The $^{26}\text{Al}$ yields in single stars

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Outline

• Motivations;
• $^{26}$Al yields in single stars;
• The influence of $^{26}$Al isomeric state;
• Conclusions.
$^{26}$Al in meteorites & the Galaxy

- A direct proof of the ongoing nucleosynthesis in our galaxy
- The total amount of live $^{26}$Al is $2.0 \pm 0.3$ solar mass
- The source of $^{26}$Al favor massive star


- Give more information about the birth of the Solar System.
- The decay of $^{26}$Al in the ESS could have important consequences to our earth.

M. Lugaro, et al., 2018 PPNP 102, 1.
Possible $^{26}$Al sources

- Hydrostatic H-burning
- Explosive H-burning
- Hydrostatic Ne/C-burning
- Explosive Ne/C-burning
- Spallation of cosmic rays
- Single stars
- Binary stars

N. Prantzos et al., 1996, PR, 267, 1
C. Iliadis et al., 2011 APJ 193, 16.
M. Lugaro, et al., 2018 PPNP 102, 1.

The $^{26}$Al sources are still debating……
The one-dimensional open source code: MESA is used to do the calculations [http://mesa.sourceforge.net/](http://mesa.sourceforge.net/) (64 isotopes + 557 reactions, Z = 0.014)

- The more initial stellar mass the more $^{26}$Al production in stars.
- Above $30M_\odot$: the yields in winds agree with Limogi’s, even if the metallicities are different (Limogi’s: $Z = 0.02$)
- At $10M_\odot$ & $20M_\odot$: the yields are bigger than Limogi’s.
- At $5M_\odot$: the yields enhanced a lot?

M. Limongi et al., 2006, APJ 647,483
The $^{26}\text{Al}$ in the outer convection mixing is bigger at $5M_{\odot}$;

- Dredge up appear at $5M_{\odot}$, no dredge up at $10M_{\odot}$;
- The dredge up mixing increase the yields in winds.
Reaction flux to determine the important reactions

For the reaction $N_i(A_i Z_i) + N_j(A_j Z_j) \leftrightarrow N_k(A_k Z_k) + N_l(A_l Z_l)$, its reaction net flux of nucleus $i$ is calculated by the following formula:

$$
\int_{t_1}^{t_2} \int_0^M \dot{X}_{mti} dmdt = \int_{t_1}^{t_2} \int_0^M (-\dot{X}_{mt(i\to k)} + \dot{X}_{mt(k\to i)}) dmdt
$$

$$
= \int_{t_1}^{t_2} \int_0^M N_i \left( -\frac{X_{mti}^N_i X_{mtj}^N_j}{A_i^{N_i - 1} A_j^{N_j} N_i! N_j!} [ij]_{mtk} + \frac{X_{mtl}^N_l X_{mtk}^N_k A_i}{A_l^{N_l} A_k^{N_k} N_l! N_k!} [lk]_{mti} \right) dmdt.
$$

where $\dot{X}_{mti}$ is the mass fraction rate of nucleus $i$ from this nuclear reaction in cell $m$ at time of $t$, $N_i$ is its number contained in this reaction, $[ij]_k = (\rho_b N_A)^{N_i + N_j - 1} \langle ij \rangle$, $\rho_b$ is the baryon density and $\langle ij \rangle$ represents the reaction rate between $i$ and $j$. In case of decay, $N_j$ and $N_l$ will be zero. The reaction forward mass flow is $\dot{X}_{ml(i\to k)} = N_i \frac{X_{mti}^N_i X_{mtj}^N_j}{A_i^{N_i - 1} A_j^{N_j} N_i! N_j!} [ij]_{mtk}$ which decreases the abundance of nucleus $i$. $\dot{X}_{ml(k\to i)} = N_i \frac{X_{mtl}^N_l X_{mtk}^N_k A_i}{A_l^{N_l} A_k^{N_k} N_l! N_k!} [lk]_{mti}$ is the reaction backward mass flow which increases the abundance of nucleus $i$. 
The reaction sensitivity to the yields of $^{26}$Al are still going on.
The influence of $^{26}$Al isomeric state

4 states
11 states

Weisskopf approximation
The influence of $^{26}$Al isomeric state

- The new $\gamma$ - decay rates between the ground and isomeric states of $^{26}$Al increase the $^{26}$Al yields (in wind), 4% at 5M$_{\odot}$ and 60% at 50M$_{\odot}$.
- The effects at other stellar masses are still calculating.
Conclusions

- The $^{26}$Al sources are still debating;
- In single stars, the more stellar mass the more $^{26}$Al production;
- The $^{26}$Al yields in winds agree with other works at above $30M_\odot$; at $10M_\odot$ and $20M_\odot$ our results are higher;
- The dredge up mixing at $5M_\odot$ enhance $^{26}$Al yields in winds;
- For the future sensitivity test the reaction flux is used to decide which reaction is more important;
- The new $\gamma$ - decay rates between the $^{26}$Al ground and isomeric states increase the $^{26}$Al yields.
谢谢
Köszönöm
Thank you for your attention