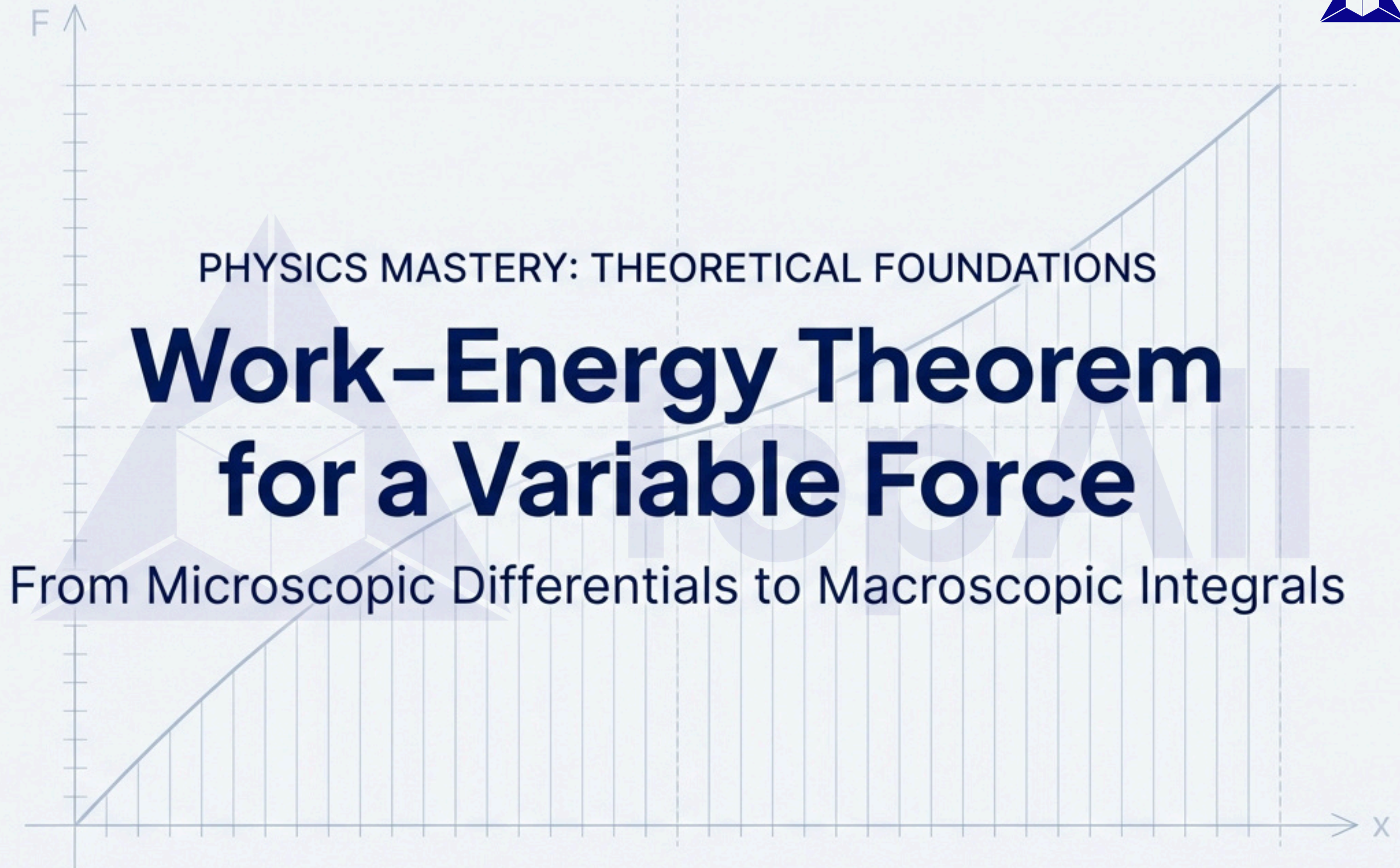




PHYSICS MASTERY: THEORETICAL FOUNDATIONS

Work-Energy Theorem for a Variable Force

From Microscopic Differentials to Macroscopic Integrals

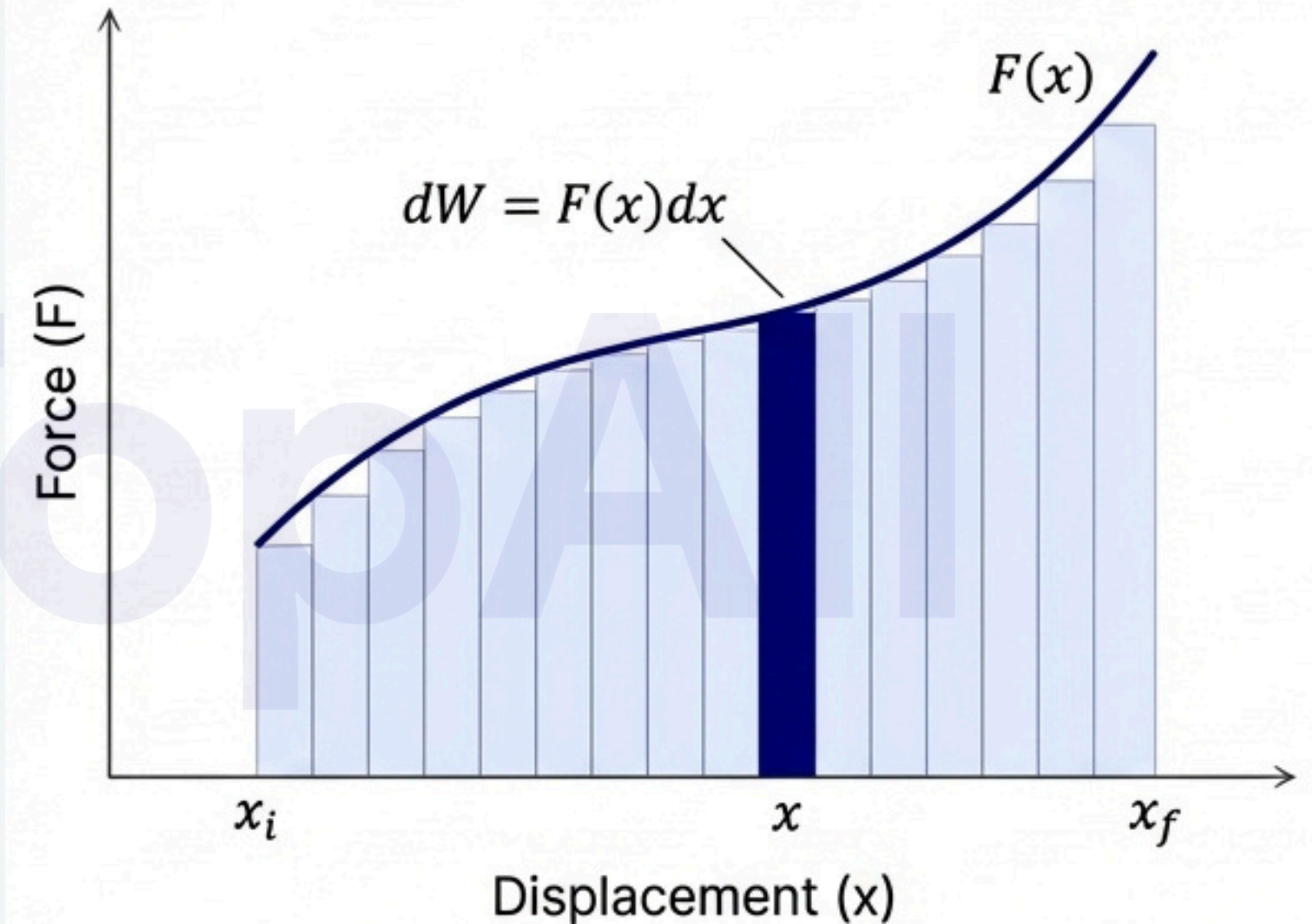
The Reality of Real-World Forces

Constant Force

- **Math:** Algebra ($W = F \cdot \Delta x$)
- **Graph:** Area of a simple rectangle
- **Application:** Basic Kinematics

Variable Force

- **Math:** Calculus ($W = \int F dx$)
- **Graph:** Area under a dynamic curve
- **Application:** Real-world dynamics (springs, friction, orbits)



Total work is the limit of the sum: $W = \int_{x_i}^{x_f} F(x) dx$

The Microscopic View: Differential Form

Kinetic Energy Rate

$$\frac{dK}{dt} = \frac{d}{dt} \left(\frac{1}{2} m v^2 \right) = m v \frac{dv}{dt}$$

Applying Newton's 2nd Law ($ma = F$)

Force Substitution

$$\frac{dK}{dt} = F \cdot v$$

Substituting velocity ($v = \frac{dx}{dt}$)

The Differential Form

$$\frac{dK}{dt} = F \frac{dx}{dt} \Rightarrow dK = F dx$$

The Exact Instant: A tiny change in position (dx) yields a tiny change in energy (dK).



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$$E=mc^2$$



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The Macroscopic View: Integral Form

The Integration

$$\int_{K_i}^{K_f} dK = \int_{x_i}^{x_f} F dx$$



The Final Theorem

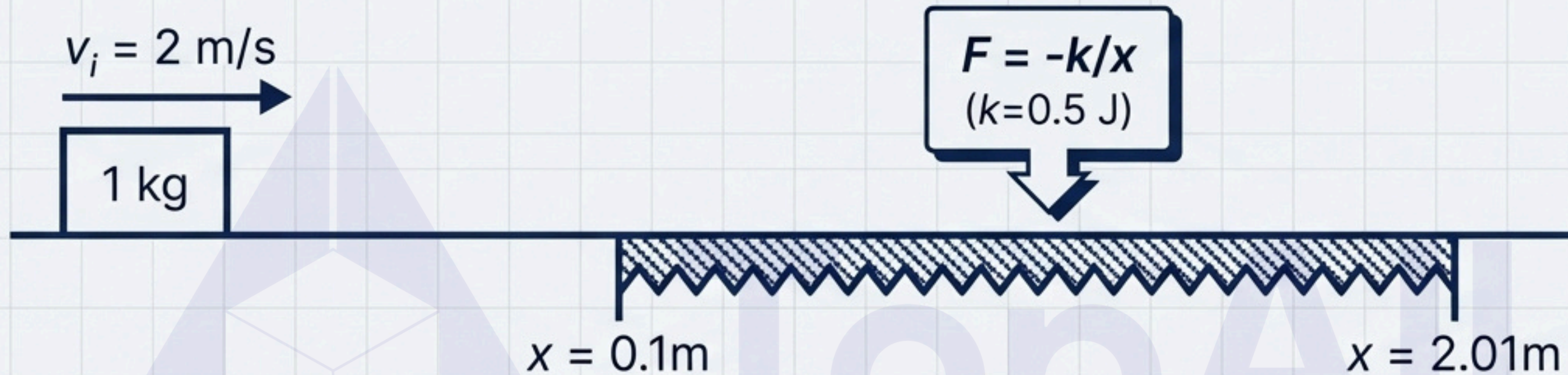
$$K_f - K_i = W_{net}$$

$(\Delta K = W)$



SYNTHESIS: The Work-Energy Theorem is actually the integral form of Newton's Second Law. While $F=ma$ gives spatial information at an exact instant of time, $\Delta K = W$ integrates that temporal information over an interval.

Applied Motion: The Rough Patch



Step 1: Setup

$$K_f - K_i = \int_{0.1}^{2.01} \left(-\frac{k}{x} \right) dx$$

Step 2: Solution

$$K_f - \frac{1}{2}(1)(2)^2 = -0.5 \ln(20.1)$$

$$K_f = 2 - 1.5 = 0.5 \text{ J}$$

$$v_f = 1 \text{ m/s}$$

Core Concept Mastery



$\Delta K = \int F dx$ — The **change in kinetic energy** is equal to the net work done, even when the force constantly changes.



Area Under the Curve — Work done against a variable force maps directly to the geometric area under the $F - x$ curve.



Scalar Limitation — Because it is a scalar relationship, this theorem drops the directional vector information inherently contained in Newton's 2nd Law.

Integration bridges the instant (dt) to the interval (Δx).



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