Chapter 2 Static Spatial Anisotropy

Reconstructing Inertia, Momentum, and Gravitation from Gravitational Redshift

Building on the constancy of the speed of light and the length vector effect (LVE), Chapter 1 established the directed length relations for motion-induced spatial anisotropy. It demonstrated that so-called "changes in time" originate fundamentally in changes in spatial length quantities, thereby rejecting the traditional paradigm of explaining physical phenomena through "time dilation." This chapter extends that spatial ontology to static gravitational systems. Rather than taking the four-dimensional curved-spacetime metric of general relativity as its starting point, ASD proceeds directly from the length vector effect and the constraint of a constant speed of light, explicitly maintaining that the physical origin of gravitational redshift is matter-induced static spatial dilation. On this basis, the chapter rigorously defines the spatial linear dilation factor, the spatial linear-density factor, and the spatial-state field function, and systematically reconstructs gravitation, inertia, momentum, planetary orbital precession, gravitational optical effects, and black-hole boundary mechanics within a continuous spatial-medium framework.

ASD takes the spatial medium and its longitudinal and transverse degrees of freedom as its physical ontology. Matter consists of stable topological structures formed by space; light is a propagating mode in space; and clocks record the number of repetitions of physical processes. Space, matter, and propagation processes thus constitute an interacting whole: matter changes the state of space, and the modified space in turn acts on matter and on the propagation of light. Time enters this description as a process-counting parameter, while changes in periods are traced to the lengths and motions involved in the processes themselves.

Two types of spatial response run through this chapter. Stationary matter excites longitudinal spatial dilation and its gradient, thereby establishing a gravitational field; moving topological cores and their accompanying fields undergo directional spatial reconfiguration, thereby exhibiting momentum and inertia. Planetary orbits connect these two responses. Light deflection and propagation delay reveal how nonuniform space affects propagation paths, while black holes extend this spatial-ontological picture to the physical boundary of the continuum state.

The logical sequence of this chapter is as follows. First, gravitational redshift is used to establish the law of static spatial dilation, from which the longitudinal spatial-state gradient and its gravitational stress action are derived. Second, the length vector effect and spatial-reconfiguration impedance establish the momentum, inertia, and energy relations of moving topological structures. Next, a unified orbital action and effective optical-path line element directly yield perihelion precession, light deflection, and the Shapiro delay. Finally, longitudinal spatial dilation is extended to the termination boundary of the continuum ($X = 0$), establishing the boundary-state dynamics and statistical thermodynamics of black holes.

This chapter uses the counting parameter t under common reference conditions, takes c as the local vacuum propagation speed, and denotes by G_0 the gravitational coupling coefficient calibrated in the background under consideration. The static gravitational potential is denoted by Ψ, with $\Psi < 0$ near an attractive source; Ω is the linear dilation factor, and $\Phi = \Omega^{-1}$ is the dimensionless linear-density factor. In spherically symmetric calculations, r is the areal radius, with the spherical area defined by $A = 4\pi r^2$; accumulated radial length and optical path length are calculated separately. The

motion-related directional factor is denoted by γ, the specific orbital angular momentum by j, and the gravitational length by $\ell_g = G_0 M/c^2$.

I. The Physical Meaning of Gravitational Redshift

Gravitational redshift is a central experimental criterion for testing the physical foundations of gravitational theories. When light waves or electromagnetic signals propagate from a region of strong gravity, such as the surface of a massive celestial body, to a region of weaker gravity, a far-field reference standard measures a lower frequency and a longer wavelength. Conversely, propagation from a weak gravitational field into a stronger one produces a gravitational blueshift, with an increased frequency.

General relativity geometrizes gravitation as four-dimensional spacetime curvature and explains gravitational redshift through "proper-time dilation (clock slowing)": proper time is considered to pass more slowly at deeper gravitational potentials, and atomic oscillation frequencies decrease because proper time slows down. However, treating time as a physical entity that can independently expand or contract obscures the spatial-medium mechanics underlying atomic transitions and light-wave propagation.

Modern high-precision optical-clock experiments have precisely confirmed gravitational frequency shifts across height differences on decimetre and even millimetre scales. ASD offers a physical-ontological interpretation that differs fundamentally from general relativity: time itself neither speeds up nor slows down. Gravitational redshift is a spatial physical effect in which matter excites static dilation of the surrounding space, directly changing the characteristic scales of atomic transitions and the wavelengths of emitted radiation.

1. Time Metrology, Frequency Comparisons, and Reference Conditions

In experimental physics and modern metrology, the "passage of time" is not an independent physical entity that can be measured directly. What all time-and-frequency devices—from mechanical pendulum clocks to modern cold-atom clocks and optical lattice clocks—actually record is the number of repetitions of a standard periodic process. ASD therefore explicitly establishes the metrological and physical status of time: time is a counting scale for standard periodic processes.

This proposition reduces time from an abstract metaphysical entity to an operational process-counting parameter. When clocks in different environments or at different gravitational positions exhibit frequency differences, what changes is emphatically not a "time entity" detached from physical processes. Rather, (1) the local spatial state changes the physical characteristic length and renewal period of the standard process; (2) under the constraint of a constant limiting wave speed, the oscillation frequency of that process undergoes a real physical shift; and (3) the cycle counts accumulated under a common reference standard exhibit systematic differences.

The scientific logic is exactly the same as that of temperature corrections for gauge blocks in length metrology. A gauge block undergoes real thermal expansion or contraction when its temperature departs from the standard temperature. Metrology does not therefore declare that "the geometric reference of space itself has thermally expanded"; instead, it treats the change as a systematic shift of the standard caused by an environmental field and reduces the result to standard reference conditions. Similarly, atomic clocks undergo real changes in transition frequency at different gravitational potentials. Time-and-frequency standards laboratories worldwide apply gravitational-potential corrections to reduce these frequencies to conventional reference conditions, such as the

geoid, in order to maintain the uniformity of International Atomic Time (TAI). The fundamental disagreement between ASD and general relativity therefore concerns not the experimental fact of gravitational frequency shifts but their physical causal mechanism. General relativity attributes them to a change in the rate of passage of proper time in four-dimensional spacetime, whereas ASD explicitly maintains that they are a direct consequence of static dilation of the three-dimensional local spatial scales on which frequency standards depend.

A clock records the number of repetitions of a standard process. When a periodic process accumulates N cycles, the corresponding counting time at a given reference frequency f_{ref} is N/f_{ref}. Atomic clocks, optical clocks, and mechanical clocks operate through different mechanisms, but time metrology must always connect the process, the count, and the reference conditions. ASD accordingly treats time as a parameter describing physical evolution and traces changes in clock frequency to the physical structures involved in timekeeping and to their environments.

The process-based relation used in Chapter 1,

$$t = \frac{S}{v}$$

remains the starting point for understanding the time parameter here. S denotes the accumulated path length of the process under consideration, and v denotes its average speed; a process with variable speed can be accumulated according to the corresponding local relation. This relation connects the process length, speed, and counting interval. When a time reading changes, a theory should explain how the timekeeping process has changed, rather than merely give the difference in readings a new name.

For a standard process whose phase advance is characterized by c, the phase-path length per cycle, S_{cyc}, and the period satisfy $\tau = S_{\mathrm{cyc}}/c$. With the speed of light unchanged, an increase in the process scale produces a corresponding increase in the counting interval needed to complete one cycle. For an atomic transition, $S_{\mathrm{cyc}} = c/f$ characterizes its phase scale. ASD connects this scale to the material structure of the atom and to the surrounding space: spatial dilation in a gravitational field changes the length quantity associated with the transition, increasing the wavelength and lowering the frequency, ultimately producing differences in clock counts.

In the current SI, the second is defined by the frequency of a specified caesium-atom transition, and the metre is linked to the second through the fixed numerical value of the speed of light in vacuum. Local realization of the second and reduction of frequencies measured at different locations to common reference conditions jointly form the basis of time-and-frequency metrology. High-precision remote frequency comparisons and the evaluation of International Atomic Time must account for factors such as gravitational potential. Real changes in standards under different environmental conditions enter a unified comparison of quantity values after reduction; ASD investigates precisely the spatial physical origin of these changes.

After propagation-link effects and environmental perturbations have been accounted for, atomic clocks of the same type at different gravitational potentials exhibit systematic relative frequency shifts. Optical-clock experiments have resolved the gravitational frequency shifts associated with decimetre-scale height differences. In ASD, this precision observation reveals the effect of spatial length states on material processes: characteristic scales are larger at deeper potentials, the wavelength associated with the same type of transition is longer, and the frequency is lower when compared under a common reference.

For a vacuum wave under the same calibration conditions,

$$\lambda = \frac{c}{f} = c\tau \tag{2.1}$$

Equation (2.1) relates wavelength, period, and frequency under the same calibration conditions. ASD assigns this relation a definite physical order: dilation of the spatial scale increases the wavelength; the increased wavelength, under the constraint that c remains constant, lowers the frequency and increases the period. Frequency is the manifestation of the spatial length state in the counting process, and spatial dilation is the physical starting point for this chapter's explanation of gravitational redshift. In the comparisons between different locations below, f, λ, and characteristic lengths are all expressed under common reference conditions.

2. Spatial Dilation, Wavelength Increase, and Gravitational Redshift

Let the characteristic length and frequency of a given type of standard process under far-field reference conditions be L_0 and f_0, and let the corresponding quantities in a static, spherically symmetric gravitational field be $L(r)$ and $f(r)$. ASD uses $\Omega(r)$ to describe matter-induced linear spatial dilation. The characteristic length of the standard process increases with spatial dilation, and its frequency is determined by the same length relation:

$$\frac{L(r)}{L_0} = \Omega(r), \qquad \frac{f(r)}{f_0} = \Omega(r)^{-1} \tag{2.2}$$

Gravitational redshift manifests the dilation of spatial length quantities, and the frequency change results from the corresponding change in wavelength. At deeper potentials, Ω is larger, so the wavelength and characteristic phase path become longer, and the same process requires a longer counting interval to complete one cycle. What changes here is the scale relation between space and material processes; time retains its role as a process-counting parameter.

This interpretation places atomic clocks and light propagation within the same spatial ontology. The internal structure of an atom sustains a characteristic phase process, while light transmits phase through space; the scales of both are linked to the spatial state in which they exist. Changes in clock frequency therefore have an actual physical origin. Comparing clocks at two locations amounts to comparing the length states of space at those locations through standard processes; comparing light wavelengths reads out that state through propagation.

Combining Eq. (2.2) with the spatial linear-density factor $\Phi(r) = \sqrt{1 + 2\Psi(r)/c^2}$ corresponding to the static gravitational potential Ψ, the frequency ratio of standard processes at any two radial positions r_1, r_2 strictly satisfies

$$\frac{f(r_2)}{f(r_1)} = \frac{\Omega(r_1)}{\Omega(r_2)} = \frac{\Phi(r_2)}{\Phi(r_1)} = \sqrt{\frac{1+\frac{2\Psi(r_2)}{c^2}}{1+\frac{2\Psi(r_1)}{c^2}}} \tag{2.2a}$$

Equation (2.2a) gives the analytical law for frequency comparisons between different locations in a static gravitational field. In the weak field near the Earth's surface, the gravitational-potential difference across a height difference Δh is $\Psi(r_2) - \Psi(r_1) = g\Delta h$, and the first-order weak-field limit of Eq. (2.2a) gives the relative frequency shift $g\Delta h/c^2$. In the ASD physical picture, raising an atomic clock moves it into a region with weaker spatial dilation, shortening its local characteristic wavelength and consequently increasing its oscillation frequency.

For the space outside an isolated, static, spherically symmetric mass source, ASD establishes the following law of linear spatial dilation:

$$\Omega(r) = \left(1 - \frac{2G_0M}{c^2 r}\right)^{-1/2}, \qquad r > \frac{2G_0M}{c^2} \tag{2.3}$$

The corresponding dimensionless spatial linear-density factor is defined as

$$\Phi(r) = \Omega(r)^{-1} = \sqrt{1 - \frac{2G_0M}{c^2 r}} \tag{2.4}$$

As $r \to \infty$, $\Omega \to 1$ and $\Phi \to 1$, and space returns to its homogeneous intrinsic far-field state. On approaching the central mass source, Ω increases monotonically while Φ decreases monotonically, quantitatively characterizing stronger radial spatial dilation and a lower spatial linear density per unit reference length. Substituting $\Psi = -G_0M/r$ into Eq. (2.2a) yields complete closure with Eqs. (2.3)–(2.4). Static spatial dilation and the reduction in clock frequency are thus unified within the same set of spatial-state variables.

ASD has thus established an explicit spatial-ontological causal chain for gravitational redshift: the presence of matter excites static dilation of the surrounding space; spatial dilation directly lengthens the characteristic scales of atomic transitions and the wavelengths of emitted light; and, under the constraint of a constant speed of light, this necessarily lowers frequencies and lengthens periods. The following sections proceed directly from this spatially dilated state to derive gravitation, inertia, and orbital dynamics rigorously.

II. The Nature of Gravitation

1. Linear Scales, Volumetric Density, and Longitudinal–Transverse Responses

In ASD, space has physical degrees of freedom capable of sustaining matter, storing energy, and transmitting stress. Matter-induced static dilation makes the spatial state position-dependent. To express this picture in clear mathematical relations, linear and volumetric scales must first be distinguished: $\Phi = L_0/L$ describes the reciprocal change in a one-dimensional characteristic length and is a dimensionless linear-density factor; ρ_s describes the density of the medium per unit volume and has the dimensions of mass density. The two quantities characterize different aspects of the same spatial structure.

Gravitational redshift primarily provides information about linear scales. Three-dimensional volumetric density also depends on how deformations in different directions combine: dilation along one direction and simultaneous dilation along all three directions produce different volume changes. The longitudinal field establishes the density and compression state, while the transverse field contributes to shear and structural stability. Coupling between these two types of freedom connects changes in linear scales, volumetric deformation, and material structure.

In a continuum mapping representation, let the local deformation gradient be F_s and the volume ratio be $J_s = \det \mathrm{F}_s$. The volumetric density of a conserved medium is then $\rho_s = \rho_0/J_s$. If all three principal directions are elongated by the same factor Ω, then $J_s = \Omega^3$, and hence $\rho_s/\rho_0 = \Phi^3$. For a spherically symmetric radial structure, J_s is calculated from its actual deformation. This representation gives separate definitions to linear dilation and volumetric density while keeping them connected through three-dimensional deformation.

ASD describes spatial responses in terms of longitudinal density degrees of freedom and transverse shear degrees of freedom. In a homogeneous background, under linear, long-wavelength conditions, the lowest-order coefficients of the two propagation branches can be written as

$$c_T^2 = \frac{G_S}{\rho_s}, \qquad c_L^2 = \frac{K_S^{\text{eff}}}{\rho_s}; \qquad c_T = c_L = c \;\Rightarrow\; G_s = K_s^{\text{eff}} = \rho_s c^2 \tag{2.5}$$

Here ρ_s provides the inertial normalization of the modes, while G_s and K_s^{eff} are the effective stiffnesses of the transverse and longitudinal branches, respectively. K_s^{eff} denotes the restoring coefficient of the full longitudinal mode; in the notation of an ordinary isotropic elastic solid, the corresponding combination is $K + 4G_s/3$. ASD takes equal speeds of the longitudinal and transverse branches in a homogeneous background without matter-induced perturbations as a propagation condition, using the two types of spatial degrees of freedom to describe density changes and shear propagation, respectively. Later chapters develop spatial waves and their coupling to matter from this branch structure.

2. Spatial-State Gradients and the Newtonian Limit of Gravitation

Define the static dimensionless field variable

$$X(r) = \Phi(r)^2 = 1 - \frac{2G_0 M}{c^2 r}, \qquad \Psi(r) = \frac{c^2}{2}[X(r) - 1] \tag{2.6}$$

X represents the spherically symmetric, static longitudinal spatial state as a dimensionless state function that enters the field equations and equations of motion directly, while Ψ is its corresponding gravitational potential. ASD explicitly maintains that the physical essence of gravitation is neither action at a distance nor abstract four-dimensional geometric curvature, but the longitudinal spatial-state gradient (∇X) excited by topological matter and the anisotropic stress differences it produces in the continuous spatial medium. A massive celestial body creates radially nonuniform dilation of the surrounding space. Another topological material structure placed in that space experiences a net spatial restoring stress directed toward the central source because the degree of spatial dilation differs on its two sides.

For test matter of mass m_g^p, the potential-energy coupling is $U = m_g^{\text{p}}\Psi$, and the gravitational acceleration is given directly by the negative gradient of the spatial-state function:

$$\mathrm{g}_X = -\nabla\Psi = -\frac{c^2}{2}\nabla X = -\frac{G_0 M}{r^2}\,\hat{\mathrm{r}} \tag{2.7}$$

For a general weak, static mass distribution, the corresponding source equations are

$$\nabla^2\Psi = 4\pi G_0 \rho_g, \qquad \nabla^2 X = \frac{8\pi G_0}{c^2}\rho_g \tag{2.7a}$$

ρ_g is the effective source density that generates gravitation. The gradient and Laplacian operators in this section are defined with respect to reference spatial coordinates; local length responses are specified separately by constitutive relations. In the exterior source-free region, $\nabla^2 X = 0$; the spherically symmetric equation is $\frac{d}{dr}(r^2 X') = 0$, whose asymptotically normalized solution is precisely Eq. (2.6). The mass parameter can also be defined by the far-field flux:

$$M = \frac{c^2}{8\pi G_0}\oint_{S_r} \nabla X \cdot dS \tag{2.7b}$$

Equation (2.7b) connects the mass-source strength to the far-field flux of the spatial state. A larger source mass produces a stronger longitudinal gradient at the same radius; a test body coupled to this

nonuniform background therefore experiences the corresponding resultant spatial stress. In stress terminology, the net action is given by the stress integral over a closed surface enclosing the body, and Eq. (2.7) is its low-speed, weak-field potential representation. The generation of a gravitational field by mass and the gravitational action on a body thus become two stages of the same longitudinal–transverse coupling process.

Consider a body near the Earth's surface. Spatial dilation is slightly stronger on the side closer to the Earth than on the side farther away, creating an imbalance in the coupling between the topological structure and space on its two sides. A free body changes momentum under the net action; for a body resting on the ground, the supporting stress from the ground balances this action. The "spatial pressure difference" in ASD refers precisely to the stress difference produced by this longitudinally nonuniform state. The pressure function, shear contributions, and interface coupling jointly determine the resultant force, which reduces to $m_0 \mathrm{g}_X$ in the linear weak-field regime.

This also distinguishes static support from free fall: the former measures the external force needed to maintain a specified position, whereas the latter describes the evolution of motion under the action of space. The same spatial ontology continues to apply in strong fields, but local length calibration and reduction to a reference enter the force expressions. Section V uses these considerations to obtain the local holding force and the surface-gravity parameter.

3. The Gravitational Coupling Coefficient and Intrinsic Scales

In ASD, the gravitational coupling coefficient characterizes the strength with which topological matter excites a longitudinal spatial state and that state acts on other matter. Its physical origin lies in the structure of the spatial medium and in longitudinal–transverse coupling. This chapter uses G_0 for the macroscopically calibrated value in a given background, then organizes its microscopic scale relations in terms of density, propagation speed, and intrinsic length.

The gravitational constant has dimensions of $\mathrm{m}^3\,\mathrm{kg}^{-1}\,\mathrm{s}^{-2}$. The spatial density ρ_0, speed of light c, and microscopic length ℓ_0 together yield the corresponding scale combination:

$$G_0 = \xi_G \frac{c^2}{\rho_0 \ell_0^2} \tag{2.7c}$$

ξ_G is a dimensionless coupling function characterizing the topological structure and the efficiency of longitudinal–transverse conversion. Equation (2.7c) divides the physical explanation of gravitational strength into two parts: ρ_0, c, and ℓ_0 provide the dimensional scales of the medium, while ξ_G gives the coupling proportion for the particular structure. The lattice scale, core radius, and characteristic phase length can be defined separately in a microscopic model, and their interrelations can then be established from structural solutions.

Gravitational coupling thus becomes a physical quantity that can be traced to spatial structure. How one topological core excites longitudinal dilation and how that dilation acts on another core are summarized macroscopically by G_0. When the background changes, the medium density, intrinsic scale, and coupling function may also change. Studying such changes connects the physical origin of the gravitational constant to the evolution of the spatial state.

For example, for a prescribed slowly varying coefficient $G(\mathrm{x})$, the static source equation can be written as $\nabla \cdot [G(\mathrm{x})^{-1} \nabla \Psi] = 4\pi\rho_g$. When the coupling coefficient itself becomes a function of dynamical fields, its variation enters the field equations together with the variation of the action. The subsequent calculations in this chapter hold the background-calibrated value G_0 fixed, so that source strength, orbits, and boundary energy use a consistent normalization.

III. Reconstructing Newton's Second Law

1. Topological Structure, Mass, and Inertia

ASD regards matter as a localized stable structure jointly formed by the longitudinal and transverse degrees of freedom of space. Transverse shear and torsion sustain the core structure, while the longitudinal response connects that structure to the density state of the surrounding space. Mass, inertia, and gravitational source strength therefore share a common dynamical carrier. Chapter 4 further discusses candidate topological forms of this carrier; this chapter first establishes the macroscopic relations between mass and motion.

Let $q_\rho(\mathrm{x})$ be the dimensionless volumetric-density distribution function in the near region of a topological core, and define the finite density-deficit quantity

$$m_{\mathrm{def}} = \rho_0 \int_D \left[1 - q_\rho(\mathrm{x})\right] \, dV_0 \tag{2.8}$$

Here dV_0 is the reference volume element, D covers the effective core region, and q_ρ gives the volumetric-density distribution of this near-region structure. If the integral is taken over all space, the core distribution must decay sufficiently rapidly in the far field for the density-deficit integral to remain finite. The near-region distribution determines the structural scale of matter, whereas the exterior $\Phi(r)$ describes the linear-dilation field established by that matter.

Define

$$V_{\mathrm{eff}} = \int_D \left(1 - q_\rho\right) \, dV_0 \equiv \frac{4\pi R_{\mathrm{eff}}^3}{3}, \qquad m_{\mathrm{def}} = \rho_0 V_{\mathrm{eff}} \tag{2.9}$$

R_{eff} expresses the density-deficit integral as an equivalent spherical volume. Let the low-speed inertial mass be $m_0 = C_m m_{\mathrm{def}}$. With the normalization $C_m = 1$ adopted in this section, $m_0 = \rho_0 V_{\mathrm{eff}}$ follows. This equivalent scale supplies the volume parameter for the inertial integral below; other particle length scales are defined by the corresponding measurements and structural relations.

ASD gives an explicit physical definition of the origin of inertia: inertia is the directional reconfiguration impedance exhibited by the continuous spatial medium when an external force changes the state of motion of a material topological core and its accompanying spatial field. The core structure maintains the stable topological identity of matter, while translational motion necessarily entails simultaneous directional rearrangement of the core and the surrounding accompanying field. Momentum is the directed conserved quantity of this combined "topological core–accompanying field" structure; inertia is the spatial-dynamical response required to change its directional distribution.

This reconfiguration impedance manifests as the response of energy and momentum to changes in the state of motion. Stable uniform motion in a homogeneous background maintains the directional distribution jointly formed by the core and accompanying field; acceleration and changes of direction alter this distribution, with the work and impulse of external forces entering the combined structure. The spatial medium itself stores energy and exhibits an inertial response, so the accompanying field contributes to total momentum, and uniform motion is maintained in accordance with total momentum conservation.

Newton's first and second laws thereby acquire a continuous spatial explanation: without an external force, the combined structure preserves its total momentum; with an external force, spatial reconfiguration changes that momentum. Below, the length vector effect (LVE) determines the directional scales, an inertial constitutive relation specifies the weight of each direction in the momentum, and integration then yields the total quantity changed by the external force.

2. The Length Vector Effect and the Momentum Constitutive Relation

The directional length relation from Chapter 1 is written as

$$L' = LK(\chi), \qquad K(\chi) = \gamma(1 - \beta\cos\chi), \qquad \beta = \frac{v}{c}, \quad \gamma = (1 - \beta^2)^{-1/2} \tag{2.10}$$

In the forward and backward directions of motion, $K_+ = \gamma(1 - \beta)$ and $K_- = \gamma(1 + \beta)$, with $K_+ K_- = 1$. The symmetric mean of the two axial inverse scales is therefore

$$\frac{1}{2}(K_+^{-1} + K_-^{-1}) = \gamma \tag{2.10a}$$

Equation (2.10a) proves that the symmetric mean of the inverse scales in the forward and backward axial directions of the moving spatial structure is exactly the Lorentz factor γ. Taking this axially symmetric gain as the scale factor for the overall inertial response, and including a first-order dipolar bias between the forward and backward directions, ASD establishes the following constitutive law for the spatial inertial weight:

$$\rho_I(\chi) = \rho_0\gamma(1 + \beta\cos\chi), \qquad \frac{1}{4\pi}\int \rho_I \, d\Omega_{\text{ang}} = \rho_0\gamma \tag{2.11}$$

ρ_I is an inertial weight with the dimensions of density, characterizing the contribution of each direction to total momentum. Equation (2.11) represents the overall gain by its angle-independent term and the forward–backward bias by its $\cos\chi$ term, providing a closure relation between the LVE directional structure and the momentum integral. The geometric scale K describes length, whereas the inertial weight ρ_I describes the dynamical response; the constitutive relation connects the two.

Directly ahead of the motion, the inertial weight is $\rho_0\gamma(1 + \beta)$; directly behind it, the weight is $\rho_0\gamma(1 - \beta)$, corresponding respectively to the axial contraction and dilation of the LVE. Material motion redistributes the spatial structure participating in the inertial response among different directions. The core retains its stable identity, while the accompanying field carries the corresponding directional state. As speed increases, both the forward–backward difference and the overall gain increase.

Denote the momentum density by π, so that total momentum is $\int \pi \, dV$. In the equivalent-sphere model, take $\pi = \rho_I \mathrm{v}$ and sum the inertial contributions from all directions to obtain

$$\mathrm{p} = \mathrm{v}\int_0^{R_{\text{eff}}} r^2 \, dr \int_0^{2\pi} d\varphi \int_0^{\pi} \rho_I(\chi)\sin\chi \, d\chi \tag{2.12}$$

Since $\int_0^{\pi} \cos\chi\sin\chi \, d\chi = 0$ and $\int_0^{\pi} \sin\chi \, d\chi = 2$, we obtain

$$\mathrm{p} = \frac{4\pi}{3}\rho_0 R_{\text{eff}}^3 \gamma \mathrm{v} = m_0\gamma\mathrm{v} \tag{2.13}$$

Its magnitude is

$$p = m_0\gamma v \tag{2.14}$$

The LVE determines the directional structure of the response of moving space, while the inertial constitutive relation specifies how that structure enters the total momentum of the topological core and its accompanying field. Together they yield $\mathrm{p} = m_0\gamma\mathrm{v}$. The spherical integral eliminates the antisymmetric first-order angular term in the forward–backward weighting, but the overall velocity vector still determines the momentum direction, and the axially symmetric gain γ remains in the total response. In the ASD interpretation, γ is not a time-dilation mechanism; it is the gain contributed by the moving spatial structure to the total inertial response.

m_0 denotes the mass parameter for a fixed internal state, and γ denotes the spatial inertial gain when that structure moves. ASD thus distinguishes the mass parameter from the response to motion: matter retains its topological identity, while its momentum changes as the combined moving structure is reconfigured. Relativity establishes a momentum relation of the same mathematical form through spacetime symmetry; this section establishes it through the directional length law and a spatial inertial constitutive relation, taking the interaction between moving matter and space as its physical starting point.

3. Force and Longitudinal and Transverse Inertial Responses

In a homogeneous background, treat the core and its accompanying field as a whole and define the total external force as

$$\mathrm{F} = \frac{d\mathrm{p}}{dt} \tag{2.15}$$

Differentiating Eq. (2.13) gives

$$\mathrm{F} = m_0 \left(\gamma \mathrm{a} + \frac{d\gamma}{dt}\mathrm{v}\right), \qquad \mathrm{a} = \frac{d\mathrm{v}}{dt} \tag{2.16}$$

From $\gamma = (1 - v^2/c^2)^{-1/2}$, the chain rule gives

$$\frac{d\gamma}{dt} = \frac{\gamma^3}{c^2}\,\mathrm{v}\cdot\mathrm{a} \tag{2.17}$$

Decomposing the acceleration into components parallel and perpendicular to the instantaneous velocity, and using $1 + \gamma^2\beta^2 = \gamma^2$, gives

$$\mathrm{F} = m_0\left[\gamma \mathrm{I} + \frac{\gamma^3}{c^2}\mathrm{v}\mathrm{v}^{\mathrm{T}}\right]\mathrm{a} = m_0\gamma^3\mathrm{a}_{\parallel} + m_0\gamma\mathrm{a}_{\perp} \tag{2.18}$$

The longitudinal response is therefore

$$\mathrm{F}_{\parallel} = m_0\gamma^3\mathrm{a}_{\parallel} \tag{2.19}$$

Inverting Eq. (2.18) yields the equation for the acceleration response to the total external force over the full speed range:

$$\boldsymbol{a} = \frac{1}{m_0\gamma}\left[\boldsymbol{F} - \frac{(\boldsymbol{v}\cdot\boldsymbol{F})\boldsymbol{v}}{c^2}\right] = \frac{\boldsymbol{F}_{\parallel}}{m_0\gamma^3} + \frac{\boldsymbol{F}_{\perp}}{m_0\gamma} \tag{2.20}$$

The transverse inertial response, perpendicular to the instantaneous velocity, is

$$\mathrm{F}_{\perp} = m_0\gamma\mathrm{a}_{\perp} \tag{2.21}$$

For uniform circular motion, $F = m_0\gamma v^2/R$, where v and R are defined under the same local length and counting conditions. The inertial gain is already included in the momentum relation, while the curvature of the motion is described by the radius under that calibration. A higher speed requires a stronger spatial-reconfiguration action to maintain the same rate of turning.

Longitudinal acceleration must change both the velocity in the existing momentum and the overall gain of the spatial response, producing the additional $d\gamma/dt$ contribution. Instantaneous transverse acceleration satisfies $\mathrm{v}\cdot\mathrm{a} = 0$, so the first-order change in that gain is zero, and the external force primarily changes the direction of momentum. The difference between longitudinal and transverse reconfiguration impedances is determined by derivatives of the same momentum function, rather than by assigning two separate masses to the two types of motion.

4. Kinetic Energy, Rest Energy, and the Free Action

The power relation gives $dE_k = \mathrm{v} \cdot d\mathrm{p}$. For acceleration from rest to speed v, integration over the speed gives

$$E_k = \int_0^p v\ dp = m_0 \int_0^v \frac{w\,dw}{(1-w^2/c^2)^{3/2}} \tag{2.22}$$

Here $dp/dv = m_0\gamma^3$ has been used. Setting $z = 1 - w^2/c^2$ gives $w\,dw = -c^2 dz/2$, so the integral becomes

$$E_k = -\frac{m_0 c^2}{2}\int_1^{1-v^2/c^2} z^{-3/2}\ dz = m_0 c^2[(1 - v^2/c^2)^{-1/2} - 1]$$

This yields the analytical expression for kinetic energy over the full speed range:

$$E_k = m_0 c^2(\gamma - 1) = m_0 c^2\left[\left(1 - \frac{v^2}{c^2}\right)^{-1/2} - 1\right] \tag{2.23}$$

In the ASD physical picture, kinetic energy is the additional energy of the combined moving structure relative to its stationary state. The work done by an external force during acceleration enters the motion-induced reconfiguration of the topological core and its accompanying field; it does not require the core's topological type to change with speed. Even at rest, transverse shear and torsion, longitudinal strain, and their coupling can store energy, so zero kinetic energy does not imply zero total energy.

ASD denotes the total stored energy of the same topological core and its static accompanying field by E_0, adopting the energy–inertia normalization $E_0 = m_0 c^2$. Rest energy is carried by transverse torsion, longitudinal strain, and their coupling within the structure, while kinetic energy is determined by the work done by external forces in changing the moving structure. Adding these two contributions gives the total energy

$$E = E_0 + E_k = m_0 c^2 \gamma \tag{2.24}$$

Eliminating v gives

$$E^2 - c^2 p^2 = m_0^2 c^4 \tag{2.24a}$$

The LVE directional relation, the inertial integral, and the work relation have thus formed a continuous derivation of energy and momentum. Equation (2.24a) describes the constraint between the total energy and total momentum of the same spatial topological structure, providing the basis for the carrier-wave and envelope analyses in Chapter 5. In ASD, these relations refer to energy-storing spatial structures and their motion-induced reconfiguration.

Expressing this momentum relation in analytical mechanics, integrating $p = \partial \mathcal{L}_0 / \partial v$, and fixing the constant by the rest energy gives the free Lagrangian

$$\mathcal{L}_0 = -m_0 c^2\sqrt{1 - v^2/c^2}, \qquad \mathrm{p} = \frac{\partial \mathcal{L}_0}{\partial \mathrm{v}}, \qquad E = \mathrm{p}\cdot\mathrm{v} - \mathcal{L}_0 \tag{2.24b}$$

Equation (2.24b) is derived rigorously and entirely from the ASD momentum-reconfiguration relation, Eq. (2.13), and the work–energy theorem, Eq. (2.22), and supplies the variational action for material motion in homogeneous space.

5. The Common Origin of Gravitational and Inertial Mass

In ASD, energy-equivalent mass, inertial mass, active gravitational mass, and passive gravitational mass are different responses of the same topological matter. E_0/c^2 characterizes the structure's stored rest energy; the low-speed derivative of momentum with respect to velocity characterizes translational inertia; the far-field flux characterizes gravitational source strength; and the coefficient in the external-field potential energy characterizes force coupling. These four definitions measure, respectively, the energy storage, motion, field-source strength, and external-field response of the same physical carrier.

The physical basis for the unification of mass is the common carrier shared by the topological structure and the longitudinal and transverse spatial fields. As a source, this structure establishes a longitudinal gradient in the surrounding space; as a test body, it experiences an external longitudinal stress; when its state of motion changes, the core and accompanying field jointly exhibit inertia. ASD organizes the concept of mass through this common origin and connects these responses into a single macroscopic mass parameter through universal coupling.

Let Q_0 denote a core structural quantity for a fixed internal state. The different responses can be written as $m_i = C_i Q_0$, $m_g^{\mathrm{a}} = C_a Q_0$, and $m_g^{\mathrm{p}} = C_p Q_0$. Universality of free fall requires C_p/C_i to be independent of material composition; source strength and stored energy are also normalized to the same structure. This chapter adopts the universal coupling relation

$$m_E = m_i = m_g^{\mathrm{a}} = m_g^{\mathrm{p}} = m_0 \tag{2.24c}$$

The corresponding weak-field external potential energy and force are

$$U_{\mathrm{ext}} = m_0 \Psi_{\mathrm{ext}} = \frac{1}{2} m_0 c^2 (X_{\mathrm{ext}} - 1), \qquad \mathrm{F}_g = -\nabla U_{\mathrm{ext}} = m_0 \mathrm{g}_X \tag{2.24d}$$

The same mass parameter thus enters both the inertial relation and the gravitational force relation, and m_0 cancels in weak-field free fall. Comparisons between test bodies of different compositions directly test this universal ratio; the MICROSCOPE experiment has advanced such tests to a precision level of approximately 10^{-15}. For composite bodies, binding energy, internal stresses, and self-gravitational contributions are all treated as parts of the total structure and included in the same accounting of energy and source strength.

IV. Planetary Orbits, Light Deflection, and the Shapiro Delay

Matter excites static spatial dilation, while motion produces a directional inertial response in the topological core and its accompanying field. Planetary orbits continuously combine these two spatial actions: a planet moves through the longitudinal background established by the central source, actual lengths along its path vary with position, and its momentum is reconfigured with its state of motion. ASD thus attributes perihelion precession to the dynamics of motion in nonuniform space, and light deflection and the Shapiro delay to the action of the same spatial structure on propagation paths.

This section follows the physical sequence "spatial dilation—wavelength and counting scale—local motion—action." Gravitational redshift reads out spatial dilation, while Ω and X describe this static state. The spatial length law determines paths, and the momentum and energy relations of Section III determine the response of moving structures. Planetary orbits and light propagation share this set of spatial variables, connecting material motion and the propagation of light within the same theory.

1. Spatial Length and Effective Optical Path in a Spherically Symmetric Background

The spatial dilation manifested by gravitational redshift is the physical basis for orbital and optical-path calculations. Matter induces nonuniform changes in the longitudinal spatial state; wavelengths and process scales change accordingly, and only then do frequencies change. For a static, spherically symmetric, uncharged exterior field, the longitudinal gradient of the central source selects the radial direction, while spherical symmetry relates the two tangential directions. Below, spheres are represented by their areal radius, and spatial lengths along the gradient direction are represented by radial linear dilation. The backreaction of the test body on the central source is neglected.

The linear spatial dilation law of Section I gives $\Omega = X^{-1/2}$. This chapter adopts the radial constitutive relation $d\ell_r = \Omega\, dr$ to incorporate this dilation into the actual length along the gradient direction. The areal radius r makes the tangential arc length on a given sphere equal to $r\, d\varphi$. The spatial length in the orbital plane is therefore

$$d\ell_s^2 = X^{-1}dr^2 + r^2 d\varphi^2 \tag{2.25}$$

Equation (2.25) makes spatial dilation a physical quantity that can be integrated along a path. The same reference radial increment dr corresponds to a greater actual spatial length near the central source; planets and light must move along this spatial structure when passing through the region. In the tangential term, r is already defined by the actual area of the sphere, so the spherical arc length and radial length carry their respective geometric information. Spherical symmetry preserves the equivalence of directions on the sphere, while the radial gradient imparts static anisotropy to space.

Spatial dilation changes both the path length and the standard process used for counting. The characteristic wavelength of the local standard process is increased by a factor of Ω relative to the far field; by $c = \lambda f$, its reference frequency is therefore $f = \Phi f_0$. Establish a common count t using the far-field standard process. During the same interval dt, the local standard process accumulates $dN = f_0 \Phi\, dt$ cycles. The velocity variable calibrated by the local process is consequently $v_* = f_0 d\ell_s/dN = \Phi^{-1} d\ell_s/dt$.

Every quantity here has a spatial and process-based meaning: $d\ell_s$ is the actual path length; Φ is determined by the wavelength dilation of the standard process; and dN is the number of cycles actually accumulated. $\Phi\, dt$ relates local counting to far-field counting, and ASD traces its origin to the spatial scale of the standard process. Local laws of motion can thus be applied continuously at different gravitational positions, while time consistently retains its status as a counting parameter.

For the local light-propagation condition $v_* = c$, the corresponding reference optical path satisfies

$$d\ell_{\mathrm{opt}}^2 = \Phi^{-2} d\ell_s^2 = X^{-2}dr^2 + X^{-1}r^2 d\varphi^2, \qquad dt = \frac{d\ell_{\mathrm{opt}}}{c} \tag{2.26}$$

The same optical-path line element gives the radial factor $X^{-1} = \Omega^2$ and the tangential factor $X^{-1/2} = \Omega$. One radial factor of Ω comes from dilation of the path itself; the other comes from dilation of the wavelength associated with the counting standard and its conversion to the reference. The tangential spatial length is already contained in the areal radius, while the counting conversion still enters through the same Ω. These two components jointly determine the propagation optical path in any direction.

For a general light path, the radial and tangential displacements are first substituted into Eq. (2.26), and the optical path length is then accumulated along the path. Nearly radial propagation, grazing propagation, and orbiting propagation are all described by the same line element. The directional

structure of space enters the propagation law through a quadratic form, while the local propagation speed of light remains c throughout.

The spatial dilation read out by gravitational redshift has now entered both the actual path and the reference optical path. Material motion uses spatial length and local velocity; light propagation uses the same length and the constraint set by c. ASD constructs a common background for these two types of motion from one set of spatial states. The spatial inertial relations of Section III are incorporated into that background next.

2. An Orbital Action Consistent with the Free Momentum Relation

Section III obtained the local free Lagrangian $\mathcal{L}_0$ from spatial inertial relations. In nonuniform space, the velocity governing the response of the topological core and accompanying field is v_*. For a fixed internal state, this chapter adopts universal static energy coupling: Φ converts the local structural energy to common reference conditions. This coefficient is consistent with the wavelength and period relations of the standard process, and the action increment is written as $\mathcal{L}\,dt = \mathcal{L}_0(v_*)\Phi\,dt$.

The spatial length law gives $v_*^2 = \dot{r}^2/X^2 + r^2\dot{\varphi}^2/X$. Substitution into the free action yields

$$\mathcal{L} = -m_0c^2\Phi\sqrt{1 - v_*^2/c^2} = -m_0c^2\sqrt{X - \frac{\dot{r}^2}{c^2X} - \frac{r^2\dot{\varphi}^2}{c^2}} \tag{2.27}$$

Dots denote derivatives with respect to the reference counting parameter t. Equation (2.27) embeds the free action established in Section III from the LVE and inertial reconfiguration into the statically dilated space excited by the central mass source. As $X \to 1$, space returns to a homogeneous background and Eq. (2.27) reduces to Eq. (2.24b); when the body is at rest ($\boldsymbol{v}_* = 0$), its reference energy is $m_0c^2\Phi$. Motion-induced inertial reconfiguration and static gravitational dilation are thus unified within the same Lagrangian system.

The orbital effect of spatial dilation has two interrelated aspects: changes in path length change the local velocity, while conversion of structural energy to the reference changes the position-dependent energy. Both enter the action, and variation produces forces, velocity corrections, and conserved quantities simultaneously. ASD thus connects the weak-field form of the Newtonian potential and the high-speed momentum relation within a single dynamics.

Differentiating the Lagrangian in Eq. (2.27) with respect to the generalized velocities directly gives the radial and angular canonical momenta:

$$p_r = \frac{\partial L}{\partial \dot{r}} = \frac{m_0\dot{r}}{X\sqrt{X - \frac{\dot{r}^2}{c^2X} - \frac{r^2\dot{\varphi}^2}{c^2}}}, \qquad p_\varphi = \frac{\partial L}{\partial \dot{\varphi}} = \frac{m_0r^2\dot{\varphi}}{\sqrt{X - \frac{\dot{r}^2}{c^2X} - \frac{r^2\dot{\varphi}^2}{c^2}}} \tag{2.28}$$

Equation (2.28) fully incorporates the coupled modulation of orbital momentum by the radial spatial dilation factor X and motion-reconfiguration impedance.

To simplify the derivation of the conserved quantities and orbital equation, denote the dimensionless positive-definite function under the square root by

$$D = X - \frac{\dot{r}^2}{c^2X} - \frac{r^2\dot{\varphi}^2}{c^2} > 0 \tag{2.29}$$

Since φ does not appear explicitly in $\mathcal{L}$, the canonical angular momentum is conserved. The conserved quantity per unit mass is

$$j = \frac{1}{m_0}\frac{\partial \mathcal{L}}{\partial \dot{\varphi}} = \frac{r^2\dot{\varphi}}{\sqrt{D}} \tag{2.30}$$

The static background has no explicit dependence on the counting parameter t, so the system Hamiltonian, or total reference energy, is strictly conserved. Substitution of Eq. (2.28) into the Legendre transform gives the dimensionless conserved energy:

$$\mathcal{E} = \frac{E_\infty}{m_0 c^2} = \frac{p_r \dot{r} + p_\varphi \dot{\varphi} - \mathcal{L}}{m_0 c^2} = \frac{X}{\sqrt{D}} \tag{2.31}$$

j has the dimensions of length squared divided by time, while $\mathcal{E}$ is the dimensionless reference energy. They arise from spherical symmetry and the static background, respectively, and describe the angular momentum and energy preserved as the planet moves through dilated space. These two conserved quantities allow the reference counting parameter to be eliminated directly, yielding an equation for the shape of the orbit.

3. The Radial Equation and Perihelion Precession

Let

$$u(\varphi) = \frac{1}{r}, \qquad u' = \frac{du}{d\varphi} \tag{2.32}$$

Equation (2.30) and the chain rule give

$$\dot{\varphi} = j\sqrt{D}\, u^2, \qquad \dot{r} = -j\sqrt{D}\, u' \tag{2.33}$$

Substituting these expressions back into Eq. (2.29) gives

$$D = X - \frac{j^2 D}{c^2 X} u'^2 - \frac{j^2 D}{c^2} u^2$$

Dividing first by D, then multiplying by X, and using $X^2/D = \mathcal{E}^2$, gives

$$u'^2 = \frac{c^2}{j^2}(\mathcal{E}^2 - X) - Xu^2 \tag{2.34}$$

Differentiating with respect to φ, cancelling $2u'$ where $u' \neq 0$, and extending the result to turning points by continuity gives

$$u'' = -\frac{c^2}{2j^2}\frac{dX}{du} - Xu - \frac{1}{2}u^2\frac{dX}{du} \tag{2.35}$$

Write $\mu = G_0 M$ and $\ell_g = \mu/c^2$, so that $X = 1 - 2\ell_g u$ and $dX/du = -2\ell_g$. Substituting term by term into the preceding equation, the first term is μ/j^2, the second is $-u + 2\ell_g u^2$, and the third is $\ell_g u^2$. Hence

$$u'' + u = \frac{\mu}{j^2} + 3\ell_g u^2 \tag{2.36}$$

Equation (2.36) is the orbital equation of the spherically symmetric spatial dynamics developed in this chapter. The Newtonian term determines the basic scale of the ellipse, whereas $3\ell_g u^2$ grows as the planet approaches the central source, changing the coordination between radial and azimuthal motion. In the present areal-radius representation, $-Xu$ contributes $2\ell_g u^2$, and the derivative term of X contributes a further $\ell_g u^2$; both contributions arise from the same coupling between spatial length and inertia.

Neglecting the correction term gives the Newtonian ellipse

$$u_0(\varphi) = \frac{1}{p_{\text{orb}}}(1 + e\cos\varphi), \qquad p_{\text{orb}} = \frac{j^2}{\mu} = a(1 - e^2) \tag{2.37}$$

The last equality holds for the zeroth-order ellipse, where a is the semimajor axis and e is the eccentricity. Set $u = u_0 + \delta u$ and use the zeroth-order solution only in the correction term. Then

$$\delta u'' + \delta u = \frac{3\ell_g}{p_{\mathrm{orb}}^2}(1 + 2e\cos\varphi + e^2\cos^2\varphi) \tag{2.38}$$

Using $\cos^2\varphi = (1 + \cos 2\varphi)/2$, the right-hand side separates into a constant term, a $\cos\varphi$ term, and a $\cos 2\varphi$ term. The constant term adjusts the mean scale of the ellipse, while the second-harmonic term produces a bounded deformation. The term at the fundamental frequency that shifts the perihelion from one revolution to the next is

$$\frac{6\ell_g e}{p_{\mathrm{orb}}^2}\cos\varphi \tag{2.39}$$

Since $(d^2/d\varphi^2 + 1)(\varphi\sin\varphi) = 2\cos\varphi$, its secular solution is

$$\delta u_{\mathrm{sec}} = \frac{3\ell_g e}{p_{\mathrm{orb}}^2}\varphi\sin\varphi \tag{2.40}$$

Introducing the precession-rate parameter $\kappa = 3\ell_g/p_{\mathrm{orb}}$, represent the elliptic orbit with secular precession by a rotating-ellipse function:

$$u_{\mathrm{prec}}(\varphi) = \frac{1}{p_{orb}}\{1 + e\cos[(1-\kappa)\varphi]\}, \qquad \kappa = \frac{3l_g}{p_{orb}} = \frac{3G_0M}{a(1-e^2)c^2} \tag{2.41}$$

Expanding Eq. (2.41) to first order in κ matches Eq. (2.37) and the secular solution in Eq. (2.40). The azimuthal-angle interval between two successive perihelia is $2\pi/(1-\kappa)$, so the perihelion advance per revolution and its leading-order analytical expression are

$$\Delta\varpi = \frac{2\pi}{1-\kappa} - 2\pi = \frac{2\pi\kappa}{1-\kappa} = \frac{6\pi G_0 M}{a(1-e^2)c^2} + O\left(\frac{\ell_g^2}{p_{\mathrm{orb}}^2}\right) \tag{2.42}$$

Using the solar gravitational parameter $\mu_\odot \simeq 1.3271244 \times 10^{20}\,\mathrm{m^3 s^{-2}}$ and Mercury's $a \simeq 5.79 \times 10^{10}$ m and $e \simeq 0.2056$, the central-field correction in this chapter gives approximately 0.1035 arcseconds per revolution, equivalent to approximately 43.0 arcseconds per Julian century. In a complete ephemeris, this contribution enters the orbital fit together with perturbations from other planets, solar multipole moments, and other effects.

This result has a direct spatial interpretation in ASD. As a planet moves from aphelion toward perihelion, it enters progressively more dilated space, and its path scale, local velocity, and inertial gain change together; on leaving perihelion, these quantities readjust continuously. The azimuthal angle corresponding to one complete radial oscillation therefore exceeds 2π, and the perihelion advances in the orbital direction on each revolution. Precession measurements test this combined relation between spatial structure and the structure associated with motion.

4. The Unified Optical Path in Isotropic Coordinates

Light deflection and propagation delay use the same Fermat functional,

$$T[\Gamma] = \frac{1}{c}\int_\Gamma d\,\ell_{\mathrm{opt}}, \qquad \delta T = 0 \tag{2.43}$$

The Fermat condition identifies the actual light path as a path of stationary phase; in strong-lensing configurations, multiple stationary light paths may exist. To make directional gradients more transparent in weak-field calculations, introduce the isotropic radial coordinate ρ and define

$$r = \rho\left(1 + \frac{\ell_g}{2\rho}\right)^2, \qquad q = \frac{\ell_g}{2\rho}, \qquad 0 < q < 1 \tag{2.44}$$

This gives $X = (1-q)^2/(1+q)^2$ and $dr/d\rho = 1-q^2$. After substitution into Eq. (2.26), the radial and tangential terms have the same scale factor:

$$d\ell_{\text{opt}} = n_{\text{iso}}(\rho)\sqrt{d\rho^2 + \rho^2 d\varphi^2}, \qquad n_{\text{iso}} = \frac{(1+q)^3}{1-q} \tag{2.45}$$

This transformation combines the previously separate radial and tangential components into a scalar coefficient n_{iso} multiplying the reference Euclidean line element. The physical state of space remains unchanged; the radial coordinate changes from the areal radius r to ρ. Expressing the optical path, impact parameter, and endpoint positions under the same coordinate transformation allows ray integrals to be evaluated directly.

Rational decomposition of the isotropic effective refractive index in Eq. (2.45) gives the weak-field expansion

$$n_{iso}(\rho) = 1 + \frac{4q+3q^2+q^3}{1-q} = 1 + \frac{2\ell_g}{\rho} + O\left(\ell_g^2/\rho^2\right) \tag{2.46}$$

The coefficient 2 emerges naturally after coordinate transformation of the full optical path, which combines radial spatial dilation with conversion of the counting scale. It enters both light deflection and propagation delay, expressing the spatial origin common to these two phenomena. The optical path is always integrated along the trajectory, and the directional information of space is already contained in this transformed expression.

5. Light Deflection in a Gravitational Field

In the isotropic coordinate plane, take the unperturbed ray to propagate along the x axis at $y = b$, and set $\rho = \sqrt{x^2 + b^2}$. By Fermat's principle, if s_0 is the reference Euclidean arc length and $\mathrm{e} = dx/ds_0$, the ray equation is

$$\frac{d}{ds_0}(n_{\text{iso}}\mathrm{e}) = \nabla n_{\text{iso}} \tag{2.47}$$

Taking the transverse partial derivative of the linearized refractive-index distribution $n_{iso}(\rho)$ along the reference light path $y = b$ gives the equation for the rate of wavefront deflection:

$$\frac{d\theta}{dx} = \frac{\partial n_{\text{iso}}}{\partial y}\bigg|_{y=b} = -\frac{2l_g b}{(x^2+b^2)^{3/2}} \tag{2.48}$$

The negative sign indicates deflection toward the central mass. Integrating along a path emitted and received in the far field gives

$$\alpha_{\text{def}} = 2\ell_g \int_{-\infty}^{+\infty} \frac{b\,dx}{(x^2+b^2)^{3/2}} \tag{2.49}$$

An antiderivative of the integrand is $x/\left[b\sqrt{x^2+b^2}\right]$. Evaluating it at positive and negative infinity gives the difference $2/b$, yielding the integrated total deflection angle:

$$\alpha_{def} = \frac{4G_0 M}{c^2 b} \tag{2.50}$$

For a ray grazing the solar limb, estimating b from the nominal solar radius of approximately 6.957×10^8 m gives a first-order deflection of about 1.75 arcseconds. Here b is the impact parameter normalized at infinity; at the present accuracy it can be estimated by the distance of the solar limb from the centre.

ASD interprets light deflection as phase-governed path selection in nonuniform space. Spatial dilation is stronger on the side closer to the central source, giving a larger increase in propagation

optical path. This transverse difference continuously rotates the wavefront direction, bending the ray toward the mass source. The stationary condition of Fermat's principle expresses this phase relation as the ray equation. The local propagation speed remains c; what changes is the spatial length actually traversed by light and its distribution along the path.

6. The Shapiro Delay

For fixed endpoints in a static weak field, the same optical path gives the propagation time

$$T[\Gamma] = \frac{1}{c}\int_{\Gamma} n_{\mathrm{iso}}\, ds_0 \tag{2.51}$$

Taking the gravity-free straight-line length R_{12}, defined using the same coordinates and endpoints, as the reference, define the one-way gravitational delay as

$$\Delta T = T - \frac{R_{12}}{c} \tag{2.52}$$

Because the first variation of Euclidean arc length vanishes for the straight reference path Γ_0 between fixed endpoints, integrating the linearized refractive-index increment $n_1 - 1 = 2l_g/\rho$ along Γ_0 gives the one-way gravitational propagation delay:

$$\Delta T = \frac{2G_0M}{c^3}\int_{\Gamma_0} \frac{ds_0}{\rho} \tag{2.53}$$

Let the endpoints on opposite sides of the point of closest approach correspond to $x = -x_1$ and $x = x_2$, with $\rho_i = \sqrt{x_i^2 + b^2}$. Then

$$\Delta T = \frac{2G_0M}{c^3}\int_{-x_1}^{x_2} \frac{dx}{\sqrt{x^2+b^2}} \tag{2.54}$$

Using

$$\int \frac{dx}{\sqrt{x^2+b^2}} = \ln\left(\frac{x+\sqrt{x^2+b^2}}{b}\right)$$

and simplifying with $\rho_1 - x_1 = b^2/(\rho_1 + x_1)$, we obtain

$$\Delta T = \frac{2G_0M}{c^3}\ln\left[\frac{(\rho_1+x_1)(\rho_2+x_2)}{b^2}\right] \tag{2.55}$$

Denote the reference straight-line distance between the endpoints by $R_{12} = x_1 + x_2$. Using the identity $\rho_i - x_i = b^2/(\rho_i + x_i)$, Eq. (2.55) can be written equivalently in a form involving distances alone:

$$\Delta T = \frac{2G_0M}{c^3}\ln\left(\frac{\rho_1+\rho_2+R_{12}}{\rho_1+\rho_2-R_{12}}\right) \tag{2.56}$$

The arguments of the logarithms in Eqs. (2.55) and (2.56) satisfy the exact algebraic identity

$$\frac{(\rho_1+x_1)(\rho_2+x_2)}{b^2} = \frac{\rho_1+\rho_2+R_{12}}{\rho_1+\rho_2-R_{12}} \tag{2.57}$$

For round-trip signal propagation between static, fixed endpoints, the analytical expression for the total round-trip gravitational delay is

$$\Delta T_{round} = 2\Delta T = \frac{4G_0M}{c^3}\ln\left(\frac{\rho_1+\rho_2+R_{12}}{\rho_1+\rho_2-R_{12}}\right) \tag{2.58}$$

Equation (2.58) gives a closed expression for the static round-trip gravitational delay at arbitrary endpoint positions. When both endpoints are far from the point of closest approach ($\rho_1, \rho_2 \gg b$), $\rho_i +$

$x_i \to 2\rho_i$, and the logarithmic term naturally reduces to the familiar far-zone asymptotic form $\ln(4\rho_1\rho_2/b^2)$.

In ASD, the Shapiro delay arises from the additional optical path accumulated as light traverses a gravitationally dilated region. The path itself lengthens with spatial dilation, and the local standard scale used to record the propagation process is linked to the same spatial state. After the entire process is reduced to a common reference, a light pulse requires a longer counting interval than in a gravity-free background; the increment is the additional reference optical path divided by c. The constancy of the local speed of light is maintained throughout.

Light deflection and the Shapiro delay read out, respectively, the transverse variation and the pathwise accumulation of the same spatial dilation: transverse gradients change the propagation direction, while path integrals change the arrival count. Planetary orbits connect this spatial structure to the inertial reconfiguration of topological matter. Together, these three classes of phenomena express the central physical theme of ASD: the central source changes space, and the modified space acts simultaneously on material motion and light propagation.

General relativity describes these phenomena through the geodesics of matter and light in four-dimensional spacetime geometry; ASD constructs them from spatial dilation, process counting, and spatial inertial relations. Under the constitutive relations adopted in this section, the spatial line element, optical path, and orbital action have the same mathematical forms as the corresponding expressions for the Schwarzschild exterior field; optical geometry also has a corresponding representation in standard theory. This identity of mathematical form makes the two interpretations yield the same results within this domain. The theoretical content of ASD lies in establishing the physical origin of these relations in a spatial medium.

V. Black Holes

As the central mass source becomes highly concentrated, longitudinal dilation of the surrounding space increases sharply, and the local spatial scales of light propagation and material motion approach the limit sustainable by the continuum. On this basis, ASD establishes a strong-field boundary principle grounded in the ontology of the spatial medium: a black-hole horizon is not a geometric hypersurface leading to an interior singularity, but the physical termination boundary of the three-dimensional continuous spatial-medium state. As a physical entity, a black hole consists jointly of the states of this spatial termination boundary and its exterior spatial field; its mass, spin angular momentum, information storage, and thermodynamic radiation are all carried directly by this physical boundary.

1. The Exterior-Field Limit and the Boundary-Ontological Picture

Extending the preceding spherically symmetric exterior response to strong fields, define

$$r_h = \frac{2G_0M}{c^2}, \qquad X(r_h) = 0 \tag{2.59}$$

As r_h is approached from outside, $\Phi \to 0$ and $\Omega \to \infty$, and radial spatial dilation reaches its limit. Under the same spatial-scale relation, the characteristic wavelengths of standard processes increase and their reference frequencies decrease; the reference optical path accumulated in radial light propagation also grows continuously. Equation (2.59) relates this limiting position to the total mass of the central source.

The strong-field boundary hypothesis of ASD stipulates that $X = 0$ is the physical termination boundary of the continuous spatial-medium state. In this theoretical picture, $r < r_h$ is no longer posited as a continuous spatial region of the same medium. The fate of matter and information is instead described by boundary states. A black hole's mass, angular momentum, and other global parameters are carried and characterized by the boundary structure and its coupling to the exterior spatial field.

A boundary object refers to the physical degrees of freedom and their organization where the continuous spatial state terminates. Ordinary matter maintains a stable structure through a localized topological core, whereas a black hole maintains its overall state through its boundary and exterior field. Both are physical objects formed by space, but their structures are organized differently. Local strain, phase, and coupling states on the boundary provide dynamical variables for studying absorption, energy storage, and re-emission.

As incident matter approaches the boundary, the spatial length state in which it is situated continues to change, and the coupling of its core and accompanying field to the boundary gradually becomes dominant. ASD organizes the subsequent evolution as a conversion of material structure into boundary structure and the exterior field. The externally observed mass change records the change in total energy, while microscopic differences in the absorption process are carried by the joint state of the boundary and exterior field.

This section first calculates the observable scales of the boundary from exterior propagation and then discusses the states of the boundary itself. Astronomical angular scales, radial distances, signal-propagation counts, and boundary energy can thereby each be defined within the same spatial picture. The limiting dilation of space has definite manifestations in propagation and also sets the conditions connecting boundary states to the exterior world.

This boundary ontology focuses black-hole research on three continuous physical processes: how the boundary accepts incident structures, how it maintains the exterior spatial field, and how it couples stored energy and states back into propagating modes. The optical, mass, and thermodynamic calculations below describe, respectively, the path conditions, global-quantity relations, and statistical properties of these processes.

In terms of physical scale, r_h is a finite areal radius. According to Eq. (2.25), the radial spatial length and optical path length are, respectively,

$$\ell_s = \int \frac{dr}{\sqrt{X}}, \qquad \ell_{\mathrm{opt}} = \int \frac{dr}{X} \tag{2.60}$$

Substituting $X(r) = 1 - r_h/r$ into the first expression in Eq. (2.60), the integral of the actual radial spatial length from the spatial termination boundary r_h to any exterior radial position $r > r_h$ has an exact elementary antiderivative:

$$l_s(r_h, r) = \int_{r_h}^{r} \frac{dr'}{\sqrt{1 - r_h/r'}} = \sqrt{r(r - r_h)} + r_h \ln\left(\frac{\sqrt{r} + \sqrt{r - r_h}}{\sqrt{r_h}}\right) \tag{2.61}$$

Substituting $X(r) = 1 - r_h/r$ into the second expression in Eq. (2.60), the radial reference optical-path integral between any two exterior radii $r_1, r_2 > r_h$ is

$$l_{opt}(r_1, r_2) = \int_{r_1}^{r_2} \frac{dr}{X(r)} = (r_2 - r_1) + r_h \ln\left(\frac{r_2 - r_h}{r_1 - r_h}\right) \tag{2.62}$$

Comparison of the analytical expressions in Eqs. (2.61) and (2.62) shows that, as the inner endpoint approaches the spatial termination boundary ($r_1 \to r_h^+$), the actual radial spatial length

$l_s(r_h, r)$ from the boundary to any finite exterior radius converges strictly to a finite value, whereas the radial reference optical path $l_{opt}(r_1, r_2)$ tends to infinity because of its divergent logarithmic term. This analytical distinction between the local radial linear dilation factor, the actual accumulated spatial length, and the reference propagation optical path fundamentally explains why a black hole has a finite geometric boundary scale yet exhibits an infinite propagation delay for external signals.

2. Normalization of the Mass Parameter and Surface Gravity

The black-hole mass M is determined by the asymptotic flux of the exterior longitudinal spatial field, as defined by Eq. (2.7b). ASD connects this total source strength to the total stored energy of the boundary states and exterior field, retaining the energy normalization $E_{\mathrm{bdy}} = Mc^2$. Black-hole mass thus becomes a global parameter of the boundary structure, while the exterior gravitational field is the sustained action of that structure on the surrounding space.

For an ordinary topological core, mass is characterized by a near-region volumetric-density deficit and a finite structural volume; for a black hole, it is characterized by boundary states and far-field flux. At fixed G_0, M is proportional to r_h, and A_h is proportional to M^2. Here radius characterizes the boundary position, area characterizes the extent of the boundary, and mass characterizes total energy and source strength; the three are linked by the spatial boundary relation.

Extending the gradient quantity in Eq. (2.7) to the exterior boundary gives

$$\kappa_X = \frac{c^2}{2} \lim_{r \to r_h^+} X'(r) = \frac{G_0 M}{r_h^2} = \frac{c^4}{4 G_0 M} \tag{2.63}$$

κ_X characterizes the longitudinal boundary gradient normalized to the far-field reference, and its magnitude scales as M^{-1}. For a fixed mass, the exterior gradient quantity reaches a finite upper bound as the boundary is approached. This quantity is suitable for comparing boundary-field scales among black holes; the external force required for local holding is instead calculated from the relation between local energy and actual length.

The local holding force must be derived using the same energy and length calibration. From Eq. (2.27), the reference energy of a stationary test body is $E_\infty = m_0 c^2 \Phi$, so the reference work required for a radial virtual displacement is

$$dW_\infty = dE_\infty = \frac{m_0 G_0 M}{r^2 \sqrt{X}}\, dr \tag{2.64}$$

Using $d\ell_s = dr/\sqrt{X}$ and the conversion of local work to the reference, $dW_\infty = \Phi\, dW_{\mathrm{loc}}$, gives

$$\frac{F_{\mathrm{hold,loc}}}{m_0} = \frac{G_0 M}{r^2 \sqrt{X}} \tag{2.65}$$

As $r \to r_h^+$, the local holding force grows as $X^{-1/2}$, and the support needed to remain at rest tends to infinity; after conversion by the spatial scale, $\sqrt{X}\, F_{\mathrm{hold,loc}}/m_0$ tends to the finite value κ_X. These results correspond to local support and far-field normalization, respectively, and reflect the action of the same spatial dilation in two representations of quantity values.

In the ASD boundary picture, the closer one approaches the termination of the continuum state, the greater the reconfiguration action required to hold a stable test body at a fixed position. Free fall describes the body's motion in that background, whereas the holding force describes the support needed to prevent that motion; they are distinct dynamical conditions. Finite surface gravity and a divergent local holding force are determined separately by the definitions above.

3. The Photon Sphere and the Critical Shadow Scale

The photon sphere around a black hole is a critical propagation orbit formed by the spatial optical-path structure. For propagation around a sphere, the circumferential geometric scale decreases with radius, while the optical-path gain due to spatial dilation increases; the combination produces a critical location. Continuing to use Eq. (2.26), write

$$d\ell_{\mathrm{opt}}^2 = \mathcal{A}(r)^2 dr^2 + \mathcal{B}(r)^2 d\varphi^2, \qquad \mathcal{A} = X^{-1}, \quad \mathcal{B} = rX^{-1/2} \tag{2.66}$$

Let s_{opt} be the optical-path parameter, with the unit-tangent condition $\mathcal{A}^2\left(dr/ds_{\mathrm{opt}}\right)^2 + \mathcal{B}^2\left(d\varphi/ds_{\mathrm{opt}}\right)^2 = 1$. Axial symmetry gives the conserved impact parameter

$$b = \mathcal{B}^2 \frac{d\varphi}{ds_{\mathrm{opt}}} = \mathcal{B}\sin\psi_{\mathrm{opt}} \tag{2.67}$$

ψ_{opt} is the angle between the propagation direction and the radial direction, defined using the optical-path line element. Since $\mathcal{B} \to r$, b coincides with the usual impact parameter at infinity. The corresponding radial equation is

$$\mathcal{A}^2\left(\frac{dr}{ds_{\mathrm{opt}}}\right)^2 = 1 - \frac{b^2}{\mathcal{B}^2} \tag{2.68}$$

The point of closest approach satisfies $b = \mathcal{B}(r_0)$; a circular critical orbit additionally requires $d\mathcal{B}/dr = 0$. From

$$\mathcal{B}(r) = \frac{r}{\sqrt{1-2\ell_g/r}}, \qquad \mathcal{B}'(r) = \frac{1-3\ell_g/r}{\left(1-2\ell_g/r\right)^{3/2}} \tag{2.69}$$

we obtain

$$r_{\mathrm{ph}} = 3\ell_g = \frac{3G_0M}{c^2} = \frac{3}{2}r_h \tag{2.70}$$

Here $\mathcal{B}$ is a minimum and $1/\mathcal{B}^2 = X/r^2$ is a maximum. The critical light orbit is unstable under radial perturbations: a path displaced slightly outward may escape, while one displaced slightly inward propagates toward the boundary. The critical impact parameter is therefore

$$b_c = \mathcal{B}\left(r_{\mathrm{ph}}\right) = 3\sqrt{3}\,\frac{G_0M}{c^2} = \frac{3\sqrt{3}}{2}r_h \tag{2.71}$$

When an absorbing condition is imposed at the exterior boundary, rays arriving from infinity with $b < b_c$ enter the capture region, while rays with $b > b_c$ have an exterior turning point. Thus b_c gives the critical shadow scale for a distant observer. At a distance $D_{\mathrm{obs}} \gg r_h$, the angular radius is approximately b_c/D_{obs}.

The horizon radius r_h determines the medium boundary, the photon-sphere radius r_{ph} determines the unstable critical light orbit, and b_c determines the capture scale seen from far away. The brightness distribution in an actual image additionally depends on the emitting matter, absorption, scattering, viewing inclination, and instrumental response. In ASD, weak-field deflection and the strong-field photon sphere are connected by the same spatial optical-path law: far from the source it produces small path bending, while near the boundary it creates critical orbiting paths and capture regions.

4. The Azimuthal Accompanying Field of a Rotating Source

A rotating mass source continuously drives directional torsion of the surrounding spatial medium, exciting a steady azimuthal accompanying field $\mathrm{u}_{\mathrm{rot}}$ in addition to the static radial dilation. This

azimuthal accompanying field couples directly to the propagation direction of light, producing a definite directed optical-path difference between prograde and retrograde paths.

The azimuthal accompanying field extends the picture of material motion developed in Section III: the motion of a source acts on space, and the directional reconfiguration of space in turn acts on propagating modes. $\mathrm{u_{rot}}$ represents this effective transport state with the dimensions of velocity and describes the directional response of spatial degrees of freedom. Translation produces an accompanying structure along the direction of motion, while rotation organizes the directional responses at different positions into an azimuthal field.

Let the source mass-current density be $\mathrm{j}_m = \rho_m \mathrm{v}_m$, with a steady current satisfying $\nabla \cdot \mathrm{j}_m = 0$. Its total angular momentum is

$$\mathrm{J} = \int \mathrm{x}' \times \mathrm{j}_m(\mathrm{x}')\, d^3x' \tag{2.72}$$

Introduce the dimensionless coupling coefficient ζ and take the lowest-order static field equations to be

$$\nabla \cdot \mathrm{u_{rot}} = 0, \qquad \nabla^2 \mathrm{u_{rot}} = -\frac{4\pi\zeta G_0}{c^2}\mathrm{j}_m \tag{2.73}$$

Equation (2.73) is the effective field equation relating rotating mass currents to the transverse spatial response; ζ characterizes the normalization of longitudinal–transverse coupling. A steady source permits a Poisson form, while time variation of the source enters the corresponding causal propagation equation.

With a boundary condition of decay at infinity, the identity $\nabla^2|\mathrm{x}-\mathrm{x}'|^{-1} = -4\pi\delta^{(3)}(\mathrm{x}-\mathrm{x}')$ gives

$$\mathrm{u_{rot}}(\mathrm{x}) = \frac{\zeta G_0}{c^2}\int \frac{\mathrm{j}_m(\mathrm{x}')}{|\mathrm{x}-\mathrm{x}'|}\, d^3x' \tag{2.74}$$

For a localized rotating source with no overall translation, $\int \mathrm{j}_m\, d^3x' = 0$. Expanding the Green function in the far field gives

$$\frac{1}{|\mathrm{x}-\mathrm{x}'|} = \frac{1}{r} + \frac{\hat{\mathrm{r}}\cdot\mathrm{x}'}{r^2} + O(r^{-3})$$

The integral of the first term vanishes. Steadiness and localization also give

$$\int \mathrm{j}_m(\mathrm{x}')(\mathrm{x}'\cdot\hat{\mathrm{r}})\, d^3x' = \frac{1}{2}\mathrm{J}\times\hat{\mathrm{r}} \tag{2.75}$$

This identity is rigorously guaranteed by the volume-integral identity $\int \nabla\cdot\left(x'_i x'_j \mathrm{j}_m\right) d^3x' = 0$, derived from the steady, divergence-free condition: it makes the symmetric part of the first-moment tensor $\int x'_i j_{m,j}\, d^3x'$ identically zero, while its antisymmetric part is uniquely determined by the total angular-momentum vector $\boldsymbol{J}$. The exterior azimuthal dipole accompanying field of the rotating source is therefore

$$\boldsymbol{u}_{rot} = \frac{\zeta G_0}{2c^2}\frac{\boldsymbol{J}\times\boldsymbol{r}}{r^3} \tag{2.76}$$

Equation (2.76) strictly satisfies the divergence-free and harmonic equations in the exterior source-free region ($\nabla\cdot\boldsymbol{u}_{rot} = 0, \nabla^2\boldsymbol{u}_{rot} = 0$), showing that the exterior azimuthal accompanying field is determined by the source's total angular momentum and decays in amplitude as r^{-2}. Taking $\zeta = 4$ as the calibrated value of the rotational gravitational coupling gives $\boldsymbol{u}_{rot} = 2G_0(\boldsymbol{J}\times\boldsymbol{r})/(c^2 r^3)$.

Taking $\mathrm{J} = J\hat{\mathrm{z}}$ gives

$$u_\varphi = \frac{\zeta G_0 J}{2c^2 r^2}\sin\theta, \qquad \omega_{\mathrm{rot}} = \frac{u_\varphi}{r\sin\theta} = \frac{\zeta G_0 J}{2c^2 r^3} \tag{2.77}$$

u_φ tends to zero on the polar axis, expressing the reduction of azimuthal linear velocity as the distance to the axis decreases; ω_{rot}, defined by the continuous limit, retains the corresponding field angular velocity. The source's spin angular velocity describes the motion of matter itself, while $\omega_{\mathrm{rot}}(r)$ describes the azimuthal response established by that motion in the exterior space. They are connected by the source distribution and the coupling relation.

5. Directed Optical Paths and Sagnac-Type Time Differences

Taking the azimuthal accompanying-field velocity $\mathrm{u}_{\mathrm{rot}}$ as the local directional spatial-transport variable, the directed propagation coupling factor follows directly from the length vector effect (LVE) of Chapter 1:

$$K_{rot} = \gamma_{rot}\left(1 - \frac{\boldsymbol{u}_{rot}\cdot\hat{\boldsymbol{k}}}{c}\right) = \frac{1-\boldsymbol{u}_{rot}\cdot\hat{\boldsymbol{k}}/c}{\sqrt{1-u_{rot}^2/c^2}} \tag{2.78}$$

Applying this directional coupling to weak-field propagation, and retaining only the static term and the term first order in rotation, gives

$$T[\Gamma] = \frac{1}{c}\int_\Gamma d\,\ell_{\mathrm{opt}} - \frac{1}{c^2}\int_\Gamma \mathrm{u}_{\mathrm{rot}}\cdot d\mathrm{x} \tag{2.79}$$

The static part of Eq. (2.79) is determined by radial spatial dilation, and its rotational part by the projection of the azimuthal field onto the path direction. Only the first-order rotational term is retained here, and far-zone displacements are expressed in reference coordinates as $d\mathrm{x}$. Reversing the propagation direction changes the sign of the projection term while leaving the static optical path unchanged, directly revealing the difference between prograde and retrograde propagation.

Substituting the azimuthal dipole field gives

$$\delta T_{\mathrm{rot}} = -\frac{\zeta G_0}{2c^4}\int_\Gamma \frac{(\mathrm{J}\times\mathrm{r})\cdot d\mathrm{x}}{r^3} \tag{2.80}$$

Under the adopted sign convention, the corrections have opposite signs for propagation along and against the field. For the same fixed closed path C, define its positive direction to be along $\mathrm{u}_{\mathrm{rot}}$. Then

$$T_- - T_+ = \frac{2}{c^2}\oint_C \mathrm{u}_{\mathrm{rot}}\cdot d\mathrm{x} \tag{2.81}$$

Consider a circular closed light path C, coaxial with the spin axis, at fixed radial distance r and polar angle θ, with ring radius $R_\perp = r\sin\theta$ and enclosed area $A_C = \pi R_\perp^2$. Since the azimuthal field angular velocity $\omega_{\mathrm{rot}}(r)$ is strictly constant around the entire ring, the circulation integral is $\oint_C \mathrm{u}_{\mathrm{rot}}\cdot d\mathrm{x} = 2\omega_{\mathrm{rot}}A_C$. Substitution into Eqs. (2.81) and (2.77) gives the retrograde-minus-prograde propagation-time difference for the coaxial ring:

$$T_- - T_+ = \frac{4\omega_{rot}A_C}{c^2} = \frac{2\zeta G_0 J A_C}{c^4 r^3} \tag{2.82}$$

Equation (2.82) connects the azimuthal spatial state to the counting difference along a closed path. In ASD, prograde and retrograde propagation experience different directional couplings; after accumulation along the path, this difference produces comparable arrival counts. The source's azimuthal accompanying field, rotation of the apparatus itself, and endpoint motion each have their own physical variables and enter the optical path separately in a specific measurement.

Rotation thus extends the radial spatial structure of a static black hole into an exterior field with an azimuthal response. Prograde and retrograde trajectories have different propagation conditions at the same position, as a direct consequence of the azimuthal accompanying field. Extending this construction to strong fields allows further study of the directional structure of critical light orbits, capture regions, and shadows; the far-field results in this section provide the coupling form and scale for that investigation.

6. Black-Hole Information and Boundary-State Dynamics

In the ASD boundary picture, incident matter couples to the boundary and is converted into new boundary states and exterior-field states. The macroscopic mass, angular momentum, and charge of a black hole record global quantities, while the boundary structure carries microscopic states compatible with those quantities. The information problem is thus formulated as a dynamical conversion among material states, boundary states, and propagation states.

Absorption changes the organization of the original localized topological structure. The core form of the incident structure may disassemble, with its energy and state differences transferred to local boundary strain, phase distributions, and exterior-field coupling. The increase in macroscopic mass records the change in total stored energy, while the microscopic states continue to distinguish different histories of incidence. ASD thus locates mass accumulation and state storage on the same boundary object.

Denote a microscopic state on the boundary Σ_h by $\mathcal{B}[\Sigma_h]$. The conceptual process of absorption and re-emission can be written as

$$(\mathcal{B}, \mathcal{I}_{\mathrm{in}}) \to (\mathcal{B}', \mathcal{R}_{\mathrm{out}}) \tag{2.83}$$

$\mathcal{I}_{\mathrm{in}}$ is the incident state, and $\mathcal{R}_{\mathrm{out}}$ is the outward-propagating field state. Far-field mass, angular momentum, and charge provide a macroscopic characterization of the joint state, while the boundary may possess multiple microstates compatible with the same set of global parameters. Macroscopic observation coarse-grains these differences; a microscopic description retains the details of the boundary and exterior field.

Boundary re-emission is the outward channel of the same coupling process. The radiation observed externally is generated by coupling between boundary states and spatial propagating modes. Correlations between different emission times, directions, and modes provide possible carriers by which states can be transmitted from the boundary. A near-thermal intensity spectrum describes the coarse-grained energy distribution, whereas state information also involves the joint relations among modes.

For information preservation, the key issue is whether the complete state mapping retains the distinctions between different incident states. If the joint evolution of the boundary and exterior field is reversible, the input states can be distinguished in the complete output. Energy conservation governs the total quantity exchanged, while the state mapping governs how distinctions are transmitted; ASD examines both within the same boundary dynamics.

This construction explicitly identifies the spatial boundary and its exterior field as the carriers of black-hole information. The research questions include how incident topological structures disassemble, how state differences are stored, how propagating modes carry these differences, and how macroscopic near-thermal statistics emerge from microscopic states. The boundary ontology gives these questions a common physical carrier.

Absorption, storage, and radiation thus become different processes involving the same set of spatial degrees of freedom. Below, entropy is established by counting boundary microstates and then related to energy, further describing the statistical properties of this physical object.

7. Boundary Radiation, Evaporation, and Area Entropy

Boundary states release energy through coupling to exterior spatial modes. A net outward flux reduces the stored energy of the black hole, while net absorption increases it. For nonrotating, uncharged, quasistatic evolution, take $E_{\mathrm{bdy}} = Mc^2$. The energy balance is

$$c^2 \frac{dM}{dt} = P_{\mathrm{in}} - P_{\mathrm{out}} \tag{2.84}$$

At fixed G_0, $r_h = 2G_0M/c^2$ decreases together with the mass. The boundary area is defined using the areal radius introduced above, so

$$A_h = 4\pi r_h^2 = \frac{16\pi G_0^2 M^2}{c^4} \tag{2.85}$$

In ASD, evaporation therefore has a spatial-structural meaning: the boundary releases propagating modes outward, total stored energy and mass decrease, and the boundary scale contracts; accretion changes the structure in the opposite direction. The energy of the radiation comes from the energy stored in the boundary and its exterior field, and the release channels are determined by coupling between the boundary and propagating modes.

Black-hole area entropy originates directly in counting the microscopic degrees of freedom of the spatial termination boundary. Suppose the boundary consists of uniform microscopic cells of effective area a_*, each with g_* accessible microstates. The total number of independent cells within the boundary area, N_h, and the total number of boundary microstates, W, are then, respectively,

$$N_h = \frac{A_h}{a_*}, \qquad W = g_*^{N_h} \tag{2.86}$$

The total number of microstates W grows exponentially with the number of boundary cells. Boltzmann's statistical entropy relation directly yields the area-entropy law for the black-hole boundary:

$$S_{bdy} = k_B \ln W = k_B \sigma_h A_h, \qquad \sigma_h = \frac{\ln g_*}{a_*} \tag{2.87}$$

Here σ_h has the dimensions of inverse area and characterizes the density of microscopic state capacity per unit boundary area. Equations (2.86)–(2.87) rigorously establish, from microscopic boundary degrees of freedom, the area law according to which black-hole entropy is proportional to horizon area.

Area has a direct ontological meaning here. The statistical degrees of freedom are local to the boundary itself; the boundary area determines how many cells can be accommodated, and the number of accessible states within each cell determines the entropy per unit area. ASD therefore traces area entropy to the state capacity of the boundary structure: the total number of microstates grows exponentially with the number of cells, while entropy, being its logarithm, grows with area.

Boundary contraction reduces black-hole entropy in the model, while outward radiation carries energy and states into the surrounding space. Total thermodynamic entropy accounting includes the boundary, radiation, and background together, and both absorption and release are compared within this whole.

8. The First Law of Boundary Thermodynamics

For a nonrotating, uncharged, quasistatic sequence at fixed G_0, c, and σ_h, Eqs. (2.85) and (2.87) give

$$dA_h = \frac{32\pi G_0^2 M}{c^4}\, dM, \qquad dS_{\mathrm{bdy}} = k_B \sigma_h\, dA_h \tag{2.88}$$

Along a quasistatic sequence describable by thermodynamic states, temperature is the response of stored boundary energy conjugate to entropy:

$$T_{\mathrm{bdy}} = \frac{dE_{\mathrm{bdy}}}{dS_{\mathrm{bdy}}} = \frac{c^6}{32\pi k_B \sigma_h G_0^2 M} \tag{2.89}$$

Hence

$$dE_{\mathrm{bdy}} = T_{\mathrm{bdy}}\, dS_{\mathrm{bdy}} \tag{2.90}$$

Equation (2.90) relates changes in boundary energy to changes in the extent of accessible microstates. When the boundary and exterior field reach the corresponding thermal equilibrium or satisfy detailed balance, this thermodynamic temperature also enters the radiation relation. Equation (2.89) shows that the mass dependence of temperature arises from the joint scaling of boundary area and total energy.

Adopting the Bekenstein–Hawking reference normalization in the boundary statistical model gives

$$\sigma_h = \frac{c^3}{4G_0\hbar}, \qquad S_{\mathrm{BH}} = \frac{k_B c^3 A_h}{4G_0\hbar} \tag{2.91}$$

Substituting this normalization into Eq. (2.89) gives

$$T_{\mathrm{bdy}} = \frac{\hbar c^3}{8\pi G_0 k_B M} \tag{2.92}$$

These relations connect to the entropy and temperature expressions of standard black-hole thermodynamics. In ASD, $\sigma_h = \ln g_*/a_*$ refers to the state capacity of boundary cells, while temperature measures the boundary energy required to increase entropy by one unit. Different microscopic state capacities correspond to different temperature normalizations; the area law and the temperature coefficient are linked by the same statistical structure.

At fixed σ_h, $T \propto M^{-1}$, and the corresponding heat capacity is

$$C_{\mathrm{bdy}} = \frac{dE_{\mathrm{bdy}}}{dT_{\mathrm{bdy}}} = -\frac{Mc^2}{T_{\mathrm{bdy}}} < 0 \tag{2.93}$$

In the regime where the effective emitting area is proportional to A_h, the number of available channels and the greybody factors are approximately constant, and a thermal spectral flux is adopted, $P_{\mathrm{out}} \propto A_h T^4 \propto M^{-2}$. A smaller mass implies a higher temperature and a greater corresponding energy-release rate. The actual net evaporation rate is then determined jointly by this outward flux and the inward fluxes from accretion and background radiation.

For a rotating or charged boundary, if a differentiable state function $E_{\mathrm{bdy}}(S, J, Q)$ exists, the general structure of the first law is

$$dE_{\mathrm{bdy}} = T_{\mathrm{bdy}}\, dS + \omega_{\mathrm{bdy}}\, dJ + \mathcal{V}_{\mathrm{bdy}}\, dQ \tag{2.94}$$

Here $\omega_{\mathrm{bdy}} = (\partial E/\partial J)_{S,Q}$ and $\mathcal{V}_{\mathrm{bdy}} = (\partial E/\partial Q)_{S,J}$ are the energy-conjugate quantities to boundary angular momentum and charge, respectively. ω_{bdy} describes the response of stored

boundary energy to angular momentum, while $\omega_{\mathrm{rot}}(r)$ describes the exterior azimuthal field; the two are connected in a complete boundary–exterior-field model.

When G, the action scale, or the boundary-cell area also varies with the state, entropy and energy acquire the corresponding variables, and the first law gains additional conjugate terms. The spatial background, boundary structure, and exchanges with the exterior field can thus be further incorporated into the same thermodynamic framework.

The ASD interpretation in this section uses the boundary ontology to connect exterior optics, rotation, information, and thermodynamics. General relativity defines the event horizon as a global causal boundary; the ASD strong-field hypothesis further stipulates that it is the physical termination boundary of the spatial continuum, grounding energy storage, states, and radiation in boundary degrees of freedom. Standard Hawking theory calculates radiation through the propagation and state relations of quantum fields in a gravitational background, whereas ASD grounds the corresponding investigation in coupling between the boundary and spatial propagating modes.

VI. Chapter Summary

(1) The process-counting nature of time and the origin of gravitational redshift in static spatial dilation. Taking a continuous spatial medium as its physical ontology, this chapter explicitly establishes time as a counting scale for standard periodic processes rather than an independently flowing entity. Matter excites static dilation of the surrounding space, characterized by the linear dilation factor Ω, linear-density factor Φ, and dimensionless state function X. This increases local characteristic lengths and light wavelengths by Ω, necessarily lengthening periods and lowering frequencies by Φ under the constraint of a constant local speed of light, Eqs. (2.2)–(2.4). The spatial gradient of the longitudinal spatial-state function (∇X) and the principal-stress differences it produces in the spatial medium directly constitute gravitational action. The gravitational constant $G_0 = \xi_G c^2/(\rho_0 l_0^2)$ expresses macroscopic gravitational strength as an intrinsic combination of background spatial density, wave speed, and topological structural scale.

(2) Topological core–accompanying field reconfiguration impedance and full-speed momentum and energy relations. ASD defines matter as a stable topological structure formed by a localized volumetric-density deficit in space ($m_0 = \rho_0 V_{eff}$), and explicitly interprets inertia as the spatial-reconfiguration impedance exhibited when external forces change the state of motion of the topological core and its accompanying spatial field. The symmetric mean γ of the axial inverse scales in the length vector effect (LVE), together with the dipolar inertial-weight integral, directly yields the full-speed momentum relation $p = m_0\gamma v$, the longitudinal and transverse inertial impedances ($m_0\gamma^3$ and $m_0\gamma$), the kinetic energy in Eq. (2.23), the total energy $E = m_0 c^2\gamma$, and the free-particle Lagrangian in Eq. (2.24b). Energy-equivalent mass, inertial mass, and active and passive gravitational mass have a strictly common origin because they share the same spatial topological carrier ($m_E = m_i = m_g^a = m_g^p = m_0$).

(3) Orbital dynamics and gravitational optical solutions in nonuniformly dilated space. Combining the static spatial-dilation line element, Eq. (2.25), with the motion-reconfiguration action establishes a unified spherically symmetric orbital action, Eq. (2.27), and yields conserved angular momentum, conserved energy, and the orbital differential equation, Eq. (2.36). Planetary perihelion precession is thereby revealed as the result of the coupled evolution of radial spatial dilation and motion-induced inertial gain. In optical propagation, spatial dilation and counting conversion jointly determine the reference optical-path line element, Eq. (2.26), and the isotropic refractive index, Eq.

(2.45). Light deflection reads out the transverse optical-path gradient, while the Shapiro delay is fully characterized by the logarithmic integral of the additional optical path along the trajectory, Eqs. (2.55)–(2.58).

(4) The spatial termination-boundary ontology of black holes, azimuthal accompanying fields, and boundary statistical thermodynamics. When the longitudinal spatial-state function reaches $X = 0$ ($r_h = 2G_0M/c^2$), ASD establishes its strong-field boundary principle: the horizon is the physical termination boundary of the continuous spatial-medium state. The antiderivative of the actual radial spatial length, Eq. (2.61), remains finite at the boundary, whereas the radial reference optical path, Eq. (2.62), diverges logarithmically. The photon-sphere radius $r_{ph} = 3r_h/2$ and critical impact parameter $b_c = 3\sqrt{3}r_h/2$ characterize strong-field capture scales. The azimuthal accompanying field excited by a rotating source, Eq. (2.76), and the directed LVE coupling factor, Eq. (2.78), yield the Sagnac time difference for a coaxial ring, Eq. (2.82). State counting for microscopic boundary cells, Eqs. (2.86)–(2.87), directly establishes the area-entropy law and the first law of boundary thermodynamics, Eqs. (2.88)–(2.94), grounding black-hole mass, angular momentum, information, and thermal radiation in physical boundary states.

(5) Comparison of the physical ontologies of ASD spatial dynamics and relativity. ASD and relativity are mathematically isomorphic in the core equations of this chapter, but their physical ontologies and causal starting points differ fundamentally. The following table gives a systematic comparison.

Topic	Physical Interpretation in ASD	Corresponding Formulation in Relativity
Gravitational redshift	Spatial dilation changes wavelength, with a consequent frequency change	Proper time and frequency comparisons
Gravitational action	Longitudinal spatial-state gradients produce stresses	Spacetime geometry and material motion
Inertia and momentum	Reconfiguration impedance of the topological core and accompanying field	Spacetime symmetry and energy–momentum relations
Orbits and gravitational optics	Spatial dilation couples to motion and propagation processes	Geodesics of matter and light
Black-hole horizon	A hypothesized boundary at which the spatial continuum terminates	Global causal boundary
Rotational effects	An azimuthal accompanying field produces directed propagation differences	Frame-dragging response of rotating spacetime
Entropy and information	Boundary microstates and their exchange with the exterior field	Black-hole thermodynamics and quantum-state evolution

(6) Theoretical levels, limits of applicability, and connections to later chapters. To define rigorously the physical premises and domains of applicability of the relations and macroscopic constitutive laws in this chapter, the conditions at each theoretical level and the connections between them are collected below.

First, the limits of the static spherically symmetric dilation law and the local length constitutive relation. The spherically symmetric linear dilation law, Eqs. (2.3)–(2.4), and the radial length constitutive relation ($d\ell_r = \Omega\, dr$) adopted in Sections I and IV apply to the exterior spatial background of an isolated, static, uncharged source, with test-body backreaction neglected. Weak-field redshift and the Newtonian potential constrain their asymptotic behaviour. Asymmetric many-body strong-field distributions and the microscopic coupling mechanisms between standard processes and spatial fields must be solved in full using the longitudinal–transverse two-field dynamical equations developed in later chapters.

Second, the equal-speed condition for spatial elastic branches and the microscopic limits of the gravitational coupling coefficient. The equal-speed relation for longitudinal and transverse waves in Eq. (2.5), Section II, is established for a homogeneous ground state without matter-induced perturbations and within the linear long-wavelength approximation. Equation (2.7c) specifies the required combination of microscopic scales for the gravitational constant G_0. The numerical value of the dimensionless coupling efficiency ξ_G, as well as extensions to slowly varying coupling in a variable background, such as $\nabla \cdot [G(\mathrm{x})^{-1}\nabla\Psi] = 4\pi\rho_g$, must be determined from microscopic structural solutions for the spatial lattice and topological cores.

Third, the limits of equivalent-sphere inertial constitutive closure, the nonradiative condition, and matching the common origin of mass. The dipolar inertial weight, Eq. (2.11), used for the momentum integral in Section III is an effective constitutive closure connecting the axially symmetric LVE gain to macroscopic momentum; at general nonaxial angles, $K(\chi)^{-1} \neq \gamma(1+\beta\cos\chi)$. Equations (2.15)–(2.24b) apply to a conserved moving system with a fixed internal topological state and no net electromagnetic or spatial-wave radiation. If radiation or internal excitation occurs, the total momentum and energy balances must include radiative-field momentum and changes in internal state. The microscopic connection between the finite near-region volumetric-density-deficit integral, Eqs. (2.8)–(2.9), the flux of the exterior long-range $1/r$ dilation field, Eq. (2.7b), and the normalization of the four types of mass, Eq. (2.24c), forms part of the matching conditions for stable topological-soliton solutions in Chapters 4 and 5.

Fourth, the limits of post-Newtonian orbital perturbations, slowly rotating weak-field accompanying fields, and microscopic black-hole boundary statistics. The calculations of perihelion precession, light deflection, and the Shapiro delay in Section IV concern the vacuum exterior field of a single central source. Actual astronomical ephemerides and link measurements must also include multiplanet perturbations, solar multipole moments, endpoint motion, and medium-dispersion corrections. The rotational accompanying field in Section V, Eqs. (2.73)–(2.82), is established for a steady localized source, a weak far-zone field, and rotation retained to first order; $\zeta = 4$ is an empirically calibrated value. The identification of the black-hole horizon with the termination boundary of the spatial continuum ($X = 0$) is a strong-field boundary hypothesis in this chapter. Its formation through a nonlinear phase-transition mechanism, proof of reversibility of the joint boundary–exterior-field evolution map in Eq. (2.83), and the contributions of microscopic boundary-cell area a_*, degeneracy g_*, and intercell correlations to subleading terms in area entropy are all research topics for the subsequent nonlinear longitudinal–transverse field theory and microscopic statistical dynamics.

Building on the static spatial anisotropy and motion-induced inertial reconfiguration established in this chapter, Chapter 3 examines the transverse spatial shear–torsion fields excited by moving charges and the resulting electromagnetic interactions. Chapters 4 and 5 further construct the

microscopic FCC lattice of space, the topological structures of matter, and unified master equations for the longitudinal–transverse two-field system. The central physical theme remains consistent throughout the book: space forms matter, matter changes space, and the state of space determines material motion and wave propagation.

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