

Enroulement, contact et vibrations de tiges élastiques

Habilitation à diriger des recherches
soutenance le 30 Juin 2009

jury composé de :

Pierre Alart (rapporteur)

David Bensimon

Alain Cimetière

Jean-Jacques Marigo

Nguyen Quoc Son (rapporteur)

Lev Truskinovsky (rapporteur)

Plan

→ A - CV

B - Quelques études sur les tiges élastiques

C - Perspectives

Curriculum vitae

1973 naissance

1990 Bac C

1994 Maîtrise de Physique

1998 Thèse (attracteurs chaotiques, cycles limites)

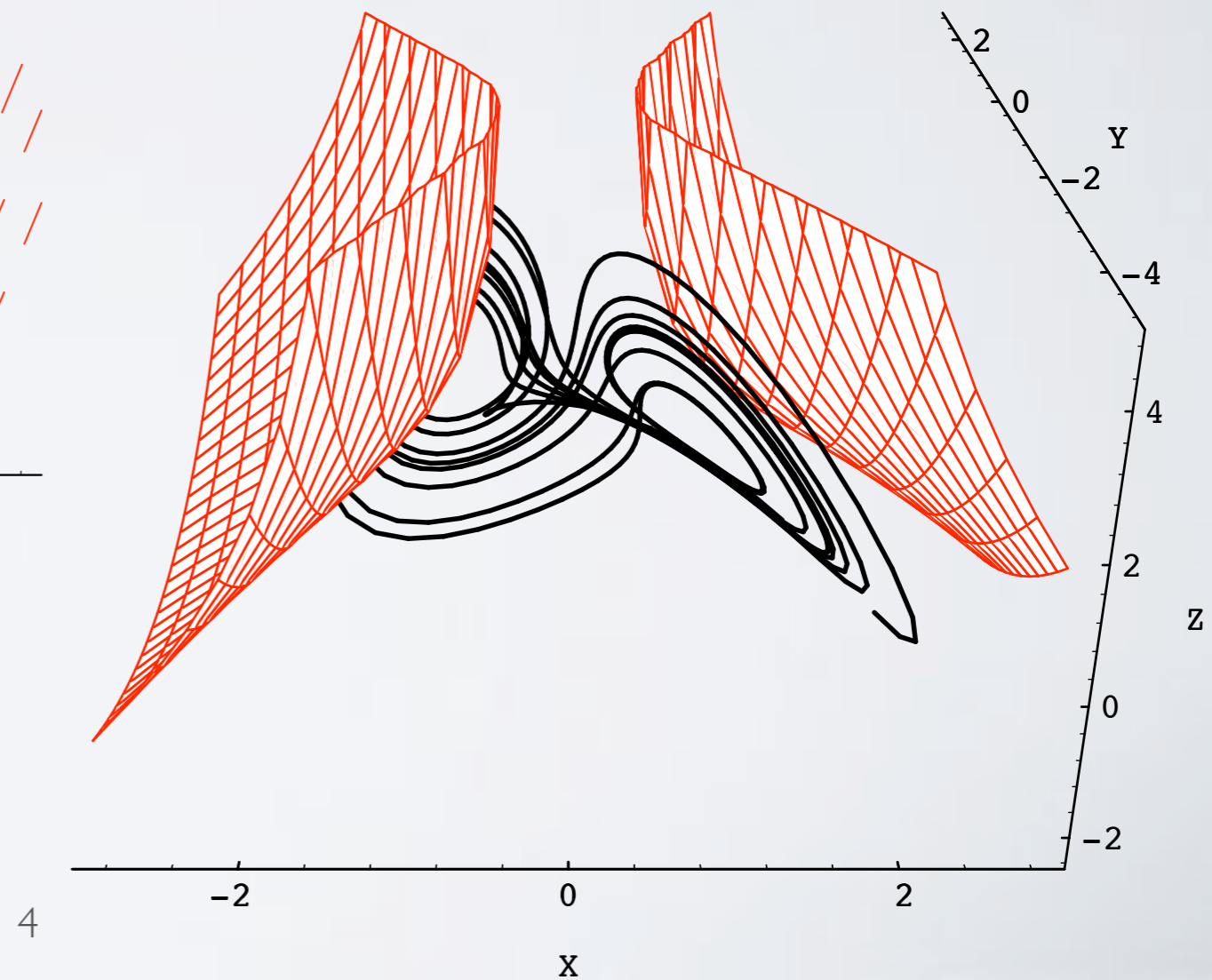
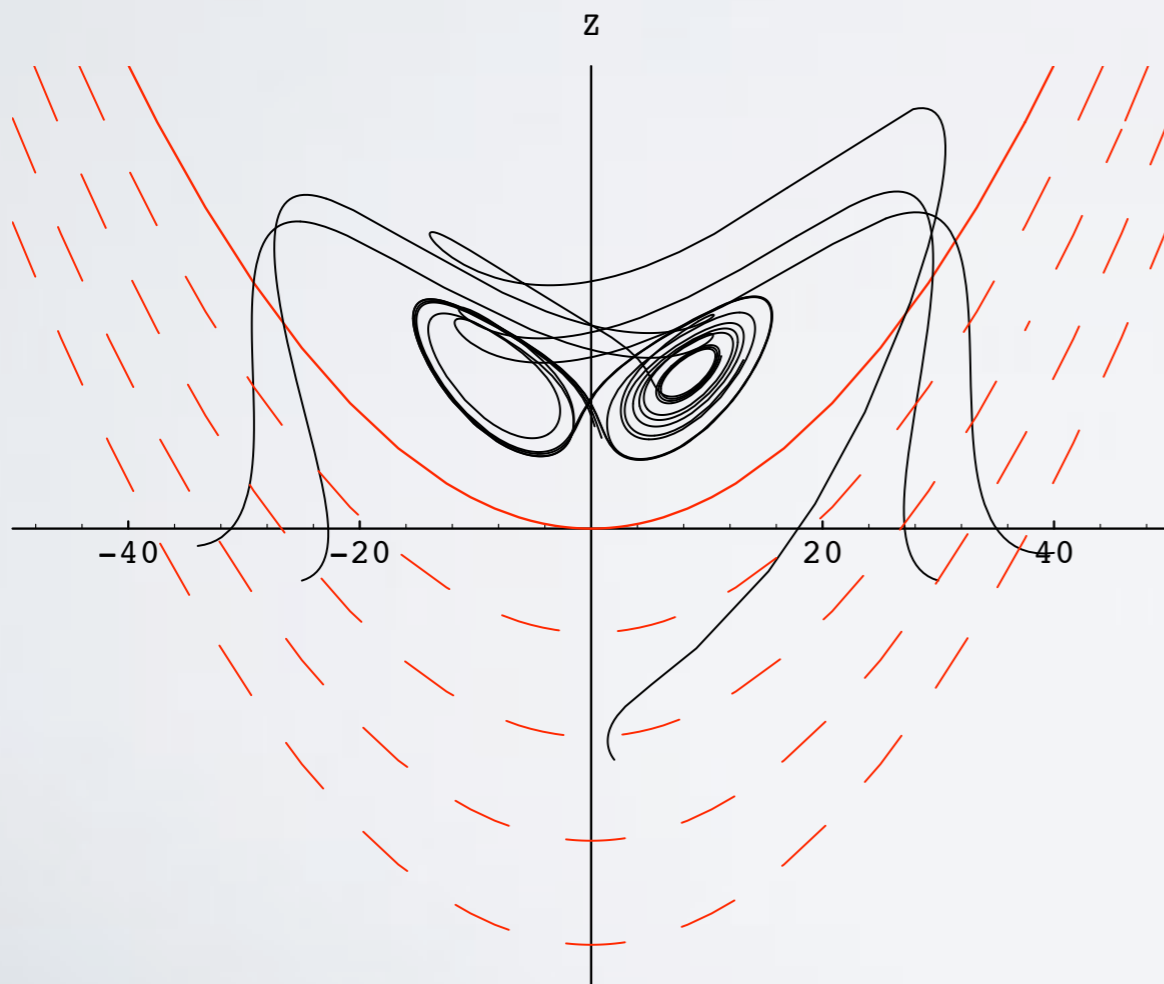
Curriculum vitae

1973 naissance

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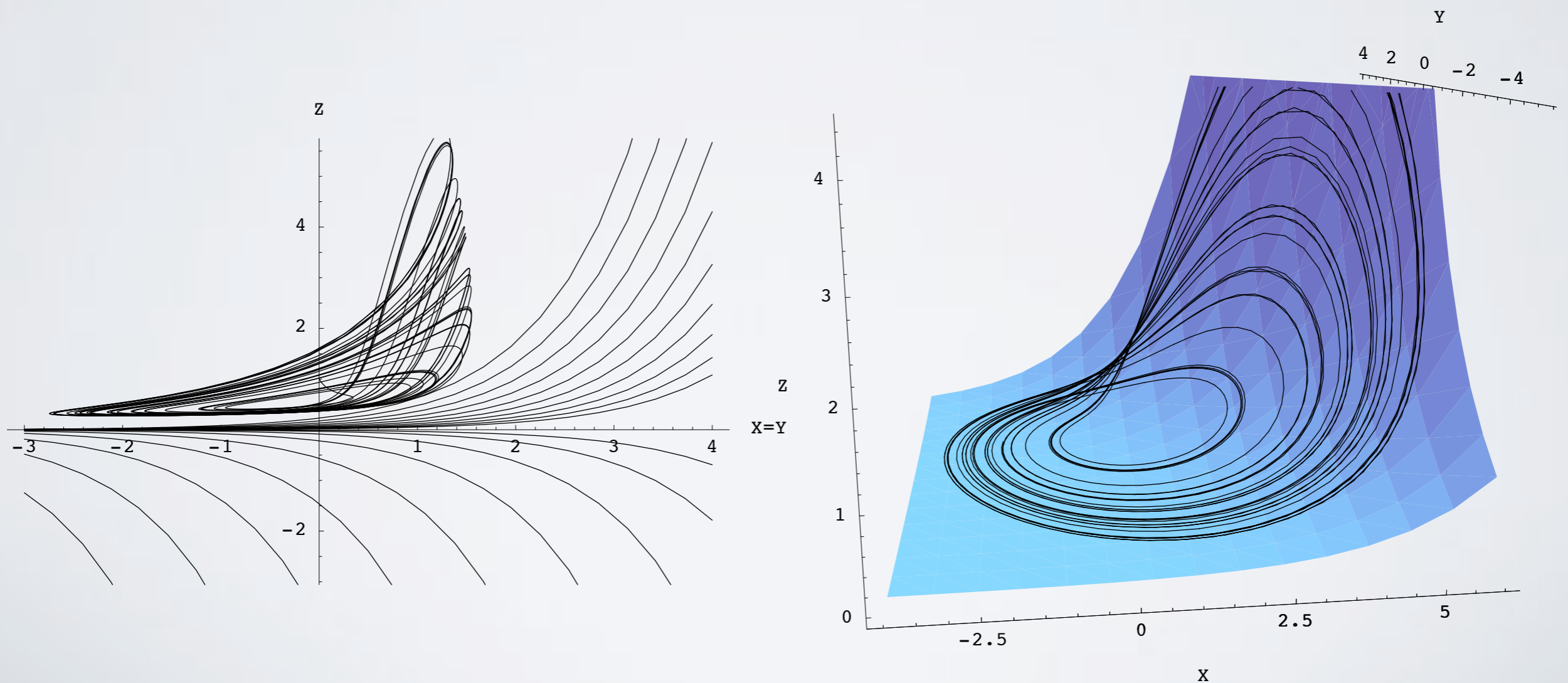
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Curriculum vitae

1973 naissance

1990 Bac C

1994 Maîtrise de Physique

1998 Thèse (attracteurs chaotiques, cycles limites)

1998-1999 Scientifique du contingent au CEA

1999-2001 Post-Doc à Londres (J.M.T.Thompson)

2001-2003 Post-Doc EPFL (Lausanne) John Maddocks

2003-2004 ATER Lab. Phys. Stat. (Martine Ben Amar)

2004- CR à l'institut d'Alembert

Curriculum vitae

conférences : nationales et internationales (20)

Curriculum vitae

conférences

publications : journaux (32) actes de conf. (11)

referee pour :

Celestial Mechanics (Springer),

European Physical Journal E (EDP Sciences),

Europhysics Letters (EDP Sciences),

International Journal of Bifurcation and Chaos (World Scientific),

International Journal of Solids and Structures (Elsevier),

Journal of Applied Mechanics

Journal of Physics A: Mathematical and General (Institute of Physics),

Journal of Nanobiotechnology (BioMed Central),

Nonlinearity (Institute of Physics),

Physics Letters A (Elsevier Sciences),

Physical Review E (American Physical Society),

Physical Review Letters (American Physical Society),

Proceedings of the Royal Society of London, A : Mathematical, Physical & Engineering sciences.

Curriculum vitae

conférences

publications

enseignement :

- tutorat ESPCI (mécanique des solides)
- ater temps plein paris 6
- EPFL assistant de cours (département math.)
- UCL (Londres) cours et tp numériques
- moniteur université de Tours (td & tp)

Curriculum vitae

conférences

publications

enseignement

services :

- site web du laboratoire LCVM (EPFL) 2001-2003
- membre du conseil du GDR «Non-Linéaire» 2006
- membre du conseil de laboratoire 2007-2008

- rencontres Non-Linéaire (thème croissance) 2005
- journée bioméca France Berkley 2005
- rencontre Mécaniciens-Physiciens 2009
- séminaire du laboratoire 2005-2009

Curriculum vitae

conférences

publications

enseignement

services

encadrement :

- doctorat N. Clauvelin (2005-2008) (avec B. Audoly)
- «internship IIT» P. Agarwal (été 2008) (avec B. Audoly)
- stage MI C. Pouchou (été 2009) (avec A. Fernandes)
- «internship IIT» V. Gaur (été 2009) (avec C. Maurini)

Curriculum vitae

conférences

publications

enseignement

services

encadrement

financements :

- ACI Jeunes Chercheurs (porteur : B. Audoly)
- CNRS / Royal Society (porteur : M. Destrade)
- PICS CNRS / USA (porteur : M. Destrade)
- BQR Paris 6 (porteur : B. Roman)
- ANR Jeunes Chercheurs (porteur A. Antkowiak)

Curriculum vitae

conférences

publications

enseignement

services

encadrement

financements

visites longue durée :

University of Arizona

6 semaines 2006

2 semaines en 2008

A. Goriely (Applied Math.) et A. Hausrath (Bio. Chem.)

Curriculum vitae

conférences

publications

enseignement

services

encadrement

financements

visites longue durée

diffusion de la Science :

2006-2007

Participation à diverses émissions ou reportages

Radio Campus, France Inter (radio)

M6, CBS Evening News, Deutsche Welle (télé)

Plan

A - CV

→ B - Quelques études sur les tiges élastiques

C - Perspectives

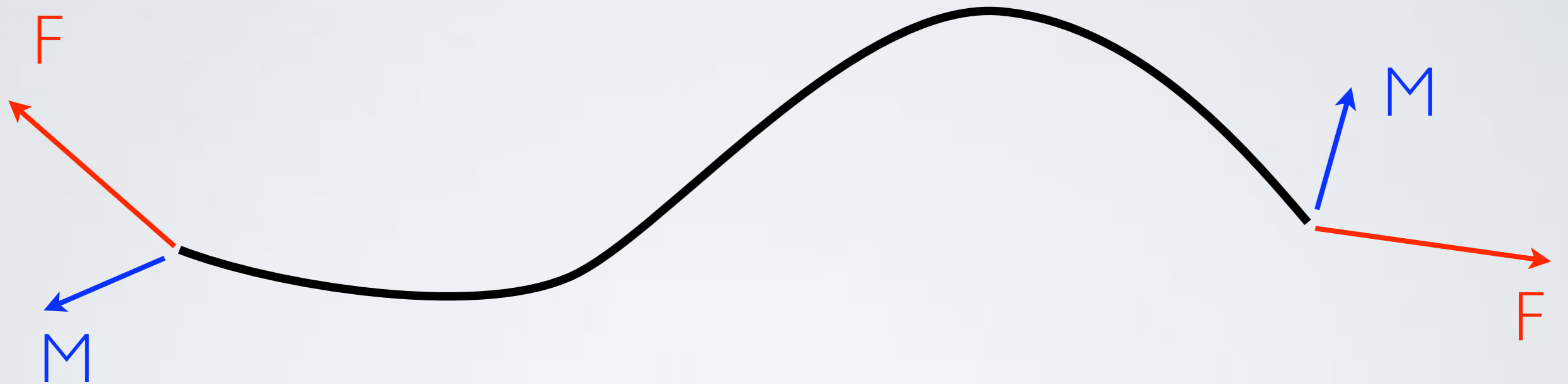
Equations de Kirchhoff



il faut :

- un grand rapport d'aspect
- ne pas trop courber

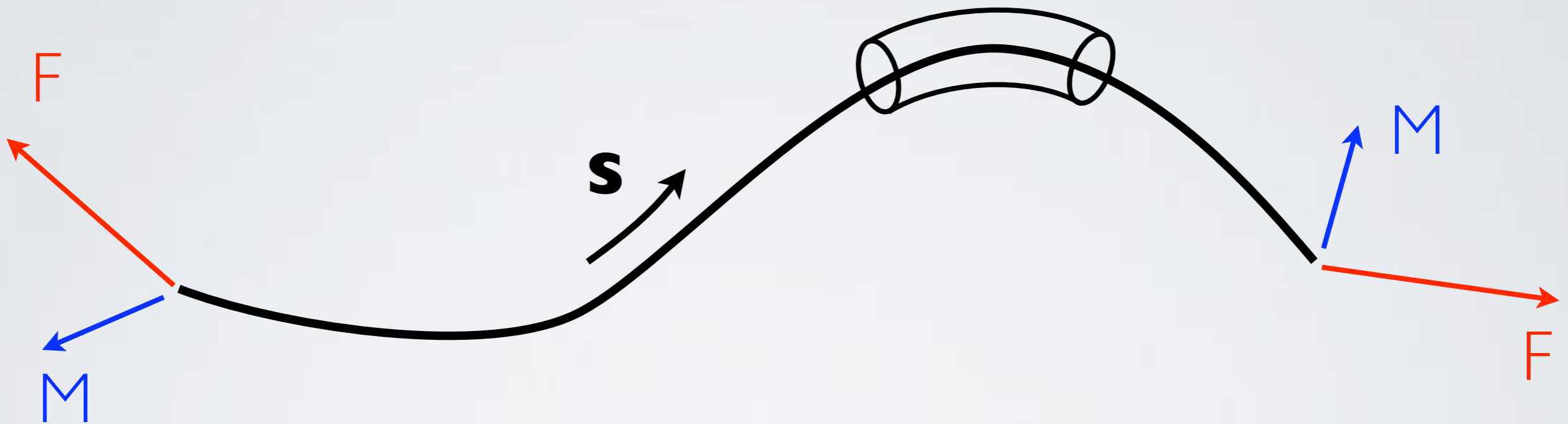
Equations de Kirchhoff



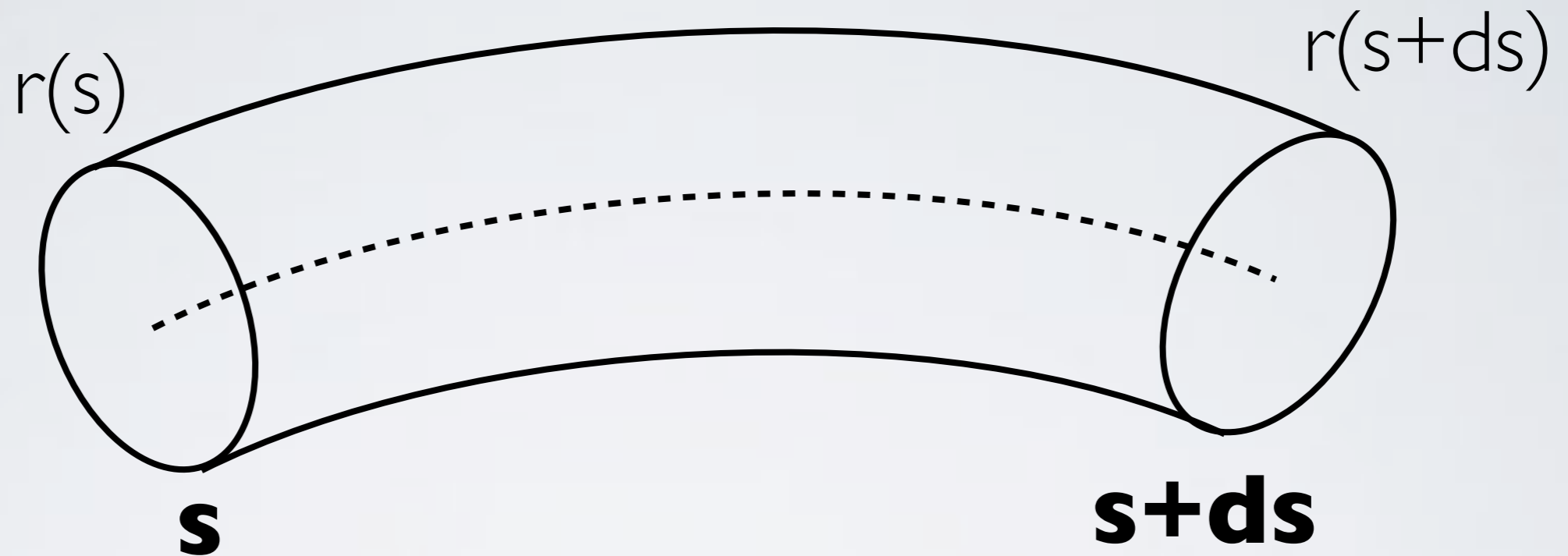
Equations de Kirchhoff



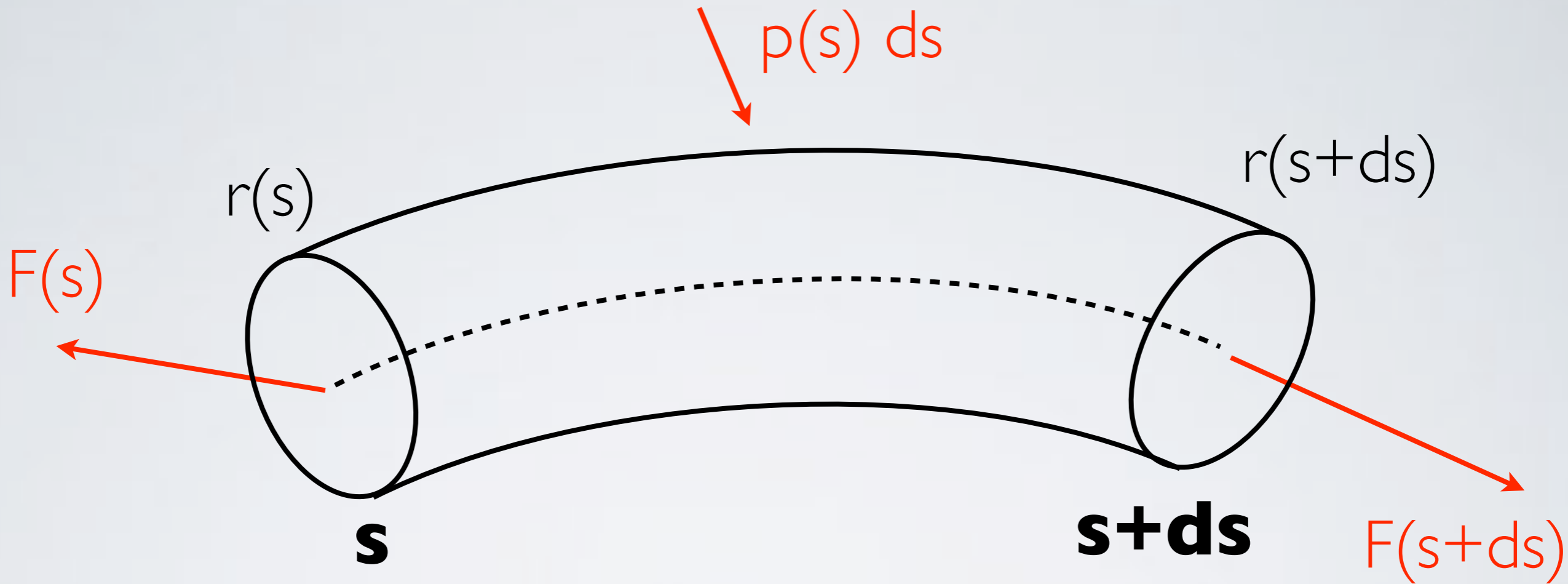
Equations de Kirchhoff



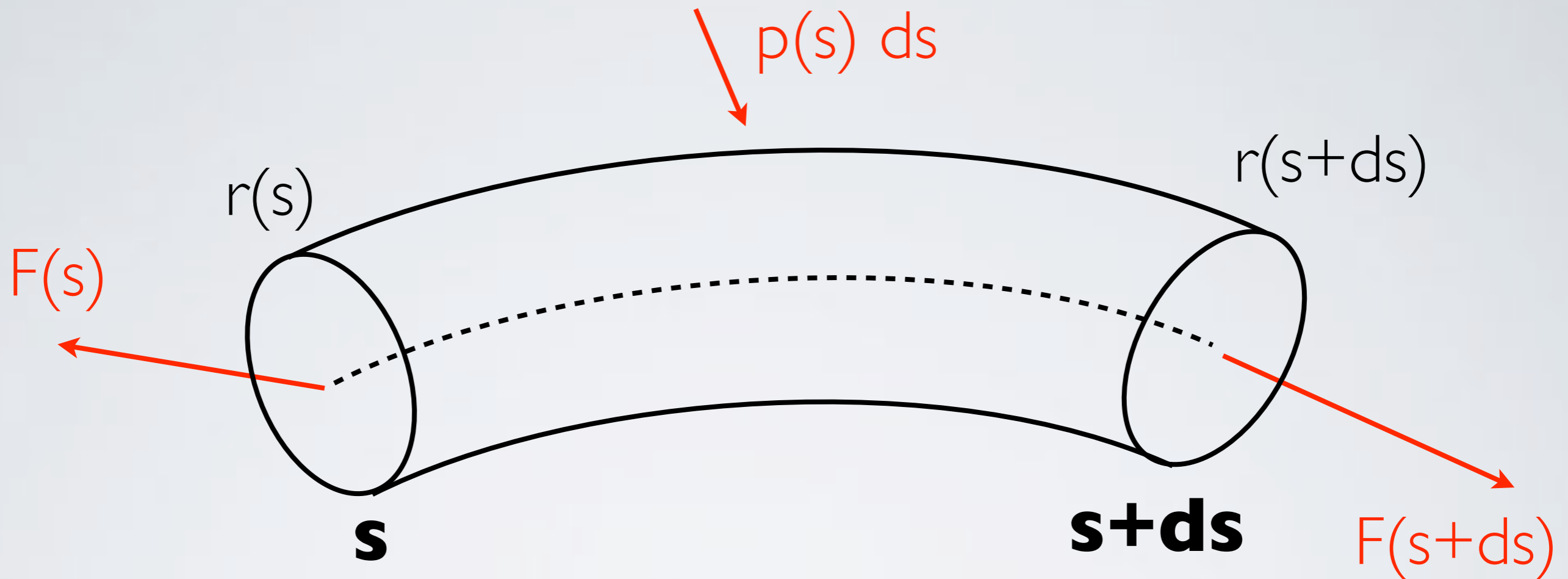
Equations de Kirchhoff



Equations de Kirchhoff



Equations de Kirchhoff

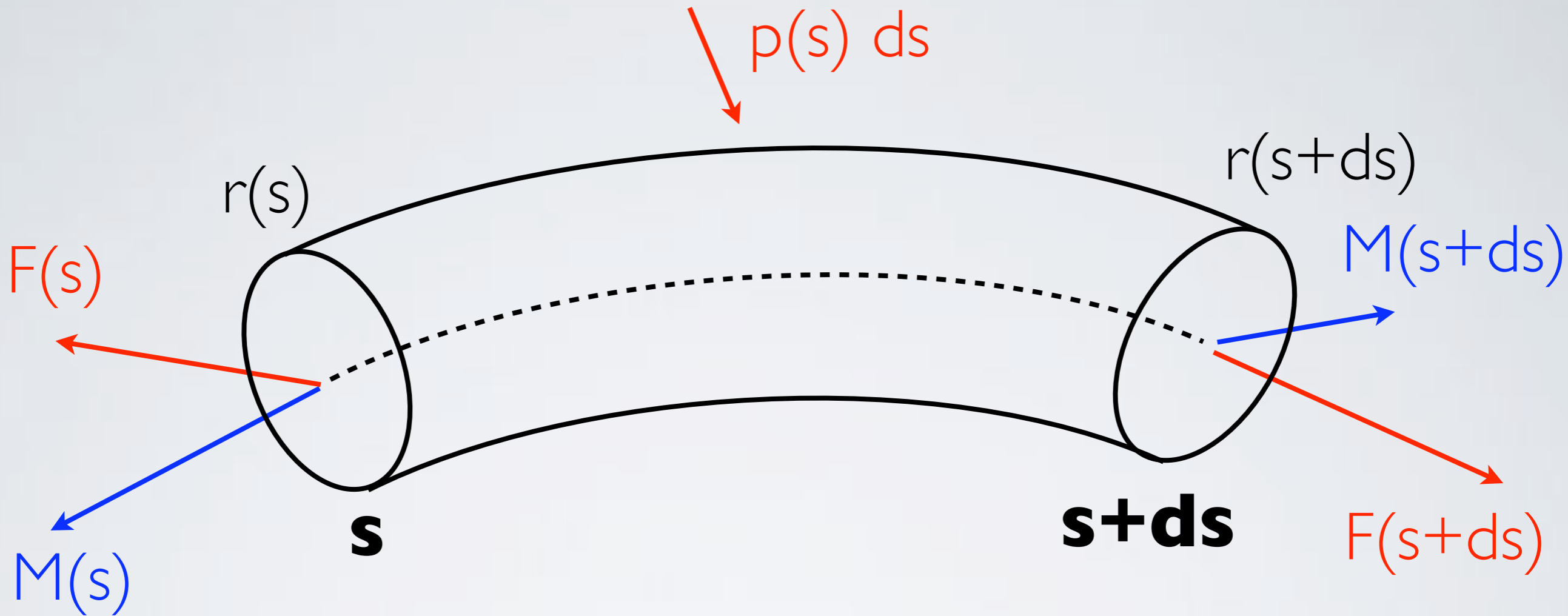


$$F(s+ds) - F(s) + p(s) ds = 0$$

Equilibre

$$F'(s) + p(s) = 0$$

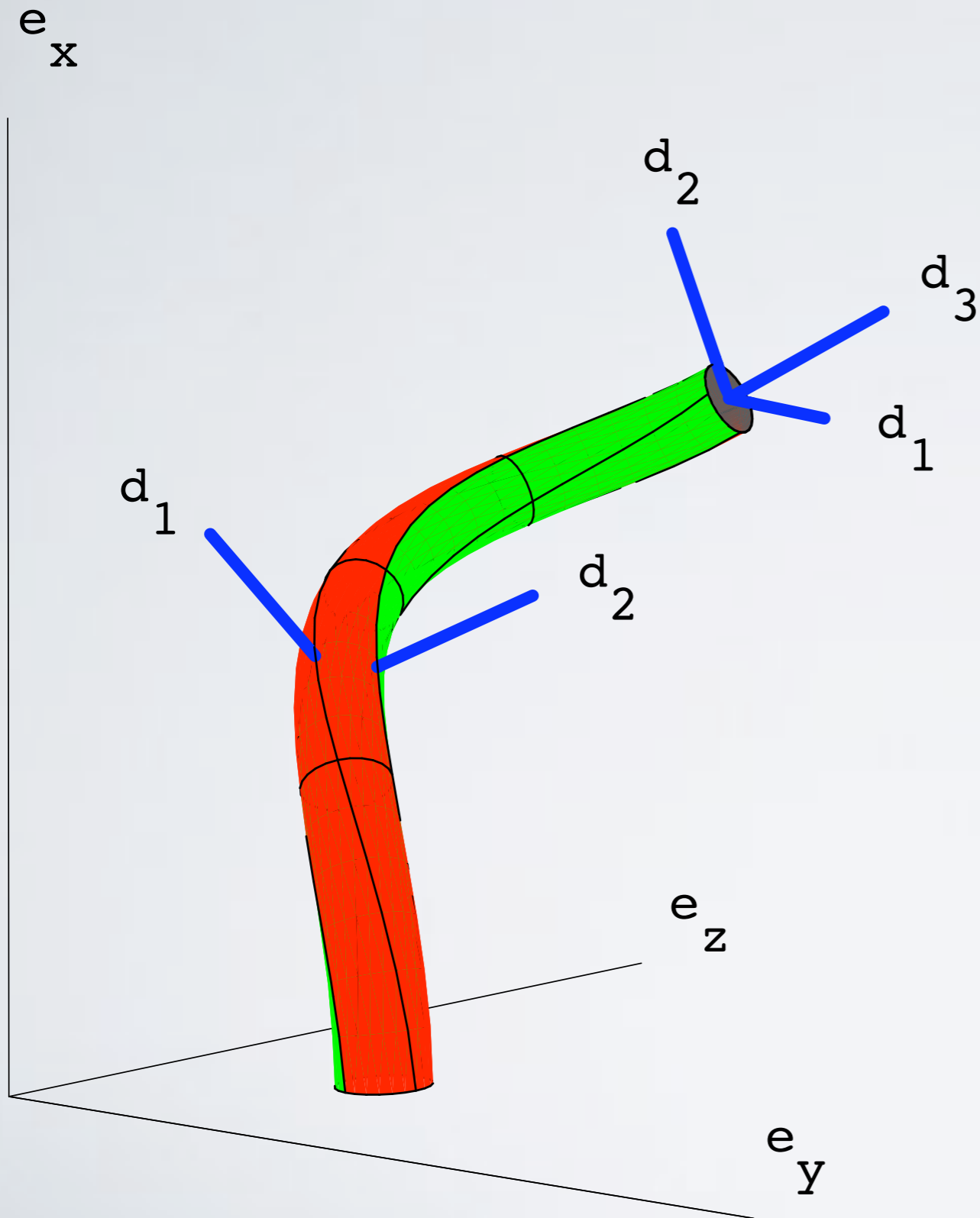
Equations de Kirchhoff



Equilibre

$$M' + r' \times F = 0$$

Equations de Kirchhoff



directeurs de Cosserat

$$d'_1 = u \times d_1$$

$$d'_2 = u \times d_2$$

$$d'_3 = u \times d_3$$

$$u = \{ \kappa_1, \kappa_2, \tau \} d_i$$

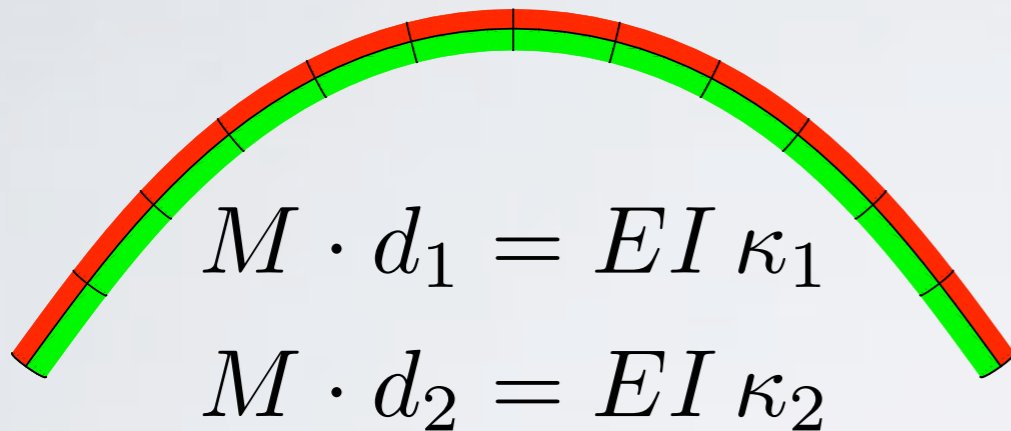
courbures

torsion

Equations de Kirchhoff

loi de comportement

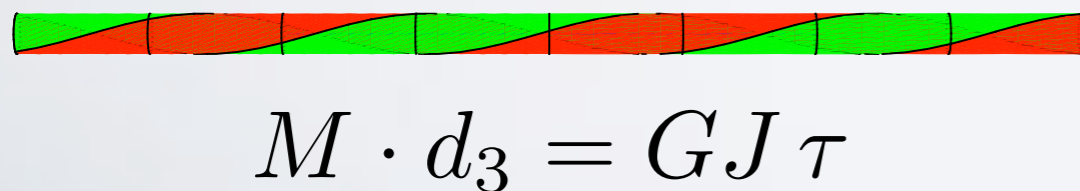
flexion



E module d'Young

I second moment de la section

torsion



G module de cisaillement

J moment polaire de la section

Kirchhoff equations

21 ODEs with variable : s

ordinary differential equations

$$\frac{d}{ds} \vec{F} = \vec{p}$$

$$\frac{d}{ds} \vec{M} = \vec{F} \wedge \vec{d}_3$$

$$\frac{d}{ds} \vec{r} = \vec{d}_3$$

$$\frac{d}{ds} \vec{d}_i = \vec{u} \wedge \vec{d}_i$$

$$m_i = K_i u_i$$

linear elasticity

21 unknowns

$$\vec{F}(s)$$

$$\vec{M}(s)$$

$$\vec{r}(s)$$

$$\vec{d}_3(s)$$

$$\vec{d}_2(s)$$

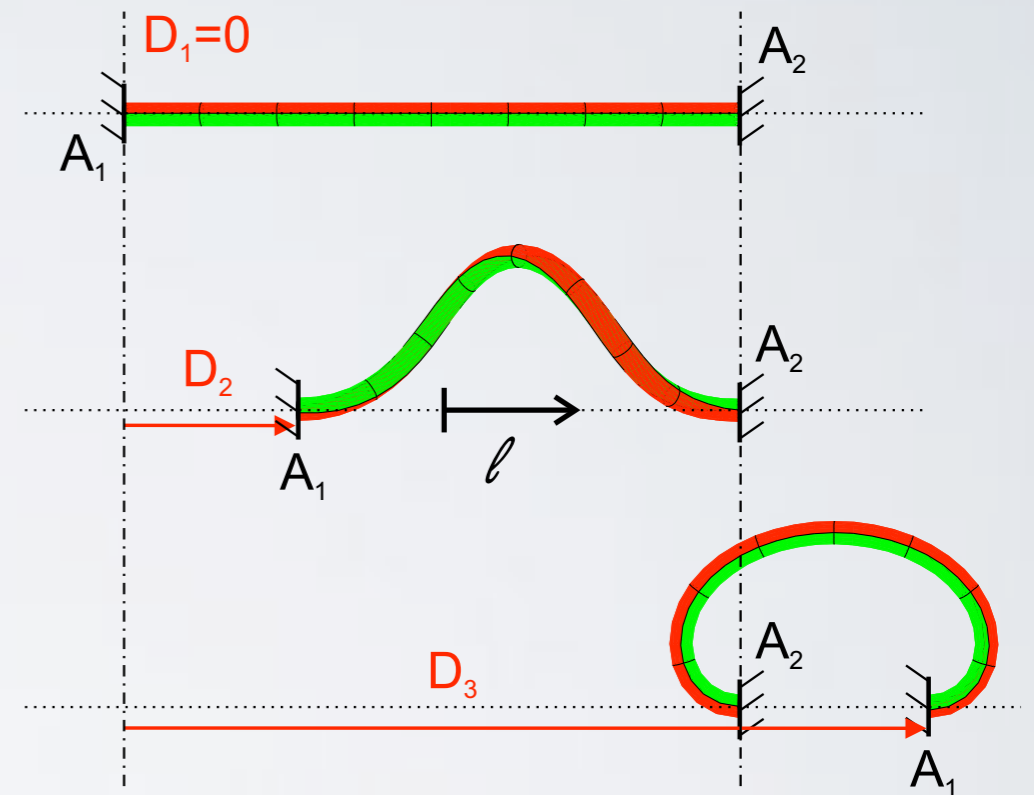
$$\vec{d}_3(s)$$

$$\vec{u}(s)$$

$$i = 1, 2, 3$$

boundary conditions

- how the rod is held
- few solutions are admissibles



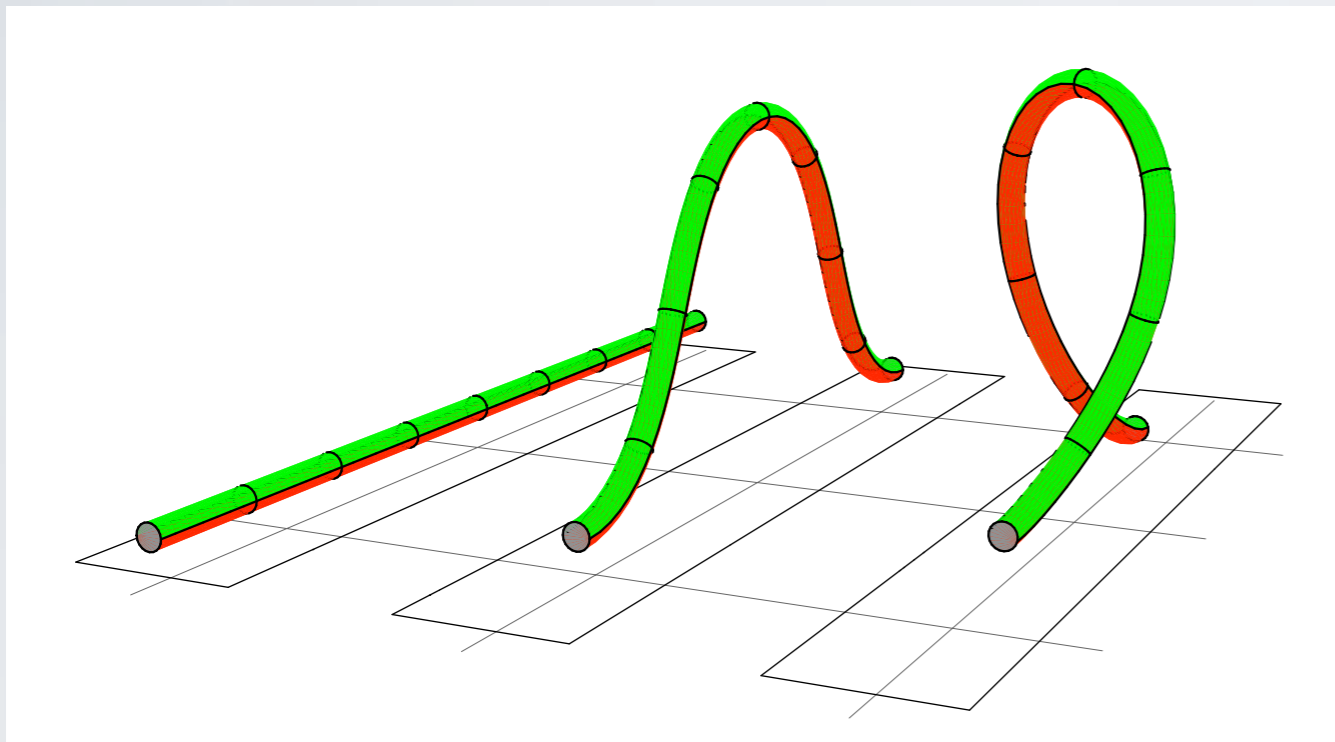
$$\vec{d}_3(A_1) = \vec{d}_3(A_2)$$

$$\vec{r}(A_2) - \vec{r}(A_1) = k \vec{d}_3(A_2)$$

$$(D = L - k)$$

Un cas d'école : tige encastrée

tige uniforme, isotrope, naturellement droite, ...

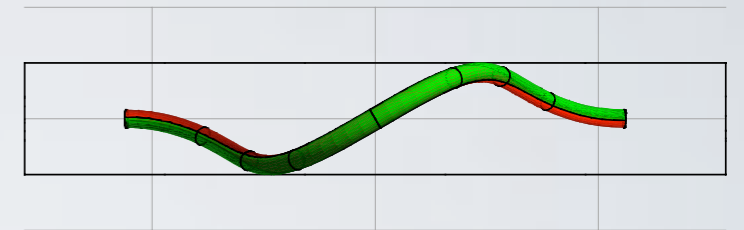
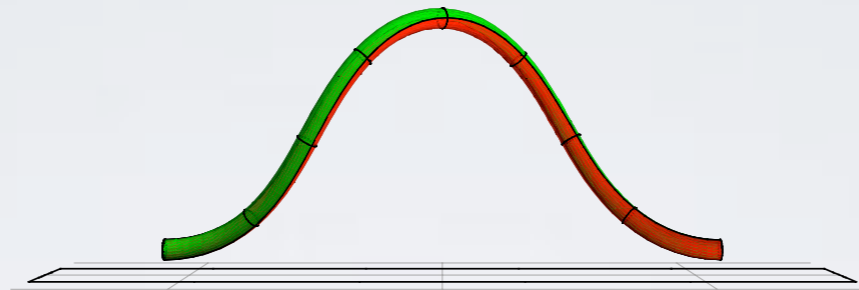
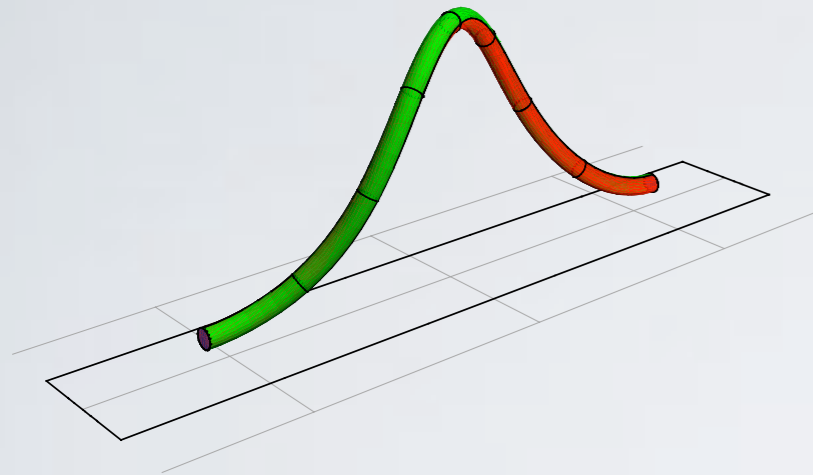


réduction système
 $21 D \Rightarrow 6D$

$$r' = d_3$$
$$d'_3 = (F \times r + M_0) \times d_3$$

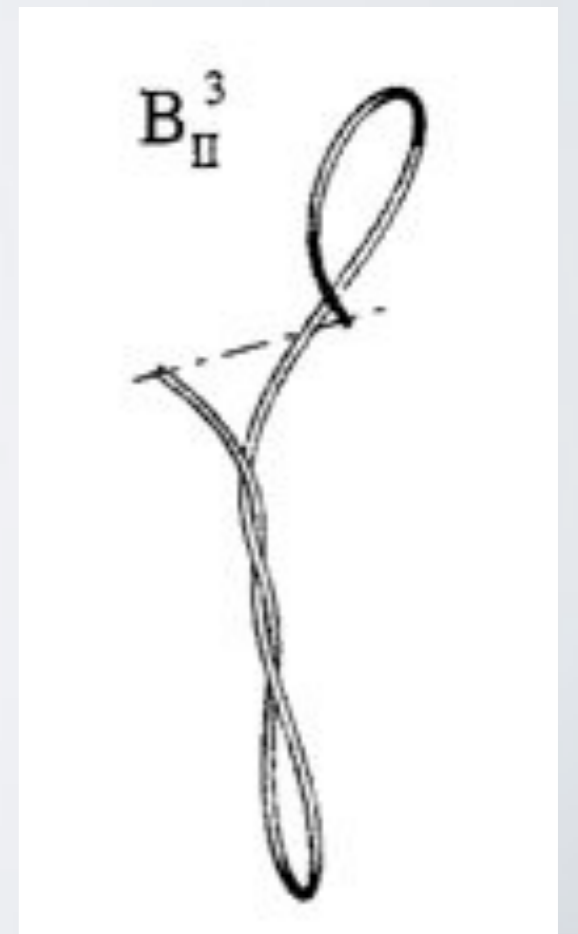
Tige encastrée : symétrie des solutions

extrémités encastrées \Rightarrow solutions symétriques

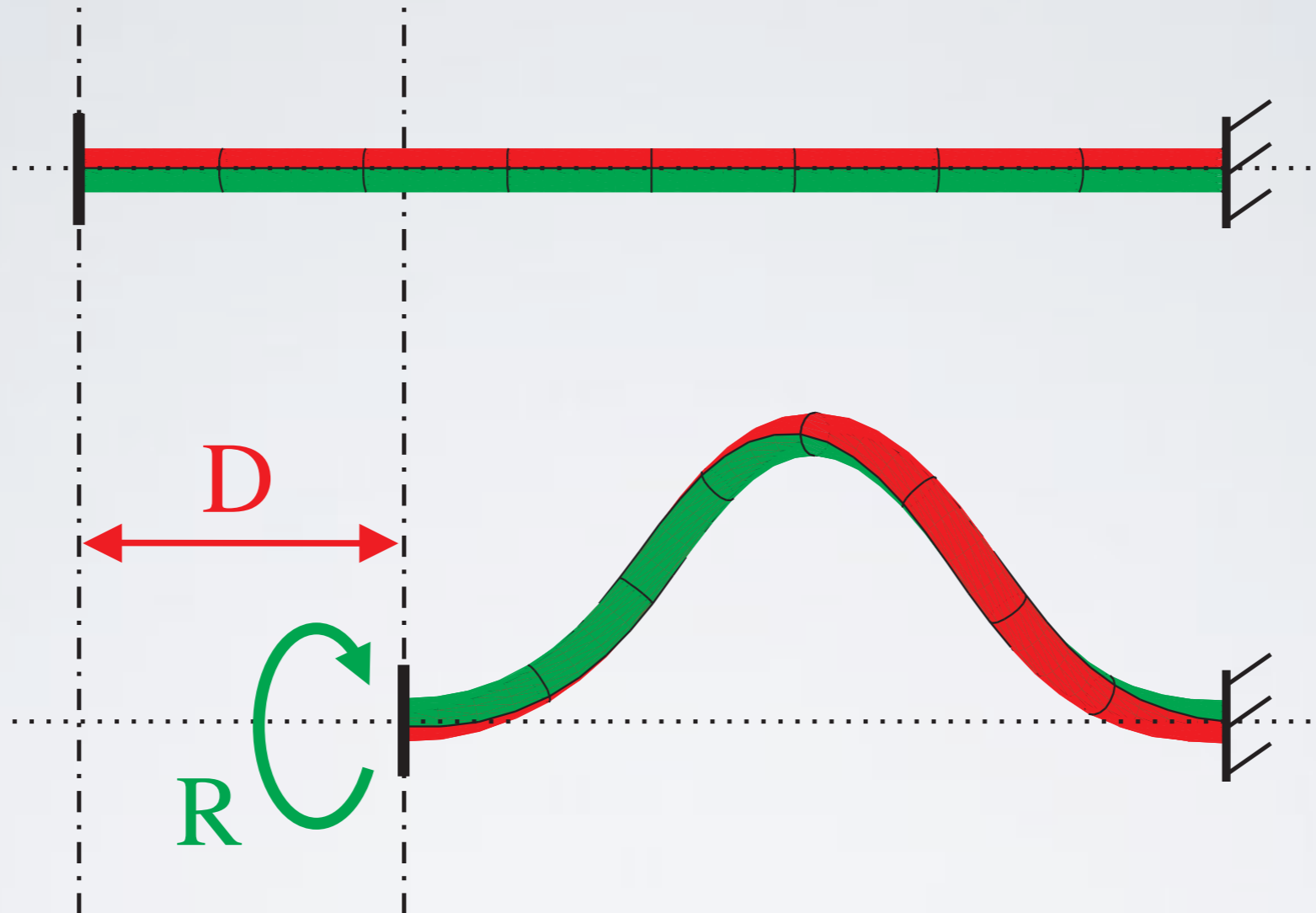


Généralisation :
contact ?
autres conditions de bords ?
tige à section anisotrope ?

D. Swigon
(PhD Rutgers)
1999

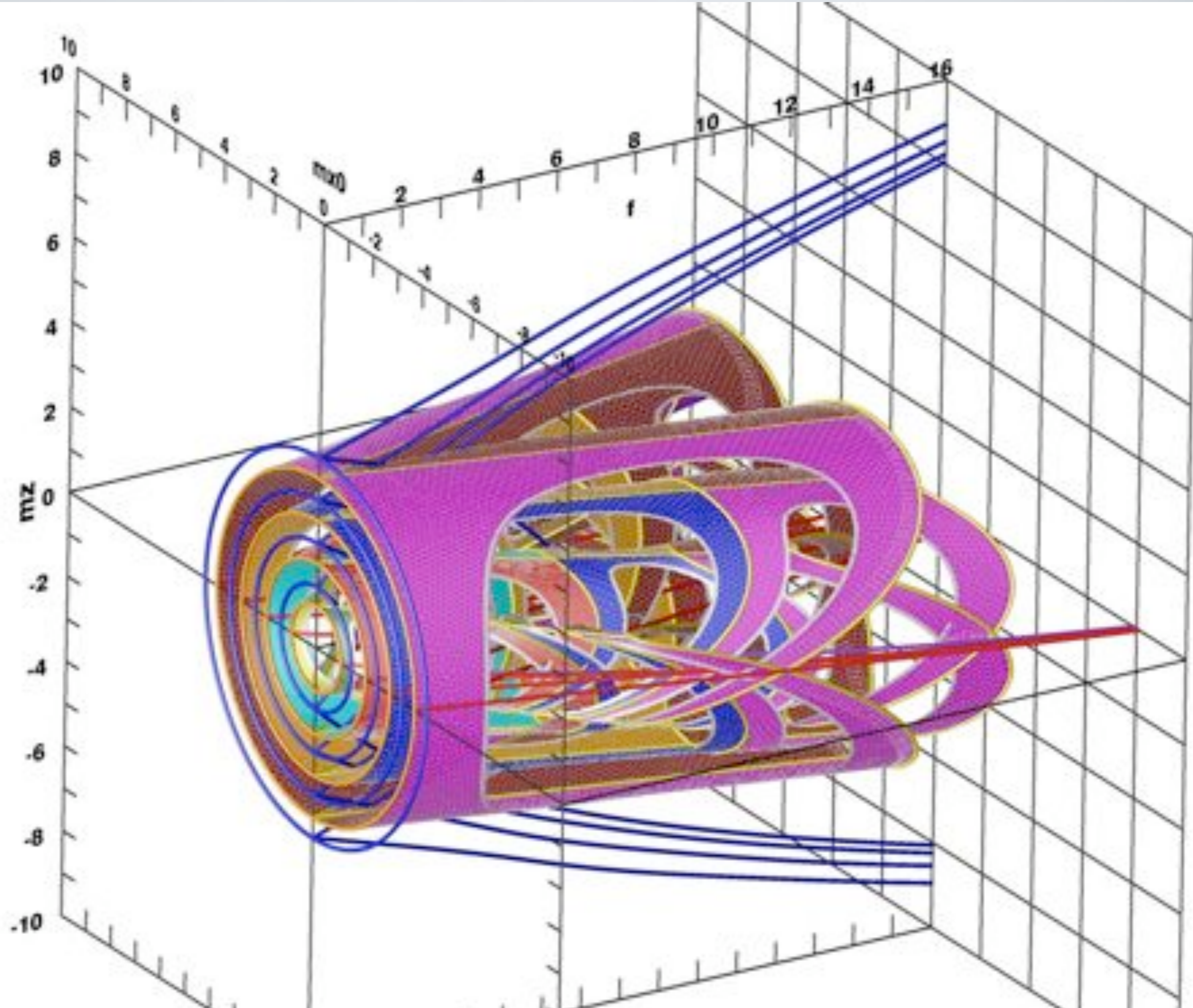


Tige encastrée : ensemble des solutions

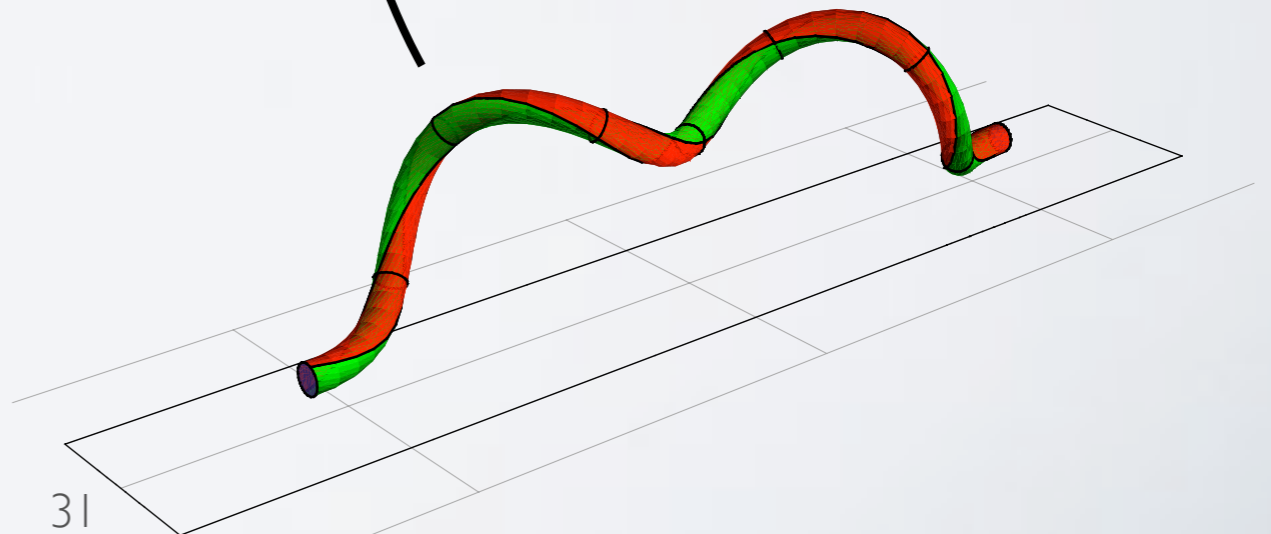
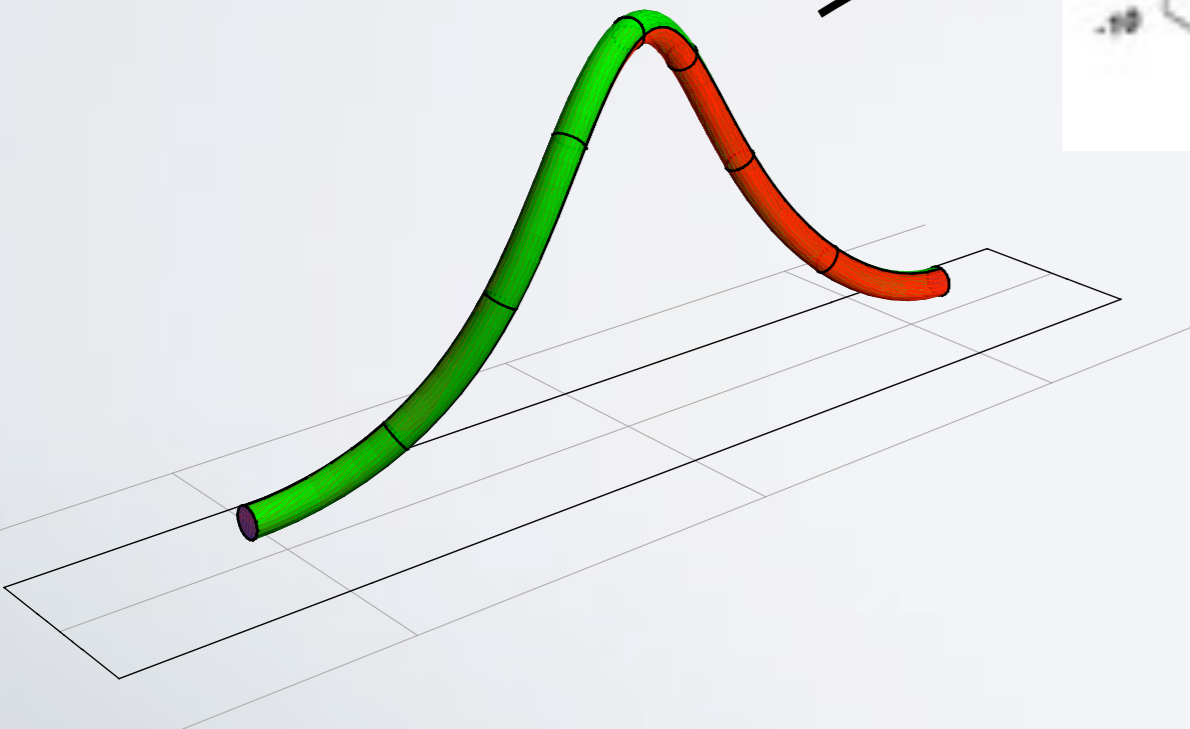
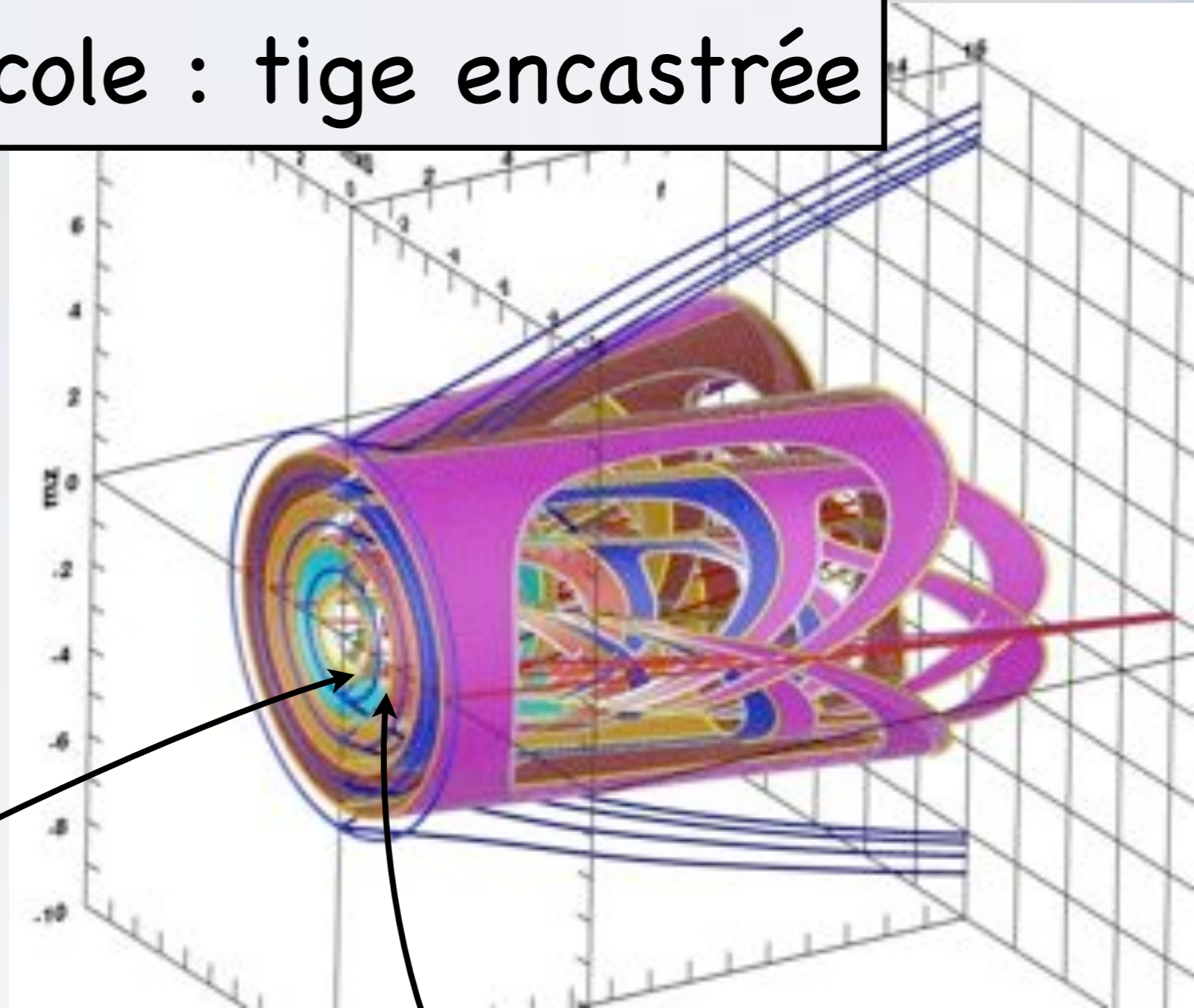
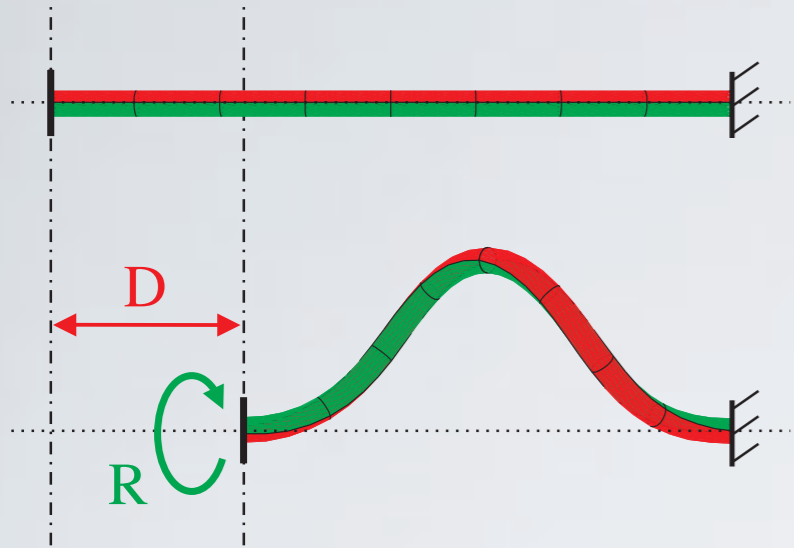


D : raccourcissement

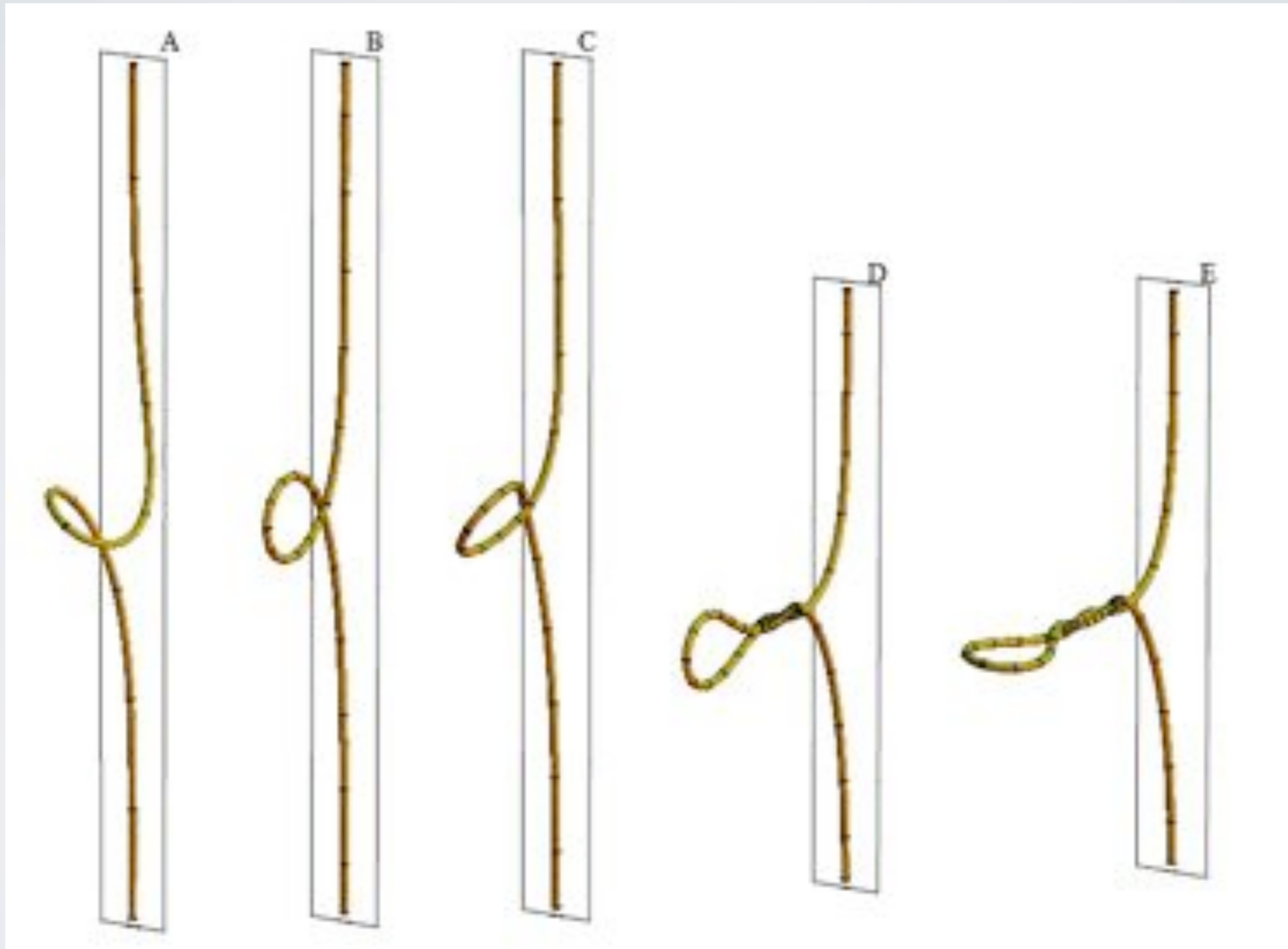
R : rotation



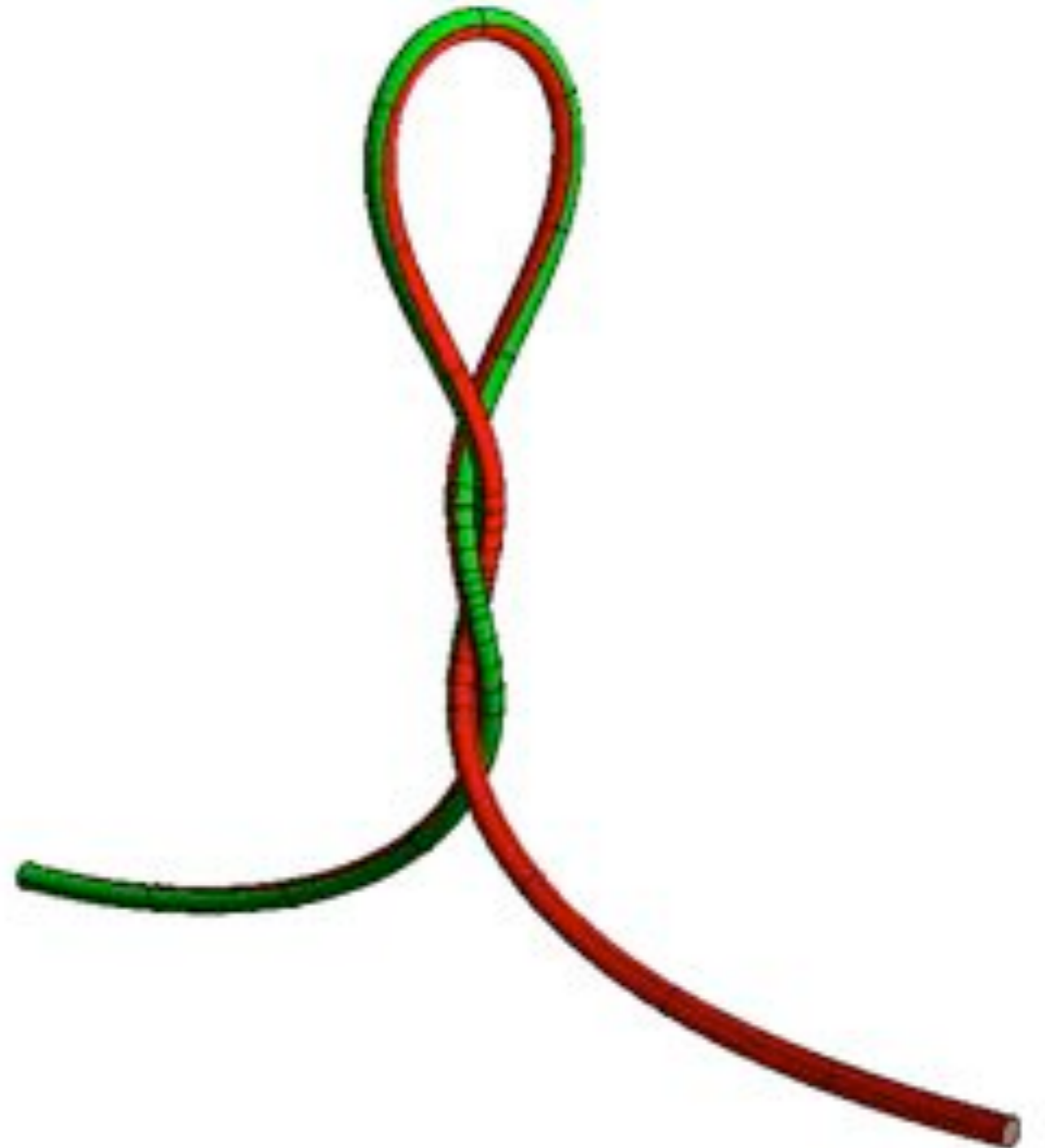
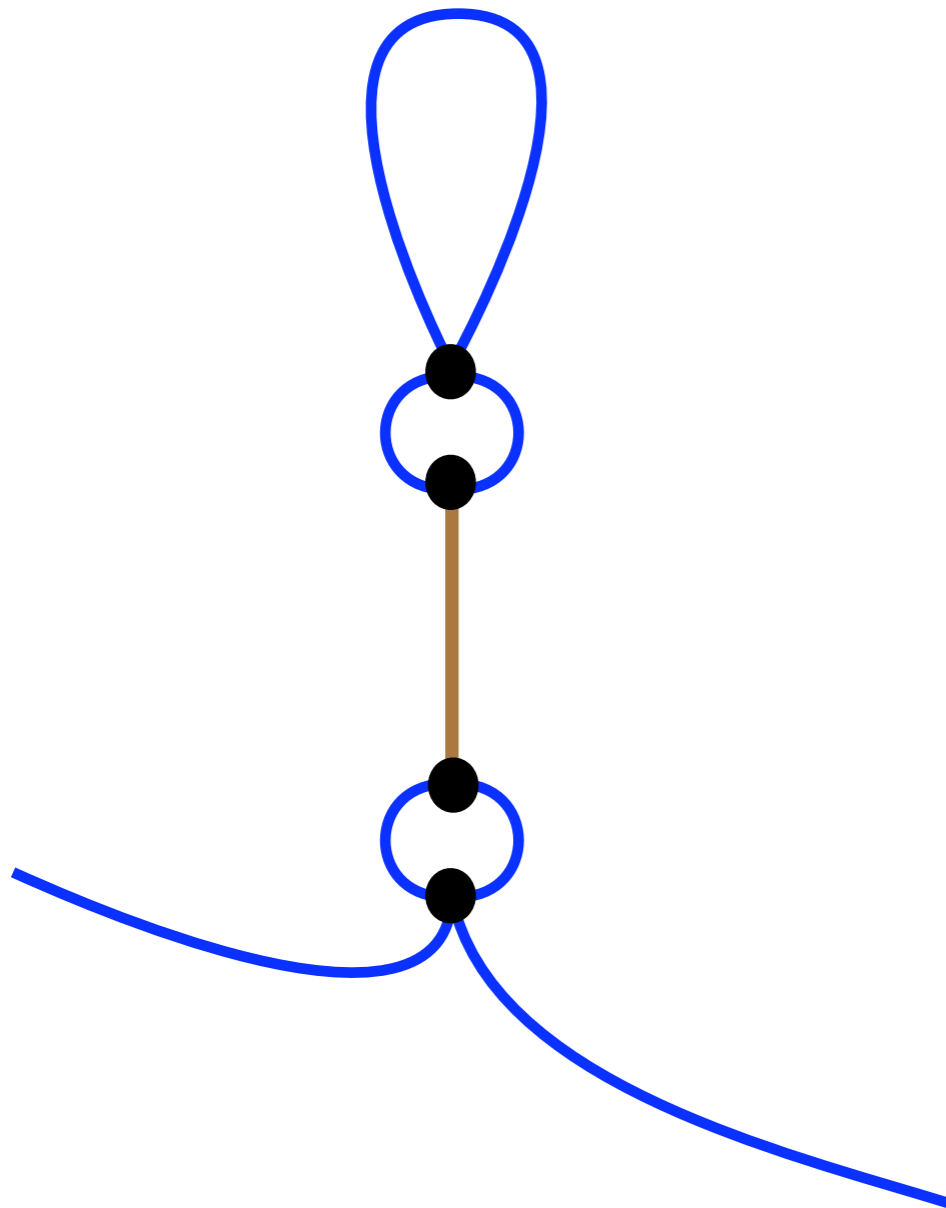
Un cas d'école : tige encastrée



Prise en compte de l'auto-contact



Topologie de l'auto-contact

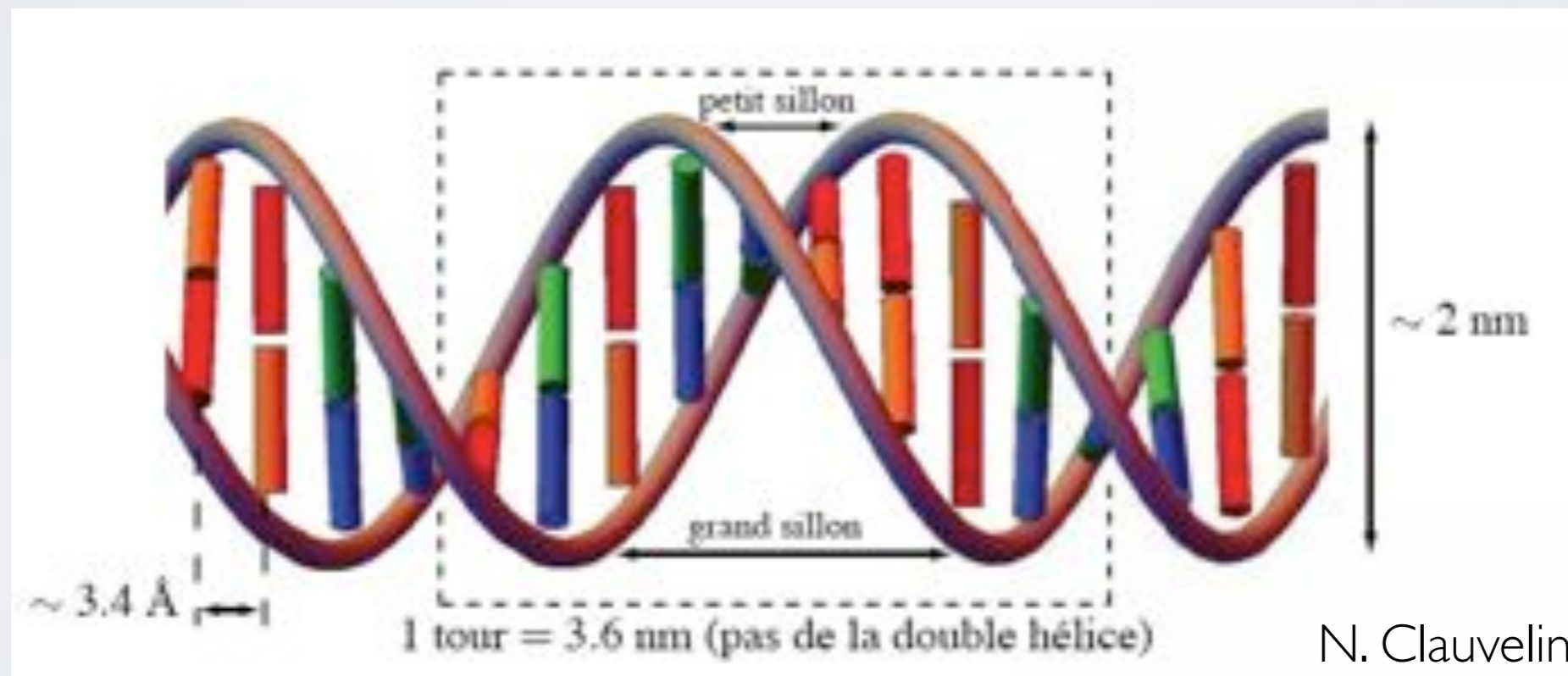


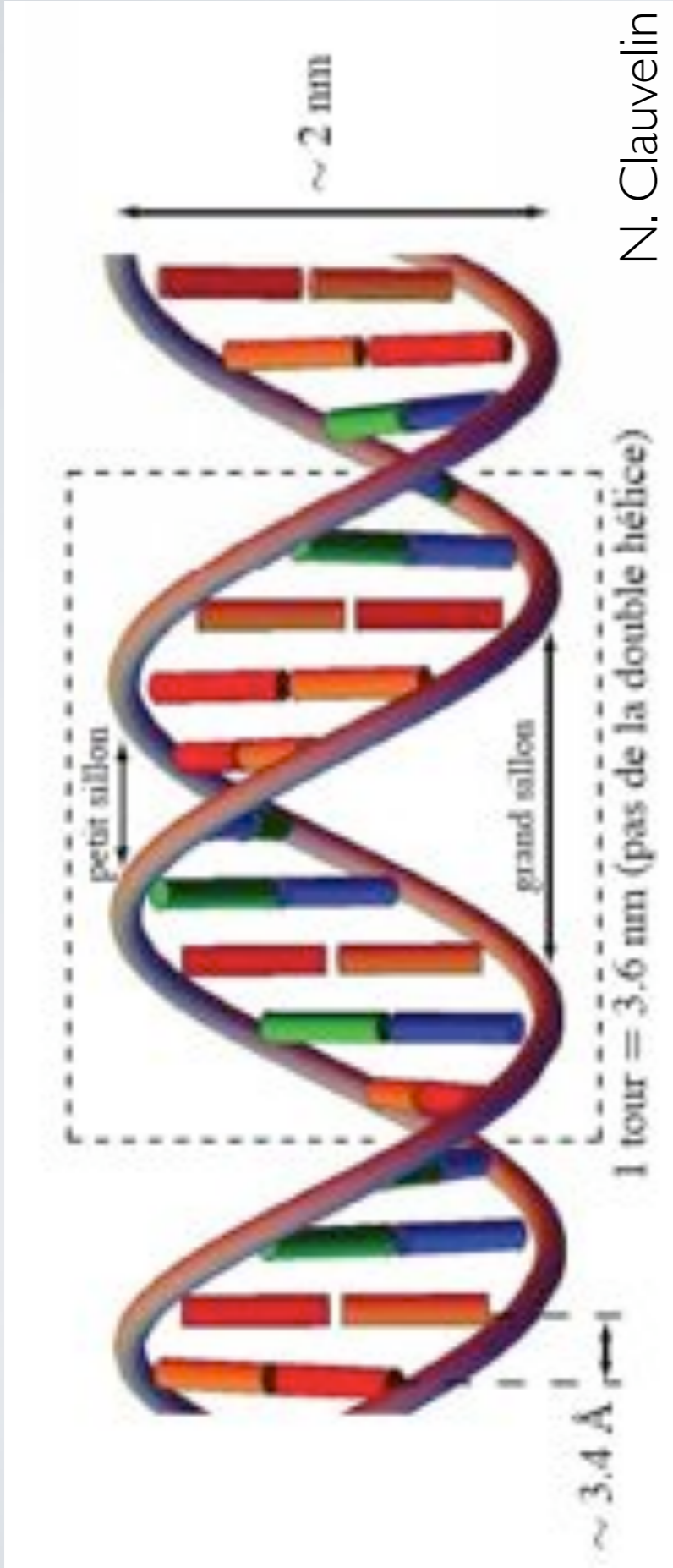
Propriétés mécaniques de l'ADN

1944 : adn porte les gènes

1953 : structure en double-hélice

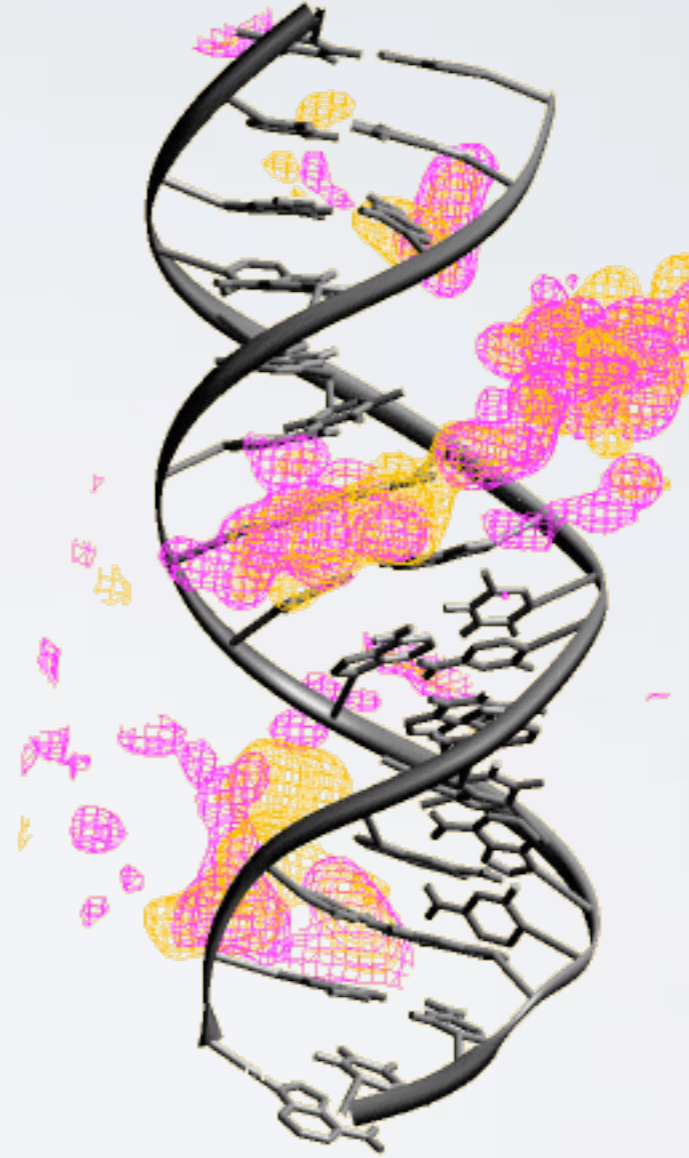
1992 : études «mécaniques» par
pinces optiques et magnétiques





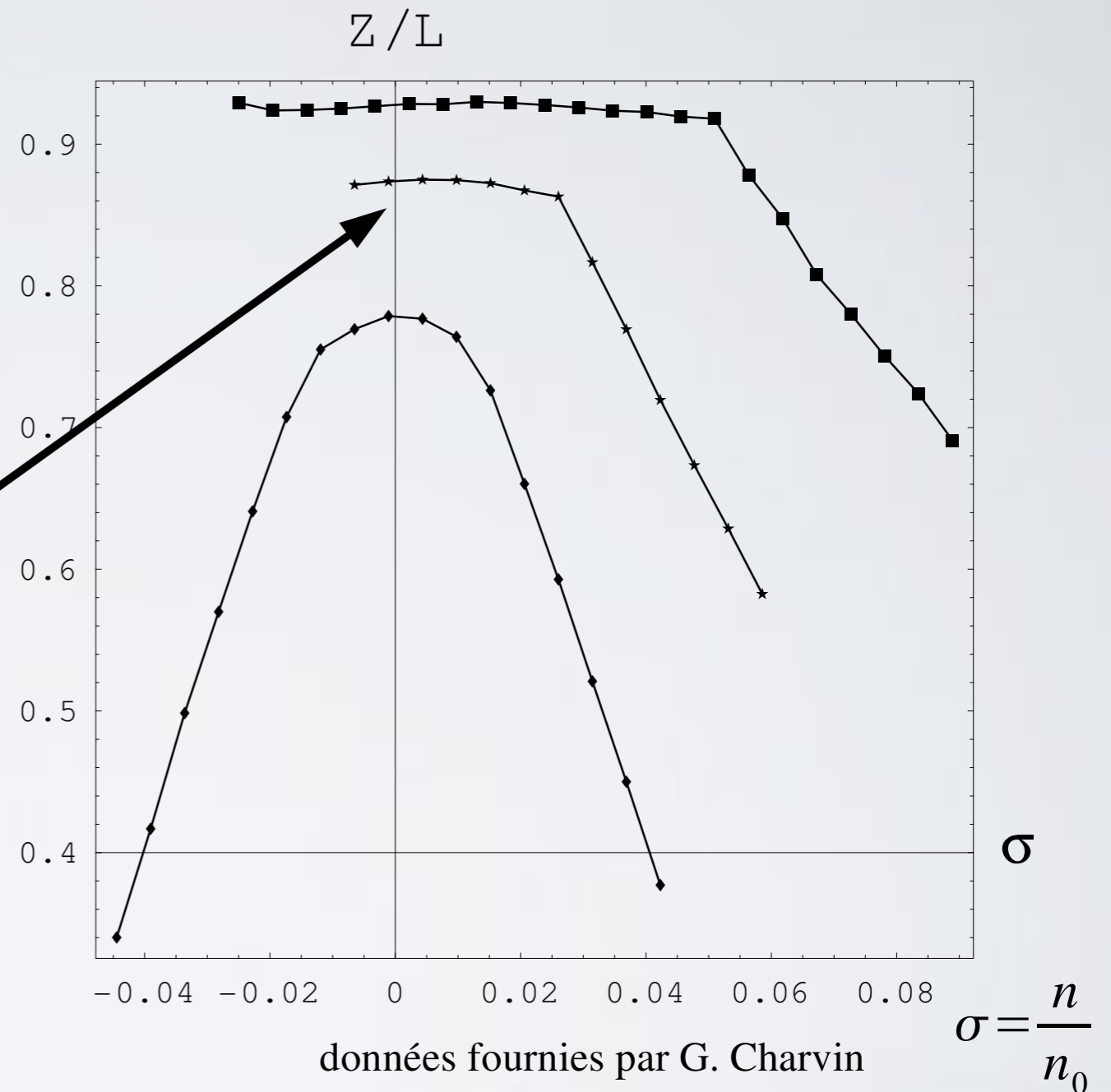
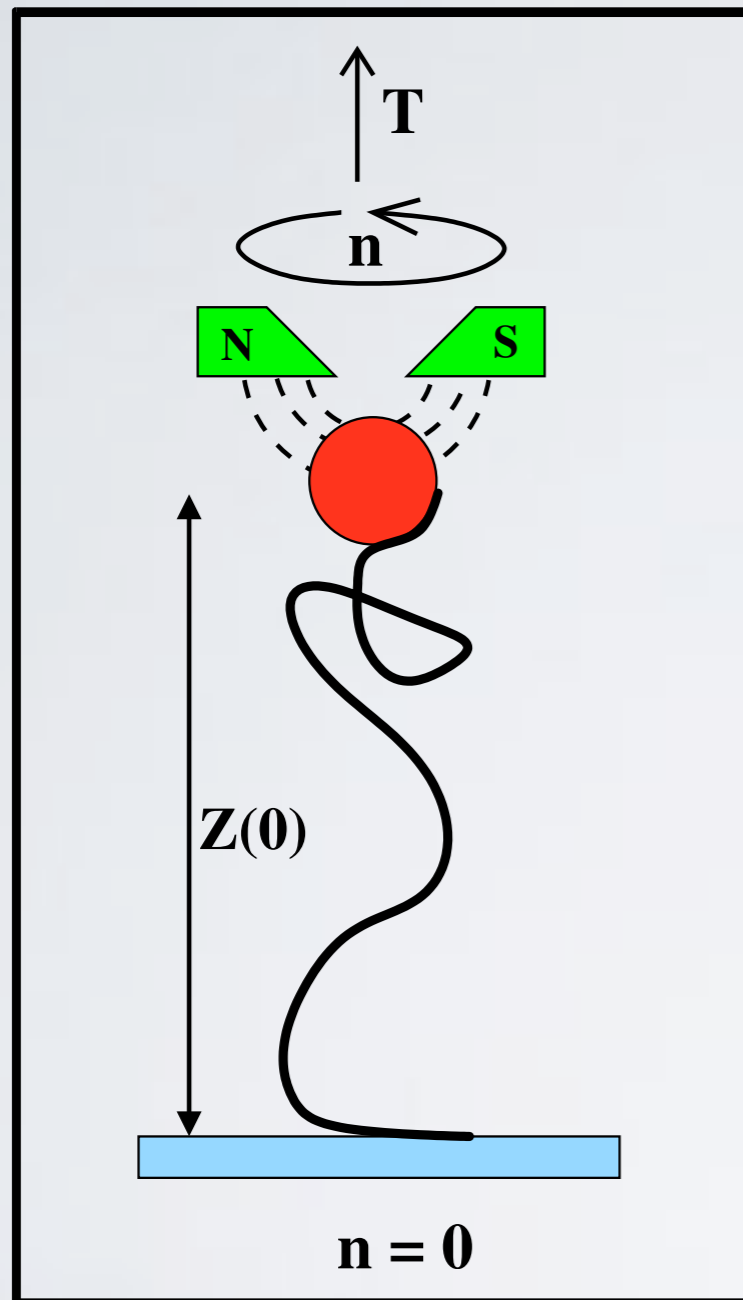
N. Clauvelin

ADN =
macromolécule chargée



Alexandre Bonvin
www.nmr.chem.uu.nl

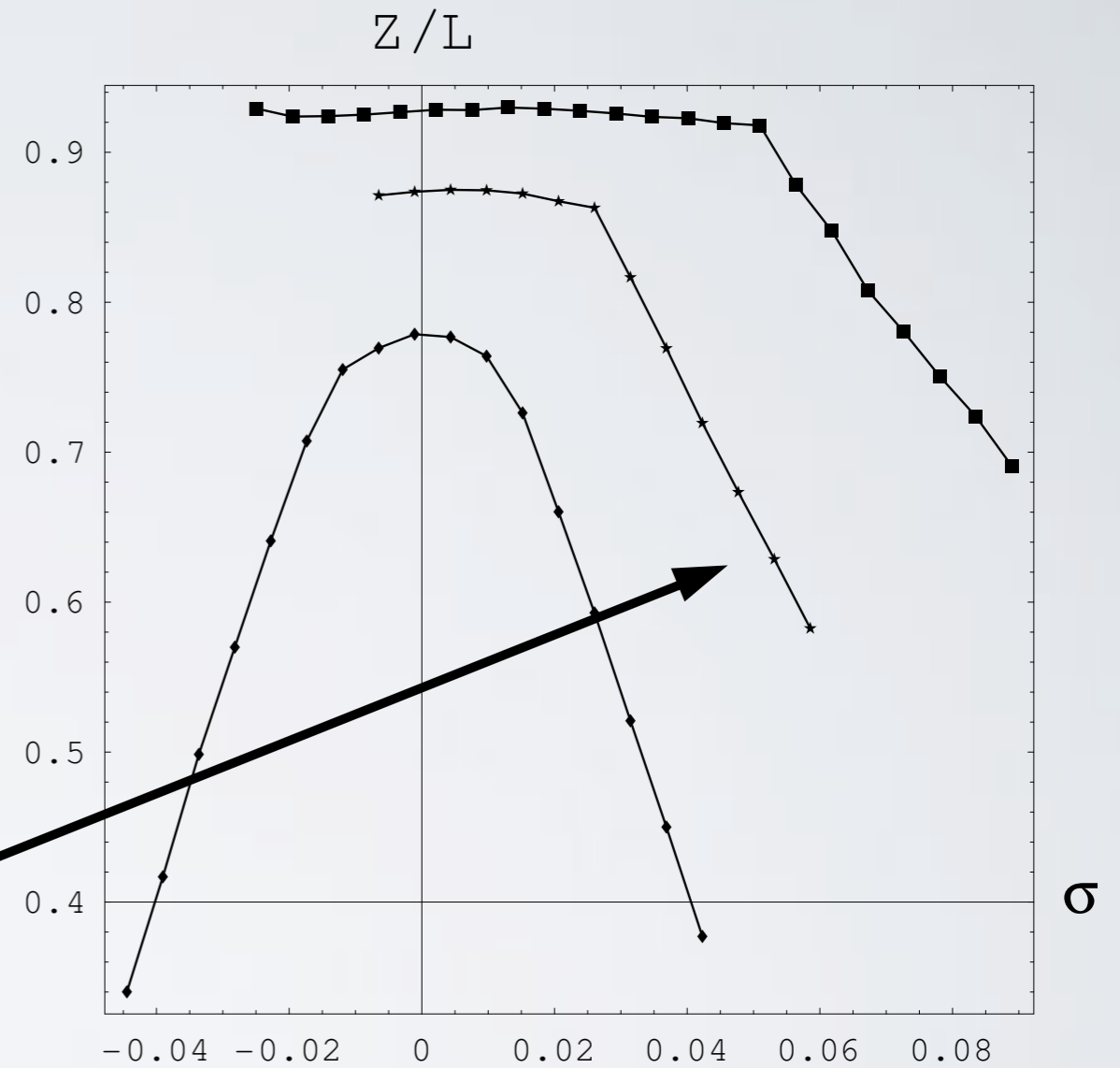
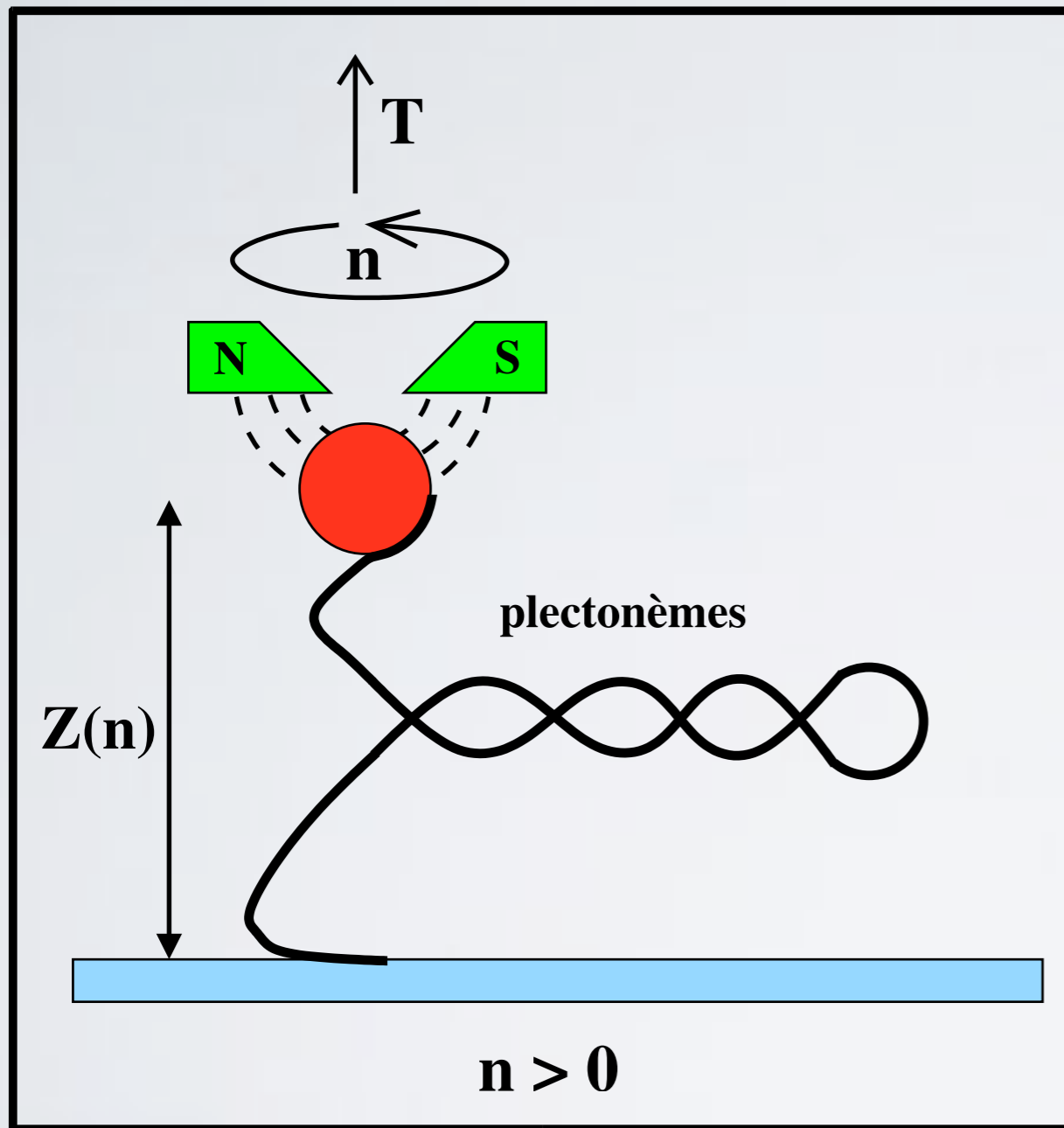
Étirement d'ADN sous contrainte de torsion



autres équipes : C. Bustamante, L. Finzi, J.-L. Viovy (Bancaud)

équipe : V. Croquette - D. Bensimon

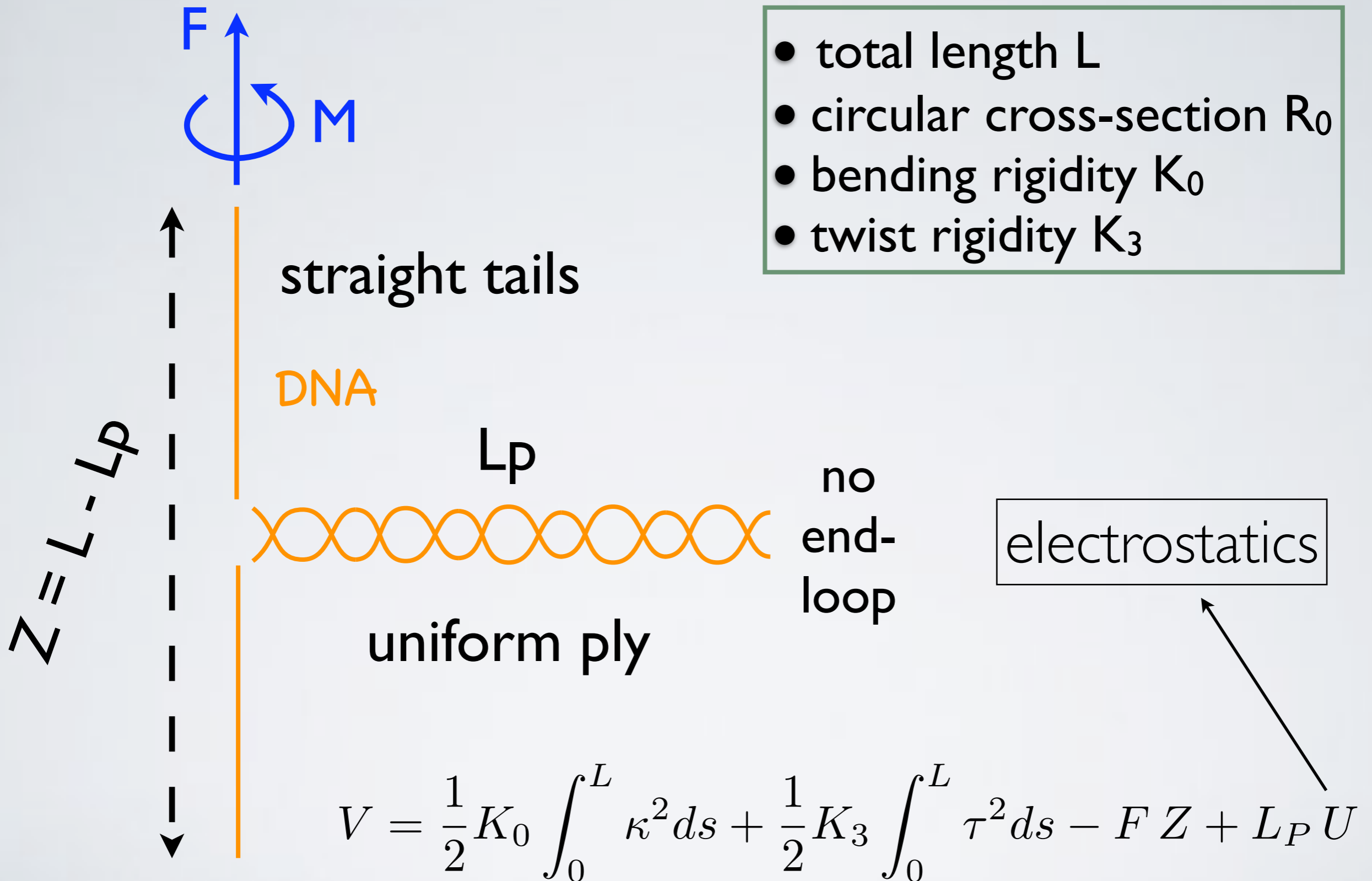
Étirement d'ADN sous contrainte de torsion



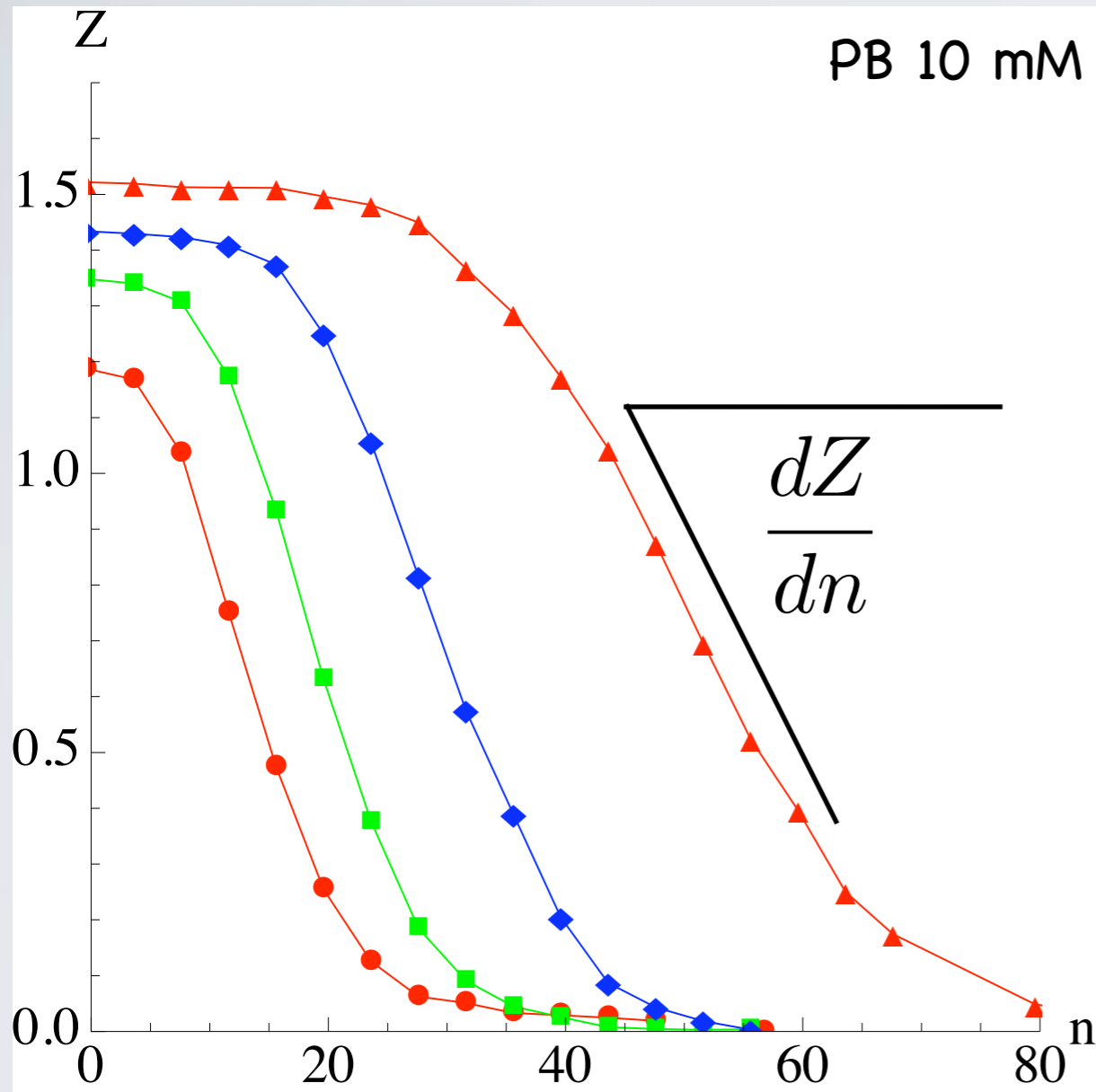
données fournies par G. Charvin

$$\sigma = \frac{n}{n_0}$$

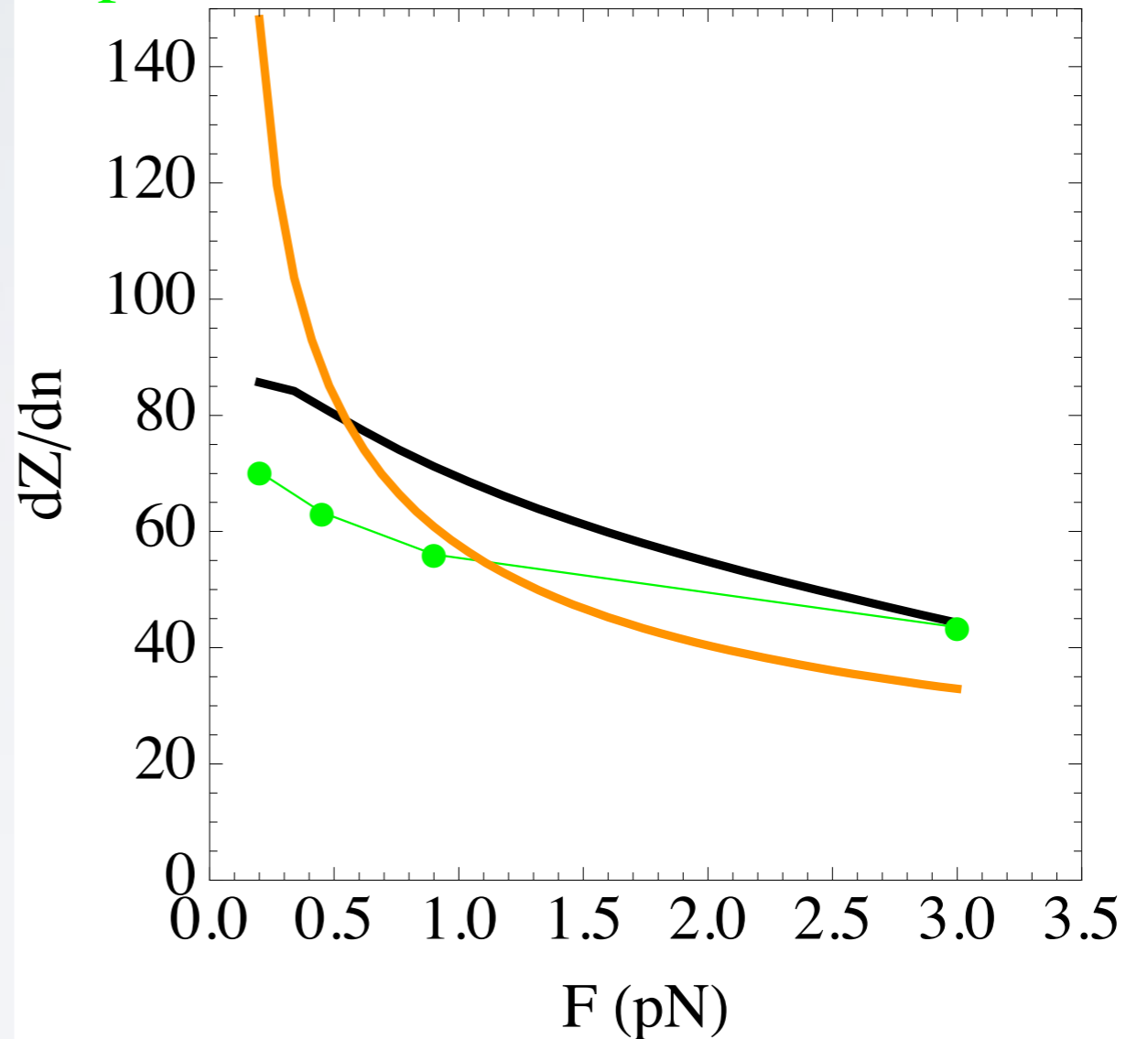
Analytical model for plectonemic DNA



ADN : comparaison expérience-théorie



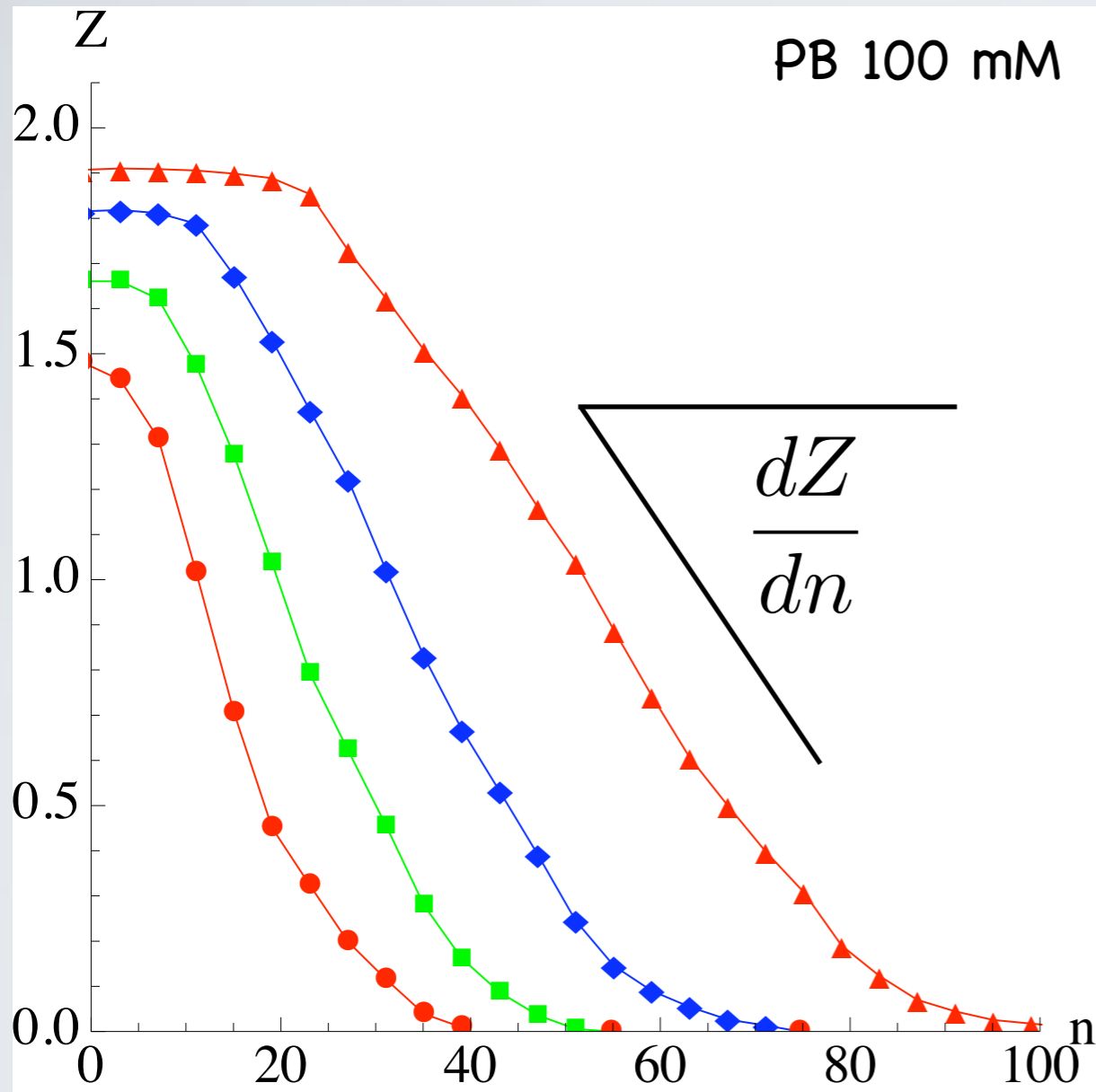
Experimental vs theoretical vs Marko slopes



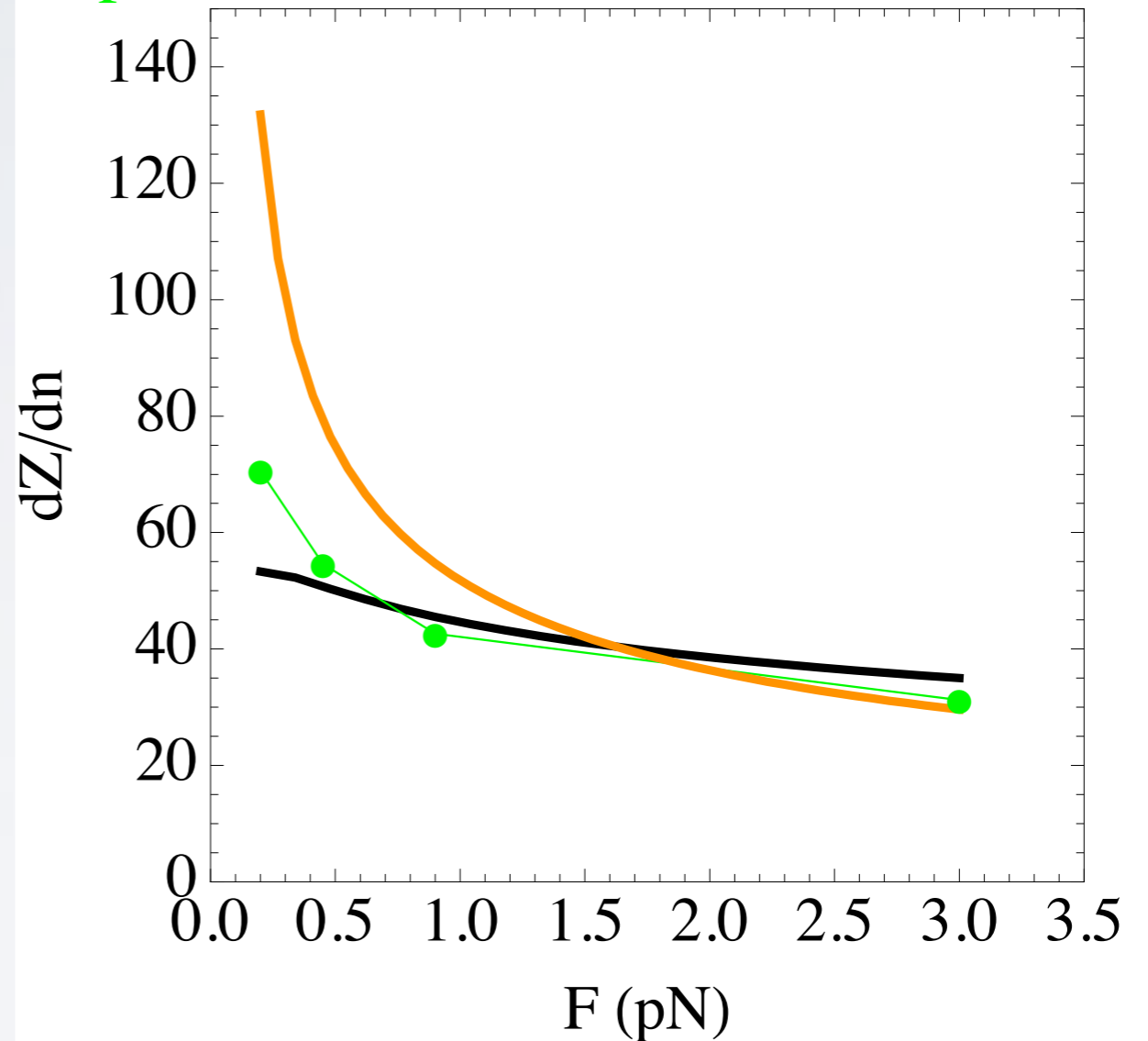
données de Gilles Charvin (ENS-Paris)

J. Marko, Phys. Rev. E. (2007)

ADN : comparaison expérience-théorie



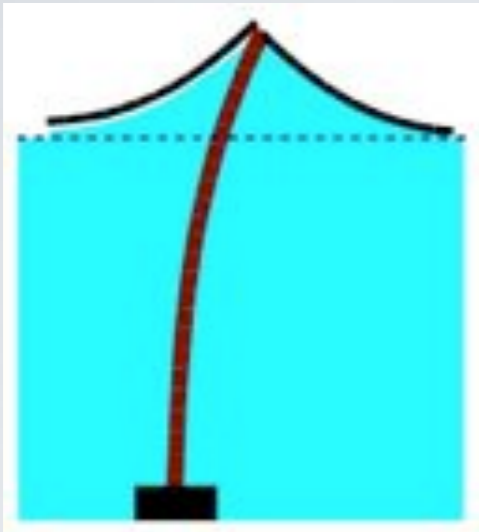
Experimental vs theoretical vs Marko slopes



données de Gilles Charvin (ENS-Paris)

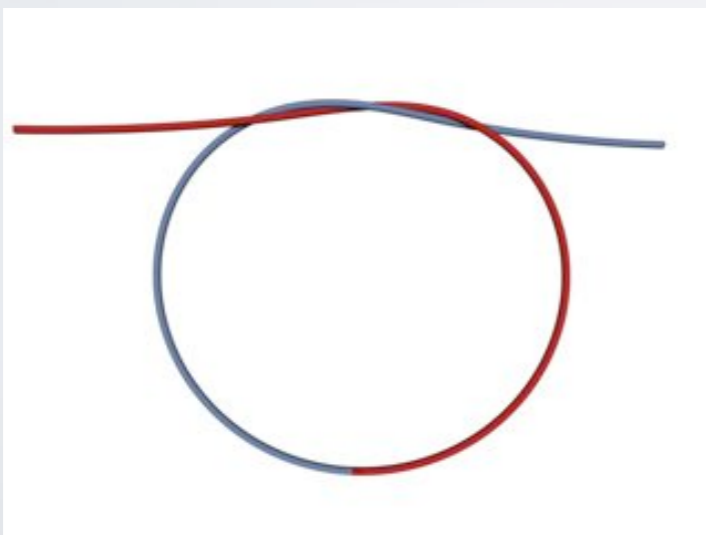
J. Marko, Phys. Rev. E. (2007)

Les tiges dans tous leurs états



Flambage
capillaire

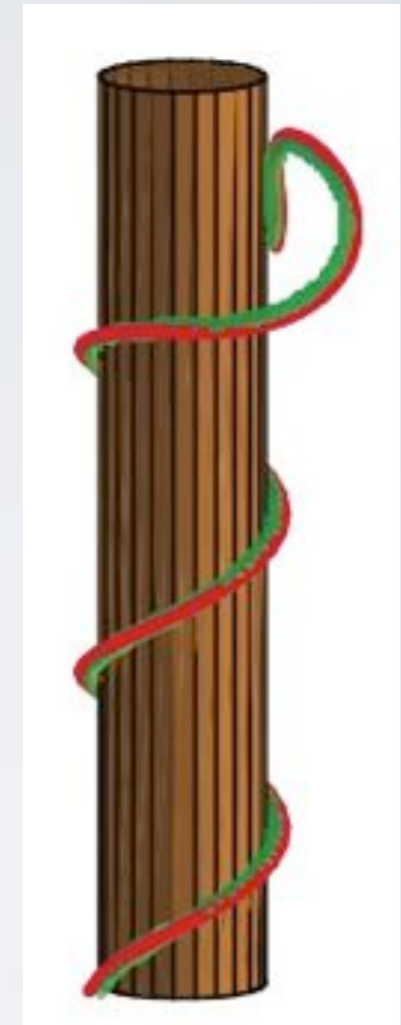
avec J. Bico, B. Roman



Noeud
élastique

avec B. Audoly, N. Clauvelin

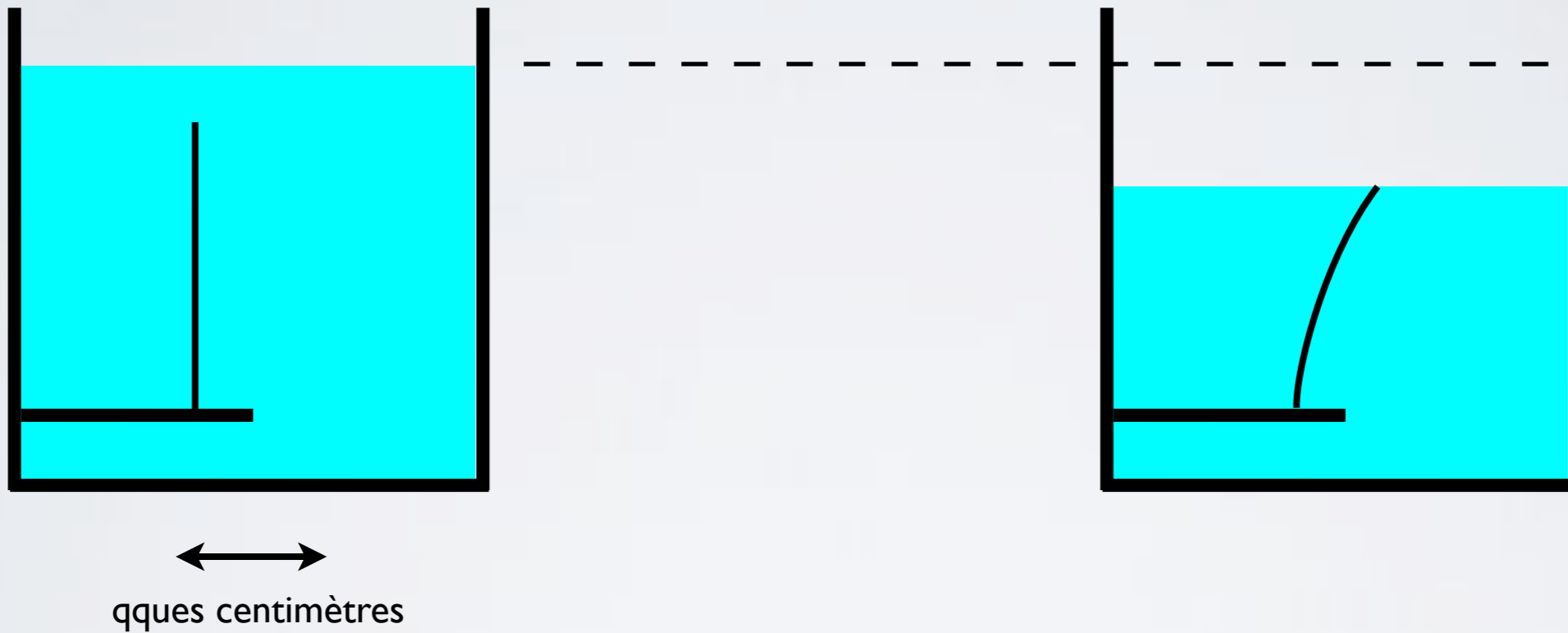
Plante
grimpante



avec A. Goriely

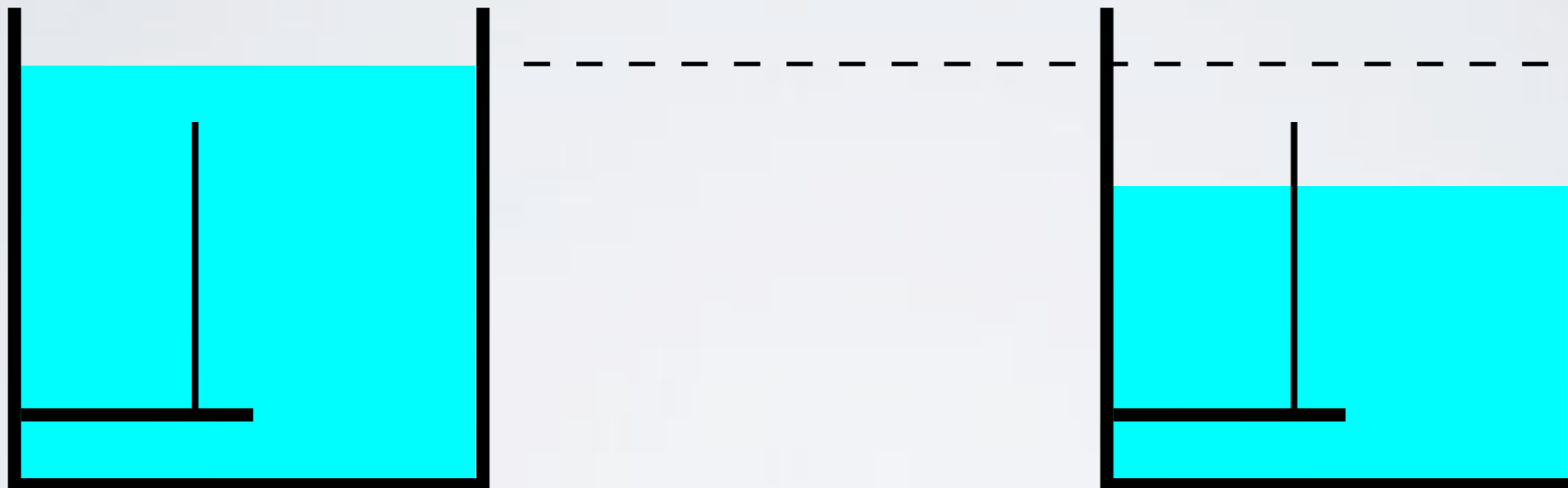
Flambage capillaire

lamelle longue $L > L_b$



Flambage capillaire

lamelle courte $L < L_b$



↔
quelques centimètres

$$L_b \propto \sqrt{\frac{EI}{\gamma w}}$$

Modélisation

- pesanteur
- Archimède
- Laplace

$$N'_x = -P_x$$

$$N'_z = -P_z$$

$$M'_y = N_z \sin \theta - N_x \cos \theta$$

$$X' = \sin \theta$$

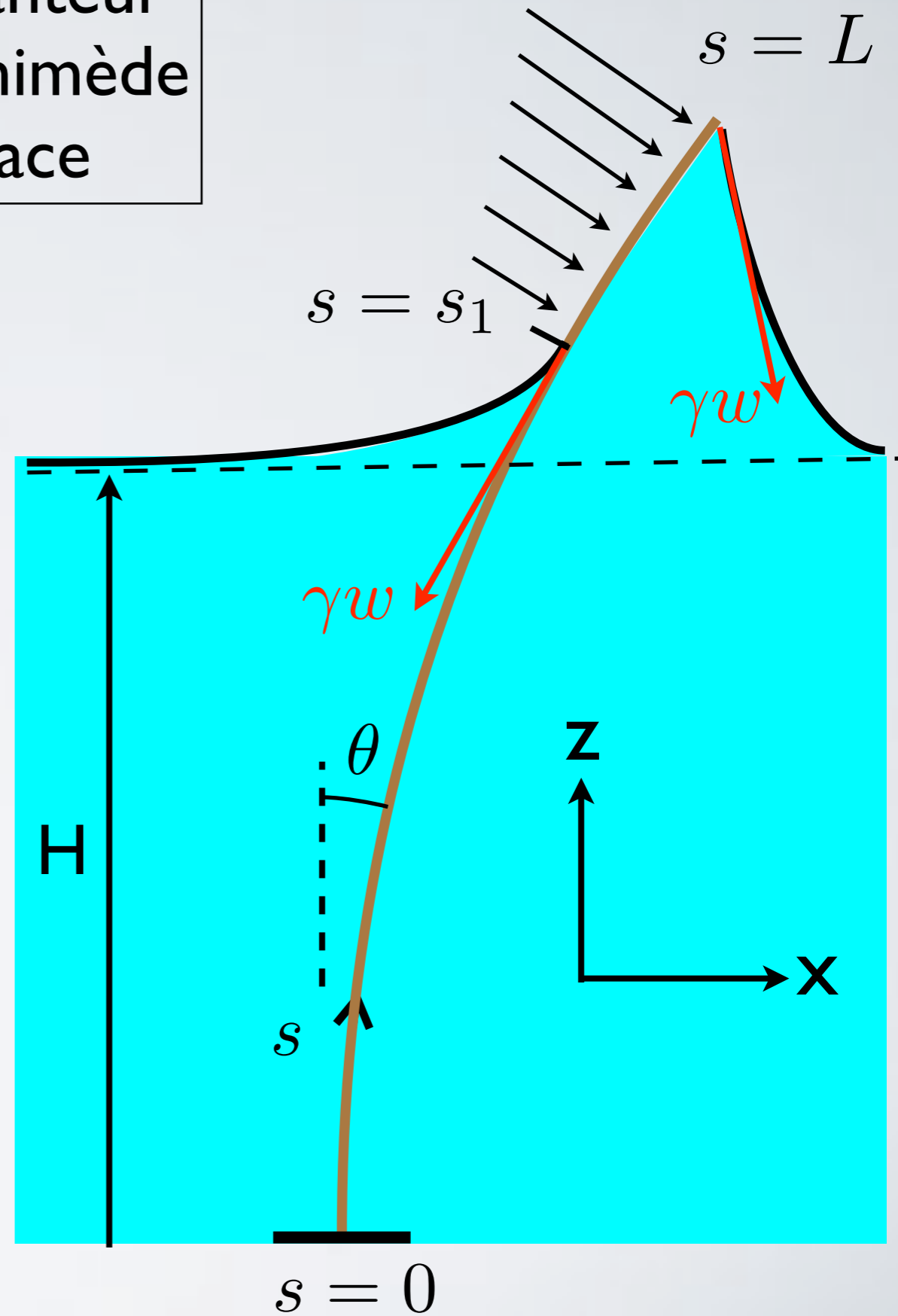
$$Z' = \cos \theta$$

$$\theta' = M_y / (EI)$$

$$' \equiv \frac{d}{ds}$$

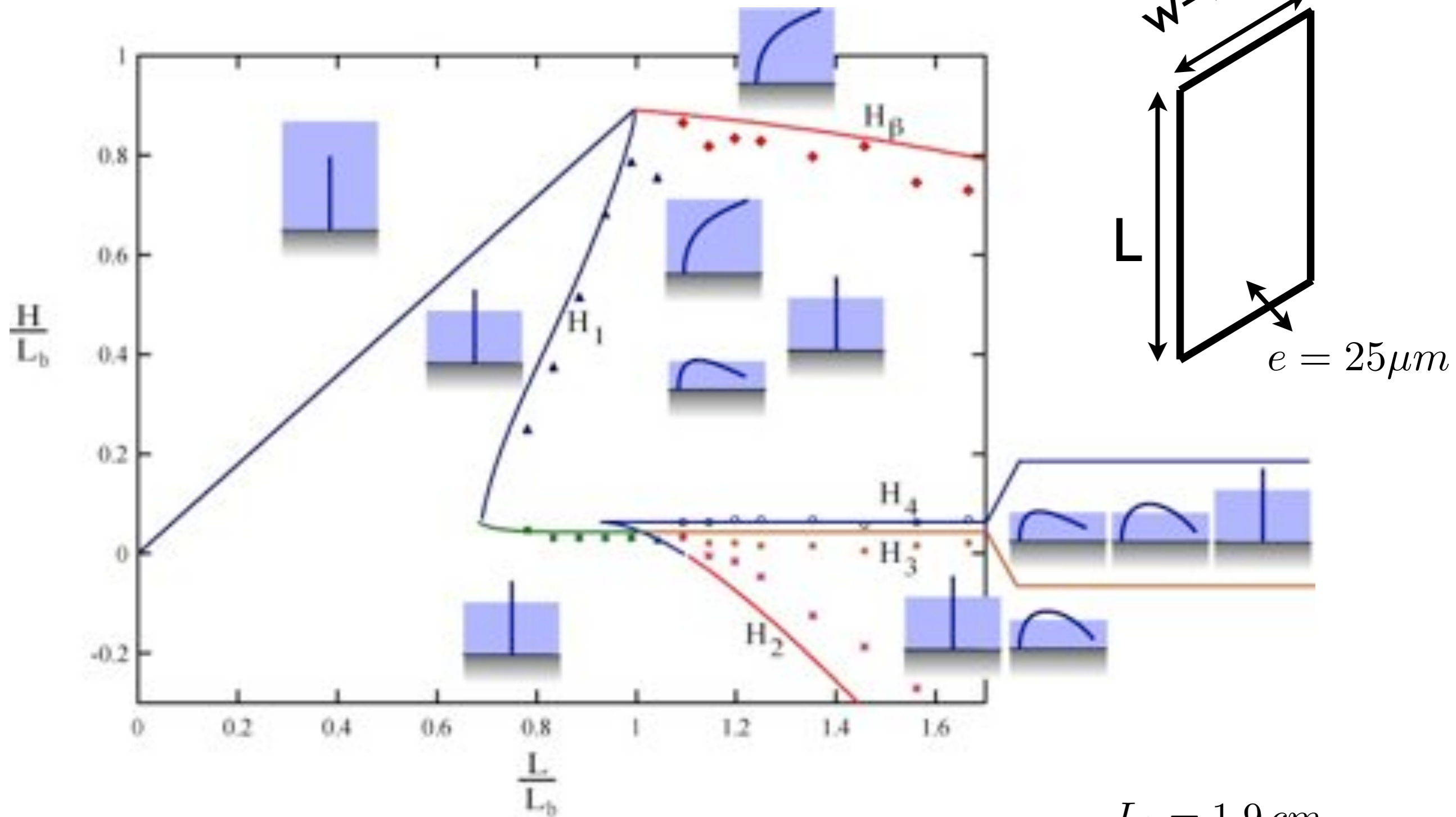
- équations de Kirchhoff
- sauts de force aux ménisques
- conditions aux bords

- suivi de courbes : AUTO 94

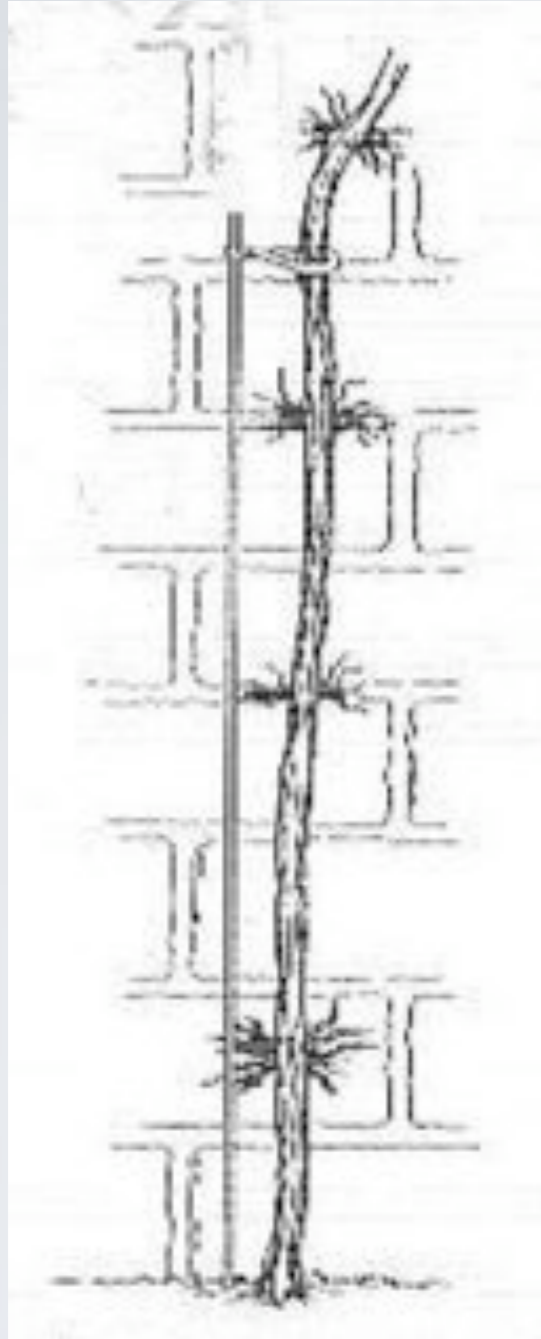


Comparaison théorie/expériences

lamelle polyester



Different kinds of climbing plants



rooter



rooter



hooker



twiner

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The Movements And Habits Of Climbing Plants



Charles Darwin

Copyrighted Material

«Most twining plants are adapted to ascend supports of moderate though of different thicknesses.»



Copyrighted Material

The Movements And Habits Of Climbing Plants



Charles Darwin

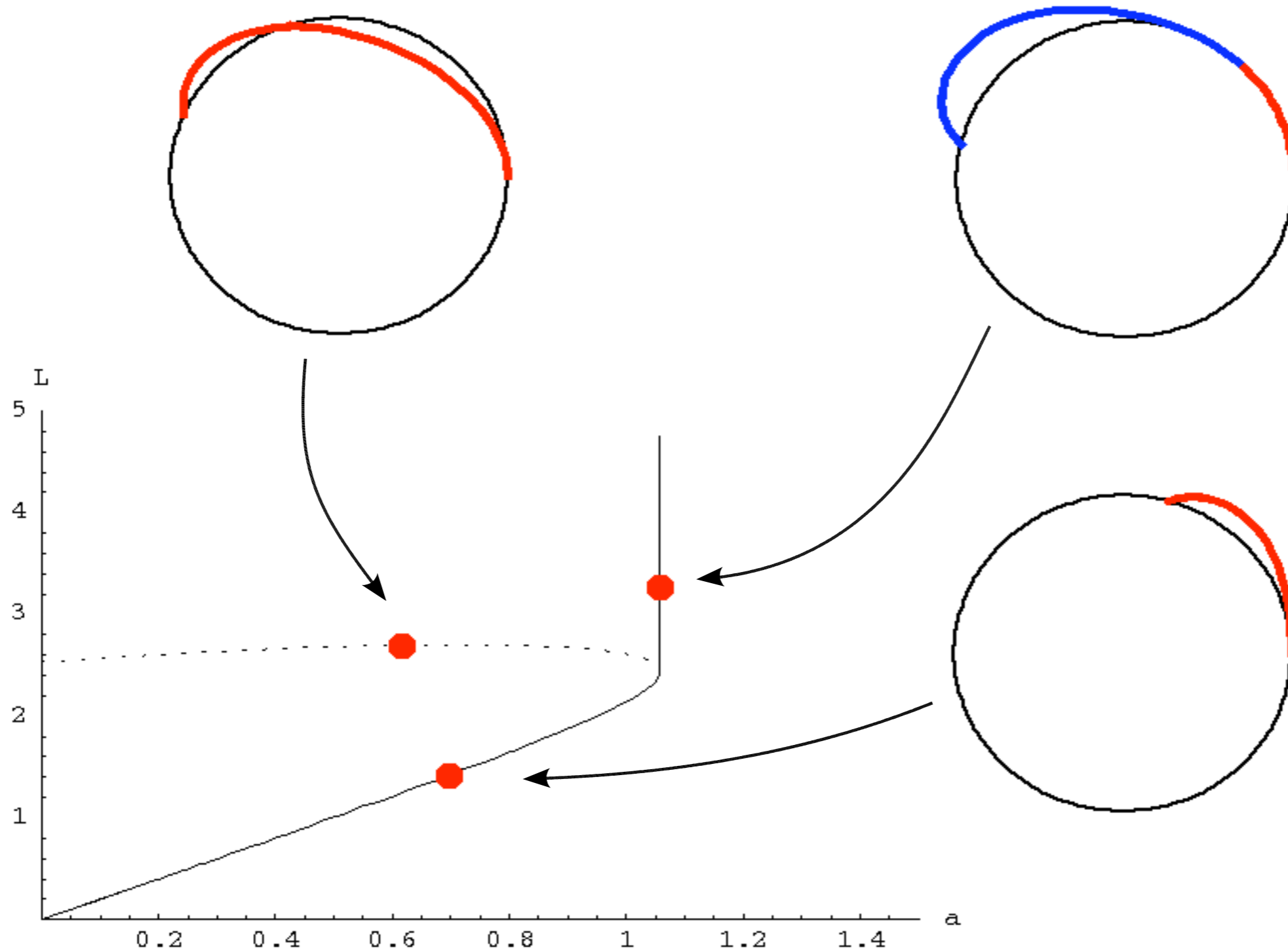
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«By what means certain twining plants are adapted to ascend only thin stems, whilst others can twine round thicker ones, I do not know.»

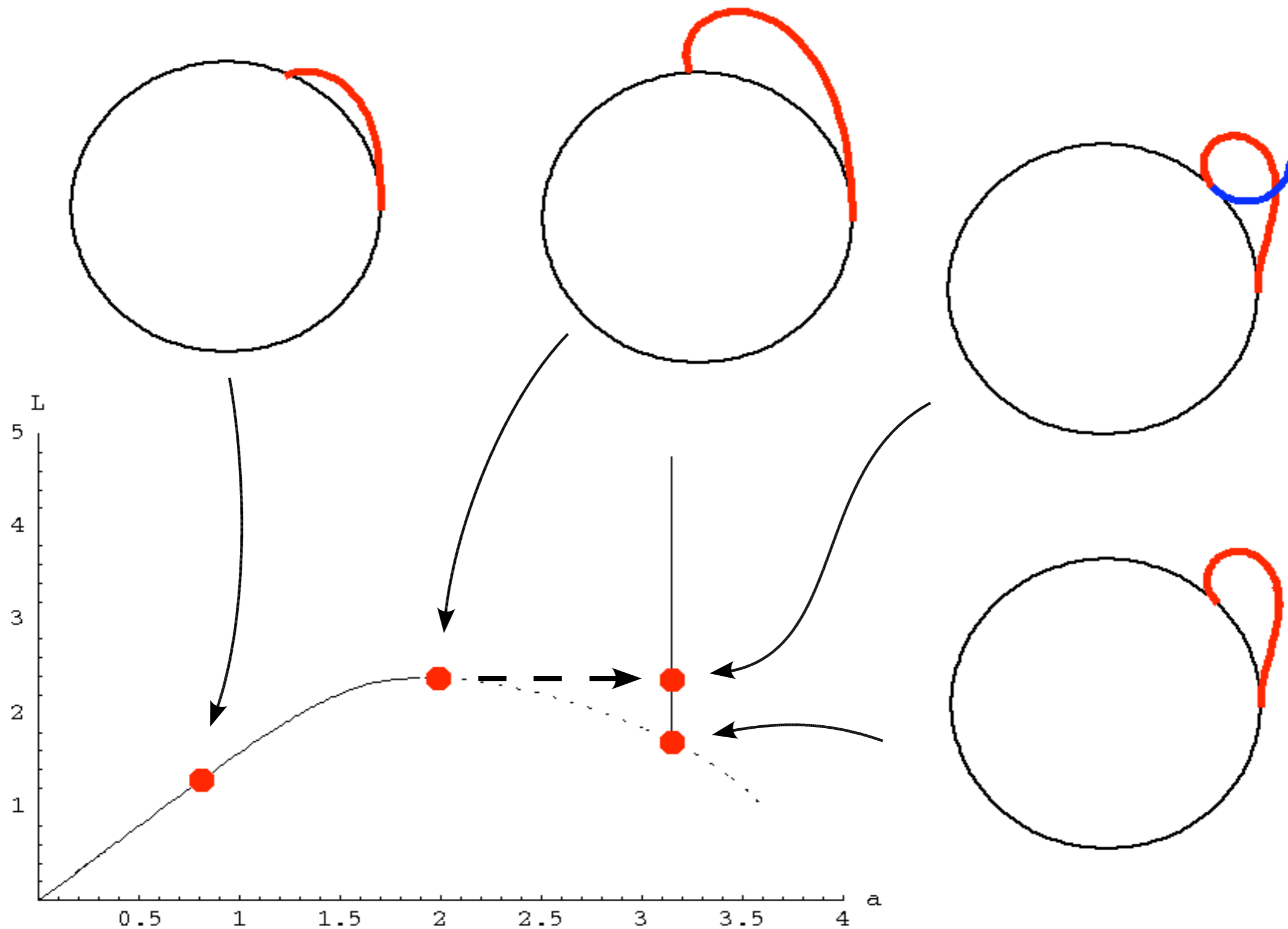


Publisher: Kessinger Publishing (2004)

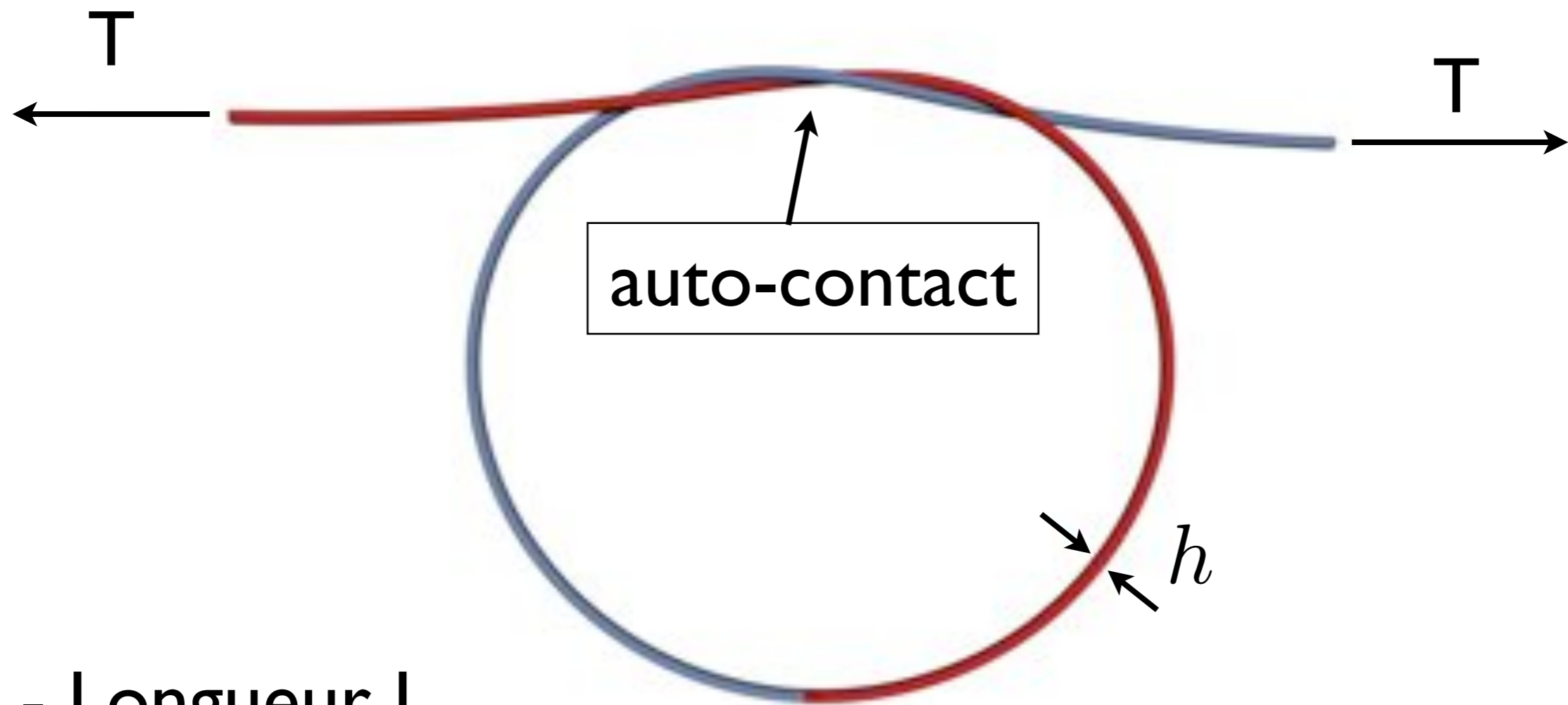
Numerical continuation of solutions : bifurcation diagram $K = R / R_0 = 3$



Numerical continuation of solutions : bifurcation diagram $K = R / R_0 = 3.5$



Noeuds élastiques



- Longueur L
- Section circulaire de rayon h
- Rigidité de flexion : $E I$
- Rigidité de torsion : $G J$

E : module d'Young

G : module de cisaillement

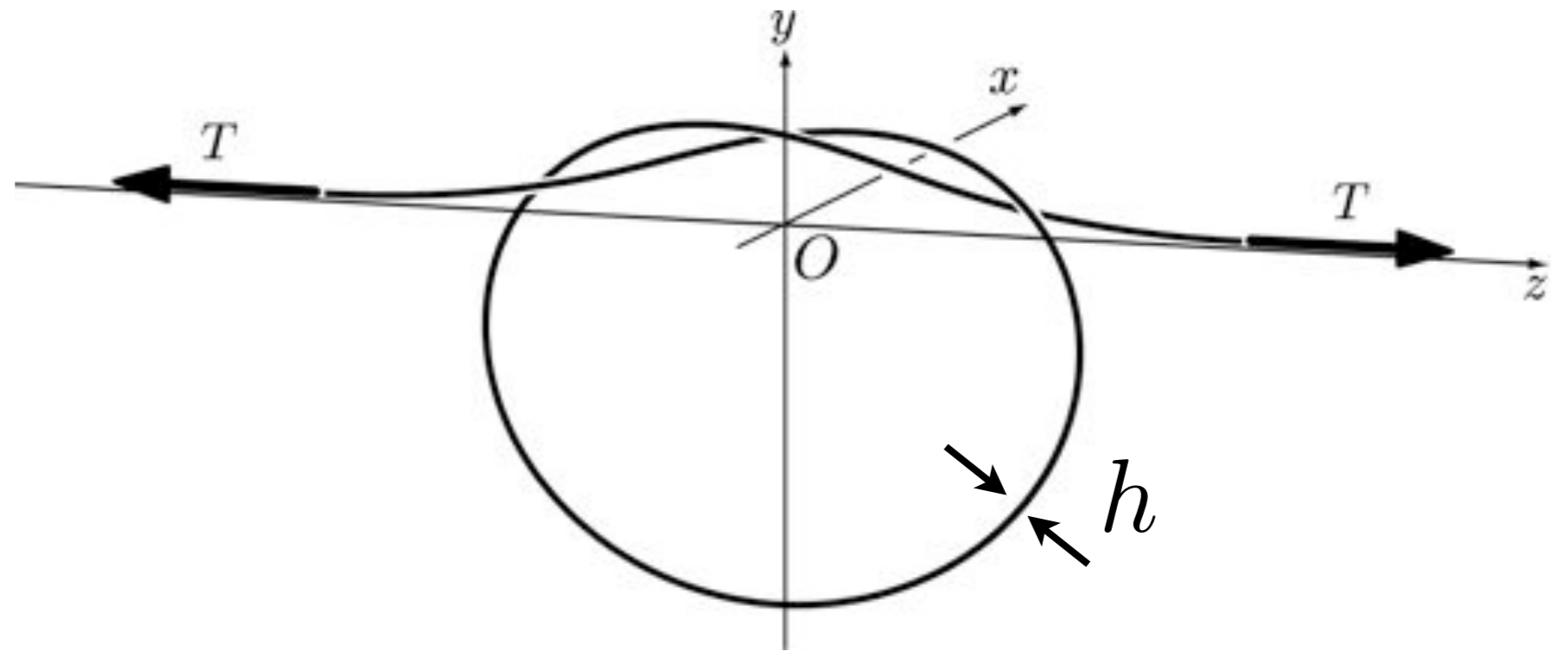
$$I = \frac{\pi h^4}{4}$$

$$J = \frac{\pi h^4}{2}$$

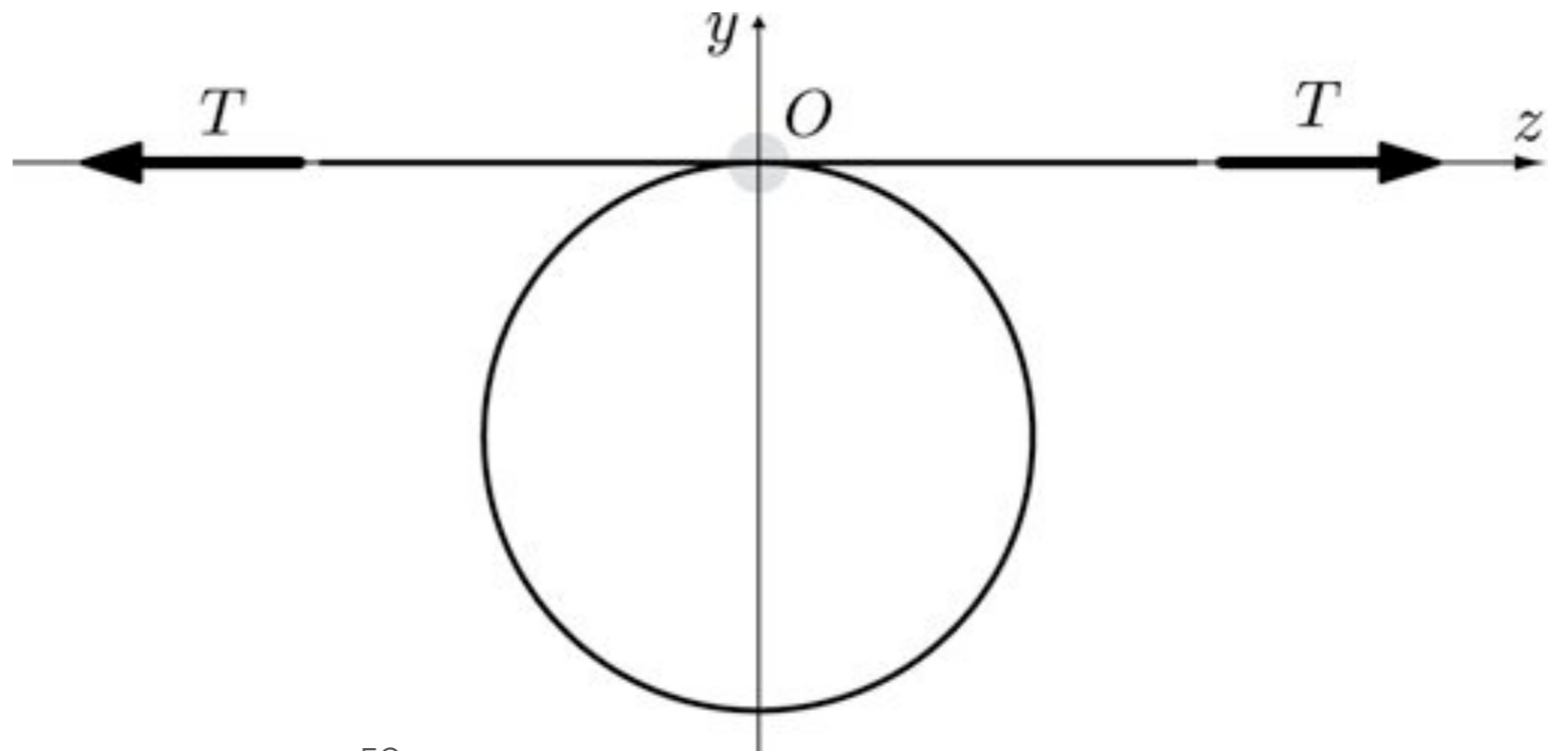
Développement asymptotique

petit paramètre

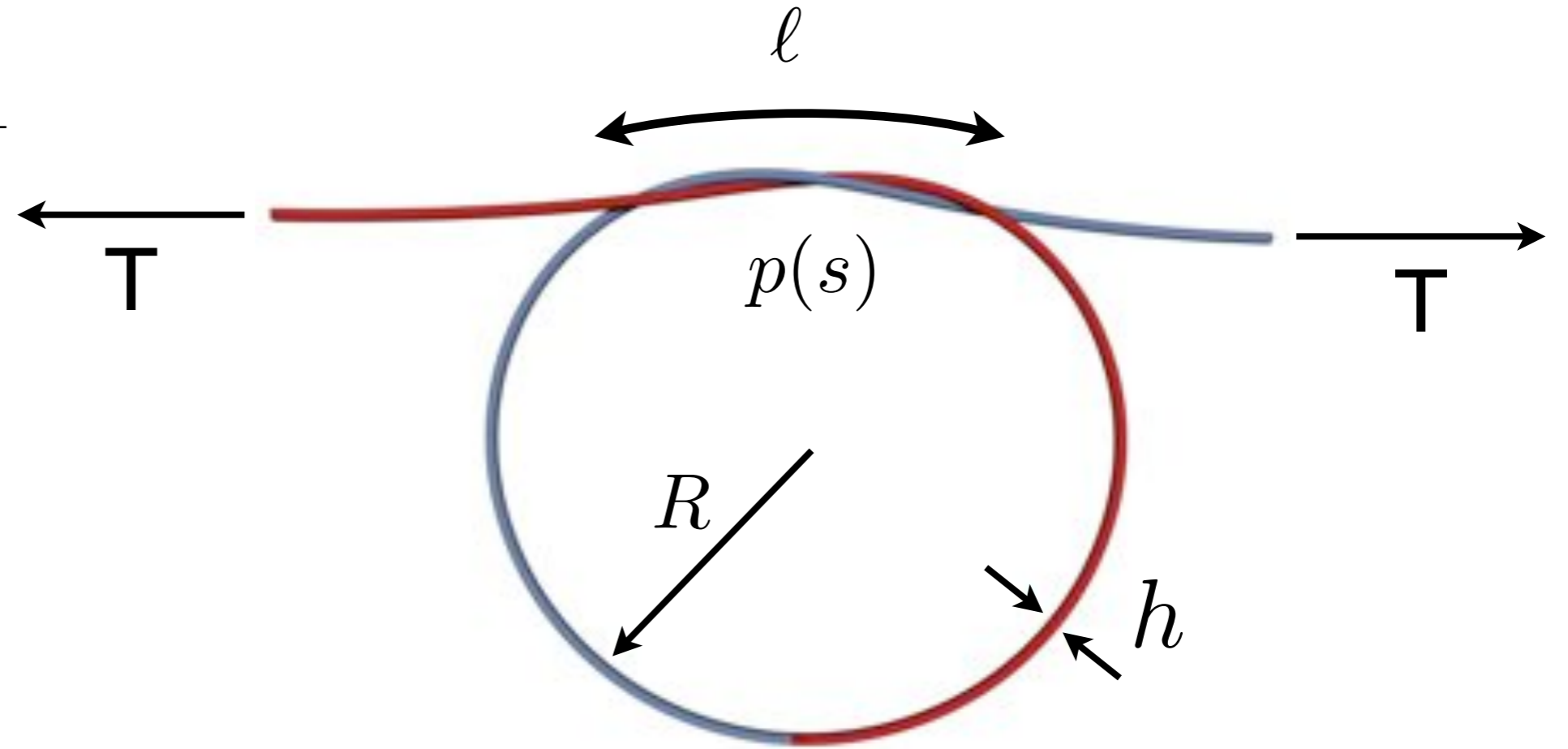
$$\epsilon = \left(\frac{2h^2 T}{EI} \right)^{1/4} \ll 1$$



$$\epsilon = 0$$
$$(h = 0)$$



Résultats



$$R = \sqrt{\frac{EI}{2T}}$$

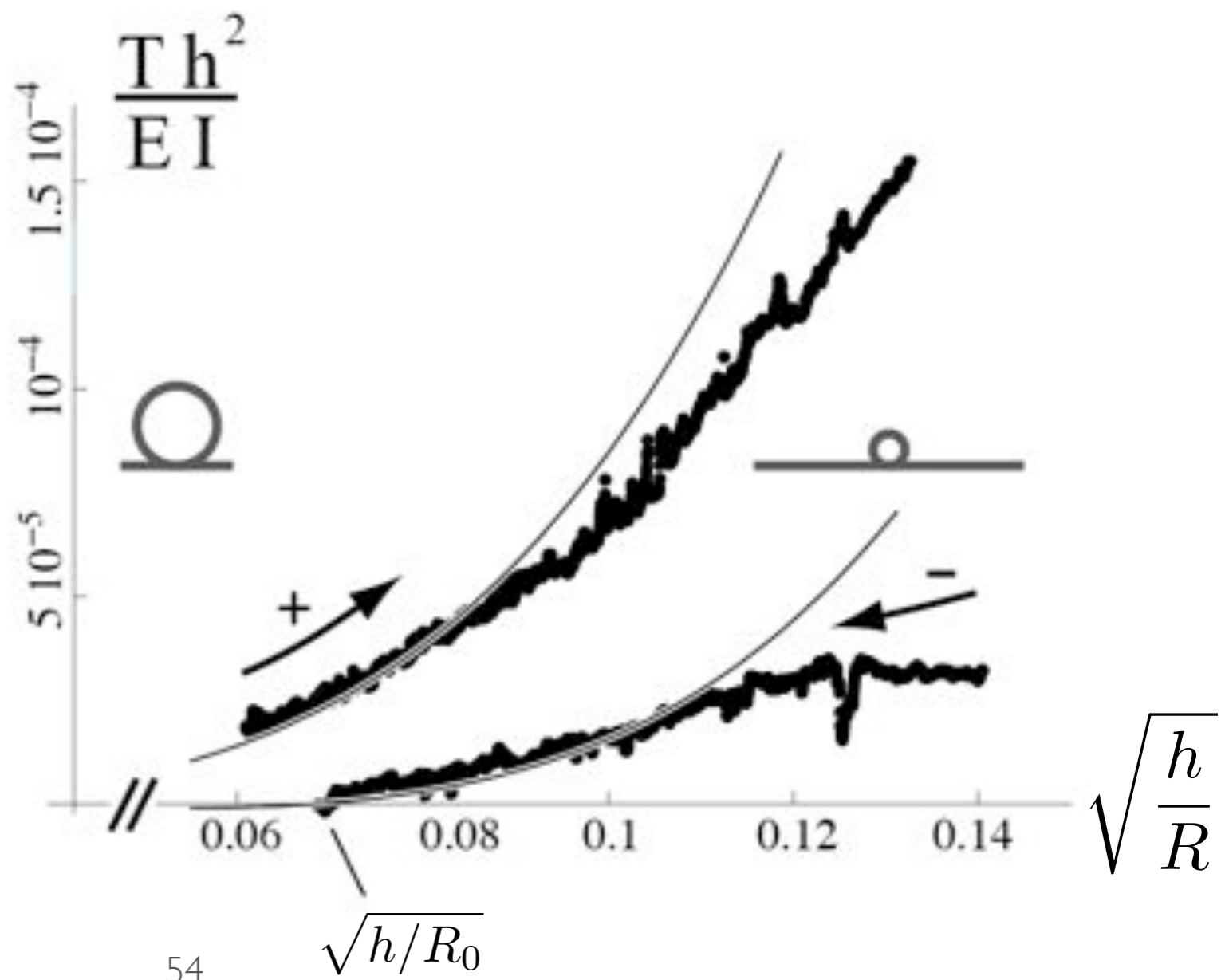
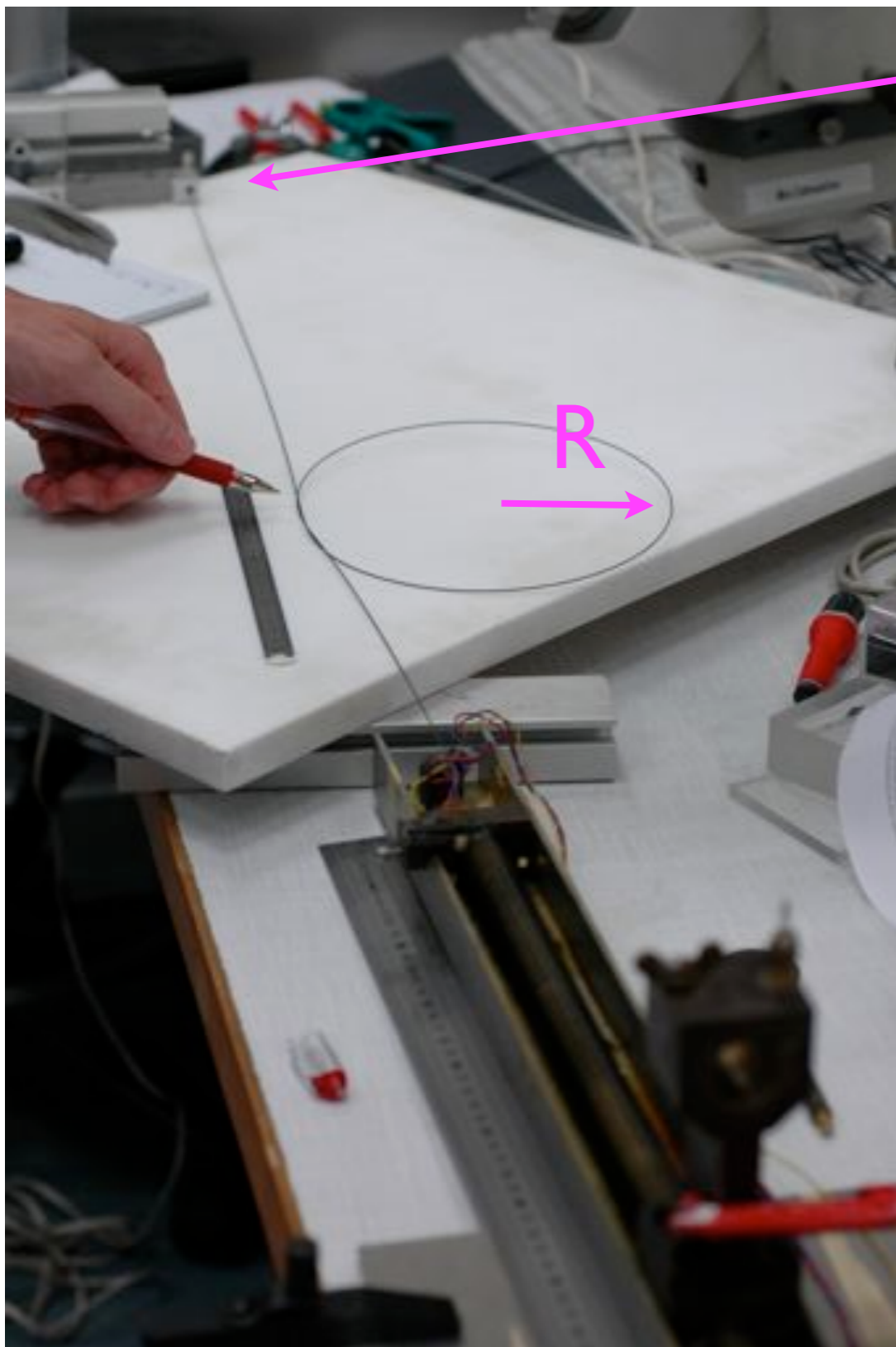
$$l = 7.01 \epsilon \sqrt{\frac{EI}{T}}$$

$$\epsilon = \left(\frac{2h^2 T}{EI} \right)^{1/4}$$

Pression de contact : $p(s)$

Force totale $P = \int_0^l p(s) ds = 0.98 \frac{T}{\epsilon}$

Expériences



Plan

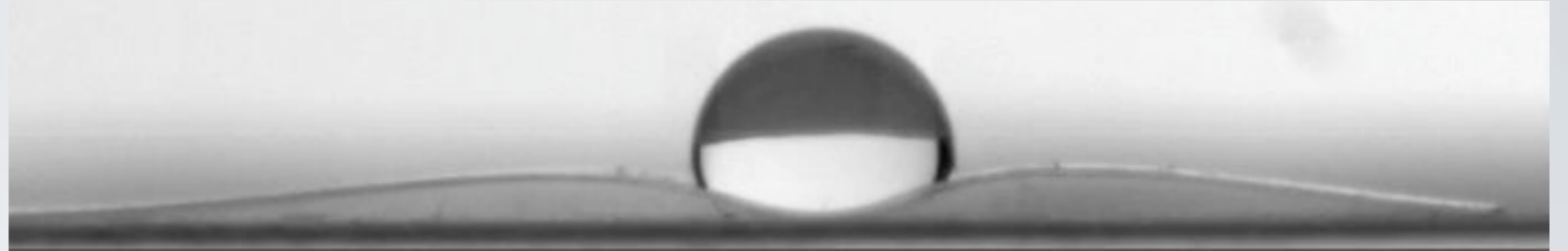
A - CV

B - Quelques études sur les tiges élastiques

→ C - Perspectives

Et maintenant ?

Origami



Vibrations



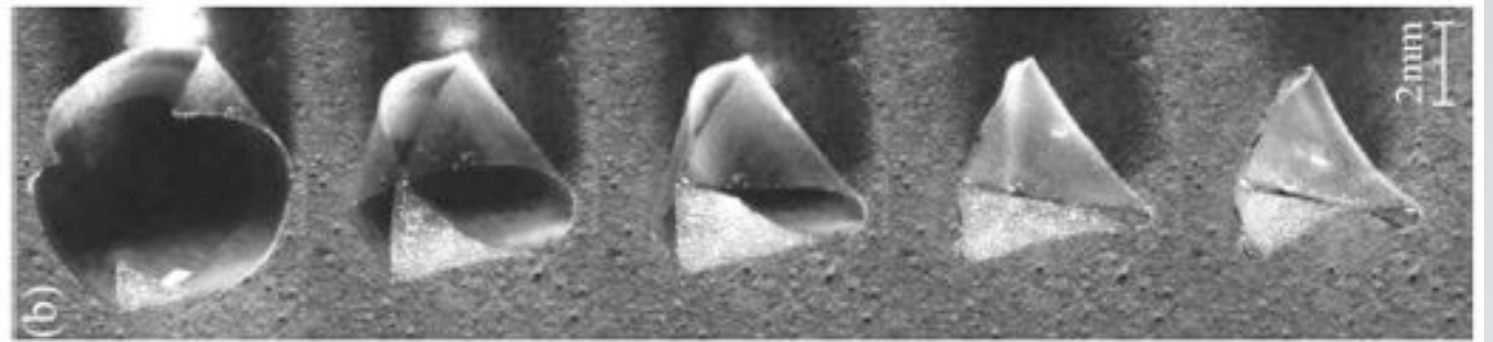
Electrostatique

ADN + protéines

Origami capillaire

statique

Py et al
Capillary origami
Phys. Rev. Lett. 2007

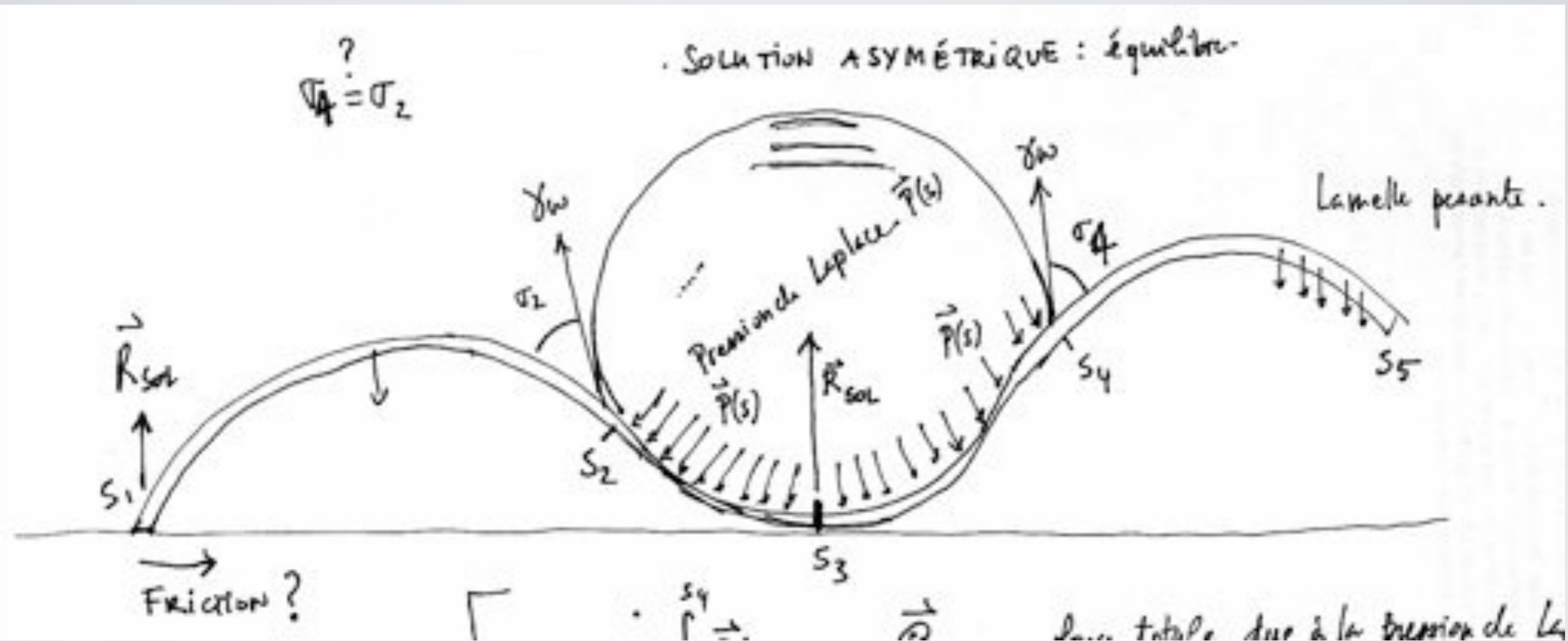


dynamique



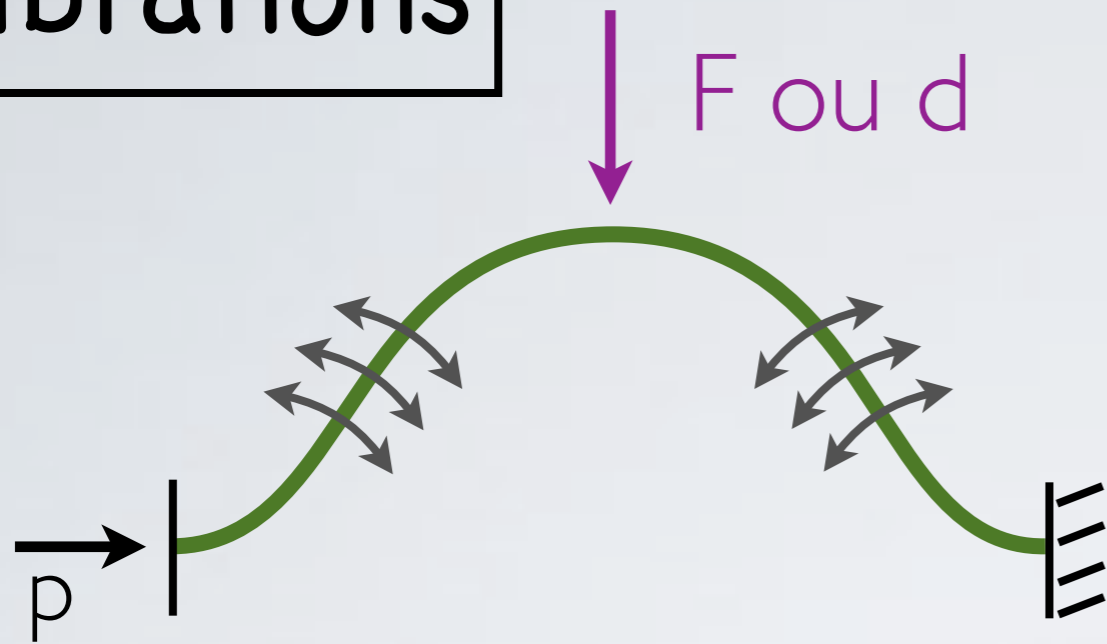
M. Rivetti
A. Antkowiak

Origami : modèle



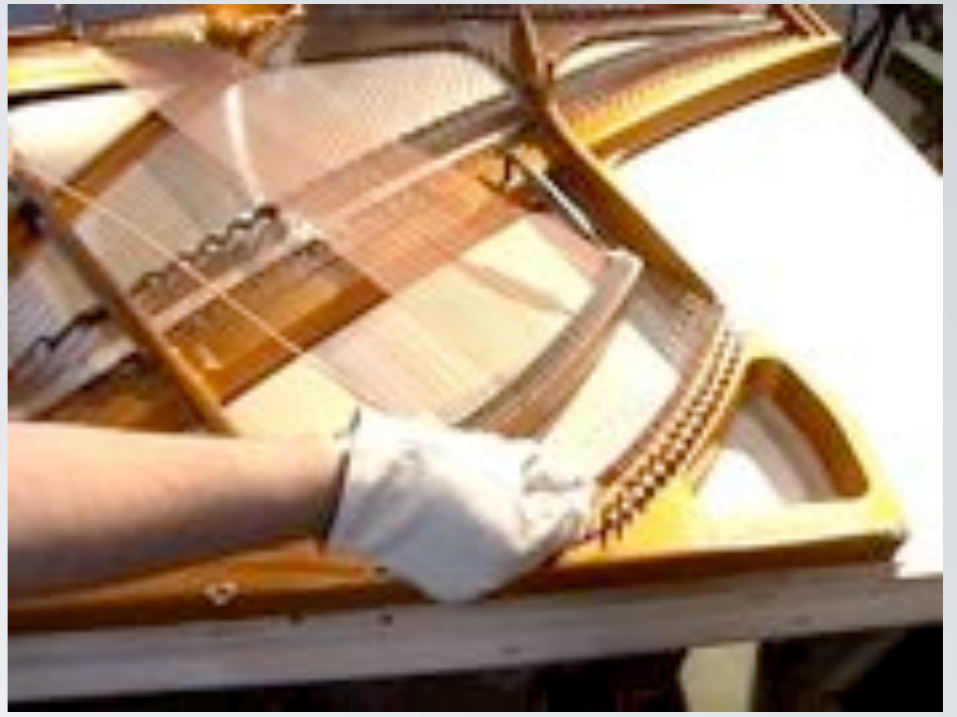
avec C. Josserand

Vibrations

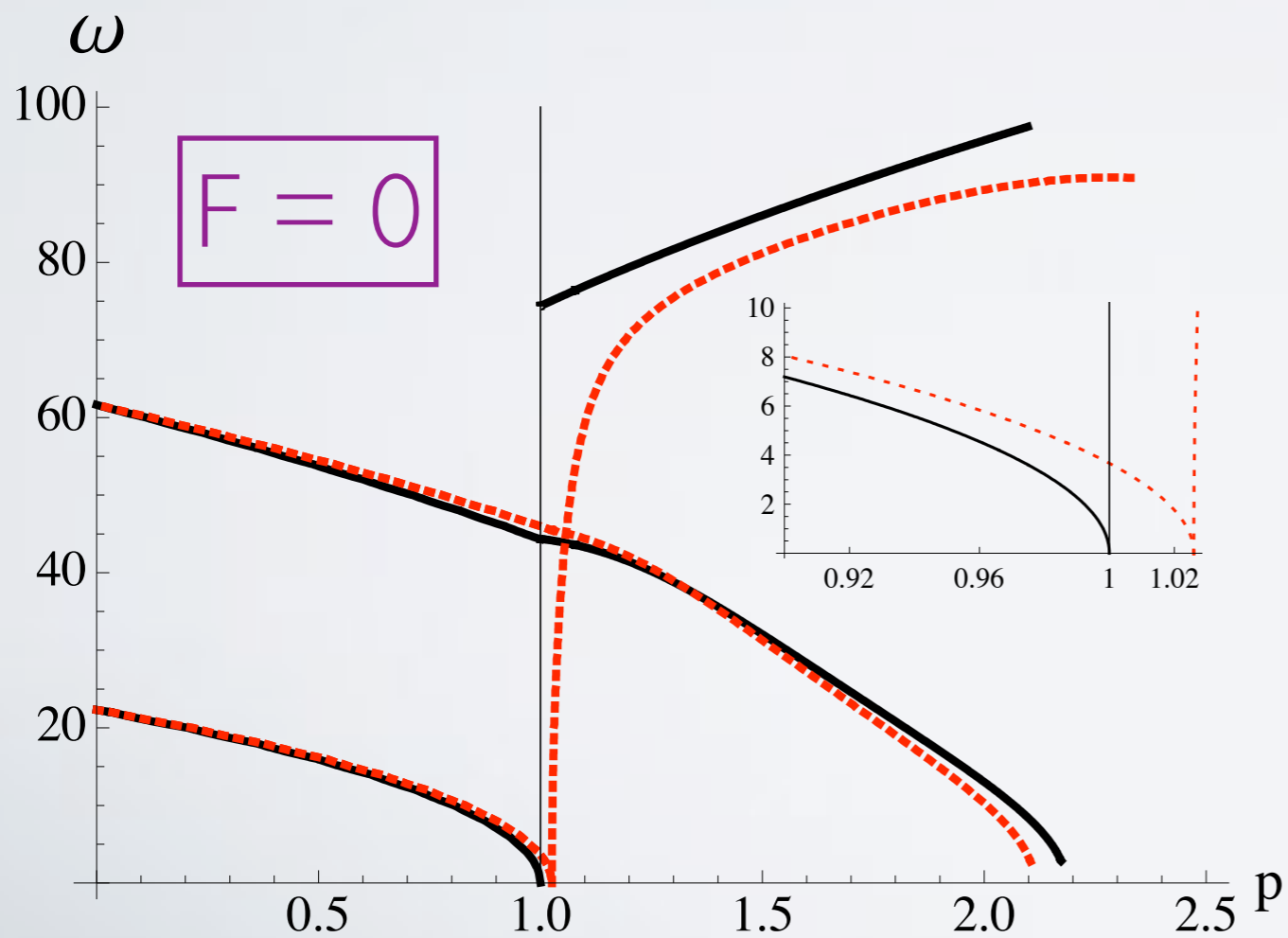


avec J. Frelat, C. Maurini

www.sauter-pianos.de



thèse A. Mamou-Mani



$F > 0$

D'où vient l'enrichissement spectral de la table d'harmonie ?

Force de contact non locale

électrostatique

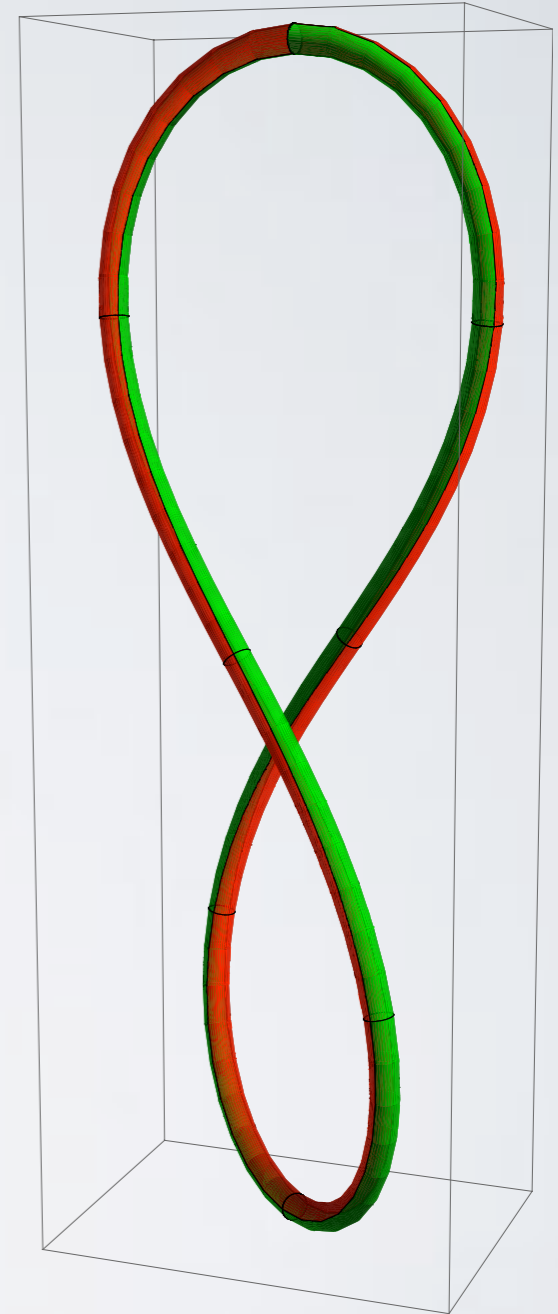


$$\frac{d}{ds}F(s) = -\lambda \int_0^L \phi(R(s) - R(\sigma))d\sigma$$

$$\frac{d}{ds}M(s) = F \times d_3$$

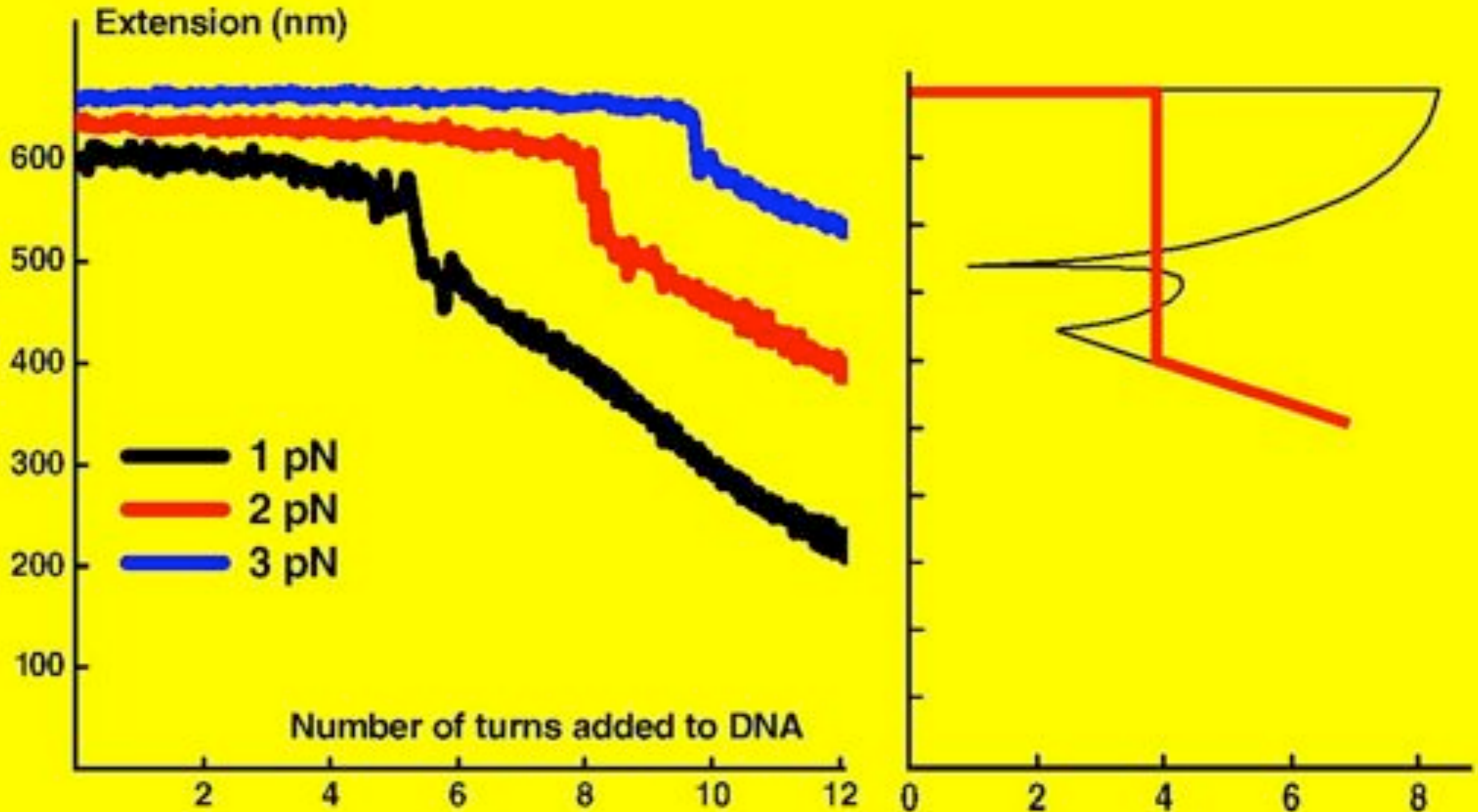
$$\frac{d}{ds}R(s) = d_3$$

$$\frac{d}{ds}d_3(s) = M \times d_3$$



ADN : Saut d'extension lors du flambage

Forth et al «Abrupt Buckling Transition Observed during the Plectoneme Formation of Individual DNA Molecules» PRL 2008



Tout ceci a été fait en collaboration

Audoly B.

Bico J.

Clauvelin N.

Goriely A.

Heijden G. (van der)

Henderson M.

Roman B.

Starostin E.

Thompson J.M.T.

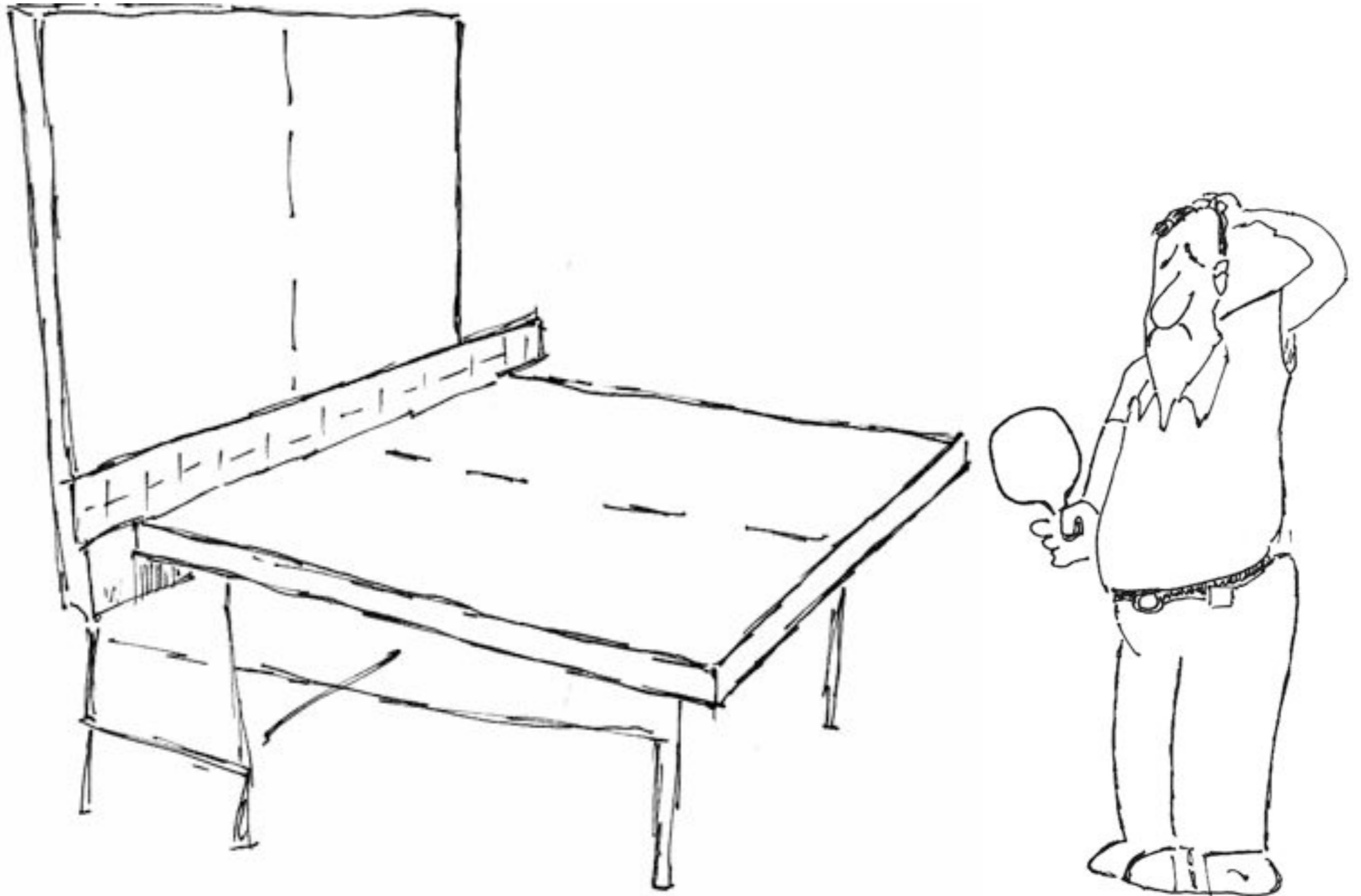
Antkowiak A.

Frelat J.

Josserand C.

Maurini C.

La recherche tout seul



La recherche en équipe

