A brief sketch of the nuclear research by LNS groups at LNS

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Nuclear Physics @ LNS

2019	2020	2021	2022/2023
ASFIN2	*ASFIN2*	*ASFIN2*	*ASFIN2*
JLAB12	*JLAB12*	*JLAB12*	*JLAB12*
NEWCHIM	*NEWCHIM*	*CHIRONE*	*CHIRONE*
NUMEN	*NUMEN*	*NUMEN*	*NUMEN*
n_TOF	*n_TOF*	*n_TOF*	*n_TOF*
	PANDORA	*PANDORA*	*PANDORA*
		+ EIC_NET (DOT.)	*EIC_NET*
			+ NUCL-EX (DOT.)

JLAB12, EIC_NET — ***Linea 1*** (QUARKS AND HADRON DYNAMICS)

CHIRONE, NUMEN_GR3
NUCL-EX.DTZ — ***Linea 3*** (NUCLEAR STRUCTURES AND REACTIONS DYNAMICS)

ASFIN, n_TOF
PANDORA — ***Linea 4*** (ASTROPHYSICS AND INTERDISCIPLINARY RESEARCHES)

Nuclear Physics @ LNS

2019	2020	2021	2022/2023
ASFIN2	*ASFIN2*	*ASFIN2*	*ASFIN2*
JLAB12	*JLAB12*	*JLAB12*	*JLAB12*
NEWCHIM	*NEWCHIM*	*CHIRONE*	*CHIRONE*
NUMEN	*NUMEN*	*NUMEN*	*NUMEN*
n_TOF	*n_TOF*	*n_TOF*	*n_TOF*
	PANDORA	*PANDORA*	*PANDORA*
		+ EIC_NET (DOT.)	*EIC_NET*
			+ NUCL-EX (DOT.)

To date, LNS hosts:

→ the largest nuclear physics community in Italy: ~90 researchers (60 FTE)

→ the largest nuclear astrophysics community

→ the two most innovative nuclear physics experiments inside INFN: PANDORA and NUMEN

Nuclear Physics @ LNS

In this presentation I will focus on:

Linea 3 experiments:

CHIRONE → investigation of nuclear structure and dynamics, from clustering to the nuclear equation of state

NUMEN → main focus on the measurement of double charge-exchange reactions, for the assessment of nuclear matrix elements

Linea 4 experiments:

ASFIN2 → nuclear astrophysics with indirect methods and study of nuclear structure of light systems of astrophysical interest

n_TOF → direct measurement of n-capture reactions

PANDORA →

Nuclear physics midterm plan

The ongoing upgrades and the forthcoming facilities have called for new ideas and physics programs to be carried out

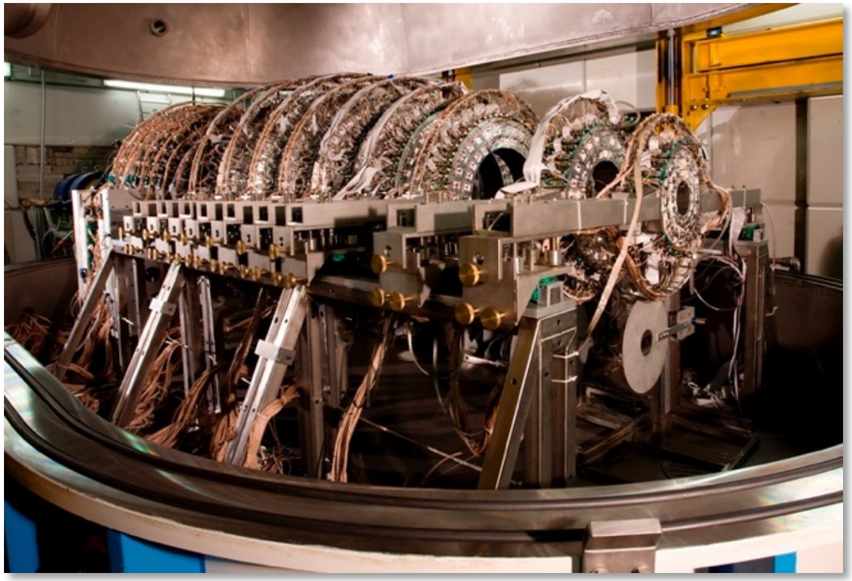
LNS session (4-5 April 2022):
https://agenda.infn.it/event/28717/

Working group (Chair)	Topic	Speaker
Nuclear Dynamics (S. Pirrone)	Heavy Ion Collision – EOS Clustering Fission Dynamics	E. De Filippo A. Di Pietro E. Vardaci
Nuclear Structure (C. Agodi)	Nuclear Matrix Elements towards $0\nu\beta\beta$: theoretical model developments Selective Study of nuclear structure response with high intensity beams and advanced spectrometry Collective modes in nuclei with stable and unstable beams	A. Gargano F. Cappuzzello G. Cardella
Nuclear Astrophysics (R. Pizzone)	Nuclear and atomics input for the quiescent stellar evolution The «explosive» universe : BBN and explosive nucleosynthesis s and r process	A. Pidatella G. G. Rapisarda M. L. Sergi
Applications (S. Tudisco)	Medical Applications Laser-Matter Interaction Plasma traps	G. Petringa G. A. P. Cirrone D. Mascali

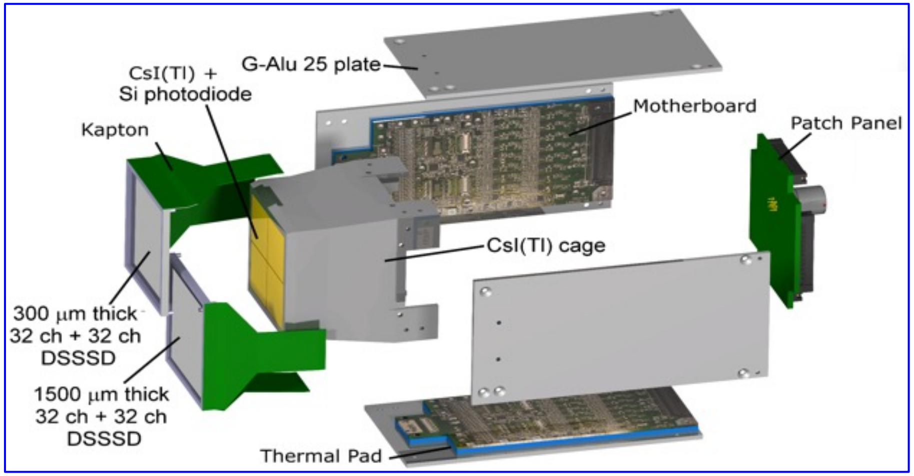
LINEA 3

CHIRONE

CHImera
R3B
hOdoscopes
Neutrons
Experiment



CHIMERA



FARCOS: Femtoscope Array for COrrelations and Spectroscopy

Study of the dependence of reaction mechanisms on isospin with innovative detections systems (CHIMERA, FARCOS, neutron detectors)

→ Research on nuclear matter under extreme considition (EOS for neutron stars, clustering in light nuclei)

- High energy and angular resolution Low thresholds (<1 MeV/A)
- Large Dynamic range (20MeV to 2GeV)
- Flexibility, modularity, transportability
- GET
- 20 telescopes

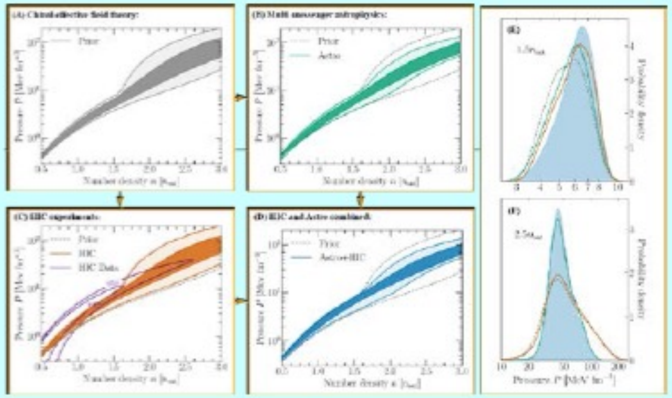
Some highlights

EOS & SIMMETRY ENERGY

Constraining Neutron-Star Matter with Microscopic and Macroscopic Collisions, S. Huth et al. **Nature 2022**
https://www.nature.com/articles/s41586-022-04750-w

Combining HIC and astrophysical results in the same Bayesian analysis to constrain neutron matter EOS

« HIC » = FOPI + ASY-EOS (1-1.5 ρ_0) + AGS
« Astro » = GW, NICER (pulsar X-ray hot spots)

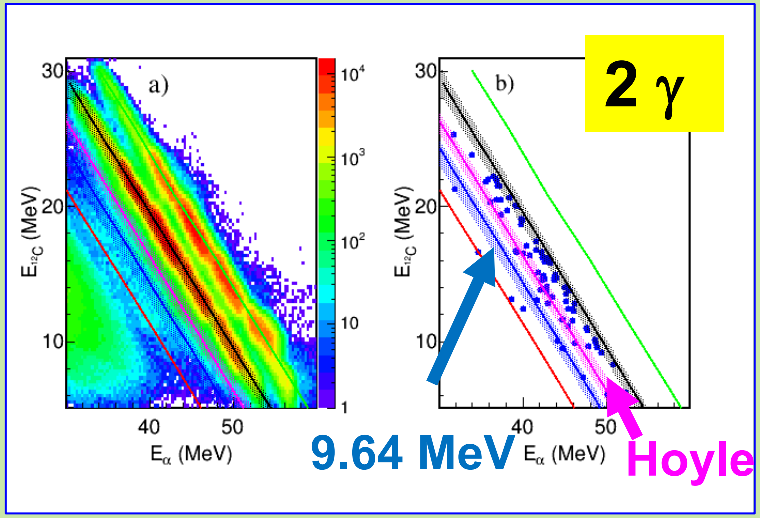


$$R_{1.4} = 12.01^{+0.78}_{-0.77}\ km \quad at\ 95\%\ CI$$

Advancing HIC experimental constraint to higher densities ≈2 ρ_0 is needed, a new experiment, ASY-EOS II (P.Russotto et al), is going to be asked (PAC-GSI 2022)

Experiment Hoyle-γ

Measurement of the Hoyle state branching ratio of ^{12}C and study of the level 9.64 MeV
$\alpha + ^{12}C$ @ 64 MeV (PRC 2021)



Investigating γ-ray decay of excited ^{12}C levels with a multifold coincidence analysis.
The aim of this work was to explore the feasibility of measuring the γ-decay widths of the 9.64-MeV state important for nucleaosynthesis in explosive scenarios

Questions to theory

1. The nuclear equation of state and its link to astrophysics
2. Dependence of the EOS and of the reaction mechanisms on the isospin
3. Investigation of cluster structure of light nuclei (rotational – vibrational bands) and implications for astrophysics
4. In the activity carried out at GSI, additional activity focused on Coulomb dissociation, fission, short-range correlations

LINEA 3

NUMEN_GR3

Extraction from measured cross-sections of “*data-driven*” information on Nuclear Matrix Elements for all the systems candidate for 0νββ

Use of nuclear reactions **(Double Charge Exchange reactions)** to stimulate in the laboratory the same nuclear transition occurring in 0νββ

Phase space factor

contains the average **neutrino mass**

$$\left(T_{1/2}^{0\nu\beta\beta}(0^+ \rightarrow 0^+)\right)^{-1} = G_{0\nu\beta\beta}\left|M^{0\nu\beta\beta}\right|^2 \left|f(m_i, U_{ei})\right|^2$$

0νββ decay half-life

Nuclear matrix element

K800 Superconducting Cyclotron

MAGNEX magnetic spectrometer

A challenging perspective at LNS in nuclear science

frontiers in Astronomy and Space Sciences
ORIGINAL RESEARCH
published: 07 May 2021
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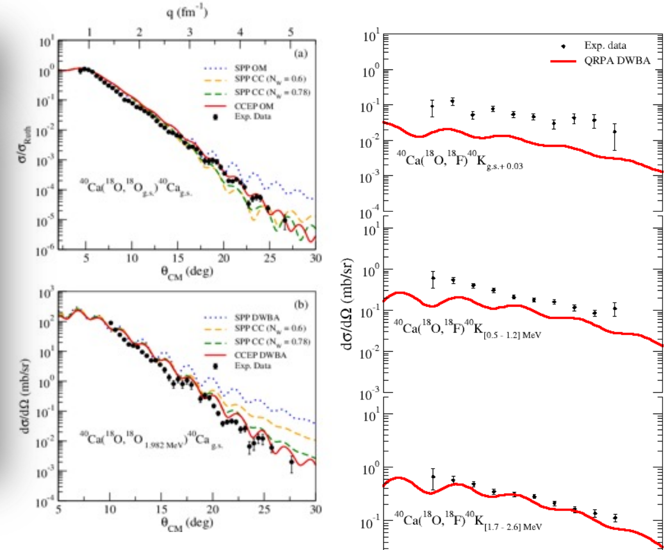
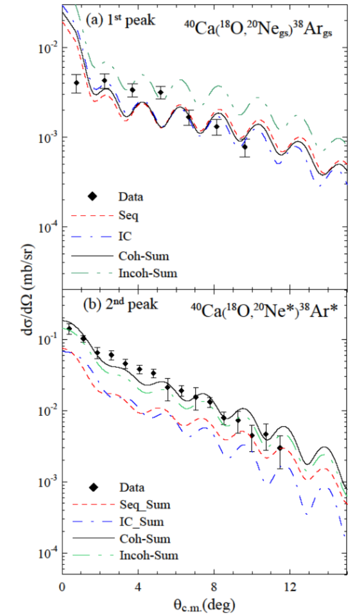
A Constrained Analysis of the $^{40}Ca(^{18}O,^{18}F)^{40}K$ Direct Charge Exchange Reaction Mechanism at 275 MeV

Manuela Cavallaro[1]*, Jessica I. Bellone[1], Salvatore Calabrese[1], Clementina Agodi[1], Stefano Burrello[2], Francesco Cappuzzello[1,3], Diana Carbone[1], Maria Colonna[1], N. Deshmukh[4], H. Lenske[5], A. Spatafora[1,3], L. Acosta[6], P. Amador-Valenzuela[7], T. Borello-Lewin[8], G. A. Brischetto[1,3], D. Calvo[9], V. Capirossi[9,10], E. Chávez[6], I. Ciraldo[1,3], M. Cutuli[1,3], F. Delaunay[11], H. Djapo[12], C. Eke[13], P. Finocchiaro[1], S. Firat[14], M. Fisichella[1], A. Foti[15], M. A. Guazzelli[16], A. Hacisalihoglu[17], F. Iazzi[9,10], L. La Fauci[1,3], R. Linares[18], J. Lubian[18], N. H. Medina[8], M. Moralles[19], J. R. B. Oliveira[8], A. Pakou[20], Luciano Pandola[1], H. Petrascu[21], F. Pinna[9,10], G. Russo[15], O. Sgouros[1], S. O. Solakci[14], V. Soukeras[1], G. Souliotis[22], D. Torresi[1], Salvatore Tudisco[1], A. Yildirin[14] and V. A. B. Zagatto[18] for the NUMEN collaboration



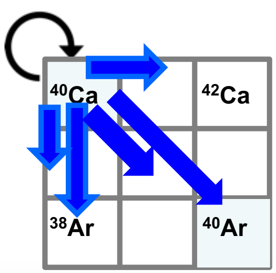
M. Cavallaro et al., Front. Astr. Sp. Sc. (2021)



J.L. Ferreira et al., PRC (2021)

A multi-channel approach to nuclear reactions

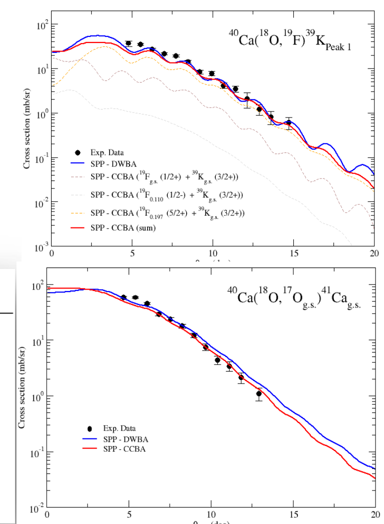
Consistent study (experimental and theoretical) of all the reaction channels competing with the double charge exchange to obtain a reliable description of the reaction mechanism and structure



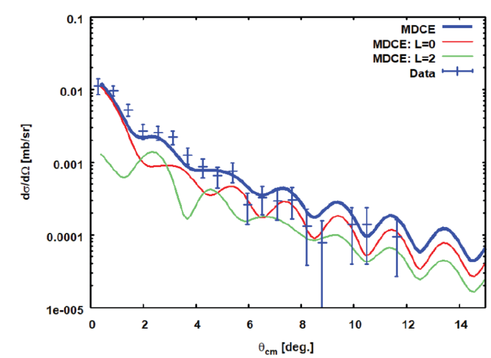
PHYSICAL REVIEW C 103, 054604 (2021)

Analysis of two-proton transfer in the $^{40}Ca(^{18}O,^{20}Ne)^{38}Ar$ reaction at 270 MeV incident energy

J. L. Ferreira,[1] D. Carbone,[2] M. Cavallaro,[2,*] N. N. Deshmukh,[2,3] C. Agodi,[2] G. A. Brischetto,[2,4] S. Calabrese,[2] F. Cappuzzello,[2,4] E. N. Cardozo,[1] I. Ciraldo,[2,4] M. Cutuli,[2,4] M. Fisichella,[2] A. Foti,[4] L. La Fauci,[2,4] O. Sgouros,[2] V. Soukeras,[2] A. Spatafora,[2,4] D. Torresi,[2] and J. Lubian[1]
(NUMEN Collaboration)



S. Calabrese et al. (to be submitted)



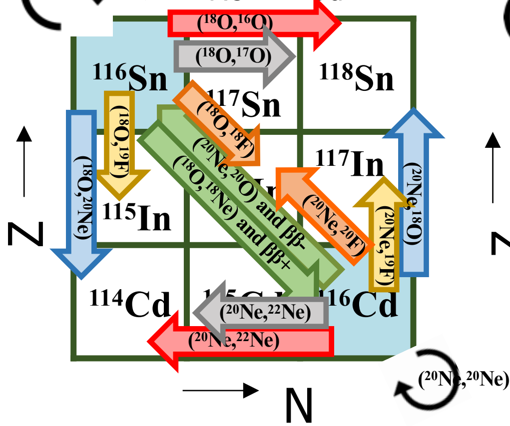
F. Cappuzzello, et al., EPJA (2015)
H. Lenske, et al., PPNP (2019)

Systems and reactions studied in NUMEN Phase 2

^{116}Cd - ^{116}Sn case

@ 15 AMeV

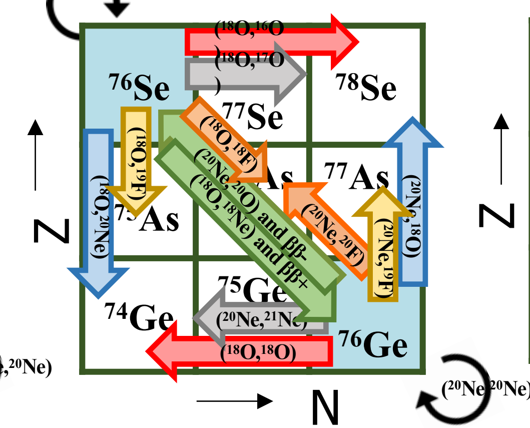
- ^{18}O + ^{116}Sn
- ^{20}Ne + ^{116}Cd



^{76}Ge – ^{76}Se case

@ 15 AMeV

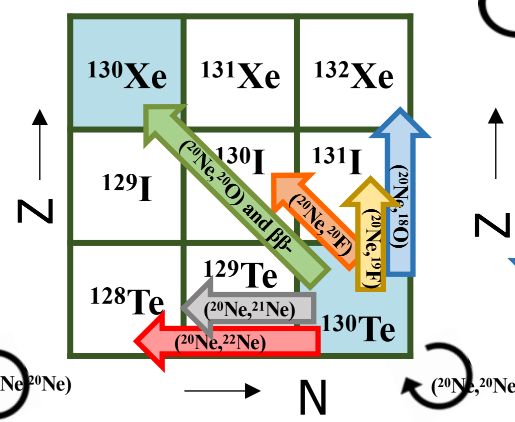
- ^{20}Ne + ^{76}Ge
- ^{18}O + ^{76}Se



^{130}Te – ^{130}Xe case

@ 15 AMeV

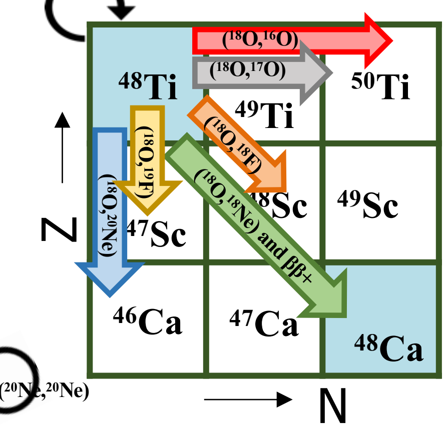
- ^{20}Ne + ^{130}Te

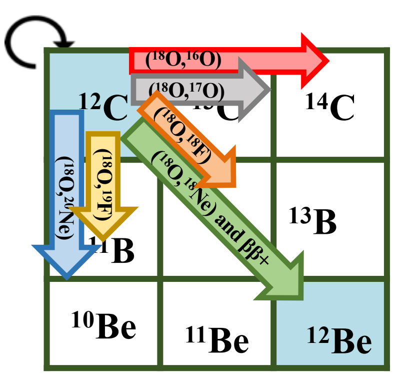


^{48}Ti – ^{48}Ca case

@ 15 AMeV

- ^{18}O + ^{48}Ti





^{12}C – ^{12}Be case at 2 beam energies

@ 15 AMeV

@ 22 AMeV

Last experiment performed at LNS after the COVID lockdown and before the shutdown of LNS facilities for the upgrade

<u>The research activity includes:</u>

→ Theoretical work focused, for instance, on the Majorana mechanism and its connection with 0νββ

→ R&D for the development of novel detectors, e.g. for high rates

Questions to theory

1. Using experimental data to refine the calculation of the nuclear matrix elements for neutrinoless double beta decay

2. Study the connection between the nuclear matrix elements for double charge-exchange reactions and the one for neutrinoless double beta decay

3. Evaluate the different contributions (as a function of energy) from the different operators to the nuclear matrix elements for double charge-exchange reactions

4. Assess the contribution from competing channels to the double charge-exchange reactions (background from multistep transfer, for instance

LINEA 4

ASFIN2

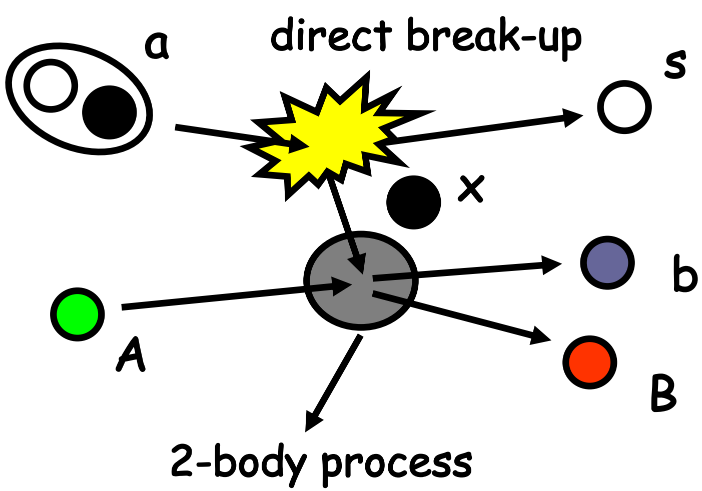
- ***Indirect methods allow to complement direct measurements*** overcoming several experimental difficulties (Coulomb barrier penetration effects, electron screening effects, background effects…);

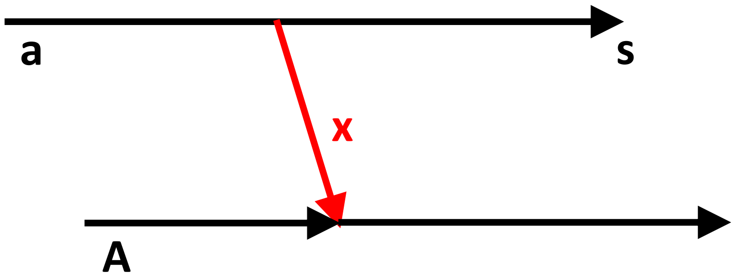
- ***ASFIN is active in the field*** of experimental nuclear astrophysics since 90's allowing to shed light on several astrophysical problems (BBN, stellar nucleosynthesis, explosive nucleosynthesis…)

- During the years, ***ASFIN applied THM but also ANC e Thick Target Inverse Kinematic (TTIK)*** methods for extracting nuclear reaction cross section of interest for astrophycis

- Indirect methods allow one to deduce the ***bare-nucleus S(E)-factor*** at ultra-low energies for astrophysical applications

Trojan Horse Method





The Asymptotic Normalization Coefficient (ANC) approach

Most important results 2021-2022

Annu. Rev. Nucl. Part. Sci. 2021. 71:345–76

ANNUAL REVIEWS

Annual Review of Nuclear and Particle Science

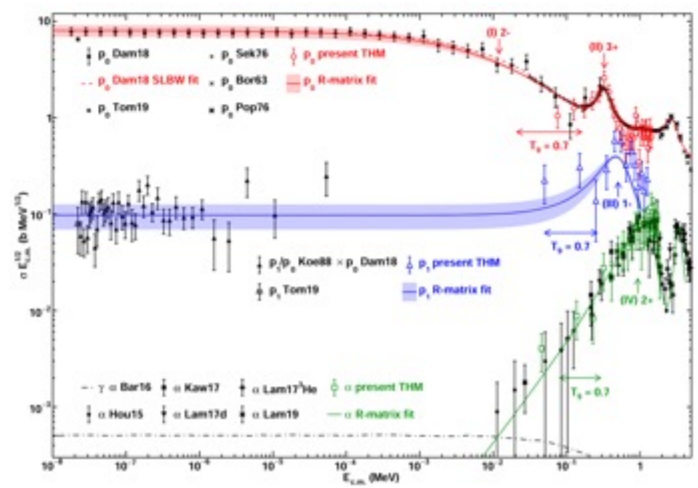
The Trojan Horse Method: A Nuclear Physics Tool for Astrophysics

Aurora Tumino,[1,2] Carlos A. Bertulani,[3] Marco La Cognata,[2] Livio Lamia,[2,4,5] Rosario Gianluca Pizzone,[2] Stefano Romano,[2,4,5] and Stefan Typel[6,7]

The Astrophysical Journal Letters, 915:L13 (14pp), 2021 July 1 https://doi.org/10.3847/2041-8213/ac061f

Constraining the Primordial Lithium Abundance: New Cross Section Measurement of the ^{7}Be + n Reactions Updates the Total ^{7}Be Destruction Rate

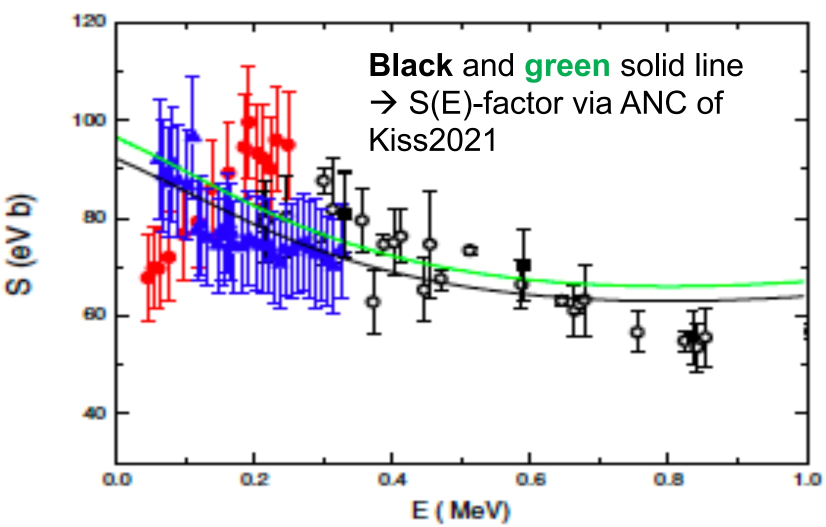
S. Hayakawa[1], M. La Cognata[2], L. Lamia[2,3,4], H. Yamaguchi[1,5], D. Kahl[6,19], K. Abe[1], H. Shimizu[1], L. Yang[1,20], O. Beliuskina[1,21], S. M. Cha[7,22], K. Y. Chae[7], S. Cherubini[2,3], P. Figuera[2], Z. Ge[8,21], M. Gulino[2,9], J. Hu[10], A. Inoue[11], N. Iwasa[12], A. Kim[13], D. Kim[13,22], G. Kiss[8,23], S. Kubono[1,8,10], M. La Commara[14,15], M. Lattuada[2,3], E. J. Lee[7], J. Y. Moon[16], S. Palmerini[17,18], C. Parascandolo[15], S. Y. Park[13,24], V. H. Phong[8,25], D. Pierroutsakou[15], R. G. Pizzone[2], G. G. Rapisarda[2], S. Romano[2,3,4], C. Spitaleri[2,3], X. D. Tang[10], O. Trippella[17,18], A. Tumino[2,9], and N. T. Zhang[10]

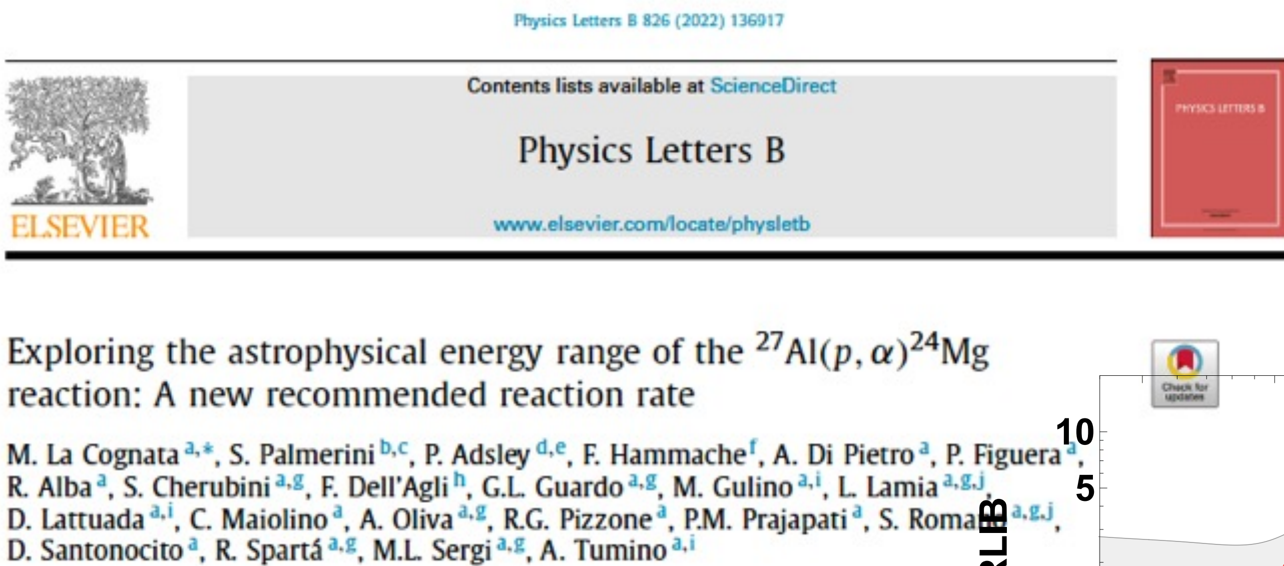


PHYSICAL REVIEW C 104, 015807 (2021)

Indirect determination of the astrophysical S factor for the ^{6}Li(p,γ)^{7}Be reaction using the asymptotic normalization coefficient method

G. G. Kiss,[1,*] M. La Cognata,[2,†] R. Yarmukhamedov,[3,‡] K. I. Tursunmakhatov,[3,4] I. Wiedenhöver,[5] L. T. Baby,[5] S. Cherubini,[2,6] A. Cvetinović,[2] G. D'Agata,[7] P. Figuera,[2] G. L. Guardo,[2,6] M. Gulino,[2,8] S. Hayakawa,[9] I. Indelicato,[2,6] L. Lamia,[2,6,10] M. Lattuada,[2,6] F. Mudò,[2,6] S. Palmerini,[11,12] R. G. Pizzone,[2] G. G. Rapisarda,[2,6] S. Romano,[2,6,10] M. L. Sergi,[2,6] R. Spartà,[2,6] C. Spitaleri,[2,6] O. Trippella,[11,12] A. Tumino,[2,8] M. Anastasiou,[5] S. A. Kuvin,[5] N. Rijal,[5] B. Schmidt,[5] S. B. Igamov,[3] S. B. Sakuta,[13] Zs. Fülöp,[1] Gy. Gyürky,[1] T. Szücs,[1] Z. Halász,[1] E. Somorjai,[1] Z. Hons,[7] J. Mrázek,[7] R. E. Tribble,[14] and A. M. Mukhamedzhanov[14]





Physics Letters B 826 (2022) 136917

Contents lists available at ScienceDirect

Physics Letters B

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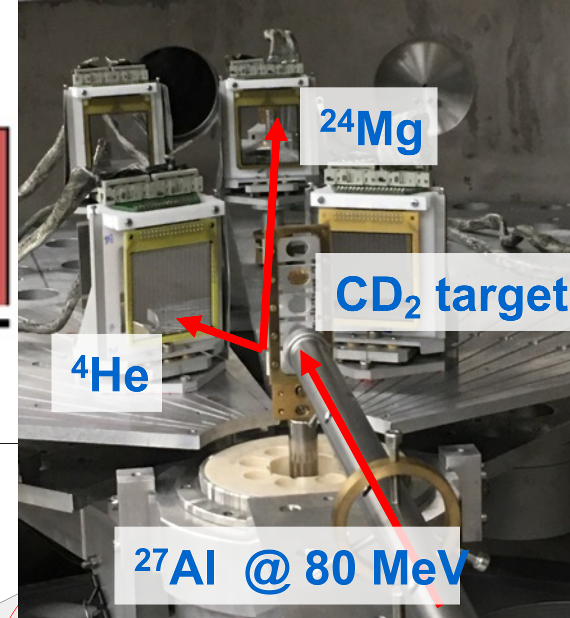
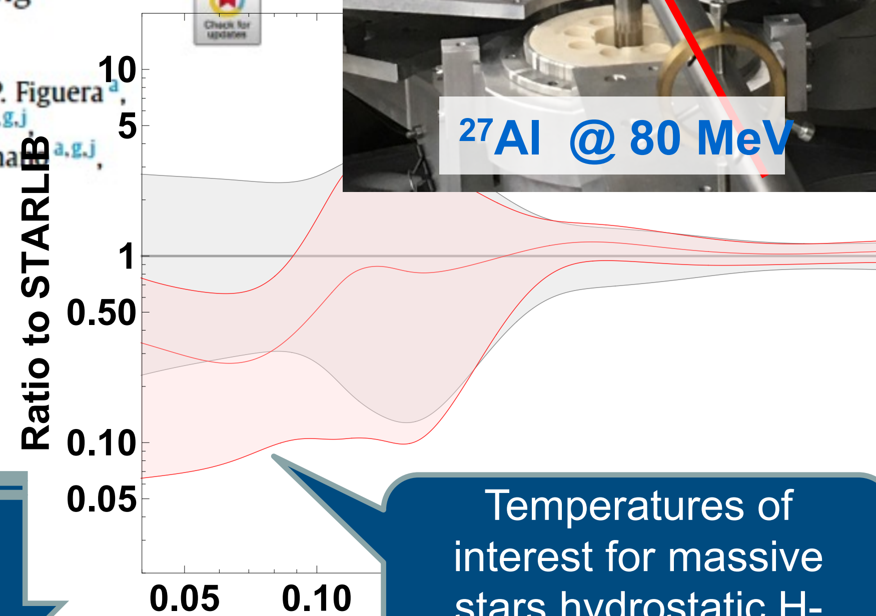
ELSEVIER

Exploring the astrophysical energy range of the $^{27}Al(p,\alpha)^{24}Mg$ reaction: A new recommended reaction rate

M. La Cognata [a,*], S. Palmerini [b,c], P. Adsley [d,e], F. Hammache [f], A. Di Pietro [a], P. Figuera [a], R. Alba [a], S. Cherubini [a,g], F. Dell'Agli [h], G.L. Guardo [a,g], M. Gulino [a,i], L. Lamia [a,g,j], D. Lattuada [a,i], C. Maiolino [a], A. Oliva [a,g], R.G. Pizzone [a], P.M. Prajapati [a], S. Romano [a,g,j], D. Santonocito [a], R. Spartá [a,g], M.L. Sergi [a,g], A. Tumino [a,i]

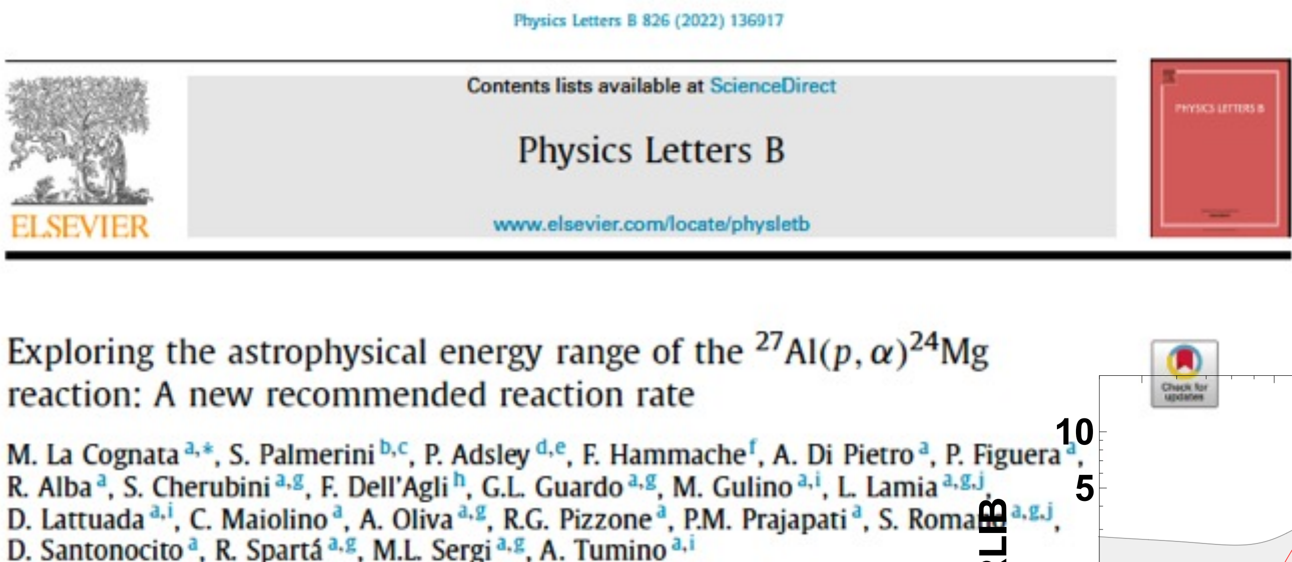




First time observation of a 80 keV resonance occurring exacting at the Gamow energy makes it possible to calculate a factor of 3 lower rate than presently used in nucleosynthesis models

Temperatures of interest for massive stars hydrostatic H-burning

Road to indirect study of the ^{26}Al+n reaction channels via a devoted THM experiment running at TRIUMF (Vancouver, Canada).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Exploring the astrophysical energy range of the $^{27}Al(p,\alpha)^{24}Mg$ reaction: A new recommended reaction rate

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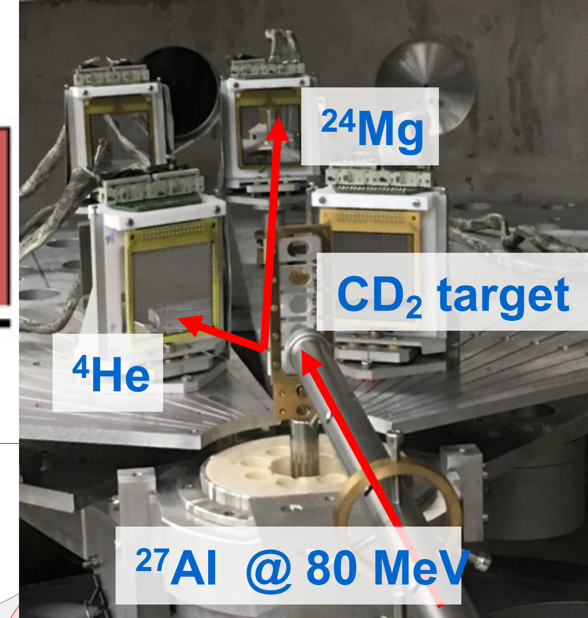
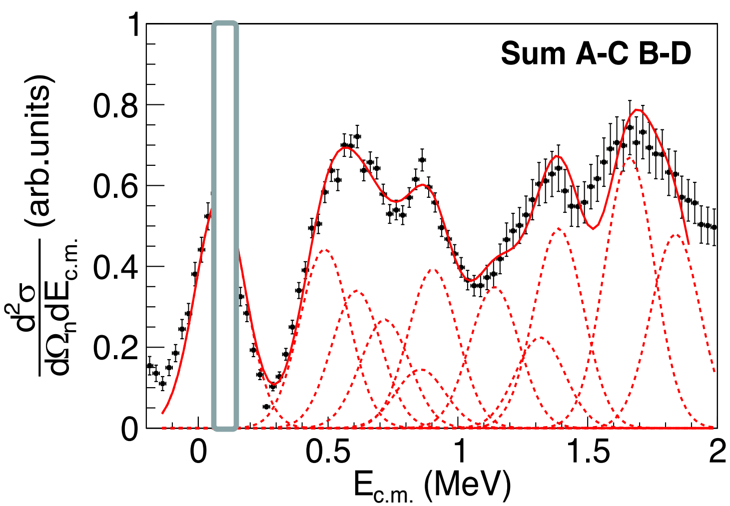
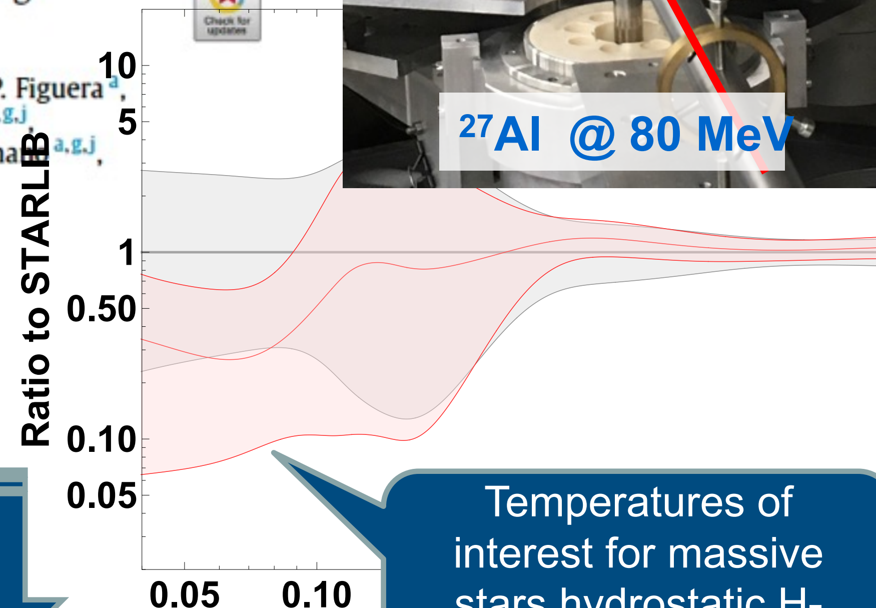






Temperatures of interest for massive stars hydrostatic H-burning

Road to indirect study of the ^{26}Al+n reaction channels via a devoted THM experiment running at TRIUMF (Vancouver, Canada).

Questions to theory

1. Connecting the ”indirect” reaction cross section to the one of astrophysical interest → refining models to reduce data rejection during the data analysis, assess systematic errors

2. Modified R-matrix for narrow and broad resonances and comprehensive R-matrix analysis (Bayesian approach)

3. For light nuclei structure studies, DWBA and/or coupled-channel analysis for transfer analisys, R-matrix for investigating clustering

4. Investigation of fusion phenomenology (including, for instance, incomplete fusion et similia) with astrophysical implications (^{12}C+^{12}C, for instance). Hindrance?

5. Analysis of the astrophysical impact

LINEA 4

n_TOF: *Neutron Time Of Flight*

The experiment uses the high neutron flux produced at CERN for investigating neutron induced reactions of interest in many fields:

→ *Applied physics (fission reactors, waste transmutation, material studies…)*

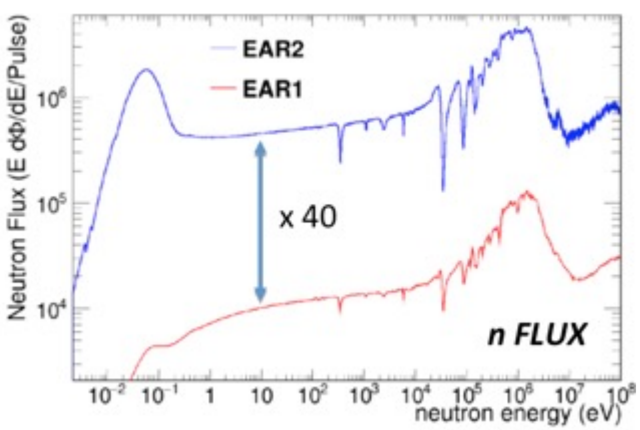
→ *Nuclear astrophysics (s-process, fission recycling in the r-process…)*

→ *Basic science (fission, spectroscopy…)*

Neutrons produced by spallation.

PS proton beam on a lead target

- ***20 GeV/c***
- ***$7 \cdot 10^{12}$ protons/pulse***
- ***Repetition rate 0.8 Hz***



Experimental Area 2

25 meV<E_n<300 MeV

10^6 n/cm^2/pulse

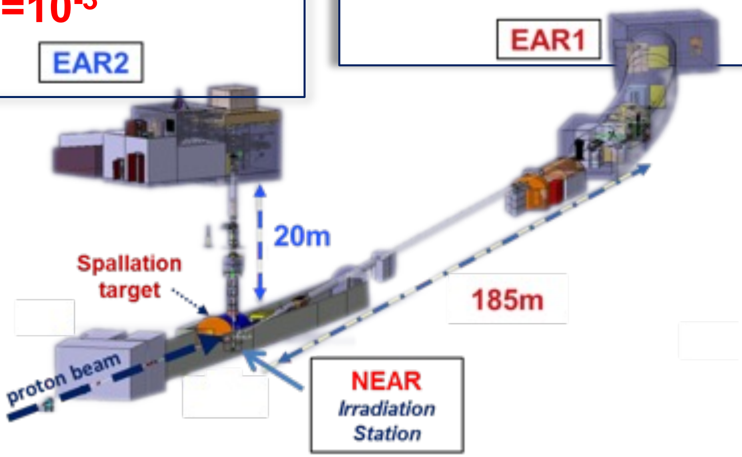
ΔE/E=10^{-3}

Experimental Area 1

25 meV<E_n<1 GeV

10^5 n/cm^2/pulse

ΔE/E=10^{-4}

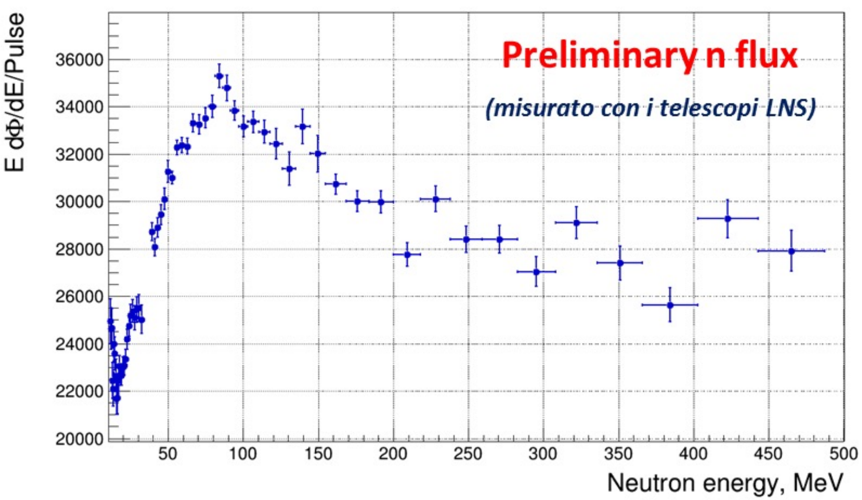


LNS & n_TOF

Recent results

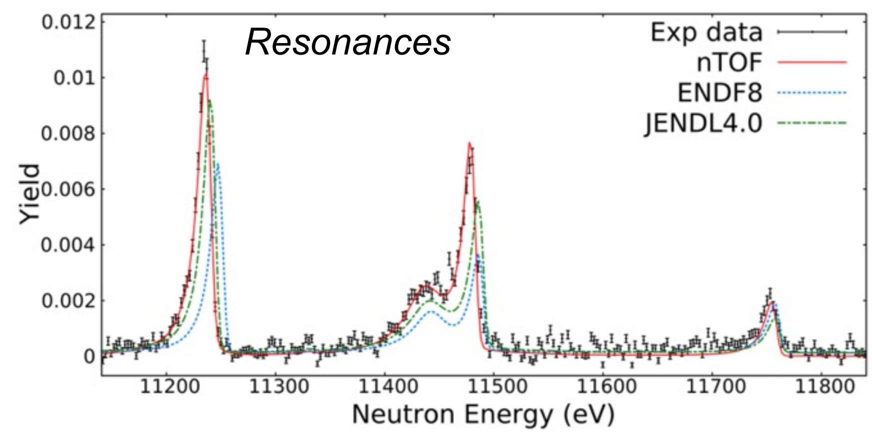
^{235}U(n,f): 15MeV ÷ 1GeV

Extremely laborious data analysis, almost completed. Thanks to the measurement of the neutron flux at energies of hundreds of MeV, we will shortly provide the first experimental data of the 235U(n,f) cross section over 200MeV.



^{140}Ce(n,γ): s process

Data analysis completed. Resonances analyzed up to 65 keV. From preliminary calculations, however, a good agreement is found with the activation measurement at 30 keV, even if there are significant differences with low-energy nuclear libraries.



Universe **2021**, *7*(6), 200

Open Access Communication

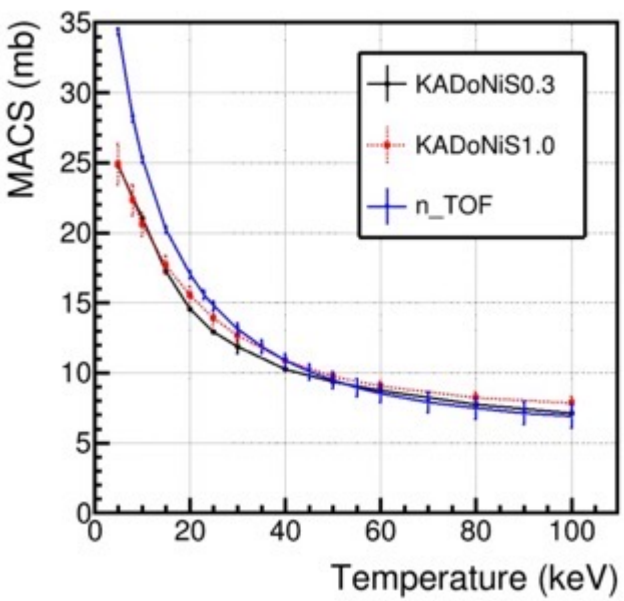
First Results of the ^{140}Ce(n,γ)^{141}Ce Cross-Section Measurement at n_TOF

by Simone Amaducci [1,2,*], Nicola Colonna [3], Luigi Cosentino [1], Sergio Cristallo [4,5], Paolo Finocchiaro [1], Milan Krtička [6], Cristian Massimi [7,8], Mario Mastromarco [9], Annamaria Mazzone [3,10], Alberto Mengoni [11], Stanislav Valenta [6], Oliver Aberle [9], Victor Alcayne [12], Józef Andrzejewski [13], Laurent Audouin [14] and nTOF coll.

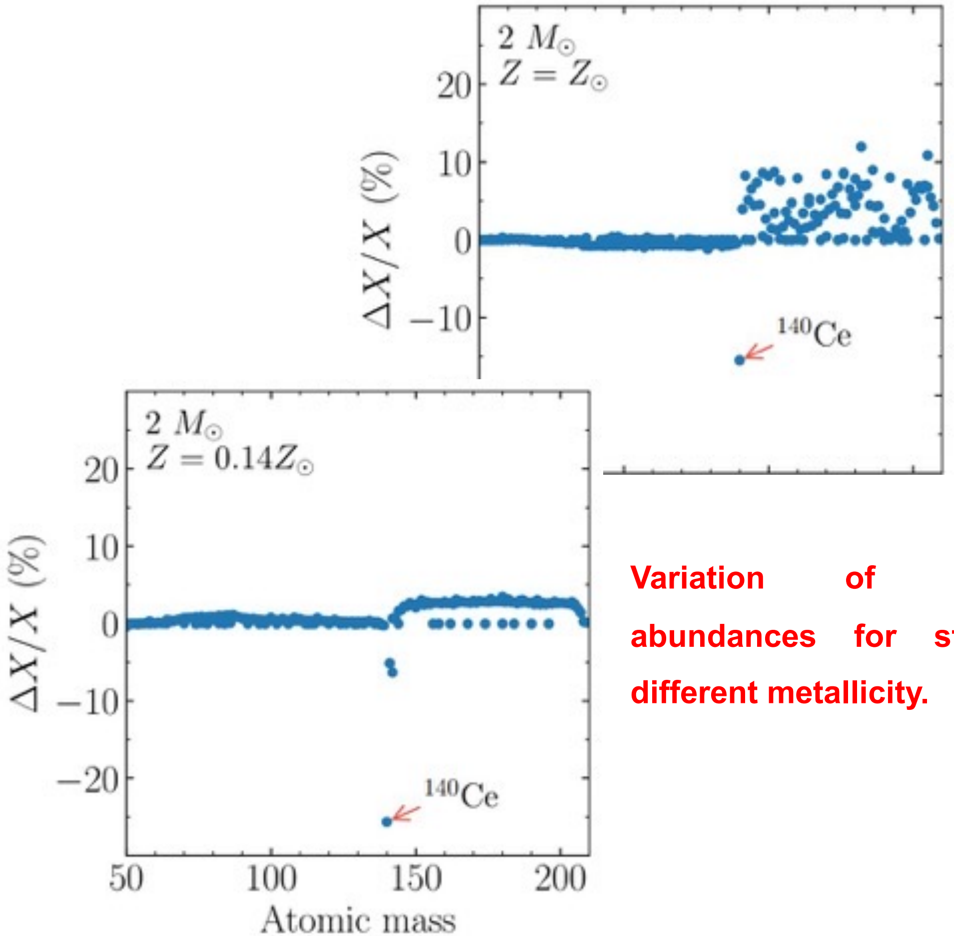
Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DEL SUD

^{140}Ce(n,γ): s process

Data analysis completed, MACS definitive, good agreement with the activation measurement at 30 keV. Important variations in the abundance of 140Ce and for all heavier elements predicted by the stellar models.



MACS up to + 40% higher at 5 keV than in the literature.



Variation of isotopic abundances for stars of different metallicity.

Questions to theory

1. Comprehensive R-matrix analysis of existing data

2. Astrophysical implications of the results

LINEA 4

PANDORA: an interdisciplinary facility to be installed at LNS

INFN

Istituto Nazionale di Fisica Nucleare

PANDORA facility will consist of:

1) **Superconducting Magnetic Plasma Trap:** it contains a plasma made of multiply charged radioisotopes
2) **HpGe Array:** it consists of 14 detectors to measure the γ rays emitted after β-decays
3) **Plasma Diagnostics System:** it consists of RF, optical and X ray spectrometers allowing direct correlation of β-decay rate to plasma density and temperature

It could *"add unique research capability"* [CVI-report 2019] in Astrophysics and Nuclear Astrophysics in laboratory

1) **for the first time, β-decay measurements** in plasmas; → **Huge impact on nuclear physics and stellar nucleosynthesis**
2) **plasma opacity measurements in conditions similar to kilonovae ejecta**; → **Heavy elements production in n-star merging**
3) **an unprecedented setup for applications**: it will be the biggest B-minimum magnetic trap with potentiality as ion source; as testbench for magnetic fusion; as radiation source for Archeometry. → **New ion and radiation sources for science and technology**

PANDORA_GR3: articoli WoS → 12 / talks → 9

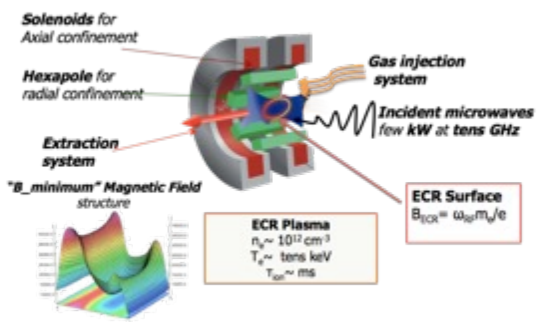
Study of beta-decay properties of highly ionized atoms of astrophysical interest:

Investigation of the dependence of decay rate on plasma parameters (T_e, ρ_e, CSD)

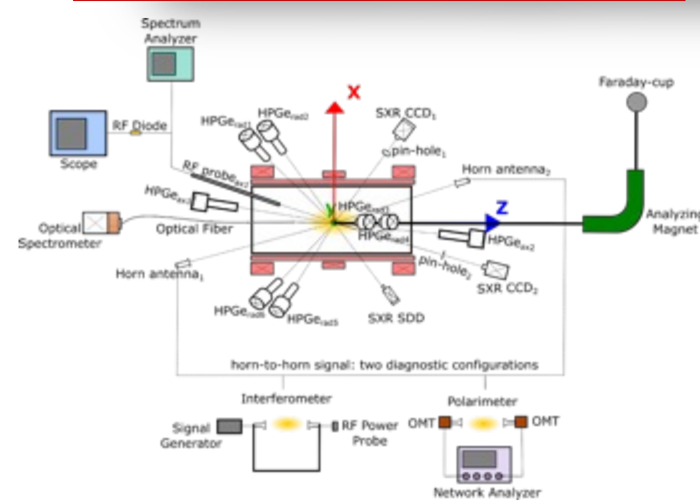
Build a magnetic trap for hot plasmas excited by e.m. waves

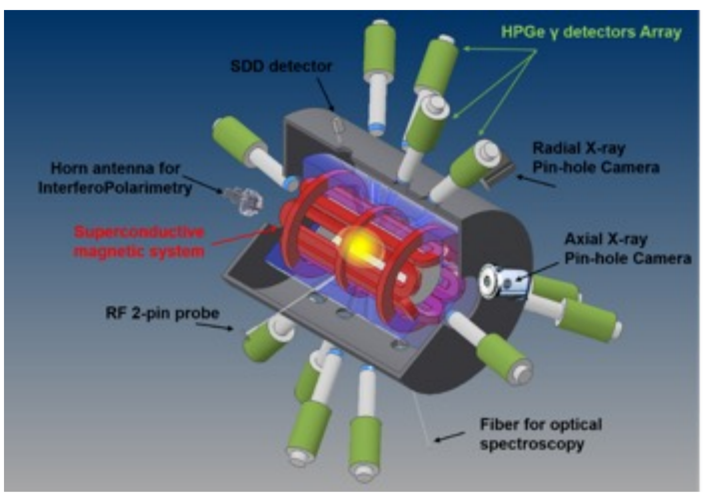
Three main pillars:

- Plasma trap
- HPGE detector array
- multidiagnostic system



PANDORA plasma multidiagnostics systems



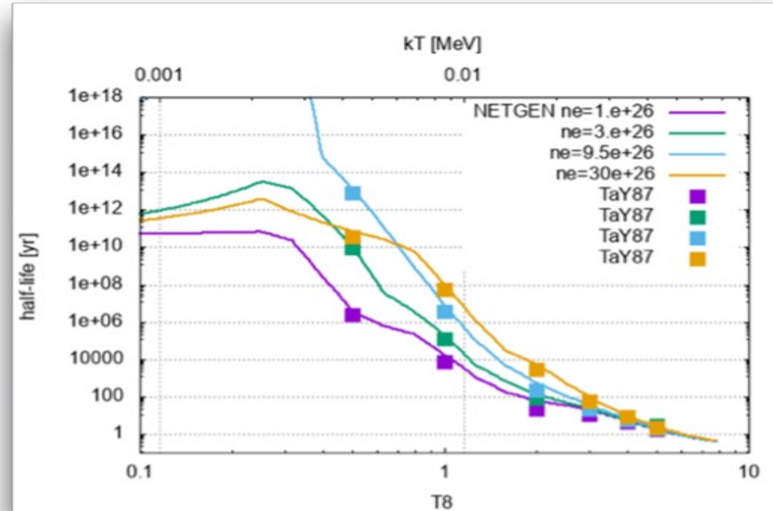


An innovative multi-diagnostic system used to correlate plasma parameters to nuclear activity has been proposed. It is based on several detectors and non-invasive techniques (*Optical Emission Spectroscopy, RF systems, InterferoPolarimetry, time- and space-resolved X-ray spectroscopy*)

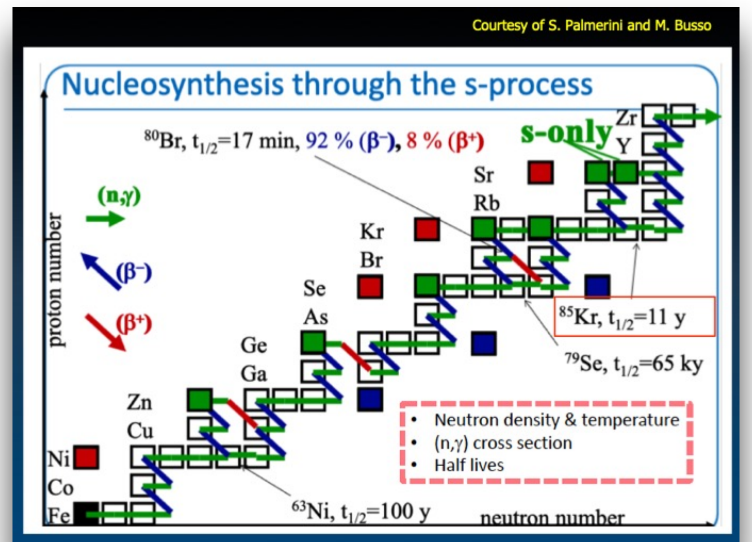
Study of beta-decay properties of highly ionized atoms of astrophysical interest:

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	3.78x10^{10}	88-400
^{134}Cs	2.06	>600
^{94}Nb	2.03x10^{4}	>700

COSMO-CHRONOMETER

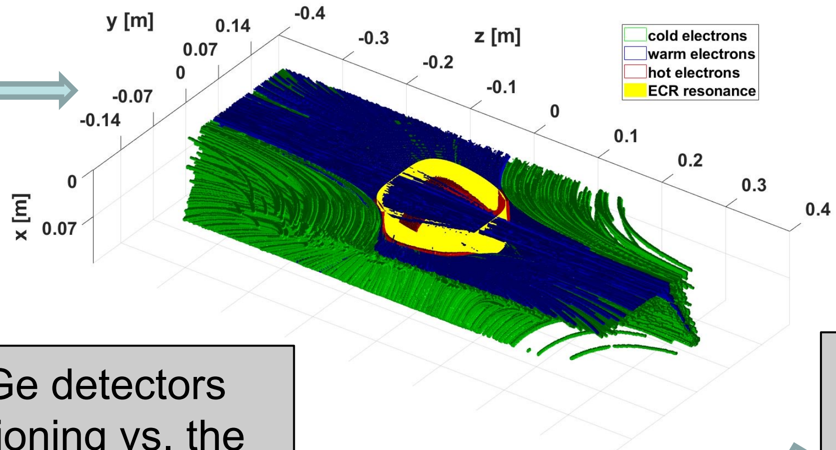
reproduction of ^{134}Ba, ^{136}Ba s-only isotope yields

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

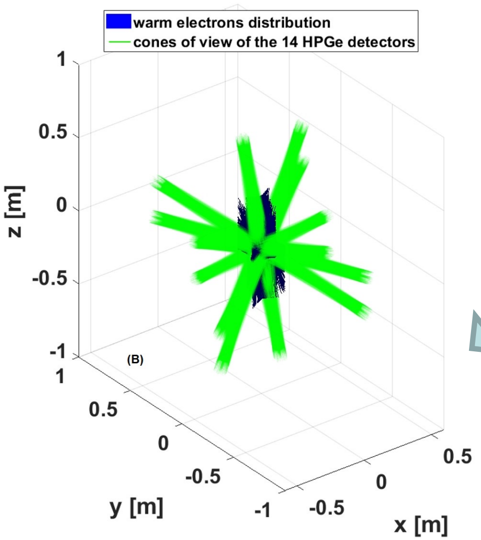
Plasma modelling

First self-consistent calculation of a high power, high density plasma

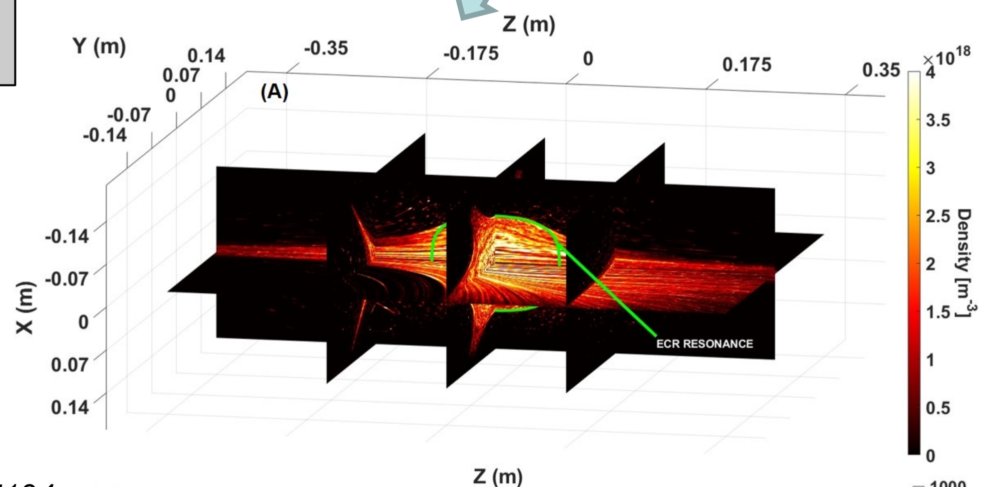
Simulation of the distribution of the different electron populations in plasma



HPGe detectors positioning vs. the warm electrons distribution !
Correct positioning



Prediction of global electrons energy and density distribution



A. Galatà *et al.*, ***Front. Phys.*** *DOI 10.3389/fphys.2022.947194*

Astrophysical Models

Investigations of s-process nucleosynthesis looking for:

- new cases of study
- Implications to (AGB) stars nucleosynthesis of the new estimations and measurements of half-lives in plasma

Improvement in stellar physics models together with 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)

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

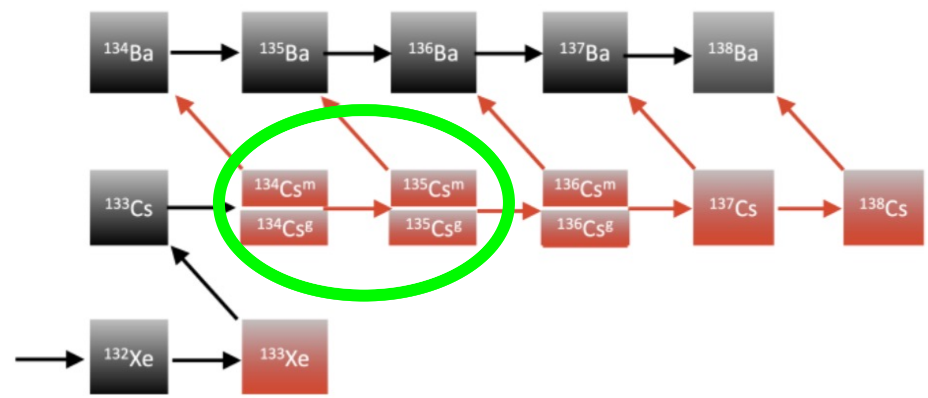
- (n,γ) MACS are from KADONIS 1.0
- (n,γ) theoretical Hauser–Feshbach computations TALYS 2008 for unstable nuclei
- rates for weak interactions from Takahashi & Yokoi (1987)

^{134,135}Cs improved nuclear input

- New Temperature dependence of ^{134}Cs
- Similar effects would be induced by variations in the ^{135}Cs neutron-capture cross section

Ba nucleosynthesis

Reproduction of the $^{134-136}$Ba galactic production calls for new nuclear physics measurements of weak interactions in ionized plasmas in nuclei with N ≈ 50 (^{84,85}Kr, ^{86,87,88}Sr, ^{93}Nb) and N ≈ 82 (^{134,135}Cs)

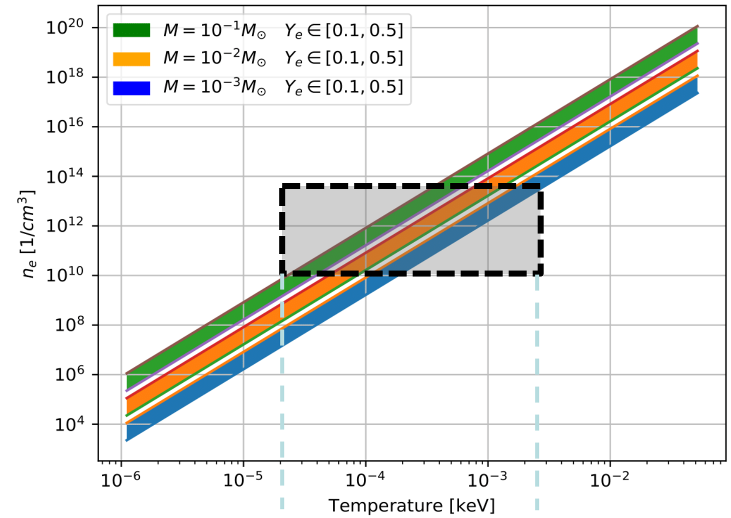


OPACITY measurements in PANDORA

The collaboration started studying the properties of the electromagnetic counterparts of gravitational waves emitted during binary merger.

Radioactive decay of synthesized r-process nuclei **power** electromagnetic transient: ***kilonovae***

The kilonovae emission is reprocessed by atomic opacities to optical and infrared wavelengths.

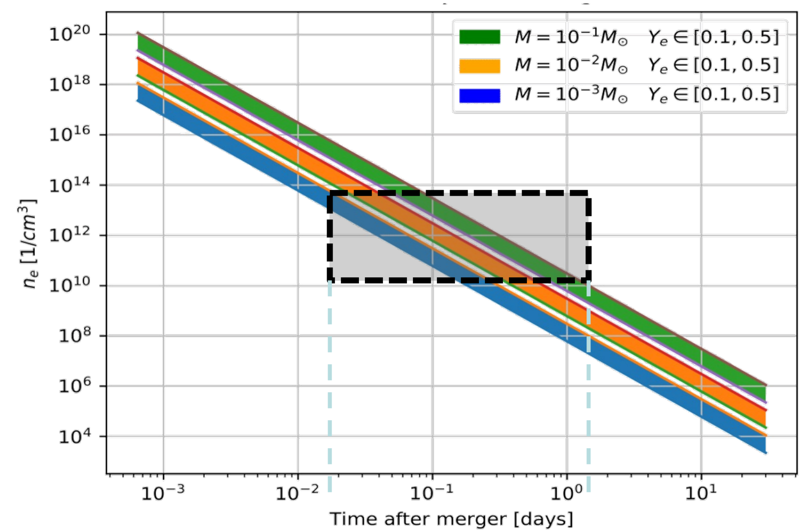


Feasibility study:

- astrophysical modelling BNS ejecta
- nuclear network for nucleosynthesis yields
- population kinetics code for synthetic spectra

Such activity is fundamental for future opacity measurements

- Shed light on *r*-process-generated metallic species at specific time stages of KN diffusion
- Role played by the opacity on KN emission, as it delivers information on the post-merging plasma ejecta composition



Pidatella, A., et al. Nuovo Cimento 44 C (2021) 65

- **Plasma density** in PANDORA: $\mathbf{10^{10\text{-}13}}$ **cm^{-3}**
- **Plasma temperature** in PANDORA: **few eV**
- **Time after merger: from 10^{-2} up to 1 days** → **blue-KN stage**

Questions to theory

1. Understanding the properties of a confined plasma → for instance MHD calculations

2. Understanding the beta decay of ions in a plasma to improve the TY 1987 theory → role of unbound electrons

3. Extensive nucleosynthesis calculations mostly focusing on the branch points

4. Simulations of kilonovae nucleosynthesis and of opacities to understand the physics of multimessenger astronomy

Thanks for your attention