Fusion Cross Sections of Astrophysics Interest Within The STELLA Project

Sandrine COURTIN1,2,3, Guillaume FRUET1,2, David G. JENKINS4, Marcel HEINE1,2, Daniele MONTANARI1,2,3, Luke G. MORRIS4, Gavin LOTAY5, Patrick H. REGAN5, Oliver S. KIRSEBOM6, Serge DELLA NEGRA7, Faïrouz HAMMACHE7, Nicolas DE SEREVILLE1, Beyhan BASTIN8, François de OLIVEIRA8, Giacomo RANDISI8, Christelle STODEL8, Christian BECK1,2 and Florent HAAS1,2.

1IPHC, Université de Strasbourg, F-67037 Strasbourg, France
2CNRS, UMR7178, F-67037 Strasbourg, France
3USIAS, F-67083 Strasbourg, France
4Department of Physics, University of York, Heslington, York YO10 5DD, United Kingdom
5Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom
6Department of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark
7IPN Orsay, UMR8608, IN2P3-CNRS, Université Paris Sud 11, 91406 Orsay, France
8GANIL CEA/DSM-CNRS/IN2P3 Caen, France

*E-mail: Sandrine.courtin@iphc.cnrs.fr

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Low energy fusion between light heavy-ions is a key feature of the evolution of massive stars. In systems of astrophysical interest, the process may be strongly affected by molecular configurations of the compound nucleus, leading to resonant S factors. In particular, the $^{12}\text{C} + ^{12}\text{C}$ fusion reaction has been the object of numerous experimental investigations. The STELLA project has been developed to extend these investigations to lower energies towards the Gamow window.

KEYWORDS: low energy fusion cross sections, light heavy-ion systems, molecular resonances, STELLA project.

1. Introduction

Fusion is the dominant mechanism in the collisions between light and medium mass heavy ions. For medium mass systems, the process has been extensively studied at sub barrier energies to understand the interplay between reaction mechanisms and nuclear structure. It was found that fusion cross sections were enhanced at moderate sub barrier energies and that fusion hindrance was observed far below the Coulomb barrier for several systems [1].

Fusion also plays a major role in the massive stars nucleosynthesis process. In a proton-rich stellar environment, the stable $^{13}\text{C}$ and $^{12}\text{C}$ are the first nuclei with sufficiently negative (p,α) Q values preventing their disappearance at low temperatures. $^{13}\text{C}$ is 100 times less abundant than $^{12}\text{C}$. The knowledge of the $^{12}\text{C} + ^{12}\text{C}$ fusion reaction is of high importance for nuclear astrophysics; it may indeed occur in several stellar environments: in the centre of massive stars during the C burning phase, in stellar explosions like type Ia.
supernovae and in the superbursts of neutron stars [2]. Stellar temperatures imply that 
Gamow energies for light heavy-ion fusion reactions are far below their Coulomb barriers. 
The corresponding cross-sections are therefore as small as the sub-nanobarn, and their 
experimental study is highly challenging. Light heavy-ion fusion reactions relevant for 
astrophysics are also those for which clustering effects have been evidenced from the 
Coulomb barrier to energies of a few MeV/nucleon [3].

![Graph showing S(E) for the $^{12}\text{C}^+^{12}\text{C}$ system.](image)

**Fig. 1.** $S$ factor $S(E)$ for the $^{12}\text{C}^+^{12}\text{C}$ system, from Ref. [4].

The $^{12}\text{C}^+^{12}\text{C}$ fusion reaction has been the subject of intensive experimental 
investigations. Some of the results are reported, in Fig. 1, from Ref. [4], along with 
extrapolations towards the Gamow region, around $E_{\text{Gamow}} = 1.5 \text{ MeV}$ (at $T = 5 \times 10^8 \text{ K}$). 
The absence of experimental data at very low energies due to the extremely low cross 
sections can be noticed, as well as orders of magnitude differences between the 
extrapolations. Interestingly enough, molecular resonances have been predicted in this 
region [5].

2. **The STELLA project**

The STELLA project (STELLlar LAboratory) has been developed to investigate fusion 
cross sections of astrophysics interest, hindrance effects and eventual molecular 
resonances in light heavy-ion systems like $^{12}\text{C}^+^{12}\text{C}$, $^{12}\text{C}+^{16}\text{O}$, $^{16}\text{O}^+^{16}\text{O}$. 
The project will measure particle-$\gamma$ coincidences making use of silicon strip detectors 
and $\text{LaBr}_3$ scintillators. The setup is presented in Fig. 2. It is installed at the Andromede 
accelerator in Orsay (France) and will make use of high intensity beams (I $>$ 1 $\mu$A) [6,7].
3. Summary

A new experimental set-up has been developed to investigate light heavy-ion fusion cross sections at energies towards the Gamow region. This setup will be installed at high intensity beam facilities.

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References