Kan et støvkorn påvirke dannelsen af en stjerne?

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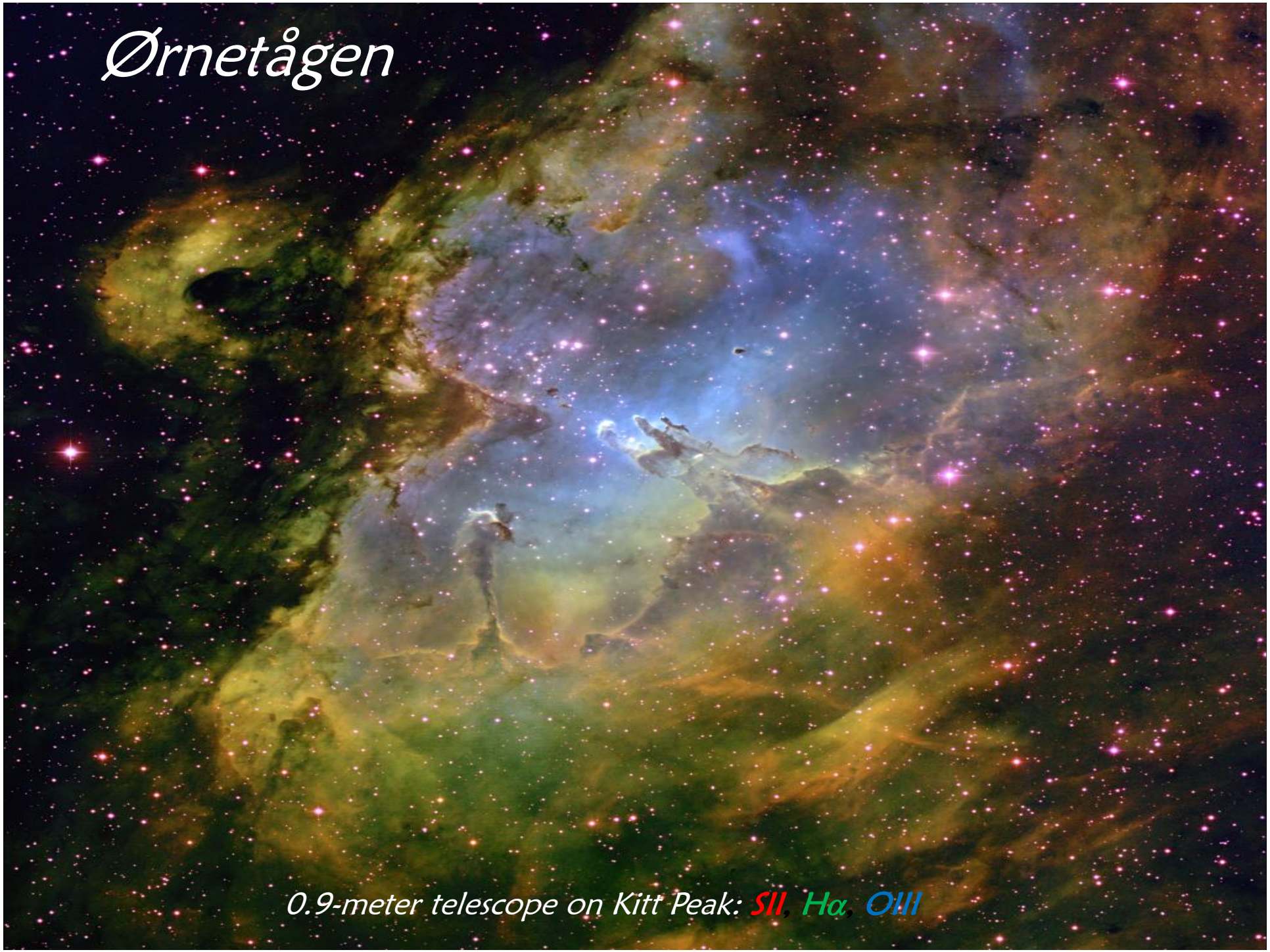
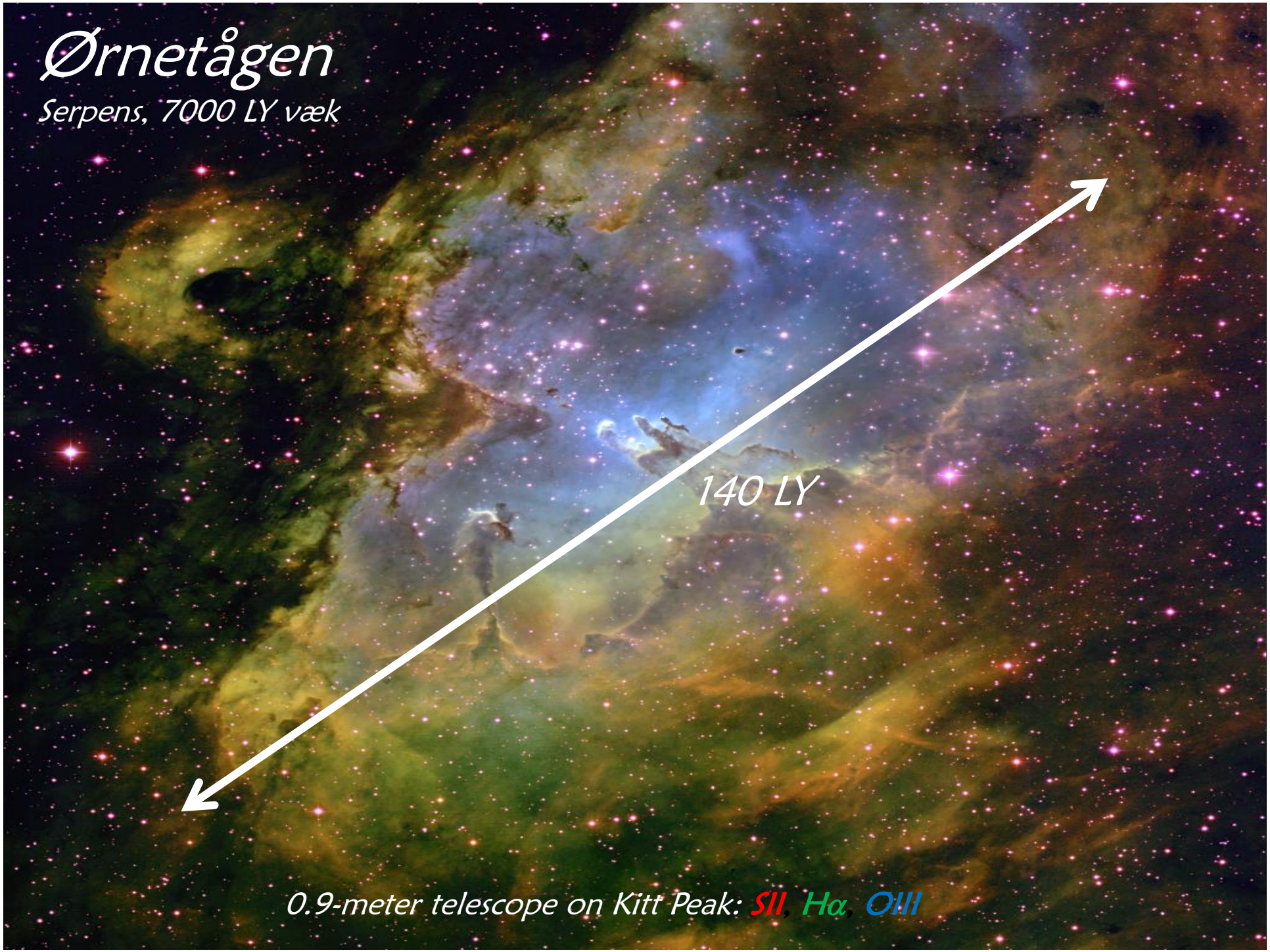
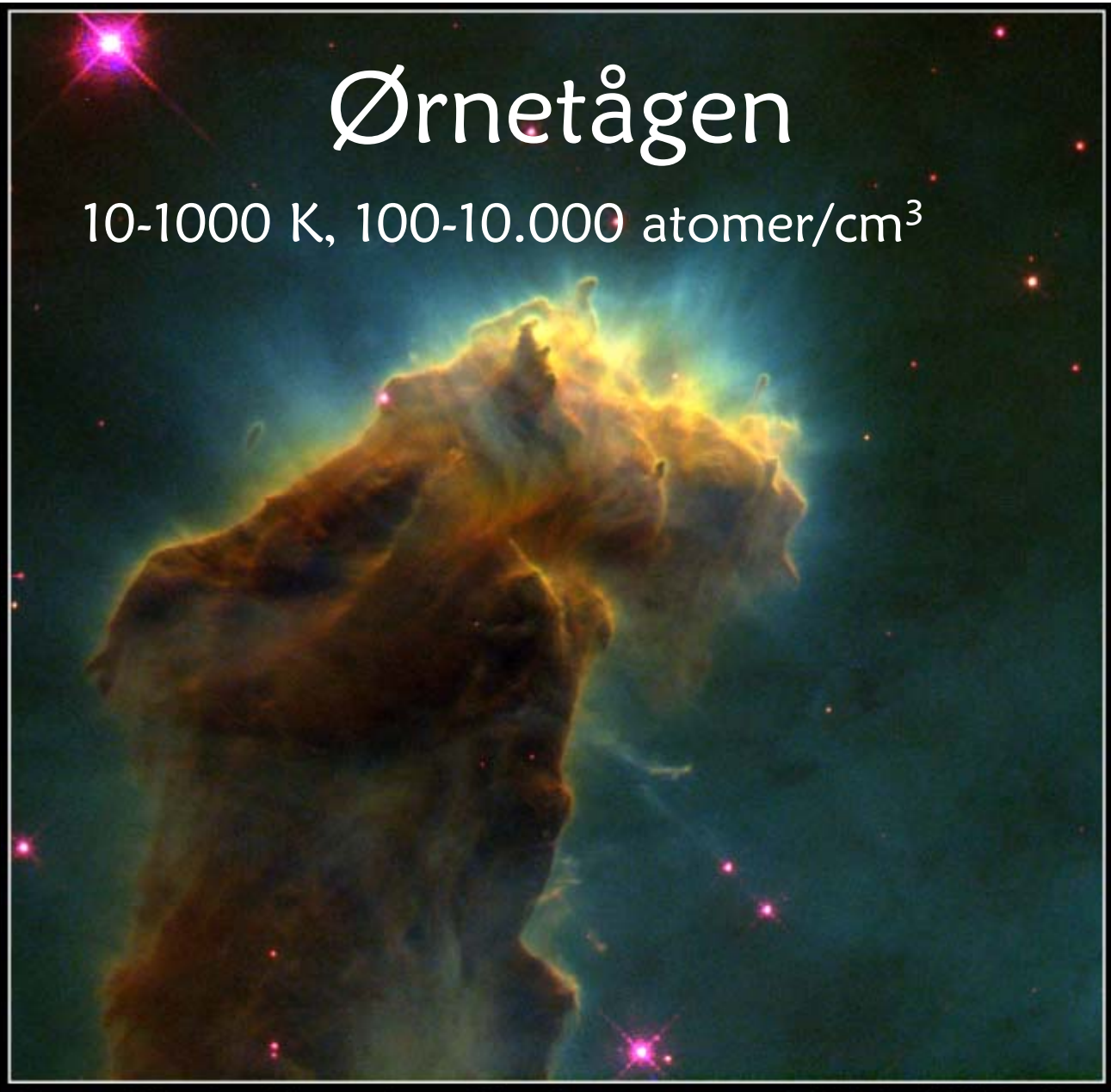
iNANO


Ørnetågen
0.9-meter telescope on Kitt Peak: SII, Hα, OIII


Ørnetågen
Serpens, 7000 LY væk
140 LY
0.9-meter telescope on Kitt Peak: SII, Hα, OIII

Ørnetågen

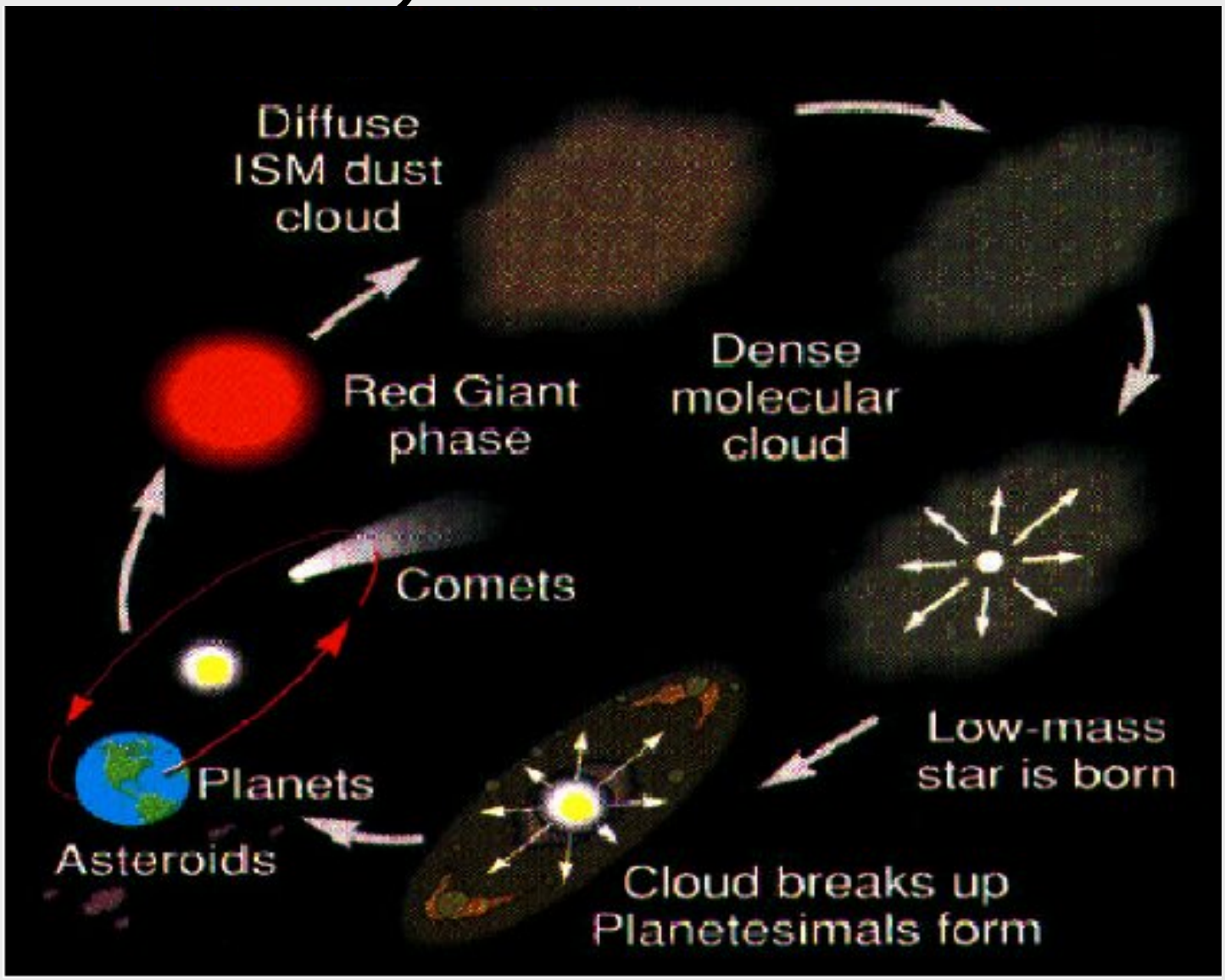
10-1000 K, 100-10.000 atomer/cm^3

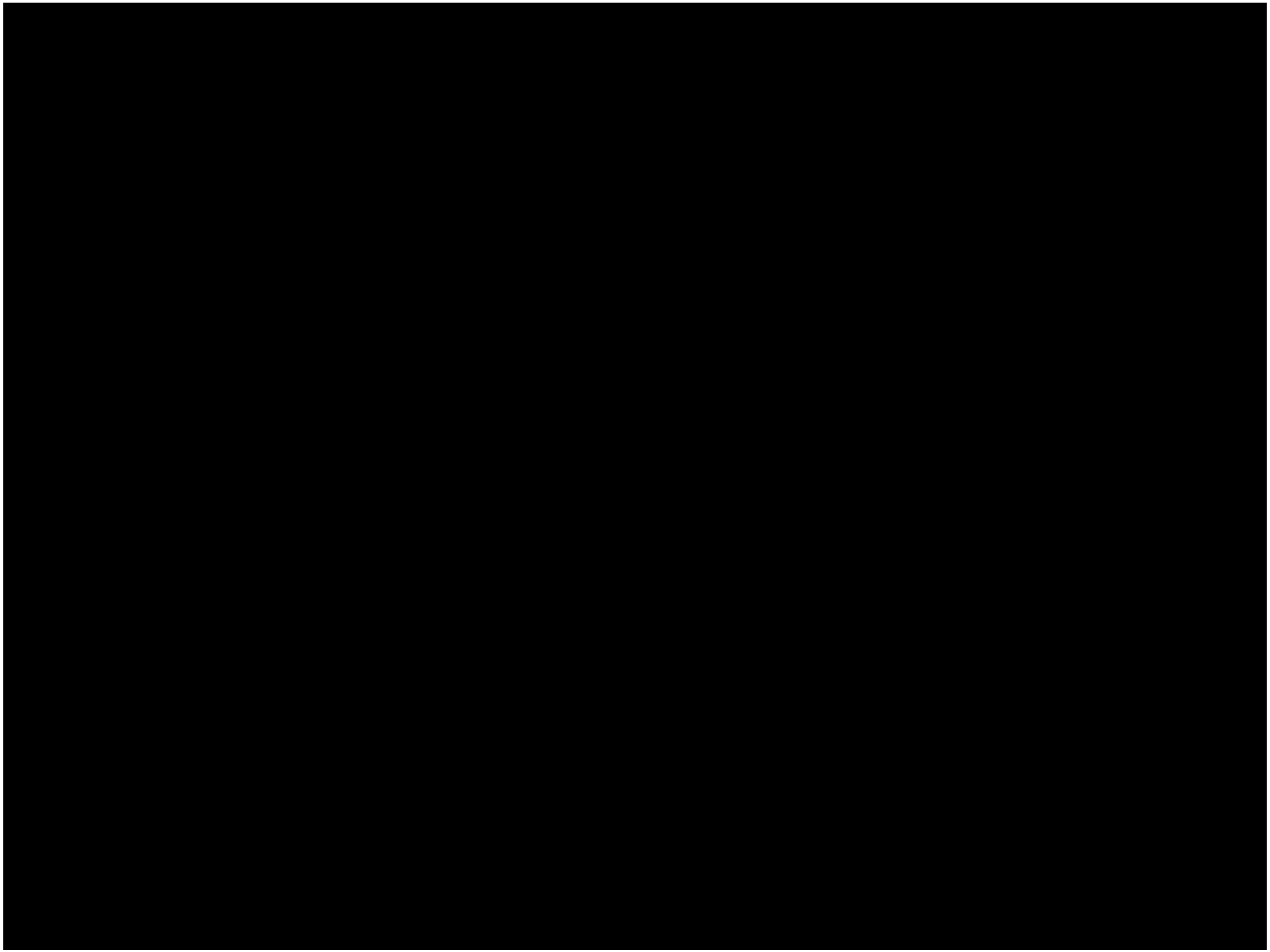


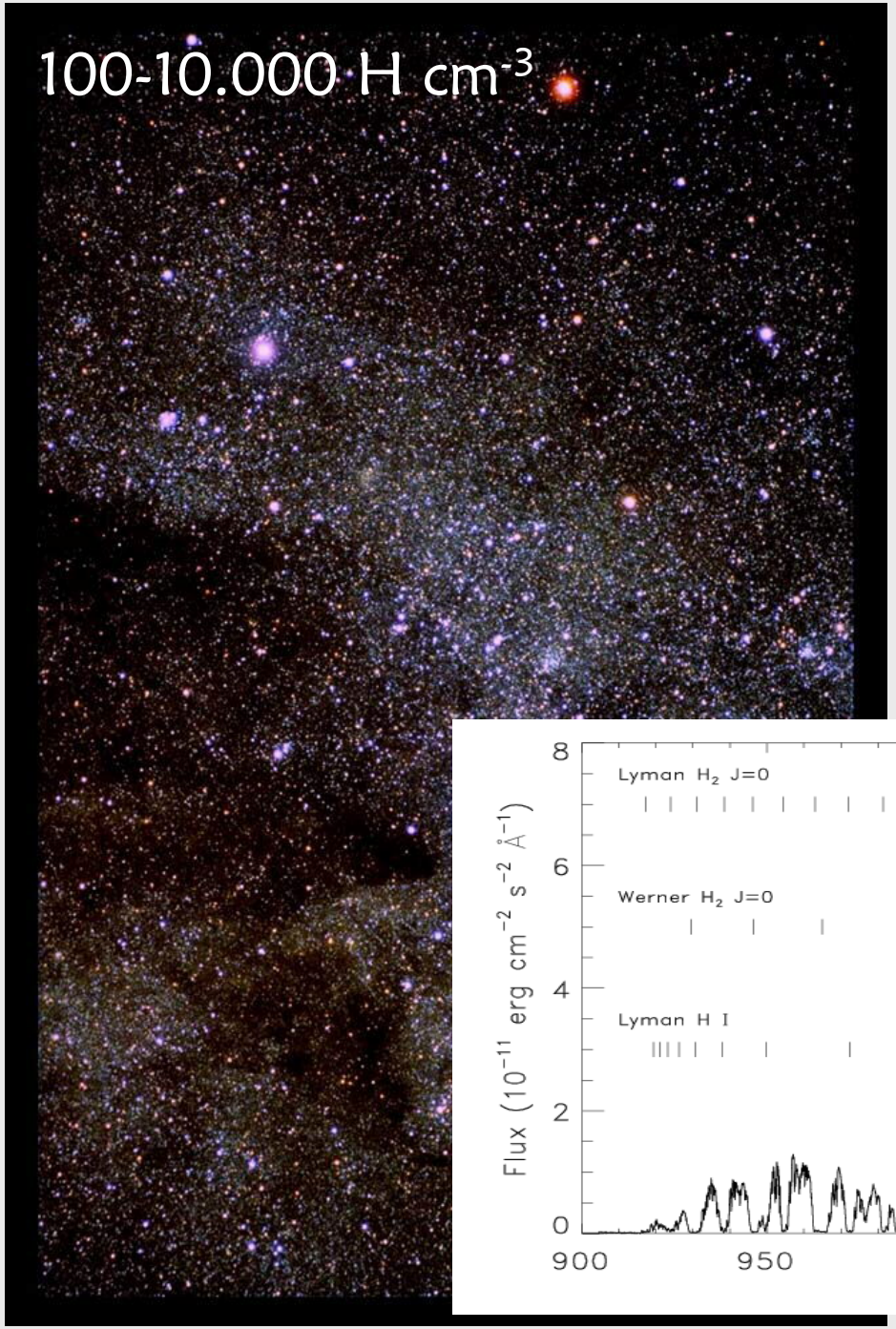
Star-Birth Clouds · M16 HST · WFPC2

PRC95-44b · ST ScI OPO · November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

Sky-udvikling – Stjernedannelse

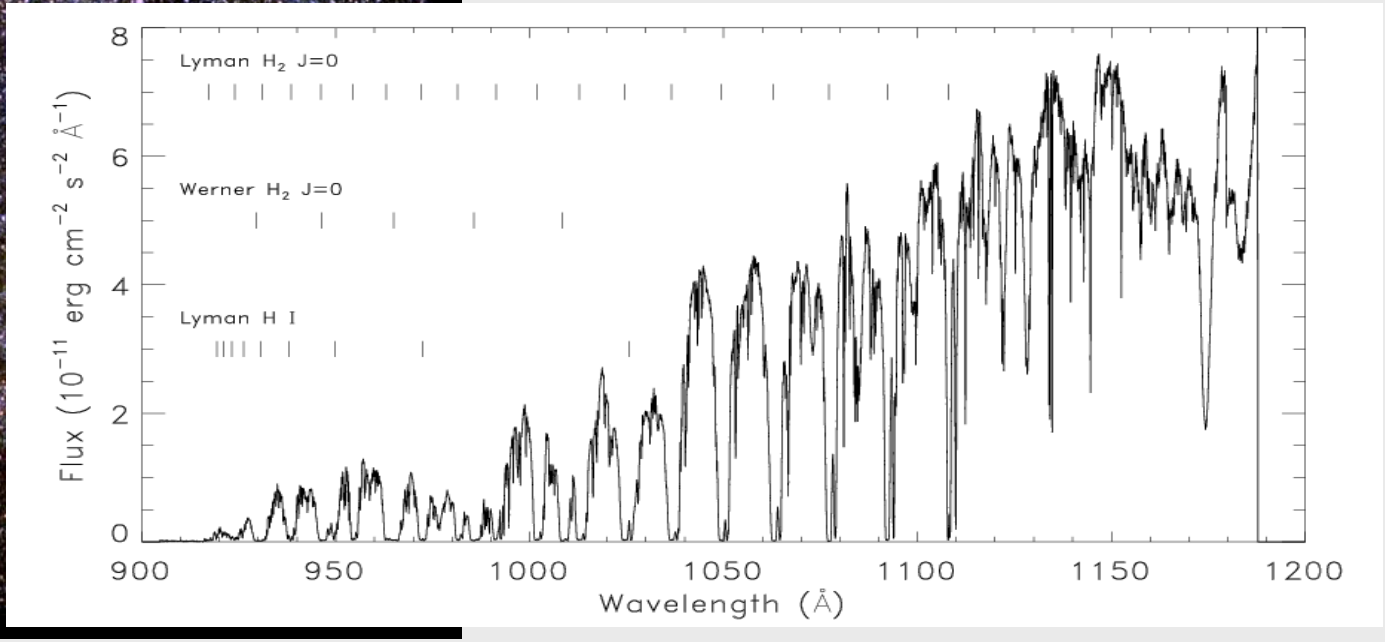




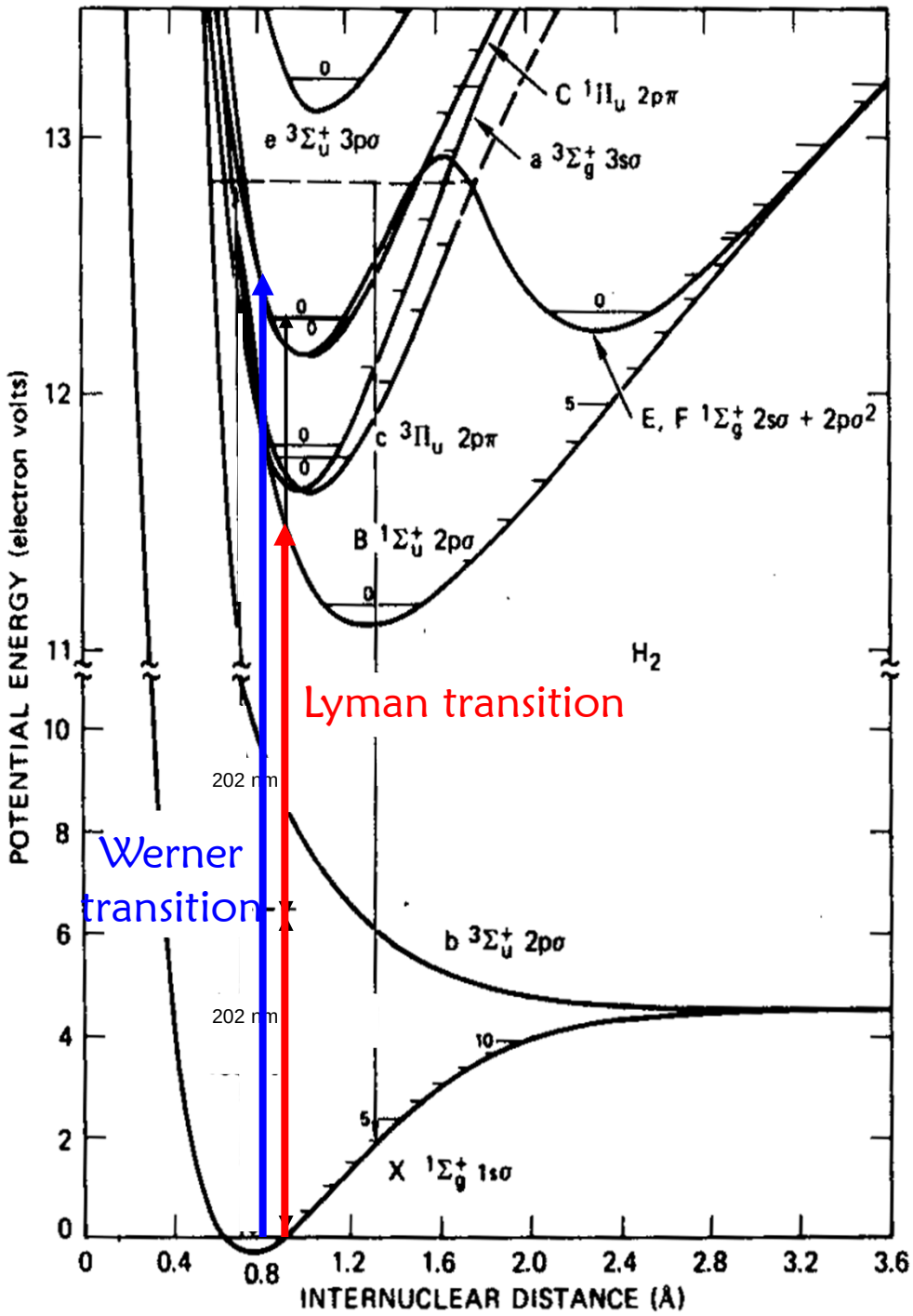


Kul-sæk tågen i Sydkorset

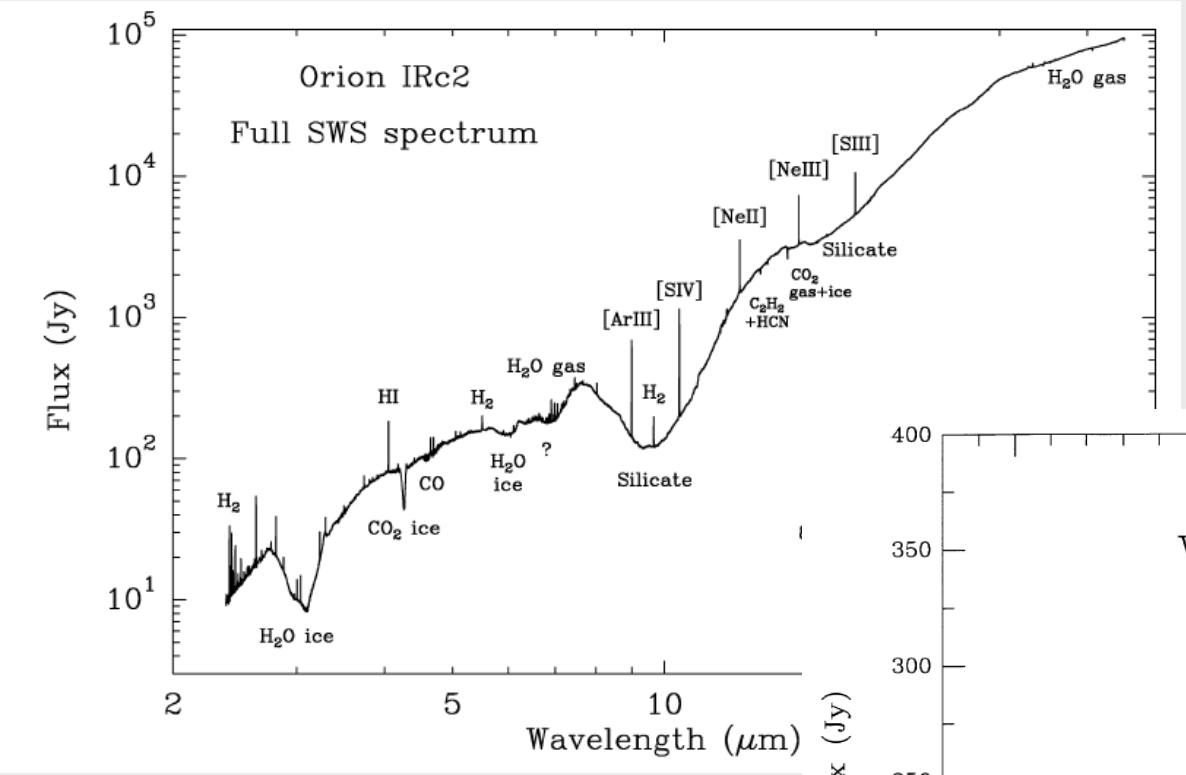
H_2 absorbtions bånd

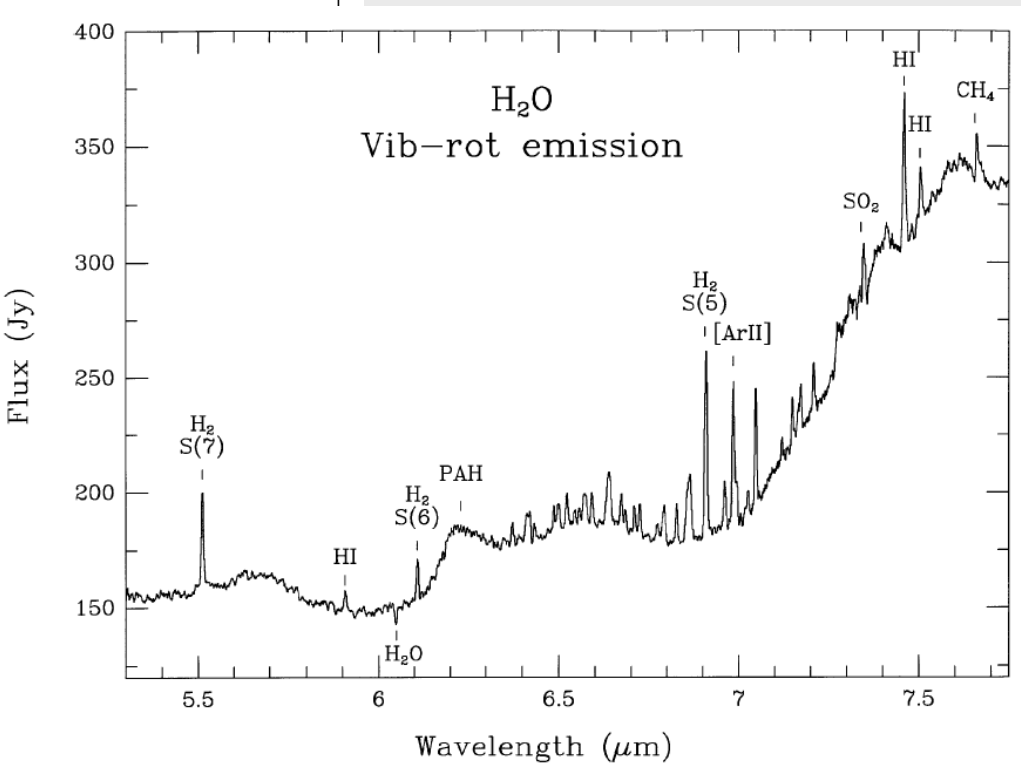


H_2 niveauer


POTENTIAL ENERGY (electron volts)
INTERNUCLEAR DISTANCE (Å)
e $^3\Sigma_u^+$ 3pσ
a $^3\Sigma_g^+$ 3sσ
C $^1\Pi_u$ 2pπ
c $^3\Pi_u$ 2pπ
B $^1\Sigma_u^+$ 2pσ
E, F $^1\Sigma_g^+$ 2sσ + 2pσ^2
b $^3\Sigma_u^+$ 2pσ
X $^1\Sigma_g^+$ 1sσ
H_2
Lyman transition
Werner transition
202 nm
202 nm

Emissions spektra





Sky sammensætning

Atomer:

H, He, O, C, N, Ne, Si, Mg, S, Fe ...

189 Molekyler:

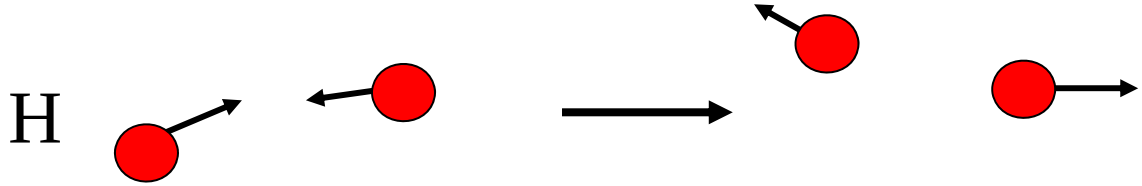
H_2 , CO, CO_2 , O_2 , H_2O, NH_3 , CH_3OH ...

Aminosyrer: glycine (CH_2NH_2COOH),

Sukker: glycolaldehyde (CH_2OHCHO)

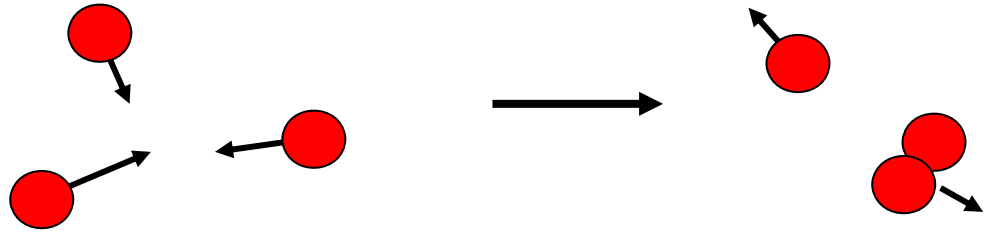
Støvkorn

H_2 dannelse



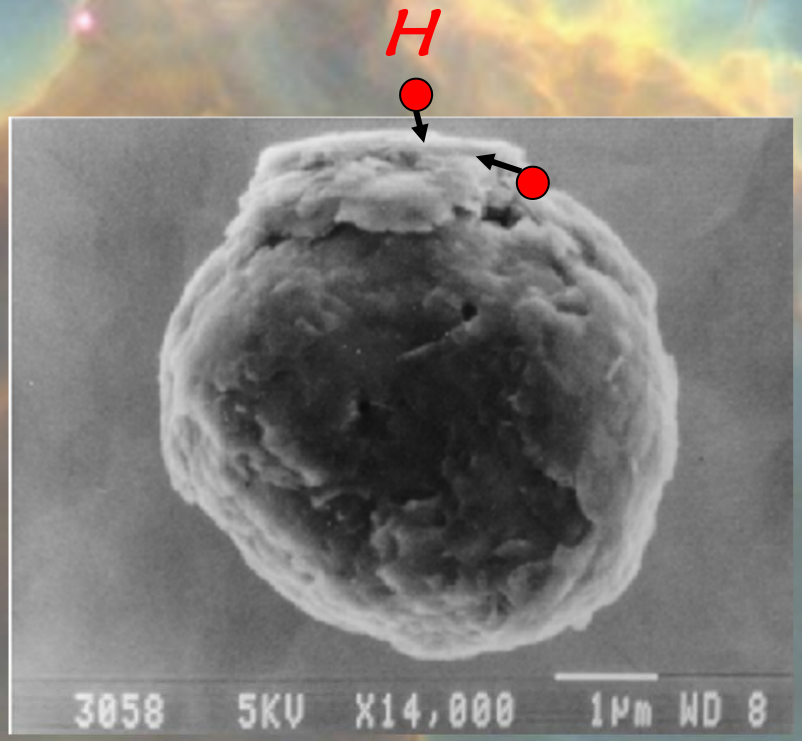
Ingen strålingsstabilisering

3-legeme kollisioner – ok ved høj tæthed

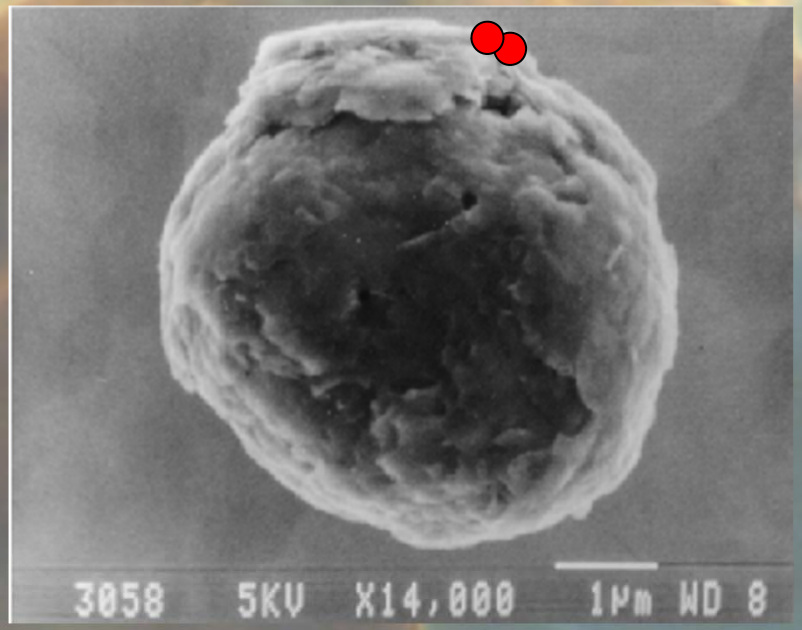


Diffuse/Tætte skytætheder => ~Ingen 3-legeme kollisioner

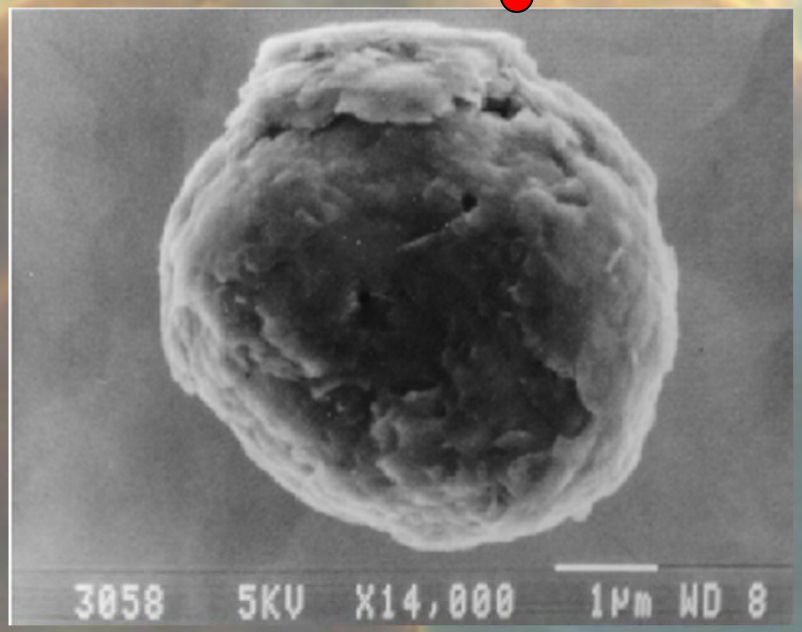
Overflade Reaktioner



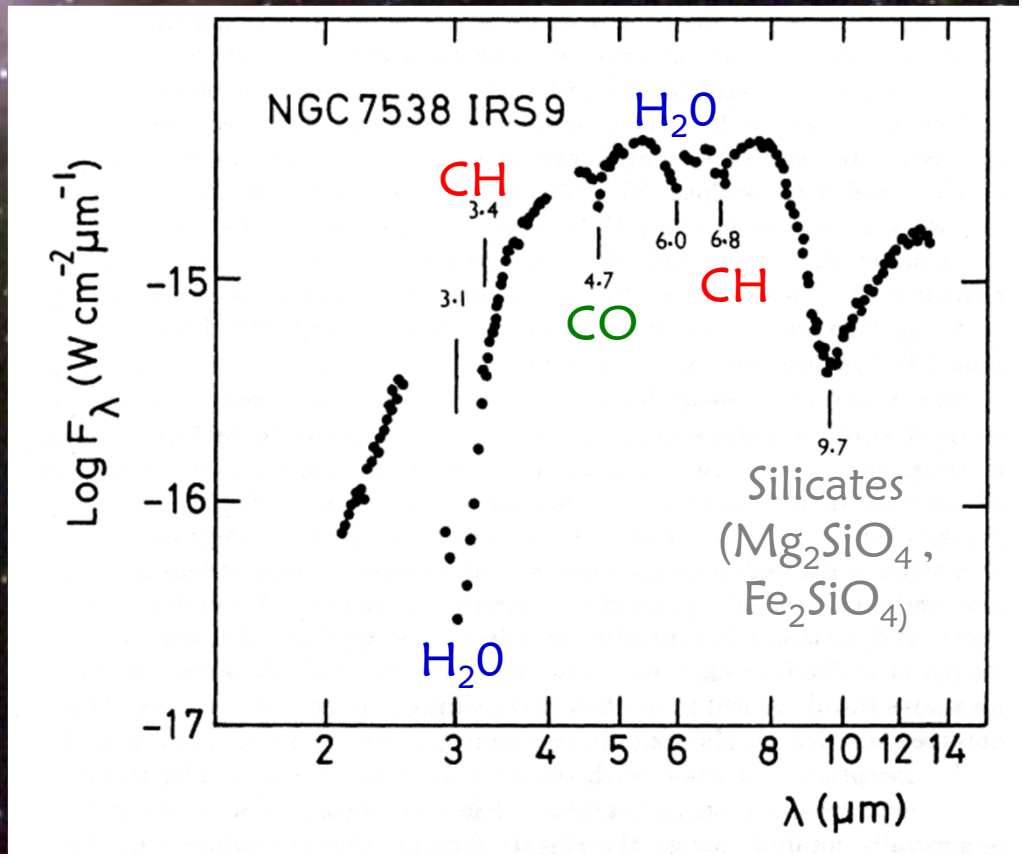
Overflade Reaktioner



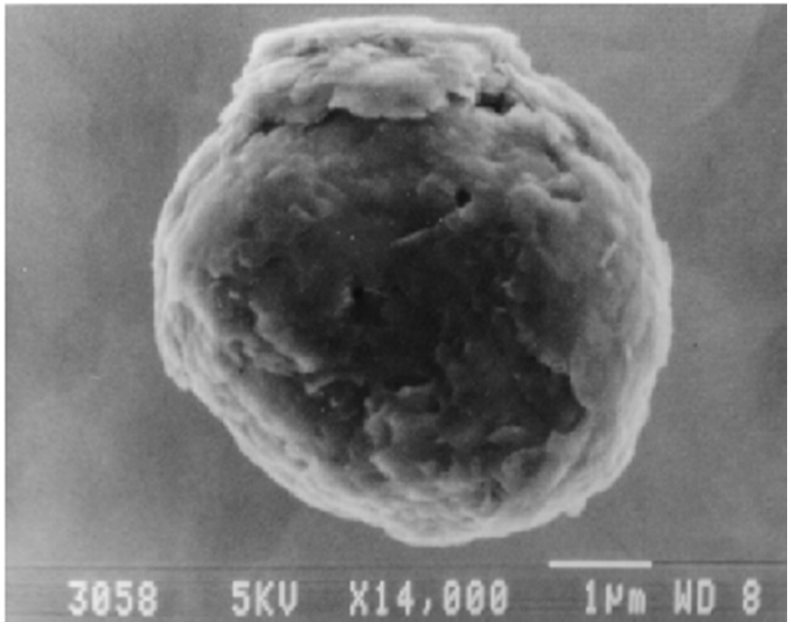
Overflade Reaktioner



Absorptions spektrum



Støvkorn



Kulkorn: Grafit, Amorft Kul, HAC, PAH, Polymerisk Carbon, Diamant

Silikater:

Olivines (Mg_2SiO_4, Fe_2SiO_4)

Is:

H_2O, CO, CO_2, CH_3OH, CH_4, H_2CO ...

Molekyle dannelse

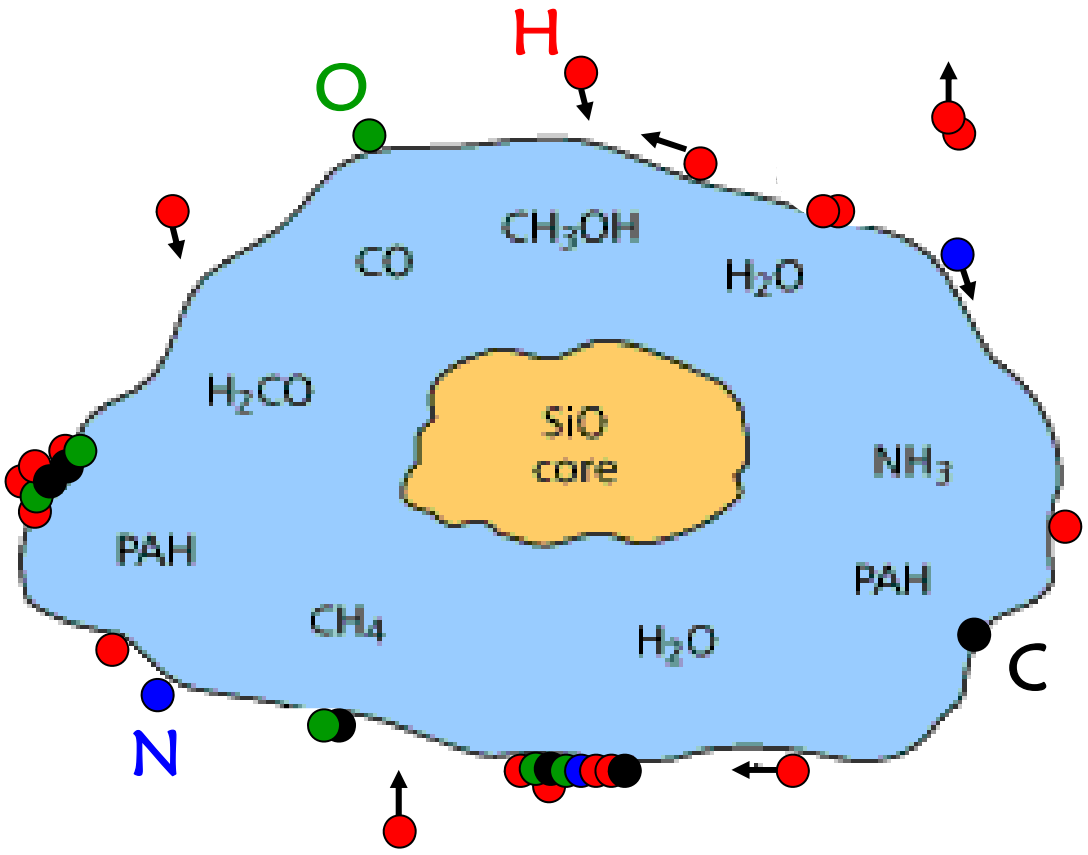
189 Molekyler:

H_2, CO, CO_2, O_2, H_2O, NH_3, CH_3OH ...

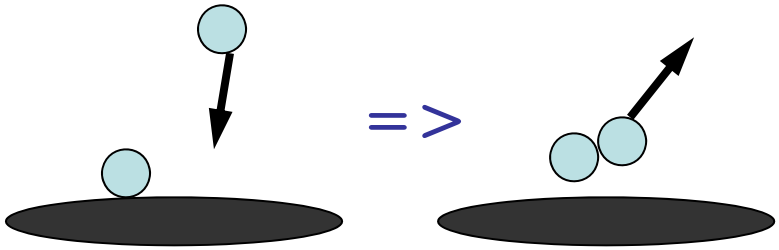
... glycine (CH_2NH_2COOH),

glycolaldehyde (CH_2OHCHO)

Overflade Reaktioner



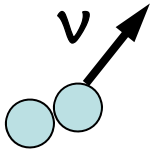
Energi fordeling ved H_2 dannelse ?



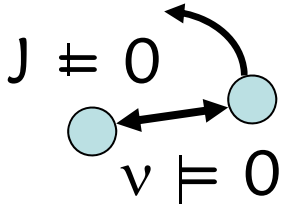
$E_{frigivet} \sim 4.5$ eV

50.000 K

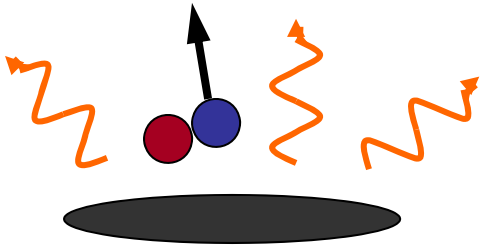
Til:



Kinetisk energi ?

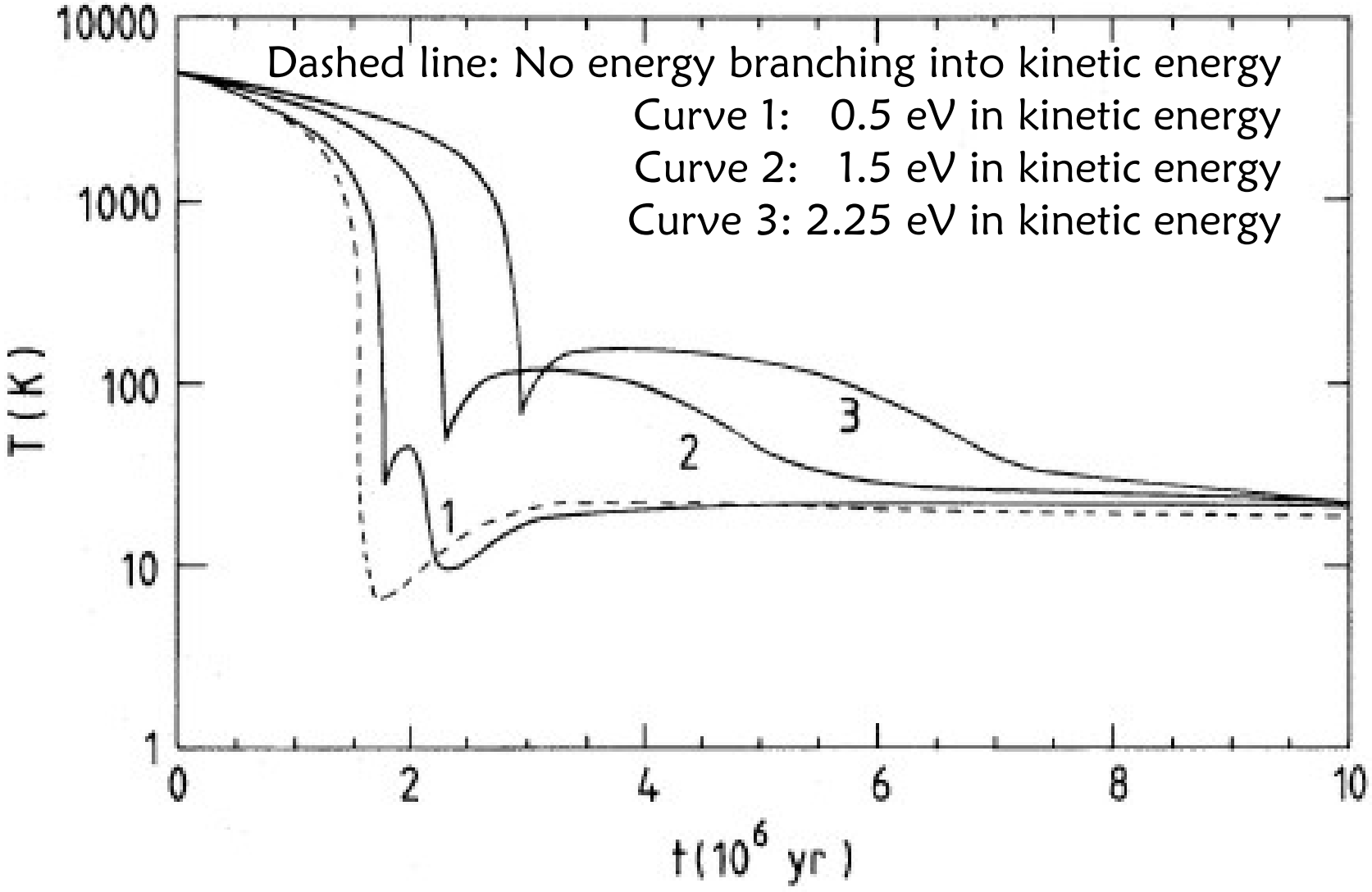


Molekylær eksitation ?



Støvkorns opvarmning ?

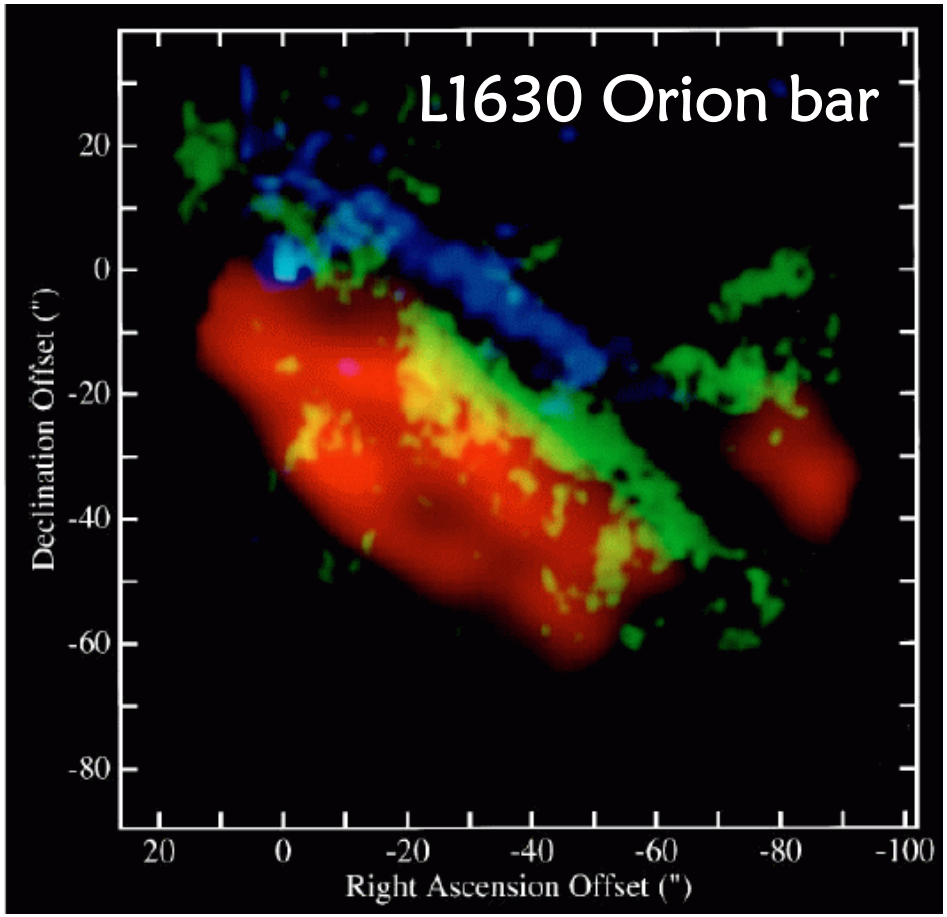
Energi frigivelse ved H_2 dannelse og termisk evolution af interstellare skyer



Flower & des Forêts, MNRAS 247, 500 (1990)

Effekten af H_2 dannelse i observationer

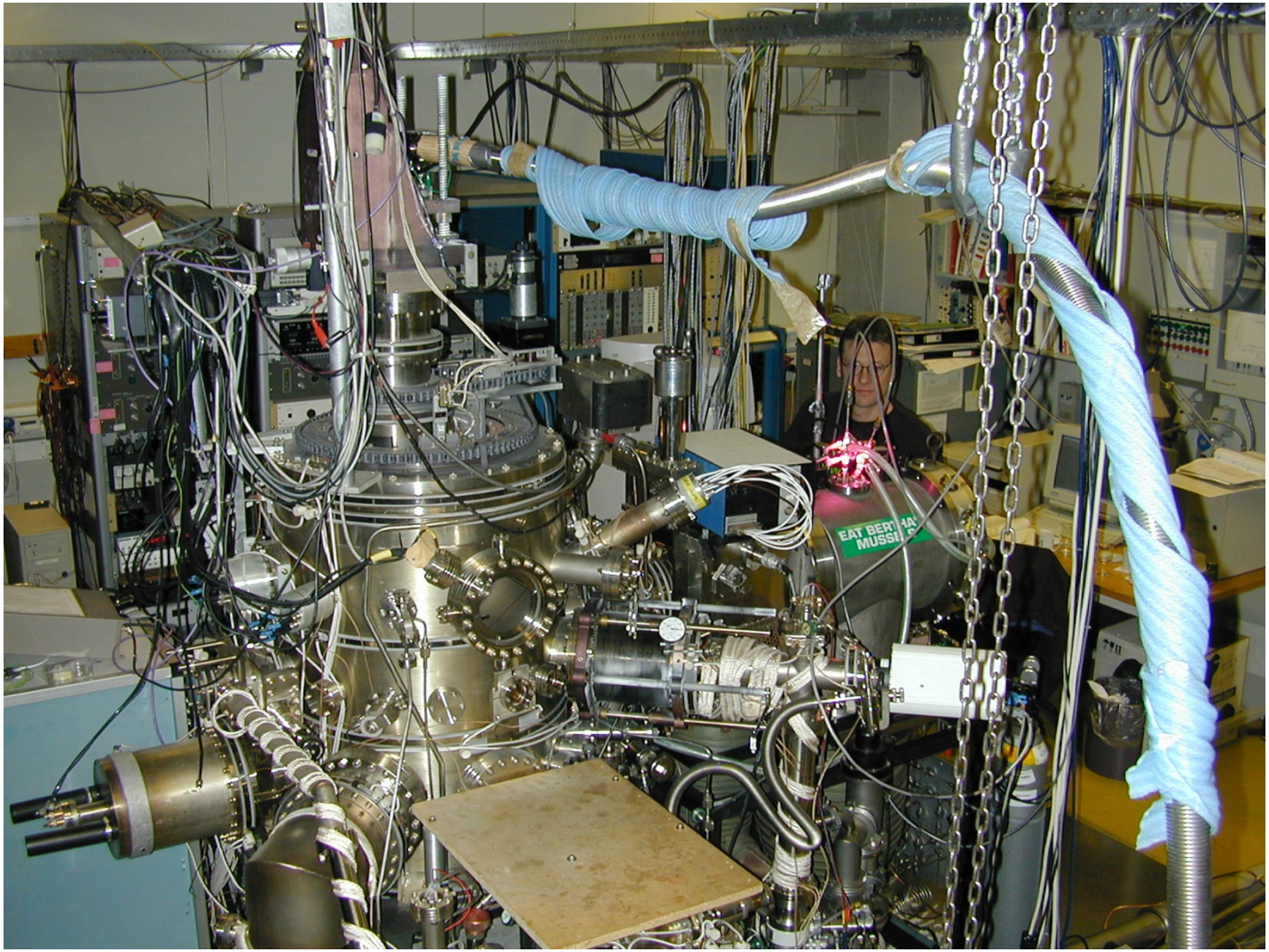
Photo Dissociations Regioner: gas temperatur: 100 – 1000K



Observationer viser overpopulation i $v=4$ Pga. H_2 dannelse i eksiterede tilstande.

Blue: PAH emission
Green: H_2 vibrational line emission (FAST)
Red: CO emission (30 m Telescope, IRAM)
Star at NW

Bringing the Interstellar medium to a laboratory near you



Genskabe interstellare betingelser ?

Interstellart tryk:

$P = 10^{-13}$ *atm*

Interstellare temperaturer:

T = 6-1000 K

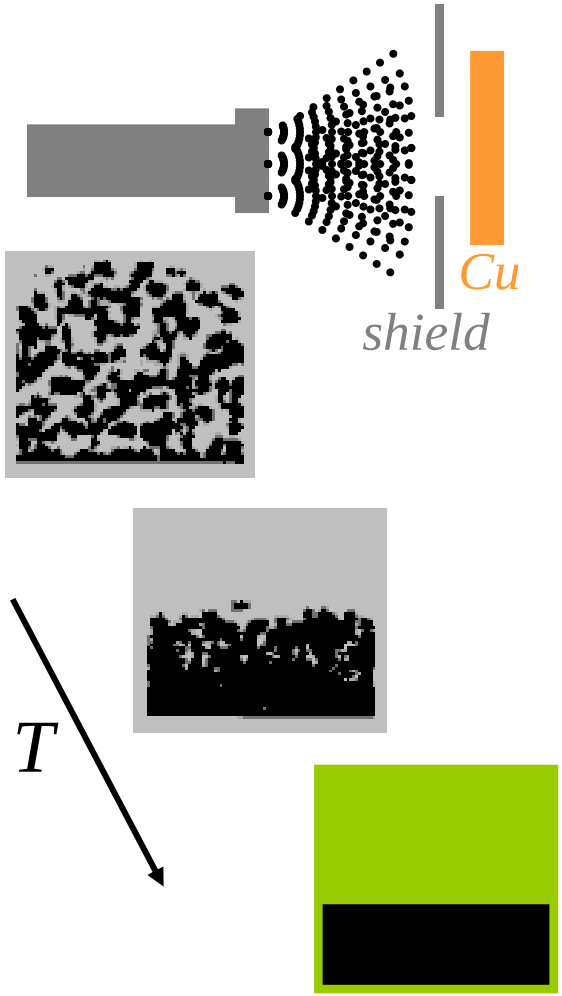
Relevante overflader:

***Is, grafit**, amorft kul, silikater*

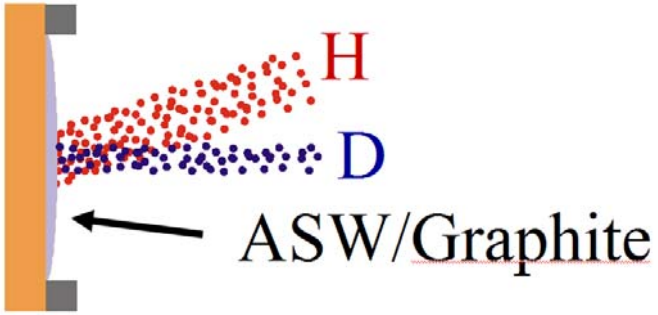
Overflader af interstellar relevans

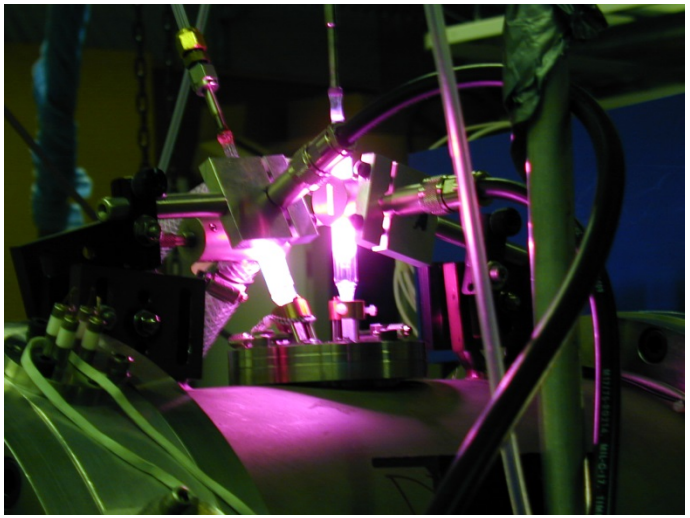
Grafit

Vand is



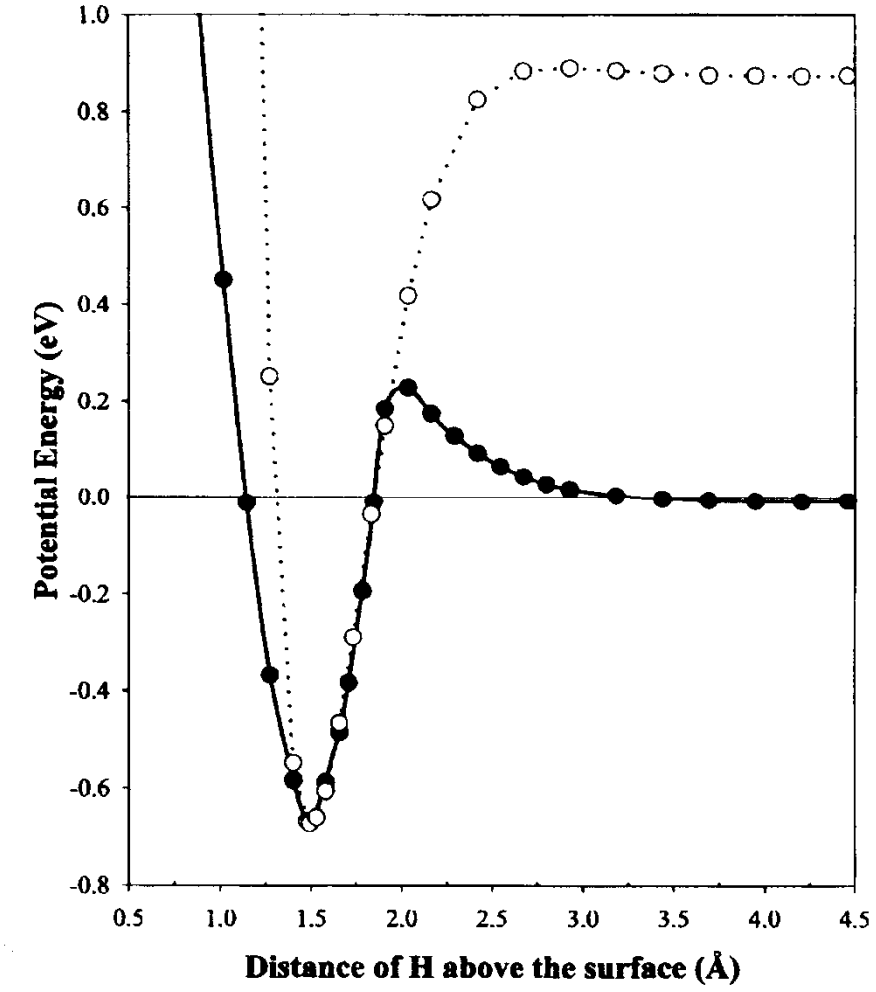
Atomar deponering



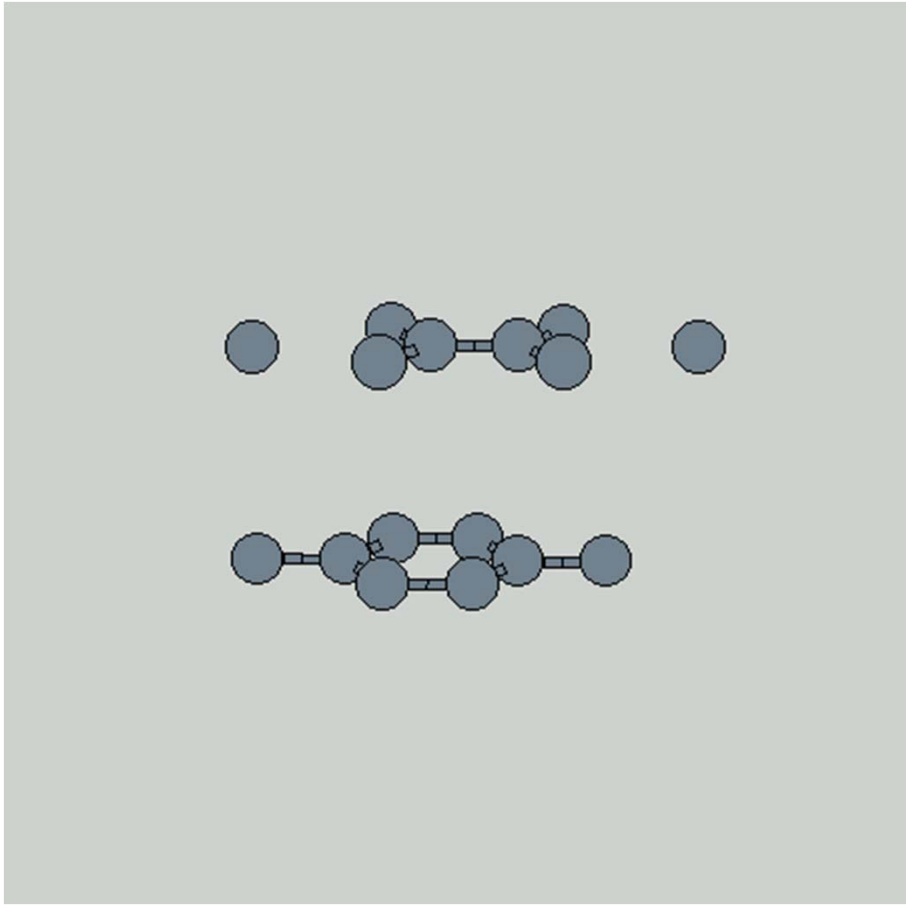


H kemisorberet på grafit

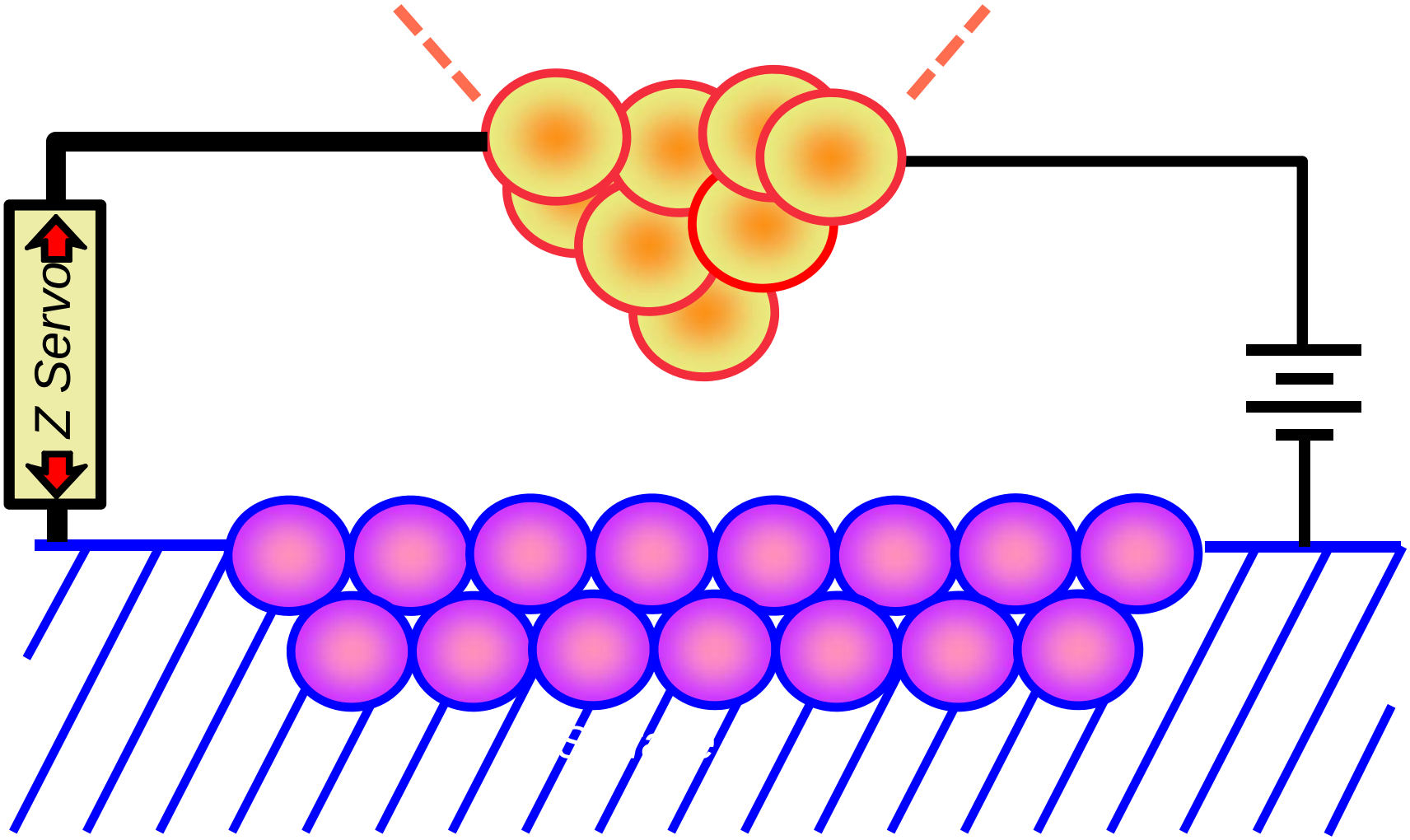
Jeloica & Sidis, Chem. Phys. Lett. ***300****, 157 (1999)*

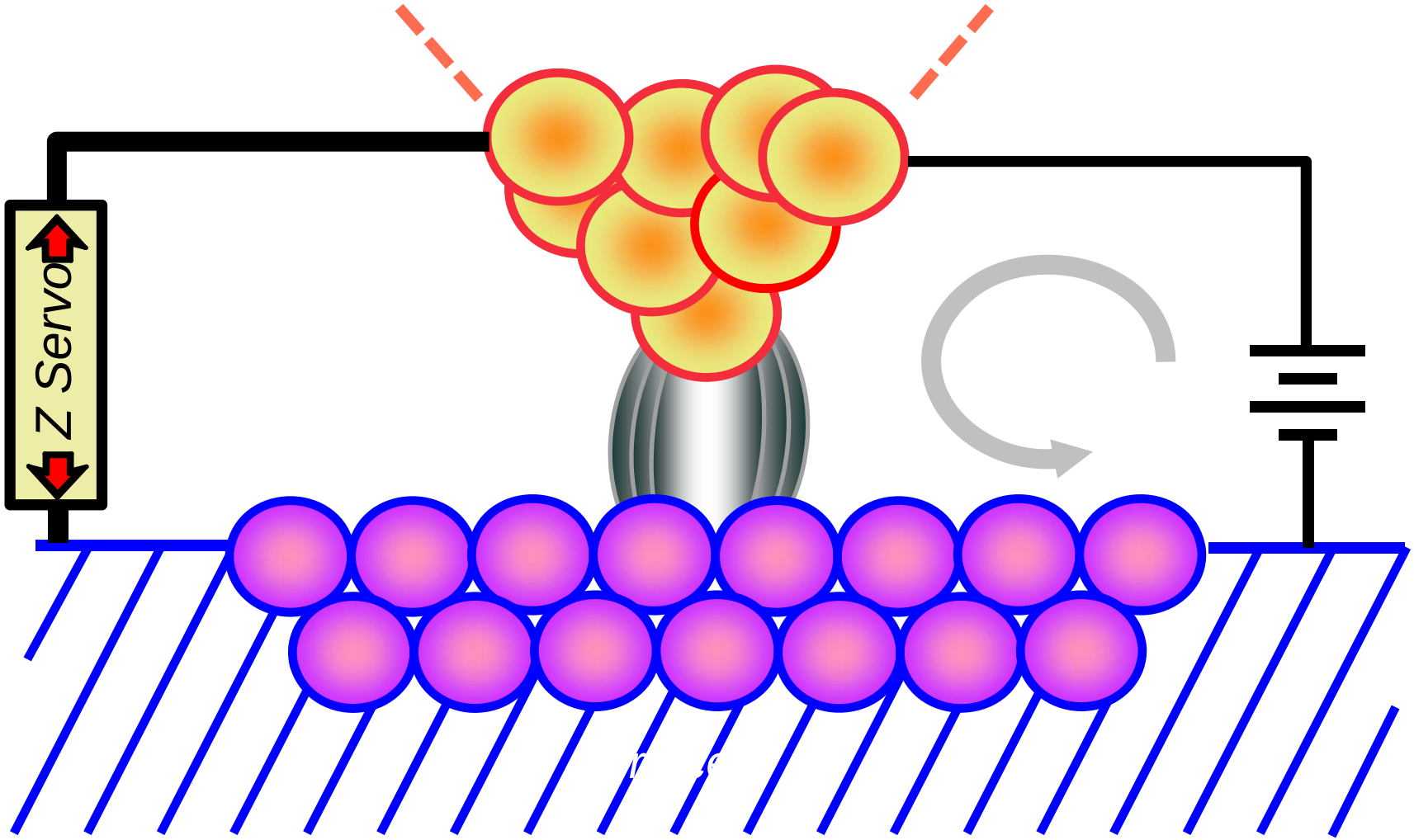


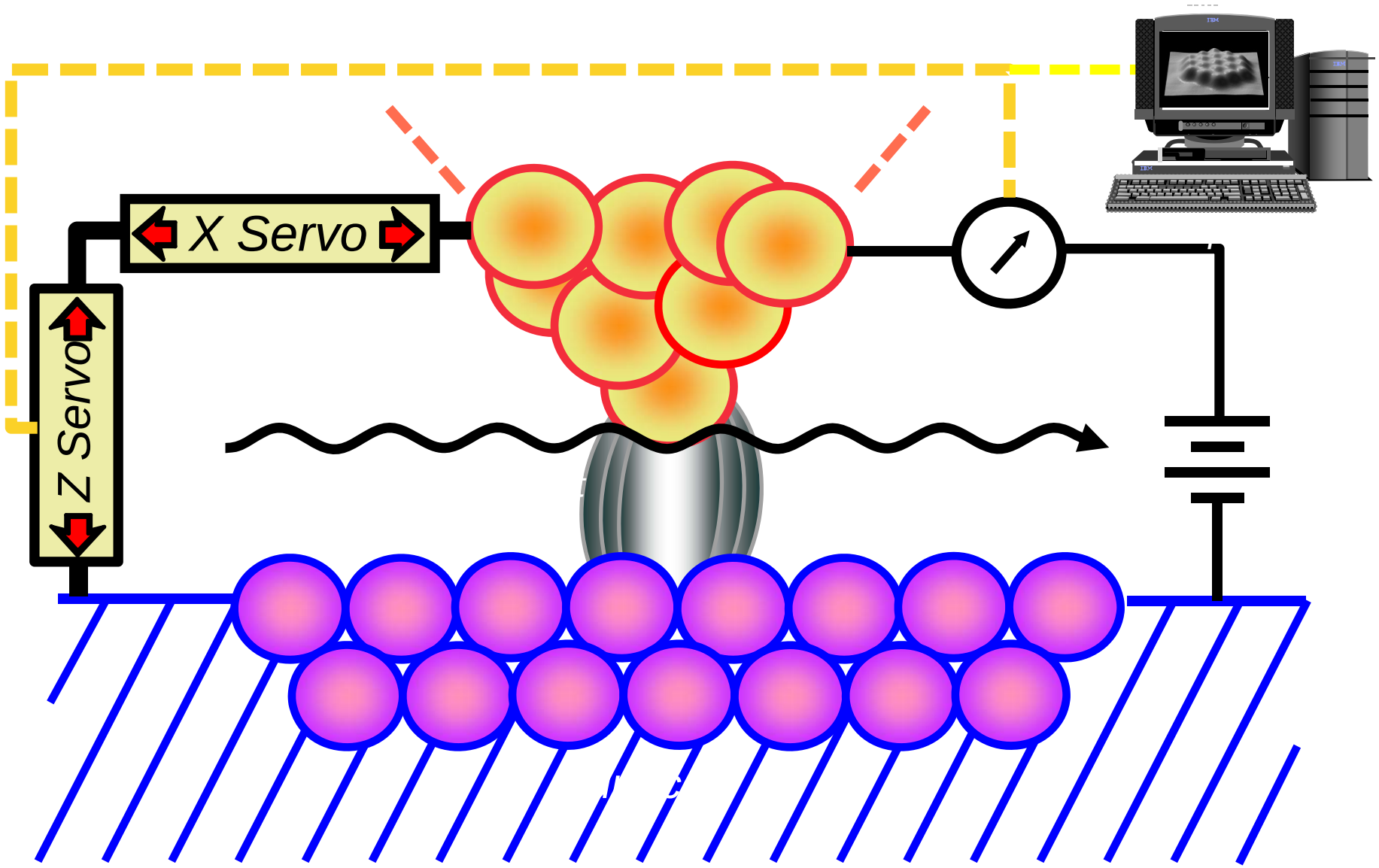
Sha et al, Surface Science 496, 318 (2002)



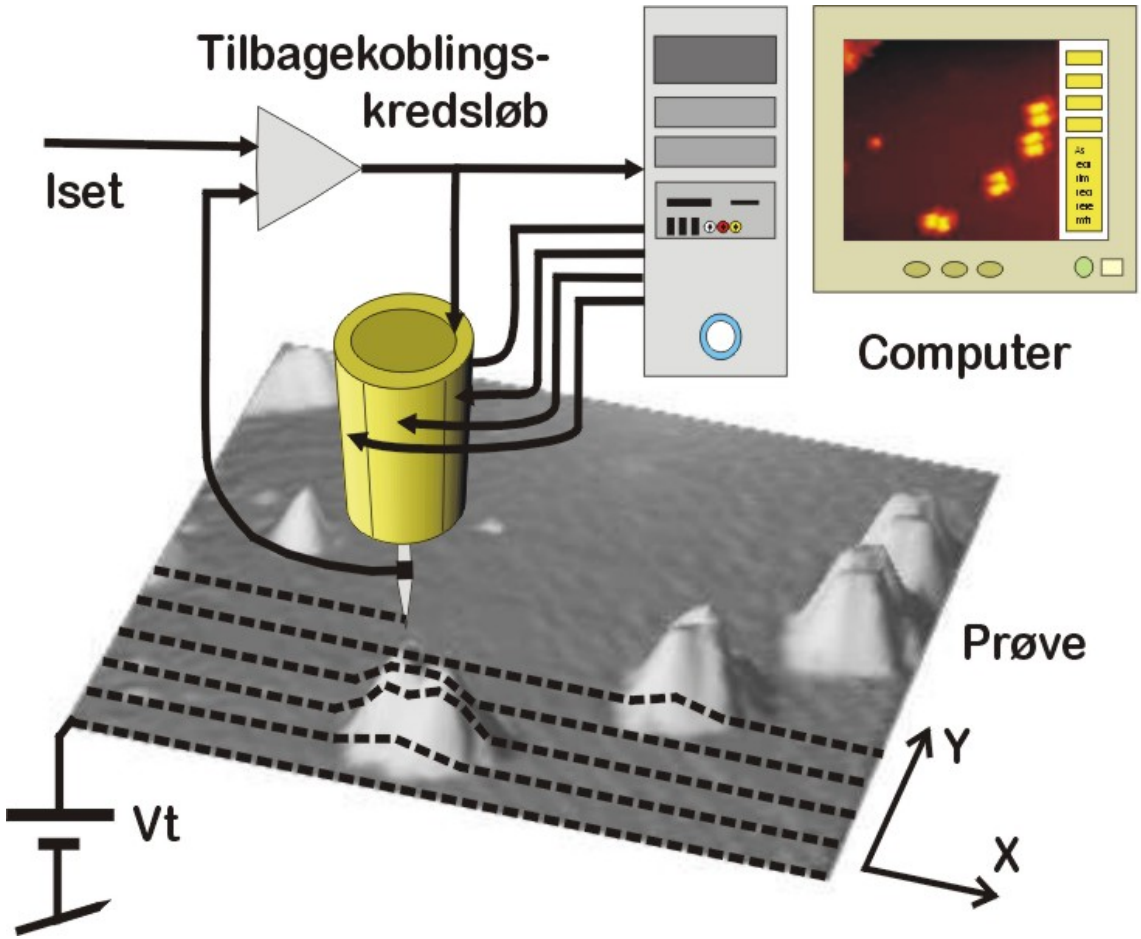
Eva Rauls


Z Servo

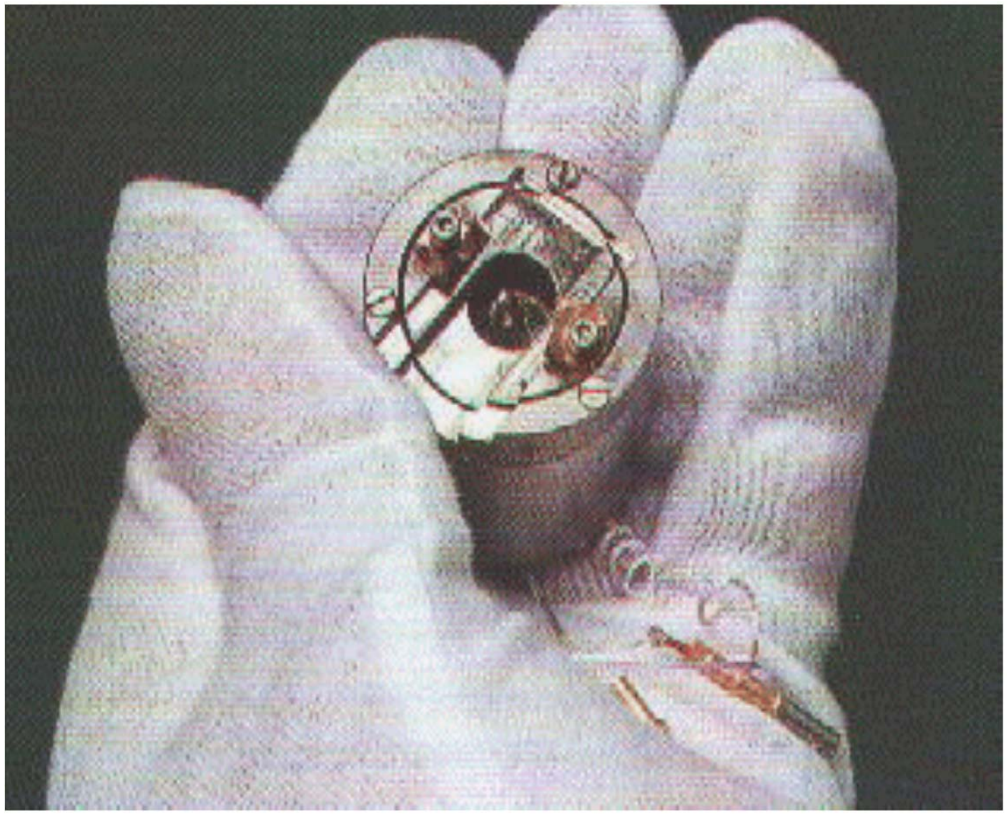

Z Servo

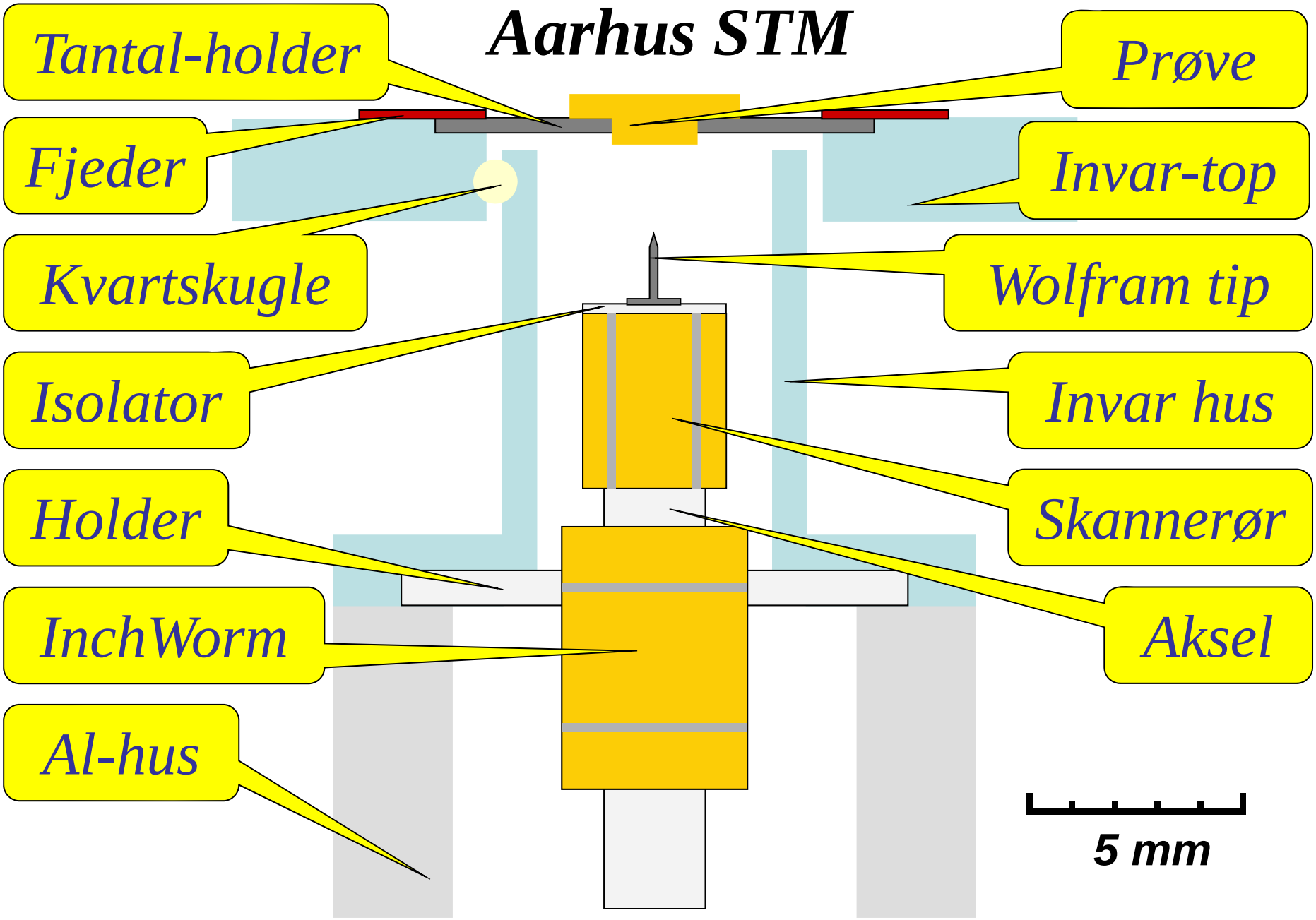

X Servo
Z Servo

STM Princip

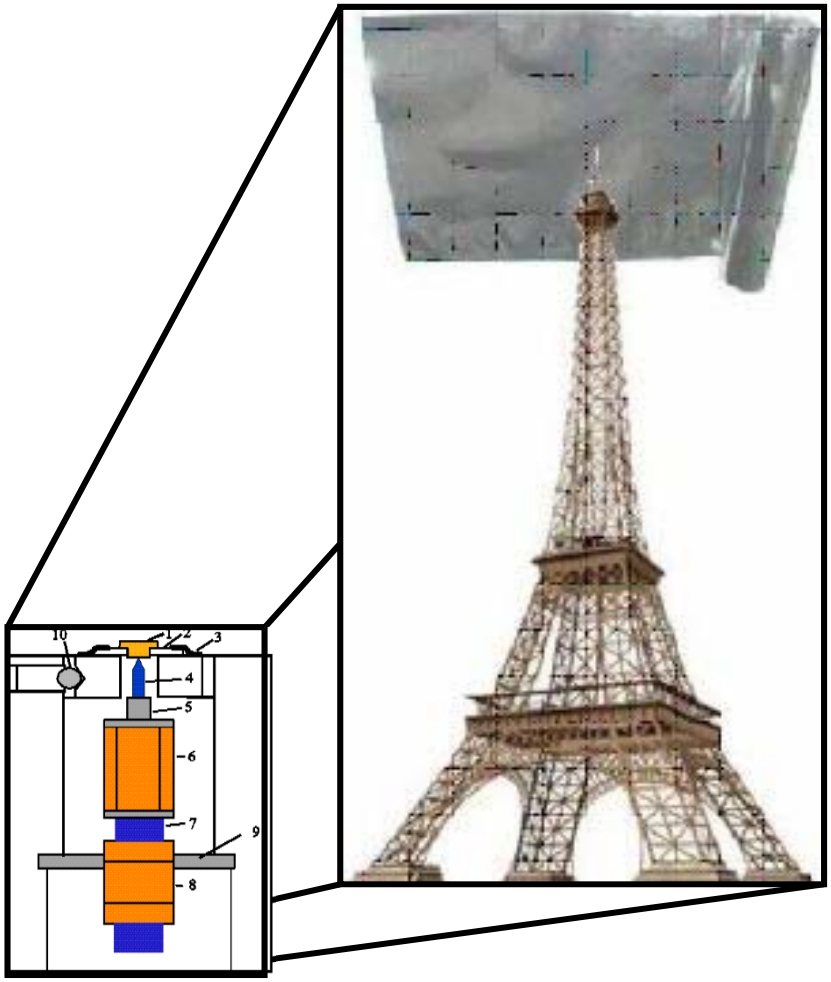


Aarhus STM




Aarhus STM
Tantal-holder
Fjeder
Kvartskugle
Isolator
Holder
InchWorm
Al-hus
Prøve
Invar-top
Wolfram tip
Invar hus
Skannerør
Aksel
5 mm

STM og vibrationer



STM nål: ca. 3 cm

Nål-prøve: 0.1 nm

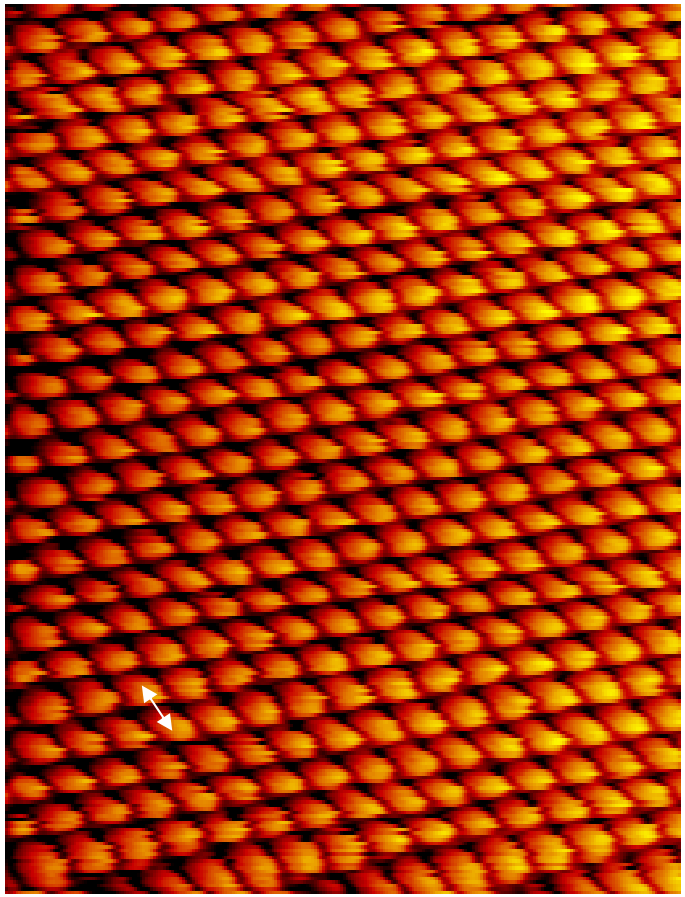
Eiffeltårnet: 320 m

Eiffeltårn – jord: 0.1 mm

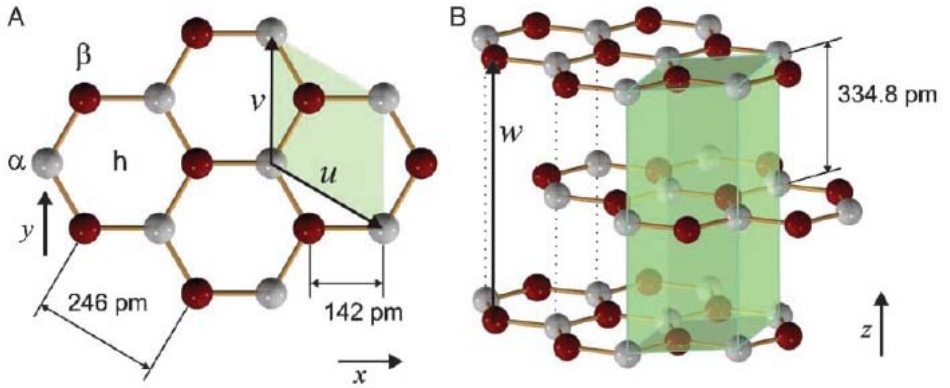
Nål-prøve vibration < 0.01 nm

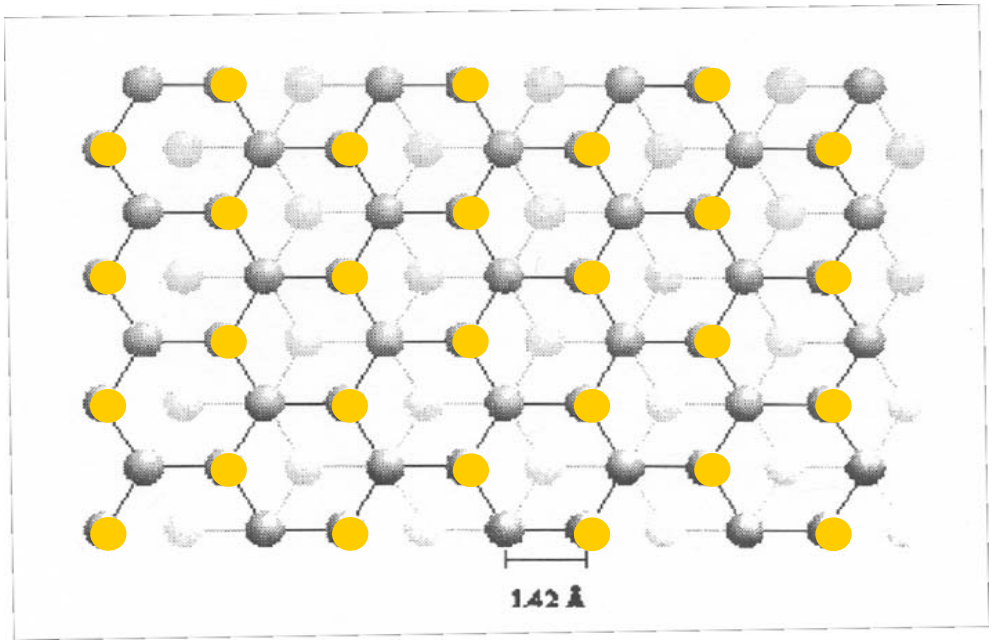
Eiffeltårn – jord vib. < 1 μm !!

STM på grafit

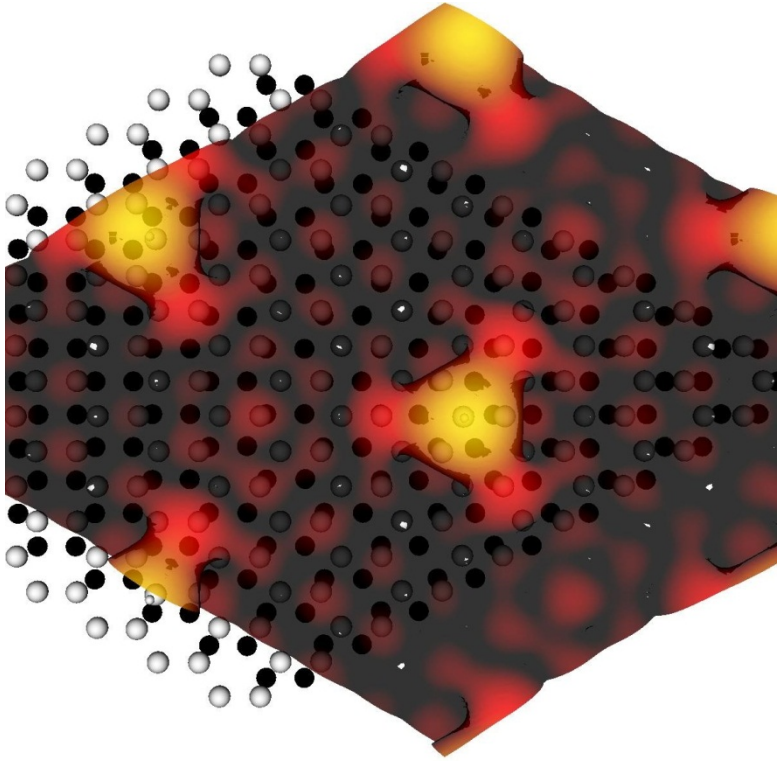


↕ 2.46 Å

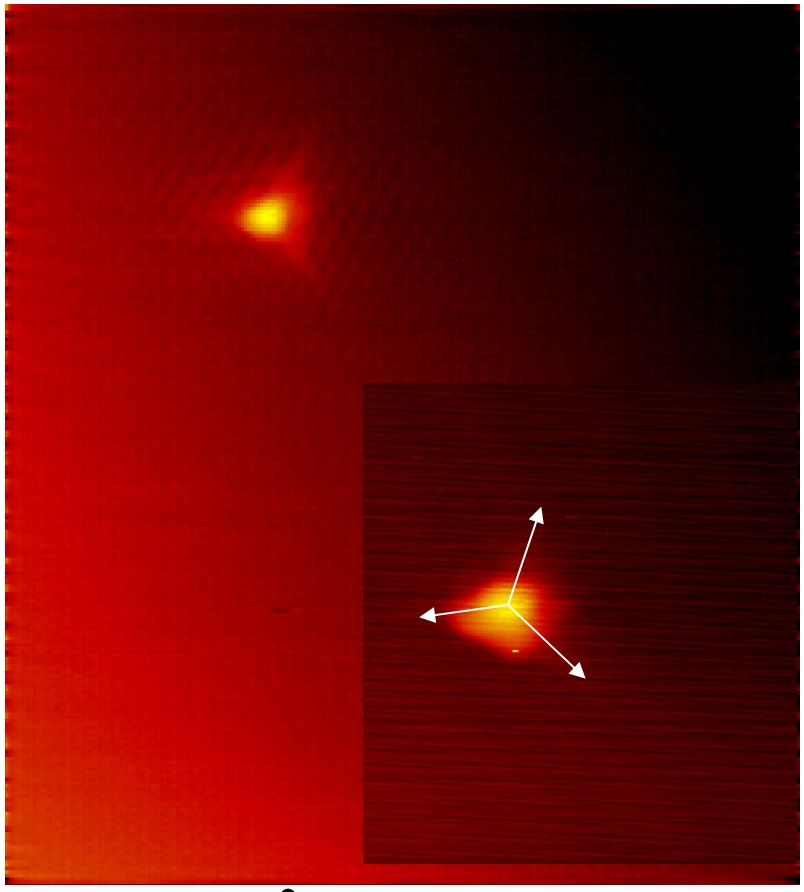




Hydrogen på grafit



Zeljko Sljivancanin

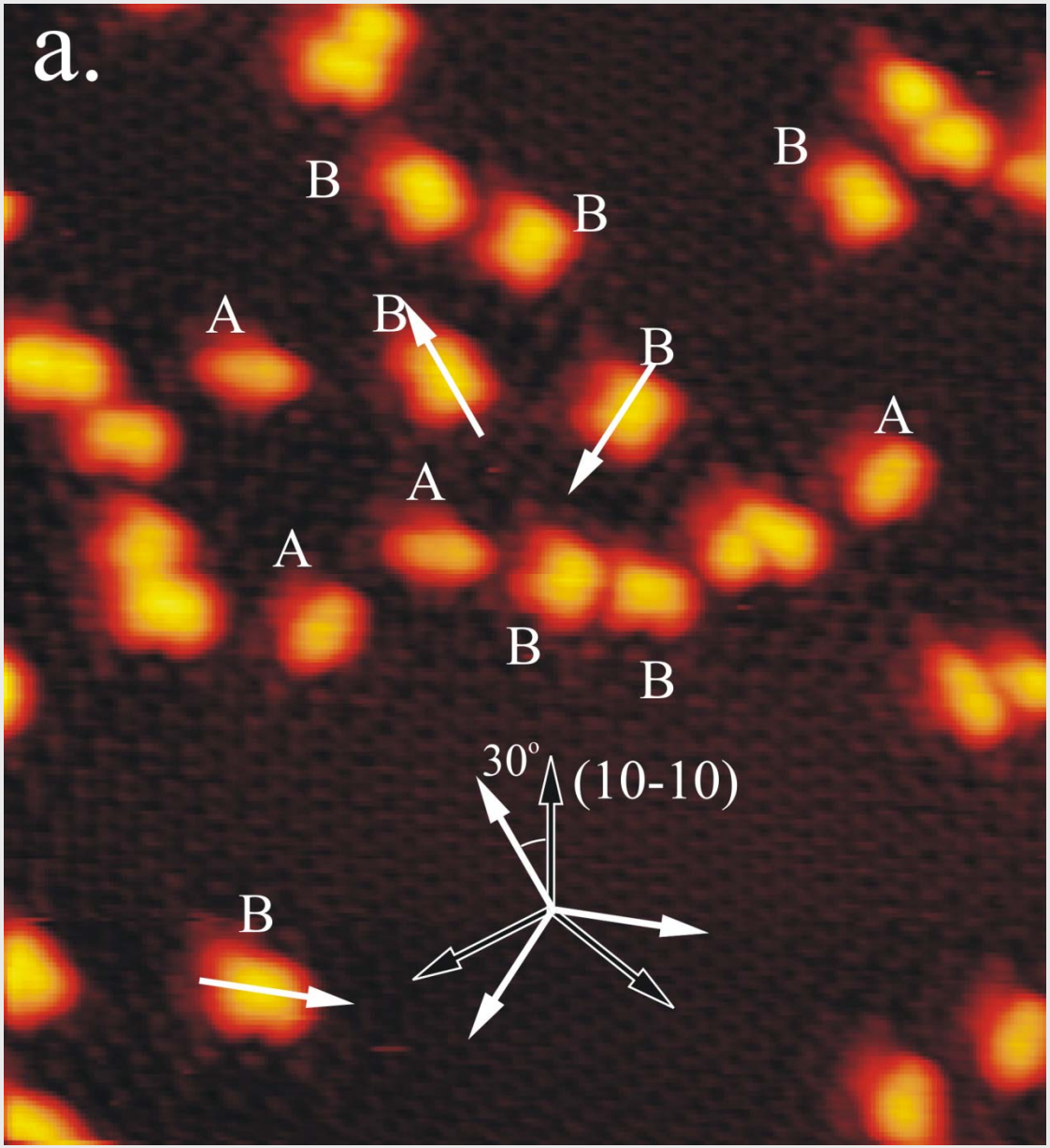


155 x 171 Å^2 , 180 K

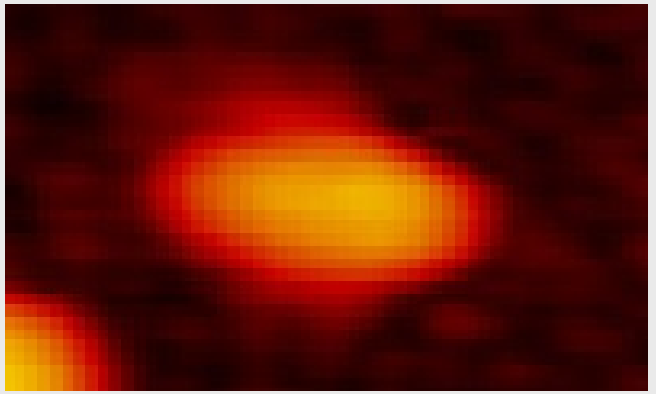
V_t~ -710mV, I_t~ -0.16nA

H-Dimerer på grafit

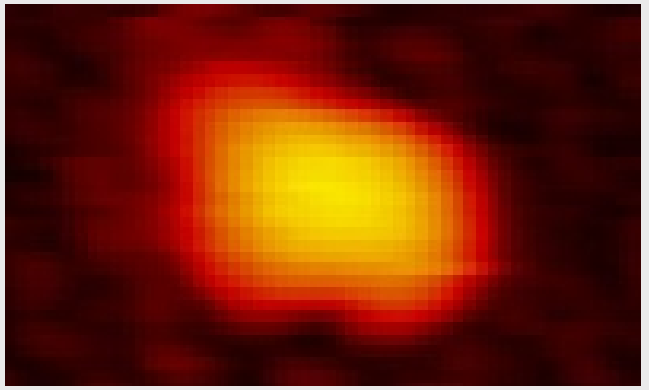
103 x 114 Å^2



Dimer A



Dimer B

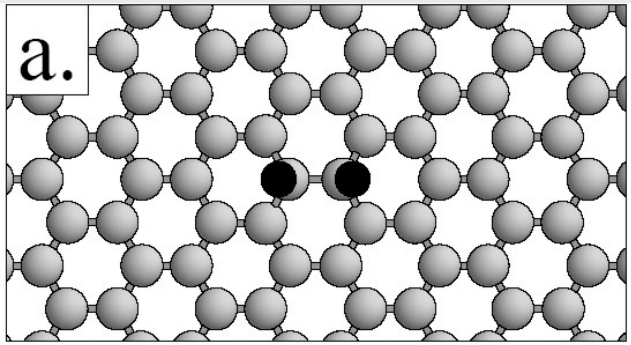


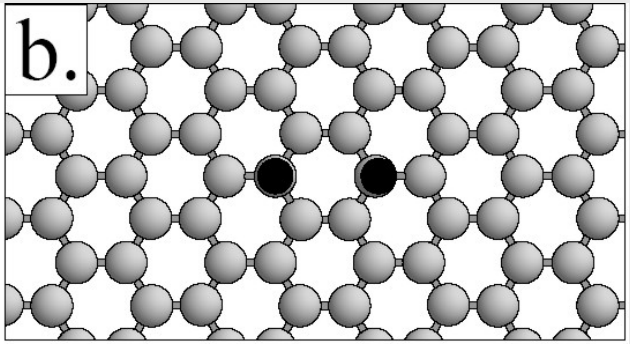
V_t = 884 mV, I_t = 0.16 n

Dimerer: Teory vs. Eksperiment

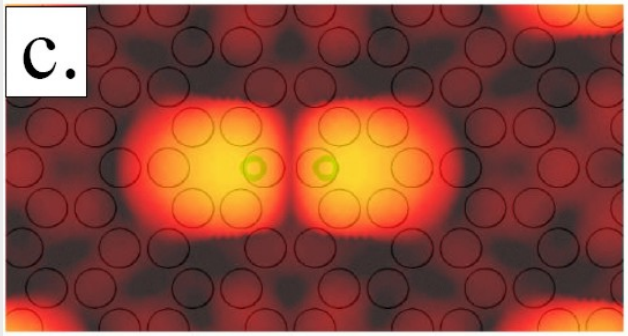
Ortho dimer - Dimer A

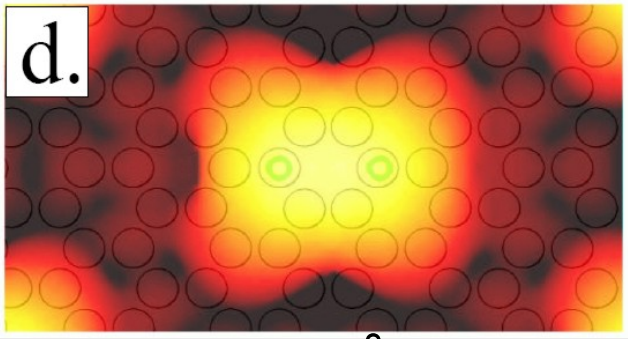
Para dimer - Dimer B





Hornekær et al. Phys. Rev. Lett. ***96****, 156104 (2006)*



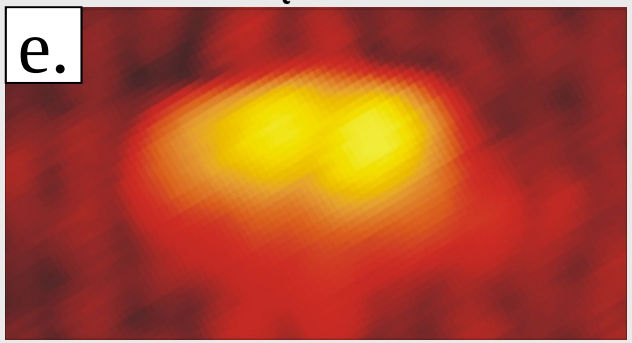


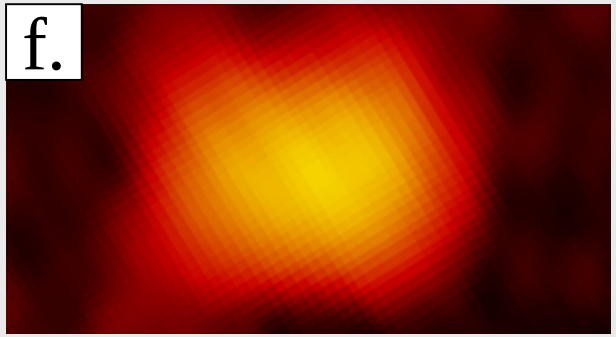
V_t=0.9 V, LDOS=1x10^{-6} (eV)$^{-1}$ Å^{-3}

Similar results for ortho dimer:

Ferro et al. Chem. Phys. Lett. ***368****, 609 (2003).*

Y. Miura et al. J. Appl. Phys. ***93****, 3395 (2003).*

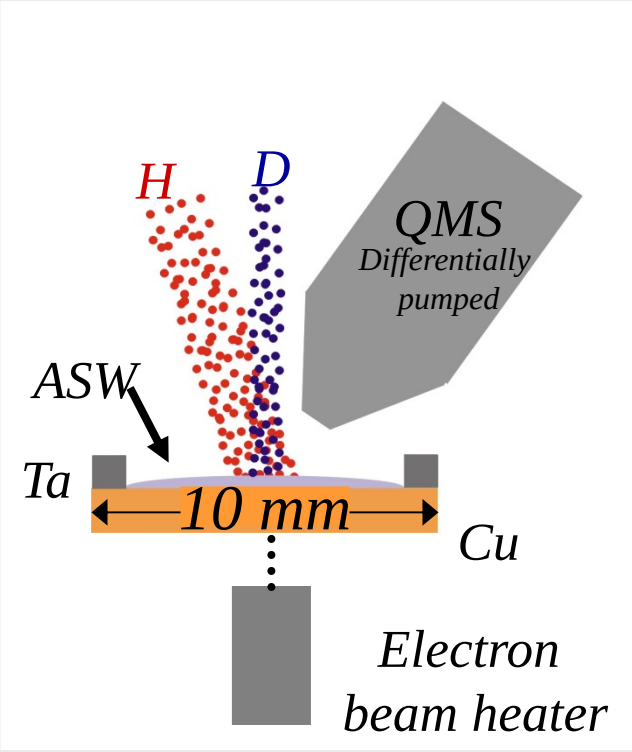


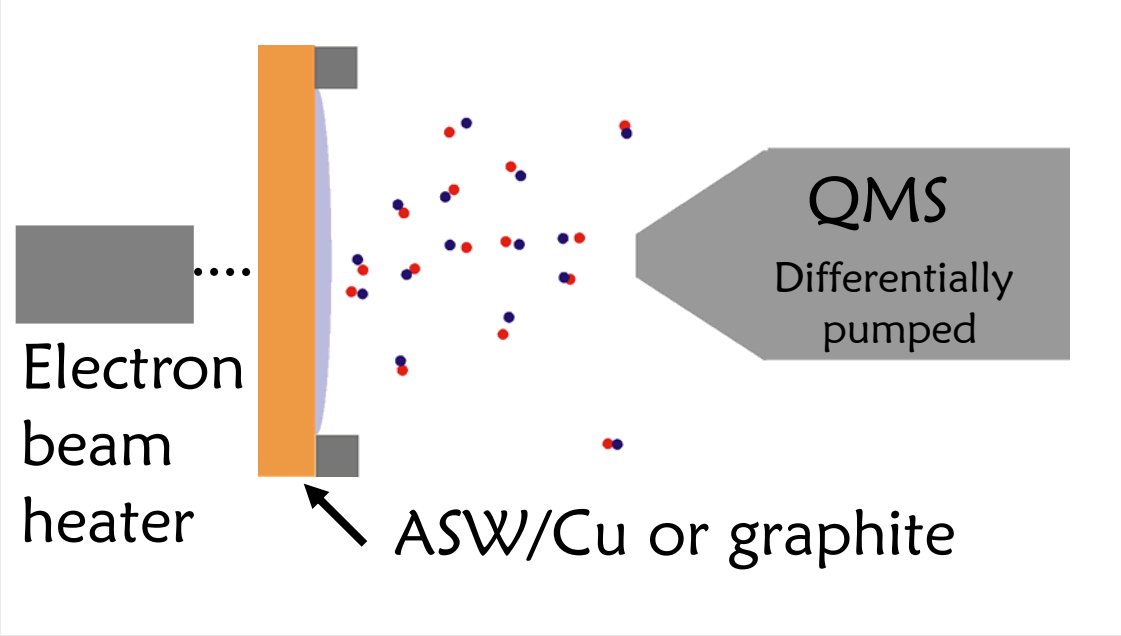


V_t = 884 mV, I_t = 0.16 nA

Bestem om reaktion forekommer og ved hvilken temperatur

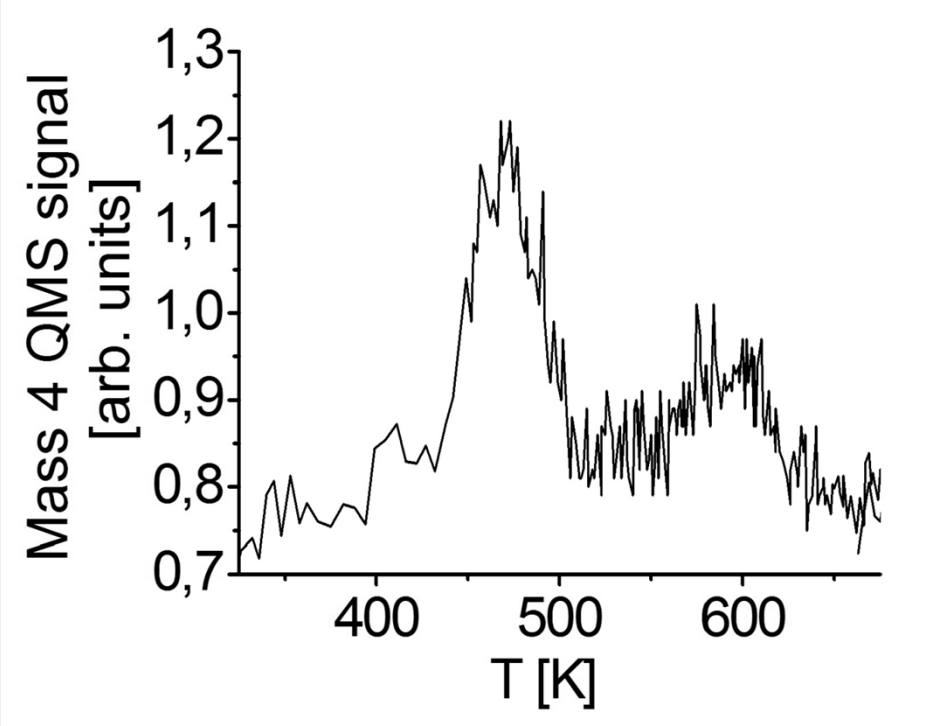
Termisk desorptions spektroskopi (TDS, TPD)





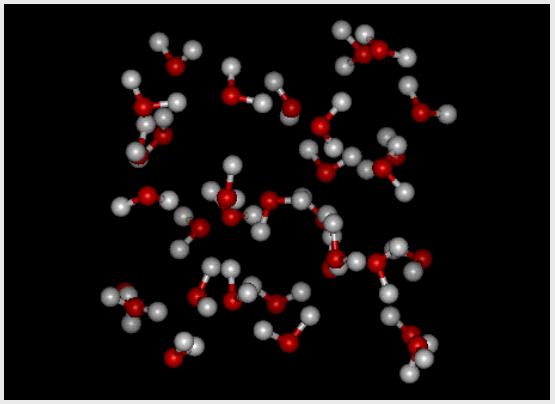
Termisk Desorptions Spectrum

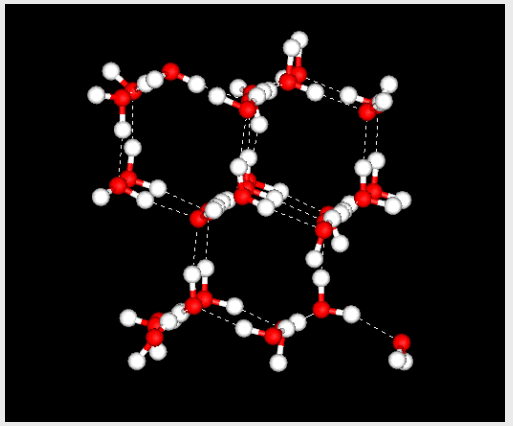
D_2 fra grafit

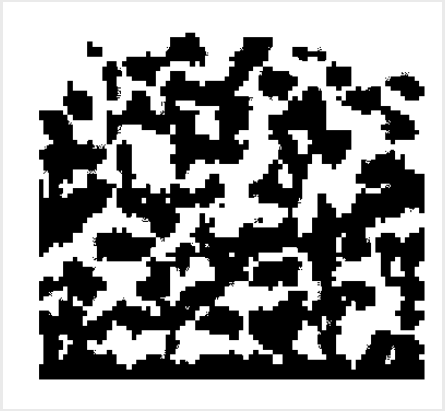


H_2 dannelse ved lavere temperaturer – is dækkede overflader

Vand is - morphology

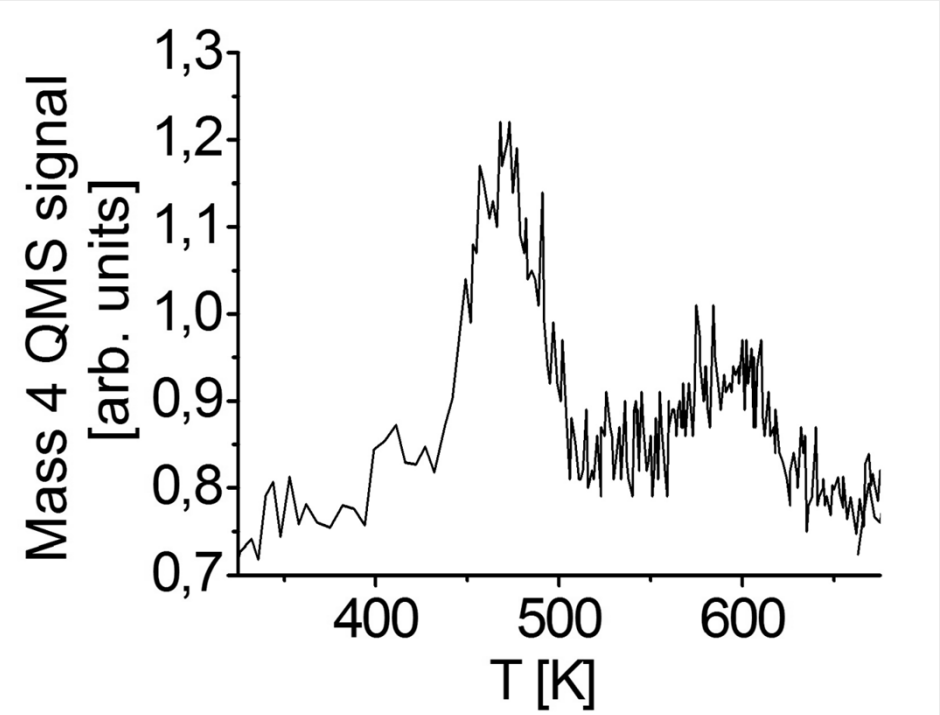




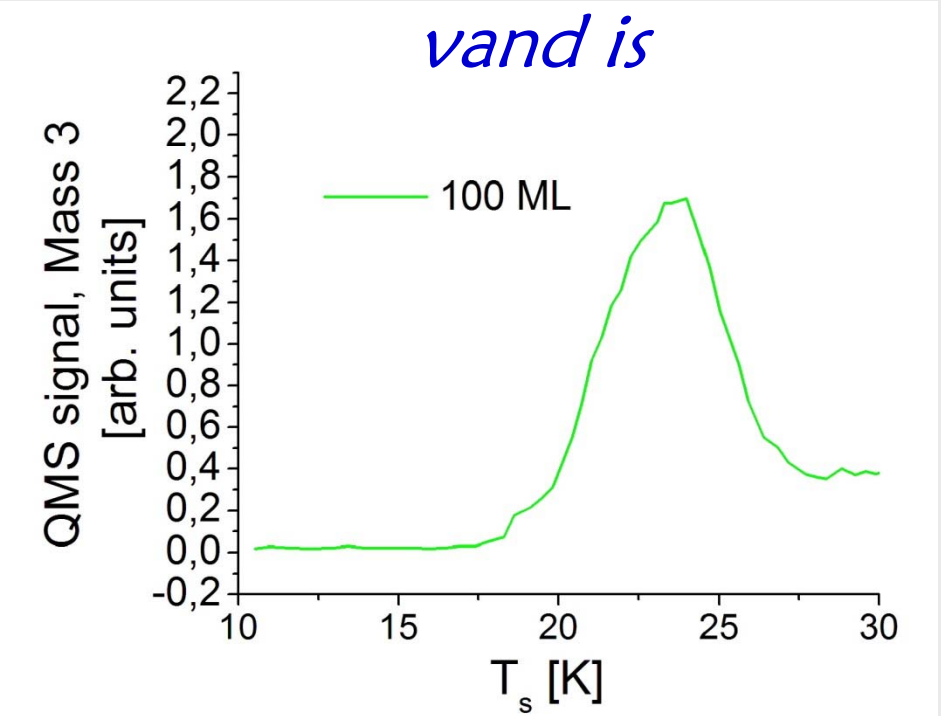


Termisk desorptions spektroskopi

D_2 fra grafit

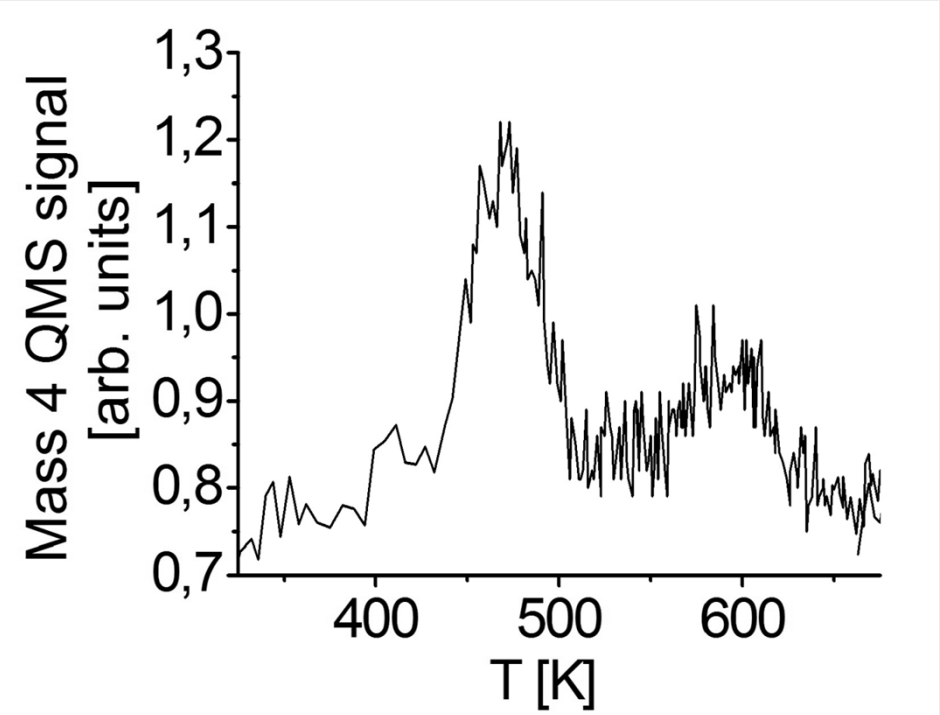


HD fra amorf vand is

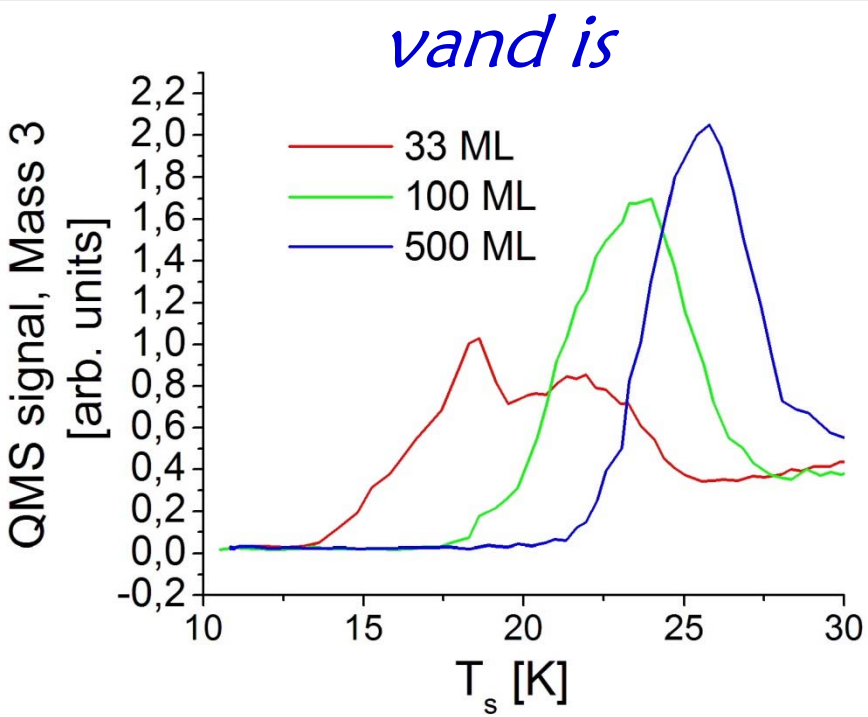


Termisk desorptions spektroskopi

D_2 fra grafit

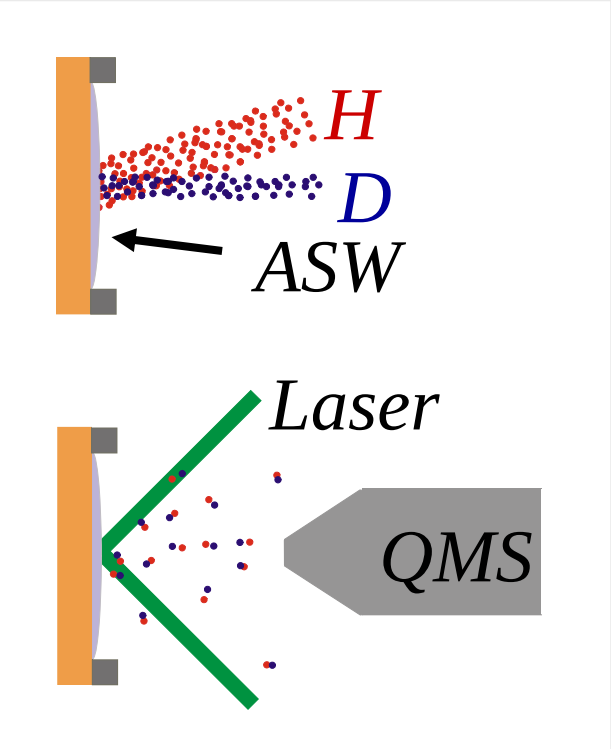


HD fra amorf vand is

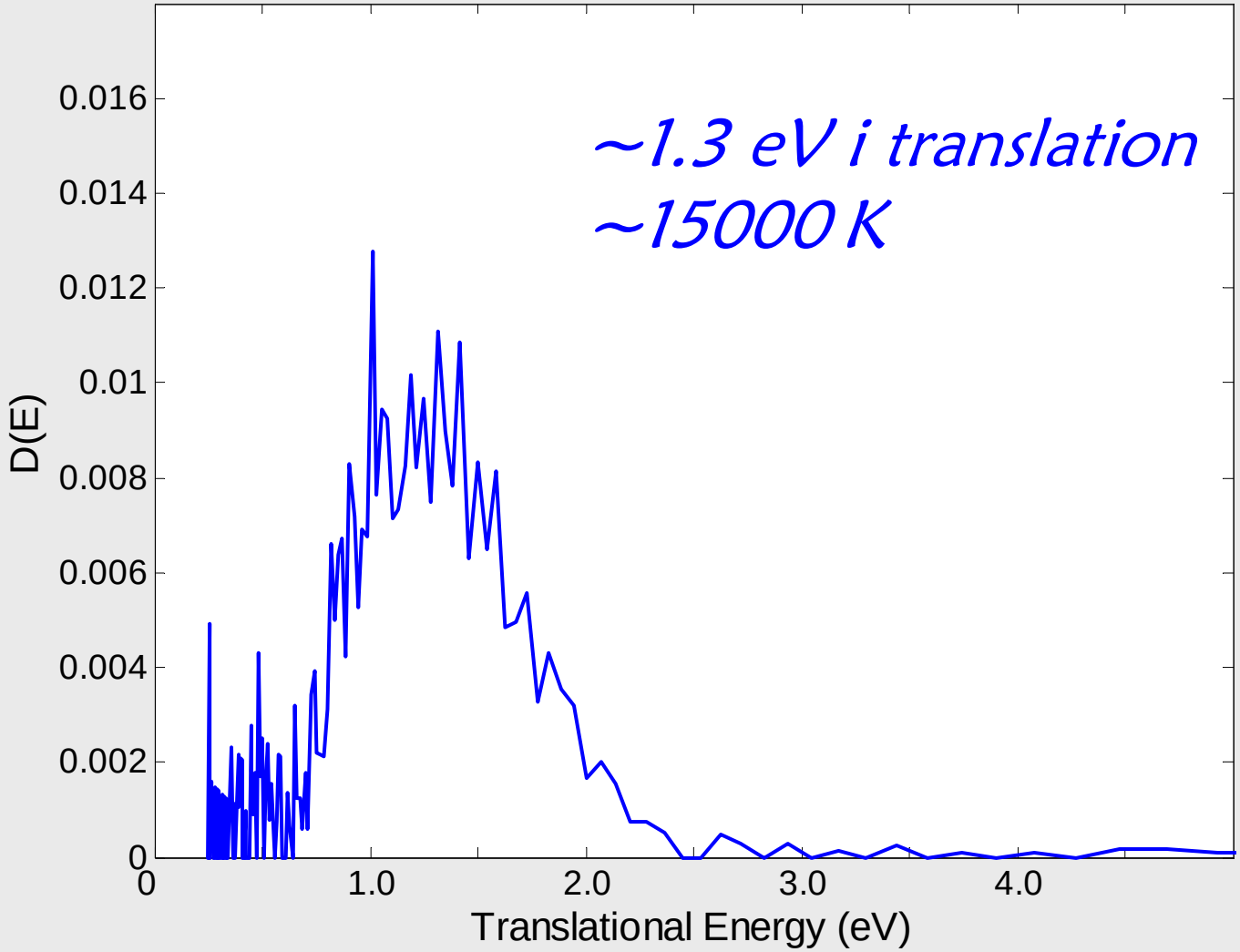


Hvordan måler vi kinetisk energi af det dannede H_2 ?

Laser desorption - Time-of-flight

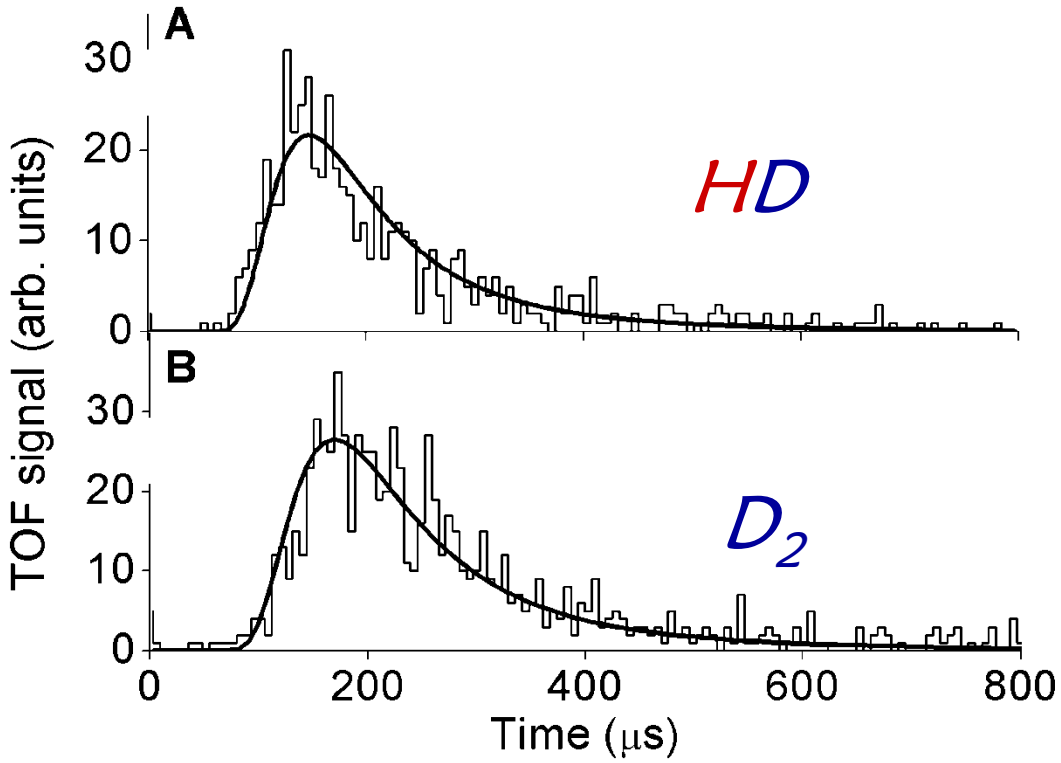


Kinetisk energi af D_2 dannet på grafit



S. Baouche et al, J. Chem. Phys. 2006

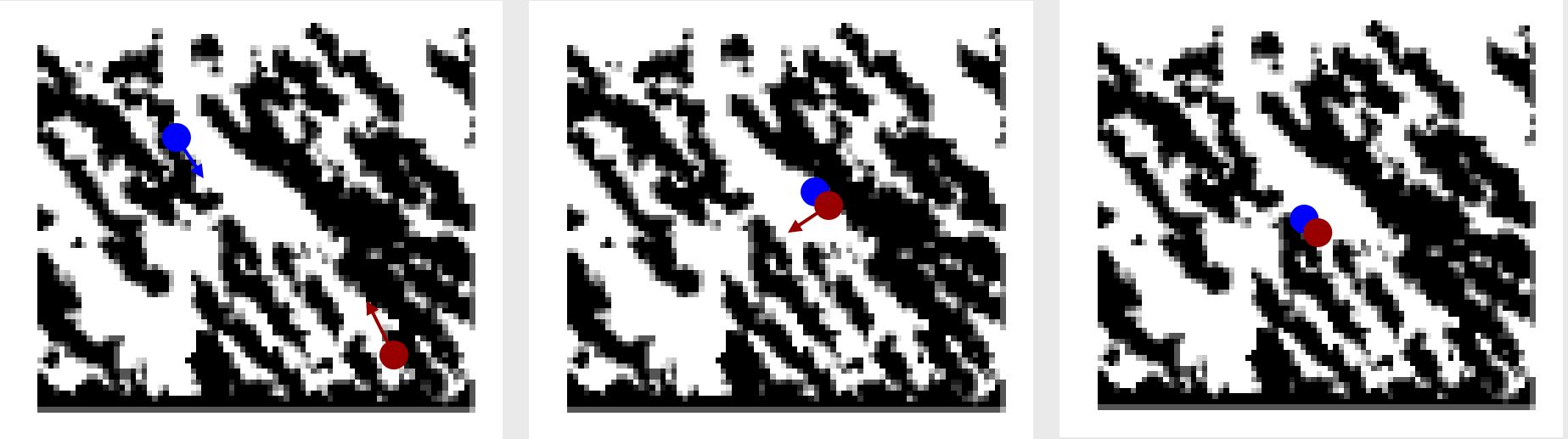
Kinetisk energi af HD dannet på porøs vand is



Solid line:
45 K Maxwell-Boltzmann velocity dist.

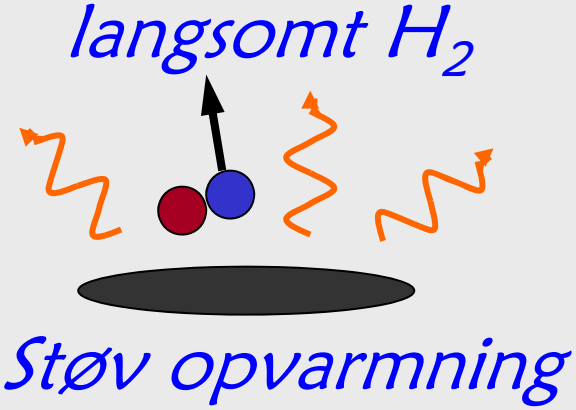
*L. Hornekær et al., Science, **302**, 1943 (2003)*

H_2 dannet på porøs vand is



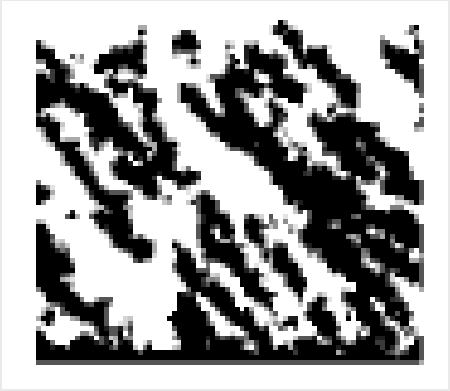
Overfladestruktur bestemmer energi-fordeling

Porøs overflade:

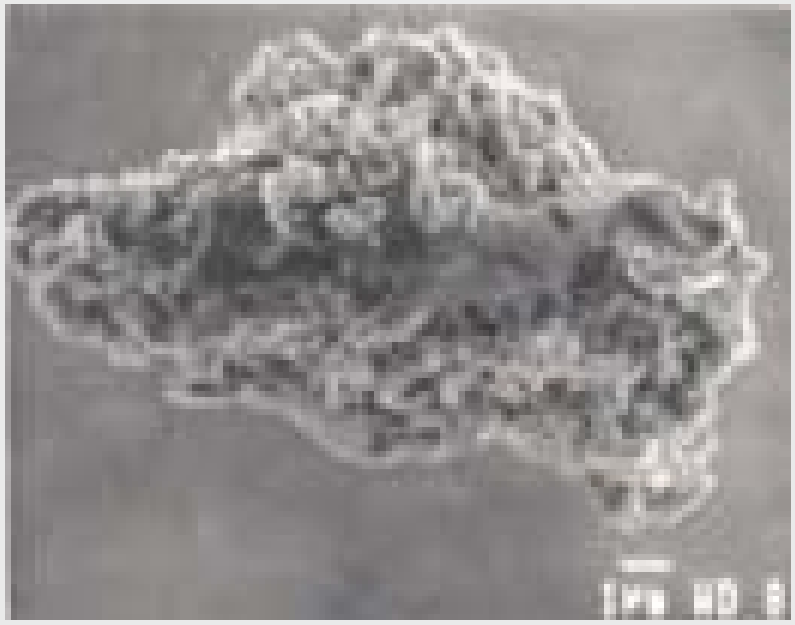


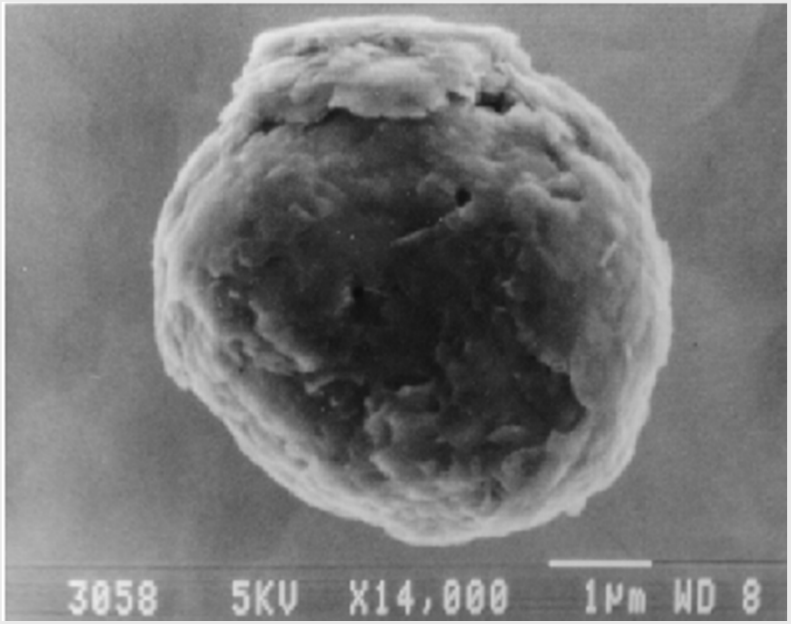
Resultat

Overfladestruktur bestemmer energi-fordeling



Støvkorns morfologi

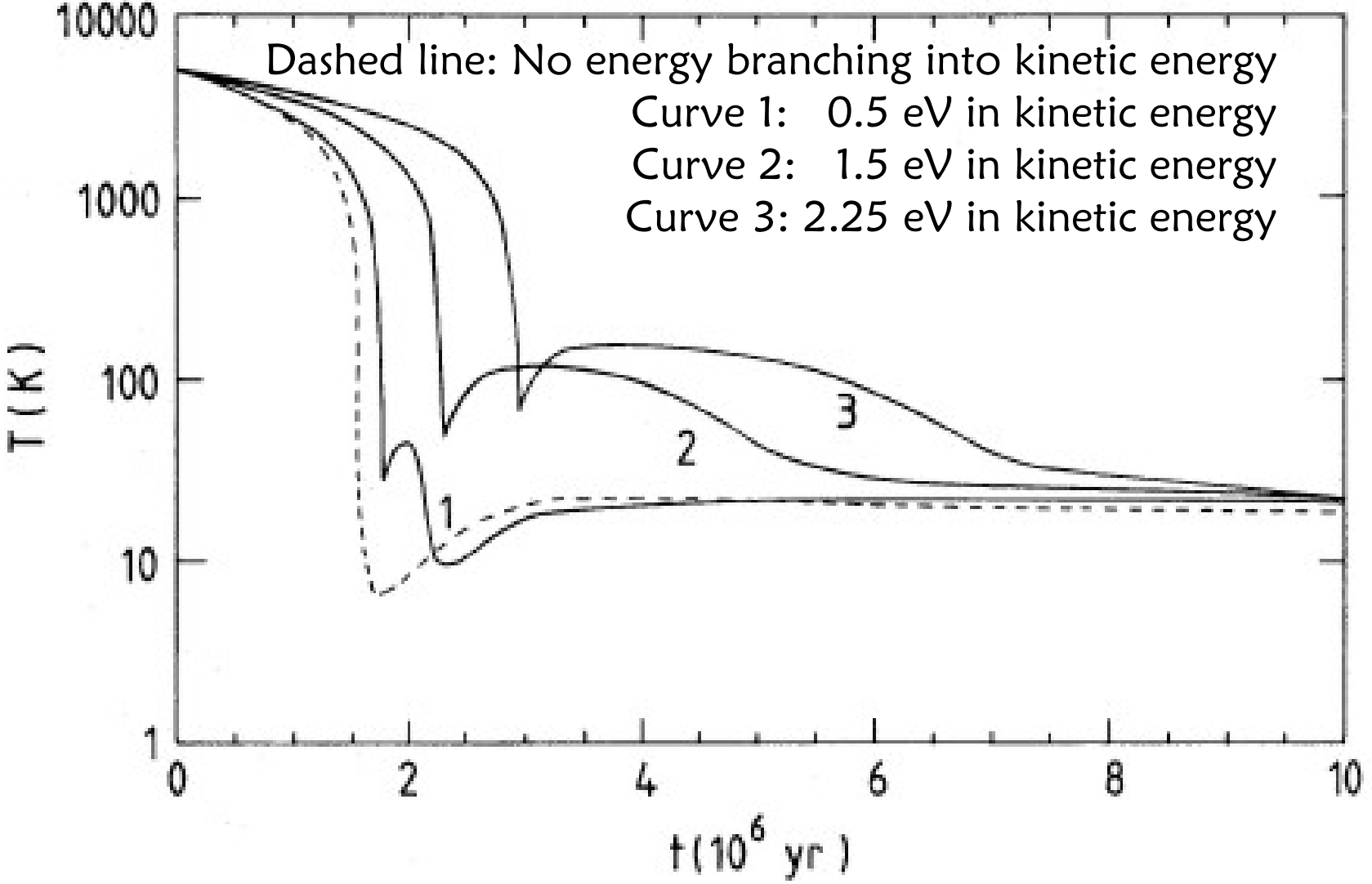




Bare korn – porøse og ikke-porøse

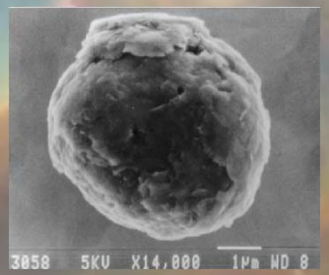
Is dækkede korn

Energi frigivelse af H_2 dannelse og termisk evolution af interstellare skyer



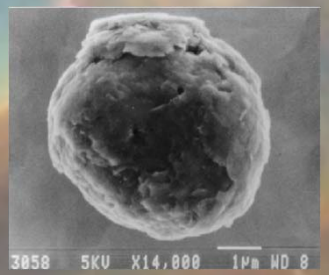
Flower & des Forêts, MNRAS 247, 500 (1990)

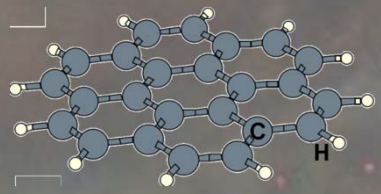
Andre veje ?

H + H + 

→ H_2

Andre veje ?

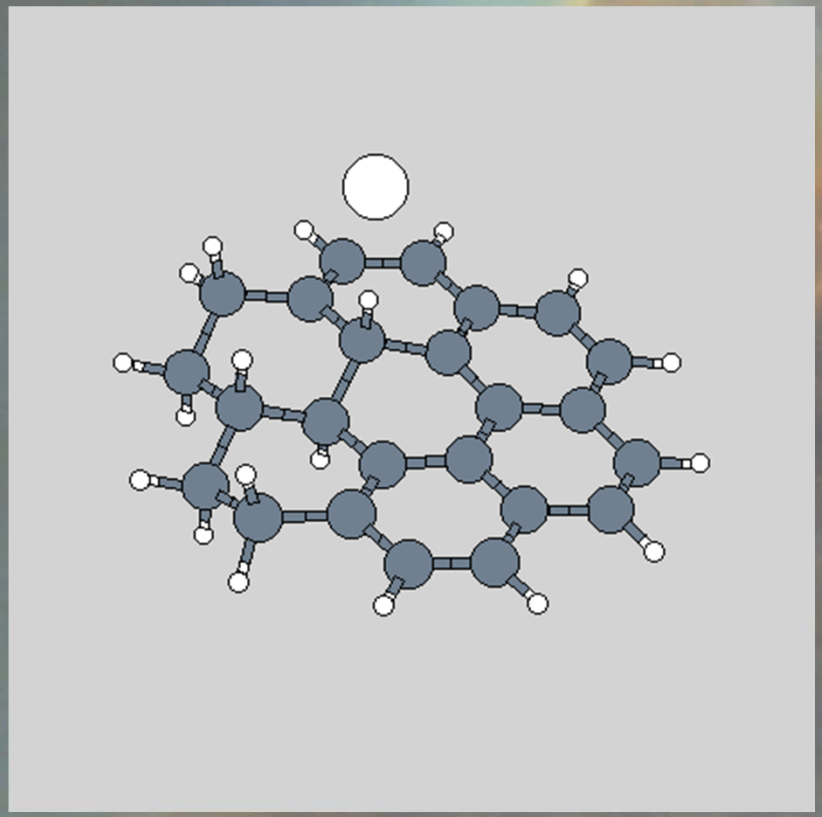
H + H +  → H_2

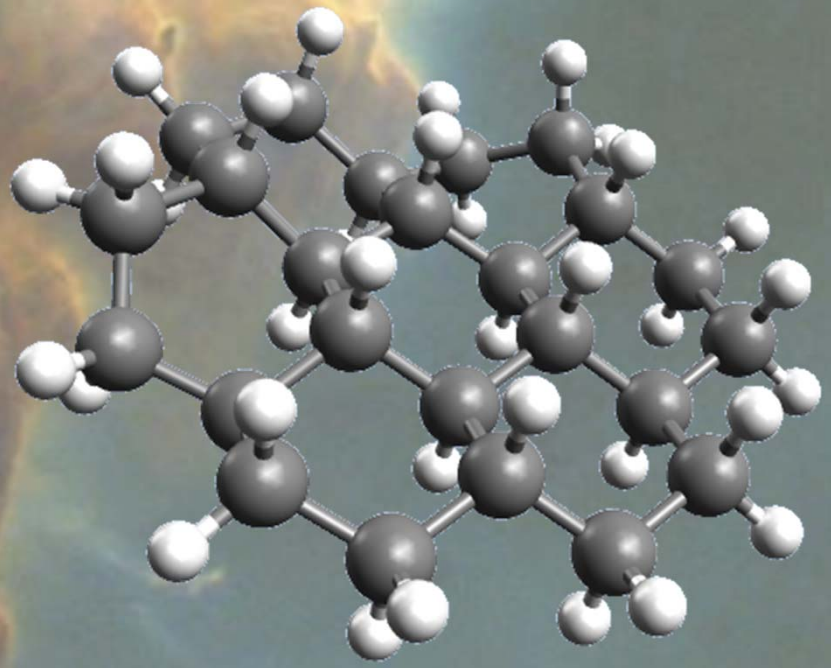
H + H +  → H_2

H-PAH vekselvirkning

Teori:

PAH kan hydrogeneres og katalysere H_2 dannelse



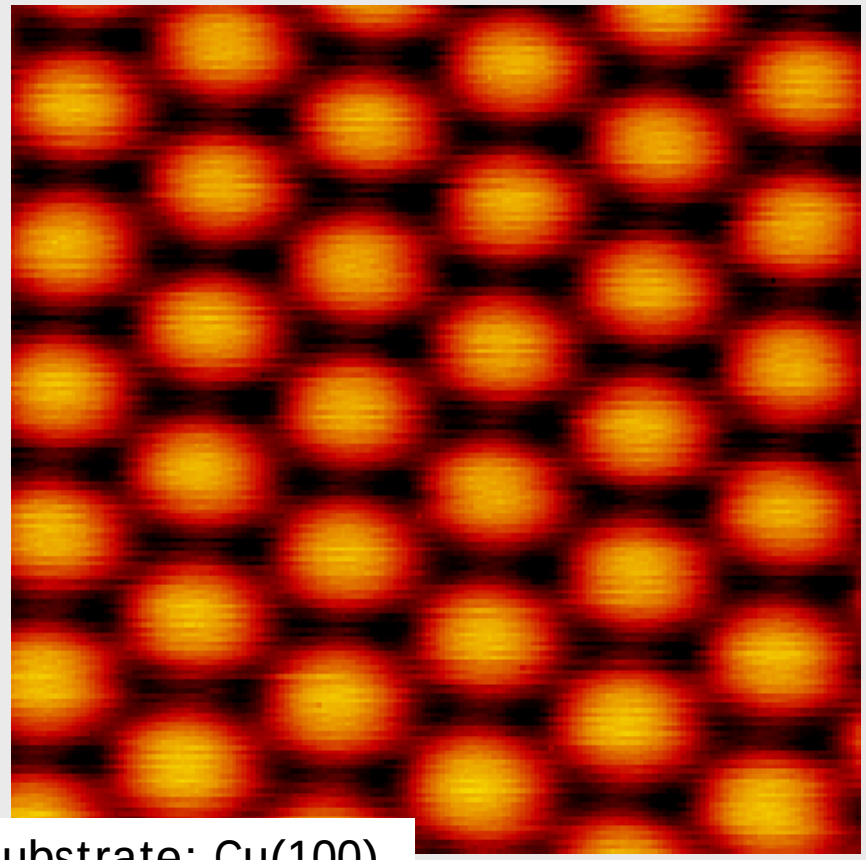


Rauls and Hornekær, Astrophys. J. 679, 531 (2008)

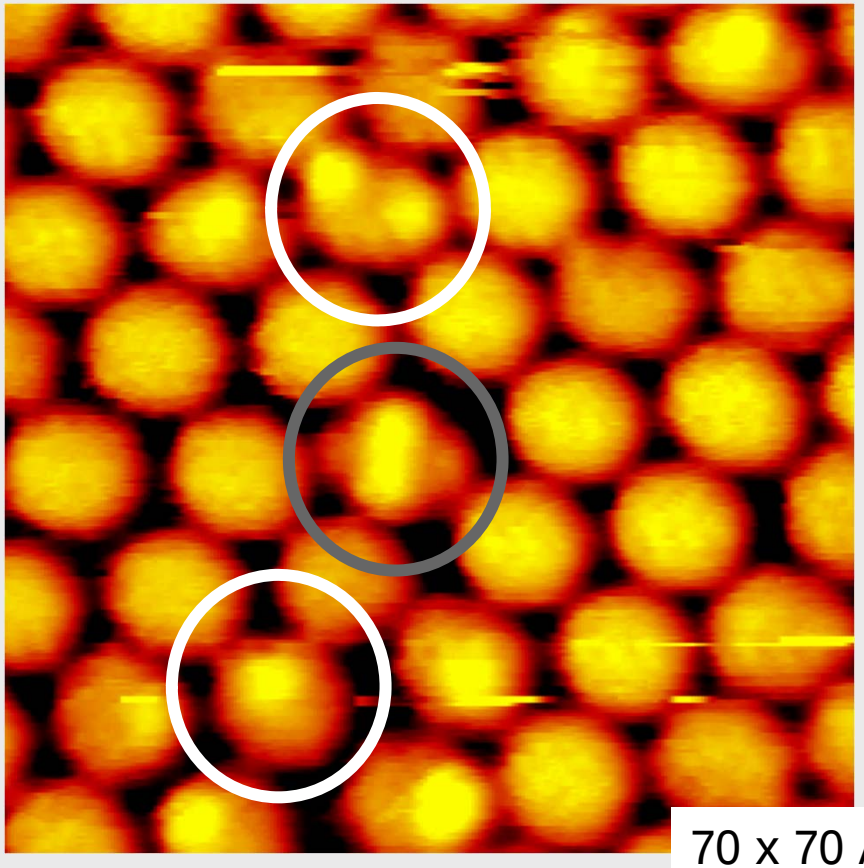
Thrower et al., Astrophys. J. 2012

Hydrogenering: STM billeder

Coronene



Coronene exposed to D



Substrate: Cu(100)

70 x 70 Å

Energy fordeling

Ukendt

Molekyle dannelse

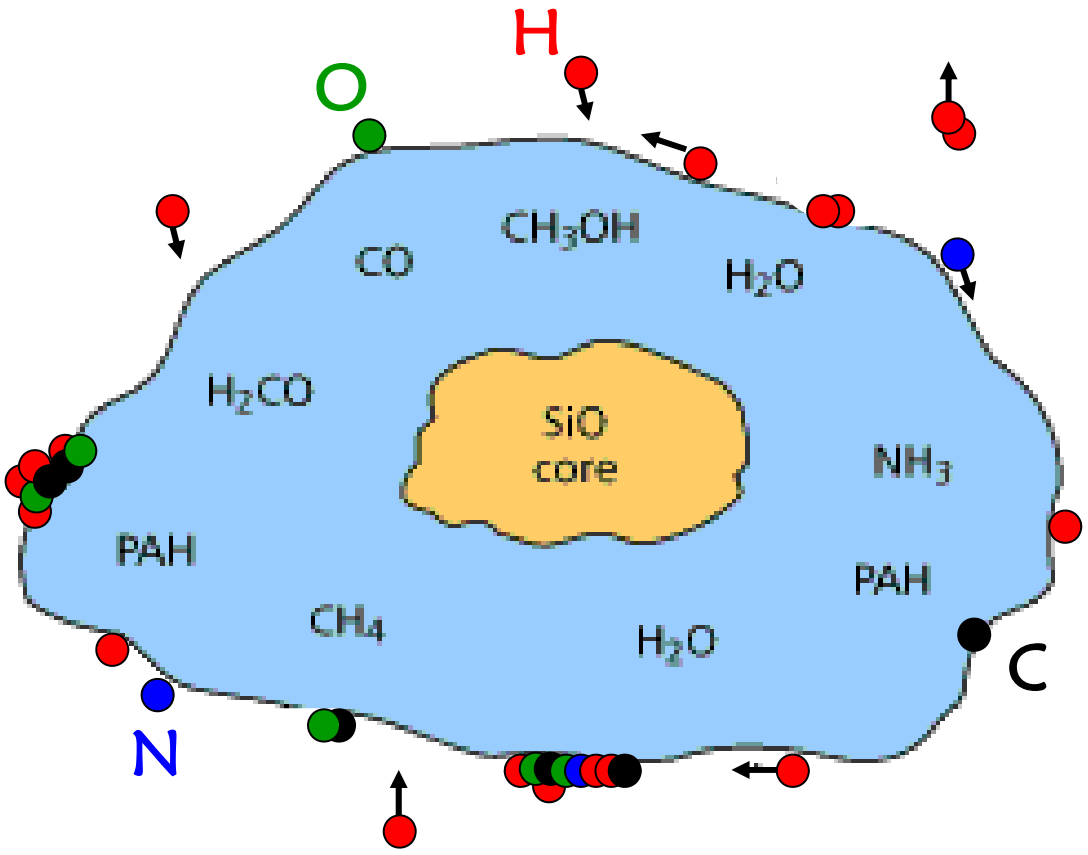
189 Molekyler:

H_2, CO, CO_2, O_2, H_2O, NH_3, CH_3OH ...

... glycine (CH_2NH_2COOH),

glycolaldehyde (CH_2OHCHO)

Overflade Reaktioner



Interstellare bio-molekyler på jorden?

50.000 ton rum-nedfald pr. år

30–100 % af vandet på jorden fra kometer

Murchison meteoritten

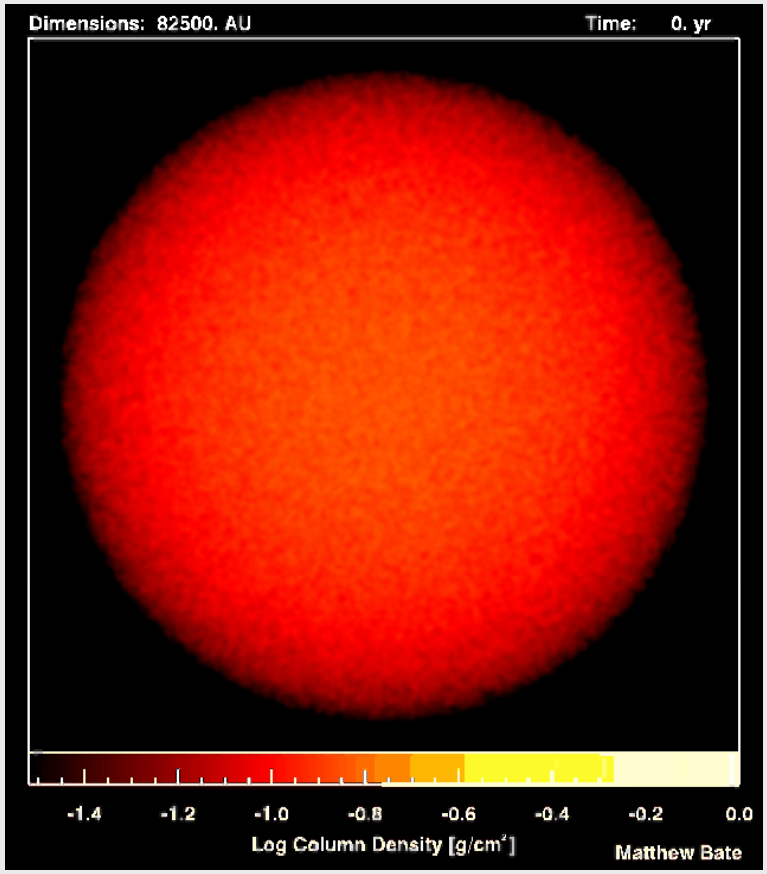
Australien 1969, 100 kg

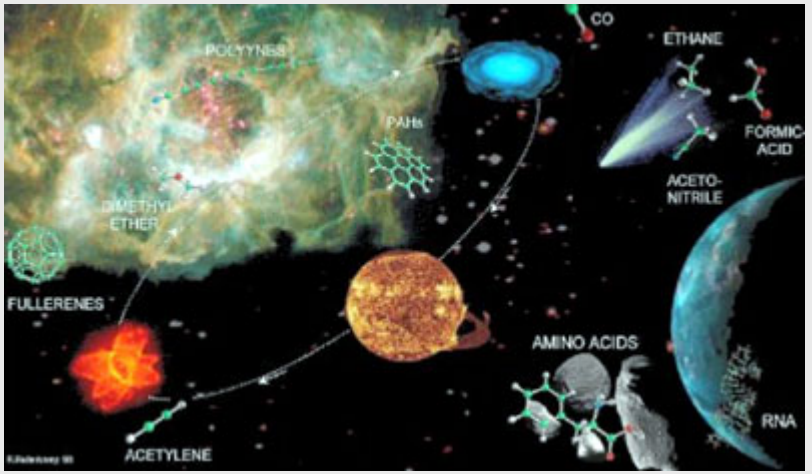
~92 aminosyrer
19 jordiske
8 vigtige for liv

~20 forskellige sukkergrupper

Laboratorie eksperimenter:

Hvor lang tid en stjerne-fødsel tager





Er livets byggesten – aminosyrer og sukkergrupper - allerede eksisterede før solsystemet blev skabt

Surface Dynamics Group

LASSIE
erc
The Danish National Advanced Technology Foundation
Forsknings- og Innovationsstyrelsen
Ministeriet for Videnskab Teknologi og Udvikling
LUNDBECKFONDEN
CARLSBERGFONDET