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A Novel Distant Masses Centrifugal Origin for Gravity

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Abstract

Gravity is a fundamental force but of unknown origin. Adding to its mystery is its infinite range and penetrating capability through anything. It causes matter particles of all kinds to attract (accelerate towards each other) with an accurate constant amount via a universal gravitational constant G, at any point in the universe. There is an equal support in physics for an innate attraction origin and an external pushing origin [5]. Evidence for a third origin appeared indirectly in Bertrand theorem showing the emergence of the inverse square law of Newton to be a direct consequence of momentum conservation. A centrifugal force has the same origin, same penetrating ability, and also radially symmetric like gravity. But has a repulsive outward direction opposite to that of gravity. We show that this similarity can be made full if this outward direction was taken to come from the distant masses at the edge of the universe instead. This causes all masses to clump together and gravity becomes both an innate momentum conserving and also a pushing-in force; away from distant masses and into the centre of local mass. Such force has normally an insignificant value, but can become significant by the accumulation of high (squared) speed and the extra-large masses involved in gravity interactions. The idea of local effects of distant masses was advocated far back by Ernest Mach and others when faced with Newton's explanation of the rotating bucket experiment and the conclusions regarding the properties of a fixed empty space. We do calculations and numerical predictions here to show the plausibility of this centrifugal origin idea, and compare the findings with those of the inverse square of Newton. We find the value of G from the mass and size of the universe together with the value of a related constant- the terminal acceleration of galaxy rotation curves- normally attributed to dark matter in the literature, but now explained in terms of distant masses. The same form of the formula for G was predicted in 1925 by Schrodinger [12]. Our results show that; a distant masses centrifugal acceleration origin for gravity is a plausible idea and the invers square law can be thought as the resultant of two individual radial accelerations similar as in the laws in the Kepler theory where the motion is described for a single object with respect to the centre of local masses.

Keywords: matter and energy, origin of gravity, centrifugal and radial forces, Mach principle, ballistic and innate gravity, equivalence principle, properties of space, the bull principle.

1 Introduction

If we excluded the tiny regions of the nuclear forces, gravity and electromagnetism are the two major force fields that govern the universe. In [2],[3] it was shown that if we presumed the universe to be composed of only radiation- free as energy and trapped as mass, it becomes possible to derive the rest of the equations of physics using conservation of momentum together with a constant speed of propagation of light. The matter attributes of electric charge, magnetic dipole moment, spin and inertia emerge naturally from the attributes of radiation trapped to go in closed loops and form the rest energy/mass or matter. The inverse square of Newton's gravity appears as a consequence of conserved momentum was shown in Bertrand theorem. What is not discussed to date, is the possibility that gravity can energy from centrifugal forces, since such forces are repulsive/expulsive and not attractive in nature. This becomes possible however, if we think in terms of the distant masses of the universe as advised by the Mach postulate. Centrifugal forces around a distant mass are directed away from distant masses and towards the centre of local masses. This provides the required pushing-in or equivalently, the attraction forces of gravity.

The centrifugal origin of gravity idea was born out of results given in previous works by the author that were both incidental [1],[4]. The first was an effort to find a simpler way to compute numerically the behaviour of many-body problem by doing the integration of a single particle path then add all such paths together to find the interaction by superposition- if possible. The unexpected result was that it was possible when using a time solution to replace the inverse square law. As a result, it was found possible to start the solution from the middle of the interaction time and be able to reproduce the rest of it exactly. This should not be possible as such a delayed start doesn't know of the state of the particle in the middle time, as it only uses the same initial conditions in each run, see Fig(1) and algorithm. Some derivations are given in the next section with a full discussion is in [1] for further details. The second incidental result was connected with the attempt to explain the terminal rotation curves of galaxies [3]. Dark matter and a modified gravity ideas were constructed to explain how stars rotate faster around galaxies than what the visible galaxy gravity forces allowed for. The author found a centrifugal force due to rotations around distant masses does produce a correct value for such acceleration which was an eye opener.

Going this way, gravity itself can be explained using the same logic. The unusual many body problem results shown in Fig (1) can then be due to simply expressing the superposition of all particles rotating around distant masses to appear as a gravity and its equivalent inverse square force. Starting the prediction in the middle didn't matter as the common time of the various interactions is preserved. That says, particles either respond to the distance between them as in the inverse square formula, or to gravity pushing each of them separately resulting in an apparent mutual attraction. As it turned out, this line of thinking proved fruitful. A formula is obtained for the gravitational constant G from the knowledge of the size and mass of the whole universe, which has the exact form expected in an old German paper by Schrodinger in 1925 [12]. The analysis of considering a time solution for the inverse square formula was first reported in [1] and reproduced here, to show that a centrifugal and the inverse square gravity forces, have the same form when using a time formula.

Popular theories that postulated gravity to be the result of agents like randomly floating corpuscles hitting particles from all directions and causing the gravity clumping phenomenon as a compressive force, were rejected as all flawed- around Newton's time. Edington and others [14], were reported to have said; It is impossible logically to explain the gravity force as not an innate force in matter. These theories have flourished because of the difficulty of imagining anything other than magic to be this innate source of attraction. The argument was later abandoned and covered under the banner of being a 'fundamental force'- meaning it is beyond discussion!! The centrifugal origin idea of the present work, has the advantages of being both innate and external. Innate as it relies on inertia and conservation of momentum to work, and external as it requires the effect of the distant masses also. More about such discussion on gravity can be found in [4 to 13]. Few important quotes from these are given in the references. Ref. [5] contains a comprehensive account of available literature.

2 Conservation of Momentum and Superposition

In [2] we showed that conservation of momentum comes from the fundamental property of symmetry of empty space, which is the critical balancing or equivalently, the impossibility of moving the centre of isolated masses from within. We also called it the 'Bull Principle' because it was first thought off by those who worshipped the Bull in the Middle east. The had it that; the universe is balanced on the tip of a Bull's horn and earthquakes happen when it is jolted from one horn to the other!! This principle is so powerful that not even a single electron or a photon can defy it and move in one direction without a similar partner moving in the opposite direction at the same time. This also proved to be a truly theory of everything, and also the source of the controversial entanglement of QM.

Mathematically, for a group of isolated masses we should have; $\sum m.dx=0$, along any line in space. By differentiating with respect to time once and twice for constant mass m we get; $\sum p=0$, and $\sum f=0$ along any line. These give the laws of conservation of momentum p and balance of forces f. Newton used geometrical arguments in his theory, to show that stable closed orbits of masses must be in a single plane and conserved momentum. Then Bertrand theorem showed later that in this case, the forces between the orbiting masses must be of an inverse square type. It could also be of the Hook's spring force type, but this case can be shown to be a special case of the first [2]. The inverse square can then be put in the retarded integral of Liénard–Wiechert to give the full form of Maxwell equations from the simple static Coulomb inverse square law of electricity, and also the Gravitomagnetic equations (linear GR) from the inverse square of Newton. This way we have the whole of physics out of the 'Bull principle'.

Following [2], we take radiation as an evaporated matter which is energy, and matter as the condensed radiation version, with all its emerging attributes of; mass, gravitation, spin, electric charge and magnetic dipole moment. Radiation itself has constant speed and carries electric, magnetic and momentum fields with it. Many aspects of physics become easier to understand using this picture and inertia being the first one. The resistance of mass to motion being dependent on the mass and how much speed to add becomes simply a matter of action and reaction and the exchange of energy/radiation. All momentum exchange between masses is provide by radiation either absorbed or emitted. The masses of billiard balls hitting each other never touch in real as an example. When they get nearer instead, electric repulsion grows larger fast and radiation is emitted (a result of the change/acceleration) that gets absorbed to increase the energy and momentum of the hit ball and reduces that of the hitting ball buy the same amount- if nothing is lost as heat to outside space for example.

We see that it then becomes of no surprise that gravity itself is a consequence of conservation of momentum- in the same way as the centrifugal force is. Usually, the centrifugal forces are insignificant, was it not for the very large number of particles and the superposition property allowed by empty space. The centrifugal force *v^2/r* has the square of velocity and a large growth in velocity effects become an important factor in making this force not only significant but a dominant force in the outside universe as a whole.

3 Centrifugal Forces due to Distant Masses

The centrifugal force f_c due to a mass m rotating around the origin at r from it, is given by; $f_c=m\,v^2/r$. The acceleration alone is simply; $a=v^2/r$. This can easily be derived geometrically as Newton did the first time, and can be found in every reference in physics. This acceleration is away from the local centre and causes few masses placed on a turning table for example, to fly away and scatter radially. This force is radial, independent of mass and like gravity can't be shielded because it is innate like inertia and conservation of momentum.

Gravity has similar attributes but acts to push masses together not out. Here where the thinking of Ernest Mach about the distant masses comes useful. For the water in a rotating bucket argument of Newton, Newton argued that space is absolute and one can look at the curvature of the water surface to find out if the bucket is rotating or the observer is, measured with respect to empty space. Ernest Mach suggested that this can't not be true and as the bucket rotates, the distant masses rotate too in the opposite direction to keep angular momentum conserved. Very much like when we walk forward, we push the earth surface to walk backward. We don't feel this back motion as the mass of earth is so large in comparison. For the same momentum in the walk, the corresponding earth motion is extremely small, and only the product/momentum $p=m.v$ is significant.

The distant masses appear fixed because of their faraway positions. Like when we are looking at the moon from a car window and seeing it fixed with respect to us and moving with the same speed of the car. The acceleration around the distant masses is given by; $a0=v^2/r_u$, where ru is the radius of the visible universe at 4.4e26m. For any small speed this is negligible. But as radiation obeys conservation of momentum and all matter is condensed radiation as given above, we should take $v=c$ and get $a0=c^2/r_u$=2.7 e -10 m/s^2. This is the acceleration that every mass experience away from the distant masses. We stress that the distant masses are everywhere around us at r_u. A centrifugal force is always away from them and into the centre of mass of the local masses creating what we feel as gravity. Replacing the velocity by c is a direct consequence of the radiation composition of matter. The equivalence principle is shown in [3] to lead to light behaving like matter in bending when passing massive objects and loosing energy and red-shifting when climbing a potential-wells, while gaining frequency in the opposite direction. Because of the $v^2/r = \boldsymbol{v.v/r}$, the centrifugal force is not sensitive to the direction of v and always in the direction of $\boldsymbol{r}$ all the time, that is away from distant masses.

The value of G can now be calculated from Newton's gravity law as; $a=4Gm_u/r_u^2=a0=c^2/r_u$, with the factor 4 coming from r_u^2 being originally a diameter square. This gives; $G= c^2\ (r_u/4)/mu$. This is the exact form speculated by Schrodinger in his 1925 paper [12]. With the estimated values of the radius r_u=4.4e26 m, and that of the mass m_u=1.45 e53 kg (could be 1e53:1e60 kg), we get an approximate value for G=6.8 e-11, with the accepted physics value at G=6.67e-11 Nm^2/kg^2. In [3], we showed that the centrifugal forces can be used to derive the universal law for gases too, without a resort to statistical mechanics. Also shown that if the gravity phase shift due to distant masses is taken as a reason for the observed galaxy phase shift, we get an expression for the Hubble constant as; $H=G\ m_u/r_u^2c$. Upon inserting G her from above, we get;

$H=c/r_u$, which is well accepted as a formula for this constant. This force appears as the hidden factor behand many of the formulae connected to motion. This shows that the centrifugal force and the distant masses are strongly present in few other processes.

4 Centrifugal and Inverse Square Accelerations Compared

We now perform simulations with the inverse square and centrifugal accelerations to find how interacting particles behave under these two forces. Any equation of motion is implicitly a function of time t, together with the initial conditions of position r and velocity $v=\dot{r}$, and driven by the force/acceleration a. We now assume this function $r=r(t)$ in the form; $r=k\ t^n$. This gives $v=dr/dt=k\ n\ t^{n-1}$, and $a=d^2r/dt^2=k\ n(n-1)\ t^{n-2}$. Equating this to the inverse square expression; $d^2r/dt^2=1/r^2$ gives; $1/(k\ t^{n})^2 = k\ n(n-1)\ t^{n-2}$. For the two sides to be equal, we must have; $k^{-2} = k\ n(n-1)$, and $-2n=n-2$. These give us; n=2/3, and k=- 9/2 (or 0, which is discarded). Thus, a solution of the inverse square force motion is given by; $r(t) = (9/2)\ t^{2/3}$, v(t)= $-3\ t^{-1/3}$, $a= t^{-4/3}$. These are Kepler type equations.

Using this time formula, it becomes possible to do particle simulation with time advancing as; $t^{2/3}$, and get an equivalent inverse square motion. This was done in [1] before and the results are repeated in Fig (1) below, with a streamlined version of the algorithm. It is almost magical to note that the calculation can be started at any time step and still produce the same particle interaction outcome. This we now know is possible only because of the use of the time formula for r and considering the interactions as the sum/superposition of paths rather than an unfolding interdependent binary interaction. All this is possible only because the linearity of potential problems of course, and the possibility of using the superposition of many solutions to arrive at the final outcome in particle interactions.

If we now continue and use the formula $r(t)$ to calculate the centrifugal acceleration $a0=v^2/r$, we find that $a0 = (kn\ t^{n-1})^2 / kt^n$, or $a0=k\ n^2\ t^{n-2}$. This is the same as obtained above from the inverse square formula. We conclude that our particle interactions can be done equally well using the inverse square or the centrifugal force formulae by assuming an individual central acceleration caused by distant masses as the root cause of gravitation. We note that in the inverse square case only the 'relative' distance (x_i-x) between particles is used, whereas in the others the individual positions from a common centre and common time x_i ,t are used. This is a reminder of Newton's absolute space and time ideas, which were fully rejected then and now!! But it is not all new of course, as in many other cases in physics we have completely different formulae producing the same outcome and one of which might seem beyond normal logic. A vivid example is the use of images in potential theory in static electricity to fully replace/remove a complex boundary and get the same solution with the aid of the mirror image sources.

If we consider the matter from the point of energy contents, we know from Kepler theory that a particle in an elliptic motion conserve the total of kinetic and potential energy. The kinetic energy per unit mass is $e_k=0.5v^2$, and the corresponding potential energy is $e_p=k/r$ where k is the gravitation coupling constant. Equating the two and dividing by r gives; $mv^2/r=k/r^2$. The factor 0.5 is dropped because there is only one body in the centrifugal case. Again, this shows the equivalence between the centrifugal and inverse square force views via an energy argument this time. By replacing v by c and using the universe values for mass and radius, the same formula for G above can be derived after substituting $k=G.m$.

5 Numerical Results

The above ideas are implemented numerically to compare the results to provide practical examples. In Fig (1) and as described above, we repeated after abbreviating and streamlining the algorithm in [1] and showed how magical the simulation results turn out be when using a time solution for the inverse square force. Due to this time formula, it is possible to start the simulation at any intermediate time and produce the rest of the interaction correctly without keying in a new starting position. A small kick is seen in the start of simulation, but the software quickly finds the correct starting position then continues the simulation to the end with identical outcomes.

In Fig (2) and associated algorithm, we use either a constant gravity acceleration pointing to the centre of mass, or one obtained from the centrifugal acceleration based on the velocities of the particles around the centre of mass. The algorithm runs twice with the same initial conditions and plots the two results together for comparison. The two figures are not exact copies, but the similarity is sufficient to show the equivalence of the two methods. The difference is in the few starting steps due to boundary conditions are not changed for in each case.

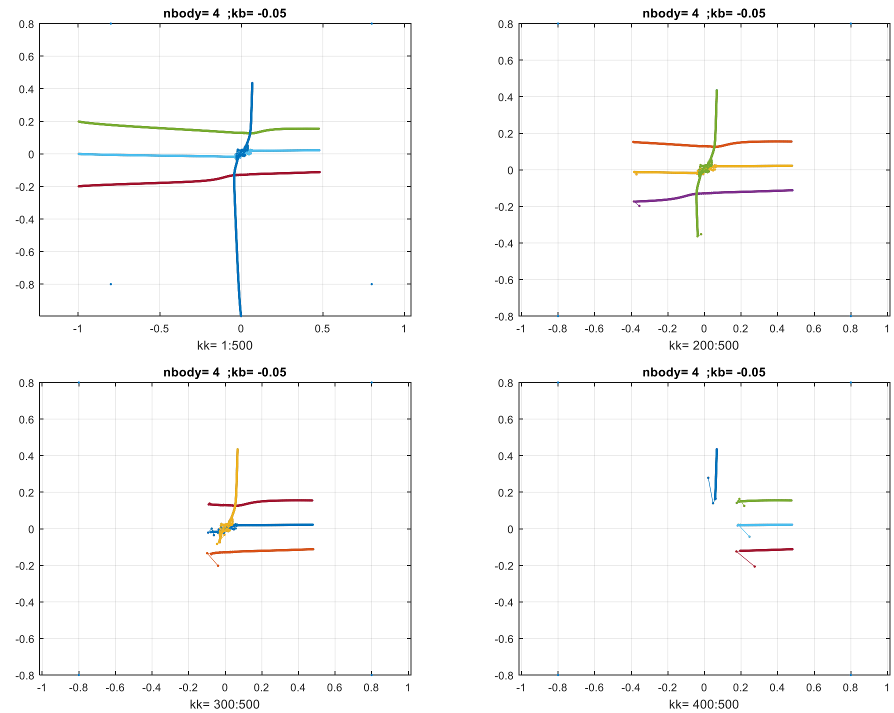
In Fig (3) and the associated algorithm, a constant acceleration is assumed to be due to the distant masses and directed towards the centre of mass of particles from any direction in 3D space. The particles don't interact with each other but only with the distant masses. However, by the properties of triangles, the force between two particles is the *difference* of the radial vector forces to every particle. In other words, the relative effects of each particle on each other is only the result of the subtraction of differences in the radial pushing forces on each particle- being not the same at the two different positions. The particle paths show the very characteristics normally seen in the inverse square interactions of a Newtonian gravity.

6 Conclusions

Gravity was described as of unknown origin by Newton, of innate nature by Kelvin and due to fast moving corpuscles hitting and pushing all matter particles together by Fatio and others. Einstein described it to be a bending in space-time by matter, which fits within the innate group. This position is still the same today. We suggested a new origin for gravity that has both an innate and an external pushing origin, which is the centrifugal acceleration away from distant masses. It is innate because its origin is in inertia and conservation of momentum, and it is external pushing-in because it is caused by the centrifugal repulsion away from distant masses- as suspected by Ernest Mach and others before. The fast and tiny corpuscles of Fatio and Le Sage theory can now be replaced by the centrifugal acceleration/pushing force of the local masses involved and away from the distant masses. The theoretical machinery of the Fatio theory can be reused here if needed, but shading is no longer needed. Our formulation also agrees with Einstein equivalence principle, and found that gravity is not only equivalent to acceleration but is an actual acceleration force. Our method gives the correct formulae for the gravitational constant in terms of distant masses, which was expected before by Schrodinger in 1925. We also get the terminal acceleration of galaxies to agree with what was measured in present day astronomy when based on the effect of distant masses. The equality of the centrifugal with that of the inverse square force can also be obtained from the constancy of total energy of any matter in orbit. Our calculations and numerical simulations show that the suggested idea for the origin of gravity is quite plausible and should be further investigated for more useful results and better understanding of any gravity interaction. It is also worth noting that the presence of a velocity squared term in the centrifugal gravity formula is necessary to avoid gravity aberrations [4] as achieved in Weber and Ritz gravitation formulations [13]. Our method of treating gravity interactions as that of single masses with respect of the local centre of mass rather than between every two masses as Newton did, is a going back to the original treatment of the subject by Kepler from which Newton derived his law.

7. Figures and Algorithms

Figure (1): Algorithm and results of the interaction of 4 particles under attraction evaluated from Kepler time formula instead of the inverse square of Newton.



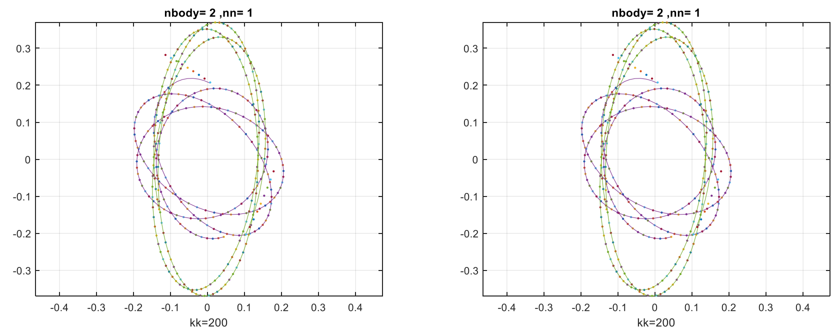
Program running times:(1, 200, 300, 400):500, the end of simulation. The algorithm is
a shortened and streamlined version of one given in [1].

```
%Kepler type formula test; r=t^(2/3).
clear all; close all;ee=1e-10;V2=[];R2=[];X=[];Y=[];
nb=4;kb=-5e-2;x=zeros(nb,1);y=x;      dt=.001;  nt=500;
ay=.2;a=1;  x(1:4)=[-a -a -a 0];y(1:4)=[ay 0 -ay -a];
av=3;vx(1:4)=[av av av 0];vy(1:4)=[0 0 0 av];
x0=x;y0=y;vx0=vx;vy0=vy;tv=1:nt; t=dt*(tv); t23=t.^(2/3);
figure(1);s=.8;plot([-s s -s s],[-s -s s s],'.');

nt1=100;for kk=nt1:nt; for jj=1:nb;  xj=x(jj); yj=y(jj); vxj=vx(jj);vyj=vy(jj);
tk=t(kk);t23k=t23(kk);  xj0=x0(jj);yj0=y0(jj);vxj0=vx0(jj);vyj0=vy0(jj);
xb=xj-x; yb=yj-y; rb2=ee+xb.^2+yb.^2; rb=sqrt(rb2);
dxj=t23k*(kb*sum(xb./rb))+(tk*vxj0);dyj=t23k*(kb*sum(yb./rb))+(tk*vyj0);
xj=xj0+dxj;  yj=yj0+dyj;  x(jj)=xj; y(jj)=yj;  vx(jj)=vxj;vy(jj)=vyj;
end; 'jj'; pause(.01);if round(kk/10)*10==kk;hold off; figure(1);axis equal; hold on;
```

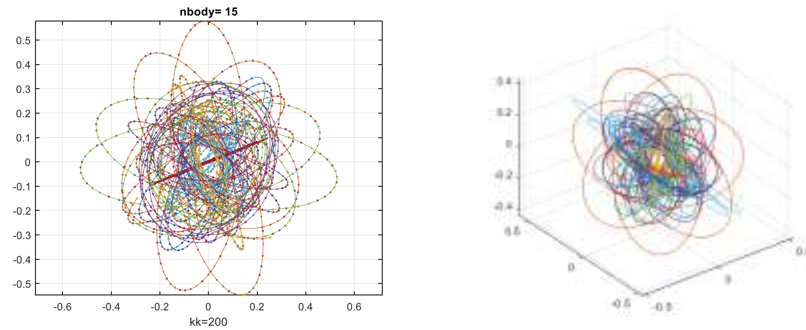
```
xlabel(['kk= ' num2str(nt1) ':' num2str(kk)]); end;plot(x,y,'.');
X=[ X x];Y=[Y y]; end;'kk';figure(1);plot(X',Y','.-');
title(['nbody= ' num2str(nb)  '  ;kb= '  num2str(kb) ]); grid on;
```

Figure (2): Simulation and results of two-point particles under attraction with forces calculated from a constant central acc. (Left) and centrifugal acc. (Right).




```
%Mach distant masses; radial and centrifugal accelerations.
clear all; close all;ee=1e-10;X=[];Y=[];Z=[];nt=200;
nb=2;kw=-2;  a=1; av=1; ar=.5;  dt=.05;
x=ar*(rand(nb,1)-.5); y=ar*(rand(nb,1)-.5);z=ar*(rand(nb,1)-.5); x1=x;y1=y;z1=z;
vx=av*(rand(nb,1)-.5); vy=av*(rand(nb,1)-.5);vz=av*(rand(nb,1)-
.5);vx1=vx;vy1=vy;vz1=vz;
for nn=1:2; x=x1;y=y1;z=z1;vx=vx1;vy=vy1;vz=vz1;
for kk=1:nt;
r2=ee+x.^2+y.^2+z.^2; r=sqrt(r2);v2=ee+vx.^2+vy.^2+vz.^2;
if nn==1;Kw=kw./r; ax=Kw.*x;ay=Kw.*y;az=Kw.*z;end;     %Centre acc.
if nn==2;Kw=kw*v2./r; ax=Kw.*x;ay=Kw.*y;az=Kw.*z;end;  %Centrifugal acc.
vx=vx+ax*dt/2;vy=vy+ay*dt/2;vz=vz+az*dt/2;
x=x+vx*dt;y=y+vy*dt;z=z+vz*dt;
pause(.01);if round(kk/10)*10==kk;hold off;figure(nn);axis equal;
hold on;xlabel(['kk=' num2str(kk)]); end;plot(x,y,'.');
X=[X x];Y=[Y y];Z=[Z z];end; 'kk';
figure(nn);plot(X',Y','');title(['nbody= ' num2str(nb) ' ,nn= ' num2str(nn)]);grid on;
%figure(2);plot3(X',Y',Z','');grid on; axis equal;
end;'nn';
```

Figure (3): Algorithm and results in 2D, 3D for 15 particles interacting under a constant central acceleration that is assumed to be the results of distant masses. The particles are non- interacting between each other.




```
%Simulate the effect of distant masses.
%acceleration kw towards the origin, constant independent of position.
clear all; close all;ee=1e-10;X=[];Y=[];Z=[];nt=200;
nb=15;kw=-6;
a=1; av=2; ar=.5;  dt=.05;
x=ar*(rand(nb,1)-.5); y=ar*(rand(nb,1)-.5);z=ar*(rand(nb,1)-.5);
vx=av*(rand(nb,1)-.5); vy=av*(rand(nb,1)-.5);vz=av*(rand(nb,1)-.5);

for kk=1:nt;
r=ee+sqrt(x.^2+y.^2+z.^2);Kw=kw./r; ax=Kw.*x;ay=Kw.*y;az=Kw.*z;
vx=vx+ax*dt/2;vy=vy+ay*dt/2;vz=vz+az*dt/2;
x=x+vx*dt;y=y+vy*dt;z=z+vz*dt;
pause(.01);if round(kk/10)*10==kk;hold off; figure(1);axis equal;
hold on;xlabel(['kk=' num2str(kk)]); end; plot(x,y,'.');
X=[X x];Y=[Y y];Z=[Z z];end; 'kk';
figure(1);plot(X',Y','');title(['nbody= ' num2str(nb)]);grid on;
figure(2);plot3(X',Y',Z','');grid on; axis equal;
```

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"Despite its ubiquity, gravity also remains one of the great mysteries of modern physics. While there remains no complete or perfect theory as to how gravity works, the volume *Pushing Gravity: New Perspectives on Le Sage's Theory of Gravitation,* which drew from the work of the 18th-century Genevan physicist Georges-Louis Le Sage, who posited that there were mechanical forces at work behind the mystery of gravity".
"In a new paper entitled "Optical gravity in a graviton spacetime" (*Optik*, Volume 260, June 2022), Edwards puts forward a novel theory of gravity based on past observations which have hinted at there being an optical medium of spacetime that not only serves as an analogue for the observable effects of gravity, but could also provide a physical means that might potentially help account for it. Such observations include the way light is deflected as it passes by mass, which as Edwards notes is "mathematically equivalent to the refraction of light in an optical medium with a density gradient."

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[13] Wikipedia, Gravity, https://en.wikipedia.org/wiki/Gravity, Quotations:
"Le Sage's theory of gravitation is a kinetic theory of gravity originally proposed by Nicolas Fatio de Duillier in 1690 and later by Georges-Louis Le Sage in 1748".
"Kant asserted that there must exist a fundamental attractive force. This was precisely the same objection that had always been raised against the impulse doctrine of Descartes in the previous century, and had led even the followers of Descartes to abandon that aspect of his philosophy".
"Subsequently, Peter Guthrie Tait called the Le Sage theory the only plausible explanation of gravitation which has been propounded at that time. He went on by saying:
The most singular thing about it is that, if it be true, it will probably lead us to regard all kinds of energy as ultimately Kinetic."
"Moreover, Lunar Laser Ranging experiments have shown that even gravitational binding energy itself also gravitates, with a strength consistent with the equivalence principle to high precision – which furthermore demonstrates that any successful theory of gravitation must be nonlinear and self-coupling. "

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