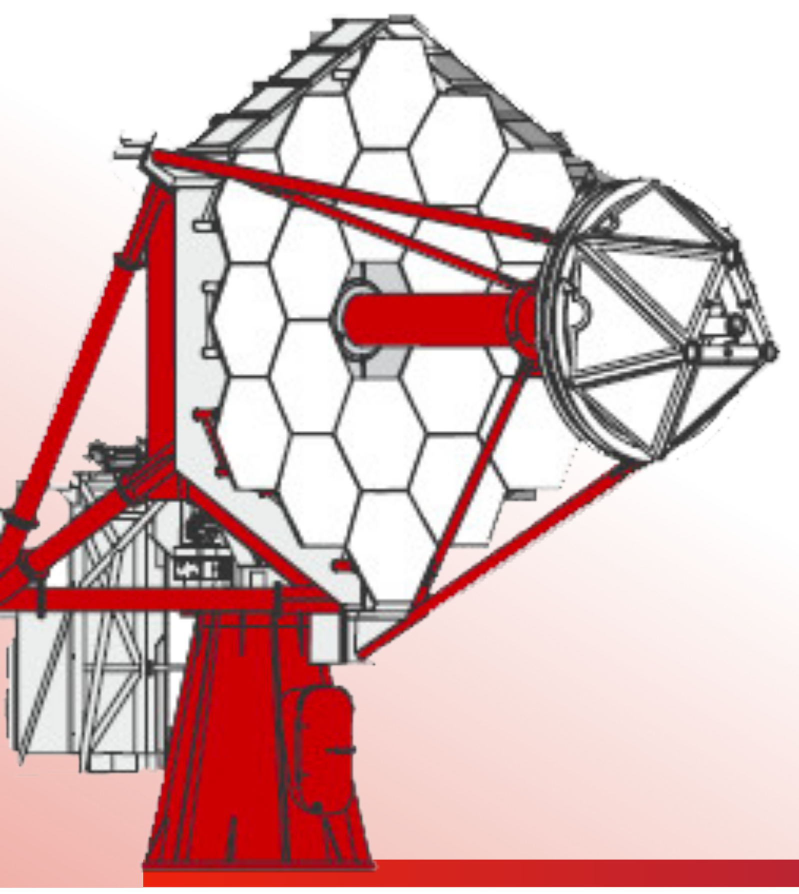

EFFECTIVE POINTING OF THE ASTRI-HORN TELESCOPE USING THE CHERENKOV CAMERA WITH THE VARIANCE METHOD

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SKY VIEW WITH THE "VARIANCE"

ASTRI-Horn is a Cherenkov telescope developed in the context of the ASTRI Project [1], installed on Mount Etna (Italy). Its innovative silicon photo-multiplier (SiPM) camera is endowed with a statistical method providing a measure of the flux from the night sky background. This ancillary output of the camera is the so-called "Variance" (σ^2) data flow and can be expressed by [2]

$$\sigma^2 = k \cdot \Phi_{sky} \quad .$$

Thanks to the Variance, we can image stars up to the 7th magnitude, but the angular resolution of the sky map is limited by the large pixel size of the telescope (11′) [3]. However, during long observing runs we can use the apparent rotation of the field of view (FOV) to improve the precision of our astrometric analyses [4].

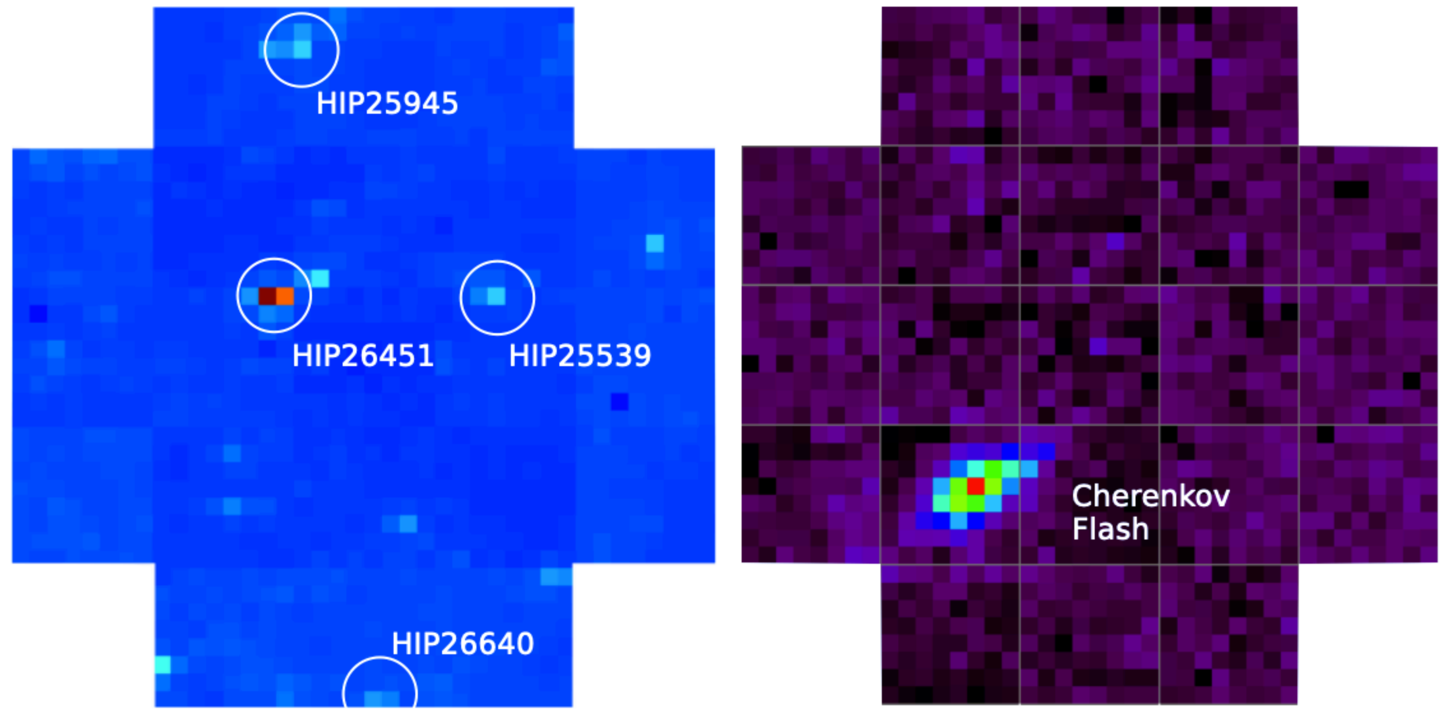
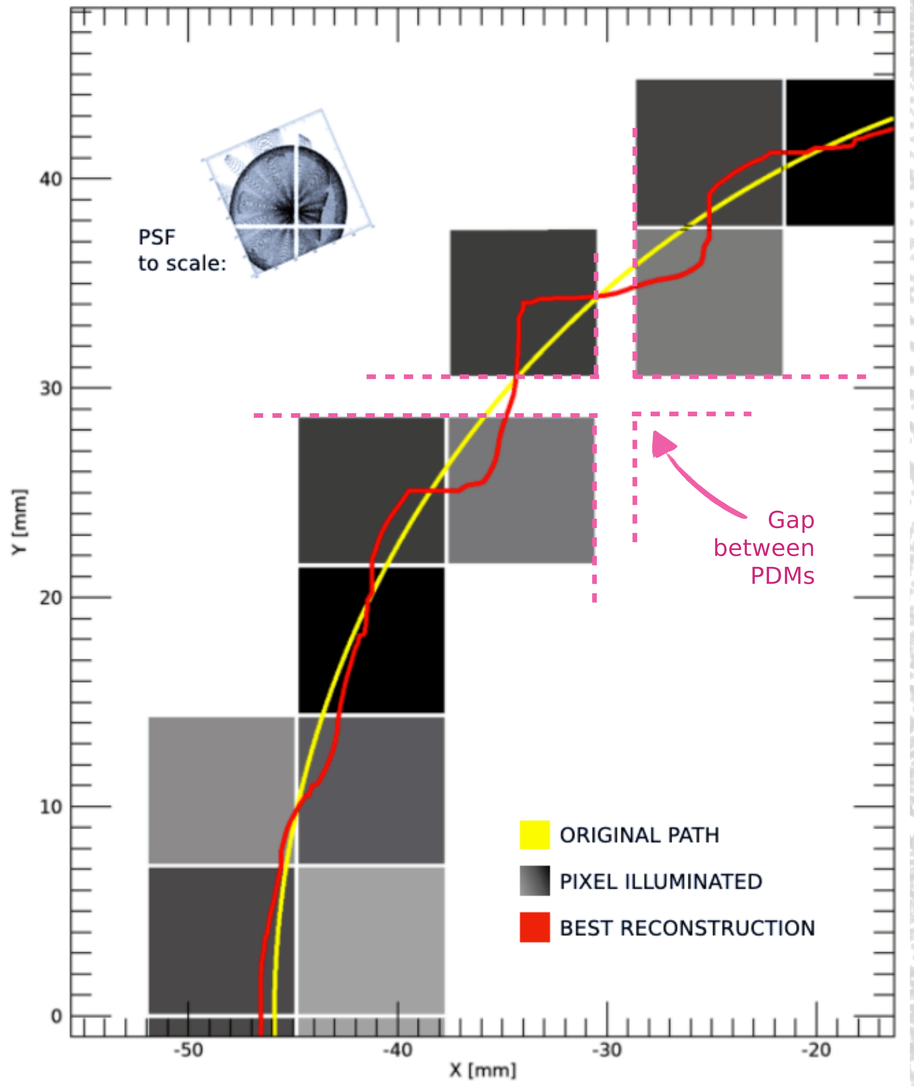


Fig.1: Left: image of the star field available from the Variance output of the camera. The ASTRI-Horn telescope is pointing towards the Crab Nebula (at the center of the FOV). Right: Cherenkov flash recorded on nanoseconds-timescale in the main camera output from the same pointing.

FIELD OF VIEW ROTATION EFFECT

Every telescope with an alt-azimuth mount presents the effect of the FOV rotation around the pointing direction, i.e. the sky coordinate aligned with the optical axis of the telescope [5]. This effect can be exploited to assess the Cherenkov camera alignment: if there is any offset between the center of rotation and the geometric center of the Cherenkov camera, then this term must be inserted in the pointing model of the telescope, enhancing the accuracy of the effective pointing of the telescope [2].



CONVOLUTION OF THE PSF OVER PIXEL

The point spread function (PSF) of the ASTRI-Horn telescope has approximately the same width of the pixels (11′) [3]. As each star spot moves across the camera, its light is integrated over pixels and the information about the original PSF centroid position cannot be directly retrieved. Our aim is now to analyse the illumination of pixels in order to retrieve the information about the star position in the camera with the precision as high as possible.

We simulated the FOV rotation and the illumination of the pixels with a custom ray-tracing program, then we tested several algorithms to reconstruct the original star path: to evaluate the accuracy of each procedure we considered the standard deviation of the points with respect to the simulated star path. We obtained a dispersion of 0.8′ and we found that the maximum deviations are in correspondence of the gaps between the tiles of pixels (photo detection modules, PDMs).

Fig.2: Simulation of a long tracking observing run: the star centroid moves along a circle (*yellow*) and its light spot is integrated over pixels (*grey scale*) allowing us to reconstruct the original path (*red*).

[1] Antonelli, talk 832, ICRC 2021
[2] Segreto et al., PoS ICRC 2019, arXiv:1909.08750
[3] Giro et al., A&A 2017, arXiv:1709.08418
[4] Iovenitti et al., in prep.
[5] Iovenitti, poster 829, ICRC 2021

TRANSFORMATION MATRIX

To reduce the distortions introduced by the large pixel size, we adopted a transformation matrix containing the displacement of spots, sampled in a fine grid all over the camera [4]. In the simulations, this procedure reduced the dispersion around the original star path of about 40% (i.e. 0.5′ RMS).

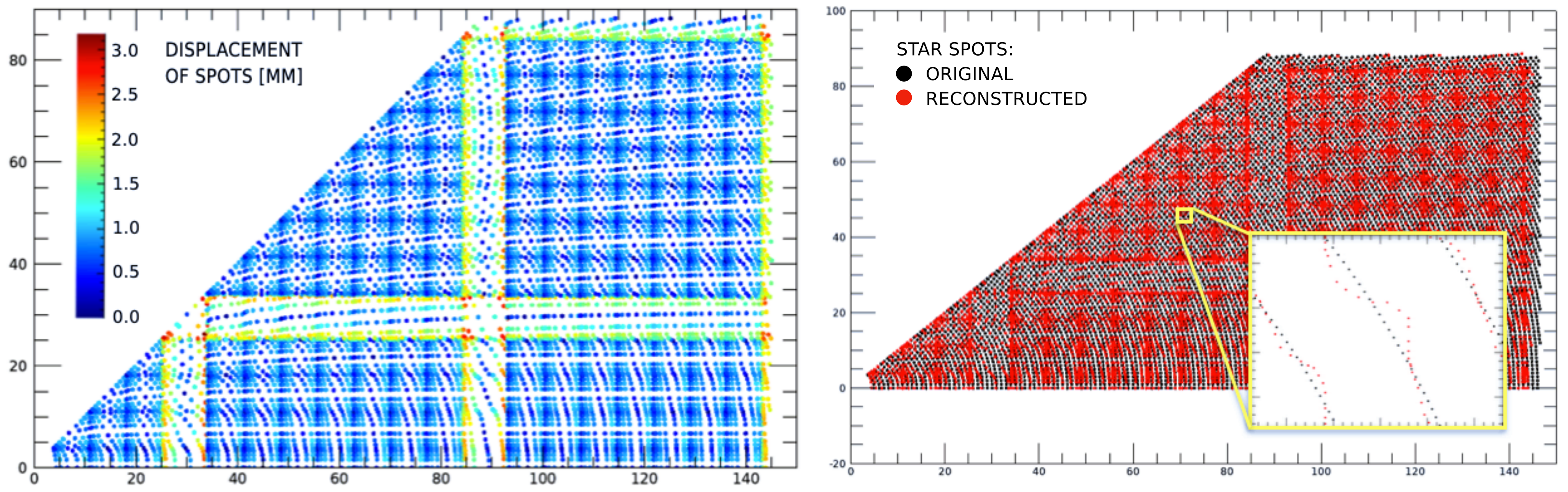


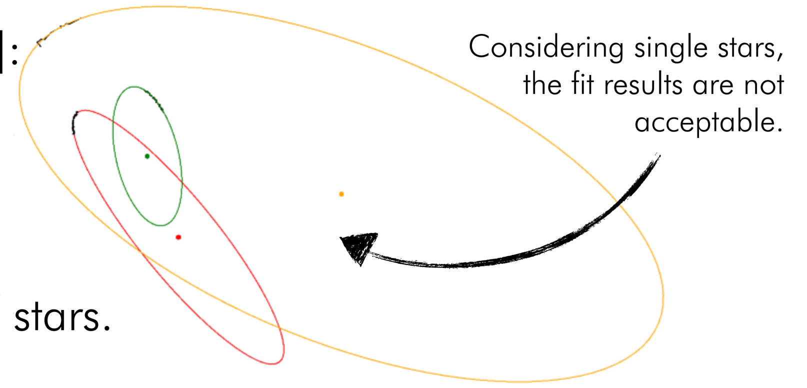
Fig.3: Transformation map (*left*) and the procedure to compute the displacement of each point (*right*).

MULTI-ELLIPSE FIT PROCEDURE

To take into account any possible deviation (e.g. a drift in the tracking) we chose to fit the data with an ellipse rather than a circle. Moreover, we fitted the selected stars *all together*, with a unique multi-ellipse function, so to reduce errors due to residual effects of large pixelization.

Free fit parameters [4]:

- X0 Y0 of center
- theta tilt angle
- eccentricity
- major semi-axes of stars.



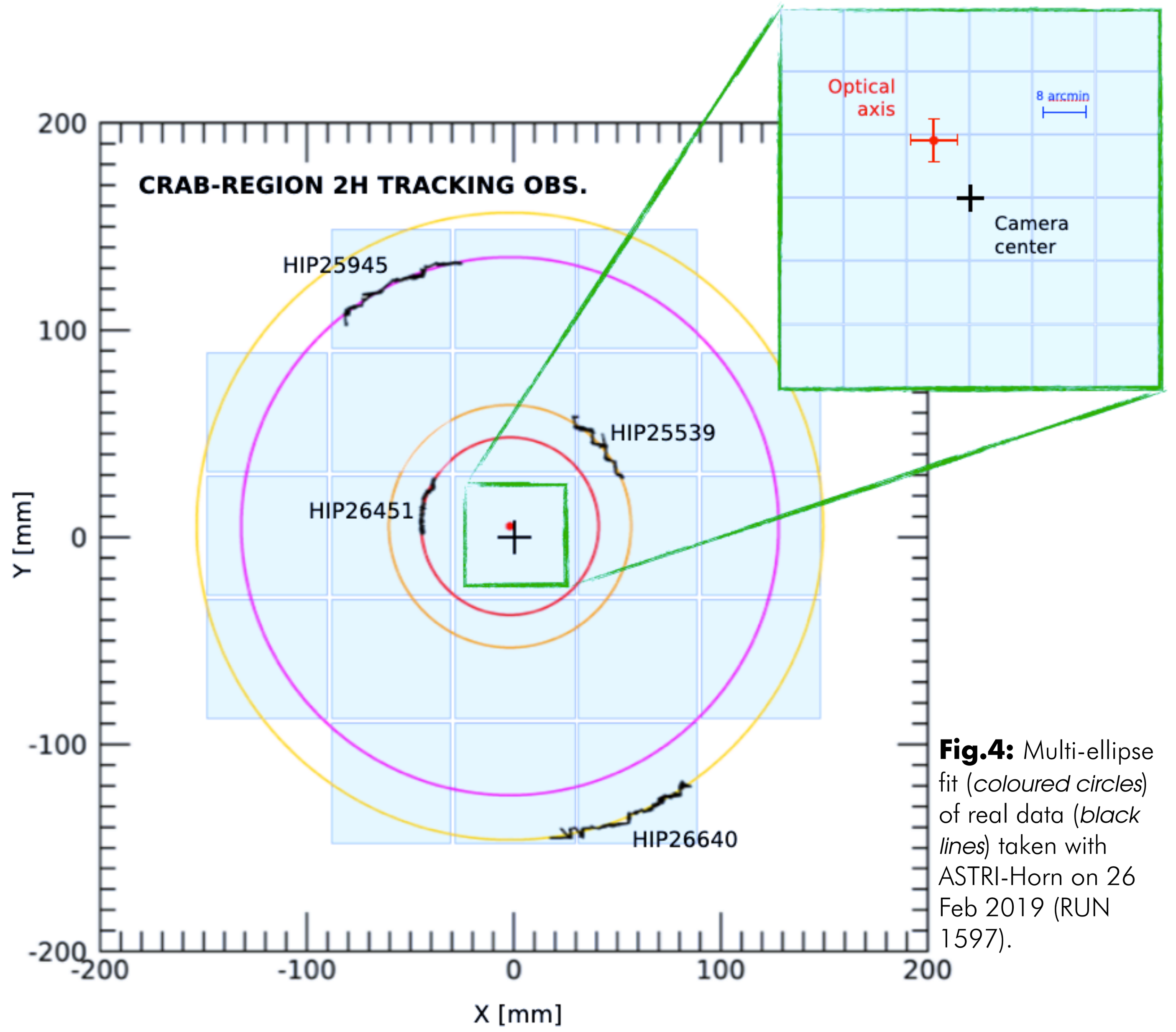


Fig.4: Multi-ellipse fit (*coloured circles*) of real data (*black lines*) taken with ASTRI-Horn on 26 Feb 2019 (RUN 1597).

ANALYSIS AND RESULTS

We performed this analysis on 3 long observing runs of the ASTRI-Horn telescope (1597, 1605, 1620), in tracking mode, considering combinations of 2, 3 and 4 stars. We evaluated the dispersion of the results to estimate the final value for the position of the optical axis and its uncertainty. In particular, we verified that there is actually an offset in the camera alignment, as it is reported in figure 4 (quantitative description in [4]). It is important to notice that the 3 runs considered here are all towards the same region (the Crab Nebula) in the same period, so the telescope performed the same movements to track the source. This could imply the same possible gravity flexure or the same possible errors of the motors' encoders. In addition, the stars available in the FOV were always the same. It will be essential to increase the statistics to support this result, and further studies based on the astrometric analysis of the FOV will confirm or discard this preliminary picture. In any case, this technique will be adopted in the assembly integration verification and calibration phase of the incoming ASTRI Mini-Array [1].