Original Research Article

The significance of Shear Stress in Cosmology

The concept of shear stress forms a fundamental base for meteorology and oceanography, which is the heritage of classical physics. In this brief note, we show by well understood physical reasoning that it is also fundamental to cosmology although this link has not been previously recognised. The key physical model is that of the sea surface where two fluids (air and water) of high density contrast interact giving rise to a constant shear stress layer and wave breaking. In cosmology, we show that two analogous, equal and opposite stress layers, due respectively to the formation of galaxies on the large scale and to their destruction by black holes on the small scale, constitute the physical model for the Universe, in which the mean shear stress is zero. The consequences of this model for the expanding Universe are presented. Two comparative images are also shown which illustrate the similarity between stress fields observed in a laboratory experiment and in the cosmos.

Introduction

The science of meteorology and oceanography is built on stress, in particular on shear stress, the importance of which far outweighs normal stress. My longstanding interest in stress began with a doctoral investigation of the circulation in rectangular basins driven by a wind stress and retarded by a bottom stress, through which a steady-state can be achieved (Bye 1965). This idealised model has many hidden secrets. In particular, what proportion of the surface shear stress is the wind stress available to the water, and what proportion is returned to the air by the wave field. This latter proportion may be called the understress (Bye 1986) in distinction to the bottom stress. Understress quantifies the loss of momentum to the air in addition to the loss of momentum to the bottom of the basin. In many situations the bottom loss is much greater than the surface loss, and also there is an imbalance between wind stress and bottom stress, which is made good by a pressure gradient due to a surface slope on the water surface set up by the side walls of the basin (Proudman 1953). In an unconfined region however an equilibrium can only be obtained by establishing a zero net stress in which the understress is equal and opposite to the wind stress. This stress balance, which is the subject of this paper, does not seem to have been previously investigated for the cosmos.

Cosmic stress

In Bye (2021a), it was shown that an approximate zero net stress occurs in the Newtonian dynamics of the planetary system (Newton 1687). This observational result has stimulated this study in which the mass of the orbiting body is expressed as an annular density (ρ) and the friction between the orbiting bodies is represented by the Prandtl frictional force (Proudman 1953) used in fluid dynamics.

The basic relation in Newton's gravitational model is, $U^2 = G (M + M_o)/R$, where U is the orbital velocity, G is the universal gravitational constant, M_o is the mass of the Sun and M is the planetary mass. In Newton's model, the orbital shear stress, $\tau_{R\varphi} = \rho |u_*| u_*$, where R is the radial co-ordinate and φ is the azimuthal co-ordinate, and u_* is the friction velocity, which in Prandtl's frictional model is, $\rho^{1/2} u_* = - \kappa [G(M_o + M)]^{1/2} d (\rho R)^{1/2}/dR$, where κ is von Karman's constant (Bye 2021a), and in the planetary system, $M_o >> M$, and for the Universe $M >> M_o$ in which $(GM)^{1/2} / R_o = c$ where c is the velocity of light and R_o is the radius of the Universe.

The stress-free condition is (ρR) = constant. The observed planetary data show that (ρR) is almost a constant between the two planetary groups, which correspond with the terrestrial and the icy planets (Bye 2021a), from which it is concluded that the frictional force, evaluated for a von Karman's constant of 0.4, as occurs in turbulent measurements on Earth (Jones and Toba 2008) is very small compared with the force of gravity, in agreement with a Newtonian stress-free gravitational model.

On the other hand, at radii outside of the region of Newtonian dynamics, either at smaller or larger scales, the friction velocity in Prandtl's frictional model is, $\rho^{1/2} u_* = - \kappa (G M)^{1/2} R^{1/2} d \rho^{1/2}/dR$ (Bye 2021b) . Here the dynamics, which may be called Einsteinian, is stress-free for ρ = constant. At the junction of the two regions, there is a constant stress layer, similar to that occurring at the sea surface which is maintained by the wave spectrum where wave breaking occurs (Jones and Toba 2008, Bye and Babanin 2019) , and the two wave properties of phase velocity in the air, and particle velocity in the water intersect.

In the Universe at the junction of the two regions of large annular density contrast, the expressions for the two friction velocities show that the orbital shear stress, $\tau_{R\varphi} = +/- \frac{1}{4} \kappa^2 \rho c^2$, where the positive sign occurs if the Newtonian dynamics occurs at a smaller radius than the Einsteinian dynamics and the negative sign occurs if the Newtonian dynamics occurs at a greater radius (Bye 2021a and b). The mean orbital shear stress within the Newtonian regime (which is our Universe) is zero, i.e. stress-free. The positive sign corresponds with the formation of galaxies and the negative sign with their destruction by black holes. This process is essentially one of chance in which an infinitesimal event, characterized famously by Ed Lorenz through a single flap of a butterfly's wings in Brazil, transforms the climate in Texas (Lorenz 1993).

Stress is a compounding of such events, and the cosmic stress model is analogous to the stress model of the circulation in a rectangular basin presented in Proudman (1953) with the substitution of the positive orbital shear stress ($\tau_{R\varphi} > 0$) for the wind stress, and of the negative orbital stress ($\tau_{R\varphi} < 0$) for the understress, and the absence of bottom stress, although of course the cosmic physics is somewhat more complex. In particular, the episodes of positive and negative orbital stress occur throughout time and space.

At the black hole interface, the constant stress layer extends outwards over the range ($R_1 \geq R \geq R_o$), and at the galactic interface, the constant stress layer extends inwards over the range ($R_1 \leq R \leq R_o$); in both instances into the region of Newtonian dynamics. On the assumption that the mean velocity of the turbulent fluctuations is the velocity of light, it was found that, $1/8\ \kappa^2 (\theta + 1)^2 = (\theta - 1)^2$ where $\theta = R_1/R_o$ (Bye 2021b). From which, at the black hole interface, the positive root yields, $\theta = 1.32$, which is consistent with the dimension of the bright ring observed around the black hole (Bye 2021b) suggesting that $\kappa = 0.4$ may be a universal constant, and at the galactic interface, the negative root yields, $\theta = 0.75$, indicating the extent of the band of galactic formation.

Observations of stress

We illustrate this discussion on a laboratory scale in a circular tank of diameter 380 mm in which wave fields are generated by rotating a transparent disk above an air gap over the contained water, and then digitally imposing a counter revolution on the imagery to bring the dominant wave motion to rest, as described in Bye and Ghantous (2012), and on the cosmic scale from telescopic observations in the neighbourhood of a galaxy (ESA/Webb 2022). In both situations, the fetch is infinite so that the turbulent stress fields, which are assumed to arise in their respective constant stress layers due to velocity shear, can be compared (Figures 1 and 2). A visual inspection shows the remarkable result that there is a clear similarity between the two fields, indicating the uniformity of the stress process over the full range of scale from laboratory to cosmic, which includes the meteorological scale.

The laboratory image was selected from the video imagery to show this similarity, however other images in which the transparent plate was rotated at a different rate and the air gap was varied gave rise to a waveform very similar to a spiral galaxy. The inference from these observations is that shear stress plays a crucial role in cosmology through a galactic generation mechanism in which the Newtonian dynamics provides the shear, which is analogous to that produced by the rotating plate in the laboratory rig.

The stress-free model of the evolving Universe

We may extend the stress-free model to a consideration of the evolution of the Universe, with due regard to the definition of time. The essential property is that there is no acceleration in a stress-free state. Hence the evolving Universe expands at the homogeneous rate ($K(t_o)$) which, at the radius (R), is satisfied by the relation, $dR/dt_R = K(t_o)$, $0 \leq t_o \leq \infty$, where t_R is the time observed at the radius (R), and t_o is the absolute time observed at the origin of the Universe ($R = 0$), and $K(t_o)$ is the observed expansion rate.

The observable time (t_R) is related to the absolute time (t_o) by the expression, $t_R = t_o + R/c$, which takes account of the difference in time between the origin and the radius (R). On differentiating this relation with respect to t_o we obtain, $dR/dt_o = K(t_o) / (1 - K(t_o)/c)$, which is the rate of expansion of the stress-free Universe at $t = t_o$ in terms of $K(t_o)$. Alternatively, we may express the rate of expansion in the form, $dR/dt_o = \beta(t_o)\, c$.

A comparison of the two expressions for the rate of expansion yields, $K = \beta c / (1 + \beta)$, from which it is clear that for an expanding Universe ($\beta > 0$), we require, $K < c$, which satisfies the Einsteinian condition on the primacy of c. It also shows that the expansion rate (βc) is equal to the velocity of light (c) for $K/c = ½$. This allows for an arbitrary formation mechanism for the Universe, provided only that $K(t_o)$ satisfies the inequality, $0 \leq K(t_o)/c \leq ½$.

There is a growing question, regarding observations of the recession rates of distant galaxies which are greater than the speed of light, see for example, Weaver/Villard (2019). The above stress-free model answers this question, and predicts that receding galaxies would be observable out to recession rates (c + K), up to fifty percent greater than the speed of light (c).

The analysis is agnostic with regard to the formation of the Universe at $t_o = 0$. In a related analysis (Bye 2021c), however, it was demonstrated that the evolutionary process may have begun from a massless state by the conversion of dark matter into ordinary matter (which is the hallmark of the Newtonian regime), rather than from a big bang.

Conclusion

This paper shows that shear stress, which has a special place in oceanography and meteorology, is also a seminal force in cosmology, and is possibly ‘ the missing something in the cosmological model ’ sought after in Weaver/Villard (2019). Figures 1 and 2 illustrate the importance of shear stress in constant stress layers ranging from the laboratory to the cosmic. Within the stress layers, there is a balance between positive and negative stress so that on average a stress-free environmental process occurs, which on the cosmic scale is responsible for $K(t_o)$, and extends from zero to infinite time, consistent with the eternal nature of the Universe.

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List of Figures

1. Waveforms occurring in a circular tank of diameter 380 mm, in which the fetch of the wind, generated by a rotating plastic disk at various rotation rates, is infinite (Bye and Ghantous 2012).

2. The chaotic galactic field observed by (ESSA/Webb **NASA & CSA** 2022)

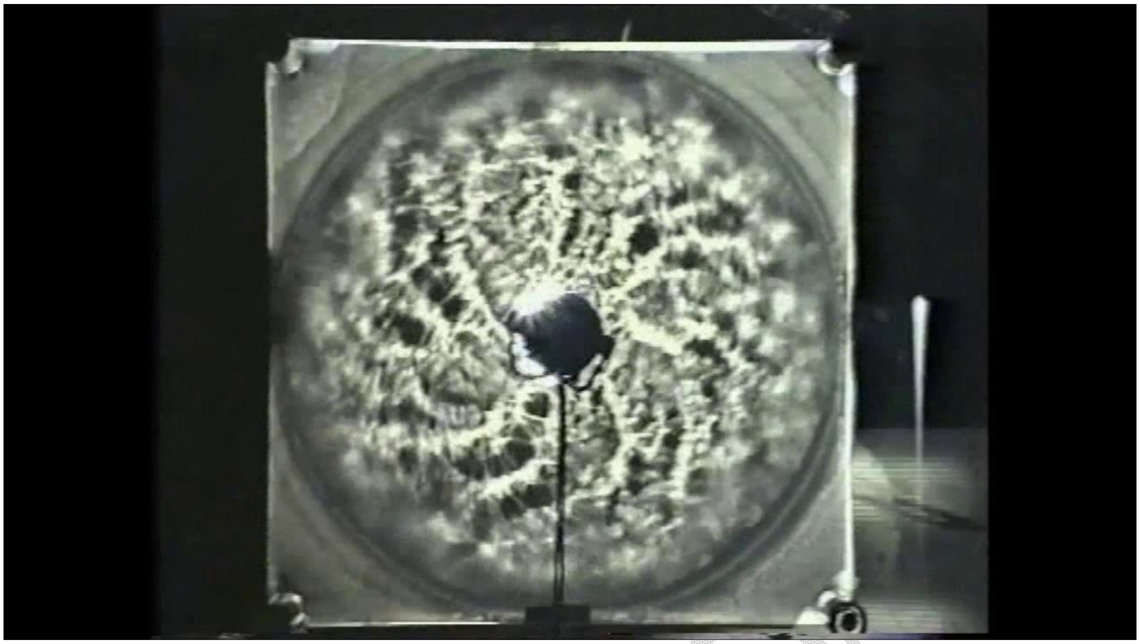

Figure 1

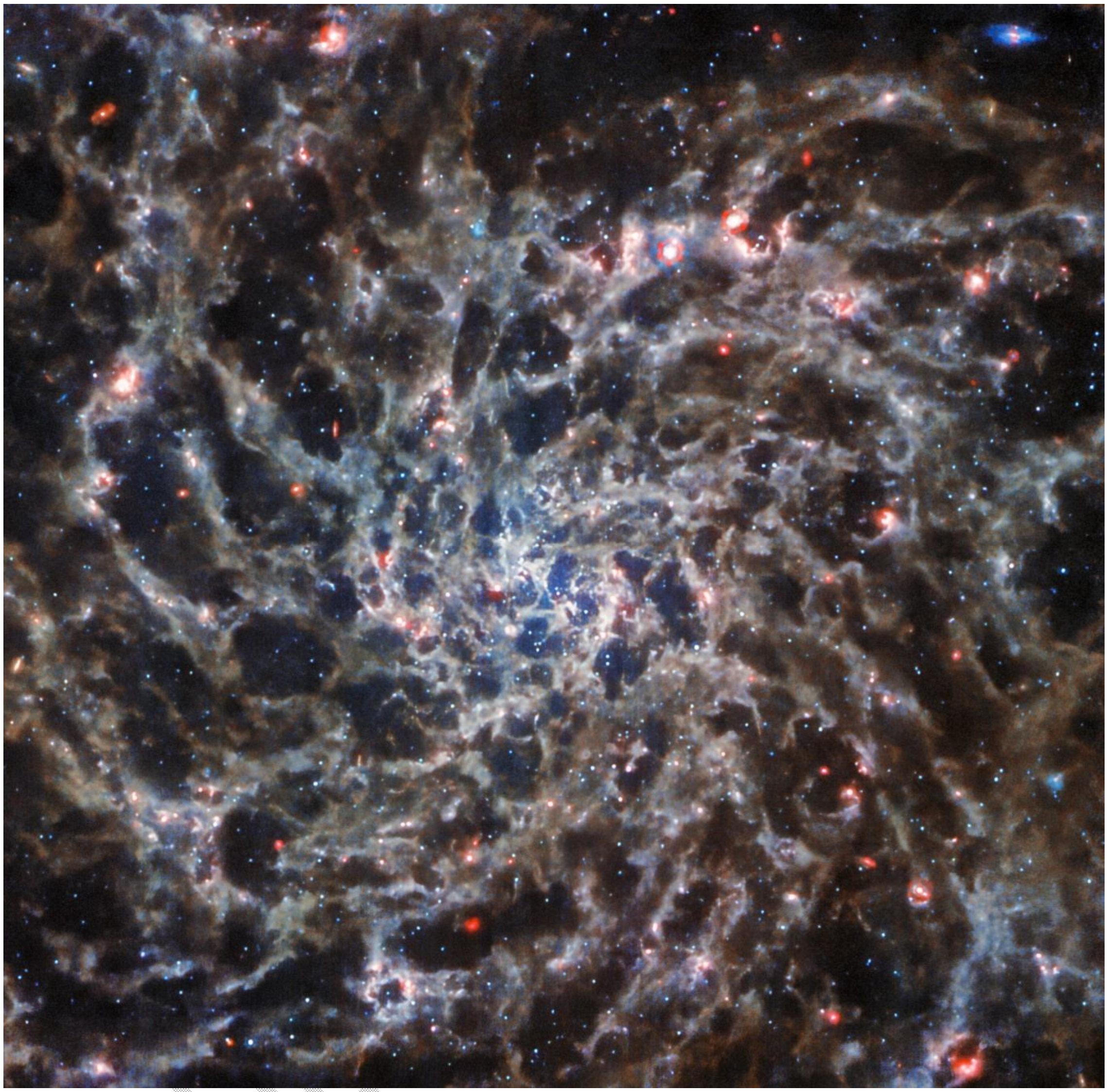

Figure 2