AMC

atomic and molecular collisions group

Excitation and Charge Exchange Phenomena in Astronomical Objects: Measurement of Cross Sections and Lifetimes

Presentation at the Topical Workshop on EUV and X-Ray Emission from Comets, Planets, and Heliospheric Gases

Jan. 16-17, 2003

A. Chutjian[1], S. Smith[1], J. Lozano[1], I. Cadez[2],

J. Greewnood[3] R. Mawhorter[4], I. Williams[3], M. Niimura[5]

[1] Jet Propulsion Laboratory, Caltech, Pasadena, CA

[2] J. Stefan Institut, Ljubljna, Slovenia

[3] Queen's University, Belfast, UK

[4] Pomona College, Claremont, CA

[5] Plasma Physics Lab., UC California, Los Angeles, CA

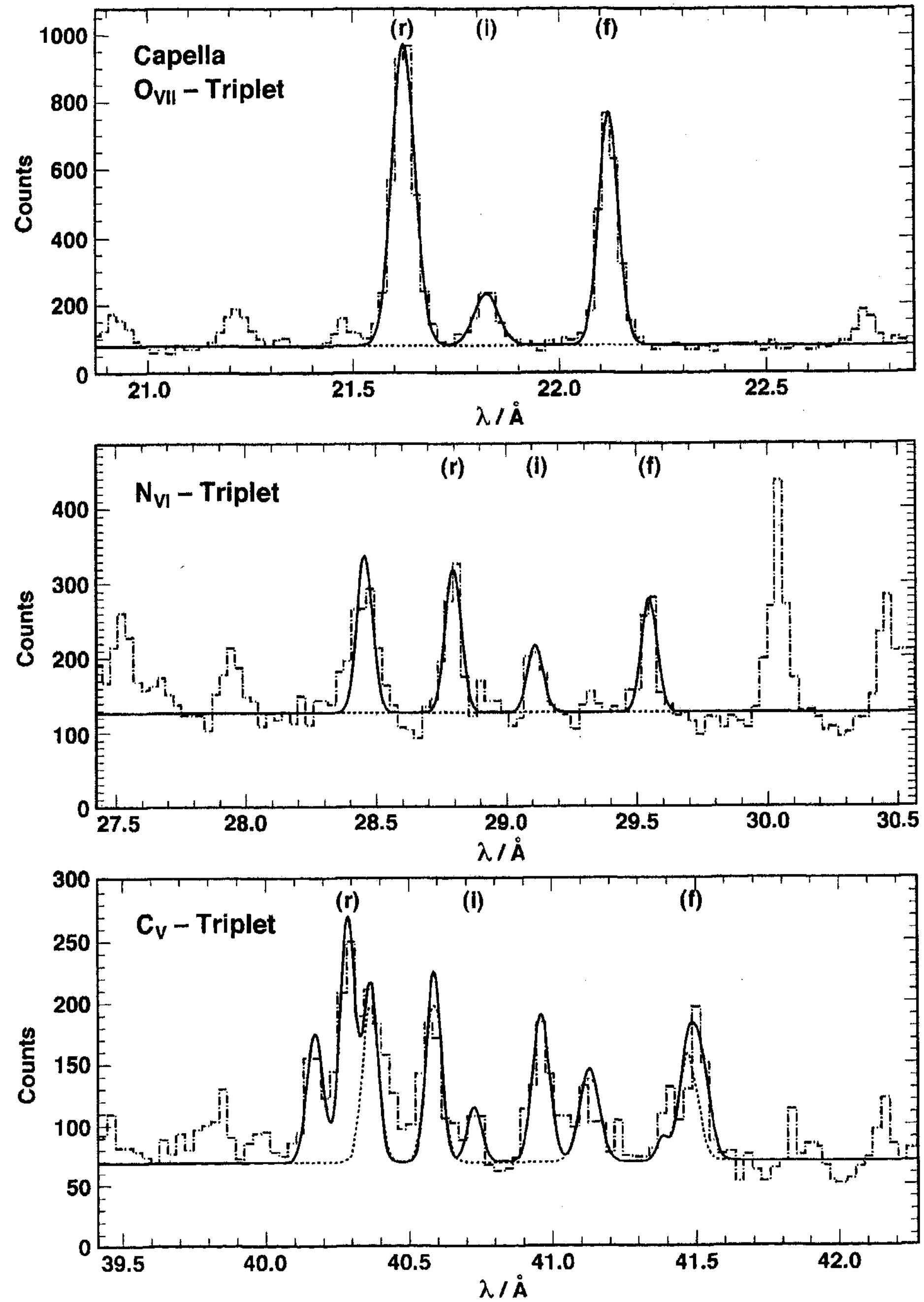
The JPL work is supported under contract with NASA, and is carried out at JPL/Caltech.

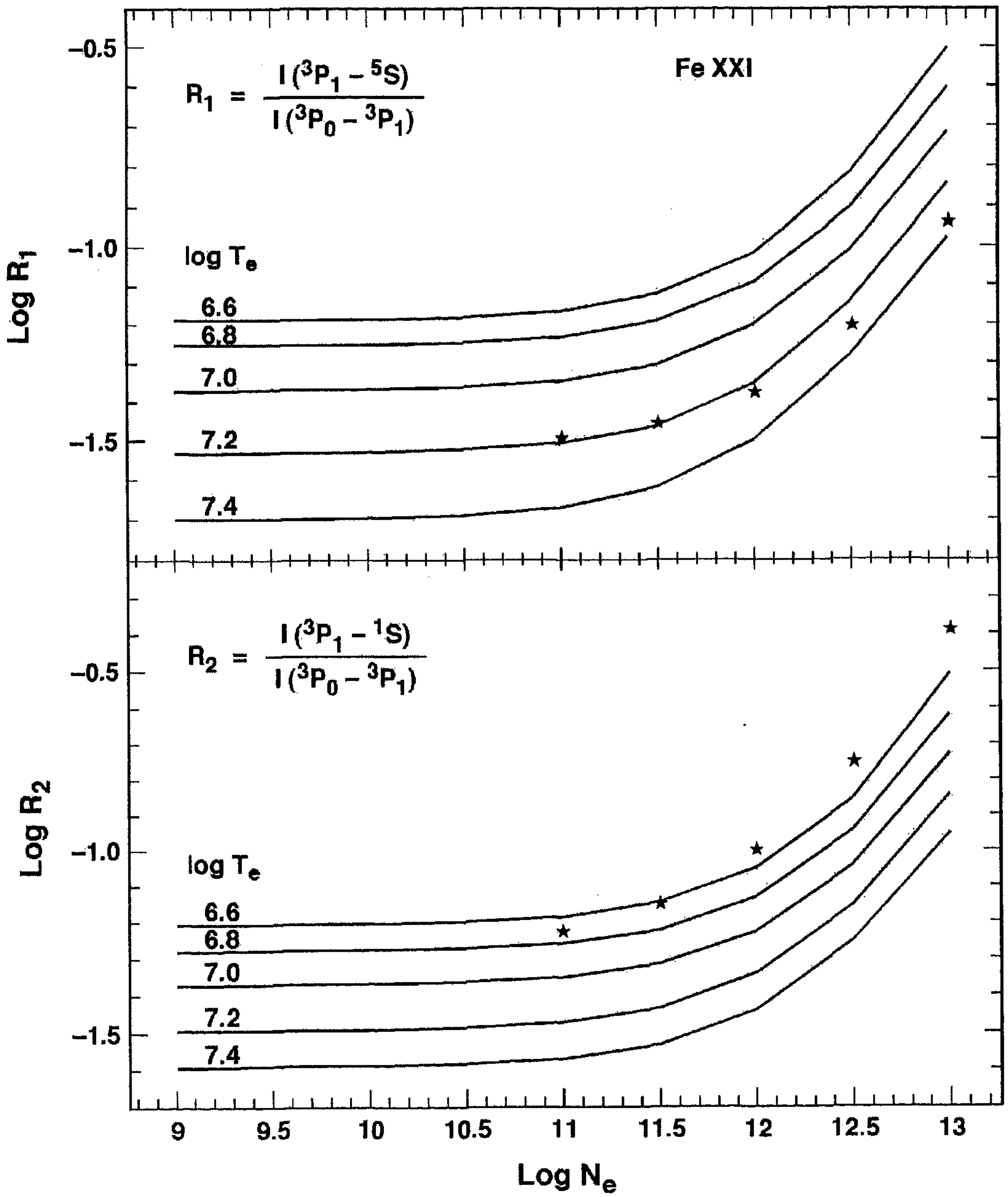
CHANDRA/LETGS at Capella

r: $1s^2\ ^1S \rightarrow 1s2p\ ^1P^o$

i: $1s^2\ ^1S \rightarrow 1s2s\ ^1S$

f: $1s^2\ ^1S \rightarrow 1s2p\ ^3S$





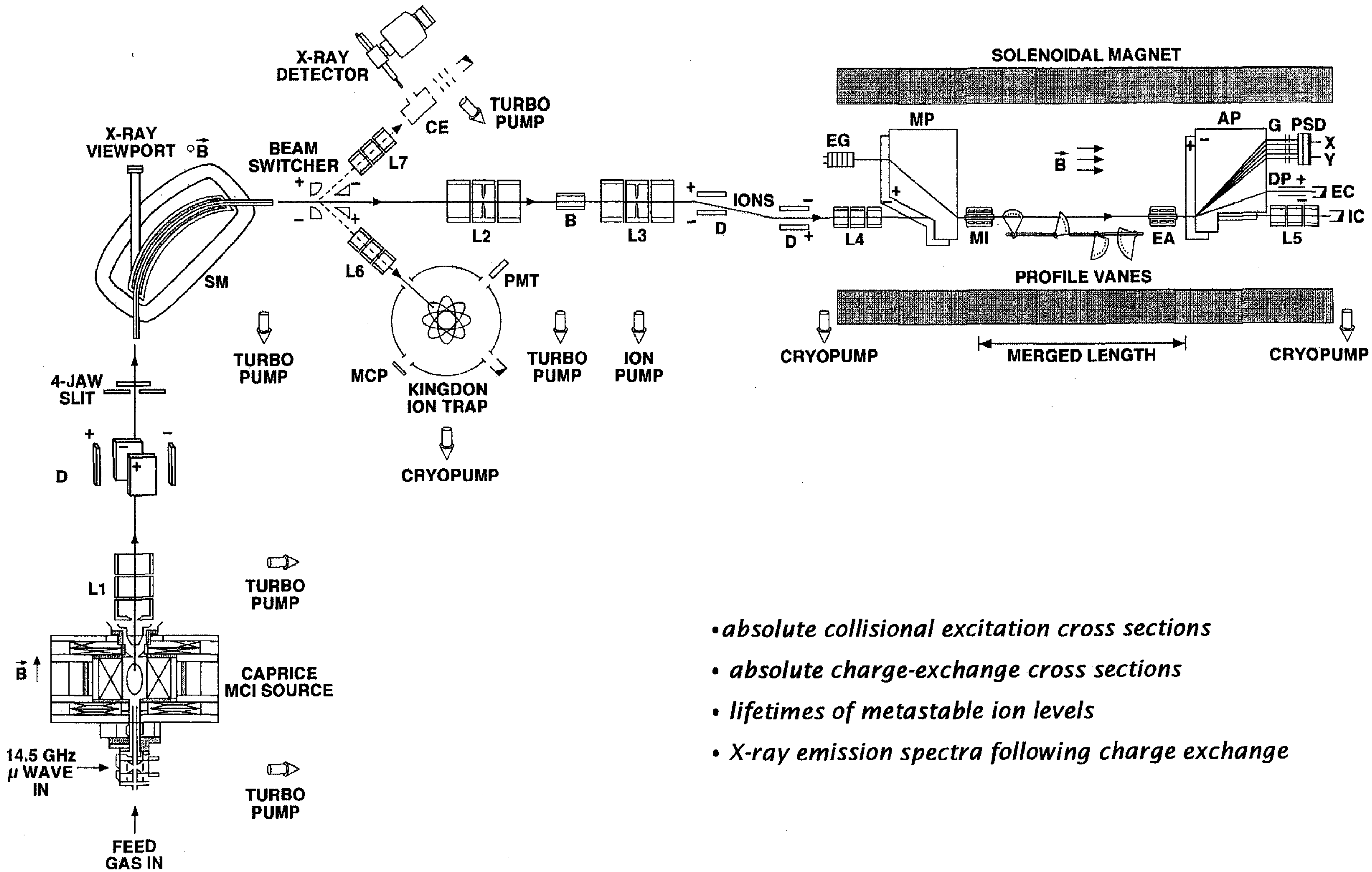
** = DW calculation (Mason et al 1979)*

—— = 15-state R-Matrix (Keenan et al, 1996)

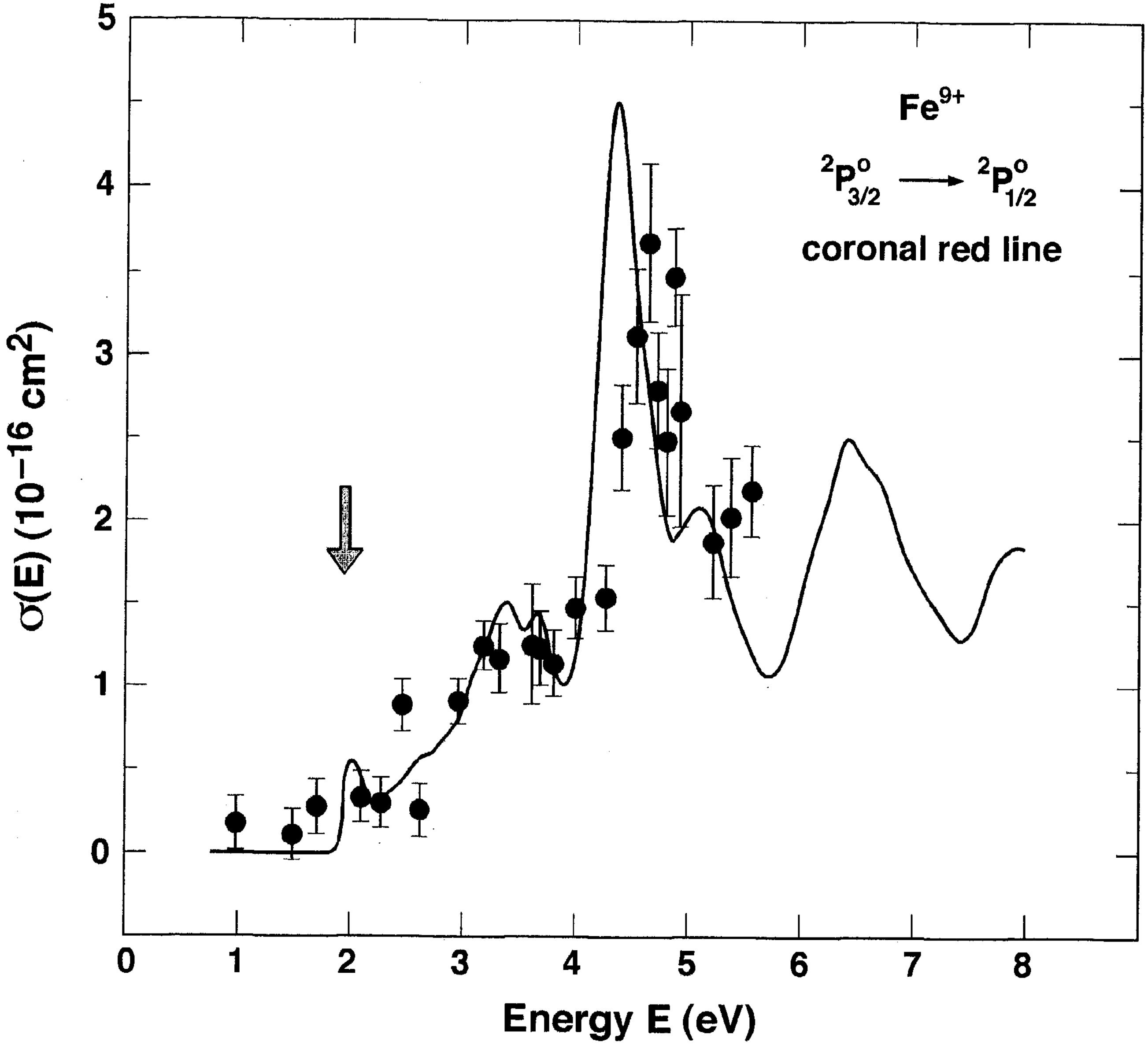
Highly-charged heavy ions present in the solar wind, and their abundance relative to the total oxygen-ion abundance (taken as unity) (adapted from Schwadron & Cravens, 2000).

HCI, X^{q+}	$[X^{q+}]/[O]$ fast	$[X^{q+}]/[O]$ slow	Energy (keV) fast	Energy (keV) slow
C^{6+}	0.085	0.318	35.0	9.95
C^{5+}	0.440	0.210		
N^{7+}	0.000	0.006	40.8	11.6
N^{6+}	0.011	0.058		
N^{5+}	0.127	0.065		
O^{8+}	0.000	0.070	46.6	13.3
O^{7+}	0.030	0.200		
O^{6+}	0.970	0.730		
Ne^{8+}	0.102	0.084	58.3	16.6
Ne^{7+}	0.005	0.004		
Mg^{10+}	0.029	0.098	70.0	19.9
Mg^{9+}	0.044	0.052		
Mg^{8+}	0.028	0.041		
Mg^{7+}	0.007	0.017		
Mg^{6+}	0.003	0.009		
Si^{10+}	0.024	0.021	81.6	23.2
Si^{9+}	0.045	0.049		
Si^{8+}	0.022	0.057		
Si^{7+}	0.002	0.000		
S^{11+}	0.001	0.000	93.3	26.5
S^{10+}	0.008	0.005		
S^{9+}	0.027	0.016		
S^{8+}	0.023	0.019		
S^{7+}	0.005	0.006		
S^{6+}	0.001	0.002		
Fe^{13+}	0.005	0.002	163	46.4
Fe^{12+}	0.017	0.007		
Fe^{11+}	0.025	0.023		
Fe^{10+}	0.025	0.031		
Fe^{9+}	0.015	0.041		
Fe^{8+}	0.005	0.034		
Fe^{7+}	0.001	0.007		

Plan of the JPL Highly-Charged Ion Facility



- *absolute collisional excitation cross sections*
- *absolute charge-exchange cross sections*
- *lifetimes of metastable ion levels*
- *X-ray emission spectra following charge exchange*



● *absolute excitation measurements (JPL, Niimura et al 2002)*

—— *49-state Breit-Pauli calculations*

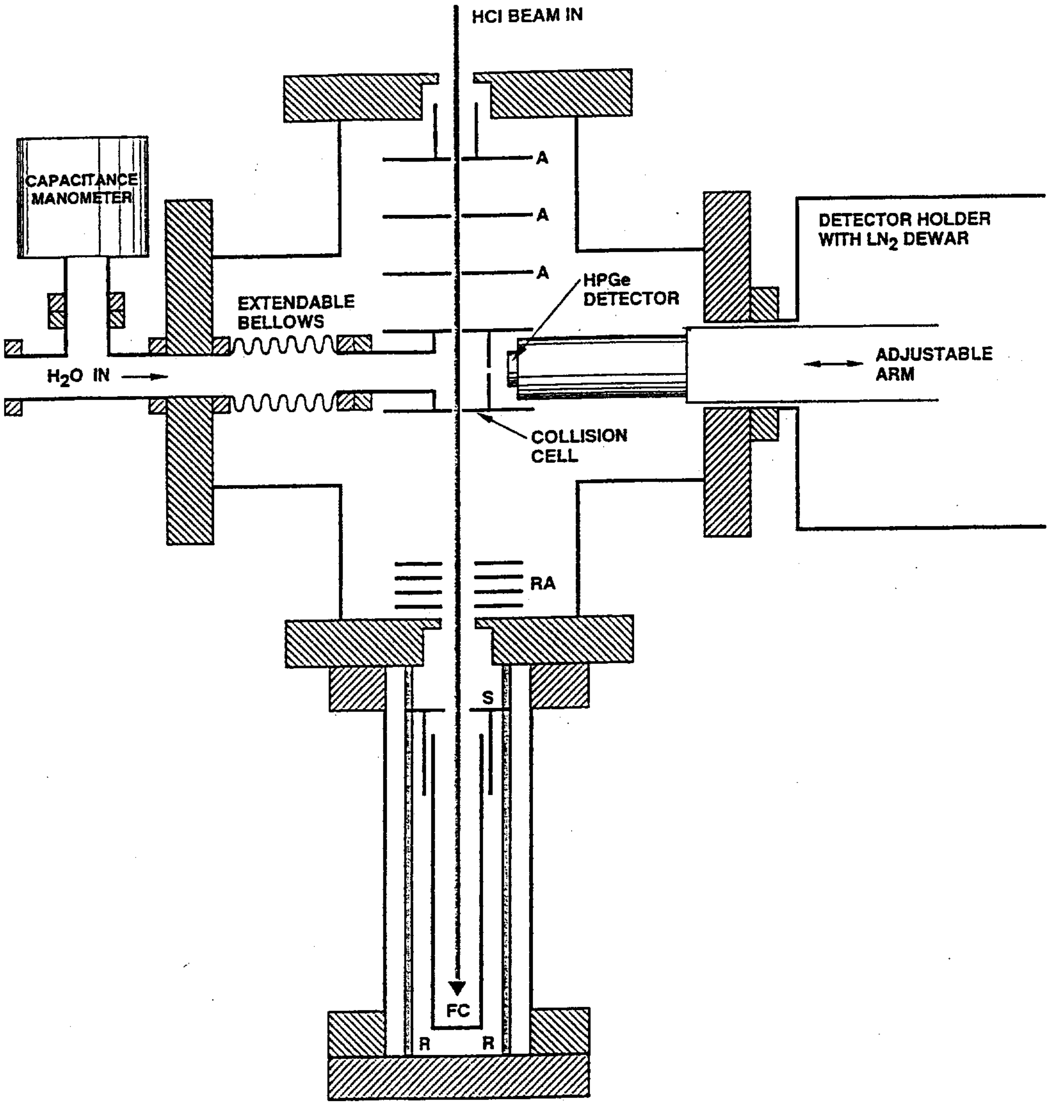


FIG. 1. Details of the charge-exchange beamline. The definitions are A, input HCI beam-defining apertures; RA, retarding-field apertures; S, secondary-electron shield; FC, Faraday cup; R, support rods; LN_2, liquid nitrogen.

$$V_R=\frac{qV_0}{(q-j)}, \tag{2}$$

where V_0 is the source voltage. Thus, it is possible to reflect the primary ion beam while charge-exchanged ions are transmitted. By raising this reflecting potential, ion currents from single and multiple charge exchanges are measured. This electric field is produced by a series of four apertures, the center two are held at the required reflecting potential, the end two at ground potential. The apertures have a large diameter and are widely spaced to give field lines that are almost parallel near the beam axis. They are also placed close to the Faraday cup to ensure that all transmitted ions are collected.

The pressure of gas in the cell is held low so that only about 1% of the ion beam charge exchanges, ensuring single-collision conditions. The cross section for the charge exchange is determined from the relationship

$$\sigma_{q,q-j}=\frac{kT}{PL}\frac{qI_{q-j}}{(q-j)I_q}, \tag{3}$$

where L is the collision length, T the gas temperature, I_q and currents I_{q-j} are measured in the same Faraday cup using the same electrometer and scale. Hence any systematic error in the absolute current measurement is eliminated in the above formula. This is an advantage over the use of channel-type multipliers, for which a linear response to ion current must be assumed. Electrometer and capacitance manometer zero offset and drift are taken into account when making measurements.

Errors in the measurements mainly arise from the pressure measurement and instability of the ion beam. As I_{q-j} and I_q cannot be measured simultaneously, a drift in ion beam current is unwelcome. In practice I_{q-j} and I_q are measured alternately multiple times, and the measurements of $\sigma_{q,q-j}$ are averaged. The standard deviation of these results is used to determine the random error due to the variability of the ion beam.

A 2-mm aperture in the cell wall allows x-rays to escape. A high-purity Ge solid state EG&G IGLET-*X* detector [43] with a high detection efficiency and moderate resolution is located at right angles to the beam axis. A 7.5-μm-thick Be window isolating the detector from the vacuum chamber introduces a transmission factor dependent on the energy of the x rays. The detector can be translated inside a flexible bel-

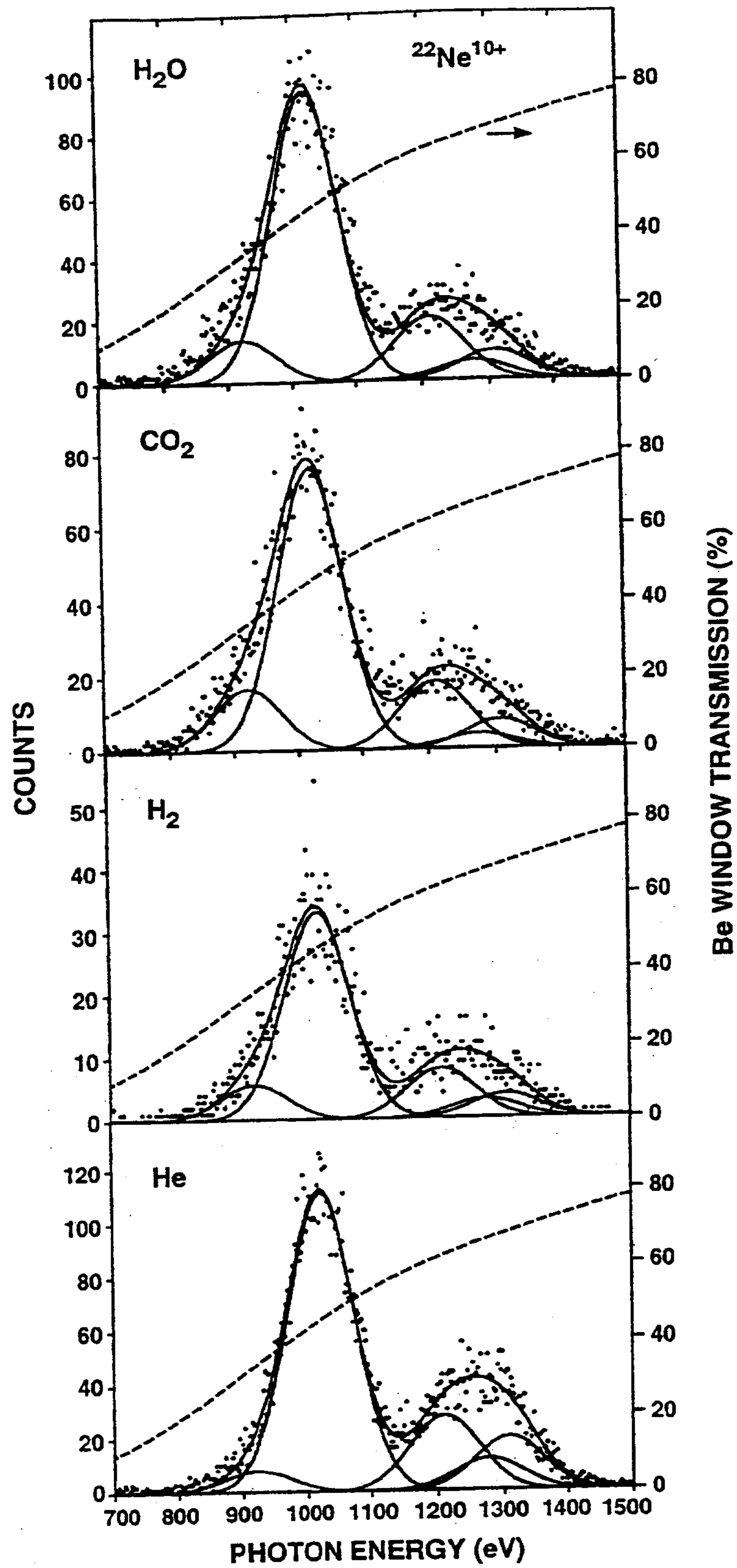


FIG. 4. X-ray spectra from collisions of Ne^{10+} in He, H_2, CO_2, and H_2O, uncorrected for transmission of the Be window on the Ge x-ray detector (given as a dashed line). The underlying curves are the Ly transitions $np \rightarrow 1s$.

$$I_0(1-P\cos^2\theta) \qquad (6)$$

have $P=0.6$. Given t
expected that alignme
for these transitions.

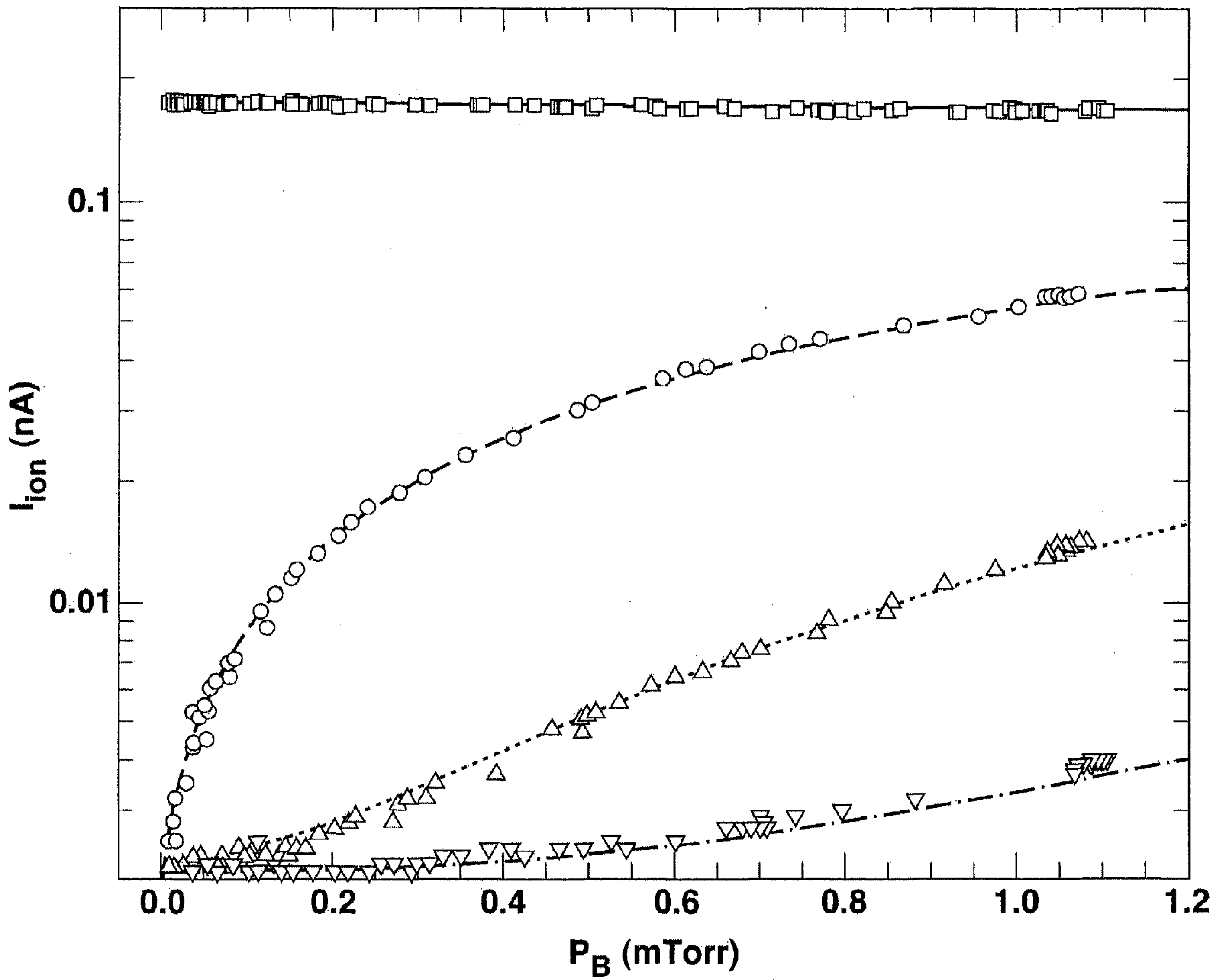
The relative contri
mined from the area
divided by the transm
izing the total spectru
sion cross sections w
line-emission contrib
are shown in Tables I

The x-ray spectra
consists of contributi
ture. Cascading follo
tions from p orbitals
proportion of these c
$2s$ metastable level t
area. By assuming a
branching ratios dete
state. If a statistical
fraction is less than 3
lation it is less than 5

Double capture ca
leading to He-like L
which preferentially
[29], enhancing the
from Figs. 4 and 5 th
trum. Its intensity i
lower ionization po
value of the initial n

With the scheme
obtain information al
of the initial capture
oretical predictions o
cluding a statistical p
contributions from t
From this analysis th
used to obtain a valu
It should be noted th
contributions from a
to enhance the Ly α
be regarded as uppe

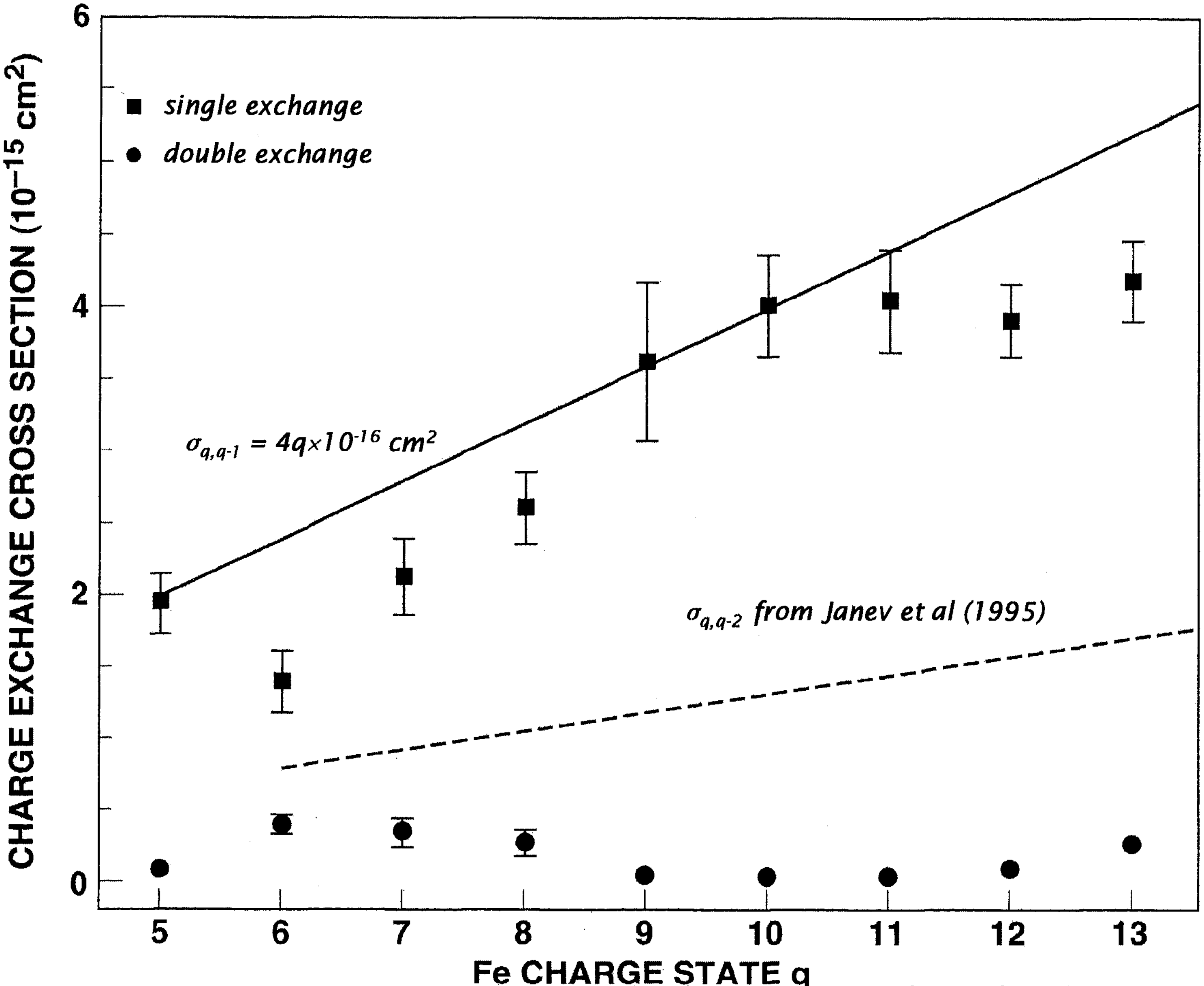
The results show
consistently lower th
tion. This is not surp
tron would not have
sion velocity of 0.3
$l=n-1$. The values
predictions of the o
barrier term [21]



Ion-Current Variation with target gas pressure for 84 keV $^{56}Fe^{12+}$ in He

□ V_{retard} = 6.0 kV   △ V_{retard} = 8.0 kV

○ V_{retard} = 7.4 kV   ▽ V_{retard} = 8.8 kV



Cadez et al, J. Phys. B., in preparation

Radiative lifetimes (τ = 541 ms) in the M1 transition $2s^2 2p^2$ $^1S_0 \rightarrow {}^3P_1$ at 232.17 nm (Smith et al, PRA, to be submitted).