Coincidence measurements of fusion reactions involving carbon and oxygen with the high-precision STELIar LAboratory

STELLA

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Carbon and oxygen burning in massive stars

 $^{12}C+^{12}C$: first heavy-ion fusion reaction to be considered

Fusion involving ¹²C and ¹⁶O: nuclear perspective



- Nuclear structure / resonances
- Molecular states
- Alpha-clustering
- Fusion hindrance
 - Observed in medium-mass range \rightarrow ¹²C and ¹⁶O systems?









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STELLA measurements of ${}^{12}C+{}^{12}C$

- Provides reliable excitation functions over 8 orders of magnitude
- Explore different regimes: hindrance regime, Gamov windows
- At the lowest energies: ≤ 100 pb cross-sections!
- Latest analysis: improved timing selection
- Next: reach the deep sub-barrier regime underground (proposal @Felsenkeller)



Fruet *et al.* PRL **124** (2020)

Nippert et al. in preparation (2024)

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Measurements of fusion reactions involving carbon and oxygen with STELLA

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Toward ${\rm ^{12}C+^{16}O}$ and ${\rm ^{16}O+^{16}O}$ with STELLA

Challenging systems: at astrophysical energies of interest: larger number of open channels \rightarrow experimental upgrade needed



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Resolving complex final states: the ${}^{12}C+{}^{16}O$ case



At energies of interest: three-body exit channels are open Measured down to ~2mbarn (γ) Christensen Nucl. Phys. A280 (1977)

\rightarrow STELLA Si detector upgrade:

- ✓ full kinematics determination
- ✓ improved angular coverage
- \checkmark adapted thickness for ${}^{\rm 12}C{+}^{\rm 16}O$



Developments in cooperation with Micron Technologies

 $\theta \sim 1^{\circ}$ res. $\phi 11^{\circ}/22^{\circ}$ res.



& DAQ upgrade

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Improved precision: energy resolution budget



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Upgrade of the beam line at Andromède

- Re-design the STELLA 90° line @Andromède
- Beam optics simulations optimized on STELLA requirements: beam spot in size and symmetry







Andromède facility, Orsay, France

• Measurement of the beam emittance planed on site this autumn

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Upgrade of the beam line at Andromède



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Conclusion and perspectives

- STELLA successfully explored fusion cross-sections down to sub-nbarn region for ¹²C+¹²C
 virtual background suppression via coincidence and ns-timing precision
- Explore next fusion systems: ${}^{12}C + {}^{16}O$ and ${}^{16}O + {}^{16}O$
 - ✓ upgrade charged-particle detectors and improve beam focusing
 - \checkmark aim: exclusive measurement, full resolution of exit channels
- Rich physics program:
 - Nuclear physics: resonances, fusion hindrance?
 - Astrophysical impact for massive stars: structure, nucleosynthesis?
 - \rightarrow New hydrodynamics calculations on-going for sensitivity studies (T. Dumont poster #107)
 - + inclusion of TDHF calculations
 - explore deep sub-barrier energies underground @Felsenkeller (ChETEC-INFRA)

Thank you for your attention!

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