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A new belt beyond Kuiper's: A belt of focal spheres between 550 and 17,000 AU for SETI and science ☆

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ABSTRACT

Gravitational lensing is one of the most amazing discoveries produced by Einstein's general theory of relativity. To date, hundreds of gravitational lenses have been observed by astronomers and they led to a number of new results in extrasolar planet search, astrophysics and cosmology. SETI also could benefit from gravitational lensing if we could just get to 550 Astronomical Units (AU) from the Sun and beyond. This is because the gravitational lens of the Sun would highly intensify any weak radio signal reaching the solar system from distant civilizations in the Galaxy, as shown by this author in his 2009 book "Deep Space Flight and Communications".

The gravitational lens of the Sun, however, has a drawback: the solar Corona. Electrons in the Corona make electromagnetic waves "diverge" and this "pushes the focus out" to distances higher than 550 AU. For instance, at the CMB peak frequency of 160 GHz, the true focus lies at 763 AU. It would be safer to let the FOCAL spacecraft reach 1000 AU.

We could get rid of all solar-Corona-related problems, however, if we could reach the six-times higher distance of 6077 AU. This is where the focal sphere of Jupiter lies. Jupiter is the second larger mass in the solar system after the Sun, but in this focal game what really matters is the ratio between the radius of the body squared and the mass of the body. In this regard, Jupiter qualifies as the second best choice for a FOCAL space mission, requiring the FOCAL spacecraft to reach 6077 AU.

What about the other planets as gravitational lenses, then? Neptune qualifies third, with a focal sphere of 13,520 AU and Saturn comes fourth with a focal sphere of 14,420 AU. But the real surprise is the Earth, that qualifies just fifth with a focal sphere of 15,370 AU, and the Earth is indeed the best body we could use as a gravitational lens since we know about its atmosphere better than about any other planetary atmosphere.

Just to complete the picture, Uranus comes sixth at 16,980 AU and Venus seventh at 17,020 AU, let alone Mars, Mercury and the Moon, all with focal spheres at 40,000 AU and beyond.

We have discovered a new belt of focal spheres. In this paper, we study it in detail for the first time, for the benefit of SETI and science.

1. Introduction: the Sun as a gravitational lens

The gravitational focusing effect of the Sun is one of the most amazing discoveries produced by the general theory of relativity. The first paper in this field was published by Albert Einstein in 1936 [1], but his work was virtually forgotten until 1964, when Sydney Liebes of Stanford

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University [2] gave the mathematical theory of gravitational focusing by a galaxy located between the Earth and a very distant cosmological object, such as a quasar.

In 1978 the first ‘‘twin quasar’’ image, caused by the gravitational field of an intermediate galaxy, was spotted by the British astronomer Dennis Walsh and his colleagues. Subsequent discoveries of several more examples of gravitational lenses eliminated all doubts about gravitational focusing predicted by general relativity.

Von Eshleman of Stanford University then went on to apply the theory to the case of the Sun in 1979 [3]. His paper for the first time suggested the possibility of sending a spacecraft to 550 AU from the Sun to exploit the enormous magnifications provided by the gravitational lens of the Sun, particularly at microwave frequencies, such as the hydrogen line at 1420 MHz (21 cm wavelength). This is the frequency that all SETI radioastronomers regard as ‘‘magic’’ for interstellar communications, and thus the tremendous potential of the gravitational lens of the Sun for getting in touch with alien civilizations became obvious.

The first experimental SETI radioastronomer in history, Frank Drake (*Project Ozma*, 1960), presented a paper on the advantages of using the gravitational lens of the Sun for SETI at the *Second International Bioastronomy Conference* held in Hungary in 1987 [4], as did Nathan ‘‘Chip’’ Cohen of Boston University [5]. Non-technical descriptions of the topic were also given by them in their popular books [6,7].

However, the possibility of planning and funding a space mission to 550 AU to exploit the gravitational lens of the Sun immediately proved a difficult task. Space scientists and engineers first turned their attention to this goal at the June 18, 1992, *Conference on Space Missions and Astrodynamics* organized in Turin, Italy, by this author. The relevant Proceedings were published in 1994 in the *Journal of the British Interplanetary Society* [8]. Meanwhile, on May 20, 1993, this author also submitted a formal Proposal to the European Space Agency (ESA) to fund the space mission design [9]. The optimal direction of space to launch the FOCAL spacecraft was also discussed by Jean Heidmann of Paris Meudon Observatory and Maccone [10], but it seemed clear that a demanding space mission like this one should not be devoted entirely to SETI. Things like the computation of the parallaxes of many distant stars in the Galaxy, the detection of gravitational waves by virtue of the very long baseline between the spacecraft and the Earth, plus a host of other experiments would complement the SETI utilization of this space mission to 550 AU and beyond.

The mission was dubbed ‘‘SETISAIL’’ in earlier papers [11], and ‘‘FOCAL’’ in the proposal submitted to ESA in 1993. FOCAL was also how the mission was dubbed in further papers (Refs. [15–18]).

In the third edition of his book ‘‘The Sun as a Gravitational Lens: Proposed Space Missions’’ [12], the author summarized all knowledge available as of 2002 about the FOCAL space mission to 550 AU and beyond to 1000 AU. On October 3rd, 1999, this book had already been awarded the Engineering Science Book Award by the International Academy of Astronautics (IAA).

Finally, in March 2009, the new and comprehensive 400-pages book by the author, entitled ‘‘Deep Space Flight and Communications – Exploiting the Sun as a Gravitational Lens’’ [19], was published. This book embodies all the previous material published about the FOCAL space mission and updates it. On November 25th, 2009, this book was presented in a talk that the author gave at the SETI Institute in Mountain View, CA, USA (You Tube site: http://www.youtube.com/watch?v=ObvKVe5H8pc).

The FOCAL name may also be regarded as an acronym for ‘‘Fast Outgoing Cyclopean Astronomical Lens’’, summarizing the mission’s main features.

2. Why 550 AU is the minimal distance that ‘‘FOCAL’’ must reach

The geometry of the Sun gravitational lens is easily described: incoming electromagnetic waves (arriving, for instance, from the center of the Galaxy) pass *outside* the Sun and pass within a certain distance r of its center. Then the basic result following from the Schwarzschild solution shows that the corresponding *deflection angle* $\alpha(r)$ at the distance r from the Sun center is given by

$$\alpha(r) = \frac{4GM_{Sun}}{c^2 r}. \quad (1)$$

Fig. 1 shows the basic geometry of the Sun gravitational lens with the various parameters in the game.

The light rays, i.e. electromagnetic waves, cannot pass through the Sun’s interior (whereas gravitational waves and neutrinos can), so the largest deflection angle

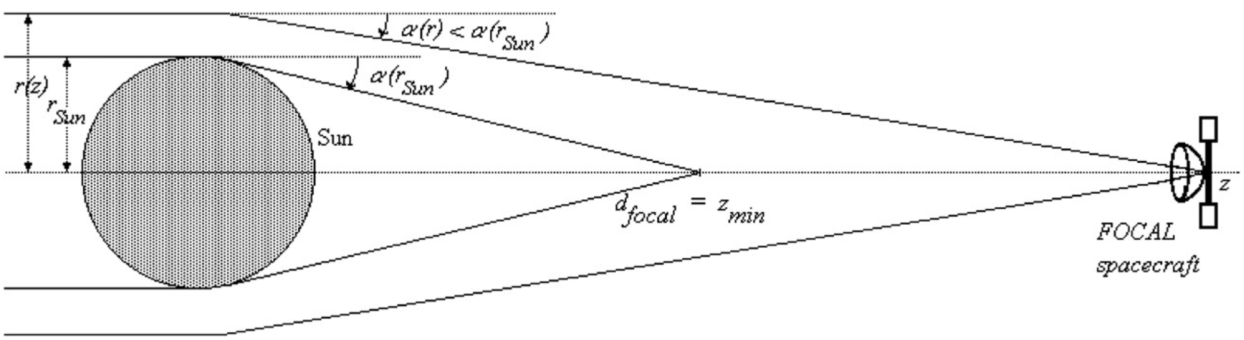

Fig. 1. *Geometry of the Sun gravitational lens*. Shown are the minimal focal length of 550 AU (=3.17 light days=13.75 times beyond Pluto’s orbit) and the FOCAL spacecraft position beyond the minimal focal length.