International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Swarm Intelligence in Cosmology and in Black Hole Study

Dr. Praseetha Pankunni[1], Dr. Natasha Pankunni[2]

[1]Guest Faculty (Former), Government Polytechnic College, Palakkad, Kerala, India.

[2]Assistant Professor, Department of Commerce and Management Studies, School of Business Studies, University of Calicut, Kerala, India.

Abstract

As Swarm Intelligence implies collective behavior of systems seen in the nature, it has applications in the study of universe which has numerous evolutionary stages comprising varied cosmological structures. Cosmology is considered to the study of the origin and evolution of the universe, in which the galaxies, comprising millions of stars and interstellar matter and the cluster structures pervaded over the space called as the large-scale structure can also be viewed as the Cosmic web, implying existence of interconnected network among those anisotropic structures. Swarm intelligence based computational method is used as a tool to study these large-scale structures, in which the algorithm models and extracts one dimensional structure. Moreover, in the process of estimating cosmological parameters, in the case of the theoretical cosmological model, Λ-Cold Dark Matter Model (LCDM), Particle Swarm Optimization (PSO) tool, which is based on the artificial intelligence technology is used. Black holes are singularities existing in space-time, and are intensive gravitating cosmic bodies from where even light cannot escape out of them. Their existence being proven recently through gravitational wave detection observations, the study of their dynamics is a subject of interest for researchers. In consideration with the black hole theory, based on its power of pulling masses towards it as they pass nearby, a newer kind of PSO algorithm is developed called as the Random Black Hole Particle Swarm Optimization (RBH-PSO) (Zhang, Liu, Tan, & He, 2008). The present study is a conceptual paper intended to explore the possibilities of swarm intelligence in cosmology.

Keywords: Black hole, Cosmology, Λ-Cold Dark Matter Model, Particle Swarm Optimization (PSO), Swarm Intelligence.

1. Introduction

Swarm Intelligence is the branch of artificial intelligence inspired by the collective behavior of animate or non-animate systems. In biological systems, there are lots of examples such as colony of ant mobilizing, flock of birds flying together, school of fish moving together so and so. The collective behavior is because of the social interaction among individual members of the group.

As far as Cosmology is considered, it is the study of the origin and evolution of the universe, in which the galaxies, comprising millions of stars and interstellar matter and the cluster structures pervaded over the space called as the large-scale structure can also be viewed as the Cosmic web, implying existence of interconnected network among those anisotropic structures (Bond, Kofman & Pogosyan 1996).

Swarm intelligence is used as a tool to study these large-scale structures, whereby the algorithm models and extracts one dimensional structure (Awad, et al., 2023). Also, in the process of estimating cosmological parameters, in the case of the theoretical cosmological model, Λ-Cold Dark Matter Model (LCDM), Particle Swarm Optimization (PSO) tool, which is based on the artificial intelligence technology is used (Prasad & Souradeep, 2014). Black holes are singularities existing in space-time, and are intensive gravitating cosmic bodies from where even light cannot escape out of them.

1.1 Particle Swarm Optimization (PSO)

This computational application of swarm Intelligence was introduced by Russel Eberhart and James Kennedy in 1995. This optimization technique has been formulated based on the bird flock movement keeping a minimum distance among each other for a considerable long distance without colliding among themselves. This technique is used for solving dynamical problems especially non-linear dynamical ones.

Figure 1: Birds moving in flocks in a coordinated manner

As shown in figure 1, the wide field of view which is the specialty of birds in respect of large size of their eyes and effective social interactions help them in such a coordinated movement. They adjust their position and velocity according to their nearest neighbors as they move together.

PSO is a heuristic method of optimization. It analyzes population study in which particles in flight are taken as the population and their difference in velocities and dynamics are adjusted according to their history of movement and optimal solution is found in the search space. The solutions of problems can be represented in an n-dimensional solution space. Each particle starts its trajectory with a velocity vector in every dimension and with a memory of its historical best position in the solution space called as its experience. This is further communicated among the swarm or part of it. Through each iteration the current position of a particle is updated only if it is better than the historic best one and all other particles in the swarm tries to mimic the swarm's best particle by adjusting their velocities and thereby moving closer towards that particle. Thus, this is how the algorithm works. The experience sharing among the particles make this technique altogether work possible.

1.2 PSO Algorithm

The original PSO algorithm is developed on the idea that each particle compares its fitness globally with the swarm of particles and making modifications in its velocity in consideration with the global best particle. The equations for velocity and position for the PSO algorithm is as shown below,

$$v_i(t+1) = v_{id}(t) + c_1 R_1 (p_{id}(t) - x_{id}(t)) + c_2 R_2 (p_{gd}(t) - x_{id}(t)) \quad \ldots\ldots(1)$$

$$x_i(t+1) = x_{id}(t) + v_{id}(t+1) \quad \ldots\ldots(2)$$

where,

v_{id} is the velocity of i^{th} particle in d^{th} dimension, t is the iteration counter, $_{id}$ is the position of i^{th} particle in d^{th} dimension of solution space, p_{id} denotes the historically best position of i^{th}particle, p_{gd} denotes the position of swarm's global best particle in d^{th} dimension, $R_1$and R_2 are n-dimensional vectors with random number in the range [0.0,1.0] and c_1 and c_{12} are positive valued weight parameters.

Hence, it is highly relevant to understand the concepts of PSO and how they are applied in cosmology. The present study intends to conceptually view the same.

2. Methodology

The present study is purely conceptual in nature. The existing literature are used to explore the possible applications of swarm intelligence in cosmology and also in black hole study.

3. Swarm Intelligence in Cosmology and in Black Hole study

In the realm of cosmology, too, where the study of the entire universe, its origin and evolution matters, there are a few instances where the idea of swarm intelligence can be applied.

Talking about the evolution of the universe, according to standard cosmology, the universe started from a big bang of explosion leading to a primordial state of plasma state of matter pervading throughout the space. As the temperature reduced, atoms and clumping began to come into exist. Then an inflationary period followed which caused the matter to further cool down and matter began clumping together forming stars, clusters, galaxies, and large-scale structures. Stars are formed from cosmic dust (nebulae) and gases, clusters comprise group of stars, clusters together form superclusters and millions of superclusters and other cosmic bodies constitute a galaxy. Galaxies are of different types according to their geometrical shape. Each galaxy is stable and they wander about the space as such in its form.

On a very large scale of universe, groups of galaxies which form the large-scale structure (LSS) seems to have a correlation between themselves. Galaxies and clusters of galaxies are formed due to the gravitational collapse which resulted in asymmetric arrangement of structures across the cosmic space. This anisotropy where clusters of different size and morphological structures lie, an cobweb like network can be seen interconnecting them with filaments and cosmic void present in between the galaxies. This network is called as the Cosmic Web.

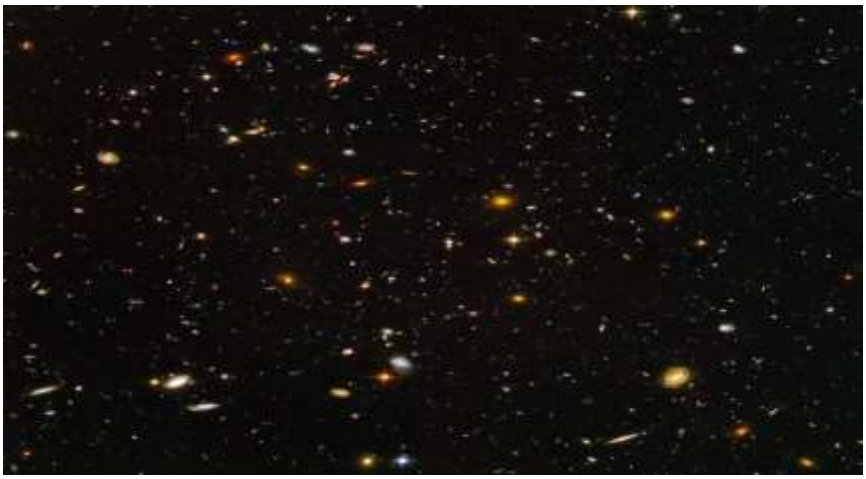

Figure 2: The Hubble Space Telescope captured this image, called the Hubble Ultra Deep Field, in 2004 by combining 800 images with a cumulative exposure of 11.3 days. It contains around 10,000 galaxies. Credit: NASA

Recent observations in cosmology points to accelerated expansion of the universe and various cosmological models are formulated to explain the current scenario. One such model is the Λ-Cold Dark Matter Model (Lambda-CDM or LCDM) model. Lambda denotes the cosmological constant while CDM refers to cold dark matter. The model considers a universe where Cosmological constant, cold dark matter and ordinary matter co-exist. Cosmological constant explaining the accelerated expansion of the universe and it represents dark energy which is an exotic form of energy with a negative pressure causing matter to get away from each other. The cosmological parameters of the model can be best fitted using several methods.

Black holes are intense gravitating cosmic bodies. They are the final evolutionary stage of stars whose masses are greater than 3 times that of Solar masses. In this stage, gravitational force is the only dominant force acting which causing it to collapse. The bounding surface of the black hole is called as the event horizon. Whatever reaches the event horizon cannot escape out of the black hole.

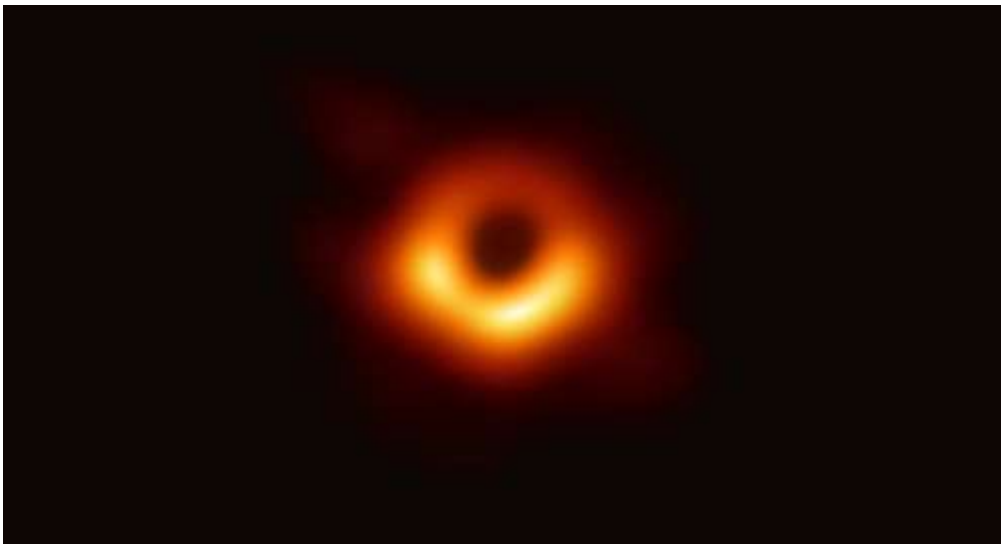

Figure 3: The first picture of a black hole was made using observations of the center of galaxy M87 taken by the Event Horizon Telescope. The image shows a bright ring formed as light bends in the intense gravity around a black hole 6.5 billion times the Sun's mass.

Credit: Event Horizon Telescope Collaboration.

The computational application of swarm intelligence called as Particle Swarm Optimization (PSO) is used for the estimation of cosmological parameters of Lambda CDM model in one dimension a modified version is used for the study of black hole pulling masses.

3.1 Cosmic web

Galaxy clusters and galaxies are distributed in the cosmic space in an interconnected manner which is called as the Cosmic Web (J. Richard Bond, 1996). The gravitational asymmetry leads to the formation of structures of different forms and shapes leading to anisotropy within the cosmic web and the web is thus with cluster of galaxies, filaments, and cosmic voids. To study the structures in the Cosmic web, the swarm intelligence-based algorithm is used (Glasgow, 2012).

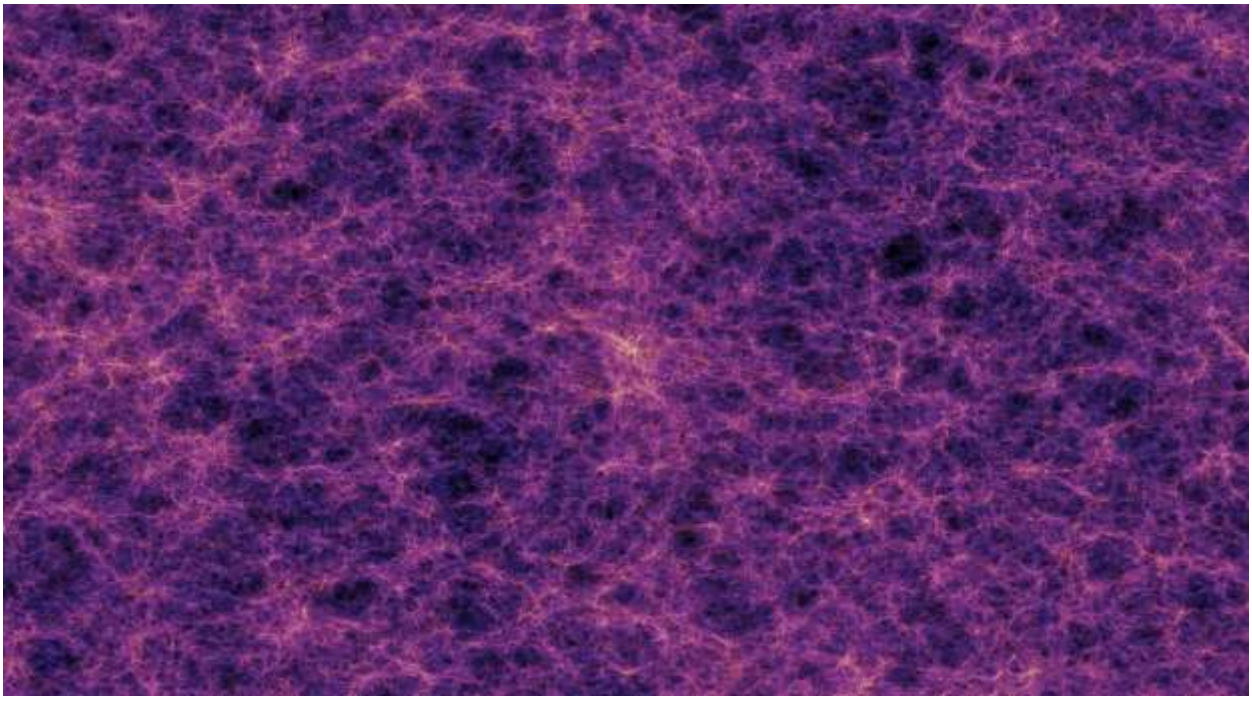

Figure 4: Gravitational collapse causing galaxies and cluster of galaxies to form an interconnected network using filaments which is the Cosmic Web. ESA/Hubble Image

One of the algorithms used for extracting and modelling the astronomical structure in the Cosmic web is Ant Colony Optimization method (Dorigo, 1997), which is an optimization technique based on the deposition of the pheromones by a colony of ants. The underlying idea behind using it as an optimization method is that the shortest path traced by the ants will be having more pheromone deposition as it is used to travel back and forth too many times by many ants. In the Cosmic web study (Petra Awad, 2023), Locally Aligned Ant Technique (Taghribi A., 2022) is used where the path of pheromones deposited by ants can be interpreted as regions of faint structures. Another technique used for the study of manifolds is Evolutionary Manifold Alignment Aware Agents (EM3A) (Mohammad Mohammadi, 2022), where the underlying idea is that the presence of manifold is associated with the region with larger pheromone concentration.

3.2 Cosmological Parameter Estimation

Numerous theoretical cosmological models are there to explain the present state of the universe. Recent observations indicate an accelerated expansion of universe. Cosmologists explained the observational

fact using an exotic form of energy called as dark energy, which is attributed with a negative pressure causing matter to part away from each other. Thus, the present universe is in the dark energy dominated era where about 70 percent of the universe consists of dark energy, dark matter constitutes 26 percent while the ordinary matter constitutes the remaining 4 percent, a very meagre share when compared to the others.

Λ-Cold Dark Matter Model (Lambda-CDM or LCDM) model is a widely accepted dark energy model successfully explaining an accelerating universe. In the study of estimating model parameters of LCDM using PSO (Souradeep, 2012), they were able to find the best fit of model parameters using WMAP-7-year data without finding statistical quantities like standard deviation which is required in the case of commonly used probability distribution method like Markov chain Monte Carlo (MCMC).

3.3 Random Black Hole Particle Swarm Optimization (RBH-PSO)

Black Holes are final evolutionary stage of stars whose core has mass thrice greater than the Solar mass. In this stage the only force field existing will be the gravity. All the stellar fuel will be used up and gravitational collapse occurs. Even light cannot escape out of the black hole. Hence black holes are not visible. The black hole surface is bounded by Event horizon. Matter entering event horizon cannot escape the black hole.

The study of black holes based on its power to pull masses towards it, as it is an intensively gravitating cosmic body is done using a modified method of PSO (Junqi Zhang, 2008). The method is called as the Random Black Hole Particle Swarm Optimization. The PSO algorithm developed is based on the following concept. A black hole is randomly generated nearer to the best particle of the swarm in each dimension of a particle. Then all other particles are pulled towards the black hole randomly with a probability 'p'. Thus, in this way a new convergence path is established and local minima as the result of premature convergence can be surpassed.

4. Conclusion

The concept of SI emphasizes the social behavior (interaction) among the individuals within a group or swarm. The PSO algorithm also ensures this. Cosmology and astronomy being a subject encompassing large scale of population, that is the universe with its cosmic bodies, large scale movement being involved of inanimate objects unlike the case of ant colony, honey bees which are living ones. Thus, the idea of SI extended to these fields have been familiarized in this paper.

5. References

1. Dorigo, M. a. (1997). Ant colony system: A cooperative learning approach to the traveling salesman problem. *IEEE*, 53 - 66.
2. Eberhart, J. K. (2001). *Swarm Intelligence.* USA: Morgan Kaufmann Publishers.
3. Glasgow, H. A. (2012). *Swarm Intelligence: Concepts, Models and Applications.* Canada K7L3N6: School of Computing, Queen's University, Kingston, Ontario, Canada K7L3N6.
4. J. Richard Bond, L. K. (1996). How filaments of galaxies are woven into the cosmic web. *Nature*, 380, pages603–606.
5. Junqi Zhang, K. L. (2008). Random black hole particle swarm optimization and its application. *IEEE*.
6. Mohammad Mohammadi, P. T. (2022). Manifold Alignment Aware Ants: A Markovian Process for Manifold Extraction. *Neural Computation*, 595–641.
7. Petra Awad, R. P. (2023). Swarm-intelligence-based extraction and manifold crawling along the

Large-Scale Structure. *Monthly Notices of the Royal Astronomical Society*, 4517–4539.

8. Souradeep, J. P. (2012). Cosmological parameter estimation using particle swarm optimization. *Phys. Rev. D 85*, 123008.
9. Taghribi A., B. K. (2022). LAAT: Locally Aligned Ant Technique for Discovering Multiple Faint Low Dimensional Structures of Varying Density. *IEEE Trans. Knowl. Data Eng.*, 6014 - 6027.