Field Guide to the Entire Universe

Let's face it: You have no idea how to make sense of 70 sextillion stars scattered across 27 billion light-years of space in the visible universe, not to mention what you should make of dark matter and dark energy. So let's go straight to the highlights—9 places in the cosmos that explain everything you need to know

By Corey S. Powell

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Sometime around 130 B.C. Greek mathematician Hipparchus broke with the oral traditions of poetry and mythology, set pen to parchment, and compiled the first written catalog of the stars. His singular document contained about 850 entries, loosely organized by constellations and coordinates. It was a modest start for a distinctly immodest project—taking stock of the entire universe and trying to figure out what, exactly, is out there.

The European Space Agency's Hipparcos satellite revisited that work about a decade ago, this time aided by digital computers and silicon light detectors. The new result: a database of more than 2.5 million stars, containing not only their locations in the sky but also their distances from Earth. And that effort pales next to the latest and most extensive mapping effort, the Sloan Digital Sky Survey. So far its astronomers have cataloged more than 100 million objects, ranging from asteroids and stars to faraway galaxies and quasars; that number will nearly double by the time the project wraps up in 2008.

Stunning as they are, the raw numbers barely hint at the immensity of this achievement. Hipparchus could record only the stars close and bright enough to show up in the skies of his hometown of Nicaea, in what is now northwestern Turkey. Modern telescopes can collect a million times as much light as the human eye, enough to take in the whole of the universe—not just what is bright and nearby. With relentless determination, researchers are learning to describe the detailed properties of star-birthing gas clouds, star-eating black holes, invisible galaxies, and even the explosive event that gave rise to it all.

This unprecedented precision makes it possible for cosmic explorers to pore over the atlas of the universe and pick out the most intriguing locales. Just as veteran travelers consult field guides to anticipate the exotic creatures and features they will encounter, so astronomical adventurers can now flip through the scientific literature for intimate portraits of the universe's most remarkable specimens.

That ability would have flummoxed the most informed scientists not so long ago. Bruce Campbell, a cunning and preternaturally patient astronomer at the University of British Columbia, spent more than a decade searching for planets orbiting other stars. He finally gave up in 1991, four years before a competing team found the first extrasolar planets. Now we do not merely know that such worlds exist; we can weigh them, sniff them, and take their temperature.

Just eight years ago, nobody knew what caused the abrupt flashes of energetic radiation known as gamma-ray bursts. Three years ago the exact age and composition of the universe were still a matter of active dispute. Just a year ago, nobody knew for certain whether some galaxies might be made up of swirling particles but no stars.

And now? Ah, but that would be getting ahead of the story. The following pages offer descriptions of nine objects that exemplify how clearly we now see the universe: no longer a set of dots and coordinates but a collection of sites and specimens as vivid as the gypsum dunes of New Mexico or the lemurs of Madagascar.

stellar nursery

NAME

NGC 1333

LOCATION

1,000 light-years from Earth in the constellation Perseus; one of the closest locations where new stars are forming

AGE

Contains several hundred young stars, most of them less than 1 million years old

Gutermuth,Porras/JPL-Caltech/NASA

GENERAL CHARACTERISTICS

The birth of new stars is one of the most public processes in the universe and also one of the most private. Anyone can see the public side: The Orion nebula, obvious even from suburban skies as a hazy patch in the middle of Orion's sword, blazes with a fluorescent glare from the rays of the largest, hottest stars birthing within. NGC 1333, part of an extensive chain of nebulas called the Perseus molecular cloud, is a more subtle place, full of dark cocoons of gas that are in the process of collapsing into medium-size stars like our sun.

Alyssa Goodman of the Harvard-Smithsonian Center for Astrophysics spearheads a study, called the Complete Survey of Star-Forming Regions, to tease out details of how stars form. One early surprise: The ostensibly dark sky around the stars in NGC 1333 is actually filled with a pervasive, diffuse infrared glow. This "cloudshine"—most likely the light of newborn stars scattered off tendrils of dust—could provide a new way to study the material from which the stars formed. It is a ghost image, tracing the patterns of the processes that created the stars within the cluster.

One of Goodman's colleagues, astronomer Lori Allen, marvels at what she can see directly in pictures of NGC 1333 taken with the orbiting Spitzer Space Telescope (left). As young stars collapse, they squeeze out jets of gas back into the surrounding nebula, producing an energetic glow. In this new view a riot of previously unseen jets overlap and intersect in a crazy-quilt pattern. "It's hard to tell where one stops and another begins," Allen says. "I wish I knew why there is so much activity here." In contrast, a superficially similar star-forming region in the constellation Serpens shows few such jets. Apparently, each region has its own personality, which probably remains imprinted in the unique characteristics of the stars and planets that it produces.

RANGE & POPULATION

Most of the stars in the Milky Way formed billions of years ago, but there are still several thousand star-formation regions in the galaxy. These regions produce about one to three new stars a year.

HOW TO SPOT IT

Look five degrees northeast of the Pleiades through a moderate amateur telescope at low power. NGC 1333 shows up as a cometlike smudge of light.

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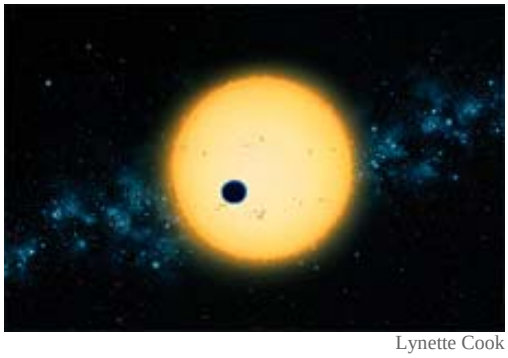
alien planet

NAME

HD 209458b, nickname Osiris

LOCATION

153 light-years from Earth in the



Lynette Cook

constellation Pegasus—a relatively close neighbor within our galaxy

AGE

4.5 billion years old, about the same as Earth

GENERAL CHARACTERISTICS

Even within the exotic category of planets that circle other stars, the one revolving around the star HD 209458 is special. Five years ago, David Charbonneau of the Harvard-Smithsonian Center for Astrophysics and Tim Brown of the National Center for Atmospheric Research in Boulder observed this planet pass in front of its star once every three days, 12 hours, and 35 minutes, each time casting an extremely slight shadow. That shadow allows researchers to stretch their senses across 900 trillion miles of space and learn exactly what a distant planet is like.

Charbonneau, Brown, and their colleagues quickly began to nail down the details. They timed the eclipses and determined that the planet follows a perfectly circular path around HD 209458, orbiting at a distance of 4.3 million miles. Another team had previously discovered the planet and measured its mass—about 220 times Earth's and roughly two-thirds as much as Jupiter's—based on the way it tugs on its parent star.

The intensity of the eclipses shows the planet is about 35 percent larger in circumference than Jupiter. Together, the numbers paint a picture of a tortured world circling so close to its star that a year speeds by in just three and a half Earth days. The furious rays pounding down on this alien planet heat it to 2,000 degrees Fahrenheit and cause it to puff up like a marshmallow over a campfire.
Later observations led by Alfred Vidal-Madjar at the Astrophysics Institute of Paris also exposed the smells of the planet, which he nicknamed Osiris. By watching starlight streaming through the planet's atmosphere, Vidal-Madjar discovered a cloud of hydrogen gas, as well as possible hints of oxygen and carbon, boiling off into space. The composition is about what you'd get if you put Jupiter under an enormous heat lamp, suggesting that Osiris is made of the same stuff as the planets in our solar system. A closer look at the eclipses might reveal atmospheric layers, clouds, and even winds.

RANGE & POPULATION

Roughly 10 percent of nearby sunlike stars have massive planets, so there may be 10 billion of them in our galaxy. Researchers know of nine eclipsing planets, including one that is bloated and another that is oddly dense.

HOW TO SPOT IT

The star HD 209458 is visible through binoculars. Light from its planet has been directly observed only by the Spitzer Space Telescope; the image above is an artist's interpretation.

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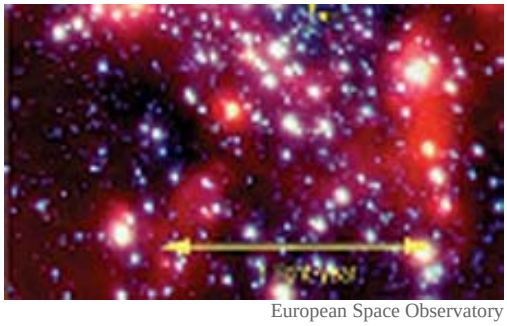
massive black hole



European Space Observatory

NAME

Sagittarius A*

LOCATION

Center of the Milky Way, 26,000 light-years away in the constellation Sagittarius

AGE

As old as the galaxy, nearly 14 billion years

GENERAL CHARACTERISTICS

The first hints of something violent at the heart of our galaxy came in the 1930s, when radio astronomer Karl Jansky detected strange emissions from that direction. In the 1970s and 1980s, better observations linked the radio noise to a compact source named Sagittarius A*; in the 1990s, other studies showed that stars near this source move rapidly. The clincher came in 2002, when Reinhard Genzel of the Max Planck Institute for Extraterrestrial Physics in Germany and his colleagues discovered a star orbiting Sagittarius A*, which allowed them to weigh the object: It is 3.6 million times as heavy as our sun. Only one thing can pack so much mass into such a small space.

"Sagittarius A* is a massive black hole, beyond any reasonable doubt," Genzel says. For such a big beast, Sagittarius A* actually causes relatively little commotion, because black holes become visible only when they are swallowing gas, and right now Sagittarius A* seems to be starving. Sudden flashes of infrared light and X-rays from the hole show that whatever meager bits of material it manages to acquire get sucked down in abrupt fits. There are many theories but no clear answers why. Genzel's team has picked up variations within those flashes, which could be a sign that the black hole rotates once every 10 minutes or so—more support for the weird notion that black holes can spin.

RANGE & POPULATION

Many other large galaxies also seem to have giant black holes in their cores. The largest, most active galaxies have far heftier ones, up to several billion times the mass of the sun. The modest size of Sagittarius A* means "the Milky Way has had a fairly peaceful history so far," Genzel says.

HOW TO SPOT IT

It's called a black hole for a reason! If you face south on a summer night you're pointed the right way, but you'll have to take that on faith.

R.Hurt (SSC)/JPL-Caltech/NASA

barred spiral galaxy

NAME

The Milky Way

LOCATION

All around; Earth is 26,000 light-years from the galaxy's center

AGE

About 13 billion years, based on recent studies of interstellar dust

GENERAL CHARACTERISTICS

It's not easy to see what our galaxy looks like since we are in the middle of it. Nevertheless, years of astronomical sleuthing, such as measuring radio emissions of gas clouds and cataloging groups of stars that all travel in similar directions, have yielded a fairly complete picture, as illustrated above. We live in a spiral-shaped galaxy that is home to as many as 400 billion stars. It has four main spiral arms; we inhabit a secondary spur of stars known as the Orion Arm.

We know a lot, but researchers keep springing surprises on us. Heidi Jo Newberg of Rensselaer Polytechnic Institute is finding streams of stars in the outer part of the Milky Way that look like the remains of independent dwarf galaxies. These objects were probably captured, torn apart, and absorbed by our galaxy. Thus, we live inside a cosmic cannibal. Joss Bland-Hawthorn of the Anglo-Australian Observatory has found a loose, faint extended disk of ancient stars surrounding the nearby spiral NGC 300. If the Milky Way has a similar suburb, our galaxy may be 200,000 light-years across, twice as large as previously estimated.

Meanwhile, Robert Benjamin of the University of Wisconsin at Whitewater is redrawing the shape of our galaxy. Using the Spitzer Space Telescope, which can see through obscuring clouds of gas and dust, he has demonstrated that the Milky Way has a complicated S-shaped form known as a barred spiral. Related work shows that our galaxy's nucleus looks rather like a football.

RANGE & POPULATION

The Milky Way is one of two giant spiral galaxies in the Local Group, a gathering of about two dozen galaxies. The Local Group in turn lies on the fringes of the much larger Virgo cluster.

HOW TO SPOT IT

The shimmering band of the Milky Way—the blended light of billions of stars—slashes across the sky on a clear night. It dominated humanity's view of the heavens until the arrival of outdoor lighting.

gamma-ray burst

NAME

GRB 050502B

LOCATION

The constellation Leo, distance not yet determined

AGE

Exploded May 2, 2005

GENERAL CHARACTERISTICS

If your eyes could see radiation a million times more energetic than light, gamma-ray bursts would drive you batty: Once a day, on average, such a flash arrives from a random direction and briefly outshines everything else in the sky—even the sun. Military satellites first detected gamma-ray bursts in the 1970s, and astronomers were baffled: Were they colliding comets, asteroid crashes on neutron stars, or exploding UFOs? (That last possibility was championed by a decidedly nonacademic journal, Weekly World News.) Three space-based satellites, culminating with the new Swift observatory, have finally nailed the true answer: The flash is the birth cry of a new black hole.

David Burrows of Pennsylvania State University analyzed a recent burst called GRB 050502B. The burst lasted just 17 seconds, but then about eight minutes later it began acting up again, emitting a series of intense X-ray hiccups. Elaborate theoretical models explain the burst as the death throes of an aging heavyweight star. The star's core collapses into a black hole, while overlying material forms a rapid, cone-shaped jet, producing the gamma-ray flash. "But the X-ray flares are a sign that this formation process is messier than we used to think," Burrows says.

The erratic behavior suggests that the newborn black hole gets busy instantly, feeding on the remains of the star from which it formed, even as much of that material is still shooting outward at breakneck speed.

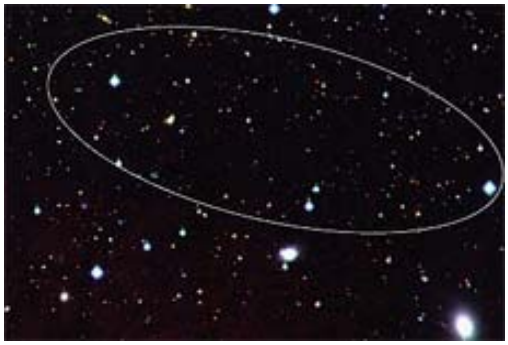
On September 4, a similar gamma-ray burst showcased just how much energy is unleashed in creating a black hole. (The infrared-light afterglow of that burst is shown at left.) A team led by Daniel Reichart of the University of North Carolina clocked the distance to the burst at 12.8 billion light-years. That makes it the most remote explosion ever observed and one of the most powerful. Because stars must predate gamma-ray bursts, Reichart and his colleagues are optimistic that such flashes will allow the study of when and where the first stars ignited after the Big Bang.

RANGE & POPULATION

Gamma-ray bursts pop off once a day on average. They occur in all directions and in all types of galaxies, but by probability most of them appear in distant galaxies.

HOW TO SPOT IT

A gamma-ray burst shines mostly in gamma rays, naturally. Some bursts produce detectable visible-light afterglows, but these are very faint and often fade within hours.



dark galaxy

NAME

Virgo H121

LOCATION

Virgo cluster, 50 million light-years from Earth

AGE

Presumably the same as the Milky Way

GENERAL CHARACTERISTICS

Virgo H121 is a galaxy trapped in perpetual darkness. In fact, it confounds all understanding of what a galaxy is. Galaxies are supposed to have stars, but this one has none. Almost by definition, galaxies are supposed to be visible objects, but this one can be seen only by radio-wave detectors. That is the only way that Robert Minchin, then at Cardiff University in Wales, and his colleagues were able to locate it—by tuning in to its feeble radio emissions.

Those emissions identify Virgo H121 as a swirling cloud of hydrogen-rich gas containing 100 million times the mass of the sun, making it larger than many dwarf visible galaxies. The speed of the cloud's rotation indicates its total mass, which leads to another surprise. In addition to the hydrogen, the galaxy is chock-full of some other form of mass that emits nothing at all, not even radio waves. Astronomers use the generic term dark matter to describe material that seems to make up the bulk of the mass of most galaxies, including our own. The nature of the dark matter is unknown. Virgo H121 is thus a double enigma: a galaxy whose ordinary matter is dark and whose bulk is dominated by a second, even darker component.

Jonathan Davies of Cardiff, one of the codiscoverers of Virgo H121, suggests that this object is merely at the extreme end of the range of galaxy evolution. Other astronomers have found dim galaxies that seem to form stars only very slowly. Virgo H121 has such a low density that it apparently never reached the point at which gravity begins to pull gas clouds together into stars.

RANGE & POPULATION

This is the only completely dark galaxy discovered, but it is unlikely to be unique.

Some computer simulations of cosmic structure imply that similar small, dark galaxies may outnumber the bright ones by as much as 100 to 1.

HOW TO SPOT IT

Ask for time on a radio telescope, or content yourself with bright galaxies instead.

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galaxy cluster

NAME

Abell 2029

LOCATION

1 billion light-years away in the constellation Serpens

AGE

5 billion years

GENERAL CHARACTERISTICS

Galaxy clusters are the largest structures held together by gravitational glue, and Abell 2029 is an ideal example of how they work. It contains about 1,000 galaxies scattered in a vaguely egg-shaped arrangement. Unlike many other clusters, which are still accumulating and absorbing new galaxies and clumps of galaxies, Abell 2029 seems to have settled down into a smooth, stable galactic swarm, buzzing leisurely about a humongous elliptical galaxy at the center. It is a snapshot of the state that every galaxy cluster is slowly evolving toward.

Like every large galaxy cluster, Abell 2029 is filled with hot gas that radiates X-rays. NASA's orbiting Chandra X-ray Observatory took the temperature of the gas, which indicates how intensely the gravitational pull of the cluster is squeezing and heating that gas—to a torrid 200 million degrees Fahrenheit. That implies the cluster is full of dark matter that outweighs the visible stars and gas by at least five to one. Equally telling, the distribution of dark matter mirrors the overall density of galaxies in different parts of the cluster. That result bolsters the leading theory that clumps of dark matter in the early universe seeded the formation of galaxies and galaxy clusters.

Last year, physicist Steve Allen of Stanford University used Abell 2029 to probe the universe's stranger invisible component: dark energy. Starting in 1998, two groups of cosmologists discovered that the expansion of the universe is accelerating, apparently prodded by a ubiquitous but unseen energy threaded through all of space. Allen and his colleagues measured the distances to Abell 2029 and 25 other galaxy clusters to perform an independent study of how the universe expands. Their results affirm that dark energy is real and show that the energy seems to remain steady over time, neither intensifying nor thinning out as the universe grows. Learning more about dark energy won't be simple, however: For a follow-up study, Allen and company say they need to increase their sample from 26 galaxy clusters to 1,000.

RANGE & POPULATION

Hubble Space Telescope observations suggest the visible universe contains at least 80 billion bright galaxies. The number of galaxy clusters is around several hundred thousand, of which astronomers have so far mapped only a few thousand.

HOW TO SPOT IT

The galaxies in most clusters are distant and dim, but the Virgo cluster—the nearest big one—contains 16 galaxies that are well within the range of a backyard telescope.

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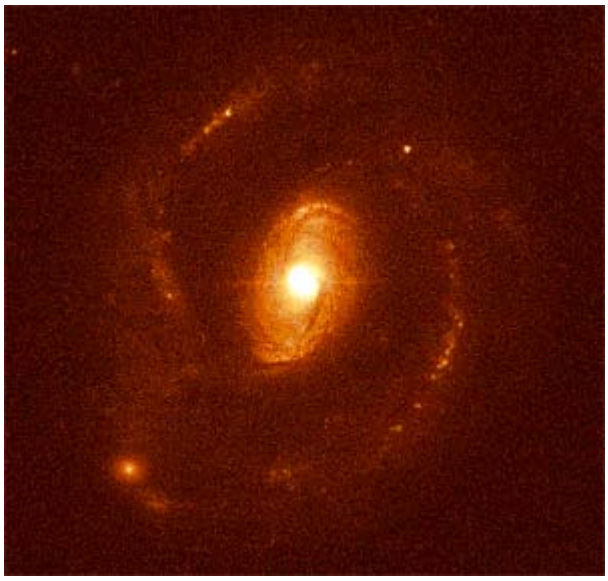
quasar



NAME

HE 0151-4326

LOCATION

10 billion light-years away ir the constellation Phoenix

AGE

3.5 billion years

GENERAL CHARACTERISTIC

A quasar is a galaxy with a brilliant, energetic central region, probably powered by a hypermassive black hole that is sucking down enormous quantities of hot gas (an extreme version of what is happening in the center of the Milky Way). Quasars are easily seen across billions of light-years of space, which makes them ideal for probing conditions in other parts of the universe. With that in mind, Patrick Petitjean at the Astrophysics Institute of Paris wondered: If you could visit a distant quasar like HE 0151-4326, would you experience the same laws of physics as you do here on Earth?

Amazingly, there are concrete ways to answer this question. If the speed of light or the nature of the electromagnetic force is different in remote parts of the universe, then atoms in faraway quasars should behave differently than they do here. That difference, in turn, should leave a discernible imprint on the light the quasars emit. A few astronomers claim to have found such imprints, which would indicate the existence of processes beyond what Einstein's general theory of relativity can explain. Petitjean recently booked 35 nights on the Very Large Telescope, the world's most powerful optical observatory, and did an independent audit of HE 0151-4326 and 14 other quasars. His experiment, the most extensive of its type, found a whole lot of nothing. Quasars may be bizarre, but they seem to obey the known laws of physics.

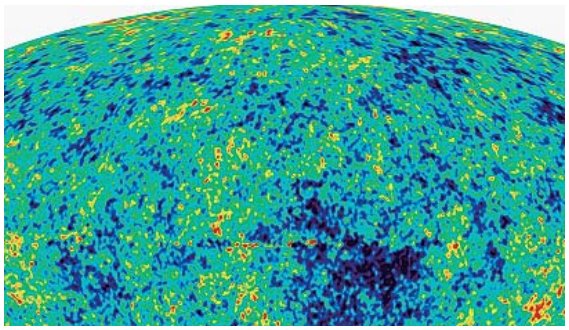
RANGE & POPULATION

Astronomers estimate there are 10 million quasars in the visible universe (shown abov is another quasar, HE 1239-2426). Most of them lie at great distances, where we see them as they were billions of years ago, because quasar activity is primarily an early stage in the evolution of a big galaxy.

HOW TO SPOT IT

3C 273, the brightest quasar, is well within the range of a moderate home telescope. Prepare to be disappointed—it looks like a nondescript, bluish star.

big bang afterglow



space thing

NAME

Cosmic microwave background

LOCATION

Arises from all parts of the sk with almost equal intensity

AGE

Emitted 13.7 billion years ag

when the universe was 380,000 years old

GENERAL CHARACTERISTICS

Welcome to the edge of the universe. The cosmic microwave background is the oldest and most distant thing humans have ever observed. It derives from the energy of the Big Bang itself. Initially, the cosmos was an opaque soup of matter and radiation. When it turned transparent at age 380,000, matter and radiation went their separate ways. The primordial radiation, greatly cooled and stretched by the expansion of the universe, is what we see today as the microwave background.

Those microwaves bristle with information about the early universe. Acoustical waves reverberating from the Big Bang created relatively hot and cold regions, visible today as relatively high-frequency or low-frequency patches of microwaves in the sky (shown below). The pattern of those patches depends on the composition of the universe. Readings from the Wilkinson Microwave Anisotropy Probe launched in 2002, combined with other observations, tell us that the universe contains 75 percent dark energy and 21 percent dark matter. Ordinary matter makes up just 4 percent of the total, and only about one-tenth of that—0.4 percent—accounts for everything we see in the night sky.

That should be surprise enough for most scientists, but a few renegades are hunting even more confounding ideas in the microwave background. A group of astrophysicists at the Max Planck Institute for Astrophysics in Germany, the University of Oslo in Norway, and the Jet Propulsion Laboratory in the United States uncovered evidence that the microwave background looks slightly different in different directions, as if the whole sky has been twisted. The implication is that the universe did not expand uniformly, in sharp contradiction to expectations. But cosmologist Ned Wright of UCLA, who has worked on the microwave background for many years, suspects the team is mistaking local distortion from the Milky Way for true properties of the distant universe.

This is the ultimate high frontier. In the days of Hipparchus, the edge of the universe was a set of imaginary crystalline spheres. Today the edge of the universe is a real, observable place where scientists can look, point, and debate the nature of the earliest moments of existence.

RANGE & POPULATION

The microwave background is everywhere, filling the entire universe in all places and all directions.

HOW TO SPOT IT

Easier than you might think. Cosmic microwaves are strong at the frequencies used for UHF broadcasts. If you have an old TV that you can tune to empty UHF stations, part of the static on the screen is microwave noise from the birth of the universe. x