

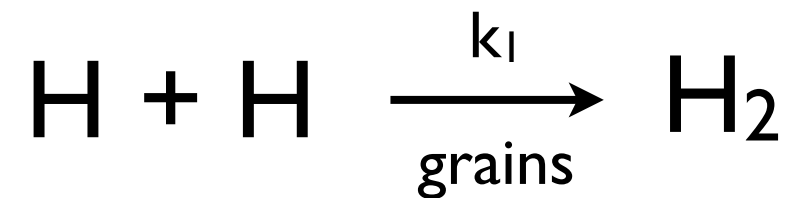
# How cosmic rays start astrochemistry



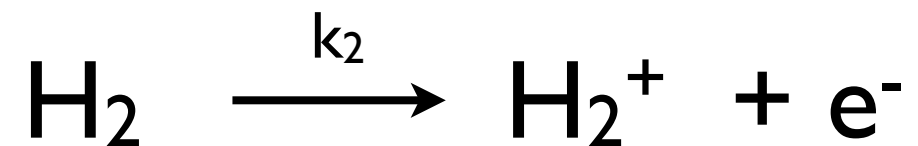
How cosmic rays start  
astrochemistry

# How cosmic rays gave me a job

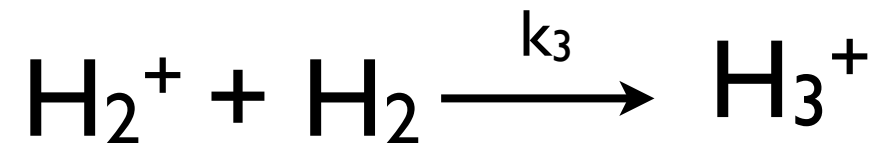
# Some basic reactions to get the chemistry started



reaction I

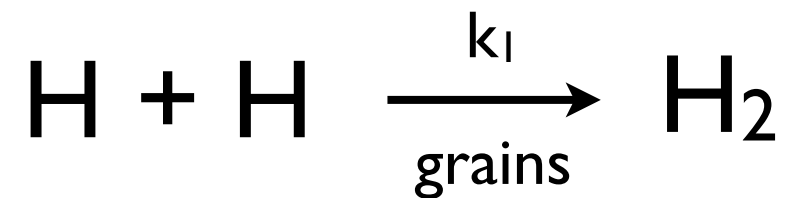


reaction II

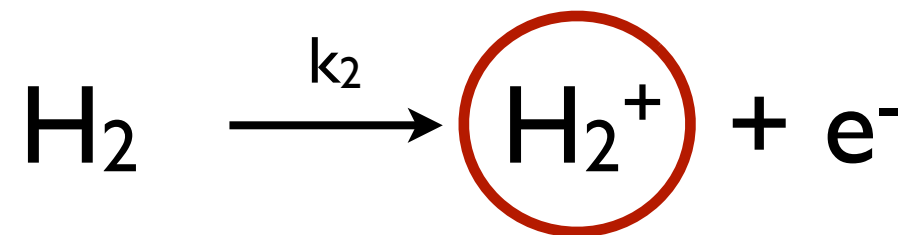


reaction III

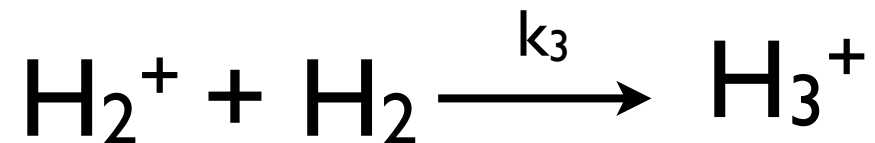
# Some basic reactions to get the chemistry started



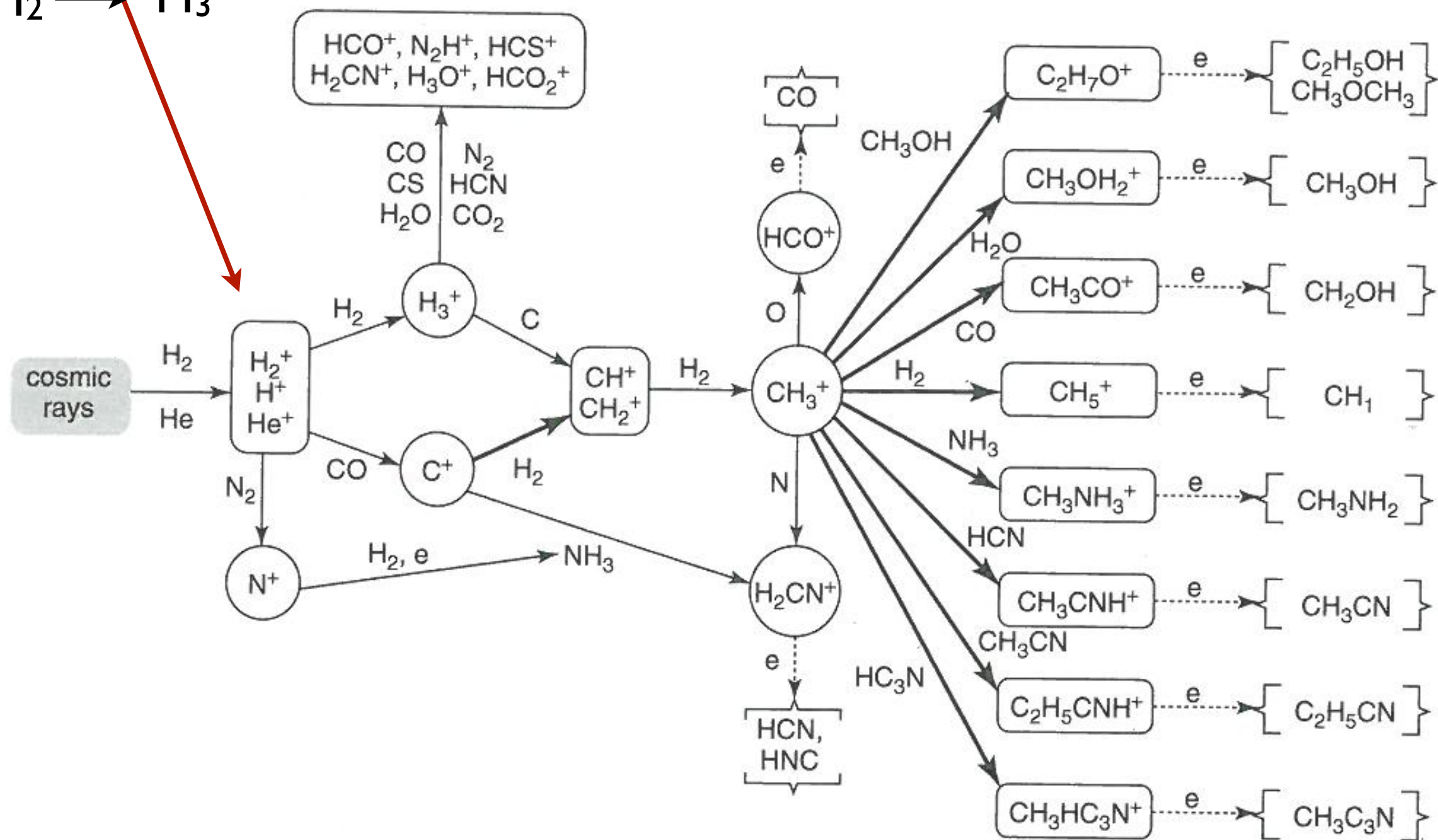
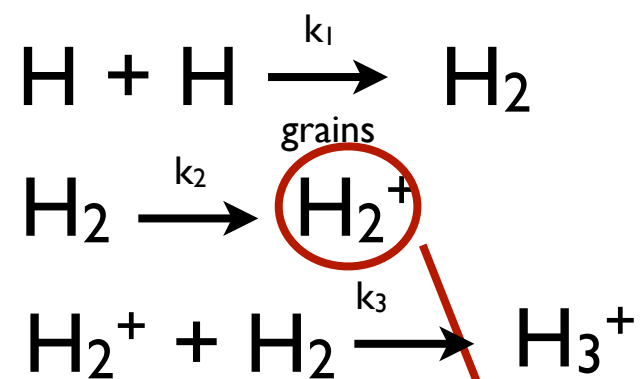
reaction I

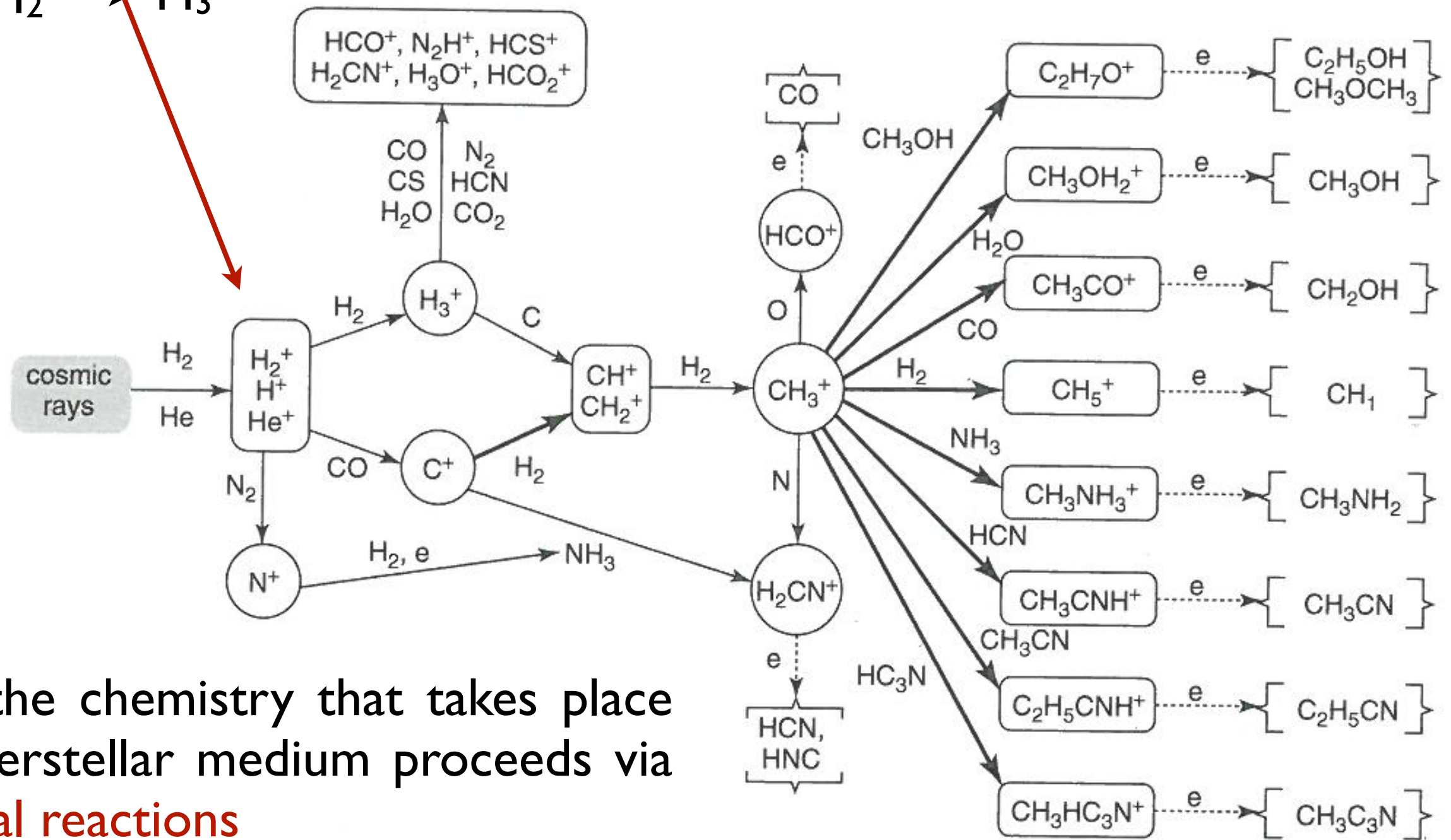
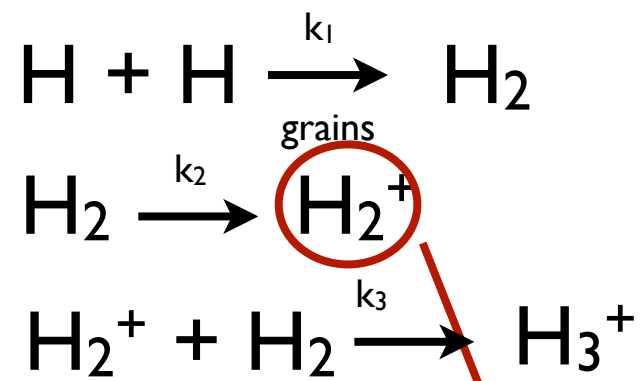


reaction II



reaction III

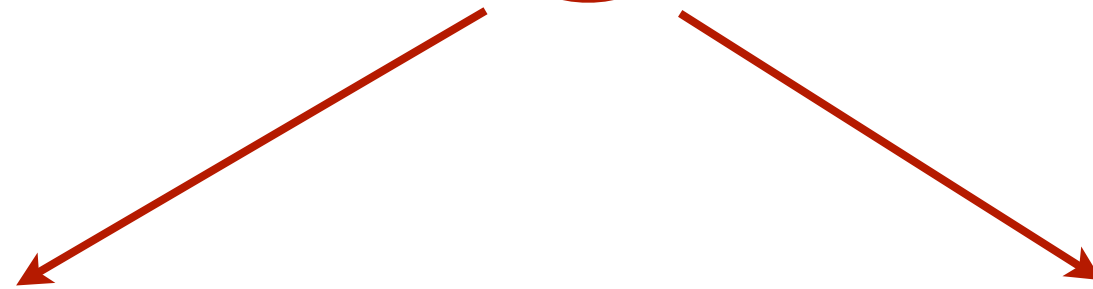
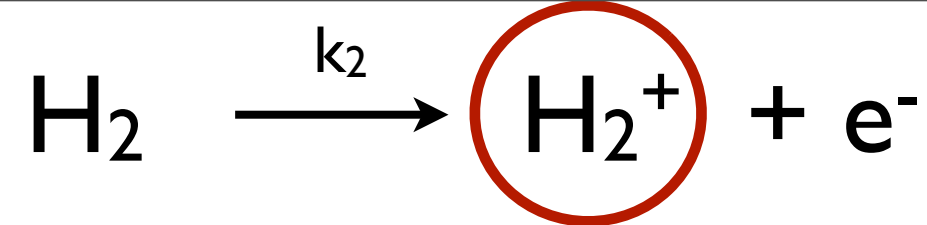




most of the chemistry that takes place  
in the interstellar medium proceeds via  
**ion-neutral reactions**

**NO ENERGY BARRIER TO OVERCOME**



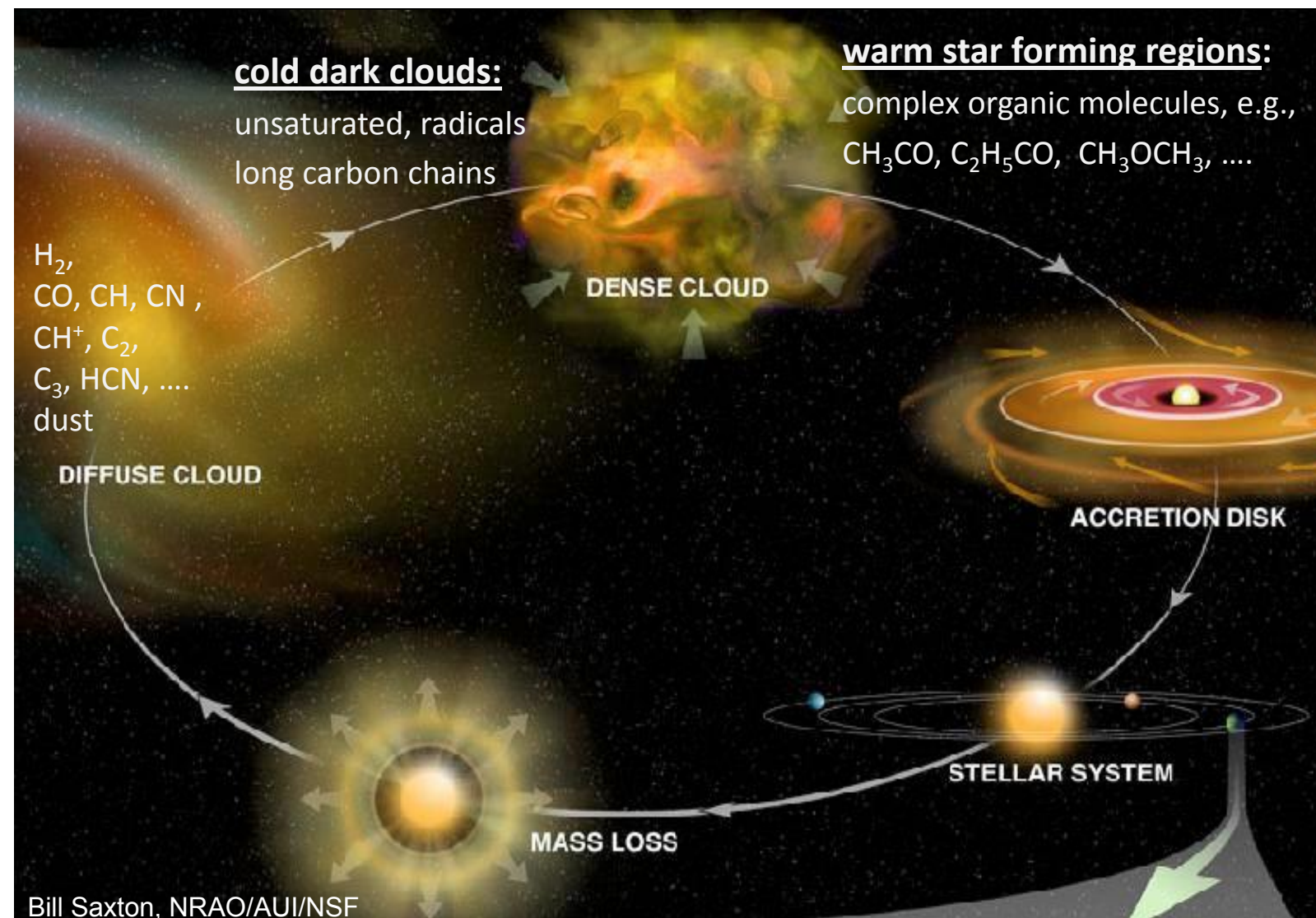


*Diffuse clouds*

photons

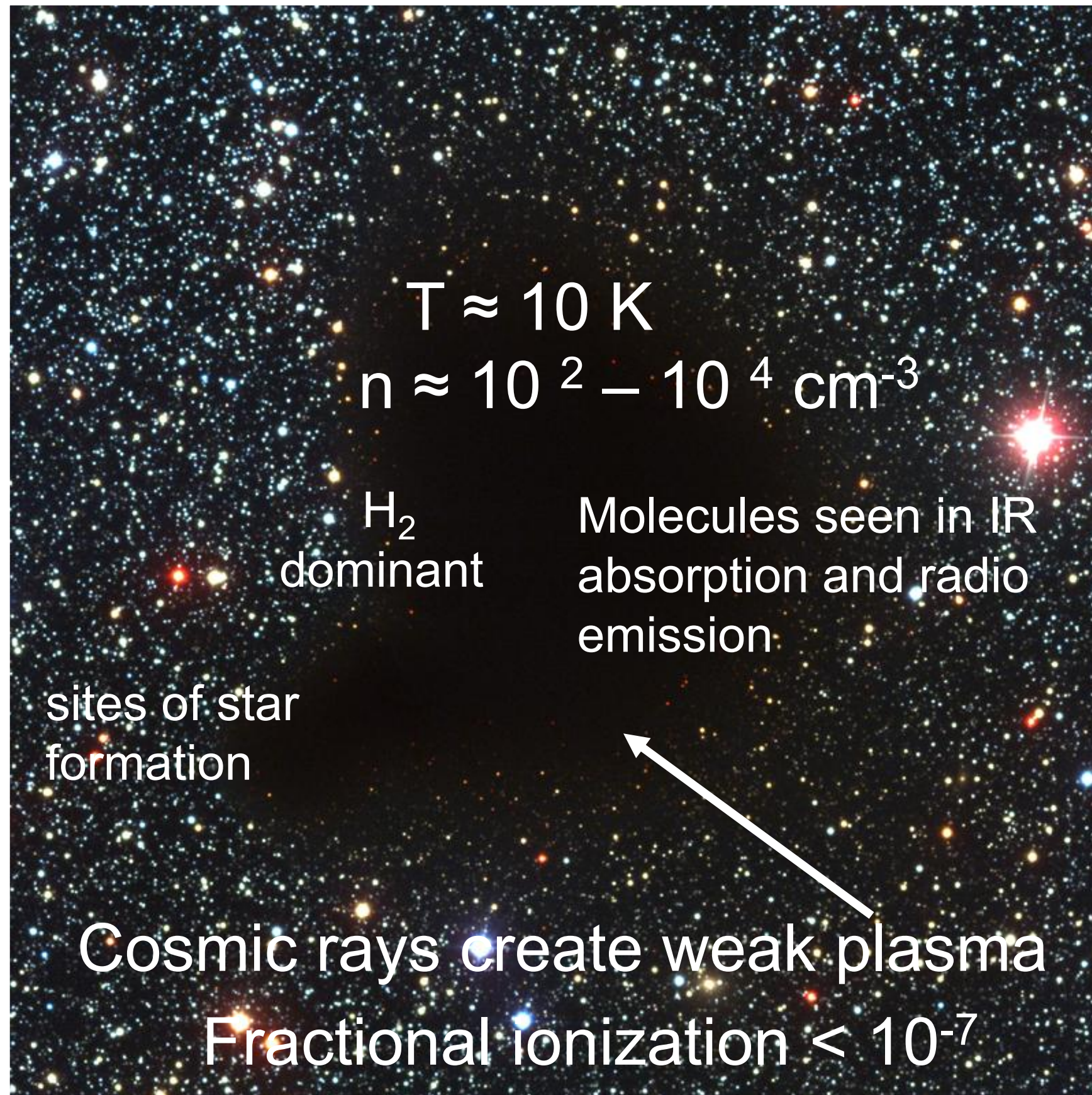
*Dense clouds*

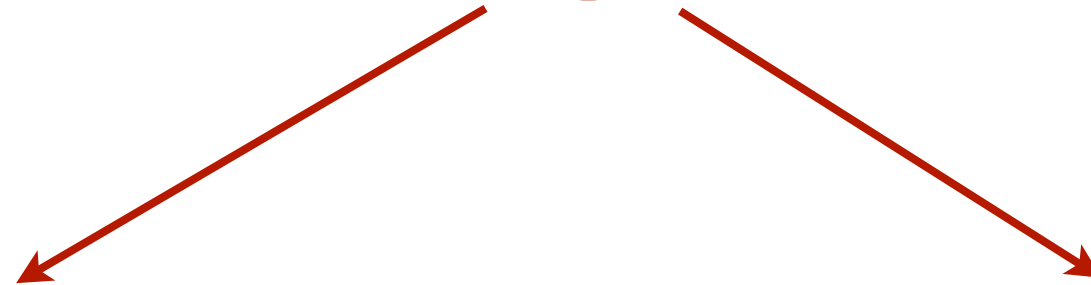
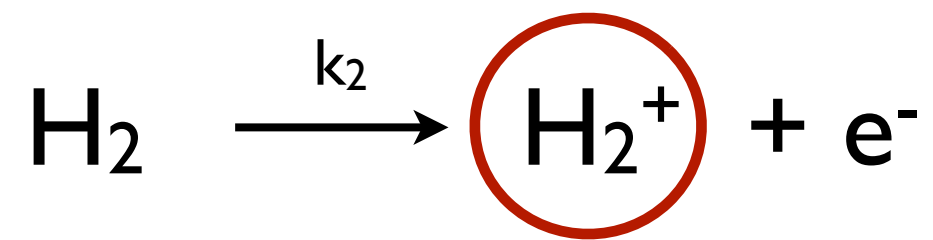
cosmic rays





# Dense interstellar clouds





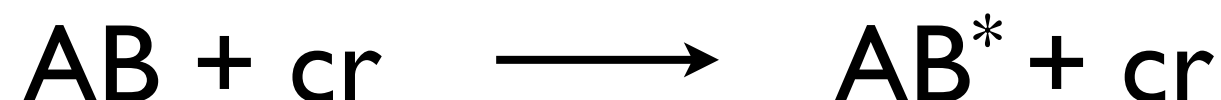
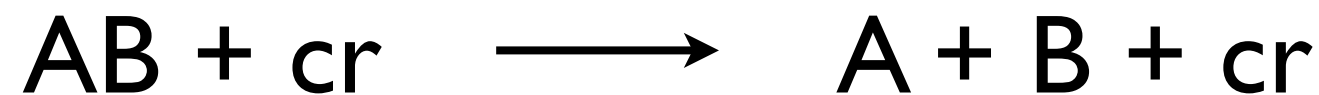
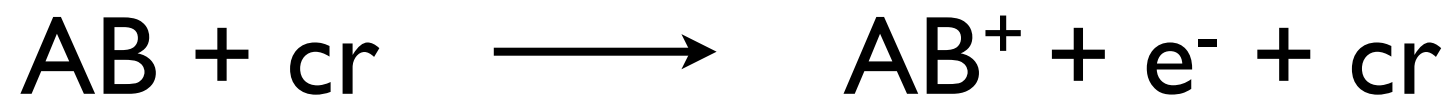
*Diffuse clouds*

↓  
photons

*Dense clouds*

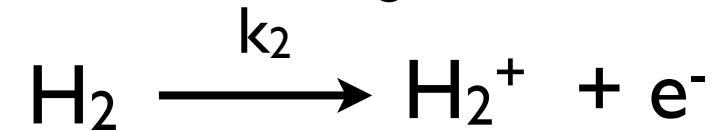
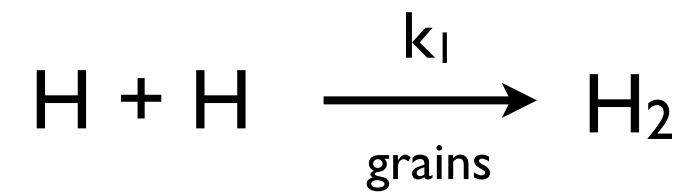
↓  
**cosmic rays**

## What cosmic rays “do” to molecules





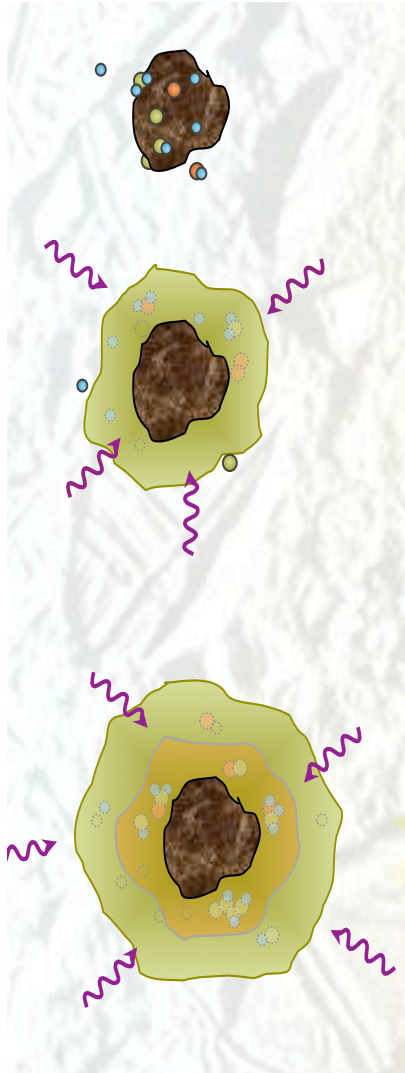
# Dense clouds



cosmic rays ionization rate:  $1\text{--}5 \times 10^{-17} \text{ s}^{-1}$  [Dalgarno 2006]

$$n(\text{H}_3^+) = \zeta n(\text{H}_2) / \left\{ \sum_{\text{X}} \overset{\text{proton transfer}}{n(\text{X})k(\text{X})} + \sum_{\text{M}} \overset{\text{charge transfer with metal atoms}}{n(\text{M})k(\text{M})} + \underbrace{\alpha n(\text{e})}_{\text{dissociative recombination with electrons}} + \underbrace{k_0 n(\text{PAH}) + k_1 n(\text{PAH}^-)}_{\text{charge transfer and neutralization with PAHs}} \right\}$$

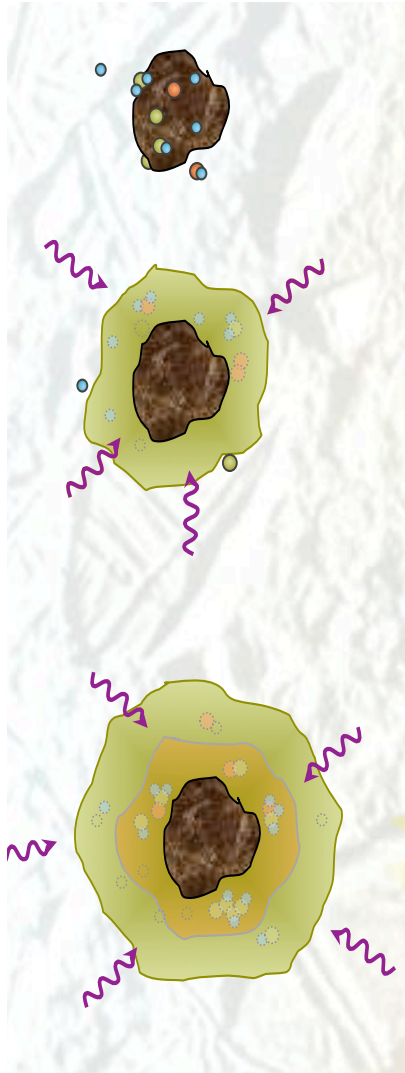
# Chemistry on dust grains



Contribution from the surface need to be considered

Cosmic rays interact also with the grains, activating the chemistry on the surfaces

# Chemistry on dust grains

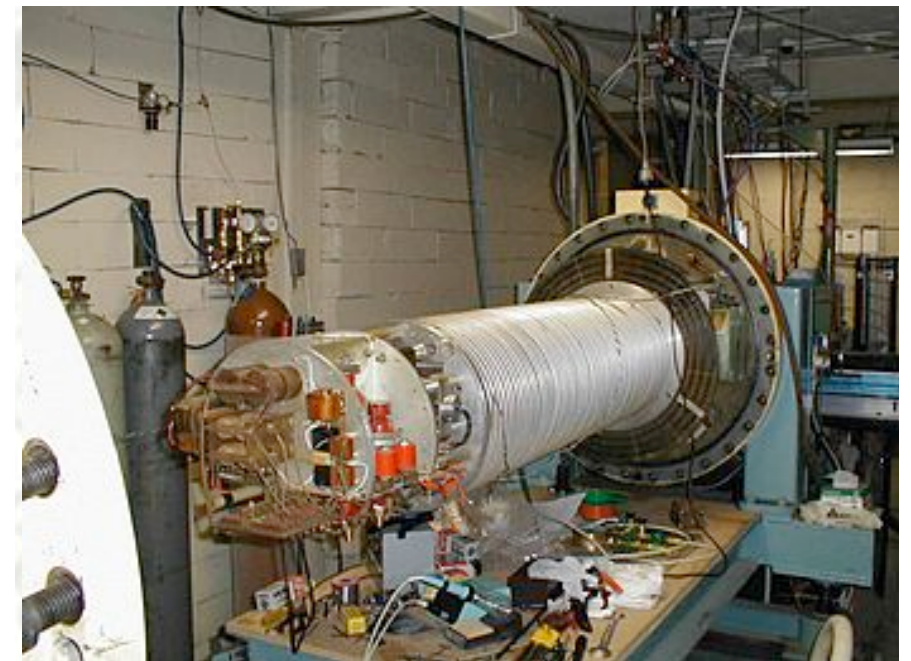


Contribution from the surface need to be considered

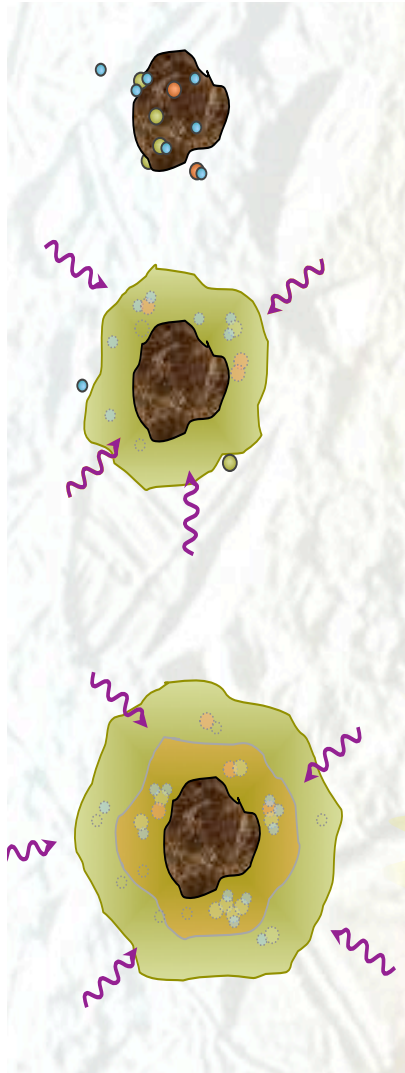
Cosmic rays interact also with the grains, activating the chemistry on the surfaces

Understanding those systems is quite complicated!

- produce a beam of cr and accelerate them to high energies (Van Der Graf accelerator)



# Chemistry on dust grains



Contribution from the surface need to be considered

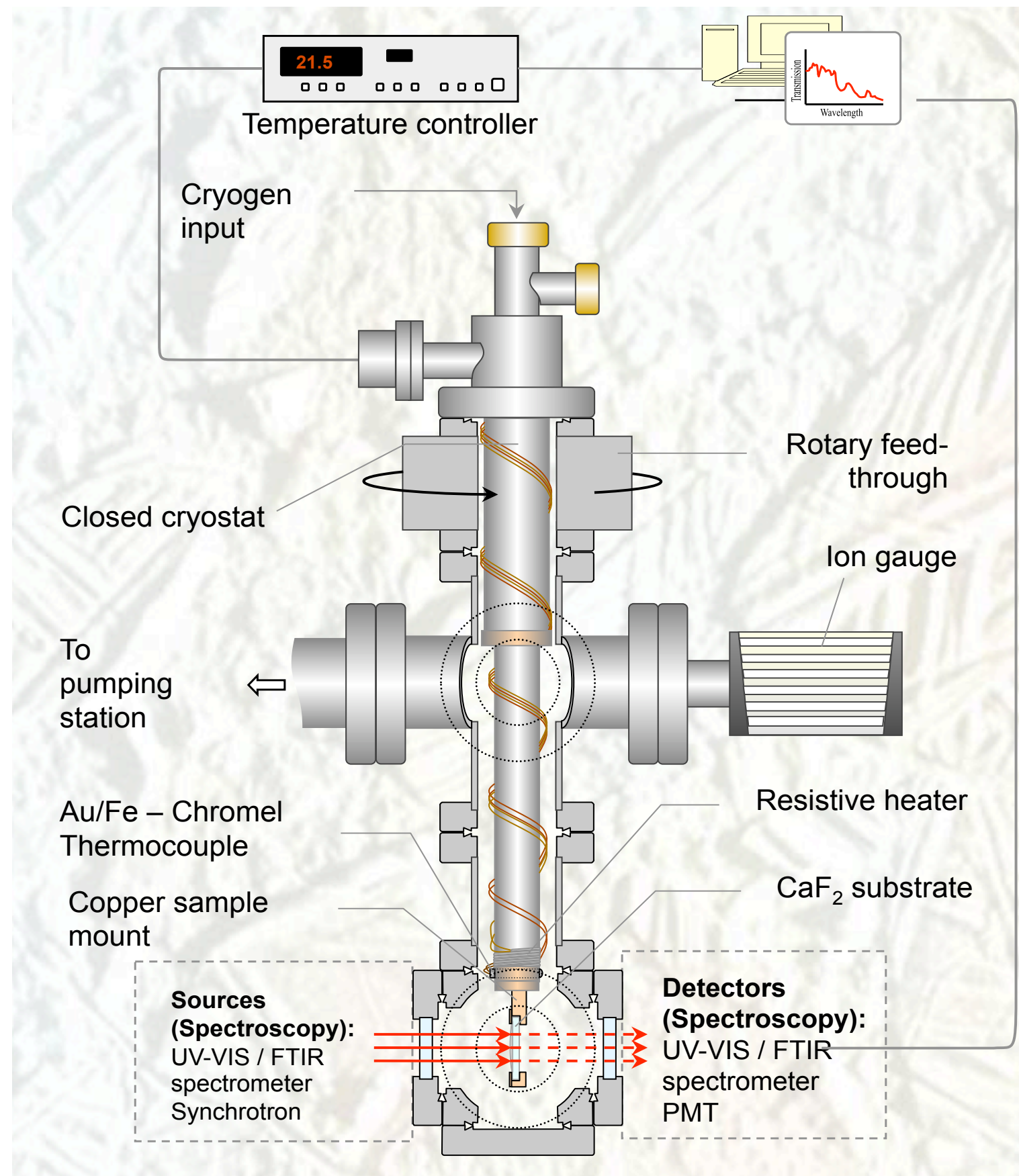
Cosmic rays interact also with the grains, activating the chemistry on the surfaces

Understanding those systems is quite complicated!

- prepare the surface (target) for collision

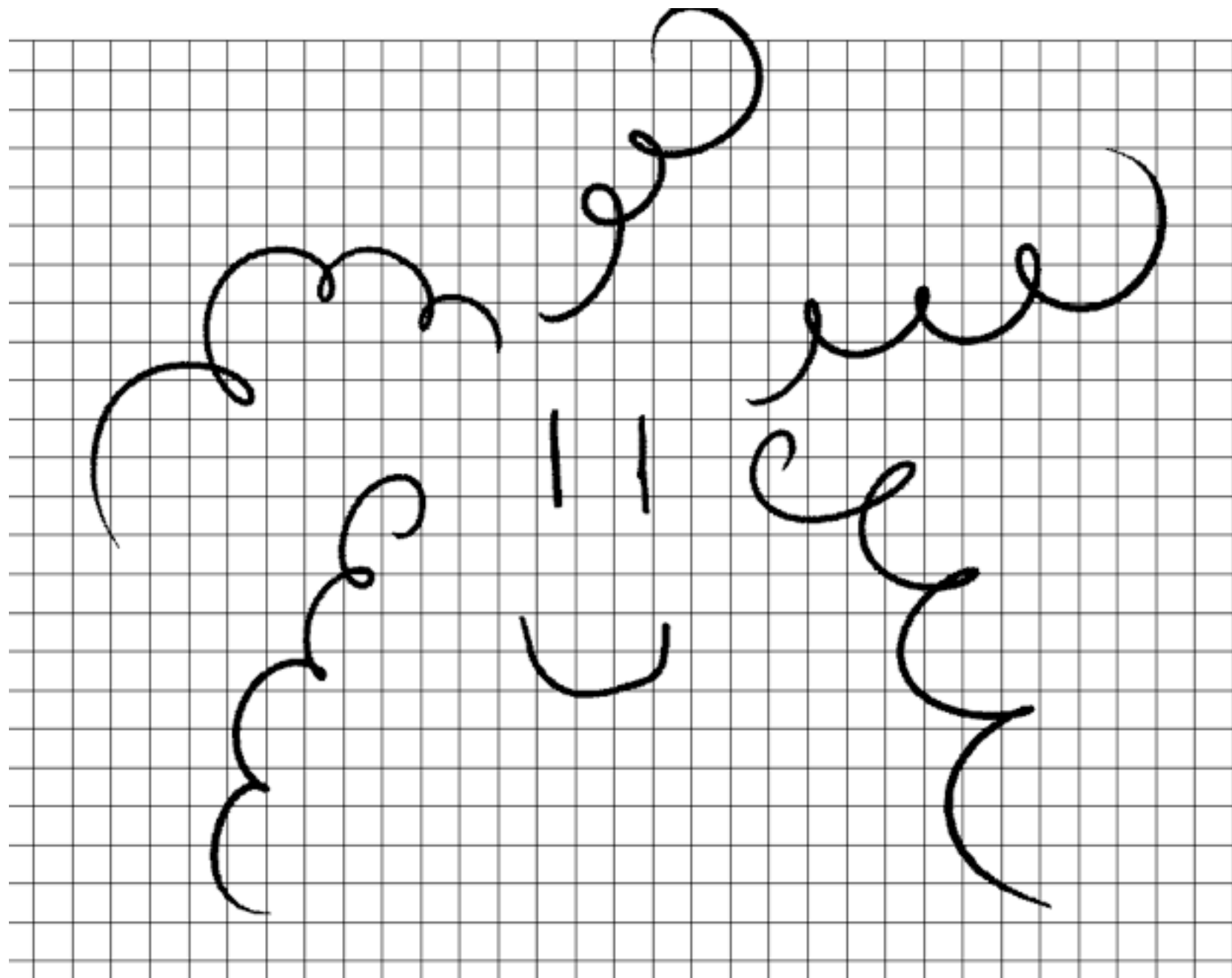
*morphology*  
*temperature*  
*mixture*





credits. Nigel Mason group, Open University (UK)





Thanks!