Why is carbon not formed in the Big Bang?

Carbon is formed from the reaction:

$$^{4}He + ^{4}He \rightarrow ^{8}Be$$
$$^{4}He + ^{8}Be \rightarrow ^{12}C$$

`Triple alpha process'

Problem: beryllium 8 is unstable - decays with a half life of ~10^{-16} s…

Reaction is possible:

- given enough time (stars, not the Big Bang)
- due to fortuitous *resonance* that favors the 2nd step of the reaction

Anthropic Principle

If the laws of physics were different (in some cases in quite minor ways) life might not be possible

Astronomical examples:

- if the Universe started off denser than it was, would have collapsed to a Big Crunch before life could have started
- if the dark energy were stronger, Universe would expand too rapidly to form stars
- possible to imagine nuclear physics such that heavy elements never form
- planetary orbits with n > 3 dimensions?

Weak anthropic principle: we would not be around to observe the Universe if it were not well suited to life, so necessarily the laws of physics must be favorable

- is this predictive?
- are there many universes?
- connection to "String theory landscape"

Star formation

Stars form out of dense, cold, often dusty, molecular gas. In spiral galaxies, star formation is concentrated along spiral arms:

Hot massive stars (blue) are bizarrely shown as red in this image…

Spiral arms are places where gas is compressed, probably the first step toward star formation.

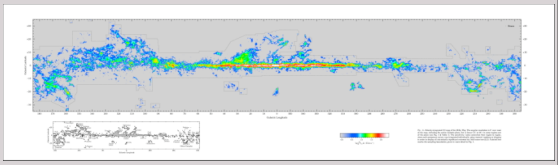
Other galaxy types

Ellipticals

Irregular

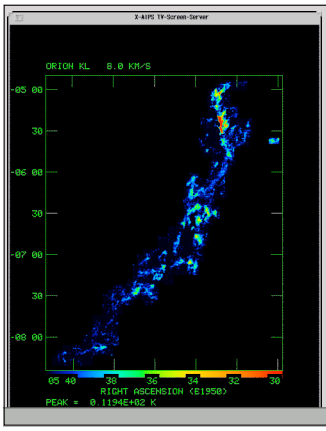
Interacting

Survey molecular clouds in our own Galaxy by looking for emission from different molecules in mm-wavelength radio surveys:



CO map - very patchy distribution of molecular clouds.

See complex molecules (e.g. HCOOH) relevant to biological chemistry



Part of Orion molecular cloud complex

Same is true on smaller scales. Observe:

Giant molecular clouds

M ~ 10^6 M_{sun}, R ~ 10s light years

→ star clusters

…on large scales, down to:

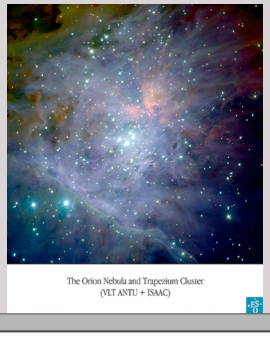
Molecular cloud cores

M ~ few Solar masses

R ~ 0.1 light years

→ one or a few stars

Most young stars seem to have formed in clusters, ranging from relatively small groups such as Taurus to much larger clusters such as Orion:



Ionizing radiation from the massive stars in Orion provides strong feedback, and tends to blow away the gas…

Most stars today probably form in environments similar to this.

Star formation

Basic process of star formation:

- gravity overcomes pressure support in a molecular cloud core
- cloud collapses to high density, forming a star
- **rotation** (angular momentum) prevents outer regions from falling onto star - settle in a rotating disk around the star instead

Process takes 10^5 - 10^6 years