



Whether it's a ball rocketing toward the net or a star shooting across the cosmos, both soccer and space are full of incredible motion, energy, and force. We can examine the spin of a curving free kick or the spin of a black hole. The collision between players mirrors the collisions between galaxy clusters.

Cosmic Pitch takes the world's most popular sport and connects it to the universal language of physics—showing how the same scientific principles that shape the "beautiful game" also govern our Universe itself.

As the world gears up for the World Cup, **Cosmic Pitch** invites players, fans, and explorers alike to see how every match on Earth reflects the science of the skies. Let's connect to the Universe: one kick, one curve, or one collision at a time.



To understand the physics of the Universe, NASA scientists look beyond what the human eye can see. Just as a coach uses different camera angles and data to track a player's performance, astronomers use a fleet of "Great Observatories" and more tools to capture the Universe in different types of light.

High-energy X-ray data from **NASA's Chandra X-ray Observatory**, as well as **ESA's XMM-Newton**, reveal the extreme physics of the cosmos—such as the 10-million-mph blast waves of supernova remnants or the frantic spin of pulsars. By combining these X-ray action shots with infrared views from the **James Webb Space Telescope** and **Spitzer Space Telescope**, and the visible light clarity of the **Hubble Space Telescope** along with ground-based optical telescopes, we get a more complete picture of cosmic motion.

This project also utilizes data from the **Solar Dynamics Observatory (SDO)** to study our Sun, the **Dawn mission** to explore asteroids, and ground-based **radio telescopes from the NSF** to track high-speed galactic jets. No matter if the action is on the pitch or in a distant galaxy, the laws of physics are the ultimate playbook.



Distance: Defining the Scale

Distance is the total length covered between two points. From the dimensions of a pitch to the diameter of a planet, distance defines the scale of every journey. On the field, a FIFA soccer field is about 110–120 yards (100–110 meters) long. To put that in perspective, to run a single mile, an athlete would have to complete approximately five-and-a-half laps around a professional soccer field. During an average match, a top professional female player, such as Spain's Aitana Bonmatí, can cover nearly 6 miles (nearly 10 kilometers) of ground.

In space, we often measure distance using the speed of light. Light travels about 650 million miles per hour (300,000 kilometers every second). Our Sun, the nearest star, is about **93 million miles** (150 million km) away. It takes light about **8 minutes** to cover that gap and reach Earth. This is one of the cosmic distances that sets the rhythm for life, seasons, and the scale of our solar system.

Speed: The Heartbeat of Motion

Speed is the measurement of distance traveled over a certain period of time. It is the pulse of both sport and space. A soccer ball struck by some of the world's best players can reach speeds of **70 to 100 mph** (110–160 kph), which is faster than a car driving down a highway.

In the cosmos, things move significantly faster. In the active galaxy **Hercules A**, for example, a supermassive black hole powers enormous jets of particles. These jets, captured through the combined telescopic eyes of **Chandra, Hubble, and the Very Large Array (VLA)**, heat vast clouds of X-ray-emitting gas as they move at hundreds of millions of kilometers per hour. Stretching nearly a million light-years across space, these jets demonstrate how speed can reshape an entire galaxy.

Acceleration: Powering Transformation

Acceleration is defined as the change of speed, or velocity, of an object over time. The change in speed allows the difference between a jog and a sprint. A top athlete can accelerate from standing still to a full sprint in less than **two seconds**—a rate of about 5 m/s².

In the Universe, acceleration drives far grander feats. In **Tycho's Supernova Remnant**, a violent explosion accelerated stellar debris at much higher rates than that of an athlete. This event created a powerful blast wave, captured in X-ray light by Chandra, that continued to accelerate until it reached about **10 million mph** (16 million kph). This acceleration powered the transformation of the remains of the star into the raw materials for future planets.

Time: Fractions of a Second to Eons

In soccer, time isn't just measured in the 90 minutes of a match—it can come down to fractions of a second. In one of the most remarkable saves in modern soccer, a goalkeeper reacted to a shot moving 190 kph in just 0.2 seconds or even faster. In that instant, the athlete processed speed and direction and moves into place faster than a blink of an eye.

In space, time operates in equally dramatic ways across an astonishing range of scales. For example, **Chandra** captures the intense, high-energy events like X-ray bursts from neutron stars that unfold in mere milliseconds – less time than the blink of an eye. Meanwhile, the **Pillars of Creation** (captured by Webb and Hubble) show giant columns of gas where stars take millions of years to form. Our own Sun has shone for 4.6 billion years and the Universe itself is estimated to 13.2 billion years old.

These timescales—ranging from fractions of a second to billions of years—remind us that every moment matters, whether it's a telescope catching a brief flash of high-energy light from across the Universe or a goalkeeper making a split-second save on the field.

Kicks: The Transfer of Energy

A "kick" occurs when a short-duration impact from one object to another causes a transfer of energy, leading to acceleration and motion. While we are familiar with a foot striking a ball on the field at **100 mph**, there are "cosmic kicks" that move entire stars.

These include stars that collapse and send themselves hurtling into space. For example, in **Puppis A**, a neutron star was "kicked" into space during the explosion of a massive star. Data from **Chandra**, **XMM-Newton**, and ground-based optical telescopes allow scientists to track this motion. These observations show that the explosion, which wasn't perfectly even in every direction, sent the neutron star traveling through space with an initial velocity of over 1.1 million mph.

A star like **Zeta Ophiuchi** can be kicked from its birthplace when a nearby star exploded, sending Zeta Ophiuchi hurtling through space like a cosmic runaway. Observations from the **Spitzer** reveal the dramatic bow shock created by this careening star -- much like the wake created by a player sprinting across a damp pitch -- while **Chandra** data captures the high-energy X-ray emission from the star itself as it races through the cosmos.

Spin: Giving Motion a Signature

Spin is defined as the motion of an object turning around a central axis. Rotational speed is measured as the number of turns an object completes over a given time—commonly calculated in revolutions per minute (RPM) or cycles per second (Hertz). Spin, or rotation, is important whether it is of a ball on the pitch or a twisting pulsar in deep space.

On the field, professional soccer players can make the ball spin between 8 and 12 revolutions per second (**up to 720 RPM**). When players curve the ball with this intense spin, air pressure differences cause it to bend through its flight—a beautiful display of physics in action.

In the cosmos, spin drives entire worlds: planets rotate, stars whirl, and neutron stars can spin hundreds of times per second. A striking example is found in the nebula **MSH 15-52**, which is powered by a neutron star (called a pulsar) spinning at about seven times every second. This rapid rotation, captured by **Chandra**, drives energetic particles outward to create a spectacular hand-shaped nebula stretching across 150 light-years of space. From the stadium to the stars, the physics of rotation governs how objects interact with the environment around them.

Collisions: Titanic Impact

A collision is when two or more moving objects come into contact and exchange forces for a brief period. On the pitch, a collision between two players moving at top speeds can generate about 8,000 Joules **of energy**—enough to lift a 23-ton block several inches.

In space, the stakes of these collisions are much higher. The asteroid **Vesta** (image captured by the **Dawn** mission) bears scars of ancient high-speed impacts that reshaped its surface. If an asteroid just 6 miles across struck Earth, it would generate over 100 billion trillion Joules of energy. On the largest scales, we see galaxy clusters—the largest structures in the Universe—collide in spectacular mergers that release more energy than anything since the Big Bang itself.

Bonus: Density & Pressure, The Cosmic Balancing Act

The nature of an object is defined by its density—its mass divided by its volume—and the internal pressure that holds its shape. A soccer ball depends on perfect internal pressure (8.5–15.6 psi) to bounce and soar. The average density of a regulation size 5 soccer ball is about **78 kg/m³**, giving it just the right "feel": light enough to fly, yet dense enough to control. To understand why this specific density matters, consider water, which has a density of about **1,000 kg/m³**. If a soccer ball were as dense as water, it would weigh about **12.5 lbs (5.7 kg)**—making it a very dangerous object to kick!

In the cosmos, density and pressure perform a similar balancing act on an astronomical scale. For billions of years, a star stays stable because the outward pressure from its nuclear furnace balances the inward crush of gravity. When that balance breaks, the results are spectacular. In the supernova remnant **N132D**, the collapse of a massive star triggered an explosion. This sent shock waves slamming into surrounding gas at millions of miles per hour, creating sudden, extreme jumps in pressure and heat that reached tens of millions of degrees.

Density in space can reach even more astonishing extremes. A **white dwarf** packs a Sun's worth of mass into a space the size of Earth, while a **black hole** concentrates matter into such a small area that extremely dense gravitational forces prevent anything – including light – from escaping. On the other end of the density spectrum, the **Helix Nebula** is a dying star that has spread its mass so far across light-years of space that its density is so low that we would generally consider it a vacuum on Earth.

From the regulation ball on the pitch to the singularity of a black hole, the balance between density and pressure shapes the nature of every object in our Universe.

Final Whistle



From the field to the farthest galaxies, physical laws connect every kick, curve, and collision. Soccer and space may seem worlds apart, but both are driven by motion, energy, and balance. These are the universal rules that shape our experience, whether in a packed stadium or a cluster of stars. When we explore the physics behind the game, we can also deepen our connection to the cosmos. As we learn, we discover that the Universe plays by the same rules we do.

Featured Missions: <link to each at nasa.gov except ours and VLA>

- Chandra X-ray Observatory
- James Webb Space Telescope
- Hubble Space Telescope
- Spitzer Space Telescope
- Solar Dynamics Observatory
- Dawn Mission
- XMM-Newton (ESA)
- Very Large Array/VLA (NSF/Radio Astronomy)

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