**Why is carbon not formed in the Big Bang?**

Carbon is formed from the reaction:

\[ ^4\text{He} + ^4\text{He} \rightarrow ^8\text{Be} \]

\[ ^4\text{He} + ^8\text{Be} \rightarrow ^{12}\text{C} \]

- The reaction is described as the "Triple alpha process".

Problem: beryllium 8 is unstable - decays with a half life of \( \sim 10^{-16} \) 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.

**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

**Other galaxy types**

- Ellipticals
- Irregular

Interacting
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