Reazioni di cattura su elementi leggeri

Maria Grazia Pellegriti

INFN – Sezione di Catania

Workshop n-TOF/Astrofisica Nucleare – 23/04/2021

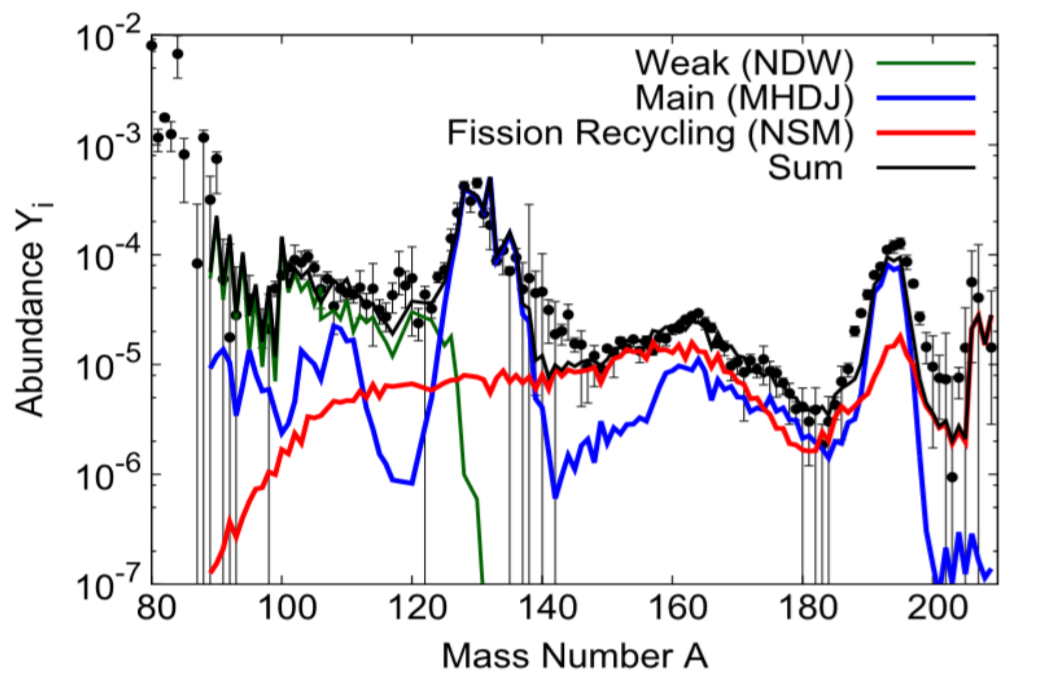
OUTLOOK

- $^{16}O(n,\gamma)^{17}O$, weak s process, r-process
- $^{10}Be(n,\gamma)^{11}Be$, r-process
- $^{11}B(n,\gamma)^{12}B$, r-process, connection to $^{8}Li(\alpha,n)^{11}B$ cross section puzzle

r-PROCESS NUCLEOSYNTHESIS

- The exact site of r-process is still unconfirmed however due to the conditions necessary: high neutron density, high temperature
- Supernovae, collapsars and neutron-star mergers are the viable candidate astrophysical sites for the r-process elements

T. Kajino, W. Aoki, A.B. Balantekin, R. Diehl, M.A. Famiano, G. J. Mathews, Current status of r -process nucleosynthesis, Prog. Part. Nucl. Phys. 107 (2019) 109



Solar-system isotopic r-process abundance pattern. Observation (black dots) vs. theoretical calculation which consists of the r-process in magneto hydrodynamic jet supernova model (blue), neutrino-heated supernova model (green), binary neutron-star merger model (red) and total sum (black).

The "universality" of r-process abundances (elemental abundances in many metal-poor stars with a pattern similar to that of the solar system r-process distribution) is quite naturally explained by supernova r-process.

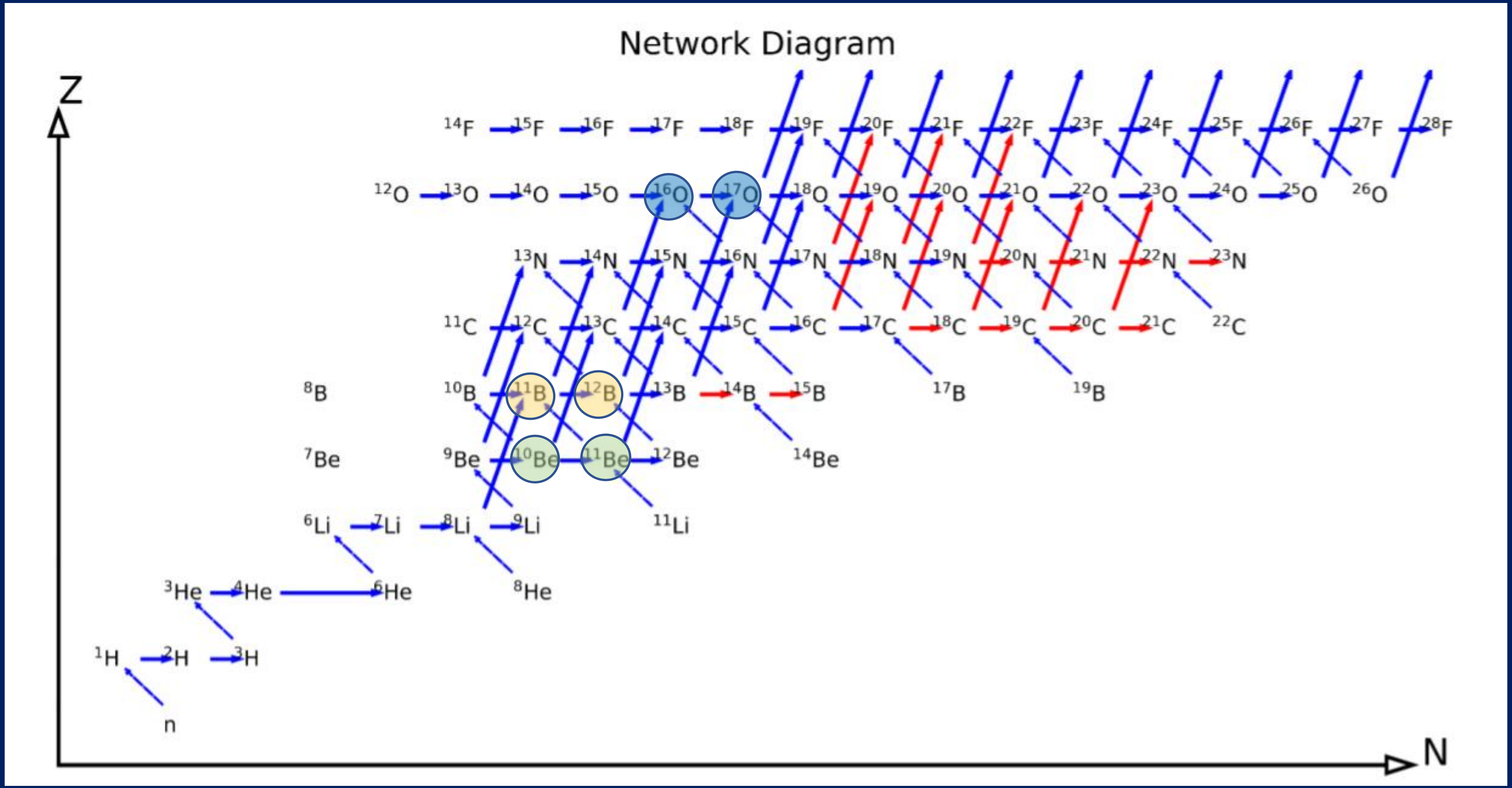
Shibagaki, T. Kajino, G. J. Mathews, S. Chiba, S. Nishimura, and G. Lorusso
Relative contribution of the weak, main and fission-recycling r-process,
Astrophys. J 816 (2016) 79

Though the importance of neutron-star mergers has been recently questioned to be the source of early Galaxy r-process, however they can contribute, with a delay by cosmological time scale of about ~100 My with respect to SN, to the solar system r-process "isotopic" pattern.

Yuta Yamazaki, Toshitaka Kajino, Grant J. Mathews, Xiaodong Tang, Jianrong Shi, Michael A. Famiano
Contribution of collapsars, supernovae, and neutron star mergers to the evolution of r-process elements in the Galaxy arXiv:2102.05891

Sensitivity of r-process nucleosynthesis to the light mass nuclear reactions

Kyungil Kim, Toshitaka Kajino, Shota Shibagaki, Youngman Kim,
CENuM-RULiC Workshop, Nov. 1, 2019



$^{16}O(n,\gamma)^{17}O$ reaction

PHYSICAL REVIEW C **102**, 044616 (2020)

Nonresonant *p*-wave direct capture and interference effect observed in the $^{16}O(n,\gamma)^{17}O$ reaction

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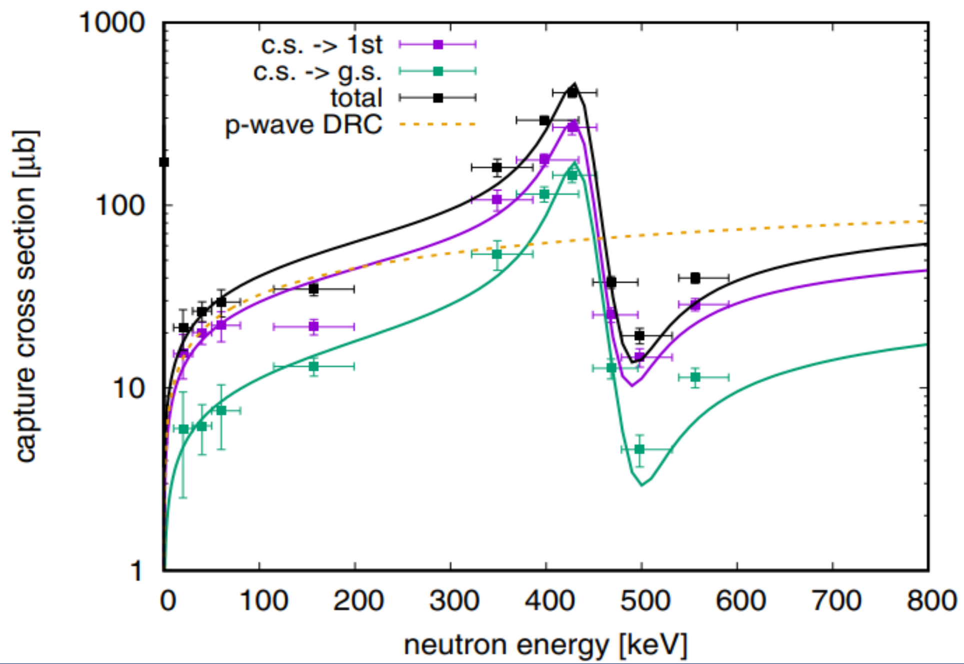

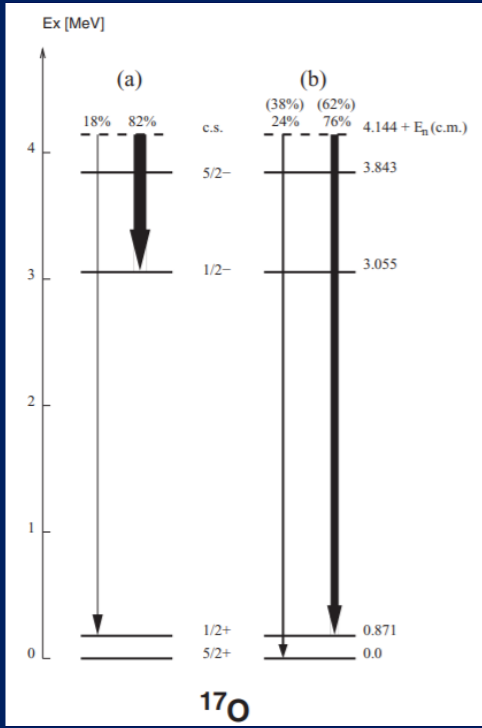

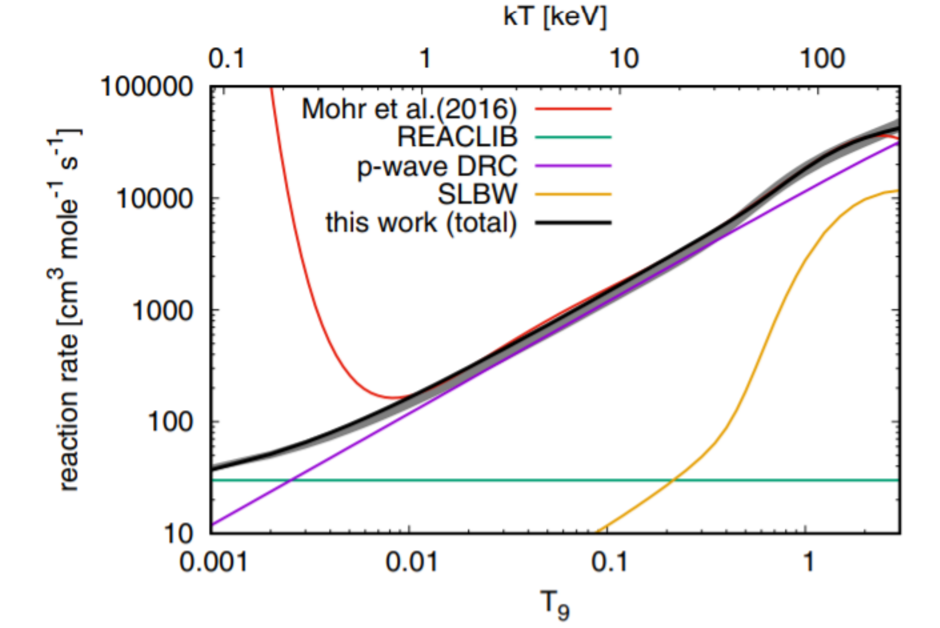

The Astrophysical Journal, 899:133 (14pp), 2020 August 20
https://doi.org/10.3847/1538-4357/aba7b4

Nuclear Structures of ^{17}O and Time-dependent Sensitivity of the Weak *s*-process to the $^{16}O(n,\gamma)^{17}O$ Rate

Meng He[1,2], Shi-Sheng Zhang[1,2], Motohiko Kusakabe[1,2], Sizhe Xu[1], and Toshitaka Kajino[1,2,3]
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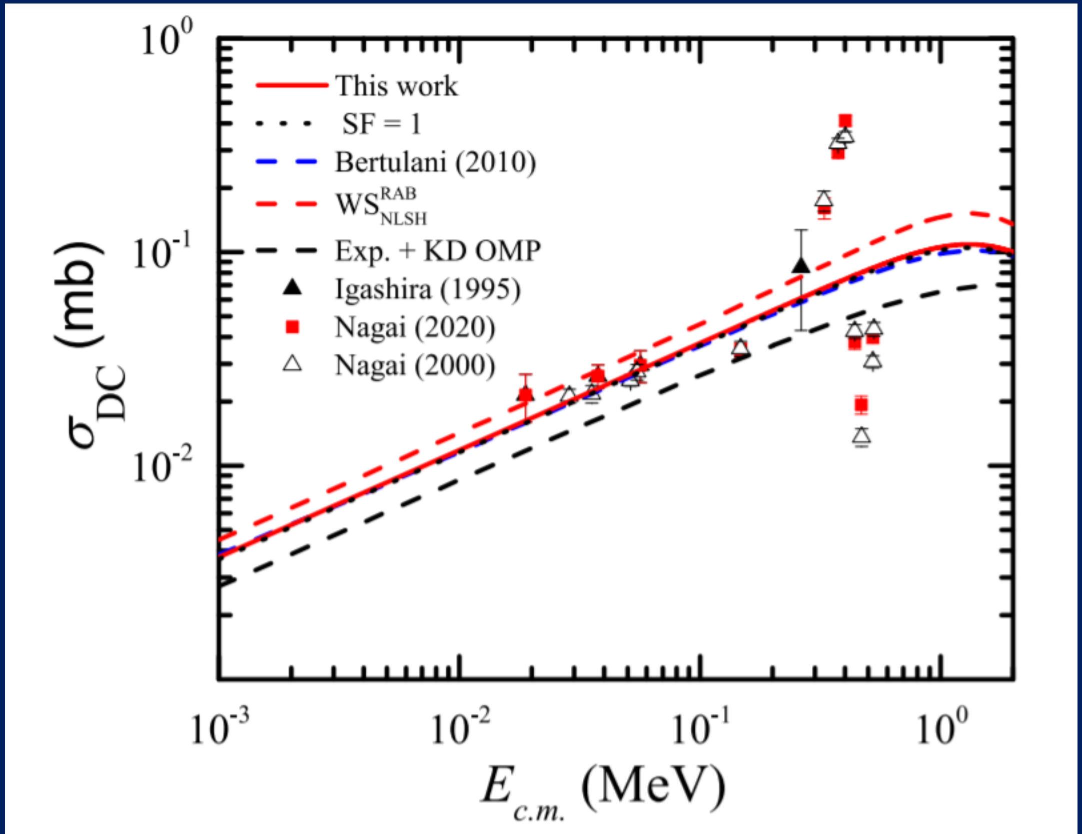
$^{16}O(n,\gamma)^{17}O$ reaction

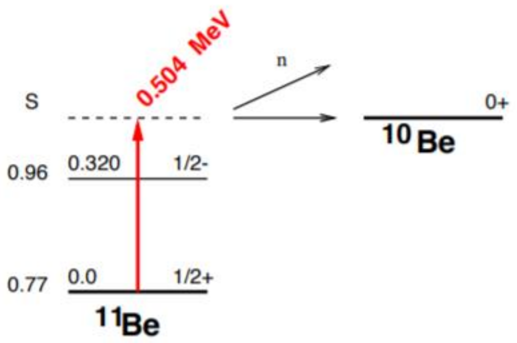


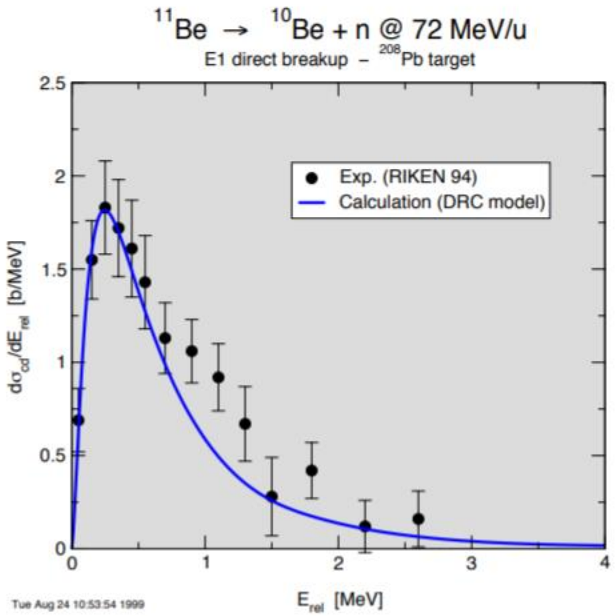
$^{10}Be(n,\gamma)^{11}Be$ reaction

Coulomb dissociation of ^{11}Be: results

The ground-state of ^{11}Be has a dominant configuration of type $|^{10}\mathrm{Be}(0^+)\otimes 2s_{1/2}; J^\pi = 1/2^+\rangle$. The Coulomb dissociation process proceeds through a direct E1 transition with strength proportional to

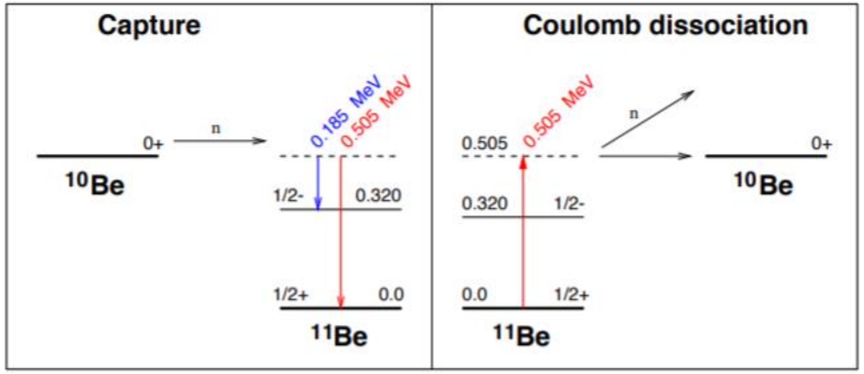
$$|\langle \psi_c(l=1)_{1/2^-,3/2^-}||\hat{E}1||\phi_b(l=0)_{1/2^+}\rangle|^2$$





Neutron capture cross section by ^{10}Be : a proposal

- Motivation 1: establish the E1 strength regardless of the reaction mechanism
- Motivation 2: measure the E1 strength leading to the 1st excited state in ^{11}Be
- Motivation 3: application to astrophysics (reaction rate needed for primordial nucleosynthesis estimation)
- ^{10}Be half-life: 1.6×10^6 yr
- ground state transition: $p \to s$ (E1)
- 1st excited state transition: $s \to p$ (E1)



Courtesy of A. Mengoni

$^{10}Be(n,\gamma)^{11}Be$ reaction

Astroparticle Physics 104 (2019) 91–101

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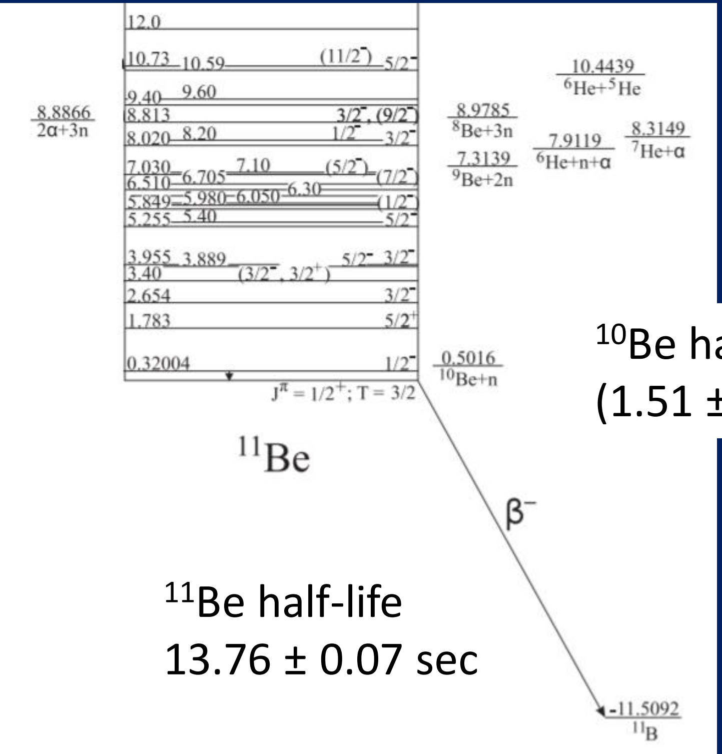
New results for neutron radiative capture on ^{10}Be at energies between 25.3 meV and 10.0 MeV

S.B. Dubovichenko[a,b], N.A. Burkova[b], N.V. Afanasyeva[a,b], A.V. Dzhazairov-Kakhramanov[a,*], A.S. Tkachenko[a,b]



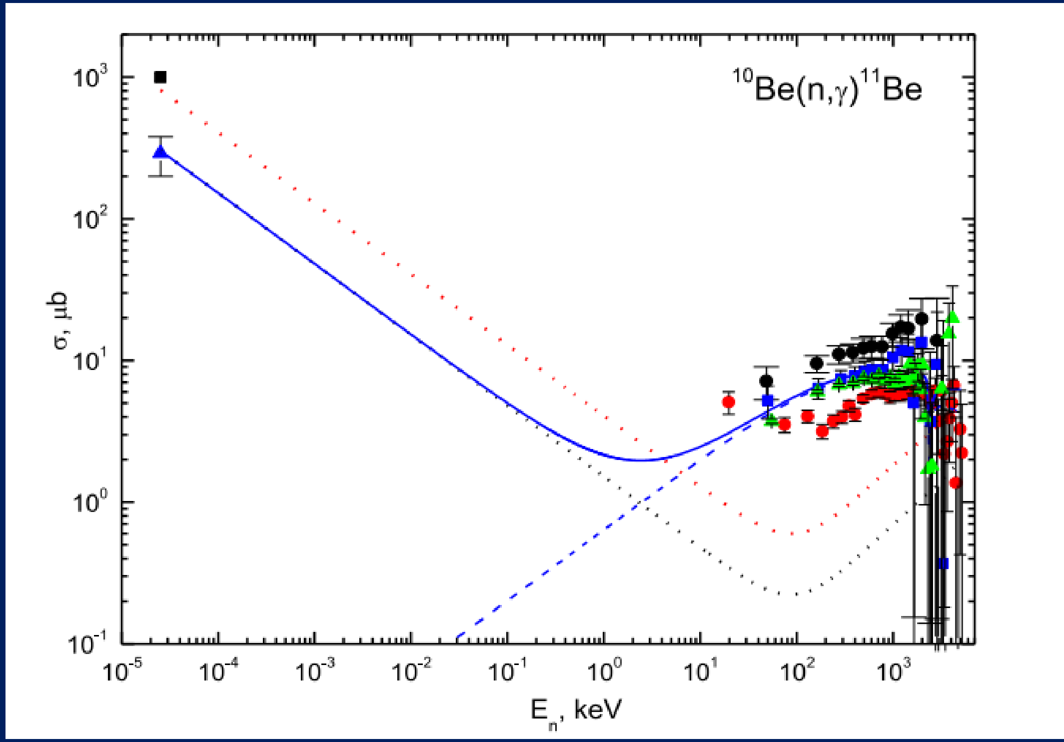
^{10}Be half-life

$(1.51 \pm 0.04) \times 10^6$ years

^{11}Be half-life

13.76 ± 0.07 sec

Total cross-sections of the $^{10}Be(n,\gamma)^{11}Be$ radiative capture



-black points represent data from Mengoni et al. 1996 (CD)
-solid blue line represents calculation from Dubovichenko 2019
-the dotted black line shows the cross sections of the transition to the 1st excited state

Nuclear structure investigation: $2\alpha+3n$, $^{8}Be+3n$, $^{9}Be+2n$

$^{11}B(n,\gamma)^{12}B$ reaction

Astroparticle Physics 123 (2020) 102481

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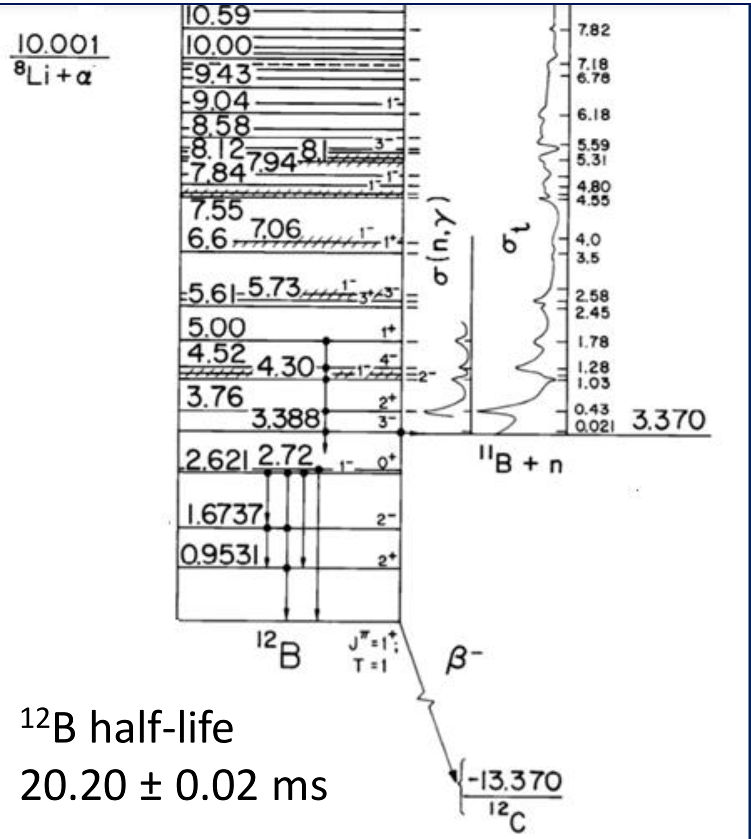
ELSEVIER

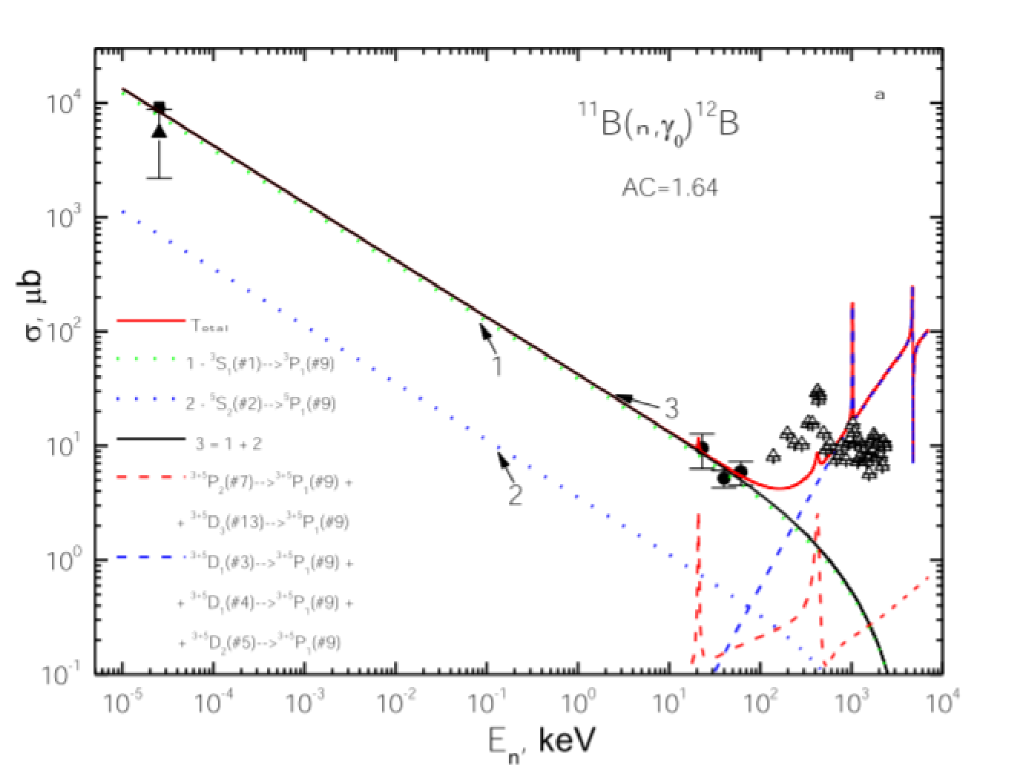
Influence of resonances on the $^{11}B(n,\gamma)^{12}B$ capture reaction rate. Capture to the ground state of ^{12}B

S.B. Dubovichenko[a,b,*], N.A. Burkova[b], A.V. Dzhazairov-Kakhramanov[a,*], A.S. Tkachenko[a,b]



^{12}B half-life
20.20 ± 0.02 ms

Total cross-sections of the $^{11}B(n,\gamma)^{12}B$ radiative capture



STATE OF THE ART OF $^{8}Li(\alpha,n)^{11}B$ EXPERIMENTAL DATA

The source of the discrepancy between the **exclusive** (obtained by measuring in coincidence both the neutron and ^{11}B ejectiles) and **inclusive** data (measuring just the *n*-channel or the ^{11}B) is unclear and represents a really open question.

INVERSE REACTION : $n(^{11}B,^{8}Li)\alpha$

T. Paradellis et al., Z. Phys. A 337 (1990) 211

INCLUSIVE MEASUREMENT: ^{11}B

R. N. Boyd, Phys. Rev. Lett.68, 1283 (1992)

X. Gu et al., Phys. Lett. B 343, 31 (1995)

EXLUSIVE MEASUREMENT : n + ^{11}B

Y. Mizoi et al., Phys. Rev. C 62, 065801 (2000)

H. Ishiyama et al., Phys. Lett. B640, 82 (2006)

S. K. Das et al., Phys. Rev. C 95, 055805 (2017)

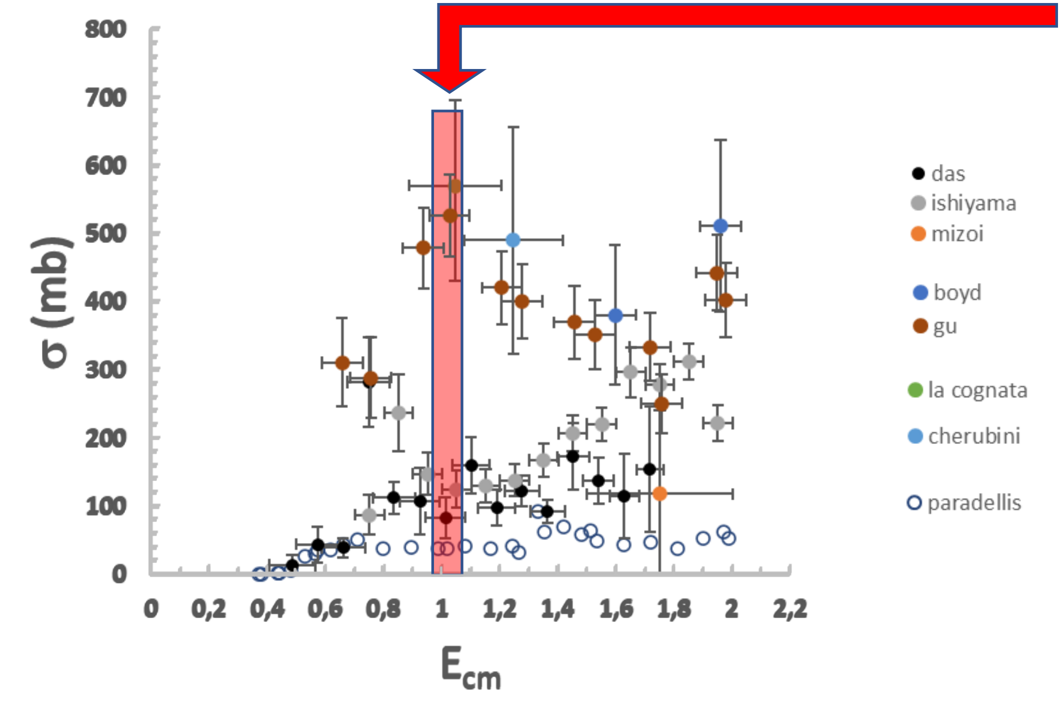
INCLUSIVE MEASUREMENT: n

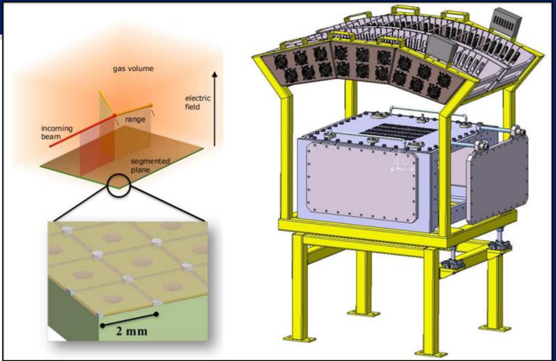
S. Cherubini et al., Euro. Phys. J. A 20, 355 (2004)

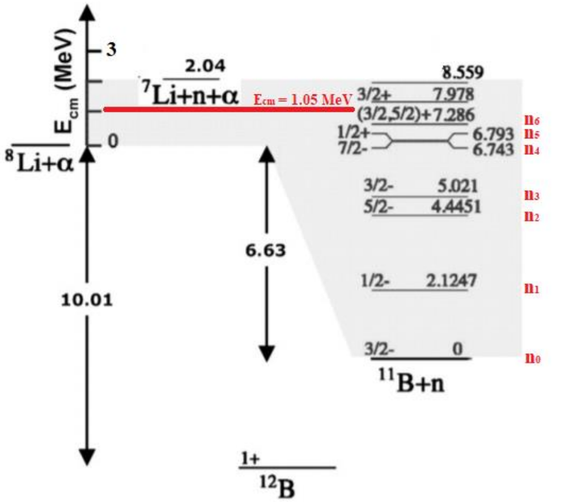
M. La Cognata et al., Phys. Lett. B 664, 157 (2008)

LoI6_20 endorsed by the GANIL PAC

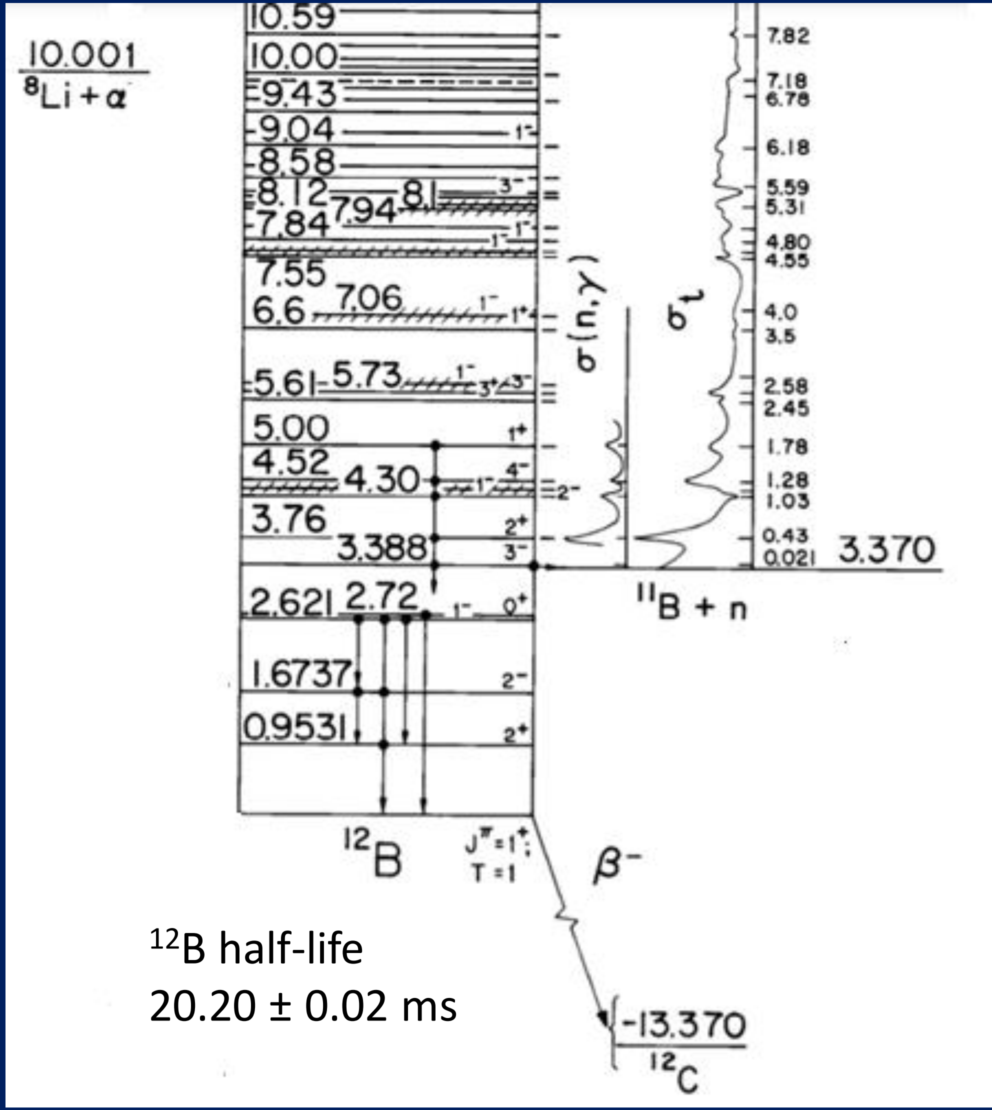
NEW INCLUSIVE (^{11}B) MEASUREMENT with ACTAR







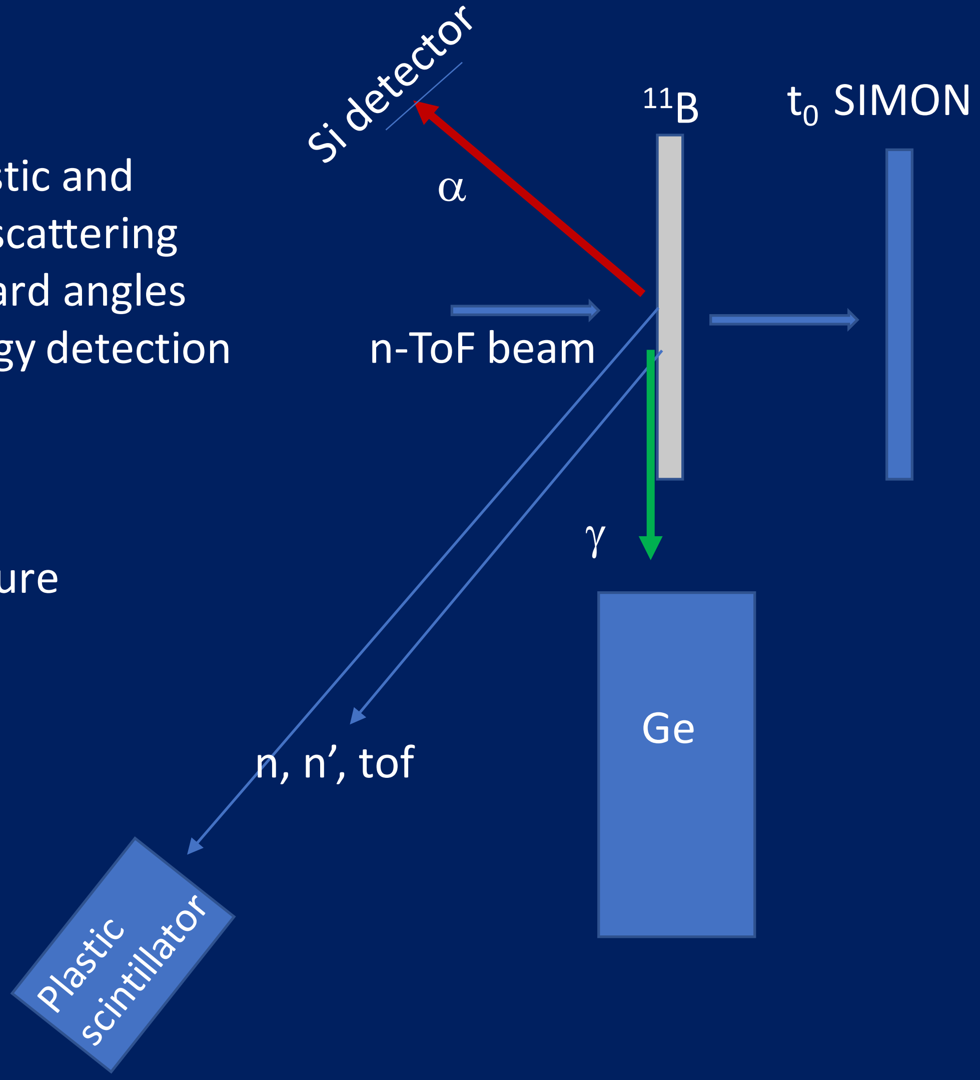
Proposed set-up for a global picture of ^{12}B



α - channel

n, n' (elastic and inelastic scattering →backward angles and energy detection with tof)

direct γ capture



Conclusions

- $^{16}O(n,\gamma)^{17}O$, stable target and ejectile, recent measurement in 2020
- $^{10}Be(n,\gamma)^{11}Be$, radioactive target and ejectile, low energy gammas
- $^{11}B(n,\gamma)^{12}B$, stable target to be enriched in ^{11}B, radioactive ejectile, multi-channels experiment to study ^{11}B and ^{12}B properties