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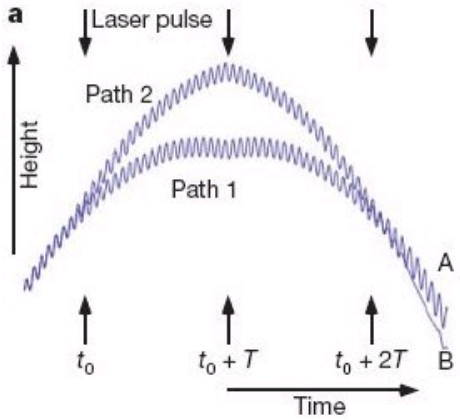
Gravity's effect on time confirmed

Feb 17, 2010 23 comments



Going up: paths followed by interfering atoms

Physicists in the US and Germany have used two fundamental tenets of quantum mechanics to perform a high-precision test of Einstein's general theory of relativity. The researchers exploited wave-particle duality and superposition within an atom interferometer to prove that an effect known as gravitational redshift – the slowing down of time near a massive body – holds true to a precision of seven parts in a billion. The result is important in the search for a theory of quantum gravity and could have significant practical implications, such as improving the accuracy of global positioning systems.

Gravitational redshift follows on from the equivalence principle that underlies general relativity. The equivalence principle states that the local effects of gravity are the same as those of being in an accelerated frame of reference. So the downward force felt by someone in a lift could be equally due to an upward acceleration of the lift or to gravity. Pulses of light sent upwards from a clock on the lift floor will be Doppler shifted, or redshifted, when the lift is accelerating upwards, meaning that this clock will appear to tick more slowly when its flashes are compared at the ceiling of the lift to another clock. Because there is no way to tell gravity and acceleration apart, the same will hold true in a gravitational field; in other words the greater the gravitational pull experienced by a clock, or the closer it is to a massive body, the more slowly it will tick.

Confirmation of this effect supports the idea that gravity is a manifestation of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies. Reinforcing the idea of space–time curvature is important when distinguishing between different theories of quantum gravity because there are some versions of string theory in which matter can respond to something other than the geometry of space–time.

Universality of freefall

Gravitational redshift, however, as a manifestation of local position invariance (the idea that the outcome of any non-gravitational experiment is independent of where and when in the universe it is carried out) is the least well confirmed of the three types of experiment that support the equivalence principle. The other two, the universality of freefall and local Lorentz invariance, have been verified

with precisions of 10^{-13} or better, whereas gravitational redshift had previously been confirmed only to a precision of 7×10^{-5}. This was achieved in 1976 by recording the difference in elapsed time as measured by two atomic clocks – one on the surface of the Earth and the other sent up to an altitude of 10,000 km in a rocket.

This kind of redshift measurement is limited by the degree of gravitational pull provided by the Earth's mass. The new research, carried out by Holger Müller of the University of California Berkeley, Achim Peters of Humboldt University in Berlin and Steven Chu, previously at Berkeley but now US secretary of energy, is limited in the same way but manages to dramatically increase precision thanks to an ultrafine clock provided by quantum mechanics.

In 1997 Peters used laser trapping techniques developed by Chu to capture caesium atoms and cool them to a few millionths of a degree above absolute zero (in order to reduce their velocity as much as possible), and then used a vertical laser beam to impart an upward kick to the atoms in order to measure gravitational freefall.

Now, Chu and Müller have re-interpreted the results of that experiment to give a measurement of the gravitational redshift.

In the experiment each of the atoms was exposed to three laser pulses. The first pulse placed the atom into a superposition of two equally probable states – either leaving it alone to decelerate and then fall back down to Earth under gravity's pull or giving it an extra kick so that it reached a greater height before descending. A second pulse was then applied at just the right moment so as to push the atom in the second state back faster toward Earth, causing the two superposition states to meet on the way down. At this point the third pulse measured the interference between these two states brought about by the atom's existence as a wave, the idea being that any difference in gravitational redshift as experienced by the two states existing at difference heights above the Earth's surface would be manifest as a change in the relative phase of the two states.

Enormous frequency

The virtue of this approach is the extremely high frequency of a caesium atom's de Broglie wave – some 3×10^{25} Hz. Although during the 0.3 s of freefall the matter waves on the higher trajectory experienced an elapsed time of just 2×10^{-20} s more than the waves on the lower trajectory did, the enormous frequency of their oscillation, combined with the ability to measure amplitude differences of just one part in 1000, meant that the researchers were able to confirm gravitational redshift to a precision of 7×10^{-9}.

As Müller puts it, "If the time of freefall was extended to the age of the universe – 14 billion years – the time difference between the upper and lower routes would be a mere one thousandth of a second, and the accuracy of the measurement would be 60 ps, the time it takes for light to travel about a centimetre."

This extreme precision could become useful as global positioning systems become ever more accurate. As Müller points out, to determine the position of an object on the ground to millimetre accuracy the atomic clocks on GPS satellites would need to operate with a precision of 10^{-17}, a figure in fact achieved recently by a clock developed at the National Institute of Standards and Technology in the US (see "New optical clock breaks accuracy record"). But at the satellites' altitude of 20,000 km, such clocks will experience a speeding up of time of about one part in 10^{10} thanks to gravitational redshift. Recovering the precision of 10^{-17} would therefore require knowing the redshift effect to a precision of 10^{-7}.

Müller hopes to further improve the precision of the redshift measurements by increasing the distance between the two superposition states of the caesium atoms. The distance achieved in the current research was a mere 0.1 mm, but, he says, by increasing this to 1 m it should be possible to detect gravitational waves, miniscule ripples in the fabric of space–time predicted by general relativity but never before observed.

The work is described in *Nature* **463** 926.

Physik Instrumente (PI)
GmbH & Co. KG
Feb 17, 2010

About the author

Edwin Cartlidge is a science writer based in Rome

23 comments

Add your comments on this article

1 **Ragtime**
Feb 17, 2010 11:20 PM
Prague, Czech Republic

Effect of dark matter to time

It would be interesting to check effect of dark matter to time as it should repulse visible matter weakly and to slow down time.

Reply to this comment | Offensive? Unsuitable? Notify Editor

2 **Babyphysicist**
Feb 19, 2010 3:51 AM

Space time

Hey, if this is indeed true, isnt this kind of a BIG deal? I mean, no ones really done any research to actually confirm Spacetime before, right?

I would just expect to hear more about it other than an article I found by chance.

Reply to this comment | Offensive? Unsuitable? Notify Editor

3 **srp**
Feb 22, 2010 5:34 PM
Quebec, Canada

Reference for you

Numerous experiments with atomic clocks of all sorts (frequency driven) and other types (all of them frequency driven) have been carried out over the past 80 years.

Most of the results are no longer in general print except in formal journals archives.

On source I can refer you to for an overview is "Gravitation & Spacetime" by Onanian & Ruffini

If you dig a little, you will find more

Reply to this comment | Offensive? Unsuitable? Notify Editor

4 **bigpapajohn2003**
Feb 19, 2010 5:54 AM
Alto, United States

Concerning this Experiment

This article is quite interesting. It is very cool that particle gravitation and quantum gravity are finally becoming sciences with extent empirical tests. Concerning the previous post, I don't believe that this is the first experiment to explore the reality of the spacetime structures posited in GR. In fact, every GR experiment affirms this structure, as they rely on predictions that are manifestations of this theory. Also, the fact that this experiment merely increased the accuracy with which this result was known, rather than establishing the result for the first time, seems to indicate that time dilation in a gravity well was well-established. As a final note, why would dark matter repel normal matter slightly (from the first comment)? I confess that I am not an expert in the field by any means, but I don't see why a particle that must interact gravitationally and not interact electromagnetically would have to or even be able to repel normal matter.

Reply to this comment | Offensive? Unsuitable? Notify Editor

5 **SteveHansell**
Feb 19, 2010 6:32 AM
San Antonio, United States

Gravitational Machine next?

This is an amazing breakthrough. Isn't it now possible that this will bring us closer to an anti-gravitational machine that operates at the quantum level? The math is now verified and confirms it can be used to fine tune the Orbital Mechanics for deep space ((craft) with mass (m) traveling near a planetary body with mass (M))? Maybe we can use new math without using the masses and substituting new time elements of gravitational wave shifts? I'm amazed that this discovery has not had major headlines. Sadly, I don't think the public will "get it" quite yet?
Anyone else agree on these comments?

Reply to this comment | Offensive? Unsuitable? Notify Editor

6 **sailor4528**
Feb 19, 2010 8:18 AM

Design of anti gravity machines

Quote:

> *Originally posted by* ***SteveHansell***
> This is an amazing breakthrough. Isn't it now possible that this will bring us closer to an anti-gravitational machine that operates at the quantum level? The math is now verified and confirms it can be used to fine tune the Orbital Mechanics for deep space ((craft) with mass (m) traveling near a planetary body with mass (M))? Maybe we can use new math without using the masses and substituting new time elements of gravitational wave shifts? I'm amazed that this discovery has not had major headlines. Sadly, I don't think the public will "get it" quite yet?
> Anyone else agree on these comments?

So, for example in the context of the earth/moon gravity field, the idea would be to produce a near earth ground level Lagrange point by some localised jiggery-pokery to substitute an equivalent for the moon's mass near ground level? Ok, let's solve the jiggery-pokery bit now. Over to you!

Reply to this comment | Offensive? Unsuitable? Notify Editor

7 **alreaud**
Feb 19, 2010 2:53 PM
Fort Collins, United States

Three Solid Theories

This is further good news confirming GR as being in the same playing field (if there was ever a doubt) as QED and the Standard Model.

Here's a question though: Why are electromagnetic forces not considered curvatures of space in the same manner that GR considers a gravitational force a curvature of space?

Edited by alreaud on Feb 19, 2010 2:55 PM. Reason: Typo, grammer, de-lint.

Reply to this comment | Offensive? Unsuitable? Notify Editor

8 **John Duffield**
Feb 19, 2010 4:28 PM
United Kingdom

alreaud, GR is a curvature of space-time. If it was a curvature of space, a thrown ball would always follow the same curved path regardless of velocity. I don't know why the electromagnetic field isn't considered to be a curvature of space. People talk happily of curl or rot and gravitomagnetics where the rotating earth exerts a frame dragging effect, but don't relate this to electron spin.

Steve/sailor, this paper itself is no big deal. All it essentially is, is "Gravitational time dilation confirmed to greater accuracy". An electromagnetically-induced gμv gradient is something different.

Ragtime, there's no evidence that dark matter repulses matter. We see gravitational anomalies, and dark matter is posited as the cause of gravitational attraction.

Bigpapa, I'd say the quantum gravity aspect of this has been overplayed.

Edited by John Duffield on Feb 19, 2010 4:32 PM.

Reply to this comment | Offensive? Unsuitable? Notify Editor

9 **Ragtime**
Feb 21, 2010 11:51 PM
Prague, Czech Republic

Quote:

> *Originally posted by **John Duffield***
> ..there's no evidence that dark matter repulses matter...

Deceleration of Pioneer anomaly is proportional to product of Hubble constant and speed of light with some 10% error.

Reply to this comment | Offensive? Unsuitable? Notify Editor

10 **bigpapajohn2003**
Feb 22, 2010 8:55 PM
Alto, United States

The nature of dark matter

Quote:

> *Originally posted by **Ragtime***
> Quote:
> > *Originally posted by **John Duffield***
> > ..there's no evidence that dark matter repulses matter...
>
> Deceleration of Pioneer anomaly is proportional to product of Hubble constant and speed of light with some 10% error.

Isn't Hubble's Constant related to the expansion of the universe and, thus, to dark energy and not dark matter?

Reply to this comment | Offensive? Unsuitable? Notify Editor

11 **pcrattray**
Feb 19, 2010 5:34 PM

space-gravity

This is fascinating, but it doesn't prove time exists does it? Just that a gravity well affects particles that we use to measure time? (I am not disputing the useful application of precision timing...)

Reply to this comment | Offensive? Unsuitable? Notify Editor

12 **gord davison**
Feb 19, 2010 7:58 PM
Brampton, Canada

Space is the illusion

I think that it could also support the theory that time is responsible for gravity.

As was stated in one of the comments posted here, the time dilation was already proven this simply (or not so simply) improves our accuracy of supporting the theoretical time dilation.

What I think is that matter/energy distorts time not space. The distortion of time, which is a dimension, gets dilated and this dilatation in time generates and acceleration which in turn looks likes a force. This is supported by the fact that never has there been found a force carrying particle for gravity.

If this is true then anti-gravity should be able to be generated by compressing the time axis. This would explain the expansion of the universe.

Reply to this comment | Offensive? Unsuitable? Notify Editor

13 **gadzirayi**
Feb 19, 2010 8:53 PM
Potchefstroom, South Africa

Principle of Equivalence

It is a mistake to think that to test the Principle of Equivalence is to test the GTR. No, that is a different matter. GTR violets the Principle of Equivalence at the affine level, for example the equations of motion must be formulated in special geodesic systems, this is nothing but a serious violation of the Principle of Relativity which is more superior to the Principle of Equivalence.

I think the GTR will fall flat on its face soon. I do believe it has taken us to greater heights but it is in need of serious revision.

Where are the results of very expensive experiment Gravity Probe B, its 3 years on now???

Edited by gadzirayi on Feb 19, 2010 9:46 PM.

Reply to this comment · Offensive? Unsuitable? Notify Editor

14 **Ragtime**
Feb 20, 2010 12:57 AM
Prague, Czech Republic

Quote:

> *Originally posted by **gadzirayi***
> Where are the results of very expensive experiment Gravity Probe B

results of GPB suffered by large noise, they didn't produced useful results.

Reply to this comment · Offensive? Unsuitable? Notify Editor

15 **gadzirayi**
Feb 20, 2010 1:25 PM
Potchefstroom, South Africa

GPB

Quote:

> *Originally posted by **Ragtime***
> Quote:
> > *Originally posted by **gadzirayi***
> > Where are the results of very expensive experiment Gravity Probe B
>
> results of GPB suffered by large noise, they didn't produced useful results.

Will these results be made available for the public to see for themselves the noise??

Just wondering ....

Reply to this comment · Offensive? Unsuitable? Notify Editor

16 **rjwozniak**
Feb 19, 2010 11:19 PM

Trouble understanding the word manifestation

I am have trouble with the word manifestation in the following sentence. Please tell me which word, or suggest your own word, that best fits in the following sentence.

Confirmation of this effect supports the idea that gravity is a manifestation of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

definition of manifestation according to www.answers.com…manifestation :
1. An act of showing or displaying: demonstration, display, exhibit, exhibition, show.
2. Something visible or evident that gives grounds for believing in the existence or presence of something else: badge, evidence, index, indication, indicator, mark, note, sign, signification, stamp, symptom, token, witness.

3. A physical entity typifying an abstraction: embodiment, exteriorization, externalization, incarnation, materialization, objectification, personalization, personification, substantiation, type.

Potential word substitutions:

1. Confirmation of this effect supports the idea that gravity is a indication of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

2. Confirmation of this effect supports the idea that gravity is a demonstration of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

3. Confirmation of this effect supports the idea that gravity is a indicator of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

4. Confirmation of this effect supports the idea that gravity is evidence of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

5. Confirmation of this effect supports the idea that gravity is a materialization of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

Reply to this comment | Offensive? Unsuitable? Notify Editor

17 **azmodean**
Feb 20, 2010 7:14 AM
Kirwan, Australia

Quote:

> *Originally posted by* ***rjwozniak***
>
> 4. Confirmation of this effect supports the idea that gravity is evidence of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.
>
> 5. Confirmation of this effect supports the idea that gravity is a materialization of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

If I can presume the intent of the writer;
5 is probably the closest, followed by 4.

Reply to this comment | Offensive? Unsuitable? Notify Editor

18 **gord davison**
Feb 20, 2010 9:16 PM
Brampton, Canada

substitute

Quote:

> *Originally posted by* ***rjwozniak***
> I am have trouble with the word manifestation in the following sentence. Please tell me which word, or suggest your own word, that best fits in the following sentence.
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> 1. An act of showing or displaying: demonstration, display, exhibit, exhibition, show.
> 2. Something visible or evident that gives grounds for believing in the existence or presence of something else: badge, evidence, index, indication, indicator, mark, note, sign, signification, stamp, symptom, token, witness.
>
> 3. A physical entity typifying an abstraction: embodiment, exteriorization, externalization, incarnation, materialization, objectification, personalization, personification, substantiation, type.
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> 4. Confirmation of this effect supports the idea that gravity is evidence of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.
>
> 5. Confirmation of this effect supports the idea that gravity is a materialization of space–time curvature because the flow of time is no longer constant throughout the universe but varies according to the distribution of massive bodies.

I pick 3

Reply to this comment | Offensive? Unsuitable? Notify Editor

19 **symmecon**
Feb 20, 2010 3:01 PM
Las Cruces, United States

The Gravity-Time Relationship Function

The excellent investigation of gravity's interaction with time deserves note, and leads to the boundary value solution for atomic topological function mapping of atomic energy and force field states and distributions. When the series differential of nuclear radiation rates for transform of mass to energy by {e=m(c^2)} physics is written as a cycle with a frequency of {Nhu=e/h}, and integrated for GT (Gravity-Time) limits, the result is an exact, picoyoctometric atomic imaging function named the GT integral RQT (relative quantum topological) atomic function.

This model defines the atom as a nucleus losing mass to forcon states of picoyoctometric size with valid joule values. That force field condenses due to radial dilution to form the energy intermedons of the 5/2 kT J heat capacity energy cloud. When the correlation function for mapping the set of virtual photons onto the manifold of the outer electron cloud region is written, a set of 26 energy waveparticle topological functions is solved. Those values intersect the sizes of the fundamental physical constants: {h, h-bar, delta, nuclear magneton, beta magneton, k(series)}. Each of the energy intermedons also pulsates by GT limits, since only time and space confine their expansion phases, and gravity is the force binding space to any waveparticle.
The GT integral atomic function images the h-bar as a magnetic energy particle diskon of ~175 picoyoctometers across, and develops the 3D interactive video atomic model as a pulsating sphere animated by superworkons.

Reply to this comment | Offensive? Unsuitable? Notify Editor

20 **RKS**
Feb 21, 2010 10:06 AM

This was experiment was successful done in 1960

R.V.Pound and G.A. Rebka Jr.
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts
April 1, 1960
Physical review Letters, Volume 4, Number 7, P.337~341

The photon source and detector were separated vertically by 74' (74 feet)

A follow-up paper confirming the early results was published a few years later:

Effect of Gravity on Gamma Radiation

R.V.Pound and J.L.Snider
Laboratory of Physics, Harvard University, Cambridge, Massachusetts
November 8, 1965
Physical review Letters, Volume 140, Number 3B, P.B788~B803

Reply to this comment | Offensive? Unsuitable? Notify Editor

21 **srp**
Feb 22, 2010 1:33 AM
Quebec, Canada

What they proved in fact is that the frequency involved varies
with distance from a large mass (the Earth).

Same proof was carried out more than once. Way back in 1972 (Hafele and Keating). In '79, Aley, Vessot and Levine and others.

Proof of time dilation only if no other cause of frequency change with gravity can be identified.

Reply to this comment | Offensive? Unsuitable? Notify Editor

22 **gord davison**
Feb 22, 2010 2:07 AM
Brampton, Canada

Good point

Quote:

> *Originally posted by **srp***
> What they proved in fact is that the frequency involved varies
> with distance from a large mass (the Earth).
>
> Same proof was carried out more than once. Way back in 1972 (Hafele and Keating). In '79, Aley, Vessot and Levine and others.
>
> Proof of time dilation only if no other cause of frequency change with gravity can be identified.

So do you have a suggestion as to what could cause a frequency shift in the presence of a gravity field?

Reply to this comment | Offensive? Unsuitable? Notify Editor

23 **srp**
Feb 22, 2010 5:46 AM
Quebec, Canada

Quote:

> *Originally posted by **gord davison***
> Quote:
>
> > *Originally posted by **srp***
> > What they proved in fact is that the frequency involved varies
> > with distance from a large mass (the Earth).
> >
> > Same proof was carried out more than once. Way back in 1972 (Hafele and Keating). In '79, Aley, Vessot and Levine and others.
> >
> > Proof of time dilation only if no other cause of frequency change with gravity can be identified.
>
> So do you have a suggestion as to what could cause a frequency shift in the presence of a gravity field?

Possibly this one.

Up and down quarks are charged. So what if nucleons radii diminished in small quantities of matter taken away from the larger mass, since they would be less attracted outwards by lessening surrounding quantities of matter?

Electronic orbitals would then also contract in sync involving higher frequencies of photons absorbed and re-emitted as electrons exite and de-excite.

Maybe other possibilities. No one seems to be exploring.

Reply to this comment Offensive? Unsuitable? Notify Editor