Shapiro Delay, a Frequency Dependent Transit Time Effect; not a Space Time Effect

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ABSTRACT

Irvin L. Shapiro first noticed in 1964 that the transit time required for a microwave signal to propagate through space, arrive at a satellite orbiting Venus or Mercury and then return back to the earth by the sun to be received at the observatory, had a measurable time delay that varied as a function of the impact parameter of the microwave beam relative to the sun. The delays were observed to be in the order of 100's of microseconds when the impact parameter of the microwave beam was at a minimum. These measurements permitted a precise determination of the electron density profile of the solar wind as a function of the radial distance r from the sun. The electron density profile of the solar wind is found to behave very nearly as an inverse square of the radial distance r from the sun. The solar wind is found to engulf the outmost planets of the solar system. The bulk of all the measurements were done using microwave frequencies from 500 MHz to 8.8MHz. Significant findings of this research reveal that, for all microwave signals propagating in the solar wind atmosphere of the solar system, the waves are subjected to a frequency dependent plasma index of refraction n that exceeds unity, i.e., n > 1.0. For optical, IR and UV wavelengths, the plasma index of refraction n is 1.0000000000 for these wavelengths which are virtually unaffected by the solar wind electron density. As a consequence of these findings, the Shapiro delay cannot be related to a space-time effect of General Relativity which is independent of frequency.

Keywords: solar wind, Shapiro delay, gravitational lensing, plasma atmosphere, electron density profile

INTRODUCTION

We shall examine clear evidence for gravitational lensing in our region of space near to us, starting with the nearest star to us. The transit time required for a microwave signal transmitted from earth into deep space, beamed at and bounced off Venus and Mercury, and then received at the antenna of an observatory on earth required a noticeable time delay. The time delay was noticeably affected by the relative position of the sun. Shapiro conducted a controlled test to measure the round-trip transit time that would be required by a time-tagged microwave signal. Careful measurements were made by Shapiro to record the relative positions of the sun and the impact parameter of beams of microwave signals bounced off the planets. After repeated measurements, varying delays in the transit time requirements of up to 200 microseconds, well within the limitations of the technology at that time in the 1960s were recorded. Noticeable transit time delays as a function of the impact parameter of the beam relative the sun known as *Shapiro delays* were recorded. The bulk of these measurements were made using microwave bands of frequencies from 500Mz up to 8.5 GHz (wavelengths from 80cm to 3.5cm). Microwave signals leaving a transmitting antenna typically will spread considerably when propagating over large astronomical distances. Such microwave probes are therefore **not** suitable for an investigation of a light bending effect at the very thin plasma rim of the sun. More importantly, the observed gravitationally lensed light of the sun have wavelengths in the optical region of from 400nm to 700nm. The light in this spectral region is apparently **not affected** at all by the electrons of the solar wind profile. Findings show that the ***index of refraction*** associated with the electron atmosphere of the solar wind for optical frequencies does not deviate from 1.0000000000.

GRAVITATIONAL LIGHT BENDING; WHAT IS IT?

We shall examine clear evidence for gravitational lensing in our region of space near to us, starting with the nearest star to us Gravitational light bending effects have been observed to be in the range of very small angles of *seconds of arc,* requiring high resolving powers of precision optical instruments to properly observe the extremely narrow regions of the solar plasma rim. All electromagnetic radiation, be it optical, infrared (IR), ultraviolet (UV) or microwave will propagate along a well defined minimum energy path in the narrow solar plasma rim exposed to the gradient gravitational field of the sun. The microwave radiation, however, has been found to be very sensitive to the electron density profile of the solar winds for virtually all space with a transit time effect engulfing the outermost planets of the solar system. The electron density profile has virtually no effect at all on the optical, IR or UV waves, thereby presenting to these waves an index of refraction for these frequencies of practically 1.0000000000 with practically **no** light bending effects at all. Moreover, there is **no** evidence of a light bending effect due to the solar winds.

3. SHAPIRO DELAY: THE DETAILS?

Historically, the microwave probes have had only the capability of investigating the propagation delays or the times-of-arrival of time tagged microwave beams that tend to spread considerably after having been transmitted from the antennas of the microwave instruments. Moreover, the *Shapiro delay* is merely a very good fit to the data dealing with the transit times of the microwave signals affected by the space properties of the electron density profile that govern the propagation of microwaves signals in the space local to the solar system. The surrounding space properties have been observed to vary and are governed by the vast quantities of solar ions injected into the space around the sun. This applies directly to the space around all other sun-like stellar systems. Hence, radio astronomy in the microwave spectrum is subject to time-delays in the signals from radio pulsars located near stellar systems that produce stellar winds.

3.1 SIGNALS FROM PULSARS AND COSMIC MICROWAVE SOURCES

It is noteworthy to mention that the *Shapiro delays* were successfully measured from the signals arriving from **radio pulsars** that are emitting in the microwave regions, belonging to a double pulsar or a system involving a pulsar and a companion which is also a stellar system like our sun. Since the emissions from the pulsars are in the microwave frequencies, one cannot expect that the pulsar signals will not exhibit delays when the microwave sources move in orbit about a second stellar system that has a stellar wind atmosphere about it pretty much like our sun. So the Shapiro delays detected from the double pulsar systems are **nothing tremendously groundbreaking** in this subject matter.

3.2 SHAPIRO DELAY VERSUS LIGHT BENDING OF RELATIVITY

From the observational evidence, the space properties governed by the expanding solar atmosphere of electrons at various positions in the solar system obviously transmit effects that are inversely proportionally to the radial distance from the sun. Historically, the recorded *Shapiro delays* appears to be greater for smaller impact parameters of the probing beams of microwave signals and decreases only slowly with increasing distances D from the sun. The *Shapiro delay*, however, varies proportionally to **1 / ln(D)**, a logarithmic function, two entirely different theoretical functions as depicted in Figure 1, describing different physical phenomena requiring entirely different theoretical explanations.
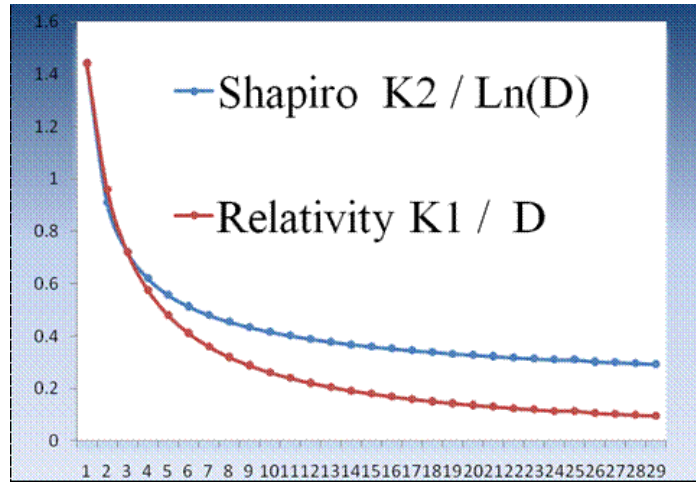
Fig. 1. Scaled Comparison of the logarithmic **1/Ln(D)** Shapiro Delay and the **1/D** Effect of the Gravitational Light Bending of General Relativity

Note here again that at a distance of 100 solar radii the value of the **Shapiro delay** has been recorded to be at least 21% of its maximum effect. One speaks of a 'long-range effect', as the 1 / ln(D) effect does **not** reach zero for large values of D. The solar wind of dense electrons apparently has a **very profound effect** on the microwave signals used by the researchers to record the Shapiro delay effects, chiefly because of the chosen wavelengths in the order of cm's. At these wavelengths, the microwave radiation is in resonance with the plasma atmosphere of the solar wind electron profiles. The solar wind effects engulf most of the planets of the solar system. It is readily seen that the **Shapiro delay** is a function of the **frequency of the microwave** beam that propagates through the solar plasma and the solar wind. The **delay** is actually a **frequency dependent transit-time effect** as well as it is dependent on the impact parameter of the beam relative to the density profile of the solar wind electrons.

The theoretical solar light bending effect of **General Relativity** is predicted to vary proportional to a 1/R effect, as illustrated in Figure 1, which was scaled to K1 / D for comparing the light bending effect of Relativity with the Shapiro delay which was scaled to K2 / Ln(D), a logarithmic effect. From this it is immediately seen that the light bending effect of Relativity and the Shapiro effect are two entirely different, unrelated concepts.

The 1/R effect of the gravitational light bending effect of General Relativity

$$\delta\theta = \frac{4GM}{Rc^2} \qquad (1)$$
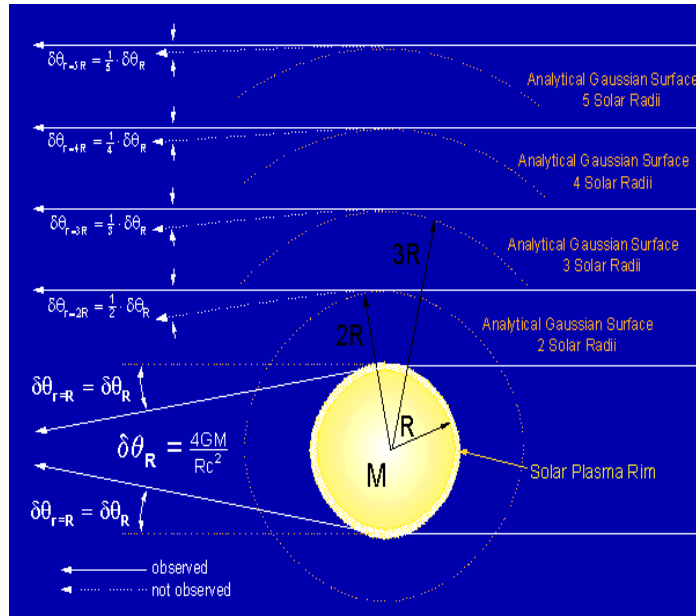
is graphically illustrated in Figure 2.

Fig. 2. Gravitational Light Bending Effect as a Function of Solar Radii R_{sun}

Recorded history of **solar light bending** in the optical region, namely the light bending effect for wavelengths in the nanometer (nm) region, has indicated a more rapid drop off for impact parameters of fraction of a solar radius into the empty vacuum space above the plasma rim of the sun. This drop off is faster than the predicted theoretical 1/R effect of General Relativity. ***It is very important to note*** that the highly dense solar wind electrons, from all observational evidence to date, have virtually **no** effect at all on the optical wavelength astronomy. (Reference 6.)

3.3 SHAPIRO DELAY: MEASURED TRANSIT-TIMES EFFECTS

Shapiro actually measured a transit-time delay that had a maximum value of 180 μs during which time the impact parameter of the microwave beam was at a minimum. This occurred during which time the planet Venus was at opposition on the date of January 25, 1970. This delay, referred to as "Excess Delay" by Shapiro himself, is depicted in Figure 3. Details on these results are given in Reference 1.
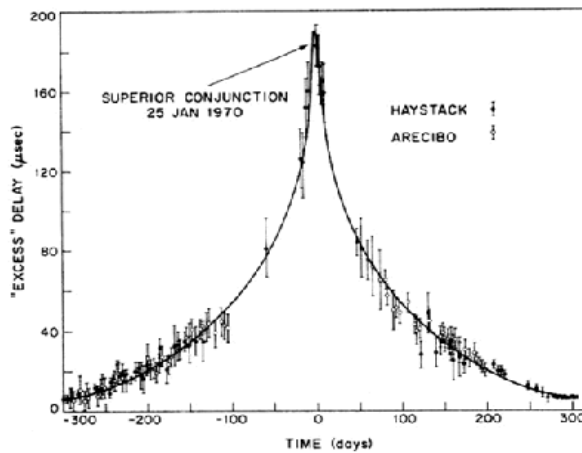

Fig. 3. Shapiro Delay of 180 μs during the Venus Opposition

As previously stated, the *Shapiro effect* appears to increase for smaller impact parameters of the probing beam of microwave signals and decreases only slowly (never going to zero) with increasing distance D from the sun. Figure 4 shows how the *Shapiro delay* slowly varies essentially proportional to 1 / ln(D), a logarithmic function. The graph clearly shows how the *Shapiro effect* never goes to zero or vanishes entirely. A clear detail discussion on this and Figure 4 is found in References 1 and 5.
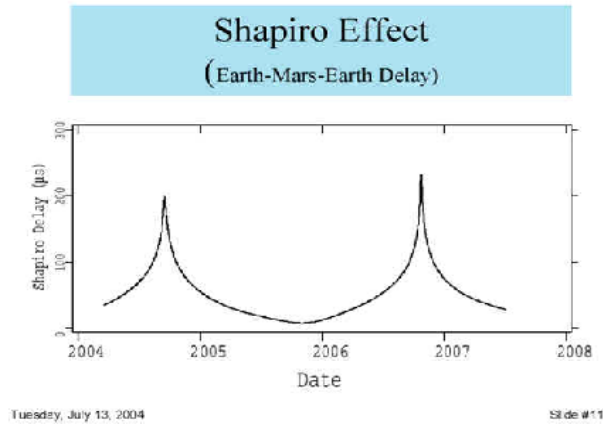

Fig. 4. Contribution of Shapiro effect to Earth-Mars-Earth delay

It is therefore clearly seen that the **Shapiro delay** is essentially a **transit-time effect** which is due to the physical characteristics of a space of an electron density profile that governs the propagation of microwaves. The gravitational light bending rule of **General Relativity** is a theoretical explanation for the **path** of the electromagnetic waves due either to a direct or an indirect interaction between the gravitational field of the sun and the bent light rays. The Shapiro delay and the gravitational light bending rule of General Relativity are two entirely different physical phenomena, requiring very different theoretical explanations.

On November 26, 1976, Shapiro calculated a time delay of 247.36 μs for the Earth-Mars-Earth roundtrip. As depicted in Figure 5, the microwave signal that is transmitted from a satellite orbiting Mercury, during which time the planets Mercury and Earth are at opposition to one another, must pass by the limb of the sun before reaching Earth. It is well known that, due to the vast quantities of solar winds that are ejected for the sun, the microwave signals must pass through a space of highly dense electrons.
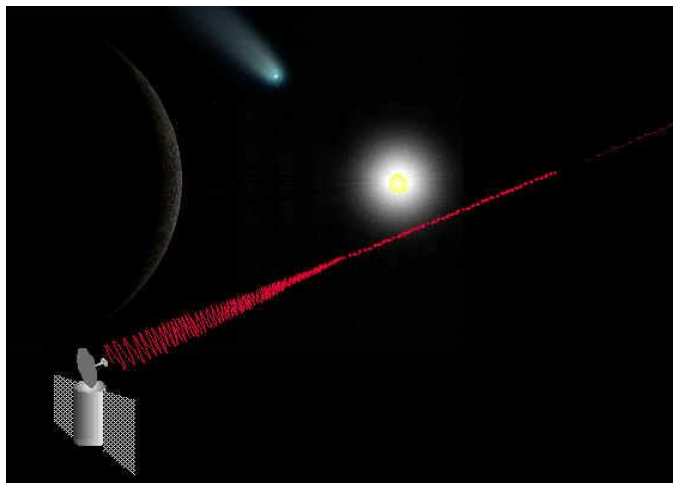

Fig. 5. Propagation in Solar Wind with Refractive Index n > 1.000000

As a consequence of the solar winds, the radial expanding supersonic atmosphere of the sun, the propagation velocity of the microwave signals vary as the waves must pass through space of varying electron densities. $N_e(r)$ is the density of the electrons present in the solar wind at a radial distance r from the center of the sun. The solar winds move with supersonic velocities up to 500 km per sec and expand out to beyond Jupiter and the outer most planets and eventually falls back as recombined matter and dust.

3.4 CALCULATION OF THE SOLAR WIND INDEX OF REFRACTION

It is easily shown that the electron densities, as observed and measured using the Viking, Mariner 6 and 7 spacecraft in references 1 thru 5, which is very prevalent throughout the solar winds, with values of $N_e(r)$ up to 10^4 electrons per cm^3, can be used to calculate the index of refraction as a function of $N_e(r)$ and N_c given by equation 2.

$$n^2 = 1 - \frac{N_e}{N_c} \qquad (2)$$

N_c is the frequency dependent the critical density given by $N_c = 1.240 \times 10^4 \, f^2$ (MHz) cm^{-3}; where f is the frequency of the microwave link. The index of refraction n is given by equation (3).

$$n = \sqrt{1 - \frac{N_e}{N_c}} \Bigg|_{\frac{N_e}{N_c} \ll 1} \cong 1 - \frac{1}{2}\frac{N_e}{N_c} \qquad (3)$$

Unfortunately, the mainstream of the Physical science community seems to view the *Shapiro delay* as a space-time effect of General Relativity. It is easily shown here that this is not at all the case and that, due to the very slow drop off trend of the *Shapiro delay* as shown in Figure 4, or the 'long-range effect' described by 1 / ln(D) and even described by Shapiro himself, an effect which never seems to go to zero, this characteristics does not fit the theoretical predictions of the space-time effect of General Relativity. The *Shapiro delay* has simple, clear classical explanations, not requiring any of the rigorous treatments of space-time or time dilations. It is easily seen that the vacuum space around the sun that includes Mercury, Venus, Earth and Mars has to have a *refractive index* n > 1.000000 from more than a century of astrophysical observations of the comets and the electron density profile of the solar winds. An estimate the refractive index of microwaves of frequencies 2.2 and 8.8GHz propagating in the vacuum space near the sun is given in Table 1.

SOLAR WIND INDEX OF REFRACTION					
r(R_{SUN})	N_e (cm^3)	N_e/N_c 2.2GHz	N_e/N_c 8.8GHz	1/n 2.2GHz	1/n 8.8GHz
200	5.4606E+00	9.0985E-11	5.6866E-12	1.0000000000	1.0000000000
150	1.0124E+01	1.6869E-10	1.0543E-11	1.0000000001	1.0000000000
100	2.4386E+01	4.0632E-10	2.5395E-11	1.0000000002	1.0000000000
50	1.1282E+02	1.8798E-09	1.1749E-10	1.0000000009	1.0000000001
40	1.8640E+02	3.1059E-09	1.9412E-10	1.0000000016	1.0000000001
30	3.5868E+02	5.9763E-09	3.7352E-10	1.0000000030	1.0000000002
20	9.1538E+02	1.5252E-08	9.5327E-10	1.0000000076	1.0000000005
15	1.7986E+03	2.9968E-08	1.8730E-09	1.0000000150	1.0000000009
12	3.0559E+03	5.0919E-08	3.1824E-09	1.0000000255	1.0000000016
11	3.7631E+03	6.2702E-08	3.9189E-09	1.0000000314	1.0000000020
3	9.2431E+04	1.5401E-06	9.6257E-08	1.0000007701	1.0000000481

Note that as the impact parameter **r**(R_{sun}) in units of solar radii decreases, the electron density $N_e(r)$ increases rapidly and the frequency dependent values for $N_e(r)/N_c$ also increases. For increased microwave frequencies above the resonance frequency of the electron plasma, the value $N_e(r)/N_c$ and thus for the index of refraction decreases. For all optical frequencies, the plasma index of refraction is practically n = 1.000000000.

Planet	Distance from Sun (m)	Transit Time (sec)
Mercury	57.9×10^9	193.13
Venus	108.2×10^9	360.92
Earth	149.6×10^9	498.01
Mars	227.9×10^9	760.19

Table 2 Transit Times (sec) assuming n = 1.000000000

3.5 INDEX OF REFRACTION N FROM THE RELATIVE TIME DELAY

Using the information given in Table 2, the round-trip-time required for the microwave signal to propagate for the path Earth-Mars-Earth, assuming an index of refraction of n = 1, is $2 \times (499.01+760.19) = 2516.40$ sec. The measured round-trip-time delay for path Earth-Mars-Earth found by Shapiro is 247.36×10^9 sec.

$$\frac{T_{Delay}}{T_{Transit\ Time}} = \frac{247.36 \cdot 10^{-6}}{2516.4} = 9.822 \cdot 10^{-8} \qquad (4)$$

Equating the ratio between the time delay and the transit time of the microwave signal, given by Equation 4, we have a time delay of 9.822×10^{-08}, an additional amount to be added onto the propagation time required for the microwave signal, ignoring other effects. One can equate the mean refractive index of the vacuum space for the entire path to be equal to the vacuum index of refraction n = 1.000000 plus an additional factor due to refraction giving a slightly larger refractive index, i.e., a larger n > 1.000000. This yields a mean index of refraction of n_{mean} = $1+9.822 \times 10^{-8}$ or 1.00000009822. This is the mean refractive index that will slow down the propagation velocity of the microwave signal so that it would arrive at a time delay of exactly 247.36×10^9 sec. Assuming the refractive index n(r) varied as a function of the radial distance from the sun, moving from the Earth to Mars and back to Earth, passing by the rim of the sun for a minimum value of r and a maximum value of n(r), and if the function f = n(r) were of the form of a triangle as given in Figures 3 and 4, or even as near trapezoid shape that is narrow at the top, where the maximum value of n(r) would be at the impact parameter of the microwave beam (a minimum r). A good approximation for n(r) at the impact parameter (a minimum r) could be a value of 1 plus 1.9644×10^{-08} or roughly $n(r_{min})$ = 1.00000019644.

In light of the fact that vast quantities of solar winds with this electron density profile are prevalent throughout the solar system, this index of refraction profile illustrated for 2.2GHz may be a reasonable estimate.

In References 3 and 5, the data for the electron density profile collected by the Viking spacecraft and analyzed for the radial distances from 4 solar radii (R_{sun}) to 200 R_{sun}. The equation that was fitted to the data in Reference 3 and graphically displayed as the "Equatorial electron density profile" was plotted on a linear scale in Figure 6 from 0 to 250 R_{sun}, a scale of from 0 to nearly 1.4 astronomical units (AU's).
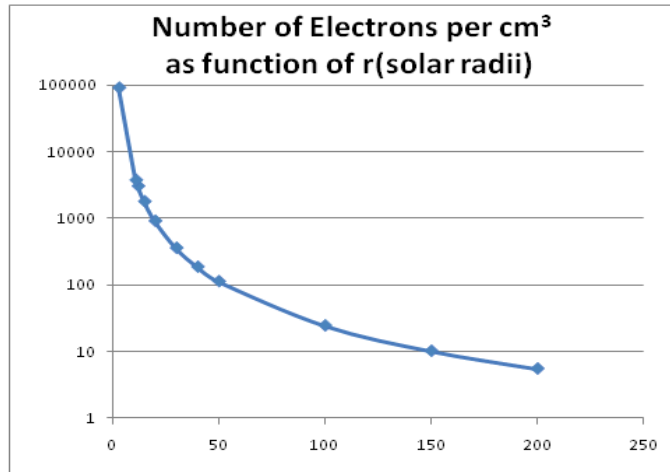
Fig. 6. N_e behaves nearly as r^{-2} **for distances beyond 1 AU or 200 R_{sun}**

Independent researchers consistently show that the electron density profile behaves very nearly as an inverse square of r, namely as r^{-2}. In reference 5 for Mariner-6, the electron density $N_e(r)(cm^{-3})$ falls off as $r^{-2.05}$ and for Mariner-7 as $r^{-2.08}$. In this same reference, a density at 1 AU of 9.1+/-2.6 electrons cm^{-3} is cited for a 6 month period of the experiment.

4.0 SUMMARY AND CONCLUSION

The *Shapiro delay* is merely a very good fit to the data dealing with the transit times of the microwave signals as function of the selected microwave frequencies of the transmitted link and as affected by the space properties of the solar wind that govern the propagation of microwaves signals in space. The *Shapiro delay* is the determination of the transit-time delay (*usually expressed in microseconds*) due to the influence of the expanding solar atmosphere (solar wind) of a measurable electron profile. The *Shapiro delay* has nothing at all to do with space-time or the gravitational solar light bending effect of General Relativity (*usually expressed in radians or seconds of arc*). Figure 7 summarizes in a picture the effect of the solar plasma rim and the electron density profile for the optical, IR and UV regions of the spectra. **This picture summarizes a horrendously misunderstood subject matter dealing with the propagation of electromagnetic waves in the atmospheres of the sun and of the stars.**
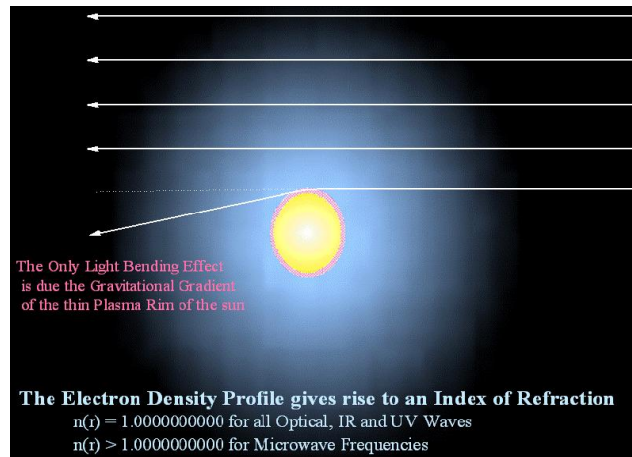

Fig. 7. Summarizing the Effect of Shapiro Delay and Light Bending

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