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# Angular-Momentum Discrepancy in the Earth–Moon System: Evidence from Direct Measurements and Deep-Time Geological Records

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Article

# Angular-Momentum Discrepancy in the Earth–Moon System: Evidence from Direct Measurements and Deep-Time Geological Records

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## Abstract

The long-term evolution of the Earth–Moon system is traditionally attributed to tidal friction, which transfers angular momentum from Earth's rotation to the Moon's orbit. Present-day measurements show that Earth's rotational angular-momentum loss closely matches the Moon's orbital gain, consistent with this framework. However, deep-time constraints from fossil growth increments and tidal rhythmites reveal a persistent and significant mismatch between these two quantities over the past 3.2 billion years. At 900 million years ago, Earth's rotational angular-momentum loss exceeded the Moon's orbital gain by ~40%, and at 3.2 billion years ago, by nearly a factor of three. These discrepancies cannot be reconciled by classical tidal friction, even when accounting for solar tides, ocean-basin evolution, atmospheric tides, or core–mantle coupling. Using empirically fitted histories of the length of day (LOD), number of days per year (DOY), and Earth–Moon distance (DOM), I show that the angular-momentum imbalance is robust and increases exponentially backward in time. The Dark Matter Field Fluid (DMFF) model provides a natural explanation: Earth loses rotational angular momentum to a pervasive dark-matter-like medium, while the Moon's orbital evolution is driven by DMFF drag and anti-gravitational effects. The DMFF-derived equations for LOD, DOY, and DOM match both modern astronomical measurements and deep-time geological records, including the critical LOD and DOM constraints at 3.2 billion years ago. The angular-momentum discrepancy is therefore not a flaw in the data but a signature of DMFF physics, revealing a deeper dynamical structure of the Earth–Moon system.

**Keywords:** Earth–Moon system; angular momentum; tidal friction; lunar recession; length of day; fossil growth increments; tidal rhythmites; deep-time geophysics; orbital evolution; dark matter field fluid (DMFF)

## 1. Introduction

The Earth–Moon system is a dynamically coupled pair whose long-term evolution influences tides, climate, biological rhythms, and Earth's rotational stability. Earth's rotation is gradually slowing, the Moon is steadily receding, and these coupled changes alter three fundamental planetary parameters: the length of day (LOD), the number of solar days per year (DOY), and the Earth–Moon distance (DOM). Understanding the evolution of these quantities is essential for reconstructing Earth's past and predicting its future.

The classical tidal-friction model attributes Earth's rotational deceleration to tidal torques raised by the Moon and Sun, with the lost rotational angular momentum transferred to the Moon's orbit [1–4]. Although this model explains many present-day observations, it faces two long-standing challenges. First, the lunar crisis: extrapolating the modern recession rate backward places the Moon inside Earth's Roche limit within ~1.5 billion years back from present, where it would have been tidally disrupted—contradicting geological evidence [5–7]. Second, the angular-momentum conservation problem: the tidal-friction model requires that Earth's rotational angular-momentum

loss must always equal the Moon's orbital gain. Whether this condition holds over geological time has remained an open question.

In recent work, I developed new equations for LOD, DOY, and DOM based on the Dark Matter Field Fluid (DMFF) model [8], originally proposed in 2004 and presented at the Division of Particles and Fields Meeting of American Physical society [9-10]. These equations match both modern astronomical measurements and deep-time constraints from fossil growth increments and tidal rhythmites.

The present paper extends that work by examining the angular-momentum dynamics of the Earth–Moon system. By combining direct measurements with fossil-fitted histories, I show that the angular-momentum budget implied by geological data cannot be explained by tidal friction alone. In contrast, the DMFF model naturally accounts for the observed imbalance and provides a physically consistent description of Earth–Moon evolution through deep time.

## 2. Present-Day Angular-Momentum Change from Direct Measurements

Earth's present-day rotational deceleration and the Moon's orbital recession are measured with exceptional precision using atomic clocks, geodetic observations [11-16], and Lunar Laser Ranging (LLR) [17-18]. These measurements provide a direct, model-independent snapshot of the angular-momentum change occurring in the Earth–Moon system today.

### 2.1. Loss Rate of Earth's Rotational Angular Momentum

The rotational angular momentum of Earth is

$$L_{rot}(t) = I\omega(t) \quad (1)$$

where  $I$  is the axial moment of inertia and  $\omega(t)$  is the angular rotation rate. For Earth's non-uniform density,

$$I = 0.3307 Mr^2 \quad (2)$$

Where,  $M$  is the mass of the Earth,  $M = 5.9742 \times 10^{24}$  kg and  $r$  is the radius of the Earth,  $r = 6371$  km.

Differentiating equation (1) gives

$$\frac{dL_{rot}}{dt} = 0.3307 M r^2 \frac{d\omega(t)}{dt} \quad (3)$$

Earth's rotation is slowing by 2.3 ms per century [15,16], corresponding to

$$\frac{d\omega}{dt} = -5.5 \times 10^{-22} \text{ rad/s}^2 \quad (4)$$

Thus, the loss rate of the Earth's rotation angular momentum is

$$\left| \frac{dL_{rot}}{dt} \right| \approx 4.411 \times 10^{16} \text{ kg} \cdot \text{m}^2/\text{s}^2 \quad (5)$$

### 2.2. Gain Rate of the Moon's Orbital Angular Momentum

The Moon's orbital angular momentum is

$$L_{orb} = m \sqrt{GM R} \quad (6)$$

Where,  $m$  is the Moon's mass,  $m = 7.35 \times 10^{22}$  kg, the  $G$  is the gravitational constant,  $G = 6.674 \times 10^{-11} \text{ m}^3/(\text{kg} \cdot \text{s}^2)$ ,  $M$  is the Earth's mass,  $M = 5.9742 \times 10^{24}$  kg,  $R$  is the distance of the Moon from Earth. Differentiating equation (6) gives

$$\frac{dL_{orb}}{dt} = \frac{1}{2} m \sqrt{\frac{GM}{R}} \frac{dR}{dt} \quad (7)$$

LLR measurements show that the moon is receding from Earth at  $3.82 \pm 0.07$  cm/yr [17].

$$\frac{dR}{dt} = (1.21 \pm 0.02) \times 10^{-9} \text{ m/s} \quad (8)$$

Yielding the gain rate of Moon's orbital angular momentum

$$\frac{dL_{orb}}{dt} \approx 4.215 \times 10^{16} \text{ kg} \cdot \text{m}^2/\text{s}^2 \quad (9)$$

### 2.3. Present-Day Comparison

From Eqs. (5) and (9),

$$\left| \frac{dL_{rot}}{dt} \right| \approx \frac{dL_{orb}}{dt} \quad (10)$$

This result is consistent with the tidal-friction model. Solar tides contribute ~46 % of the lunar tidal torque [2-3], but the near-unity ratio indicates that their effect on the present angular-momentum budget is negligible.

If tidal friction has governed the Earth–Moon system throughout its history, Eq. (10) should hold at all times. The next section tests this expectation using deep-time fossil and tidal-rhythmite data.

## 3. Deep-Time Angular-Momentum Change from Fossil and Tidal-Rhythmite Histories

Earth's ancient rotation rate is inferred from two independent archives: biological fossils and tidal rhythmites. Marine organisms such as corals, bivalves, and stromatolites record daily, monthly, and annual growth increments [5-6]. Tidal rhythmites preserve daily tidal cycles, fortnightly spring–neap cycles, monthly lunar cycles, and annual sedimentation variations [7]. These archives provide the only direct empirical record of Earth's rotation and the Moon's orbital evolution.

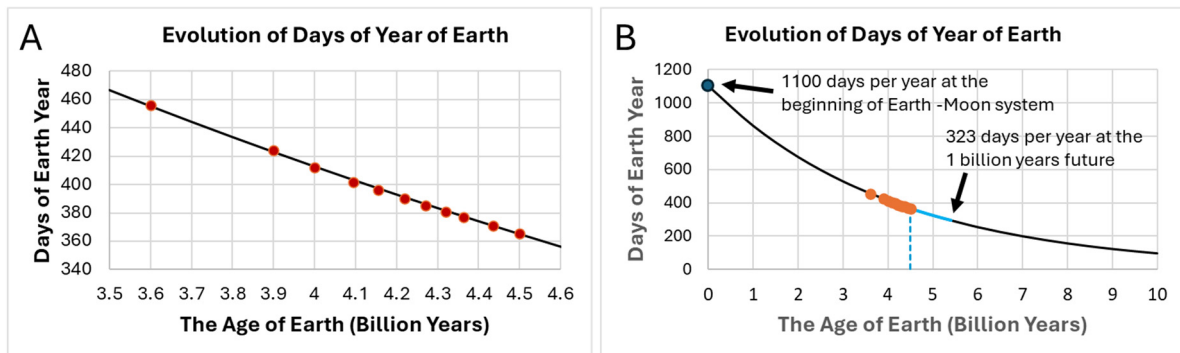
Well-preserved fossil and rhythmite records extend back to ~900 million years from present, with some constraints reaching ~3.2 billion years ago [19]. Earlier sediments were largely destroyed by metamorphism, deformation, subduction, and crustal recycling.

### 3.1. Earth's Rotational Angular-Momentum Loss over the Past 3.2 Billion Years

Figure 1 shows the evolution of DOY from the formation of the Earth–Moon system to 10 billion years. Figure 1A focuses on the interval from ~3.5 billion years of Earth age to the present, where fossil and rhythmite data was preserved well. Observed values (●) from Wells [5], Sonett [6], and modern measurements align closely with the line calculated by

$$DOY = 365.25 * \exp(0.24505 * (4.5 - t)) \quad (11)$$

Where, time  $t$  is in billion years or Ga. It is projected that at system inception, Earth had ~1,100 solar days/year. After 1 billion more years, this will drop to ~323 days/year.

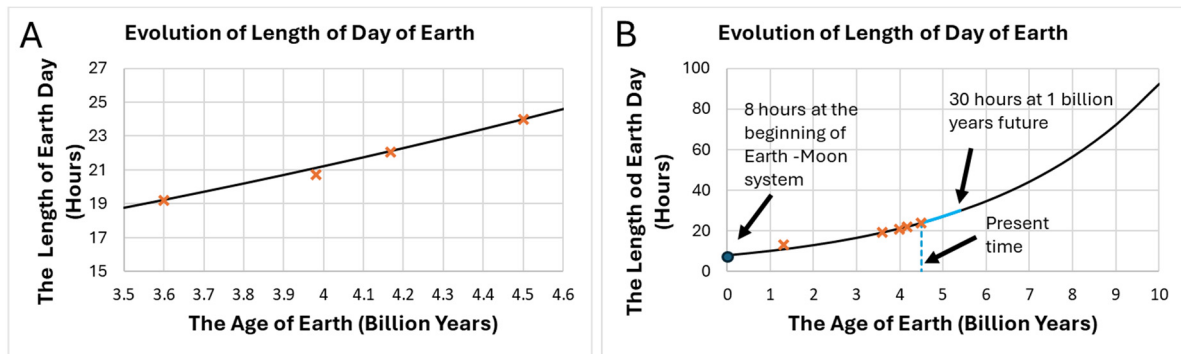


**Figure 1.** DOY evolution over 10 billion years. Observed data points (●) align well with Equation (11). At system inception, Earth had ~1,100 solar days/year. After 1 billion more years, this will drop to ~323 days/year.

Figure 2 shows LOD evolution from the formation of the Earth–Moon system to 10 billion years, fitted by

$$LOD \text{ (hour)} = 24 * \exp(-0.24505 * (4.5 - t)) \quad (12)$$

Where, time  $t$  is in billion years or Ga.



**Figure 2.** LOD evolution over 10 billion years. Observed data points (×) align well with Equation (12). At system inception, Earth had ~8 hours length of day. After 1 billion more years, this will increase to 30 hours.

A crucial independent constraint comes from Eulenfeld et al. [19], who found that at 3.2 billion years ago, the LOD was ~13 hours—closely matching Eq. (12) as shown in the Figure 2B, which provides a critical validation for the equation (12) developed from DMFF model.

The two different datasets shown in Figure 1 and Figure 2 are originated from the Earth's rotation slowing, both equations (11) and (12) can be converted to the Earth's rotation velocity

$$\omega = 2.196639 * 10^{-4} * \exp(0.24505 * (4.5 - t)) \quad (\text{rad s}^{-1}) \quad (13)$$

Where, time  $t$  is in billion years or Ga. Differentiating equation (13) gives

$$\frac{d\omega}{dt} = -1.6215 * 10^{-4} * \exp(-0.24505 * t) \quad (\text{rad s}^{-1}\text{Ga}^{-1}) \quad (14)$$

And the loss rate of the Earth's rotation angular momentum is

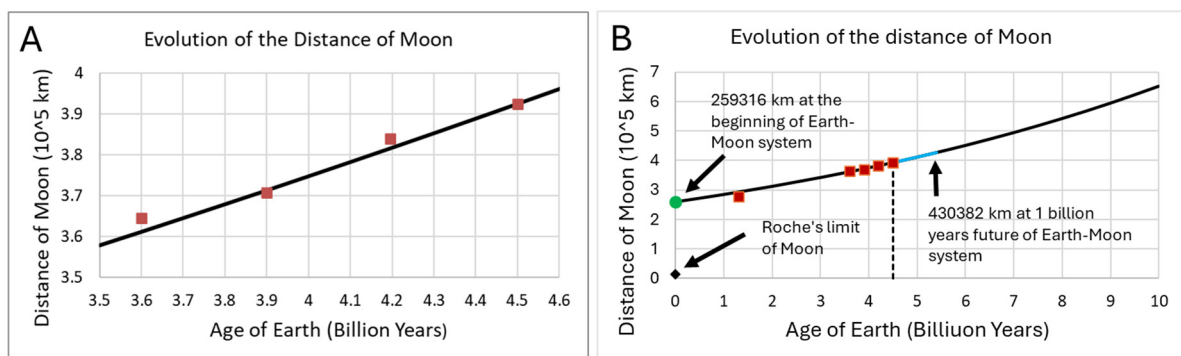
$$\left| \frac{dL_{rot}}{dt} \right| = 1.37 * 10^{17} * \exp(-0.24505 * t) \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-1} \cdot \text{Ga}^{-1} \quad (15)$$

### 3.2. Moon's Orbital Angular-Momentum Gain over the Past 3.2 Ga

Figure 3 shows DOM evolution from the formation of the Earth–Moon system to 10 billion years, fitted by

$$R(\text{km}) = 392509 * \exp(-0.092108 * (4.5 - t)) \quad (16)$$

Where, time  $t$  is in billion years or Ga.



**Figure 3.** Moon–Earth distance (center to center) evolution over 10 billion years. The observed data points are marked with (■), the solid line is the calculation values by the equation (16) developed from DMFF model. Data are from Kvale [20] and Eulenfeld [19].

Eulenfeld et al. also found that at 3.2 billion years ago, the Moon's distance was ~70 % of its present value (~277,200 km) [19], matching Eq. (16) very well as shown in Figure 3B, which provides a critical validation for the equation (16) developed from DMFF model. It is projected by DMFF model that at the system inception, the Moon's center-to-center distance from the Earth was about 259316 km which aligns remarkably well with the estimate 250,000 km found in Chaisson & McMillan's astronomy textbook [21], even though that value was likely a rounded assumption rather than a model-based calculation. The Moon's distance will increase to 430382 km in the next 1 billion years; the Moon will appear smaller and dimmer.

Differentiating equation (16) gives

$$\frac{dR}{dt} = 23885 * \exp(-0.092108 * t) \quad \text{km / Ga} \quad (17)$$

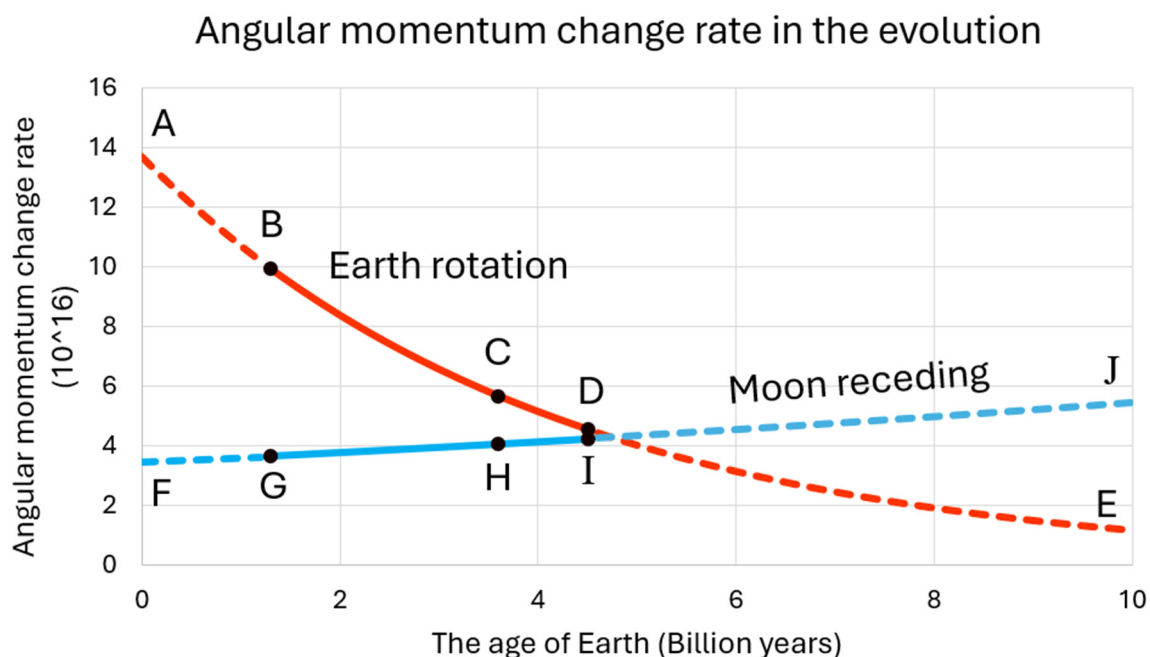
and

$$\frac{dL_{orb}}{dt} = 3.44 \times 10^{16} \times \exp(0.046054 \times t) \quad \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1} \cdot \text{Ga}^{-1} \quad (18)$$

The above three figures clearly illustrate that the calculated lines by equations (11), (12) and (16) match the fossil and rhythmite data very well, therefore, those three equations are not just theoretical equations from DMFF model, **they can also be treated as empirical numerical regression fitting equations regardless of the DMFF model for the time period of 3.2 billion year ago to present.**

### 3.3. Angular-Momentum Dynamics over Earth–Moon History

Figure 4 compares Earth's rotational angular-momentum loss (red) and the Moon's orbital gain (blue) from the formation of the Earth–Moon system to 10 billion years. The solid red line BD is calculated by equation (15) for the loss rate of the Earth's rotation angular momentum, and the solid blue line GI is calculated by equations (18) for the gain rate of the Moon's orbital angular momentum. Those two solid lines are from observed fact, not model outputs.



**Figure 4.** The loss rate of Earth's rotation angular momentum and the gain rate of Moon's orbital angular momentum. The red and blue solid lines (from 1.3 billion years to present) are calculated by equation (15) and (18) respectively. The dashed red and blue lines are extrapolations.

Present (4.5 billion years age), between point D and point I,

$$\left| \frac{dL_{rot}}{dt} \right| : \frac{dL_{orb}}{dt} \approx 1 : 1 \quad (19)$$

900 million years ago, between point C and point H,

$$\left| \frac{dL_{rot}}{dt} \right| : \frac{dL_{orb}}{dt} \approx 1.4 : 1 \quad (20)$$

The loss rate of the Earth's rotation angular momentum is 40% more than the gain rate of Moon's orbital angular momentum.

3.2 billion years ago, between point B and point G,

$$\left| \frac{dL_{rot}}{dt} \right| : \frac{dL_{orb}}{dt} \approx 2.7 : 1 \quad (21)$$

Earth's loss exceeded the Moon's gain by nearly a factor of three at 3.2 billion years ago—the same epoch independently constrained by LOD  $\approx$  13 h and DOM  $\approx$  277,200 km.

These discrepancies cannot be reconciled by classical tidal friction, even when accounting for solar tides, ocean-basin evolution, atmospheric tides, or core–mantle coupling.

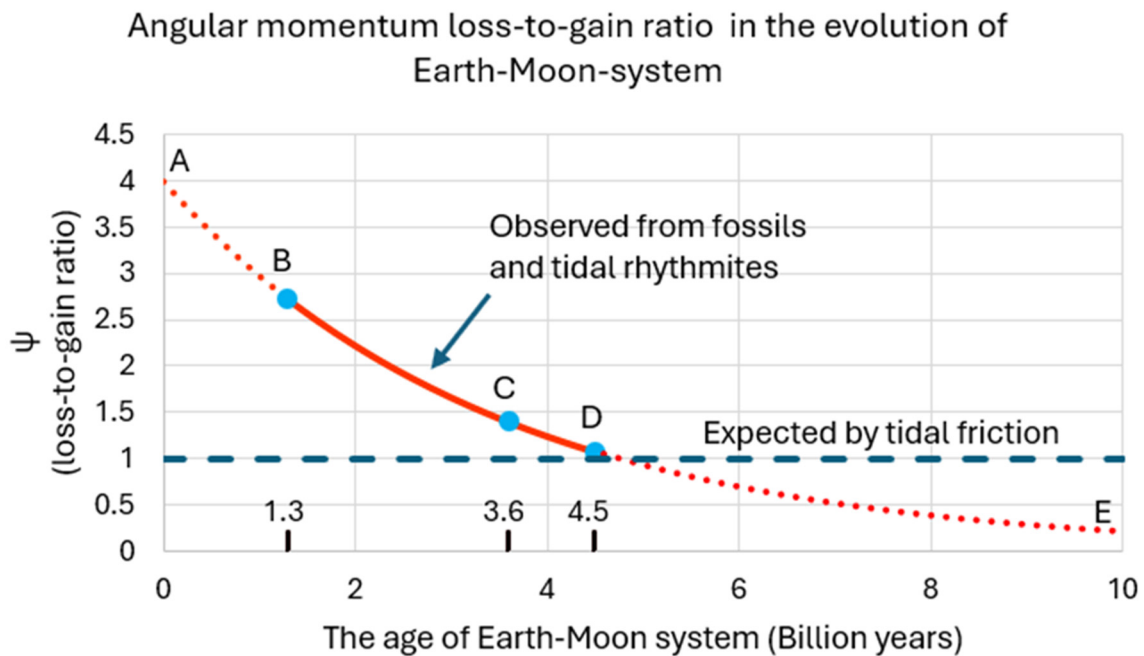
Extrapolating to the system inception between point A and F,

$$\left| \frac{dL_{rot}}{dt} \right| : \frac{dL_{orb}}{dt} \approx 4 : 1 \quad (22)$$

Actually, the loss-to-gain ratio  $\psi$  can be expressed analytically by dividing equation (15) by equation (18) as

$$\psi = 3.98 * \exp(-0.2911 * t) \quad (23)$$

Where, t is in billion years. Figure 5 shows the Loss-to-Gain ratio in the evolution of Earth Moon system. The solid red line is observed from fossils and tidal rhythmmites, dashed red lines are natural extrapolating to the beginning A and 1 billion years future E of the Earth-Moon system; the horizontal blue line is the expected 1:1 ratio by tidal friction model, where the observed ratio should be within a reasonable range around it.



**Figure 5.** Loss-to-gain ratio from 3.2 billion years ago to present (solid red) with extrapolations (dashed). Letters B–D mark fossil-derived constraints. The horizontal dashed line marks the 1:1 ratio expected under tidal friction.

The ratio has never followed the tidal-friction expectation in the past and will not do so in the future. The present-day 1:1 loss-to-gain ratio is only a transient coincidence and should not be interpreted as evidence for the tidal-friction model. Given the continuing exponential decline of the

ratio, Earth's rotational angular-momentum loss will soon fall below the Moon's orbital angular-momentum gain. If the observation favors DMFF model in the future, million years future human generations, please give me a Thumbs-Up.

A common analogy for tidal angular-momentum transfer compares the Earth–Moon system to a gymnast retracting their arms to spin faster and extending their arms outward to spin slower. However, this analogy is fundamentally misleading.

In the gymnast's case:

- The arms and torso are rigidly connected.
- They rotate with exactly the same angular velocity.
- The system is closed and behaves as a rigid body.
- Angular momentum is conserved internally within the system.

This rigid-body behavior allows angular momentum to be efficiently redistributed.

The Earth–Moon System Is a Soft, Weakly Coupled System

The Earth–Moon system differs fundamentally:

- Earth and Moon are not rigidly connected.
- They rotate at vastly different angular velocities.
- They are separated by approximately 384,000 km.
- The tidal bulge on Earth is very small.
- The coupling between Earth and Moon is weak and dissipative.

Thus, the Earth–Moon system is not a rigid body but a soft, weakly coupled, deformable system. Consequently, there is no guarantee of direct angular momentum transfer analogous to the gymnast's case. The gymnast analogy and the Earth–Moon system are therefore incompatible.

#### 4. A DMFF-Based Explanation for the Discrepancy

The DMFF model proposes that interstellar space contains a fluid-like dark matter medium that permeates ordinary matter and exerts drag-like torques.

Under DMFF:

- Earth loses rotational angular momentum to the DMFF medium.
- The Moon experiences DMFF drag and an anti-gravitational push, increasing its orbital angular momentum.
- Earth's loss and the Moon's gain arise from different mechanisms, not mutual exchange.
- Angular-momentum conservation applies to the combined Earth–Moon–DMFF system.

The DMFF model:

- fits modern atomic-clock and LLR measurements,
- reproduces fossil and tidal rhythmite-derived LOD, DOY, and DOM histories,
- is independently validated using data dated to 3.2 billion years ago, as analyzed by Eulenfeld et al.
- requires no assumptions about ocean-basin geometry or resonances,
- naturally resolves the angular-momentum discrepancy.

From the earliest days of physics, scientists have proposed that space is filled with a pervasive medium. The 19th-century ether was imagined as a continuous substance through which light waves propagated, an idea later abandoned after relativity. In the 20th century, this concept evolved into the modern interstellar medium—composed of gas, dust, plasma, and magnetic fields—and eventually into the recognition that most of the universe is dominated by invisible components: dark matter and dark energy. These entities are now understood not as mechanical media but as fundamental contributors to cosmic structure and expansion. Building on this long intellectual trajectory, the Dark Matter Field Fluid (DMFF) model reintroduces a physically meaningful medium permeating all space, but with properties consistent with modern cosmology: a fluid-like dark matter that penetrates baryonic matter, interacts weakly, and provides a mechanism for angular-momentum

exchange in systems such as Earth–Moon. The DMFF model is still in an early stage of development and will undoubtedly benefit from further refinement as additional theoretical and observational constraints become available. Other new hypotheses may come out in the future in this subject.

## 5. Conclusion

Direct measurements and deep-time fossil and rhythmite records show that the Moon's orbital angular-momentum gain has consistently been smaller than Earth's rotational angular-momentum loss. This persistent mismatch contradicts the classical tidal-friction model.

The DMFF model provides a natural explanation: a dark matter field fluid absorbs Earth's missing angular momentum while independently driving the Moon's orbital evolution. The angular-momentum discrepancy is therefore a signature of DMFF physics, revealing a deeper dynamical structure of the Earth–Moon system.

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