International Nuclear Physics Conference 2019

A clear signature of the breakup modes for ^{9}Be on a proton target at 5.6 MeV/nucleon

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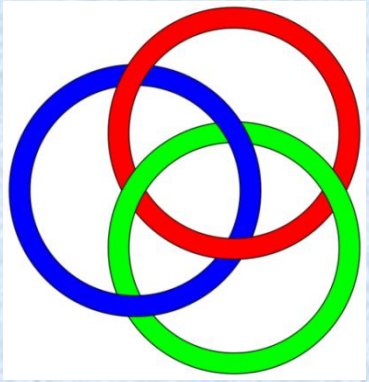
Outline

- Introduction
- Motivation
- Experimental setup
- Identification of the breakup channel
- Breakup simulations – the algorithm MULTIP
- Results
- Concluding Remarks

Borromean Rings – Symbolism throughout history

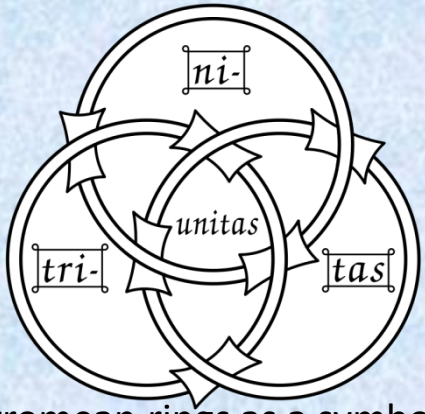
- Borromean Rings: A knot composed of 3 indissolubly linked rings.
- Symbolisms throughout history



Representation of the Borromean Rings

- Odin's Triangle: Related with the God's ability to control the human mind.
- Symbol of the Holy Trinity.
- Representation of the timeline: "Past", "Present", "Future".

Valknut symbol related with Norse God Odin



Borromean rings as a symbol of the Christian Trinity

Introduction

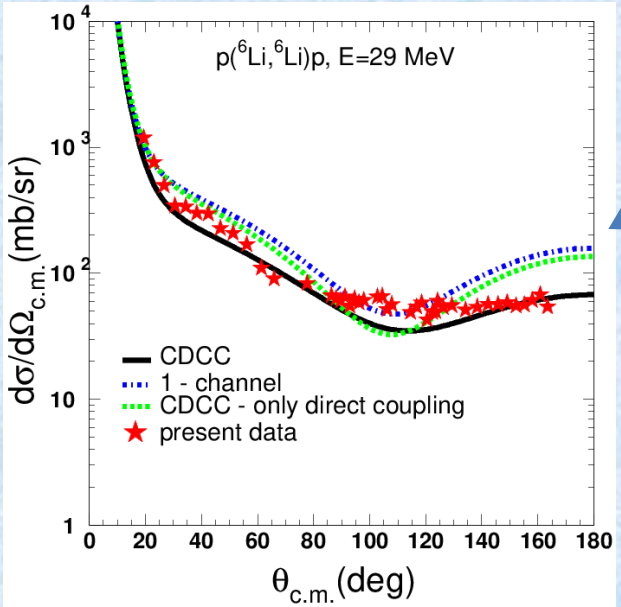
- **Weakly bound** nuclei are characterized by low binding energies and pronounced cluster structures. Such features may enhance direct reactions especially in the vicinity of the Coulomb barrier.

Offer a ground to study coupling channel effects when analyzed within the same coupled channels theory.

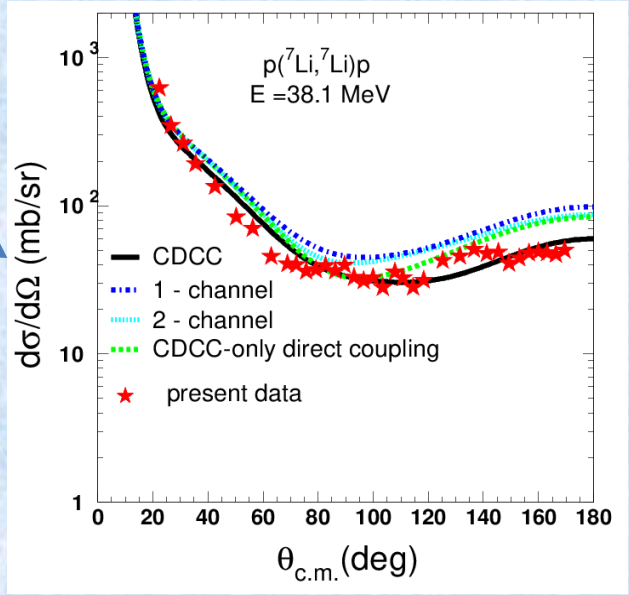
- ***Our Previous Studies:*** Elastic Scattering and breakup for the **^{6}Li+p** and **^{7}Li+p** systems. The data where analyzed under the **C**ontinuum **D**iscretized **C**oupled **C**hannels (**CDCC**) framework.

Our previous studies

^{6}Li+p



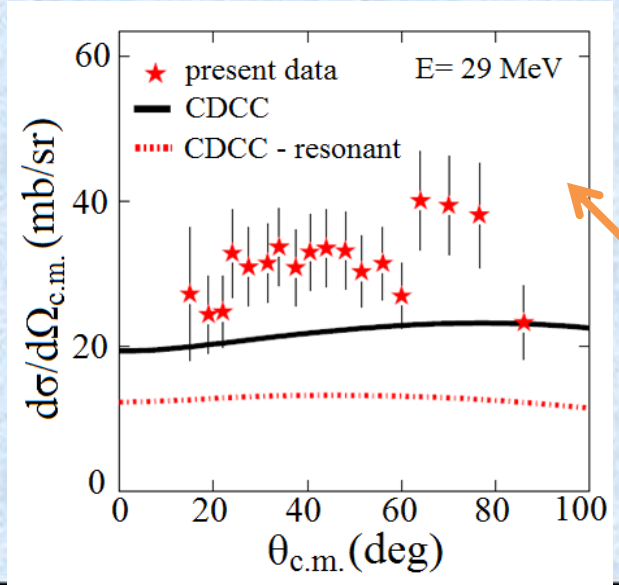
^{7}Li+p



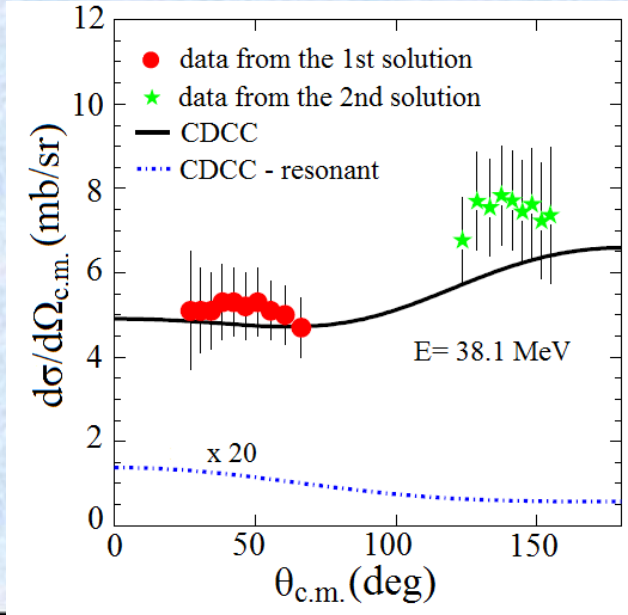
Elastic Channel

V. Soukeras et al.,
PRC 95, 054614 (2017)

A. Pakou et al.,
PRC 95, 044615 (2017)



Breakup

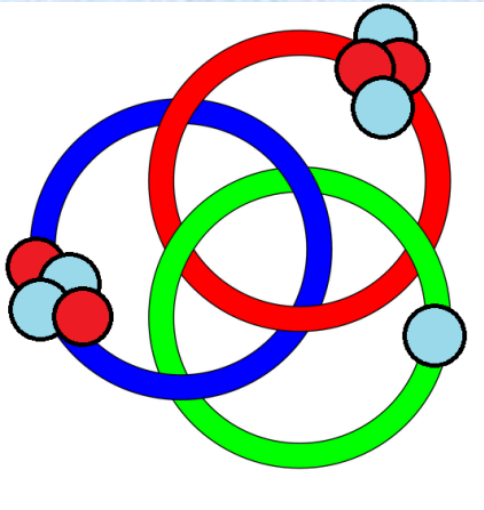


Motivation

- ^{9}Be nucleus:

  a) The only **stable weakly bound Borromean** nucleus.

  b) Contributes to the synthesis of ^{12}C via the ^{9}Be(α,n)^{12}C reaction as well as to higher mass nuclei via the r-process path.



Many studies have been devoted for the determination of the strength of each breakup mode but, contradictory results are reported.

^{9}Be breakup modes

$^{9}Be^{*} \rightarrow \alpha + \alpha + n$

$^{9}Be^{*} \rightarrow {}^{8}Be + n \rightarrow \alpha + \alpha + n$

$^{9}Be^{*} \rightarrow {}^{5}He + \alpha \rightarrow \alpha + \alpha + n$

E. Gete et al., PRC 61, 064310 (2000)
L. Buchmann et al., PRC 63, 034303 (2001)
P. Papka et al., PRC 75, 045803 (2007)
B. R. Fulton et al., PRC 70, 047602 (2004)
Y. Prezado et al., PLB 618, 43 (2015)

Experimental Setup

- The experiment was performed at the **MAGNEX** facility of INFN-LNS.

  MAGNEX **F**ocal **P**lane **D**etector (**FPD**)

  ✚

  ΔE-E telescope of the EXPADES array.

- **FPD**: Excellent energy, angular and mass resolution.

  M. Cavallaro et al., EPJA 48, 59 (2012)

- **EXPADES**:

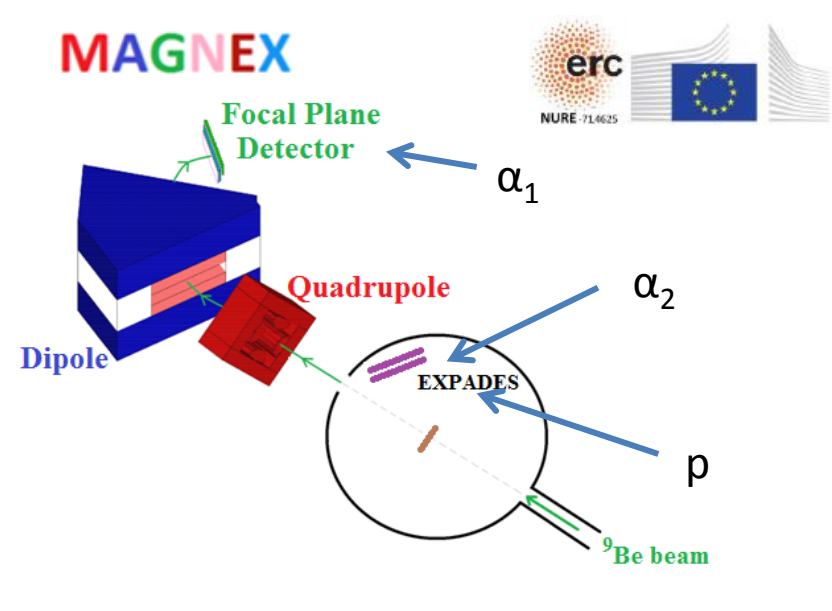
  ΔE DSSSD detector 300μm

  ✚

  Pad detector 300μm

  D. Pierroutsakou et al., NIMA 834, 46 (2016)

F. Cappuzzello et al., EPJA 52, 167 (2016)



see talks of
F. Cappuzzello and **S. Calabrese**

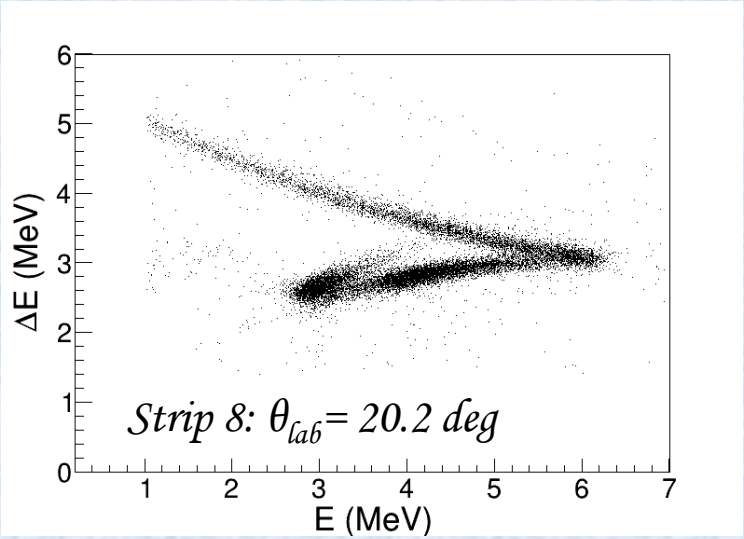
Identification of the Breakup events

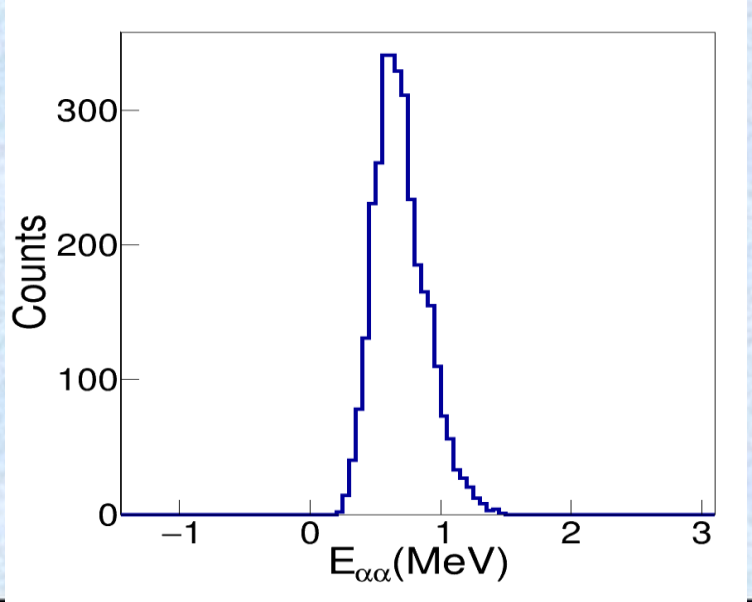
- The identification of the breakup channel was performed by means of an event by event code.

Triple Coincidence

α_1-particle @ MAGNEX + α_2-particle @ EXPADES + Proton @ EXPADES

- The energy of the undetected neutron was determined by applying the momentum conservation.
- Additional parameters like the relative energy or the two α-particles or the excitation energy of ^{9}Be were also reconstructed.





Breakup Simulations

- The coincidence spectra for each breakup mode were simulated via the M.C. algorithm **MULTIP**.

  O. Sgouros et al., EPJA 53, 165 (2017)

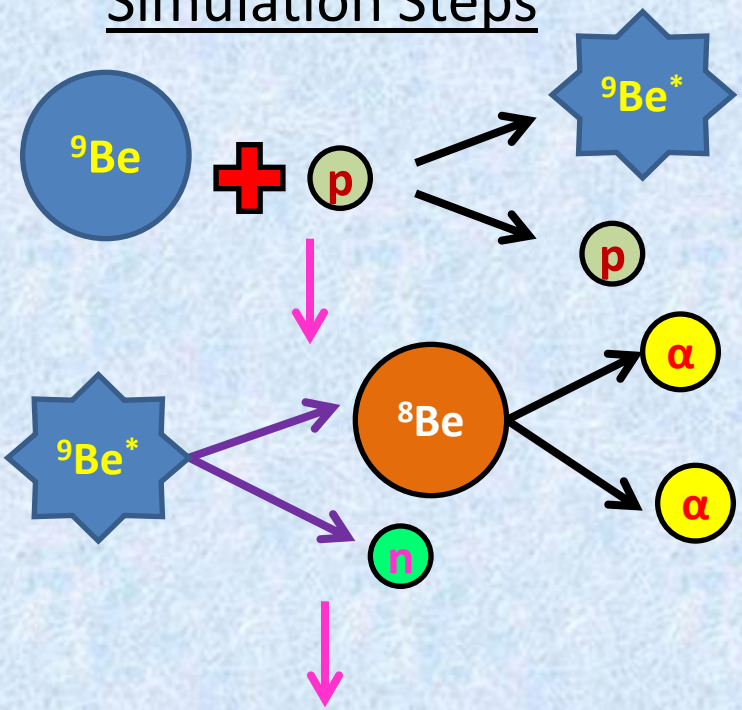
- **MULTIP** has been already used and validated with previous experimental data.

V. Soukeras et al., PRC 95, 054614 (2017)
A. Pakou et al,. PRC 95, 044615 (2017)
O. Sgouros et al., PRC 94, 044623 (2016)

Simulation Steps

a)

b)

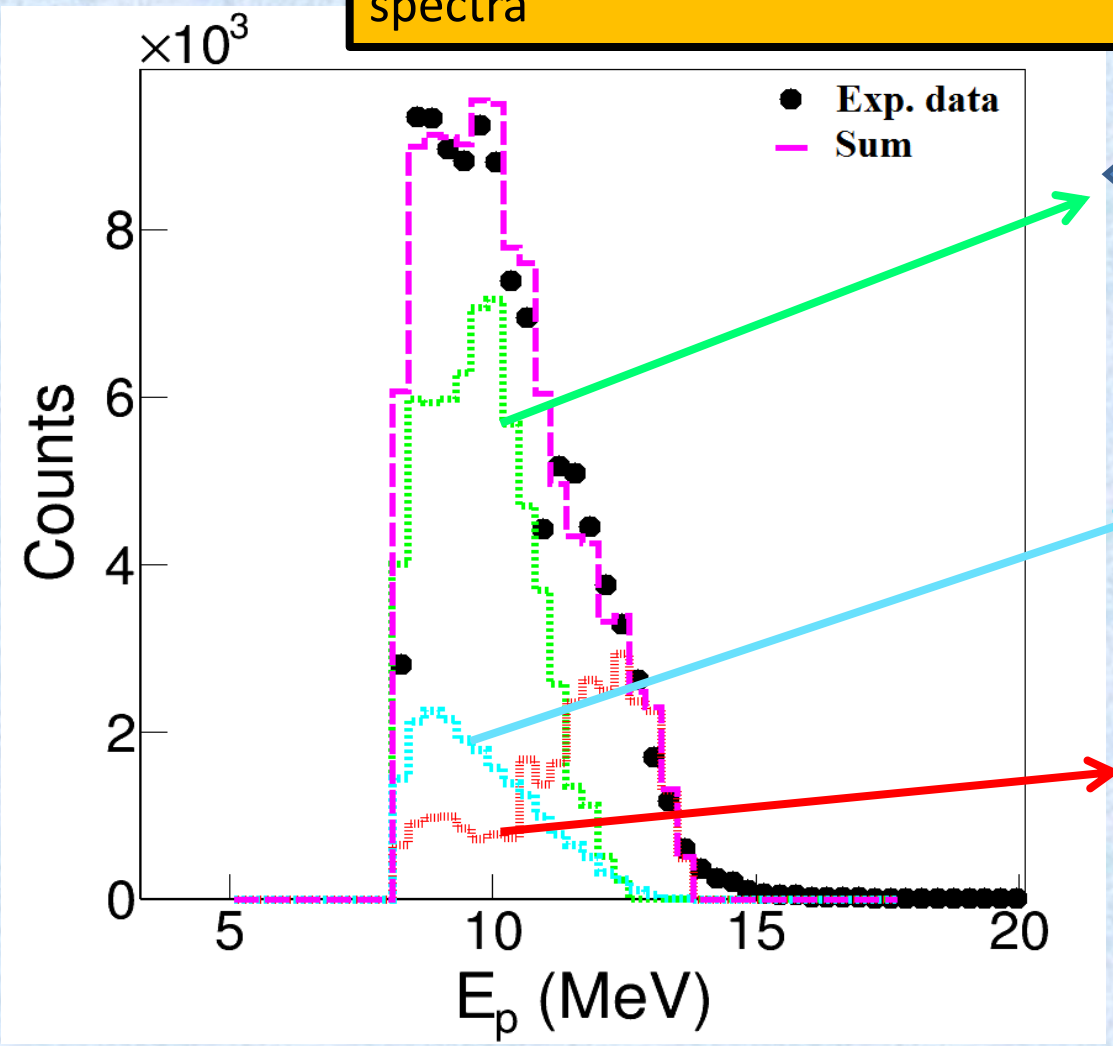


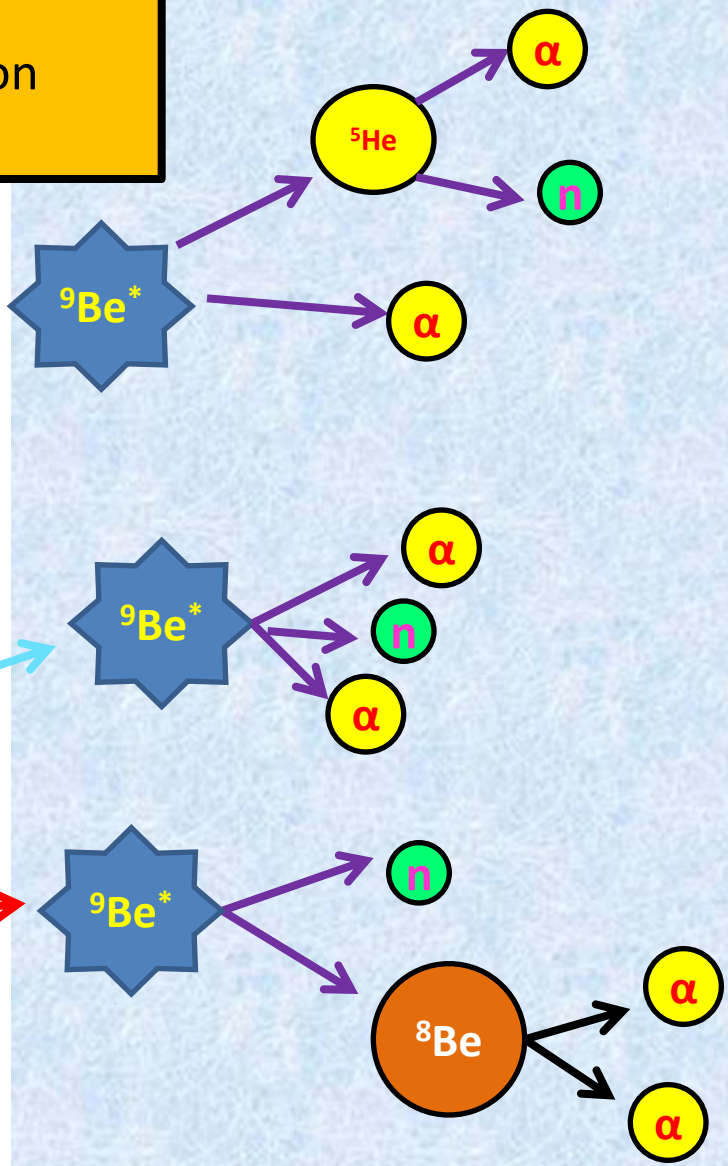
c) Evaluation of the energies and momenta of the breakup fragments in the LAB frame by applying a Galilean transformation and an axis rotation.

A similar procedure was also followed for the simulation of the other decay modes.

Deconvolution of the proton spectrum

Excellent agreement between experimental and simulated proton spectra





Summary

- **Exclusive breakup measurements** for the **Borromean ^{9}Be** on a **proton target** were performed at 5.6 AMeV.
- The recoiling proton spectra were analyzed in a **full kinematical approach** and the three breakup modes of ^{9}Be were identified by using extensive Monte Carlo simulations.
- Detection efficiencies for each breakup mode were determined via code MULTIP and the rate of each mode was deduced.
- The strongest contribution to the ^{9}Be breakup was found to be the the ^{5}He + α channel, while lesser contributions are attributed to the ^{4}He + ^{4}He + n and the ^{8}Be+n modes.

In agreement with E. Gete et al. and Y. Prezado et al.

- Our results exclude the contribution of the breakup via the ^{8}Be g.s.
- For our energy, the breakup at the ^{8}Be+n channel proceeds via the $5/2^{-}$ 2.43 MeV excited state of ^{9}Be.

Collaborators

A. Pakou[1], O. Sgouros[2], F. Cappuzzello[2,3], L. Acosta[4,5], C. Agodi[2], A. Boiano[6] , S. Calabrese[2,3], D. Carbone[2], M. Cavallaro[2], N. N. Deshmukh[2], A. Foti[2], A. Hacisalihoglu[2], N. Keeley[7], M. La Commara[6,8], I. Martel[9], M. Mazzocco[10,11], A. Muoio[2], C. Parascandolo[6], D. Pierroutsakou[6], K. Rusek[12], A. M. Sanchez-Benıtez[13], G. Santagati[2], V. Soukeras[2], G. Souliotis[14], A. Spatafora[2], E. Strano[10], D. Torresi[2], A. Trzcinska[12]

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Thank you very much for your attention