The bending of light by gravity

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The proof that light bends near a gravitational body and the attempts to explain this phenomenon is very interesting, because it led to the impetuous acceptance of Einstein's relativity theories which to some extent has guided us down the wrong path.

Newton himself queried the possibility of light being bent by gravity but it was not before the beginning of the 19th century that a German astronomer, Johann Georg von Soldner (1804), presented calculations based on Newton's corpuscular theory that light weighs and bends like high speed projectiles in a gravitational field, which produced a value of 0.87 arc second bending angle for light grazing the Sun. Fifteen years earlier Sir Henry Cavendish made the same calculations, but his results were never published (Will, (1993)). Over hundred years later, 1911, Einstein published his first paper on the bending of light based on the equivalence principle which holds that anything, regardless of mass, accelerates equally in a gravitational field. Einstein also obtained a deflection angle of

$$\alpha = \frac{2Gm_{Sun}}{c^2 r_{Sun}} \text{ (radians)} = 0.87 \text{ arc second}, \tag{1}$$

which is the Newtonian value and the same angle previously published by Soldner. It appears that Einstein and the scientific community at the time were unaware of von Soldner's paper and it was not until the year 1921 when Soldner's work was rediscovered.

About four years after his first paper in 1911, Einstein had developed the General Theory of Relativity (1915) which prompted him to modify the above Newtonian value by adding the effect of curved

$$\alpha = \frac{4Gm_{Sun}}{c^2 r_{Sun}} = 1.75 \text{ arc second}, \tag{2}$$

space thus doubling the bending angle resulting in a new value of 1.75 arc seconds (1.7505395 arc second). The new result was published by Einstein on November 18, (1915) and was experimentally verified by Crommelin and Eddington during the solar eclipse expeditions of May 29, 1919. When the sunlight was blocked by the Moon, starlight grazing the Sun's surface became visible and the bending angle of the starlight was revealed. While the expeditions were being planned, Eddington wrote: "The present eclipse expeditions may for the first time demonstrate the weight of light (*i.e.* Newton's value) and they may also confirm the added effect of Einstein's weird theory of noon-Euclidean space, or they may lead to a result of yet more far reaching consequences of no deflection" (Eddington, (1919)). The verification of Einstein's additional bending angle of 0.87" due to curved space totaling 1.75" led to instant fame and blind acceptance of his relativity theories.

Einstein's relativity theories, although they produce the right numbers, have often been criticized for being weird since they are conceptually difficult and often impossible to understand. One serious problem with Einstein's bending of light theory is the assumption that light accelerates and falls closer to a gravitating body according to the equivalence principle, which would account for the first 0.87 arc second of bend, while the rest, or 0.87 arc second, is due to the obscure warping of space. The main objection is that light does not accelerate but, on the contrary, it decelerates or slows down in a gravitational field in accordance to observations. However, the introduction of warped or curved space is what formed the basis for Einstein's General relativity theory which is a mathematical model based on geometry and rather mimics gravitation than explains it.

Let us examine what really happens when light or electromagnetic waves streak the surface of a gravitating body such as the Sun.

The free space velocity of electromagnetic waves through space is equal to the square root of the gravitational potential or gravitational tension of the Universe at our frame of reference

$$\emptyset_{univ} = \frac{GM_{univ}}{R_{univ}} = c^2 \tag{3}$$

Where $\emptyset_{univ}$ is the cosmic gravitational tension generated by the total mass M_{univ} in the Universe. The additional increase of gravitational tension by individual gravitating bodies, such as the Sun for example, will have the effect of slowing the free space value of c to an amount determined by

$$\upsilon = c\left(\frac{\phi_{univ}}{\phi_{univ} + \phi_{sun}}\right)^2 \cong \frac{c}{1 + \dfrac{2Gm}{rc^2}} \quad , \tag{4}$$

where ϕ_{sun} is the gravitational tension of the Sun at the radial distance r from the center of the Sun and m the mass within r. The above Equation (4) is in agreement with experimental data. One such experiment involved the timing of radar waves bouncing off Venus (Shapiro (1971)) while crossing the gravitational field of the Sun. The slowdown of electromagnetic waves by gravity causes the wavelength of photons to shrink and become blue-shifted.

The bending of light in gravitational fields is much better explained by Snell's law of refraction (see Fig. 1) which was experimentally established by Willebrod Snell and theoretically by René Descartes over three hundred years ago. Snell's law is based on the discovery that when light enters a medium which retards its velocity of propagation, such as a piece of glass or a gravitational field, it will bend at an angle determined by the combination of its change in velocity and angle of incidence. The advantage of using Snell's law is that it eliminates both the idea that light weighs and the notion of curved space. Snell's law (or in France, René Descartes' law) can be written as

$$n = \frac{c}{v} = \frac{\sin \alpha'}{\sin \alpha''} \tag{5}$$

where n is the index of refraction, α' the angle of incidence, α'' the angle of refraction and c the incoming speed of light and v the retarded speed of light in the refracting medium. Light is a wave and will bend when it enters the refracting medium at an angle when the velocity of propagation from one medium to the other varies. The diagram in Fig.1

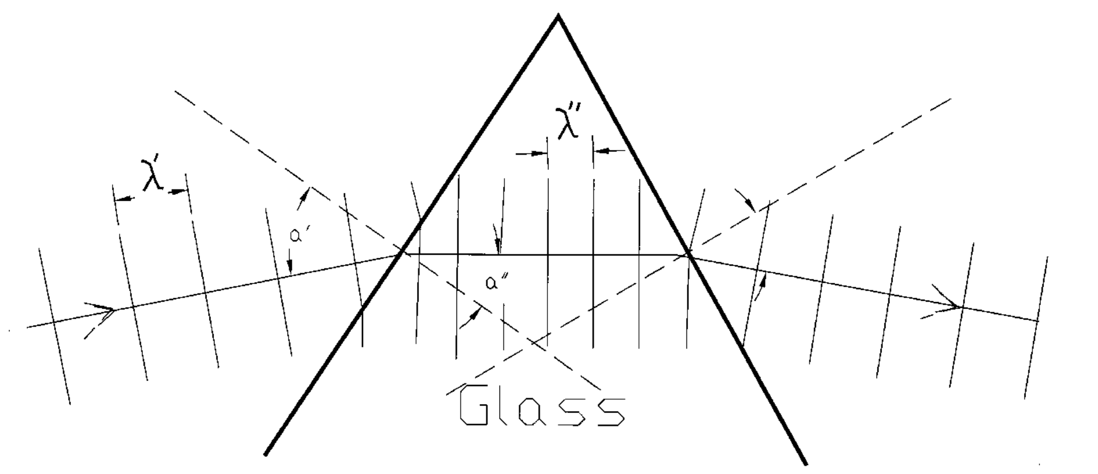

Fig. 1. A beam of light entering and exiting a glass prism showing the wavelength in the glass being shorter because of the slower velocity of propagation.

shows a train of waves entering a glass prism at an angle and how each wave-front breaks at the surface and changes direction due the change in velocity and consequent shrinkage in wavelength caused by a traffic jam effect in the slower refracting medium. Observe that the wave length λ'' of the beam inside the prism is shorter than λ' outside the prism. It is in fact the change in wavelength that causes the light beam to bend.

Note that the beam of light bends twice, once at the entrance and once at the exit of the diffracting medium. The Fig. 2 shows a beam of light

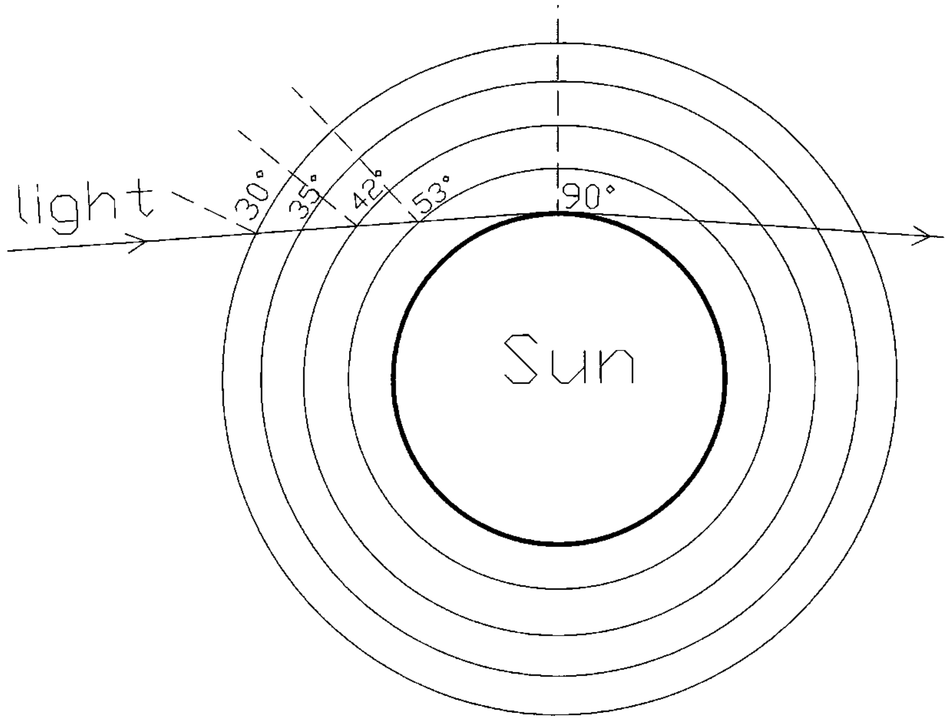

Fig. 2. A beam of light entering the gravitational field of the Sun showing the Sun's different gravitational equipotentials and corresponding angles of incidence.

entering the Sun's gravitational equipotentials and their associated angles of incidence. The angles of incidence range from 0-90° producing a mean incident angle of $\alpha' = 45°$. The optical bending of a light beam grazing the Sun's surface is therefore according to Snell's law $\alpha_{bend} = 2(\alpha' - \alpha'')$ and using the retarded velocity υ from Eq. (4)

$$n = \frac{c}{\upsilon} = \frac{\sin\alpha'}{\sin\alpha''} \qquad \alpha_{bend} = 2\left[45^\circ - \sin^{-1}\left(\frac{\upsilon \sin\alpha'}{c}\right)\right] = 1.75 \text{ second} \qquad (6)$$

The factor of "2" is necessary since light has to pass through two refractive indices, one at the entrance and one at the exit of the gravitational field, produced by the Sun. The solar gravitational deflection of electromagnetic waves has been accurately measured during the last decade for both light and radio waves. One of the latest measurements, which was reported by Lebach *et al.* (1995), and which claims a precision of 0.1% agrees with Equation (6). In fact, this value is about 1×10^{-5} arc second less than Einstein's Equation (2).

The velocity of light is constant in a gravitational equilibrium where the gravitational tension or potential Ø is constant and where no potential gradient or acceleration exists. For example, electromagnetic waves produced at Earth travel with a constant velocity relative to Earth regardless of our orbital velocity around the Sun, because the Sun's acceleration at Earth is canceled by the centrifugal acceleration produced by the Earth's circular orbit, *i.e.* the Earth will experience a uniform gravitational tension along its orbit around the Sun thus ensuring a uniform gravitational tension in its path which might be thought of as ether dragging. The Earth's own change in gravitational tension with altitude (acceleration), however, will cause a small change in the velocity of propagation with altitude. Light from extra terrestrial objects such as stars and galaxies that intersect the Earth in its orbit, will be subject to aberration. Light from these objects will be tilted just as rain will appear more and more tilted on a windshield screen when traveling at an increasing velocity. The bending due to aberration can be calculated using Snell's law where $n = (c + v_{earth})/c$.

Equation (4) shows that the velocity of electromagnetic waves cannot slow to zero no matter how strong the gravitational tension is, thus most probably ruling out the existence of so called black holes.