UPDATE OF FASTCAM, THE LUCKY IMAGING INSTRUMENT AT THE OBSERVATORIOS DE CANARIAS (OCAN)

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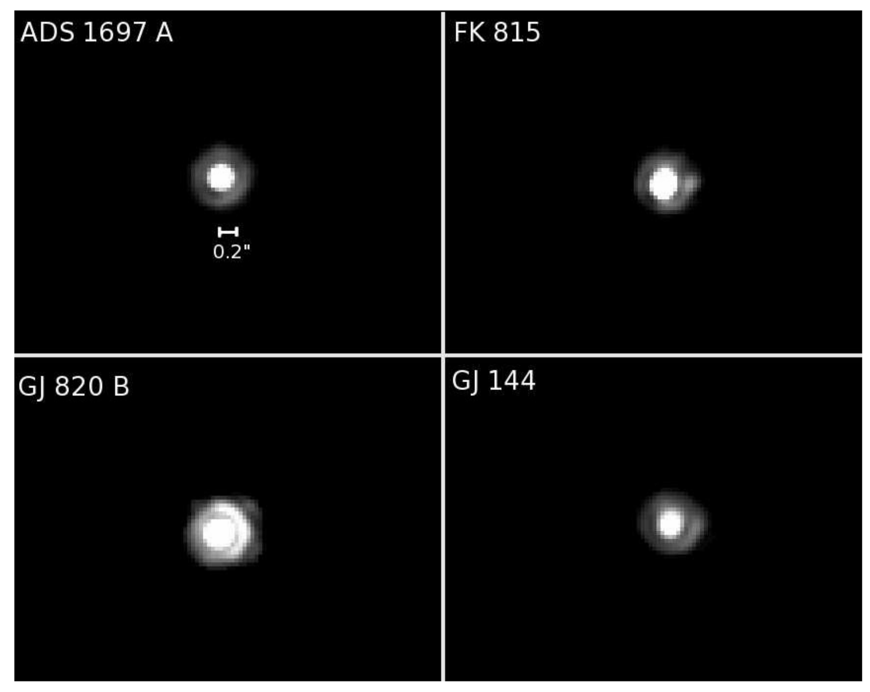
INTRODUCTION

Fastcam is an instrument that uses the **Lucky Imaging (LI)** technique to obtain **high spatial resolution** images in the optical range. It has been developed by the Instituto de Astrofísica de Canarias (IAC) in collaboration with other institutions [1].

This technique is based on recording the instants of **atmospheric stability** through very **short exposures (30-50 ms)**. The selection of those images minimally affected by turbulence allows to reach the **resolution limit of the telescope** in the optical range, offering results similar to those of space telescopes.



I-band images taken at the TCS showing the first Airy disc.

UPDATE OF THE INSTRUMENT

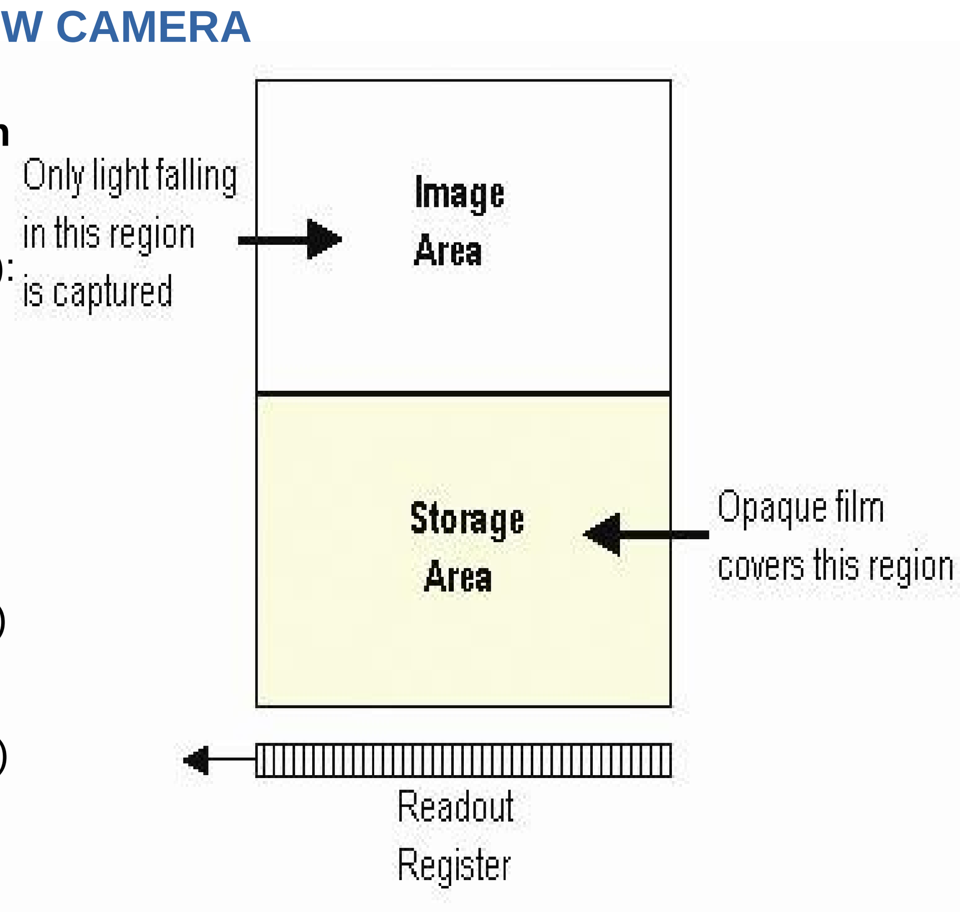
Fastcam consists of a commercial **EMCCD** (Electron Multiplying Charge Coupled Device) detector with **fast-reading** and **low-noise** together with an optical system and the acquisition, selection and process software packages.

A **new camera** has been purchased and based on it we are carrying out a complete **upgrade of the instrument** and **associated software**.

A NEW CAMERA

The new Fastcam camera is an **Andor iXon Ultra 888** detector, model DU-888U3-CS0-#BV (Back-illuminated, standard AR coated):

- 1024 x 1024 active pixels
- 13 µm pixel size
- 30 MHz max readout time
- < 1 e^- readout noise (with EM gain)
- 26 fps full frame
- 93 fps at 512x512 (Cropped mode)
- > 95% QE



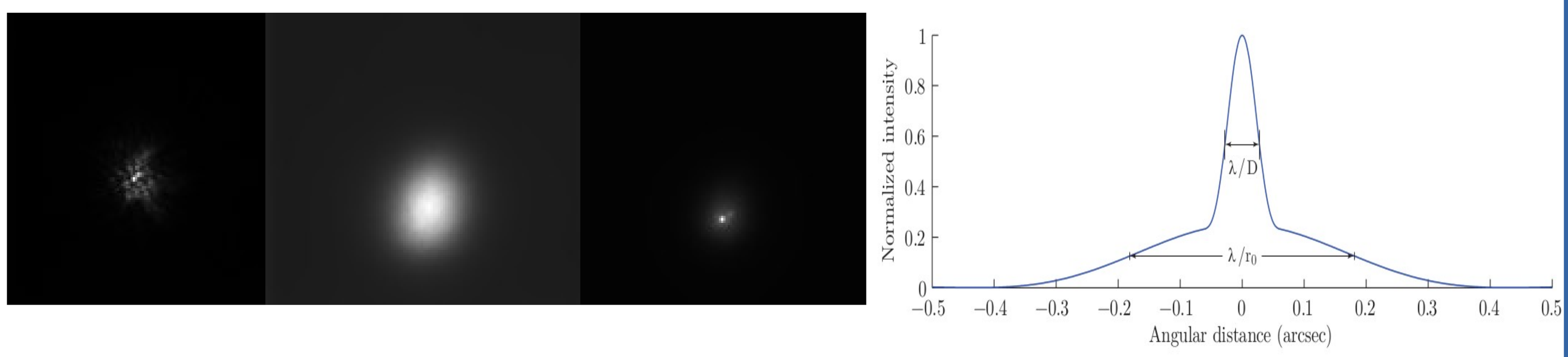
Some features of the detector are the **frame transfer mode**. This option is a special acquisition mode that contains 2 areas of approximately equal size as shown below:

1. The **Image Area**, which is at the top and farthest from the readout register. This is the light sensitive area of the CCD.

2. The **Storage Area** is located between the Image Area and the readout register. This section is covered by an opaque mask, usually a metal film, and is therefore not sensitive to light. Frame transfer devices typically have faster frame rates than full frame devices, and have the advantage of a high duty cycle, meaning the sensor is always collecting light.

All possible camera **acquisition rate** settings are summarised in the following table.

Pixel readout rates	EM Amplifier	30, 20, 10 & 1 MHz
	Conventional Amplifier	1 & 0.1 MHz
Vertical clock speed		0.6 to 4.33 µs

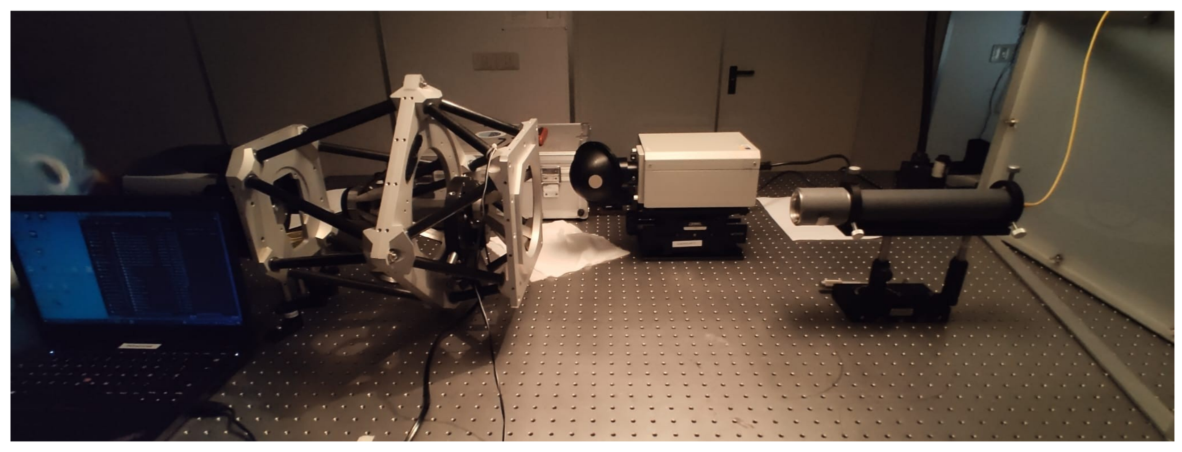


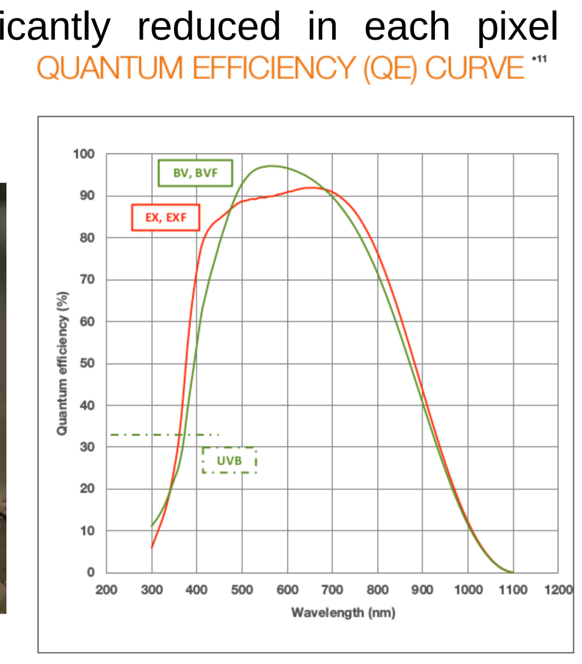
Left images: a 30ms exposure; natural seeing; 1% of 4,000 aligned and averaged images.
Right image: profile of a partially corrected image of a star, showing a diffraction-limited central core and the residual halo.

DETECTOR CHARACTERISATION

In addition to the new hardware, we are carring out a **complete characterisation** of the system both in the laboratory and in test nights at the Carlos Sanchez Telescope.

Basically, the new generation of this type of optical detectors has the great advantage of performing the electron multiplication of the signal before the readout of the detector, which means that, proportionally, the **readout noise** can be significantly reduced in each pixel compared to useful signal, down to **~1 e^- rms**.





Using Electron Multiplication, the iXon is capable of detecting single photons, therefore the actual detection limit of the camera is set by the number of 'dark' background events. These events consist of thermally generated residual electrons and **Clock Induced Charge (CIC)** electrons (also referred to as Spurious Noise), each appearing as random single spikes above the read noise floor.

This total characterisation of the system will allow optimization of the camera configurations according to the scientific objective.

SOFTWARE UPGRADE

Finally, we are carrying out a complete upgrade of the following software packages:

- New acquisition and control software.
- More robust user interface.
- Optimisation of the reduction software.

In **the LI algorithm,** the images that suffered less atmospheric distortion are detected according to a quality criterion, then re-centered and added together into a single image [2].

A limitation of the LI technique is that a corrected image of a star shows a diffraction-limited central core with a residual halo corresponding to the atmospheric turbulence that could not be corrected as it can be seen in the figure.

The new **COELI algorithm** (COvariancE of Lucky Images) [3, 4] has been designed to overcome that improving the detectability of faint objects falling inside the residual halo by analyzing the correlation between the peak pixel and the rest of the pixels of each lucky image.

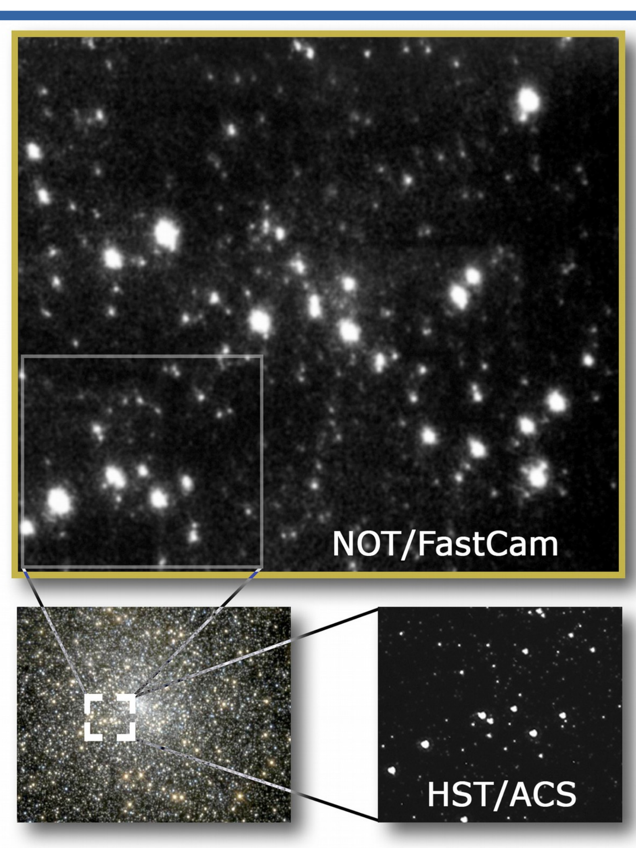


Image of the core **of the M15 globular cluster** taken with **FastCam** at **NOT** in the **I-band** compared to HST images obtained with the ACS camera (435 nm).

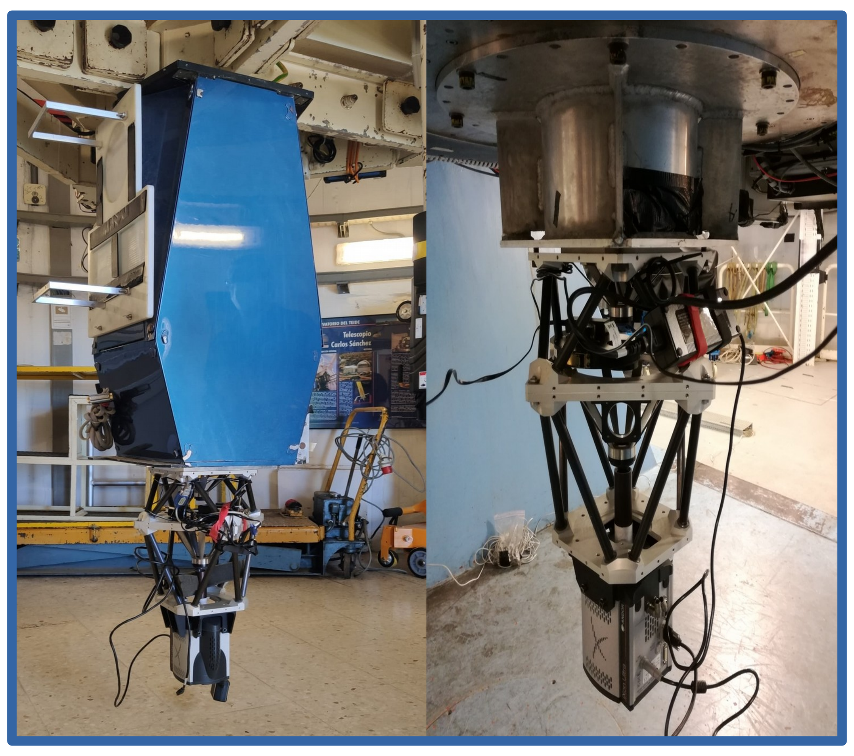
CONCLUSIONS AND FUTURE WORK

The project started in March 2006 and, since then, FastCam has been successfully tested on different OCAN telescopes and the theoretical **diffraction limit** of the following telescopes has been reached in the I band (850nm) and similar resolutions have been also obtained in the V and R bands.

Carlos Sánchez Telescope (TCS) 1.5m	0.15 "
Nordic Optical Telescope (NOT) 2.5 m	0.09 "
William Herschel Telescope (WHT) 4.2	0.07 "

For this update process we are performing observations that help us in the commissioning of the instrument to define the most appropriate configuration for each scientific case. The instrument can offer competitive observations in multiple fields of astronomy: **Solar System** with **asteroids and comet**; **Exoplanets**; Studies of **stellar formation and dynamics**; **Multiplicity of stars** in a wide range of masses and evolutionary states; **Extragalactic** resolution studies (quasars, AGNs, etc).

Fastcam is a common-user instrument at TCS since 2008 and will be offered for installation at NOT in the near future.



References:
[1] Oscoz, A. et al. 2008, Proc. SPIE, 7014
[2] Law N.M. et al., 2006, A&A 446
[3] Cagigal M.P. et al., 2016, MNRAS 455.3
[4] Cagigal M.P. et al., 2022, MNRAS 512.2