Interpreting the Solar Eclipse Data

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April 2015

Introduction

The observations of the solar eclipse of March 20, 2015 with the radio telescopes of DL0SHF showed very nicely that the obscuration of the solar disk occurs differently on different frequencies. While at 10 GHz the eclipse resembles the optical, at 1 GHz the obscuration starts earlier, is less deep, and ends later than the optical eclipse, because of the emission from the extended corona (Fig.1).

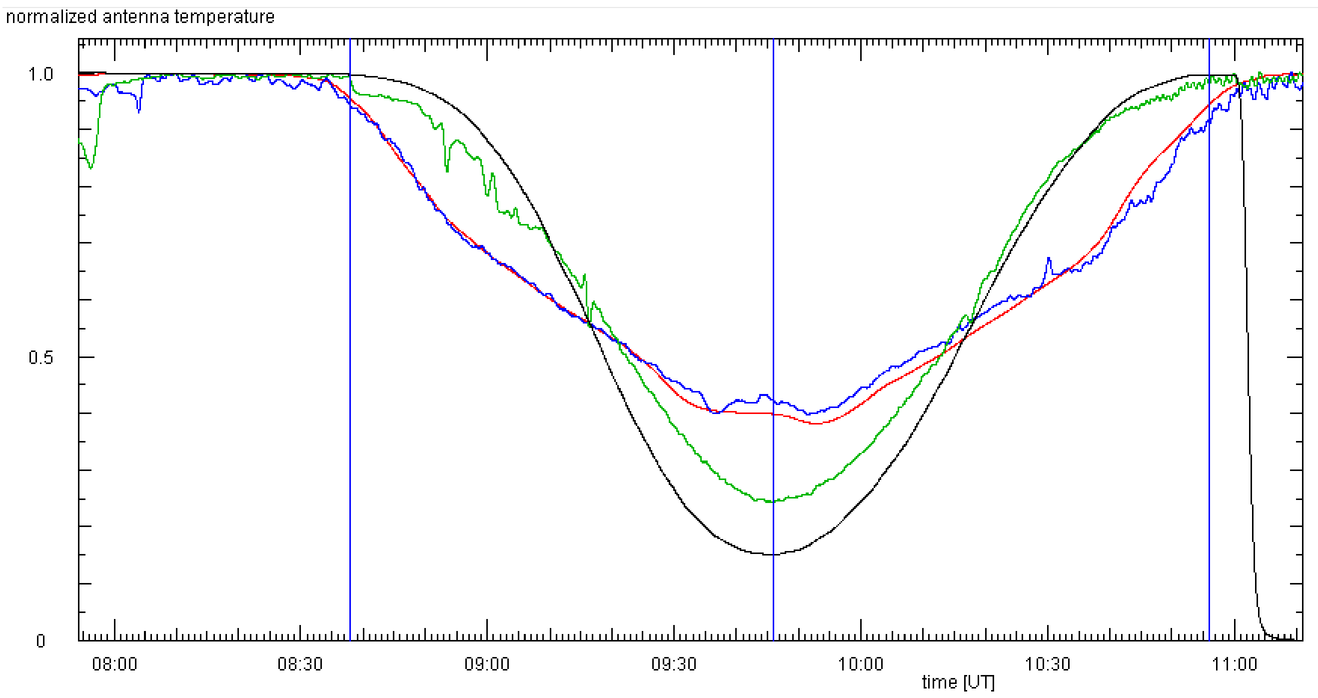

Fig. 1 *Progression of the antenna temperatures, normalized to the uneclipsed Sun, on 1.3 GHz (red), 2.3 (blue), 8.2 (green), and 10 GHz (black). Vertical blue lines mark the first and last contact with the optical disk, and the maximum eclipse.*

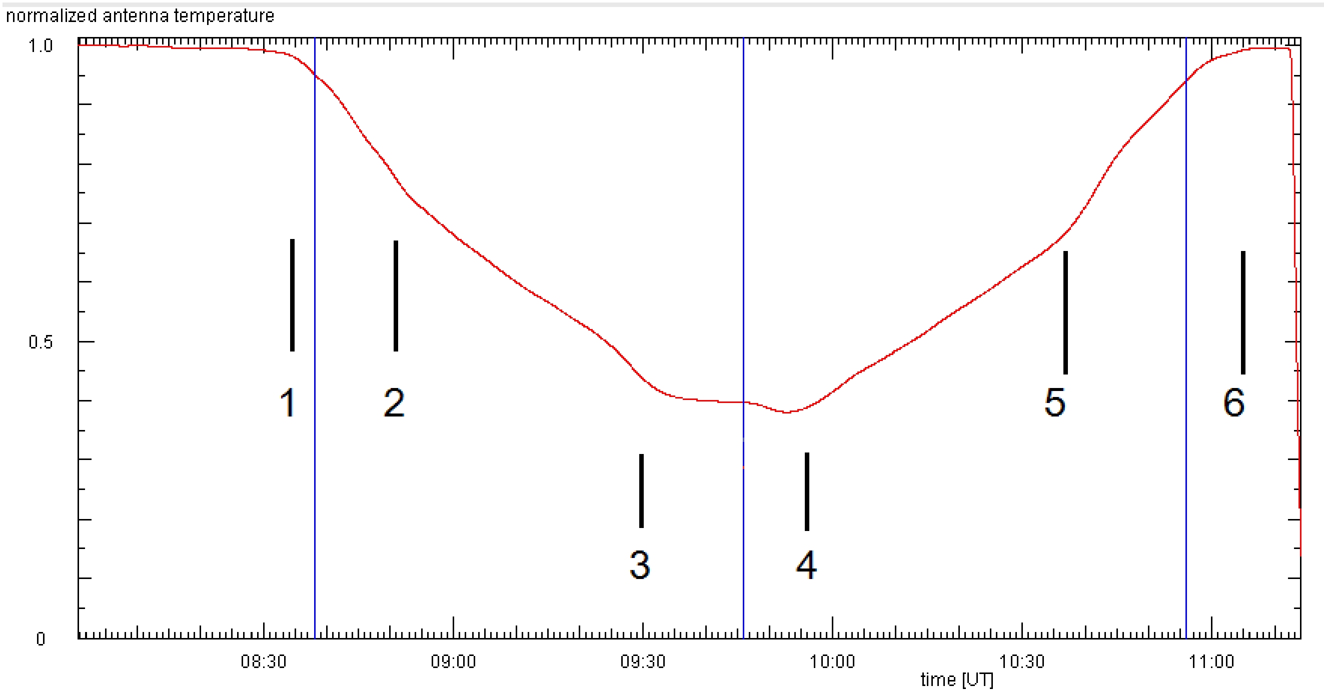

Fig. 2 *Like Fig.1, but for 1.3 GHz only*

The data on 1.3 GHz (confirmed by the 2.3 GHz data as well as the 1.3 GHz observations by F1EHN near Paris) shows a number of distinct features (Fig.2):

1. the drop in flux starts before first contact, i.e. before the Moon's disk touches the solar photospheric disk
2. a kink in the curve's flank
3. another kink before the small depression (henceforth called 'dip')… a small maximum at maximum eclipse ...
4. the second dip ends with a kink
5. another kink in the flank. Note that the region between 4 and 5 is lower and more distinct than the region between 2 and 3

There is a striking overall symmetry with respect to the time of maximum eclipse: the two kinks in the flank and the two depressions near the centre. But it is not perfect, and thus small differences would also need to be explained..

Simple Modeling

Let us use a simple model for the brightness distribution across the solar disk in order to explain the observed radio brightness curve. We shall consider a central disk to represent e.g. the photosphere, a ring around the photospheric disk for the corona, and brighter blobs for hotter regions in the corona. All these simple geometric forms shall be of uniform surface brightness. Given some dimensions of disk, ring, and blobs it is attempted to reproduce the observed curve as best as possible.

The basic parameter of the eclipse is the distance by which the Moon's centre passes closest to the centre of the solar disk. This is determined by reproducing the predicted obscuration (0.8 for Kiel), which yields the value of 0.37 solar disk radii (from Fig.3). Note that the obscuration of the disk yields a 'V'-shaped curve.

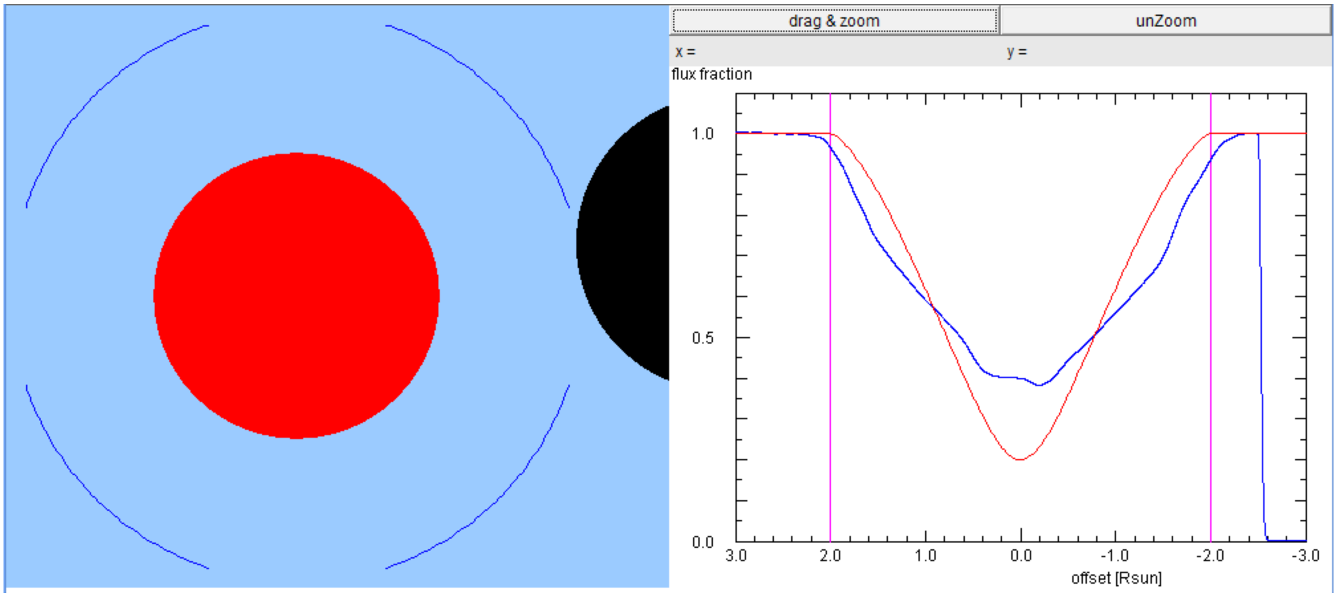

Fig. 3 *The maximum obscuration of this eclipse of 0.8 is obtained (red curve at right) by simulating the eclipse of the photosphere, represented by a disk of uniform surface brightness (left).The antenna's main lobe is wide enough to measure all emission within 1 deg radius from the Sun (blue circle). The blue curve at right iare the 1.3 GHz data.*

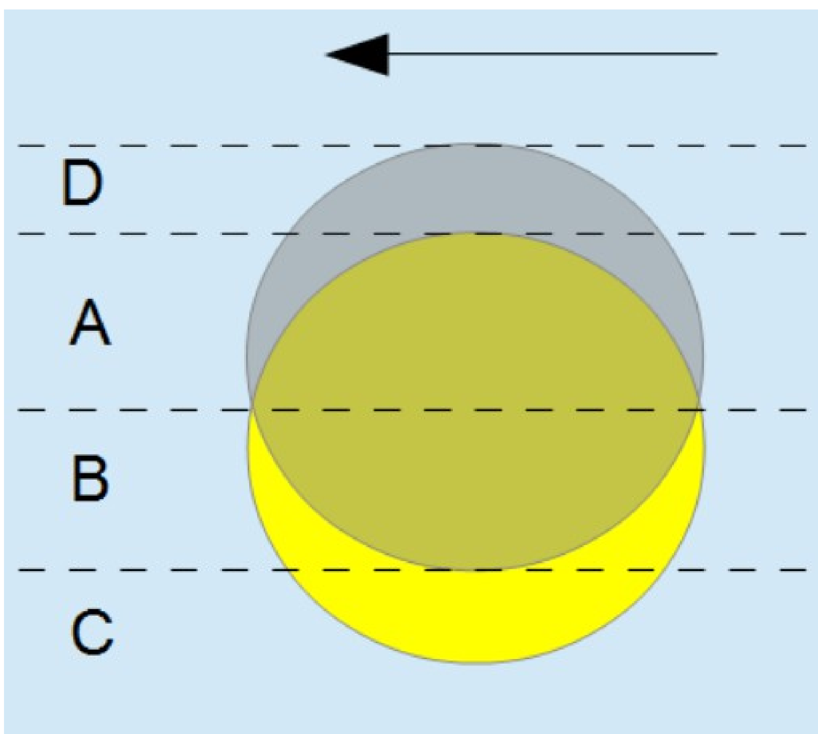

Fig. 4 *Geometrical zones that are helpful in describing the effects of the presence of bright regions on the eclipse data*

As the modeling aims to reconstruct the distribution of surface brightness in and around the Sun's disk, it is first useful to explore how the presence of a bright region at some location is mapped into the observed obscuration curve. This will be done in the following sections. For this purpose one can distinguish geometrical zones along the trajectory of the Moon, as in Fig.4:

- Zone A: any bright spot is completely obscured, and remains so for a long time
- Zone B: due to the Moon's secant the duration of the obscuration is shorter
- Zone C: everything in this region is not obscured at any time
- Zone D: these regions outside the photospheric disk can be obscured, but also for a shorter time, like in Zone B

Furthermore, in regions on the West side (at right) the obscuration starts and ends earlier than in the East side.

Ring-like Emission

Suppose that the emission is in the form of a thin ring (Fig.5). If the outer rim reaches beyond Zone D, these parts are not obscured. If also the inner radius is close to the border of Zone D, the Moon at maximum eclipse can cover only a small portion of the ring, hence almost the full brightness of the ring is observed as a peak at maximum eclipse. Before and after maximum, the Moon obscures a fair portion of the West or East limb, resulting in a strong drop in brightness. One notes that in the beginning the obscuration increases fast, as the Moon's broadside covers the Western limb, then slows down, resulting in a 'U'-shaped curve.

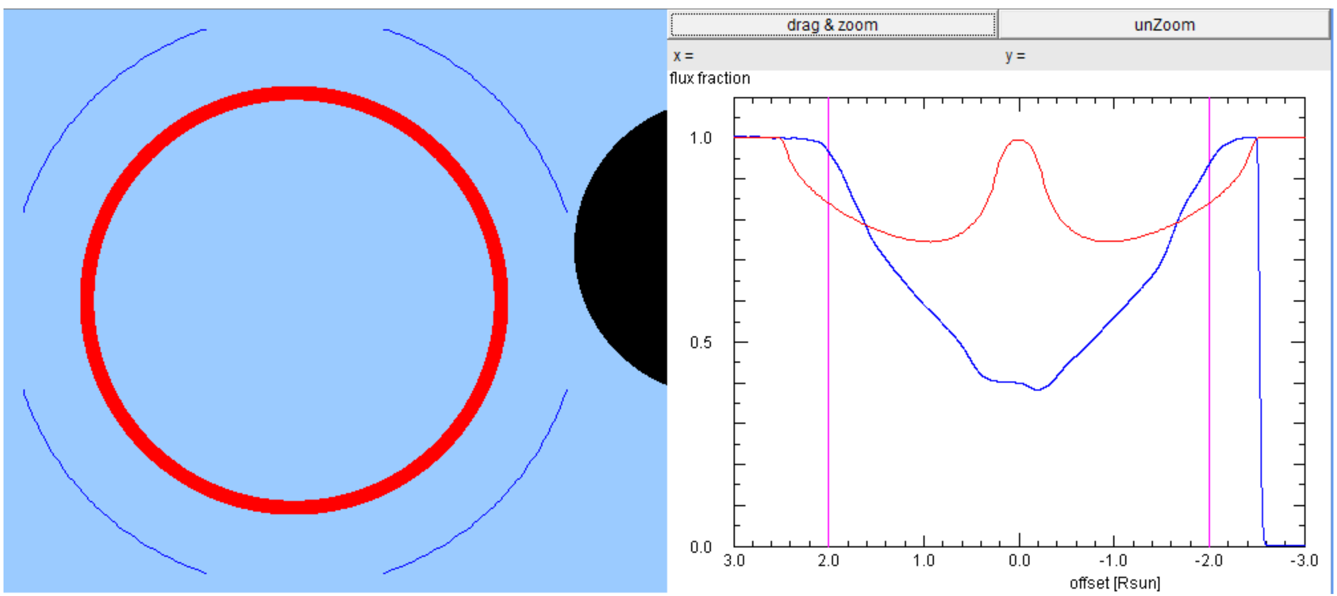

Fig. 5 *Eclipse of a thin bright ring around the photospheric disk. The inner radius is 1.4 solar disk radii, the outer,*

With a thicker emission ring (Fig.6) the stronger contribution of the inner parts make the brightness peak at maximum eclipse less prominent.

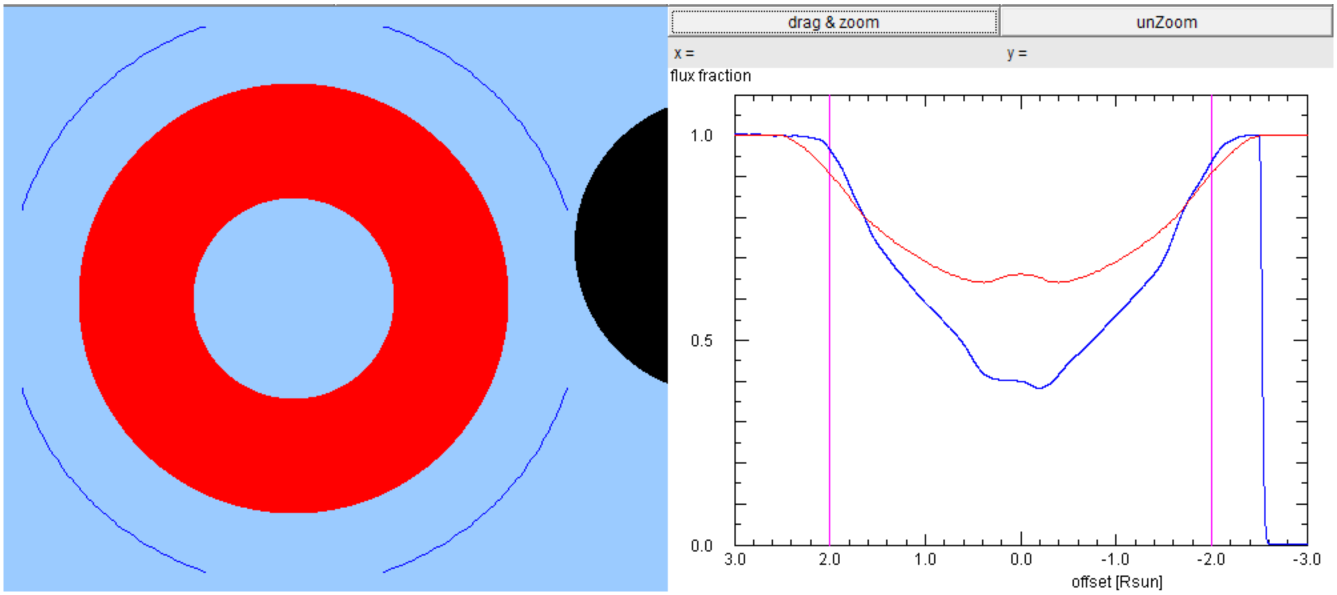

Fig. 7 *As Fig.6, but for an inner radius of 0.7 solar disk radii*

Blobs = Small Emission Regions

The real corona is not of uniform brightness as supposed in the model, as shown in Fig.8, we should look at the effects of small bright regions, anywhere on the solar disk, on the observed curve.

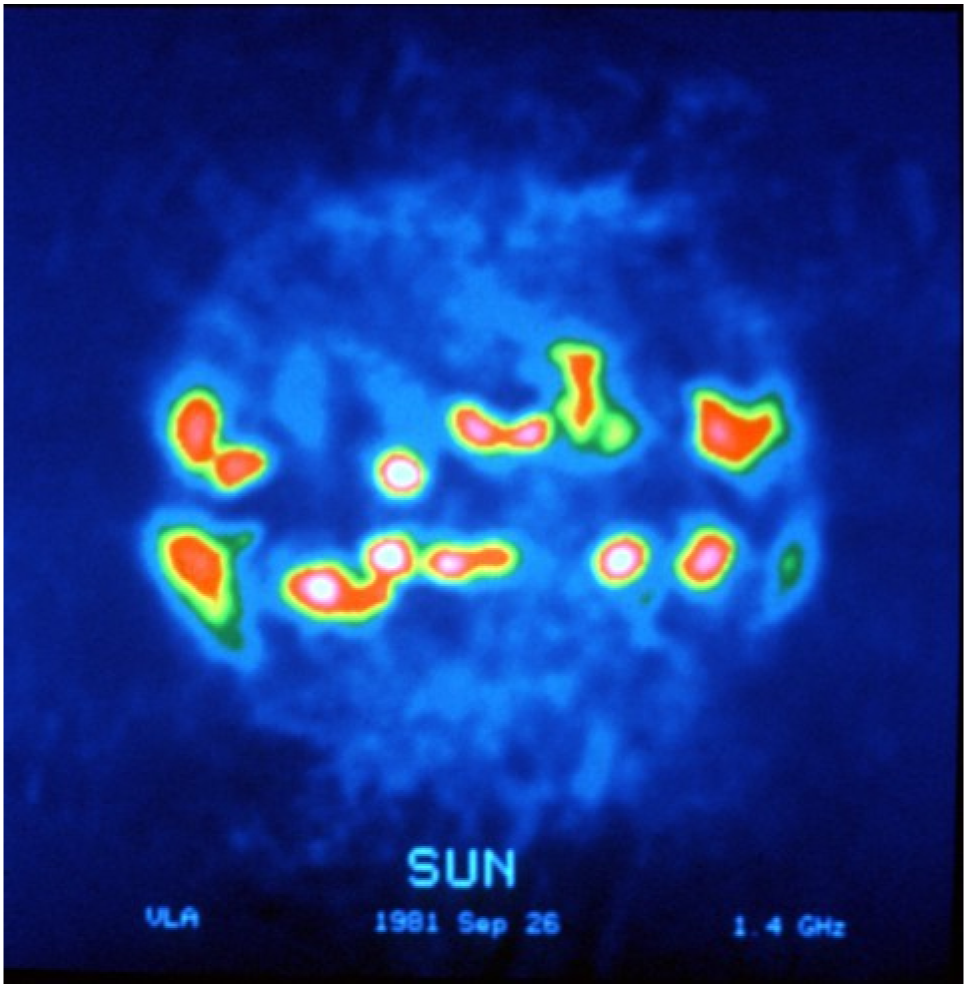

Fig. 8 *Image of the Sun at 1.4 GHz by G.A.Dulk and D.E.Gary on 1981 sep.26, using the VLA with a resolution of 40 arcsec (Image courtesy of NRAO/AUI)*

The VLA image (Fig.8), taken during the solar maximum 1981, shows a number of bright regions ('blobs') which form two bands at some latitude on both sides of the solar equator. There is a background emission covering the solar disk, but only a hint of a brightened limb on the Northern hemisphere. To quote Dulk and Gary (1981): 'There is some evidence for limb brightening … The amount is not nearly as large as was predicted in the classic paper by Smerd (1950), but is consistent with most subsequent observations. It is likely that a very narrow region of bright emission should exist within 3” to 10” of the optical limb, but in our observations such a spike would be smeared out by the 40” beam'.

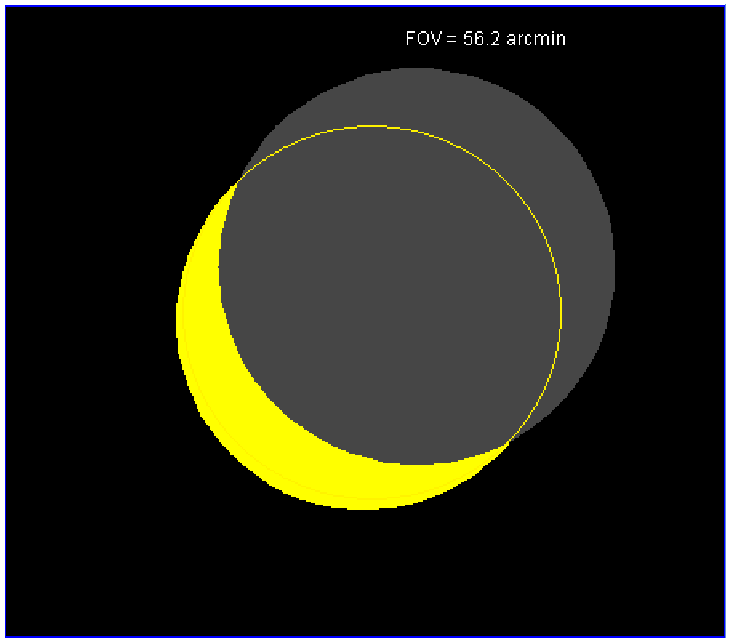

Fig. 9 *The situation near maximum eclipse, oriented in Right Ascension/Declination. The moon moves across the solar disk in North-Easterly direction.*

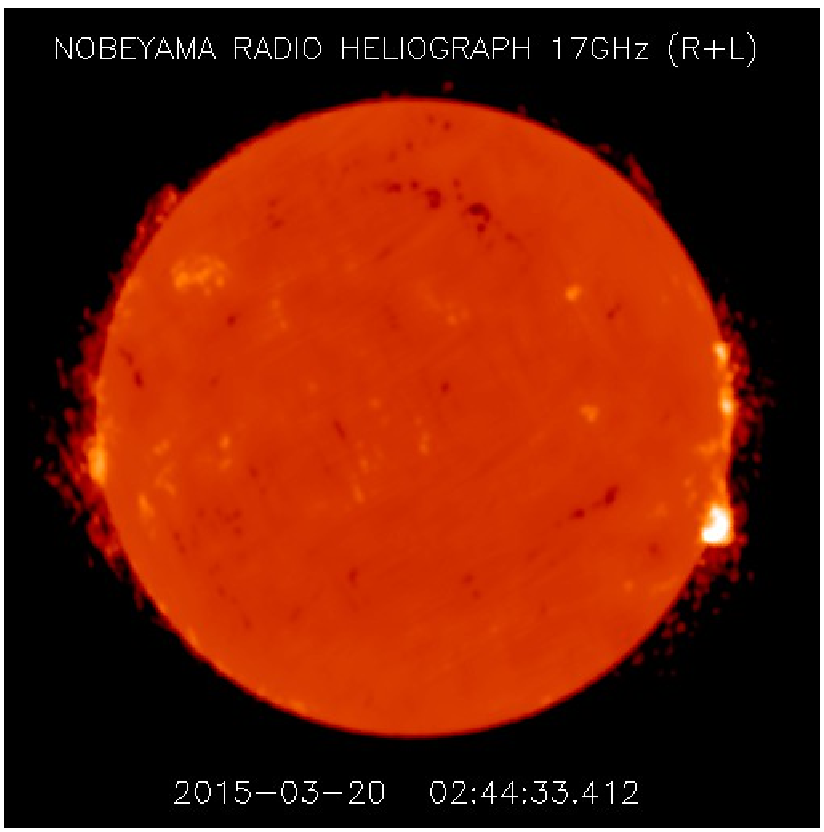

Fig. 10 *The solar image on 17 GHz some 6 hours before the eclipse, from the Nobeyama Radio Heliograph.*

For the day of the eclipse, the Nobeyama image (Fig.10) on 17 GHz shows several emission spots, which can be considered as part of a band which extends from the upper right to the lower left on the solar disk in our model simulation.

Consider first the influence of a blob in the middle of the disk (Fig.11): To emphasize the blob's impact on the curve, the solar disk is marked with a thin circumference – which for technical reasons produces the shallow depression at the curve's top part. The blob is completely obscured from offsets 1.0 to -1.0, i.e. for about half of the time between first and last contact, and symmetric to the time of maximum eclipse.

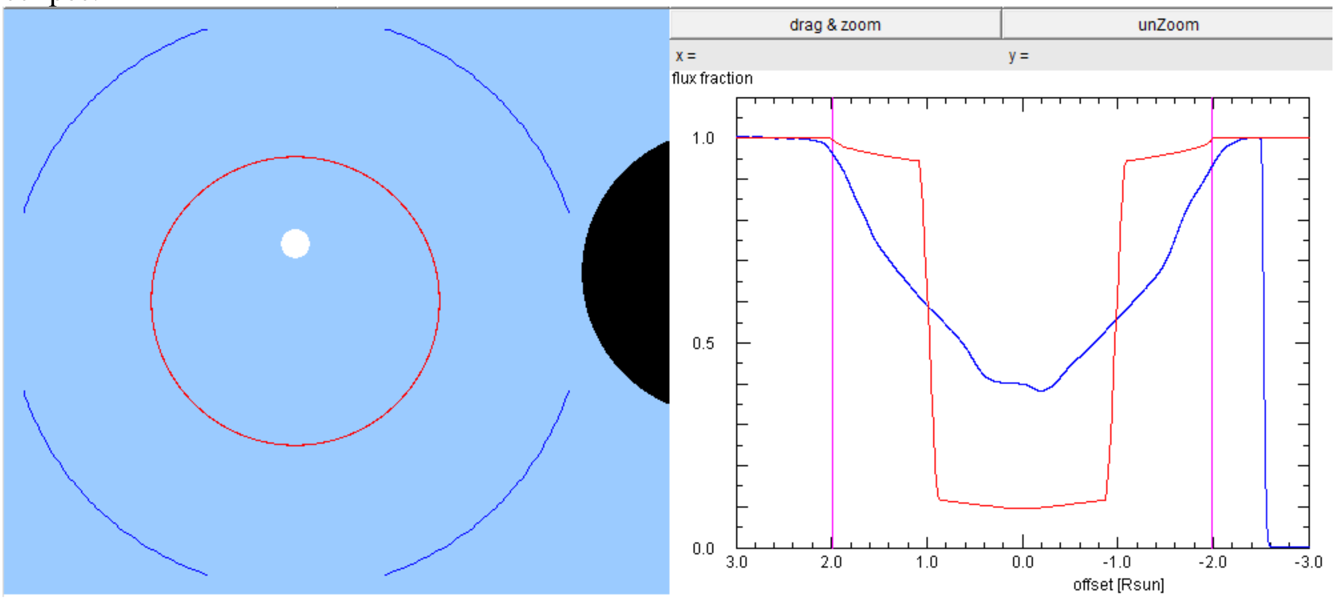

Fig. 11 *Effect of a single bright blob in the middle of Zone A*

If the blob is placed in Zone B, the obscuration is shorter (Fig.12). The same outcome results if is is placed in Zone D. It is worth pointing out that if one wanted to produce one of the dips, the emission blob would need to be small and to be placed very accurately at the Moon edge could obscure it only briefly. Thus one may exclude the formation of the dips alone by obscuration of a pair of emissions spots.

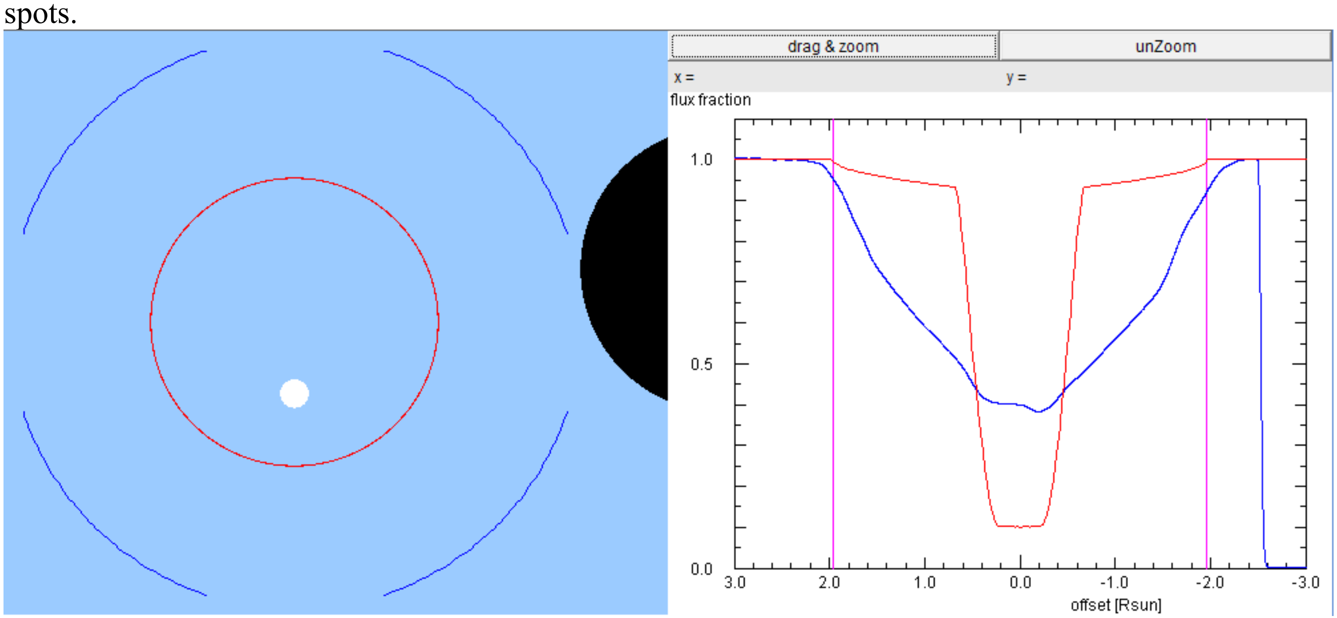

Fig. 12 *As Fig.11, but with the blob in Zone B*

A blob in the Western part of Zone A is obscured early in the eclipse, and will reappear shortly after maximum eclipse (Fig.13). It is worth noting that these times coincide rather well with the left kink in the flank and the kink after the second dip. Similarly, a blob in the Eastern part is left obscured from before the maximum to just before last contact. This could be made to coincide with the kink before the left dip and the right flank's kink. Thus these two features of the light curve have the same origin.

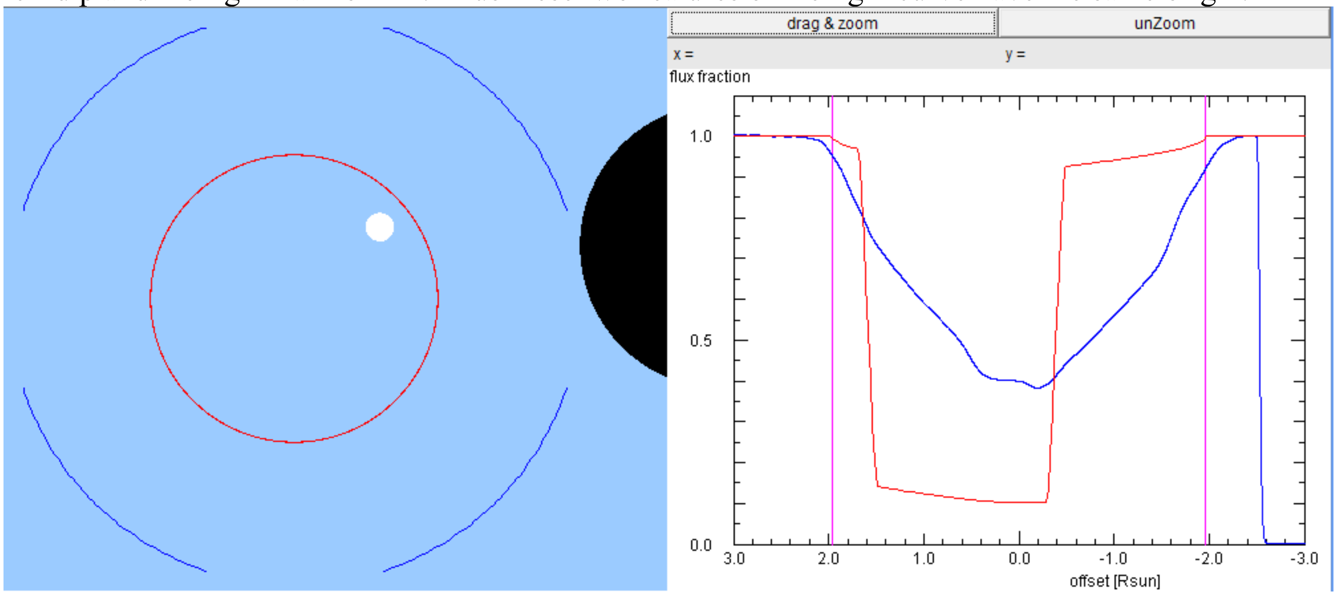

Fig. 13 *As Fig.11, but placing the blob towards the West limb of Zone A*

If the blob is placed in the lower hemisphere, near the border of Zones B and C, the obscuration is short and comes before maximum eclipse: Fig.14.

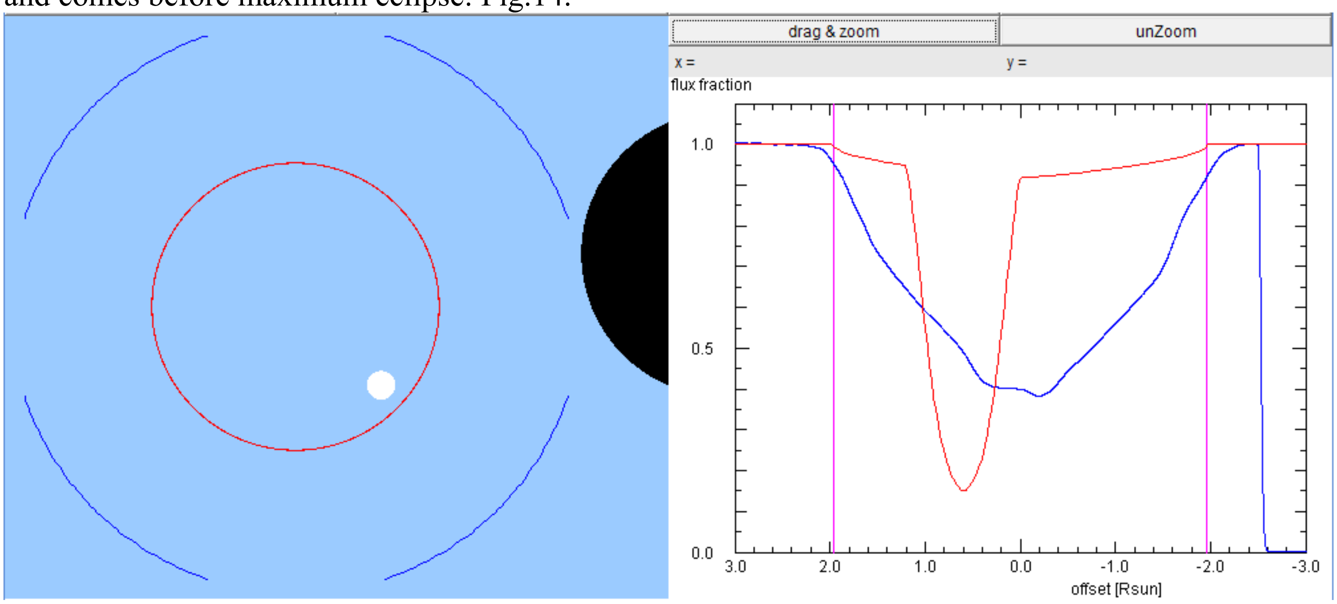

Fig. 14 *As Fig.11, but placing the blob towards the West limb of the border between Zones B and C.*

In an analogous way, a blob in the Eastern part is obscured in the late phase of the eclipse: obscuration starts sometime before maximum and ends just before last contact.

Let us now place two blobs in Zone A, symmetrical to the middle of the disk: As Fig. 15 shows, this configuration produces the two kinks in the flank of the curve, and another deep feature extending about the maximum eclipse. In this simulation there are no other substantial contributors to the emission, so that the curve is a large exaggeration, merely to emphasize the principal effects. Obviously, changing the horizontal positions of the blobs will shift the times when the kinks occur.

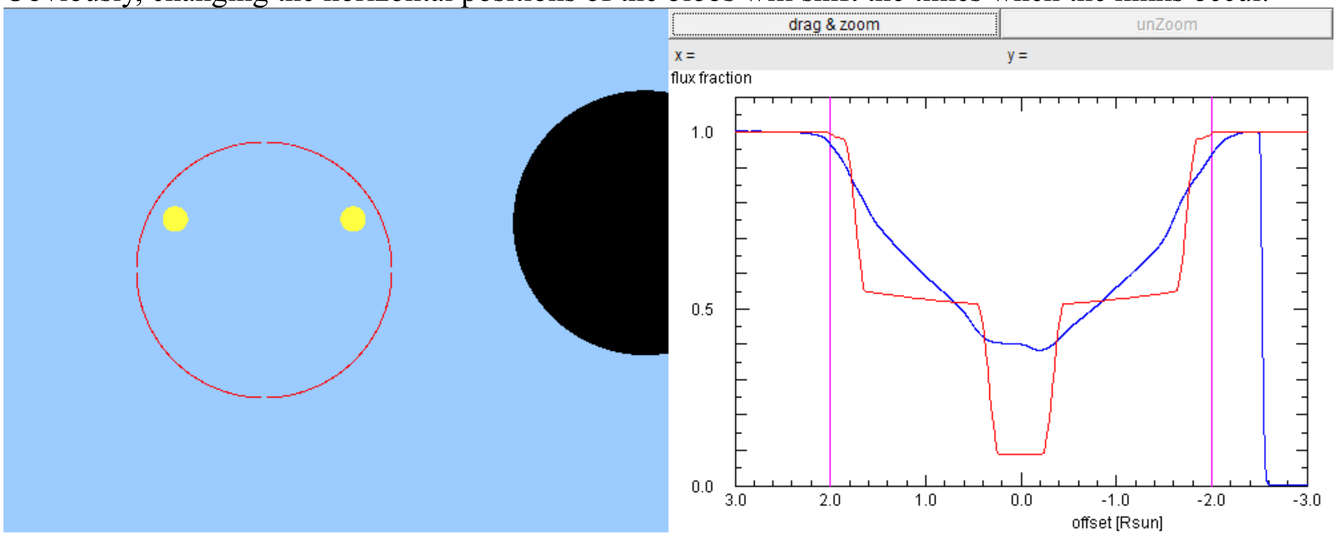

Fig. 15 *Effect of two symmetric blobs in Zone A.*

If the two blobs are placed in Zone B, the central deep dip becomes more narrow (Fig.16). If they are placed even lower, the dip disappears, as both blobs are no longer obscured at the same time.

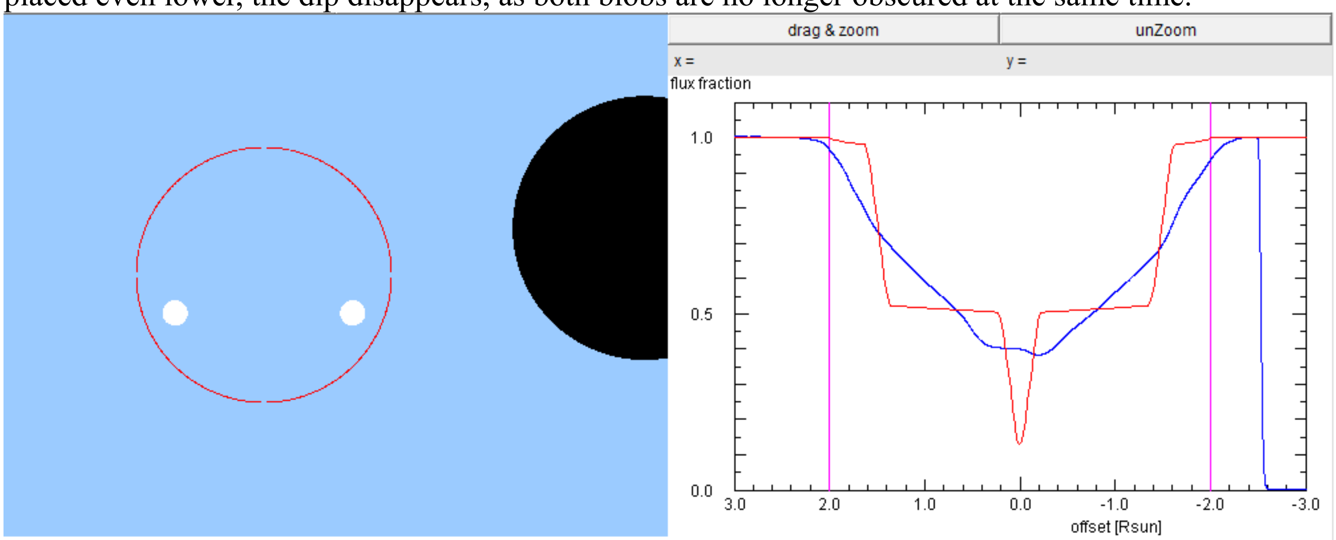

Fig. 16 *As Fig.15, but with both blobs placed so deep that the Moon can obscure both for a short moment at the same time.*

Placing the blobs in the South-East and North-West part of the disk produces – apart from the kinks in the flanks – a central dip just after the maximum eclipse (Fig.17).

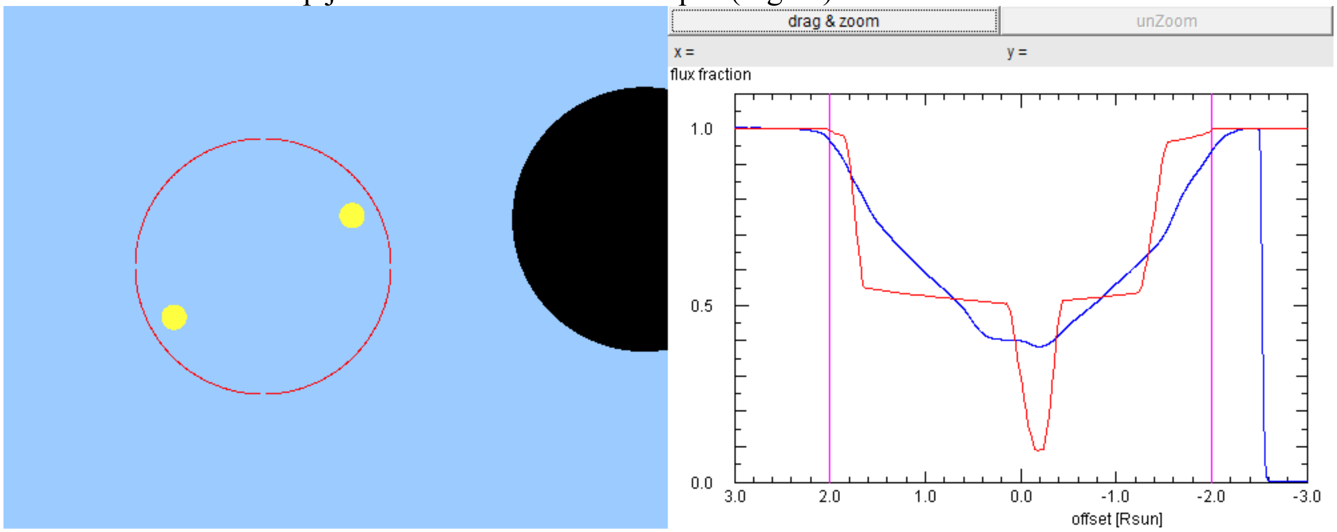

Fig. 17 *As Fig.15 but with the blobs in opposite hemispheres.*

Since the Western blob is in Zone A, its vertical position can be changed liberally without making any influence on the curve, because it is obscured by the Moon's broad East limb (Fig.18).

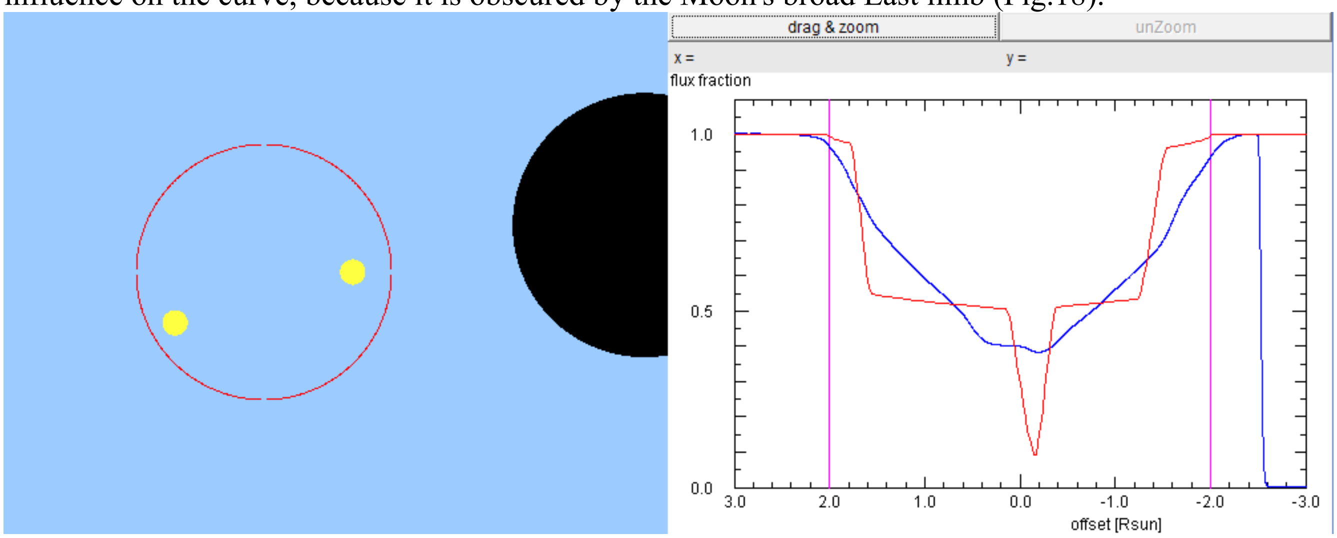

Fig. 18 *As Fig.17, but with the Western blob placed on the equator.*

So far, all other contributions to the emission had been suppressed. Adding the emission from the interior of the solar disk softens and weakens the influence of the obscuration of the blobs, and the curve becomes quite similar to what is observed. Note that the asymmetry of the central dip is already well apparent.

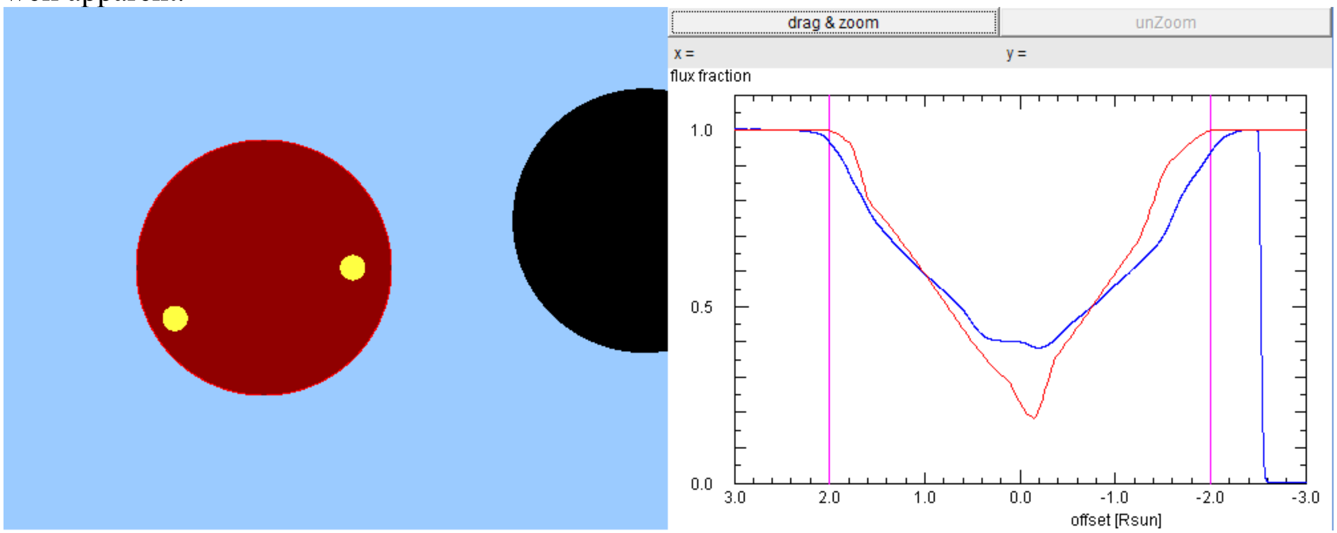

Fig. 19 *Adding the emission from the solar disk to the model of Fig.17.*

Increasing the disk brightness deepens the curve at maximum, as the obscuration of the disk comes into play.. However, this does not bring together simulated and observed curves. It turns out that adding a ring-like contribution is more helpful, as shown in Fig.20.

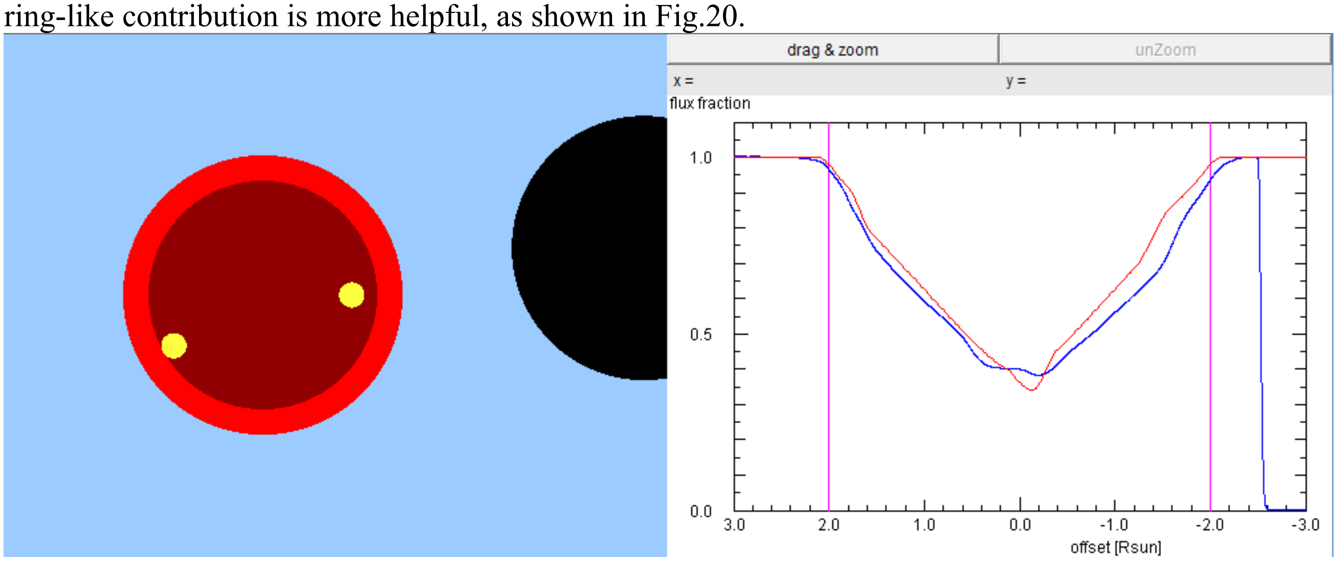

Fig. 20 *The model of Fig.19 with an additional ring-like emission.*

Further improvement is achiever by adding a third blob, in the North-East part, which deepens the first dip, because it is obscured before the maximum eclipse. The model with the assumed parameters is displayed in Fig.21. It should be emphasized that because this third blob is in Zone A, its vertical position is not well constrained.: it may be placed anywhere between the Northern limb and the equator without upsetting the fit! In this model all three blobs have the same surface brightness. Changing these values does influence the result somewhat, but the character of the curve remains the same.

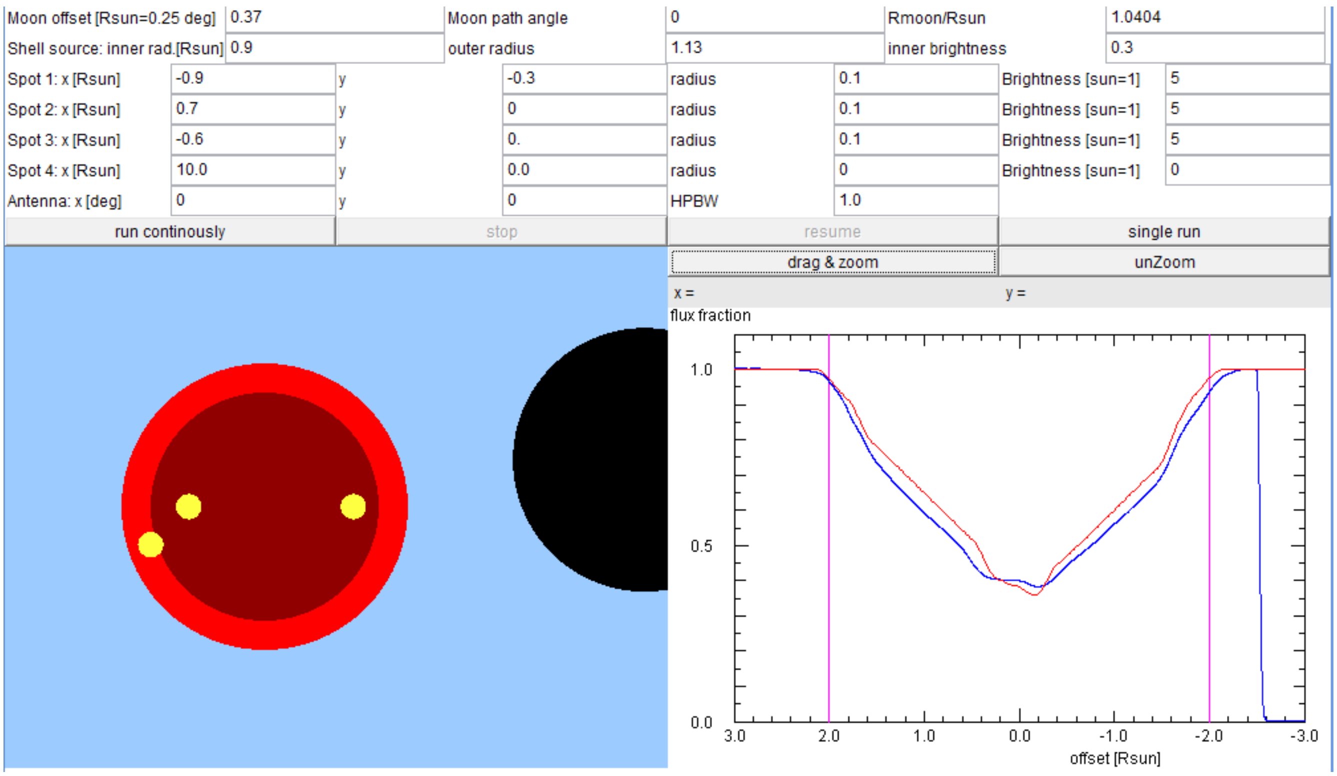

Fig. 21 *The model obtained by adding a ring-like emission to the model of Fig.20.*

Data from RATAN-600

The eclipse is observed by the RATAN-600 radio telescope in the Caucasus Mountains. Figure 22 gives the relevant data.

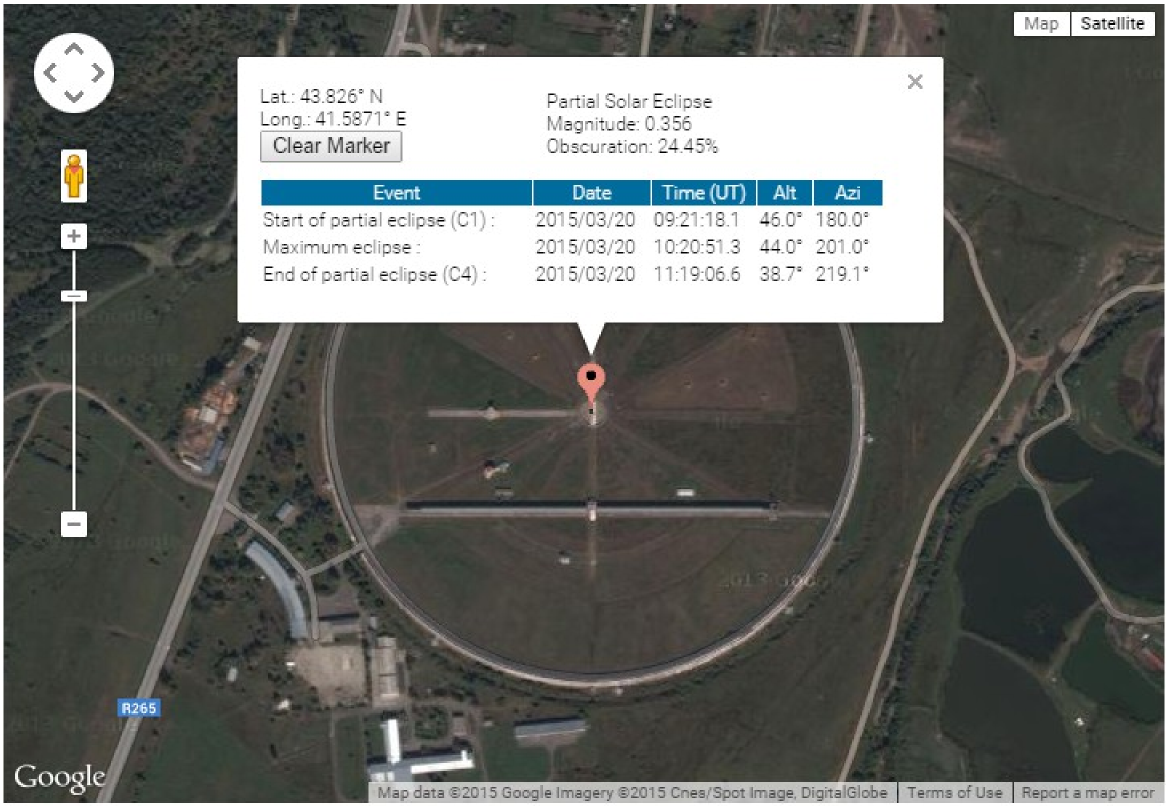

Fig. 22 *GoogleEarth map of the RATAN-600 radio telescope with the data for the eclipse.*
(from http://eclipse.gsfc.nasa.gov/SEgoogle/SEgoogle2001/SE2015Mar20Tgoogle.html*)*

The eclipse is observed on frequencies between 3 and 18 GHz. The data is presented in a graphical animation at http://www.sao.ru/Doc-en/SciNews/2015/eclipse2015/. If one takes the 3 GHz data for a an indication of the situation on 1.4 GHz, one may conclude:

Before the eclipse (Fig.22)

- there is emission by the disk
- The limbs are brightened by a component which extends further inward
- There are three bright spots:
  - Blob-300 is the weakest, in the East central part of the disk.
  - Blob-900 is a stronger one, very close to the East limb
  - Blob+700 is on the Western side

Figure 23 shows that the Western limb emission and Blob+700 are not affected by the Moon's obscuration of the disk component. However, Blob-300 starts getting covered by the Moon's disk at about UT 10:17. This obscuration lasts until about UT 11:05 (Fig.26), after the Western limb recovered its initial brightness at UT 10:40 (Fig.25).

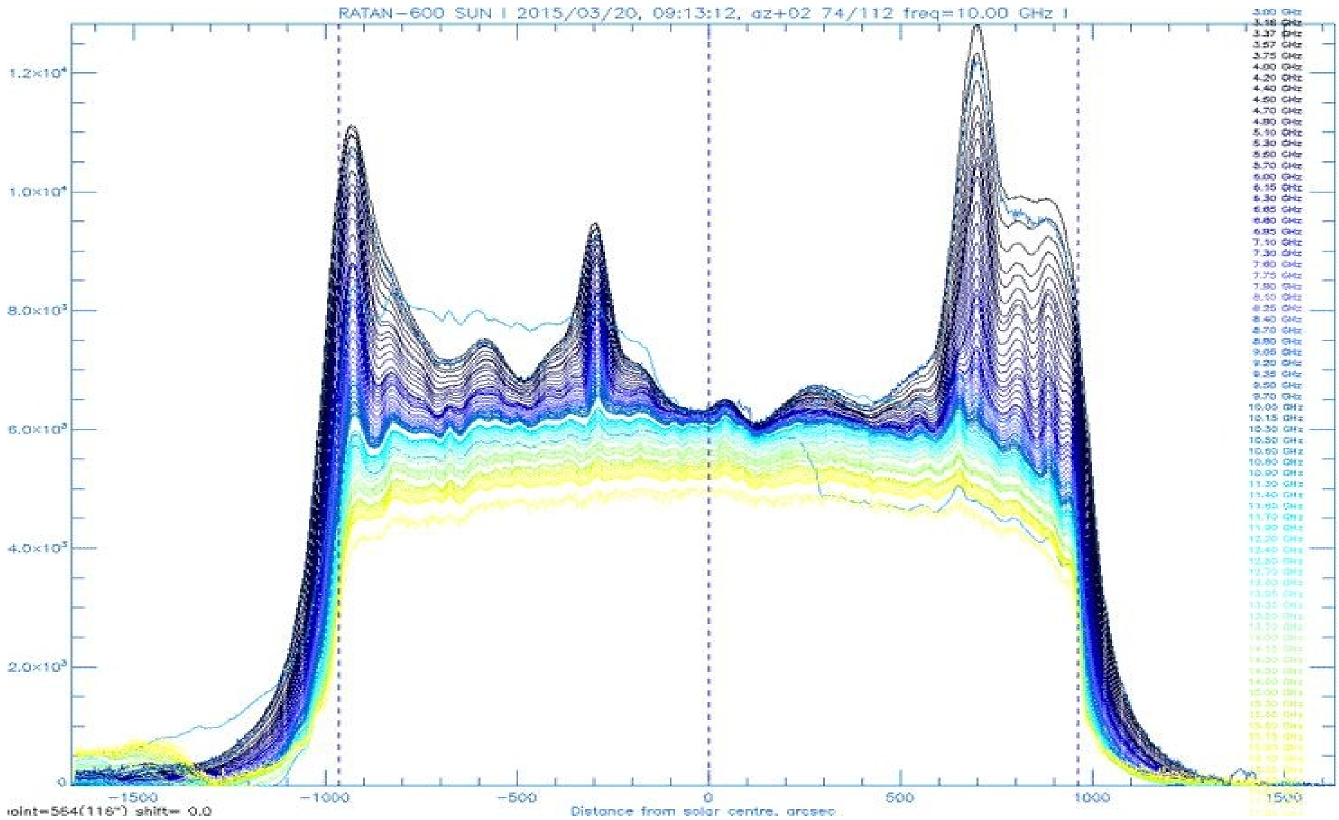

Fig. 22 *Scans of the solar disk between 3 GHz (black) and 18 GHz (yellow) from the RATAN-600 telescope: At UT 09:13:12, before first contact.*

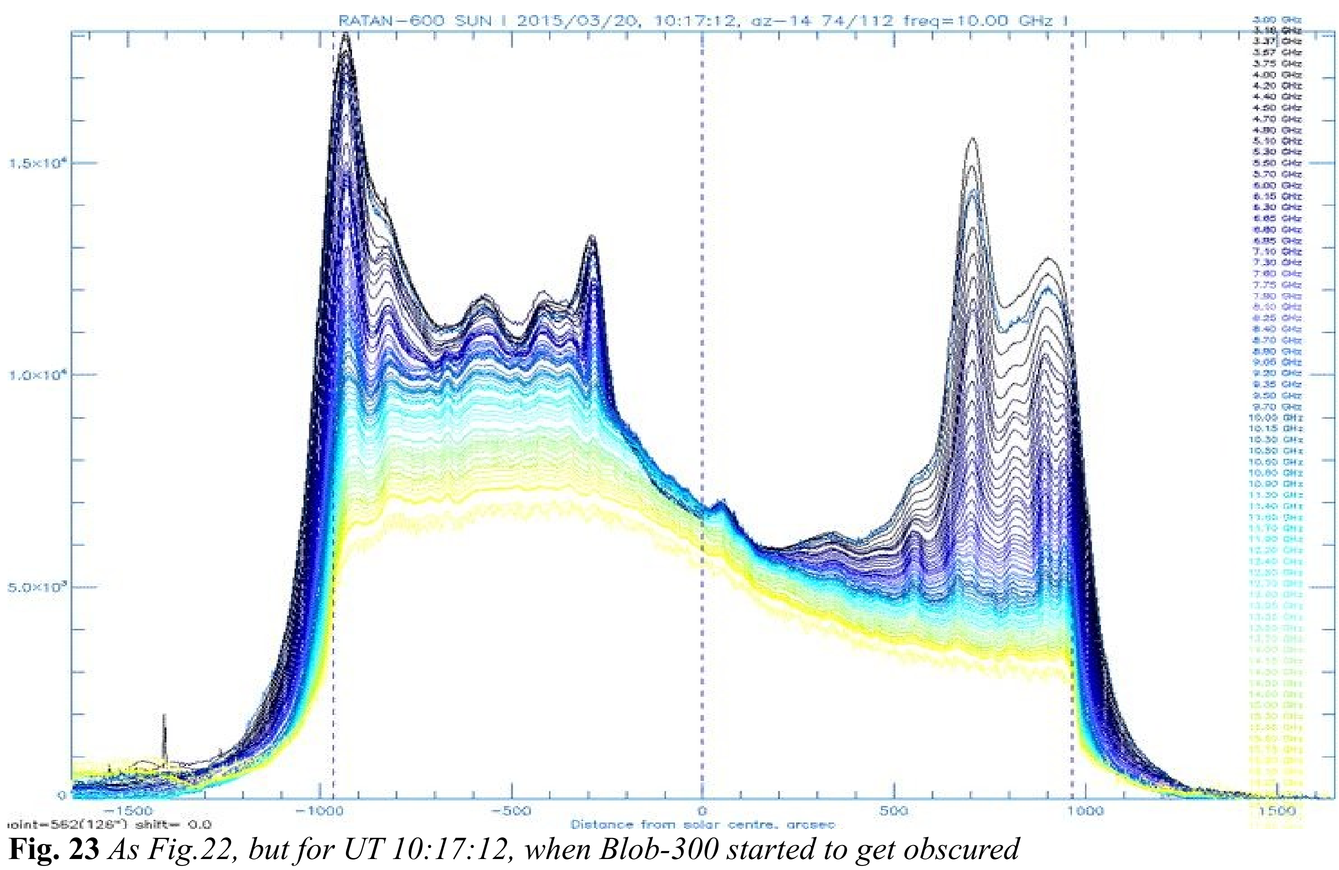

Fig. 23 *As Fig.22, but for UT 10:17:12, when Blob-300 started to get obscured*

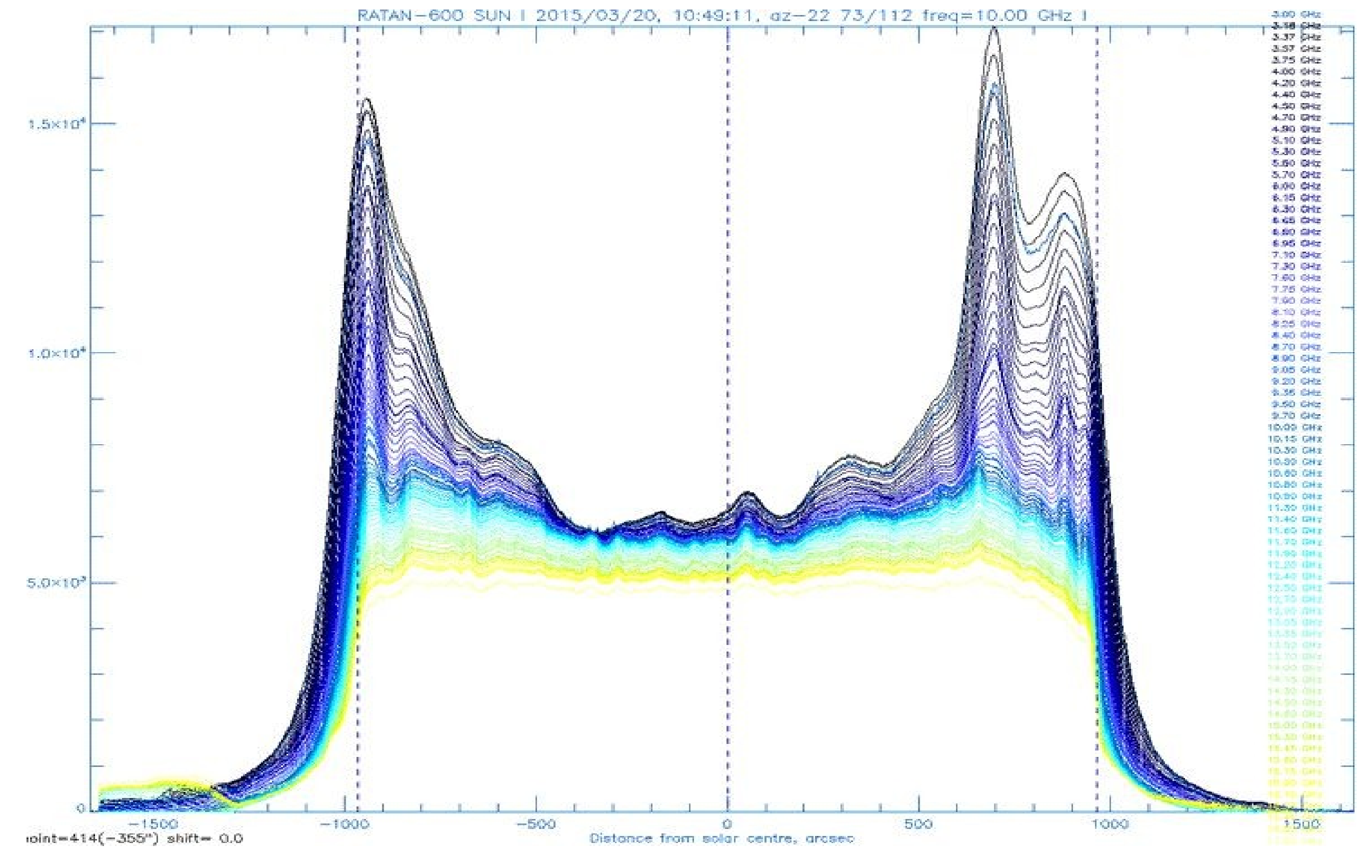

Fig. 24 *As Fig.22, but for UT 10:40:11 when the Western limb had become bright again.*

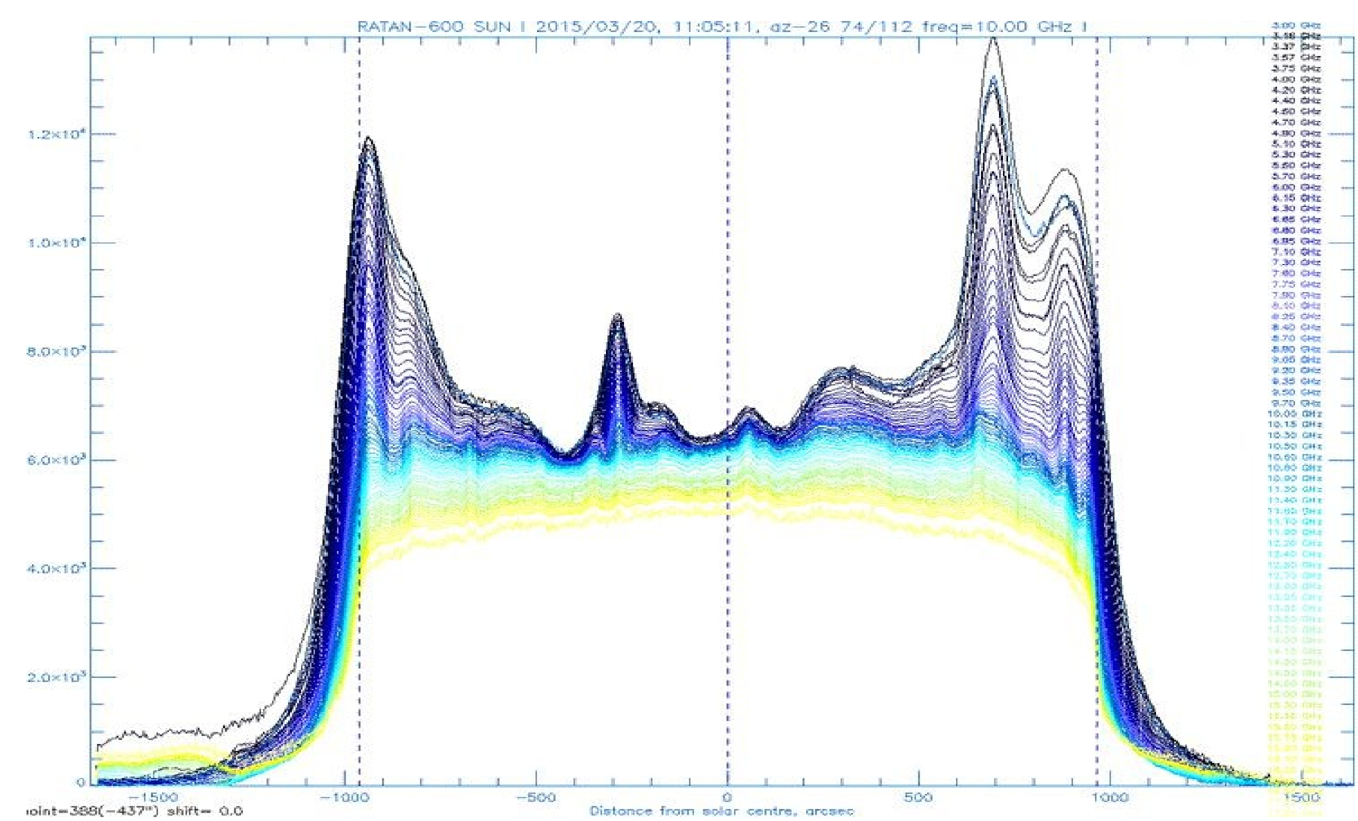

Fig. 25 *As Fig.22, but at UT 11:05:11 when Blob-300 emerged the obscuration*

Modeling the eclipse allows to identify possible position for the three blobs (Fig. 27). Since the obscuration of Blob-300 is relatively short, it must be rather close to the border of the region that the Moon obscured. For the other blobs a range of positions is possible.

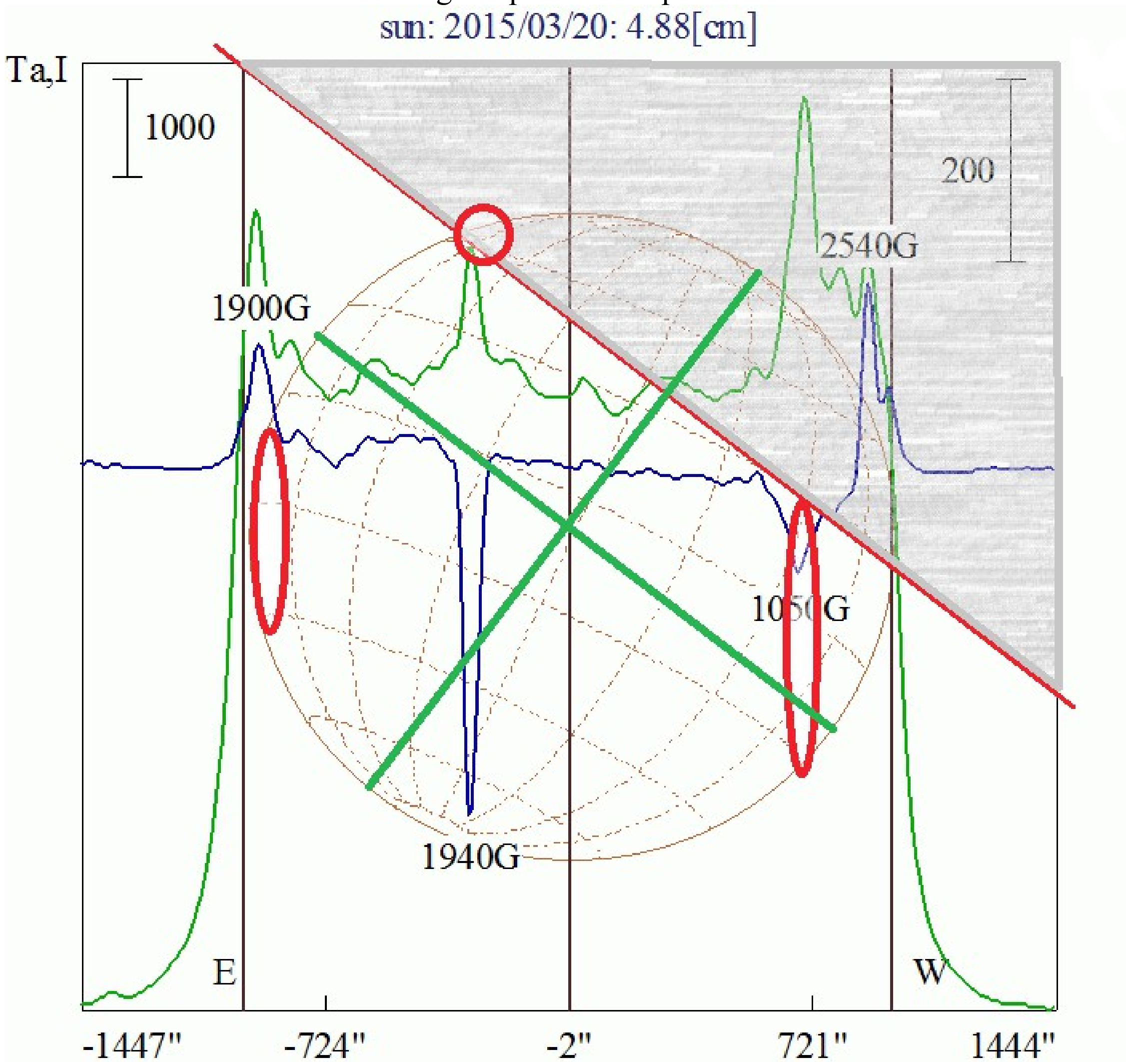

Fig. 27 *RATAN-600 observations of the magnetic flied after the eclipse (blue and green curves), superimposed on the Sun's coordinates. The gray area indicates the region which the Moon's disk covered during the eclipse. Red ovals indicate possible locations for the three emission blobs. The green lines mark the diameters parallel and perpendicular to the Moon's movement.*

From these constraints on the blobs' positions the model for the eclipse, as seen from DL0SHF, can be constructed. For Blob+700 a position in the Southern part of its permissible region and close to the limb can be excluded. With the deduced position, a suitable choice for the brightness of the disk component and the thickness of the coronal ring, along with some slight adjustments of positions and brightness of the blobs, a rather satisfactory match of the observed curve is achieved (Fig.28).
The assumptions of a simple geometry with sharp borders and a uniform surface brightness already allow it to reproduce the features of the observed curve quite well.

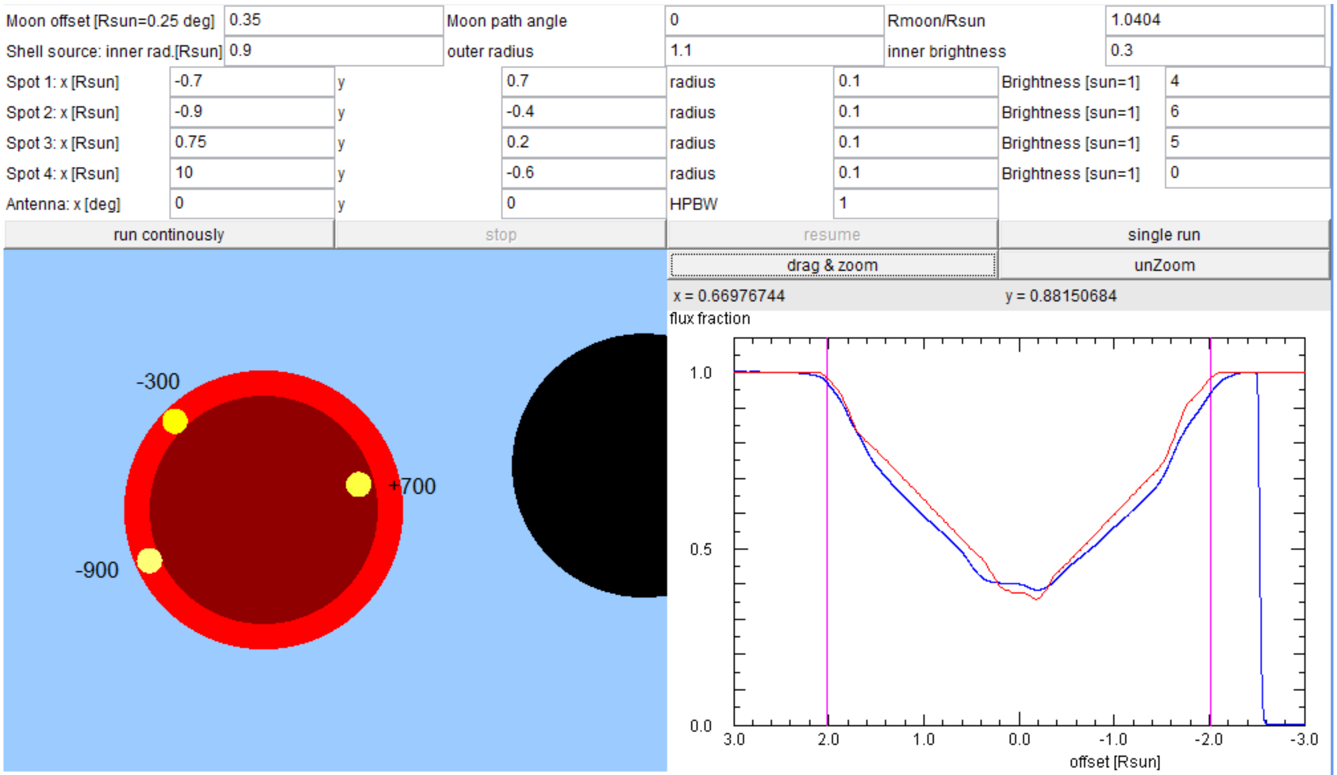

Fig. 28 *The modeling of the eclipse data of DL0SHF on 1.4 GHz, using the positions of the three emission blobs deduced from the RATAN-600 observations.*

References

- G.A.Dulk, D.E.Gary, 1983, *The Sun at 1.4 GHz: intensity and polarization,* Astronomy & Astrophysics, **124,** 103
- S.F.Smerd, 1950, *Radio-frequency radiation from the quiet Sun*, Australian Journal of Science Research, **A3**, 34
- http://eclipse.gsfc.nasa.gov/SEgoogle/SEgoogle2001/SE2015Mar20Tgoogle.html GoogleMap tool to find eclipse details for any location
- http://www.sao.ru/Doc-en/SciNews/2015/eclipse2015/ animated graphical presentation of the eclipse data taken by the RATAN-600 telescope