Direct detection of dark matter through molecular excitations

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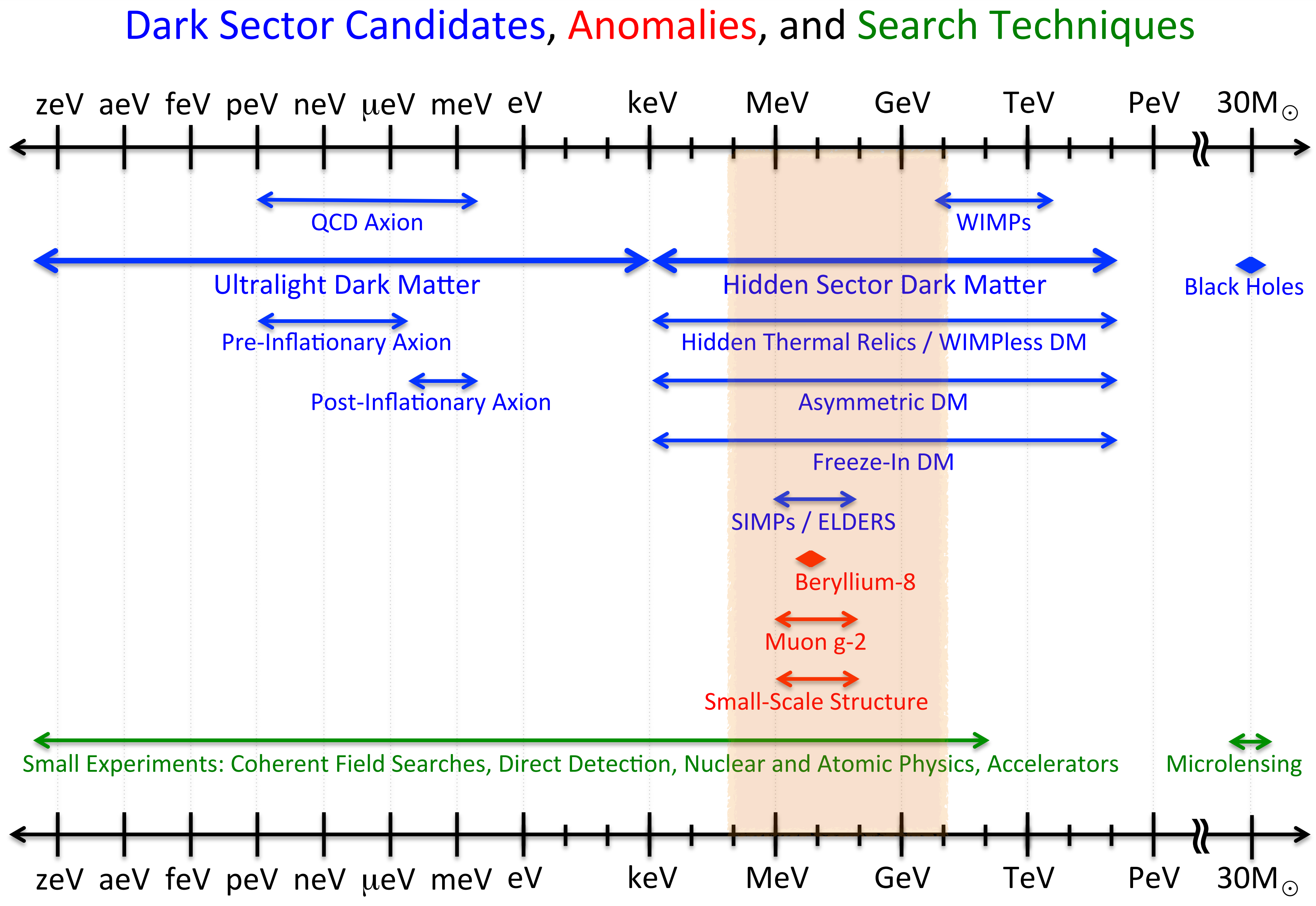
Molecules as a probe of DM?

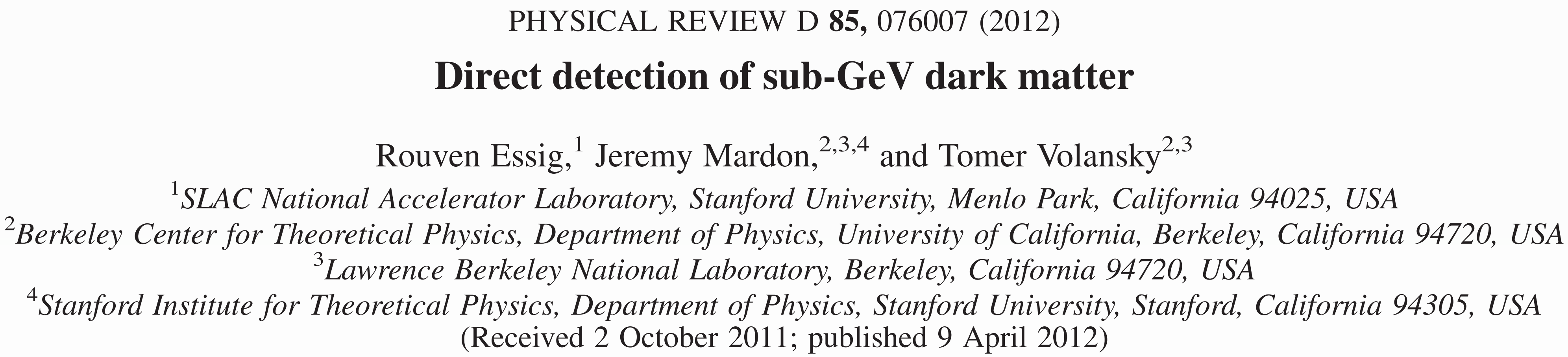
US Cosmic Visions: New Ideas in Dark Matter 2017 :
Community Report

arXiv:1707.04591v1 [hep-ph] 14 Jul 2017



Dark Sector Candidates, Anomalies, and Search Techniques

Molecules as a probe of DM?



PHYSICAL REVIEW D **85,** 076007 (2012)

Direct detection of sub-GeV dark matter

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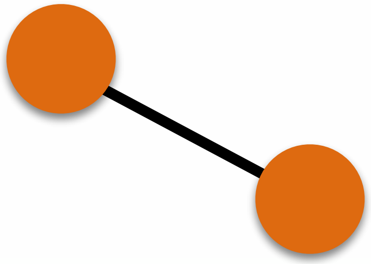
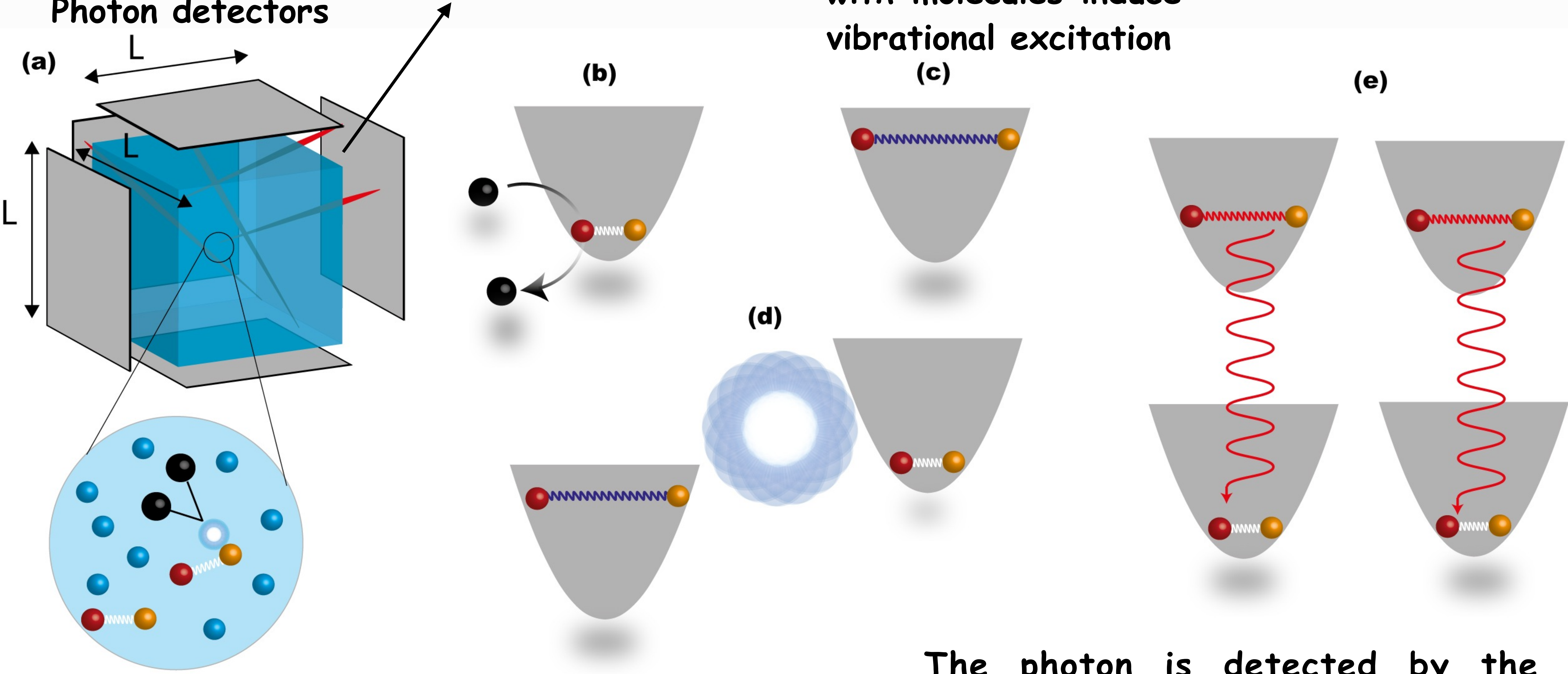
$$\boxed{E_{tot}=m_{DM}v^2/2 = 50 \text{ eV} \times (m_{DM}/100 \text{ MeV})}$$



Vibration of molecules
$m_{DM} \sim$ MeV

A novel approach for DM detection



Photon detectors

Mixed Molecular gas

DM particle collisions with molecules induce vibrational excitation

The photon is detected by the photodetectors surrounding the gas

Excited molecules decay emitting a photon

A novel approach for DM detection

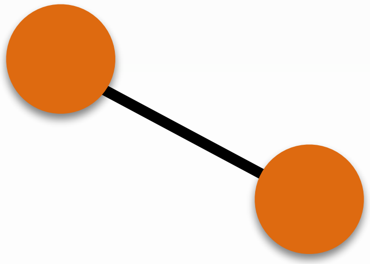
Four points to take care of

1. Spontaneous emission rate
2. Thermal population of vibrational states
3. Black Body radiation background
4. Collisional de-excitation rate

Bonus: Photon absorption

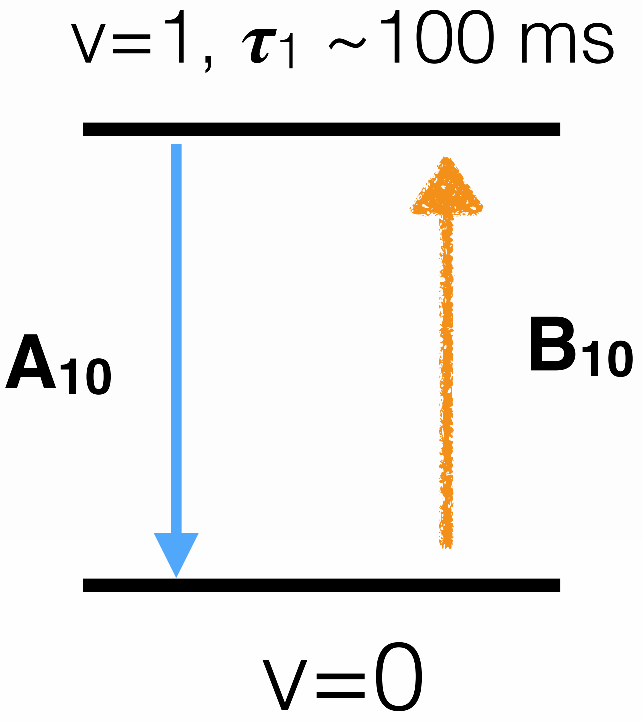
1. Spontaneous emission rate

Homonuclear

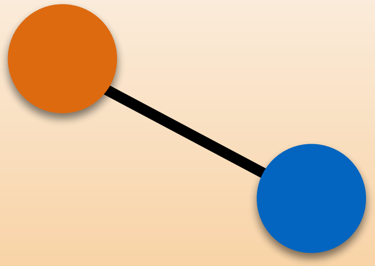


$$\frac{d\Gamma_{ij}}{d\Omega} = \frac{\alpha\omega_{ij}^5}{8\pi c^4}|Q|^2$$

$A_{10}\sim10^{-7}\ s^{-1}$



Heteronuclear



$$\frac{d\Gamma_{ij}}{d\Omega} = \frac{\alpha\omega_{ij}^3}{2\pi c^2}|d|^2$$

$A_{10}\sim10\ s^{-1}$

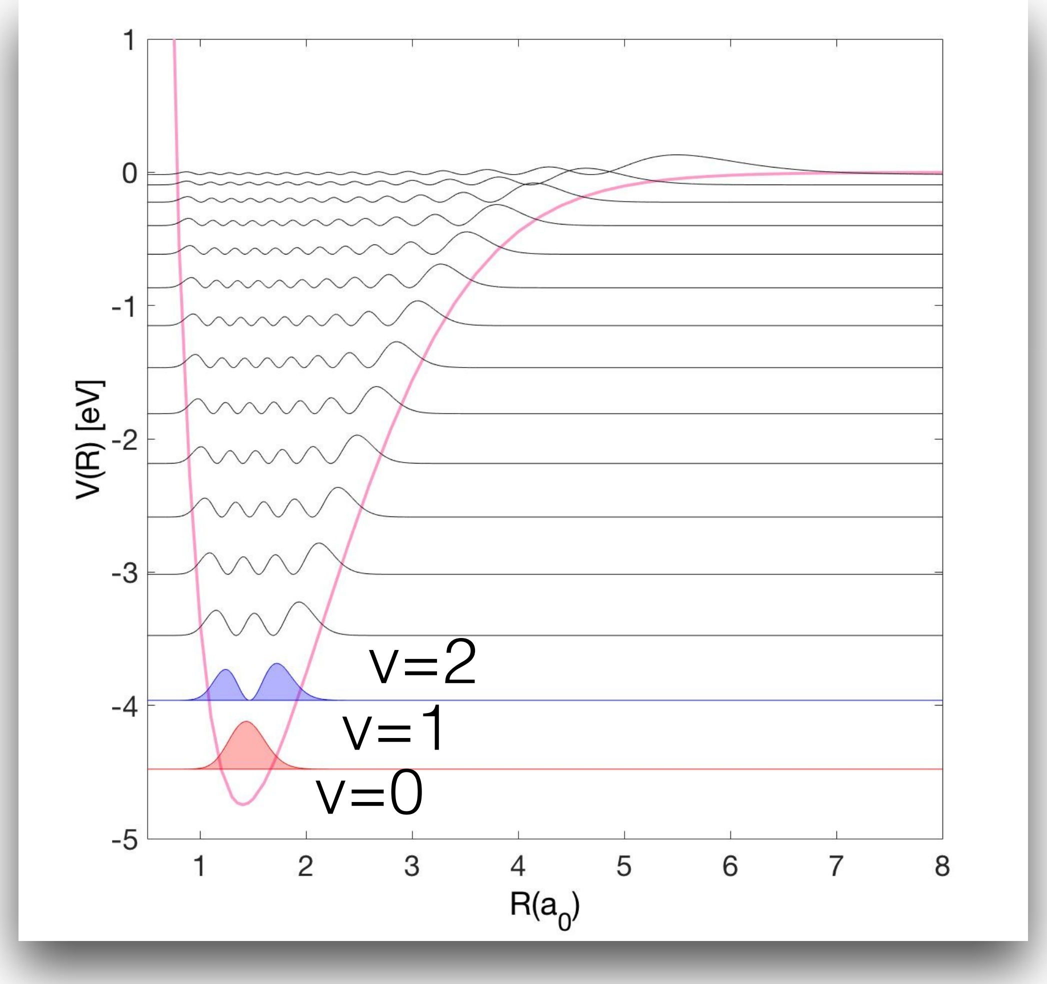
A fee to pay

Permanent dipole moment -> **faster collisional rates**
-> **BBR**

2. Thermal population

$$Z_{\text{vib}} = \sum_{\nu} e^{-\hbar\omega(\nu+1/2)/k_b T}$$

$$P_\nu = \frac{e^{-\hbar\omega(\nu+1/2)/k_b T}}{Z_{\text{vib}}}$$



We prefer lighter molecules, i.e., large vibrational spacing

The temperature has to be low enough to ensure that almost every single molecule is in the vibrational ground state

→

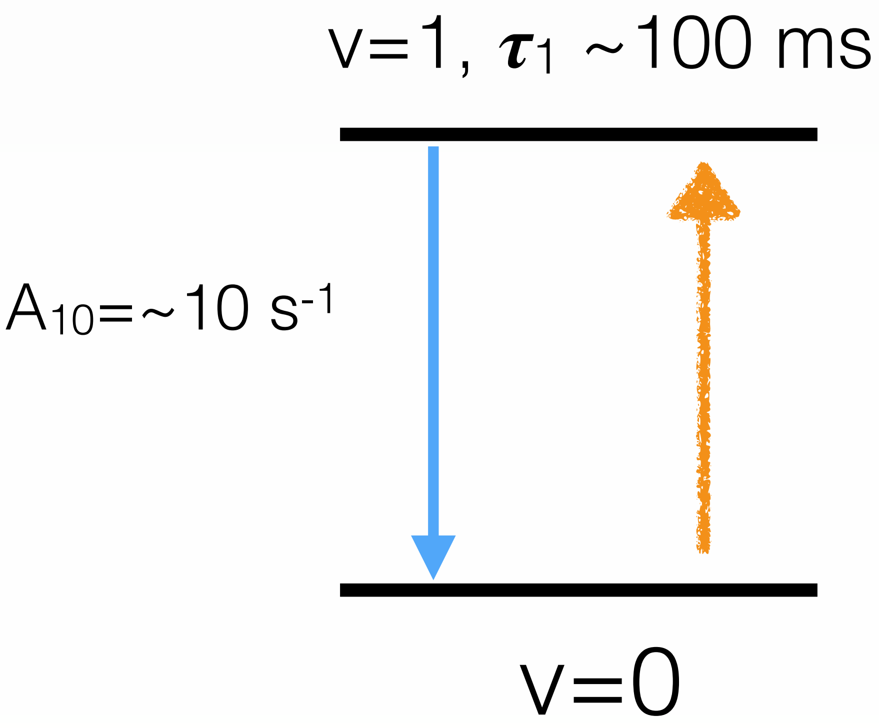
The lower the temperature the lower the pressure to avoid clustering of the gas, i.e, formation of droplets on the gas

3. Black body radiation

Dipole matrix element

Vibrational frequency

$$\Gamma_{ij}^{BBR} = \frac{8\pi^2 \boxed{|d_{ij}|^2}}{3\epsilon_o \hbar c^3} \frac{\nu^3}{\exp\frac{\hbar\nu}{k_B T} - 1}$$



v=1, τ_1 ~100 ms

A_{10}=~10 s^{-1}

v=0

We prefer lighter molecules, i.e., large vibrational spacing

Molecules with smaller dipole moment will have smaller BBR rate

Low temperatures are better!!!

3. Black body radiation

Dipole matrix element

Vibrational frequency

$$\Gamma_{ij}^{BBR} = \frac{8\pi^2 \boxed{|d_{ij}|^2}}{3\epsilon_o \hbar c^3} \frac{\nu^3}{\exp\frac{h\nu}{k_B T} - 1}$$

	H	HF	CO	NO	HCl
r		1.7	2.1	2.2	2.4
ω	453 198 466	513	269	236	371
d(D)	1.80	1.98	0.12	0.16	1.03

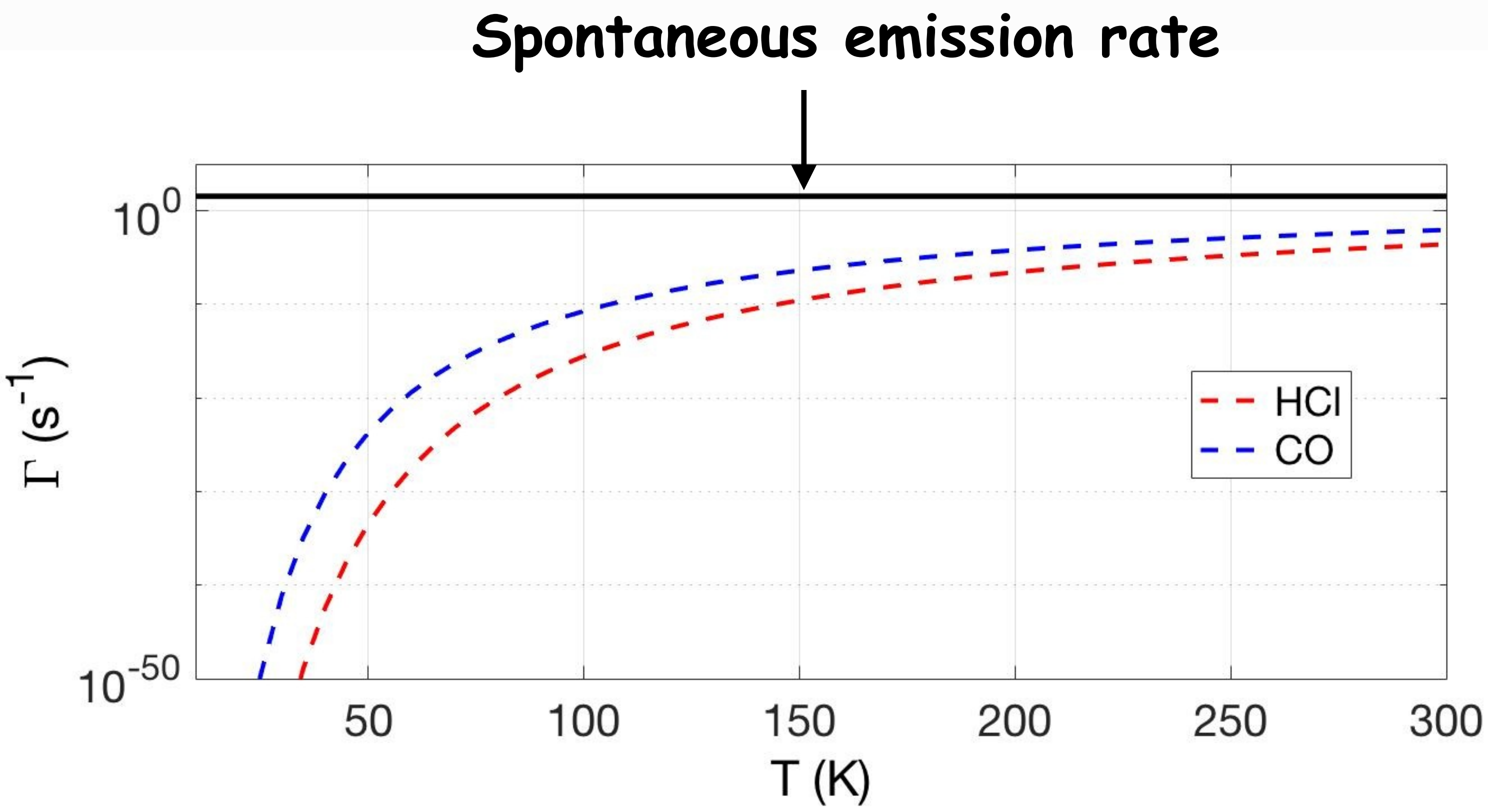
3. Black body radiation

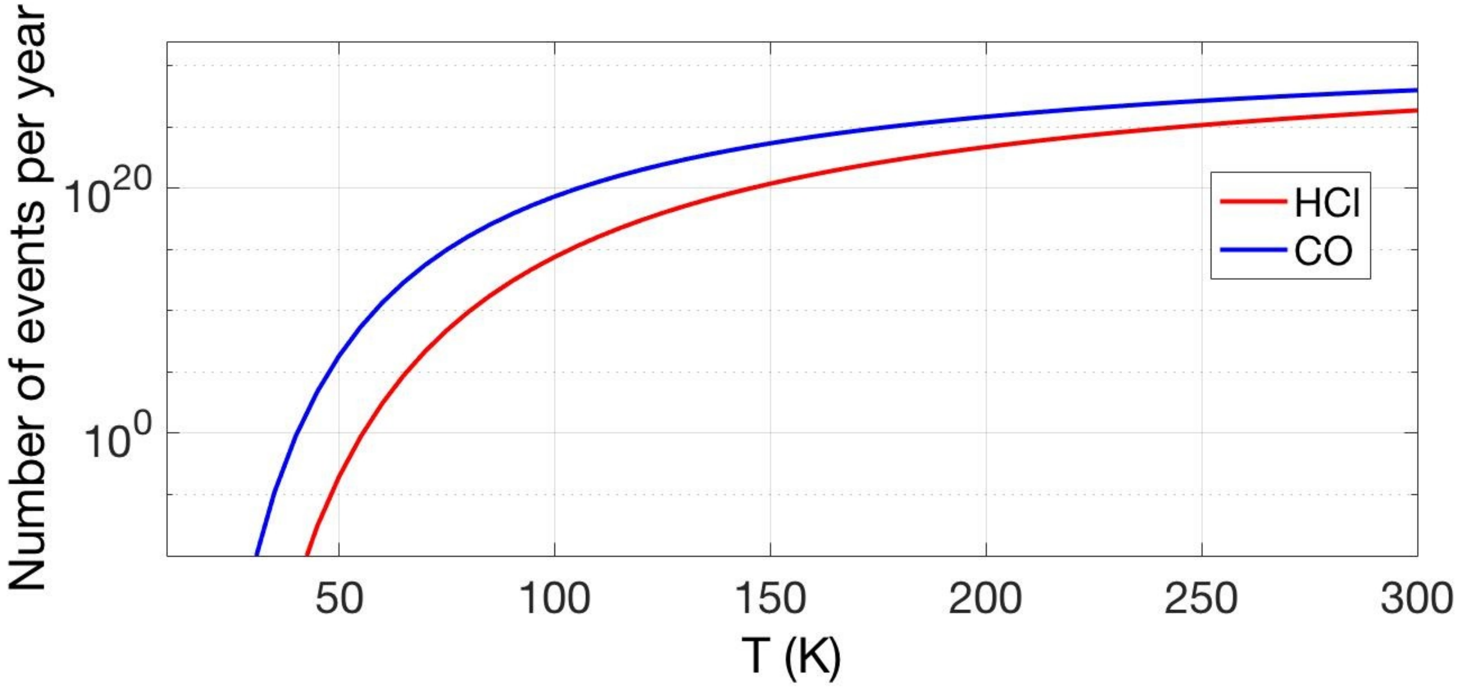
$$\Gamma_{ij}^{BBR} = \frac{8\pi^2|d_{ij}|^2}{3\epsilon_o\hbar c^3}\,\frac{\nu^3}{\exp\frac{h\nu}{k_BT}-1}$$

We need

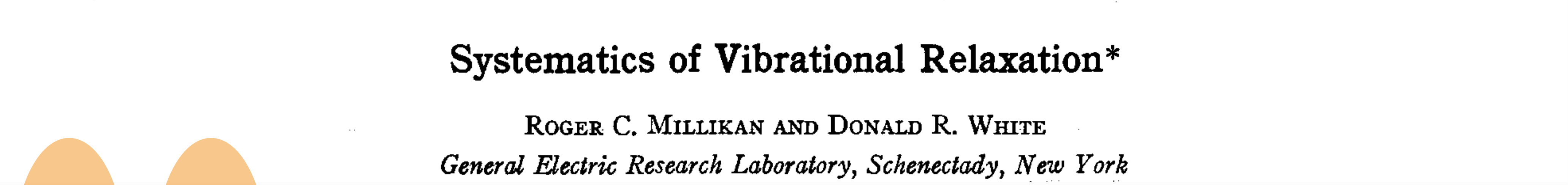
Molecules with large vibrational energy spacing

Low temperatures T≲ 60 K


Spontaneous emission rate



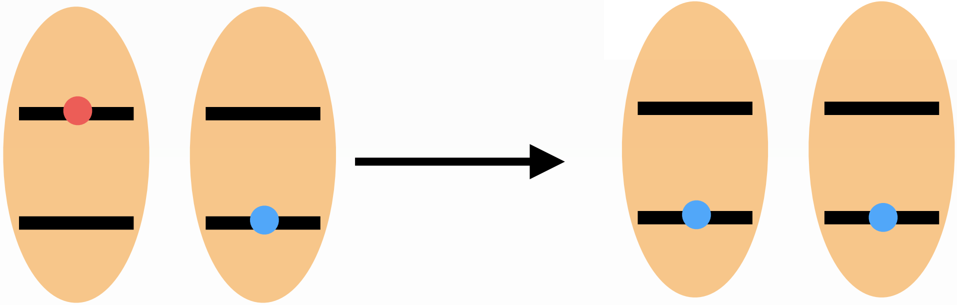
4. Collisional de-excitation



THE JOURNAL OF CHEMICAL PHYSICS VOLUME 39, NUMBER 12 15 DECEMBER 1963

Systematics of Vibrational Relaxation*

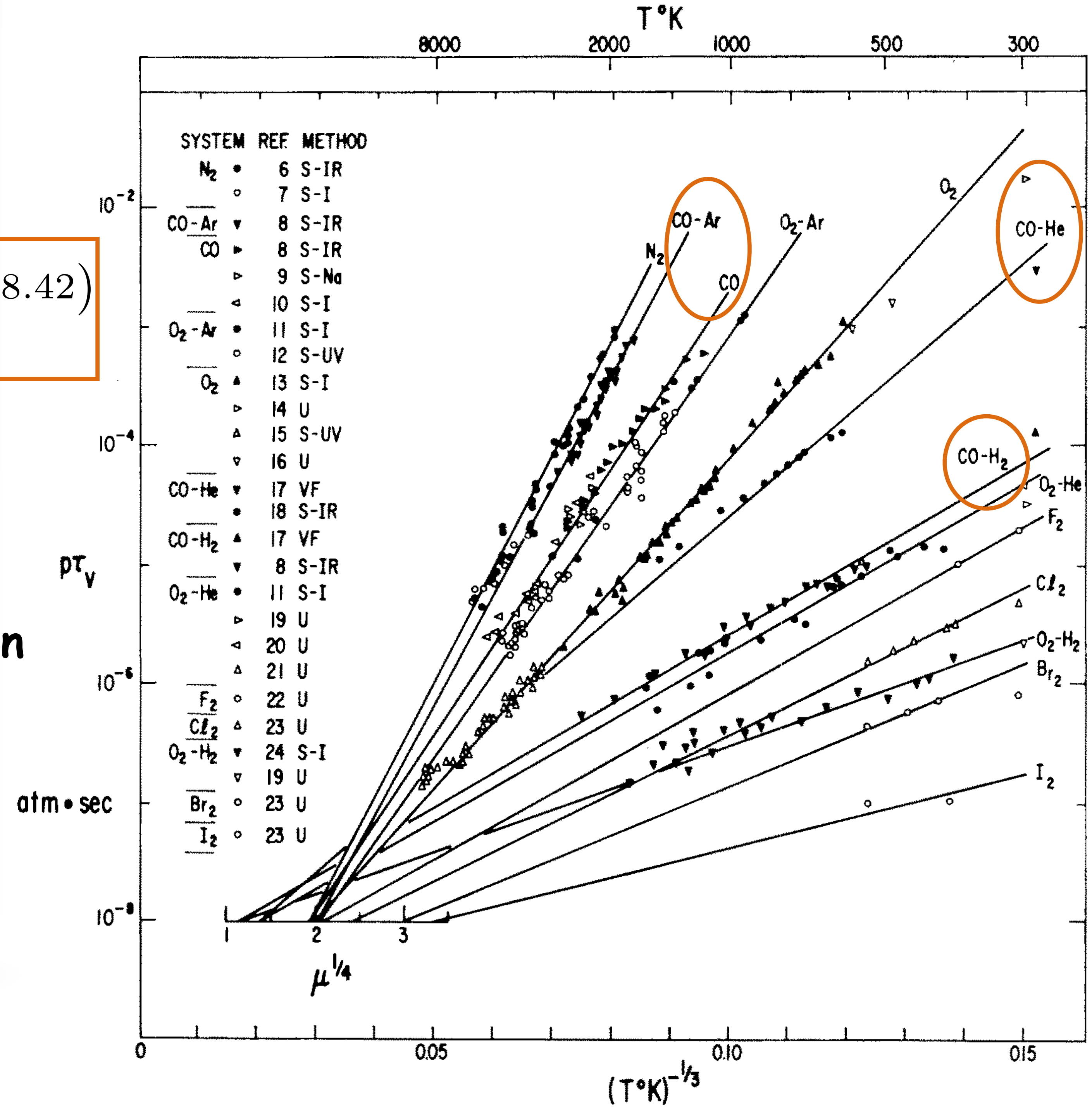
Roger C. Millikan and Donald R. White
General Electric Research Laboratory, Schenectady, New York



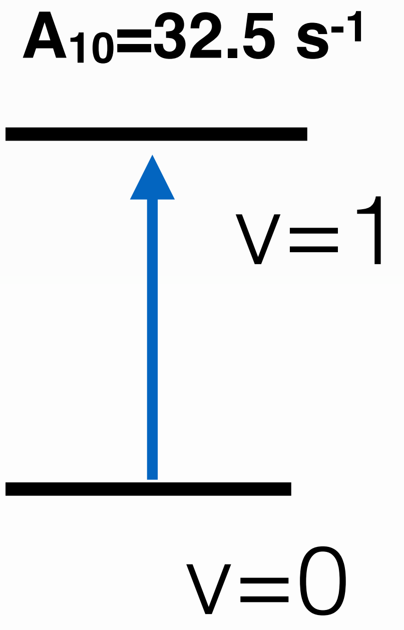
$$p\tau_v = e^{\left(1.16\times10^{-3}\mu^{1/2}\omega^{4/3}(T^{-1/3}-0.015\mu^{1/4})-18.42\right)}$$

CO shows larger vibrational quenching time
CO has a decent vibrational spacing
CO shows a regular BBR rate absorption spectra at low temperatures

CO is a great candidate

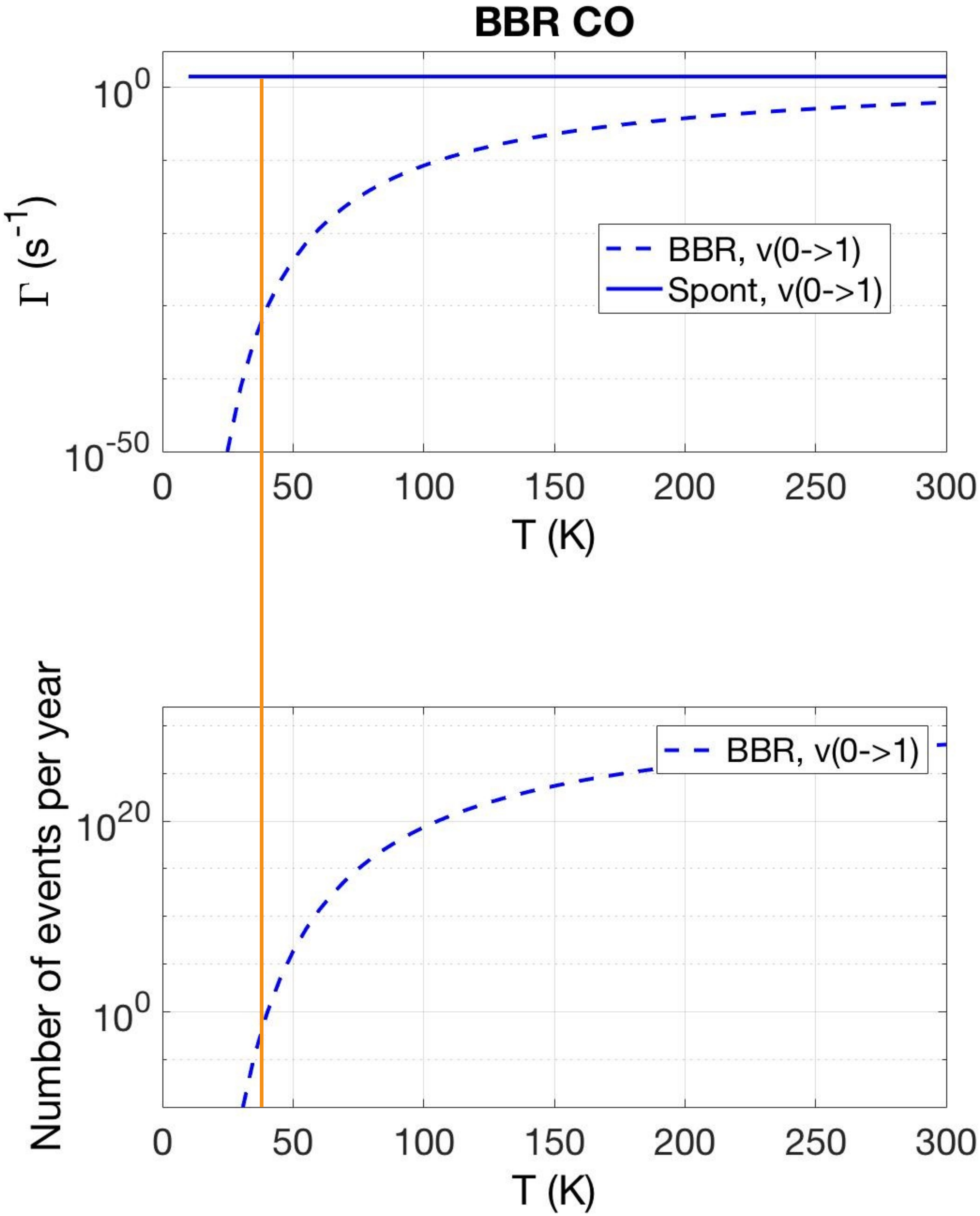


CO in detail (BBR)

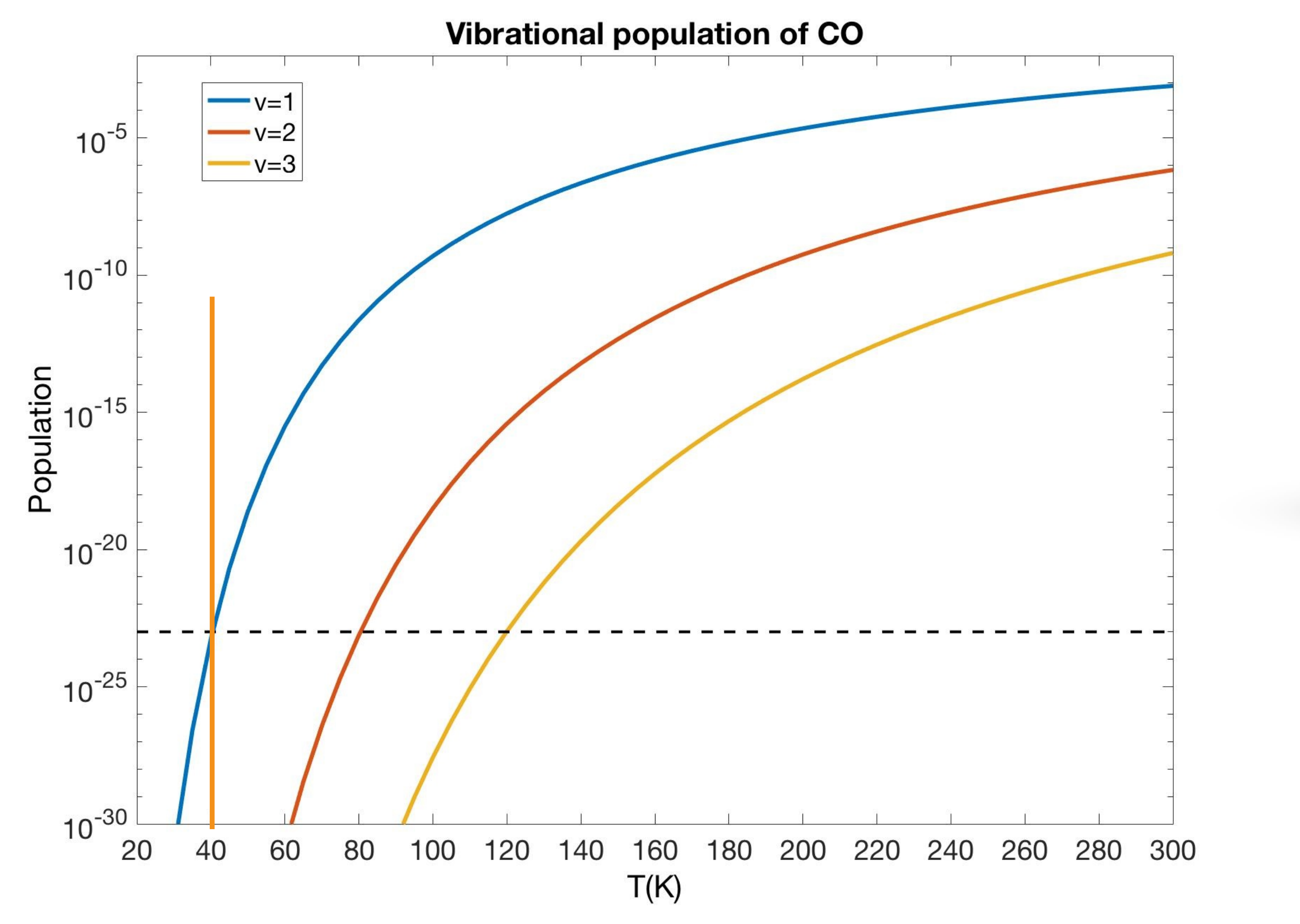


$$\Gamma_{ij}^{BBR} = \frac{8\pi^2|d_{ij}|^2}{3\epsilon_o\hbar c^3}\frac{\nu^3}{\exp\frac{h\nu}{k_B T} - 1}$$

CO @ 40K

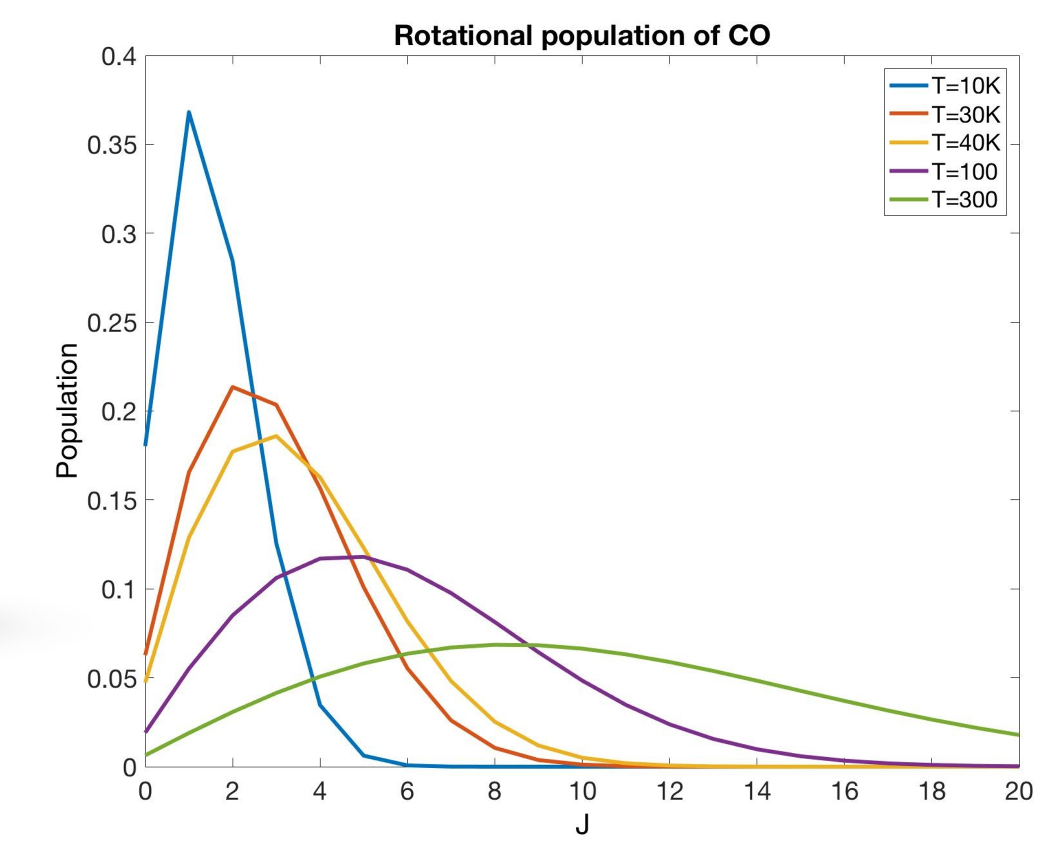


CO in detail (Rovibrational population)



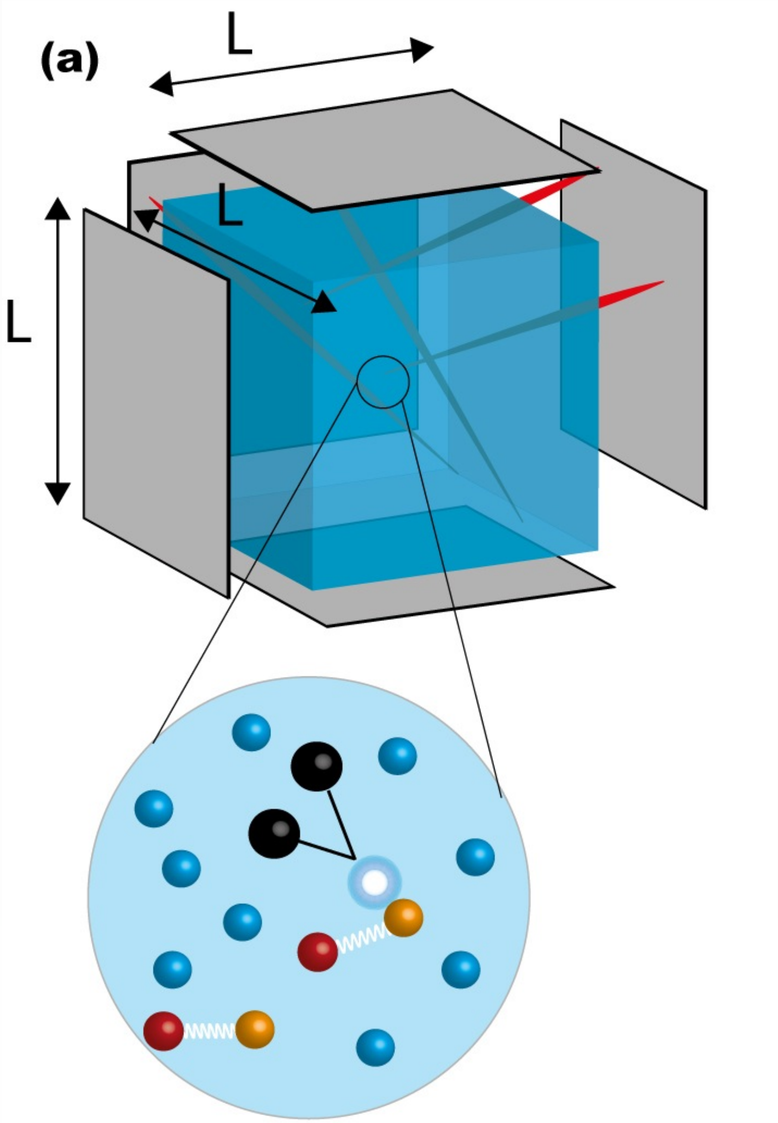
For CO @ 40 K the <u>pressure must be ≲ 0.1 mbar</u> to have all the molecules in gas phase

The rotational level distribution is accounted for in the rate calculation



CO in detail (bonus as I promised)

The emitted photon can be absorbed by another molecule before it reaches the detector



Absorption cross section

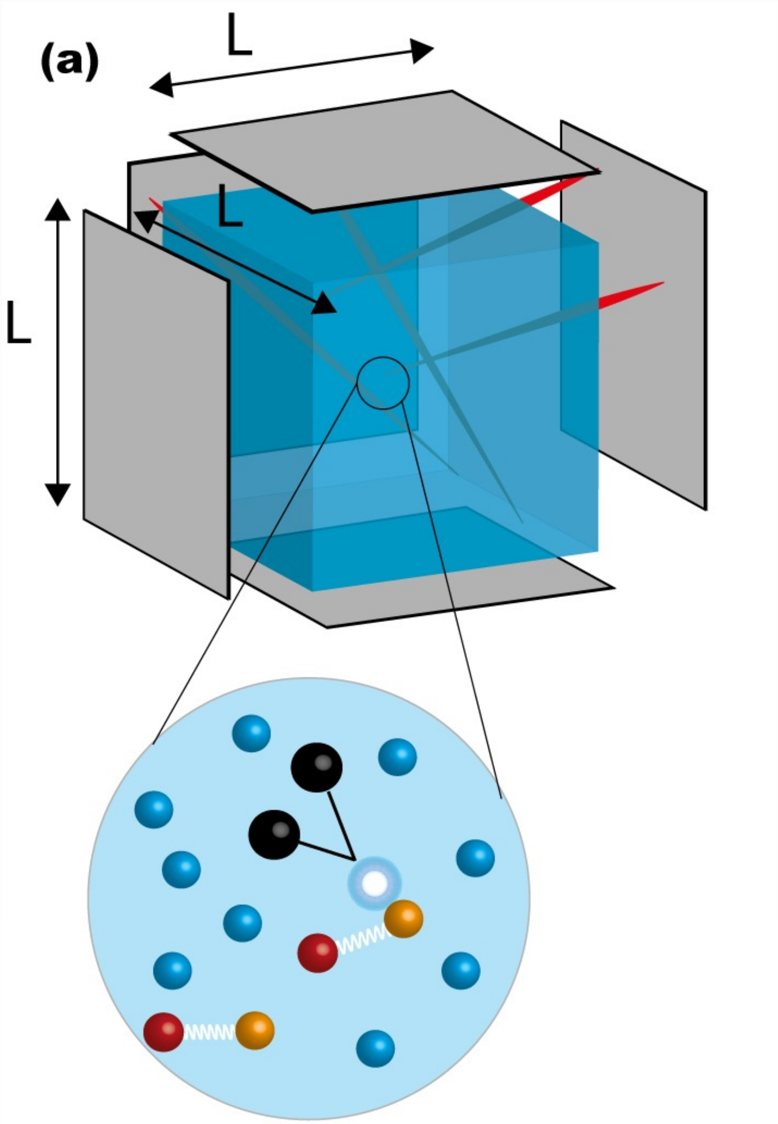
$$\sigma_{\rm abs}(\omega) = \hbar\omega B_{ij} g(\omega)$$

$$g(\omega) = \frac{1}{2\pi}\frac{\gamma_{\rm el}}{\gamma_{\rm el}^2 + (\omega-\omega_0)^2}$$

$$\gamma_{\rm el} = \rho_{\rm He}\langle\sigma_{\rm el}(v)v\rangle$$

CO in detail (bonus as I promised)

The emitted photon can be absorbed by another molecule before it reaches the detector



Absorption cross section

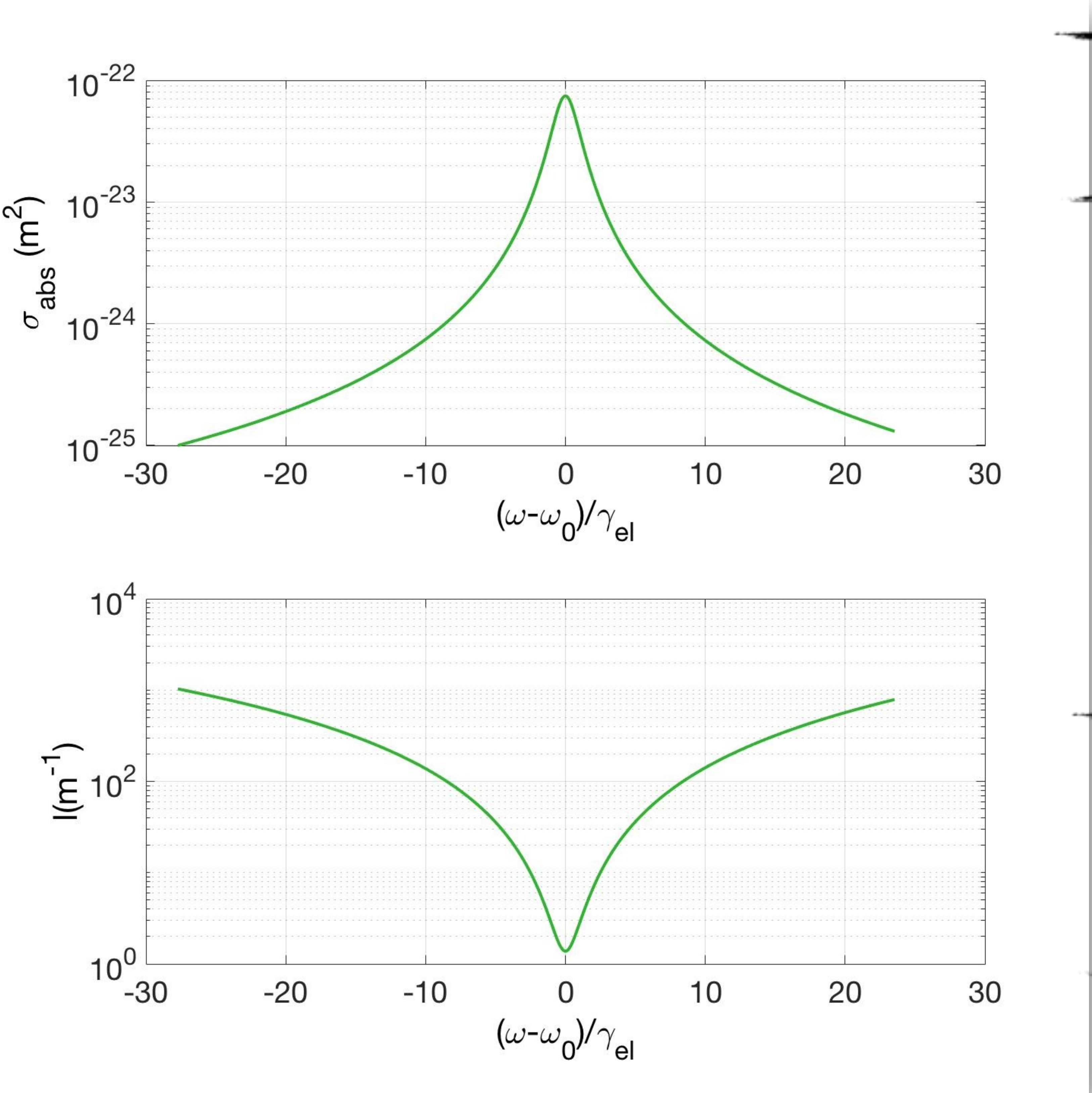
$$\sigma_{\mathrm{abs}}(\omega) = \hbar\omega B_{ij} g(\omega)$$

$$B_{ij} = \frac{\lambda^3}{8\pi h c} A_{ij}$$

$$l(\omega) = \frac{1}{\rho_{\mathrm{CO}}\sigma_{\mathrm{abs}}(\omega)}$$

CO in detail (bonus as I promised)

Absorption cross section



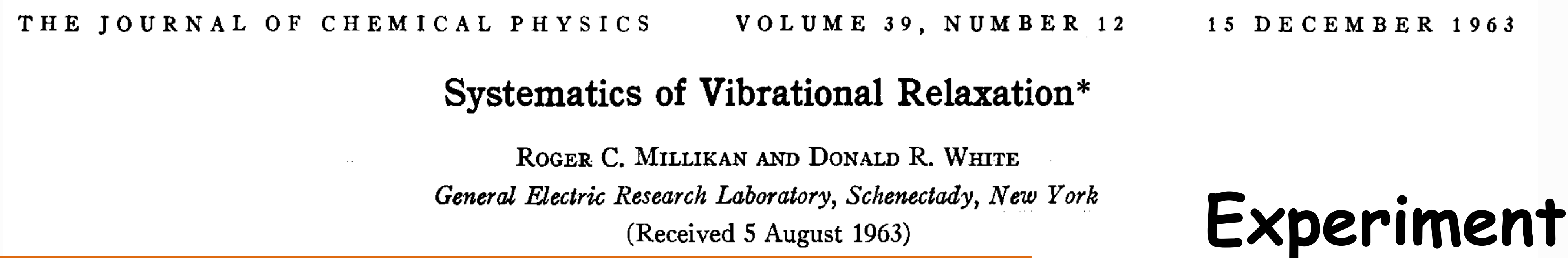
$$\sigma_{\mathrm{abs}}(\omega) = \hbar\omega B_{ij} g(\omega)$$

$P_{CO}=5\times10^{-5}$ bar

$P_{He}=0.99995$ bar

$$l(\omega) = \frac{1}{\rho_{\mathrm{CO}}\sigma_{\mathrm{abs}}(\omega)}$$

CO in detail (collisions)



THE JOURNAL OF CHEMICAL PHYSICS VOLUME 39, NUMBER 12 15 DECEMBER 1963

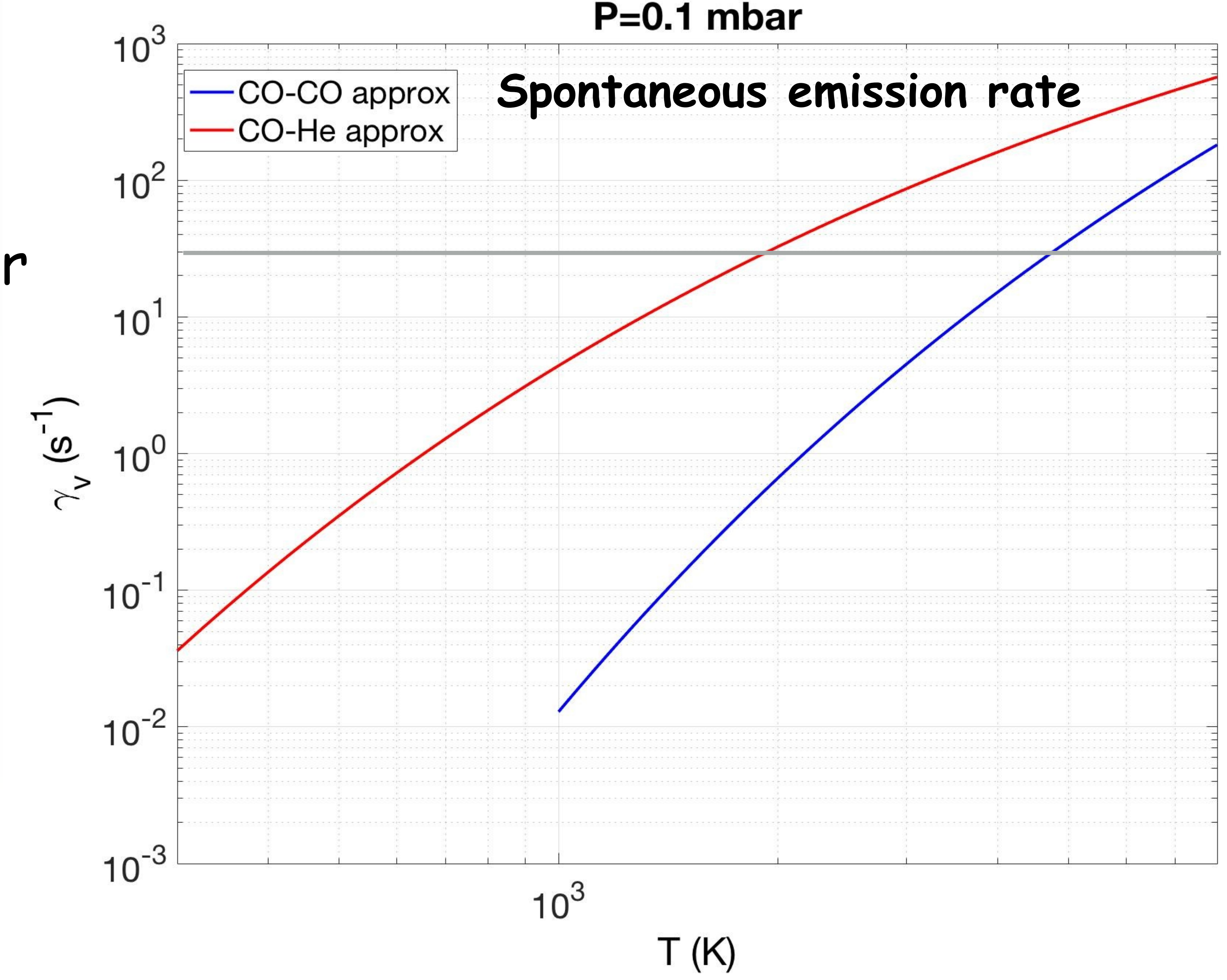
Systematics of Vibrational Relaxation*

ROGER C. MILLIKAN AND DONALD R. WHITE
General Electric Research Laboratory, Schenectady, New York
(Received 5 August 1963)

Experimental data

$$p\tau_v = e^{\left(1.16\times10^{-3}\mu^{1/2}\omega^{4/3}(T^{-1/3}-0.015\mu^{1/4})-18.42\right)}$$

Landau-Teller theory for v-v and v-t energy transfer



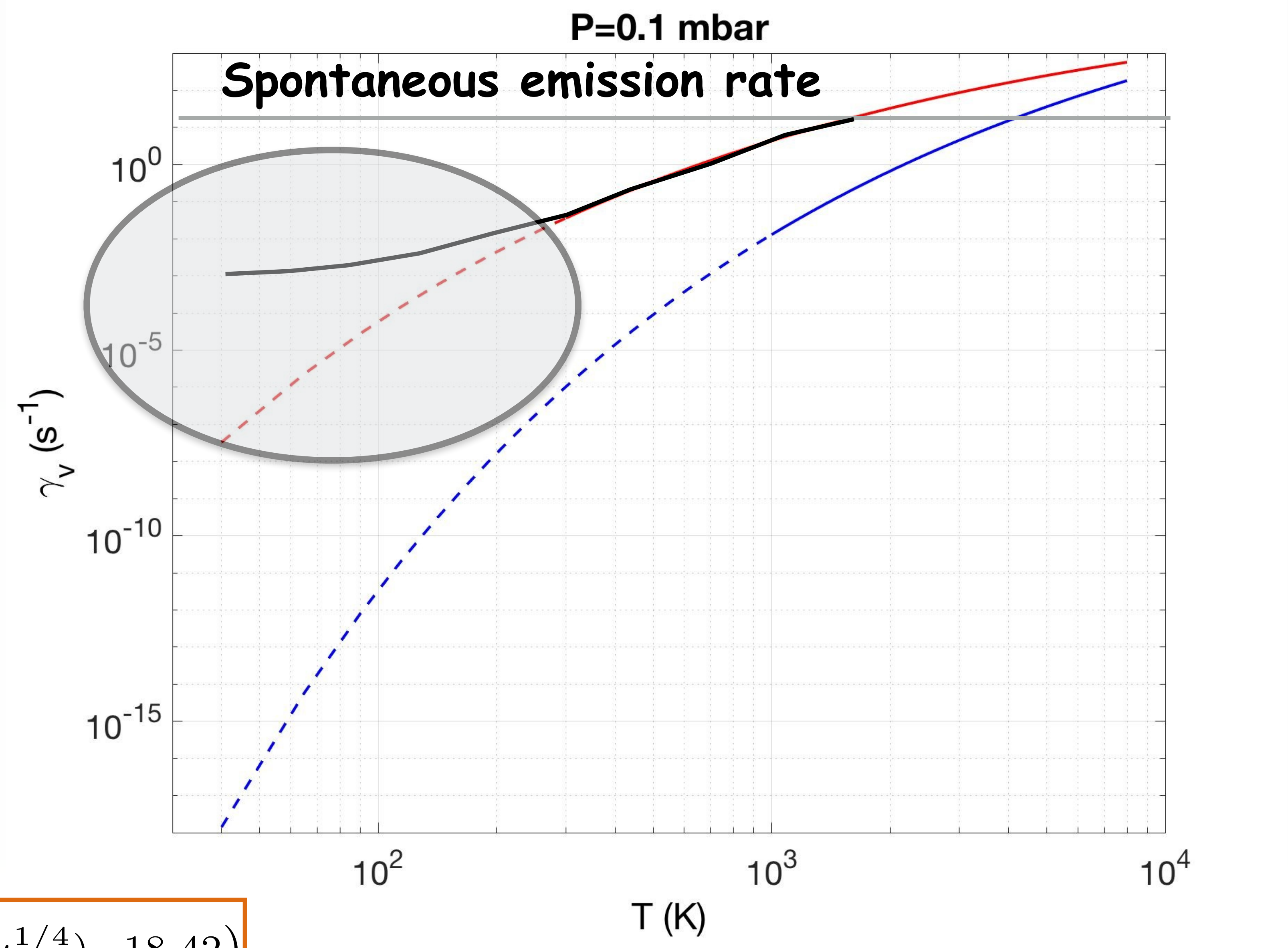
CO in detail (collisions)

JOURNAL OF CHEMICAL PHYSICS VOLUME 116, NUMBER 11 15 MARCH 2002

Vibrational relaxation of vibrationally and rotationally excited CO molecules by He atoms

Roman V. Krems[a)]

Department of Chemistry, Physical Chemistry, Göteborg University, SE-412 96, Göteborg, Sweden



Spontaneous emission rate

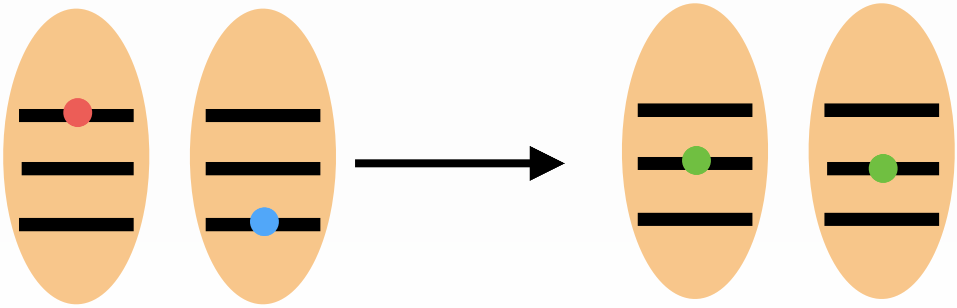
$$p\tau_v = e^{\left(1.16\times10^{-3}\mu^{1/2}\omega^{4/3}(T^{-1/3}-0.015\mu^{1/4})-18.42\right)}$$

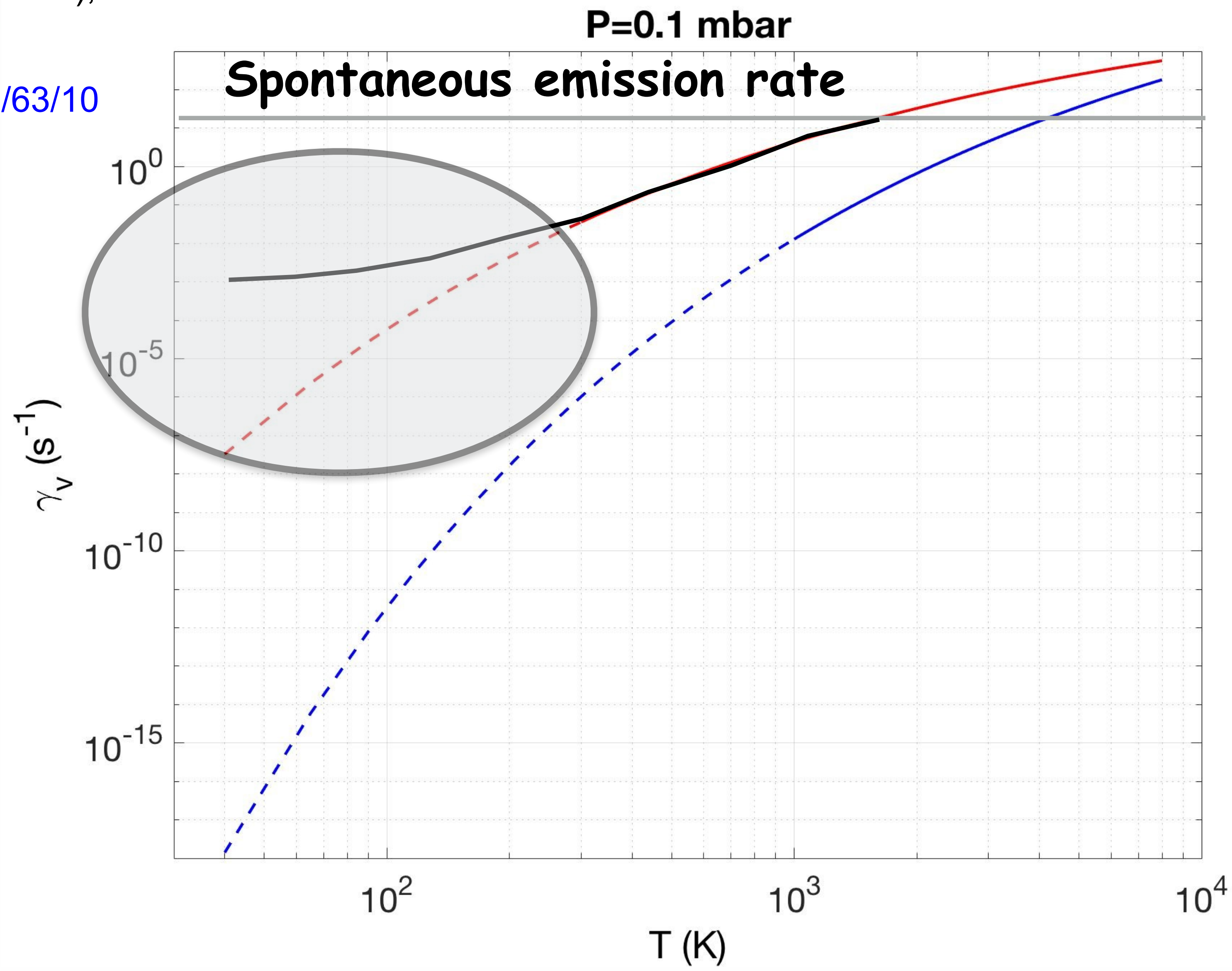
CO in detail (collisions)

Vibrational energy exchange in CO–CO collisions at low temperature

M. C. Gower, G. Srinivasan, and K. W. Billman

Citation: The Journal of Chemical Physics **63**, 4206 (1975);
View online: https://doi.org/10.1063/1.431190
View Table of Contents: http://aip.scitation.org/toc/jcp/63/10
Published by the American Institute of Physics




P=0.1 mbar

Spontaneous emission rate

CO @ 75 K

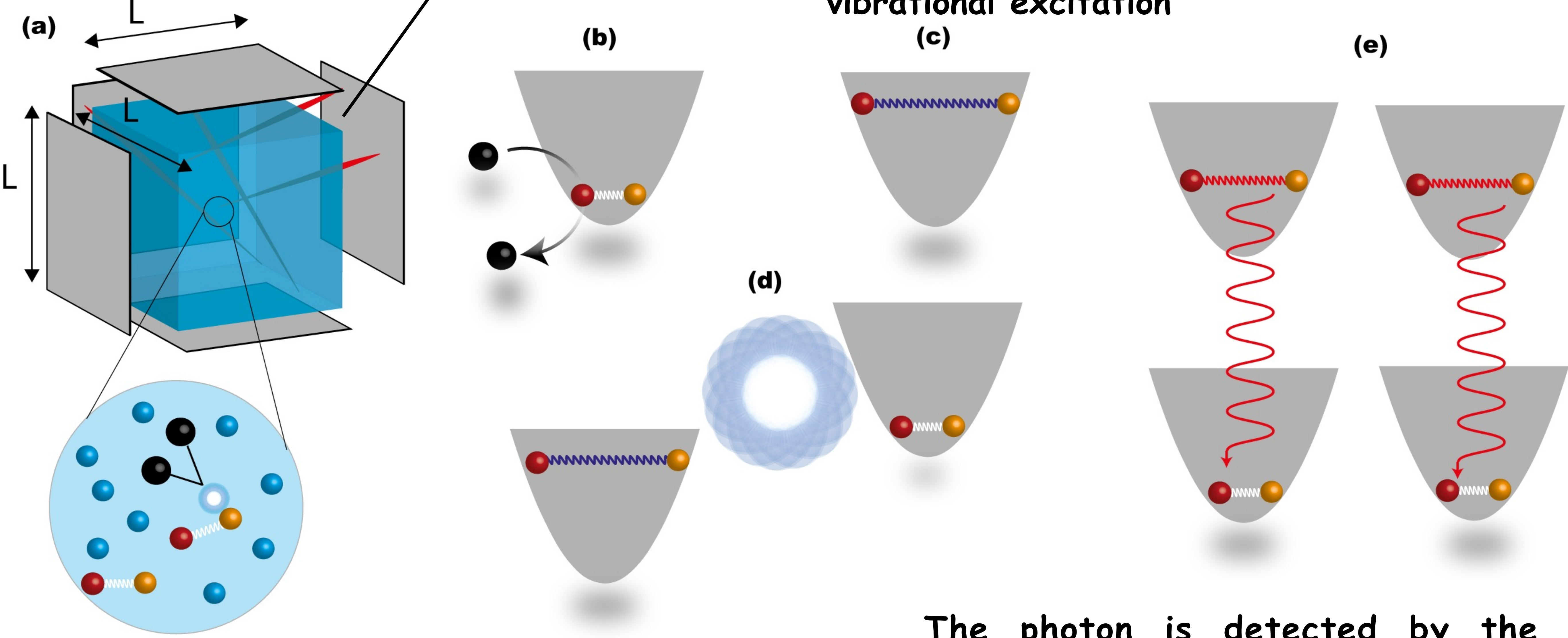
$k_{v,v-1}=1.8\times10^{-12}$ cm^3/s

A novel approach for DM detection

Photon detectors

Mixed Molecular gas

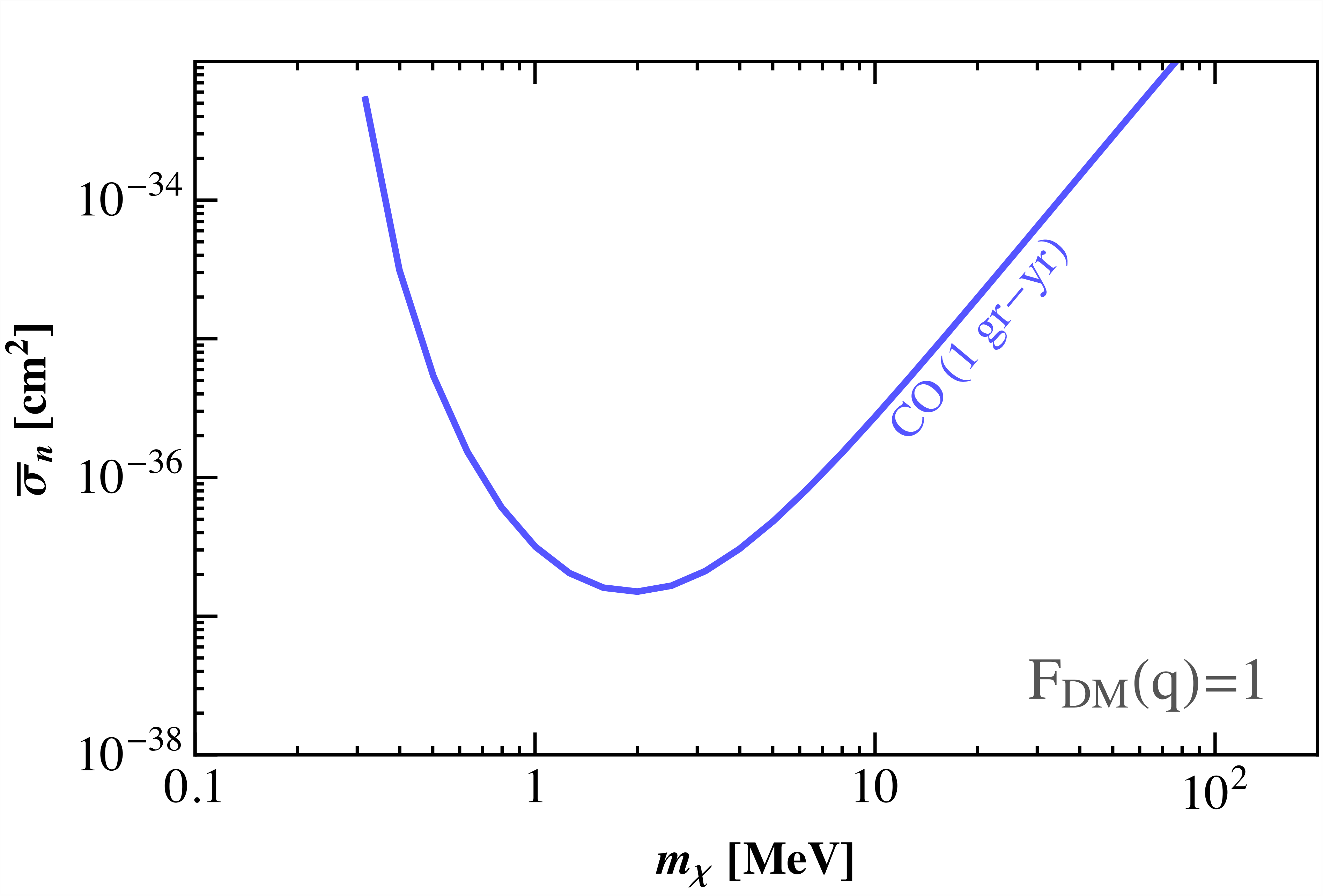
DM particle collisions with molecules induce vibrational excitation



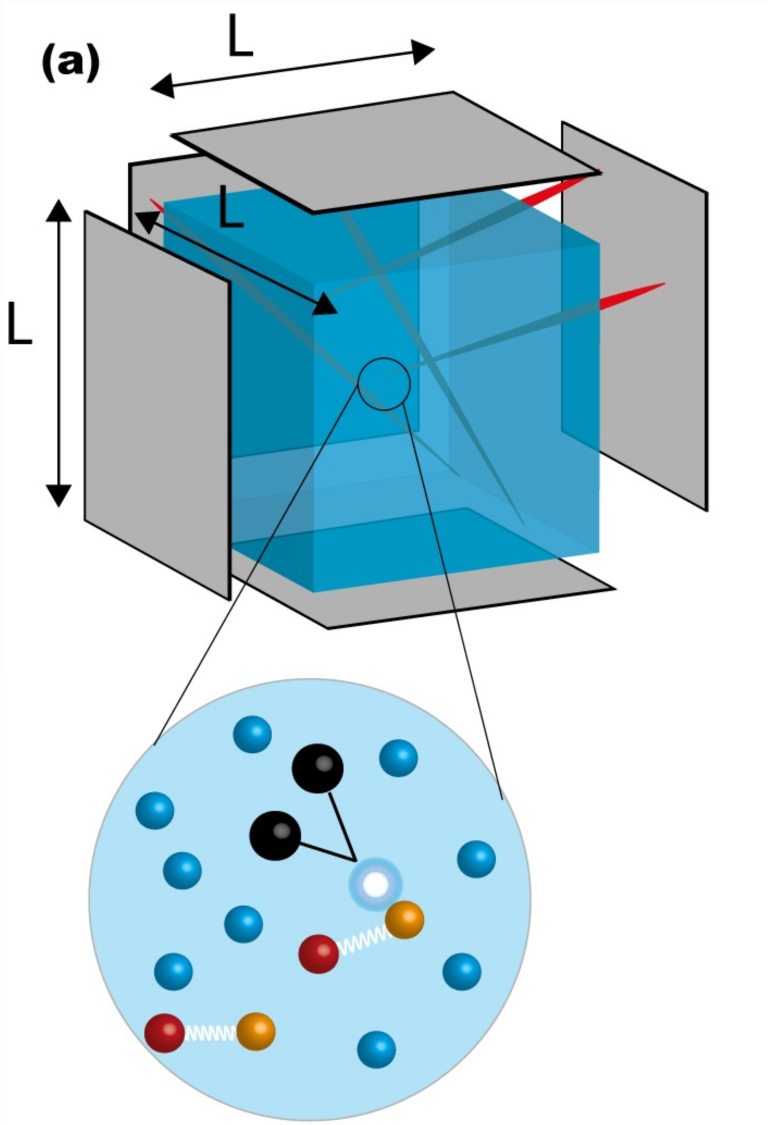
The photon is detected by the photodetectors surrounding the gas

Excited molecules decay emitting a photon

CO in detail

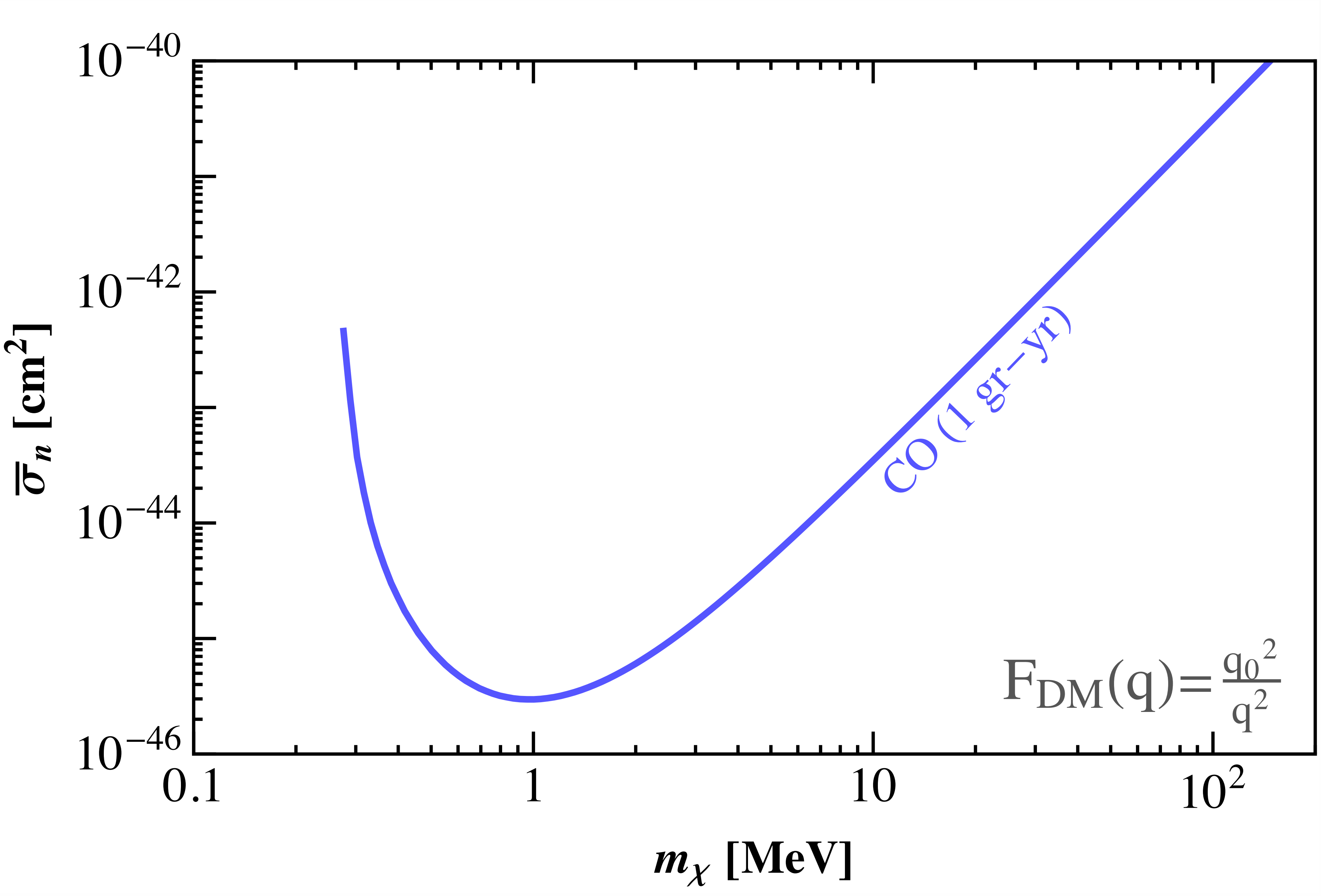


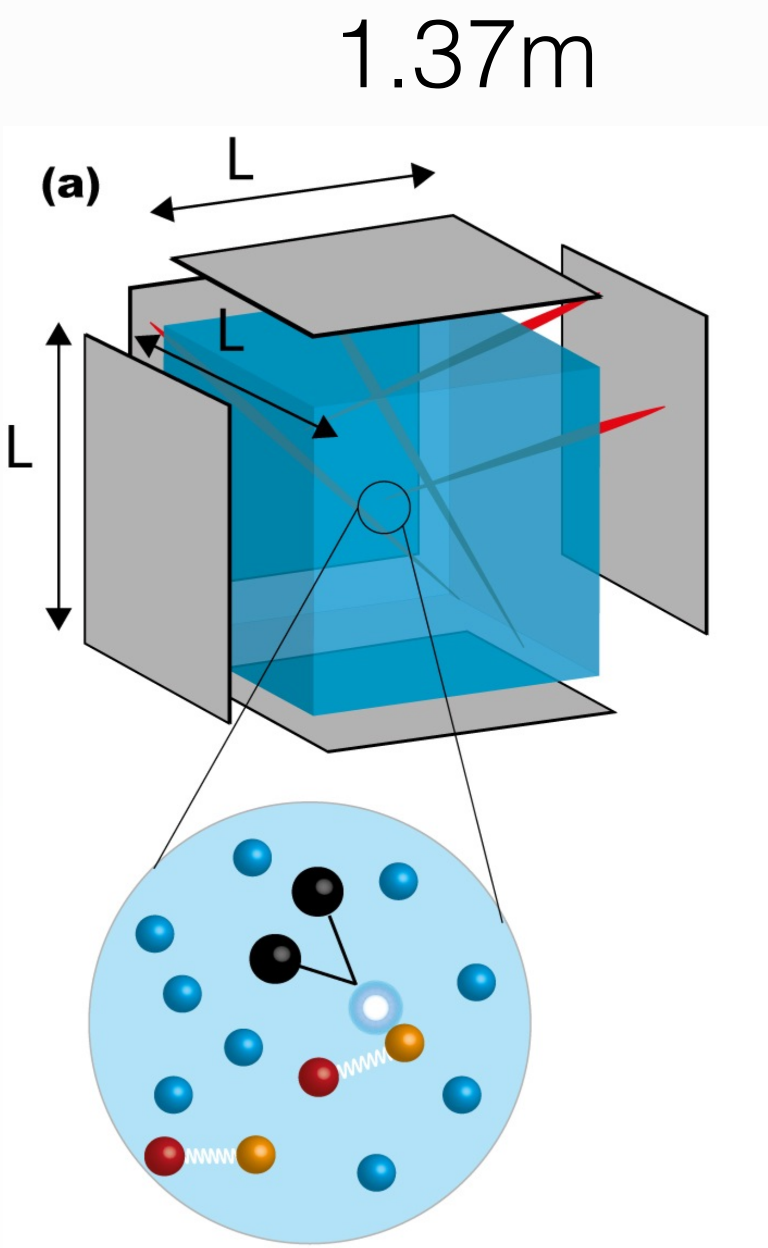
1.37m



We will be able to explore DM particles in a mass range of almost 3 orders of magnitude, from 100 keV to 100 MeV.

CO in detail





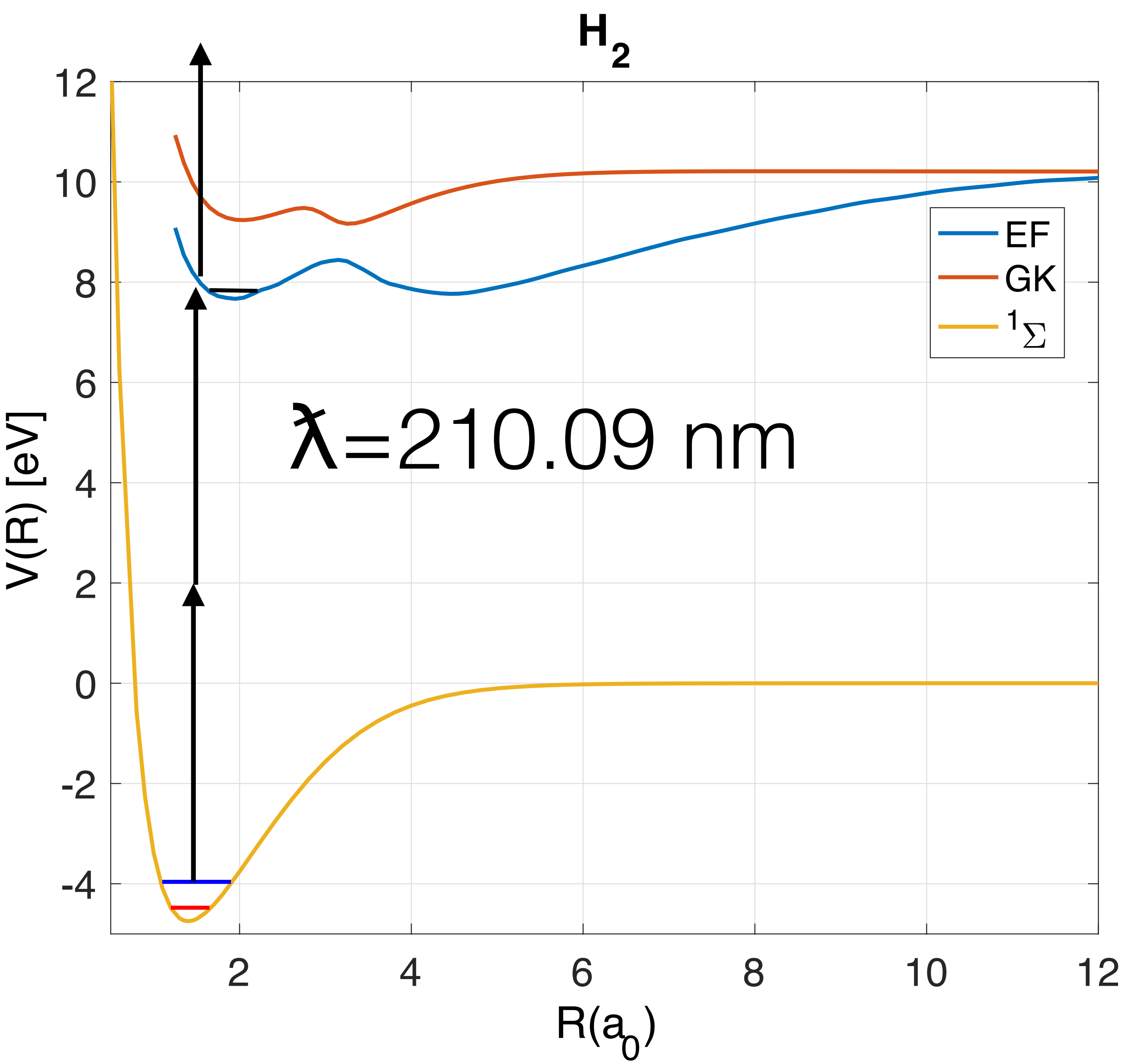
We will be able to explore DM particles in a mass range of almost 3 orders of magnitude, from 100 keV to 100 MeV.

Some future work

CO-CO accurate scattering properties

Electronic excitations?

REMPI through a dark state



That´s all folks

Thank you so much for your attention!!!!!!!!