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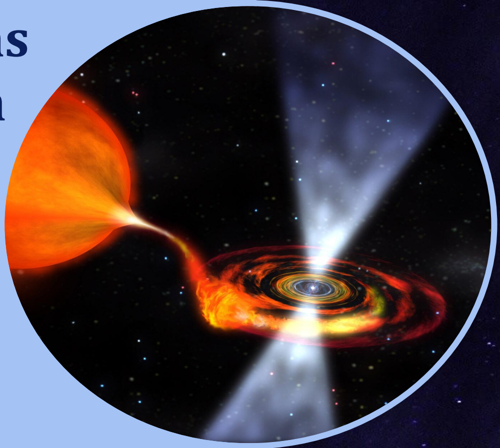
Triggering rp-process nucleosynthesis on neutron stars in binary systems through alpha capture on oxygen-15



[Image credit: ESA]

Neutron stars in binary systems are sites of very fast and violent explosions that emit flashes of light called X-ray bursts

We have studied the $^{15}O + \alpha$ reaction to determine its role in the ignition of the rp-process

This reaction acts as a bottleneck between the HCNO cycle and the nucleosynthesis of heavier elements in neutron star surfaces

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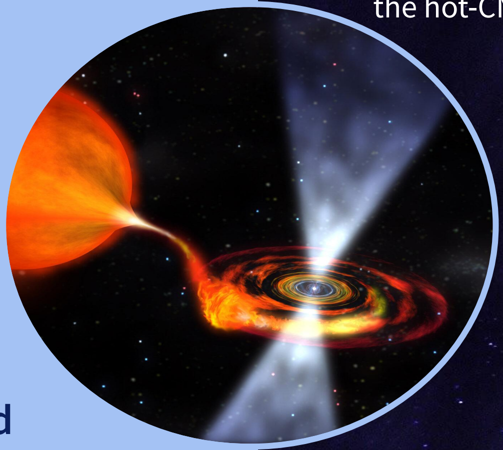
X-ray bursts are thermonuclear runaways that take place on the surface of neutron stars in a binary system



Observed light curves depend on key $^{15}O + \alpha \rightarrow {}^{19}Ne + \gamma$ reaction rate according to many sensitivity studies carried out

[1] J. Keegans et al. MNRAS, V. 485, Issue 1, Pages 620–639 (2019)
[2] R. H. Cyburt et al. Astrophys. J. 830, 55 (2016)

Accreting neutron stars

A neutron star in a binary system will attract material from its companion [1] causing:

- Increase of temperature and pressure on the surface
- Ignition of hydrogen burning through the hot-CNO cycle (HCNO)

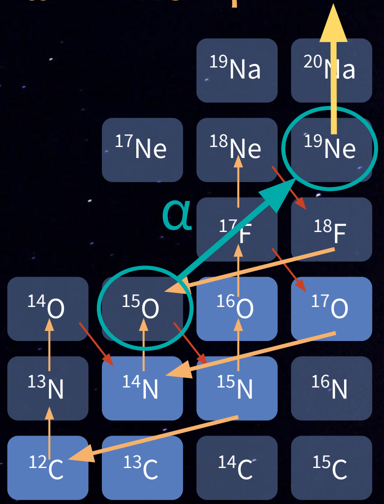
X-ray bursts

- When the temperature is hot enough, other nuclear reactions are activated
- Breakout from the HCNO cycle after the capture of an α particle
- Leading to thermonuclear runaways that emit flashes of light called X-ray bursts

Importance of the reaction: $^{15}O + \alpha \rightarrow {}^{19}Ne + \gamma$

- It regulates the flow between the HCNO cycle and the rp-process [2]
- Production of heavier elements depends on ratio between **α capture** and **β-decay**

We need a better determination of the α capture rate



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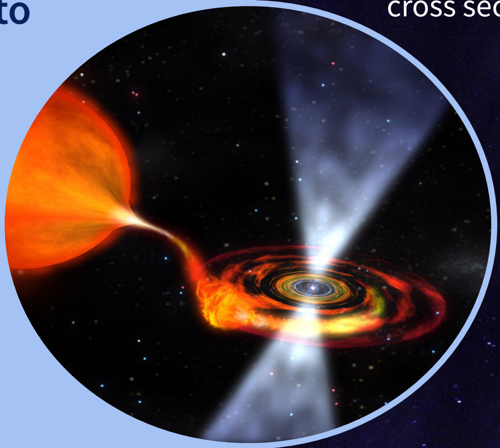
We need to understand the properties of this nuclear reaction to determine its reaction rate and to constrain the models

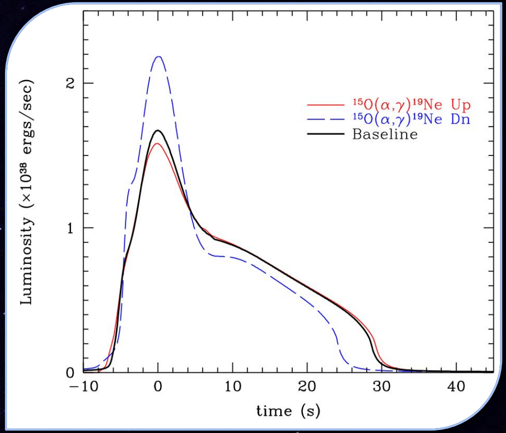


The main contributor to the reaction rate is the ^{19}Ne excited state at 4.03 MeV

[3] M. R. Hall et al. Phys. Rev. C 99, 035805 (2019)
[4] M. Assié et al. Accepted for publication in NIMA (2021)

Why is ^{19}Ne so important?

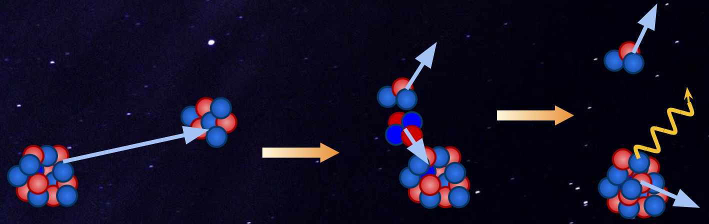
- Studying the properties of the ^{19}Ne resonances allows us to calculate the reaction rate [3]
- 4.03 MeV state biggest contribution, and it is very difficult to constrain due to its small cross section



Experiment and analysis

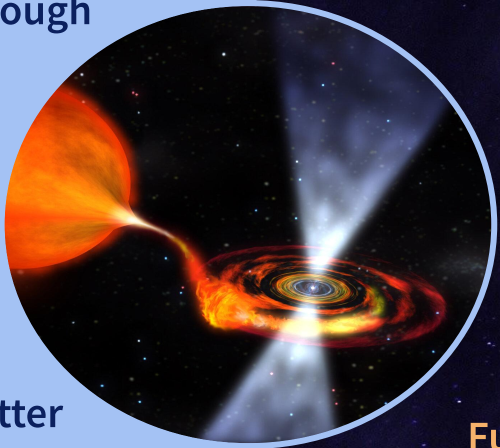
For this study, we performed an α-transfer reaction populating the ^{19}Ne excited states for temperatures up to 1GK

- Using the VAMOS + AGATA + MUGAST setup [4] at GANIL
- Detecting the ^{19}Ne recoils, the γ-rays from the deexcitation, and the ejected light particles



We isolated the α-transfer reaction by selecting the three detected particles in coincidence

The 4.03 MeV state has a very small cross section.
It has been studied for over 40 years and the results so far are not accurate enough



This experiment have achieved a better selectivity than previous work

Our final step is the calculation of the alpha capture rate and its implementation in the models.

First results on the 4.03 MeV state

With our selectivity we measured **3 candidates** of alpha transfer on the 4.03 MeV state
From this result, we estimated a preliminary value for the cross section, including its statistical error

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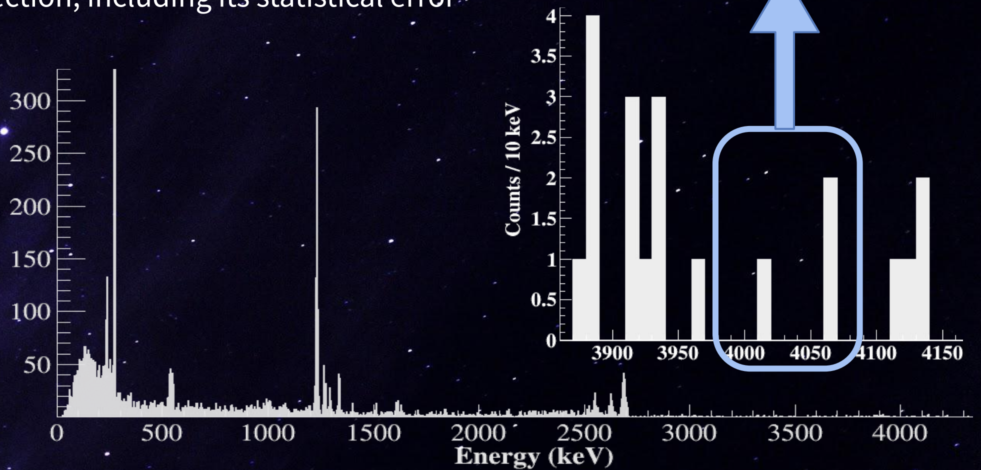
$$\sigma = 3.6^{+3.5}_{-1.9}\ \mu\text{barn}$$



Future work

Our next step is the determination of the α width (Γ_α) of the 4.03 MeV level in ^{19}Ne
From it, we will obtain its reaction rate

We will then implement the obtained Γ_α and its uncertainty in the X-ray burst models

This result will help to constrain the models!