

Du papier froissé au papier déchiré

B.Roman

J.Bico

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E.Hamm

F.Melo

USACH

Santiago Chile

B.Audoly

IJLRd'A

Paris

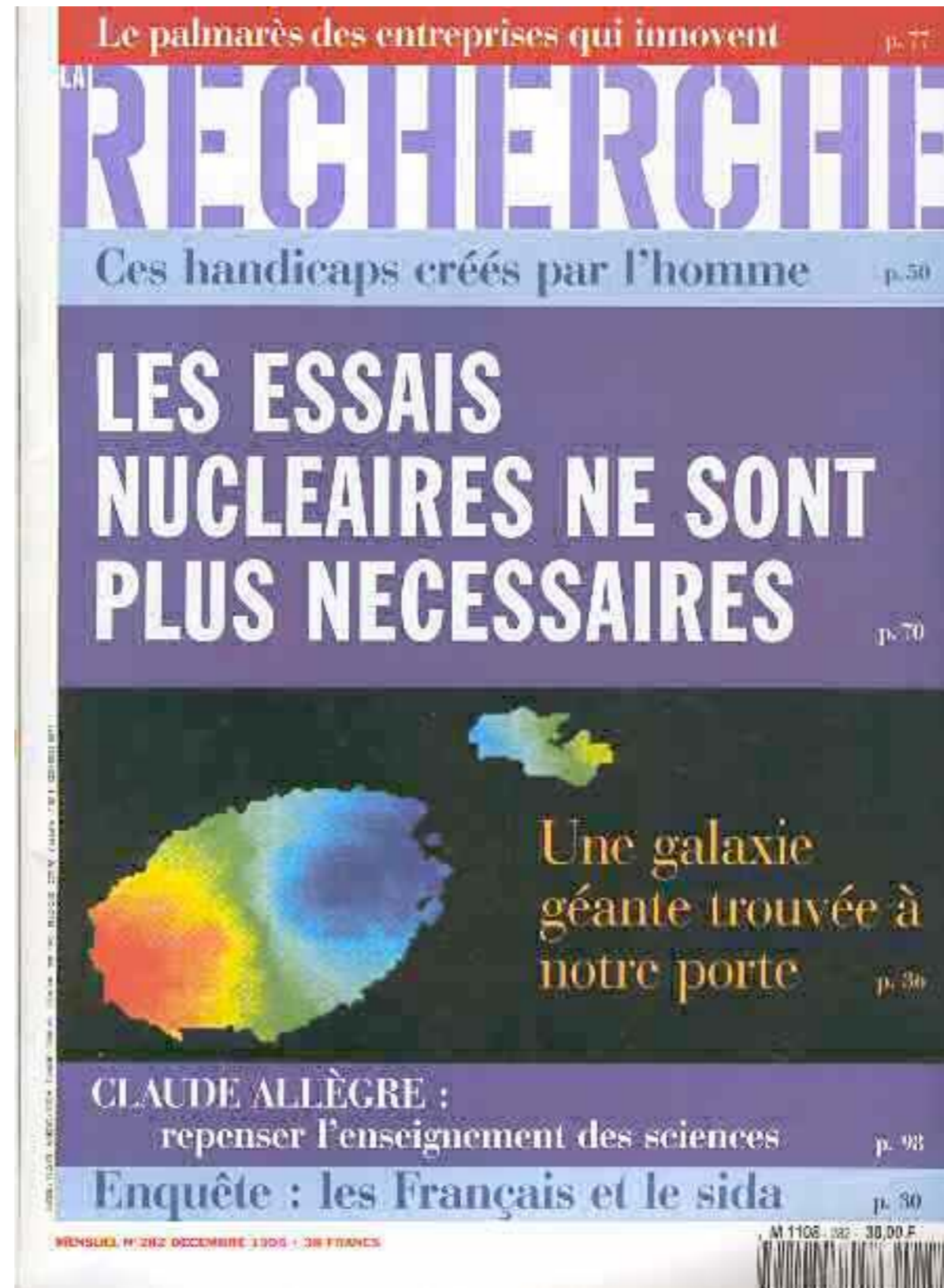
A. Takei

J.Marthelot

V.Romero

J-F. Fuentealba

A. Ibarra



décembre 1995

ANATOMIE

Martine Ben Amar et Yves Pomeau

DU PAPIER FROISSÉ

Hooke, Laplace, Gauss et l'ordinateur au chevet d'un problème banal



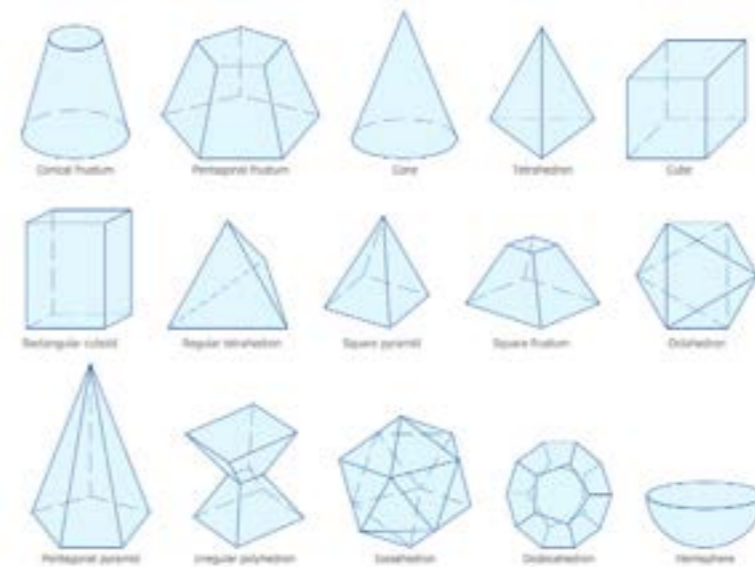
qu'y a-t-il à voir?



élasticité

+

géométrie





élasticité

+

géométrie



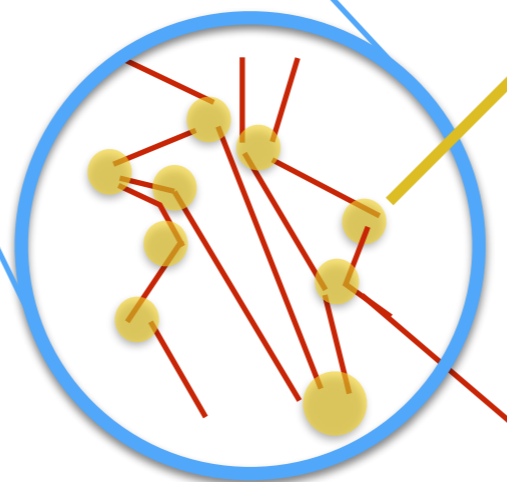
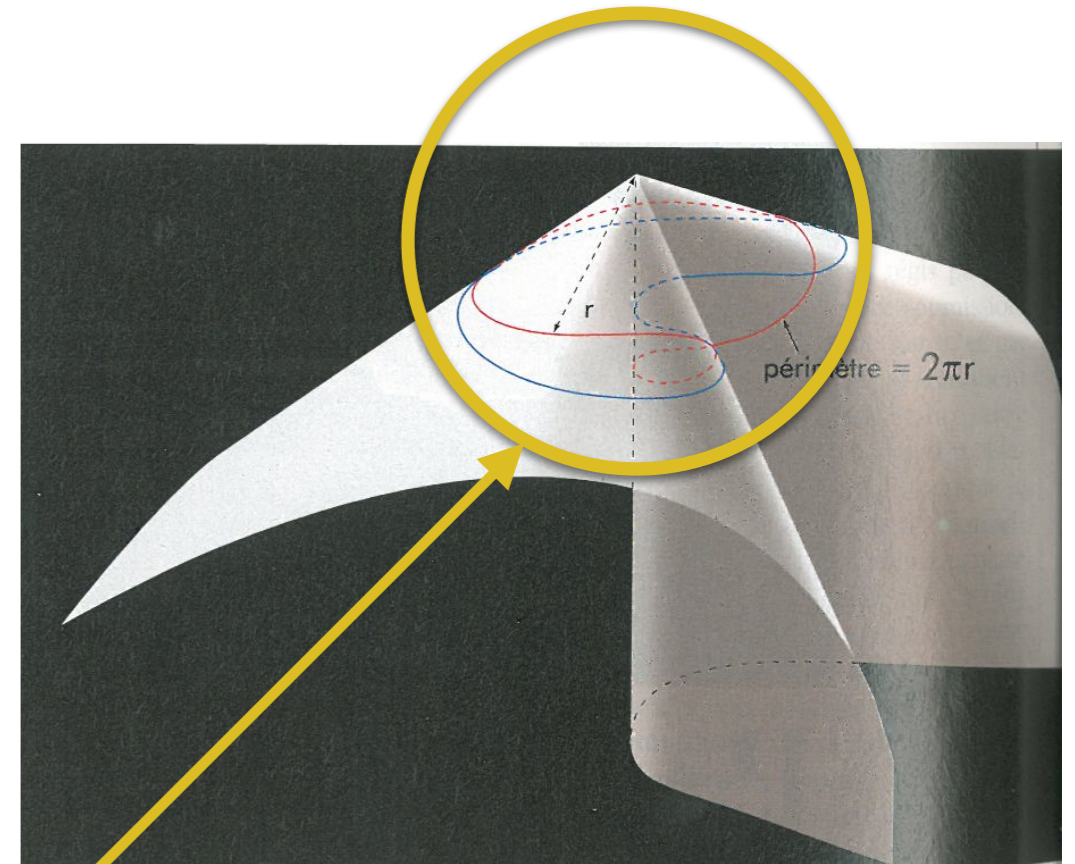
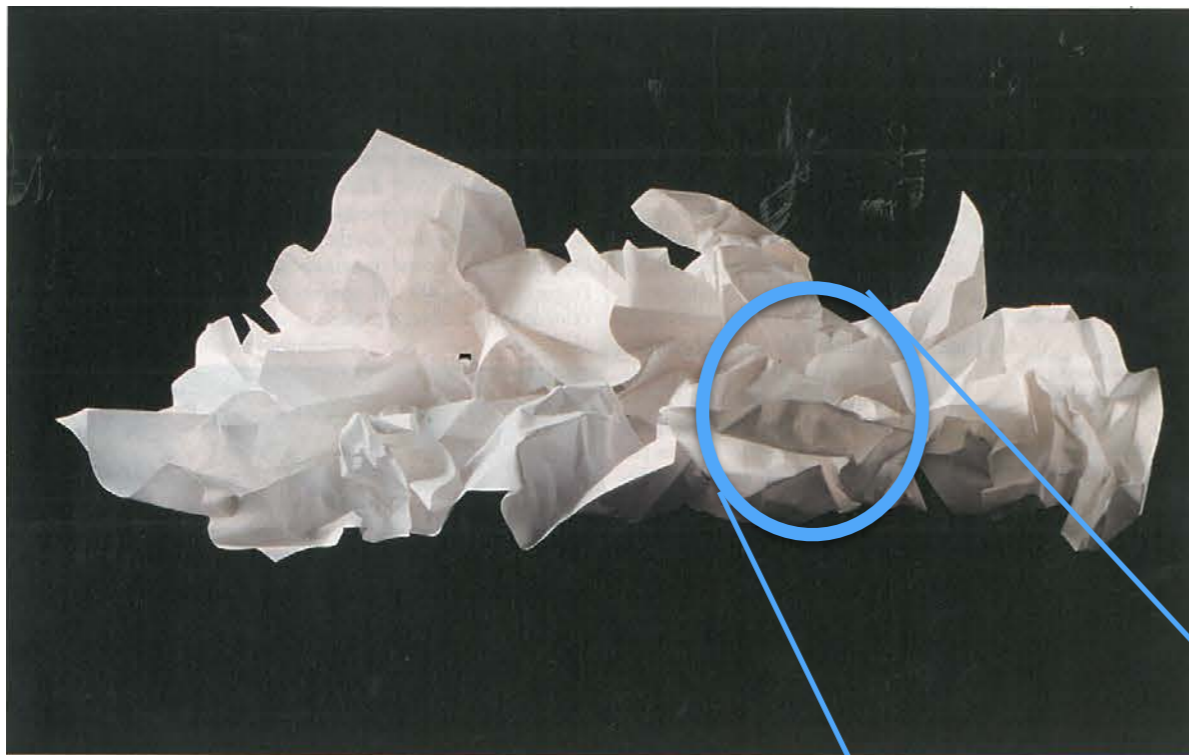
quasi-inextensible
(développable)

ANATOMIE

Martine Ben Amar et Yves Pomeau

DU PAPIER FROISSÉ

Hooke, Laplace, Gauss et l'ordinateur au chevet d'un problème banal



« d-cône »

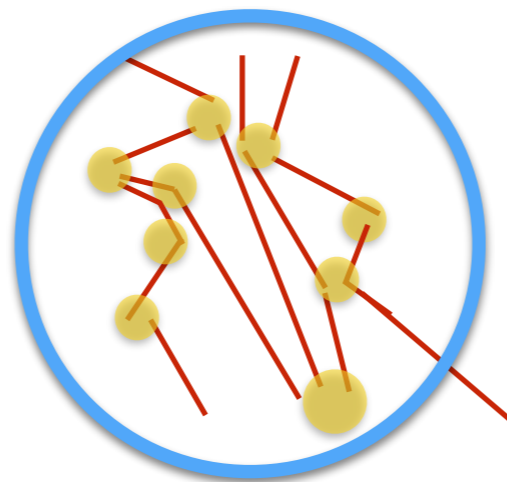
une structure
objets singuliers
géométrie + élasticité.



L de Vinci, Vierge à l'Enfant avec sainte Anne, 1501-1519

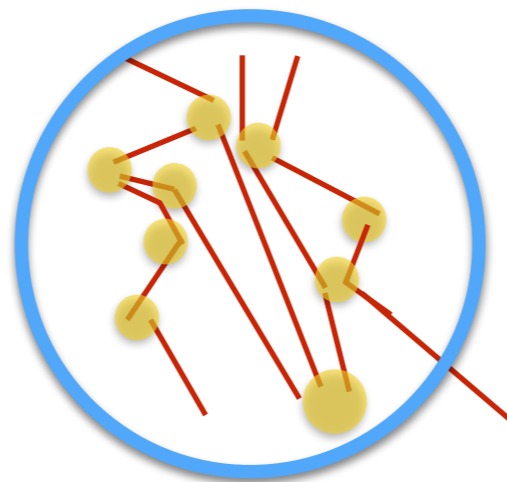


L de Vinci, Etude



- gravité ?
- tension ?
- cisaillement ?

des précurseurs
de cette vision abstraite?





Martin Schongauer,
(1450 - 1491)

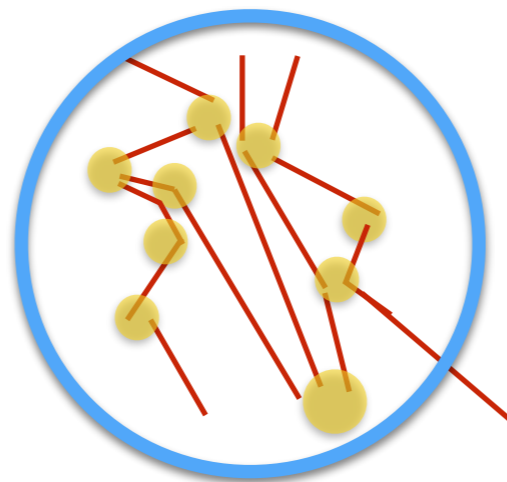
papier
froissé
abstrait?



Martin Schongauer,
(1450 - 1491)

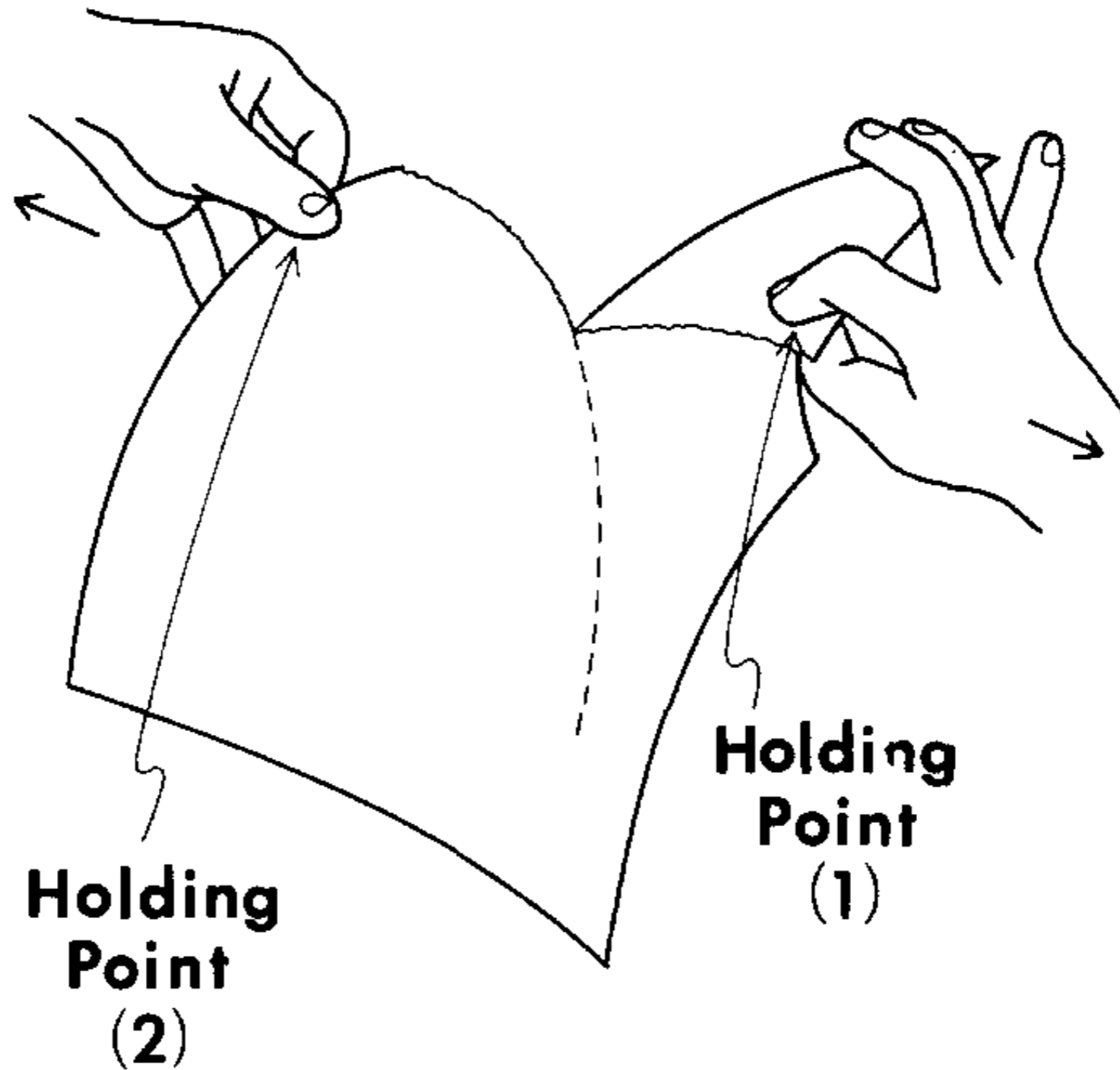
des précurseurs
de cette vision abstraite?

primitifs flamands



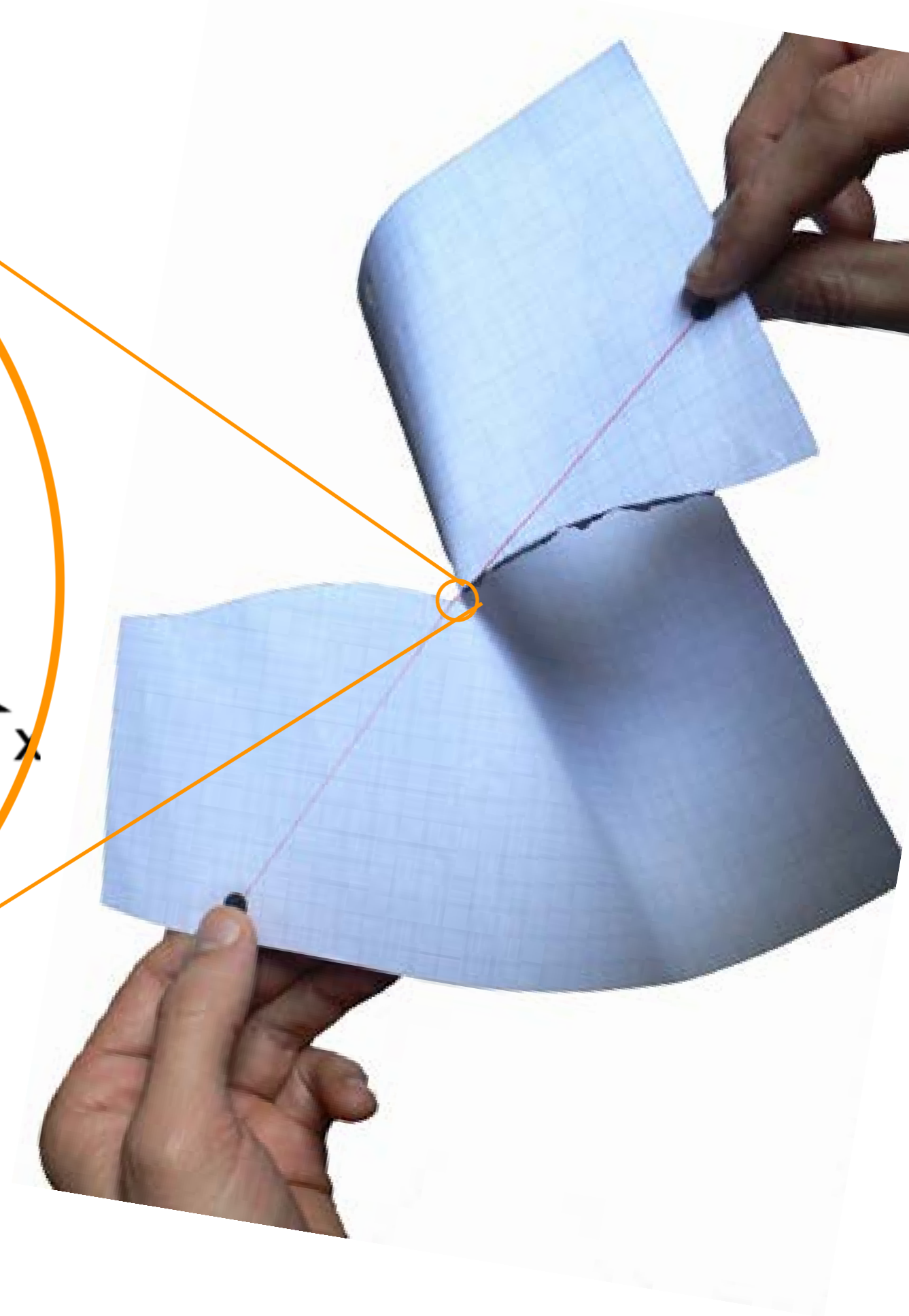
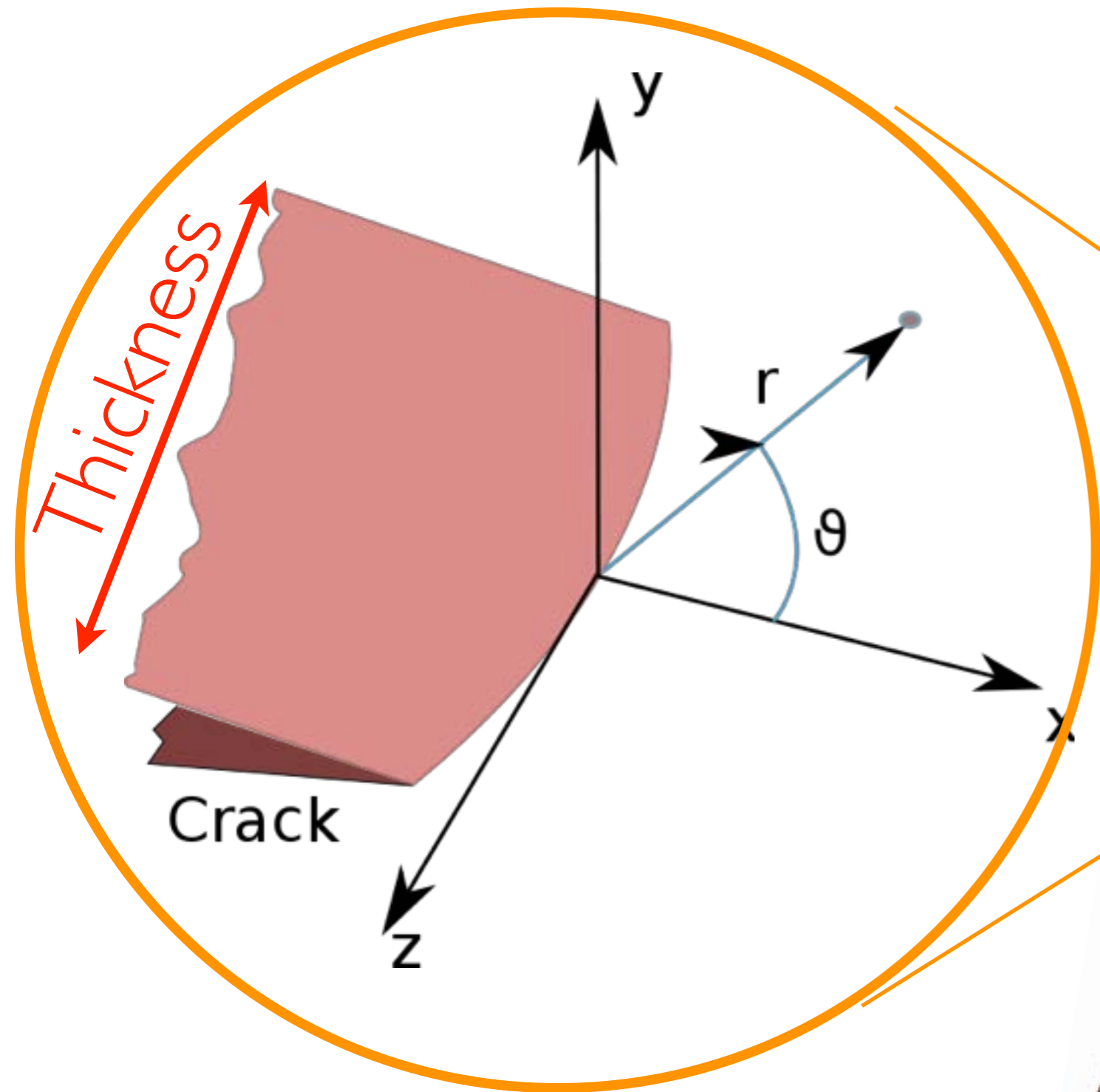
Du papier froissé au papier déchiré

Tearing problem

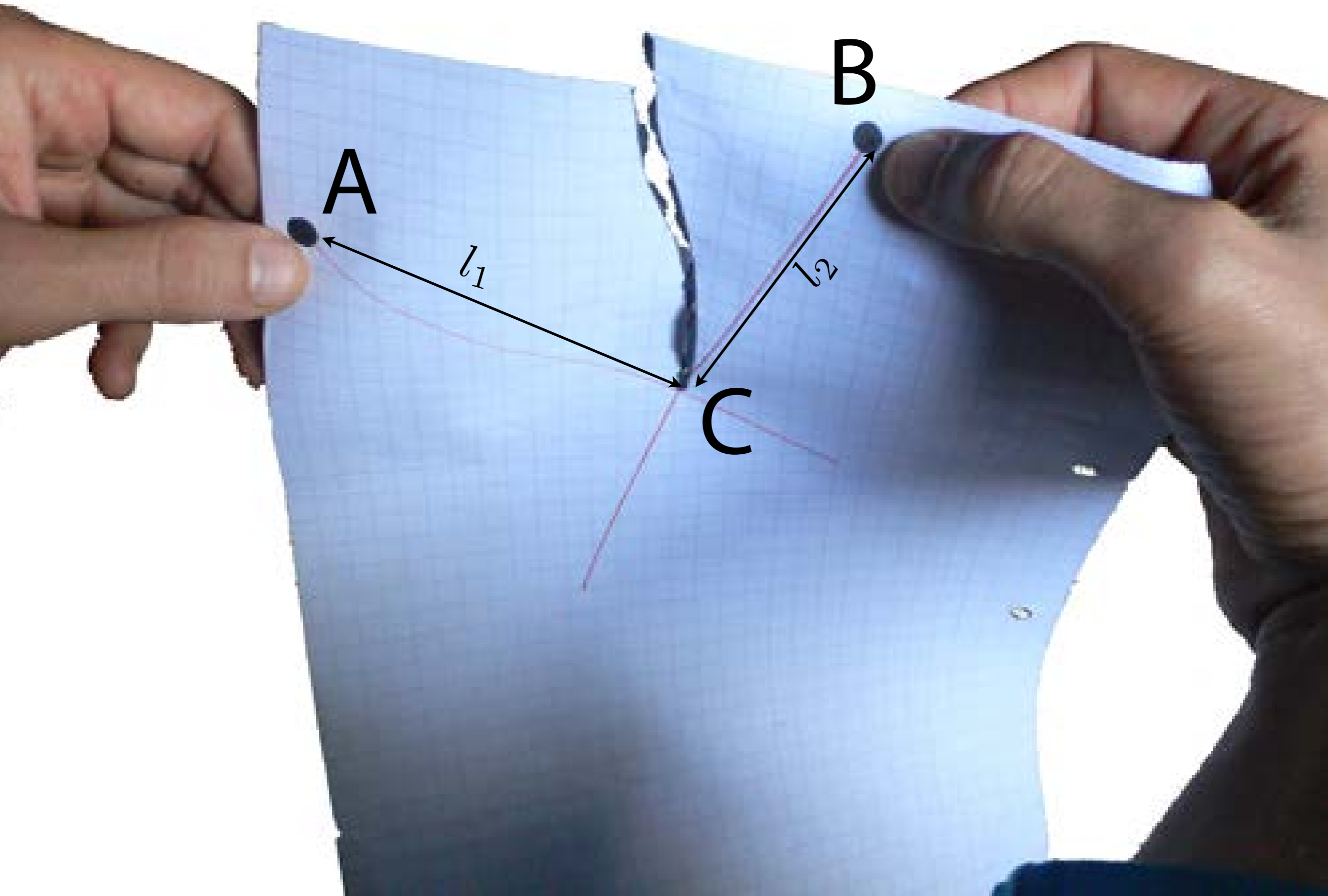


O'Keefe *Am. J. Phys.* **62** (4), April 1994

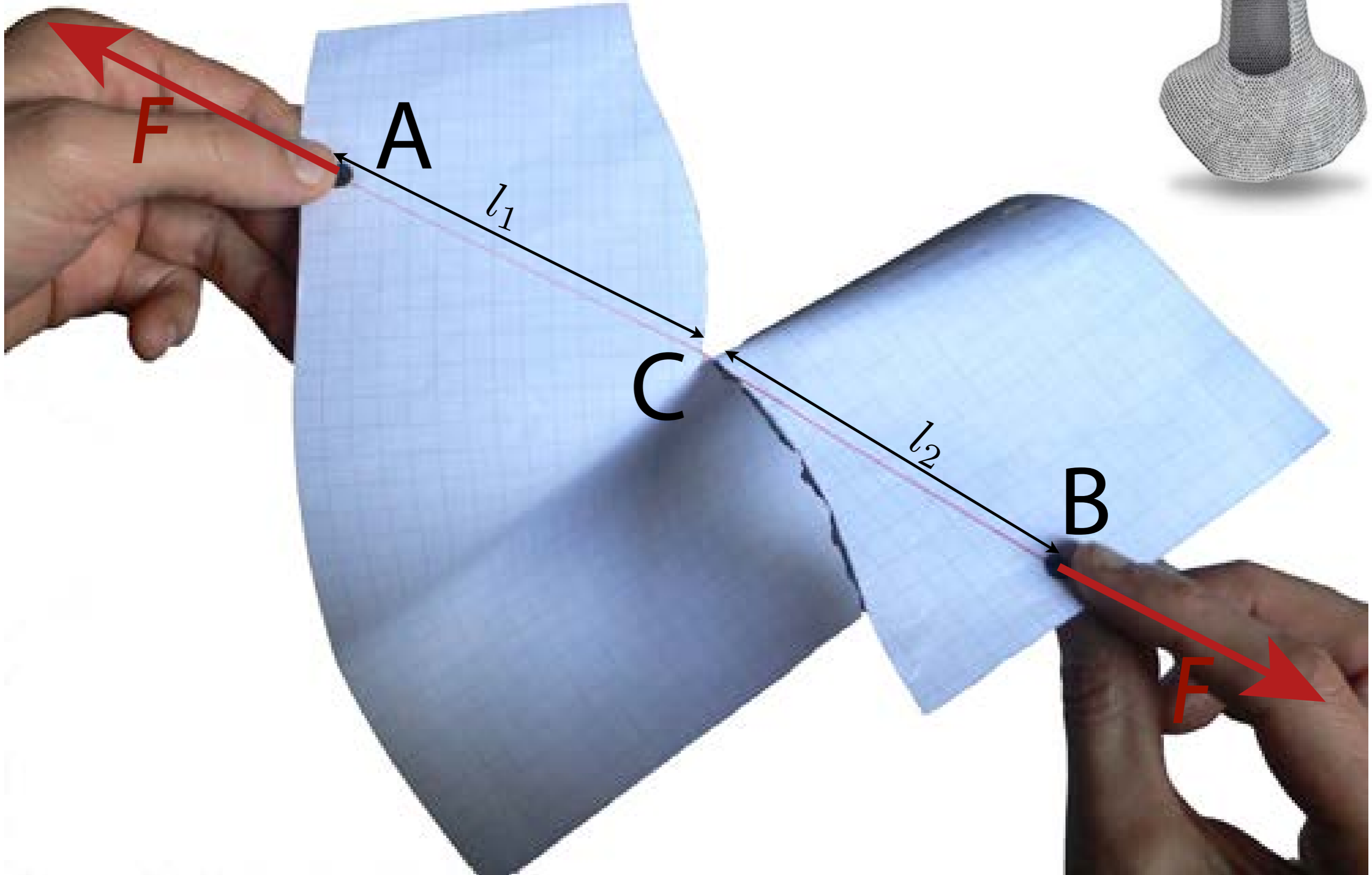
- Quelle force?
- Quelle trajectoire?



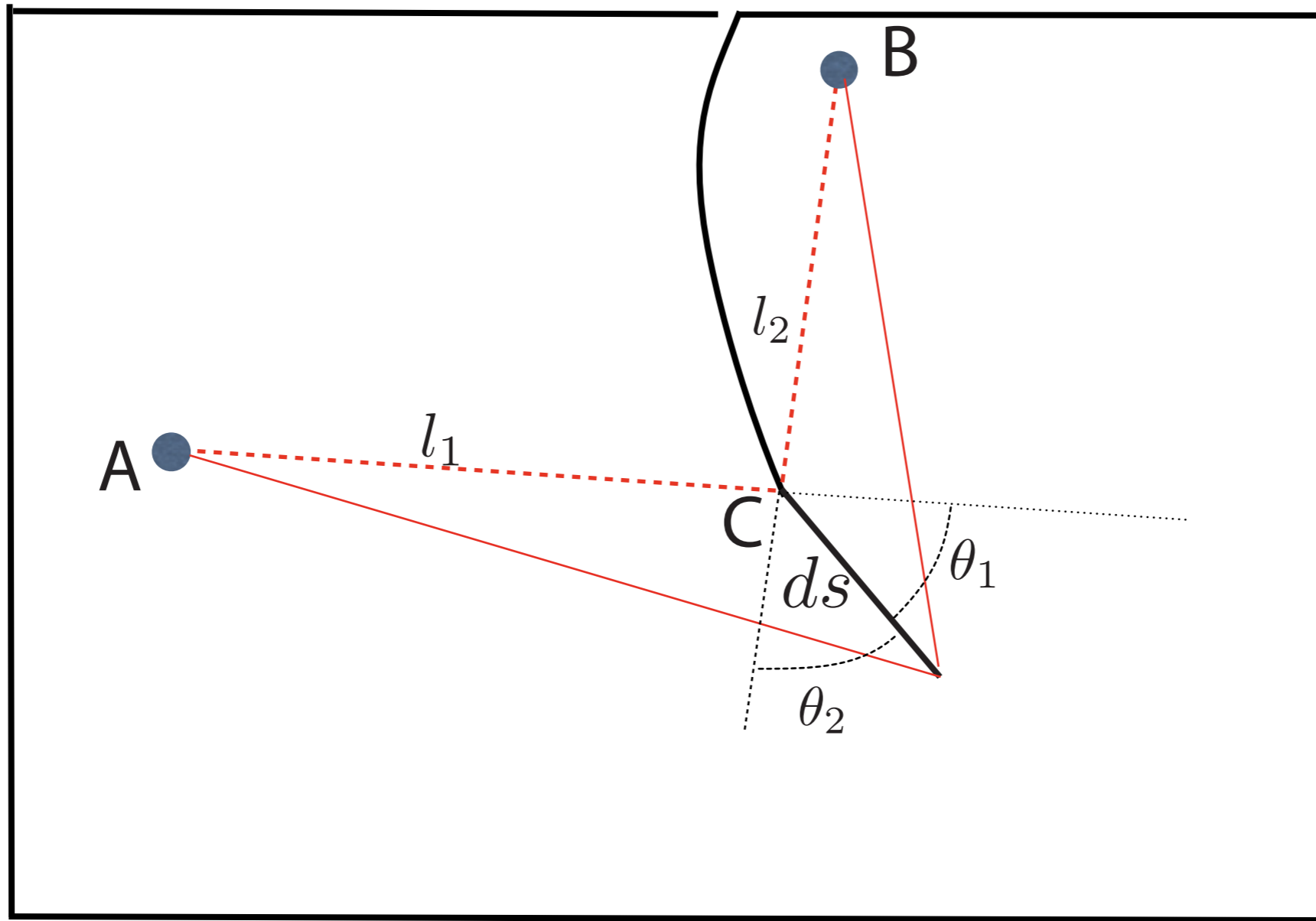
Géométrie : inextensible, infiniment flexible



Géométrie : inextensible, infiniment flexible

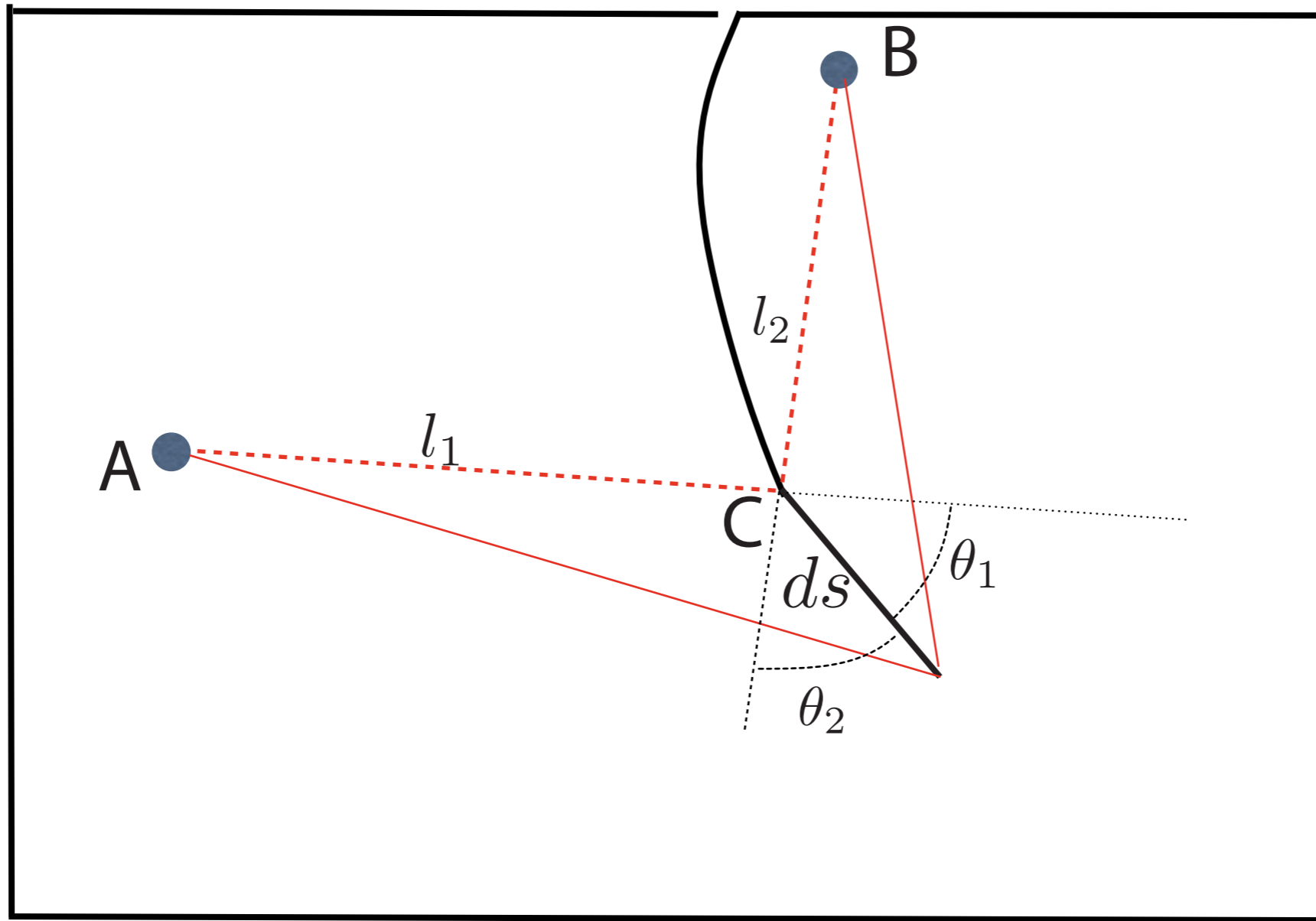


$$dW = F(dl_1 + dl_2)$$



$$F(dl_1 + dl_2) = G_c t ds$$

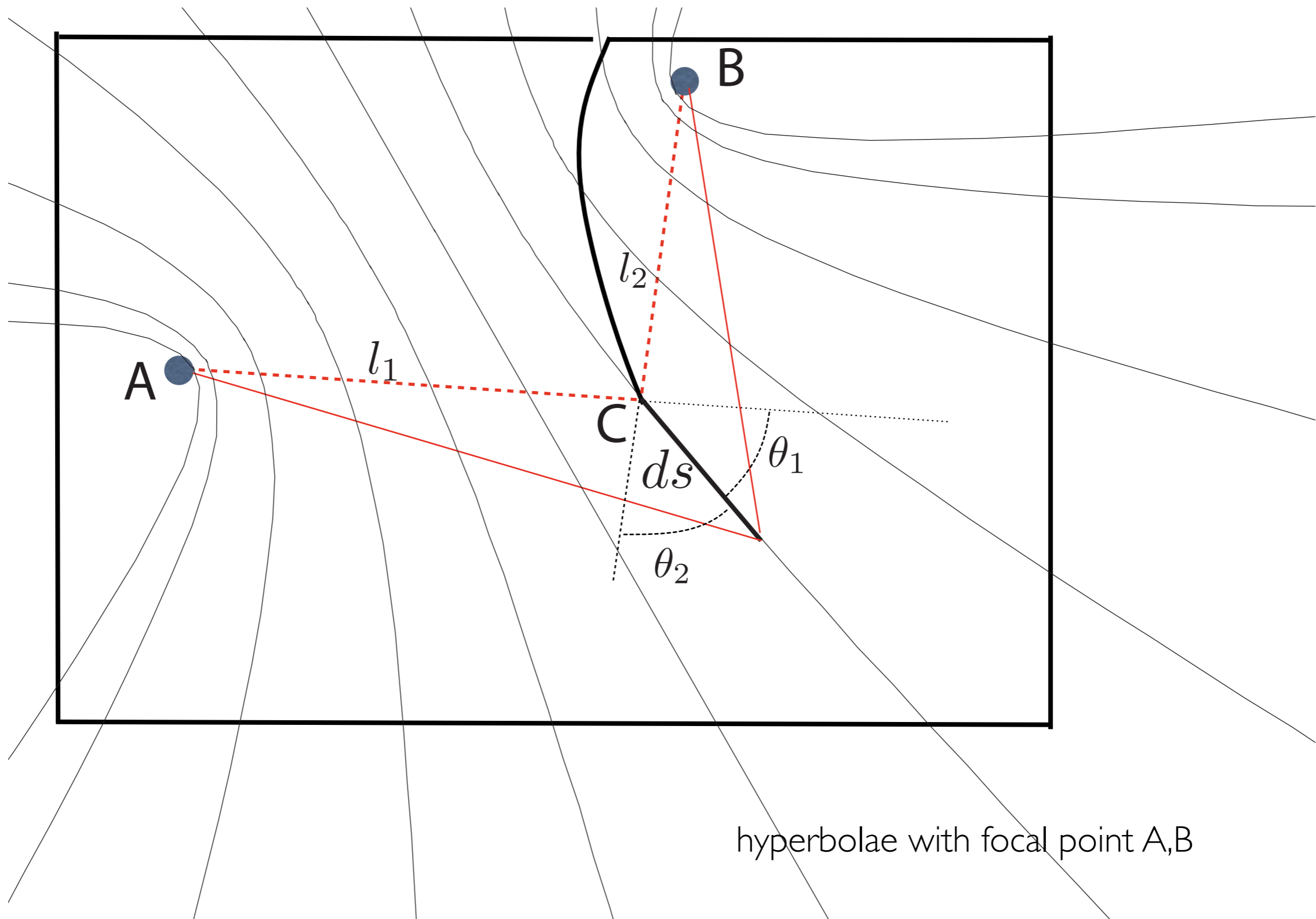
$$dW = F(dl_1 + dl_2)$$



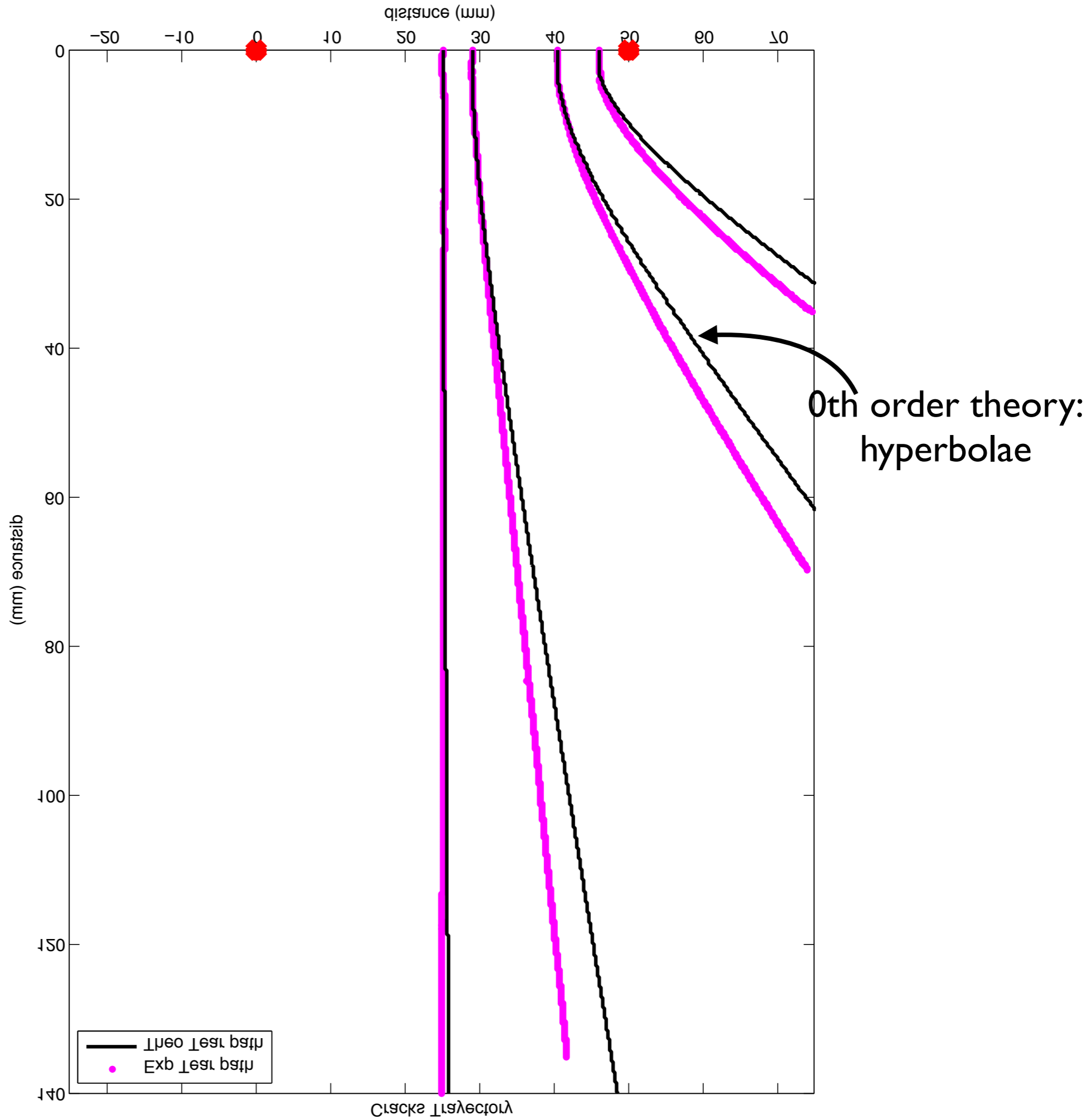
$$F(dl_1 + dl_2) = G_c t ds$$

Maximum Energy Release rate : bisector $\theta_1 = \theta_2$

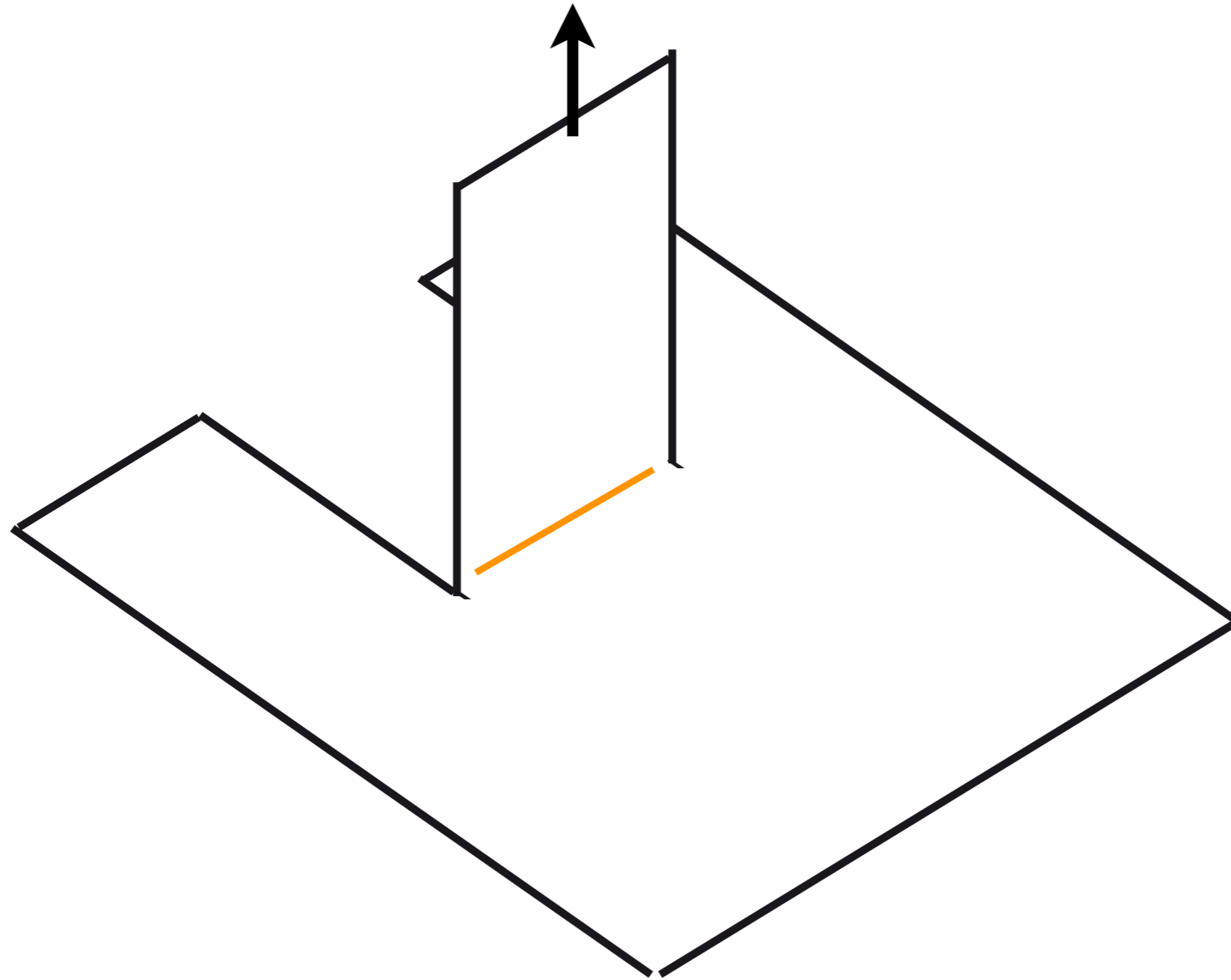
$$\theta_1 = \theta_2$$



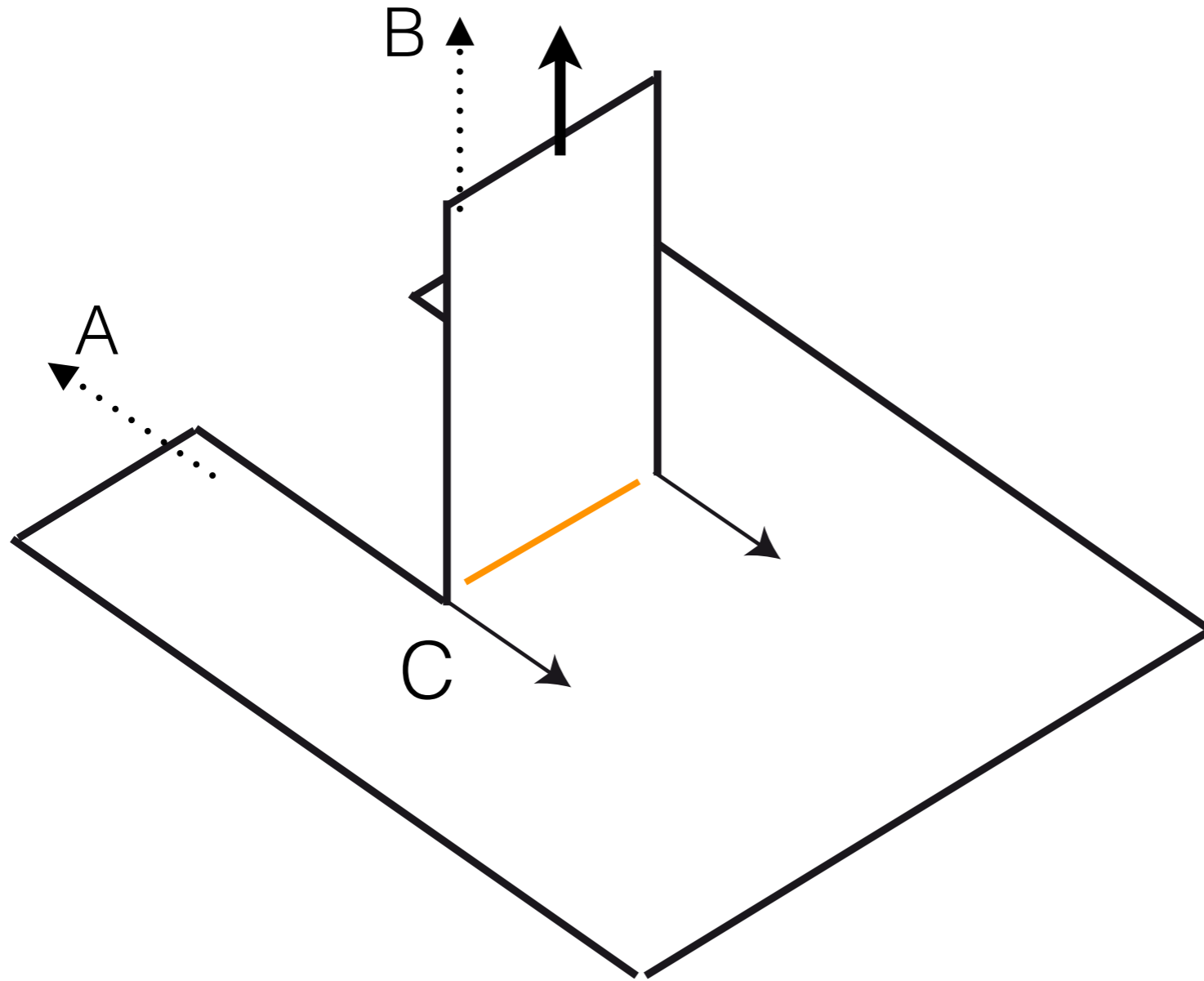
J-F Fuentealba



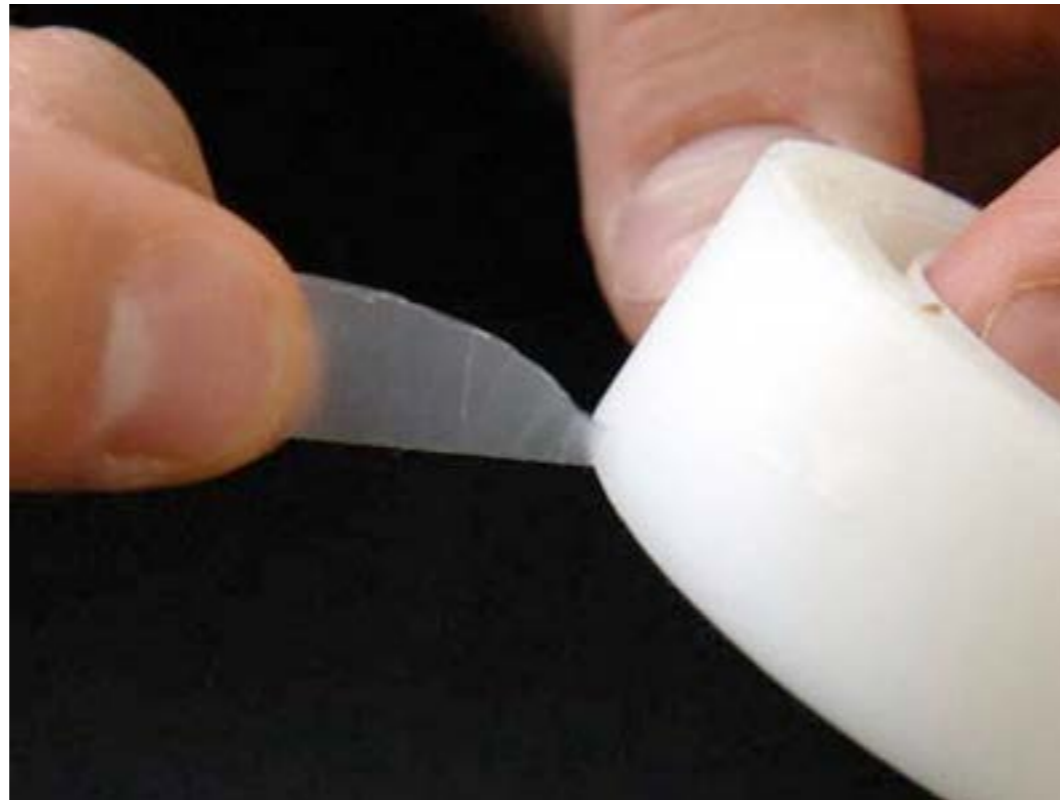
Et avec 2 déchirures?



Et avec 2 déchirures?

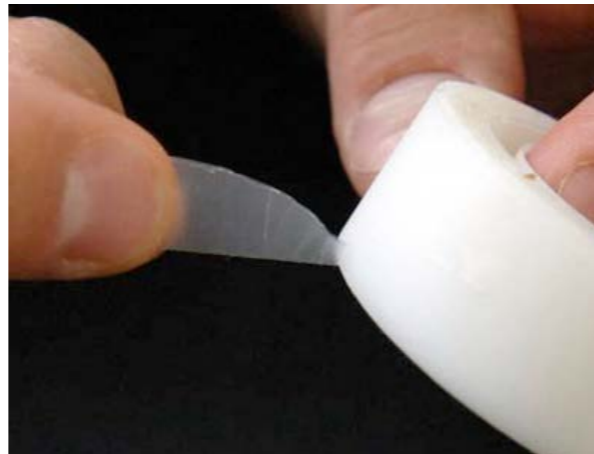


quantitative prediction :
strong adhesion case



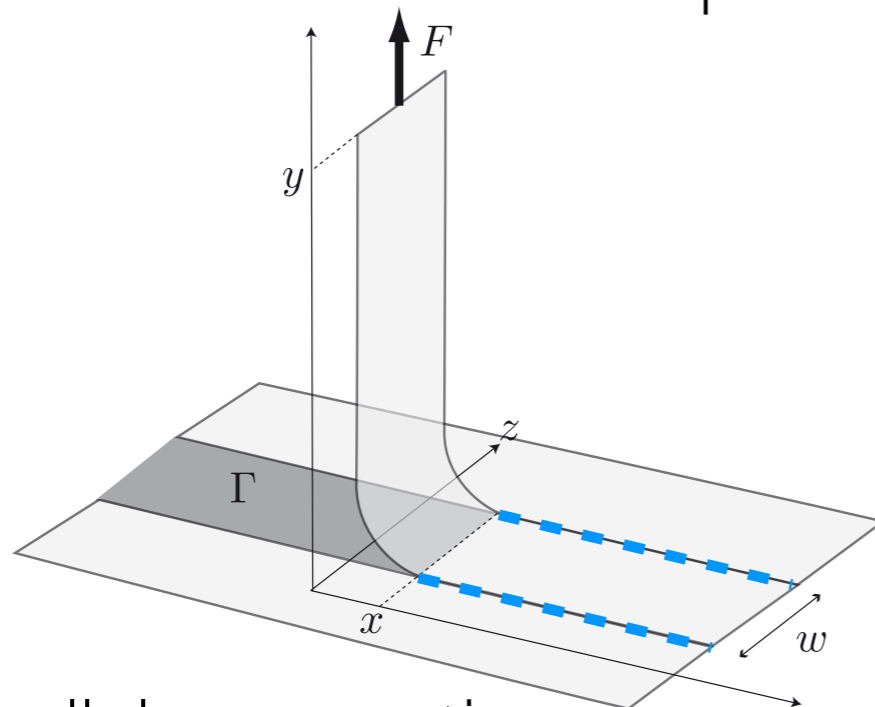
D.Coveney

quantitative prediction : strong adhesion case

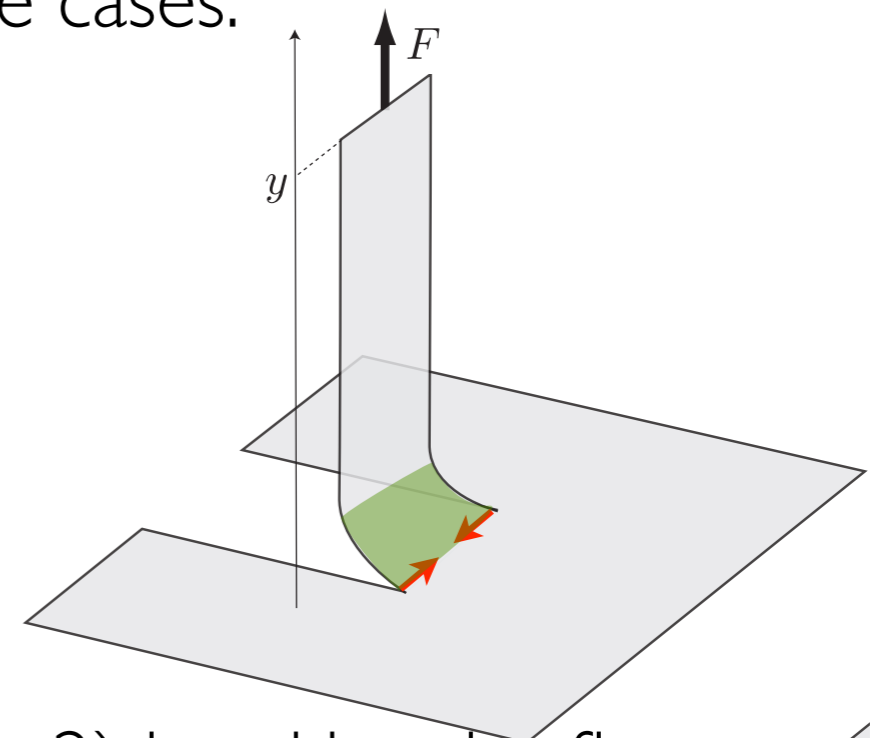


D.Coveney

Compare 2 extreme cases:

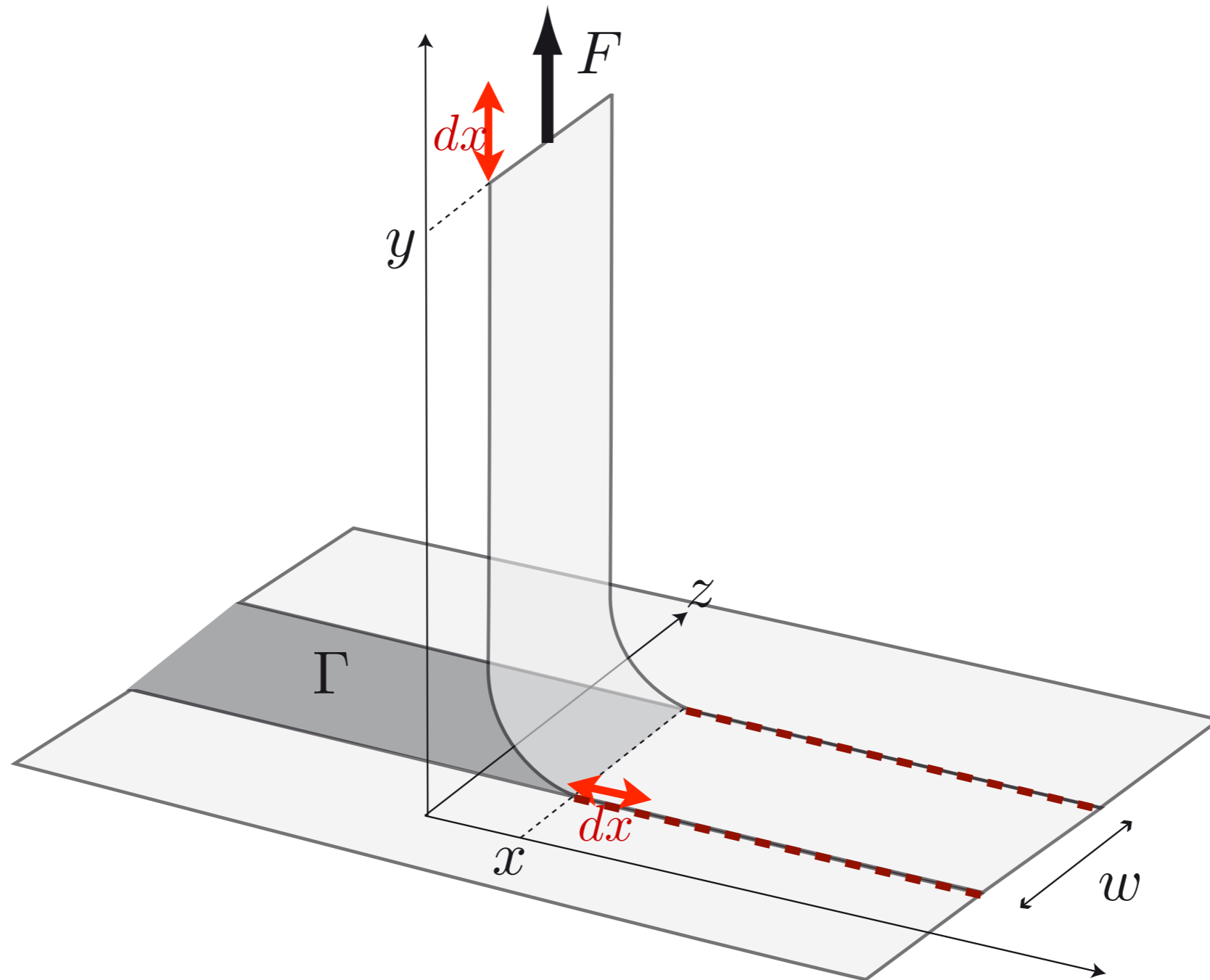


1) parallel propagation



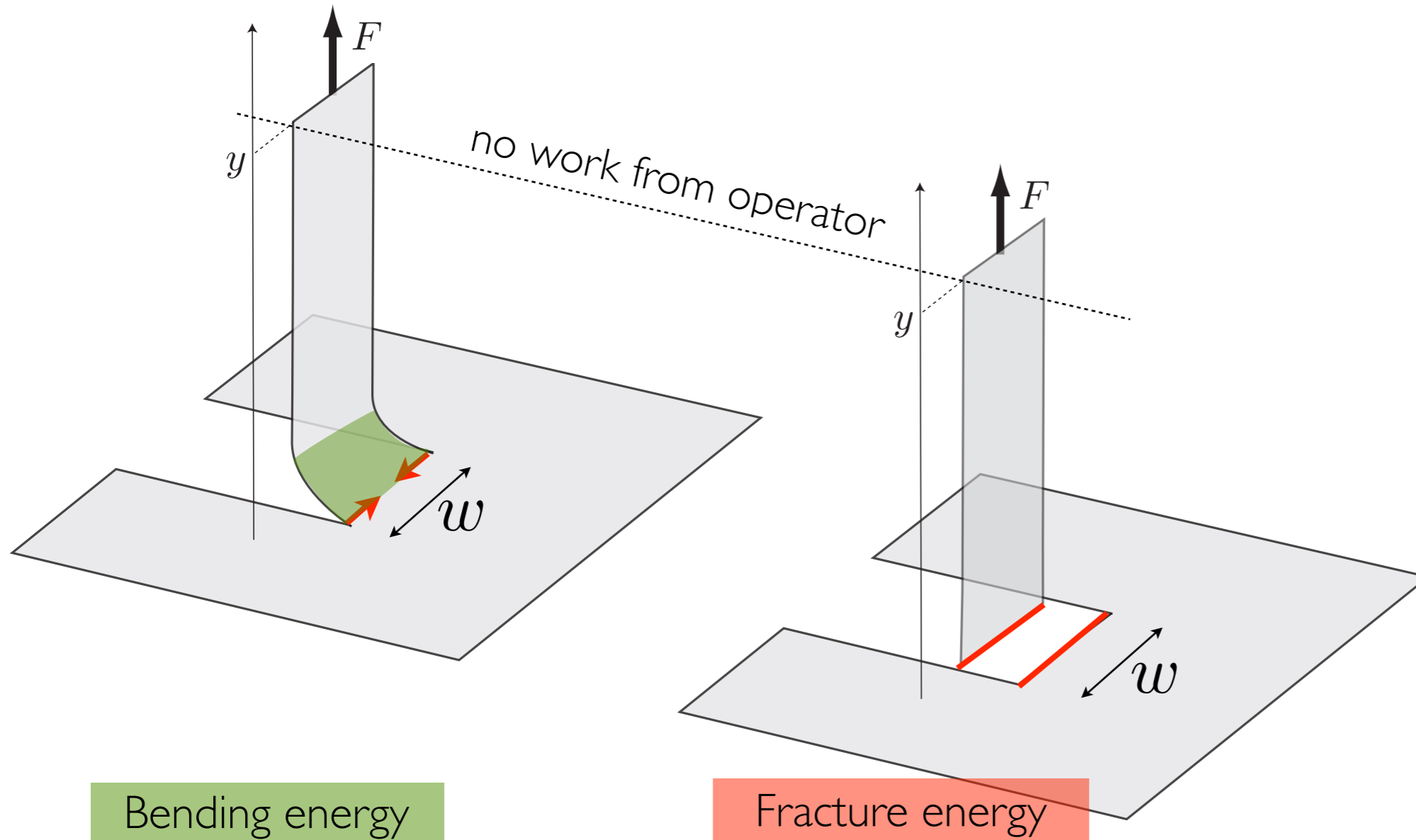
2) breaking the flap

1) parallel propagation



$$F_p = \Gamma w + \cancel{2\gamma t}$$

2) breaking the flap (no work of operator)

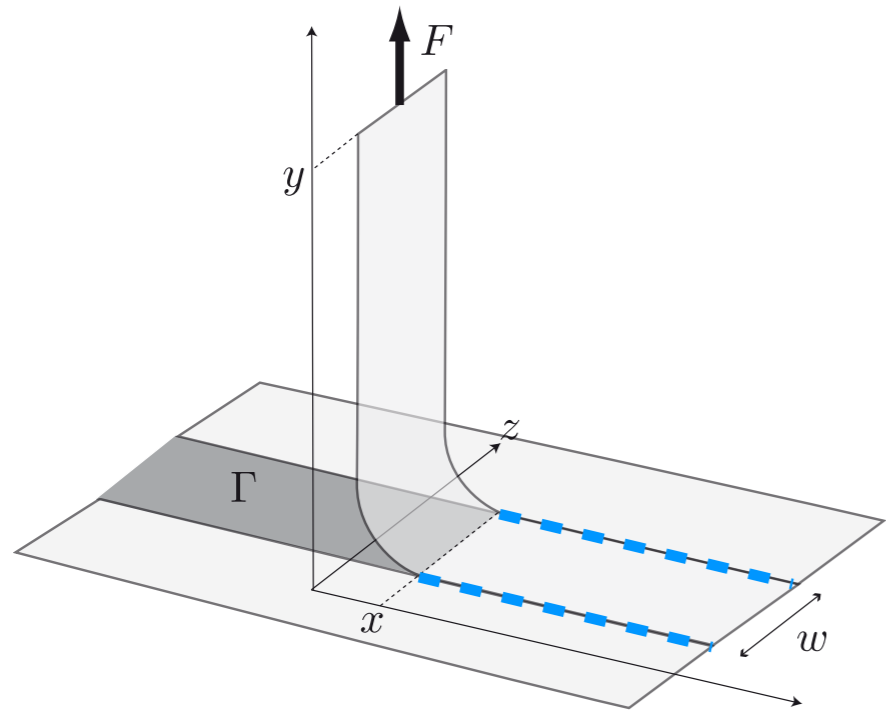


$$E_B \sim \sqrt{BwF}$$

($B \sim Et^3$ flexural rigidity)

$$G_c t w$$

propagation if $F_B \sim (G_c t)^2 \frac{w}{B}$

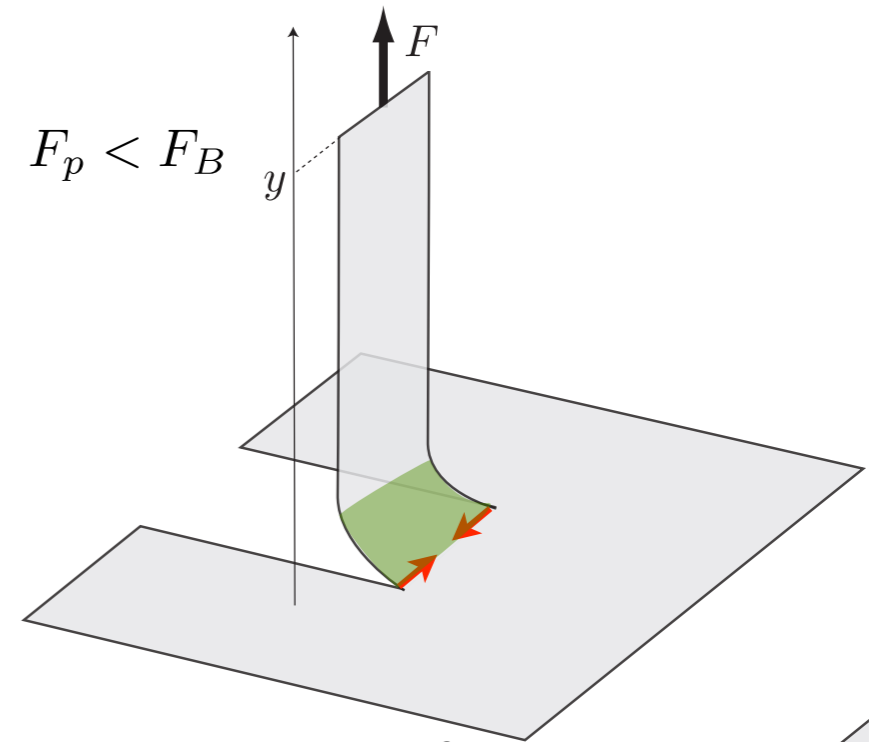


$$F_p < F_B$$

1) parallel propagation

operator's work

$$F_p = \Gamma w$$



$$F_p < F_B$$

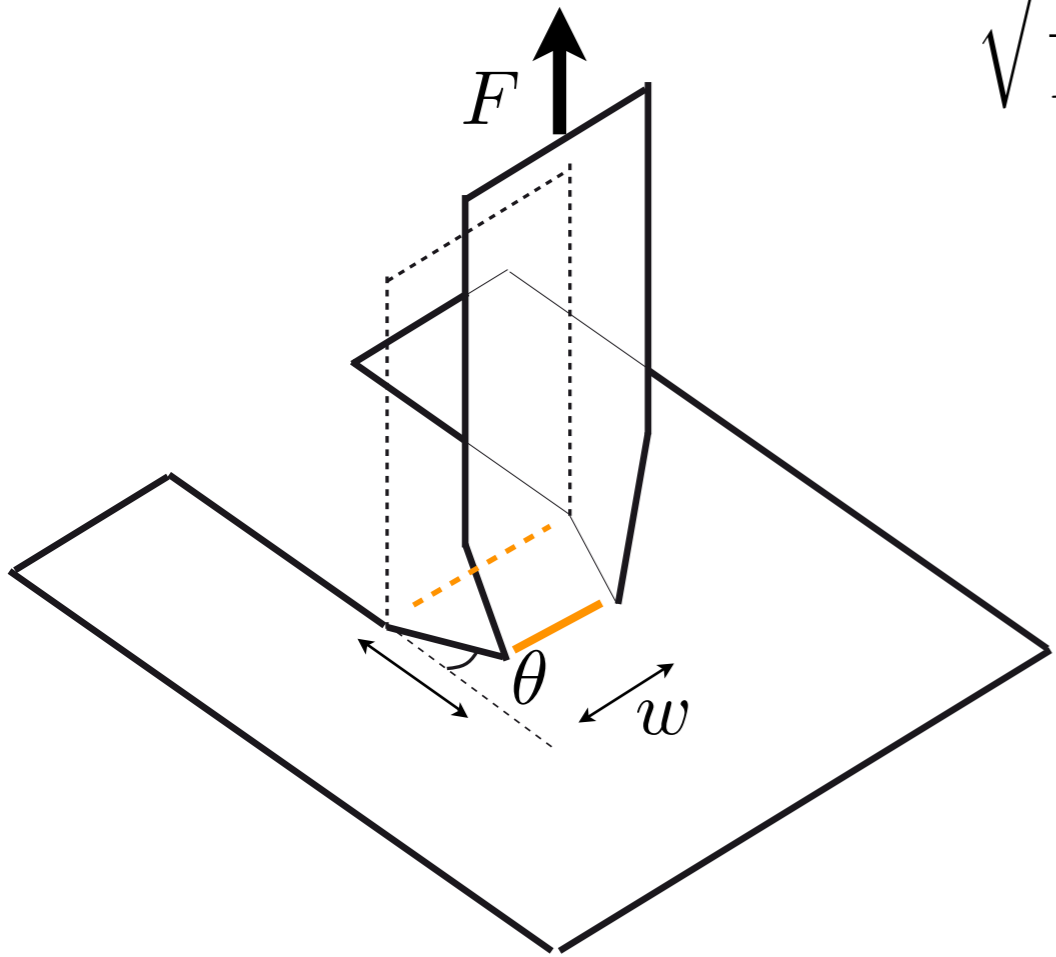
2) breaking the flap

flexural energy

$$F_B \sim (G_c t)^2 \frac{w}{B}$$

$F_p < F_B$ \longrightarrow parallel propagation

$\frac{F_p}{F_B} \sim \frac{B\Gamma}{(G_c t)^2}$ relative magnitude of converging to parallel effects

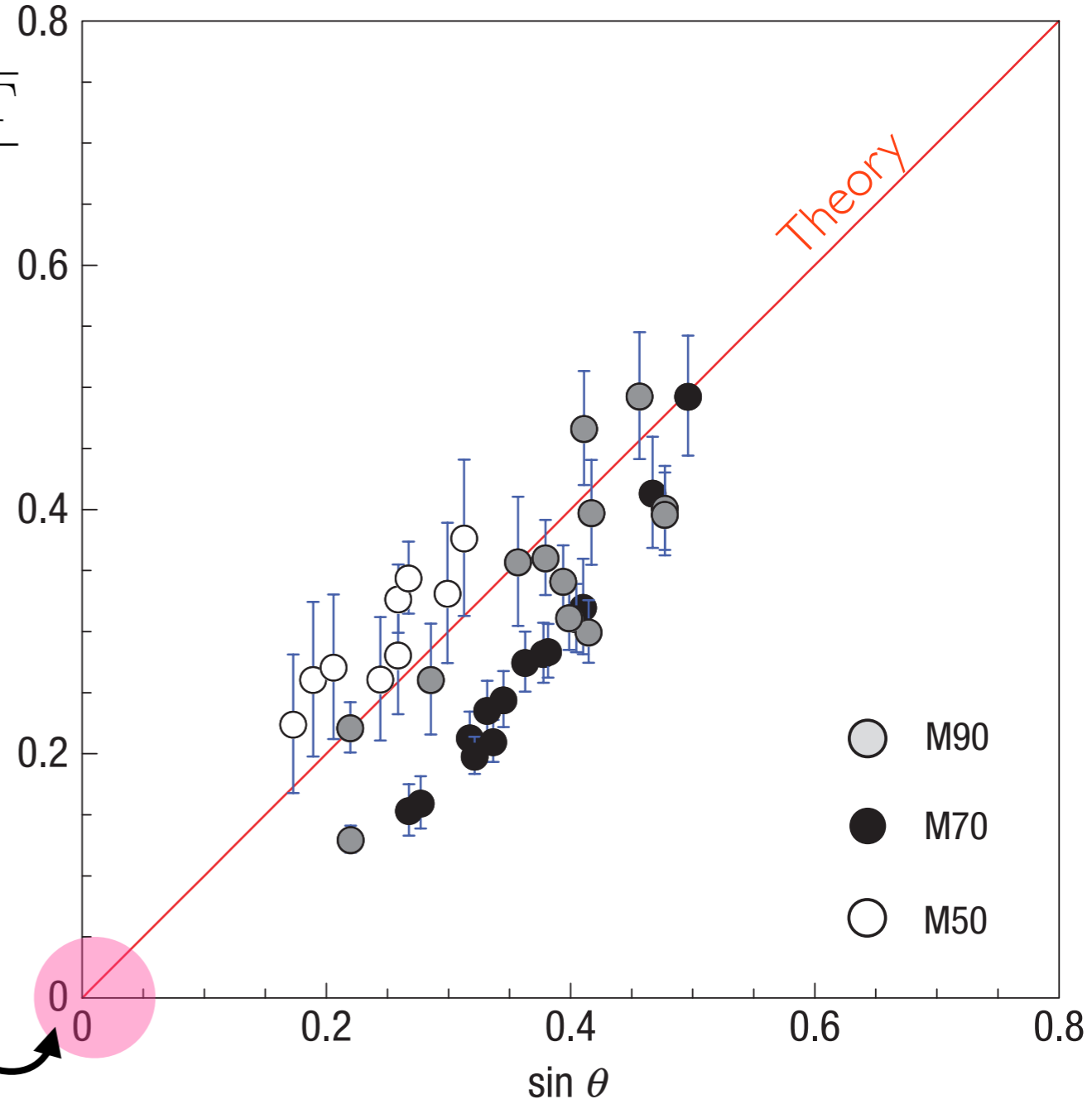


$$\sqrt{\frac{F_p}{F_B}} \sim \frac{\sqrt{B\Gamma}}{G_c t}$$

converging tears

$$\sin \theta = \frac{\sqrt{2B\Gamma}}{G_c t} \sim \sqrt{\frac{F_p}{F_B}}$$

0th order





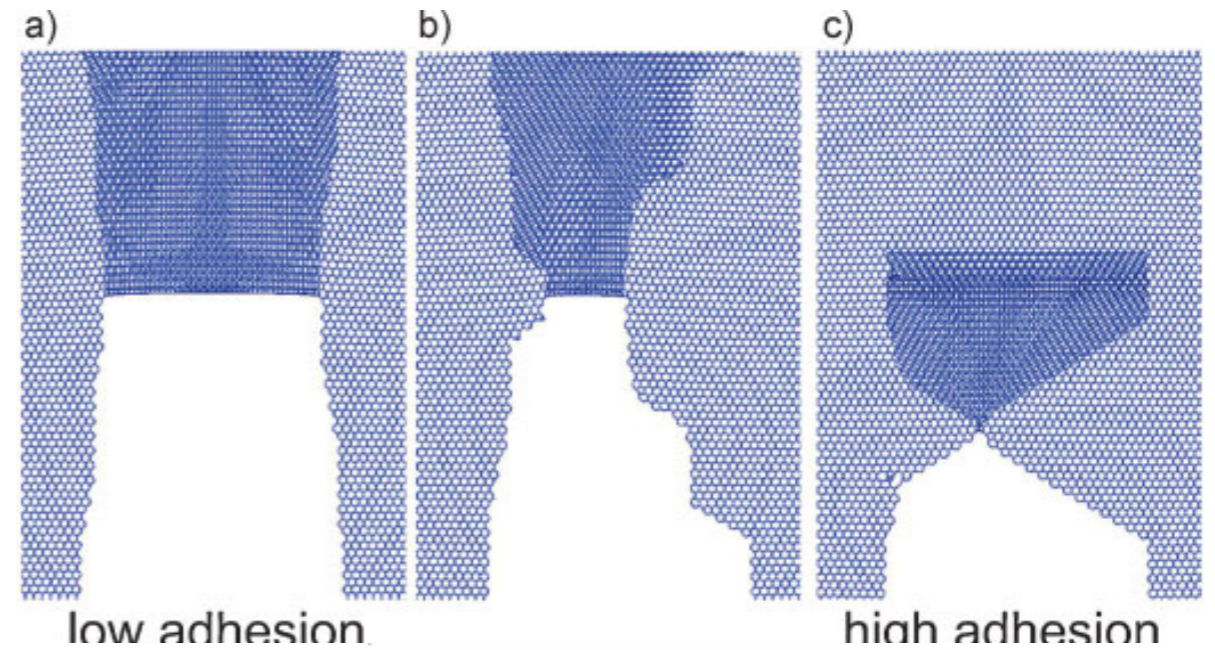
Aloha airlines 1988

metrology ?

$$\sin \theta = \frac{\sqrt{2B\Gamma}}{G_{ct}}$$

peeling tomato

graphene



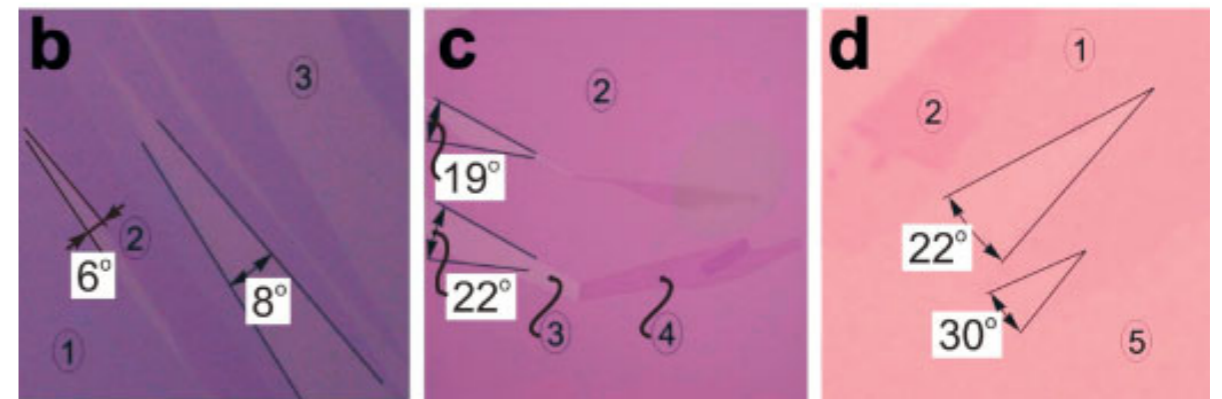
Adhesion 80 N/m

toughness $\gamma t = 8 \cdot 10^{-2} N$

Angle $\theta = 20^\circ$

$$B = (\eta \gamma t \sin \theta)^2 / 2\tau \approx 4 \times 10^{-6} J$$

Young modulus: $E \approx 70 \text{ MPa}$.
 consistent with other estimations 5 MPa to 50 MPa



Sen et al., Small 2010



Jacques Villeglé

P.Kovarik

