Why Use Solar Eclipses To Measure Our Sun?

Measuring our Sun is an extremely difficult task as it is a ball of gas having multiple layers having no sharp boundaries, the visible surface being called the photosphere. The current value for the photospheric solar radius (IAU 1976) used in all solar eclipse predictions was derived by Auwers in 1891 using a device called an heliometer, we will see later on that this value is not sufficiently accurate to time solar eclipses.

Attempts to measure our Sun using solar eclipses started in 1715 in England with partial success. The hybrid solar eclipse of 1912 over Portugal and France did produce some good results, however the knowledge of the lunar limb profile at the time was poor. Until the current decade the accuracy obtained by those attempts, using various methods, wasn’t good enough even though our knowledge of the lunar limb profile has improved tremendously.

Nowadays we know with great accuracy the ephemerides of the Sun, Moon and Earth (for at least the past 20 years), the true lunar limb profile (for the past 8 years), the position of the observer on Earth and the precise time, so what remain missing is the photospheric solar radius with great accuracy and its possible small variations.
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The solar radius we are interested in is the photospheric one, the one from the photosphere, the visible layer of our Sun.

During a total solar eclipse, 2nd contact is defined by the instant of complete photospheric extinction, that is once the last Baily’s beads are gone; 3rd contact is defined by the reappearance of the photosphere, that is the first Baily’s beads showing up between the valleys and peaks on our Moon.

Because we know accurately the positions of the Sun, Moon, the observer on the Earth’s surface, the lunar limb profile we can then deduct the photospheric solar radius provided we can accurately time 2nd and 3rd contact. Timing those contacts has always been an issue because there is room for interpretation when using the standard methods. However by combining those methods with spectroscopy and Baily’s beads simulations it is now possible to solve the problem.

Main advantages of using solar eclipses:

- Small budget: ground-based measurements with small portable equipment
- Mostly free of seeing effects: occultation occurs in space
- Differential method: the lunar disk is used as a reference
From those two pictures it is clear that the duration of totality is shorter than 2 minutes and 39 seconds as you can still see small Baily’s beads around 2\textsuperscript{nd} and 3\textsuperscript{rd} contacts, which means using a standard photospheric solar radius of 959.63” at 1au is incorrect as eclipse predictions taking into account the true lunar limb profile would result in a duration of about 2 minutes and 40 seconds. So this shows that the photospheric solar radius is necessarily bigger than the standard value. The observed true duration was about 2 minutes and 38 seconds, and this is compatible with a photospheric solar radius of about 959.98” at 1au.
Question: how to determine 2\textsuperscript{nd} and 3\textsuperscript{rd} contact accurately, that is the instants of photospheric extinction/reappearance?
Visually it is next to impossible even at high magnification because even when no Baily’s beads are visible you still have a bluish glow in the vicinity of the contacts during a couple of seconds at most.
So what’s next? Well it all begins with understanding the origin of this bluish glow, and this can be done by using spectroscopy combined with Baily’s beads simulations.
Using hybrid solar eclipses to measure our Sun with greater accuracy is the best way because there are Baily’s beads all around our Moon, which means matching Baily’s beads simulations with actual pictures is easier.

Broken annular taken without solar filter through thin clouds.
Hybrid Solar Eclipse 1987

Broken annular taken without solar filter through thin clouds.

Again with the standard photospheric solar radius of 959.63” at 1au it is impossible to get a positive match between the actual pictures and the Baily’s beads simulations. However a true radius of about 959.98” at 1au does match in terms of position, shape, brightness and timing.

Question: why not using a solar filter?
Well simply because a filter would introduce a bias in the measurements made as the filter removes some important and crucial data. Also if there are any clouds how can you be certain that they didn’t hide something because the filter is hiding the clouds as well.

Those pictures provide even more information to the trained eye, we will come to this later.
Another key hybrid solar eclipse that provides most of the answers. Again it is impossible to match the actual pictures and the Baily’s beads simulations using the standard photospheric solar radius. And we still need to adjust the solar radius to about 959.98” at 1au to have a positive match in terms of position, shape, brightness and timing.
Another key hybrid solar eclipse that provides most of the answers. Again it is impossible to match the actual pictures and the Baily’s beads simulations using the standard photospheric solar radius. And we still need to adjust the solar radius to about 959.98” at 1au to have a positive match in terms of position, shape, brightness and timing.
What is also interesting there is that we have hints of the mesosphere, a transition layer between the photosphere, that we’re trying to measure, and the pinkish chromosphere above it.

Question: Never heard of the mesosphere? Well now you do! And you’ll also learn about the Low First Ionization Potential, aka Low FIP, soon enough…
And now we’re bringing in spectroscopy to disentangle what we’re seeing. On the left a photograph taken shortly before 2\textsuperscript{nd} contact and on the right its flash spectrum. The reddish tint of the picture on the left is due to the fact that the DSLR used is unfiltered, i.e. the IR filter has been removed.

What you can see is that where you have Baily’s beads you find a continuum on the flash spectrum. Yet there is much more, next to the continuum you have hints of the mesosphere where all those discrete emission lines appear, you know those Low First Ionization Potential we were talking about earlier. And remember I also mentioned this bluish glow, well it is in fact the mesosphere, the transition layer between the photosphere and the chromosphere. So here we now have an accurate way of measuring the photospheric solar radius provided we have a match with the Baily’s beads simulations.
So now with the Baily’s beads simulation we can indeed see the bluish mesosphere exactly where it appears on the flash spectrum, but again we can have the proper match only with an increased photospheric solar radius of about 959.98” at 1au. Bingo, we nailed it!! Let’s now see how we can confirm this on an annular solar eclipse.
Hybrid Solar Eclipse 2013

Blue = photosphere
Red = mesosphere (Low First Ionization Potential emission lines from 460nm to 480nm)
Black = chromosphere
Hybrid Solar Eclipse 2013

Chromosphere with its H-alpha emission line
Hybrid Solar Eclipse 2013

Photosphere at the main Baily’s beads

Luca Quaglia
Mesosphere and its Low First Ionization Potential emission lines (4600Å to 4800Å) intermixed with some photosphere or pseudo-continuum.
Annular Solar Eclipse 2017

Let's now see how we can confirm this on an annular solar eclipse. To achieve this tour de force we're going to place ourselves willingly just barely outside the central eclipse path, yet inside the true eclipse path with our adjusted photospheric solar radius, and we'll take pictures at 2nd and 3rd contacts without any solar filter (never do this if you don't know exactly what you're doing).
Hehe we again have a match using an increased photospheric solar radius, an impossible feat using the standard radius. You can even see the chromosphere and hints of the mesosphere.
Annular Solar Eclipse 2017

Still not convinced? Well then you’d better look again.
Question: What about using a solar filter?

Well if you look at this image sequence taken near the southern limit of ASE 2012, even in high resolution I don’t think anyone can give me the 2\textsuperscript{nd} contact time or even tell me if they’re was a 2\textsuperscript{nd} contact at all. The fact is, there was actually a 2\textsuperscript{nd} contact and this is clear when using Solar Eclipse Maestro’s Baily’s beads simulations. Yet without the help of the simulations and also because of the use of a solar filter it is next to impossible to get any meaningful information from this otherwise nice sequence.
TSE 2017 White Light

Solar Eclipse Maestro

Dimitry Zaitsev
What’s Next

Our master plan was to do an extensive campaign during TSE 2017, doing also some outreach in college and universities as we needed volunteers, with at least 30 identical measurement stations, both on the northern and southern limits (same time to execute an even more accurate differential measurement), and also at different times along the central eclipse path.

We applied for a NASA grant which unfortunately didn’t come through. Missing such a unique opportunity was a shame because we could have expected some truly great results from this campaign. A scaled down experiment was executed and preliminary results do confirm a larger true photospheric solar radius.

Looking forward to more opportunities in 2019 and 2020 in both Chile and Argentina. A collaborative effort is mandatory.
Argentina July 2019

Northern edge: Barrick Gold Veladero mine at 4,400 to 5,200 meters (14,500 to 17,000 feet)

Southern edge: San Juan
Argentina July 2019

Northern edge: Barrick Gold Veladero mine at 4,400 to 5,200 meters (14,500 to 17,000 feet)

Southern edge: San Juan
Argentina/Chile July 2019

Cerro Las Tórtolas: 6,160 meters (20,210 feet)
Chile July 2019

Northern edge: Giant Magellan Telescope (GMT) [http://www.gmto.org/](http://www.gmto.org/)

Solar Eclipse Maestro

- Specialized application
- Computations at maximum accuracy (atmospheric refraction, lunar limb profile, Baily’s beads, sky chart, apparent horizon, etc.)
- Control your DSLRs or CCDs
- E-Flight planning and execution
- And much more
- Available for lunar eclipses and solar transits also
  - Lunar Eclipse Maestro
  - Mercury Venus Transit Maestro

http://xjubier.free.fr/sem
Chile July 2019
TLE July 2018: South Africa

Omicron Capricorni

20:32 UTC
TLE July 2018: South Africa
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- Joel Moskowitz and Glenn Schneider (ASE 2012 pictures)
- Solar Eclipse Maestro – Xavier Jubier
  - http://xjubier.free.fr/sem