Quantum vacuum as the cause of the phenomena usually attributed to dark matter

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Abstract

- We show that if quantum vacuum fluctuations are virtual gravitational dipoles, then the phenomena usually attributed to hypothetical dark matter, may be considered as a consequence of the gravitational polarization of the quantum vacuum by the immersed baryonic matter; apparently, at least mathematically, the galactic halo of dark matter can be replaced by the halo of the polarized quantum vacuum.The eventual gravitational effects of the quantum vacuum “enriched” with virtual gravitational dipoles, can be revealed by the study of orbits of tiny satellites in trans-Neptunian binaries (for instance UX 25 and Eris-Dysnomia).

The working hypotheses

*(1) Quantum vacuum fluctuations are virtual gravitational dipoles**

*(2) The Standard Model matter** and quantum vacuum are **the only** matter-energy content of the Universe*

* A virtual gravitational dipole is defined in analogy with an electric dipole: two gravitational charges of the opposite sign at a distance smaller than the corresponding reduced Compton wavelength

**Standard Model Matter means matter made from quarks and leptons interacting through the exchange of gauge bosons

Important Note: We do not modify the Standard Model of Particles and Fields and its understanding of quantum vacuum! Gravity is not included in the Standard Model.

What if *quantum vacuum fluctuations are virtual gravitational dipoles*? Summary of consequences.

Our working hypothesis might be the basis for a new model of the Universe. According to the new model, ***the only* content of the Universe is the known Standard Model matter** (i.e. matter made from quarks and leptons interacting through the exchange of gauge bosons) *immersed in the quantum vacuum* "enriched" with virtual gravitational dipoles. Apparently, **what we call dark matter and dark energy, can be explained as the local and global effects of the gravitational polarization of the quantum vacuum by the immersed baryonic matter**. Further, **the hypothesis leads to a *cyclic model* of the Universe with cycles alternatively dominated by matter and antimatter**; with each cycle beginning with a macroscopic size and the accelerated expansion. Consequently, there is *no singularity*, *no need for inflation field*, and there is an elegant explanation of the matter-antimatter asymmetry in the universe: **our universe is dominated by matter because the previous cycle of the Universe was dominated by antimatter**. The forthcoming experiments (AEGIS, ALPHA, GBAR …) will reveal if particles and antiparticles have gravitational charge of the opposite sign, while study of orbits of tiny satellites in trans-Neptunian binaries (e.g. UX25) can be a reasonable test of some astronomical predictions of the theory.

Reminder: Quantum vacuum in QED
an “ocean” of virtual electric dipoles

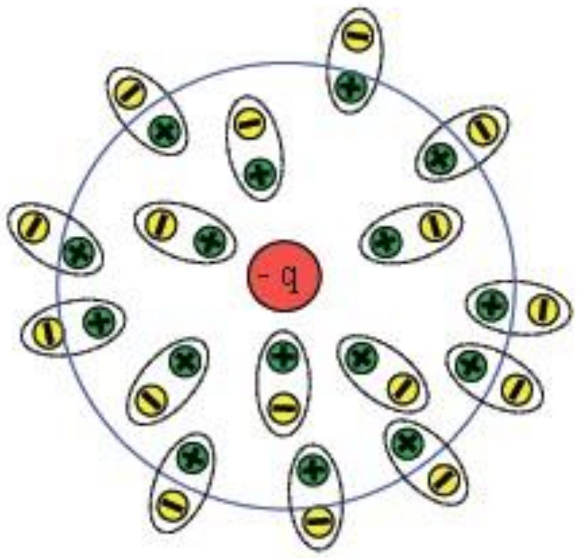
In QED quantum vacuum can be considered as an omnipresent “ocean” of virtual electric dipoles (for instance electron-positron pairs) with random orientation

Reminder: Quantum vacuum in QED

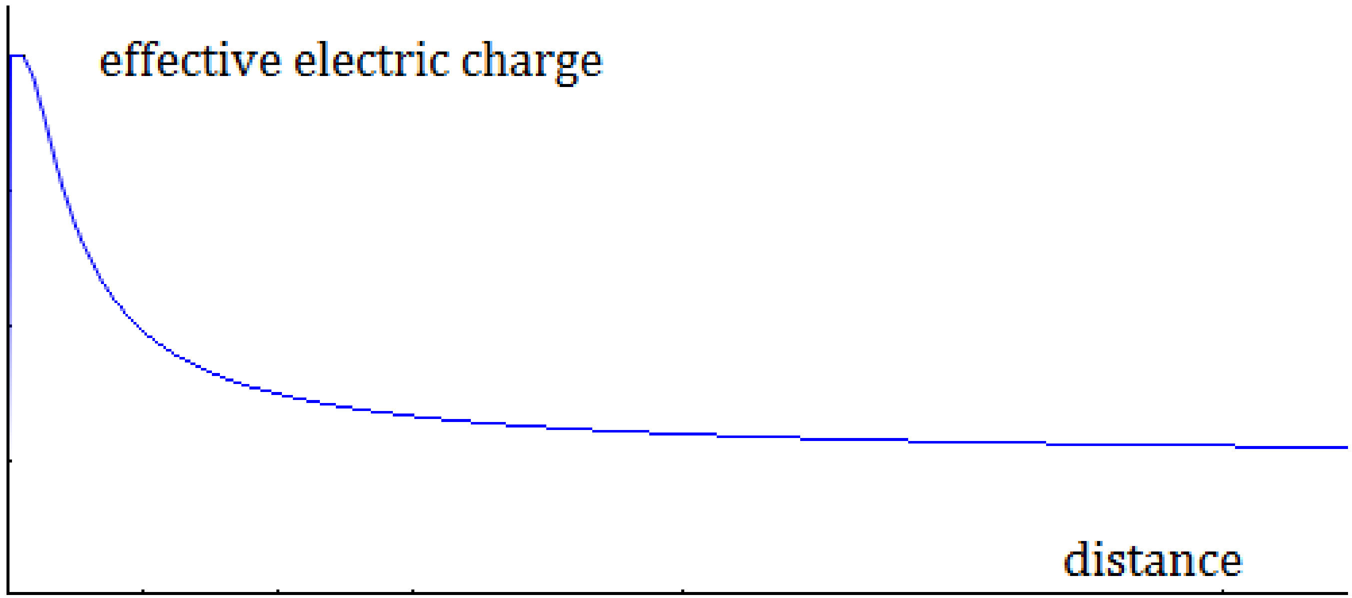
a **halo** of the polarized quantum vacuum

- The random orientation of virtual dipoles can be perturbed by a very strong electric field
- Example: The electric field of an electron at the distance of its Compton Wavelength is of the order of **10^{14} V/m**. Such a strong field perturbs the random orientation

Electron "immersed" in the quantum vacuum produces around itself **a halo** of non-random oriented virtual electric dipoles, i.e. **a halo of the polarized quantum vacuum**.



Reminder: Quantum vacuum in QED
the effective electric charge of electron



- The halo screens the "bare" charge of an electron; what we measure is the effective electric charge which *decreases* with distance!
- The effects of screening are not significant after a characteristic distance (which is of the order of the Compton wavelength)

Major consequences of the working hypothesis

- A quantum vacuum fluctuation is a system with zero gravitational charge, but a non-zero gravitational dipole moment

$$\left|\vec{p}_g\right| < \frac{\hbar}{c}$$

- **Gravitational polarization density** $\vec{P}_g$ i.e. the gravitational dipole moment per unit volume, *may be attributed to the quantum vacuum*.

Random orientation of dipoles

$$\vec{P}_g = 0$$

Saturation*

the gravitational polarization density has the maximal magnitude

$$P_{g\,\max} = \frac{A}{\lambda_m^3}\frac{\hbar}{c}$$

*Saturation is the case when as the consequence of a sufficiently strong external gravitational field, all dipoles are aligned with the field

The effective gravitational charge

- In a dielectric medium the spatial variation of the electric polarization generates a charge density known as the bound charge density. In an analogous way, the gravitational polarization of the quantum vacuum should result in

the effective gravitational charge density of the physical vacuum

$$\rho_{qv} = -\nabla \cdot \vec{P}_g$$

Immediate questions

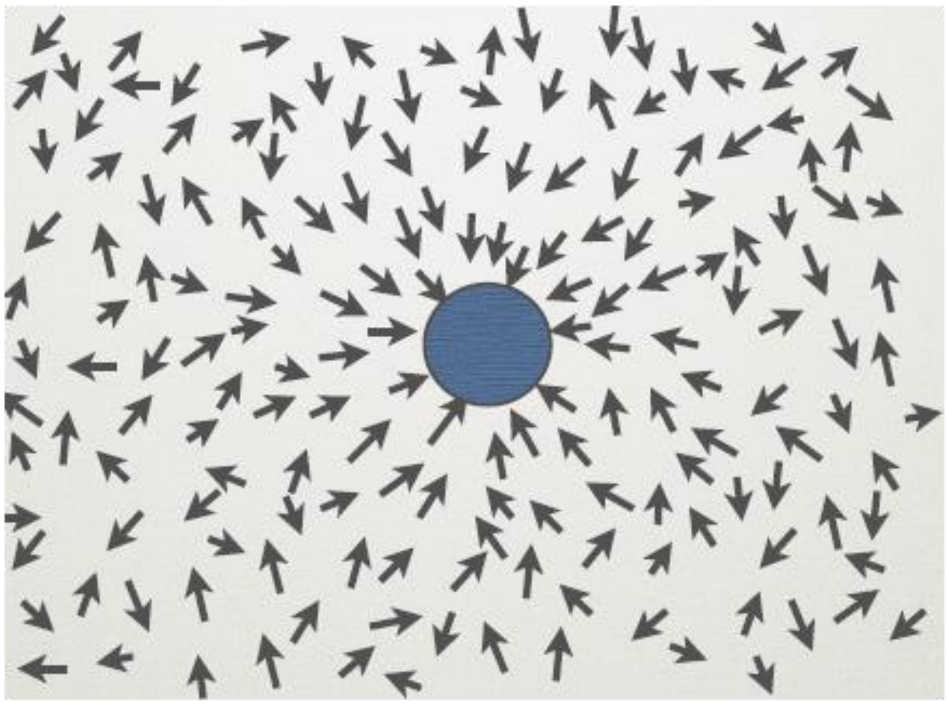
- **Can the effective gravitational charge density** of the quantum vacuum in galaxies and clusters of galaxies **explain phenomena usually attributed to dark matter**.
- **Can quantum vacuum as cosmological fluid of the effective gravitational charge explain phenomena usually attributed to dark energy**.
- What might be **effects of conversion of quantum vacuum fluctuations into real particles** in extremely strong gravitational field.

According to the working hypothesis quantum vacuum is an "ocean" of virtual gravitational dipoles

Randomly oriented gravitational dipoles (without an immersed body)

The gravitational charge density of the quantum vacuum is zero, what is **the simplest solution to the cosmological constant problem**. A tiny, **effective gravitational charge density** might appear as the result of the immersed Standard Model matter

Halo of non-random oriented dipoles around a body (or a galaxy)



- **Random orientation** of virtual dipoles **might be broken** by the immersed Standard Model matter
- Massive bodies (stars, black holes …) but also multi-body systems as galaxies are surrounded by an invisible ***halo of the gravitationally polarized quantum vacuum*** (i.e. a region of *non-random* orientation of virtual gravitational dipoles)
- The halo of the polarized quantum vacuum acts as an **effective gravitational charge**

This halo is well mimicked by the artificial stuff called dark matter! I joke, but it might be true. Gravitational polarization of the quantum vacuum might be the true nature of what we call dark matter.

Gravitational field around a spherical body

In the case of spherical symmetry the general equation for the effective gravitational charge density

$$\rho_{qv} = -\nabla \cdot \vec{P}_g$$

reduces to

$$\rho_{qv}(r) = \frac{1}{r^2}\frac{d}{dr}\left(r^2 P_g(r)\right); \quad P_g(r) \equiv \left|\vec{P}_g(r)\right| \geq 0$$

Problem: Function $P_g(r)$ is not known

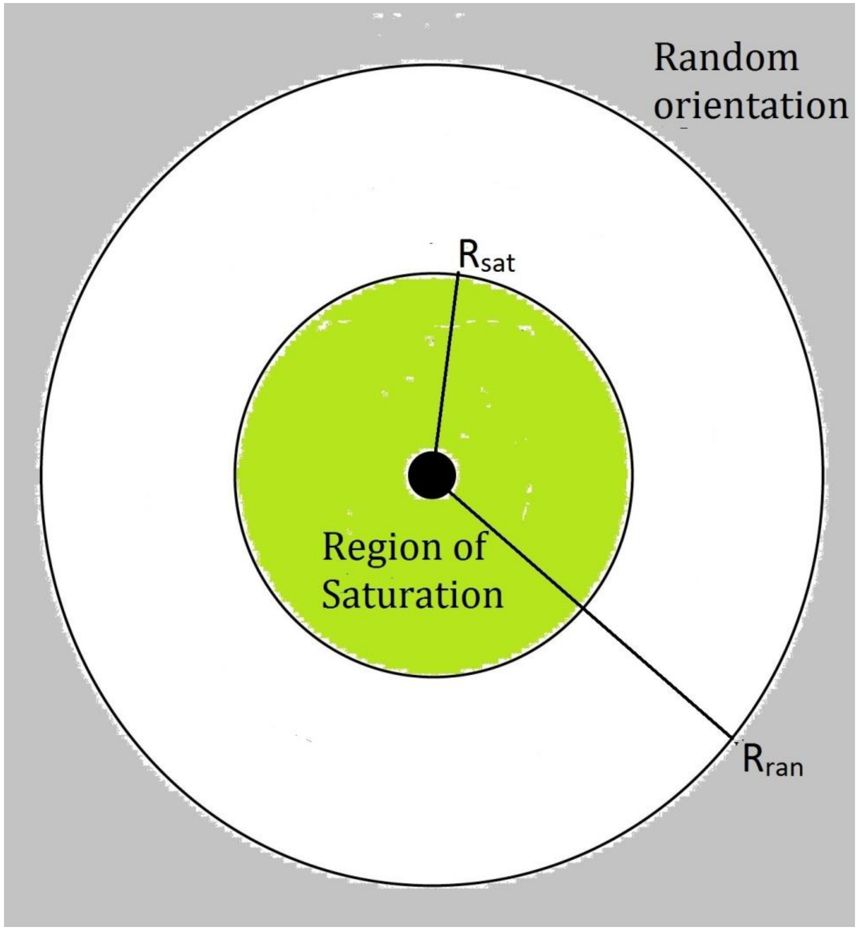
However we know that roughly there are 3 regions

The region of saturation in which the gravitational polarization density can be approximated by its maximal magnitude $P_{g\max}$.

The region dominated by random orientation with $P_g(r) = 0$

Between these two regions $P_g(r)$ decreases from the maximum magnitude to zero

Schematic presentation of regions



The region of saturation

- The region of saturation: Roughly a spherical shell with the inner radius R_b (the radius of the body with the baryonic mass M_b) and the outer radius R_{sat} estimated to be

$$R_{sat} \approx \lambda_m \sqrt{\pi \frac{M_b}{m_\pi}}, \; m_\pi \; and \; \lambda_m \; correspond \; to \; a \; pion$$

- The effective gravitational charge density and the effective gravitational charge within the sphere of radius r , are

$$\rho_{qv}(r) = \frac{2P_{g\max}}{r}, \; M_{qv}(r) = 4\pi P_{g\max} r^2$$

- A good theoretical upper limit for $P_{g\max}$ (which can be used as a reasonable approximation) is

$$P_{g\max} < \frac{1}{4\pi} \frac{kg}{m^2} \approx 38 \frac{M_{Sun}}{pc^2}$$

Gravitational effect of the quantum vacuum in the region of saturation

- **Important conclusion**: as the result of the gravitational polarization of the quantum vacuum *in the region of saturation*, there is an additional anomalous constant gravitational field oriented towards the center

$$g_{v\max} = \frac{GM_v(r)}{r^2} = 4\pi G P_{g\max}$$

- If such an acceleration exists it causes a retrograde precession of the perihelion of the Satellite in a binary; precession per orbit in radians is:

$$\Delta\omega_{qv} = -2\pi\, g_{qv} \sqrt{1-e^2}\, \frac{a^2}{G\mu}$$

a -the semi-major axis of the orbit; ***e***-eccentricity, **μ-** total mass of binary

- Good news: In the case of some trans-Neptunian binaries (for instance UX25) this constant anomalous acceleration of the order of $10^{-11}\, m/s^2$ can be measured

Gravitational polarization outside the region of saturation

- Considering quantum vacuum as an ideal system of non-interacting gravitational dipoles in an external gravitational field (analogous to polarization of a dielectric in external electric field, or a paramagnetic in an external magnetic field) leads to

$$M_{qv}(r) = 4\pi P_{g\max} r^2 \tanh\left(\frac{R_{sat}}{r}\right), \quad r < R_{ran}$$

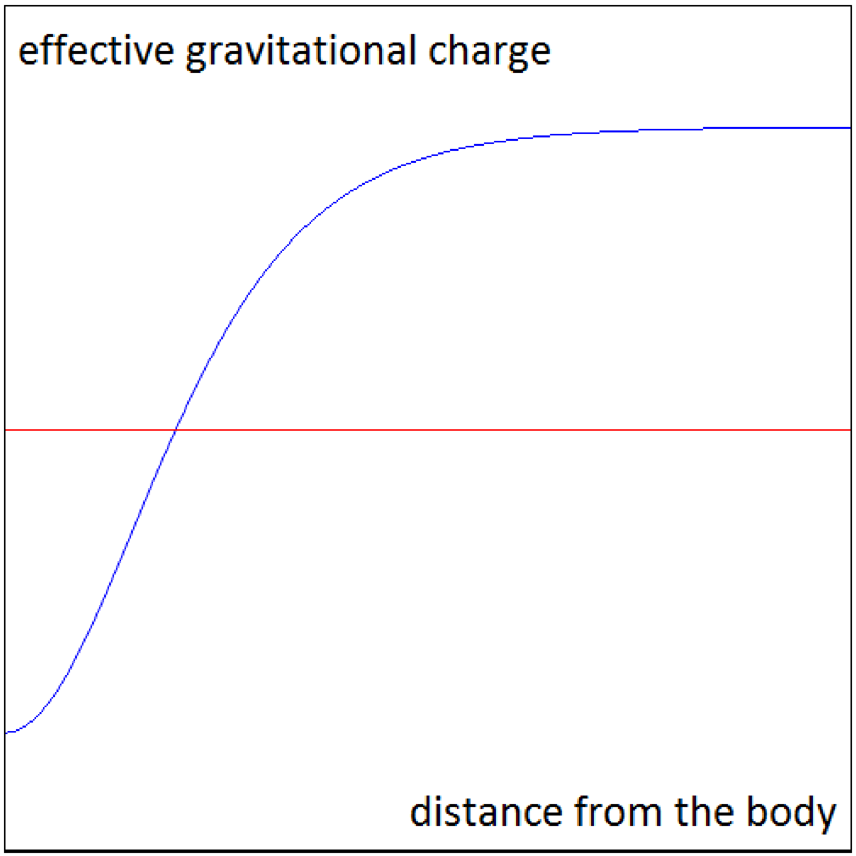
R_{ran} is a characteristic radius after which random orientation is dominant. For $r > R_{ran}$ the function $M_{qv}(r)$ doesn't increase more with distance and has a constant value $M_{qv\max}$.

Important note: It is obvious that gravitational field can align only quantum vacuum fluctuations which are gravitational dipoles but not electric dipoles; for instance random orientation of electron-positron pairs cannot be broken by a gravitational field, while neutrino-antineutrino pairs and gluon fluctuations might be aligned.

The size and the effective gravitational charge of a halo

- Roughly speaking there is a maximum size of the halo for each massive body, galaxy or cluster of galaxies. Simply, after a characteristic size the random orientation of dipoles dominates again.
- A halo of the maximum size can be formed only if other bodies are sufficiently far. For instance, in competition with the Sun, our Earth cannot create a large halo, but if somehow we increase the distance of the Earth from the Sun, the size of the spherical halo of the Earth would increase as well, reaching asymptotically a maximum size .
- The key point is that with the increase of the size of a halo also increases the effective gravitational charge distributed within the halo.

How the effective gravitational charge of a body depends on distance from it



- **The effective gravitational charge** of a body (blue line) increases from the "**bare**" charge measured at its surface to a constant maximum charge at a large distance from the body
- Competing gravitational field of other bodies can prevent the effective gravitational charge to increase above a limit presented by the red line
- The maximum effective charge can be reached only if other bodies are sufficiently far

Comparison with the empirical evidence
Example 1:Tully-Fisher relation

- **Tully-Fisher relation** is one of the most robust **empirical results**, unexplained by "dark matter"; basically it is a scaling relation of the same form as our analytical result

$$V_{rot}^4 = G^2 \frac{m_\pi M_b}{\pi \lambda_\pi^2}$$

(relating limit of rotation velocity in disk galaxies with the baryonic content of the galaxy)

- Let us note that at this point (Tully-Fisher relation) MOND is more successful than "dark matter" theory. The significant success of MOND is a sign that there is something special about their acceleration $a_0 \approx 1.2 \times 10^{-10}\, m/s^2$. However, according to our model **there is no any modification of the Newton's law**, as proposed by MOND, for gravitational fields weaker than a_0 . In our model, a_0 is rather **a transition point**, **from saturation in stronger fields to non-saturated polarization in weaker fields**.

Comparison with the empirical evidence
Example 2: Surface density of “dark matter”

- Following Slide 15

$$\frac{M_{qv}(r)}{4\pi r^2} \approx P_{g\,\max} \equiv \text{constant}$$

which is a prediction universally valid for all galaxies!

- It is exactly what has been observed [Kormendy and Freeman 2004, Donato 2009]. Let us note that astronomers have no any physical interpretation of the critical distance and that so far this result escapes explanation within dark matter theory.
- Next Slide contains comparison of our result and observations

Continued from the previous Slide

Dopita (2012) has found, as he said the excellent agreement, between our theoretical result (blue line) and observations

Scaling Laws for Dark Matter Halos of Galaxies 391

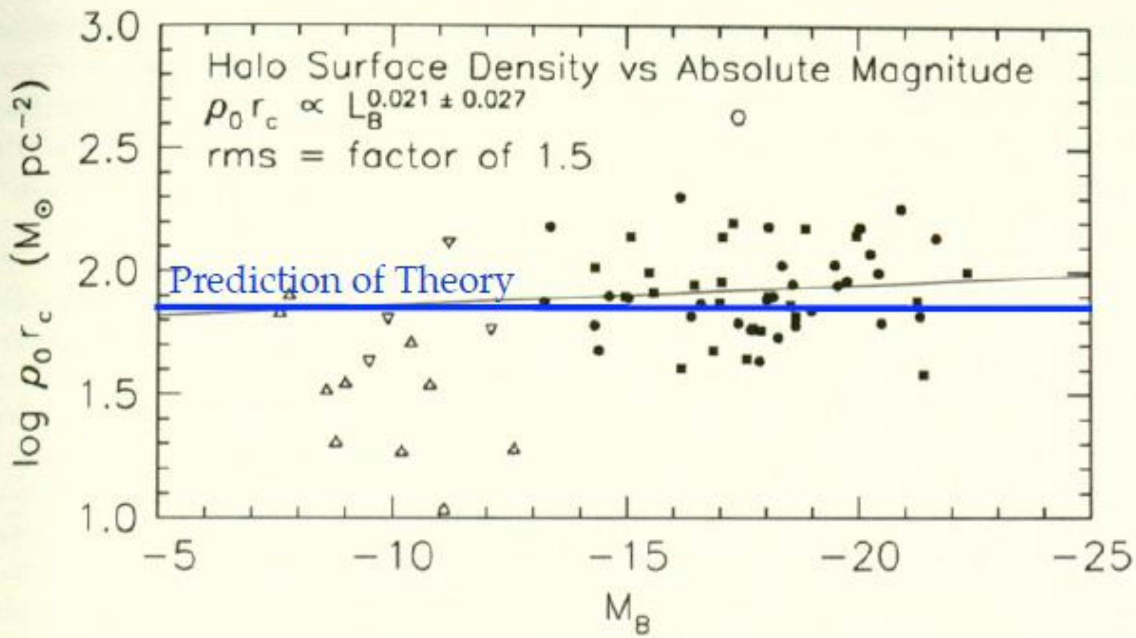


Figure 5. Logarithm of $\rho_0 r_c$, which is proportional to the projected surface density of DM halos, as a function of absolute magnitude. The symbols are the same as in Figures 2 – 4. The straight line (*key*) is a least-squares fit to the Sc – Im galaxies omitting NGC 4605. Within the errors, the surface densities of DM halos of late-type galaxies are independent of galaxy luminosity.

Comparison with the empirical evidence

Example 4:The total mass of Milky Way within 260kpc

- According to astronomical observations [Boylan-Kolchin 2013] the median Milky Way mass within 260kpc is

$$M_{MW}(260kpc) = 1.6 \times 10^{12} M_{Sun}$$

with a 90% confidence interval of

$$[1.0 - 2.4] \times 10^{12} M_{Sun}$$

- Our theoretical estimate

$$M_{MW}(260kpc) \approx 1.45 \times 10^{12} M_{Sun}$$