Herschel Pointing : Status, Impact on Map-Making, and Coming Improvements

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Herschel pointing accuracy

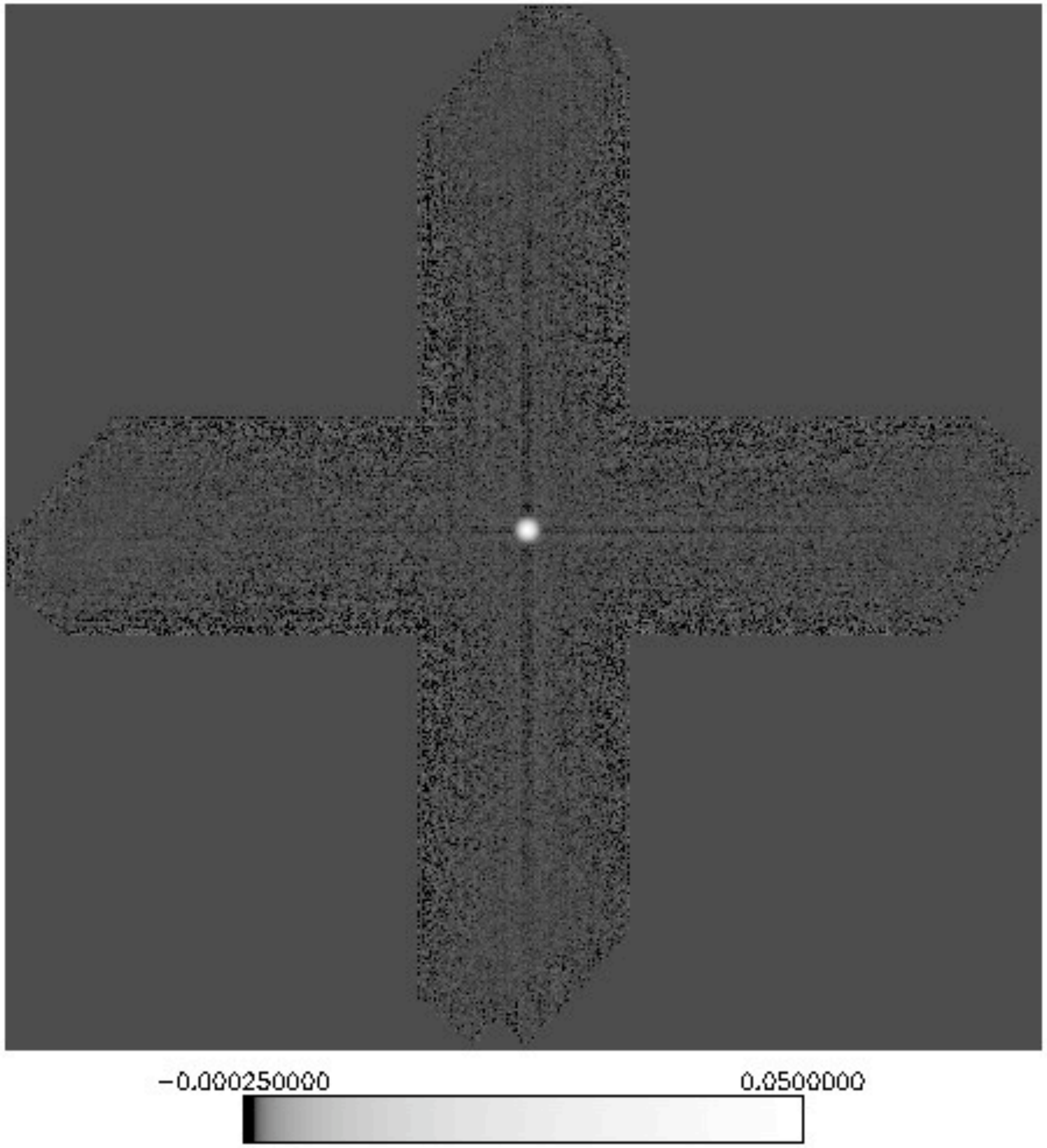
- There are two types of "pointing accuracy":
  - How accurate is Herschel ability to point toward a commanded attitude ?
  - How accurate is our determination of where Herschel is pointing at any given time ?
- Only the second one matters for map making.

Pointing Accuracy Impact in Map Making

- Astrometric issues
- Signal to noise loss
- Artifacts on bright sources

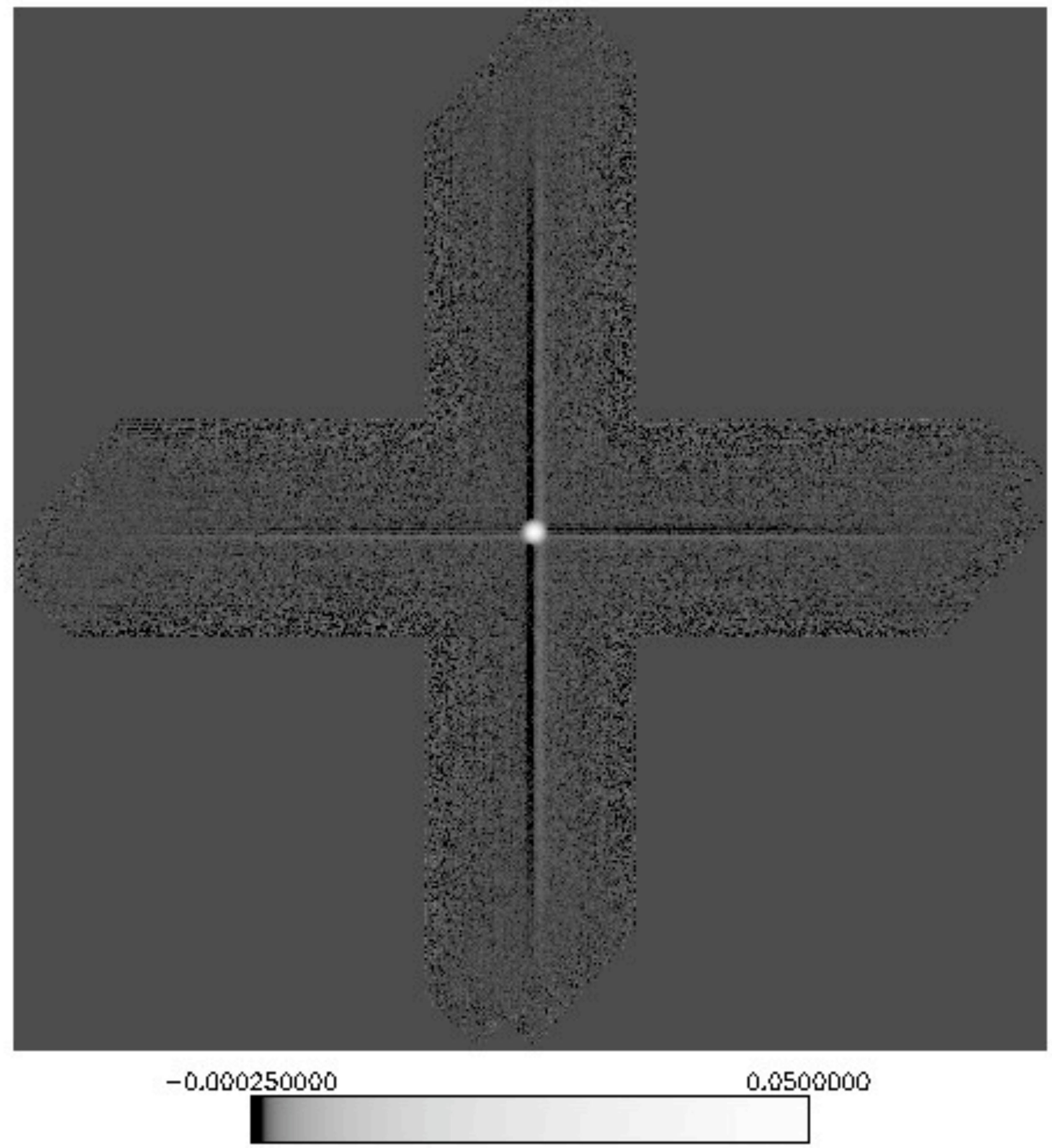
Cross-like artifacts in inversion methods

- Scan and cross-scan over a bright gaussian source
- On board compression: 4 frames
- Perfect pointing accuracy



Cross-like artifacts in inversion methods

- Scan and cross-scan over a bright gaussian source
- On board compression: 4 frames
- 2.45" 1 σ pointing offsets between scans



Components of a detector pointing

- The accuracy of the position of a detector on the sky depend on four elements:
  - Herschel attitude and velocity accuracy
  - Instrument position in Herschel focal plane
  - Time synchronization between satellite and instrument clock
  - Instrument focal plane geometry

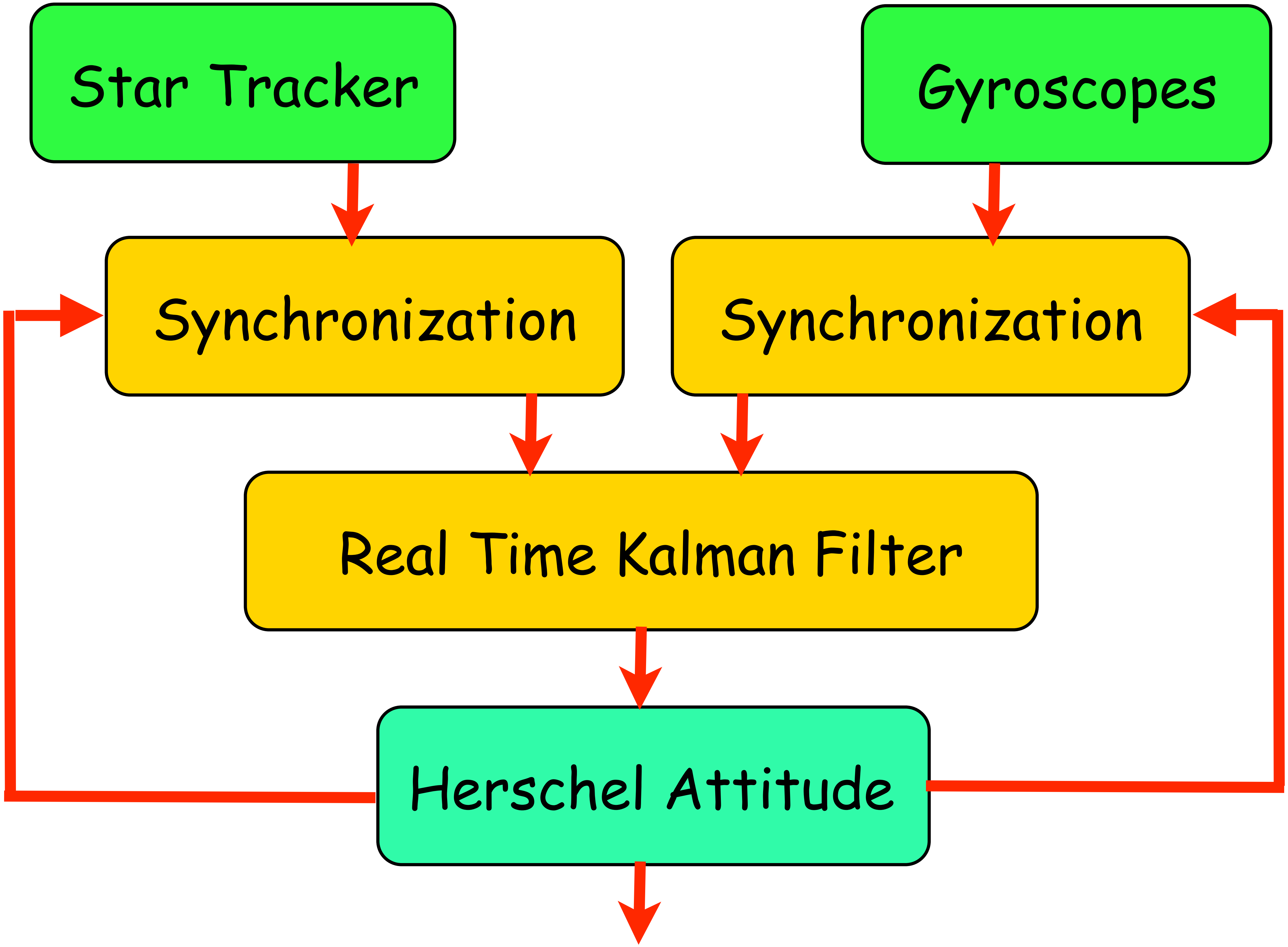
Herschel Attitude Accuracy

- ESA uses three different types of errors to describe how accurate the pointing (in the first sense) is:
    - APE : Absolute Pointing Error
    - RPE : Relative Pointing Error
    - SRPE : Spatial Relative Pointing Error
- The physical origin of SRPE and APE is the same, so APE is the error that we are getting when making maps larger than a few arcmin.
- Remember that all errors are 1 σ, so the odds are good that your actual error is larger.

Herschel pointing products

- The attitude we get in the pointing product has been for a long time just the attitude derived on board by the ACMS

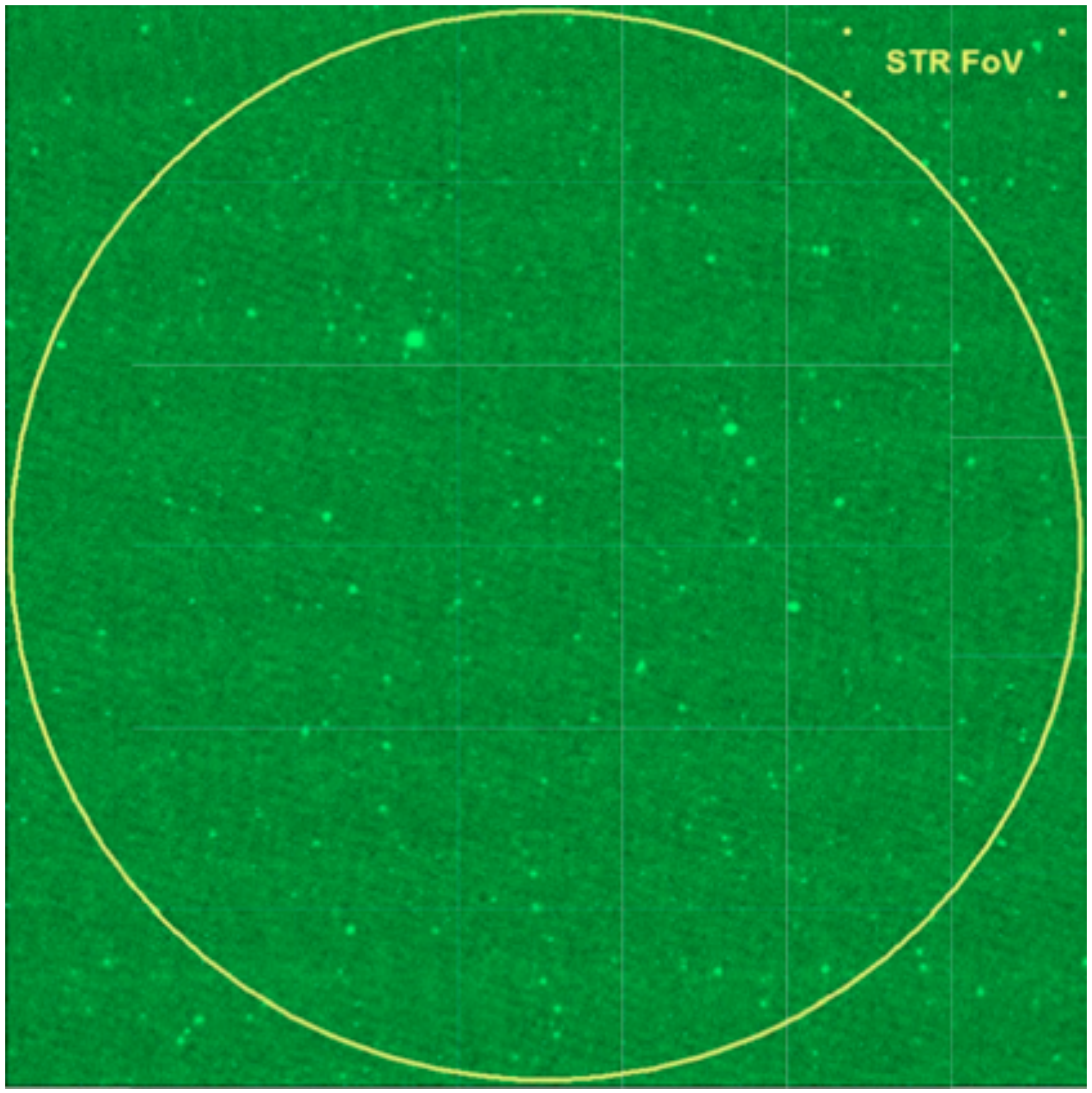
Herschel ACMS



Herschel Star Tracker (STR)

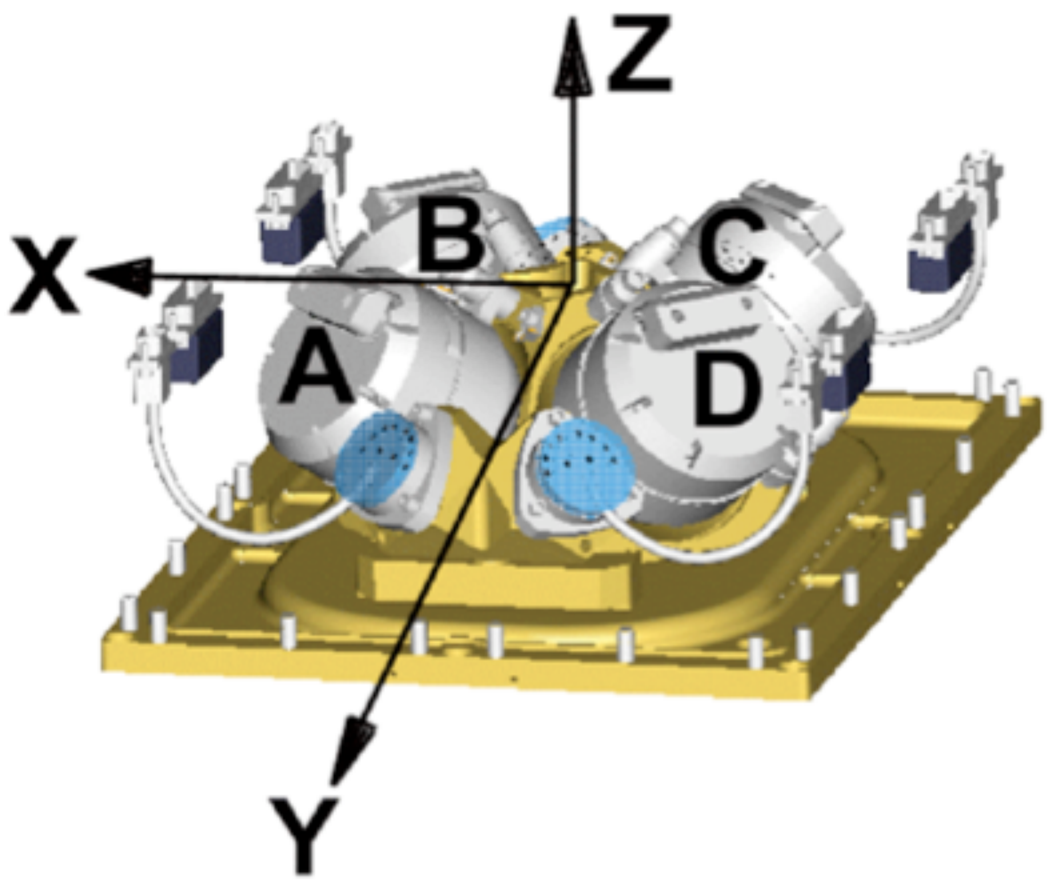
- Herschel uses 1 STR from Galileo Avionica
- STR is a small CCD camera with its software.
- Can figure out the direction it is pointing to.
- Can track 9 stars at 4Hz or 18 stars at 2 x 2Hz

Herschel STR



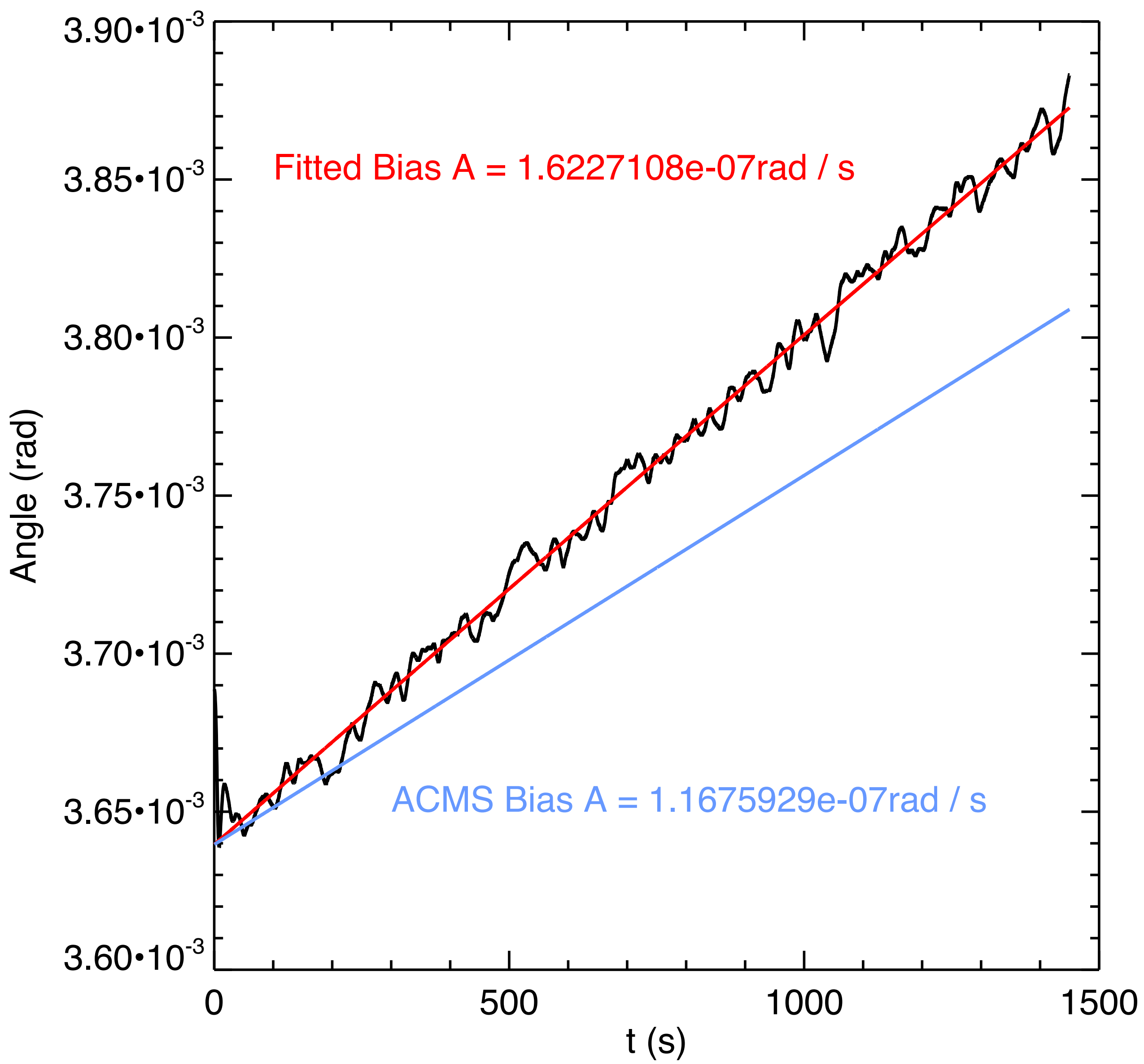
- Wide field: 16°
- Individual star positions are measured with an accuracy of 2 to 4″
- Best theoretical accuracy is 0.9″ (1σ) for direction and 6.5″ (1σ) for roll
- Requirement are 1″ (1σ) for direction and 10″ (1σ)

Herschel Gyroscopes (GYR)



- Herschel uses 4 Gruman-Northtop Space Inertial Reference Units
- Can measure a rotation of the spacecraft very accurately: 0.0005"/s

Herschel GYR

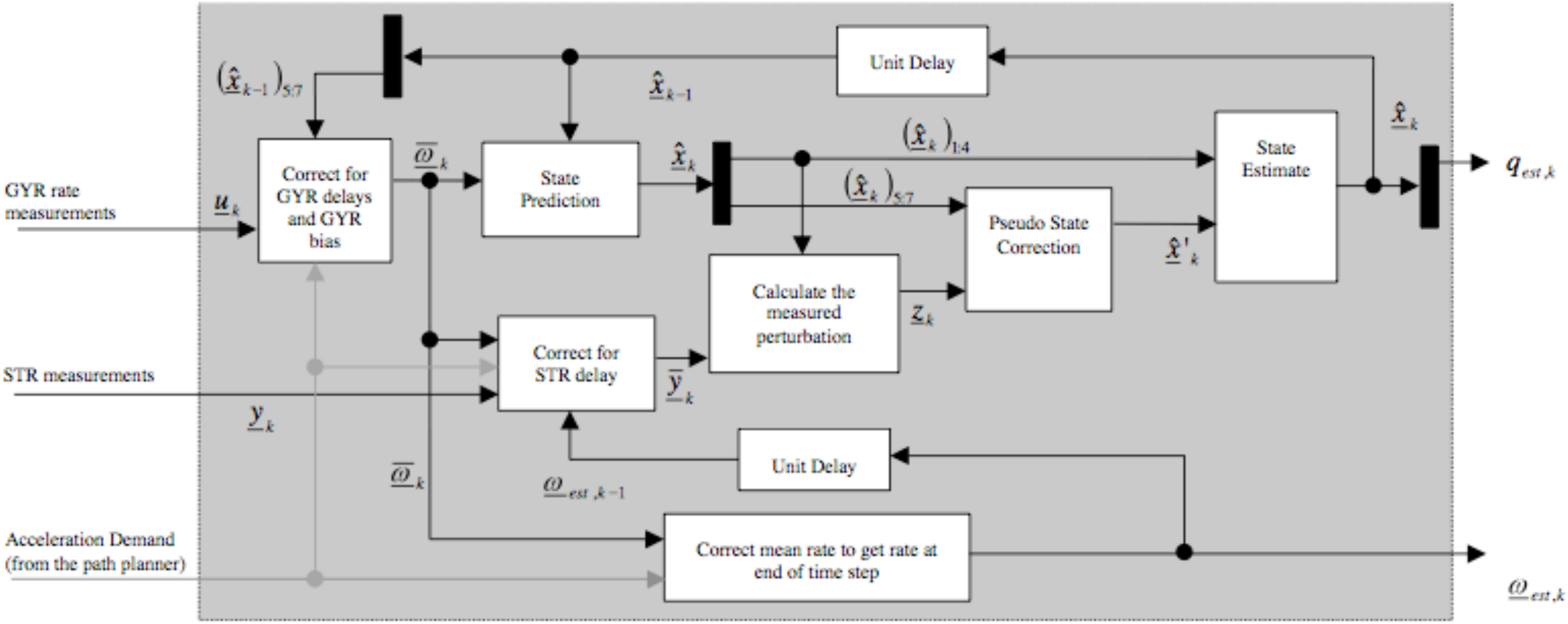


- GYR are subject to drift: even when the spacecraft is not moving, they register a rotation.
- This bias is not constant, but varies slowly.

Herschel ACMS

- The ACMS job is three-fold
  - synchronize the output of the STR and GYR subsystem
  - determine the attitude of Herschel and the GYR biases
  - command trajectory adjustements to stick to the planned one.

Herschel ACMS

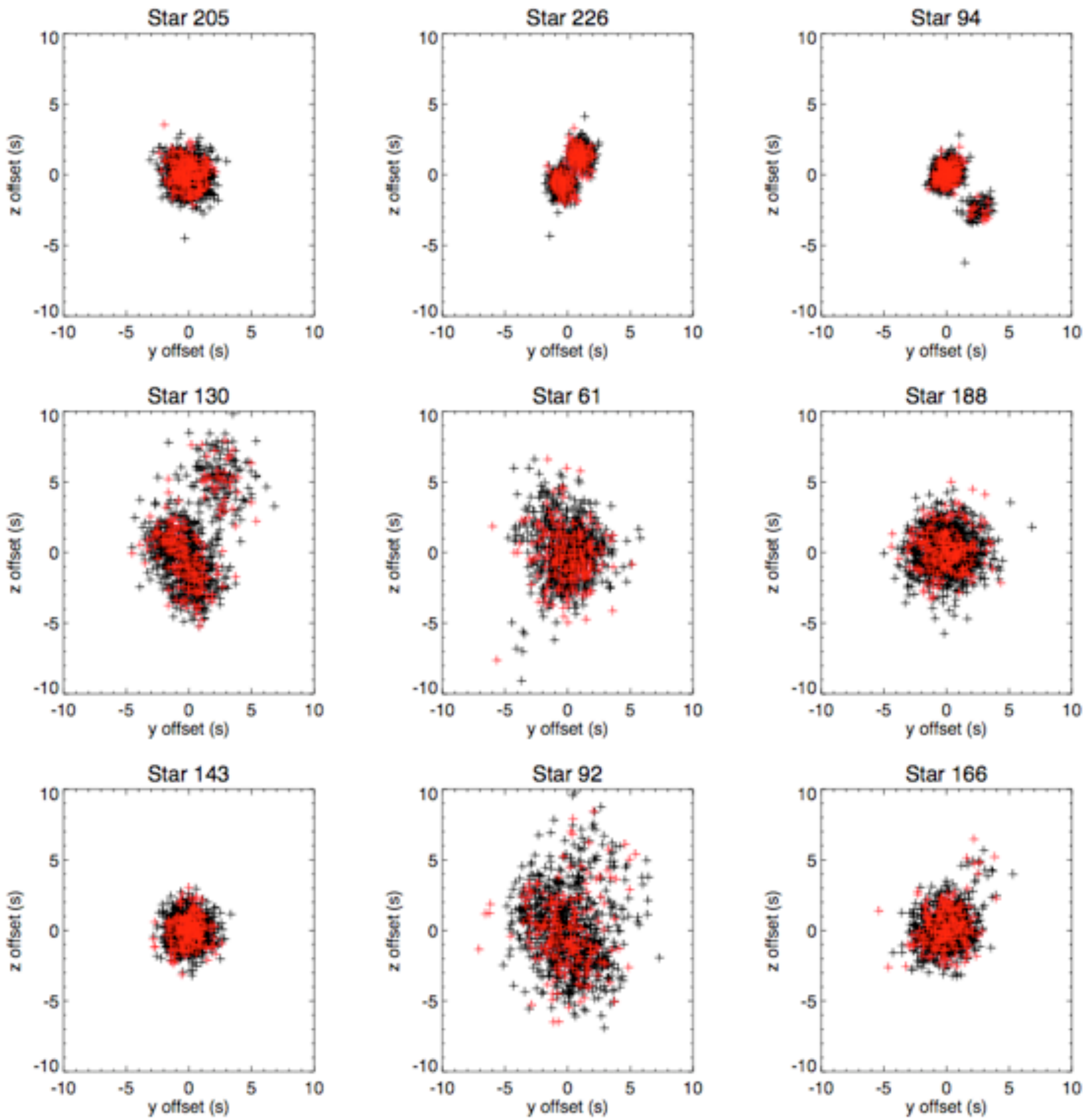


- The state vector is the attitude quaternion plus the GYR bias

Herschel ACMS

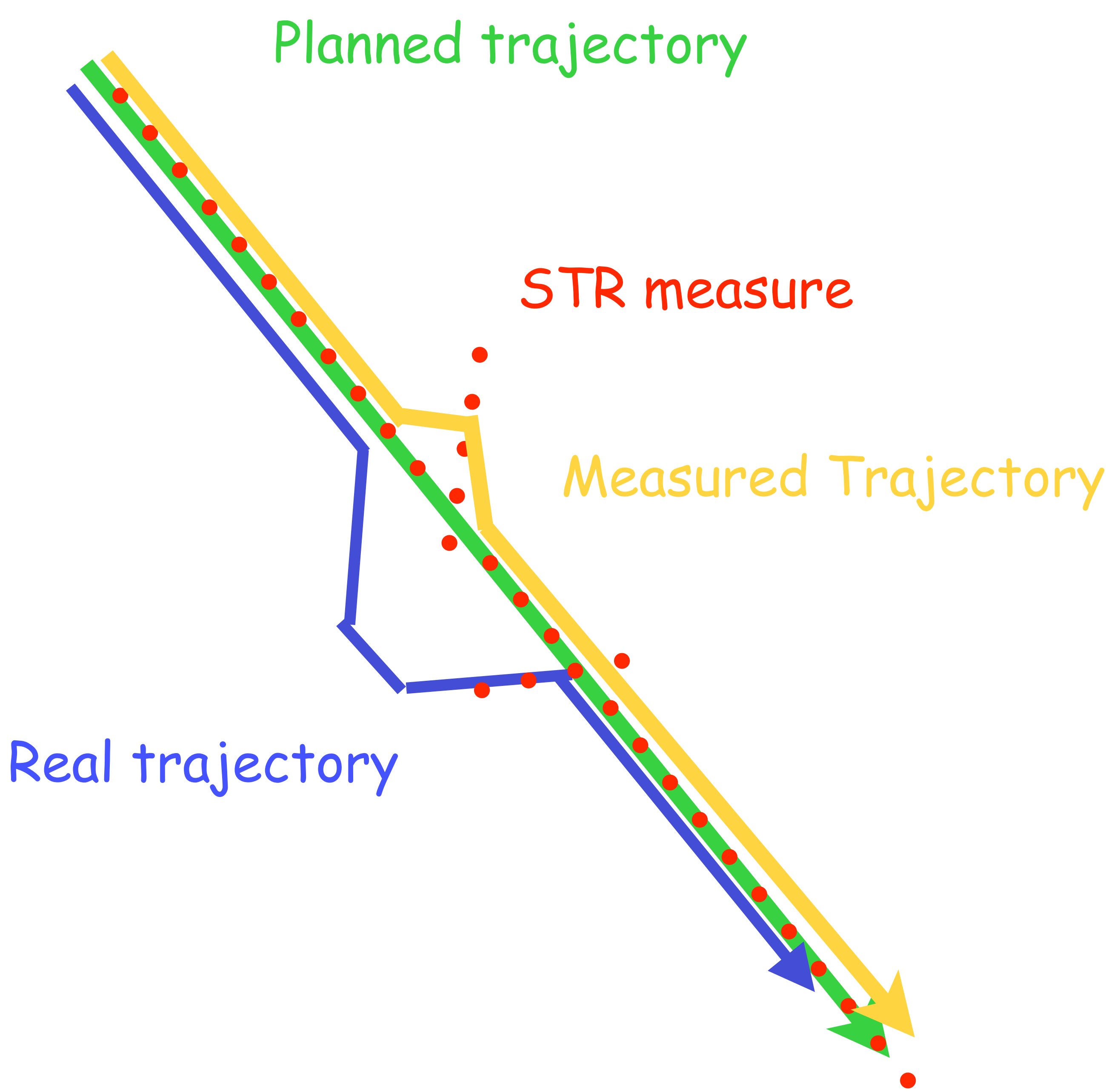
- The Kalman filter is used to determine the GYR biases from the STR, and increase the accuracy of the STR from the GYR
- The gains of the Kalman filter give a heavy weight on the STR, so that the satellite is immune to GYR unknown drift, but sensitive to STR glitches.

Herschel STR output



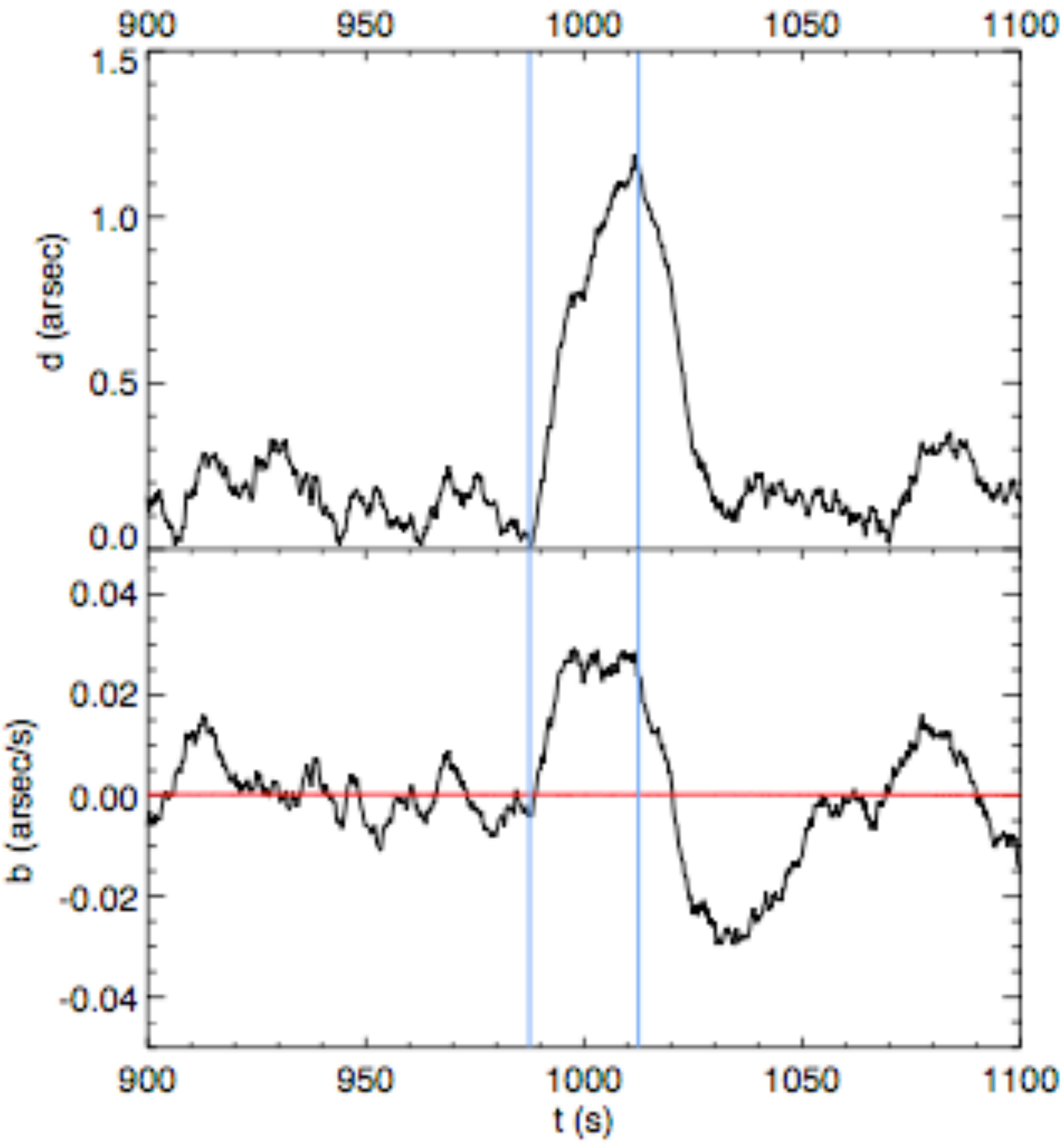
- Star positions measured by the STR during a long staring observation

Speedbumps.



- In the beginning of the mission, there were a lot of hot pixels in the CCD STR, causing some erroneous position measuements

Speedbumps



- Because of the high weight on STR vs. GYR, the Kalman filter incorrectly change the GYR bias instead of filtering the STR data

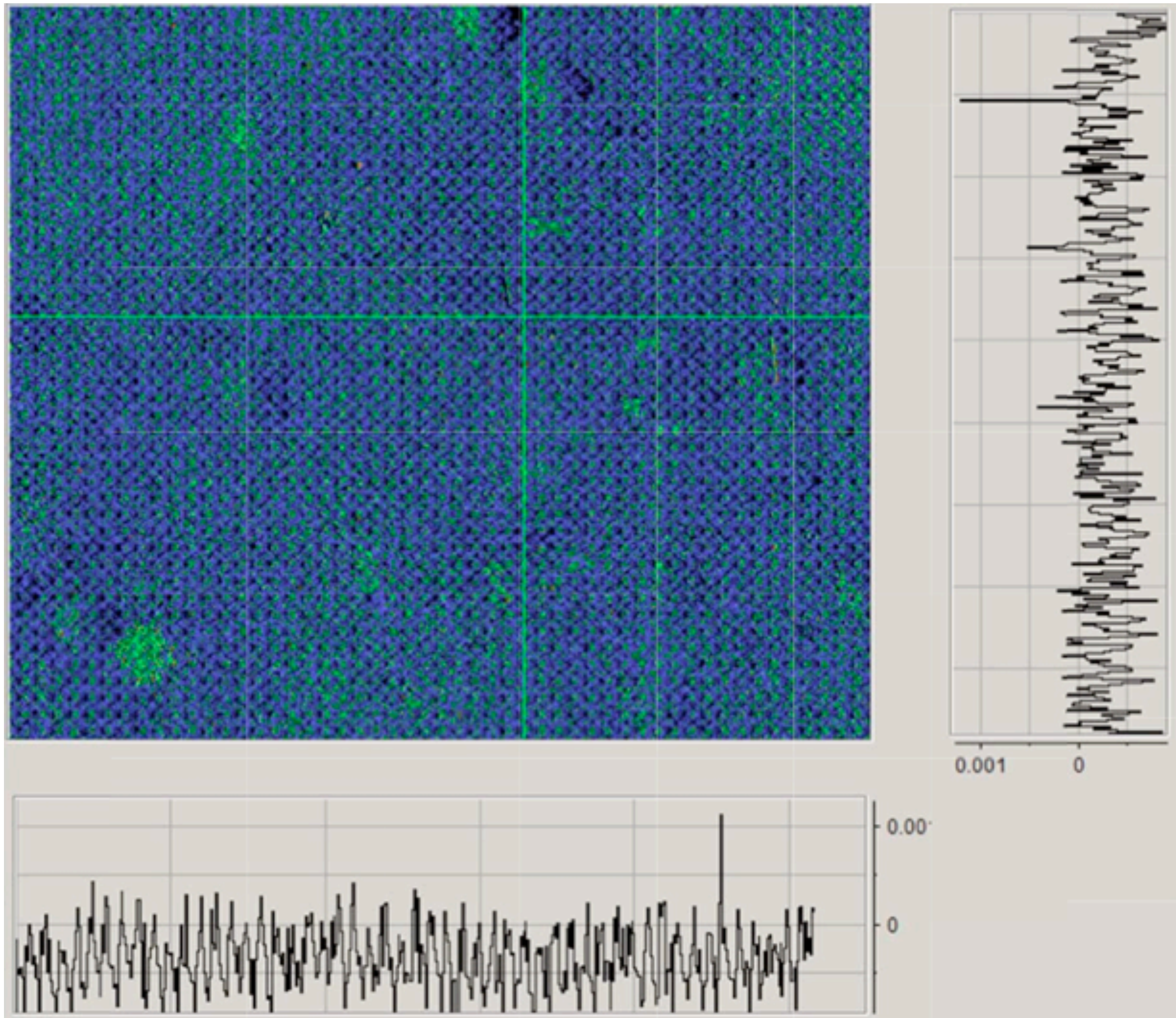
A provocative statement...

- The ACMS is continuously calibrating a very accurate sensor (the GYR) with a poorly accurate one (the STR)

Solving the speedbumps

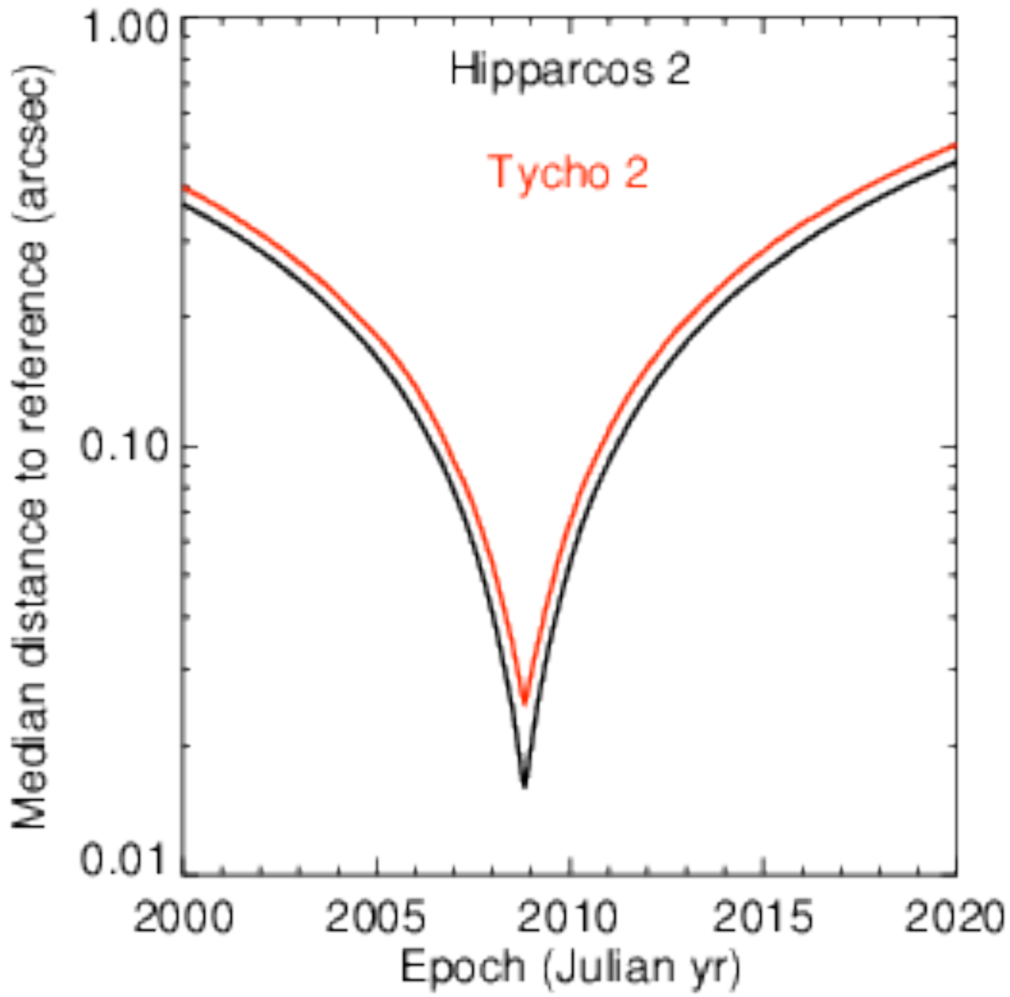
- In order to lower the number of STR CCD hot pixels, it was decided to lower its operating temperature from 20°C to -10°C from OD 320 onward
- At the time, nothing was changed in the ACMS parameters
- The PACS-ICC, given the difficulties of having a source in the slit, launched a dedicated analysis of the pointing

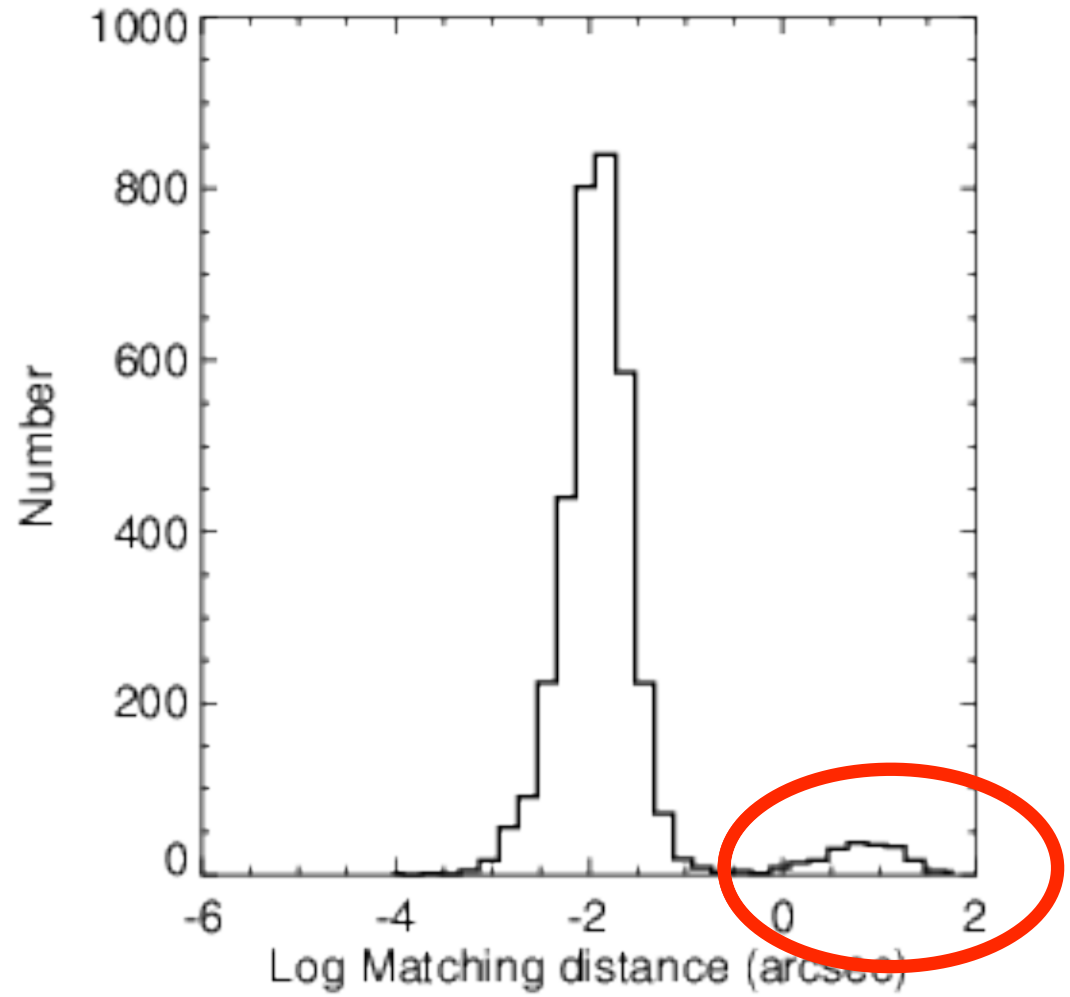
Calibrating the STR



- A complete analysis of all the ACMS telemetry was done
- Resulted in corrected distortion maps of the STR CCD

Analysis of the STR star catalog





- The stars used for guiding were checked.

The timeline of pointing accuracy

Period (OD)	Info	APE
1-319	CCD 20°C	2″
320-761	CCD -10°C	2.4″
762-865	1D corr.	1.5″
866-1010	2D corr.	1.0″
1011-1031	Full dist.	0.9″
1032-	clean cat	0.8″

Pointing Reconstruction

- The improved calibration that are now used on board are also used to derive a correction to the pointing during OD 320-1011.
- This correction is a bias, applied to the on board derived attitude
- The pointing we get is still using on baord GYR info with bias derived from the wrong STR info
- There is a new ACMS product containing all the STR and GYR telemetry

The ACMS product

- Contains the STR star measurements at 1 Hz
- Contains the STR star J2000 positions

- The full raw GYR data at 4 Hz

Next steps

- The PACS-ICC is developing a new approach using a least-square estimation of the pointing.
- We use a full correction of the STR output, taking into account sub pixel CCD distortions (not implemented on board)
- Uses the 1 Hz STR and 4 Hz GYR

An almost linear problem

- The measure:

$$\vec{y}_i = (\alpha_{STR}, \delta_{STR}, \phi_{STR}, \theta_1, \theta_2, \theta_3, \theta_4)^T$$

- The attitude:

$$\vec{a}_i = (\alpha, \delta, \phi)^T$$

- The system:

$$\vec{y} = H(\alpha, \delta, \phi, b_1, b_2, b_3, b_4)\vec{a}$$

Rewrite the system

- The measure vector

$$\vec{y}_i = \begin{pmatrix} \alpha_{STR} \\ \delta_{STR} \\ \phi_{STR} \\ \theta_{1,i} - \theta_{1,i-1} - b_1 \Delta t \\ \theta_{2,i} - \theta_{2,i-1} - b_2 \Delta t \\ \theta_{3,i} - \theta_{3,i-1} - b_3 \Delta t \\ \theta_{4,i} - \theta_{4,i-1} - b_4 \Delta t \end{pmatrix}$$

- The acquisition equation

$$\vec{y} = (H_{STR}, H_{GYR}(\alpha, \delta, \phi))\, \vec{a}$$

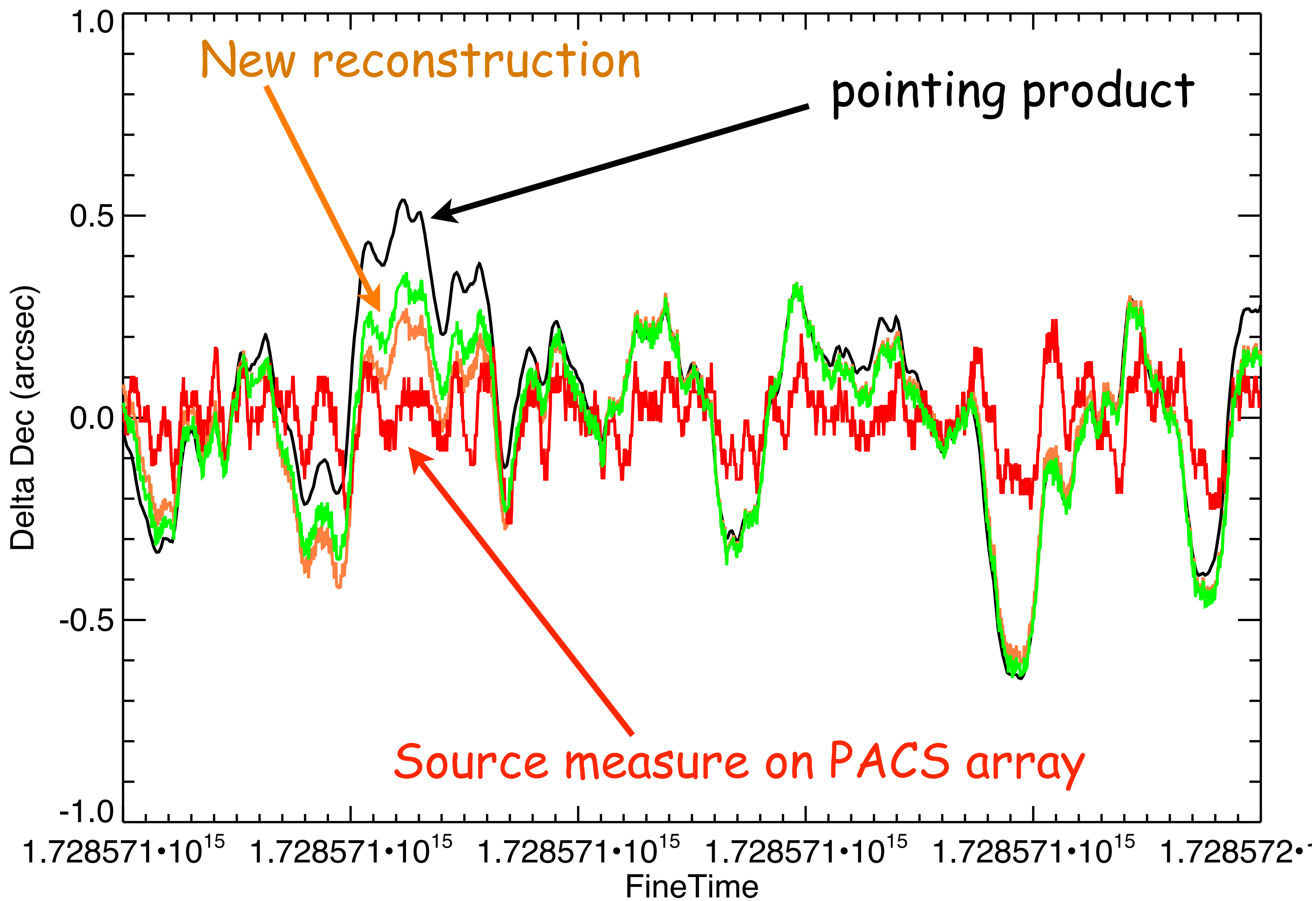
Do a classical LS and iterate

- Assume b, use the STR data (interpolated) to build H.
- Solve with a pre-conjugate gradient method

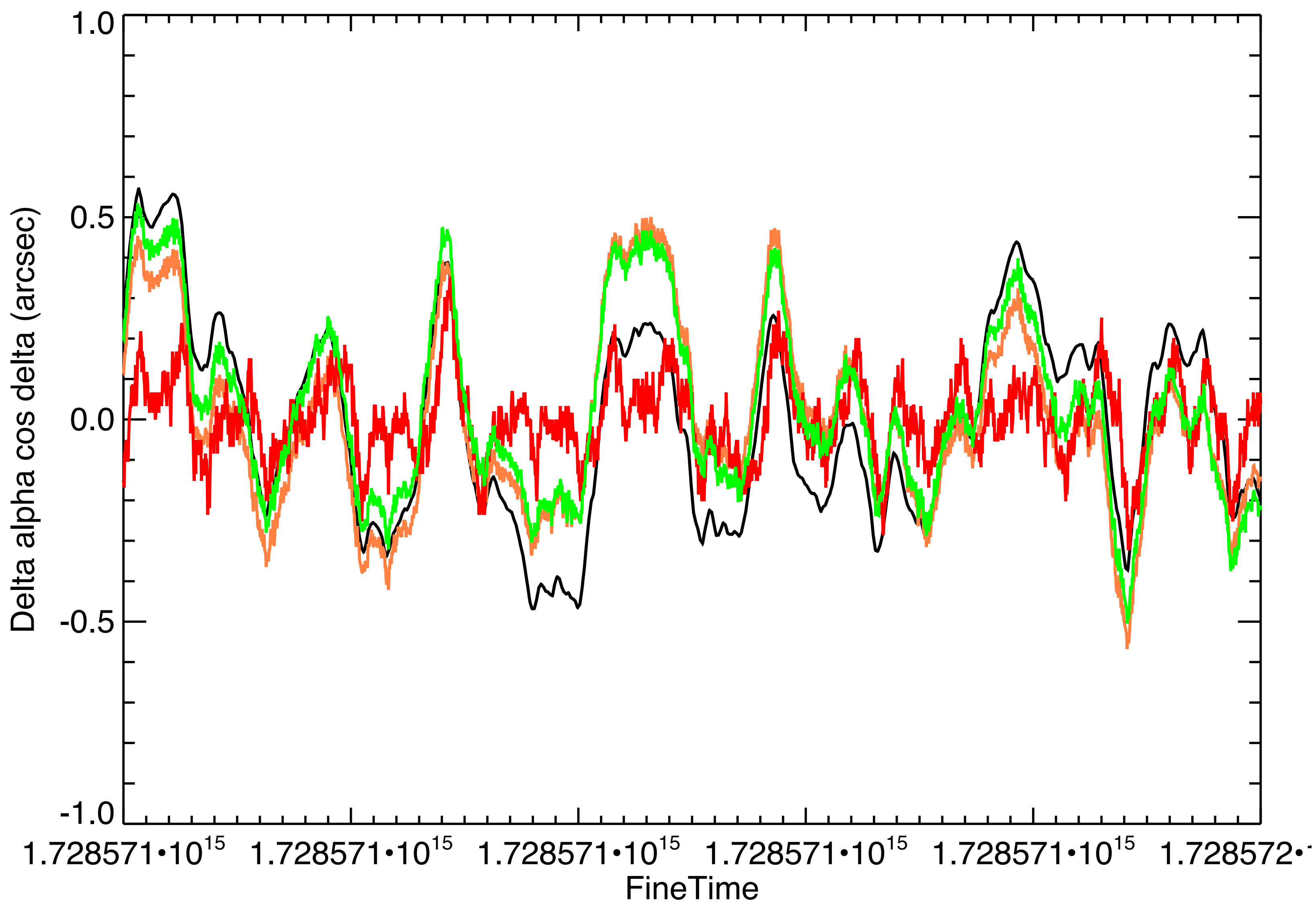
$$\vec{x} = (H^T N^{-1} H)^{-1} H^T N^{-1} \vec{y}$$

- Iterate with the new biases and attitudes

R Dor observations



R Dor Observations



Note : the full inversion iterated 20 times takes ~20s on my laptop

Conclusions

- The final pointing reconstruction accuracy should be of the order of 0.3"
- An approximate solver is being implemented in hipe - may not work on fast scans as it does not synchronizes the sensors
- The PACS ICC will soon revise the focal plane geometry of the instrument
- The ACMS of future missions should be treated as an instrument