



Bending Gravity into Light

We turn Einstein's theory inside out, transforming gravitational dynamics into the language of electromagnetic materials. By extending Plebanski's 1960 map, we encode Einstein's entire ADM system within a dielectric medium. The result? Real gravitational physics modeled as engineered optical media: light itself becomes the sculptor of spacetime geometry!



Splitting Spacetime into Slices

How does gravity evolve? ADM formalism answers clearly: it splits spacetime into 3-D slices evolving in time. Each slice has geometry described by

$$ds^2 = -\alpha^2 dt^2 + \gamma_{ij}(dx^i + \beta^i dt)(dx^j + \beta^j dt).$$

Einstein's equations become constraints that each slice must satisfy: Hamiltonian constraint

$$({}^3R + K^2 - K_{ij}K^{ij}) = 16\pi G \rho,$$

Momentum constraint

$$D_j(K^{ij} - \gamma^{ij}K) = 8\pi G j^i.$$

Geometry changes slice by slice, just like frames in a film.

Optics Mirrors Gravity

A stationary optical metric in transformation optics,

$$ds^2 = g_{00} dt^2 + 2g_{0i} dt dx^i + g_{ij} dx^i dx^j,$$

mirrors ADM's gravitational slicing:

$$g_{00} = -\alpha^2, \quad g_{0i} = \gamma_{ij}\beta^j, \quad g_{ij} = \gamma_{ij}.$$

This optical-ADM match hints that engineered media can encode full gravitational dynamics, the spark for our study.

The Key Equation

Plebanski's groundbreaking insight:

$$\epsilon_{ij} = \mu_{ij} = -\frac{\sqrt{-g} g_{ij}}{g_{00}}, \quad g_i = \frac{g_{0i}}{g_{00}}$$

This equation bridges Einstein's gravity and Maxwell's electromagnetism. It's the hidden symmetry we use to turn curved space into clear glass.

When Light Creates Gravity

By treating the field's own energy ρ and momentum $\mathbf{j}$ as the matter terms, we complete Einstein's ADM equations inside the medium.

- Effective energy density

$$\rho = \frac{1}{2\epsilon_0} (\mathbf{D} \cdot \mathbf{E} + \mathbf{B} \cdot \mathbf{H}),$$

- Effective momentum flux

$$\mathbf{j} = \epsilon_0^{-2} \mathbf{E} \times \mathbf{H}.$$

The medium now hosts genuine gravitational self-interactions—the self-gravity of pure electromagnetic fields!

DESIGNER'S REMARKS

Result - Engineered dielectrics replicate gravitational dynamics.

Limitations - Model fixes α and omits strong fields, loss, and dispersion.

Outlook - Next-gen metamaterials could let us test geometrodynamics in the lab.

Optical Analog of Gravity Waves

In the weak-field limit our mapped system produces metric ripples that obey

$$\frac{1}{c^2} \partial_t^2 \delta \epsilon_{ij}^{TT} - \nabla^2 \delta \epsilon_{ij}^{TT} = 0.$$

Identifying these with dielectric fluctuations, we obtain optical copies of gravitational waves. Thus, gravitational-wave physics becomes a tabletop optical experiment!

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