Can There Be Life in Outer Space?

Presented By: Dr. Jose’ D’Arruda
Pembrooke Professor of Physics
TO BOLDLY GO WHERE NO MAN HAS GONE BEFORE

Dr. Jose D’Arruda
University of North Carolina Pembroke
Well, I think we should at least say, "Hi". What's the worst that could happen?
I come in peace!
"We come to this planet in search of a movie deal — like 'E.T.'"
IDIOT! I TOLD YOU WE WERE FLYING TOO LOW!
"With these clever disguises we'll be able to move freely among the earthlings and observe them undetected!"
Just the facts, mam.
Just the facts.
THE SEARCH FOR LIFE IN OUTER SPACE
How Big is Big?
Betelgeuse

Antares

Jupiter is invisible at this scale
Sun (1 pixel)
Sirius
Pollux
Arcturus
Rigel
Aldebaran
How Many is a LOT?
Just look at all those stars, Becky... There must be hundreds of 'em!
Carl Sagan says there are a hundred billion stars in our galaxy, and there are a hundred billion galaxies, and each galaxy contains a hundred billion stars! Sort of puts things in perspective, doesn't it? Charlie Brown?

I miss my dog...
The Nature of the Stars
"You're 'only' ten minutes late? — do you realize how far the Universe has expanded in those ten minutes?"
SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U. S.
Sputnik means satellite in Russian. It was shaped like a sphere and had four radiating radio antennae.

It was launched on October 4th, 1957.
SIGNALS FROM THE SATELLITE

Ham operator Roy Welch of Dallas, seated, plays a tape-recorded signal from the Russian space satellite for fellow hams at the State Fair of Texas. Welch recorded the signals on a receiver at his home.
This is a replica of one of the earliest telescopes made by Galileo Galilei (1564-1642) after he learnt of the invention of the telescope in 1608. This refracting telescope magnifies only 14 times and gives a very restricted field of view. As a result Galileo was only able to view about a third of the Moon through his telescopes. However, despite these limitations, Galileo published 'Sidereus Nuncius' ('The Starry Messenger') in 1610, which describes the celestial sights he saw with his new telescope. These included craters on the Moon, the phases of Venus and the moons of Jupiter. This facsimile was made in 1923 at the Museo di Fisica e Storia Naturale, in Florence, Italy where the original still resides.
The 100-inch Hooker telescope at Mount Wilson Observatory that Hubble used to measure galaxy distances and a value for the rate of expansion of the universe.
ARE YOU TRYING TO GIVE ME A HEART ATTACK ????
Annie Jump Cannon (1863-1941, American) was a member of the famous group of Harvard astronomers called 'Pickering's Women'. The director of the Harvard College Observatory, Edward Pickering, hired a number of women to sort through and organize mounds of data on the stellar classification of stars. The stars were classified by their spectra, and Annie Cannon was the most prolific and careful of the workers. She single-handedly classified 400,000 stars into the scheme we use today (O B A F G K M), and discovered 300 variable stars. She paved the way for women entering the astronomical field.
An electronic device is commonly used to record the image at a telescope’s focus.

Sensitive light detectors called charge coupled devices (CCDs) are often used at a telescope’s focus to record faint images.
Hubble Deep Field South Target

Turning its vision toward southern skies, the Hubble Space Telescope made a 10-day-long observation across the universe to uncover thousands of never-before-seen galaxies.
186,000 miles per second is not only a good idea...

IT'S THE LAW!
Spiral Galaxies
Elliptical Galaxies
Irregular Galaxies
Barred Spiral Galaxies
The Coma Cluster of Galaxies
Cosmic Distance Ladder
Scale drawing of measured triangle

\[ D = B \tan A \]

Distance to be found

Known

Baseline (known)

Scale: 1 cm = 1 meter

90°
Parallax

\[ p = \text{parallax of star A} \]

Baselines:
- January
- July

Star appears here in July
- Star appears here in January
Cosmic Distance Ladder
Inverse Square Law

\[
\frac{36}{1^2} = 36 \text{ photons/m}^2 \\
\frac{36}{2^2} = 9 \text{ photons/m}^2 \\
\frac{36}{3^2} = 4 \text{ photons/m}^2
\]
Cosmic Distance Ladder
Variable Star Light Curves

Mira – A long-period variable star

Period

Brightness


Time (years)

Cepheid – A Short-period variable star

3.52 days

Time
(a) Mira at minimum

(b) Mira at maximum
Measuring Distance to a Galaxy Using Cepheid Variables as Standard Candles

\[ \frac{B_\star}{B_g} = \left( \frac{d_g}{d_\star} \right)^2 \quad \text{or} \quad \frac{d_g}{d_\star} = \sqrt{\frac{B_\star}{B_g}} \]
The spectra of stars reveal their chemical compositions as well as surface temperatures.

- Stars are classified into spectral types (subdivisions of the spectral classes O, B, A, F, G, K, and M), based on the major patterns of spectral lines in their spectra.
HOW DO WE MEASURE DISTANCE?

- Gauging a galaxy’s actual distance is difficult.
- Hubble managed it by observing the apparent brightness of stars called Cepheid variables, whose intrinsic brightness is known.
CEPHEID VARIABLES

- The most important variables stars in astronomy
- In 1912 Henrietta Leavitt discovers a relationship between a cepheids period of light change with its absolute brightness
- Comparing this absolute brightness with its apparent brightness we can determine its distance with the inverse square law.
Henrietta Leavitt Calibrates the Stars
Henrietta Swan Leavitt (1868-1921).

• Working at Harvard College Observatory, Leavitt precisely calibrated the photographic magnitudes of 47 stars to which all other stars could be compared.

• Humanity's understanding of the relative brightness and variability of stars was revolutionized by her work.
Leavitt published her findings in 1912 -- in a chart of 25 cepheid periods and their apparent brightness. Using this, astronomers only needed to know the period of a cepheid variable to figure out how bright, and therefore how far away it was. Until then, methods for measuring distances in space only worked within about 100 light years. With Leavitt's findings, distances of cepheids could be determined up to 10 million light years. This became the "yardstick to the universe" used by Edwin Hubble and others to make discoveries that changed our view of our galaxy and the universe.
Astronomers have found that there is a relation between the period of a Cepheid and its luminosity.

Find the period. This gives the luminosity (absolute brightness). Measure the apparent brightness (what we see). With the inverse square law, determine the distance to the cepheid using the luminosity and apparent brightness.

This enables astronomers to determine distances.
Cosmic Distance Ladder
WHAT IS A TYPE IA SUPERNOVA?

• Type Ia supernova occur when a white dwarf, an aging star about the same size of the earth but with roughly the same mass of the sun, a million times more dense than ordinary matter, accumulates too much matter from a companion star.
In 1987 a nearby supernova gave us a close-up look at the death of a massive star. SN 1987A was a supernova in the Large Magellanic Cloud (a nearby dwarf galaxy). It occurred approximately 168,000 light-years from the earth.
The Remnant of Crab Supernova is a Neutron Star called a Pulsar which rotates 30 times a sec emitting a beam of x-ray at each rotation.
Just after a new moon, when the sky is dark, we make images of 50 to 100 patches of sky, each containing roughly a thousand distant galaxies. Three weeks later, the same patches are imaged again.
Search Strategy

Perlmutter et al. (1996a)

RESULT: ~10 SNe Ia Discovered Before Maximum, at New Moon => Follow-up

Scheduled Follow-Up Photometry
Scheduled Follow-Up Spectroscopy
Light Curves

Perlmutter et al. (1996b)
The surprising discovery that the universe is accelerating, and thus is likely to go on forever, is based on observations of these type Ia supernovae.
The image illustrates the electromagnetic spectrum and the role of atmospheric windows in blocking certain wavelengths. Here's a breakdown of the key points:

- **X-rays and Ultraviolet** (short wavelengths): Ultraviolet radiation is absorbed by ozone in the upper atmosphere.
- **Visible Light**: Visible light passes through the atmosphere.
- **Infrared**: Water and carbon dioxide in atmosphere block nearly completely.
- **Radio Waves**: Electric charges in the upper atmosphere block completely.

The diagram also shows:

- A satellite above the atmosphere to observe infrared, X-ray, and ultraviolet radiation.
- Infrared mostly absorbed by water vapor and carbon dioxide.
- Optical and radio telescopes:
  - Optical telescope: Visible light passes through the atmosphere.
  - Radio telescope: Infrared mostly absorbed by water vapor and carbon dioxide.
“Nothing yet. ...How about you, Newton?”
"It's black, and it looks like a hole. I'd say it's a black hole."
spacetime around the Sun today

spacetime around the Sun compressed to a white dwarf

spacetime around the Sun compressed to a black hole
An astronaut descending down towards the event horizon of the BH will be stretched vertically (tidal effects) and squeezed laterally.

This effect is called “spaghettification.”
The Butterfly

A Lesson on Evolution
Stellar Evolution: The Deaths of Stars

A planetary nebula

A supernova remnant
In 1987 a nearby supernova gave us a close-up look at the death of a massive star.
1. The star ejects a doughnut-shaped cloud of gas and dust from its equator.

2. The star then ejects gas from its entire surface.

3. The doughnut channels the ejected gas into two oppositely directed streams.

(c) Gas ejected from the star
Outer ring at edge of swept-up gas from earlier mass loss

Inner ring of swept-up red-supergiant gas

Supernova remnant. A dark, invisible outer portion surrounds the brighter inner region lit by radioactive decay.

An explanation of the rings
Supernova 1987A seen in 1996

- SN 1987A
- Outer rings
- Inner ring, about 1.3 ly (0.4 pc) in diameter
Where did it all come from?

Where did it all come from?
Maybe...

We Don't Believe In You!
Emission and Absorption of Light

Energy released as electron drops

Emitted electromagnetic wave = photon

Nucleus
Emission Spectrum of Hydrogen and Helium

Hydrogen

Orbit 6→2
Orbit 5→2
Orbit 4→2
Orbit 3→2

300 nm  400 nm  500 nm  600 nm  700 nm

486 nm  656 nm

Helium
Types of Spectra

Continuous

Emission line (hydrogen gas)

Absorption line (hydrogen gas)
And Now, the Biggest Question in the Universe
THE FATE OF THE COSMOS

• Some say the world will end in fire,
• Some say in ice........

• “Fire and Ice,”  Robert Frost, 1923
After years of observations using telescopes all around the globe, the international Supernova Cosmology project led by astrophysicist Saul Perlmutter has gathered enough compelling evidence to predict the fate of the universe.
Our Galaxy was the Universe

1917 Einstein and other physicists believed our own Galaxy was all there was to the universe:

- a uniformly dense collection of stars and other matter floating in the void
- problem was, Einstein’s new General Theory of Relativity would not allow for a static universe
Einstein’s fudge factor

- Cosmological Constant \( \Lambda \)
- Many values of \( \Lambda \) are allowed
- Einstein picks a value which gives solutions for a static universe

\[
R_{ij} - \frac{1}{2} R g_{ij} - \Lambda g_{ij} = \frac{8 \pi G} {c^4} T_{ij}
\]
“matter tells space-time how to curve, and space-time tells matter how to move”

John A. Wheeler

- One of the fundamental ideas in general relativity is that matter and energy act to curve space-time, ie they tell the metric equation how to behave.

- It is Einstein’s field equations that describe this mathematically

\[ R_{ij} - \frac{1}{2} R g_{ij} - \lambda g_{ij} = \frac{8 \pi G}{\zeta^4} T_{ij} \]
An Expanding Universe

• Then in 1929
• Hubble finds the universe full of countless galaxies and
• Hubble discovers light from galaxies are redshifted
Hi z Supernova Team

Supernova Cosmology Project
Fifth Force?
Indirect Detection

Galaxy Rotation - Missing Mass
Cosmic Acceleration & Dark Energy

- Evidence for cosmic acceleration is very solid (meets “Sagan criterion”)
- Understanding is not
- No evidence that dark energy is not the energy of the quantum vacuum
- Many important projects underway
Dark energy may be the most profound problem in all of science today.
A lot at stake!

Cosmic destiny (can't understand)

Quantum vacuum energy

Inflation related?

Narcissistic behavior

Neutrino mass

Same scale

What is DARK ENERGY?

Dark it?

Superstrings

Solution?

Supersymmetry

SUSY \Rightarrow D_{\text{vac}} = 0

SUSY \Rightarrow D_{\text{vac}} \neq 0

Surprise

???

New grav = physics

Self acceleration

... SWEDISH GOLD OPPORTUNITIES

Why now?
SOLVING THE COSMIC ACCELERATION RIDDLE WILL REQUIRE A CRAZY, NEW IDEA!

NB: NOT EVERY CRAZY IDEA IS A SOLUTION TO A PROFOUND
The Composition Of the Universe

Most of it is invisible.

- **1%** The visible universe (Stars, planets, dust)
- **3%** Hot interstellar and intergalactic gas
- **22%** Dark matter
- **74%** Dark energy

**Dark matter** and **dark energy** are similar only in name. Both are called “dark” because their presence is inferred by the gravitational behavior of visible matter. Dark matter encourages the growth of structure, while dark energy impedes structural formation.

SOURCES: Patricia Burchat, staff reports
GRAPHIC: By Patterson Clark, The Washington Post
Einstein recanted too soon.

- Observations of distant type Ia supernova place them significantly farther away than would be expected from their redshifts.
- Something is pushing everything apart faster than it did in the early universe.
- Cosmological constant $\Lambda$ is the best candidate.
- Vacuum energy density.
Startling Discovery Confirmed

• So instead of slowing down, as everyone has expected, the universe is in fact speeding up. This acceleration appears to be due to the cosmology constant, lamda, which may represent as much as 70% of the total mass density of the universe.

• Lamda’s exact nature remains a mystery, the universe may expand forever!
COSMIC STUFF

0.5% STARS + 33% DARK MATTER + 66% DARK ENERGY

- 0.01% PHOTONS (COSMIC MICROWAVE BACKGROUND)
- 4+1% ATOMS
  - 0.02% C, N, O, ... Fe, ... U
  - 0.5% STARS
  - 3.5% DIFFUSE GAS
  - 0.0001% BHZ
- 30 ± 4% EXOTIC DARK MATTER
  - 0.1-5% NEUTRINOS
  - ? AXIONS
  - ? NEUTRALINOS
- 66 ± 4% DARK ENERGY
  - ? VACUUM ENERGY
  - ? QUINTESSENCE

96% IN NEW FORMS OF MATTER & ENERGY
“it ain’t over till it’s over”
General Relativity Effects Near Black Holes (3)

**Time dilation**

Clocks starting at 12:00 at each point.

After 3 hours (for an observer far away from the BH):

Clocks closer to the BH run more slowly.

Time dilation becomes infinite at the event horizon.

Event Horizon
General Relativity Effects
Near Black Holes (4)

Gravitational Red Shift

All wavelengths of emissions from near the event horizon are stretched (red shifted).

⇔ Frequencies are lowered
Black Holes

Just like white dwarfs (Chandrasekhar limit: $1.4 \, M_{\text{sun}}$), there is a mass limit for neutron stars:

Neutron stars cannot exist with masses $> 3 \, M_{\text{sun}}$

We know of no mechanism to halt the collapse of a compact object with $> 3 \, M_{\text{sun}}$.

It will collapse into a single point – a *singularity*:

=> A Black Hole!
**Escape Velocity**

Velocity needed to escape Earth’s gravity from the surface: $v_{esc} \approx 11.6 \text{ km/s}$.

Now, gravitational force decreases with distance ($\sim 1/d^2$) => Starting out high above the surface => lower escape velocity.

If you could compress Earth to a smaller radius => higher escape velocity from the surface
At a distance, the gravitational fields of a black hole and a star of the same mass are virtually identical.

At small distances, the much deeper gravitational potential will become noticeable.
Observing Black Holes

No light can escape a black hole

=> Black holes cannot be observed directly.

If an invisible compact object is part of a binary, we can estimate its mass from the orbital period and radial velocity.

Mass $> 3 \, M_{\text{sun}}$

=> Black hole!
THE DISTANCE LADDER

- parallax
- redshift
- inverse square law
- cepheid variables
- type Ia supernova
these stars can thus be used as “standard candles” to measure distance, as more distant cepheids appear dimmer (apparent brightness), but their period is not effected by their distance.

Hubble compared the redshift with the distance and discovered the expansion.
Scientists figured that over the 12-15 billion years of the universe, the expansion would slow down slightly, thanks to the pull of gravity that every galaxy exerts on each other. But spotting such a change would require probing deep into space by looking at stars glittering billions of light years away, too far for *cepheid* to be seen.
Supernova Explosions of Type I and II

**Before**
1. Companion star adds mass to white dwarf.

**Collapse**
2. \( M \) becomes > 1.4 \( M_\odot \)

**Explosion**
3. Explodes as a Type I supernova.

- White dwarf
- White dwarf collapses, heats and...
- Probably no remnant.

---

**A**
- White dwarf \( M < 1.4 \ M_\odot \)

---

**B**
- Massive star, perhaps in red giant stage, with all fuel consumed in core.

**Explodes as a Type II supernova.**

**4. Black hole leaves**
- or

**Neutron star**
Type Ia supernova are white dwarfs which have a companion star and are slurping up matter from the companion. They become denser and denser until a runaway thermonuclear firestorm ignites. This nuclear cataclysm blows the dwarf star completely apart, spewing out material at about 10,000 kilometers per second.
Nova Outburst in a Binary System

We see

Hydrogen rich material from companion, accreted on white dwarf.

Companion star

White dwarf explodes as nova

Companion star

We see

“New” star
Hydrogen rich material fuses into helium, exploding, and blows accreted material off white dwarf. Explosion = Nova outburst.
SUPERNOVA COSMOLOGY PROJECT

1998 BREAKTHROUGH OF THE YEAR
This observer sees blueshift

This observer sees redshift
The Expansion of the Universe
The Origin of the Redshift

As space expands it “stretches” the light waves moving through it, increasing their wavelength, $\lambda$.

Short wavelength implies hot. Long wavelength implies cool.
HUBBLE’S LAW

• He also finds that distant galaxies are redshifted more than light from the closer galaxies therefore......

• the universe is indeed expanding

• Hubble discovered that the speed of recession is proportional to the distance
Galaxies Farther Away Recede Faster: Hubble’s Law
Estimating the Age of the Universe

\[ D = V \cdot t \]

Therefore, \[ t = \frac{D}{V} \]

But according to Hubble Law, \[ V = D \cdot H \]

Therefore, \[ t = \frac{D'}{D'H} = \frac{1}{H} \]
A Line of Galaxies Illustrating Hubble’s Law

- Milky Way
  - A: 750 km/s
- 10 Mpc
- 20 Mpc
- 30 Mpc
  - B: 1500 km/s
  - C: 2250 km/s
  - D: 3000 km/s
A BIG MISTAKE?

- Einstein dismissed his cosmological constant idea as

  “the biggest blunder of my life”
The Nature of the Universe Debate

- most believed that the universe was slowing down, due to gravity acting on matter in the universe. The question was...
  - How quickly was it slowing down?
  - What is the mass density of the universe?
  - Enough to reverse the expansion and eventually end the universe in a Big Crunch?
NEW KIND OF STANDARD CANDLE

• Type Ia Supernovas
• So for the past 20 years, astronomers have turned to the brightness of supernovae which happen nearly the same way each time. But these massive explosions are rare, only 2 or 3 erupt in a typical galaxy per millennium.
How often do Type Ia supernova occur?

- Type Ia supernova are rare, in a typical galaxy they may occur two or three times in a thousand years - and to be useful they must be detected while they are still brightening.
Although such stellar explosions in our own galaxy are very rare if you could monitor a few thousand other galaxies you can expect about one type Ia will appear every month. Indeed, there are so many galaxies in the universe that somewhere in the sky supernova bright enough to study are occurring every few seconds.
The glow of this expanding fireball takes about 3 weeks to reach its maximum brightness and then declines over a period of months. These supernova vary slightly in their brilliance, but there is a pattern: bigger, brighter explosions last somewhat longer than fainter ones.
Type Ia supernova are so similar, whether nearby or far away, that the time at which the explosion starts can be determined just by looking at their spectrum.

Type Ia Explosions are so bright that for a few days they can be brighter than the entire galaxy.
COSMOLOGY PROJECT

- So by monitoring how long they last, astronomers can correct for the difference and deduce their inherent brightness to within 12 percent.
- Over the past few years modern light detectors have made these flashers the best calibrated standard candles known to astronomers.
Astronomers Find a Way

- The deployment of large electronic light detectors on giant telescopes produce digital images of faint objects over sizeable swaths of the sky. A single exposure from these new cameras covers an area about as big as the full moon and creates a picture of 5000 galaxies in 10 minutes.
Preview CO
THE PROCEDURE IS SIMPLE

- Finding distant supernova Ia is just a matter of taking a picture of the same part of the sky a few weeks apart and searching for changes that might be exploding stars. Because the digital light detectors can count photons in each picture element precisely, we simply subtract the first image from the second and look for significant differences from zero.
WHAT’S THE WEATHER?

• Because we are checking thousands of galaxies in each pair of images we can be confident that the search of multiple pairs will find many supernova-as long as the weather is good.
1. Photometry of SN – galaxy (2 colors)

2. Fit to low-z SN light curves (K-corrected & time-dilated)

3. Fit cosmology
Type Ia Supernovae

Light Curves

SN 1997ap at $z = 0.83$
observed from the ground and with the HST


We observe most of the supernovae for approximately two months in both the R and I bands (corresponding approximately to the restframe B and V bands for the median redshift). At high redshifts, a significant fraction of this host galaxy light is within the seeing disk of the supernova, so final observations about one year later are usually necessary to observe (and subtract) the host galaxy light after the supernova has faded. The plots to the left and the right show just the R band light curves for about half of the 40 supernovae that have been completely observed and analyzed so far. The plots above show the highest redshift spectroscopically confirmed supernova, which was observed with the Hubble Space Telescope.
Two Technological Enablers:
1. Large CCD Cameras
2. SNe Ia: Bright, Standardizable Candles
• Then with the help of the Keck Telescope in Hawaii we confirm the spectrum and redshift. We then call the Hubble telescope into action to study the most distant supernova, giving much more accurate data than can be achieved from the ground.
THE UNSEEN EFFECT OF DARK MATTER
Overview

• Definition
• Current Understanding
• Detection Methods
• Cosmological Impact
Definition of Dark Matter

Matter that can be seen by its gravitational effects, but does not emit light.

Dark Matter

Not Dark Matter
Hot or Cold?

Dark matter comes in two forms:

**Hot Dark Matter (HDM)**
- very small particles (neutrinos)
- relativistic velocities

**Cold Dark Matter (CDM)**
- more massive and slower
- able to form smaller structures like galaxies
Baryons vs. Non-Baryons

CDM could be made of two types of matter

**Baryons**
- Strongly interacting fermions
- "Normal" matter

The most famous baryons are the protons and neutrons which make up most of the mass of the visible matter in the universe

**Non-Baryons**
- Formed during the Big Bang
- Suitable candidate not directly observed (yet)
Baryonic matter is matter composed mostly of baryons (by mass), which includes atoms of any sort (and thus includes nearly all matter that we may encounter or experience in everyday life, including our bodies). Non-baryonic matter, as implied by the name, is any sort of matter that is not primarily composed of baryons. This might include such ordinary matter as neutrinos or free electrons; however, it may also include exotic species of non-baryonic dark matter, such as supersymmetric particles, or black holes. The distinction between baryonic and non-baryonic matter is important in cosmology, because Big Bang nucleosynthesis models set tight constraints on the amount of baryonic matter present in the early universe.
MAssive Compact Halo Objects

- Brown Dwarfs
- Exist in the halo of galaxies
- Attempts to explain Cold Dark Matter without new particles
Weakly Interacting Massive Particles

• Undiscovered non-baryonic particle
• Interacts only through the weak and gravitational forces
• High mass corresponds to a lower kinetic energy, making the particle “cold”
Supersymmetry

• Several candidates for WIMPs are predicted by supersymmetry

• Neutralinos are the most probable
  • non-interacting
  • Combination of Z-boson, photon, and Higgs boson superpartners
Consensus?

- No WIMPs have been directly observed.
- Groups studying MACHOs have not found enough objects to account for the missing mass problem.
- Cold Dark Matter probably a mixture of both baryonic and non-baryonic matter.
- We still do not know for sure.
Looking for WIMPs

Several groups are currently running experiments to find WIMPs

• Cryogenic Dark Matter Search (CDMS)
  • Cryogenically cooled crystals

• DAMA experiment
  • Scintillation detectors

Both detect the collision between a WIMP and target nuclei
Universal Composition

- Dark Energy: 73%
- Cold Dark Matter: 23%
- Atoms: 4%
Universal Implications

\[ \Omega = \text{Actual Density} / \text{Critical Density} \]
Universal Overview

- Dark matter slows the universal expansion rate
- Density of dark matter affects the fate of the universe
  - Low density leads to accelerating expansion
  - High density leads to Big Crunch
- Dark matter density affects the universal geometry
  - Low density leads to open universe
  - High density leads to closed universe
• Current measurements indicate a flat universe with accelerating expansion
• The existence of dark matter can explain these observations
• Detecting dark matter can confirm measurements
The summit of Cerro Tololo in Chile
New observations have smashed the old view of our universe.

What now?
<table>
<thead>
<tr>
<th>Force</th>
<th>Relative strength</th>
<th>Particles exchanged</th>
<th>Particles on which the force can act</th>
<th>Range</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>1</td>
<td>Gluons</td>
<td>Quarks</td>
<td>$10^{-15}$ m</td>
<td>Holding nuclei together</td>
</tr>
<tr>
<td>Electromagnetic</td>
<td>$\frac{1}{137}$</td>
<td>Photons</td>
<td>Charged particles</td>
<td>Infinite</td>
<td>Holding atoms together</td>
</tr>
<tr>
<td>Weak</td>
<td>$10^{-4}$</td>
<td>Intermediate vector bosons</td>
<td>Quarks, electrons, neutrinos</td>
<td>$10^{-16}$ m</td>
<td>Radioactive decay</td>
</tr>
<tr>
<td>Gravitational</td>
<td>$6 \times 10^{-39}$</td>
<td>Gravitons</td>
<td>Everything</td>
<td>Infinite</td>
<td>Holding the solar system together</td>
</tr>
</tbody>
</table>
Neutrinos emanate from supernovae like SN 1987A. More than 99% of the energy from such a supernova is emitted in the form of neutrinos from the collapsing core.
We live in a universe

- governed by physical laws. The universe is understandable.
- where the speed of light is finite. We can look back in time.
- that had a beginning about 14 billion years ago.
- illuminated by starlight -- for now.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>The Big Bang (New Year's Day)</td>
</tr>
<tr>
<td>February</td>
<td>Milky Way forms</td>
</tr>
<tr>
<td>March</td>
<td>Sun and planets form</td>
</tr>
<tr>
<td>April</td>
<td>Oldest known life (single celled)</td>
</tr>
<tr>
<td>May</td>
<td>First multicellular organisms</td>
</tr>
<tr>
<td>June</td>
<td>訪れ \n</td>
</tr>
</tbody>
</table>

1. **January 1**: Dinosaurs wiped out by asteroid or comet.
2. **January 2**: Apes appear.
3. **January 3**: First human ancestors to walk upright.
4. **January 4**: Homo erectus appears.
5. **January 5**: Anatomically modern humans appear.
6. **January 6**: Invention of writing.
7. **January 7**: Pyramids built in Egypt.
8. **January 8**: 1 second before midnight: Voyage of Christopher Columbus.
Published Light Curves for Nearby Supernovae

![Light Curves for Nearby Supernovae](image-url)
How Earth Fits into the Universe
Origin of White Dwarf Stars

Star expands into red giant as hydrogen in its core is used up.

Outer layers driven off by radiation pressure

Outer layers become planetary nebula—a shell of expanding gas. Shell finally dissipates, leaving core star.

Low mass star like the Sun, burning hydrogen.

With no fuel available for it to burn, core star cools, becomes a white dwarf.
What is the Nature of the Dark Energy?

Can We Tell?
What is the Nature of Dark Matter?

How does dark matter interact with ordinary baryonic matter? Is it wimpy?

Is it made of Supersymmetric Neutralinos, Axions or?
Welcome to basic astronomy. Before we start, are there any questions?

Yeah, like, what makes astronomy different from astrology?

Lots and lots of math.
The International Year of Astronomy 2009 (IYA2009) is a global celebration of astronomy and its contributions to society and culture and marks the 400th anniversary of the first use of an astronomical telescope by Galileo Galilei.
We live in a universe

governed by physical laws. The universe is understandable.

where the speed of light is finite. We can look back in time.

that had a beginning about 14 billion years ago.

illuminated by starlight -- for now.
that evolves in our galaxy
And about once a year a star is born
In our galaxy

(Painting by William K. Hartmann. Used with permission.)
And about

Every ten years or so, a star runs out of fuel and dies.
dying stars leave behind compact remnants: white dwarfs, neutron stars, and black holes.
gravity creates illusions

• yet gravity always wins in the end.
where stars form clusters,
galaxies, and
clusters of galaxies.
where galaxies collide.
where black holes with masses of billions of suns, power the central engines of galaxies.

Les Quasars (Quasi Stellar Radio Sources)
where once a day a star explodes in a gamma ray burst, releasing the energy of 1000 suns.
where all heavy elements have been created in stars.
You are made of "star stuff".
full of debris
where life developed at least once.
TO BOLDLY GO WHERE NO MAN HAS GONE BEFORE

Dr. Jose D’Arruda
University of North Carolina Pembroke
Gail Graham, 17, Killed In Westport Crash

Seven years-ago, Gail R. Graham of 31 Old Bedford Road, was killed instantly in a crash on Old Bedford Road today. According to police, she was traveling east on the road when her car collided with a car on the opposite side of the road.

The car, police said, was traveling west on Old Bedford Road at the time of the accident. The impact was so severe that it caused major damage to both vehicles. Gail Graham was pronounced dead at the scene.

Family of Ten As Flames Devour Two-Story Home

Ten members of a family, including eight children, were killed when their two-story home caught fire.

A neighbor described how the fire started near the kitchen and quickly spread throughout the house.

Tension Rises in Cuban Rebels Delay Attacks

HAVANA, Cuba (AP) - Tension mounted toward a fever pitch in Cuba today as the deadline passed for the ouster of Fidel Castro, who has been in power for 36 years.

An unconfirmed report in Havana said that Cuban communists were planning a military operation to oust Castro. The report said that up to 10,000 armed men were preparing to attack Castro's stronghold.

Hungary Must Fight Own Battles

STALINVAROS, Hungary (AP) - Soviet Premier Nikita Khrushchev warned Hungarian communists today that a new revolt against the government could lead to war.

Speaking to an outdoor crowd of 20,000 in this steel mill town built by the communists and named after their leader, Khrushchev said: "We have no choice but to fight."

Lana Turner's Daughter Stabs Mother's Suitor

HOLLYWOOD, Calif. (AP) - Lana Turner's 19-year-old daughter stabbed her mother's suitor to death in their home.

Speaking to an outdoor crowd of 20,000 in this steel mill town built by the communists and named after their leader, Khrushchev said: "We have no choice but to fight."

WHERE 10 DIED IN FLAMES: Torance Flook, 34, his eight children and their maternal grandmother, Mrs. Mary Blane, 63, died when fire destroyed this frame house just outside the borough of Jersey Shore today.

Youths' Rocket Blast Shakes Wide Area

An attempt to launch a home-made "Missiles" by several Fall River juveniles resulted in an explosion which shook the

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Youths' Rocket Blast Shakes Wide Area

An attempt to launch a homemade "Spunik" by several Fall River juveniles resulted in an explosion which shook the Brightman Street section of Somerset about 8:30 last night.

Newly appointed Somerset Police Chief John O. Soares said the attempt was made by "three or six" Fall River youths near the shoreline on Riverside Avenue, opposite the Stop and Shop market.

The blast, which was heard as far as the high school, about a mile and a half away, attracted hundreds of persons to the scene and caused traffic to come to a "standstill."

No injuries were reported.

Cruiser Shook

Chief Soares said he and Patrolman Roland Rivard were traveling south on Riverside Avenue when the explosion shook the cruiser car.

Soares said he looked over to the riverbank and saw "a large cloud of smoke," which Patrolman Rivard said resembled a mushroom.

Rivard drove the cruiser toward the river and Soares walked toward the bridge. The chief said he then saw a youth run up the riverbank.

River Plunge

The boy, he said, "took off" when he saw him and in running down toward the river, fell into the water.

The chief said the juvenile then jumped to his feet and began running along the riverbank.

Soares said he "lost track" of the youth, but spotted him on the Brightman Street Bridge about 15 minutes later with two other "future scientists."

The youth, Soares said, was "soaking wet."

More Questions

The chief took the boy home to change his clothing and told the youth's parents to bring him to the Somerset police station today for further questioning.

Soares said he would question the boy concerning what was used in the "bomb," and to make sure that a similar thing does not happen again.

The chief said such "experiments" could result in serious injury.

Almost all shoppers in the store across the street rushed out when the explosion occurred.

Investigating in addition to Soares and Rivard were Constables Herbert Menezes and Joseph Bouchard.

Sunny Skies For Easter

The weatherman promises sunny skies and balmy Spring breezes tomorrow for area Christians who, with Christians throughout the world, will unite for the joyous Easter celebration.

Traditional religious and family observances will have the blessings of Old Sol if the weatherman is right.

Hundreds of others will attend special masses and services throughout area churches.

Badly Burned In Explosion

A laboratory technician experimenting with a chemical mixture
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The Hubble Deep Field
**Mira** — A long period variable star

**Cepheid** — A short period variable star

*Period ~ 3.5 days*