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The Modified Interfacial Gravity: Unifying CDM, MOG, and MOND

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I. Introduction

The previous paper [1]proposes a repulsive force between baryonic matter and dark matter to explain galaxy evolution. In this paper, the repulsive force is described as the modified interfacial gravity (MIG) which is the modified gravity in the interfacial region between homogeneous baryonic matter region and homogeneous dark matter region. As a result, the MIG model contains both dark matter and modified gravity to unify the CDM (Cold Dark Matter) model[2], MOG (Modified Gravity)[3,4], and MOND (Modified Newtonian Dynamics)[5,6,7].

The two major models for galaxy are the CDM model and the modified gravity models including MOG and MOND. CDM contains no modified gravity, while the modified gravity models contain no dark matter. Dark matter was originally proposed to account for the asymptotically flat rotation curve in outer galaxy and to keep galaxy together based on only the Newtonian gravity. CDM has the Navarro–Frenk–White (NFW) profile [2] derived from N-body collisionless dark matter simulations based on only the Newtonian gravity. The highest density is at the center as the central cusp. Baryonic matter is dragged along by the gravitationally dominant dark matter, resulting in the first protogalaxies consisting of hydrogen, helium, and dark matter. Modified gravity was originally proposed in MOND and MOG to account for the asymptotically flat rotation curve in outer galaxy and to keep galaxy together based on only baryonic matter. MOND and MOG propose the region (outer galaxy) for modified gravity in addition to the separate region (inner galaxy) for the Newtonian gravity.

CDM explains well and easily large-scale phenomena such as galaxy clusters and the universe evolution, while the modified gravity models explain well and easily small-scale phenomena such as galaxy. However, CDM[8] faces considerable difficulties to explain galaxy-scale phenomena, such as the observed absence of the cusp density in dwarf galaxies, the formation of long thin spiral galaxies, and the continuous failure to detect dark matter directly on earth. The modified gravity models require additional assumptions and complications to explain large-scale phenomena such as the observed dark matter halos in galaxy clusters, the observed gravitational lensing of dark matter, and the observed peaks in CMB (Cosmic Microwave Background) [8]. Furthermore, the modified gravity models essentially are valid only on galactic scales. Extremely low acceleration experiments (below the acceleration constant a_0) have been conducted, finding no departure from Newton's second law in laboratory conditions [9].

A possible solution to the dilemma of CDM and the modified gravity models is to combine both dark matter and modified gravity in a single model for galaxy. The proposed single model is the MIG model. The proposed modified interfacial gravity is the modified

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gravity in the interfacial region between homogeneous baryonic matter region and homogeneous dark matter region, so MIG contains both modified gravity and dark matter to unify CDM, MOG, and MOND.MIG combines the existence of cold dark matter from CDM, the repulsive Yukawa force from MOG, and the critical homogeneous surface density derived from the acceleration constant a_0 from MOND [10,11]. The repulsive Yukawa force in outer galaxy in MOG is equivalent to the interfacial repulsive Yukawa force in the interfacial region to separate baryonic matter region and dark matter region in MIG. The modified interfacial gravity is interfacial gravity interacting with the interfacial repulsive Yukawa force. The modified interfacial gravity emerges in the interfacial region between dark matter region and baryonic matter region only when the homogeneous surface density is above the critical homogeneous surface density in both dark matter region and baryonic matter region. The critical homogeneous surface density is derived from the acceleration constant a_0 from MOND.CDM and MIG are identical during the very early universe below the critical homogeneous surface density and before the emergence of the interfacial repulsive force. After the emergence of the modified interfacial gravity by dense giant molecular clouds in the universe, MOND, MOG, and MIG are identical for the baryonic matter galaxy structure. As a result, MIG is the unified model of galaxy to unify CDM, MOG, and MOND as the different aspects of MIG. MIG explains both galaxy-scale and large-scale astronomic phenomena.

Section IIexplains the modified interfacial gravity in the interfacial region between dark matter region and baryonic matter region. Section III describes the evolution of galaxies, dark matter halos, dwarf galaxies, and globular clusters. Section IV describes dark matter halos for galaxy clusters.

II. The Modified Interfacial Gravity

Dark matter in MIG is cold dark matter without electromagnetism as in CDM. The origin of dark matter without electromagnetism is explained in Reference [12]. The paper posits the modified interfacial gravity (MIG) as the modified gravity in the interfacial region between homogeneous baryonic matter region and homogeneous dark matter region. The MIG model contains both dark matter and modified gravity to unify the CDM, MOG, and MOND.

In MIG, the interfacial repulsive Yukawa force in the interfacial region to separate baryonic matter region and dark matter region is equivalent to the repulsive Yukawa force in outer galaxy for MOG.A repulsive Yukawa force was proposed as additional force for baryonic matter in MOG [3]. A Yukawa force appears only in a specific range. In MOG, the modified gravity is gravity interacting with the repulsive Yukawa force. In Scalar-Tensor-Vector Gravity (STVG) [3] of MOG, the radial acceleration, a, acquires a Yukawa modification as in Equation (1) as explained in Reference [3].

$$a = -\frac{GM}{r^2} + \frac{GM}{r^2}\left\{\sqrt{\frac{M_0}{M}}\left[1 - \exp\left(-r/r_0\right)\left(1 + \frac{r}{r_0}\right)\right]\right\} \qquad (1)$$
$$= a_{inner\ galaxy} + a_{outer\ galaxy}$$

where G is the gravitation constant , r is the distance, $r_0$is the starting distance for the Yukawa modification, M is the enclosed mass, and M_0 is a coupling constant of the Yukawa modification. The equation shows the two regions consisting of the Newtonian region (inner galaxy) with $a = GM/r^2$.and the repulsive Yukawa force region (outer galaxy) with the acceleration resulted from gravity interacting with the Yukawa vector force field and $r >> r_0$.

The repulsive Yukawa force in outer galaxy for MOG is equivalent to the interfacial repulsive Yukawa force in the interfacial region to separate baryonic matter region and dark matter region in MIG. (The interfacial repulsive Yukawa force is the repulsive force between baryonic matter and dark matter [1].) The modified interfacial gravity is interfacial gravity interacting with the interfacial repulsive Yukawa force.

The four separate regions in the galaxy structure for MIG are the core (inner) baryonic matter galaxy with the Newtonian gravity, the interfacial (outer) baryonic matter galaxy with the modified interfacial gravity, the interfacial (inner) external dark matter halo with the modified interfacial gravity, and the core (outer) external dark matter halo with the Newtonian gravity as Figure 1.

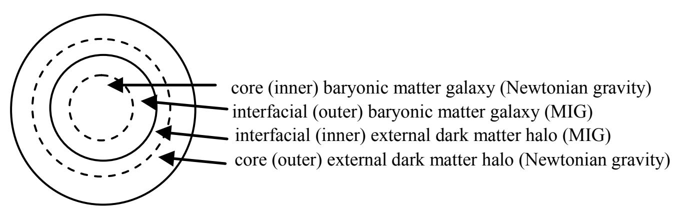

Figure 1 : the dark matter region and the baryonic matter regions

For MIG, from the rotation velocity, $V = (ar)^{1/2}$ and Equation (1), the rotation velocity can be derived as Equation (2).

$$V = \sqrt{\frac{GM}{r}} + \sqrt{\frac{GM}{r}}\left\{\sqrt{\frac{M_0}{M}}\left[1 - \exp\left(-r/r_0\right)\left(1 + \frac{r}{r_0}\right)\right]\right\}^{1/2}$$
$$= V_{core} + V_{interfacial} \qquad (2)$$
$$= V_{inner\ galaxy} + V_{outer\ galaxy}$$

Equation (2) is the rotation velocity equation for MOG. Equation (2) shows that the rotation velocities are different in the core region with $V = (GM/r)^{1/2}$ and in the interfacial region with the velocity resulted from gravity interacting with the Yukawa vector force field. From the rotation velocities of a number of galaxies, the value of M_0

is found to be 9.6 x 10^{11} M_{sun} and r_0 is found to be 13.92 kpc. Equation (2) yields a flat rotation curve in the interfacial region (outer galaxy). The rotation velocity equation of MOG as Equation (2) for the inner galaxy and outer galaxy can fit well the observed rotation curves of galaxies.

There are the Newtonian attractive gravity and the interfacial repulsive Yukawa force in the interfacial region. The dominate force is the Newtonian attractive gravity that disrupts the interfacial repulsive Yukawa force. The modified interfacial gravity is interfacial gravity interacting with the interfacial repulsive Yukawa force. The modified interfacial gravity between dark matter region and baryonic matter region emerges only when the homogeneous surface density in both dark matter region and baryonic matter region is above the critical homogeneous surface density to overcome the disruption of the Newtonian gravity. As shown later, the critical homogeneous surface density is derived from the acceleration constant a_0 from MOND.

Such emergence of the modified interfacial gravity is similar to the emergence of superconductivity. Among electrons, there are Coulomb repulsion and phonon attraction to form the Cooper pairs. The dominant force is Coulomb repulsion that disrupts phonon attraction. Superconductivity emerges only when the density of a dense-correlated electron system is above the critical density to overcome the disruption of Coulomb repulsion [13.14]. Superconductivity emerges with Coulomb repulsion in the two different regions: the short-distance superconductivity and the long-distance Coulomb repulsion as in the Hubbard model [15]. In the same way, the modified interfacial gravity emerges with Newtonian gravity in two different regions: the interfacial region for the modified interfacial gravity and the core region for the Newtonian gravity.

The critical homogeneous surface density is derived from the acceleration constant a_0 from MOND [10, 11]. (Below the critical homogeneous surface density, MIG is identical to CDM without modified interfacial gravity.) Milgrom found that the preferred surface density of giant molecular clouds in the galaxy can be derived from a_0 of MOND [10]. The critical homogeneous surface density Σ_0 is such surface density [11],

$$\begin{aligned} \Sigma_o &= a_0 / 2\pi G \\ &= 138 M_{sun}\, pc^{-2} \end{aligned} \qquad (3)$$

where a_0 is the acceleration constant (= 1.2 x 10^{-10} m s^{-2}), a_0 is the acceleration at the critical homogenous surface density and G is the gravitational constant.

The core acceleration a_c ($a_c > a_0$) in the core region is unchanged as Newtonian acceleration a_n. In the interfacial region, the interfacial acceleration a_i is the Newtonian acceleration a_n ($a_n < a_0$) interacting with the interfacial force derived from a_0 at the critical homogeneous surface density, resulting in the geometric mean [5] as $(a_n a_0)^{1/2}$ in Equation (4).

$$\begin{aligned} a_c &= a_n \\ a_i &= \sqrt{a_n a_0} \\ a_n &= a_i^2 / a_0 \end{aligned} \qquad (4)$$

From the Newtonian gravity (GMm/r^2) and the Newtonian acceleration formula (F = ma), the core acceleration a_c in the core region is as Equation (5),

$$\begin{aligned} F_c &= m a_n \\ &= m a_c \\ &= \frac{GMm}{r^2} \\ a_c &= \frac{GM}{r^2} \end{aligned} \qquad (5)$$

From the Newtonian gravity (GMm/r^2) and the Newtonian acceleration formula (F = ma), the interfacial acceleration a_i in the interfacial region is as Equation (6).

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$$\begin{aligned} F_i &= m a_n \\ &= m a_i^2 / a_0 \\ &= \frac{GMm}{r^2} \\ a_i &= \frac{\sqrt{GMa_0}}{r} \end{aligned} \qquad (6)$$

From V^2 = ar, Equation (5), and Equation (6), the rotation velocity V can be expressed as Equation (7).

$$\begin{aligned} V^2 &= V_c^2 + V_i^2 \\ &= V_{inner\ galaxy}^2 + V_{outer\ galaxy}^2 \\ &= \frac{GM}{r} + \sqrt{GMa_0} \end{aligned} \qquad (7)$$

Equation (7) is the rotation velocity equation for MOND. Equation (7) shows that the rotation velocities are different in the core region with V^2 = GM/r and in the interfacial region with $V^2 = (GMa_0)^{1/2}$ resulted from gravity interacting with the interfacial force at the critical homogeneous surface density. The rotation velocity equation of MOND as Equation (7) for the inner galaxy and outer galaxy can fit well the observed rotation curves of galaxies. The calculated rotation curves from MOND (Equation (7) and MOG (Equation (2)) are very similar [3].

III. The Evolution of Galaxies, Dark Matter Halos, Dwarf Galaxies, and Globular Clusters

Without the emergence of the modified interfacial gravity between dark matter region and baryonic matter regi on and below the critical homogeneous surface density, the models of galaxy evolution are the same in CDM and MIG in the period from the beginning of the universe to the coexistence of the large baryonic matter region as large dense

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primordial molecular cloud and the large dense dark matter region. For the first few hundred thousand years after the Big Bang, the universe was a hot and murky mess, with no light radiating out. About 400,000 years after the Big Bang, temperatures in the universe cooled, electrons and protons joined to form neutral hydrogen as the recombination. The inhomogeneous structure in CMB (cosmic microwave background)[16] was observed as in both CDM and MIG. MOG and MOND without some form of non-baryonic dark matter cannot explain the peaks in CMB easily.

Dark matter halos were formed as in N-body collisionless dark matter simulations. They followed the NFW profile where the highest density is at the center as the central cusp. Baryonic matter was dragged along by the gravitationally dominant dark matter with the highest density at the center. When the temperature dropped to ~ 1000°K, at the center of a dark matter halo, some hydrogen atoms paired up to create the primordial molecular layers. Molecular hydrogen cooled the primordial molecular layers by emitting infrared radiation after collision with atomic hydrogen. The further cosmic cooling reduced the gas pressure and allowing the molecular layers to continue contracting into gravitationally bound baryonic matter dense primordial molecular clouds. This process is the cooling flow for baryonic matter flowing to molecular clouds. The size of a molecular cloud increased by the process of gas accretion of cooling flow as in both CDM[[17]] and MIG.

In MIG, when the dense baryonic matter cloud and the dark matter region reached the critical homogeneous surface densities [10, 11]the modified interfacial gravity appeared to separate the dense baryonic matter molecular cloud and the dense dark matter region into two completely separate regions, the homogeneous baryonic matter region and the homogeneous dark matter region. Since there was much more dark matter than baryonic matter, the nearly homogeneous baryonic matter region was surrounded by the nearly homogeneous dark matter region. The baryonic matter region became the baryonic matter droplets surrounded by the dark matter medium in the baryonic matter-dark matter emulsion, which is like oil-water emulsion with oil as the oil droplet surrounded by water medium. The homogeneous baryonic matter droplet are shown as A and B in Figure 2.

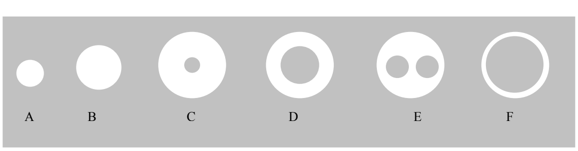

Figure 2 : homogeneous baryonic matter droplets (A, and B), and the heterogeneous baryonic matter droplets (C, D, E, and F)

Initially, the baryonic matter droplets were small. They increased in size by the cooling flow, gravity, and mergers with other small baryonic matter droplets. In MIG, the reduction of the interfacial repulsive Yukawa force between the baryonic droplets and the dark matter medium by the mergers of the droplets increased the rate of the mergers faster than the rate of the mergers of dark matter halos in CDM without the interfacial repulsive Yukawa force. The merger is analogous to the merger of the droplets in an unstable emulsion. The fast rate of the mergers in MIG explains the observation of very massive galaxy clusters at high redshifts sooner than expected in CDM[18]. Gradually, they became large homogeneous baryonic matter droplets. When three or more large homogeneous baryonic matter droplets merged, large dark matter regions were likely trapped in the merged droplet, resulting in heterogeneous baryonic matter droplets. To minimize the interfacial repulsive Yukawa force inside a heterogeneous baryonic matter droplet, dark matter regions inside the baryonic matter droplet merged into one or two dark matter regions inside the baryonic matter droplets, resulting in the heterogeneous baryonic matter droplets (C, D, E, and F in Figure 2). Surrounded by dark matter halo, a heterogeneous baryonic matter droplet contained the dark matter core and the baryonic matter shell. There were two modified interfacial gravities as the pressures between the dark matter core and the baryonic matter shell and between the baryonic shell and the external dark matter halo. In the equilibrium state, the internal pressure between the dark matter core and the baryonic matter shell was same as the external pressure between the baryonic shell and the dark matter halo.

The further cooling and the condensation of the primordial molecular clouds created the gaps and the random distribution of first stars in the baryonic matter shell. The gaps allowed the dark matter in the dark matter core to leak out, resulting in a tunnel between the dark matter core and the external dark matter halo. The continuous leaking of the dark matter expanded the tunnel. Consequently, the dark matter in the dark matter core rushed out of the dark matter core, resulting in the "droplet eruption" with the "ejected dark matter jet". A cause for the droplet eruption is the reduction of the interfacial repulsive Yukawa force by the merger of dark matter in the dark matter core and dark matter in the external dark matter halo. The kinetic energy of the ejected dark matter jet was derived from the interfacial repulsive Yukawa force between the dark matter core and the baryonic matter shell. The droplets acquired their droplet rotations from tidal interactions with other droplets, so the ejected dark matter jet was emitted largely along the rotating droplet's rotation axis, analogous to the jet moving in the same direction as the rotating neutron star's rotation axis.

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During the droplet eruption, the ejected dark matter jet inevitably carried some baryonic matter out of the droplet along the droplet rotation axis. The baryonic matter in the ejected dark matter jet resulted eventually in the dwarf galaxies which are observed as satellite galaxies arranged on a plane. The explanation of dwarf galaxies is similar to the explanation by Noam I. Libes kind who proposes that the satellite galaxies did not flock to the Milky Way from all directions, but were shot towards it along cosmic superhighways (filaments) of dark matter, thus giving the satellites a preferred direction and alignment [19]. Under gravity, orbiting a galaxy, the dwarf galaxies from the ejected dark matter jet largely inhabit a single plane analogous to moons around a giant planet. Such dwarf galaxy planes for galaxy systems by MIG are confirmed by Ibata et al [20]. Among 380 galaxy systems in the nearby universe (redshift $z < 0.05$), their finding may indicate that co-rotating planes of satellites, similar to that seen around the Andromeda galaxy, are ubiquitous in nature,

The ejection of the dark matter from the dark matter core left a hole in the core of the droplet. The external pressure (the interfacial repulsive force) from the external dark matter halo caused the collapse of the baryonic matter droplet. The droplet collapse is like the collapse of a balloon as the air (as dark matter) moving out the balloon rapidly. The droplet collapse forced the head-on collisions of the primordial molecular clouds in the baryonic matter shell. In the center of the collapsed baryonic matter droplet, the head-on collisions of the primordial molecular clouds generated the shock wave as the turbulence in the collided primordial molecular clouds. The turbulence triggered the collapse of the core of the primordial cloud. The core fragmented into multiple stellar embryos, in each a protostar nucleated and pulled in gas. Without the heavy elements to dissipate heat, the mass of the primordial protostar was 500 to 1,000 solar masses at about 200°K. The primordial protostar shrank in size, increased in density, and became the primordial massive star when nuclear fusion began in its core. The aggregation of primordial stars formed the nuclei of the the protogalaxies. The star formation from the droplet collapse and head-on collision was highly efficient, which was confirmed by the observation of the completion of the rapid and explosive reionization process by extremely bright and active first galaxies in the period at least 250 million years shorter than expected [21]. The protogalaxies evolved into the first generation galaxies. Reference [1] describes how C, D, E, and F in Figure 2 turn into elliptical, spiral, barred spiral, and irregular galaxies, respectively, as the first generation galaxies that constitute the major part of the observed galaxies as follows.

$$\text{dark matter halo with dark matter and baryonic matter} \xrightarrow{cooling} \textit{baryonic matter molecular cloud region} + \textit{dark matter region} \xrightarrow{repulsive\ force} \text{homogeneous baryonic matter droplet surrounded by external dark matter halo} \xrightarrow{merger} \textit{heterogeneous baryonic matter droplet} \xrightarrow{cooling} \textit{gaps in baryonic matter droplet} \xrightarrow{eruption,\ collapse,\ and\ collision} \textit{protostars} \xrightarrow{nuclear\ fusion} \textit{primordial stars} \xrightarrow{aggregation} \text{the nuclei of the protogalaxies} \rightarrow \textit{the first generation galaxies}$$

The galaxy formation of the first generation galaxies in MIG is similar to a top-down formation as proposed by Olin Eggen, Donald Lynden-Bell, and Allan Sandage [22]. They proposed a top-down formation of galaxies through a monolithic collapse of a large gas cloud. The formation of galaxy by the droplet collapse from the droplet eruption allows the central region of a galaxy to produce high angular momentum from the external pressure (the interfacial repulsive Yukawa force) of the external dark matter halo in accordance with the Tully-Fisher relation in MOND[23] and to produce longthin disk for spiral galaxy as observed. The bigger the hole was during the droplet eruption and collapse, the thinner and longer the disk became. In CDM, the galaxy formation is through a bottom-up formation from the mergers of smaller galaxies to form larger galaxies in the manner of hierarchical formation. CDM without extensive modifications and fine tunings cannot produce high angular momentum and long thin disks for spiral galaxies, including numerous bulgeless spiral galaxies [8]. CDM also has the problem with the failure of to detect directly dark matter on earth. Dark matter has not been detected by the contact (interaction) between dark matter and baryonic matter. The absence of dark matter on earth is further confirmed by the study of the detailed set of measurements of planetary orbits by Nikolay Pitjev and Elena Pitjeva [24]. Their conclusion is that the gravitational effect of dark matter on the solar system is negligible. In MIG, galaxy interior is essentially dark matter-free, so it is not possible to detect dark matter on earth by the contact (interaction) between dark matter and baryonic matter.

There were large, medium, and small heterogeneous baryonic matter droplets for the droplet eruption. The timing for the droplet eruption depends on the cosmic temperature and the sizes of the droplets. At the cosmic temperature considerably below 1000°K, the droplet eruption for all different sizes of the droplets occurred within a certain period when the universe was a few hundred million years old. With the shorter distance for the dark matter in the dark matter core to travel to the outside of the droplet, the droplet eruption for smaller droplet occurred earlier. The times for the completed droplet collapse are also different for different sizes of the droplets. The completed droplet collapse took shorter time for a smaller hole left by ejected dark matter in a smaller droplet. The completed

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droplet collapse led to the collision that produced the stars for the nuclei of protogalaxy, so the formation of stars in protogalaxy was faster for the smaller droplets. Protogalaxy evolved into galaxy. Consequently, the ages of majority of stars increase with decreasing size of galaxy.

When the universe was a few billion years old, and the galaxies were still in the protogalaxy stage without full development, large protogalaxies accreted the surrounding small and medium protogalaxies, and turned them into metal-poor globular clusters without external dark matter halos [25] in galactic halos. (Some of the accreted protogalaxies had their own accreted protogalaxies.) As a result, the stars in globular clusters derived from medium and small size baryonic matter droplets in general are older than the stars in the host large galaxies. The tidal interactions with the host galaxy stripped off largely outer stars and gases from a globular cluster. A similar approach was proposed by Patrick Cote et al. who proposed the assembly of the globular cluster system via the accretion of metal-poor protogalaxies by the dominant host protogalaxy (protobulge)[26].

The dwarf galaxies in the dwarf galaxy planes of large galaxies are derived from the ejected dark matter jets during the droplet eruption as mentioned before. Without the dark matter cores, these dwarf galaxies did not have droplet collapse, so these dwarf galaxies do not contain nuclei. The star formation came from the turbulences through the movement of the ejected dark matter jet and the gravitational interactions with parent large galaxies. The dwarf galaxies contain both metal-poor stars from the early formation of stars and metal-rich stars from the late formation of stars. Unlike globular clusters, the dwarf galaxies have external dark matter halos. As a result, the rotation velocities in the dwarf galaxies with external dark matter halos follow MOND, while the rotation velocities in globular clusters without dark matter halos follow the Newtonian gravity without dark matter [25].

IV. Dark Matter Halo in Galaxy Cluster

A galaxy cluster consists of hundreds to thousands of galaxies bound together by gravity. In MIG, in addition to normal galaxies, there are dwarf dark matter halos without baryonic matter droplet and dwarf dark halos with small baryonic matter droplets. When the baryonic matter primordial molecular clouds were formed in some dwarf dark matter halos, the molecular clouds below the critical homogeneous surface density resulted in dwarf dark matter halos without baryonic matter droplet. In some dwarf dark matter halos, baryonic matter droplets formed were too small to develop significant numbers of stars, resulting in the observed ultra-faint dwarf galaxy [27] for dwarf dark matter with small baryonic matter droplets. The gravitational attraction of dwarf dark matter halos without baryonic matter droplet, ultra-faint dwarf galaxies, and normal galaxies brings about dark matter halos for galaxy clusters.

A recent study of fifty individual galaxy clusters finds that the density is observed to decrease outwards from the center of these galaxy clusters in excellent agreement with the predictions of dark matter halos in CDM models [28]. The method to measure dark matter density consists of measuring the slight distortion of background galaxies induced by the gravitational deformation of space–time along the line of sight. This gravitational lensing locates and measures the amount of dark matter, even though it is transparent on the image. The fifty observed galaxy clusters have individual variations for central concentrations. For all fifty observed galaxy clusters, the obtained map of the mean dark-matter distribution is symmetrical with a central cusp to be consistent with the NFW model. Without the active involvement of the modified interfacial gravity, the models for the evolution of dark matter halo for galaxy cluster are the same in CDM and MIG. MOND without 2eV neutrinosor non-baryonic form cannot explain dynamics and lensing of galaxy clusters.

V. Summary

The paper posits the modified interfacial gravity (MIG) as the modified gravity in the interfacial region between homogeneous baryonic matter region and homogeneous dark matter region. The MIG model contains both dark matter and modified gravity to unify the CDM (Cold Dark Matter) model, MOG (Modified Gravity), and MOND (Modified Newtonian Dynamics). In MIG, the interfacial repulsive Yukawa force in the interfacial region to separate baryonic matter region and dark matter region is equivalent to the repulsive Yukawa force in outer galaxy in MOG. The modified interfacial gravity is interfacial gravity interacting with the interfacial repulsive Yukawa force. The modified interfacial gravity emerges in the interfacial region between dark matter region and baryonic matter region only when the homogeneous surface density is above the critical homogeneous surface density in both dark matter region and baryonic matter region. The critical homogeneous surface density is derived from the acceleration constant a_0 from MOND. The four separate regions in the galaxy structure in MIG are the core (inner) baryonic matter galaxy with the Newtonian gravity, the interfacial (outer) baryonic matter galaxy with the modified interfacial gravity, the interfacial (inner) external dark matter halo with the modified interfacial gravity, and the core (outer) external dark matter halo with the Newtonian gravity. Dark matter in the external dark matter halo is cold dark matter without electromagnetism as in CDM. CDM and MIG are identical during the very early universe below the critical homogeneous surface density and before the emergence of the modified interfacial gravity. After the emergence of the modified interfacial gravity by dense giant molecular clouds during the early universe, MOND, MOG, and MIG are identical for baryonic matter galaxy structure. MIG explains galaxy evolution, globular clusters, dwarf galaxy plane, dark matter halo in galaxy cluster, the rotation velocities, and the failure to detect directly dark matter on earth.

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