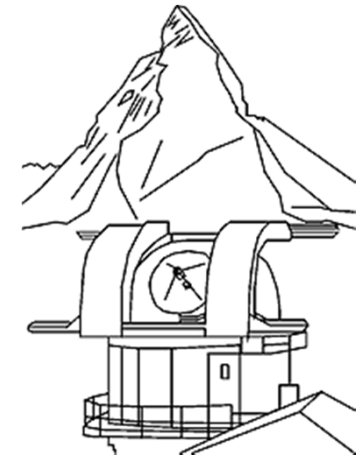


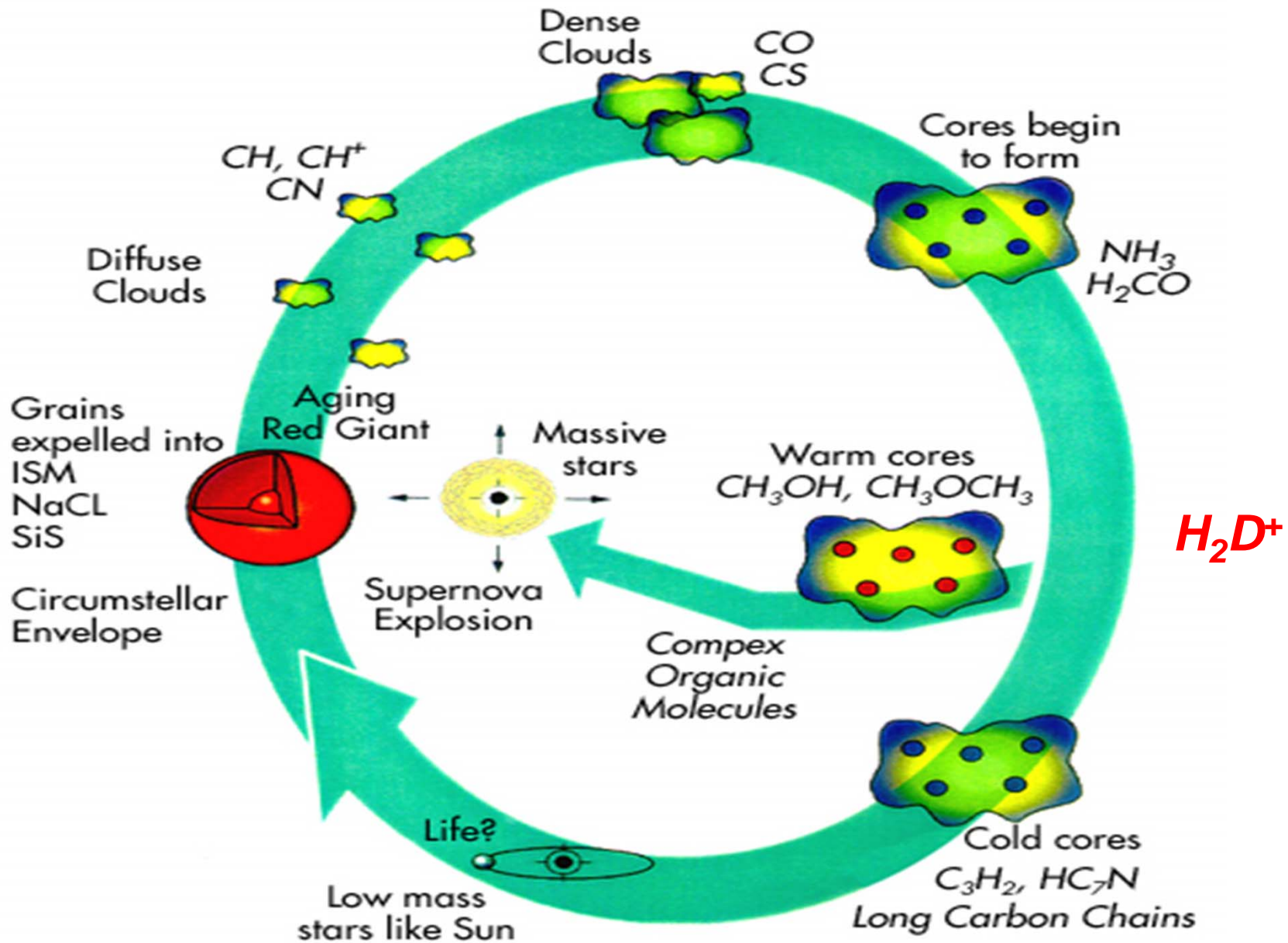
# ***Cold Chemistry in Space and Laboratory***

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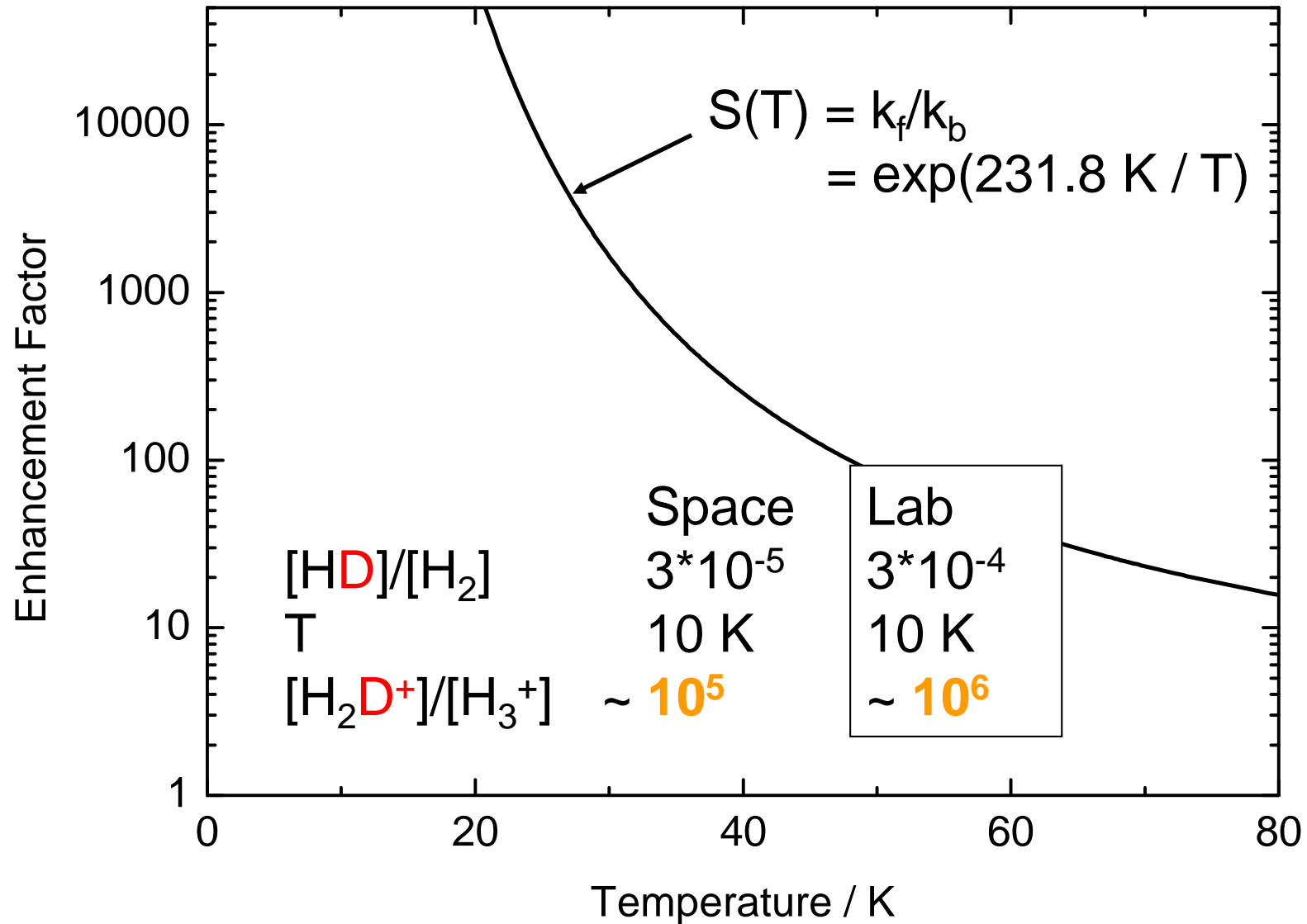


- $\text{H}_2$  Formation, OPR and Chemical Clocks
- $\text{H}_3^+ / \text{H}_2\text{D}^+$  Isotopic Fractionation,  $\text{H}_3^+ / \text{H}_2\text{D}^+$ , OPR
- $\text{H}_2\text{D}^+ + \text{H}_2$  THz Spectroscopy in Lab and Space

# Life cycle of Stars



# Isotopic Fractionation



# Experimental Method: Electrodynamical Trapping



Sandra Brünken

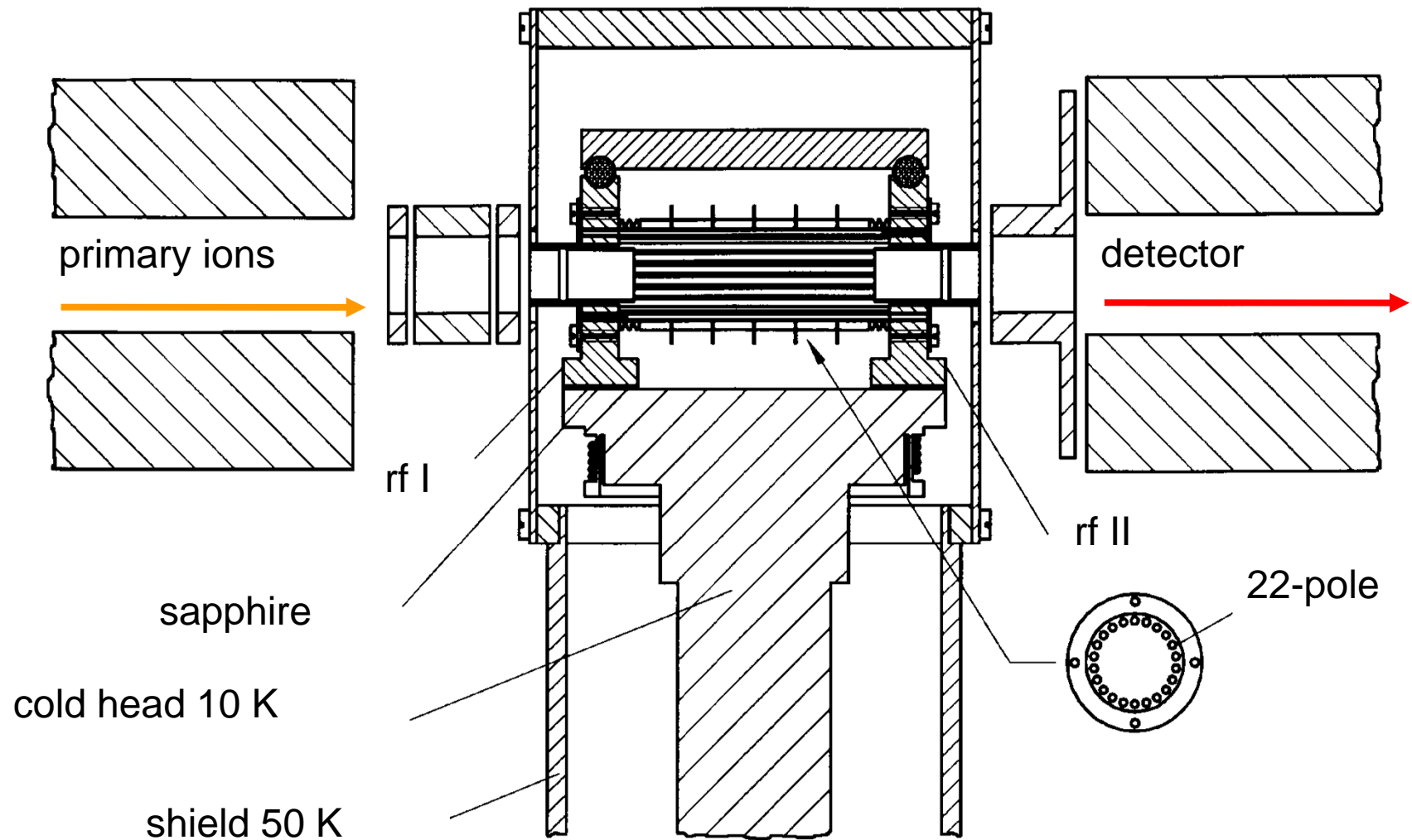


Dieter Gerlich



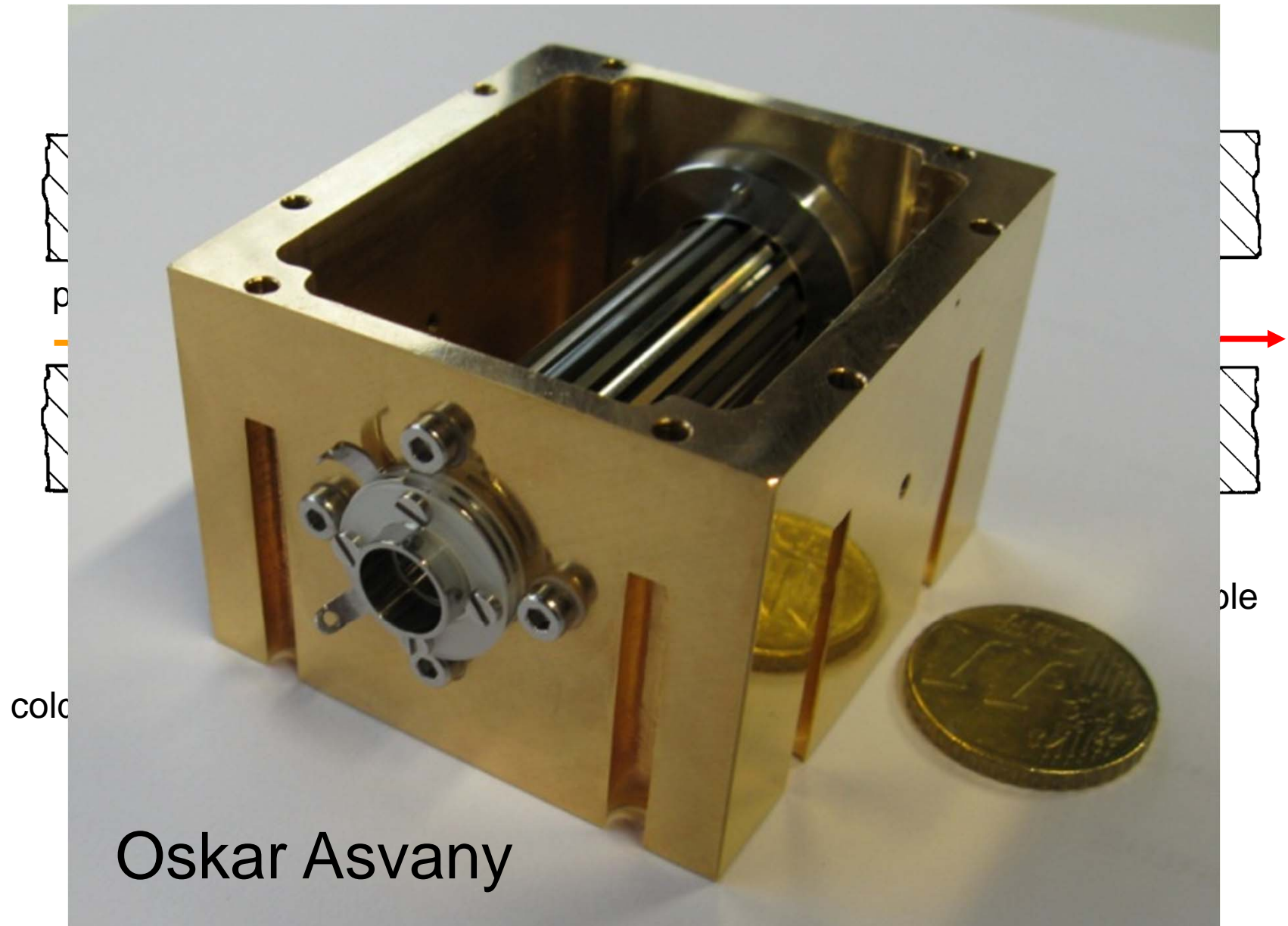
Oskar Asvany

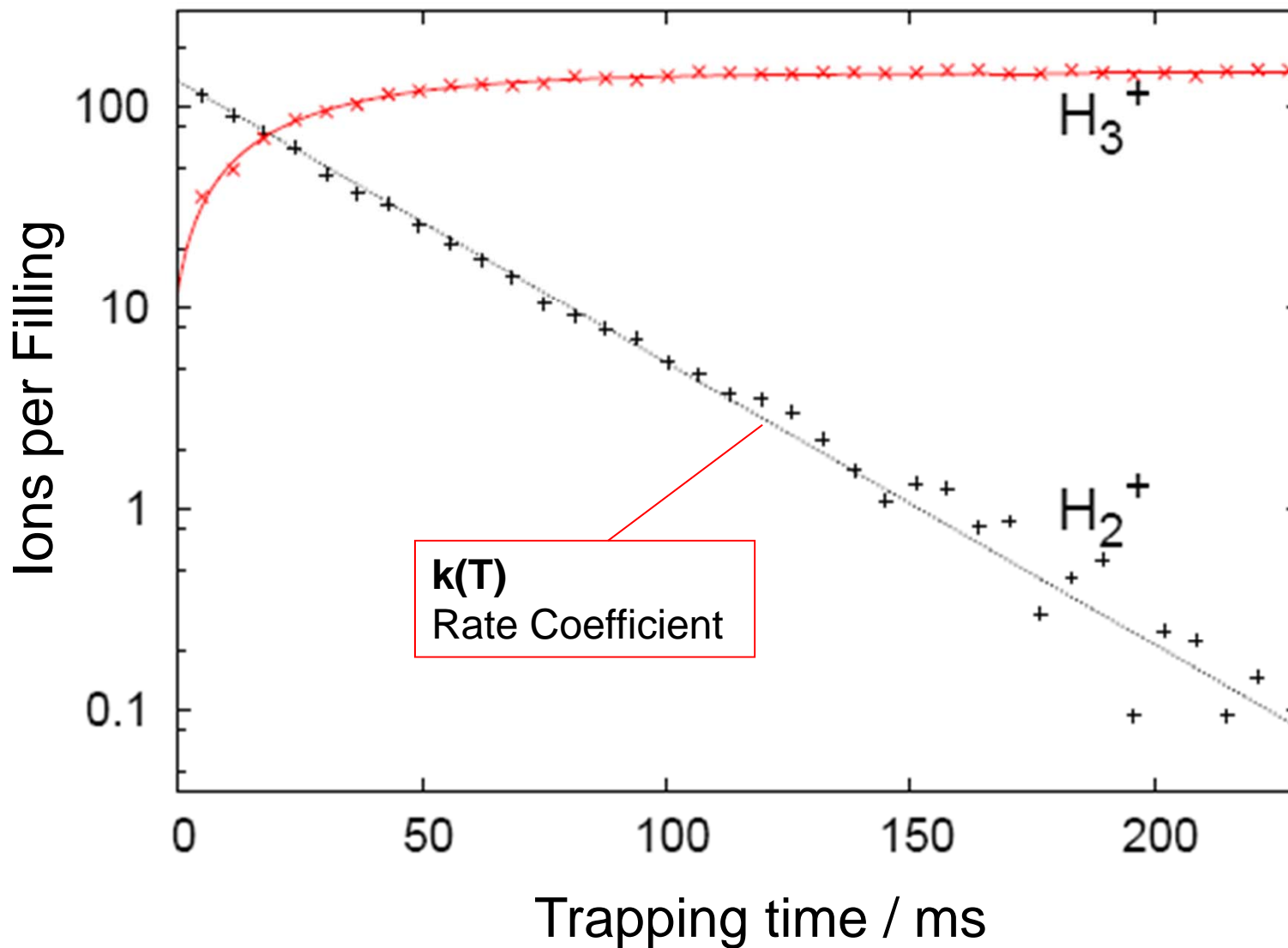
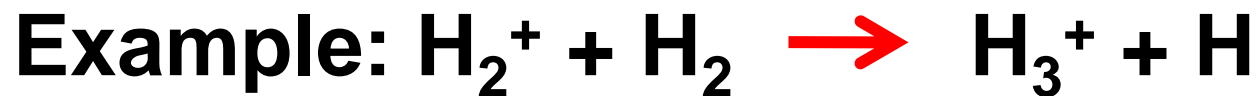
# 22-Pole Low Temperature Ion Trap

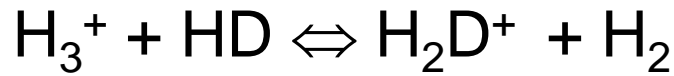




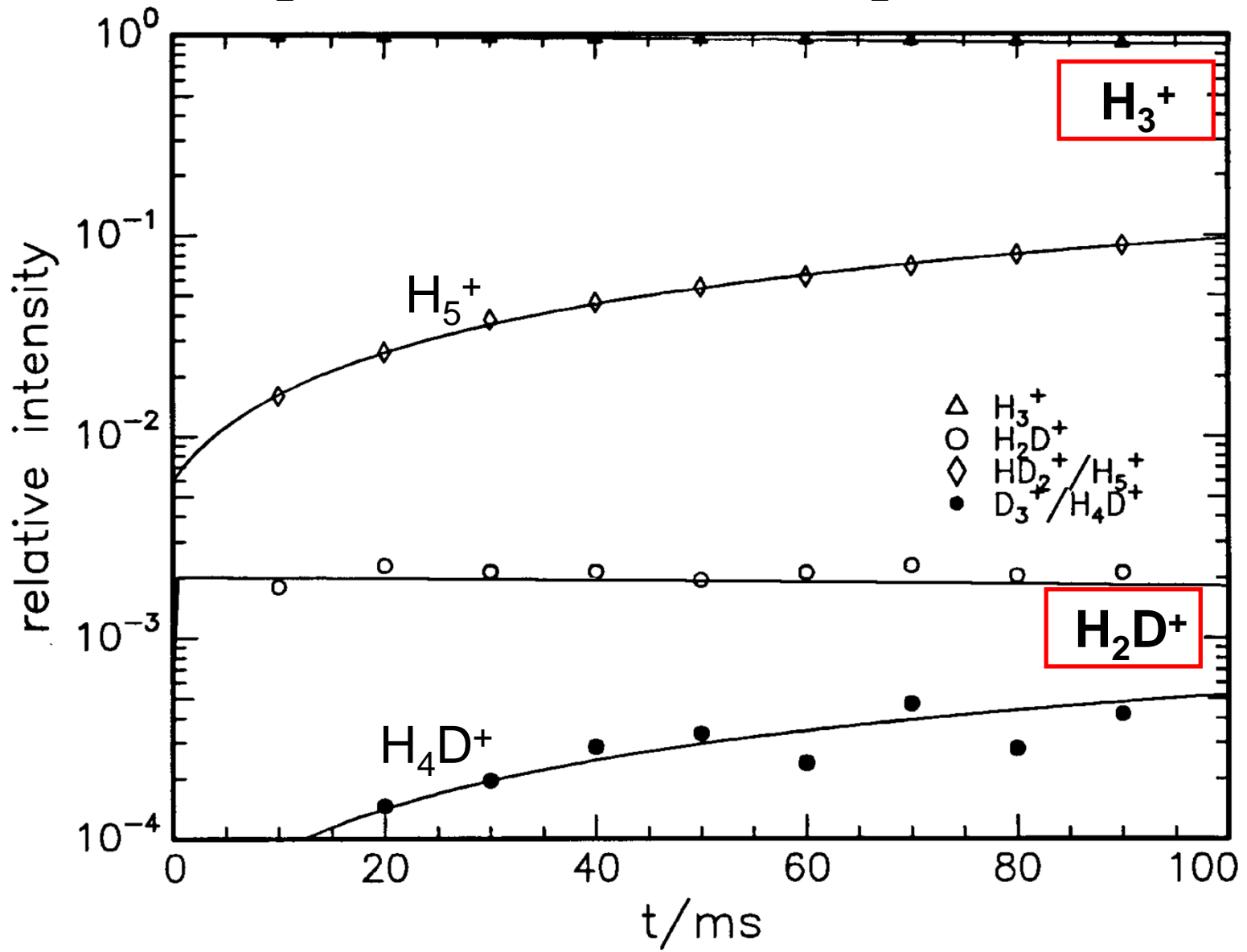
# 22-Pole Low Temperature Ion Trap





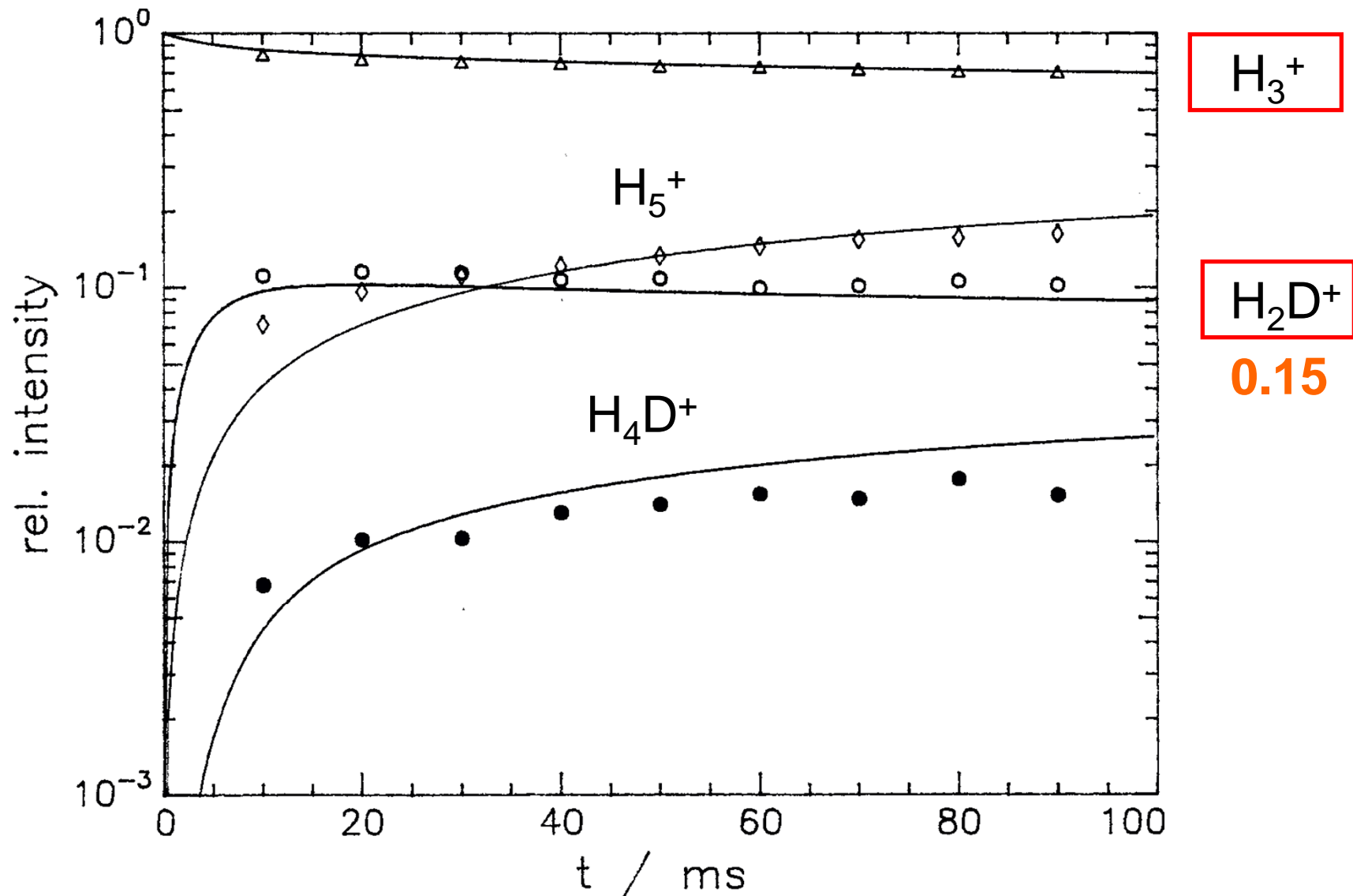
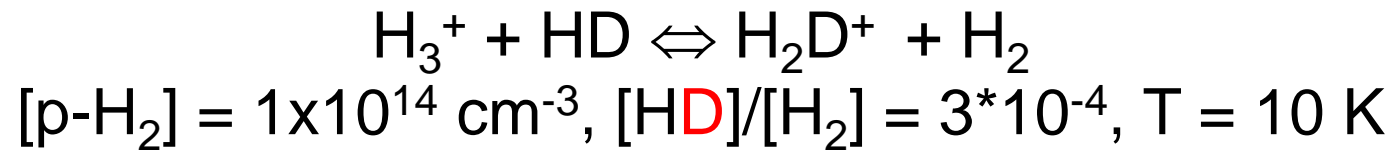


$[n\text{-H}_2] = 1.4 \times 10^{14} \text{ cm}^{-3}$ ,  $[\text{HD}]/[\text{H}_2] = 3 \times 10^{-4}$ ,  $T = 10 \text{ K}$



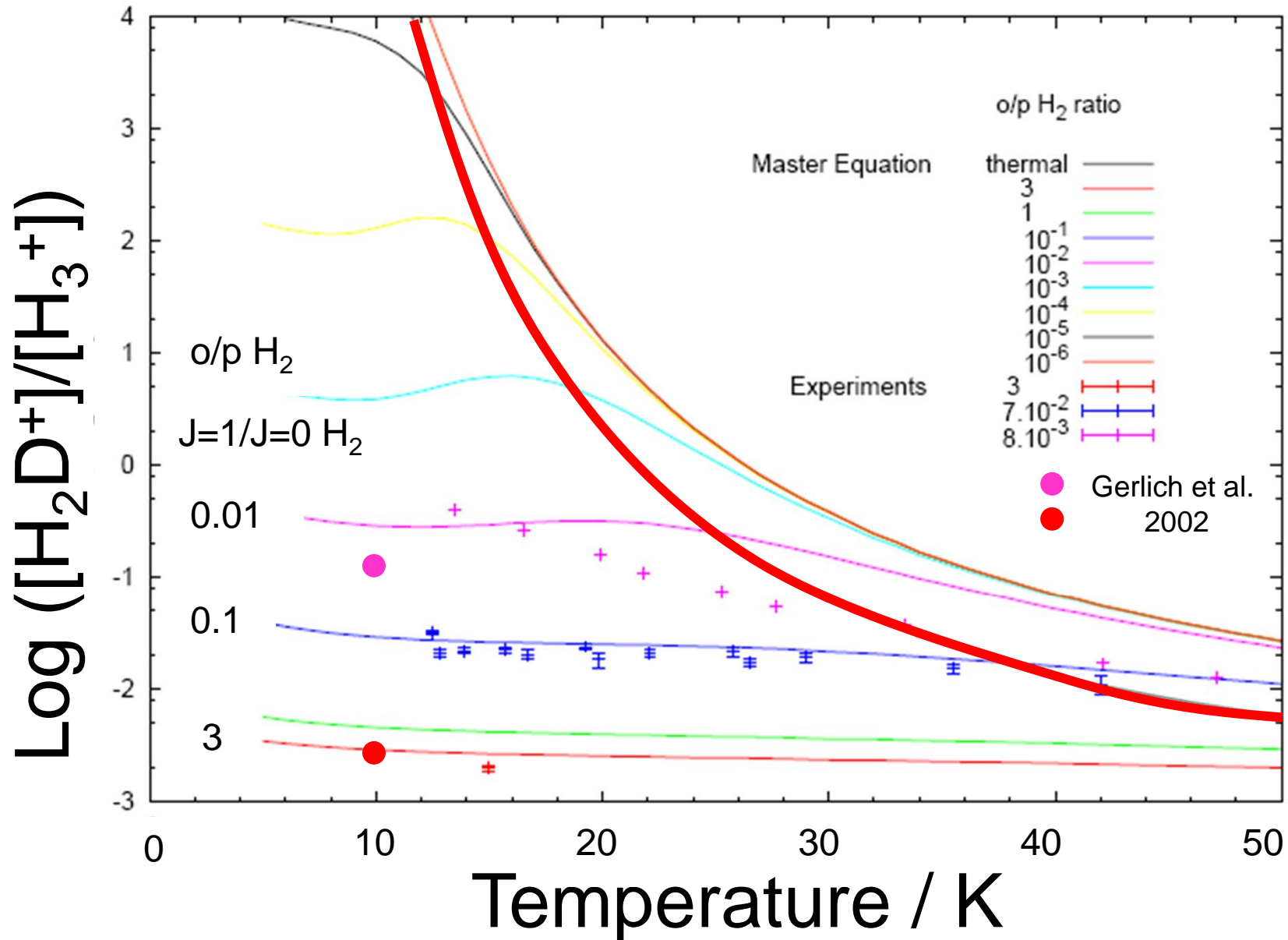
0.002



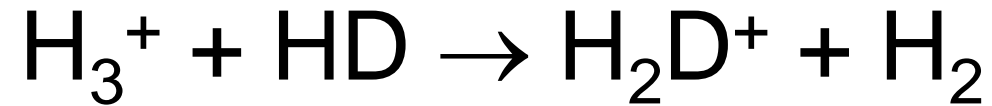


# Experimental Results & Modelling

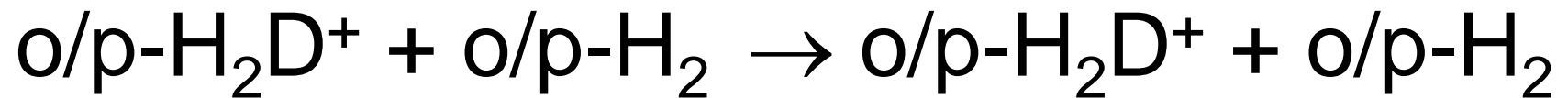
Hugo et al., J.Chem.Phys. 2009, **130**, 164302

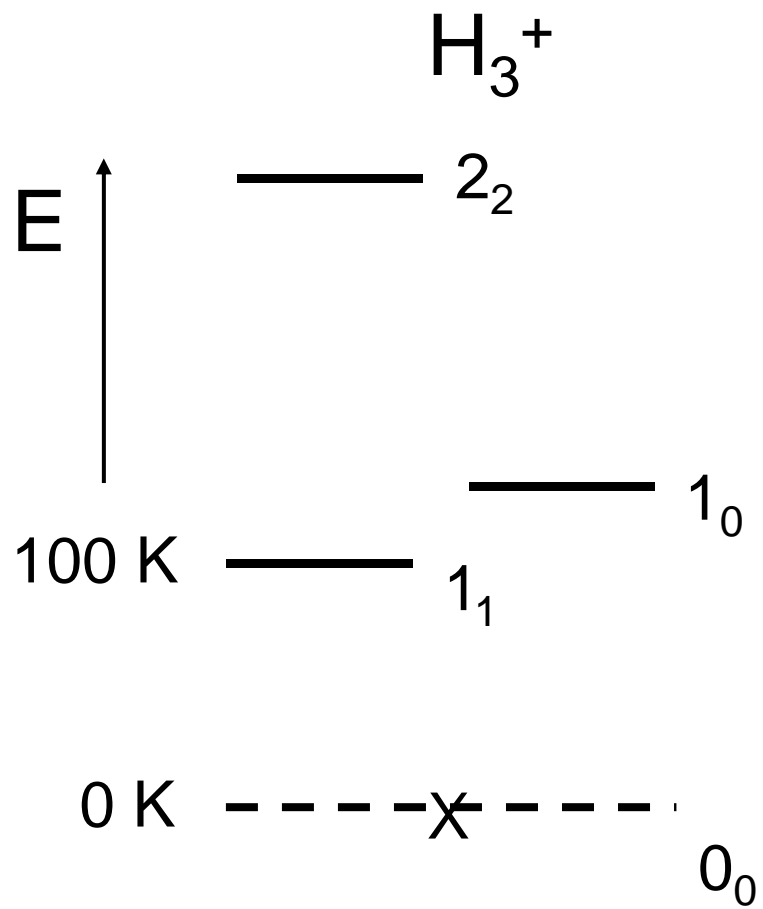


# Isotopic Fractionation



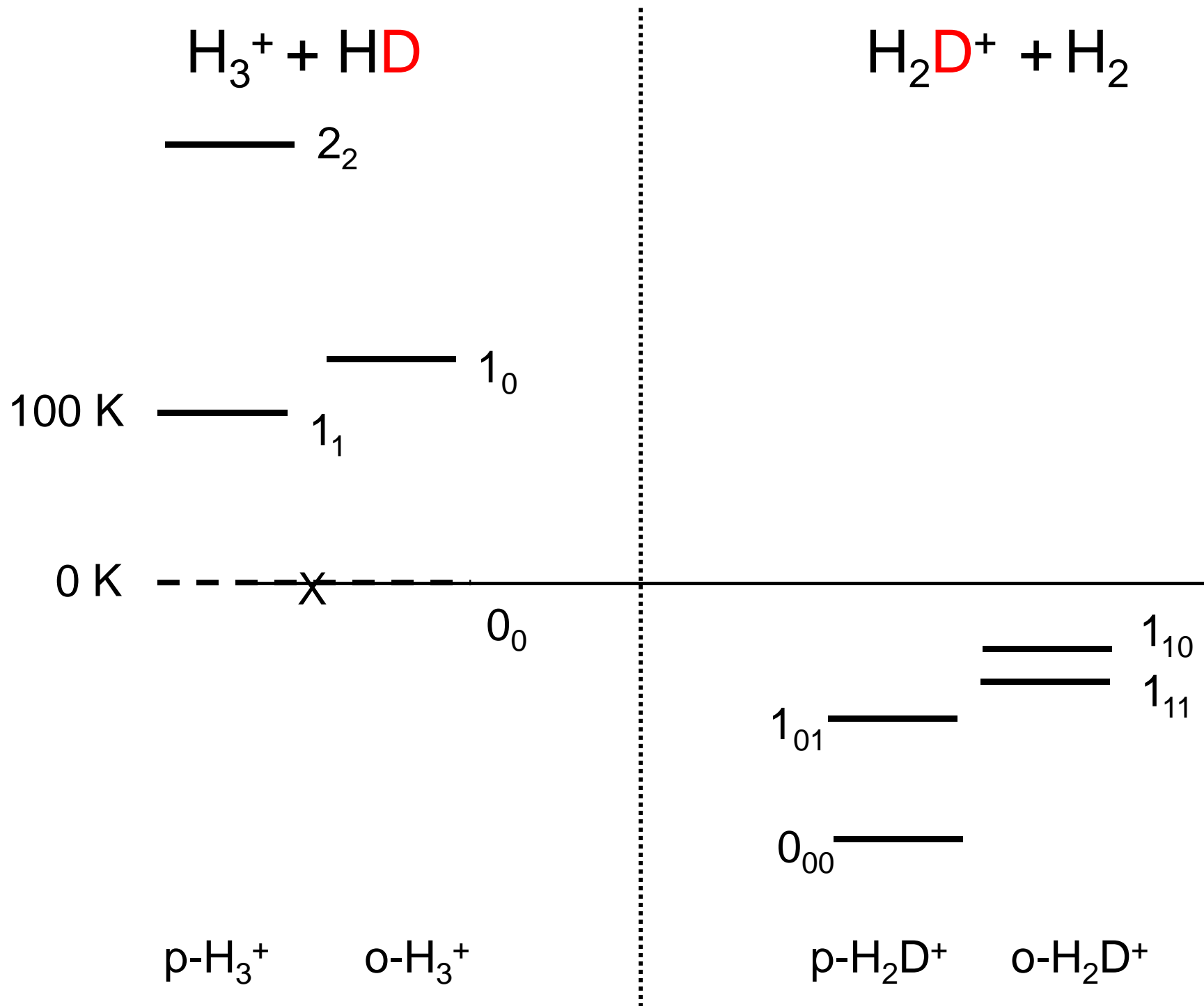
and the  $\text{H}_2 / \text{H}_2\text{D}^+$  OPR

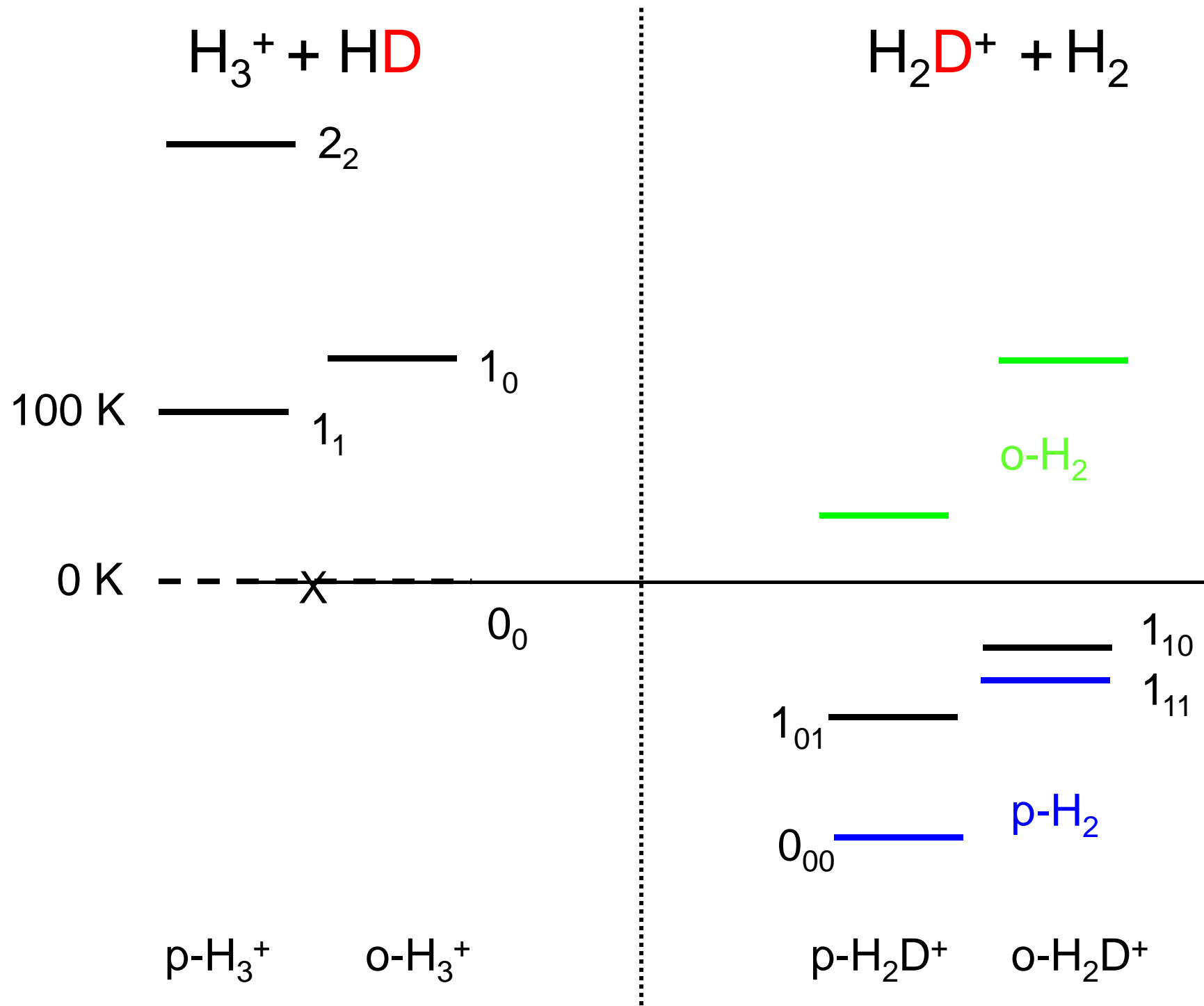




Lowest energy levels of  $H_3^+$





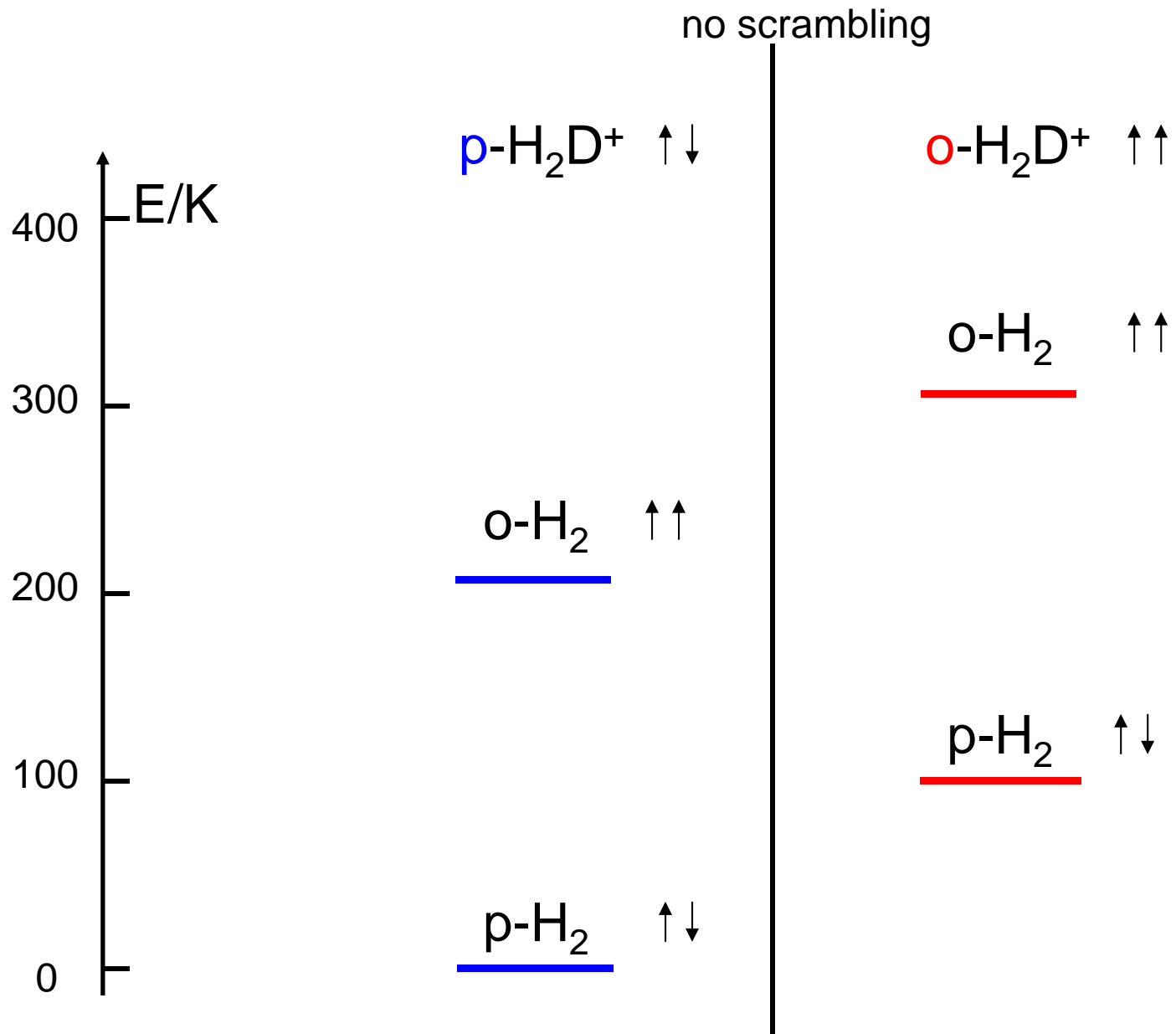




# ***Role of Nuclear Spin?***

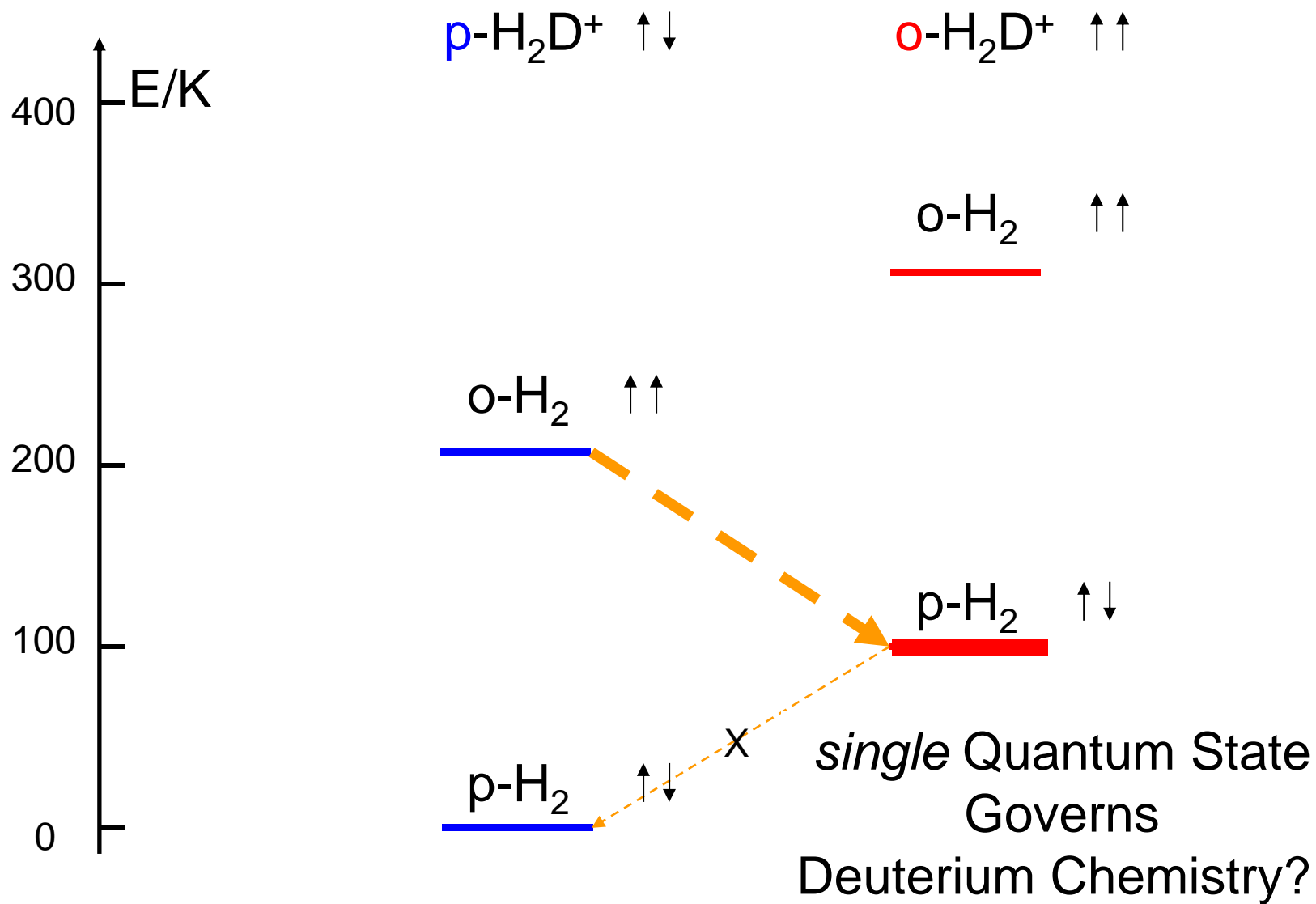
Conservation laws: E, J, P, I, ...

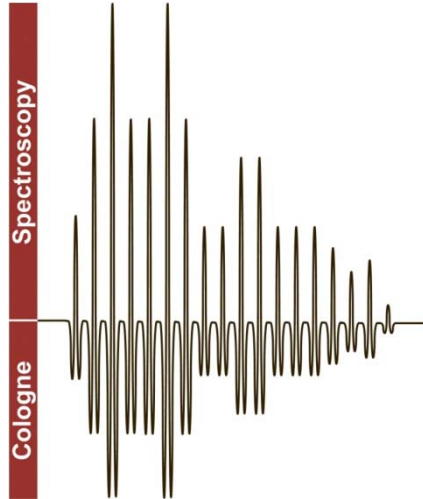
# Para – Ortho Conversion



# Para – Ortho Conversion

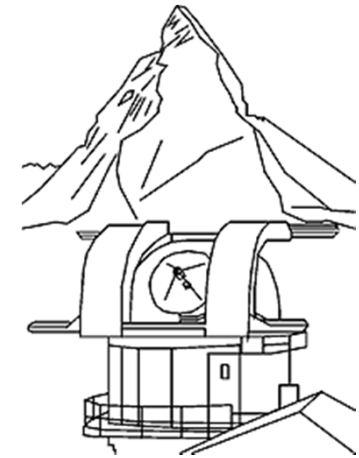
scrambling





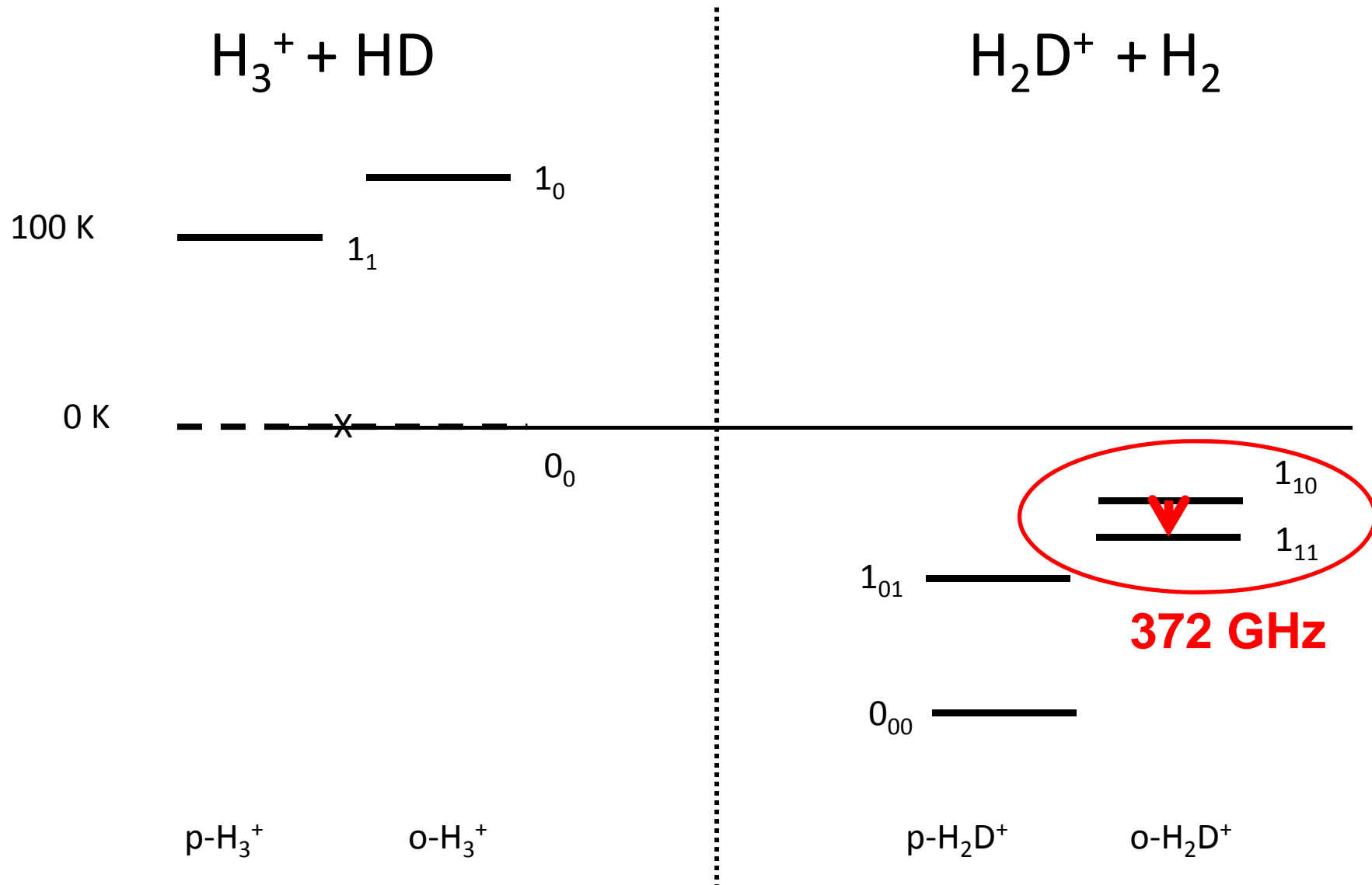
# ***Cold Chemistry in Space and Laboratory***

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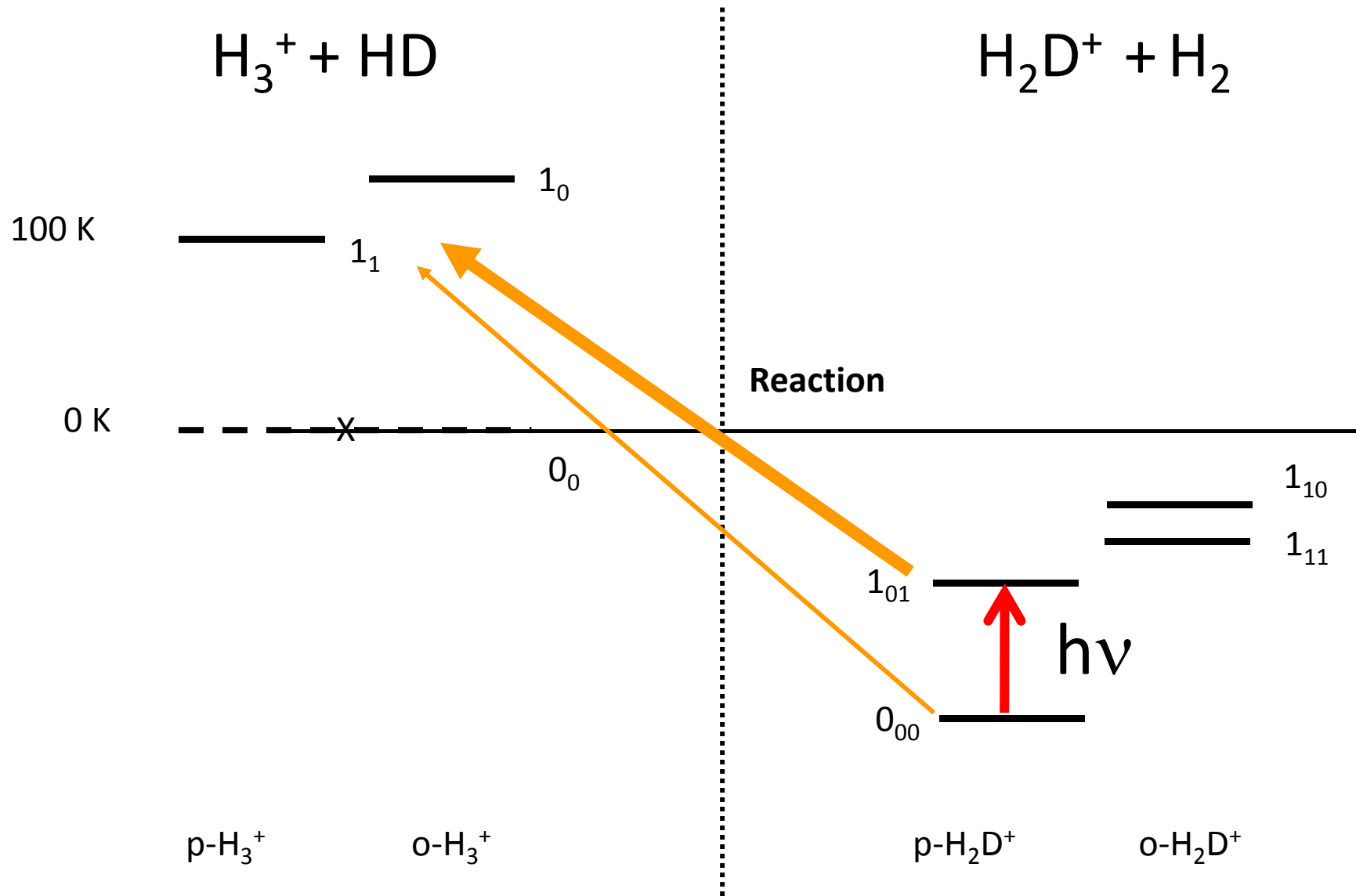


- H<sub>2</sub> Formation, OPR and Chemical Clocks
- H<sub>3</sub><sup>+</sup> / H<sub>2</sub>D<sup>+</sup> Isotopic Fractionation, H<sub>3</sub><sup>+</sup>/H<sub>2</sub>D<sup>+</sup>, OPR
- H<sub>2</sub>D<sup>+</sup> + H<sub>2</sub> THz Spectroscopy in Lab and Space

# H<sub>2</sub>D<sup>+</sup> Detection in Space

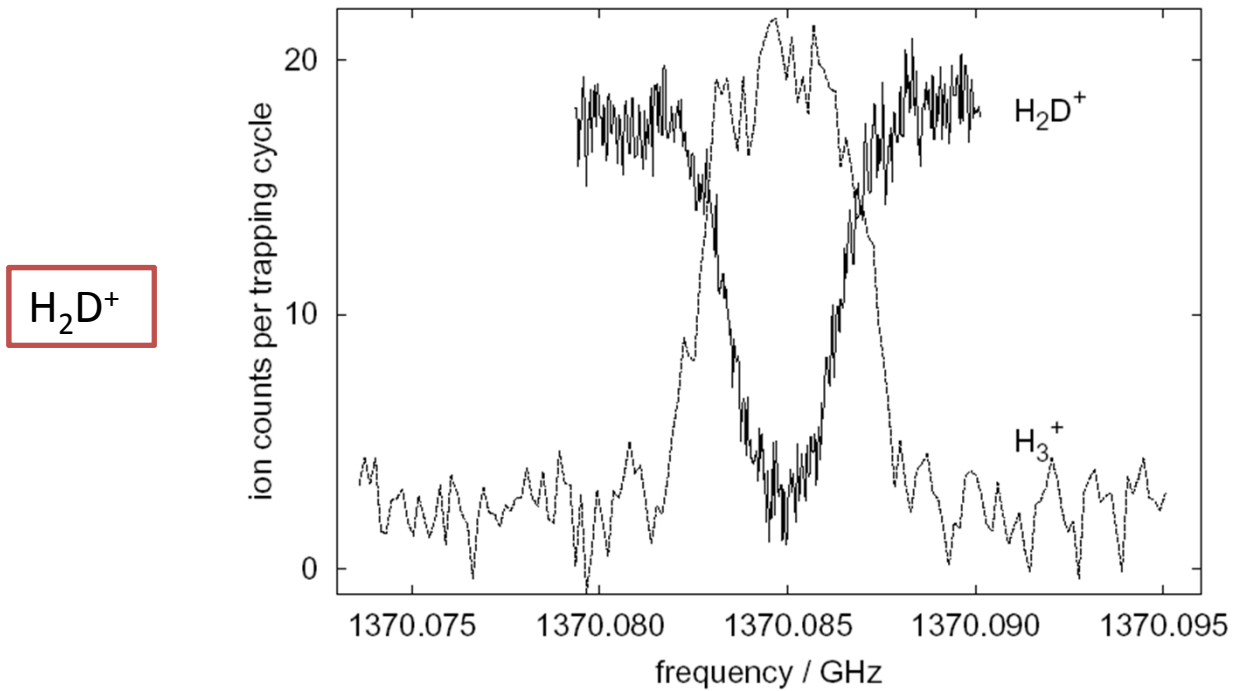


# Light Induced Reactions probing $\text{H}_2\text{D}^+$





## Results



	$\text{H}_2\text{D}^+ 1_{01} \leftarrow 0_{00}$
this work	1370084.880(20)
<i>ab initio</i> <sup>a</sup>	1369991.8
unpublished value <sup>b</sup>	1370146.0(3)

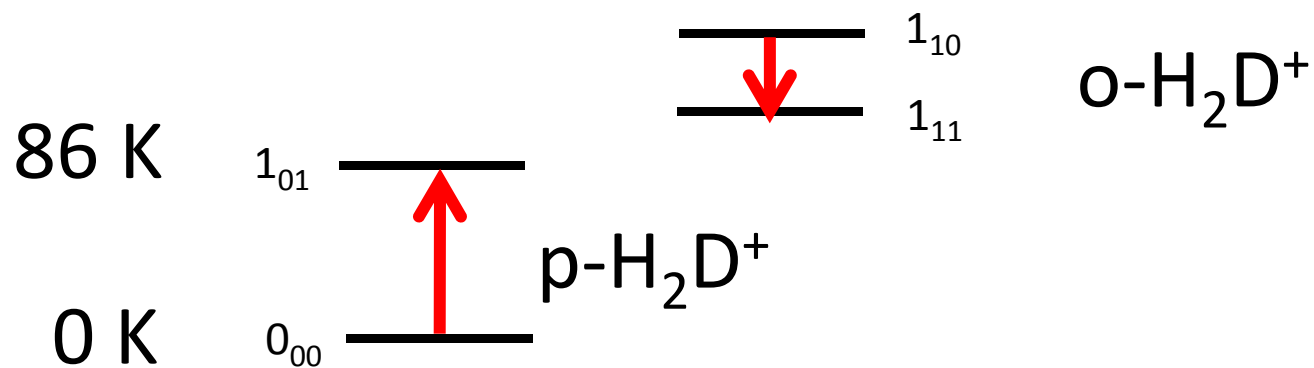
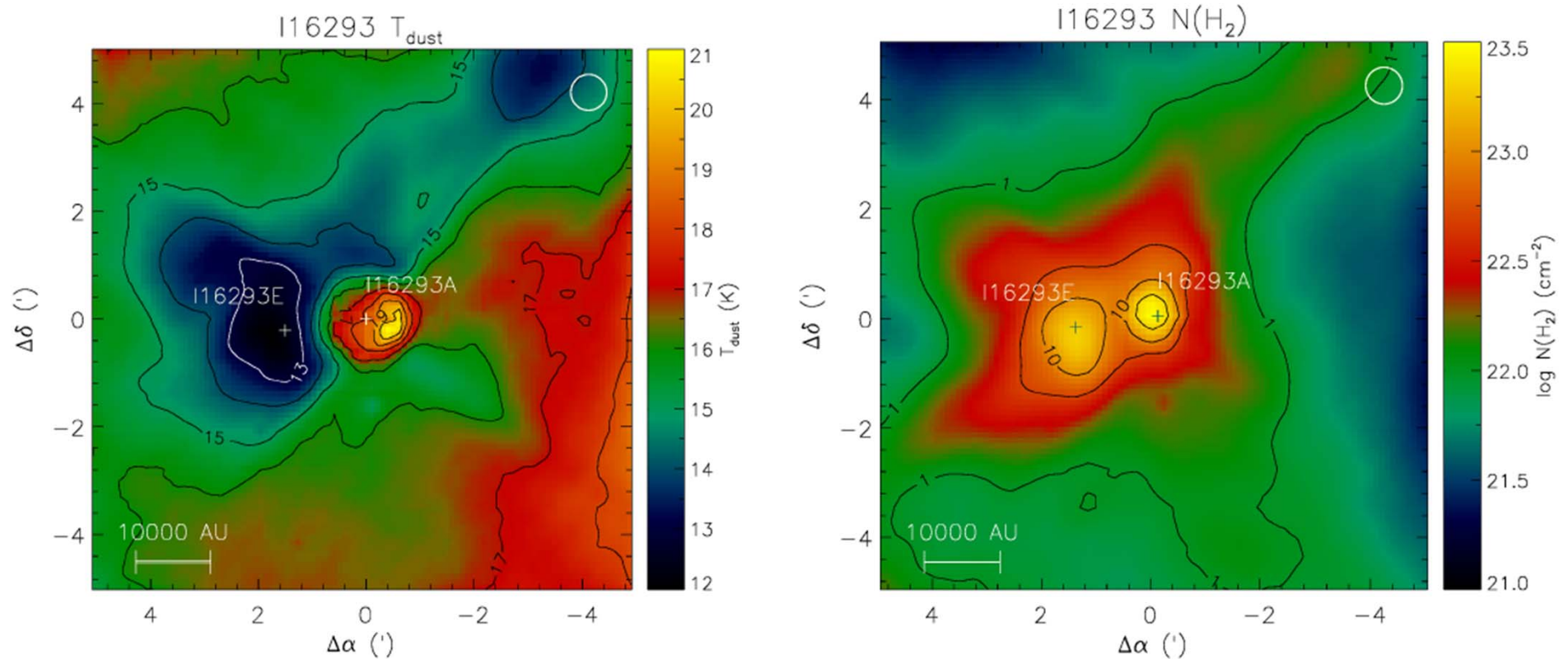
# SOFIA



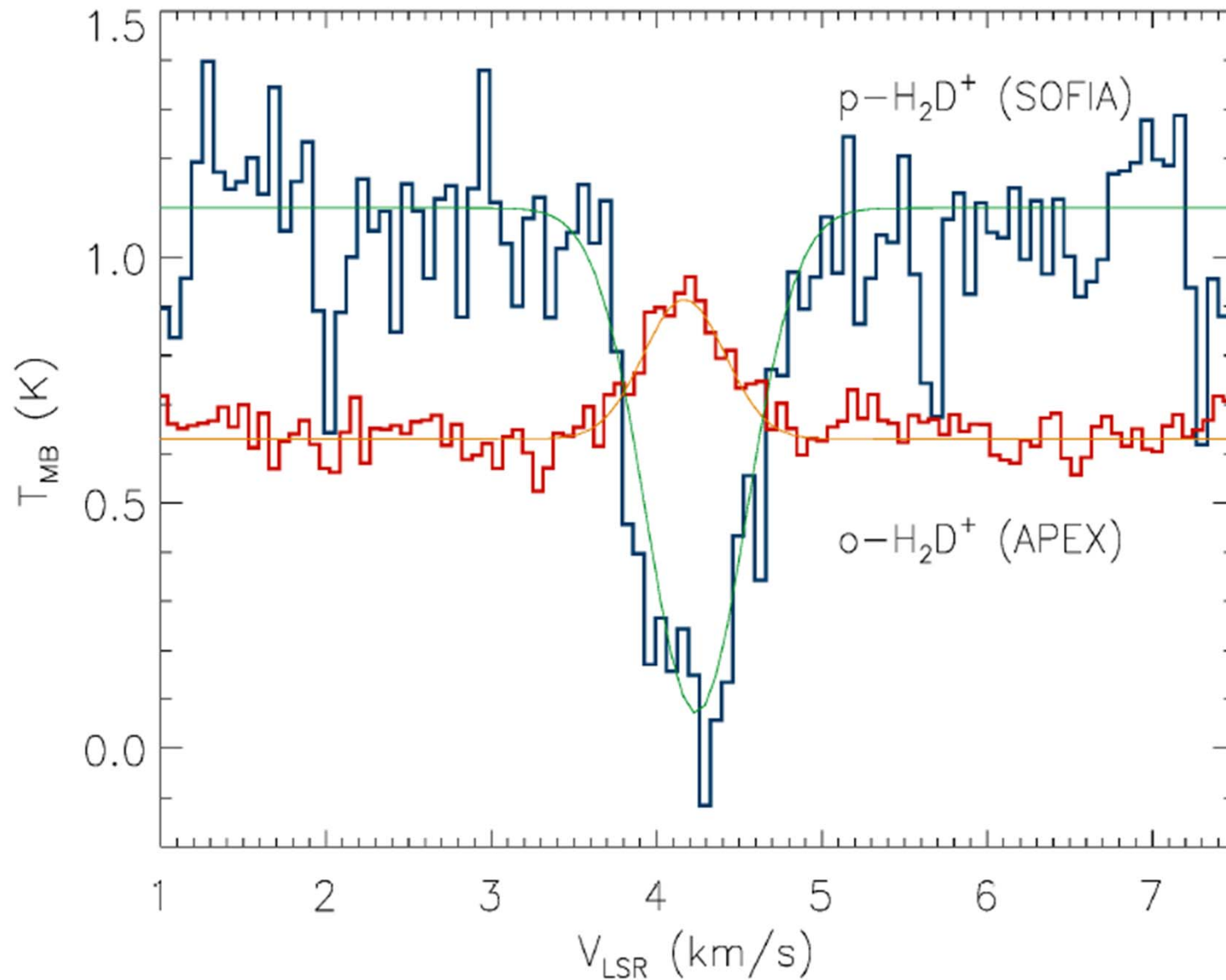
$U_{00}$   
380(20)  
0(3)

$\Delta = 62 \text{ MHz (!)}$

# Protostellar Cloud Core I16293A

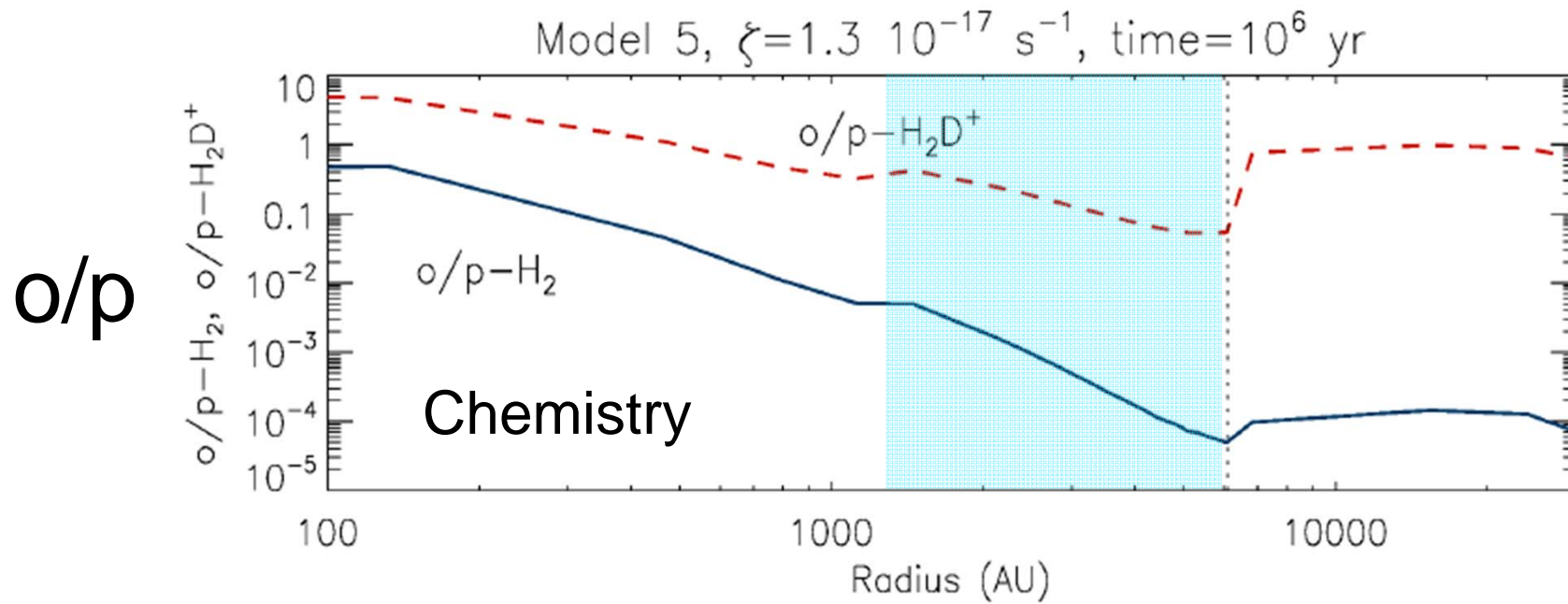
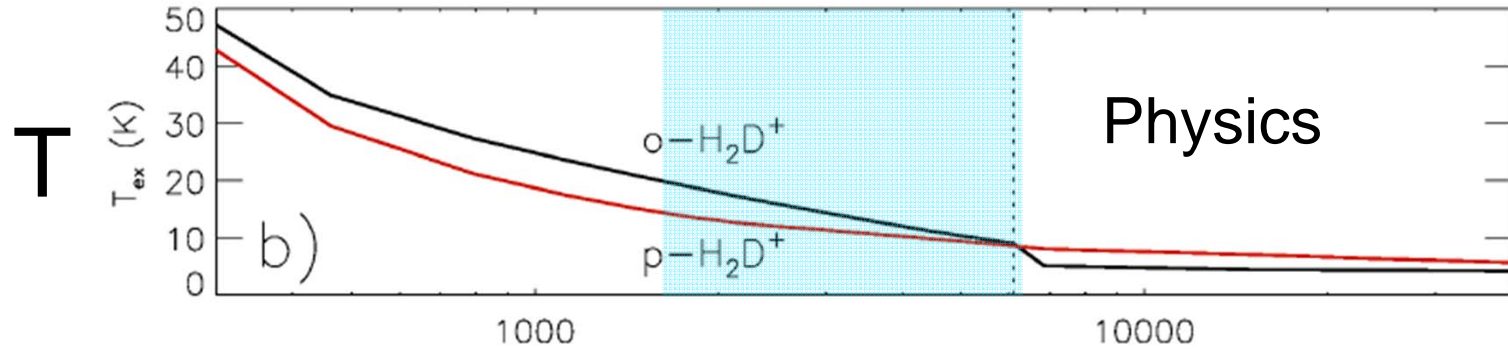
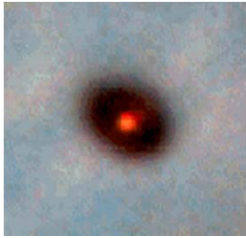


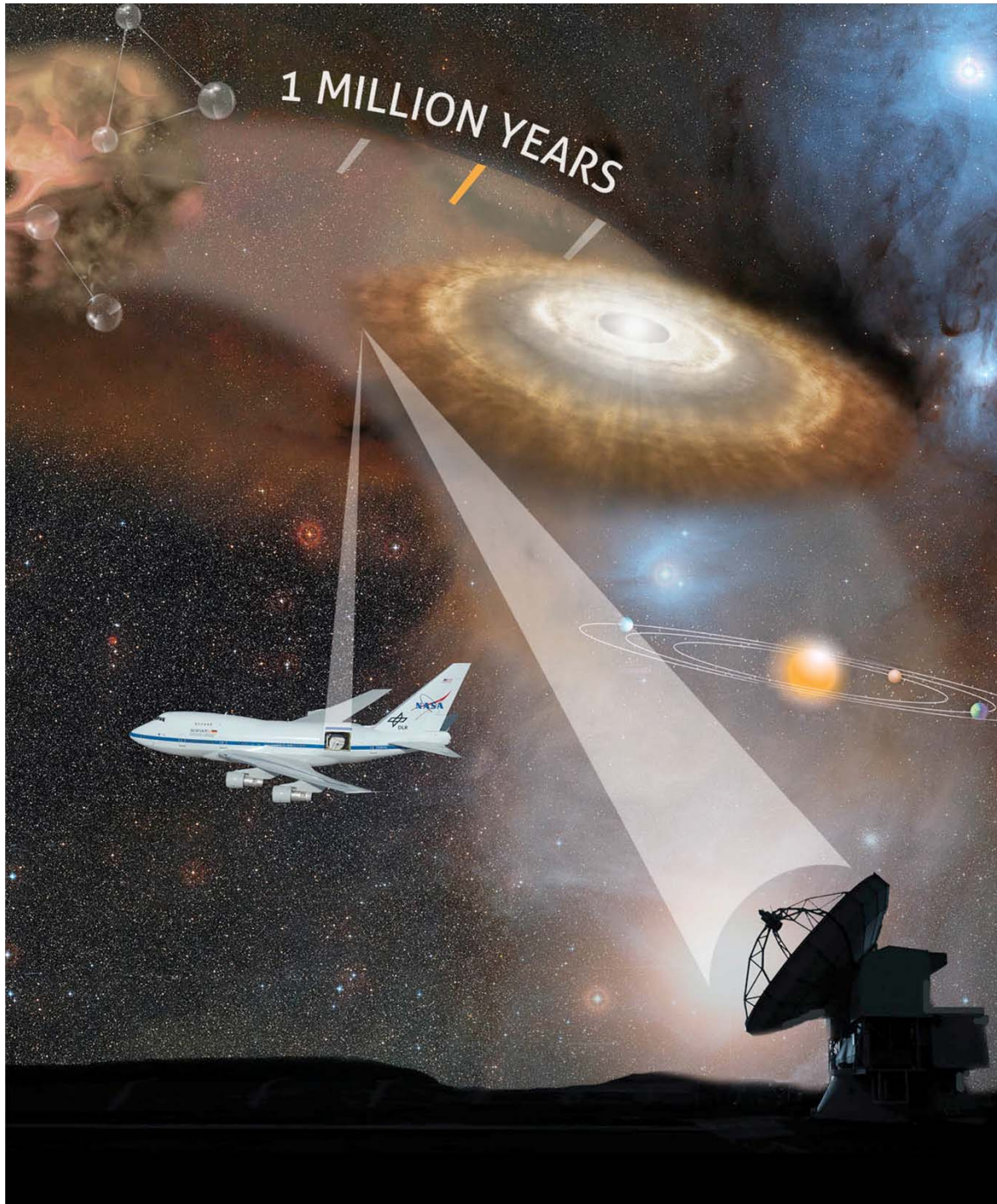
# Para-H<sub>2</sub>D<sup>+</sup> found in Space





# Astrochemical Modelling



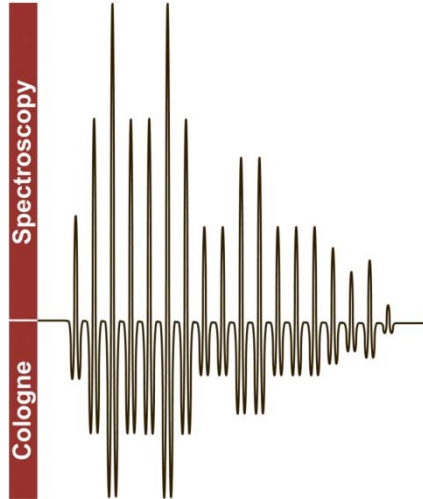


$\text{H}_2\text{D}^+$  observations  
give an age of at least  
one million years for a  
cloud core forming  
Sun-like stars

S. Brünken et al.  
Nature

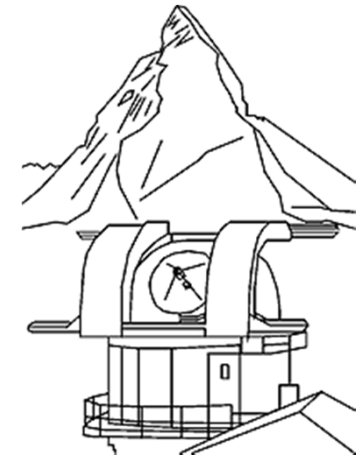
doi:10.1038/nature13924





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- $\text{H}_2$  Formation, OPR and Chemical Clocks
- $\text{H}_3^+ / \text{H}_2\text{D}^+$  Isotopic Fractionation,  $\text{H}_3^+ / \text{H}_2\text{D}^+$ , OPR
- $\text{H}_2\text{D}^+ + \text{H}_2$  THz Spectroscopy in Lab and Space