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Transits of Mercury and General Relativity from observations, and the 2019 November 11 transit

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Abstract

The transit of Mercury of November 11 2019, provides the opportunity to test a method of measuring the solar diameter and shape (due to the oblateness) better than 0.1", or 70 km of resolution on the Sun. Beyond the General Relativity implications of Mercury itself, we exploit the most precise ephemerides to achieve 0.1" with ground-based instruments of the solar diameter, of which monitoring the secular variations (related to our climate), as well as transient variations as potential proxies of major flares and Coronal Mass Ejections (to predict space weather).

1. Introduction

The theory of General Relativity of Albert Einstein solved the problem of the anomalous precession of the perihelion of Mercury of 43" per century. From observations this value was known since the second half of 1800 and it was the aim of research of Urbain Joseph Le Verrier [11] after finding Neptune in 1846 using calculus. Here we start from the simple fact that in November transits Mercury is 10" while in May it is 12" wide as seen from the Earth; since the duration of the ingress/egress phases of a transit last about 2 to 3 minutes and are symmetrical, 43" would correspond to about 10 minutes of time in the transits. Since the perihelion position is a calculated point, we concentrate on the observational uncertainties achievable from ground observations of the transit phenomenon, connecting to the measurements of the solar diameter through the historical transits of Mercury made by I. I. Shapiro in 1980 and repeated with satellite observations by J. Pasachoff with TRACE and M. Emilio with SOHO. Some attempts made from ground are also reviewed in view of preparing the strategy of the observations of the next transit of November 11, 2019. The sphericity of the Sun versus its oblateness is also a matter of relativistic relevance, discussed by R. Dicke at Princeton in 1967, though the oblateness reported by Dicke et al. turned out to be intensity oblateness linked to the distribution of faculae. The oblateness is detectable with high precision measurements and in the Mercury transits.

2. Mercury transits & solar radius

The transits of Mercury have been used to evaluate the variations of the solar radius since their observations at the telescope (1631 on) by Shapiro (1980 [1]), after the claiming by J. Eddy (1979 [2]) of the smaller diameter of the Sun during the annular eclipse of 9 may 1567 observed in Rome by Clavius. This controversial theme continued in the "SOLE" paper for the Solar Disk Sextant balloon borne. Further investigations carried by M. Emilio (2012 [5]) on the SOHO data of the Mercury transits of 2003 and 2006 pointed again towards a constant Sun. Sigismondi reviewed classical and recent (2016 [6]).

3. Relationship between Mercury transit and General Relativity

Mercury appears as a disc of 12" on May transits and 10" for the November ones. The amount of shift in perihelion precession per century is 43", corresponding to 4 diameters of Mercury. The ingress and the egress of the transits of Mercury on the solar disk are two occasions for measuring accurately its position or the solar diameter & shape. With Gaussian methods the perihelion is found, but here we want to stress the other connections between Mercury transit and General Relativity.
Mercury contact timings with the solar limb are potentially the best positioning observing methods for the planet, by using the solar disk as a standard. Conversely Mercury can be used to test the length of a solar chord, assuming the Sun perfectly circular. Furthermore assuming a perfect knowledge by the ephemerides of the position of Mercury the shape (oblateness) of the Sun can be assessed, as the Brans-Dicke theory alternative to General Relativity

required observationally (1967 [7,8]). The position of the Sun and of Mercury are now well known because of a very high statistics in the modern ephemerides. Moreover the problem of the "black drop" [9] has to be overcome by an extrapolation.

4. Observational strategies

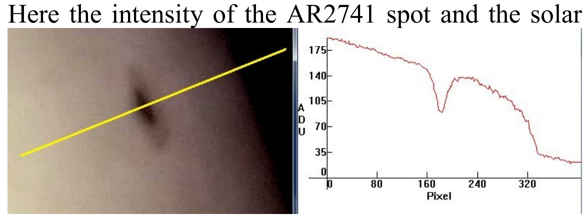
The amount of daily seeing in normal groundbased environments is around 2", except for some specialized telescopes, specific sites sites, and solar telescopes in orbit, where it is not better than 0.5". The success in timing the transit of Mercury for the purpose of assessing the solar diameter is by achieving an absolute time resolution better than 0.1s.

This can be obtained only statistically, by a sequence of "lucky images" of 1" of resolutions, obtained within the 100 s of the next transit ingress/egress: the extrapolation to zero of the chord chopped on the solar limb by the disk of Mercury. Since in 100 s the planet scan 10" each second corresponds to 0.1".
*Space Instruments: SOHO and SDO will be ready to observe the transit. But a higher cadence should be set for the ingress and egress.
*Provisional Ground Network: Pawel Rudawy at Bialkow Coronograph; Michele Bianda at Locarno IRSOL gregorian telescope; Cyril Bazin and Serge Koutchmy at the Carte du Ciel of Paris; C. Sigismondi applies to use the solar tower of Monte Mario of 26 cm f/100; Rio de Janeiro Heliometer; IBIS at Dunn Solar Telescope, at Sacramento Peak New Mexico, Williams College telescope, Massachusetts, SPSO South Pole MOTH. H. Altafi in Tehran, Iran, and X. Wang in Hauirou, China.

5. Simulations with real observations

The observation of the big solar spot AR2740 allowed us to test the lucky imaging in the worst case: telescope indoor and big turbulence through a window. Some details of the umbra are visibile, as well as two over three pores at 14:50 UT of may 7, 2019. A practical resolution of 1.5" for the second pore is attained. The spot is 40" wide, particularly big. Same size for the AR2741. Telescope: SC 8"/f10 with full aperture glass filter (once belonging to the Science Museum of Virginia) at 270x with eyepiece Plőssl 7.5mm (Taiwan), afocal video with Samsung J5 smartphone at 4x digital zoom. Crisper images have been seen using the Plőssl 25 mm Meade 3000, but the video with more detail was the one at larger magnification. This video shows less detail than the eye, but it is possible that the lucky imaging will give accurate timing and allow us to do an accurate extrapolated fit to the zero cord.

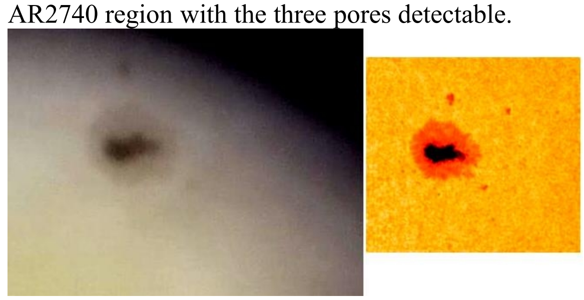
Here the intensity of the AR2741 spot and the solar



limb profile are seen on the graph. The inflexion point for determining the solar limb is detectable within 1 pixel (0.6"), as well as the texture of the faculae between the spot and the solar limb. There is a lucky image about each second. This makes possible the 0.1" final resolution on the solar limb positioning through Mercury's contact.

The darkness of Mercury is much deeper than the umbra of the sunspot -as Angelo Secchi [10] said for Venus- even if its surface will be brightened by the light of the solar limb, with a strong radial derivative.

AR2740 region with the three pores detectable.



The curved area on the right up is due to unwanted vignetting. Comparison image 4096x4096 px SDO

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