Stellar species and evolution

3.15 Chemical evolution of galaxies

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3.5 Chemical evolution of galaxies

- Baryonic matter in the early universe immediately after the Big Bang hydrogen H 76％、helium He 24%, lithium Li a bit!

The birth of stars <=> Death of a star
Repeated events increase the amount of metals contained in interstellar gas, and stars born from gas also have a certain amount of metals.

This is because metals heavier than helium are produced inside stars and are expelled during the final stages of their evolution.

The pattern of chemical composition depends on the mass distribution of stars formed up to that point.
The evolution of metallicity and chemical composition over time is called the chemical evolution of a galaxy.

3.5.1 Basic quantities of chemical evolution

- ϕ(m) initial mass function

M represents the mass of the star

- TsF Star formation time scale

Star formation decreases over time (gas decreases)

$$\psi(t) \propto \exp(-t/T_{\mathrm{SF}})$$

3.5.1 Basic quantities of chemical evolution

- The elemental composition of a galaxy is determined by the speed and mass distribution of stars formed within it.

$$\psi(t) \propto \rho_{\mathrm{gas}}^{n}$$

- Equation 3.14

ψ(t) Star formation rate at time(t)

ρgas gas density

N is a power exponent

The denser the gas, the more likely it is that stars will form.

The star formation rate is proportional to a power of the gas density

When n=1, the star formation rate is proportional to the gas density. When n=1.4, the observational result is correct (Schmidt's law).

Disk galaxies Galaxies that contain disk structures

Starburst Galaxy: A galaxy that is rapidly producing stars with masses more than 10 times that of the Sun.

- Equation for normalizing the initial mass function (IMF)

$$\int_{m_l}^{m_u} m\phi(m)dm = 1\ M_\odot$$

- The relative number of stars born within a certain mass range (m to m + dm) is defined as proportional to ϕ(m)dm.

What Figure 3.20

- There is a clear proportional relationship between gas density and star formation rate (as gas increases, so does the star formation rate).

- The slope is constant（1.4?)

3.5.1 Basic quantities of chemical evolution

- When the total mass of the newly born star is M*

Number of stars in the mass range (n,m + dm)

$$(M_*/M_\odot)\phi(m)dm$$

Masses of stars in the (N,m + dm) mass range

$$(M_*/M_\odot)m\phi(m)dm$$

number of stars (range : n, m + dm)

$\frac{\text{new mass}}{\text{solar mass}} \times \text{IMF} \times dm$

mass of stars (range: n, m + dm)

$\frac{\text{new mass}}{\text{solar mass}} \times \frac{\text{mass}}{m} \times \text{IMF} \times dm$

Ml and mu are the range of masses that can exist as stars.
The lower limit, mi, is approximately 0.08 solar masses.
The upper limit, mu, is approximately 100 solar masses.

$$\int_{m_l}^{m_u} m\phi(m)dm = 1\ M_\odot$$

3.5.1 Basic quantities of chemical evolution

- How to find the initial mass function

First, determine the stellar luminosity function based on accurate distance estimates.

→ Find the current mass function

→ It is necessary to correct for the effects of stellar evolution, the behavior of stellar lifetimes and past star formation rates, etc.

3.5.1 Basic quantities of chemical evolution

- IMF initial mass function

The lighter it is, the more stars produce!

Figure 3.21
Horizontal axis: logarithm of mass
logm / M solar mass Logarithm of the value divided by the solar mass
Vertical axis: Logarithm of the value of the initial mass function (how many stars are born at a certain mass)

Salpeter
Massive stars, stars more massive than the Sun (m > 1 solar mass)
ϕ(m) is roughly proportional to the negative alpha power of m
α (slope) is 2.35

In 2002, Kruba reevaluated the initial mass function near the Sun: the lighter the star, the gentler the slope!
傾き α

α = 0.3 (mass M is less than 0.08 solar masses)
α = 1.3 (0.08 solar mass < mass M < 0.5 solar mass)
α = 2.3 (0.5 solar mass < mass M < 1.0 solar mass)
α = 2.7 (1.0 solar mass < mass M < 100 solar masses) The more massive the star, the more rapid the rate of loss!!

3.5.2 The basic formula for chemical evolution

- Organizing the basic equations of chemical evolution

Mg: Mass of interstellar gas in the system

Ms: Mass existing as a star

Z: Amount of metals contained in the gas

F: Rate at which gas flows in

E: Rate at which gas flows out

e: The rate at which gas is expelled from a star into interstellar space by stellar winds and supernova explosions

3.5.2 The basic formula for chemical evolution

$$\frac{dM_s}{dt} = \psi - e \tag{3.16}$$

$$\frac{dM_g}{dt} = -\psi + e + F - E \tag{3.17}$$

- Equation 3.16

Change in mass of a star over time
= star formation rate at time t - rate at which gas is released from the star into interstellar space

- Equation 3.17

The change in the mass of interstellar gas in the system over time
= - star formation rate at time t + rate of gas ejected from the star into interstellar space + rate of gas inflow - rate of gas outflow

Equation 3.17 calculates the time change in the mass of interstellar gas by taking into account the inflow and outflow of gas.

The change in mass of the entire system over time can be expressed as the rate at which gas flows in minus the rate at which gas flows out.

3.5.2 The basic formula for chemical evolution

Mrem r(m): Mass of the remnant star (white dwarf, etc.) left after the ejection
mt: represents the mass that ends its life at t such that r(m) = t
e:The rate at which gas is released from stars into interstellar space

$$e(t) = \int_{m_t}^{\infty} (m - m_{\mathrm{rem}})\psi(t - \tau(m))\phi(m)dm$$

The rate at which gas is emitted from a star into interstellar space at a given time t
= Integral over the range from ∞ to mass M at time(t)

(mass m - remnant mass Mrem) × star formation rate × (time t - stellar lifetime r(m)) × ϕ(m) initial mass function (is the last dm a derivative?)

3.5.2 The basic formula for chemical evolution

- Mg: Mass of interstellar gas in the system
- Z: Amount of metals contained in the gas
- ZF: Metal content of the incoming gas
- ZE:Metal content of the escaping gas

$$\frac{d(ZM_g)}{dt} = -Z\psi + e_Z + Z_F F - Z_E E$$

Metallicity in the gas × Mass of the interstellar gas in the system
= - Z Metallicity in gas × Star formation rate + Rate of gas ejected from stars into

interstellar space × Metallicity in gas + Metallicity in incoming gas × Rate of gas inflow - Metallicity in outgoing gas × Rate of gas outflow