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Is there light matter

Answer 1: I'm not sure if other scientists would answer this question why I do it, but I think this is a very philosophical question that depends on what you mean by matter. If you are asking if the light carries energy and momentum, the answer is definitely yes. But you might want to say, is light a particle? Quantum mechanics make this question a bit cloudy: everything, including light, in quantum mechanics is both a particle and a wave (actually, it's something defined that has wave-like and particle-like properties). So if you think matter is something that's made of particles, it's all important or not depending on how you look at it. In fact, I think that's the wrong way to think about it. What you really want to know is: does light have properties that other types of particles don't have? The answer is yes. Most of the particles that make up everything we traditionally call matter are called fermions. Things like photons are called bosons. There are many properties not shared by fermions and bosons - one is that two fermions cannot exist in exactly the same state. Two bosons, on the other hand, can exist in the same state. Although there are composite composite particles composed of smaller fermions that behave like bosons, the fundamental particles that are bosons - we believe are fundamental, anyway - behave differently than the fundamental particles that are fermions. To make a long short history, these differences in properties are responsible for the way these particles manifest themselves on large scales in the everyday world, where quantum mechanics is not important. A boson appears as a kind of field or wave, and can be directly related to one of the four forces (electromagnetism, gravity, strong force, and weak force) while fermions form individual particles such as atoms. Therefore, there is definitely a sense in which light is very, very different from electrons or protons. I'm not sure if I'd call light matter or not, though. You can certainly do some of the things you would think that only traditional matter can do - like carrying momentum and transferring it in a collision. But it certainly has some properties that are fundamentally different from the things that make up traditional matter (things that are made of atoms). Light, or Visible Light, commonly refers to electromagnetic radiation that can be detected by the human eye. The entire electromagnetic spectrum is extremely wide, ranging from low-energy radio waves with wavelengths measured in meters, to high-energy gamma rays with wavelengths that are less than 1 x 10-11 Electromagnetic radiation, as the name suggests, describes fluctuations in electric and magnetic fields, transporting energy at the speed of light (which is 300,000 km/sec through a vacuum). Light can also be described in terms of a flow of photons, packets of energy without mass, each with wavy properties at the speed of light. A photon is the least (quantum) amount of energy that can be transported, and it was the understanding that light traveled in discrete quanta that were the origins of Quantum Theory. Figure 1: The electromagnetic spectrum, highlighting the narrow window of visible light that is detectable by the human eye. Visible light is not inherently different from other parts of the electromagnetic spectrum, except that the human eye can detect visible waves. This actually corresponds only to a very narrow window of the electromagnetic spectrum, ranging from about 400 nm for violet light to 700 nm for red light. Radiation less than 400 nm is known as Ultra-Violet (UV) and radiation over 700 nm is known as infrared (IR), none of which can be detected by the human eye. However, advanced scientific detectors, such as those manufactured by Andor, can be used to detect and measure photons in a much wider range of the electromagnetic spectrum, and also up to much lower amounts of photons (i.e. much weaker light levels) than the eye can detect. How does light interact with matter? It is no coincidence that humans can 'see' the light. Light is our main means of perceiving the world around us. In fact, in a scientific context, light detection is a very powerful tool for polling the universe around us. As light interacts with matter it can be altered, and by studying the light that has originated or interacted with matter, many of the properties of that matter can be determined. It is through the study of light that, for example, we can understand the composition of stars and galaxies that are many light-years away or observe in real time the microscopic physiological processes that occur within living cells. Matter is made up of atoms, ions or molecules and it is through their interactions with light that it gives rise to the various phenomena that can help us understand the nature of matter. Atoms, ions, or molecules have defined energy levels, usually associated with the energy levels that electrons in matter can contain. Light is sometimes generated by matter, or more commonly, a photon of light can interact with energy levels in several ways. Figure 2 – Example of Jablonski diagram, illustrating the transitions between the various energy states of molecules after interaction with a photon. We can represent the energy levels of matter in a scheme known as a Jablonski diagram, depicted in Figure 2. An atom or molecule in the lowest possible energy state, known as the ground state, can absorb a photon that that the atom or molecule meets a higher energy level state, known as an excited state. Therefore, matter can absorb light from characteristic wavelengths. The atom or molecule normally remains in an excited state just to very short time and relaxes back to the state of the ground by a number of mechanisms. In the example shown, the initially excited atom or molecule loses energy, not emitting a photon, but relaxes to the intermediate state of lower energy by internal processes that normally heat matter. The intermediate energy level is then relaxed to the ground state by the emission of a lower energy photon (longer wavelength) than the photon that was initially absorbed. How do we study matter using light? Since photons that are absorbed or emitted by matter will be of a characteristic energy, when the light that has interacted with matter is subsequently divided into its constituent wavelengths using a spectrograph, the resulting spectral signature tells us a lot about the matter itself. The broad field of spectroscopy constitutes a multitude of spectroscopic techniques, such as raman spectroscopy, absorption/transmission/reflection spectroscopies, atomic spectroscopy, laser-induced decomposition spectroscopy (LIBS) and transient absorption spectroscopy, providing a wealth of useful information about the scientific properties of atoms and molecules, as well as being able to very specifically identify presence and determine the amount of materials. Find out more about advanced methods for detecting light Not to be confused with Antimatter, Dark Energy, Dark Fluid or Dark Flow. For other uses, see Dark Matter (disambiguation). Hypothetical form of matter comprising most of the matter in the universe Part of a series on Physical Cosmology Big Bang Universe Age of the Universe Chronology of the Universe Early Universe Planck period Great era unification electroweak era Quark epoch Hadron epoch Lepton epoch Epoch Epoguía Big Bang nucleosíntesis Inflation Ages Stelliferous Was Background Radiation Background (CBR) Gravitational Wave Background (GWB) Cosmic Microwave Fund (CMB) Cosmic Neutrino Fund (CNB) Cosmic Infrared Fund (INB) Expansion The Law of the Future Hubble ? Redshift Expansion of the universe Accelerating the expansion of the Comoving universe and the appropriate metric distances FLRW Friedmann Equations Inhomogene Cosmology Future of an Expanding Universe Final Destination of the Universe Death by Heat of the Big Rip Universe Big Crunch Big Bounce Components Components Structure Lambda-CDM Barionic Matter Model Exotic Matter Energy Negative Energy Vacuum Energy Vacuum Energy Radiation Background Radiation Dark Energy Quintaessence Energy Ghost Matter Dark Matter Hot Dark Matter Dark Radiation Dark Fluid Radiation Mirror Structure Structure Formation Galaxy Large-scale structure Large quadsar Galaxy Galaxy Filament Galaxy Group Galaxy Group Local Group Galaxy Dark matter halo Star cluster Solar system Void Experiments BOOMERanG Cosmic Background Explorer (COBE) Dark Energy Survey Euclid Illustris project Vera C. Observatory of the Rubin Observatory Space Observatory Sloan Digital Sky Survey (SDSS) 2dF Galaxy Redshift Survey (2dF) UniverseMachine Wilkinson Microwave AnisotropyProbe (WMAP) Scientists Aaronson Alfvén Alpher Bharadwaj Copernicus by Sitter Dicke Eddington Ehlers Einstein Ellis Friedn Gamow Guth Guth Hubble-tre Linde Mather n Schmidt Schwarzschild Smoot Starobinsky Steinhardt Suntzeff Suntzeff Tolman Wilson Zeldovich Subject History Discovery of Cosmic Radiation of Air Furnaces History of Big Bang Theory Religious Interpretations of Big Bang Theory Cosmology Timeline The category Astronomy portalvte dark matter is a form of matter that is believed to represent approximately 85% of matter in the universe and about a quarter of its total mass-energy density or about 2,241×10-27 kg/m3. Their presence is implicit in a variety of astrophysical observations, including gravitational effects that cannot be explained by accepted theories of gravity unless more matter is present than can be seen. For this reason, most experts think that dark matter is abundant in the universe and has had a strong influence on its structure and evolution. Dark matter is called dark because it does not appear to interact with the electromagnetic field, which means that it does not absorb, reflect or emit electromagnetic radiation, and is therefore difficult to detect. [1] Primary evidence of dark matter comes from calculations showing that many galaxies would fly separately, or that they would not have formed or would not have moved as they do, if they did not contain a large amount of invisible matter. [2] Other lines of evidence include observations in gravitational lens[3] and cosmic microwave background, along with astronomical observations of the current structure of the observable universe, the formation and evolution of galaxies, the location of mass during galactic collisions,[4] and the movement of galaxies within cluster galaxies. In the standard Lambda-CDM model of cosmology, the total mass-energy of the universe contains 5% ordinary matter and energy, 27% dark matter and 68% of a form of energy known as dark energy. [8] Dark matter therefore makes up 85% of the total mass mass, while dark energy plus dark matter makes up 95% of the total mass-energy content. [12] Because dark matter has not yet been directly observed, if any, it should hardly interact with ordinary baryonic matter and except through gravity. Most dark matter is thought to be non-baric in nature; may be composed of some uncovered subatomic particles. [b] The main candidate for dark matter is a new guy that has not yet been discovered, in particular massive particles weakly interacting (WIMP). [13] Many experiments to directly detect and study dark matter particles are being actively carried out, but none have yet been successful. [14] Dark matter is classified as cold, hot or hot according to its speed (more precisely, its free transmission length). Today's models favor a cold dark matter scenario, in which structures emerge from gradual particle accumulation. Although the existence of dark matter is generally accepted by the scientific community,[15] some astrophysicists, intrigued by certain observations that do not fit into some dark matter theories, advocate several modifications of the standard laws of general relativity, such as modified Newtonian dynamics, tensor-vector-scalar gravity, or entropic gravity. These models attempt to take into account all observations without invoking additional non-barionic matter. [16] Beyond the standard modelThe standardThe CMS particle collider of the Large Hadron Collider representing a Higgs boson produced by colliding protons that decompose into hadron and electron jets Model Model Standard Hierarchy Hierarchy Problem Dark matter Dark Energy Quintessence Ghost Energy Dark Radiation Dark Photon Dark Problem Constant Cosmological Problem Problem Strong CP Problem Neutrino Oscillation Theories All The hypothesis of the mathematical universe Great Unified Theory Dirac Marine Technicolor Kaluza–Klein Quantum Field Theory Quantum Field Theory in Curved Space Thermal Quantum Field Theory Topological Quantum Field Theory Quantum Field Theory conforming to Two-dimensional Formed Field Theory Liouville Field Theory 6D Field Theory (2.0) Supercon Field Theoryformal Quantum Mechanics Quantum Cosmology Cosmology Brane String Theory String Theory Mirror Theory Randall-Sundrum Matter Model Broglie-Bohm Stochastic Theory Eigenstate The Yang-Mills Theory Hypothesis N - 4 Supersimmetric Yang–Mills Theory Twistor String Theory Dark Fluid Superfluid Vacuum Theory Doubly Special Relativity of Sitter Invariant Special Relativity Thermodynamics Thermodynamic Thermodynamics Electronic Physics Clueless Physics Meter Theory Theory of Gravitation Delcatyl Theory of Obstogravation Theory Hidden Wave Theory Pilot Wave Theory Mirror CPT Supersymmetry Quantum Geometry Loop Cosmo Causal Onrication Causal Triangulation fermion systems Causal sets Event symmetry Quantum gravity conical Microclassical quantum gravity Vacuum Superfluid Experiments ANNIE Gran Sasso INO LHC SNO Super-K Tevatron NOvA vte History Early History The dark matter hypothesis has an elaborate history. [17] In a talk given in 1884,[18] Lord Kelvin estimated the of dark bodies in the Milky Way of observed velocity dispersion of stars orbiting around the center of the galaxy. By using these measurements, he estimated the mass of the galaxy, which determined that it is different from the mass of visible stars. Lord Kelvin concluded so many of our stars, perhaps a vast majority of them, can be dark bodies. [20] In 1906 Henri Poincaré in The Milky Way and Gas Theory used dark matter, or matiére obscure in French, in the discussion of Kelvin's work. [20] The first to suggest the existence of dark matter using stellar speeds was Dutch astronomer Jacobus Kapteyn in 1922. [23] Dutchman and radio astronomy pioneer Jan Oort also hypothesized the existence of dark matter in 1932. [25] Oort was studying stellar movements in the local galactic neighborhood and found that mass on the galactic plane must be greater than observed, but this measurement was later determined to be erroneous. [26] In 1933, Swiss astrophysicist Fritz Zwicky, who studied galaxy clusters while working at the California Institute of Technology, made a similar inference. [28] Zwicky applied the virial theorem to the Coma Cluster and obtained evidence of invisible mass he called dunkle Materie ('dark matter'). Zwicky estimated its mass based on the movements of galaxies near its edge and compared it to an estimate based on its brightness and number of galaxies. He estimated that the cluster had about 400 times more mass than was visually observable. The gravitational effect of visible galaxies was too small for such rapid orbits, so the mass must be hidden from view. Based on these conclusions, Zwicky inferred that an undiscovered species provided the associated mass and gravitational attraction to hold the cluster together. [29] Zwicky's estimates were out by more than one order of magnitude, mainly due to an outdated value of the Hubble constant; [30] The same calculation today shows a smaller fraction, using larger values for the light mass. However, Zwicky correctly concluded from his calculation that most of the matter was dark. [20] Other indications that the mass-light ratio was not a unit came from measurements of the galaxy's rotation curves. In 1939, Horace W. Babcock reported the rotation curve for the Andromeda Nebula (now known as the Andromeda galaxy), suggesting that the mass-luminosity ratio increased radially. [31] He attributed it to the absorption of light within the galaxy or to the modified dynamics in the outer parts of the spiral and not to the lost matter it had discovered. Following Babcock's 1939 report of unexpectedly rapid rotation on the outskirts of the galaxy and of a mass-light ratio of 50; in 1940 Jan Oort discovered and wrote about the large non-visible halo of NGC 3115. [32] Vera Rubin,Kent Ford and Ken Freeman's work in the 1960s and 1970s[33] provided more evidence, also using galaxy rotation curves. [36] Rubin and Ford worked with a new spectrograph to measure the velocity curve of the spiral galaxies bordered more accurately. [36] This result was confirmed in 1978. [37] Influential work presented the results of Rubin and Ford in 1980. [38] They showed that most galaxies must contain approximately six times more dark than visible mass; [39] Thus, around 1980 the apparent need for dark matter was widely recognized as a major unresolved problem in astronomy. [34] At the same time Rubin and Ford were exploring optical rotation curves, radio astronomers were making use of new radio telescopes to map the 21 cm atomic hydrogen line in nearby galaxies. The radial distribution of interstellar atomic hydrogen (H-I) often extends to much larger galactic radii than those accessible by optical studies, extending the sampling of rotation curves – and therefore from total mass distribution – to a new dynamic regimen. Andromeda's early mapping with the 300-foot telescope at Green Bank[40] and the 250-foot plate at Jodrell Bank[41] already showed that the H-I rotation curve did not track Keplerian's expected decline. As the most sensitive receivers became available, Morton Roberts and Robert Whitehurst[42] were able to track Andromeda's rotational speed at 30 kpc, well beyond optical measurements. Illustrating the advantage of plotting the gas disc in large spokes, Figure 16 of that document[42] combines optical data[36] (the cluster of points in the radii of less than 15 kpc with a single point later) with H-I data between 20-30 kpc, exhibiting the flatness of the rotation curve of the outer galaxy; the solid curve that reaches its maximum point in the center is the density of the optical surface, while the other curve shows the accumulated mass, increasing linearly to the outermost extent. At the same time, the use of interferometric matrices for H-I extragalactic spectroscopy was being developed. In 1972, David Rogstad and Seth Shostak[43] published H-I rotation curves of five spirals mapped with the Owens Valley interferometer; the rotation curves of the five were very flat, suggesting very large values of mass-light ratio on the outer parts of their extended H-I discs. A current of observations in the 1980s supported the presence of dark matter, including the gravitational lens of background objects by clusters of galaxies,[44] the distribution of hot gas temperature in galaxies and clusters, and the pattern of anisotropies at the cosmic microwave bottom. According to consensus among cosmologists, dark matter is mainly composed a type not yet characterized as a subatomic particle. [45] The search for this particle, by a variety of means, is one of the greatest efforts in particle physics. [14] Technical definition See also: Friedmann equations In standard cosmology, matter is anything whose energy density is scaled with the inverse inverse scale factor, i.e. ∝ a-3. This contrasts with radiation, which scales as the fourth inverse power of the scale factor ∝ a-4, and a cosmological constant, which is independent of a. These scales can be intuitively understood: For an ordinary particle in a cubic box, doubling the length of the sides of the box decreases the density (and therefore energy density) by a factor of 8 (or 23). In the case of radiation, the energy density decreases by a factor of 16 (or 24), because any act whose effect increases the scale factor must also cause a proportional red displacement. A cosmological constant, as an intrinsic property of space, has a constant energy density regardless of the volume considered. [46] In principle, dark matter means all components of the universe that are not visible, but still obey ∝ a-3. In practice, the term dark matter is often used to mean only the non-baryonic component of dark matter, i.e. excluding missing barions. Context will generally indicate what meaning is intended. Observational Evidence Game Media This artist's impression shows the expected distribution of dark matter in the Milky Way galaxy as a blue halo of material surrounding the galaxy. [47] Galaxy Rotation Curves Main Article: Galaxy Rotation Curve Rotation Curve of a Typical Spiral Galaxy: Predicted (A) and Observed (B). Dark matter can explain the flat appearance of the velocity curve to a large radius. The arms of spiral galaxies revolve around the galactic center. The luminous mass density of a spiral galaxy decreases as it goes from center to outskirts. If the light mass were all matter, then we can model the galaxy as a point mass in the center and test masses orbiting around it, similar to the Solar System. [d] From Kepler's Second Law, rotational speeds are expected to decrease with the distance from the center, similar to the Solar System. This is not observed. [48] Instead, the rotation curve of the galaxy remains flat as the distance from the center increases. If Kepler's laws are correct, then the obvious way to resolve this discrepancy is to conclude that the mass distribution in spiral galaxies is not similar to that of the Solar System. In particular, there is a lot of non-luminous matter (dark matter) on the outskirts of the galaxy. Speed Dispersions Main article: Speed scattering stars in linked systems must obey the virial theorem. The theorem, along with the measured speed distribution, can be used to measure mass distribution in a linked system, such as elliptical galaxies or Globular. With a few exceptions, the speed dispersion estimates of elliptical galaxies[49] do not match the expected velocity dispersion of the observed mass distribution, even assuming complicated distributions of stellar orbits. [50] As with galaxy rotation curves, the obvious way to resolve the discrepancy discrepancy to postulate the existence of non-luminous matter. Galaxy clusters Galaxy clusters are particularly important for dark matter studies, as their masses can be estimated in three independent ways: From scattering at radial speeds of galaxies within the clusters of X-rays emitted by hot gas in clusters. From the X-ray energy spectrum and the flow, temperature and density of the gas can be estimated, thus giving the pressure; assuming that the pressure and severity balance determine the mass profile of the cluster. The gravitational lens (usually from more distant galaxies) can measure cluster masses without relying on dynamic observations (e.g. velocity). Generally, these three methods reasonably agree that dark matter exceeds visible matter by approximately 5 to 1. [51] Gravitational Lens Strong Gravitational Lenses observed by the Hubble Space Telescope in Abell 1689 indicates the presence of dark matter – enlarge the image to see the lens arches. Play media Rotating disc galaxy models in the present (left) and ten billion years ago (right). In today's galaxy, dark matter, shown in red, is more concentrated near the center and rotates faster (exaggerated effect). Dark matter map for a sky patch based on the gravitational lens analysis of a Kilo-Degree survey. [52] One of the consequences of general relativity is massive objects (such as a cluster of galaxies) that lie between a more distant source (such as a quasar) and an observer must act as a lens to bend light from this source. The more massive an object is, the more lens will be observed. The strong lens is the observed distortion of the background galaxies in arcs when their light passes through a gravitational lens. It has been observed around many distant groups including Abell 1689. [53] By measuring the distortion geometry, the mass of the intermediate cluster can be obtained. In the dozens of cases in which this has been done, the mass-light ratios obtained correspond to the dynamic measurements of dark matter of the clusters. [54] The lens can result in multiple copies of an image. By analyzing the distribution of multiple copies of images, scientists have been able to deduce and map the distribution of dark matter around the MACS J0416.1-2403 galaxy cluster. [56] The weak gravitational lens investigates the tiny distortions of galaxies, using statistical analysis of vast galaxy surveys. By examining the apparent deformation of the shear of adjacent background galaxies, the average distribution of dark matter can be characterized. The mass-light correspond to dark matter densities predicted by other large-scale structure measurements. [57] Dark matter does not bend the light itself; mass (in this case the mass of dark matter) doubles the space-time. Light follows the curvature of space-time, resulting in the lens effect. [59] Cosmic cosmic microwave Main article: Cosmic microwave background Although both dark matter and ordinary matter are matter, they do not behave in the same way. In particular, in the early universe, ordinary matter was ionized and interacted strongly with radiation through Thomson's dispersal. Dark matter does not interact directly with radiation, but it does affect the WBC by its gravitational potential (mainly on a large scale), and by its effects on the density and speed of ordinary matter. Disturbances of ordinary and dark matter, therefore, evolve differently over time and leave different footprints on the cosmic microwave background (CMB). The cosmic microwave background is very close to a perfect black body, but contains very small temperature anisotropies of a few parts in 100,000. A map of the sky of anisotropies can be broken down into a spectrum of angular power, which is observed to contain a series of acoustic peaks in almost equal spacing but different heights. The series of peaks can be predicted for any assumed set of cosmological parameters using modern computer codes such as CMBFAST and CAMB, and the coincidence of theory with data therefore restricts cosmological parameters. [60] The first peak mainly shows the density of baryonic matter, while the third peak relates mainly to the density of dark matter, measuring the density of matter and the density of atoms. [60] CMB anisotropy was first discovered by COBE in 1992, although this had too thick a resolution to detect acoustic peaks. After the discovery of the first acoustic peak by the BOOMERanG balloon-transmitted experiment in 2000, the power spectrum was accurately observed by WMAP in 2003-2012, and even more precisely by the Planck spacecraft in 2013-2015. The results support the Lambda-CDM model. [62] The observed CMB angular power spectrum provides powerful evidence in support of dark matter, as its precise structure is well adjusted by the Lambda-CDM model,[62] but difficult to reproduce with any competitive model, such as modified Newtonian dynamics (MOND). [63] Formation of the structure Main article: 3D map of large-scale distribution structure formation of dark matter, reconstructed from weak gravitational lens measurements with the Hubble Space Telescope. [64] The formation of the structure refers to the post-Big Bang period when density disturbances collapsed to form stars, galaxies, and clusters. Before the formation of the structure, Friedmann's solutions to general relativity describe a homogeneous universe. Later anisotropies gradually grew and condensed the homogeneous universe into larger stars, galaxies, and structures. Ordinary matter is affected by radiation, which is the dominant element of the universe in very early times. As a result, their density disturbances are washed and cannot be condensed into structure. [65] If there were only ordinary matter in the universe, there would not have been enough time to disturbances to grow in the galaxies and clusters currently seen. Dark matter provides a solution to this problem because it is not affected by radiation. Therefore, your density disturbances can grow first. The resulting gravitational potential acts as an attractive potential well for ordinary matter that collapses later, accelerating the process of forming the structure. [66] Bullet Cluster Main article: Bullet Cluster If dark matter is not exist, then the next most likely explanation should be general relativity – the prevailing theory of gravity – is incorrect and should be modified. The Bullet Cluster, the result of a recent collision of two galaxy clusters, provides a challenge for modified gravity theories because its apparent center of mass is very displaced from the baryonic center of mass. [67] Standard dark matter models can easily explain this observation, but modified gravity has a much more difficult time,[68][69] especially since observational evidence is independent of the model. [70] Supernova distance measurements type Ia main articles: Supernova type Ia and Form of the Universe Type Ia supernovae can be used as standard candlesticks to measure extragalactic distances, which in turn can be used to measure the speed with which the universe has expanded in the past. [71] Data indicate that the universe is expanding at an accelerated rate, the cause of which is usually attributed to dark energy. [72] Since observations indicate that the universe is almost flat,[73][74][75 the total energy density of everything in the universe is expected to add to 1 (otot ≈ 1). The measured dark energy density is 0.690 ≈; the energy density of ordinary matter (baryonic) observed is ≈ 0.0482 and the energy density of the radiation is negligible. This leaves a lack ≈ of ≈ 0.258 which, however, behaves like a matter (see technical definition section above) – dark matter. [76] Sky surveys and acoustic oscillations baryon Main article: Baryon Acoustic Oscillations Baryon's acoustic oscillations (BAO) are fluctuations in the density of visible baryonic matter (normal matter) of the universe on a large scale. They are expected to arise in the Lambda-CDM model due to acoustic oscillations in the photon-barion fluid of the primitive universe, and can be observed in the cosmic microwave background angular power spectrum. BAO configures a preferred length scale for barions. As dark matter and baryons clustered after recombination, the effect is much weaker on the distribution of the galaxy in the nearby universe, but is detectable as a subtle preference (≈1 percent) so that pairs of galaxies are separated by 147 Mpc, compared to those separated by 130-160 Mpc. This feature was theoretically predicted in the 1990s and then discovered in 2005, in two major redshift surveys of the galaxy, the Sloan Digital Sky Survey and the 2dF Galaxy Redshift Survey. [77] Combining the CMB CMB WITH BAO measurements of galaxy red displacement surveys provides an accurate estimate of the Hubble constant and average matter density in the Universe. [78] The results are compatible with the Lambda-CDM model. Redshift Space Distortions Red displacement surveys of large galaxies can be used to make a three-dimensional map of the galaxy's distribution. These maps are slightly distorted because distances are estimated from observed red offsets; the red shift contains a contribution of the so-called peculiar speed of the galaxy, in addition to the hubble's dominant expansion term. On average, superclusters are expanding more slowly than the cosmic mean due to their severity, while gaps are expanding faster than average. On a red displacement map, galaxies in front of a supercluster have excessive radial speeds towards it and have slightly higher red displacements than their distance would imply, while galaxies behind the supercluster have slightly low red displacements for their distance. This effect causes the superclusters to appear crushed in the radial direction, and also the gaps are stretched. Their angular positions are not affected. This effect is not detectable for any structure as the true form is not known, but can be measured averaging in many structures. It was predicted quantitatively by Nick Kaiser in 1987, and first decisively measured in 2001 by the 2dF Galaxy Redshift Survey. [79] The results are in accordance with the Lambda-CDM model. Lyman-alpha Forest Main article: Lyman-alpha forest In astronomical spectroscopy, the Lyman-alpha forest is the sum of absorption lines derived from the Lyman-alpha transition of neutral hydrogen in the spectra of distant galaxies and quasars. Lyman-alpha forest observations can also restrict cosmological models. [80] These restrictions are in accordance with those obtained from WMAP data. Theoretical Composition Classifications There are several hypotheses about what dark matter might consist of, as set out in the following table. Unresolved problems in physics: What is dark matter? How was it generated? (more unresolved problems in physics) Some dark matter hypotheses[8] Light bosons chromodynamic quantum chromodynamic axions-like particles fuzzy cold dark matter Neutrinos Sterile model neutrinos weak scale supersymmetry dimensions little Higgs effective field theory simplified models other particles Weakly interacting massive particles self-interaction dark matter superfluid theory macroscopic black holes Massive Compact Halo Objects (MaCHOs) Macroscopic Dark Matter (Macros) Modified Gravity (MOG) Modified Newtonian Dynamic (MoND) Tensor-vector-Scalar Gravity (TeVeS) Entropic Gravity Dark matter can refer to any substance that predominantly interacts through gravity with visible matter (e.g. stars and planets). Therefore, in principle it does not have to be composed of a new type of fundamental particle, but could, at least in part, be standard baryonic matter, such as protons or neutrons. However, for the reasons described below, most scientists think that dark matter is dominated by a non-baryonic component, which is probably composed of a currently unknown fundamental particle (or similar exotic state). The Fermi-LAT media observations of dwarf galaxies provide new perspectives on dark matter. Baryonic matter Baryons (protons and neutrons) make up ordinary stars and planets. However, baryonic matter also encompasses less common non-primordial black holes, neutron stars, weak old white dwarfs, and brown dwarfs, collectively known as massive compact halo objects (MACHOs), which can be difficult to detect. [88] However, multiple lines of evidence suggest that most dark matter is not made of baryons: Enough diffuse, baryonic gas or dust would be visible when backlit by the stars. The Big Bang nucleosynthesis theory predicts the observed abundance of chemical elements. If there are more baryons, then there should also be more helium, lithium and heavier elements synthesized during the Big Bang. [90] Agreement with observed abundances requires baryonic matter to consist of 4–5% of the critical density of the universe. In contrast, large-scale structure and other observations indicate that the total density of matter is approximately 30% of the critical density. [76] Astronomical searches for gravitational microlensing in the Milky Way found that at most only a small fraction of the dark matter can be in dark, compact and conventional objects (MACHOs, etc.); the excluded range of masses of objects is from half the mass of the Earth to 30 solar masses, covering almost all plausible candidates. [92] Detailed analysis of small irregularities (anisotropies) of the cosmic microwave background [95][96] Detailed analysis of small irregularities (anisotropies). [97] Observations by WMAP and Planck indicate that about five-sixths of total matter is in a form that interacts significantly with ordinary matter or photons only through gravitational effects. Non-baryonic matter Candidates for non-baryonic dark matter are hypothetical particles such as axions, sterile neutrinos, weakly interacting massive particles (WIMPs), massive particles that interact gravitationally (GIMPs), supersymmetric particles, or primordial black holes. [98] The three types of neutrinos already observed are in fact abundant, and dark, and matter, but because their individual masses, however uncertain, are almost certainly too small they can only supply a small fraction of dark matter, due to the boundaries derived from large-scale structure and high-displacement galaxies. [99] Unlike baryonic matter, nobaryonic matter did not contribute to the formation of elements in the early universe (Big Bang nucleosynthesis)[13] so its presence is revealed only through its gravitational effects, or weak lenses. In addition, if the particles it is composed of are supersymmetric, they can undergo annihilation interactions with themselves, which can result in observable byproducts such as gamma rays and neutrinos (indirect detection). [89] Aggregation of dark matter and dense objects of dark matter If dark matter is composed of weakly interacting particles, an obvious question is whether it can form objects equivalent to planets, stars, or black holes. Historically, the answer has been that it cannot, [100][101][102] due to two factors: It lacks an efficient means of losing energy[102] Ordinary matter forms dense objects because it has numerous ways of losing energy. Losing energy would be essential for the formation of objects, because a particle that gains energy during compaction or inward fall under gravity, and cannot otherwise lose it, will heat up and increase speed and momentum. Dark matter seems to lack the means to lose energy, simply because it is not able to interact strongly in other ways, except through gravity. The virial theorem suggests that such a particle would not remain attached to the object it gradually forms – as the object began to form and compact, the particles of dark matter within it would accelerate and tend to escape. It lacks a number of interactions needed to form structures [102] Ordinary matter interacts in many different ways. This allows the matter to form more complex structures. For example, stars form through gravity, but particles within them interact and can emit energy in the form of neutrinos and electromagnetic radiation through fusion when they become energetic enough. Protons and neutrons can bind through strong interaction and then form atoms with electrons largely through electromagnetic interaction. But there is no evidence that dark matter is capable of such a wide variety of interactions, as it seems to interact only through gravity (and possibly through some means no stronger than weak interaction, although until dark matter is better understood, this is only hopeful speculation). In 2015-2017 the idea of dense dark matter was composed of primordial black holes, made a comeback[103] after the results of gravitational wave measurements that detected the fusion of intermediate mass black holes. Black holes with about 30 solar masses are not expected to form by stellar collapse (usually less than 15 solar masses) or by the fusion of black holes in galactic centers (millions or billions of solar masses). Black holes of intermediate mass were proposed causing the fusion formed in the dense hot early stage of the universe because denser regions collapse. A subsequent study of about a thousand supernovae did not detect gravitational lens events, when about eight would be expected to be expected if primordial black holes of intermediate mass above a certain mass range represented most dark matter. [104] The possibility of primordial black holes the size of an atom representing a significant fraction of dark matter was ruled out by measurements of positron and electron flows outside the Sun's heliosphere by the Voyager 1 spacecraft. Small black holes are theorized to emit Hawking radiation. However, the detected flows were too low and did not have the expected energy spectrum, suggesting that the small primordial black holes are not widespread enough to take into account dark matter. [105] However, research and theories proposing dense dark matter accounts for dark matter continue from 2018, including approaches to cooling dark matter. [106][107] and the question remains unresolved. In 2019, the lack of microlensing effects on Andromeda's observation suggests that there are no small black holes. [108] However, there is still a largely unrestricted mass range smaller than that which may be limited by optical microlensing observations, where primordial black holes can explain all dark matter. [110] The free transmission length Dark matter can be divided into hot, warm, cold categories. [111] These categories refer to speed rather than a real temperature, indicating the extent to which the corresponding objects moved due to random movements in the early universe, before they slowed down due to cosmic expansion – this is an important distance called free transmission length (FSL). Primary density fluctuations smaller than this length are washed out as particles extend from ruddy regions to low-density regions, while larger fluctuations are not affected; therefore, this length sets a minimum scale for subsequent formation of the structure. Categories are set with respect to the size of a protogalaxy (an object that then evolves into a dwarf galaxy): dark matter particles are classified as cold, warm, or hot according to their FSL; much smaller (cold), similar (warm), or much larger (hot) than a protogalaxy. [112][113] Mixtures of the above are also possible: a mixed dark matter theory was popular in the mid-1990s, but was rejected after the discovery of dark energy. Recognition[edit] Cold dark matter leads to a bottom-up formation of the structure with galaxies forming first and clusters of galaxies at a last stage, while hot dark matter would result in a top-down formation scenario with large aggregations of matter forming early, then in separate galaxies; [necessary clarification] the latter is excluded by observations of high displacement galaxies. [14] Effects of the fluctuation spectrum These categories also correspond to the effects of the jitter spectrum and the interval following the Big Bang in which each type became un relativistic. Davis and others wrote in 1985:[114] Candidate particles can be grouped into three categories based on their effect on the jitter spectrum (Bond et al. 1983). If dark matter is made up of abundant particles of light that remain relativistic until shortly before then it can be called hot. The best candidate for hot dark matter is a neutrino ... A second possibility is that dark matter particles interact weaker than neutrinos, are less abundant, and have a mass of order 1 keV. Such particles are called warm dark matter, because they have lower thermal speeds than massive neutrinos ... there are currently few candidate particles that fit this description. Gravitinos and fotinos have been suggested (Pagels and Primack 1982; Bond, Szalay and Turner 1982) ... Any particle that became non-regressive very early, and therefore were able to spread an insignificant distance, are called cold dark matter (CDM). There are many candidates for the CDM, including supersymmetric particles. — M. Davis, G. Efstathiou, C.S. Frenk, and S.D.M. White, The evolution of large-scale structure in a universe dominated by cold dark matter Alternative definitions Another approximate dividing line is warm dark matter became undercovered when the universe was approximately 1 year old and 1 million its current size and in the radiation-dominated era (photons and neutrinos), with a photon temperature of 2.7 million Kelvin. The standard physical cosmology gives the particle horizon size as 2 c t (speed of light multiplied by time) in the radiation-dominated era, therefore 2 light years. A region of this size would expand to 2 million light-years today (absent structure formation). The actual FSL is approximately 5 times the previous length, as it continues to grow slowly as particle speeds decrease inversely with the scale factor after they become non-relativistic. In this example, the FSL would correspond to 10 million light-years, or 3 megaparsecs, today, around the size of an average large galaxy. The photon temperature of 2.7 million K gives a typical photon energy of 250 electronvolts, thus establishing a typical mass scale for warm dark matter: particles much more massive than this, such as GeV-TeV WIMP mass, would become non-relativistic long before a year after the Big Bang and therefore have FSLs much smaller than a protogalaxy, making them cold. In contrast, much lighter particles, such as neutrinos with masses of only a few EVs, have FSLs much larger than a protogalaxy, qualifying them as hot. Cold dark matter Main article: Cold dark matter Cold dark matter offers the simplest explanation for most cosmological observations. It is dark matter composed of components with a much smaller FSL than a protogalaxy. This is the focus for dark matter research, as hot dark matter does not seem able to support the formation of galaxies or galaxy clusters, and most particle candidates slowed down early. The components of cold dark matter are unknown. Possibilities range from large objects such as MACHOs (such as black holes[115] and preon stars[116]) or RAMBO (such as bunches of brown dwarfs), to new particles such as WIMP and axions. Studies of Big Bang nucleosynthesis and gravitational lenses convinced most cosmologists[14][117][118][119][120][121] that MALES[117][119] cannot compose more than a small fraction of dark matter. [8] According to A. Peter: ... The only really plausible candidates for dark matter are new particles. [121] The 1997 DAMA/NaI experiment and its successor DAMA/LIBRA in 2013 claimed to directly detect dark matter particles passing through the Earth, but many researchers remain skeptical, as the negative results of similar experiments seem incompatible with DAMA's results. Many supersymmetric models offer the candidates for dark matter in the form of the wiMPy Lightest supersymmetric particle (LSP). [122] Separately, there are heavy sterile neutrinos in non-supersymmetric extensions to the standard model that explain the small mass of neutrinos through the saw mechanism. Warm dark matter Main article: Warm dark matter Warm dark matter comprises particles with an FSL comparable to the size of a protogalaxy. Predictions based on warm dark matter are similar to those for cold dark matter on large scales, but with less small-scale density disturbances. This reduces the predicted abundance of dwarf galaxies and can lead to lower density of dark matter in the central parts of large galaxies. Some researchers consider this to be a better fit to observations. A challenge for this model is the lack of particle candidates with the required mass = 300 eV to 3000 eV. Awards[edit] No known particles can be classified as warm dark matter. A postulated candidate is the sterile neutrino: A heavier and slower form of neutrino that does not interact through weak force, unlike other neutrinos. Some modified gravity theories, such as scalar-tensor-vector gravity, require warm dark matter to make their equations work. Hot dark matter Main article: Hot dark matter Hot dark matter consists of particles whose FSL is much larger than the size of a protogalaxy. Neutrino qualifies as one such particle. They were discovered independently, long before the hunt for dark matter: they were postulated in 1930, and detected in 1956. The mass of neutrinos is less than 10-6 that of an electron. Neutrinos interact with normal matter only through gravity and weak force, making them difficult to detect (weak force only works at a small distance, so a neutrino triggers a weak force event only if it hits a front nucleus). This makes them weakly particles of light (WILP), unlike WIMP. The three known flavors of neutrinos are electron, muon and tau. Its masses are slightly different. Neutrinos oscillate between flavors as they move. It is difficult to determine an exact upper limit on the collective mean mass of the three neutrinos (or for any of the three individually). For example, if the average mass of neutrinos were over 50 eV/c2 (less than 10-5 of the mass of an electron), the universe would collapse. CMB data and other methods indicate that its average mass probably does not exceed 0.3 eV/c2. Therefore, observed neutrinos cannot explain dark matter. [123] Because galaxy-sized density fluctuations are eliminated by free transmission, hot dark matter implies that the first objects that can form are huge supercluster-sized pancakes, which are then fragmented into galaxies. Deep-field observations instead show that galaxies formed first, followed by clusters and super clusters as galaxies cluster. Dark matter particle detection If dark matter is composed of subatomic particles, then millions, possibly billions, of such particles must pass through every square centimeter of the Earth every second. [125] Many experiments aim to test this hypothesis. Although WIMP are popular search candidates,[14] the Axion Dark Matter Experiment (ADMX) searches for axions. Another candidate is particles from heavy hidden sectors that only interact with ordinary matter through gravity. These experiments can be divided into two classes: direct detection experiments, which seek the dispersal of dark matter particles from atomic nuclei within a detector; and indirect detection, which seek products from the annihilations or decay of dark matter particles. [99] Direct detection Additional information: Massive particles weakly interacting: Direct detection direct detection experiments aim to observe low-energy retractions (usually a few keVs) of nuclei induced by interactions with dark matter particles, which (in theory) are passing through the Earth. After such recoil, the core will emit energy in the form of twinkling light or tables as they pass through sensitive sensing devices. To do this effectively, it is crucial to keep a bottom low, so such experiments operate underground to reduce cosmic ray interference. Examples of underground labs with direct sensing experiments include the Stawell mine, the Soudan mine, Sudbury's SNOLAB underground lab, the Gran Sasso National Laboratory, the Canfranc Underground Laboratory, the Boulby Underground Laboratory, the Deep Underground Science and Engineering Laboratory, and the China Jinping Underground Laboratory. These experiments mainly use cryogenic or noble liquid detector technologies. Cryogenic detectors operating at temperatures below 100 mK detect heat produced when a particle hits an atom in a crystal absorber Germanium. Noble liquid detectors detect the twinkling caused by a collision of particles in liquid xenon or argon. Cryogenic detector experiments include: CDMS, CRESST, EDELWEISS, EURECA. Noble liquid experiments include ZEPLIN, XENON, DEAP, ArDM, WARP, DarkSide, PandaX and LUX, the Great Underground Xenon experiment. Both techniques focus heavily on your to distinguish background particles (which are predominantly dispersed from electrons) from dark matter particles (which are dispersed in the nuclei). Other experiments include SIMPLE and PICASSO. There has no current conclusive evidence of detection of dark matter from a direct sensing experiment, which instead leads to strong upper limits on the mass and cross-section of interaction with nucleons of such dark matter particles. [126] DAMA/NaI and more recent DAMA/LIBRA experimental collaborations have detected an annual modulation in the rate of events in their detectors[127][128] which they say is due to dark matter. This results from the expectation that as the Earth orbits the Sun, the detector's speed relative to the dark matter halo will vary by a small amount. This statement is not confirmed until now and is at odds with the negative results of other experiments such as LUX, SuperCDMS[129] and XENON100. [130] A special case of direct sensing experiments includes those with directional sensitivity. This is a search strategy based on the movement of the Solar System around the Galactic Center. [132] A low-pressure time projection camera provides access to information on recoil tracks and restricts WIMP core kinematics. WIMPs that come from the direction in which the Sun travels (approximately towards Cygnus) can then be separated from the background, which must be isotropic. Directional dark matter experiments include DMTPC, DRIFT, Newage, and MIMAC. Indirect detection Collage of six cluster collisions with dark matter maps. Clusters were observed in a study of how dark matter in galaxy clusters behaves when clusters collide. [135] Play multimedia video about the possible gamma ray detection of the annihilation of dark matter around supermassive black holes. (Duration 0:03:13, see also file description.) Indirect detection experiments look for products of self-annihilation or decay of dark matter particles in outer space. For example, in high-density regions of dark matter (for example, the center of our galaxy) two particles of dark matter could annihilate to produce gamma rays or particle-antiparticle pairs of the Standard Model. [134] Alternatively, if a dark matter particle is unstable, it could decay into the standard model (or other) particles. These processes could be detected indirectly through excess gamma rays, antiprotons or positrons emanating from high-density regions in our galaxy or others. [137] An important difficulty inherent in such searches is that several Astrophysics can mimic the expected signal of dark matter, so multiple signals are likely to be required for conclusive discovery. [99] Some of the particles of dark matter passing through the Sun or Earth can disperse from atoms and lose energy. Therefore, dark matter can accumulate in the center of these bodies, increasing the chance of This could produce a distinctive signal in the form of high-energy neutrinos. [138] Such a signal would be a strong indirect test of WIMP dark matter. [14] High-energy neutrino telescopes such as AMANDA, IceCube and ANTARES are looking for this signal. [139] LIGO's detection in September 2015 of gravitational waves opens up the possibility of observing dark matter in a new way, particularly if it is in the form of primordial black holes. [140][141][142] Many experimental searches have been carried out to seek such an emission of the annihilation or decline of dark matter, examples of which follow. The Energetic Gamma Ray Experiment Telescope observed more gamma rays in 2008 than expected from the Milky Way, but scientists concluded that this was probably due to an incorrect estimate of telescope sensitivity. [143] The Fermi Gamma-ray Space Telescope is looking for similar gamma rays. [144] In April 2012, an analysis of previously available data from its Gran Area Telescope instrument produced statistical evidence of a 130 GeV signal in gamma radiation from the center of the Milky Way. [145] The annihilation of WIMP was seen as the most likely explanation. [146] At higher energies, soil-based gamma-ray telescopes have set limits on the annihilation of dark matter in dwarf spheroidal galaxies[147] and in galaxy clusters. [148] The PAMELA experiment (launched in 2006) detected excess positrons. They could be from the annihilation of dark matter or pulsars. No excess antiprotons were observed. [149] In 2013, the results of the International Space Station's alpha magnetic spectrometer indicated an excess of high-energy cosmic rays that could be due to the annihilation of dark matter. [150][151][152][153][154][155] Collider seeks dark matter An alternative approach to detecting dark matter particles in nature is to produce them in a laboratory. Experiments with the Large Hadron Collider (LHC) may be able to detect dark matter particles produced in collisions of the LHC proton beams. Because a dark matter particle should have negligible interactions with normal visible matter, it can be indirectly detected as (large amounts of) energy loss and impulse escaping detectors, provided that other (non-negligible) collision products are detected. [156] Restrictions on dark matter also exist in the LEP experiment using a similar principle, but sounding the interaction of dark matter particles with electrons rather than quarks. [157] Any discovery of collider searches must be corroborated by discoveries in the indirect or direct sensing sectors to show that the uncovered particle is, in fact, dark matter. Alternative hypotheses Additional information: Alternatives to general relativity Because dark matter has not yet been conclusively identified, many other hypotheses have emerged with the aim of explaining observational phenomena that dark matter was to explain. The most common method is to modify general relativity. General relativity is well tested at scales of the solar system, but its validity on galactic or cosmological scales has not been well tested. A modification appropriate to general relativity can conceivably eliminate the need for dark matter. The best known theories of this class are MOND and its relativistic generalization of tensor-vector-scalar gravity (TeVeS),[158] f(R) gravity,[159] negative mass, dark fluid,[160][161][162] and entropic gravity. [163] Alternative theories abound. [165] A problem with alternative hypotheses is that observational evidence for dark matter comes from so many independent approaches (see the observational evidence section above). Explaining any individual observation is possible, but explaining all of them is very difficult. However, there have been some scattered successes for alternative hypotheses, such as a 2016 gravitational lens test in entropic gravity. [166] The predominant view among most astrophysicists is that while changes to general relativity can conceivably explain some of the observational evidence, there is probably enough information to conclude that there must be some kind of dark matter. [169] In popular culture Main article: Dark matter in fiction The mention of dark matter is made in works of fiction. In such cases, it is usually attributed extraordinary physical or magical properties. Such descriptions are often inconsistent with the hypothetical properties of dark matter in physics and cosmology. See also Theories related Dark Energy – unknown property in cosmology that causes the expansion of the universe to accelerate. Conforming Gravity – Gravity Theories That Are Invariable Under Weyl Transforms Density Wave Theory – A theory of compressed gas waves, which move slower than the galaxy, maintain the structure of the Entropic Gravity galaxy – Theory in modern physics that describes gravity as an entropic force Dark Radiation – A postulated type of radiation that mediates interactions of dark matter Mass Gravity – Theory of Gravity in which graviton has Non-zero mass particle physics – A speculative theory that conjectures a form of matter that cannot be explained in terms of particles SPE experiments, an LZ search apparatus experiment, large underground dark matter particle explorer (DAMPE) detector, a General MultiDark antiparticle spectrometer space mission, an Illustris Project research program – Computer simulated universes , Future Circular Collider astrophysical simulations, an accelerator research infrastructure of Dark Matter Tsyld – Dark Matter Test Theorists Weakly with Candidates for Massive Particles with Masses Less than 1 GeV Mirror Matter – A Hypothetical Counterpart of Ordinary Matter Exotic Matter – Any Type of Neutral Non-Barin Matter · Neutral eigenstate formed from calibre superparts and higgs Dark Galaxy bosons – A Hypothetical galaxy with none, or very few, field stars climbing dark matter – Classic, minimally coupled, scalar field postulated to account for dark matter deduced Dark Matter Self-interacting Dark Matter Dark Matter – A hypothetical form of dark matter consisting of particles with strong autonomous interactions Particles Massive Weakly Interacting (WIMP) – Hypothetical particles believed to constitute dark matter Massive particles strongly interacting (SIMP) – Hypothetical particles that interact strongly with ordinary matter, but that could form the dark matter deduced despite this Chameleon particle – Hypothetical scalar particles that couples import more weakly than gravity Another Gala Center Excess GeVCtic - Unexplained Gamma Radiation in the Center of the Milky Way Galaxy Halo, this is 26.8/4.9 ≈ 26.8) to 0.845 - A small portion of dark matter could be baryonic and/or neutrinos. See Baryonic dark matter. Dark energy is a term often used today as a substitute for the cosmological constant. It's basically the same, except that dark energy can depend on the scale factor in some unknown way rather than necessarily being constant. This is a consequence of the shell theorem and the observation that spiral galaxies are largely symmetrical (in 2D). • Astronomers define the term baryonic matter to refer to ordinary matter made of protons, neutrons and electrons, including neutron stars and black holes of the collapse of ordinary matter. Strictly speaking, electrons are non-baryon leptons; but because their number is equal to protons, while their mass is much smaller, electrons make a negligible contribution to the average density of baryonic matter. Baryonic matter excludes other known particles, such as neutrinos. Primordial black holes are hypothetical and can act like dark matter or baryonic matter, so they are usually called baryonic or non-baryonic. Annual Review of Astronomy and Astrophysics. 25: 425–472. Bibcode:1987ARA&A... 25..425T. doi:10.1146/annurev.aa.25.090187.002233. A dark matter story. 2017. The Planck mission puts the universe in a sharp focus. NASA mission pages. March 21, 2013. Dark Energy, Matter NASA Science: Astrophysics. June 5, 2015. Ade, P.A.R.; Aghanim, N.; Armitage-Caplan, C.; (March 22, 2013). Planck 2013 results – I. Overview of scientific products and results – Table 9. Astronomy and Astrophysics. 1303: 5062. arXiv:1303.5062. ...

doi:10.1142/S0217732305017391. S2CID 119405319. Are there dark stars or dark galaxies made of dark matter? Cornell University - Ask an astronomer. Archived from the original on 2 March 2015. A b Buckley, Matthew R.; Difranzo, Anthony (February 1, 2018). Synopsis: A Way to Cool Dark Matter. Physical review letters. 120 (5): 051102. arXiv:1707.03829. Bibcode:2018PhRvL.120e1102B. doi:10.1103/PhysRevLett.120.051102. PMID 29481169. S2CID 3757868. Archived from the original on 26 October 2020. A widespread belief in dark matter is that it cannot cool down by radiating energy. If it could, then it could be grouped together and create compact objects in the same way that baryonic matter forms planets, stars, and galaxies. Observations so far suggest that dark matter does not do that – it resides only in fuzzy halos ... As a result, it is extremely unlikely that there will be very dense objects such as stars made of dark matter entirely (or even mostly). A b Siegel, Ethan (28 October 2016). Why doesn't dark matter form black holes? Forbes. Cho, Adrian (February 9, 2017). Is dark matter made of black holes? Science. doi:10.1126/science.aal0721. Black holes can't dark matter. astronomy.com. 18 October 2018. Retrieved 7 January 2019. Voyager 1 spacecraft ages undermines idea dark matter is small black holes. sciencemag.org January 9, 2019. Retrieved January 10, 2019. There could be entire stars and planets made of dark matter. Buckley, Matthew R.; Difranzo, Anthony (2018). Dark matter structures collapsed. Physical review letters. 120 (5): 051102. arXiv:1707.03829. Bibcode:2018PhRvL.120e1102B. doi:10.1103/PhysRevLett.120.051102. PMID 29481169. S2CID 3757868. Niikura, Hiroko (April 1, 2019). Microlensing restrictions on primordial black holes with subaru/HSC Andromeda observations. Astronomy of Nature. 3 (6): 524–534. arXiv:1701.02151. Bibcode:2019NatAs... 3..524N. doi:10.1038/s41550-019-0723-1. S2CID 118986293. Katz, Andrey; Kopp, Joachim; Sibiryakov, Sergey; Xue, Wei (December 5, 2018). Femtolensing by revisited dark matter. Journal of Cosmology and Physics of the Astroparticle. 2018 (12): 005. arXiv:1807.11495. Bibcode:2018JCAP... 12..005K. doi:10.1088/1475-7516/2018/12/005. ISSN 1475-7516. S2CID 119215426. Montero-Camacho, Paulo; Fang, Xiao; Vasquez, Gabriel; Silva, Makana; Hirata, Christopher M. (August 23, 2019). Resisiting restrictions on primordial black holes in asteroid mass as dark matter candidates. Journal of Cosmology and Physics of the Astroparticle. 2019 (8): 031. arXiv:1906.05950. Bibcode:2019JCAP... 08..031M. doi:10.1088/1475-7516/2019/08/031. ISSN 1475-7516. S2CID 189897766. Silk, Joseph (2000). IX. The Big Bang: Third edition. Henry Holt and Company. ISBN 978-0-8050-7256-3. Vittorio, N.; J. Silk (1984). Large-scale anisotropy of the cosmic microwave background in a universe dominated by cold dark matter. Astrophysics diary letters. 285: L39–L43. Bibcode:1984ApJ... 285L.. 39V. doi:10.1086/184361. Umemura, Masayuki; Satoru Ikeuchi (1985). Formation of subgalactic objects within the dark matter of two components. Astrophysical Journal. 299: 583–592. Bibcode:1985ApJ... 299..583U. doi:10.1086/163726. Davis, M.; Efstathiou, G.; Frenk, C.S.; White, S.D.M. (May 15, 1985). The evolution of large-scale structure in a universe dominated by cold dark matter. Astrophysical Journal. 292: 371–394. Bibcode:1985ApJ... 292..371D. doi:10.1086/163168. Hawkins, M.R.S. (2011). The case of primordial black holes as dark matter. Monthly Notices of the Royal Astronomical Society. 415 (3): 2744–2757. arXiv:1106.3875. Bibcode:2011MNRAS.415.2744H. doi:10.1111/j.1365-2966.2011.18890.x. S2CID 119261917. Hansson, J.; Sandin, F. (2005). Preon Stars: A new class of cosmic compact objects. Physical Letters B. 616 (1–2): 1–7. arXiv:astro-ph/0410417. Bibcode:2005PhLB.. 616....1H. doi:10.1016/j.physletb.2005.04.034. S2CID 119063004. a b c Carr, B.J.; (2010). New cosmological restrictions on primordial black holes. Physical Review D. 81 (10): 104019. arXiv:0912.5297. 81j4019C. doi:10.1103/PhysRevD.81.104019. S2CID 118946242. A b Peter, A.H.G. (2012). Dark Matter: A Brief Brief arXiv:1201.3942 [astro-ph.CO]. A b Garrett, Katherine; Dada, Gintaras (2011). Dark Matter: A First. Advances in Astronomy. 2011 (968283): 1–22. arXiv:1006.2483. Bibcode:2011AdAst2011E... 8G. doi:10.1155/2011/968283. S2CID 119180701. MALES can only explain a very small percentage of the noluminous mass in our galaxy, revealing that most dark matter cannot be strongly concentrated or exists in the form of baryonic astrophysical objects. Although microlente surveys discard baryonic objects such as brown dwarfs, black holes, and neutron stars in our galactic halo, can other forms of baryonic matter most dark matter? The answer, surprisingly, is 'no'... - Bertone, G. (2010). The moment of truth for WIMP's dark matter. Nature. 468 (7322): 389–393. arXiv:1011.3532. Bibcode:2010Natur.468.. 389B. doi:10.1038/nature09509. PMID 21085174. S2CID 4415912. Olive, Keith A (2003). TASI conferences on dark matter. 21. arXiv:astro-ph/0301505. Jungman, Gerard; Kamionkowski, Marc; Griest, Kim (March 1, 1996). supersycmetric dark matter. Physics Reports. 267 (5–6): 195–373. arXiv:hep-ph/9506380. Bibcode:1996PhR... 267..195J. doi:10.1016/0370-1573(95)00058-5. S2CID 119067698. Neutrinos as dark matter. Astro.ucla.edu. 21 September 1998. Retrieved January 6, 2011. Gaitskell, Richard J. (2004). Direct Detection of Dark Matter. Annual Review of Nuclear and Particle Sciences. 54: 315–359. Bibcode:2004ARNPS.. 54..315G. doi:10.1146/annurev.nucl.54.070103.181244. S2CID 11316578. Neutral Dark Matter. Retrieved 26 December 2011. Griest, Kim. WIMP and MACHOs (PDF). Retrieved 26 December 2011. Drees, M.; Gerbier, G. (2015). Dark Matter (PDF). Chin. Physics.C. 38:090001. Bernabei, R.; Belli, P.; Cappella, F.; Cerulli, R.; Dai, C.J.; d'Angelo, A.; (2008). First DAMA/LIBRA results and results combined with DAMA/NaI. Eur. Phys. J.C. 56 (3): 333–355. arXiv:0804.2741. Bibcode: 2008EPJC... 56..333B. doi:10.1140/epjc/s10052-008-0662-y. S2CID 14354488. • Drukier, A.; Freese, K.; Spergel, D. (1986). Detect candidates for cold dark matter. Physical exam D. 33 (12): 3495–3508. Bibcode:1986PhRvD.. 33.3495D. doi:10.1103/PhysRevD.33.3495. PMID 9956575. Davis, Jonathan H. (2015). The past and future of direct detection of light dark matter. Int. J. Mod. A. 30 (15): 1530038. arXiv:1506.03924. Bibcode:2015IJMPA.. 3030038D. doi:10.1142/S0217751X15300380. S2CID 119269304. Aprile, E. (2017). Find electronic modulation of the rate of reverse events with 4 years of XENON100 data. Phys. Rev. Lett. 118 (10): 101101. arXiv:1701.00769. Bibcode:2017PhRvL.118j1101A. doi:10.1103/PhysRevLett.118.101101. PMID 28339273. S2CID 206287497. Stonebraker, Alan (January 3, Synopsis: Dark-Matter Wind Sways through the Seasons. Física – Sinopsis. Sociedad Física Estadounidense. doi:10.1103/PhysRevLett.112.011301. doi:10.1103/PhysRevLett.112.011301. Lee, Samuel K.; Lisanti, Mariangela; Peter, Annika H.G.; Safdi, Benjamin R. (January 3, 2014). Effect of gravitational concentration on annual modulation in direct dark matter detection experiments. Phys. Rev. Lett. 112 (1): 011301 [5 pages]. arXiv:1308.1953. Bibcode:2014PhRvL.112a1301L. doi:10.1103/PhysRevLett.112.011301. PMID 24483881. S2CID 34109648. The Dark Matter Group. An Introduction to Dark Matter. Dark matter research. Sheffield: University of Sheffield. Retrieved 7 January 2014. Blowing in the Wind. Kavli News. Sheffield: Kavli Foundation. Retrieved 7 January 2014. Scientists at Kavli MIT are working on ... a tool to track the movement of dark matter. Dark matter even darker than I once thought. Space Telescope Science Institute. Retrieved 16 June 2015. Bertone, Gianfranco (2010). Dark Matter In The Centers of Galaxies. Dark Particle Matter: Observations, Models, and Searches. Cambridge University Press. 83–104. arXiv:1001.3706. Bibcode:2010arXiv1001.3706M. ISBN 978-0-521-76368-4. Ellis, J.; Flowers, R.A.; Freese, K.; Ritz, S.; Seckel, D.; Silk, J. (1988). Cosmic Ray Restrictions on The Annihilation of Relic Particles in galactic Halo (PDF). Physical Letters B. 214 (3): 403–412. Bibcode:1988PhLB.. 214..403E. doi:10.1016/0370-2693(88)91385-8. Freese, K. (1986). Can scalar neutrinos or massive dirac neutrinos be the lost Mass? Physical Letters B. 167 (3): 295–300. Bibcode:1986PhLB.. 167..295F. doi:10.1016/0370-2693(86)90349-7. Randall 2015, p. 298. Sokol, Joshua; (February 20, 2016). The waves of Surfing's gravity. New Scientist. No. 3061. Did the gravitational wave detector find dark matter? Johns Hopkins University. June 15, 2016. Retrieved 20 June 2015. While its existence has not been established with certainty, primordial black holes have been suggested in the past as a possible solution to the mystery of dark matter. Because there is so little evidence of them, however, the primary hypothesis of dark-black hole matter has not gained great follow-up among scientists. LIGO's findings, however, elevate perspective again, especially as the objects detected in that experiment adjust to the predicted mass for dark matter. Predictions made by scientists in the past had conditions at the birth of the universe would produce many of these primordial black holes distributed approximately evenly in the universe, grouping in halos around galaxies. All of this would make them good candidates for dark matter. • Bird, Simeon; Cholis, Illian (2016). LIGO detection of dark matter?. Physical review letters. 116 201301. arXiv:1603.00464. Bibcode:2016PhRvL.116t1301B. doi:10.1103/PhysRevLett.116.201301. PMID 27258861. S2CID 23710177. Stecker, F.W.; Hunter, S.; Kniffen, D. (2008). The likely cause of the EGRET GEV anomaly and its implications. Astroparticle physics. 29 (1): 25–29. arXiv:0705.4311. arXiv:0705.4311. doi:10.1016/j.astropartphys.2007.11.002. S2CID 15107441. • Atwood, W.B.; Abdo, A.A.; Ackermann, M.; Althouse, W.; Anderson, B.; Axelsson, M.; (2009). The Large Area Telescope in the Fermi Gamma-ray Space Telescope Mission. Astrophysical Journal. 697 (2): 1071–1102. arXiv:0902.1089. Bibcode:2009ApJ... 697.1071A. doi:10.1088/0004-637X/697/2/1071. S2CID 26361978. Weniger, Christoph (2012). An attempted line of gamma rays from the annihilation of dark matter in the Fermi Great Zone Telescope. Journal of Cosmology and Physics of the Astroparticle. 2012 (8): 7. arXiv:1204.2797. Bibcode:2012JCAP... 08..007W. doi:10.1088/1475-7516/2012/08/007. S2CID 119229841. Cartlidge, Edwin (April 24, 2012). Gamma rays suggest dark matter. Institute of Physics. Retrieved 23 April 2013. Albert, J.; Aliu, E.; Anderhub, H.; Antoranz, P.; Backes, M.; Baixeras, C.; (2008). Upper limit for the emission of γ rays above 140 GeV of the dwarf spheroidal galaxy Draco. The Astrophysical Journal. 679 (1): 428–431. arXiv:0711.2574. Bibcode: 2008ApJ... 679..428A. doi:10.1086/529135. S2CID 15324383. Aleksiá, J.; Antonelli, L.A.; Antoranz, P.; Backes, M.; Baixeras, C.; Balestra, S.; (2010). Magic Gamma-Ray Telescope observation of the Perseus Cluster of galaxies: Implications for cosmic rays, dark matter, and NGC 1275. The Astrophysical Journal. 710 (1): 634–647. arXiv:0909.3267. Bibcode: 2010ApJ... 710..634A. doi:10.1088/0004-637X/710/1/634. S2CID 53120203. Adriani, O.; Barbarino, G.C.; Bazilevskaya, G.A.; Bellotti, R.; Boezio, M.; Bogomolov, E.A.; (2009). An abundance of abnormal positrons in cosmic rays with energies 1.5–100 GeV. Nature. 458 (7238): 607–609. arXiv:0810.4995. Bibcode:2009Natur.458.. 607A. doi:10.1038/nature07942. PMID 19340076. S2CID 11675154. Aguilar, M.; (AmS Collaboration) (April 3, 2013). First result of the alpha magnetic spectrometer on the International Space Station: Measurement of Accuracy of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV. Physical review letters. 110 (14): 141102. Bibcode:2013PhRvL.110n1102A. doi:10.1103/PhysRevLett.110.141102. PMID 25166975. • Collaboration with AMS (April 3, 2013). First result of the alpha magnetic spectrometer experiment. Archived from the original on 8 April 2013. Retrieved 3 April 2013. Heilprin, John; Borenstein, Seth (April 3, 2013). Scientists find an indication of dark matter in the cosmos. Associated Press. Retrieved 3 April 2013. Amos, Jonathan (April 3, 2013). Alpha magnetic spectrometer focuses on dark matter. Bbc. Retrieved 3 April 2013. Perrotto, Trent J.; Byerly, Josh (April 2, 2013). NASA TV Briefing discusses the results of the alpha magnetic spectrometer. Nasa. Retrieved 3 April 2013. Overbye, Dennis (April 3, 2013). clues to the mystery of dark matter. The New York Times. Retrieved 3 April 2013. Kane, G.; Watson, S. (2008). Dark matter and What is the connection?. Modern Physics Letters A. 23 (26): 2103-2123. arXiv:0807.2244. Bibcode: 2008MPLA... 23.2103K. doi:10.1142/S0217732308028314. S2CID 119286980. Fox, P.J.; Harnik, R.; Kopp, J.; Tsai, Y. (2011). LEP shines light on dark matter. Rev. D. 84 (1): 014028. arXiv:1103.0240. Bibcode:2011PhRvD.. 84a4028F. doi:10.1103/PhysRevD.84.014028. S2CID 119226535. For a review, see: Kroupa, Pavel; (December 2012). The failures of the Cosmology Standard Model require a new paradigm. International Journal of Modern Physics D. 21 (4): 1230003. arXiv:1301.3907. Bibcode:2012IJMPD.. 2130003K. doi:10.1142/S0218271812300030. S2CID 118461811. For a review, see: Salvatore Capozziello; Mariafelicia De Laurentis (October 2012). The problem of dark matter from the point of view of gravity f(R). Annalen der Physik. 524 (9–10): 545. Bibcode:2012AnP... 524..545C. doi:10.1002/andp.201200109. Bring balance to the Universe. University of Oxford. Bring balance to the universe: The new theory could explain the lack of 95 percent of the cosmos. Phys.Org. A Unifying Theory of Dark Energy and Dark Matter: Negative Masses and Creating Matter within a Modified CDM Framework. Astronomy and Astrophysics. 620: A92. arXiv:1712.07962. Bibcode:2018A&a... 620A.. 92F. doi:10.1051/0004-6361/201832898. S2CID 53600834. New theory of gravity could explain dark matter. phys.org November 2016. Mannheim, Phillip D. (April 2006). Alternatives to dark matter and dark energy. Progress in Particle and Nuclear Physics. 56 (2): 340–445. arXiv:astro-ph/0505266. Bibcode:2006PrPNP.. 56..340M. doi:10.1016/j.ppnp.2005.08.001. S2CID 14024934. • Joyce, Austin; (March 2015). Beyond the cosmological standard model. Physics Reports. 568: 1–98. arXiv:1407.0059. Bibcode: 2015PhR... 568....1J. doi:10.1016/j.physrep.2014.12.002. S2CID 119187526. Verlinde's new theory of gravity passes the first test. December 16, 2016. Brouwer, Margot M.; (December 11, 2016). First test of Verlinde's theory of emerging gravity using weak gravitational lens measurements. Monthly Notices of the Royal Astronomical Society. 466 (which will appear): 2547–2559. arXiv:1612.03034. Bibcode:2017MNRAS.466.2547B. doi:10.1093/mnras/stw3192. S2CID 18916375. Einstein's first gravity rival test kills dark matter. December 15, 2016. Retrieved 20 February 2017. Sean Carroll (May 9, 2012). Dark matter against modified gravity: A three-way dialogue. Retrieved 14 February 2017. Randall, Lisa (2015). Dark matter and dinosaurs: the amazing interconnection of the universe. New York: Ecco / Harper Collins Publishers. ISBN 978-0-06-232847-2. More hossenfelder reading, Sabine; McGaugh, Stacy S. (August 2018). Is it matter Real?. American scientist. Vol. 319 No. 2. 36–43. External links Wikimedia Commons has media related to Dark Matter. Dark Dark in Curlie Dark Matter (Astronomy) in the Encyclopedia Britannica A History of Dark Matter. Ars Technica. February 2017. What is dark matter? CosmosMagazine.com. Archived from the original on 20 November 2015. Missing Dark Matter in a Galaxy Far Away, Tech Explorer news item, from a 2020 Astrophysical Journalarticle, DOI: 10.3847/1538-4357/abc340 Kroupa, Pavel (August 18, 2010). The dark matter crisis. published in General. scilogs.com. Helmholtz Alliance for the Physics of Astroparticles. January 26, 2018. NASA finds direct evidence of dark matter (Press Release). Nasa. August 21, 2006. Tuttle, Kelen (August 22, 2006). Dark Matter Observed. SLAC (Stanford Linear Accelerator Center) today. Astronomers claim the first finding of 'dark galaxy'. New Scientist. February 23, 2005. Sample, Ian (December 17, 2009). Dark Matter Detected. Guardian. London, United Kingdom. Retrieved 1 May 2010. Tremaine, Scott. dark matter conference (Video). Nic. The astronomers' doubts about the Dark Side... Science Daily. Gray, Meghan; Merrifield, Mike; Copeland, Ed (2010). Haran, Brady (ed.). Dark Matter. Sixty symbols. University of Nottingham. Carmeli, Oded (February 27, 2017). The physicist who denies that dark matter exists. Cosmos in Nautilus. Retrieved from

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