INTERNATIONAL YOUNG
PHYSICISTS' TOURNAMENT
1993

Part two

GRAVITATION

DECREASE OF A FUNDAMENTAL CONSTANT

Fourth completely revised version, in English

WHEE KY MA

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An elaboration of the problems referring to the gravitational constant G, being 2, 3, 4 and 5.

CONTENTS

Annotations

- **The ultimate presentation is executed by one person only.**
- **This version probably will be the final one.**
- **For the presentation two overheadprojectors are necessary.**
- **Most of the text is summarized on sheets, elaborated in the appendix.**
- **In the text some things are the same in different problems. In that case I inserted them twice.**

Chris Bakker
Whee Ky Ma

Groningen,
June 1993

THE PROBLEMS

The problems 2 up to and including 5 of the sixth International Young Physicists' Tournament refer to the slow decrease of the gravitational constant G from April 1, 1993 to May 1, 1993, by 10 %, after which date the value stays constant.

[We have to consider the relations on the sun, the interactions between sun and earth and the relations on earth. For the values of the quantities on April, 1 I use index 0, for those on May, 1 index e.]

Introduction to each part

$G_0 = 6{,}6730 \cdot 10^{-11}\ Nm^2kg^{-2}$
$G_e = 0{,}90 \cdot 6{,}67 \cdot 10^{-11} = 6{,}0057\ Nm^2kg^{-2}$

The unit of G is either $N\ m^2\ kg^{-2}$ or $m^3\ kg^{-1}\ s^{-2}$. The latter is the most accurate, because it uses the basic units of the SI-system. Of course, the former is also good.
From these data an equation can be formed, for G as a function of t, time in days (that is more meaningful than in seconds):

$$G(t) = G(0) - \frac{0{,}10\ G(0)}{30}\ t = G(0)\,(1 - 3{,}33 \cdot 10^{-3}\ t)$$

We have started from the supposition that the decline of G in the time is linear, because in the problem is to be found that the decline is gradual, and a linear decline seems the most logical for that, and probably not an exponential one.

Though the assignment is to consider changes in both periods, apart from each other, in some cases this isn't necessary, because the situation in the second period is the same as the final situation of the first period. Other changes, begun in the first period, continue in the second period and after.

PART 1 **THE SUN**

1.0 Introduction

NEW SHEET

I will treat the subject in accordance to this scheme (see sheet). It is a great pity that only a quarter of an hour is available, because it is a complex and extensive subject.
[See previous page.]

1.1 The radius of the sun

NEW SHEET

For the gravitational force the following equation holds:

$$F_G = G\,\frac{m_1 m_2}{r^2}$$

It will be clear that by a decrease of the gravitational constant by ten percent the gravitational force decreases by ten percent too.
Out of this formula the factor of increase cannot be calculated directly. You have to use the equilibrium of forces in the sun:

gravitational contraction = gas pressure

The gravitational contraction is the contraction caused by the gravitational force, so it is an inwards directed force. The gas pressure is the pressure which the gas exercises outwards.
Of course, also radiation pressure exists, outwards too, but this is a relatively weak force and it is neglectable here.
When these two quantities have the same value, an equilibrium exists. This is the case when the volume of the sun is constant. The gravitational contraction and the gas pressure follows these expressions:

$$F_G = G\frac{m_1 m_2}{r^2} \quad so \quad F_G \sim \frac{G}{r^2}$$

$$F_{gasdruk} \sim \frac{1}{V} \quad so \quad F_{gasdruk} \sim \frac{1}{r^3}$$

Because of the decline of G the gravitational force decreases first with factor 0,90. The radius thus increases, so the gravitational force declines still more. At the same time the gas pressure declines too, with this factor, till a new equilibrium is reached. This is the case when these two factors are the same.
That means that: $\mathbf{f_r = 1/f_G = 1/0{,}90 = 1{,}111}$
So the radius of the sun increases with 11,1 percent. The new radius is: $\mathbf{696{,}0 \cdot 10^6 \cdot 1{,}111 = 773{,}3 \cdot 10^6\ m}$

The radius can also made dependent of the time in days. This is the result of the calculation (see sheet). I shall not do such a calculation for all quantities which are mentioned, because that is not meaningful.
The radius increase has many consequences for the emission of radiation.

1.2 Emission of radiation and particles

NEW SHEET

Structure of the sun and its consequences

The sun has a structure which is typical for stars. I will describe it shortly, because there are many changes which have to do with it.

Almost all of the radiation emitted by the sun is generated in the core of the sun, which extends to a quarter of the distance to the surface. The core contains not less than 40 percent of the totl mass of the sun. The temperature there is about 15 million degrees Celsius. The area conducts as an ideal gas, but with inordinate atoms. Also pressure and density are immensely high (see sheet), so that nuclear fusion reactions can take place.

Energy transport occurs in the layer round about, the radiative zone, where energy is transmitted by means of radiation, up to three quarters of the radius, especially as X-rays. It is a rather quiet zone. Gradually the high-frequent radiation is changed into lower frequencies, so that at last visible light develops.

Outside this zone the temperature has become low enough to make the gas strongly untransparent. Then a turbulent convection starts (that is energy transport by means of gas flow), by which the energy is transferred to the visible surface of the sun. There the thermic energy is transformed into light and infra-red radiation, which is emitted into space. This process between production and emission of energy can last some millions of years.

Now the values of some quantities of the sun can be calculated:
All new data are to be found in this table (see sheet).

NEW SHEET

The **radius** of the sun increases with factor 1,11.
So the **volume** of the sun increases with $(1,11)^3 = 1,372$
This has various consequences:

1) first for the **density**; of course it decreases by fact o r 1,372
2) secondly for the **gas pressure**, already mentioned; it declines by 1,372 too.
   This means that the **number of molecules** in which the pressure is high enough to let nuclear fusion take place, decreases. This has two effects:
   a) The **emitted energy** declines, so that also the **magnitude**, that is the apparent brightness, declines.

How, is to be seen in this graphics, where pressure, temperature nd energy are plotted as a function of the distance from the core of the sun. Here you can see that the minimum pressure for nuclear fusion reactions is at the edge of the core, 2,2 $\cdot 10^{10}$ atmosphere. When the volume increases by a factor 1,372, the pressure decreases in the whole sun by 1,372. The pressure required for nuclear fusion is constant, so the pressure has to be now ***minimum*** *x* ***1,372 = 2,2 x 10^{10} - 1,372 = 3,0 x 10^{10}****, to reach the minimum later. From the graphics you can read off the factor which the radius participating in the nuclear fusion decreases by. This factor is* ***0,237/0,250 = 0,95*** *The volume decreases by* ***$(0,95)^3$ = 0,85*** *The intensity of nuclear fusion decreases by the same factor as the volume, so by* ***0,85*** *too. The quantity of produced energy and the quantity of emitted energy is dependent on it, so it becomes:*

$$P_{produced;e} = P_{emitted;e} = 0,85 \cdot 3,90 \cdot 10^{26} = 3,32 \cdot 10^{26}\ W$$

<u>All</u> sorts of radiation are involved, so not only visible light.

b) The **temperature** decreases, so that the **maximum wave length** shifts to a higher value.

It isn't true that the decline of the intensity of nuclear fusion causes a temperature decrease directly at the surface. As I said, the transport lasts millions of years, so changes will be visible just much later. I will calculate the temperature of the surface after those millions of years. I have supposed that the emitted energy has the same value as the produced energy. (See sheet)

$$T_0 = \sqrt[4]{\frac{P}{A \cdot \sigma}} = \sqrt[4]{\frac{3,90 \cdot 10^{26}}{4\pi (696,0 \cdot 10^6)^2 \cdot 5,67 \cdot 10^{-8}}} = 5,80 \cdot 10^3\ K$$

$$T_e = \sqrt[4]{\frac{P}{A \cdot \sigma}} = \sqrt[4]{\frac{3,32 \cdot 10^{26}}{4\pi (773,3 \cdot 10^6)^2 \cdot 5,67 \cdot 10^{-8}}} = 5,28 \cdot 10^3\ K$$

Of course, this relation is also important for the temperature on earth. If matters will have gone so far as that, temperature decreases even more. The law of Stefan-Boltzmann can be used because the spectrum of the sun is essentially the spectrum of a ideal black body.
All temperaturen are surface temperatures.
The temperature decline also has its effect on the emitted maximum wave-length. This can be calculated with Wien's law:

$$Old: \quad \lambda_{max} = \frac{k_W}{T} = \frac{2,90 \cdot 10^{-3}}{5,80 \cdot 10^3} = 500 \ nm$$

$$New: \quad \lambda_{max} = \frac{k_W}{T} = \frac{2,90 \cdot 10^{-3}}{5,28 \cdot 10^3} = 549 \ nm$$

Magnitude

The magnitude is the apparent brightness of stars, so the luminosity as we observe it from earth. Yet long ago people divided the stars up into six classes, with the brightest stars as first class. Later it appeared, that a star of the first class emits about hundred times more light than a star of the sixht class. That is why the factor between two successive classes is defined as $\sqrt[5]{100} \approx 2,5$. In the table you can see the magnitudes of some very bright stars. The sun has a magnitude of - (minus) 26,78, so it is much larger than a star of magnitude one. You can see that the earth gets far less light from the other stars. Some calculations can be made about the magnitude:

$$L_x = (\sqrt[5]{100})^{1-M_x} \cdot L_1$$

L is the luminosity and X is a certain value. You can draft the following expression for the quotient of the original and the new luminosity.

$$\frac{L_e}{L_0} = \frac{(\sqrt[5]{100})^{1-M_e}}{(\sqrt[5]{100})^{1-M_0}} = (\sqrt[5]{100})^{1-M_e-(1-M_0)} = (\sqrt[5]{100})^{M_0-M_e}$$

$$\frac{L_e}{L_0} = 0,852 \rightarrow M_0 - M_e = \sqrt[5]{100} \log 0,852 = -0,174$$

This means: $\mathbf{M_e = 0,174 - M_0 = 0,174 - 26,78 = -26,61}$

Then this is the new magnitude of the sun. But the distance from the earth to the sun also increases, so the magnitude becomes even less negative. That is also in force for all other stars.

Emission of particles - solar wind

The sun continuously in all directions emits a large flow of electric charged particles - the **solar wind**. It mainly consists of protons and electrons of hydrogen and helium. It is so-called **solar plasma**. The mean velocity of the particles is about 500 km per second, but it changes in time and place.

Sometimes there is an inordinate **strong activity** on the sun, going together with a larger amount of sunspots and solar plasma. This means a larger and vehement flow, with velocities of not less than about 2000 km per second. This has many consequences for the earth; because it is an electromagnetic pheno-

menon, **magnetic storms** arise, and **polar lights**. As well many **extreme weather situations** occur, and in the long run a **glacial period** can take place.

The change of the gravitational constant can have an influence on the solar wind. Above the surface of the sun namely there is a layer of very hot gas, which doesn't belong to the sun itself. This layer is called the **corona**; it is surrounded by a network of magnetic field lines. At some places there are gaps in the corona, through which the solar wind leaves the sun surface. Because of the increase of the radius, the area of gaps increases. Now there are two possibilities:

- Also the amount of solar plasma increases; then the electromagnetic phenomena caused by the solar wind will increase in number.
- The amount of solar plasma remains constant; then the density of the solar wind decreases, so that the phenomena will be weaker.

Because of the increase of the radius the escape speed on the sun decreases, so that gas molecules will leave the surface easier. If this is also the case with the solar plasma there will be emitted more charged particles, so that the first scenario will be the most probable.

1.3 The evolution of the sun

The evolution of stars and its consequences

The decrease of the intensity of the nuclear fusion has certainly effects on the further evolution of the sun, or of stars in general. I will talk about it shortly, though it is a long-term change, because it starts in the period we have to consider, and because it is very important. The evolution proceeds as follows:

In the gas- and dust-cloud which were the galaxies in the beginning, on certain places accumulations of matter developed. Let us follow now the evolution of the sun. The gravitation brought the particles nearer to each other, and because of the growth of the attractive force the concentration started to shrink. The particles were accelerated, which caused a higher temperature. When temperature and pressure were high enough, the hydrogen-helium conversions started and the compact gas mass begun to radiate. A star was born. The sun shrinked a little more, till it reached the present situation.

In the long run the **core of helium grows larger** and larger, because the nuclear fusion reactions are taking place in **more and more exterior layers**. When the hydrogen in the core is exhausted, the **core will be pressed together** by the heavy heliumlayers. The **temperature around the core grows higher** and the conversions will take place in the zones around, so that **more radiation is produced** and the star will expand and become hotter. This stadium of red giant lasts relatively shortly. The hydrogen outside the core runs out and in the core more and more helium accumulates. It shrinks and temperature increases. When the temperature has become hunderd million degrees, the **helium will fuse into carbon**. When all helium is consumed, the sun will blow its exterior layers away in explosions and form a **planetary nebula**. A little, hard carbon core remains, with a temperature of about 10 000 K, a **white dwarf**, not larger than

earth. The little star will have an enormous density and it will be incredibly bright.

As a result of the changes the mass in the core will decrease. The hydrogen will be **consumed earlier** and it will be necessary earlier to use the exterior layers. The **evolution will happen quicker**. The sun, and the earth too, will die after less time.

1.4 The position in the galaxy

NEW SHEET

This is the Milky Way galaxy. The sun is in the middle of this square. The sun describes a **circular orbit** around the centre of the galaxy. The radius of this circle is 3 x 10^{20} m, 300 thousand billion kilometer. The sun slowly circles around in 245 million years; that means a velocity of 250 km/sec.

The sun experiences an attractive force from the centre of the galaxy, with an enormous amount of stars. This gravitational force functions as **centripetal force.**

The new orbit of the sun circling around the centre of the galaxy is **comparable** with the new orbit of the earth circling around the sun and of the moon around the earth, and of all other celestial bodies in the universe. That is why this change is so important.

We can understand the new orbit by considering the conditions of the sun in the time. We can start from two laws:

a) Starting from the law of constant energy
b) Starting from the law of constant angular momentum

I will treat both of these lines, because you cannot say initially which is true.

A STARTING FROM THE LAW OF CONSTANT ENERGY

The gravitational force which works upon the sun functions as centripetal force. In the situation of equilibrium this equation holds: $\mathbf{F_G = F_{CP}}$. This is equivalent with:

$$G \frac{m_S\, m_C}{r^2} = \frac{m_S\, v^2}{r} \qquad (1)$$

The sun possesses both potential and kinetic energy. The potential energy is the same as the gravitational energy. The kinetic energy can with the equation (1) be written with the same quantities:

$$U_{pot} = -\, G \frac{m_S\, m_C}{r}$$

$$U_{kin} = \frac{1}{2}\, m_S\, v^2 = \frac{1}{2}\, \frac{m_S\, m_C}{r} \qquad \text{(zie (1))}$$

Now a formula can be made for the total energy:

$$U_{tot} = U_{pot} + U_{kin} = -G\frac{m_A m_Z}{r} + \frac{1}{2}G\frac{m_A m_Z}{r} = -\frac{1}{2}G\frac{m_A m_Z}{r}$$

We can suppose that the total energy does not change.
U_{tot} is constant.
When G declines up to 0,90 G also r declines up to 0,90 r. Because G and r decline with the same factor, also the potential energy is the same as in the beginning. The kinetic energy therefore does not change either. This means that the velocity will be the same.

B STARTING FROM THE LAW OF CONSTANT ANGULAR MOMENTUM

The both theories have completely opposite results. I will show how the law of constant angular momentum works.

The angular momentum is defined as the equivalent of the momentum (**betekent: "impuls"!**) in linear motion.

The formula of the angular momentum thus is: **L = mvr.**
In the situation of equilibrium (**$F_G = F_{CF}$**) this equation holds:

$v = \sqrt{(GM/r)}$: v is directly proportional to $\sqrt{G/r}$.

L is therefore proportional to $\sqrt{G/r} \times r = \sqrt{G \cdot r}$,
because the masses are constant. According to the theory of constant energy both G to r decline, so the angular momentum declines. That is contrary to the law of constant angular momentum, which says that the total angular momentum doesn't change.
According to the law of constant angular momentum **the radius increases when G decreases, and by the same factor.**
This means that the total energy of the system grows larger!

It is more logical that the sun goes outwards. During the expansion of the universe G also declines, and as a result of that the galaxies grow larger. It is thus also experience that celestial bodies go and describe a larger orbit. It can be explained physically as follows.
When G declines, there has to be a force, like the Big Bang, which universe still expands by.

ENERGY IS SUPPLIED from outside the system. This agrees with the law of constant angular momentum.

Because there is a central force, angular momentum doesn't change.

CONCLUSION: THE SUN, THE OTHER STARS, THE PLANETS, THE MOONS, THE GALAXIES, ALL GO OUTWARDS.

The radius increases by 1,111. It becomes $3,3 \times 10^{20}$ m, as is to be seen in the table.
The velocity changes with factor $\sqrt{(0,90)^2} = 0,90$.
Therefore the time of revolution ($2\pi r/v$) changes with factor $1/(0,90)^2 = 1,235$. It becomes $1,235 \times 2,45 \times 10^9 = 3,02 \times 10^9$ years
Every galaxy will therefore turn around slower.

PART 2 THE EARTH

2.0 Introduction

NEW SHEET

I will treat the subject in accordance to this scheme (see sheet). It is a great pity that only a quarter of an hour is available, because it is a complex and extensive subject.
$G_0 = 6,6730 \cdot 10^{-11}\ Nm^2kg^{-2}$
$G_e = 0,90 \cdot 6,67 \cdot 10^{-11} = 6,0057\ Nm^2kg^{-2}$

The unit of G is either N $m^2\ kg^{-2}$ or $m^3\ kg^{-1}\ s^{-2}$. The latter is the most accurate, because it uses the basic units of the SI-system. Of course, the former is also good.
From these data an equation can be formed, for G as a function of t, time in days (that is more meaningful than in seconds):

$$G(t) = G(0) - \frac{0,10\ G(0)}{30}\ t = G(0)\,(1 - 3,33 \cdot 10^{-3}\ t)$$

We have started from the supposition that the decline of G in the time is linear, because in the problem is to be found that the decline is gradual, and a linear decline seems the most logical for that, and probably not an exponential one.

Though the assignment is to consider changes in both periods, apart from each other, in some cases this isn't necessary, because the situation in the second period is the same as the final situation of the first period. Other changes, begun in the first period, continue in the second period and after.

2.1 The orbit of the earth

NEW SHEET

The earth describes a **circular orbit** around the sun. The radius of this circle is $149,6 \times 10^9$ meter.

The earth experiences an attractive force from the centre of the galaxy, with an enormous amount of stars. This gravitational force functions as **centripetal force.**

The new orbit of the earth circling around the sun is **comparable** with the new orbit of the stars circling around the centre of the galaxy and of the moon around the earth, and of all other celestial bodies in the universe. That is why this change is so important.

We can understand the new orbit by considering the conditions of the earth in the time. We can start from two laws:
a) Starting from the law of constant energy
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The gravitational force which works upon the earth functions as centripetal force. In the situation of equilibrium this equation holds: $\mathbf{F_G = F_{CP}}$. This is equivalent with:

$$G \frac{m_S\, m_C}{r^2} = \frac{m_S\, v^2}{r} \qquad (1)$$

The earth possesses both potential and kinetic energy. The potential energy is the same as the gravitational energy. The kinetic energy can with the equation (1) be written with the same quantities:

$$U_{pot} = - G \frac{m_S\, m_C}{r}$$

$$U_{kin} = \frac{1}{2} m_S\, v^2 = \frac{1}{2} \frac{m_S\, m_C}{r} \qquad \text{(see (1))}$$

Now a formula can be made for the total energy:

$$U_{tot} = U_{pot} + U_{kin} = - G \frac{m_A\, m_Z}{r} + \frac{1}{2} G \frac{m_A\, m_Z}{r} = - \frac{1}{2} G \frac{m_A\, m_Z}{r}$$

We can suppose that the total energy does not change.
U_{tot} is constant.
When G declines up to 0,90 G also r declines up to 0,90 r. Because G and r decline with the same factor, also the potential energy is the same as in the beginning. The kinetic energy therefore does not change either. This means that the velocity will be the same.

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The angular momentum is defined as the equivalent of the momentum (**betekent: "impuls"!**) in linear motion.

The formula of the angular momentum thus is: **L = mvr.**
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It is more logical that the earth goes outwards. During the expansion of the universe G also declines, and as a result of that the galaxies grow larger. It is thus also experience that celestial bodies go and describe a larger orbit. It can be explained physically as follows.
When G declines, there has to be a force, like the Big Bang, which universe still expands by.

ENERGY IS SUPPLIED from outside the system. This agrees with the law of constant angular momentum.

Because there is a central force, angular momentum doesn't change.

CONCLUSION: THE EARTH, THE SUN, THE OTHER STARS, THE GALAXIES, AND ALL OTHER CELESTIAL BODIES GO OUTWARDS.

The radius increases by 1,111. It becomes 184,7 x 10^9 m, as is to be seen in the table.
The velocity changes with factor $\sqrt{(0,90)^2} = 0,90$.
Therefore the time of revolution ($2\pi r/v$) changes with factor $1/(0,90)^2 = 1,235$. It becomes 1,235 x 365,256 = 450,933 days.
Every month now has 27,6 days.

PART 2 THE EARTH

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From these data an equation can be formed, for G as a function of t, time in days (that is more meaningful than in seconds):

$$G(t) = G(0) - \frac{0,10\ G(0)}{30}\ t = G(0)\,(1 - 3,33 \cdot 10^{-3}\ t)$$

We have started from the supposition that the decline of G in the time is linear, because in the problem is to be found that the decline is gradual, and a linear decline seems the most logical for that, and probably not an exponential one.

Though the assignment is to consider changes in both periods, apart from each other, in some cases this isn't necessary, because the situation in the second period is the same as the final situation of the first period. Other changes, begun in the first period, continue in the second period and after.

2.1 The orbit of the earth

NEW SHEET

The earth describes a **circular orbit** around the sun. The radius of this circle is $149,6 \times 10^9$ meter.

The earth experiences an attractive force from the centre of the galaxy, with an enormous amount of stars. This gravitational force functions as **centripetal force.**

The new orbit of the earth circling around the sun is **comparable** with the new orbit of the stars circling around the centre of the galaxy and of the moon around the earth, and of all other celestial bodies in the universe. That is why this change is so important.

We can understand the new orbit by considering the conditions of the earth in the time. We can start from two laws:
a) Starting from the law of constant energy
b) Starting from the law of constant angular momentum

I will treat both of these lines, because you cannot say initially which is true.

NEW SHEET

A STARTING FROM THE LAW OF CONSTANT ENERGY

The gravitational force which works upon the earth functions as centripetal force. In the situation of equilibrium this equation holds: $\mathbf{F_G = F_{CP}}$. This is equivalent with:

$$G \frac{m_S\, m_C}{r^2} = \frac{m_S\, v^2}{r} \qquad (1)$$

The earth possesses both potential and kinetic energy. The potential energy is the same as the gravitational energy. The kinetic energy can with the equation (1) be written with the same quantities:

$$U_{pot} = - G \frac{m_S\, m_C}{r}$$

$$U_{kin} = \frac{1}{2}\, m_S\, v^2 = \frac{1}{2} \frac{m_S\, m_C}{r} \qquad \text{(see (1))}$$

Now a formula can be made for the total energy:

$$U_{tot} = U_{pot} + U_{kin} = - G \frac{m_A\, m_Z}{r} + \frac{1}{2}\, G \frac{m_A\, m_Z}{r} = - \frac{1}{2}\, G \frac{m_A\, m_Z}{r}$$

We can suppose that the total energy does not change.
U_{tot} is constant.
When G declines up to 0,90 G also r declines up to 0,90 r. Because G and r decline with the same factor, also the potential energy is the same as in the beginning. The kinetic energy therefore does not change either. This means that the velocity will be the same.

B STARTING FROM THE LAW OF CONSTANT ANGULAR MOMENTUM

The both theories have completely opposite results. I will show how the law of constant angular momentum works.

The angular momentum is defined as the equivalent of the momentum (**betekent: "impuls"!**) in linear motion.

The formula of the angular momentum thus is: **L = mvr.**
In the situation of equilibrium ($\mathbf{F_G = F_{CP}}$) this equation holds:

$v = \sqrt{(GM/r)}$: v is directly proportional to $\sqrt{G/r}$.

L is therefore proportional to $\sqrt{G/r} \times r = \sqrt{G \cdot r}$,
because the masses are constant. According to the theory of constant energy both G to r decline, so the angular momentum declines. That is contrary to the law of constant angular mo-

mentum, which says that the total angular momentum doesn't change. According to the law of constant angular momentum **the radius increases when G decreases, and by the same factor.**
This means that the total energy of the system grows larger!

It is more logical that the earth goes outwards. During the expansion of the universe G also declines, and as a result of that the galaxies grow larger. It is thus also experience that celestial bodies go and describe a larger orbit. It can be explained physically as follows.
When G declines, there has to be a force, like the Big Bang, which universe still expands by.

ENERGY IS SUPPLIED from outside the system. This agrees with the law of constant angular momentum.

Because there is a central force, angular momentum doesn't change.

CONCLUSION: THE EARTH, THE SUN, THE OTHER STARS, THE GALAXIES, AND ALL OTHER CELESTIAL BODIES GO OUTWARDS.

The radius increases by 1,111. It becomes 184,7 x 10^9 m, as is to be seen in the table.
The velocity changes with factor $\sqrt{(0,90)^2} = 0,90$.
Therefore the time of revolution ($2\pi r/v$) changes with factor $1/(0,90)^2 = 1,235$. It becomes 1,235 x 365,256 = 450,933 days.
Every month now has 27,6 days.