# FLUID MECHANICS IN THE COSMOS – AN OVERVIEW

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**Abstract :** This specific paper is the foremost of a series of papers on the subject matter - "Fluid Mechanics in the Cosmos ( Universe)", which address the fundamental issues regarding the fundamental differences between terrestrial fluids and astrophysical fluids. This paper provides an introductory description of earthly fluids and astrophysical fluids, their behavioral dynamics in stars, galaxies, interstellar medium, intergalactic medium etc in an astrophysical context.

**Keywords:** ISM – Interstellar medium , IGM – Intergalactic medium , Super nova explosion, Blast waves, X- ray bursts, Gamma ray bursts, compact objects, neutron stars, white dwarfs.

## 1. Objective of Research

This theoretical work is being done to understand the intricate connection between the astrophysical fluids in action in the Universe and how they affect the local space weather conditions surrounding the planet earth in terms of space based and earth based technologies, which is clearly evident from the impact of the solar storms ( Magnetic storms or Geomagnetic storms etc) on these technologies. There is always ample room for unique beahvior of cosmic objects like stars – compact objects like neutron stars, white dwarfs, supernova explosions of gigantic and massive stars, accretion discs in case of binary star systems etc, but the underlying fundamental principles of the behavioral dynamics of the cosmical fluids in the Universe might be in general the same.

## 2. Introduction

The study of fluids on the earth popularly known as ( Terrestrial ) fluid mechanics does not need any kind of introduction, due to the diversified applications it has in scientific research, engineering, medical science, industry and defense sectors. Sometimes, it appears that students enrolled in various undergraduate and graduate courses at various universities worldwide feel ( in the beginning of the course) that fluid mechanics ( terrestrial) is very much dry (and boring !) , but gradually get excited, when they are informed how fluid mechanics is in action, at the cosmological scales, when it comes to the study of stellar winds ( solar wind), stellar interior dynamics, star formation zones, clouds of interstellar gas and dust, internal structural stratification of compact objects like neutron stars, white dwarfs, blast waves, X- ray ,gamma ray bursts and related accretion phenomena etc.

## 3. Discussion and Analysis

### 3.1- Fluids – Understanding made 'simple'

' Fluids' are the things that flow (or) 'tend to flow'. Practically speaking, a solid body (rigid body) doesn't flow and hence we are left with the other two conventional states of matter – liquids and gases. Since, both these states possess ' flow characteristics' , we consider them both as 'fluids'. The study of 'plasma' and 'BEC- Bose Einstein condensate' is presently out of the scope of this current paper. Unlike fluids, solids are the bodies in which atoms are held rigidly in some form of lattice [crystalline and amorphous solids]. However, the present understanding of solid bodies is based on earthly (terrestrial) conditions. Glass although a solid, exhibits a typical behavior is out of the scope of the present paper. If we need to regard certain bodies as fluids ( based on terrestrial conditions) , then we need to understand the general problem regarding their flow characteristics and the various circumstances at which they attain 'equilibrium'. Therefore, we try to tackle these issues in an astrophysical context which forms the subject matter of these series of papers.

An interesting aspect is that, although fluids are mostly composed of particles at a microscopic level, the various hydrodynamic equations treat the fluid as a continuous medium with well-defined macroscopic properties, say for example pressure (or) density at each point. At this juncture, it is not practically possible to follow the trajectories of the individual particles. Therefore it is quite convenient for us to average their properties. In a similar vein, we can also try to treat the dynamics of the various stars in the galaxies as a form of a fluid dynamical problem in which the stars can be considered as individual particles in a fluid and the entire galaxy as the fluid itself. The same principles can be applied to determine the average or mean properties of the stars – say pressure, velocity or density etc.

Since, this is a series of papers, we will mainly be concerned with conventional fluids - mostly liquids and gases. Specifically, we don't find liquid- state apart from in the high pressure environments of planetary interiors and planetary surfaces, we specifically deal with the gaseous phase at various temperature ranges. Some of these gases – mostly the degenrate ones that compose much of the compact objects such as white dwarfs, neutron stars etc bear very meagre resemblance at a microscopic level to the conventional gases under the terrestrial ( earthly) laboratory conditions.

We have a property known as 'Compressibility' which is unique to gases, as opposed to liquids. Gases behave more or less in an incompressible manner, when it comes to terrestrial applications that generally involve subsonic flows, but the situations are quite different when it comes to astrophysical contexts, where the gases are subjected to intense accelerations, mostly due to gravity to high Mach number.

### 3.2 – Fluids in the Universe

The conventional matter composed of protons and neutrons ( often termed as baryonic matter – protons and neutrons being considered as heavy, when compared with electrons which are the fundamental lighter particles in the Universe) in the galaxy ( Milky way ! ) is approximately divided between the stars and distributed gas in the ratio 5:1. If we take the entire universe, the ratio is much uncertain all the time, but the gas fraction can be considerably higher.

### 3.2.1 – Stars and the Sun

Stars are mainly gaseous bodies – mainly hydrogen and helium with intense temperatures that range between millions of kelvin in their cores – nuclear reaction zones to thousands of degrees at their surfaces. In the particular case of our nearest star – the Sun, the mean density is the same as that of water, but this ssstatistic doesn't convey the strong internal stratification of density – the core density exceeds the density at photosphere – the visible surface of the Sun by 11 orders of magnitude. For certain purposes, the stellar interiors can be regarded as static, i.e. in a state of of balancing of gravitational force directed inward and the pressure gradient directed ourtward. Moreover, in practice, the gas in many stars is subjected to various internal motions such as convective currents and low amplitude internal oscillations etc. Just above the photosphere, the gas density falls with increasing height and the temperature rises ( as per the modern observations) , attaining 30,000 K in the chromosphere layer, a zone where many stellar emission lines originate. At much greater distances, the gas can be 'magnetically heated' to temperatures of around $10^6$ K ( 1 Million kelvin), this Coronal region being a strong source of X-rays.

### 3.2.2 – ISM and IGM – Interstellar medium and Intergalactic medium

The other main fluid component in the Universe, the distributed gas in the ISM and IGM is much more diversified in its characteristic properties. For example, the mean density of the gas in our Milky Way galaxy is approximately a million per cubic metre – which is extraordinarily dilute, when compared to $2.7\times 10^{25}$ particles per cubic metre of a gas at standard temperature and pressure at terrestrial conditions. This number averages over a rich multi-phase medium, consisting of warm atomic gas roughly at 10,000 K, hot phase at 1 million Kelvin, the supernova explosions being the source of the intense heat and a cold molecular phase , as much as 10 K , if well shielded from radiation from intensely bright stars. We can also see the extreme contrast in the densities between these phases, from nearly 1000 particles per cubic metre for the hot phase to approximately 10 ^5 – 10 ^6 particles per cubic metre for the warm atomic phase to nearly 10 ^8 particles per cubic metre as a mean for molecular clouds – the most dense cores within these molecular clouds having densities in excess of 10 ^13 particles per cubic metre. Outside the galaxies, the densities can be considerably lower, with large regions containing less than 1 particle per cubic metre.

Although stars, the ISM and the IGM together mostly constitute the bulk of the fluids in the Universe, there are a number of other examples of astrophysical fluids of our interest. These include stellar winds ( that includes solar wind etc), accretion discs on a wide range of scales. The equations of state for the white dwarfs, neutron stars etc are totally different from the conventional gases under terrestrial conditions having varied relations between pressure, density and temperature. In the same manner, the internal structure of the giant gaseous planets such as Jupiter, Saturn etc can be determined as a fluid dynamical problem, but still there are certain considerable uncertainities for a proper equation of state for hydrogen under extreme conditions of density, pressure in the relevant temperature range.

Finally, the equation of state is of utmost importance, when it comes to fluid dynamical problems in the cosmos. We begin with the mathematical treatment of various cosmical fluid dynamical problems from the next consecutive papers.

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**Conclusion**
An overview of the cosmic fluids is described in this paper. Some good examples like the stars, ISM, IGM etc have been provided in order to understand how the fluid mechanics at the cosmic level is different from that of terrestrial fluid mechanics. Fluid mechanics at the cosmic level turns out to be of much importance to understand the influence of solar wind on the various planetary atmospheres which form the playground for the disruption of various space based and earth based technological systems. On the other hand, the study of cosmic fluid mechanics can be of pure research interest for astronomers and astrophysicists alike. The mathematical analysis and treatment will begin from the next consecutive paper.

**Limitations and Further Scope**
This paper is an overview of the fluids in the Cosmos and hence limitations and further scope cannot be described here.

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