Binney & Tremaine 1st ed 9.2

Chemical evolution

Enrichment of the interstellar medium (ISM) happens when massive stars go supernova and the ejecta are spread into the ISM, and mixed there, by the SN winds

Massive stars also have stronger winds than low mass stars, so this helps too

The one-zone model is the first, simplest, model to predict how the metallicity in the gas changes as this enrichment continues

Assume we have a mass of gas, initially metal-free — M_g. As enrichment occurs, metals will be ejected into the gas, mass M_h.

So the metallicity of the gas will be

$$Z = \frac{M_h}{M_g}$$

Q Think of the IMF, and stellar evolution. Which stars will do the 'heavy lifting' of chemical enrichment? Which can be ignored here?

Let's form a generation of stars. The IMF will determine the proportion of stars of each mass.

Assume that we already have mass M_s of stars and form additional mass $\delta' M_s$

Assumption: instantaneous recycling — heavy elements will be returned to the ISM immediately

$\boxed{Q}$ Is this a reasonable assumption?

We also assume that the elements are well-mixed in the gas at all times (cf SN winds)

$\boxed{Q}$ To set up an equation for how the metallicity of the gas changes as generations of star formation continue, we need to think about sources and sinks of metals. Massive stars provide the source — what about any way of removing metals from the enrichment process ?

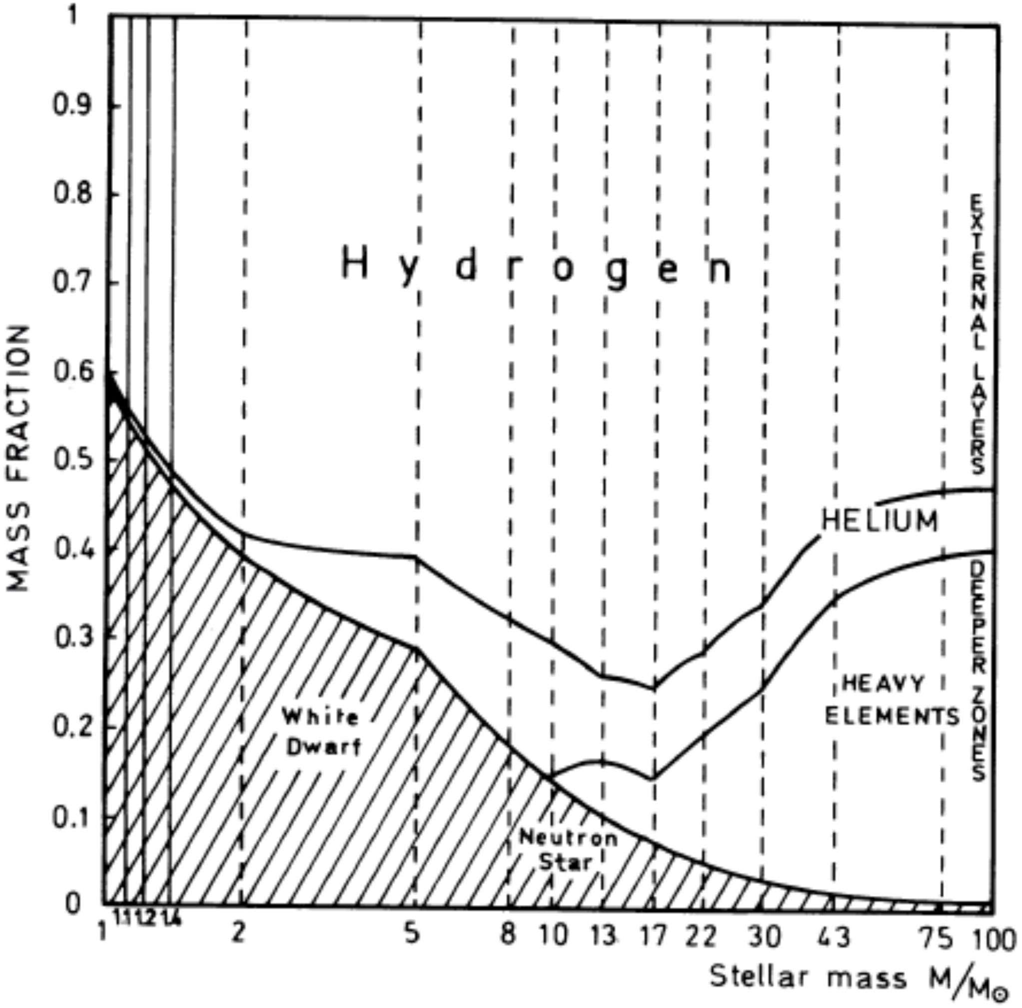

FIG. 1.—Zones of different element production and mass locking. The mass fraction of a star fossilized as a white dwarf or neutron star and the complement ejected in the interstellar medium is plotted against stellar mass. The different regions delimited by dashed and full lines allow us to evaluate the nucleosynthetic yields for different mass ranges.

Low mass stars will sit on the main sequence for a long time and then evolve to become a white dwarf. In both cases, the metals they contain will be removed from the enrichment process

Higher mass stars will lock up some part of their mass in neutron stars or black holes …. The amount will depend on the details of the supernova explosion. The diagram on the left gives one theoretical estimate of this.

Francois et al 90

Of the new generation of stars formed, some will go supernova (immediately, in our instantaneous recycling approximation) and so add gas and metals back to the ISM. The rest will remain as long lived stars.

Mass of stars from $\delta' M_s$ remaining after massive stars die : δM_s

Mass of heavy elements formed by this generation of stars :

$$p \, \delta M_s$$

p is an important quantity called the <u>yield</u>

$\boxed{Q}$ Could we calculate the value of p theoretically?

What would we need to model?

Change in heavy element content of gas from this generation of stars:

$$\delta M_h = \underset{\substack{\nearrow \\ \text{added by SNe}}}{p\,\delta M_s} - \underset{\substack{\nwarrow \\ \text{locked up in low mass } *\text{s}}}{Z\,\delta M_s} = (p - Z)\,\delta M_s$$

Change in metallicity of interstellar gas:

$$\delta Z = \delta\left(\frac{M_h}{M_g}\right) = \frac{\delta M_h}{M_g} - \frac{M_h}{M_g^2}\delta M_g$$

$$= \frac{1}{M_g}\left(\delta M_h - Z\,\delta M_g\right)$$

Since mass is conserved here (only way to lose gas is to make stars) "CLOSED BOX MODEL"

$$\delta M_s = -\delta M_g$$

We combine equation for δm_h with the above equation for δZ and find (eliminating m_s)

$$\delta Z = -p \frac{\delta m_g}{m_g}$$

If the yield stays the same for each generation (should it? Why or why not?) we can integrate

$$\boxed{Z(t) = -p \ln\left[\frac{m_g(t)}{m_g(0)}\right]}$$

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566 Chapter 9: Stellar Evolution in Galaxies

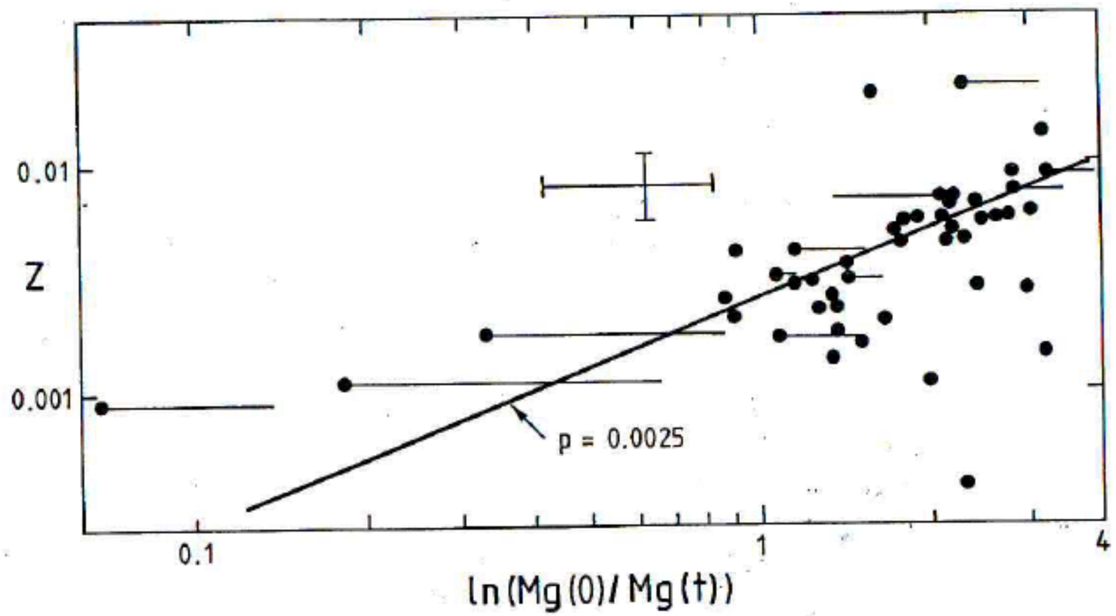


Figure 9-5. Metallicity Z of gas in irregular galaxies versus the galaxies' current gas fraction $M_g(t)/M_{\rm tot} = M_g(t)/M_g(0)$. The cross indicates a typical uncertainty. (After Pagel 1986.)

We can measure the yield using the slope of the line in the diagram above.

Q: for a gas-rich dIrr galaxy like the ones shown in this plot, how would you measure the gas fraction on the x axis? Hint: telescopes using different spectral regions required….

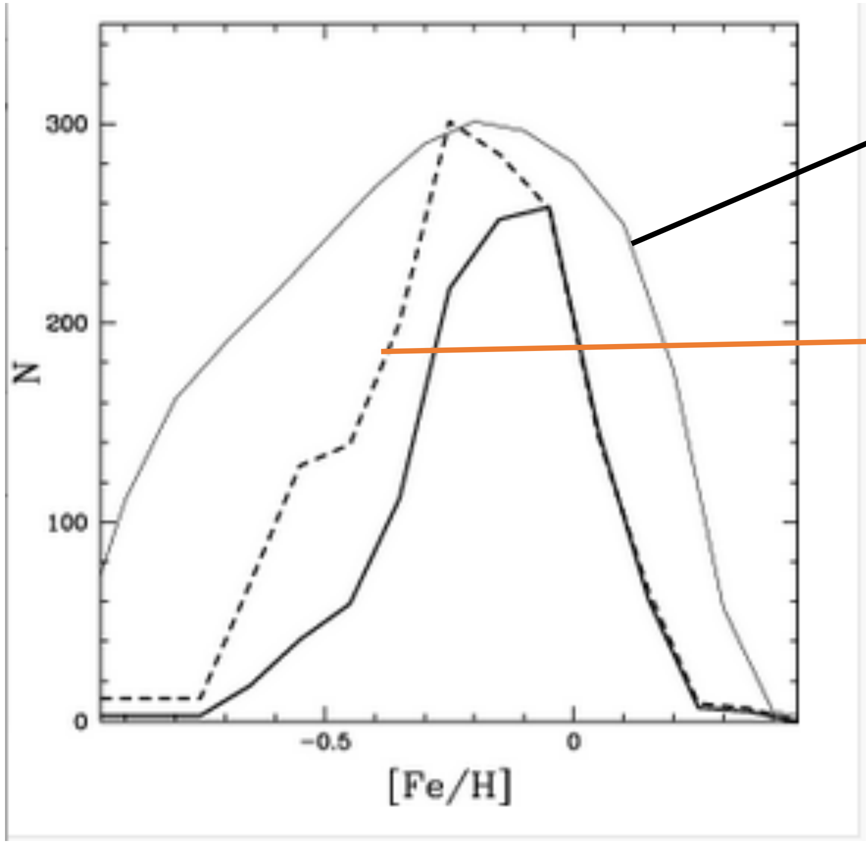
Q: how will the metallicity distribution of stars in a galaxy differ from that of the ISM? Why?

We can also derive an equation for the metallicity distribution of stars formed via this simple process :

Mass of stars with metallicity less than a given value $Z(t_1)$:

$$
\begin{aligned}
M_s\left[<Z(t_1)\right] &= M_s(t_1) \\
&= M_g(0) - M_g(t_1) \\
&= M_g(0)\left[1 - e^{-Z(t_1)/p}\right]
\end{aligned}
$$

This equation, when compared to the distribution of metallicities in stars near the Sun, is not a good fit



Closed box model

Data for stars in solar neighborhood

This is known as the G dwarf problem
Because G dwarfs are long enough lived to be good tracers of the stellar metallicity distribution

Holmberg et al 2007

Modifying the closed box model

Q: what are some possible modifications of our very simple model which might help?

1. Think of a globular cluster or low mass galaxy
It's quite likely that the SN energy will move
gas to more than the escape velocity

So, gas removal can stop chemical evolution
and leave a metal-poor population

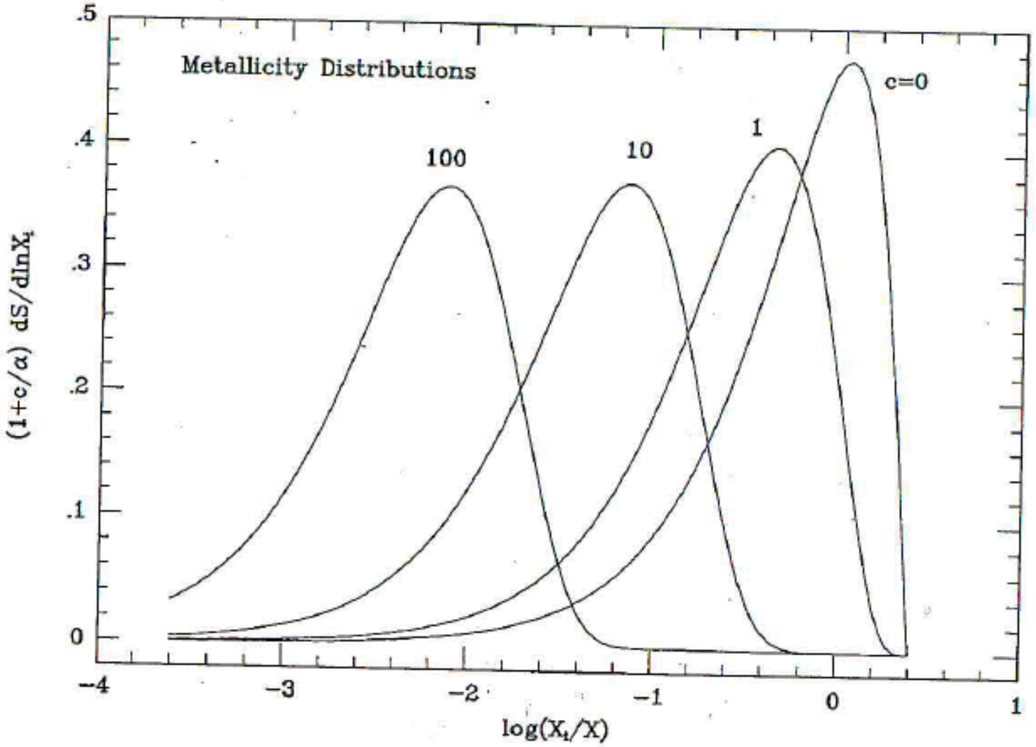


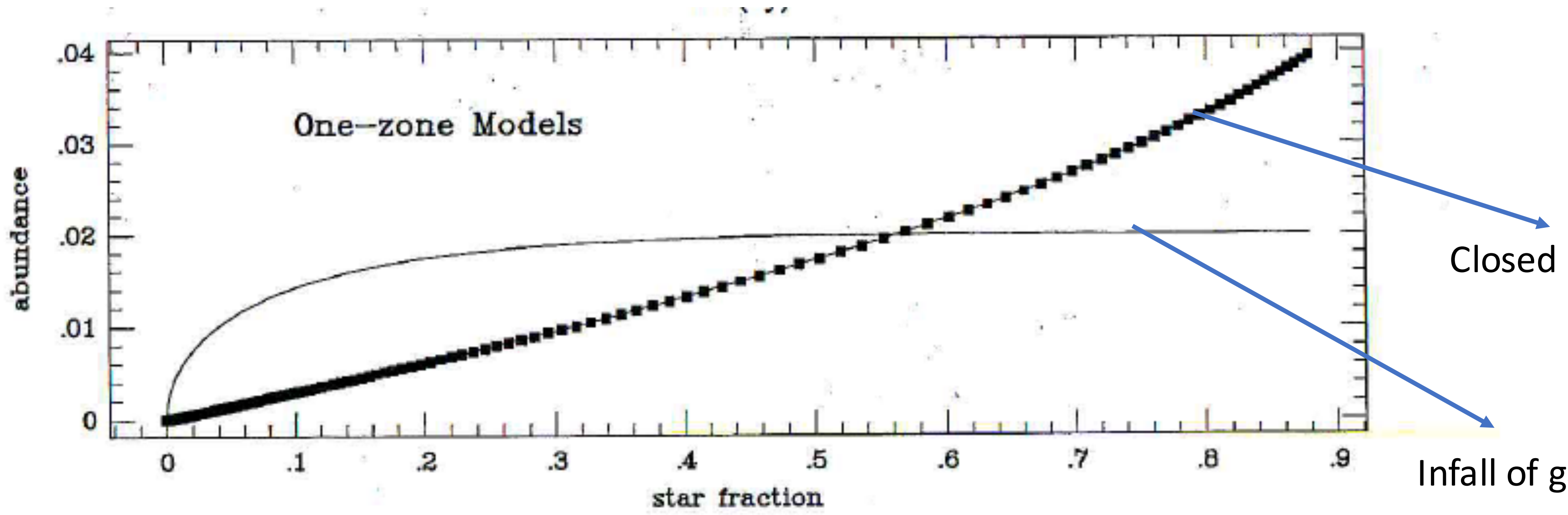
Fig. 14.5. Metallicity Distribution

Arnett (96)

A low mean metallicity can be obtained by removing gas from the star forming process. This is likely how globular clusters and dwarf galaxies are so metal poor.

2. Infall of gas onto the star forming region
This will continue star formation and change the ratio of metal poor to metal richer stars

(a popular solution to G dwarf problem which makes sense cosmologically — why?)



Closed box

Infall of gas added

Fig. 14.4. One-Zone Models

arnett (96)

Infall can change the shape of the metallicity distribution function and so solve the problem with the MDF in the solar neighborhood.

3. Move some stars around so that what we measure is not what was originally formed here

4. Change the yield

5. Pre-enrich

If the gas that formed the disk was already enriched before it started to form the disk that will also change the metallicity distribution