Preprints.org

Article

Not peer-reviewed version

Dark-Matter and Gravitational Details That Explain Otherwise Seemingly Unexplained Cosmic Data

Thomas Buckholtz *

Posted Date: 7 May 2025

doi: 10.20944/preprints202505.0381.v1

Keywords: standard cosmological model; dark matter; dark energy; rate of expansion of the universe; galaxy formation; Hubble tension; S8 tension

 doi:10.20944/preprints202505.0381.v1

Article

Dark-Matter and Gravitational Details That Explain Otherwise Seemingly Unexplained Cosmic Data

Thomas J. Buckholtz

National Coalition of Independent Scholars, 125 Putney Road, Battleboro, Vermont 05301, USA; tjb@alumni.caltech.edu

Abstract: We provide quantitative explanations for known ratios of dark-matter effects to ordinary-matter effects, and we suggest explanations for the rate of expansion of the universe and for cosmology tensions. Our work features a well-defined specification for dark matter. Our work features multipole expansions that combine Newtonian gravity and special-relativistic interpretations of properties of objects. Our work adds one integer-based equation to successful popular modeling. Some solutions of the equation help to quantitatively explain dark-matter-to-ordinary-matter ratios and help to suggest insight regarding galaxy formation, rate-of-expansion phenomena, the Hubble tension, and the S8 tension.

Keywords: standard cosmological model; dark matter; dark energy; rate of expansion of the universe; galaxy formation; Hubble tension; S8 tension

---

1. Introduction

This unit discusses context for our work; lists data that our work seeks to fit and explain; previews applications of methods that our work uses; and suggests that our work stems from, embraces, suggests improvements to, and does not intrude on successful mainstream cosmology.

1.1. Context for Our Work

This unit discusses opportunities that our work attempts to capture.

Popular modeling, including the standard cosmological model, approximately fits some cosmic data and leaves unresolved some key aspects [1–3].

One key unresolved aspect features the opportunity to explain some phenomena that popular modeling sometimes associates with effects of other than ordinary matter. Starting in the 1930s, people observed cosmological phenomena that popular modeling seemed unable to fit or explain based on stuff that people observed electromagnetically [4,5]. Popular modeling associates such phenomena with notions that there is more gravitational attraction (of visible stuff toward other visible stuff) than popular modeling suggests based on the presence of only visible stuff. Some popular modeling suggests that fitting or explaining observed data could have bases in stuff that people do not see. Here, the word see associates with the phrase observe via electromagnetic radiation. Popular modeling suggests using the two-word term dark matter to name such not-seen stuff. Popular modeling suggests various candidate specifications for dark matter [6,7]. (We note, as an aside, that either one of the two-word terms ordinary matter and baryonic matter pertains to, generally, the stuff that people do see.)

One key unresolved aspect features the opportunity to explain changes in the so-called rate of expansion of the universe. Notions that the universe might, in some sense, expand or contract date to the 1920s [8,9]. The rate of expansion features notions of typical speeds at which neighboring similar large objects move apart from each other. Popular modeling sometimes associates the two-word term dark energy with forces that might associate with gravity and that might seem to drive objects away from each other. Non-colliding galaxy clusters might be such large objects. Popular modeling suggests

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

two relevant multibillion-year eras in the evolution of the universe. During the earlier era, the rate (or typical speed) is positive and decreases as the universe evolves. During the later era, the rate is positive and increases. Popular modeling generally has suggested that the later era includes today. Popular modeling that might fit or explain the changes during either one of the two eras seems not to extrapolate to fit or explain the changes during the other era [10].

1.2. Cosmic Data That We Try to Explain

This unit discusses cosmological data that we try to explain. Some data associate with observed ratios of not-ordinary-matter effects to ordinary-matter effects. Some data associate with eras in the rate of expansion of the universe. Some data associate with large-scale lumpiness of stuff.

The following observed ratios of not-ordinary-matter effects to ordinary-matter effects provide a basis for our work.

- 1:1 – Amount of some depletion of cosmic microwave background radiation [11–13].
- 1:0+ – Amounts of stuff in some individual galaxies [14–22].
- 0+:1 – Amounts of stuff in some individual galaxies.
  - Redshifts of more than approximately seven [23,24].
  - Redshifts of approximately six [25].
  - Redshifts of less than six through redshifts of nearly zero [26–33].
- $\sim$ 4:1 – Amounts of stuff in some individual galaxies [34,35].
- 5+:1 – Amounts of stuff in many individual galaxies [14,36].
- 5+:1 – Amounts of stuff in many individual galaxy clusters [36–40].
- 5+:1 – Densities of the universe [41].

A notion of eras in the rate of expansion of the universe provides a basis for our work.

Popular modeling suggests two observed multibillion-year eras [42–45]. Chronologically, the first multibillion-year era associates with a positive rate of expansion that decreases as time increases. The second multibillion-year era associates with a positive rate of expansion that increases as time increases.

Popular modeling suggests that popular modeling does not adequately explain some aspects regarding the two multibillion-year eras. Popular modeling sometimes associates the two-word phrase Hubble tension with the lack of an adequate explanation for some data [46].

Popular modeling might provide hints that the second multibillion-year era might be ending [47,48] and that a new era, which would associate with a positive rate of expansion that decreases as time increases, might be starting.

A notion of large-scale lumpiness of stuff provides a basis for our work.

Popular modeling tries to explain observed large-scale lumpiness of stuff. Popular modeling suggests that popular modeling overestimates large-scale lumpiness [49–56]. Popular modeling sometimes associates the two-element phrase S8 tension with some such overestimates.

1.3. A Summary of Unexplained Cosmic Data and a Preview of Our Methods

This unit summarizes unexplained cosmic data that we seek to fit and explain. This unit previews aspects of the methods that we use to fit and explain such data.

The first column of Table 1 lists phenomena that our work seeks to and seems to help explain. The other columns preview aspects of our methods. Our methods embrace notions that not-ordinary-matter effects associate with dark matter.

Table 1. Phenomena that our work seems to help explain. DM:OM denotes ratios of dark-matter effects to ordinary-matter effects. CMB denotes cosmic microwave background radiation. The second column suggests approximate characterizations of explanations that we suggest. The rightmost two columns point to some of our bases for the explanations. Isomers refers to a notion that nature includes six similar, but not necessarily identical, instances of each one of most elementary particles. SPRISENG abbreviates SPecial-Relativity-Inspired Suggested Extensions to Newtonian Gravity.

Phenomena	Explanation	Isomers	SPRISENG
Dark-matter elementary particles	Quantitative	x	
Dark-matter stuff	Quantitative	x	
DM:OM regarding some depletion of CMB	Quantitative	x	
Galaxy evolution and DM:OM regarding some galaxies	Quantitative	x	x
DM:OM regarding some galaxy clusters	Quantitative	x	
DM:OM densities of the universe	Quantitative	x	
Dark-energy gravitational phenomena	Qualitative	x	x
Eras in the rate of expansion of the universe	Qualitative	x	x
Hubble tension	Qualitative	x	x
S8 tension	Qualitative	x	x

In general, we suggest the following notions.

- Our work comports with successful popular modeling, reuses aspects of successful popular modeling, extends present popular modeling, and enables capturing physics opportunities that present popular modeling seems not to capture.
- Our notions of basing a specification for dark matter on isomers and of using multipole expansions to help explain repelling aspects of gravity preceded [57] the availability of enough data to help us adequately hone our work or to suggest that data might lend enough credibility to our approach.
- There now is enough data to suggest that our work provides a credible candidate basis for extending aspects of cosmology that associate with the popular modeling terms dark matter and dark energy.
- Our work suggests observations that people might want to make to verify or refute aspects of present popular modeling and to verify or refute aspects of our work.

2. Methods

This unit develops methods to fit and explain specific data.

2.1. Suggestions That Underlie Our Work

This unit discusses suggestions that we make and that underlie our work.

We suggest that the not-ordinary-matter effects associate with dark matter. We suggest that the appearances, in the relevant ratios, of approximate integers have significance.

Popular modeling suggests that the second 1 in the 1:1 ratio associates with effects of ordinary-matter hydrogen atoms. These atoms deplete, via hyperfine transitions, cosmic microwave background radiation. We suggest that the first 1 in the 1:1 ratio associates with dark-matter hydrogen-like atoms. Popular modeling associates ordinary matter with a set of elementary particles. We suggest that, for our work, the ordinary-matter set of elementary particles includes all known elementary particles except the photon. We suggest that the dark-matter hydrogen-like atoms associate with a set of elementary particles that has similarities to, but does not equal, the ordinary-matter set of elementary particles.

We use the word isomer to denote such a set of elementary particles.

Based on the prevalence of 5+:1 ratios, we suggest that nature includes six isomers. We number the isomers. Isomer-0 associates with ordinary matter. Each one of isomer-1 through isomer-5 associates with dark matter. Based on the pluses in the 5+:1 ratios, we suggest that four of the dark-matter

 doi:10.20944/preprints202505.0381.v1

isomers are less like isomer-0 than is the one dark-matter isomer that associates with the first 1 in the ratio 1:1.

Based in part on observations of neutrino oscillations [58], popular modeling suggests that, at least for neutrinos, flavour eigenstates do not necessarily equal mass eigenstates.

Regarding similarities and differences between isomers, we suggest the following notions. Across the six isomers, counterpart elementary particles have the same masses. Differences between isomers can associate with differences between matches between charged-lepton flavours and charged-lepton masses. Differences between isomers can associate with differences regarding handedness for elementary particles that exhibit handedness. (The following are examples of popular modeling notions that pertain regarding handedness. Each elementary fermion exhibits handedness. Zero-mass elementary particles do not exhibit handedness. Zero-spin elementary particles do not exhibit handedness.) Three isomers associate with left-handedness. Three isomers associate with right-handedness.

We suggest that one can extend notions of Newtonian gravity by considering possible parallels between gravitation and electromagnetism. (Here, we introduce this notion. Later, we provide details.) Electromagnetism includes, in a list of properties of objects, both charge and magnetic moment. Newtonian gravitation considers mass, which might be an analog to charge, but not object-intrinsic angular momentum, which might be an analog to magnetic moment. We suggest that considering gravitational parallels to special relativistic notions regarding contributions by properties of objects to electromagnetic fields might prove useful. We point to the notion that contributions to gravitational interactions that associate with the object-intrinsic angular momentum of one object and with the mass of a second object associate with dilution or sign-reversal regarding a net gravitational attraction that might otherwise associate just with the attraction that associates with the masses of the two objects. (We note here, as an aside, that we anticipate discussing the following. We associate the word perceived with special relativistic notions that perceived values of the properties of an object can vary based on a choice of a frame of reference. Dilution of perceived charge can associate with notions that are more general than just magnetic moment. Dilution of perceived mass can associate with notions that are more general than just object-internal angular momentum.)

We suggest that decreases in the rate of expansion associate with components of gravitational force that pull galaxy clusters toward each other. We suggest that increases in the rate of expansion associate with components of gravitational force that push galaxy clusters away from each other.

We suggest that aspects related to isomers, gravitational components of force that pull objects toward each other, and gravitational components of force that push objects away from each other can help explain the Hubble tension and the S8 tension.

2.2. Suggested Similarities and Differences Between Isomers of Elementary Particles

This unit suggests similarities and differences between the six isomers of elementary particles.

Table 2 suggests a numbering scheme for the six isomers, specifications for the one ordinary-matter isomer and the five dark-matter isomers, and aspects of the stuff that associates with each isomer.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

Table 2. Matches between masses and flavours, for isomers of elementary fermions. The symbol l_{isomer} denotes the isomer number. The symbol $l_{isomer-pair}$ denotes the isomer-pair number. The masses of counterpart elementary particles are, across the isomers, the same. Handedness associates with whether the relevant handed elementary particles are left-handed or right-handed. For each row, the quarks column assigns the three flavour numbers in the order of increasing geometric-mean mass, with the geometric mean associating with the masses for the two quarks that are relevant to the flavour. (The following pertain for the ordinary-matter isomer. Flavour-1 associates with the up quark and the down quark. Flavour-2 associates with the charm quark and the strange quark. Flavour-3 associates with the top quark and the bottom quark.) For each row, the leptons column assigns the three flavor numbers in the order of increasing mass for the one charged lepton that is relevant to the flavour. (The following pertain for the ordinary-matter isomer. Flavour-1 associates with the electron. Flavour-2 associates with the muon. Flavour-3 associates with the tau.) The stuff column identifies stuff made from the isomer as OM, as in ordinary matter, or DM, as in dark matter. The acronym SEA abbreviates our term significantly-electromagnetically-active. The stuff that associates with DM (SEA) interacts electromagnetically with itself on a par with OM stuff interacting electromagnetically with OM stuff. The acronym MEA abbreviates our term marginally-electromagnetically-active. The stuff that associates with MEA interacts electromagnetically with itself marginally, perhaps mostly via the magnetic moments of zero-net-charge objects. PMN abbreviates the two-element term popular-modeling notion. We suggest that some dark matter associates with popular modeling notions of CDM. The acronym CDM abbreviates the popular modeling term collisionless dark matter. We suggest that some dark matter associates with popular modeling notions of self-interacting dark matter. The acronym SIDM abbreviates the popular modeling term self-interacting dark matter.

l_{isomer}	$l_{isomer-pair}$	Handedness	Flavours - quarks	Flavours - leptons	Stuff	PMN
0	0	Left	1, 2, 3	1, 2, 3	OM (SEA)	OM
1	1	Right	1, 2, 3	3, 1, 2	DM (MEA)	CDM
2	2	Left	1, 2, 3	2, 3, 1	DM (MEA)	CDM
3	0	Right	1, 2, 3	1, 2, 3	DM (SEA)	SIDM
4	1	Left	1, 2, 3	3, 1, 2	DM (MEA)	CDM
5	2	Right	1, 2, 3	2, 3, 1	DM (MEA)	CDM

We suggest that the fermion flavour-and-mass pairings for isomer-1, isomer-2, isomer-4, and isomer-5 led to stuff that associates with those isomers forming stable counterparts to isomer-0-stuff neutrons and to stuff that associates with isomer-1, isomer-2, isomer-4, and isomer-5 not forming significant numbers of counterparts to isomer-0-stuff atoms. We use the one-element term alt-isomer to designate an isomer other than isomer-0 and isomer-3. For each one of the six isomers, a charged baryon that includes exactly three flavour-3 quarks is more massive than the counterpart, within the same isomer, zero-charge baryon that includes exactly three flavour-3 quarks. For example, the hadron that includes just two tops and one bottom has a larger total mass than does the hadron that includes just one top and two bottoms. Per Table 2, alt-isomer flavour-3 charged leptons are less massive than isomer-0 flavour-3 charged leptons. When flavour-3 quark states are much populated, the stuff that associates with an alt-isomer converts more charged baryons to zero-charge baryons than does the stuff that associates with isomer-0. Eventually, regarding the stuff that associates with the alt-isomer, interactions that entangle multiple W bosons result in the stuff that associates with the alt-isomer having more counterparts to isomer-0 neutrons and fewer counterparts to isomer-0 protons than does the stuff that associates with isomer-0. The sum of the mass of a counterpart-to-isomer-0 proton and the mass of an alt-isomer flavour-1 charged lepton exceeds the mass of a counterpart-to-isomer-0 neutron. Compared to isomer-0 neutrons, alt-isomer neutrons scarcely decay.

Regarding DM (SEA), we note that some observational results [59–61] suggest that some dark matter might comport with popular modeling notions of self-interacting dark matter [6,62]. Some popular modeling results [63–66] point to possible benefits of considering that some dark matter is self-interacting dark matter.

 doi:10.20944/preprints202505.0381.v1

2.3. SPRISENG - A Suggested Extension of Newtonian Gravity

This unit suggests adding properties, other than mass and spatial distributions of mass, to the list of Newtonian-gravity gravitational properties of objects.

We discuss interactions between an object-A and an object-P. The A in object-A associates with the two-word term active properties. Popular modeling associates active properties with the notion of properties about which fields, such as electromagnetic fields and gravitational fields, convey information. The P in object-P associates with the two-word term passive properties. Popular modeling associates passive properties with interactions, by object-P, with fields that associate with objects, such as object-A, other than object-P.

The following notions contrast aspects of Newtonian force equations and special relativistic interpretations of the values of properties of objects.

- In Newtonian physics, the values of intrinsic properties (such as mass and charge) of an object-A are invariant to special-relativistic notions of the motion of object-A with respect to an observer of object-A (or with respect to a reference frame) and are invariant to special-relativistic notions of the relative motion of object-A with respect to an object-P.
- In special relativity, the values of an intrinsic property of an object-A can vary, based on a choice of an observer or a frame of reference. Here, one can consider that object-P is an observer. The magnitudes of the variations, away from values that associate with a frame of reference in which object-A is at rest, can associate with a nonzero velocity and with nonzero values for the object-A intrinsic-property current that associates with an intrinsic property of object-A.

We discuss Newtonian gravity.

Eq. (1) describes an aspect of the motion of object-P [67]. G is the gravitational constant. m_A is the mass of object-A. Mass is a scalar property. m_P is the mass of object-P. r is the scalar distance that object-P is away from object-A. $\bigtriangledown$ is the gradient operator. $\bigtriangledown$ produces a 3-vector from a scalar. F_P is the force that object-P feels. F_P is a 3-vector. Object-P might sense effects of that force via an accelerometer that associates with object-P.

$$Gm_A m_P(-\nabla(1/r)) = F_P \tag{1}$$

Eq. (1) describes, for example, motion in which one body orbits the other body. Newtonian physics includes the notion that each of the two objects can exhibit nonzero motion. In Newtonian physics, each one of m_A and m_P is invariant to a special-relativistic choice of a frame of reference. We use the notation $m_{X,rest}$ to denote the rest mass of object-X. Regarding special relativity, a rest property of object-X associates with a frame of reference in which object-X is not moving. For Newtonian gravity, we suggest that Eq. (2) and Eq. (3) pertain in all frames of reference.

$$Gm_{A,rest} m_{P,rest}(-\nabla V) = F_P \tag{2}$$

$$V = 1/r \tag{3}$$

Eq. (4) provides notation for the 3-vector velocity of object-A relative to object-P.

$$v_{A,rel.to.P} \tag{4}$$

$v_{A,rel.to.P}$ is not necessarily relevant regarding Eqs. (1), (2), and (3).

We shift our focus away from gravitation. We focus on special relativity.

In some of the following equations, the following notions pertain. A numeric subscript denotes the rank of the relevant tensor. For example, one denotes a 1-tensor (as in a 3-vector). $|\cdots|^2$ denotes the mathematical notion of a tensor dot product. The dimensions of square of energy associate with

 doi:10.20944/preprints202505.0381.v1

each term in an equation. E_0 associates with special-relativistic notions of energy. m_0 associates with special-relativistic notions of rest mass. p_1 associates with special-relativistic notions of momentum. We associate $|p_1|^2$ with the square of a motion-related energy that an observer might associate with nonzero linear momentum. These equations do not explicitly specify factors for converting values of properties, such as momentum or angular momentum, to values of energies.

Eq. (5) echoes aspects of special relativity.

$$|E_0|^2 = |m_0|^2 + |p_1|^2 \tag{5}$$

We shift our focus to a combination of Newtonian gravitation and perceptions, that comport with special relativity, of properties of objects.

Object-P perceives an object-A mass m_A that associates with E_0 and that is greater than the rest mass $m_{A,rest}$ of object-A when $v_{A,rel.to.P}$ is nonzero. (By definition, $m_{A,rest} = m_0$.) Object-P perceives an object-A mass current that associates with p_1 and that is nonzero when $v_{A,rel.to.P}$ is nonzero.

Eq. (5) is quadratic with respect to properties of objects.

In popular modeling, dynamics equations, such as Eq. (2), are linear with respect to properties of objects.

Discussion below related to Eq. (13) and so-called case-e1 shows how popular modeling can, in effect, correct a scalar potential that would associate with m_A and with a nonzero mass current to comport with a scalar potential that would associate with $m_{A,rest}$ and with Eq. (2). (That discussion involves familiar concepts, such as the scalar potential and the vector potential, that associate with electromagnetism.) A key notion is that, regarding dynamics, effects that associate with p_1 can dilute effects that associate with E_0. Regarding an interaction between an object-A and an object-P for which the only nonzero gravitational property is mass, the component of gravity that associates with E_0 for object-A associates with attraction of object-P toward object-A. Regarding an interaction between an object-A and an object-P for which the only nonzero gravitational property is mass, the component of gravity that associates with p_1 for object-A associates with repulsion of object-P away from object-A.

Popular modeling suggests properties other than mass that might be candidates for our notions of gravitational properties. One such property might be object-internal angular momentum.

We expand our focus to a combination of Newtonian gravitation and perceptions, that comport with extensions to special relativity, of properties of objects.

We associate $|s_1|^2$ with the square of a spin-related energy that an observer might associate with nonzero (intrinsic to the object) angular momentum. We suggest that transiting from zero intrinsic angular momentum to nonzero intrinsic angular momentum associates with adding energy. We suggest Eq. (6).

$$|E_0|^2 = |m_0|^2 + |p_1|^2 + |s_1|^2 \tag{6}$$

Discussion below related to Eq. (13) and so-called case-e2 shows how popular modeling can, in effect, correct a scalar potential that would associate with m_A and with a nonzero object-internal angular momentum to comport with a scalar potential that would associate with $m_{A,rest}$ and with Eq. (2). (That discussion involves familiar concepts, such as the scalar potential and the vector potential, that associate with electromagnetism.)

We suggest that Eq. (6) can associate with modeling that associates with a spherically symmetric object.

We suggest that transiting from modeling that associates with a spherically symmetric object to modeling that can associate with a non-spherically-symmetric object can associate with an equation of the form that Eq. (7) shows. E_2 can associate with a moments-of-inertia tensor and can correct for a lack of spherical symmetry. In effect, regarding dynamics, p_3 corrects p_1. s_3 corrects s_1.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

$$|E_0|^2 + |E_2|^2 = |m_0|^2 + |p_1|^2 + |s_1|^2 + |p_3|^2 + |s_3|^2 \tag{7}$$

Eq. (8), with $m_0 = m_{A,rest}$, provides perspective regarding developing a multipole expansion for the $m_{A,rest}$ in Eq. (2).

$$|m_0|^2 = +|E_0|^2 - |p_1|^2 - |s_1|^2 + |E_2|^2 - |p_3|^2 - |s_3|^2 \tag{8}$$

We define the symbol n_k to be one plus the rank of the relevant tensor. For example, for a one-tensor, $n_k = 2$.

Equations such as Eq. (8) are quadratic with respect to properties of objects.

In popular modeling, dynamics equations, such as Eq. (2), are linear with respect to properties of objects. Per discussion below related to Eq. (13) and case-e2, notions of binding (or object-internal) energies are not necessarily relevant.

We shift our focus back to just gravitation.

Table 3 lists some gravitational object-intrinsic properties that an object-P might associate with an object-A.

Table 3. Some gravitational object-intrinsic properties that an object-P might associate with an object-A. For each nonzero-valued intrinsic property, there is a contribution (to an overall potential) that has radial characteristics that associate with $V(r) \propto r^{-n_r}$. r denotes the distance from object-A. For a property for which $n_k > 1$, non-constant angular-dependence pertains regarding that property's contribution to an overall $V(r)$. Uses of the words monopole, dipole, and so forth associate with values of n_r and echo popular modeling uses of the words. Regarding mass, one set of three independent parameters associates with position. Also, the word scalar associates with zero-tensor. Regarding angular momentum, one set of three independent parameters associates with position. Another set of three independent parameters associates with the three components of the angular momentum 3-vector. Also, the word vector associates with one-tensor. Regarding moments of inertia, one set of three independent parameters associates with position. Another set of three independent parameters associates with the three on-diagonal components of the 3-by-3 symmetric moments-of-inertia tensor. Another set of three independent parameters associates with three off-diagonal components of the 3-by-3 symmetric moments-of-inertia tensor. The case of rotating moments of inertia adds, compared to the case of moments of inertia, one set of three parameters that associate with the angular velocity 3-vector that associates with the rotation of object-A. We suggest that the notion of four-tensor pertains. Throughout this table, n_k equals the number of sets of three parameters. EM abbreviates the word electromagnetic. NNR denotes not necessarily relevant for our discussion. We anticipate de-emphasizing the notion of possibly relevant intrinsic-property hexadecapole potentials.

One-body intrinsic property	n_k	n_r	Potential	Notes re potential	EM analog
Mass	1	1	Monopole	Zero-tensor	Charge
Angular momentum	2	2	Dipole	One-tensor	Magnetic moment
Moments of inertia	3	3	Quadrupole	Two-tensor	NNR
Moments-of-inertia rotation	4	4	Octupole	Three-tensor	NNR
NNR	5	5	Hexadecapole	Four-tensor	NNR

We suggest that Table 3 associates with a new type of gravitational multipole expansion. In each of popular modeling multipole expansions and our multipole expansions, an expansion features a series of terms. Each term contributes via addition or subtraction to a notion of an overall spatial potential. In popular modeling, a multipole expansion tends to have a basis in a spatial distribution of one property such as charge or mass. Our multipole expansions feature one object that models spatially as somewhat pointlike and physically as having at least one nonzero-valued property.

Popular modeling suggests that the object-property of mass is always nonnegative. In the context of two-body interaction potentials, the contribution that associates with the mass of object-A interacting with the mass of object-P associates with a pull component of force.

 doi:10.20944/preprints202505.0381.v1

For each intrinsic property, there is also a property for which the name is the one-body-intrinsic-property name followed by the word current. The notion of current associates with a set of three velocity parameters. The n_k for a current exceeds by one the n_k for the counterpart intrinsic property. The n_r that associates with a current equals the n_r that associates with the counterpart intrinsic property. (We note, as an aside, that we suggest that, for the same n_r, a continuation to an n_k that exceeds by two the n_k for the counterpart intrinsic property would associate with a nonzero acceleration and with the notion that, from the perspective of object-P, object-A would model as part of a system, of objects, for which the system does not necessarily include object-P.)

Table 4 lists some contributions, by an object-A, to gravitational forces, as perceived by an object-P. Table 4 extends Table 3.

Table 4. Some contributions, by an object-A, to gravitational forces, as perceived by an object-P. The value of each property is the value as perceived by object-P. Pull associates with notions of attraction of object-P toward object-A. Push associates with notions of repulsion of object-P away from object-A. RSD abbreviates the three-word term radial spatial dependence that associates with the component of force. The values of the exponents for RSD items echo the popular modeling notion that a force can associate with the gradient of a potential. Type associates with relevant intrinsic properties. Notions of monopole, dipole, and so forth echo popular modeling use of such terms. For example, a row for which the RSD is r^{-2} associates with a potential, that associates with object-A, for which $n_r = 1$. However, for a current property, the velocity-related 3-vector associates with an extra (compared to for the counterpart intrinsic property) notion of angular dependence. For example, for the second row in the table, the force varies based on the angle with respect to the velocity-related 3-vector that associates with the object-A mass current, even though, for the first row, the force does not vary based on angular coordinates.

Object-A property	n_k	Object-P property	Force	RSD	Type
Mass	1	Mass	Pull	r^{-2}	Monopole
Mass current	2	Mass	Push	r^{-2}	Monopole
Angular momentum	2	Mass	Push	r^{-3}	Dipole
Angular-momentum current	3	Mass	Pull	r^{-3}	Dipole
Moments of inertia	3	Mass	Pull	r^{-4}	Quadrupole
Moments-of-inertia current	4	Mass	Push	r^{-4}	Quadrupole
Moments-of-inertia rotation	4	Mass	Push	r^{-5}	Octupole
Moments-of-inertia-rotation current	5	Mass	Pull	r^{-5}	Octupole
Mass	1	Angular momentum	Push	r^{-3}	Dipole
Mass current	2	Angular momentum	Pull	r^{-3}	Dipole
Angular momentum	2	Angular momentum	Pull	r^{-4}	Quadrupole
Angular-momentum current	3	Angular momentum	Push	r^{-4}	Quadrupole
Moments of inertia	3	Angular momentum	Push	r^{-5}	Octupole
Moments-of-inertia current	4	Angular momentum	Pull	r^{-5}	Octupole
Moments-of-inertia rotation	4	Angular momentum	Pull	r^{-6}	Hexadecapole

For a pair of rows, in Table 4, that associate with the object-P property of mass and with the same RSD, we suggest that the pull (or push) that associates with an object-A intrinsic property dominates the push (or, respectively, pull) that associates with the counterpart object-A intrinsic-property current. We suggest that, at least statistically, similar notions pertain regarding each pair of rows in Table 4 that associates with the object-P property of angular momentum and with the same RSD.

For a pair of rows, in Table 4, that associate with the object-P property of mass and with two different object-A non-current properties such that one row associates with pull and the other row associates with push, we suggest that dominance with respect to pull or push depends on r. For example, consider the object-A properties of mass and angular momentum. For adequately large values of r, pull dominates. For lesser values of r, push can dominate. (We note, as an aside, that for yet lesser values of r, the notion that the objects are not colliding might no longer pertain.)

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

2.4. Instances of Properties of Objects, Plus Reaches per Instance of Contributions to Fields

This unit suggests that two integers, a number of instances and a reach per instance, associate with each electromagnetic property of objects and with each gravitational property of objects. This unit suggests a formula that interrelates, for each property, the number of instances and the reach per instance. This unit suggests that determining numbers of instances and reaches per instance is key to our fitting and explaining cosmic data and to our providing insight about cosmology tensions. This unit suggests, for some properties, numbers of instances and reaches per instance that help fit and explain data.

Popular modeling suggests that ordinary matter does not, at least much, sense electromagnetic phenomena that might associate with dark matter. We suggest that each isomer associates with its own instance of the electromagnetic monopole property, which is charge. We say that a monopole contribution to the electromagnetic field has a reach of one isomer. An object that associates just with one isomer might sense monopole electromagnetic contributions that associate with other same-isomer objects. An object that associates just with one isomer would not sense monopole electromagnetic contributions that associate just with objects that do not associate with the same isomer.

Popular modeling suggests that ordinary matter and dark matter sense each other gravitationally. We suggest that all six isomers associate with a common instance of the gravitational monopole property, which is mass. We say that a monopole contribution to the gravitational field has a reach of six isomers. An object that associates just with one isomer senses monopole gravitational contributions that associate with objects that associate just with any one isomer or that associate with more than one isomer.

We use the symbol n_{in} to denote the number of instances of a property. We use the symbol $R_{/in}$ to denote the reach of an instance of the property. The reach is a number of isomers. Each one of n_{in} and $R_{/in}$ is a positive integer.

We suggest that, for each electromagnetic property and for each gravitational property, Eq. (9) pertains.

$$n_{in} \cdot R_{/in} = 6 \tag{9}$$

Eq. (9) pertains regarding properties, such as properties that Table 3 lists, of individual objects.

To the extent that no property associates with $n_{in} = 2$ and $R_{/in} = 3$, for components, such as components that Table 4 lists, that associate with two-body interactions, we suggest that Eq. (10) and Eq. (11) pertain. $\max(S)$ denotes the maximum value of elements of the set S. $\min(S)$ denotes the minimum value of elements of the set S.

$$n_{in} = \max(\{n_{in,property.of.A}, n_{in,property.of.P}\}) \tag{10}$$

$$R_{/in} = \min(\{R_{/in,property.of.A}, R_{/in,property.of.P}\}) \tag{11}$$

Some aspects of our attempts to fit data associate with suggesting numbers of instances and reaches per instance for aspects, of gravitational fields, that associate with gravitational properties of objects. Some aspects of our attempts to provide insight regarding cosmological tensions use numbers of instances and reaches per instance for aspects, of gravitational fields, that associate with gravitational properties of objects. Some aspects of our attempts to fit data associate with suggesting numbers of instances and reaches per instance for aspects, of electromagnetic fields, that associate with electromagnetic properties of objects.

Table 5 suggests instances and reaches per instance for some one-body gravitational properties and for some one-body electromagnetic properties.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

Table 5. Instances and reaches per instance for some one-body gravitational properties and for some one-body electromagnetic properties. Reach/instance denotes reach, in number of isomers, per instance. G2BF denotes gravitational two-body force. The gravitational instances, reaches, and G2BF information pertain for interactions with the mass of a second object. The choice of a reach per instance of one isomer for blackbody temperature associates with the notion that people do not observe thermal radiation from stars other than ordinary-matter stars. TBD denotes to be determined. We suggest that the reach per instance for magnetic moment might be one. We suggest that the reach per instance of hyperfine state might be two or six. NR denotes not relevant.

Type of property	n_k	Intrinsic property	Instances	Reach/instance	G2BF
Gravitational	1	Mass	1	6	Pull
Gravitational	2	Internal angular momentum	3	2	Push
Gravitational	3	Moments of inertia	6	1	Pull
Gravitational	4	Rotating moments-of-inertia	TBD	TBD	Push
Electromagnetic	1	Charge	6	1	NR
Electromagnetic	2	Blackbody temperature	6	1	NR
Electromagnetic	2	Magnetic moment	TBD (6)	TBD (1)	NR
Electromagnetic	TBD	Hyperfine state	TBD (3 or 1)	TBD (2 or 6)	NR

More generally, we suggest that people might want to consider using present and future data to suggest numbers of instances for each one of various properties.

2.5. Cosmic Clumping of Stuff

This unit suggests that, from the perspective of dominant multipole aspects of gravitational forces, the formation and evolution of smaller cosmic objects occur more quickly than do the formation and evolution of larger cosmic objects.

We assume, for discussion purposes, that, at some time in the evolution of the universe, stuff (ordinary matter and dark matter) had a uniform spatial distribution. We assume that, at that time, bunches of stuff were moving away from each other. We de-emphasize notions related to properties that associate with the word current.

We consider Newtonian notions. We consider two spatially non-overlapping, similarly-sized spherical regions of stuff. The amount of stuff in each region scales as the cube of the radius of the region. The monopole contribution to the gravitational force that one region exerts on the other region scales inversely as the square of the distance between the centers of the two regions. If one scales the two radii and the one distance similarly, the monopole aspect of gravitational force scales as $r^3 r^3 r^{-2} = r^4$. Dipole aspects scale as $r^3 r^3 r^{-3} = r^3$. Quadrupole aspects scale as $r^3 r^3 r^{-4} = r^2$. Octupole aspects scale as $r^3 r^3 r^{-5} = r^1$. Hexadecapole aspects scale as $r^3 r^3 r^{-6} = r^0$.

We suggest that the following notions pertain for Newtonian models and for other relevant popular modeling models.

We suggest notions that might associate with observed and possible clumping, at various scale sizes, in the history of the universe. Hexadecapole attraction might be scale-invariant and might not necessarily be adequately relevant for this discussion of clumping. Across a range of sizes, octupole repulsion was dominant at some time. Smaller clumps transited a sequence, of octupole repulsion to quadrupole attraction and onward, faster than did larger clumps. Typically, pairs of neighboring solar-system-sized clumps transited to dominance by monopole attraction before pairs of neighboring galaxy-sized clumps transited to dominance by monopole attraction. Typically, pairs of neighboring galaxy-sized clumps transited to dominance by monopole attraction before pairs of neighboring galaxy-cluster-sized clumps might transit to dominance by monopole attraction.

2.6. Single-Object Properties and Regional Properties

This unit discusses possible associations between our notions of single-object properties and general-relativistic notions of regional properties such as energy density.

Our work above has bases in properties of individual objects. Popular modeling includes two properties, energy and momentum, of objects that our work above scarcely mentions.

We suggest (based in part on Eq. (6)) that, from a standpoint of object-P, each $n_k \leq 2$ gravitational intrinsic property of object-A contributes nonnegatively to a pointlike energy that object-P can associate with object-A. The mass of object-A can associate with a ground-state energy of object-A. Nonzero internal angular momentum associates with energy that is above ground-state energy.

Similarly, we suggest that each one of mass current and angular-momentum current contributes a pointlike momentum that object-P can associate with object-A.

General relativity has bases in a stress-energy tensor that has bases in properties (such as densities) that associate with regions.

Table 6 suggests associations between SPRISENG properties of objects and general relativistic properties that associate with regions.

Table 6. Associations between SPRISENG properties of objects and general relativistic properties that associate with regions. We suggest that these associations might suffice for discussions in this paper.

SPRISENG properties (of objects)	General-relativistic properties (of regions)
Energy	Energy density
Energy minus rest mass	Pressure
Momentum	Momentum density and energy flux
Momentum minus mass-current	Momentum flux and shear stress

3. Results

This unit summarizes notions that our methods fit otherwise seemingly unexplained cosmic data, including data about dark-matter effects, the rate of expansion of the universe, and galaxy evolution. This unit summarizes suggestions that our work provides insight regarding cosmology tensions.

This unit generally follows a sequence that the rows of Table 1 suggest.

3.1. Dark-Matter Elementary Particles and Dark-Matter Stuff

This unit points to the notion that our work suggests a well-defined and possibly useful specification for dark-matter elementary particles. This unit points to the notion that our work suggests a description of dark-matter stuff that has bases in those dark-matter elementary particles.

We suggest that most dark matter comports with popular modeling notions of collisionless dark matter and that some dark matter comports with popular modeling notions of self-interacting dark matter.

Table 2 suggests a numbering scheme for our suggested six isomers of most elementary particles, specifications for the one ordinary-matter isomer of elementary particles and the five dark-matter isomers of elementary particles, and aspects of the stuff that associates with each isomer.

3.2. Hyperfine Depletion of Cosmic Microwave Background Radiation

This unit suggests that our work explains the observed depletion of cosmic microwave background radiation for which half of the depletion associates with hyperfine transitions in hydrogen atoms.

Regarding the observed depletion of cosmic microwave background radiation, popular modeling suggests that the second 1 in the 1:1 ratio associates with hyperfine effects of ordinary-matter hydrogen atoms. We suggest that the first 1 in the 1:1 ratio associates with hyperfine effects of hydrogen-like atoms that associate with isomer-3.

We suggest that above-discussed notions of two-body electromagnetism might not suffice to ascribe a number of instances and a reach per instance that would associate with atomic-state transitions.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

For example, a hydrogen-atom object-A might not model as a one-body system but might model as a two-body system, with one-body being the atomic nucleus and one-body being the electron cloud.

Table 5 suggests that the reach for hyperfine-transition phenomena might be either two or six. A reach of two can suffice to explain the notion that isomer-3 hydrogen-like atoms can absorb, via hyperfine transitions, energy that associates with contributions, by ordinary-matter stuff, to electromagnetic fields. A reach of six might be appropriate, given that four dark-matter isomers might not underlie an adequately significant number of hydrogen-like atoms.

3.3. Galaxy Formation and Galaxy Evolution

This unit suggests galaxy formation scenarios that seem to explain seemingly naturally preferred known ratios, for galaxies, of dark-matter presence to ordinary-matter presence.

The solar system that includes the Earth associates with the notion of a solar-system-size clump of stuff that associates with just one isomer. Our solar system is not spatially spherical.

We suggest that many other such one-isomer, not-spatially-spherical, somewhat-solar-system-sized clumps exist and generally date to early in the history of the universe. We suggest that such clumps associate with nonzero moments of inertia. Discussion above suggests that moments of inertia is a quadrupole gravitationally attractive property. Table 4 and Table 5 suggest that a reach per instance of one isomer pertains.

We suggest that, during some period early in the history of the universe, quadrupole gravitational attraction dominated regarding interactions between neighboring same-isomer, solar-system-sized clumps. Table 4 and Table 5 suggest that a reach per instance of one isomer pertains. We suggest that solar-system-sized clumps clumped to form the halos of galaxies.

We suggest that the discussion above explains 1:0+ ratios that pertain to some early galaxies and 0+:1 ratios that pertain to some early galaxies.

We suggest that some later 1:0+ galaxies and some later 0+:1 galaxies retain their ratios from early in the evolution of the universe.

For each of some $\sim$ 4:1 galaxies, we suggest the following scenario. The galaxy started as a 0+:1 galaxy. Table 4 and Table 5 suggest that a reach per instance of two isomers pertains for dipole interactions. Reach-2 repelling dipole contributions to gravity drove away some ordinary-matter stuff and the stuff that associated with one dark-matter isomer. That one dark-matter isomer is isomer-3. Table 4 and Table 5 suggest that a reach per instance of six isomers pertains for monopole interactions. Reach-6, attracting monopole contributions to gravity attracted remaining nearby stuff. The galaxy evolved to a ratio of $\sim$ 4:1.

For each of some $\sim$ 4:1 galaxies, we suggest the following scenario. The galaxy started as a 1:0+ galaxy. Table 4 and Table 5 suggest that a reach per instance of two isomers pertains for dipole interactions. Reach-2 repelling dipole contributions to gravity drove away some dark-matter stuff but essentially no ordinary-matter stuff. Table 4 and Table 5 suggest that a reach per instance of six isomers pertains for monopole interactions. Reach-6 attracting monopole contributions to gravity attracted remaining nearby stuff. The galaxy evolved to a ratio of $\sim$ 4:1.

Many later galaxies are 5+:1 galaxies. We suggest that many 5+:1 galaxies resulted from mergers of smaller, previous galaxies. We suggest that such mergers associate with monopole gravitational attraction. Table 4 and Table 5 suggest that a reach per instance of six isomers pertains. We suggest that the earliest mergers that led to a 5+:1 galaxy could have been mergers that involved 1:0+ galaxies and 0+:1 galaxies.

3.4. The Pluses in 5+:1 Ratios of Dark-Matter Effects to Ordinary-Matter Effects

This unit suggests explanations for the pluses in the 5+:1 ratios of dark-matter effects to ordinary-matter effects.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

Popular modeling suggests that 5+:1 ratios of dark-matter effects to ordinary-matter effects pertain for many galaxies, many galaxy clusters, and for densities of the universe.

We suggest that nature might include electromagnetic properties (of objects) that would associate with reach-6. Table 5 provides a possible example. Based on the reach-6 properties, early in the evolution of the universe, more electromagnetic energy would flow from isomer-pair-0 stuff to isomer-pair-1 stuff than would flow from isomer-pair-1 stuff to isomer-pair-0 stuff. Similarly, based on the reach-6 properties, early in the evolution of the universe, more electromagnetic energy would flow from isomer-pair-0 stuff to isomer-pair-2 stuff than would flow from isomer-pair-2 stuff to isomer-pair-0 stuff.

We suggest that the electromagnetic energy flow imbalances would result in the existence of more isomer-pair-1 stuff than isomer-pair-0 stuff and in the existence of more isomer-pair-2 stuff than isomer-pair-0 stuff. We suggest that the flows would not disturb a one-to-one ratio of presence of isomer-3 stuff to presence of isomer-0 stuff.

We suggest that these energy flow imbalances might have produced (or, at least, contributed to) the pluses in the 5+:1 ratios of dark-matter presence to ordinary-matter presence.

Our work does not necessarily rule out the possibility that some portions of (or the entireties of) the pluses in the 5+:1 ratios of dark-matter presence to ordinary-matter presence associate with axions or with other popular modeling suggestions regarding the nature of dark matter.

3.5. Collisions of Galaxy Clusters

This unit suggests that our specification for dark matter might not necessarily be incompatible with data about collisions of galaxy clusters.

Our specification for dark matter might not necessarily be incompatible with data about collisions, such as the Bullet Cluster collision, of two galaxy clusters [68,69]. Popular modeling suggests two types of trajectories for stuff. Most dark matter, from either one of the clusters, exits the collision with trajectories that are consistent with having interacted just gravitationally with the other cluster. Ordinary matter stars, from either cluster, exit the collision with trajectories that are consistent with having interacted just gravitationally with the other cluster. However, ordinary matter intergalactic medium, from either cluster, lags the cluster's ordinary matter stars and dark matter. Popular modeling suggests that the ordinary matter intergalactic medium interacted electromagnetically with the other cluster's ordinary matter intergalactic medium, as well as gravitationally with the other cluster. We suggest that the four alt-isomers do not form much electromagnetically active intergalactic medium. We suggest that further analysis of data might help determine the validity of our notion that isomer-3 would form electromagnetically interactive intergalactic medium.

3.6. Eras in the Rate of Expansion of the Universe

This unit suggests that eras in the rate of expansion of the universe associate with multipole aspects of gravitational interactions between galaxy clusters.

Popular modeling suggests that, in our terms, monopole pull gravity generally dominates for neighboring non-colliding solar systems. Popular modeling suggests that, in our terms, monopole pull gravity generally dominates for neighboring non-colliding galaxies. We suggest that observations that associate with the six-word term rate of expansion of the universe associate with interactions between neighboring non-colliding galaxy clusters.

Table 7 suggests possible explanations for some phenomena regarding the evolution of the universe.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

Table 7. Possible explanations for some phenomena regarding the evolution of the universe. We suggest the possibilities that this table lists for before inflation and for the start of inflation. (Some popular modeling suggests notions of a so-called big-crunch.) Popular modeling suggests an inflationary epoch. Observations suggest the two multibillion-year eras. We (and possibly some observations) suggest a possible period after the later multibillion-year era. ROE abbreviates the six-word phrase rate of expansion of the universe. The words push and pull refer to gravitational effects. NNCGC abbreviates the four-element term neighboring non-colliding galaxy clusters.

Phenomena	Explanation
Before inflation	Hexadecapole pull
Start of inflation	Pauli-exclusion bounce
Early inflationary epoch ROE	Octupole push (between proto NNCGC)
Start of the earlier multibillion-year era (decreasing ROE)	Quadrupole pull (between NNCGC)
Start of the later multibillion-year era (increasing ROE)	Dipole push (between NNCGC)
After the later multibillion-year era (decreasing ROE)	Monopole pull (between NNCGC)

There may be no data that directly pertain to before or during the would-be inflationary epoch [70–74]. Above, we note that some recent data hint at an era that could follow the later multibillion-year era. Our notions regarding before inflation, early in the inflationary epoch, and after the later multibillion-year era might comport with some popular modeling notions of bounce cosmology [75,76].

Regarding dominance by hexadecapole gravitational attraction, one might need to suggest a non-gravitational mechanism that associates with a transition from a big crunch [77] to a big bang. Without a notion such as the notion of a bounce based on fermion particles and the Pauli-exclusion principle, hexadecapole pull might lead toward effects that would associate with 32-pole aspects. The word dotriacontapole and the word triacontadipole associate with 32-pole. Assuming that hexadecapole gravitational attraction pertained, we suggest that the reach per instance for each one of hexadecapole gravitational attraction and octupole gravitational repulsion might be six isomers. Consequences of those reaches being six might associate with notions that, throughout the known evolution of the universe, large-scale densities of stuff tend to be, to a first approximation, spatially uniform [78].

This paper de-emphasizes the possibility that popular modeling will identify structures larger than galaxy clusters for which people will discuss notions that parallel notions that we associate with rates of expansion or rates of contraction. (We note, as an aside, that, to the extent that such larger structures follow our notions of multipole gravity, perhaps dipole repulsion dominates for interactions between some such structures now and for some time into the future.)

3.7. The Hubble Tension

This unit suggests that our work provides a qualitative explanation for the Hubble tension.

Popular modeling estimates for a Hubble constant that would associate with the early universe suggest a Hubble constant that is significantly less than estimates for a Hubble constant that would associate with the recent universe. Estimates tend to associate [79] with Eq. (12). c denotes the speed of light. ρ denotes energy density and is nonnegative. P denotes pressure and is nonpositive.

$$-(c\rho + 3P) \tag{12}$$

Popular modeling suggests that an increasing rate of expansion associates with Eq. (12) evaluating to a positive number. Popular modeling suggests that a decreasing rate of expansion associates with Eq. (12) evaluating to a negative number.

Table 7 suggests that interactions between galaxy clusters provide a basis for the rate of expansion. Regarding around the beginning of the multibillion-year era of decreasing rate, attraction (between neighboring non-colliding galaxy clusters) that associates with $n_k = 3$ two-body gravitational pull dominates regarding changes in the rate of expansion. Regarding around the beginning of the multibillion-year era of increasing rate, repulsion (between neighboring galaxy clusters) that associates with $n_k = 2$ two-body gravitational push dominates regarding changes in the rate of expansion.

Table 8 suggests dominant contributions to pressure, relevant to popular modeling rate-of-expansion calculations, at selected times in the evolution of the universe. In Table 8, each one of the two numerically specified pairs of one n_{in} and one $R_{/in}$ comports with Table 5 and with data about galaxy evolution.

Table 8. Dominant contributions to pressure, relevant to popular modeling rate-of-expansion calculations, at selected times in the evolution of the universe. The information about dominant property, n_k, gravitational instances n_{in}, and reaches per instance $R_{/in}$ pertains for interactions with the mass of a second object. TBD denotes to be determined. We do not know of enough data to determine the two TBD integers. PNR denotes possibly not relevant. For the possible future era, we suggest that the property of pressure loses significance compared to the significance of energy density.

Approximately at the start of ...	Dominant property	n_k	n_{in}	$R_{/in}$
Inflation	Moments-of-inertia rotation	4	TBD	TBD
The multibillion-year era of decreasing rate	Moments of inertia	3	6	1
The multibillion-year era of increasing rate	Internal angular momentum	2	3	2
A possible future era	(None)	PNR	PNR	PNR

We suggest that a reach per instance of one for pressure associates with the start of the multibillion-year era of decreasing rate of expansion of the universe. We suggest that a reach per instance of two for pressure associates with the start of the multibillion-year era of increasing rate of expansion of the universe. We suggest that extrapolating from so-called early-universe pressures would lead to underestimations of so-called later-universe pressures. Underestimations of later-universe pressures would associate with underestimations of later-universe values of the Hubble constant.

3.8. The S8 Tension

This unit suggests that our work provides a qualitative explanation for the S8 tension.

We suggest that large-scale lumpiness associates, at least in part, with an $n_k = 4$-through-$n_k = 2$ sequence that we suggest above regarding galaxy evolution and regarding the rate of expansion of the universe. We suggest that popular modeling would underestimate repulsion that we associate with $n_k = 2$. We suggest that the underestimate associates with overestimates, by popular modeling, of large-scale lumpiness.

4. Discussion

This unit discusses notions of how our work fits with and might help enhance popular modeling that pertains to cosmology. This unit suggests some possible opportunities for observational or experimental work that might help regarding verifying or refuting aspects of our work.

4.1. Parallels Between Gravitational Dynamics and Electromagnetic Dynamics

This unit provides perspective, based on familiar electrodynamics, regarding our methods that merge Newtonian gravitational forces and special relativistic properties of objects.

We focus on electromagnetism. (We suggest, as asides, the following notions. People have familiarity with aspects of electromagnetism that associate with special relativity. People do not have as much familiarity with parallel aspects of gravitation that might associate with special relativity. Our work might have some parallels to work that popular modeling associates with the word gravitoelectromagnetism [80–83].)

We consider cases in which an object-P experiences electromagnetic forces that associate with an object-A.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

Relevant quantities include $q_{P,rest}$, $q_{A,rest}$, $v_{A,rel.to.P}$, q_A, ϕ_A, and A_A. q denotes charge. q_A, ϕ_A, and A_A denote respectively the charge that object-P would associate with object-A, the electromagnetic scalar potential that object-P would associate with object-A, and the electromagnetic 3-vector vector potential that object-P would associate with object-A. In popular modeling, ϕ_A and A_A combine to form a special relativistic 4-vector. Each item of the form X_A can refer to a retarded-time quantity. For each one of q_A, ϕ_A, and A_A, the magnitude (near object-P) of the value increases with increasing $|v_{A,rel.to.P}|$. For each one of q_A and ϕ_A, the magnitude (near object-P) of the value does not depend on the 3-vector direction that associates with $v_{A,rel.to.P}$.

We suggest that Eqs. (3) and (13) pertain in all frames of reference. ε_0 denotes the vacuum electric permittivity. q denotes charge.

$$-(1/(4\pi\varepsilon_0))q_{A,rest}q_{P,rest}(-\nabla(1/r)) = F_P \quad (13)$$

Popular modeling provides the following equations. E_A denotes the electric field that object-P associates with object-A. v_P denotes the velocity of object-P. B_A denotes the magnetic field that object-P associates with object-A. Each one of E_A, v_P, and B_A is a 3-vector. The scalar potential ϕ_A and the vector potential A_A combine to form a 4-vector. $\partial.../\partial t$ denotes a partial derivative with respect to time. The equations are invariant with respect to a choice of a frame of reference. Values for a variable in an equation can vary, based on the choice of a frame of reference.

$$F_P = q_P(E_A + (v_P \times B_A)) \quad (14)$$

$$E_A = -\nabla\phi_A - \partial A_A/\partial t \quad (15)$$

$$B_A = \nabla \times A_A \quad (16)$$

We discuss interpretations with respect to the rest frame that associates with object-P. (We note, as an aside, that choosing this rest frame associates with standardizing some notions regarding the time t, though this paper does not necessarily directly take advantage of such standardization. Choosing this rest frame associates with standardizing notions of lengths, such as distances r away from object-A.) This paper acknowledges and de-emphasizes notions that distances r may pertain to present times for object-P and earlier times for object-A. We suggest that, for the purposes of this paper, time delays regarding the propagation of information about object-A are not necessarily adequately important to warrant more careful attention to the delays. Eq. (17) pertains.

$$v_P = 0 \quad (17)$$

Thus, based on Eq. (14), the value of B_A is not relevant regarding F_P. However, Eq. (15) suggests that A_A can still have relevance regarding F_P.

We use the symbol μ_A to denote the magnetic moment that object-P associates with object-A. μ_A is a 3-vector.

We discuss a so-called case-e1.

For case-e1, we make the following assumptions. $q_{A,rest} \neq 0$. $\mu_{A,rest} = 0$. $q_{P,rest} \neq 0$. No electromagnetic property, other than $q_{P,rest}$, of object-P is nonzero.

Popular modeling suggests that the following equations pertain. I_A is the charge current (or current of charge) that associates with object-A. I_A is a 3-vector. I_A associates with both the charge q_A and the velocity $v_{A,rel.to.P}$. $A_{A,I}$ is a 3-vector. $A_{A,I}$ contributes to A_A.

$$\phi_A \propto q_A/r \quad (18)$$

 doi:10.20944/preprints202505.0381.v1

$$A_{A,I} \propto I_A/r \tag{19}$$

Popular modeling suggests that, if object-P would infer that the magnitude of $v_{A,rel.to.P}$ is nonzero, object-P would infer that $|\nabla\phi_A|/|\nabla\phi_{A,rest}|$ exceeds one, that $q_A/q_{A,rest}$ exceeds one, and that $|E_A|/|E_{A,rest}|$ exceeds one.

We suggest that, to maintain Eq. (15) and parallels to Newtonian gravity, one can select a new (additive) contribution $A_{A,v}$ to A_A to satisfy Eq. (20).

$$-\nabla\phi_{A,rest} = E_A = -\nabla\phi_A - \partial A_{A,v}/\partial t \tag{20}$$

$$A_A = A_{A,I} + A_{A,v} \tag{21}$$

We suggest that we can consider (for purposes of this discussion) using popular modeling for which each one of q_A, ϕ_A, $v_{A,rel.to.P}$, I_A, and $A_{A,I}$, is a constant with respect to the time t. If object-A models as pointlike, one way to effect Eq. (15) features using Eq. (22).

$$A_{A,v} = (-\nabla\phi_A - (-\nabla\phi_{A,rest}))t \tag{22}$$

The $A_{A,v}$ that Eq. (22) suggests associates with 3-vectors that exhibit radial spatial dependencies of $1/r$, point along radii with respect to the position of object-A, and otherwise do not vary based on angular coordinates. Except at $r = 0$ (which is not physically relevant), the contributions to B_A are $\nabla \times A_{A,v}$, which is zero.

Regarding Eqs. (18) and (19), q_A is the charge that object-P infers for object-A and I_A is the charge current that object-P infers for object-A. Based on the factor $1/r$ in Eq. (18), popular modeling associates the word monopole with the q_A-related contribution to the overall potential that associates with F_P. Based on the factor $1/r$ in Eq. (19), we associate the word monopole with the I_A-related contribution to the overall potential that associates with F_P.

We suggest that, from the perspective of object-P, effects that associate with nonzero charge current I_A dilute effects that associate with nonzero charge q_A. The magnitude of the dilution depends on the magnitude of I_A. (The magnitude of I_A associates with $|v_{A,rel.to.P}|$.) The magnitude of the dilution does not depend on the direction of I_A.

For case-e2, we make the following assumptions. $v_{A,rel.to.P} = 0$. $q_{A,rest} \neq 0$. $\mu_{A,rest} \neq 0$. Object-A includes sub-objects that have charges that have the same sign as $q_{A,rest}$. Object-A includes no sub-objects that have charges for which the signs are the opposite of the sign of $q_{A,rest}$. Motions, within object-A, of charged sub-objects account for the entirety of $\mu_{A,rest}$. $q_{P,rest} \neq 0$. No electromagnetic property, other than $q_{P,rest}$, of object-P is nonzero.

While $v_{A,rel.to.P} = 0$ pertains regarding object-A, $|v_{sub.object.of.object.A,rel.to.P}| > 0$ pertains for each moving charged sub-object of object-A. Popular modeling suggests that charges add. Paralleling case-e1, we suggest that object-P would infer that $|\nabla\phi_A|/|\nabla\phi_{A,rest}|$ exceeds one, that $q_A/q_{A,rest}$ exceeds one, and that $|E_A|/|E_{A,rest}|$ exceeds one.

We suggest that, from the perspective of object-P, effects that associate with nonzero magnetic moment μ_A dilute effects that associate with nonzero charge q_A. The magnitude of the dilution depends on the magnitude of μ_A. The magnitude of the dilution does not depend on the direction of μ_A.

Popular modeling associates the factor $1/r^2$ with the μ_A-related contribution to the overall potential that associates with F_P. Popular modeling associates the word dipole with the μ_A-related contribution to the overall potential that associates with F_P.

Regarding F_P, we suggest that, for case-e2, dipole effects dilute monopole effects.

We note that the notion of a binding energy that might be necessary to keep object-A intact is not necessarily relevant for case-e2.

(We note, as asides, the following notions. Popular modeling includes cases, such as for bar magnets, in which objects model as having zero charge and nonzero magnetic moment. We do not explore such cases. We do not explore popular modeling notions that there might be more than one popular modeling definition of magnetic moment for such cases and that the definitions might not be equivalent regarding special-relativistic transformations [84]. We do not try to develop gravitational parallels to such cases. Also, there are other cases that we do not explore. For example, one can consider cases in which sub-objects of object-A have same-signed charges and the motions of the sub-objects are such that contributions toward a might-be object-A magnetic moment tend to cancel each other. We do not try to develop gravitational parallels to such cases.)

We shift our focus away from electromagnetism and toward gravitation.

We suggest that the property object-internal angular momentum provides a gravitational analog to the electromagnetic property of magnetic moment.

We suggest, by analogy to case-e2 with the sign of the charge of object-A being opposite to the sign of the charge of object-P, the following notions regarding gravitational interactions. The pair of object-A mass and object-P mass contribute toward gravitational pull (or gravitational attraction) of object-P toward object-A. The pair of object-A internal angular momentum and object-P mass contribute toward gravitational push (or gravitational repulsion) of object-P away from object-A. The notion of a binding energy, for object-A, is not necessarily relevant.

4.2. General Relativity

This unit discusses relationships between our work and some applications of general relativity.

Our work and applications of general relativity have some seeming similarities or compatibilities and some seemingly possible differences or seemingly possible incompatibilities.

One might note differences between the situations for which our notions might add insight and situations for which general relativity seems to add insight. For example, our notions might seem not to have direct use for detailed calculations regarding collisions or mergers involving objects such as black holes or neutron stars. Also, our notions might seem not to have adequately novel direct use for detailed calculations regarding situations for which general relativity seems to have satisfied so-called precision tests [85].

Our work suggests that general relativity might not be adequately accurate regarding circumstances for which at least one of the following sentences pertains. Non-gravitational effects, such as electromagnetic effects, are significant. The isomeric composition of stuff varies significantly between regions. Significant (or dominant) effective reaches per instance vary with time.

4.3. Our Work and the Term ΛCDM

This unit discusses relationships between our work and the terms CDM and Λ that associate with the popular modeling term ΛCDM, as in ΛCDM model of cosmology.

People discuss successes of and possible problems with ΛCDM-cosmology popular modeling [1].

Our work suggests that popular modeling notions of CDM (as in cold dark matter, but not as in collisionless dark matter) can pertain regarding (perhaps all) dark matter. Our work suggests that popular modeling notions of collisionless dark matter can pertain regarding somewhat more than 80 percent of dark matter and do not pertain regarding somewhat less than 20 percent of dark matter.

Our work does not necessarily directly address the extent to which popular modeling notions of Λ (as in a cosmological constant) pertain. However, Λ associates with the use of general relativity and some of our previous remarks might shed light on possible limitations regarding the adequate applicability of general relativity.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2025 doi:10.20944/preprints202505.0381.v1

4.4. Our Work and the Standard Cosmological Model

This unit discusses relationships between our work and the standard cosmological model.

Our work tries to fit about ten data clusters or data points. Some of the data clusters or data points are approximate ratios of dark-matter effects to ordinary-matter effects. Some of the data clusters or data points associate with inflection points regarding the rate of expansion of the universe. Each one of some of the data clusters associates with numerous observations. The inflection point regarding the start of the second multibillion-year era in the rate of expansion of the universe provides an example. One of the data points associates with some depletion of cosmic microwave background radiation and with one observation.

Our work seems to offer viable candidate explanations for the about ten data clusters or data points.

Our work does not try to suggest an alternative to the standard cosmological model.

Our work might offer notions that can inform understanding, refining, or replacing aspects of the standard cosmological model. For example, our notions regarding a candidate specification for dark matter and regarding reaches might lead to refining aspects of the standard cosmological model.

4.5. Suggestions for Observational Work

This unit suggests some opportunities, to which our work points, for verifying or refuting aspects of our work, pinpointing opportunities for observational or experimental work, and so forth.

We suggest considering possible synergies between galaxy-evolution studies and our work. To what extent does our work comport with early-universe galaxy-formation and galaxy-evolution? Did nature form at least as many 1:0+ (or, dark-matter) galaxies as 0+:1 (or, ordinary-matter) galaxies? To what extent does it seem reasonable that some of today's 1:0+ galaxies and 0+:1 galaxies maintained those ratios from early in the evolution of the universe? To what extent do our suggested scenarios for the formation of ∼4:1 galaxies comport with nature?

We suggest considering observational work, regarding the aftermath of galaxy-cluster collisions, that could help verify or refute our notions of significantly-electromagnetically-active dark matter. To what extent does isomer-3 intergalactic medium exist? To what extent does isomer-3 intergalactic medium lag other dark-matter stuff?

We suggest considering observational (and perhaps even experimental) work that could help verify refute or extend a table, such as Table 5. Which reach pertains for hyperfine phenomena? Which reach or reaches pertain for atomic transitions that are not hyperfine transitions? To what extent might data suggest a reach for magnetic moment? To what extent do the reaches for $n_k + 1$ current properties comport with the reaches for the counterpart n_k intrinsic properties?

We suggest considering experimental work that might detect dark matter of the types that we suggest.

We suggest considering work that would test general relativity for circumstances in which our work would suggest that dominant isomeric compositions change spatially.

We suggest considering work that would test general relativity for circumstances in which our work would suggest that dominant reaches change temporally or spatially.

4.6. Suggestions for Enhancing Popular Modeling

This unit suggests some opportunities, to which our work points, for enhancing popular modeling.

We suggest considering how to evolve popular modeling to embrace notions that, while much dark matter might qualify as collisionless dark matter, significant amounts of dark matter might not qualify as collisionless dark matter.

We suggest considering how to incorporate notions regarding instances and reaches per instance into popular modeling and into numerical simulations.

 doi:10.20944/preprints202505.0381.v1

We suggest considering the extent to which popular modeling might benefit by using the series gravitational scalar potential, gravitational vector potential, gravitational two-tensor potential, and so forth.

We suggest considering the notion that transitions from gravitational octupole push to gravitational quadrupole pull to ... to gravitational monopole pull associate with or might extend popular modeling notions of phase transitions. We suggest considering the notion that such transitions seem to scale from interactions between neighboring non-colliding solar-system sized objects to interactions between neighboring non-colliding larger objects.

5. Conclusions

We suggest explanations for approximately ten cosmological phenomena for which the standard cosmological model seems not to provide adequately precise explanations. Some of the phenomena associate with the terms dark matter, dark energy, rate of expansion of the universe, galaxy formation, Hubble tension, and S8 tension. The explanations have bases in our notions of isomers of elementary particles and in our notions of special-relativity-inspired suggested extensions to Newtonian gravity.

The following remarks provide some details.

We try to explain some cosmological data clusters or data points that the standard cosmology model seems not to explain adequately well. Some of the data clusters or data points associate with ratios of dark-matter effects to ordinary-matter effects. Some of the data clusters or data points associate with large-scale notions, such as the rate of expansion of the universe and large-scale clumping of stuff.

Our methods feature two novel concepts.

One concept is that dark matter and ordinary matter have a common basis in six isomers of a set of known elementary particles. One isomer associates with ordinary matter. Five isomers associate with dark matter. One dark-matter isomer underlies stuff that is a right-handed complement to ordinary-matter stuff, which associates with the notion of left-handedness. That dark-matter stuff comports with popular modeling notions of self-interacting dark matter. The other four dark-matter isomers underlie stuff that comports with popular modeling notions of collisionless dark matter.

The other concept is that a new use of multipole-expansion mathematics points, for interactions between two objects, to aspects of gravitational interactions. Our multipole notions feature multiple properties of a single object, whereas popular modeling multipole expansions tend to feature spatial distributions of one property. With respect to the mass of a second object, gravitational monopole, quadrupole, and hexadecapole intrinsic-properties of a first object associate with gravitational attraction between the two objects. With respect to the mass of a second object, gravitational dipole and octupole intrinsic-properties of a first object associate with gravitational repulsion between the two objects.

We combine the two concepts and thereby suggest new insight regarding and explanations for the cosmological data clusters and data points. We suggest bases for some cosmology tensions.

We suggest notions about how our methods and results might help people understand and improve popular modeling notions regarding various aspects of the standard cosmological model.

Acknowledgments

The following people provided useful mathematical perspective: Charles K. Chui and Tom Lawrence.

Declarations

This study created no new data.

This research received no funding.

The author declares no conflicts of interest.

References

1. Philip Bull, Yashar Akrami, Julian Adamek, Tessa Baker, Emilio Bellini, et al. Beyond ΛCDM: Problems, solutions, and the road ahead. *Physics of the Dark Universe*, 12:56–99, June 2016. DOI: 10.1016/j.dark.2016.02.001.
2. Eleonora Di Valentino. Challenges of the Standard Cosmological Model. *Universe*, 8(8), August 2022. DOI 10.3390/universe8080399.
3. James Binney, Roya Mohayaee, John Peacock, and Subir Sarkar. Manifesto: challenging the standard cosmological model. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 383(2290), February 2025. DOI: 10.1098/rsta.2024.0036.
4. Fritz Zwicky. The Redshift of extragalactic Nebulae. *Helvetica Physica Acta*, (6):110–127, 1933. Link: https://ned.ipac.caltech.edu/level5/March17/Zwicky/translation.pdf.
5. F. Zwicky. On the Masses of Nebulae and of Clusters of Nebulae. *The Astrophysical Journal*, 86(86):217, October 1937. DOI: 10.1086/143864.
6. Katherine Garrett and Gintaras Duda. Dark Matter: A Primer. *Advances in Astronomy*, 2011:1–22, 2011. DOI: 10.1155/2011/968283.
7. A. Arbey and F. Mahmoudi. Dark matter and the early Universe: A review. *Progress in Particle and Nuclear Physics*, 119:103865, July 2021. DOI: 10.1016/j.ppnp.2021.103865.
8. Georges Lemaitre. Un Univers homogene de masse constante et de rayon croissant rendant compte de la vitesse radiale des nebuleuses extra-galactiques. *Annales de la Societe Scientifique de Bruxelles*, 47:49–56, April 1927. Link: https://archives.uclouvain.be/ark
9. Edwin Hubble. A relation between distance and radial velocity among extra-galactic nebulae. *Proceedings of the National Academy of Sciences*, 15(3):168–173, March 1929. DOI 10.1073/pnas.15.3.168.
10. Daniel Scolnic, Adam G. Riess, Yukei S. Murakami, Erik R. Peterson, Dillon Brout, et al. The Hubble Tension in Our Own Backyard: DESI and the Nearness of the Coma Cluster. *The Astrophysical Journal Letters*, 979(1):L9, January 2025. DOI 10.3847/2041-8213/ada0bd.
11. Judd D. Bowman, Alan E. E. Rogers, Raul A. Monsalve, Thomas J. Mozdzen, and Nivedita Mahesh. An absorption profile centred at 78 megahertz in the sky-averaged spectrum. *Nature*, 555(7694):67–70, March 2018. DOI 10.1038/nature25792.
12. Rennan Barkana. Possible interaction between baryons and dark-matter particles revealed by the first stars. *Nature*, 555(7694):71–74, March 2018. DOI 10.1038/nature25791.
13. Paolo Panci. 21-cm line Anomaly: A brief Status. In *33rd Rencontres de Physique de La Vallee d'Aoste*, July 2019. URL: https://cds.cern.ch/record/2688533.
14. Joshua D. Simon and Marla Geha. Illuminating the darkest galaxies. *Physics Today*, 74(11):30–36, November 2021. DOI 10.1063/pt.3.4879.
15. Charles Day. A primordial merger of galactic building blocks. *Physics Today*, 2021(1):0614a, June 2021. DOI 10.1063/PT.6.1.20210614a.
16. Yuta Tarumi, Naoki Yoshida, and Anna Frebel. Formation of an Extended Stellar Halo around an Ultra-faint Dwarf Galaxy Following One of the Earliest Mergers from Galactic Building Blocks. *The Astrophysical Journal Letters*, 914(1):L10, June 2021. DOI 10.3847/2041-8213/ac024e.
17. Elena Asencio, Indranil Banik, Steffen Mieske, Aku Venhola, Pavel Kroupa, and Hongsheng Zhao. The distribution and morphologies of Fornax Cluster dwarf galaxies suggest they lack dark matter. *Mon Not R Astron Soc*, June 2022. DOI 10.1093/mnras/stac1765.
18. Massimo Meneghetti, Guido Davoli, Pietro Bergamini, Piero Rosati, Priyamvada Natarajan, Carlo Giocoli, Gabriel B. Caminha, R. Benton Metcalf, Elena Rasia, Stefano Borgani, et al. An excess of small-scale gravitational lenses observed in galaxy clusters. *Science*, 369(6509):1347–1351, September 2020. DOI 10.1126/science.aax5164.
19. Joshua D. Simon and Marla Geha. The Kinematics of the Ultra-faint Milky Way Satellites: Solving the Missing Satellite Problem. *Astrophys. J.*, 670(1):313–331, November 2007. DOI 10.1086/521816.
20. Shannon Hall. Ghost galaxy is 99.99 per cent dark matter with almost no stars. *New Scientist*, August 2016. URL: https://www.newscientist.com/article/2102584-ghost-galaxy-is-99-99-per-cent-dark-matter-with-almost-no-stars/.
21. Pieter van Dokkum, Roberto Abraham, Jean Brodie, Charlie Conroy, Shany Danieli, Allison Merritt, Lamiya Mowla, Aaron Romanowsky, and Jielai Zhang. A High Stellar Velocity Dispersion and ~100 Globular

Clusters for the Ultra-diffuse Galaxy Dragonfly 44. *Astrophysical Journal*, 828(1):L6, August 2016. DOI 10.3847/2041-8205/828/1/l6.

22. Kristi A Webb, Alexa Villaume, Seppo Laine, Aaron J Romanowsky, Michael Balogh, Pieter van Dokkum, Duncan A Forbes, Jean Brodie, et al. Still at odds with conventional galaxy evolution: the star formation history of ultradiffuse galaxy Dragonfly 44. *Monthly Notices of the Royal Astronomical Society*, 516(3):3318–3341, August 2022. DOI 10.1093/mnras/stac2417.
23. Peter Behroozi, Risa Wechsler, Andrew Hearin, and Charlie Conroy. UniverseMachine: The correlation between galaxy growth and dark matter halo assembly from z = 0-10. *Monthly Notices of The Royal Astronomical Society*, 488(3):3143–3194, May 2019. DOI 10.1093/mnras/stz1182.
24. R. Genzel, N. M. Forster Schreiber, H. Ubler, P. Lang, T. Naab, R. Bender, L. J. Tacconi, E. Wisnioski, S. Wuyts, T. Alexander, et al. Strongly baryon-dominated disk galaxies at the peak of galaxy formation ten billion years ago. *Nature*, 543(7645):397–401, March 2017. DOI 10.1038/nature21685.
25. R. Herrera-Camus, N. M. Forster Schreiber, S. H. Price, H. Ubler, A. D. Bolatto, R. L. Davies, D. Fisher, R. Genzel, D. Lutz, T. Naab, et al. Kiloparsec view of a typical star-forming galaxy when the Universe was $\sim$1 Gyr old. *Astronomy and Astrophysics*, 665:L8, September 2022. DOI: 10.1051/0004-6361/202142562.
26. Pavel E. Mancera Pina, Filippo Fraternali, Elizabeth A. K. Adams, Antonino Marasco, Tom Oosterloo, Kyle A. Oman, Lukas Leisman, Enrico M. di Teodoro, Lorenzo Posti, Michael Battipaglia, et al. Off the Baryonic Tully-Fisher Relation: A Population of Baryon-dominated Ultra-diffuse Galaxies. *Astrophysical Journal*, 883(2):L33, September 2019. DOI 10.3847/2041-8213/ab40c7.
27. Pavel E. Mancera Pina, Filippo Fraternali, Tom Oosterloo, Elizabeth A. K. Adams, Kyle A. Oman, and Lukas Leisman. No need for dark matter: resolved kinematics of the ultra-diffuse galaxy AGC 114905. *Mon. Not. R. Astron Soc.*, December 2021. DOI 10.1093/mnras/stab3491.
28. Qi Guo, Huijie Hu, Zheng Zheng, Shihong Liao, Wei Du, Shude Mao, Linhua Jiang, Jing Wang, Yingjie Peng, Liang Gao, et al. Further evidence for a population of dark-matter-deficient dwarf galaxies. *Nature Astronomy*, 4(3):246–251, November 2019. DOI 10.1038/s41550-019-0930-9.
29. Pieter van Dokkum, Shany Danieli, Roberto Abraham, Charlie Conroy, and Aaron J. Romanowsky. A Second Galaxy Missing Dark Matter in the NGC 1052 Group. *Astrophysical Journal*, 874(1):L5, March 2019. DOI 10.3847/2041-8213/ab0d92.
30. Sebastien Comeron, Ignacio Trujillo, Michele Cappellari, Fernando Buitrago, Luis E. Garduno, Javier Zaragoza-Cardiel, Igor A. Zinchenko, Maritza A. Lara-Lopez, Anna Ferre-Mateu, and Sami Dib. The massive relic galaxy NGC 1277 is dark matter deficient. From dynamical models of integral-field stellar kinematics out to five effective radii, March 2023. DOI: 10.48550/ARXIV.2303.11360.
31. Pieter van Dokkum, Zili Shen, Michael A. Keim, Sebastian Trujillo-Gomez, Shany Danieli, Dhruba Dutta Chowdhury, Roberto Abraham, Charlie Conroy, J. M. Diederik Kruijssen, et al. A trail of dark-matter-free galaxies from a bullet-dwarf collision. *Nature*, 605(7910):435–439, May 2022. DOI 10.1038/s41586-022-04665-6.
32. Aaron J. Romanowsky, Enrique Cabrera, and Steven R. Janssens. A Candidate Dark Matter Deficient Dwarf Galaxy in the Fornax Cluster Identified through Overluminous Star Clusters. *Research Notes of the AAS*, 8(8):202, August 2024. DOI: 10.3847/2515-5172/ad7112.
33. Maria Luisa Buzzo, Duncan A. Forbes, Aaron J. Romanowsky, Lydia Haacke, Jonah S. Gannon, et al. A new class of dark matter-free dwarf galaxies? I. Clues from FCC 224, NGC 1052-DF2 and NGC 1052-DF4. Preprint, 2025. DOI: 10.48550/ARXIV.2502.05405.
34. J. Jimenez-Vicente, E. Mediavilla, C. S. Kochanek, and J. A. Munoz. Dark Matter Mass Fraction in Lens Galaxies: New Estimates from Microlensing. *Astrophysical Journal*, 799(2):149, January 2015. DOI 10.1088/0004-637x/799/2/149.
35. J. Jimenez-Vicente, E. Mediavilla, J. A. Munoz, and C. S. Kochanek. A Robust Determination of the Size of Quasar Accretion Disks Using Gravitational Microlensing. *Astrophysical Journal*, 751(2):106, May 2012. DOI 10.1088/0004-637x/751/2/106.
36. Man Ho Chan. Two mysterious universal dark matter–baryon relations in galaxies and galaxy clusters. *Physics of the Dark Universe*, 38:101142, December 2022. DOI: 10.1016/j.dark.2022.101142.
37. Ewa L. Lokas and Gary A. Mamon. Dark matter distribution in the Coma cluster from galaxy kinematics: breaking the mass-anisotropy degeneracy. *Monthly Notices of The Royal Astronomical Society*, 343(2):401–412, August 2003. DOI 10.1046/j.1365-8711.2003.06684.x.

38. Elena Rasia, Giuseppe Tormen, and Lauro Moscardini. A dynamical model for the distribution of dark matter and gas in galaxy clusters. *Monthly Notices of The Royal Astronomical Society*, 351(1):237–252, June 2004. DOI 10.1111/j.1365-2966.2004.07775.x.
39. Lawrence Rudnick. The Stormy Life of Galaxy Clusters: astro version. Preprint, January 2019. DOI 10.48550/arXiv.1901.09448.
40. Lawrence Rudnick. The stormy life of galaxy clusters. Physics Today, January 2019. DOI 10.1063/pt.3.4112.
41. R. L. Workman and Others. Review of Particle Physics. *PTEP*, 2022:083C01, 2022. DOI: 10.1093/ptep/ptac097.
42. N. G. Busca, T. Delubac, J. Rich, S. Bailey, A. Font-Ribera, D. Kirkby, J.-M. Le Goff, M. M. Pieri, A. Slosar, E. Aubourg, et al. Baryon acoustic oscillations in the Lyα forest of BOSS quasars. *Astronomy and Astrophysics*, 552(A96), April 2013. DOI 10.1051/0004-6361/201220724.
43. S. Perlmutter, G. Aldering, G. Goldhaber, R. A. Knop, P. Nugent, P. G. Castro, S. Deustua, S. Fabbro, A. Goobar, Groom, et al. Measurements of Ω and Λ from 42 high-redshift supernovae Ω. *Astrophysical Journal*, 517(2):565–586, June 1999. DOI 10.1086/307221.
44. Adam G. Riess, Alexei V. Filippenko, Peter Challis, Alejandro Clocchiatti, Alan Diercks, Peter M. Garnavich, Ron L. Gilliland, Craig J. Hogan, Saurabh Jha, Robert P. Kirshner, et al. Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant. *Astronomical Journal*, 116(3):1009–1038, September 1998. DOI 10.1086/300499.
45. Adam G. Riess, Louis-Gregory Strolger, John Tonry, Stefano Casertano, Henry C. Ferguson, Bahram Mobasher, Peter Challis, Alexei V. Filippenko, Saurabh Jha, Weidong Li, et al. Type Ia Supernova Discoveries at z > 1 from the Hubble Space Telescope: Evidence for Past Deceleration and Constraints on Dark Energy Evolution. *Astrophysical Journal*, 607(2):665–687, June 2004. DOI 10.1086/383612.
46. Eleonora Di Valentino, Olga Mena, Supriya Pan, Luca Visinelli, Weiqiang Yang, et al. In the realm of the Hubble tension - a review of solutions. *Classical and Quantum Gravity*, 38(15):153001, July 2021. DOI: 10.1088/1361-6382/ac086d.
47. DESI Collaboration, K. Lodha, R. Calderon, W. L. Matthewson, A. Shafieloo, M. Ishak, et al. Extended Dark Energy analysis using DESI DR2 BAO measurements, 2025. DOI: 10.48550/ARXIV.2503.14743.
48. DES Collaboration, T. M. C. Abbott, M. Acevedo, M. Adamow, M. Aguena, et al. Dark Energy Survey: implications for cosmological expansion models from the final DES Baryon Acoustic Oscillation and Supernova data, 2025. DOI: 10.48550/ARXIV.2503.06712.
49. Christopher Wanjek. Dark Matter Appears to be a Smooth Operator. *Mercury*, 49(3):10–11, October 2020. URL: https://astrosociety.org/news-publications/mercury-online/mercury-online.html/article/2020/12/10/dark-matter-appears-to-be-a-smooth-operator.
50. Charlie Wood. A New Cosmic Tension: The Universe Might Be Too Thin. *Quanta Magazine*, September 2020. URL: https://www.quantamagazine.org/a-new-cosmic-tension-the-universe-might-be-too-thin-20200908/.
51. Maria Temming. Dark matter clumps in galaxy clusters bend light surprisingly well. *Science News*, September 2020. URL: https://www.sciencenews.org/article/dark-matter-clumps-galaxy-clusters-bend-light-surprisingly-well.
52. Khaled Said, Matthew Colless, Christina Magoulas, John R. Lucey, and Michael J. Hudson. Joint analysis of 6dFGS and SDSS peculiar velocities for the growth rate of cosmic structure and tests of gravity. *Monthly Notices of The Royal Astronomical Society*, 497(1):1275–1293, July 2020. DOI 10.1093/mnras/staa2032.
53. Supranta S. Boruah, Michael J. Hudson, and Guilhem Lavaux. Cosmic flows in the nearby Universe: new peculiar velocities from SNe and cosmological constraints. *Monthly Notices of The Royal Astronomical Society*, August 2020. DOI 10.1093/mnras/staa2485.
54. Kyu-Hyun Chae, Federico Lelli, Harry Desmond, Stacy S. McGaugh, Pengfei Li, and James M. Schombert. Testing the Strong Equivalence Principle: Detection of the External Field Effect in Rotationally Supported Galaxies. *The Astrophysical Journal*, 904(1):51, November 2020. DOI 10.3847/1538-4357/abbb96.
55. Eleonora Di Valentino, Luis A. Anchordoqui, Ozgur Akarsu, Yacine Ali-Haimoud, Luca Amendola, et al. Cosmology intertwined III: fσ8 and S8. *Astroparticle Physics*, 131:102604, September 2021. DOI: 10.1016/j.astropartphys.2021.102604.
56. Ryo Terasawa, Xiangchong Li, Masahiro Takada, Takahiro Nishimichi, Satoshi Tanaka, et al. Exploring the baryonic effect signature in the Hyper Suprime-Cam Year 3 cosmic shear two-point correlations on small

scales: The S8 tension remains present. *Physical Review D*, 111(6):063509, March 2025. DOI: 10.1103/physrevd.111.063509.

57. Thomas J. Buckholtz. *Models for Physics of the Very Small and Very Large*, volume 14 of *Atlantis Studies in Mathematics for Engineering and Science*. Springer, 2016. Series editor: Charles K. Chui. DOI: 10.2991/978-94-6239-166-6.
58. S. Bilenky. Neutrino oscillations: from an historical perspective to the present status. *Journal of Physics: Conference Series*, 718:062005, May 2016. DOI: 10.1088/1742-6596/718/6/062005.
59. Sudhakantha Girmohanta and Robert Shrock. Fitting a self-interacting dark matter model to data ranging from satellite galaxies to galaxy clusters. *Physical Review D*, 107(6):063006, March 2023. DOI: 10.1103/PhysRevD.107.063006.
60. Xingyu Zhang, Hai-Bo Yu, Daneng Yang, and Haipeng An. Self-interacting Dark Matter Interpretation of Crater II. *The Astrophysical Journal Letters*, 968(1):L13, June 2024. DOI: 10.3847/2041-8213/ad50cd.
61. D. Cross, G. Thoron, T. E. Jeltema, A. Swart, D. L. Hollowood, et al. Examining the self-interaction of dark matter through central cluster galaxy offsets. *Monthly Notices of the Royal Astronomical Society*, 529(1):52–58, February 2024. DOI: 10.1093/mnras/stae442.
62. David N. Spergel and Paul J. Steinhardt. Observational Evidence for Self-Interacting Cold Dark Matter. *Physical Review Letters*, 84(17):3760–3763, April 2000. DOI: 10.1103/PhysRevLett.84.3760.
63. Daneng Yang, Ethan O. Nadler, and Hai-Bo Yu. Testing the parametric model for self-interacting dark matter using matched halos in cosmological simulations. *Physics of the Dark Universe*, 47:101807, February 2025. DOI: 10.1016/j.dark.2025.101807.
64. Gonzalo Alonso-Alvarez, James M. Cline, and Caitlyn Dewar. Self-Interacting Dark Matter Solves the Final Parsec Problem of Supermassive Black Hole Mergers. *Physical Review Letters*, 133(2):021401, July 2024. DOI: 10.1103/PhysRevLett.133.021401.
65. Xingyu Zhang, Hai-Bo Yu, Daneng Yang, and Ethan O. Nadler. The GD-1 Stellar Stream Perturber as a Core-collapsed Self-interacting Dark Matter Halo. *The Astrophysical Journal Letters*, 978(2):L23, January 2025. DOI: 10.3847/2041-8213/ada02b.
66. Manuel A. Buen-Abad, Zackaria Chacko, Ina Flood, Can Kilic, et al. Atomic Dark Matter, Interacting Dark Radiation, and the Hubble Tension. 2024. DOI: 10.48550/arXiv.2411.08097.
67. Isaac Newton. Philosophiae Naturalis Principia Mathematica. 1687. DOI: 10.3931/E-RARA-440.
68. M. Markevitch, A. H. Gonzalez, D. Clowe, A. Vikhlinin, W. Forman, C. Jones, S. Murray, and W. Tucker. Direct Constraints on the Dark Matter Self-Interaction Cross Section from the Merging Galaxy Cluster 1E 0657-56. *Astrophysical Journal*, 606(2):819–824, May 2004. DOI 10.1086/383178.
69. Emily M. Silich, Elena Bellomi, Jack Sayers, John ZuHone, Urmila Chadayammuri, et al. ICM-SHOX. I. Methodology Overview and Discovery of a Gas-Dark Matter Velocity Decoupling in the MACS J0018.5+1626 Merger. *The Astrophysical Journal*, 968(2):74, June 2024. DOI: 10.3847/1538-4357/ad3fb5.
70. Alan H. Guth. Inflationary universe: A possible solution to the horizon and flatness problems. *Physical Review D*, 23(2):347–356, January 1981. DOI: 10.1103/PhysRevD.23.347.
71. Martin Bucher, Alfred S. Goldhaber, and Neil Turok. Open universe from inflation. *Phys. Rev. D*, 52:3314–3337, September 1995. DOI 10.1103/PhysRevD.52.3314.
72. Tao Zhu, Anzhong Wang, Gerald Cleaver, Klaus Kirsten, and Qin Sheng. Pre-inflationary universe in loop quantum cosmology. *Phys. Rev. D*, 96:083520, October 2017. DOI 10.1103/PhysRevD.96.083520.
73. Brian Green. *Until the End of Time: Mind, Matter, and Our Search for Meaning in an Evolving Universe*. Alfred A. Knopf, February 2020. Link: https://www.penguinrandomhouse.com/books/549600/until-the-end-of-time-by-brian-greene/.
74. Mark P. Hertzberg. Structure Formation in the Very Early Universe. *Physics Magazine*, 13(26), February 2020. DOI 10.1103/physics.13.16.
75. Robert Brandenberger and Patrick Peter. Bouncing Cosmologies: Progress and Problems. *Foundations of Physics*, 47(6):797–850, February 2017. DOI: 10.1007/s10701-016-0057-0.
76. Georgios Minas, Emmanuel Saridakis, Panayiotis Stavrinos, and Alkiviadis Triantafyllopoulos. Bounce Cosmology in Generalized Modified Gravities. *Universe*, 5(3):74, March 2019. DOI: 10.3390/universe5030074.
77. Bartjan van Tent, Paola Delgado, and Ruth Durrer. Constraining the Bispectrum from Bouncing Cosmologies with Planck. *Physical Review Letters*, 130(19):191002, May 2023. DOI: 10.1103/physrevlett.130.191002.

 doi:10.20944/preprints202505.0381.v1

78. Kelvin K. S. Wu, Ofer Lahav, and Martin J. Rees. The large-scale smoothness of the Universe. *Nature*, 397(6716):225–230, January 1999. DOI: 10.1038/16637.
79. J. R. L. Santos, P. H. R. S. Moraes, D. A. Ferreira, and D. C. Vilar Neta. Building analytical three-field cosmological models. *The European Physical Journal C*, 78(2), February 2018. DOI: 10.1140/epjc/s10052-018-5614-6.
80. O Heaviside. A gravitational and electromagnetic analogy the electrician, 31 281-2 (1893). *Reproduced in (1.) O. Heaviside, Electromagnetic Theory*, 1:455–465.
81. O. Heaviside. *Electromagnetic Theory*. Number v. 1 in AMS Chelsea Publishing Series. American Mathematical Society, 2003. ISBN: 9780821835579.
82. Jairzinho Ramos Medina. *Gravitoelectromagnetism (GEM): A Group Theoretical Approach*. PhD thesis, Drexel University, August 2006. Link: https://core.ac.uk/download/pdf/190333514.pdf.
83. Giorgio Papini. Some Classical and Quantum Aspects of Gravitoelectromagnetism. *Entropy*, 22(10):1089, September 2020. DOI: 10.3390/e22101089.
84. Alexander L. Kholmetskii, Oleg V. Missevitch, and Tolga Yarman. RELATIVISTIC TRANSFORMATION OF MAGNETIC DIPOLE MOMENT. *Progress In Electromagnetics Research B*, 47:263–278, 2013. DOI: 10.2528/pierb12110903.
85. Clifford M. Will. The confrontation between general relativity and experiment. *Living Reviews in Relativity*, 17(1), June 2014. DOI: 10.12942/lrr-2014-4.