The Search for Intelligent Life in the Universe

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Galaxies

- Galaxies are self-gravitating systems with up to a trillion stars and diameters of 10–25 kpc.
- The observed universe has billions of galaxies; our Galaxy is known as the Milky Way.
- Galaxies are classified according to shape. It’s unknown if galaxies evolved from one class into another.
- Our galaxy is a barred spiral.
Galaxies

• Galaxies aren’t randomly distributed but tend to cluster. Cluster sizes range from a few dozen members, as in our Local Group, to 10,000 like the Virgo Cluster.

• Galaxies began forming 12.5 Gyr ago when the universe was 1 Gyr old.

• Quasars may be young galaxies

• Galaxies are believed to consume neighboring galaxies. The Milky Way has consumed several nearby dwarf galaxies; the Magellanic Clouds will be consumed in the near future.

"You've seen spiral galaxies, you've seen elliptical galaxies..."
Structure of the Milky Way

- The Milky Way is a barred spiral galaxy with $2 \sim 4 \times 10^{11}$ stars, $6 \times 10^{11} \, M_\odot$ of stars and gas and $30 \times 10^{11} \, M_\odot$ of dark matter.

- Major components include the nucleus (bulge), halo and disk (spiral arms.)

- The galactic center, as do most galaxies, contains a supermassive black hole ($3 \times 10^6 \, M_\odot$, called Sagittarius A).

- The galaxy’s disk contains molecular clouds, young stars, and galactic clusters, largely concentrated in a ring around the bar and in 4 major spiral arms. Most current star formation occurs here. The disk diameter is about 100,000 lt.-yrs.
• The Sun is located at the inner rim of the Orion Arm, 8 kpc from the galactic center.

• The galaxy’s nucleus is bar-shaped, about 8 kpc long, and composed of old red stars.

• The galactic halo is a spheroid of old stars and globular clusters with a diameter estimated at 60 kpc. The galaxy’s dark matter is uniformly distributed within the halo.

• Spiral arms are logarithmic spirals \( r = ae^{b\theta} \), just like a nautilus shell or a hurricane.
Components of the Galaxy

- The disk contains open clusters; the halo contains globular clusters.
- Molecular clouds are the birthplaces of stars and contain gas (atoms and molecules) and dust grains.
- The material between stars (99% gas, 1% dust) comprises the interstellar medium (15% of visible mass of Galaxy).
- 75% by mass of gas is H, 23% is He. Many molecules are observed, most complex ones are organic.
Gas and Dust

- Dust is composed of heavy elements and ices (H$_2$O, CO$_2$).
- Gas and dust obscure starlight.
- Some gas reflects light, some radiates light and radio waves.
- Radio emissions are used to map galactic motions and structure.
Observing Interstellar Molecules

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<thead>
<tr>
<th>Simple Hydrides, Oxides, Sulfides, Halides, and Related Molecules</th>
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<tbody>
<tr>
<td>H₂</td>
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<td>HCl</td>
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<td>H₂O</td>
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<th>Nitriles, Acetylene Derivatives, and Related Molecules</th>
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<tr>
<td>HCN</td>
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<td>H₂CCN</td>
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<td>CCCO</td>
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<td>CCCS</td>
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<td>HCl≡CCHO</td>
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<td>CCC*</td>
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<tr>
<th>Aldehydes, Alcohols, Ethers, Ketones, Amides, and Related Molecules</th>
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<tbody>
<tr>
<td>H₂C—O</td>
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<tr>
<td>H₂C—S</td>
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<td>H₂C—CH—O</td>
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<td>(CH₃)₂CO?</td>
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<th>Cyclic Molecules</th>
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<td>C₅H₂</td>
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<th>Ions</th>
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<th>Radicals</th>
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<td>NH</td>
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<td>CH₂</td>
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<tr>
<td>C₂H</td>
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Spin-flip radiation from hydrogen atoms. The state where the spins of the proton and electron are aligned has a slightly higher energy than the state where the spins are opposed. The energy change between the two states is \( \Delta E = h\nu = hc/\lambda \), leading to a frequency of \( \nu = 1420 \text{ MHz} \) or a wavelength of \( \lambda = c/\nu = 21.1 \text{ cm} \).
Implications of ISM Organic Molecules

- Formed in harsh conditions, but formation aided by dust.
- Organic molecules seem to be preferred over other varieties.
- How complex can they get?
- Complexity should be greater in comets, planetary atmospheres, planetary surfaces.
- PolyAromatic Hydrocarbons (PAHs) and amino acids found in meteorites.
- Could living molecules or viruses form?
- Could primitive life travel in comets or meteorites from planet-to-planet or star-to-star (panspermia)?

"Sure it's beautiful, but I can't help thinking about all that interstellar dust out there."
The Main Evidence for a Big Bang

- Hubble discovered in the 1920’s that the universe is expanding. Galaxy redshifts \( z = \frac{v}{c} \) increase with distance: **Hubble’s Law:** \( v = H_0 \, D \)

Hubble’s constant is \( H \approx 68 \) km/sec/Mpc. Note relation to \( D = vt \) which gives the age of the universe as
\[
t = \frac{D}{v} = H_0^{-1} \approx 14.4 \text{ Gyr.}
\]

Universe has not expanded at a constant rate; still the estimated age is about 13.8 Gyr.
Cepheid Variables and Hubble’s Law

1929 (Hubble)

\[ H_0 = 500 \text{ km s}^{-1} \text{ Mpc}^{-1} \]

2004

\[ H_0 = 62 \text{ km s}^{-1} \text{ Mpc}^{-1} \]

2001

\[ H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1} \]
• Cosmic Microwave Background (CMB) radiation with $T = 2.7$ K (Predicted by Alpher, Herman and Gamow in 1948 and discovered by Penzias and Wilson in 1965, who received 1978 Nobel Prize).

This originated at the decoupling era when the universe was 300,000 yrs old and hot ($T \approx 3000$ K).

• Cosmic nucleosynthesis of light elements (He, Li, Be, B) when the universe was seconds old and hotter ($T \approx 10^9$ K). Produced composition of 75% H and 25% He by mass, observed in oldest stars.
"The whole universe is expanding, so why be surprised that we're drifting apart?"

"Hold on to your hats, we're picking up another big bang."

"Is that it? Is that the big bang?"

The universe before the big bang (actual size)

Believes universe is expanding
Believes universe is contracting
Believes universe is stable
Future of the Universe

Depends upon density $d$: $\Omega_0 = d_0 / d_{c0}$

$d_{c0} = 3H_0^2 / 8\pi G \approx 3$ H atoms/m$^3$ (critical density)

- $\Omega_0 > 1$ ($d > d_c$): closed universe, bound, eventually recontracts.
- $\Omega_0 < 1$ ($d < d_c$): open universe, unbound, expands forever.
- $\Omega_0 = 1$ ($d = d_c$): critical case, expansion stalls, but no recontraction.

Observed abundances of light nuclei ($^1H$, $^2He$, $^3He$, $^2H$, $^7Li$) agree with theory if the density of baryonic matter (neutrons, protons, nuclei) is about 4% of critical ($\Omega_{baryon} \approx 0.04$). This is the same as a baryon-to-photon ratio about $10^{-6}$. 

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AST 248, Lecture 5
Dark Matter

Measurements of our Galaxy's mass and motions of galaxies in clusters imply a large amount of “missing mass” or dark matter ($\Omega_{dm} \approx 0.26$) that is not in the form of baryons. What it is made of is unknown. Moreover, observations of

- cosmic background fluctuations
- very distant Type I supernovae

imply that

- the universe’s expansion is now accelerating, not decelerating as gravity alone would cause
- the total $\Omega_0$ is 1 (i.e., the universe is critical).
This implies the existence of yet another form of mass-energy, the so-called **dark energy**, with $\Omega_{de} \approx 0.7$. Therefore

$$\Omega_{de} + \Omega_{dm} + \Omega_{baryon} = \Omega_0 = 1.$$  

Dark energy is not matter and no one knows what it could be; one suggestion is that it is the exotic matter that was proposed for faster-than-light travel.
"Dr. Renly believes he’s close to the answer. He discovered that the clusters of galaxies spell out something, but he’s still missing a few letters."

S. Harris
Afterglow Light Pattern 380,000 yrs.

Dark Ages

Development of Galaxies, Planets, etc.

Dark Energy Accelerated Expansion

Inflation

Quantum Fluctuations

1st Stars about 400 million yrs.

Big Bang Expansion

13.7 billion years
Inflation as Solution to Big Bang Problems

- Horizon: why is background radiation uniform when it originates from regions that are now causally disconnected?
- Flatness: If $\Omega_0$ is not exactly 1, then $\Omega$ is much different from 1 in distant past.
- Smoothness: where did perturbations in nearly uniform universe originate? Without these perturbations, stars and galaxies would never have formed.

About $10^{-36}$ seconds after birth, parts of the universe massively expanded like weak parts of inflating balloon. Expansion was so great, they now appear flat ($\Omega = 1$). All observable matter was causally connected before inflation, so uniform temperature maintained after inflation. Perturbations needed for star formation come from quantum fluctuations.
$k\nu = 1/4$

$1/2$

$2/2$

$3/4$

$\ell \sim 200$

$\theta \sim 1^\circ$

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History of the Universe

Heads or Hadrons？ Form a nucleus
Quark-hadron transition

Light elements created - D, He, Li

Nucleosynthesis

Matter domination

Recombination

Epoch of gravitational instability

Galaxy formation

Quasars

Solar system

Life on Earth

Today $t_0$
P.A.M. Dirac pointed out in 1937 that ratio of electrical to gravitational forces in H atom is about $10^{39}$. This is the same of the size of the observable universe to the size of the proton! Why? Must gravity be weakening in order to keep these numbers the same, since the universe is expanding?

R. Dicke suggested an anthropic argument: The lifetimes of stars is controlled by the ratio of the electrical and gravitational forces, but the size of the universe by the time since the Big Bang. Therefore, the size of the universe at the time WE can observe it is controlled by the same ratio since stellar lifetime is needed for biological evolution.
Excited state in $^{12}\text{C}$ at exactly right level for triple-$\alpha$ process (He fusion) to synthesize C and get around the problem that no stable elements of mass 5 or 8 exist.

The strength of the nuclear weak force controls the neutrino flows that help ensure supernova explosions, which are necessary to create heavy elements. Otherwise, black holes would always form, trapping the heavy elements within.
Cosmic Anthropic Principle

- We must take into account the selection effects imposed by our status as living observers.
- Fundamental constants of nature $G$, $m_e$, $m_p$, $m_n$, $e$, $\hbar$, $c$ have values that permit existence of intelligence. Is this chance or necessity? (Weak Anthropic Principle)
  - Perhaps constants are related through a Grand Unified Theory
  - Perhaps life is not so dependent upon fine-tuning of constants
The Universe must have properties that allow life to develop at some stage (Strong Anthropic Principle):

- Are observers necessary for the universe to exist?
- Are there multiple universes, so that there is a finite chance that intelligence can develop in one of them?
- Suggests that intelligence is rare and maybe unique.

Carter deduces that if biological evolution and stellar evolution times are not related, life is rare.

- Will intelligence last forever once it comes into existence? (Final Anthropic Principle)
- Participatory Anthropic Principle: we participate in creation of universe (Quantum Entanglement).