Carbon-enhanced metal-poor stars as a consequence of inhomogeneous metal mixing

Tilman Hartwig

Today on arXiv:1812.01820
Carbon-enhanced metal-poor stars

see also:
Piercarlo, Suda-san, this afternoon

Saga database, Suda-san

CEMP stars: [C/Fe] > 0.7
Decreases with metallicity

"cosmic time"
Is iron well mixed with alpha-elements?

Aspherical Explosions (Tominaga-san, Rana)?

Chiaki-san & Britton: homogeneous mixing (Z+H) only on scales <10pc
See also Ritter+15,16, Sluder+16

Introduction

Tilman Hartwig
After PopIII SN: several clumps may form

What happens to second clump?

New Scenario

Tilman Hartwig
Carbon-enhanced metal-poor stars as a consequence of inhomogeneous mixing of metals in the interstellar medium?

Tilman Hartwig

New Scenario
Characteristic Timescales

Kelvin-Helmholtz:  
\[ t_{KH} = 0.1 \text{ Myr} \left( \frac{M_*}{10 M_\odot} \right)^2 \left( \frac{R_*}{5.3 R_\odot} \right)^{-1} \left( \frac{L_*}{5750 L_\odot} \right)^{-1} \]

LW dissociation:  
\[ t_{dis} = 0.2 \text{ Myr} \left( \frac{M_{\text{clump}}}{1000 M_\odot} \right)^{1/3} \left( \frac{n}{10^3 \text{ cm}^{-3}} \right)^{2/3} \left( \frac{D}{10 \text{ pc}} \right)^2 \]

Collapse time:  
\[ t_{coll} = \max(t_{ff}, t_{cool}) \]

Cooling Rate:  
\[ \frac{\Lambda_{\text{CHI}}}{\text{erg cm}^{-3} \text{s}^{-1}} = 4.8 \times 10^{-21} \left( \frac{n_H}{10^3 \text{ cm}^{-3}} \right)^2 \exp \left( - \frac{92 \text{ K}}{T} \right) \times 10^{[C/H]} \]

Condition:  
\[ t_{coll1} + t_{KH} + t_{dis} < t_{coll2} \]

\[ \Delta [C/H] > [C/H] + 3.6 + \log_{10} \left( \frac{13000 + 2 \times 10^5 d_{10}^2 n_3^{2/3} + 1.5 \times 10^6 n_3^{-1/2}}{1.7 \times 10^6 n_3} \right) \]

Methodology  
Tilman Hartwig
Characteristic Timescales, illustrated

\[ t_{\text{coll}} / \text{yr} \]

\[ \Delta [\text{C/H}] \]

\[ \Delta t_{\text{coll}} \]

clump1

clump2

\[ \text{compare Omukai+05} \]

Methodology

Tilman Hartwig
Results

Required Inhomogeneity

\[ \Delta[C/H] \]

\[ pc \]

Gen Chiaki

Mattis Magg

Chia Jung Hsu

Li-Hsin Chen

Myoungwon Jeon

Britton Smith

Tilman Hartwig
Required Inhomogeneity

Results

\[ \Delta [C/H] \]

Δ[C/H]~1 is reasonable (Sluder+16)

100% of CEMP-no stars

0% of CEMP-no stars
Comparison to Observations

- 0-22% of CEMP-no stars can be explained for $\Delta [\text{C/H}] \sim 1$
- up to 89% for $\Delta [\text{C/H}] \sim 2$
Inhomogeneous Mixing: The Enemy of "Stellar Archaeology as a Time Machine to the First Stars"

yt: "Color Ink Drops in Water Slow Motion HD" by Abracadabra TV

Outlook

Tilman Hartwig
A novel formation scenario for carbon-enhanced metal-poor stars

- 0-89% of CEMP-no stars could have formed by inhomogeneous metal mixing
- Caveats: only carbon (no dust or oxygen), simplistic analytical treatment
- Mathematica notebook public on gitlab
- Next step: 3D simulations
- Inhomogeneous metal mixing: general importance for interpreting stellar abundance patterns

Summary

Tilman Hartwig