Nuclear Beta-Decay of Highly-Ionized Heavy Atoms in Stellar Interior PART II

Kohji Takahashi @Giulianova/13.07.2025

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1. THE AIM

As in PART I

(KT & Yokoi 1981~1987)

+ M.Arnould ULB 1983~ for astrophyical applications

Theoretical Predictions of the Transition Rates of Nuclear ß-Decays in the S-Process Environments

Nuclear ß-decays modes

M Arnould and K Takahashi

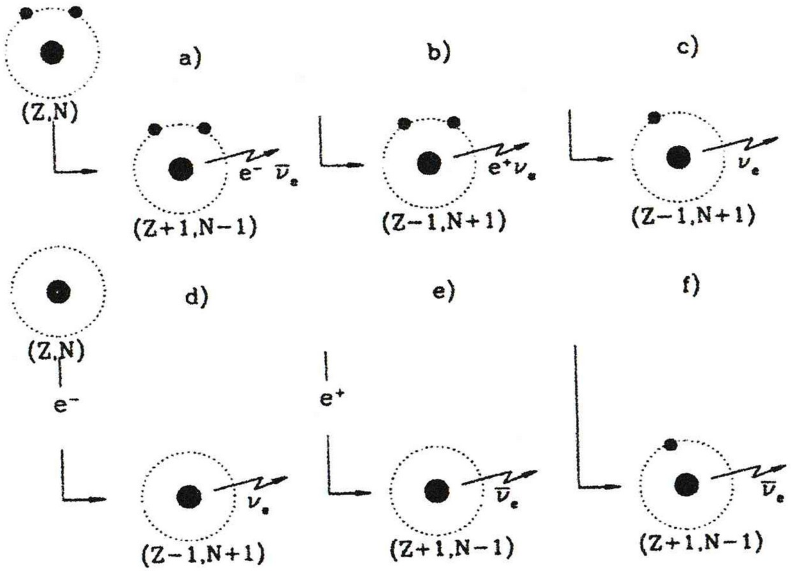
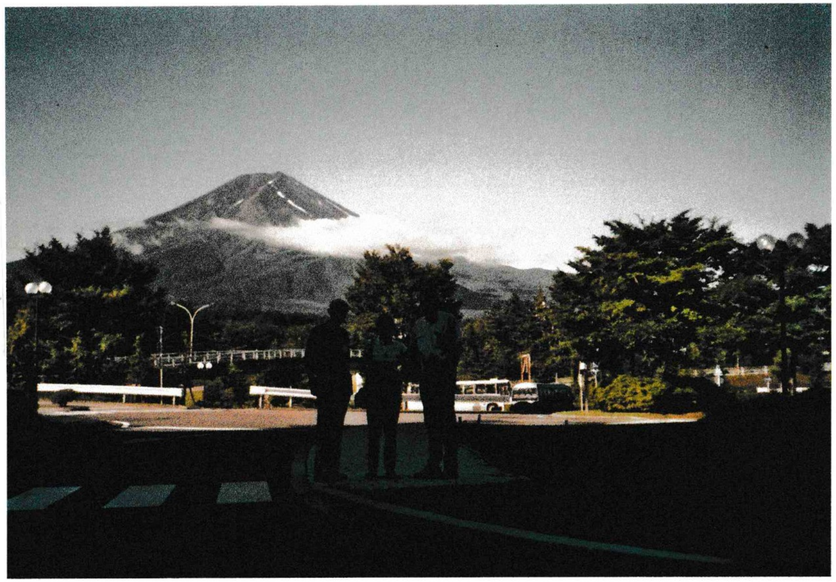
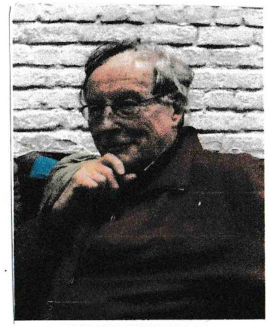


Figure 12. Various nuclear β-decay modes: (*a*) β^- decay, (*b*) β^+ decay, (*c*) orbital-e^- captu (*d*) continuum-e^- capture, (*e*) continuum-e^+ capture, and (*f*) bound-state β decay. The proce (*a*)–(*c*) are the usual decay modes in the laboratory, while (*d*)–(*f*) can occur under stellar conditi

2. Why Now?

Personally: --- in memory of





Franz Kappeler (1942-2021) & **Michael J. Pearson** (1933-2024)

Technically:

Computational limitations encountered in PART I

**= not only in CPU time,
but also the infrastructures and budgets!**

→ solved in the advent of high-performance PCs

(in buttering-up mode)

*** Theoretically: Advanced s-process models**

- **Low-Mass Stars (~ 2002: FRANEC)**

- **Intermediate-Mass Stars (post-I.Iben, @ULB)**

- **Massive Stars (2001~ 2009: @ Clemson)**

*** Experimentally:**

- **Bound-State Beta-Decays @ GSI storage-ring**
- **Pandora Project @ lns.infs ECRIS**

Comments **on** **B**ound-**S**tate-**B**eta-**D**ecays Measured @ GSI

Terrestrial !

- ^{163}**Dy**$^{+63}$ (1992) (- **stable if neutral**) → ^{163}**Ho**$^{+63}$
  $t_{1/2}$ = 47 ± 5 d vs. 50 d (KT+ 1988) cf. **R. A. Ward**(^{164}Er ☼ problem)

- ^{187}**Re**$^{+75}$ (1996) (-long-lived (**50*10^9 yr**) **if neutral**) → ^{187}**Os**$^{+75}$
  $t_{1/2}$ = 33 ± 2 **yr** vs. 42 yr cf. + **Arnould** (r-process Chronometry)

→ *f t* –value : lepton phase volume (theoretical) x

the measured half-life **=** (Nuclear Matrix Elements)$^{-1}$

ft (terrestrial) → ***f*_☼ *t*** (stellar)

$^{205}Tl^{+81} \rightarrow {}^{205}Pb^{+81}$ **(G.Leckenby++Y.Litvinov++ 2024)**

→ **Detector for Solar-Neutrino Problem (Freedman,1986)**

→ **S-Chronometry in the Early Solar System (+ Arnould 1985)**

log-ft-values:

Measured: 5.9

PART I: 5.4

Ogawa & Arita (nuclear shell model, 1988)

5.3 valence nucleons

6.0 + the core polarisation – perfect!

→ **needs some improvements e.g.**

*** compare s-process models/codes**

*** consider chemical evolution (e. g. Schramm-Wasserburg 1970)**

Comments on PANDORA Project @ lns.infs ECRIS

***As I understand*:**

- valuable to calibrate temperature-dependence of predicted ß⁻ decay rates in the 0.01 keV ~ 100 keV range

- if no appreciable density-dependence (i.e high Q-value)

- must involve γ- rays one way or another

Please shout if I am wrong!!

3. EMPHASIS

A: Extensions to

* **Higher Temperatures ($T8 > 5$) :**
at least increases nuclear-physics uncertainties

* **Lower Densities ($\rho Ye < 166$ g/cm^3):**
at least increases atomic-physics uncertainties

B: Evaluating Atomic-Physics Uncertainties

by relying on:

Relativistic Self-Consistent Mean Field Method

(Hartree-Fock-Dirac Liberman et al., 1971)

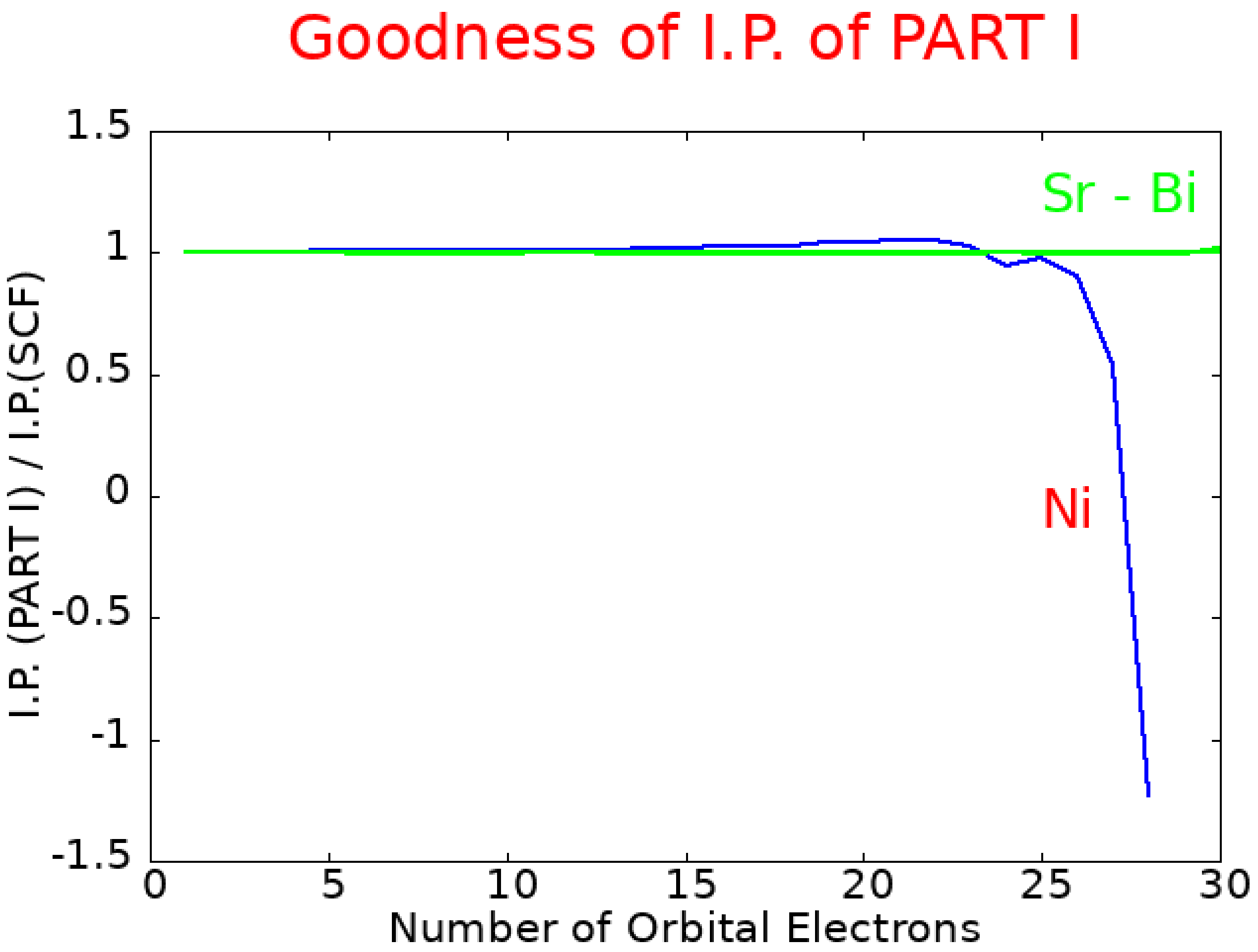
EXAMPLES that follow:

(1) Ionization Potentials

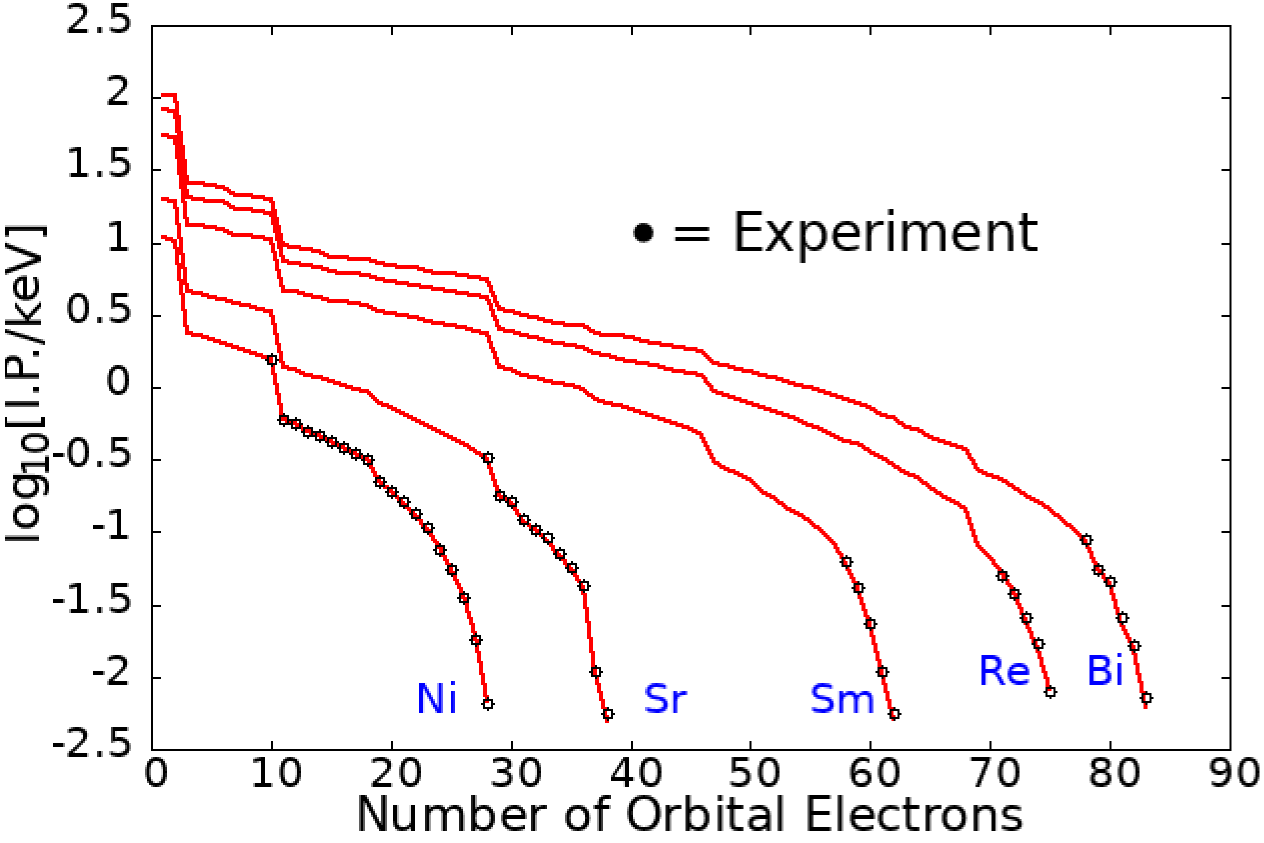
(2) Positrons?

(3) Saha (LTE) Ionization Equation

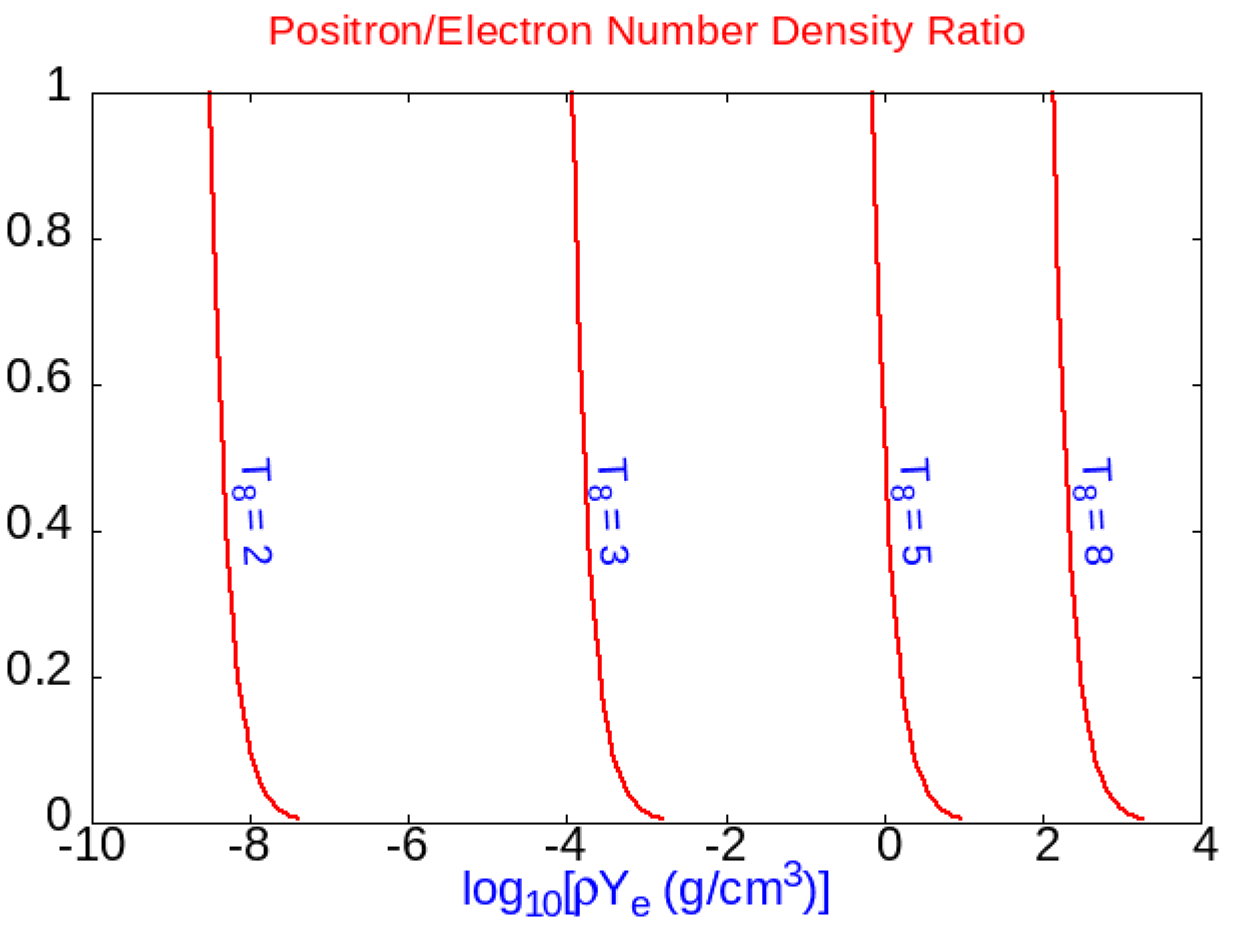
(1) Ionisation Potentials



Hartree-Fock-Dirac I.P.



(2) Positrons (in High-Temperature, Low-Density Regime)



(3) SAHA Equilibrium Equation (Os ions)

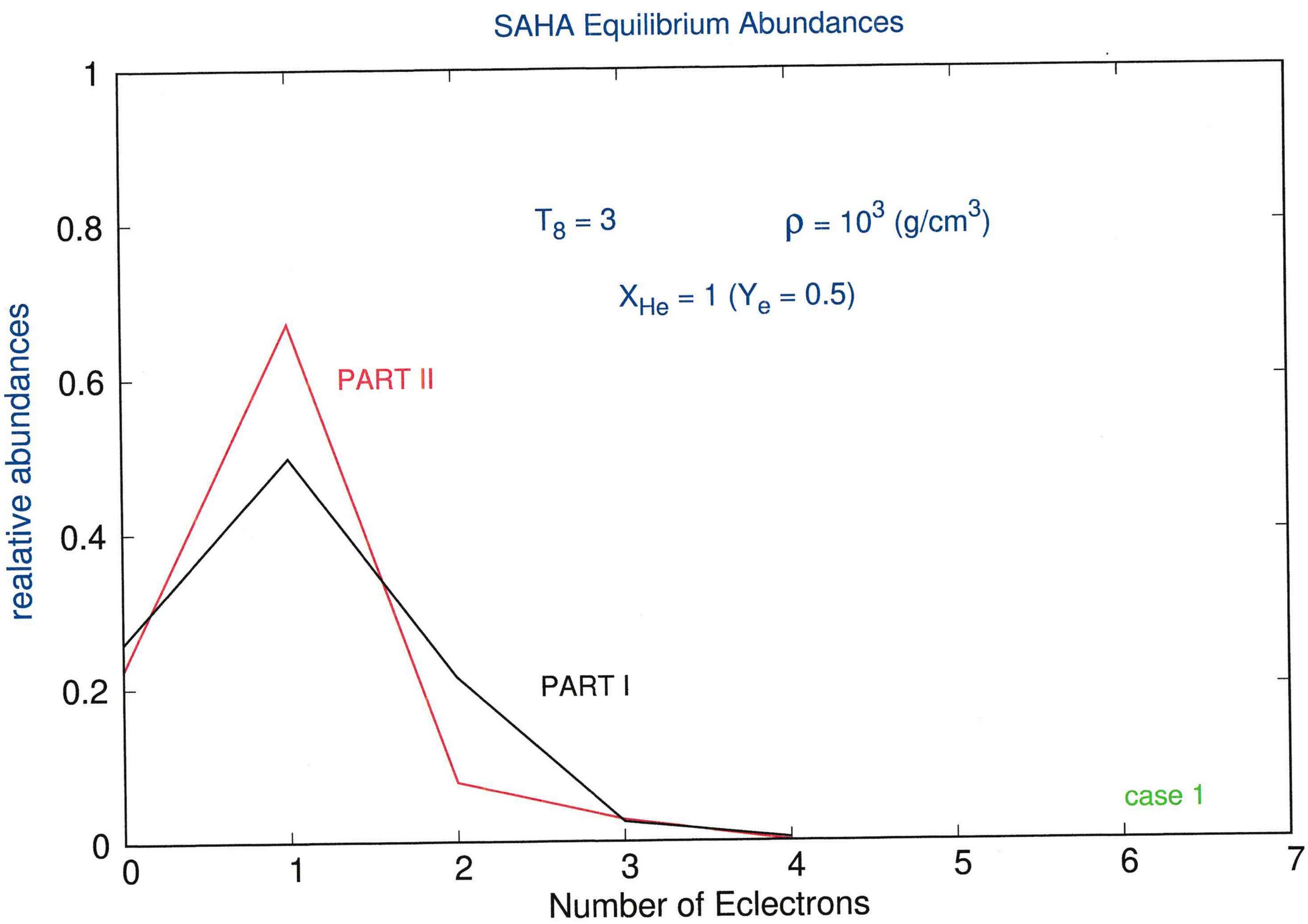
case 1: T8 = 3 ρ = 1000 (g/cm^3) Ye = 0.5

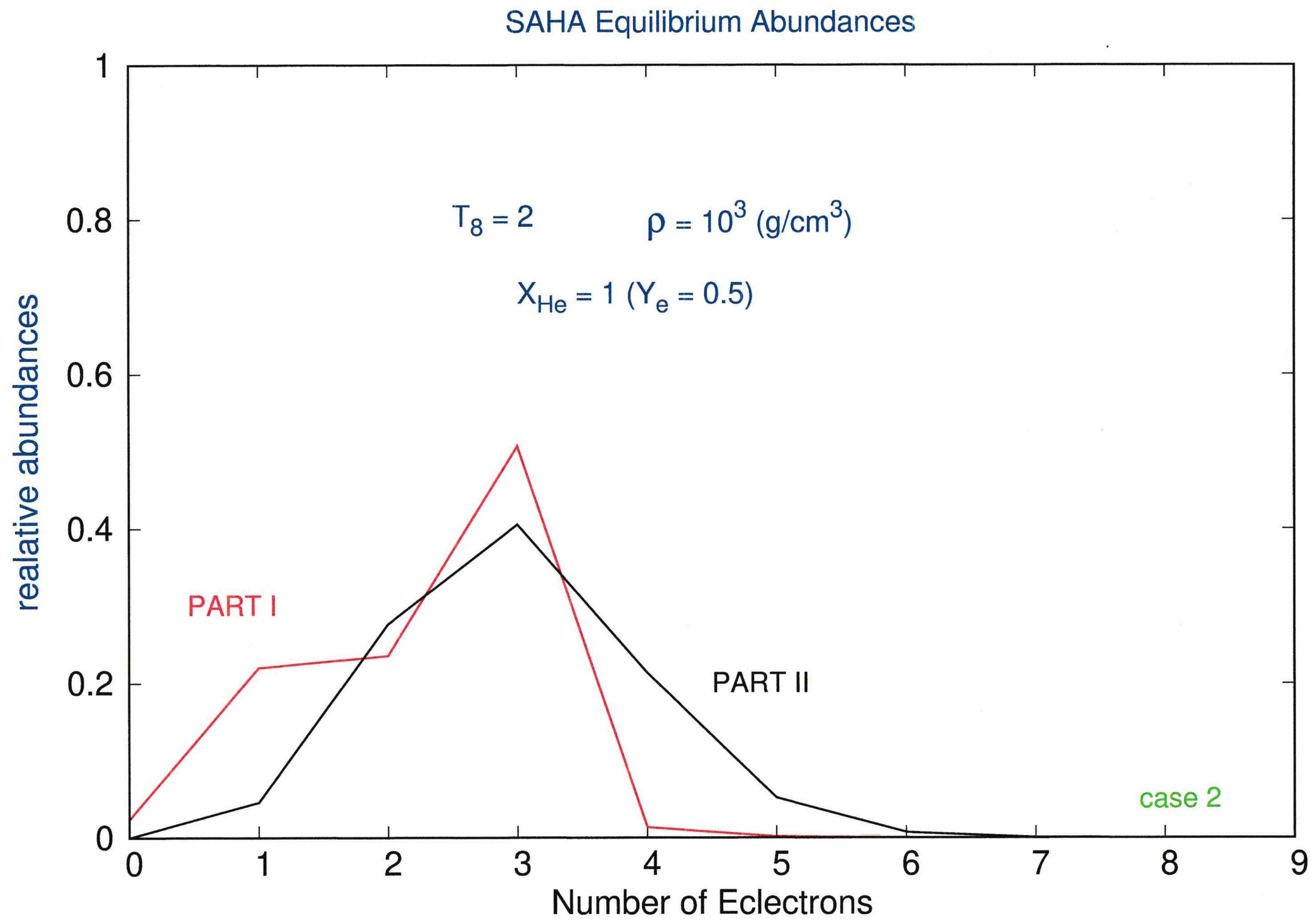
case 2: T8 = 2 ρ = 1000 (g/cm^3) Ye = 0.5

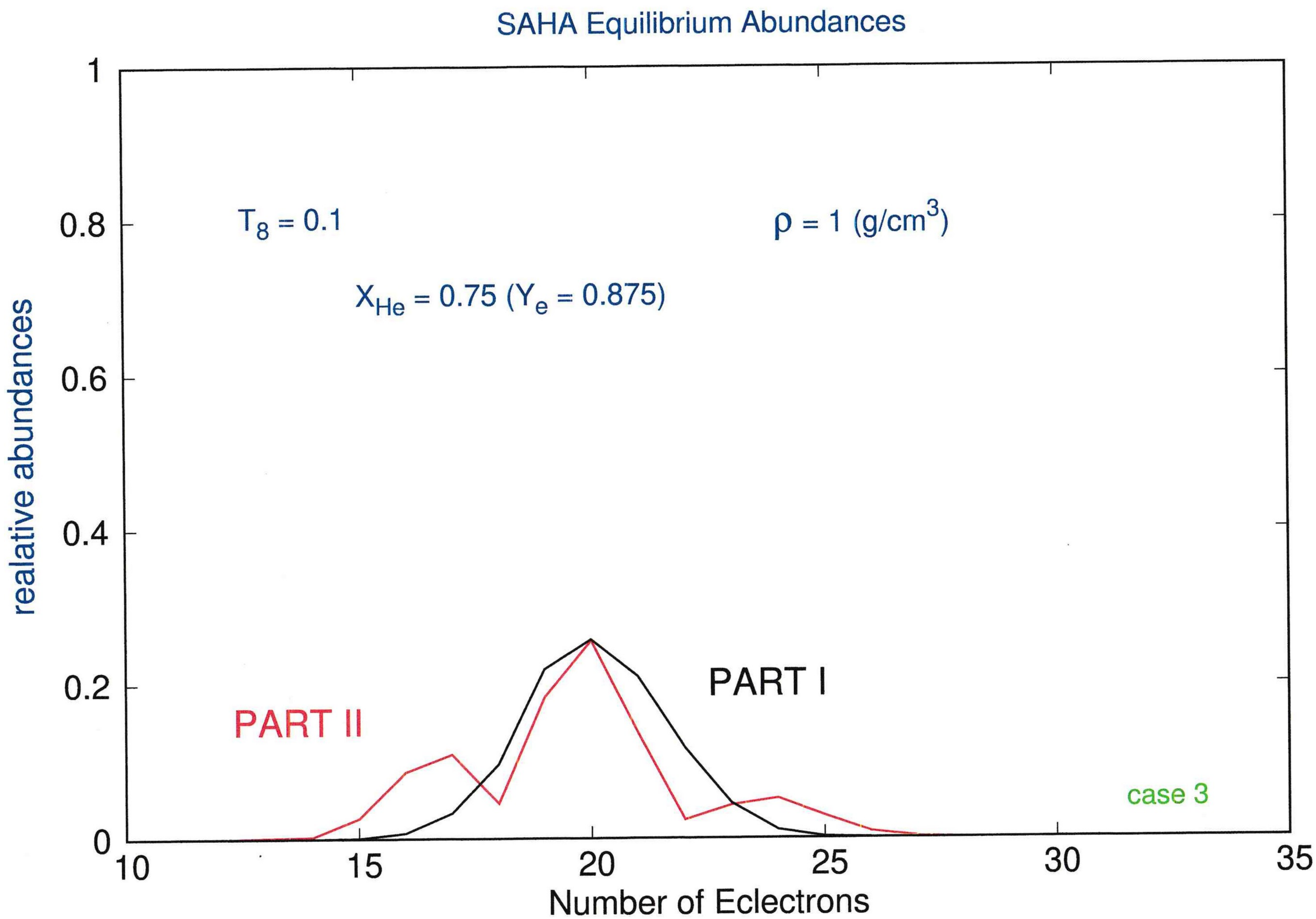
case 3: T8 = 0.1 ρ = 1 (g/cm^3) Ye = 0.875

PART I

PART II


SAHA Equilibrium Abundances
$T_8 = 3$
$\rho = 10^3$ (g/cm^3)
$X_{He} = 1$ ($Y_e = 0.5$)
PART II
PART I
case 1
realative abundances
Number of Eclectrons
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7


SAHA Equilibrium Abundances
$T_8 = 2$
$\rho = 10^3$ (g/cm^3)
$X_{He} = 1$ ($Y_e = 0.5$)
realative abundances
Number of Eclectrons
PART I
PART II
case 2
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7
8
9


SAHA Equilibrium Abundances
1
0.8
0.6
0.4
0.2
0
realative abundances
$T_8 = 0.1$
$\rho = 1$ (g/cm^3)
$X_{He} = 0.75$ ($Y_e = 0.875$)
PART I
PART II
case 3
10
15
20
25
30
35
Number of Eclectrons

THE CATCH is….

STAY TUNED!

p.s. **At least a few contributions to this conference have partially dealt with the problems discussed here, including those by B. Mishra and by S. Taioli. Also see the complihensive review by G. Martinez-Pinedo)**