PolarEx

A facility for on-line nuclear orientation at ALTO

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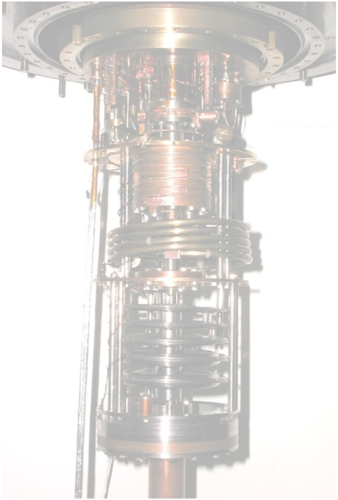
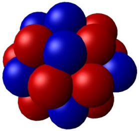
November 2019

Advanced commissionning of PolarEx via multipole mixing ratio measurements

- Introduction to Nuclear Physics
- Physics motivations and principles
- PolarEx set-up
- Current status of my PhD

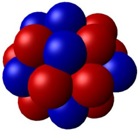


The nucleus



Nucleus : A nucleons (N neutrons and Z protons)

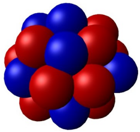
The nucleus



Nucleus : A nucleons (N neutrons and Z protons)

- Strong nuclear interaction
- Weak nuclear interaction
- Electromagnetic interaction
- Gravitationnal interaction

The nucleus



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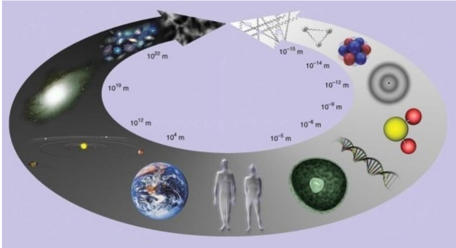
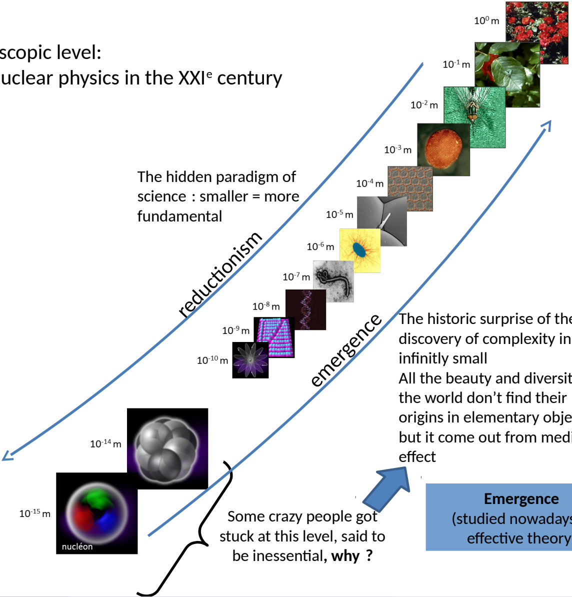


The nucleus

Emergence at the microscopic level:
The great challenge of nuclear physics in the XXI^{e} century

The hidden paradigm of science : smaller = more fundamental

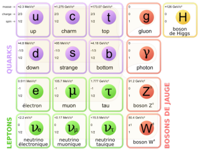


The historic surprise of the discovery of complexity in the infinitly small
All the beauty and diversity of the world don't find their origins in elementary object, but it come out from medium effect

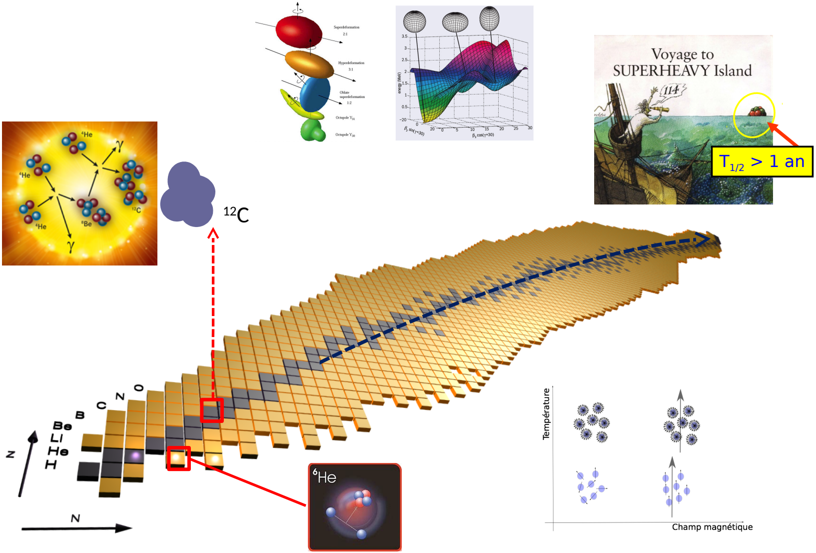
Emergence
(studied nowadays in effective theory)

Some crazy people got stuck at this level, said to be inessential, **why ?**

SU(3)×SU(2)×U(1)



The Nuclear Chart



Nuclear Structure

⇒ The nucleus is a complex quantum many-body system

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Goal of Nuclear Physics :

- Understand the Nuclear interaction
- Explain and predict properties of the nucleus

How ?

Nuclear Structure

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Goal of Nuclear Physics :

- Understand the Nuclear interaction
- Explain and predict properties of the nucleus

How ?⇒ Probe the limits of nuclear models

- Measure basic parameters of exotic nuclei (mass, half-life, spin, parity ...)
- Measure fine caracteristics of nulei in extreme conditions

Achievable observables

Low Temperature Nuclear Orientation (LTNO)

Study of nuclear magnetic properties of nuclei under extreme conditions

$B \sim 10 - 100\ T$
$T \sim 7 - 20\ mK$

Achievable observables

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- Indirect measurement of multipolarity mixing ratio δ

$$\delta = \frac{\langle I_f | \, O(\sigma' L') \, | I_i \rangle}{\langle I_f | \, O(\sigma L) \, | I_i \rangle} \text{ and } \delta^2 = \frac{P'_\gamma(\sigma' L')}{P_\gamma(\sigma L)}$$

Achievable observables

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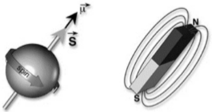
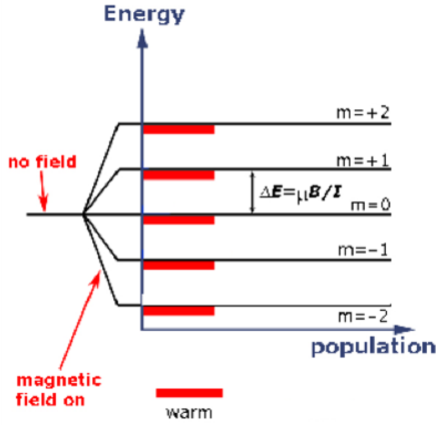


- Indirect measurement of multipolarity mixing ratio δ
- Direct measurement of nuclear magnetic moments μ
- Applications in solid state physics (H_{Hf})

Nuclear Physics

$$\delta = \frac{\langle I_f | O(E2) | I_i \rangle}{\langle I_f | O(M1) | I_i \rangle} \text{ and } \delta^2 = \frac{P_\gamma(E2)}{P_\gamma(M1)}$$

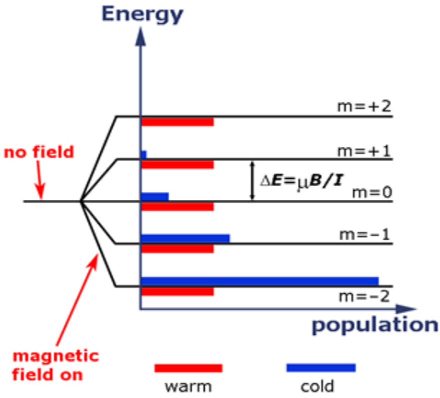
Introduction to LTNO



$B = B_{applied} + H_{Hf}$

Magnetic field on
$\Rightarrow$ Zeeman Splitting

$N \propto e^{\frac{\Delta E}{k_b T}}$

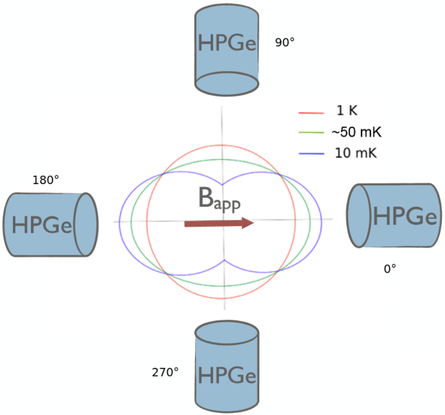


$B = B_{applied} + H_{Hf}$

Very low temperatures
$\Rightarrow$ Boltzmann distribution

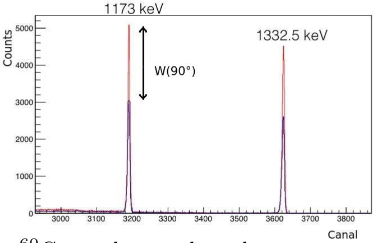
$N \propto e^{\frac{\Delta E}{k_b T}}$

Introduction to LTNO



Very low temperatures + High magnetic field

⇒ Angular distribution of the emission is anisotropic $W(\theta)$

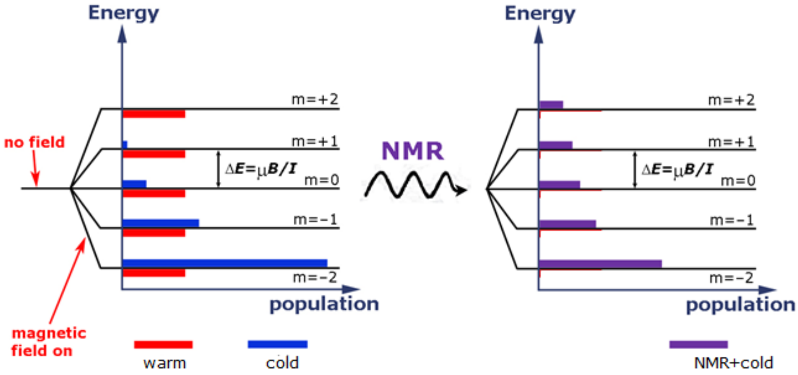


^{60}Co used as nuclear thermometer

Angular distribution of the emission

$$W(\theta) = \frac{N_{cold}(\theta)}{N_{warm}(\theta)}$$

Introduction to LTNO



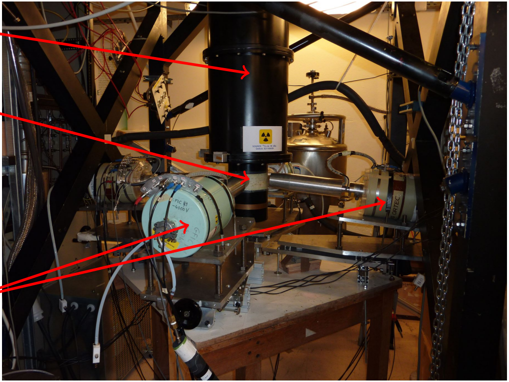
$$B = B_{applied} + H_{Hf}$$

RF on ⇒ Destroy the anisotropy

What is Polarex ?

The Set-up

- A ^{3}He - ^{4}He dilution refrigerator
- A supraconductor magnet
- A ferromagnetic foil for the implantation of the nuclei
- 4 HPGe detectors with associated electronic
- Nuclear magnetic resonance

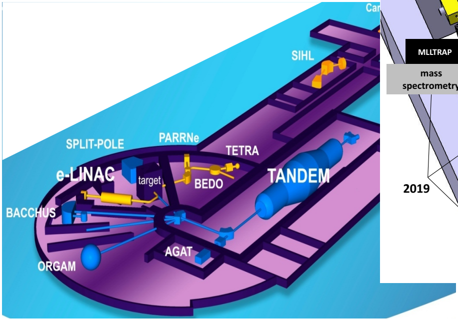


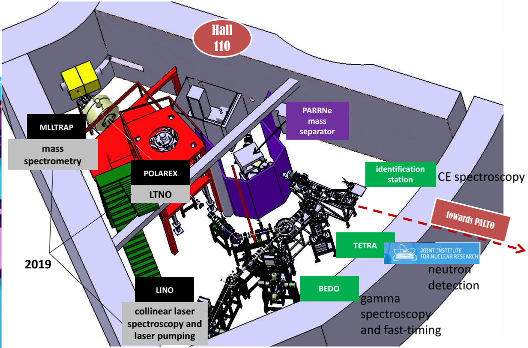
What is Polarex ?

Location

Located at ALTO in Orsay, France

Black off-line Green on-line





Current Analysis : Corrections

Source : ^{54}Mn, ^{56,57,58}Co and ^{59}Fe, fusion-evaporation d+Fe 11 MeV/A

- Standard high precision spectrometry technics

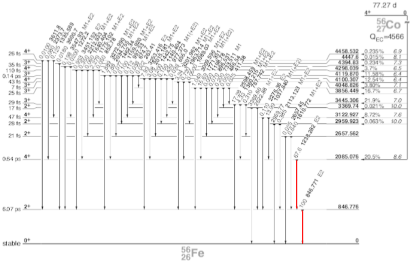
Critical points :

- Evaluation of the temperature (^{60}Co inside the refrigerator)
- Correction of the dead time
- Correction of the activity $\Lambda = exp(-\lambda \Delta t)$

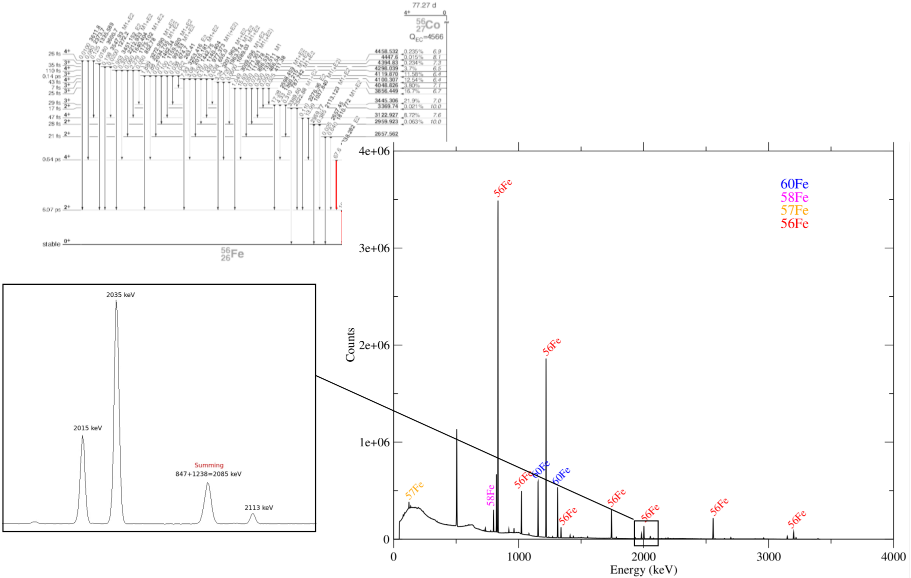
$$n(\theta) = \sum_{runs} \frac{N(\theta)}{(T_{tot} - T_{dead}(\theta))\Lambda}$$

- Last on going correction : Coincidence summing effects

Current Analysis : summing and simulation

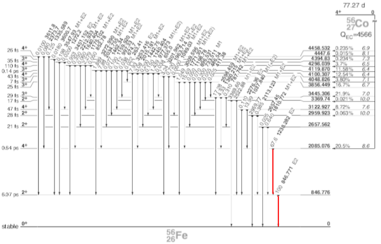


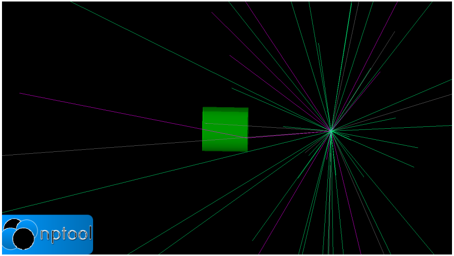
Current Analysis : summing and simulation



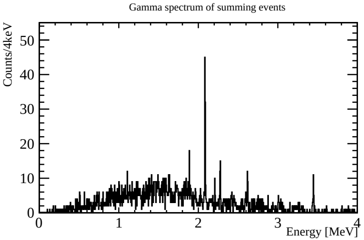
Current Analysis : summing and simulation

Work in progress





- Simulation with Geant4
- Same amount of summing events
- Algorithm in the ProcessHits to tag summing events
- Summing identification
- Correction in the actual data



Current status of my PhD

Development for the experiment

The ongoing analysis is almost over ⇒ mixing ratio δ measurement

We plan to perform a commissioning of the NMR ⇒ magnetic moment measurement

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The ongoing analysis is almost over $\Rightarrow$ mixing ratio δ measurement

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BOOM FESTIVAL

What's next ?

In 2019 NMR commissioning : magnetic moment measurement ^{139}Ce

Off-line physics case : Study of Pm isotopic chain (A=147, 149, 151)

- Measurement of H_{Hf} of Pm in Fe
- Measurement of the magnetic moments of these Pm isotopes

Then... by 2020

On-line physics case :
Study of magnetic moments of Sb (A=$130^{g,m}$, $132^{g,m}$, $134^{g,m}$)

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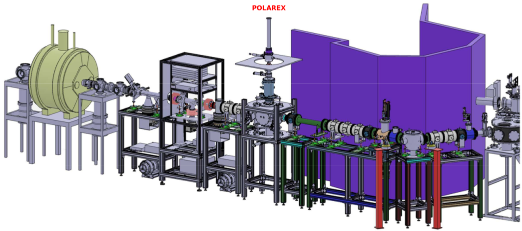
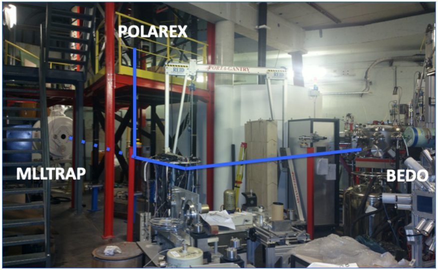
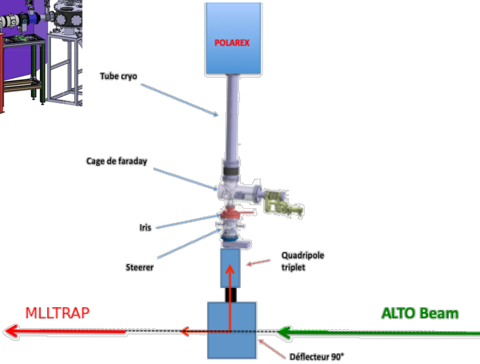
Thank you for your attention

Thanks to collaborators : I. Deloncle, C. Gaulard, F. Ibrahim, F. Le Blanc, S. Roccia, D. Verney and ALTO staff

New line under construction

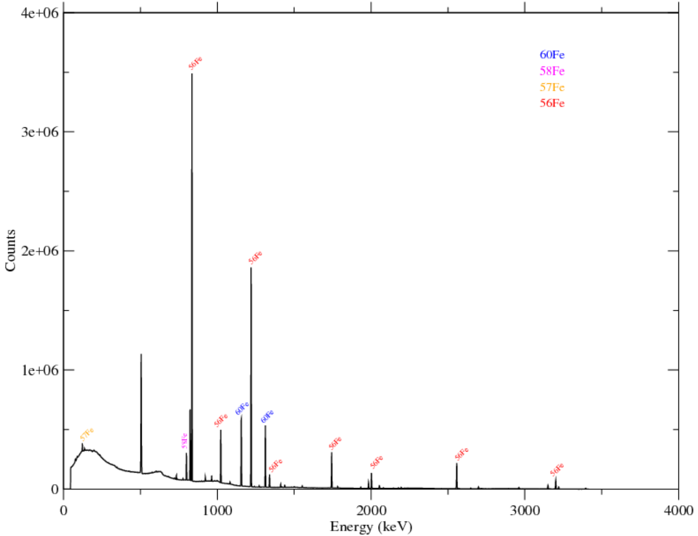






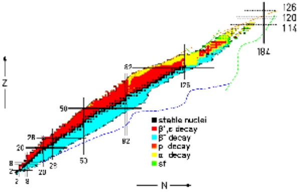
Sources of ^{54}Mn, ^{56,57,58}Co and ^{59}Fe

Produced by fusion-evaporation d+Fe at 11 MeV/A



Polarex : Which Nuclei ?

- Limitation on the life-time
  - Need time to reach a thermal equilibrium
- Minimum flux of 10^3 ions/s ...
- ... and a maximum of 10^7 ions/s
- Need energy of at least 40 keV



⇒ At the end, around 300 nuclei are accessible at ALTO for On-Line Nuclear Orientation method

Off-line study : Pm

- H_{Hf} in Fe is badly known : $400 \pm 100\ T$
- $\mu(^{147}\mathrm{Pm})$ is known by laser spectroscopy : +2.58(7)
- Measurement of the resonant frequency (LTNO/NMR)
  $\Rightarrow \Delta E = \mu B / I$
  $\Rightarrow$ Precise H_{Hf} in Fe at Pm site
- Measurement of the magnetic moments of ^{149,151}Pm isotope

^{147}Pm : 2.62 y
^{149}Pm : 53.08 h
^{151}Pm : 28.4 h

LTNO Calculations

$$W(\theta) = \frac{N_{cold}(\theta)}{N_{warm}(\theta)} = 1 + \sum_{\lambda} B_{\lambda}(I_0, T) U_{\lambda} Q_{\lambda} A_{\lambda} P_{\lambda}(cos\theta)$$

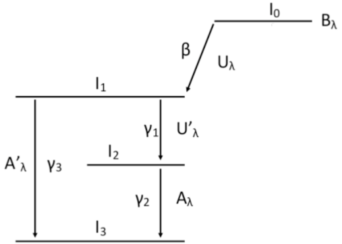
$$W(0) = 1 + B_2U_2Q_2A_2 + B_4U_4Q_4A_4$$
$$W(\pi/2) = 1 - \tfrac{1}{2}B_2U_2Q_2A_2 + \tfrac{3}{8}B_4U_4Q_4A_4,$$

$$A_2 = \frac{\tfrac{3}{8}(1 - W(0)) + (W(\pi/2) - 1)}{-\tfrac{7}{8}B_2U_2Q_2}$$
$$A_2' = \frac{\tfrac{3}{8}(1 - W'(0)) + (W'(\pi/2) - 1)}{-\tfrac{7}{8}B_2'U_2'Q_2'}$$

$$\frac{A_2}{A_2'} = \frac{\tfrac{3}{8}(1 - W(0)) + (W(\pi/2) - 1)}{\tfrac{3}{8}(1 - W'(0)) + (W'(\pi/2) - 1)}$$
$$\frac{A_4}{A_4'} = \frac{\tfrac{1}{2}(1 - W(0)) - (W(\pi/2) - 1)}{\tfrac{1}{2}(1 - W'(0)) - (W'(\pi/2) - 1)},$$

Angular distribution of the emission

$$W(\theta) = \frac{N_{cold}(\theta)}{N_{warm}(\theta)} = 1 + \sum_{\lambda} B_\lambda U_\lambda Q_\lambda A_\lambda P_\lambda(cos\theta)$$



$B_\lambda(I_0, T)$: Orientation parameter
$U_\lambda(I_i, I_f)$: Deorientation coefficient
$Q_\lambda(\theta)$: Solid angle correction
$A_\lambda(\delta)$: Angular distribution
$P_\lambda(cos\theta)$: Legendre polynomial

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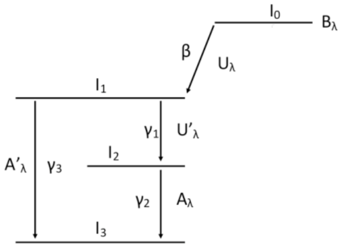

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B_λ depends on the spin and the temperature

LTNO Method

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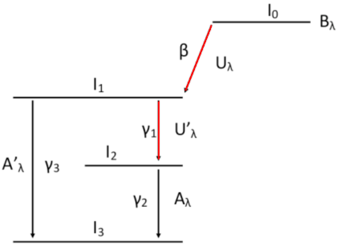

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U_λ occurs at each "hidden" transition

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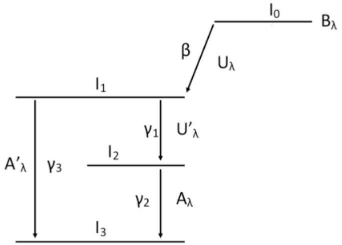

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The multipole mixing ratio δ is taken from A_λ

LTNO Method

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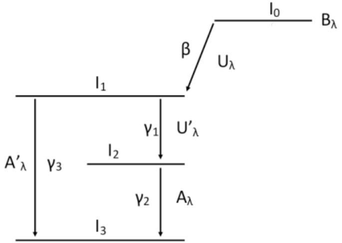

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$$A_\lambda = \frac{F_\lambda(L, L, I_f, I_i) + 2\delta F_\lambda(L, L', I_f, I_i) + \delta^2 F_\lambda(L', L', I_f, I_i)}{1 + \delta^2}$$