DATED HISTORY

Condensed Timing Geometry From Clock-Rate Scalars to Holonomy and Spin-2 Structure

May timing-geometry proposal. Scalar differences telescope exactly. The proposed microscopic spin-2 completion requires additional connection data.

Manuscript · p. 1, abstract

Condensed Timing Geometry: Observable Spacetime as a Sheaf of Clock-Connection Closures

Evidence · Scalar source/window residual audit

Condensed Timing Geometry

From Clock-Rate Scalars to Holonomy and Spin-2 Structure

Joshua Farrow
Independent Research

May 2026

Abstract

This paper develops *Condensed Timing Geometry*, a framework for approaching observable spacetime through clock-readable structures rather than assuming a manifold as the primitive object. The starting layer is scalar timing: a local clock-rate shift that can model redshift-like effects. The first theorem of the framework is negative but constructive: scalar timing is holonomy-free. If relative timing offsets are derived from a single scalar field, their sum around any closed loop vanishes. Scalar timing can therefore describe local clock slowdown, but it cannot by itself encode curvature, synchronization failure around loops, or gravitational radiation.

The next layer is a timing connection: an edge- or path-valued assignment of relative clock offsets. Its loop holonomy measures the failure of global clock synchronization and gives the first curvature-like observable. In weak-field general relativity, this object has a natural physical anchor in the gravitomagnetic g_{0i} sector: rotating mass-energy currents produce frame-dragging and Sagnac-like synchronization effects. Full gravitational radiation, however, requires a further lift to a symmetric metric perturbation and its transverse-traceless spin-2 sector. Numerical consistency tests using scalar-vector-tensor decomposition confirm that scalar, vector, and pure-gauge components do not fake spin-2 radiation, while the transverse-traceless tensor sector carries two helicity-2 polarizations.

Severe scalar closure tests across cubic, periodic cubic, Poisson-Delaunay, and random geometric graph substrates further support this hierarchy. Even when a diffusion estimator approaches $d_{\text{eff}} \approx 3$, the scalar shell-response estimator does not close in the same window; the best periodic cubic case gave $d_{\text{eff}}^{(\text{diff})} \approx 2.96$ but $d_{\text{eff}}^{(\Lambda)} \approx 1.97$. Thus scalar timing is not rejected; it is placed. It is the redshift-readable layer, not the whole geometry. Curvature requires a connection, and gravitational radiation requires a spin-2 tensor sector.

Contents

1 Introduction **2**

2 Scalar timing: the first readable layer **2**
2.1 Theorem 1: scalar timing is holonomy-free 3

3 From scalar load to timing connection **3**
3.1 Local curvature versus topological holonomy 3

4 Observable geometry as gluing **4**

5 Physical anchor: the gravitomagnetic sector **4**

6 Why the connection is still not full gravity **5**

7 Spin-2 numerical consistency tests **5**
7.1 Projector and controls 5
7.2 Helicity test 5

8 Severe scalar closure tests **6**

9 Claim hierarchy **7**

10 What this framework does and does not say **8**
10.1 What it says 8
10.2 What it does not say 8

11 Conclusion **9**

1. Introduction

A clock is one of the most direct probes of geometry. In general relativity, gravitational fields alter proper time. Two clocks at different potentials tick at different rates; clocks transported around rotating systems can fail to return globally synchronized. Precision timing is therefore not merely a measuring tool placed inside spacetime. It is one of the ways geometry becomes visible.

This paper asks what follows if timing is treated as the first observable layer of geometry. The answer is a hierarchy, not a single field. A scalar clock-rate field can represent local time dilation, but scalar timing alone is too weak to describe curvature. A scalar gives values at points. Curvature appears when relative timing offsets around loops fail to close. This requires a connection. Gravitational radiation requires still more: the transverse-traceless spin-2 part of a symmetric metric perturbation.

The central claim is therefore not that clocks alone prove a new theory of gravity. The claim is narrower and more useful:

> Observable spacetime, when approached through clocks, appears as a layered structure: scalar timing for local clock-rate shifts, timing connection for synchronization holonomy, and spin-2 tensor modes for gravitational radiation.

This gives a clean ladder:

$$\Lambda \;\longrightarrow\; A_i \;\longrightarrow\; F = \mathrm{d}A \;\longrightarrow\; h_{\mu\nu} \;\longrightarrow\; h_{ij}^{\mathrm{TT}}. \tag{1}$$

Here Λ is a scalar timing load, A_i is a timing connection, $F = \mathrm{d}A$ is curvature or loop holonomy, $h_{\mu\nu}$ is a weak-field metric perturbation, and h_{ij}^{TT} is the transverse-traceless radiative sector of linearized gravity.

The most important feature of this ladder is that each level has a different job. The scalar level explains clock slowdown. The connection level explains failure of global synchronization. The tensor level explains gravitational waves. Collapsing these levels into one scalar object produces attractive analogies but not gravity.

2. Scalar timing: the first readable layer

Let $\Lambda(x)$ denote a scalar timing load. Operationally, it changes the local clock rate by

$$\omega_{\mathrm{eff}}(x) = \frac{\omega}{1 + \alpha\Lambda(x)}, \tag{2}$$

or, in the weak-load regime $|\alpha\Lambda| \ll 1$,

$$\frac{\delta\omega}{\omega} \approx -\alpha\Lambda(x). \tag{3}$$

This scalar law is useful. It captures the form of a local redshift-like effect: clocks in regions of higher scalar load tick more slowly. In a discrete setting, we may regard Λ_i as a scalar assigned to vertices of a graph. A timing offset between neighboring vertices can then be defined by a difference

$$A_{ij}^{(\Lambda)} = \Lambda_j - \Lambda_i. \tag{4}$$

This looks like a connection on edges, but it is a special kind of connection: an exact one. It comes entirely from a scalar potential.

2.1. Theorem 1: scalar timing is holonomy-free

Let $G = (V, E)$ be a graph and let $\Lambda : V \to \mathbb{R}$ be any scalar timing field on its vertices. Define the edge timing offset

$$A_{ij}^{(\Lambda)} = \Lambda_j - \Lambda_i \tag{5}$$

for each oriented edge (i, j). For any closed loop $\gamma = (i_0, i_1, \ldots, i_n = i_0)$,

$$\oint_\gamma A^{(\Lambda)} = \sum_{m=0}^{n-1} (\Lambda_{i_{m+1}} - \Lambda_{i_m}) = 0. \tag{6}$$

Thus scalar-derived timing offsets have zero loop holonomy.

Interpretation. A scalar timing field can create local gradients and redshift-like differences, but it cannot encode a nonzero synchronization gap around a closed loop. In cohomological language, scalar-derived offsets are exact 1-cochains. They lie in the image of the coboundary operator and vanish on cycles. Therefore scalar timing cannot by itself carry curvature in the loop-holonomy sense.

This theorem does not make scalar timing irrelevant. It identifies its proper role. Scalar timing is the first readable layer of time geometry. It is not the curvature-bearing layer.

3. From scalar load to timing connection

The minimal curvature-bearing timing object is not a scalar but a connection. On a graph, a timing connection assigns an oriented relative clock offset to each edge:

$$A_{ij} = -A_{ji}. \tag{7}$$

Unlike an exact scalar difference, a general connection need not sum to zero around a loop. Its loop holonomy is

$$\mathrm{Hol}_\gamma(A) = \oint_\gamma A = \sum_{(i,j)\in\gamma} A_{ij}. \tag{8}$$

If $\mathrm{Hol}_\gamma(A) \neq 0$, then clocks synchronized locally along the path cannot be synchronized globally around the loop. The loop fails to close. This is the first curvature-like observable in a clock-based geometry.

3.1. Local curvature versus topological holonomy

The word holonomy has two related but physically distinct meanings in this framework.

1. **Local curvature holonomy.** Around a contractible loop, nonzero holonomy measures curvature enclosed by that loop. In a discrete complex, this is represented by a plaquette value

$$F = \mathrm{d}A. \tag{9}$$

This is the coexact, locally radiative sector.

2. **Topological holonomy.** Around a non-contractible loop, holonomy may be nonzero even when $F = 0$ everywhere locally. This is the harmonic sector: flat but globally twisted. It is analogous to Aharonov-Bohm-type structure or global clock synchronization failure around a rotating frame.

Both obstruct global synchronization, but they are not the same object. Local curvature can radiate. Topological holonomy can be static and globally nontrivial.

4. Observable geometry as gluing

The timing-connection view naturally fits a sheaf-like language. A collection of observers may each synchronize clocks on a local patch. If all local synchronizations agree on overlaps and extend to one global clock assignment, then the timing data glue into a global section. If they agree locally but no global assignment exists, there is an obstruction.

This is the same mathematical shape that appears in the sheaf-theoretic account of contextuality and nonlocality: local data may be compatible on contexts while failing to admit a single global assignment. In the timing setting, the obstruction is not primarily a philosophical claim; it is directly measurable as loop holonomy.

Thus the framework can be summarized as:

$$\text{global clock exists} \quad \Longleftrightarrow \quad \oint_\gamma A = 0 \text{ for all relevant loops.} \tag{10}$$

When this fails, the geometry is not just a scalar clock-rate landscape. It contains synchronization curvature.

5. Physical anchor: the gravitomagnetic sector

A timing connection should not be introduced as an arbitrary new field. There is already a real weak-field gravitational structure with this form. In the weak-field expansion

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}, \tag{11}$$

the components h_{00}, h_{0i}, and h_{ij} play different roles. The scalar part h_{00} is associated with the Newtonian or gravitoelectric potential. The mixed components h_{0i} behave, in the slow-motion weak-field limit, like a gravitomagnetic vector potential. Rotating mass-energy currents produce frame dragging, and global clock synchronization around loops can fail in Sagnac-like ways.

This identifies a natural physical home for the timing connection:

$$A_i \quad \leftrightarrow \quad h_{0i} \text{ / gravitomagnetic slice.} \tag{12}$$

This does not make every timing connection gravitational. It says that the clock-connection object is not an empty abstraction. General relativity already contains a clock-synchronization connection in its weak-field decomposition. The source is not electric charge, as in electromagnetism, but mass-energy current and rotation.

6. Why the connection is still not full gravity

A 1-form connection can propagate waves. This is true in electromagnetism and in lattice gauge models. But propagation alone is not the signature of gravity. The decisive radiative signature of weak-field gravity is spin 2: two transverse-traceless tensor polarizations with helicity ± 2.

Therefore the timing connection is an intermediate layer. It captures synchronization holonomy and gravitomagnetic-like structure, but it is not by itself the full gravitational field. Full weak-field gravity requires the symmetric metric perturbation $h_{\mu\nu}$, and in vacuum its radiative degrees of freedom are contained in

$$h_{ij}^{\mathrm{TT}}. \tag{13}$$

The correct completion is not

$$\Lambda \to A_i \quad \text{and stop}, \tag{14}$$

but rather

$$\Lambda \to A_i \to h_{\mu\nu} \to h_{ij}^{\mathrm{TT}}. \tag{15}$$

7. Spin-2 numerical consistency tests

As a consistency check, we implemented the standard scalar-vector-tensor decomposition of a spatial symmetric perturbation h_{ij} at fixed Fourier mode. A symmetric 3×3 tensor has six independent components. For a nonzero wavevector, these split into

$$2_{\mathrm{scalar}} + 2_{\mathrm{vector}} + 2_{\mathrm{TT}} = 6. \tag{16}$$

The two transverse-traceless components are the candidate spin-2 gravitational-wave sector.

7.1. Projector and controls

For each nonzero wavevector k, define the transverse projector

$$P_{ij} = \delta_{ij} - \frac{k_i k_j}{|k|^2}. \tag{17}$$

The transverse-traceless projection is

$$h_{ij}^{\mathrm{TT}} = P_i{}^a P_j{}^b h_{ab} - \frac{1}{2} P_{ij} P^{ab} h_{ab}. \tag{18}$$

The numerical implementation satisfies the expected separation:

These controls matter. They show that scalar, vector, and pure-gauge inputs do not masquerade as spin-2 radiation under the projector.

7.2. Helicity test

For a wave propagating along a fixed axis, a spin-1 vector polarization transforms with phase $e^{\pm i\psi}$ under rotation by angle ψ, while a spin-2 tensor polarization transforms with phase $e^{\pm 2i\psi}$. The numerical helicity test gives slopes -1.000 for the vector state and -2.000 for the TT tensor state.

Table 1: Spin-2 consistency checks for the scalar-vector-tensor decomposition.

Check	Result
Scalar sector dimension	2
Vector sector dimension	2
TT spin-2 sector dimension	2
Total dimension	6
Max off-diagonal Gram error	2.22×10^{-16}
Random tensor reconstruction error	1.33×10^{-16}
Scalar-to-TT leakage	0
Vector-to-TT leakage	0
Pure gauge-to-TT leakage	0
TT retention error	1.76×10^{-16}

Interpretation. These tests do not prove that a microscopic substrate generates gravity. They identify the target structure any such substrate must reproduce. Scalar timing is not enough. A vector timing connection is not enough. The gravitational-radiation sector must separate as a helicity-2 transverse-traceless tensor mode.

8. Severe scalar closure tests

The scalar layer can still be tested directly. If scalar timing alone were sufficient to carry the geometric burden, one would expect a common scaling window in which the same operator simultaneously supports a diffusion dimension near three, a scalar shell-response dimension near three, and a good timing law.

The closure criterion is

$$d_{\mathrm{eff}}^{(\mathrm{diff})} \approx d_{\mathrm{eff}}^{(\Lambda)} \approx 3 \tag{19}$$

in the same scaling window where the scalar timing law fits. This criterion is intentionally severe: a transient pass through $d \approx 3$ is not enough. The estimators must agree in one stable window.

We ran scalar closure tests across several graph substrates: cubic lattice, periodic cubic lattice, Poisson-Delaunay graph, and random geometric graph. The largest system size tested was $N = 4096$. The strongest near-pass occurred on a periodic cubic substrate, where the diffusion estimator approached three. However, the scalar shell-response estimator remained near two rather than three.

Table 2: Summary of severe scalar timing closure tests.

Substrate/test	Size	Key estimate	Closure result
Periodic cubic best case	$N = 1000$	$d_{\mathrm{eff}}^{(\mathrm{diff})} = 2.96$, $d_{\mathrm{eff}}^{(\Lambda)} = 1.97$	fail
Cubic lattice summary	$N = 1000$	$d_{\mathrm{eff}}^{(\mathrm{diff})} = 1.23$, $d_{\mathrm{eff}}^{(\Lambda)} = 2.14$	fail
Poisson-Delaunay	$N = 500$	$d_{\mathrm{eff}}^{(\mathrm{diff})} = 2.12$, $d_{\mathrm{eff}}^{(\Lambda)} = 2.02$	fail
Random geometric graph	$N = 500$	no stable scalar closure window	fail

The differing cubic labels reflect different finite-size, periodic-boundary, and averaging choices. The important point is stable across them: no tested substrate produced a shared window where

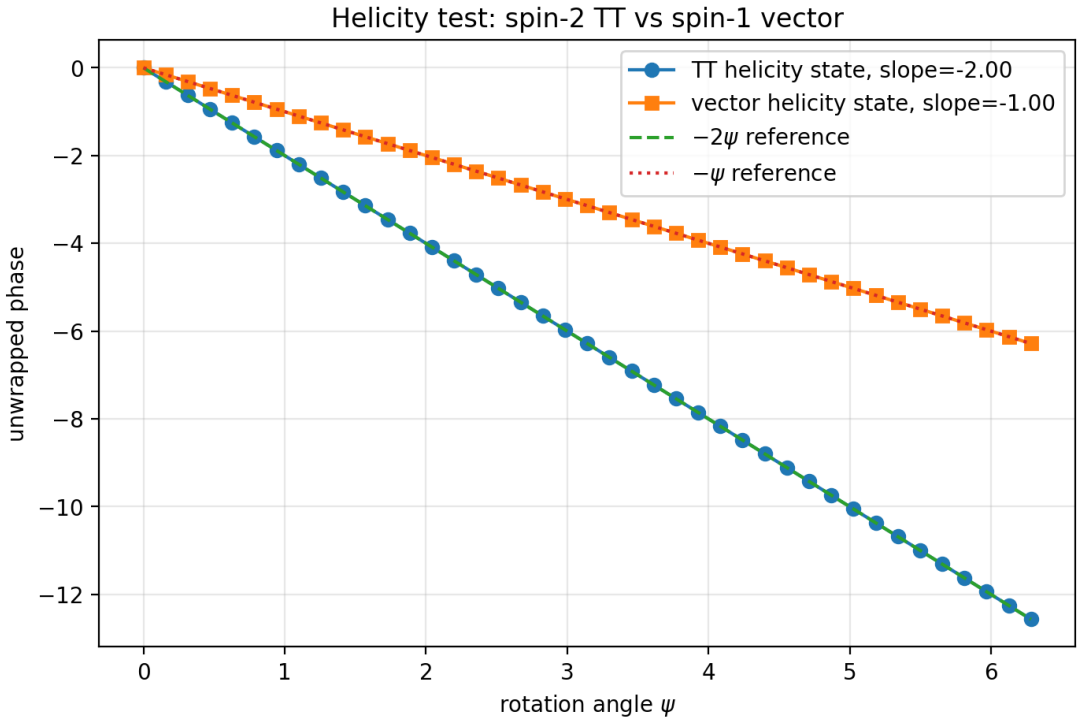

Figure 1: Helicity phase test. The vector mode transforms with helicity 1, while the transverse-traceless tensor mode transforms with helicity 2. This is the key distinction between connection-like propagation and gravitational-wave-like propagation.

scalar diffusion and scalar shell response both closed near $d \approx 3$.

Interpretation. This negative result strengthens the hierarchy of the paper. Scalar timing can be meaningful as a local redshift-like observable, but it does not close as a complete geometric sector in the tested substrates. Connection and tensor degrees of freedom are therefore not decorative additions. They are structurally required if the goal is curvature and gravitational radiation.

9. Claim hierarchy

The framework is strongest when its claims are sorted by status.

Table 3: Claim hierarchy for Condensed Timing Geometry.

Claim	Status	Meaning
Scalar timing is holonomy-free	theorem	Exact scalar-derived offsets vanish around closed loops.
Timing connection can carry loop holonomy	definition/standard	A general 1-form can have nonzero circulation around loops.
Local curvature and topological holonomy are distinct	standard	Contractible loops measure local curvature; non-contractible loops can carry flat global twists.

Claim	Status	Meaning
The timing connection has a gravitomagnetic anchor	weak-field GR interpretation	The g_{0i} sector plays a vector-potential-like role for frame dragging and clock synchronization.
TT spin-2 sector separates from scalar/vector/gauge controls	numerical consistency test	The Fourier-space SVT/TT projector gives two clean helicity-2 modes.
Scalar timing alone closes as full geometry	tested and not supported here	Severe scalar closure tests found no shared $d \approx 3$ scalar window.
A microscopic substrate generates the TT sector	open	Requires deriving h_{ij}^{TT} from specific dynamics, not merely projecting it once introduced.
Full emergent gravity follows	open	Requires field equations, sources, gauge structure, infrared limit, and empirical coupling.

10. What this framework does and does not say

10.1. What it says

- Local clock-rate shifts are scalar timing observables.
- Scalar timing cannot carry loop holonomy by itself.
- Curvature first appears as failure of global synchronization, represented by a timing connection with nonzero loop holonomy.
- The weak-field gravitomagnetic sector supplies a physical anchor for clock-connection language.
- True gravitational radiation requires a transverse-traceless spin-2 tensor sector.
- Severe scalar closure tests support the placement of scalar timing as an incomplete but useful layer.

10.2. What it does not say

- It does not claim that scalar timing alone is gravity.
- It does not claim that a vector timing connection is automatically gravity.
- It does not claim that the numerical projector generates gravity from a microscopic substrate.
- It does not solve dimensional selection.
- It does not derive the Einstein equations.
- It does not claim experimental detection of a new field.

The paper therefore uses the word gravity only at the tensor-completion level. Scalar timing and clock-connection holonomy are necessary pieces of a clock-readable geometry, not sufficient proofs of general relativity.

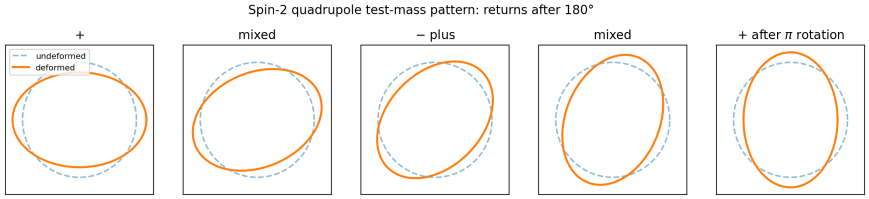

Figure 2: Test-ring quadrupole pattern for a transverse-traceless spin-2 mode. The deformation has the characteristic plus/cross structure and returns to itself under a 180-degree rotation.

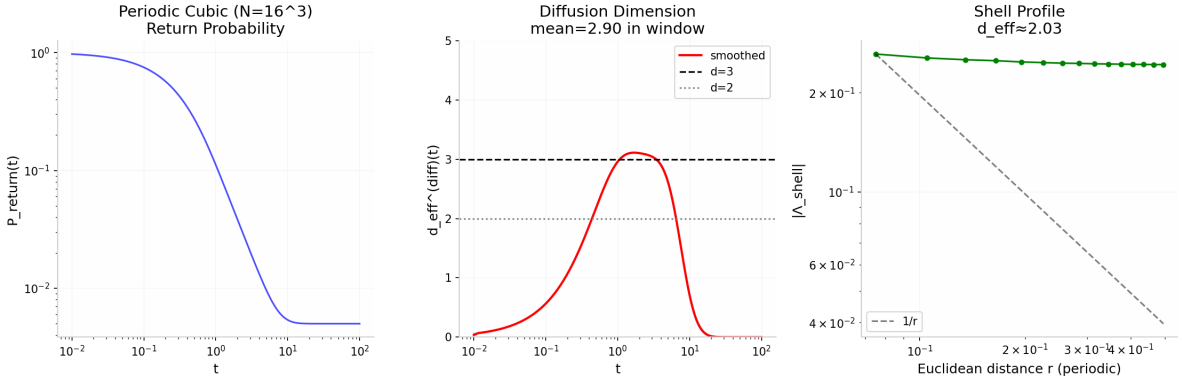

Figure 3: Periodic cubic scalar closure test. The diffusion estimator can approach the three-dimensional reference in a finite window, but the scalar shell profile remains close to a two-dimensional response. This is the key scalar closure failure: the two estimators do not agree near three in the same scaling window.

11. Conclusion

Condensed Timing Geometry begins with the observation that clocks make geometry visible. But the clock-readable structure is layered. A scalar timing load can model local clock slowdown, yet any timing offsets derived from a scalar are exact and holonomy-free. Curvature begins when timing offsets form a connection whose loop sums need not vanish. In weak-field gravity, this connection has a natural home in the gravitomagnetic sector. Full gravitational radiation requires one further lift to the transverse-traceless spin-2 sector of a symmetric metric perturbation.

The numerical results in this paper draw a clean boundary. Scalar closure tests fail to produce a complete three-dimensional scalar geometry across the tested substrates. In contrast, the tensor testbed cleanly separates scalar, vector, gauge, and TT sectors, with the TT sector carrying the expected helicity-2 signature. The result is not a completed theory of quantum gravity. It is a disciplined map of what must be present before a timing-based approach can honestly speak of gravity:

$$\text{redshift } (\Lambda) \quad \rightarrow \quad \text{synchronization holonomy } (A, F) \quad \rightarrow \quad \text{spin-2 radiation } (h_{ij}^{\mathrm{TT}}). \tag{20}$$

Future work must derive the connection and tensor sectors from a concrete microscopic substrate, show their gauge structure and source coupling, and recover the appropriate infrared field equations. Until then, the framework should be read as a sharp hierarchy of necessary structures, not as a finished gravitational theory.

References

[1] S. Abramsky and A. Brandenburger, "The sheaf-theoretic structure of non-locality and contextuality," *New Journal of Physics* 13, 113036 (2011).

[2] S. Abramsky, S. Mansfield, and R. Soares Barbosa, "The cohomology of non-locality and contextuality," arXiv:1111.3620 (2011).

[3] M. Desbrun, A. N. Hirani, M. Leok, and J. E. Marsden, "Discrete exterior calculus," arXiv:math/0508341 (2005).

[4] T. Regge, "General relativity without coordinates," *Nuovo Cimento* 19, 558-571 (1961).

[5] B. Mashhoon, "Gravitoelectromagnetism: A brief review," arXiv:gr-qc/0311030 (2003).

[6] C. W. F. Everitt et al., "Gravity Probe B: Final results of a space experiment to test general relativity," *Physical Review Letters* 106, 221101 (2011).

[7] B. P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration), "Observation of gravitational waves from a binary black hole merger," *Physical Review Letters* 116, 061102 (2016).

[8] C. W. Misner, K. S. Thorne, and J. A. Wheeler, *Gravitation*. W. H. Freeman (1973).

[9] R. M. Wald, *General Relativity*. University of Chicago Press (1984).