SPECKLE INTERFEROMETRY OF BINARY ASTEROIDS FROM THE MAIN BELT. Carlos A. Guerrero[1], Joel H. Castro-Chacón[1,2], Joannes B. Hernández-Águila[1], José S. Silva[1,2], Mauricio Reyes-Ruiz[1], Benjamín Hernández-Valencia[1], Edilberto Sánchez[1]. [1]Instituto de Astronomía, Universidad Nacional Autónoma de México, Ensenada, B.C., México, [2]ICONACYT-Instituto de Astronomía, Universidad Nacional Autónoma de México, Ensenada, B.C., México

Introduction: The real limitation for the resolution of ground-based telescopes is the atmosphere. A telescope of any aperture size will rarely achieve better spatial resolution than 1” in visible light, due to the fact that changes in the refractive index of the atmosphere, resulting from differences in temperature, density, wind speed, etc., introduce temporal and spatial correlations in the PSF. However, they are expected to be of lesser intensity with reduced exposure times. There are several alternatives to overcome the atmospheric turbulence, namely: taking the telescopes into outer space, active optics, adaptive optics, long-base interferometry, speckle interferometry, etc.

In particular, speckle interferometry has been very successful in identifying close binary stars, taking advantage of the fact that analyzing the interference effects in short-exposure expositions, we can attain diffraction-limited resolution images.

In the absence of the atmosphere, the resulting image of an astronomical point-source in the detector would be a radially symmetrical PSF, with a bright central nucleus and a succession of concentric rings, representing the two-dimensional intensity distribution in the image. However, atmospheric turbulence distorts the wave front and changes the position of the astronomical objects under observation, which is evident in long-integrated exposures ($t \geq 1$ s) resulting in the enlargement of the PSF, producing the “seeing disk”

The idea behind speckle interferometry is to “freeze” the atmosphere, in order to analyze the evolution of the interference pattern, analyzing the images before the seeing disk becomes the dominant feature of each frame. Typical observing cadence in speckle interferometry is 50 Hz. In Figure 1 we show four consecutive frames for the binary star WDS 20239-4225, in which we can clearly see the speckle formed pattern.

For contrast, we show the long exposure image of the same binary star in Figure 2. We can see that any structure is totally destroyed.

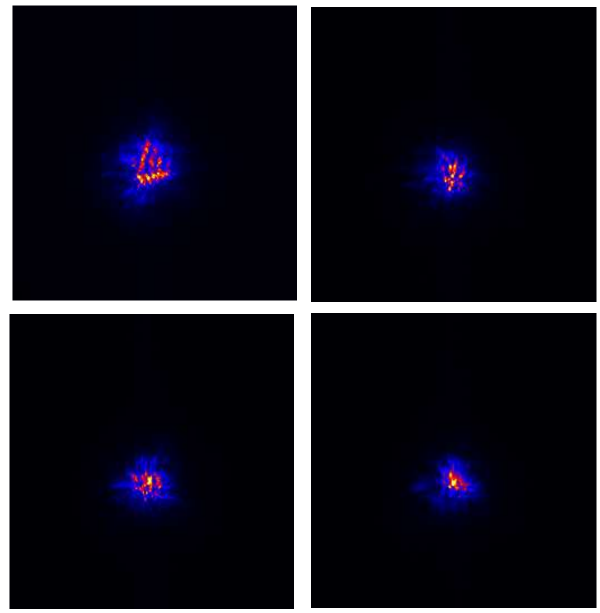

Figure 1. Four consecutive specklegrams of the binary star WDS 20239-4225. Exposure time of 20 ms for each frame, with a separation of 0.37”.

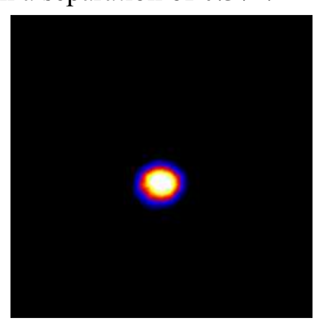

Figure 2. Long exposure image (2 s) of WDS 20239-4225.

Results. We applied the speckle interferometry observing technique [1] to the Kleopatra asteroid, which is known to have at least two orbiting moons [2]. We observed Kleopatra two times in the night of October 27th of 2018, at the San Pedro Mártir Observatory, located in Ensenada, Baja California, México. Each observation was carried out with two hours of difference. At the time, Kleopatra had a visual magnitude V = 11.36 and it was located at 2.1 AU.

In Figure 3 we present the two long exposure images (2 s) of Kleopatra. In this figure we can see the change in the relative position of the secondary asteroid. The total observing area is 10.24”.

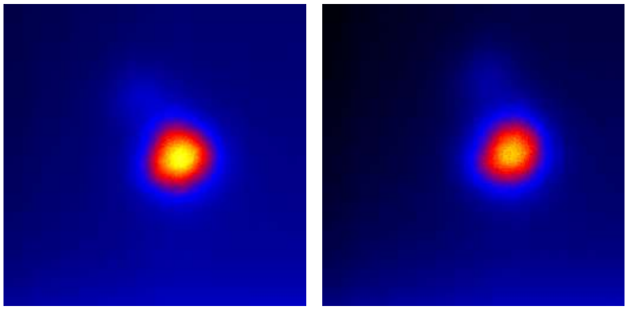

Figure 3. Change in the relative position of the secondary asteroid in Kleopatra. Long exposure images of 2 s each.

In order to study the interference pattern, we apply a standard Fourier analysis to calculate the power spectrum (PWS) and then the auto-correlation function (ACF) to extract the astrometric parameters. The PWS represents the spatial frequency distribution of the speckles of each frame. The ACF is a mathematical function that contains all the astrometric information of the system, represented by three points correlated to the primary source and the position of the secondary.

In the top row of Figure 4 we present the PWS of each observation of Kleopatra, while the bottom row shows the respective ACF. The PWS of a typical binary star is axially symmetrical, whereas the PWS of Kleopatra presents a different structure. This could be related to the form of the asteroid, meaning that it is possible that we also resolved the “disk”, although this will require further investigation.

From the astrometric measurements we estimated the following parameters: for the first observation (2018-10-27T10:51:41) $\theta = 310.5° \pm 1.1°$ and $\rho = 0.51'' \pm 0.01''$, which corresponds to a physical separation of 776.1 ± 7.8 km. For the second observation (2018-10-27T12:41:10), we estimated $\theta = 347.4° \pm 1.3°$ and $\rho = 0.52'' \pm 0.02''$, equivalent to 791.9 ± 10.2 km. Unfortunately, we could not continue to observe during that night. But the estimated period of rotation of Kleopatra is 2.32 d [3], meaning that we are, in principle, capable of reconstruct the orbit in three nights of observation.

Conclusions: We presented here the speckle-interferometry technique up until now not usual in Solar System observations, as method for measuring the position angle and separation between members of binary asteroids, using ground-based telescopes. We propose that this technique, successfully used in the search of binary and multiple stars in the Milky Way, provides the angular resolution necessary to spatially resolve binary objects with a minimum physical separation of ~150 km between them, situated within a maximum distance of ~3.5 AU, in the Main-belt asteroids, using 2-m class, ground-based telescopes. A better knowledge of the number and distribution of these multiple systems will contribute in understanding the origin and evolution of the earliest Solar System.

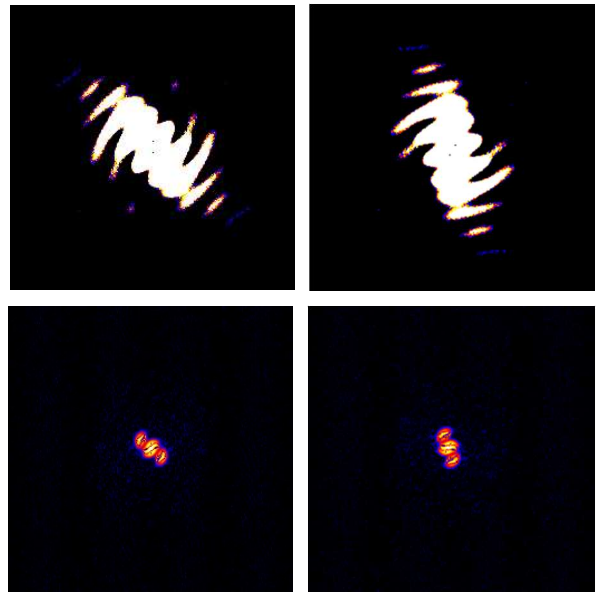

Figure 4. (Top) PWS of Kleopatra with 2 h of separation. (Bottom) ACF of the PWS. We can see the relative change in the astrometry, modulo 180°.

Acknowledgements: Observations were carried out at the San Pedro Mártir Observatory. The authors gratefully acknowledge financial support from the CONACYT #283800 project.

References: [1] Guerrero C. A., Orlov V. G., Borges Fernandes M., Ángeles F., 2018, MNRAS, 475, 1725

[2] Marchis F., et al., 2017, AGUFM.P33, 2017, P33G-03.

[3] Lakdawalla, Emily (23 February 2011). "*A dog-bone-shaped asteroid's two moons: Kleopatra, Cleoselene, and Alexhelios*". The Planetary Society. Retrieved 10 July 2019.