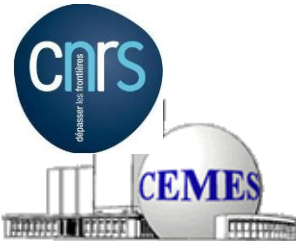


2 nm

La mécanique des molécule-machines: roues, engrenages, moteurs et véhicules

C. Joachim
GNS & MANA Satellite
CEMES-CNRS
Toulouse
A*STAR VIP IMRE
Singapore

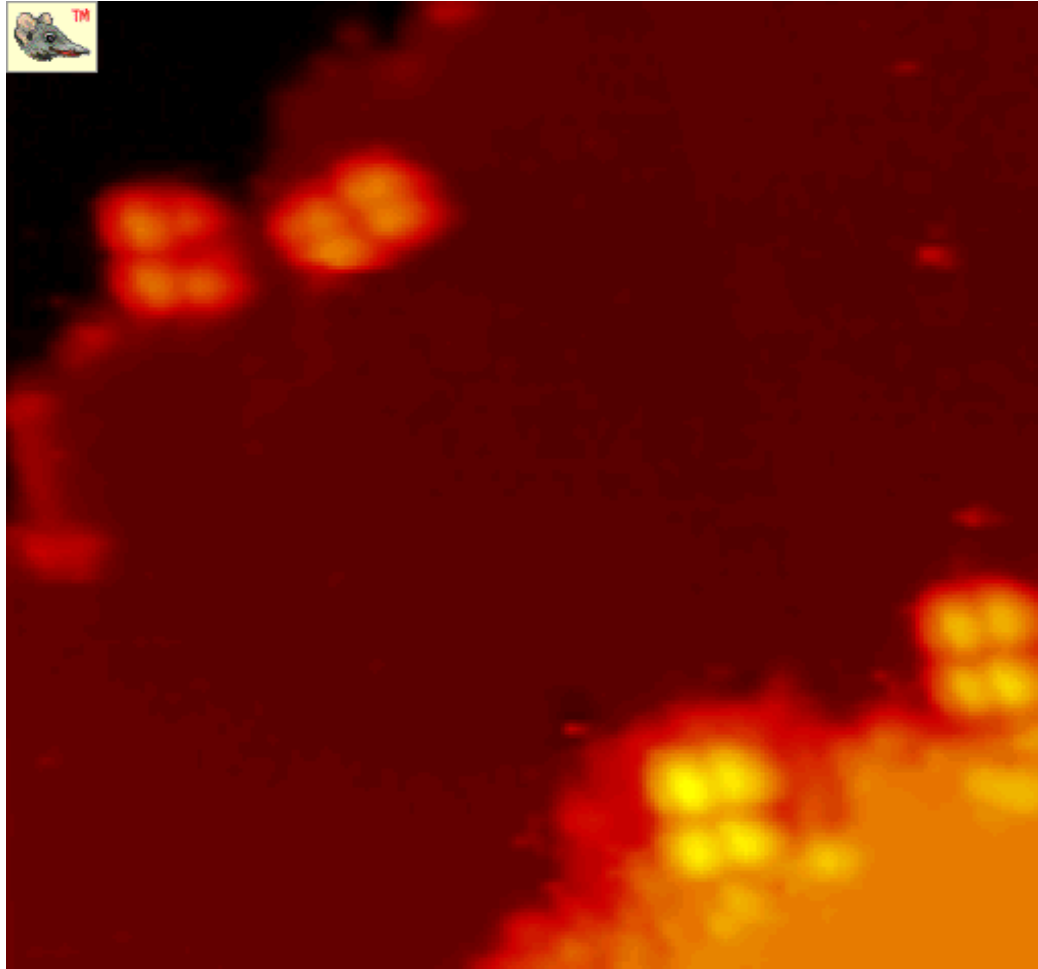


1) Maitriser le mouvement d'une seule molécule

2) Transmettre du mouvement

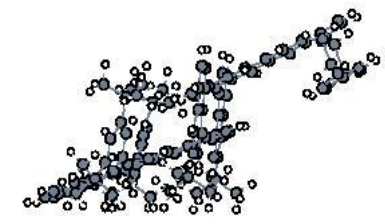
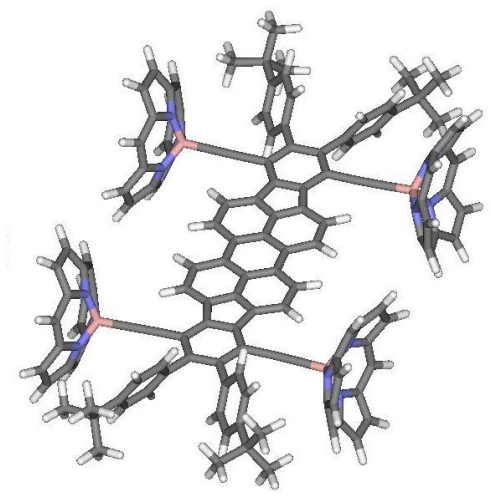
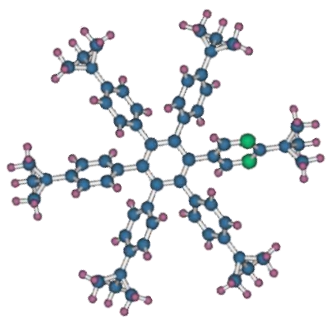


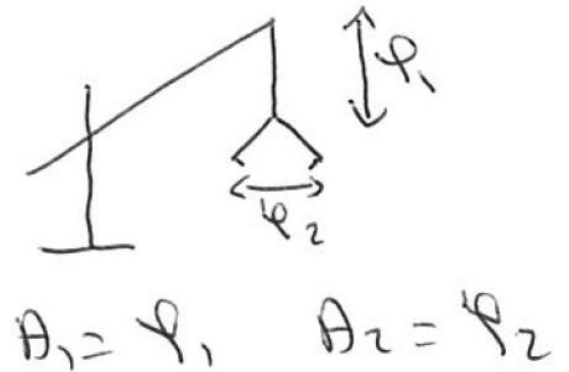
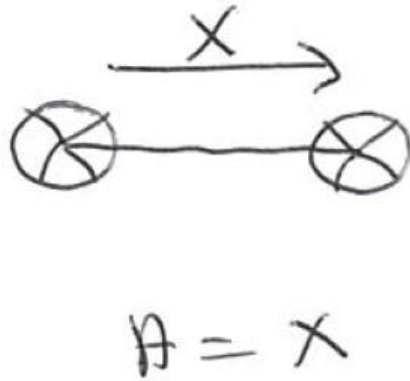
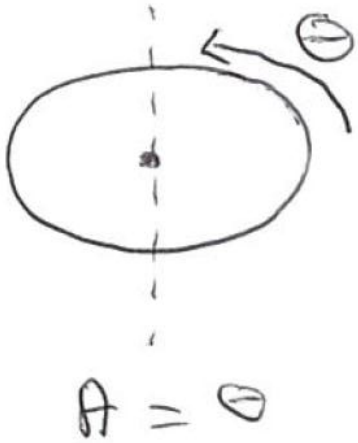
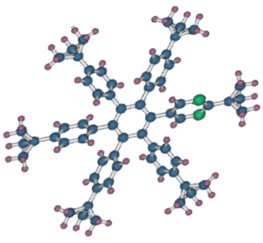
1) Maitriser le mouvement d'une seule molécule



on Cu(110)

250 K





$$\Psi(\vec{R}_j, \vec{r}_i, t) \longrightarrow \Psi(A, \vec{a}_{j-1}, \vec{r}_i, t)$$

$$\langle \hat{A} \rangle = \langle \Psi(t) | \hat{A} | \Psi(t) \rangle$$

$$\frac{d\langle \hat{A} \rangle}{dt} ?$$

$$\frac{d\langle \hat{A} \rangle}{dt} ?$$

$$i\hbar \frac{\partial}{\partial t} \Psi(t) = (\hat{H}_0 + \hat{I}(t)) \Psi(t)$$



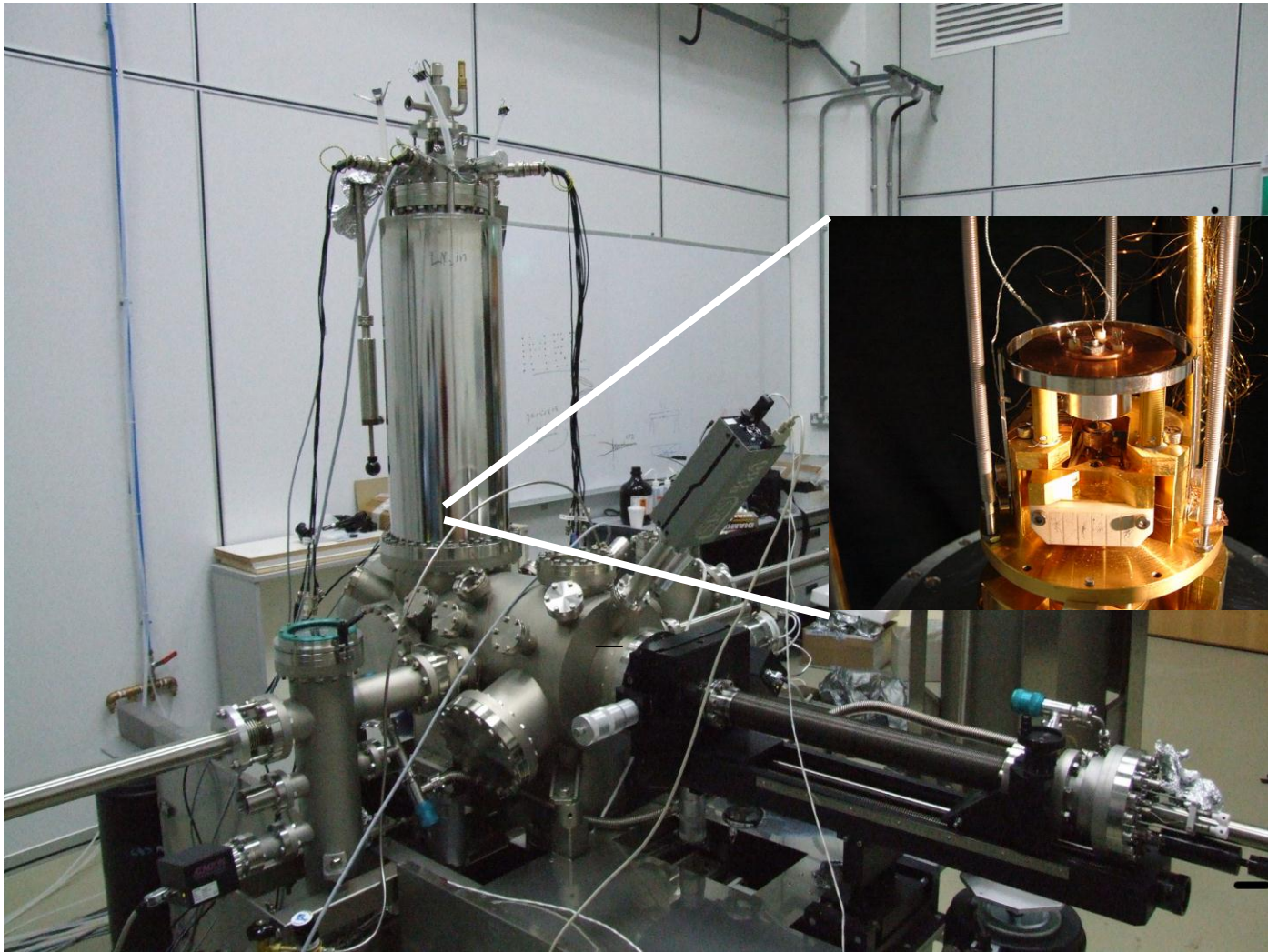
$$\hbar \frac{d\langle \hat{A} \rangle}{dt} = \vec{\nabla}_{\langle \hat{A} \rangle} V_F(\langle \hat{A} \rangle) + \hbar \frac{d\langle \hat{A} \rangle}{dt} + F(\langle \hat{I}(t) \rangle)$$



Molécule froide (piège optique)

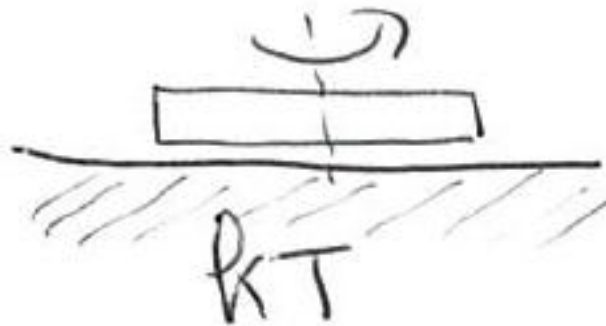


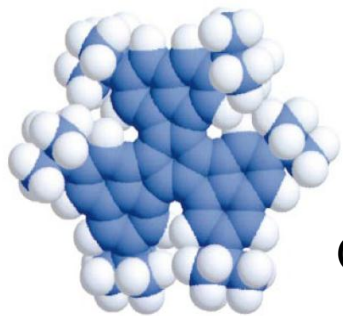
Molécule sur une surface



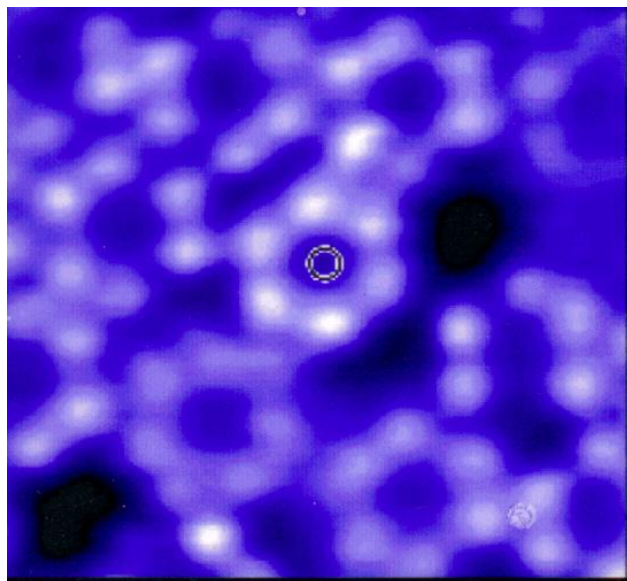
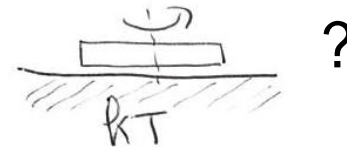
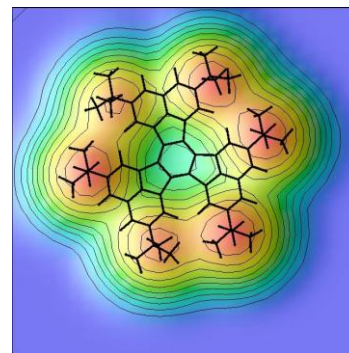
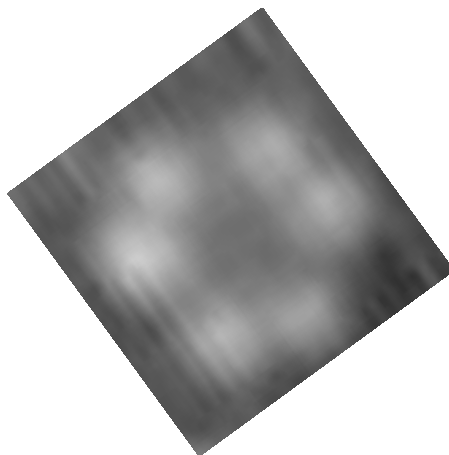
The LT-UHV STM Createc Machine

Molécule sur une surface (1)

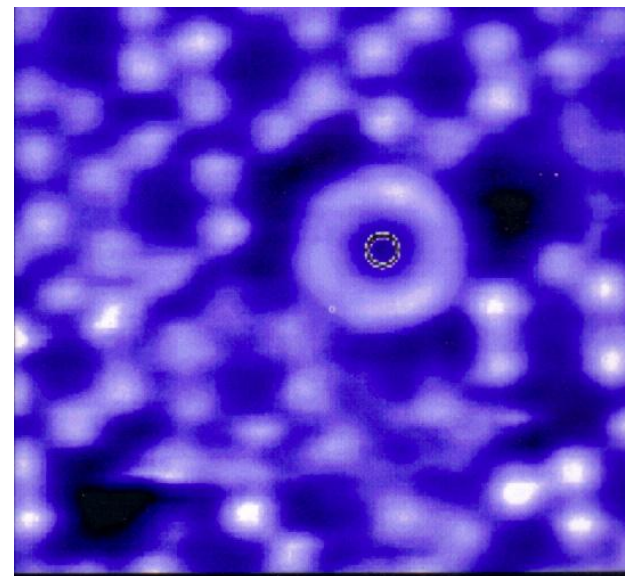




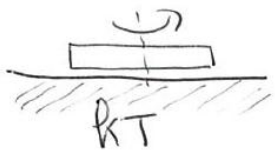
On Cu(100)



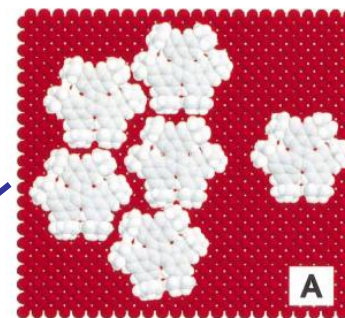
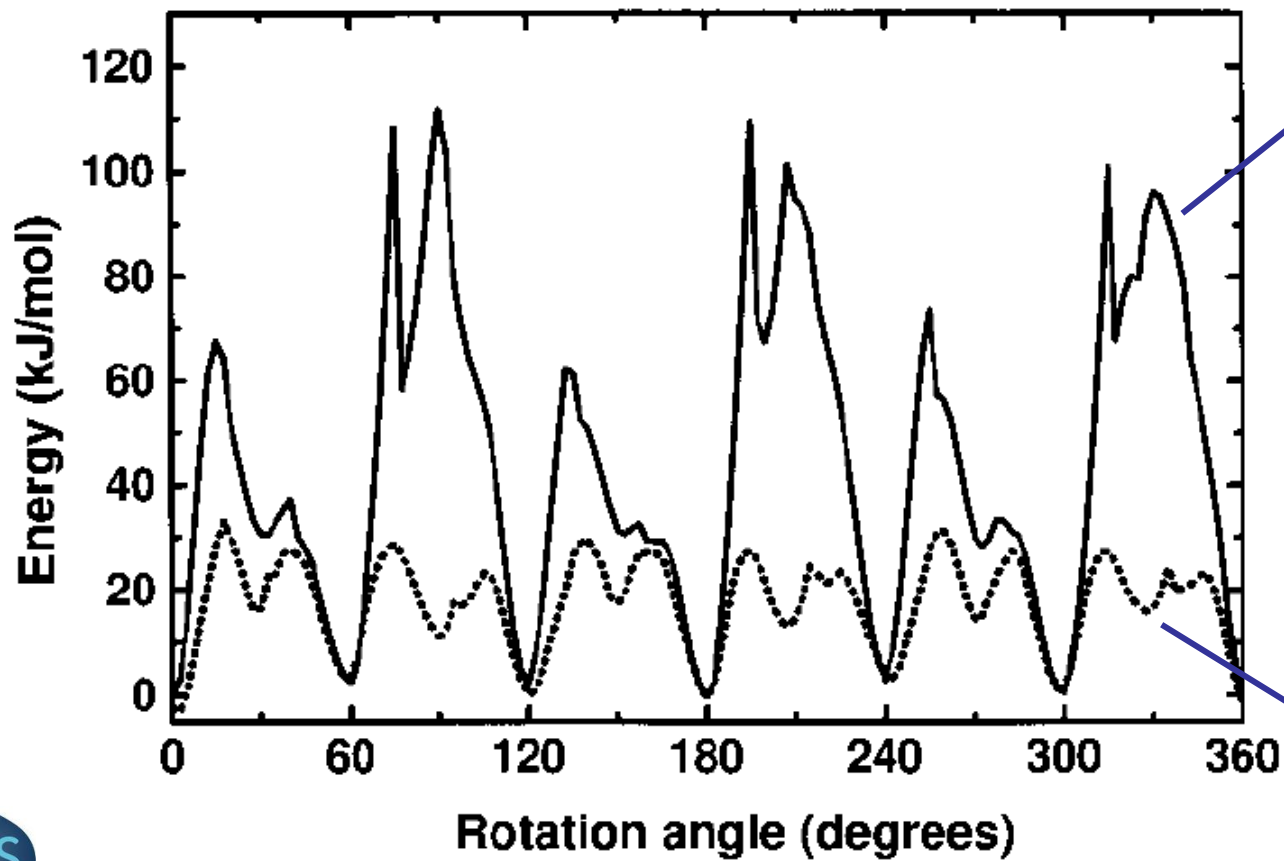
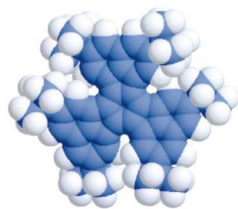
STM
↔
Manipulation



T = 300 K




?





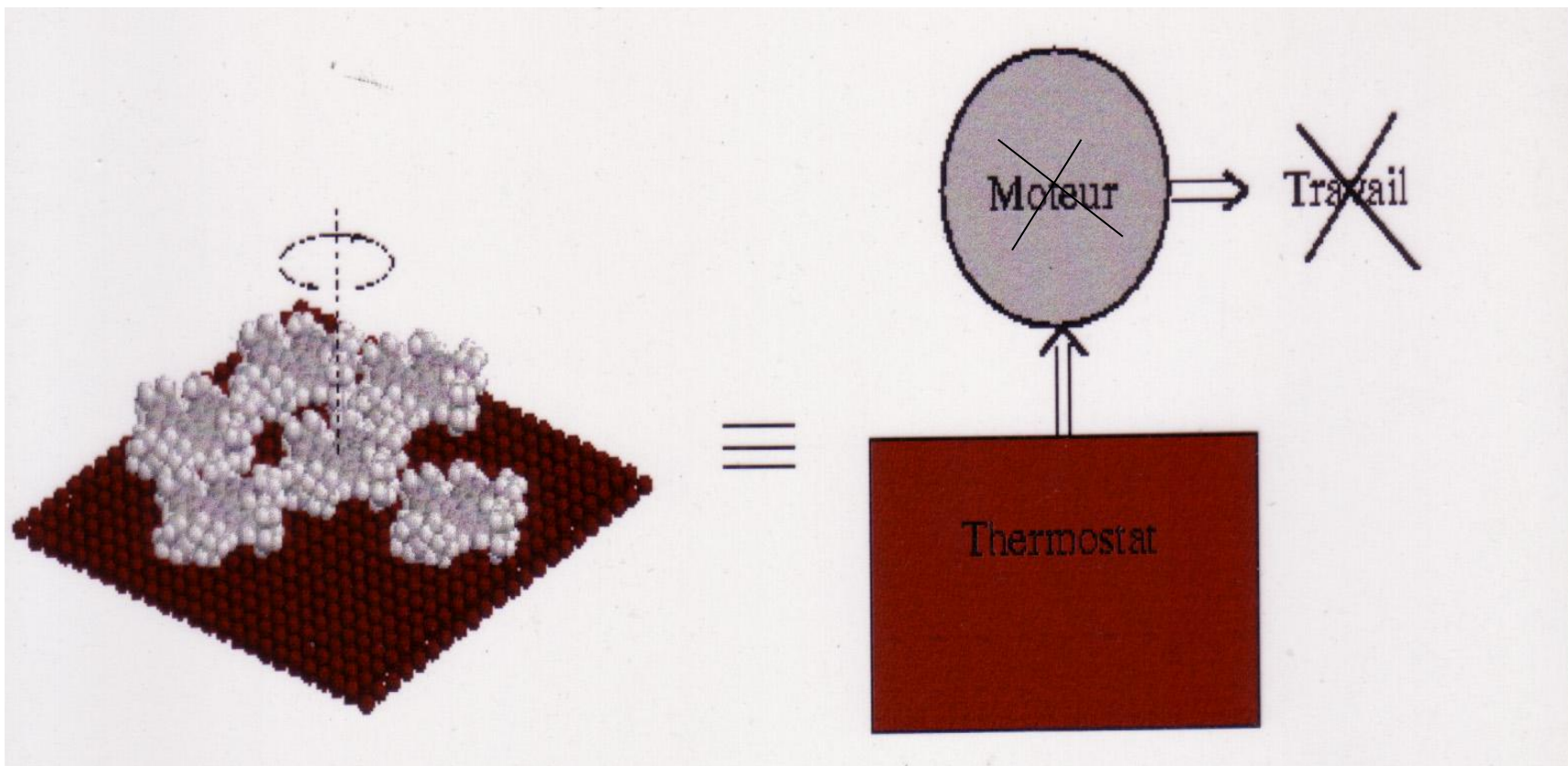
$$k \frac{d}{dt} \langle \hat{A} \rangle = \vec{\nabla}_{\langle \hat{A} \rangle} V_F(\langle \hat{A} \rangle) + \mu \frac{d}{dt} \langle \hat{A} \rangle + F(\langle I(\hat{A}) \rangle)$$

$$I \frac{d^2 \theta}{dt^2} = -\nabla V(\theta) - \mu \frac{d\theta}{dt} + F(t)$$

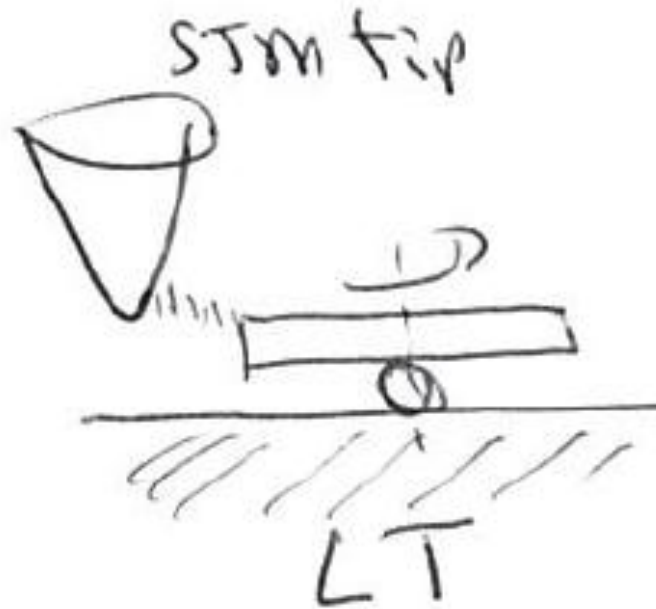

$$E_g(\theta) = a(x) \sin(k\theta)$$

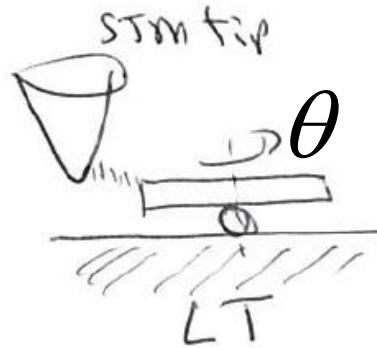


kT



Molécule sur une surface (2)



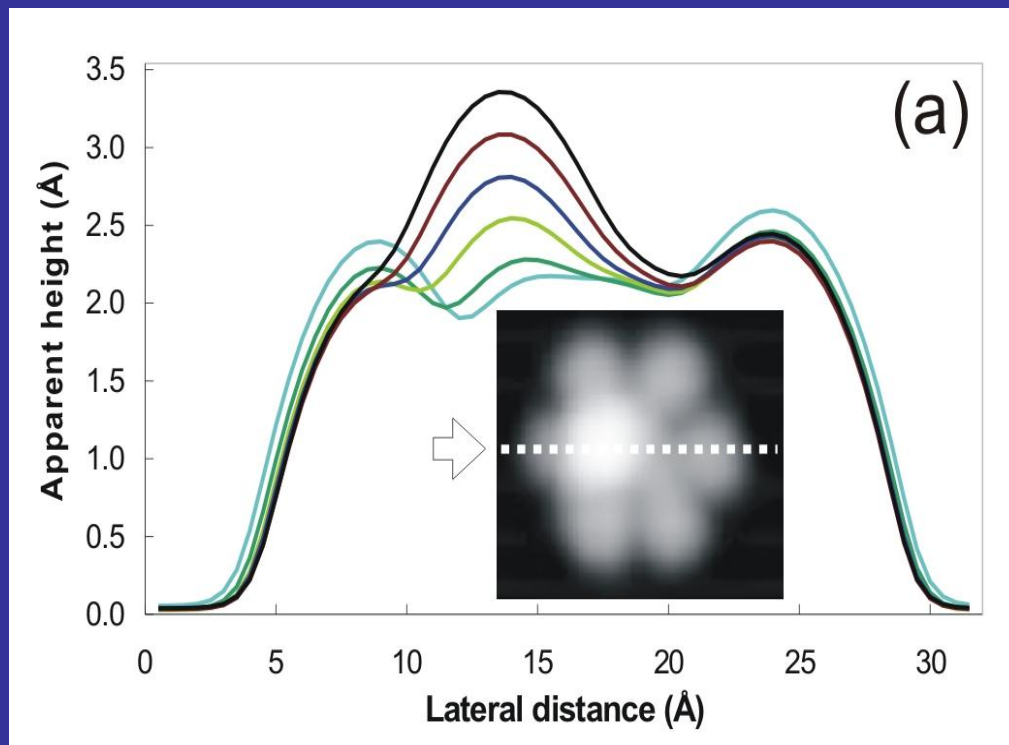
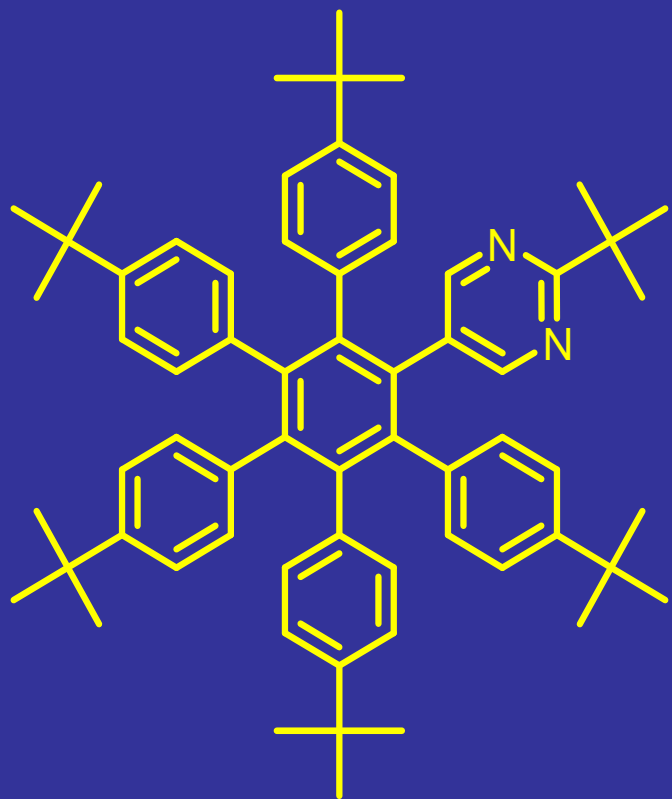


$$I \frac{d^2 \theta}{dt^2} = -\nabla V(\theta) - \mu \frac{d\theta}{dt} + F(t)$$

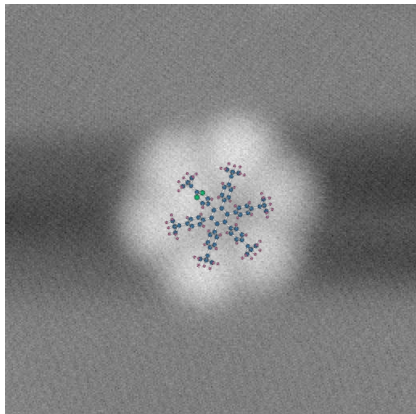


$$E_g(\theta)$$

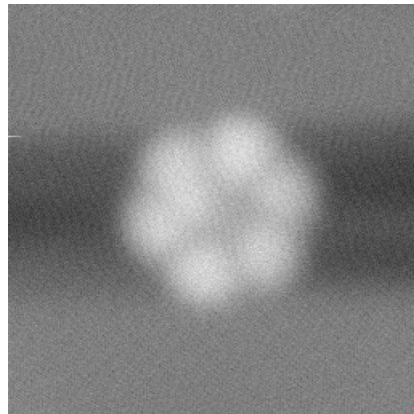
Une molécule engrenage tagée



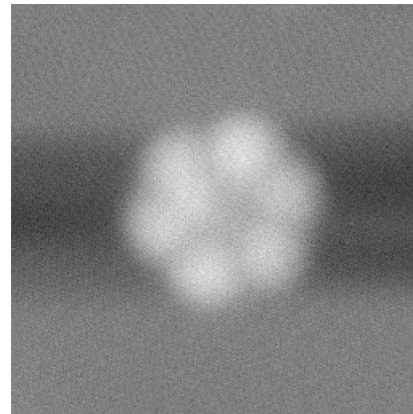
LT UHV STM images on Au(111)



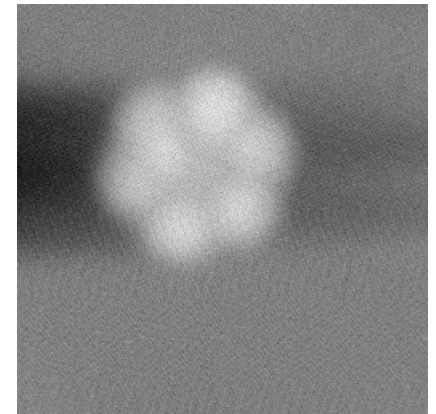
500 mV



1.0 V

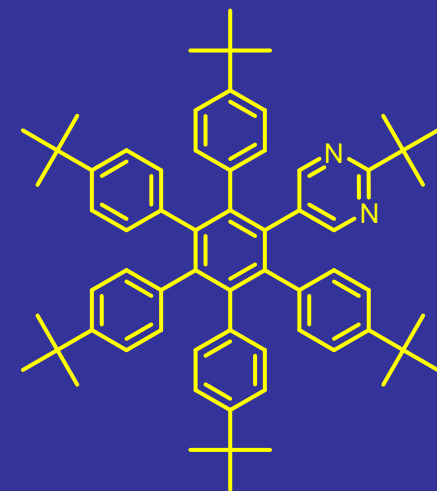
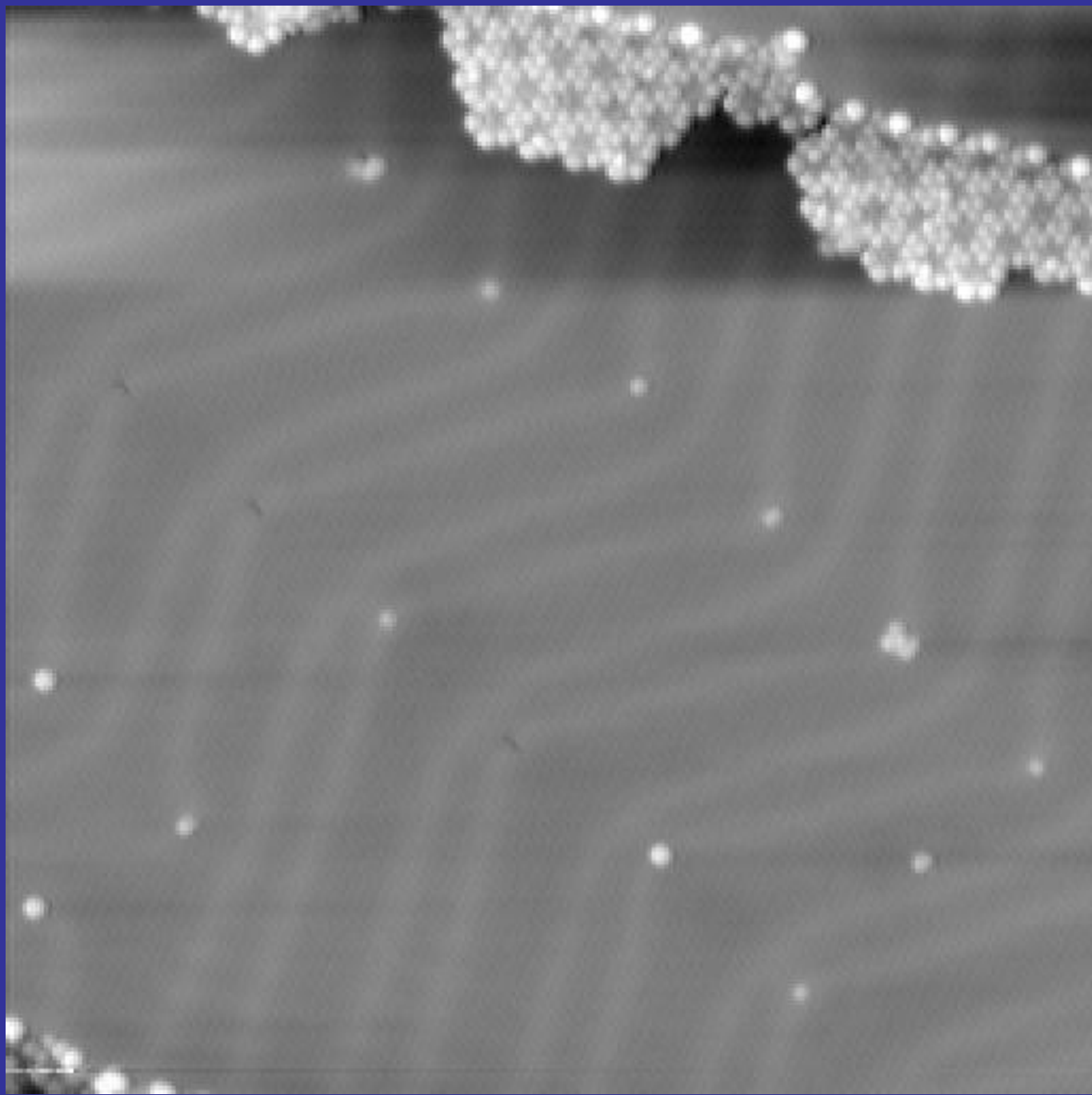


1.5 V



2.2 V

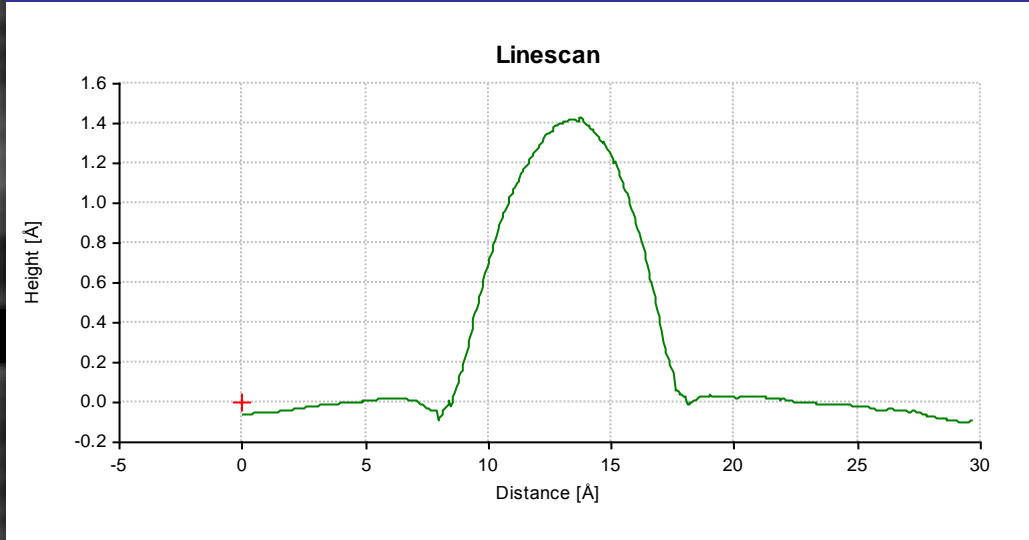
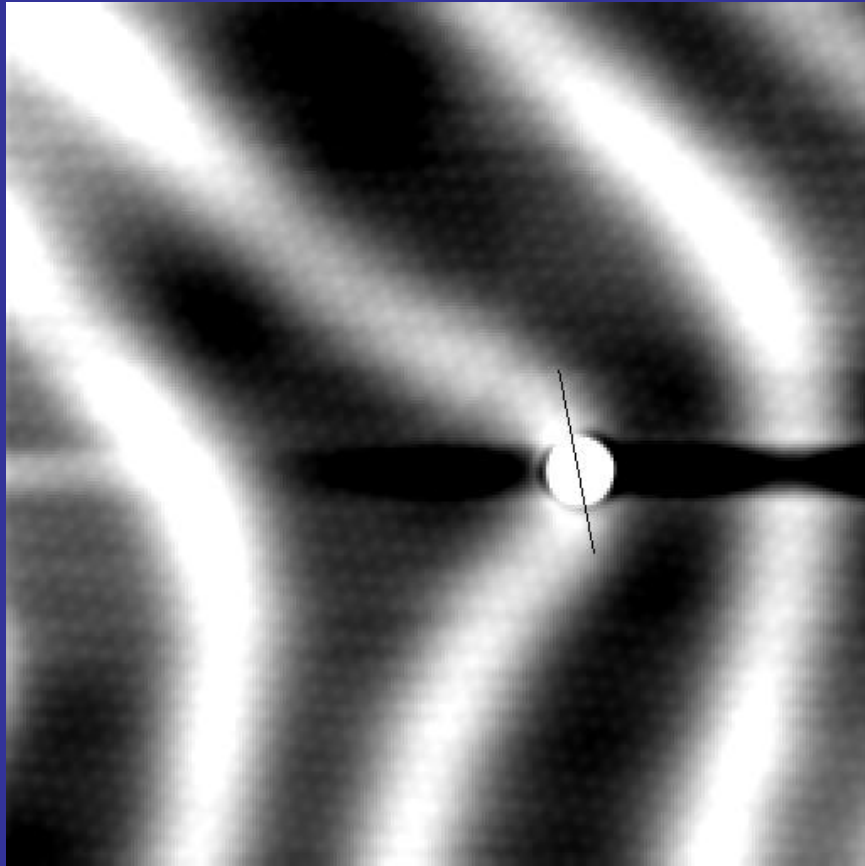
images taken at 5.5 pA



10 pA 800 mV

LT UHV STM
5 K

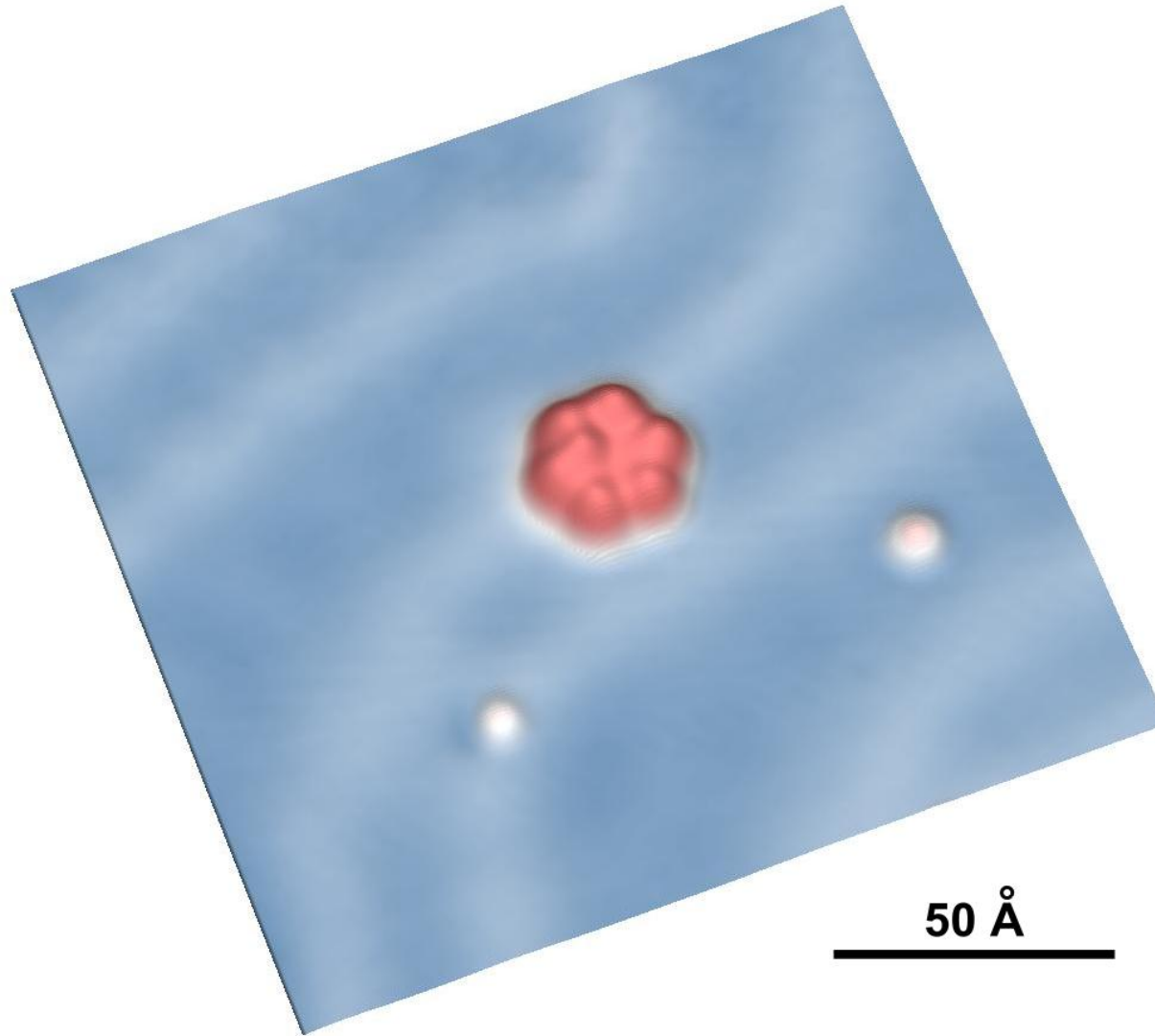
Au(111)



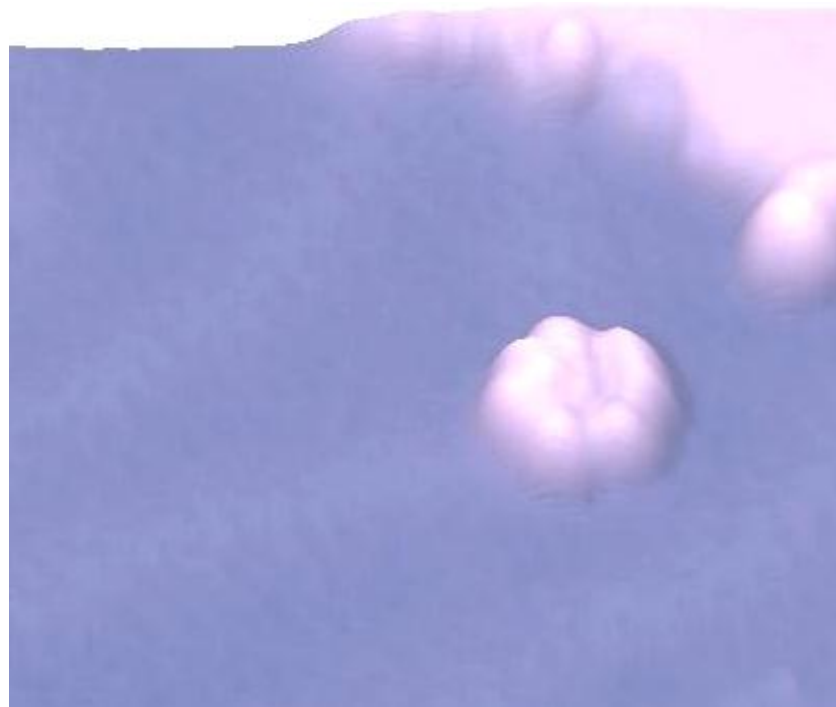
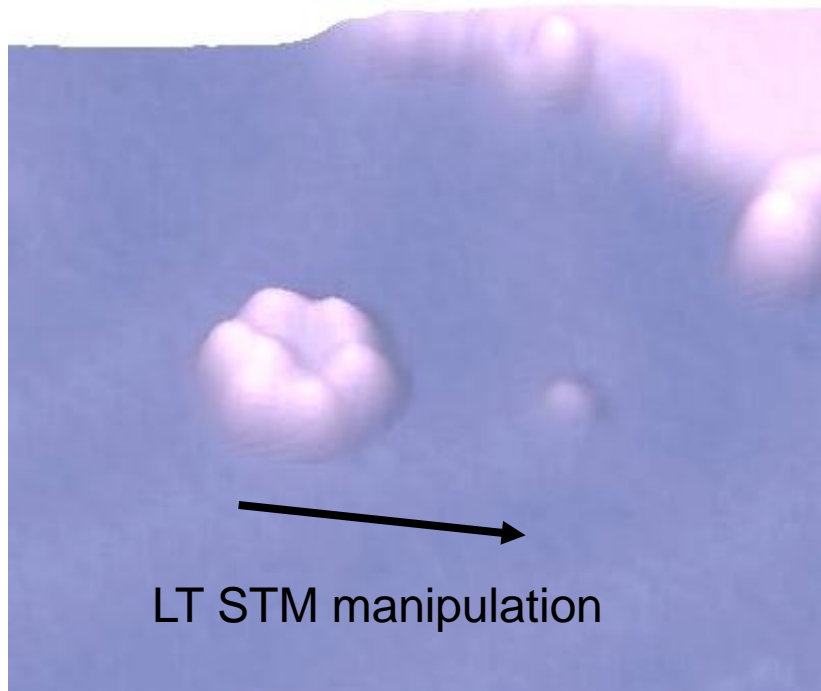
Height aprox 1.4 Å

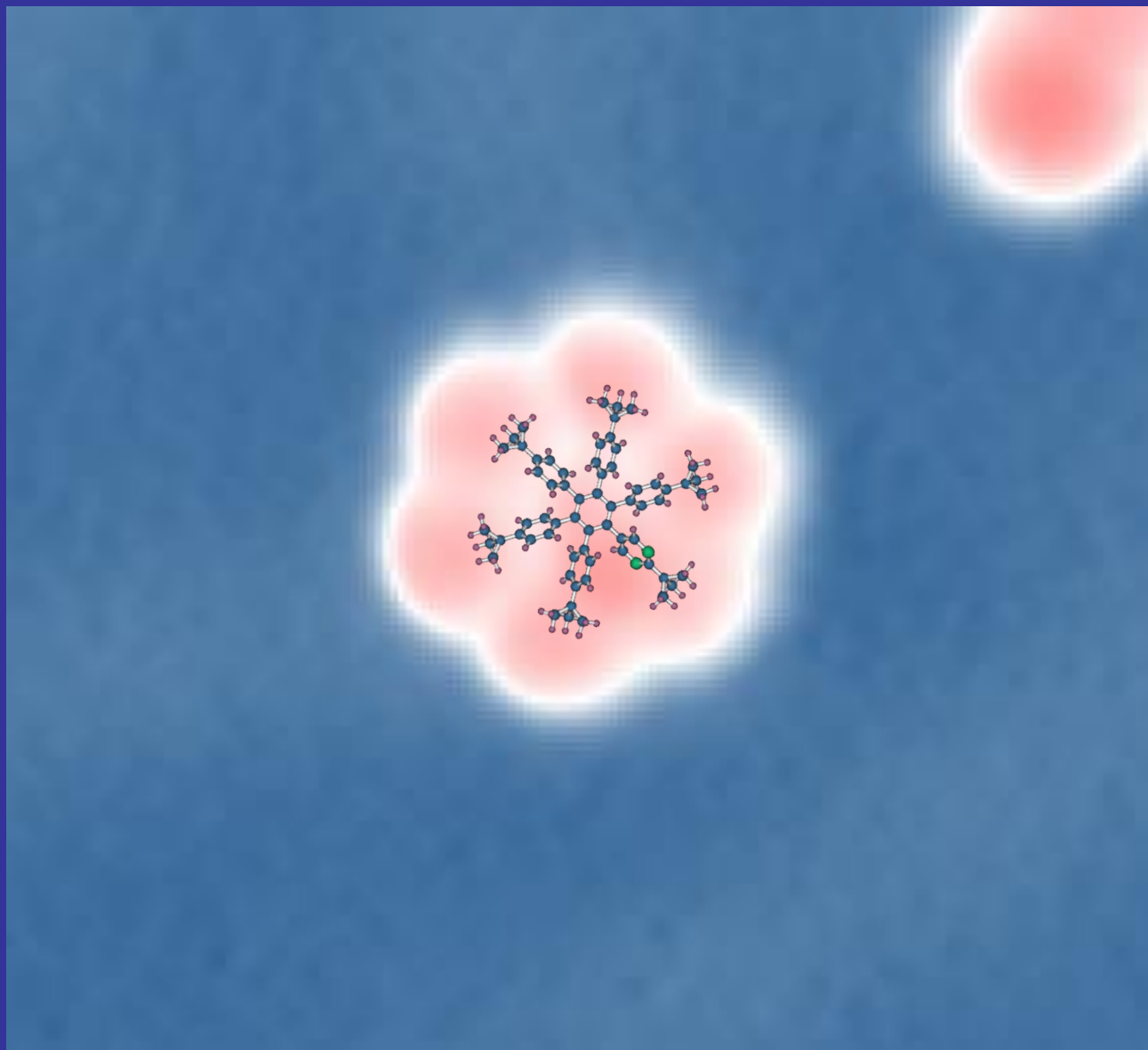
5.2×10^{-11} A 100 mV

molecule Gear on Au(111)

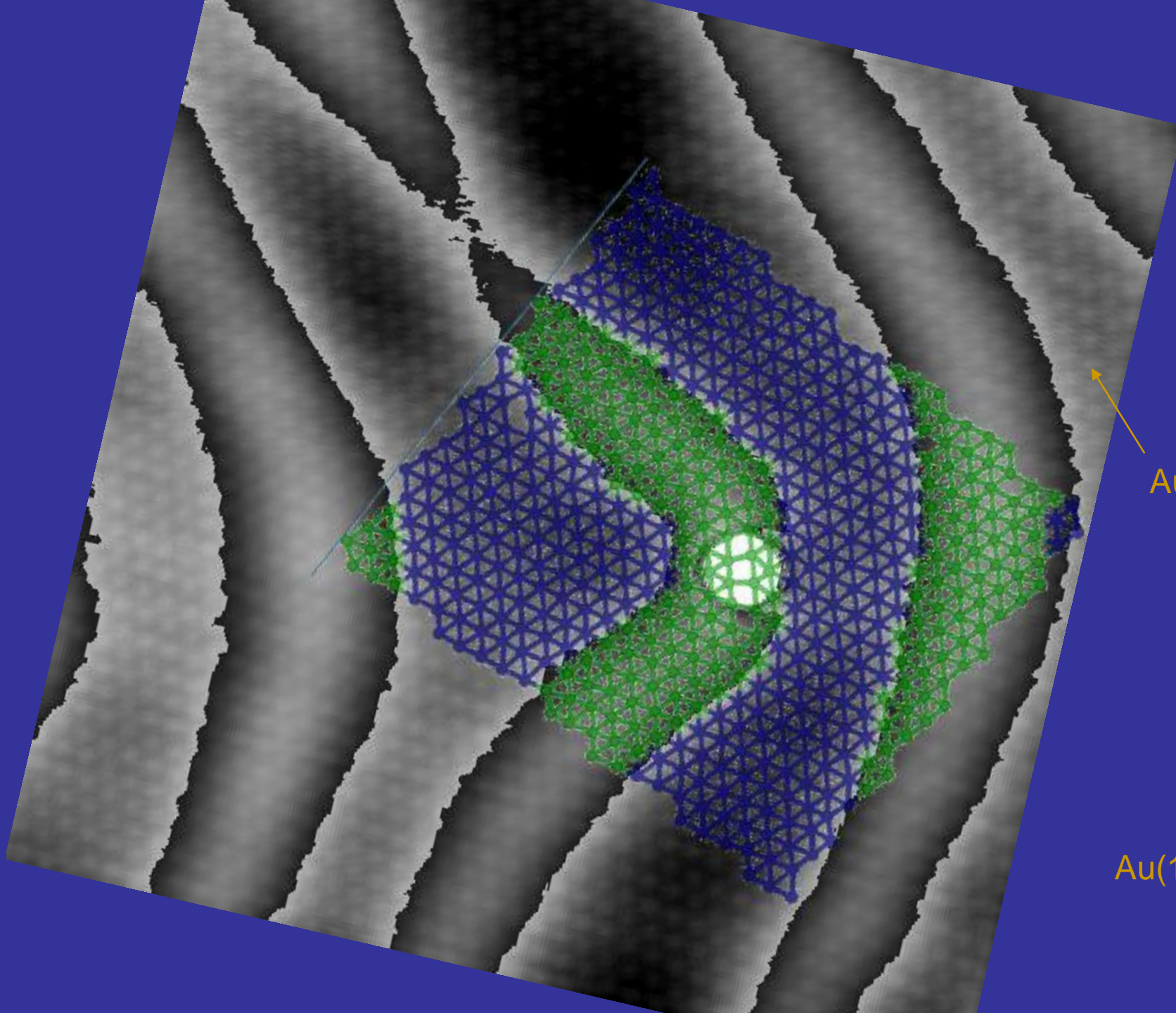


LT-UHV-STM image, $I=1$ pA, $V= 500$ mV





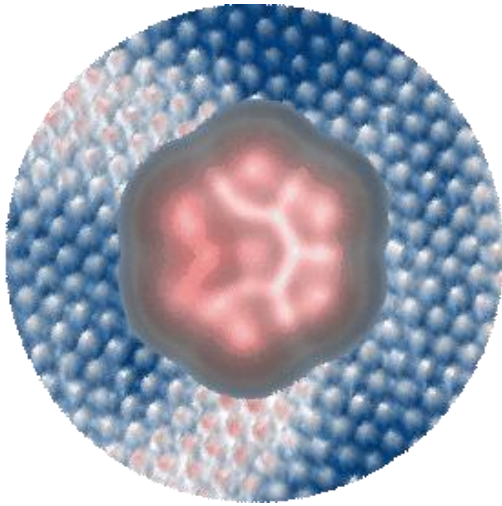
C. Manzano, Nature Mat., 8, 576 (2009)



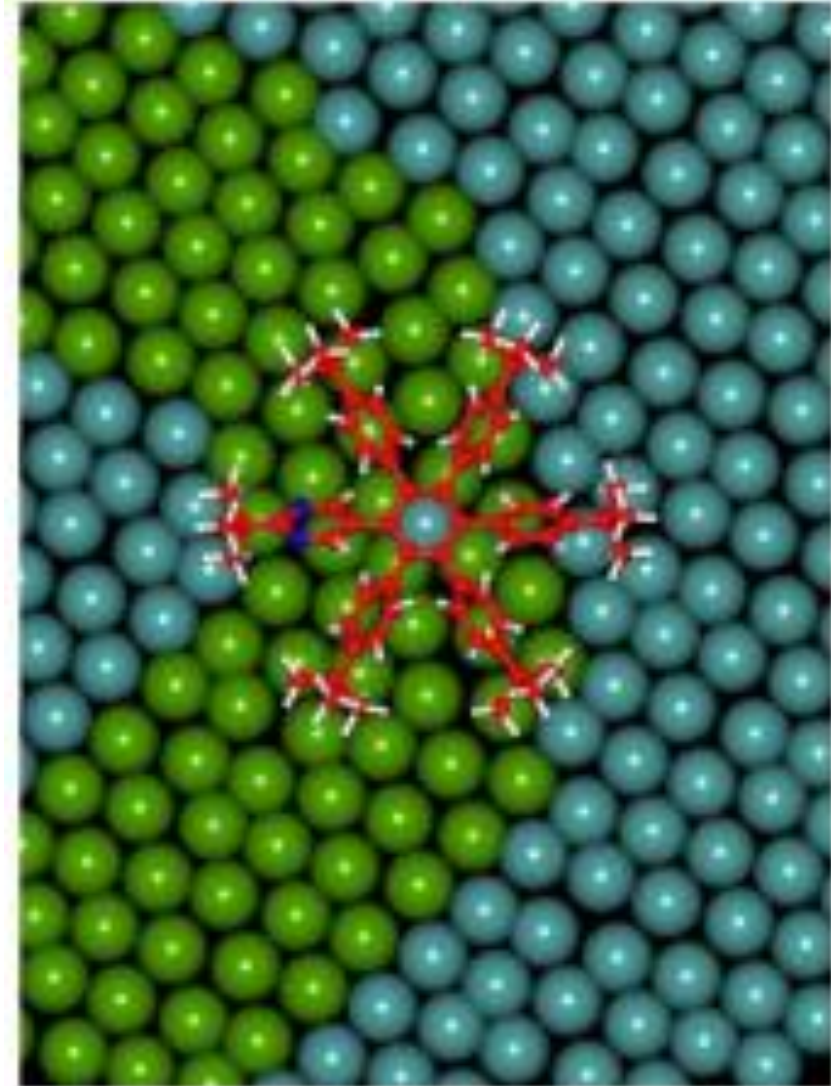
Au

Au(111)

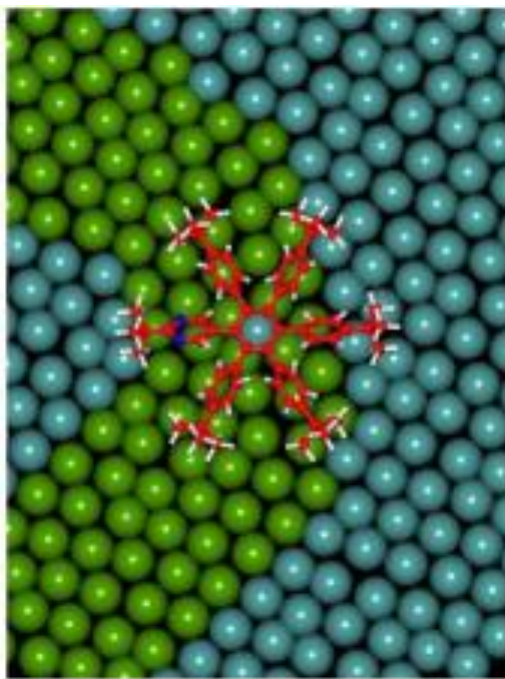
Mounting the gear on the Au(111) reconstruction ?



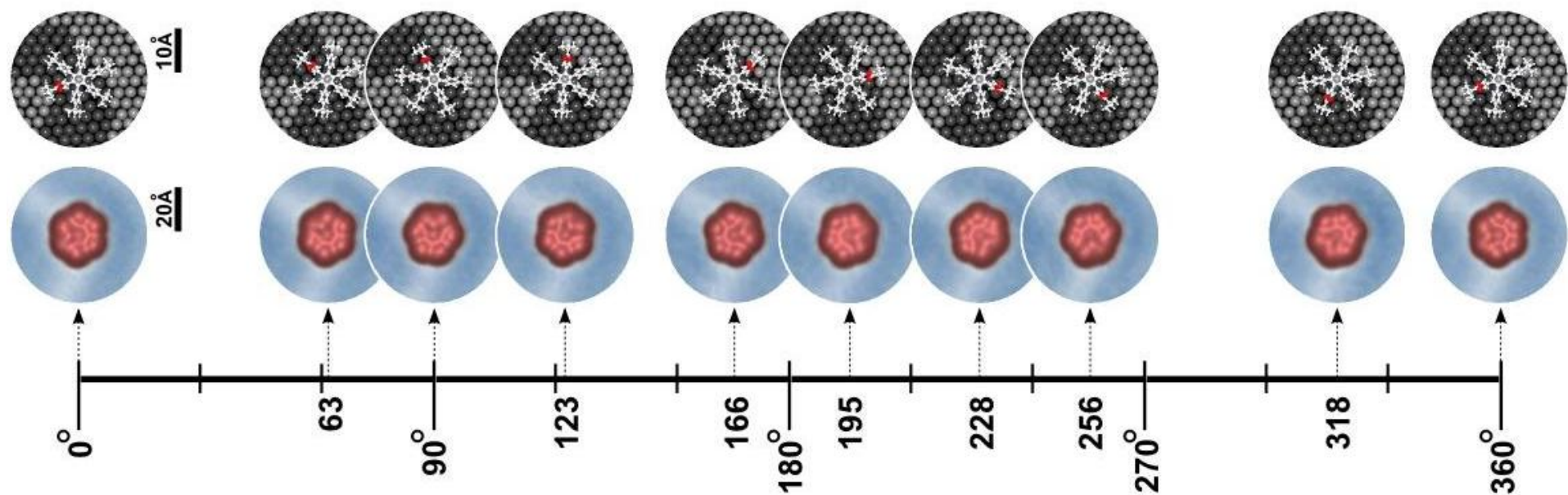
Au(111) reconstruction

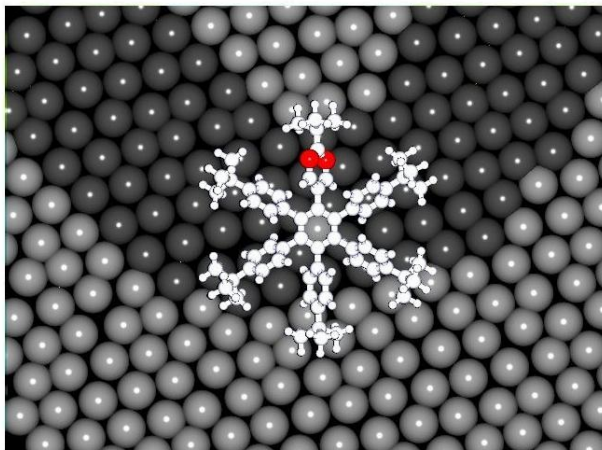


Step by step
decomposition
of the rotation

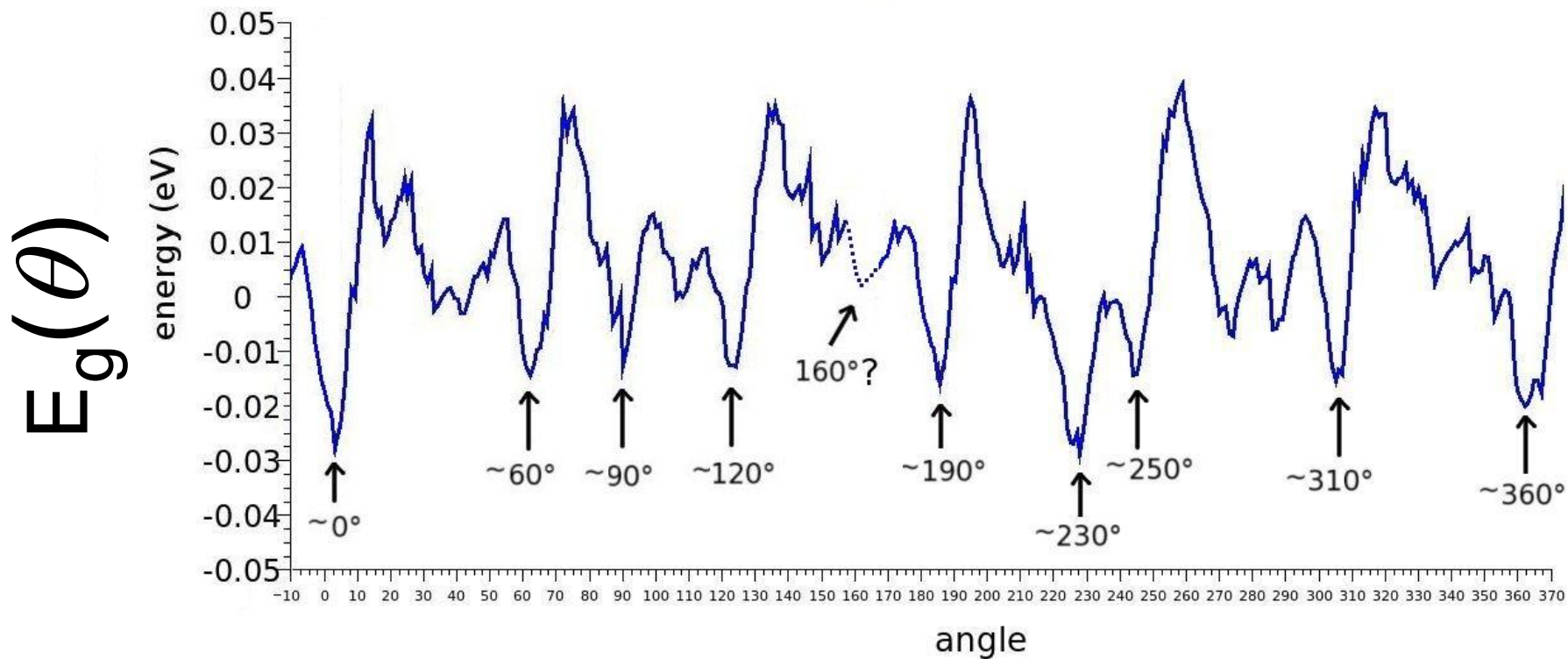


$$E_g(\theta)$$





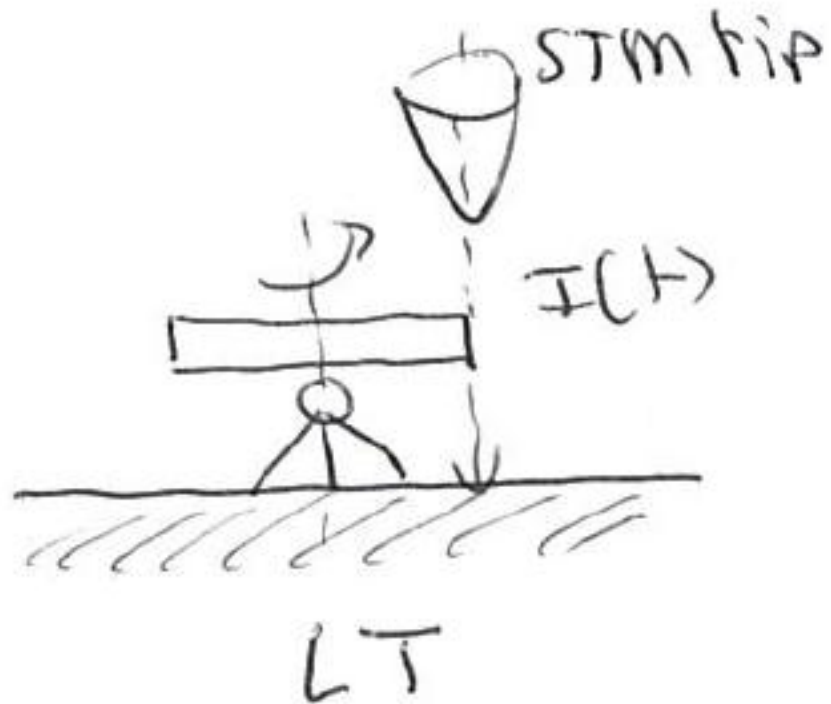
The 9 stations explored
by the molecule gear



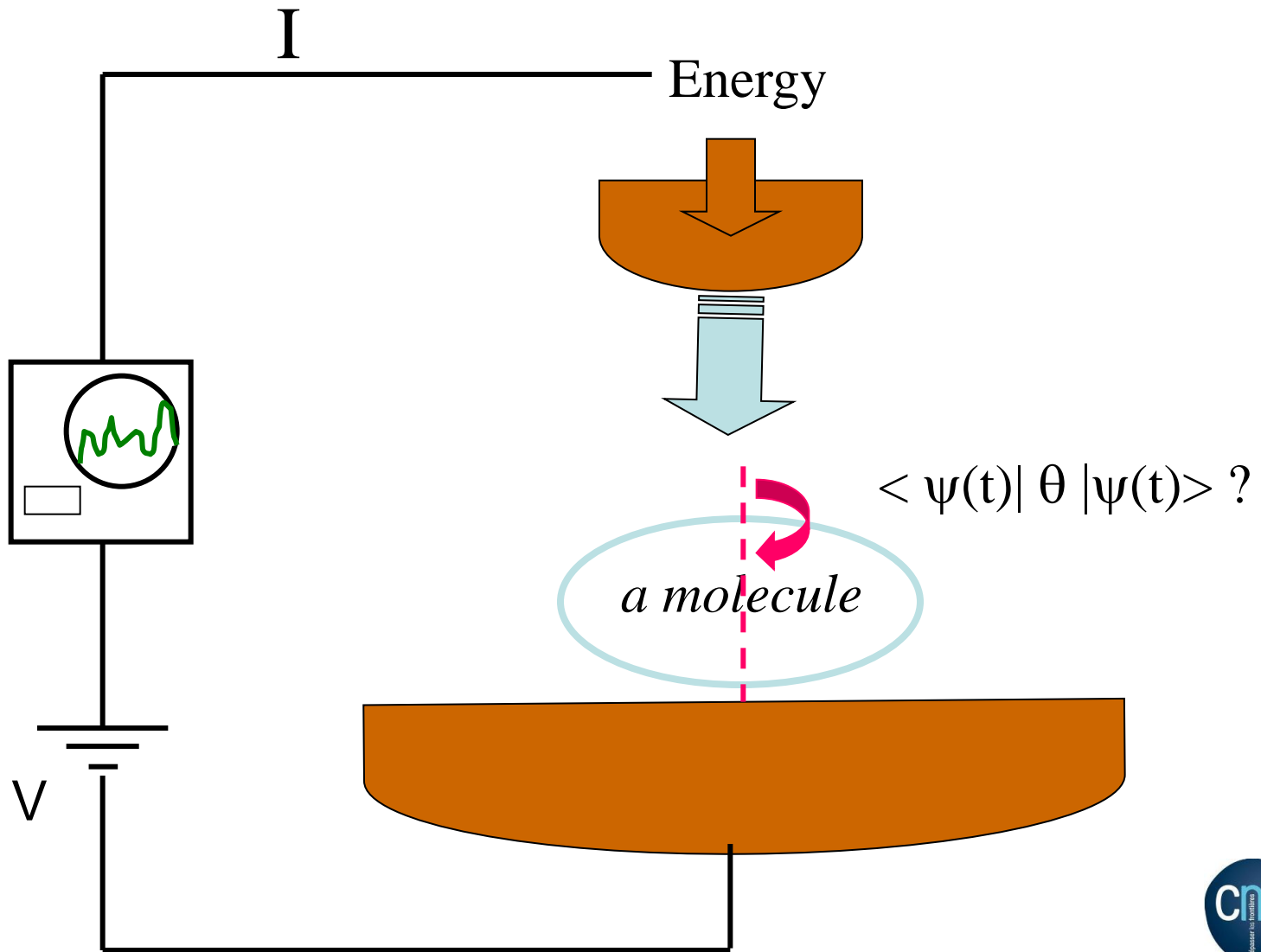
ASED+ calculations

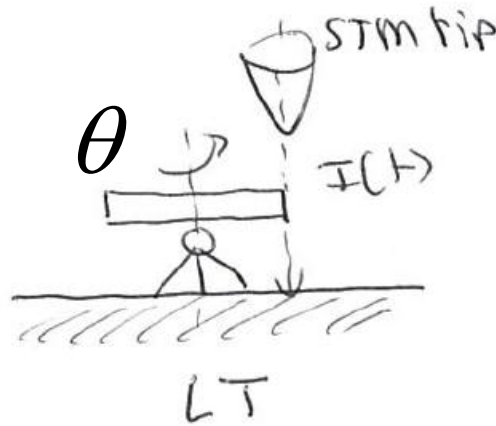
C. Manzano, Nature Mat., 8, 576 (2009)

Molécule sur une surface (3)



Shot noise driving of a rotation ?

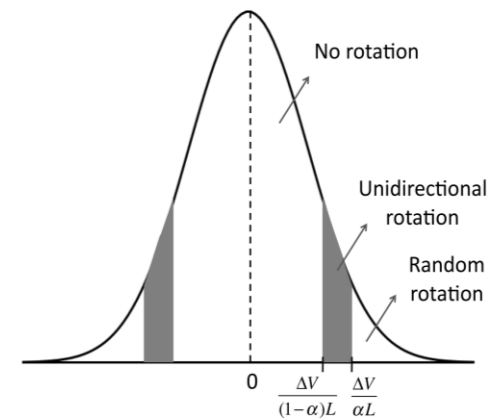




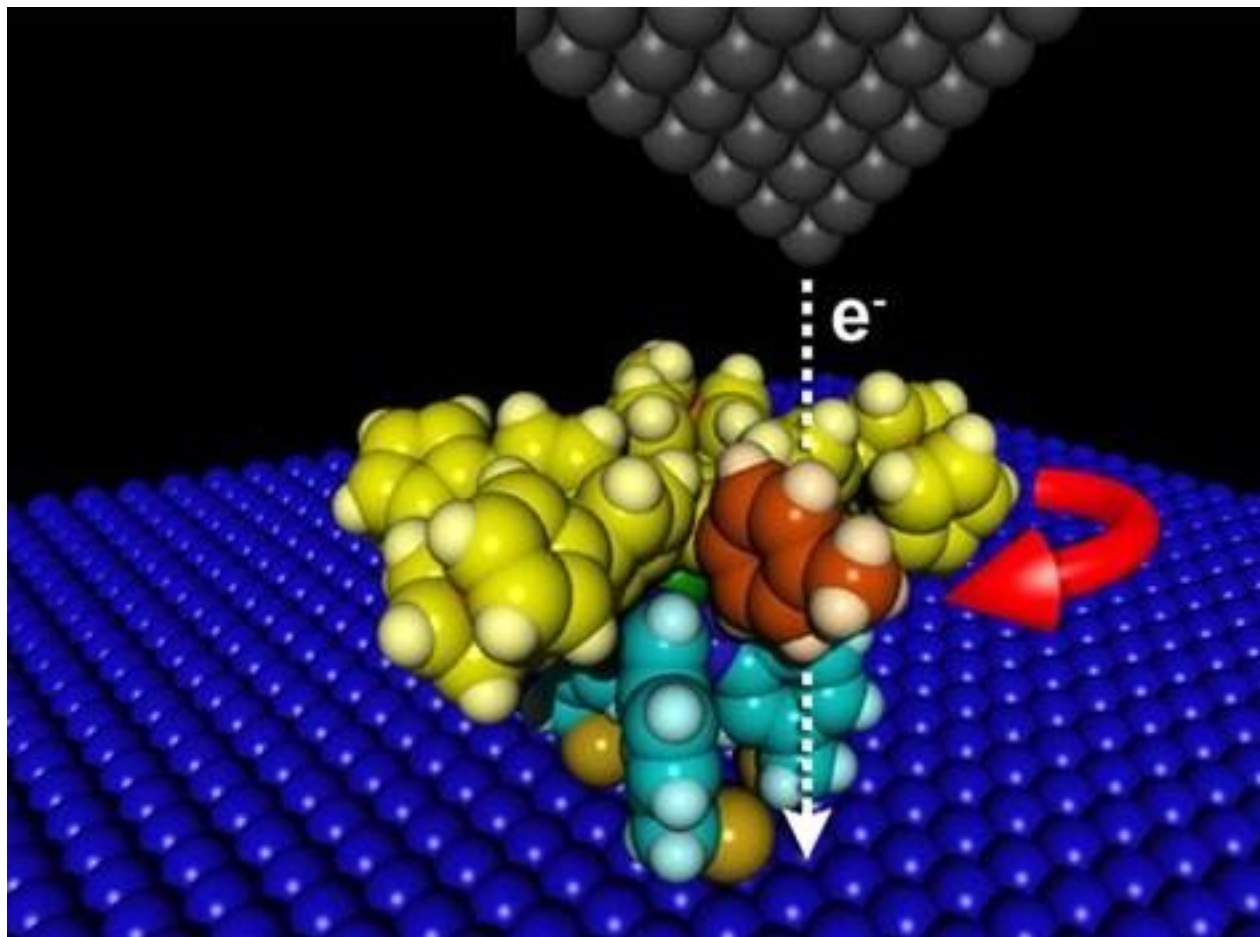
$$I \frac{d^2 \theta}{dt^2} = -\nabla V(\theta) - \mu \frac{d\theta}{dt} + F(t)$$



$$a_1(t) E_g(\theta) + a_2(t) E_{\pi^*}$$

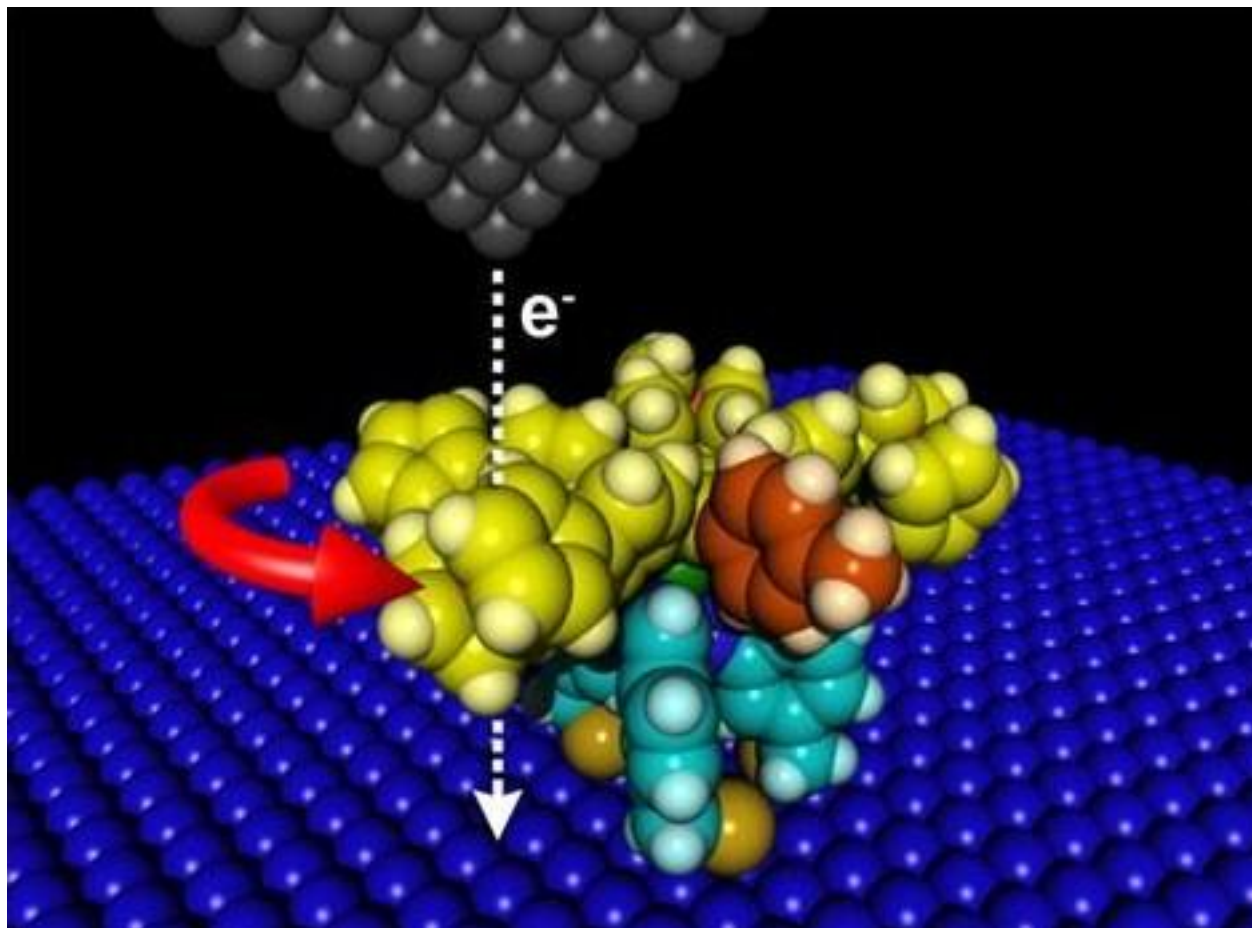


Tunnel current (Shot noise)



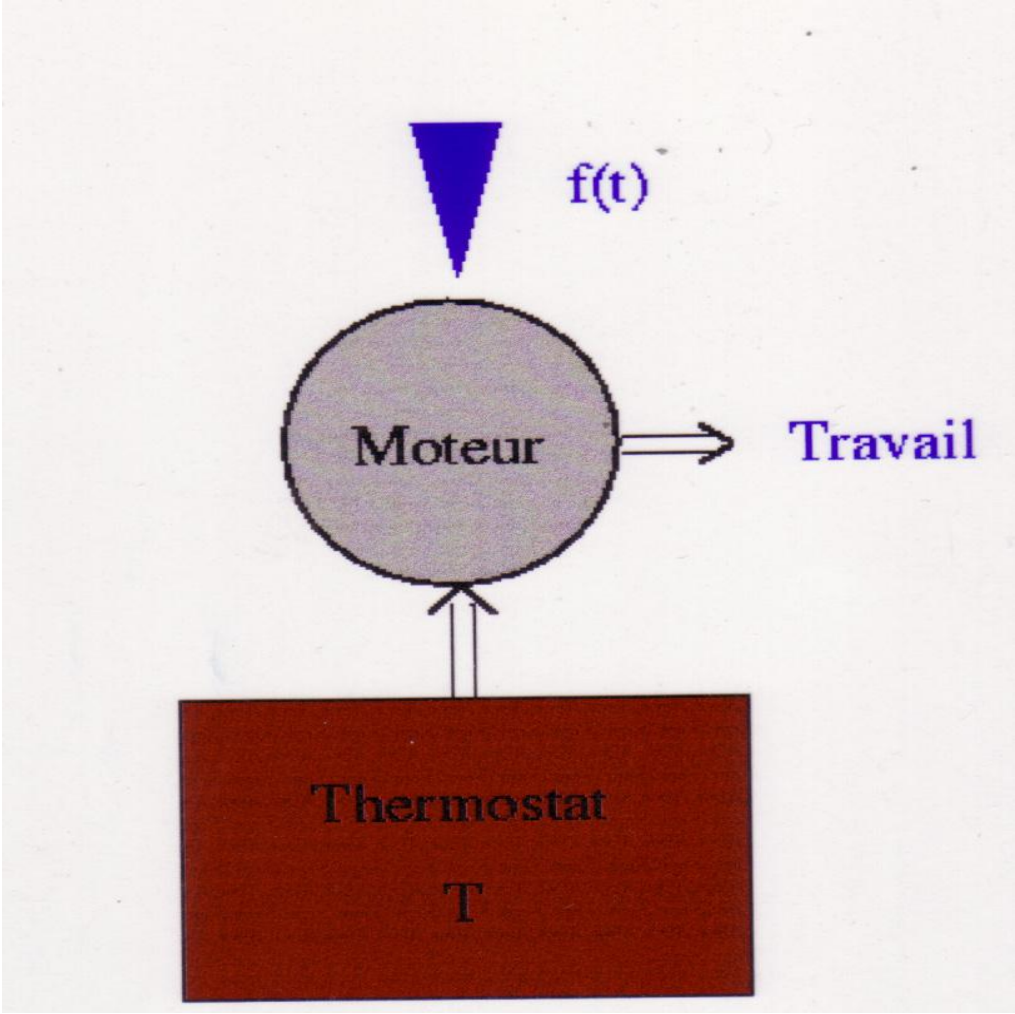
$$E_{\pi^*}^1$$

U.G.E. Perera, F. Ample, H. Kersell, Y. Zhang, G. Vives, J. Echeverria, M. Grisolia, G. Rapenne, C. Joachim, S.-W. Hla, Nature Nano., in press (2012).



$$E_{\pi^*}^2$$

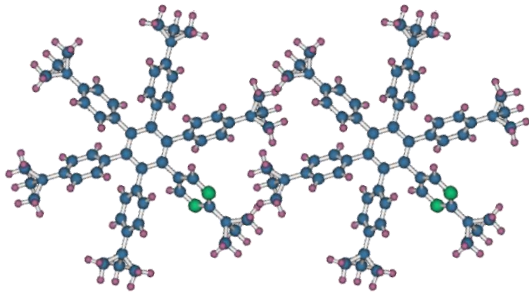
U.G.E. Perera, F. Ample, H. Kersell, Y. Zhang, G. Vives, J. Echeverria, M. Grisolia, G. Rapenne, C. Joachim, S.-W. Hla, Nature Nano., in press (2012).



?

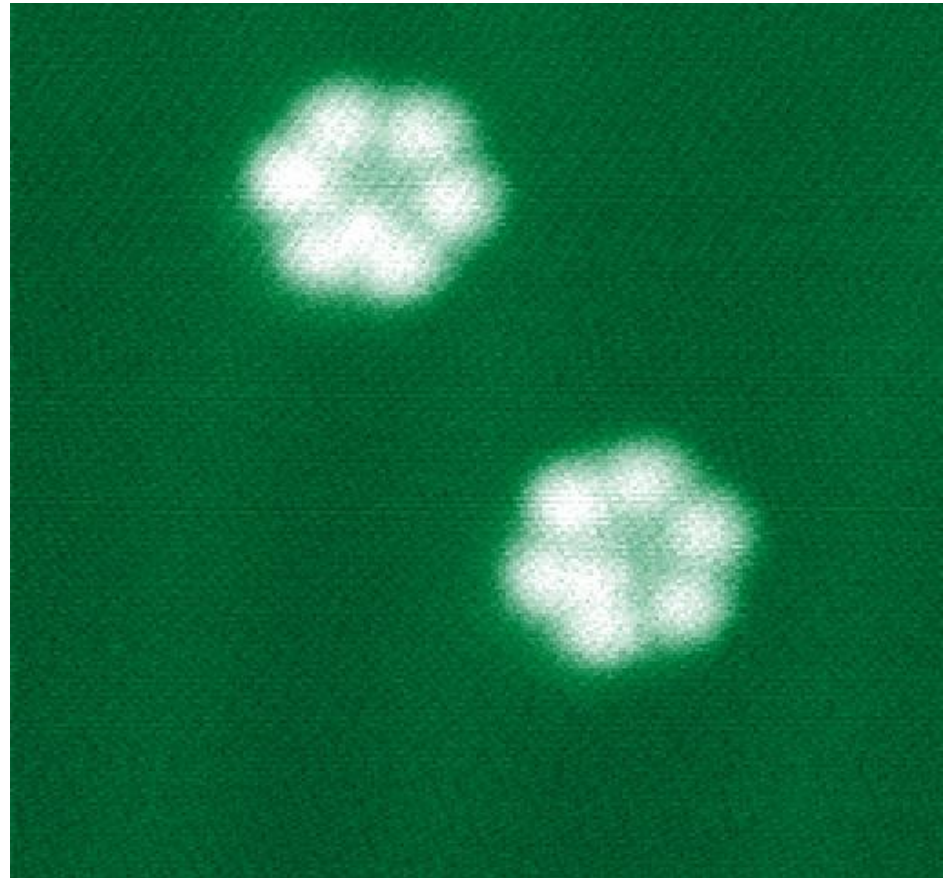
2) Transmettre du mouvement



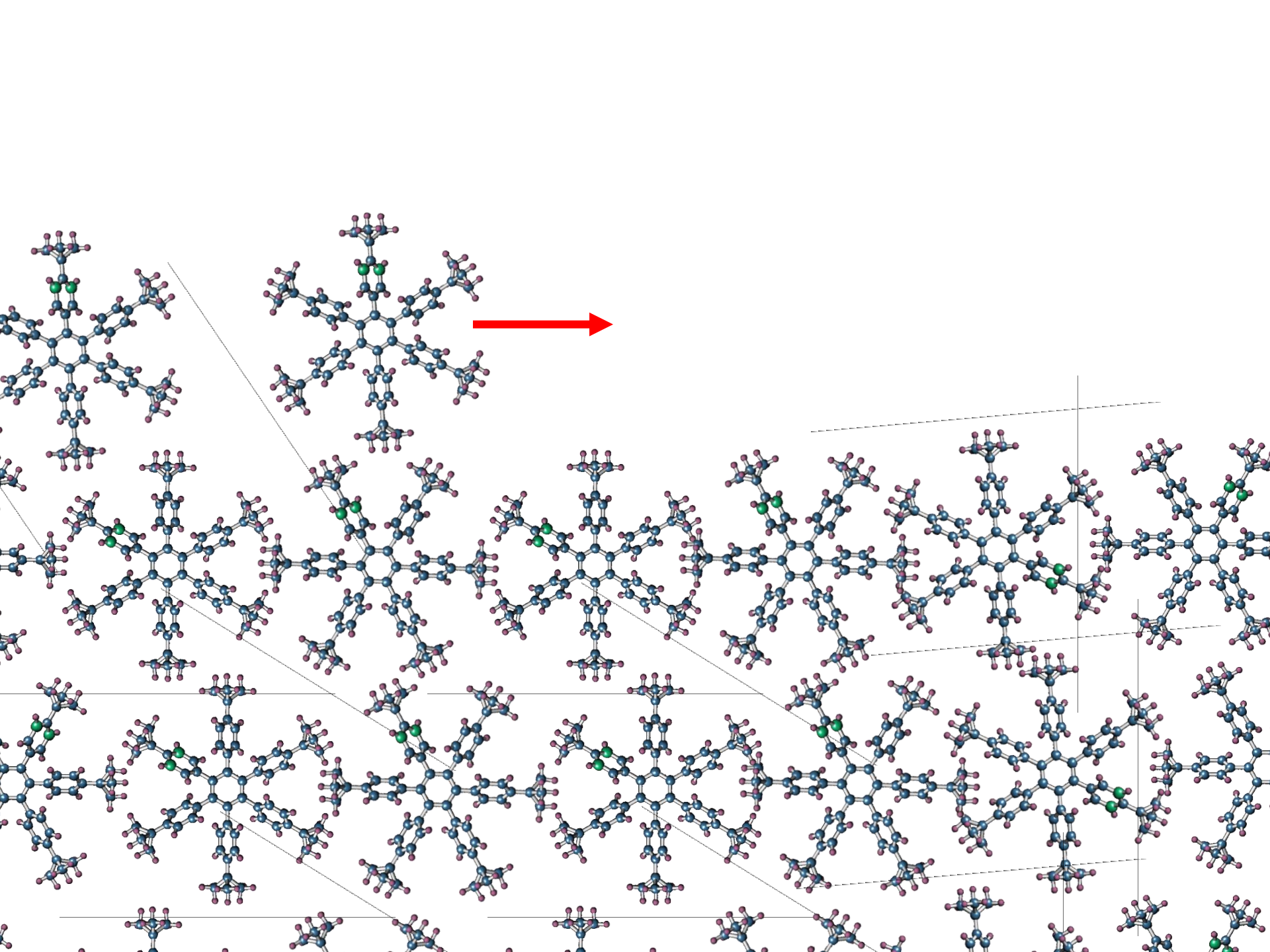


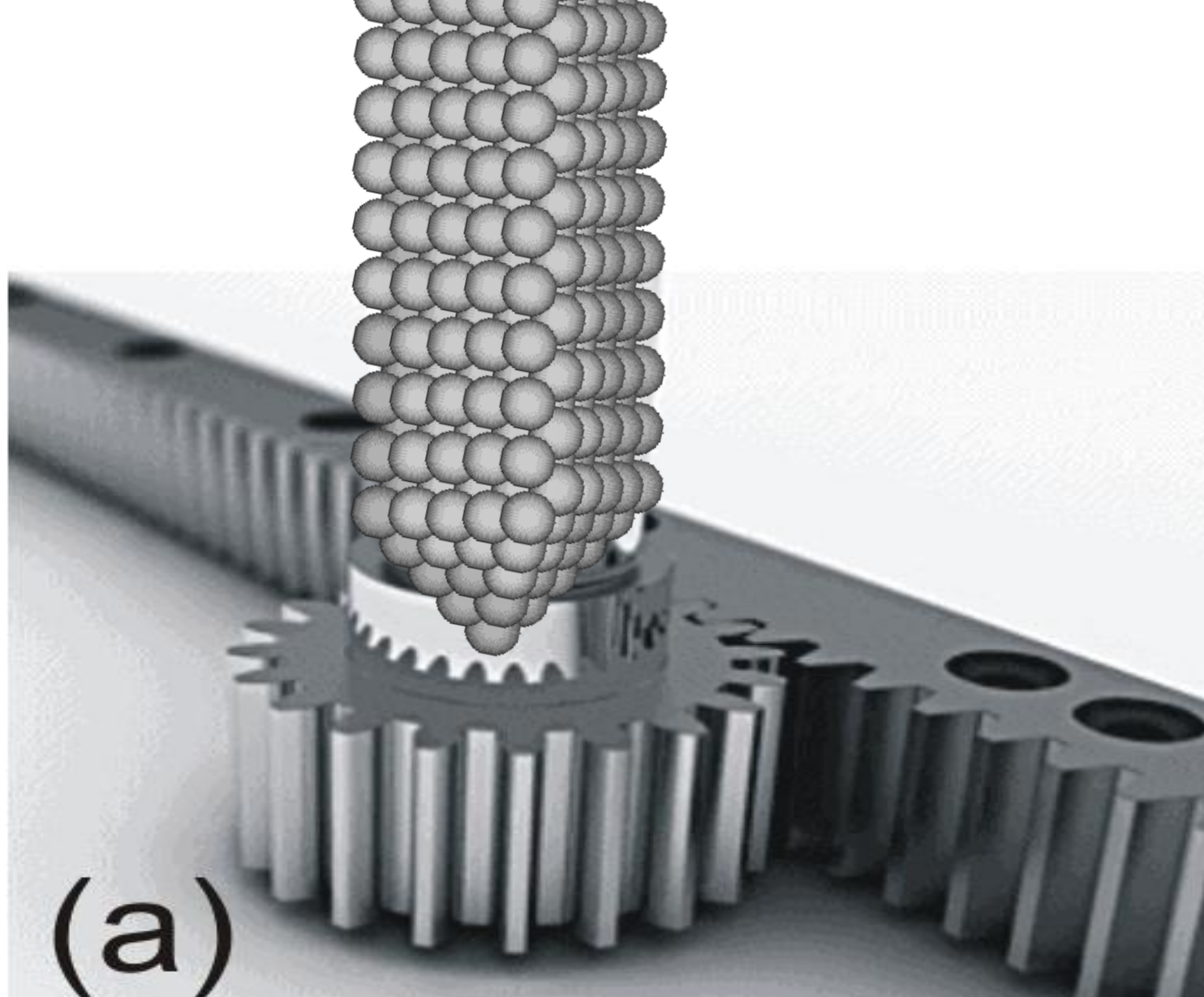
Construction
d'un train de 2 engrenages?

1.2 nm

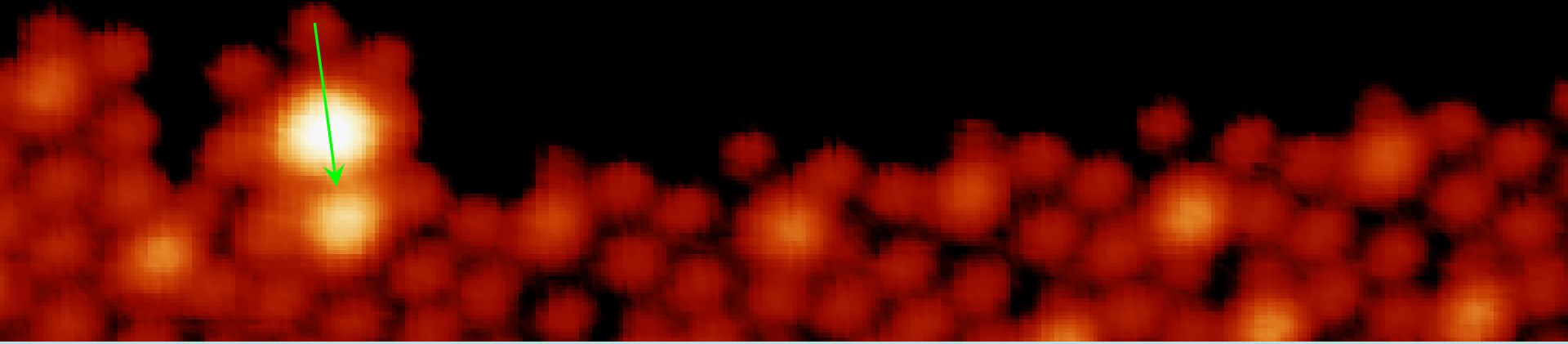






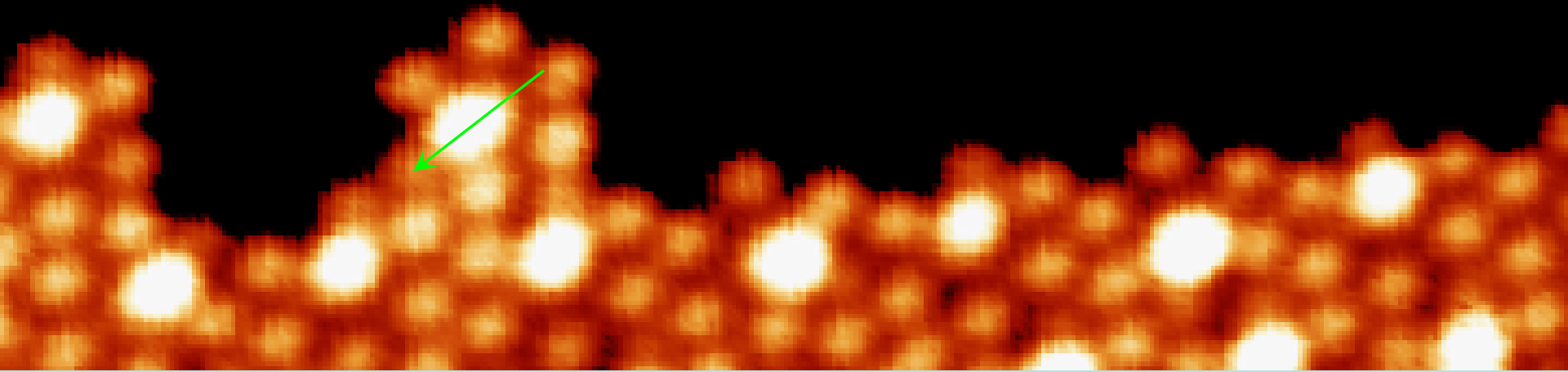


0 deg
reference point

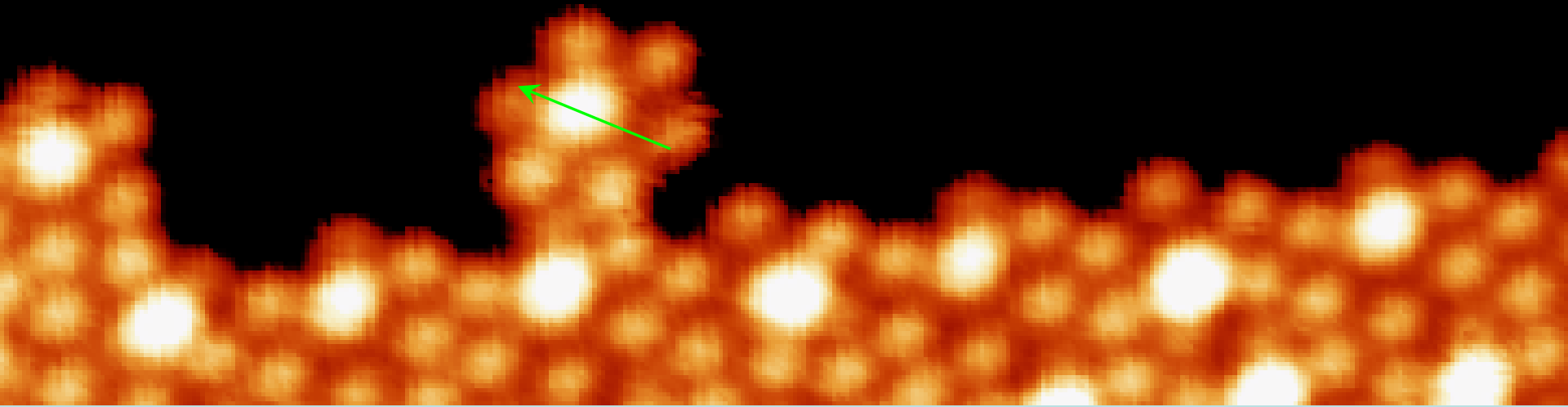


Manipulations are performed always starting from the center of the molecule moving parallel to the island border, with a length equal to a molecular radius.

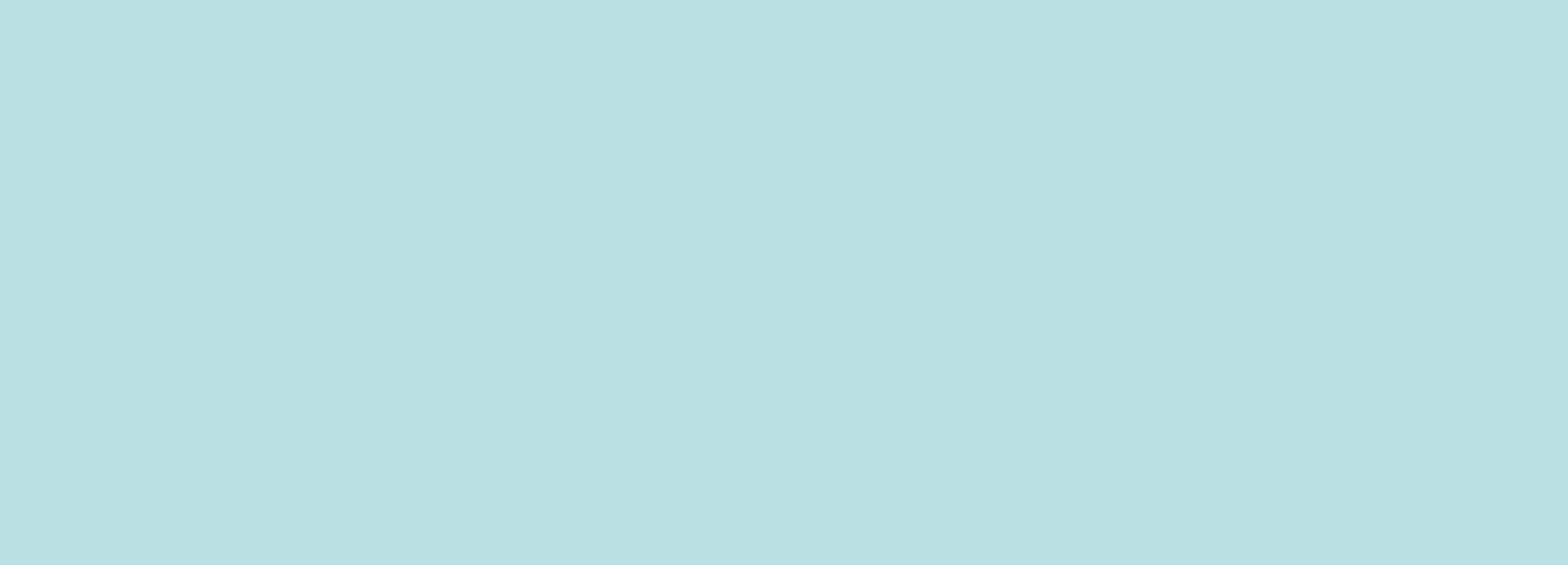
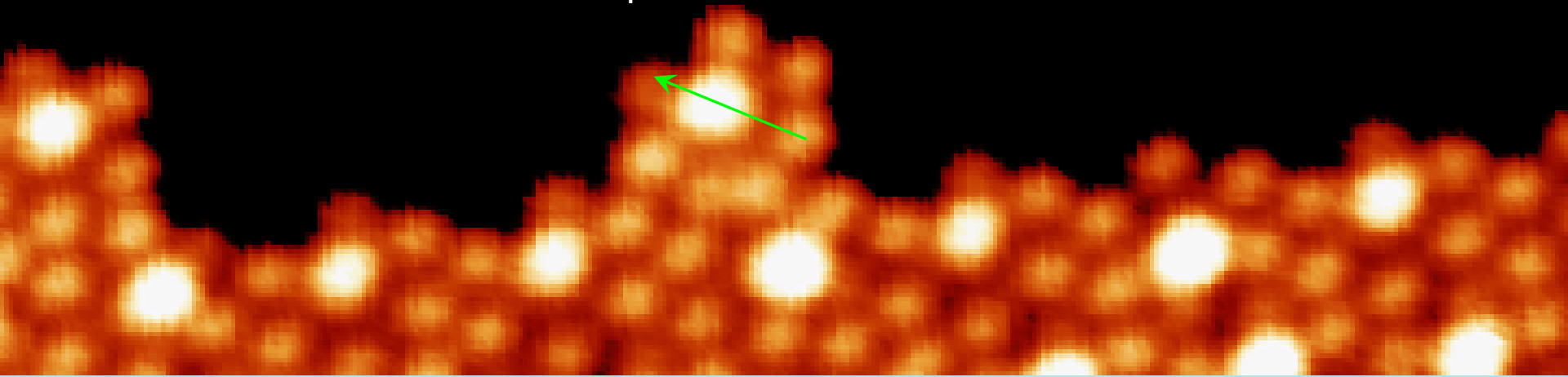
60 deg step
to stable position



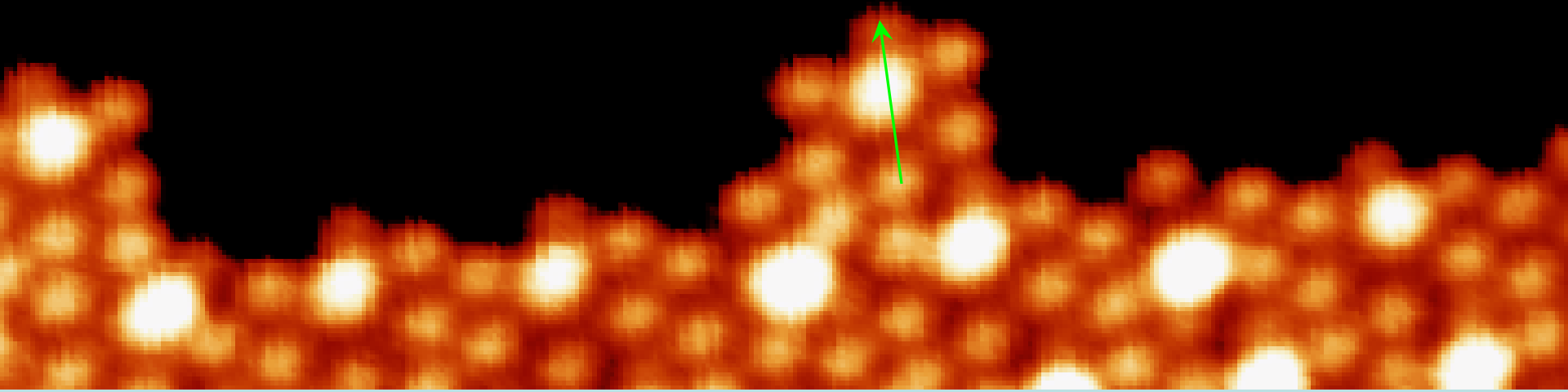
60 deg halfstep to
unstable position



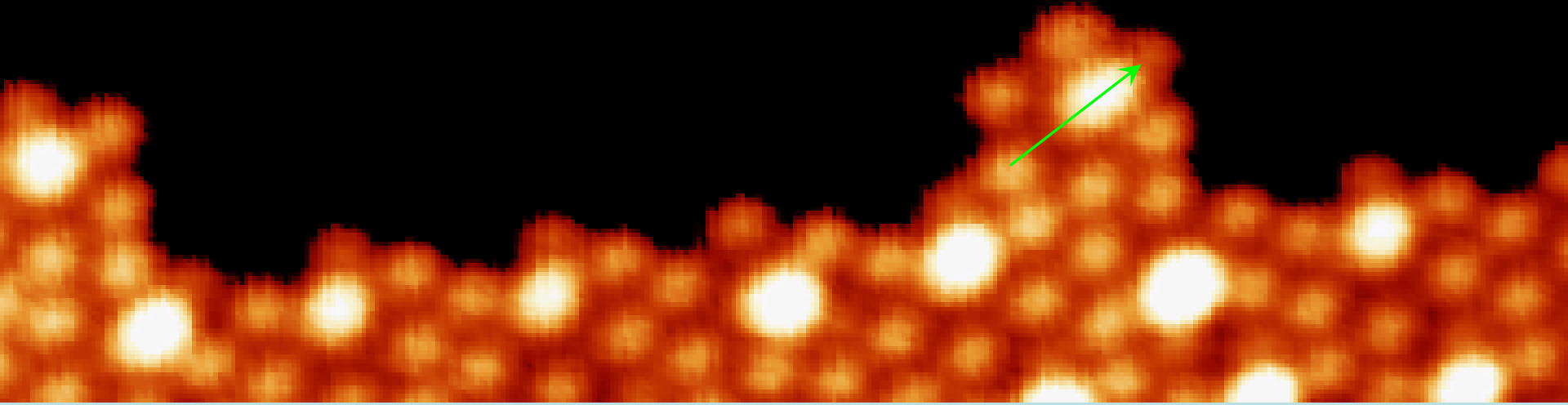
0 deg halfstep
(sliding) to stable
position



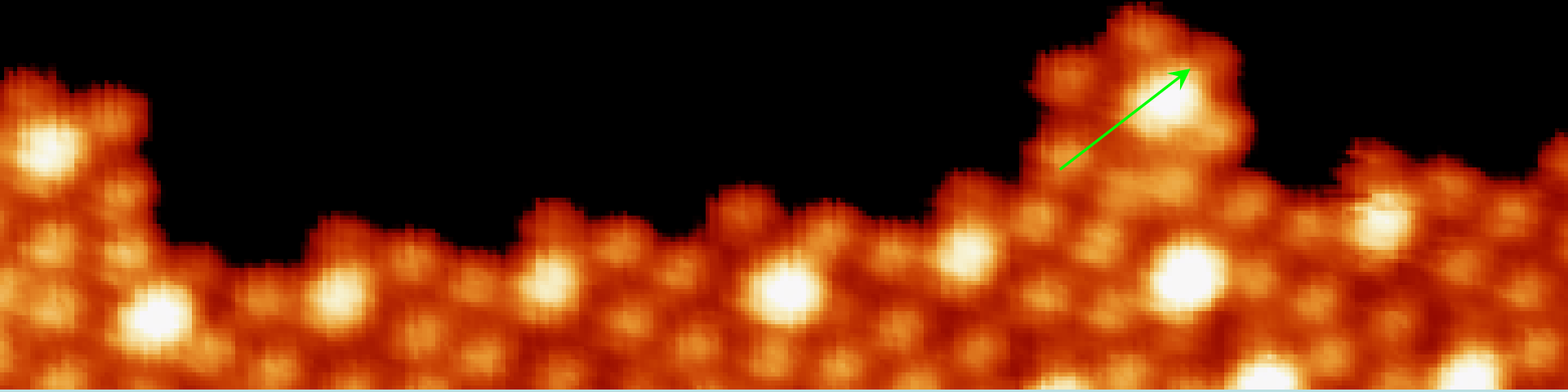
60 deg step
to stable position



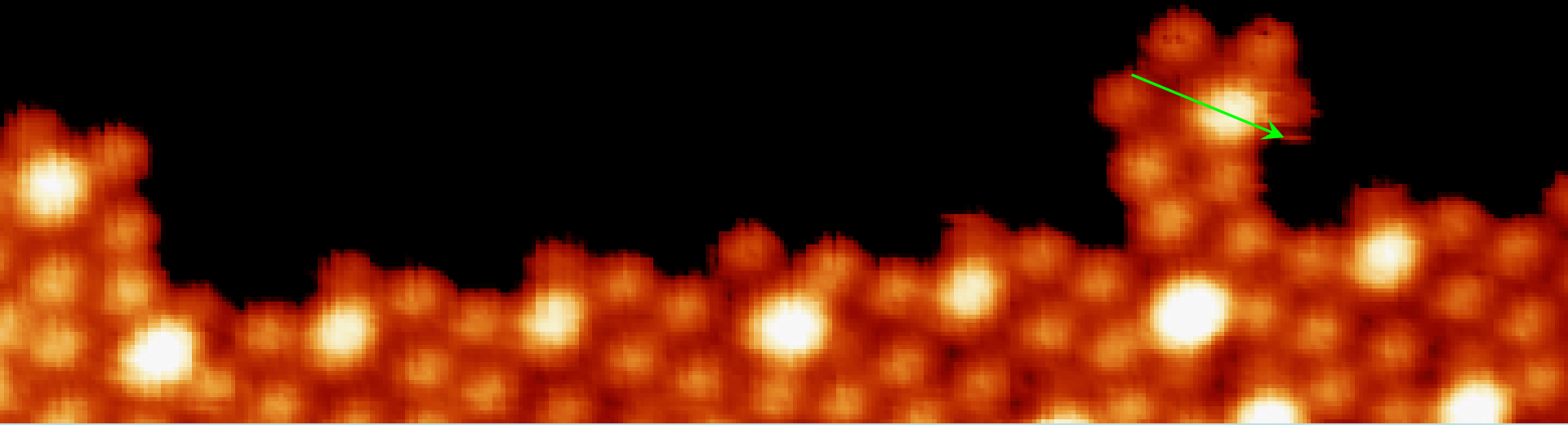
60 deg step
to stable position



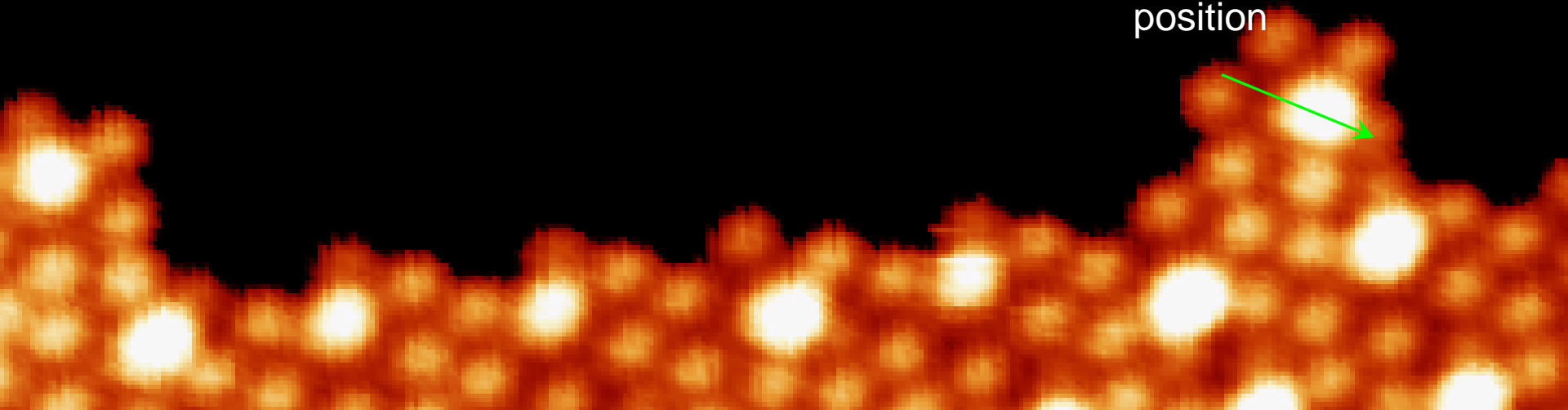
60 deg step
to stable position

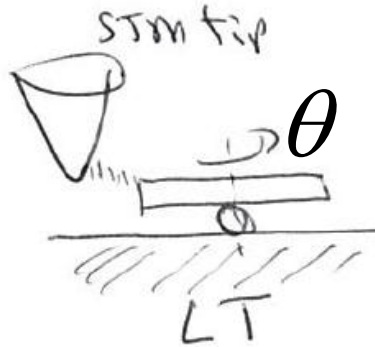


60 deg halfstep
to unstable position



0 deg halfstep
(sliding) to stable
position

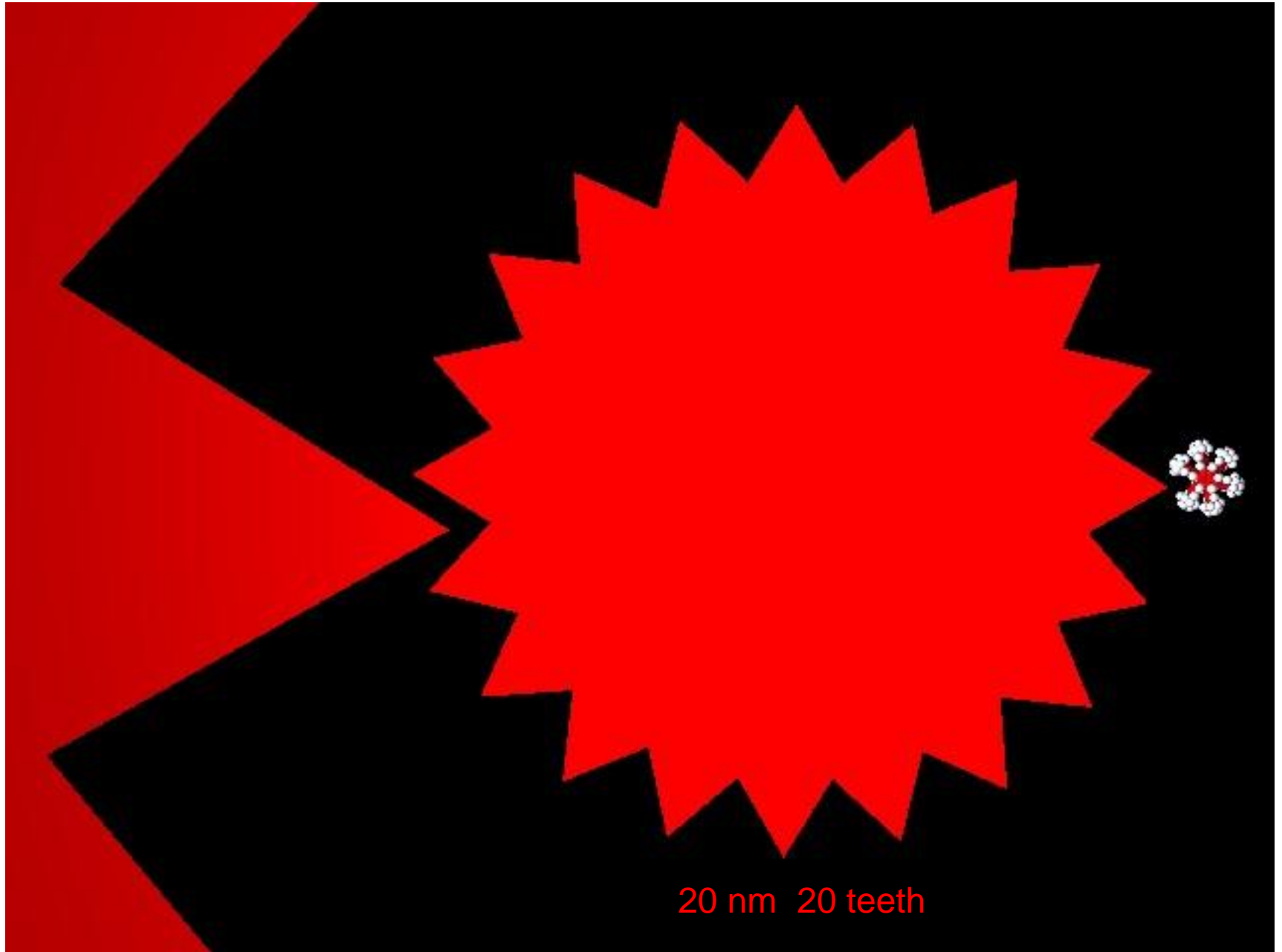




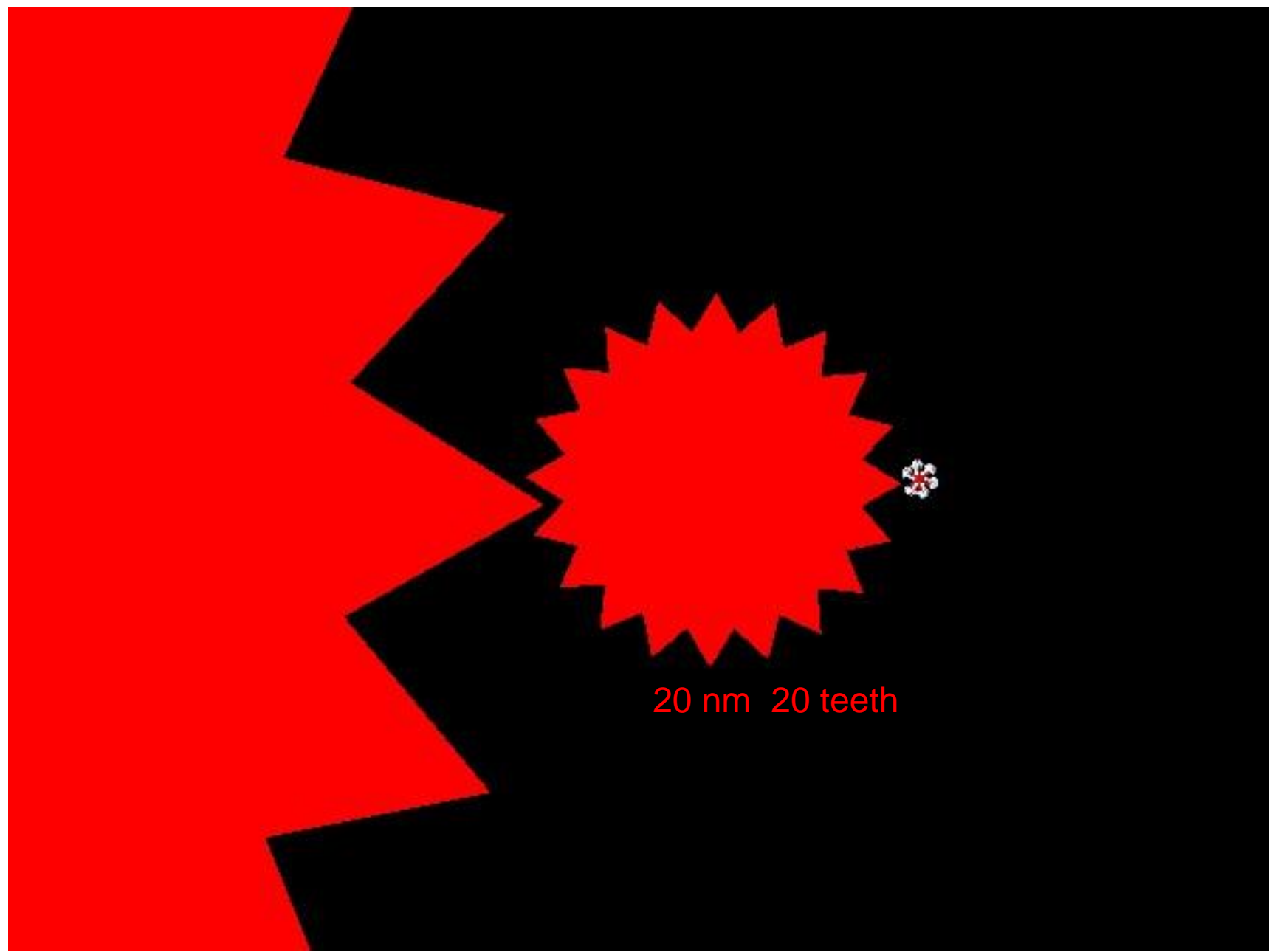
$$I \frac{d^2 \theta}{dt^2} = -\nabla V(\theta) - \mu \frac{d\theta}{dt} + F(t)$$



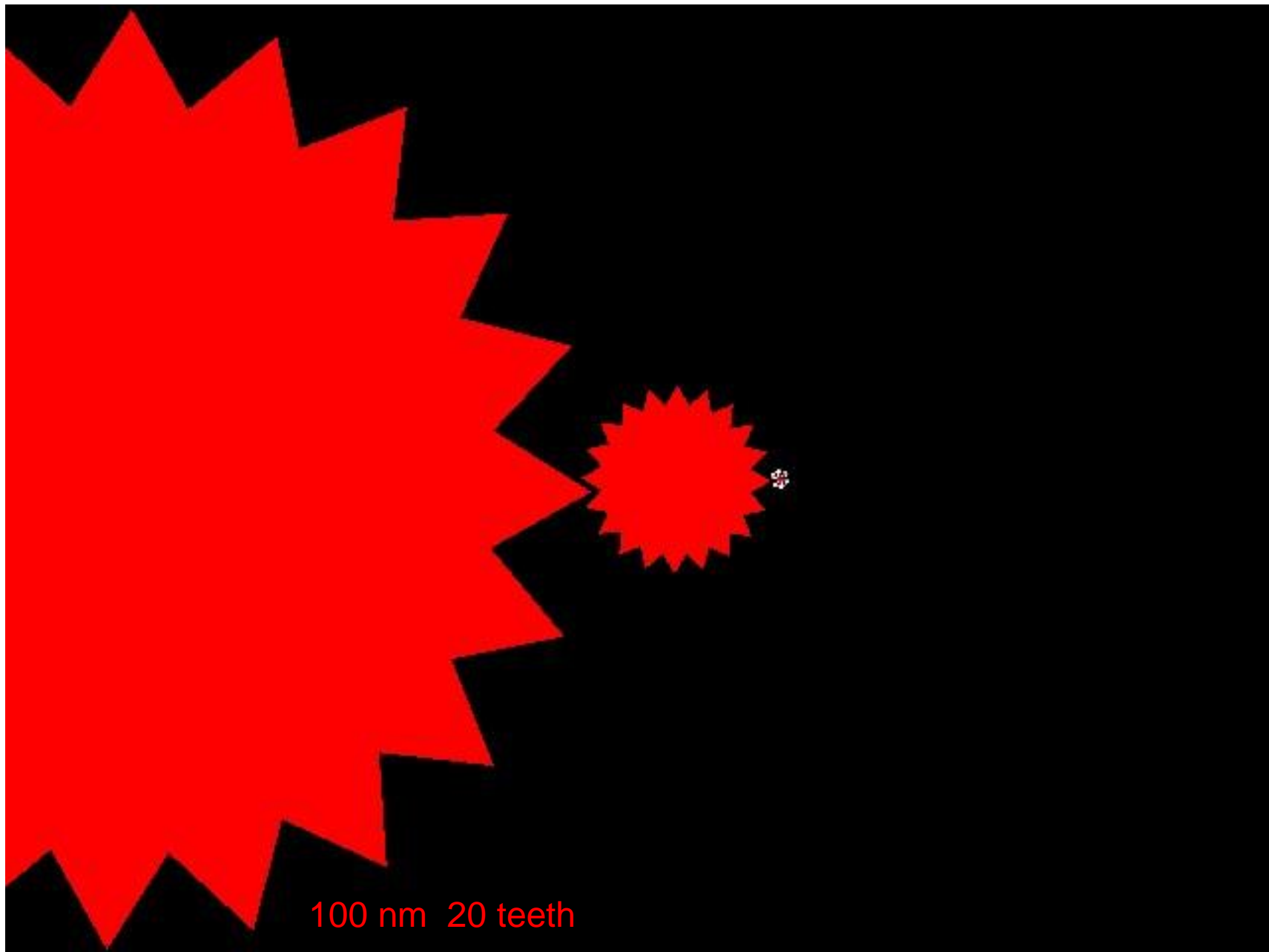
$$E_g(\theta) + a_0 \sin(k \cdot \theta)$$



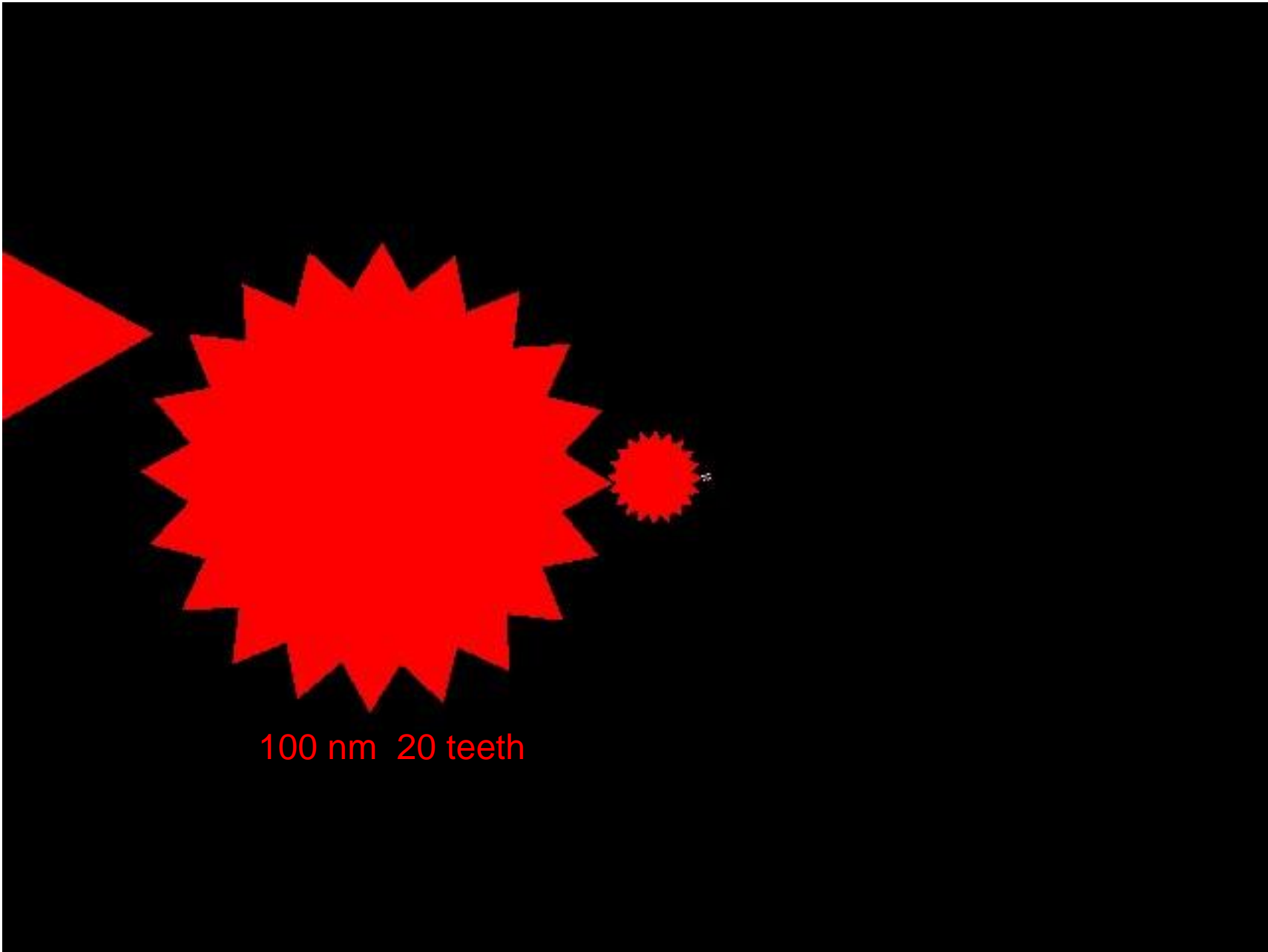
20 nm 20 teeth



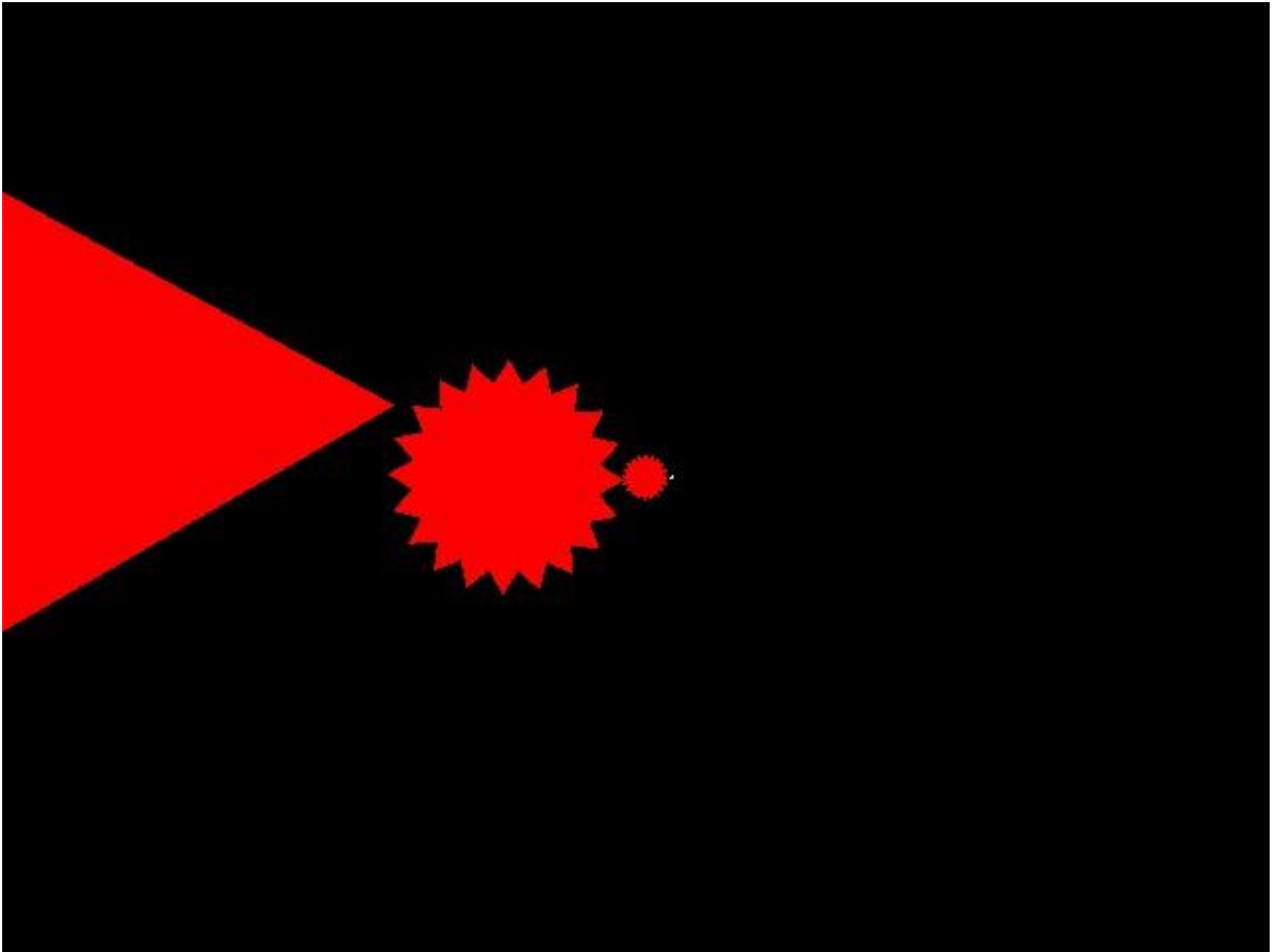
20 nm 20 teeth

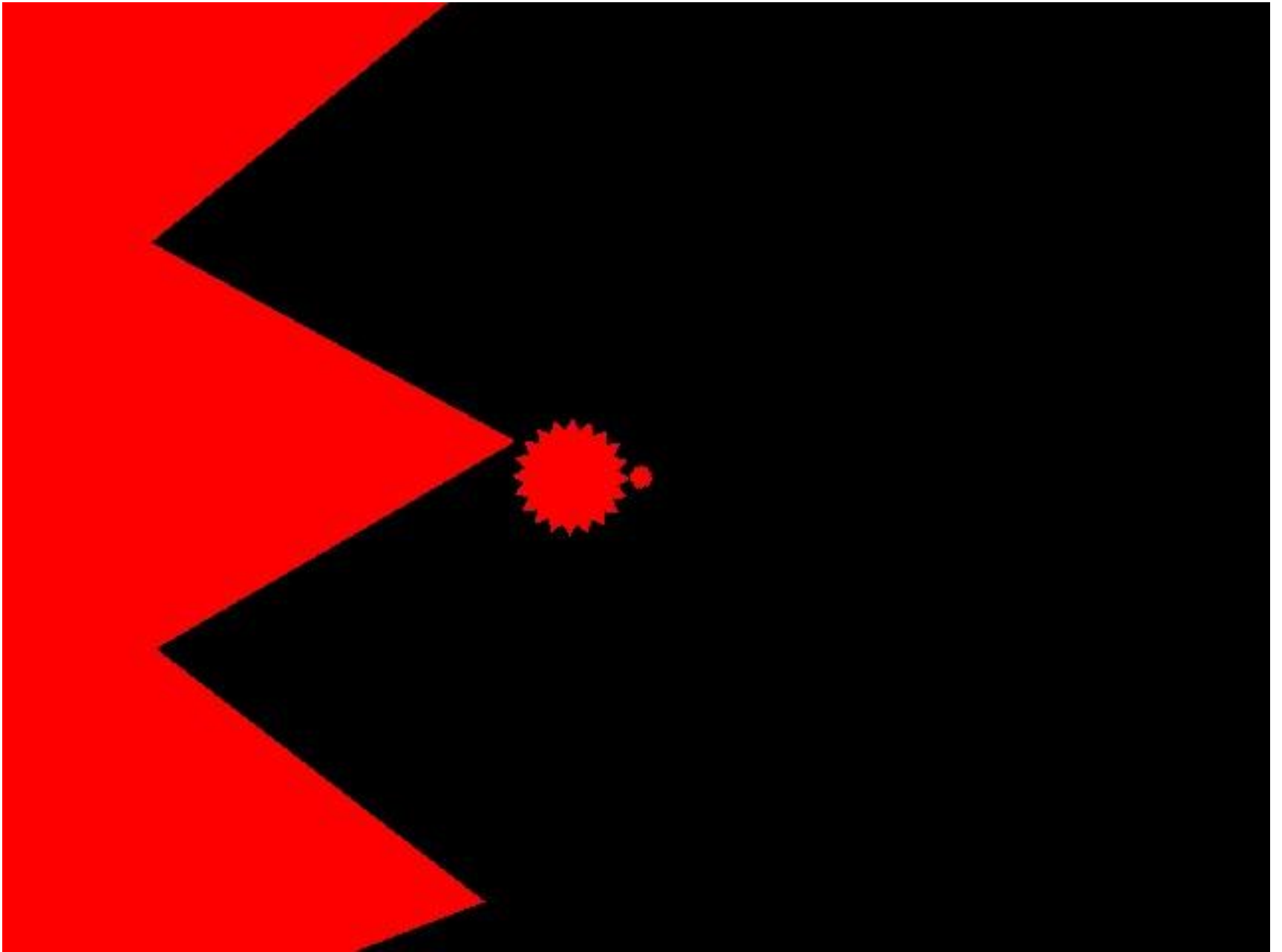


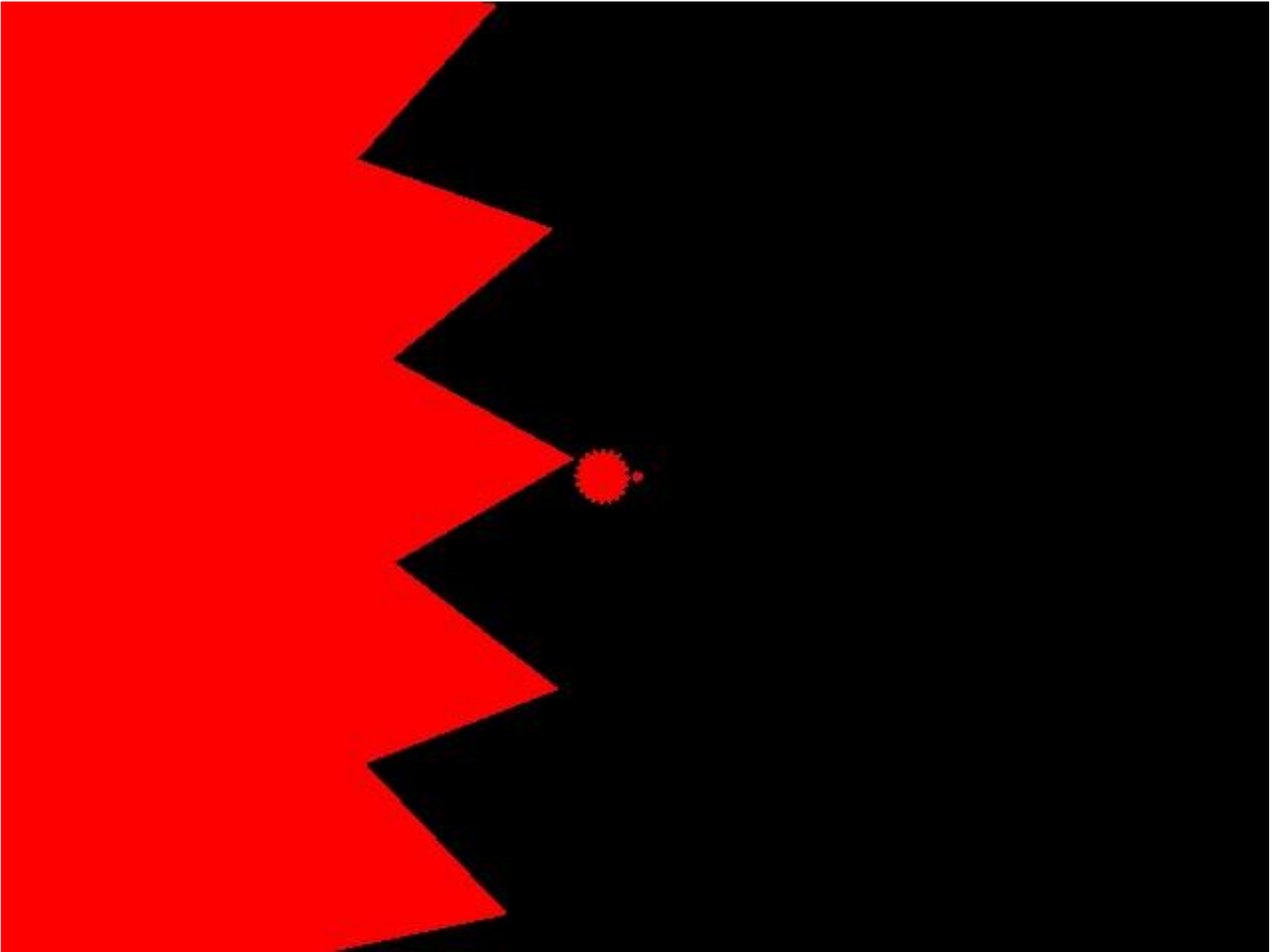
100 nm 20 teeth

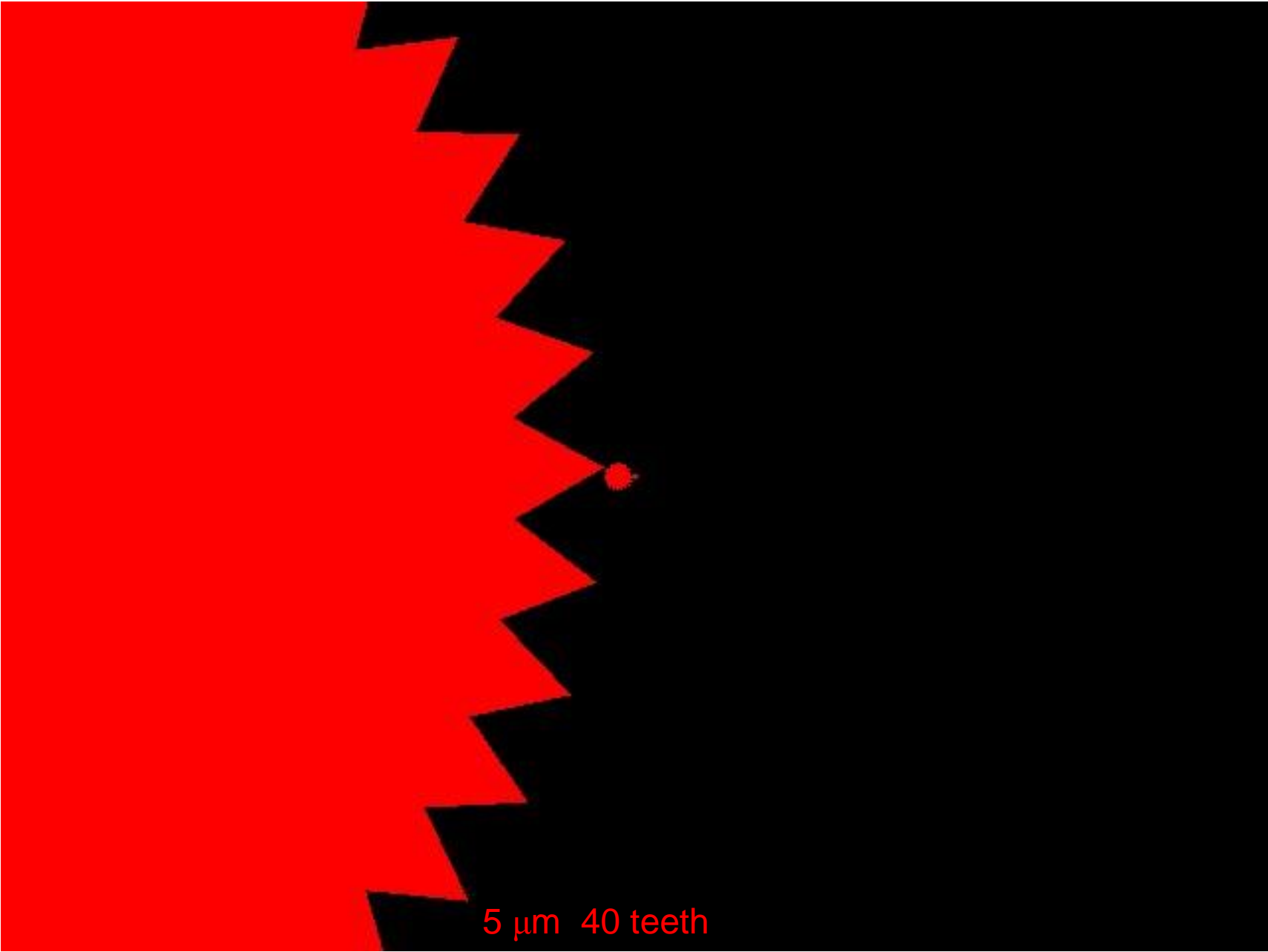


100 nm 20 teeth

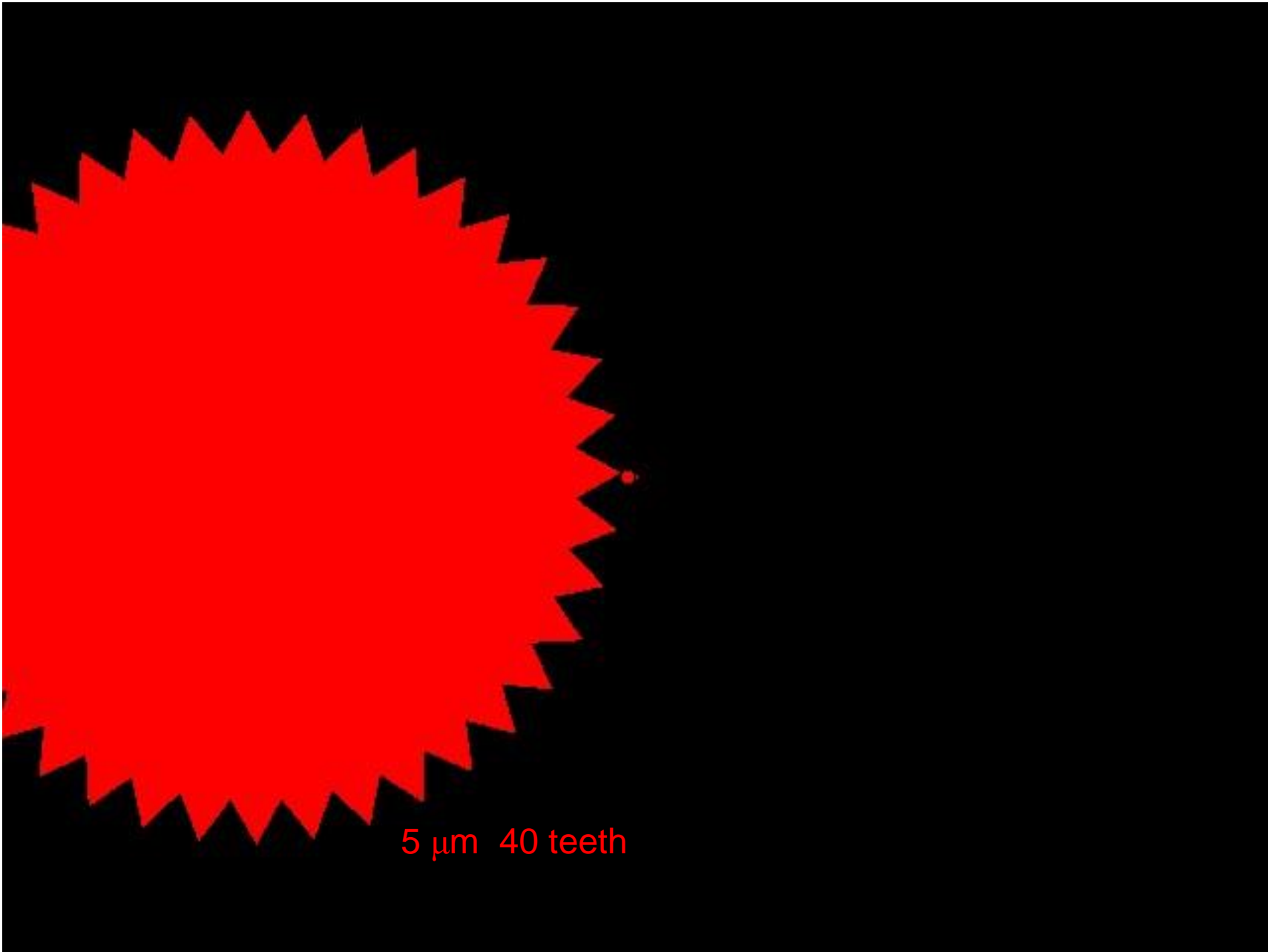




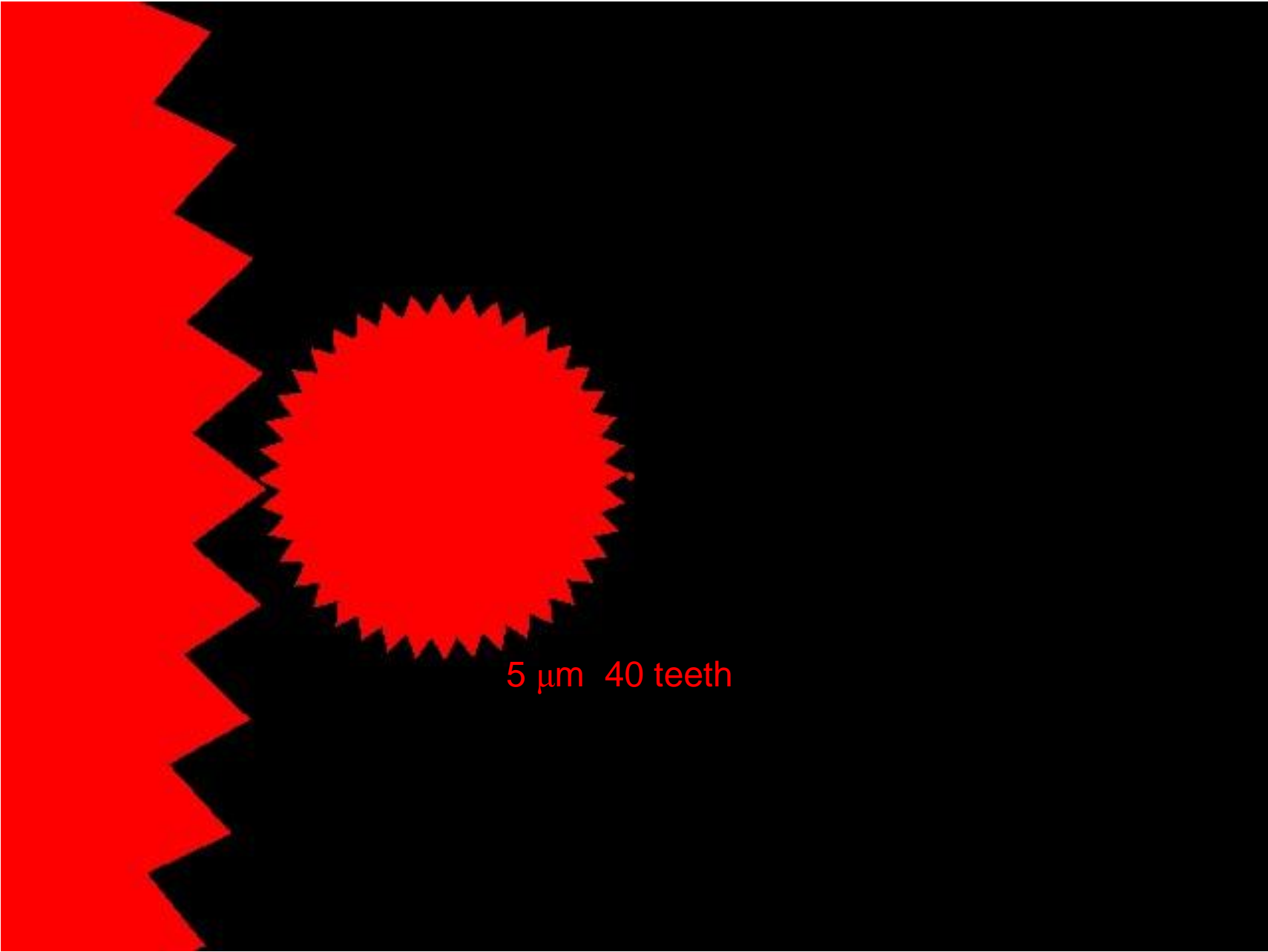




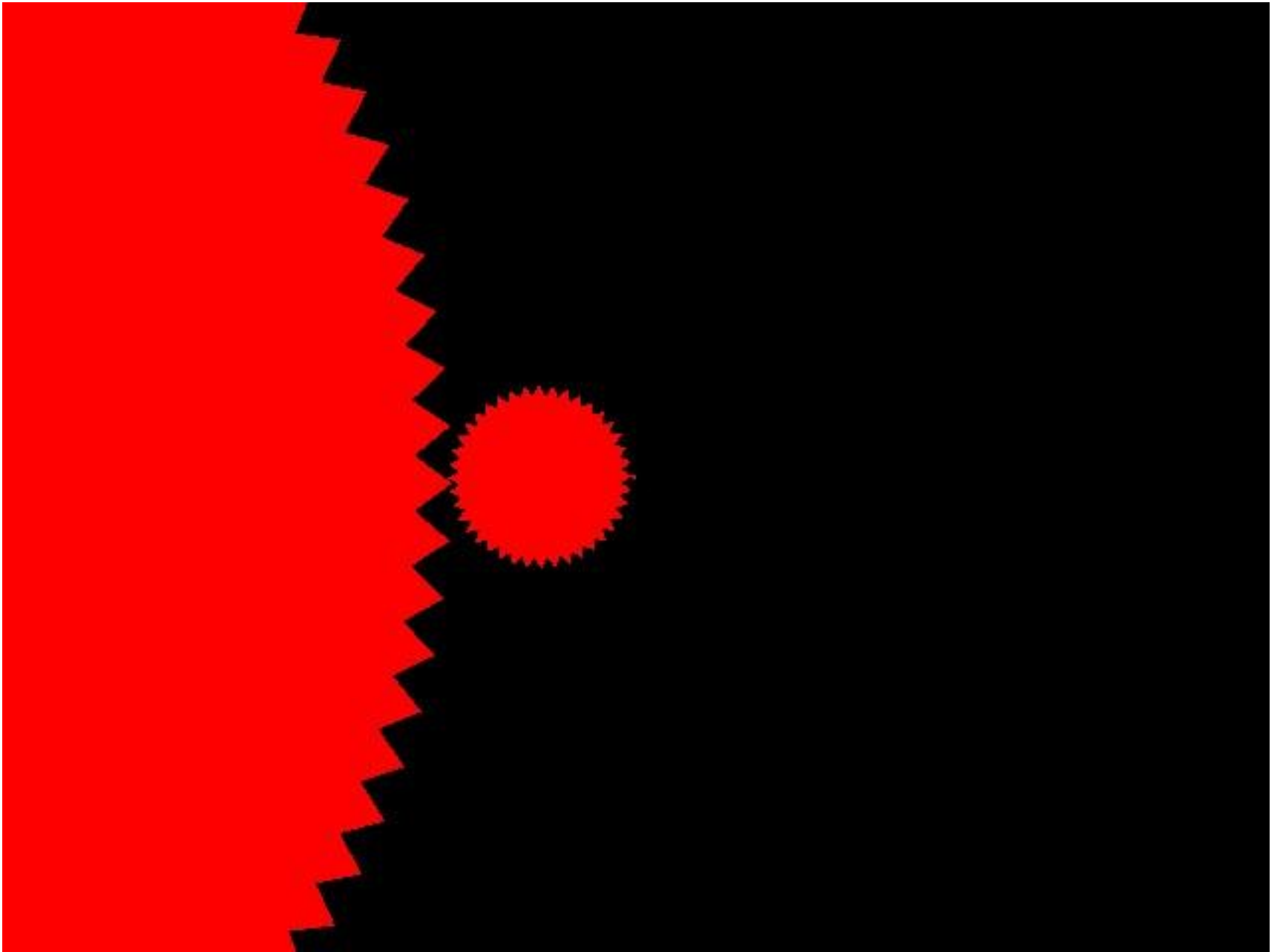
5 μ m 40 teeth

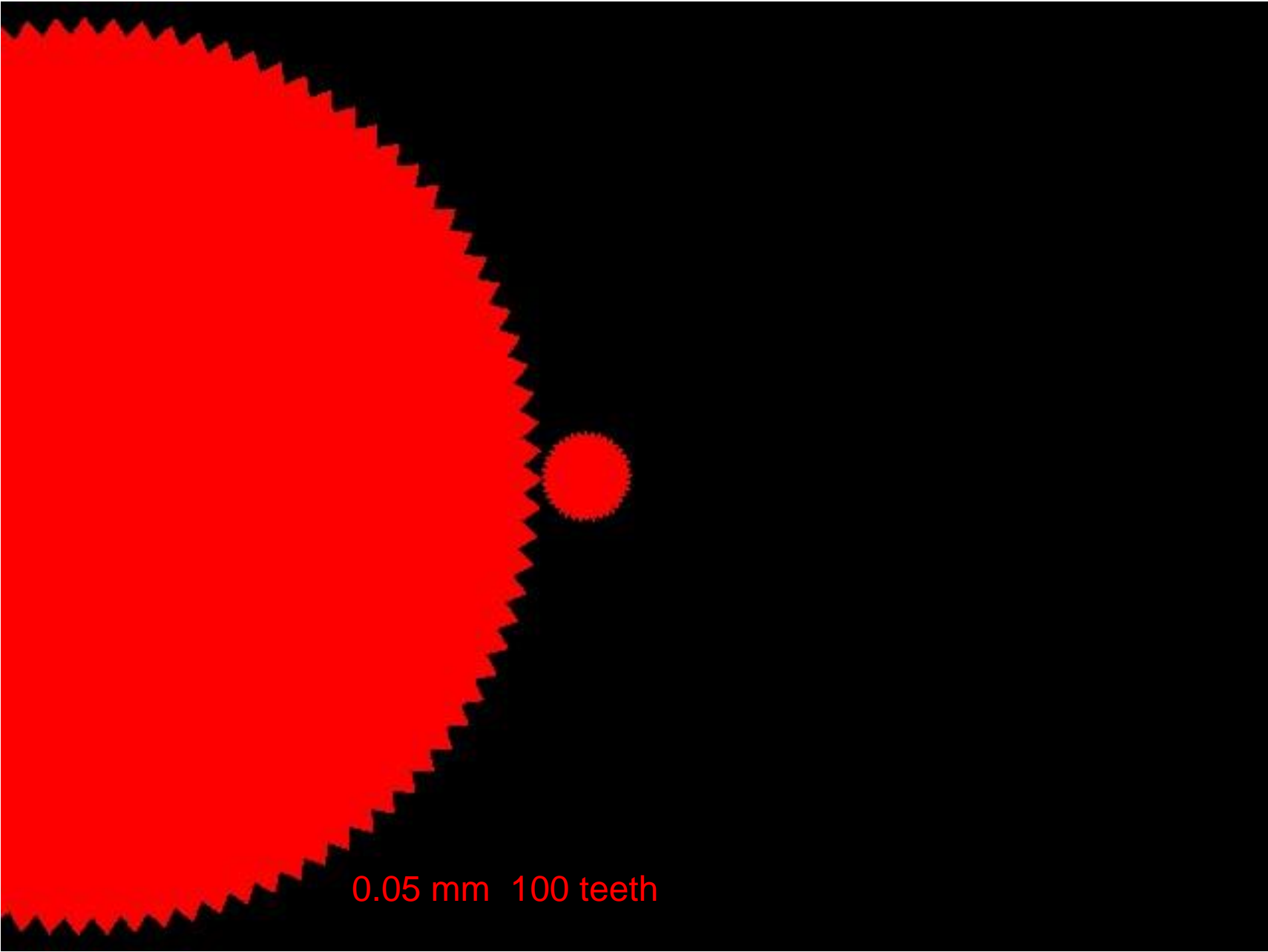


5 μm 40 teeth

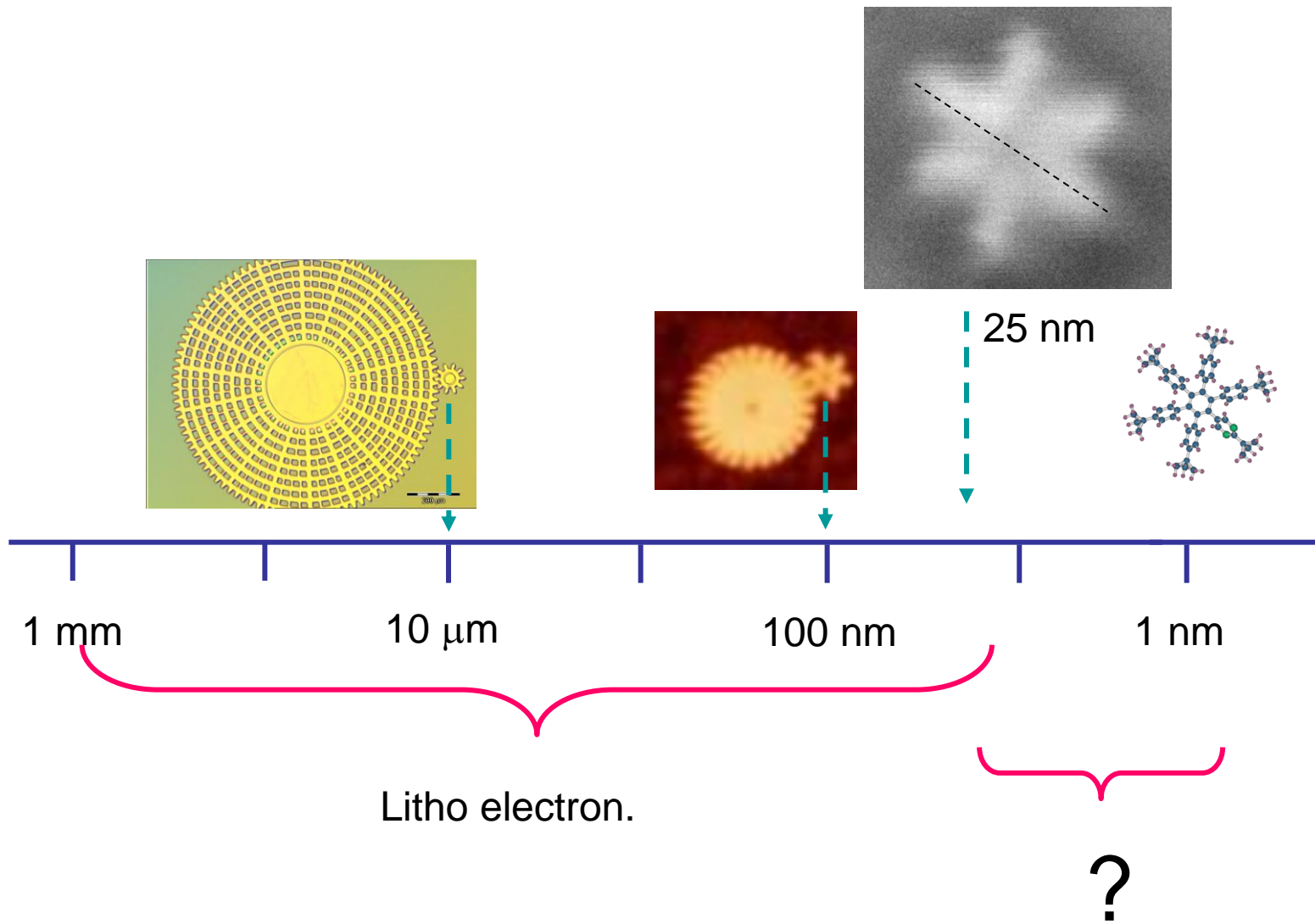


5 μ m 40 teeth





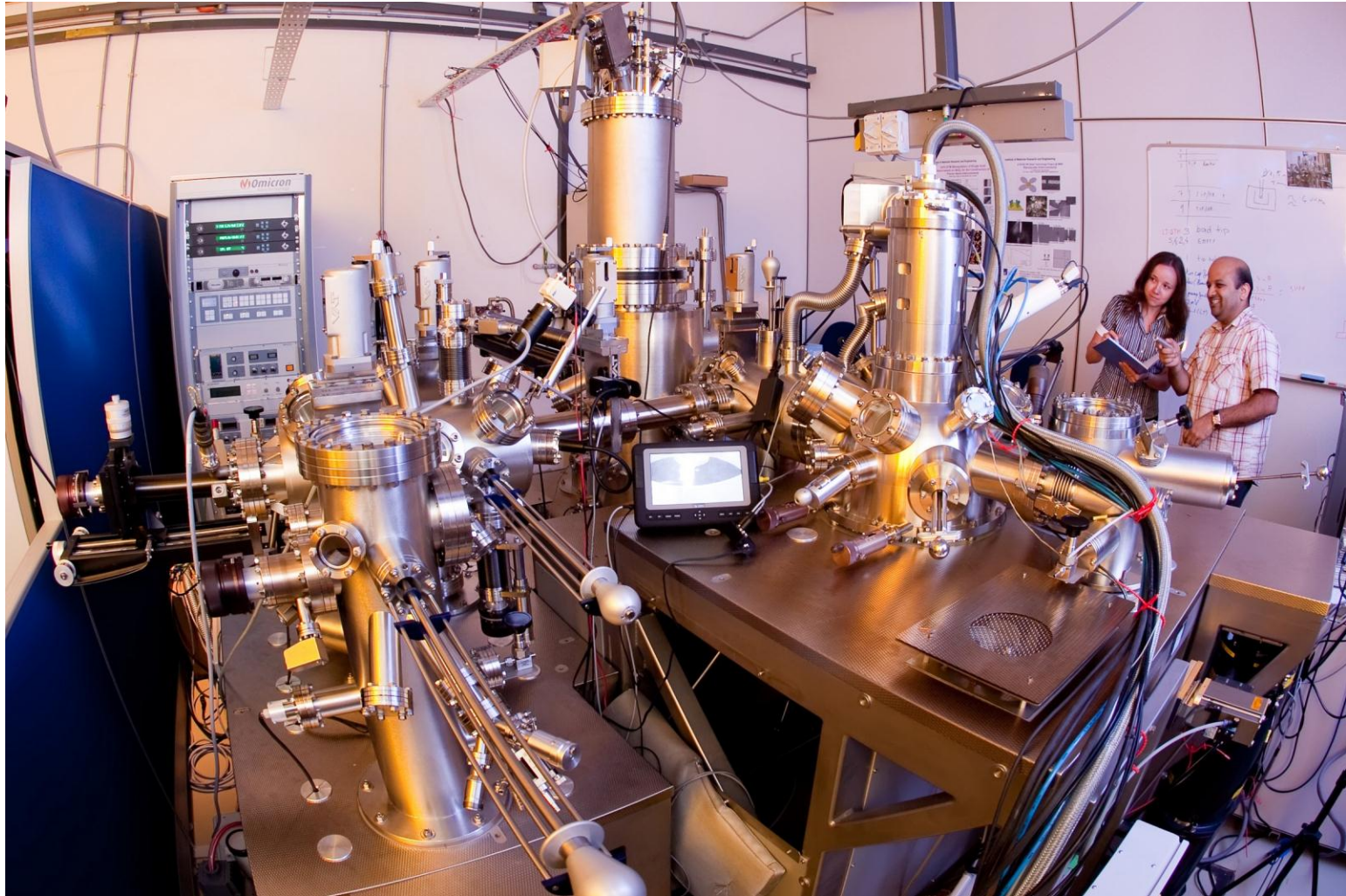
0.05 mm 100 teeth



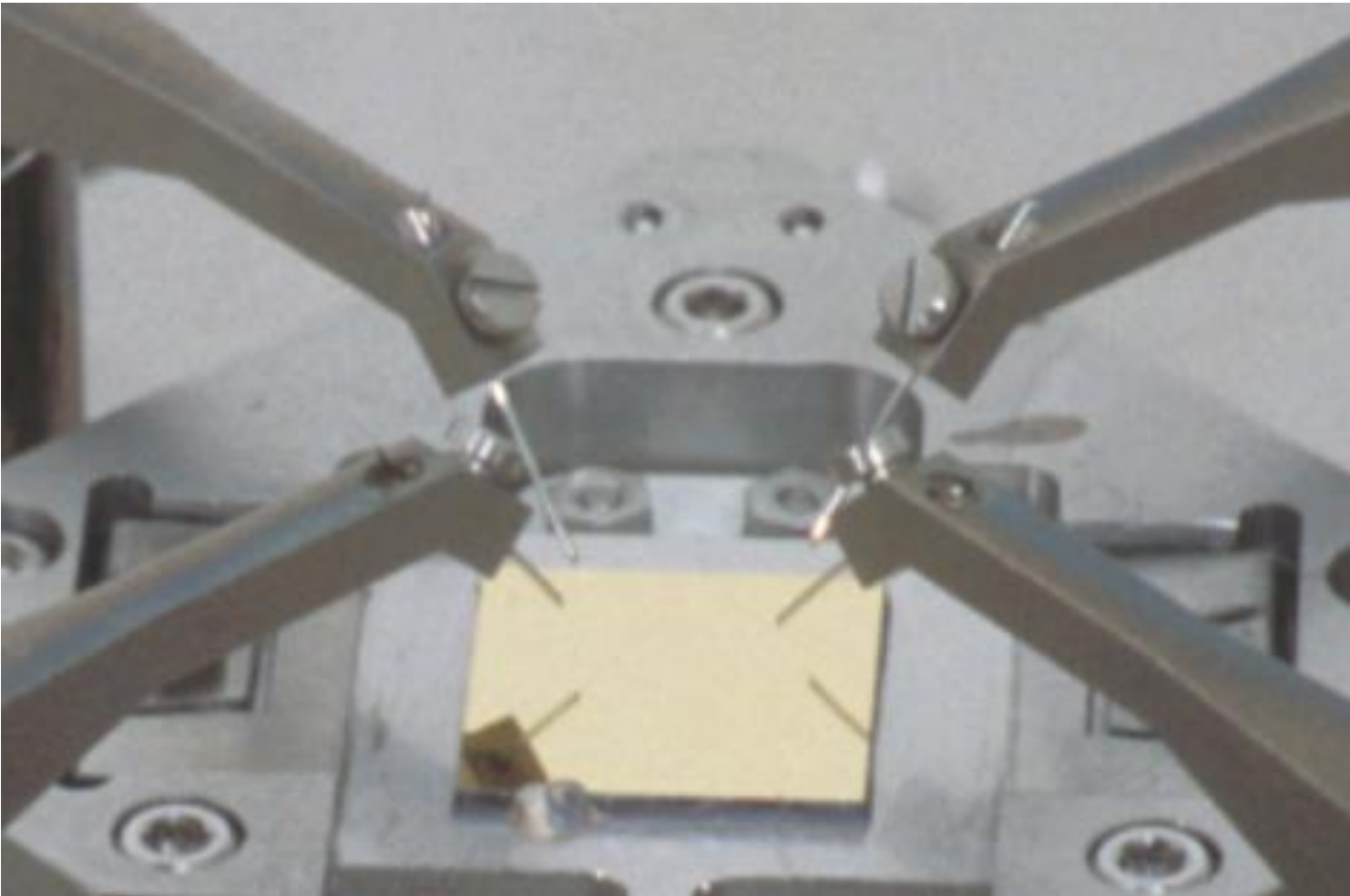
Deng Jie, C. Troadec, F. Ample and C. Joachim *Nanotech*, 22, 275307 (2011).



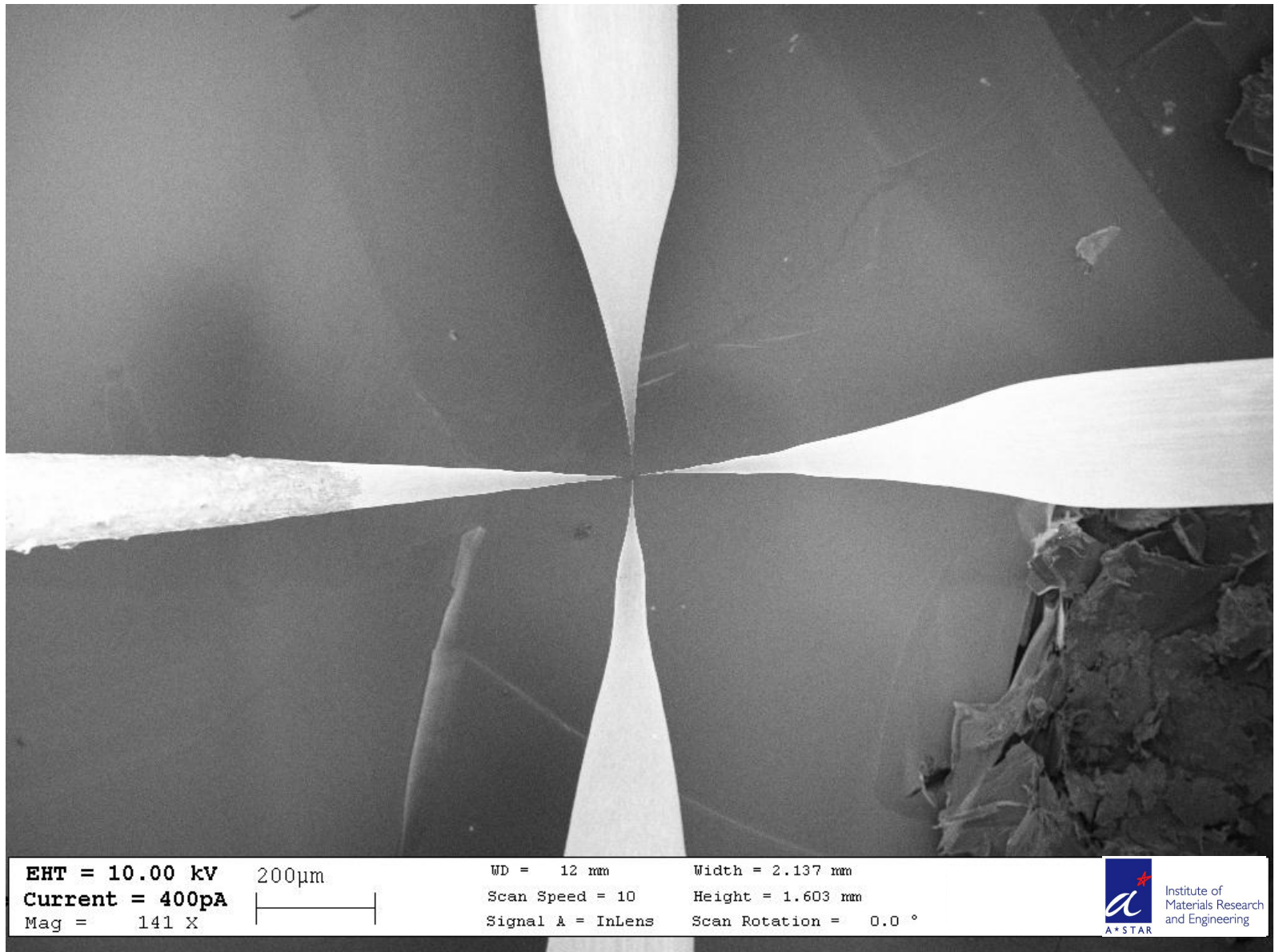
3 pointes
+ un train de 3 engrenages
(1875)



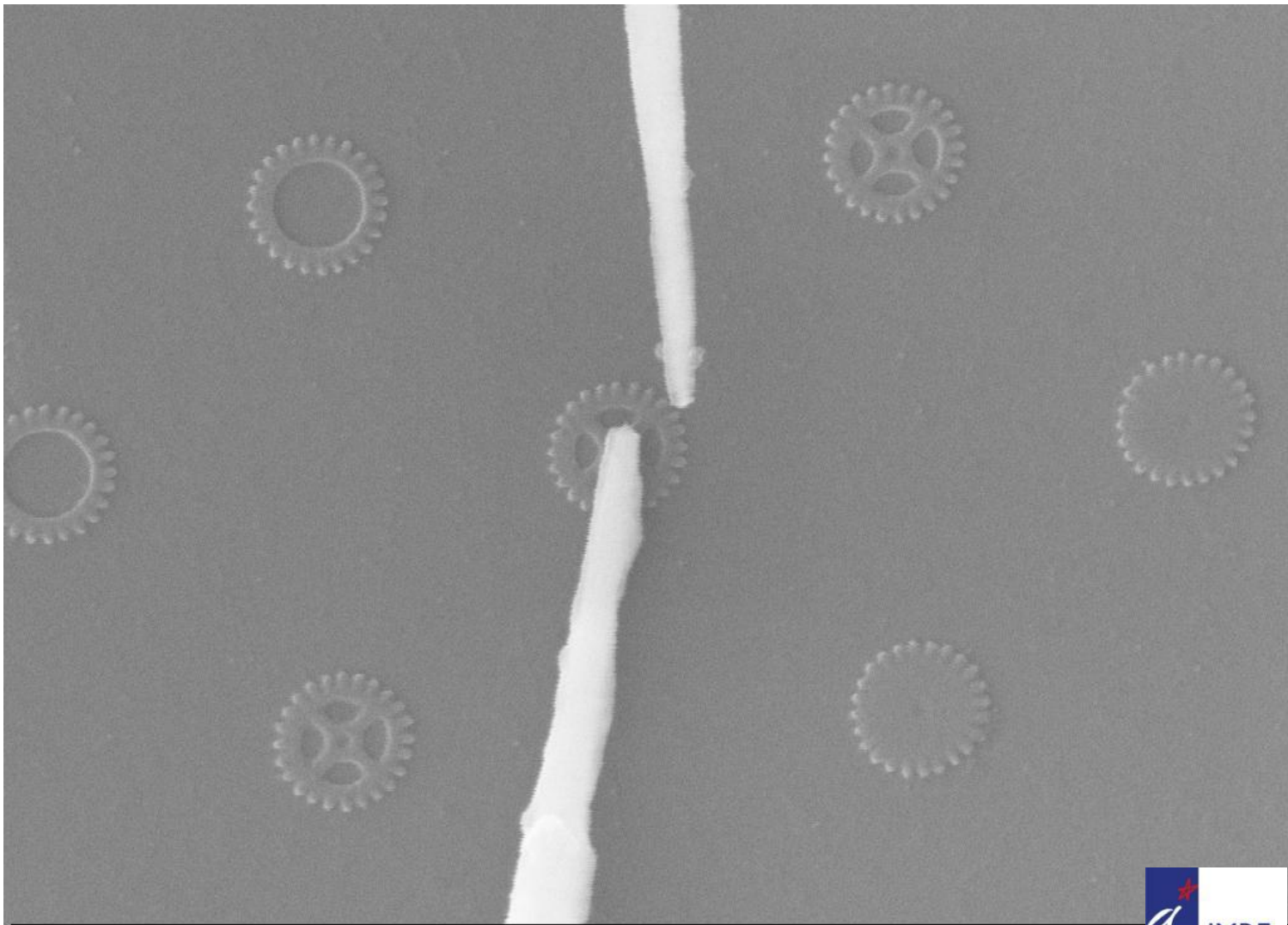
A*STAR IMRE Singapore Atomic scale interconnection machine
Omicron UHV 4 STM system



Omicron UHV 4 STM system



4 UHV-STM tips positioned under the UHV SEM



Mag = 281.10 K X
EHT = 15.00 kV

200 nm
|-----|

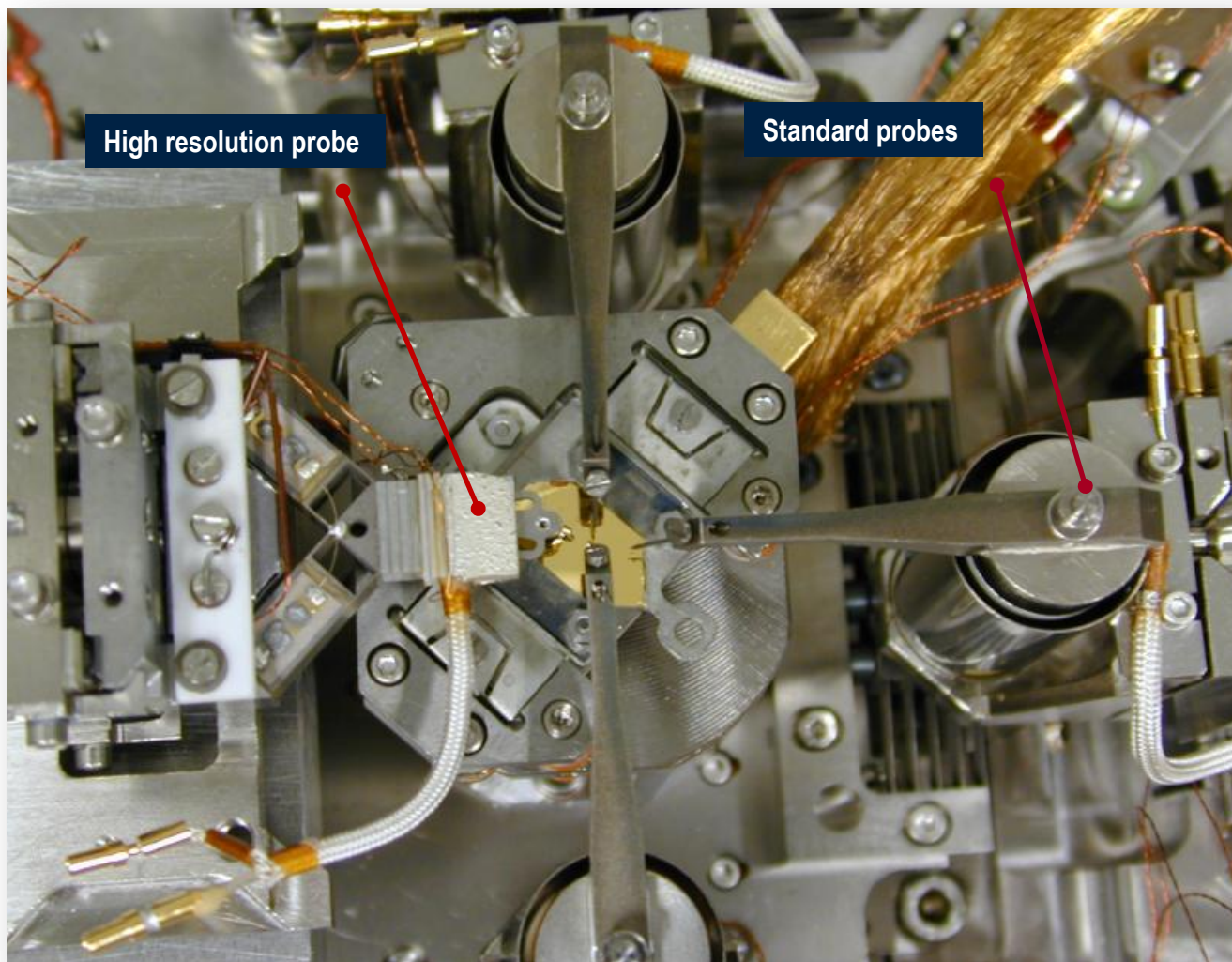
WD = 13.8 mm
Signal A = InLens
Probe Current = 200pA

Width = 3.273 μ m
Height = 2.455 μ m
Scan Speed = 11
Scan Rotation = 0.3

Time :15:37:52
Date :5 Sep 2011



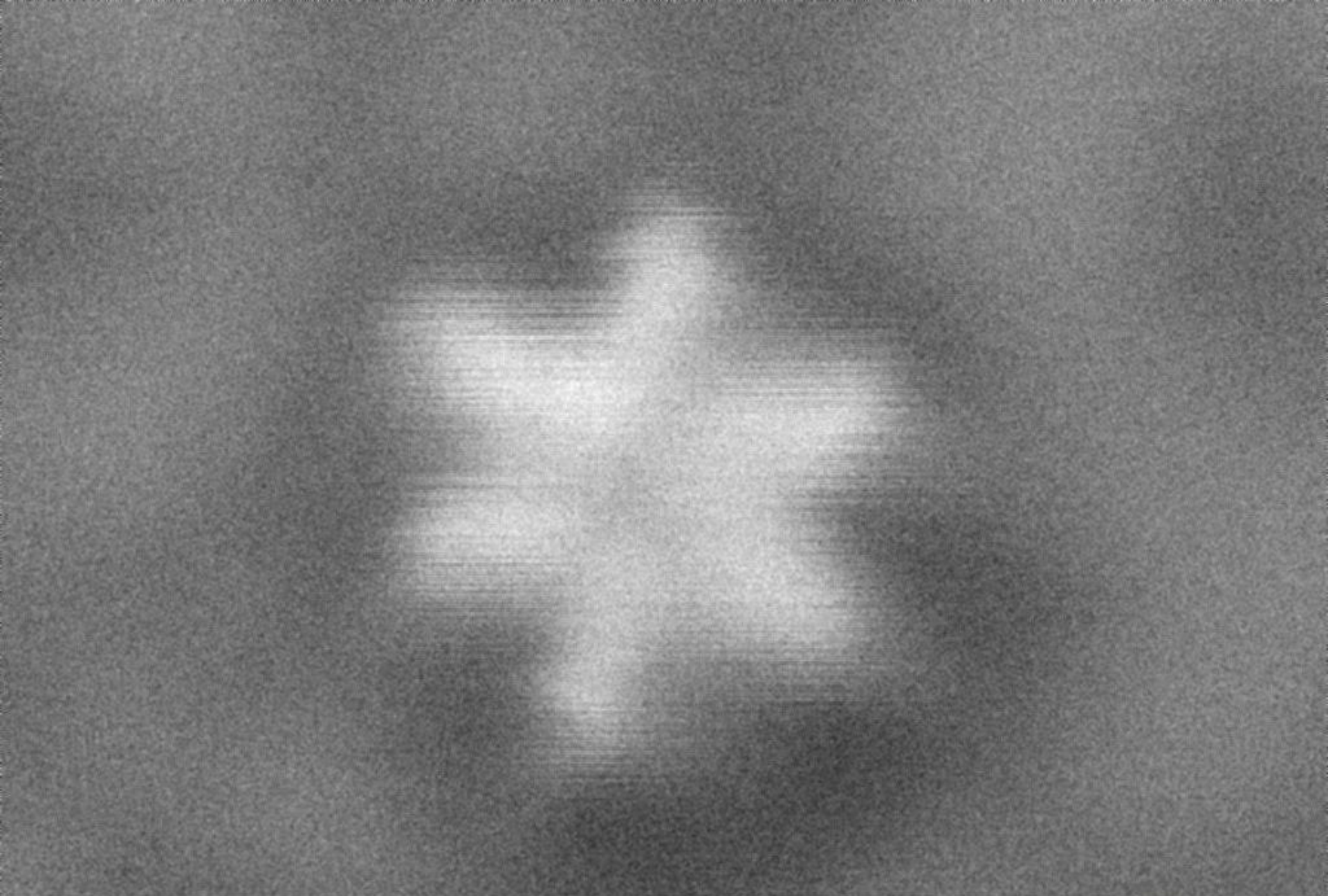
UHV Gemini 31 on NanoProbeHR 18



High resolution probe

Standard probes

Nanoprobe stage



Mag = 2571.51 K X

10 nm

EHT = 15.00 kV



Cycle Time = 5.1 Secs
WD = 14.3 mm
Scan Speed = 7
Probe Current = 400pA

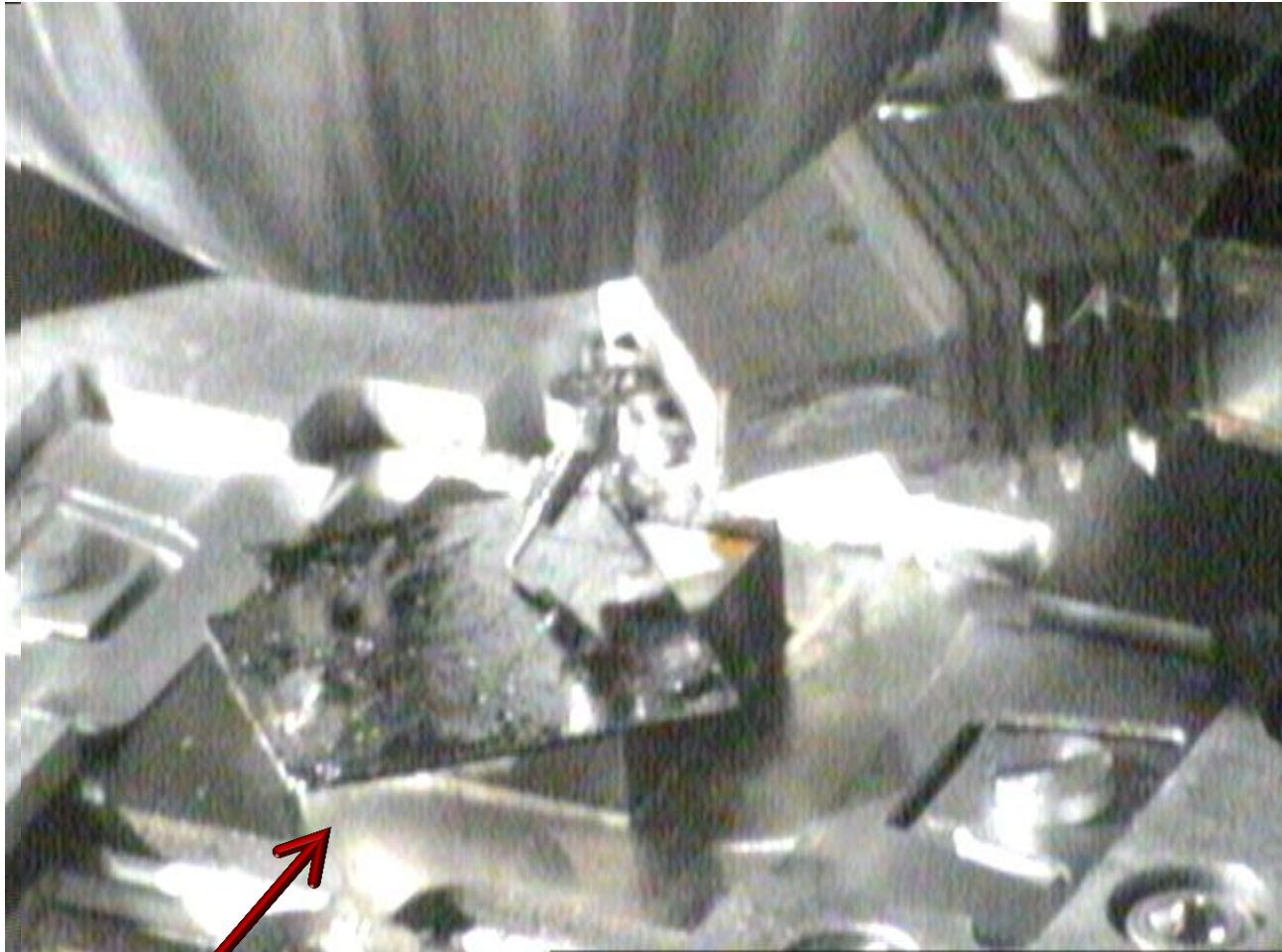
Line Avg.Count = 1
Width = 114.3 nm
Height = 85.75 nm
Signal A = InLens

Noise Reduction = Pixel Avg.
Time :12:18:58
Date :4 Sep 2012



IMRE

CCD camera view of Sample (Gears)+ HR scanner



Direction of sample loading to the stage

Mag = 298.56 K X

100 nm

EHT = 15.00 kV



Cycle Time = 48.7 Secs

WD = 14.3 mm

Scan Speed = 10

Probe Current = 400pA

Line Avg.Count = 1

Width = 984.7 nm

Height = 738.6 nm

Signal A = InLens

Noise Reduction = Pixel Avg.

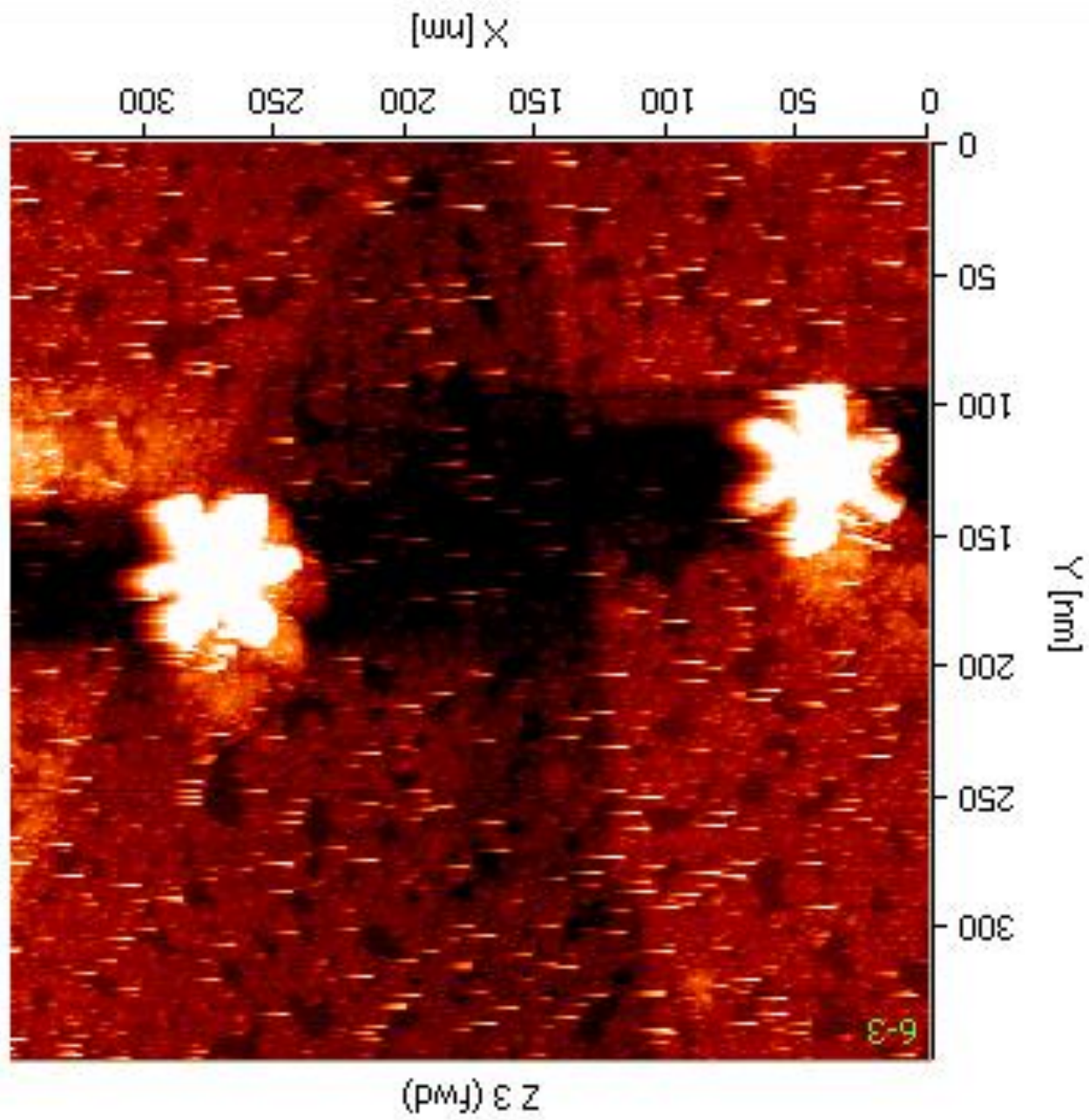
Time :17:07:41

Date :4 Sep 2012

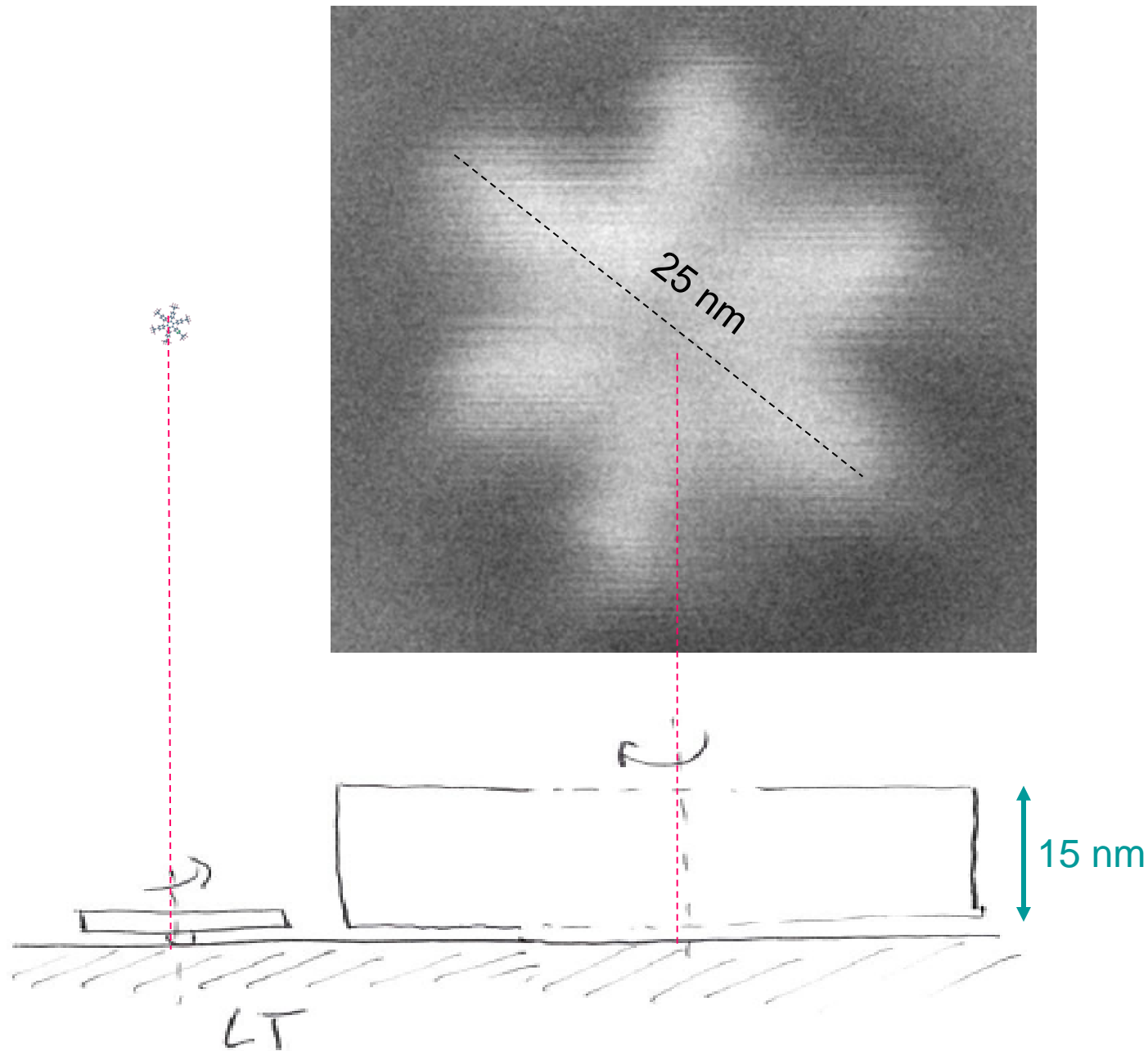


IMRE

UHV Gemini 31 on NanoProbeHR 18



Z 3 (fwd)



Conclusions

- 1) Maitriser le mouvement d'une seule molécule
- 2) Transmettre du mouvement





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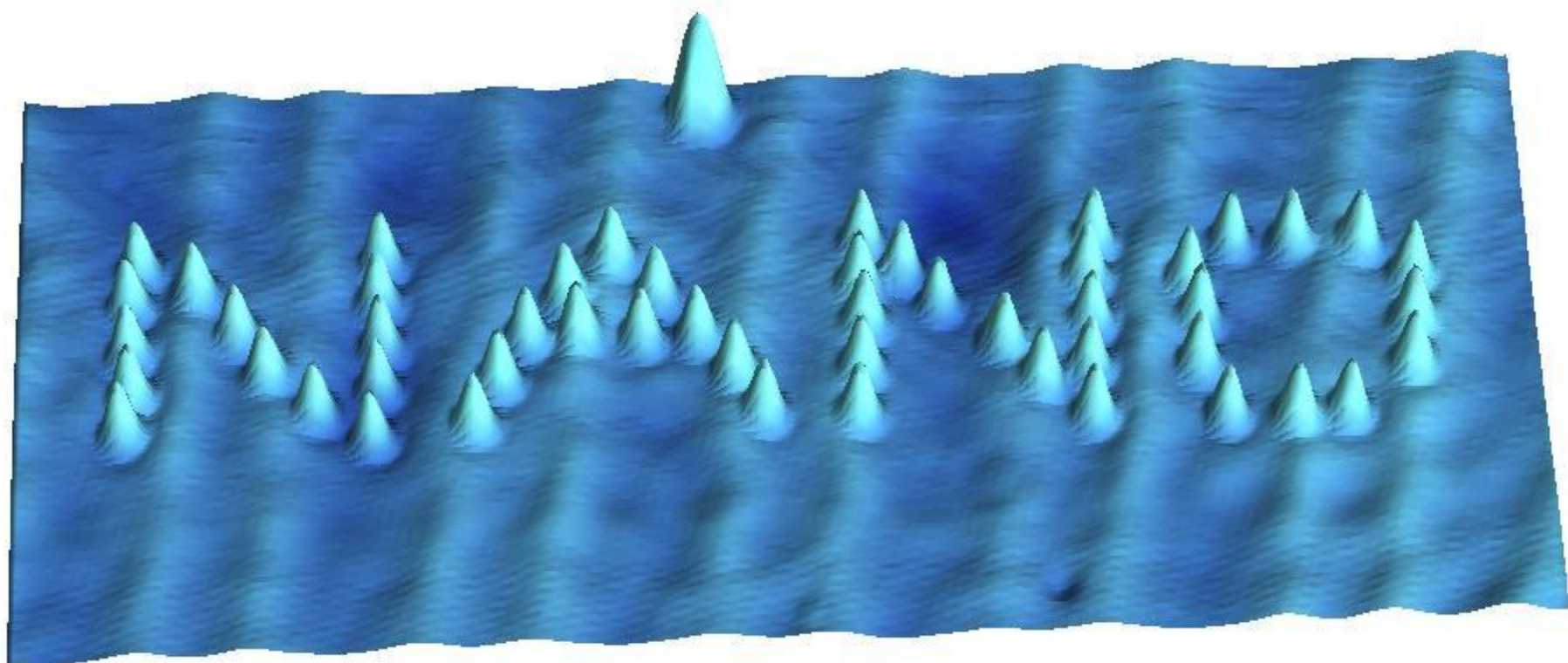
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C. Troadec
Deng Jie



Institute of
Materials Research
and Engineering



2 nm