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The Planets

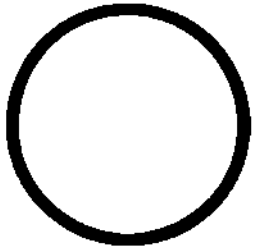
Dava Sobel

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MODEL WORLDS



My planet fetish began, as best I can recall, in third grade, at age eight – right around the time I learned the Earth had siblings in space, just as I had older brothers in high school and college. The presence of the neighbouring worlds was a revelation at once specific and mysterious in 1955, for although each planet bore a name and held a place in the Sun's family, very little was known about any of them. Pluto and Mercury, like Paris and Moscow, only better, beckoned a childish imagination to ultra-exotic utopias.

The few sure facts about the planets suggested fantastic aberrations, ranging from unbearable extremes of temperature to the warping of time. Since Mercury, for example, could circle the Sun in only eighty-eight days, compared to the Earth's 365, then a year on Mercury would whiz by in barely three months, much the way

'dog years' packed seven years of animal experience into the dog owner's one, and thereby accounted for the regrettably short lives of pets.

Every planet opened its own realm of possibility, its own version of reality. Venus purportedly hid lush swamps under its perpetual cloud cover, where oceans of oil, or possibly soda water, bathed rain forests filled with yellow and orange plant lie. And these opinions issued from serious scientists, not comic books or sensational fiction.

The limitless strangeness of the planets contrasted sharply with their small census. In fact, their nine-ness helped define them as a group. Ordinary entities came in pairs or dozens, or quantities ending in a five or a zero, but planets numbered nine and nine only. Nine, odd as outer space itself, could nevertheless be counted on the fingers. Compared to the chore of memorizing forty-eight state capitals or significant dates in the history of New York City, the planets promised mastery in an evening. Any child who committed the planets' names to memory with the help of an appealing nonsense-sentence mnemonic – 'My very educated mother just served as nine pies' – simultaneously gained their proper arrangement in progression outward from the Sun: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto.

The manageable sum of planets made them seem collectible, and motivated me to arrange them in a

shoe-box diorama for the science fair. I gathered marbles, jack balls, ping-pong balls, and the pink rubber Spaldeens we girls bounced for hours on the sidewalk, then I painted them with tempera, and hung them on pipe cleaners and string. My model (more like a doll's house than a scientific demonstration) failed to give any real sense of the planets' relative sizes or the enormous distances between them. By rights I should have used a basketball for Jupiter, to show how it dwarfed all the others, and I should have mounted everything in a giant carton from a washing machine or a refrigerator, the better to approximate the Solar System's grandiose dimensions.

Fortunately my crude diorama, produced with a complete lack of artistic skill, did not kill my beautiful visions of Saturn suspended in the perfect symmetry of its spinning rings, or the mutating patterns on the Martian landscape, which were attributed, in scientific reports of the 1950s, to seasonal cycles of vegetation.

After the science fair, my class staged a planets play. I got the part of 'Lonely Star' because the script called for that character to wear a red cape, and I had one, left over from a Hallowe'en costume. As Lonely Star, I soliloquized the Sun's wish for companionship, which the planet-actors granted by joining up with me, each in a speech admitting his own peculiarities. The play's most memorable performances were delivered by 'Saturn', who twirled two hula-hoops while reciting her

lines, and 'The Earth', plump and self-conscious, yet forced to announce matter-of-factly, 'I am twenty-four thousand miles around my middle.' Thus was the statistic of the Earth's circumference indelibly impressed upon me. (Notice we always said 'the Earth', in those days. 'The Earth' did not become 'Earth' until after I came of age and the Moon changed from a nightlight to a destination.)

My role as Lonely Star helped me appreciate the Sun's relationship to the planets as parent and guide. Not for nothing is our part of the universe called the 'Solar System', in which each planet's individual makeup and traits are shaped in large measure by proximity to the Sun.

I had omitted the Sun from my diorama because I hadn't understood its power, and besides, it would have posed an impossible problem of scale.* Another reason for leaving out the Sun, and likewise the Moon, was the bright familiarity of both objects, which seemed to render them regular components of the Earth's atmosphere, whereas the planets were glimpsed only occasionally (either before bedtime or in a still-dark, early-morning sky), and therefore more highly prized.

* In his ingenious pamphlet, 'The Thousand-Yard Model, or, The Earth as a Peppercorn,' Guy Ottewell guides the construction of a scale model Solar System using a bowling ball for the Sun. The eight-thousand-mile-wide Earth, here reduced to a peppercorn, takes its rightful place seventy-eight feet (!) from the bowling ball.

On our class trip to the Hayden Planetarium, we city kids saw an idealized night sky, liberated from the glare of traffic signals and neon lights. We watched the planets chase each other around the heavens of the dome. We tested the relative strength of gravity with trick scales that told how much we'd weigh on Jupiter (four hundred pounds and more for a normal-sized teacher) or Mars (featherweights all). And we gawped at the sight of the fifteen-ton meteorite that had fallen from out of the blue over Oregon's Willamette Valley, posing a threat to human safety that few of us had thought to fear.

The Willamette meteorite (still on permanent display at what is now the Rose Center for Earth and Space) was said to be, incredibly, the iron-nickel core of an ancient planet once in orbit around the Sun. That world had shattered somehow, several billion years back, setting its fragments adrift in space. Chance had nudged this particular piece toward the Earth, where it hurtled down to the Oregon ground at tremendous speed, burning up from the heat of friction, and hitting the valley floor with the impact of an atom bomb. Later, as the meteorite lay still over eons, the acidic rains of the Pacific northwest chewed large holes in its charred and rusted hulk.

Here was a primal scene to upset my innocent planet ideas. This dark, evil invader had no doubt consorted in space with hordes of other stray rocks and metal

chunks that might strike the Earth at any moment. My Solar System home, will that moment a paragon of clockwork regularity, had turned into a disorderly, dangerous place.

The launch of Sputnik in 1957, when I was ten, scared me to death. As a demonstration of foreign military strength, it gave new meaning to the school-wide air raid drills in which we crouched under our desks for pretended safety, our backs to the windows. Clearly we still had more to dread from angry fellow humans than from wayward space rocks.

All through my teens and twenties, as the country realized the young president's dream of a rocket to the Moon, clandestine rockets in missile silos kept collective nightmares alive. But by the time the Apollo astronauts brought back their last batch of Moon rocks in December 1972, peaceful, hopeful spaceships had landed also on Venus and Mars, and another, the US *Pioneer 10*, was en route to a Jupiter flyby. Throughout the 1970s and 1980s, hardly a year passed without an unmanned excursion to another planet. Images radioed home to Earth by robot explorers painted detail upon detail on the planets' long-blank faces. Whole new entities came to light, too, as spacecraft encountered literally dozens of new moons at Jupiter, Saturn, Uranus and Neptune, as well as multiple rings around all four of those planets.

Even though Pluto remained unexplored, deemed too

distant and too difficult to visit, its own unexpected moon was discovered accidentally in 1978, through careful analysis of photographs taken by ground-based telescopes. Had my daughter, born in 1981, attempted her own diorama of the revised and expanded Solar System when she turned eight, she would have needed handfuls of jellybeans and jawbreakers to model the many recent additions. My son, three years her junior, might have opted to model his on our home computer.

Despite the increased population of the Solar System, its planets stayed stable at nine, at least until 1992. That year, a small, dark body, independent of Pluto, was detected on the Solar System's periphery. Similar discoveries soon followed, until the total number of diminutive outliers grew to seven hundred over the ensuing decade. The abundance of mini-worlds made some astronomers wonder whether Pluto should continue to be regarded as a planet, or reclassified as the largest of the 'trans-Neptunian objects'. (The Rose Center has already excluded Pluto from the planetary roll call.)

In 1995, only two years after the first of Pluto's numerous neighbours was found, something even more remarkable came to light. It was a bona fide new planet – of a different Sun-like star. Astronomers had long suspected that stars other than the Sun might have their own planetary systems, and now the first one had surfaced at 51 Pegasi, in the constellation of the flying horse. Within months, other 'exoplanets' – as the newly

discovered extra-solar planets were quickly dubbed – turned up at stars such as Upsilon Andromedae, 70 Virginis b, and PSR 1257+12. At least 120 additional exoplanets have since been identified, and refinements in discovery techniques promise to uncover many more in the near future. Indeed the number of planets in our Milky Way Galaxy alone may far exceed its complement of one hundred billion stars.

My old familiar Solar System, once considered unique, now stands as merely the first known example of a popular genre.

As yet, no exoplanets have been imaged directly through a telescope, so their discoverers are left to imagine what they look like. Only their sizes and orbital dynamics are known. Most of them rival giant Jupiter in heft, because large planets are easier to find than small ones. Indeed, the existence of exoplanets is deduced from their effect on their parent star: Either the star wobbles as it yields to the gravitational attraction of unseen companions, or it periodically dims as its planets pass in front and impede its light. Small exoplanets, the size of Mars or Mercury, must also orbit distant suns, but, being too tiny to perturb a star, they elude detection from afar.

Already planetary scientists have appropriated the name 'Jupiter' as a generic term, so that 'a jupiter' means 'a large exoplanet', and the mass of an extremely large exoplanet may be quantified as 'three jupiters' or four.

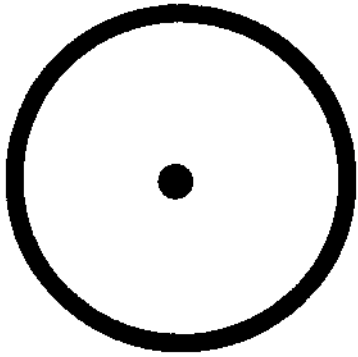
In the same fashion, 'an earth' has come to represent the most difficult, most desirable goal of today's planet hunters, who are devising ways to probe the Galaxy for petite, fragile spheres in the favoured shades of blue and green that hint at water and life.

Whatever daily concerns dominate our minds at the dawn of the present century, the ongoing discovery of extra-solar planetary systems defines our moment in history. And our own Solar System, rather than shrink in importance as one among many, proves the template for comprehending a plethora of other worlds.

Even as the planets reveal themselves to scientific investigation, and repeat themselves across the universe, they retain the emotional weight of their long influence on our lives, and all that they have ever signified in Earth's skies. Gods of old, and demons, too, they were once – they still are – the sources of an inspiring light, the wanderers of night, the far horizon of the landscape of home.

2

GENESIS



'In the beginning, God created the heaven and the earth,' the first book of the Bible recounts. 'And the earth was a formless void and darkness covered the face of the deep, while a wind from God swept over the face of the waters. Then God said, "Let there be light"; and there was light.'

The energy of God's intent flooded the new heaven and earth with light on the very first day of Genesis. Light's potent good thus pervaded the evenings and the mornings when the seas separated from the dry lands, and the earth brought forth grass and fruit trees – even before God set the sun, moon and stars in the firmament on the fourth day.

The scientific Creation scenario likewise unleashes the universe in a burst of energy from a void of timeless darkness. About thirteen billion years ago, scientists say, the hot light of the 'Big Bang' erupted, and separated

itself instantly into matter and energy. The next three minutes of cooling precipitated all the atomic particles in the universe, in the unequal proportions of 75 per cent hydrogen to 25 per cent helium, plus minuscule traces of a few other elements. As the universe expanded exponentially in all directions and continued to cool, it shed no new light for at least a billion years – until it begat the stars, and the stars began to shine.

New stars lit up by pressuring the hydrogen atoms deep within themselves to fuse with one another, yielding helium and releasing energy. Energy fled the stars as light and heat, but helium accumulated inside them, until eventually it, too, became a fuel for nuclear fusion, and the stars melded atoms of helium into atoms of carbon. At later stages of their lives, stars also forged nitrogen, oxygen and even iron. Then, literally exhausted, they expired and exploded, spewing their bounty of new elements into space. The largest and brightest stars bequeathed to the universe the heaviest of elements, including gold and uranium. Thus the stars carried on the work of Creation, hammering out a wide range of raw materials for future use.

As the stars enriched the heavens that had borne them, the heavens gave rise to new generations of stars, and these descendants possessed enough material wealth to build attendant worlds, with salt seas and slime pits, with mountains and deserts and rivers of gold.

In its own beginning, some five billion years ago, the

star that is our Sun arose from a vast cloud of cold hydrogen and old stardust in a sparsely populated region of the Milky Way. Some disturbance, such as he shock wave from a nearby stellar explosion, must have reverberated through that cloud and precipitated its collapse: Widely dispersed atoms gravitated into small clumps, which in turn lumped together, and kept on aggregating in an ever-quickening rush. The cloud's sudden contraction raised its temperature and set it spinning. What had once been a diffuse, cool expanse of indeterminate shape was now a dense, hot, spherical 'proto-solar nebula' on the verge of starbirth.

The nebula flattened into a disk with a central bulge, and there in the heart of the disk the Sun came to light. At the moment the Sun commenced the self-consumptive fusion of hydrogen in the multi-million-degree inferno of its core, the outward push of energy halted the inward gravitational collapse. Over the ensuing few million years, the rest of the Solar System formed from the leftover gas and dust surrounding the infant Sun.

The Book of Genesis tells how the dust of the ground, moulded and exalted by the breath of life, became the first man. The ubiquitous dust of the early Solar System – flecks of carbon, specks of silicon, molecules of ammonia, crystals of ice – united bit by bit into 'planetesimals', which were the seeds, or first stages, of planets.

Even as they assembled themselves, the planets asserted their individuality, for each one amassed the

substances peculiar to its location in the nebula. At the hottest part, flanking the Sun, Mercury materialized from mostly metallic dust, while Venus and Earth matured where rocky dust as well as metal proliferated. Just past Mars, tens of thousands of rocky planetesimals availed themselves of plentiful carbon supplies, but failed to amalgamate into a major planet. These herds of unfinished worlds, called 'asteroids', still roam the broad zone between Mars and Jupiter, and their territory, the 'Asteroid Belt', marks the Solar System's great divide: on its near-Sun side lie the terrestrial planets; on the far side, the frigid gaseous giants grew.

The planetesimals at greater distances from the Sun, at lower temperatures, assimilated stores of frozen water and other hydrogen-containing compounds. The first one to reach appreciable proportions then attracted and held onto great quantities of hydrogen gas, and thus grew into Jupiter, the mammoth planet whose mass doubles that of all the other combined. Saturn, too, aggrandized itself with gas. Farther out from the Sun, where dust proved even colder and scarcer, planetesimals took longer to develop. By the time Uranus and Neptune had achieved sufficient mass to pad themselves with hydrogen, the bulk of that gas had already dissipated. At Pluto's remove, only rock shards and ices were to be had.

All the while the planets were forming, projectiles flew through the young Solar System like avenging angels. Worlds collided. Icy bodies struck the Earth to

disgorge a few oceans' worth of water. Rocky bodies rained fire and destruction. In one such cataclysm 4.5 billion years ago, a hurtling Mars-sized object (roughly half as big as Earth) thrust itself into the Earth. The impact and upheaval blasted molten debris into near-Earth space, there to orbit as a disk before cooling and coalescing into the Moon.

The violence of the Solar System's formative period ended shortly thereafter, about four billion years ago, in a final paroxysm descriptively termed 'the late heavy bombardment'. In those ancient days, many still-wandering planetesimals crashed into existing planets, which incorporated them at once. Multitudes of other small bodies were forcibly ejected, by gravitational interactions with the giant planets, to a distant land of Nod in the outer Solar System.

The young Sun shone but faintly on the planets, growing gradually hotter and more luminous over its first two billion years, as it stored up helium in its core. At present, in middle age, the Sun continues to brighten while converting seven hundred million tons of hydrogen to helium *every second*. Even at this galloping rate of consumption, the Sun's abundant hydrogen guarantees three to five billion more years of dependable light. But inevitably, as the Sun switches over to helium fusion, it will become so hot as to boil away Earth's oceans and smite the life it spawned there. The ten-fold temperature increase required to burn helium will see the hotter Sun

turn red, and swell in size until it swallows up the planets Mercury and Venus, and melts the surface of the Earth. One hundred million years later, when the Sun has reduced more helium to carbon ash, it will shrug off its outer layers and dispatch them past Pluto. A larger star could resort to carbon burning at that point, but our Sun, a relatively small star by the standards of the universe, will be unable to do so. Instead, it will smoulder as an ember, and shed a fading light on the charred cinder where God once walked among men. This dim future, however, lies so far ahead as to allow the descendants of Adam and Noah ample time to find another new home.

The glorious Sun of our time, the planets' progenitor and chief source of energy, embodies 99.9 per cent of the mass in the Solar System. Everything else – all the planets with their moons and rings, plus all the asteroids and comets – account for only .1 per cent. This gross inequity between the Sun and the sum of its companions defines their balance of power, for the universal law of gravity decrees that the massive shall have dominion over the less massive. The Sun's gravity keeps the planets in orbit and also dictates their speeds: the closer they are to the Sun, the faster they go. The Sun, in turn, bends to the will of the concentrated mass of stars at the centre of our Milky Way Galaxy, around which it orbits once every 230 million years, carrying the planets along with it.

Just as they feel the Sun's attraction more or less keenly, according to their distance, so too do the planets partake of the Sun's light and heat. Solar energy diminishes an intensity as it radiates through interplanetary space. And so, while parts of Mercury bake at five hundred degrees, Uranus, Neptune and Pluto remain perpetually deep-frozen. Only in the Solar System's milder middle section, called the habitable zone, have conditions supported the flourishing of 'great whales, and every living creature that moveth, which the waters brought forth abundantly, after their kind, and every winged fowl after his kind: and . . . cattle, and creeping things, and beast of the earth . . .'

The planets return the favour of the Sun's light by reflecting its rays, and in this manner they pretend to shine, though they emit no light of their own. The Sun is the Solar System's sole light-giving body; all the others glow by reflected glory. Even the full Moon that illumines so many lovely Earthly evenings owes its silvery light to Sunbeams bouncing off the dark lunar soil. The Earth shines just as beautifully when viewed from the Moon, and for the same reason.

The play of mirrored light from Venue, close to the Sun and also closest to Earth, makes that planet appear by far the brightest one to our eyes. Jupiter, though much larger, lies many millions of miles beyond, and therefore pales in comparison in our night sky. The even further worlds of Uranus and Neptune, immense as they

are, catch and toss back so little light that Uranus can only occasionally be discerned (as a mere point of light) by the naked eye, Neptune never.

Although Pluto, too, is impossible for us to see without a telescope, other objects on the outskirts of the Solar System can and sometimes do flare into sudden visibility. When disturbed by a chance encounter, an ice-rock denizen from Pluto's depths may be pushed Sunward and transformed from a dull lump into a spectacular *comet*. Basking in the Sun's warmth, the frozen body heats up and throws out a trailing tail of castoff gas and icy dust that sparkles with the Sun's reflection. The brilliance fades and disappears, however, after the comet rounds the Sun and returns to the outer Solar System.*

The visits of comets, long interpreted as signs and wonders, have recently sketched the true extent of the Sun's domain. By tracing the visible parts of comet paths, and extrapolating the rest, astronomers have shown that numerous comets hail from out beyond Pluto's neighbourhood, from a second comet reservoir, hundreds of times further away. Despite their unimaginable distance, these bodies still belong to the Sun, still heed the Sun's gravity, still receive some glimmer of the Sun's light.

* Discarded comet dust litters interplanetary space, and when the Earth trundles into a patch of it, the particles that fall through the atmosphere are incinerated, appearing as isolated 'shooting stars' or whole showers of meteors.

Sunlight, which darts through space at the dazzling speed of 186,000 miles per second, takes ages to emerge from the dense interior of the Sun. Light advances only a few miles per year near the Sun's core, where the crush of matter repeatedly absorbs it and impedes its escape. Radiating this way, light may journey for a million years before reaching the Sun's convective zone, there to catch a quick ride-up and out on roiling eddies of rising gas. As soon as these eddies release their cargoes of light, they sink back down, to soar again later with more.

The light-emitting, visible surface of the Sun – the photosphere – seethes as though boiling from the constant tumult of energy release. Gas bubbles bursting with light give the photosphere a grainy complexion, marred here and there by pairs of dark, irregularly shaped sunspots, with black centres and grey, graded shading around them like the penumbras of shadows. Sunspots designate areas of intense magnetic activity on the Sun, and their darkness bespeaks their relative coolness of about 4000°K, compared to neighbouring areas at nearly 6000.* The level of solar activity rises and falls in cycles averaging eleven years, and sunspots

* Degrees K, for Kelvin, are the same size as degrees Celsius (or centigrade) – almost double the value of Fahrenheit degrees. However the Kelvin scale starts lower, at –273°C, or 'absolute zero', the point at which all motion ceases, and has no upper limit, which makes it useful for describing the temperatures of stars.

mingle, morph, and multiply according to this same schedule. Their number and distribution vary like famine and plenty, from no spots at 'solar minimum', or just a few spots dotting the Sun's high latitudes, to 'solar maximum' five to six years later, when hundreds of them crowd closer to the equator. Although sunspots seem to gather and scud like clouds across the photosphere, really it is the Sun's rotation that carries them around.

The Sun rotates on its axis approximately once a month, in a continuation of the spinning motion it was born in. Being an enormous ball of gas, the Sun spins complexly, in layers of various speeds. The core and its immediate surroundings turn at one rate, as a solid body. The overlying zone spins faster, and above that, the visible photosphere whirls around at several different rates, more quickly at the Sun's equator than near its poles. These combined, contrary motions whip the Sun into a fury, with consequences felt clear across the Solar System.

The 'solar wind', a hot exhalation of charged particles (reminiscent of the 'wind from God'), blows out from the turbulent Sun and keeps up a constant barrage on the planets. Were it not for the protective envelope of Earth's magnetic field, which deflects most of the solar wind, only ocean life could withstand the onslaught. From time to time, especially during solar maximum, the steady solar wind is augmented by sudden blasts of

higher-energy particles from solar flares on the Sun's surface, or by gargantuan blobs of ejected solar gas. Such outbursts can disable our communications satellites and disrupt power grids, causing blackouts. In milder doses, particles of solar wind trickle into the upper atmosphere near the North and South Poles, initiating cascades of electrical charge that draw curtains of coloured lights across the sky – the so-called Northern and Southern Lights. Other planets also sprout colourful auroras in response to the solar wind, which billows on past Pluto all the way to the heliopause – the undiscovered boundary where the Sun's influence ends.

From the Earth, we see the Sun as a blazing circle in the sky, brighter but no bigger than the circumference or the Full Moon. The 'two great lights', as the Sun and Moon are described in Genesis, make a matched pair. For although the Moon measures only one four-hundredth the Sun's million-mile diameter, it nevertheless lies four hundred times closer to Earth. This uncanny coincidence of size and distance enables the puny Moon to block out the Sun whenever the two bodies converge on their shared path across Earth's sky.

Approximately once every two years, some narrow swath of Earth – as often as not a godforsaken, all but inaccessible place – is blessed with a total solar eclipse. There, dusk will fall and dawn break twice on the same day, and the stars come out with the Sun still overhead. Temperatures may drop ten or fifteen degrees at a stroke,

allowing even the most jaded observer to sense the bizarre disorientation that birds and animals share as they hasten to their nests or burrows through the sudden midday darkness.

No total eclipse can last much longer than seven minutes, because of the Earth's persistent turning on its axis and the Moon's unwavering march along its orbit. But totality of the briefest duration affords sufficient reason for scientific expeditions and curious individuals to travel halfway around the world, even if they have seen an eclipse before.

At totality, when the Moon is a pool of soot hiding the bright solar sphere, and the sky deepens to a crepuscular blue, the Sun's magnificent corona, normally invisible, flashes into view. Pearl and platinum-coloured streamers of coronal gas surround the vanished Sun like a jagged halo. Long red ribbons of electrified hydrogen leap from behind the black Moon and dance in the shimmering corona. All these rare, incredible sights offer themselves to the naked eye, as totality provides the only safe time to gaze at the omnipotent Sun without fear of requital in blindness.

Moments later, the shadow of the Moon passes and the natural world order is restored by the ordinary grace of the Sun's familiar light. But visions of the eclipse persist among viewers, as though a miracle had been witnessed. Is it an accident that the Solar System's sole inhabited planet possesses the only satellite precisely

sized to create the spectacle of a total solar eclipse? Or is this startling manifestation of the Sun's hidden splendour part of a divine design?