Darshana Jolts

The World Above – 2

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Stellar Distances: *Stars are trillions of miles away and more.*

Those twinkling little stars way up there seem to be very, very far away. Many ancients believed they were all at the same distance from us, fixed like little candles on the dome of an arena. That was the celestial sphere beyond whose shell there was a frightening void.

But how high was the ceiling that enclosed the universe, how far were the stars that light up the nocturnal sky? No one could say. Aristotle said that the earth could not be moving because if it did, the positions of the fixed stars would be changing as well. Some tried to speculate on the matter. After the Copernican revolution, Kepler thought the stars were some 600 billion miles away, while Newton suspected the distance to be of the order of twelve trillion miles. These, of course, were mere guesses. How else could one know anything on this question?

Human ingenuity had learned to determine the distance of faraway objects by the method of parallax: by measuring or estimating the angle subtended by a distant object from the end-points of a base line one can determine the distance by knowing the length of the base line. Looking at a raised finger on an outstretched arm, one will notice its shift (with respect to a background) when seen with one eye closed, and then the other. The apparent shift will gradually disappear as we see objects farther and farther away[1]. Thus, even if one saw a star from two equatorially opposite spots on earth, one would observe no change in a star's position. What we may conclude from this is that stars are way too far.

It occurred to Friederich Bessel[2] in the first decade of the nineteenth century that perhaps the earth's orbit around the sun, then estimated to be about 300 million km[3], may be taken as a

[1] Draw a narrow isosceles triangle with a small base d. If the base line regarded as (almost) the arc of a circle whose center is at the vertex, the base line subtends the vertical angle q. Expressed in radians, $q = R/d$, where R is almost equal to the distance of the vertex from the base. Also known as the triangulation method, it had been used to determine the distance of the moon from the earth.

[2] Bessel began as an accountant with a modest pay and became a first rate mathematician/astronomer.

[3] This again is another *darshana* jolt. Most ancient astronomers merely guessed the earth–sun distance. It was only in the last third of the seventeenth century that Jean Richer and Giovanni Domenico Cassini, by measuring the parallax of Mars between two places on earth (Paris and Cayenne) arrived at a first measured estimate of the distance of the sun from the earth.

baseline to observe a star. In other words, note the star's position now and six months later. A slight shift, if observed, would enable us to estimate the star's distance.

So Bessel focused his observation of a faint star in the constellation called the Swan[4], using an instrument called *heliometer*. His method was successful, after he spent a year and a half on the project. From the parallax shift, the distance of this star was estimated to be some thirty six trillion miles! And it is one of the closer stars to our solar system. Incidentally, this was also the first directly demonstrable evidence of the Copernican theory: for now, one could actually *see* a measurable evidence of the earth's motion around the sun. Bessel's success inspired other astronomers to measure other stellar distances. More sophisticated techniques were also developed in this regard. In the twentieth century Walter Sydney Adams initiated a method based on a relationship connecting the apparent luminosity, apparent brightness, and distance. This spectroscopic parallax method has been used to determine the distances of thousands of stars[5].

Bessel's was undoubtedly one of the major conquests of the human mind and of human ingenuity. Estimating the distance of a celestial body at such an unimaginably great distance is impressive enough. But of no less significance is the fact that all of a sudden the universe became, to the human mind, an unimaginable, yet *measurable* stretch of vastness, as against the abstract and helpless cry of infinity at the skies of generations past. There is a significant difference between exclaiming in awe about how big something is and stating precisely its dimensions.

It is sometimes said that science, and more specifically astronomy, reveals how puny humans are in the context of the cosmic expanse. This statement is valid only if we confine ourselves to the physical scale. But if we consider the cosmos in terms of the mind, we know of nothing that is grander in achievement. No planet or star, as far as we know, has any knowledge of us humans as we have of them.

Double Stars: ***Not all stars are lonely entities.***

When we look at any star at night with our naked eyes, it seems to be a single twinkling entity. When in 1650 the Jesuit astronomer Giovanni Battista Riccioli turned his telescope towards the star Mizar in the handle of the Big Dipper it revealed itself to be two stars close to each other[6]. This was the first observation of a so-called *double star*. Since then hundreds of double stars

[4] The technical name for the star is 61 Cygni.

[5] For details, see Helen Wright, 'Adams, Walter Sydney', *Dictionary of Scientific Biography* 1, Charles Scribner's Sons,, New York, pp.54–58, 1970.

[6] Robert Aitken, Grant, *The Binary Stars*, Dover, New York, 1964.

have been detected and catalogued. The double nature may seem to be so, simply because though light-years apart they happen to be very much in the same line of light; in which case they are known as *optical double stars*. Or, it could be that they are really bound to each other in their mutual gravitational field. Then they are known as *binary stars*. A catalogue of stars, published in 1782, contained 227 double stars. Another one, published only two years later, had 432 on its list. Friedrich Georg Struve was a famous hunter of double-stars: his catalogue contained 3112 of them[7]. We now know of triple and multiple stars, and of star clusters consisting of thousands of closely-bound stars. Who could have thought in the era of pre-telescopic astronomy that not all stars are lonely in the celestial wilderness!

Stellar Motion: *Stars are not fixed, they are in motion.*

In ancient astronomy stars were pictured as being fixed on the celestial dome or as moving in perfect circles. The image of the fixed Pole Star is conveyed by Shakespeare's Julius Caesar[8]:

> *But I am constant as the Northern Star,*
> *Of whose true fixed and resting quality*
> *There is no fellow in the firmament.*

One important practice of scientists is to keep a log of what they do and observe. Nowhere has this been done with greater devotion than in astronomy where, since ancient times, one has been keeping accurate records of the position of stars in the sky. This was good because in 1718 Edmund Halley noticed that at least three important stars seemed to have changed their traditionally recorded positions. It was thus discovered that stars are in fact moving every which way. As a result of careful observations over many decades astronomers now also know the speeds with which various stars are moving, and along which directions. Given that interstellar distances are unimaginably vast, those motions are only barely perceptible even over many long years, indeed centuries. If we look at the sky a billion years from now, the stars would all be scattered very differently from how they seem today. Astrological fantasies based on the animal-appearances of constellations on the zodiac should really seem baseless, not to say silly, when one considers it all from this perspective.

Stellar Evolution: *Stars are born and they evolve.*

All things living have birth, growth, and eventually death. But rocks and stones and particles

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7 For more information on Struve, see, A H Batten, The Struves of Pulkovo – A Family of Astronomers, *Journal of the Royal Astronomical Society of Canada*, Vol.71, p.345. 1977.

8 William Shakespeare, *Julius Caesar* (III, i, 60–62).

of sand seem to remain for ever, if left alone. And it looks as if things in heaven have been the way they are at all times since the dawn of Creation, and may be there forever and forever, never to perish. In other words, it was believed by the ancients that the sun and the stars, the moon and other planets have always been there, and will persist as such till the last gasp of the world. For long centuries it was a tenet that matters celestial were incorruptible, preserving form and stability for all of time[9].

This view changed after the rise of modern science. The idea arose that stars begin as very hot and luminous bodies, and gradually cool down. In the closing decade of the nineteenth century Joseph Norman Lockyer came up with an idea: that stars were formed from a primeval plethora of meteors which gradually coalesced to form the more massive stars[10]. This crude idea, initially and appropriately rejected in its first formulation, was nevertheless revolutionary in that it spoke of the genesis of a star: an idea never before considered seriously.

The work of Henry Norris Russell and others, though beginning from very different data, suggested a mechanism by which stars are born, grow and age. Their work turned out to be a more scientifically sustainable exploration of the conceptual leap from the worldview which Lockyer had initiated, namely that the same star that is bright and brilliant now was once no more than a mammoth blob of un-bright matter, and that some distant day from now, it will cease to shine[11].

This should be equally true of the most effulgent star of all (from our vantage point): our own sun, which too will fade away some day. The discovery of the atomic nucleus clarified in greater detail how the processes occur, and now we know that gradually immense amounts of matter come together by virtue of gravitation, and when such enormous amounts are crushed under stupendous pressure, it all begins to heat up. And at the extraordinary temperatures which are of the order of a few million degrees, nuclear reactions begin to set in. At this point the star is born.

Stars in their Old Age: ***Old stars die in different ways.***

As the stars live through astronomical stretches of time, they gradually spend up much of their energy, for though huge, this is not limitless. So there will come a stage when the stars will no

[9] Ancient Hindu and Buddhist philosophers, however, had the insight to say that nothing is really permanent, that, like physical life, even the earth and the stars would also ultimately dissolve. In the Hindu vision Shiva is the principle of dissolution.

[10] Sir Norman Lockyer, *The meteoritic hypothesis: a statement of the results of a spectroscopic inquiry into the origin of cosmical systems*, Macmillan and Company, London, 1890.

[11] Dina Prialnik, *An Introduction to the Theory of Stellar Structure and Evolution*, Cambridge University Press, 2000.

longer be as brilliant. With the power of mathematics and a grasp of the laws that make the world tick, astrophysicists can foresee the final fate of a stellar body. Careful reasoning and modeling reveals that the end product of a star is very much dependent on the amount of mass that came to form it in the first place. A star of the mass of the sun will degenerate into what is called a white dwarf of about 0.6 its initial mass. These are relatively stable structures, lasting for billions of years.

Depending on its initial mass, the star may explode into a supernova or degenerate further into a black dwarf. If the mass of the white dwarf is above 1.4 solar mass for stars made up of carbon, nitrogen, neon or magnesium, it could become a neutron star or a supernova. This result was derived by Subrahmanian Chandrasekhar in the 1930s[12]. 1.4 times the solar mass is therefore called the *Chandrasekhar limit*. Very massive stars may also eventually be reduced to a black hole[13]. In other words, depending on how massive a star is, it might end up as a white dwarf, a supernova, or a black hole. We may note in passing that the eminent astrophysicist Arthur Eddington tried to stand in the way of Chandrasekhar's discovery being accepted [14].

Analysis shows further that it is only in the core of super-hot supernovas that the heavier elements in the universe can be synthesized. What this means is that the phosphorus and calcium, the carbon and iodine that make up our bodies were manufactured in the heart of supernovas[15]. As Carl Sagan put it, "We are made of star-dust." Not even the most imaginative of the ancients came up with this picture! As the *Upanishads* declare that our consciousness is a fragment of a cosmic consciousness[16], astrophysics tells us that our material bodies are from fragments of supernovas.

Nebulas and Galaxies: *Many worlds form our world.*

Many ancient peoples had observed the faint whitish patch in the summer sky, which looks like a stream of spilled milk in high heavens. So it came to be known as the *Milky Way*. As mentioned earlier, it was described in poetic and mythic terms in many cultures, with the associated

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[12] G Srinivasan, (ed.) *From White Dwarfs to Black Holes: The Legacy of S Chandrasekhar*, The University of Chicago Press, Chicago, 1997.

[13] For more on black holes, see Kitty Ferguson, *Black Holes in Space–Time*, Watts Franklin, New York, 1991.

[14] Arthur I Miller, *Empire of the Stars: Obsession, Friendship, and Betrayal in the Quest for Black Holes*, Houghton Mifflin, New York, 2005. It is important not be attribute Eddignton's reaction to any kind of racism. He would have reacted the same way if Chandrasekhar had been a Frenchman or an American or even a fellow Briton. Scientists generally don't like their theories to be overthrown by others.

[15] Ken Croswell, *The Alchemy of the Heavens: Searching for Meaning in the Milky Way*, Anchor Books, 1996.

[16] *Chandogya Upanishad* 6.8., *tat tvam asi* (Thou art That).

mystery. Galileo's little device with two lenses revealed it to be an agglomeration of countless distant stars, which was another major transformation of the traditional worldview.

When, in the course of the 18th century, astronomers began to explore the southern skies (from South Africa) they not only noted new constellations there[17], but they also happened to observe certain hazy patches, which looked like clouds in the far away regions of the stellar world. The French astronomer Nicolas Louis de Lacaille listed forty two of them in the middle of the 18th century[18]. His compatriot, Charles Messier, an avid comet-hunter, published a classic catalog in 1774 which has served astronomers for many generations[19]. Some of the more famous of the nebulae, such as Andromeda galaxy and the Crab nebula, were recorded by Messier. Today most nebulae and galaxies are referred to by their Messier number. Thus, for example, M 31 refers to the Andromeda galaxy and M1 to the Crab nebula. These celestial objects came to be called *nebulae* (Latin for *clouds*). By the beginning of the 19th century, William Herschel began to take great interest in them, cataloging thousands of nebulae. He rightly suspected that, like our own Milky Way, these too were vast congregations of countless stars. He had the intuitive suspicion that these must be located far away from our Milky Way, and so he described them as *island universes*. This was a most fantastic notion, for it expanded our imagination to more than one universe!

In the first decades of the twentieth century, the work of Edwin Hubble and others led to newer techniques for determining the distances of some of the nebulae[20]. It turns out that some of these nebulae were far too distant to be within our Milky way. Thus, they were shown to be distinct from and independent of our own galaxy: very much the island worlds that Herschel had suspected. When this was announced in the closing month of 1924 at the American Astronomical Society meeting, the world did not know that a tremendous jolt had been given to our worldview: we live in a universe (our Milky Way) which is but one of several such universes. There are countless galaxies, each a vast congregation of billions and billions of stars, and separated from one another by millions of light years. Hubble presented a systematic classifi-

[17] Some ancient Indian star observers seem to have been aware of some southern constellations. The Trishanku mentioned in Valmiki's *Balakanda* (Sarga 60) is said to refer to the Southern Cross. In modern times, the Nizamiah Observatory (at Ameerpet near Hyderabad) took part in a project to map the sky. It played an important part in the first ever international project for collaboratively photographing and mapping the skies – the *Carte du Ciel*. It may be mentioned in passing that the eminent Indian astronomer Vainu Bappu (once president of the International Astronomical Union and after whom a comet is named) was at this observatory. For more on this, see, *The Hindu*, May 27, 2003.

[18] David S Evans, *Lacaille: astronomer, traveller; with a new translation of his journal*, Pachart, Tucson, 1992.

[19] Stephen James O'Meara, *Deep Sky Companions: The Messier Objects,* Cambridge University Press, 1998.

[20] Gale Christianson, *Edwin Hubble: Mariner of the Nebulae*, Farrar Straus & Giroux, NY, 1995.

[21] E P Hubble, *The Realm of the Nebulae*, CT. New Haven, 1936.

cation of the galaxies in terms of their appearance: as spiral, circular, elliptic, and irregular[21].

If we take off in an imaginary vehicle into space, we will be transported past planets and their satellites, dodging asteroid belts between Mars and Jupiter, crossing remote outskirts of our solar system where comets are swinging near their aphelions. We will move beyond our own solar system, amidst stars and more stars, and then go beyond the periphery of our galaxy, and zoom still more, passing millions of galaxies on the way.

Composition of Stars: *Stars are made of the same elements as earth.*

In the ancient world one imagined the planets, the sun and the stars to be made up of a substance quite different from what makes the terrestrial world. Up until the middle of the nineteenth century the general consensus among scientists was that the chemical composition of stars could never be known, for how can we ever get a chunk of stellar matter here into our laboratories for chemical analysis?

The spectroscope was invented in 1814 by Joseph von Fraunhofer, orphaned when he was barely eleven[22]. If the telescope brought planets and stars closer to us, the spectroscope was to do something no less spectacular: It was to reveal to us the chemical elements in the sun and the star. Fraunhofer himself studied the light from the sun, using his instrument, identifying hundreds of dark lines in the solar spectrum, and the spectrum of the star Sirius. It took a few more decades before it was recognized that these were absorption spectra from specific elements. Thus it was that we have come to know about the constitution of stars[23]. More remarkably, by noting that certain lines from the sun did not correspond to any known element on earth, it was surmised that there was perhaps a hitherto unknown element in the sun. It was therefore dubbed helium[24]. Note the utterly fantastic nature of this discovery: a new element was discovered, not in a chemical laboratory using beakers and balances, but in the light from the sun. As Warren de la Rue exclaimed, "If we were to go to the sun, and to bring some portions of it and analyze them in our laboratories, we could not examine them more accurately than we can by this new mode of spectrum analysis[25]." Likewise we now know about the chemical composition of many stars trillions of kilometers away. If this doesn't impress a person, little

[22] See in this context Myles W Jackson, *Spectrum of Belief: Joseph von Fraunhofer and the Craft of Precision Optics*, MIT Press, Cambridge, MA, 2000.

[23] The credit for correlating solar spectra with chemical elements goes to Robert Wilhelm Bunsen (of burner-fame) and Gustav Robert Kirchhoff whose laws of electrical circuits are known to students of electricity.

[24] The yellow line in the chromosphere of the sun was first observed in Guntur (India) by Pierre Janssen in 1868, and soon thereafter by Norman Lockyer also. Both are credited with the discovery of helium which was named by Edward Frankland, from the Greek word *helios* for the sun.

[25] W De la Rue, *Chem. News,* Vol.4, p.130, 1861.

else of modern science will. Those who understand and appreciate such feats will hesitate to claim that the ancients knew all about modern science.

The Expanding Universe: ***Our unbounded universe is ceaselessly increasing in size.***

In a homogeneous and isotropic universe, only three things are possible: the universe remains static, it expands uniformly, or it contracts uniformly. One of the theoretical consequences of Einstein's very successful theory of general relativity was that the universe must be either expanding or contracting: an utterly unimaginable idea at the time. So he fudged with his equations, inserting an appropriate parameter, to dodge such a dynamical universe. Several years later, the eminent observational astronomer Edwin Hubble's careful collection of spectra from distant galaxies revealed that those galaxies were in fact receding away at incredibly fast speeds. This led one to the idea of an *expanding universe*, not unlike a balloon that is being blown, with ink-spots on the surface of the balloon representing various galaxies. In other words, galaxies are advancing relentlessly every which way. Physical space extends only as far as material galaxies have gushed forth.

All this is also based on the notion that the universe preserves common features from no matter where it is observed and along whatever direction. This is what one calls the *cosmological principle*[26]. At first blush, the vast interstellar space up there appears to be three-dimensional, flat, unbounded, and infinite. But 20th century physics has revealed that it is neither flat nor unbounded, nor infinite for that matter. The deeper we probe into the nature of perceived reality, the stranger we find its roots to be.

Cosmic Birth: ***It all started with a Big Bang.***

So the galaxies are receding from one another at stupendous speeds: the farther a galaxy, the faster it is running away. We get the picture of an expanding universe, one whose limits keep moving continuously. This suggests how the universe may have begun: Perhaps it was all concentrated at some minuscule point whence a stupendous explosion gave birth to the world of matter and energy, reminding us of a Cosmic Egg from which everything came to be[27]. The burst of this primeval atom, as it once was called, is referred to as the big bang. Big is a small word to describe it. It was stupendous, to say the least. But, in truth, it was no bang, for there was neither sound nor ear to hear. It was the birth of matter and energy, of space and time, and in

[26] For more details, see Andrew Liddle, *An Introduction to Modern Cosmology,* John Wiley & Sons, 2003.

[27] In this context, see Simon Singh, *Big Bang: The origins of the universe*, Fourth Estate, New York, 2004. See also, Harry Nussbaumer and Lydia Bieri, *Discovering the expanding universe*, Cambridge University Press, Cambridge, 2009.

a poetic vision, birth from a golden womb (*Hiranyagarbha*)[28]. Yes, in the language of Hindu mythic vision, it was a Brahmic creation[29]. The enormous matter which thus emerged in a split microsecond, congregated into isolated globules which, through gravitational enticements, formed themselves into mammoth contracting masses that eventually became the myriad stars that illumine the sky. The initial shattered outburst probably led to the splinter-like recession of the various galaxies which came to be formed over incredible stretches of time. This is the model of cosmic birth offered by current cosmology. There is no guarantee it will be accepted as the scientific truth a century and more from now. For such is the destiny of many fundamental physical theories: now to be proclaimed as the final answer, only to be modified or rejected by a future generation of probing observers and theorizing modelers.

Dark Matter and Energy: *The universe has invisible massive material components.*

More than sixty years ago, Fritz Zwicky surmised from his study of the motions of galactic clusters that the Milky Way should be far more massive than we had been led to believe by merely estimating the number of visible stars in our system[30]. Could it be that we were too hasty in concluding that much of the matter in the physical universe is to be found in flashing stars? Were we right in imagining that only what was visible existed? If a simple stone lies in pitch darkness, and it does not glow, would it be visible? If tenuous gases filled interstellar space and themselves emitted no visible rays, would we observe them? Should matter necessarily have to be bright to exist in the stretches of space? These are pertinent questions, and to say no, no, and no to each one of these is not only reasonable, but promises to offer a clue to the puzzle of the missing mass. Maybe the universe is more massive than what we had thought. Maybe there is more than mere cosmic dust in the expanse of interstellar space. Maybe there are vast amounts of *dark matter* in the heavens.

But what is this dark matter we think pervades the world? Once it was believed that this was made up of the mysterious neutrinos that are known to be zooming past and through every region of space and through every star in the world. But this idea has now been pretty much abandoned. Could dark matter consist of splinters from the primordial blow-up that caused the universe in the first place, messy discharges that accompanied cosmic birth? This was another idea popular years ago, but now it too has lost adherents. Or is dark matter simply a grandiose collection of non-luminous rocks and planets, much like the asteroids of our own solar system, and/or sterile stellar debris, worn out remnants of pulsars and pent-up stars, a great many perhaps, but mere

[28] The *Hiranyagarbha Sukta* (10.121) of the *Rig Veda* refers to this as the ultimate origin of all Creation.

[29] In Puranic legends, Brahmà, the self-born (*svayambhù*) gave rise to *Hiranyagarbha*.

[30] Not as well known as others, Zwicky was a prolific astronomer. He has left for astronomers a catalogue (in six volumes) of thirty thousand galaxies.

dead-weight in the throbbing stellar multitude? Some have suggested that dark matter could well account for more than 99% of the mass of the universe[31]. If this were so, we have been once again proved wrong in our assessment of what kinds of matter populate our universe.

But how are we to see objects that by definition are invisible? By indirect means, of course. After all, that is how we became aware of the planets Neptune and Pluto. Dark matter, if it existed in significant quantities, would have an effect on galactic motions. Then too, if such great masses lie interspersed in space, their pull would be considerable even on light which would thus be deviated by what has been called a *gravitational lens*. Astronomers have been scanning the skies and tracking the rotations of galaxies precisely to detect such influences. They have been measuring with uncanny precision the orbital motions of the minor galaxies that circumambulate our own. Their data seem to suggest that our own galaxy must be at least five times more massive than what seems to be the case when only all the shining stars are taken into account! Searching for a descriptive acronym, astronomers have hit upon MACHO to describe such matter: MAssive Compact Halo Objects. It also conveys the dominant role it plays in directing galactic motions[32]. None of this is firm and final. Astronomers are still more or less in the dark about dark matter and dark energy, so theoretical conjectures are many.

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[31] See in this context, Michael Riordan and David Schramm, *The Shadows of Creation: Dark Matter and the Structure of the Universe*, New York, 1991.

[32] C Alcock *et al*, The MACHO Project: Microlensing Results from 5.7 Years of LMC Observations, *Astrophys. J.*, Vol.542, pp.281–307, 2000.

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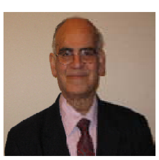

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