AGB star nucleosynthesis: when new data from nuclear physics help to solve puzzles

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Low mass star contribution to the chemical evolution of galaxies

- Supernovae stars produce the most part of nuclei in the galaxies.
- 50% of nuclei are produced by low mass stars.

The lower is the mass, the larger is the number of stars.

from: M. Wiescher, JINA lectures on Nuclear Astrophysics
Low mass star contribution to the chemical evolution of galaxies

- The lower is the mass, the larger is the number of stars
- $M < 3M_\odot$

IRC+10216 C-star is the brightest object on the sky at mid infrared

*NN2015*
Grains & challenges from RGB & AGB stars

C/O ≥ 1  
SiC grains

C/O < 1  
Oxide grains

Hoppe NewAR 2002

Zinner 2004

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Grains & challenges from RGB & AGB stars

C/O ≥ 1 SiC grains

C/O < 1 Oxide grains

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Hoppe NewAR 2002

Zinner 2004

NN2015
Energy range of the H-burning shell

Temperature:
8.3 $10^7$ K $\leftarrow$ 3 $10^6$ K

Conversion Factors Between Units of Energy
3.45 keV $\leftarrow$ 0.25 keV

Most effective energy ($^{17}$O +p reactions)
125 keV $\leftarrow$ 36.5 keV

\[ N_A \langle \sigma v \rangle = N_A \frac{(8/\pi)^{1/2}}{\mu^{1/2}(k_BT)^{3/2}} \int_0^\infty \sigma E \exp(-E/k_BT) dE, \]

\[ E_0 = \left( \frac{\mu}{2} \right)^{1/3} \left( \frac{\pi e^2 Z_1 Z_2 k_B T}{\hbar} \right)^{2/3} = 0.1220(Z_1^2 Z_2^2 A)^{1/3} T_9^{2/3} \text{ MeV} \]
**Reaction rates from determined by THM**

\[ ^{17}\text{O}(p, \alpha)^{14}\text{N} \]

Sergi et al. 2015 PRC in press

POSTER n.37

\[ ^{18}\text{O}(p, \alpha)^{15}\text{N} \]


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<td>20 keV</td>
<td>8.3(^{+3.8}_{-2.6} ) 10(^{-19} )</td>
<td>6(^{+17.5}_{-5} ) 10(^{-19} )</td>
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<td>90 keV</td>
<td>1.8 ± 0.3 10(^{-7} )</td>
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Reaction rate from determined by THM

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La Cognata et al. 2010

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$^{18}\text{O}(p, \alpha)^{15}\text{N}$ and the challenging Nitrogen isotopic ratio in SiC grains
$^{17}\text{O}+\text{p}$ reaction rates and Oxide grains

- RGB stars with $1M_{\odot} < M_\star < 2M_{\odot}$ and solar composition
- AGB stars with $M_\star < 2M_{\odot}$ and solar composition
$^{17}\text{O}+\text{p}$ reaction rates and Oxide grains

- Low mass RGB stars ($M_\star<2M_\odot$) are progenitor of group 1 grains
- Extra-mixing in AGB stars account for isotopic composition of Group 2 oxide grains

$^{17}\text{O}+\text{p}$ from Chafa et al. 2007

Palmerini et al. 2011
$^{17}$O+p reaction rates and Oxide grains

- Mass range of stellar progenitors of group 2 oxide grains is $1M_\odot < M_\star < 1.2M_\odot$

- Group 2 grains might be divided in 2 subgroups because of the progenitor mass
Aluminum isotopic ratio: a possible solution from nuclear physics?

How to reach $^{26}\text{Al}/^{27}\text{Al}>0.02$ shown by part of group 2 grains?
Aluminum isotopic ratio: a possible stellar solution from nuclear physics

- The measurement of $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$ excludes that a solution coming from nuclear data (Strieder et al. 2012)

Extra-mixing

Convective envelope

H-burning shell

- What about the mixing profile?
How does $^7$Li come from the Cosmos?

- **Nucleosynthesis**: Light elements created - O, He, Li
  - $t = 1$ second
  - $T = 1$ MeV
  - $\sim 10^9$ e

- **Quark-hadron transition**: Hadrons form - protons & neutrons
  - $T = 1$ GeV
  - $t = 10^{-6}$ s

- **Electroweak phase transition**: Electromagnetic & weak nuclear forces become differentiated: $SU(3)\times SU(2)\times U(1)$
  - $T = 10^2$ GeV
  - $t = 10^{-11}$ s

- **Grand unification transition**: $G \rightarrow SU(3)\times SU(2)\times U(1)$
  - $T = 10^7$ GeV
  - $t = 10^{-5}$ s

- **The Planck epoch**: The quantum gravity barrier
  - $T = 10^{16}$ GeV
  - $t = 10^{-43}$ s

- **Today $t_0$**
  - Life on earth
  - Solar system
  - Quasars

- **Galaxy formation**
  - Epoch of gravitational collapse
  - $t = 400,000$ years
  - $T = 3000$ K (1 eV)

- **Recombination**
  - Helium-adatoms decouples (CBB)
  - Matter domination
  - Onset of gravitational instability
  - $t = 3$ minutes

- **Molecular Cloud**

- **Solar System**

- **Salar de Uyuni**

...and a well-known Cosmological problem

S. Palmerini
A new estimation of $^7$Be life-time in Stellar Conditions

Sun:
$T = 1.57 \times 10^7$ K
$\rho = 160 \text{ g/cm}^3$

RGB & AGB:
$T = 5 \times 10^7 - 2 \times 10^6$ K
$\rho = 0.01 - 100 \text{ g/cm}^3$

The Poisson–Boltzmann approach (the other "classical" one) does not hold outside the conditions of the solar nucleus. In particular, at lower temperatures and densities, where a large part of the Li production occurs (because the competing proton captures on $^7$Be become ineffective).
Li in AGBs and the ‘new’ $^7$Be life time

$^3$He

$^7$Be

$^4$He

$^7$Li

$(p, \alpha)$ $^4$He

$(e^-, \gamma)$ $^7$Li

$(p, \gamma)$ $^8$B($\beta$) $^8$Be $\rightarrow$ 2$\alpha$

$^8$Be $\rightarrow$ 2$\alpha$

Figure 1. Electron-capture half-life in days for $^7$Be as a function of $\rho$ and $T$.

(A color version of this figure is available in the online journal.)
In nuclear astrophysics

- Sometimes solutions come from nuclei ($^{17}\text{O}/^{16}\text{O}$ in grains)

- Sometimes solutions come from stars ($^{26}\text{Al}/^{27}\text{Al}$ in grains)

- Other times we do not know yet ($^{14}\text{N}/^{15}\text{N}$ in grains and the Li problem)

- In any case it is necessary to collaborate