Variations of a grand gravitational theme:
Dynamics, Equivalence Principle, Universality of Free Fall and the Principle of Relativity

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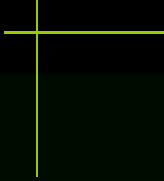unni@tifr.res.in

LIGO-India Project

The LIGO-India proposal is to build and operate the third aLIGO detector in India, with components and hardware originally meant for one of the US aLIGO detectors. Thus the LIGO-India detector will be the third vertex of the aLIGO network, working like a large gravitational wave telescope.

Possibility of strong revival of experimental gravitation in India

The IndiGO Consortium

www.gw-indigo.org
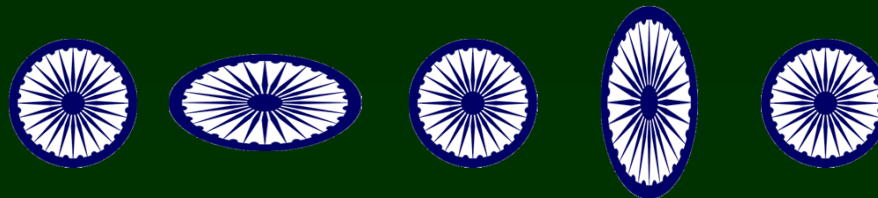
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HENRI POINCARÉ

ON THE DYNAMICS OF THE ELECTRON

(Poincare, 1900, 1904)

It appears that this impossibility to detect the absolute motion of the Earth by experiment may be a general law of nature; we are naturally inclined to admit this law, which we will call the *Postulate of Relativity* and admit without restriction.

Lorentz's idea may be summed up like this: if we are able to impress a translation upon an entire system without modifying any observable phenomena, it is because the equations of an electromagnetic medium are unaltered by certain transformations, which we will call *Lorentz transformations*. Two systems, one of which is at rest, the other in translation, become thereby exact images of each other.

Principle of Relativity

It is known that Maxwell's electrodynamics -- as usually understood at the present time -- when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena... Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the `light medium' suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest.

They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.

We will raise this conjecture (the purport of which will hereafter be called the `Principle of Relativity') to the status of a postulate...

(Einstein 1905)

(Newton's) Law of Dynamics

AXIOMS, OR LAWS OF MOTION (from Newton's Principia, Eng. Translation 1729)

LAW I.
Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.

LAW II. The alteration of motion is ever proportional to the motive force imposed ; and is made in the direction of the right line in which that force is impressed. If any force generates a motion, a double force will generate double the motion, a triple force triple the motion, .

LAW III. To every action there is always opposed an equal reaction : or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.
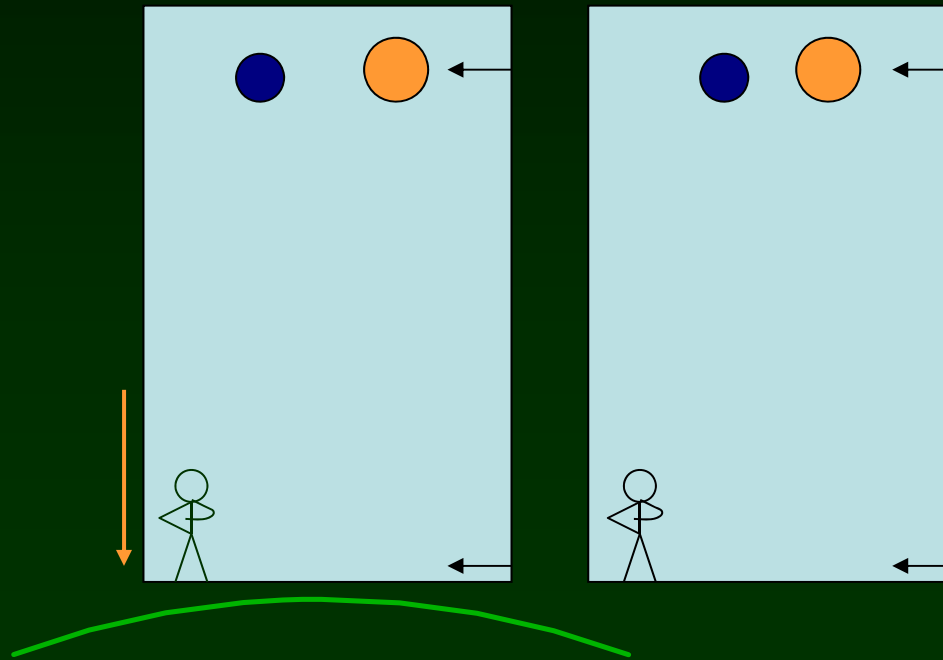
Equivalence Principle

a) The postulated equivalence of 'inertia' and the charge of gravity (expts.)

b) The postulated equivalence of a uniform gravitational field and a uniformly accelerated frame.

$$\vec{F} = m_g \vec{g}$$

$$\vec{a} = \vec{F} / m_i$$

$$\vec{a}_g = \left(\frac{m_g}{m_i} \right) \vec{g} \equiv \vec{g}$$

Inertia is identical to the gravitational charge

Principle of Relativity, Relativistic Effects, Dynamics (in general frames), Equivalence Principle, Universality of Free Fall.

All of these have the same content and origin. They are consequences of the nearly homogenous and isotropic distribution of matter and its gravity in the universe.

Universe with all its matter content and gravity existed ages before we started making our theories…

All our fundamental theories of the physical world were completed well before we acquired ANY significant knowledge about the physical universe, its content and its long term evolution.

In particular, the theories of relativity and dynamics (including QM) as well as the theory of gravity were developed assuming an EMPTY universe.

However, the gravitational potentials of the matter in the universe is a billion (10^9) times larger than our local potentials, and if these have any say in dynamics, then we have completely missed that out in our theories. All our experimental tests, in contrast, are in the unavoidable presence of cosmic gravity.

So, empirical evidence includes all cosmic gravitational effects, whereas fundamental theories, as constructed, do not – A reconsideration becomes essential.
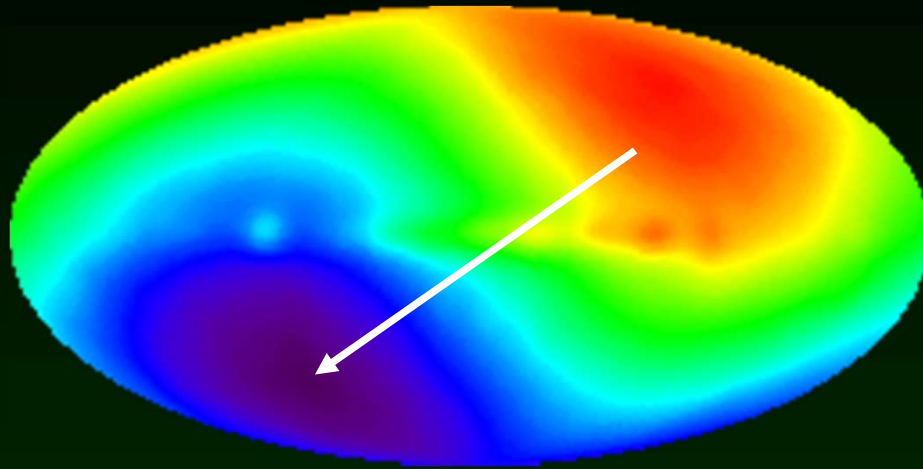
300 Million
Light years
(up to Coma)

10 Billion
Light years
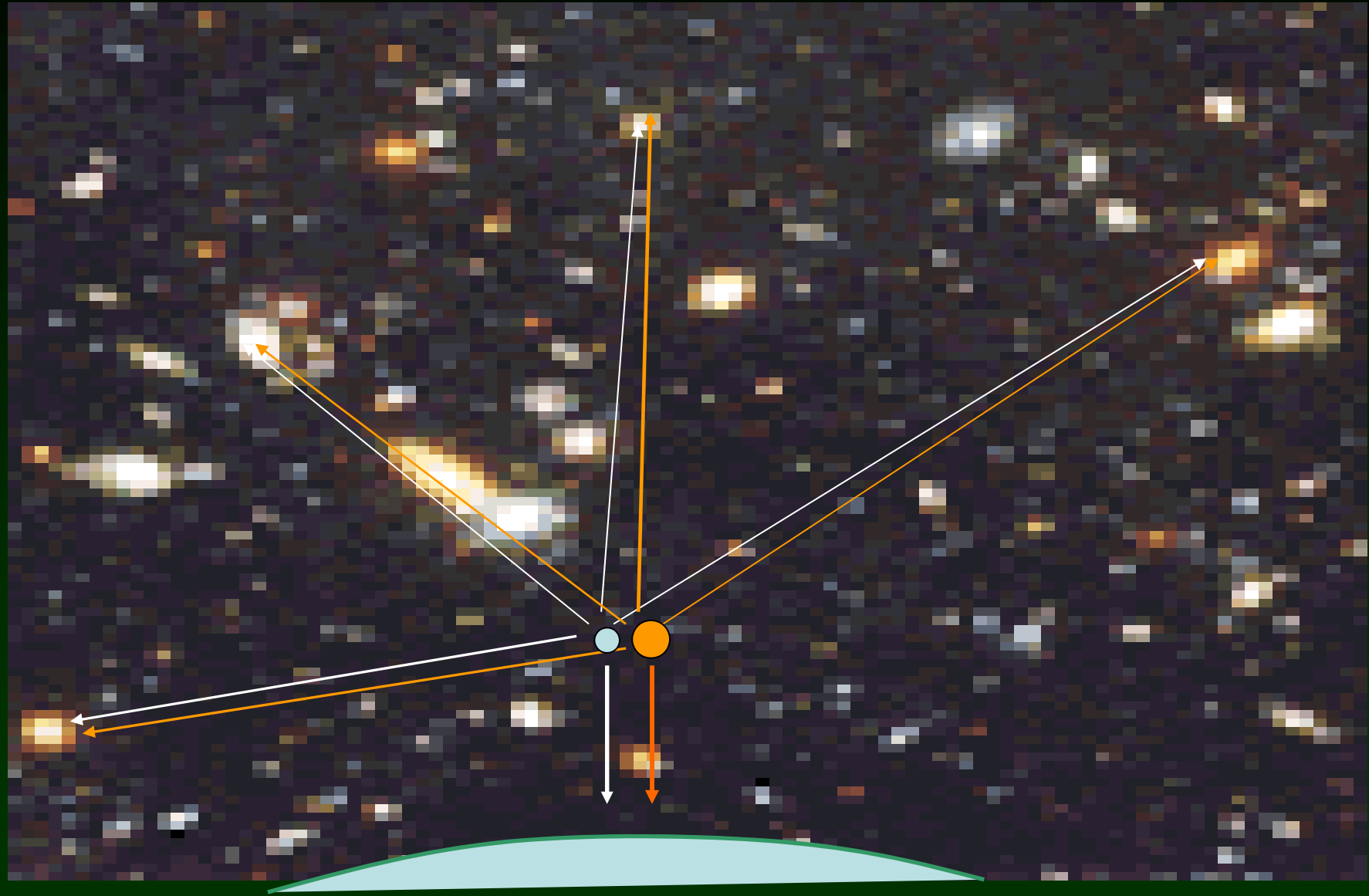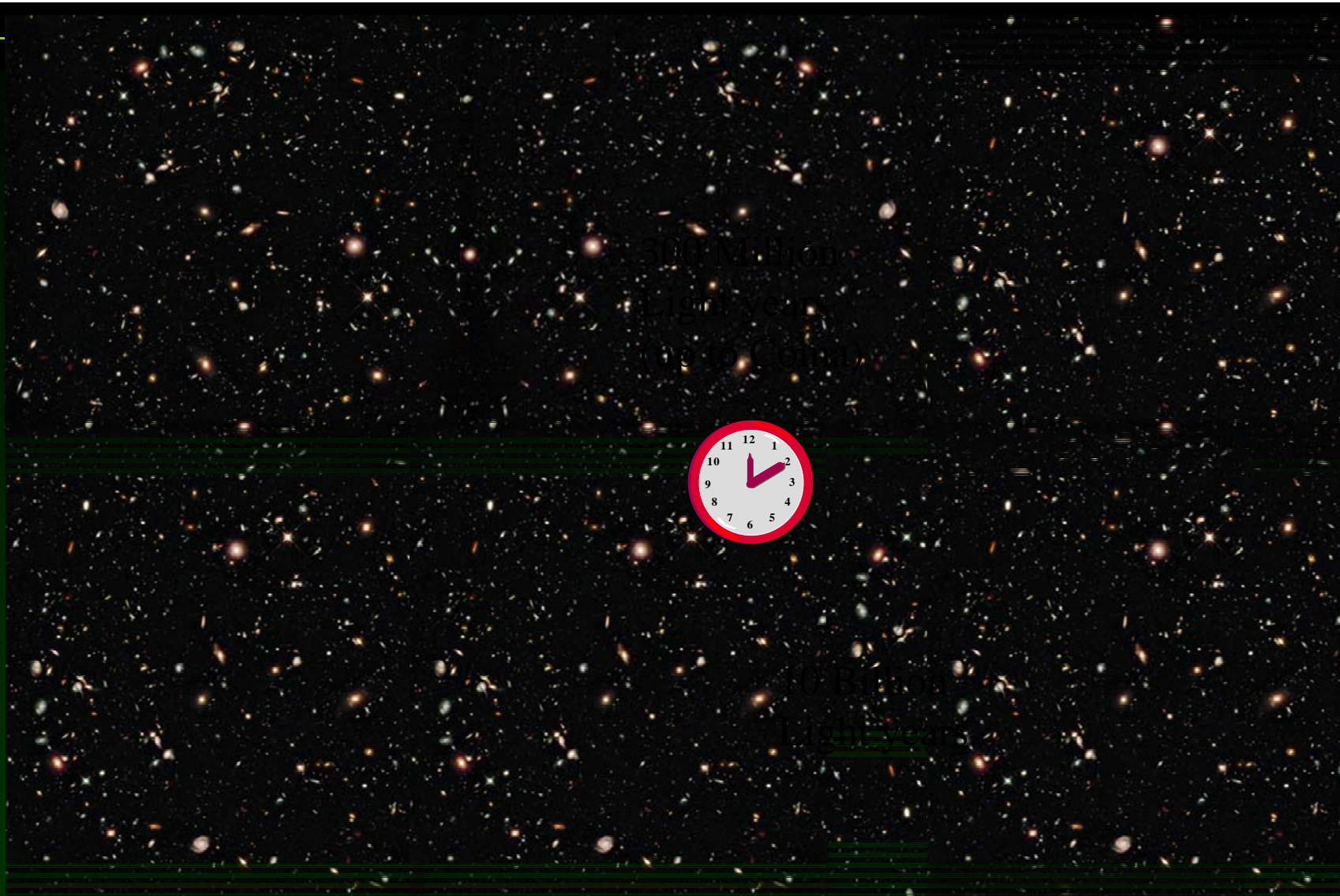
$$\Phi_U \approx \int_{All\,Galaxies} G \cdot (4\pi\rho R^2 dR)\,/\,R \approx 2\pi G\rho R^2{}_H$$

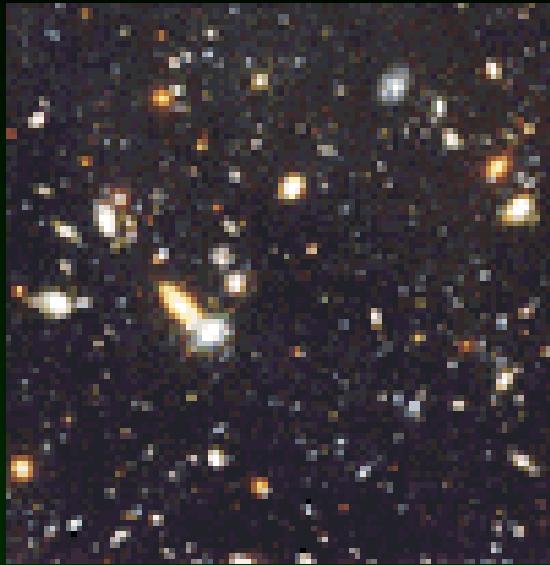# Moving through the Universe and its CMB marker
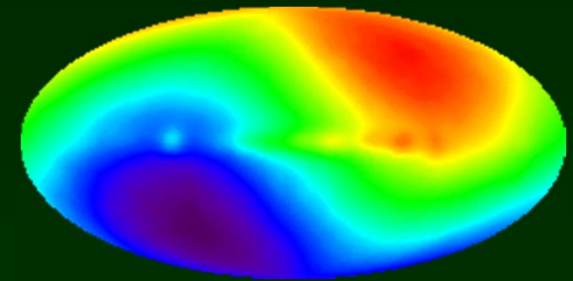

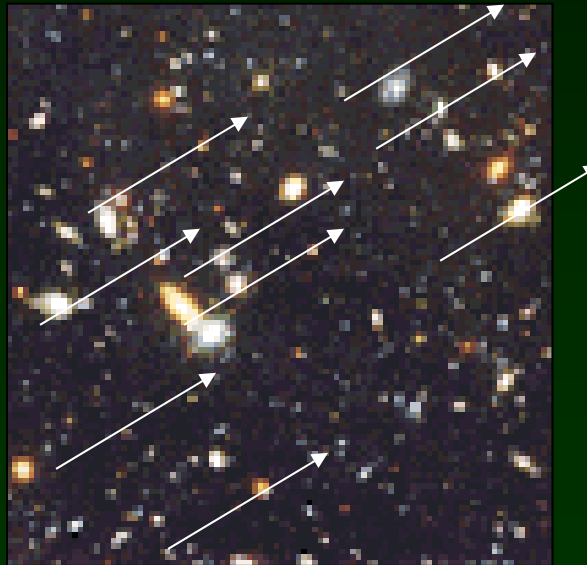Absolute velocity

Absolute (universal) time
Same as average T

Every observer can decide whether he is moving or not, and all clocks in the universe can be synchronized to this temperature.

Universe with matter and radiation

There is ONE special frame in which V=0

In all other frames,

SPACE is anisotropic in the frame of a moving observer.
There is a large current of matter (the charge of gravity)

$$
\begin{bmatrix}
g_{00} = -1 & g_{01} = 0 & 0 & 0 \\
g_{10} = 0 & g_{11} = 1 & 0 & 0 \\
0 & g_{21} = 0 & g_{22} = 1 & 0 \\
0 & 0 & 0 & g_{33} = 1
\end{bmatrix} + L(v_r : x, t) \rightarrow
$$

$$
\begin{bmatrix}
g_{00} = -1 & g_{01} = 0 & 0 & 0 \\
g_{10} = 0 & g_{11} = 1 & 0 & 0 \\
0 & g_{21} = 0 & g_{22} = 1 & 0 \\
0 & 0 & 0 & g_{33} = 1
\end{bmatrix}
$$

Isotropic Empty space remains isotropic and empty after Lorentz transformations on coordinates

But, space is NOT empty…

A physical and logically consistent boost transformation should have returned an anisotropic homogenous metric, reflecting the symmetry of the transformed space.

$$ds^2 = -dt^2 + a^2(t)\{dx^2 + dy^2 + dz^2\}$$

In a frame moving through this matter filled universe, there is a large matter-current and space is ANISOTROPIC

$$x' = x - Vt, \quad t' = t \rightarrow$$

$$
\begin{bmatrix}
g'_{00} = -(1 - v^2/c^2) & g'_{01} = v/c & 0 & 0 \\
g'_{10} = v/c & g'_{11} = 1 & 0 & 0 \\
0 & g'_{21} = 0 & g'_{22} = 1 & 0 \\
0 & 0 & 0 & g'_{33} = 1
\end{bmatrix}
$$

Galilean boost gives the physically consistent metric – flat and anisotropic

$$
\begin{bmatrix}
g'_{00} = -(1 - v^2/c^2) & g'_{01} = v/c & 0 & 0 \\
g'_{10} = v/c & g'_{11} = 1 & 0 & 0 \\
0 & g'_{21} = 0 & g'_{22} = 1 & 0 \\
0 & 0 & 0 & g'_{33} = 1
\end{bmatrix}
$$

Both time dilation and length contraction follows from this anisotropic transformed metric, with 'absolute velocity' (velocity relative to the cosmic frame) in the Lorentz factors instead of relative velocities.

Gravitational potential "here"

Earth: $\dfrac{GM_E}{c^2 R_E} \sim 10^{-9}$

Sun: $\dfrac{GM_S}{c^2 R_S} \sim 10^{-8}$

Galaxy: 10^{-6}

Distant masses dominate!

$$\Phi_{gU} \approx 10^{17} \ \mathrm{m}^2/s^2$$

$$\Phi_{gE} \approx 10^8 \ \mathrm{m}^2/s^2$$

$$\sqrt{1 - \dfrac{v^2}{c^2} \dfrac{v^2}{\Phi_U}}$$

$$\Phi_{gU} \approx c^2 !$$

300 Million
Light-years
(Virgo Cluster)

10 Billion
Light-years

$$\Phi_U \approx \int\limits_{All\,Galaxies} G \cdot (4\pi\rho R^2 dR)/R \approx 2\pi G \rho R^2{}_H$$

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0 & g'_{21} = 0 & g'_{22} = 1 & 0 \\
0 & 0 & 0 & g'_{33} = 1
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$$

Galilean boost gives the physically consistent metric – flat and anisotropic

Cosmic Relativity:

Cosmic Gravity, or Gravitational potentials due to all the matter in the universe, determine ALL dynamics and relativistic phenomena, including time dilation, length contraction, propagation of light and its maximum speed etc.
Cosmic gravity determines Principle of relativity and the law of motion, and the Principle of Equivalence is its direct consequence.

Unnikrishnan,
gr-qc//0406023, 0406043
in Advances in Theoretical Physics (World Scientific, 2008)
in Physical Interpretations of Relativity Theory (2006)
Int. Jl. Mod. Phys. (2014)
Cosmic Relativity: Dynamics and Relativity in the once-given Universe, Physics monograph (2015)

Some Immediate Results

Dynamics and Relativity from Cosmic Gravity

$$\vec{A}_G = \frac{\vec{v}}{c}\Phi_U \rightarrow (\frac{\vec{v}}{c\sqrt{1-v^2/c^2}}\Phi_U) = \gamma\vec{v}\frac{\Phi_U}{c}$$

Principle of Relativity as unobservability of this 'gauge' potential.
Same as statement of Lorentz/Galileo Invariance or invariance under boosts.

$$\vec{F}_G = -\frac{m_g\,\partial\vec{A}_G}{c\,\partial t} = -\frac{m_g\Phi_G}{c^2}\left(\frac{d\vec{v}}{dt}\gamma + \gamma^3\vec{v}(\vec{v}\cdot\vec{a})\right): \quad \text{Faraday-Lenz}$$

$$\gamma m a_\perp + \gamma^3 m a_\parallel$$

$$F = m_g\frac{\Phi_U}{c^2}\vec{a} = m_i\vec{a}$$

NEWTON'S LAW FROM COSMIC GRAVITY
It is already relativistic and 'gravito-magnetic'

$$\vec{p} \leftrightarrow m_g\vec{A}_g \rightarrow \vec{F} = \frac{d\vec{p}}{dt}$$

$$F = m_g \frac{\Phi_U}{c^2} \vec{a} = m_i \vec{a}$$

NEWTON'S LAW FROM COSMIC GRAVITY
It is relativistic and 'gravito-magnetic'
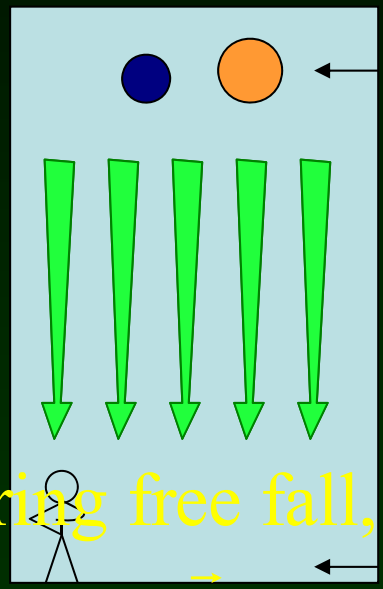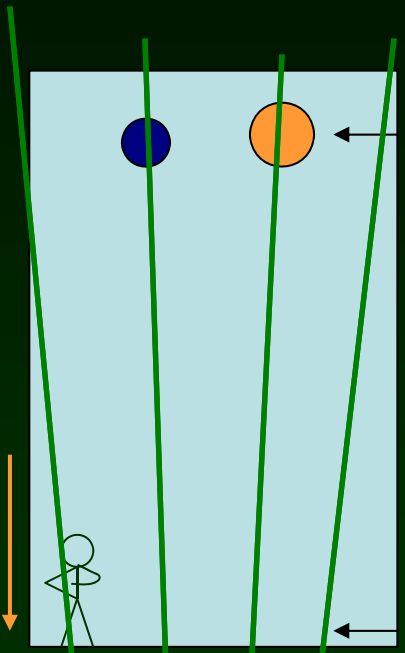
$$m_i / m_g = -\Phi_U / c^2$$

EQUIVALENCE PRINCIPLE FROM COSMIC GRAVITY

If dynamics respects Newton's law it respects Equivalence principle as well!

Enormous implications for experimental tests - for example, antiparticles…

The result that Newton's law of motion and the WEP have exactly the same cosmic gravitational origin and physical content implies that all test systems that follow Newton's law in any experiment (even in non-gravitational fields) also obeys the WEP, to the same accuracy!
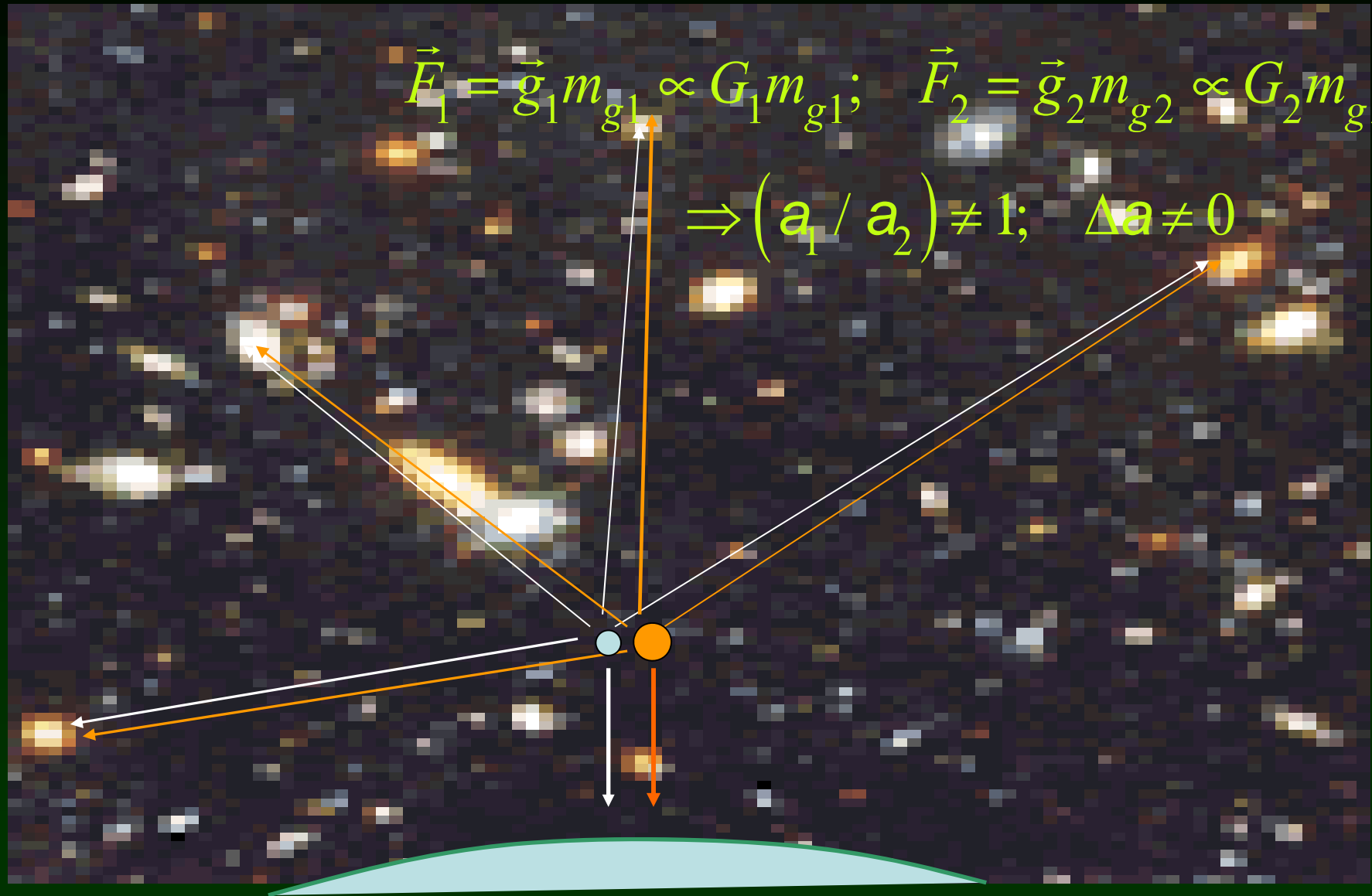
C. S. Unnikrishnan, Int. Jl. Mod. Phys. (2014)

During free fall,

$$\vec{\nabla}\phi_l = -\frac{d\vec{A}_U}{dt}; \quad \vec{A}_U = v(t)$$

$$\vec{F}_1 = \vec{g}_1 m_{g1} \propto G_1 m_{g1}; \quad \vec{F}_2 = \vec{g}_2 m_{g2} \propto G_2 m_{g2}$$

$$\Rightarrow (a_1 / a_2) \neq 1; \quad \Delta a \neq 0$$

$$\vec{a}_g = \left(\frac{m_g}{m_i} \right) \vec{g} \longrightarrow G_j$$

$$\vec{F}_G = -\frac{m_g}{c} \frac{\partial \vec{A}_G}{\partial t} = -\frac{m_g \Phi_G}{c^2} \frac{d\vec{v}}{dt} \equiv m_i \vec{a}$$

FF experiment does no detect a composition-dependent G in this case (long range)

Even if G is composition dependent, universality of free fall could be intact!

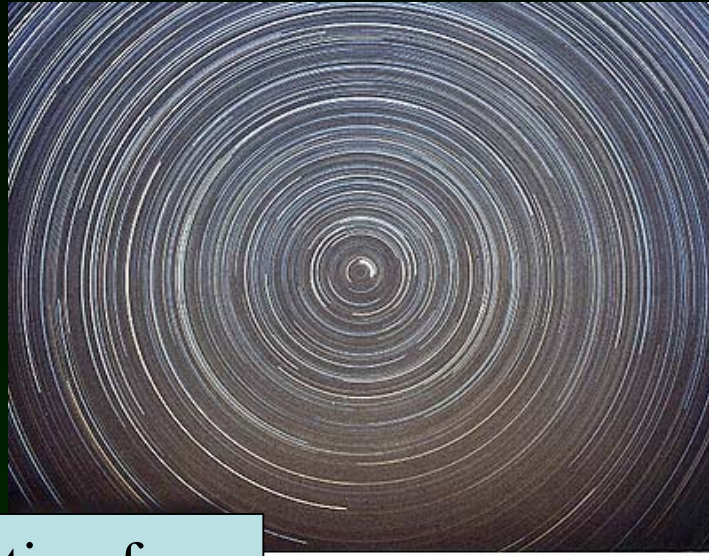The relativistic action for the free particle

$$S = -mc \int ds$$

$$S = -mc^2 \int ds / c = -mc^2 \int (1 - v^2 / c^2)^{1/2} dt$$

$$ds^2 = g_{ij} dx^i dx^j \rightarrow ds = g_{ij} p^i dx^j = p_j dx^j$$

$$\text{Phase } \Phi = \tfrac{1}{\hbar} \int m_g c \, ds = \tfrac{1}{\hbar} \int p_i dx^i \rightarrow \tfrac{1}{\hbar} \int E \, dt - p \, dx$$

Other obvious cosmic gravity effects (speculated and even calculated earlier)

Universe in rotating frame

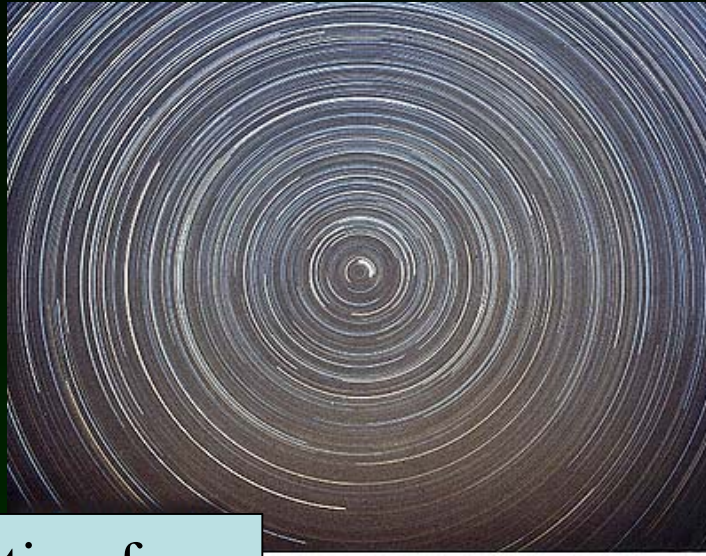Currents of mass generates a vector potential.

'A' changes direction…

$$\frac{d\vec{A}}{dt} = \frac{\Phi_U}{c^2} v \frac{d\vec{v}}{dt} = v \frac{2\pi}{(2\pi r / v)} = \frac{v^2}{r}$$

Centrifugal force is clearly of cosmic gravitational origin

(Mach, Sciama…)

Other obvious cosmic gravity effects (speculated and even calculated earlier)

Spin Physics

$$E = \vec{s} \cdot \vec{B}_{gU}; \ \vec{\tau} = \vec{s} \times \vec{B}_{gU}$$

Universe in rotating frame

Currents of mass generate large vector potential

And its 'curl' is a strong gravito-magnetic field

$$B_{gU} \equiv \nabla \times \vec{A}_g = \frac{\Phi_U}{c^2} \nabla \times \vec{V} = 2\vec{\Omega}$$

Gravitational Lorenz Force $\vec{v} \times \vec{B}_g = 2\vec{v} \times \vec{\Omega}$

Coriolis forces are clearly of cosmic gravitational origin

Sagnac as integral over area of the interferometer loop.

Spin Physics

$$E = \vec{s} \cdot \vec{B}_{gU}; \ \vec{\tau} = \vec{s} \times \vec{B}_{gU}$$

Spin is the current of the charge of gravity and all spin-dependent dynamics and phases have a cosmic gravitational link.

Some results for quantum dynamics:

1) Origin (reason) for the spin-statistic connection - relative phase in the scattering amplitudes of two particles comes out to be the right ones for spin-statistics connection (gr-qc//0406043)

2) Thomas precession has cosmic gravitational contribution

3) Two new results → The fictitious field and its flux-quanta required for the Composite Fermions in fractional quantum Hall effect
→ Electron transport in chiral molecules and spin valves

Effective 'magnetic' fields (in the frame of the charged particle)

$$\mu \cdot B_f \Leftrightarrow s \cdot B_g^U \rightarrow g\mu_B B_f = \frac{\hbar}{2} B_g^U$$

With $\mu_B = \dfrac{e\hbar}{m}, B_f = \dfrac{m_g v}{er}$ ~ 4000 Tesla in chiral molecules !

All our theories are constructed and TESTED in the background gravity of the entire matter in the universe. There are no experimental tests in the absence of this cosmic gravity, and there will not be any that can avoid it. Therefore, ALL theories have to incorporate this EVER-PRESENT gravitational background a priori.

Einstein's equation needs an important correction.

$$R_{ik} - \frac{1}{2} g_{ik} R - \kappa T_{ik}^{(U)} = \kappa T_{ik}^{(M)}$$

Warning:
Removal gives the wrong theory

So the 'vacuum' Einstein equation is

$$R_{ik} - \frac{1}{2} R g_{ik} - \kappa T_{ik}^{(U)} = 0 \text{ and not } R_{ik} = 0$$

The gravitational effects of the entire matter in the universe determines, as an absolute frame with universal time, the laws of motion and all relativistic effects. With no postulates and assumptions, this paradigm gives us the principle of relativity, laws of dynamics, all measurable relativistic effects, and reveals the true nature of inertia and equivalence principle. Most importantly, it agrees with all experimental tests imagined till now.

The theory of Cosmic Relativity unifies Lorentz-Poincare and Mach.

It has several crucial predictions that are different from that of conventional relativity, touching on propagation light, electrodynamics of moving charges, transported clocks etc., and most of them are now experimentally verified. More experiments are in progress.

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Concluding remarks

The physics of dynamics and relativity is intimately related to and entirely determined by matter and and gravity of the universe.

Newton's law is shown to be cosmic gravito-magnetic induction, and the equivalence principle is just another statement of this fact.

Cosmic Relativity replaces all postulates and axioms of dynamics and relativity with gravitational consequences of the real observed universe.

A paradigm change in which the gravitational effects of the entire matter in the universe determines as an absolute frame the laws of motion and all relativistic effects based on motion relative to the cosmic frame, replacing completely the theory of relativity based on relative velocities, is natural and unavoidable.

The earlier this is recognized and discussed, the larger will be the gains for fundamental physics