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DIFFRACTO-ASTROMETRY WITH HUBBLE SPACE TELESCOPE AND ADAPTIVE OPTICS IMAGES

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RESUMEN

Como continuación del trabajo de Allen et al. (1974, 2004) acerca de los movimientos internos de sistemas tipo Trapecio, decidimos investigar la posibilidad de realizar astrometría de precisión sobre imágenes del Telescopio Espacial Hubble (HST) y sobre imágenes obtenidas con sistemas de óptica Adaptativa (OA). Una región muy bien observada por el HST es la del Trapecio de Orión. Los archivos del HST contienen observaciones de acceso público de este Trapecio tomadas con la WFPC/WFPC2 durante un intervalo de 16 años (1991–2007). Con la utilización de nuevas técnicas (a las que llamamos Difracto Astrometría) determinamos la separación entre las componentes A y E del Trapecio de Orión con una precisión que llega a 0.03″ sobre imágenes saturadas. Estas técnicas parecen ser muy prometedoras para explotar no solamente el banco de datos públicos del HST, sino también imágenes obtenidas con telescopios que utilizan técnicas de OA. Para demostrar este último punto, usamos estas mismas técnicas para realizar astrometría de precisición sobre imágenes IR del Trapecio de Orión obtenidas con el sistema Multi-Conjugate Adaptive Optics (MCAO) del VLT.

ABSTRACT

Following the lead established by Allen et al. (1974, 2004) in the study of internal movements in Trapezium-type systems, we decided to investigate the possibility of performing precision astrometry on Hubble Space Telescope (HST) images and on images obtained with Adaptive Optics (AO) systems. A region widely observed by the HST is that of the Orion Trapezium. The HST archive contains public domain observations of this Trapezium obtained with the WFPC/WFPC2 during a 16 year time interval (1991–2007). Applying new techniques (which we call Diffracto-Astrometry) we have determined the separation between components A and E of the Orion Trapezium with a precision reaching down to 0.03″ on saturated images. These techniques appear to be very promising for exploiting, not only the important HST public image data base but also images obtained at telescopes using AO techniques. In order to demonstrate this last point, we use these same techniques to carry out precision astrometry on IR images of the Orion Trapezium obtained with the Multi-Conjugate Adaptive Optics (MCAO) system at the VLT.

Key Words: astrometry — stars: kinematics — stars: open clusters and associations — techniques: high angular resolution — techniques: image processing

1. INTRODUCTION

In this paper we present preliminary astrometric results obtained with new techniques developed by us and designated as Diffracto-Astrometry. These techniques should enable us to determine, with a great deal of accuracy, absolute stellar positions on non-saturated as well as on saturated images taken with the Hubble Space Telescope (HST) and/or with telescopes that utilise Adaptive Optics (AO), and relative positions with even better accuracy.

The most innovative of these methods make use of the image produced by the secondary mirror support ("spider") as well as the concentric rings of the diffraction pattern of the stars. A first application of these techniques to HST images of the Orion Trapezium enabled us to measure the separation between its A and E components. In order to test the applicability of these techniques to AO images, we also used Orion Trapezium IR images taken with the Multi-Conjugate Adaptive Optics (MCAO) system at the VLT.

In § 2 we present the image data, § 3 explains the new techniques in detail, § 4 presents some preliminary results, and finally, § 5 gives our conclusions.

2. THE IMAGE DATA

The image data were taken from the public HST data bank for the WFPC/WFPC2 (Multimission Archive at the Space Telescope Science Institute (MAST) accessible on the Internet at `http://archive.stsci.edu/`), and from IR images taken

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with the MCAO system at the VLT (Bouy et al. 2008).

In the HST archive there are approximately 500 Trapezium images taken with the Wide Field Planetary Cameras (WFPC/WFPC2). In most cases the star images are saturated and present CCD "bleeding" and other artifacts such as "ghosts", cosmic rays, etc. The images are in FITS format and each complete frame has a size of 10 MB.

On most of the HST images the Trapezium image is on one of the Wide Field Camera CCDs (CCDs 2, 3, or 4) with a sampling of $0.0995''$/pixel resulting in an individual WF CCD Field of View (FoV) of $80'' \times 80''$ as shown in Figure 1. Sometimes the image is on the Planetary Camera CCD (CCD 1) with a sampling of $0.0455''$/pixel resulting in a FoV of $36'' \times 36''$ as illustrated in Figure 2.

The VLT MCAO Trapezium images were taken during the first on-sky demonstration run (from 25th March to 6th April, 2007) in the J, H, Ks and $Br\gamma$ ($2.166\,\mu$m) filters. The pixel scale was $0.028''$/pixel for a total FoV of $57.3''$ (see Figure 4).

The FITS format images were processed by us using specifically developed IDL programmes and with the SAOimage DS9 Astronomical Data Visualization Application.

3. DIFFRACTO-ASTROMETRY AND ITS TECHNIQUES

Diffracto-Astrometry is a methodology developed by us with the aim of measuring absolute and relative stellar positions and displacements on diffraction-limited images such as archival HST images and also AO images. Application of this methodology is independent of whether or not the stellar images are saturated.

These techniques require a specific sequence of steps which have to be followed in order to ensure minimum systematic errors in the results.

In what follows we describe the steps we took in the application of these techniques to the measurement of the relative position between components A and E of the Orion Trapezium (OT).

First, we selected images of the OT from the MAST. We then chose several images of the OT according to criteria regarding date, filter, exposure time and CCD (PC or WF) on which the OT image falls entirely in one CCD. We selected images in which the OT appeared as close to the centre of the CCD as possible, in order to avoid, to a maximum extent, any geometrical distortions.

Once we had a set of images that satisfied all the necessary criteria, we found the relative position of the photocentres by application of either/all of the following "centering" techniques which utilise the characteristics of the diffraction pattern: (i) Location of the centre by prolonging the traces of the "spider", (ii) Fitting concentric circles to the diffraction ring pattern and (iii) Location of the stars' emis-

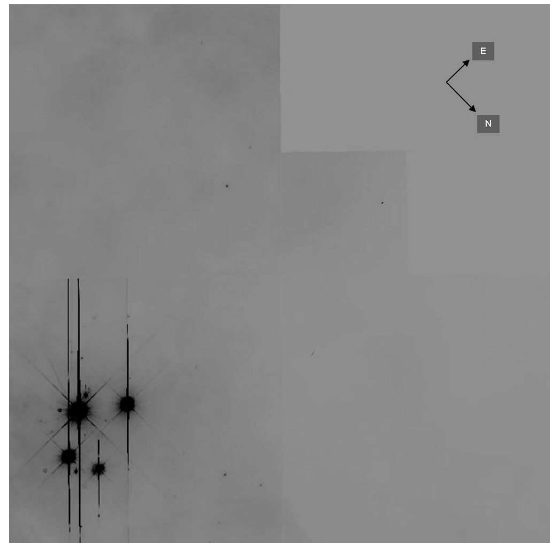

Fig. 1. HST image of the Orion Trapezium on one of the Wide Field Camera CCDs. This image has an integration time of 80 seconds in the F439W filter taken on 10th April 2005. Note that star images are saturated and present CCD "bleeding".

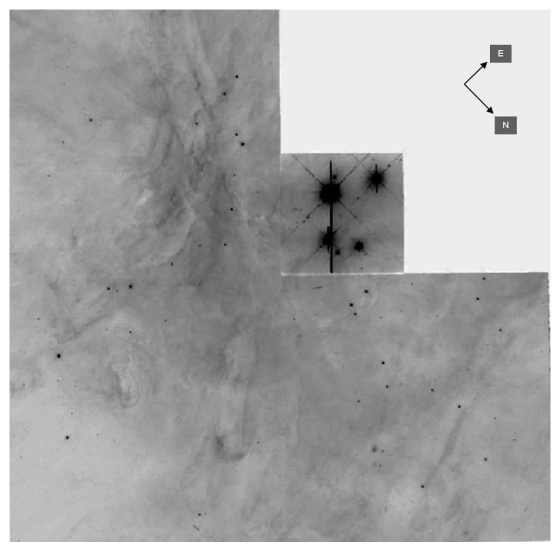

Fig. 2. HST image of the Orion Trapezium on the Planetary Camera CCD. This image has an integration time of 100 seconds in the F502N filter taken on 21st March 1995. Note that star images are saturated and present CCD "bleeding".

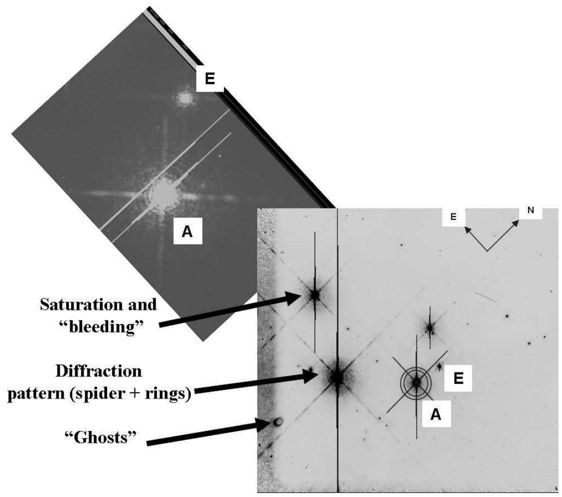

Fig. 3. An example of HST/WFPC2 Image of the Orion Trapezium A and E components. In this composite image, taken on 21st March 1995 (100 sec exposure time, filter F673N) the CCD "bleeding" is present in the saturated components. In the zoomed image we can also distinguish the diffraction pattern in the shape of a cross produced by the secondary mirror support ("spider"), as well as the diffraction rings for each of the stellar components.

sion maxima by fitting a 2D Gaussian or Lorentzian function (a Lorentzian PSF approximates the diffraction pattern of a perfect telescope outside the terrestrial atmosphere better than a Gaussian PSF), masking the saturated and bled pixels (see Figure 3). All three techniques attempt to locate the photocentre position with a subpixel precision.

It is important to note that for the application of the "spider" technique we select HST images for which the relative position between the "spider" and the CCD rows differs by 45° so that the CCD bleeding does not overlap with the "spider" image.

4. PRELIMINARY RESULTS

Once we had a determination for the positions of components A and E of the OT, we were able to determine the magnitude of their separation for different epochs.

4.1. *Results from HST images*

During the initial test phase of our techniques we measured 4 HST images taken at different epochs. Information about these images is given in Table 1. We would like to point out that the image from 1991.5 was obtained with the WFPC1 and the HST uncorrected optical system which suffered from strong spherical aberration, thus producing a larger uncertainty.

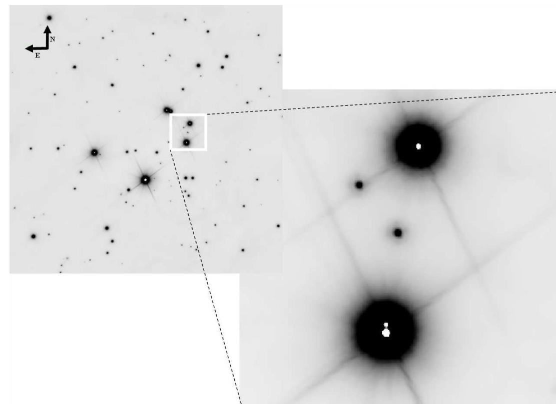

Fig. 4. Orion Trapezium K-band image, taken with the Adaptive Optics system MCAO at the VLT. In the zoomed image of the A and E components we can clearly distinguish the cross-like diffraction pattern produced by the "spider" from the secondary mirror.

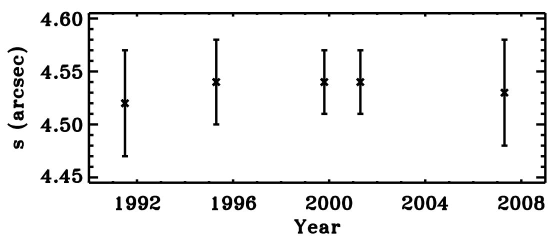

Fig. 5. Separation between components A and E of the Orion Trapezium for different epochs. The points were obtained from HST and AO (most recent point) images with the techniques described in this paper.

TABLE 1

AE SEPARATION FROM HST IMAGES

Date	($''$)	$\pm$ ($''$)	CCD/Filter
1991.5	4.52	0.05	WF F547M
1995.3	4.54	0.04	PC F631N
1999.8	4.54	0.03	WF F631N
2001.3	4.54	0.03	PC FR418N

4.2. *Results from AO images*

In Figure 4 we show the K-band image of the Orion Trapezium, taken on April 4th, 2007 with the Adaptive Optics system MCAO at the VLT. On this image, the brightest stellar components are saturated and we can clearly distinguish (in the zoomed part of Figure 4) the cross-like diffraction pattern produced by the "spider" of the secondary mirror which allows us to use our approach in order to determine the position of the photocentre with good precision.

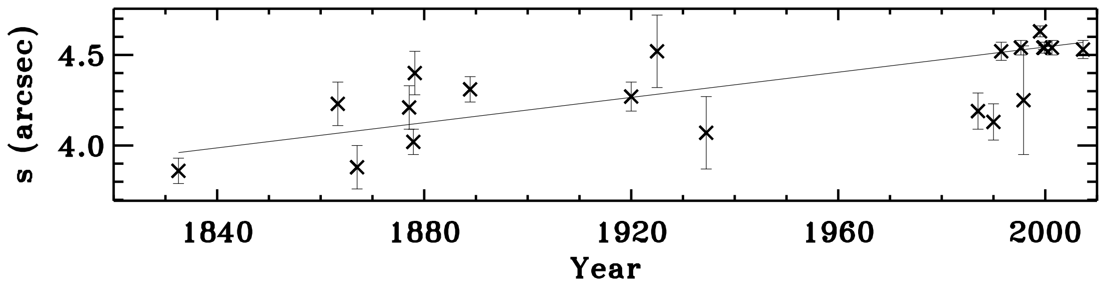

Fig. 6. Time evolution of the separation between components A and E of the Orion Trapezium. The straight line represents a weighted least-squares fit to all the data points obtained from the literature and our measured data points. The value of its slope implies a relative proper motion of 3.5 mas/year.

We performed measurements on the MCAO-VLT K image using SAOimage DS9. We also carried out the measurements with the "spider" traces fitting technique.

The measurements were consistent and resulted in a separation of $4.53'' \pm 0.05''$.

4.3. *Combined results: HST and AO*

Figure 5 shows the separation between Orion Trapezium components A and E measured at different epochs. The points were obtained from HST and AO images with the techniques described in this paper.

In Figure 6 we show our measured points along with different measurements from the literature of the separation between Orion Trapezium components A and E compiled by Allen et al. (2004). Note the accuracy of our points (reaching down to $0.03''$) plotted at the extreme right of the figure. A weighted least-squares fit was performed on the points in order to calculate the relative proper motion. It resulted in a value of 3.5 milli-arcseconds per year which corresponds to a transversal separation speed of 6.9 km/s $\pm$ 1 km s^{-1} calculated using the newly determined distance to the Orion Nebula of 414 pc (Menten et al. 2007).

5. SUMMARY AND CONCLUSION

In this paper we describe new techniques (Diffracto-Astrometry) for performing precision astrometry on saturated images or on images that present characteristic diffraction patterns, such as archival HST images and/or AO images.

We present preliminary results for the measurement of the separation of the components A and E of the Orion Trapezium. Application of our techniques on selected HST images produced an average separation between components A and E of $4.54'' \pm 0.05''$.

Application to AO test images produced results which were consistent, and resulted in a separation of components A and E of $4.53'' \pm 0.05''$.

These results, combined with previous separation measurements imply a transversal separation speed of components A and E of 6.9 km s^{-1} $\pm$ 1 km s^{-1}.

The Diffracto-Astrometry techniques appear to be a very promising tool for high precision measurements on all types of astronomical images, especially on images which are usually discarded because of saturation.

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