BAM/DASS: data analysis software for sub-microarcsecond astrometry device

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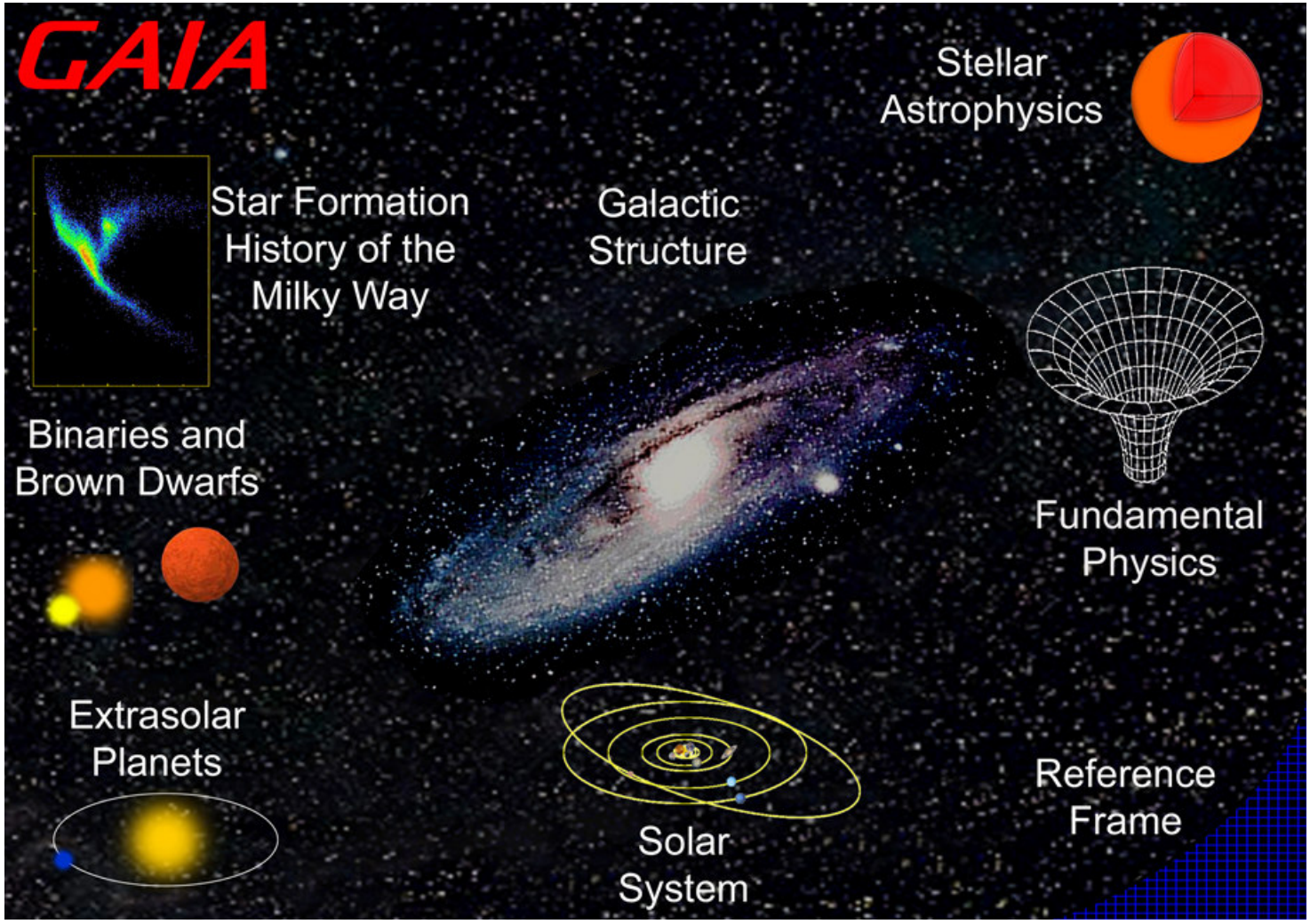
INAF - Osservatorio Astronomico di Torino

Overview

- Gaia Basic Angle, what is it?
- BA variations Monitoring during operations: why and how
- BAM data analysis software description
- Conclusions


GAIA
Stellar Astrophysics
Star Formation History of the Milky Way
Galactic Structure
Binaries and Brown Dwarfs
Fundamental Physics
Extrasolar Planets
Solar System
Reference Frame

Gaia expected performances

	Hipparcos	Gaia
Magnitude limit	12	20 mag
Completeness	7.3 – 9.0	20 mag
Bright limit	0	6 mag
Number of objects	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance	1 kpc	50 kpc
Quasars	None	5×10^5
Galaxies	None	$10^6 – 10^7$
Accuracy	1 milliarcsec	7 µarcsec at V = 10 10-25 µarcsec at V = 15 300 µarcsec at V = 20
Photometry	2-colour (B and V)	Low-res. spectra to V = 20
Radial velocity	None	15 km/s to V = 16-17
Observing	Pre-selected	Complete and unbiased

Gaia: complete, faint, accurate (from www.rssd.esa.int)

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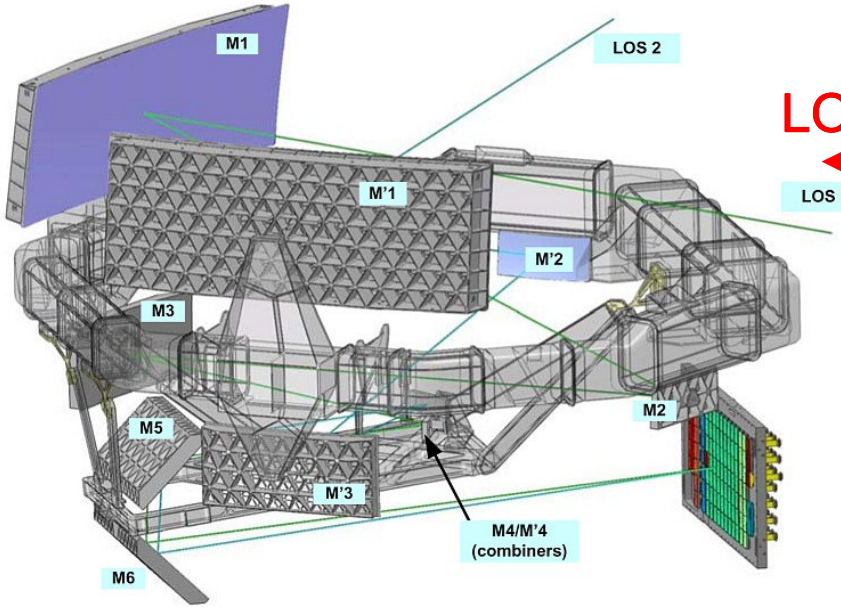
→ Stringent requirements in Instrument performances

Gaia – Optical design



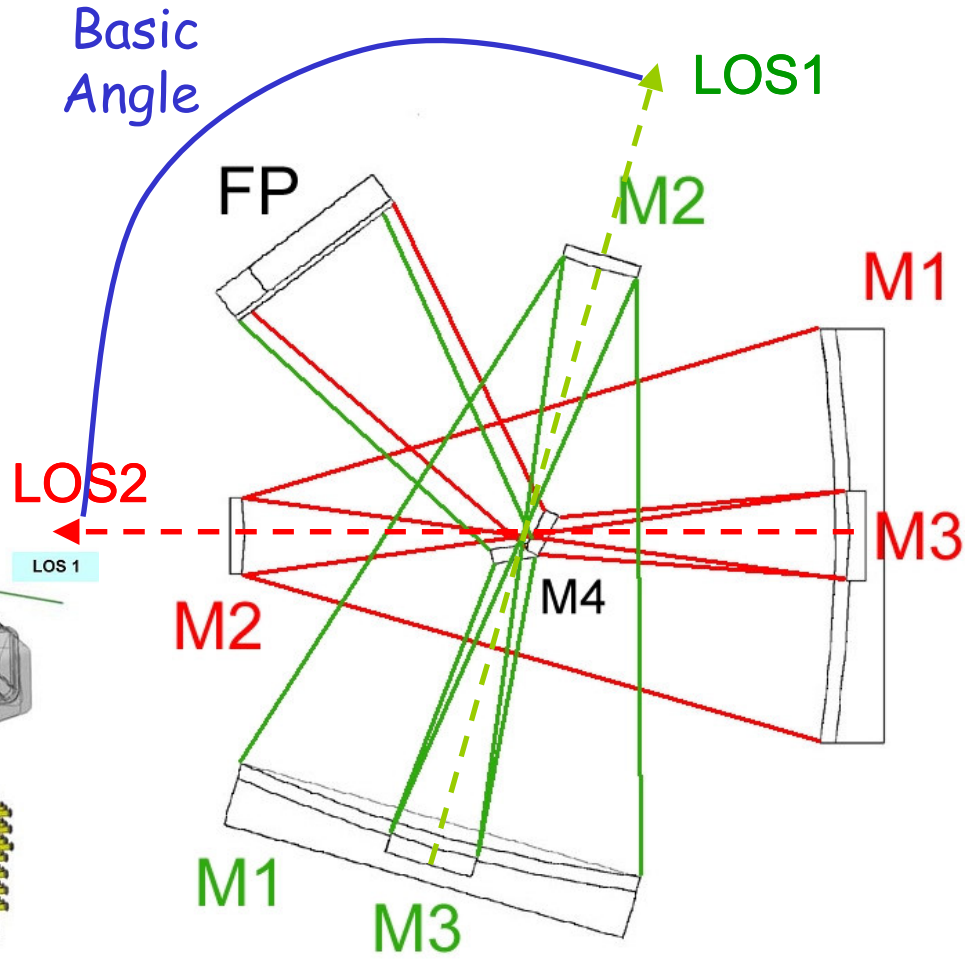
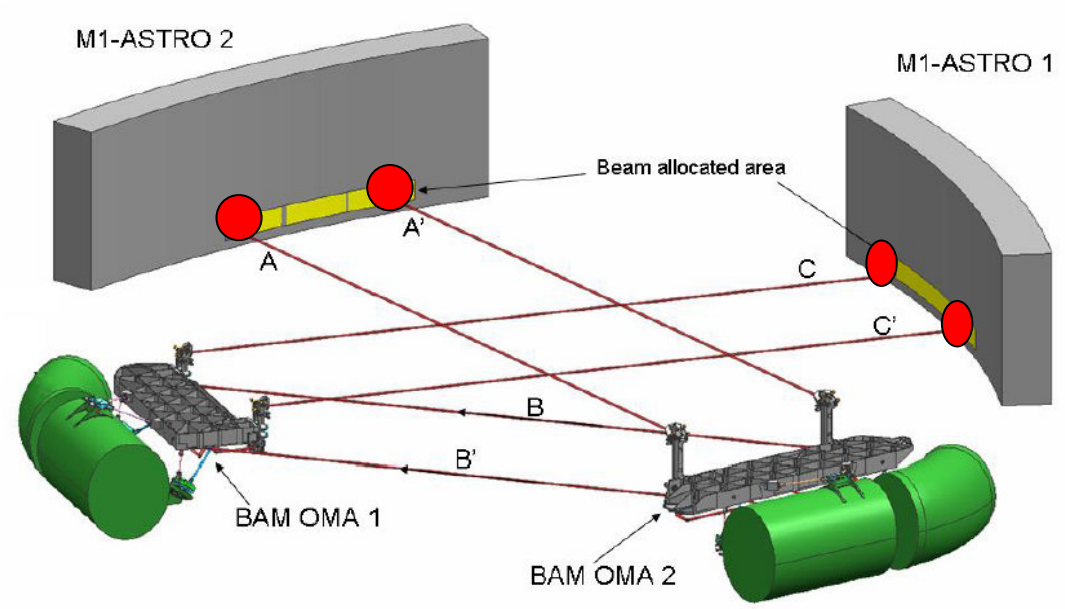


Image credit: www.rssd.esa.int

Basic Angle Monitoring



BA monitoring necessary because expected BA variations may be too large to cope with expected perf.

Req: accuracy of 0.5 μas rms over a period of 5 minutes

Image credit: Meijer et al., SPIE 7010

Gaia – Focal Plane

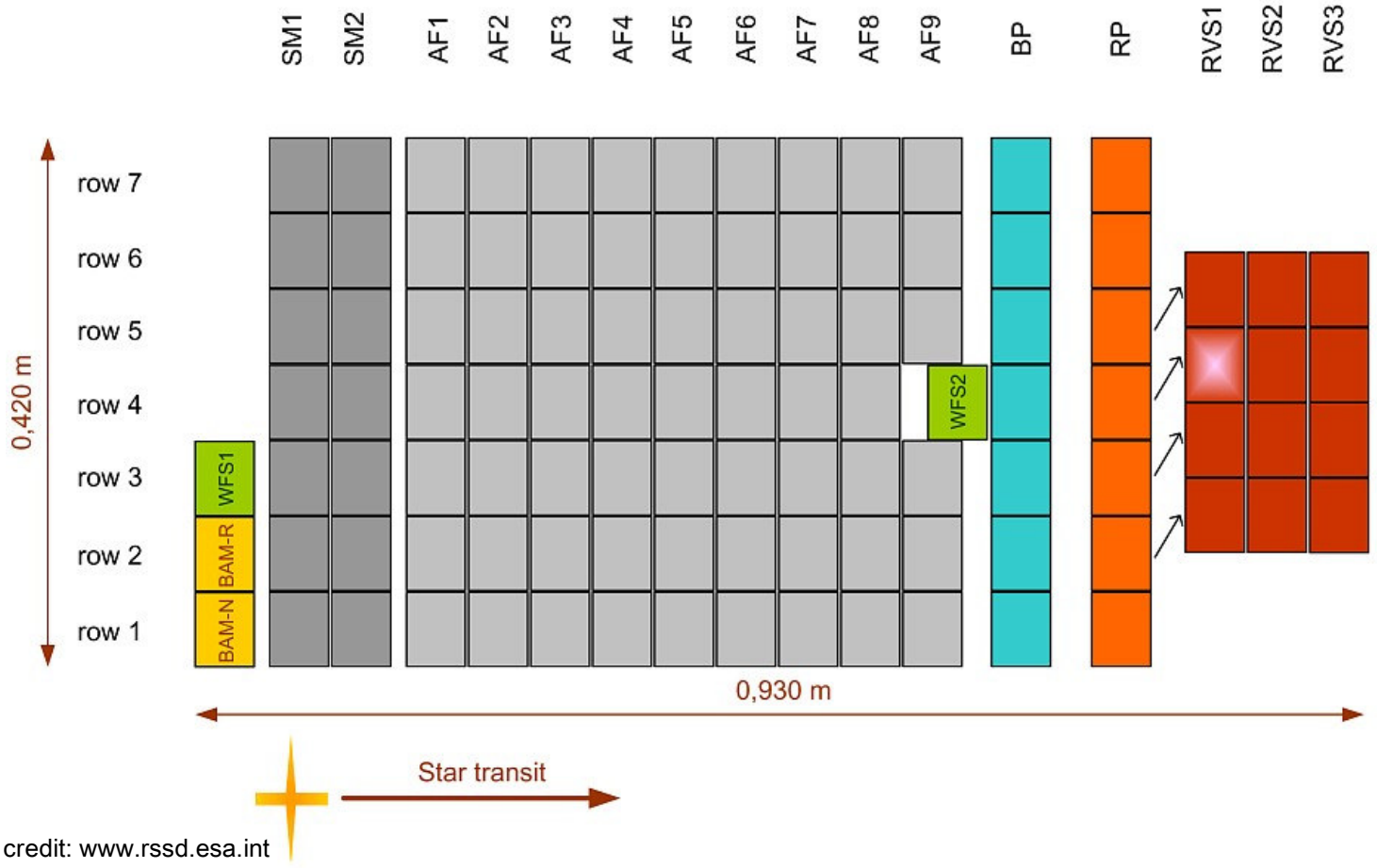
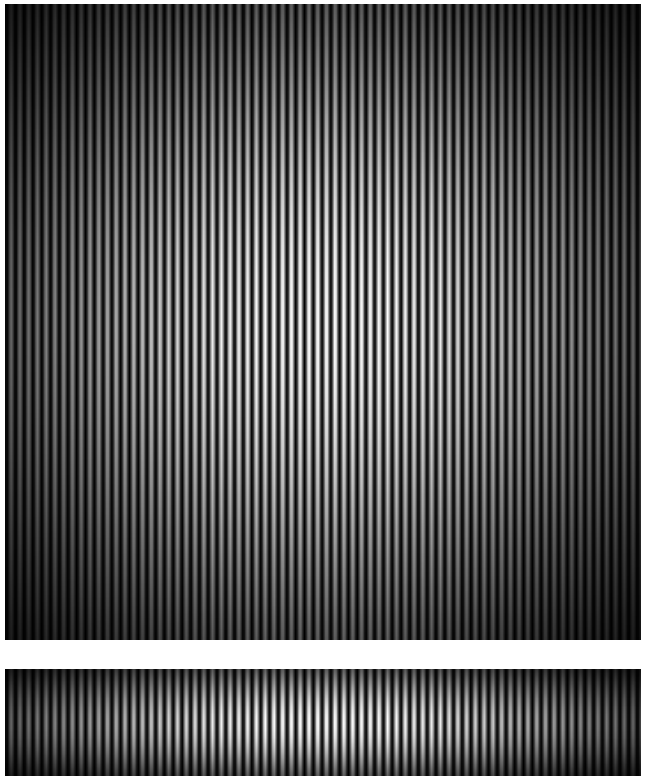
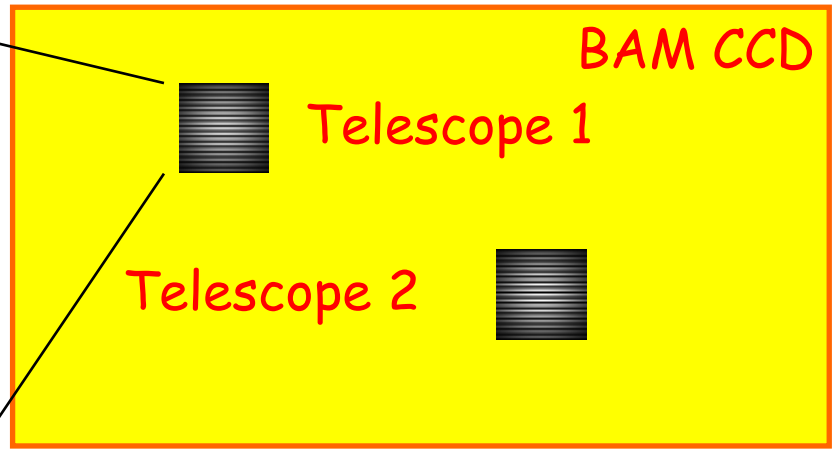


Image credit: www.rssd.esa.int

Raw data: fringe image



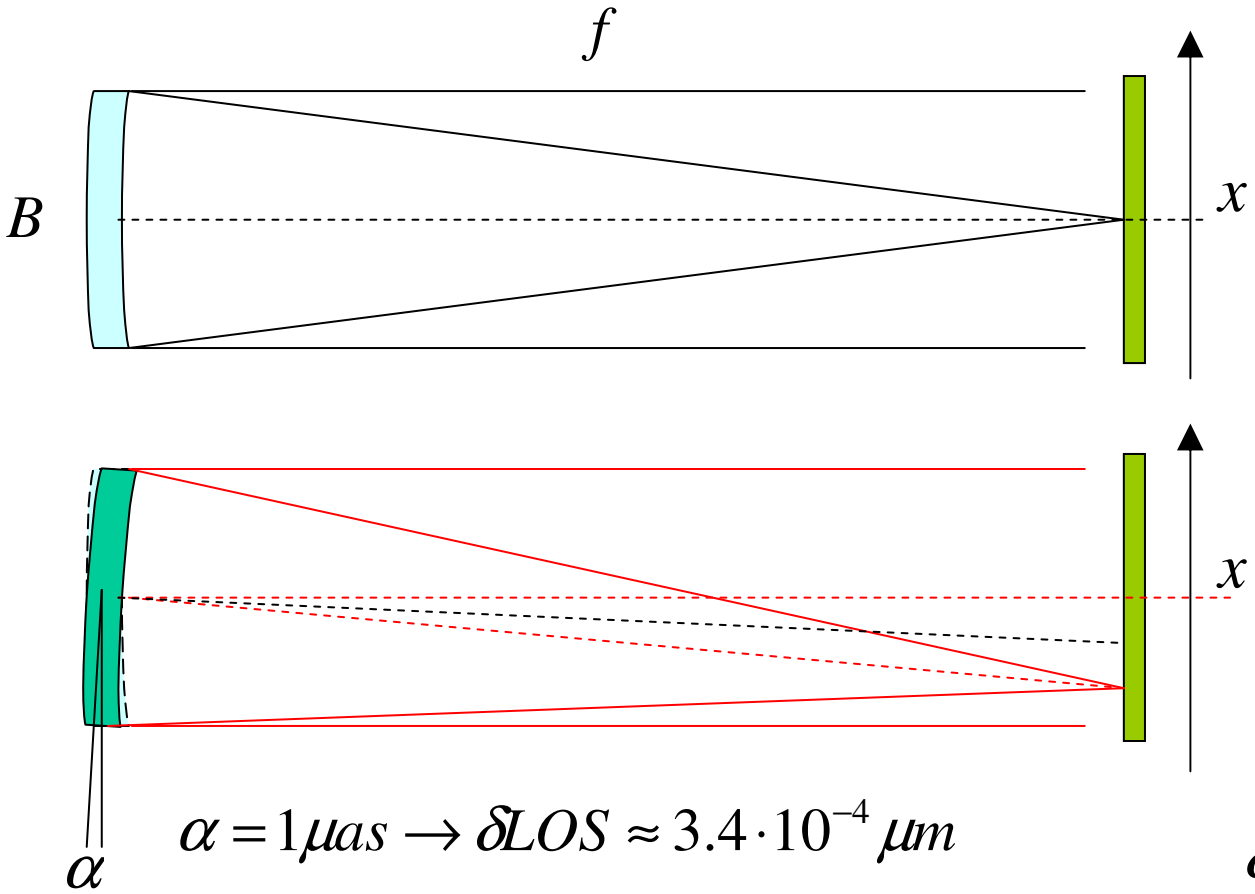


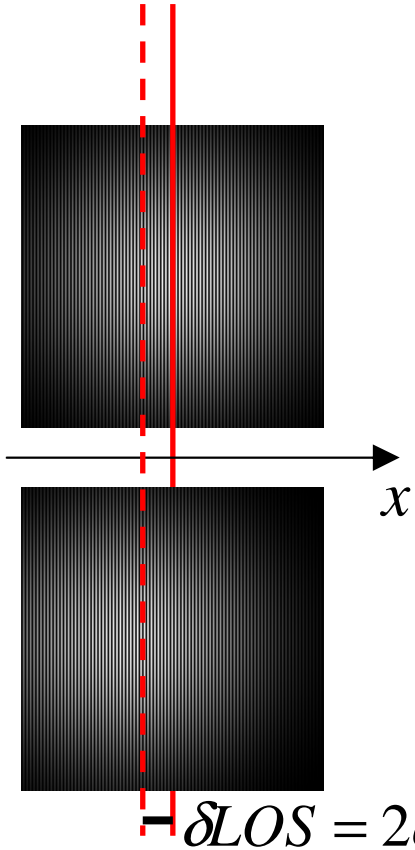
Physical window onto the CCD: Size is 360 x 120 pixels = 3.6 x 3.6 mm^2

Logical window size is 360 pixels x 60 samples (binning x 2 AC scan)

Telemetry rate: 2/3 couples of images every minute ~ 7.9e6 mission

Raw data: fringe image



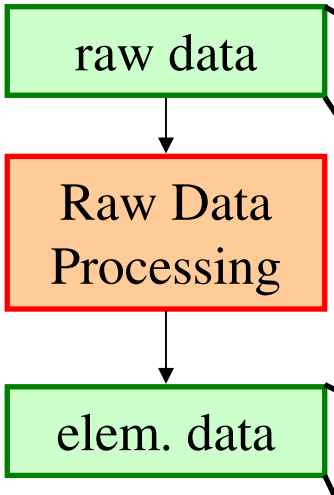


$$\alpha = 1\mu as \rightarrow \delta LOS \approx 3.4 \cdot 10^{-4}\,\mu m$$

$$\delta LOS = 2\alpha f$$

$$\delta BA = \delta LOS_2 - \delta LOS_1$$

BAM/DASS

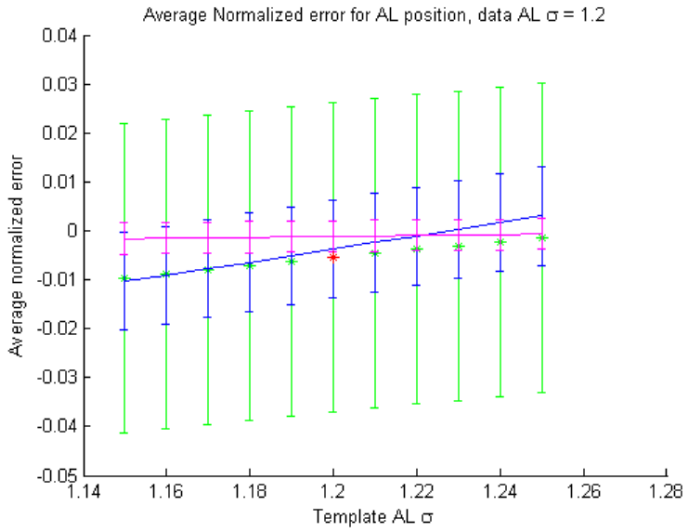


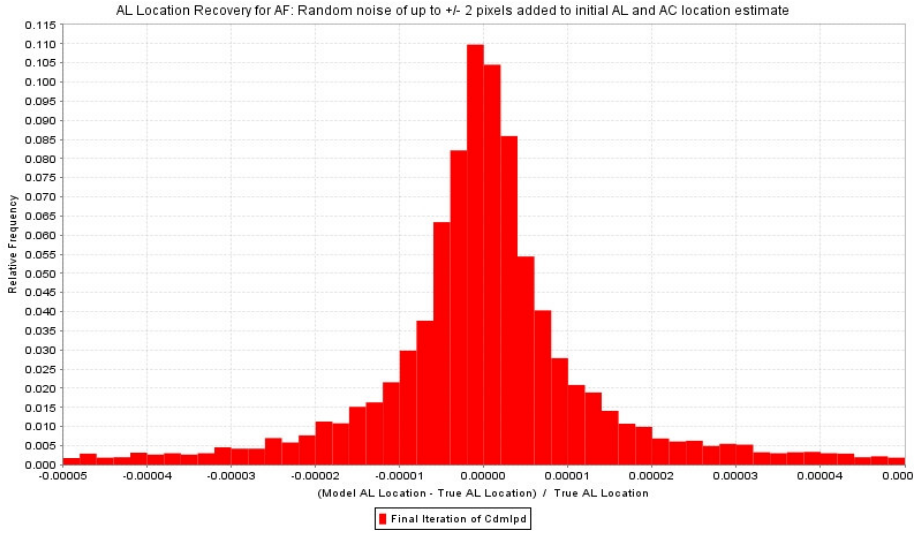
#	Name	Description	Det. Desc.	Type	Multiplicity	Units
1	solutionId	Solution Identifier	View	long		
3	bamId	Unique identifier of the BAM Measurement	View	long		
4	acqTime	Acquisition time (OBMT)	View	long		Time[ns]
5	swCmdAck	Commands acknowledged	View	byte		
6	ccdRow	Row of BAM CCD	View	byte		
7	ac	AC position of the window	View	short		
8	samples	BAM pattern	View	int	[21600]	

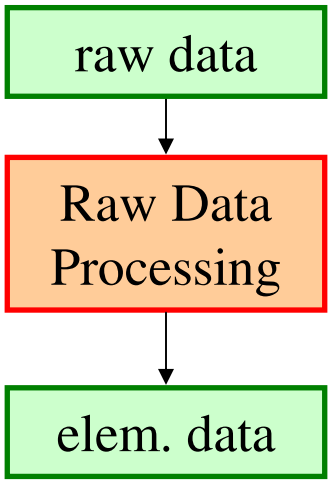
#	Name	Description	Det. Desc.	Type	Multipli...	Units
1	solutionId	Solution Identifier	View	long		
3	bamId	Unique identifier of the BAM Measure...	View	long		
4	measurementTi...	Measurement time	View	long		Time[ns]
5	fringeAlPos	Along Scan position fringe	Add	float		Length & Distance[pix...
6	fringeAlPosErr	Along Scan position fringe error	Add	float		Length & Distance[pix...
7	fringeAcPos	Across Scan position fringe	Add	float		Length & Distance[pix...
8	fringeAcPosErr	Across Scan position fringe error	Add	float		Length & Distance[pix...
9	fringeFlux	Flux (TBD)	Add	float		Flux[e-/s]
10	fringeFluxErr	Flux error	Add	float		Flux[e-/s]
11	fringeContrast	Contrast	Add	float		
12	bamInfo	Valid data	Add	byte		
13	algorithm	Algorithm used	Add	int		

Raw Data Processing algorithm

- Four fringe location estimation algorithms (ML,LS,CC,Barycentre)
- Current estimated accuracy ~ 4/5 x 10^{-5} μm (single fringe image, fringe model perfectly known)
- Req. accuracy challenging, but seems feasible

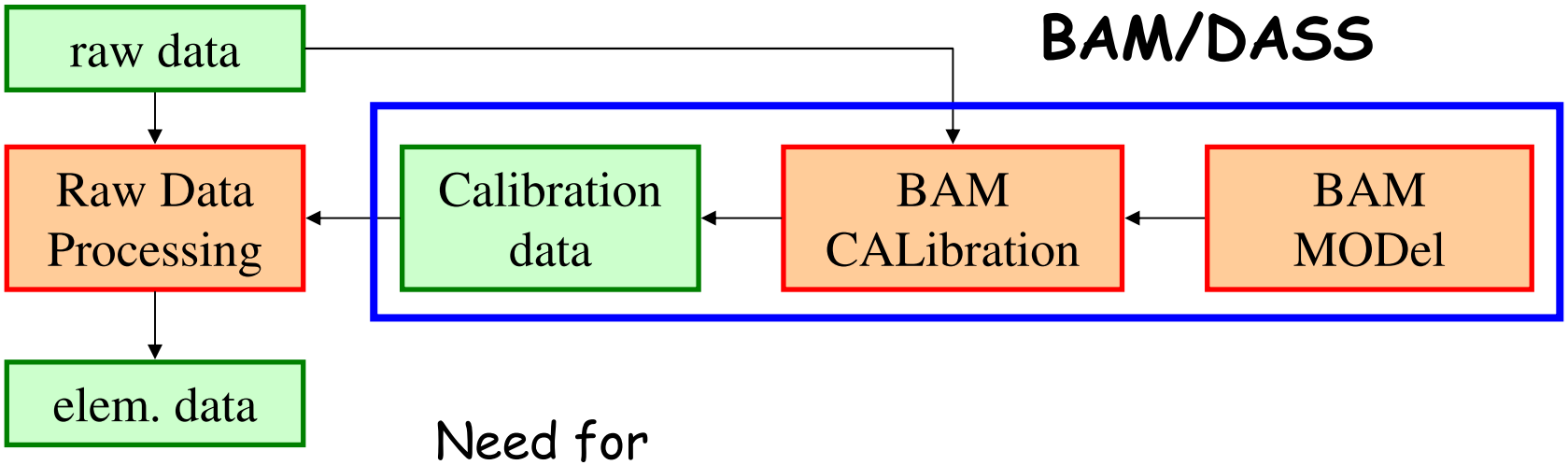






BAM/DASS

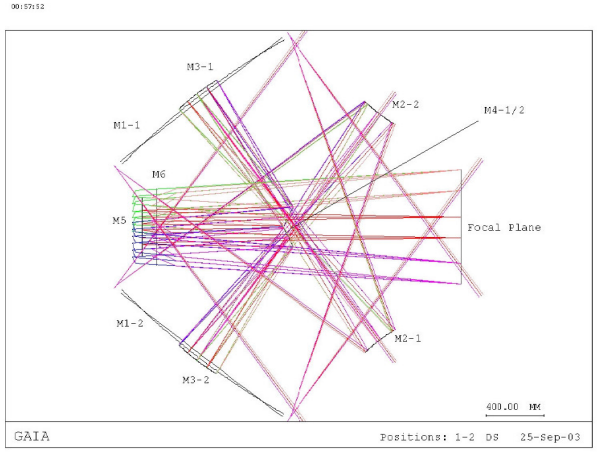
- Problems:
  - the value of some parameters of the fringe model will not be known once in flight, and will change with time (periodic fluctuations, drifts,…)
- Variability may be caused by many factors:
  - Charge Transfer Inefficiency due to Radiation Damage on CCD
  - Transit of parasitic stars onto the BAM CCD
  - BAM device intrinsic variability (e.g. laser stability, optics,…)
  - higher order aberrations variability in the Telescopes
  - …



Need for

- a realistic BAM model and a
- algorithm to periodically determine the value of the parameters

BAM Model



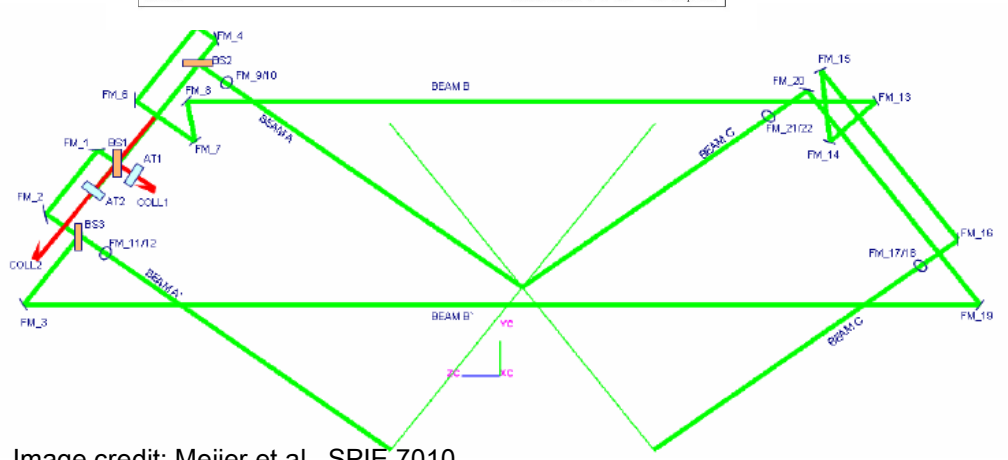


Image credit: Meijer et al., SPIE 7010

- BAM device optical design is merged with the Gaia telescopes optical design
- Complete light-train coded (BAM+Telescopes)
- enables complete sensitivity analysis and determination of the most important degrees of freedom.

BAM Model / Analytical

- The ray-tracing code is not suitable for easy and compact description. -> analysis and translation into an analytical model

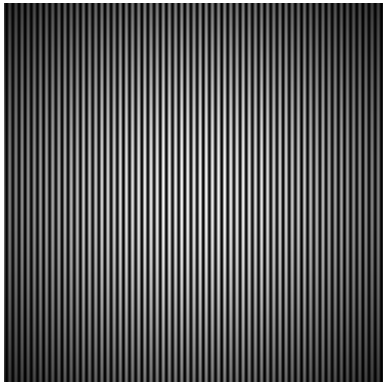
- Current analytical description:

$$fp(i,j) = k \cdot Airy\left(\frac{D}{\lambda f} r_{ij}\right) \cdot \left\{1 + V\cos\left[\frac{2\pi B}{\lambda f}\left(x_i - x_0\right)\right]\right\}$$

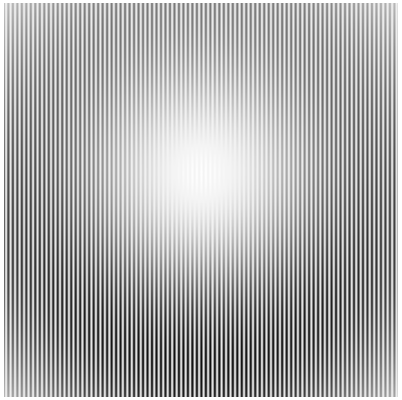
where

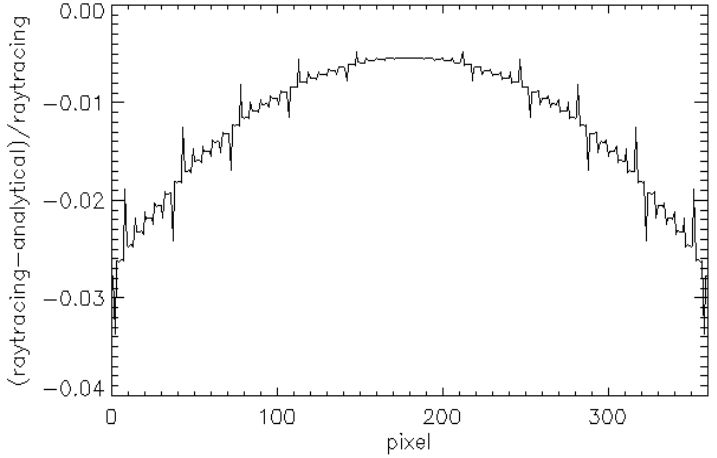
$$\begin{cases} x_i = R(i - i_0) + 2 \cdot \delta LOS \cdot f \\ y_j = R(j - j_0) \end{cases} \qquad r_i = \sqrt{x_i^2 + y_i^2}$$

BAM Models results - comparison



Raytracing





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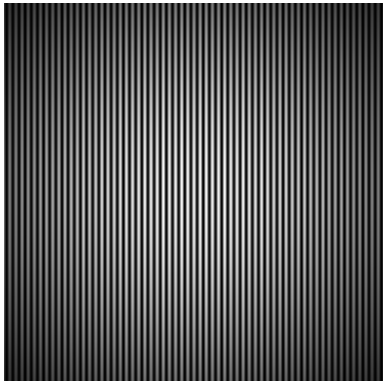
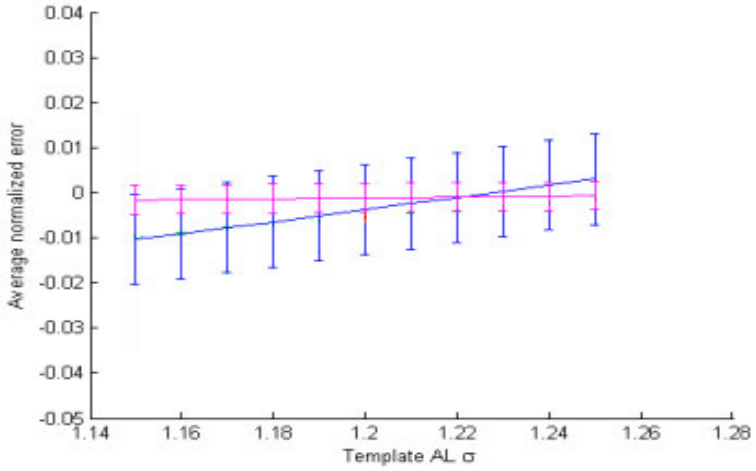


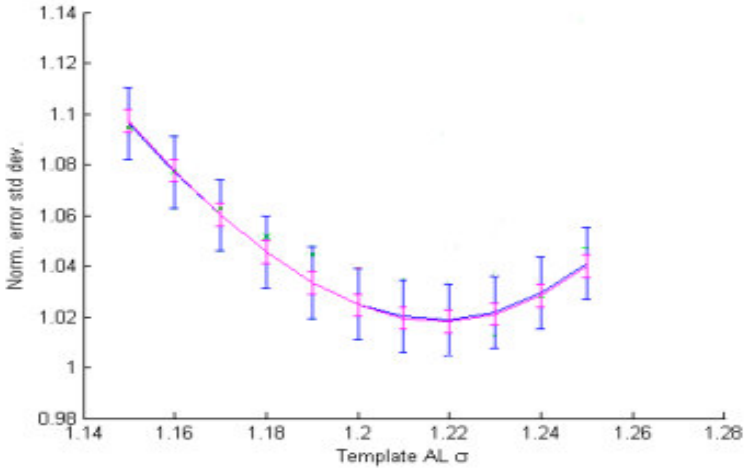
Analytical

Analytical / raytracing
discrepancies confined ~ 2-3%
without any param adjustement!

BAM Calibration

- By calibration we intend here the estimation of the value of the parameters of the model that are frozen during the location estimation process. This is a crucial step to obtain good final results.

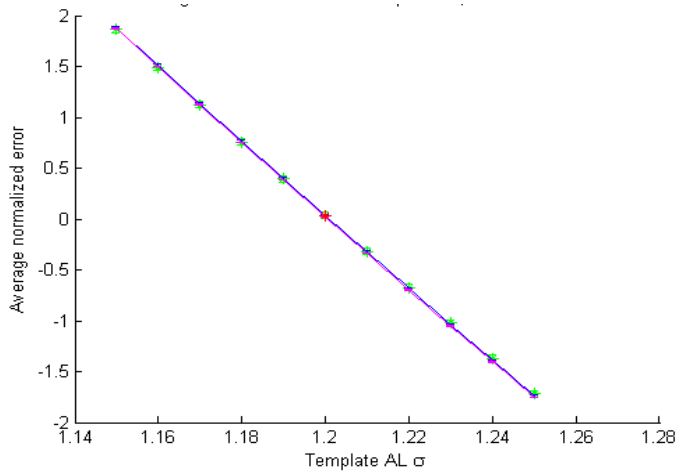


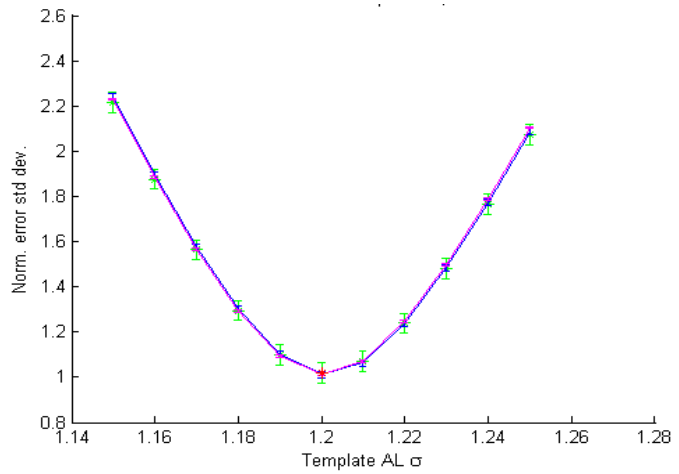


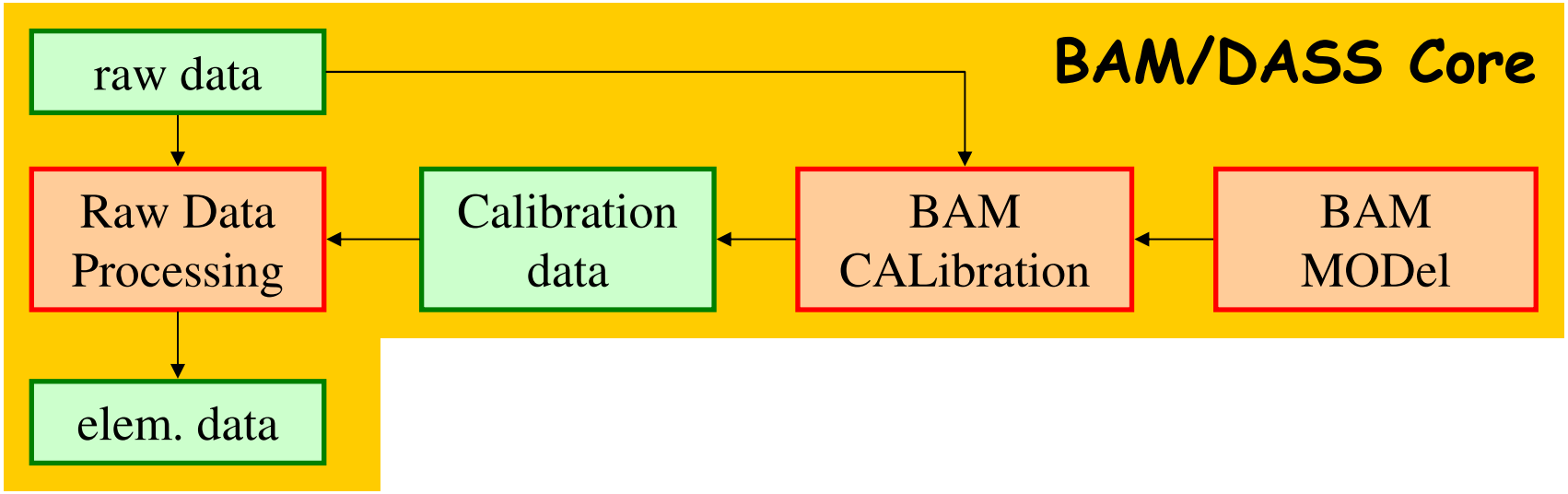
Effect of over-/under- estimation of the image width

BAM Calibration

- in some cases (symmetric shape) the fringe location estimation is unbiased, but the associated error increases
- in case of asymmetries and flux evaluation, estimation is biased





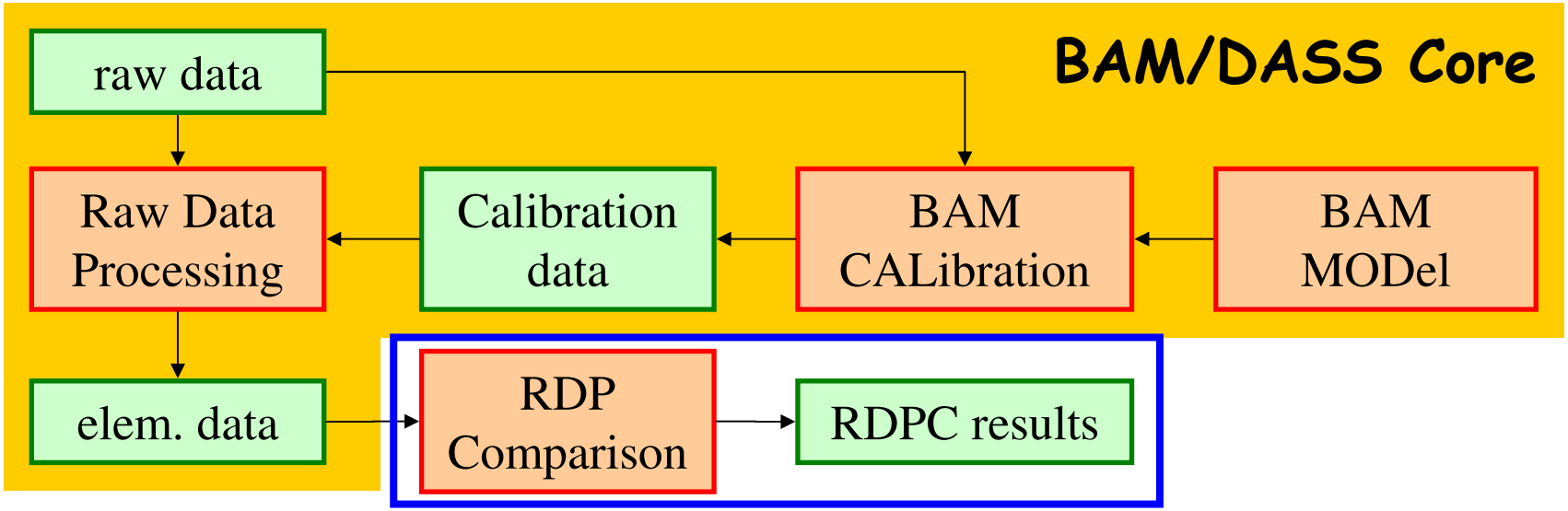

BAM/DASS Core
raw data
Raw Data Processing
elem. data
Calibration data
BAM CALibration
BAM MODel

Raw Data Processing algorithms

We want to compare the results from different algorithm types, in order to chose the one that gives the best performances (also during operations)

Currently we have three (four) algorithms implemented:

- Maximum Likelihood (maximisation of the ML function)
- Least Squares (Minimisation of the LS function)
- Cross-correlation (Maximisation of the CC function)
- Barycentre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RDP Comparison
RDPC results

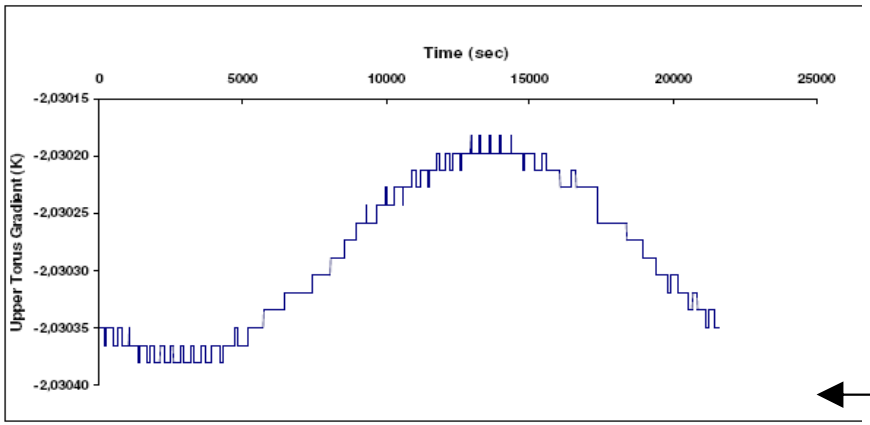
Long and Mid Term Analysis

Basic Angle variations will be found and determined independently of BAM (on timescales > 1day) by the astrometric solutions (AGIS, FL)

Mid and Long term analysis of the BAM measurements will allow comparison with AGIS and FL estimates, thus enabling us to verify consistency between different systems.

Moreover, Mid and Long Term analysis can provide information about variability on large timescales of some instrument parameters

Basic Angle Variation Model

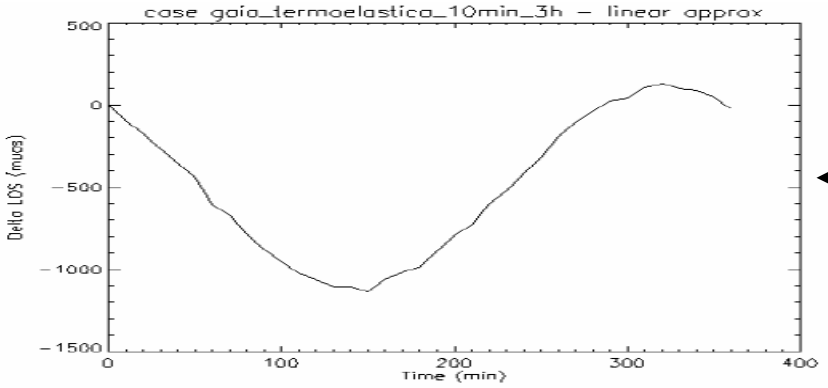


$$\delta LOS_T \approx \sum_{i=1}^{3} K_t^i \cdot d\tau_T + K_c^i \cdot dc_T + K_p^i \cdot dp_T$$

$$\delta BA \approx \delta LOS_1 - \delta LOS_2$$

Sinusoidal behaviour expected (P = 6 hours)

Thermal perturbation (M1#1 – M2#2) ~ 200 μK peak to peak



BA response ~ 1200 μas

- dBA/dT ~ 6 μas / μK (Gardiol et al., SPIE 5497)

Monitoring of instrument performances

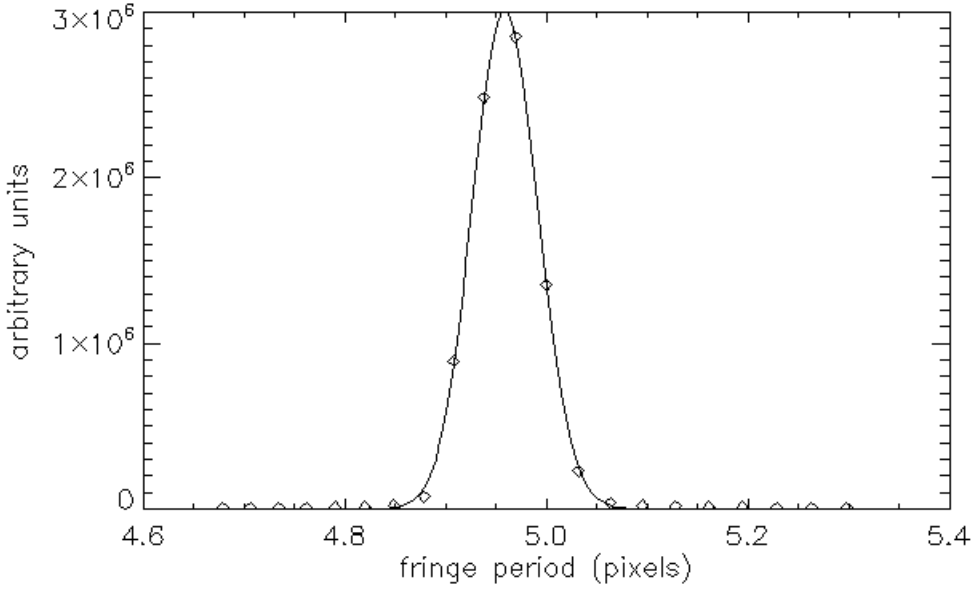
- EXAMPLE: Monitoring the fringe period over time.

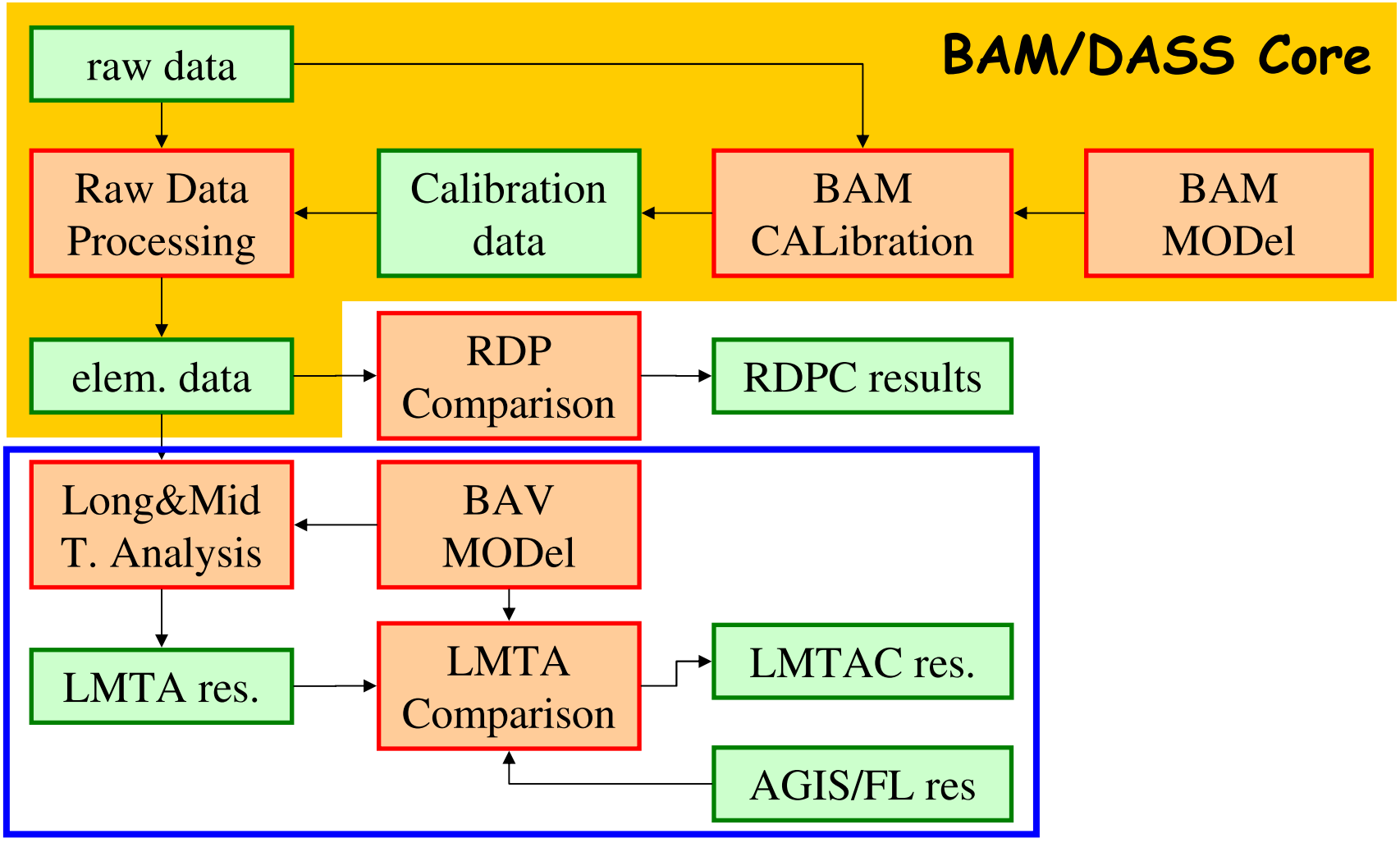
Fringe period is given by $\Delta x_p = \frac{\lambda f}{B}$

- "True" value =4.95833 px

SINGLE MEASURE
- Estimated =4.95835 px
- σ =0.03237 px (6.5e-3)

1080 MEASURES (~6 h)
- σ = 0.00098 px (2.0e-4)

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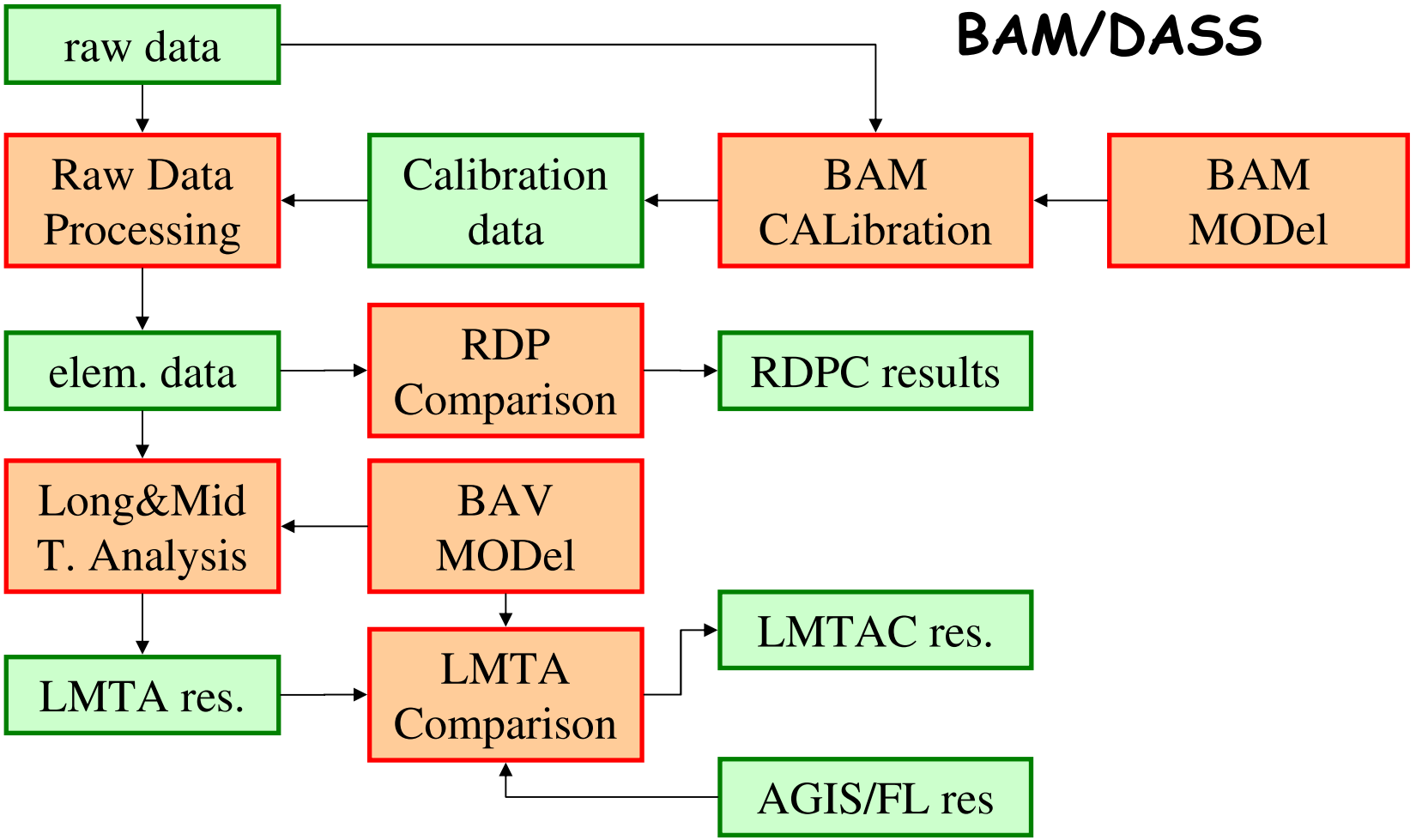
LMTA Comparison
LMTAC res.
AGIS/FL res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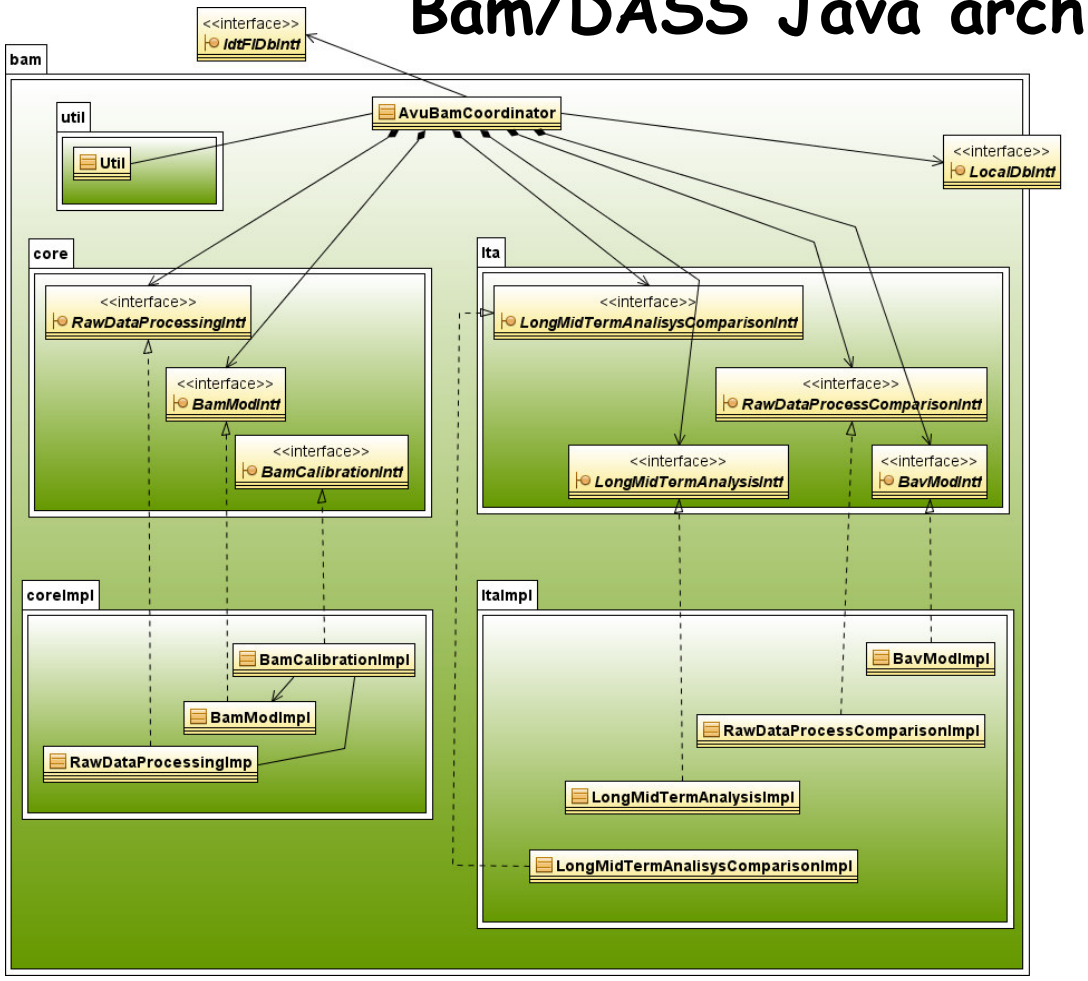
Bam/DASS Java architecture



Left: BAM Core

prototype implemented, under testing

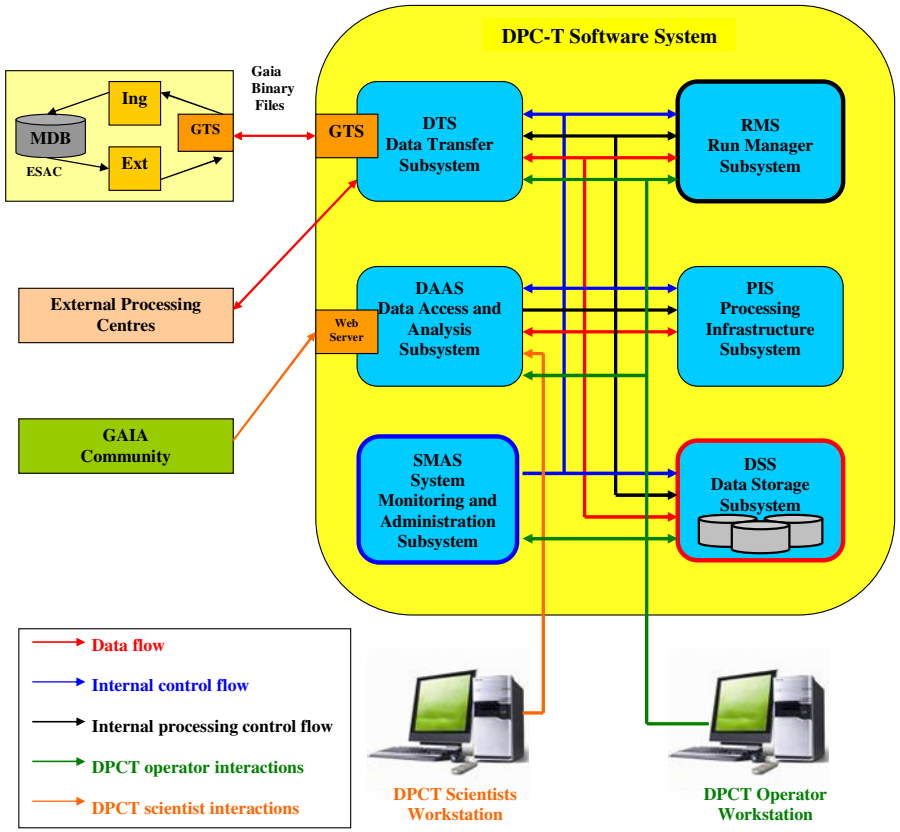
Right: Long/Mid Term Analysys

under development

Top: Interfaces

Bottom: Implementations

Data Processing Center – Torino (Altec)



Conclusions

- Basic Angle monitoring is crucial to reach Gaia astrometric expected performances
- Basic Angle monitoring at the required level of accuracy is challenging but feasible
- Criticality: realistic and faithful description of the fringe image (calibration). May depend on HW quality (stability over time).
- Data anaysis SW architecture defined (BAM SRS/SDD passed CDR)
- BAM core prototype modules implemented, currently under test at DPC-T
- Experience acquired so far may be useful to other similar missions

ADASS LIII (2043)
in Torino ?

Thank you!