Testing a Particle Model of Gravity and Light: What the G1 Sea Would Show

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Abstract. A particle model of gravity and light, the four universal motions, replaces fields with one kind of particle, the G1, moving in four ways: randomly (gravitic), in orbits (magnetic), in streams (electric) and in spaced groups (luminic). Space holds a sea of G1s moving at random, and gravity is the shadow two bodies cast on each other in that sea. This paper lists what the model says can be measured, and what result would count against each part of it. Newton's constant comes apart as $G = \kappa^2\rho/4\pi$, where κ is how much of the G1 rain one kilogram of matter stops and ρ is the strength of the sea. The model gives the form of G and of Coulomb's constant, not their values. Eight tests are proposed. The main one is a shortfall of gravitational mass that grows with a body's density times its radius and not with its composition; this form is already in the shielding literature, and a detection of it would measure the sea. The others are the uniformity of G; a residual drag that would measure the speed of the sea; departures from Coulomb's law; a floor on the number of G1s that stand in the place of one electron (tens of billions, from the smallest atomic emissions, under two stated assumptions); the mass of excited ions, which forces the model to state how much mass a released group of G1s carries; the best pinhole size and its dependence on the rim; and the light that reaches a dark band in the double-slit experiment. Pulsar timing in a triple star system bounds κ about seven thousand times more tightly than lunar ranging if the model applies to neutron-star matter. Each test is tied to the mechanism its failure would require the model to rebuild.

Keywords: push gravity; gravitational shielding; equivalence principle; Newton's constant; Majorana effect; four universal motions

1 Introduction

The central claim of this paper is narrow. A particle model of gravity and light, the four universal motions [1–3], makes statements that can be measured, and this paper lists them: what each test measures, the form or size the model expects, and what result would count against it. It does not argue that the model is right. Where existing data already bound a quantity, the bound is applied.

Two rules govern how results are read. First, the model is judged by its own mechanism, not by agreement with a mathematical description it does not share; only factual disagreement with measurement counts. Second, a failed test is read as a failure of one mechanism inside the model, and the paper says in each case which mechanism that would be (§6). The tests are chosen so that they over-determine the model: several independent routes reach the same few quantities, and if the routes disagree, the disagreement points to the joint that failed.

Every assumption is stated where it is used. The model does not derive the value of Newton's constant G, of Coulomb's constant, or of the mass, speed or number of the G1 particle. None is claimed here as derived.

2 The model in a page

There is one kind of particle, the G1, and it moves in four ways [2, 3]:

- **Gravitic motion**: random, in all directions. Space is filled with a sea of G1s moving this way.
- **Magnetic motion**: orbiting.
- **Electric motion**: streaming. G1s stream from negative to positive, the same direction as electrons.
- **Luminic motion**: in groups, here called *processions*, with a gap between one group and the next. The spacing of the groups is the colour of the light.

Gravity is shadowing. A lone body is struck equally from every side by the sea and feels no net push. Two bodies each block part of the rain that would have reached the other, so each is pushed toward the other. There is no pulling force. This is the mechanism of Fatio and Le Sage [4, 5], with the particles of the sea identified with the particles of light.

Matter is nearly transparent to the rain. Almost every G1 passes through a body without being deflected. This is what makes gravity act on mass rather than on surface area, and it is the origin of the main test (§4.1).

Levels. The same mechanism repeats one level down, with a finer and faster rain of G2 particles, and gives Coulomb's law. The G2 sea has no physical description yet; this paper uses only the fact that it would act on charges as the G1 sea acts on masses.

Charge is a count: the number of G1s an atom holds compared with the number it settles at.

Electrons. Where the textbook has one electron, the model has a quanta of G1s: the one particle is replaced by a very large number of G1s, not built out of them. The cloud around a hydrogen atom is that many particles instead of one electron, and wherever an experiment appears to release or measure a single electron, what it releases or measures is such a quanta. §4.5 sets a floor on how many G1s stand in the place of one electron.

Particles of the sea rarely meet. G1–G1 encounters are almost never. Where opposed orbits meet (the Dinu effect), the paths of the G1s are disrupted by G2 gravity, not by G1s striking one another.

The model is not an aether theory. The sea is not a medium that carries waves; light is G1s travelling in groups, and gravity is G1s travelling at random.

3 The chain from G to the sea

Let the sea contain n G1s per cubic metre, each of mass m_G, moving at speed v in random directions. The push they deliver on one square metre facing one direction, per unit solid angle, is $\rho/4\pi$, with

$$\rho \equiv n\, m_G\, v^2 \qquad [\text{Pa}], \tag{1}$$

which this paper calls the *strength* of the sea. It has the units of a pressure. Let κ (m^2/kg) be the area of rain that one kilogram of matter stops. Because matter is nearly transparent, a body of mass m stops rain over an area κm. Two bodies d apart then push each other together with

$$F = \frac{\kappa^2 \rho}{4\pi}\,\frac{m_1 m_2}{d^2}, \qquad \text{so} \qquad G = \frac{\kappa^2 \rho}{4\pi}. \tag{2}$$

The 4π is the solid angle of the whole sky. Equation (2) is not new: it is the transparent limit of the shielding theories of Majorana and his successors, and has been written in this form, or its

cross-section-per-nucleon equivalent, by Nali [6] and Fedosin [7]. What the model adds is a reading of each factor: κ is a property of matter, ρ a property of empty space, and 4π geometry.

Assumption S (uniform sea). G is the same everywhere only if ρ is the same everywhere. The model assumes this; it does not derive it.

Because G is measured, any measurement of κ gives the strength of the sea:

$$\rho = \frac{4\pi G}{\kappa^2}. \tag{3}$$

The present bound on κ. κ is the gravitational shielding coefficient, written h by Majorana [8]. Eckhardt [9] bounded it with lunar laser ranging; Williams, Turyshev and Boggs [10] repeated the analysis on a later solution and found $h = (3 \pm 5) \times 10^{-23}$ cm^{2}g^{-1}, consistent with zero (their §7.1). Taking the one-sigma uncertainty as the scale of the bound,

$$\kappa \lesssim 5 \times 10^{-24} \text{ m}^2\text{kg}^{-1}. \tag{4}$$

(A more cautious reading, the central value plus two sigma, gives 1.3×10^{-23} m^{2}kg^{-1}, and every bound below that depends on κ^2 weakens by a factor of about seven.) With $G = 6.674 \times 10^{-11}$ m^{3}kg^{-1}s^{-2}, equation (3) gives

$$\rho \gtrsim 3.4 \times 10^{37} \text{ Pa}, \tag{5}$$

which, divided by c^2, is more than a thousand times the density of nuclear matter. If the G1s of the sea move at the speed of light ($v = c$, Assumption L of §7), the mass of G1s in each cubic metre is $n\,m_G = \rho/c^2 \gtrsim 3.7 \times 10^{20}$ kg m^{-3}. §5 shows that pulsar timing, if it applies, raises these floors by a factor of about fifty million.

Coulomb's constant has the same anatomy one level down:

$$\frac{1}{4\pi\varepsilon_0} = \frac{\rho_{G2}}{4\pi}\left(\frac{s_e}{e}\right)^2, \tag{6}$$

where ρ_{G2} is the strength of the G2 sea and s_e is the area of G2 rain blocked by one unit of charge e. Again only the form is claimed.

What gravity alone can and cannot measure. Gravity sees the sea only through $\rho = n\,m_G\,v^2$. No measurement of G and κ, however precise, separates the mass, speed and number density of the G1. The speed needs the anisotropy test of §4.3. The mass and number density need a count of how many G1s replace one electron, and nobody has yet proposed a way to make that count; §4.5 gives only a floor.

4 The tests

Table 1 summarises the eight tests. Each is then described: what it measures, what form or size the model expects, and what would count against the model.

Table 1: The proposed tests. "Form" means the shape of a dependence; "size" a number. Where the model gives only the form, a measurement calibrates the size.

Test	Measures	Expected form or size	Counts against the model
1. Column-density shortfall	κ, hence ρ	$m_g/m_i = 1 - f\kappa\bar{\rho}R$; depends on $\bar{\rho}R$, not composition	A free-fall difference that tracks composition at fixed $\bar{\rho}R$
2. Uniformity of G	ρ by place, depth, time, direction	No variation (Assumption S)	A reproducible variation not traced to apparatus
3. Residual drag / anisotropy	Speed v of the sea	Drag $\propto u/v$; self-shielding residual $\sim$0.12 of the Sun's pull	The residual is already excluded (open, §4.3)
4. G2 level	ρ_{G2}, s_e/e	Inverse square, exact charge step, both to the precision of G2 transparency	A departure from either not traced to apparatus
5. Floor on N	m_G, n (bounds)	$N \geq 4.3 \times 10^{10}$ or 8.7×10^{10}	An emission smaller than one G1 group would allow
6. Excited-ion mass	Mass carried by a released group	$\Delta m = E/c^2$ or $2E/c^2$ (open, §4.6)	Disagreement with the model's stated choice
7. Pinhole	Group spacing and timing	$d^* \approx 2\sqrt{sf}$; blue hole $\approx \frac{1}{6}$ smaller than red; rim dependence	No rim dependence beyond what edge diffraction gives
8. Double slit	Timing of processions	Light at a dark band arrives at half the spacing (twice the frequency)	No doubled-frequency light at a dark band

4.1 Test 1: the column-density shortfall (the main test)

Mechanism. A body's outer layers shadow its interior from the rain, so the interior stops less than its share. Its gravitational mass therefore falls short of its inertial mass. For a sphere of mean density $\bar{\rho}$ and radius R, to first order in κ,

$$\frac{m_g}{m_i} = 1 - f\,\kappa\,\bar{\rho}\,R, \tag{7}$$

with $f = 3/4$ for a uniform sphere [8, 11]. For a density profile $\rho(r) = \rho_0(1 - r^2/R^2)^n$, Russell gives $f = (2n+3)^2/(12n+12)$; for the Earth $n \approx 0.8$ and $f \approx 0.98$ [10, 11].

What the model predicts. The *form*, not the size. The shortfall depends on the column density $f\bar{\rho}R$ and on nothing else about the body. Two bodies of the same column density must fall alike whatever they are made of; two bodies of different column density must differ in proportion to the difference in $f\bar{\rho}R$. The size is set by κ, which the model does not predict, so a detection calibrates κ and, through (3), gives the first direct measurement of the sea.

What is and is not new. The form (7) is not new. It is Majorana's [8], its coefficient is Russell's [11], and Williams, Turyshev and Boggs write it as their equation (23) and use it to obtain the bound (4) [10]; Nali [6] gives it with the same equivalence-principle reading. The bound (4) itself came from an equivalence-principle test, so the lunar-ranging data cannot be counted again as a test of (7). What this paper adds is the emphasis. Almost all equivalence-principle experiments are designed to find a dependence on composition, using test masses of the same size and different materials. In those experiments $\bar{\rho}R$ is tiny and nearly equal for both masses, so they are blind to

(7). The model says the search should be redirected: compare bodies of the *same* composition and *very different* column density, and treat a composition signal at fixed column density as evidence against the model.

Where to look. The column densities that matter span many decades: laboratory masses ($\bar{\rho}R \sim 10^2$ kg m^{-2}), the Moon ($f\bar{\rho}R = 4.4 \times 10^9$), the Earth ($3.4 \times 10^{10}$) [10], the Sun and planets, white dwarfs ($\sim 10^{16}$) and neutron stars ($\sim 5 \times 10^{21}$). Systems in which two bodies of very different column density fall in the field of a third are the natural laboratories; §5 applies the best of them.

Counts against the model: a difference in free fall that follows composition at fixed column density; or a detected shortfall that does not scale with $f\bar{\rho}R$ across bodies.

4.2 Test 2: uniformity of G

Mechanism. G varies if and only if the sea varies, in proportion: $\delta G/G = \delta\rho/\rho$, since κ belongs to matter.

Measurement. Compare G by place, by depth underground, by time, and by the orientation of the apparatus. A variation of G with direction would show the rain is stronger from some directions than others; with time, that the sea changes.

Expected: no variation (Assumption S). The model gives no size for a variation, because it does not derive the uniformity it assumes.

Counts against Assumption S: a reproducible variation not traced to the apparatus. Such a result would not refute shadowing; it would show where the rain differs.

4.3 Test 3: residual drag and anisotropy

Mechanism. A body moving at speed u through the sea meets more rain ahead than behind. If every crossing G1 had the same chance of deflection, the resulting drag would be of order u/v of the push, far too large to allow orbits. The model cancels it with a *time-inside rule*: the chance that a G1 is deflected in crossing a body is proportional to the time it spends inside, that is, inversely proportional to the closing speed, as the capture of slow neutrons follows the $1/v$ law. G1s met head-on cross faster and are deflected less often; the rule cancels the drag exactly for each thin layer of matter.

The residual. The cancellation is not exact for a whole body. A body is many layers deep, and rain deflected in its outer layers no longer reaches its inner ones on its original line. The authors' own evaluation leaves a residual drag of about $\frac{3}{8}\tau$ of the uncancelled drag, with $\tau = 2\kappa\bar{\rho}R$. For a planet this is about one eighth of the Sun's pull on it, and it does not depend on κ. **This residual is not removed by the model as it stands, and planetary ephemerides already exclude it.** It is stated here as an open failure (§6), not as a prediction waiting for data.

What the test measures. Any anisotropy that depends on a body's velocity through the sea scales with u/v. Bounds on preferred-frame effects from lunar ranging, planetary ephemerides, binary pulsars and torsion balances [12] therefore bound v once the mechanism that sets the residual is fixed. With the residual unresolved, this test cannot yet be read; it becomes the only route to v once it can.

4.4 Test 4: the G2 level

Mechanism. By (6), Coulomb's law is the shadowing law in the G2 sea. Its inverse square is exact for the same geometric reason gravity's is, and charge adds exactly only while the bodies that carry it are transparent to the G2 rain; the first correction has the same column-density form as (7), with a G2 opacity κ_2 in place of κ.

Measurement. Tests of Coulomb's law for departures from the inverse square, especially at short range, and tests of the exactness of the charge step (the neutrality of atoms and molecules) probe ρ_{G2} and s_e/e. The inverse square is confirmed to about 3×10^{-16} in the exponent [13], and the neutrality of matter to about $10^{-21}e$ per atom [14].

Expected: no departure at present precision. Because the G2 fields have no physical description yet, the model cannot say at what precision a departure should appear.

Counts against the model: a departure from the inverse square, or from exact charge additivity, that does not take the column-density form.

4.5 Test 5: a floor on the number of G1s that replace one electron

Let N be the number of G1s that stand in the place of one electron. (N counts the particles that replace the electron; it is not a count of parts that an electron is made of.) The model gives a lower bound on N, not N. Appendix A gives the calculation; it rests on two assumptions:

(A) an emission is the release of a whole number $n_{\mathrm{rel}} \geq 1$ of G1s moving at c;
(B) the energy assigned to the release is $n_{\mathrm{rel}} \cdot \frac{1}{2} m_G c^2$ (or $n_{\mathrm{rel}}\, m_G c^2$; see Test 6).

The smallest atomic emissions observed set the tightest bound. With the hydrogen 166α recombination line ($E = 5.89\ \mu$eV) the result is

$$m_G \leq 2.1 \times 10^{-41}\ \mathrm{kg}, \qquad N \geq 4.3 \times 10^{10}, \qquad n \geq 1.8 \times 10^{61}\ \mathrm{m}^{-3}, \tag{8}$$

and without the factor $\frac{1}{2}$ in (B), $m_G \leq 1.05 \times 10^{-41}$ kg, $N \geq 8.7 \times 10^{10}$, $n \geq 3.6 \times 10^{61}$ m^{-3}. Either way N is at least tens of billions.

Counts against the model: an emission smaller than one G1 group allows, if (A) holds. The model can escape the bound only by giving up (A) for emissions at these energies. A direct simulation of a release, following individual G1s, would test (A) and is proposed as part of this test.

4.6 Test 6: the mass of excited ions

Measurement. Penning-trap mass spectrometry now resolves the mass difference between the ground state and a long-lived excited electronic state of a single highly charged ion. For $^{208}\mathrm{Pb}^{41+}$, PENTATRAP measured the excitation as a mass difference of 31.2(8) eV/c^2, with a fractional mass uncertainty of 4×10^{-12}, in agreement within one standard deviation with two independent atomic-structure calculations of the excitation, 31.68(13) and 31.76(35) eV [15]. For $^{187}\mathrm{Re}^{29+}$ the same group measured 202.2(17) eV/c^2 at a precision of 10^{-11} on the frequency ratio [16]. In both cases the mass gained on excitation equals the calculated energy of the excitation over c^2, to the 3 per cent precision of the lead measurement.

What the model owes. When an excited ion returns to its ground state it releases a group of G1s. If the energy assigned to the released G1s is $\frac{1}{2}\Delta m\,c^2$, the ion must lose twice the mass that the excitation energy alone would suggest: about 63 eV/c^2 for the lead state, not 31. If it is $\Delta m\,c^2$, the model agrees with the measurement. **The model has not yet stated which.** The question is open, and this paper does not settle it. The measurement above already discriminates between the two answers, provided the calculated excitation energy is accepted as the energy of the light the ion would emit; a direct comparison of a Penning-trap mass difference with a spectroscopically measured transition in the same ion would remove that proviso.

Counts against the model: disagreement with whichever answer the model states.

4.7 Test 7: the pinhole

Mechanism. A procession whose groups are spaced s apart (the colour) passes through a hole of diameter d and travels a depth f to the screen. A group crossing at distance r from the axis reaches the centre of the image later than one through the centre, by a path difference $r^2/2f$. Groups arriving in step reinforce; groups arriving out of step do not.

Prediction. The sharpest image comes from a hole of diameter

$$d^* = c_p\sqrt{sf}, \tag{9}$$

with the constant c_p set by the criterion of sharpness: about 1.4–1.6 if the criterion is half the light in the central spot, about 1.9 for four-fifths, and 2.0 for the brightest point on the axis (a first-zone argument gives $d^* = 2\sqrt{sf}$). These constants were obtained numerically by the authors (to about 0.1), not from a published treatment. With $c_p = 2$: for $f = 50$ mm, $d^* = 0.30$, 0.33 and 0.36 mm for $s = 450$, 550 and 650 nm; for $f = 100$ mm, 0.42, 0.47, 0.51 mm; for $f = 150$ mm, 0.52, 0.58, 0.63 mm. A blue pinhole should be smaller than a red one, by about a sixth between 450 and 650 nm. The weight of the halo relative to the spot should fall as $1/d$.

What is and is not new. The square-root law and constants of this size are the classical results of wave optics: Petzval's $\sqrt{2f\lambda}$ and Rayleigh's $1.9\sqrt{f\lambda}$ [17, 18]. Equation (9) therefore agrees with existing measurements but does not distinguish the model from wave optics. What does is the second route: in the model the rim of the hole deflects groups, so the best hole should shift with the rim's edge profile, thickness and material, beyond the dependence on edge geometry that diffraction theory already gives.

Weak joint. The rule that groups arriving at in-between lags combine as partly in step is an assumption. The model's double-slit account works out only the two extremes, fully in step and fully out of step.

Counts against the model: no dependence of d^* on rim material once edge geometry is matched.

4.8 Test 8: the double slit

Mechanism. Processions from the two slits arrive at a dark band exactly out of step, so the groups from one slit fall midway between those from the other.

Predictions. (i) What arrives at a dark band is a procession at half the original spacing: light at twice the frequency, not an absence of light. (ii) A detector at one slit disturbs the timing of the processions through it, leaving two blobs and no fringes.

Status. Prediction (ii) agrees with the standard result and does not distinguish the model. Prediction (i) does: in linear optics, nothing at twice the frequency reaches a dark fringe. A spectrometer or a detector blind to the original colour but sensitive at half the wavelength, placed at a dark band and shielded from scattered light, tests it. Neither prediction has been tested as stated.

Counts against the model: no light at twice the frequency at a dark band, at a sensitivity where the model's account says it should be seen. (The model owes the expected intensity.)

5 What existing data already bound

Composition. Gravity acts on κm, so if κ differed between materials, free fall would depend on composition. The MICROSCOPE satellite found no composition dependence at the level of about 10^{-15} [19]. In the model this says that κ is the same for titanium and platinum to that precision, which the model requires: κ belongs to matter as such, not to a kind of matter.

Column density, Earth and Moon. The lunar-ranging bound (4) limits the shortfall (7) to about 2.2×10^{-14} for the Moon and 1.7×10^{-13} for the Earth [10].

Column density, neutron stars. The pulsar PSR J0337+1715 and an inner white dwarf fall together in the field of an outer white dwarf. Timing of the pulsar bounds the fractional difference in their free fall to $\Delta = (+0.5 \pm 1.8) \times 10^{-6}$ at 95 per cent confidence [20, 21]. The pulsar has mass $1.44\,M_\odot$ and, for a radius of about 12 km, $\bar{\rho}R \approx 4.7 \times 10^{21}$ kg m^{-2}; the white dwarf's column density is smaller by about five orders of magnitude. Reading Δ through (7) with $f \approx 3/4$ gives

$$\kappa \lesssim 7 \times 10^{-28}\ \mathrm{m^2 kg^{-1}}, \tag{10}$$

about seven thousand times tighter than (4). Through (3) it raises the floor on the sea by the square of that factor, to $\rho \gtrsim 1.7 \times 10^{45}$ Pa, and with $v = c$ to $n\,m_G \gtrsim 2 \times 10^{28}$ kg m^{-3}; the floor on n in (8) rises by the same factor. Two assumptions enter: that neutron-star matter stops the rain per kilogram as ordinary matter does, and that the neutron star is still transparent to the rain (here $\tau = 2\kappa\bar{\rho}R \lesssim 7 \times 10^{-6}$, so it is). This reading of the pulsar data is the authors' calculation; it has not, to their knowledge, been published, and it should be checked.

Uniformity of G in time. Lunar ranging bounds $|\dot{G}/G|$ at the level of 10^{-13} yr^{-1} [22]; in the model the strength of the sea has changed by at most about 0.1 per cent over the age of the universe. Laboratory values of G disagree with one another by several parts in 10^4, more than their quoted uncertainties [23]. The disagreement is usually attributed to the apparatus; Test 2 would ask whether any of it follows place or direction.

Preferred-frame effects. The bounds on velocity-dependent anisotropy [12] are far below the residual drag of Test 3, which is why that residual is listed as a failure (§6).

Coulomb's law and neutrality. See Test 4 [13, 14].

Excited-ion masses. See Test 6 [15, 16].

6 Where the model can fail, and what each failure would mean

A failure points to a mechanism to rebuild, not to abandoning the model.

- **A composition-dependent violation at fixed column density** (Test 1): κ is not universal; the account of how matter stops the rain must be rebuilt.
- **A variation of** G (Test 2): Assumption S fails; the sea is not uniform, and the model must say why.
- **The self-shielding residual** (Test 3), already in conflict with planetary motion: the time-inside rule, or the account of how deflected rain leaves a body, must be rebuilt for bodies many layers deep. This is the most pressing failure the model now carries.
- **A departure at the G2 level** (Test 4): the G2 account, which has no physical description yet, must supply one.
- **An emission below the floor** (Test 5): assumption (A), whole-number release, fails.
- **Excited-ion masses** (Test 6): the model's statement of how much mass a released group carries fails.
- **No rim dependence of the best pinhole, or no doubled frequency at a dark band** (Tests 7, 8): the account of how groups combine at a screen must be rebuilt.

Over-determination is the point. Tests 1, 3 and 5 reach the same three quantities n, m_G and v by independent routes. If the routes disagree, one joint has failed, and the disagreement says which.

7 What is not yet known

- The model gives the form of G and of Coulomb's constant, not their values. It gives a floor on N, not N.
- **Assumption L.** The particles of the sea are assumed to be the same as the particles of light, so that $v = c$.
- **Assumption M.** Mass is assumed to add across the N G1s that replace one electron, so that the mass attributed to an electron is the mass of that quanta.
- **Shot noise.** Shot-noise measurements find carriers of one electron charge in tunnel junctions and ordinary conductors [24], twice that at normal-metal/superconductor junctions [25, 26], and fractions of it only in the fractional quantum Hall regime [27, 28]. If free G1s carry the current, the model owes an account of why the noise counts charge in these units.
- **The G2 fields** have no physical description yet.
- **The energy carried by a released group**, $\frac{1}{2}\Delta m\, c^2$ or $\Delta m\, c^2$, has not been stated by the model (Test 6).
- **Precision.** The precision needed for some cross-checks, in particular a measurement of κ rather than a bound, may not yet exist.
- **Mass and number density.** Gravity measures only $n\, m_G\, v^2$. Separating m_G and n needs a count of N, and no way to make that count has yet been proposed.

8 Conclusion

The four-motions model is a particle model of gravity and light that can be tested. Its main gravitational prediction, a shortfall of gravitational mass that depends on column density and not on composition, is already written in the shielding literature; what the model adds is a reason to search for it in that form, and a reading of any detection as a measurement of the sea through $\rho = 4\pi G/\kappa^2$. Existing data bound the sea from below, very strongly if pulsar timing applies. The model carries one known conflict with observation, the self-shielding drag residual, and one unstated

choice, the mass carried by a released group, both of which are named here so that a reader can hold the model to them.

A The floor on N

Step 1. By (A) and (B), a release of $n_{\mathrm{rel}} \geq 1$ G1s at speed c is assigned the energy $E = n_{\mathrm{rel}} \cdot \frac{1}{2} m_G c^2$. Hence $m_G = 2E/(n_{\mathrm{rel}} c^2) \leq 2E/c^2$, and the smallest observed emission gives the tightest bound.

Step 2: the smallest atomic emissions. The hydrogen 166α radio recombination line has rest frequency 1424.734 MHz [29], in agreement with the Rydberg formula for the transition $n = 167 \to 166$ (1424.734 MHz with the reduced-mass Rydberg constant). Then $E = hf = 9.440 \times 10^{-25}$ J $= 5.89$ μeV. (The 21 cm hyperfine line at 1420.406 MHz gives 9.412×10^{-25} J, almost the same.) Recombination lines of higher order are lower still in frequency, so this choice is not the smallest emission possible, only a well-measured one.

Step 3. $m_G \leq 2E/c^2 = 2.1 \times 10^{-41}$ kg.

Step 4. By Assumption M, $N = m_e/m_G \geq 9.109 \times 10^{-31}/2.1 \times 10^{-41} = 4.3 \times 10^{10}$.

Step 5. With $n\, m_G \geq 3.7 \times 10^{20}$ kg m^{-3} from (5), $n \geq 3.7 \times 10^{20}/2.1 \times 10^{-41} = 1.8 \times 10^{61}$ m^{-3}. With the pulsar bound (10) the floor on n rises by the same factor of about fifty million.

Without the factor $\frac{1}{2}$. If $E = n_{\mathrm{rel}}\, m_G c^2$, then $m_G \leq 1.05 \times 10^{-41}$ kg, $N \geq 8.7 \times 10^{10}$, and $n \geq 3.6 \times 10^{61}$ m^{-3}.

Escape route. If an emission at these energies is not a whole-number release, Step 1 fails and there is no floor.

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