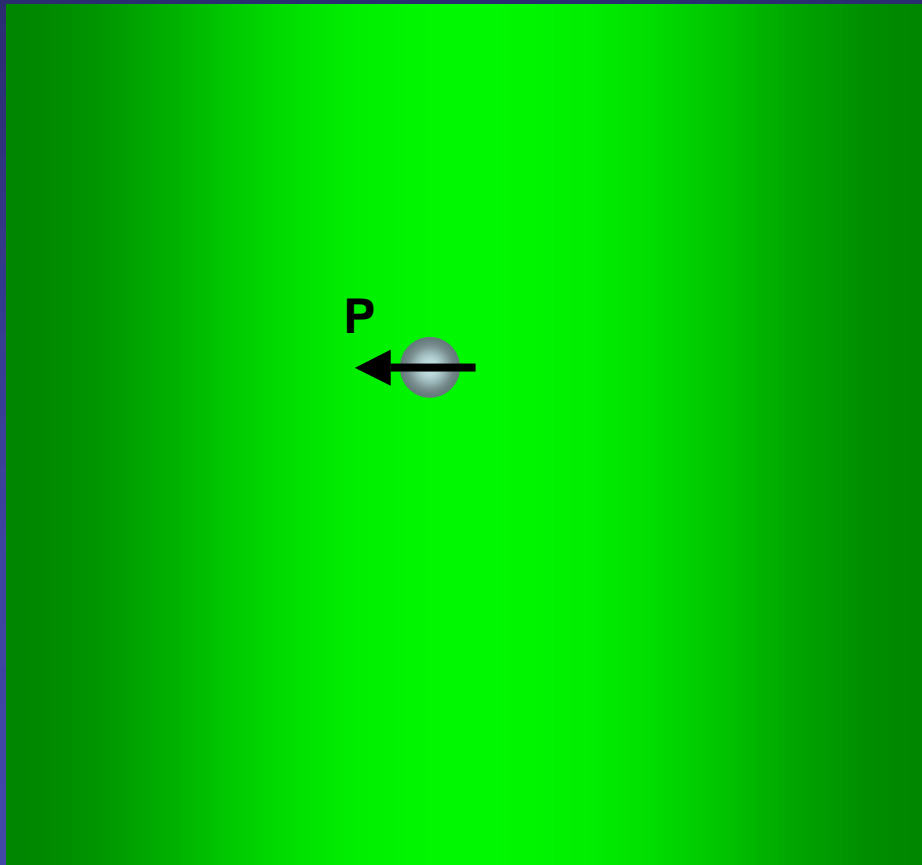


# Forces de cohésion entre grosse gouttelettes





# Régime dipolaire ( $ka < 1$ )



$$\dot{P} = 4\pi\epsilon_0\alpha.\dot{E}$$

$$\alpha = \left( \frac{n^2 - 1}{n^2 + 2} \right) a^3$$

Polarisabilité

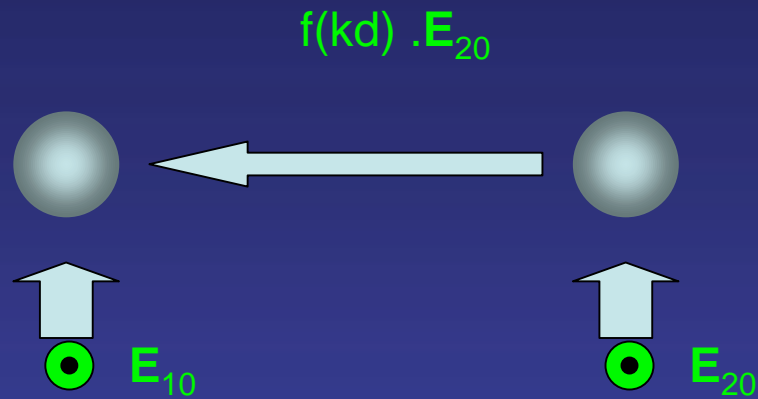
Potentiel  
de piégeage

$$W = -2\pi.k^2\alpha \frac{I}{k^2c}$$

Scattering  
force

$$F = \frac{1}{6\pi} (k^3\alpha)^2 \frac{I}{k^2c} \frac{\vec{k}}{k}$$

# Forces de cohésions entre deux dipôles ( $ka < 1$ )



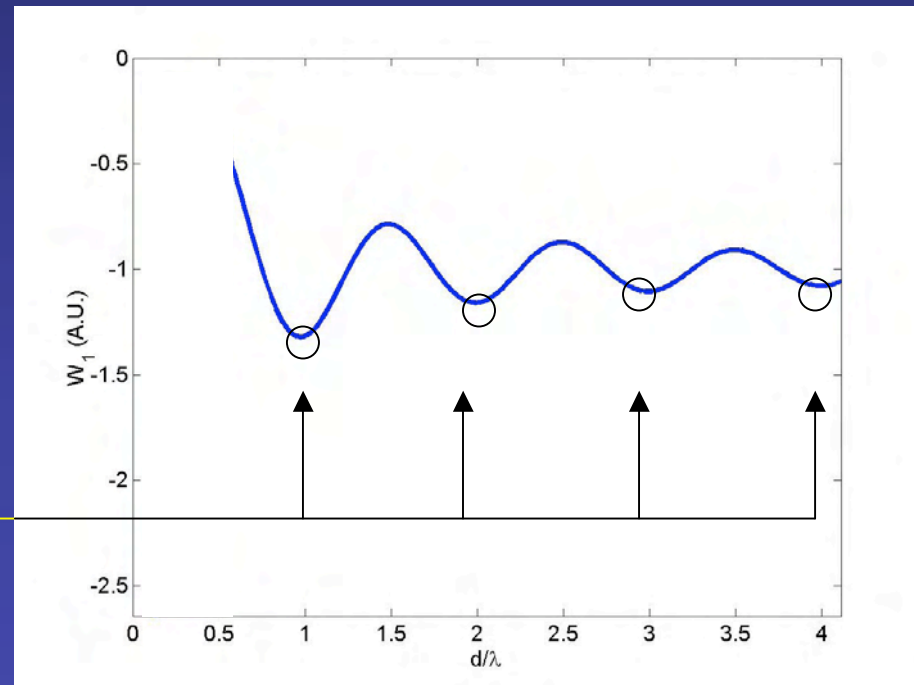
$$\langle W_1 \rangle_t = -4\pi\alpha\epsilon E_0^2 \left| \frac{1}{1 - f(kd)} \right|^2$$

$$f(kr) = k^3\alpha \left( 1 - \frac{1}{(kr)^2} + \frac{i}{kr} \right) \frac{e^{ikr}}{kr}$$

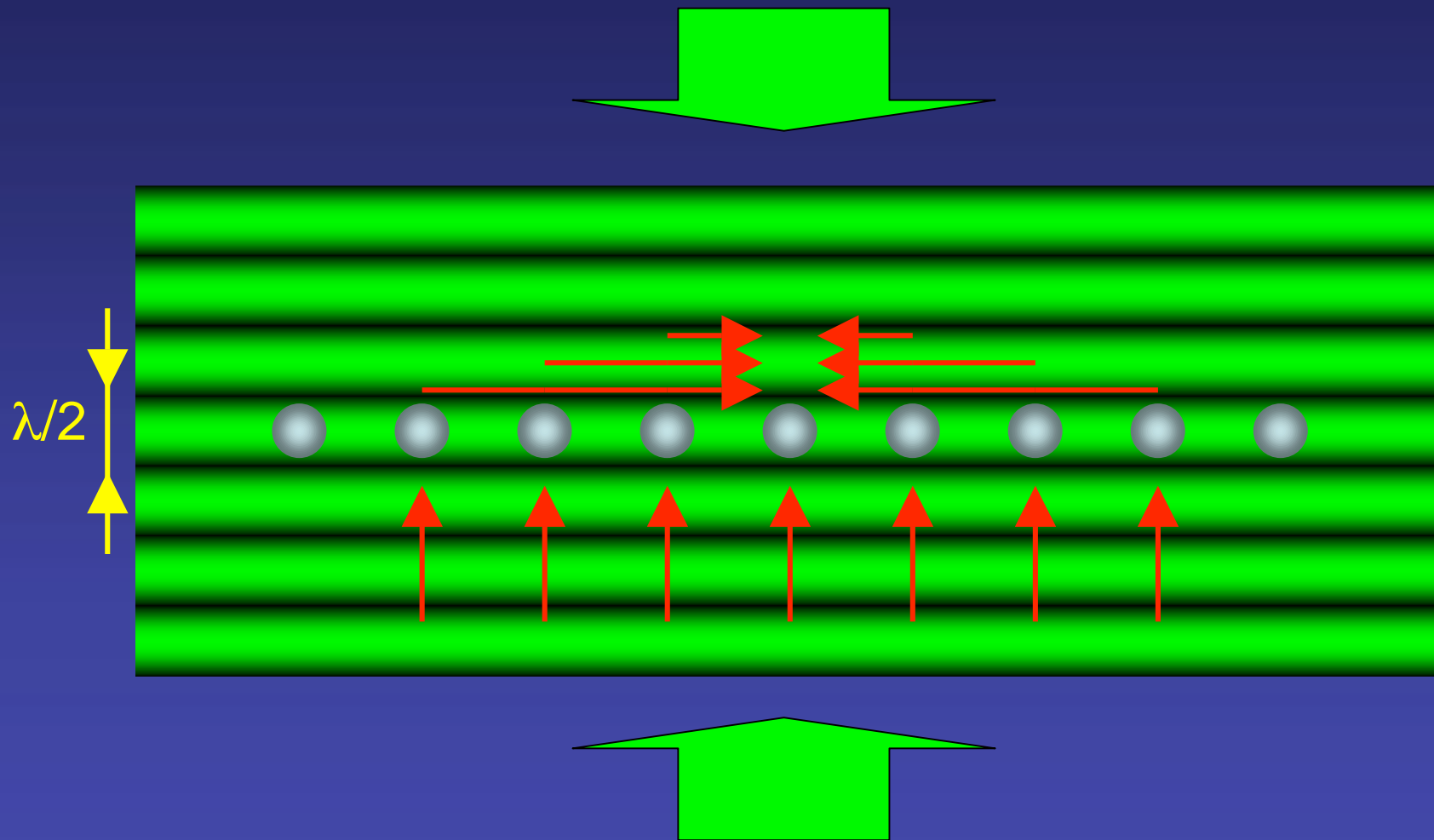
# Interaction à longue distance

$$\langle W_1 \rangle_t \simeq -4\pi\alpha\epsilon E_0^2 \left( 1 + \frac{2k^3 \alpha \cos(kd)}{kd} + O\left(\frac{1}{(kd)^2}\right) \right)$$

- Positions d'équilibre stable tout les  $\lambda$



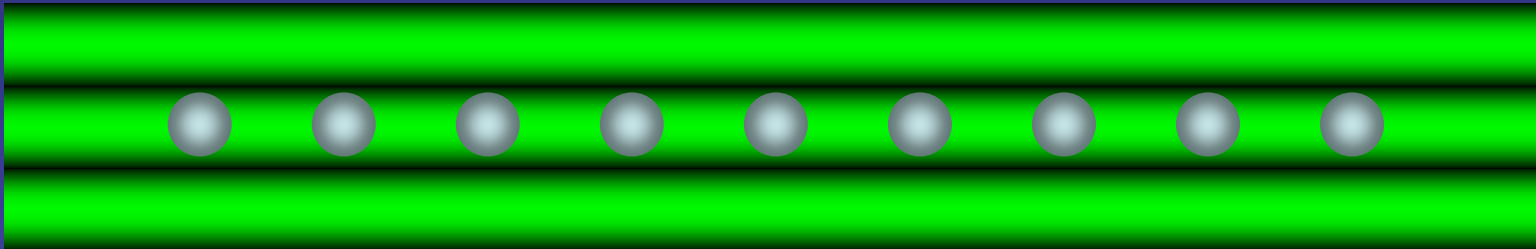
# Chaîne de pas $\lambda$



# Champ diffusé et propagé dans la chaîne

$$E_{0,p} = E_0 + \sum_{q \neq p} E_{s,q}(p)$$

$$E_{s,q}(p) = f(kr_{pq}) \cdot E_{0,q}$$

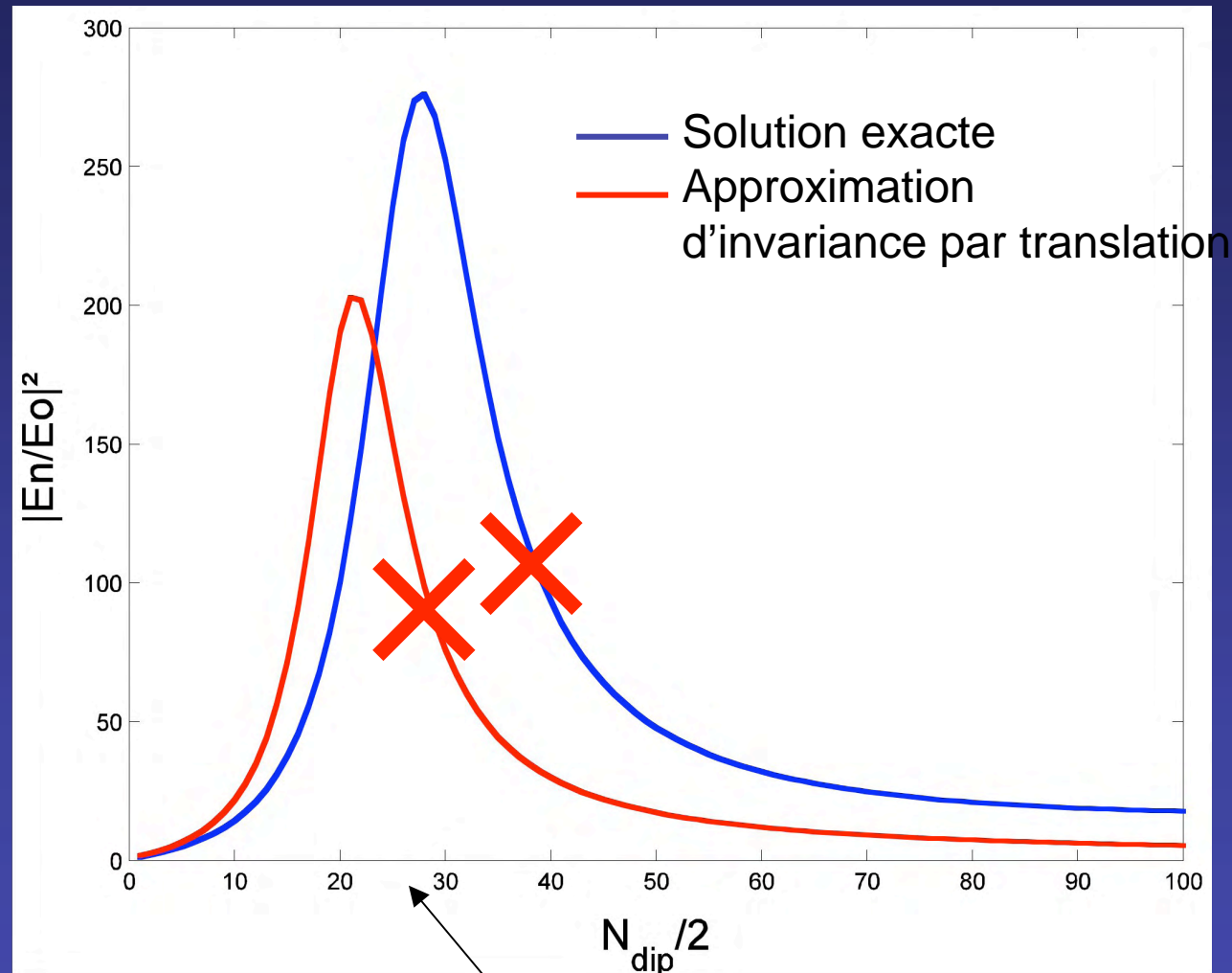


Approximation d'invariance par translation:

$$E_{0,0} = E_0 \frac{1}{1 - k^3 \alpha \sum_{q \neq 0} \left( 1 - \frac{1}{(qkr)^2} + \frac{i}{qkr} \right) \frac{e^{iqkr}}{qkr}}$$

# Exaltation de champ

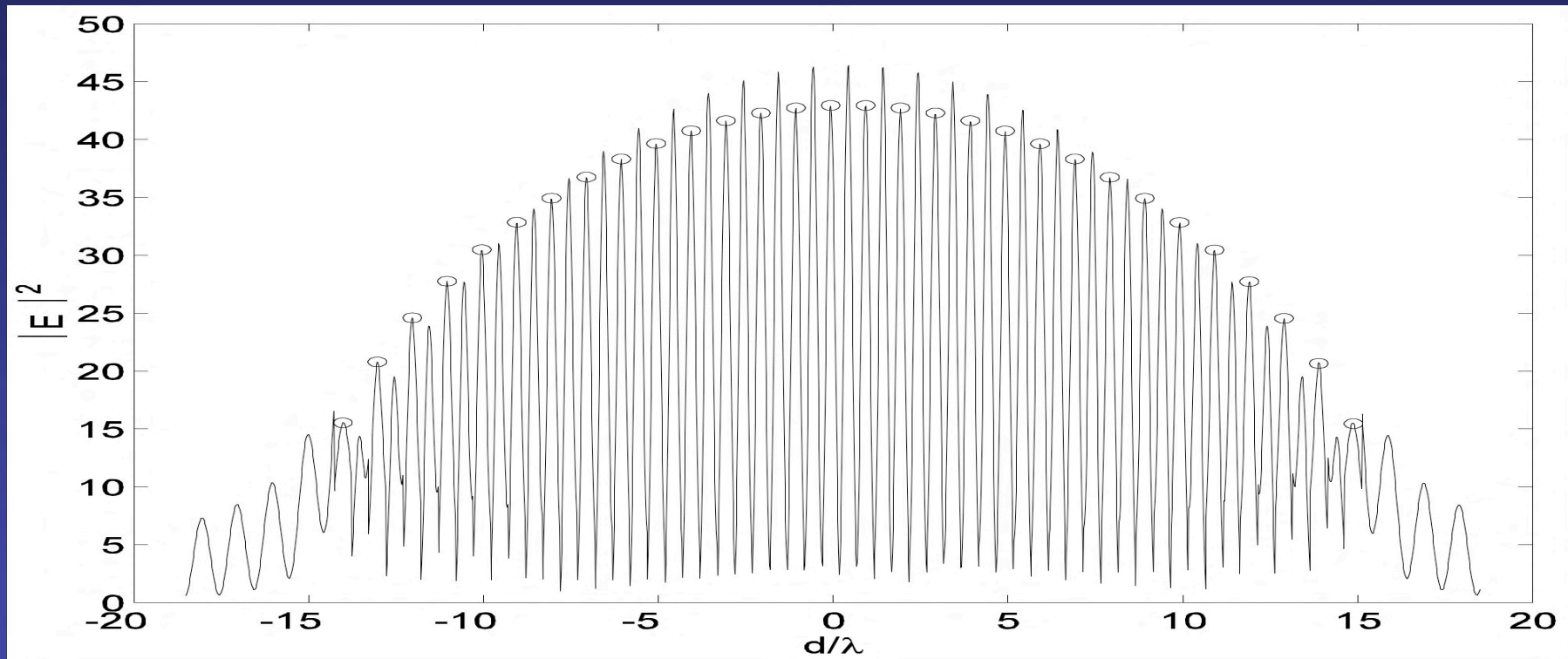
$k^3\alpha=0.86$



M. Guillon, Opt. Exp. 14, 3045-3055 (2006)

$$\ln(N) \sim \frac{1}{k^3\alpha}$$

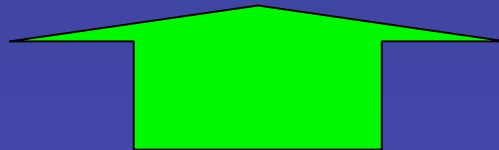
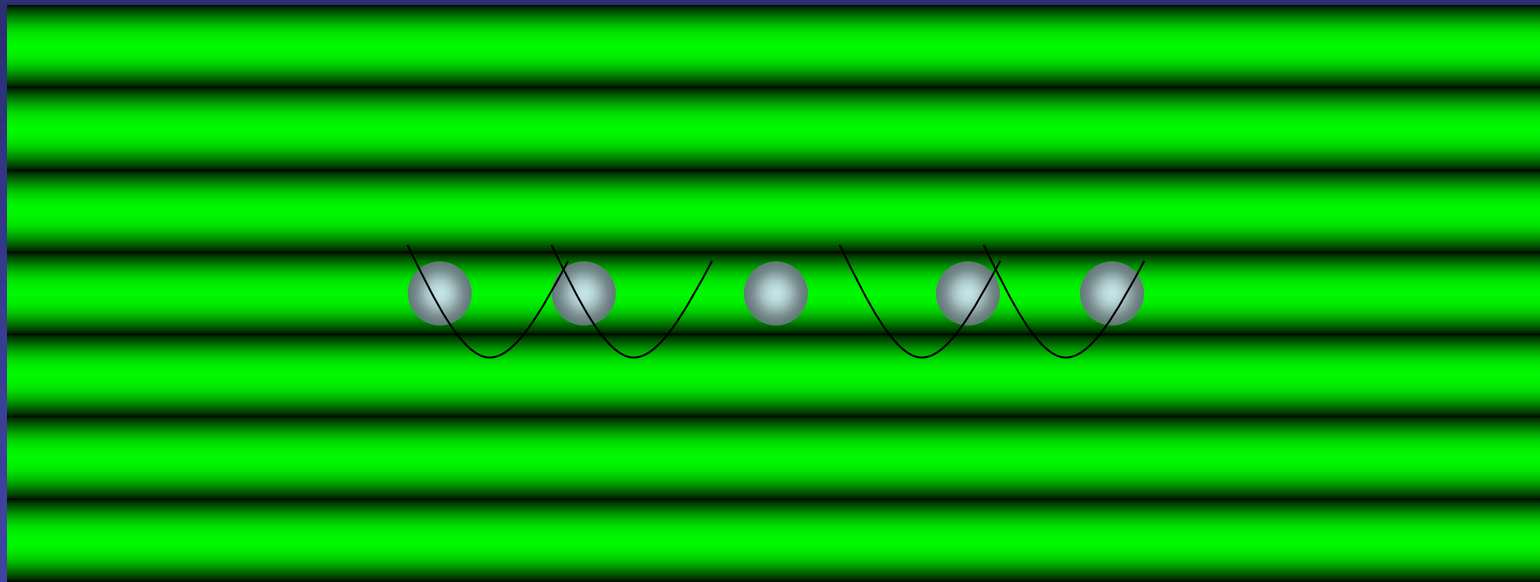
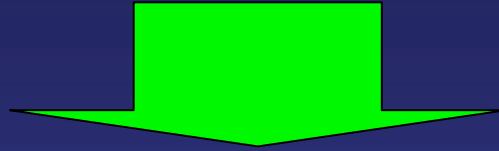
# Energie de cohésion dans la chaîne



$$N_{\text{dip}}=30$$

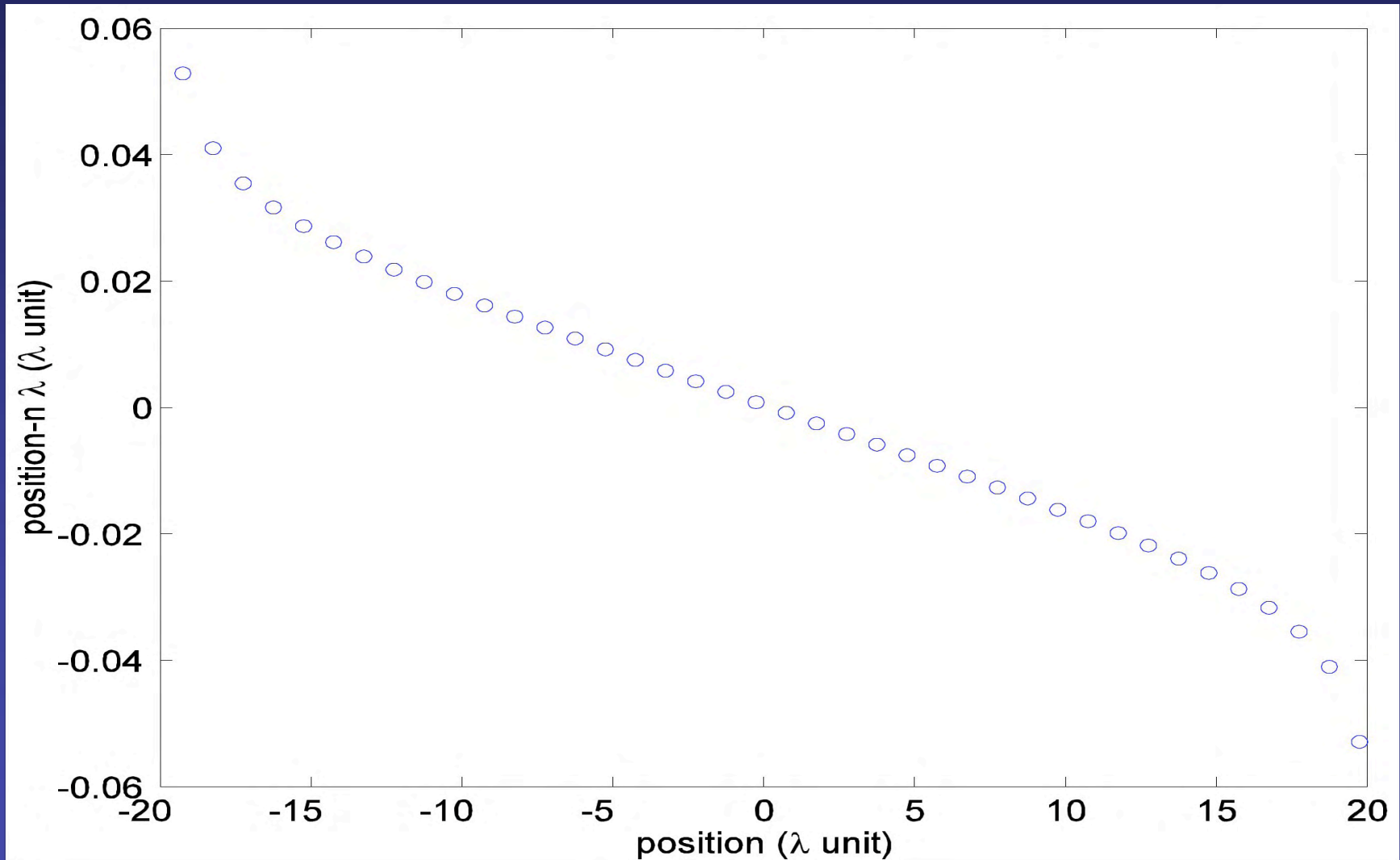
$$k^3\alpha=0.86$$

# Auto-organisation par pression de radiation





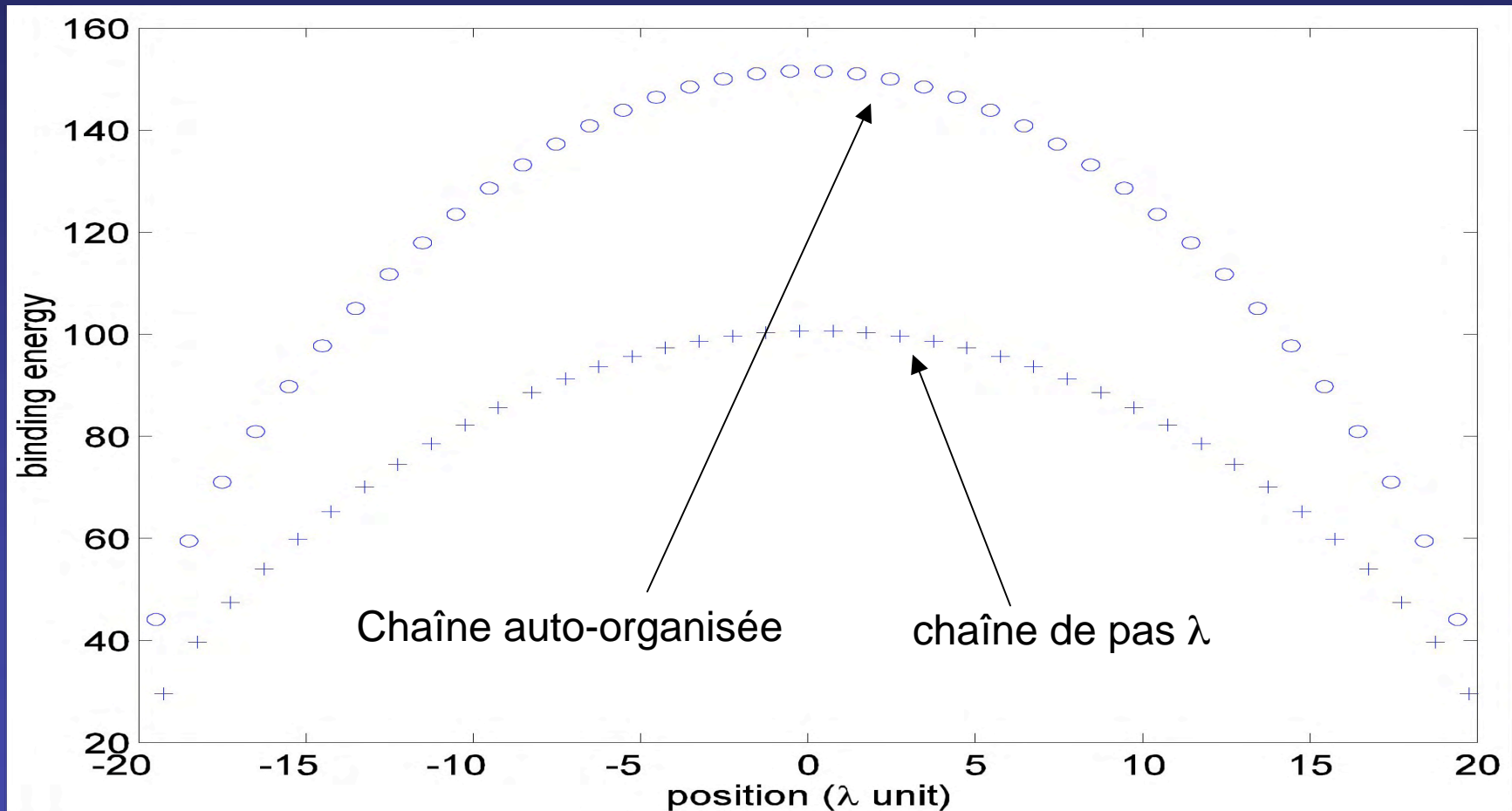
# Ecart à la périodicité $\lambda$



$k^3\alpha=0.86$

$N_{\text{dip}}=40$

# Forces de cohésion: effet de l'auto-organisation

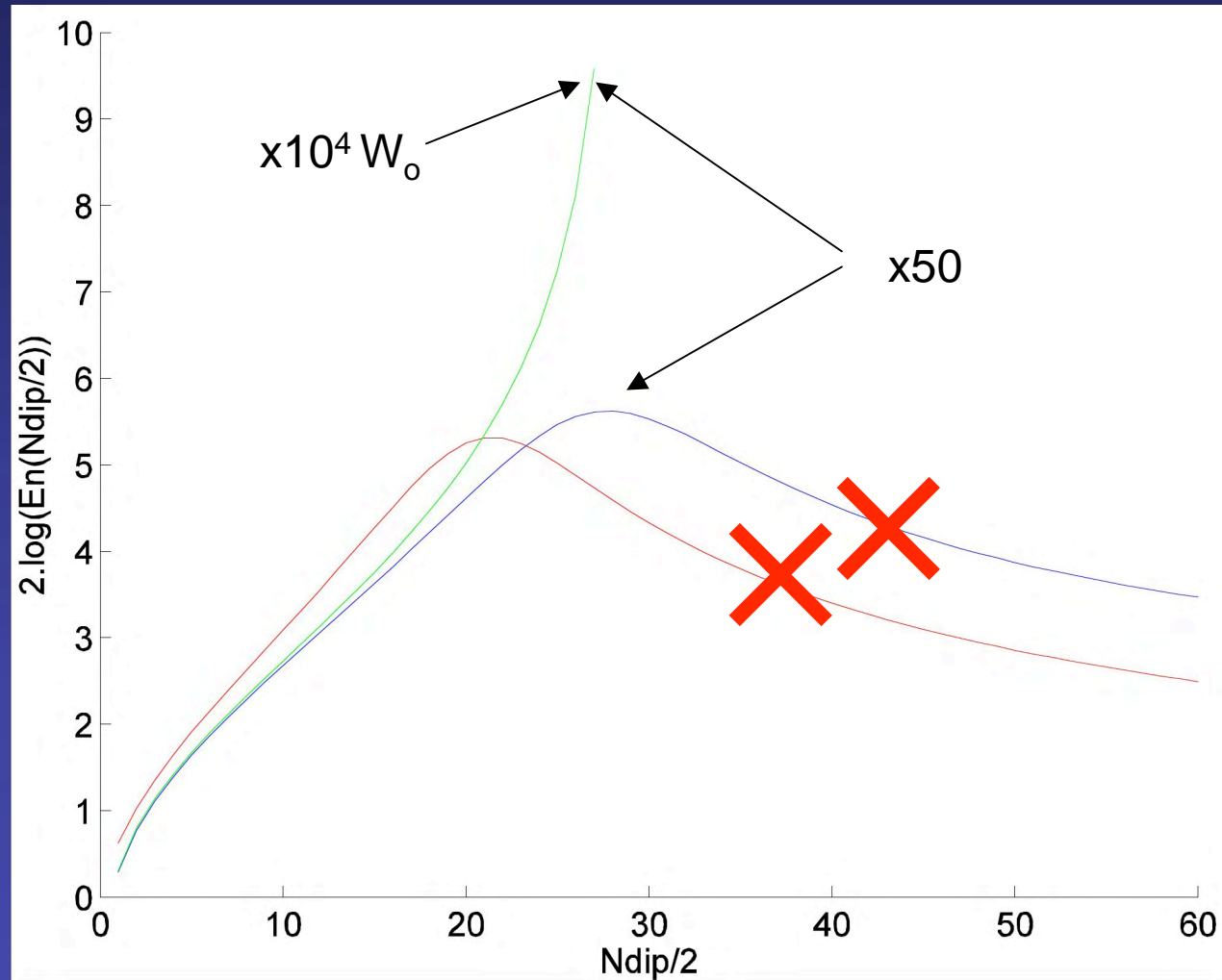


$$k^3\alpha=0.86$$

$$N_{\text{dip}}=40$$

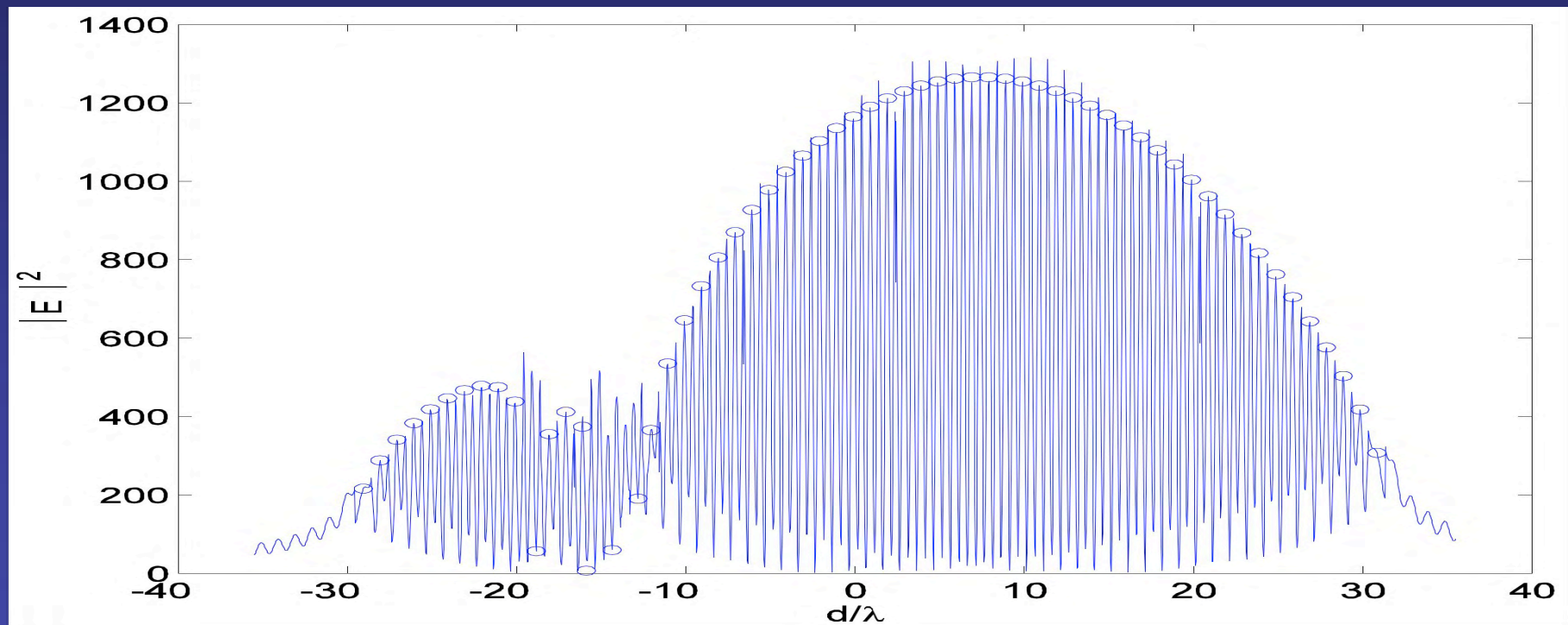
# Self-arrangement

$k^3\alpha=0.86$



M. Guillon, Proc. SPIE, San José, 6483-1 (Jan. 2007)

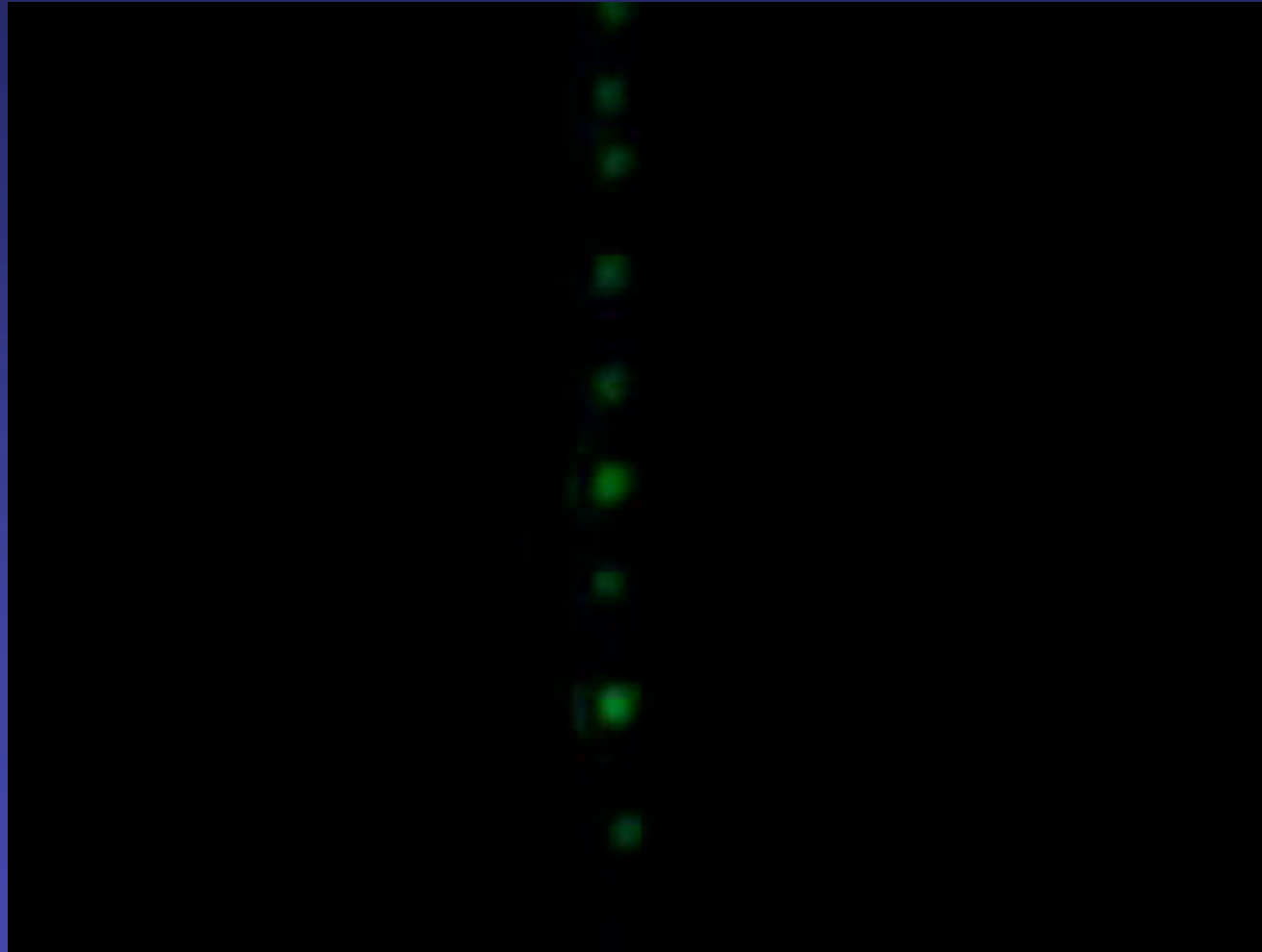
# Instabilité des longues chaînes



$$N_{\text{dip}}=60$$

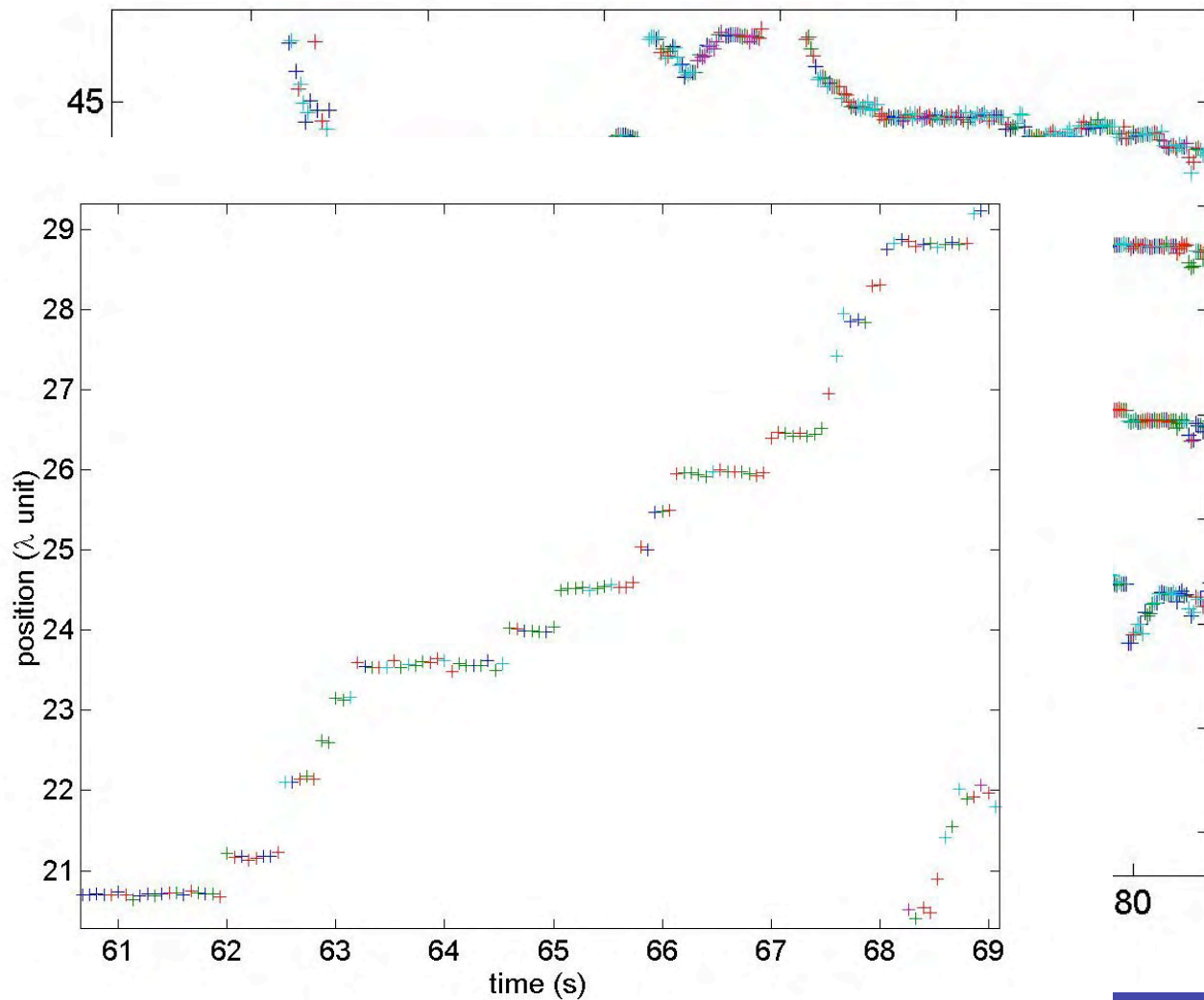
# Chaîne de gouttelettes

5 $\mu$ m

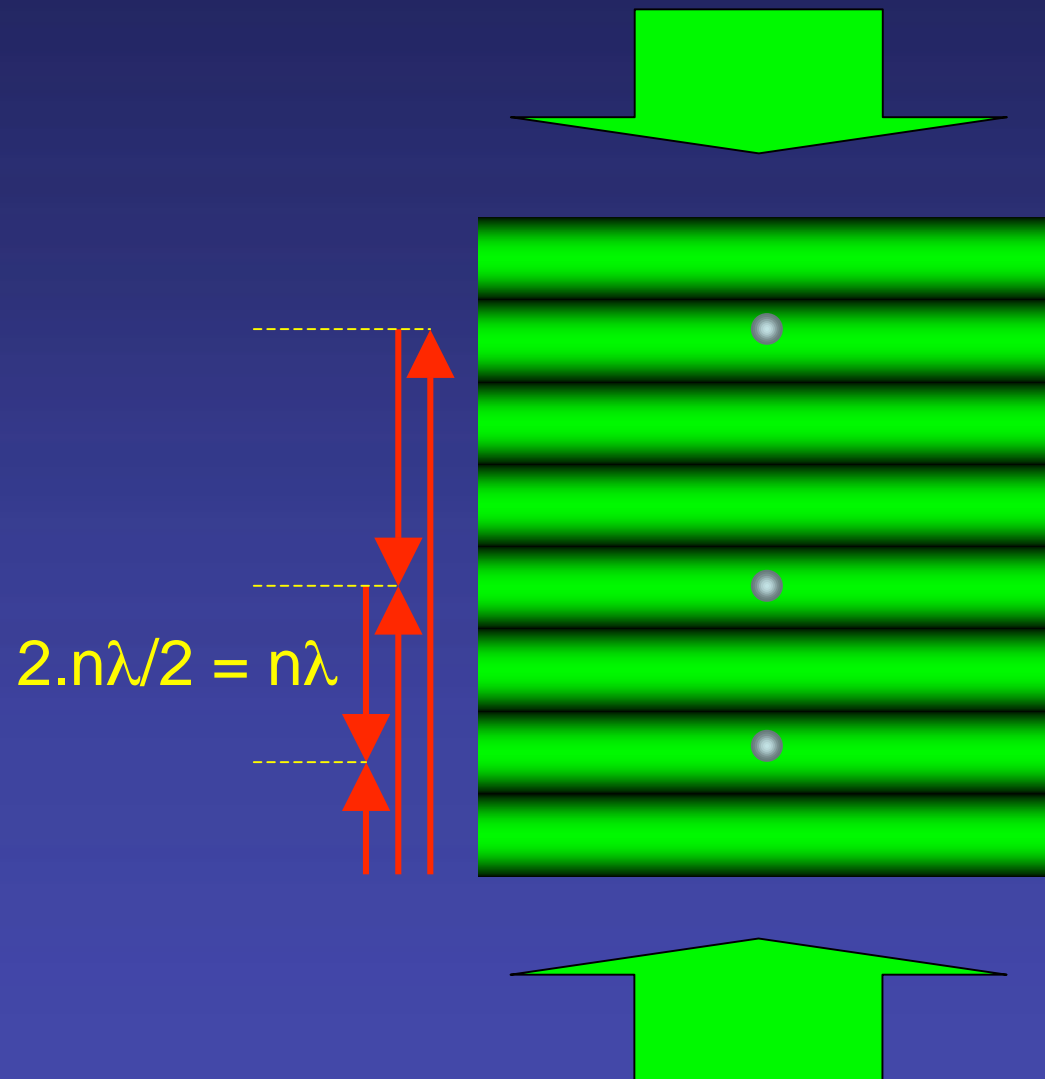


M. Guillon, Proc. SPIE, San José, 6483-1 (Jan. 2007)

# Structure de la chaîne: effet des interactions optiques



# Piégeage dans les franges

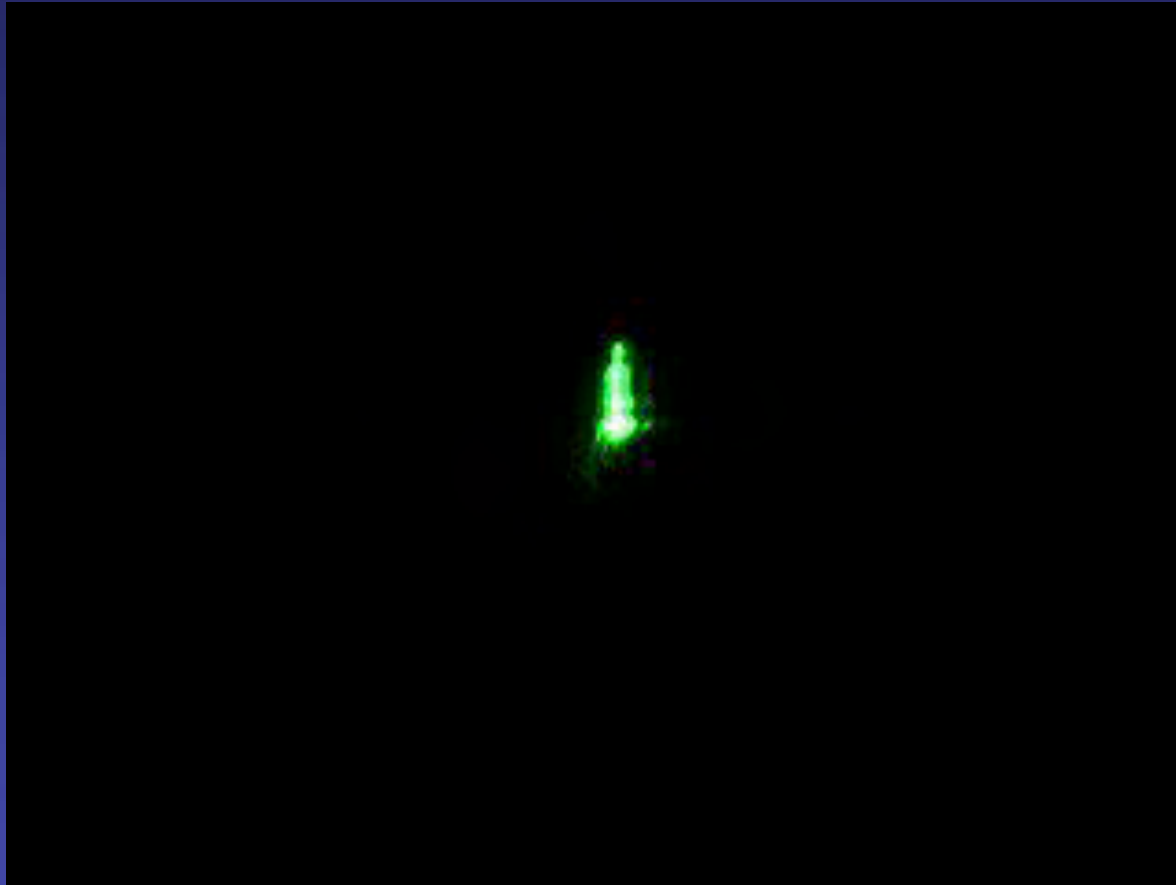


# Paramètres expérimentaux

- Gouttelettes d'eau salée
- Contrast d'indice entre 1.33 et 1.54
- Diamètre des particules  $< 800\text{nm}$
- Distance de séparation moyenne  $\sim 4\mu\text{m}$
- Particules chargées



# Force non-conservative.



$$\del F = -\text{grad}(V)$$

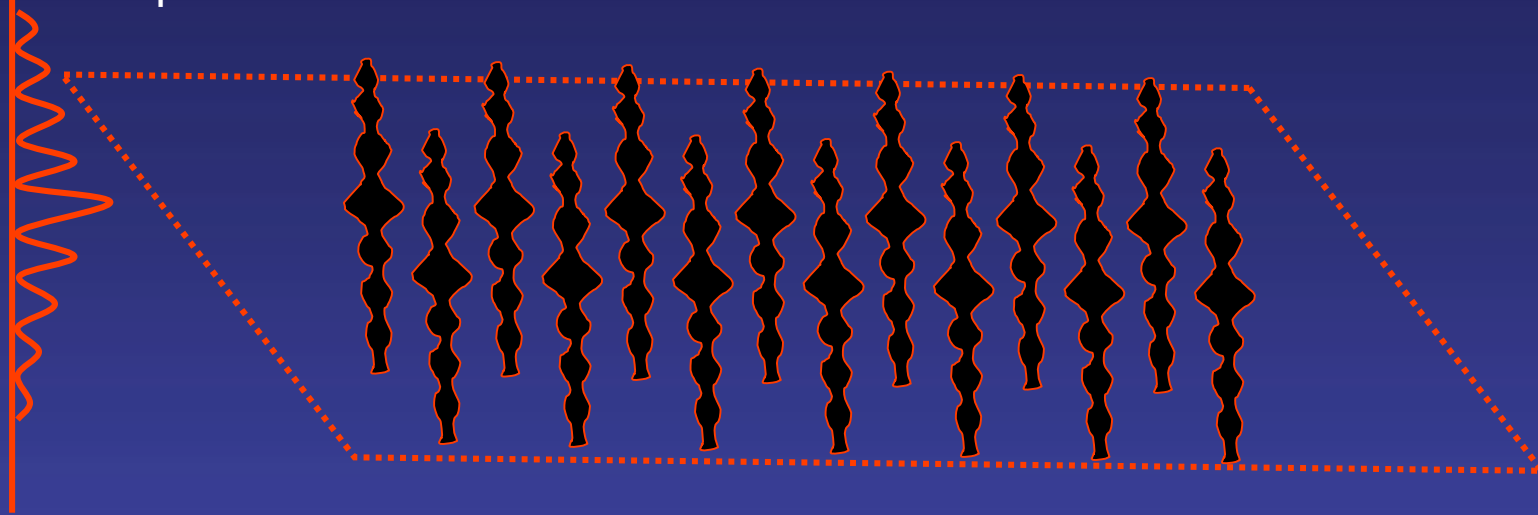
# Particules à piéger...

- Solide
  - Dispersion (forces de Van der Waals)
  - Taille
  - Forme
- Gouttelettes
  - Photopolymerisation?
  - Dispersion de tailles
- Gaz
  - PhotoCVD

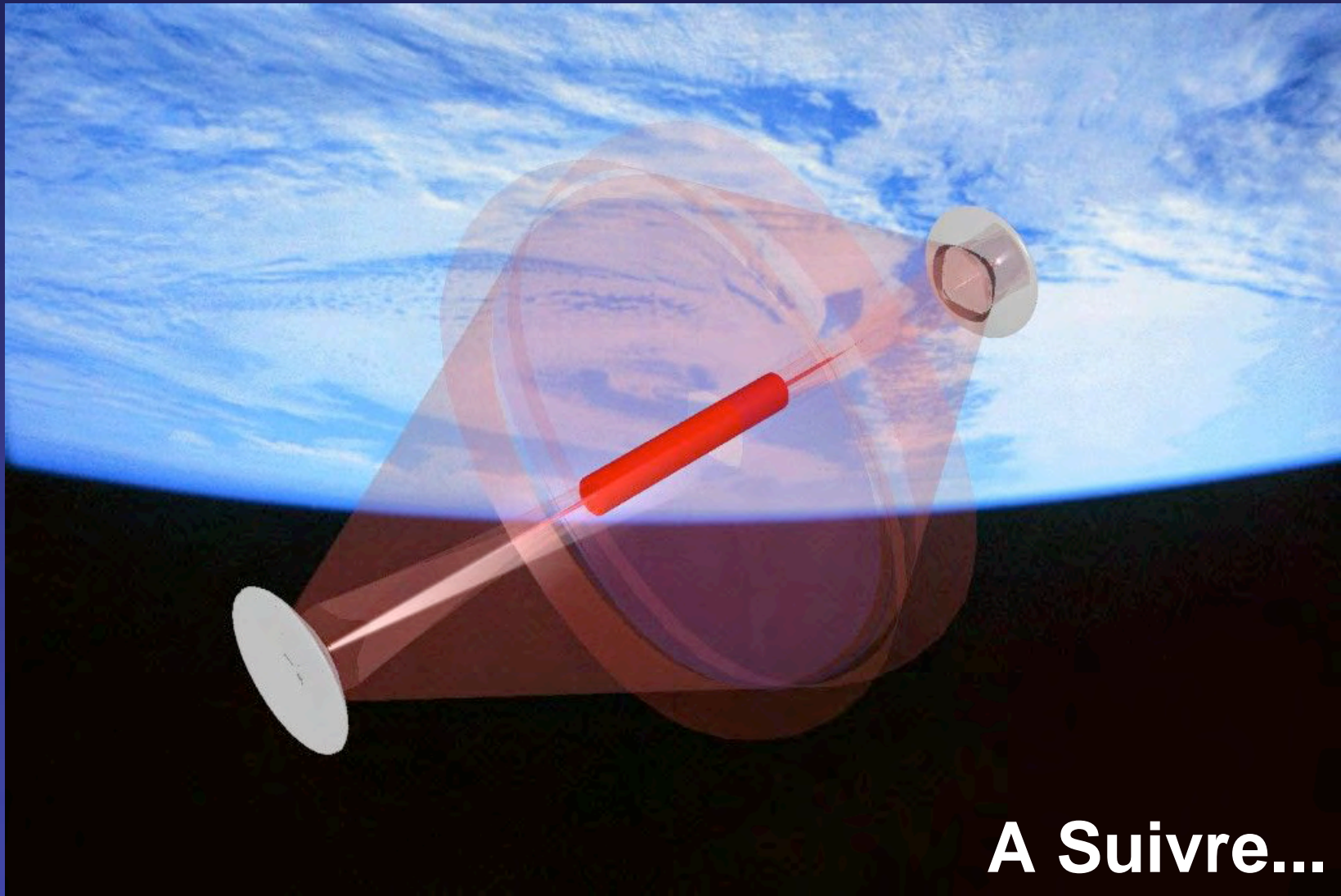
# Miroir large bande:

des quilles?

Ondes stationnaires  
polychromatiques



- Miroir large-bande pour l'observation
- 50% de réflectivité à la longueur d'onde de piégeage
- ... forces de cohésions optiques optimisées entre les quilles



**A Suivre...**