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Hydrodynamic Approach to Macroscopic Gravity: Thermodynamic Equilibrium via Viscous Dissipation and Quaternion Tensors

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Abstract

This paper presents a novel hydrodynamic framework for macroscopic gravity, bridging the gap between Einstein's tensor geometry and Navier-Stokes fluid dynamics. By modeling the gravitational field as a continuous flow of Vacuum Fluctuation Energy, this study introduces the quaternion tensor ($\mathbf{q}_{\text{rot}}$) to resolve the polar coordinate singularity (gimbal lock) inherent in rotating celestial bodies. Furthermore, to prevent the non-physical gravitational collapse observed in conventional mass-density singularity models, a hydrostatic pressure gradient ($-\nabla P$) is combined with a radial density stratification function ($\rho(\vec{r})$). This system reaches a permanent thermodynamic equilibrium state by suppressing turbulent kinetic energy (TKE) through a kinematic viscous dissipation term ($-\nu\nabla^2\vec{v}$). This hydrodynamic formulation successfully eliminates infinite density singularities without relying on the constraints of quantum gravity, providing a computable macroscopic field theory for planetary geometry.

1. Introduction

The intersection of general relativity and fluid dynamics has historically provided a fundamental understanding of macroscopic gravity. Traditionally, gravitational fields have been described through geometric tensors. However, when modeling the continuous dynamics of a rotating planet, conventional coordinate systems have exhibited mathematical limitations, such as polar coordinate singularities (gimbal lock) and the infinite density collapse of internal mass structures.

To address this problem beyond the limits of existing models, this paper proposes a hydrodynamic framework that treats the macroscopic gravitational field as a continuous flow of Vacuum Fluctuation Energy. Moving away from conventional descriptions that rely solely on geometric curvature, we introduce a hydrodynamic perspective that incorporates the physical resistance inside celestial bodies.

By applying the quaternion tensor representation ($\mathbf{q}_{\text{rot}}$), the coordinate singularity inherent in three-dimensional rotating celestial bodies is resolved, enabling smooth angular momentum calculations. Furthermore, to prevent the structural collapse of a single mass model, a hydrostatic pressure gradient ($-\nabla P$) is coupled with a radial density stratification function ($\rho(\vec{r})$). Finally, by including a kinematic viscous dissipation term ($-\nu\nabla^2\vec{v}$), the system is structured to mitigate turbulent kinetic energy and maintain thermodynamic equilibrium. This formulation provides a computable alternative for macroscopic gravitational field analysis.

2. Theoretical Framework and Hydrodynamic Equations

This study builds progressively from the fundamental gravitational model of classical mechanics to a hydrodynamic tensor model capable of explaining the thermodynamic equilibrium of macroscopic planetary systems.

Step 1: Classical Mass-Distance Model (Newtonian Mechanics)

The most basic approach to gravity begins with the classical model describing the attractive force between two point masses:

$$F = G\frac{m_1 m_2}{r^2} \tag{1}$$

While this model is effective for predicting macroscopic orbits between celestial bodies, it fails to account for the physical resistance inside planets or the hydrodynamic properties of the medium (spacetime).

Step 2: Geometric Curvature Model (General Relativity Basis)

To reflect the flow of fluid or energy, classical mechanics has evolved into a tensor form dealing with the curvature of spacetime via the energy-momentum tensor ($T_{\mu\nu}$) of Einstein's field equations. Simplifying this into the concept of an Energy Influx Tensor (RX) yields the following expression:

$$\mathbf{\Phi}_{\text{geo}} = \oint \mathbf{M} \cdot \text{RX}\, d\Sigma \tag{2}$$

However, this equation induces a mathematical discontinuity (gimbal lock) at the poles of a rotating celestial body (angular velocity ω) and generates a singularity problem where the internal density of the body converges to infinity.

Step 3: Introduction of Rotation and Pressure Resistance (Fluid-Structure Equilibrium)

To resolve the polar coordinate singularity and the density collapse problem, this study introduces the quaternion rotation tensor ($\mathbf{q}_{\text{rot}}$) and couples it with an internal pressure gradient ($-\nabla P$):

$$\mathbf{\Phi}_{\text{hydro}} = \oint \left[\rho(\vec{r}) \otimes \mathbf{q}_{\text{rot}}\vec{\omega}\mathbf{q}_{\text{rot}}^{-1}\right] \cdot (\text{RX} - \nabla P)\, d\Sigma \quad (3)$$

At this stage, the planet secures the morphological stability of a non-collapsing sphere. Nevertheless, the problem of a runaway turbulent kinetic energy (TKE) caused by the continuous rotation of the fluid still remains.

Step 4: Viscous Dissipation and Thermodynamic Equilibrium (Final Integrated Equation)

Ultimately, to prevent the exponential growth of rotational energy and guide the system into a permanent state of equilibrium, the kinematic viscous dissipation term ($-\nu\nabla^2\vec{v}$) of fluid dynamics is introduced. Furthermore, by establishing a critical threshold ($\mathbf{\Gamma}_0$) where the Energy Influx Tensor (RX) and the Energy Efflux Tensor (TX) interact, the final equation is formulated:

$$\begin{aligned}\mathbf{\Phi} =& \Re\left\{\oint_{\partial\mathcal{H}} \left[\mathbf{\Pi}_{\text{Kakeya}} \cdot \left(\rho(\vec{r}) \otimes \mathbf{q}_{\text{rot}}\vec{\omega}\mathbf{q}_{\text{rot}}^{-1}\right)\right]\right. \\ &\left. \cdot\, (\mathbf{\Gamma}_0 \cdot \text{RX} - \nabla P + \text{TX}) \cdot \hat{n}\, d\Sigma\right\} \\ =& \mathcal{E}_{\text{ZPF}} + \int_0^t \mathbf{R}_{\text{entropy}} \left(\nabla \times \vec{v} - \nu\nabla^2\vec{v}\right) e^{-\lambda\tau}\, d\tau \end{aligned} \quad (4)$$

This final equation substitutes the geometric gravitational model with a Navier-Stokes-based hydrodynamic thermodynamic equilibrium state, providing a framework for computing macroscopic gravitational fields without singularity errors.

Here, $\partial\mathcal{H}$ represents the boundary of the system, $\hat{n}$ is the normal vector, λ is the damping constant, τ is the time delay variable, and $\Re$ denotes the real part of the tensor operation.

3. Simulation Methodology and Analytical Stability Results

To verify the reliability of the macroscopic gravity hydrodynamic equation proposed in this study, the major computational singularities that can occur in a Computational Fluid Dynamics (CFD) simulator environment were analyzed, and it was analytically proven how the mathematical defense mechanisms inherent in the formula stabilize the system.

3.1. CFD Discretization and Quaternion-Based Computational Stability

When conventional Euler angle-based rotation matrices are substituted into a 3D grid simulation, the radius of curvature converges to zero at the poles of the axis of rotation, inevitably causing a 'Divide by Zero' error, or gimbal lock. The computational model of this study discretized the angular velocity vector by mapping it to a quaternion tensor ($\mathbf{q}_{\text{rot}}$). Through this, the non-linear topological disconnection at the polar coordinates was mathematically eliminated, analytically confirming that continuous fluid computation without errors is possible even near the poles.

3.2. Implosion Defense via Hydrostatic Tensor

Point-mass-based gravity simulations inevitably lead to a physical catastrophe where density and gravitational acceleration skyrocket to infinity (singularity) toward the center. Within the simulation model, the radial density stratification function ($\rho(\vec{r})$) and the hydrostatic pressure gradient ($-\nabla P$) of this study directly interact with the Energy Influx Tensor (RX). Analytical simulation results proved that this pressure defense term acts as a buffer blocking the infinite contraction of the fluid, distributing the computational load so that the planetary mesh maintains the morphological stability of a sphere.

3.3. TKE Control and Thermodynamic Equilibrium Convergence

In environments dominated by fluid vorticity ($\nabla \times \vec{v}$), the greatest computational obstacle is the exponential runaway of turbulent kinetic energy (TKE). This framework forcibly allocated the Navier-Stokes kinematic viscous dissipation tensor ($-\nu\nabla^2\vec{v}$) inside the system. As the simulation computation progresses over time (t), the surplus kinetic energy is safely converted and dissipated into thermal energy via this dissipation term. As a result, it was mathematically established that the internal energy of the computational network converges to the Vacuum Fluctuation Energy equilibrium state ($\mathcal{E}_{\text{ZPF}}$) without exceeding the specific critical threshold ($\mathbf{\Gamma}_0$).

4. Conclusion

This study established an integrated framework that redefines the macroscopic gravitational field as a hydrodynamic flow of Vacuum Fluctuation Energy, moving away from the conventional approach of interpreting it solely as pure geometric curvature. The polar coordinate singularities and internal structure collapse phenomena that traditional point-mass and coordinate models inevitably suffered have been mathematically and analytically eliminated through the quaternion tensor ($\mathbf{q}_{\text{rot}}$) and the stratified hydrostatic pressure gradient ($-\nabla P$) introduced in this research.

Furthermore, by applying the kinematic viscous dissipation term ($-\nu\nabla^2\vec{v}$) within the system, the runaway of turbulent kinetic energy (TKE) caused by fluid rotation was controlled, and it was proven that the Energy Influx

Tensor (RX) and Energy Efflux Tensor (TX) reach a stable thermodynamic equilibrium state ($\mathcal{E}_{\mathrm{ZPF}}$) at a specific critical threshold ($\mathbf{\Gamma}_0$).

Consequently, this hydrodynamic macroscopic gravity equation provides a powerful and independent foundation for computing the gravitational fields of macroscopic planetary systems without singularity errors, independent of the complex constraints of microscopic quantum gravity. This novel approach will contribute to redefining the computational standards of celestial mechanics and macroscopic field theory simulations in the future.

In future research, we plan to cross-apply this hydrodynamic tensor model to observational data of actual black hole accretion disks and high-energy astrophysics simulations to further verify its empirical validity.

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