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THE APRIL 8, 2005, ECLIPSE WHITE-LIGHT CORONA

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Abstract. The hybrid solar eclipse of April 8, 2005, provided a good opportunity to observe the white-light solar corona, even though the eclipse lasted just 30 seconds and could be seen only from ships in the Pacific Ocean. During the eclipse, we detected a unique 'cloud' of particles in the white-light corona above the west limb $\approx 260^\circ - 270^\circ$. We compare this feature with EUV images from SOHO. The feature's density and temperature seem comparable to a coronal condensation, and, like a coronal condensation, it is connected to the emergence of material from the solar surface without a flare. However, the morphology of the feature shows clear differences from a classical coronal condensation.

1. Introduction

It has been known for a long time that the shape of the white-light corona reflects the distribution of both large- and small-scale magnetic fields on the solar surface (summarized, for example, in Pasachoff and Golub, 1997). During solar eclipses, observations of the white-light solar corona allow us to fill in missing data (observations of the corona within two radii of the Sun) that cannot be obtained with LASCO/SOHO. In this paper, we present both the ground-based and SOHO observations of the solar corona for the eclipse day, especially its processed and combined structure to several solar radii and an interesting unique 'cloud' of particles observed above the west solar limb.

2. Observations

The hybrid (partially total and partially annular) solar eclipse that occurred on April 8, 2005, achieved totality only in the middle of the Pacific Ocean, far from any continents or islands (maps are available at *http://www.eclipses.info*). Several astronomers took advantage of commercial eclipse expeditions to observe the eclipse. Astronomers were on board the ships *Galápagos Legend*, *Paul Gauguin*, and *World Discoverer*. Unfortunately, clouds that ended at the *Paul Gauguin* just as the eclipse began prevented cameras on our gyro platform from acquiring data, so we will deal only with data from the other ships. Their positions and eclipse durations are as follows.

Galápagos Legend Data
Position: longitude – 109°30.0′ W, latitude – 1°19.35′ S, elevation: ∼10 m for the deck; second contact: 21:15:06.2 UT, third contact: 21:15:38.7 UT.
Predicted duration (F. Espenak, private communication), without accounting for the diamond rings: 32.5 seconds.
World Discoverer
Position: longitude – 129°38.67′ W, latitude – 22°37.19′ S, elevation: ∼10 – 15 m for the deck; second contact: 19:51:19 UT, third contact: 19:51:52 UT.

The following equipment was used to take pictures of the solar corona:
Galápagos Legend:
Zeiss 8/500 mm telephoto lens, Canon EOS 3000, Fujicolor 800
Nikon 500 mm f/8 telephoto lens; Nikon F4, Fujicolor 800
Nikon 80 – 400 mm f/5.6 VR (vibration reduction) zoom lens at 400 mm; Nikon F5; Fujicolor 800, Kenyon Labs KS-6 gyro
World Discoverer:
Canon zoom lens EF 100 – 400 mm at 400 mm, Canon EOS 1d Mark II digital camera
Maksutov-Cassegrain MC 3M-5CA lens, Canon EOS 300X, Fujicolor 800.

Though the engines were shut off for totality, the ships still rocked with a period of ≈10 s, making it feasible to use only lenses with focal lengths up to 500 mm. The eclipse images we obtained were scanned and reduced by one of us (M.D.) to yield the best possible display resolution; Druckmüller's method of coronal image processing, in detail, is currently under review (Druckmüller, Rušin, and Minarovjech, 2006).

Though SOHO's instruments observed the sun, including its limb, before, during, and after totality, TRACE was pointed on the solar disk and so did not provide data that overlap with the images presented here.

3. Results

Aboard the *Galápagos Legend*, totality was measured to be 29.5 ± 1 seconds (F. Bruenjes, private communication (*www.moonglow.net*)); the *World Discoverer* saw 33.0 ± 1 seconds of totality. Though we were limited to the focal lengths described earlier, a new image processing method enabled us to study the white-light corona in detail over a wide luminosity range, and thus to see detail at a distance of several solar radii (*http://www.zam.fme.vutbr.cz/∼druck*). The method was described at the Solar Eclipse Meeting held at Milton Keynes by Druckmüller and Rušin (2004) and automates many steps that had previously been applied step by step (*http://www.wendycarlos.com*; *http://www.williams.edu/astronomy/eclipse* for 1998 and 1999).

A composite image (*World Discoverer* and *Galápagos Legend*) of the corona is shown in Figure 1. The corona is visible up to at least three solar radii from the limb. North is up, east is left.

Other than the feature boxed in Figure 2, there are several other phenomena worth mentioning. The white-light corona shows the well-developed polar rays typically seen near the minimum of the sunspot cycle (Golub and Pasachoff, 1997, 2001; Rušin, 2005) which we would expect as the minimum between cycles 23 and 24 is predicted to be in mid 2007.5 (Rybanský, Minarovjech, and Rušin, 2003). The apparent diameters of the Sun and Moon were almost the same during totality (which is what made this eclipse a hybrid). As a result, the chromosphere could be clearly seen throughout the eclipse around a large fraction of the solar rim, thus allowing us to observe several small prominences surrounded by coronal cavities.

Figure 1. The image-processed white-light corona on April 8, 2005. The image is a combination of 40 images taken on board *World Discoverer* and *Galápagos Legend* by all the authors.

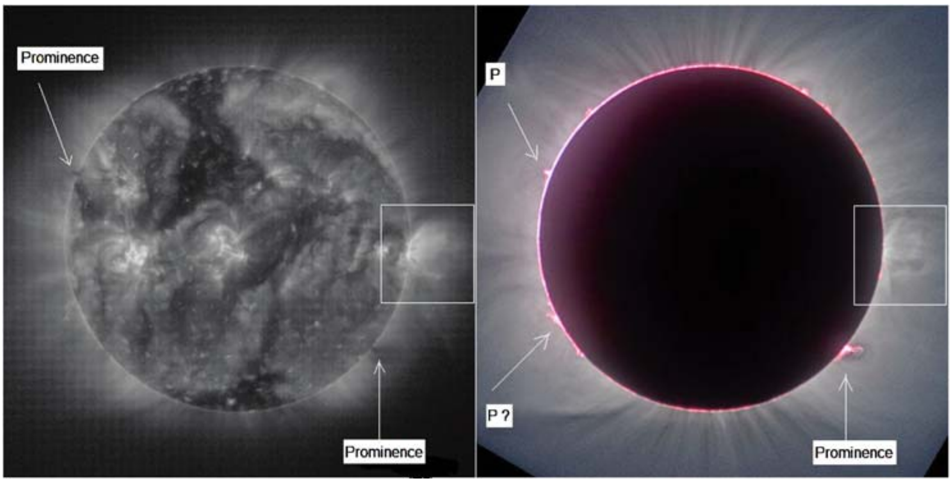

Figure 2. The SOHO 195 Å (Fe XII) EUV corona (*left*), and our image-processed inner white-light corona (*right*), both from April 8, 2005. *Boxes* indicate a space in the corona where a prominent feature, to be discussed in detail below, was detected. The letter *P* indicates prominences, which are *red* in the white-light corona and *dark* in the EUV corona. North is up.

The most interesting feature is seen boxed in the right-hand part of both of the images in Figure 2, at a position angle of $\approx 260^\circ - 270^\circ$. The feature is relatively highly structured and bright in comparison with its surroundings. As experienced observers of the eclipse corona, we could say that this irregular feature is not a classical coronal condensation as described by, i.e., Waldmeier (1963a,b) and Saito and Billings (1964). According to their conclusions, the coronal condensation observed during the February 5, 1962, eclipse was structureless (like a “white prominence”) with a density of 10^{10} cm^{-3} and temperature of $(2-4) \times 10^6$ K. Generally, coronal condensations are connected with highly developed sunspot groups. They are also a source of X-ray emission, radio emission, and 569.4-nm emission.

Unlike a classical coronal condensation, the feature in our images is relatively large, has a complex structure, and is located around a *small* sunspot group. However, the feature is relatively bright, so it must be as dense and hot as the surrounding corona. This differentiates our feature from prominences, which have a low temperature in comparison with the solar corona, resulting in red Hα emission, which we have not found. We have never seen nor heard reports of a feature like the one we have observed.

4. Comparison with SOHO Data

We compared our eclipse results with the data from several SOHO telescopes/instruments. The Sun in Hα (Figure 3), observed from Big Bear Solar

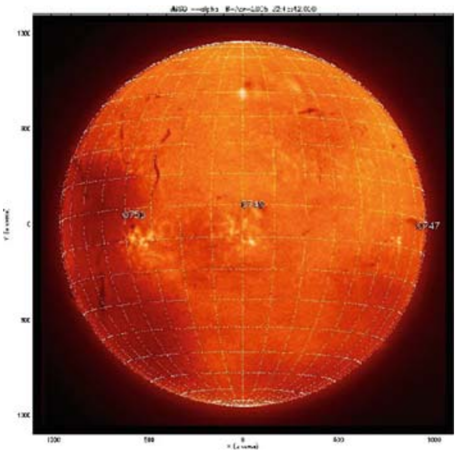

Figure 3. The Sun in Hα (Big Bear Solar Observatory/New Jersey Institute of Technology).

Observatory, was relatively quiescent. Three sunspot groups were observed. One of them, AO 0747, was very close to the west limb, near the coronal feature. No prominences were seen nearby. The Sun in the He II line (304 Å), observed from the Extreme-ultraviolet Imaging Telescope (EIT) on SOHO, is shown in Figure 4a and b. An eruptive prominence appeared above AO 0747 at 13:19 UT, yet it is absent at 21:19 UT, close to eclipse time at the *Galápagos Legend*. Above AO 0747 are bright plages that are connected to the corona (the connection is seen as small bright regions in Figure 4a). The second He 304 Å image (Figure 4b) shows a very thin bright plage at the solar limb as well as a faint feature in the corona. This material of the feature, which is especially bright in the EIT observations at

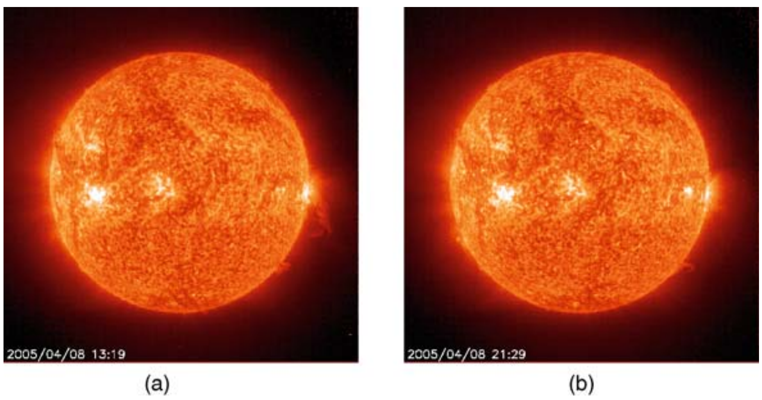

Figure 4. (a and b) The Sun in He II (304 Å) from EIT on SOHO. (a) 13:19 UT, about 6 h before the eclipse. (b) 21:29:23 UT, close to eclipse time (EIT images from NASA/GSFC and ESA).

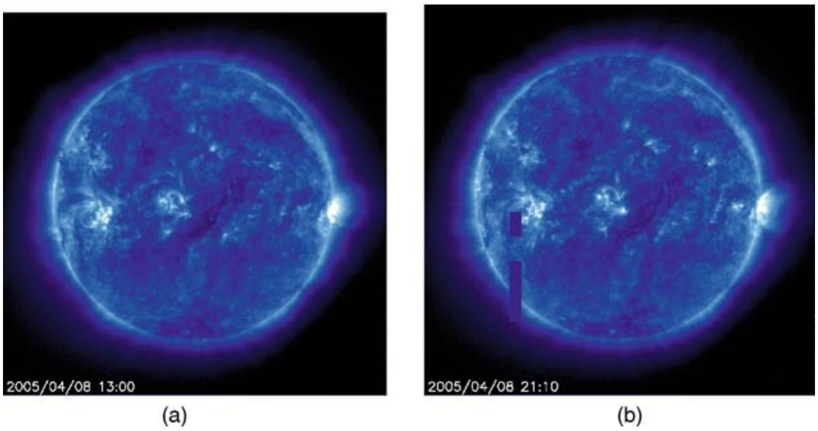

Figure 5. (a and b) The 171 Å EUV (Fe IX/Fe X; 1 million K) solar corona from EIT on SOHO. (a) 13:55 UT, about 6 h before eclipse time. (b) 21:10 UT, shortly before eclipse time at the *Galápagos Legend* and 01:20 UT after the *World Discoverer* observations (EIT images from NASA/GSFC and ESA).

coronal temperatures, is hot, of coronal temperatures, not cool, of chromospheric temperatures.

A similar time sequence for the EUV corona as for the He II Sun was obtained by EIT in the 171 Å line (Figure 5a and b). In these, the feature is seen as a very bright, nearly compact system of thin loops above AO 0747. The loops become significantly less dense as they move away from the solar limb. A very bright knot can also be seen in the southern part of the feature, which seems to correspond to a similar knot in the He II solar image from 13:19. The 171 Å EUV Sun at 21:10 shows some splitting of the dense compact loops in the northern part of the feature. However, there are no other large differences observed in general, except for the height and general appearance of the feature.

Figure 6 shows the EUV corona in the 284 Å line. The core of the feature is relatively compact and bright, reaching a height of 52 000 – 56 000 km above the solar limb. The outer part of the feature consists of many individual thin loops with differing heights and inclinations to the line of sight. Some of the loops reached heights above the Sun of 210 000 – 220 000 km. Again, the outer loops are much less dense, especially in the southern part of the feature.

Separate and composite images of the [Fe XII] 195 Å and white-light coronas are shown in Figure 7. These images show that the feature under study is not identical in EUV 195 Å and in white light; still the resemblance is very close. Loops are seen in the white-light corona as well, forming the northern border of the feature. The biggest difference is in the southern part of the feature, where in the white-light image two dark bubbles (cavities) are seen, separated by a fine white-light loop. The thin dark areas in the 195 Å EUV feature nearly correspond to small prominences or macrospicules seen in the white-light corona in red Hα.

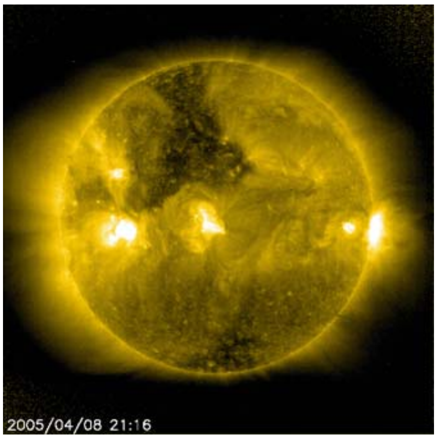

Figure 6. The 284 Å (Fe XV; 2–2.5 million K) corona from the EIT on SOHO (EIT images from NASA/GSFC and ESA).

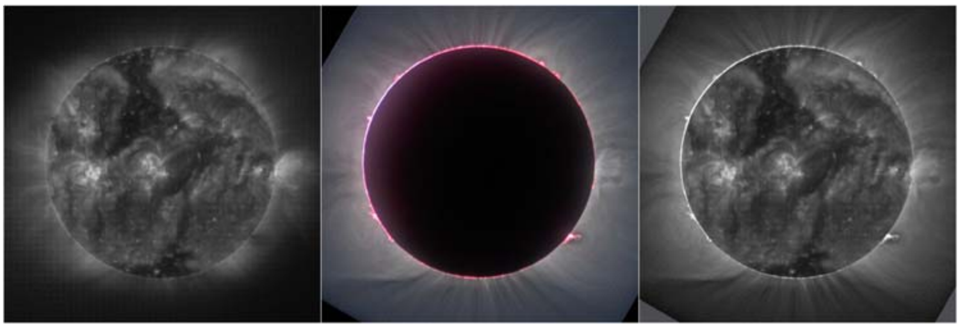

Figure 7. The EUV 195 Å (*left*: Fe XII; 1.5 million K), the white-light corona (*middle*), and a composite of the EUV 195 Å Sun and the white-light corona (*right*) (EIT images from NASA/GSFC and ESA).

The 195 Å (Figure 2, left) and 284 Å corona (Figure 6) show two very dark filaments above the NE and SW limbs that are cool prominences. These prominences show readily on the white-light eclipse observations. Comparing the eclipse images (and these prominences) with the EIT/SOHO images allowed us to orient the eclipse and space observations highly precisely.

The white-light corona was stable, as the bright helmet streamer seen above the feature (with the SOHO C2 coronagraph) retained the same shape for at least 4 h, from 19:55 to 23:50. To reach the observed height, the minimum velocity of the ejected material should have been $50\,\mathrm{km\,s^{-1}}$. Such a velocity is high for coronal motions. The processed and combined white-light corona, from both SOHO and ground-based, for the April 8, 2005, eclipse is shown in Figure 8.

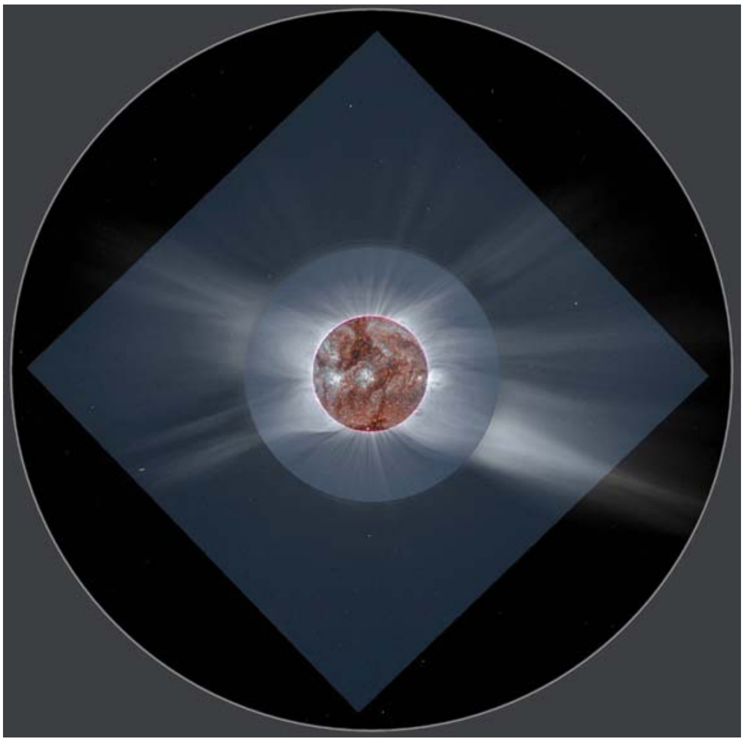

Figure 8. The processed white-light corona on April 8, 2005, combined with SOHO data (EIT and LASCO data from NASA/GSFC, NRL, and ESA). Observation times for space-borne SOHO images: LASCO C2, 19:49:55 UT; He II (304 Å), 21:29:23 UT; Fe XII (195 Å), 19:48:11 UT.

5. Conclusions

From the ships in the Pacific Ocean, we observed a unique white-light coronal feature during the total solar eclipse of April 8, 2005. It is not a classical coronal condensation as described by Waldmeier (1963a,b) and Saito and Billings (1964), nor a coronal mass ejection. A comparison of eclipse observations with several SOHO images of the EUV corona at different wavelengths shows very close connections between the white-light feature and the feature seen in the EUV corona. We conclude that the eclipse feature, which we could call an 'exceptional/special condensation,' or 'brightening,' is connected with a quiescent active region that has well-developed plages above it. Probably, the white-light 'coronal condensation,' as observed during total solar eclipses, is actually a complex of thin coronal loops.

Some other conclusions from the comparison between the white-light and EUV coronas are as follows:

(a) The EUV corona has almost the same structure as the white-light corona. Some coronal structures are better seen in the white light than in EUV, e.g., some loops.

Because the eclipse was visible only from the mid-Pacific, the variety of images obtained was very limited. We have no other high-resolution coronal forbidden-line images at our disposal, so at this stage we cannot decide what portion of the radiation from the studied coronal "brightenings" comes from emission lines (such as the green line, Fe XIV), EUV-permitted lines, or from continuum.

(b) The positions of prominences in both observations can be easily recognized, except for the very bright prominence located in the SE of the white-light image. A possible explanation of this peculiarity is that the prominence observed in the white-light corona had such a short duration that it was not visible at the different time of the SOHO observation. The time shift between these images (see Figure 2) is 1 h and 26 minutes.

(c) The edge of the helmet streamer (see Figure 8) is located at the border of a coronal hole, indicating the shape of the open magnetic field lines there.

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