From Clock Synchronization to **Conventionalistic Gravitation**

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Where is this lecture coming from?

Past lectures that I delivered at ISU to the MSS Class:

- 2025: Sagnac Effect – from Inertial Navigation to Cosmology
- 2024: Workshop on the Physical Theory of Quantum Positioning Systems
- 2023: Theory of relativity and satellite navigation

Before my lecture in 2025 I published a first article:

- N. Lori, C.J. de Matos, “Varying Newton gravitational “constant’’ cosmology”, Annals of Physics 478 (2025) 170014

After my lecture in 2025 I published a second article:

- C.J. de Matos, “Consequences of the Sagnac effect for Newton’s bucket experiment”, Next Research 5 (2026) 101337

- This lecture presents the latest developments of the scientific research that I published in Annals of Physics and Next research and became a new theory of gravitation which I designated by “Conventionalistic theory of gravitation” while preparing this lecture, and which I am currently consolidating /developing / questionning.

Conventionalistic physics

Conventionalistic principle:
The laws of physics are independent of clock synchronization.

Consequences:
1. It is impossible to measure the **one-way speed of light**
2. The **two-way speed** of light is invariant for all observers
3. There is no absolute **present moment → Spacetime** is four-dimensional
4. The coupling between spacetime and matter (G) is variable in order to preserve the **hypothesis of locality** and the **equivalence principle** (i.e. to preserve the covariance of spacetime curvature) and the **covariance** of the laws of physics

Theoretical outcome of using the Conventionalistic principle:
- Conventionalistic formulation of **Brans-Dicke theory** of gravitation **→ Conventionalistic Gravitation**
- Conventionalistic cosmology – **no absolute cosmological history**

Why do we need clock synchronization?

Key Idea:

To measure time consistently in a reference frame, clocks at different locations must be synchronized.

Problem:

- Events happen at different places.
- We need a common time reference.
- Signals take time to travel.

Einstein's solution:

Use **light signals** because

- **Two-way speed of light** in vacuum is constant $c = 3 \times 10^8\ [m/s]$.
- Einstein **additionally postulated** that the speed of light has the same value in all directions.

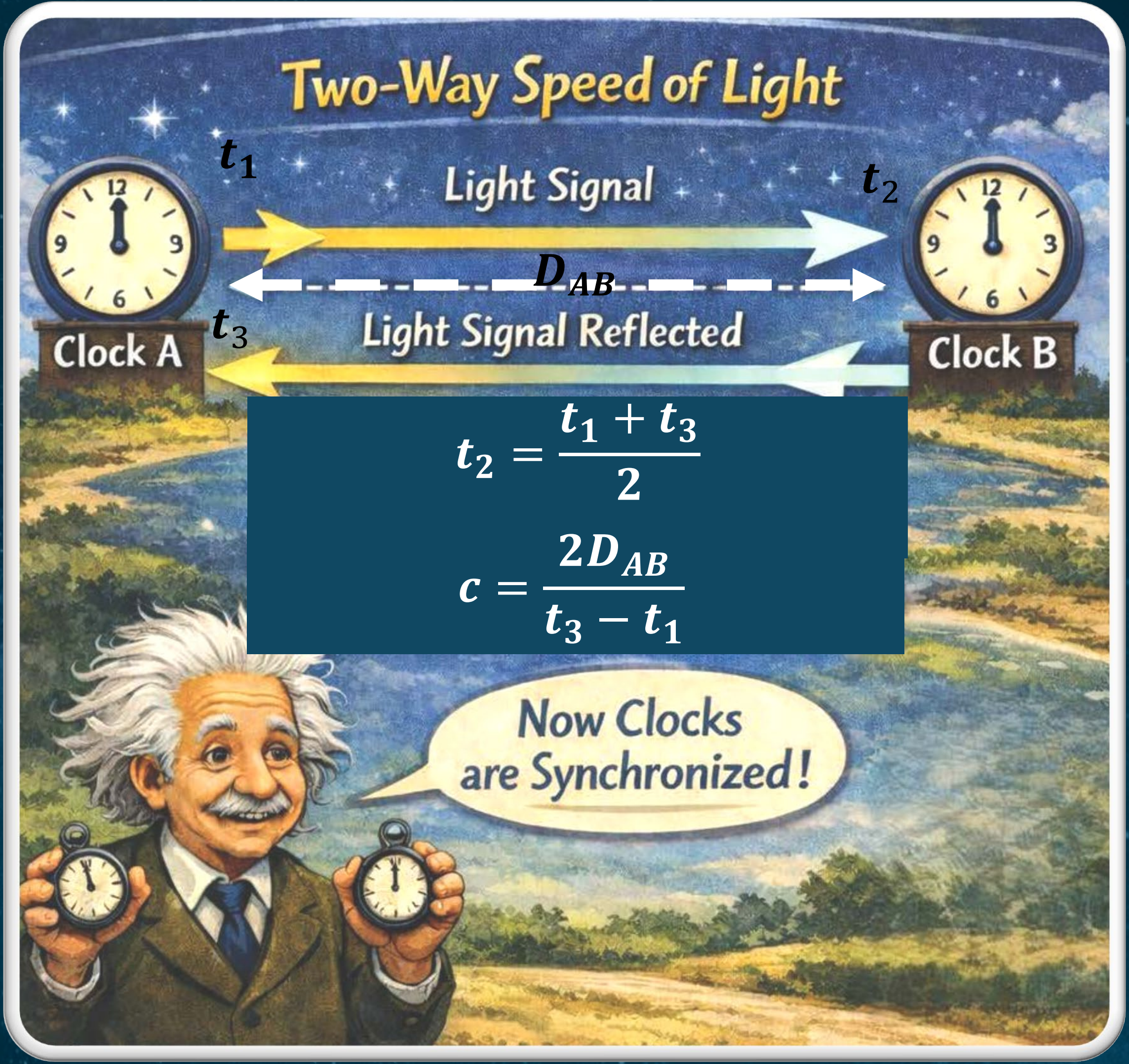
Einstein synchronization procedure

Key steps:

1. t_1 is the time reading at position A (clock A) when a light signal is sent to position B (clock B)
2. t_2 is the time reading at B when the signal arrives and is reflected
3. t_3 is the time reading at A when the signal reflected at B arrives at A

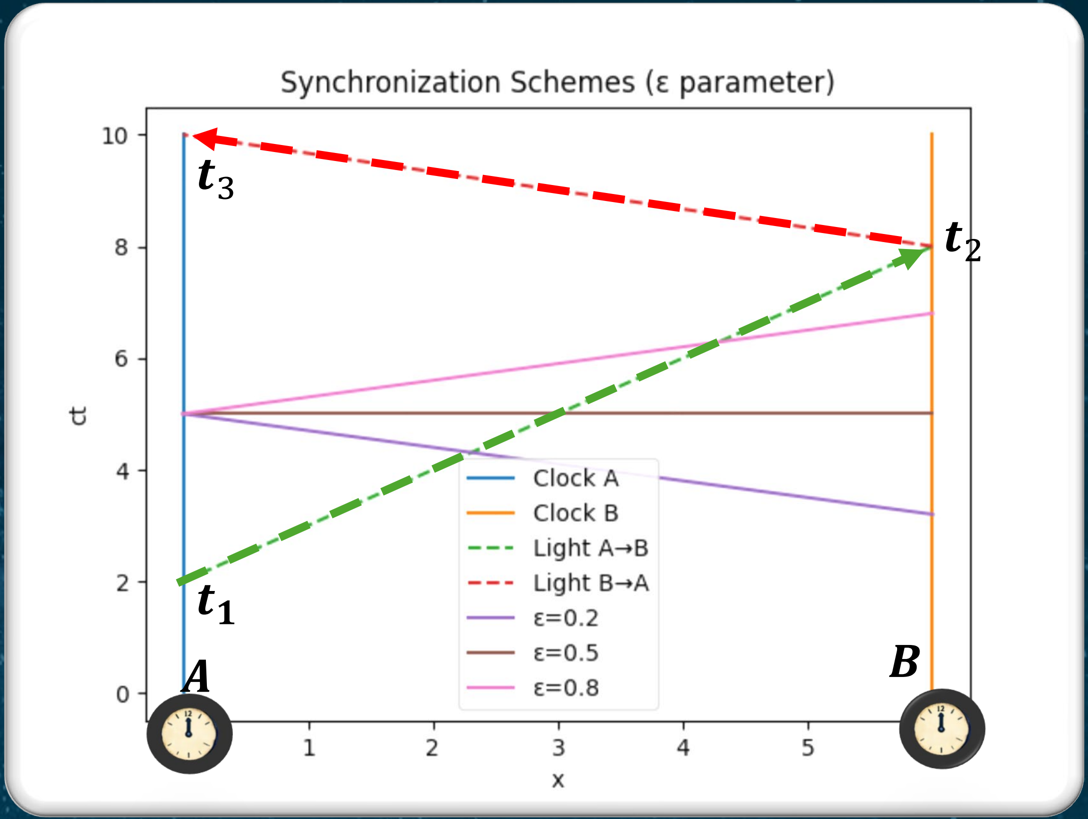
$$t_2 = t_1 + \varepsilon(t_3 - t_1)$$

- Any value $0 < \varepsilon < 1$ is equally valid
- **Einstein choose $\varepsilon = 1/2$** meaning that:
  - Travel time A → B equals travel time B → A
  - **One-way light speed** assumed identical both ways.
  - The formula for the speed of light *c* in the picture is the **two-way speed** of light

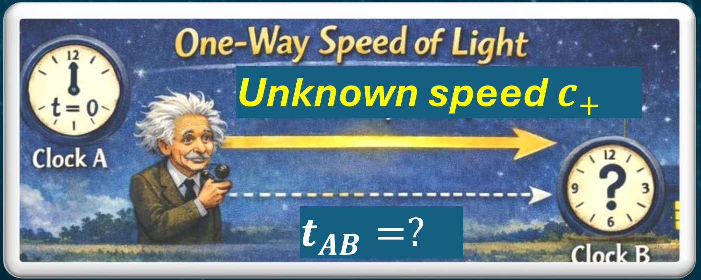


Minkowski Spacetime illustration of ε-synchronization schemes

- **Since light is the fastest causal chain, all events, or time points, occurring at A between t_1 and t_3 are excluded from causal connection with the event occurring at time t_2 in B. Therefore, anyone of these events may be called simultaneous with the latter event (B at t_2). This result formulates the relativity of simultaneity.**



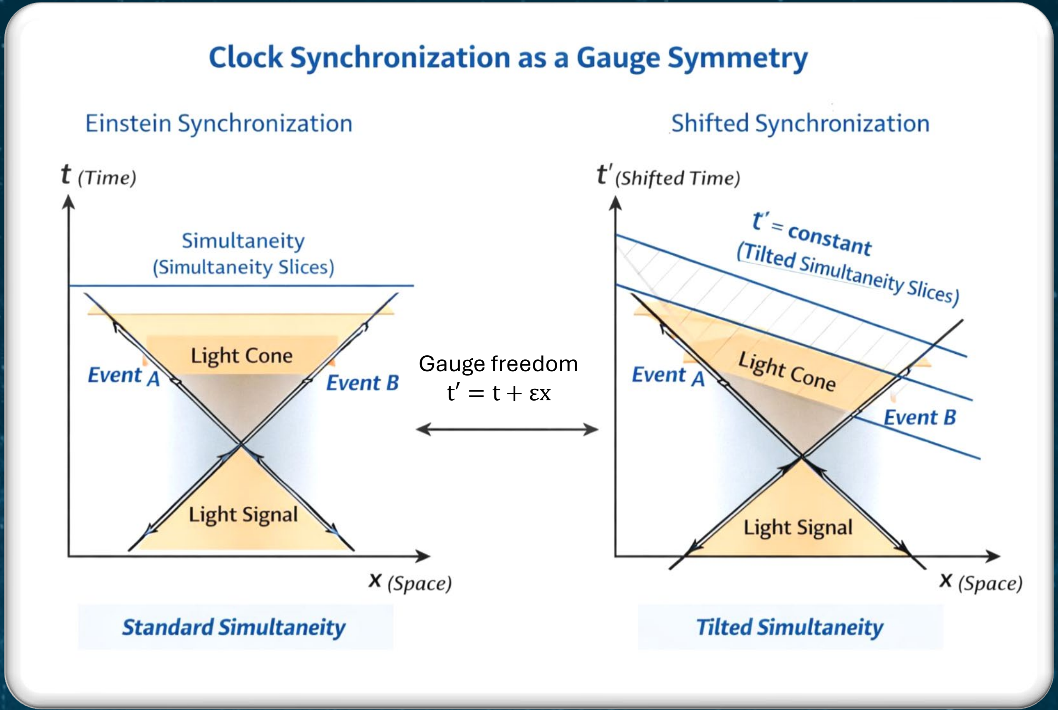
- One way speed of light from A to B : $c_+ = \frac{c}{2\varepsilon}$
- One way speed of light from B to A : $c_- = \frac{c}{2(1-\varepsilon)}$
- The ratio of these one-way speeds of light is $\frac{c_+}{c_-} = \frac{\varepsilon}{1-\varepsilon}$ and therefore, in the case of $\varepsilon \neq 1/2$ these one-way speeds of light are unequal. But no fact of nature would be contradicted if we choose values of $\varepsilon \neq 1/2$ because the two-way speed of light c remains invariant for all clocks / observers!
- **The one-way speed of light cannot be measured**



Simultaneity (the present) is a convention

- Definition of Simultaneity in a reference frame depends on the value of ε that we arbitrarily choose in that reference frame.
- Different observers may disagree on synchronized clocks.
- What is Simultaneous in one frame will not be simultaneous in another frame.
- We can adopt different definitions of simultaneity corresponding to different one-way speed of light, they are physically equivalent because the two-way speed of light is always invariant.
- There is no observable difference when adopting an isotropic or an anisotropic speed of light – we can say that this choice is conventional
- We can speak interchangeably of conventionality of simultaneity, conventionality of synchronization, **conventionality of the present moment**, or conventionality of the one-way speed of light

- Einstein synchronization protocol favoured $\varepsilon = 1/2$ for the foundation of special relativity time measurements, because it simplifies calculations: $c_+ = c_- = c$



Gauge synchrony potentials A_μ

- Synchronization freedom must be consistent under local spacetime-dependent redefinitions of the time reference $\lambda(x)$

$$t_B = t_A + \varepsilon(t_{A'} - t_A) = t_A + \lambda\left(\frac{x}{c}\right)$$

$$t \longrightarrow t + \lambda(x)$$

- This forces us to introduce a compensating gauge potential to preserve invariance of derivatives, leaving all physical observables invariant.

$$\partial_\mu t \longrightarrow \partial_\mu t + \partial_\mu \lambda(x)$$

That extra term ruins invariance. The comparison between clocks now depends on our arbitrary local shift.

Covariant derivative $\longrightarrow$ $D_\mu t = \partial_\mu t + A_\mu$

$$A_\mu \longrightarrow A_\mu - \partial_\mu \lambda(x)$$

$$D_\mu t = \partial_\mu\big(t + \lambda(x)\big) + A_\mu - \partial_\mu \lambda(x) = D_\mu t$$ $\longleftarrow$ The comparison becomes invariant.

Gauge synchrony fields $F_{\mu\nu}$

Thanks to gauge synchrony potentials:

✓ Clock comparison no longer depends on arbitrary local shifts of ε

✓ Synchronization becomes well-defined

The gauge potential cancels the ambiguity.

The gauge synchrony potential gives raise to a gauge synchrony field that tells us how to transport time information consistently through spacetime.

The gauge synchrony potential is equal to the four velocity $D_\mu t = \partial_\mu t + A_\mu = \left(\partial_\mu t + \frac{1}{c^2} A_\mu\right)$ $[s/m]$ $[m/s]$	**The gauge synchrony fields are deduced from the gauge synchrony potentials**
$A^\mu = U^\mu = (\gamma c, \gamma \vec{v})$ where $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ is the Lorentz factor	$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$ $[1/s]$

Gauge synchrony antisymmetric tensor $F_{\mu\nu} \equiv (\vec{a}/c, \vec{\Omega})$

$[m/s^2]$ $[m/s]$

$$F_{\mu\nu} = \begin{bmatrix} 0 & a_x/c & a_y/c & a_z/c \\ -a_x/c & 0 & -\Omega_z & \Omega_y \\ -a_y/c & \Omega_z & 0 & -\Omega_x \\ -a_z/c & -\Omega_y & \Omega_x & 0 \end{bmatrix}$$

$[1/s]$ $[1/s]$

This tensor is also called **"acceleration – rotation tensor"** and results from the **"conventionalistic principle"**

Acceleration and rotation gauge synchrony fields

- rotation (angular velocity) and acceleration are gauge synchrony fields that affect Einstein synchronization protocol!

For a frame rotating with constant angular velocity Ω about the z axis

- The time offset wrt Einstein protocol is $\boldsymbol{\Delta t \approx \frac{L\Omega r}{c^2} = \frac{2\pi r^2 \Omega}{c^2}}$ this is the **Sagnac desynchronization effect** between two clocks moving forward and backward wrt the rotating frame along closed paths.
- Rotation modifies Einstein Synchronization as $\boldsymbol{\varepsilon = \frac{1}{2}\left(1 + \frac{\Omega r}{c}\right)}$

For a uniform translation acceleration a along the x direction

- The Einstein synchronization offset is $\boldsymbol{\Delta t \approx \frac{aL^2}{2c^3}}$
- The new synchronization parameter is $\boldsymbol{\varepsilon = \frac{1}{2}\left(1 + \frac{aL}{c^2}\right)}$ it results the **kinematic gravitational redshift** in the accelerated frame (from equivalence principle we extrapolate that in a constant gravitational field we should measure $\boldsymbol{\varepsilon = \frac{1}{2}\left(1 + \frac{\Phi}{c^2}\right)}$ where Φ is the gravitational potential difference over the distance L.

- All synchro protocols with epsilon between 0 and 1 are equivalently correct! **The value of epsilon is conventional** and transforms between observers / frames according to gauge synchronization fields

Integrable and non-integrable synchrony fields

Let us consider a synchrony gauge potential $v(x)$

- $$\frac{dt'}{dx} = \frac{dt}{dx} + \frac{v(x)}{c^2}$$

Integrating around a closed countour:

- $$\Delta t = \oint \frac{v}{c^2}\, dx = \oiint \frac{\nabla \times v}{c^2}\, d\sigma = \oiint \frac{\Omega}{c^2}\, d\sigma$$

Non-integrable synchrony field

- $$\Omega = \nabla \times v \neq 0 \rightarrow \Delta t \neq 0$$

It is impossible to synchronize the clocks along a closed contour and to define a global time for the rotating referential

Integrable synchrony field

- $$\Omega = \nabla \times v = 0 \rightarrow \Delta t = 0$$

It is possible to synchronize the clocks along a closed contour and to define a global time for the non-rotating referential

- Imagine a rotating ring
  - We synchronize clock A -> B ->C ->...-> A using light signals
  - When we return to A, the clock is off by the Sagnac time
  - Changing ε only shifts the intermediate readings , but the final loop discrepancy remains!

Gravitational Coupling Strength G

Newtonian Mechanics

$$\vec{F} = -G\frac{Mm}{r^2}$$

The gravitational constant G defines the coupling strength between mass and the gravitational field

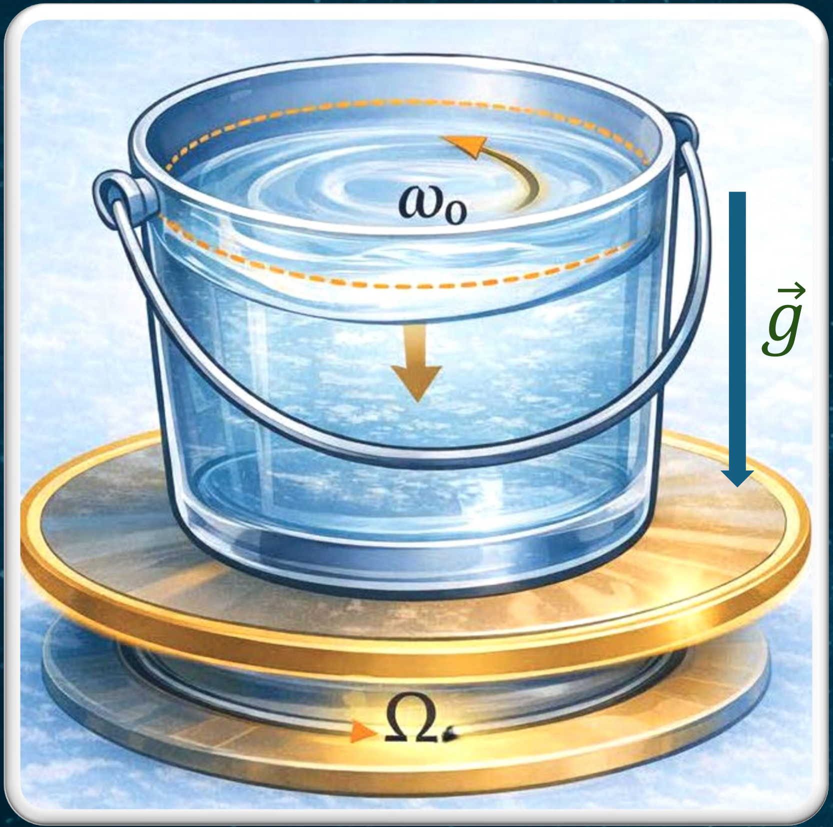
Einsteinian General Relativity

$$E_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

The gravitational constant G defines the coupling strength between spacetime curvature and matter

In Newton and Einstein's theories the gravitational coupling strength is **a fundamental absolute constant of nature G**

Sagnac effect and equivalence principle



Invariant meniscus depth variation of water in Newton's bucket with respect to all observers is only possible if G varies.
[C.J. de Matos, NEXRES 5 (2026) 101337]

- We carry out Newton's rotating bucket experiment on top of a disc rotating wrt an inertial frame in a constant gravitational field.
- Independently of the direction of rotation of the bucket the variation of the meniscus depth must be the same for all observers since the inertial mass and the gravitational mass of the water are always equal according to the **equivalence principle** (gravity equilibrates centripetal acceleration)
- However on the disc, we must take into account the **Sagnac time delay** on the angular velocity of the bucket, which appears when we compare the period of rotation of the bucket when it is rotating in the same direction as the disc (+) and when it is rotating in the opposite direction (-). This causes a change in the meniscus depth which is different for the observer attached to the bucket and the observers attached to the disc and located in the laboratory. Hence the equivalence principle is violated
- The only possibility to save the equivalence principle would be to have a variation of G according to $\frac{\Delta G}{G_N} = \frac{G_+ - G_-}{G_N} = 2\,\frac{\Delta t_{Sagnac}}{T_0}$

  Where $T_0 = 2\pi/\omega_0$ is the proper period of rotation of the bucket and $\Delta t_{Sagnac} = \frac{4A\Omega}{c^2}$ is the Sagnac time delay.

Acceleration translation lenght

- The acceleration translation length is built from the scalar contraction of the acceleration-rotation tensor

$$\boxed{\lambda_t = \frac{c}{\sqrt{\frac{1}{2}F_{\mu\nu}F^{\mu\nu}}} = \frac{c}{\sqrt{\left|\Omega^2 - \frac{a^2}{c^2}\right|}}}$$

- This length is fully covariant

- If $a \longrightarrow 0$ and $\Omega \longrightarrow 0$ then $\lambda_t \longrightarrow \infty$ and the observer would be purely inertial

- The acceleration translation length λ_t defines the extension over which the hypothesis of locality and the principle of equivalence apply:
  - We can only consider locally that an acceleration is equivalent to a gravitational field $\vec{a} = -\vec{g}$ only in frame with size $L \leq \lambda_t(a) = \frac{c^2}{g}$
  - We can only consider locally that a gravitomagnetic field is equivalent to an angular velocity $\vec{\Omega} = -\vec{B}_g$ only in frame with size $L \leq \lambda_t(\Omega) = \frac{c}{B_g}$

Check-Point

Conventionalistic principle: The laws of physics are independent of clock synchronization.

Antisymmetric acceleration-rotation tensor whose components are gauge synchrony fields $(\vec{a}, \vec{\Omega})$

$$F_{\mu\nu} = \begin{bmatrix} 0 & a_i \\ -a_i & \varepsilon_{ijk}\Omega_k \end{bmatrix}$$

Sagnac effect for two couterpropagating observers on a rotating frame

$$\Delta t = 2 \oiint \frac{\Omega}{c^2}\, d\sigma = \frac{4\pi r^2 \Omega}{c^2} = \frac{4A\Omega}{c^2}$$

Acceleration translation length defines the scale over which the hypothesis of locality and the principle of equivalence are valid

$$R \leq \lambda_t = \frac{c}{\sqrt{\frac{1}{2} F_{\mu\nu} F^{\mu\nu}}} = \frac{c}{\sqrt{\left|\Omega^2 - \frac{a^2}{c^2}\right|}}$$

The Sagnac effect requires that ***G* varies for Newton's bucket** in a rotating frame to preserve the principle of equivalence

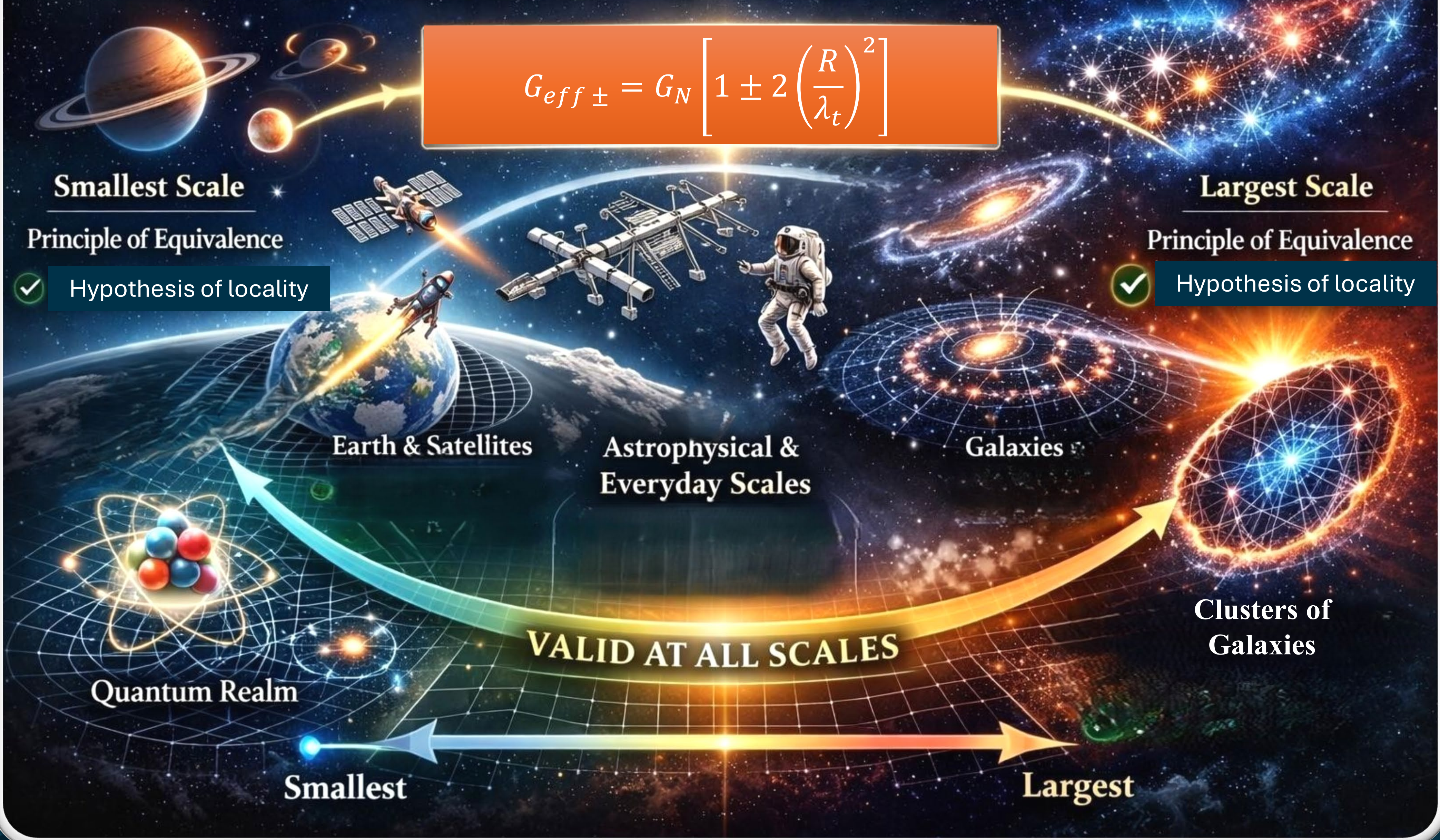
$$G_{\pm} = G_N \left(1 \pm \frac{2A\Omega\omega_0}{\pi c^2}\right)$$

The hypothesis of locality and the principle of equivalence are valid **at all scales** if G varies according to

$$G_{eff\,\pm} = G_N \left[1 \pm 2\left(\frac{R}{\lambda_t}\right)\right]^2$$

Variation of G and of Acceleration Translation length λ_t ensures Principle of Equivalence and Hypothesis of Locality at all Scales R

$$G_{eff\,\pm} = G_N \left[1 \pm 2 \left(\frac{R}{\lambda_t} \right)^2 \right]$$



Brans-Dicke theory of gravitation

Einstein Theory

Einstein Field Equations (EFE)

$$E_{\mu\nu} = \frac{8\,\pi\,G}{c^4} T^M_{\mu\nu}$$

Bianchi identity

$$\nabla^\mu E_{\mu\nu} = 0$$

Conservation of energy momentum

$$\nabla^\mu T_{\mu\nu} = 0$$

Equations of motion

$$x_\mu(\tau)$$

Variable G in GR leads to violation of energy conservation

G variation only affects the metric tensor (Einstein tensor) but not the equations of motion (Energy impulsion tensor)

Brans-Dicke (BD) Theory

1 BD Field Equations

$$E_{\mu\nu} = \frac{8\,\pi}{c^4\,\phi}\left[T^M_{\mu\nu} + T^\phi_{\mu\nu}\right]$$

Where $\phi = \frac{1}{G}$ scalar field and $T^\phi_{\mu\nu}$ is the energy momentum tensor o the ϕ

2 ϕ is coupled to matter through an invariant wave equation

$$\nabla_\mu \nabla^\mu \phi = \frac{8\,\pi}{\mathrm{c}^4(3 + 2\omega_{\mathrm{bd}})} \mathrm{T}^{\mu}_{\mathrm{M}\,\mu}$$

Where ω_{bd} is the unitless BD parameter which is constant in BD theory

3 In the limit of $\omega_{\mathrm{bd}} \to \infty$, the wave equation

$$\nabla_\mu \nabla^\mu \phi \to 0 \xrightarrow{\text{yields}} \phi = \frac{1}{\mathrm{G_N}} + \delta\phi \cong \frac{1}{\mathrm{G_N}} \text{ is constant}$$

and $\partial_\mu \phi \to 0$ we recover EFE

The physical origine of G variation and of the constant ω_{bd} are not explained by BD theory

Brans-Dicke theory of gravitation REVISITED

Brans-Dicke (BD) Theory

Effective value of G in the **post-Newtonian approximation** of BD theory

$$G_{eff} = G_N \left[\frac{2 + \frac{4}{\omega_{bd}}}{2 + \frac{3}{\omega_{bd}}} \right]$$

G variation ~~only~~ affects the metric tensor (Einstein tensor) ~~but not~~ and the equations of motion (Energy impulsion tensor)

Conventionalistic theory of G variation

Sagnac G variation, when $\Omega = \omega_0$:

$$G_{\pm} = G_N \left(1 \pm \frac{2A\Omega^2}{\pi c^2} \right)$$

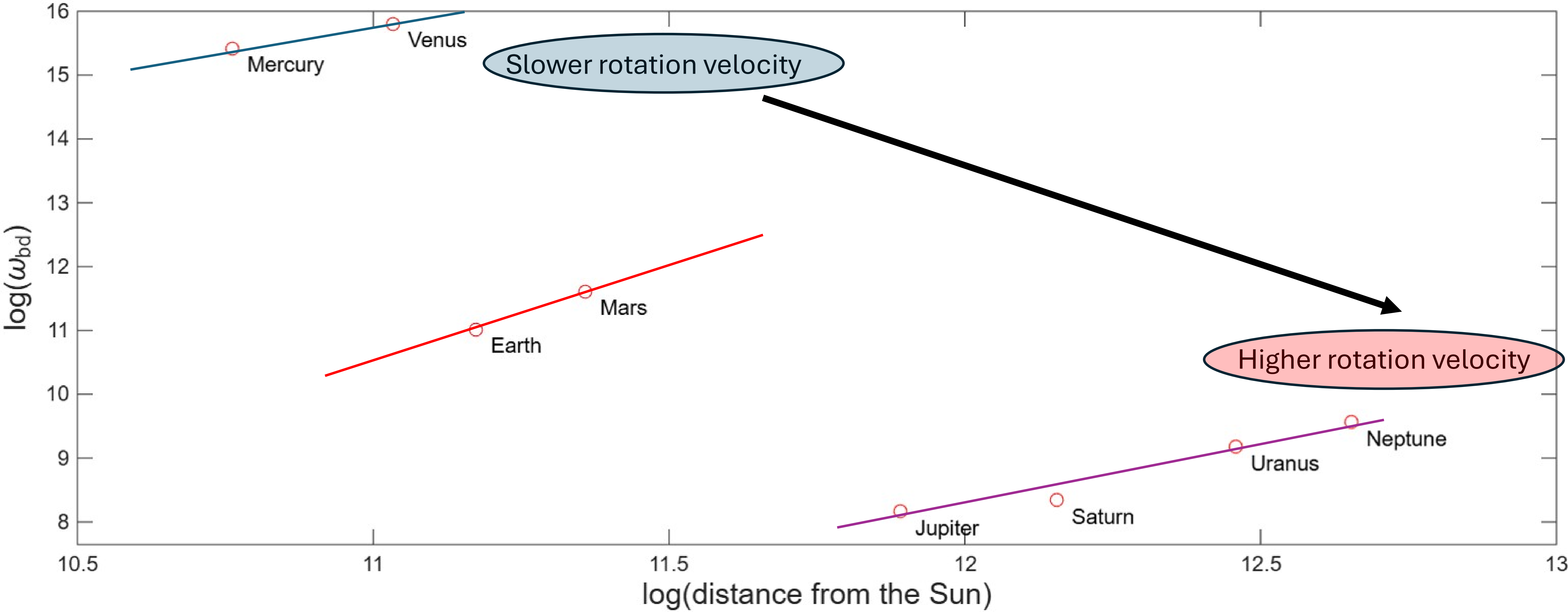
Conventionalistic Theory of Gravitation

The Brans-Dicke parameter ω_{bd} **is not constant** and must depend on relative motion between observers **in order to preserve energy conservation**

$$\boxed{\omega_{bd} = \pm \frac{1}{4} \left(\frac{c}{v} \right)^2 - \frac{3}{2}}$$

In the limit of $v/c \to 0$, the BD parameter $\omega_{\text{bd}} \to \infty \xrightarrow{\text{yields}} \mathrm{G_{eff}} = \mathrm{G_N}$ is constant and we recover Einstein's theory of general relativity

Brans-Dicke parameter ω_{bd} in the solar system



Is there a fundamental meaning to these 3 lines being almost parallel?

Sagnac G waves in vacuum

In BD theory G waves result from the wave equation coupling $\phi = 1/\mathrm{G}$ with matter

In vacuum $\mathrm{T}^{\mu}_{\mathrm{M}\,\mu} = 0$

$$\boxed{\nabla_\mu \nabla^\mu \phi = \frac{8\,\pi}{\mathrm{c}^4(3+2\omega_{\mathrm{bd}})} \mathrm{T}^{\mu}_{\mathrm{M}\,\mu} = 0}$$

This is the condition to recover a constant G and General Relativity from BD theory. However, in conventionalistic gravitation the local variation of G in a rotating frame can propagate through vacuum in spacetime.

$$G_{eff\,\pm} = G_N \left[1 \pm 2\left(\frac{R}{\lambda_t}\right)^2\right]$$

$$\phi = \frac{1}{G_{eff\,\pm}} = \frac{1}{\mathrm{G_N}}\left(1 \pm \frac{\mathrm{R}^2}{\lambda_{\mathrm{t}}^2}\right) = \frac{1}{\mathrm{G_N}} \pm \frac{1}{\mathrm{G_N}}\frac{\mathrm{R}^2}{\lambda_{\mathrm{t}}^2} = \frac{1}{\mathrm{G_N}} \pm \delta\phi \text{ with}$$

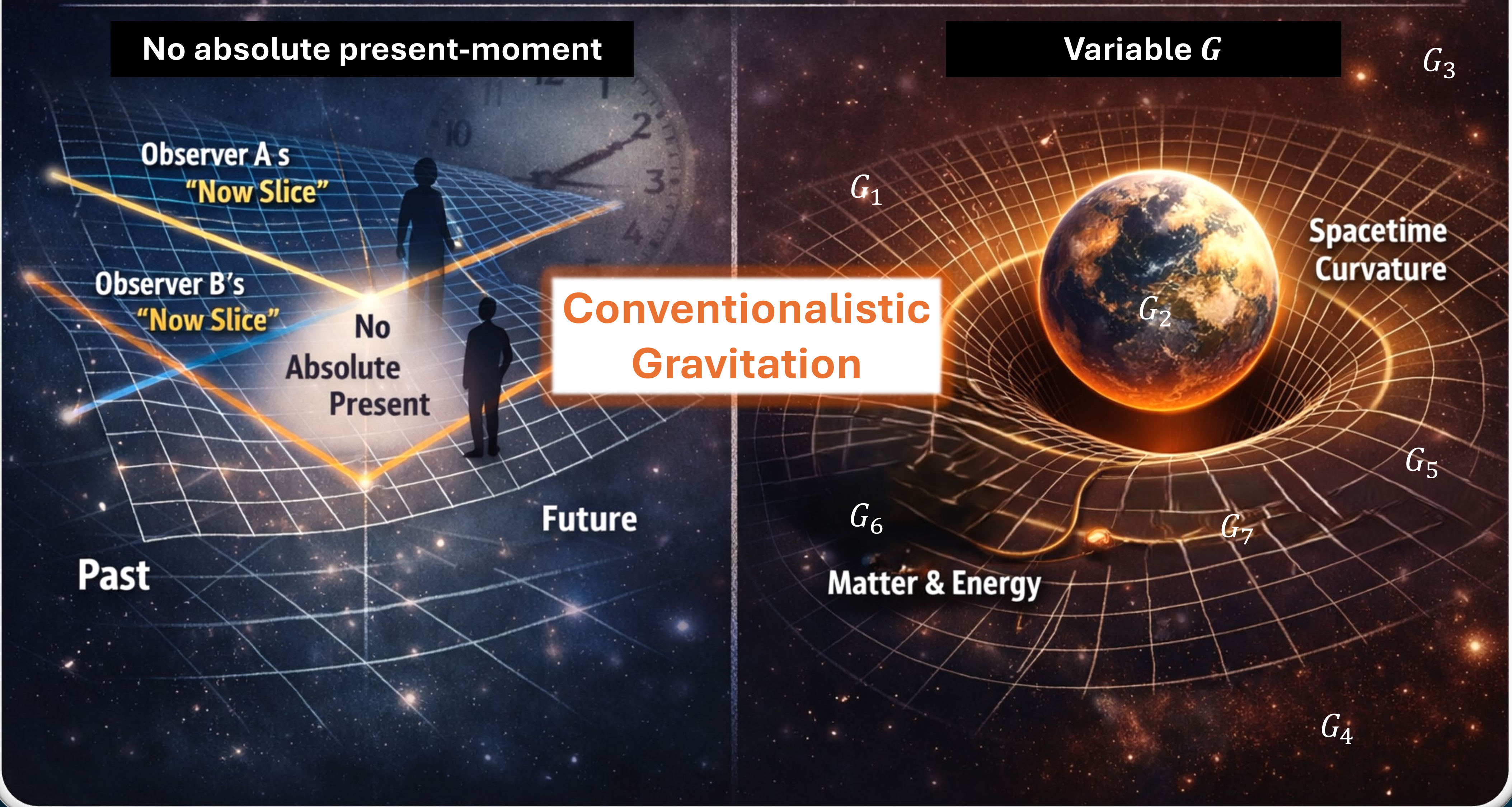
$$\nabla^2 \phi = \frac{1}{\mathrm{c}^2}\frac{\partial^2 \phi}{\partial \mathrm{t}^2} \qquad \frac{\mathrm{R}^2}{\lambda_{\mathrm{t}}^2} \ll 1$$

The one-dimensional far field solution $(\mathrm{x} \gg \mathrm{R})$ is:

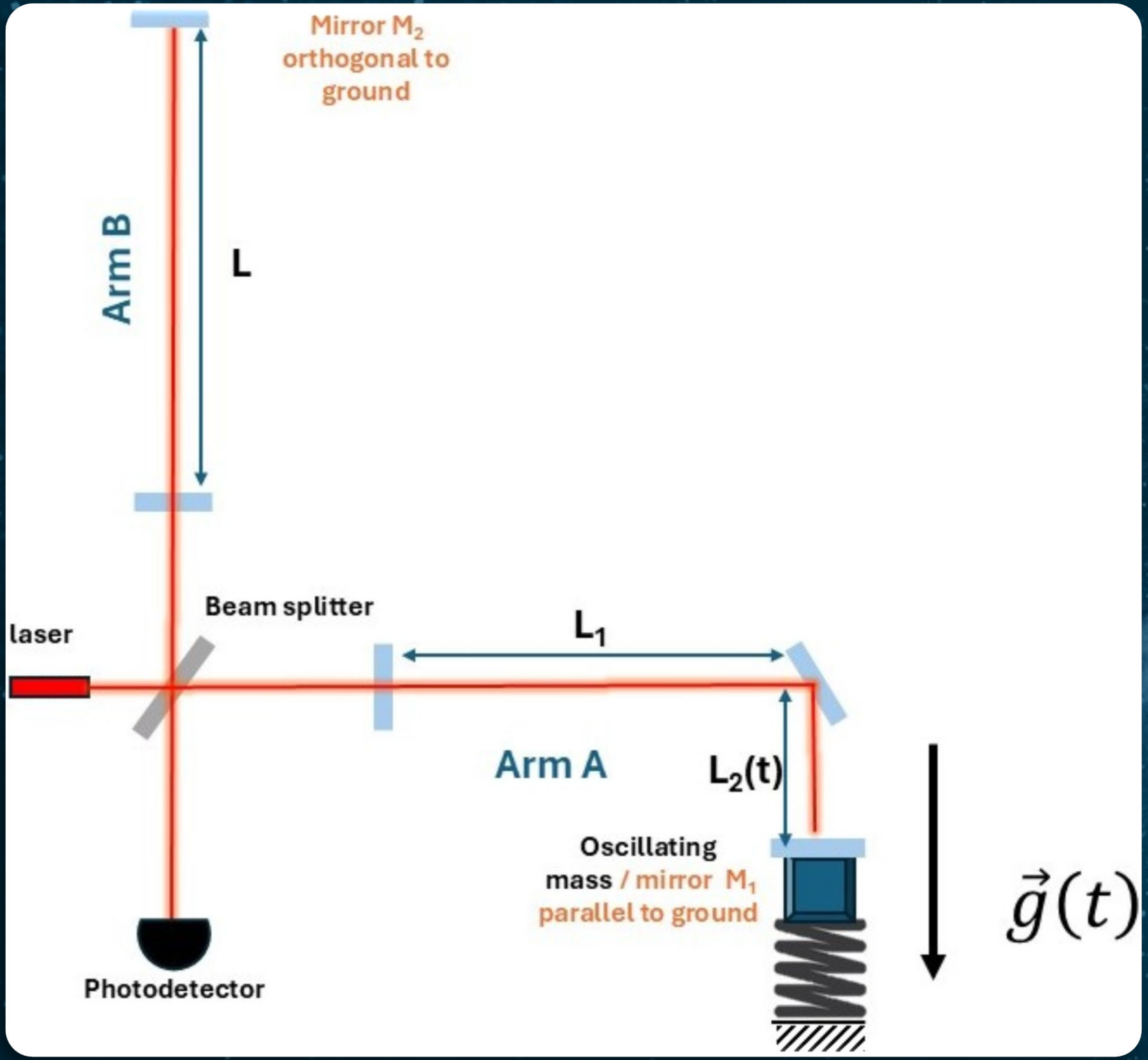
$$\delta\phi(\mathrm{x},\mathrm{t}) = \frac{1}{\mathrm{G_N}}\frac{\mathrm{R}^2}{\lambda_{\mathrm{t}}^2} \sin\left(\frac{\mathrm{c}}{\lambda}\mathrm{t} + \frac{\mathrm{x}}{\lambda}\right) \text{ with } \mathrm{R} \ll \lambda \ll \lambda_{\mathrm{t}} \text{ and } \lambda_{\mathrm{t}} = \frac{\mathrm{c}}{\Omega} \;\Longrightarrow\; \boxed{\delta\phi(x,t) = \frac{1}{G_N}\frac{v_t^2}{c^2} sin\left(\frac{c}{\lambda}t + \frac{x}{\lambda}\right)}$$

Therefore, Conventionalistic Gravitation only reduces to GR in the limit of $v_t/c \to 0$, i.e in the absence of the Sagnac effect for any observer.

The conventionality of simultaneity not only **undermines** the notion of a **unique present moment** and thereby supports a **four-dimensional spacetime picture of reality**, but it also **sets the gravitational coupling of spacetime with matter.**



Measuring G variations on earth



OptoMechanical Interferometric Gravimeter (**OMIG**)

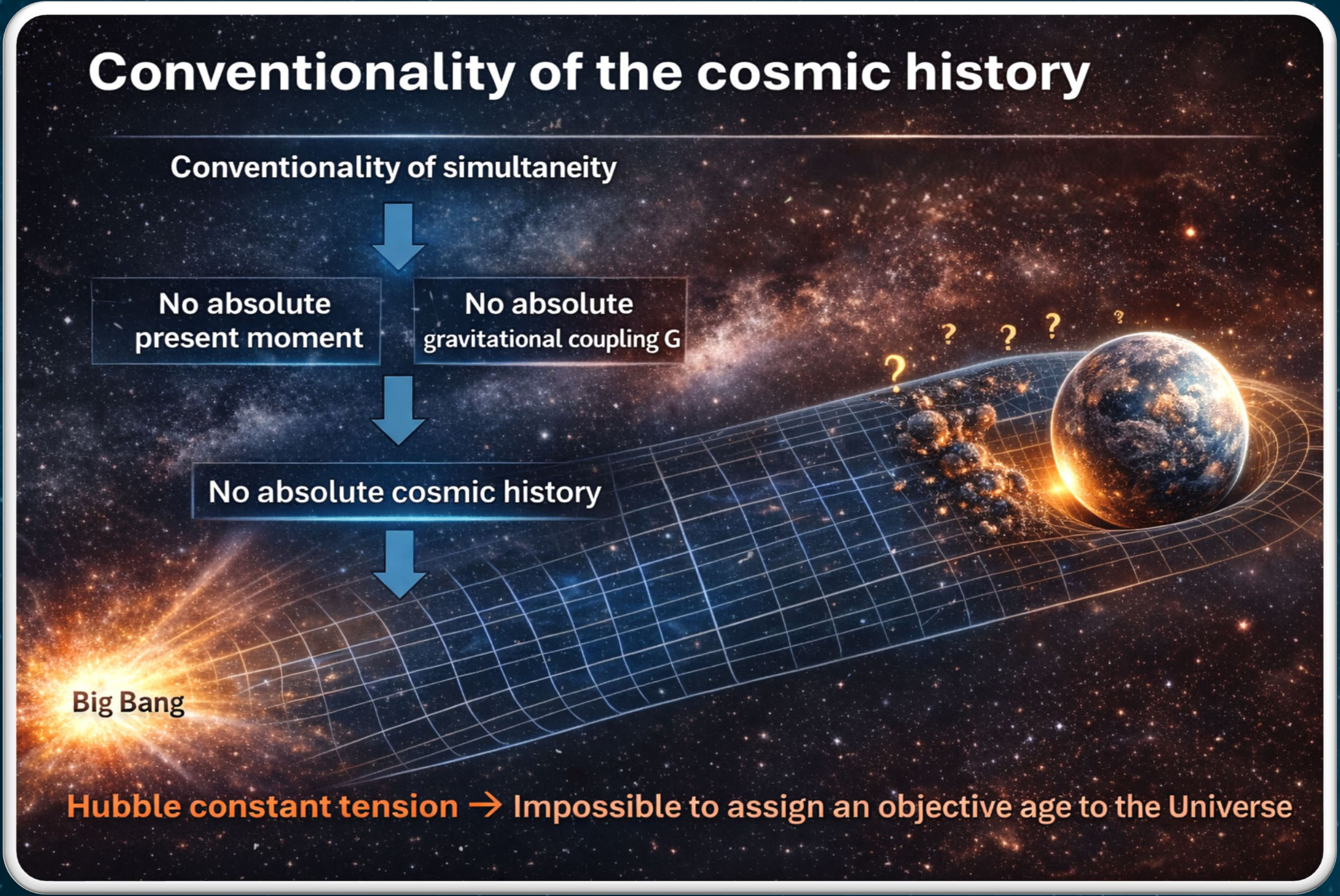
$$\left[\frac{\Delta G}{G_N}\right]_{Earth} \cong 10^{-12}$$

Measurements signals of **OMIG** with amplitude identical to LIGO – Femtometer arm length variation!!

Is anyone interested in setting up the **OMIG project?**

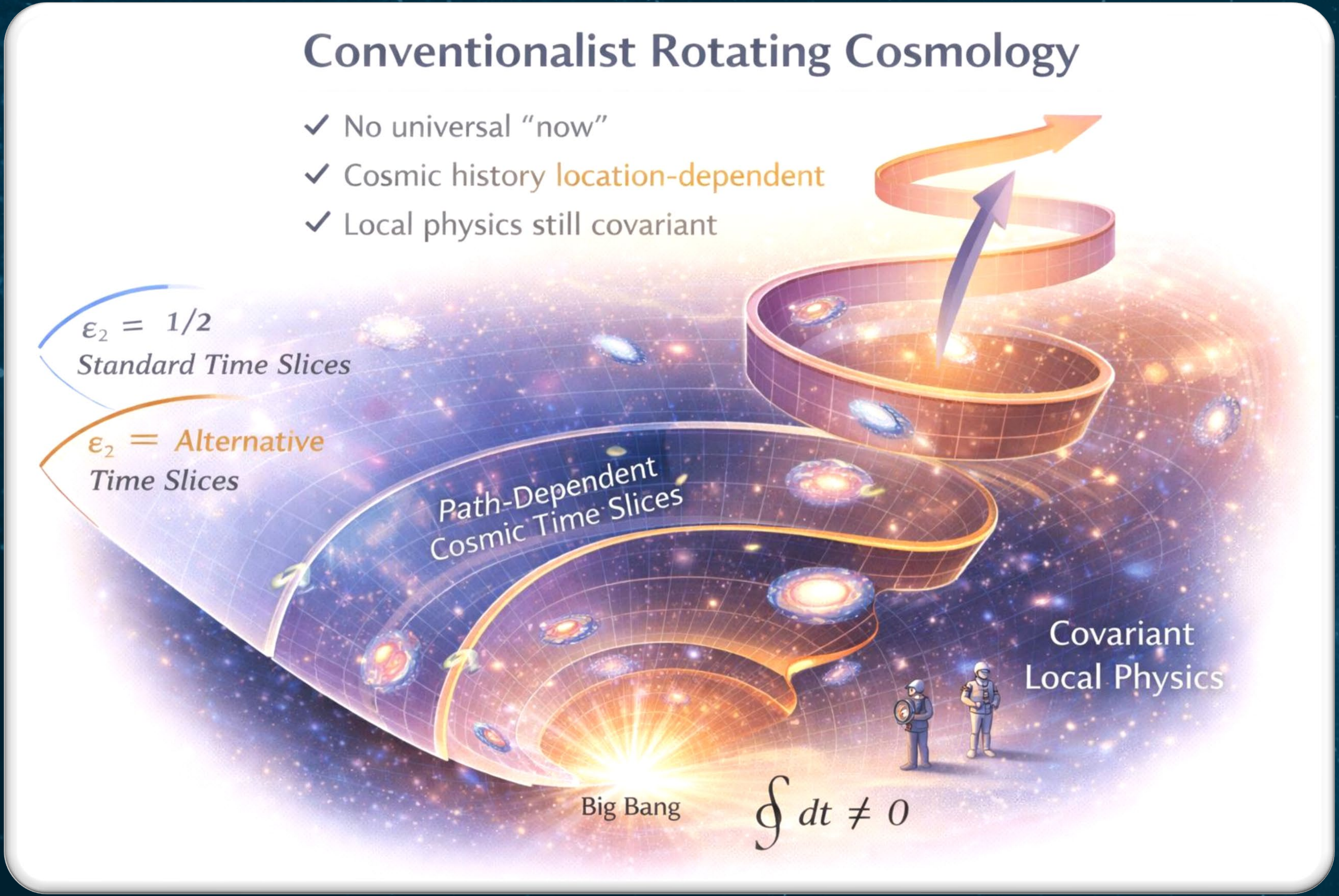
ΩiG

Could the age of the universe be anisotropic ??



Looking at the universe in different directions would lead to different cosmic histories and different cosmic ages

Cosmological Conclusions



- Rotation introduces a Sagnac-like effect on cosmological scale → no global "now".
- Varying G extends applicability of local equivalence principle → local physics behaves normally.
- Covariance cares only about local laws, not whether a global cosmic time exists.
- In other words: even if there is no universal cosmic history, physics remains locally consistent and covariant, provided the equivalence principle and locality hold at all scales (thanks to a variable G).

Philosophical Conclusions

- There is no absolute cosmic history.
- There is no absolute cosmic plan,
- Only a cosmic presence without an absolute present moment.
- History is a local concept.
- The present moment has only meaning locally (and it is conventional).
- Local histories are possible, but they are conventional!!
- Local history is objective , because the laws of physics are invariant, but it is conventional

Looking ahead

1. Is the act of measurement in quantum mechanics conventionalistic ?
2. If yes, could this yield to a new interpretation of quantum mechanics that would make it compatible with the theory of relativity?

If after this lecture you are interested in working with me on the development of the "Conventionalistic Theory of Gravitation" please contact me at:

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This presentation is supported by a detailed Scientific Note which is available upon direct request.