Electron collisions with H_2^+, HD^+ and D_2^+: computation of cross sections and rate coefficients, and comparison with storage ring measurements

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$$AB^+(N_i^+, v_i^+) + e^- \longrightarrow A + B$$

MAR

Dissociative Recombination: DR

Ro-Vibrational (de)Excitation: RV(d)E $\longrightarrow AB^+(N_f^+, v_f^+) + e^-$

Dissociative Excitation: DE $\longrightarrow A + B^+ + e^-$ **MAD**

Dissociative recombination (MAR)
Dissociative excitation (MAD)

of several molecular cations invoked in the previous talks

H_2^+ and others (will be shown at the end)

Talks of:

Ivo CLASSEN,

Richard ENGELN,

Dirk WÜNDERLICH,

Kevin VERHAEGH

Mathias GROTH,

Annarita LARICCHIUTA

,...

IAEA | 50 years of INIS International Nuclear Information System

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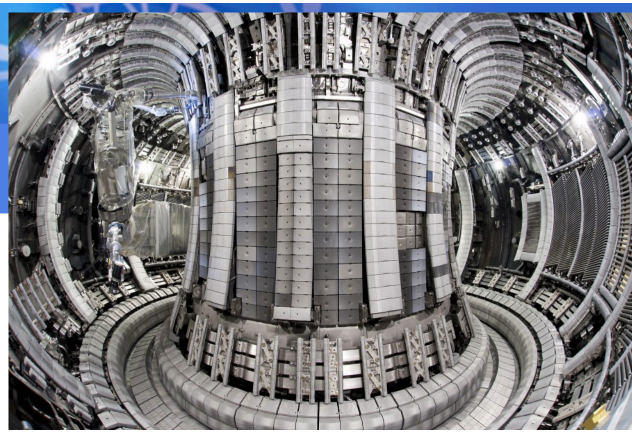


META

Collision processes in low-temperature hydrogen plasmas

Janev, R.K.; Reiter, D.; Samm, U.

Forschungszentrum Juelich GmbH (Germany). Inst. fuer Plasmaphysik, EURATOM Association, Trilateral Euregio Cluster

Citation Export ···

Abstract

[en] Collision processes among the constituents of low-temperature hydrogen plasmas (e, H, H^+, H^-, H_2, H_2^+, H_3^+) play a key role in technical plasma applications as well as in the boundary regions of magnetically confined fusion plasmas. In this work a review of the current knowledge on their cross sections is presented. Collision processes of electronically and vibrationally excited species are also included in the present review. The energy range in which these processes are considered extends from thermal energies to several hundreds electronvolts (and to the keV region for some heavy-particle collision processes). The available experimental and theoretical cross section information is critically assessed and

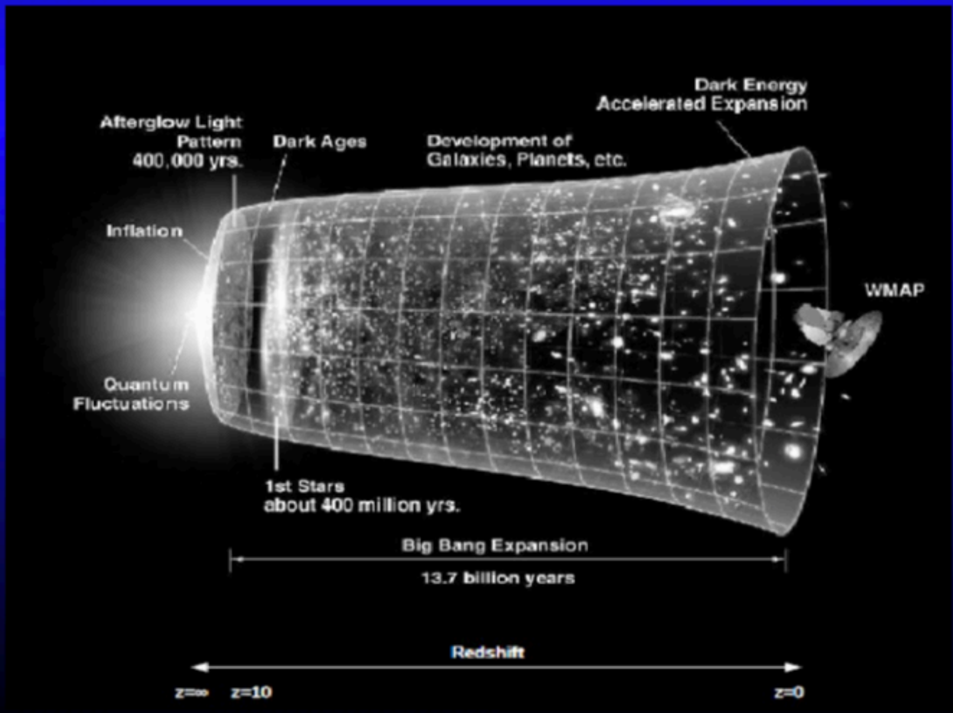
on the collision processes taking place in hydrogen plasmas in the temperature range from 0.01 eV to several hundreds eV. This temperature range covers the typical temperature conditions of many astrophysical and laboratory plasmas in-

DENSITIES AND TEMPERATURE RANGES:
PRIMORDIAL UNIVERSE CHEMISTRY

Densities ~ 10^{5}- 10^{-7}cm^{-3}

T ~ 30000 K – 0.003 K

Coppola, Galli et al, 2011-…



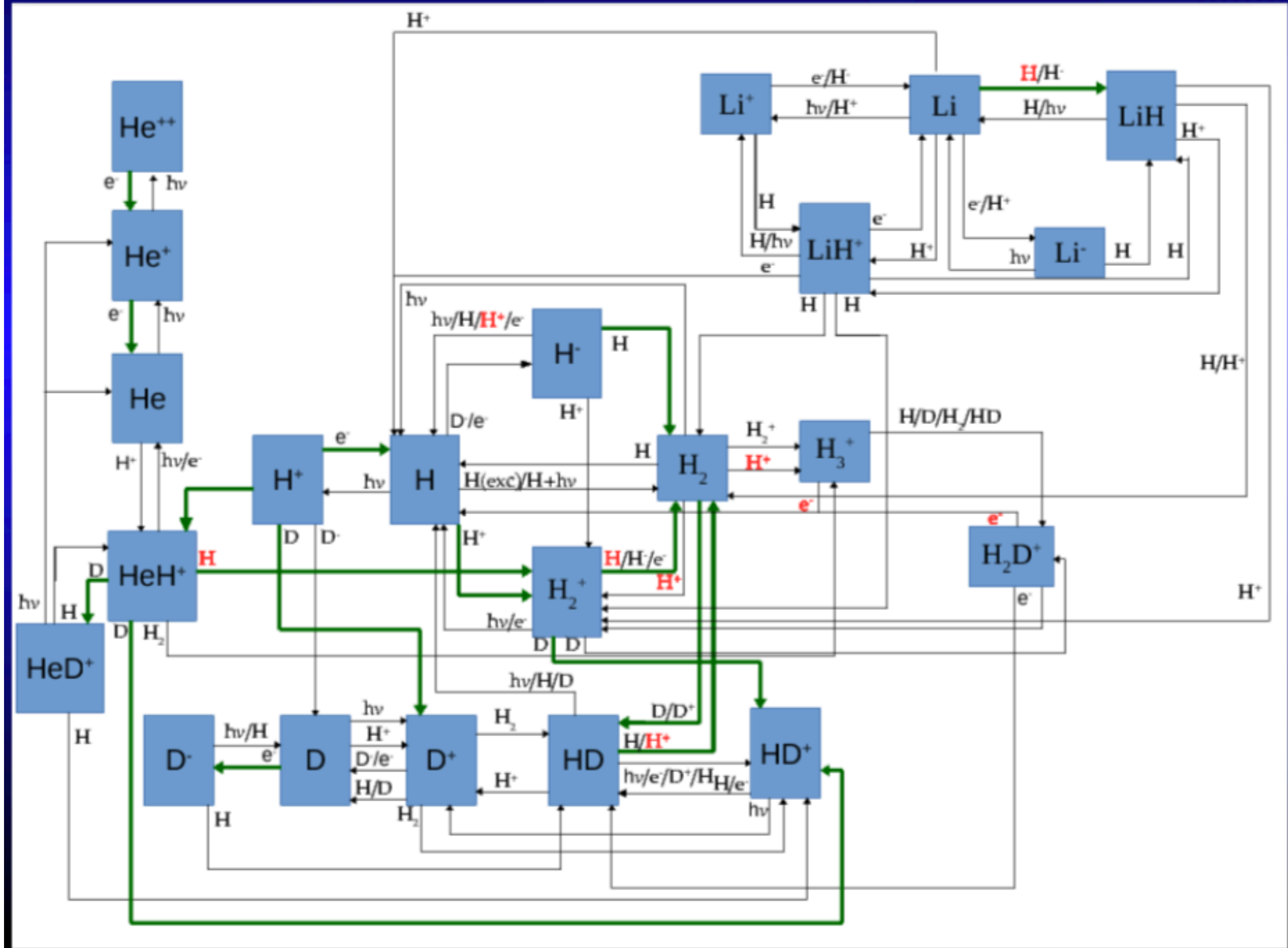
$$\frac{dn_i}{dt} = k_{form} n_j n_k - k_{dest} n_i + \ldots$$

$$\frac{dn_i}{dz} = \frac{dt}{dz} \frac{dn_i}{dt}$$

$$n(z) = \Omega_b n_{cr} (1+z)^3$$

7/62

KINETIC MODEL: CHEMICAL NETWORK



Coppola, Galli et al, 2011-…

22 species
~ 200 reactions

state-to-state

~ 50 species
~ 2500 reactions

Typical behaviour
of
e^-/H_2^+ (HD^+, D_2^+) recombination

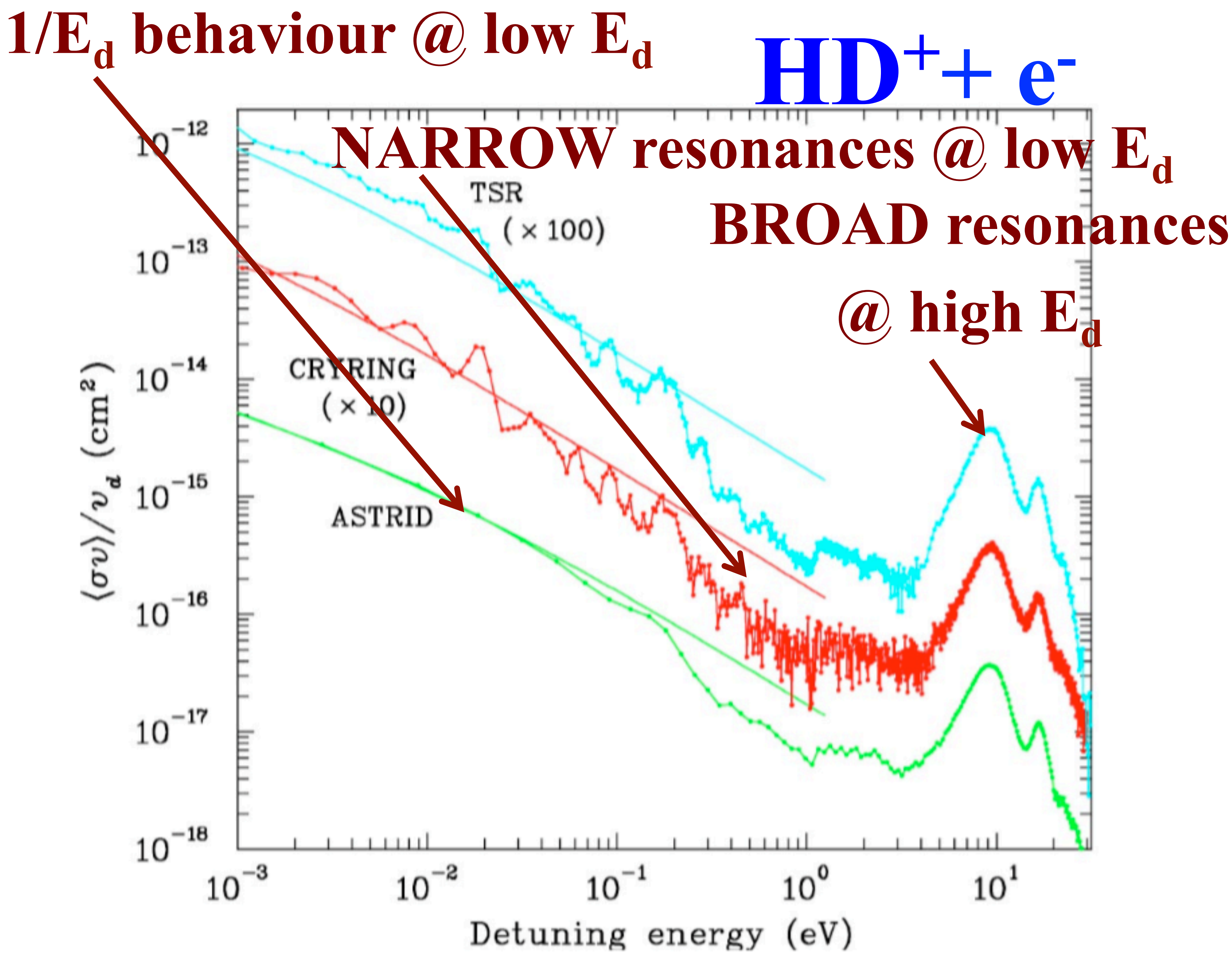
ALL 3 EUROPEAN

storage rings:

PHYSICAL REVIEW A **68**, 042702 (2003)

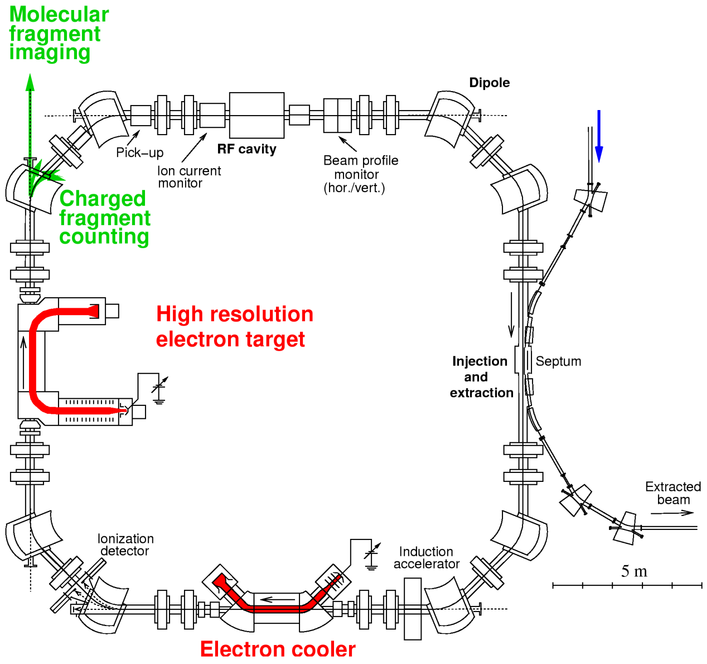
Absolute high-resolution rate coefficients for dissociative recombination of electrons with HD^+: Comparison of results from three heavy-ion storage rings

A. Al-Khalili,[1,2] S. Rosén,[1] H. Danared,[3] A. M. Derkatch,[1] A. Källberg,[3] M. Larsson,[1] A. Le Padellec,[1,4] A. Neau,[1] J. Semaniak,[2] R. Thomas,[1,5] M. af Ugglas,[3] L. Vikor,[1] W. Zong,[1] W. J. van der Zande,[5,*] X. Urbain,[6,†] M. J. Jensen,[6] R. C. Bilodeau,[6] O. Heber,[7] H. B. Pedersen,[6] C. P. Safvan,[6] L. H. Andersen,[6] M. Lange,[8,‡] J. Levin,[8] G. Gwinner,[8] L. Knoll,[8] M. Scheffel,[8] D. Schwalm,[8] R. Wester,[8] D. Zajfman,[7,8] and A. Wolf[8]



1/E$_d$ behaviour @ low E$_d$
HD$^+$+ e$^-$
NARROW resonances @ low E$_d$
BROAD resonances
@ high E$_d$
TSR
(× 100)
CRYRING
(× 10)
ASTRID
$\langle \sigma v \rangle / v_d$ (cm^2)
Detuning energy (eV)

How one measures ?



...+

Convolution with ANISOTROPIC Maxwell Distribution: **< 2012**

$$\alpha = \langle \mathrm{v}\sigma \rangle = \int\int\int \sigma(\mathrm{v})\mathrm{v} f(\mathrm{v}_d, \mathbf{v}) d\mathbf{v} \qquad (1)$$

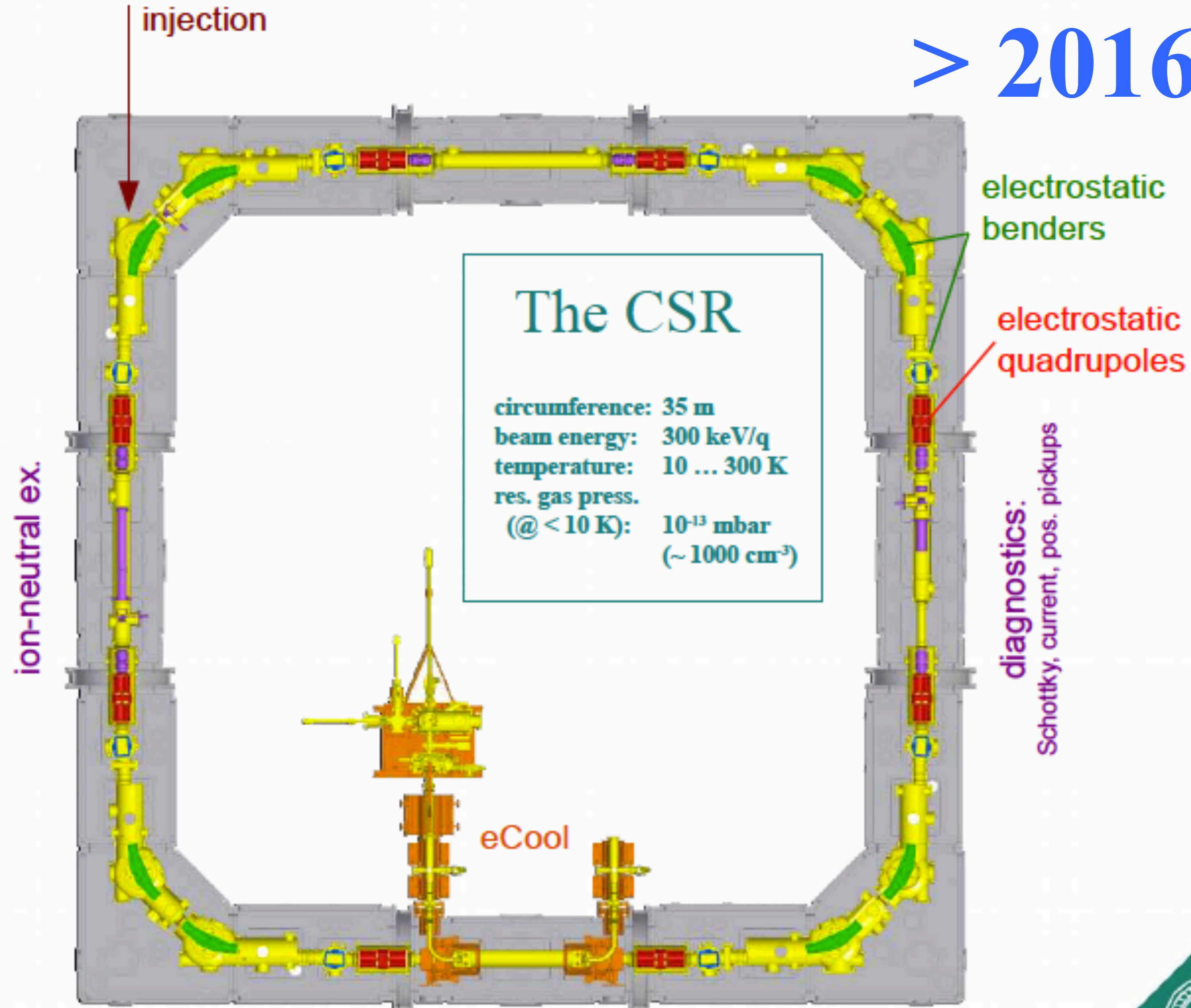
$$f(\mathrm{v}_d, \mathbf{v}) = \frac{m}{2\pi k T_{e\perp}} exp\left(-\frac{m\mathrm{v}_\perp^2}{2kT_{e\perp}}\right) \sqrt{\frac{m}{2\pi k T_{e\|}}} exp\left(-\frac{m(\mathrm{v}_\| - \mathrm{v}_d)^2}{2kT_{e\|}}\right) \qquad (2)$$

Best parameters:

T_{long} = 20 μeV= 0,23 K=0,16 cm^{-1}

T_{trans} = 500 μeV= 5,80 K=4,03 cm^{-1}

> 2016


injection
electrostatic benders
electrostatic quadrupoles
ion-neutral ex.
diagnostics:
Schottky, current, pos. pickups
eCool
The CSR
circumference: 35 m
beam energy: 300 keV/q
temperature: 10 … 300 K
res. gas press.
(@ < 10 K): 10⁻¹³ mbar
(~ 1000 cm⁻³)

Towards STATE-to-STATE results,

i.e.

ROTATIONALLY &

VIBRATIONALLY

resolved xs & rates.

On the theoretical side···

Physica Scripta. T96, 52–60, 2002

Takagi: e$^-$/H_2^+ dynamics

Dissociative Recombination and Excitation of H_2^+, HD^+, and D_2^+ with Electrons for Various Vibrational States

H. Takagi*

School of Medicine, Kitasato University, 1-15-1 Kitasato, Sagamihara, Kanagawa, 228-8555 Japan

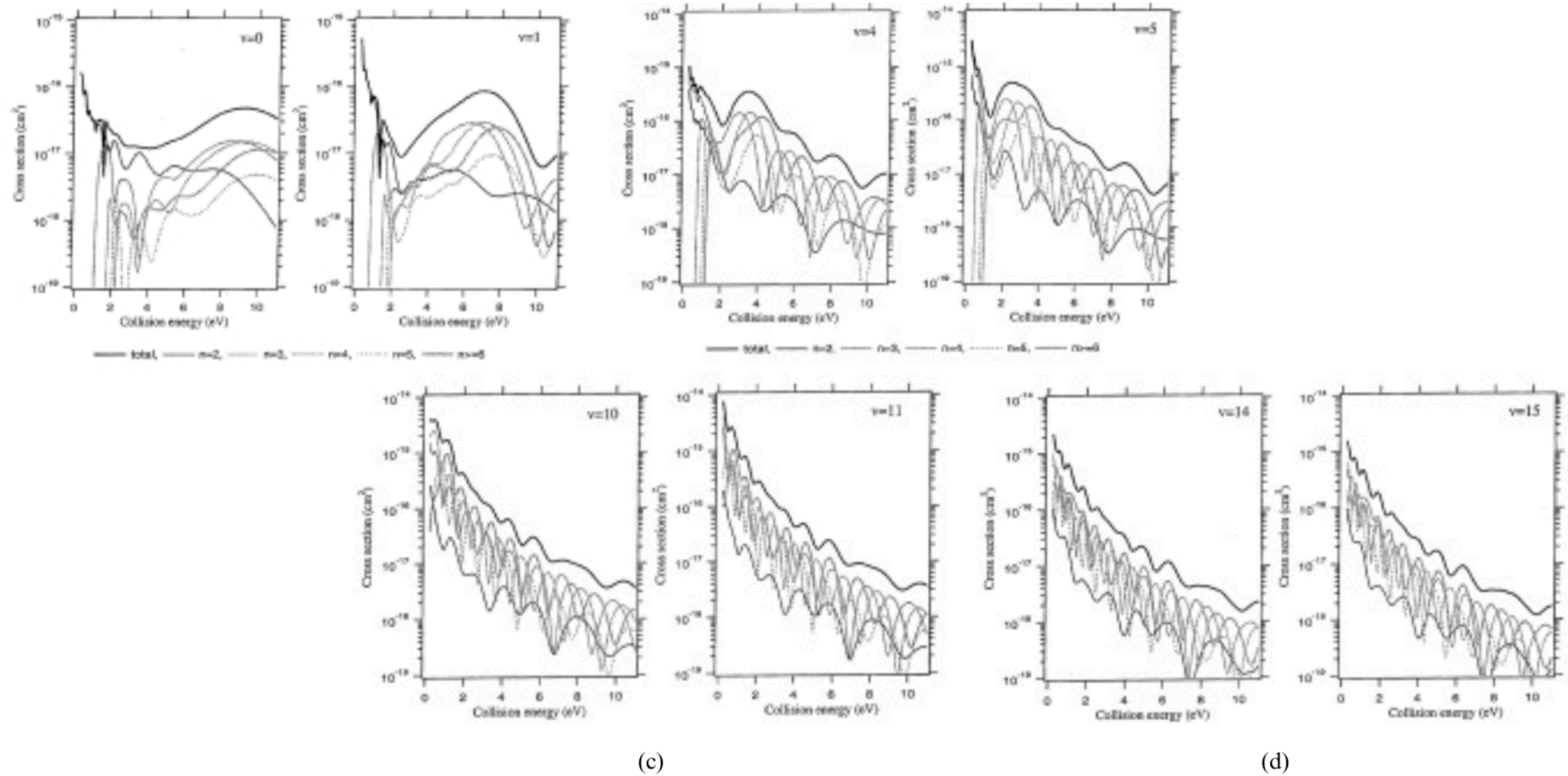


Fig. 4a–d. DR cross section of H_2^+ for each initial vibrational state v. The dark bold line indicates the total DR cross section. Other lines show the partial cross sections of producing the excited atoms of principle quantum number n, whose value is indicated in the figure. The symbol $n >= 6$ means $\infty \geq n \geq 6$.

$$AB^+(N_i^+, v_i^+) + e^- \longrightarrow A + B$$ Dissociative Recombination: DR

Dissociative Excitation: DE $$\longrightarrow A + B^+ + e^-$$

$$AB^+: H_2^+, HD^+, D_2^+$$

WHY new calculations ?

1) Different – some updated - molecular structure data

2) Data on ro-vibrational transitions

$$AB^+(N_i^+, v_i^+) + e^- \longrightarrow A + B$$ Dissociative Recombination: DR

Ro-Vibrational (de)Excitation: RV(d)E $$\longrightarrow AB^+(N_f^+, v_f^+) + e^-$$

Dissociative Excitation: DE $$\longrightarrow A + B^+ + e^-$$

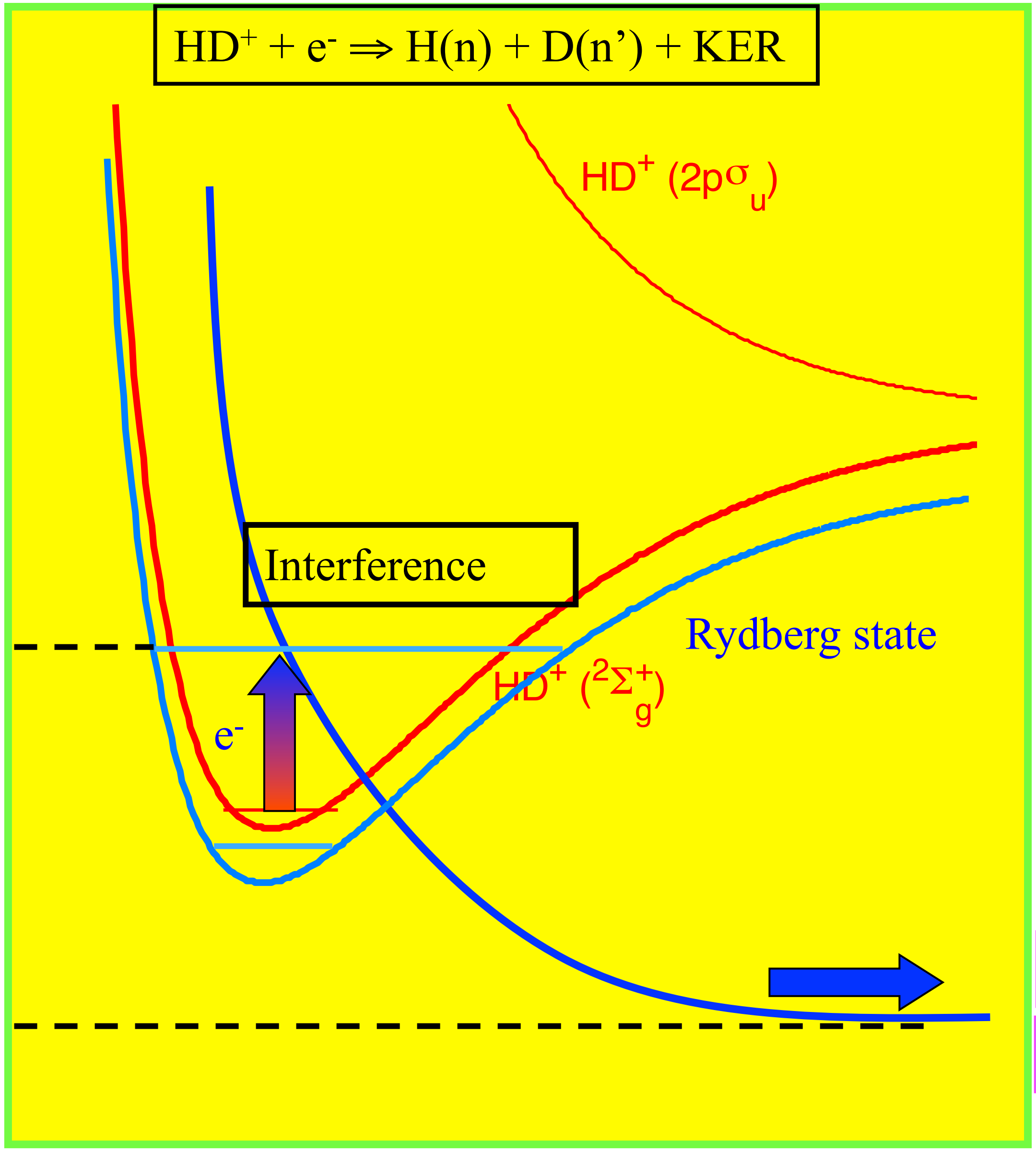
$$AB^+: H_2^+, HD^+, D_2^+$$

Electron-cold molecular ion reaction: Dissociative Recombination

D. Zajfman

Indirect process

Direct process



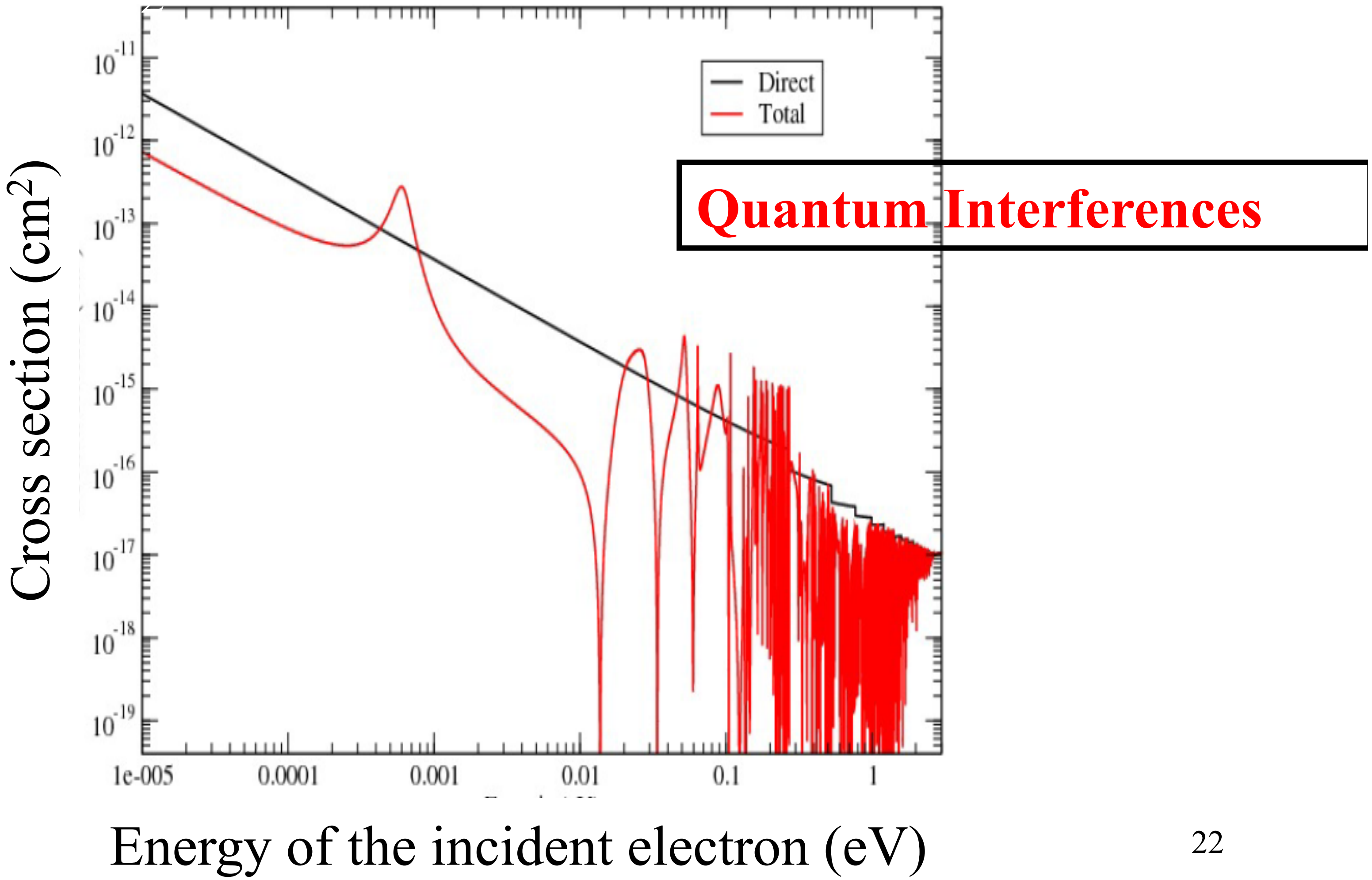
Kinetic Energy Release

H(1s)+D(2l)

D(1s)+H(2l)

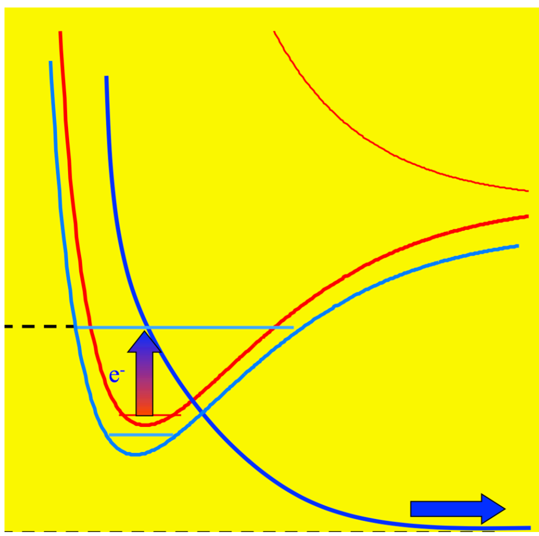
H_2^+: DR xs

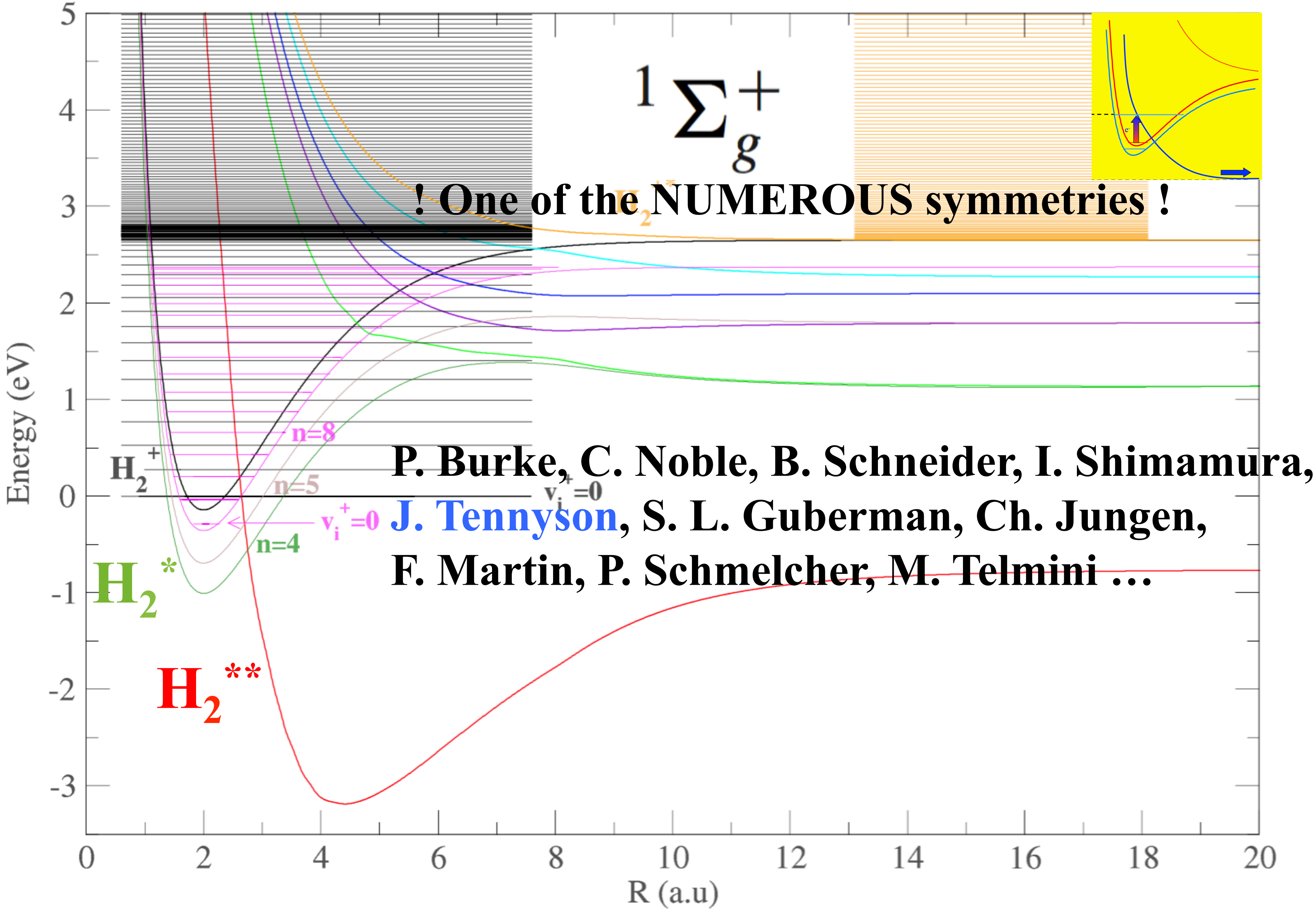
Total (direct & indirect) vs **direct** mechanisms



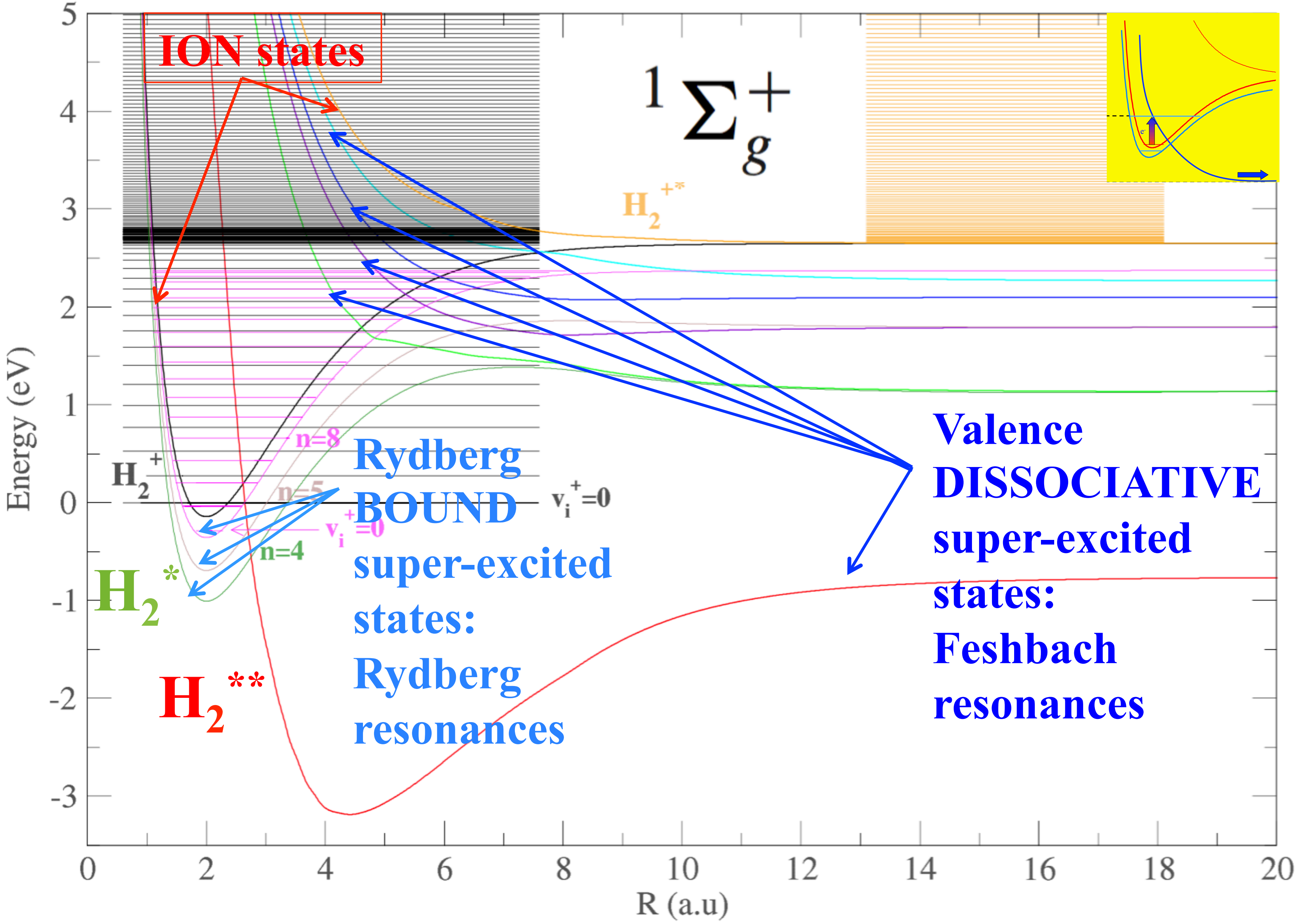
The relevant

POTENTIAL ENERGY CURVES

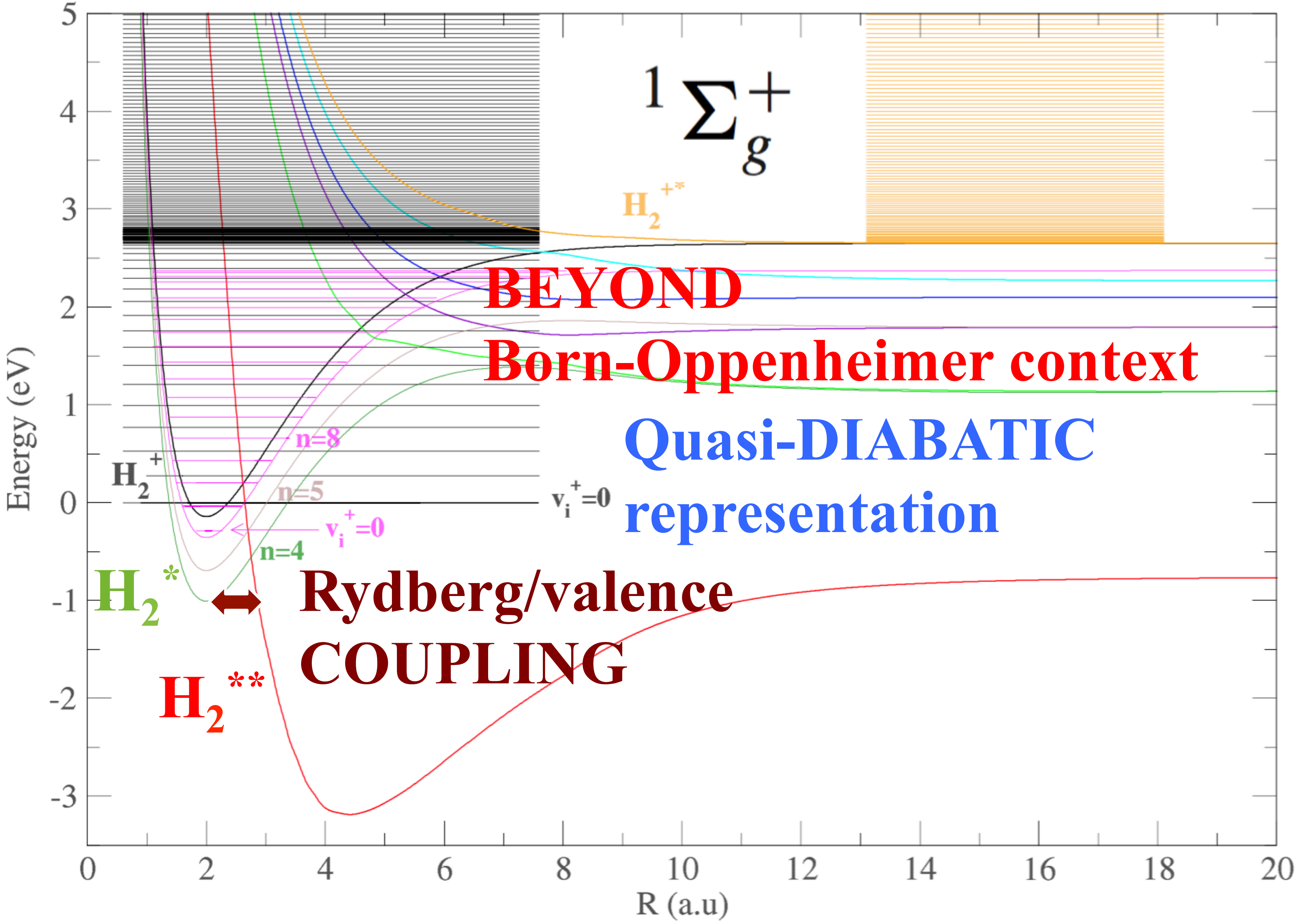




$^1\Sigma_g^+$
! One of the NUMEROUS symmetries !
P. Burke, C. Noble, B. Schneider, I. Shimamura,
J. Tennyson, S. L. Guberman, Ch. Jungen,
F. Martin, P. Schmelcher, M. Telmini …
Energy (eV)
R (a.u)
H_2^+
H_2^*
H_2^{**}
n=8
n=5
n=4
$v_i^+=0$

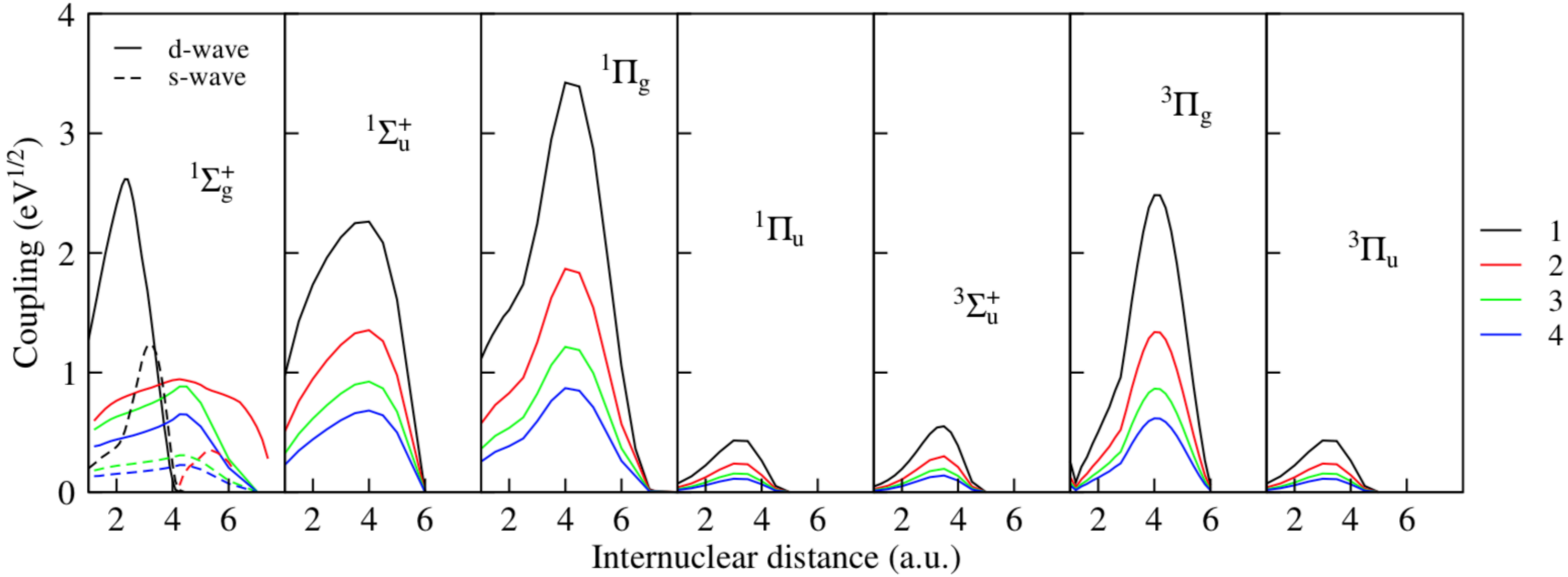


ION states
$^1\Sigma_g^+$
H_2^{+*}
H_2^+
$v_i^+=0$
n=8
n=5
n=4
Rydberg BOUND super-excited states: Rydberg resonances
Valence DISSOCIATIVE super-excited states: Feshbach resonances
H_2^*
H_2^{**}
Energy (eV)
R (a.u)

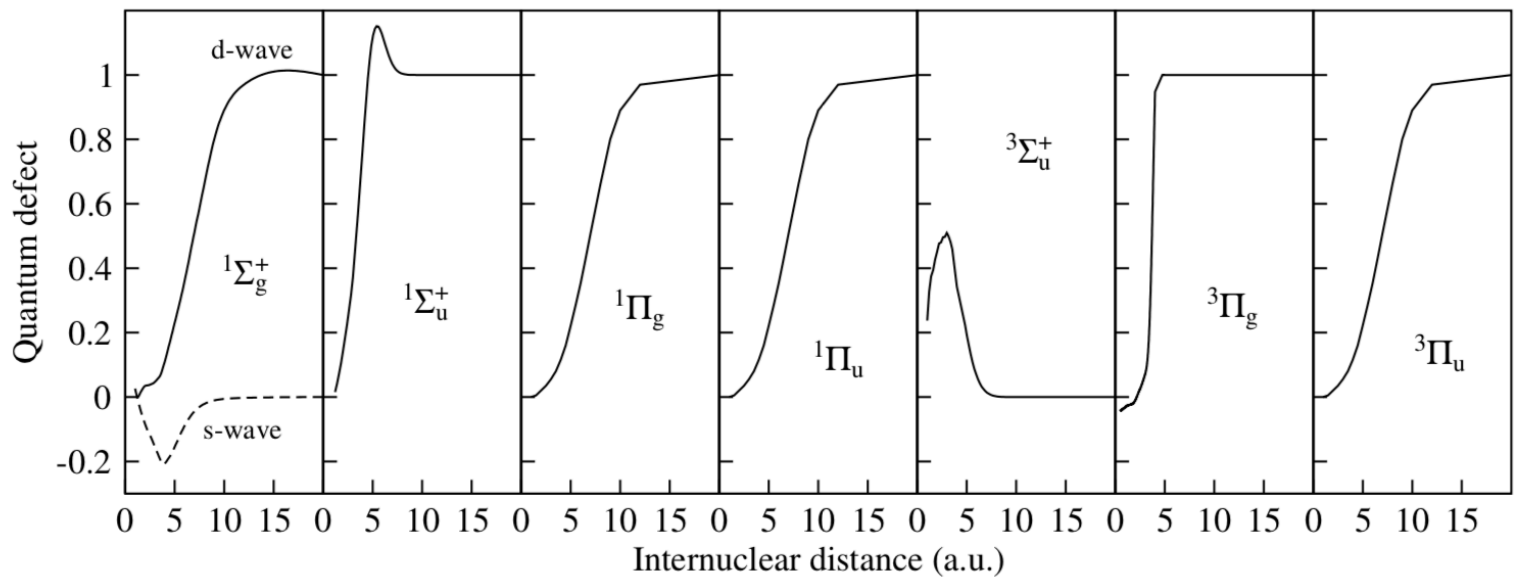


$^1\Sigma_g^+$
H_2^{+*}
BEYOND
Born-Oppenheimer context
Quasi-DIABATIC
representation
n=8
n=5
n=4
H_2^+
$v_i^+=0$
$v_i^+=0$
H_2^*
Rydberg/valence
COUPLING
H_2^{**}
Energy (eV)
R (a.u)

H_2



d-wave
s-wave
$^1\Sigma_g^+$
$^1\Sigma_u^+$
$^1\Pi_g$
$^1\Pi_u$
$^3\Sigma_u^+$
$^3\Pi_g$
$^3\Pi_u$
1
2
3
4
Coupling (eV$^{1/2}$)
Internuclear distance (a.u.)



d-wave
s-wave
$^1\Sigma_g^+$
$^1\Sigma_u^+$
$^1\Pi_g$
$^1\Pi_u$
$^3\Sigma_u^+$
$^3\Pi_g$
$^3\Pi_u$
Quantum defect
Internuclear distance (a.u.)

How do we compute electron-impact recombination and excitation?

Main THEORETICAL approach: MQDT

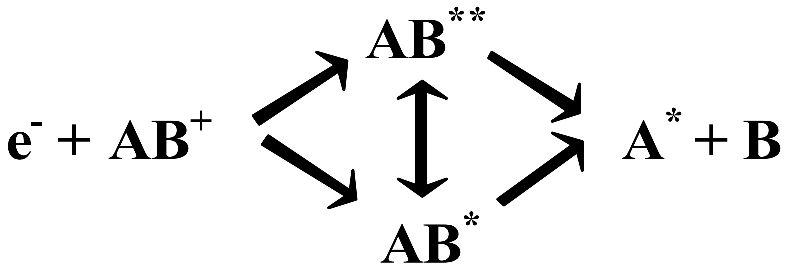
Multichannel Quantum Defect Theory

Seaton (1958-1983), Fano, Jungen, Greene, Giusti -Suzor (1970-…),…

Quantum Interferences

DIRECT

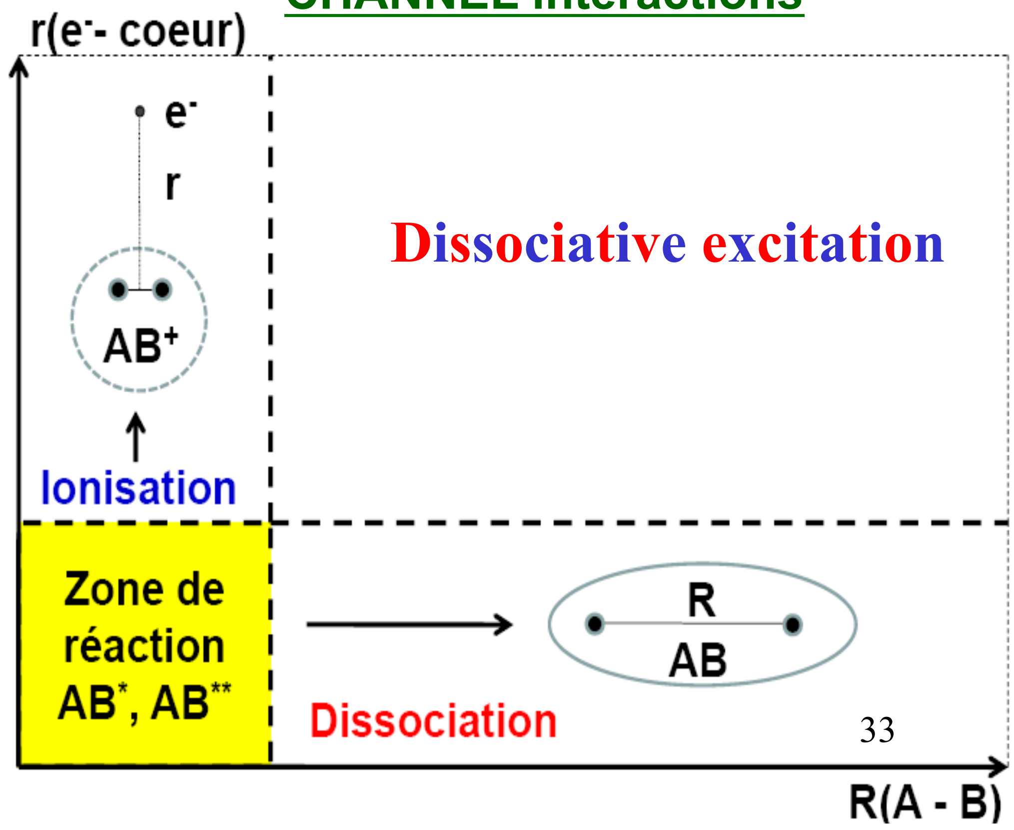
Dissociative state



Bound (Rydberg) state

INDIRECT

CHANNEL interactions



The various mechanisms which drive the DYNAMICS depend on the ENERGY:

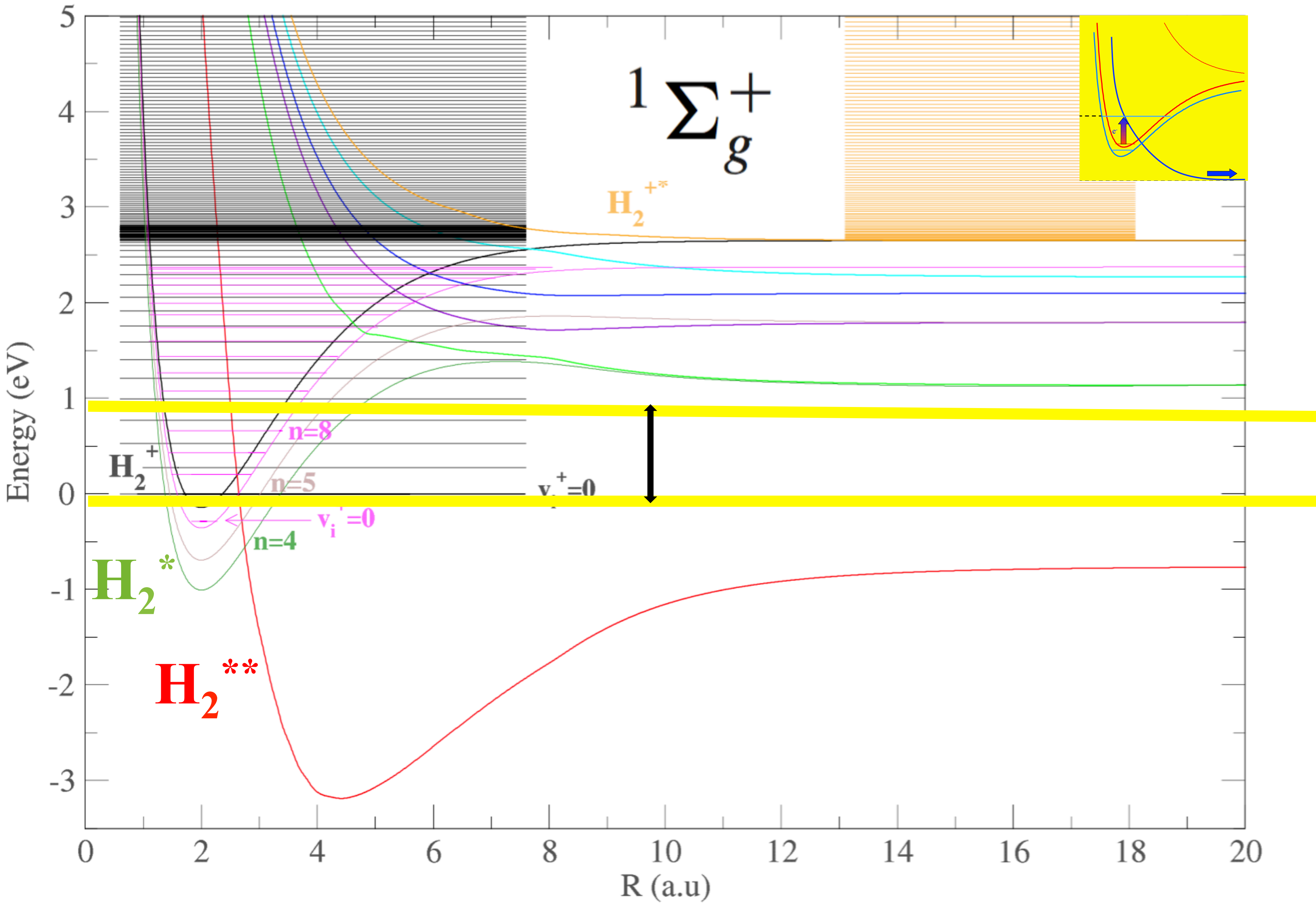
“Very” Low Energy:

ROTATION and Vibration,

DISCRETE ro-vibrational spectrum,

“Fano”resonances,

maximum ACCURACY



Energy (eV)
R (a.u)
5
4
3
2
1
0
-1
-2
-3
0
2
4
6
8
10
12
14
16
18
20
$^1\Sigma_g^+$
H_2^{+*}
n=8
H_2^+
n=5
$v_i^+=0$
$v_i^+=0$
n=4
H_2^*
H_2^{**}

PHYSICAL REVIEW A 90, 012706 (2014)

Rotational transitions induced by collisions of HD^+ ions with low-energy electrons

O. Motapon,[1,2] N. Pop,[3] F. Argoubi,[4] J. Zs Mezei,[2,5,6] M. D. Epee Epee,[1] A. Faure,[7] M. Telmini,[4] J. Tennyson,[8] and I. F. Schneider[2,5]

HD^+ + e^-

↓

HD^*,HD^{**}

↓

H + D

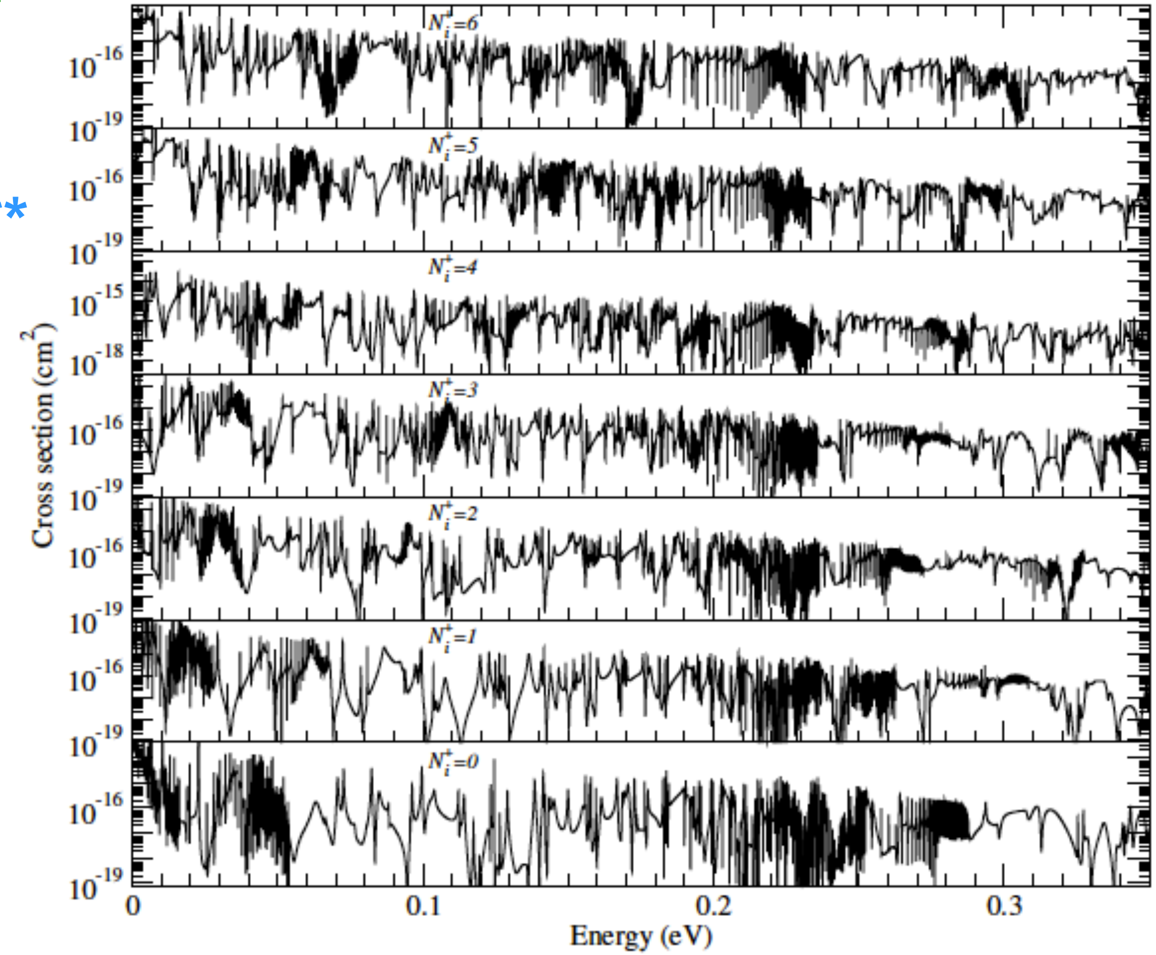
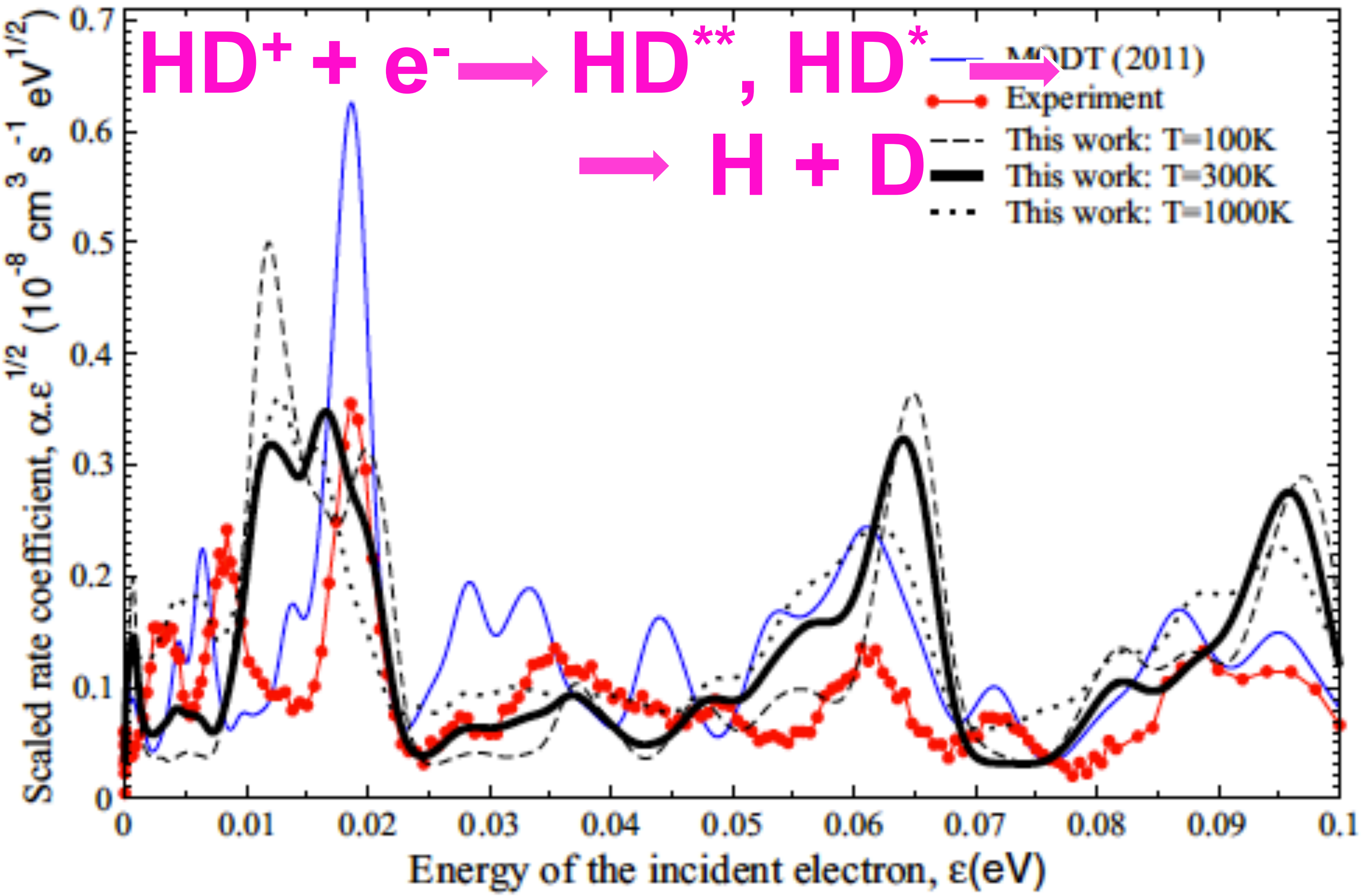


Figure 3. DR cross sections of HD^+ initially in one of its lowest rotational level N_i^+ (vibrational ground state).

PHYSICAL REVIEW A **90**, 012706 (2014)

Rotational transitions induced by collisions of HD^+ ions with low-energy electrons

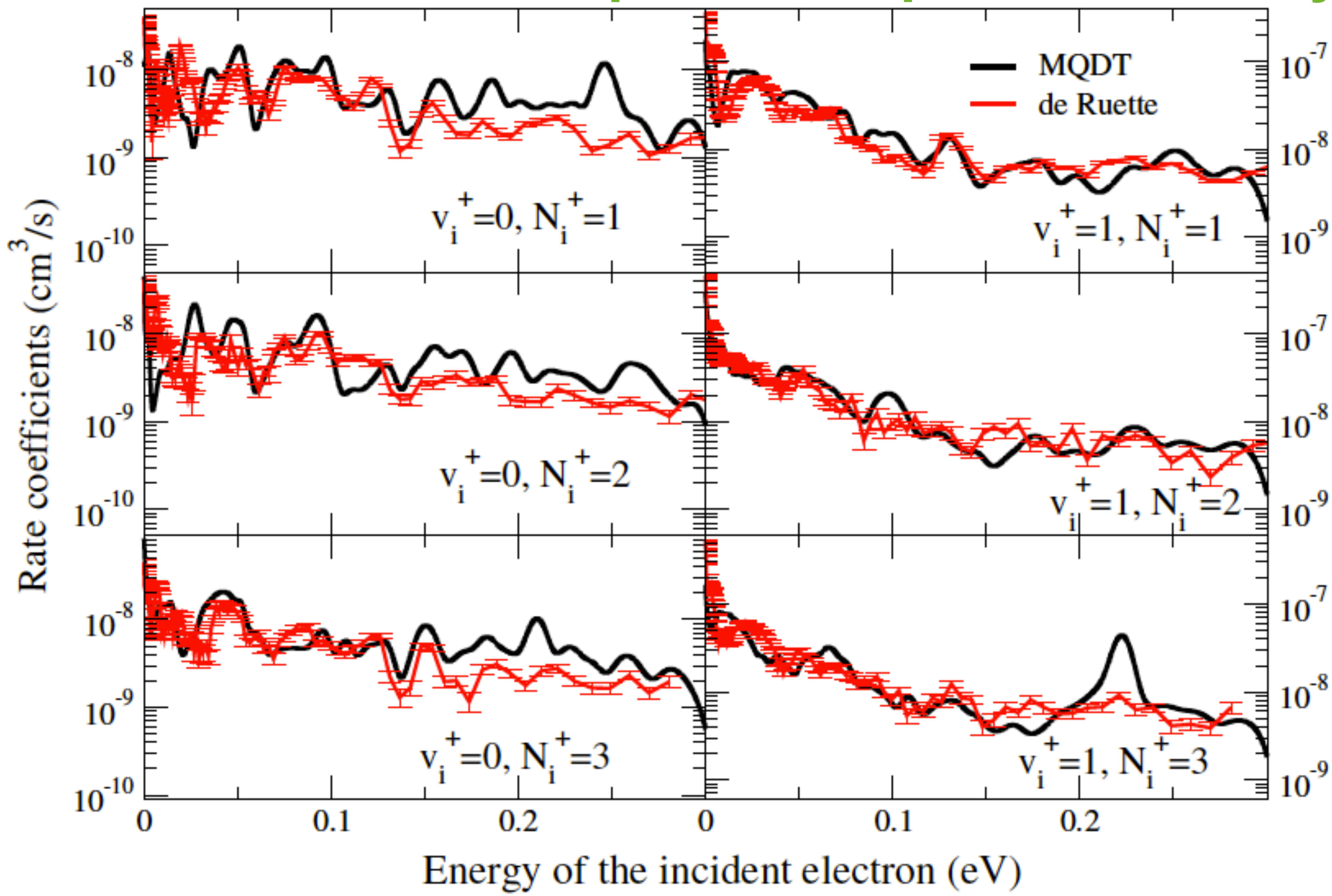
O. Motapon,[1,2] N. Pop,[3] F. Argoubi,[4] J. Zs Mezei,[2,5,6] M. D. Epee Epee,[1] A. Faure,[7] M. Telmini,[4]
J. Tennyson,[8] and I. F. Schneider[2,5]



N. De Ruette, X. Urbain, O. Novotny, A. Wolf,…. @ TSR vs MQDT

$H_2^+(N_i^+, v_i^+) + e^- \rightarrow H + H$

1st state-to-state comparison experiment/theory



How important is the target excitation ?

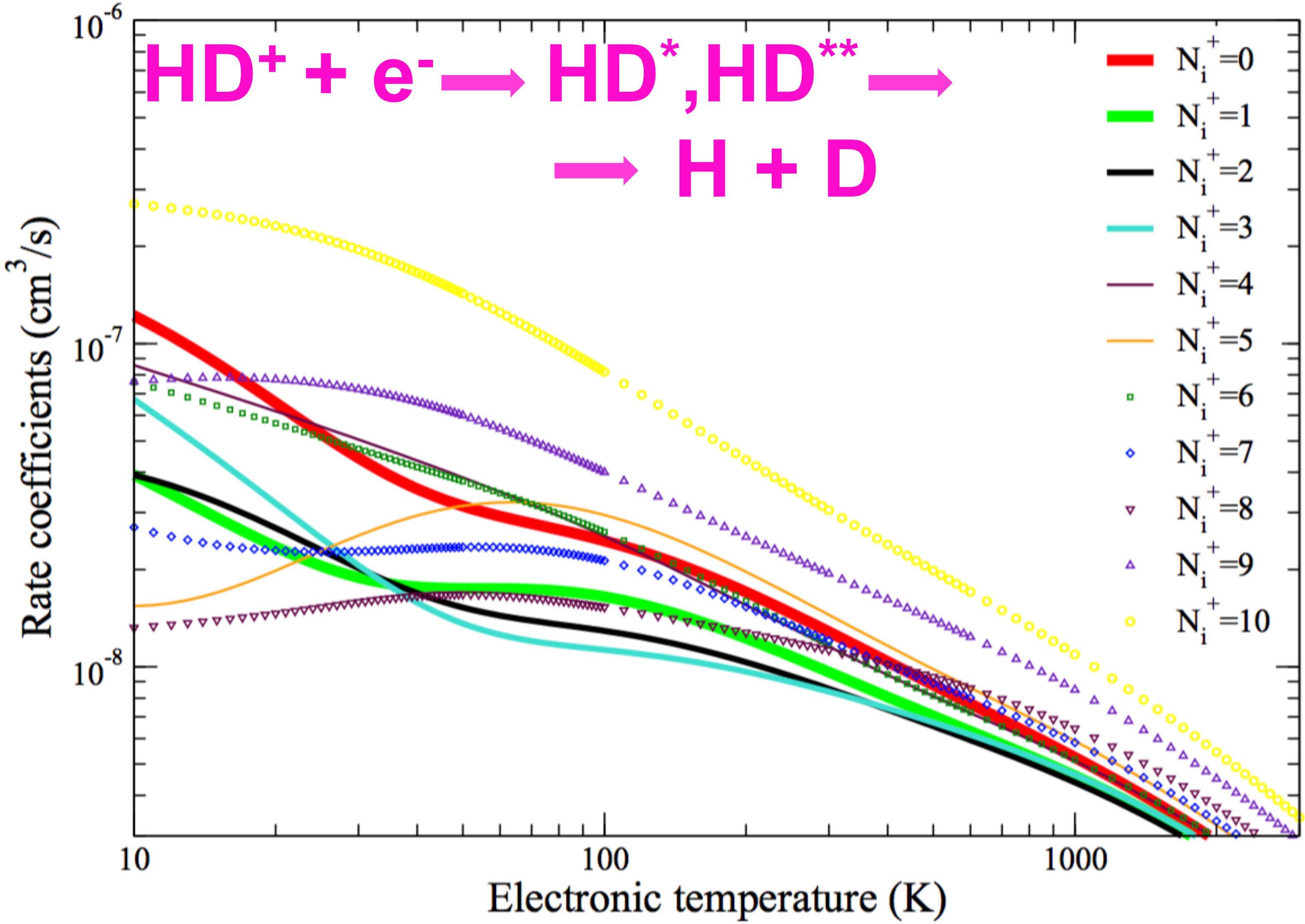


FIG. 9. (Color online) Maxwell isotropic rate coefficients for the dissociative recombination $HD^+(X\,^2\Sigma_g^+)$ with $v_i^+ = 0$ as a function of initial rotational level, $N_i^+ = 0$ to 10 .

$H_2^+ + e^-$

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **455,** 276–281 (2015)

Reactive collisions of very low-energy electrons with H_2^+: rotational transitions and dissociative recombination

M. D. Epée Epée,[1] J. Zs Mezei,[2,3,4] O. Motapon,[1,5★] N. Pop[6] and I. F. Schneider[2,3★]

[1] *LPF, UFD Mathématiques, Informatique Appliquée et Physique Fondamentale, University of Douala, P. O. Box 24157, Douala, Cameroon*
[2] *Laboratoire Ondes et Milieux Complexes, UMR 6294 CNRS and Université du Havre, 25, rue Philippe Lebon, BP 540, F-76058 Le Havre, France*
[3] *Laboratoire Aimé Cotton CNRS-UPR-3321, Université Paris-Sud, Orsay F-91405, France*
[4] *Laboratoire des Sciences des Procédés et des Matériaux, UPR 3407 CNRS and Univ. Paris 13, 99 avenue Jean-Baptiste Clément, F-93430 Villetaneuse, France*
[5] *Faculty of Science, University of Maroua, PO Box 814 Maroua, Cameroon*
[6] *Department of Physical Foundation of Engineering, University Politechnica of Timisoara, Bv Vasile Parvan No 2, 300223, Timisoara, Romania*

$H_2^+(N_i^+) + e^- \longrightarrow H_2^{**}, H_2^* \longrightarrow H_2^+(N_f^+) + e^-$

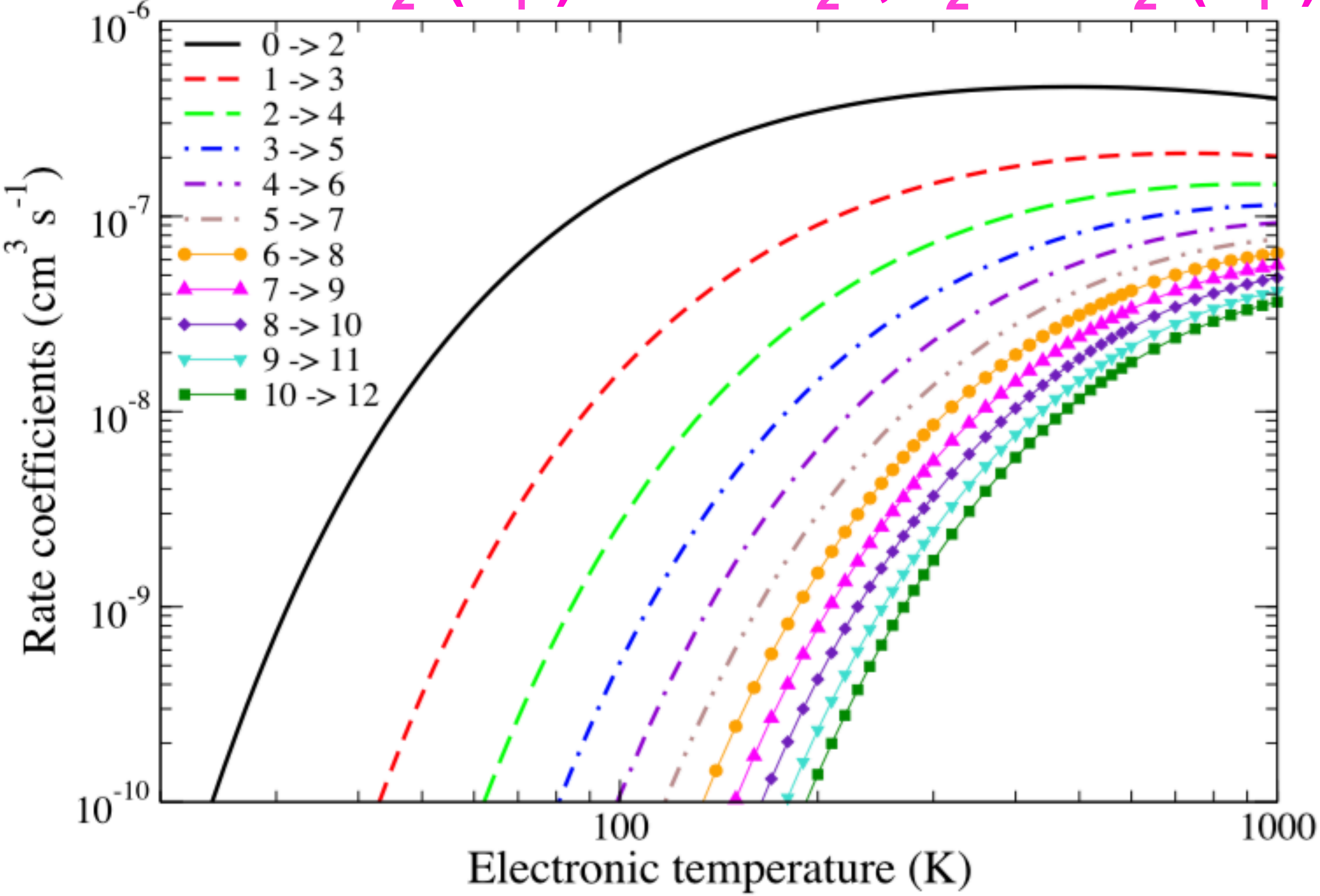
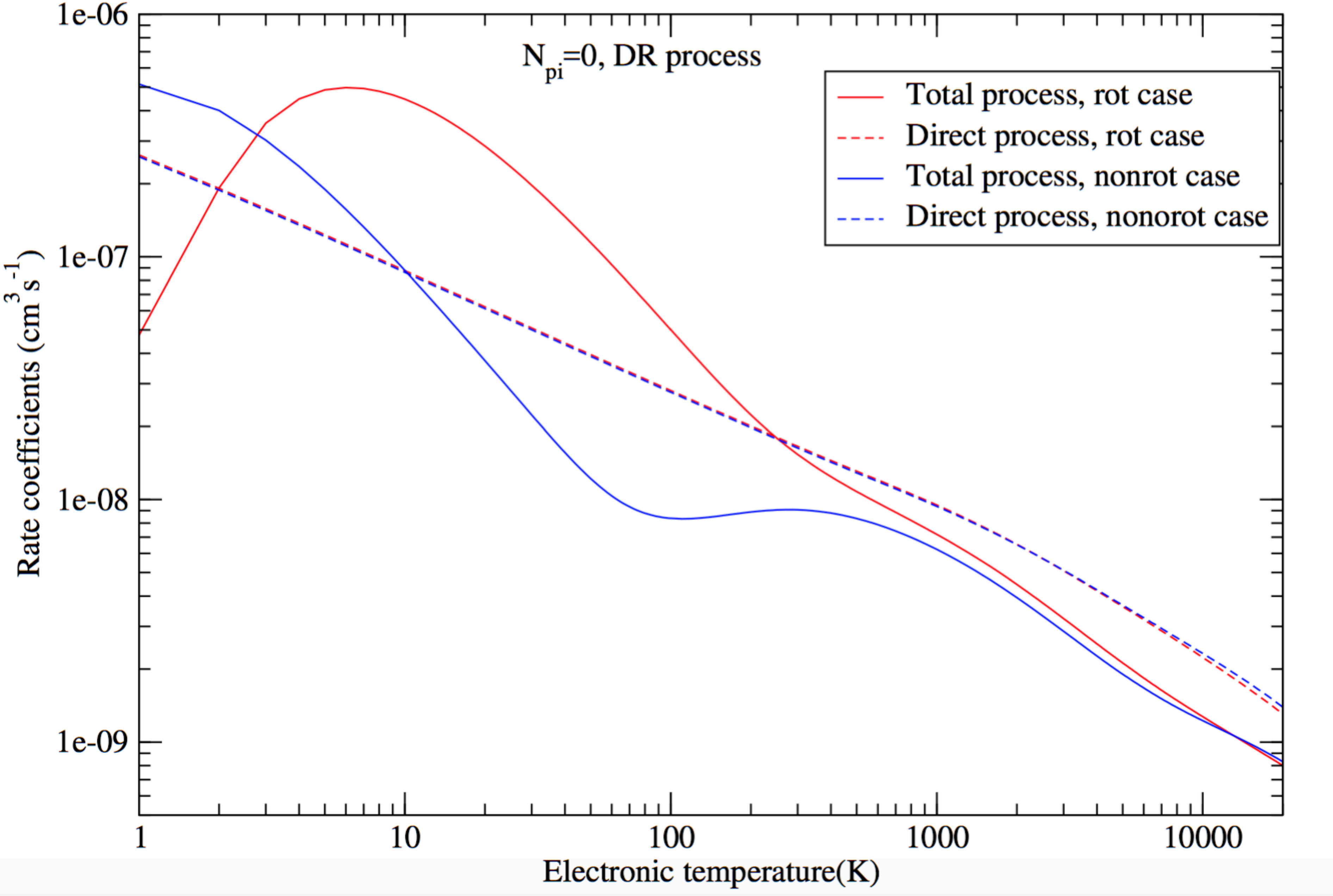


Figure 3. Maxwell rate coefficients for rotational excitation $N_i^+ \rightarrow N_i^+ +$ 2, with $N_i^+ = 0$ to 10 of $H_2^+(X^2\Sigma_g^+)$ on its ground vibrational level $v_i^+ = 0$.

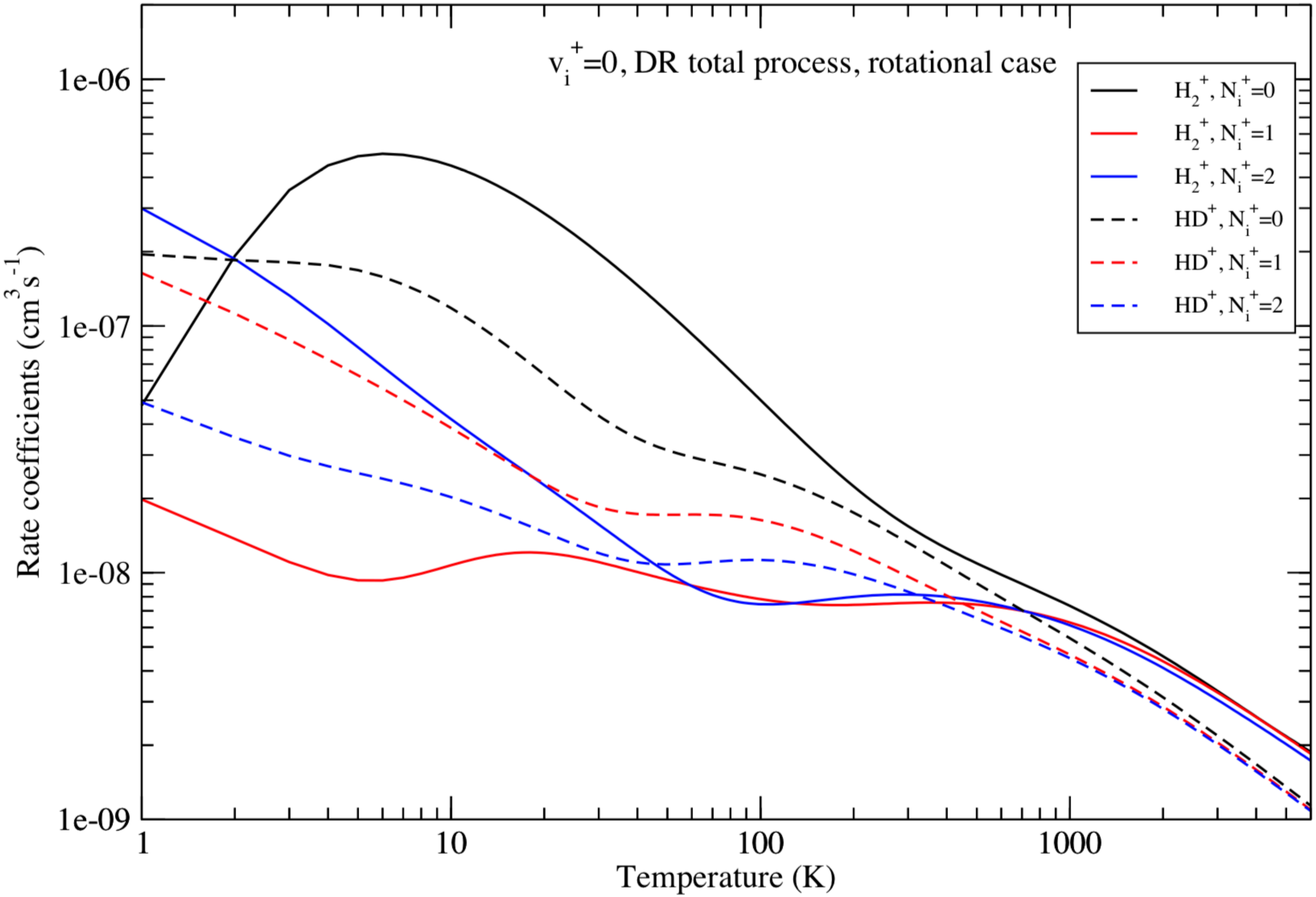
How important are the RESONANCES ?

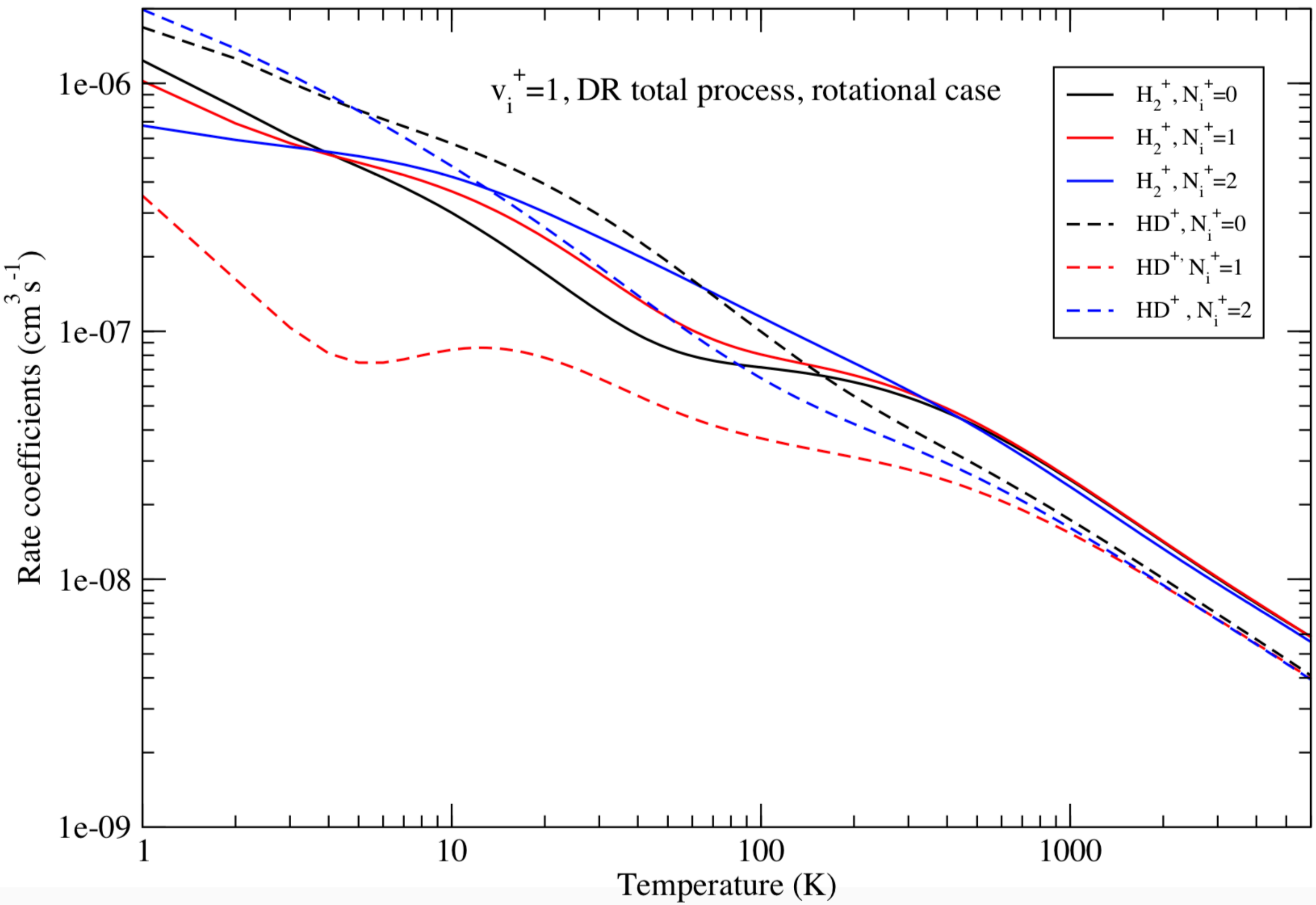
How important are the ROTATIONAL effects ?

$H_2^+(N_i^+=0)+e^- \longrightarrow H_2^{**}, H_2^* \longrightarrow H+H$



Focus on ISOTOPIC effects


v_i^+=0, DR total process, rotational case
H_2^+, N_i^+=0
H_2^+, N_i^+=1
H_2^+, N_i^+=2
HD^+, N_i^+=0
HD^+, N_i^+=1
HD^+, N_i^+=2
Rate coefficients ($cm^3 s^{-1}$)
Temperature (K)
1e-06
1e-07
1e-08
1e-09
1
10
100
1000


v_i^+=1, DR total process, rotational case
H_2^+, N_i^+=0
H_2^+, N_i^+=1
H_2^+, N_i^+=2
HD^+, N_i^+=0
HD^+, N_i^+=1
HD^+, N_i^+=2
Rate coefficients ($cm^3 s^{-1}$)
1e-06
1e-07
1e-08
1e-09
1
10
100
1000
Temperature (K)

HD^+ DR & rovibrational transitions for « ALL » the rovibrational levels

Table 1. The energy of the first 30 ro-vibrational levels of HD^+ $X^1\Sigma_g^+$ electronic state relative to the ground $(N_i^+, v_i^+) = (0, 0)$ level.

no	(N_i^+, v_i^+)	energy(eV)	no	(N_i^+, v_i^+)	energy(eV)
1	(0,0)	0.0000	16	(4,1)	0.289
2	(1,0)	0.0054	17	(5,1)	0.314
3	(2,0)	0.0163	18	(11,0)	0.337
4	(3,0)	0.0325	19	(6,1)	0.344
5	(4,0)	0.0539	20	(7,1)	0.379
6	(5,0)	0.0804	21	(12,0)	0.394
7	(6,0)	0.112	22	(8,1)	0.418
8	(7,0)	0.148	23	(13,0)	0.455
9	(8,0)	0.189	24	(9,1)	0.461
10	(9,0)	0.234	25	(0,2)	0.462
11	(0,1)	0.237	26	(1,2)	0.467
12	(1,1)	0.242	27	(2,2)	0.477
13	(2,1)	0.253	28	(3,2)	0.492
14	(3,1)	0.268	29	(10,1)	0.508
15	(10,0)	0.284	30	(4,2)	0.511

HD^+ DR & rovibrational transitions for « ALL » the rovibrational levels

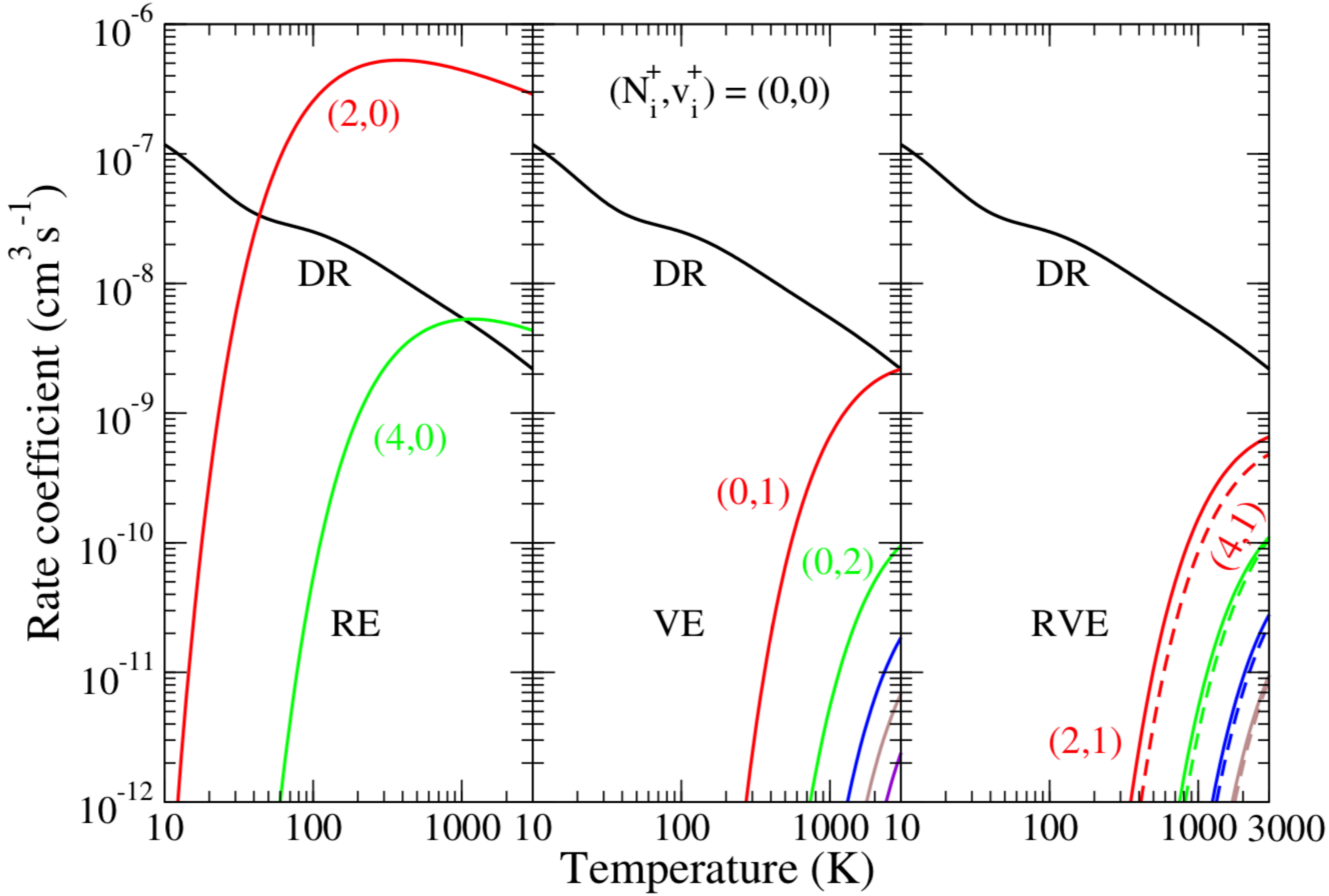


Figure 1. Maxwell rate coefficients of the ground HD $^+(X^2\Sigma_g^+)$ molecular target for Dissociative Recombination (DR) and Rotational Excitation (RE) in the left, DR and Vibrational Excitation (VE) in the middle and DR and mixed Ro-Vibrational Excitations (RVE) in the right panels.

HD^+ DR & rovibrational transitions for « ALL » the rovibrational levels

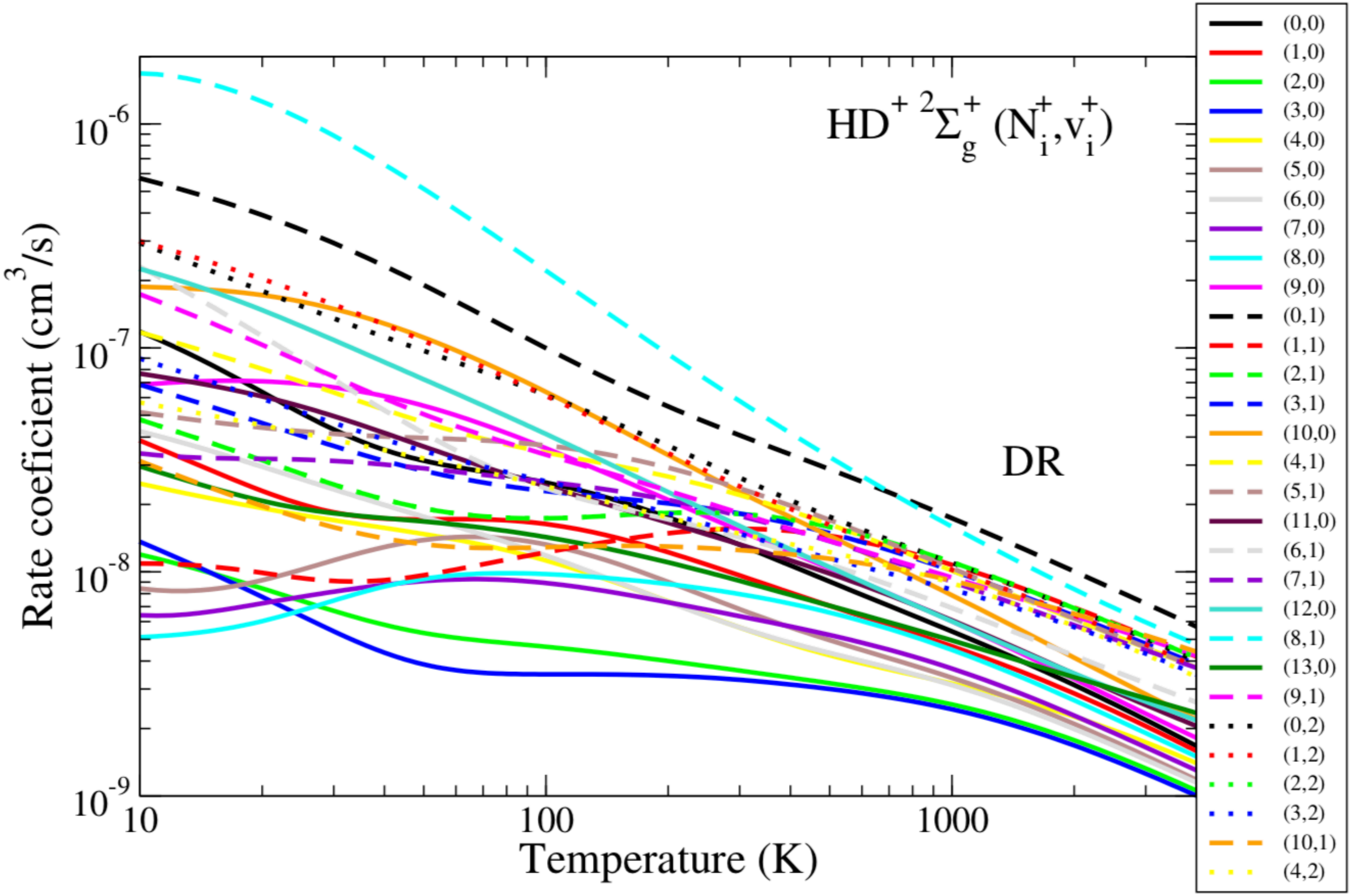


Figure 2. DR Maxwell rate coefficients for the lowest 30 ro-vibrational levels of $HD^+(X^2\Sigma_g^+)$ molecular target.

HD^+ DR & rovibrational transitions for « ALL » the rovibrational levels

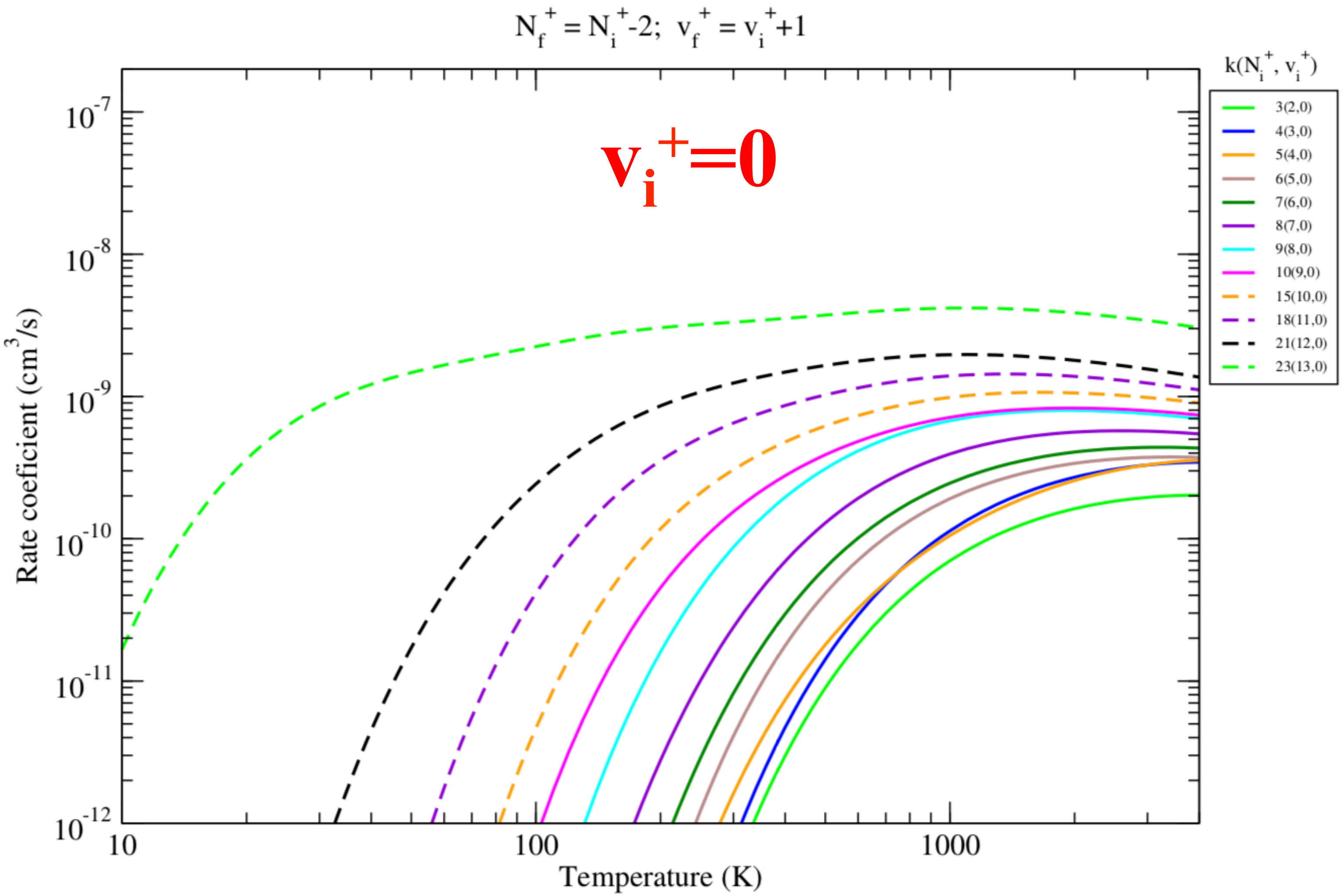


Figure 22. Electron-impact rotational de-excitation ($\Delta N^+ = -2$) and vibrational excitation ($\Delta v^+ = 1$) of HD^+ $[^2\Sigma_g^+ \ (N_i^+, v_i^+ = 0)]$:

HD^+ DR & rovibrational transitions for « ALL » the rovibrational levels

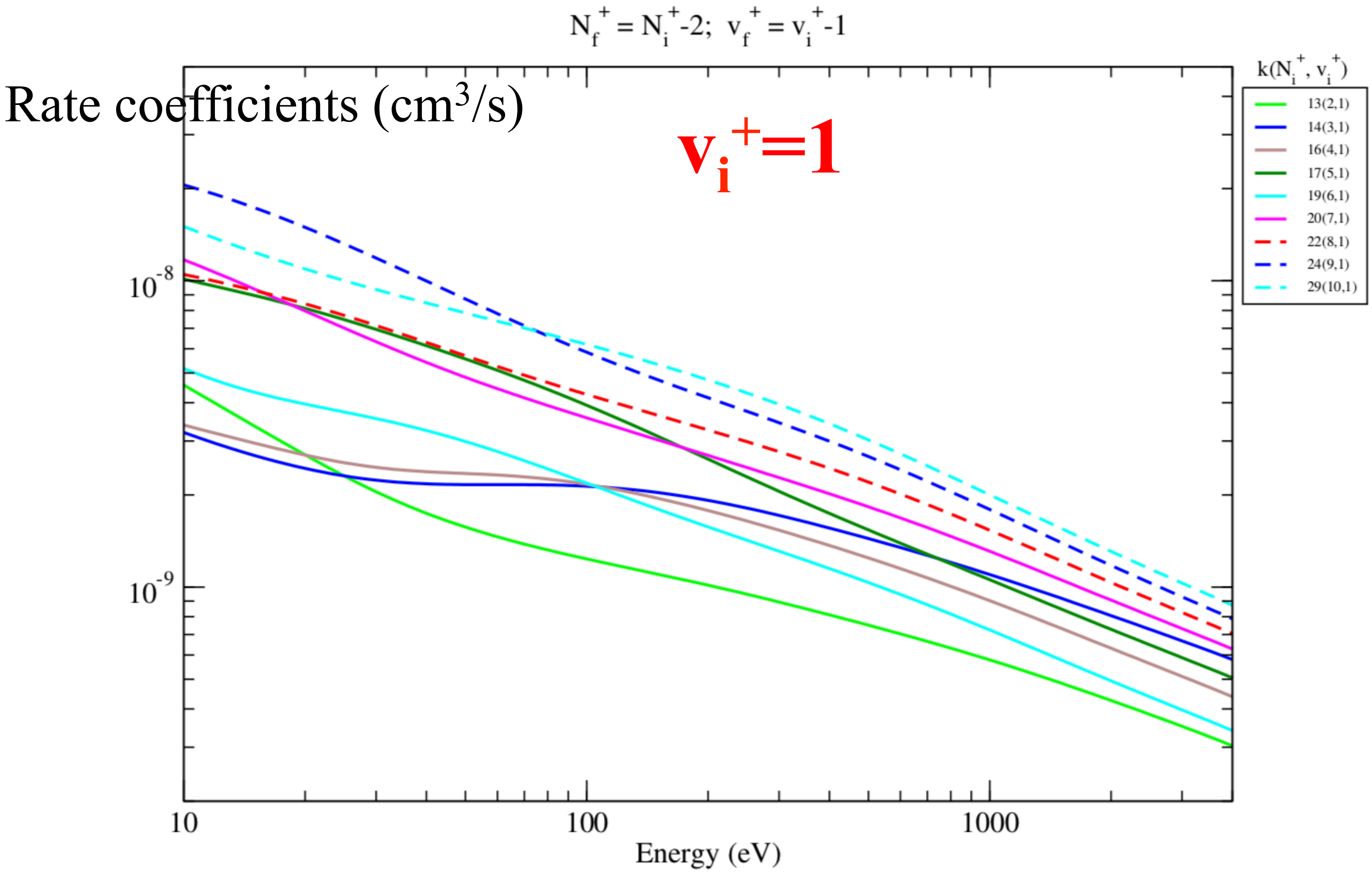


Figure 25. Electron-impact rotational and vibrational de-excitation ($\triangle N_i^+ = -2$, $\triangle v_i^+ = -1$) of HD^+ [$^2\Sigma_g^+$ (N_i^+,v_i^+=1)]: The effect of the ro-vibrational excitation of the target.

D_2^+ DR & rotational transitions for vibrationally relaxed states

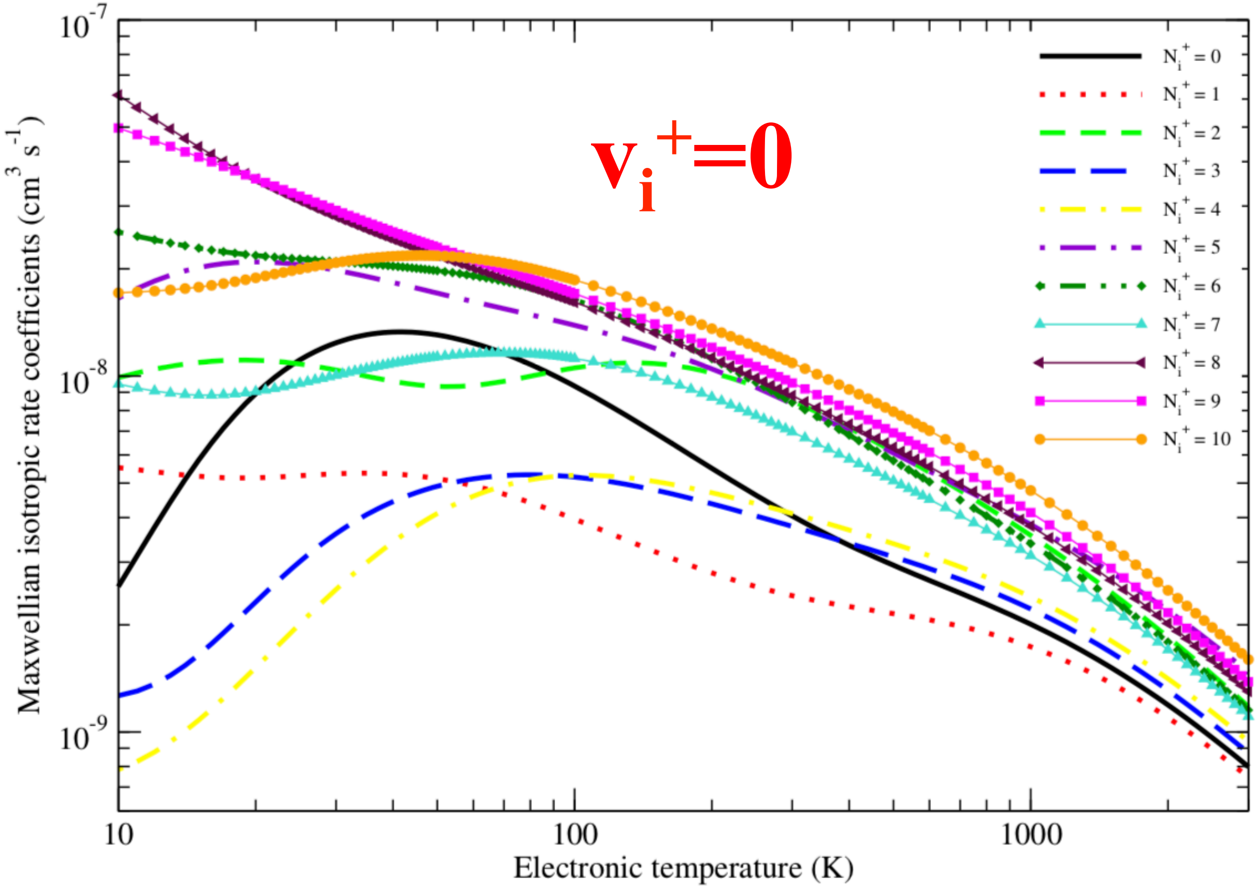
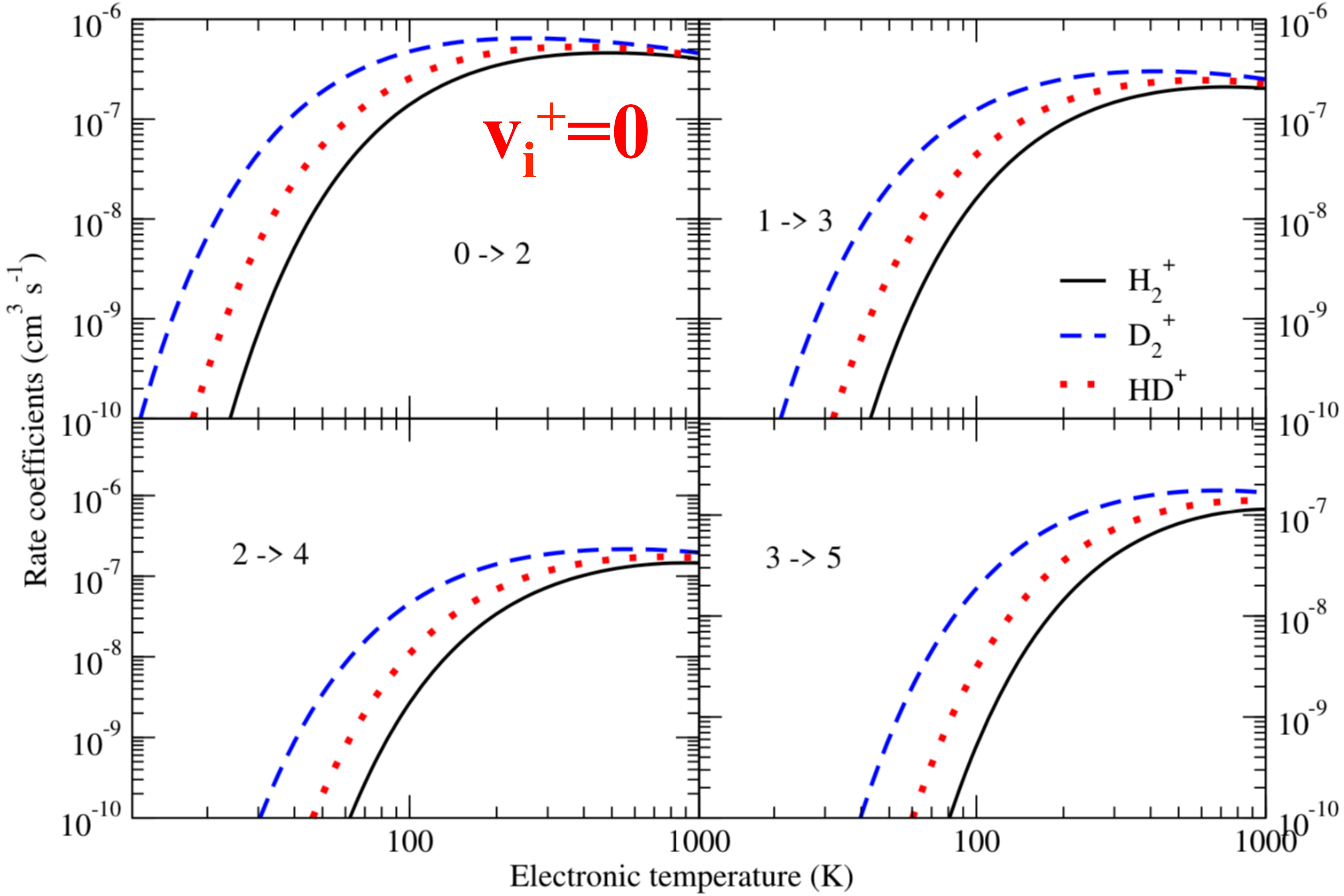
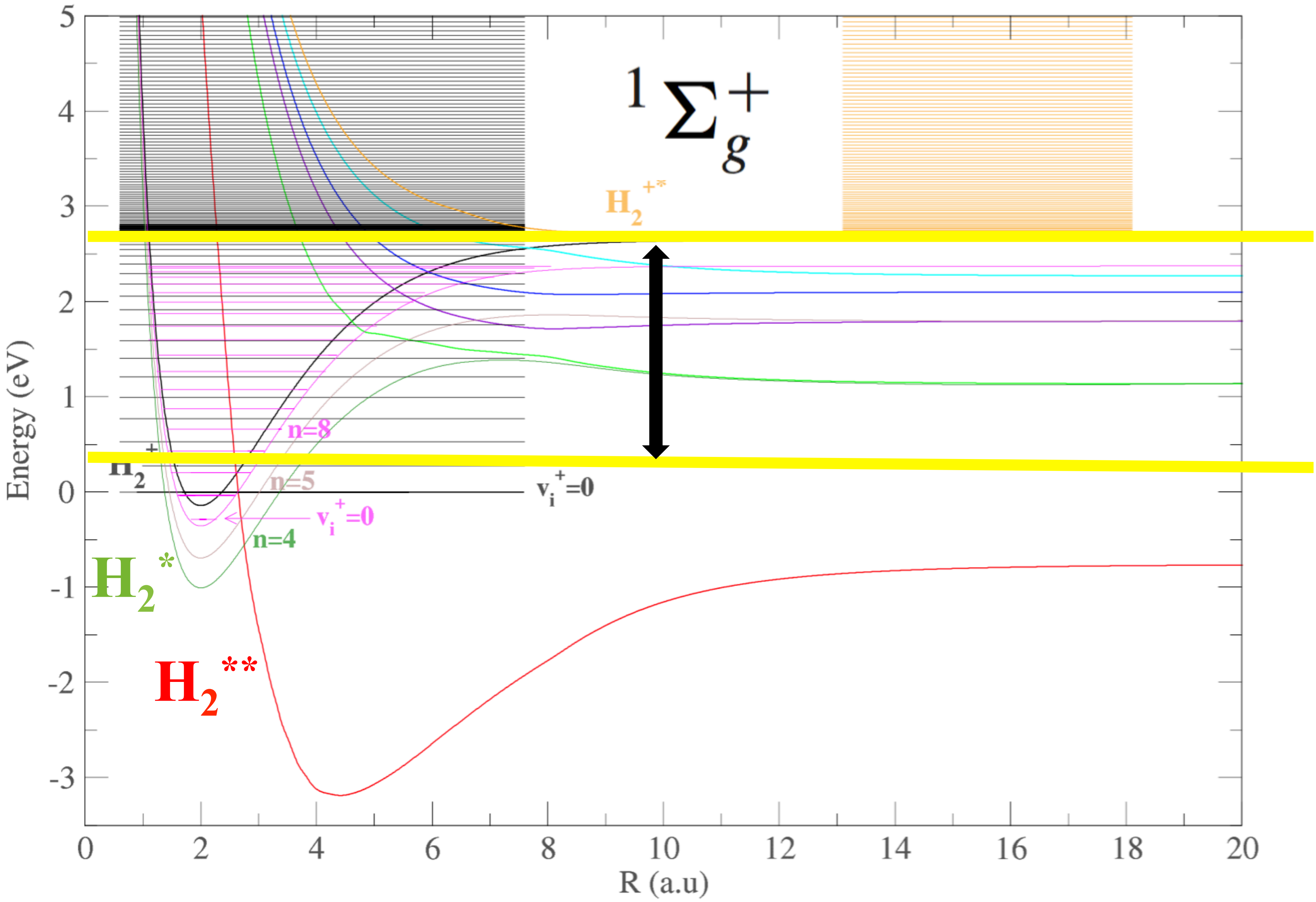


Figure 2. Maxwell rate coefficients for the dissociative recombination of $D_2^+(X^2\Sigma_g^+)$ on its ground vibrational level $v_i^+ = 0$, as a function of its initial rotational level, $N_i^+ = 0$ to 10.

D_2^+ vs HD^+ vs H_2^+: rotational transitions for vibrationally relaxed states

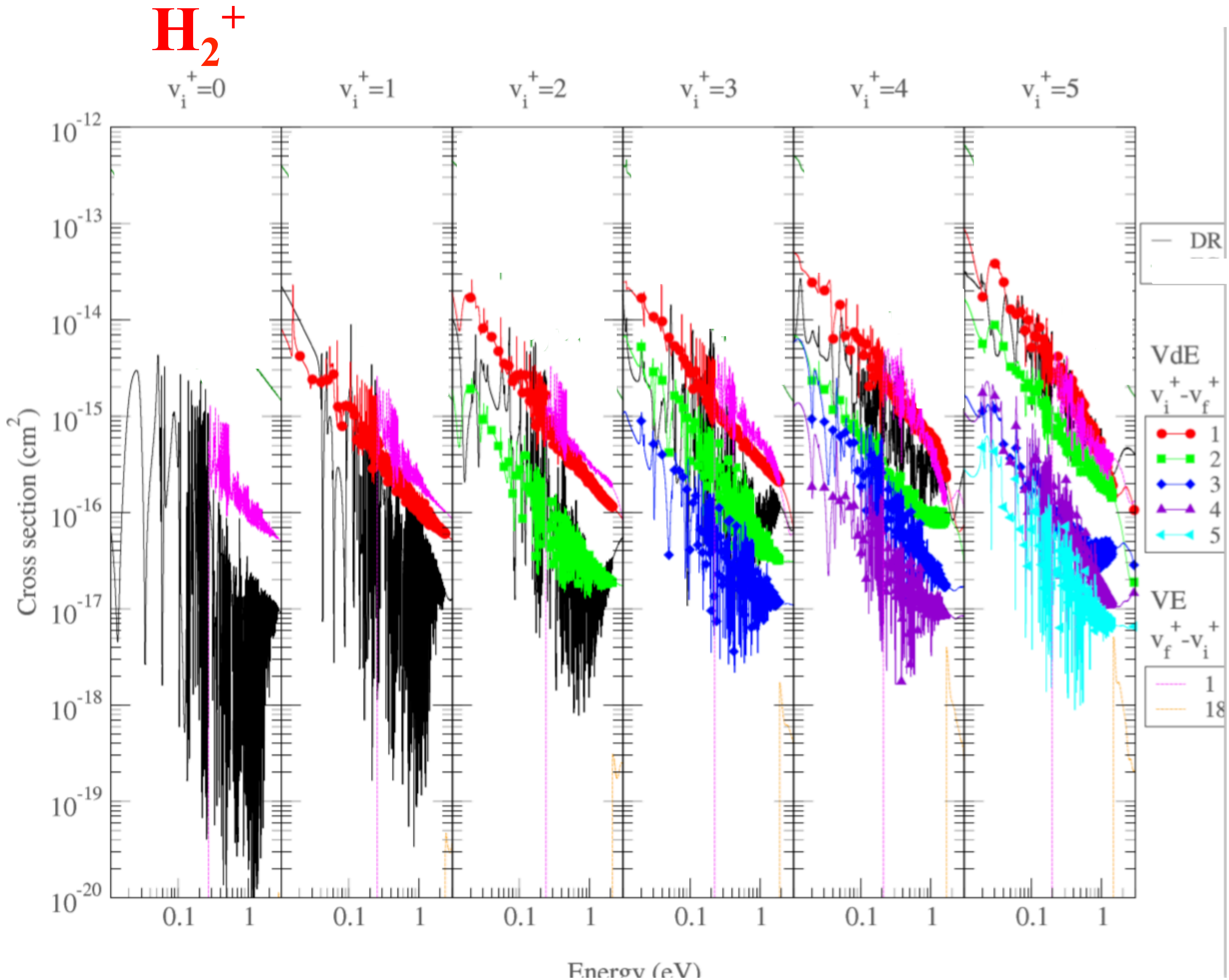


“Moderately” Low Energy:
“NO rotation”,
DISCRETE vibrational spectrum,
“Fano” RESONANCES



Energy (eV)
R (a.u)
$^1\Sigma_g^+$
H_2^{+*}
H_2^+
$v_i^+=0$
n=8
n=5
n=4
$v_i^+=0$
H_2^*
H_2^{**}
5
4
3
2
1
0
-1
-2
-3
0
2
4
6
8
10
12
14
16
18
20

Moulane 2017, Colboc 2016



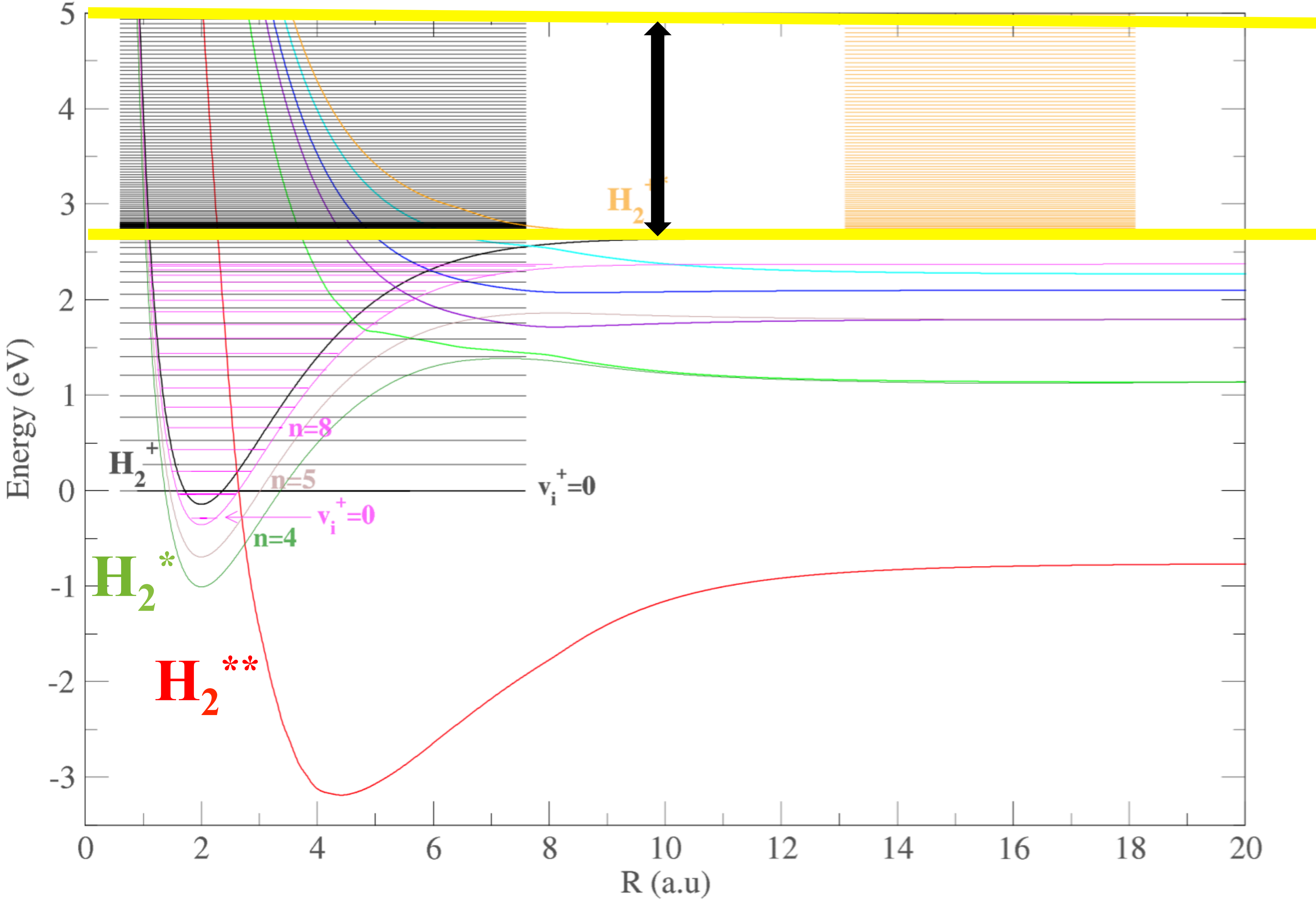
High Energy:

“NO rotation”,

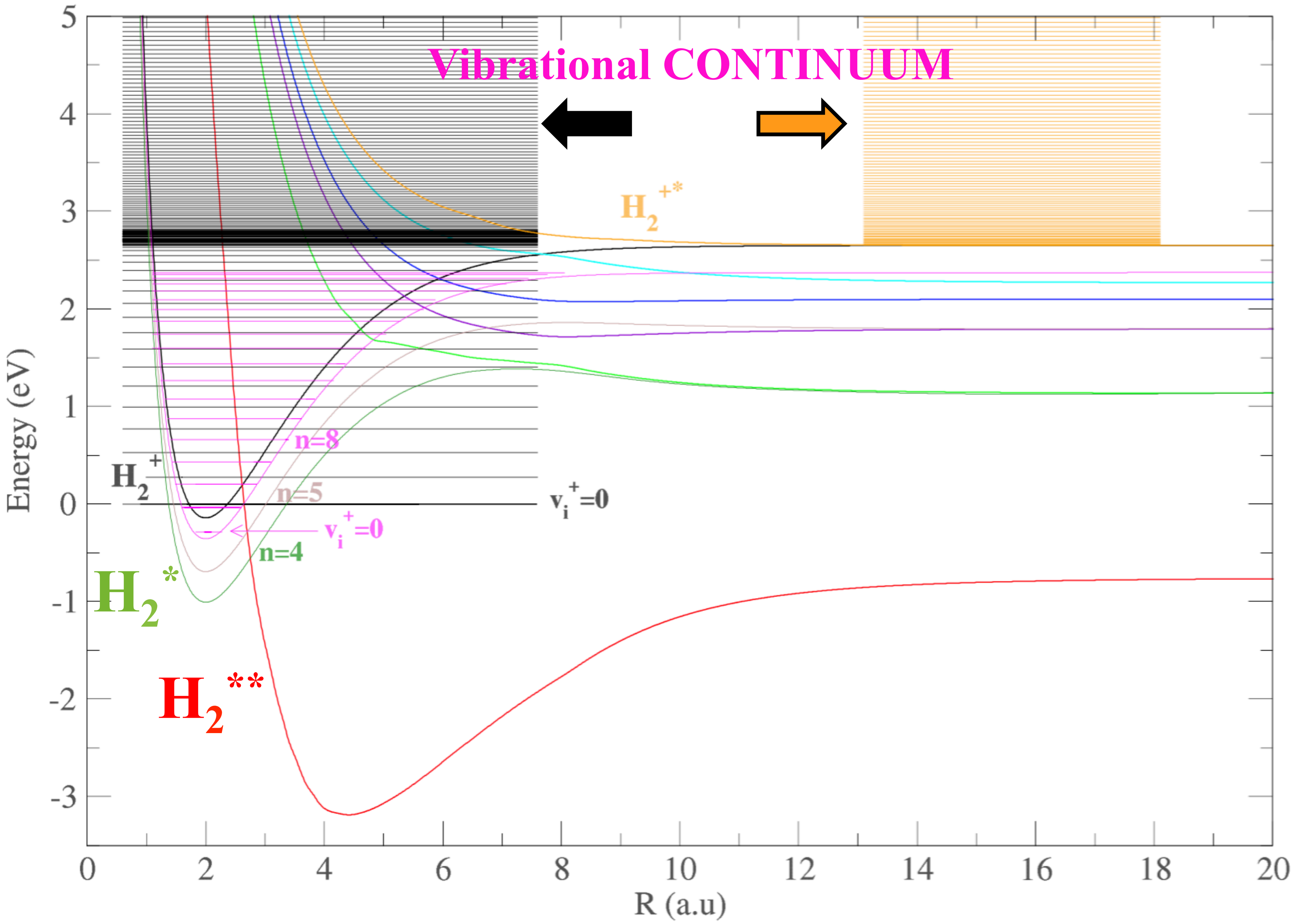
DISCRETE & CONTINUUM

vibrational spectrum,

NO “Fano” RESONANCES



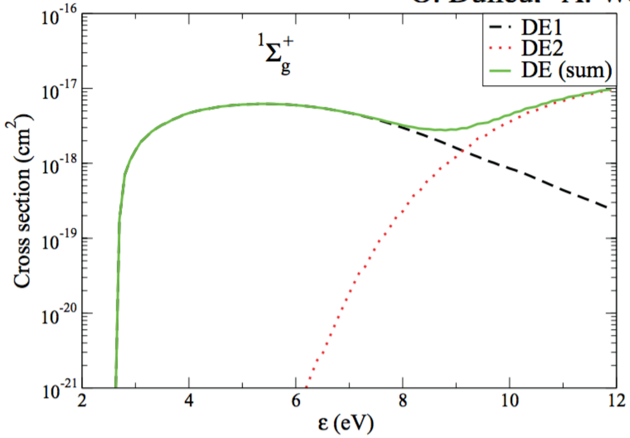
5
4
3
2
1
0
-1
-2
-3
Energy (eV)
0
2
4
6
8
10
12
14
16
18
20
R (a.u)
H2+
H2+
n=8
n=5
n=4
vi+=0
vi+=0
H2*
H2**

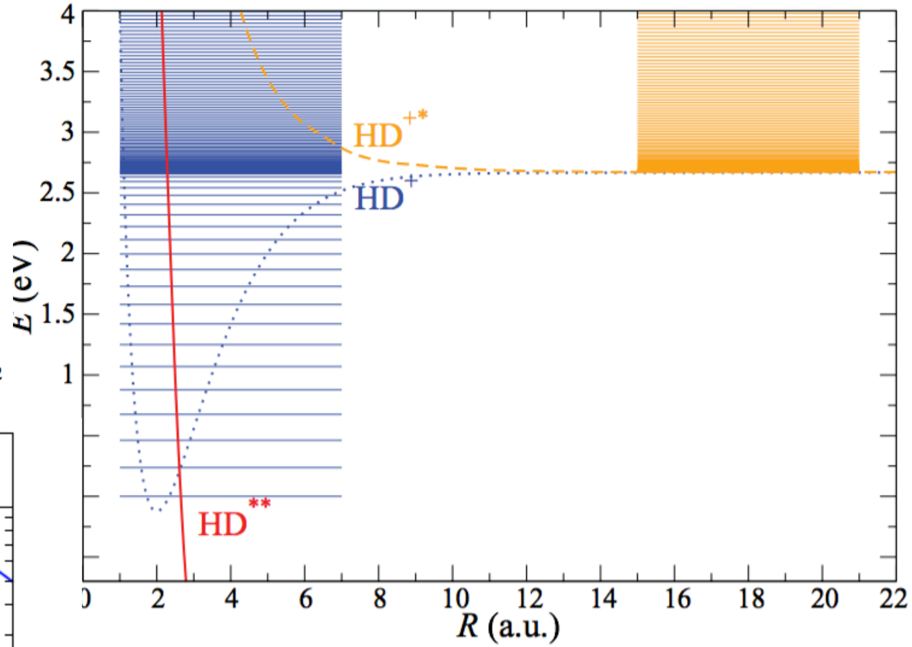

Vibrational CONTINUUM
Energy (eV)
R (a.u)
H2+*
H2+
H2*
H2**
n=8
n=5
n=4
vi+=0
vi+=0
5
4
3
2
1
0
-1
-2
-3
0
2
4
6
8
10
12
14
16
18
20

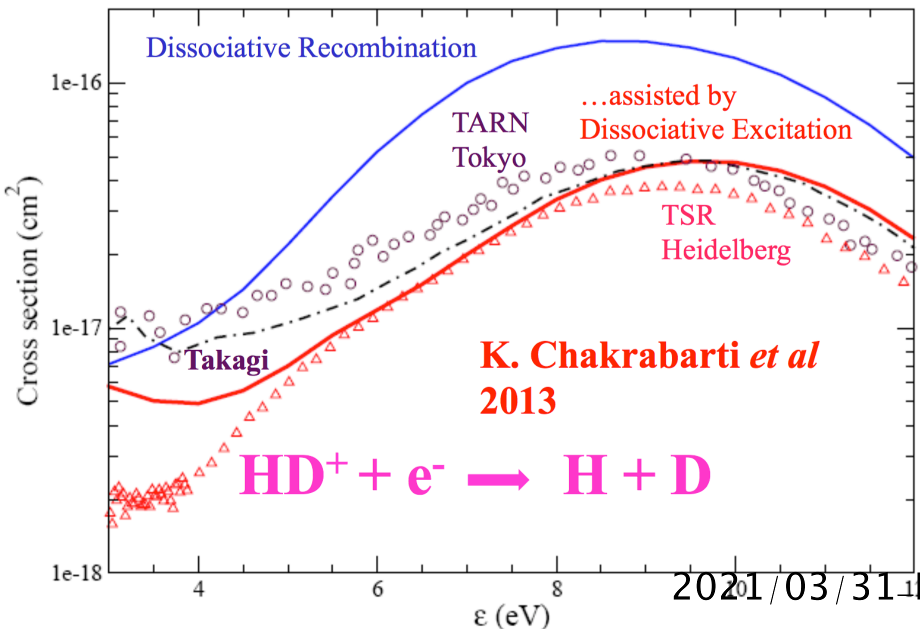
PHYSICAL REVIEW A **87**, 022702 (2013)

Dissociative recombination of electrons with diatomic molecular cations above dissociation threshold: Application to H_2^+ and HD^+

K. Chakrabarti,[1,2] D. R. Backodissa-Kiminou,[1] N. Pop,[3] J. Zs. Mezei,[1,4,5] O. Motapon,[6] F. Lique,[1]
O. Dulieu.[4] A. Wolf,[7] and I. F. Schneider[1]

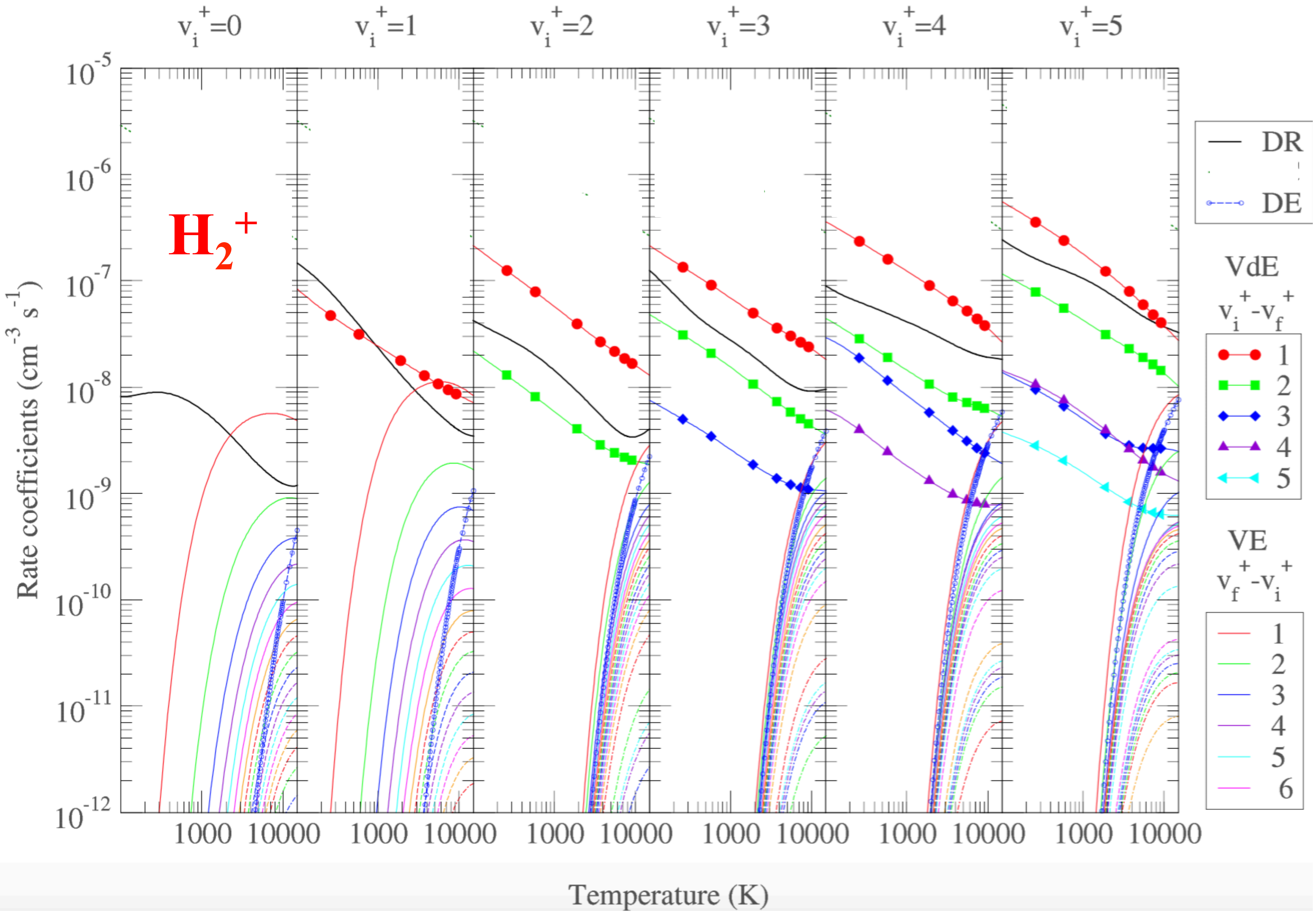




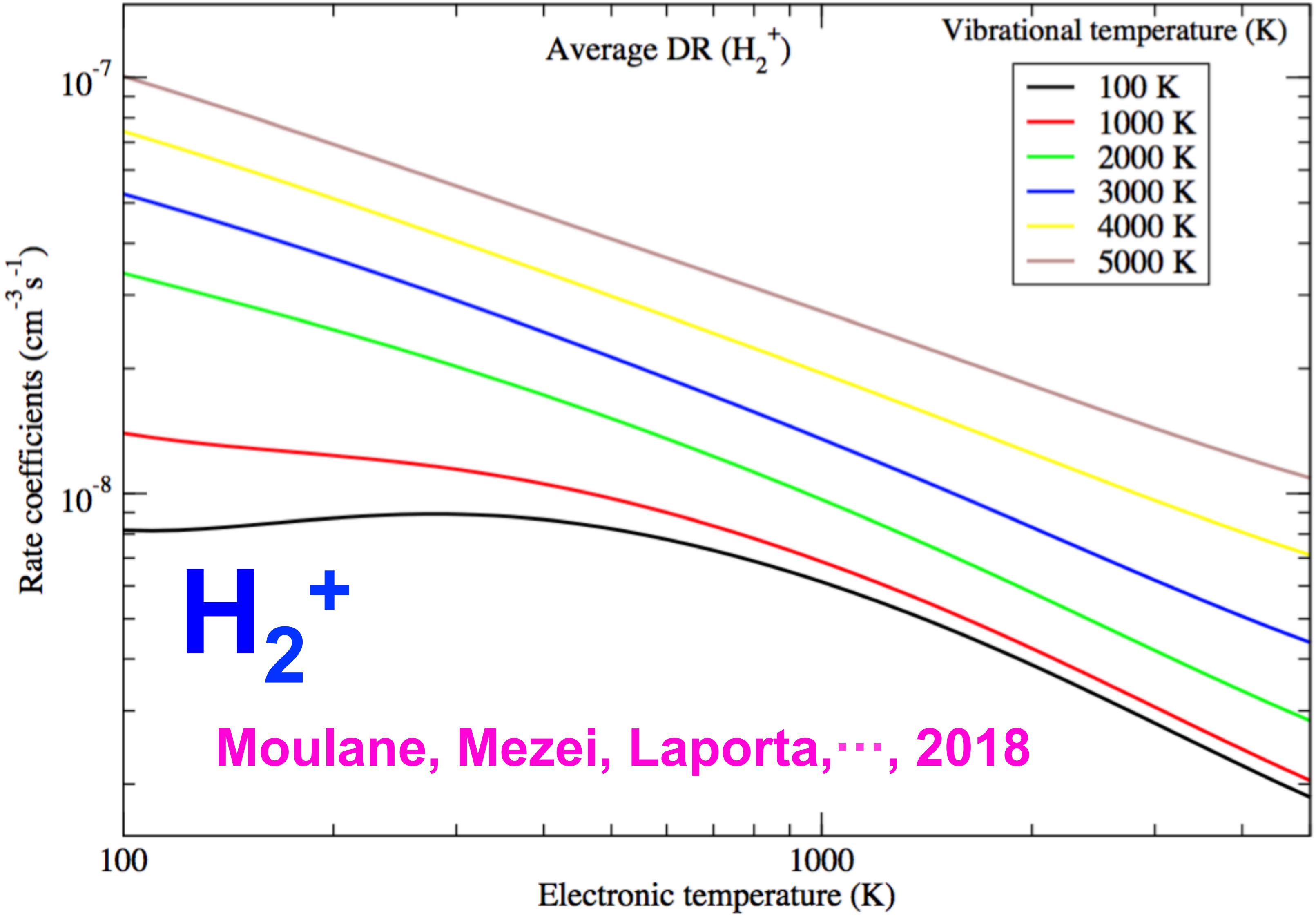


HIGH energy:
vibrational continuum
effective, Dissociative Excitation

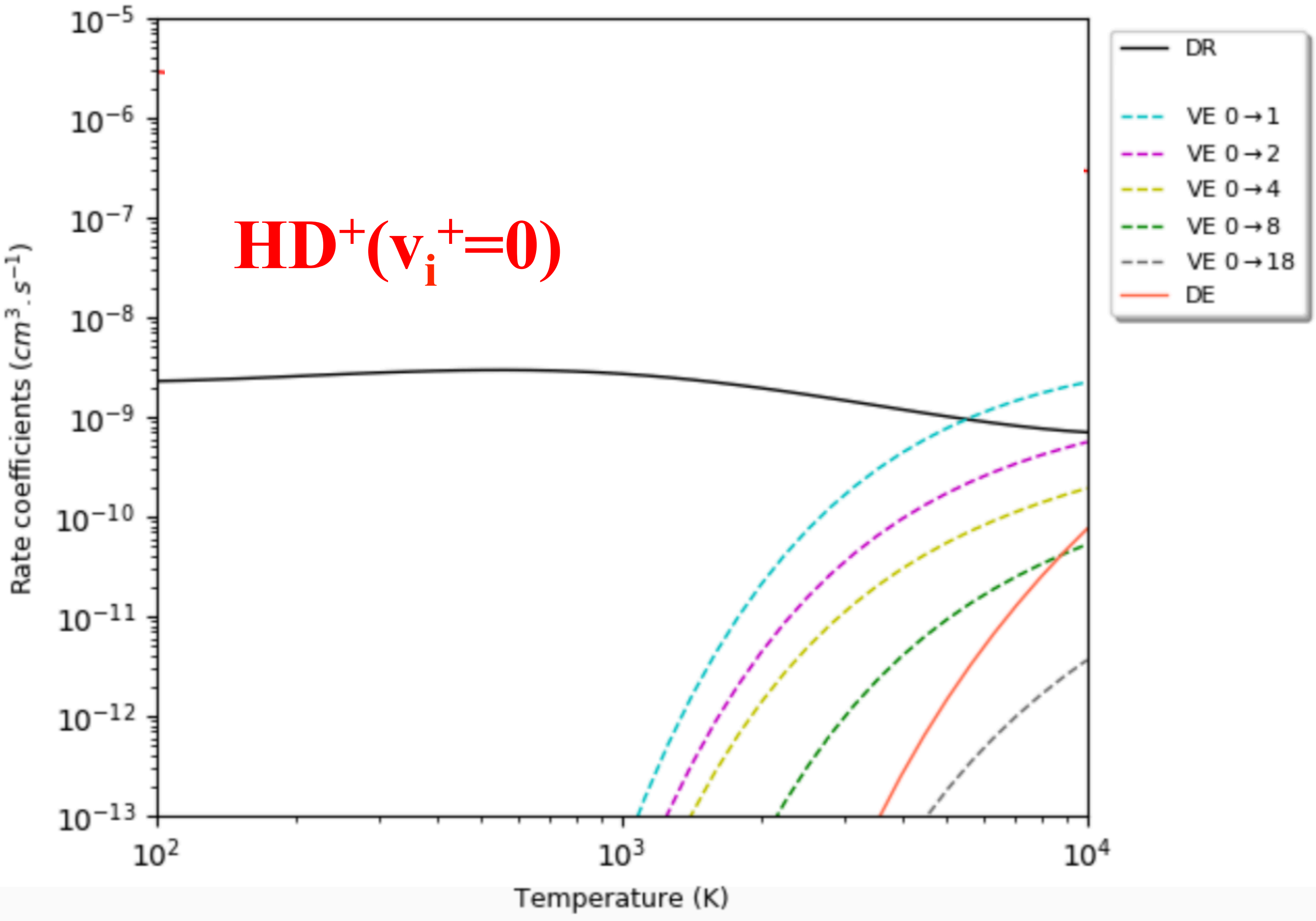
Moulane 2017



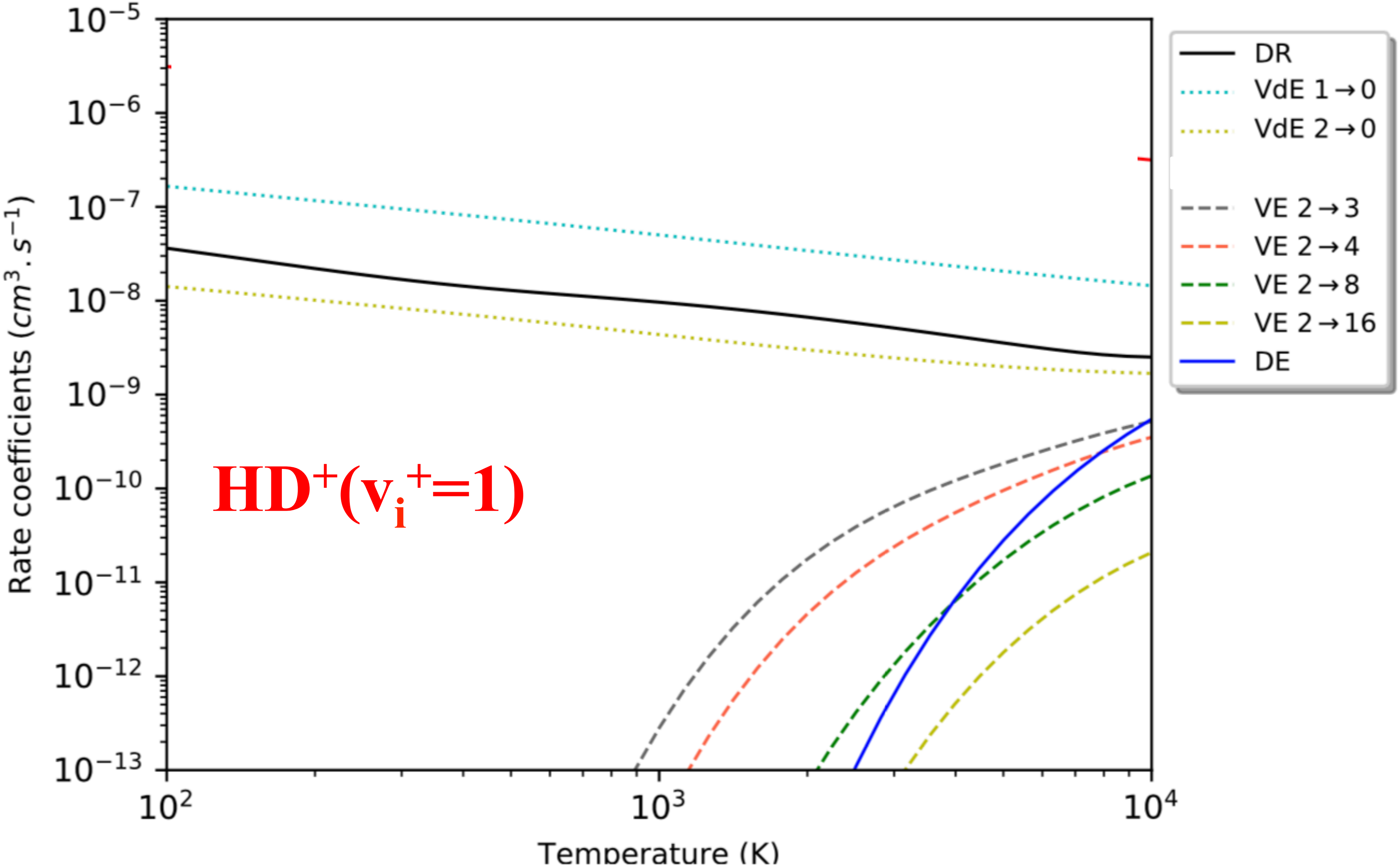
Rate coefficients depending on T_e and T_v



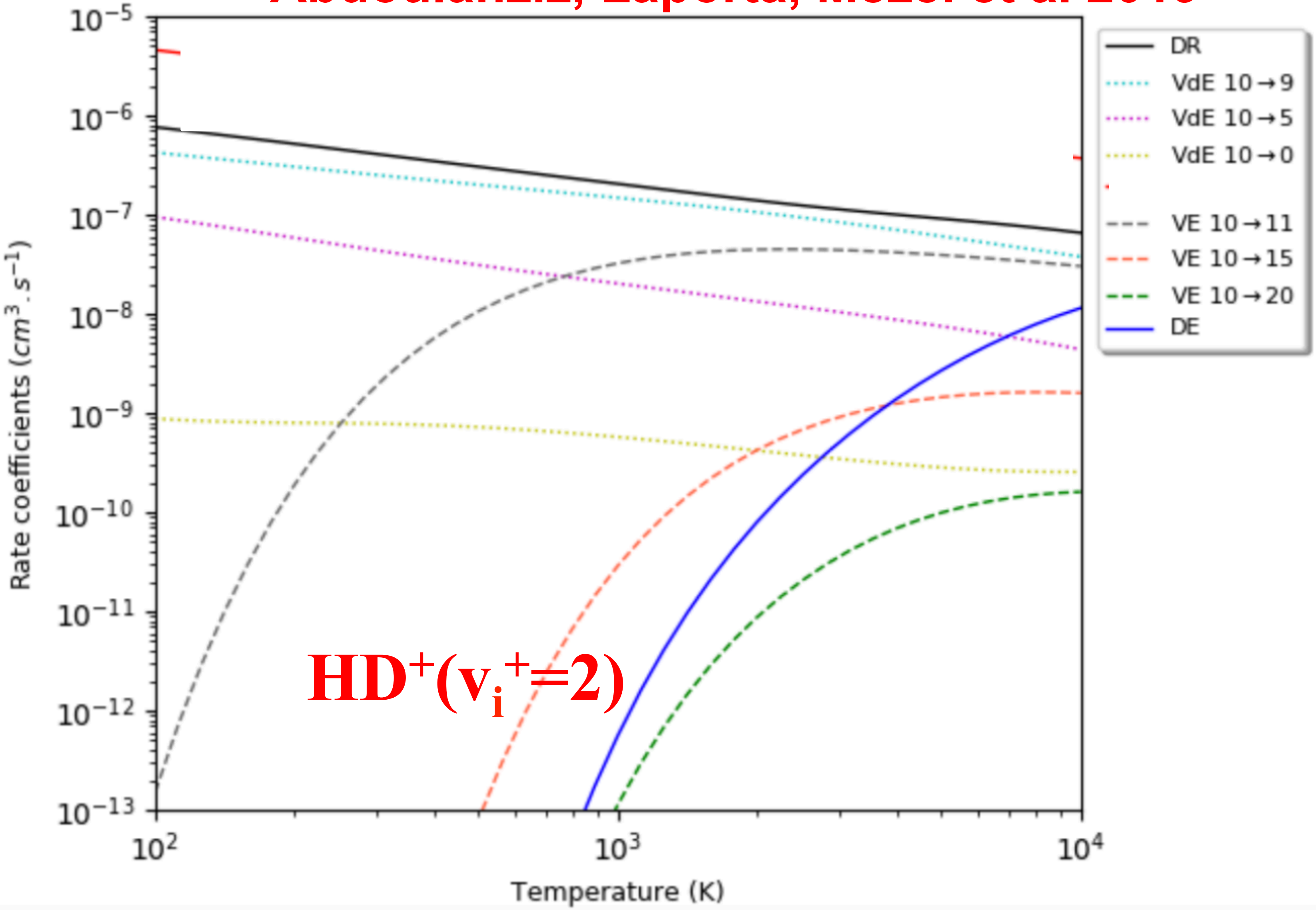
Abdoulanziz, Laporta, Mezei et al 2019



Abdoulanziz, Laporta, Mezei et al 2019

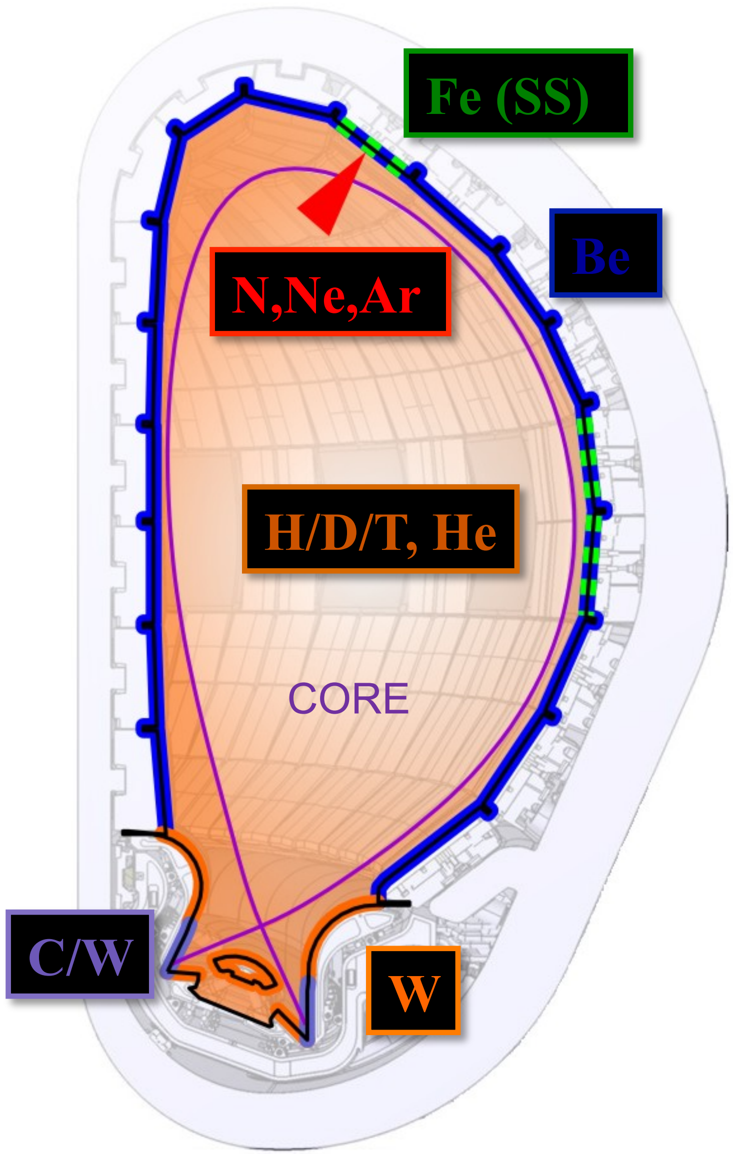


Abdoulanziz, Laporta, Mezei et al 2019



HYDRIDES !

List of the main elements relevant to the ITER plasma (D. Reiter)



BeH$^+$ + e$^-$

Atomic Data and Nuclear Data Tables 115–116 (2017) 287–308

Contents lists available at ScienceDirect

Atomic Data and Nuclear Data Tables

journal homepage: www.elsevier.com/locate/adt

ELSEVIER

2017

Low-energy collisions between electrons and BeH$^+$: Cross sections and rate coefficients for all the vibrational states of the ion

CrossMark

S. Niyonzima [a,b], S. Ilie [a,c], N. Pop [a,c], J. Zs. Mezei [a,d,e,f], K. Chakrabarti [g], V. Morel [h], B. Peres [h], D.A. Little [i], K. Hassouni [d], Å. Larson [j], A.E. Orel [k], D. Benredjem [e], A. Bultel [h], J. Tennyson [i], D. Reiter [l], I.F. Schneider [a,e,*]

IOP Publishing

Plasma Physics and Controlled Fusion

Plasma Phys. Control. Fusion 59 (2017) 045008 (10pp)

https://doi.org/10.1088/1361-6587/aa5c56

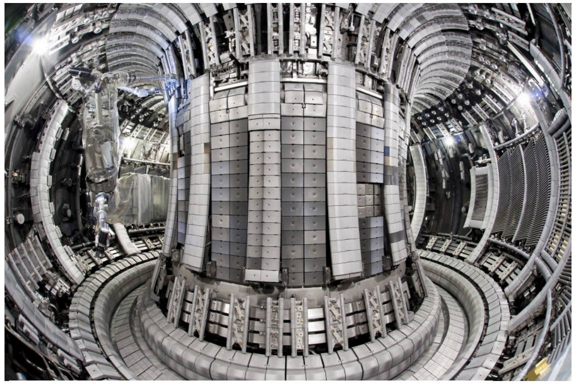
2017

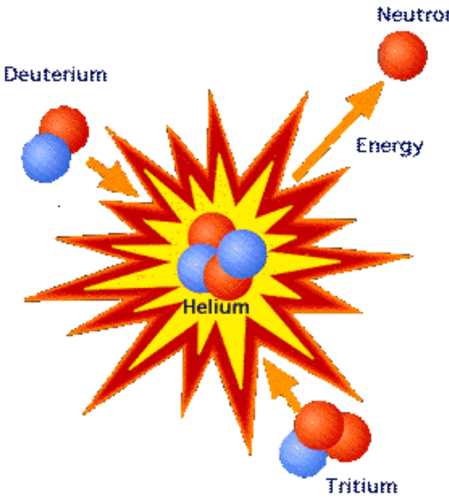
Theoretical resonant electron-impact vibrational excitation, dissociative recombination and dissociative excitation cross sections of ro-vibrationally excited BeH$^+$ ion

V Laporta[1,2], K Chakrabarti[3], R Celiberto[1,4], R K Janev[5], J Zs Mezei[6,7,8,9], S Niyonzima[6,10], J Tennyson[2] and I F Schneider[6,8]

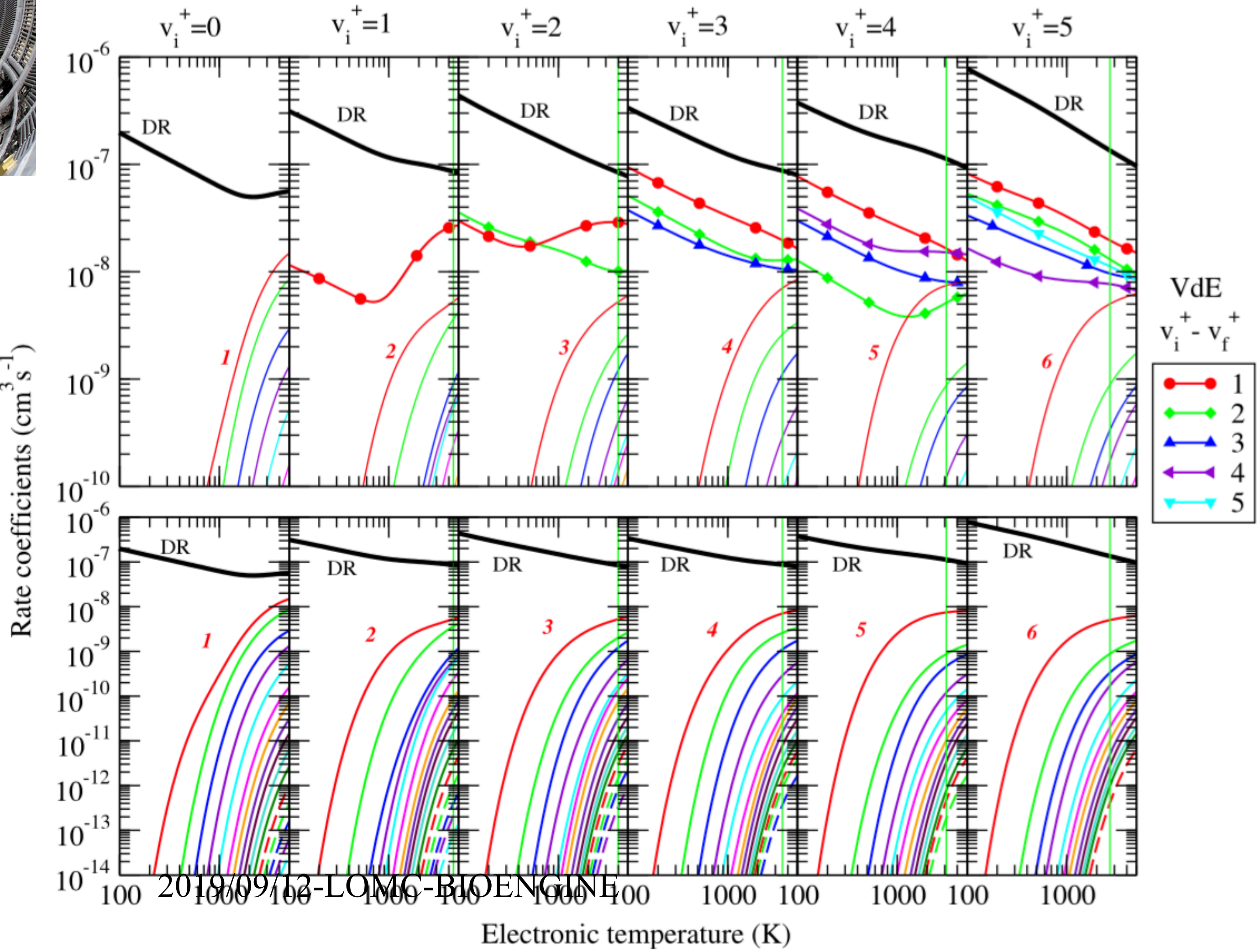
$BeH^+ + e^-$

2017





Neutron
Deuterium
Energy
Helium
Tritium



$v_i^+=0$
$v_i^+=1$
$v_i^+=2$
$v_i^+=3$
$v_i^+=4$
$v_i^+=5$
DR
Rate coefficients ($cm^3 s^{-1}$)
Electronic temperature (K)
VdE
$v_i^+ - v_f^+$
1
2
3
4
5

$BeD^+ + e^-$

2018

N. Pop, S. Niyonzima, J. Zs. Mezei, …

Plasma Sources Sci. Technol. **27** (2018) 025015 (10pp) https://doi.org/10.1088/1361-6595/aaabef

Low-energy collisions between electrons and BeD^+

S Niyonzima[1,2], N Pop[3], F Iacob[4], Å Larson[5], A E Orel[6], J Zs Mezei[2,7,8], K Chakrabarti[9], V Laporta[2,10], K Hassouni[7], D Benredjem[11], A Bultel[12], J Tennyson[10], D Reiter[13] and I F Schneider[2,11]

$BeT^+ + e^-$

2021

ARTICLE IN PRESS

Atomic Data and Nuclear Data Tables xxx (xxxx) xxx

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/adt

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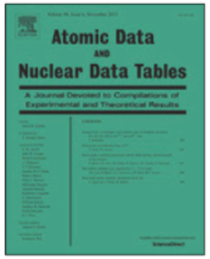
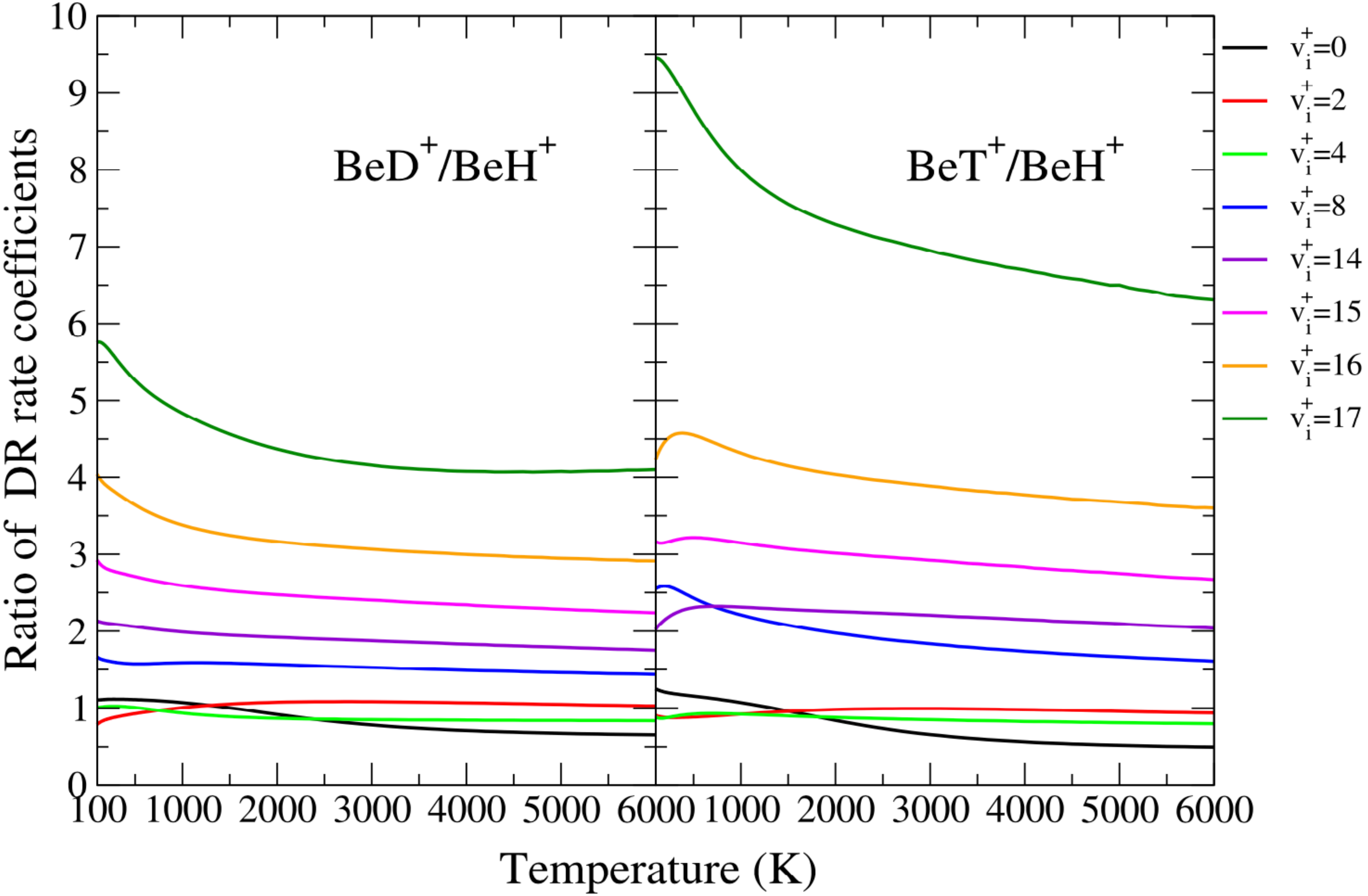
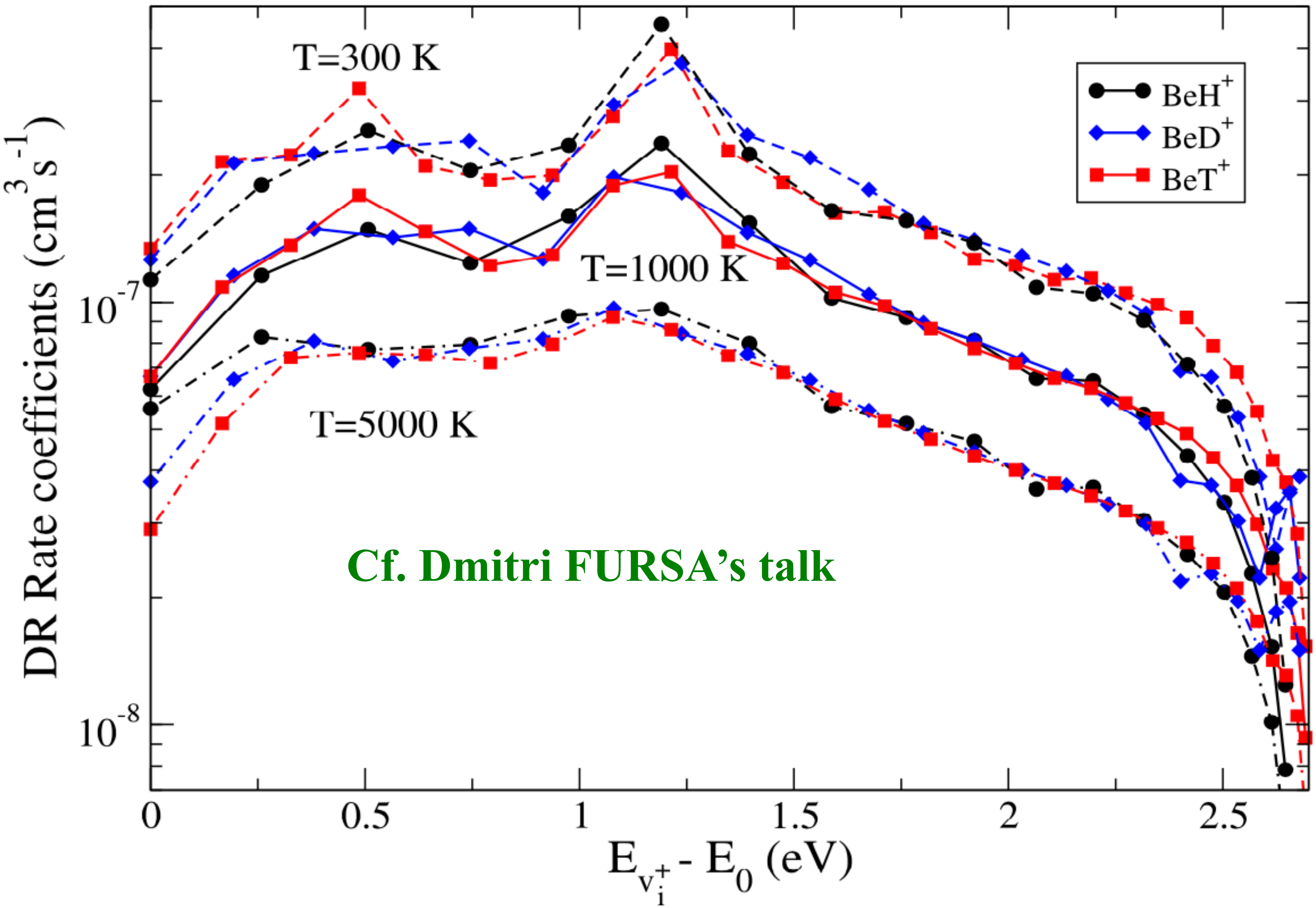


Reactive collisions between electrons and BeT^+: Complete set of thermal rate coefficients up to 5000 K

N. Pop [a], F. Iacob [b,*], S. Niyonzima [c], A. Abdoulanziz [d], V. Laporta [e], D. Reiter [f], I.F. Schneider [d,g], J.Zs. Mezei [d,h]



Ratio of DR rate coefficients
Temperature (K)
BeD+/BeH+
BeT+/BeH+
v+i=0
v+i=2
v+i=4
v+i=8
v+i=14
v+i=15
v+i=16
v+i=17
0
1
2
3
4
5
6
7
8
9
10
100
1000
2000
3000
4000
5000
6000


DR Rate coefficients (cm3 s-1)
10-7
10-8
0
0.5
1
1.5
2
2.5
Ev+i - E0 (eV)
T=300 K
T=1000 K
T=5000 K
BeH+
BeD+
BeT+
Cf. Dmitri FURSA's talk

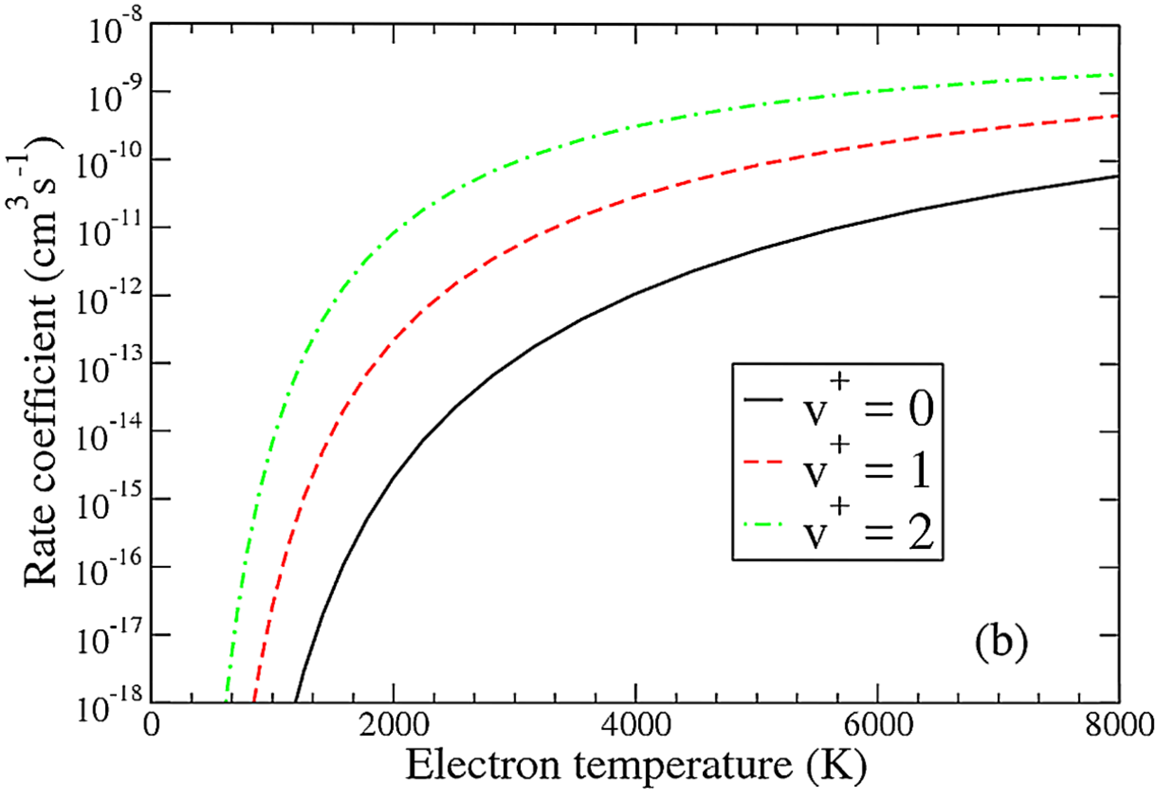
Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **479,** 2415–2420 (2018)
Advance Access publication 2018 June 12
doi:10.1093/mnras/sty1549

V. Laporta, A. Abdoulanziz,
E. Roueff,⋯

Theoretical study of ArH^+ dissociative recombination and electron-impact vibrational excitation

A. Abdoulanziz,[1] F. Colboc,[1] D. A. Little,[2] Y. Moulane,[3,4] J. Zs. Mezei,[1,5,6] E. Roueff,[7] J. Tennyson,[2] I. F. Schneider[1,8] and V. Laporta[1,2★]



$ArH^+ + e^-$
2018

E. Djuissi, V. Laporta, et al
2019-2021

$ArH^{+} + e^{-}$

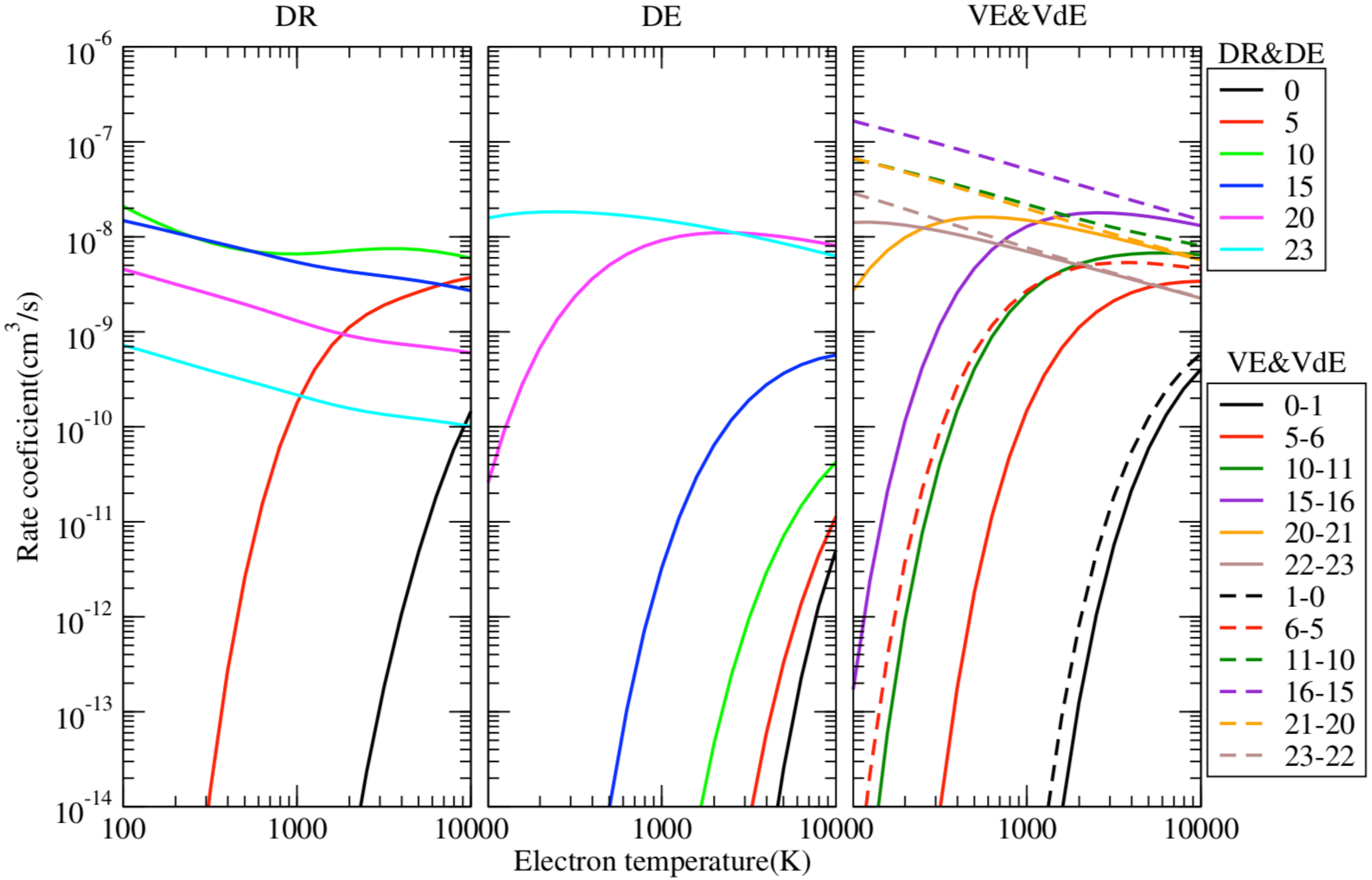
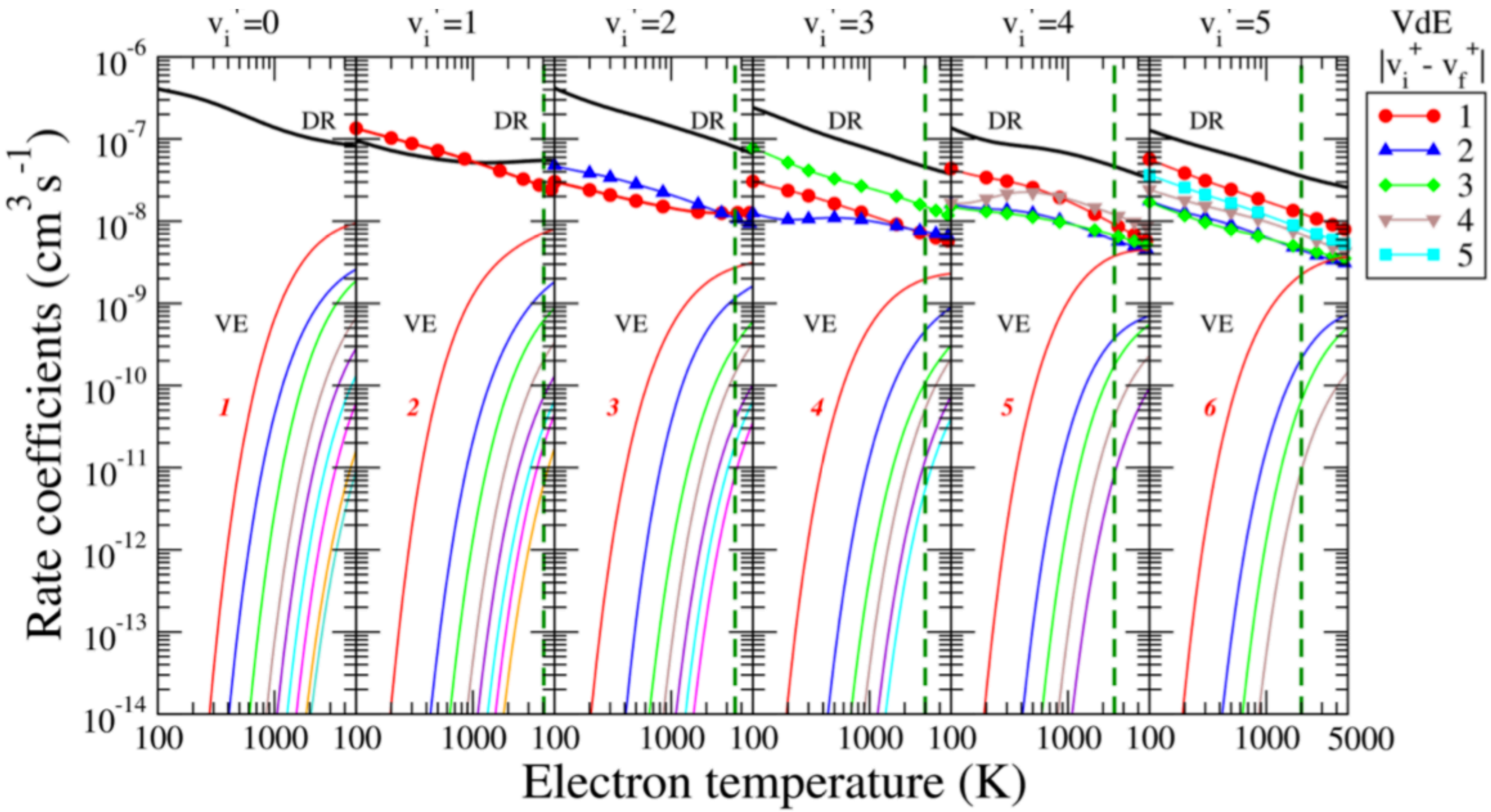


FIG. 3: Rate coeficient curves of the dissociative recombinaison and the competitve process (DE, EC, VE and VdE)

A. Abdoulaziz, J. Zs. Mezei, et al
2021

$N_2^+ + e^-$



What about
WH^+ ? $W_mX_n^+$?

CONCLUSIONS

Temporary captures into super-excited states:
HUGE RESONANT EFFECTS

Dependence of the cross section and
rate coefficients on the
INITIAL ro-vibrational level:
STRONG

We provide STATE-TO-STATE
cross sections & rate coefficients

SUPORT

AGENCE NATIONALE DE LA RECHERCHE ANR

IAEA
International Atomic Energy Agency
Atoms For Peace

REGION HAUTE NORMANDIE

ADAS
Atomic Data and Analysis Structure

INSTITUT Energie Fluides Environnement iefe

FR FCM
Fédération de Recherche
Fusion par Confinement Magnétique - ITER

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PicoLIBS (2014-2018)

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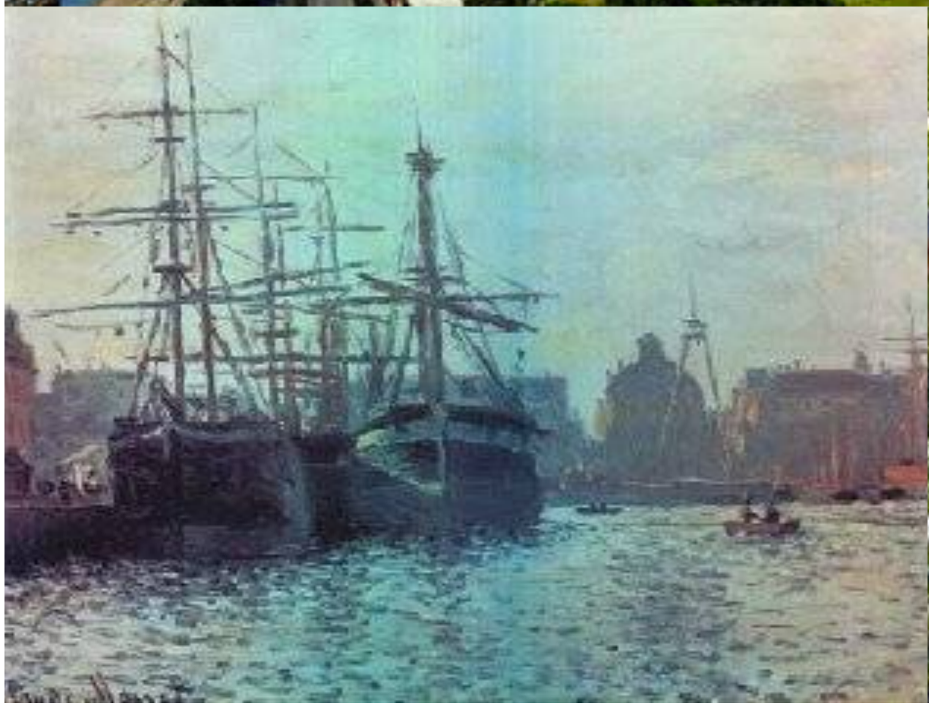
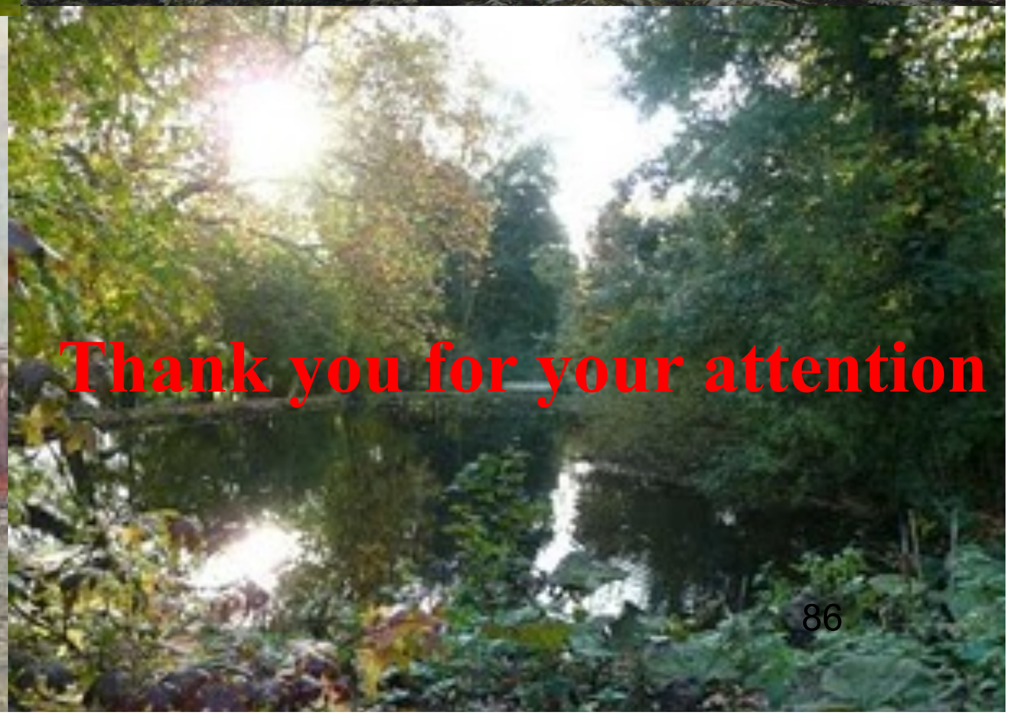
RIN-VIRIDIS-CO2 (2018-2019)

RÉGION NORMANDIE

PCMI/INSU (2018-2020)


1 16:30




Thank you for your attention