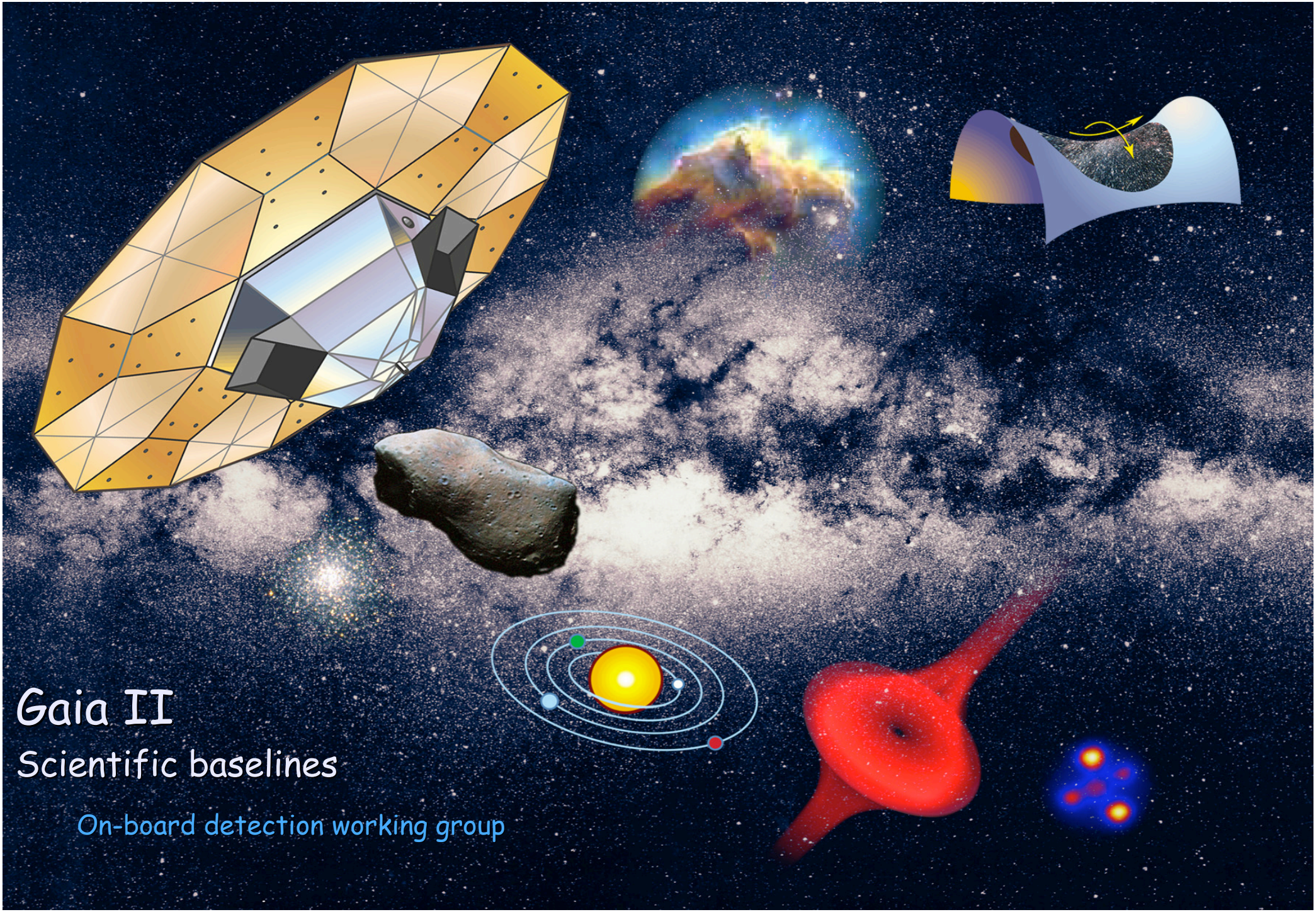
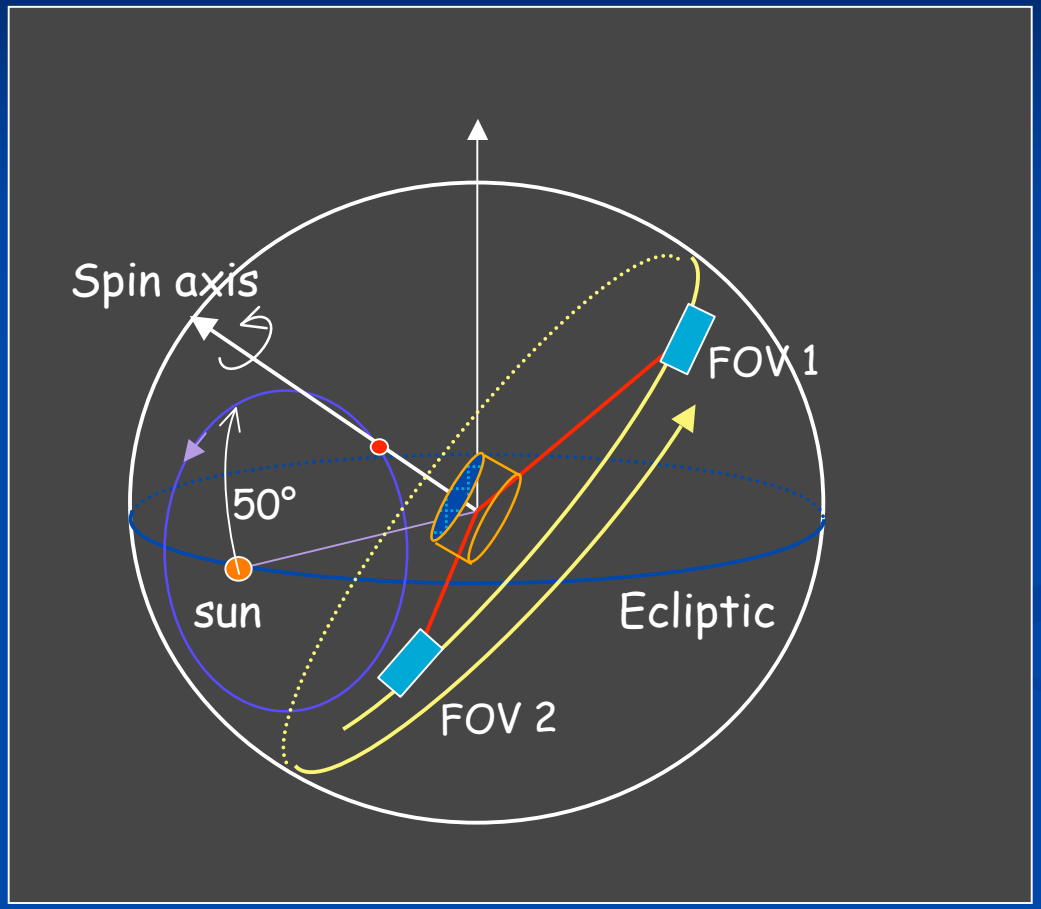

Gaia II
Scientific baselines
On-board detection working group

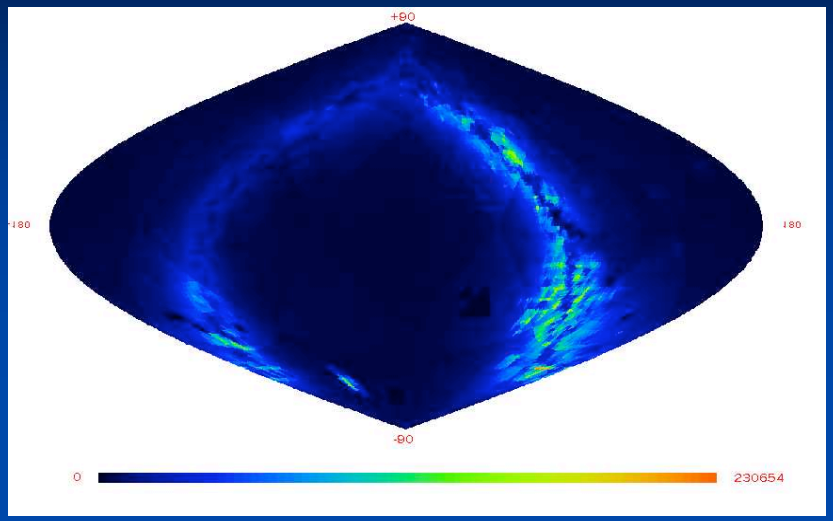
The instruments

Scanning law



Spin axis 50° to Sun
Scan rate: 60 arcsec/s
Spin period: 6 hours

Scanning law

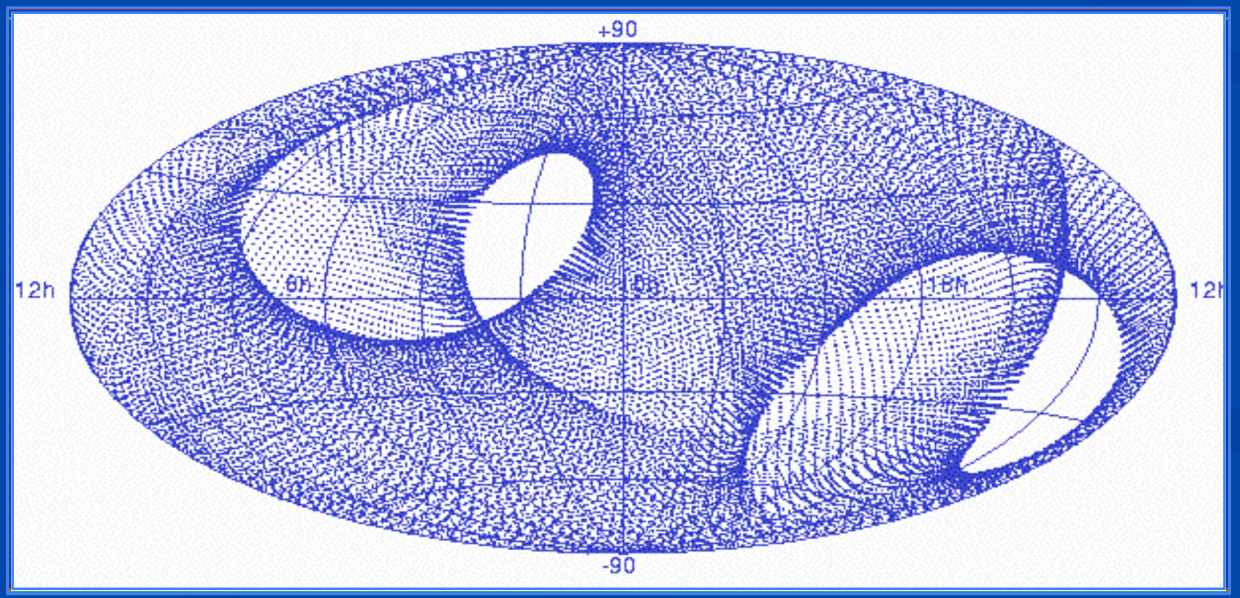


30 days

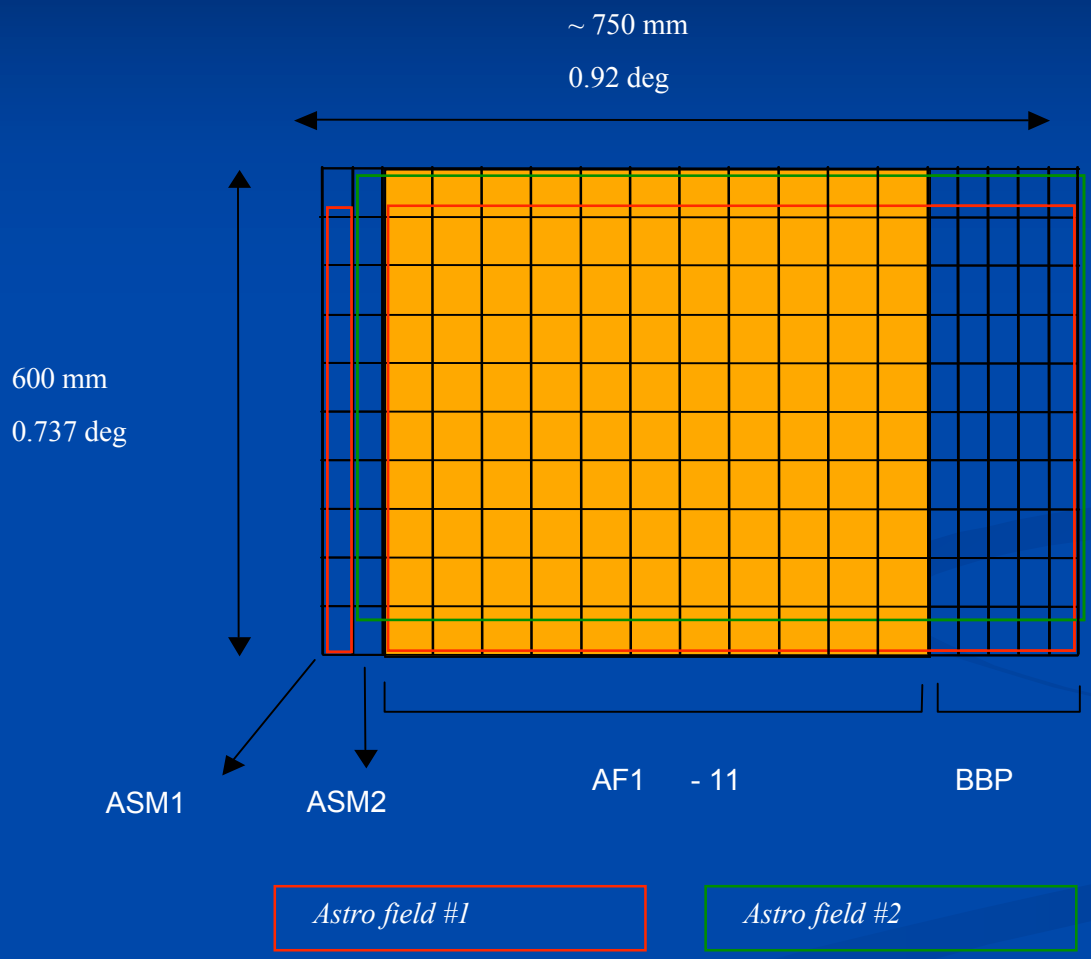
60 days

100 days

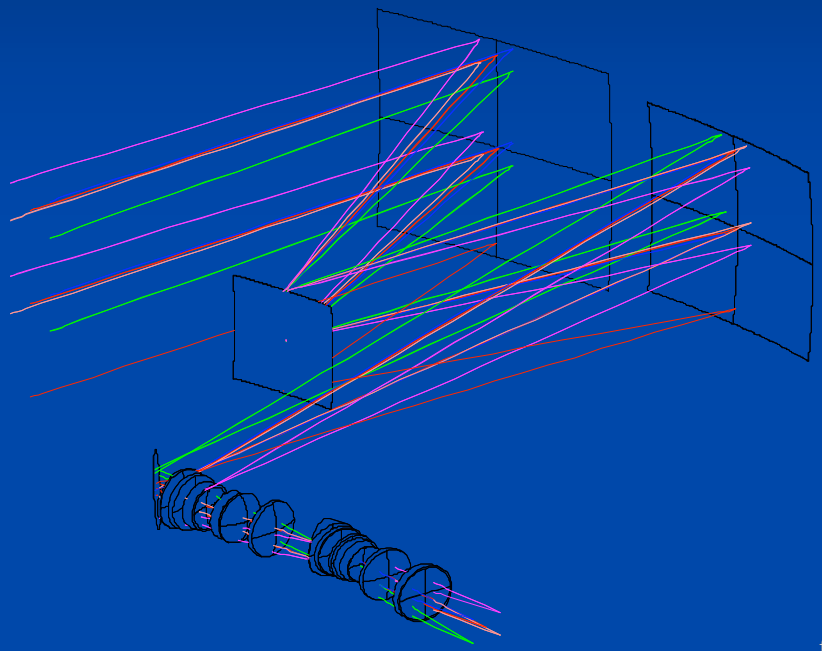
The stellar density in equatorial coordinates

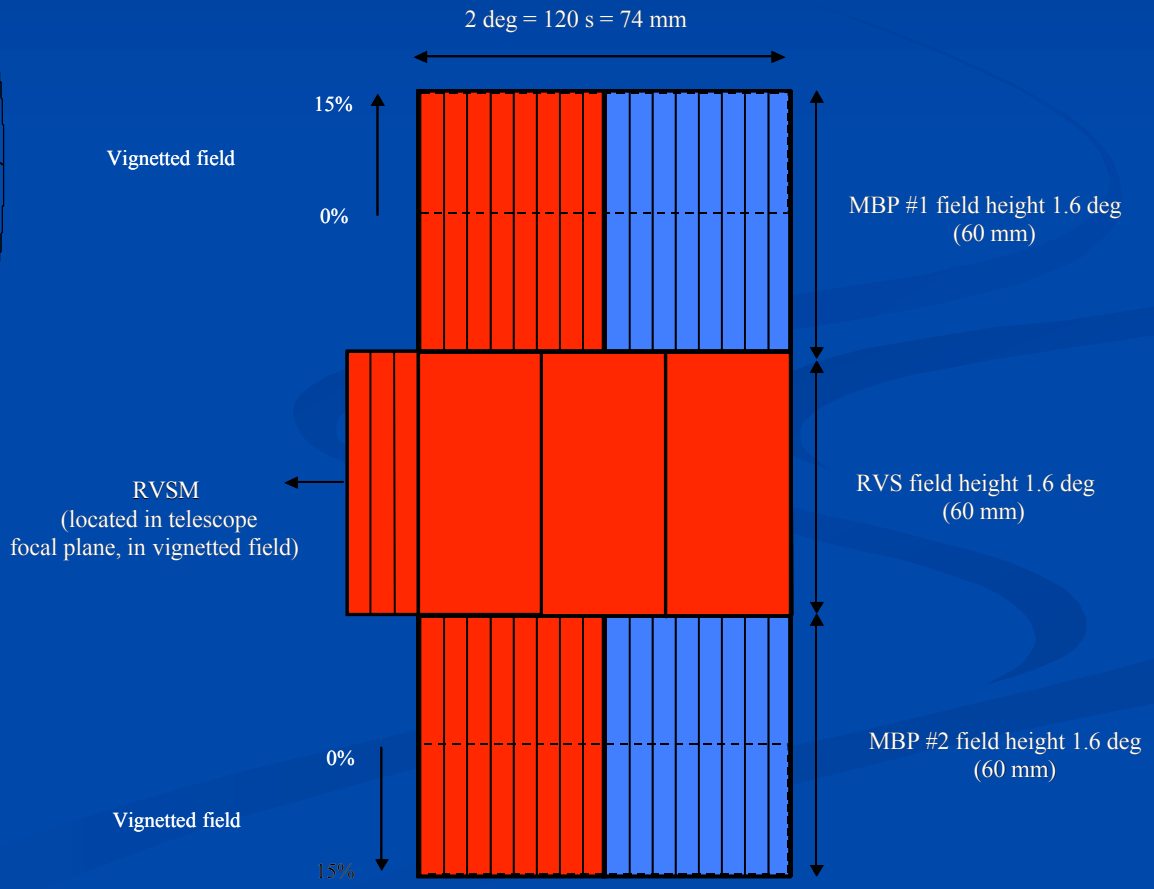


Astrometric focal plane



Spectrometer and MBP/RVS focal plane





Basic unchanged principles

- Two viewing directions with 106^0 basic angle
- Separate spectroscopic telescope including the medium-band photometer and the radial velocity spectrometer
- The on-board detection (except for bright stars)
- The limiting magnitude G=20
- The astrometric accuracies as a function of magnitude
- Satellite at the L2 position, coverage ~ 8 hours / 24
- Telemetry rate at about 1 Mbps on average

What has changed

- The fairing diameter reduced from 4.2 m to 3.8 m for a Soyuz launch
- The revised optical design has a shorter focal length and an intermediate focus
- The lower distortion allows larger CCD chips, smaller number of CCDs
- A longer integration time per chip (from 0.9 s to 3.3 s)
- Both viewing directions are now superimposed on a single focal plane
- The two fields having different cross-scan motions
- Some complications in terms of on-board object detection and windowing
- A slower spin rate of 60 arcsec/s (reduced from 120 arcsec/s)
- increasing the elementary integration time and reducing the telemetry further
- with some impact on the regularity of sky sampling
- Smaller sun aspect angle of 50^0 (reduced from 55^0) due to the smaller sun-shield
- Degrading slightly the decoupling of the astrometric parameters.

GENERAL PARAMETERS		
□	**Former Design**	**New Design**
Observing time L	L = 4 years	L = 5 years
Scan rate □	120 arcsec/s	60 arcsec/s
Precession period $\square_p$	70 days	70 days
Rotation axis	55° from sun direction	50° +/- 0.1° from sun direction
Star population V < 20 Average value «□Worst case□»	□ N_s = 25 000 stars/deg^2 3 000 000 stars/deg^2	□ N_s = 25 000 stars/deg^2 3 000 000 stars/deg^2
Total number of observed stars	~ 1 billion	~ 1 billion

(from Astrium final report)

PARAMETERS OF THE ASTROMETRIC INSTRUMENT		
□	**Previous Design**	**New Design**
Basic angle	106 deg	106 deg
Entrance pupil	1.7 m x 0.7 m	1.4 m x 0.5 m
Focal length	50 m	46.67 m
Field of view (effective)	0.32 deg^2	> 0.4 deg^2
FOV height	0.66 deg across	0.66 deg across scan
Spot sampling	6 pixels	6 pixels
Pixel size	9 μm x 27 μm	10 μm x 30 μm
CCD active area	29 mm x 58 mm	45 mm x 59 mm
Number of CCDs in Astro fields	2 x 17 x 10 = 340	11 x 10 = 110
Sky mapper CCDs	2 x 70 = 140	2 strips x 10 CCDs = 20
Broad Band Photometry	2 x 4 x 10 = 80	5 x 10 = 50
Total number of CCDs	560	180
Wavelength band	Defined by CCD QE	Defined by CCD QE
CCD Quantum efficiency	CCD #3	CCD #3
Pixel MTF	0.4 @ Nyquist freq.	GST Study Report values
TDI integration time per chip	0.9 s	3.3 s
Overall aberration WFE	36 nm rms	45 nm rms
TDI errors	0.3 pixel rms	0.2 pixel rms
Optical transmission	> 0.9	> 0.86

(from Astrium final report)

USEFUL FIGURES FOR ASTRO INSTRUMENT		
Parameter	**Previous design**	**New Design**
Focal plane scale	1 arcsec = 242 m Pixel along scan = 9 m = 37.1 mas Pixel across scan = 27 m = 111 mas	1 arcsec = 226 m Pixel along scan = 10 m = 44.2 mas Pixel across scan = 30 m = 133 mas
Airy radius @ l = 0.7 m	Along scan : 20.6 m (85 mas) Across scan : 50 m (206 mas)	Along scan : 23.3 m (103 mas) Across scan : 65.3 m (289 mas)
Star speed along scan	Entrance space : 120 arcsec/s Focal plane : 29.1 mm/s	Entrance space : 60 arcsec/s Focal plane : 13.6 mm/s
Star speed across scan (maximum value)	Entrance space : 171 mas/s Focal plane : 41.4 m/s	Entrance space : 171 mas/s Focal plane : 38.6 m/s
Time-Field correspondence	1 s = 120 arcsec = 0.033 deg 1 pixel along scan = 0.309 ms	1 s = 60 arcsec = 0.0167 deg 1 pixel along scan = 0.735 ms
Astro field-of-view	Effective FOV: W = 0.32 deg_ FOV across scan: H_x = 0.66 deg FOV along scan: H_y = 0.56 deg FOV swept per second : $H_x.w$ = 0.022 deg_/s	Effective FOV: W = 0.415 deg_; FOV across scan: H_x = 0.66 deg FOV along scan: H_y = 0.66 deg FOV swept per second : $H_x.w$ = 0.011 deg_/s
Integration time	TDI integration time : t_e = 0.9 s (26.2 mm or 2912 pixels) Integration time per passage : t = 15.3 s Total integration time over the lifetime : T = LW/(4p) = 978 s	TDI integration time : t_e = 3.3 s (~ 45 mm or 4500 pixels) Integration time per passage : t = 38.2 s Total integration time over the lifetime : T = LW/(4p) = 1587 s
Average total number of focal plane passages per star per telescope.	N = T/t = 64 observations (or great circles)	N = T/t = 41 observations (or great circles)
Star number and flow (per telescope)	Average star flow : N_s H_y w = 550 stars/s Average number of stars in the FOV : N_s W = 8 000 stars Rate of processed stars: N_s W/t_e = 8 890 stars/s	Average star flow : N_s H_y w = 275 stars/s Average number of stars in AF FOV : N_s W = 10 000 stars Rate of processed stars: N_s W/t_e = 3 145 stars/s

(from Astrium final report)

Spectrometer Telescope (common to RVS and MBP)		
□	**Previous Design ***	**New Design**
Entrance pupil	0.75 m x 0.7 m	0.5 m x 0.5 m
Focal length	4.17 m	2.1 m
Field of view (optical)	4 x 1 deg^2	2 x 4.8 deg^2
Optical transmission	> 0.92	> 0.92
Medium Band Photometry (MBP)		
□	**Previous Design ***	**New Design**
Field of view (optical)	2 x 1 deg^2	2 x 3.2 deg^2
Pixel dimensions	10x10 μm^2=0.5x0.5$arcsec^2$	10x15 μm^2=1x1.5$arcsec^2$
CCD active area	7.25 x 73 mm^2	3.36 x 59 mm^2
# of CCDs (sky mapper excluded)	15	30
Number of MBP wavelength bands	11	11
Available integr. time/star passage	33 s	82.5 s
Total integration time/ star over 5 yr	3 400 s	16 800 s
Radial Velocity Spectrometer (RVS)		
□	**Previous Design ***	**New Design**
Field of view (optical)	2 x 1 deg^2	2 x 1.6 deg^2
Pixel dimensions	20 x 20 μm^2 = 1 x 1$arcsec^2$	10x15 μm^2= 1x1.5$arsec^2$
CCD active area	73 x 24 mm^2	10 x 59 mm^2
# of CCDs (sky mapper excluded)	6	3
Spectral range	847 – 870 nm	848 – 874 nm
Spectral sampling	0.75 A per pixel	0.375 A per pixel
Number of spectral samples per star	330	694
Available integr. time/ star passage	60 s	101 s
Total integration time/ star over 5 yr	6 100 s	10 100 s

(modifications from Astrium final report)

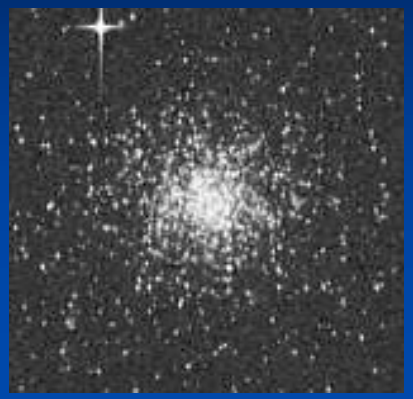
Scientific requirements for the focal plane

- The mission
  - Astrometry, photometry, spectroscopy
  - Object counts and implications
  - For which objects (stars, galaxies, asteroids, background)
- The astrometric focal plane
  - A global vision
    - On-board detection
  - The CCDs
    - Samples, patches and windows
- Travelling in the focal plane
- The spectro focal plane

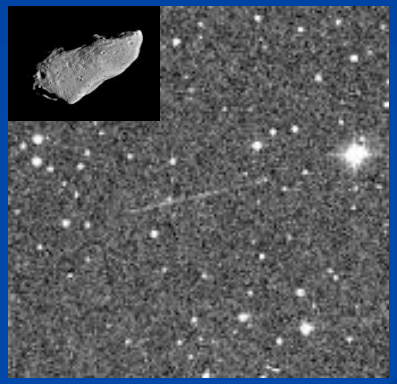
Overall description

- Many ways to describe the focal plane !
  - Science (function): ASM (detection) AF (astrometry) BBP (photometry)
  - Reading (algo+elect.): ASM1/2 (all read) AF+BBP (selected)
  - Sampling (electronics): ASM (2x2) AF1(1x2) AF2-10 AF11 BBP
  - Patches (telemetry): - several differences -
  - Activation: redundancies AF2 if AF1 fails Other

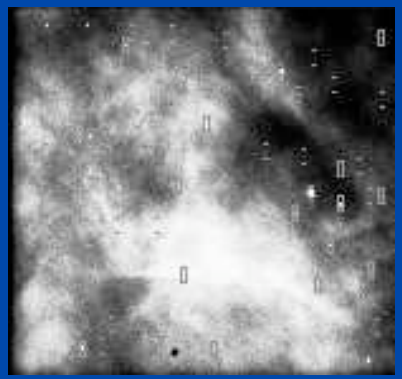
Various objects



Globular cluster



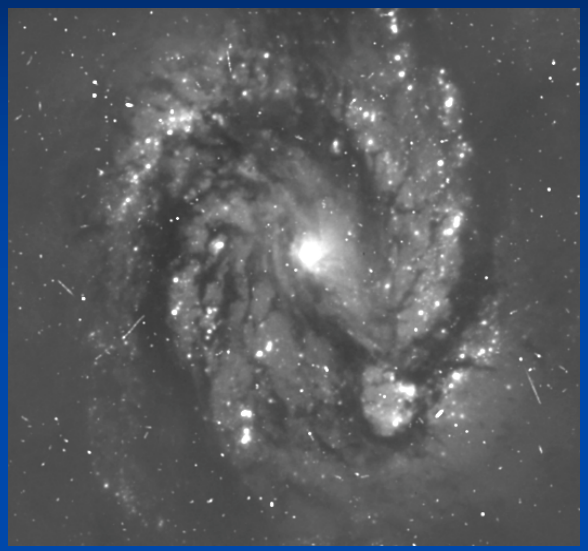
Near-Earth Objects



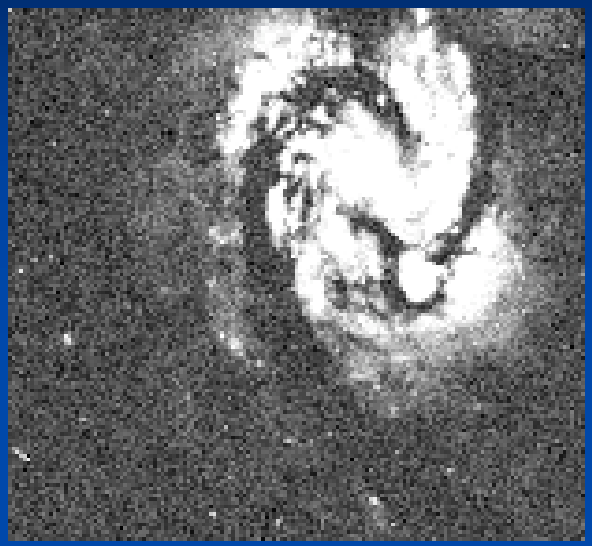
High background

- Stars
  - High density
- NEO
  - Motion during integration
- Galaxies
  - Large area

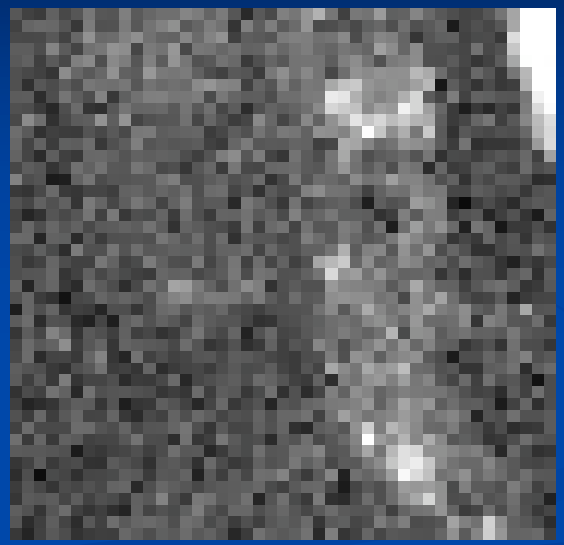
Galaxies



The M100 galaxy with HST



in ASM1

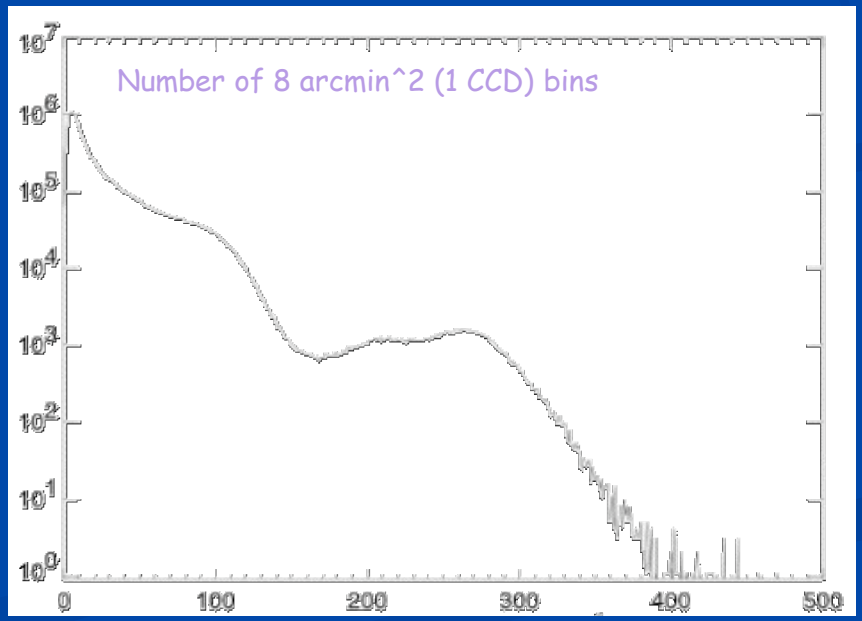


zoomed

- Unresolved galaxies are not a priority
- observed however

Object counts

- 3 levels of buffer or CPU maxima
  - Maximum on a CCD (when observing a globular cluster)
  - Maximum on the focal plane (when the satellite observes the galactic center)
  - Maximum Telemetry (great-circle along the galactic plane)



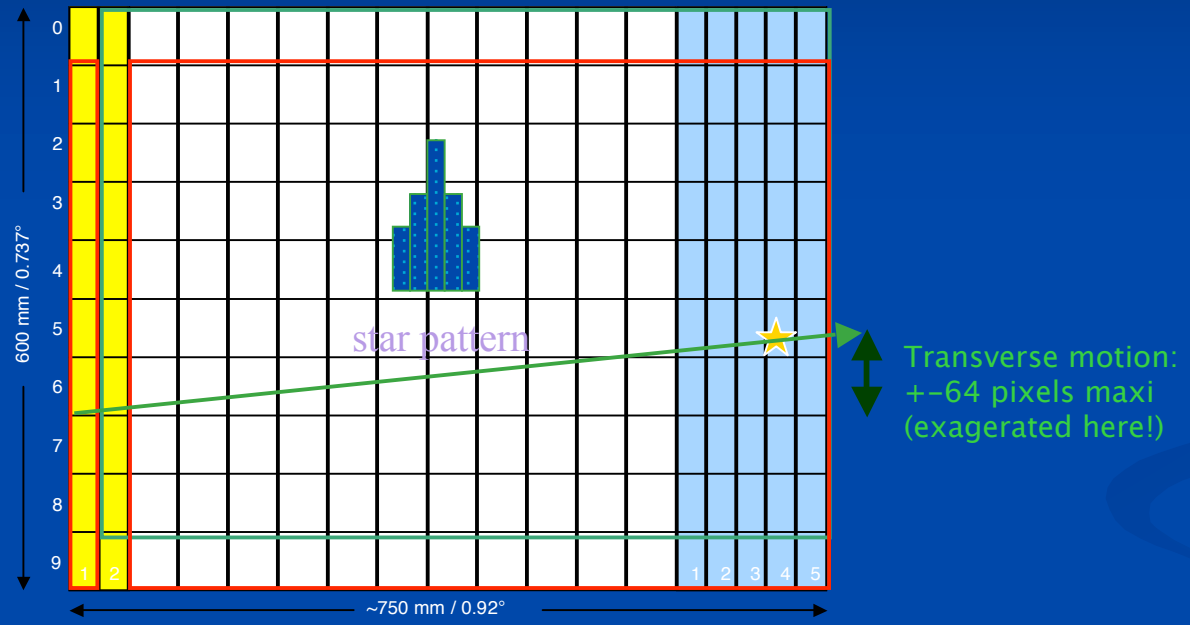
Number of stars per bins in USNO A1 (G<19)

Astrometric focal plane

ASM1-2
2600x1966, 1.9s

BBP1-5
2600x1966, 1.9s

<-- AF1-11 : 4500x1966, 3.3s -->

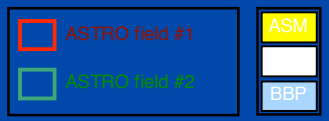


Transverse motion:
+-64 pixels maxi
(exagerated here!)

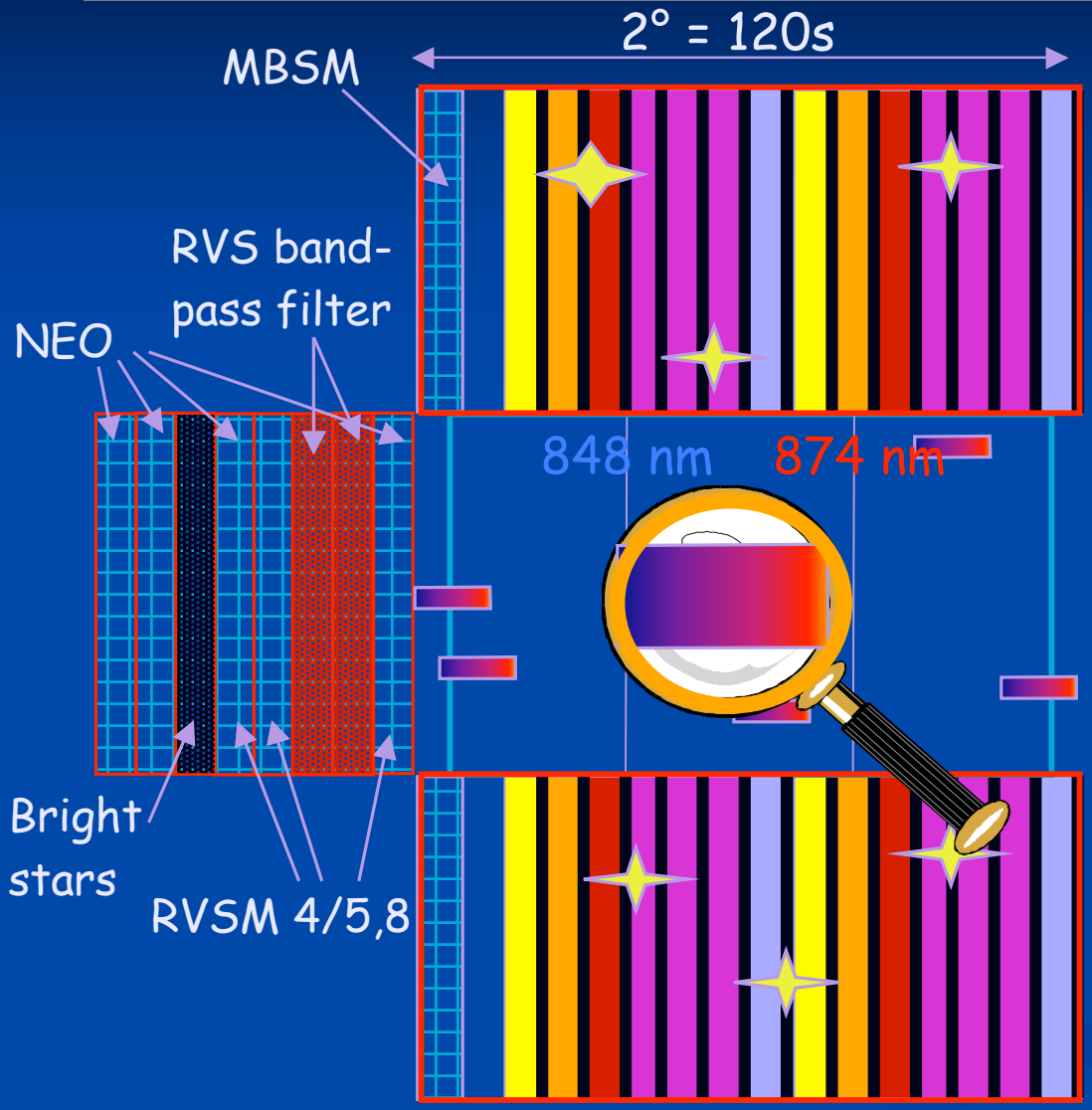
Sky Mapper

Astrometric Field

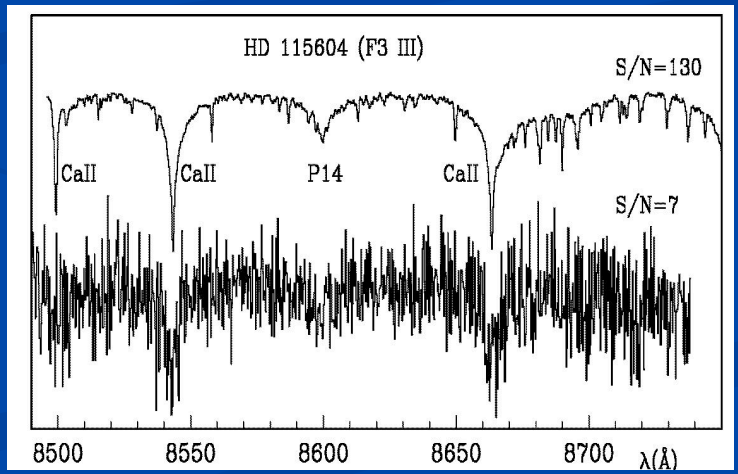
Broad Band Photometry



Spectro field



- Confirmation and redundancy
  - For spectro sky mapper
- Two MBP fields
  - 1+15 CCDs =1+11 filters TBC

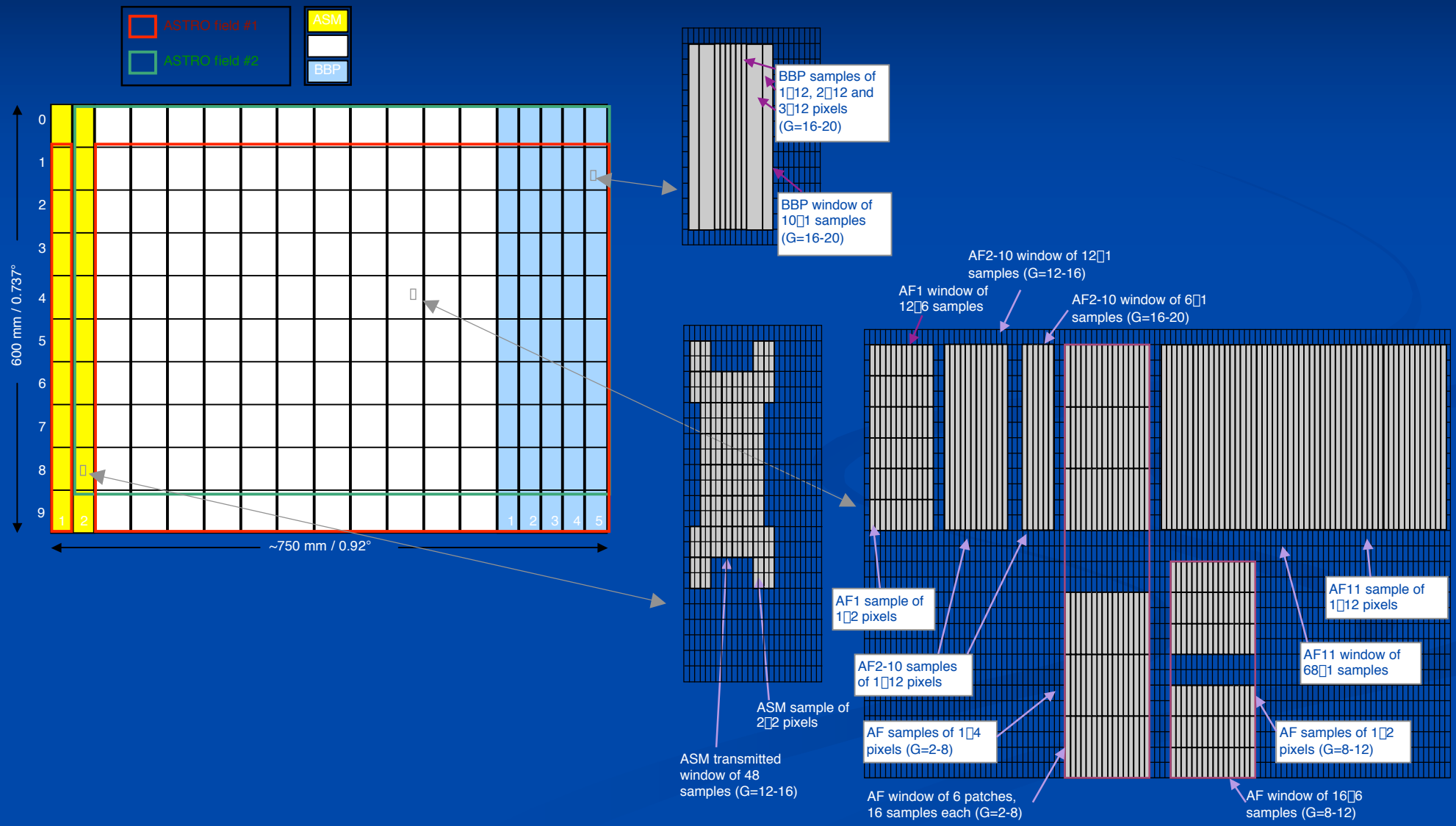


Sampling

Sampling and patches

- Scientific Requirements
  - Highest precision along-scan
  - Highest signal/noise : smallest read-out noise : electronic binning
  - Enough flux per object for on-ground reconstruction (two close objects)
- Technical Constraints
  - CPU: limited instantaneous number of objects
  - Telemetry: small number of patches, size of patches
  - Number of samples AC fixed by the max. density
    - 3.10^6 in astro
    - $\sim 10^5$ in MBP, TBC

Sampling in the astrometric field

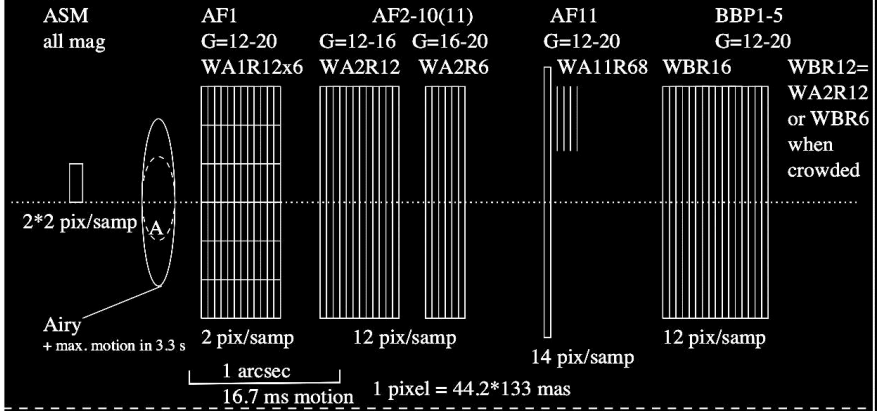


Sampling in Astro and MBP

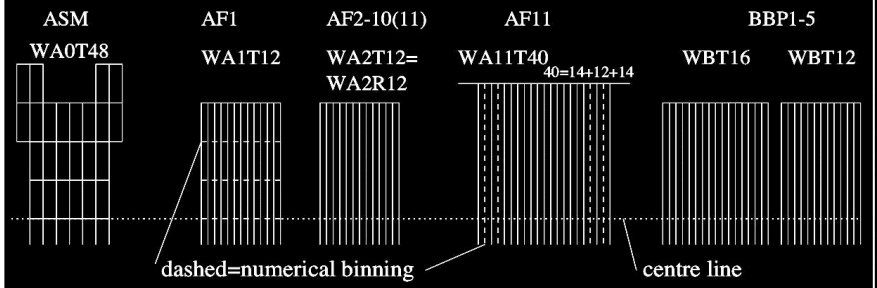
A Sampling in Astro - Scheme C - see CUO-113

ASM = Astro Sky Mapper; AF = Astrometric Field; BBP = Broad-Band Photometer
Windows: WAn for ASM, AF; WBn for BBP; WMn for MBP; WYnn with distance Y=nn
e.g.: WA1R12x6 for AF1= read 12x6 samples; WA2T6= transmit 6 samples; WA0T= transmit for ASM

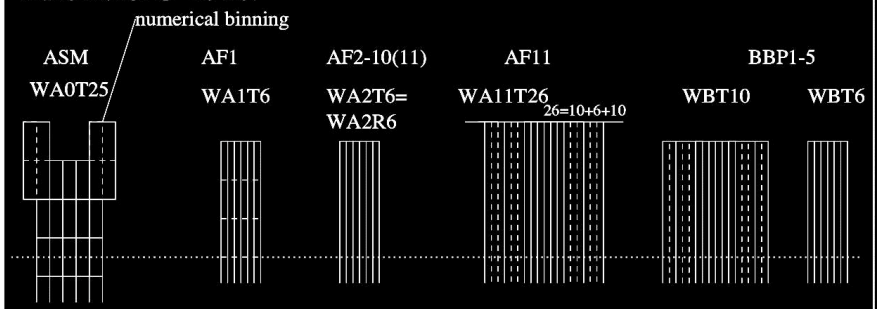
Read:



Transmit for G=12-16:

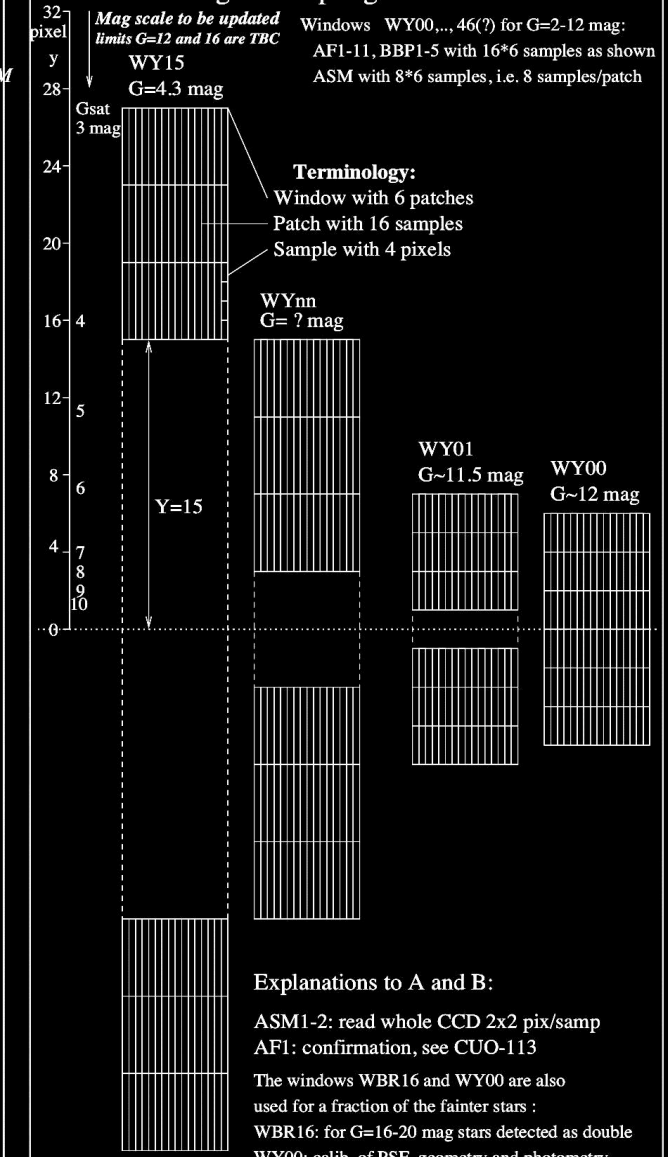


Transmit for G=16-20:



Copenhagen University Observatory - E. Hoeg - 21 October 2002

B G=2-12 mag Sampling in Astro - Scheme C



Windows WY00,.., 46(?) for G=2-12 mag:
AF1-11, BBP1-5 with 16*6 samples as shown
ASM with 8*6 samples, i.e. 8 samples/patch

Explanations to A and B:

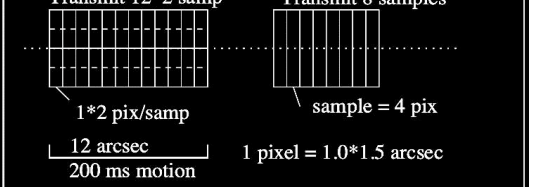
ASM1-2: read whole CCD 2x2 pix/samp
AF1: confirmation, see CUO-113

The windows WBR16 and WY00 are also used for a fraction of the fainter stars :
WBR16: for G=16-20 mag stars detected as double
WY00: calib. of PSF, geometry and photometry for G=12-20, see Section 2 of CUO-113

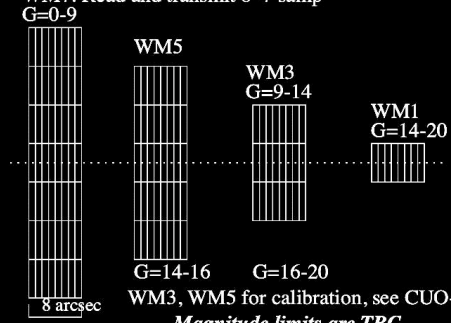
samp11

C Sampling in MBP

MBSM = Medium-Band Sky Mapper
MBP = Medium-Band Photometer



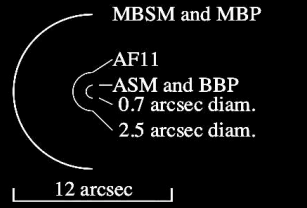
Calibration with 3 windows WM7, 5, 3 for G=0-20 mag:
WM7: Read and transmit 8*7 samp



WM3, WM5 for calibration, see CUO-91
Magnitude limits are TBC

D Imaging around detected stars

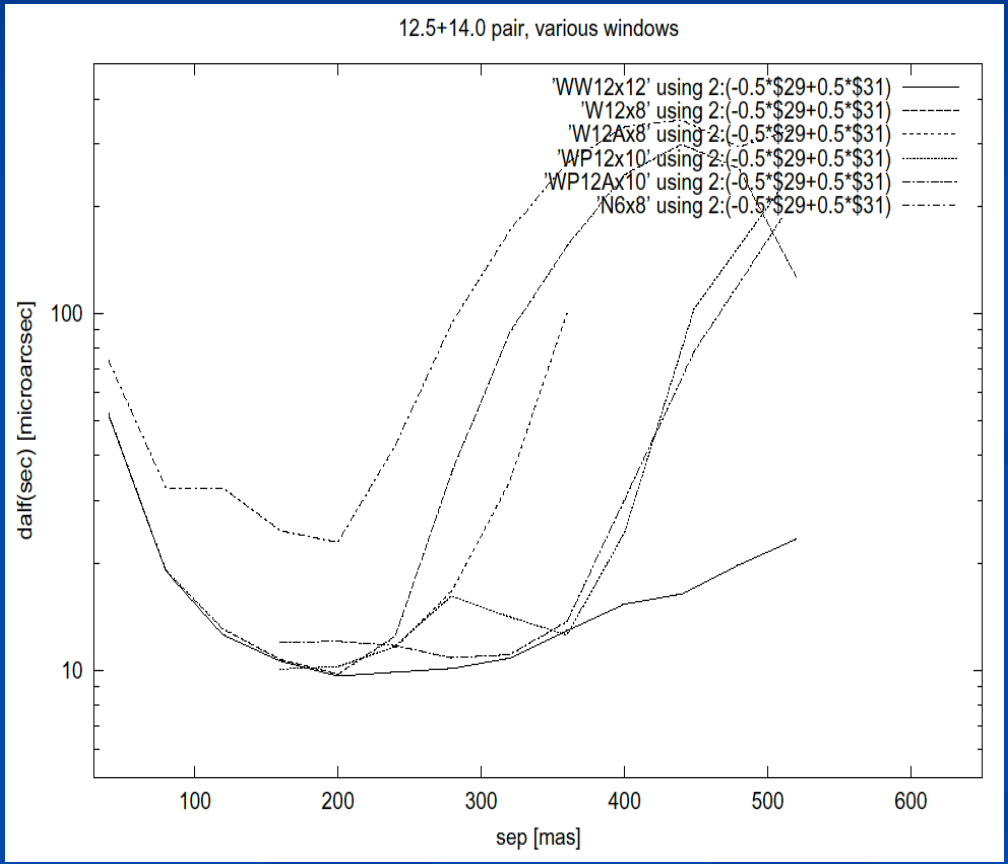
Detection in G-band
and multi-colour photometry



CUO - 21 Oct. 2002

Patches for double stars

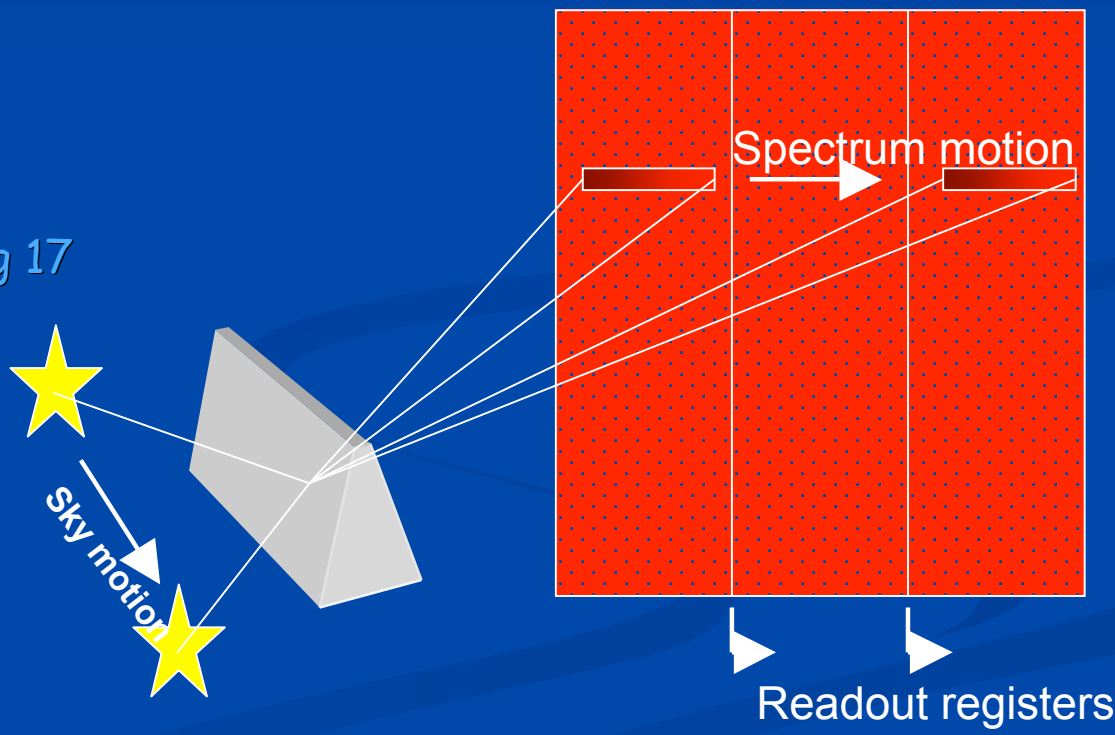
- A large fraction of stars have a companion
  - Plus optical companion in dense areas
- Data reduction complicated
- One or several patches
  - Depends on the separation between components
- Size of patches is critical
  - Both components may be damaged if only a small part of one component is in the patch



RVS

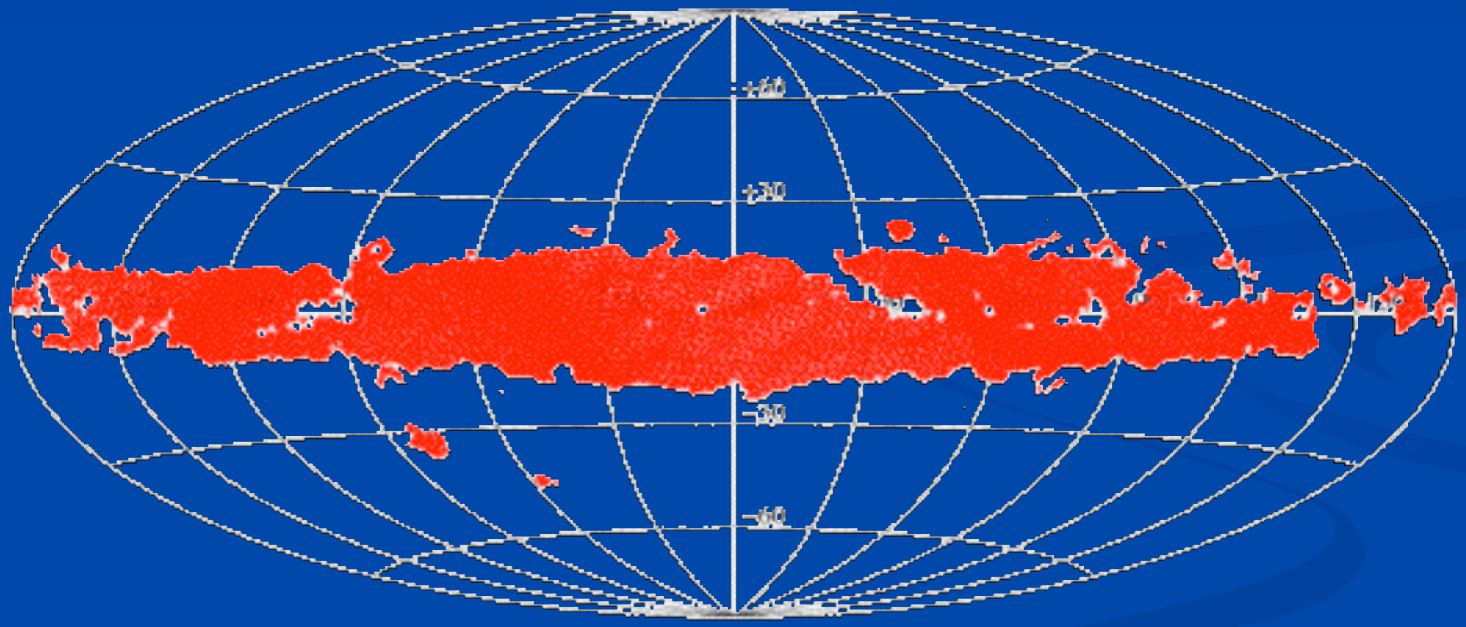
RVS specific problems

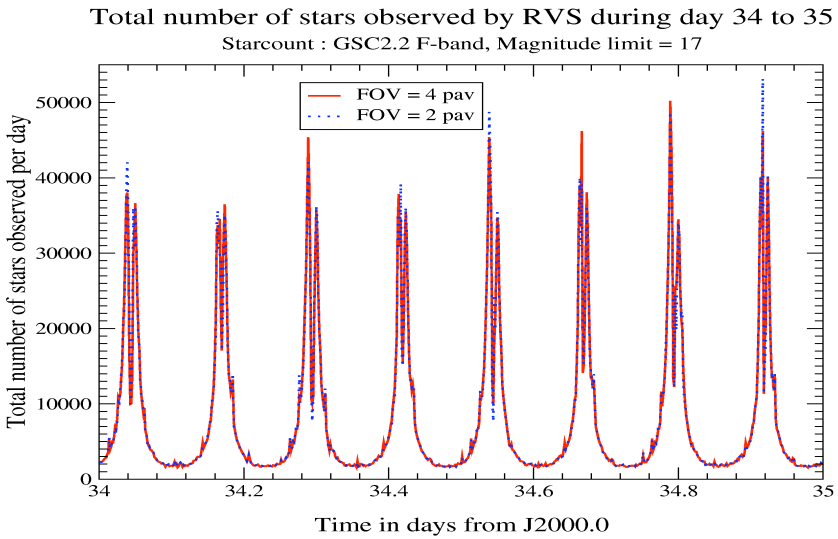
- High resolution gives a better precision on radial velocity
- R=11500 means 694 pixels AL
- Large crowding
- Transverse motion : signal over several pixel AC
- Less than 1 photon/pixel at mag 17
- Thus the rotation mechanism
- 3 CCDs instead of 6 suggested

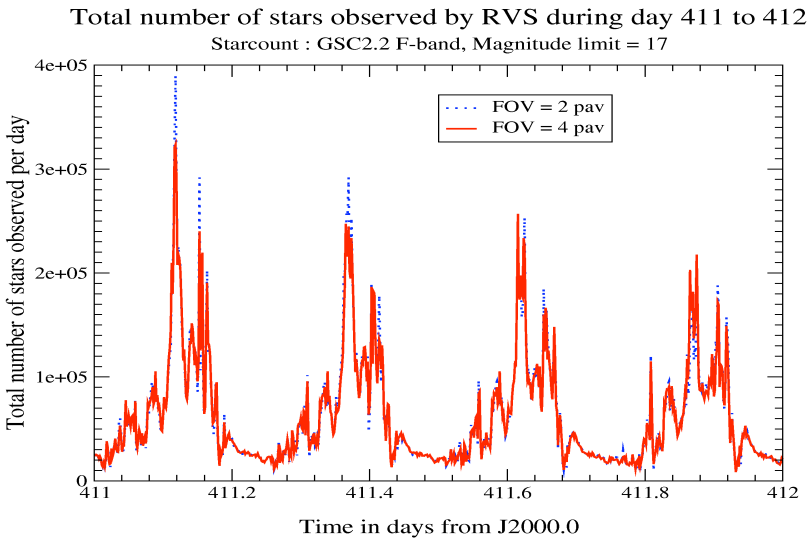


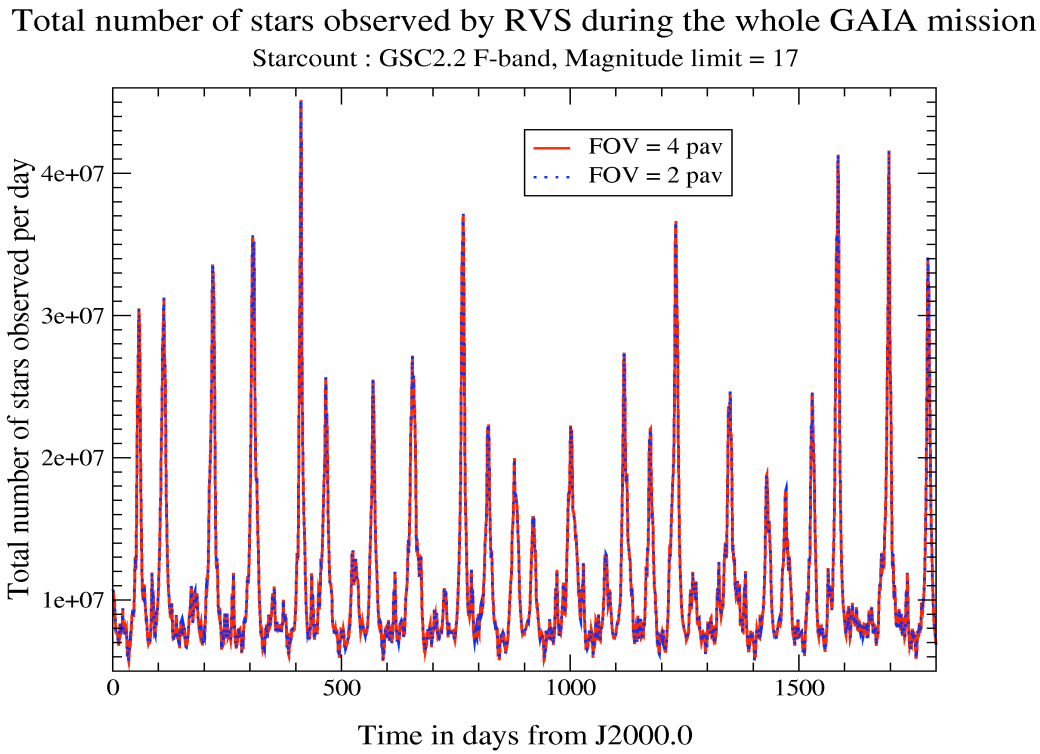
RVS full CCDs

- When crowding is such high that the RVS CCD should be entirely downloaded?
- Galactic coordinates, limiting magnitude=17, R=10000, row/spectrum=2




Total number of stars observed by RVS during day 34 to 35
Starcount : GSC2.2 F-band, Magnitude limit = 17
FOV = 4 pav
FOV = 2 pav
Total number of stars observed per day
Time in days from J2000.0


Total number of stars observed by RVS during day 411 to 412
Starcount : GSC2.2 F-band, Magnitude limit = 17
FOV = 2 pav
FOV = 4 pav
Total number of stars observed per day
Time in days from J2000.0


Total number of stars observed by RVS during the whole GAIA mission
Starcount : GSC2.2 F-band, Magnitude limit = 17
FOV = 4 pav
FOV = 2 pav
Total number of stars observed per day
Time in days from J2000.0

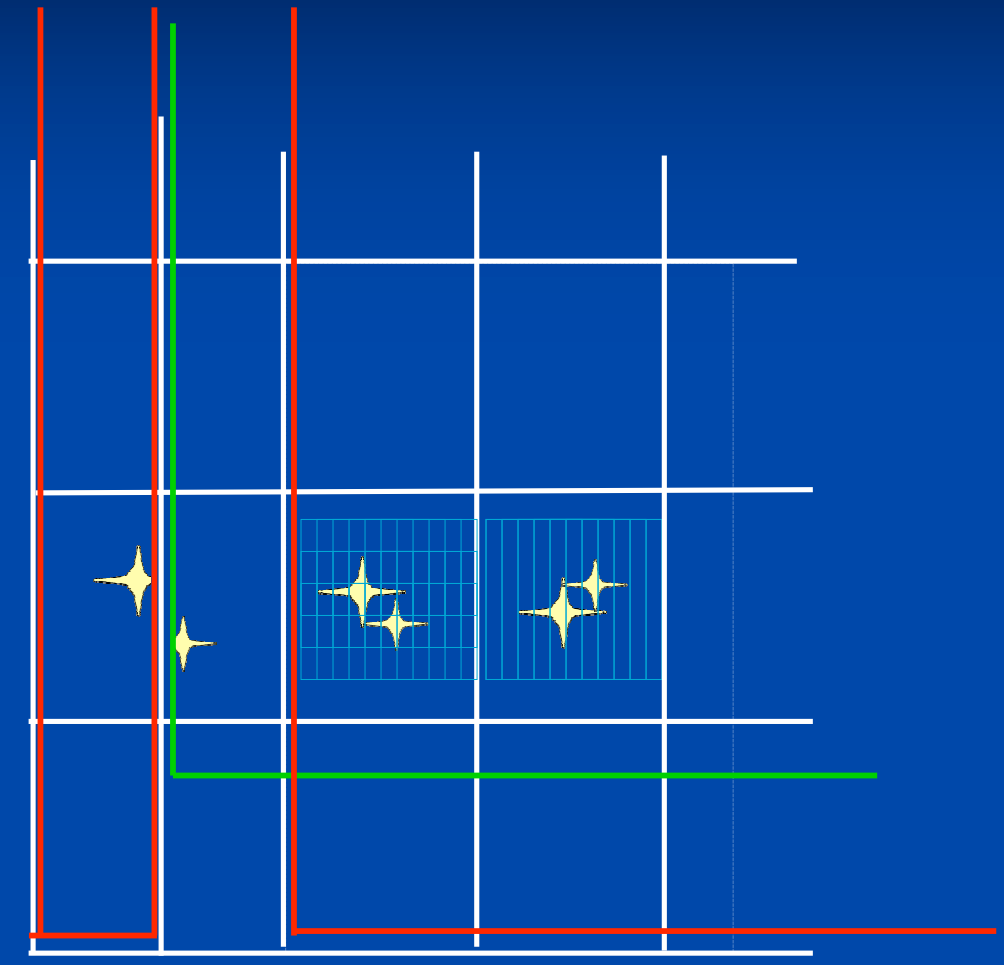
RVS algorithms

- Pre-processing
  - Detection
  - All RVSM read TBC
  - Then whole reading of the 3 RVS CCDs
- Post-processing (TBC)
  - Selection/windowing
    - 694 x 1 or 2 depending on PSF/pixels positions
  - Summing of the 3 CCD?
  - Extraction of Ca II lines for faint stars?
  - Classical compression
  - Possible calibrations
    - angle of rotation mechanism

Observing strategy

All this TBC in a forthcoming document

Instrument/detection/selection



- Instrument
  - 2 FOVs, different transverse motion
  - One sky mapper for each binning 2x2
  - Confirmation in AF1 binning 1x2
  - 9 following AF binning 1x12
  - Binning 1x because all contribute to astro. precision
  - AF2 could play AF1 role when failure
- Detection
  - All samples read in ASM
  - Detection occur (in some sliding window)
  - Results sent for selection
- Selection and tracking
  - Management of which patches to observe in AF1
  - Ask for AF1 samples
  - Confirms detection
  - Send a patch (was 5x5 samples in former design)
  - Compute at regular intervals the motion
  - Tracking for AF2, etc.

Detection - requirements

- Observations
  - G < 20^m completeness
  - For fainter objects, download at least position+magnitude+background from ASM
  - Galaxies and nebulae? Not a priority
- False detections
  - Larger number of patches in AF1 to cope with false detections/cosmic rays
- Precision
  - Good enough for object tracking
  - For scan rate computation (~1mas/s)
- Classification
  - For priority levels
- Processing should be
  - fast <1.9+3.3s (ASM1), <5.5s (RVSM),
  - robust

Selection - requirements

- After detection:
  - Which objects to observe
  - How (centering, size, overlapping, …) in each CCD (=observing strategy)
  - What to download
- A priority
  - To bright stars
  - May also depend on other criteria
- Selection reproducible on ground (censorship)
- Constraints
  - Limited number of patches should cope with high density fields
  - Take care of double stars (no sample overlapping)
  - Storage (possible downlink failure)
  - Telemetry (some great circles ~ along the galactic plane)