2009 Astrophysics Division Government Performance and Result Act Input text.

ASTROPHYSICS

The NAC Astrophysics Subcommittee finds that all outcomes in sub-goal 3D (3D.1 -- 3D.4) were fully met by NASA this year and assigns a rating of "green" to each one. Supporting evidence, with citations and relevant URLs, is given for each outcome below.

Sub-goal 3D: Discover the origin, structure, evolution, and destiny of the Universe, and search for Earth-like planets.

Outcome 3D.1 Progress in understanding the origin and destiny of the Universe, phenomena near black holes, and the nature of gravity.

In the past year observations from NASA's space astronomy observatories have greatly advanced our understanding of the origin and characteristics of black holes, their role in galaxy evolution, and the physics of processes in extreme environments. We now know the age, shape, and expansion rate of the Universe to high precision, and have an independent probe of dark energy, its major constituent.

1. The Cosmic Microwave Background Radiation

The NASA satellite WMAP, observing the most ancient light in the Universe, has published its most complete results yet, based upon 5 years of data, accurately pinning down features of the Universe today and revealing hints about how it began. The cosmic microwave background radiation is the oldest light in the Universe, having last scattered from matter 380,000 years after the big bang, a time well before stars and galaxies were born. The WMAP team has determined the age of the Universe to be 13.7 billion years (with accuracy better than 1%), its shape (uncurved) with a precision of 0.5%, and its rate of expansion (Hubble constant) with accuracy better than 4%. The WMAP results have also shown that only 4.6% of the Universe exists in atoms, with the remainder in dark matter and dark energy, mysterious forms of matter and energy that control the evolution of the Universe and that are not yet thoroughly understood by physicists. The determination of the amount of dark matter is the most accurate yet and the measurement of dark energy gives strong independent support to other methods that have revealed its existence (e.g., distance supernovae and clusters of galaxies). These WMAP results also provide evidence for an inflationary epoch just a tiny fraction of a second immediately after the big bang during which the Universe expanded by a greater factor than it has since, and during which quantum fluctuations were blown up to astrophysical size and became the seeds for the formation of all galaxies and other structures in the Universe. The WMAP data are now the standard against which scientists in the world test other observational results or new theoretical models about how the Universe began.

http://adsabs.harvard.edu/abs/2009ApJS..180..330K
http://adsabs.harvard.edu/abs/2009ApJS..180..306D
http://adsabs.harvard.edu/abs/2009ApJS..180..296N
http://adsabs.harvard.edu/abs/2009ApJS..180..283W
http://adsabs.harvard.edu/abs/2009ApJS..180..265G
http://adsabs.harvard.edu/abs/2009ApJS..180..246H
http://adsabs.harvard.edu/abs/2009ApJS..180..225H

http://www.nasa.gov/home/hqnews/2006/mar/HQ_06097_first_trillionth_WMAP.html

Good illustration:
http://map.gsfc.nasa.gov/media/060915/060915_CMB_Timeline150.jpg

2. The Most Distant GRB

NASA's Swift satellite and an international team of astronomers have found a gamma-ray burst that smashes the previous record for the farthest object with a well measured distance. The event, called GRB 090423, occurred when the Universe was only 630 million years old -- less than five percent of its present age -- and 9.3 times smaller than its current size. The photons observed by the Swift satellite spent 13 billion years in transit. Once here, they were detectable only thanks to the superb sensitivity of the Swift satellite, and the remarkable intensity of gamma ray bursts, which are the brightest known explosions in the Universe. Gamma ray bursts like GRB 090423 arise from the deaths of some extremely massive, bright stars. The detection of GRB 090423 is the first direct observation of any star at so great a distance, and provides a first look at the early populations of stars that brought an end to the cosmic ``dark ages.'' Observing directly the death of a star very early in the Universe helps us understand how these stars formed, and also pinpoints the presumed location of the most distant galaxy yet. Finally, since a gamma ray burst explosion leaves behind a black hole, this discovery sets yet another record -- for the most distant black hole known.

http://arxiv.org/abs/0906.1577
http://arxiv.org/abs/0906.1578
http://www.nasa.gov/mission_pages/swift/bursts/cosmic_record.html

3. Jets in GRS 1915

Jets from supermassive black holes have been identified as a likely method for regulating the cooling of gas near the centers of galaxies and clusters of galaxies. This is important because the rate at which gas cools largely determines the rate at which stars form out of the gas. The regulation process also impacts the rate of growth of the black hole itself.

A new study using high resolution spectral data from NASA's Chandra X-ray Observatory looks at the famous Galactic black hole candidate GRS 1915+105 (GRS 1915 for short). This system contains a black hole about 14 times the mass of the Sun that is feeding off material from a nearby companion star. As material from the companion star swirls toward the black hole, an accretion disk forms around the black hole. GRS 1915 also contains a relativistic jet and shows a high degree of variability in its brightness; these features have led astronomers to call this system a ``microquasar'' because of the similarities it shares with the more distant and significantly more massive and luminous quasars.

The new Chandra investigation reveals that the jet in GRS 1915 may be periodically choked off when a hot wind, seen in X-rays, is driven off the accretion disk around the black hole. The wind shuts down the jet by depriving it of matter that would have otherwise fueled it. Conversely, once the wind dies down, the jet can re-emerge. The jet and wind around this black hole appear to be in a sort of tug of war. Sometimes one is winning and sometimes the other one gets the upper hand. The latest Chandra results also show that the wind and the jet carry about the same amount of matter away from the black hole. This is evidence that the black hole is somehow regulating its accretion rate, which may be related to the toggling between mass expulsion via either a jet or a wind from the accretion disk. Self-regulation is a common topic when discussing supermassive black holes, but this is the first clear evidence for it in stellar-mass black holes.

http://adsabs.harvard.edu/abs/2009Natur.458..481N
http://chandra.harvard.edu/press/09_releases/press_032509.html

4. Chandra Cluster Cosmology

Using NASA's Chandra X-ray Observatory, astronomers have provided new, independent evidence for the acceleration of the expansion of the Universe and with it, a new probe of the mysterious ``dark energy'' that is causing that acceleration. This work, which took years to complete, used the effect of the accelerated expansion on the formation on the most massive collapsed objects in the Universe, clusters of galaxies. Researchers used Chandra to observe the hot gas in dozens of clusters of galaxies, and thereby determined the variation in the distribution of the masses of clusters over time. Their results were consistent with accelerated expansion caused by dark energy.

These new results are consistent with the other methods probing dark energy (supernovae, cosmic microwave background radiation and the distribution of galaxies), and this both strengthens the case for the existence of dark energy and offers a new means of probing cosmic acceleration. In particular, the study of clusters provides the means of testing whether or not cosmic acceleration might be due to a breakdown of general relativity. So far, general relativity shows no signs of breaking down.

http://adsabs.harvard.edu/abs/2009ApJ...692.1060V
http://chandra.harvard.edu/press/08_releases/press_121608.html
Good image: http://chandra.harvard.edu/photo/2008/darkenergy/

5. Gamma-ray Pulsars

NASA's Fermi Gamma-ray Space Telescope has discovered 12 new gamma-ray-only pulsars and has detected gamma-ray pulses from 18 others. The finds are transforming our understanding of how these stellar cinders work. A pulsar is a rapidly spinning and highly magnetized neutron star, the crushed core left behind when a massive sun explodes. Pulsars are important tools for studying the physics of strong gravity environments. Most were found through their pulses at radio wavelengths, which are thought to be caused by narrow, lighthouse-like beams emanating from the star's magnetic poles. If the magnetic poles and the star's spin axis don't align exactly, the spinning pulsar sweeps the beams across the sky. Radio telescopes on Earth detect a signal if one of those beams happens to swing our way. A new class of gamma-ray-only pulsars shows that the gamma rays must form in a broader region than the lighthouse-like radio beam, far above the neutron star. Pulsars are phenomenal cosmic dynamos. Through processes not fully understood, a pulsar's intense electric and magnetic fields and rapid spin accelerate particles to speeds near that of light. Gamma rays let astronomers glimpse the particle accelerator's heart.

http://adsabs.harvard.edu/abs/2008Sci...322.1218A
http://www.nasa.gov/mission_pages/GLAST/news/dozen_pulsars.html

Outcome 3D.2 Progress in understanding how the first stars and galaxies formed, and how they changed over time into the objects recognized in the present Universe.

New observations from NASA telescopes have led to major advances in the understanding of the birth and evolution of galaxies. Periods of intense star formation in galaxies (called ``starbursts'') leave their mark on large and small galaxies alike. Dwarf galaxies are forming out of the flotsam of the early Universe, while bars appear to mark galaxy adulthood. Colossal collisions of galaxy clusters predicted by theory have now been seen.

1. Sweeping Starbursts

An analysis of archival images of small, or dwarf, galaxies taken by NASA's Hubble Space Telescope suggests that starbursts, intense regions of star formation, sweep across the whole galaxy and last 100 times longer than astronomers previously thought. The longer duration may affect how dwarf galaxies change over time, and therefore may shed light on galaxy evolution. Dwarf galaxies are considered to be the building blocks of the large galaxies seen today, so the length of starbursts is important for understanding how galaxies evolve. Hubble's superb resolution allowed astronomers to pick out individual stars in the galaxies and measure their brightness and color, two important characteristics astronomers use to determine stellar ages. By determining the ages of the stars, the astronomers could reconstruct the starburst history in each of the three galaxies they studied. This analysis shows that starburst activity in a dwarf galaxy happens on a global scale, with pockets of intense star formation propagating throughout the galaxy, like a string of firecrackers going off. The duration of all the starburst events in a single dwarf galaxy would total 200 million to 400 million years. Two of the galaxies, NGC 4068 and IC 4662, show active, brilliant starburst regions in the Hubble images. The most recent starburst in the third galaxy, NGC 4163, occurred 200 million years ago and has faded from view. About 300 million to 400 million years ago, star formation occurred in the outer areas of these galaxies. Then it began migrating inward as explosions of massive stars triggered new star formation in adjoining regions. Starbursts are still occurring in the inner parts of NGC 4068 and IC 4662.

http://adsabs.harvard.edu/abs/2009ApJ...695..561M
http://hubblesite.org/newscenter/archive/releases/2009/19/full/

2. BLAST and the IR Background

A recent study with the Balloon-borne Large Submillimeter Telescope (BLAST) has determined that the far-infrared background (FIRB), originally discovered by COBE in 1996, arises from the cumulative emission from large numbers of individual galaxies at redshifts $z > 1.2$. These individual galaxies (``starbursts'') are forming stars at a prodigious rate (100's of times the rate of star formation in the Milky Way), but because they are deeply enshrouded in dust, most of the optical starlight they produce is absorbed and re-radiated largely in the far infrared and submillimeter bands. Research in this area aims at a better understanding of these dust-enshrouded galaxies (including their evolutionary history), their relationship, if any, with other galaxies, and their associations with larger-scale structures in the Universe.

BLAST's extragalactic survey, taken at wavelengths of 0.25, 0.35, and 0.5 millimeters, provides new cosmological limits on the abundance and brightness of starburst galaxies for both the low- and high-redshift Universe. The BLAST team chose to map a particular region of the sky called the Great Observatories Origins Deep Survey-South (GOODS-South), which was studied at other wavelengths by NASA's three ``Great Observatories'' the Hubble, Spitzer, and Chandra Space Telescopes. In one epic 11-day balloon flight, BLAST found more than 10 times the total number of submillimeter starburst galaxies detected in a decade of ground-based observations. From this the BLAST team was able to conclude that their number counts of galaxies were sufficient to account for the FIRB.

http://adsabs.harvard.edu/abs/2009Natur.458..737D

3. Growing Up Barred

In a landmark study of more than 2,000 spiral galaxies from the largest galaxy census conducted by NASA's Hubble Space Telescope, astronomers found that so-called barred spiral galaxies, galaxies with large cigar-shaped bars of stars in their central regions (our Milky Way is a barred spiral), were more than 3 times less plentiful 7 billion years ago than they are today, in the local Universe. Bars are perhaps one of the most important catalysts for changing a galaxy. They force a large amount of gas towards the galactic center, fueling new star formation, building central bulges of stars, and feeding massive black holes. The study's results confirm the idea that bars are a sign of galaxies reaching full maturity as their ``formative years'' end. This new detailed look at the history of bar formation, made with Hubble's Advanced Camera for Surveys, provides clues to understanding how spiral galaxies evolve over time.

http://adsabs.harvard.edu/abs/2008ApJ...675.1141S
http://hubblesite.org/newscenter/archive/releases/galaxy/spiral/2008/29/full/
Good image:
http://hubblesite.org/newscenter/archive/releases/galaxy/spiral/2008/29/image/a/

4. Colliding Clusters

The most crowded collision of galaxy clusters ever seen has been identified by combining information from three different telescopes. Using data from NASA's Chandra X-ray Observatory, the Hubble Space Telescope, and the Keck Observatory on Mauna Kea, Hawaii, astronomers were able to determine the three-dimensional geometry and motion in the system MACSJ0717.5+3745 (or MACSJ0717 for short), located about 5.4 billion light years from Earth. They found that four separate galaxy clusters are involved in an active triple merger, the first time such a phenomenon has been documented.

In MACSJ0717, a 13-million-light-year-long filament of galaxies, gas and dark matter are pouring into a region already full of matter. As a consequence of the tremendous energy released by the collision, MACS0717 has one of the highest temperatures ever seen in such a system, about 20 keV. While the filament leading into MACJ0717 had been previously observed, the new results show for the first time that it was the source of this galactic pummeling. Although radial velocity information and X-ray/optical offsets indicate that all three mergers proceed along distinctly different directions, the partial alignment of the merger axes points to a common origin in the large-scale filament south-east of the cluster core. There is also tantalizing, if circumstantial, evidence for direct, large-scale heating of the intracluster medium by contiguous infall of low-density gas from the filament. Computer simulations show that the most massive galaxy clusters should grow in regions where large-scale filaments of intergalactic gas, galaxies, and dark matter intersect, and material falls inward along the filaments. The new multiwavelength data appear to confirm these simulations.

http://adsabs.harvard.edu/abs/2009ApJ...693L..56M
chandra.harvard.edu/press/09_releases/press_041609.html

5. A New Recipe for Dwarf Galaxies

NASA's Galaxy Evolution Explorer (GALEX) has, for the first time, identified dwarf galaxies forming out of nothing more than pristine gas likely leftover from the early Universe. Dwarf galaxies are relatively small collections of stars that often orbit around larger galaxies like our Milky Way. The findings surprised astronomers because most galaxies form in association with a mysterious substance called dark matter or out of gas containing metals. The infant galaxies spotted by GALEX are springing up out of gas that lacks both dark matter and metals. Though never seen before, this new type of dwarf galaxy may be common throughout the more distant and early Universe, when pristine gas was more pervasive. Astronomers spotted the unexpected new galaxies, which display the ultraviolet signature of young stars emanating from several clumps of gas inside the Leo Ring, a huge cloud of hydrogen and helium that traces a ragged path around two massive galaxies in the constellation Leo. The cloud is thought likely to be a primordial object, an ancient remnant of material that has remained relatively unchanged since the very earliest days of the Universe. Identified about 25 years ago by radio waves, the ring cannot be seen in visible light. Large, pristine clouds similar to the Leo Ring may have been more common throughout the early Universe, and consequently may have produced many dark-matter-lacking, dwarf galaxies yet to be discovered.

http://adsabs.harvard.edu/abs/2009Natur.457..990T
http://www.galex.caltech.edu/newsroom/glx2009-01r.html

6. Baby Boom Galaxy

Researchers using a number of Earth-based optical and radio telescopes and the Spitzer Space Telescope have discovered a new record-holder as the brightest starburst galaxy in the very distant Universe. The galaxy, dubbed the Baby Boom galaxy, is forming new stars at a rate of 1,000 to 4,000 per year, compared to the Milky Way's very modest 10 stars per year. The significance of this find is that the galaxy has been calculated to lie a whopping 12.3 billion light years away, which means that it's taken 12.3 billion years for the light we see from the galaxy to reach us. That's looking back to a time when the Universe was a mere 1.3 billion years old.

But to have so young a galaxy undergoing a major ``baby boom,'' forming most of its stars all at once in cosmic terms, seems to go against the most commonly held theory of galaxy formation. According to this theory, called the Hierarchical Model, galaxies build up their star totals over time by absorbing small pieces of galaxies, and not in one big burst as the Baby Boom galaxy appears to be doing. The question scientists must answer now is whether most massive galaxies formed early in the Universe like the Baby Boom galaxy, or whether it's an exception. Answering this question will help scientists determine to what degree the Hierarchical Model of galaxy formation still holds true, and will help to refine our understanding of how galaxies formed and how they have changed over the history of the Universe.

http://adsabs.harvard.edu/abs/2008ApJ...681L..53C
http://www.spitzer.caltech.edu/Media/releases/ssc2008-12/release.shtml

7. Globulars Form Where the Stars Are

Globular star clusters, dense bunches of hundreds of thousands of stars, have some of the oldest surviving stars in the Universe. A new study of globular clusters outside our Milky Way Galaxy has found evidence that these hardy pioneers are more likely to form in dense areas, where star birth occurs at a rapid rate, instead of uniformly from galaxy to galaxy. Astronomers used NASA's Hubble Space Telescope to identify over 11,000 globular clusters in the Virgo cluster of galaxies. Comprised of over 2,000 galaxies, the Virgo cluster is the nearest large galaxy cluster to Earth, located about 54 million light-years away. The sharp vision of Hubble's Advanced Camera for Surveys resolved the star clusters in 100 galaxies of various sizes, shapes, and brightness, even in faint, dwarf galaxies. The team found a bounty of globular clusters in most dwarf galaxies within 3 million light-years of the cluster's center, the densest part of the galaxy cluster where the giant elliptical galaxy M87 resides. The number of globular clusters in these dwarfs ranged from a few dozen to several dozen, but these numbers were surprisingly high for the low masses of the galaxies they inhabited. By contrast, dwarfs in the outskirts of the cluster had fewer globulars. Studying globular star clusters is critical to understanding the early, intense star-forming episodes that mark galaxy formation.

http://adsabs.harvard.edu/abs/2008ApJ...681..197P
http://hubblesite.org/newscenter/archive/releases/star-cluster/2008/30/

Outcome 3D.3 Progress in understanding how individual stars form and how those processes ultimately affect the formation of planetary systems.

The Spitzer Space Telescope, one of NASA's Great Observatories, has been especially prolific in star formation science this year, providing new insights into how stars form and how their natal disks of dust and gas go on to form their planetary systems.

1. Generations of Stars Pose for Family Portrait

A new image from NASA's Spitzer Space Telescope tells a tale of life and death amidst a rich family history. The striking infrared picture shows a colorful cosmic cloud, called W5, studded with multiple generations of blazing stars. It also provides dramatic new evidence that massive stars -- through their brute winds and radiation -- can trigger the birth of stellar newborns.

The most massive stars in the Universe form out of thick clouds of gas and dust. The stars are so massive, ranging from 15 to about 60 times the mass of our sun, that some of their material slides off in the form of winds. The scorching-hot stars also blaze with intense radiation. Over time, both the wind and radiation blast away surrounding cloud material, carving out expanding cavities. Astronomers have long suspected that the carving of these cavities causes gas to compress into successive generations of new stars. As the cavities grow, it is believed that more and more stars arise along the cavities' expanding rims. The result is a radial "family tree" of stars, with the oldest in the middle of the cavity, and younger and younger stars farther out.

Astronomers used Spitzer's infrared vision to peer through the dusty clouds in W5 and get a better look at the stars' various stages of evolution. They found that stars within the W5 cavities are older than stars at the rims, and even older than stars farther out past the rim. This ladder-like separation of ages provides some of the best evidence yet that massive stars do, in fact, give rise to younger generations. Millions of years from now, the massive stars in W5 will die in tremendous explosions. When they do, they will destroy some of the young nearby stars -- the same stars they might have triggered into being.

http://adsabs.harvard.edu/abs/2008ApJ...688.1142K
http://www.spitzer.caltech.edu/Media/releases/ssc2008-15/release.shtml
Good image: http://www.spitzer.caltech.edu/Media/releases/ssc2008-15/ssc2008-15a.shtml

2. Baby Stars Finally Found in Jumbled Galactic Center

Astronomers have at last uncovered newborn stars at the frenzied center of our Milky Way galaxy. The discovery was made using the infrared vision of NASA's Spitzer Space Telescope. The heart of the Milky Way is cluttered with stars, dust and gas, and at its very center, a supermassive black hole. Conditions there are harsh, with fierce stellar winds, powerful shock waves and other factors that make it difficult for stars to form, yet it is stuffed with 10 percent of all the gas in the galaxy -- and loads and loads of stars.

Before now, there were only a few clues that stars can form in the Galaxy's core. Astronomers had found clusters of massive adolescent stars, in addition to clouds of charged gas -- a sign that new stars are beginning to ignite and ionize surrounding gas. Past attempts had been unsuccessful in finding newborn stars, but by scanning large Spitzer mosaics of our galactic center, astronomers narrowed in on more than 100 candidates. These candidate newborns were examined with Spitzer's spectrograph - an instrument that breaks light apart to reveal its rainbow-like array of infrared colors. Molecules around stars leave imprints in their light, which the spectrograph can detect.

The results revealed three stars with clear signs of youth, for example, certain warm, dense gases. These youthful features are found in other places in the Galaxy where stars are being formed. The young stellar objects are all less than about 1 million years old. They are embedded in cocoons of gas and dust, which will eventually flatten to disks that, according to theory, later lump together to form planets.

http://adsabs.harvard.edu/abs/2009AAS...21431506A
http://www.spitzer.caltech.edu/Media/releases/ssc2009-13/release.shtml
Good image: http://www.spitzer.caltech.edu/Media/releases/ssc2009-13/ssc2009-13a.shtml

3. Cool Stars Have Different Mix of Life-Forming Chemicals

Life on Earth is thought to have arisen from a hot soup of chemicals. Does this same soup exist on planets around other stars? A new study from NASA's Spitzer Space Telescope hints that planets around stars cooler than our sun might possess a different mix of potentially life-forming, or "prebiotic," chemicals. Astronomers used Spitzer to look for the prebiotic chemical hydrogen cyanide in the planet-forming material swirling around different types of stars. Hydrogen cyanide is a component of adenine, which is a basic element of DNA. DNA can be found in every living organism on Earth. The researchers detected hydrogen cyanide molecules in disks circling yellow stars like our sun -- but found none around cooler and smaller stars, such as "M-dwarfs" and "brown dwarfs" common throughout the Universe.

Young stars are born inside cocoons of dust and gas, which eventually flatten to disks. Dust and gas in the disks provide the raw material from which planets form. Scientists think the molecules making up the primordial ooze of life on Earth might have formed in such a disk. Prebiotic molecules, such as adenine, are thought to have rained down to our young planet via meteorites that crashed on the surface. Could the same life-generating steps take place around other stars? To find out, astronomers used Spitzer's infrared spectrograph, revealing signatures of chemicals in a sample of stars about one to three million years old, an age when planets are thought to be growing. They found that the cool stars, both the

M-dwarf stars and brown dwarfs, showed no hydrogen cyanide at all, while 30 percent of the sun-like stars did.

The team did detect their baseline molecule, acetylene, around the cool stars, demonstrating that the experiment worked. This is the first time that any kind of molecule has been spotted in the disks around cool stars. The findings have implications for planets that have recently been discovered around M-dwarf stars. Some of these planets are thought to be large versions of Earth, the so-called super Earths, but so far none of them are believed to orbit in the habitable zone, where water would be liquid. If such a planet is discovered, could it sustain life? With the new Spitzer results, astronomers have another piece of data to consider: these planets might be deficient in hydrogen cyanide, a molecule thought to have eventually become a part of us.

http://adsabs.harvard.edu/abs/2009ApJ...696..143P
http://www.spitzer.caltech.edu/Media/releases/ssc2009-09/release.shtml

4. White Dwarfs Shed Light on Planet Birth

Astronomers are finding an unexpected place to study the evolution of planets: around stars in the end stages of their lives. Observations made with the Spitzer Space Telescope have revealed six white dwarf stars to be surrounded by the remains of shredded asteroids.

Planets and asteroids form out of the dusty material that swirls around newborn stars and sticks together, growing into planets, with asteroids as smaller leftovers. When a star like our sun nears the end of its life, it puffs up into a ``red giant'' that consumes its inner planets and jostles the orbits of the rest. The star ultimately blows off its outer layers, its core shrinking to a dense, hot remnant called a white dwarf. And if a jostled asteroid wanders too close, the star's gravity will shred it into tiny pieces and dust that absorb the star's energy and re-emit it as heat, or infrared light, that Spitzer can detect. That's what astronomers say happened in the case of the six newly-observed white dwarfs, as well as two observed previously.

Spitzer's infrared spectrograph, an instrument that breaks light into its component wavelengths or energies, can also identify the chemical makeup of the dust, and finds that the material contains a glassy silicate similar to olivine, a mineral commonly found on Earth, but little carbon. These results generally match what scientists see in asteroids circling our own sun.

What these dying stars are revealing is that the same materials that make up Earth and the other rocky bodies orbiting the sun could be common in the Universe. And if the materials are out there, so may be other rocky planets, perhaps even other Earths. Spitzer's white dwarfs may thus help to shed light on the story of planet formation in the Universe.

http://adsabs.harvard.edu/abs/2009AJ....137.3191J
http://www.spitzer.caltech.edu/Media/releases/ssc2009-01/release.shtml

5. Shocking Planetary Ingredients

Recent Spitzer findings suggest that one way to whip up planetary ingredients is to shock them into existence. Researchers using the Spitzer Space Telescope to study five planet-forming disks around young stars have found the spectral signatures of silicate crystals requiring high heating followed by rapid cooling in order to form. These silicate crystals, essentially high-temperature forms of quartz called cristobalite and tridymite, are found in volcanic flows on Earth and in some meteorites that land here, and are known to exist in comets. But how do they form around stars in dusty disks that are normally cooler than required to forge these crystals?

Scientists propose that flash heating caused by shock waves is the answer. When clouds of gas swirling around stars at high speeds collide, the researchers think they can generate shock waves, or supersonic waves of pressure, that can heat areas of the disk to temperatures high enough to produce the silicate crystals. Some theorists think that shock waves might also accompany the formation of giant planets.

The findings are in agreement with local evidence from our own solar system. Spherical pebbles, called chondrules, found in ancient meteorites that fall to Earth are also thought to have been crystallized by shock waves in our solar system's young planet-forming disk. With the help of Spitzer, scientists are finding evidence for similar processes in planet-forming disks around other stars, as they continue to study how those processes affect the formation of planetary systems.

http://adsabs.harvard.edu/abs/2009ApJ...690.1193S

http://www.spitzer.caltech.edu/Media/releases/ssc2008-20/release.shtml

Outcome 3D.4 Progress in creating a census of extra-solar planets and measuring their properties.

This year, two new techniques have been added to astronomers' toolkits for discovering planets: direct imagery and astrometry (measurements of how a star wobbles on the plane of the sky). As each year goes by, we learn more about the properties of exoplanets. The Jupiter-sized planet HD 189733b was discovered this decade, then its atmosphere was found to contain water vapor, then later methane. Now, Hubble Space Telescope observations show that its atmosphere also contains carbon dioxide.

1. Hubble Directly Observes a Planet Orbiting Another Star

NASA's Hubble Space Telescope has taken the first visible-light snapshot of a planet circling another star. Estimated to be no more than 3 times Jupiter's mass, the planet, called Fomalhaut b, orbits the bright southern star Fomalhaut, located in the constellation Piscis Austrinus, or the Southern Fish.

In 2004, the coronagraph in the High Resolution Camera on Hubble's Advanced Camera for Surveys produced the first-ever resolved visible-light image of the region around Fomalhaut. It clearly showed a ring of protoplanetary debris approximately 21.5 billion miles across and having a sharp inner edge. This large debris disk is similar to the Kuiper Belt, which encircles the solar system and contains a range of icy bodies from dust grains to objects the size of dwarf planets, such as Pluto.

The Hubble observers proposed in 2005 that the ring was being gravitationally modified by a planet lying between the star and the ring's inner edge. Now, Hubble has actually photographed a point source of light lying 1.8 billion miles inside the ring's inner edge. This planet orbits Fomalhaut at a distance about 10 times the distance of the planet Saturn from our Sun.

http://adsabs.harvard.edu/abs/2008Sci...322.1345K
http://www.nasa.gov/mission_pages/hubble/science/fomalhaut.html
Good image:
http://www.nasa.gov/images/content/289900main_fomalhaut_actuallabel_HI.jpg

2. Hubble Finds Carbon Dioxide on an Extrasolar Planet

NASA's Hubble Space Telescope has discovered carbon dioxide in the atmosphere of a planet orbiting another star. This is an important step along the trail of finding the chemical biotracers of extraterrestrial life as we know it. The Jupiter-sized planet, called HD 189733b, is too hot for life. But the Hubble observations are a proof-of-concept demonstration that the basic chemistry for life can be measured on planets orbiting other stars. Organic compounds can also be a by-product of life processes, and their detection on an Earth-like planet may someday provide the first evidence of life beyond Earth. Astronomers used Hubble's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) to study infrared light emitted from the planet, which lies 63 light-years away. Gases in the planet's atmosphere absorb certain wavelengths of light from the planet's hot glowing interior. Astronomers identified not only carbon dioxide, but also carbon monoxide. The molecules leave their own unique spectral fingerprint on the radiation from the planet that reaches Earth. This is the first time a near-infrared emission spectrum has been obtained for an exoplanet.

http://adsabs.harvard.edu/abs/2009ApJ...690L.114S
http://hubblesite.org/newscenter/archive/releases/star/extrasolar%20planets/2008/41/full/

3. Astronomers Observe Planet with Wild Temperature Swings

NASA's Spitzer Space Telescope has observed a planet that heats up to red-hot temperatures in a matter of hours before quickly cooling back down. The "hot-headed" planet is HD 80606b, a gas giant that orbits a star 190 light-years from Earth. It was already known to be quite unusual, with an orbit shuttling it nearly as far out as Earth is from our sun, and much closer in than our planet Mercury. Astronomers used Spitzer to measure heat emanating from the planet as it whipped behind and close to its star. In just six hours, the planet's temperature rose from 800 to 1,500 Kelvin (980 to 2,240 degrees Fahrenheit). The extreme temperature swing indicates that the air near the planet's gaseous surface must quickly absorb and lose heat. This type of atmospheric information revealing how a planet responds to sudden changes in heating -- an extreme version of seasonal change -- had never been obtained before for any exoplanet.

http://adsabs.harvard.edu/abs/2009Natur.457..562L
http://www.spitzer.caltech.edu/Media/releases/ssc2009-02/release.shtml