Optical telescope for the ARIES21

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Informe Técnico IT-OAN 2007-25

Change Record

Version	**Date**	**Author**	**Remarks**
1.0	03-12-2007	P. de Vicente	First version

Índice

1. Introduction

This report describes the works peformed with the optical telescope that is installed at the 40 m radiotelescope. Since these works are still ongoing, updates will be added to the report and summarized in the revision historic table.

The CCD, the optical focuser and the optical telescope were assembled together in the lab in 2006. Tests were performed then to check the correct behaviour of all of them. The telescope was installed in February 2007 and first observations were done in June 2007. A realignment of the telescope is pending so that its optical axis matches the radio axis of the 40 m paraboloid.

The aim of the optical telescope is to help with the pointing of the 40 m antenna and check its tracking. This instrument has already proved to be very useful spotting problems with the servos and the software at the Antenna Control Unit, ACU. Currently it is not foreseen to use the optical telescope for photometry since it is unknown if it has enough quality.

2. Final selection of the optical telescope components

Planesas (2005) describes the requirements that should be fulfilled to install an optical telescope at the 40 m radiotelescope and proposes some solutions. For the telescope type and model and mount location we adopted one of the proposed choices. For the CCD we adopted a different solution than those proposed and we also added a remote focuser. If the optical telescope proves to be useful for other tasks in the long term it may be necessary to devote more time to improve the current installation by, for example, making the cover remotely controlled.

2.1. Location

The location was chosen taking into account, the space the telescope would need, that it should be protected from the outdoor weather, and the cabling and additional equipment it requires in situ. It was also decided that the optical telescope would be permanently installed in its final location. These two set of conditions excluded the possibility to install the telesope in the main reflector, close to the central ring.

The telescope was finally mounted in the subreflector cabin. Inside the cabin, the space is limited by the door, the lateral walls which form an acute angle with the floor, a girder and a metalic structure to which some power boxes are attached. See figure 1. The telescope lens peeps slightly out of the wall, towards the sky and opposite to the main reflector. It is located at the bottom left, approximately 1 m below the optical beam. Figure 2 shows a photograph of the rear surface of the subreflector cabin. Four elements protrude from the surface: on top a motor with a metalix string, at the upper left corner an optical beacon, at the bottom left corner the cover of the optical telescope and at the bottom right corner the holography horn.

Access to the subreflector is done using a cherrypicker or an elevator platform when the antenna points towards the horizon.

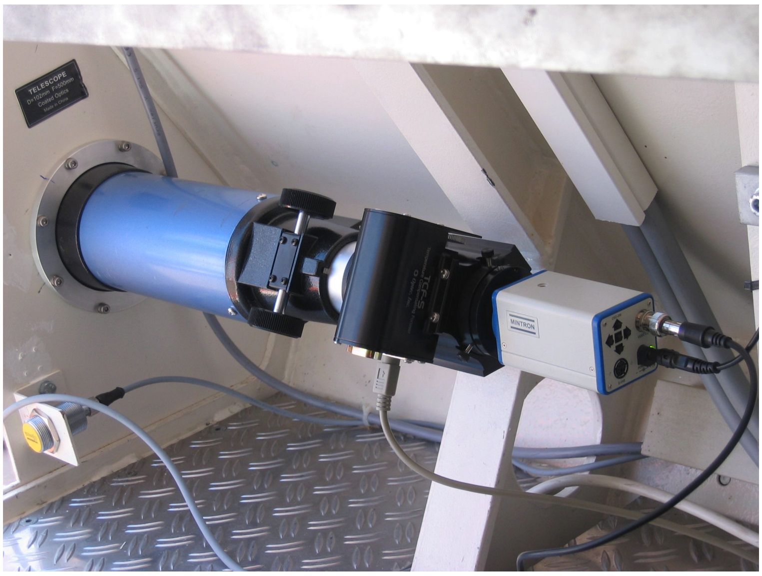

Figura 1: *Photograph inside the subreflector cabin, where the telescope is housed. The size of the telescope is limited by the form of the wall, the girder and the rear metalic structure (hardly seen in the photograph). The camera was not upside down as with the definitive setup.*

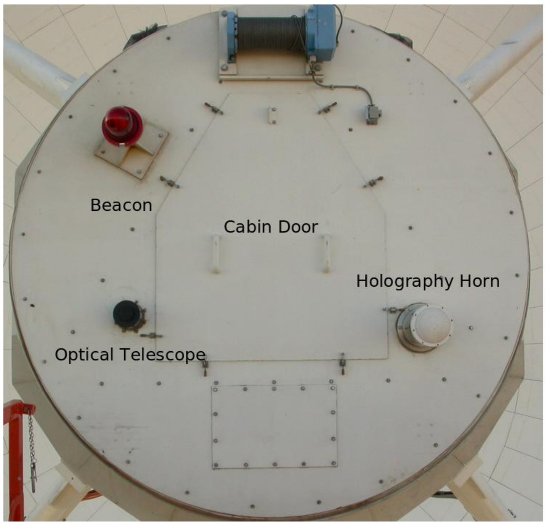

Figura 2: *Photograph of the subreflector cabin wall from outside. The optical beam and the optical telescope are to the left and the holography horn to the right. The cabin is accesible through the door once it has been removed from its location using the handles.*

2.2. Optical Telescope

The selected optical telescope was a SkyWatcher SW1025. The selection was done taking into account its size (D = 102 mm, f = 500 mm, length 50 cm) and the available space in the subreflector cabin.

The aperture is limited by the form of the wall to which we attach the lens. There is only space approximately for a 100 mm lens since some extra space was necessary for a larger support ring that attaches the telescope to the wall. The focal length is limited by the available free space inside the subreflector cabin, between the wall and a metalic structure.

The optical telescope is a two-element, air-spaced, achromatic refractor. The outer surface of the lens is multi-coated with silicon dioxide to protect it from outdoor weather and with magnesium fluoride, an antireflective material. According to the manufacturer the resolving power is $\theta_d = 1{,}13''$. The scale in the focal plane is $0{,}41''/\mu$m and the size of a pixel at the focal plane should be $< 45\,\mu$m.

The telescope was delivered with a lens, its metalic cell, a hollow tube with a manual focuser and a cover that splits in two parts: a small 15 cm long hollow tube, and a small plastic cover which can be taken out of the tube. This plastic cover has a smaller cover 6 cm diameter inside, that can be released independently. One adaptor for an eyepiece was also included.

2.3. CCD

One of the most important reasons for choosing the CCD was that it could generate images in real time to be able to see the pointing and tracking errors while moving the radiotelescope. The camera had to be non-cooled to avoid complexity at the subreflector cabin and have the largest sensitivity under these constraints.

The selected model was a 12V1C-EX from Mintron. Letter "C" stands for PAL video system for Europe. This camera generates black and white composite video and S-video. The CCD mounts an ICX249AL Sony chip 8 mm diagonal. The chip has 752 horizontal time 582 vertical effective pixels. The chip size is 7.95 mm $\times$ 6.45 mm and the size of each pixel is 8.6 μm $\times$ 8.3 μm.

Video frames are delivered with a frequency of 1/50 seconds $=$ 0.02 seconds. The lowest integration time is 1/100,000 seconds. The camera provides a "star light mode", in which it can store 1 to 128 fields. This means that the maximum integration time is 128 / 50 seconds $=$ 2.56 seconds. When used with the Skywatcher telescope the angular size of each pixel in the sky is $0{,}41 \cdot 8{,}6\mu\mathrm{m} \simeq 3{,}5''$ and the whole sky area covered $54{,}32 \times 44{,}07''$.

The camera can be configured through a menu using five push buttons on its rear surface. The camera was modified in our labs to include a small microprocessor that allowed its remote operation from an RS232 port. This work is descibed by de Vicente et al. (2006a).

Table 1 summarize the characteristics of the Mintron 12V1C.

This camera is usually sold for surveillance purposes and therefore, when its orientation is upwards, the image is also upwards. This behaviour is opposite to what one should expect when using a normal refractor where the image is formed inverted (upside down) on the focal plane.

Property	Value
Model	12V1C-EX
TV system	CCIR
Image sensor	1/2 inch sensor (Sony ICX249AL)
Number of pixels	795(H) × 596(V)
Scanning system	625 lines, 50 frames/second
Sync system	Internal / VD-Lock (optional)
Minimum illumination	Normal model: 0.05 Lux (F1.2 , 5600K 30 IRE)
	Stellar light mode: 0.0005 Lux (F 0.8 , 5600K 10 IRE)
Resolution	600 LTV
White balance	Mode: ATW / AWC / FIX (Zero color rolling)
	Range: 3200 - 10000 K (2200 - 15000 K with S filter)
Gain control	Mode: AGC (ON / OFF)
	Range: 0 - 18 dB
Signal to noise ratio	52dB (minimum) / 60 dB (typical) (AGC OFF)
Auto iris	A.E.S. / DC
A.E.S	1/50 1/100,000 sec.
Video output	Composite and Y/C 1.0V p-p at 75 ohms
Gamma correction	0.45
Operation temperature	-20 to 50 C
Operation humidity	$>$ 85 %
Power source	DC 12 V ±1V / 180mA
Serial number	H11058065
W/O	AF9400305

Cuadro 1: *Main features of Mintron camera model 12V1C.*

2.4. Focuser

A TCFS focuser was purchased to allow remote focusing. Planesas (2003) does not propose any device for this task but it was thought that the whole optical system being in a remote location with dificult access required a remotely controlled system that allowed to modify the focus. Temperature can vary 40 degrees from winter to summer and such a system is necessary. The selected one was a temperature compensated focuser from Optec, model TCF-S.

This instrument is decribed by de vicente et al (2006b). The TCF-S has a range of 7000 steps, each step 0.002032 mm (approximately 1/3 of the visible light). It can be operated remotely from an RS 232 port. It has got a temperature probe so that in one of its working modes the system automatically compensates the focus by reading the environment temperature.

2.5. Video Grabber

A video grabber PCI card was chosen to capture the video from the Mintron CCD. It was required that it accepted composite video, any PAL format, a resolution of 760 × 570 pixels and support for Linux kernels 2.4 and 2.6 series. The preselected models were the FlashBus Spectrim Lite model from IntegralTech technologies and the Picasso model from Arvoo. We finally chose the Flashbus Spectrim since the Linux software was available through Internet and Arvoo web pages were not Linux friendly.

This video grabber card required some modifications on the software the company provides. The card has been installed on a 32 bit PC since there seems to be some problems with Linux software with 64 bit computers and powerful graphics cards like ATI FireGL V7200. Some additional software tasks were performed to suceessfully generate continuous images onto disk and a crosshair on the live image. All works regarding the video grabber are described in a report currently under preparation (Barbas 2008).

3. Mounting the telescope

The whole optical telescope system was mounted in the lab and tested there. Image 3 shows the system on a table prior to being mounted. To the end of the optical tube an Optec 2 inch Male Barrel (part number 17459) was mounted. This piece was screwed to the focuser input. On the output end of the focuser a 2 inch to 1 1/4 inch Optec adapter (part 17662) was mounted. The camera has a 1 inch female thread. To connect the camera to the Optec adapter we used a generic C mount 1 inch to 1 1/4 adapter. The larger end of this adapter is a tube that is inserted inside the Optec 17662 one and fixed with one external screw.

Altough it is strongly recommended not to unmount the lens from its cell, we unmounted it to insert a rubber toroid 0.7 cm thick in front of the lens. This was done to avoid water leakeage from outdoors, coming inside the tube of the telescope and reaching the CCD chip. This operation might have affected the alignment of the lens and hence shifted the focus from the optical axis. The lens was cleaned with special tissue and isopropilic alcohol.

Software development and tests for the camera and the focuser were performed at the lab and are described by de Vicente et al (2006a, 2006b).

Figura 3: *Photograph of the pieces that compose the optical telescope plus the focuser and the CCD camera. From left to right: Mintron camera (1 inch thread), 1 inch to 1 1/4 inch adapter, 1 1/4 inch to 2 inch adapter, Optec TCFS focuser, 2 inch Male Barrel, Skywatcher tube with 2 inch thread.*

Prior to mounting the telescope at the subreflector, some works had to be done inside the subreflector cabin to accomodate free space to house the telescope. This involved moving cables and a power distribution box inside the cabin and also moving one of the locks that keep close the subreflector cabin door. At the workshop, an aluminium ring with a concentric hole that houses a rubber toroid was manufactured. This ring has 10 screws with an Allen head around its circumference. The external diameter of the aluminium ring is 150 mm and the internal is 119 mm. The inner carved ring where the rubber toroid is housed has an inner diameter of 120 mm and an outer diameter of 135 mm.

A hole with an approximate diameter of 115 mm was made on the rear wall of the subreflector using a metalic saw. The optical telescope was unmounted separating the tube from the lens cell and inserting from the rear the metalic piece that holds it against the wall. The outer end of the lens cell was passed through the hole and later the metalic piece was screwed to the subreflector wall from inside (Figure 5).

Once the metalic ring was attached to the cabin wall, the optical tube was screwed into the inner end of the lens cell. Then the module with the adaptor, focuser and CCD camera was attached to the telescope. The elements were oriented so that the focuser protrusions do not hit any wall and the cables in the connectors run freely without hitting the metalic structure. The CCD was turned upside down because in the normal position the cable connectors at the rear face protude and may hit a metalic structure behind the camera. The camera was set horizontal with the help of a water level.

The TCFS was commanded position 3500 (its nominal center position) and then using live video from the camera the manual focuser of the SkyWatcher was selected by hand and fixed with a screw. A mark with a non erasable pen was done in the tube in case somebody changes the manual focus. Figure 6 shows a photograph of the definitive setup. Later, a plastic sleeve was laid covering the CCD and focuser to avoid water that may leak into the cabin from outdoors. The sleeve may strech allowing the CCD to move relative to the focuser. The sleeve is attached to the tube with a plastic tie while the other end has an elastic band that leaves a small hole through which the cables from the CCD and focuser pass through.

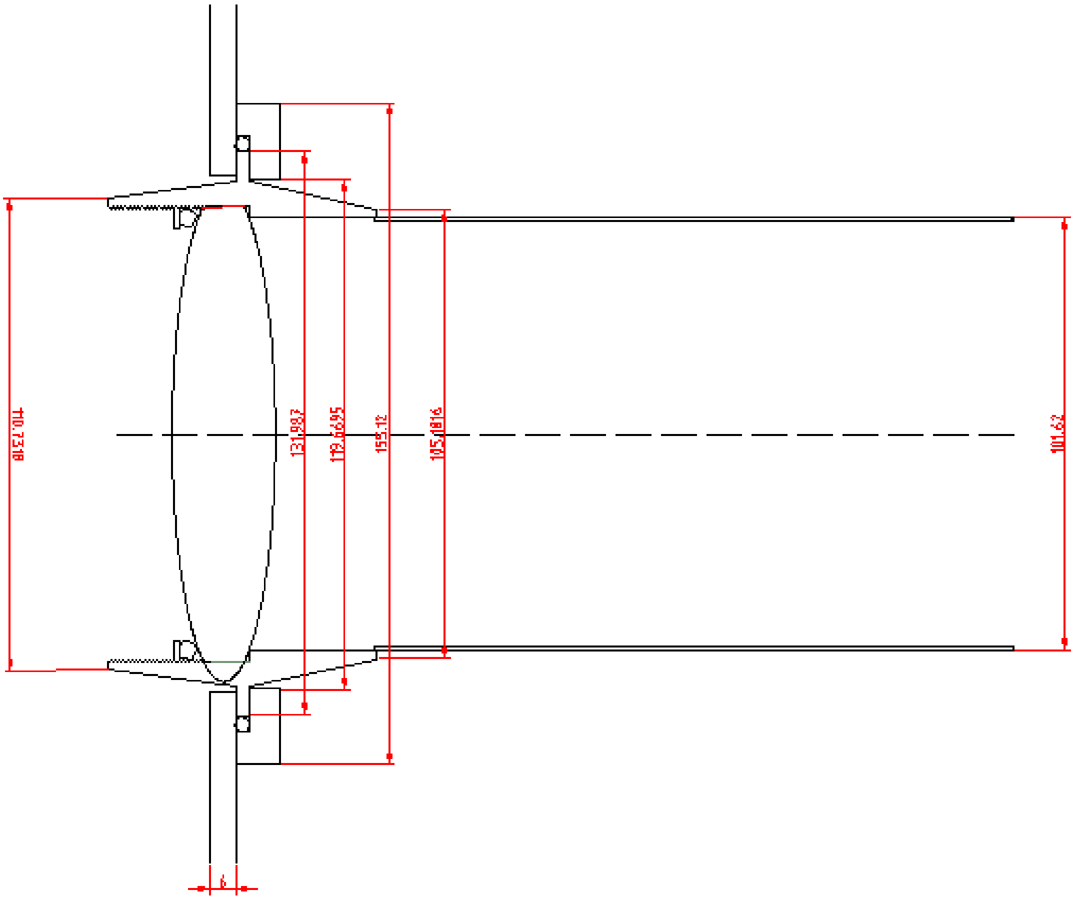

Figura 4: *Sketch with the cut of the wall, the lens cell, the metalic ring and the tube of the telescope with dimensions of each piece. The depicted lens is not to scale.*

Figura 5: *Photograph while screwing the metalic ring to the subreflector wall. The lens can be seen inside its cell. The outer end of the cell passes through the hole in the suubreflector cabin wall and protrudes a couple of cm outside.*

Figura 6: *Photograph of the final mount prior to covering the telescope with a waterproof sleeve. .*

4. Remote control

A solution to operate remotely the telescope cover was studied, but since we found no simple solution this feature was not implemented. Hence, prior to observing with the telescope, it is necessary to use the elevator platform or the cherrypicker to reach the subreflector and take out the larger plastic cover. The cover tube is left inserted around the lens cell because it shields the lens from spureous light, like that coming from the optical beacon close to it. The smaller plastic cover is never removed. Its usage would reduce the amount of light reaching the lens although it would not affect the available field of view defined by the CCD camera.

The CCD camara and the focuser are operated from a Lantronix serial to ethernet converter, model xxx. The Lantronix converter is connected to an 8 electrical port ethernet 100 Mb/s switch in the subreflector cabin. This switch provides access to all equipment in the subreflector cabin. All the electrical equipment can be switched off from a general switch in the receiver cabin.

We have investigated the influence of the beacon and apparently it does not interfere the observer. However the optical beacon can be switched off using an ethernet electrical switch.

5. Calibration

5.1. CCD size, orientation and deformation

The size of the CCD was calibrated at first taking an image of the Moon. The size of the Moon tipically ranges between $29{,}3'$ and $34{,}1'$. For the date of the observations the size was $30{,}9'$ (see figure 7) and the calculated field of view of the camera $42{,}2' \times 31{,}7'$. This value does not match the expected angular size of the CCD according to the pixel size and the number of pixels provided by the manufacturer of the CCD. We have not found yet an explanation to this behaviour. The most plausible one is that the real size of the CCD is smaller than expected.

Deformation was checked by drawing a circle on top of the moon image. We did not detect a visible deformation in the produced images.

The angular size of the CCD field of view along the X axis and its horizontality was measured by looking a source traversing the CCD while transiting along the local meridian. The telescope was stopped at an azimuth of 180 degrees and at the expected elevation for the transit. This operation requires the pointing of the telescope to be known and corrected.

Elevation during transit changes slightly if the CCD field of view is small, because the hour angle is close to 0 ($H \simeq 0$):

$$\sin el = \sin lat \sin \delta + \cos lat \cos \delta \cos H \tag{1}$$

Sources with a declination similar to latitude should be avoided since the elevation at transit is close to zenith. If the antenna has a collimation error in azimuth, the correction at the zenith is huge and therefore has to be known very precissely. Besides, the pointing correction at the 40m dish is currently limited to 2 degrees, which means that big collimation errors prevent a good pointing correction beyond a certain elevation. At the moment of this report the collimation error in azimuth for the optical telescope is approximately $1500''$. This corresponds to an error

Figura 7: *Photograph of the Moon at 40 degrees elevation (november 2nd 2007). Expected size was 30.9 arcmin. A circle has been painted to check for deformations in the image.*

in azimuth of 2 degrees at 80 degrees elevation. Therefore, currently at the 40 m dish, it is not practical to use sources with declinations higher than 30 degrees for estimating the CCD size.

The CCD size and horizontality was estimated looking at Venus on December 12th 2007. At the time of observation, Venus declination was -12 degrees. The time elapsed for the whole transit was 178 ± 1 seconds. The Earth has an angular velocity of $15''$/second. Therefore:

$$\theta_x = 15\,\Delta t\; cos\delta \pm 15\;\cos\delta = 15\,178\cos(-12^\circ) \pm 14 = 2611'' \pm 14'' = 43{,}5' \pm 0{,}2' \qquad (2)$$

where δ is the declination of the source. Therefore the horizontal size of the CCD is $43.5'$ and the vertical size $32.7'$.

The elevation change since the source appears on one side of the CCD and it arrives at the center of it, is given by a change of the hour angle of ± 89 seconds $(20')$ around cero, and it is negligible:

$$\delta \sin el \simeq \delta el = \cos lat \cos\delta(1 - \cos(20')) = 1{,}27\,10^{-5} = 2{,}8'' \qquad (3)$$

Therefore the asumption that the trajectory of the source is a line is justified. Figure 8 shows a composite image of Venus at intervals of 10 seconds across the CCD. The angle between the trajectory and the horizontal axis of the CCD is 1.8 degrees approximately; smaller azimuths are at a larger elevation, and larger azimuths are at a smaller elevation.

5.2. Focus search

The focus was determined observing the moon at different environment temperatures. Version 1 for this report: only done at one temperature.

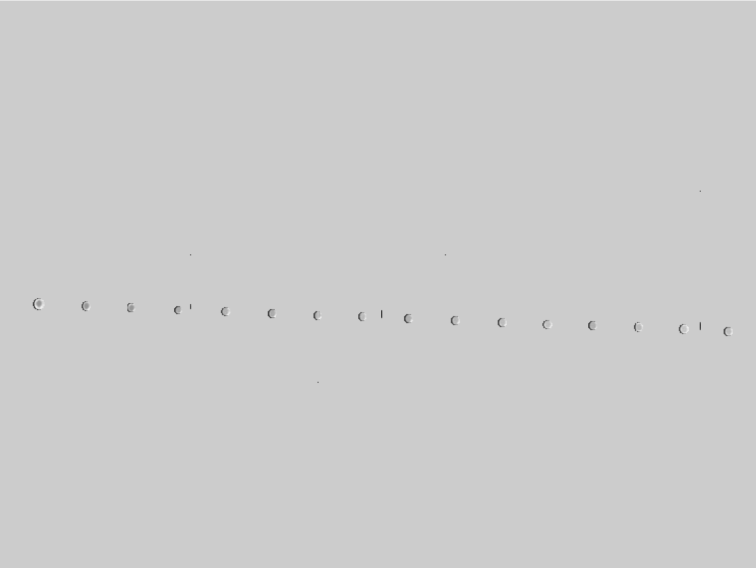

Figura 8: *Transit of Venus. Composite image at intervals of 10 seconds. The image has been edited and shows strange artifacts, like the size being different at different moments and some arc shapes surrounding the central position.*

5.3. CCD setup

The camera can be configured using a menu. It is possible to control the quantity of light detected on the CCD changing the electronic shutter speed. To obtain a higher integration times, it is also possible to add frames up to 2.5 seconds. Finally the gain of the pixels can be modified.

Images can be digitally zoomed around the center from 1 to 2. This may be interesting for planets and large sources. The image can be flipped around a vertical axis of symmetry; that is, the right side can be the left and viceversa. Unfortunately the camera does not allow to put the image upside down, so this effect is been implemented at the video grabber software component.

Other features like writing titles on the image or masking out parts of the image are not usually interesting for astronomical observations.

The electronic shutter speed can be controlled manually or automatically. The automatic mode is called ELC, and adjusts the shutter speed to get a given average level of light on the whole CCD. This feature, useful for surveillance cameras, is a nuisance for astronomy since it often leads to saturation of the images. Astronomical sources for a telescope finder are point like; therefore most of the pixels are black, and only a small fraction are bright. The ELC reduces the shutter speed to get the maximum light in the background.

It is possible to observe astronomical sources with magnitudes equal or smaller than 1 during daytime. Under these circumstances the camera may be used with ELC mode. ELC may be adjusted from 1 to 9 in steps of 1. The default ELC level is 5. Venus requires to reduce the ELC light level to 1 since the camera saturates and generates a bright wide spot. Vega usually is best seen during daytime using ELC = 7. When using ELC the shutter speed being used is unknown.

Observations at night require using ALC. Under this mode, the shutter speed can be changed manually from 1/50 to 1/12000 seconds. Low shutter speeds allow to detect sources with magnitude 13. Dimmer sources can be detected using the integration frame mode, which allows to store up to 128 frames. For the smaller shutter speed this means 2.56 seconds. Each step of ELC mode matches one shutter speed.

Figure 9 shows two Venus images taken at night using ELC and ALC with a shutter speed of 1/12000. The ELC mode saturates the pixels around the source and shows an unrealistic size and form of the source. ALC shows the true size of the source.

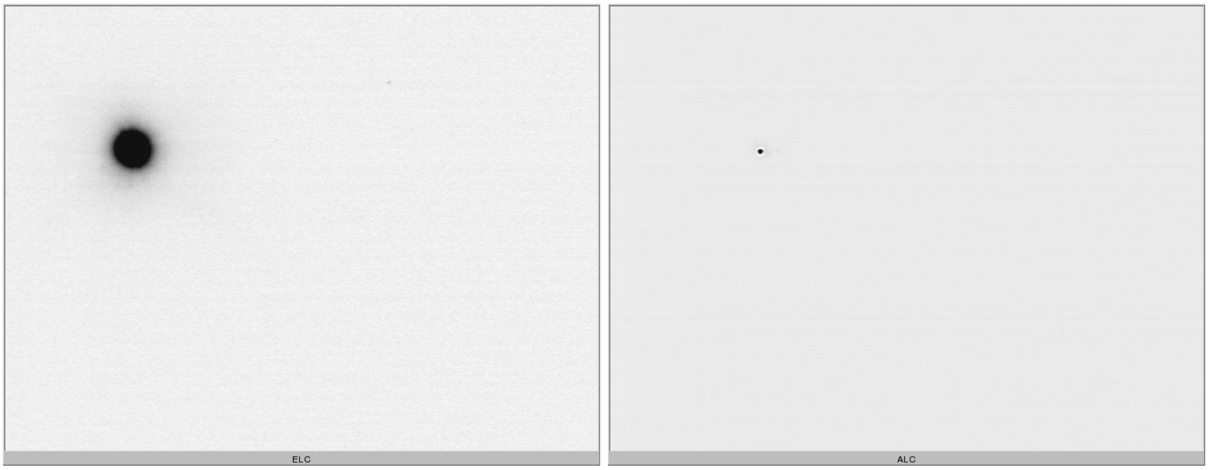

Figura 9: *Images of Venus at night. The image light is inverted. Left panel: ELC (Electronic Light Control), Right panel: ALC (Automatic Light Control) with a shutter speed of 1/12000.*

Referencias

[1] P. Planesas, IT OAN 2005-1.

[2] P. de Vicente, J.A. López Pérez, D. Cordobés, R. Bolaño, C. Almendros, IT OAN 2006-2.

[3] P. de Vicente. IT OAN 2006-5

[4] L. Barbas et al. OAN technical report in preparation.