Stellar species and evolution

3.4 Metal-poor stars and Population III

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3.4 Metal-poor stars and Population III

- In stars with low metallicity [Fe/H] below -2.5, the composition of the gas that forms the material is roughly equivalent to one supernova explosion.

- Stars with low metal content → Fewer supernovae

- Low-mass, metal-poor stars are old and formed in the early galaxy

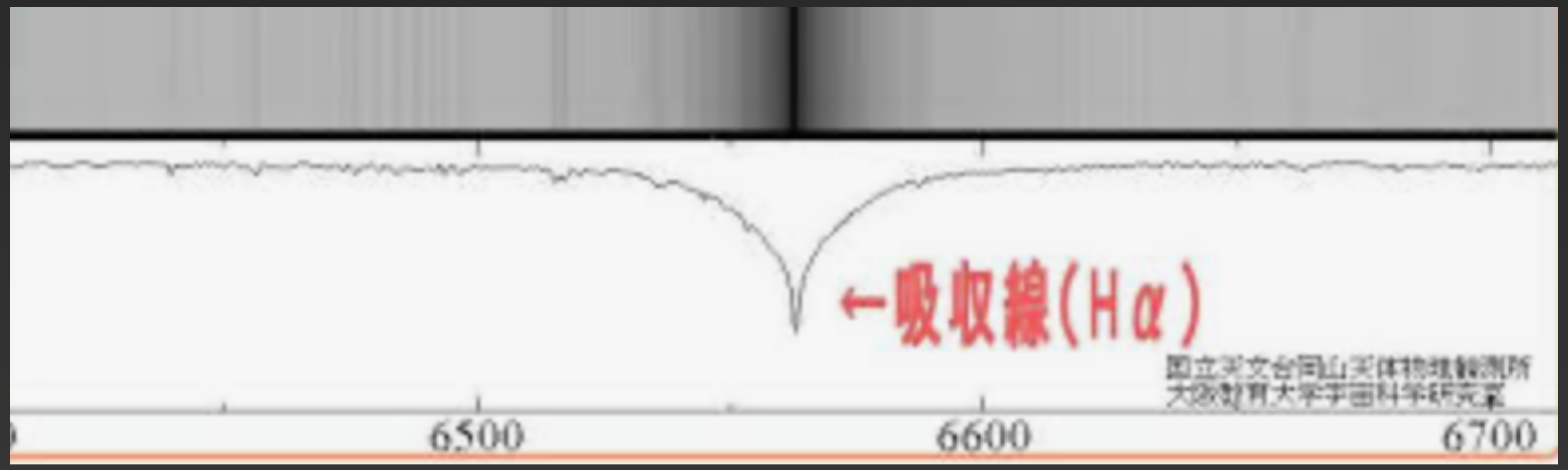
- Low mass stars live longer

3.4.1 Spectra and compositions of metal-poor stars

- What we can learn from Figure 3.14
Comparison of the Sun (Fe/H=0), Fe/H=-3.2, and Fe/H=-5.6

Stars with low metallicity have weaker absorption lines, while stars with high metallicity have stronger absorption lines.

- What are absorption lines?
When light emitted from a celestial body passes through gas, dust, and other materials along the way, certain wavelengths of light are absorbed, resulting in a dark line appearing in the spectrum (indicated by the arrow).
- If we consider the first stars born in the universe to be first-generation stars, then these stars are second-generation stars, so by studying them we can investigate the element production that occurred in the first generation of supernova explosions.



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3.4.1 Spectra and compositions of metal-poor stars

- α element

About Figure 3.15

This shows the relationship between the magnesium (Mg) to iron (Fe) ratio (Mg/Fe) and the iron (He) to hydrogen (H) ratio for stars in the solar neighborhood.

Magnesium (Mg) is emitted from Type II supernovae, and iron (Fe) is emitted from Type Ia supernovae.
The composition ratio of magnesium (Mg) and iron (Fe) on the vertical axis of the graph depends on the ratio of the two supernova explosions.

It is extremely difficult to measure the metallicity of stars with low metallicity! High-dispersion spectrometer

One star way off✴
High in magnesium, low in iron

3.4.1 Spectra and compositions of metal-poor stars

- Three things to know

1.At metallicity [Fe/H] < -1, the composition ratio of magnesium Mg to iron Fe is greater than 1.
The gas that makes up these stars is supplied with heavy elements by Type II supernova explosions.

2. [Fe/H] < -2.5: Metal-poor stars have a distribution of magnesium (Mg) and iron (Fe) ratios over a certain fraction.
→ After further cycles of star formation and supernovae, the variability disappears.

3. In stars with [Fe/H] greater than -1, the magnesium (Mg) and iron (Fe) abundances are close to zero, and sufficient time has passed for a Type Ia supernova explosion to occur, providing a large supply of iron (Fe).

Near the Sun → Many stars belong to the galactic disk! Some stars just happen to fall from the halo (as if they are just following the path along the way).
Stars with low metallicity are generally considered to be halo stars (temporarily arriving due to vertical motion, etc.)

3.4.1 Spectra and compositions of metal-poor stars

- Neutron capture reaction

Review: Elements heavier than iron are produced by neutron capture reactions
The r-process is fast, and the s-process is slow

Investigating chemical composition from the spectra of metal-poor stars
(Because it has not experienced a supernova explosion like the one that occurred in the past, it better reflects the elemental composition that was created.)

3.4.1 Spectra and compositions of metal-poor stars

- About Figure 3.16

Heavy element pattern of a red giant with extremely low metallicity [Fe/H] = -3.1

This indicates that the r-process, similar to that of the solar system, has occurred despite the star having a low metal content.

In other words,

- High in r-process elements

The composition of heavy elements in stars is almost the same as the composition of r-process elements in the solar system → Elements seen in the solar system today were already created at this time

-The r-process occurs when a massive star undergoes a supernova explosion, even without any special conditions.

-Since the r-process occurs in only a small percentage of stars, it is thought that the r-process was created in a concentrated manner during the explosion of a certain massive star.

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3.4.1 Spectra and compositions of metal-poor stars

- Figure 3.17

This shows the percentage of stars with elemental abundances (metallicity [Fe/H] = -2.7) created via the S process.

Barium (Ba) and lead (Pb) are abundant. Strontium is not a good match because these light elements are not produced in large quantities during the s-process in low-metallicity stars.

Even in stars with similar metallicity, the elemental composition can vary quite a bit!
Which mechanism created more of the elements - elements that were likely created in the early universe, or s-process elements in RGB stars?
We can look into this and verify our models.

3.4.2 Extremely metal-poor stars

- Some stars with very low metallicity ([Fe/H] < -2.5) show characteristic elemental abundances compared to stars with higher metallicity → Carbon-rich stars (CEMP stars)

- The carbon content is high relative to iron, with [C/Fe] > 1.
Such stars have a high concentration of s-process neutron capture elements such as barium (Ba).
→ One of the causes of the carbon excess is thought to be the origin of AGB stars.

3.4.2 Extremely metal-poor stars

- AGB stage stars

Normal Population I and Population II stars
Carbon produced by internal nuclear combustion is transported into the star's surface convection zone (third dredge-up).

Extremely metal-poor, such as [Fe/H] < -2.5
The convection zone caused by the helium flash reaches the hydrogen-burning core → hydrogen burns violently → The surface convection zone penetrates inward → carbon is transported to the surface → This is the origin of a CEMP star!

- Carbon excess in pre-AGB stars

The star is currently or was once in a binary system → the companion star evolves into an AGB star → gas falls from it

- There are various possible origins for the carbon excess...CEMP stars with low s-process elements

It's been updated over the last 20 years or so.
Origin wasn't CEMP, but it looks like there's a carbon surplus.
However, stars that appear to be carbon-rich are also (under discussion) fast-rotation stars.
This is because massive stars burn hydrogen before developing iron.

-There was a lot of research into finding stars with low metal content (in the early 2000s. Subaru included!). What elements besides iron?
I noticed that there were surprisingly many stars with high carbon content.
There were stars with high amounts of elements produced by the R process, stars with high amounts of elements produced by the s process, and stars with neither (perhaps the first star also had an influence).

3.4.2 Extremely metal-poor stars

- In stars with even lower metallicity, where [Fe/H]<-3, the cobalt Co/iron Fe and zinc Zn/iron Fe ratios are high, and the chromium Cr/iron Fe ratio is low.

→ These cannot be explained by a normal supernova explosion.

1. Consider a hypernova, which has a large explosive energy and high temperature.
2. The actual explosion is not spherically symmetric, but aspherically symmetric.
3. Consider a process in which elements created inside are released in the axial direction.

→ It can explain the observed composition ratio well!

Extremely metal-poor stars discovered in the Milky Way（[Fe/H]=-5.4、[Fe/H]=-5.2)

These stars are carbon-rich（[C/Fe]～+4)

The sun's chemical composition standards are changing

- The chemical composition of the Sun is the gold standard for determining the chemical composition of other stars.
- The gas composition has remained unchanged since the Sun was formed 4.6 billion years ago.
  (What will happen to the outer layers of the Sun once it reaches the helium-burning stage?)

- Previous standards

solar metal content ＝ 0.0170 ～ 0.0201

Hydrogen to metal ratio（Z/X) = 0.0229 ～ 0.0274

（Z/X) = 0.0170/1-0.0170

= 0.0170/0.983

Carbon (C), nitrogen (N), oxygen (O), and iron (Fe) revised downwards

- New standards

solar metal content ＝0.0134

Hydrogen to metal ratio（Z/X) = 0.0134 /1-0.0134

I thought about this, but if you subtract 0.0134 from 1 you get helium, so I don't think that's what we want to find in the first place! I should have thought more about what that number represents.

= 0.0134/0.9866

= Approximately 0.0136

When the new standard is used, the composition of nearby young stars is consistent, but it no longer matches previous results on solar oscillations.

If the new standard is decisively correct, I wondered if there was something wrong with the way the calculations were done.