

COSMOLOGY FOR DUMMIES EXPLAINED

COSMOLOGY FOR DUMMIES EXPLAINED: UNRAVELING THE UNIVERSE'S GRANDEST MYSTERIES

COSMOLOGY FOR DUMMIES EXPLAINED UNVEILS THE BREATHTAKING SCOPE OF THE UNIVERSE, FROM ITS FIERY BIRTH TO ITS ULTIMATE FATE. HAVE YOU EVER GAZED AT THE NIGHT SKY AND WONDERED ABOUT THE IMMENSE SCALE AND INTRICATE WORKINGS OF EVERYTHING AROUND US? THIS ARTICLE IS YOUR FRIENDLY GUIDE TO UNDERSTANDING THE FUNDAMENTAL CONCEPTS OF COSMOLOGY, THE SCIENTIFIC STUDY OF THE UNIVERSE AS A WHOLE. WE'LL EMBARK ON A JOURNEY THROUGH TIME AND SPACE, EXPLORING THE BIG BANG, THE EXPANSION OF THE COSMOS, THE ENIGMATIC NATURE OF DARK MATTER AND DARK ENERGY, AND THE ONGOING QUEST TO COMPREHEND OUR PLACE WITHIN THIS VAST COSMIC TAPESTRY. GET READY TO HAVE YOUR MIND EXPANDED AS WE DEMYSTIFY THE MOST PROFOUND QUESTIONS ABOUT EXISTENCE.

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WHAT IS COSMOLOGY?

COSMOLOGY, AT ITS HEART, IS THE SCIENCE DEDICATED TO UNDERSTANDING THE UNIVERSE IN ITS ENTIRETY. IT'S NOT JUST ABOUT LOOKING AT STARS AND PLANETS THROUGH A TELESCOPE; IT'S ABOUT PIECING TOGETHER THE GRAND NARRATIVE OF COSMIC EXISTENCE. THIS INVOLVES STUDYING THE ORIGIN, EVOLUTION, STRUCTURE, AND ULTIMATE DESTINY OF THE COSMOS. COSMOLOGISTS ASK THE REALLY BIG QUESTIONS: HOW DID EVERYTHING BEGIN? HOW HAS IT CHANGED OVER BILLIONS OF YEARS? WHAT ARE THE FUNDAMENTAL LAWS THAT GOVERN ITS BEHAVIOR? AND WHAT WILL BECOME OF IT ALL IN THE UNIMAGINABLY DISTANT FUTURE?

THINK OF COSMOLOGY AS THE ULTIMATE DETECTIVE STORY, WHERE THE UNIVERSE ITSELF IS THE CRIME SCENE, AND THE CLUES ARE SCATTERED ACROSS VAST DISTANCES AND BILLIONS OF YEARS. SCIENTISTS USE A BLEND OF OBSERVATION, THEORETICAL PHYSICS, AND SOPHISTICATED MATHEMATICAL MODELS TO RECONSTRUCT THE COSMIC PAST AND PREDICT ITS FUTURE. IT'S A FIELD THAT CONSTANTLY PUSHES THE BOUNDARIES OF HUMAN KNOWLEDGE, FORCING US TO CONFRONT OUR OWN INSIGNIFICANCE AND OUR PROFOUND CONNECTION TO EVERYTHING THAT EXISTS.

THE BIG BANG THEORY: THE UNIVERSE'S EXPLOSIVE BEGINNING

THE PREVAILING SCIENTIFIC MODEL FOR THE UNIVERSE'S ORIGIN IS THE BIG BANG THEORY. THIS ISN'T AN EXPLOSION IN SPACE, BUT RATHER AN EXPANSION OF SPACE ITSELF. APPROXIMATELY 13.8 BILLION YEARS AGO, THE ENTIRE OBSERVABLE UNIVERSE WAS CONCENTRATED INTO AN INCREDIBLY HOT, DENSE POINT. THEN, FOR REASONS STILL BEING EXPLORED, THIS POINT BEGAN TO EXPAND RAPIDLY, A PROCESS THAT CONTINUES TO THIS DAY. AS THE UNIVERSE EXPANDED, IT COOLED, ALLOWING FUNDAMENTAL PARTICLES TO FORM, THEN ATOMS, AND EVENTUALLY THE STARS AND GALAXIES WE OBSERVE TODAY.

IT'S CRUCIAL TO UNDERSTAND THAT THE BIG BANG WASN'T AN EVENT THAT HAPPENED SOMEWHERE. IT HAPPENED EVERYWHERE. IMAGINE THE SURFACE OF AN EXPANDING BALLOON; EVERY POINT ON THE SURFACE IS MOVING AWAY FROM EVERY OTHER POINT. SIMILARLY, AS SPACE ITSELF STRETCHED, GALAXIES MOVED APART, CREATING THE VAST COSMIC DISTANCES WE SEE. THE BIG BANG THEORY IS SUPPORTED BY A WEALTH OF OBSERVATIONAL EVIDENCE, MAKING IT THE CORNERSTONE OF MODERN COSMOLOGY.

EVIDENCE FOR THE BIG BANG

THE PRIMARY Pillars supporting the Big Bang theory are compelling. Firstly, there's the observed recession of galaxies, which we'll discuss more shortly. Secondly, the existence of the cosmic microwave background radiation, a faint afterglow of the Big Bang, is a direct prediction of the theory. Finally, the abundance of light elements like hydrogen and helium in the universe aligns perfectly with the predicted proportions formed during the early hot, dense phase of the cosmos.

THE EXPANDING UNIVERSE: EVIDENCE AND IMPLICATIONS

ONE OF THE MOST PROFOUND discoveries in cosmology is that the universe is not static but is continuously expanding. This means that galaxies are, on average, moving away from each other. The further away a galaxy is, the faster it appears to be receding. This observation, first made by Edwin Hubble, is the bedrock of our understanding of cosmic evolution.

IMAGINE BAKING a raisin bread loaf. As the dough rises, the raisins (representing galaxies) move further apart from each other. The raisins that are already further apart will move away from each other at a greater speed than those that are closer. This analogy, while simplified, captures the essence of cosmic expansion – space itself is stretching, carrying galaxies along with it.

HUBBLE'S LAW AND REDSHIFT

THE EVIDENCE for cosmic expansion comes primarily from the phenomenon known as redshift. When light from distant galaxies is analyzed, its spectrum is shifted towards the red end. This redshift is analogous to the Doppler effect for sound: as a sound source moves away from an observer, its pitch lowers. Similarly, as a light source moves away, the wavelengths of its light are stretched, appearing redder. Hubble's Law quantifies this relationship, stating that the recessional velocity of a galaxy is directly proportional to its distance.

THE IMPLICATIONS of an expanding universe are immense. It suggests a finite age for the universe and points towards a time when everything was much closer together, leading directly to the Big Bang model. It also raises questions about the rate of expansion and how it might have changed over cosmic history.

THE COSMIC MICROWAVE BACKGROUND RADIATION: A SNAPSHOT OF THE EARLY UNIVERSE

THE COSMIC MICROWAVE BACKGROUND (CMB) radiation is arguably the most compelling piece of evidence for the Big Bang theory. It's a faint, uniform glow of microwave radiation that pervades the entire universe. This radiation is essentially the leftover heat from the Big Bang, dating back to about 380,000 years after the initial expansion began.

IN THE EARLY universe, it was so hot and dense that light couldn't travel freely; it was constantly scattering off charged particles. As the universe expanded and cooled, it eventually reached a point where electrons and protons could combine to form neutral atoms. This event, known as recombination, allowed photons (light particles) to travel unimpeded for the first time. The CMB is the fossilized light from this pivotal moment, stretched by billions of years of cosmic expansion into the microwave spectrum we detect today.

ANISOTROPIES IN THE CMB

WHILE THE CMB APPEARS REMARKABLY UNIFORM, HIGHLY SENSITIVE INSTRUMENTS HAVE DETECTED TINY TEMPERATURE FLUCTUATIONS, OR ANISOTROPIES, WITHIN IT. THESE SUBTLE VARIATIONS, ON THE ORDER OF PARTS PER HUNDRED THOUSAND, ARE INCREDIBLY IMPORTANT. THEY REPRESENT THE SEEDS OF COSMIC STRUCTURE – THE SLIGHT OVERDENSITIES AND UNDERDENSITIES IN THE EARLY UNIVERSE THAT, OVER EONS, GREW DUE TO GRAVITY TO FORM THE GALAXIES, CLUSTERS, AND SUPERCLUSTERS WE OBSERVE TODAY. STUDYING THESE ANISOTROPIES ALLOWS COSMOLOGISTS TO PRECISELY DETERMINE PARAMETERS LIKE THE AGE, COMPOSITION, AND GEOMETRY OF THE UNIVERSE.

DARK MATTER AND DARK ENERGY: THE UNIVERSE'S HIDDEN INGREDIENTS

AS OUR UNDERSTANDING OF THE UNIVERSE HAS DEEPENED, WE'VE REALIZED THAT THE VISIBLE MATTER – STARS, PLANETS, GAS, AND DUST – CONSTITUTES ONLY A SMALL FRACTION OF ITS TOTAL CONTENT. THE MAJORITY IS MADE UP OF MYSTERIOUS SUBSTANCES KNOWN AS DARK MATTER AND DARK ENERGY. THESE ARE "DARK" BECAUSE THEY DON'T INTERACT WITH LIGHT, MAKING THEM INVISIBLE TO OUR TELESCOPES AND DIFFICULT TO DETECT DIRECTLY.

DARK MATTER IS AN INVISIBLE FORM OF MATTER THAT EXERTS GRAVITATIONAL INFLUENCE. WE INFER ITS PRESENCE BECAUSE THE GRAVITATIONAL PULL REQUIRED TO HOLD GALAXIES AND GALAXY CLUSTERS TOGETHER IS FAR GREATER THAN WHAT CAN BE ACCOUNTED FOR BY VISIBLE MATTER ALONE. IT'S LIKE A COSMIC GLUE, HOLDING THE LARGE-SCALE STRUCTURES OF THE UNIVERSE IN PLACE. DARK ENERGY, ON THE OTHER HAND, IS AN EVEN MORE ENIGMATIC FORCE THAT IS DRIVING THE ACCELERATED EXPANSION OF THE UNIVERSE.

THE MYSTERY OF DARK ENERGY

THE DISCOVERY THAT THE UNIVERSE'S EXPANSION IS ACCELERATING, RATHER THAN SLOWING DOWN DUE TO GRAVITY AS EXPECTED, WAS A MAJOR SURPRISE IN COSMOLOGY. THIS ACCELERATION IS ATTRIBUTED TO DARK ENERGY, A HYPOTHETICAL FORM OF ENERGY THAT PERMEATES ALL OF SPACE AND EXERTS A REPULSIVE FORCE. WHILE ITS PRECISE NATURE REMAINS UNKNOWN, IT IS THOUGHT TO CONSTITUTE ABOUT 68% OF THE TOTAL ENERGY DENSITY OF THE UNIVERSE. UNDERSTANDING DARK ENERGY IS ONE OF THE MOST PRESSING CHALLENGES IN MODERN PHYSICS, WITH PROFOUND IMPLICATIONS FOR THE FUTURE OF THE COSMOS.

- DARK MATTER: ESTIMATED TO BE ABOUT 27% OF THE UNIVERSE'S MASS-ENERGY.
- DARK ENERGY: ESTIMATED TO BE ABOUT 68% OF THE UNIVERSE'S MASS-ENERGY.
- ORDINARY MATTER: ONLY ABOUT 5% OF THE UNIVERSE'S MASS-ENERGY.

THE STRUCTURE OF THE UNIVERSE: FROM GALAXIES TO COSMIC WEB

WHEN WE LOOK OUT INTO THE NIGHT SKY, WE SEE INDIVIDUAL STARS AND GALAXIES. HOWEVER, ON THE LARGEST SCALES, THE UNIVERSE IS NOT UNIFORMLY DISTRIBUTED BUT IS ORGANIZED INTO AN INTRICATE, FILAMENTARY STRUCTURE KNOWN AS THE COSMIC WEB. THIS WEB CONSISTS OF VAST, EMPTY VOIDS SEPARATED BY IMMENSE WALLS AND FILAMENTS OF GALAXIES AND GALAXY CLUSTERS.

GALAXIES THEMSELVES ARE NOT ISOLATED ENTITIES BUT ARE OFTEN FOUND IN GROUPS AND CLUSTERS. THESE CLUSTERS, IN TURN, ARE PART OF EVEN LARGER SUPERCLUSTERS. THE GRAVITATIONAL INTERACTIONS BETWEEN MATTER, GUIDED BY THE

INITIAL DENSITY FLUCTUATIONS SEEN IN THE CMB, HAVE SCULPTED THIS GRAND COSMIC ARCHITECTURE OVER BILLIONS OF YEARS. THE COSMIC WEB IS A TESTAMENT TO THE POWER OF GRAVITY AND THE SLOW, STEADY MARCH OF COSMIC EVOLUTION.

GALAXY FORMATION AND EVOLUTION

THE FORMATION OF GALAXIES IS A COMPLEX PROCESS THAT BEGINS WITH THE GRAVITATIONAL COLLAPSE OF OVERDENSE REGIONS IN THE EARLY UNIVERSE. THESE COLLAPSING CLOUDS OF GAS AND DARK MATTER EVENTUALLY FRAGMENT, IGNITING STAR FORMATION AND LEADING TO THE BIRTH OF PROTOGALAXIES. OVER TIME, THESE PROTOGALAXIES MERGE AND INTERACT, GROWING INTO THE DIVERSE ARRAY OF GALAXIES WE SEE TODAY – FROM ELEGANT SPIRAL GALAXIES LIKE OUR OWN MILKY WAY TO MASSIVE ELLIPTICAL GALAXIES. UNDERSTANDING THE DETAILED PROCESSES OF GALAXY FORMATION AND EVOLUTION IS A KEY AREA OF ONGOING COSMOLOGICAL RESEARCH.

THE FATE OF THE UNIVERSE: POSSIBLE END SCENARIOS

THE ULTIMATE FATE OF THE UNIVERSE IS A QUESTION THAT HAS CAPTIVATED SCIENTISTS AND PHILOSOPHERS FOR CENTURIES. BASED ON OUR CURRENT UNDERSTANDING, PARTICULARLY THE INFLUENCE OF DARK ENERGY, SEVERAL SCENARIOS ARE POSSIBLE, THOUGH ONE SEEMS MOST LIKELY GIVEN THE OBSERVED ACCELERATED EXPANSION.

IF THE AMOUNT OF DARK ENERGY REMAINS CONSTANT OR INCREASES, THE UNIVERSE WILL LIKELY CONTINUE TO EXPAND AT AN ACCELERATING RATE INDEFINITELY. THIS SCENARIO, SOMETIMES CALLED THE “BIG FREEZE” OR “HEAT DEATH,” WOULD LEAD TO A UNIVERSE THAT BECOMES INCREASINGLY COLD, DARK, AND EMPTY AS GALAXIES DRIFT FURTHER APART, STARS EVENTUALLY BURN OUT, AND EVEN BLACK HOLES EVAPORATE OVER UNIMAGINABLE TIMESCALES. HOWEVER, IF THE NATURE OF DARK ENERGY WERE TO CHANGE, OTHER FATES COULD EMERGE.

THE BIG RIP AND THE BIG CRUNCH

ANOTHER THEORETICAL POSSIBILITY IS THE “BIG RIP.” IF DARK ENERGY WERE TO GROW IN STRENGTH OVER TIME, IT COULD EVENTUALLY BECOME SO POWERFUL THAT IT OVERCOMES ALL FUNDAMENTAL FORCES, TEARING APART GALAXIES, STARS, PLANETS, AND EVEN ATOMS THEMSELVES. CONVERSELY, IF DARK ENERGY WERE TO WEAKEN OR DISAPPEAR, AND IF THE UNIVERSE CONTAINED ENOUGH MASS, GRAVITY COULD EVENTUALLY HALT THE EXPANSION AND CAUSE THE UNIVERSE TO COLLAPSE BACK IN ON ITSELF IN A “BIG CRUNCH,” POTENTIALLY LEADING TO ANOTHER BIG BANG IN A CYCLICAL UNIVERSE MODEL. HOWEVER, CURRENT OBSERVATIONAL EVIDENCE STRONGLY FAVORS THE BIG FREEZE SCENARIO.

- BIG FREEZE: THE MOST LIKELY SCENARIO, LEADING TO A COLD, DARK, AND EMPTY UNIVERSE.
- BIG RIP: A THEORETICAL SCENARIO WHERE DARK ENERGY TEARS EVERYTHING APART.
- BIG CRUNCH: A SCENARIO WHERE THE UNIVERSE COLLAPSES BACK ON ITSELF.

CURRENT FRONTIERS IN COSMOLOGICAL RESEARCH

COSMOLOGY IS A DYNAMIC AND RAPIDLY EVOLVING FIELD, WITH SCIENTISTS CONSTANTLY PUSHING THE BOUNDARIES OF OUR KNOWLEDGE. NEW TELESCOPES AND OBSERVATIONAL TECHNIQUES ARE PROVIDING UNPRECEDENTED DATA, ALLOWING US TO PROBE DEEPER INTO THE UNIVERSE’S PAST AND WITH GREATER PRECISION. AREAS OF INTENSE RESEARCH INCLUDE:

- UNDERSTANDING THE FUNDAMENTAL NATURE OF DARK MATTER AND DARK ENERGY.
- INVESTIGATING THE VERY EARLIEST MOMENTS AFTER THE BIG BANG, PERHAPS EVEN BEFORE INFLATION.
- SEARCHING FOR EVIDENCE OF OTHER UNIVERSES (THE MULTIVERSE HYPOTHESIS).
- REFINING OUR MEASUREMENTS OF COSMIC EXPANSION AND ITS HISTORY.
- EXPLORING THE ROLE OF QUANTUM MECHANICS IN THE EARLY UNIVERSE.

THE QUEST TO UNDERSTAND THE COSMOS IS A JOURNEY OF CONTINUOUS DISCOVERY. EACH NEW FINDING OPENS UP MORE QUESTIONS, DRIVING FURTHER EXPLORATION AND INNOVATION. THE FUNDAMENTAL QUESTIONS ABOUT OUR ORIGINS AND OUR PLACE IN THE UNIVERSE CONTINUE TO INSPIRE AWE AND FUEL SCIENTIFIC INQUIRY, PROMISING EXCITING REVELATIONS FOR GENERATIONS TO COME.

THE SEARCH FOR EXTRATERRESTRIAL LIFE

WHILE NOT STRICTLY WITHIN THE DOMAIN OF COSMOLOGY, THE STUDY OF EXOPLANETS AND THE CONDITIONS NECESSARY FOR LIFE ARE DEEPLY INTERTWINED WITH OUR UNDERSTANDING OF THE UNIVERSE. COSMOLOGISTS PROVIDE THE FRAMEWORK FOR UNDERSTANDING THE COSMIC ENVIRONMENTS WHERE LIFE MIGHT ARISE, AND THE SHEER SCALE OF THE UNIVERSE SUGGESTS THAT THE POSSIBILITY OF LIFE ELSEWHERE IS NOT JUST SCIENCE FICTION, BUT A PLAUSIBLE OUTCOME OF COSMIC EVOLUTION.

GRAVITATIONAL WAVES: A NEW WINDOW ON THE UNIVERSE

THE DIRECT DETECTION OF GRAVITATIONAL WAVES HAS OPENED UP AN ENTIRELY NEW WAY TO OBSERVE THE UNIVERSE. THESE RIPPLES IN SPACETIME, PREDICTED BY EINSTEIN, ARE GENERATED BY CATAclysmic EVENTS LIKE THE MERGER OF BLACK HOLES AND NEUTRON STARS. BY STUDYING GRAVITATIONAL WAVES, COSMOLOGISTS CAN PROBE PHENOMENA THAT ARE INVISIBLE TO ELECTROMAGNETIC RADIATION, PROVIDING UNIQUE INSIGHTS INTO SOME OF THE MOST EXTREME AND ENERGETIC PROCESSES IN THE COSMOS AND OFFERING COMPLEMENTARY DATA FOR COSMOLOGICAL MODELS.

FAQ: COSMOLOGY FOR DUMMIES EXPLAINED

Q: WHAT IS THE SIMPLEST WAY TO UNDERSTAND THE BIG BANG?

A: THE BIG BANG IS BEST UNDERSTOOD NOT AS AN EXPLOSION IN SPACE, BUT AS THE RAPID EXPANSION OF SPACE ITSELF, STARTING FROM AN EXTREMELY HOT AND DENSE STATE ABOUT 13.8 BILLION YEARS AGO. EVERYTHING IN THE UNIVERSE BEGAN EXPANDING FROM THIS INITIAL POINT.

Q: IF THE UNIVERSE IS EXPANDING, WHAT IS IT EXPANDING INTO?

A: THIS IS A COMMON MISCONCEPTION. THE UNIVERSE IS NOT EXPANDING INTO ANYTHING. SPACE ITSELF IS STRETCHING. THINK OF IT LIKE THE SURFACE OF A BALLOON BEING INFLATED; THE SURFACE GETS LARGER, BUT IT'S NOT EXPANDING INTO AN EXTERNAL SPACE. ALL OF SPACE IS INCREASING IN VOLUME.

Q: HOW DO SCIENTISTS KNOW ABOUT DARK MATTER IF THEY CAN'T SEE IT?

A: SCIENTISTS INFER THE EXISTENCE OF DARK MATTER BY OBSERVING ITS GRAVITATIONAL EFFECTS ON VISIBLE MATTER. GALAXIES ROTATE FASTER THAN THEY SHOULD BASED ON THEIR VISIBLE MASS, AND GALAXY CLUSTERS ARE HELD TOGETHER MORE STRONGLY THAN EXPECTED. THESE OBSERVATIONS SUGGEST AN UNSEEN MASS – DARK MATTER – IS PROVIDING THE EXTRA GRAVITATIONAL PULL.

Q: WHAT IS THE DIFFERENCE BETWEEN DARK MATTER AND DARK ENERGY?

A: DARK MATTER IS A FORM OF MATTER THAT EXERTS A GRAVITATIONAL PULL, HOLDING STRUCTURES LIKE GALAXIES TOGETHER. DARK ENERGY, ON THE OTHER HAND, IS A MYSTERIOUS FORCE THAT CAUSES THE UNIVERSE'S EXPANSION TO ACCELERATE, ACTING AS A KIND OF ANTI-GRAVITY.

Q: IS THE BIG BANG THE ABSOLUTE BEGINNING OF EVERYTHING?

A: ACCORDING TO THE STANDARD BIG BANG MODEL, IT MARKS THE BEGINNING OF OUR OBSERVABLE UNIVERSE AND THE LAWS OF PHYSICS AS WE KNOW THEM. HOWEVER, THERE ARE THEORETICAL IDEAS, SUCH AS THE CONCEPT OF AN INFLATIONARY EPOCH PRECEDING THE BIG BANG OR CYCLICAL UNIVERSE MODELS, THAT EXPLORE POSSIBILITIES FOR WHAT MIGHT HAVE EXISTED "BEFORE" OR COULD LEAD TO FUTURE COSMIC CYCLES.

Q: WHAT IS THE COSMIC MICROWAVE BACKGROUND RADIATION?

A: THE CMB IS THE FAINT AFTERGLOW OF THE BIG BANG, A UNIFORM BATH OF MICROWAVE RADIATION THAT FILLS THE UNIVERSE. IT'S ESSENTIALLY THE OLDEST LIGHT WE CAN DETECT, PROVIDING A SNAPSHOT OF THE UNIVERSE WHEN IT WAS ONLY ABOUT 380,000 YEARS OLD.

Q: COULD THE UNIVERSE COLLAPSE AT SOME POINT?

A: WHILE A SCENARIO CALLED THE "BIG CRUNCH" IS THEORETICALLY POSSIBLE, CURRENT OBSERVATIONS OF THE ACCELERATED EXPANSION DRIVEN BY DARK ENERGY MAKE THIS OUTCOME UNLIKELY. THE MOST FAVORED SCENARIO IS THE "BIG FREEZE" OR "HEAT DEATH," WHERE THE UNIVERSE CONTINUES TO EXPAND AND COOL INDEFINITELY.

Q: WHAT ARE THE BIGGEST UNANSWERED QUESTIONS IN COSMOLOGY TODAY?

A: SOME OF THE BIGGEST MYSTERIES INCLUDE THE EXACT NATURE OF DARK MATTER AND DARK ENERGY, THE REASON FOR THE UNIVERSE'S ACCELERATED EXPANSION, WHETHER THERE ARE OTHER UNIVERSES (THE MULTIVERSE), AND WHAT HAPPENED IN THE VERY FIRST MOMENTS AFTER THE BIG BANG.

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