s-PROCESSING FROM MHD-INDUCED MIXING AND ISOTOPIC ABUNDANCES IN PRESOLAR SiC GRAINS

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CONTRIBUTION OF LMS TO GCE

Despite their low masses LMS are so numerous to contribute for 75% to the total mass return from stars to the ISM (Sedlmayr 1994);

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A physical mechanism that allows: the formation of the $^{13}\text{C}$ pocket

$\rightarrow$ proton penetration from the envelop during the TDU $\rightarrow ^{12}\text{C}(p,\gamma)^{13}\text{N}(\beta^+ \nu)^{13}\text{C}$

$\rightarrow ^{14}\text{N}$ is the most important neutron poison.
MIGHT STELLAR MAGNETIC FIELDS TRIGGER THE FORMATION OF A 13C-POCKET SUITABLE TO ADDRESS OBSERVATIONAL CONSTRAINTS?
(MHD) 13C-POCKET FORMATION: UP-FLOW OF MAGNETISATED MATERIAL

$\rho \propto r^k, k < -1$;
$P_m > 1$
Small magnetic diffusivity $\nu_m$

\begin{align*}
    v_r &= \Gamma r^{-(k+1)} \\
    \Gamma &= v_P r_p^{k+1}.
\end{align*}

\begin{align}
    \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) &= 0 \\
    \rho \left[ \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} - c_d \mathbf{v} + \nabla \Psi \right] - \mu \Delta \mathbf{v} + \nabla P + \frac{1}{4\pi} \mathbf{B} \times (\nabla \times \mathbf{B}) &= 0 \\
    \frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{v} \times \mathbf{B}) - \nu_m \Delta \mathbf{B} &= 0 \\
    \nabla \cdot \mathbf{B} &= 0
\end{align}

\begin{align}
    \rho \left[ \frac{\partial \epsilon}{\partial t} + (\mathbf{v} \cdot \nabla) \epsilon \right] + P \nabla \cdot \mathbf{v} - \nabla \cdot (\kappa \nabla T) + \frac{\nu_m}{4\pi} (\nabla \times \mathbf{B})^2 &= 0.
\end{align}

Simplest and FASTEST solution satisfying boundary conditions
The density of envelope material injected (downflow mass) into the He-layers will vary as:

\[ \frac{d \rho_d}{\rho_d} = +\alpha dr \]

corresponding to an exponential profile:

\[ \rho_d(r) = \rho_{d,0} e^{-\alpha(r_e - r)} \]

We multiplied for the infinitesimal element of volume:

\[ dM_d(r) = 4\pi r^2 \rho_e e^{-\alpha(r_e - r)} dr. \]

After integration between envelope border and the innest layer, we obtain:

\[ \Delta M_d^H \approx 0.714 \frac{4\pi \rho_e}{\alpha} \left\{ \left[ r_e^2 - \frac{2}{\alpha} r_p + \frac{2}{\alpha^2} \right] - \left[ r_p^2 - \frac{2}{\alpha} r_p + \frac{2}{\alpha^2} \right] e^{-\alpha(r_e - r_p)} \right\} \]

Comparing this result with the mass transported by magnetic buoyancy

\[ M_{up} = \dot{M} \cdot \Delta t = 4\pi r_e^2 \rho_e u_e f_1 f_2 \Delta t \]

we obtain the amount of proton injected in the He-rich region for the formation of the \(^{13}\)C-pocket.
(MHD) 13C-POCKET FORMATION

Convective envelope

To the stellar surface

Thermal pulse

TDU

H-burning shell

13C pocket

C-O core

N&B conditions are satisfied

the exact analytical solutions of the MHD equations are held.

the formation of 13C-pocket is allowed
**MHD) 13C-pocket formation**

N&;&B
conditions are satisfied

the $^{13}$C-reservoir formed as a consequence of magnetic buoyancy is an almost "flat" pocket of about $5 \times 10^{-3} M_\odot$. 

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The physical structure of the He-rich layers in an AGB star of $1.5 M_\odot$ and solar metallicity at the 6th TDU. The abundance of $^{13}$C profile is more extended and flatter than provided by models based on more traditional, exponentially-decreasing proton penetration. (A color version of this figure is available in the online journal.)

The possibility to do that as compared to the duration of an individual TDU phenomenon, the magnetic field) vary on time scales that are extremely long (density, temperature, pressure, rotational velocity and model-dependencies other than those contained in the initial conditions on the TP-AGB. As shown, the density and buoyancy acting as coe-

As is common with sets of (partial) differential equations, in the family of solutions fulfilling all the requirements, the time integral of the mentioned function is time-independent. In it, the mentioned function will assume some specific values. Hence, in the simple geometry adopted, the induction velocity is negligibly small in these conditions.

In the simple one-dimension problem, the code by S. Palmerini et al. (2003) was recalculated by us for this paper with the Schwarzschild criterion for convection, with the code by Nucci and Busso (2014) that involved quantities are expressed in meaningful units and only ($_{N&B}$) the time integral of $\mathbf{v}$ must be chosen to have dimensions $[\text{cm}^{-1}]$. Hence we have actually two arbitrary and independent parameters $k$ and $C$ and $B$ that we may want to adopt.

As mentioned, another critical condition occurring in the time scale of our interest. This simply means that rotational equilibrium is satisfied ($\omega$ and $\delta$)

\[ \frac{\rho}{\rho_0} = \left( \frac{r}{r_0} \right)^{4.437} \]
\[ \frac{P}{P_0} = \left( \frac{r}{r_0} \right)^{5.641} \]
\[ \frac{T}{T_0} = \left( \frac{r}{r_0} \right)^{1.345} \]
3 TESTS FOR OUR MODEL

The solar main component

A nice fit to O and Al isotopic ratio of oxide grains (group 2)

[X(i)/Fe] abundances in a post-AGB
Figure 1

C/O > 1 SiC grains

Mainstream ~93%  AB grains 4–5%
C grains  X grains  ~1%
Y grains  ~1%  Z grains  ~1%
Nova grains

The figure shows the isotopic ratios of nitrogen and carbon in presolar SiC grains, with a logarithmic scale for the number density. The isotopic ratios are plotted against each other, with the isotopic compositions of solar material and terrestrial material indicated. The figure includes a legend for the different grain types, with mainstream grains shown in blue, AB grains in yellow, C grains in green, X grains in blue triangles, Y grains in green diamonds, Z grains in red squares, and nova grains in red.

1.4 Presolar Grains

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Acknowledgments

References

Traditionally, astronomers have studied the stars by using, with a rare exception, electromagnetic radiation received by telescopes on and above the Earth. Since the mid-1980s, an additional field of astronomy has grown to an extent that not only has revolutionized our understanding of the stars but has also opened up an entirely new window on the universe: the study of microscopic presolar grains found in primitive meteorites. These grains had apparently formed in stellar outflows of late-type stars of low mass (1–3 M⊙) in the thermally pulsing asymptotic giant branch (AGB) phase or in the planetary nebula (PN) phase. They survived the formation of the solar system and have been preserved in the interstellar medium (ISM), where they were enriched via the diffusion of interstellar gas into the gas phase of the interstellar medium. The interstellar medium (ISM) then condensed into the protosolar nebula, which eventually formed the planets of our solar system. Presolar grains are believed to have condensed into SiC (C/O > 1) and other refractory elements and carbonaceous material. In contrast, the study of stellar grains permits information about galactic chemical evolution, physical conditions in the stellar environments, and the processes that occur during the formation of the solar system.

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Figures 3–5

Al/\text{Si}: A comparison of Al/Si ratios in a large number of individual grains of different types. The Al/Si ratio is plotted against the atomic number of the element. The legend indicates the different grain types, with mainstream grains shown in blue, AB grains in yellow, C grains in green, X grains in blue, Y grains in green, Z grains in red, and nova grains in red.

Nitrogen and carbon isotopic ratios of individual presolar SiC grains are shown in the figures. The isotopic compositions are plotted against each other, with the isotopic compositions of solar material and terrestrial material indicated. The figures include a legend for the different grain types, with mainstream grains shown in blue, AB grains in yellow, C grains in green, X grains in blue, Y grains in green, Z grains in red, and nova grains in red.

1.4.4 Analysis Techniques

1.4.5 Astrophysical Implications of the Study of Presolar Grains

1.4.6.1 Mainstream Grains

1.4.6.2 Type Y and Z Grains

1.4.6.3 Type AB Grains

1.4.6.6 Type C Grains

1.4.8 Graphite

1.4.8.1 Physical Properties

1.4.9 Oxygen-Rich Grains

1.4.9.2 Silicate Grains

1.4.10 Diamond

S. Palmerini        NIC 2018

http://dx.doi.org/10.1016/B978-0-08-095975-7.00101-7

By the 1950s, it had been conclusively established that the solar system is believed to have formed from a mix of this material. In fact, the original work by Burbidge et al. and Cameron (1957) argued that nucleosynthesis and stellar evolution, presolar grains provide information about galactic chemical evolution, physical conditions in the stellar environments, and the processes that occur during the formation of the solar system. The interested reader is therefore referred to some detail in the laboratory. Their stellar origin is recognized by their isotopic compositions, which are completely different from those of the solar system abundances (See Anders and Grevesse, 1989; Asplund et al., 2005; Timmes et al., 1995). Although elements from carbon on up are produced by nuclear reactions during the planetary nebula phase from the hot remaining white dwarf star and has the composition of helium-shell material. The white dwarf star and has the composition of helium-shell material. The white dwarf star and has the composition of helium-shell material.
Being close (or having) to $N=50$, $^{90,91,92}\text{Zr}$ are very sensitive to the $^{13}\text{C}$ pocket employed in calculations.

$$\delta(^{i}\text{X}/^{k}\text{X}) = \left[\frac{(^{i}\text{X}/^{k}\text{X})_{\odot}}{(^{i}\text{X}/^{k}\text{X})_{\odot}} - 1\right] \times 1000$$
Model Comparison with Grains: Zirconium

![Graph showing model predictions for zirconium isotopes](image)

- **2M, Z_c**
- **2M, Z_c/2**
- **2M, Z_c/3**
- **3M, Z_c**
- **3M, Z_c/2**
- **3M, Z_c/3**
- **1.5M, Z_c/3**

The recommended Zr production in AGB models is compared with grain data from Torino AGB models. The figure illustrates the comparison between the predicted and observed zirconium isotopic ratios for different AGB model predictions. The graphs show the enrichment of Zr isotopes in the grains relative to the standard solar abundance, with the 2D plots highlighting the trends for different AGB model scenarios. The inset graph provides a closer look at the isotopic ratios for a specific model prediction, indicating the agreement between theoretical predictions and observed grain data.
Liu et al. 2014 improve the agreement with the data by expanding the pocket and flattening the 13C profile with respect to their original exponential 13C decay. These are exactly the characteristics of “our” 13C reservoir.

Palmerini et al. 2018 MHD

G-component
Relevant tests on the extension of the pocket and on the form of the 13C distribution can then be obtained by the relative trends of Cs and its nuclei. The rare Y and Z grains also originate from the L15_d4 pocket. Each model prediction for matching the grain data to the pocket uncertainties, we can find in [2]

The rare Y and Z grains also originate from the L15_d4 pocket. Each model prediction for matching the grain data to the pocket uncertainties, we can find in [2]
Below the convective envelopes of low mass red giant stars (AGB and RGB) the exact analytical solutions of the MHD equations are held.

The physical conditions of the region below the convective envelope (during TDU) allow the buoyancy of magnetized structures which might drive the formation of a $^{13}$C-pocket suitable to account for the s-isotope abundances found in MS presolar SiC grains (fits are in general of a quality comparable to the best ones in literature).

The MHD mixing parameters are related to the intrinsic property of the stellar structure and linked to the particular polytropic transformation that best represents the thermodynamics of the environment.

HOWEVER: an AGB star affected by MHD mixing cannot be responsible, by itself, for the enrichment in short lived nuclei of the Early Solar System …see poster n.89.

THANK YOU! GRAZIE!
92-94-95-98-100\textsuperscript{96}Mo/\textsuperscript{96}Mo FROM MHD POCKET

\begin{align*}
\delta^{(92\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(92\text{Mo}/96\text{Mo})} \\
\delta^{(93\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(93\text{Mo}/96\text{Mo})} \\
\delta^{(94\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(94\text{Mo}/96\text{Mo})} \\
\delta^{(95\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(95\text{Mo}/96\text{Mo})} \\
\delta^{(96\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(96\text{Mo}/96\text{Mo})} \\
\delta^{(97\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(97\text{Mo}/96\text{Mo})} \\
\delta^{(98\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(98\text{Mo}/96\text{Mo})} \\
\delta^{(100\text{Mo}/96\text{Mo})} & \text{ vs } \delta^{(100\text{Mo}/96\text{Mo})}
\end{align*}

1.5M, Z_\odot/3
2M, Z_\odot
2M, Z_\odot/2
3M, Z_\odot
3M, Z_\odot/2
3M, Z_\odot/3
$\delta^{10^{4}\text{Ru}/100\text{Ru}}$ FROM MHD POCKET

1.5$M_\odot Z_\odot$/3
2$M_\odot Z_\odot$
2$M_\odot Z_\odot$/2
3$M_\odot Z_\odot$
3$M_\odot Z_\odot$/2
3$M_\odot Z_\odot$/3