



# Nuclear Astrophysics @ GANIL

François de Oliveira Santos

GANIL-SPIRAL2

# Last 15 years astrophysics @ GANIL

<b>E400S</b>	<b>F. de Oliveira, L. Achouri et al.</b>	<b>EPJA 24</b>
<b>E442S</b>	<b>I. Stefan et al.</b>	<b>PRC 90</b>
<b>E521S</b>	<b>F. de Grancey et al.</b>	<b>PLB 758</b>
<b>E521aS</b>	<b>M. Assié et al.</b>	<b>PLB 721</b>
<b>EXXX</b>	<b>L. Gaudefroy, O. Sorlin et al.</b>	<b>EPJA 27</b>
<b>EXXX</b>	<b>S. Giron, F. Hammache et al.</b>	<b>Submitted</b>
<b>E560S</b>	<b>M. Aliotta et al.</b>	<b>To be continued</b>
<b>E561S</b>	<b>D. Mountford, A. Murphy et al.,</b>	<b>PRC85</b>
<b>E563</b>	<b>S. Harissopulos, P. Ujic et al.</b>	<b>To be continued</b>
<b>E578S</b>	<b>P. Ujic et al.</b>	<b>PRL110</b>
<b>E568S</b>	<b>P. Ujic, A. Ajevremovic et al.</b>	<b>Thesis C. Fontbonne</b>
<b>E641S</b>	<b>B. Bastin, F. Boulay et al.</b>	<b>To be submitted</b>
<b>...</b>		

+ 9 Ph.D. Thesis

+ Indirect experiments (nuclear structure, dynamics etc...)

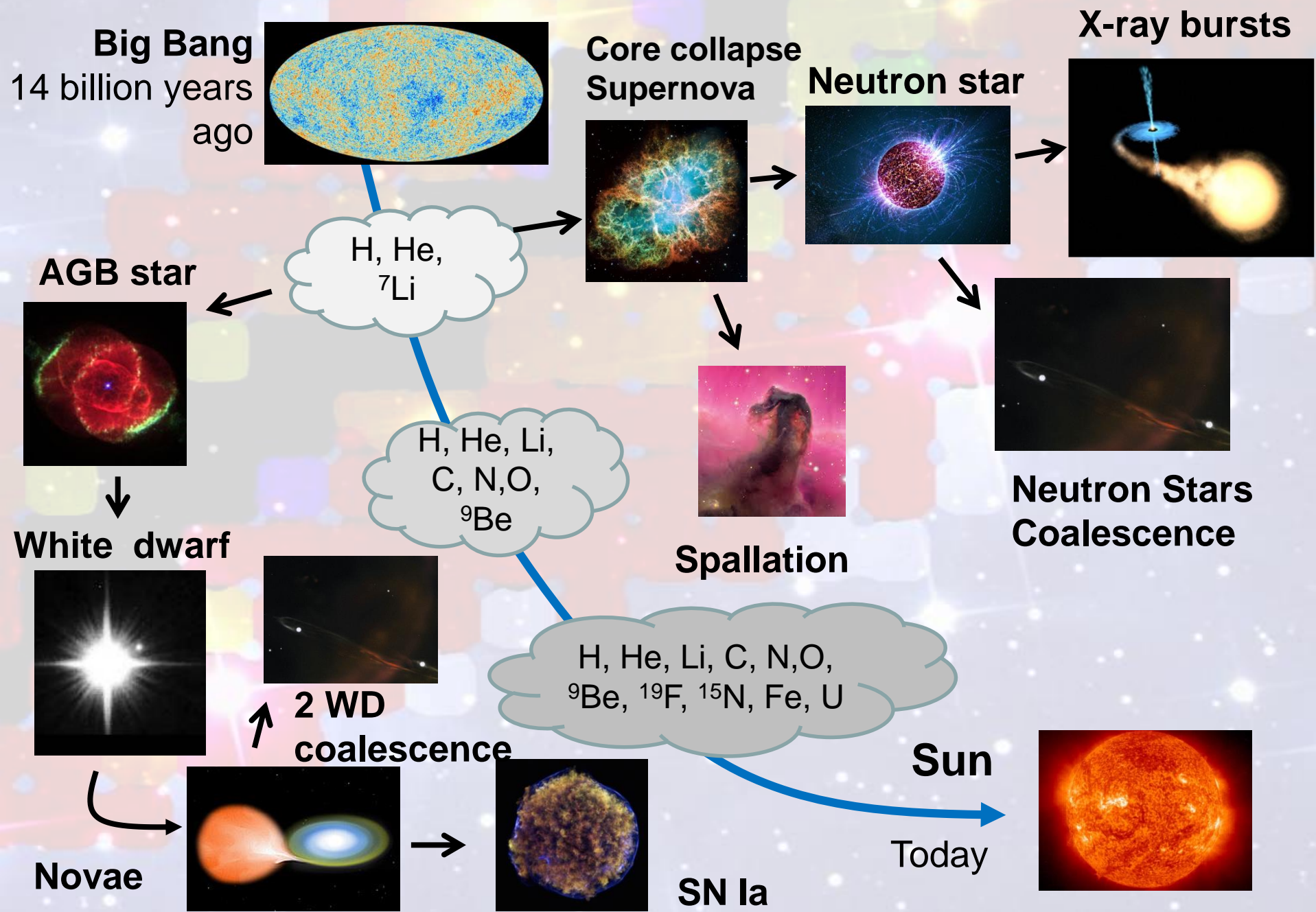
People @ GANIL: F. de Oliveira + B. Bastin + A. Fantina + collaborations (LPC)

Coordination in France: F. Hammache (Orsay)

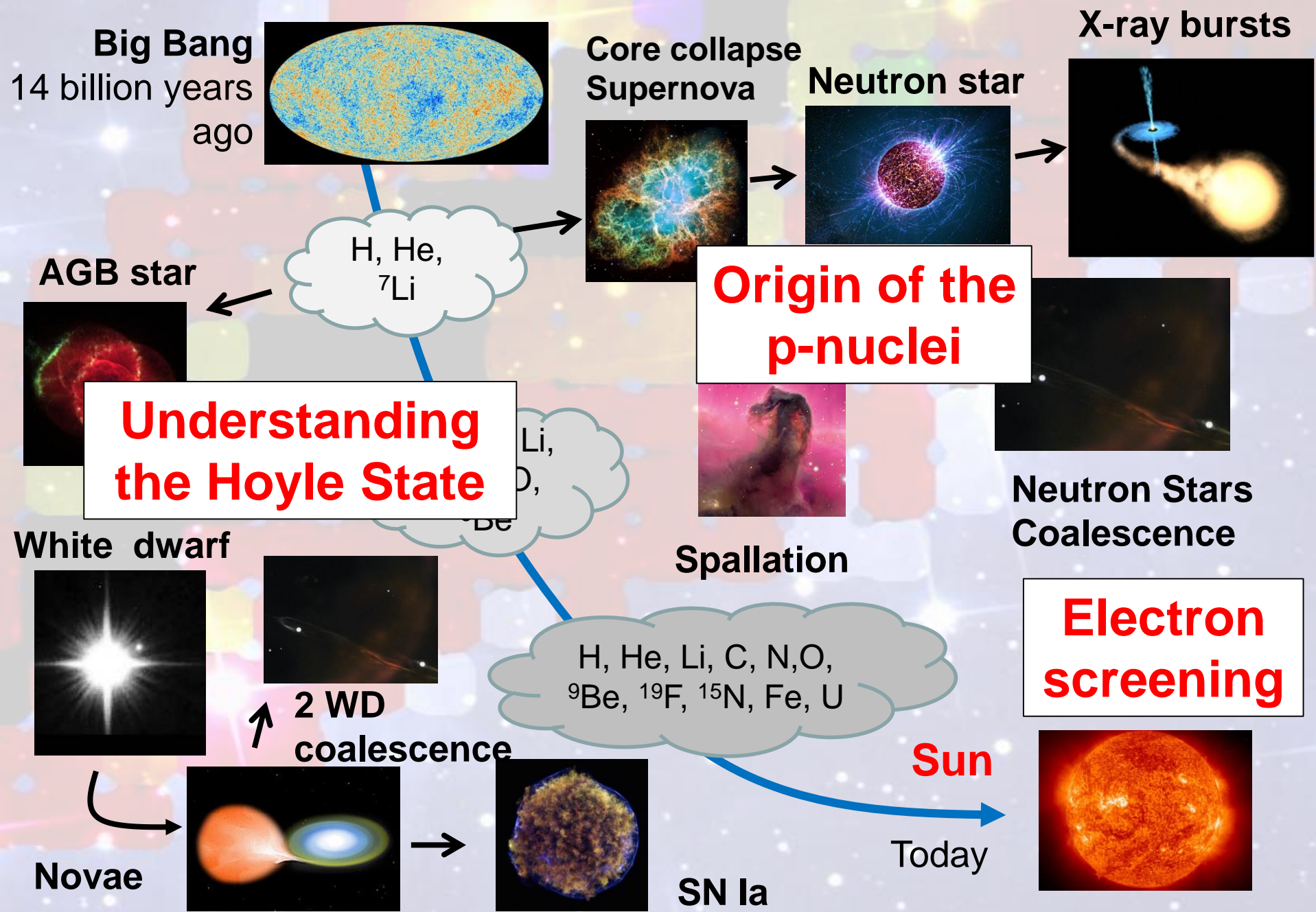
Long term collaboration with Romania: C. Borcea...



# Motivations



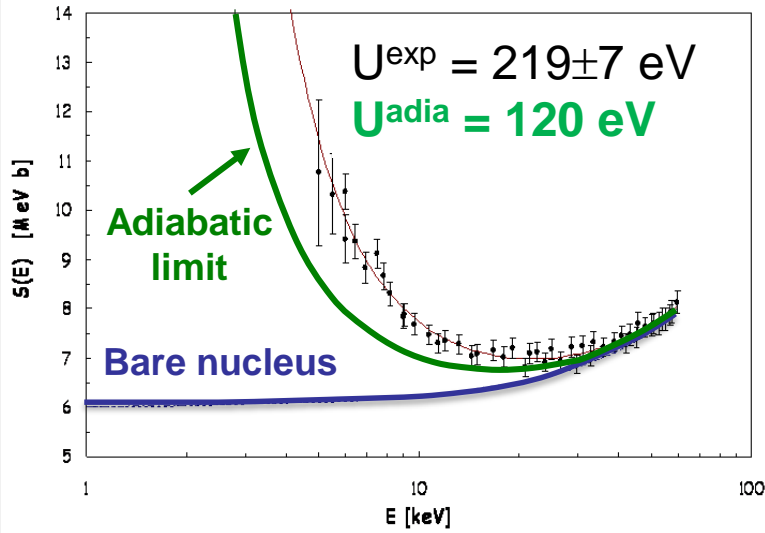
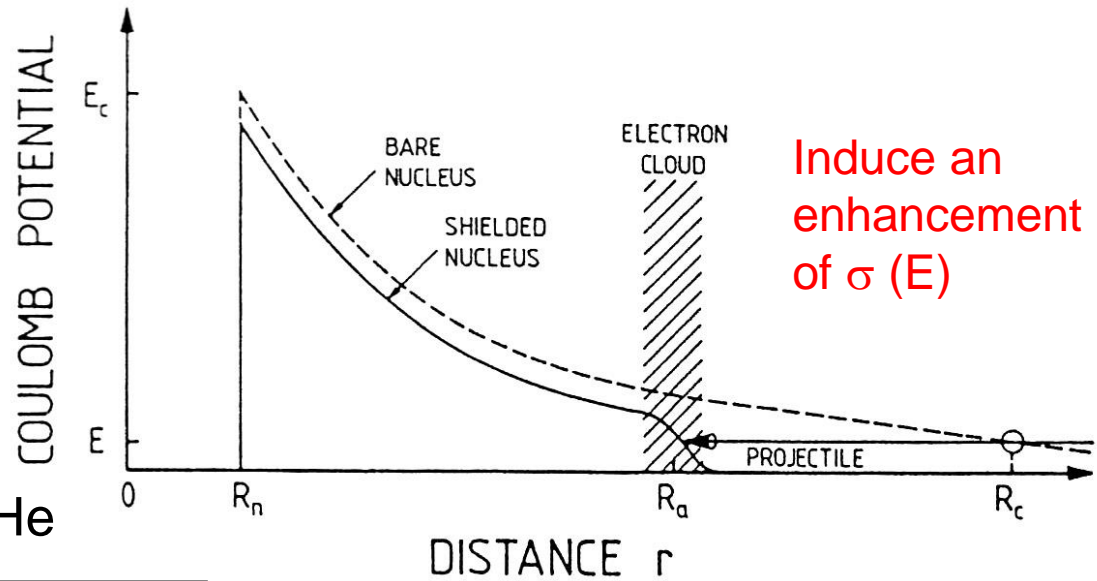
# Motivations



# The Electron Screening effect



Direct  ${}^3\text{He}(d,p){}^4\text{He}$



**Table 1**

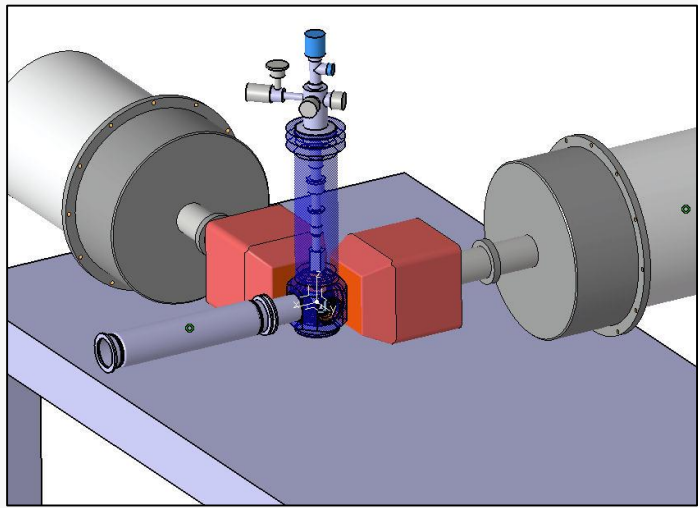
The experimental values of the electron screening adiabatic limits,  $U_e^{adlim}$ .

	Reaction	$U_e^{adlim}$ (eV)	$U_e^{exp}$ (eV)
[1]	${}^2\text{H}(d, t){}^1\text{H}$	14	$19.1 \pm 3.4$
[2]	${}^3\text{He}(d, p){}^4\text{He}$	65	$109 \pm 9$
[3]	${}^3\text{He}(d, p){}^4\text{He}$	120	$219 \pm 7$
[4]	${}^3\text{He}({}^3\text{He}, 2p){}^4\text{He}$	240	$305 \pm 90$

**Big puzzle**  
**Still not understood**

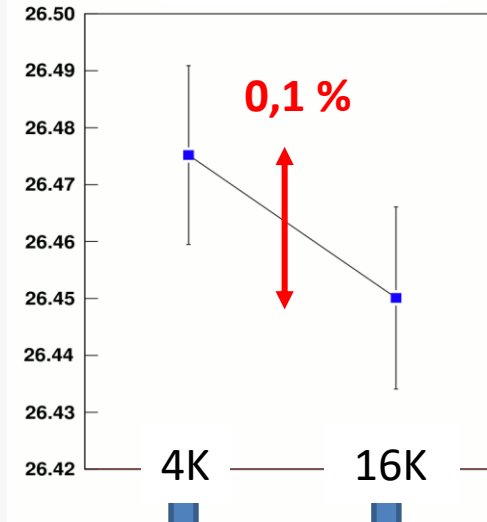
$U^{exp} > U^{adiabatic\ limit}$





An experiment performed at GANIL/SPIRAL with 2 beams  $^{19}\text{Ne}$  /  $^{19}\text{O}$  at  $5 \cdot 10^5$  pps 4 AMeV Implanted in a cooled Niobium foil

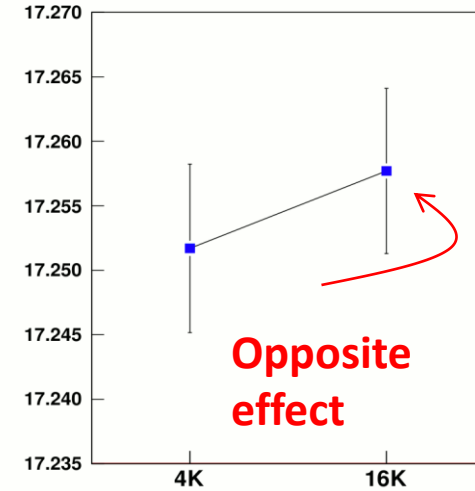
$^{19}\text{O}$  half-life  
 $\beta^-$  decay



Superconductor

Metal

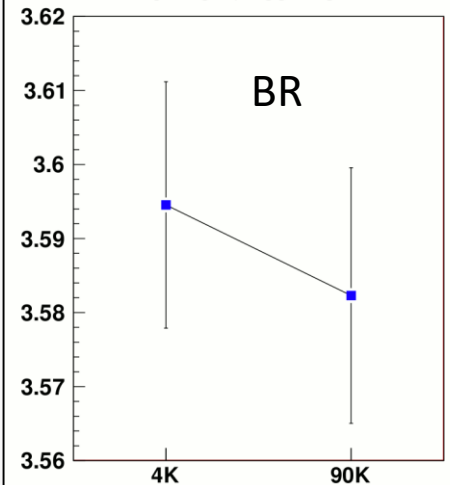
$^{19}\text{Ne}$  half-life  
 $\beta^+$  decay



## Conclusions

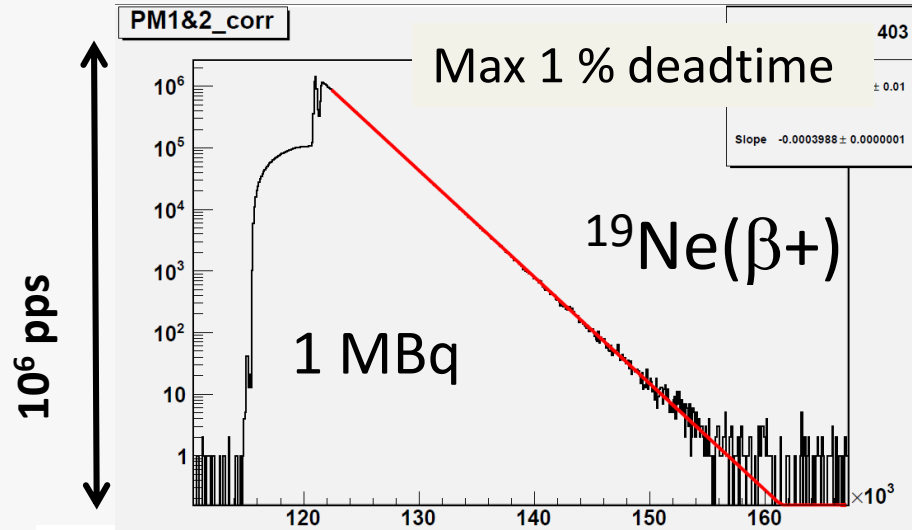
- No superScreening observed
- Measured:  $\Delta U_e (^{19}\text{Ne}) = 110(90)$  eV and  $\Delta U_e (^{19}\text{O}) = 400(320)$  eV
- In agreement with classical model  $\Delta U_e = 0$  (adiabatic limit)
- Impact on standard model test (precision  $\sim 3 \cdot 10^{-4}$ )
- New experimental technique developed

197 keV / 1554 keV

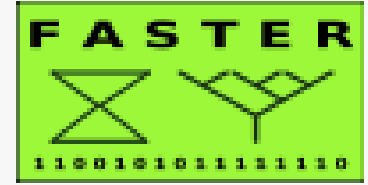


P. Ujic et al.  
PRL 110 (2013)

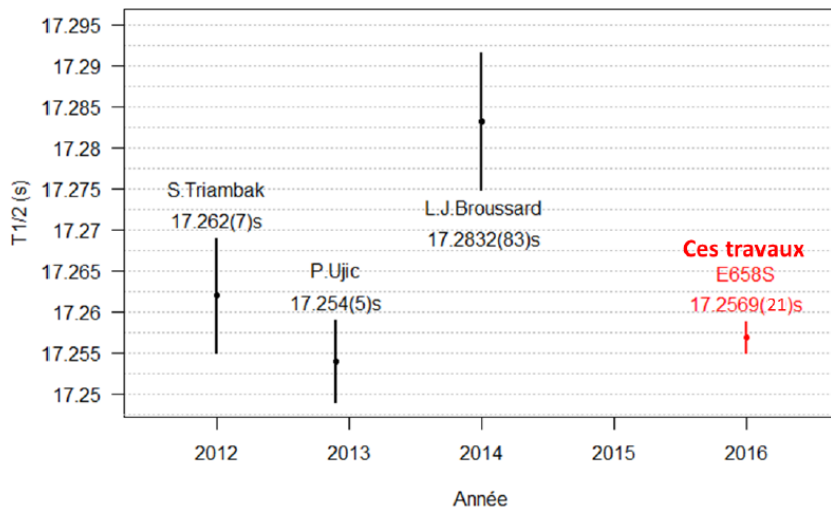
# A new experiment performed



2 targets (Pb, CsI)



FASTER digital acquisition system



Deep analysis of the data

- Pile-up
- Baseline fluctuations
- Photomultiplier gain fluctuations

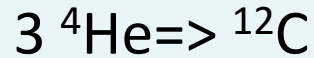
Collaboration E568S: P. Ujic, C. Fontbonne, F. Rotaru, et al.

Thesis of **Cathy Fontbonne** (LPC) 1<sup>st</sup> February 2017

Next: The most accurate of the world!?  $\sim 10^{-5}$   $E_c \sim 10\text{eV}$

# Understanding the Hoyle state

Triple alpha reaction and the Hoyle state

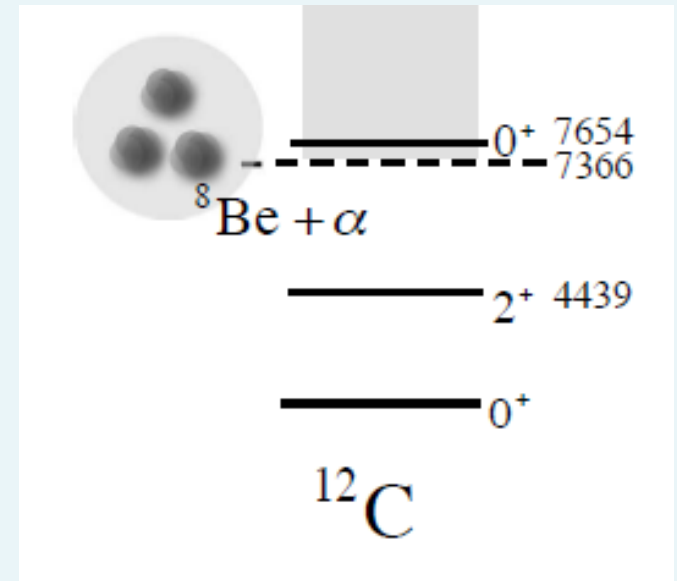


**Puzzle : Anthropic principle**

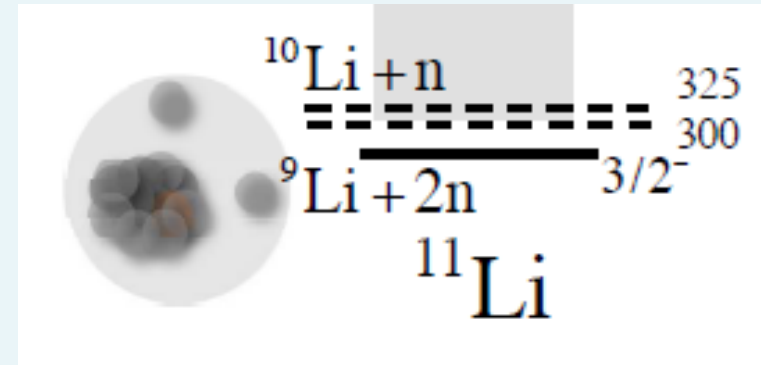
## Ikeda conjecture

The coupling to a nearby cluster decay channel induces cluster correlations

*J. Okolowicz, M. Ploszajczak and W. Nazarewicz Prog. Theor. Phys. Supplement 196 (2012) 230.*



The Hoyle state



Dineutron halo



# Is clustering a generic near-threshold phenomenon?

The case of  $^{15}\text{F}$

Studied at GANIL

$^{14}\text{O}(p,p)^{14}\text{O}$  in inverse kinematics

$E = 6.0 \text{ MeV/u}$

using a  $150 \mu\text{m}$  thick  $(\text{CH}_2)_n$  target

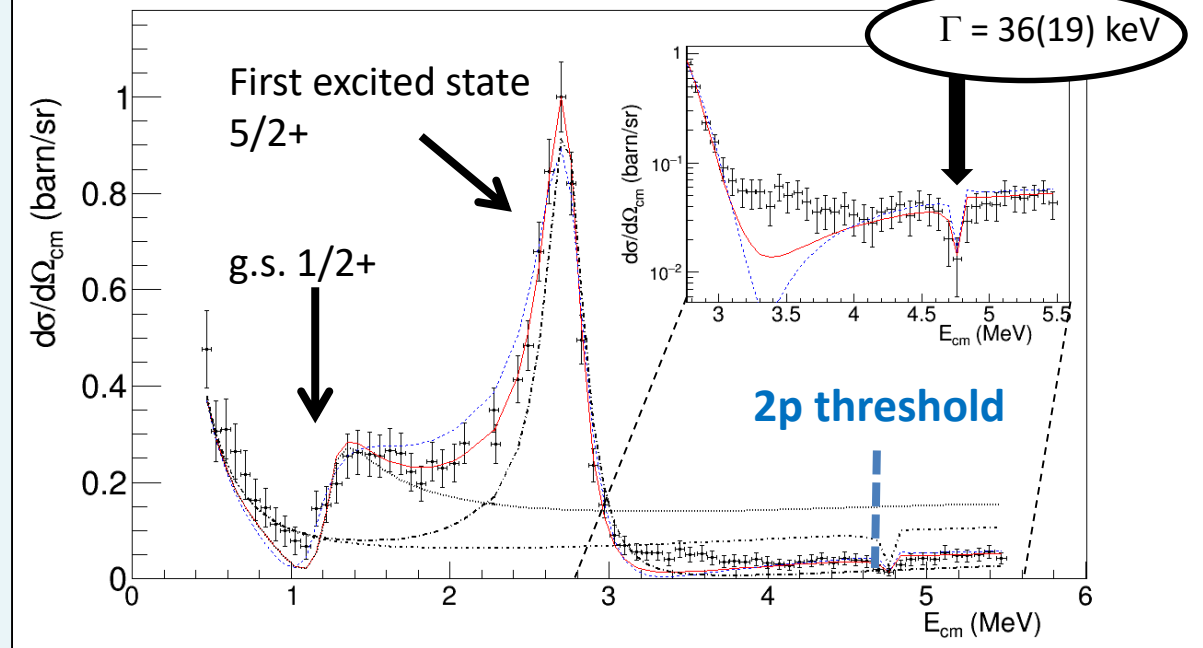
$i = 1.88(1) \times 10^5 \text{ pps}$  100.0(1) % pure

An above-barrier narrow resonance in  $^{15}\text{F}$ .

**De Grancey, F., Mercenne, A.,** de Oliveira Santos, F., Davinson, T., Sorlin, O., Angélique, J. C., et al.

Physics Letters B, 758, 26-31. (2016)

A narrow  $\frac{1}{2}$ - state observed



## Conclusions:

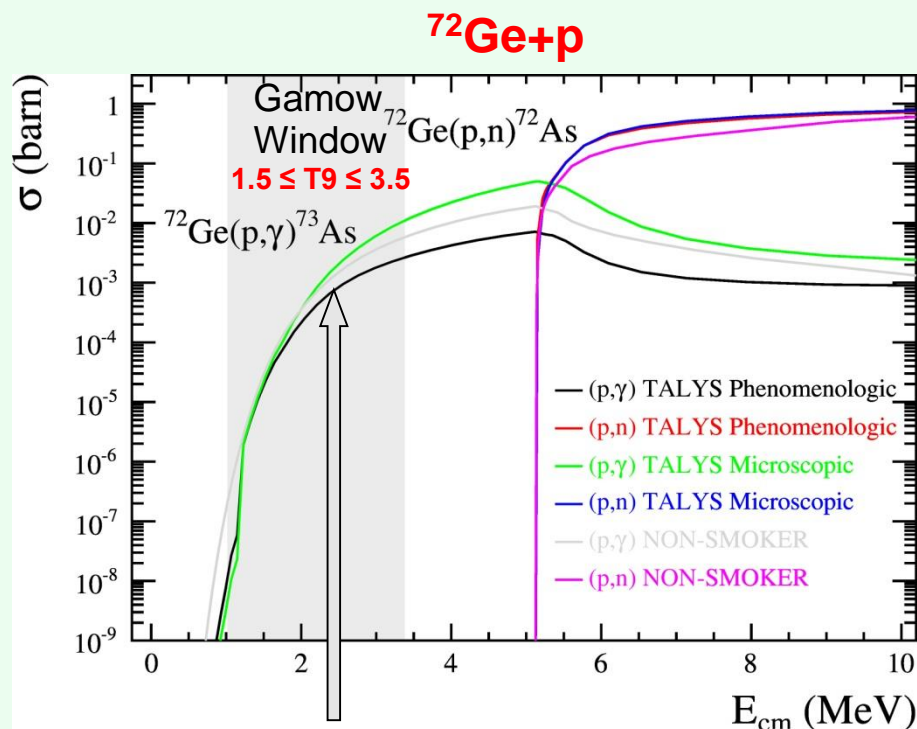
- A hint for strong  $2p$  correlation, “ $^2\text{He}$ ” cluster, observed in  $^{15}\text{F}$ , at the  $2p$  threshold.
- It seems to confirm that clustering is a generic near-threshold phenomenon...

New proposal accepted: The fastest  $\gamma$ -transition I. Stefan et al.

# Measurement of the $^{72}\text{Ge}(p,\gamma)^{73}\text{As}$ @ IFIN (2017)

B. Bastin, G. Randisi *et al.*

- Unmeasured (unsuccessful attempt with a natural Ge target)  
-> use of enriched target (>95%)
- Large cross section variations using different theoretical inputs



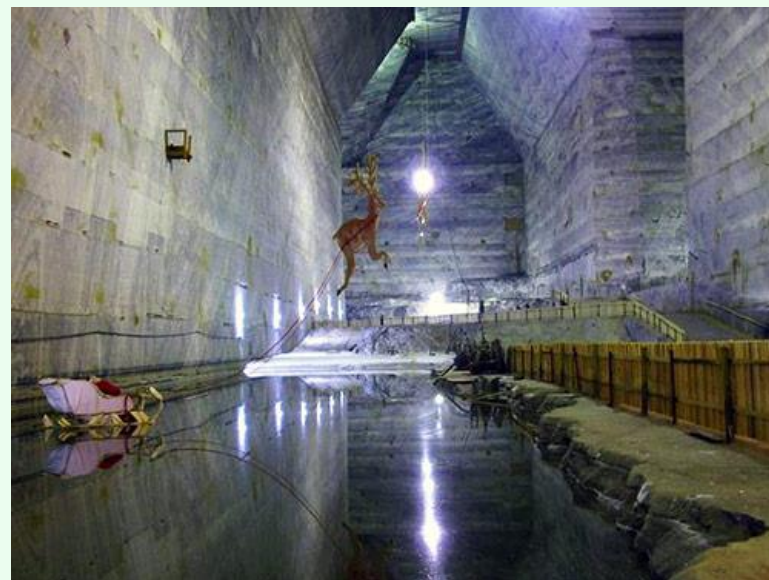
Large discrepancy of models at 2.5 MeV

## Activation technique

$E_p=2.5\text{MeV}$  T irradiation=10h

3MV Tandetron accelerator

SLANIC Salt mine  $\rightarrow$  low background



**Thank you for your attention**

Many thanks to all collaborators