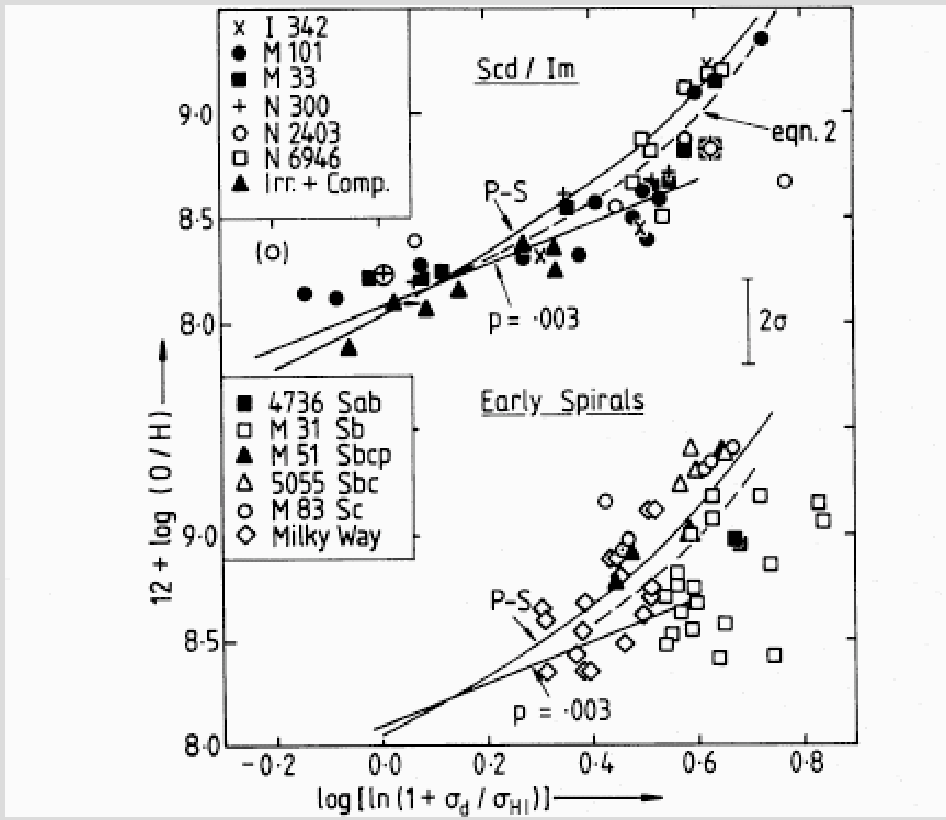
# Chemical evolution

Observation of spiral and irregular galaxies show that the fraction of heavy elements varies with the fraction of the total mass which is in the form of gas:

heavy
element
abundance




gas fraction

Simplest model to understand these observations is the **one-zone** model *(Sparke & Gallagher 4.3).*

Consider the history of an annulus of a spiral galaxy at some radius R. Make several simplifying assumptions:

- No material (gas, stars) enters or leaves the annulus
- Initially the annulus contains only gas, with no heavy elements (i.e. just hydrogen, helium)
- As stars are formed, massive stars explode `instantaneously' as supernovae, returning enriched gas to the ISM
- Turbulent motions keep the gas well mixed, so it has a single well-defined composition

How does the metal fraction of the gas evolve with time?

Let mass of interstellar gas in annulus be $M_g$
Mass of heavy elements in gas $M_h$

Define **metallicity:** $Z \equiv \frac{M_h}{M_g}$

Suppose the mass of stars at this time is $M_s$
Imagine forming new stars, with mass □'$M_s$

Of these:

- Stars with mass M > 8 Solar masses explode rapidly as supernovae, returning metals to the ISM
- Lower mass stars, with mass □$M_s$, remain

The mass of heavy elements produced by this episode of star formation is p□$M_s$, defining the **yield** p.

Total change in the mass of heavy elements due to star formation is then:

$$\Delta M_h = p\Delta M_s - Z\Delta M_s = (p - Z)\Delta M_s$$

existing metals locked up in low mass stars

Corresponding change in metallicity is:

$$\Delta Z = \Delta\left(\frac{M_h}{M_g}\right) = \frac{\Delta M_h}{M_g} - \frac{M_h}{M_g^2}\Delta M_g = \frac{1}{M_g}\left(\Delta M_h - Z\Delta M_g\right)$$

By conservation of mass:

$$\Delta M_s = -\Delta M_g$$

Combining the two previous equations get:

$$\Delta Z = -p \frac{\Delta M_g}{M_g}$$

Can write this as a differential equation:

$$\frac{dM_g}{dZ} = -\frac{M_g}{p}$$

If p is a constant (ie does not vary between subsequent generations of stars), then this integrates immediately to give:

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

Gas mass over total mass

(using assumption that Z(t=0) was zero). Relation of this form is very roughly what is observed in some galaxies.