PhD SCHOOL IN PHYSICS, ASTROPHYSICS AND APPLIED PHYSICS
UNIVERSITÀ DEGLI STUDI DI MILANO
CICLE XXXIV

Cycle of seminars *"Theory and Pheno"* offered by
the National Institute of Nuclear Physics
at the Physics Dept. in Genova

Astrometry techniques for the calibration of the ASTRI telescope with the Variance method

Speaker:
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Università di Genova - Physics Department (DIFI)
Via Dodecaneso 33, Genova.
(Mar 10, 2022)

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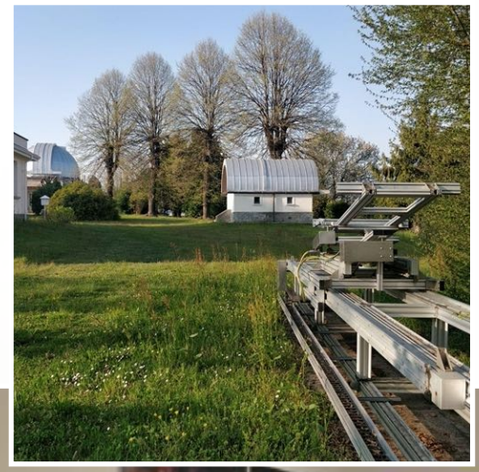
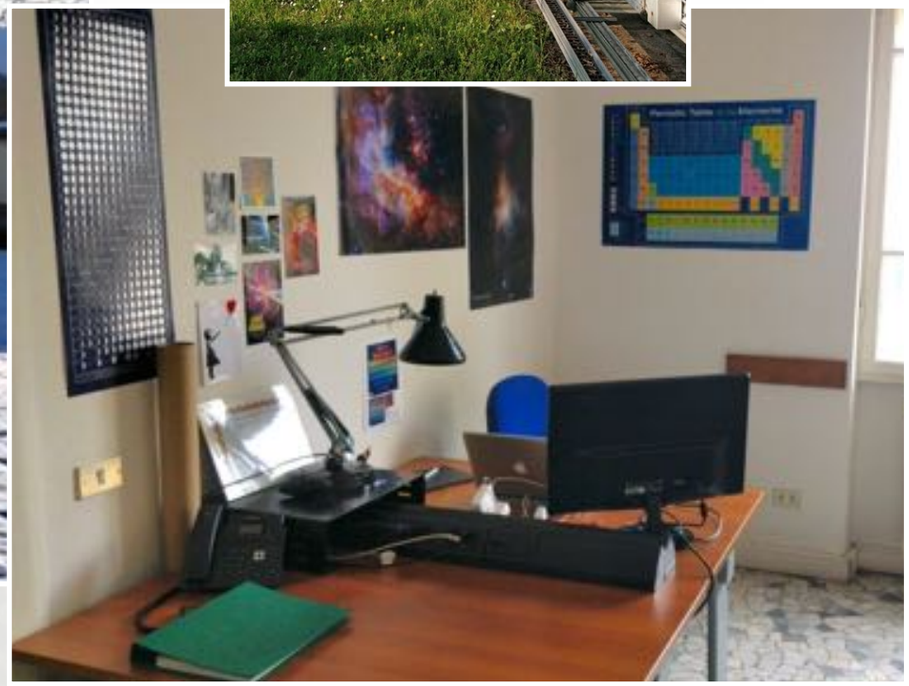
CICLE XXXIV

Work carried out in Merate (INAF - Osservatorio Astronomico di Brera)





Università di Genova - Physics Department (DIFI)
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(Mar 10, 2022)

OUTLINE:

PART 1 ***The ASTRI project***

PART 2 ***Variance images***

PART 3 ***Camera axis alignment***

PART 4 ***Star field astrometry***

PART 5 ***Conclusion***

The VHE Gamma-Ray sky

Binary
Systems

Gamma
Ray
Burst

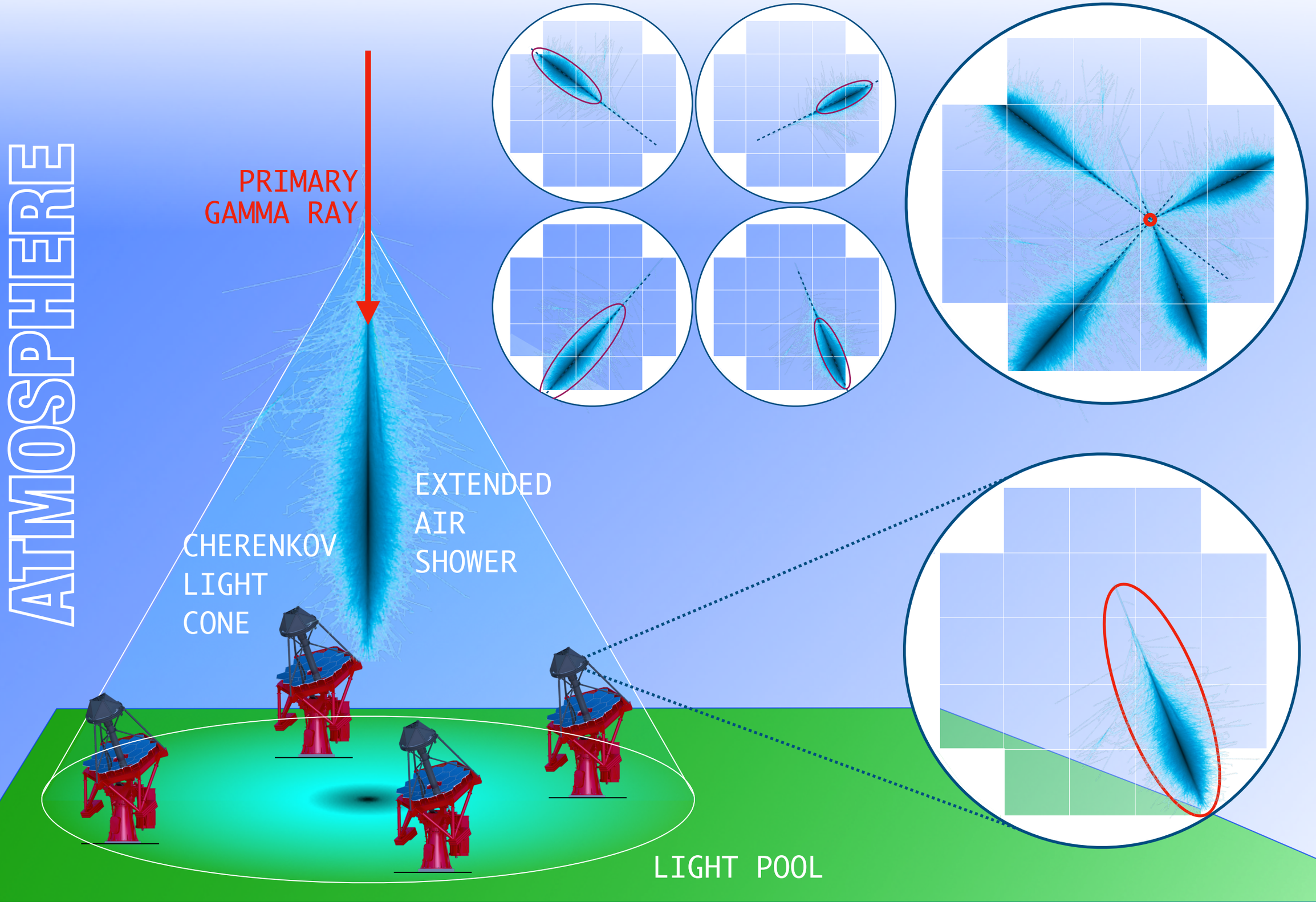
Pulsar
Wind
Nebulae

GW events

Active
Galactic
Nuclei

Super
Nova
Remnants

The Cherenkov Flash



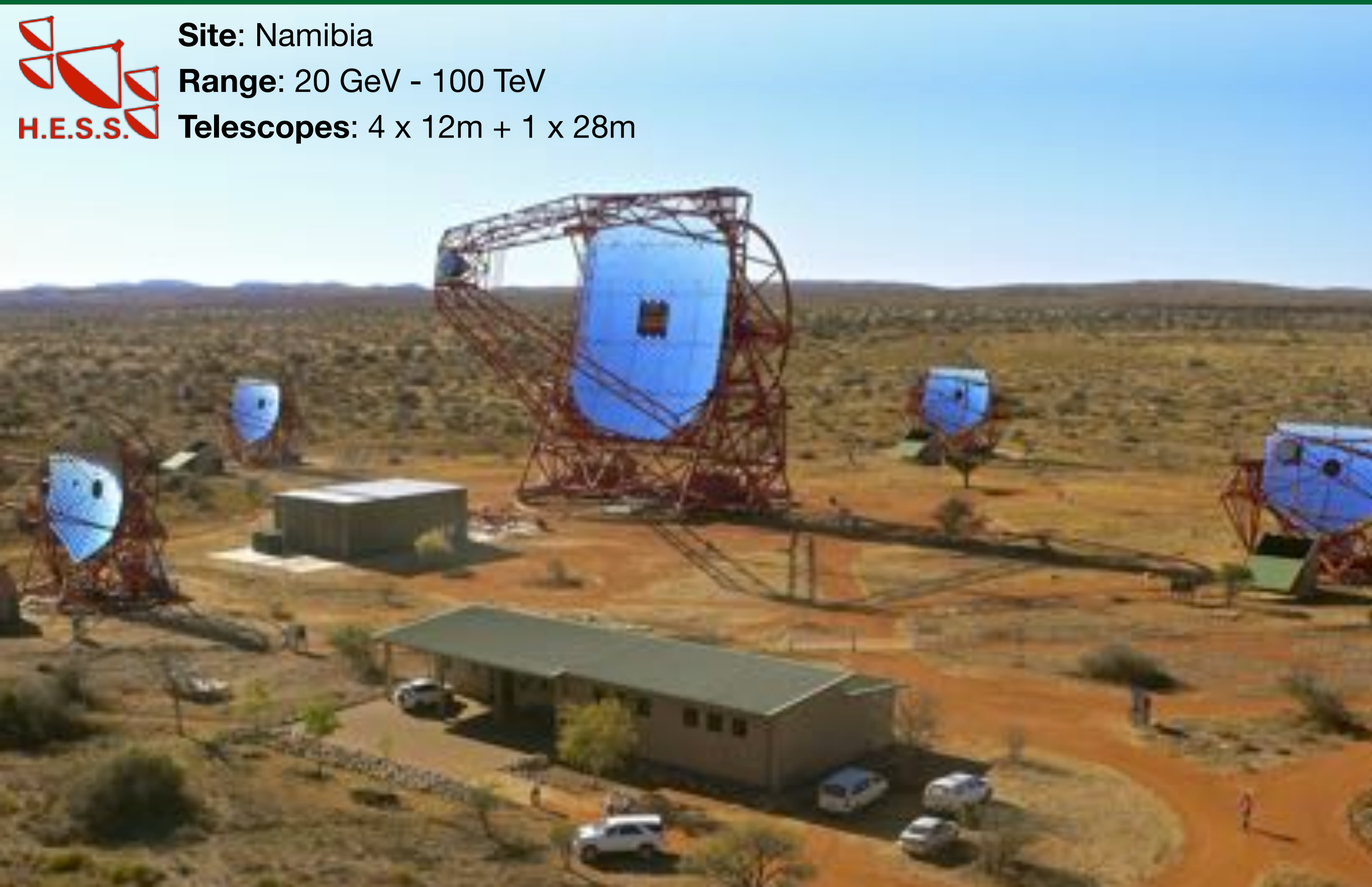
Imaging Atmospheric Cherenkov Telescopes

H.E.S.S.

Site: Namibia

Range: 20 GeV - 100 TeV

Telescopes: 4 x 12m + 1 x 28m



Imaging Atmospheric Cherenkov Telescopes

Site: Arizona

Range: 100 GeV - 10 TeV

Telescopes: 4 x 12m

Imaging Atmospheric Cherenkov Telescopes

Site: La Palma

Range: 25 Gev - 30 TeV

Telescopes: 2 x 17m

The future of IACTs: CTA observatory

Site: Atacama desert + La Palma island

Range: 20 Gev - 300 TeV

Telescopes: **LST**(8) + **MST**(40) + **SST**(70)

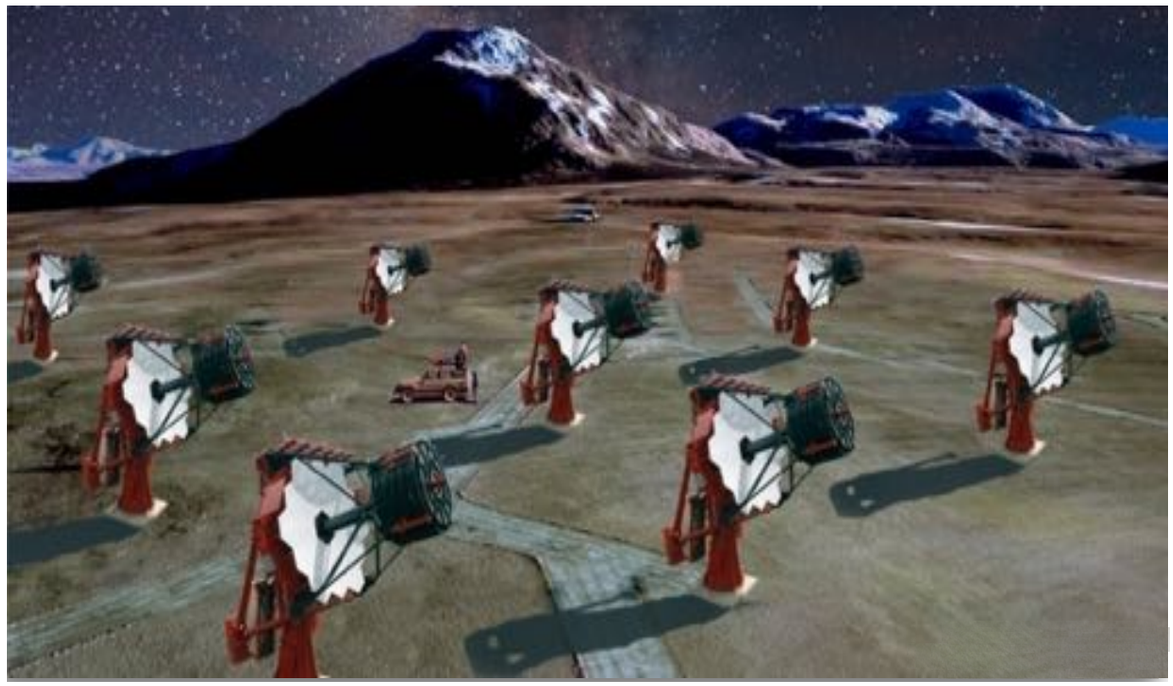
The ASTRI project

Astrofisica con **S**pecchi a **T**ecnologia **R**eplicante **I**taliana

an Italian project for gamma-ray ground-based studies (end-to-end development of a new telescope)

1 The ASTRI-Horn telescope
(Italy, Mount Etna)
prototype

2 The ASTRI mini-array
(9 telescopes, Tenerife)
observatory

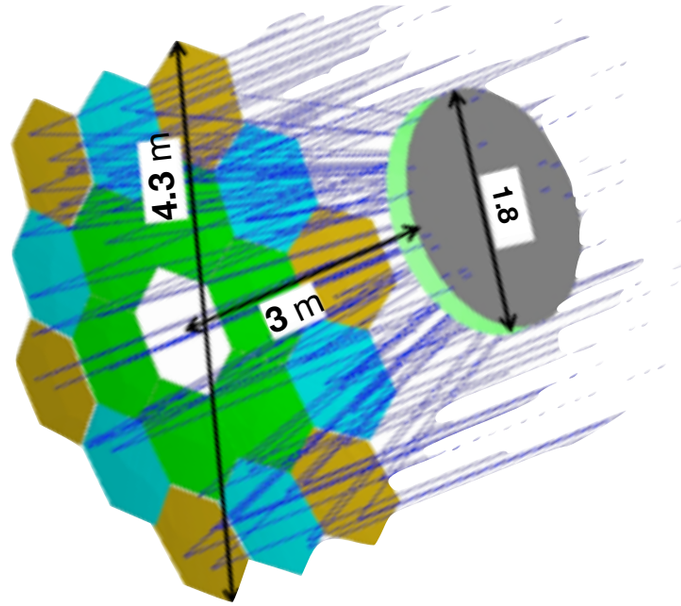


Scuderi et al., 2018 (arXiv:10.1117/12.2312453)

Opto-mechanical novelties

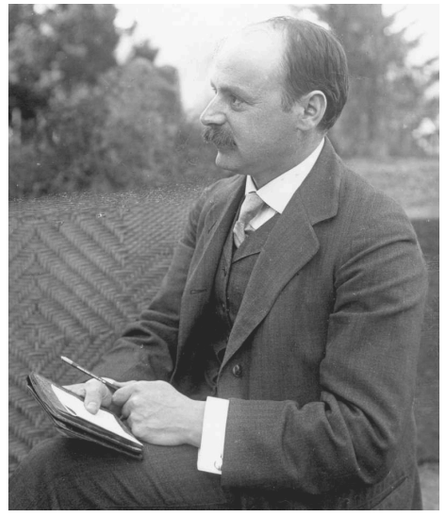
A REVOLUTIONARY DESIGN!

- First **dual-mirror** in IACT
- First **Schwarzschild-Couder** (SC) telescope



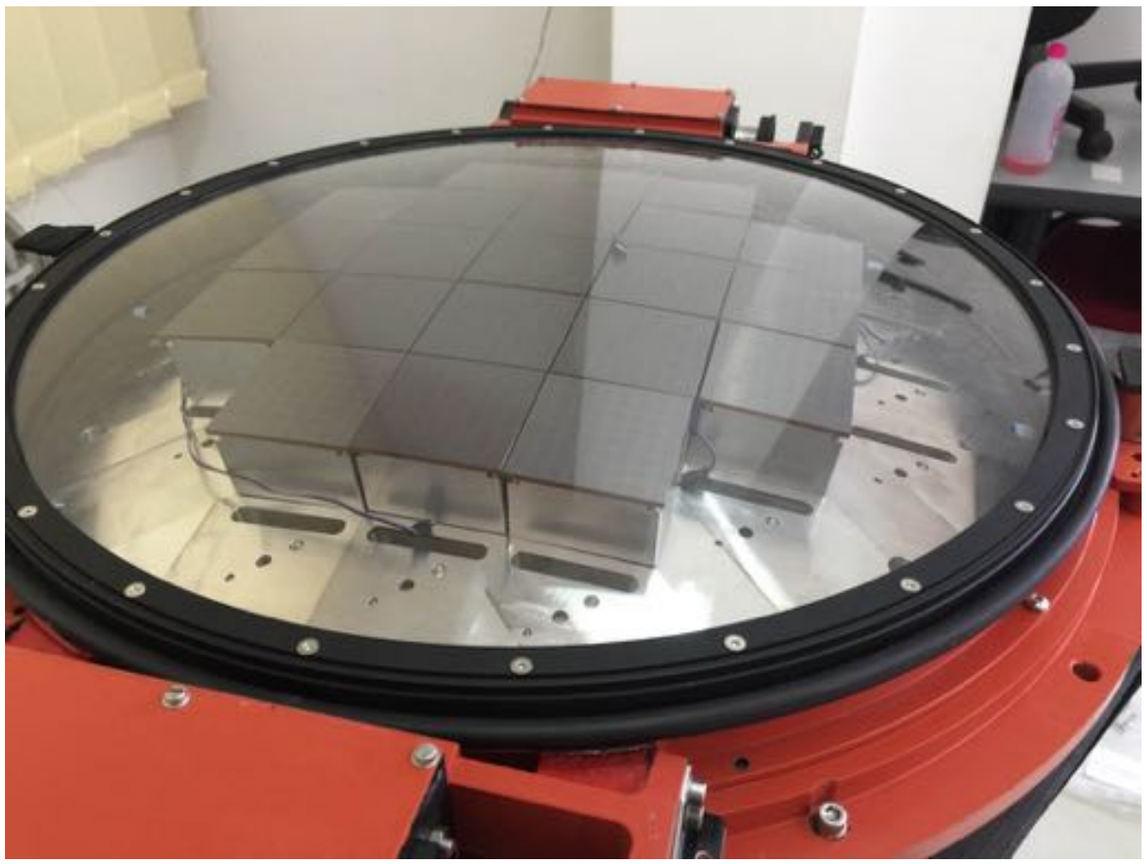
Advantages of SC configuration:

- ☑ Aplanatic FoV → no coma and spherical aberration
- ☑ Double reflection → short focal length
- ☑ Small plate-scale → large FoV (~10°) w small camera (~50cm)
- ☑ Flat PSF to wide angle → constant angular resolution across FoV



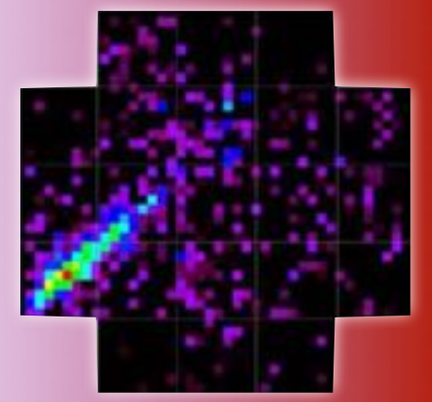
Giro et al., 2017 (arXiv:1709.08418)

The Cherenkov camera



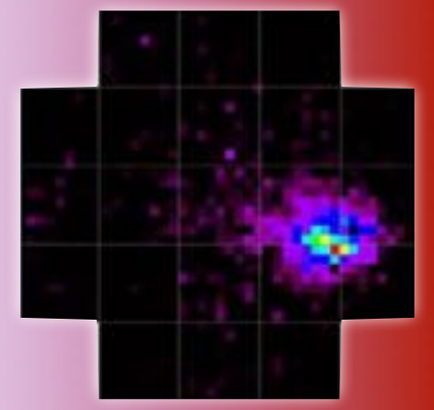
Curved focal plane

21 Photo Detection Module (PDM)
64 SiPM detectors each (pixels)
200-1000 nm range

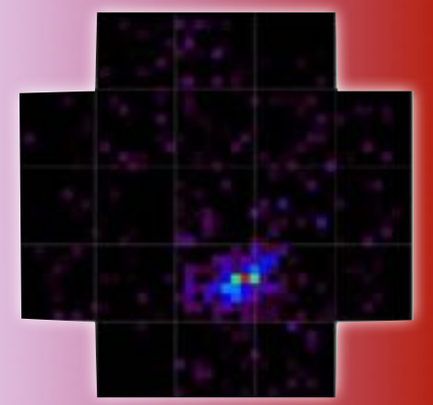


Imaging properties

7 mm pixel size
0.18 deg



Electronics optimized
to detect ~25 ns signals
in *acquirement* modality



BLIND
to star field and PSF

REAL DATA!

OUTLINE:

PART 1 ***The ASTRI project***

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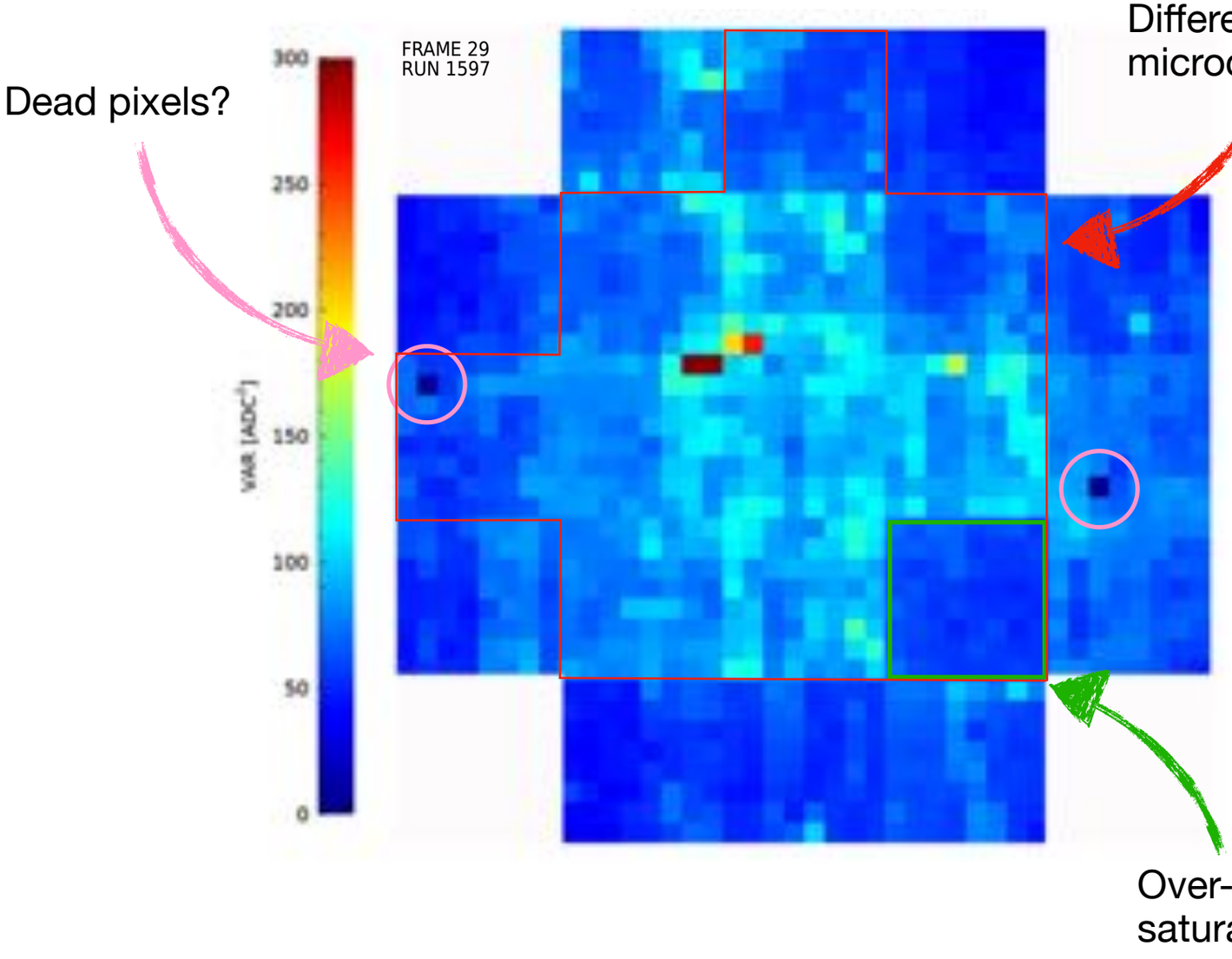
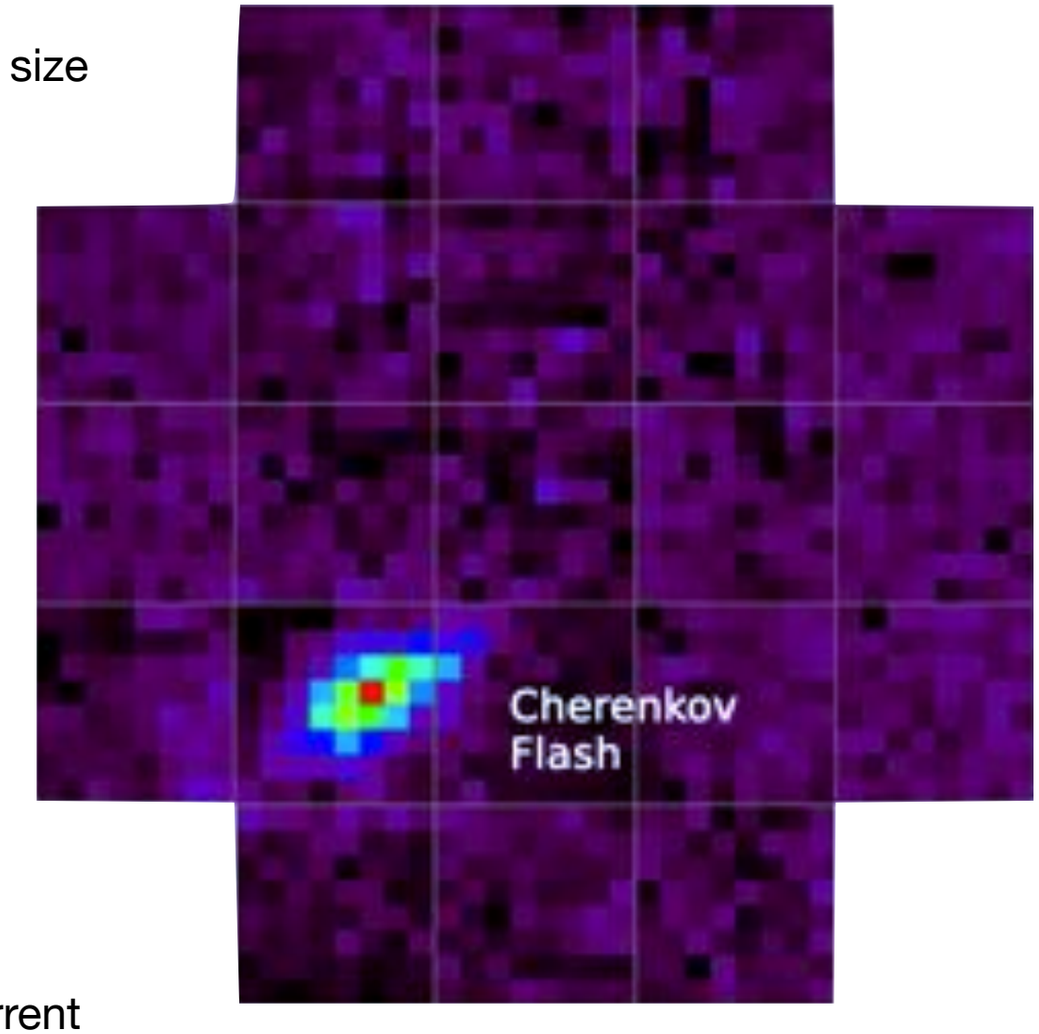
The VARIANCE method

Random sampling of ADC pedestal value





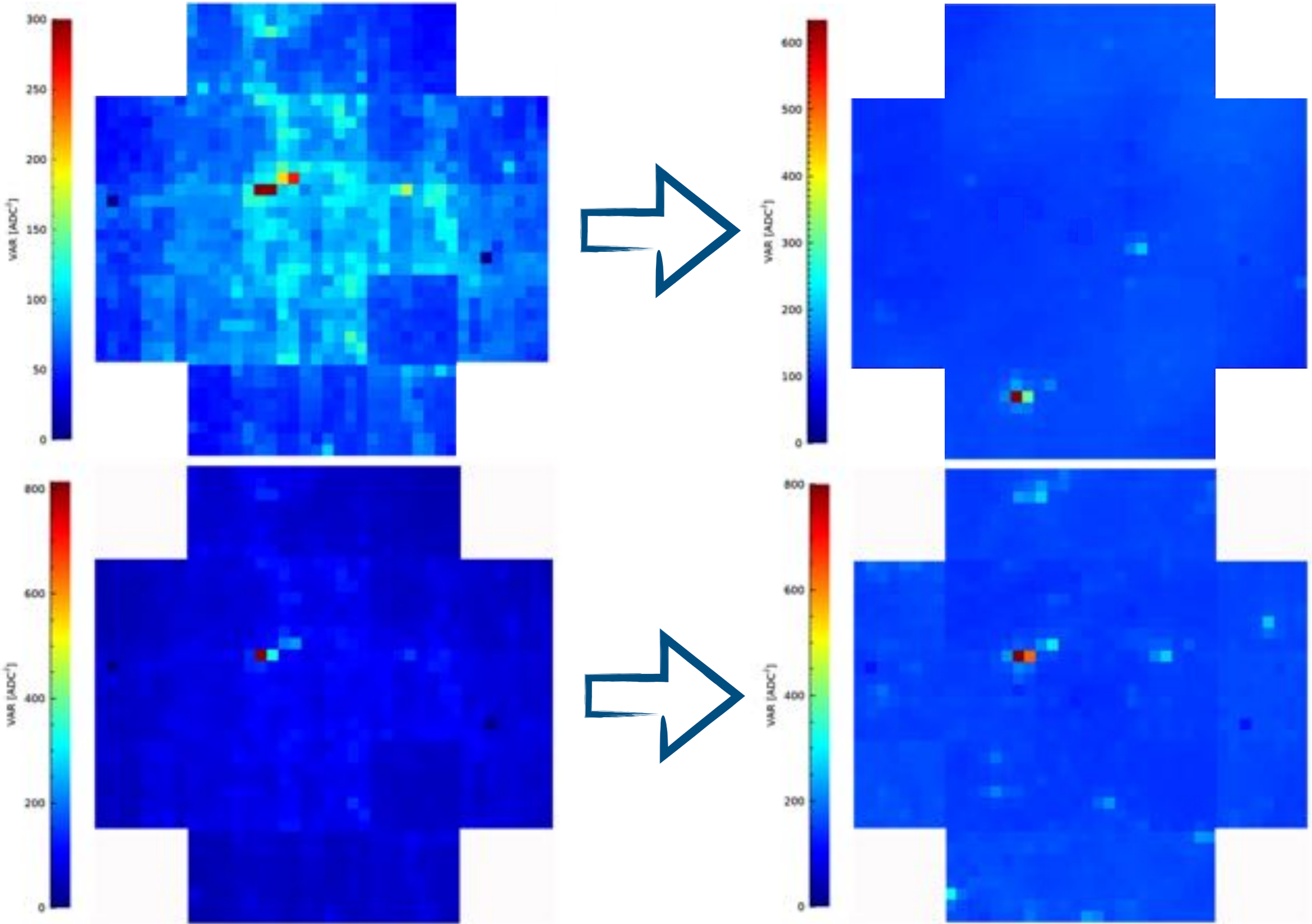
Raw images:

- Coarse pixel resolution
- 8th visual magnitude

Segreto et al., ICRC 2019, 36-791s

Statistical Calibration

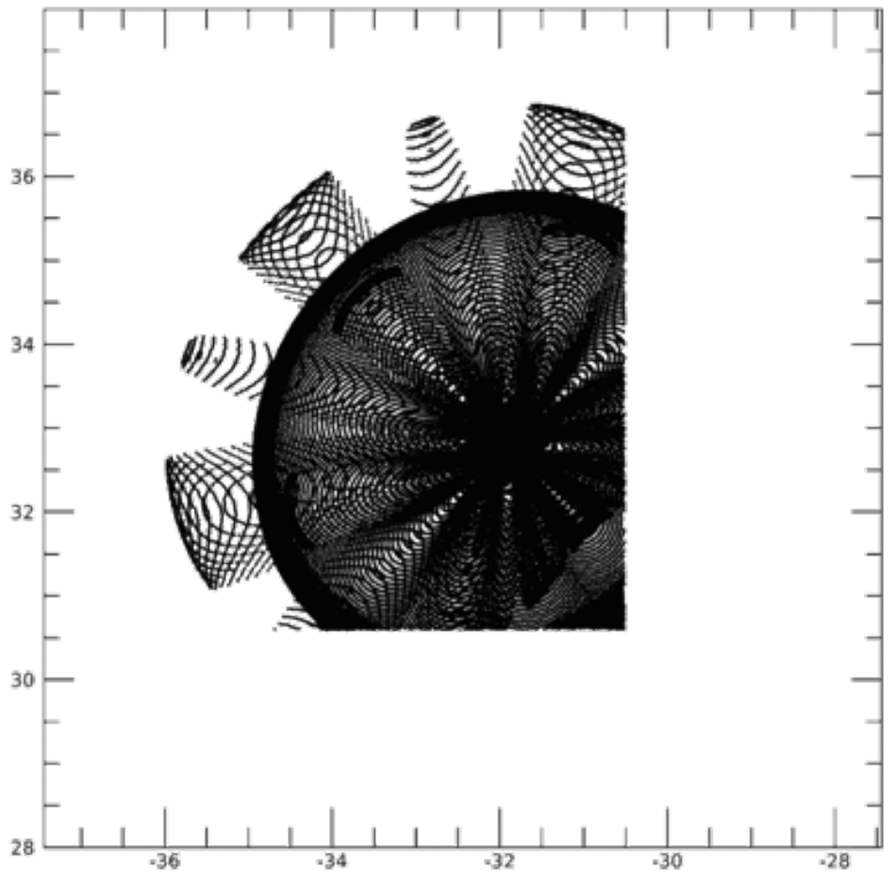
FRAME 1366 RUN 1599



FRAME 69 RUN 1597

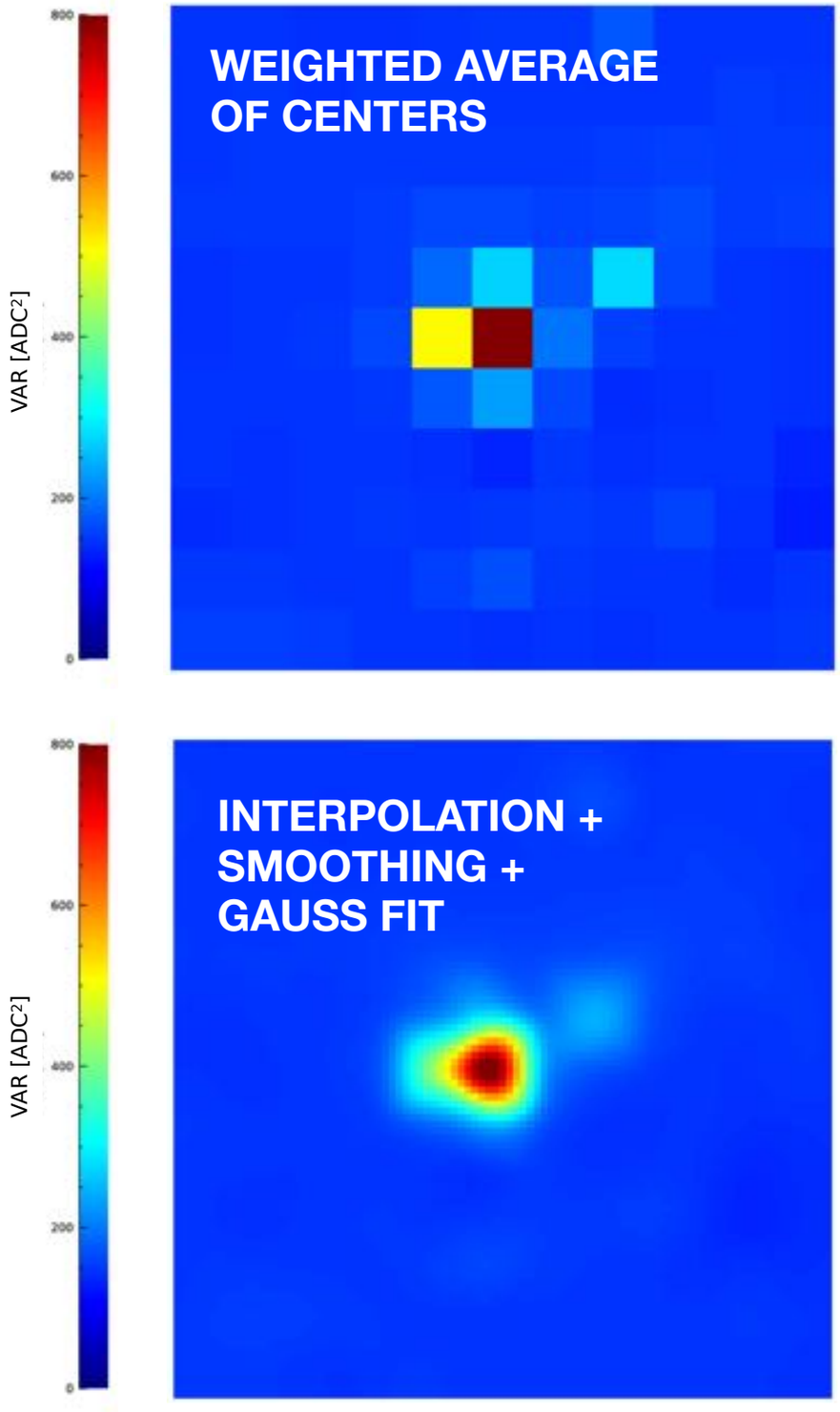
Information loss

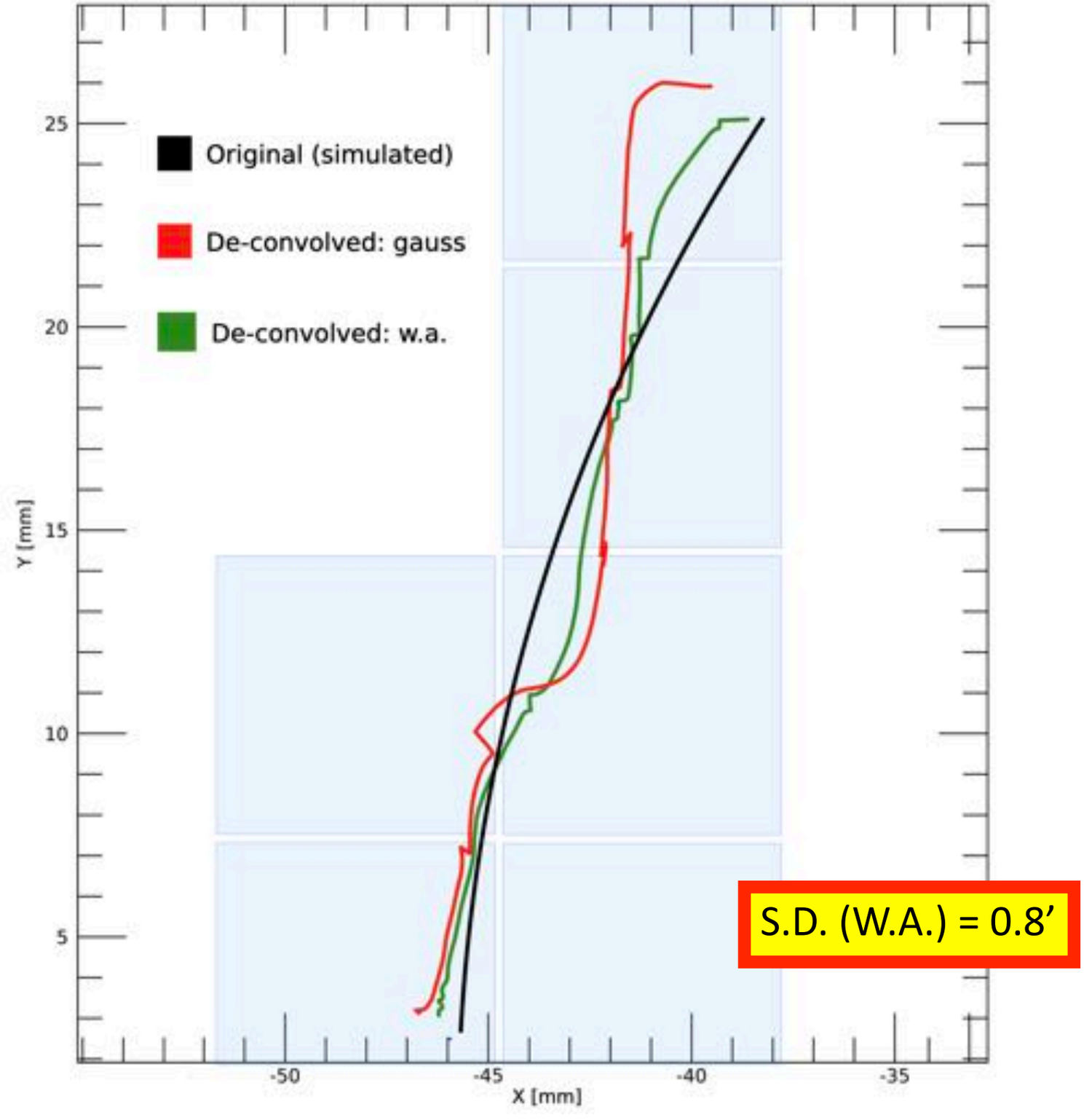
WHAT TELESCOPE DOES…



…WHAT WE WANT TO DO

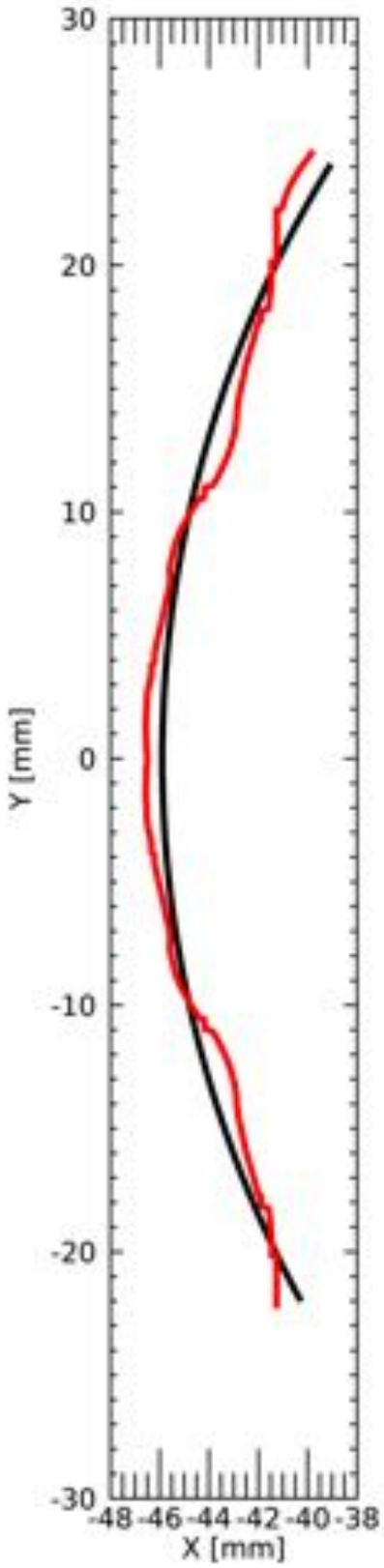
Fitting strategy: Results

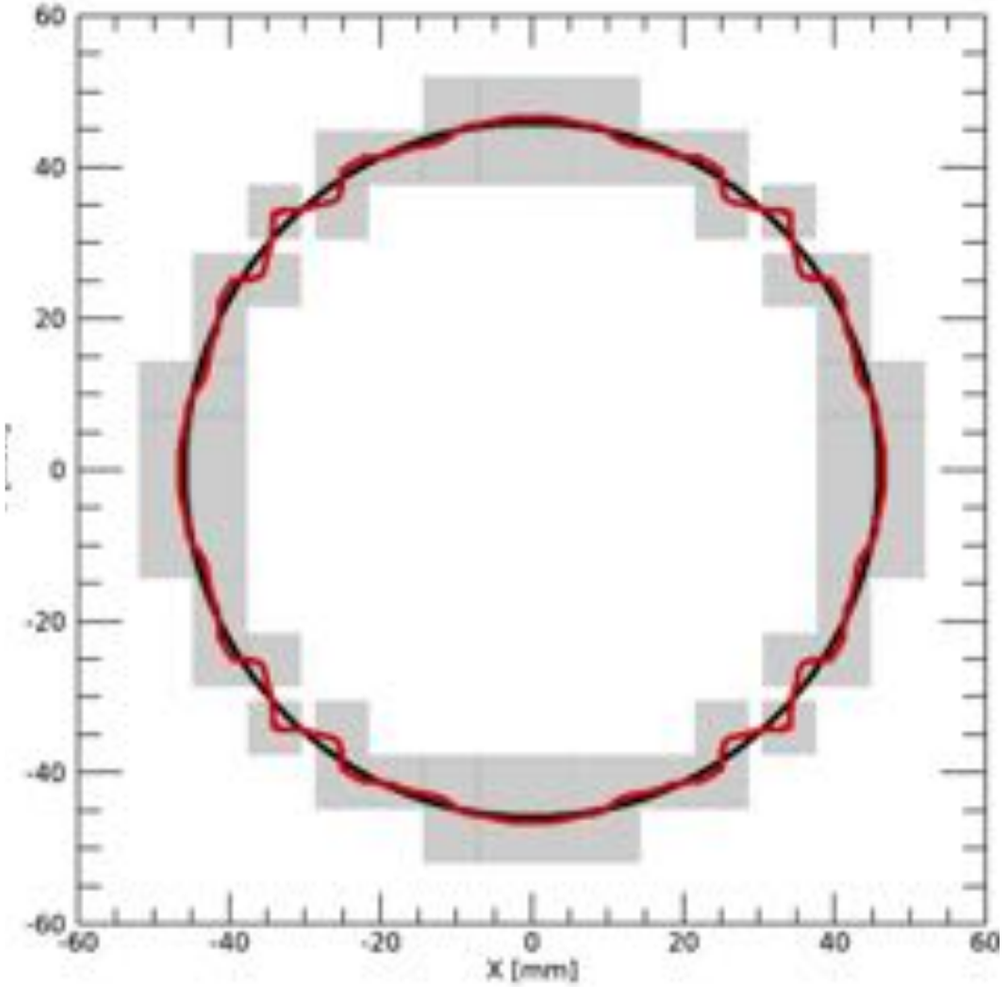




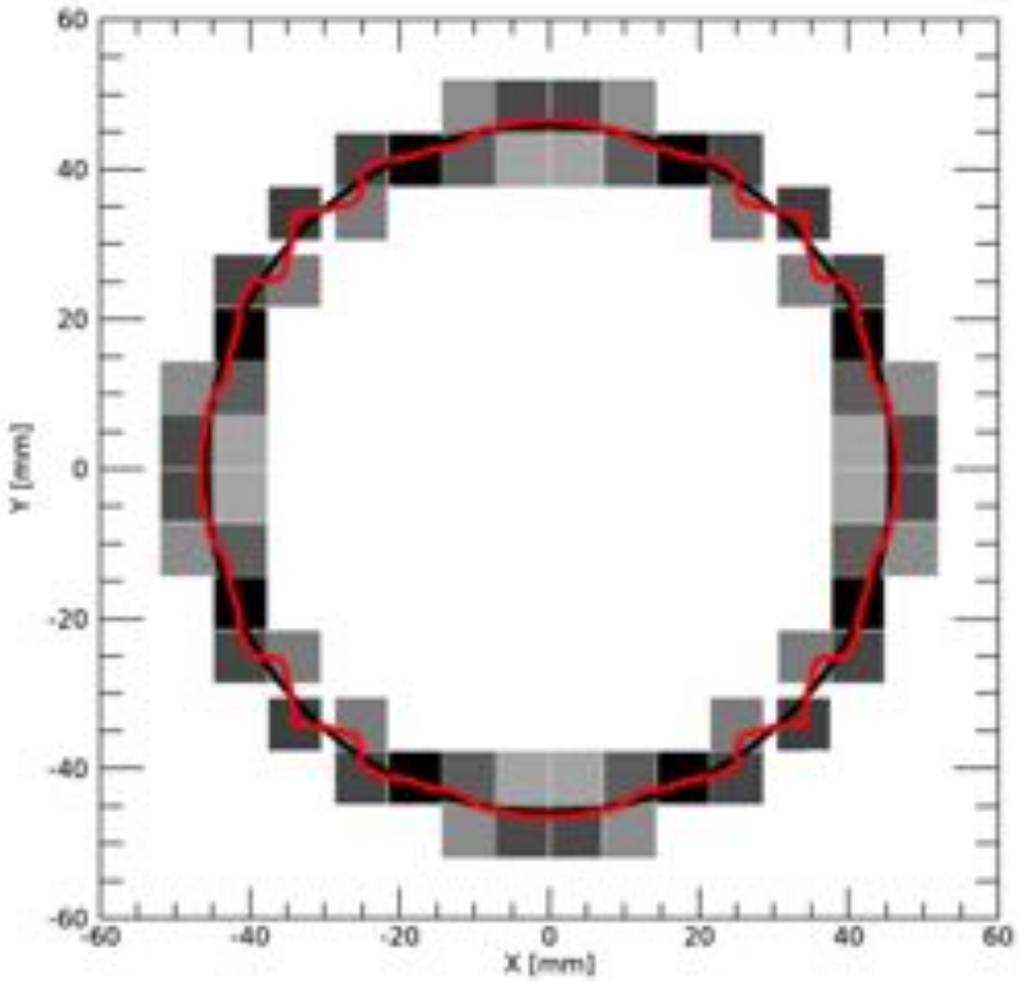
S.D. (W.A.) = 0.8’

Residual effects of convolution



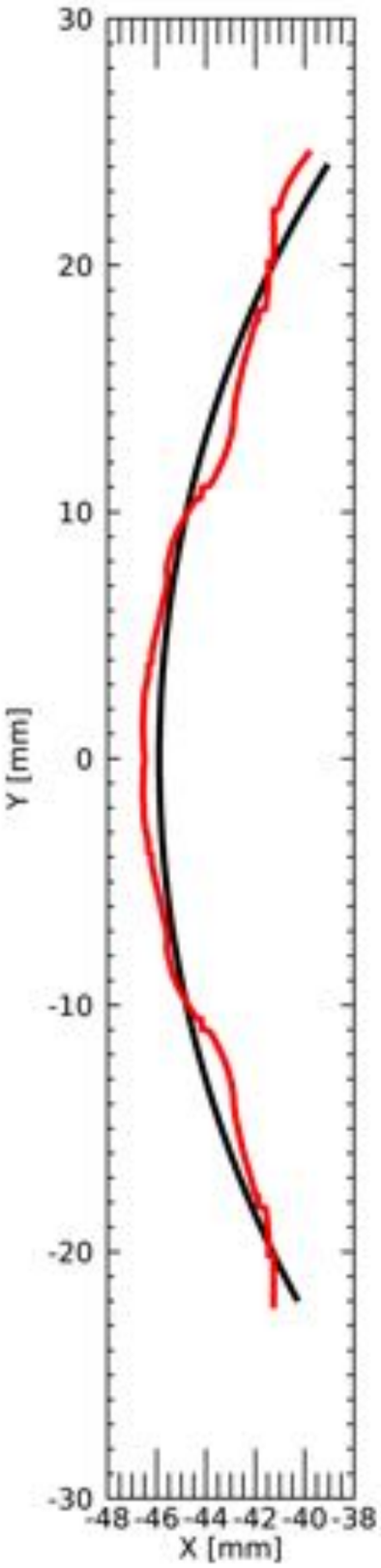


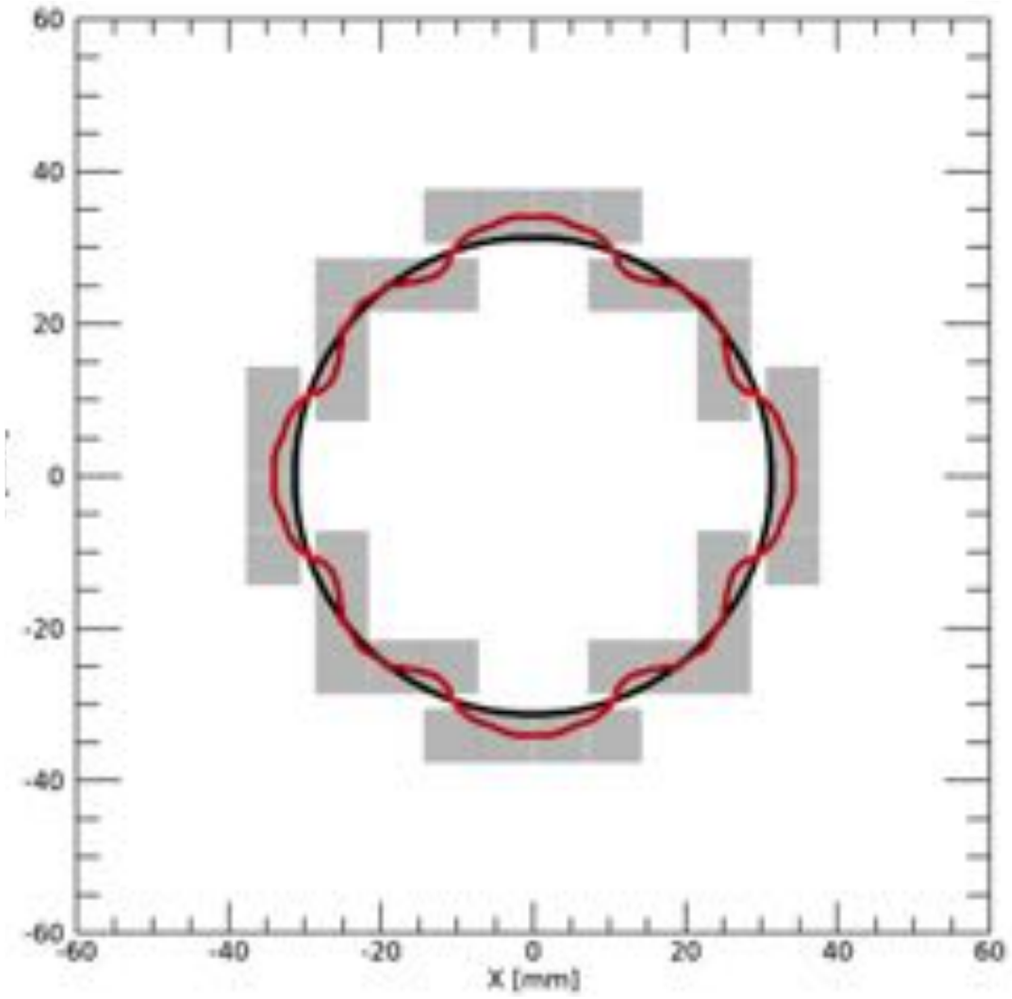
4h @0.1 Hz
Zeta Tau (ID:1597)



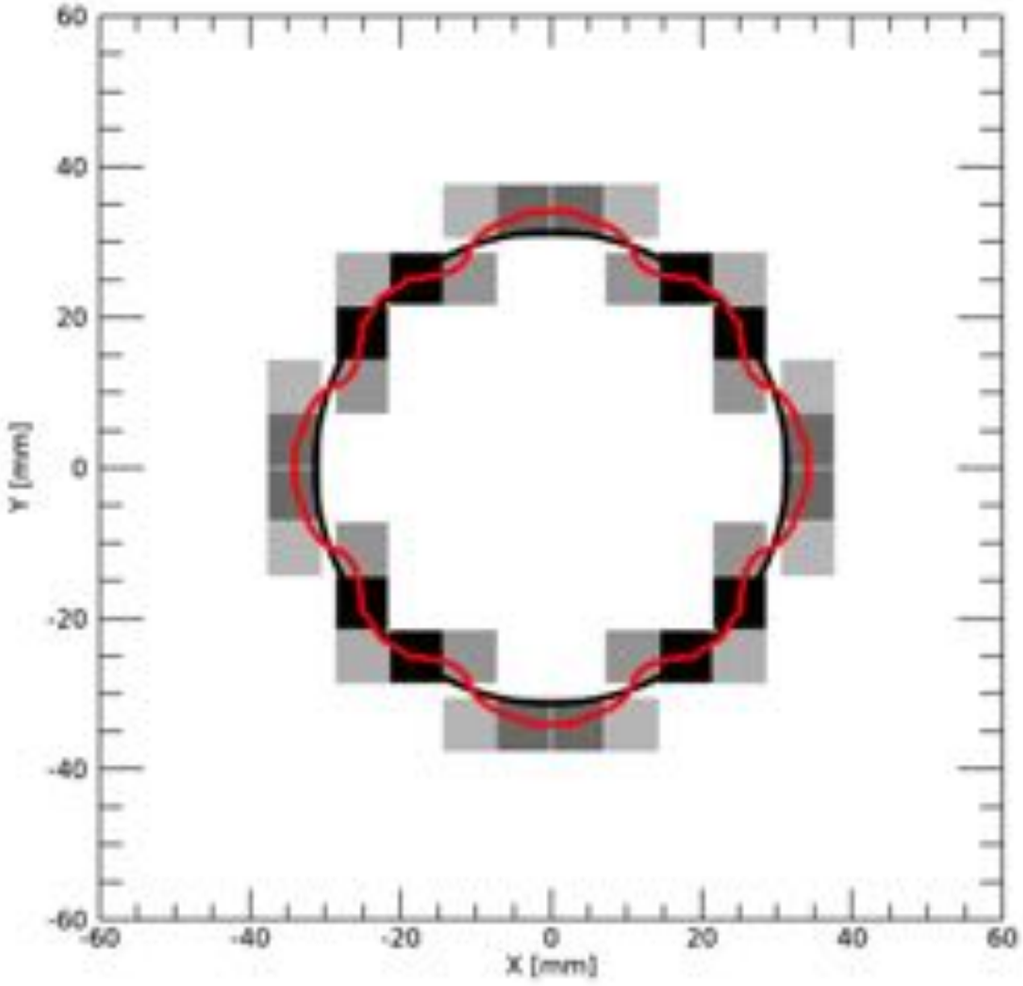
Zeta Tau (ID:1597)
24h @0.1 Hz
D0 = ~45mm
(execution time:
24 min)

Residual effects of convolution



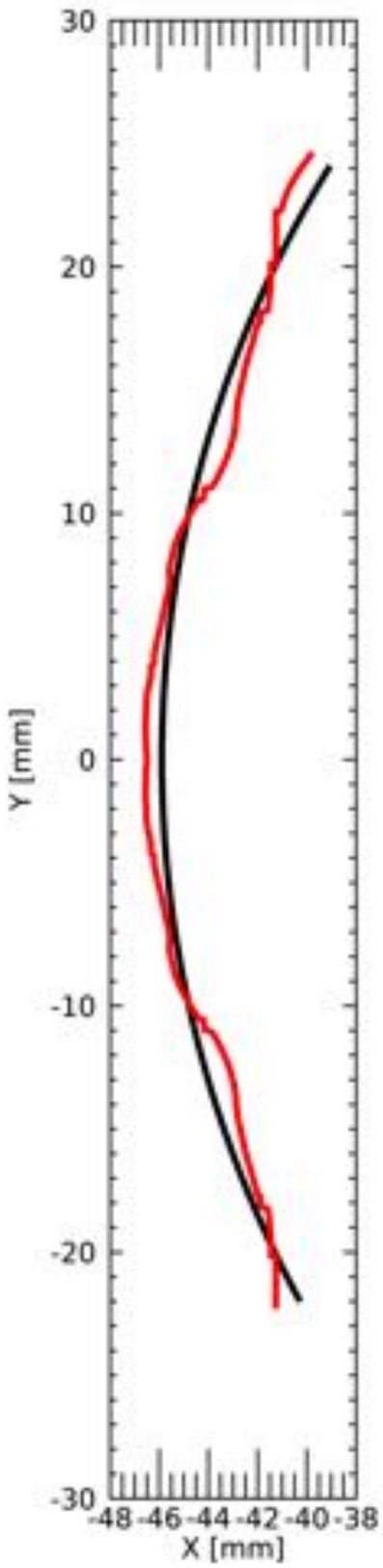


4h @0.1 Hz
Zeta Tau (ID:1597)

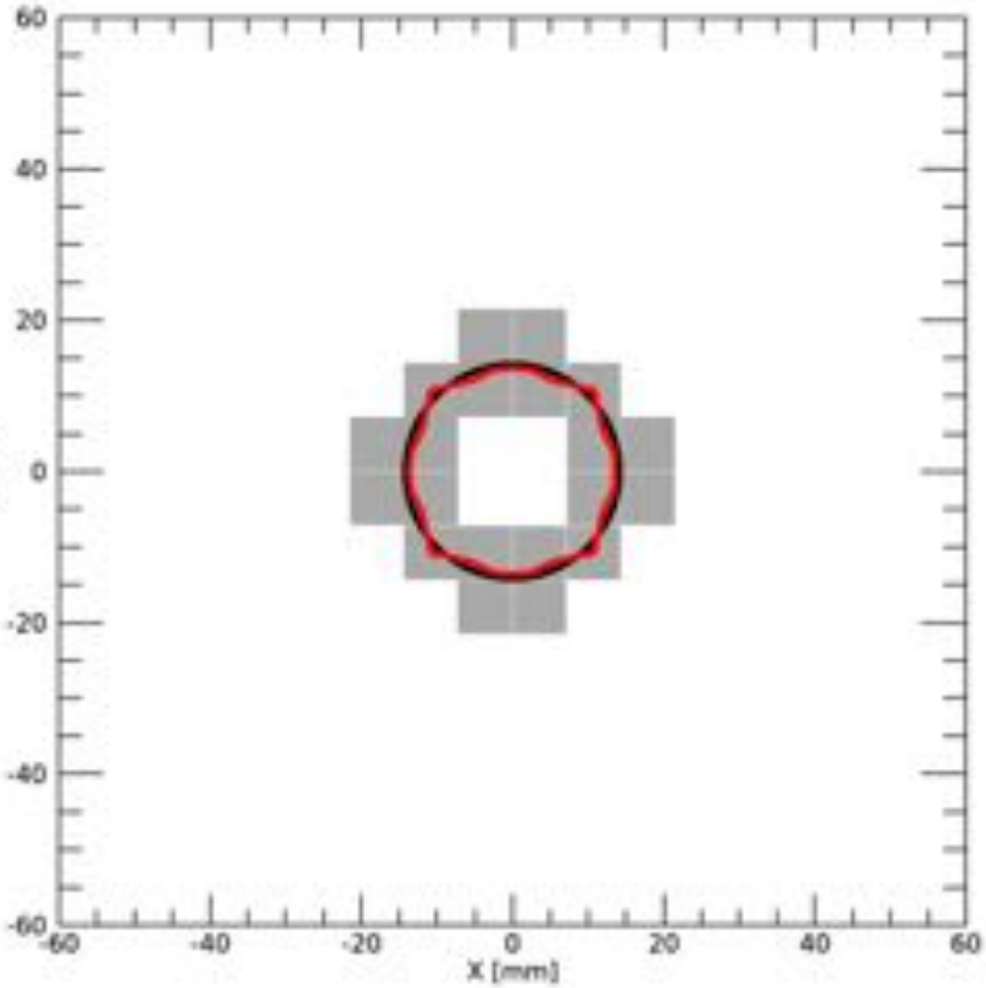


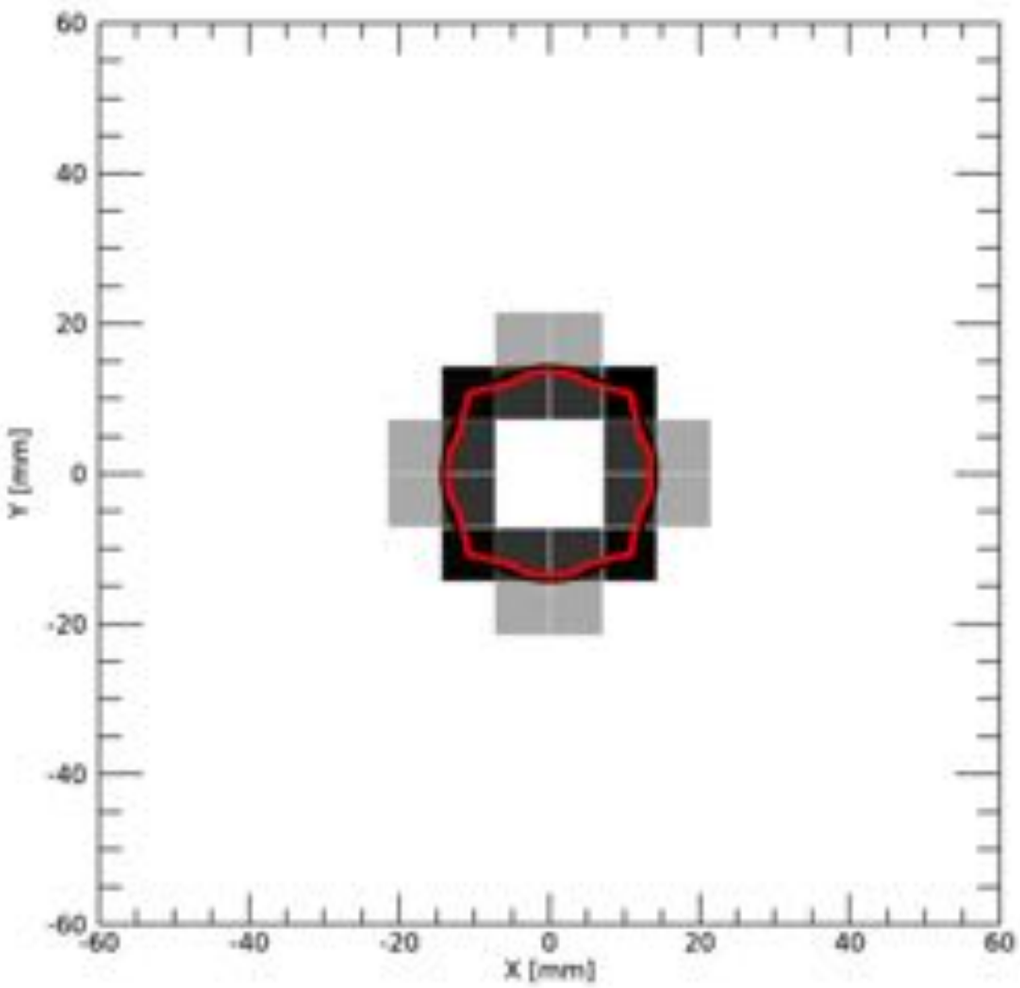
(X0,Y0)=(20,24)
24h @0.01 Hz
D0 = ~30mm
(execution time:
2.5 min)

Residual effects of convolution



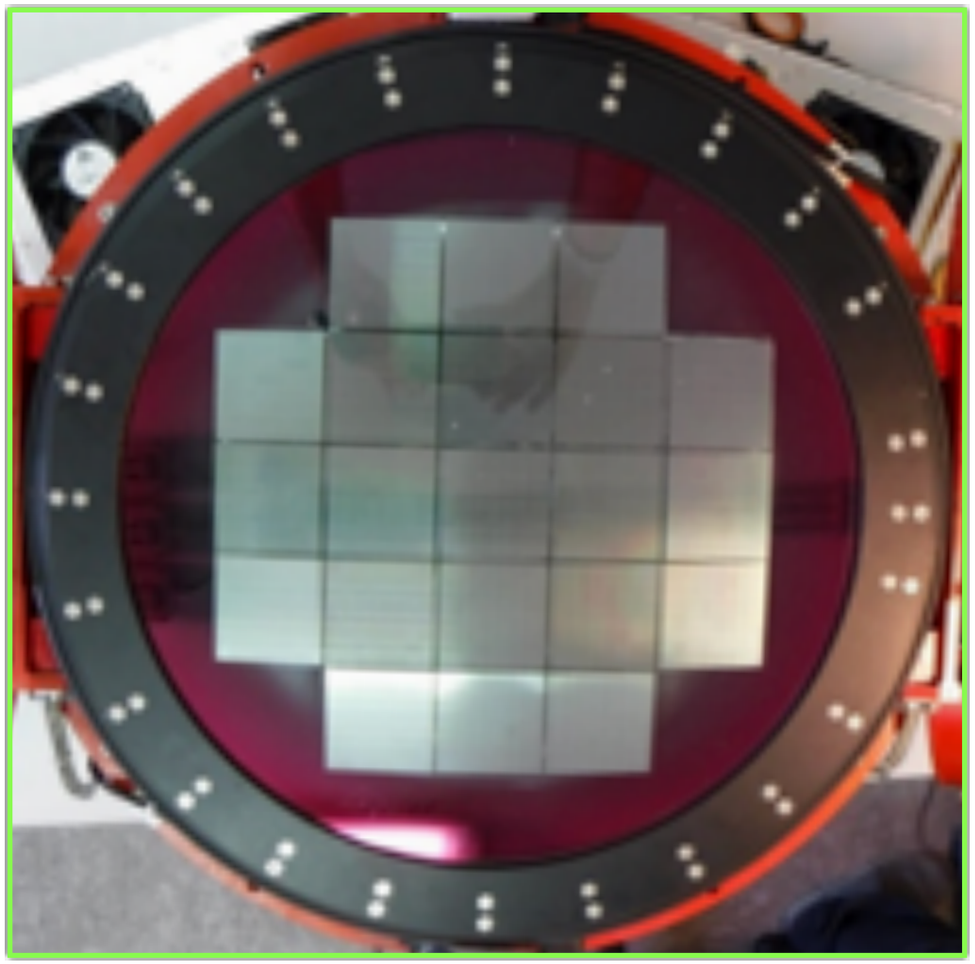
4h @0.1 Hz
Zeta Tau (ID:1597)

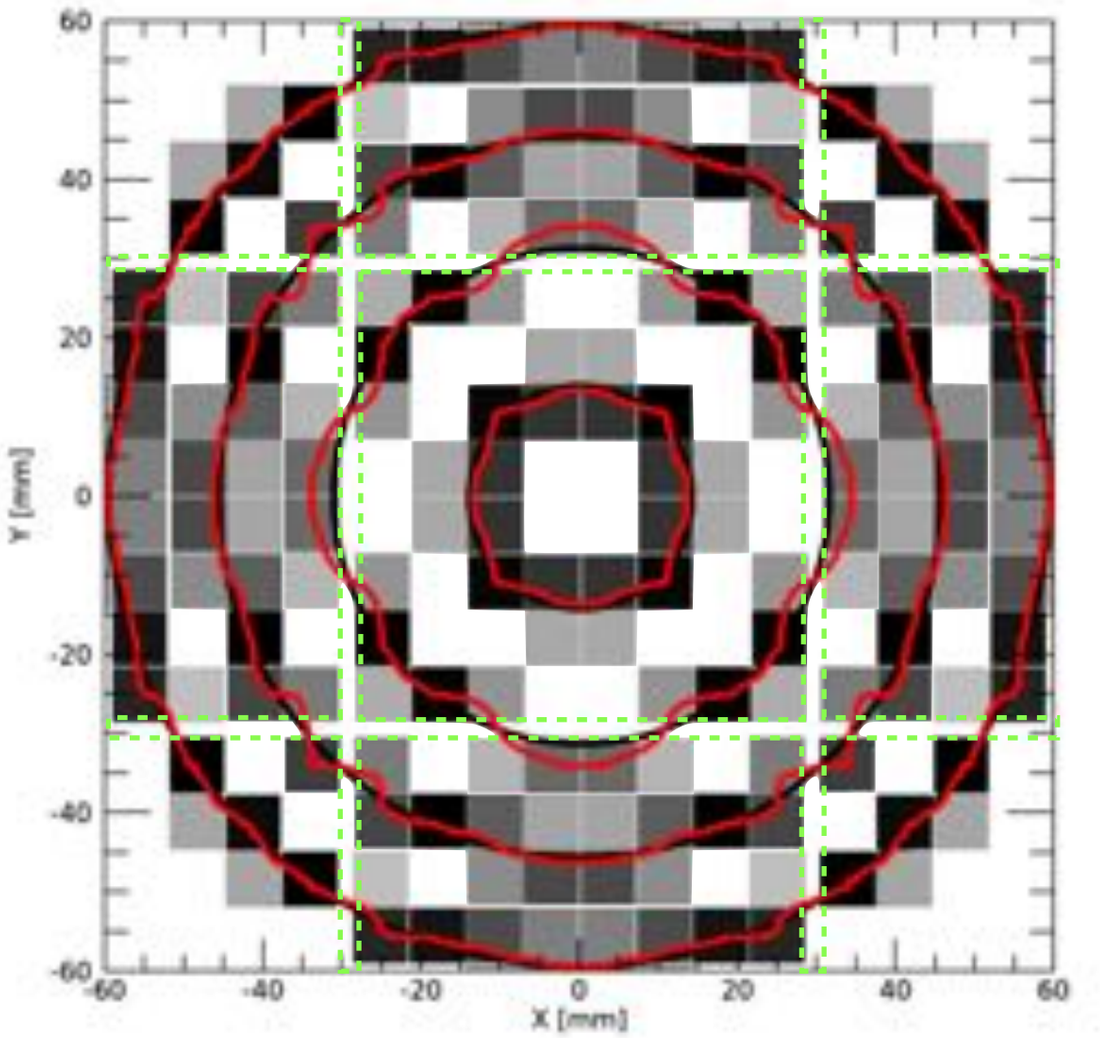




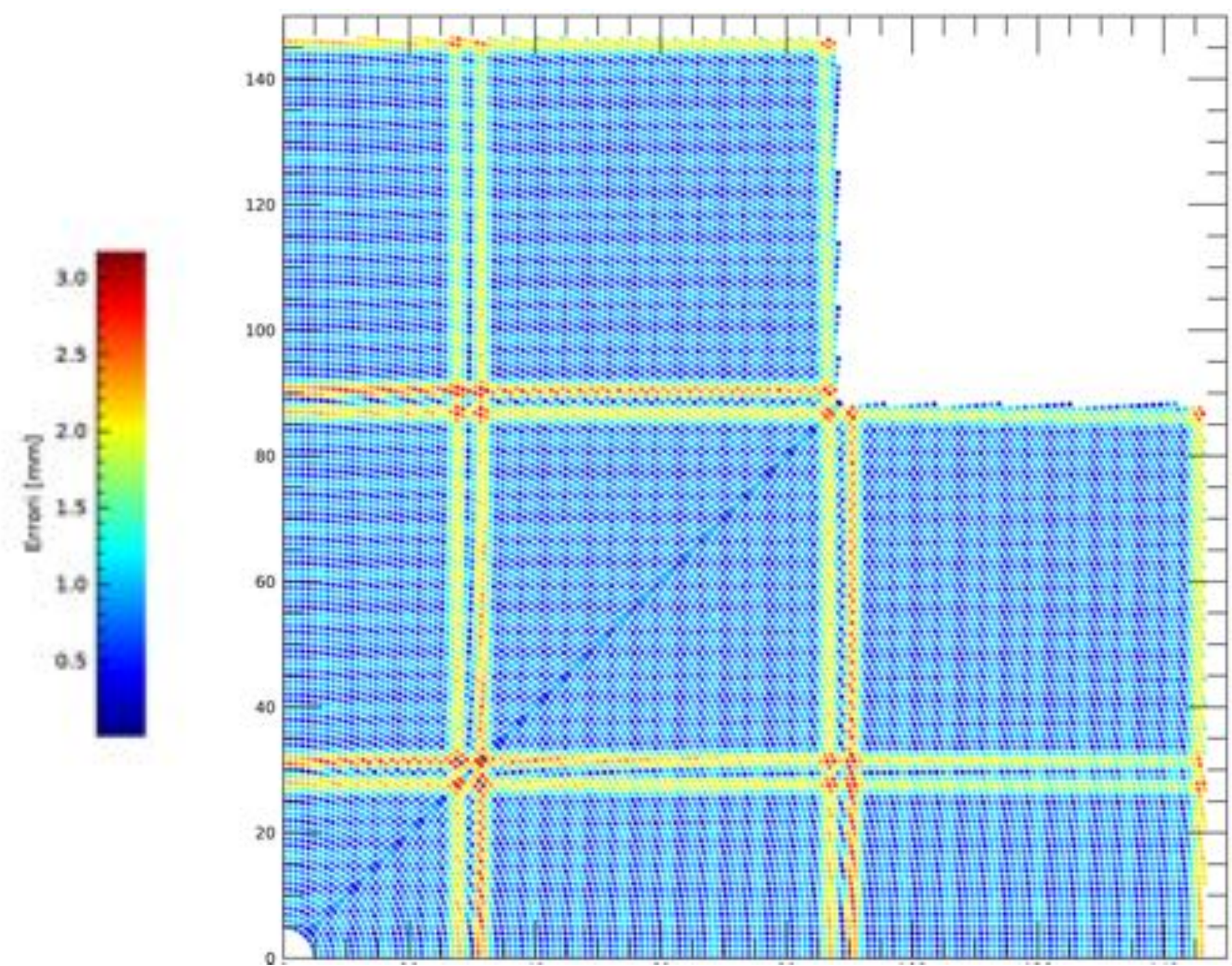
(X0,Y0)=(10,10)
24h @0.005 Hz
D0 = ~14mm
(execution time:
1.1 min)

Effects of gaps between the PDM

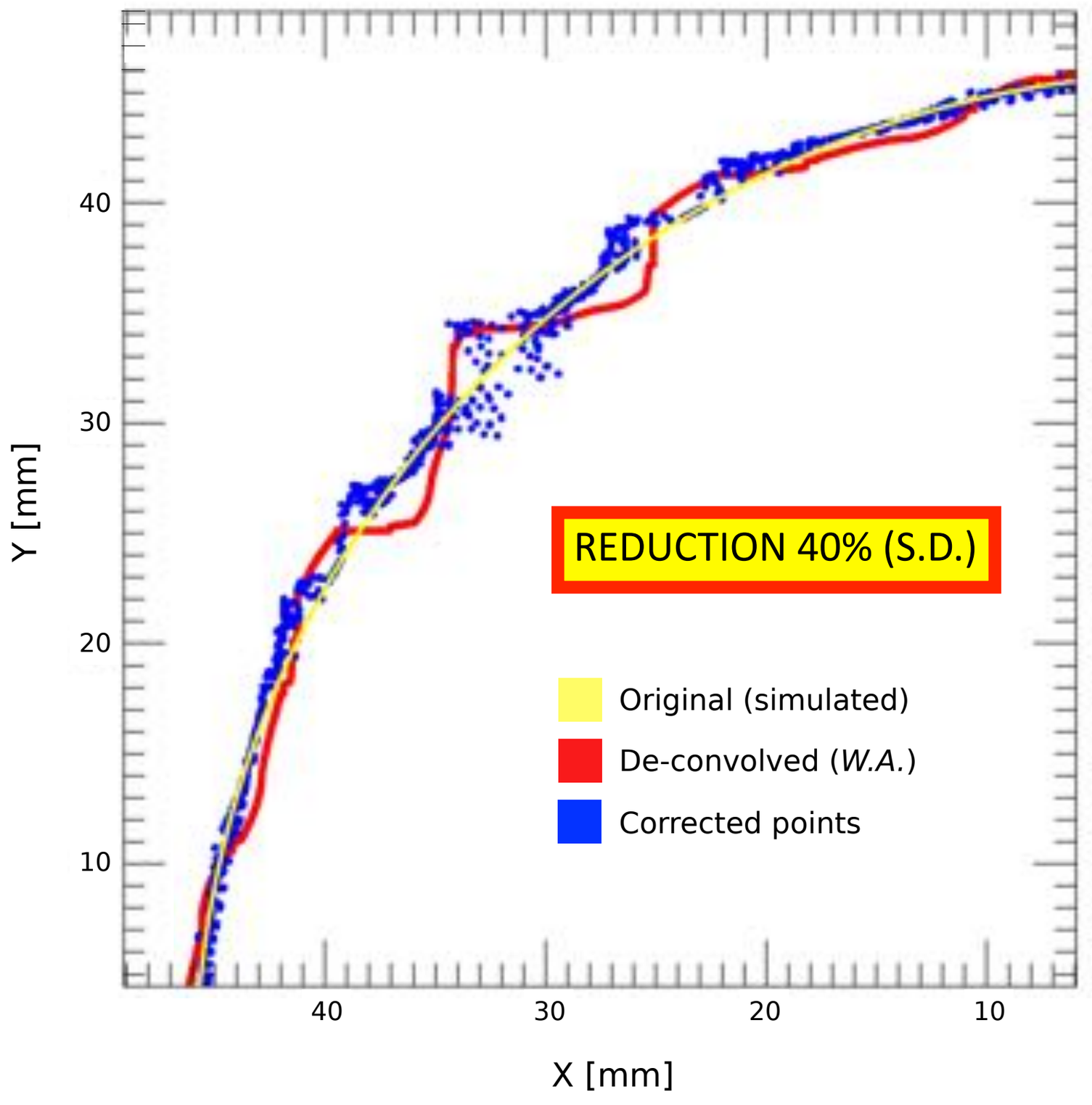




Correction strategy: transformation matrix



RESULTS


40
30
20
10
Y [mm]
40
30
20
10
X [mm]
REDUCTION 40% (S.D.)
Original (simulated)
De-convolved (W.A.)
Corrected points

OUTLINE:

PART 1 ***The ASTRI project***

PART 2 ***Variance images***

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PART 5 ***Conclusion***

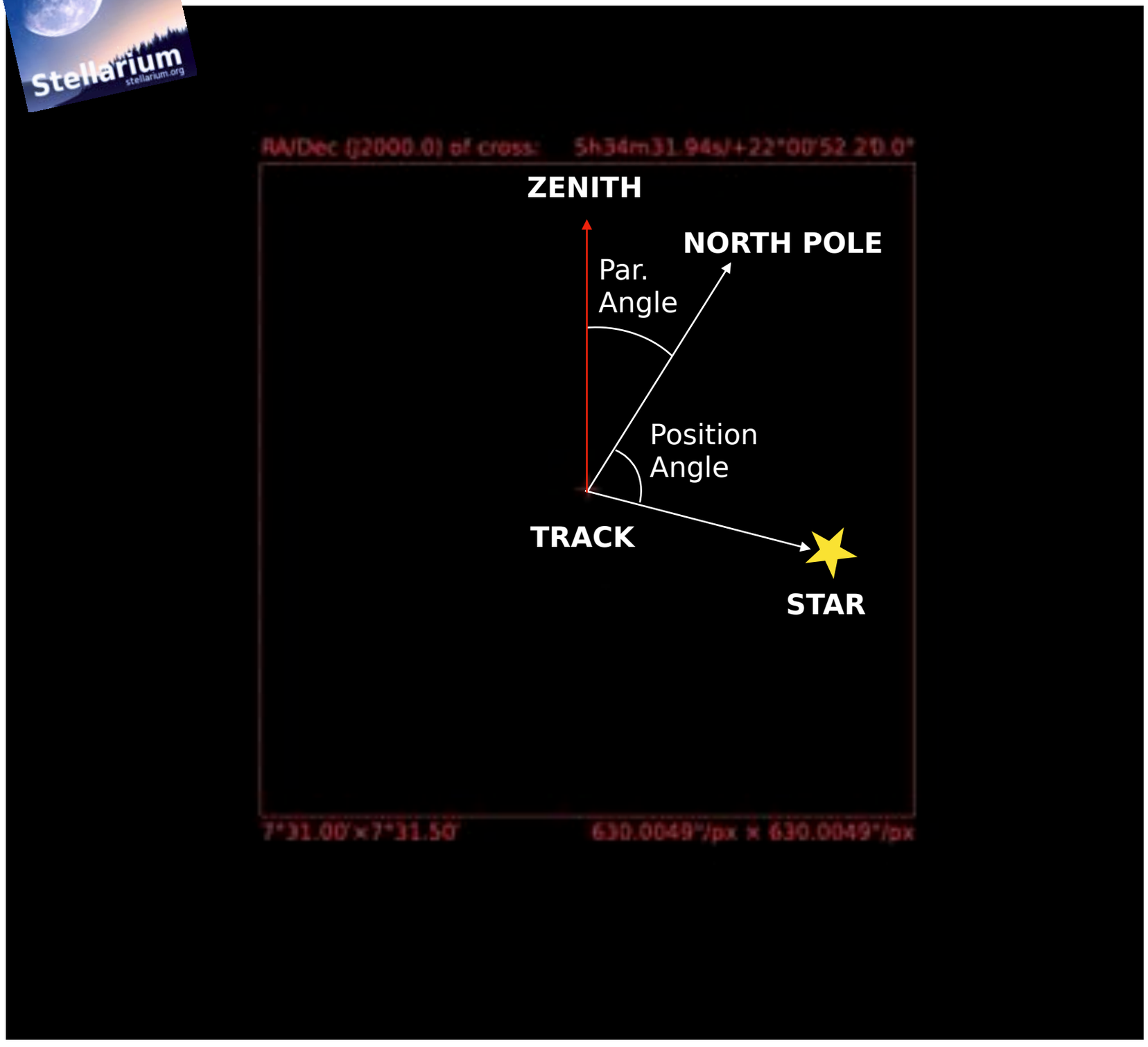
The concept

Altazimuth mount

FoV rotation while tracking an object

Can we use it to assess the opto-mechanical properties of the telescope?

Simulation of the FoV rotation



No ground,
no atmosphere.

FoV, mount and location of ASTRI- Horn (w camera reduced to 21 PDM).

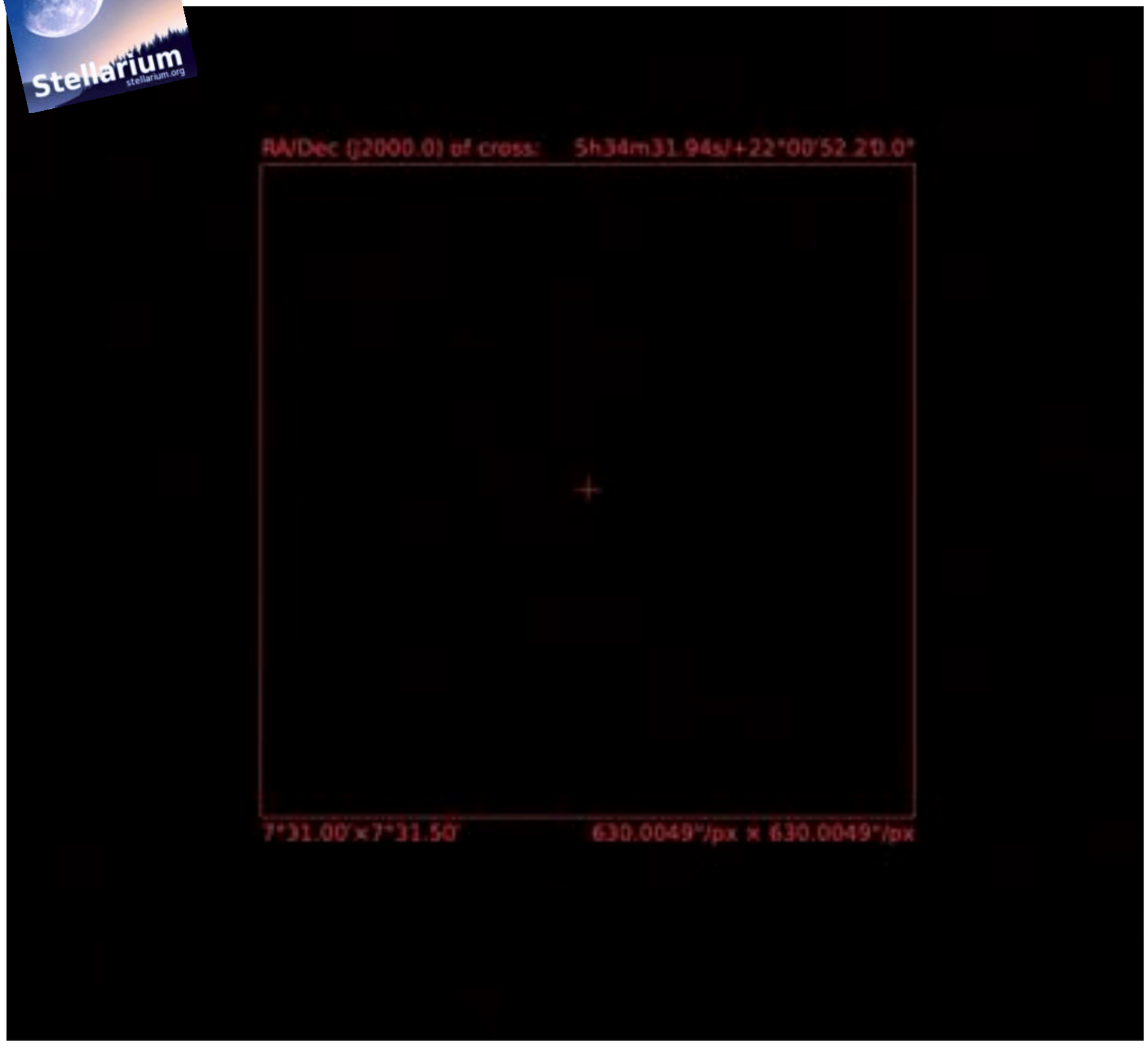
<u>Date:</u>
2019-02-26 (RUNID 1597).

<u>Tracking:</u>
CRAB coords (Ra, Dec in J2000 epoch).

<u>Dec < lat:</u>
NON CIRCUMPOLAR STAR

<u>FoV rotation:</u>
NOT COMPLETE AND ALTERNATE (CW/CCW.)

Simulation of the FoV rotation



With ground,
with atmosphere.

FoV, mount and location of ASTRI- Horn (w camera reduced to 21 PDM).

Date:
2019-02-26 (RUNID 1597).

Tracking:
CRAB coords (Ra, Dec in J2000 epoch).

Dec < lat:
NON CIRCUMPOLAR STAR

FoV rotation:
NOT COMPLETE AND ALTERNATE (CW/CCW.)

Simulation of the FoV rotation

With ground,
no atmosphere.

FoV, mount and location of ASTRI- Horn (w camera reduced to 21 PDM).

Date:
2019-02-26 (RUNID 1597).

Tracking:
MIZAR coords (Ra, Dec in J2000 epoch).

Dec > lat:
CIRCUMPOLAR STAR

FoV rotation:
COMPLETE AND CONTINUOUS (CCW.)

Star coverage software

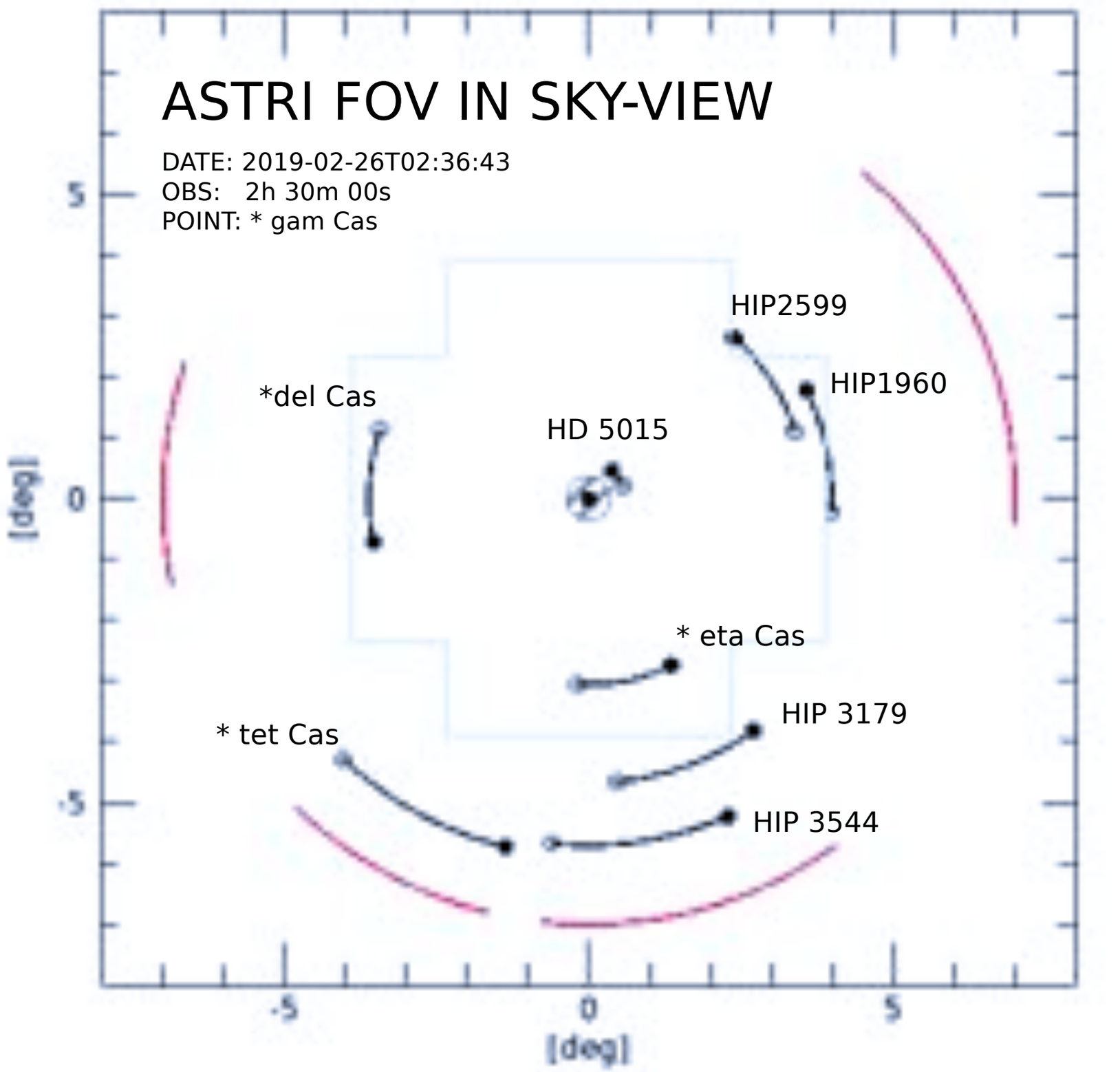
OUTPUT

ANGULAR COVERAGE:
23.7% inside borders
42.2% outside borders

ANGULAR COVERAGE:
23.7% inside borders
42.2% outside borders

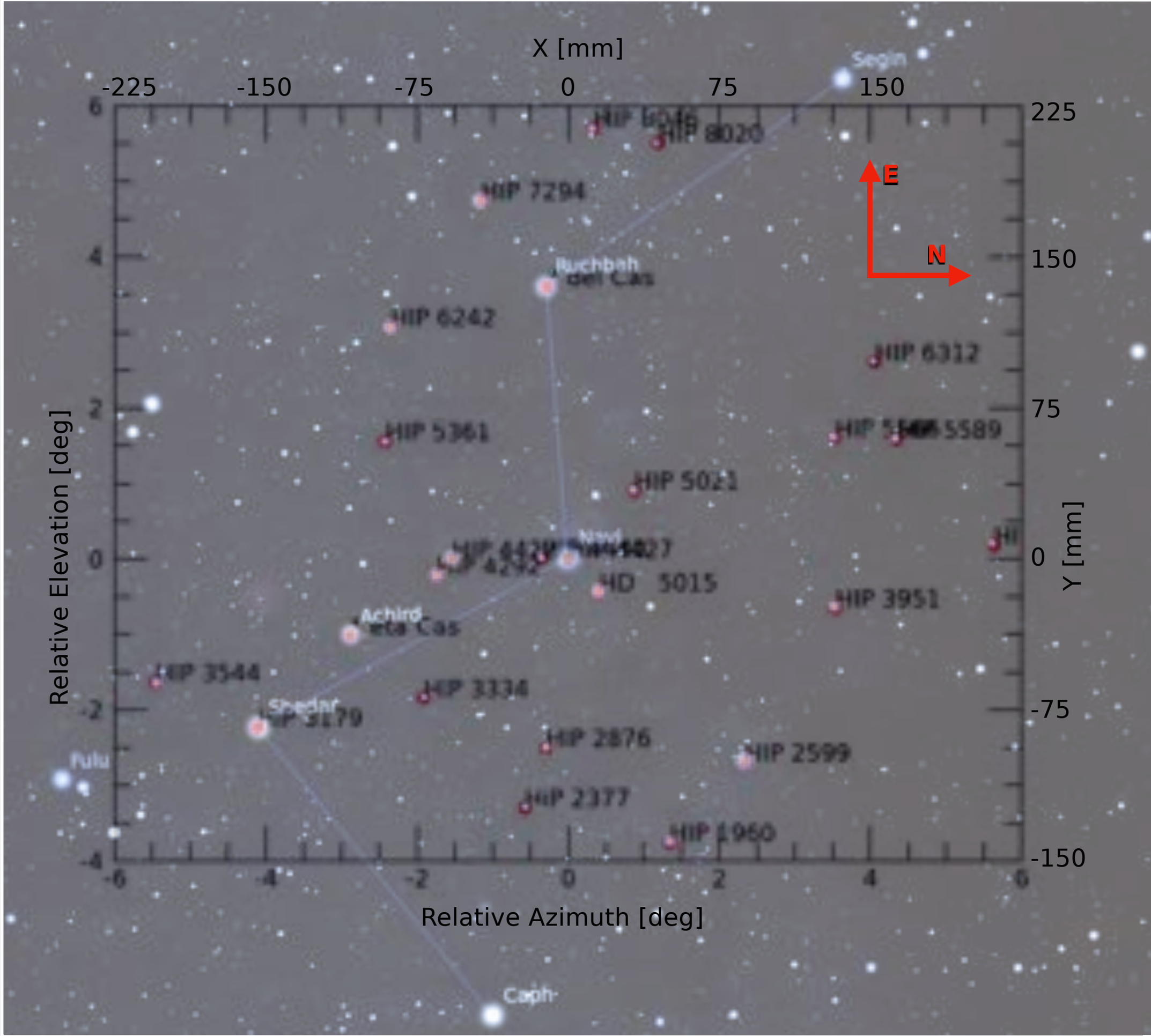
LEGEND

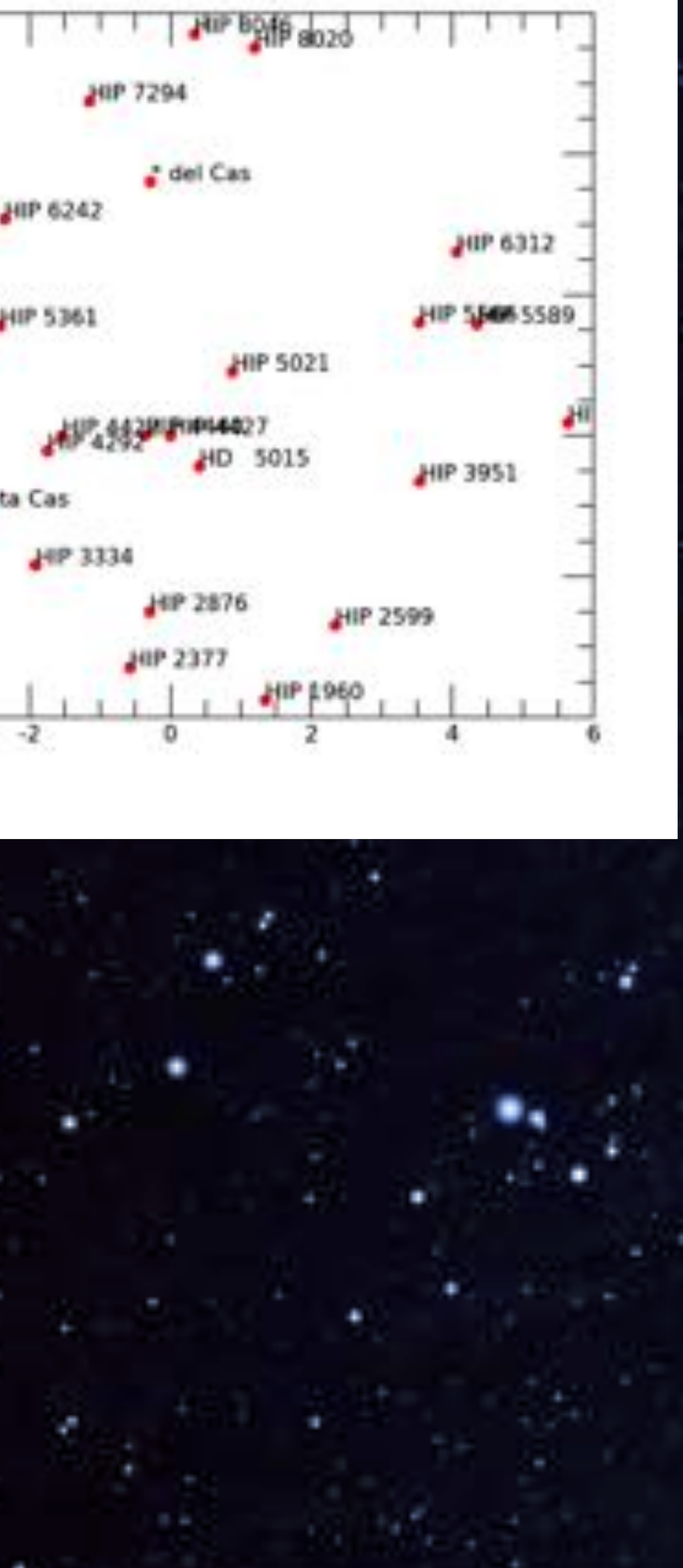
- INITIAL STAR POSITION
- FINAL STAR POSITION
- STAR TRAIL
- ANGULAR COVERAGE
- ASTRI CAMERA
- CENTER REGION

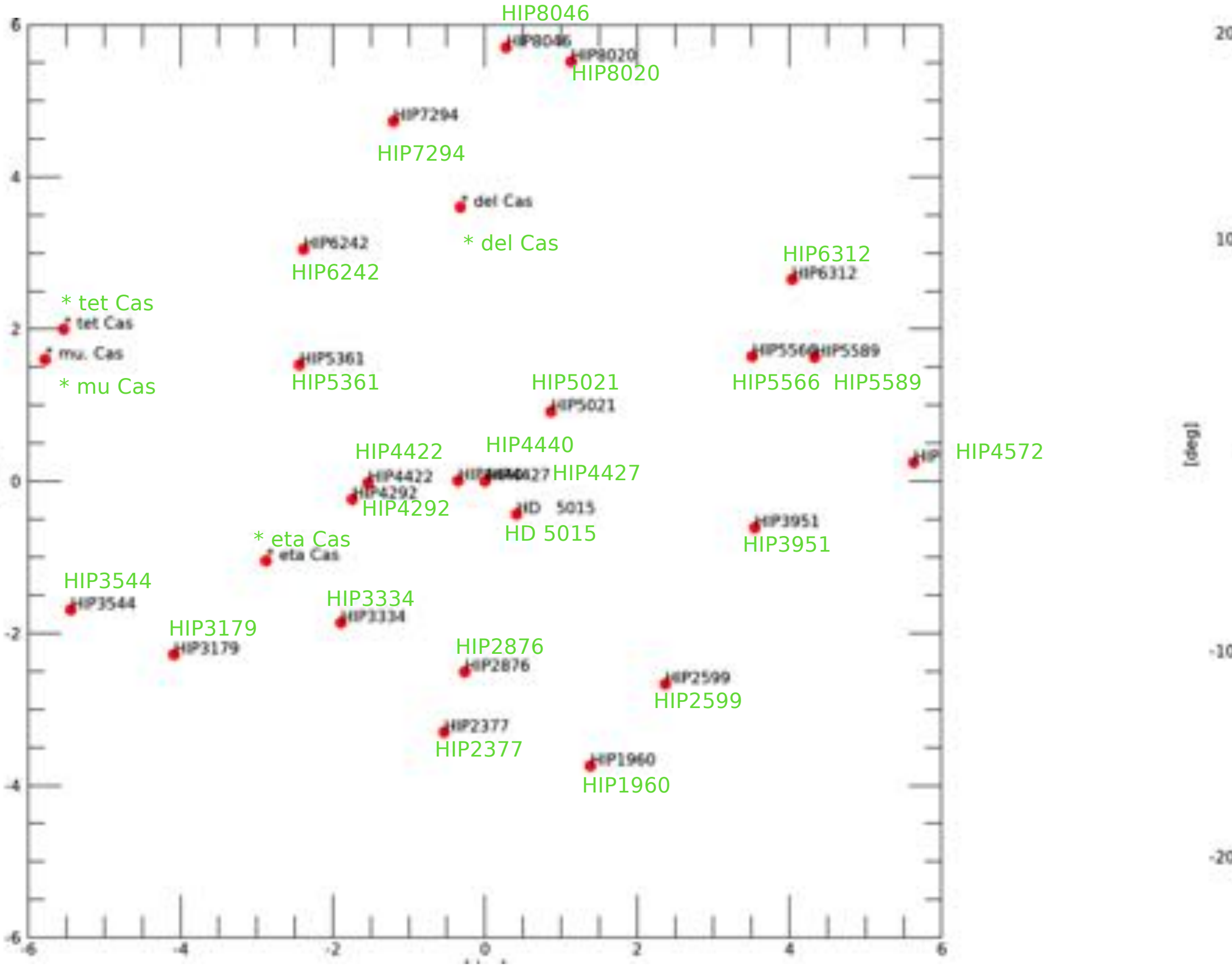


Navi (γ Cas)

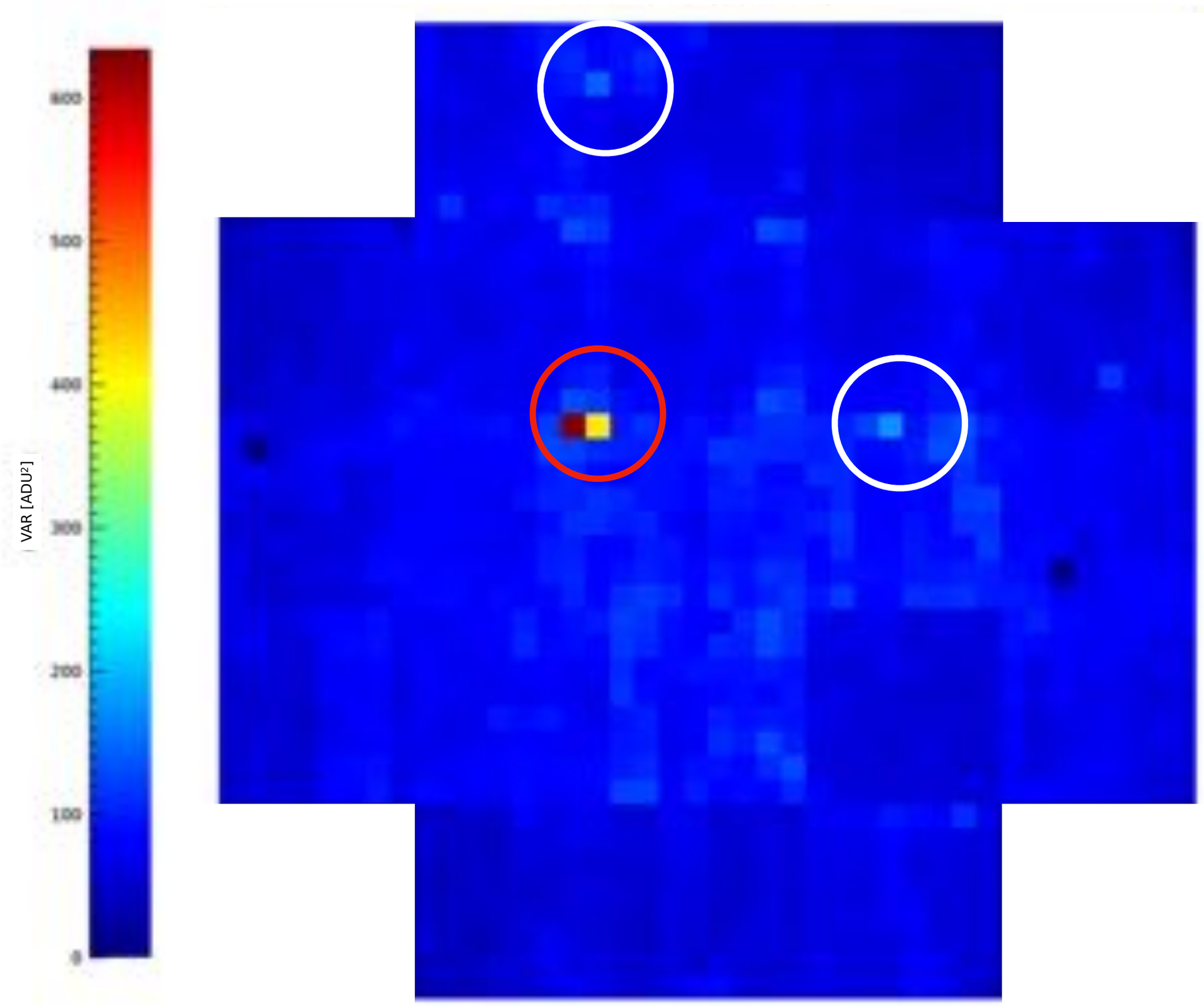
- HIP 4427 -



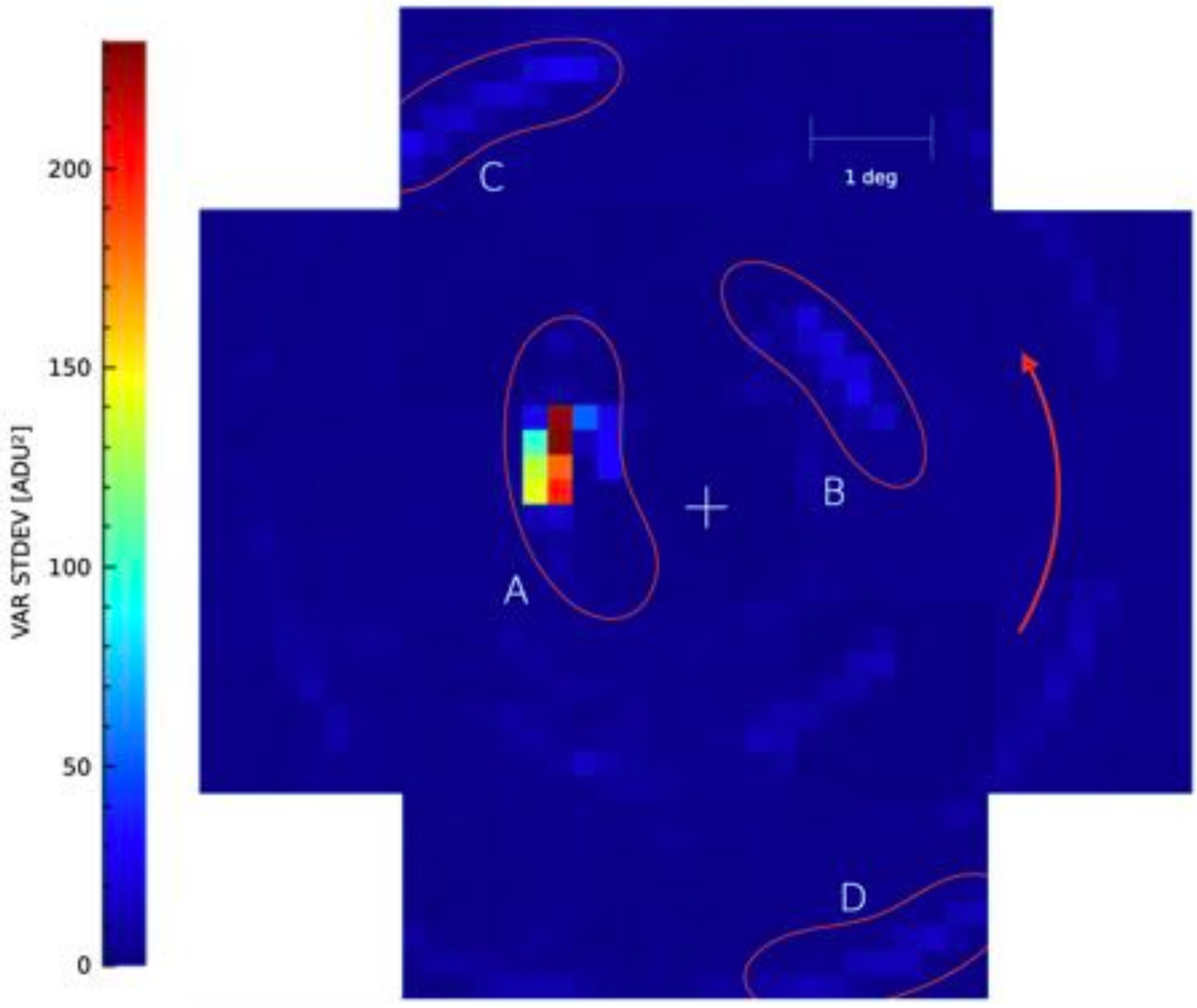

HIP 8020
HIP 7294
* del Cas
HIP 6242
HIP 6312
HIP 5361
HIP 5589
HIP 5021
HIP 4292
HD 5015
HIP 3951
ta Cas
HIP 3334
HIP 2876
HIP 2599
HIP 2377
HIP 1960
-2
0
2
4
6


HIP8046
HIP8020
HIP7294
del Cas
* del Cas
HIP6242
HIP6312
* tet Cas
tet Cas
mu. Cas
* mu Cas
HIP5361
HIP5021
HIP5566
HIP5589
HIP4422
HIP4440
HIP4427
HIP4572
HIP4292
HD 5015
HIP3951
* eta Cas
eta Cas
HIP3544
HIP3334
HIP3179
HIP2876
HIP2599
HIP2377
HIP1960
[deg]

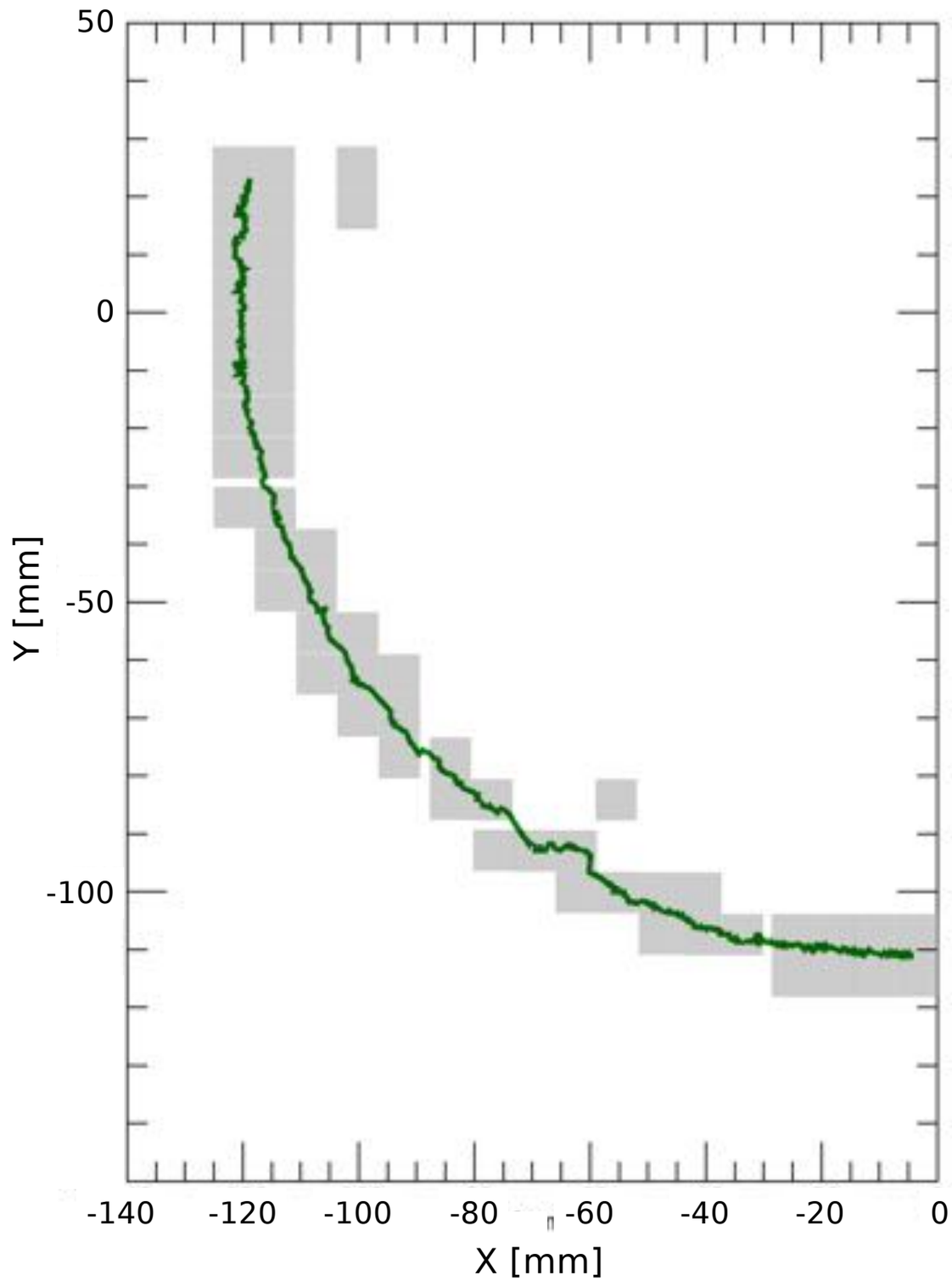
Find Spots

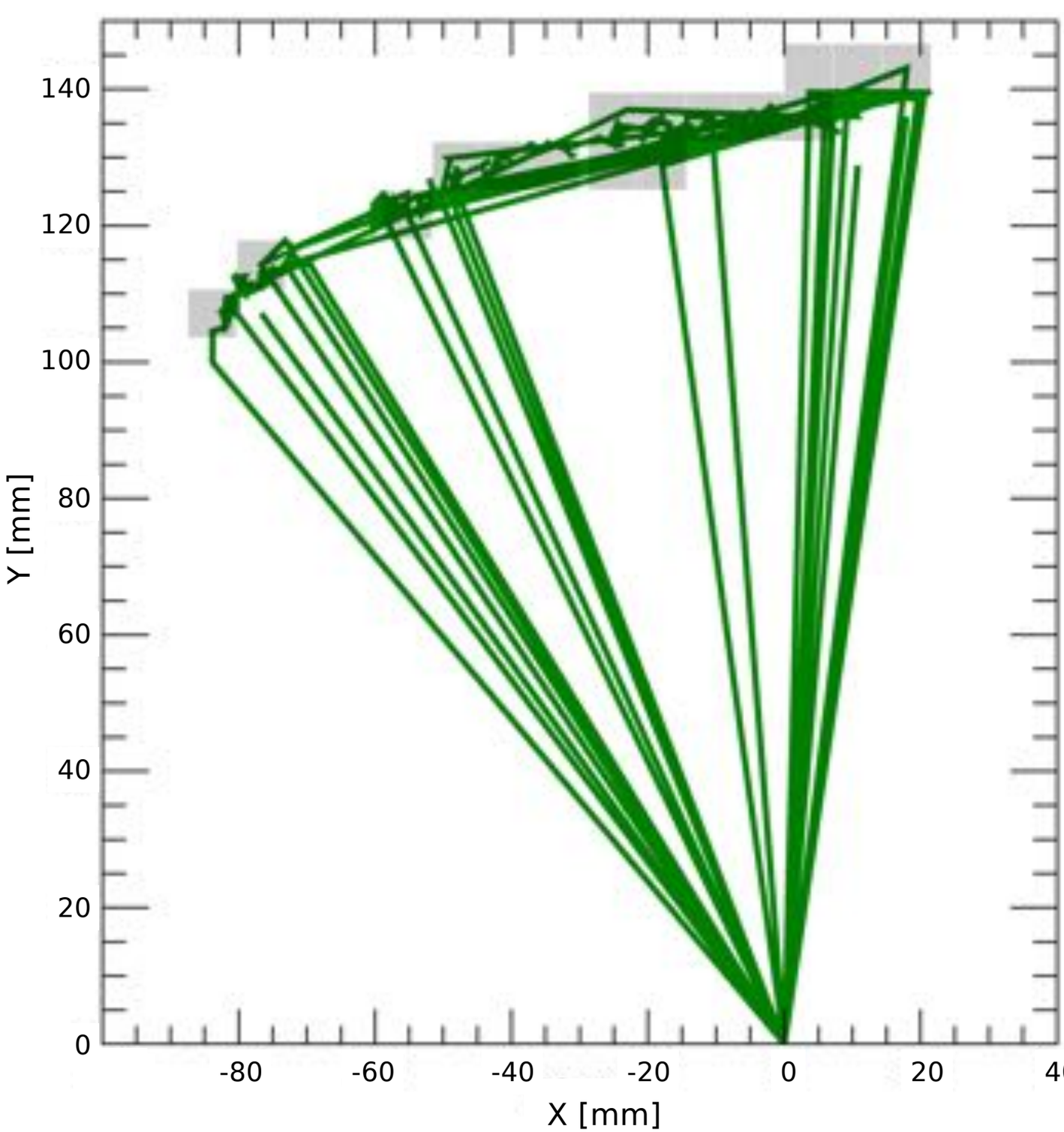


Detect movements

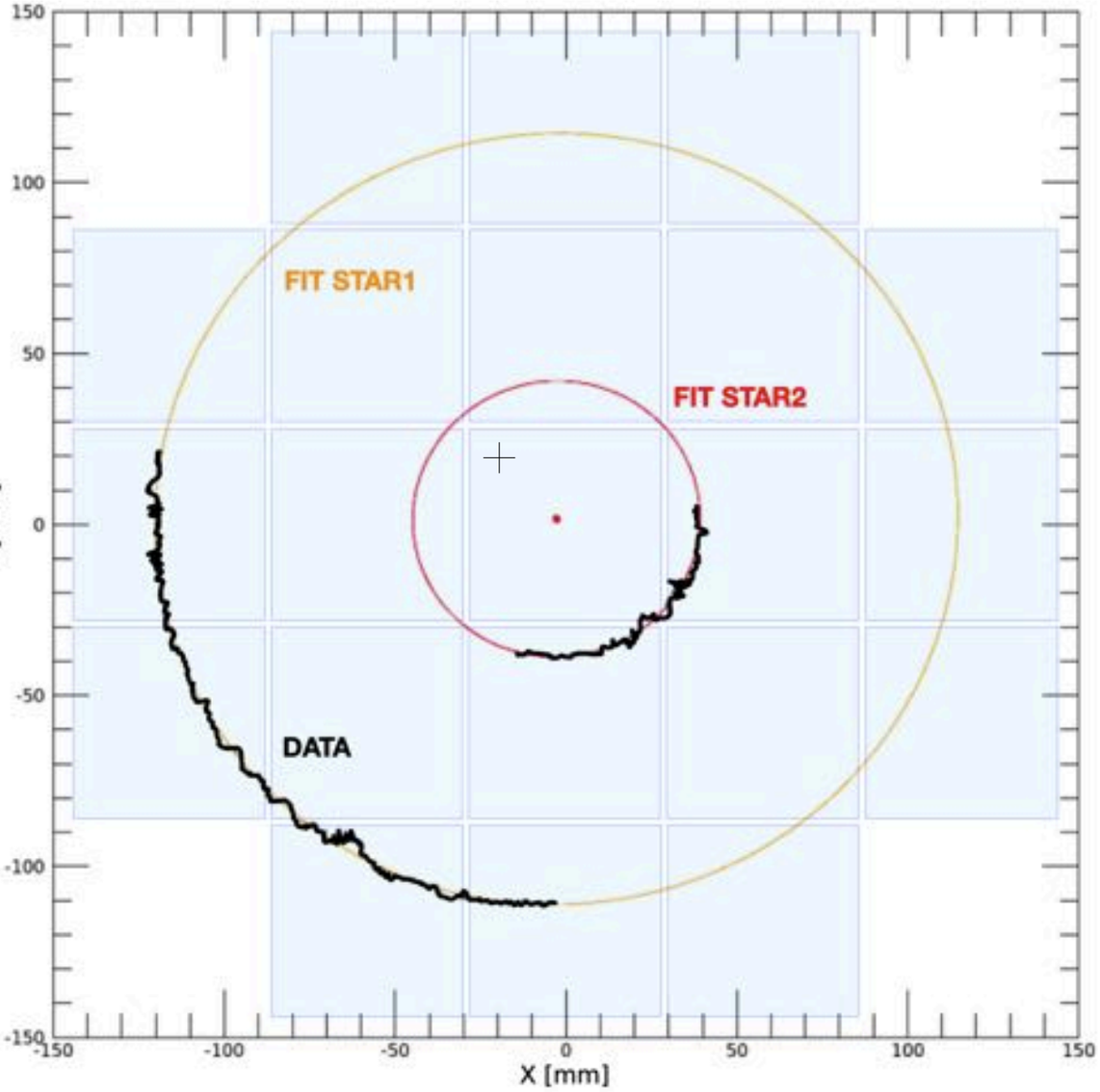


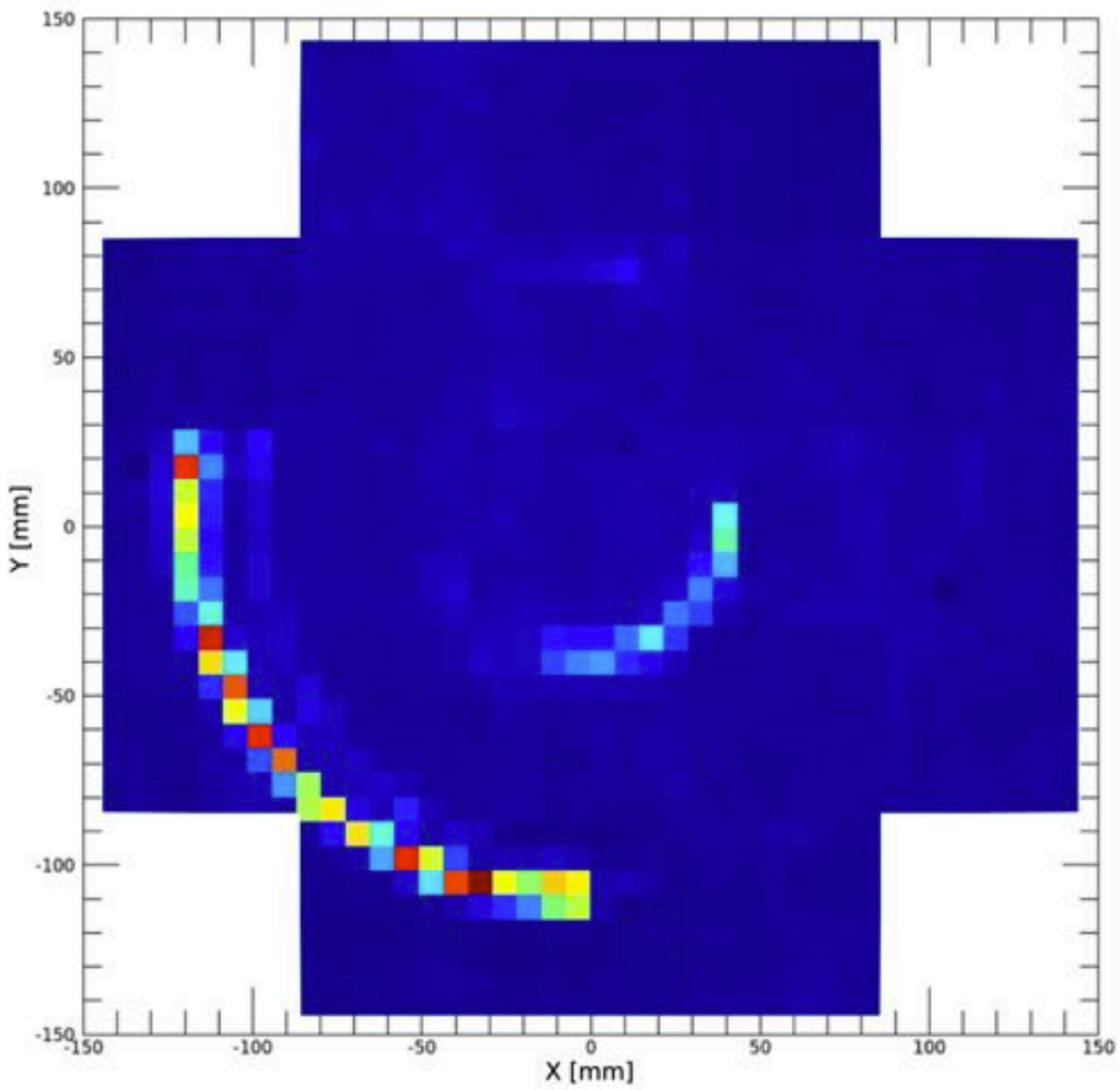
Clean data


50
0
-50
-100
Y [mm]
-140
-120
-100
-80
-60
-40
-20
0
X [mm]

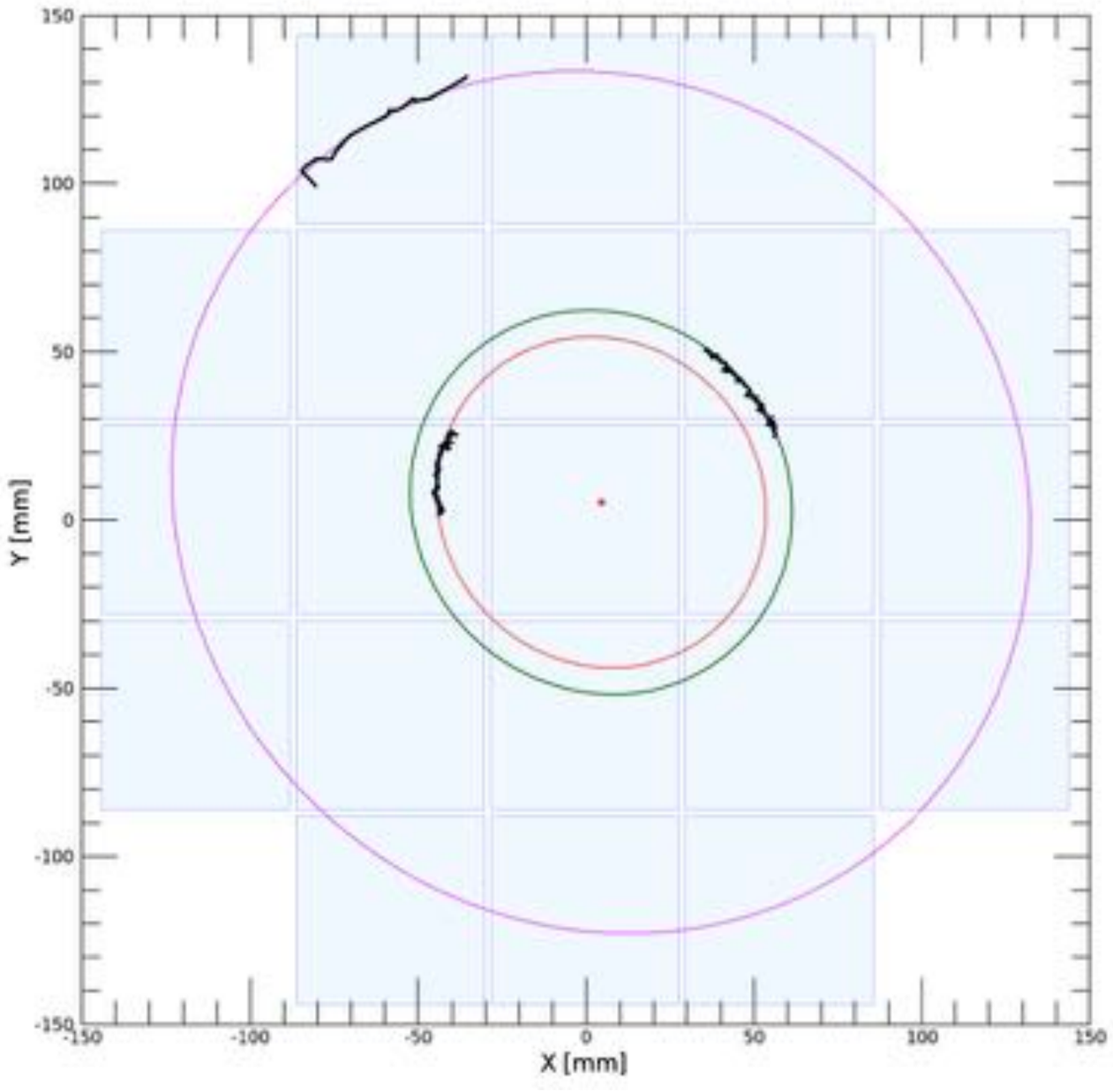

140
120
100
80
60
40
20
0
Y [mm]
-80
-60
-40
-20
0
20
40
X [mm]

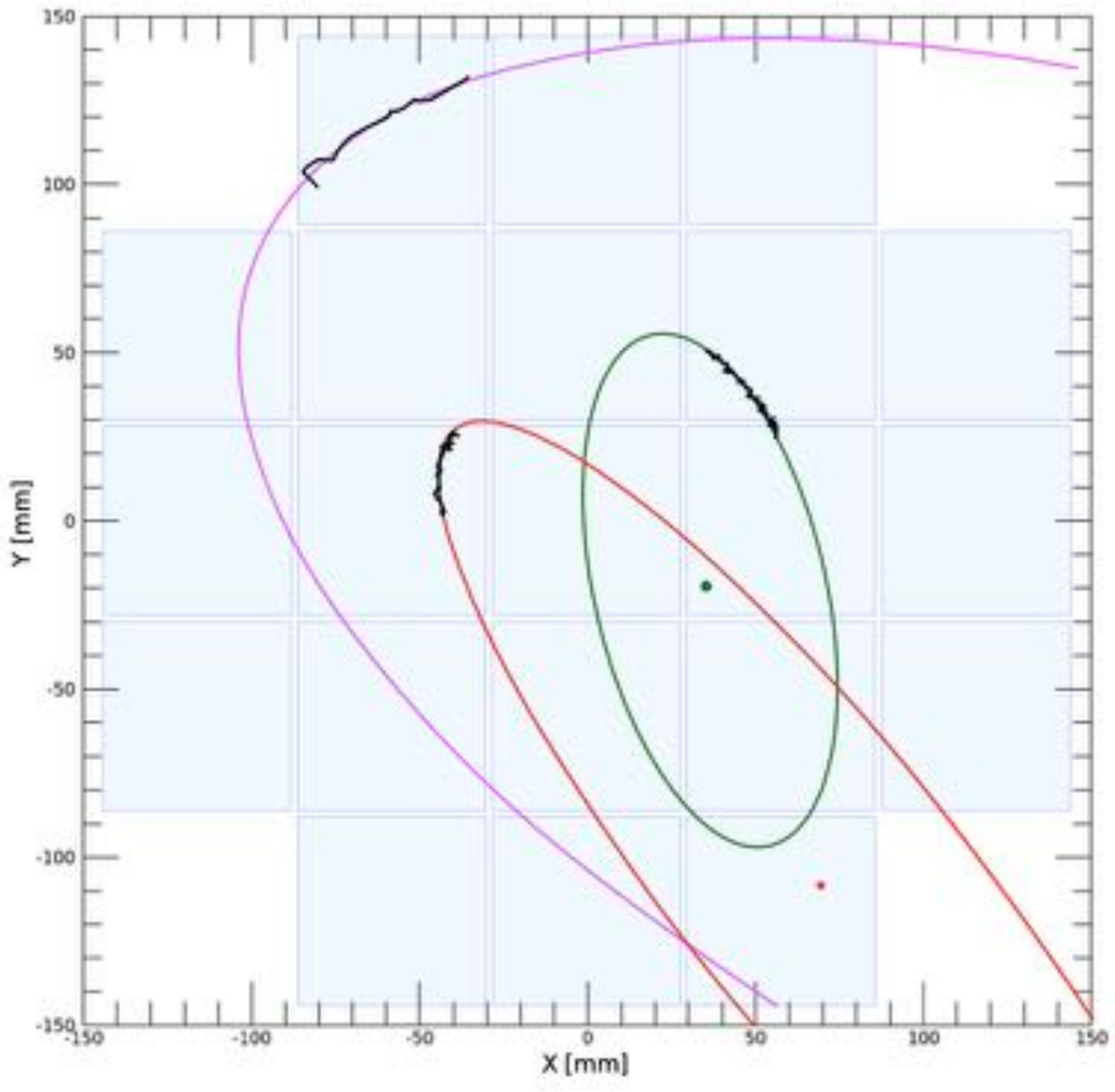
Long run on Algenubi



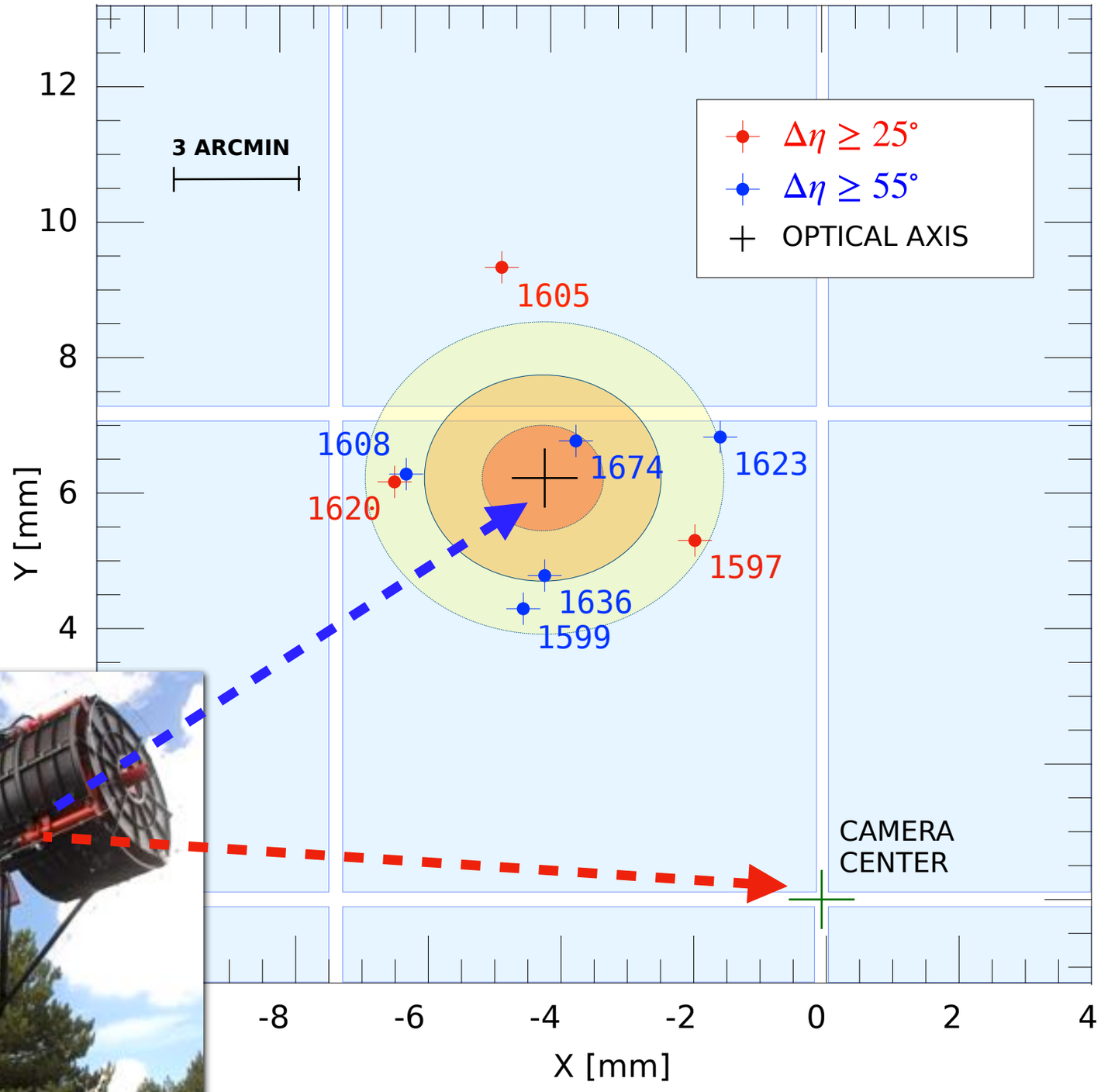


MULTI-ELLIPSE FIT





RESULTS


3 ARCMIN
$\Delta\eta \geq 25^\circ$
$\Delta\eta \geq 55^\circ$
OPTICAL AXIS
1605
1608
1674
1623
1620
1597
1636
1599
CAMERA CENTER
Y [mm]
X [mm]
12
10
8
6
4
-8
-6
-4
-2
0
2
4

OUTLINE:

PART 1 ***The ASTRI project***

PART 2 ***Variance images***

PART 3 ***Camera axis alignment***

PART 4 ***Star field astrometry***

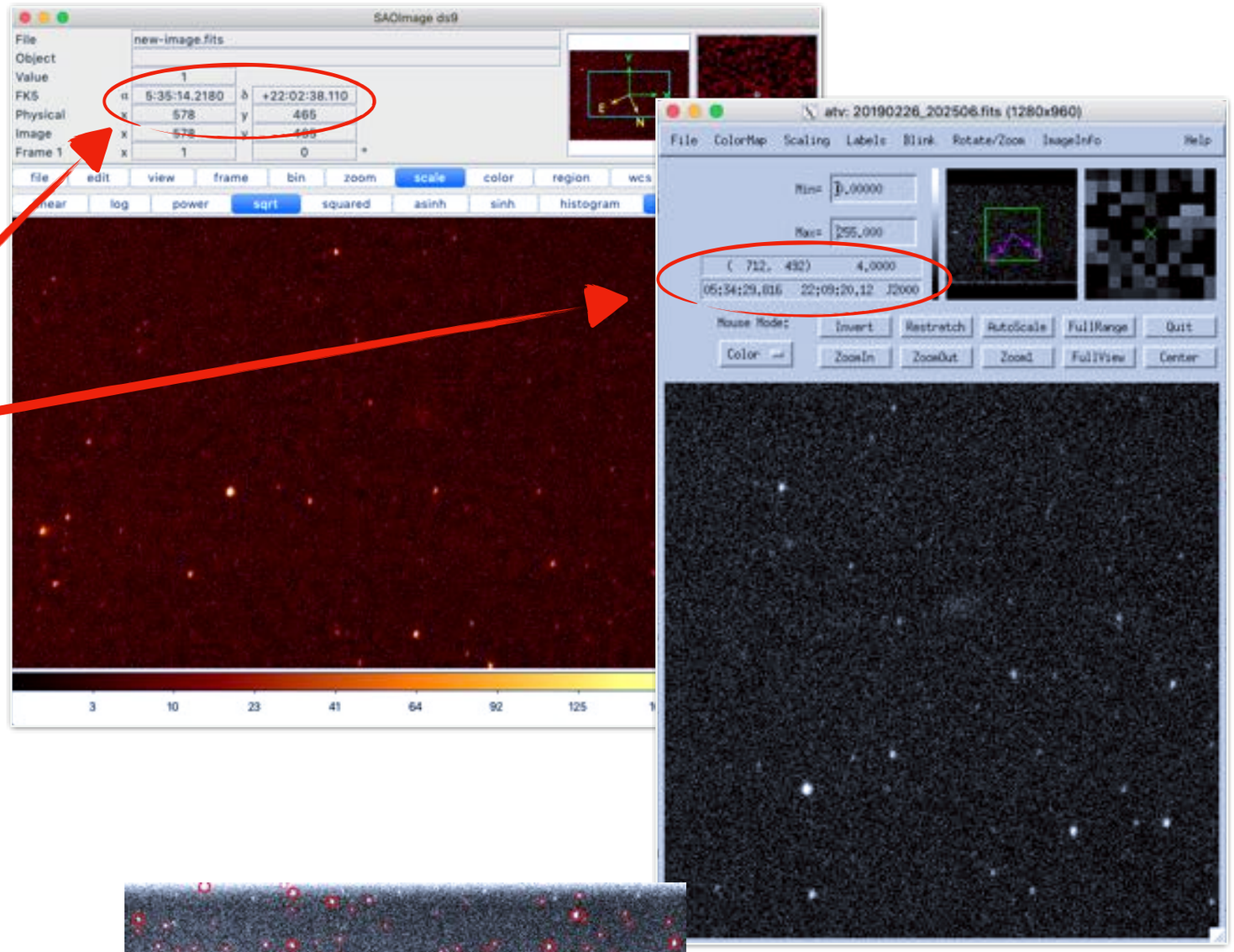
PART 5 ***Conclusion***

THE ASTROMETRIC PROBLEM

Objectives:

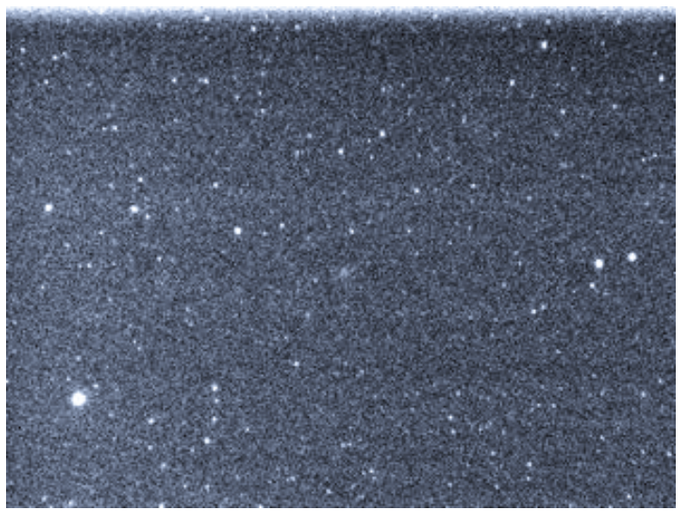
- Measure actual pointing
- Check pointing model
- Optics assessment

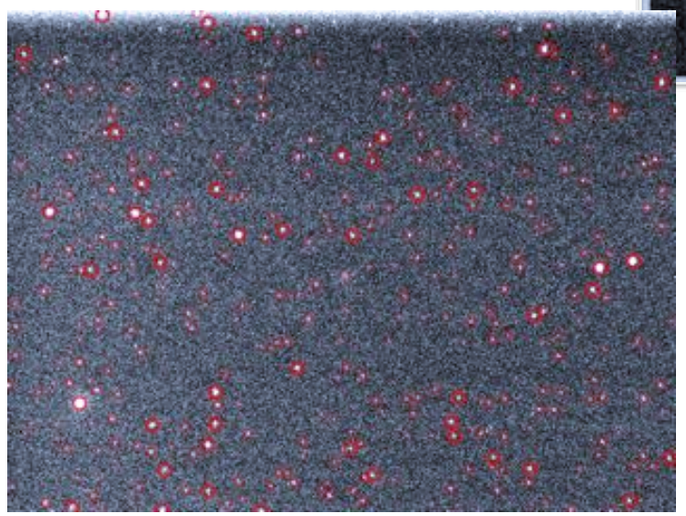
= create a *WCS file* associated to the image containing the information on the reference system for every pixel.



Astrometry.net

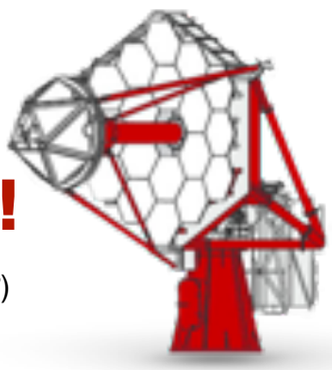
(beautiful presentation)





FAILS WITH ASTRI!

(40 px in ~8°)



PRELIMINARY TEST

ORION

(cam view)

MAG − 7 (in VAR)

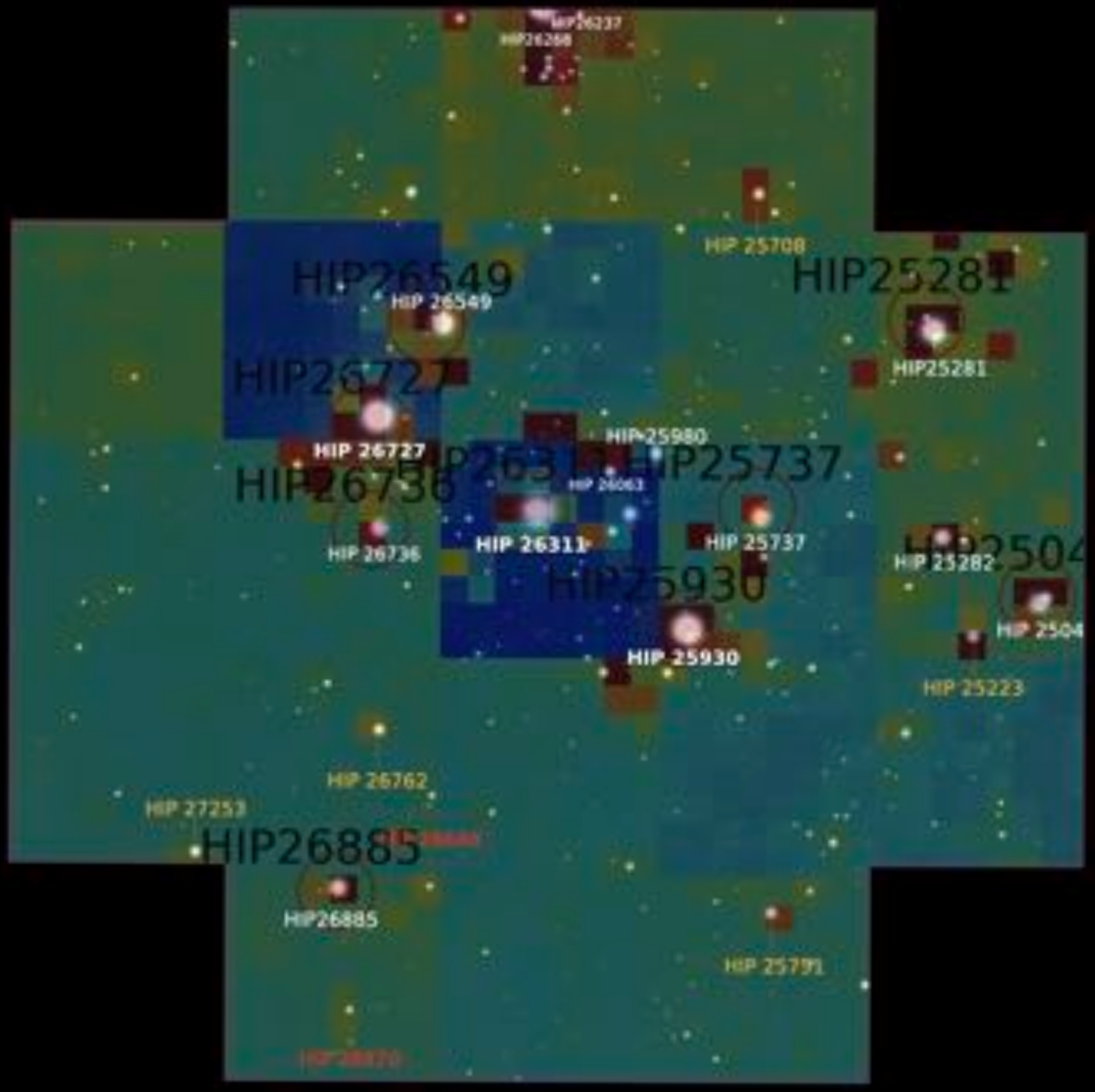
MAG > 5 (in VAR)

IDENTIFICATED IN VAR

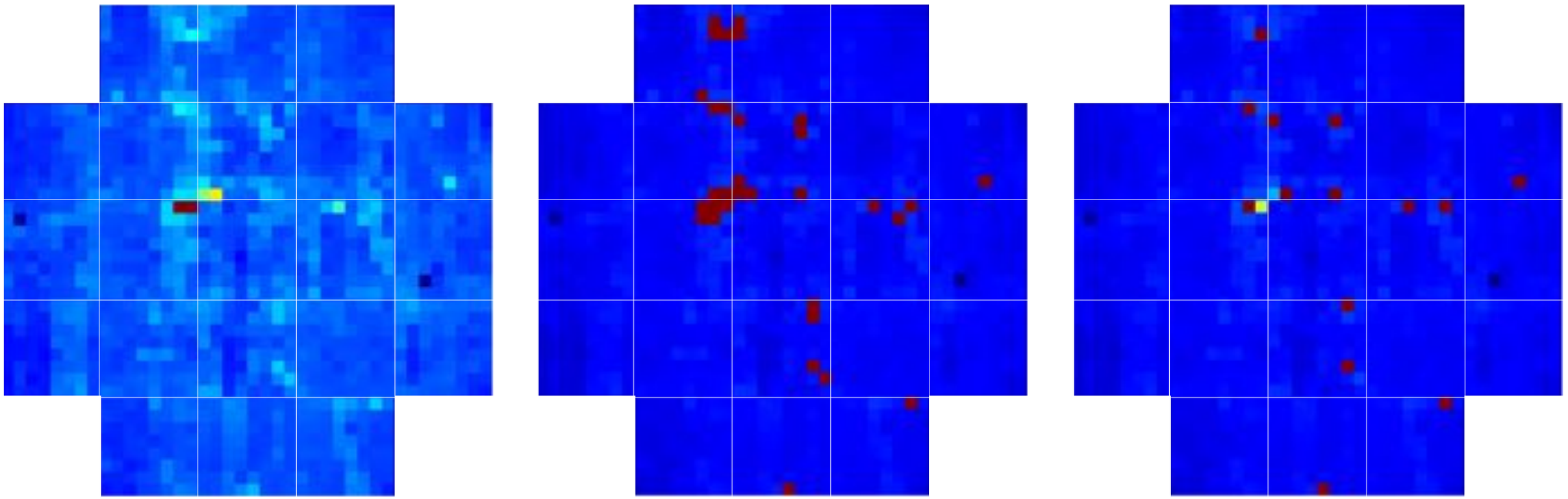
PRELIMINARY TEST

ORION

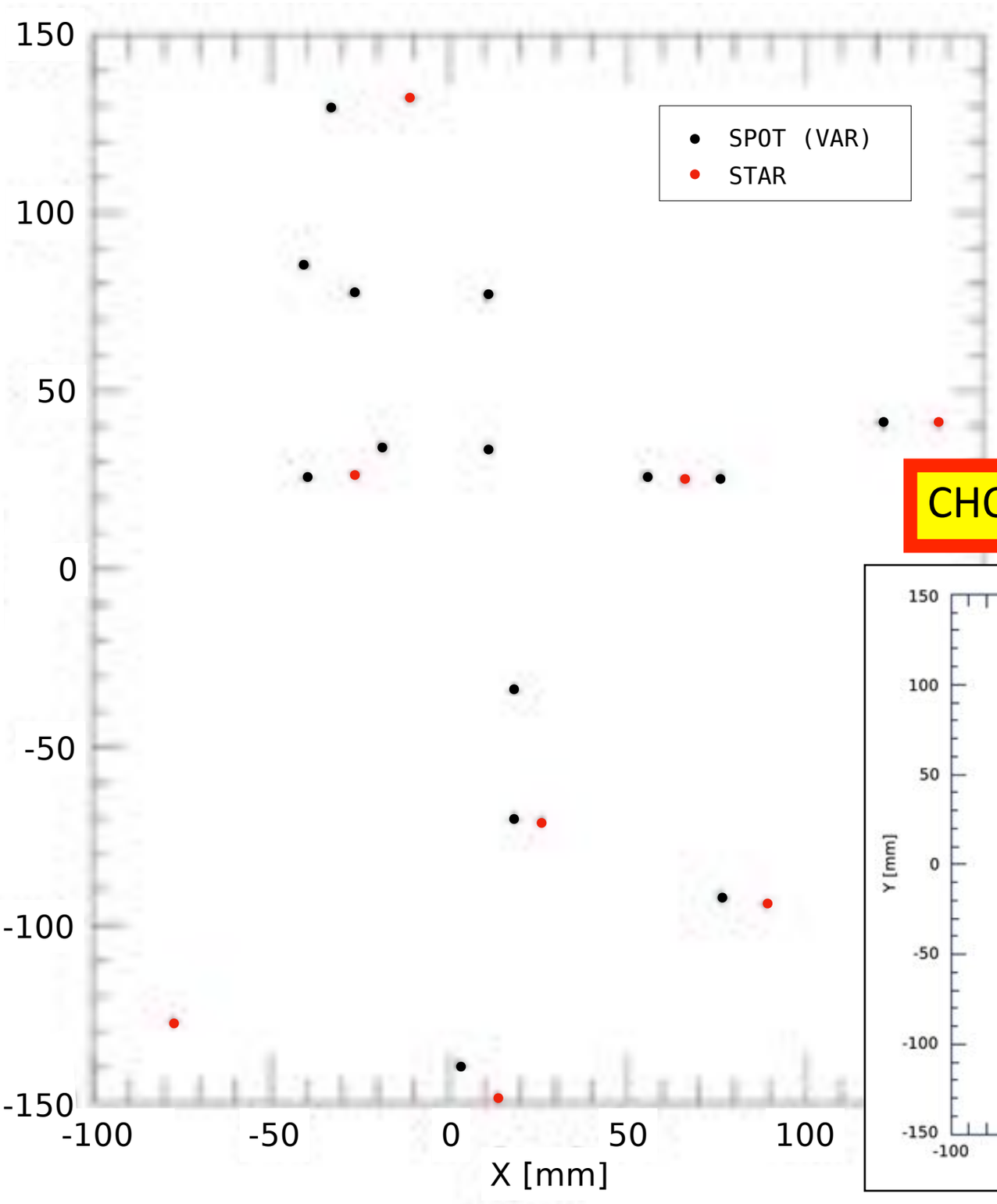
(cam view)



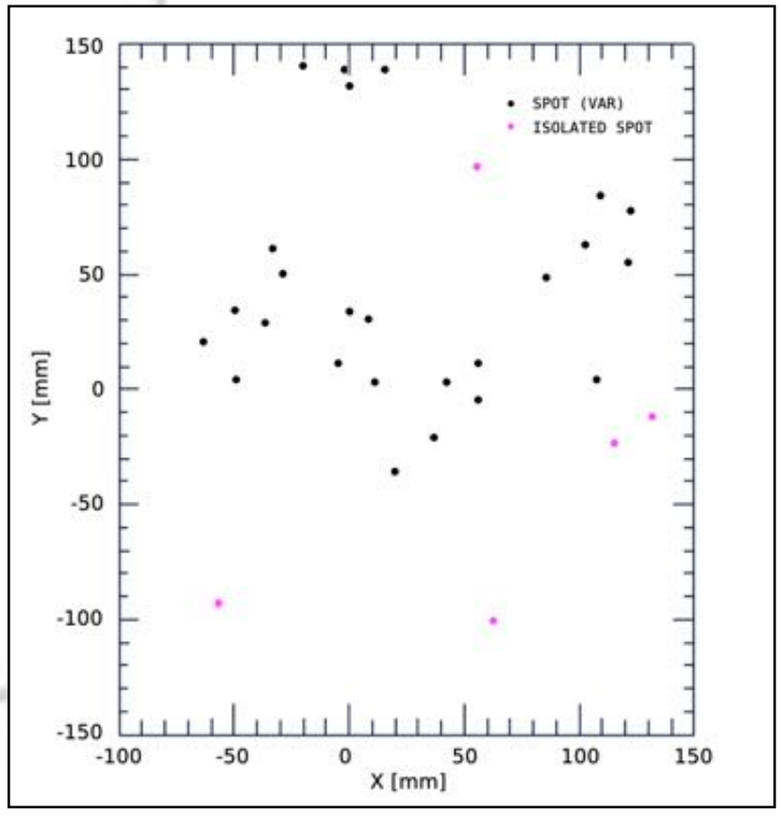
FIND SPOTS



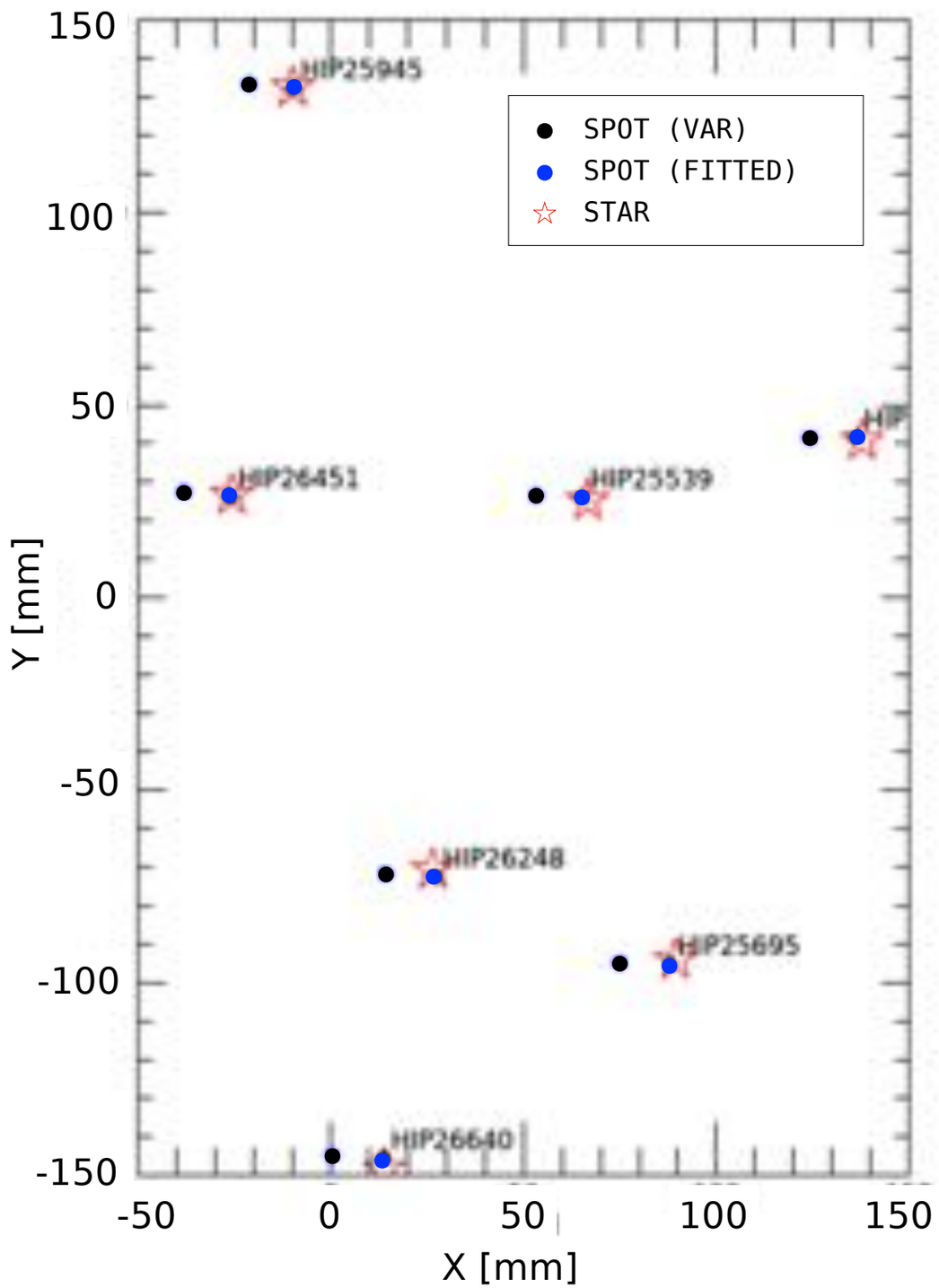
PLOT SPOTS AND STARS



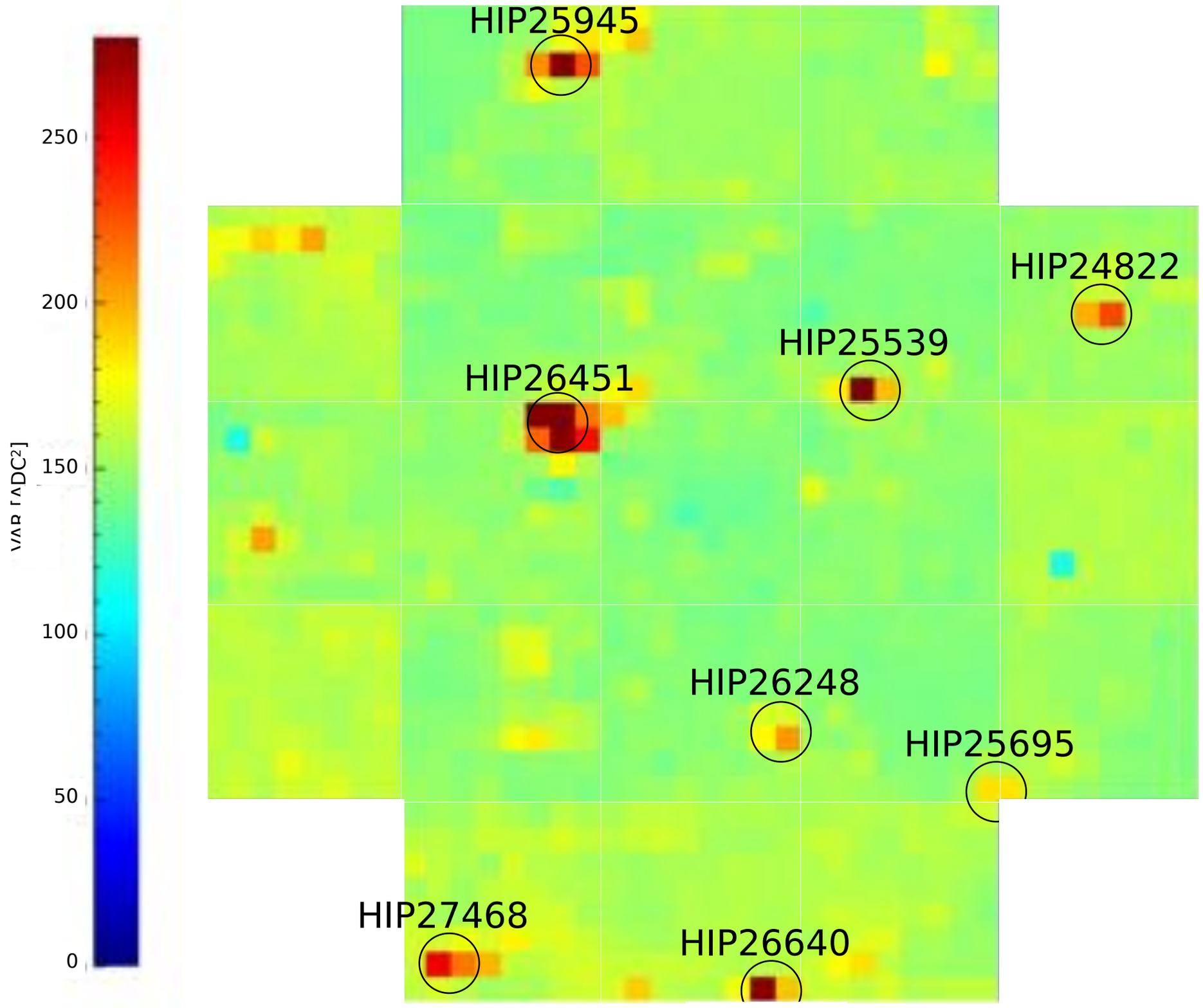
CHOOSE ISOLATED ONES



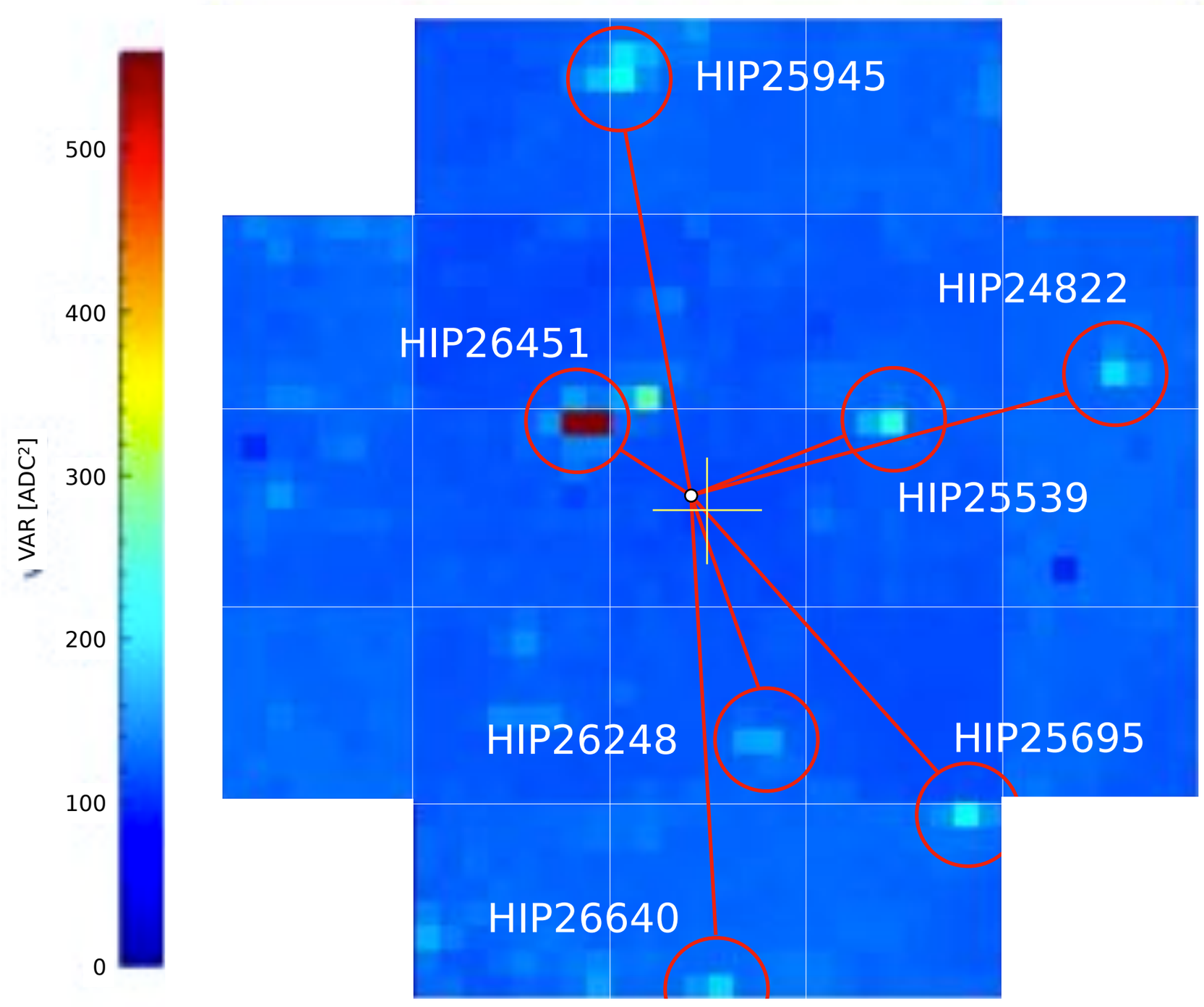
WHY DON'T WE USE A FIT?



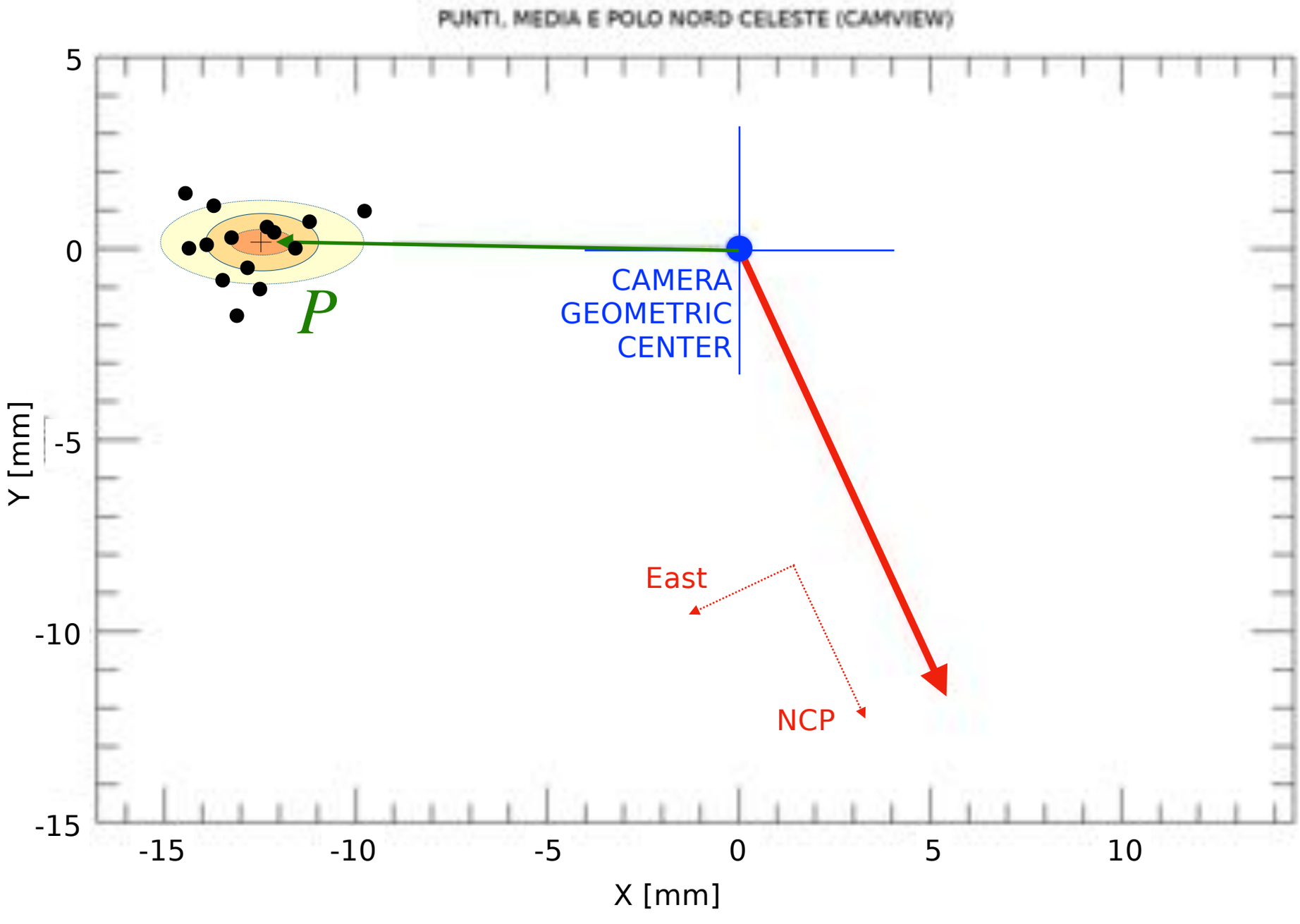
“ASTROMETRY” SOLUTION



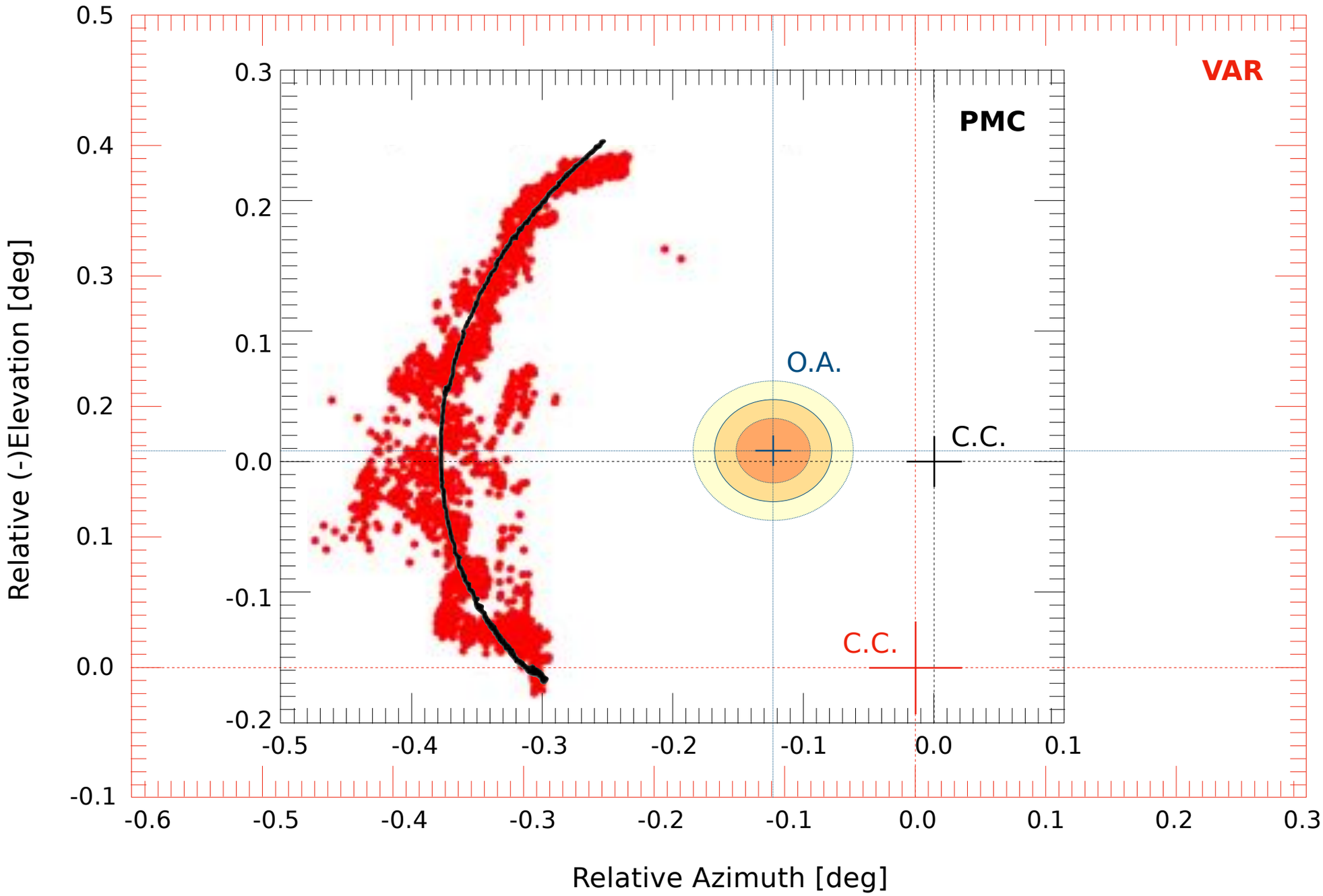
POINTING DIRECTION



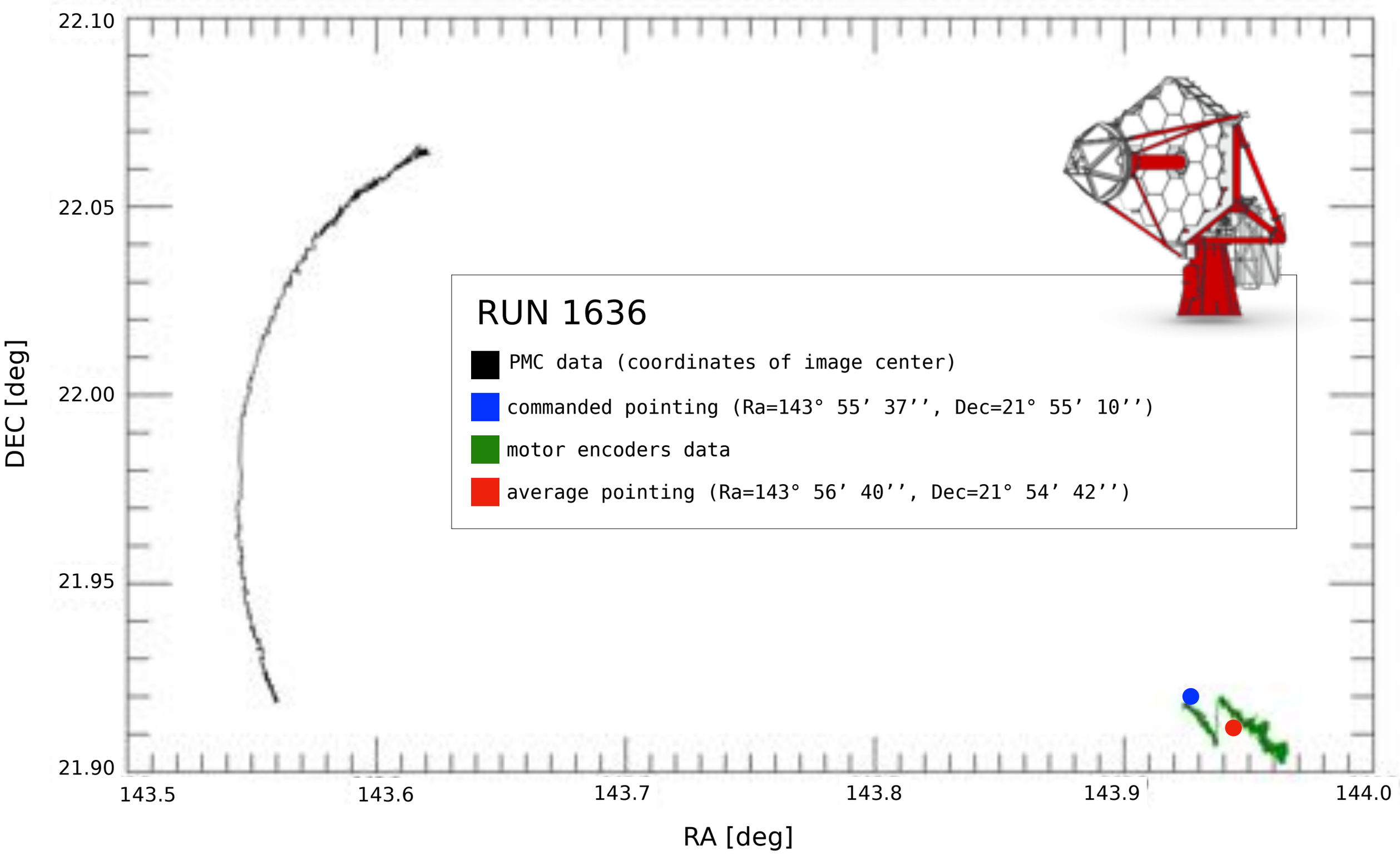
POINTING ASSESSMENT



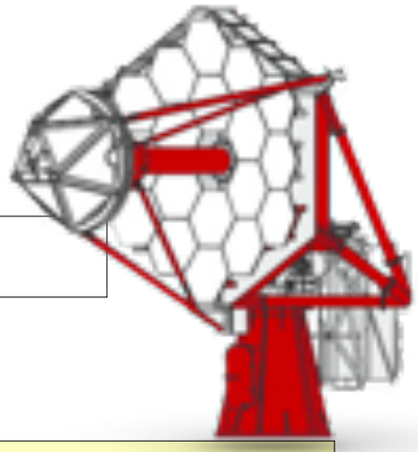
RESULTS


VAR
PMC
O.A.
C.C.
C.C.
Relative (-)Elevation [deg]
Relative Azimuth [deg]
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3

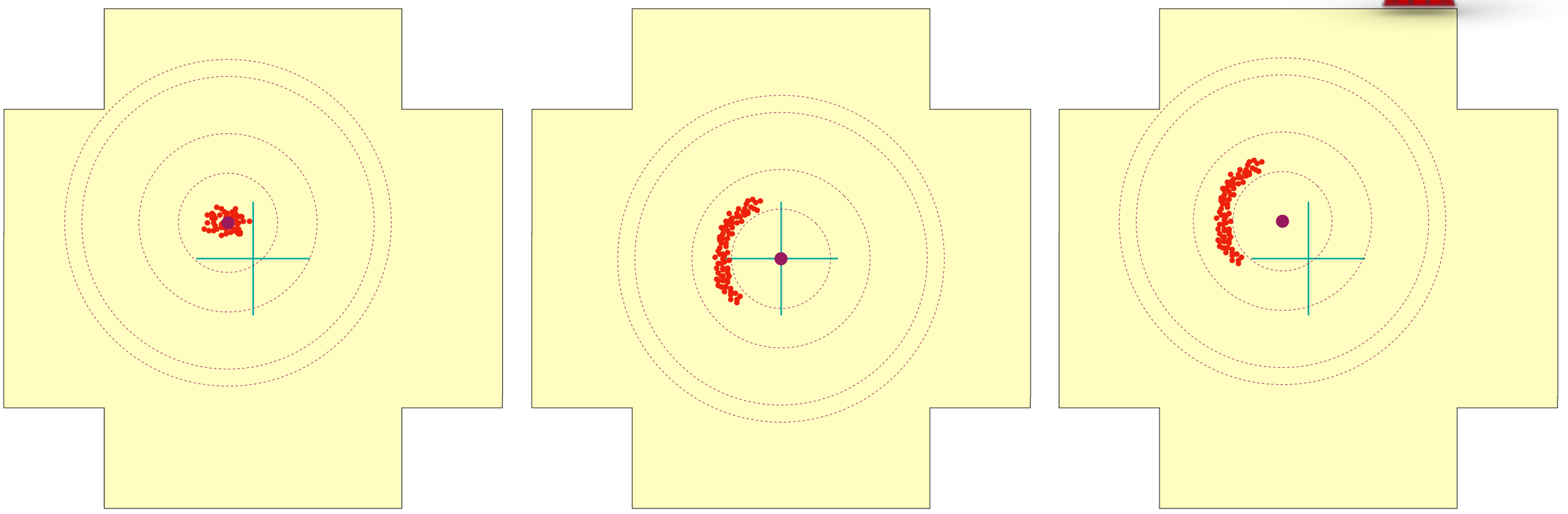
PMC CHECK


RUN 1636
PMC data (coordinates of image center)
commanded pointing (Ra=143° 55’ 37’’, Dec=21° 55’ 10’’)
motor encoders data
average pointing (Ra=143° 56’ 40’’, Dec=21° 54’ 42’’)
22.10
22.05
22.00
21.95
21.90
DEC [deg]
143.5
143.6
143.7
143.8
143.9
144.0
RA [deg]

SCHEME OF THE SITUATION



optical axis nominal pointing camera center



1)DE-CENTERING: YES
POINTING ERROR: NO

2)DE-CENTERING: NO
POINTING ERROR: YES

3)DE-CENTERING: YES
POINTING ERROR: YES

OUTLINE:

PART 1 ***The ASTRI project***

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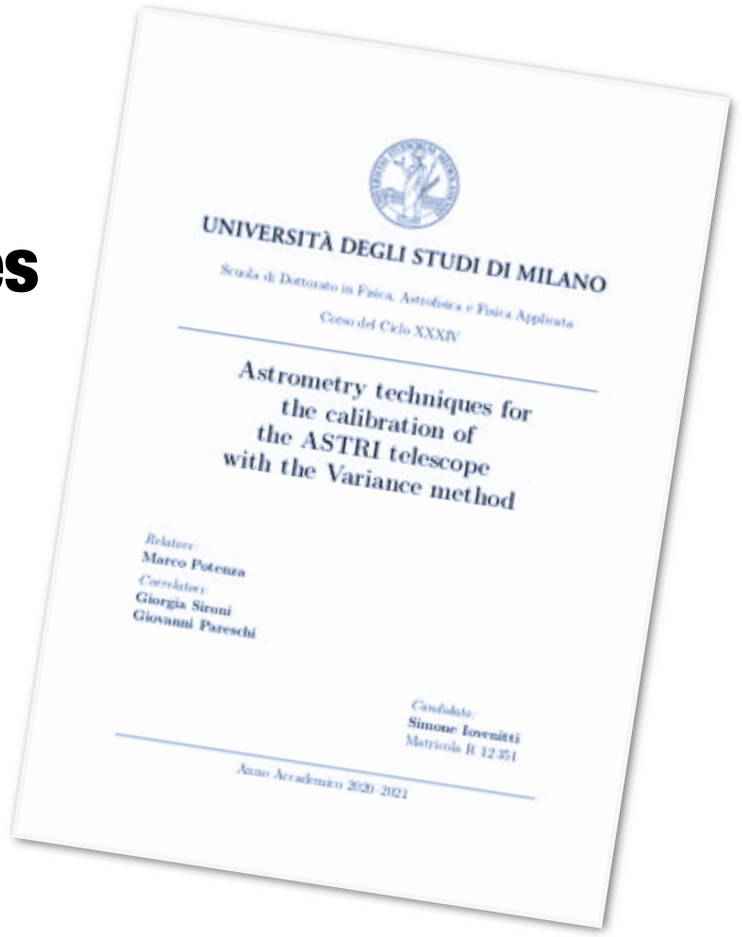
Summary of main results

- **Deep study of telescope optical response**
- **Correct important systematic errors (alignment)**
- **Monitor pointing performances**
- **Definition of effective calibration procedures**
- **Additional work on mirrors and coatings**



UNIVERSITÀ DEGLI STUDI DI MILANO

Scuola di Dottorato in Fisica, Astrofisica e Fisica Applicata

Ciclo XXXIV

Astrometry techniques for the calibration of the ASTRI telescope with the Variance method

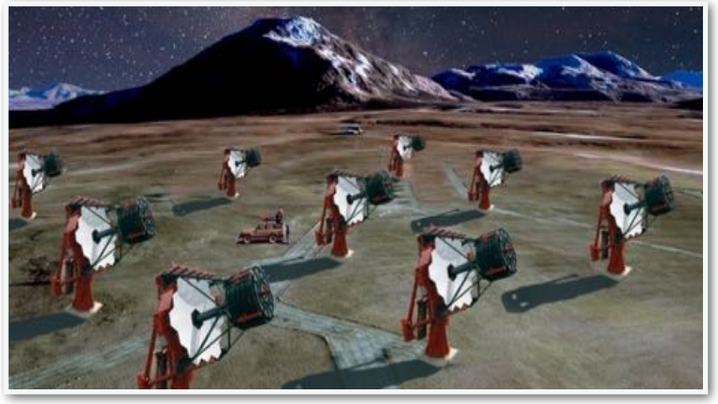
Relatore:
Marco Potenza

Correlatore:
Giorgia Sironi
Giovanni Pareschi

Candidato:
Simone Iovenitti
Matricola R 12 351

Anno Accademico 2020/2021

Publications



Inserted into the Calibration Plan of the ASTRI MiniArray (conference paper, Mineo et al., 2021)

Inserted into the Online Observation Quality System (conference paper, Parmiggiani et al., 2021)

"Assessment of the Cherenkov camera alignment through Variance images for the ASTRI telescope", Iovenitti et al.

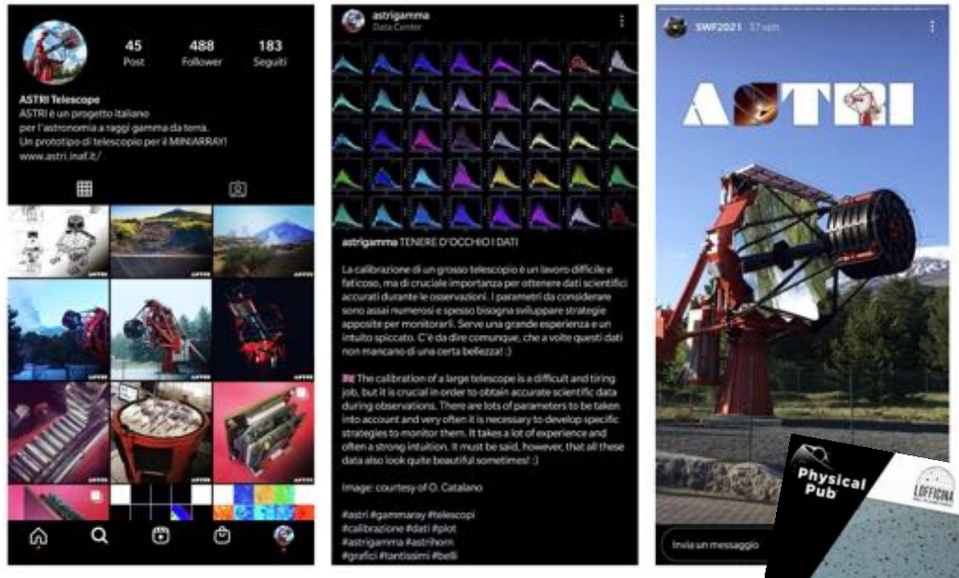
(Second revision in progress)

"Effective pointing of the ASTRI-Horn telescope using the Cherenkov camera with the Variance method" (conference paper, Iovenitti et al., 2021)

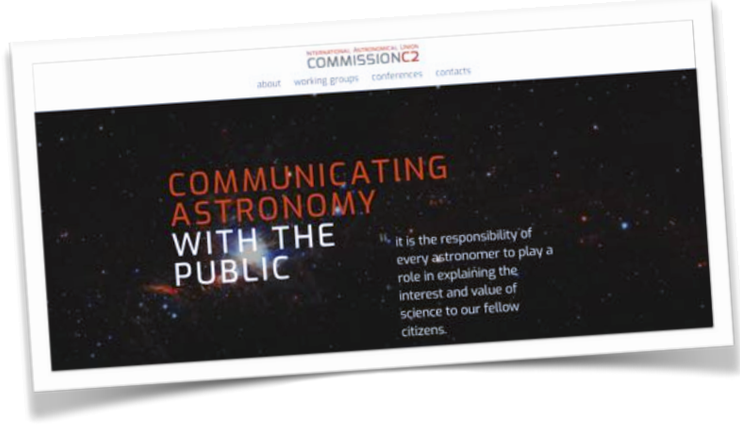
"Star coverage", a simple tool to schedule an observation when FOV rotation matters (conference paper, Iovenitti, 2021)

Outreach

@ASTRIGAMMA



BERGAMOSCIENZA [*] Festival della Scienza



+ *“Astro-photography as an effective tool for Outreach and Education: IACTs in exposition” (Iovenitti et al., ICRC2021 proceedings)*
+ *“How to (dis-)assemble a planetary system” (Iovenitti et al., CAP2021 proceedings)*

Future perspectives

Future perspectives

Thank you.