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IS IT WORTH RE-DOING THE EDDINGTON EXPERIMENT? - A FEASIBILITY ASSESSMENT AT SOLAR ECLIPSES 2005-2006 IN LIBYA

JEAN-LUC L. J. DIGHAYE
EurAstro Association, Helfendorfer Str. 7/4, D-81671 Munich, Germany

Abstract. We describe an experimental set-up, comprising a full-frame digital single-lens reflex camera and an apochromat refractor, for measuring light bending using stars at the time of the annular solar eclipse of 2005 and the total solar eclipse of 2006 in Libya. We identify data reduction problems, and we propose further experiments. We ask for volunteers who could assist us in reducing the data.

Key words: Eddington, general relativity, solar eclipse

1. Introduction

In 1919, Sir Arthur Eddington attempted to measure the bending of the light emanating from stars situated in the background of the totally eclipsed Sun (Eddington, 1920), as foreseen by Einstein's newly discovered theory of general relativity. Results were somewhat controversial (von Mettenheim, 1996); however, they generally supported Einstein's theory. The bending effect, though, is tiny - it amounts to 1.75 arcsec at the solar limb, and it decreases as the inverse of the apparent distance of the star to the Sun's centre - and Eddington's set-up suffered from several error sources, one of them being the lack of temporal stability of the photographic plates used back them. The errors could only be mitigated by choosing a long focal length telescope, which in turn was rendered possible by the presence of many bright stars, belonging to the Hyades cluster, in the vicinity of the eclipsed Sun.

There have been few successful attempts to repeat Eddington's experiment since then. One example was the expedition to the eclipse of 30 June 1973 by the Texas Mauritanian Eclipse Team (Brune *et al.*, 1976; Jones, 1976). Heavy dedicated equipment was mandatory. Now, with large electronic detectors becoming available to amateur astrophotographers, it would be interesting to assess whether the inherent better stability of those detectors, together with the ease of data processing, would yield meaningful results of star displacements if the experiment would be re-done using telescopes of modest focal length. This should be considered as a technical achievement rather than further evidence towards Einstein's theory, now widely accepted, and for which much more accurate tests exist.

2. Location

In order to compare the disturbed positions of the stars (i.e. during the eclipse) with the undisturbed ones, the reference star field should be imaged during the night, under conditions as close as possible to those of the eclipse, comprising:

- same height and orientation in the star field in the sky;
- same temperature and atmospheric pressure.

The first condition implies that the reference images should be taken from the same place as the eclipse field (or from an equivalent place of comparable latitude and elevation); a time separation of approximately 6 months between reference images and total eclipse is preferred, so that the reference field can be imaged in the middle of the night.

There is a fortuitous opportunity in Libya, occurring at the Annular Solar Eclipse (ASE) of 03 October 2005, and the Total Solar Eclipse (TSE) of 29 March 2006. Such eclipses occur at an interval of approximately 6 months, and the respective paths of the ASE and the TSE cross each other in a rather sunny, observation-friendly region of hills and cliffs called Djebel Maaruf. The coordinates of the intersection point are 25.156°N 18.576°E.

Strictly speaking, there is no need for an ASE six months before or after a TSE - reference images do not necessitate an eclipse. However, the present circumstances allow for a preliminary test of the TSE set-up during the ASE.

Libya, at the beginning of October, is warmer than at the end of March, but it is also warmer around the end of the morning - even with an eclipse occurring - than in the late evening. Thus, with some luck, the temperature would not be too different when reference images and eclipse images are taken. However, a calibration in temperature of the set-up is foreseen.

Whereas tour operators could freely organise expeditions to the Libyan desert at the time of the ASE, we were informed that only a few authorised operators would be allowed into restricted places at the time of the TSE. Anticipating such restrictions, the ASE expedition was complemented by a site evaluation in the area of the planned Eclipse-City camp (24.496°N 17.960°E) where the Solar Physics / Solar Eclipse (SPSE) international symposium was intended to be held.

3. Set-up (ASE'05) and error sources

Astrometric reference images were taken both at Eclipse-City and Djebel Maaruf, using:

- a Tele Vue 101/540 four-lens apochromat refractor, hereafter TV;
- a Canon EOS 1Ds Mark II digital single-lens reflex camera (size 24x36 mm, 16.7 megapixels), used at full resolution, raw+jpeg mode, ISO 100, noise reduction on, several images taken at 1/4s, 1s, 4s and 15s exposure times; and
- a Vixen equatorial mount.

Image registrations took place during the nights before 03 October 2005, at the time when the reference field had the same altitude and azimuth as during the upcoming TSE. Due to a power supply shortage, flat fields and dark exposures were taken afterwards, at the approximate midnight temperature in the desert i.e. 25°C, with the camera turned on about 1/4 hour in advance to simulate actual imaging conditions.

The reference star field was unfortunately poor in bright stars, so that a short focal length was used in order to include enough reference stars (see Figure 1), such

as:
- SAO 109297 (7.64 mag) & 109296 (8.02 mag) to the upper left
- SAO 109315 (6.40 mag) & 109278 (7.48 mag; close to the Sun) to the lower left;
- SAO 109206 aka CF Psc (ca. 6.89 mag) to the upper right;
- SAO 109216 (7.17 mag) to the lower right.

(Note: object NGC 128 is assumed to be invisible during TSE'06).

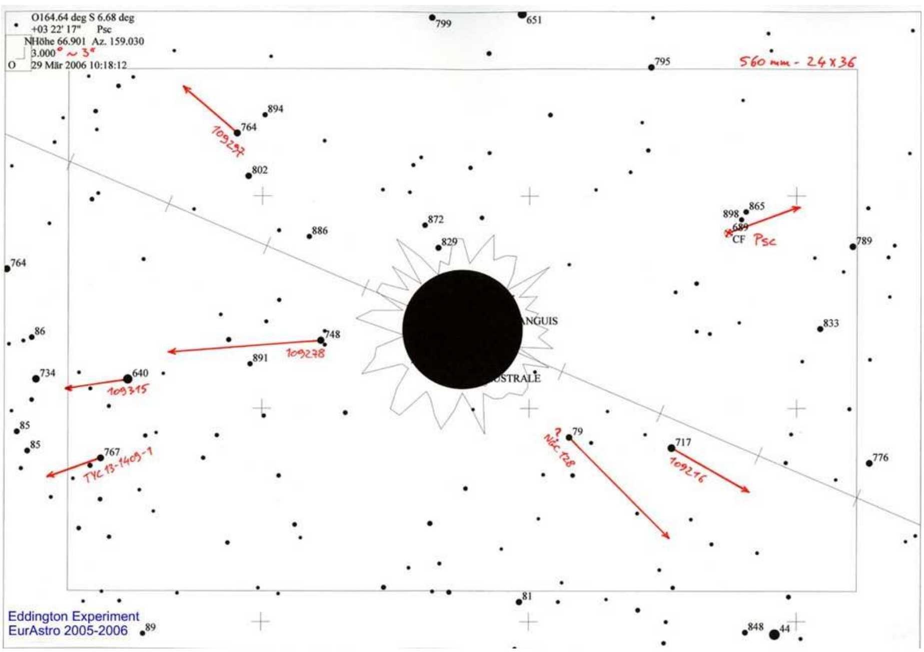

Fig. 1. Reference field showing exaggerated star displacements.

In Figure 1, the separation between vertical cross-hairs is 1 degree, whereas the arrows showing the displacement of some stars have the same scale for 1 arcsec, i.e. they are exaggerated 3600 times. All the displacements are below 1 arcsec, to be compared with the scale of the images which is 2.75 arcsec/pixel. Hence the centroid of the stars must be determined with sub-pixel accuracy, which requires a careful measurement error analysis, including, in addition to the factors envisaged by Jones (1976):

noise reduction: dark fields and flat fields must be acquired; the Canon sensitivity has to be set to ISO 100 which provides the best signal/noise ratio;

correct exposure: bracketing, especially during TSE'06, must be performed so that the pixel counts are sufficient, without saturating the detector. According to Espenak and Anderson (2004), correct exposure for the solar corona between 0.5 to 4 solar radii are comprised between 1/30 and 1/2 s at ISO 100;

distortion control: reference images were taken at several slightly different locations in the sky, so that the field closest to the actual images taken during

TSE'06 could be used; the other images were used too, in order to evaluate the incidence of optical distortion when reference images and eclipse images do not exactly coincide, and the systematic effect of atmospheric refraction;

temperature-induced scale changes: images of further reference star fields, taken at higher and lower temperatures, respectively, could be compared in order to assess the thermal expansion of the optical system (telescope, camera, detector). This need not be done in Libya - any star field being visible at the same place of the sky when such respective images are taken, e.g. during a warm summer evening and a cold winter dawn, will suffice;

atmospheric turbulence control: reference images should be compared and/or averaged to estimate the effect of atmospheric turbulence, or any other phenomenon related to anomalous atmospheric refraction, on astrometric positions (Hamammu, 2005). In view of the potential importance of that effect, a large number of reference images were taken in 2005.

4. Set-up (TSE'06) and preliminary assessment

The EurAstro expedition to Libya 2006 was carried out within the frame of the SPSE. The observation point was close to the nominal Eclipse-City location, and substantially the same set-up as for ASE'05 (see Section 3 above) was used. The sky was cloud-free, with little suspended sand and aerosol content. Temperatures varied between 21°C and 27°C during eclipse, therefore staying close to the thermal conditions of the reference images. Actual exposure times have been stored in the headers of all the images taken. Figure 2 is a processed, low-resolution composite image showing earthshine, solar prominences and coronal structure. Unprocessed full resolution single frames show stars down to about 8 mag, and processed composite images could yield even more stars usable for astrometry.

5. Data reduction strategy

Before TSE'06, the following strategy was considered:

- The visibility of the stars in the TSE images must be assessed first:

  A. if stars are visible in the TSE images, then proceed with data reduction;

  B1. if stars are not visible and the weather was the culprit, then try again at TSE'08;

  B2. if stars are not visible and the set-up is the culprit, then another set-up should be used for further experiments.

- Case A implies to evaluate the luminosity gradients in the images, and if possible to develop a mathematical model to remove such gradients. Then, in the correctly exposed images, the centroids of the stars must be measured as previously indicated, and their position corrected in view of the error sources previously identified. If there are residuals between the reference images and the eclipse images, and those residuals show a fair agreement with Einstein's predictions, then the experiment will be considered a success.

Fig. 2. Processed composite image taken during TSE'06.

- Cases B1 and B2 necessitate further experimentation. In particular, it is noted that the sky region next to the eclipsed Sun during the TSE of 01 August 2008 is richer in stars, including star cluster M44 (too far away, though, to be used for accurate measurements).

EurAstro will send at least one team for observing TSE'08, maybe from Mongolia or China. Since we do not intend to travel twice to Mongolia - or another remote place - with heavy equipment just for the sake of validating an experiment of little scientific importance, the reference star field should be imaged, about 6 months before or after TSE'08, from an appropriate European location.

A set-up for case B2 was already tested during a EurAstro mission to Crete in 2004. It comprises a LORVAF 200/1600 three-lens apochromat refractor and a M100B equatorial mount.

In view of the encouraging results obtained as stated in section 4 above, the data reduction can begin as foreseen in step A. This calls for coordinated activities.

6. Coordinated activities

The reduction of the data obtained before ASE'05 and at TSE'06 involves a lot of work, especially in view of the large number of usable images. Such work could be of rewarding didactic value to students or academic institutions. The author would be glad to send them, for instance by CD or DVD, all of our raw images. EurAstro is an informal nonprofit association, therefore we intend to provide the information, and further support if needed, free of charge; also, most of our members are amateur astronomers, not professionals. If the results of the data reduction are of personal interest to the student or professional having performed them, we agree that he or she could use them freely.

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