Astrophysical Thinking SS 2018

hand in May 31

Question 11: Metal enrichment of galaxies

- No need to look up any text books! No need to type your answers!

The metal enrichment of galaxies is often studied in one-zone models. The relevant equations are:

$$dM_{\text{gas}} = dM_{\text{gas,infall}} - (1 + \epsilon_{\text{out}})dM_{\text{star}} \tag{1}$$

$$dM_{\text{star}} = \frac{M_{\text{gas}}}{t_{\text{dep}}}dt, \tag{2}$$

and

$$dM_{\text{Z}} = [y - (1 + \epsilon_{\text{out}})Z]dM_{\text{star}} + r_Z Z dM_{\text{gas,infall}}. \tag{3}$$

Here, M_{gas} is the current gas mass of the galaxy, M_{star} is its stellar mass, and $Z = M_{\text{Z}}/M_{\text{gas}}$ is its metallicity. Furthermore, ϵ_{out} is the mass-loading factor of outflows ($dM_{\text{gas,outflow}} = \epsilon_{\text{out}} dM_{\text{star}}$), t_{dep} is the gas depletion time, y is the *yield* (the mass of new metals added to the ISM by supernovae normalized to the mass of newly formed, long-lived stars), and $r_Z Z$ is the metallicity of any gas being accreted by the galaxy. This model ignores a variety of complications, e.g., stellar mass loss, but is sufficient for our purposes.

- Can you explain this model and the various terms in the equations?

1 Closed Box

Consider the special case of neither inflows nor outflows and assume the galaxy consists only of primordial gas initially.

- Derive an equation that relates the ISM metallicity of the galaxy to the gas fraction ($f_{\text{gas}} = M_{\text{gas}}/(M_{\text{gas}} + M_{\text{star}})$).
- Derive the time evolution of M_{gas} and Z under each of the following assumptions: (i) the depletion time t_{dep} is constant, and (ii) the SFR is constant.
- Can you guess which of these cases would be more typical for an elliptical galaxy or for a disk galaxy in today's Universe?

The metallicity of stars reflects the metallicity of the ISM in which they were born. In the following, you may assume that today's metallicity of the galactic ISM is about $Z = 0.014$ and the yield is ~ 0.03.

- What is the fraction of stars with a stellar metallicity less than 35% of the current ISM metallicity relative? Compare this number to the observed number of 2%. What conclusions do you draw?

2 Open Box

Inflows and outflows may change the fraction of low metallicity stars.

- Derive the relation between Z and $f_{\rm gas}$ if the galaxy experiences outflows (but not inflows). What do you conclude from this result?

- Now assume the galaxy experiences both inflows and outflows of gas. For simplicity, let the net inflow rate be such that the gas mass in the galaxy remains constant. What is the fraction of mass in stars with a stellar metallicity less than 35% of the current ISM metallicity? How do results change with mass loading factor and the metallicity of the infalling gas? Can you explain these findings in a simple way?

3 Bonus question [optional]

- Assume again that the gas mass in the galaxy does not change with time. Can you write down the ISM metallicity in the limit $t \to \infty$ as a function of y, r_Z, and $\epsilon_{\rm out}$?

- Observations and numerical simulations suggest that the mass loading factor is higher for lower mass galaxies. What do you conclude regarding the metallicity of low and high mass galaxies?