DE LA RECHERCHE À L'INDUSTRIE

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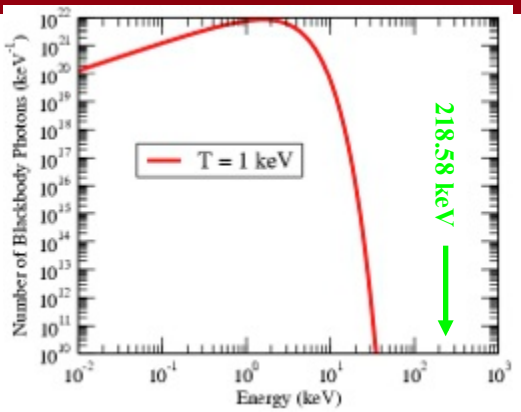
Indirect Deexcitation Of ^{84}Rb in a Plasma Created at PHELIX

The Final Experiment ?

γ detector



Phelix

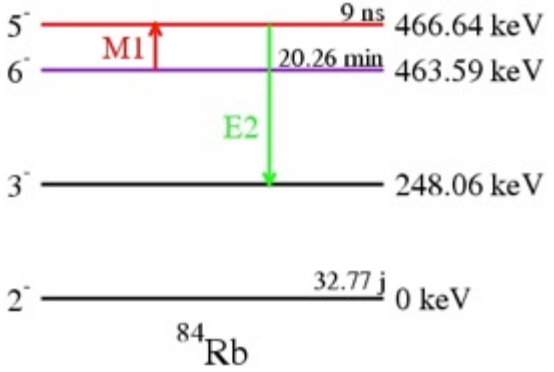
^{11}B

GSI

1 hour

^{76}Ge

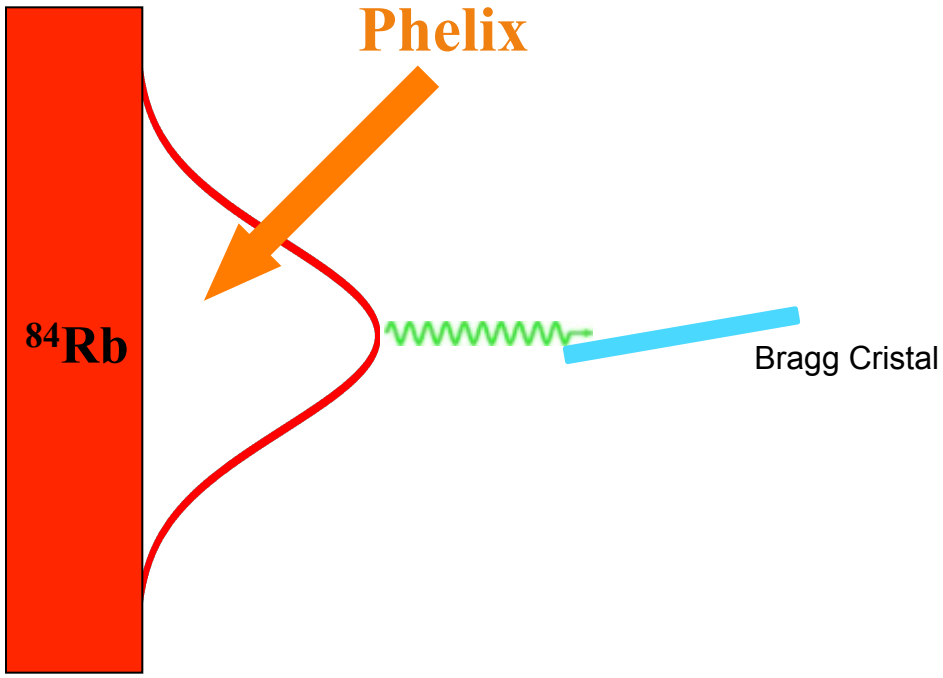
γ : E=218.58 keV



$^{76}Ge(^{11}B,3n)^{84}Rb^{m}$

CEA-CENBG-GSI Collaboration

The Preliminary Experiment



CEA-CENBG-GSI Collaboration

Spectrum Evaluation

- NEET Evaluation
  - Nuclear Transition Energy : 3.05 keV now 3.50 keV
  - Requires precise knowledge of atomic transition energy
- MCDF (Multi-Configuration Dirac-Fock)
  - Hamiltonian diagonalization for each J
  - Precise atomic energies $\frac{\Delta E}{E} \approx 10^{-3}$
  - Very Long Calculation Times
  - Not the best way to get a spectrum
  - Is probably best to get line energies for NEET calculations

Spectrum Evaluation

- Spectrum

$$S(E) = \sum_{Q} P_Q \sum_{i} P_i \frac{\Gamma}{(E - \Delta E_i)^2 + \frac{\Gamma^2}{4}}$$

- Configuration Probability : Grand Canonical Partition Function

$$P_Q P_i = \frac{(2j_i + 1) e^{-\frac{E_i}{kT} - Q\eta}}{\sum_{k} (2j_k + 1) e^{-\frac{E_k}{kT} - Q\eta}}$$

η : reduced chemical potential

Configuration Interaction

Configuration Interaction (CI)	With	Without
Definition	(n,l) (not j)	(n,l,j)
	$(1s)^2\ (2s)^1\ (4p)^1$ ➔ $(1s)^2\ (2s)^2$	$(1s_{1/2})^2\ (2s_{1/2})^1\ (4p_{3/2})^1$ ➔ $(1s_{1/2})^2\ (2s_{1/2})^2$
Calculation Time	Long (very long…)	Long (much less so…)
Configuration Number	Not so Huge	Huge
Precision	Even Better	Quite Good

Spectrum Evaluation

- Configuration Numbers
  - Electrons from n=1 to n=6
  - Transitions : n=3,4,5,6 ➔n=2
  - Initial Configurations : 1s filled

Charge State	With CI	Without CI
	(All Transitions)	($3s_{1/2}$ to $2p_{1/2}$ only)
34+	19	1
33+		33
32+		559
31+		6,741
30+	32,699	57,520
29+	127,956	418,359
28+	444,310	2,591,331
27+	1,395,835	14,049,302
26+	4,026,185	68,016,688

Configuration Selection is **mandatory**

Configuration Selection

- Goal : Eliminate the less probable configurations
  - Problem : Partition function cannot be evaluated yet
    - Configurations probabilities are unknown
  - Configuration probability estimation: Bernoulli
    - Sub-shells occupation from average atom model

$$P_i \approx \prod_k C_{D_k}^{n_k} \left(p_k\right)^{n_k} \left(1-p_k\right)^{D_k - n_k}$$

  - Configurations are ordered by decreasing probability

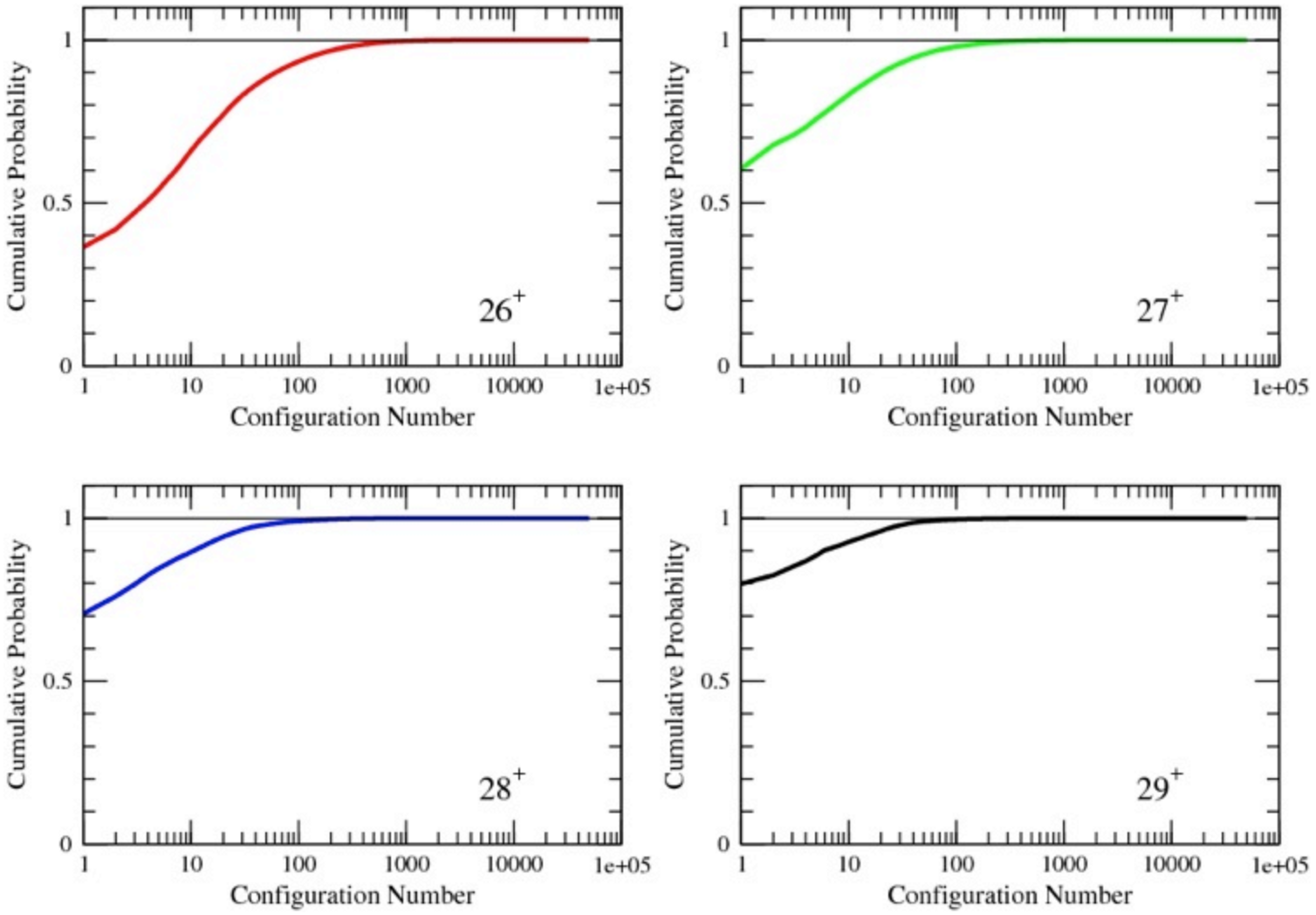
$$P_1 > P_2 > P_3 > \ldots > P_N$$

  - Configurations selection under cumulated $P_{threshold}$

$$\sum_{k=1}^{N_{sel}} P_k \geq P_{threshold}$$

Configuration Selection

T_e = 270 eV

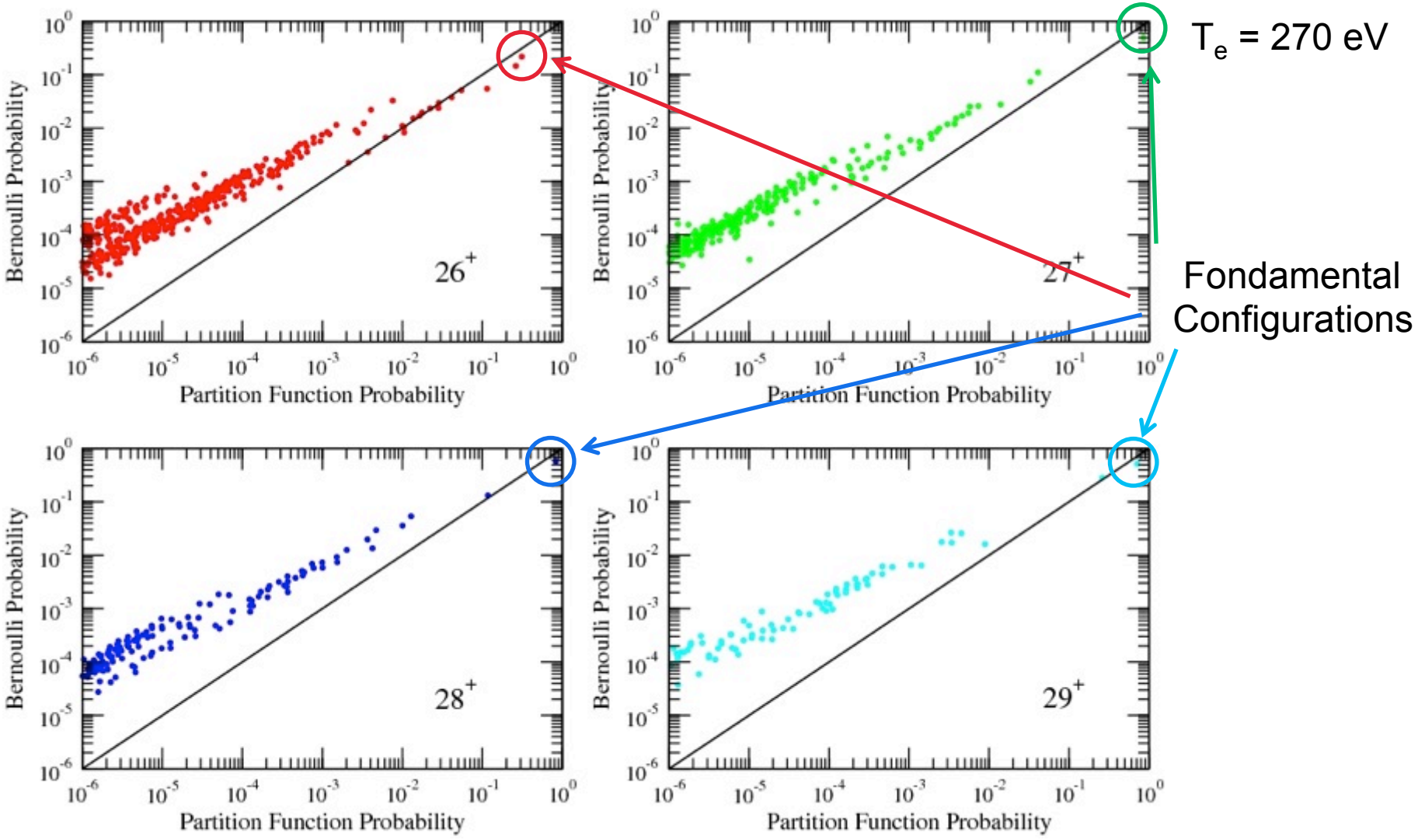


Configuration Selection

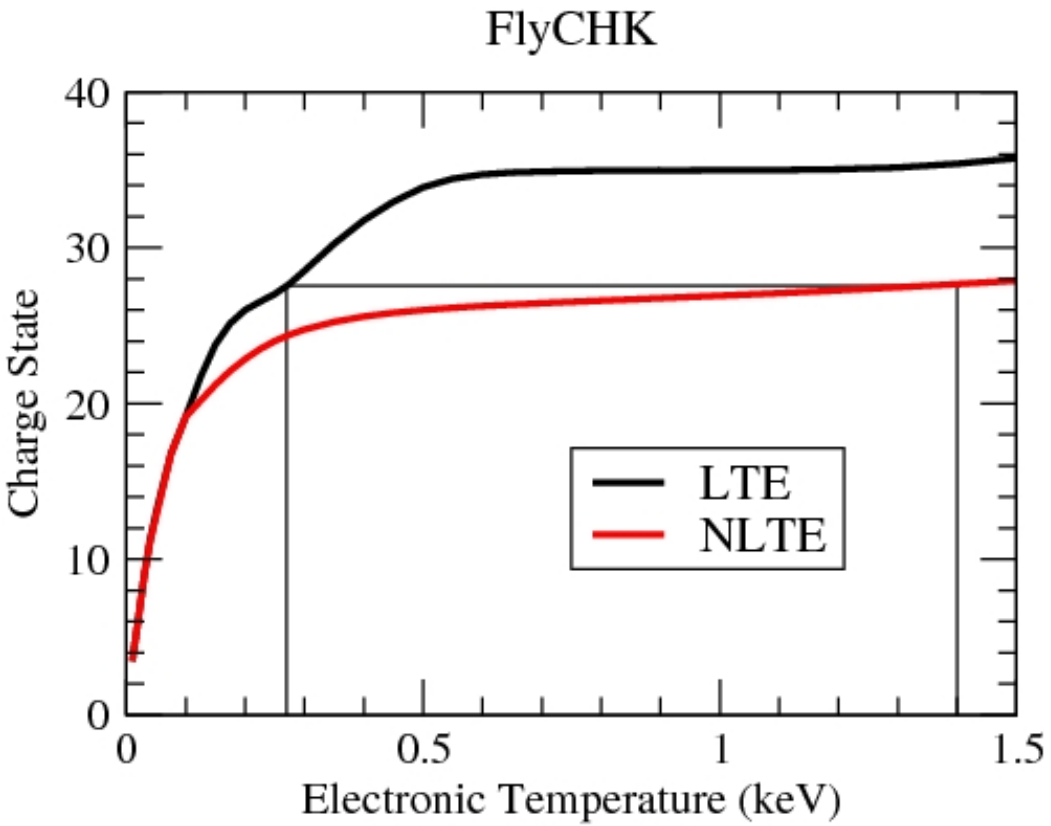
- Configuration Numbers
  - Initial Configurations : 1s full, electrons from n=1 to n=6

Charge State	With CI (All Transitions)		Without CI ($3s_{1/2}$ to $2p_{1/2}$ only)	
	Total	Selected (99,9 %)	Total	Selected (99 %)
34+	19	19	1	1
33+	190	180	33	3
32+	1,325	397	559	5
31+	7,220	869	6,741	6
30+	32,699	1,529	57,520	12
29+	127,956	1,956	418,359	19
28+	444,310	1,704	2,591,331	30
27+	1,395,835	2,821	14,049,302	37
26+	4,026,185	5,225	68,016,688	87

Bernoulli vs Partition Function



Charge States under Non LTE Conditions



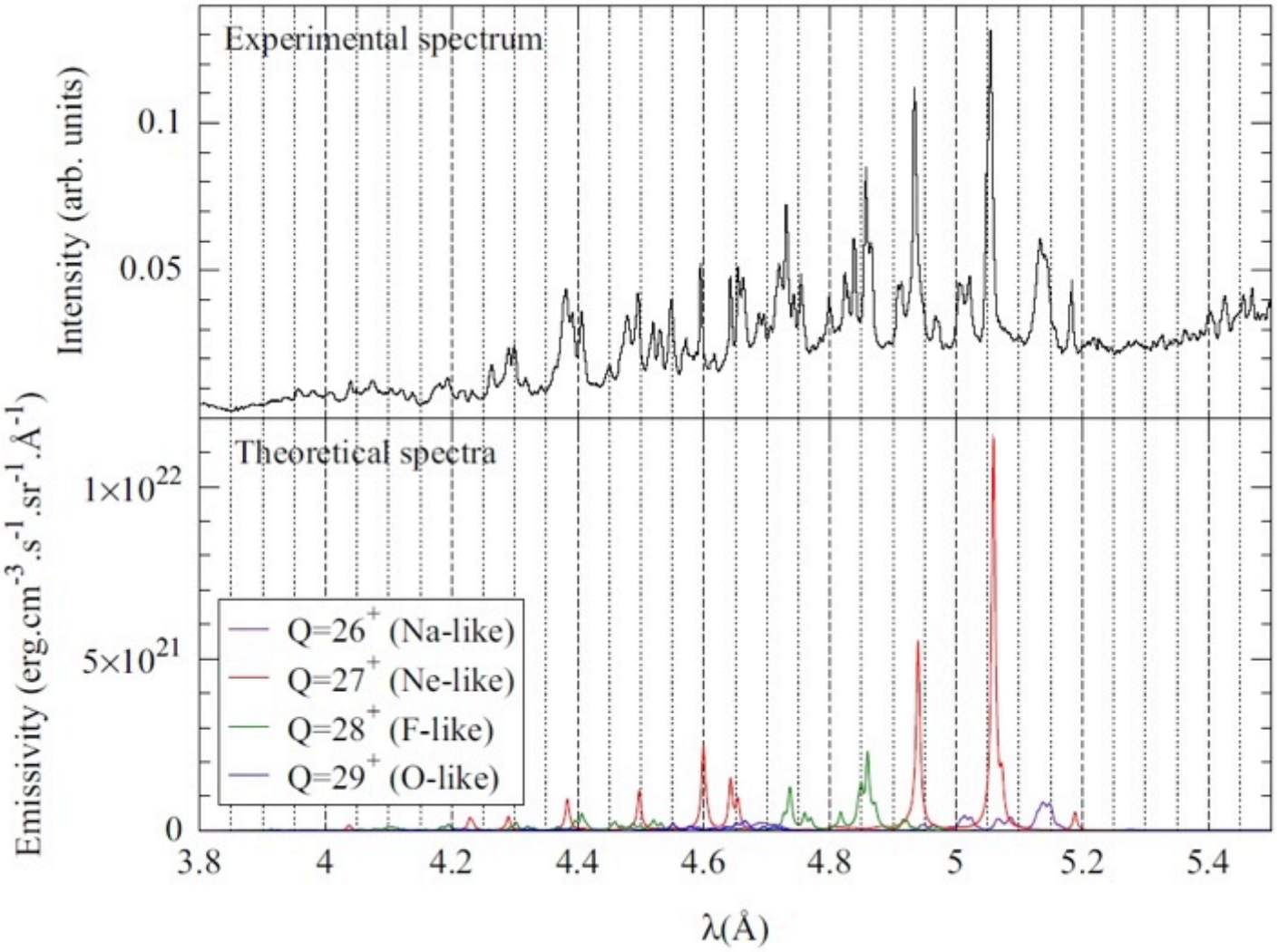
T_z = 270 eV
T_{HETL} = 1.4 keV

Ionic Fraction

Q	P_Q
26^+	8.48 %
27^+	39.5 %
28^+	39.1 %
29^+	11.0 %
30^+	1.05 %

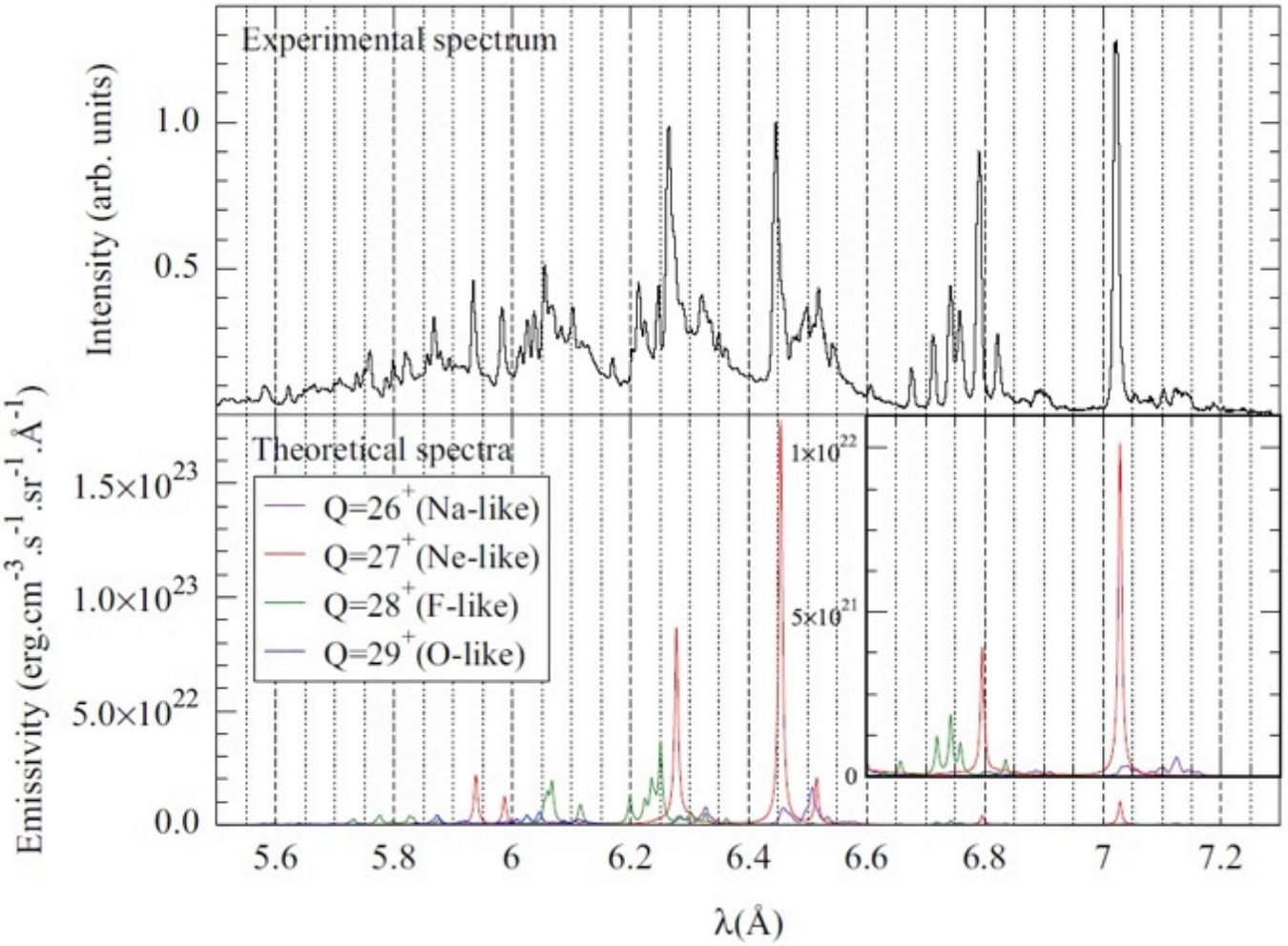
From AVERROES & FlyCHK

Experimental Spectrum vs MCDF Spectrum (no CI)



D. Denis-Petit et al., JQSRT 148 (2014) 70-89

Experimental Spectrum vs MCDF Spectrum (no CI)



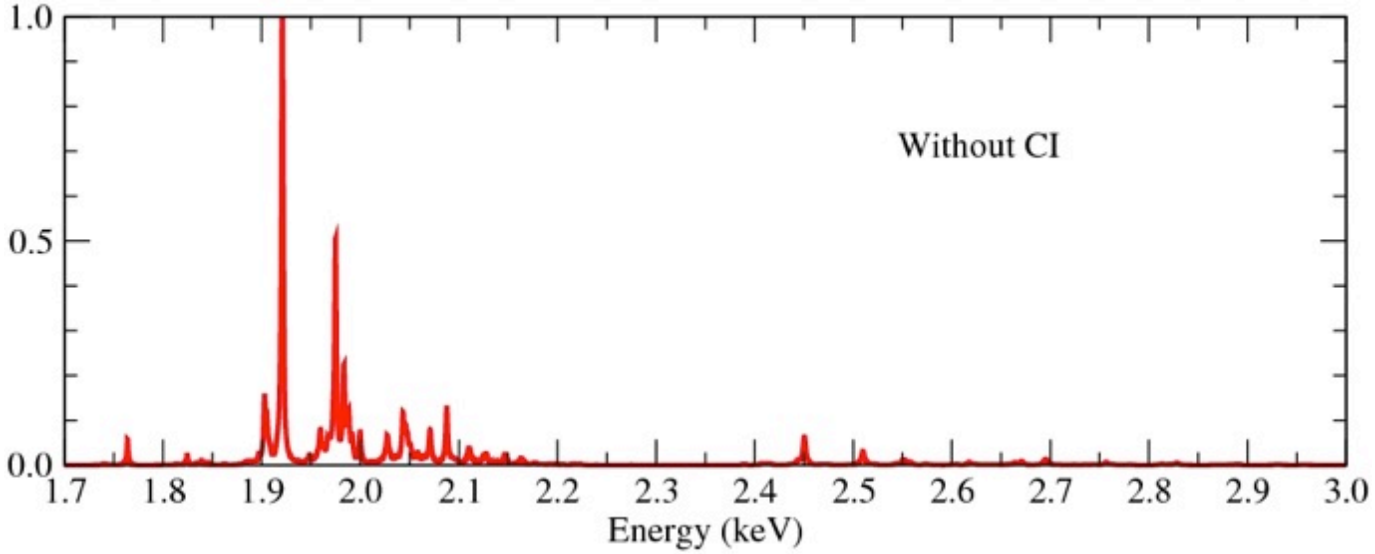
D. Denis-Petit et al., JQSRT 148 (2014) 70-89

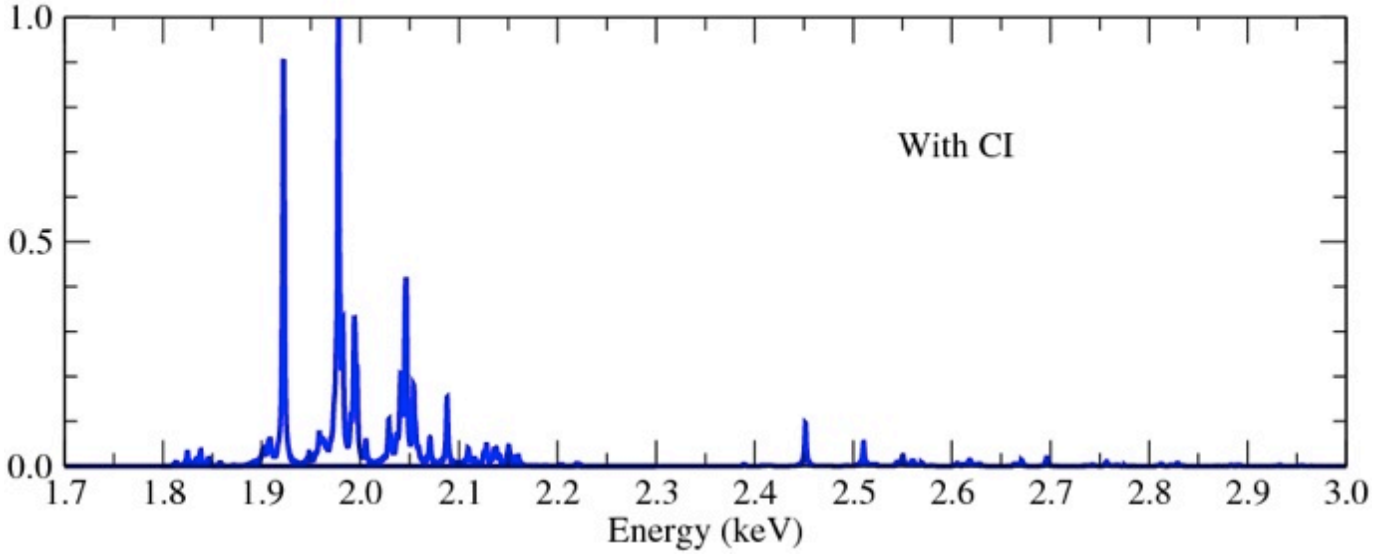
Spectrum Analysis

- Most lines have been identified
  - Energy, initial configuration, angular momentum
  - More than 50 new lines previously unidentified
- Charge states distribution
  - Ionization temperature model is fine
- Line intensities are globally good within a factor of 2 or 3
  - Exception around 7 Å

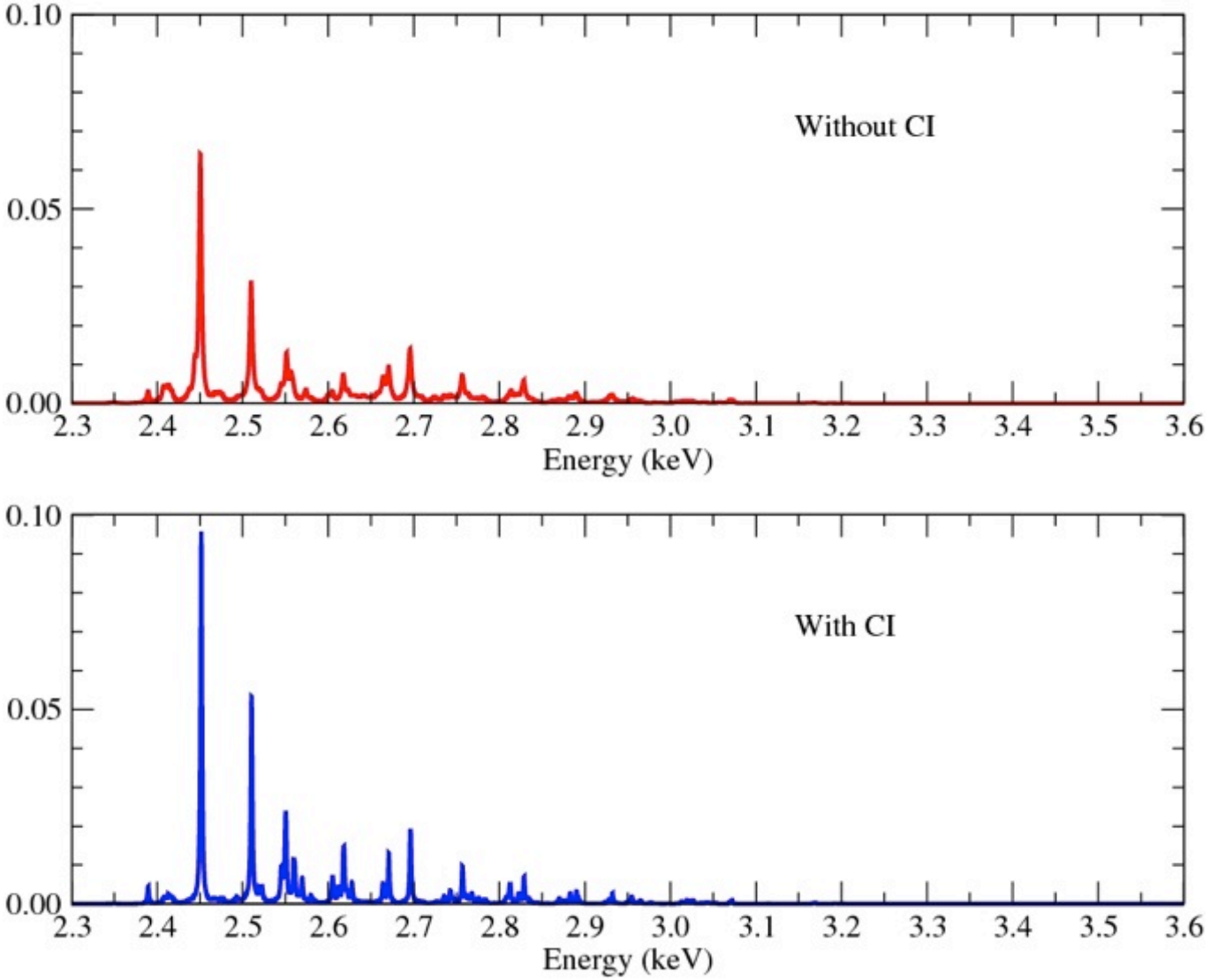
Spectrum with CI vs without CI

T_e = 270 eV





Spectrum with CI vs without CI

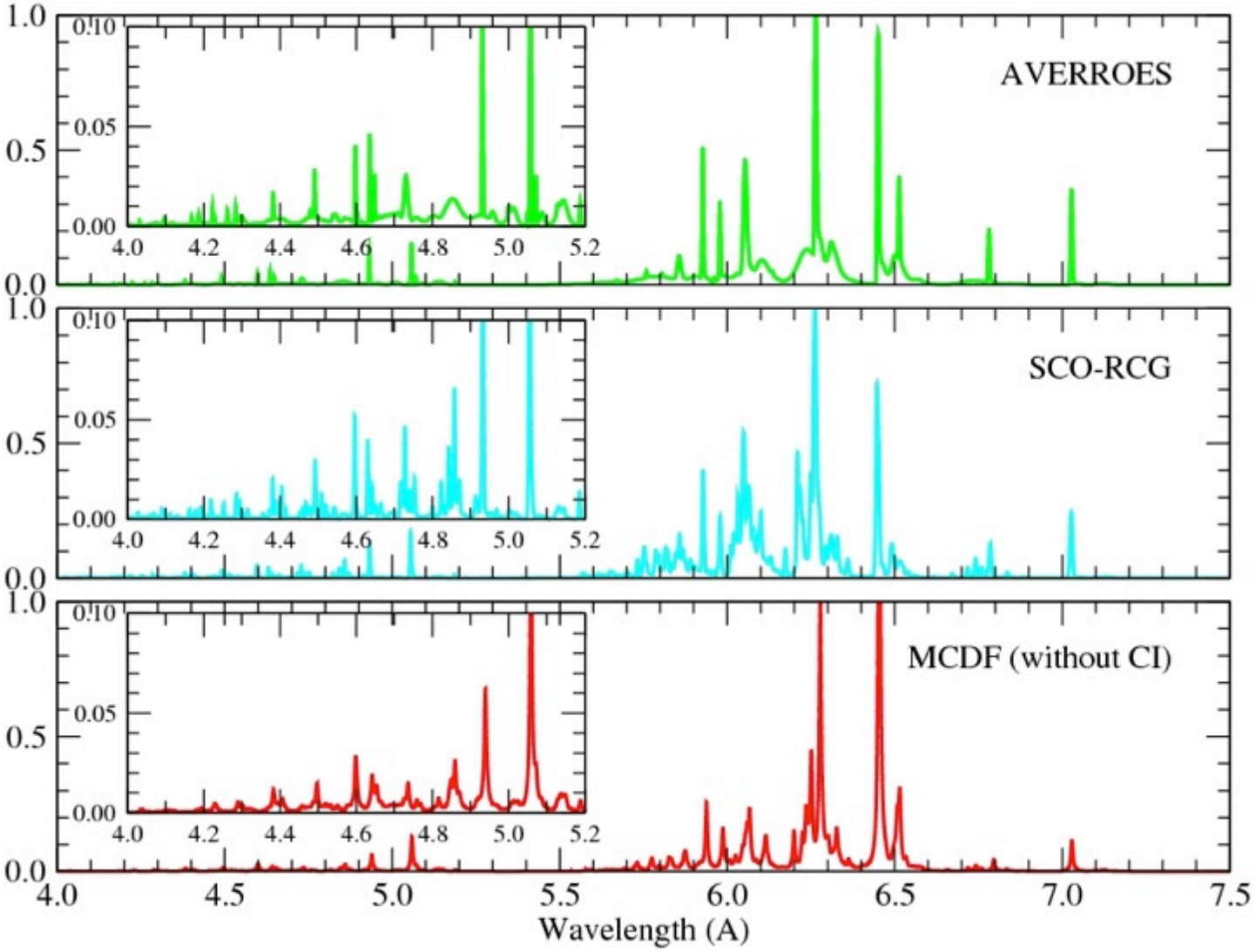


T_e = 270 eV

Alternative Atomic Physics Models

- AVERROES
  - Superconfigurations approach
  - Native non-LTE
  - Partial LTE within superconfigurations
- SCO-RCG
  - Combines statistical and detailed approach
  - SOSA (Spin Orbit Split Array)
  - Transition arrays subdivided into sub arrays (SO effect)

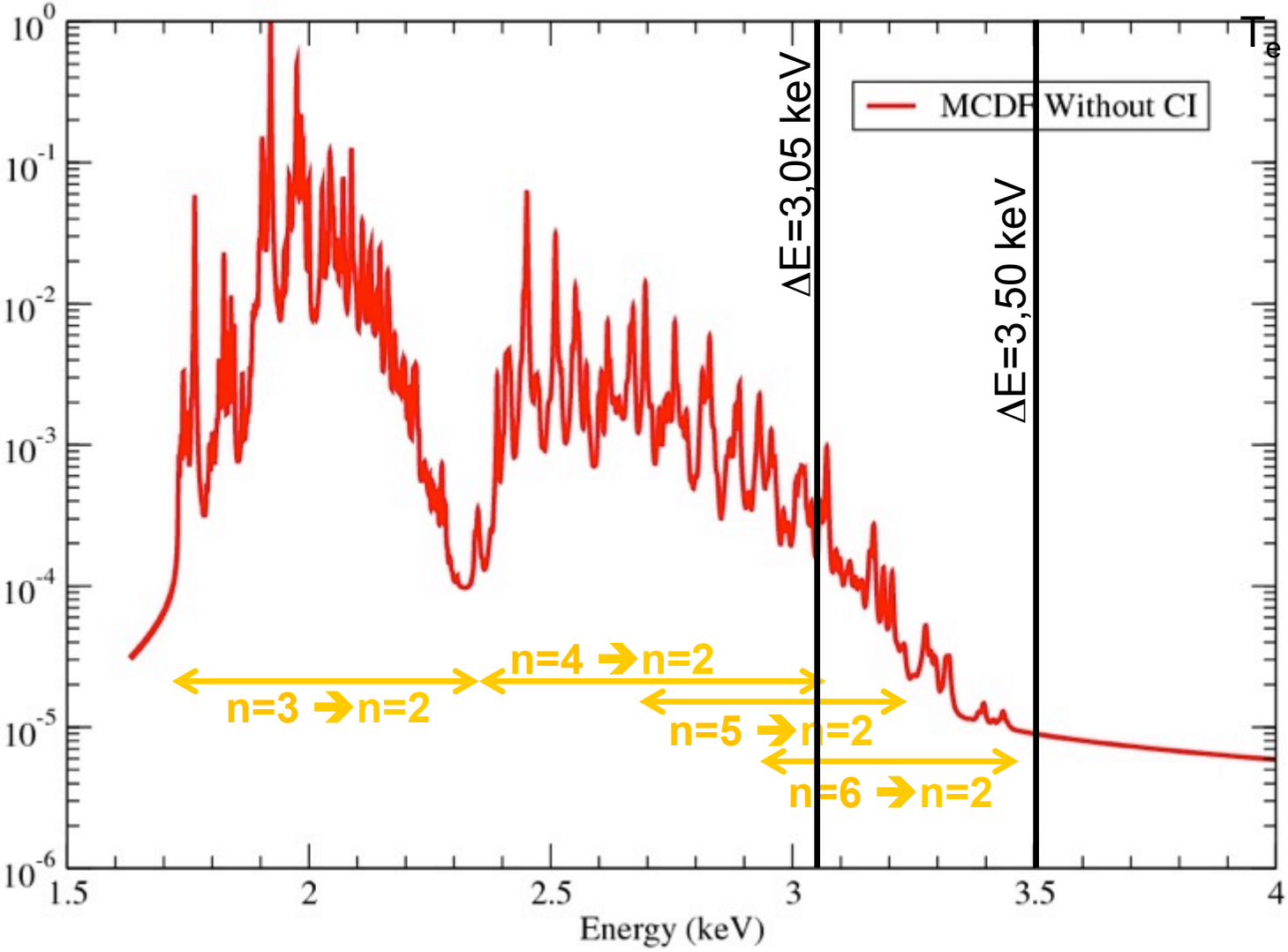
Spectrum



T_e = 270 eV

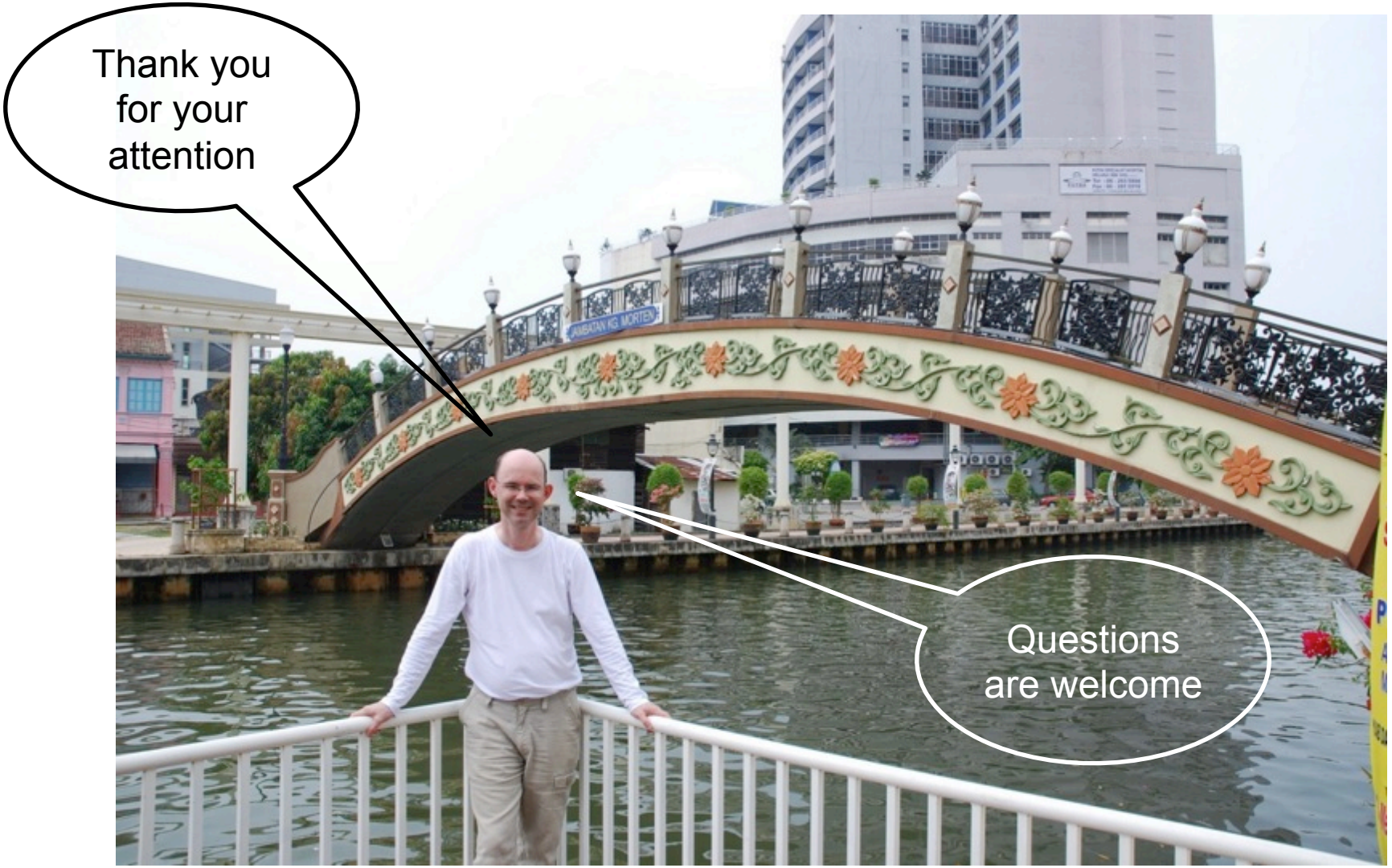
AVERROES and SCO-RCG : Courtesy of F. Gilleron & J. C. Pain

What about the new transition energy ?



Conclusion & Perspectives

- Experimental spectrum is well restituted
  - MCDF calculations with or without CI
  - Very time consuming
  - Agreement with AVERROES calculations
- Rubidium 84 is probably not the best candidate
  - n=4,5,6 ➔n=2 nearly impossible with ΔE=3,50 keV
  - Higher transition energy than expected
  - Optimum Charge state for NEET is now $30^{+}/32^{+}$
- Future NEET calculations
  - Will require MCDF with CI
  - Alternate ADAM model (see next talk with M. Comet)


Thank you for your attention
Questions are welcome