IUCAA-07-2002

IUCAA -07/2002

March ' 2002

FERMILAB
JUL 2 6 2002
LIBRARY

The Relativistic world : A Common Sense Perspective*

By

Naresh Dadhich

* Text of the Inaugural address delivered at Symposium on Cosmology and Astrophysics, 29-30 January 2002 held at Department of Physics, Jamia Millia Islamia, Delhi.

Inter-University Centre for Astronomy and Astrophysics

An Autonomous Institution of the University Grants Commission

Preprint Request (Please quote the preprint number)
email : prepm@iucaa.ernet.in
Fax : 020-5680760
Post : IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India

The Relativistic World: A Common Sense Perspective[1]

Naresh Dadhich
Inter-University Centre for Astronomy and Astrophysics,
Pune, India.

The Relativistic World: A common sense perspective

First of all I thank the organizers of the workshop for asking me to give the keynote address. What is expected of it is perhaps to say something profound and interesting which should be accessible to anyone who ventures to step into the lecture hall. This is of very tall order for a person like me. Since my good friends have posed some confidence in me, I shall try my best to live up to their expectations and the occasion.

I would attempt to present to you a new way of looking at things - a farmer's perspective. What I mean by that is to get to the basic root of concepts with a minimal degree of mathematical and technical sophistication, common sense being the sole guide and torch bearer. That means what I am going to talk should in principle be accessible and hence satisfying one of the key criteria for a key note address.

The concepts of space, time and matter are universal and fundamental. A view consistent with the contemporary understanding of these basic concepts should permeate a rational and truthful world view. By world view I would mean a broad enough framework to probe and understand the world around us, the Universe. For this a correct and proper understanding of space, time and matter is therefore of primary importance. In this lecture, I shall essentially address to these concepts and shall attempt to thread a profound synthesis, which is given the name, Relativistic World.

1. The Newtonian World

[1]Text of the keynote address delivered at Symposium on Cosmology and Astrophysics, 29-30 January 2002 held at Department of Physics, Jamia Millia Islamia, Delhi.

In the Newtonian world, space, time and matter are independent and externally provided entities. That is, the question of their creation and existence is not admitted. Motion is described by the three laws of motion governing motion of all that moves. The interaction between bodies in the Universe is described by the law of gravitation which prescribes universal attraction between all bodies and its measure is proportional to their masses and inversely proportional to square of the distance separating them.

The first law of motion makes an equivalence statement that Uniform Motion (motion with a constant speed in a straight line) is equivalent to No Motion (rest). That is, it is impossible to distinguish between these two states by performing any physical experiment. Any deviation from this would signal presence or application of an external field or force. In a force free region, a particle would either be at rest or in uniform motion depending upon the initial condition. It would continue in this state until a force acts on it. The only way force makes its presence felt is by changing the velocity of the particle it is acting on.

Conversely if something is moving in a straight line, either there acts no force on it or it acts in the same direction of motion. If something moves in a straight line in all directions, that means no force is acting on it unless there exists in Nature a force which is isotropic - acting in all directions at the same time. If there doesn't exist such a force in Nature and yet there exists something that moves in a straight line in all directions, its velocity must be a universal constant. So long as everyone agrees on its straight line motion, its velocity must be the same constant for everyone.

Now the question arises, does the Newtonian mechanics permit such a universal velocity which is the same for all observers irrespective of their relative motion? Obviously not because the law of addition of velocity reads as $w = u + v$ where u is the velocity of a particle relative to an observer who is moving with velocity v relative to you. According to this law w can never be equal to u unless $v = 0$.

If there exists in Nature a physical entity which propagates in a straight line in all directions, it cannot be accommodated in the Newtonian mechanics and we will have to seek a new mechanics.

Inertial frame (IF) is a frame which is free of all forces. It is a measure of zero force. All interactions/forces will be measured relative to it. It is therefore of fundamental importance to actually realise such a frame. There are four basic forces in Nature, two of which are short range nuclear forces while electromagnetic and gravitation are long range. One doesn't have to worry about nuclear forces, while it is possible to shield electromagnetic force by proper prescription of charges and currents but it is impossible to shield gravity. Any rearrangement of matter distribution will not be able to remove gravity because unlike electromagnetic field which is both attractive as well as repulsive, it is always attractive. That means it is impossible to realise IF in practice.

Not quite so. Galileo made a fundamental discovery by dropping two unequal mass bodies of different composition that gravity is a truly democratic force it pulls everything equally irrespective of its mass and composition. This gives a remarkable message that gravity can be removed locally by letting the frame fall freely along with everything else. Two freely falling particles will have uniform relative motion between them which is the indication of absence of force between them. This region could only be local, freely falling lift, because all particles fall towards a point, the centre of force. The extent of the force free region is determined by the degree of accuracy required for force freeness.

We thus come to the conclusion that IF could exist only locally. We can only obtain LIFS (local IFs) in actuality and there can exist no global IF. With this the first law of motion would state that all LIFs are equivalent for investigation of any physical phenomenon.

Let us once again bring back the thing which has universal constant velocity relative to all observers. Gravitation is also universal force and hence it must act on everything. The only measure of action of any force is the change it produces in velocity of the particle being acted upon.

The key question is how to make the thing that has universal constant velocity feel the gravitational force, because its velocity cannot change. The incorporation of the universal constant velocity in mechanics asked for new

mechanics, and now the incorporation of such a particle's interaction with gravitation asks for a new theory of gravitation.

We have thus argued that the Newtonian world is unsustainable if a particle of universal constant velocity does exist in Nature, and we have to seek new world which we call Relativistic.

2. Living with Light

Light is in fact that thing which is, even in the Newtonian world, supposed to move in a straight line in all directions. Hence its velocity must be constant for all observers. It is important to note that we have reached this important inference of constancy of velocity of light within the Newtonian framework without reference to light being an electromagnetic wave propagating in an all pervading medium called vacuum. And this fact is in direct conflict with the Newtonian mechanics. This logical inconsistency had lived with the theory over 300 years until the beginning of the previous century.

2.1 Special Relativity

The incorporation of universal constant velocity of light gives rise to the relativistic mechanics, known as the theory of special relativity. It approximates to the Newtonian mechanics when velocities involved are small compared to the velocity of light. This was the reason that we could live with the inconsistency of principle for so long because we did not encounter velocities comparable to velocity of light which could expose the inconsistency in observation. Since the velocity of light is a universal constant, it binds space and time into a synthetic entity spacetime. That is, we cannot confine anything solely to space or to time, and all physical happenings happen in spacetime. For instance, distance could be measured in seconds, distance traveled by light in so many seconds, and conversely time in metres, time taken by light to travel so many metres.

The immediate consequence of this synthesis is the path dependence of time. It is common knowledge that the distance between two points depends upon the path you take to go from one point to the other. Since there now exists the equivalence between space and time, whatever happens to space mea-

surements must happen to time measurements. Consider the time interval between taking off a spaceship and its landing back after a space voyage. The time interval between these two events would be different in the ground based clock and the spaceship borne clock. Since the two clocks take different paths between the two events, they must read differently because like distance time interval is also path dependent. There is nothing unusual in it except that such a situation does not occur in our daily living. That is why it is not so familiar. An immediate corollary follows, the absolute simultaneity is untenable for spatially separated events because the signal of their occurrence would in general reach different observers at different times. The events would be simultaneous only for an observer who is equidistant from the two events.

Further it leads to the equivalence of mass and energy indicated by the famous equation, $E = Mc^2$, whose practical and devastating power has been demonstrated by the atomic bomb. The name of Einstein, the creator of the relativistic mechanics, has become synonymous with this equation and to his horror and discomfort inseparable from atom bomb.

At the basic paradigm level we move from 3-dimensional space and 1-dimensional time to the 4-dimensional spacetime. That is, we live in a 4- dimensional Universe. This is a major step forward.

2.2 General Relativity

Gravitation is universal and hence it must interact with everything including light. The question is how to make it interact with light because its velocity cannot change. Here we are faced with a contradiction in principle. Light must feel gravity yet its velocity must not change. In the conventional framework, one can't feel force without its velocity changing. What is required of light is that it should bend as it grazes close to a massive body. Could it be achieved without changing its velocity?

Consider a piece of wood floating in a river. It bends as the river snakes along. Could a similar happen to light. It propagates in space, and the only way light can bend is that space bends. That means gravity must bend/curve space around a massive body so that light could automatically bend. We have

now made another very profound discovery that gravitational field must curve space, and since space and time have already been synthesized, it must curve spacetime. That is the only way to describe gravitation honestly is through the curvature of spacetime. A very radical and revolutionary conclusion. The study of gravitation through the curvature of spacetime is known as general relativity. Once again, this contradiction in principle was not appreciated until 1916. There has emerged no significant new fact about gravitation that has asked for a new theory. It was only a matter of principle which was true even in Newton's time. Had it not been for Einstein's unflinching adherence to principle it would have perhaps been not addressed until much later. This gives a good measure of Einstein's character and priority in science.

Note that what the British astronomer, Eddington measured at the time of total solar eclipse in 1919 was not the bending of light but rather bending of space around the Sun by its own gravity. It is like we see the Sun going round the Earth but in fact it is the other way round. Similarly we though see the light bending but it is in fact the space bending. Gravity produces curvature in spacetime and motion under gravity is simply free motion (of both particles and light) relative to the curved spacetime.

We have now achieved a grander and profounder synthesis of spacetime with gravitation which is produced by matter, and hence of spacetime and matter. This is something new for physics. No other force makes such a demand on spacetime. For all other forces spacetime background is given and it is neither affected by nor does it affect. Gravity radically changes this paradigm, it works through spacetime curvature. Spacetime no longer remains an inert background but becomes dynamic which is essentially the dynamics of gravitational field.

3. Relativistic World

First the universal character of light velocity led us to binding of space and time into spacetime and to the relativistic mechanics called special relativity. Next light's interaction with gravity could only be mediated through curved space. We can say that light bends space. Gravitation can hence only be described by the spacetime curvature and this description is called general relativity (GR). It ceases to be an external force but instead becomes the

property of spacetime geometry.

Relativistic world is characterized by the synthesis of universal entities of space, time, velocity of light and gravitation (matter). The important lesson we learn from this is that all that which is universal must be synthesized. Never mind even if it requires endowing space and time with curvature, a very unusual phenomenon. Spacetime encompasses everything in the Universe. That is the nature of spacetime structure is determined by the matter energy distribution in the Universe. It is therefore no surprise that GR, which is a theory of gravitation as well as of spacetime, should admit the question of beginning of time;i.e. beginning or birth of the Universe (spacetime). It is a perfectly physics question which of course has philosophical overtones.

The Universe becomes a natural arena for application of GR and the study of the Universe of as a whole is called cosmology, which what is the subject matter of discussion for this workshop. The two most remarkable predictions of the Relativistic World are the beginning of the Universe in an explosive Big Bang and the death of a massive star in a black hole. A black hole is a highly compact object producing very high field which in turn curves space around it so confiningly that even light cannot propagate out of it (Recall that light can only move along the space curvature). Since light cannot come out of black hole, nothing else could as well. It is an object whose boundary surface has turned one way, things can go into it but nothing can come out. No information can come out from inside of it.

When a massive enough star has exhausted its nuclear fuel so that its own gravity could not be checked, it shrinks without limit to form a black hole. It would contain inside it a singular state where physical parameters become infinite. Similar is the case at the big bang.

4. End of everything

The breakdown of theory is called by the beautiful name of singularity. It indicates a situation where physical parameters of the theory become untenable by attaining infinite values. For singularity in GR would mean spacetime curvature along with energy density becoming infinite. It would mark breakdown of spacetime curvature. The singularity in GR not only marks the end

of GR, but also of everything else. No other physical theory or structure can survive in absence of the proper spacetime background. Thus like gravity its singularity is also universal.

5. Looking ahead

Gravity is a universal interaction and it is therefore not a force like other forces but is a property of spacetime structure of the Universe. The question is how do we address the singularity in the structure of spacetime, indicating its breakdown not only for description of gravity but also as background for all physical phenomena. It indicates the end of everything, and should the answer of it be the Theory of Everything? So do the proponents of the string theory claim. The string theory is one of the proposals for a covering theory to GR which is vigorously being pursued. It proposes in principle a grand vision of synthesis of all forces, quantization of gravity and origin of matter in the Universe. All this is supposed to happen in 10 dimensions. The extra space dimensions are supposed to be compact and manifest only at a very high energies. GR would be the low energy limit of the theory. There is however no natural and unique way to come from 10 to 4 dimensions.

The other approach is that of canonical quantum gravity a la Abhay Ashtekar et al. How to tailor spacetime geometry so that it becomes amenable to quantization? It is essentially the quantization of spacetime geometry. New mathematical tools and constructs as well as new concepts are being developed so as to handle discretization of inherently continuum structure of spacetime. They are in fact evolving quantum geometry. This proposal remains confined to the familiar 4-dimensions.

Both the approaches have about equal share of success, for instance in understanding black hole entropy to some extent. Yet they have both long way to go. The string theory has a strong backup of the large particle physics community while the canonical quantization is pursued mainly by a small group of relativists. The two approaches are quite different, the former relies on the field theoretic techniques and concepts while the latter on the geometric constructs. The two will have to converge as they asymptotically approach the ultimate theory of spacetime, which may or may not be a theory of everything! At any rate, one thing is certain that we do need a new theory

which could be string theory or canonical quantum gravity, or something else!

Let us try to see into the unknown on the basis of wisdom gained from our past experience. From Newton to Einstein, the guiding force was light, its constant speed and its interaction with gravity. The latter required space to be curved. On the basis of these simple facts, we could argue that gravitational potential should not only give the acceleration to ordinary particles but also curve space for photons to feel gravity. Since acceleration is given by gradient, constant potential has no dynamical effect. Photons through space curvature directly feel the potential and hence they are sensitive to its value. Therefore constant potential is not ignorable as it does produce non-zero curvature. The Einstein theory has thus to determine in contrast to the Newtonian theory potential absolutely. The journey from old to new theory is always of synthesis. It is the good old Newtonian potential with its zero fixed at infinity. This is a new synthesis.

Further, as there exists the escape velocity threshold for timelike particles, there should also exist a similar threshold for photons. Photons cannot turn back like ordinary particles, the only way they could be kept bound to a gravitating body is that they are not let to propagate out of a compact surface. Since photons define the limiting threshold for propagation of any physical information, from such a surface nothing can come out. It then becomes a oneway surface defining the horizon of a black hole. The existence of black hole then becomes a natural requirement the moment we have photons to contain.

Such profound and distinguishing features of GR could be deduced in principle without reference to the full theory.

The point I wish to make is that it should always be possible to anticipate and deduce some of the features of the new theory. Now when we wish to go beyond Einstein in the high energy regime, what kind of new features could one expect? Unfortunately, there does not seem to be anything like light showing us the path. One possible entity for synthesis is gravitational field energy like the gravitational potential in the Newton-Einstein synergy. In GR, it only manifests through the space curvature. In the high energy limit, could it happen that it becomes concrete like other matter fields. Perhaps it

may be the right direction to look for.

The measure of a theory is the kind of questions it admits. New theory admits questions that were not admissible in the earlier theory. For instance, it is a valid question to ask in GR, when did the spacetime (the Universe) begin? And the answer is that it had its explosive birth in hot big-bang about 15-20 billion years ago. The next question in this series for the new theory to answer would be, what is the spacetime made of? That is the fundamental question which should be answered by the new theory.

A fundamental theory also has an impact on the world view. The view that has gained acceptance amongst people at large. For instance, the fact that the earth is not flat but is a curved surface like a ball has been internalized and assimilated in the knowledge base of the present day society. At a slightly higher degree of abstraction, the fact that material bodies attract each-other by an invisible force of gravity has also descended down to the common knowledge culture. The next step of advancement in the similar vein would be the assimilation of the fact that massive bodies curve the space around them. That is the abstract spacetime manifold (the Universe) we live in is not flat but is curved. One of the ways to measure this curvature is by measuring bending of light when it grazes a massive body like a star. Thus the geometry of spacetime should be of as general a concern as the geometry of the planet earth we live on. The only difference is that the former is an abstract entity while the latter is the concrete rock and sand.

Like gravity social interaction is also universal and of great consequence for our existence and well being. It should thus also attract collective concern and attention of all of us with utmost seriousness and commitment. We should never forget the fellow citizens who have been contributing from their honest earnings for our upkeep as well as for the facilities we use for our work. Apart from contributing to the knowledge base by our work in our specific discipline, as persons of learning and more importantly practitioners of scientific method we also owe to the society a studied and responsible participation in the discourses on the issues of wider social relevance.

Let us try to emulate the basic gravitational property of interaction with one and all, and come closer. If this is realised in the true spirit of both

science and society, there is a good reason for hope for harmony, peace and an enlightened world community. This is a matter of gravity for one and all, once again a universal pronouncement of profound significance and value.

I close by quoting Ghalib, the great Urdu poet of the 18th century.

کیا فرض ہے کہ سب کو ملے ایک سا جواب
آؤ نہ ہم بھی سیر کریں کوہ طور کی

क्या फ़र्ज़ है कि सब को मिले एक सा जवाब
आओ न हम भी सैर करें कोहे तूर की

kya farz hai ki sab ko mile ek sa jawab
Ao na ham bhi sair karen koh-e toor ki.