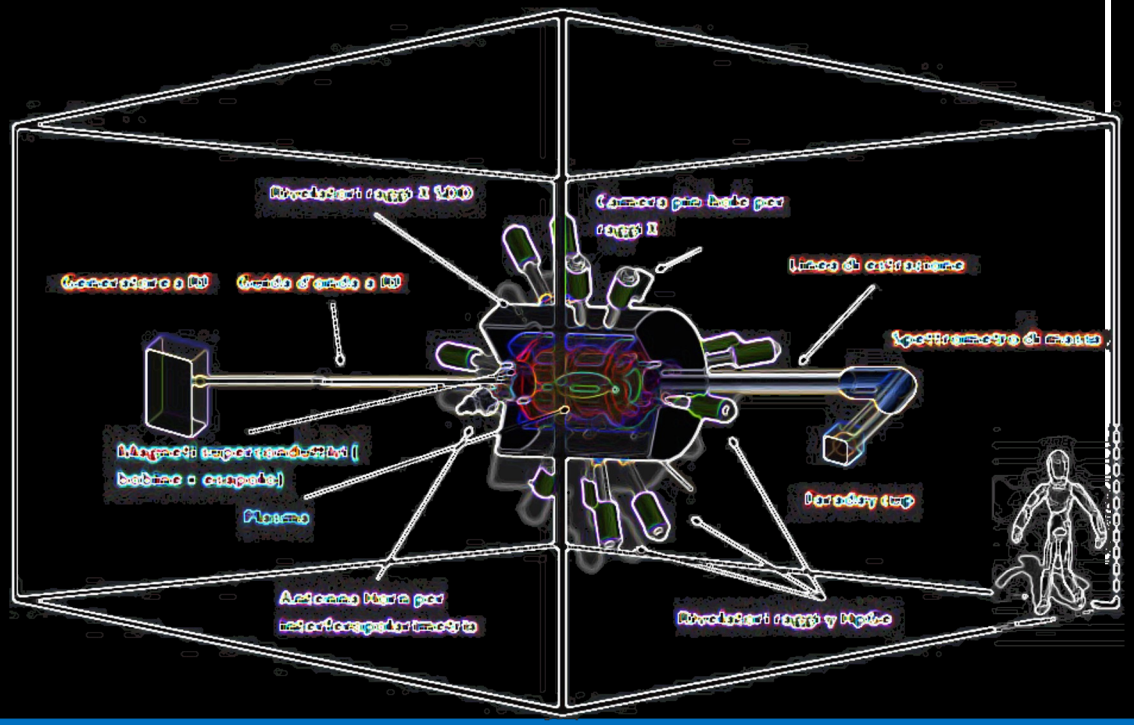
PANDORA:



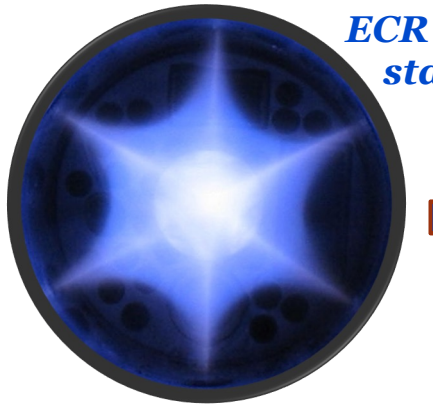
Plasmas for
Astrophysics
Nuclear
Decay
Observation and
Radiation for
Archaeometry

Resp. Locale S.Palmerini

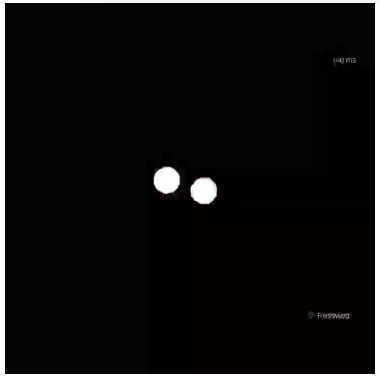
M. Bezmalinovich, M. Busso, S. Simonucci, F. Triggiani, D. Vescovi. (3.2 fte)

PANDORA main goal

- Investigating β-radioactivity in a «stellar» environment

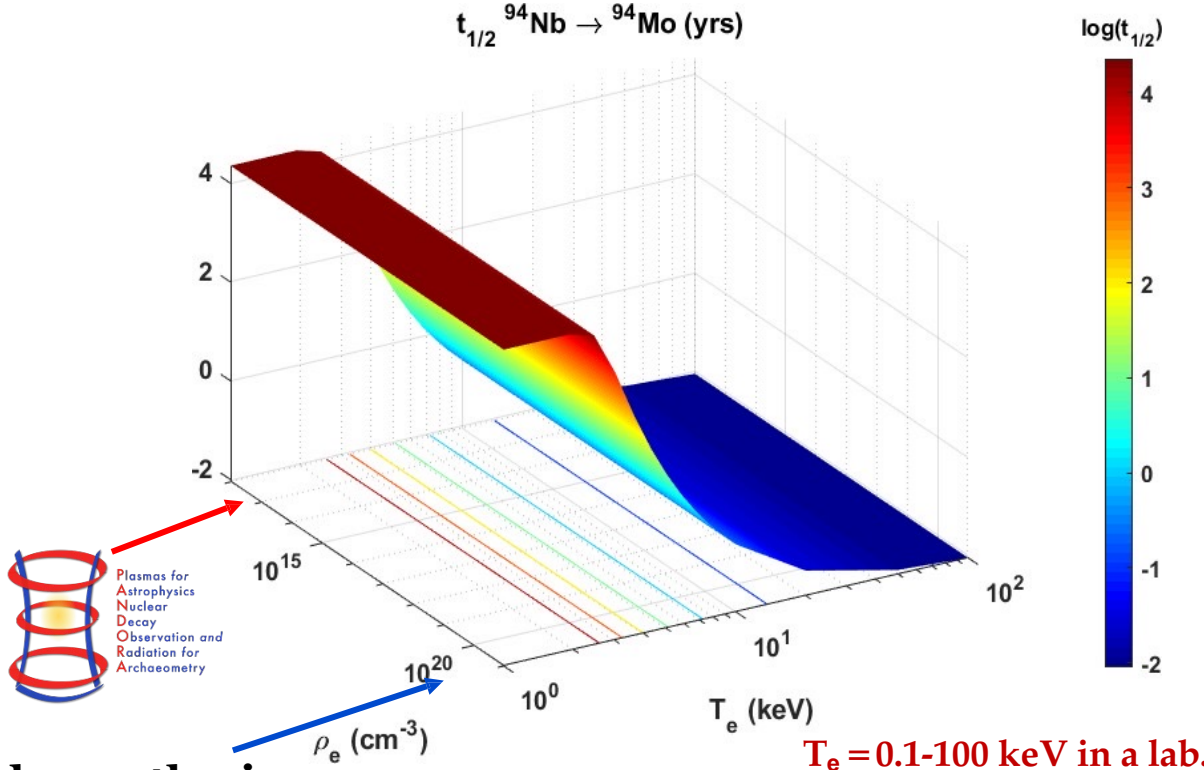


From a laboratory ECR "Plasma star" to…



Additional Goal

- Measuring plasma opacity relevant for compact binary ejecta (Kilonovae)



Nucleosynthesis in stars

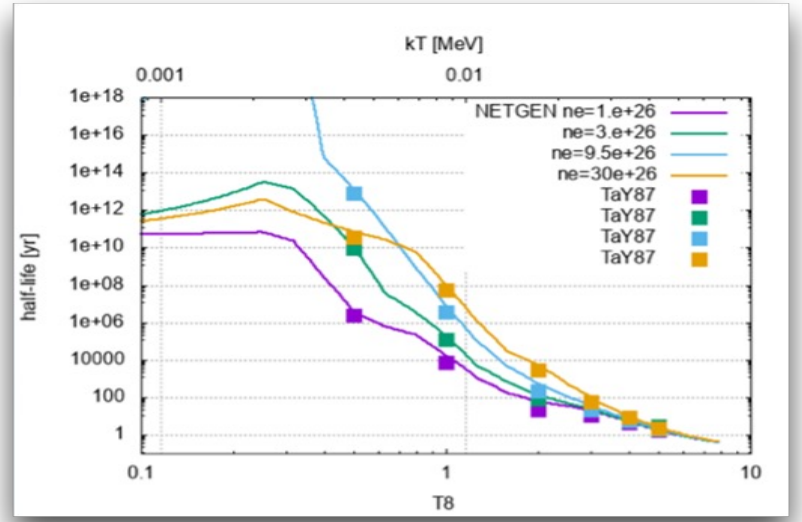
T_e = 0.1-100 keV in a lab. Magnetoplasma

Variation with T_e stronger than with ρ so "stellar effect" can be modelled in ECR plasmas

PANDORA main goal: *Investigating β-radioactivity in a «stellar» environment*

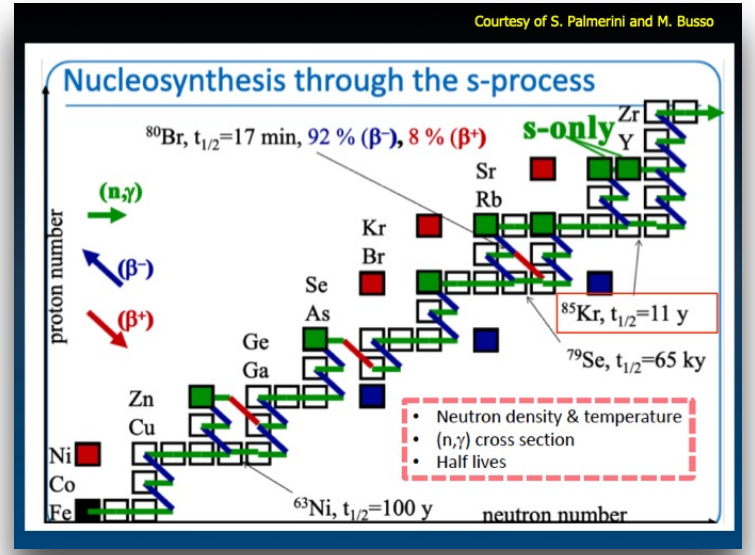
Make β-decay measurements in plasmas of astrophysical interest: many isotopes can change their lifetime of several order of magnitude when ionized!!

The effect is mainly driven by the opening of a new decay channel: the bound state beta decay



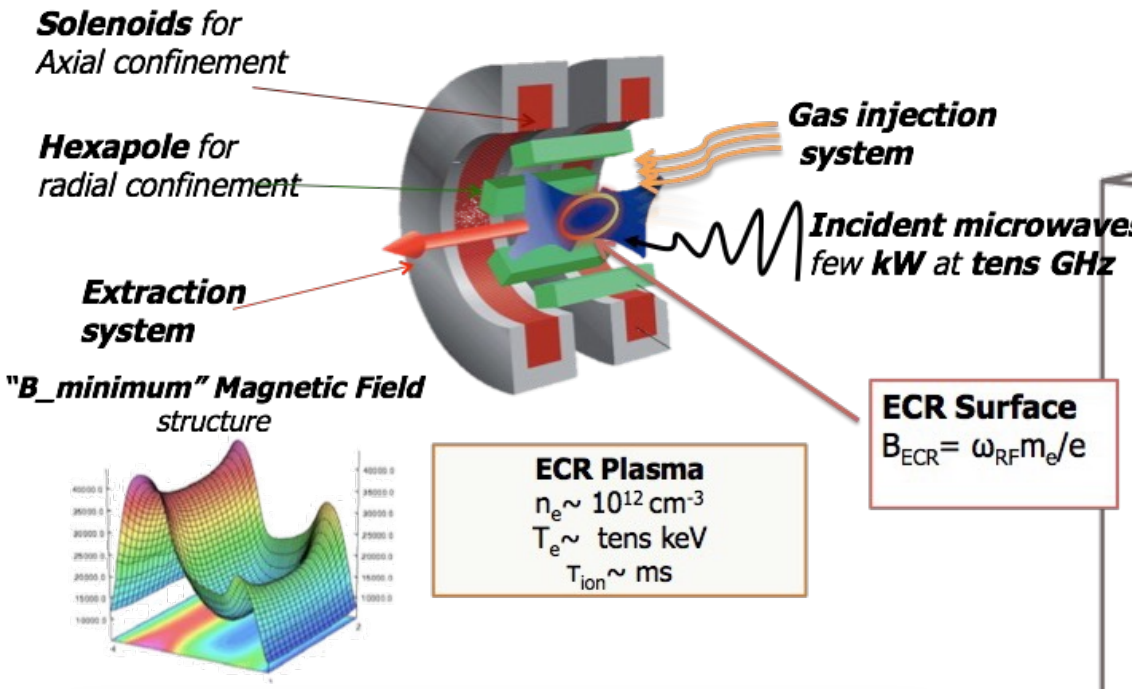
Takahashi et al. 1987, Phys Rev C 36, 1522.

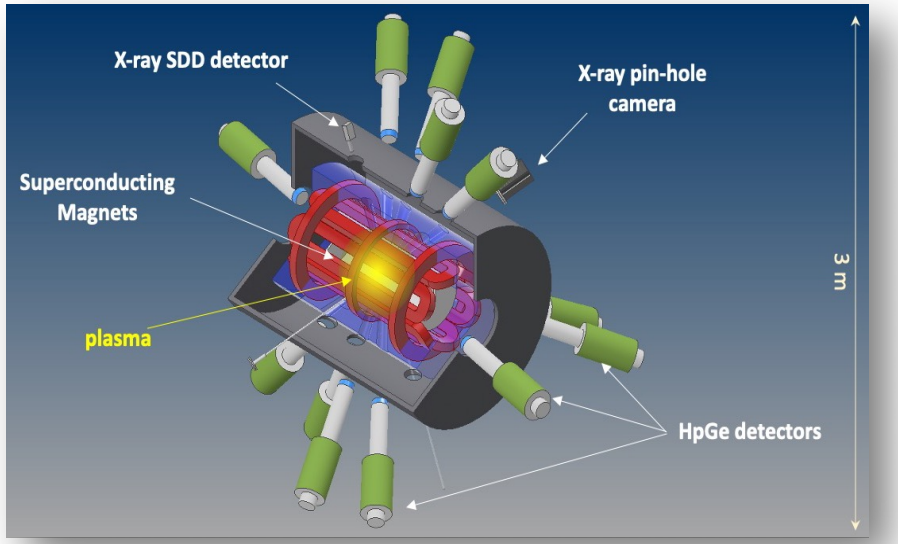
Direct implication on branching points in s-process nucleosynthesys chain competition of neutron capture vs β-decay

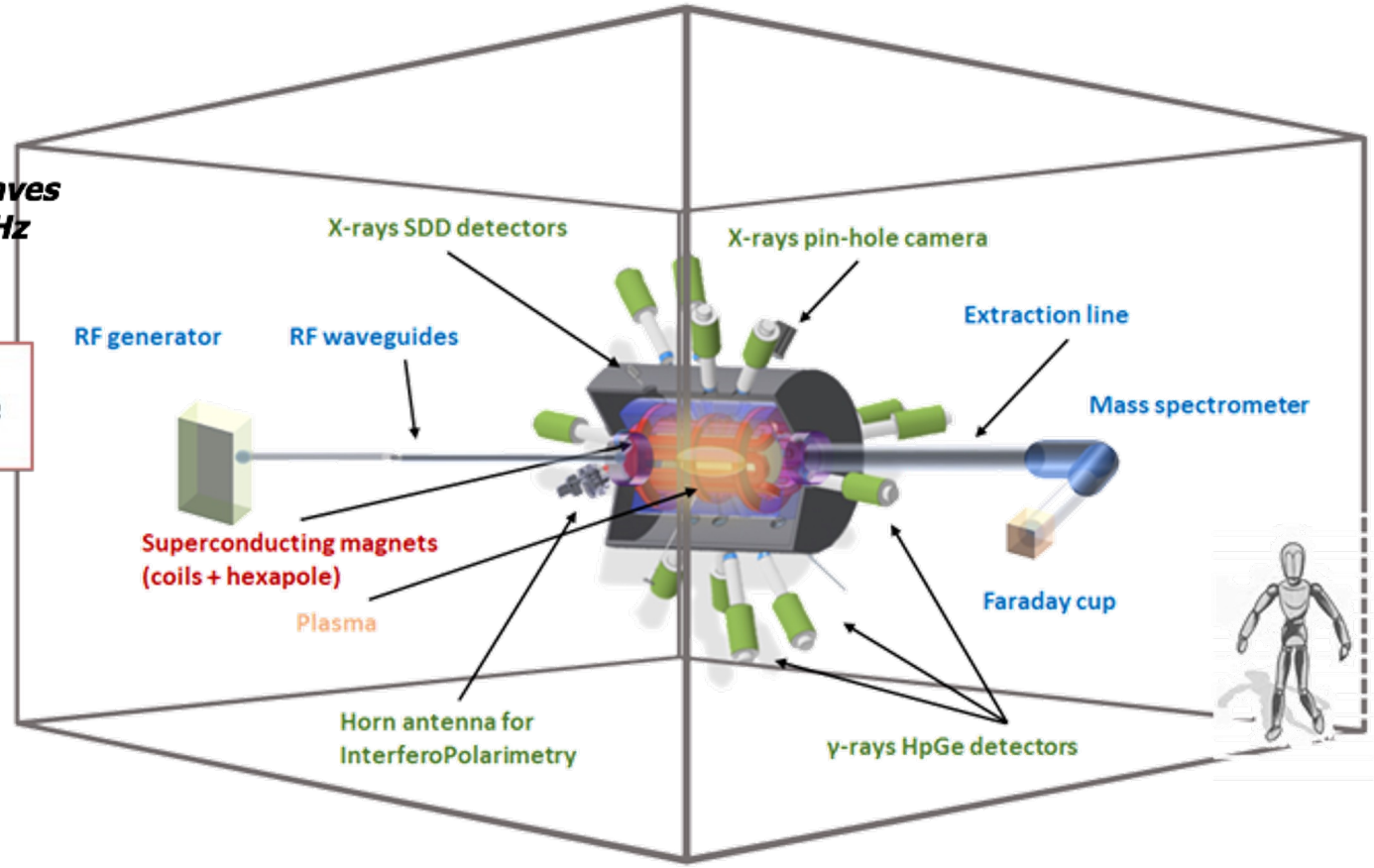


Isotope	$T_{1/2}$ (yr)	Eγ (keV)	
^{176}Lu	3.78×10^{10}	88-400	→ COSMO-CHRONOMETER
^{134}Cs	2.06	>600	→ reproduction of ^{134}Ba, ^{136}Ba s-only isotope yields
^{94}Nb	2.03×10^{4}	>700	

→ **Solving the puzzle about the contribution of s-processing to ^{94}Mo: β-decay or binary stars**







Magnetic traps for hot plasmas excited by e.m. waves

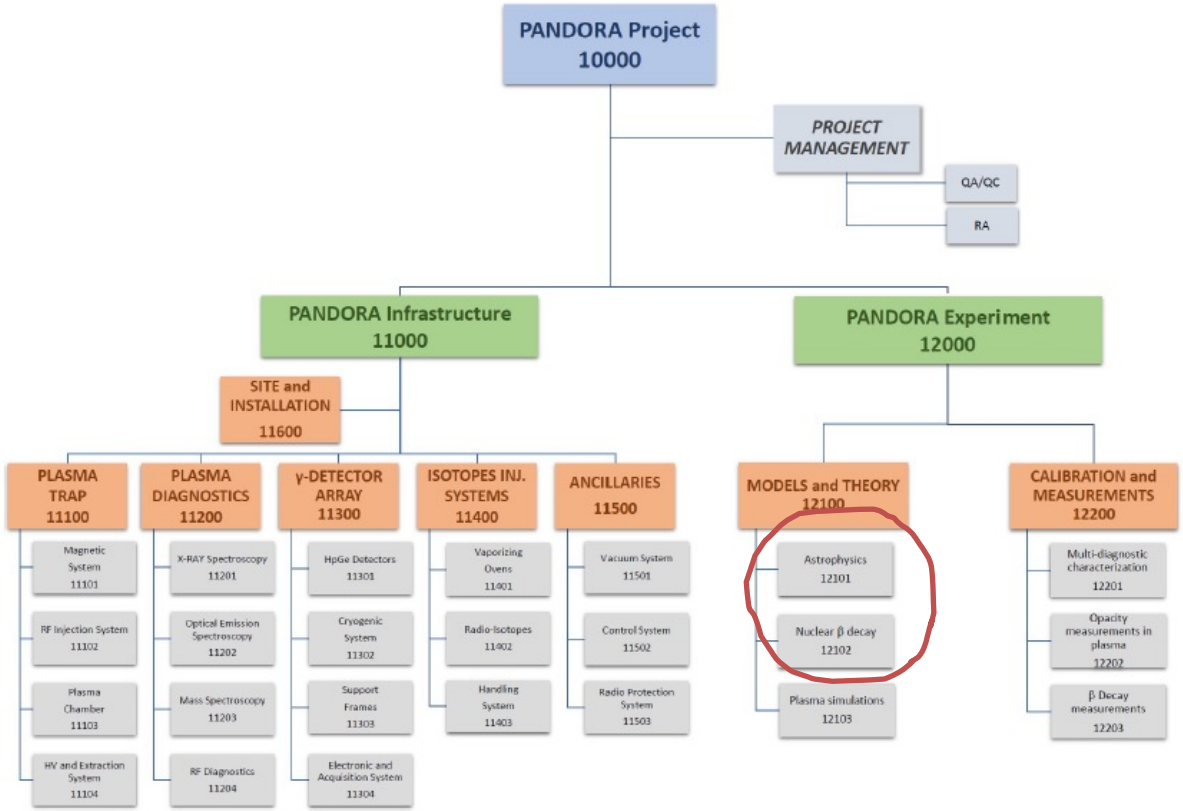
Partnerships and Organization

Contribution (official sites with budget and local responsible)

- People: 45 in Italy + 25 abroad, for a total of 70. FTE= 22 (2022)
- Special Topic pubblished on Frontiers in Physics and Frontiers in Astronomy and Space Science

Structure of the project

Workflow of actions and responsibilities have been provisionally defined at this level



Budget table updates

ITEM	*Total per item*	Already funded					expected	
		2020	2021 assegnato	2021*	2022	2023	2024	
Plasma Trap	**1570,5**	**91,5**	**220**	**990**	**35**	**235**		**1571,5**
RF system	**490**	240	0				250	**490**
Plasma chamber	**225**	35	10		100	40	20	**205**
HV&Extraction Syst.	**125**					45	80	**125**
OES+Mass spectr.	**155**		25		35	95		**155**
HPGe array+mech.	**1210**				30			**1210**
Isotope Injection	**203,5**	5,5	38			80	80	**203,5**
Vacuum&Controls	**150**				50		100	**150**
	4140 k€	**372**	**293**	**990**	**250**	**495**	**530**	**4140**
				after TDR approval				

In-kind temporary (2023-2025) contribution from GAMMA collaboration

INFN

Collaboration Agreement
GAMMA and PANDORA
INFN - CSN3

I - PREAMBLE

This document outlines the project of an experimental arrangement between the GAMMA and PANDORA Collaborations and Laboratori Nazionali del Sud (LNS) for the use of 16 HPGe GAMMA detectors (GASP-type) in the period 2023 - 2025 at LNS.

During the period of validity of this agreement, the home-base of the GAMMA detectors is defined as the Laboratori Nazionali di Legnaro (from now the home-base), where the HPGe detectors have been operated since more than 30 years.

II – PURPOSE OF THIS AGREEMENT

The present Collaboration Agreement (hereinafter named: CA) aims at establishing a framework of convergent activities and scientific goals among the GAMMA and PANDORA collaborations. Those will benefit of the parallel methodologies, approaches, tools and specific research scopes that are proposed and implemented by the two collaborations, in a context involving Nuclear Physics and other disciplines, such as Astrophysics and Cosmology, as well as other possible elements of impacts for the society and applied/industrial research. Among the others, it is worth mentioning nuclear phenomena (reactions and decays) that can be investigated by gamma-spectroscopy and are relevant to shed light on the nucleosynthesis of the elements in the Universe.

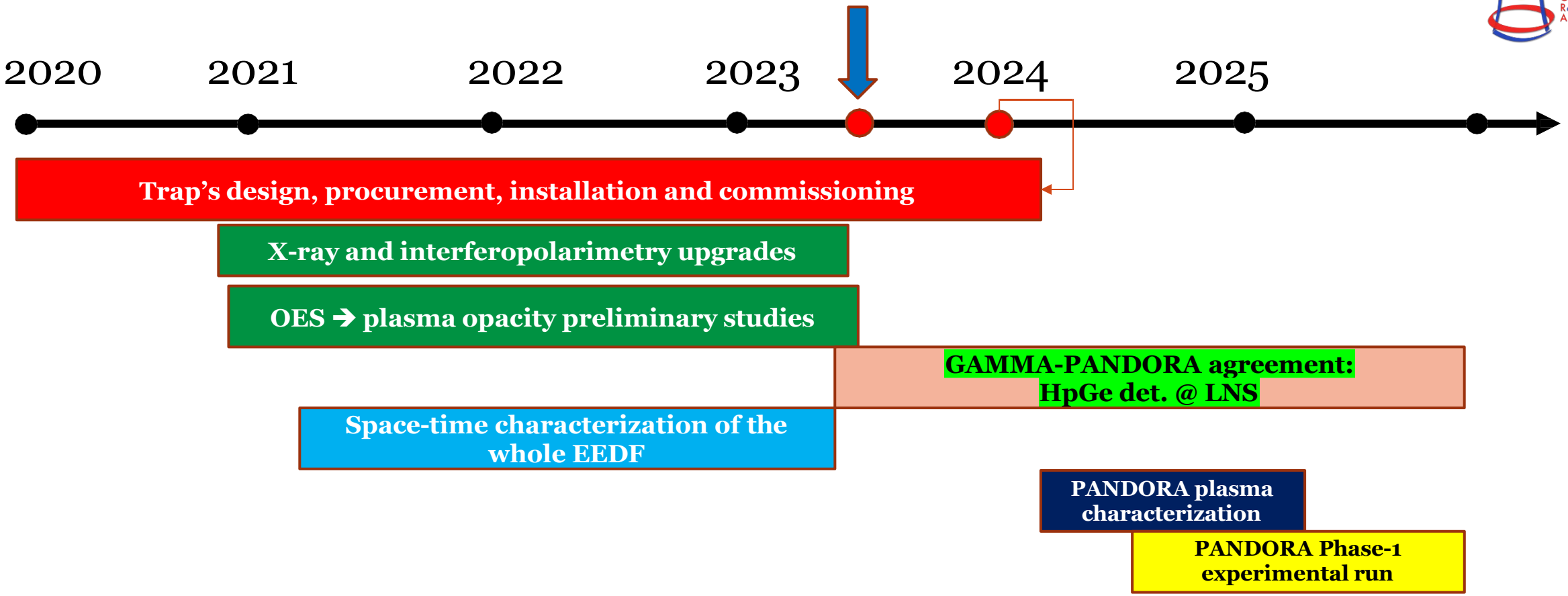
- New diagnostics proposed by GANIL/CNRS ➔ Thomson Scattering
- GSI is already contributing with in-kind vaporization systems
- INAF in-kind contribution by SARG spectrometer (installed in 2019)

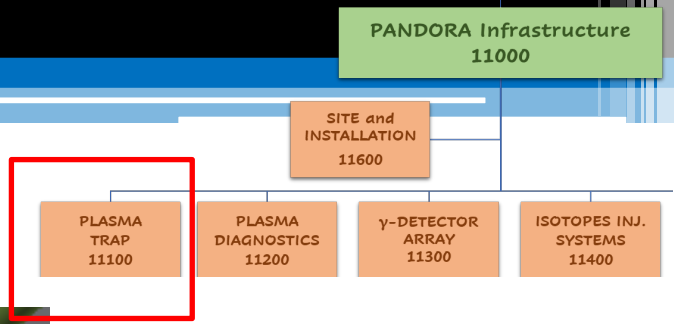
INFN LNS

Plasmas for Astrophysics Nuclear Decay Observation and Radiation for Archaeometry

PANDORA Timescale – GANTT "master"

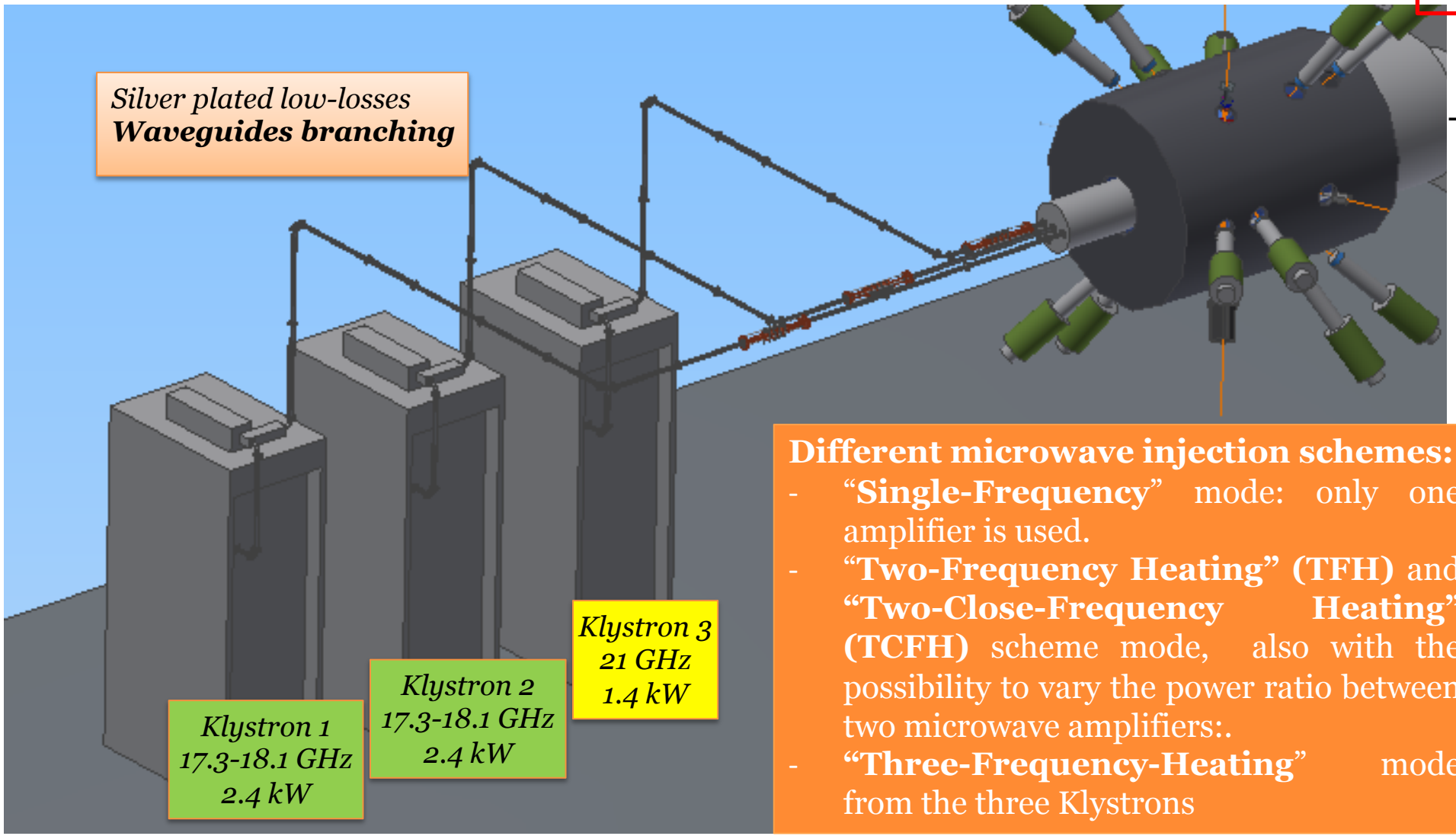
Plasmas for Astrophysics Nuclear Decay Observation and Radiation for Archaeometry





MAIN SUBSYSTEMS UPDATES: RF system

GREEN: already purchased
YELLOW: planned to be procured in 2024



Different microwave injection schemes:

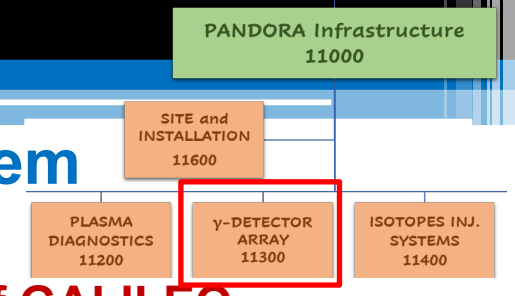
- "**Single-Frequency**" mode: only one amplifier is used.
- "**Two-Frequency Heating" (TFH)** and "**Two-Close-Frequency Heating" (TCFH)** scheme mode, also with the possibility to vary the power ratio between two microwave amplifiers:.
- "**Three-Frequency-Heating**" mode from the three Klystrons

Target power density of 1.38 kW/

PANDORA ECR plasmoid volume ~ 3 l

required total microwave power $P_{MW} \approx 4$ kW

"compliant" with the planned total amount of power delivered by the three klystrons 6 kW to reach high charge states

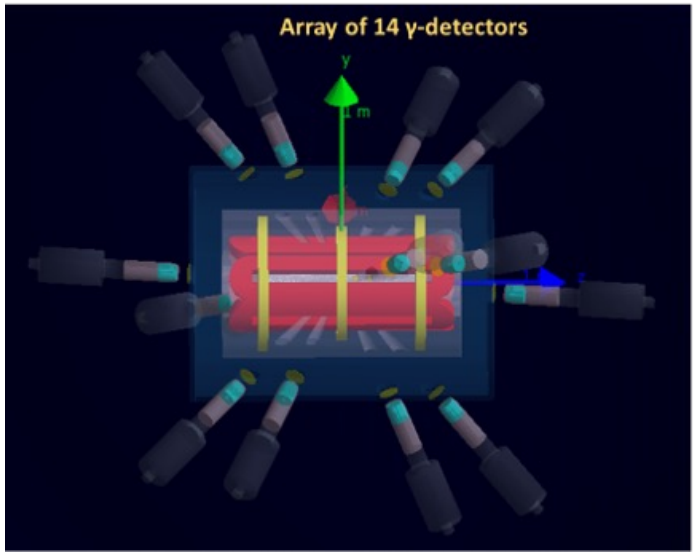


MAIN SUBSYSTEMS UPDATES: HPGE detection system

The detection setup is made of an array of 14 HPGe detectors placed around the trap

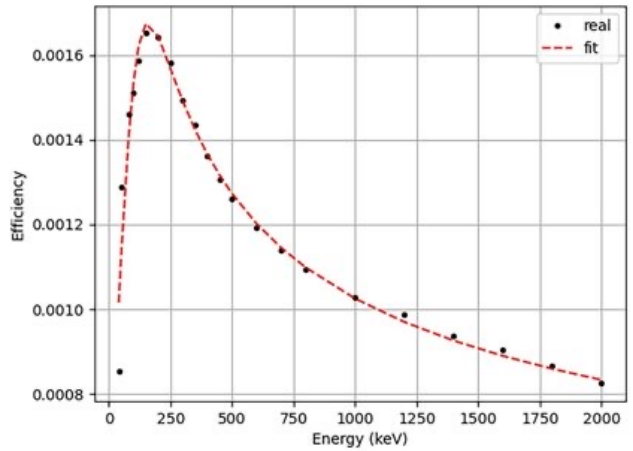
PANDORA-GAMMA Coll. Agreement signed in Oct. 2021 to use 16 HPGe detectors of GALILEO

- Time window from 2023 till the end of 2025
  - Ideal plan to move detectors to LNS in the second half of 2023
  - Really important to avoid delays in the time schedule
- It would allow to fully exploit PANDORA potentialities in the first experimental campaign
- Know-how/expertise transfer started with joint activities between LNS-LNL.
- Realization of a HPGe lab for the detectors maintenance started @LNS

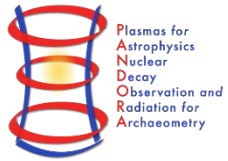


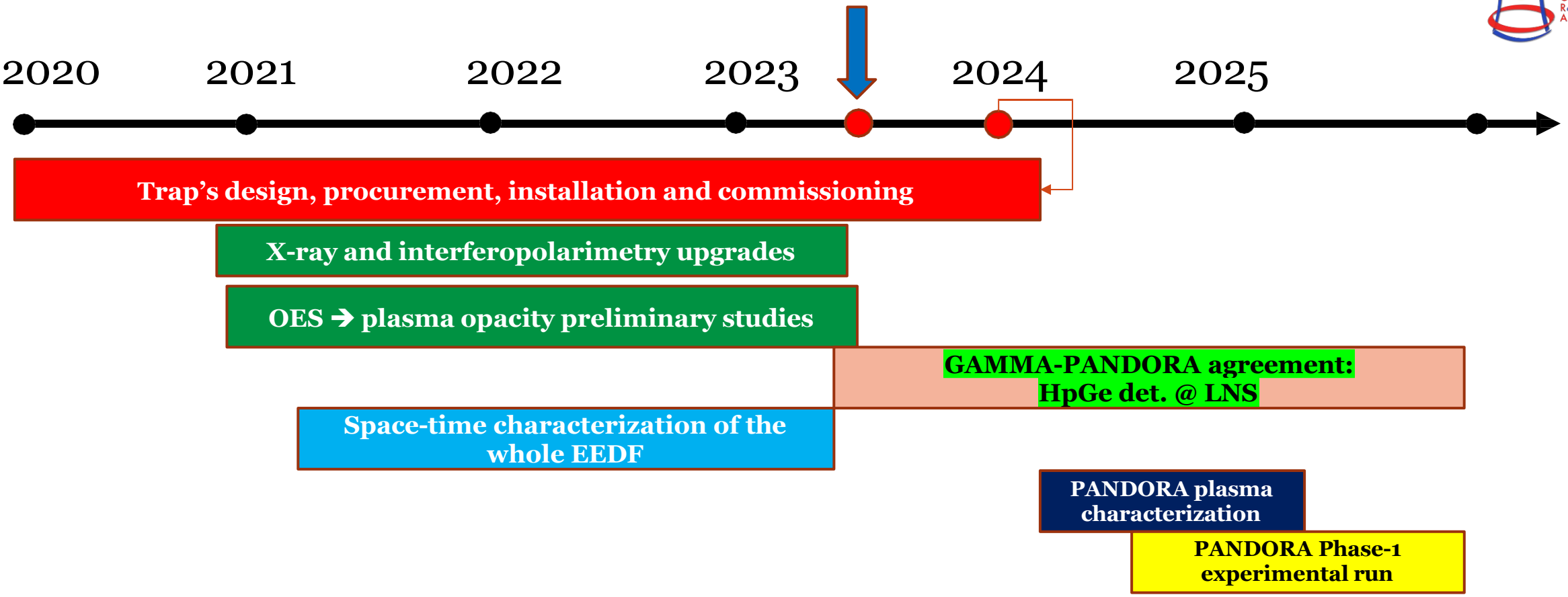
Main issues carefully evaluated:

- Photopeak detection efficiency (interplay between detector number and mechanical constraint)
- Signal to noise ratio (high background self-generated inside the trap)
- Magnetic field effects on HPGe charge collection

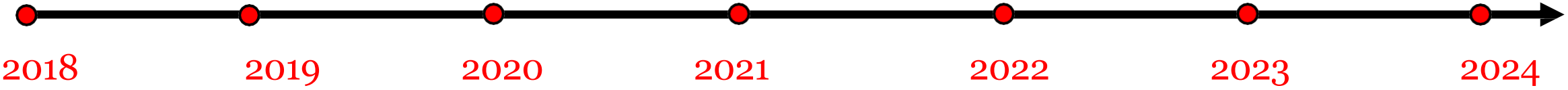


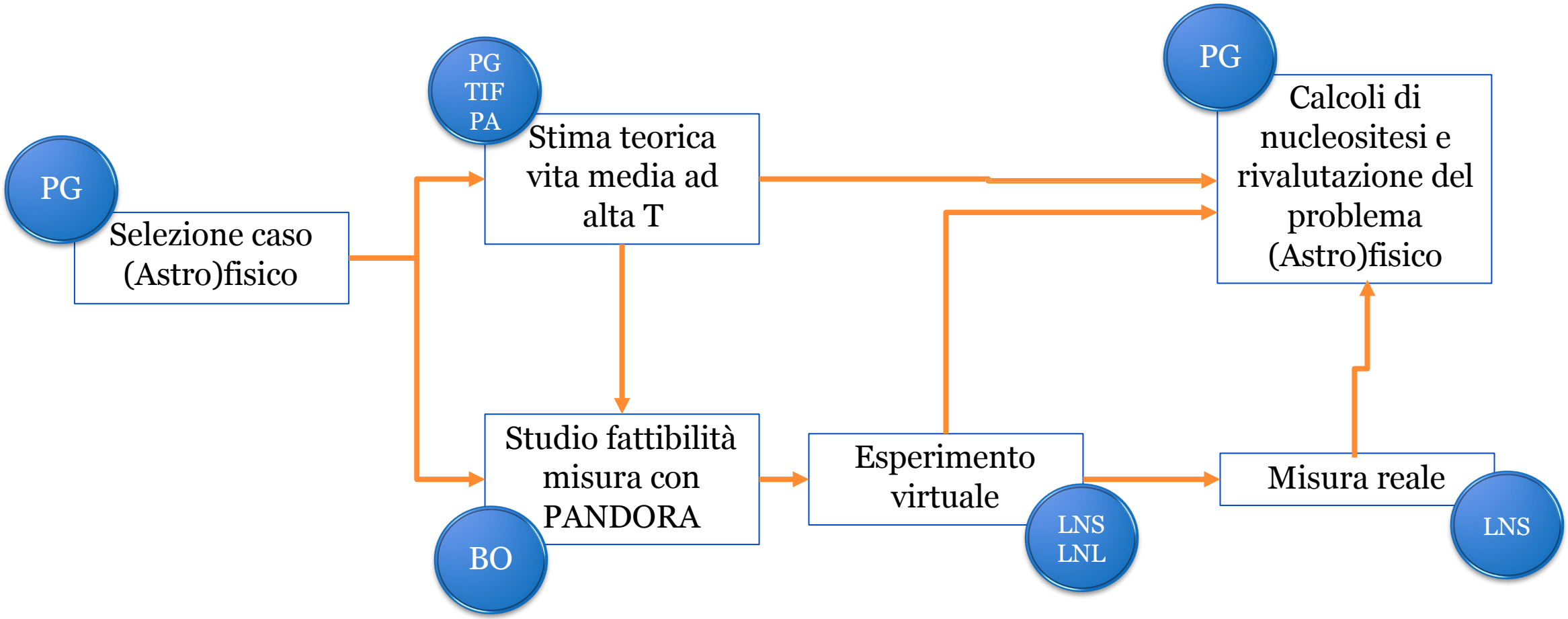
PANDORA Timescale – GANTT "master"





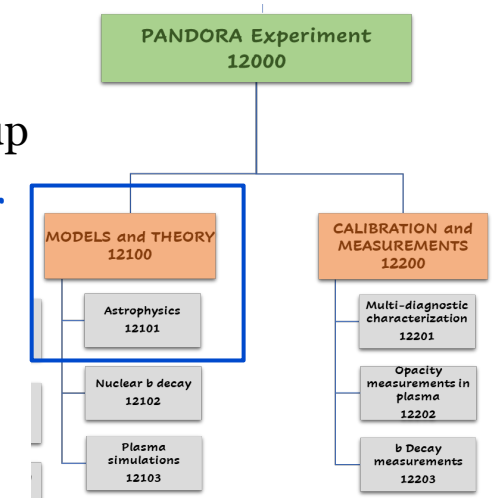
Physics cases and theoretic estimate of decay rates (WG di Perugia)




PG
Selezione caso (Astro)fisico
PG
TIF
PA
Stima teorica vita media ad alta T
Studio fattibilità misura con PANDORA
BO
Esperimento virtuale
LNS
LNL
Misura reale
LNS
PG
Calcoli di nucleositesi e rivalutazione del problema (Astro)fisico

MAIN SUBSYSTEMS UPDATES: Models and Theory

Perugia group



The study of isotopic ratios of s-process elements in presolar grain put important constraints to nuclear and stellar parameters in AGB star nucleosynthesys. (Palmerini et al. Astrophys. Journ. 921:7 (2021))

Such constraints (^{134,136}Ba galactic production) call for new nuclear physics measurements of weak interactions in ionized plasmas as well as of n-capture cross sections in nuclei with N ≈ 50 (^{84,85}Kr, ^{86,87,88}Sr, ^{93}Nb) and N ≈ 82 (^{134,135}Cs) magic numbers

^{134,135}Cs ST nuclear input doesn't fit solar constraints

- (n,y) MACS are from KADONIS 1.0
- (n,y) theoretical Hauser–Feshbach computations TALYS 2008 for unstable nuclei
- rates for weak interactions from Takahashi & Yokoi (1987)

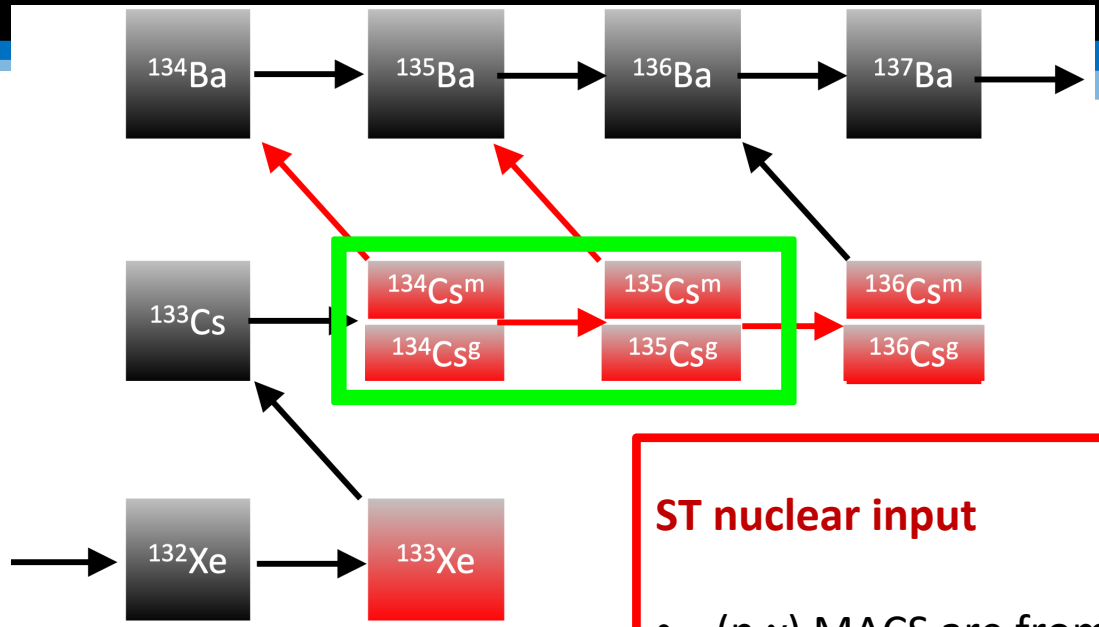
^{134,135}Cs improved nuclear input

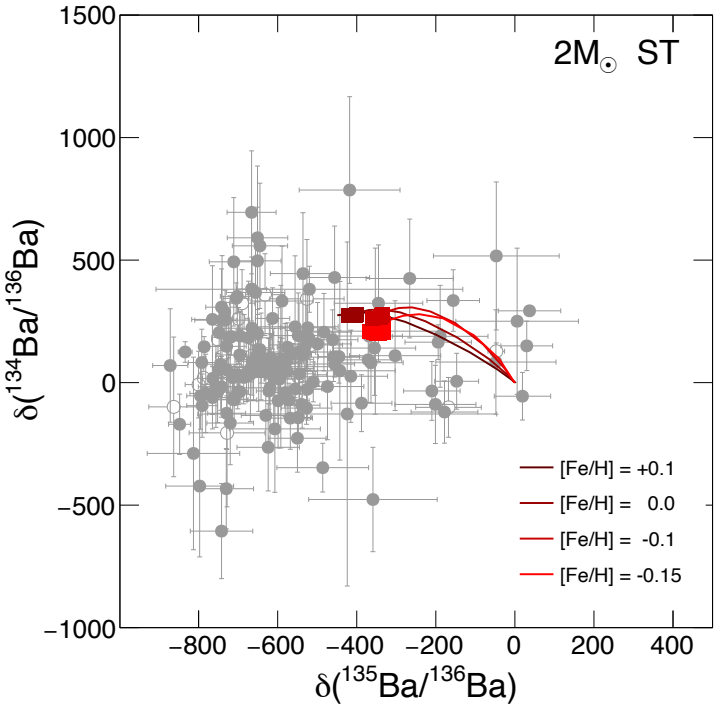
- Temperature enhancement of ^{134}Cs less steep than so far assumed in TY 1987
- Similar effects would be induced by variations in the ^{135}Cs neutron-capture cross section

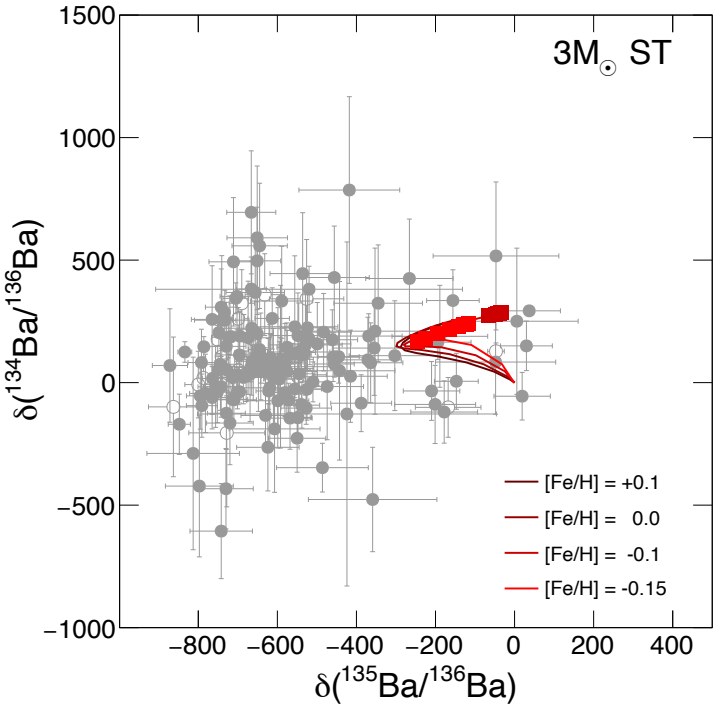
Milestone 2021 100 %

s-process...around N = 82

Ba isotopic ratios are sensitive to the (n,g) cross sections (only theoretical values exist) and b-decay of ^{134}Cs and ^{135}Cs at T > 2 10^8K.





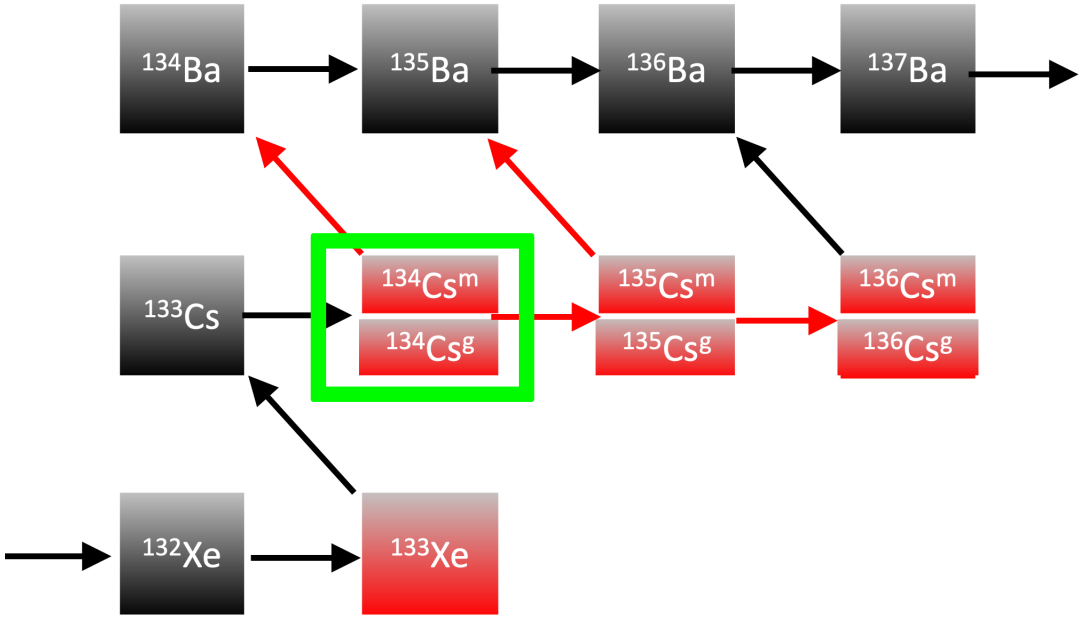


ST nuclear input

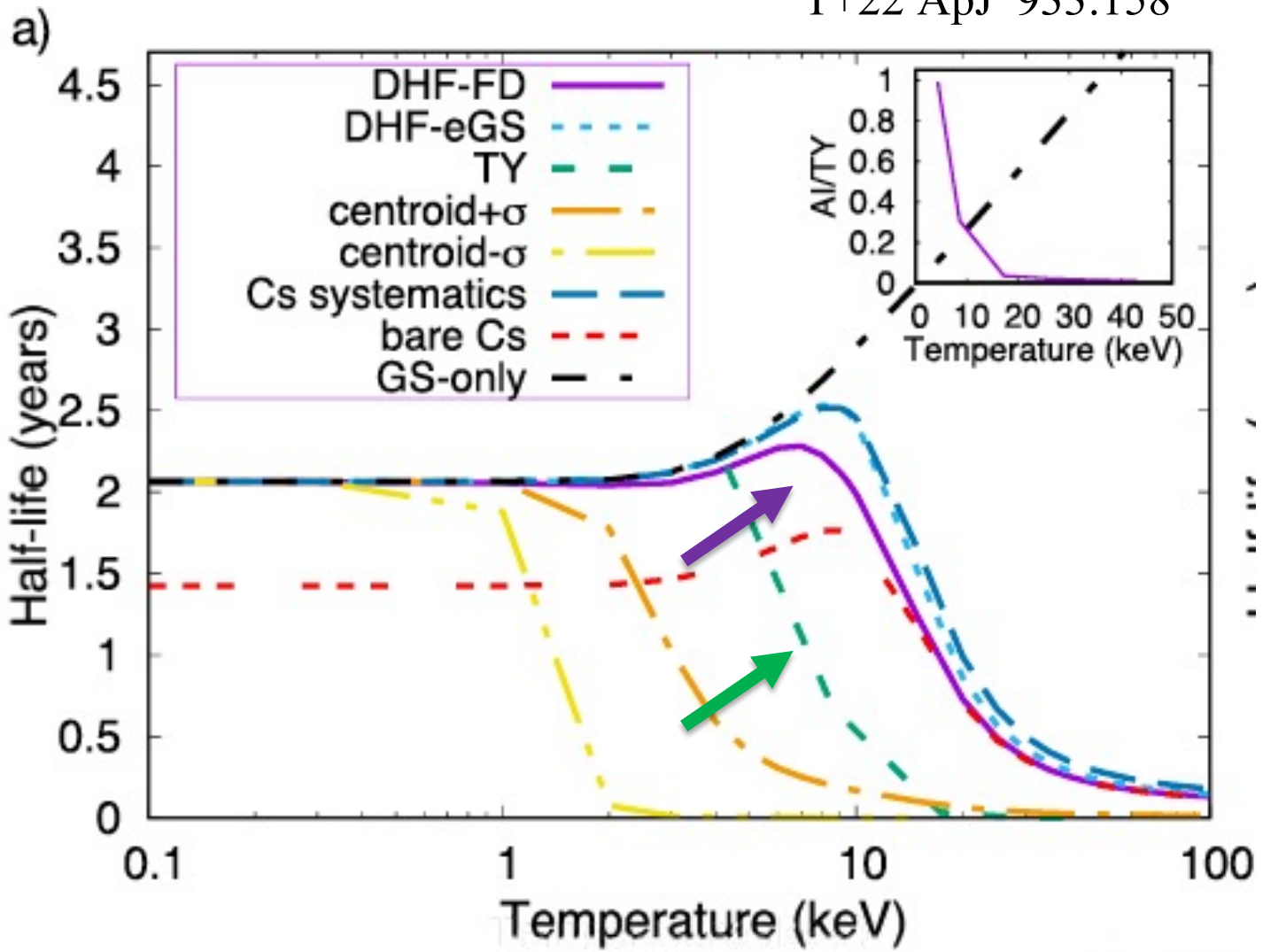
- (n,γ) MACS are from KADONIS 1.0
- (n,γ) theoretical Hauser–Feshbach computations TALYS 2008 for unstable nuclei
- rates for weak interactions from Takahashi & Yokoi (1987)

s-process …around N = 82…

With a new estimate of the b-decay rate of ^{134}Cs from DHF calculations…



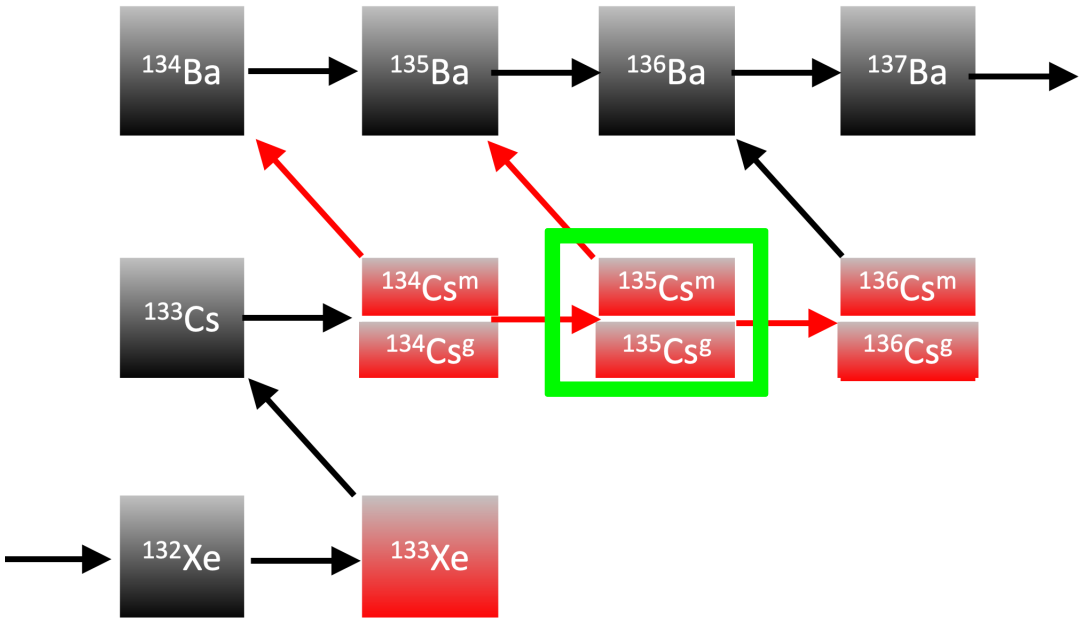
T+22 ApJ 933:158

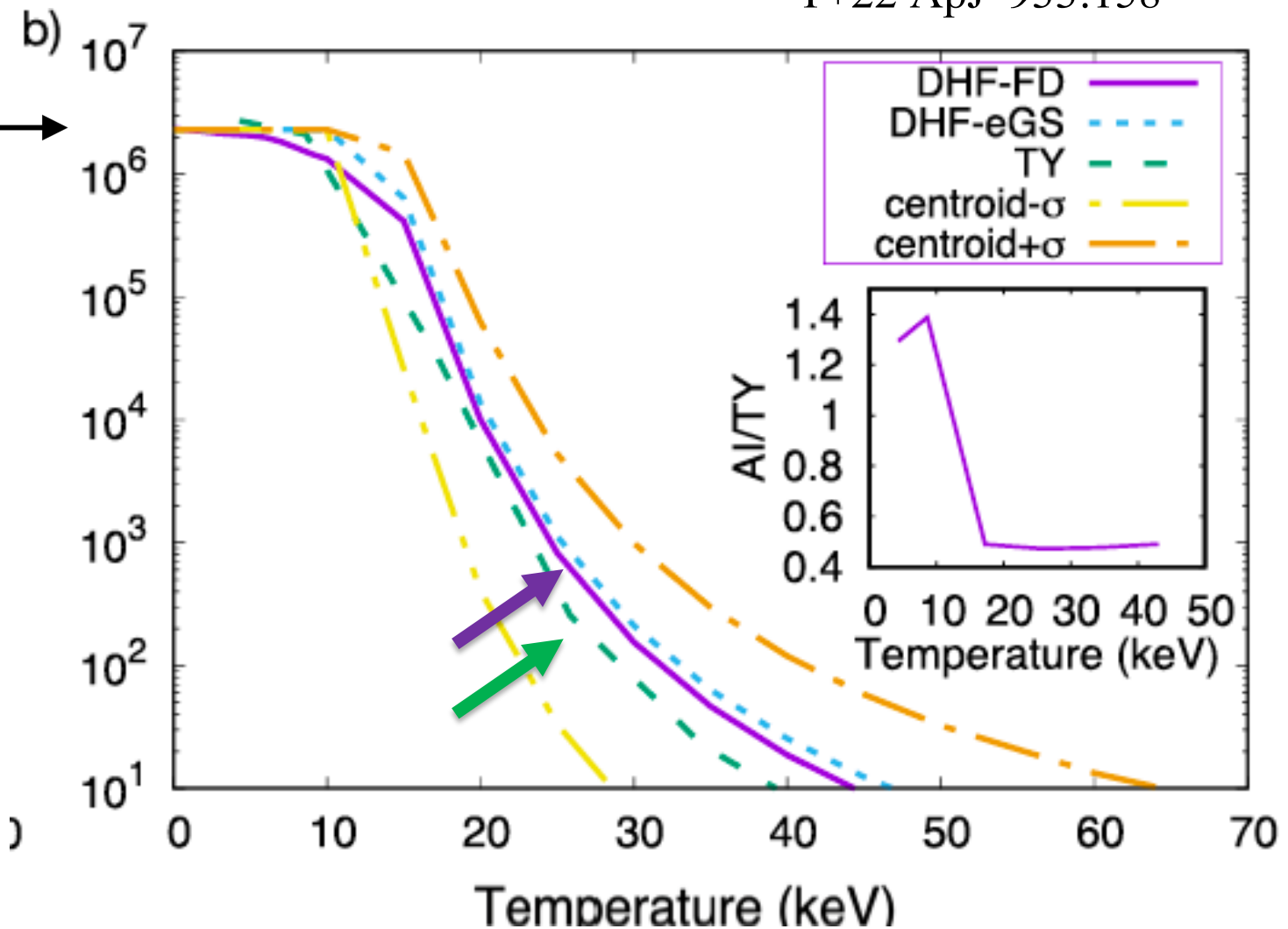


s-process …around N = 82

With a new estimate of the b-decay rate of ^{135}Cs from DHF calculations…

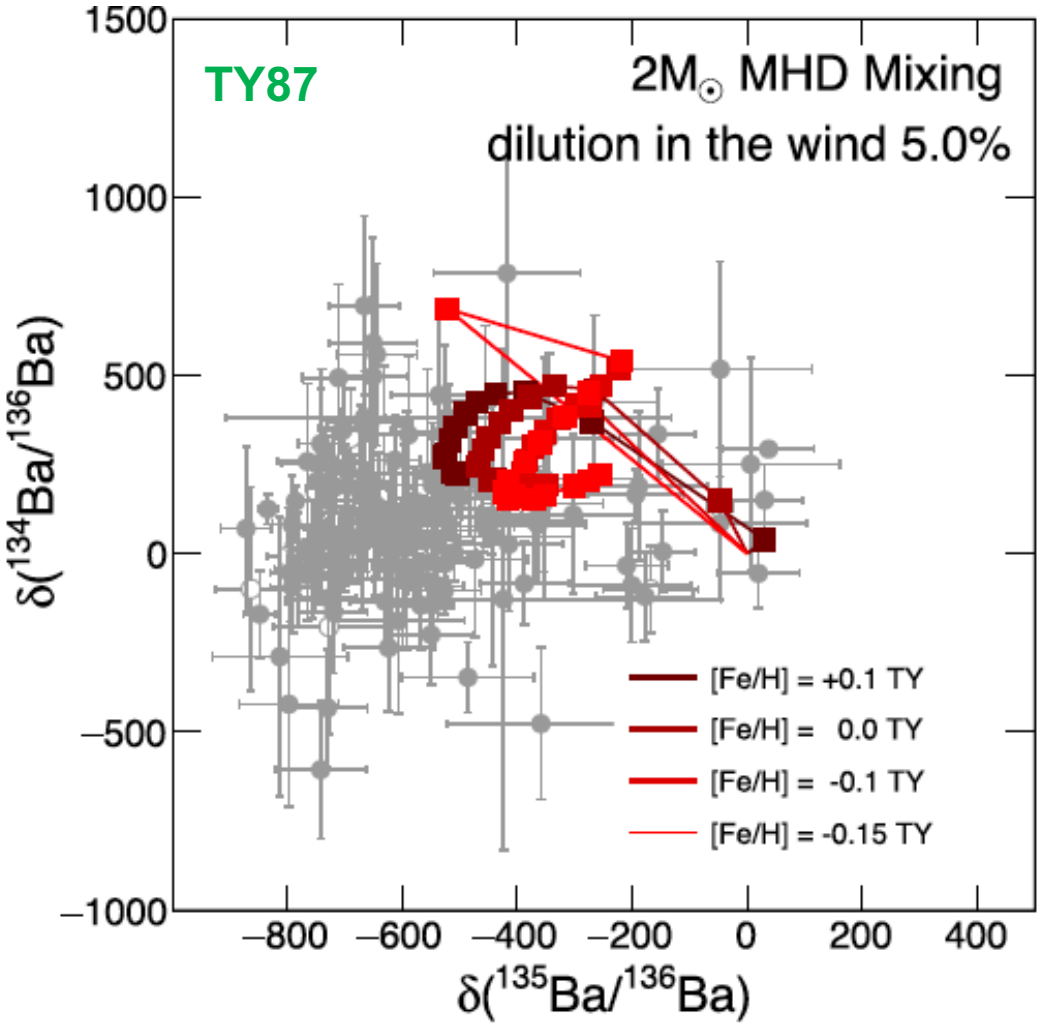
T+22 ApJ 933:158

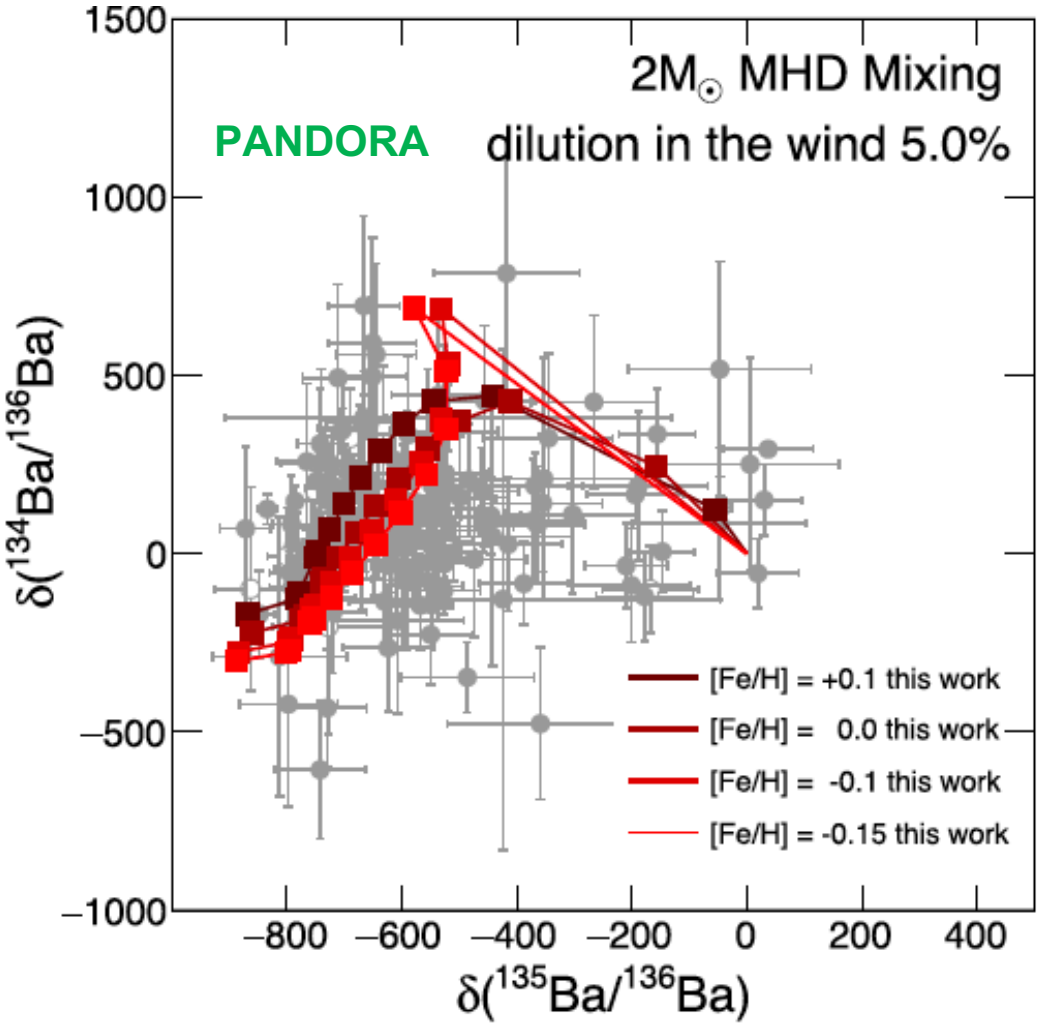




s-process ...around N = 82...

With a new estimate of thr b-decay rate of ^{134}Cs at high T.





Relativistic quantum computational approach for the study of electroweak decay processes in astrophysical scenario

[F. Triggiani PhD project]

- Developement of a quantum relativistic computational method to determine the self-consistent numerical solution of the Dirac equation for many-body systems (mean field approximation).
- The program estimates electroweak decay rates of nuclei of astrophysical as a function of temperature and density.

- β^- decay of $^{10}_{4}\mathrm{Be}$
- electron capture of $^{18}_{9}\mathrm{F}$
- β^- decay of $^{63}_{28}\mathrm{Ni}$
- electron capture of $^{7}_{4}\mathrm{Be}$
- β^- decay of $^{176}_{71}\mathrm{Lu}$
- β^- decay of $^{93}_{40}\mathrm{Zr}$
- β^- decay of $^{85}_{36}\mathrm{Kr}$
- β^- decay of $^{87}_{37}\mathrm{Rb}$
- β^- decay of $^{14}_{6}\mathrm{C}$

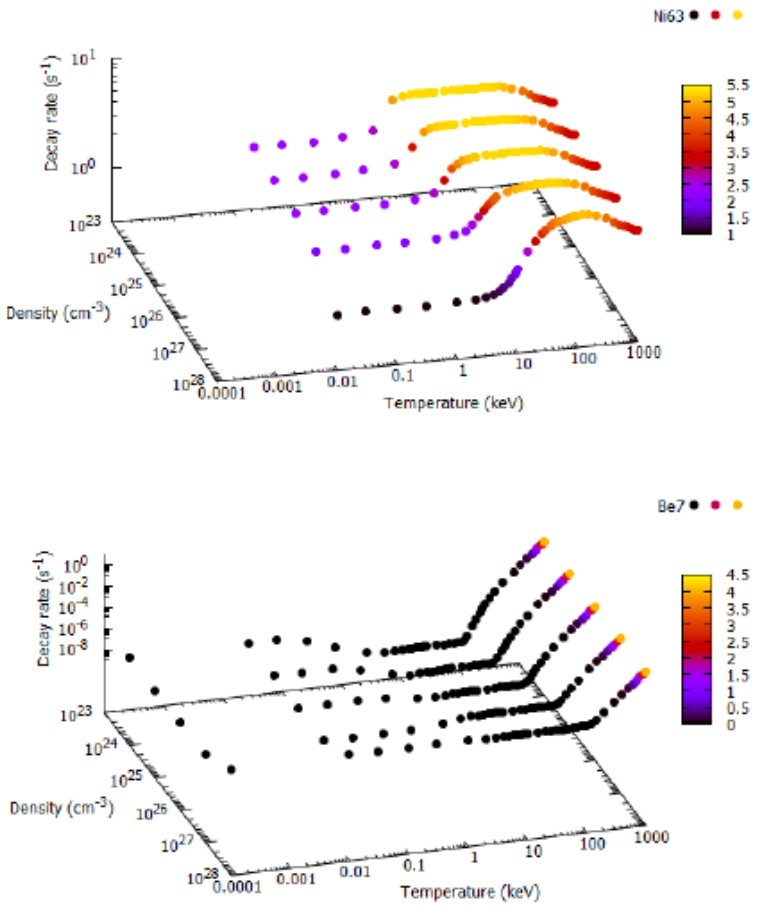


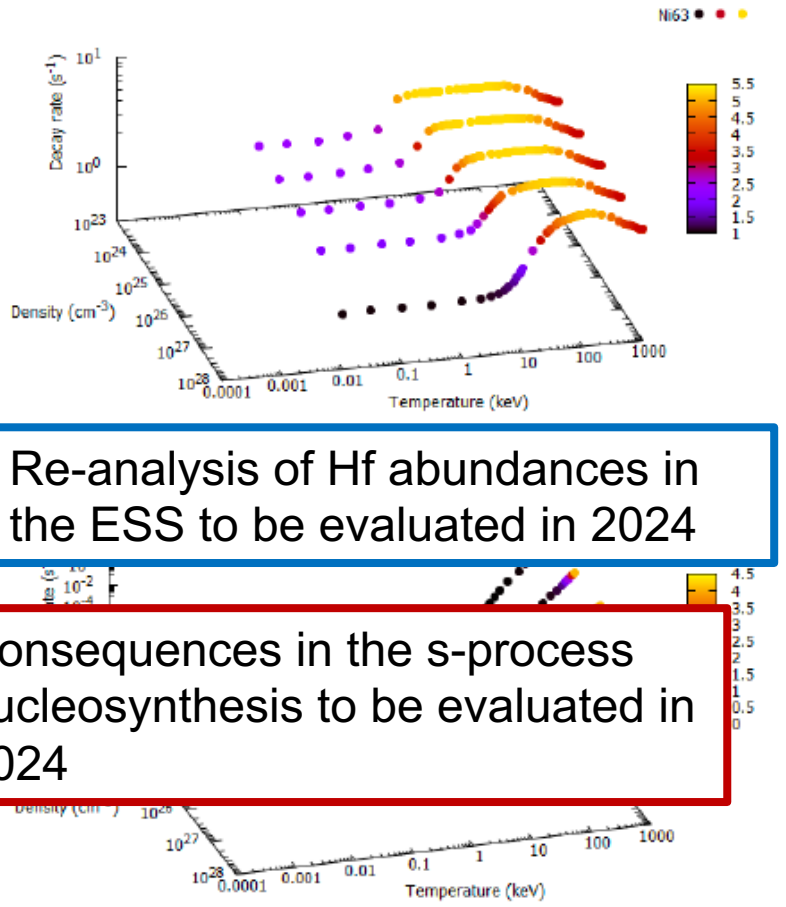
Figure 1: Decay rates of $^{63}_{28}\mathrm{Ni}$ and $^{7}_{4}\mathrm{Be}$ as a function of temperature and proton density.

Relativistic quantum computational approach for the study of electroweak decay processes in astrophysical scenario

[F. Triggiani PhD project]

- Developement of a quantum relativistic computational method to determine the self-consistent numerical solution of the Dirac equation for many-body systems (mean field approximation).
- The program estimates electroweak decay rates of nuclei of astrophysical as a function of temperature and density.

- β^- decay of $^{10}_{4}\mathrm{Be}$
- electron capture of $^{18}_{9}\mathrm{F}$
- β^- decay of $^{63}_{28}\mathrm{Ni}$
- electron capture of $^{7}_{4}\mathrm{Be}$
- β^- decay of $^{176}_{71}\mathrm{Lu}$
- β^- decay of $^{93}_{40}\mathrm{Zr}$
- β^- decay of $^{85}_{36}\mathrm{Kr}$
- β^- decay of $^{87}_{37}\mathrm{Rb}$
- β^- decay of $^{14}_{6}\mathrm{C}$



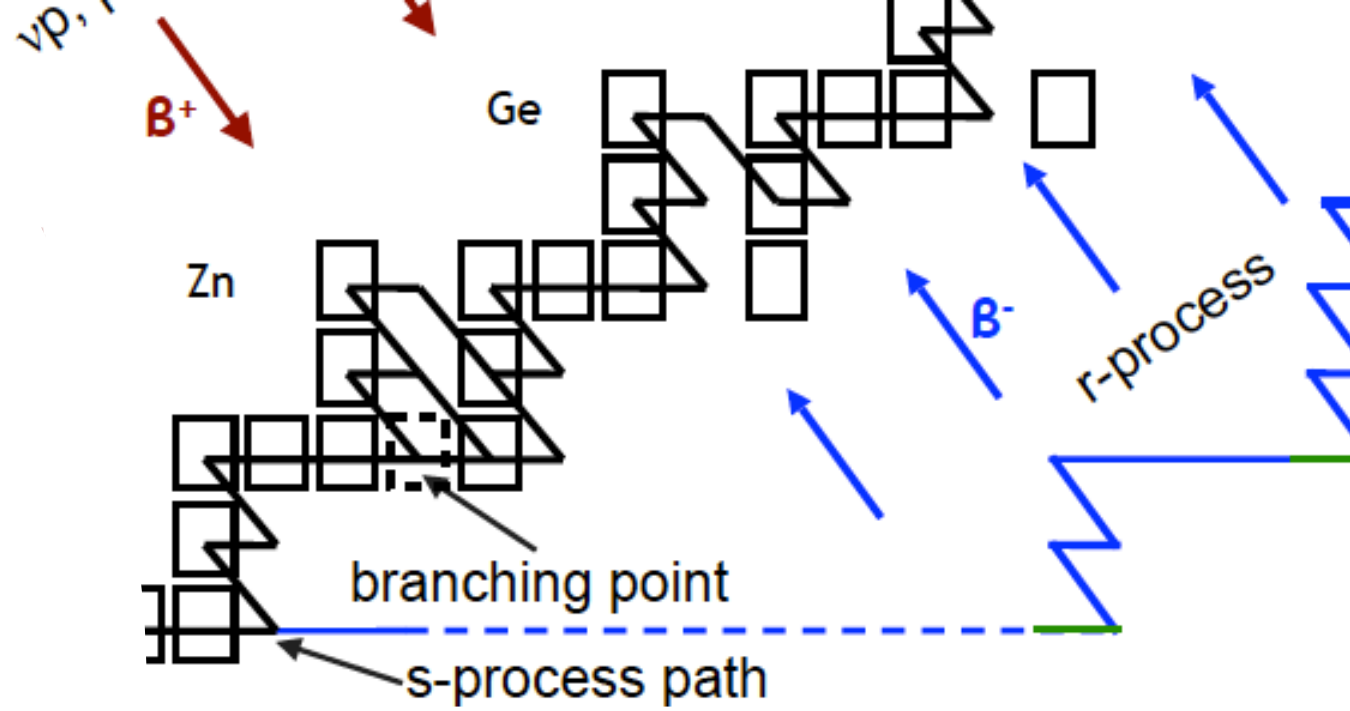
Re-analysis of Hf abundances in the ESS to be evaluated in 2024

Consequences in the s-process nucleosynthesis to be evaluated in 2024

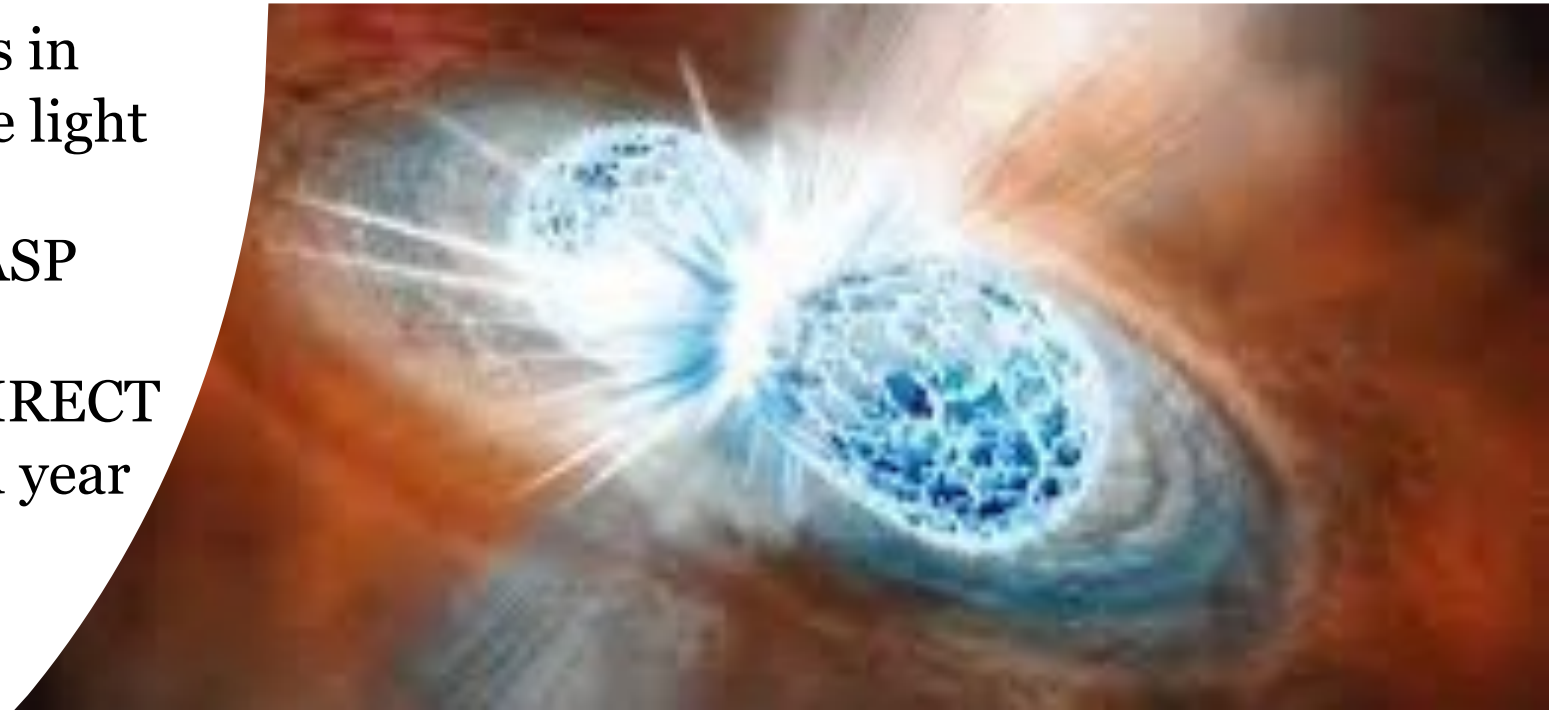
Figure 1: Decay rates of $^{63}_{28}\mathrm{Ni}$ and $^{7}_{4}\mathrm{Be}$ as a function of temperature and proton density.

Understanding r-process and Kilonovae aspects in the multimessenger hera

[M.Bezmalinovich PhD project]



- r-process nucleosynthesis following the coalescence NS-NS or NS-BH.
- Determination of plasma opacities in KN and numerical modeling of the light curve
- Updating the atomic input of GRASP (General Relativistic
- Atomic Structure Package) and DIRECT code Work planned for the second year
- r-nucleosynthesis via SKYNET



PREVENTIVI ECONOMICI

- Mobilità dottorandi LNS e TIFPA (M.B e F.T.).....8k€
  (s.j. ass. bonus dottorandi CSN3)
- Partecipazione 5 ric. di PG ad un PANDORA coll. meeting.....2.5k€
- 2 meeting WP «nucleosynthesis».....1.5K€
- 2 meeting WP «theor. Nucl. Modelling».....1.5K€
- Contributo pubblicazioni open access.....2k€