Galactic Enrichment: Setting the Stage for Planets

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From the cosmic soup to Earth

Big Bang and neutral hydrogen

First stars

Stellar explosions and stellar winds

Interstellar gas

Stars and planets

NASA, the CfA Press Room and wikimedia commons
Outline

1. The galactic recycling process
   1. Stars
   2. Interstellar medium
2. How metals escape from stars
   1. Stellar Winds
   2. Stellar explosions
3. Planets in the Milky Way Galaxy
   1. Build up of metals
   2. Which parts are habitable
What is a galaxy?
The universe

Our neighborhood in the universe

Each dot is an individual galaxy

Image: SDSS Collaboration
A spiral galaxy

The galaxy M10

Each dot is a star

Image: NASA/HST
The solar system

[Image: NASA]

Not to scale!

Earth
Galactic recycling

Interstellar Medium: Gas Nebulae

Stars and planets

Winds & explosions

Images: NASA/HST, SOHO
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How do metals get out of stars?

- Stars like the sun live billions of years
  - Metals are trapped!

- More massive stars burn brighter, live shorter lives

- Escape routes for metals:
  - Winds
    - Millions of yrs
  - Explosions
    - Weeks

Cat's eye nebula:
Central star sheds mass at 20,000,000,000,000 tons/sec
Stellar winds

- Stars: hot balls of gas
- Pressure: force pushing outward
- Gravity *binds* the star against this pressure
- The outskirts of massive or giant stars are less bound
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Gravitational well

NASA/SOHO
Star sizes

- M-type star
  - 0.1 M$_\odot$
  - 0.15 R$_\odot$
- Sun
  - 1 M$_\odot$
  - 1 R$_\odot$
- O-type star
  - 60 M$_\odot$
  - 15 R$_\odot$
- Betelgeuse
  - Red supergiant
  - 20 M$_\odot$
  - 1200 R$_\odot$

M$_\odot$ = solar mass
R$_\odot$ = solar radius

Image: Bjorn Thorisson
What's in the stellar wind?

- H & He will be lost first
- Heavier elements can be brought to surface by mixing
Stellar explosions

- Outbursts and Novae
  - ~100,000x as bright as the sun
  - Star is left behind
  - Eta Carinae: lost ~30x the mass of the sun

- Supernovae
  - ~1,000,000,000x as bright as the sun
  - Star is destroyed
    (compact object or black hole may be left behind)
New elements from supernovae

Supernova nucleosynthesis:
  ● Extreme conditions not found anywhere else in the universe
    ○ Core Temperature: \(~10,000,000,000\) °C
    ○ Core density: \(~10,000,000\)x density of solid lead
    ○ Ejecta Speed: \(~10\)% the speed of light (NY to SF in 1/10 sec)
  ● The only way to produce the heaviest elements
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Elements After the Big Bang

Almost purely H, He - no metals
Elements in the Earth's Crust

Almost all metals!
Elements in the Solar System

Still mostly H and He! ~2% metals
Is our place in the Milky Way special?

Image: NASA/JPL-Caltech/R. Hurt
Chemical enrichment: Building the Milky Way Galaxy

- History of the Milky Way
  - >10 billion years
  - Billions of supernovae
  - ~10 billion solar masses of metals
  - Metals centrally concentrated

Models following on Naab & Ostriker (2006), MNRAS 366 3
The Galactic Habitable Zone

A delicate balance:

- **Safety**: In hospitable if too many supernovae
- **Time**: It takes billions of years to develop intelligent life
- **Metals**: Too few supernovae - not enough metal

Image: adapted from Lineweaver et al. 2004 (Science 303, 5654) with permission