Orestes Tumbarell Aranda

Candidate for the position
"Postdoctoral research associate for the project Cluster of Excellence Quantum Universe"
offered by the
Deutsches Elektronen-Synchrotron

Outline

- *I - Work and scientific career*

  ** Undergraduate, Masters and Ph.D. studies*
  ** Skills*
  ** Projects*

- *II - Future Research*

  ** Objectives*
  ** Relationship with the Cluster of Excellence Quantum Universe.*

Part I *Undergraduate Studies*

Institution: Instituto Superior de Tecnologías y Ciencias Aplicadas (InSTEC)
Havana, Cuba (2008-2013)
Discipline: Nuclear Physics

- *Topics usually offered as part of the Physics program.*

  ** Classical and Quantum Mechanics.*
  ** Classical Electrodynamics.*
  ** Statistical Physics.*
  ** Mathematical Analysis.*
  ** Differential Equations and The Calculus of Variations.*
  ** Integral Equations.*
  ** Second Order Partial Differential Equations.*

Part I Undergraduate Studies

Specific topics:

** Experimental Methods of Nuclear Physics.*
- Interaction of Radiation with the Substance.
- Nuclear Radiation Detectors.
- Particle Acelerators.
** Neutron Physics*
** Theory of Nuclear Reactions*
** Courses on Electronics*
** Dosimetry and radiological protection.*
** Nuclear Materials Science.*
** Theory of the Atomic Nucleus.*

Part I Undergraduate Studies

Bachelor's degree dissertation:
"Non-extensive statistics.
Application to the nuclear fission process."

** Classical Information Theory*
** Non-extensive statistics[1].*
q-Entropy (pseudo-additive)

$$S_q \equiv \langle ln_q \frac{1}{p_i} \rangle = \sum_{i=1}^{W} p_i \, ln_q \frac{1}{p_i} = \frac{1 - \sum_{i=1}^{W} p_i^q}{q-1}$$

$$S_q(A+B) = S_q(A) + S_q(B) + (1-q) S_q(A) S_q(B)$$

- Study of thermal neutron induced fission.

- *Calculation of the parameter q for different reactions.*
- *Estimation of the excitation energy and the number of neutrons emitted by the resulting fragments.*

➔ *Demonstrate the ability to combine the knowledge coming from several branches for explaining a nuclear process.*

Part I *Undergraduate Studies*

High Energy Physics Summer-School (2013)

Deutsches Elektronen-Synchrotron (DESY)
CMS Group
Supervisor: Hannes Jung

- *Investigate details of the hadronic final state in proton-proton interactions. Monte Carlo simulations were compared with measurements of charged particle production made at both CDF (Fermilab) and CMS (CERN) experiments.*

My work: *Implement the measurement into a computational routine that could be used by the CMS collaboration for tuning of Monte Carlo parameters.*

Part I — Masters Studies

Institution: Universidade Estadual de Santa Cruz (UESC)
Ilheus, Bahia, Brazil (2014-2016)
Discipline: Nuclear Physics

- *Modeling and simulation of spallation nuclear reactions[2].*

Spallation: *nonelastic nuclear reactions that occur when energetic particles, for example, protons, neutrons, or pions interact with an atomic nucleus.*

** Source of neutrons and radioactive isotopes.*
** Accelerator-driven systems (ADS) for energy production.*
** Radioactive waste treatment.*
** Study the properties and behavior of nuclei at high temperature*

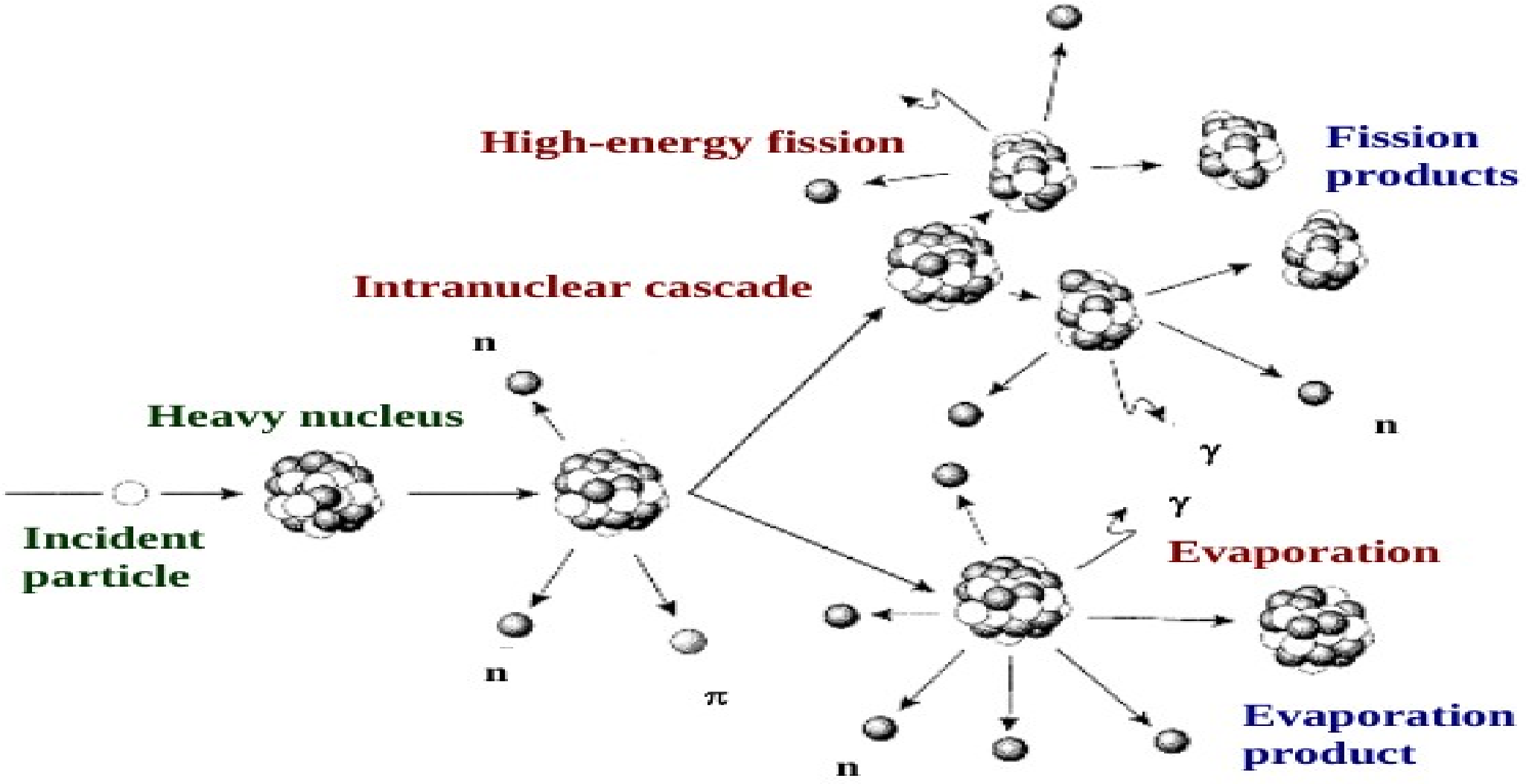
Part I

Masters Studies

Spallation: Two stages mechanism

1- Intranuclear cascade.

2- De-excitation of the compound nucleus.



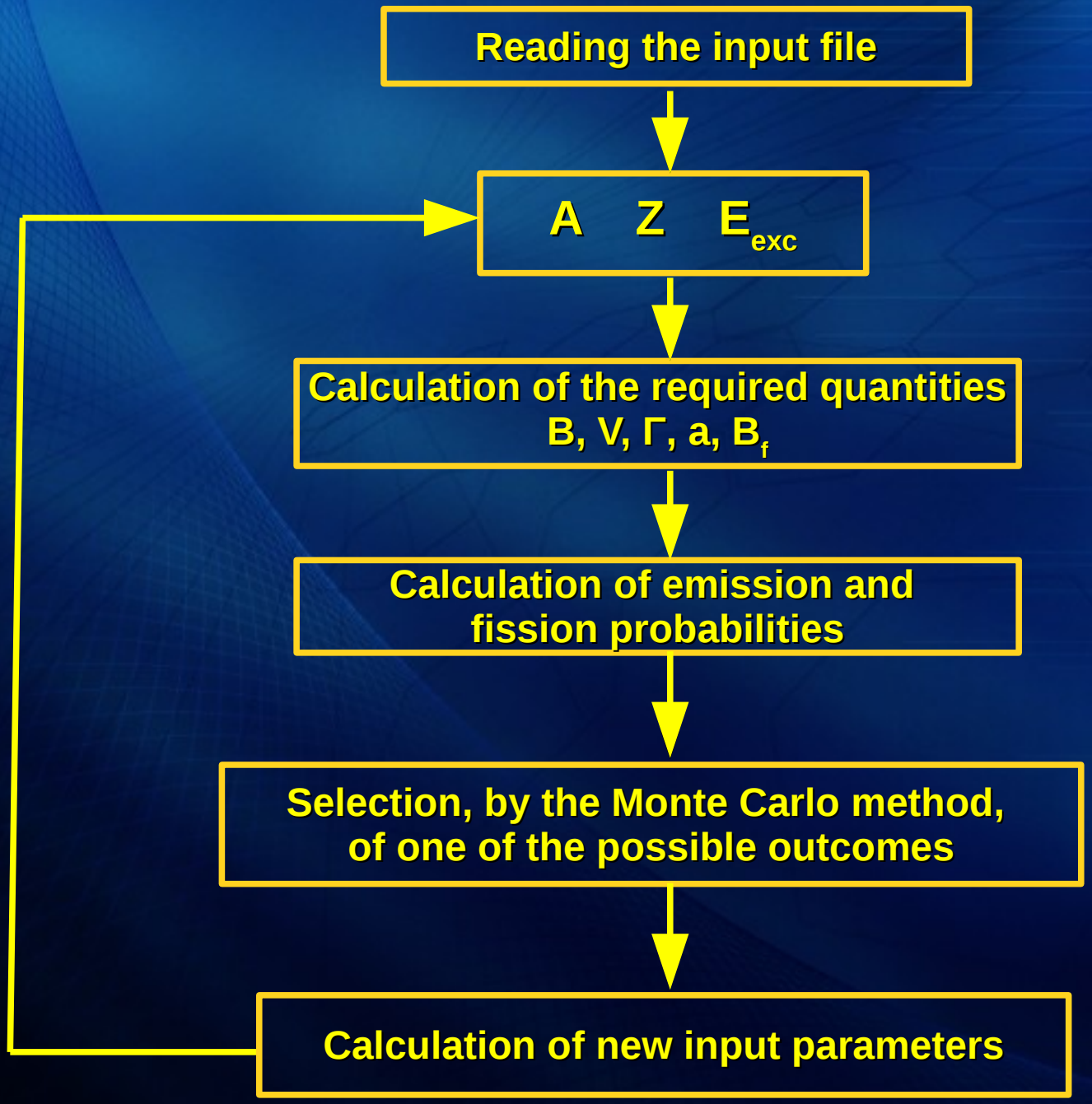
Part I — Masters Studies

- *CRISP^3 (Collaboration Rio-Ilhéus-São Paulo)*
  Computational code for the simulation of nuclear reactions at energies between 40MeV-4GeV of the incident particle.
  Written in C++. ROOT based.

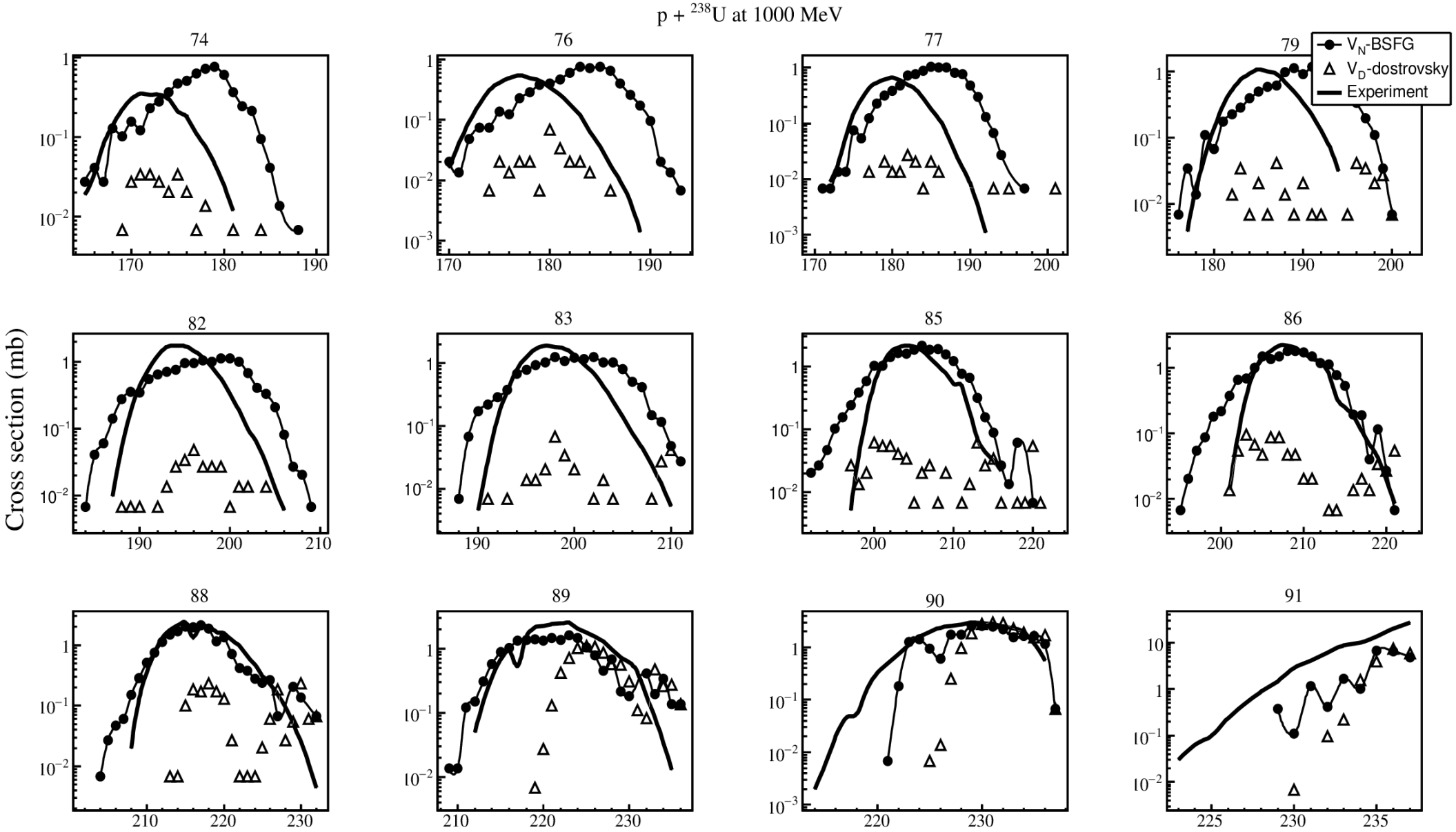
  Modular structure
  - MCMC (Monte Carlo Multicollisional):
  Intranuclear cascade.
  - MCEF (Monte Carlo for Evaporation-Fission):
  De-excitation stage.
  - multimode_fission:
  Determining the distribution of fission fragments.
  - Langevin:
  Dynamic study of the fission process.

My work focused on the study of the de-excitation stage

Operation of the MCEF

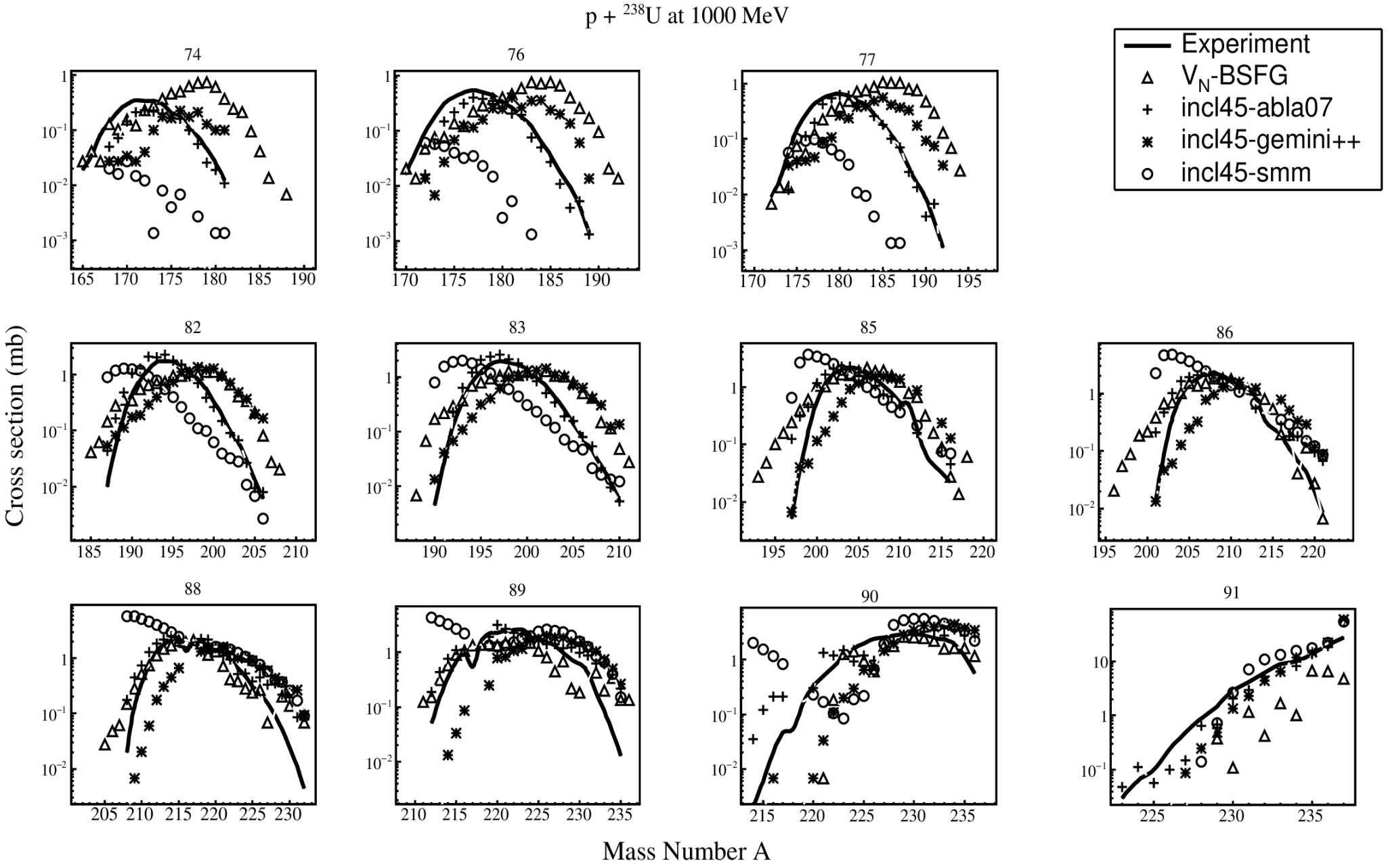


The cycle ends when either fission occurs or the excitation energy is lower than the neutron binding energy



Isotopic distribution for the reaction $p + {}^{238}\mathrm{U}$ at 1000 MeV.

O Tumbarell et al 2018 J. Phys. G: Nucl. Part. Phys. 45 115103



Isotopic distribution for the reaction $p + {}^{238}\mathrm{U}$ at 1000 MeV.

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Part I *Masters Studies*

- *Study of both the code and the models implemented within it.*
- *Identification of free parameters.*
- *Proposal and implementation of new models.*

** Better agreement between simulations and experimental results.*

- *Publication of articles[4-6].*
- *Thesis Title:*
  "Development of a physical-computational model for the study of proton-induced spallation nuclear reactions"

Part I *Ph.D. Studies*

Institution: Universidade de Brasília (UnB)
Brasilia, Federal District, Brazil
Ph.D. in Theoretical Physics (2016-2020)

- *Diffusion Process[7-10].*

Diffusion: *spontaneous transport process that occurs due to a difference in the concentration of some magnitude between two systems (or between regions belonging to the same system).*

- Langevin Equation Formalism[11]

** Very intuitive, can be generalized to various contexts.*
** Brownian motion.*
** Ergodic hypothesis.*
** Second Law of Thermodinamics.*
** The Fluctuation-Dissipation Theorem[12].*

Part I — Ph.D. Studies

- *Pattern formation in the spatial distribution of a one-species population.*

This topic has traditionally been addressed from the establishment of conservation equations that take into account, in the most realistic way possible, the factors that affect the size of the population studied.

Reaction-Diffusion Equations[13,14]:

$$\frac{\partial u_{N_P}(\vec{x},t)}{\partial t} = \Gamma(u_{N_P},\vec{x},t) + \vec{\nabla}\cdot\left(D\vec{\nabla}u_{N_P}(\vec{x},t)\right)$$

u: Population density
D: Diffusion coefficient
Γ: Source term

The solutions usually manifest a series of interesting phenomena, such as critical behavior, the presence of various stationary states, spatial patterns, wavefronts, and oscillations.

- **Our proposal (one-dimensional case):**

$$\frac{\partial u(x,t)}{\partial t} = a\hat{H}(g_\alpha, u(x,t)) - bu(x,t)\hat{H}(g_\beta, u(x,t))$$

* Malthus Model (exponential growth)
* Verhulst Model (logistic growth)
* Fisher-Kolmogorov Equation

Now we choose

$$\hat{H}(g_\kappa, u) = \int_\Omega g_\kappa(x - x')u(x', t)dx'$$

$$g_\kappa(x) = \begin{cases} \frac{1}{2\kappa}, & |x| < \kappa, \\ 0, & \text{otherwise}, \end{cases}$$

- **Our proposal (one-dimensional case):**

$$\frac{\partial u(x,t)}{\partial t} = \frac{1}{2\alpha}\int_{x-\alpha}^{x+\alpha} u(x',t)dx' - u(x,t)\frac{1}{2\beta}\int_{x-\beta}^{x+\beta} u(x',t)dx'$$

* Periodic Boundary Conditions:

$$u(x,t) = u(x \pm L, t)$$

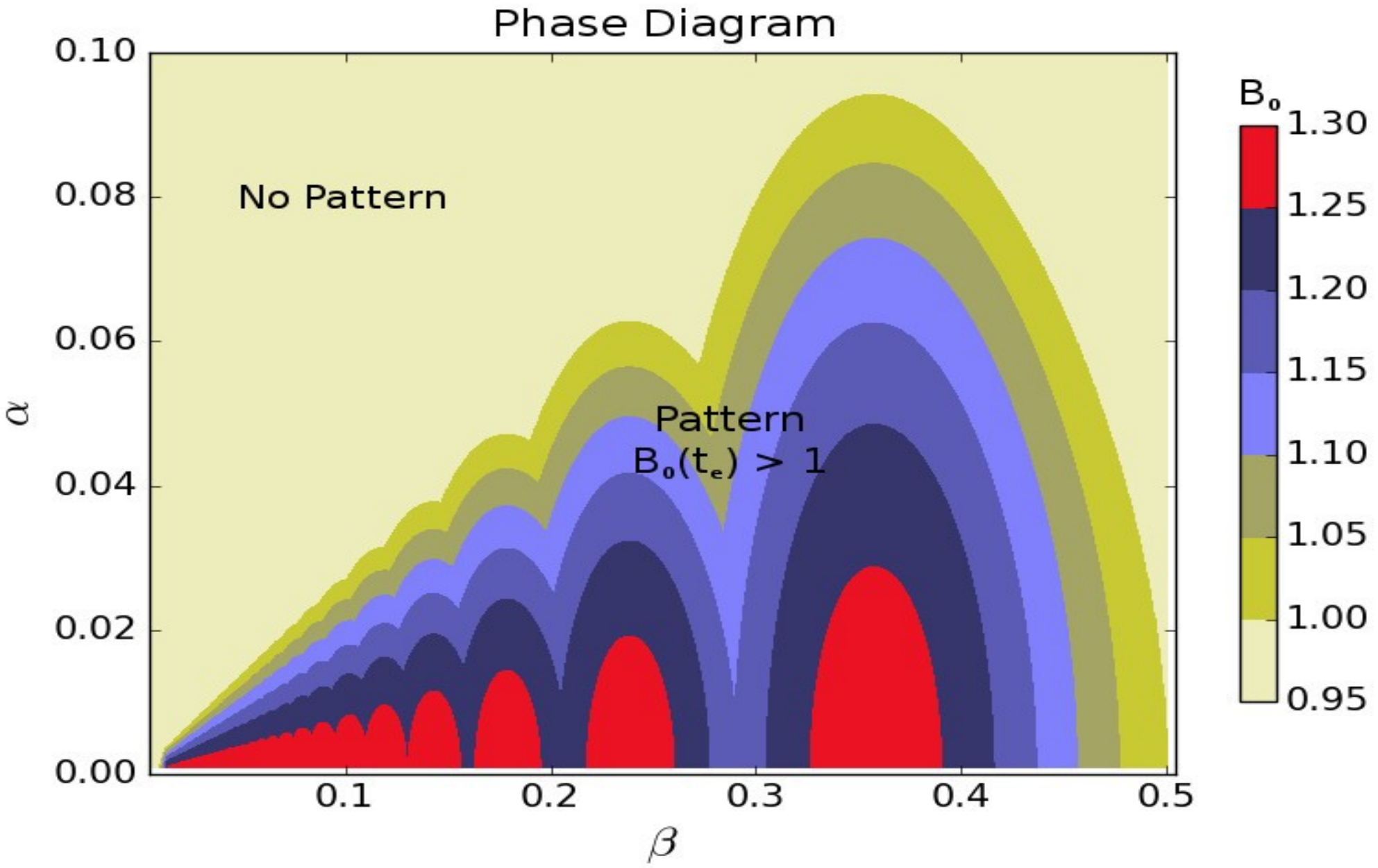
$$u(x,t) = B_0(t) + \sum_{n=1}^{\infty} B_n(t)\cos(k_n x)$$

$$k_n = 2\pi n$$

Stability Analysis:

$B_0(t_e)$ determines the existence of a phase space.

$$B_0(t_e) = \frac{f(k_M\alpha)}{1 + f(k_M\beta)} > 1.$$


Phase Diagram
No Pattern
Pattern
$B_0(t_e) > 1$
α
β
0.10
0.08
0.06
0.04
0.02
0.00
0.1
0.2
0.3
0.4
0.5
B_0
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95

Part I — Ph.D. Studies

- **Our proposal (one-dimensional case):**

$$\frac{dB_0(t)}{dt} = -\frac{1}{2}\sum_{n=1}^{\infty} B_n^2(t) f(k_n\beta) + B_0(t) - B_0^2(t),$$

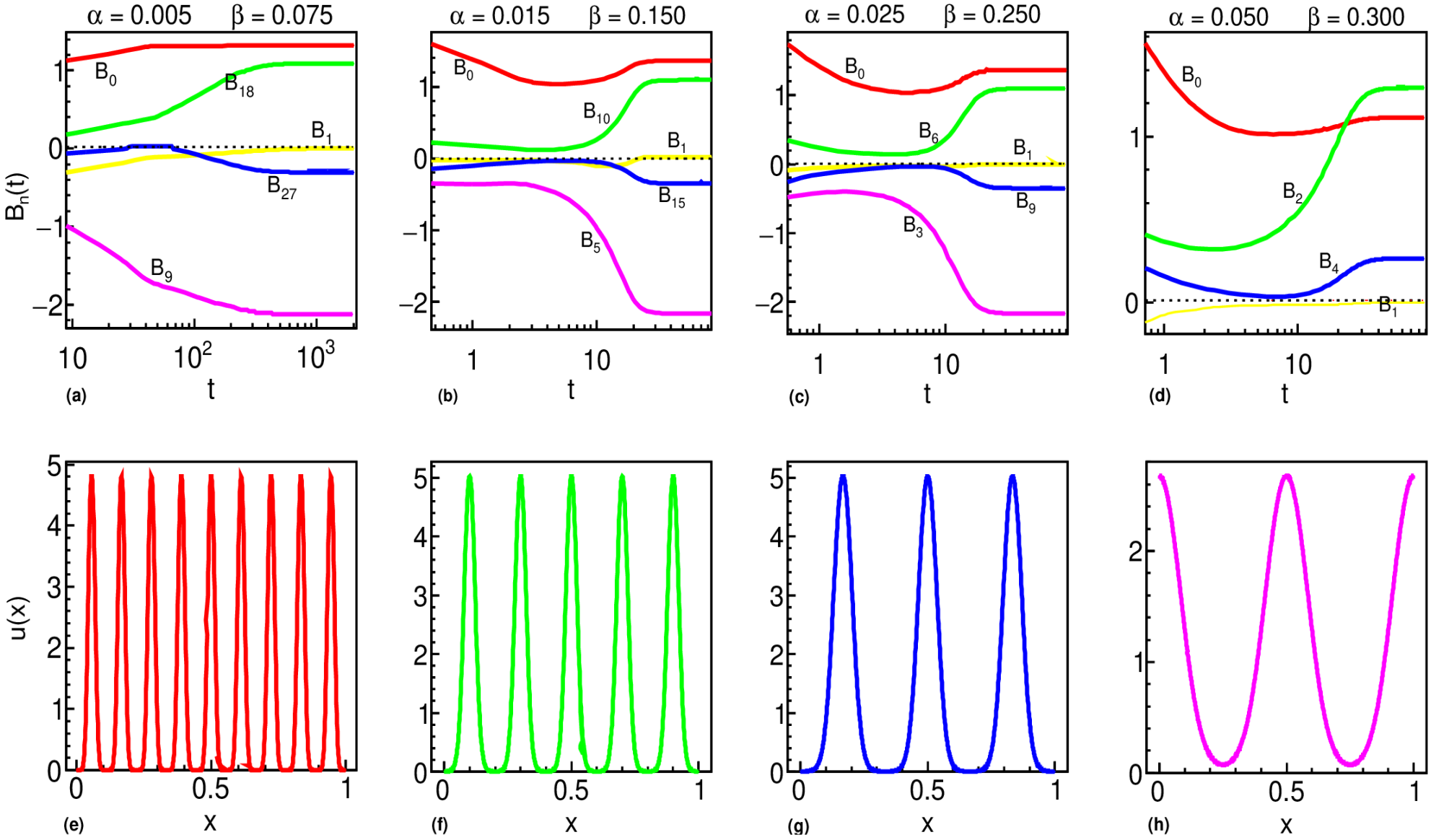
$$\frac{dB_n(t)}{dt} = \psi_n(t) + \gamma_n(t) B_n(t), \qquad (n \geq 1),$$

Riccati Equation

Linear Equation

Implemented via Python routines

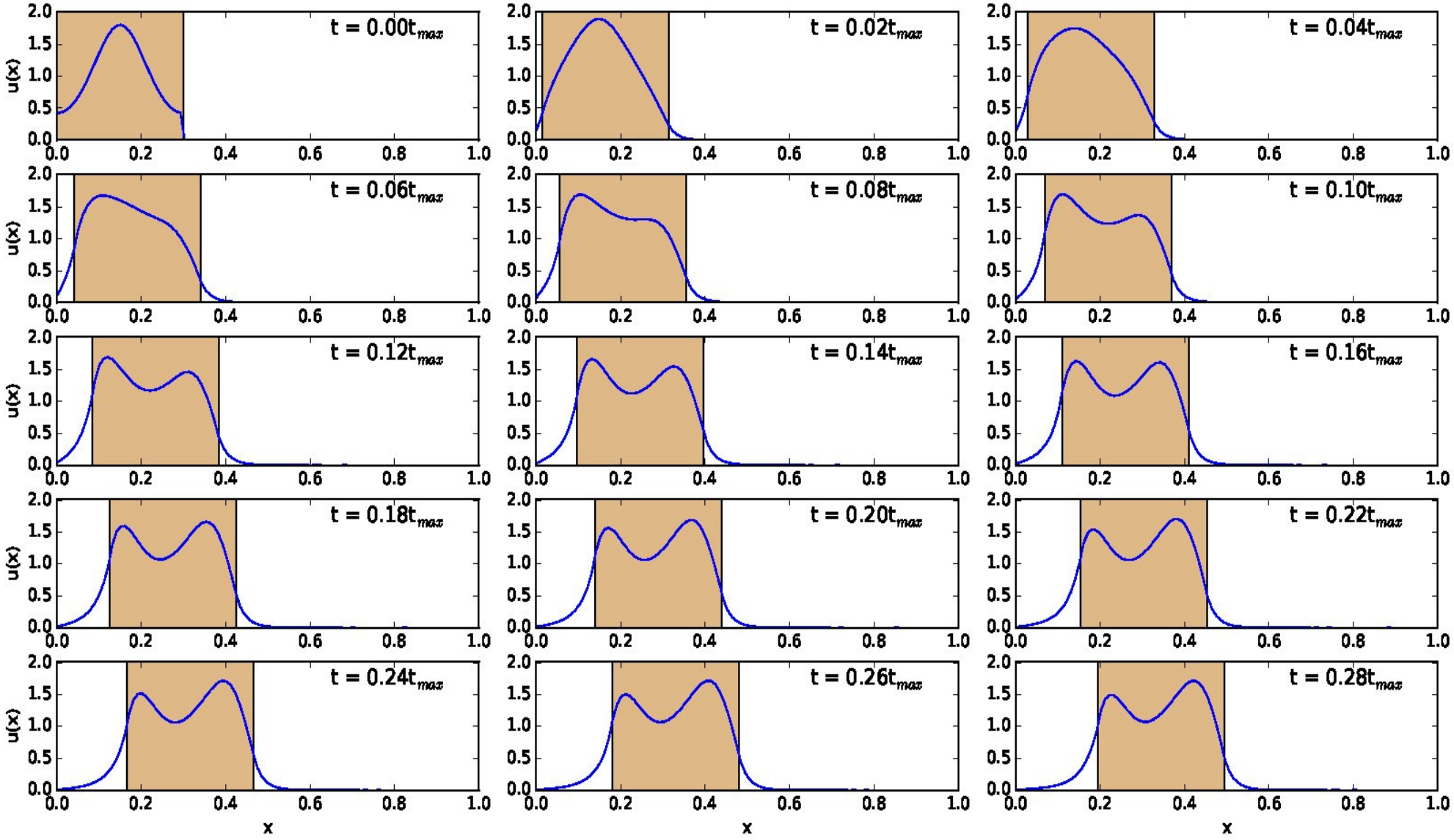
$$\begin{aligned}
f(k_n\kappa) &= \frac{\sin(k_n\kappa)}{k_n\kappa}, \\
\gamma_n(t) &= f(k_n\alpha) - B_0(t)\left[1 + f(k_n\beta)\right] - \frac{1}{2}B_{2n}(t)\left[f(k_n\beta) + f(k_{2n}\beta)\right], \\
\psi_n(t) &= -\frac{1}{2}B_{n/2}^2(t) f(k_{n/2}\beta) \\
&- \frac{1}{2}\sum_{\substack{m=1 \\ m\neq n}}^{\infty} B_m(t)\left\{ B_{n+m}(t)\left[f(k_m\beta) + f(k_{n+m}\beta)\right] + B_{n-m}(t)\left[f(k_m\beta) + f(k_{n-m}\beta)\right] \right\},
\end{aligned}$$



$$u(x,t) = B_0(t) + \sum_{n=1}^{\infty} B_n(t)\cos(k_n x)$$

Part I — Ph.D. Studies

Simulation of bacterial populations subjected to inhomogeneous lighting



Our model can reproduce experimental results[15]!!!

Part I Ph.D. Studies

- *New mathematical model to solve numerically the Riccati equation.*
- *Development of a model for bacterial pattern formation which explores the evolution of the colony towards a state in which the population size is maximum.*
- *Description of some experimental results that other models employed previously had not been able to obtain.*

- *Submission and publication of articles[16-18].*
- *Thesis Title:*

  "Study of Pattern Formation in Population Dynamics using Reaction-Diffusion Equations"

Part II *Future Research*

Explore challenging topics in Physics, using skills and knowledge that I already have, as well as acquiring new ones.

** Relativistic heavy-ion collisions, which are believed to lead to the formation of the Quark-Gluon Plasma[19-28].*

- Heavy quarks as test particles.

** Dark matter / energy[29,30].*

** Quantum Information Theory[31].*

Starting Point:

Relationship between Particle Physics and reaction-diffusion equations

Part II Future Research

The concept of population can also include subatomic particles and galaxies.

$$\frac{\partial u_{N_P}(\vec{x},t)}{\partial t} = \Gamma(u_{N_P},\vec{x},t) + \vec{\nabla}\cdot\left(D\vec{\nabla}u_{N_P}(\vec{x},t)\right)$$

Instead of purely diffusive processes, we could consider the current densities, which is common in particle physics, leading to a hydrodynamic description for studying the expansion of the quark-gluon plasma created in heavy ion collisions[32-34].

A similar approach could be used to study the expanding universe. The source term would be a function of the dark matter / energy, which guarantee the maintenance of the expansion.

Part II Future Research

Fluctuation-Dissipation Theorem

Order ⟷ *Disorder*

Problem of Measurement

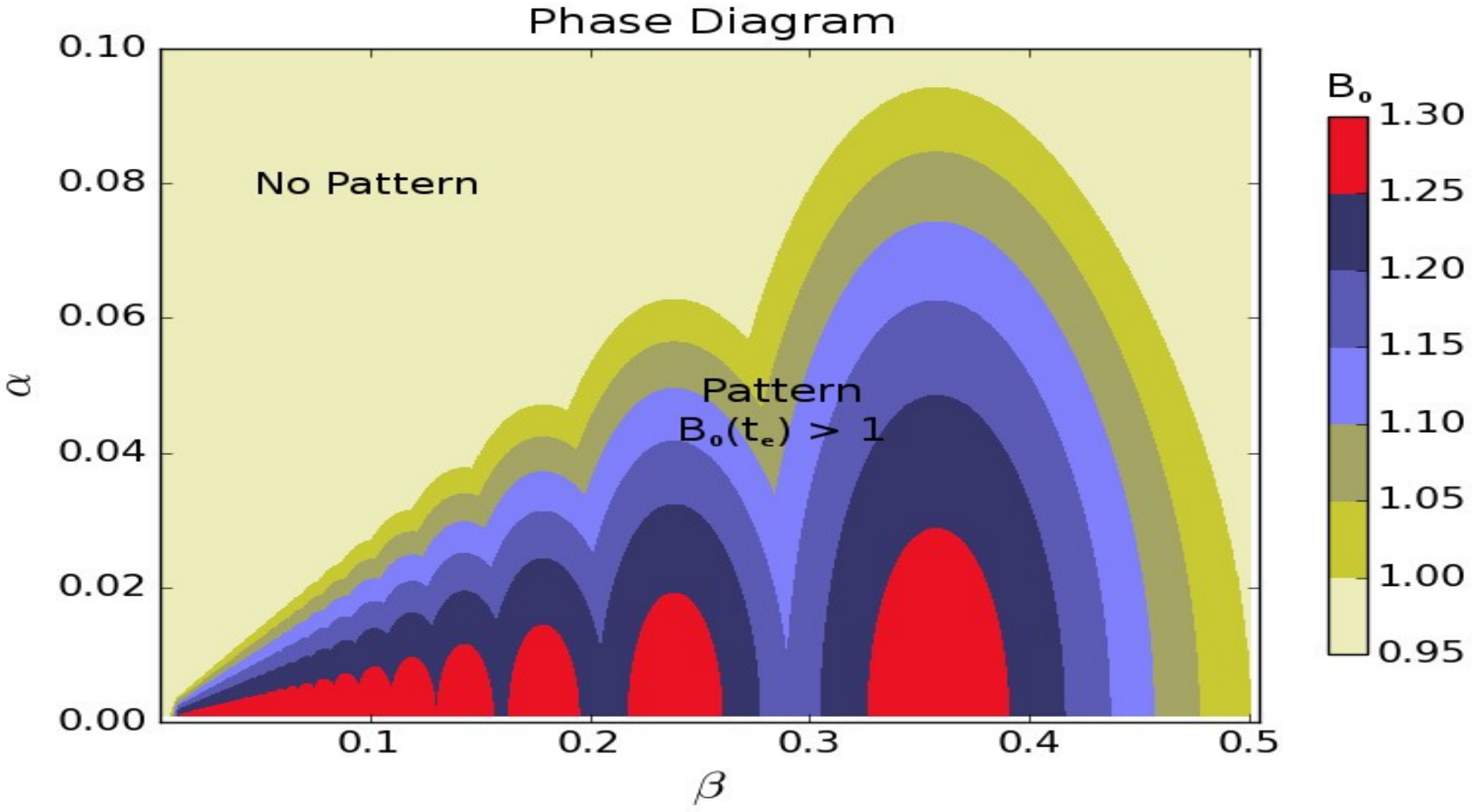
How to obtain useful information without destroying the quantum state.

- Quantum Teleportation

- Relationship between decoherence and scrambling, generated in a quantum circuit[35].

Part II Future Research

Universality and scale invariance



There will be some relationship with the QCD phase diagram?

The Cluster of Excellence "Quantum Universe" offers an unparalleled opportunity to address all those questions

Thanks for your attention

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