Outline of Astronomy
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PHYS>Astronomy

astronomy

Physical sciences {astronomy} can be about cosmology, galaxies, stars, planets, moons, meteors, and comets.

PHYS>Astronomy>Universe

universe

Reality is a self-contained, integrated matter and energy structure {universe}|.

principles

Universe has physical laws, which are probably constant in space and time. Physical laws are deterministic. Physical processes are the same forward and backward in time. Physical processes are the same in any space direction and dimension, so directions are equivalent. Physical processes are the same right-handed or left-handed, so rotation directions are equivalent. Physical processes are the same for positive and negative charges.

Motions have time symmetry, spatial symmetry, and rotational symmetry, which are equivalent to conservation laws of energy, momentum, and angular momentum, respectively [Feynman, 1965]. However, whole universe has time-flow asymmetry, because entropy increases and because processes as a totality only go forward in time. Also, weak nuclear force has slight time asymmetry and parity asymmetry. (When weak force became independent of electromagnetic force, less than one second after universe origin, matter became favored over antimatter.) However, all physical processes have overall symmetry for combined charge, time, and parity symmetries.

Space and time unite into space-time. All motions, including accelerated motions, are relative, so observers in different reference frames, moving and/or accelerating at different velocities, see the same objects at different velocities through time, the same objects with different contractions along velocity direction, and the same events at different times. No physical things travel faster than light speed. However, non-material geometric relations, and so space itself, can expand or contract faster than light speed.

Physical objects and events are both matter-like and wave-like. Quantum-mechanical waves determine object positions, and quantum-mechanical particles determine energies. Observed physical quantities and physical changes have "action" quanta (and so energy, momentum, space, and time quanta). Energy, momentum, space, and time are subject to the uncertainty principle, so small distances and times must have high energies and momenta. In local observable space and time, object and event behaviors appear random and probabilistic, because quantum energy states can fill in different ways. In systems with widely separated parts, events can appear acausal or instantaneous [Feynman, 1965].

beginning

Universe began with maximum energy density, temperature, pressure, and spatial curvature, and minimum volume and entropy. Space then expanded, decreasing energy density, temperature, pressure, and spatial curvature, and increasing volume and entropy.

age

Universe is 13.72 x 10^9 years old (so people can observe universe objects up to 13.72 x 10^9 light years away).

radius

Universe radius is 7.8 x 10^10 light-years or 10^34 meters.

dimensions

Space has three infinite real-number dimensions. Perhaps, space has curled-up real-number dimensions. Perhaps, universe has infinite and/or curled-up imaginary-number dimensions. Time has one real-number dimension. Perhaps, time has one imaginary-number dimension. Time and space dimensions interact to make one unified space-time.

homogeneity

All universe regions are essentially the same.

isotropy

All three real-number infinite dimension are equivalent, so physical laws are independent of direction.

no rotation

Universe and space do not rotate. (Space rotation allows travel to past along rotating space-time dimensions.)

matter

Universe mass is 2 x 10^56 grams. Inertial mass is same as gravitational mass. Matter amount is much more than antimatter amount, so baryon number is positive. Neutrino number is small compared to total radiation, so lepton number is small.

matter: ordinary matter

Visible matter is stars and hot gases, which have detectable electromagnetic radiation. Visible matter is 0.4% of universe mass-energy. One-third of baryons and leptons are in visible matter. Invisible matter is cool gases, planets, dust, dim stars, and black holes, which have low-intensity electromagnetic radiation and so are too dim to detect. Invisible matter is 3.7% of universe mass-energy. Two-thirds of baryons and leptons are in invisible matter. Ordinary matter (visible and invisible) is 99.95% baryons and 00.05% leptons and is 4.1% of universe mass-energy.

matter: dark matter

Dark matter is (unknown) subatomic particles that do not interact with electromagnetic radiation. Dark matter is 25% of universe mass-energy.

energy

Object kinetic energy is a negligible fraction of universe mass-energy. Electromagnetic radiation is 0.9% of universe mass-energy.

energy: dark energy

Dark energy is (unknown) space intrinsic energy that does not interact with electromagnetic radiation. Dark energy is 70% of universe mass-energy.

mass-energy

Universe has matter and energy, and total mass-energy is constant. Universe only exchanges energy between kinetic and potential mechanical, electromagnetic, nuclear, and gravitational energies. Nuclear fission and fusion exchange potential and kinetic energy and release heat, mostly as electromagnetic radiation. Electric charges move, exchanging potential and kinetic energies. Electromagnetic radiation transfers hotter-object kinetic energy to cooler-object kinetic energy. Gravitational collapse changes potential to kinetic energy and makes heat.

Space expansion makes larger volume. Cosmic microwave background radiation redshifts and decreases photon energy, so average random positive kinetic energy decreases. Negative dark energy increases. Gravitational positive potential energy increases. All changes cancel, so total universe energy is constant.

density

Universe average mass-energy density is 10^-29 g/cm^3. At this density, gravity is enough for stars, galaxies, and galaxy clusters to form. At this density, universe expansion continuously slows and stops at infinity, so space has no curvature (is "flat"). Observed cosmic-microwave-background-radiation intensity is same as expected intensity, so light from 13.72 billion years ago traveled in straight (not curved) lines, confirming zero space curvature. (Positive curvature concentrates light, like positive-curvature lenses, making higher intensity. Negative curvature spreads light, like negative-curvature lenses, making lower intensity.)

density: variation

Cosmic microwave background radiation has maximum temperature differences at different points of 1 in 10000. Therefore, 13.72 billion years ago, maximum spatial-region energy-density variations, caused by region random quantum-mechanical states, were 1 in 10000. Energy-density-variations are gravitational differences, which allowed stars, galaxies, and galactic clusters to form.

sound waves

Before 300,000 years after universe origin, universe had free baryons and leptons and was hot dense plasma. Radiation traveled short distance before encountering matter (universe was opaque). Dense matter can carry sound waves, because particles are close enough to interact. Perhaps, because cosmic inflation was rapid, and gravity and internal-radiation pressure synchronized oscillations, sound waves were in phase during inflation. Perhaps, cold dark matter and/or cosmic inflation synchronized oscillations. Sound-wave compressions compressed particles together (and heated plasma), and sound-wave rarefactions spread particles apart (and cooled plasma), causing energy-density variations. In-phase sound waves have harmonics. Maximum and minimum densities were fundamental wavelength apart, one million light-years. Secondary maximum and minimum densities were first-harmonic wavelength apart. Tertiary maximum and minimum densities were second-harmonic wavelength apart, and so on. Fourth-harmonic wavelength was 10,000 light-years.

About 300,000 years after universe origin, free baryons and leptons became neutral-charge atoms. Atom density was lower than plasma density. Radiation traveled far before encountering matter (universe became transparent). That radiation is cosmic microwave background radiation. Because matter and radiation had exchanged freely up to that time, both had same temperature (3000 K), so cosmic microwave background radiation frequency distribution corresponded to temperature 3000 K, which was visible-light frequencies. Atoms were too far apart to interact, and so did not carry sound waves, so no more density variations occurred.

Because universe space-time expansion redshifts source frequencies, cosmic microwave background radiation now has microwave frequencies and frequency distribution corresponding to temperature 2.7 K. Now, cosmic microwave background radiation has same density and temperature variations as at 300,000 years after universe origin, 1 part in 10000. Because universe space-time expansion has increased space distances, fundamental-wavelength density and temperature variations are now over separations of one billion light-years. Fourth-harmonic wavelength is now ten million light-years.

Fundamental, first, second, and third harmonics have same intensity variations, 1 part in 10000 (scale-invariance).

About 300,000 years after universe origin, when neutral atoms formed, average distance between atoms was 10000 light-years. (Space expansion has made that distance ten million light-years.) Fourth-harmonic and higher-harmonic wavelengths were shorter than average distance between atoms, so those distances have almost no density variations.

curvature

Mass-energy density creates gravitational force and field. Mass-energy density determines space-time curvature at space-time points. Space-time curvature is gravitational-energy-field gradient. At universe origin, mass-energy density was maximum, space-time curvature was maximum, and gravitational force was maximum. Space expansion decreases curvature.

entropy

Beginning universe had low entropy, with high symmetry, united forces, and no particles. Beginning universe was in thermal equilibrium, but soon after was not in thermal equilibrium, so entropy transferred among stars, planets, particles, and radiation. Universe entropy always increases. Forces pull things together to make smaller and more complex structures with more motion and more random motion, as potential energy becomes kinetic energy. Motions push things apart to make larger and less complex structures with less motion, as kinetic energy becomes potential energy.

expansion

Milky-Way-like galaxies have similar light-frequency distributions. Earth observers see lower-frequency light {redshift} from distant galaxies than from nearby galaxies. By Doppler effect, observers see that light from objects moving away has lower frequency. Distant-galaxy percent red-shift increase exactly correlates to galaxy percent distance increase, so red shift proves space expansion at all points.

Space expands at same rate in all directions. Like balloon surfaces, space expands at same rate from all points. Because space expands from every point, far objects move away faster than near objects. Moving-away speed {recession velocity} v varies directly with distance d away: v = H * d, where H is Hubble constant (which is constant over space but may not be constant over time). Space expansion makes distances between galaxies increase, but does not move galaxies. Because space itself is expanding, objects are not in motion in space, and special relativity does not apply, so recession velocity can be greater than light speed. Just after universe origin, points 10 centimeters away from a point expanded away at light speed. Now, points 14 trillion light years {Hubble distance} from a point expand away at light speed. Nearest galaxy clusters have frequency 1.5 times lower. Cosmic microwave background radiation, 13.72 billion light-years away, has frequency 1000 times lower, and recession velocity is 1/50th of light speed. (Cosmic microwave background radiation was emitted 13.72 billion years ago, and 13.72 billion light-years away, but by now those radiation sources have expanded to 46 billion light-years away.) Light from 16 billion light years away has frequency so low that photons are not detectable.

Expansion increases volume and cools universe.

At universe origin, expansion rate was maximum, and gravity maximally opposed universe expansion. Soon after universe origin, expansion rate of space itself became constant. From universe origin to five billion years ago, universe expansion made average mass-energy density decrease, so gravity decreased and expansion rate decreased more slowly. Since five billion years ago, expansion rate has been increasing exponentially. Hubble constant is proportional to distance increase ds between objects over time dt, divided by distance s: H ~ (ds/dt) / s.

forces

Universe forces are strong nuclear force, electromagnetism, weak nuclear force, and gravity, in order of decreasing strength. Matter and energy interact through exchange of energy-bearing subatomic particles.

waves

Curvature exerts tidal forces on objects and fields. Changing electromagnetic fields can cause electric-force dipole moments and electromagnetic waves. Changing gravitational fields can cause gravity quadrupole moments and gravity waves.

structures

Universe gravitation clusters particles, forming galactic clouds. Largest space structures are 10^24 meters across. Galactic and intergalactic cloud positions and motions have same distribution as cosmic microwave background radiation. Galactic clouds and their dark matter form galaxies. Galaxy gas motions form stars. Stars generate energy by fusion. During final fusion stages, large stars explode, forming heavy atomic nuclei and dispersing them into space. Some stars have planets. Some planets have carbon, oxygen, metals, phosphorus, and sulfur. Some planets have radioactive nuclei, so they melt and make decreasing-density layers, including surface water and atmosphere. Some planets are in orbits allowing liquid water. Some planets have moons, so they have tides. Some stars last a long time, are not too hot or cool, and do not cool too fast, so planets exist for long enough time that life has time to develop.

gamma rays

Small black holes, supermassive black-hole particle jets colliding with photons, and magnetars emit gamma rays. Perhaps, high-mass supersymmetric-particle collisions emit gamma rays, because they are antiparticles of themselves.

island universe

Galaxies {island universe} lie apart in the ocean of space.

isotropy

Universe dimensions are equivalent, and universe is the same in all directions {isotropism} {isotropy}|. Only infinite universes can be isotropic. Finite universes cannot be isotropic.

supergalactic plane

Milky Way and neighboring galaxies are in one plane {supergalactic plane}.

PHYS>Astronomy>Universe>Cosmology

cosmology

Universe history {cosmology}| cycles between endpoints (oscillating theory), is unchanging (steady-state theory), or began by space expansion {universe, history} {universe, origin} [Greene, 1999] [Mach, 1885] [Mach, 1906] [Rees, 1997] [Rees, 1999] [Rees, 2001] [Smolin, 2001] [Weinberg, 1972] [Weinberg, 1977 and 1993] [Weinberg, 1992] [Weyl, 1952].

before universe

Perhaps, before universe origin, there was only nothingness, there was already space and/or time, or there were also mathematical and/or physical laws.

Nothingness has properties. Nothingness has no time or space and so no dimensions. It has no ground-state, zero, or complex-number energy, because it has no dimensions and so no motions or fields. It has no matter, motions, forces, fields, radiation, energy, temperature, or pressure. It is homogeneous and has only one phase. It has no quanta. It has zero entropy. Perhaps, by uncertainty principle, nothingness can create relativistic quantum-mechanical virtual particles.

Perhaps, universes spontaneously arise from empty space, if space has negative energy, which causes space expansion.

Perhaps, mathematical/physical laws cause universes to arise, if they imply space and time.

dimensions

If universe has no time dimension and any number of space dimensions, or any number of time dimensions and no space dimension, motion, energy, momentum, and space-time do not exist.

If universe has one or more time dimensions and more than three spatial dimensions, gravity and electromagnetism strength decrease more quickly with distance, so star and planet orbits and electron orbits, respectively, are too lightly bound and are unstable. With one or more time dimensions and fewer than three spatial dimensions, gravity and electromagnetism decrease less quickly with distance, so stars and planets and electrons quickly move to center, and stars, planets, and electrons do not exist.

If universe has more than one time dimension and one space dimension, fields are unstable. If universe has more than one time dimensions and more than one space dimension, physical events are unpredictable.

Electron current, magnetic field, and atom radius define three space dimensions, so electromagnetism requires at least three infinite spatial dimensions. Space cannot have more than three infinite spatial dimensions, because then electron current, magnetic field, and atom radius have two or more independent relations for electric and magnetic fields.

String theory and brane theory require three infinite spatial dimensions and seven or eight curled-up spatial dimensions. Quantum-loop theory defines three infinite spatial dimensions.

Perhaps, dimension number, length, and geometry were or are in flux. Dimension number varies from zero to infinite. Dimension lengths vary from zero to infinite length. Dimension geometries vary from linear to curved to curled up. Perhaps, dimensions evolve by physical processes to stable numbers, lengths, and geometries. Perhaps, energy and matter distributions dynamically determine dimension number, length, and geometry. Perhaps, multiverses or different universe regions have different dimensions.

Perhaps, beginning universe had zero dimensions. Perhaps, because fewer dimensions make lower entropy, universe has four-dimensional space-time because it has lowest entropy consistent with maximum energy. Perhaps, universe has optimum number, length, and geometry of space-time dimensions to allow highest number of states, most stability, and most symmetries. Perhaps, universe is like one fiber bundle, with one n-sphere as base space.

space expansion

Universe expands at same rate at all points and in all directions equally.

At its origin, universe had maximum space expansion rate. Gravity is attractive and slows expansion rate. If universe average mass-energy density is high enough, gravity eventually stops expansion, and then universe contracts back to singularity. If expansion rate had always been smaller by 10^-10 than it was, universe collapses back to singularity in one million years.

If universe average mass-energy density is low enough, gravity never stops space expansion, and universe expands at ever slower rate. If universe average mass-energy density is even lower, gases cannot condense, and galaxies and stars do not form. If expansion rate had always been greater by 10^-10 than it was, universe is like empty space in one million years. Therefore, space expansion rate has been and will be such that universe will expand to infinity, at which expansion rate will finally be zero.

entropy

At universe origin, entropy was minimum. If early-universe entropy per baryon was more, no protogalaxies form. Universe entropy is always increasing. Perhaps, universe expansion contributes to increasing universe entropy.

density variations

At neutral-charge atom formation, with matter-radiation decoupling, 300,000 years after universe origin, if universe had too-slight mass-energy density irregularities, gravity does not form galactic clusters, no protogalaxies form, and no galaxies form. If universe had slighter mass-energy density irregularities than it does, galaxies are farther apart and have fewer and smaller stars. If universe had too-great mass-energy density irregularities, galaxies are smaller and have bigger stars, so stars become dark and cool more quickly.

Cosmic microwave background radiation has variations over space. Cosmic microwave background radiation polarization has fundamental frequency and wavelength, as well as C1-dipole, C2-quadrapole, and C3-octopole multipoles. Dark energy makes ecliptic C2 and C3 multipoles align with equinoxes and solar-system-motion direction, not be random as required by inflation theory. Dark energy makes some C2 and C3 multipoles align with Milky-Way-and neighboring-galaxy supergalactic plane, not be random. Dark energy makes some C2 and C3 multipoles lower intensity than higher-C multipoles, though inflation theory requires that all multipoles have same intensity. Dark energy makes cosmic-microwave-background-radiation intensity variation over space separations greater than 60 degrees not correlate with that at smaller separations, though inflation theory requires that all separation distances have same intensity variation.

gravitation

Gravity binding-energy-to-rest-mass ratio is 10^-5, so gravity is weak. If ratio was higher, matter clustering is so great that gravity is stronger than dark energy, soon overcomes initial space expansion, and contracts matter into giant black holes. If ratio was lower, gravity is too weak to cluster matter, no galaxies or stars form, and space expands faster forever.

If dark energy was too little and gravity was too much, universe quickly re-collapses. To prevent quick contraction, matter and dark matter must be less than three times universe dark energy. If dark energy was too much and gravity was too little, universe expands before atoms can form or galaxies can form. To allow galaxy formation, dark energy must be less than 140% of universe mass.

Quantum gravity or other combination of gravitation and quantum mechanics determines universe origin. Perhaps, universe origin involved quantum-mechanical tunneling.

gravity: internal pressure

Mass m has energy E: E = m * c^2, where c is light speed. Mass can convert to kinetic energy, which causes external pressure. Increased kinetic energy increases temperature, and increased temperature pushes particles farther apart against gravity, increasing positive potential energy and making positive internal pressure. In general relativity, at space-time points, gravity G depends on mass-energy density M plus three times internal pressure P: G ~ M + 3*P. Solids do not change volume at constant temperature, so they have zero internal pressure. Hot gas has more positive potential energy than cold gas and so has more internal pressure and more gravity. Photons have zero rest mass but have radiation pressure that makes internal pressure P one-third mass-energy density M, so gravity doubles: M + 3 * (M/3) = 2*M.

electromagnetism

Electromagnetic radiation can transport energy over infinite distances. Electromagnetism determines inorganic-and-organic-chemical bonding and reactions. If electromagnetic force was stronger, electrons fall into protons, and atoms do not form. If electromagnetic force was weaker, electrons are too fast for capture in atom orbits, and atoms do not form. For example, if electromagnetism was only 4% weaker, hydrogen atoms cannot form.

If protons were 0.2 percent more massive, protons decay to neutrons. If electron and proton charge was slightly different, electrons cannot orbit protons, and atoms do not form.

strong force

Strong nuclear force holds atomic-nucleus protons together and determines fission and fusion reactions. Strong-nuclear-force strength determines star energy radiation and atomic-nuclei radioactivity levels. If strong force was stronger, only large atomic nuclei form, and no hydrogen persists. For example, if strong nuclear force was only several percent stronger, carbon cannot form from beryllium and helium. If strong nuclear force was 2% stronger, protons cannot form from quarks. If strong force was weaker, only small atomic nuclei form. For example, if strong nuclear force was 2% weaker, small nuclei are unstable.

strong nuclear and electromagnetic forces

Universe strong nuclear force and electromagnetic force have relative strengths that allow stable deuterium, stable carbon, few radioactive atoms, stable stars, and weak gravity. If strong nuclear force was stronger and electromagnetic force was same, stars explode. If strong nuclear force was weaker and electromagnetic force was same, deuterium is unstable. If strong nuclear force was same and electromagnetic force was stronger, carbon is unstable. If strong nuclear force was stronger and electromagnetic force was stronger, all atoms are radioactive.

weak force

Weak nuclear force determines fission and fusion reactions, radioactivity from nuclei, and planet melting. If weak force was stronger, nuclear fusion is faster, stars live shorter, and heavy elements cannot form. If weak force was stronger, universe has less dark matter, because, in first second of universe, dark matter stays in equilibrium with other matter longer. If weak force was weaker, nuclear fusion is slower, stars live longer, and hydrogen cannot form. If weak force was weaker weak, universe has more dark matter.

force unity

At 10^-43 seconds (Planck time) after universe origin, with universe at 10^32 K, all forces and interactions have Planck time, so all forces are the same {unity of forces}. Higher temperature makes gravitation increase greatly in strength (because internal pressure is more), weak force increase in strength (because average distance is smaller), electromagnetism change little (because radiation can have any frequency), and strong force decrease in strength (because average distance is smaller). Therefore, at universe origin, with highest temperature, all forces become equal in strength (and in other properties). Space expansion cooled universe and broke symmetry, so first strong force separated, and then electromagnetism and weak force separated.

universe-origin theories

General relativity, quantum mechanics, cosmology, and logic contribute to theories of how universe began {universe-origin theories}. The universe had no beginning or began as white-hole space-time singularity, as quantum foam, as quantum branes or loops, or from nothing [Adams, 2002] [Barrow and Tipler, 1986] [Greene, 1999] [Greene, 2003] [Kauffman, 1993] [Mach, 1896] [Mach, 1906] [Price, 1996] [Rees, 1997] [Rees, 1999] [Rees, 2001] [Sklar, 1977] [Smolin, 1997] [Weinberg, 1972] [Weinberg, 1992] [Weinberg, 1993] [Weyl, 1952].

energy

By observation and calculation, at universe origin, space had smallest volume, same total energy as now, and highest energy density. Highest energy density made greatest space curvature, which is consistent with smallest 3-sphere volume. Because beginning universe was smallest volume, distances were shortest, and potential energy was lowest, so kinetic energy and temperature were highest.

energy: conservation in closed universe

By observation, universe has no energy influx from outside universe or energy outflow to outside universe. Universe total energy is constant.

energy: positive

Universe attractive forces, mainly gravity, cause positive energy, so objects have positive potential and kinetic energy. Local positive energy density varies with both rest-mass and relativistic-mass distributions.

energy: dark energy

By observation (Brian Schmidt) [1998], universe has repulsion that is expanding space, so space has negative intrinsic energy. Negative-energy causes uniform space expansion and so does work to add intrinsic negative energy to added space. Because space-expansion volume varies directly with intrinsic-energy work, space has constant negative intrinsic-energy density. Therefore, space has had constant dark-energy density since universe began. By calculation, universe has 70% dark energy and 30% matter. The future will disclose what dark energy is.

energy: amount is arbitrary

Because only energy changes have physical significance, absolute energy amount has no physical meaning. Energy level is arbitrary, so energy level is only relative, not absolute. Any physical state can be set to zero energy, and other states differ in energy from that state. For example, in earth's gravitational field, potential energy can be zero at Earth's surface or zero at infinite distance. If physical states can have arbitrary energy levels, total universe energy amount is arbitrary.

By special and general relativity, energy amounts are relative to reference-frame observer velocity. For example, for high-velocity observers, kinetic energy can be zero. If reference frame is arbitrary, total universe energy is arbitrary.

Photon energy varies directly with electromagnetic-wave frequency. Moving relative to light sources changes wave frequency and so observed photon energy. For observers moving away from source at high velocity, frequency red-shifts to near zero. For observers moving toward source at high velocity, frequency can blue-shift to arbitrarily high values. Because observer reference frame is arbitary, total universe photon energy is arbitrary.

energy: space vacuum

By observation, universe space curvature is close to zero, so universe average energy density is close to zero, meaning positive average mass-energy density and negative average intrinsic-energy density are close to equal. Closed universes do not change total energy, so average positive energy density and average negative energy density stay close to equal for closed universes.

Empty space has no energy from mass or relativistic mass, so space vacuum is set to zero average energy density. Other-states energy densities are relative to vacuum-state energy density.

energy: highest

Because shortest quantum-mechanical wavelengths mean highest frequencies, shortest spaces and times require highest energy (uncertainty principle), and universe began with shortest diameter, so universe began with highest energy density.

Universe has wide number ranges. Gravitational force has no limit in distance or amount. Strong force to gravitational force ratio is about 10^40. Because forces have wide ranges, universe can have wide energy ranges.

In empty space, positive energy density and negative energy density can be arbitrarily high, as long as positive energy density equals negative energy density so that energy density is zero. Universe can have arbitrarily high energies and energy fluctuations. Energy fluctuations can temporarily reach energy densities great enough to make particles.

general-relativity singularity

Because energy density, internal pressure, and gravity were highest, general relativity theorizes that universe began as a space-time singularity. Universe was a point both in and out of space-time. Singularities have smallest space volume and greatest space curvature. Singularities have perfect symmetry, homogeneity, unity, and order. Perhaps, all universes are similar.

quantum-mechanics closed universe

Because empty-space distances are shortest, space vacuum has uncertainty-principle energy fluctuations that can be large enough to make particles. Because both closed universes and space vacuum have zero energy flux, zero average energy density, and high energy-density variance, closed universes can arise spontaneously and randomly from space vacuum. Boundary conditions determine universe properties.

multiverse

If closed universes arise spontaneously from existing space vacuum, the number of space points is infinite. An infinite number of universes, with different laws and properties, can arise. Alternatively, each universe that has cosmic inflation has an infinite number of space points at which sub-inflations can spontaneously arise. Because space expands rapidly and separates them, the universes are independent.

quantum field theories

Quantum field theories show how particles and antiparticles arise in strong force fields, how virtual particles make force fields, and how space and time arise.

Quantum electrodynamics shows how time arises in strong force fields. Strong electromagnetic and weak-force fields make non-linear-wave time quanta (instanton), lasting for one electronic transition or one quantum tunneling.

Quantum gravity shows how space arises in strong gravitational fields. Strong gravitational fields make non-linear-wave space quanta, over one Planck distance, area, or volume, from no space and no time, and so start spaces with zero average energy density.

Therefore, strong fields can make space and time quanta and so start universes. Boundary conditions determine universe properties.

quanta

Universe space, time, energy, and momentum have non-zero minima and increase by discrete amounts (quanta). Particle energy quanta vary directly with quantum-mechanical resonating-wave harmonic frequencies (and particle momentum quanta vary inversely with quantum-mechanical resonating-wave harmonic wavelengths). Lowest-energy quanta associate with fundamental frequency. Because they have higher energy, higher-frequency quantum states have lower probability.

quanta: discrete non-zero energy levels

If protons and electrons can have zero-energy states, electrons can spiral into atomic nuclei, preventing atoms from existing. Particles and waves exist for long times and so have non-zero minimum energy.

If protons and electrons can have energy states that vary continuously, orbits can continuously decay, and electrons can spiral arbitrarily close to atomic nuclei, preventing atoms from existing. Discrete states maintain orbits, because moving from lowest orbit to no orbit cannot conserve energy, momentum, and angular momentum simultaneously. Particles and waves exist for long times and so have discrete energy levels.

If energy can vary continuously, particles and waves can have infinitesimal energy increases, each with the same small finite probability, so total energy can become infinite with measurable probability (ultraviolet catastrophe). If energy can vary only by discrete amounts, higher-energy increases have lower probability, so infinite total energy has zero probability. Higher-energies have lower probabilities, so particles and waves have discrete energy levels.

virtual particles

Physical-mathematical operators that conserve quantities, such as energy conservation, have average quantity zero. For commutative operators, operation order does not matter, so they have one more symmetry: variance quantity zero. Non-commutative operators that conserve quantities have average quantity zero but variance quantity non-zero. Action in physics multiplies energy and time non-commutatively, so action has energy fluctuations with zero averages but positive or negative variances (uncertainty principle). Space vacuum has short distances and high momenta, and short times and high energies. Therefore, space vacuum can have high enough positive or negative energy fluctuations to spontaneously create short-time energy quanta (virtual particles). Because particles are numerous, even low-probability high-energy-density states occur within moderate times, so space vacuum makes numerous virtual particles.

By observation, two positive-energy virtual particles (particle-pair) can arise spontaneously and simultaneously from empty space. Two particles allow charge and momentum conservation. The virtual particles have zero or opposite charges.

By observation, after short lifetime over small distance, virtual particles interact with zero-charge or opposite-charge virtual particles and spontaneously and simultaneously disappear, making two photons of electromagnetic energy.

The creation-and-annihilation process conserves mass-energy over long enough times and wide enough lengths.

In quantum mechanics, energy fields are streams of virtual-particle zero-rest-mass photons, zero-rest-mass gravitons, massive strong-force bosons, or massive weak-force bosons emitted from charges, masses, quarks, or leptons, respectively. Photons and gravitons are zero-rest-mass bosons that both propagate at light speed, so electromagnetism and gravity have effects over infinite distances.

antiparticles

By observation, when a particle meets its antiparticle, the particles annihilate, canceling electric charge and converting all mass to photons of electromagnetic energy. All quantum numbers become zero. Therefore, antiparticles always have charge opposite to that of their particles.

Both matter and antimatter have positive mass and attractive gravity. Antimatter does not have antimass or repulsive antigravity. Because they are the exact opposite of particles, antiparticles must have the same mass as their particles.

By special relativity, particles can only move forward in space-time. When a particle moving forward in space-time meets its antiparticle, momentum cancels, mass cancels, and only energy remains. Because particles and antiparticles have same mass and speed, momentum cannot cancel if antiparticles move forward in space-time, so antiparticles move backward in space-time. Because a particle and its antiparticle annihilate, a particle moving forward in space-time is equivalent to its antiparticle moving backward in space-time.

In quantum mechanics, all possible particle and antiparticle trajectories have wavefunctions and probabilities, and space-vacuum quantum energy fluctuations make virtual particles and antiparticles with measurable probabilities. By observation, a real particle can disappear at one location, and then a real particle can re-appear at the same time at a nearby location. Space-vacuum quantum energy fluctuations made the particle's virtual antiparticle arise earlier in space-time where the particle re-appeared. The virtual antiparticle went backward in space-time to where the particle disappeared and annihilated it at the observed time, the same time as the particle re-appeared at the nearby location.

antiparticles: antimatter

At universe beginning, because matter and antimatter have same physical laws and processes, universe had equal matter and antimatter amounts. Matter-antimatter annihilations made radiation, which is part of cosmic microwave background radiation. During annihilation, weak-force parity-and-time asymmetries left one part matter (and no antimatter) after every billion annihilations, so universe has only some matter: one proton for every billion radiation photons.

electric charge

At universe origin, very high temperature unified the strong force, weak force, and electromagnetism, so quark creation and lepton creation coupled. That coupling balanced positive and negative charge creation, so universe has no net charge.

dark matter

By calculation, stars move faster in their galactic orbits than galaxy visible and non-visible ordinary matter can make them move, and galactic-cloud ordinary-matter mass does not make enough gravity to form galaxies, so galaxies must have more matter (dark matter) than just ordinary matter. By calculation, universe has nine times more dark matter than ordinary matter. Dark matter is invisible, because it does not interact with electromagnetic radiation. The future will disclose what dark matter is.

time

Universe began a definite time ago, and observations indicate that universe will keep expanding indefinitely, so past time was not infinitely long ago, but future time will be or approach infinite time.

space

By observation, space is isotropic and homogeneous and probably began that way.

By calculation and observation, universe began with finite volume, and space has expanded ever since. Space expansion has reduced object gravitational attraction, space curvature, and outward kinetic energy. By observation, space expansion rate is increasing, so space will expand faster. Universe has large volume now and will approach infinite volume.

space: curvature

By general relativity, positive space curvature reduces distances, and negative space curvature increases distances. Because observed cosmic-microwave-background-radiation irregularities equal expected cosmic-microwave-background-radiation irregularities [1997], space on average has no curvature.

By calculation, universe average mass-energy density (positive and attractive) equals average dark-energy density (negative and repulsive), so space on average has no curvature.

space-time

Space and time unite in continuous space-time. By special relativity and experiment, time dimension relates to space dimensions by light speed: time-dimension time times light speed is space-dimension length. All objects move through space-time at light speed. Space-time has no time flow or direction, so space-time represents all previous and future times in the same way as spatial dimensions represent all points in all directions.

space-time: why was space three-dimensional?

Space is where energy is, so energy makes space. More space dimensions means more energy but less energy density. Zero space dimension has no energy and no energy density. One space dimension makes energy be one-dimensional longitudinal waves, so energy is too low and energy density is too high. Two space dimensions make energy be longitudinal and one-plane-transverse waves, so energy is too low and energy density is too high. Three space dimensions make energy be longitudinal and two-coordinate transverse waves, so energy density not too low or too high. Four space dimensions make energy be longitudinal and three-coordinate transverse waves, so energy is too high and energy density is too low.

Continuous four-dimensional space-time is stable and allows motion, potential, and energy. Space-time is unstable with more than three spatial dimensions and/or more than one time dimension, because gravity is too weak. With two or fewer space dimensions, kinetic energy is too small, and space does not expand. With four or more space dimensions, kinetic energy is too great, and space expands rapidly to make near vacuum.

space: expansion

At universe origin, although energy density and internal pressure were highest and so gravity was highest, space had smallest possible volume, and random-motion kinetic energy was highest and overcame gravity greatest, so space expansion rate was highest. However, because gravity was highest, expansion-rate decrease rate was greatest.

entropy

Planck-size discrete units have information bits. At universe origin, volume was smallest, so entropy was lowest.

Beginning universe had smallest volume, fewest allowable number of dimensions, fewest states, fewest information bits, most force symmetries, no matter, highest energy, and highest temperature, all of which make entropy lower, so total universe entropy was lowest.

Continuous systems have infinitesimal energy increases, each with the same small finite probability, and so infinitely many possible states. Discrete systems have lower-probability higher-energy states, so entropy is lower.

entropy: fractal processes

Perhaps, to minimize volume and dimension number, beginning universe had fractal processes. Fractal processes have high order and so low entropy. Moreover, fractal processes can make unlimited energy and energy ratios, because they repeat indefinitely.

symmetries and conservation laws

At universe origin, space-time, general relativity, quanta, and quantum mechanics began. Beginning universe had deterministic physical laws with time, space, and handedness symmetries.

Because physical laws are the same for forward and backward time (isochrony), space-time has energy conservation (least action over time), so universe total energy stays constant.

Because physical laws are the same for any space direction (isotropy), space-time has momentum conservation (least action over distance), so universe has no net motion.

Because physical laws are the same for right-handed and left-handed systems (symmetry), space-time has angular-momentum conservation (least action over rotation), so universe has no net rotation.

Future physical theories will account for all universe properties, including universe origin and its properties.

space-expansion causes

Immediately after universe beginning, space itself expanded equally at all points in all directions at highest rate (the "Big Bang"). Why did space expand at universe origin {space-expansion, causes} {Big Bang, causes}?

beginning-universe properties

By observation and calculation, at universe origin, space had smallest volume, and universe had same energy as now, so space had highest energy density. Because space had shortest distances, universe had lowest potential energy and highest kinetic energy and temperature. At highest temperature, forces unify and have greatest strength, so beginning universe had only radiation of one unified type, with zero rest mass, light speed, highest wave frequency, shortest wavelength, and highest radiation internal and external pressure. Because mass-energy density and internal pressure were highest, universe had highest gravity and space curvature, consistent with smallest 3-sphere volume. Because entropy varies directly with volume and inversely with gravity, beginning universe had lowest entropy.

space filling

Space is where matter and radiation are. Radiation-wave random reflections, refractions, and diffractions, and particle random motions and collisions, send waves and particles in all directions, so particles and waves fill space homogeneously and isotropically.

expanding space

In systems, most particle random motions and collisions, and most radiation-wave reflections, refractions, and diffractions, move particles and radiation apart, where they are less likely to encounter other particles and radiation and so less likely to change direction, so they continue moving apart. As particles and radiation move apart, space volume increases, mass-energy density decreases, potential energy increases, kinetic energy decreases, temperature decreases, internal pressure decreases, gravity decreases, and space curvature decreases.

Space expansion stretches lengths between particles and radiation. Space expansion adds quantum lengths between particles and waves.

expanding space: waves and particles remain intact

If particles are points, they have no insides, so space-expansion forces do not change point-particles. If particles have internal forces, those forces are much greater than space-expansion forces and particle-collision forces, so space-expansion forces do not change particles. Wave electromagnetic forces are very much stronger than gravity, and waves do not have collisions, so space-expansion forces do not change wave internal structure.

forces

Gravity is attractive and has infinite range, so it always opposes particle and radiation separation. Electromagnetism has infinite range but is attractive and repulsive and so has no overall effect on particle and radiation separation. Strong and weak nuclear forces have short range and so do not affect particle and radiation separation.

general relativity

Object random motions are mostly outward and so separate objects, increasing potential energy and decreasing kinetic energy, temperature, mass-energy density, and space curvature. Outward force varies directly with temperature (and so with mass and speed). If object kinetic energy overcomes gravity, kinetic energy decreases, and gravitational potential energy increases, by the same amounts. Total energy stays constant.

Matter, antimatter, and radiation have positive mass, positive energy, positive mass-energy density, and positive internal pressure, so gravity is positive and attractive, and gravitational energy is positive energy. Attractive gravity makes positive space curvature. Masses gravitationally attract each other at any distance less than infinite distance, so masses tend to move relatively closer, decreasing potential energy and increasing kinetic energy, temperature, mass-energy density, and space-time curvature. Gravitational force varies directly with mass and varies inversely with distance squared. General relativity adds internal pressure as a relativistic source of gravity, so objects with higher temperature have more gravity.

Objects with higher temperature also have greater outward motion. Because increased gravity is a relativistic effect of higher temperature and increased outward motion is a direct effect of higher temperature, higher temperature increases outward motion more than it increases gravity, and so increases space expansion. At universe origin, temperature was highest, and radiation external pressure was highest, so space expansion rate was highest.

Gravity and temperature vary directly with total energy at universe origin, but in different ratios. Because space expansion decreases temperature and gravity unequally, space expansion rate decreases over time.

Because gravity and temperature vary with energy at different rates, space has zero probability of neither expanding nor contracting. Universe is always changing.

quantum mechanics and vacuum intrinsic energy

By observation, space has a constant negative intrinsic-energy (dark-energy) density that causes repulsion (antigravity) and uniform space expansion. Dark energy can do negative work. Negative work decreases negative kinetic energy as it pushes space apart, and increases negative potential energy in the added space. (Positive work decreases positive kinetic energy and increases positive potential energy.) Dark energy adds intrinsic energy and adds space in exact proportion, so space always has constant dark-energy density.

Dark-energy strength was much lower than object random motions at universe origin and contributed little to original rapid space expansion.

quantum mechanics and vacuum intrinsic energy: expansion rate

Dark-energy repulsion also pushes particles and radiation apart, increasing positive potential energy and decreasing positive kinetic energy, decreasing mass-energy density and space curvature. Total energy stays constant, as required for closed systems.

For closed universes, because positive energy changes and negative energy changes always offset, universe positive energy and negative energy can be any amount. Mass-energy density and intrinsic-energy density can be any value, so space expansion rate can be any value for closed universes. By observation, universe has had periods of greatly differing space-expansion rates, such as initial expansion rate, the very high cosmic-inflation rate, and ever-slower expansion rates.

gravity at very short distances

Perhaps, gravity is repulsive at very short distances and very high temperatures.

string theory at very short distances

String theory theorizes that, when universe diameter was Planck length or less, strings repulsed, making gravity repulsive and space curvature negative, so space expanded rapidly.

string-theory inflatons

Perhaps, spontaneous symmetry breaking disunified forces, phase transition made string/brane scalar (inflaton) field, and inflaton-field repulsions caused space expansion.

space-expansion rate

At universe origin, unified force was greatest, and space expansion decreased at highest rate.

At any instant, space-expansion rate depends on initial radiation-velocity-driven space-expansion rate, initial unified-force/gravity space-contraction rate, and constant dark-energy antigravity space-expansion rate.

As space expands over time, distances between objects increase, so gravitational potential energy increases and object kinetic energy decreases, so object average speed becomes less, temperature decreases, and space-expansion rate decreases.

Gravity space-contraction rate depends on mass-energy density and on internal pressure, so it decreases as space volume increases. As space expands over time, gravity always decreases space-expansion rate, but ever more slowly.

Universe dark-energy density is constant, so it constantly increases space-expansion rate.

After initial expansion, object kinetic-energy expansion force decreases, gravity contraction force decreases, and dark-energy expansion force is small compared to them, so space-expansion rate decreases.

Eventually, dark-energy expansion force, plus object kinetic-energy expansion force, overcome gravity contraction force, and space expands ever faster.

entropy

Space expansion makes more volume, more states, more information bits, fewer force symmetries (as forces separated from other forces), more matter, same energy, lower temperature, and higher entropy, and so more entropy.

deceleration parameter

Gravity slows universe expansion rate {deceleration parameter}.

universe history

The universe began 13.72 billion years ago {universe history}.

before Planck time

Quantum mechanics and general relativity theorize that universe began with smallest 3-sphere volume, densest energy, highest pressure, greatest space curvature, and highest temperature. Because volume was smallest, universe had lowest entropy. Because temperature and external pressure were highest, space had highest expansion rate (Big Bang).

Before elapsed time was Planck time, 10^-43 seconds, time had quanta, random perturbations, expansions, contractions, and inhomogeneities. Space volume had diameter less than Planck length, 10^-35 meters. Indeterminate space and time dimensions superimposed and interchanged, with no distance metric, so things had indeterminate sizes. Quantized space had random expansions and contractions; tears and joins; loops, handles, holes, nodes, knots, links, kinks, and entanglements; rotations, spins, twists, and windings; phases, boundaries, inhomogeneities, and overlaps; asymmetries, anisotropies, and discontinuities; and relaxations, nonstandard fields, and nonstandard forces. This "quantum foam" was like periodic orbits in chaotic systems.

before Planck time: energy

Total universe energy was same as now. Because space volume was smallest, energy density was highest. Because universe had shortest size and time, by uncertainty principle, universe had highest energy and energy fluctuations. Because many bosons can occupy the same space, even the smallest universe can have any number of high-energy real and virtual bosons and can have any energy level.

before Planck time: temperature and pressure

Because kinetic energy was highest, temperature and pressure were highest. Radiation frequency was highest, so radiation energy and pressure were highest.

after Planck time

From 10^-43 seconds after universe origin (diameter 10^-35 meters) to 10^-39 seconds after (diameter 10^-15 meters), space expansion pushed masses farther apart and increased potential energy, so kinetic energy decreased and universe cooled. Quantum mechanics and general relativity theorize that quantum foam became continuous four-dimensional space-time as universe temperature and pressure decreased. Space, time, energy, and momentum had discrete quanta, and physical processes followed quantum-mechanics and general-relativity laws.

after Planck time: radiation only

Because gravitation, electromagnetism, strong nuclear force, and weak nuclear force differentiate only at lower temperatures, universe had only one unified force. Supersymmetry united bosons and fermions. Because distances were short, potential energy was low, and kinetic energy was high. Because temperature was too hot to allow matter formation, universe had only zero-rest-mass radiation, traveling at light speed at high frequency with short wavelength.

after Planck time: physical laws

Universe had special relativity, general relativity, and quantum mechanics. Because universe had only radiation, universe had no particles and so no particle Standard Model. Because forces had not yet differentiated, universe did not have quantum electrodynamics or quantum chromodynamics. Energy, momentum, and angular momentum conservation began.

cosmic inflation

After 10^-39 seconds after universe origin, space expansion rate became extra-fast for less than one second, after which time it returned to regular space expansion rate.

particle formation

After that, protons, neutrons, and electrons formed, and then helium atomic nuclei formed.

atom formation

When universe was 300,000 years old, neutral-charge hydrogen and helium atoms formed, leaving 3000-K (visible-wavelength) radiation.

galaxies

Between 12 and 9 billions years ago, galaxies formed, and since then supernovas have made carbon, oxygen, and other atomic nuclei.

now

Now, universe has 400 billion galaxies, about 3 million light-years apart, averaging 100 billion stars. Universe has more than 100 billion planets.

Universe has 75% hydrogen nuclei and atoms and 25% helium nuclei and atoms.

The 3000-K radiation has become 3-K (microwave) radiation, streaming almost uniformly from all space directions, proving that universe began hot and then space expanded.

future

One hundred fifty billion years from now, recession velocity of the galaxy cluster nearest to the Milky Way Galaxy (in the Virgo Cluster) will exceed light speed. Light from galaxy-cluster stars (small ones will still be shining) will have red-shifted to frequency 5000 times lower. Cosmic microwave background radiation will have temperature near absolute zero.

Two trillion years from now, recession velocity of the very-small-so-still-shining stars closest to the sun will exceed light speed, and its light will have red-shifted to frequency near zero, so those photons will have lowest energy, and cosmic microwave background radiation will have temperature essentially absolute zero.

Much longer than two trillion years from now, solar system, earth, and molecule particles and radiation will spread apart to almost infinite distances, and universe will have absolute zero temperature.

outside universe

If multiverse does not exist, adjacent to universe {outside universe} is only non-physical nothingness. If multiverse exists, outside universe is empty space-time, and an unlimited number of other universes, with the same or different properties, are farther away in space and time.

cosmogony

Religions, mythologies, and traditions have universe creation and origin theories {cosmogony}|. Cosmology is a science.

cosmic horizon

If, due to space expansion, Earth observers are moving away from a light source faster than light speed, that light cannot reach Earth. Earth observers can see cosmic microwave background radiation, which was emitted 13.72 billion years ago and has redshift 1000 times. However, light sources 16 billion light-years away are expanding away at light speed, so that is the current maximum distance {horizon, cosmic} {cosmic horizon} from which light will eventually reach Earth. Because space expansion is exponentially increasing, in future cosmic horizon will decrease.

horizon problem

From universe origin to 300,000 years later, from any space point most other space points had space expansion rate faster than light speed. Because universe radius was larger than cosmic horizon, light from most early-universe space points did not reach most other space points, and space did not reach thermal equilibrium {thermalization}. Space was non-homogeneous, and space regions had different temperatures, mass-energy densities, and space curvatures. However, cosmic microwave background radiation has same temperature to 1 part in 10,000, showing that universe is almost homogeneous. How did space regions beyond each other's cosmic horizons become almost homogeneous {horizon problem}? Perhaps, beyond current cosmic horizon, universe is not really homogeneous. Perhaps, random quantum-mechanical processes kept variations to 1 part in 10000. Perhaps, in-phase sound waves caused compressions and rarefactions of 1 part in 10000. Perhaps, early-universe space inflation greatly decreased space curvature, mass-energy density, and temperature, so variations greatly decreased.

Olber paradox

If universe is infinite and static, galaxies are at all sky directions, so night sky is bright, but night sky is dark {Olber's paradox} {Olber paradox}. Because universe is finite and expanding, galaxies separate far, and night sky is dark.

wormhole

Perhaps, space regions can tunnel {wormhole}| through space-time to other space regions. Wormholes require energy to warp space-time. Gravity collapses wormholes. Negative energy resists gravity, so wormholes with negative-energy particles are stable. Positive energy assists gravity, so wormholes with positive-energy particles are unstable. Perhaps, wormholes allow energy from future and past to interchange, with positive feedback, and/or allow travel to future and past. In string theory, strings can tear space-time.

degeneracy pressure

Massive objects strongly attract atoms gravitationally. In large stars, gravity pulls atoms into each other up to maximum hot-gas density, which is about 0.5 g/cm^3. Uncertainty principle prevents distances from being zero. Pauli exclusion principle prevents particles from having same location (state). In matter, uncertainty principle and Pauli exclusion principle cause quantum-mechanical resistance pressure {degeneracy pressure}, so matter resists further compression. Degeneracy pressure varies directly with gravitational force and with mass-energy density, not with temperature. In white-dwarf stars, gravity decreases electron distances causing electron degeneracy pressure. In neutron stars, gravity overcomes electron degeneracy pressure, and decreases neutron distances, causing neutron degeneracy pressure.

electroweak phase transition

About 10^-11 seconds after universe origin, electromagnetic force and weak nuclear force decoupled {electroweak phase transition} at temperature 10^15 K.

heat death

Perhaps, trillions of years from now, universe will be near absolute zero temperature and in thermal equilibrium {heat death}, when space expansion is much larger than now.

PHYS>Astronomy>Universe>Cosmology>Energy

dark energy

Space has intrinsic negative energy {dark energy}|. Dark energy is 70% of universe mass-energy (ordinary matter and dark matter are 30%). Perhaps, dark energy is virtual particles that have negative energy {vacuum energy} and repulse masses. Perhaps, dark energy involves new forces and interactions, such as quintessence. Perhaps, dark energy uses hidden space dimensions.

As they travel, electron, muon, and tau neutrinos, which have different masses, interconvert. Perhaps, neutrino-mass changes make dark energy, as they oscillate matter quark flavors. Dark-energy density is similar to neutrino density.

Perhaps, supernova changes or distant-particle effects cause space expansion, so there is no dark energy. Perhaps, rippling long-wavelength waves still travel after cosmic inflation and increase in intensity, expanding universe indefinitely, so there is no dark energy. Perhaps, non-linear mass interactions (backreaction) contribute to space expansion.

density

Dark energy density is 10^-26 kg/m^3. Dark-energy density variation over space is zero, because dark-energy particles do not attract each other, so space has constant dark-energy density over time and space.

When energy is negative, force is repulsive, so positive space expansion amount equals added negative energy amount, keeping dark-energy density same when universe is small or large.

space expansion

After cosmic inflation ended, 1 second after universe origin, dark energy causes universe space expansion.

internal pressure

Rubber membranes resist stretching (expansion) and compressing (contraction). Stretched rubber membranes try to contract (like gravity) and have positive (attractive) restoring force, potential energy, and internal pressure. Compressed rubber membranes try to expand (like antigravity) and have negative (repulsive) restoring force, potential energy, and internal pressure. Quantum vacuum has negative (repulsive) force that expands space, increasing negative potential energy (dark energy) by subtracting universe positive kinetic energy, and so cooling the universe. Quantum vacuum has negative internal pressure between one-third and one of mass-energy density, so repulsive antigravity is between zero and negative two times mass-energy density: M + 3 * -(M/3) = 0 and M + 3 * -M = -2*M.

universe

In early universe, dark-energy repulsion and gravitational attraction clustered matter into protogalaxy filaments. Filaments formed galaxy clusters. Galaxy clusters stopped forming six billion years ago, as space expansion made mass-energy density lower and gravity less, while dark-energy density stayed constant. Clusters allow galaxy collisions, so older galaxies have irregular shapes (while younger galaxies are spirals). Colliding galaxies increase star formation. Star formation became low six billion years ago.

Before five billion years ago, mass-energy density was higher than dark-energy density, so universe initial expansion slowed. Five billion years ago, mass-energy density became equal to dark-energy density. After five billion years ago, mass-energy density became less than dark-energy density, and universe expansion accelerated. In the future, dark energy will cause faster separation of galaxy clusters, then galaxies, then stars and planets, then molecules, and finally atoms.

heavy elements

If dark energy was stronger, filaments are fewer, clustering is less, and star formation is less, so fewer supernovas make fewer heavy elements. If dark energy was weaker, filaments are more numerous, and clustering is more, but star formation makes smaller stars, which do not supernova to make heavy elements. Universe dark-energy density maximizes heavy-element formation.

backreaction

Perhaps, non-linear mass interactions {backreaction} contribute to space expansion.

average weak energy condition

For ordinary matter, average vacuum fluctuation energy is zero {average weak energy condition}. For exotic matter, average can be negative.

cosmological constant

When calculations showed that general-relativity equations require that universe expand forever, Einstein introduced extra space-time force {cosmological constant}|, whose attractive force balanced space expansion and maintained static and infinite universe. However, recent observations show that, though gravity slows expansion, space expansion is accelerating, requiring repulsive cosmological constant. Perhaps, dark energy or quintessence supplies cosmological constant. Perhaps, universe angular momentum causes cosmological constant (but universe does not rotate).

cosmological constant problem

By virtual-particle quantum mechanics, space contains very high vacuum energy. If so, universe has very high curvature. By virtual-particle quantum mechanics, cosmological constant is 120 orders of magnitude greater than cosmological constant that balances gravity, but observations show that space has zero curvature {cosmological constant problem}. Perhaps, space has negative pressure to counterbalance vacuum energy. Perhaps, constant negative dark energy counterbalances vacuum energy.

flatness problem

Observed universe mass-energy density is the density (critical density) that makes space curvature zero. If early-universe mass-energy density was 10^-14 more than early-universe critical density, later-universe density becomes much higher than later-universe critical density, and space becomes more curved and more closed. If early-universe mass-energy density was 10^-14 less than early-universe critical density, later-universe density becomes much lower than later-universe critical density, as space becomes less curved and more open. Therefore, because universe space curvature is zero now, early-universe space had zero curvature, an unlikely situation {flatness problem}. Perhaps, though early universe did not have critical density, early-universe cosmic inflation reduces space curvature.

phantom energy

Perhaps, dark energy can become more repulsive energy {phantom energy} as time increases.

quintessence field

Perhaps, dark energy is repulsive field {quintessence, field}|, not virtual particles or vacuum energy. Quintessence is higher at higher potential energy and zero at lowest potential energy, so quintessence (and cosmological constant) decrease over time as universe expands. Perhaps, space negative pressure or quantum effects cause quintessence.

Quintessence field strength is almost zero. If strength was more, space expansion is so great that only radiation can exist. If strength was less, space expansion is so small that only matter can exist.

spall zone

When rock hits another rock, pressure waves spread from surface and from inside. When inside pressure wave reaches surface, reflection changes phase by 180 degrees. At a thin layer {spall zone} at surface, pressure wave from surface and pressure wave from reflection almost cancel, and surface pressure is near zero. However, pressure just below surface is high, and rock erupts through surface. In cosmology, expanding universe has spall zones.

PHYS>Astronomy>Universe>Cosmology>Matter

dark matter

In universe's first second, gravity and weak force formed baryon and non-baryon subatomic particles {dark matter}| that do not interact with electromagnetic radiation and move much slower than light speed {cold dark matter}. Because they do not interact with electromagnetic radiation, dark-matter particles are invisible. (Planets, cool gas, dust, and black holes interact with electromagnetic radiation and, though not visible, are not dark matter.)

Dark matter has mass. Dark matter is 23% of universe mass. Observed galaxy star (and gas) rotation rates show that dark-matter mass is nine times visible-matter mass.

Dark-matter particles have irregular mass differences. Because they do not have smooth small-scale mass differences, dark matter is not subatomic particles that move at near light speed {hot dark matter}.

About 900 million years after universe origin, 12.8 billion years ago, dark matter formed clouds, with masses million times Sun mass. From then until 7 billion years ago, clouds contracted and merged and made evenly spaced spherical clouds, with masses five to ten times more than visible and non-visible ordinary matter there. These clouds have enough matter to make gravity form galaxies. If matter was only ordinary matter, density is not enough to let gravity form galaxies. Because galaxies have five to ten times smaller volume than dark-matter clouds, dark-matter density and ordinary-matter density are approximately equal.

Because they have mass, dark-matter particles exchange potential and kinetic energy with gravitational fields, which change as particles move, so dark-matter particles and gravitation fields settle into virial equilibrium.

Dark-matter particles never collide.

smoothness problem

Universe matter distribution is more even than expected by particle statistics {smoothness problem}.

PHYS>Astronomy>Universe>Cosmology>Matter>Particle

ylem

Perhaps, real particles {ylem} can come from virtual-particle pairs, making universe more homogeneous.

ghost condensate

Perhaps, new subatomic-particle types {ghost condensate} can make outward pressure that prevents gravitational collapse.

lightest superpartner particle

Perhaps, cold-dark-matter particles are superpartner particles {lightest superpartner particle} (LSP).

photino

Perhaps, dark matter is neutrinos or supersymmetric particles {photino} {Zino} {Higgsino}.

weakly interacting massive particles

Perhaps, cold dark matter is subatomic particles {weakly interacting massive particles} (WIMP) {neutralino} from universe origin that do not interact with electromagnetic radiation and move slowly.

PHYS>Astronomy>Universe>Cosmology>Radiation

cosmic microwave background

Microwave radiation {cosmic microwave background}| (CMB) {microwave background} {background radiation, microwave} comes from all universe directions. Cosmic microwave background radiation is same visible-light-frequency radiation that was in hot plasma before plasma cooled enough, to 3000 K, for neutral-charge atoms to form, 300,000 years after universe origin, and comes from 13.72 billion light years away.

temperature

At that distance, recession velocity is near light speed, and redshift divides frequency by 1000, so radiation is now microwaves, with effective temperature 2.7 K.

temperature fluctuations

Cosmic-microwave-background temperature varies over space by less than 1 part in 10000. Temperature variations have Gaussian distribution. Temperature fluctuations arose from early-universe in-phase acoustic waves, density differences, and gravity waves. Gravitational waves cause red-shift and blue-shift. Gravitational-wave handedness causes polarization curls. Gravitational lensing affects CMB.

Largest same-temperature structures have one-degree diameter. Temperature variations depend on in-phase acoustic-wave wavelength, such as the largest spatial distance {first Doppler peak}. The four largest spatial distances have same intensity differences {scale-invariance}.

Sachs-Wolfe effect

Gravity affects photon trajectories and energies. About 300,000 years after universe origin, when neutral-charge atoms formed, photons in higher-density regions lost more energy than photons in lower-density regions {Sachs-Wolfe effect}, because they had to overcome more potential energy. Sachs-Wolfe effect cancels gravity-photon effects.

If photons enter higher-energy-density regions and then exit them, universe space-expansion energy makes photons have higher energies than before {integrated Sachs-Wolfe effect}.

Sunyaev-Zel'dovich effect

Galaxy-cluster plasma scatters cosmic microwave background radiation {Sunyaev-Zel'dovich effect}.

varying speed of light

Perhaps, universe is homogeneous because light can go faster than light speed {varying-speed-of-light theory} {varying speed of light} (VSL). Fast light can bring all universe regions into contact, making one closed system (with nothing outside, before, or after), and so make thermal equilibrium, so there was no need for cosmic inflation.

x-ray background radiation

During universe first seconds, subatomic-particle creation made x-rays {background radiation, x-ray} {x-ray background radiation} that still travel through universe.

PHYS>Astronomy>Universe>Cosmology>Singularity

event horizon

High-enough mass-energy density makes high-enough gravity to make space curvature so high that radial matter and radiation curve back into the region and so cannot leave. Space-time singularities have a surface {event horizon} beyond which no particles or radiation can escape. Therefore, outside observers cannot detect physical processes in the space {hidden region} inside event horizon. For black holes and other spherical objects with no charge and no angular momentum, event-horizon radius is two times object mass. For such spherically symmetric singularities, space-time has Schwarzschild metric. For non-spherically-symmetric singularities, space-time has Kerr metric.

photon layer

At event horizon, gravity potential energy equals light kinetic energy, so photons orbit singularity in stable and unstable circular orbits, making a photon layer.

inside horizon

To observers inside event horizon, all matter and radiation appear to move toward singularity center. Observers inside event horizon see nothing outside horizon, because high gravity slows time so much that radiation frequency red-shifts to very low, so photons have almost no energy and are undetectable.

outside horizon

To observers outside event horizon, objects falling toward singularity appear to slow to a stop at horizon, because time slows greatly in high gravity. Because high gravity makes object part closer to singularity have much more acceleration than farther part, objects falling toward singularity elongate perpendicular to event-horizon surface. Outside event horizon, observers can measure only electric charge, mass (monopole moment), and angular momentum (dipole moment).

cosmic censorship hypothesis

Outside observers cannot see universe singularities {cosmic censorship hypothesis}. Universe has no singularities without an event horizon ("naked" singularities). All singularities have an event horizon. Outside observers cannot see space-time time-like singularities (ideal points) {strong cosmic censorship hypothesis}. Universe singularities can be space-like or light-like (null) but not time-like. Outside observers far away in space-time cannot see time-like singularities {weak cosmic censorship hypothesis}.

Universe can have singularities without an event horizon. Spinning or charged black holes can lose event horizons after small charge or spin increases or small mass decreases. Exploding black holes can expose singularities. Perhaps, cosmic censorship is true only if cosmological constant is zero or negative.

white hole

Some singularities {white hole}| emit particles and/or radiation. In quantum theory, small singularities emit particles and/or radiation rapidly, while black holes emit slowly. Perhaps, universe has large white holes.

PHYS>Astronomy>Universe>Cosmology>Singularity>Black Hole

black hole

Supernova remnant stars and galaxy centers {black hole}| have high-enough mass-energy density to cause high-enough gravity so that object escape velocity is higher than light speed, so matter and radiation cannot leave the black hole. Outside observers receive no radiation, so black holes are not visible. Gravity is so strong that space curvature is so high that it curves moving matter and radiation back into the black hole or into orbit around the black hole.

stars

Some stars with more than 2.25 Sun mass become supernovas. After supernova, remaining neutron star has mass two times Sun mass and diameter 2000 meters. When neutron-star nuclear fusion slows, black holes form in one second, with no measurable diameter but with close event horizon. Galaxies average 10^6 star black holes.

galaxies

Galactic centers, including Milky Way and Cygnus X-1, have one large black hole. Galactic centers have high star concentrations and stars collide and merge to make larger mass, until mass is so high, black hole forms. Then black hole attracts more mass and grows larger. Galactic-center black holes contain mass from 10 million stars and have no measurable diameter but distant event horizon.

mass

Black holes can have unlimited mass and gravity.

density

High-enough gravity can overcome neutron-degeneracy pressure, so neutrons compress into each other, making density greater than in atomic nuclei.

diameter

Black holes are space-time singularities. Black holes have no measurable diameter. Black holes are outside space and so are one point in time.

rotation

Non-rotating black holes far from matter have a point singularity. Space around non-rotating black holes far from matter has Kerr metric.

Black holes probably rotate with angular momentum equal to mass. Rotating black holes have ring-shaped singularity, perpendicular to rotation axis. Perhaps, objects can go through ring center and come out into negative or antigravity space. Spinning black holes produce long gamma-ray bursts.

electric charge

Black holes can have positive or negative electric charge. Black holes can have only small charge {no hair}, because they rapidly attract or repel nearby charges and become neutral.

sizes and lives

Early universe probably had enough radiation pressure to create tiny black holes. Planck-size black holes have mass 10^-8 kilograms, density 10^97 kg/m^3, and radius 10^-35 meters. Smaller black holes compress neutrons more, as inverse square of mass. Hawking radiation evaporates them quickly.

Ball-size black holes are hotter than the hottest star center.

Mountain-mass black holes have mass 10^12 kilograms and proton-sized radius. Hawking radiation evaporates them in 10^12 years at 10^12 K.

Sun-mass black holes have mass 10^30 kilograms, density 10^19 kg/m^3, and radius 3000 meters. Hawking radiation evaporates them in 10^64 years at temperature 10^-6 K.

radiation

Black-hole event horizons have high space curvature and high tidal forces, and so form virtual-particle pairs. Sometimes, one virtual particle enters black hole, and the other escapes and becomes a real particle (Hawking radiation). It is like quantum tunneling. In-falling and escaping particles carry energy. Negative energy flows into black hole, reducing mass-energy density, and positive energy escapes, reducing mass-energy, so energy conservation energy holds overall, but black-hole mass and energy decrease. Hawking radiation decreases black-hole mass and energy, so event horizon has shorter radius and smaller surface area.

Spatial-surface gravity determines particle-creation amount. Mass-energy-loss rate varies inversely with mass squared, so smaller black holes radiate more rapidly and lose mass faster. Smallest ones can explode. Smallest ones radiate particles with no spin. Small ones radiate neutrons and other neutral particles with spin in equatorial plane. Large ones radiate protons, electrons, and other charged particles. Largest ones radiate photons and gravitons. Equal numbers of baryons and anti-baryons leave black holes.

However, outside space also creates virtual photons, and some enter black holes, so typical black holes probably are in thermal equilibrium with surrounding space and do not evaporate.

temperature

Hot objects radiate to cooler objects. Warm objects radiate infrared light. Light-frequency distribution depends on object temperature. Black holes radiate Hawking radiation, and event-horizon temperature determines frequency distribution. Event-horizon temperature varies inversely with black-hole surface area and mass. Smaller black holes have higher energy-to-mass ratio and so higher temperature. Large black holes have event-horizon temperatures near absolute zero. Tiny-black-hole event-horizon temperatures are 10^21 K.

Black holes have high gravity and attract outside particles. In-falling particles add heat and increase event-horizon temperature.

Hawking radiation reduces black-hole mass more than it reduces energy, so energy-to-mass ratio increases, and so event-horizon temperature rises.

Black-hole event-horizon temperature results from quark and gluon motions. Black holes have strongly interacting quarks and gluons, which have low shear viscosity. Temperature T varies directly with acceleration a: T = (h / (2 * pi * c)) * a, where c is light speed, and h is Planck constant. T = kappa / (2 * pi), where kappa = (h/c) * a. Particles have high acceleration at event horizon. Larger black holes have smaller particle accelerations, and so lower event-horizon temperatures. Temperature represents quantum-fluctuation strength.

Classically, emitting thermal radiation from hot bodies removes energy and makes surface have lower temperature, because hotter-than-average particles preferentially leave. Does only cooler-than-average radiation leave black holes, so they get hotter? Is virtual radiation thermal emission or another radiation kind?

entropy

Black holes have entropy proportional to star information that becomes lost when star collapses. From outside, only black-hole event horizons are observable, so event horizons carry all information. Black-hole entropy S depends on event-horizon surface area A: S = A * k * c^(3/4) * h * G, where k is Boltzmann constant, c is light speed, h is Planck constant, and G is gravitational constant.

In cosmological units, entropy S varies directly with event-horizon surface area A divided by four: S = A / (4 * h * G), where h is Planck constant and G is gravitational constant in Planck units. Partition-function P logarithm is negative of free energy FE divided by temperature T: ln(P) = - FE / T. Free energy FE is energy E plus temperature T times entropy S: FE = E + T*S.

Because things can only go into black holes, and nothing can come out except Hawking radiation, event-horizon surface area and entropy typically increase. If black hole and space are in thermal equilibrium, surface area and entropy stay constant. If Hawking radiation is more than photon and particle entry from space, surface area and entropy decrease. Black-hole entropy relates thermodynamics and quantum gravity.

entropy: information

When black holes form, where does information about matter type and distribution {multipole moment} go? Information can be at event horizon, below event horizon, in black hole, or at singularity. Outside observers never see information loss, because they see time slow and light red-shift but never see black hole form.

Information has quantum-mechanical limits.

By string theory, black holes seem to destroy information but actually just transfer it {AdS/CFT correspondence}.

gravity

Gravity strength is the same at all event-horizon points {zeroth law of black-hole mechanics}. The zeroth thermodynamics law says all points in contact are at same temperature (thermal equilibrium).

energy

Mass or energy change dE is event-horizon spatial-area change dA times constant kappa / (8 * pi), plus angular-momentum change dJ times omega constant, plus charge change dQ times psi constant {first law of black hole mechanics}: dE = (kappa / (8 * pi)) * dA + omega * dJ + psi * dQ, where kappa is event-horizon gravity strength. The first thermodynamics law says total energy is constant.

temperature

Event-horizon gravity strength is like thermodynamic temperature. Event-horizon spatial area is like thermodynamic entropy. Because null geodesics have no observable future and can never converge, event-horizon spatial-area change dA never decreases over time {second law of black hole mechanics}: dA >= 0. The second thermodynamics law says entropy never decreases.

accretion disk

If double stars have one black hole and one ordinary star, black hole can pull gas from star, making a disk {accretion disk}. Gas has fast-moving charged particles, whose magnetic interactions cause turbulence (magnetorotational instability). Gas particles closer to black hole are faster. Magnetic attractions slow near-black-hole gas particles, so they move closer to black hole. Magnetic attractions speed far particles, so they move farther from black hole. Overall potential energy decreases, and kinetic energy increases (generating heat), providing energy for accretion disk to radiate.

Bekenstein bound

Black holes have maximum entropy and information. Outside observers cannot see inside event horizons, so black-hole information is in event-horizon surface area. More massive black holes have larger event-horizon surface areas. By quantum-loop theory, event-horizon surfaces have area quanta, which hold one information bit. Larger event-horizon surfaces have more area quanta, hold more bits, and represent more entropy. Event-horizon surface area varies directly with black-hole entropy. Event-horizon surfaces have maximum entropy {Bekenstein bound}. If mass-energy falls into black hole, black-hole mass-energy increases, event-horizon surface area increases, and entropy increases. regions bounded by event horizons have limited information amounts.

ergosphere

Rotating black holes have a region beyond event horizon but inside stationary limit {ergosphere}. Ergosphere particles appear to have negative energy to outside observers.

gyromagnetic ratio

For charged rotating stationary black holes, angular momentum and magnetic moment are in same direction and their ratio {gyromagnetic ratio} is 2. Angular momentum is 2*m*e*w, and magnetic moment is m*e*w, where m = mass, e = charge, and w = angular velocity. (Electrons also have gyromagnetic ratio 2.)

Hawking radiation

Black-hole event horizons have high space curvature and high tidal forces, and so form virtual-particle pairs. Sometimes, one virtual particle enters black hole, and the other escapes and becomes a real particle {Hawking radiation}. It is like quantum tunneling. In-falling and escaping particles carry energy. Negative energy flows into black hole, reducing mass-energy density, and positive energy escapes, reducing mass-energy, so energy conservation energy holds overall, but black-hole mass and energy decrease {black hole evaporation}. Hawking radiation decreases black-hole mass and energy, so event horizon has shorter radius and smaller surface area.

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magnetorotational instability

If double stars have one black hole and one ordinary star, black hole can pull gas from star, making an accretion disk. Gas has fast-moving charged particles, whose magnetic interactions cause turbulence {magnetorotational instability} (MRI).

Roche limit

At a radius {Roche limit} around black holes, gravity equals electric force.

Schwarzschild radius

From black-hole center, the farthest distance {Schwarzschild limit} {Schwarzschild radius} from which light cannot escape is 2 * G * m / c^2, where G is gravitational constant, m is mass, and c is light speed. Larger-mass black holes have farther Schwarzschild limit.

unitarity

After objects fall into black holes, outside observers cannot observe object properties, because nothing can come out except Hawking radiation, which is random and has no information. Outside observers can only measure total black-hole mass, charge, and angular momentum. All object information is lost, but there should be information conservation {black hole information paradox}. By string theory and quantum-loop theory, because strings are unitary, information is constant {unitarity} {unitary process}, and object information goes into event-horizon surface area. Perhaps, when black holes evaporate and so have no event horizon, outside observers can see all information again.

PHYS>Astronomy>Universe>Cosmology>Theories

anthropic cosmological principle

Perhaps, universe physical parameters require life {strong anthropic principle} {anthropic cosmological principle} [Barrow and Tipler, 1986], because universe properties must be such that humans can observe them. Perhaps, universe physical parameters allow life {weak anthropic principle}, because universe properties must be such that life exists.

Big Bang theory

Universe began with small volume, high energy, high mass-energy density, high temperature, high pressure, and high spatial curvature, and then rapidly expanded {Big Bang}, increasing spatial volume, decreasing mass-energy density, decreasing temperature, decreasing pressure, and decreasing spatial curvature.

All space points moved away from each other, so farther points moved away faster. From any space point (at any time), if a second point is at distance x and moves away from first point at velocity v, and a third point is at twice that distance 2*x, third point moves away from first point at velocity 2*v. If second point is between first and third points, first and third points move away from second point at same velocity v. Space has no central point or region. Big Bang was space expansion, not an explosion into existing space.

cosmological natural selection

Universes that make more black holes propagate more universes similar to themselves and so come to dominate {cosmological natural selection}. (The universe reached its low-probability parameters by self-organization and other selection mechanisms.)

ergodicity

Perhaps, universe distribution came from one quantum path over infinite space. Perhaps, universe distribution came from decoherence making quantum mechanics approximate classical mechanics. Both scenarios result in same universe distribution {ergodicity}.

God of the Gaps argument

Issues that science cannot answer require outside agents to resolve them {God of the Gaps argument}.

holographic principle

Universe regions have information. Total is 10^60 bits. Universe regions have boundary surfaces, such as sphere around galaxy dark matter or event-horizon around black holes. For outside observers, all region information flows through boundary surface to observer, so boundary surface holds region information, though surface has lower dimension than region. If observer is far away, bounding-surface physics can represent region physics {holographic principle}. Perhaps, region physics projects onto boundary surface, and boundaries are like holograms {strong holographic principle}. Perhaps, region information projects onto boundary surface, and bounding surface has information channels {weak holographic principle}.

hologram

Just as surfaces can hold holograms, from which coherent light can make three-dimensional images, two-dimensional surface boundaries can contain all information needed to describe three-dimensional space regions. For example, superstring theory for anti-de-Sitter space-time five-dimensional regions is equivalent to conformal quantum-field theory of four-dimensional surface-boundary-point particles.

string theory

Hyperbolic-space regions have constant surface boundary. In string theory, boundary-surface gluon strings represent one quantum information bit and have thickness and strong-force color. String thickness represents space-point distance from boundary surface. Color represents information about space-point's quantum state. String number varies directly with space-region radius, so larger radius makes large boundary surface. Surface-string interactions represent gravitons.

Newtonian dynamics modification

Newtonian dynamics modifications {Modifications of Newtonian dynamics} (MOND) {Newtonian dynamics modification} do not require dark matter to provide extra gravity needed to form galaxies.

multiverse

Perhaps, space {multiverse} has separate independent universes, with different phases. Perhaps, multiverse is still making and ending universes.

Level I multiverse

If space is infinite (or sufficiently large), and matter has even spatial distribution, universe objects and events repeat {Level I multiverse}.

Level II multiverse

Perhaps, if Level-I-multiverse universes are infinite in number, each universe has different dimension numbers and physical constants {Level II multiverse}. In string theory, quantum-field inflatons make space expand. For small quantum-field fluctuations, local bubbles form in universes. For example, if space starts with nine dimensions, only three expand, Alternatively, matter is in only three dimensions. Local bubbles become different universes, with different properties. Space inflation continues, making distances between bubbles expand faster than light, so universes are separate. Perhaps, vibrations between parallel three-dimensional universes along fourth dimension create and destroy universes. Perhaps, universes begin and end at black holes.

Level III multiverse

In quantum-mechanics many-worlds interpretation, all possible events occur (with different probabilities), making universe branches, which repeat {Level III multiverses}, and so do not become infinite in number. Observers see only one world by decoherence. All possible worlds are wavefunction-solution superpositions. Number of universes does not increase exponentially as time goes forward but stays constant, because they only repeat.

Level IV multiverse

Universes can vary in physical laws. Perhaps, all possible mathematical structures and universes exist {Level IV multiverse}.

oscillating theory

Universe cycles between Big Bang and Big Crunch {oscillating theory}.

parallel universes

Perhaps, other universes {parallel universes} exist simultaneously with, or before or after, universe.

plurality of worlds

Universe probably is just one of many possible universes {plurality of worlds}. Because bosons have unique quantum-number sets, and space-time is relative, not absolute, many universes exist [Sklar, 1993]. Space-time quantum-mechanical and statistical fluctuations determine each universe's physical laws.

steady-state theory

Universe is unchanging {steady-state theory}.

Wheeler-DeWitt equations

Gravity curves space-time, and space-time curvature accelerates mass. In one quantum-mechanical cosmology {Wheeler-DeWitt equations} {quantum-constraints equations}, universe wavefunction depends on gravity and space-time curvature [DeWitt, 1965].

Deriving general relativity from quantum-loop-theory supergravity makes universe wave equations have infinite numbers of exact solutions. Solutions are non-intersecting no-kink quantum loops or are intersecting symmetric quantum loops. Quantum-loop area represents energy, so quantum loops have quantum area, and minimum area is ground state. Using quantum-loop theory, solutions can be independent of space-time {diffeomorphism constraints}.

With those constraints, quantum-loop intersection topology, knots, and kinks define space dimensions, so quantum loops determine space dimensions.

Wheeler-Feynman absorption theory

In non-expanding empty space, radiation from sources decreases proportional to distance-from-source squared. In expanding universes, expansion reduces net distances, so radiation from sources decreases less than distance-from-source squared. It is like space absorbs less radiation {Wheeler-Feynman absorption theory}.

PHYS>Astronomy>Universe>Cosmology>Theories>Inflation

inflation in cosmology

Perhaps, 10^-36 to 10^-34 seconds after universe origin, starting at temperature 10^28 K, space-expansion rate increased exponentially, and universe expanded 10^28 to 10^30 times in 1 second {inflationary cosmological model} {theory of inflation} {inflation, cosmology}| {inflation scenario} {cosmic inflation}. From initial singularity, universe can go to any state, so expansion or no-expansion probabilities are not determinable. Perhaps, inflation was only in the universe. Perhaps, inflation was in a region (multiverse) millions of times bigger than universe and so affected many universes.

before

At universe origin, universe had light-speed maximum-frequency radiation that made maximum temperature and pressure. Immediately after, universe had space expansion. Space expansion cooled universe evenly, except for quantum fluctuations (which correspond to observed cosmic-microwave-background-radiation density fluctuations) that averaged 1 part in 10000. Immediately, high gravitation, due to high mass-energy density, decreased space-expansion rate.

phase transition

Perhaps, as universe cooled, it did not change phase, but entered a "supercooled" state, prolonging the phase, so vacuum of space {false vacuum} had higher stored potential energy. That potential energy was gravitationally repulsive and exponentially increased space-expansion rate, causing exponential volume increase. Space expansion exceeded light speed.

end

After one second, high-expansion phase ended. Uncertainty-principle gravitation-and-electromagnetic-field quantum fluctuations made different space regions, of different sizes, stop inflation at slightly different times. Stopping inflation released false-vacuum energy, and uncertainty-principle quantum fluctuations made local regions have different matter and radiation densities, and perhaps different physical laws and constants. Inflation continued between stopped-inflation regions, spreading those regions far apart, so they became completely separate.

More likely, uncertainty-principle gravitation-and-electromagnetic-field quantum fluctuations made different space regions, of different sizes, increase or prolong inflation (chaotic inflation). In those inflating regions, local regions stopped inflation and made separate universes with different matter and radiation densities, and perhaps different physical laws and constants. Space inflation continued indefinitely in most space regions. Perhaps, some are still inflating.

Perhaps, space has hidden dimensions, so separate universes are at the same space point.

after

After one second, universe had matter and radiation, with density variations of 1 part in 10000.

effects

If universe had cosmic inflation, initial universe was small enough so that all points were within each other's cosmic horizon, so space was in thermal equilibrium, explaining why cosmic microwave background radiation is almost homogeneous. After inflation ended, temperature, density, magnetic-field, electric-field, and gravity differences were still 1 part in 10000. Temperature fluctuations have Gaussian distribution. Inflation affected all sizes, except the smallest, equally, so cosmic-microwave-background temperature fluctuations have same amplitude over different large-size space regions.

Inflation makes space curvature much flatter than otherwise.

Inflation caused gravity waves but few high-frequency gravity waves.

cause

Perhaps, antimatter has negative gravity and caused cosmological inflation.

If space dimensions are dynamic, high-dimensional spaces rapidly expand or contract.

zero total energy

Matter and radiation have positive mass and positive kinetic energy. Masses and charges in (infinite) fields have potential energy, which can scale from zero at object surface to infinite at infinite distance. At infinity, if total energy is zero, kinetic energy is zero, and potential energy is zero. At object surface, if total energy is zero, kinetic energy is positive, and potential energy is negative. By this convention, in infinite fields, total object energy is always zero.

In expanding universes, galaxies are moving apart while gravitation tries to pull them together. Space expansion gives galaxies positive kinetic energy, and gravitational attraction gives galaxies negative potential energy. Mass-energy density causes gravitation field strength, which is space curvature. In a flat universe, space curvature is zero, so total galaxy energy can be zero.

By relativity, gravity depends on sum of mass-energy density M and on internal pressure P: G ~ M + 3 * P. Hot gas has slightly more internal pressure than cold gas, and so has slightly more gravity. Photon gas has radiation (internal) pressure equal to one-third its energy density, doubling gravity: M + 3 * P = M + 3 * (M/3) = 2*M. Objects can have negative internal pressure. For example, compressed rubber membranes tend to repulse molecules, by negative internal restoring force, so internal potential energy is negative. Quantum vacuum has negative (repulsive) force that expands space, increasing negative potential energy (dark energy) by subtracting universe positive kinetic energy, and so cooling the universe. Quantum vacuum has negative internal pressure between one-third and one of mass-energy density, so repulsive antigravity is between zero and negative two times mass-energy density: M + 3 * -(M/3) = 0 and M + 3 * -M = -2*M.

Kinetic energy makes positive pressure, which can do work, reducing kinetic energy and pressure. Potential energy makes no pressure. Quantum vacuum has negative potential energy and so negative internal pressure, which causes repulsion and makes space expand. During expansion, negative internal pressure does negative work on quantum vacuum to expand space, and negative potential energy becomes negative kinetic energy, which is the same as subtracting positive kinetic energy. Space expansion increases total negative energy, by subtracting positive energy, because total energy is constant. Because space expansion causes negative-energy density, space expansion increases at same rate as negative energy addition, so quantum vacuum has constant negative-energy density. Starting at universe origin, space expands with constant negative energy density. During this process, total-energy quantum fluctuations cause a small fraction of positive kinetic energy to become matter and radiation.

inflaton field

The Higgs field can reach higher-energy levels {inflaton field}. Perhaps, high potential energy from Higgs-field particles {inflaton} caused gravitational repulsion and accelerated universe expansion. Higher-energy levels are unstable. However, because initial universe is precisely homogeneous, universe does not change phase (supercooling) as it expands and cools, but prolongs inflation before changing phase. (If liquids have no nucleation sites as they cool, they supercool below temperature at which crystallization typically occurs, then they crystallize at lower temperature.) Perhaps, if supercooling delayed force decoupling, later decoupling released extra energy, which worked like antigravity and caused 10^100 times more space-vacuum negative pressure than before.

bubble nucleation

Perhaps, one inflaton falls, in one quantum jump, from supercool to zero energy, which acts as a seed for other inflatons to fall, so inflation-stopping spreads at light speed {bubble nucleation}. Perhaps, inflatons have different energies and fall through many quantum jumps. Some high-energy inflatons cannot fall back down, because other inflatons already fill lower energy levels. Inflation-stopping does not spread, prolonging inflation. Different space points have different periods of inflation (chaotic inflation).

PHYS>Astronomy>Universe>Cosmology>Theories>String Theory

pre-big-bang theory

String theories describe what cosmology was like before universe origin and what happened to begin universe. String theory allows more high-frequency gravity waves than inflation theory or ekpyrotic theory, so observing gravity waves can test string theories {pre-big-bang theory}. In fact, universe has few high-frequency gravity waves and some low-frequency gravity waves. Perhaps, universe has small-scale and large-scale strings. Perhaps, universe origins involve quantum-mechanical tunneling.

dilaton

Force strengths depend on string 11th-space-time-dimension length (dilaton). Short dilatons represent weak nuclear forces. Long dilatons represent strong nuclear forces. Dilaton lengths represent electromagnetism, and dilaton length variations change electromagnetic fields.

Before universe origin, dilatons are long, and forces are strong. At universe origin, dilatons are short, and forces are weak. Observing intergalactic magnetic-field changes is a test for dilatons and so can indicate universe-origin conditions.

axion

Magnetic-field photons can make dilaton-related strings (axion) that have less than one millionth electron mass, no charge, and zero average quantum field. Magnetic-field axions can make photons. Therefore, axions allow strong nuclear forces to maintain charge-parity (CP) symmetry between antiparticles and particles.

Cosmic-microwave-background temperature fluctuations are small, have Gaussian distribution, and have same amplitude for large space regions. Cosmic-microwave-background temperature fluctuations arise mostly from density differences and partly from gravity waves. However, string theories without axions allow no density differences. Axions determine large-scale universe temperature fluctuations [Adams, 2002].

string hole

Smaller strings have higher vibration frequencies and so higher masses. The smallest strings have highest mass and smallest size and so can be like black holes {string hole}.

conflagration scenario

Because many D-branes occupy high-dimensional space and D-branes attract each other, D-brane pairs collided, making universes' origins {ekpyrotic scenario} {conflagration scenario}. As D-branes mutually move closer, space contracts. If D-branes mutually move farther, space expands. Adjacent D-branes can repeatedly collide and separate, in contraction and expansion cycles.

pre-big-bang scenario

Perhaps, before universe origin, time reversal and T-duality caused universe contraction, with matter accreting into string holes (pre-big-bang theory) {pre-big-bang scenario}. As space filled with string holes, universe was like string-hole gas. String-hole gas had smooth string-size distribution (unlike chaotic conditions at black-hole surfaces). Smooth size distribution allowed large string holes to form. Inside the largest string hole, matter reached maximum allowable density and temperature, causing an emission-singularity white-hole.

PHYS>Astronomy>Galaxy

galaxy of stars

Galaxies {galaxy} evolve and have shapes.

number

Universe has 10^11 galaxies, in clusters of 5 to 10,000. Galaxies average 10^7 light-years apart. Between galaxies is pure hydrogen.

names

Famous galaxies are Milky Way Galaxy with Sun, Andromeda or Messier 23, Whirlpool or Messier 51, Centaurus A, and Sombrero.

age

Oldest galaxy is 12 x 10^9 light-years away.

evolution

Originally, universe had density variations in which all wavelengths superimposed (pink noise). Smaller regions had higher densities. As universe expanded, differences exaggerated, because high-density regions became less dense more slowly. As gravity became stronger than expansion, such regions attracted more matter and dark matter and began to collapse, to make sphere with high density at center and low density at edge.

Infalling matter became hot, as potential energy became kinetic energy, and collisions randomized motions. Matter also radiated and cooled. At hydrostatic equilibrium, gravitation inward balanced pressure outward, as in Earth atmosphere. Matter sphere contracted and increased angular speed, becoming disk.

evolution: waves

In galaxies, stars have elliptical orbits, but gravity among stars makes orbits precess, because galaxies have no large central mass. Orbits can align and make galactic waves. Waves cause higher and lower gas-and-star-concentration regions. Waves transport angular momentum.

evolution: shapes

Galaxy shape depends on rotation rate. Slow rate makes elliptical galaxies, which are 20% of galaxies, are large, and have old stars. Medium rate makes spiral galaxies, which are 50% of galaxies, with old stars in center and new stars in or out of arms, created by gravitational effects. Spiral is tight for slower rotation and open for faster. Fast rotation rate makes barred-spiral galaxies, which are 30% of galaxies.

Interstellar star and gas waves, gravitational contraction, radiative cooling, relaxation to equilibrium, and galaxy interactions cause galaxy shapes. Waves make barred, barred-spiral, and spiral galaxies and change shapes continuously. If star orbits shift, spiral galaxies form. Spiral galaxies have a central black hole, which eventually adds no more matter. If star orbits align, barred galaxies form. If central star orbits align but outer star orbits shift, barred spiral galaxies form. Irregularly shaped galaxies are small, form near regularly shaped galaxies, and form after explosions or collisions.

collisions

Galaxy gravitational pull causes tides in small galaxies that pass by and pulls them apart, so they spiral into larger galaxy. If equal-size galaxies collide, larger elliptical galaxy forms. Elliptical galaxies can have outer disk.

collisions: starburst

Colliding galaxies can make many new stars {starburst} in ten million years.

collisions: stellar stream

In galaxies, stars can move as groups {stellar stream}, because they came from absorbed dwarf galaxies, such as Sagittarius dwarf galaxy and Canis Major dwarf galaxy.

matter

In galaxies, 90% of matter is in stars, with mostly hydrogen and helium gas between stars. More than 50 molecules are in space. Main ones are hydrogen, methane, hydrogen cyanide, water, ammonia, and cyanogen. Space carbon molecules have no rings. Strong infrared radiation makes molecules in dust clouds or ionized hydrogen gas.

matter: gas

Hydrogen spheres, with density three atoms per liter, surround galaxies. Hydrogen masses {intermediate velocity clouds} (IVC) {medium velocity clouds} surround galaxies and move toward galactic plane by galactic-fountain mechanism. Hydrogen masses {high velocity cloud} (HVC), 10% of galactic mass, surround galaxies and move toward galactic plane from intergalactic space.

center

Large galaxies have central supermassive black hole, which sends hot-gas jets out both poles, using inflowing gas from equator. Outflowing hot gas prevents surrounding cluster hot gas from cooling. Cluster gas heats as it gravitationally collapses. Sound waves spread energy.

21-centimeter line

Emission at wavelength 21 centimeters {21-cm line} {21-centimeter line} shows hydrogen gas. Neutral hydrogen atoms have electron spins that can align or anti-align. Aligned spins have higher energy than anti-aligned spins.

corotation circle

At intermediate radius {corotation circle}, stars orbits precess at same rate.

Hubble constant

Galaxy-recession velocity is galaxy distance times universe expansion rate {Hubble constant}| {Hubble's law}.

hydrostatic equilibrium

Galaxy matter contracts to make pressure. At equilibrium {hydrostatic equilibrium}, gravitation inward balances pressure outward.

Lindblad resonance

At larger and smaller radius, star orbits synchronize precession {Lindblad resonance} (Bertil Lindblad), so precession and star always meet at same orbit place, as planetary rings do.

Milky Way Galaxy general

Sun is in a galaxy {Milky Way galaxy}.

properties

Diameter is 100,000 light-years, 10^29 meters. Thickness is 3000 light-years. Mass is 10^44 grams. Speed is 60 km/s toward Hydra constellation, where mass of 10^49 grams at 2.5 x 10^8 light-years causes this motion.

properties: shape

Barred-spiral disk has two large arms, Sagittarius and Perseus.

properties: age

Age is 12,000,000,000 years.

stars

Galaxy has 10^11 stars and 10^8 stars with planets. Inner stars revolve faster. Dozens of absorbed satellite galaxies cause galaxy star layers.

stars: cluster

300 groups {open cluster}, of 1000 stars each, with diameter 10 light-years, have many young, blue-white stars.

neighbors

Near galaxy are two irregularly shaped galaxies of 10^9 stars each, Large Magellanic Cloud and Small Magellanic Cloud. Eleven satellite galaxies include Sagittarius dwarf galaxy, opposite Sun on other galaxy side.

pink noise

Originally, universe had density variations in which all wavelengths superimposed {pink noise}.

virial equilibrium

Dark matter never collides, so particles only exchange potential and kinetic energy with gravitational fields. Fields change as particles move and eventually settle into equilibrium {virial equilibrium}, so dark matter forms sphere.

PHYS>Astronomy>Galaxy>Parts

active galactic nucleus

Colliding galaxies add matter and make a central supermassive black hole {active galactic nucleus} (AGN), whose infalling matter makes light, forms accretion disk, and/or sends out plasma jets. Quasars are active galactic nuclei. AGN are less than one light-year diameter, down to light-minutes.

Bok globule

Large and small regions {Bok globule} have cool interstellar gas and dust.

galactic corona

Hot gas {galactic corona} surrounds galaxies.

galactic fountain

Giant stars heat and ionize interstellar gas, which rises out of galactic plane, cools, and falls in again {galactic fountain}.

galactic halo

Galaxies have 10^10 stars {galactic halo} outside disk.

galactic nucleus

Galaxies have central spherical star concentrations {galactic nucleus}|, 20,000 light-years diameter, with many exploding stars and massive black holes.

globular cluster

When galaxies collide, groups {globular cluster}| of millions of same-age stars form. Milky Way has 200 groups of 10^6 stars each, with diameter 100 light-years.

interstellar dust

Particles {interstellar dust}| are between stars. Interstellar dust is 1% of interstellar matter, which is 99% hydrogen and helium. 10% is 0.005-nm carbon and hydrogen particles. 80% is 0.35-nm mostly iron, carbon, and silicate particles with organic mantles. Mantles can be simple organic molecules, like formaldehyde, or complex organics {polycyclic aromatic hydrocarbons} (PAH), caused by different ultraviolet-radiation levels. 10% is 0.002-nm polycyclic aromatic hydrocarbons.

source

Most interstellar dust came from red-giant nova atmospheres.

gas

In dense clouds, which are colder, water and ammonia stick to dust. Otherwise, radiation evaporates gas from surfaces.

comets

Comets are dust grains stuck together.

interstellar gas

Gas {interstellar gas}| can be 88% hydrogen and 12% helium, because most helium is still in stars. Formaldehyde absorption, at wavelength 6 centimeter, shows dense hydrogen locations.

Magellanic Stream

Gas flows {Magellanic Stream} around galaxy in Magellanic-Cloud orbits.

nebula

Gaseous nebulae {nebula}| include Coal Sack, Crab Nebula, Great Nebula in Orion, Horsehead, Lagoon Nebula in Sagittarius, Monoceros, Nebula in Serpens, North America, Rosette Nebula, Trifid, and Veil Nebula or Cygnus Loop.

quasar

Galaxy-like objects {quasar}| can emit 10,000 times normal-galaxy energy in infrared or radio waves, have diameter 1000 times solar-system diameter, last only 10^9 years, and number 14,000,000.

PHYS>Astronomy>Galaxy>Kinds

dwarf galaxy

Small galaxies {dwarf galaxy} with irregular shapes contain primordial matter, often atomic hydrogen. Dwarf galaxies do not form stars unless they undergo collision and have starbursts. After many collisions and starbursts, they become globular clusters.

galactic cluster

Galaxies have groups {galactic cluster}|. Cluster has diameter 10 million light-years, has thousand galaxies, and has even dark-matter and hot-gas distribution. Hot gas radiates x-rays. In early universe, radiation energy was high compared to gravity, so mass fluctuations were small. Only later did mass differences increase with time. Over distances of 1,000,000,000 light-years, galaxy density varies by 1/10. At larger volumes, grouping decreases, so universe is homogeneous. Early galaxies clustered more than dark matter.

For x-ray emitting galactic clusters, temperature varies directly with mass.

galaxy group

Closest spiral galaxy is Andromeda galaxy or Messier 31, 2 x 10^6 light-years away and twice as large as Milky Way. Milky Way Galaxy and Andromeda Galaxy are in Local Group {galaxy group}, which contains 40 dwarf galaxies. Local Group is near edge of Virgo Cluster, which contains hundreds of galaxies. The Great Attractor is another large galaxy group, 200,000,000 light years diameter.

radio galaxy

Colliding galaxies {radio galaxy}| can emit three times more radio waves than light waves.

Seyfert galaxy

Regular-size spiral galaxies {Seyfert galaxy} can emit 100 times more infrared radiation than normal galaxies, from small central nuclei filled with fast moving ions. They last only 10^8 years.

supercluster

Galactic clusters form groups {supercluster}, with diameter 30,000,000 light-years. Superclusters form groups {wall}, with diameter 300,000,000 light-years. Walls do not appear to have groups. Great Wall is 200,000,000 light years away.

ultraluminous infrared galaxy

Luminous infrared galaxies {ultraluminous infrared galaxy} (ULIRG) were abundant among early galaxies.

PHYS>Astronomy>Star

star

Stars {star} have different sizes and ages.

names

Famous stars are Aldebaran, Algol, Altair, Antares, Arcturus, Betelgeuse, Canopus, Capella, Deneb, Polaris or North Star, Pollux, Procyon, Regulus, Rigel, Sirius, Spica, and Vega. Sirius or Dog Star is brightest star. Six-star groups {Pleiades} can be in winter sky. Sky can have star clusters {Hyades}.

nearby stars

Nearest star is dwarf star Proxima Centauri, at 4.2 light years. The class-G star Alpha Centauri is at 4.3 light-years. Nearest single class-G star with possible life is Tau Ceti, at 11.2 light-years. The nearest stars lie in five general directions away from Earth.

planet

20% of stars have planets, typically one or two times Jupiter size.

first stars

The first stars formed 100,000,000 years after universe origin. They were 100 to 1000 times more massive than Sun. They were 4 to 14 times wider. They were 1 to 20 million times brighter. They had surface temperature 100,000 K. They lasted only 3 million years, forming big black holes.

first stars: reionization

Light from first stars ionized hydrogen and helium {reionization} and caused 5% to 17% of CMB.

asterism

The 250 Chinese constellations {asterism} have five or six stars each.

bipolar outflow

Young star spouts material from both poles {bipolar outflow}.

Chandrasekhar limit

Some red-giant stars have mass less than 1.25 Sun mass {Chandrasekhar limit}.

constellation

Major constellations {constellation}| are Andromeda, Bootes, Canis Major, Cassiopeia, Draco, Hercules, Orion, Pegasus, Perseus, Ursa Major or Great Bear, and Ursa Minor or Little Bear.

HII region

Dense and visible ionized-hydrogen spheres {HII region} {emission nebula}, at 5000 K to 20000 K, can be around blue-white stars.

Main Sequence

After formation, star masses correlate with other star properties {Main Sequence}. Main-Sequence stars have mass and brightness that depend on surface temperature, which determines color. 98% of stars are on Main Sequence.

types

Giant blue stars are 30,000 K at surface, have masses 60 times Sun mass, last 10^8 years, are in class O, and have strongly ionized gases.

Blue-white stars are 20,000 K at surface, last 10^8 years, are in class B, have much neutral helium, and are 10% of stars.

White stars are 11,000 K at surface, are in class A, and are predominantly hydrogen.

Yellow-white stars are 7800 K at surface, are in class F, and have hydrogen decreasing and metals increasing.

Yellow stars are 6700 K at surface, are in class G, and have metals predominant.

Yellow-orange stars are 5600 K at surface and last 10^10 years.

Orange stars are 4500 K at surface, are in class K, and metals surpass hydrogen.

Red stars are 3400 K at surface, are 0.1 Sun mass, last 10^11 years, are in class M, have titanium oxide, and have weak violet light.

1% of stars are fainter than class M stars: class W, class R, class N, and class S.

lifetimes

Large stars live shorter, because they burn faster.

rotation

Main-Sequence stars rotate every 4 hours to 30 days. Bigger stars spin faster.

evolution

Over time, Main-Sequence stars increase diameter by 30% and double brightness, but surface temperature and mass stay constant. Stars accumulate helium at center, as nuclear fusion turns hydrogen into helium.

large stars

Large stars can be 40 to 120 times more massive than Sun, such as Pistol Star and LBV 1806-20. Stars cannot be larger, because higher temperature blows gases away faster.

planetary nebula

At red-giant-phase end, stars with less than eight solar masses blow away outer layers {planetary nebula}|, at 10 km/s increasing to 1000 km/s, during 100,000 to 1,000,000 years. Gas rings fluoresce by ultraviolet light from remaining hotter star layers. Magnetic fields and companion stars shape planetary nebulae. Faster winds can push into slower winds to make gas rings {interacting stellar winds hypothesis}, but most nebula do not follow this model. Planetary nebula include Ant, Blue Snowball, Bug, Calabash, Cat's Eye, Dandelion Puff Ball, Egg, Hubble's Double Bubble, Red Rectangle, Ring, Southern Crab, Stingray, Starfish twins, and Twin Jet.

standard lights

RR Lyrae variable stars and blue horizontal branch (BHB) stars have standard intrinsic visible-light intensities {standard lights}. Type-1a-supernova intrinsic brightness varies directly with time visible, so brighter lasts longer (galaxies have one every hundred years). Quasars have standard intrinsic ultraviolet-light intensities. Comparing observed brightness to intrinsic brightness measures object distance, because brightness decreases with distance squared.

water maser

Galactic water-vapor clouds {water maser} have star formation.

Zodiac

Twelve constellations {Zodiac}| are in ecliptic. Sun is in Aquarius 1/21 to 2/20, Pisces 2/21 to 3/20, Aries 3/21 to 4/20, Taurus 4/21 to 5/20, Gemini 5/21 to 6/20, Cancer 6/21 to 7/20, Leo 7/21 to 8/20, Virgo 8/21 to 9/20, Libra 9/21 to 10/20, Scorpius 10/21 to 11/20, Sagittarius 11/21 to 12/20, and Capricorn 12/21 to 1/20.

PHYS>Astronomy>Star>Sun

Sun star

Earth has a star {Sun}.

location

Sun is in galaxy horizontal plane, 27,000 light-years, 2/3 galaxy radius, from galaxy center, in Sagittarius arm.

orbit

Orbit around galaxy takes 2.5 x 10^6 years.

speed

Speed through space is 12 miles/second. Speed around galaxy is 150 miles/second.

formation

Sun and solar system formed 4,600,000,000 years ago, from gas cloud.

energy

Sun electromagnetic radiation is 10^33 ergs per second. Photons from Sun hit Earth with energy 1 eV, which is average needed for chemical reactions.

properties

Sun gas has atomic nuclei and electrons, with density 1.5 g/cm^3 at surface. Sun has average size. Mass is 2 x 10^30 kilograms, 10^6 times Earth mass. Diameter is 432,000 miles.

temperature

Temperature is 10^7 K at center and 5800 K at surface.

rotation

Equator rotates once every 27 days, around axis perpendicular to ecliptic. Polar regions rotate once every 23 to 24 days.

vibration

Sun vibrates with period 10 to 48 minutes after surface activity.

cycle

Sunspots, solar flares, and magnetic storms follow cycle of 11.1 years, with maximum at 1994 and 2005.

limb-darkening

Light intensity from edge is 70% less than from center {limb-darkening}. Center is hotter. Edge is cooler. Edge light has to travel longer through Sun atmosphere.

parhelion

Bright spots can be at Sun sides {parhelion}.

PHYS>Astronomy>Star>Sun>Layers

inner core of Sun

Inner sphere {inner core, Sun} has most of Sun mass and rotates once a day.

radiative zone

In next layer {radiative zone}, heat transfers only by radiation, not convection.

convective zone

In layer {convective zone} under surface, turbulence and shock waves transfer heat by convection and make sunspots. Convective zone has 1% of Sun mass and 20% of radius.

granulation on Sun

Convective-zone gas-circulation pattern has 1,000,000-m swirls {granulation} and 30,000,000-m swirls {supergranulation}.

sunspot

Strong magnetic fields near surface cause lower darker regions {sunspot}| of cooler 3900-K gas. Sunspots last 1 to 21 days and are 1 to 10 times wider than Earth. Sunspots start as small specks in horizontal belt, coagulate to make east-west pair, and then drift toward equator. Small sunspots {pore, Sun} can be near sunspots.

photosphere

Above convective zone is layer {photosphere} that makes visible light, at 5700 K.

chromosphere

The layer {chromosphere} above photosphere makes star color, at 4500 K to 35,000 K. Photosphere and chromosphere are 9000 miles thick.

spicule of Sun

Chromosphere has luminous-material columns {spicule, Sun} 500,000 meters wide and 1,000,000 meters high, lasting 10 minutes.

inner corona

Above chromosphere, low-density yellow layer {inner corona} extends from 9000 miles above surface to 300,000 miles above surface and is 10^5 to 10^6 K. Temperature is due mostly to solar flares. Alfven magnetic waves, whose field can oscillate but at constant pressure or which can change pressure like sound waves, affect temperature slightly. Corona temperature and density decrease over poles {coronal hole}.

solar flare

High-speed electron and atomic-nucleus streams {solar prominence} {solar flare}| arch from chromosphere into inner corona, up to 400,000,000 meters high and 50,000,000 meters wide, for up to 30 minutes. Solar flares can make x-rays. Sunspots and solar flares can have large plasma ejections {coronal mass ejection} (CME).

cause

Magnetic lines with opposite polarity squeeze together along current sheet, where they break to form new ends that connect {magnetic field reconnection} {Sweet-Parker magnetic reconnection} {slow reconnection} {Petschek magnetic reconnection} {fast reconnection} with opposite-polarity lines and annihilate.

Alfven wave

Corona high temperature is due mostly to solar flares. Magnetohydrodynamic waves {Alfven wave}, whose field can oscillate but at constant pressure or which can change pressure like sound waves, affect temperature slightly.

K corona

Above inner corona, a low-density white gas layer {outer corona} {K corona} ends 10^6 miles from surface.

solar wind

Outer corona expands away from Sun in waves {solar wind}|, as 5 x 10^5 tons of charged particles per second leave at 500,000 meters per second.

F corona

Cool gas and dust {F corona} surround outer corona.

heliosphere

Sun has a magnetosphere {heliosphere}. Ionized-gas convection makes magnetic fields. Because Sun plasma conducts, magnetic fields flow around convective zone and core. Faster rotation at equator wraps magnetic force lines around Sun, making stronger magnetic field than with no wrapping: 1000 gauss rather than 1 gauss like Earth. Magnetic-force lines repulse each other, making gas less dense there.

PHYS>Astronomy>Star>Kinds

blue dwarf

Stars {blue dwarf} with mass less than 0.25 Sun mass can burn all hydrogen and then become white dwarfs.

brown dwarf

Stars {brown dwarf} can have mass 13 to 80 times Jupiter mass or 7% Sun mass. Color is red, because it is ten times hotter than Jupiter. It burns deuterium but not hydrogen. It cannot burn lithium but has methane. Galaxy has 100,000,000,000 brown dwarfs. Objects {sub-brown dwarf} with mass less than 13 times Jupiter mass do not burn but only have heat from gravitational collapse.

Cepheid variable

In red-giant stars with mass more than 1.5 times, but less than 3 times, Sun mass, helium nuclear fusion to carbon at 10^8 K causes explosion. Stars {Cepheid variable star} {yellow supergiant} have a carbon center, helium layer, hydrogen-fusion layer, and hydrogen layer. Old stars in globular clusters and galactic nuclei are Cepheid variables {type-two Cepheid variable}.

double star

65% of all stars are pairs {double star} or higher multiples. Large star typically has smaller stars circling it. Probably all stars have companion stars, black-dwarf companions, or planets. 15% of stars have black-dwarf companions. Perhaps, galaxies have 3000 x-ray-emitting double stars {x-ray star} with white-dwarf, pulsar, or black-hole companions.

dwarf star

Stars {dwarf star} can have less than 10% Sun mass.

gravastar

Black holes {gravastar} can contain dark energy, which has negative gravity. Surface is ordinary matter.

gray hole

Almost black holes {gray hole} can let light out, but then it falls back in.

magnetar

Short-duration gamma-ray flares can come from stars {magnetar}, as star quakes disrupt magnetic field.

massive compact halo object

Dwarf stars {massive compact halo object} (MACHO) can be dark matter.

multiple star

65% of all stars are pairs or higher multiples {multiple star}. Large stars typically have smaller stars circling. Probably all stars have companion stars, black-dwarf companions, or planets. 15% of stars have black-dwarf companions.

neutron star

Stars {neutron star}| can be mostly neutrons, with density the same as atomic nuclei.

layers

Neutron stars have heavy-particle nucleus, neutron layer, elements up to atomic mass 140, and gas layer.

size

Neutron stars are 10,000-meter diameter and have mass the same as Sun mass.

temperature

Neutron stars have high temperature, because gravitational collapse turns potential energy into random kinetic energy.

spin

Neutron stars spin at 1 Hz to 30 Hz, because any initial rotation increases as diameter decreases.

magnetism

Few rotating neutron stars are magnetic, with magnetic field 10^12 times Earth field.

process

Neutron star starts with mass between 1.4 and 2.5 Sun mass. If mass is more, it becomes black hole rather than neutron star. If mass is less, it becomes white dwarf. After fusion forms iron at center, and nuclear reactions stop, heat and pressure decrease, and gravitational attraction causes a Type-Ib, Type-Ic, or Type-II supernova. Supernova explosions are typically asymmetric and push star through space at up to 1000 km/s. After supernova, gravitation is so great that it overcomes electron degeneracy pressure, and atoms collapse, leaving only neutrons, to keep total charge zero. Neutron stars balance gravity by neutron degeneracy pressure.

bursts

Once every 10 million years in galaxy, neutron stars collide and emit gamma-ray bursts {gamma-ray burst} (GRB). Neutron-star collisions make 95% of nuclei heavier than iron.

nova

In red-giant stars with mass less than 1.25 Sun mass {Chandrasekhar limit, nova}, outer layers expand away by explosions {nova}|. For several months, nova radiates energy 10^6 times Sun energy. At any moment, galaxy has 1000 novas.

White dwarf remains. White dwarfs are 5% to 10% of all stars. White dwarfs fuse all hydrogen into helium, and then fuse all helium into carbon. Helium fusion is hotter than hydrogen fusion, so star is white. White dwarfs keep contracting and exploding. White dwarfs in binary star systems explode off outer layers every 30 to 50 years.

population I star

Young stars {population I star}, like Sun, have many metals, so they can have rocky planets.

population II star

Old stars {population II star} are in globular clusters, galactic halo, and galactic nucleus and have only hydrogen and helium, so they have no rocky planets.

pulsar

Neutron stars {pulsar}| can emit radio waves with 1000 times greater intensity than Sun radiation. From them, Earth observers receive dozens of microwave pulses per second. Galaxy has million pulsars.

accretion-powered pulsar

Pulsars {accretion-powered pulsar} can accrete matter from companion stars and have matter-accretion disks that spin almost as fast as pulsar. Disk charge acceleration emits x-rays, not radio waves, because gravitational force is very high.

magnetar

Neutron-star magnetars can have magnetic field 10^10 tesla. Strong magnetic field accelerates charges, emitting x-rays constantly.

rotation-powered pulsar

Most pulsars {rotation-powered pulsar} emit microwave radiation by magnetic-field rotation. Such pulsars have magnetic fields 10^{12} times Earth magnetic field and spin dozens of times per second. Pulsar radiation causes rotation-powered pulsars to spin slower as rotational energy is lost.

Rotation-powered pulsars can have companion stars and can accrete matter, typically increasing pulsar spin but weakening magnetic field. These pulsars spin tens or hundreds of times each second.

Rotation-powered pulsars {strong-field pulsar} can have stronger 10^{8}-tesla magnetic fields and spin once each second.

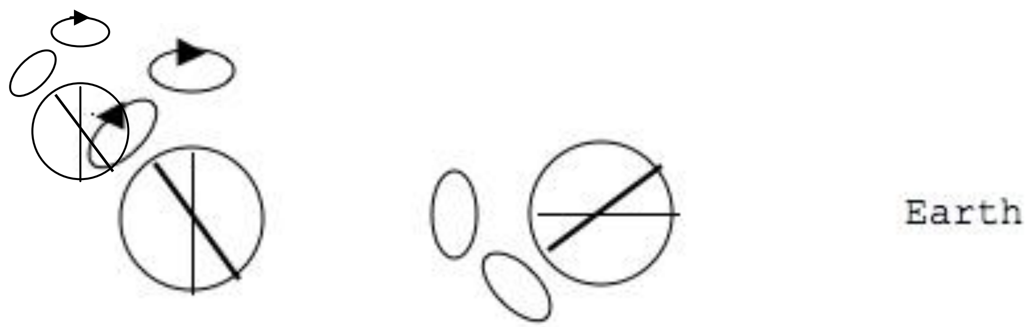
rotation-powered pulsar: poles

Magnetic poles typically do not align with spin axis. Magnetic field rotates at angle to pulsar rotation, causing electric fields. Electric fields accelerate charges from pulsar surface. Magnetic field aligns accelerated charges along magnetic poles. Accelerated charges have almost light speed and emit synchrotron-radiation microwaves. Synchrotron radiation lowers relativistic mass, to keep charges below light speed.

When charges have almost light speed, special relativity causes light waves not to radiate in all directions but form a beam in motion direction. Synchrotron radiation aligns along magnetic-pole axis. Microwave beams continuously radiate from both poles, in opposite directions. See Figure 1.

Because pulsars spin, magnetic-pole axis rotates. Axis can point toward Earth once each rotation. For most pulsars, magnetic-pole axis never points toward Earth. Because pulsars rotate, magnetic-pole axis can never constantly point at Earth.

Figure 1



pulsating star

Stars {pulsating star}, like RR Lyrae stars, can be average-size stars that can double brightness over hours or years, as they expand and contract up to 30%. Ion and helium layers change depth and cause brightness changes. Pulsating stars are less than 1% of stars.

red dwarf

After white dwarf is mostly carbon, it cools, first to yellow and then to red {red dwarf}. Eventually, it becomes dark.

red giant

Main-Sequence stars accumulate helium at center, as nuclear fusion turns hydrogen into helium. In stars with average mass, 30% of stars, when helium becomes more than hydrogen, helium fuses to make carbon. This makes star hotter, so hydrogen nuclear fusion becomes faster. Outer hydrogen layer expands. After 10^9 years, outer layer is thousands of times bigger and is cooler, so star {red giant}| is red.

supernova

Massive stars have extreme novas {supernova}|. For several months, star radiation is 10^9 times Sun radiation. Only 1% of stars become supernovas, so one galaxy has one supernova every 50 years. Sumerians saw a supernova (Mul Nun-ki) [-3000] in Vela. A supernova [185] lasted 20 months and was as bright as Moon. Supernova [393]. A supernova [1006] lasted years and was as bright as Moon. A type-2 supernova [1054] formed the Crab nebula. Supernova [1181]. Tycho observed a Type-1a supernova [1572], as bright as Venus. Kepler observed a supernova [1604].

Supernovas make all titanium through iron nuclei, mostly carbon, oxygen, silicon, magnesium, and iron. Supernovas also make five percent of elements heavier than iron.

T-Tauri star

Very young stars {T-Tauri star} have gas and dust around them.

Type 1a supernova

Starting with hydrogen, stars first make helium, then carbon and oxygen, then heavier nuclei, such as silicon, sulfur, and calcium. Heat dissipates, and star stops fusion. Star still has high temperature and turbulence. Helium rises to surface, and heavier nuclei go to core. White-dwarf stars have no hydrogen and are small. White dwarfs orbiting stars with larger diameters but smaller masses can become supernovas {Type 1a supernova} {supernova 1a}. White dwarfs accrete gas from other star, until gas has enough matter to pressure star core to restart nuclear reactions. From carbon and oxygen, chain reactions produce nickel, iron, and cobalt and, after several seconds, explode star.

Type 2 supernova

Stars with mass 8 to 25 times Sun mass start with hydrogen and first make helium, then carbon and oxygen, then heavier nuclei, such as silicon, magnesium, and iron. Such massive stars can fuse nuclei to make elements up to iron, which requires temperature 10^12 K. Such stars have turbulent hydrogen, helium, carbon, oxygen, silicon, magnesium, and iron layers, from surface to core, respectively. Star diameter is more than four million kilometers. Iron cannot fuse to anything else, so core becomes cooler and has less pressure. At critical pressure, gravitation collapses iron nuclei in one second to make neutron star. Gravitation continues to pull matter inward, and nuclei bounce off neutron star turbulently at supersonic speed, making shock waves. Nuclei stream inward between shock-wave sides. Neutrinos heat shock-wave gas, which keeps expanding. Shock waves explode star {Type 1b supernova} {Type 1c supernova} {Type 2 supernova} {supernova 2}. Asymmetrical explosion pushes neutron star to speeds up to 1000 km/s. Explosion makes high temperature and pressure and can make elements higher than iron. Perhaps, higher-element making involves antineutrinos. Higher-element making uses energy rather than making energy, absorbs heat, and cools core. Expansion weakens, and gravitational collapse takes several minutes.

white dwarf

In red-giant stars with mass less than 1.25 Sun mass {Chandrasekhar limit, white dwarf}, as outer layers expand away by nova explosions, Earth-size star {white dwarf} remains. Electron-degeneracy pressure counterbalances gravity, so atoms do not collapse. White dwarfs are 5% to 10% of all stars.

PHYS>Astronomy>Solar System

solar system

Sun, planets, asteroids, moons, and comets {solar system}| formed 4,600,000,000 years ago. Solar system has 10^13 meter diameter, has mass 10^36 grams, and will last 10^16 seconds.

space between planets

Space between planets has 10 ions per cubic centimeter.

space erosion

Space objects erode by 0.001 meters every 10^6 years.

Pioneer spacecraft

Pioneer 10 and Pioneer 11 spacecraft photographed Jupiter and Saturn [1972 to 1973] and are now outside solar system. At 10 astronomical units, they slowed from projected speed {Pioneer anomaly}. Researchers do not yet know slowdown direction. If it is toward Sun, it indicates something new about gravity. If it is toward Earth, it indicates something about light velocity. If it is along motion direction, it indicates something about inertia or drag. If it is along spin axis, it indicates something about Pioneer spacecraft.

satellite moon

Moons {satellite}| can be close to planets in circular orbits near ecliptic {regular moon} or far from planets in elliptical orbits out of ecliptic {irregular moon}. Regular moons formed from planetary dust cloud. Irregular moons formed in Kuiper belt or as asteroids. Planet can capture irregular moon when two nearby potential moons interact to slow one down. Planet gravitation must be more than Sun gravitation in that region {Hill sphere}. Orbit shape and tilt relate {Kozai resonance}. Triton is largest irregular moon. Small moons can form from large-moon breakup.

tidal torque

Gravitational forces {tidal torque} cause planet and moon water and land movements (tide). Friction causes tides to be slower than gravitational forces. Sun tidal torque affects Mercury and Venus spin. Jupiter and Saturn tidal torques affect inner-moon spins.

troilite

Mars has magnesium and iron silicates, iron-sulfur rocks {troilite}, and free iron.

PHYS>Astronomy>Solar System>Axis Tilt

autumnal equinox

Earth-axis tilt causes a day {autumnal equinox}| with equal daylight and dark in autumn.

summer solstice

Earth-axis tilt causes a longest-daylight day {summer solstice}|.

vernal equinox

Earth-axis tilt causes a day {vernal equinox}| with equal daylight and dark in spring.

winter solstice

Earth-axis tilt causes a shortest-daylight day {winter solstice}|.

PHYS>Astronomy>Solar System>Comet

comet

Solar system has objects {comet}| that start outside Pluto orbit. Famous comet is Halley's comet, which neared Sun in 1986 and has 76-year orbit.

composition

Comets have frozen water, iron, silicate, carbon, and nickel, plus ammonia, carbon dioxide, methane, cyanogen, and hydrogen cyanide.

parts

Comets have central ball {nucleus, comet} and coma.

size

Comets have average diameter 2000 meters.

number

More than 1,000,000,000,000 comets exist, with total mass 1 to 1000 times Earth mass.

orbit

Comets have elliptical orbits, averaging 10,000 years, in same motion direction as planets, extending up to 1/5 distance to nearest star. Comet orbits change as they come close to Sun, because hot side evaporates more than cold side and spin interacts with Sun gravity.

tail

As comets approach Sun and evaporate, they leave curved dust tails along motion path. As comets approach Sun, solar wind creates straight ion tails, away from Sun.

meteor showers

Comet dust causes meteor showers, which happen 600 times a year. Meteor-shower names are the name of the constellation in which they appear: Quadrantids in January, Lyrids in April, Aquarids in May, Perseids in August, Draconids in October, Orionids in October, Taurids in November, and Geminids in December.

coma of comet

Comets have a central nucleus surrounded by a dust and gas cloud {coma, comet}.

Oort cloud

Most comets lie in circular orbits {Oort cloud}| beyond Pluto, where they formed. From there, passing star can push them into elliptical orbit. Some comets lie in Kuiper belt.

gegenschein

Comet debris causes faint patch {counterglow} {gegenschein}|, 10 degrees diameter, in night sky in direction opposite Sun.

zodiacal light

Comet debris causes faint glow {zodiacal light}| along ecliptic, which is 10 degrees above horizon, in eastern sky before sunrise or in western sky after sunset.

PHYS>Astronomy>Solar System>Eclipse

lunar eclipse

Moon enters Earth shadow {lunar eclipse}| 0 to 3 times a year.

solar eclipse

Moon passes in front of Sun {solar eclipse}| 2 to 5 times a year.

PHYS>Astronomy>Solar System>Moon

Moon as satellite

A satellite {Moon} orbits Earth.

properties

Diameter is 2,000,000 meters. Mass is 1/80 of Earth mass. Surface area equals Africa area. Density is 2/3 of Earth density. Gravity is 1/5 of Earth gravity.

orbit

Orbit tilts at 5-degree incline to Earth orbit. Moon is 376,000,000 meters from Earth. Gravitational effect of Earth spin moves Moon slowly away from Earth. 4,000,000,000 years ago, Moon was 100,000,000 meters from Earth.

rotation

Moon rotates every 27.3 days, keeping same side toward Earth, ever since 10^9 years ago.

temperature

Surface temperature is 200 C by day and -150 C at night.

atmosphere

Moon has thin atmosphere with no water.

layers

Core has radius 400 miles and is molten. Peridotite and dunite lie from 400 miles from center to 40 miles below surface. Peridotite and dunite are oxide rocks like those in Earth mantle. Basalt layer lies from 40 to 15 miles deep. Crust is anorthositic rock 60,000 meters thick, with some granite.

surface

Surface has basalt rock from volcanoes that erupted more than 3,000,000,000 years ago, making mountains 8000 meters high. Mare basalt, from partial interior melting, is in plains {maria}. Another basalt type has anorthositic rock and KREEP norite from mountain {highland} partial melting. KREEP norite has potassium, rare earths, and phosphorus.

craters

Most craters are more than 4,000,000,000 years old. Largest crater is 250,000-meter diameter and 1000 meters high. Craters are 10 to 20 times bigger than their meteors.

history

Moon began when Mars-sized body collided with Earth and splashed material into orbit. It is much less likely that it began from smaller bodies in orbit around Earth or by capture. Orbiting material gravitated together and melted surface. Lighter molecules rose to surface and cooled to become crust. Later, before 4.2 x 10^9 years ago, meteorites pressed highland rocks together to make breccia. Then crust formed again. Then KREEP norite formed around Mare Imbrium. Then large impacts 4 x 10^9 years ago made maria basins. Then volcanoes erupted for 0.7 x 10^9 to 1.0 x 10^9 years, filling maria with lava. Finally, Moon cooled.

features

Tycho crater is at low center. Copernicus crater is at left center. Archimedes crater is at low center. Ptolemaeus crater is at center. Carpathian Mountains are around Copernicus. Mare Imbrium plain or Sea of Rains is at left and up. Mare Serenitatis or Sea of Serenity is at right and up. Mare Tranquillitatis or Sea of Tranquillity is at right center. Oceanus Procellarum is at left center. South Pole is in Aitken Basin on far side.

phases

Moon has phases. New moon is thin crescent. Crescent moon is fuller. First-quarter moon has light on left half, with Sea of Tranquility and Pyrenees Mountains. Gibbous moon is between first quarter and full. Full moon is a circle. Gibbous moon is between third quarter and full. Third-quarter moon has light on right half, with Sea of Shadows and Carpathian Mountains. Crescent moon is less. New moon is thin crescent.

earthshine

Moon parts not in direct sunlight can reflect light that first bounced off Earth {earthshine}.

lunar halo

Moonlight refraction by thin, high, icy clouds causes white, 22-degree ring {lunar halo} {aureole, Moon}, and sometimes 46-degree ring, around Moon.

mascon

Dense masses {mascon} under lunar maria are buried asteroids or heavy lava.

PHYS>Astronomy>Solar System>Moon>Period

sidereal month

By star positions, Moon orbit is 27.3 days {sidereal month} and tilts at 5-degree incline to Earth orbit.

synodic month

Time between new moons is 29-1/2 days {lunar month} {synodic month}.

PHYS>Astronomy>Solar System>Moon>Rock

anorthositic rock

Basalt can have plagioclase feldspar formed by crystal fractionation {anorthositic rock} and KREEP norite from partial mountain/highland melting. KREEP norite has potassium, phosphorus, and rare earths.

hapkeite

Meteor collisions vaporize and fuse iron and silicon {hapkeite}.

mare basalt

Basalt {mare basalt}, from partial interior melting, can be in maria.

PHYS>Astronomy>Solar System>Orbit

orbit of planet

Planets orbit the Sun {orbit, planet}| {planetary orbit}.

Bode law

Planets and asteroid belt lie at 4, 7, 10, 16, 28, 52, 100, 196, 388, and 772 units from Sun {Bode's law} {Bode law}.

conjunction of planets

Planets can be in line with Sun and Earth {conjunction, planet}|, on far side of Sun {inferior conjunction} or on same side as Earth {superior conjunction}.

ecliptic

planet-orbit plane {ecliptic}|.

elongation of orbit

Seen from Earth, Venus or Mercury has distance {elongation} from Sun.

occultation

Bodies can pass in front of other bodies {occultation}|.

retrograde motion

Seen from Earth, planets and their moons periodically appear to move backward {retrograde motion}.

transit of Venus

Mercury and Venus can pass in front of Sun {transit}|.

PHYS>Astronomy>Solar System>Orbit>System

epicycle

In ancient theories of Earth-centered universe, orbits were circles and circles of circles {epicycle} {epicycle construction} {eccentric construction}.

geocentric system

Perhaps, Earth is near solar-system center {geocentric system}.

heliocentric system

Sun is near solar-system center {heliocentric system}.

PHYS>Astronomy>Solar System>Orbit>Changes

precession of the equinoxes

Earth axis points slightly more counterclockwise, looking north, each year {precession of the equinoxes}| {equinox precession} and completes circle in 22,000 to 26,000 years. Moon nutation orbital-plane changes cause precession rate to vary over an 18.6-year cycle. Orbit variations also have 41,000-year and 100,000-year cycles.

nutation of Earth

Moon orbital-plane changes cause precession rate to vary over an 18.6-year cycle {nutation, Earth orbit}|.

PHYS>Astronomy>Solar System>Orbit>Orbital Points

apogee

Orbit around Earth has point {apogee} farthest from Earth.

perigee

Orbit around Earth has point {perigee} nearest Earth.

aphelion

Orbit around Sun has point {aphelion} farthest from Sun.

perihelion

Orbit around Sun has point {perihelion} nearest Sun.

first point of Aries

At vernal equinox, Sun is at a celestial-sphere point {first point of Aries}.

Lagrangian point

For two objects in space, five points {Lagrangian point} {libration point} have equal competing gravities. Three are unstable, but two are stable.

PHYS>Astronomy>Solar System>Planet

planet

Planets {planet} are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Neptune, and Uranus.

planet formation

Planets form after star forms. 20% of stars have planets. Multiple stars probably do not have planets.

planet formation: materials

Iron, silicates, magnesium, aluminum, and calcium oxides are 0.5% of dust-and-gas-cloud mass and are solid at planetary-cloud temperatures and pressures. Water, methane, and ammonia are 1.5% of dust-and-gas-cloud mass and freeze at temperature -120 C at pressures in dust-and-gas cloud. Hydrogen and helium are 98% of dust-and-gas-cloud mass and are gases at planetary-cloud temperatures and pressures.

planet formation: temperature

Dust-and-gas-cloud temperatures stay constant at each distance from star during planet formation. Planetary-cloud inner region is 3 x 10^9 meters from star, at temperature 1600 K. Water is liquid 1.3 x 10^11 meters from star, because temperature is less than 100 C and more than 0 C.

planet formation: process

When stars form, dust-and-gas clouds become disks. Disks are thickest at 1.5 x 10^12 meters from center.

Disc contraction leaves behind flat ring 10^9 to 10^12 meters thick, with temperature from 1800 C to -250 C, total mass equal to new star mass, and dust particles 10^-6 meters diameter.

Dust particles stick together to make one-micron-diameter chunks. Making micron-size particles takes 100,000 years. Dust particles stick together beyond distance where temperature is less than 1800 K. Small grains flow with gas.

Millimeter-size dust hits gas and slows. At distance at which water freezes {snow line}, dust does not slow, because water evaporates inside that distance and gas is faster than dust grains. Orbits are elliptical.

Dust particles larger than millimeter diameter fall toward planet and cannot stay in orbit, because gas orbits slower than them, they hit gas, and slow.

Over one million years, kilometer-size planetesimals form, removing all dust.

For 100,000 years, inside distance where water freezes, planetesimals collide to make planets one-tenth Earth mass. For one to ten million years, outside distance where water freezes, planetesimals collide to make planets four times Earth mass. Interactions make spherical orbits.

planet formation: large planets

Ten-times-Earth-mass bodies, just outside distance where water freezes, can attract gas that cools by heat transfer through translucent gas. Large planets cause waves in gas that slow planet. Gas giant planets do not form if they spiral in too fast or stay too hot. Making large planets typically requires heavy elements and medium-to-large stars. It also requires that gas does not deplete too fast.

Planets like Earth are too small to attract hydrogen gas. Planets like Uranus and Neptune are just big enough to collect gases heavier than hydrogen. Planets like Jupiter can attract all gases, no matter what temperature.

planet formation: solar wind

After planets form, solar wind and radiation blow away uncondensed dust and gases.

planet formation: gas giant

For several million years, first gas-giant planet disturbs other planetesimals and gas and spirals nearer to star, or stays near original position and more gas giants form beyond it, as matter spirals in and accumulates at border cleared by gas giant.

planet formation: rocky planet

Rocky planets gather material over fifty million years. After rocky planets reach full size, heat from radioactivity melts planet. Layers with different densities form over 10^9 years. Iron is in center, silicates and oxides are near surface, and carbon dioxide, sulfur dioxide, hydrogen sulfide, methane, ammonia, and water vapor are in atmosphere. After layering, cooling forms rocky crust on planet surface.

atmosphere

Atmospheres lose gases by Jeans escape, hydrodynamic escape, polar wind, charge exchange, and solar wind. Water breakdown can lead to hydrogen loss and excess oxygen.

chthonian planet

Gaseous planets {chthonian planet} can lose atmosphere and have only rocky core.

PHYS>Astronomy>Solar System>Planet>Atmosphere

charge exchange

Fast charged particles can capture electrons {charge exchange}, become neutral, and escape atmosphere, because magnetic field does not attract them. Earth hydrogen loss is mostly by this process.

polar wind

Magnetic particles can travel out from poles {polar wind}, along magnetic field lines that do not close. Earth hydrogen loss is partly by this process. Earth helium loss is mostly by this process.

Jeans escape

Gaseous planets can lose gas by evaporation from atmosphere top {Jeans escape}. Earth hydrogen loss is partly by this process.

hydrodynamic escape

Gaseous planets can lose gas by high heating and upward airflow {hydrodynamic escape}, sweeping all molecule weights along.

PHYS>Astronomy>Solar System>Planet>Planets

Mercury planet

Planets {Mercury, planet} can be nearest to Sun.

properties

Diameter is 5,000,000 meters. Mass is 5% Earth mass. Density is slightly less than Earth density. Gravity is one-third Earth gravity.

properties: temperature

Surface temperature is 350 C by day and -170 C at night.

properties: rotation

Mercury rotates every 59 days on axis tilted 28 degrees to ecliptic, because Sun gravity couples spin to orbit.

properties: magnetism

Mercury has tiny magnetic field.

properties: orbit

Mercury is 58,000,000,000 meters from Sun. It has elliptical orbit of 88 days, tilted at 7 degrees to ecliptic.

layers

Mercury has iron core out to 3/4 radius. Mantle has igneous rocks, silicates, iron, and titanium glasses. Thin surface layer has fine, dark silicates. Surface is similar to Moon. It has shallow cliffs greater than 100,000 meters long, caused by crust tightening. It has no large craters. Higher gravity than Moon kept secondary craters near craters, so surface has plains between craters and basins.

atmosphere

Mercury has no atmosphere.

moons

Mercury has no moons.

Venus planet

Planets {Venus, planet} {morning star} {evening star} can be second nearest to Sun.

properties

Diameter is 12,000,000 meters, slightly smaller than Earth diameter. Mass is 88% Earth mass. Density is slightly less than Earth density. Gravity is 85% Earth gravity.

properties: rotation

Venus rotates every 243 days on axis tilted 3 degrees to ecliptic, with direction opposite to all other planets except Uranus.

properties: temperature

Surface temperature is 474 C, because atmosphere traps heat.

properties: magnetism

Venus has no magnetic field.

properties: orbit

Venus is 107,000,000 meters from Sun. Circular orbit takes 243 days and is in ecliptic.

layers

Crust is like Earth crust. Surface has loose granite rocks and many large shallow craters filled by flows from volcanoes.

atmosphere

Thick, layered atmosphere has carbon dioxide at pressure 90 atmospheres, with no oxygen and only water traces. Slow winds are at surface. Fast higher winds blow in spin direction. Lowest clouds are 35,000 meters high and 400 K. Temperature at cloud tops is -33 C. Clouds are 75% sulfuric acid. Because dust in clouds reflects light, only 1% of sunlight reaches surface.

Venus atmosphere is so thick that it refracts light by 90 degrees, so light scattering causes red appearance. Refraction is so great that whole planet surface is visible from any surface point.

moons

Venus has no moons.

Earth planet

Planets {Earth} can be third nearest to Sun.

properties

Diameter is 7917 miles, or 13,000,000 meters, at equator. Circumference is 24902 miles. Diameter at equator is 26.7 miles more than diameter through poles. Density is 5.5 g/cm^3, highest in solar system. Mass is 10^30 grams. Earth will last 10^16 seconds.

properties: orbit

Earth is 149,000,000,000 meters from Sun. One orbit takes 365 1/2 days in a sidereal year. Speed around Sun is 18 miles/second. In Northern Hemisphere, summer is seven days longer than winter, because Earth is closer to Sun then.

properties: rotation

Rotational speed at equator is 0.3 miles/second. Earth turns 15 degrees each hour, as it rotates every 24 hours west to east. Spin slows through tidal interaction with Moon and Sun. 4 x 10^9 years ago, day was 10 hours long. In Cambrian Era, day was 21 hours long. Axis tilts 23.5 degrees from orbit plane.

properties: temperature

Average surface temperature is 22 C. Heat is half from radioactive decay and half from kinetic energy gained from potential-energy loss as matter gathered by gravity at formation.

atmosphere

Air is 10^-6 of Earth weight. Average surface pressure is one atmosphere. Hydrogen-gas halo {geocorona} goes out to 15 radii, emitting ultraviolet light.

moon

Earth has one moon.

Mars planet

Planets {Mars, planet} can be fourth nearest to Sun.

properties

Diameter is 6,800,000 meters. Mass is 12% Earth mass. Density is 4 g/cm^3. Gravity is 38% Earth gravity.

properties: rotation

Mars rotates every 24.5 hours on axis inclined 23 degrees to orbit.

properties: orbit

Mars is 227,000,000,000 meters from Sun. It has slightly elliptic orbit of 1.88 years, slightly inclined to ecliptic.

properties: magnetism

Mars has no magnetic field.

properties: temperature

Surface temperature is 250 K, with high 290 K.

formation

Rapid matter accretion at solar-system beginning melted crust in just 10^5 years. Then iron and iron-sulfur core formed. Crust cooled. Plains and volcanoes formed 3.5 x 10^9 years ago. Crust has no plates or movement. Crust has stretched since forming.

surface

North is low plain with few craters. South is highlands with many craters. Tharsis Plateau is at equator, with very high volcanoes. Volcanoes are over hot spots around equator.

surface: sand

Surface has rocks and red dust. Sandstorms are 300 km/hr. When Mars is farthest from Sun, great dust storm lasts 3 months.

surface: rocks

Mars has magnesium and iron silicates, iron-sulfur rocks (troilite), and free iron. Dark regions have basalt, such as plagioclase and pyroxene. Northern plains are andesite. Hematite is near equator.

surface: water

Surface has phyllosilicate clays and hydrated iron oxides, which indicate water, but no carbonates. Surface has sedimentary rocks with sulfur and hydrates. Sulfur degrades carbonates and inhibits clay formation. Mars dried out and cooled between 3.5 billion years ago and 2.5 billion years ago. Water ice extends deep into surface, except at equator.

surface: ice caps

Polar ice caps are water ice with some carbon-dioxide ice. At maximum, they are 10% of surface. Layered regions near poles show changes.

atmosphere

Mars has thin atmosphere, with surface pressure 0.01 atmosphere. Atmosphere has carbon dioxide, water traces, and no oxygen. Clouds are over volcanoes. Thin clouds are over poles.

landmarks

Nix Olympia or Olympus Mons is 15 miles high and 370 miles across. Mars Rift Valley is 3000 miles long and 1500 miles wide. Coprates is a large river-like system. Hellas crater is a featureless bowl-shaped region. Valles Marineris canyon is north of south highlands. Argyre Basin has 1000 km diameter.

moons

Two small moons are in rapid close orbit. Phobos is larger, and Deimos is smaller.

Jupiter planet

Planets {Jupiter, planet} can be fifth nearest to Sun and largest planet.

properties

Diameter is 142,000,000 meters. Mass is 318 times Earth mass. Density is 1.33 g/cm^3, because it is 80% hydrogen. Gravity is 2.64 times Earth gravity.

properties: rotation

Jupiter rotates every 10 hours on axis inclined 3 degrees to orbit.

properties: magnetism

Magnetic radiation fields are 10 to 10^5 stronger than Earth fields and make a flat disc 4 x 10^6 miles diameter.

properties: temperature

Surface temperature is 128 K, and surface radiates heat.

properties: orbit

Jupiter is 778,000,000,000 meters from Sun. Circular orbit of 12 years slightly inclines to ecliptic.

layers

Jupiter has a rocky core. Around core is a 46,000,000-meter-diameter metallic ionized liquid-hydrogen layer, at temperature 11,000 K to 30,000 K and pressure 10^7 lb/in^2 or 3 x 10^6 atmosphere. This layer has convection currents that create magnetism and heat flow. 46,000,000 to 70,000,000 meters diameter is liquid hydrogen with 20% helium. Above that layer is a gaseous hydrogen-and-helium layer.

atmosphere

Atmosphere is 1,000,000 meters thick and has layers. First is water drops and ice. Then frozen ammonia is at temperature 110 K. Above that is methane. Gaseous hydrogen is at top. Atmosphere has red and brown belts. Cooler belts are lighter, and hotter belts are darker. Great red spot is swirling gas fed by smaller vortices and is a stable non-linear system. Atmosphere winds are up to 300 km/hr.

moons

Jupiter has 15 moons, four large. Ganymede is size of Mercury. Callisto is smaller than Ganymede and has ice-rock interior. Perhaps, Callisto has water layer. Io has salt, gaseous sodium cloud, and many active volcanoes. Europa is Moon size.

Saturn planet

Planets {Saturn, planet} can be sixth nearest to Sun and second-largest planet.

properties

Diameter is 121,000,000 meters. Mass is 95 times Earth mass. Density is 0.7 g/cm^3, because it is 66% hydrogen. Gravity is 1.14 times Earth gravity.

properties: rotation

Saturn rotates every 10 hours on axis tilted 27 degrees to orbit.

properties: temperature

Surface temperature is -170 C.

properties: orbit

Saturn is 1,427,000,000,000 meters from Sun. Circular orbit of 29.5 years slightly inclines to ecliptic.

layers

Core is rock, 20,000,000-meter diameter. Around core is ice 5,000,000 meters thick. Around ice layer is metallic hydrogen 8,000,000 meters thick. Around that layer is molecular hydrogen.

atmosphere

Atmosphere is like Jupiter. Saturn has yellow and green belts. Perhaps, dark particles in atmospheres of Saturn, Titan, and Jupiter are polymers.

moons

Saturn has 10 moons. Titan is largest moon, with diameter 5,000,000 meters. It is the only moon with atmosphere, mainly nitrogen, and has opaque red methane and hydrogen clouds. It has rock core, wet water and ammonia mantle, and ice crust. Surface temperature is -180 C.

Iapetus has surface organic material. Enceladus has diameter 504 kilometers, has rocky core, has icy surface, has liquid water under surface, has tidal forces, makes water jets from south-pole plain that add water to E-ring, and has organic compounds. Other main moons, from inner to outer, are Prometheus, Epimetheus, Pandora, Janus, Mimas, Enceladus, Tethys, Dione, and Rhea.

rings

Rings of ice crystals and ice-coated dust 1-centimeter diameter are from 15,000,000 to 79,000,000 meters. Rings are 0.1 to 16,000 meters thick. Outer E-ring goes from Mimas to between Dione and Rhea.

Uranus planet

Planets {Uranus, planet} can be seventh nearest to Sun and third-largest planet.

properties

Diameter is 50,000,000 meters. Mass is 14.5 times Earth mass. Density is 1.6 g/cm^3, because it is 15% hydrogen. Gravity is 1.17 of Earth gravity.

properties: rotation

Uranus rotates every 11 hours on axis almost parallel to orbit plane, 82 degrees to vertical, in opposite direction from Earth direction.

properties: temperature

Surface temperature is 70 K.

properties: orbit

Uranus is 2,860,000,000,000 meters from Sun. Circular orbit of 84 years is in ecliptic.

layers

Rocky core is 16,000,000-meter diameter, at 4000 K and surface pressure 2 x 10^6 atmosphere. Ice layer is 8,000,000 meters thick. Around that layer is molecular hydrogen. Uranus has solid-methane outer layer.

atmosphere

Atmosphere has hydrogen, helium, and methane. Uranus has greenish color.

moons

Uranus has five moons.

Neptune planet

Planets {Neptune, planet} can be eighth nearest to Sun and fourth-largest planet [discovered 1846].

properties

Diameter is 45,000,000 meters, four times Earth diameter. Mass is 17 times Earth mass. Density is 2.3 g/cm^3, because it is 25% hydrogen. Gravity is 1.18 of Earth gravity.

properties: rotation

Neptune rotates every 16 to 18 hours on axis tilted 29 degrees to orbit.

properties: magnetism

Neptune has magnetic field.

properties: temperature

Surface temperature is 50 K to 55 K.

Like Jupiter and Saturn, Neptune has internal heat source. Neptune radiates more than twice as much energy as it receives from Sun.

orbit

Neptune is 30 times farther from Sun than Earth, 4,500,000,000,000 meters from Sun. Circular orbit of 165 years slightly inclines to ecliptic.

layers

Neptune has rocky core, 16,000,000-meter diameter. Around core is ice 8,000,000 meters thick. Around that layer is molecular hydrogen.

atmosphere

Atmosphere is mostly hydrogen and helium with some methane. Blue color results from red-light absorption by methane. Neptune has argon clouds. Neptune has rapid winds in horizontal bands and has large storms or vortices. Winds are fastest in solar system, reaching 2000 kilometers per hour. Large dark oval revolves around Neptune every 18 hours. Second dark spot revolves around Neptune every 16 hours.

moons

Neptune has many moons. Triton is main moon and is bigger than Moon. Gravitational effect of smaller moon defines rings. Adams Ring is 63,000 km from center of Neptune. Leverrier Ring is 53,000 km. Galle Ring is 42,000 km. All rings are closer to Neptune than Moon is to Earth.

PHYS>Astronomy>Solar System>Planetoid

planetoid

Solar system has dwarf planets {planetoid}.

asteroid

Pieces {asteroid}| from former planetary formation lie between Mars and Jupiter, 2.6 x 10^6 miles from Sun. Asteroids cluster and so came from collisions between many bodies 50,000 to 200,000 meters diameter. More than 10,000 asteroids exist. 2000 are relatively large.

names

Ceres has diameter 800,000 meters and is largest. Pallas, Juno, Vesta, and Hygiea have diameter more than 200 miles. Trojans are at the two stable Lagrangian points in Jupiter's orbit. Apollos go inside orbit of Mercury. Icarus goes to within 1.9 x 10^6 miles of Sun.

orbit

Asteroids have elliptical orbits. Jupiter gravity and asteroid collisions cause some orbits to be so elliptical that they go within 30,000,000,000 meters of Sun.

meteors

Meteors are asteroids. Iron meteorites {S class meteorite} are 10^9 years old. Stony meteorites are 1 x 10^6 to 100 x 10^6 years old. They are the main asteroids in inner asteroid belt. Carbonaceous chondrite meteorites {C class meteorite} {D class meteorite} are 4.6 x 10^9 years old and have solid grains from original solar-cloud dust. They are the main asteroids in outer belt and are darker and redder. Type C1 has same composition as Sun, with no silicate pea-size chondrules. Types C2 and C3 have iron, nickel, and rock, unlike Sun, and have chondrules.

centaur as planetoid

Planetoids {centaur, solar system}, such as Chiron, can orbit elliptically between Neptune and asteroid belt. Composition is like meteorites and comets.

Kuiper belt

Solar system has an icy-planetoid ring {Kuiper belt}|, starting at Neptune and extending to Pluto, 4.6 billion miles from Sun. Kuiper-belt planetoids can orbit once every 200 to 400 years. Planetoids, such as Eris (Xena or 2003 UB313), can have highly elliptical orbits. Eris [2005] has methane surface, is three times larger than Pluto, has small moon (Gabrielle), and orbits at 45 degrees to ecliptic. Astronomers also discovered Sedna [2003] and Quaoar [2002].

plutino

Pluto and other planetoids {plutino} can orbit in resonance with Neptune. As Neptune orbits thrice, they orbit twice.

Pluto as planetoid

Small planets {Pluto, planetoid} are planetoids.

properties

Diameter is 2,400,000 meters. Mass is 0.1 Earth mass. Density is probably like that of rock. Gravity is less than Moon gravity.

properties: rotation

Pluto rotates every 6.4 days.

properties: temperature

Surface temperature is 43 K.

properties: orbit

Pluto averages 5,900,000,000,000 meters from Sun, with highly elliptical orbit of 248 years, inclined 17 degrees to ecliptic. It has seasons. Pluto is in Kuiper belt.

surface

Surface has frozen nitrogen, carbon monoxide, methane, and water.

atmosphere

Atmosphere is rapidly evaporating.

moons

Pluto has one moon, Charon, 1,200,000-meter diameter and 19,000,000 meters away.

PHYS>Astronomy>Instruments

astrolabe

Instruments {astrolabe}| can measure time by bright-star positions.

equatorial armillary

Instruments {equatorial armillary} can plot planet and star declinations and right ascensions and so measure time (Tycho Brahe).

equatorial mounting

Telescope mountings {equatorial mounting} can rotate around Earth axis to measure right ascension and rotate around axis {declination axis} perpendicular to Earth axis to measure declination.

Foucault pendulum

Instruments {Foucault pendulum} can demonstrate that Earth rotates.

orrery

Instruments {orrery} can be mechanical solar-system models, showing planets rotating around Sun.

plinth

Instruments {plinth}| can use block to measure Sun-elevation angle at noon.

quadrant as instrument

Instruments {quadrant, instrument} can measure star elevation.

reticule

Telescopes and micrometers can have line arrays {reticule}.

triquetrum
Instruments {Ptolemy's rules} {triquetrum} can measure star elevation angle as star crosses meridian.

PHYS>Astronomy>Instruments>Telescope

Cassegrain reflector
Telescopes {Cassegrain reflector telescope} can use main mirrors to reflect to small mirrors and back through hole in main mirror.

Coude system
Telescopes {Coudé system} can observe bright objects using objective mirrors that send light to concave mirrors that send light to flat rotatable mirrors and eyepieces, along mounting axis parallel to Earth axis.

reflecting telescope
Telescopes {reflecting telescope} can observe visible stars using parabolic mirrors as objectives.

refracting telescope
Telescopes {refracting telescope} can observe stars using biconvex objective lens.

Schmidt telescope
Telescopes {Schmidt telescope} can be wide-field refracting telescopes with lenses to correct for spherical aberration.

PHYS>Astronomy>History

Nicholas Copernicus [Copernicus, Nicholas]
astronomer
Poland
1543
On the Revolutions of the Celestial Orbs [1543]
He lived 1473 to 1543 and invented heliocentric theory of solar system.

Johannes Kepler [Kepler, Johannes]
astronomer
Tübingen, Poland/Prague, Czech Republic
1596 to 1627
Cosmographic Mystery [1596]; Dream or Astronomy of the Moon [1611]; Harmony of the Universe [1619]; Rudolphian Tables [1627]
He lived 1571 to 1630 and invented planetary-motion laws (Kepler's laws). Kepler's first law [1609] is planets move in elliptical orbits around Sun, with Sun at one ellipse focus. Kepler's second law [1609] is planets sweep out equal ellipse areas in equal times. Kepler's third law is planet period squared is proportional to average distance from Sun cubed.

Tycho Brahe [Brahe, Tycho]
astronomer
Denmark/Hamburg, Germany
1598
Mechanical Instruments of Astronomy [1598]
He lived 1546 to 1601 and accurately recorded star and planet positions.

Edmund Halley [Halley, Edmund]
astronomer
England
1682

He lived 1656 to 1742 and discovered Halley's comet [1682].

Caroline Herschel [Herschel, Caroline]
astronomer
Germany
1783 to 1797
She lived 1750 to 1848 and discovered nebulae [1783] and comets [1786 to 1797].

Harlow Shapley [Shapley, Harlow]
astronomer
USA
1911
Flights from Chaos: A Survey of Material Systems from Atoms to Galaxies [1923]; Galaxies [1943]
He lived 1885 to 1972 and measured star distances and Sun galaxy position [1911].

Otto Struve [Struve, Otto]
astronomer
Germany
1929
On the Axial Rotation of Stars [1929]
He lived 1897 to 1963 and studied star rotations.

Karl Jansky [Jansky, Karl]
astronomer
USA
1931
He lived 1905 to 1950 and started radio astronomy [1931].

Grote Reber [Reber, Grote]
astronomer
Germany
1937
He lived 1911 to 2002 and studied radio galaxies using his invention, the radio telescope [1937].

Carl Seyfert [Seyfert, Carl]
astronomer
USA
1944
He lived 1911 to 1960 and found Seyfert galaxies [1944].

Harrison Brown [Brown, Harrison]
astronomer/earth scientist
USA
1947 to 1953
He lived 1917 to 1986 and studied meteorites [1947 to 1953].

Jan Oort [Oort, Jan]
astronomer
USA
1950
He lived 1900 to 1992 and found comet belt around solar system (Oort cloud) [1950].

Walter Baade [Baade, Walter]
astronomer
Germany/USA
1952

He lived 1893 to 1960 and measured interstellar distances and studied Cepheid variable stars [1952].

Frank Low [Low, Frank]
astronomer
USA
1961
He used infrared astronomy using his germanium bolometer [1961].

Peter van de Camp [van de Camp, Peter]
astronomer
USA
1963
He lived 1901 to 1995 and found planet around Bernard's star [1963].

Jocelyn Bell [Bell, Jocelyn]
astronomer
England
1967
She lived 1943 to ? and discovered pulsars [1967].

Carl Sagan [Sagan, Carl]
astronomer
USA
1977 to 1992
Dragons of Eden [1977]; Cosmos [1980: with Ann Druyan]; Shadows of Forgotten Ancestors [1992: with Ann Druyan]
He lived 1934 to 1996.

PHYS>Astronomy>History>Ancient Astronomy

moon phases
astronomer
Egypt
-4500
Egyptian astronomers noted eclipses and Moon phases.

constellations
astronomer
Egypt/Sumer
-3000
Egyptian and Sumerian astronomers identified constellations and star motions.

planet motions
astronomer
Babylonia
-2000
Babylonian astronomers recorded Moon and Venus cycles.

Lagadha
astronomer
India
-1350
Vedic Text on Light [-1350: Vedic astronomy]
He described Sun and Moon motions.

calendar Sothis

astronomer
Egypt
-1300
Egyptian astronomers measured years by the star Sothis (Sirius).

spherical Earth
astronomer
Egypt/Babylonia
-500 to -400
spherical Earth [-500 to -400]
Aristotle wrote that Earth is spherical and people had known it for long time.

Aristarchus of Samos
astronomer
Alexandria, Egypt/Samos, Ionia
-260
He lived -310 to -250, invented heliocentric theory [-260], calculated Earth-to-Sun distance to Earth-to-Moon distance ratio from angle at half moon, found Moon distance and size from Earth shadow on Moon during lunar eclipse, and stated causes of night and day and seasons.

Hipparchus
astronomer
Greece
-134
He lived -190 to -120 and measured relative star brightness, equinox precession [-150], and Moon size from lunar-eclipse parallax [-130].

Mayan astronomers
astronomer
Copan, Mexico
776
Mayan astronomers gathered to correct their two calendars.

PHYS>Astronomy>History>Cosmology

Henrietta Swan Leavitt [Leavitt, Henrietta Swan]
astronomer
USA
1908 to 1912
She lived 1868 to 1921. Cepheid-variable brightness varies directly with logarithm of period {period-luminosity relationship} [1908 and 1912].

Ejnar Hertzsprung [Hertzsprung, Ejnar]
astronomer
Germany
1911
He lived 1873 to 1067 and studied star classification and evolution {Hertzsprung-Russell diagram} [1911].

Vesto M. Slipher [Slipher, Vesto M.]
astronomer
USA
1912
He lived 1875 to 1969, measured extra-galactic-star and galaxy spectra, discovered that most spectra were red-shifted, and calculated their recessional velocities [1912].

Henry Norris Russell [Russell, Henry Norris]

astronomer
England
1913
He lived 1877 to 1057 and studied star classification and evolution (Hertzsprung-Russell diagram) [1913].

Edwin P. Hubble [Hubble, Edwin P.]
astronomer
USA
1926 to 1929
He lived 1899 to 1953, discovered galaxies (nebula) and classified them [1926], and compared galaxy recessional velocities and distances to formulate Hubble's law [1929, with Milton L. Humason].

Georges Lemaître [Lemaître, Georges]
astronomer
Belgium/England/USA
1927 to 1931
He lived 1894 to 1966 and used general relativity to show that universe is expanding [1927], conjecturing that it began as a point (Primeval Atom) [1931].

Fritz Zwicky [Zwicky, Fritz]
astronomer
Germany
1933 to 1937
He lived 1898 to 1974. Coma-cluster galaxies move so fast that the cluster would dissipate, so there must be more mass there [1933]. Gravitational lensing can test relativity, magnify distant objects, and find missing matter [1937].

George Gamow [Gamow, George]
astronomer
USA
1937 to 1966
Mr. Tompkins in Wonderland [1937]; One Two Three ... Infinity [1950]; Thirty Years That Shook Physics [1966]
He lived 1904 to 1968, predicted microwave background radiation [1948], and calculated helium and lithium production from hydrogen just after universe origin. He expanded Big-Bang theory, with Ralph Alpher, Robert Hermann, and James Follin.

Subramanyan Chandrasekhar [Chandrasekhar, Subramanyan]
astronomer
India
1939 to 1987
Introduction to the Study of Stellar Structures [1939]; Truth and Beauty: Aesthetics and Motivations in Science [1987]
He lived 1911 to 1995 and stated mass limit for making neutron star instead of white-dwarf star, 1.4 times solar mass (Chandrasekhar limit).

Margaret Burbridge [Burbridge, Margaret]
astronomer
USA
1957
She lived 1919 to ? and demonstrated how red giant stars can make carbon, oxygen, and iron [1957: with Geoffrey Burbridge, William Fowler, and Fred Hoyle].

Fred Hoyle [Hoyle, Fred]
astronomer
England
1959
Black Cloud [1959: Organic molecules in cloud can have metabolism]

He lived 1915 to 2001, propounded universe steady-state theory, and demonstrated how red-giant stars can make carbon, oxygen, and iron [1957: with Geoffrey Burbridge, William Fowler, and Margaret Burbridge].

Chia-Chiao Lin [Lin, Chia-Chiao]/Frank Shu [Shu, Frank]
astronomer
USA
1960 to 1970
Galaxy bars and spirals are compressions in star galactic waves.

Thomas Gold [Gold, Thomas]
astronomer
USA
1962 to 1999
Deep Hot Biosphere [1999]
He lived 1920 to 2004 and propounded universe steady-state theory {time-symmetric universe}. He suggested that oil came to early Earth from space.

Arno Penzias [Penzias, Arno]/Robert Woodrow Wilson [Wilson, Robert Woodrow]
astronomer
USA
1965
Penzias lived 1933 to ?. Wilson lived 1936 to ?. They discovered cosmic background radiation as uniform space black-body microwave noise, with temperature 3 K [1965].

Allan Sandage [Sandage, Allan]
astronomer
USA
1969
He lived 1926 to ?. Hubble constant is decreasing [1969].

Joseph Weber [Weber, Joseph]
astronomer
USA
1969
He lived 1919 to 2000 and found gravity waves [1969].

Vera Cooper Rubin [Rubin, Vera Cooper]
astronomer
USA
1973
She lived 1928 to ?. Milky-Way-Galaxy star (and gas) rotation rate is faster than expected if all mass is visible matter, implying invisible matter [1973].

Andrei Linde [Linde, Andrei]
astronomer
USA
1986
He lived 1948 to ?. Inflation never stops, because quantum fluctuations can randomly continue or stop (chaotic inflation) [1986], making many separate universes with different physical laws.

Martin Rees [Rees, Martin]
astronomer
England
1997 to 2001
Before the Beginning [1997]; Just Six Numbers [1999]; Our Cosmic Habitat [2001]
He lived 1942 to ? and studied pre-big-bang theories.

Saul Perlmutter [Perlmutter, Saul]
astronomer
USA
1998
He showed that universe is expanding faster, not slowing, and hypothesized different energy type (dark energy) as cause [1998].

Brian Schmidt [Schmidt, Brian]
astronomer
Australia
1998
He showed that universe is expanding faster, not slowing, and hypothesized different energy type (dark energy) as cause [1998].

Fred C. Adams [Adams, Fred C.]
astronomer
England
2002
Our Living Multiverse [2002]
Our universe is one of many universes (multiverse), with different physical parameters.

PHYS>Astronomy>History>Invention

Christiaan Huygens [Huygens, Christiaan]
astronomer/mathematician/physicist/inventor
Netherlands
1656 to 1675
pendulum clock [1656]; spiral balance spring for clocks [1675]
He lived 1629 to 1695 and saw Venus clouds, Saturn rings, and Jupiter red spot. He invented a light-wave theory using Huygen's principle and contributed to calculus. He improved clocks {spiral balance spring}.

Nicolas Cassegrain [Cassegrain, Nicolas]
astronomer/inventor
France
1672
reflector telescope [1672]
He lived 1625 to 1712 and invented two-mirror reflector telescope.

Bernhard Schmidt [Schmidt, Bernhard]
astronomer/inventor
Estonia/Germany
1931
Schmidt telescope [1931]
He lived 1879 to 1935 and invented Schmidt telescope [1931].

PHYS>Astronomy>History>Star Catalogers

John Flamsteed [Flamsteed, John]
astronomer
London, England
1729
Celestial Atlas [1729]
He lived 1646 to 1719 and found 300 star positions.

Charles Messier [Messier, Charles]

astronomer
Paris, France
1771 to 1784
Catalog of Nebulae and Star Clusters [1771 to 1784]
He lived 1730 to 1817 and published a star catalog [1771 to 1784].

William Herschel [Herschel, William]
astronomer/chemist
London, England
1773 to 1781
Catalogue of One Thousand New Nebulae and Clusters of Stars [1782 to 1802]
He lived 1738 to 1822, studied infrared light [1773 to 1781], first saw Uranus [1781], and published a star catalog [1782 to 1802]. Solar system is moving through space [1783].

Friedrich Argelander [Argelander, Friedrich]
astronomer
Germany
1862
Bonner Survey [1862]
He lived 1799 to 1875 and found 300,000 star positions.

Annie Jump Cannon [Cannon, Annie Jump]
astronomer
USA
1911 to 1914
Henry Draper Catalog [1914]
She lived 1863 to 1941, cataloged many stars, and invented star spectral classification system: O, B, A, F, G, K, and M.

Bernard Lovell [Lovell, Bernard]
astronomer
England
1957
He lived 1913 to ? and used radio astronomy at Jodrell Bank [1957].