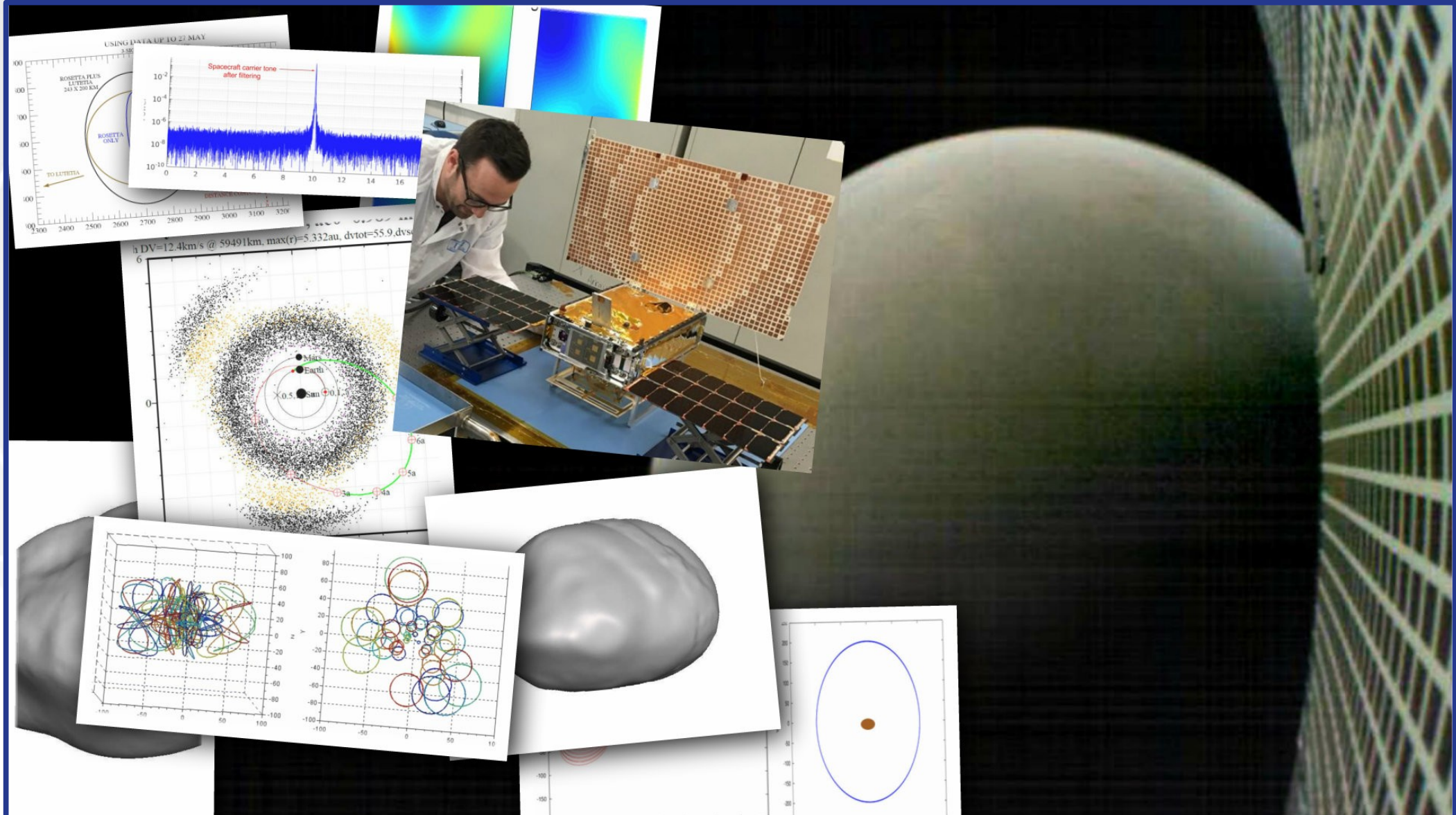


Astrometry on board OPS-SAT1 ?

Boris Segret, Youssoupha Diaw, Valery Lainey
with a **strong** support by OPS-SAT Team

contact.census@obspm.fr



sources :
 NASA MarCO, JIVE VLBI, ESA ROSETTA, CNES MMX, Etude NOIRE, MAT, CelestiaMotherlode

For:

- ▶ Astrometric small dataset
- ▶ Deep-space Navigation
- ▶ Space Situational Awareness
- ▶ Debris chasing & removal
- ▶ Clock synchronization

Precise directions of...

- ★ planets' moons
 - ▶ from cruise
 - ▶ from surface (Mars)
- ★ unresolved asteroids
 - ▶ PHA, GEO
 - ▶ Main belt as Nav beacon
- ★ debris



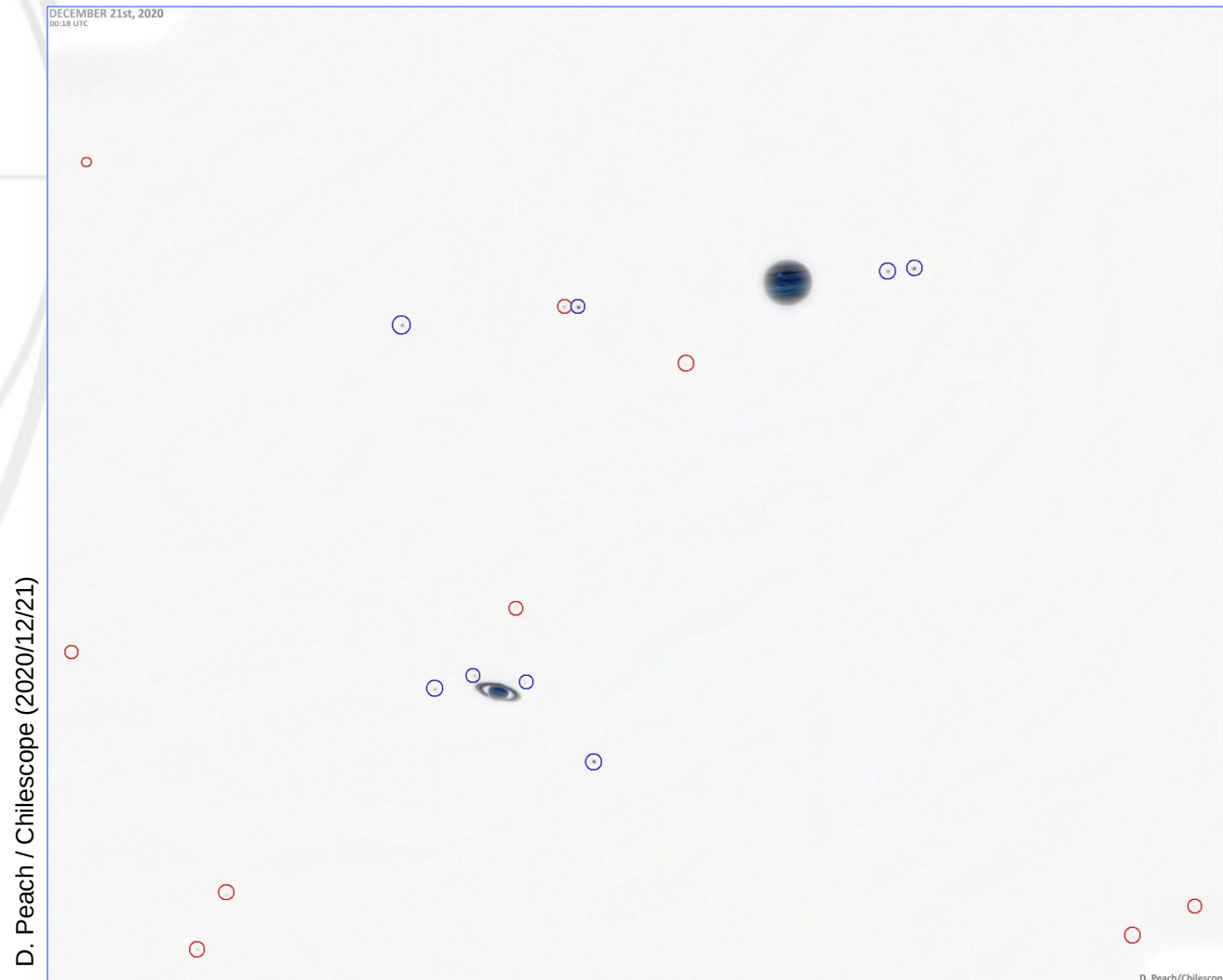
D. Peach / Chilescope (2020/12/21)

i.e. small astrometric dataset, for:

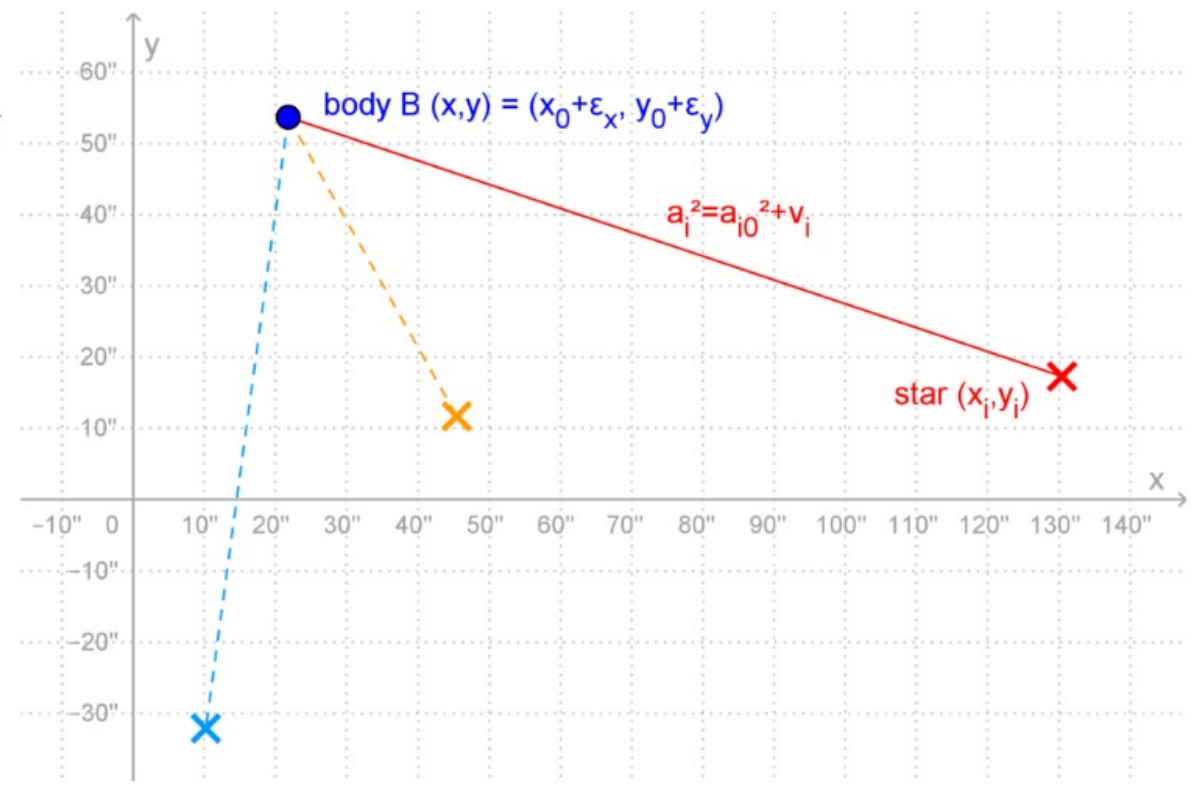
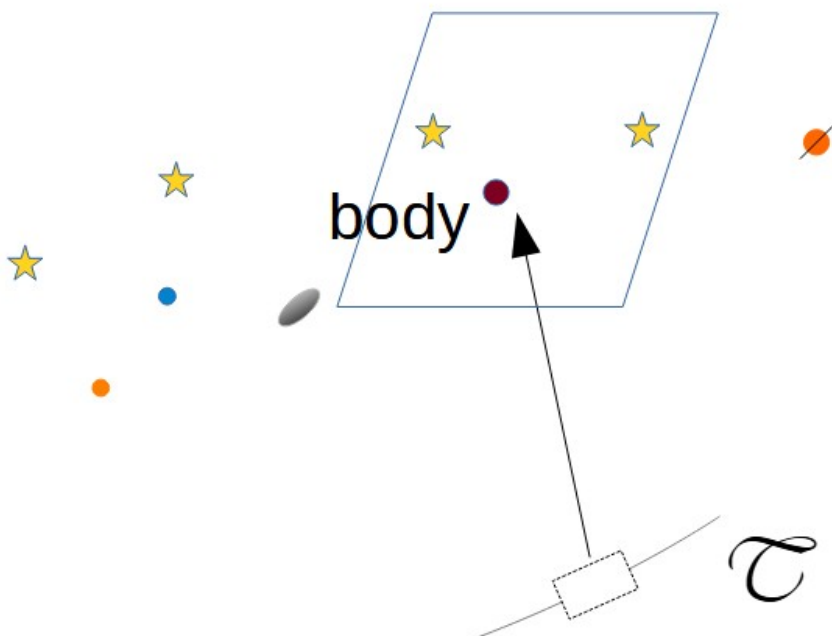
- ▶ Deep-space Navigation
- ▶ Space Situational Awareness
- ▶ Debris chasing & removal
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Precise directions of...

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- ★ debris



Could we refined a beacon's direction with visible stars?



Regions of interest defined from on-board ADCS:

- ▶ Gnomonic projection
- ▶ Centroiding of the beacon
- ▶ Centroiding of known stars
- ▶ Refined location (x,y) in FoV
- ▶ Reverse gnomonic projection

Several techniques available on ground, not on board.

- ▶ Milli-arcsec accuracy on ground

(target) Sub-Arcsec accuracy on board

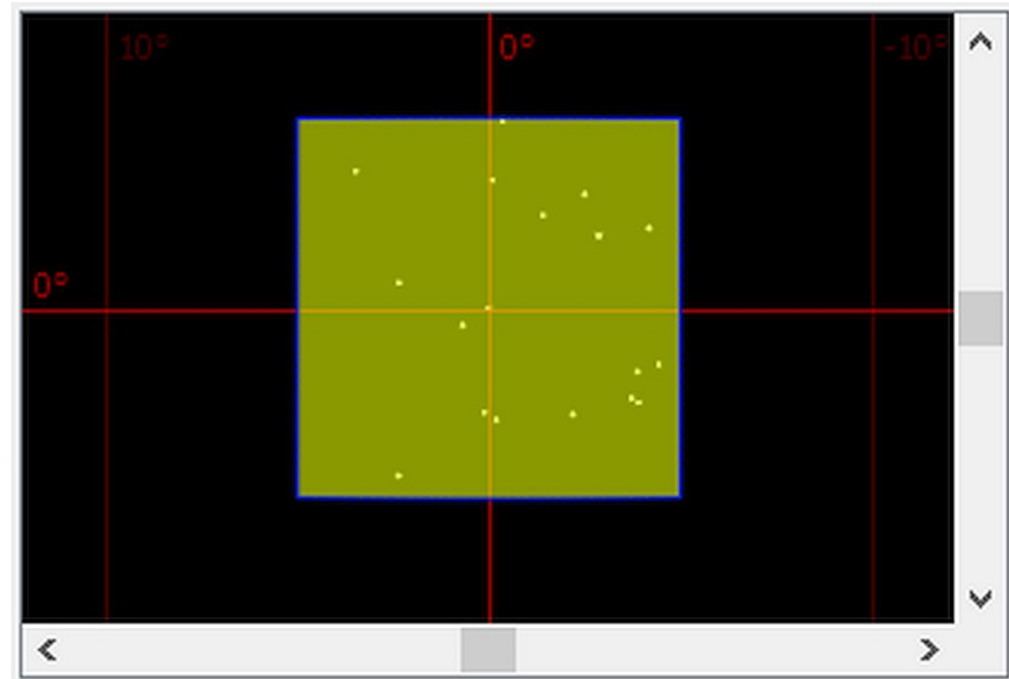
Typical CubeSat datasheet

★ Imager

- ▶ $\sim 10^\circ$ FoV
- ▶ Specified for Earth Obs

★ ADCS

- ▶ APE 0.1° ($1\sigma \dots 3\sigma$)
- ▶ AKE 15-30 arcsec ($1\sigma \dots 3\sigma$)



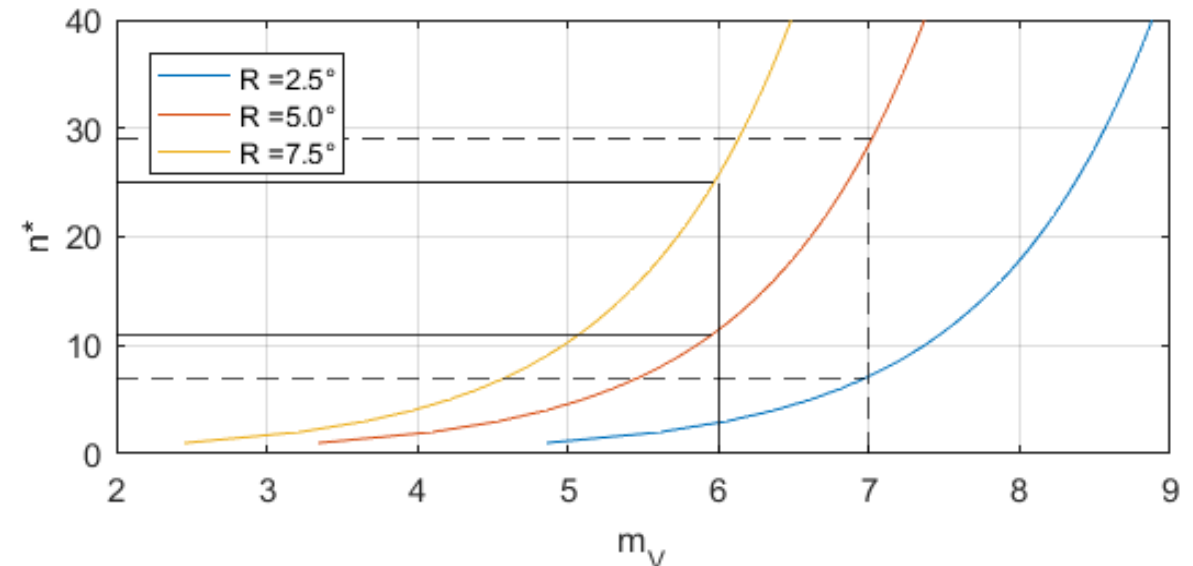
Let's design an experiment for OPS-SAT:

★ Select star fields

★ Use one of it as a beacon

★ Run multiple measurements

★ Extract statistics



SEPP: I/F to OBC

IADCS-100 by Berlin Space Technologies

★ RW x6, MTQ x3

★ ST-200

- ▶ AKE 30 arcsec (3σ), 1Hz
- ▶ Sensitivity up to Mv 6
- ▶ in (X,Y) plane

IMS-100 by Berlin Space Technologies

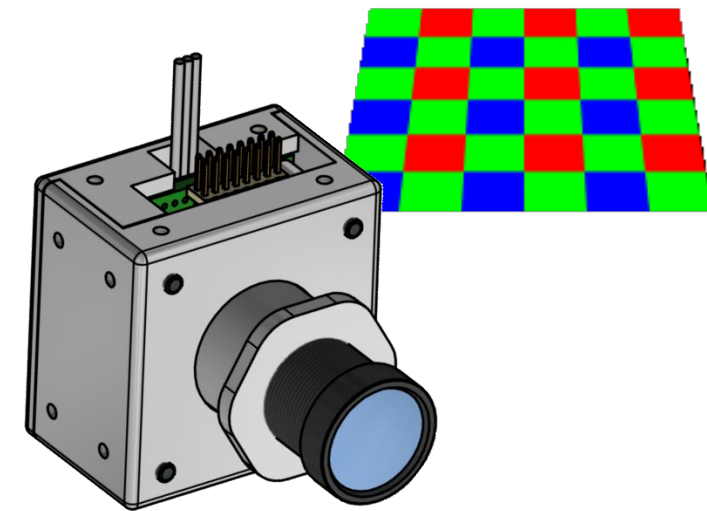
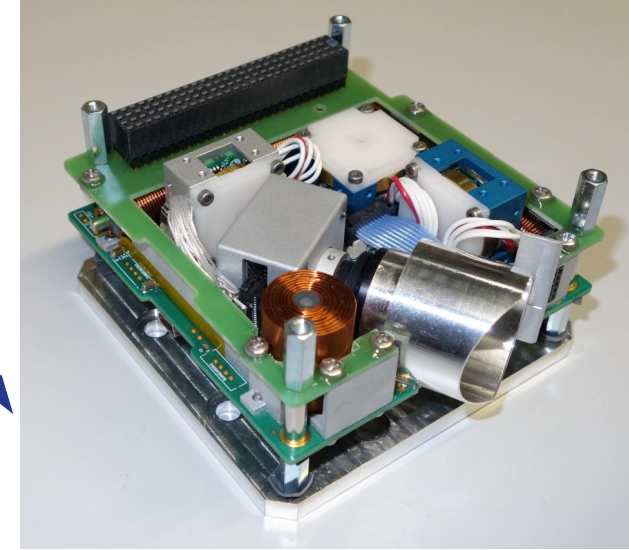
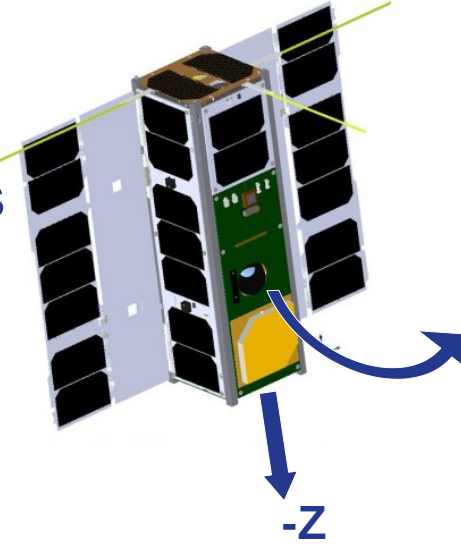
★ FoV $\sim 10^\circ$, pointed to -Z

★ RGGB Bayer pattern

- ▶ 2048x1944 px
- ▶ 12-bit / RAW

We got selected: “Exp.ID 156”

- ▶ but characterization for astrometry



Our goal: Refined absolute direction of foreground objects

- ★ Expected foreground object in the field of view ($10^\circ \times 10^\circ$)
- ★ Expected known stars in regions of interest
- ★ On-board processing to reach sub-arcsec accuracy

Bonus: characterization of platform's stability

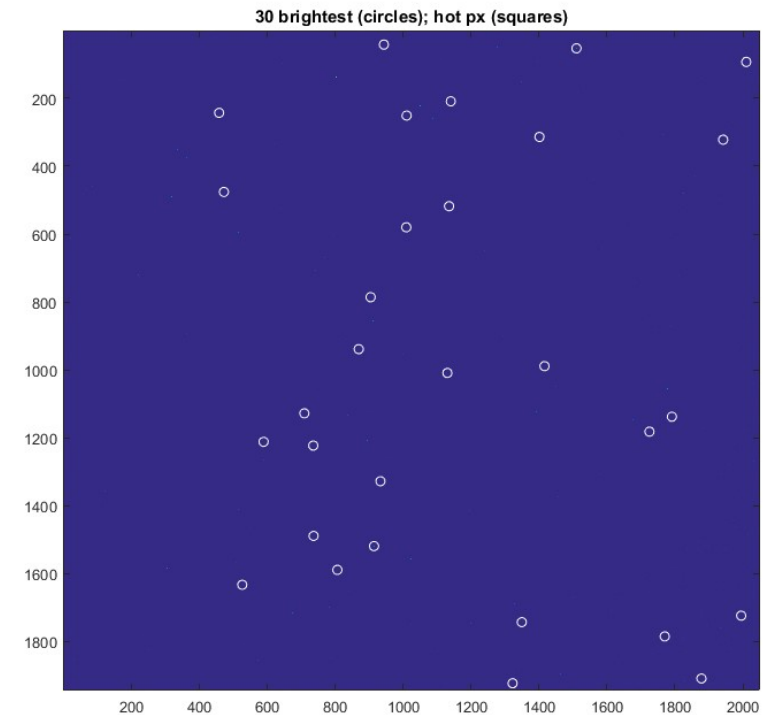
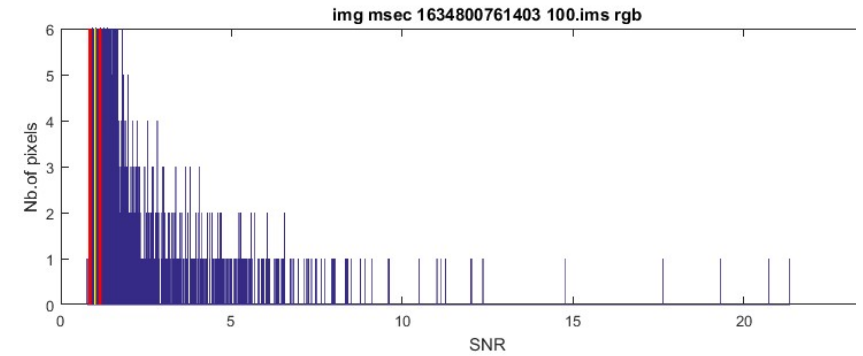
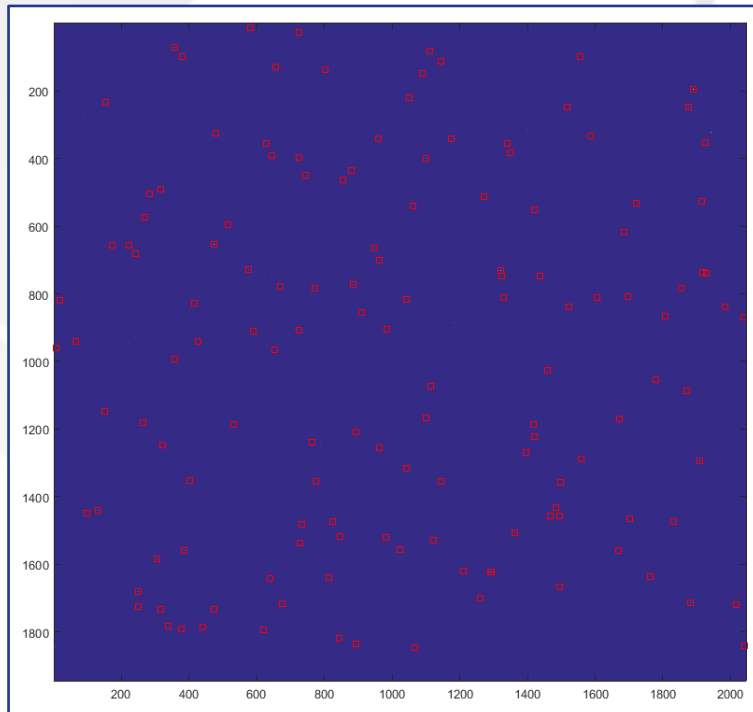
Open-source?

- ★ Why not the image post-processing
- ★ If YOU are interested, we could offer it as a ProAm experiment

At first we need to see stars...

Candidates were “hot” pixels... a lot of hot pixels

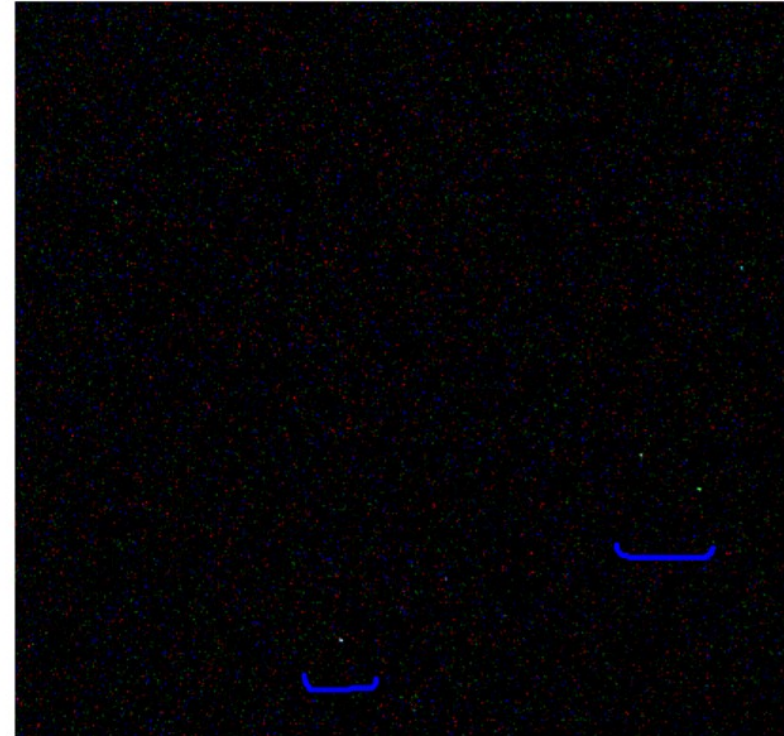
Or candidates were “cosmics”... a lot of cosmics



Dear Boris,

We downloaded more images with 500ms exposure and this time it looks like we can see stars!

At least on the post-processed images we can see dots that have the same distance between them on several pictures:



Names and timestamps:

`img_msec_1636537884803_500.ims_rgb -> 10 November 2021 09:51:24.803 UTC`

`img_msec_1636537961522_500.ims_rgb -> 10 November 2021 09:52:41.522 UTC`

(credit: OPS-SAT Team, Vladimir & Dominik)

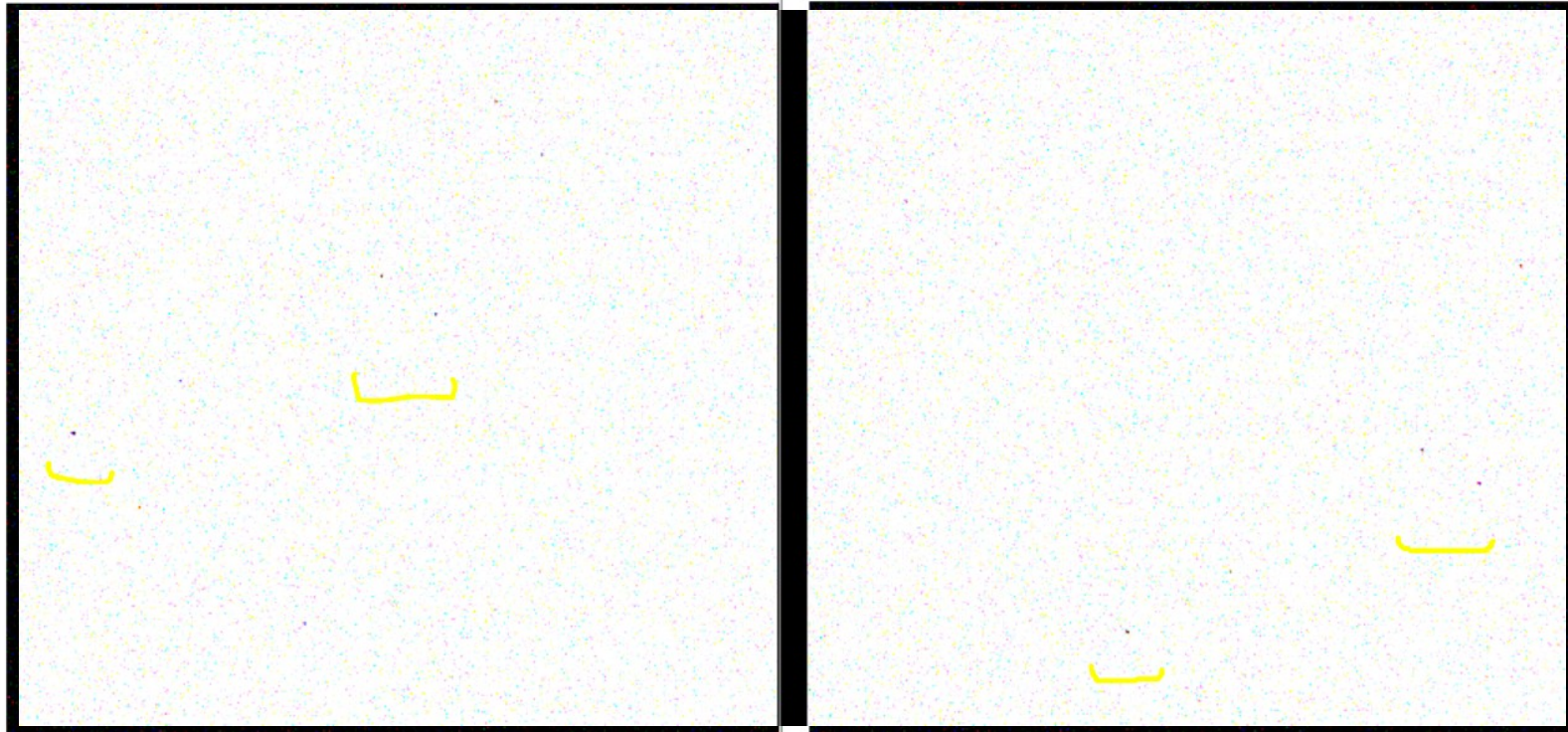
- ★ Quick removal of “high” pixels
- ★ Submission to Astrometry.net

=> and we got a match

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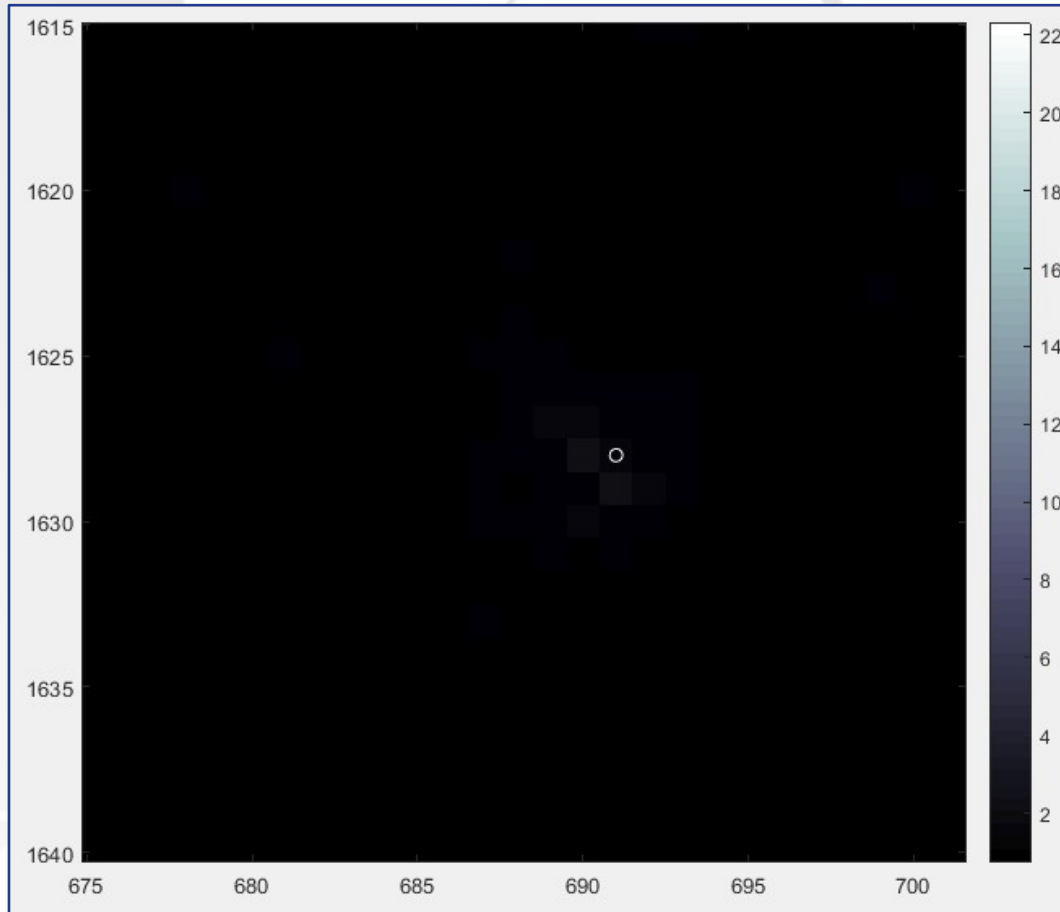
(credit: OPS-SAT Team, Vladimir & Dominik)

Quick removal of “high” pixels

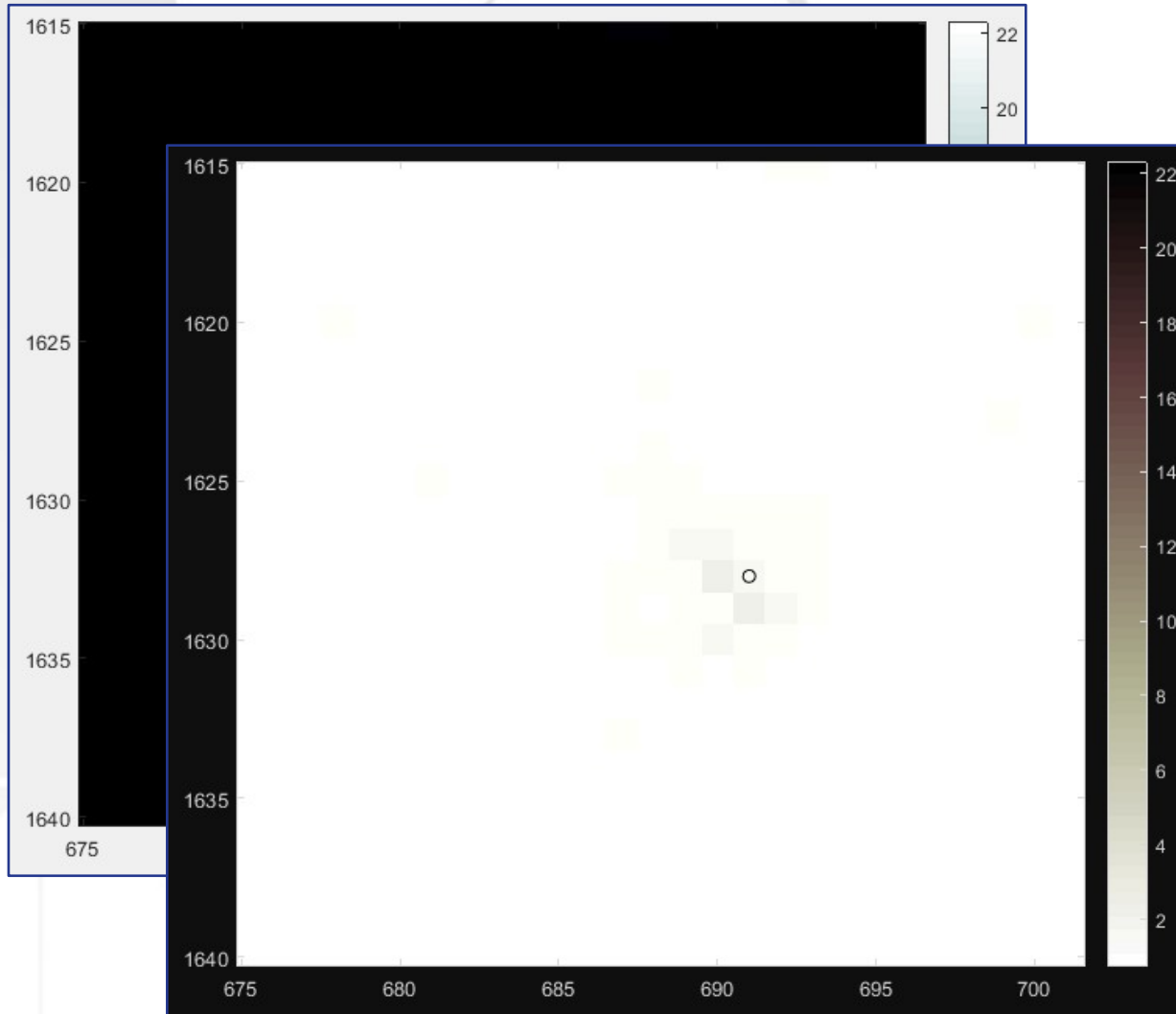
Submission to Astrometry.net

=> and we got a match

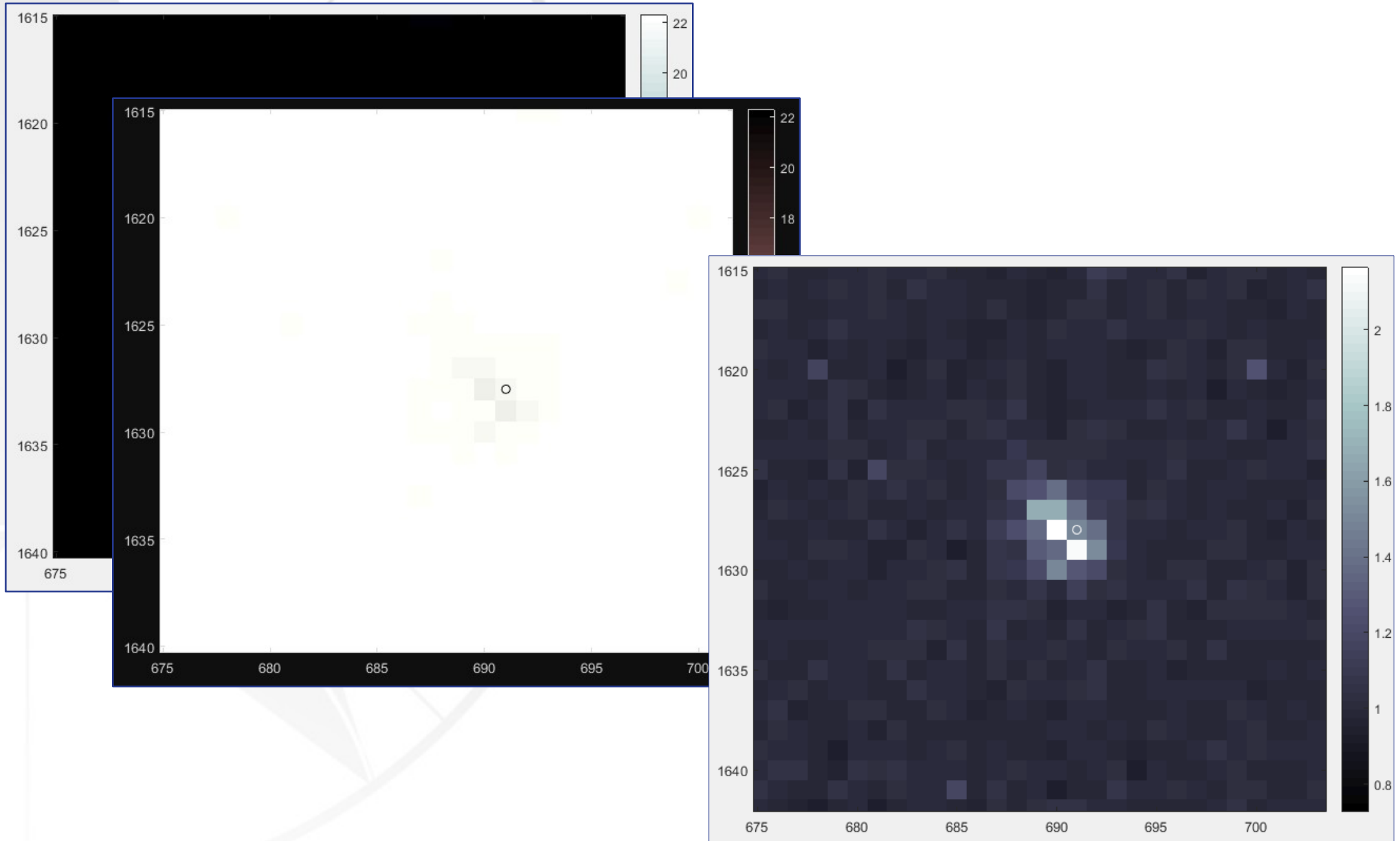
Eventually, indeed we can see stars



Eventually, indeed we can see stars



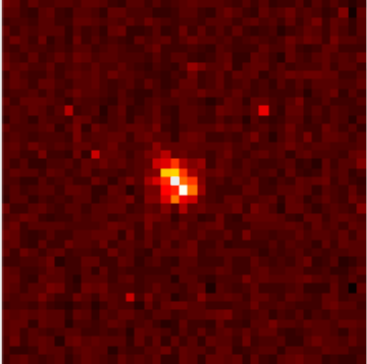
Eventually, indeed we can see stars



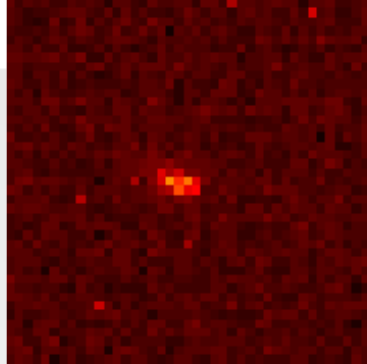
Many stars

First 14 areas in img msec 1636538036883 500

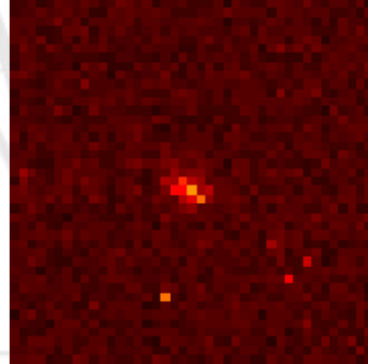
[691 1628], Tot.SNR=11.9



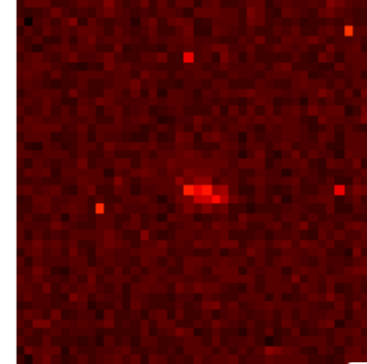
[1639 1239], Tot.SNR=6.1



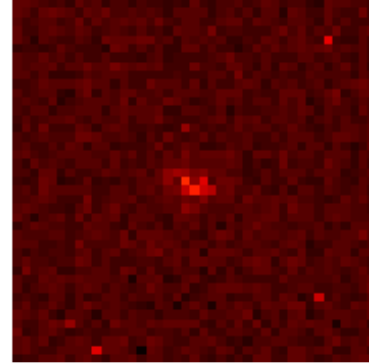
[1486 1147], Tot.SNR=5.6



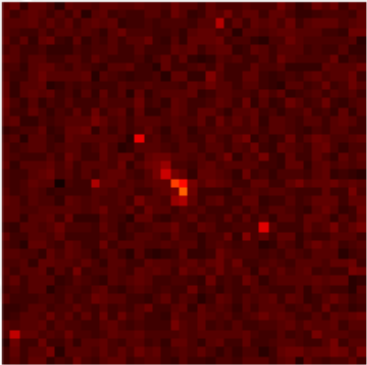
[1889 789], Tot.SNR=4.4



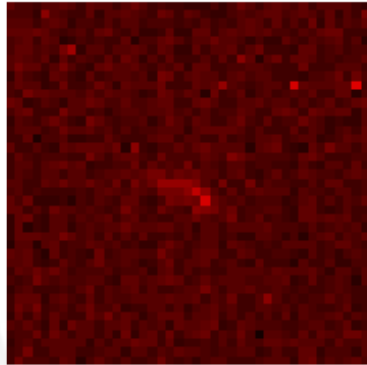
[1756 657], Tot.SNR=4.2



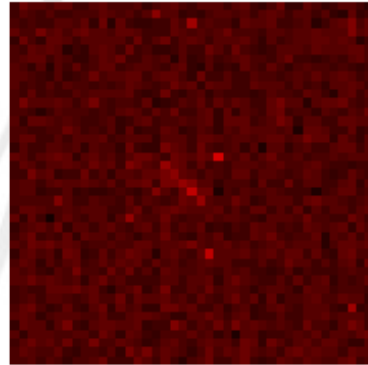
[968 1469], Tot.SNR=3.6



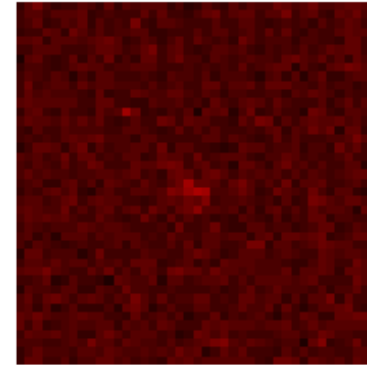
[110 466], Tot.SNR=3.2



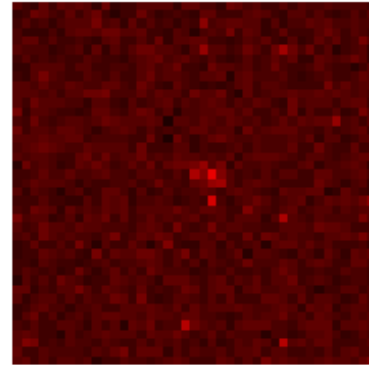
[350 583], Tot.SNR=2.6



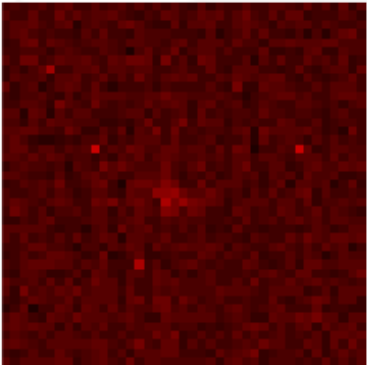
[882 1813], Tot.SNR=2.5



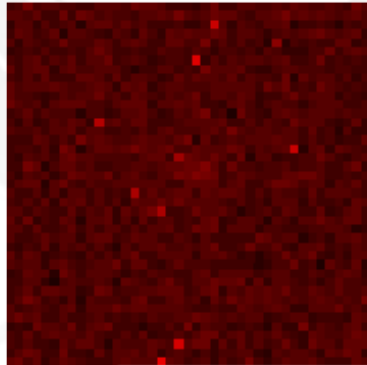
[1465 486], Tot.SNR=2.5



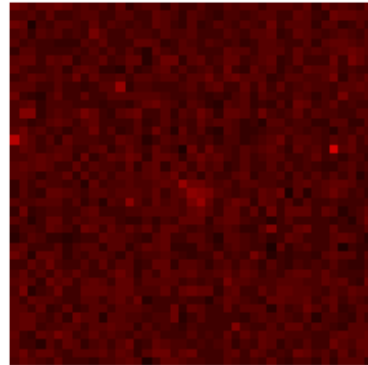
[1965 1903], Tot.SNR=2.4



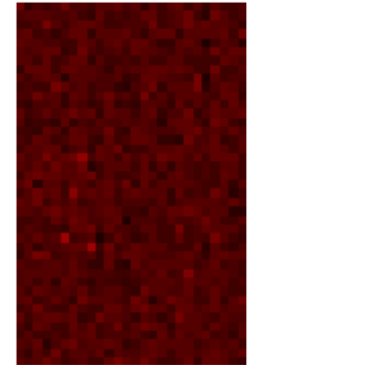
[1485 511], Tot.SNR=2.4



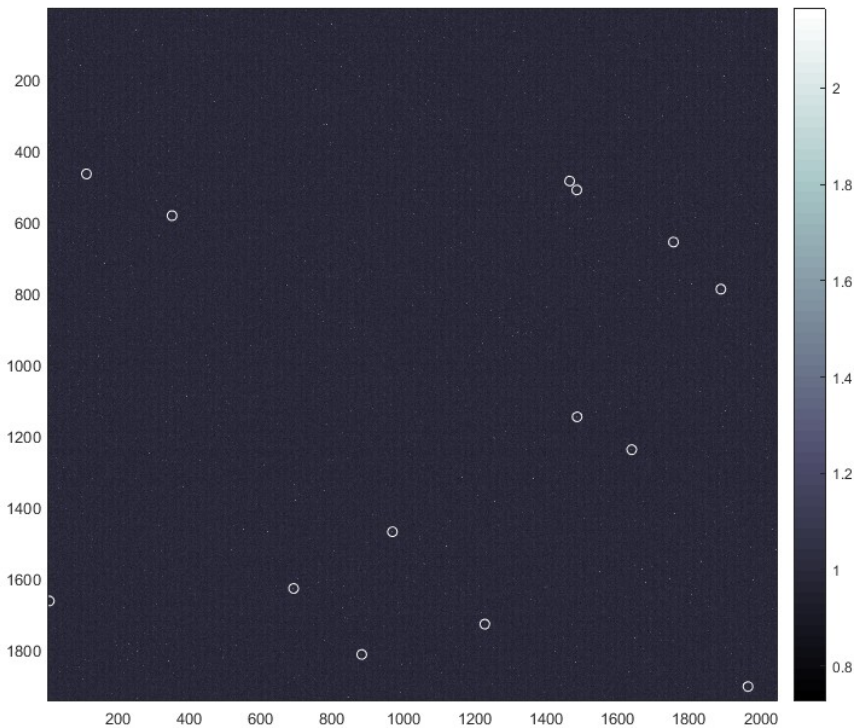
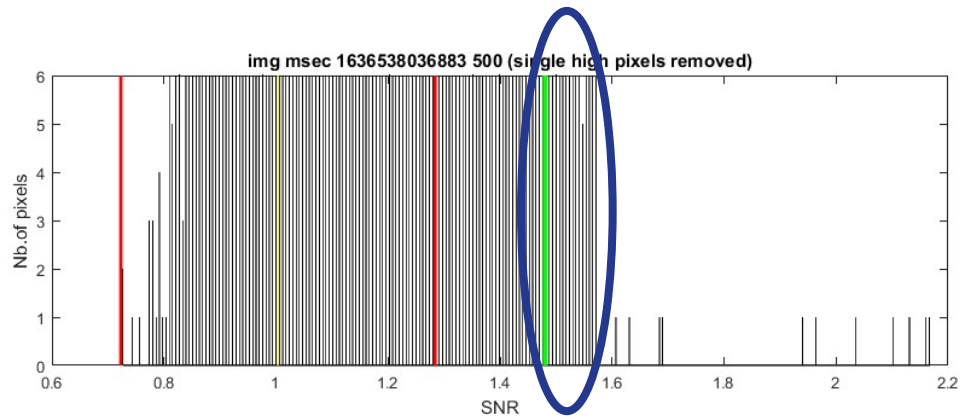
[1227 1728], Tot.SNR=2.2



[6 1663], Tot.SNR=2.1



*More than 10 stars
at Tot.SNR > 2*



NOTE: signins should be working again... but read about account migration. Not signed in | Sign in

Astrometry.net

Home Explore Upload API Support

Images > [img_msec_1636538036883_500.png](#)

Submitted by anonymous (1)
on 2021-12-01T15:39:01Z
as "img_msec_1636538036883_500.png"
(Submission 5278766)
under Attribution 3.0 Unported

Job Status

Job 5981991:
Success

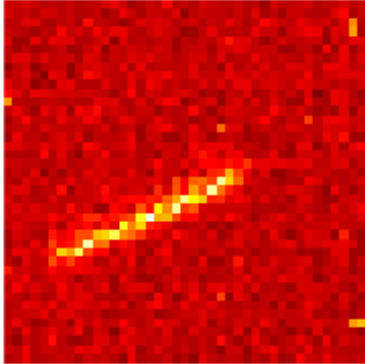
Calibration

Center (RA, Dec): (3.791, -5.272)
Center (RA, hms): 00^h 15^m 09.840^s
Center (Dec, dms): -05° 16' 18.071"
Size: 10.3 x 9.81 deg
Radius: 7.122 deg
Pixel scale: 18.2 arcsec/pixel
Orientation: Up is 349 degrees E of N

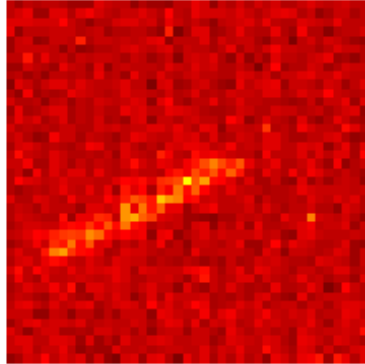
WCS file: [wcs.fits](#)
New FITS image: [new-image.fits](#)
Reference stars nearby (RA,Dec table): [rdls.fits](#)
Stars detected in your images (x,y table): [axy.fits](#)
Correspondences between image and reference stars (table): [corr.fits](#)
Legacy Surveys sky browser: [browse the sky](#)
KMZ (Google Sky): [image.kmz](#)
World Wide Telescope: [view in WorldWideTelescope](#)

First 10 areas in img msec 1637067864308 800

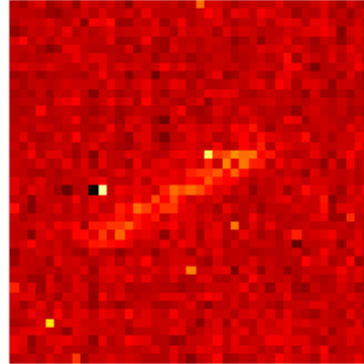
[714 1298], Tot.SNR=5.4



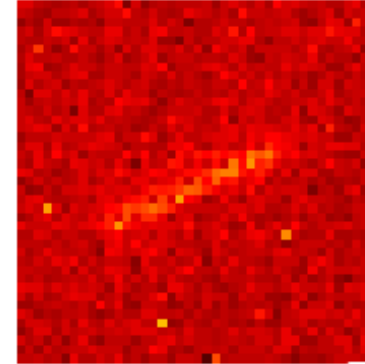
[1954 1320], Tot.SNR=4.8



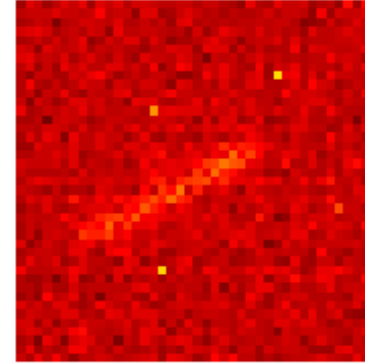
[1937 353], Tot.SNR=4.3



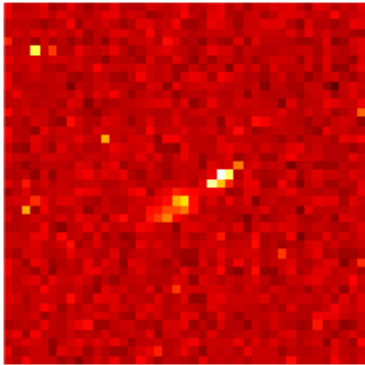
[509 761], Tot.SNR=4.0



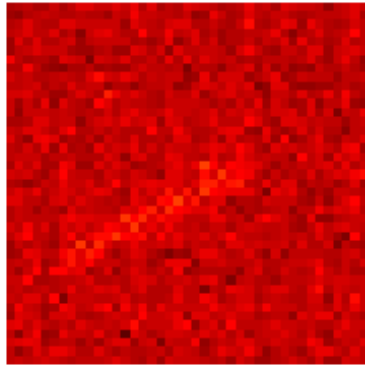
[1665 90], Tot.SNR=3.7



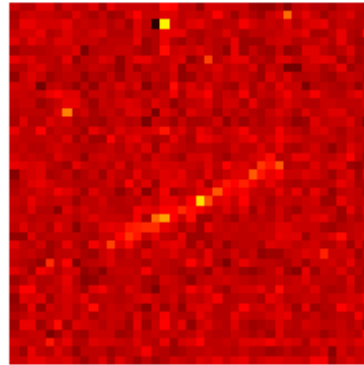
[1108 257], Tot.SNR=3.1



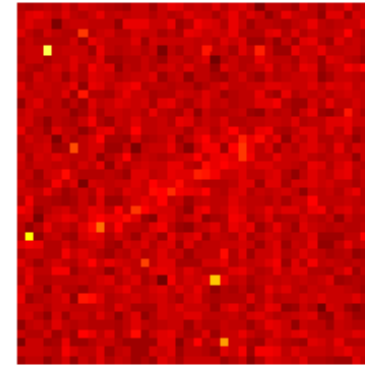
[1685 298], Tot.SNR=2.8



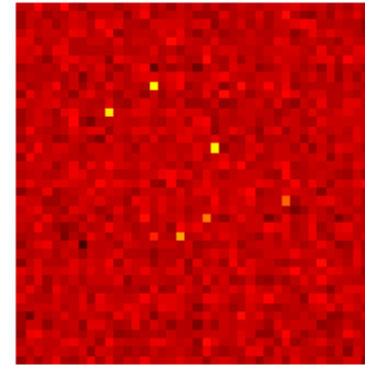
[966 720], Tot.SNR=2.5



[1683 1125], Tot.SNR=2.1



[374 562], Tot.SNR=1.4



Powerful stars are diluted in tens of pixels

=> not an issue if stars are reliably expected in a region of interest (RoI)

=> 500ms better than 800ms

★ Flux is better concentrated

★ Easier match with Astrometry.net

★ Jitter still strong in addition of drift

Noise characterization with a Bayer matrix

Removing:

- ★ “high” isolated pixels (hot/dead or cosemics) ~1200
- ★ “spread” cosemics (2-3 pixels) ~100, manually
- ★ Output to “hot pixel” monitoring

Sorting remaining cosemics and stars, manually

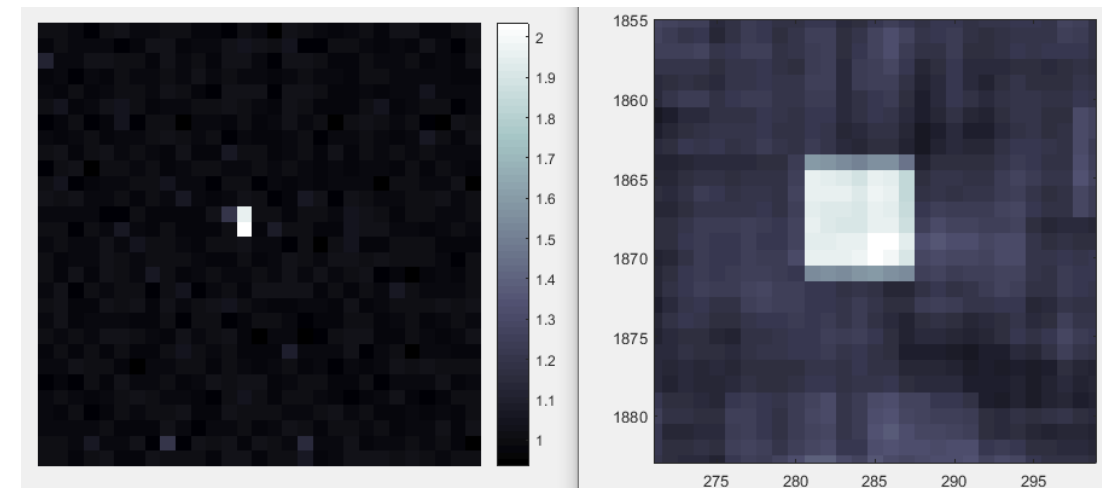
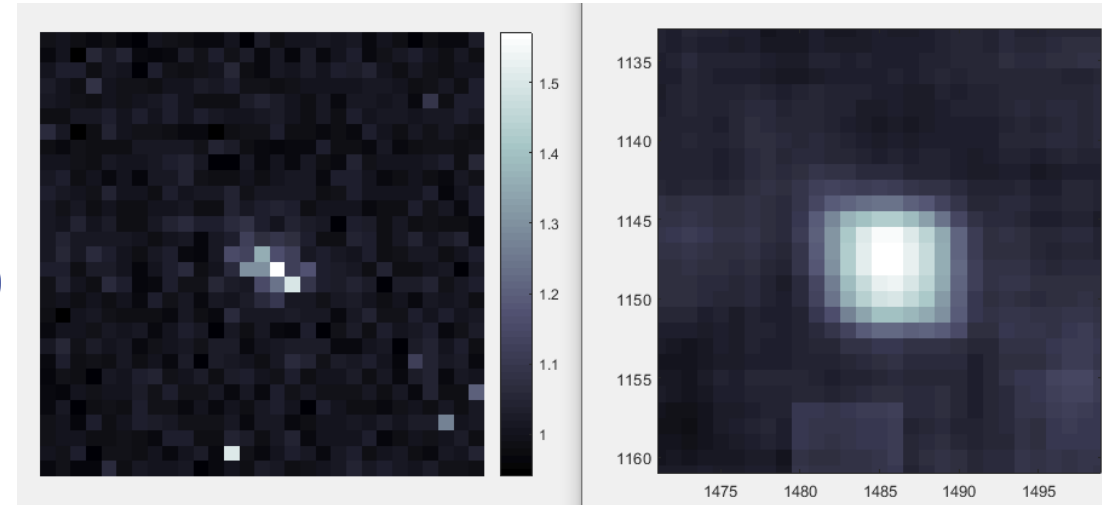
- ★ 7x7 convolution to identify star areas
- ★ More “high” pixels, ~10..50 with $\text{SNR} > \text{Noise} + 3\sigma$

Field of view characterization

- ★ From Astrometry.net: absolute orientation
 - ▶ Transform into quaternions
- ★ From OPS-SAT: iADCS/ST quaternions
 - ▶ then interpolation
 - ▶ then inverse gnomonic projection

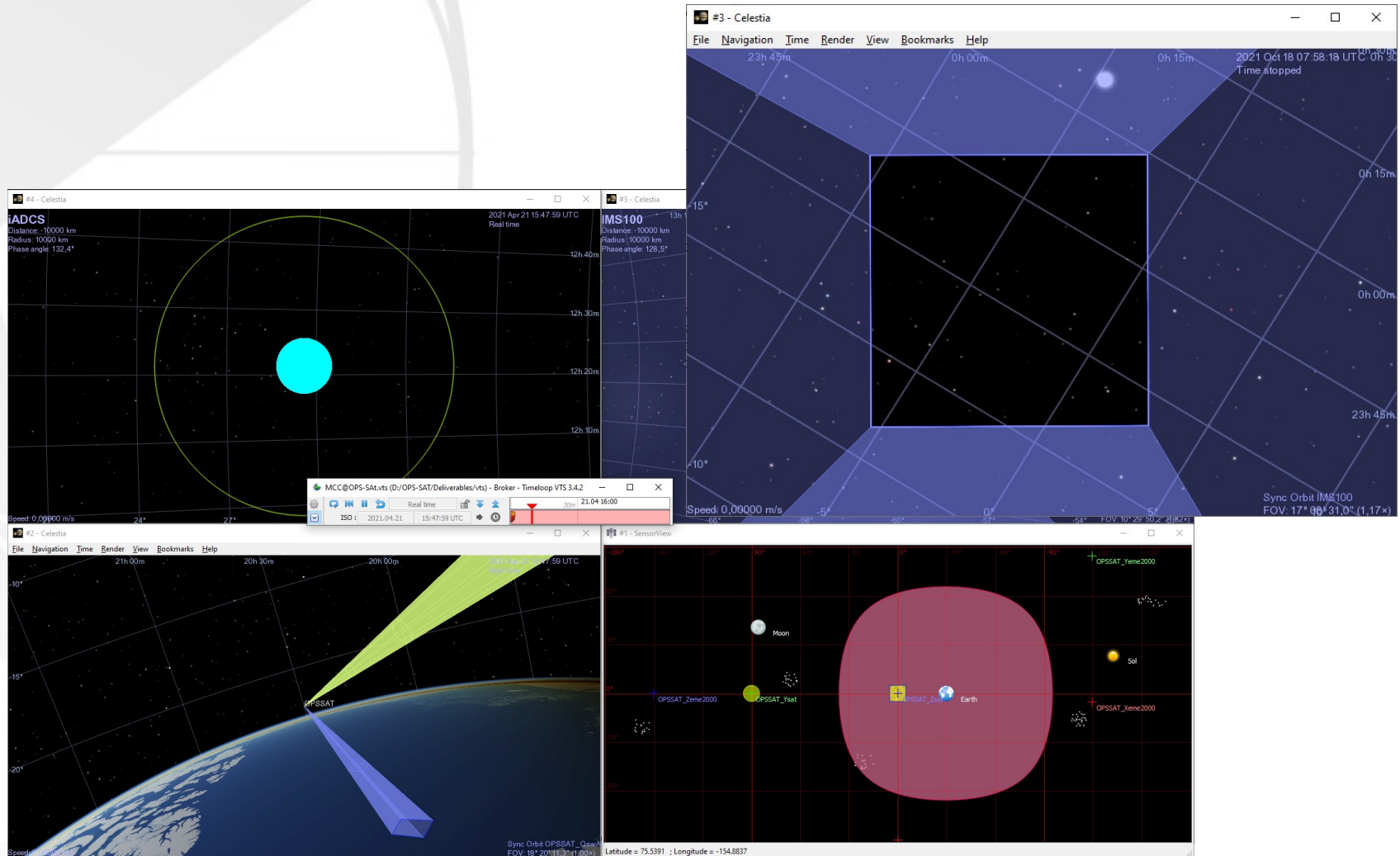
=> reconstructed mission with VTS

=> investigations on the sources of jitter



VTS to display the reconstruction

ascii formats to VTS © CNES





NanoCam



Request reinforced astrometric capabilities

★ ADCS:

▶ Sources of jitter:

- vibrations from the reaction wheels
- wobbling from the ADCS' control laws

▶ ST avoidance angle (straylight from structure edges?)

▶ Simplified ADCS operations

★ Imager:

▶ sensitivity to compensate for Bayer pattern

▶ shielding

▶ Imager/OBC pre-processing of raw pictures

*Lesson for **all** CubeSats: characterize the ADCS!*



contact.census@obspm.fr
https://census.psl.eu/



Project “processSkyPictures” on gitlab.com

for astrometry with OPS-SAT

<https://gitlab.com/cceres-docks/processskypictures>