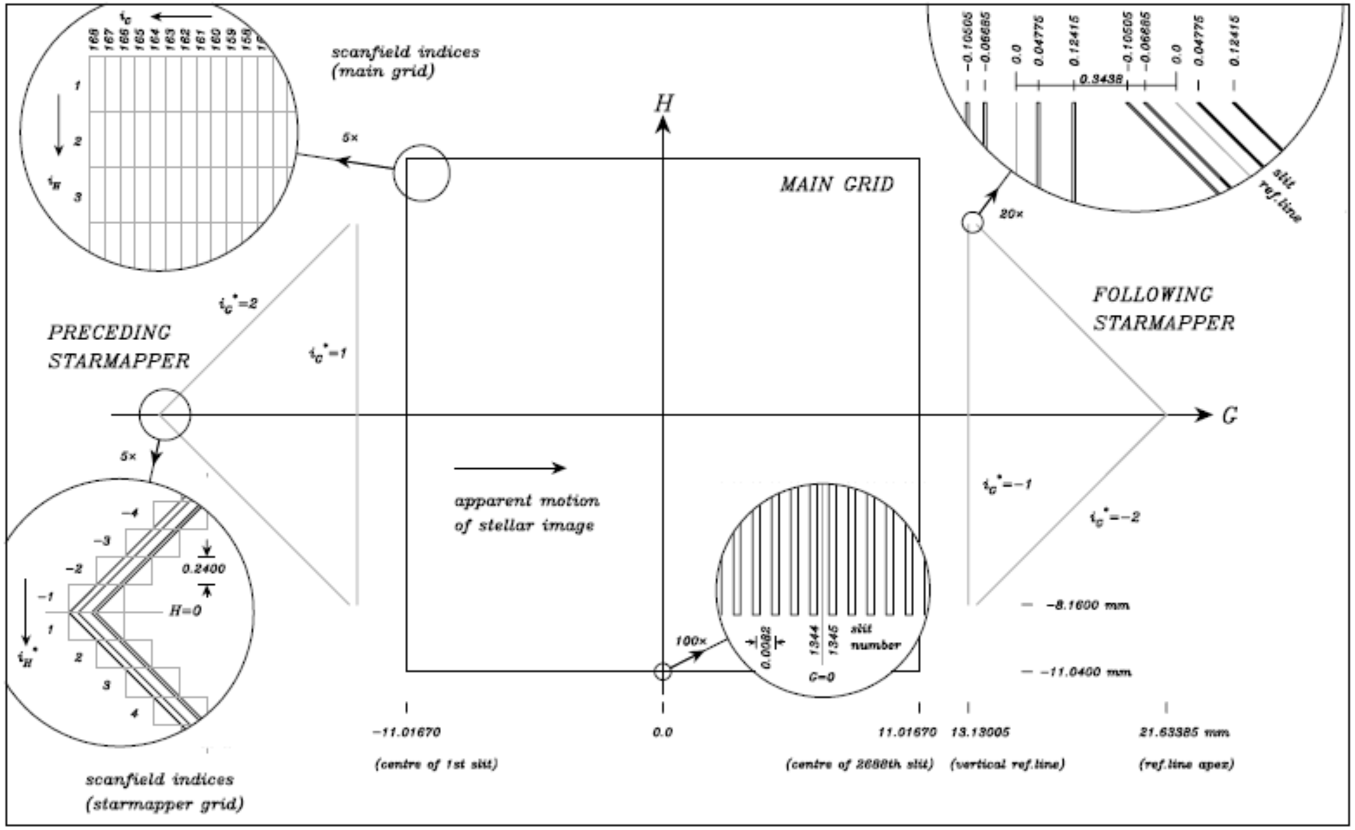
Modelling the Hipparcos attitude

A lesson to be learned for Gaia (?)

Overview

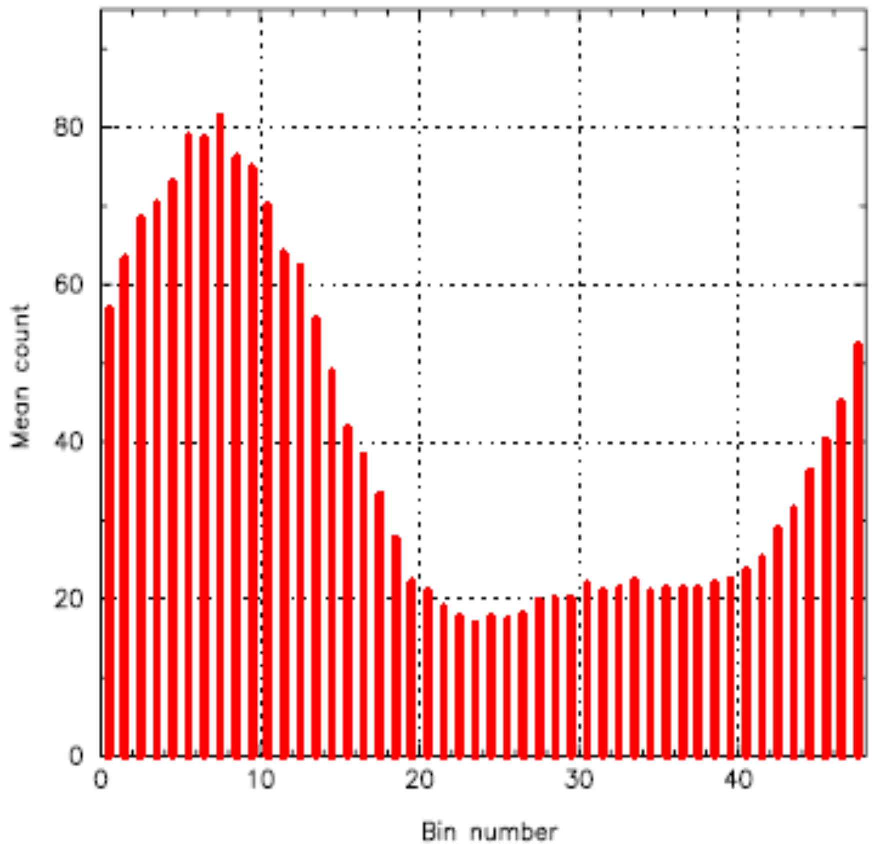
- Hipparcos and Gaia measure transit times
- Satellite attitude relates “transit times” to “position angles” (abscissae)
- Satellite attitude describes the motions of the payload
- Understanding those motions helps in the attitude modelling
- Improved attitude modelling reduces calibration errors
- Attitude modelling uses the same abscissa data as are used for the astrometric parameter determinations
- Attitude calibration errors cause correlated errors in the abscissa residuals
- Reducing attitude calibration errors improves the accuracies of the brightest stars and reduces error correlations

The Hipparcos detector grid



The modulated signal

- First and second harmonic to allow for detection and analysis of double stars
- Signal sampled at 1200 Hz
- Data folded to single modulated signal
- Modulation phase provided transit time



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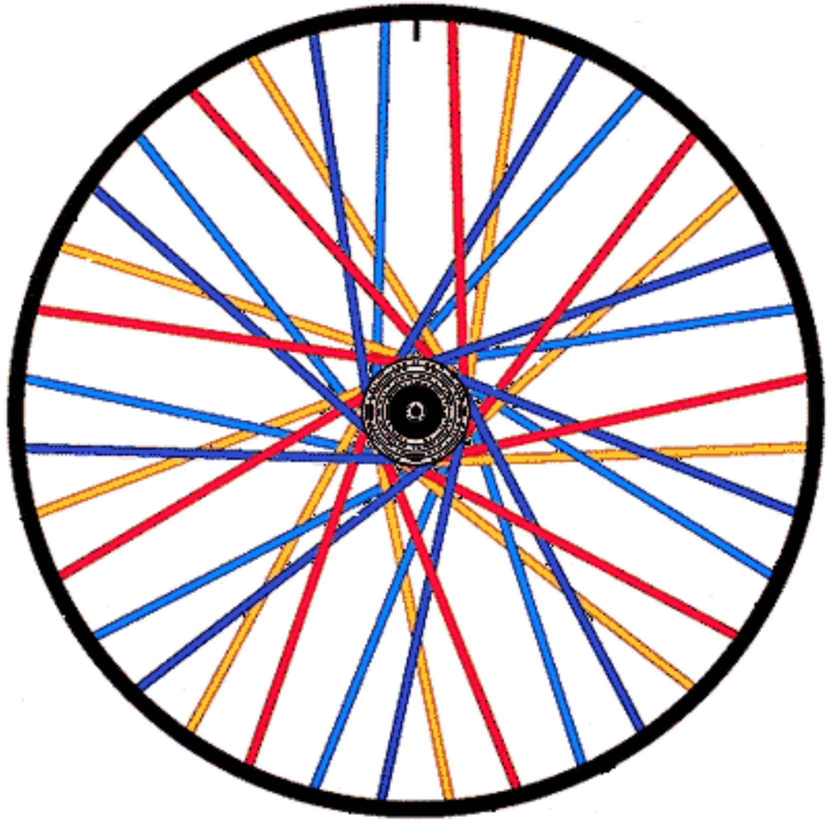
Linking time to direction

- Like building a bicycle wheel
  - Hub: stellar positions
  - Rim: times of observation
  - Spokes: attitude
- Note that here too for stability there are two “fields of view”
  - Orange and red spokes: FoV1
  - Light and dark blue spokes: FoV2
- Here the “basic angle” is close to 180 degrees



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Satellite motions

- Satellite motions are mainly ruled by torques
  - External torques (solar radiation, gravity gradient, magnetic)
  - Internal torques (Thruster firings, excess heat release)
- Treat satellite as rigid body
  - Rates obtained through integration over the Euler equations
  - Positions obtained through integrating rates
- Most torques are (quasi) continuous functions of time
  - The attitude-position model needs still to be continuous in its second derivative
  - 3rd order spline is not sufficient
  - 5th order spline in positions provides 3rd order spline fit for torques

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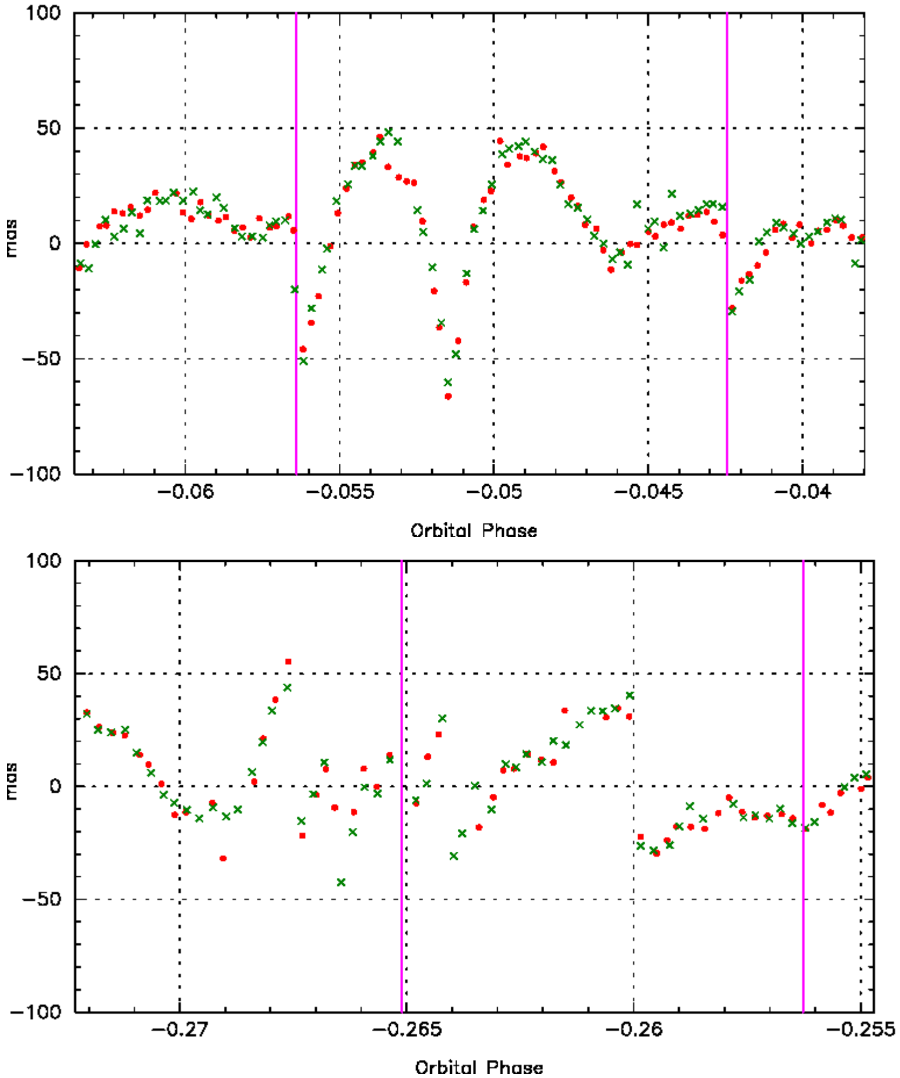
Disturbances to the attitude

- External hits by micro-meteorites
  - Very small dust particles
  - Typical rate changes of order 10 mas/s
  - Around 100 events detected over the mission
- Non-rigidity events, clanks
  - Thermal adjustments of the solar panel hinging
  - For one panel this was not continuous
  - About 1600 events detected



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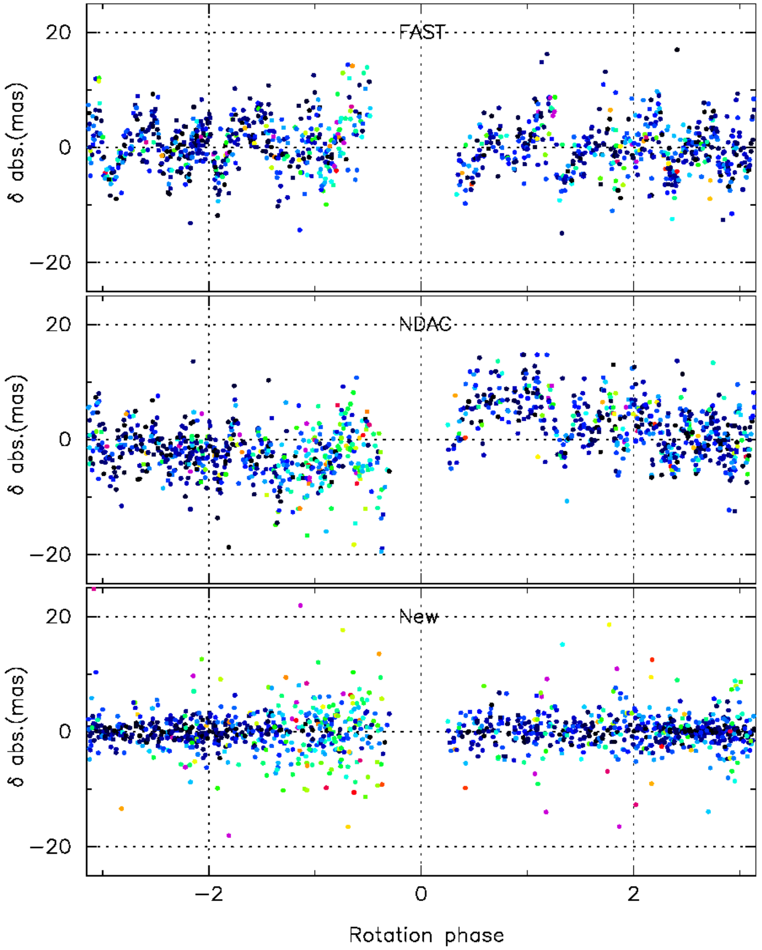
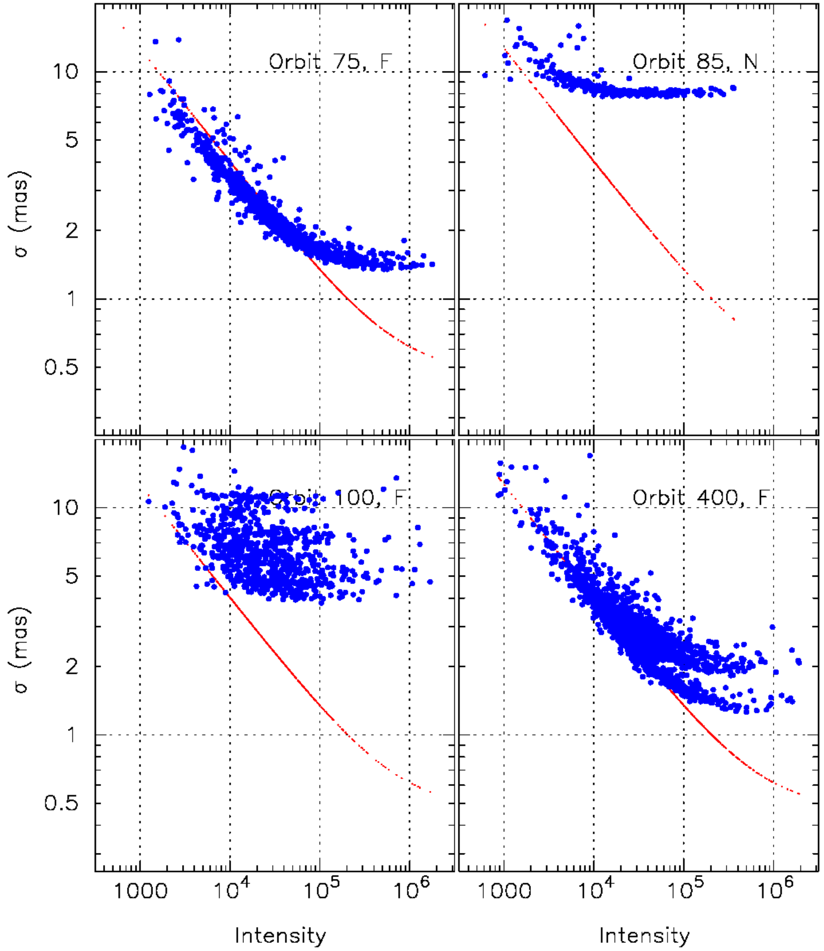
Correlations and formal errors





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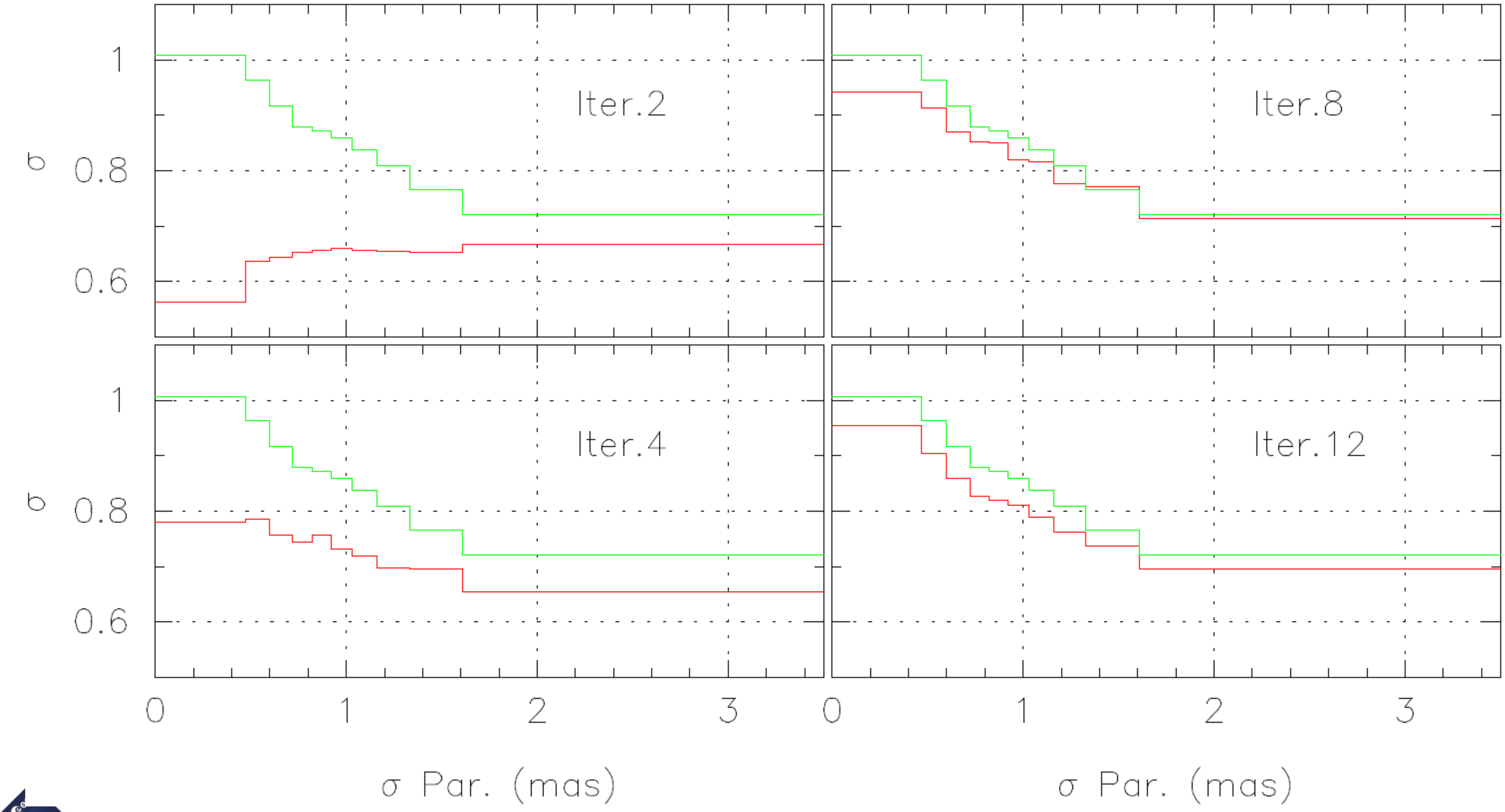
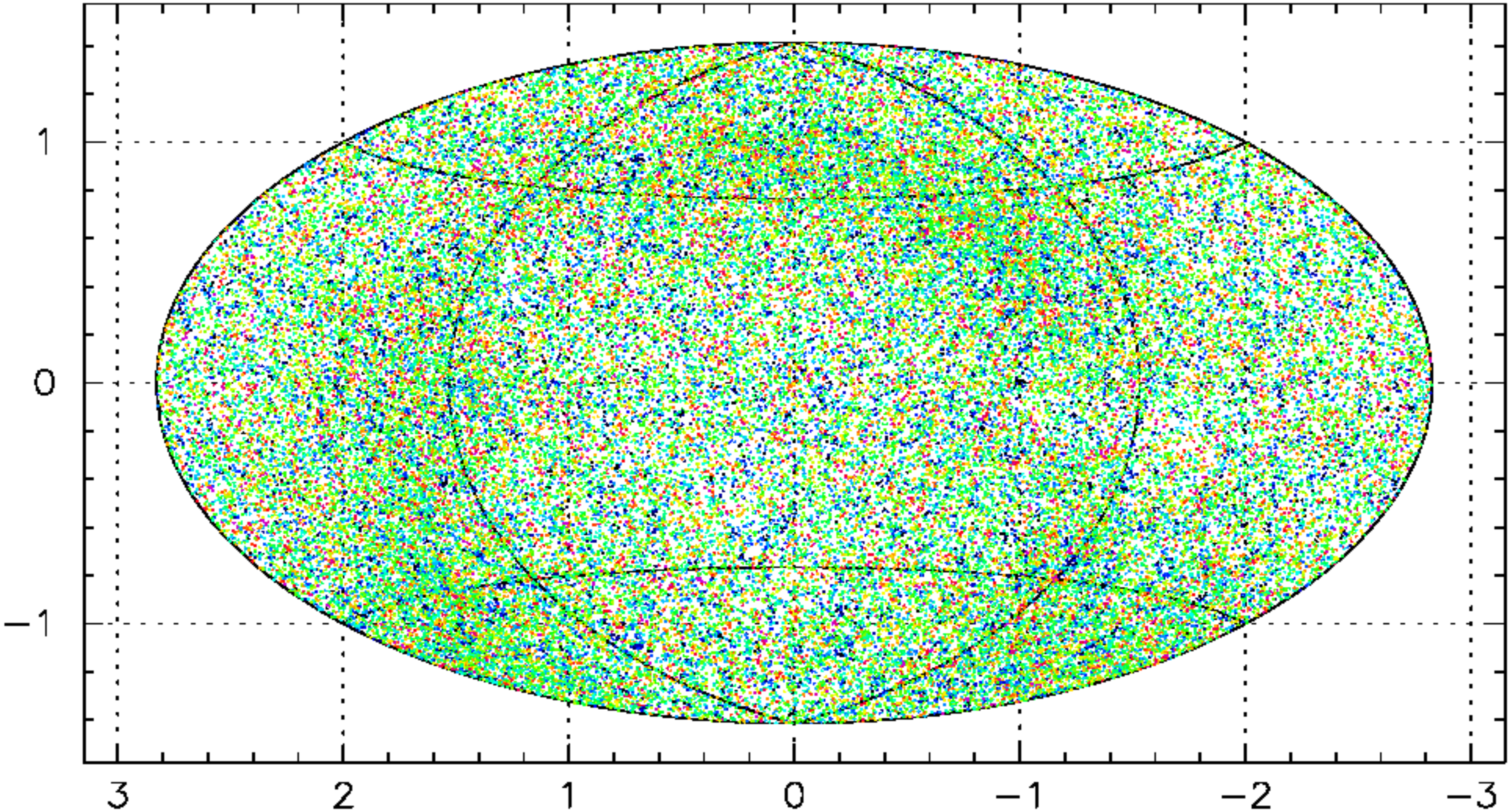
AGIS applied to Hipparcos

- Iterative solutions for the attitude and the astrometric parameters
  - Instrument modelling and basic angle solutions are part of the astrometric parameter solution
  - Very different parameter spaces
  - Still difficult to separate
  - Contributions of the two FoVs need to be balanced
    - If you pull one spoke in your wheel to much, it buckels
  - Iterations needed to remove the “memory” of the old solution
    - Total of 15 iterations were made
  - Differences with old solution showed “hot-spots” in the old catalogue
    - Accidental accumulations of local attitude errors

Loosing memory



Hotspots, old – new Hipparcos



Astrometric stochastic solutions

- Used when no sense could be made of the data
  - 1561 cases in the original catalogue
  - Of these, 962 were properly resolved in the new reduction
    - Excess noise in the old reduction was caused by accidental local accumulation of attitude errors
  - Remainder probably due to unresolved orbital motions
  - The impression that many earlier stochastic solutions were not due to orbital motions had been suggested before when these stars were investigated for binarity from the ground
    - Work by Dimitri Pourbaix et al.

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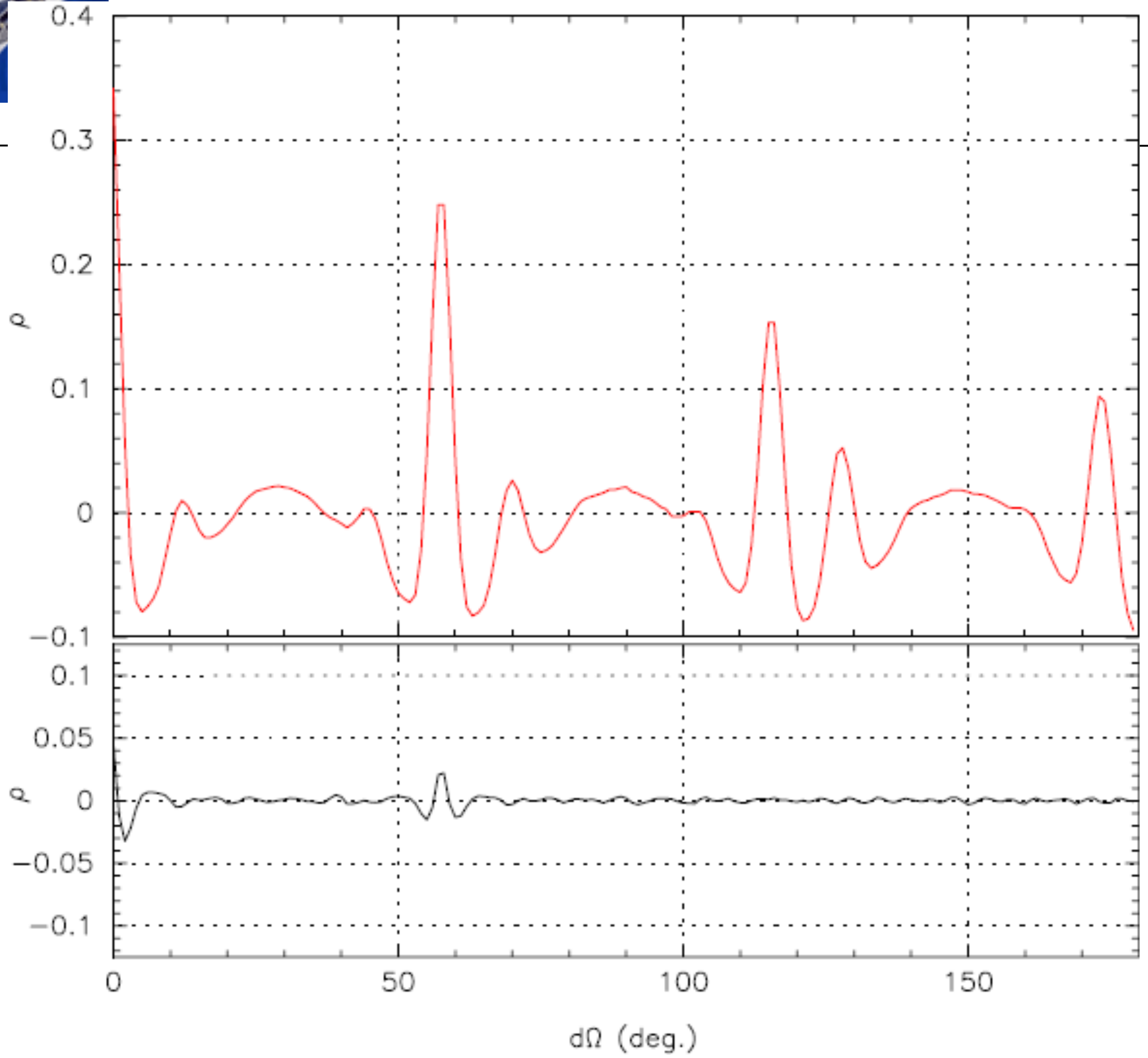
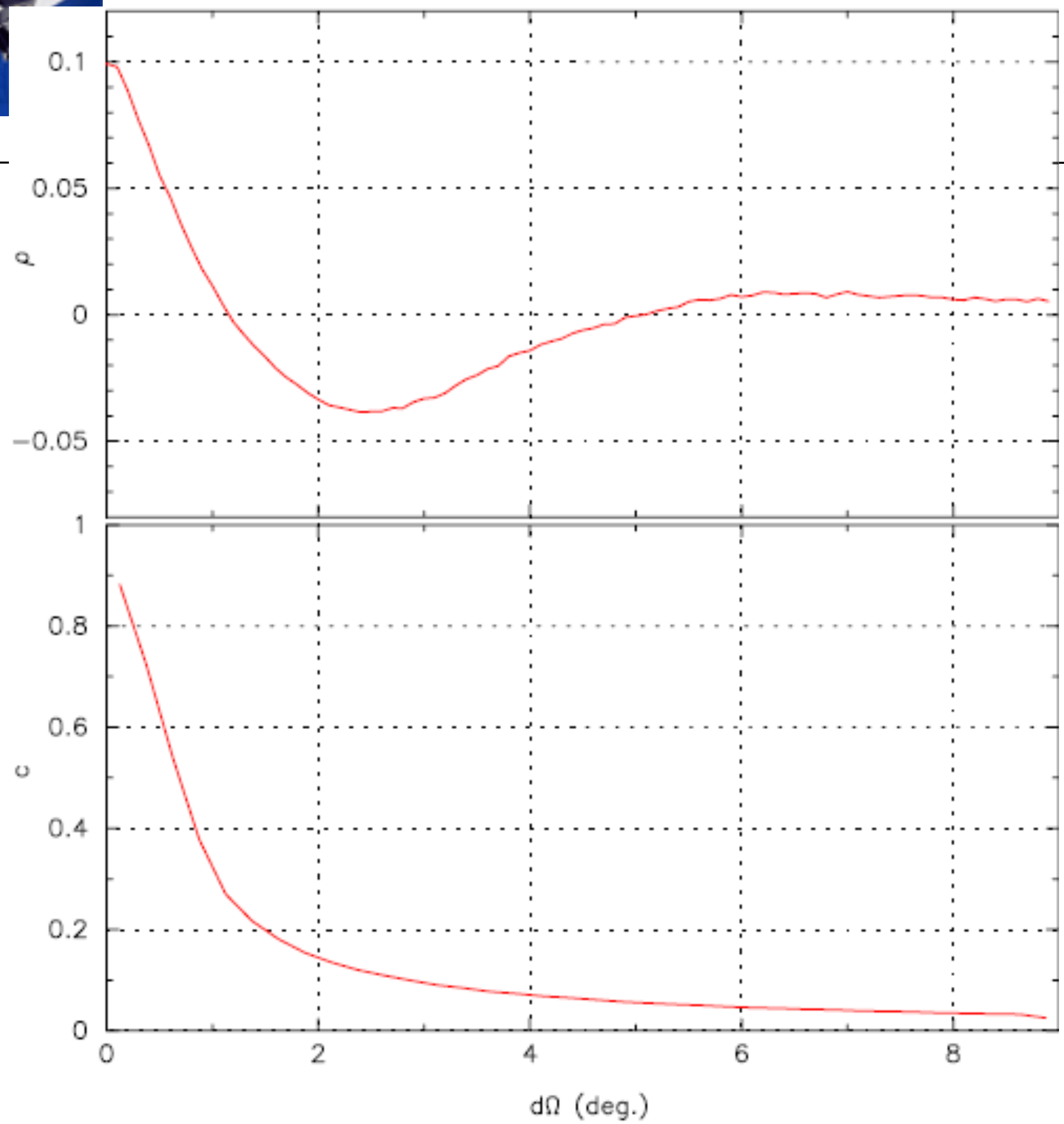
Abscissa correlation Levels, orbit data



Old reduction

New reduction

Abscissa correlations
Circle data



New reduction

Coincidence statistics

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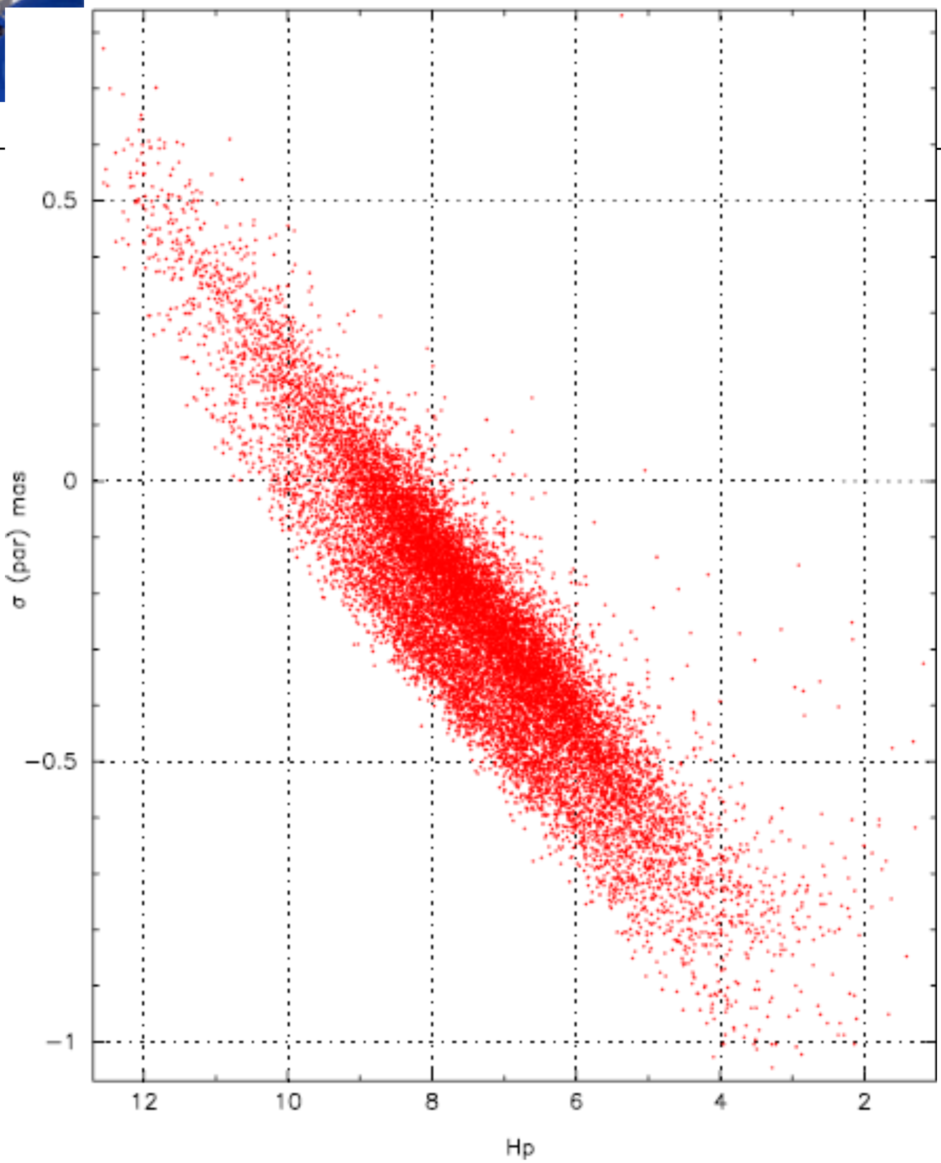
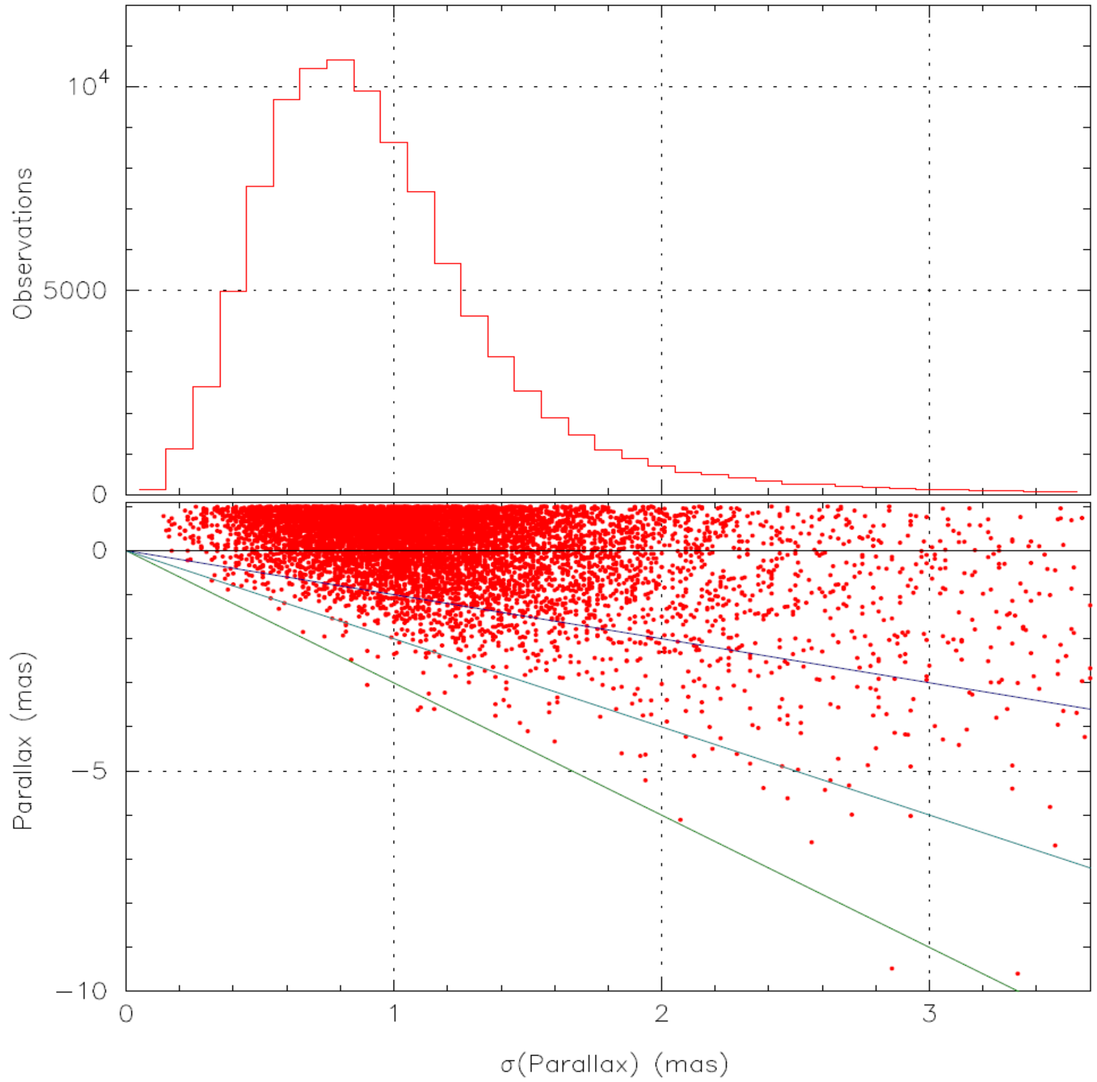
Parallax accuracies



Old solution

New solution

Accuracy verification



Conclusions

- Understanding the peculiarities of the satellite attitude was important for Hipparcos data
  - Including this understanding in the attitude modelling brought down the attitude calibration noise by a factor 5, to 0.6 mas
  - This reduced abscissa error correlations by more than an order of magnitude
    - Reflects on reliability of cluster parallaxes
  - The overall improvement in parallax errors translates into an increase by a factor 2.16 in application weight over the whole catalogue, average parallax error went down from 0.96 to 0.66 mas
    - For stars brighter than Hp=7 the average parallax error is now 0.3 mas, the increase in weight for these stars is a factor 4.3

Some references

- Van Leeuwen & Fantino, 2005, A&A 439, p791
  - A new reduction of the raw Hipparcos data
- Van Leeuwen, 2005, A&A 439, p805
  - Rights and wrongs of the Hipparcos data.
- Van Leeuwen, 2007, ASSL Vol.350, incl. DVD with data
  - Hipparcos, the New Reduction of the Raw Data
- Van Leeuwen, 2009, A&A 497, p209
  - Parallaxes and proper motions for 20 open clusters as based on the new Hipparcos catalogue

VizieR On-line Data Catalog: I/311